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# BE Department Annual Report 2012

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**Abstract**

The Beams Department hosts the Groups responsible for the beam generation, acceleration, diagnostics, controls and performance optimization for the whole CERN accelerator complex. This Report describes the 2012 highlights for the BE Department.

# LHC:

## BE-ABP Group

### LHC Operation (protons and heavy ions)

The year 2012 was an extraordinary one for the LHC, thanks to the excellent performance of several systems, with a record peak luminosity at 4 TeV corresponding to 77% of the 7 TeV design luminosity. The machine optics was measured and corrected to unprecedented levels, reaching a record low beta-beating of 7 % at top energy with squeezed beams. Techniques for safe measurements of the available aperture at the inner triplet (which, together with the collimator hierarchy, determines the minimum achievable β*) have been developed and successfully used in all running conditions. The LHC machine proved to perform equally well with both squeezed and unsqueezed optics. A special optics, featuring very high β* values has been developed, tested, and commissioned, reaching a new record of 1000 m simultaneously in IP1 and IP5. However, despite the excellent performance of the LHC, the intensity ramp-up was perturbed by several types of transverse coherent instabilities.

At the end of the year, an instability leading to emittance blow-up at the end of the betatron squeeze could not be cured and therefore remains a potential worry for future operation. Furthermore, the rms bunch length was increased to ~ 10 cm to cope with beam-induced RF heating issues observed in some equipment. Several mitigation measures have been taken for future operation, which will be put in place during LS1.

One of the major limitations for increasing the beam intensities further was the heating of the ferrites of the injection kickers requiring some cooling time between physics fills. A significant reduction of the heating has been achieved by increasing the number of conductors in the screen of one of the kicker modules from 15 to 19 after detailed electro-magnetic simulation studies (see Fig. 1).

Following the 2011 decision to make a first run of the LHC with proton-lead collisions in 2012, the heavy-ion team prepared further studies of the beam dynamics with moving beam-beam encounters and completed the preparations for this new mode of operation of the LHC in collaboration with colleagues in the ABP, RF and OP groups. The pilot physics run in September was a spectacular success, opening up a new physics programme for the LHC. Within a single, meticulously planned fill, it was possible to commission the new operation procedures, including injection and ramping of two beams with unequal RF frequencies, validate the minimum necessary collimation setup with sacrificial bunches and put 12 bunches into collision, providing the new asymmetric collisions to ALICE, ATLAS, CMS and LHCb. Although the luminosity was relatively low (~ 1026 cm-2 s-1), the increase in centre-of-mass energy to 5.02 TeV, a factor 25 compared to previous collisions of a similar type, was the largest in the history of particle accelerators.

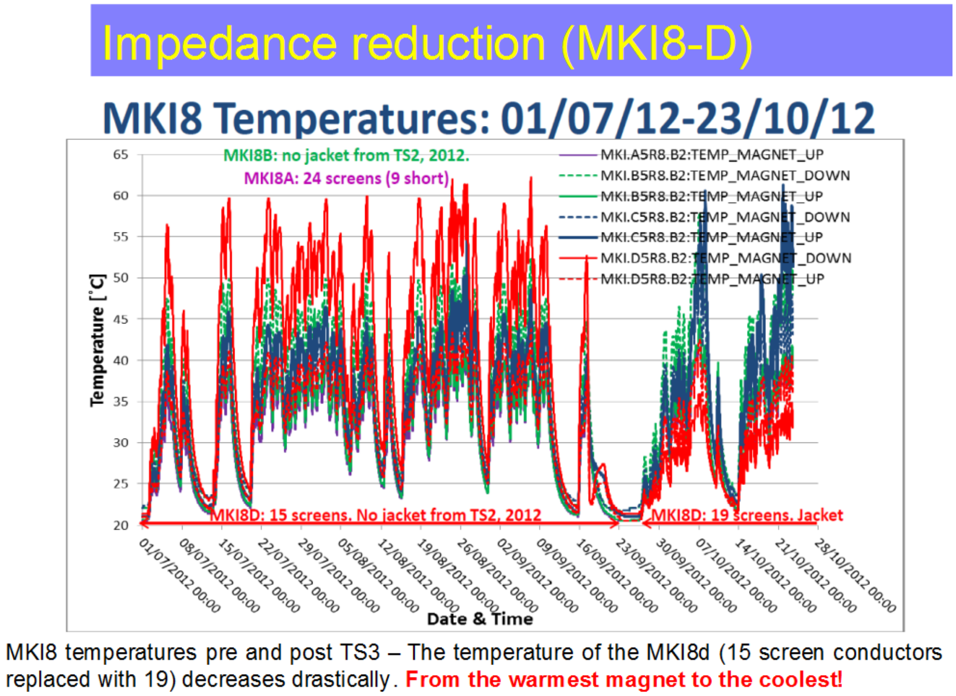



**Figure 1: Temperature of the injection kicker module MKI8-D before and after its replacement during the Technical Stop 3 (in red).**

## BE-BI Group

### LHC Beam Instrumentation

#### Beam Loss Measurement Systems

The LHC beam loss monitoring system was upgraded in 2012 to provide data at 12Hz in addition to the standard 1Hz continuous update rate. This was achieved by careful optimisation of the front-end software and significantly reduced the time required for collimator optimisation. Setting-up the collimators consists of moving each jaw towards the beam until a loss signal is detected from the BLM monitors located close by. Although this procedure was automated during 2012, the 1Hz data update rate from the BLMs made the whole procedure quite long and the increased data rate dramatically cut down the time required for a full collimator set-up.

#### Beam Intensity Measurement Systems

The LHC machine protection system uses many pieces of equipment to increase its redundancy and reliability and the fast beam current change monitor is a recent addition. Its purpose is to provide redundant information to the BLMs, detecting losses in total beam intensity distributed over pre-defined time intervals ranging from 1 to 1024 turns. The system uses the analogue signal from LHC fast beam current transformers (BCTFs) to calculate the magnitude of the 40 MHz signal component, which is then used to detect the intensity change during the corresponding time duration. A beam dump interlock is triggered if the loss exceeds an energy dependent threshold. The overall block diagram of the system is shown in Fig 2.

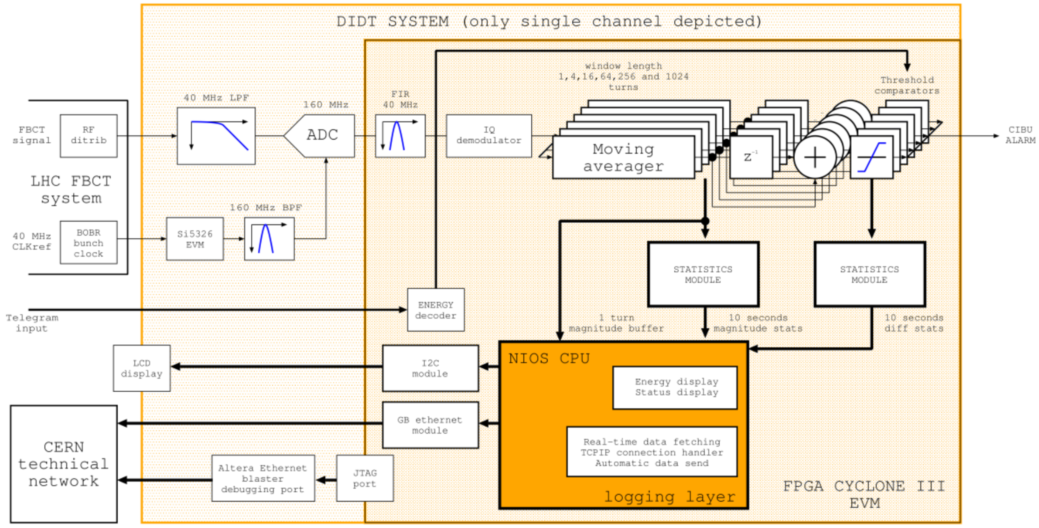



**Figure 2: Fast Beam Current Change Monitor block diagram showing the data flow from left to right**

A first prototype system was installed in the LHC during 2012, and the results are currently being analysed for providing a fully operational installation after LS1.

## Beam Position Measurement Systems

Originally developed to process signals from collimator BPMs, orbit measurement using a compensated diode detector scheme has already demonstrated to be robust, simple and in addition provide an excellent position resolution. During 2012 prototypes were also installed on some standard LHC BPMs and shown to have a resolution well below a micrometre. Results from measurements performed during a Van der Meer scan are presented in Fig. 3. The plan is to slowly equip the LSS 1,2,5 & 8 BPMs with this system in parallel to the standard BPM electronics, with priority given to the BPMs closest to the interaction regions.

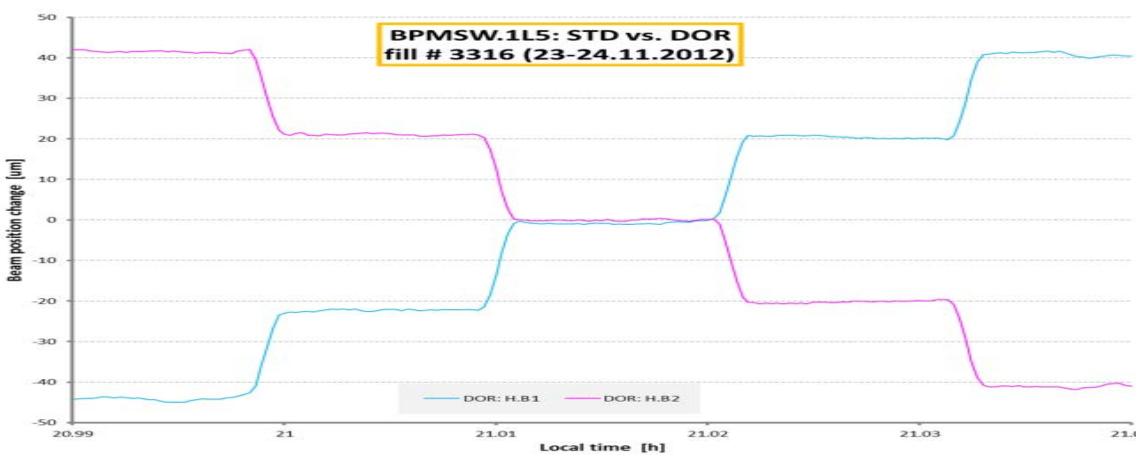



**Figure 3: (Left) Schematic of the Diode Orbit observation system (Right) Beam orbit measured by both the standard LHC BPM electronic and the Diode Orbit system during a Van Der Meer scan on LHC.**

## LHC Tune Measurement System

The tune monitoring system in nearly all of CERN's accelerators is now based on direct diode detection, allowing operation with sub-micron beam oscillations. Despite this sensitivity in the

LHC the tune measurement system was seen to be incompatible with the operation of the transverse damper at high gain. This had a direct impact on beam operation, forcing the choice to be made between a high damper gain to control beam instabilities and reliable tune signals. A solution for this was found during the summer of 2012 based on the development of a new tune front-end, which enables gating on selected bunches for which the damper can operate at lower gain. The system processes the electrode signals using a hybrid to reduce the signal amplitude, allowing an RF switch to be used for gating the signal. After the success of the first prototype, the system was quickly made operational for the rest of the year.

### Synchrotron light monitors (BSRT)

During the 2012 LHC run a lot of effort was put into improving the performance of the synchrotron light monitor. As well as improving the quality and accuracy of the measurements, extended functionalities such as the introduction of so-called "fast scans" were implemented. Before 2012, the BSRT images were acquired once per second. As bunch by bunch measurement require gating the intensifier of the camera on each individual bunch to be measured, acquiring the data from each bunch slot for the whole ring took more than one hour. By introducing changes to the low-level software it was possible to increase the readout speed to 16 images per second, so that sampling the whole ring (1380 filled bunch-slots) was possible in only 5 minutes. This proved to be very useful for studying the instabilities observed during the optics squeeze and while bringing the two beams into collision. Typical results, showing emittance blow-up towards the tail of some batches can be seen in Fig 4.

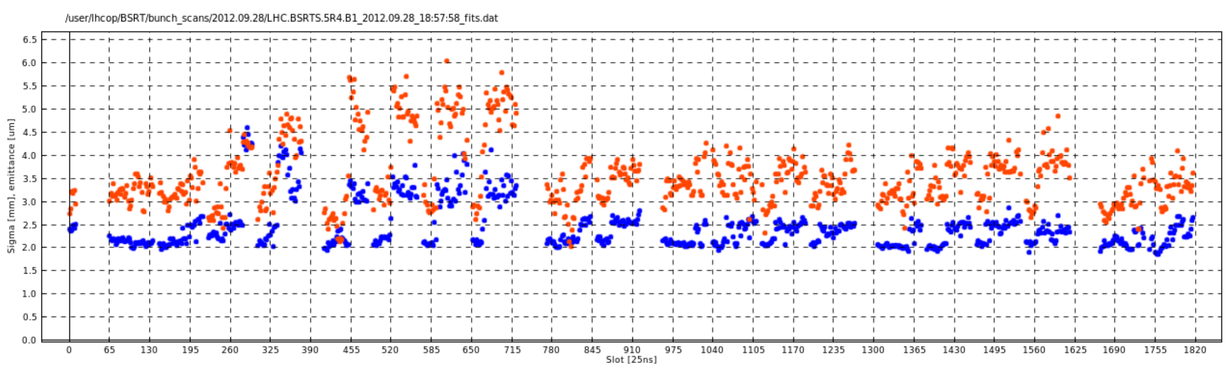



**Figure 4: Bunch by bunch emittance measurement with the BSRT (blue horizontal, orange vertical).**

As the bunch intensity was increased it became evident that the BSRT system was suffering from RF induced heating of the extraction mirror, damaging the mirror surface and deforming the mirror support. Modifications were made to both mirror and its support which improved the performance of the system. Considerable heating was nevertheless still observed and a completely new design is therefore being investigated for implementation during LS1.

## BE-CO Group

### Post Mortem Analysis (PMA)

The new data collection and grouping mechanism implemented for the LHC Injection Quality Check allows starting the data analysis before all the relevant data arrived thus saving time while filling the LHC. The saved time is estimated to be 1 hour of LHC physics per 5 days and will increase with the number of bunches.

### The Logging Service

TIMBER, the interactive graphical tool of the Logging Service is used extensively in the CCC and from office desktops (as shown below). Its functionality was significantly enhanced with the release of version 5.


## BE-OP Group

Following an excellent year in 2011 in which ~5.5 fb-1 of proton-proton collisions at 3.5 TeV were delivered to both ATLAS and CMS, the 2012 run was intended to further extend performance reach. For the 2012 run, beam energy was raised to 4 TeV, the beta squeeze target was set to 60 cm, and the target average bunch intensity set to 1.6x1011 protons. To ensure expedient luminosity delivery it was decided to continue with 50ns bunch spacing, and push back the 25 ns scrubbing program to late in the 2012 run.

The 2012 LHC run eventually exceeded expectations, with a final delivered luminosity of over 23 fb-1 for both ATLAS and CMS, and the mid-year announcement of the discovery of a Higgs-like particle. This excellent result, along with a proton-lead pilot run, a high-beta physics program at 1km, a 25ns scrubbing run and pilot 25 ns physics fill, and a vigorous machine development program, underlined this highly successful run.

After short periods of hardware commissioning and beam commissioning, physics operation started on the 4th of May and continued until the 17th of December, since the run was extended to maximize the dataset for studies of the newly discovered Higgs-like particle. LHC machine availability for the 2012 proton-proton run is defined by the run period after commissioning, but excluding technical stop and machine development periods. Around 37% of the run was spent in physics (stable beams) operation for a total of ~1757 hours of physics, compared to 32% in 2011. For proton-proton operation, the default filling scheme was with 1374 bunches per beam and 50ns spacing between bunches, which gave 1368 colliding bunches in ATLAS and CMS, 1262 in LHCb, and no colliding bunches in ALICE. Due to detector constraints, ALICE data taking was done with collisions generated by main bunch-satellite bunch collisions, which gave a reduced rate compatible with the ALICE detector. With the schedule and availability as outlined above, the machine was able to deliver integrated luminosities of 23.3 fb-1 for both ATLAS and CMS and over 2.1 fb-1 to LHCb.

The typical target bunch intensity at injection was 1.6x1011 protons per bunch, which translated into a bunch charge of ~1.5x1011 protons at declaration of stable beams. Beam instabilities during the squeeze and before colliding the beams were a serious concern all along the run, resulting in August in a flip of the Landau octupole polarity. The Landau octupoles had to be pushed close to their nominal current, and the most effective cure for the instabilities was the head-on beam-beam effect. As a consequence no instabilities were observed with stable colliding beams. The tight collimator settings associated to the small beta* required improved orbit stability during the squeeze, this was achieved with a combination of higher orbit feedback bandwidth and feed-forward of the corrections. Transverse emittances stayed relatively constant over the year despite the mid-year move from the Q26 to Q20 SPS optics which significantly reduced the transverse emittance at injection. This improvement in emittance at injection could not be translated into gains for collisions, the source of emittance blow-up in the ramp being still unknown.

Operating the LHC with stored beam energies that reached up to 140 MJ was only possible due to the experience with and confidence into the machine protection systems gained in the two previous running periods, when the stored beam intensity was slowly increased. The intensity increase in May 2012 was quick and not limited by machine protection issues. UFOs continued to affect operation with approximately 20 beam dumps, but a good conditioning was observed during the run, as well as during the 25 ns scrubbing period.

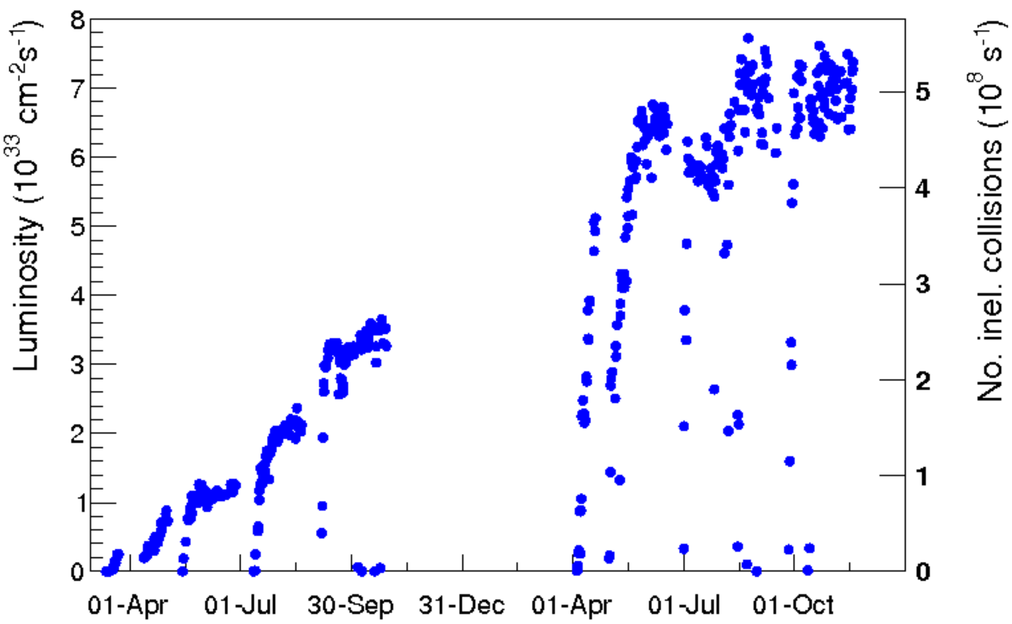



**Figure 5: Evolution of the peak luminosity in 2011 and 2012.**

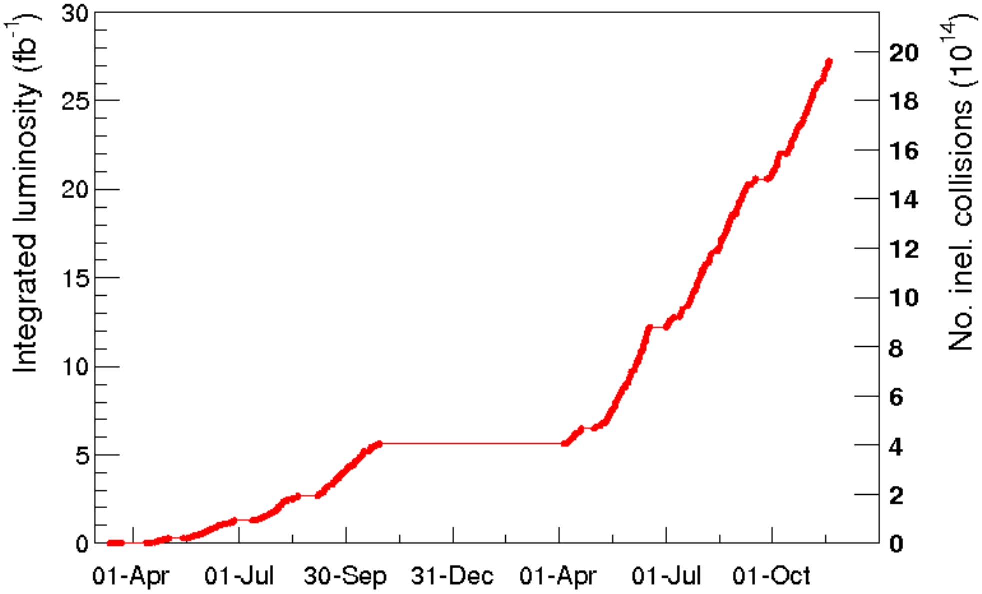



**Figure 6: Integrated luminosity in 2011 and 2012.**

## BE-RF Group

### LHC Operation RF

The year 2012 will be remembered as the *annus mirabilis* of the LHC for a long time – not only the discovery of the Higgs, also the performance and reliability were beyond expectations. The BE-RF group has significantly contributed to this success: The LHC RF system performed very well and did not limit the evolution of peak or integrated luminosity. The increased single bunch intensity (up to $1.65 \cdot 10^{11}$ ppb) did not introduce longitudinal instabilities or led to klystron saturation. Klystrons were routinely operated with up to 165 kW at flat top ($V_{RF} = 12$ MV). Capture losses were negligible (below 0.5%) with the injection voltage at 6 MV. The RF systems contributed on average less than 1 trip per week to the fault statistics, getting better over the year. But also those few trips were carefully analysed and addressed. The two main culprits found were spurious crowbar events of the old technology thyratrons and "filament current" errors, caused by old high-voltage connectors, recuperated from LEP and now seriously ageing. Figure 7 shows the solutions studied or in implementation addressing these two issues.

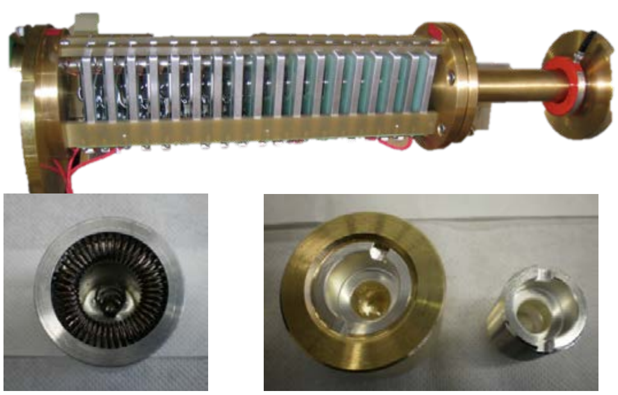


**Figure 7 top: Thyristor-stack to replace thyratron; bottom: old technology HV connector (left), new, improved version (right).**

The transverse damping system, a.k.a. ADT, has become an essential tool to operate the LHC with nominal beam current; it takes care of injection and abort gap cleaning, it damps injection oscillations, is now fully compatible with the BBQ tune measurement system and is itself capable of measuring the tune as illustrated in Figure 9. In 2012, the bandwidth of the ADT system was increased to be fast enough for bunch by bunch selectivity. It also proved useful for well controlled, beam induced quench tests.

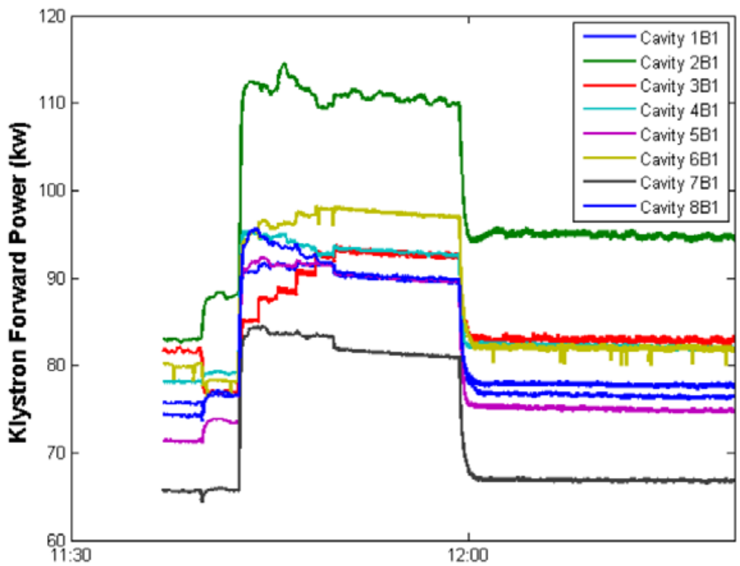



**Figure 8: Average klystron forward power, 654 bunches, fill 3327, demonstrating the "full detuning" scheme for reduced power need, description see text.**

The "nominal" LHC beam current with 25 ns bunch spacing is 0.58 A. The RF/LLRF systems are currently set up for extremely stable RF voltage (minimizing transient beam loading effects). If this scheme is preserved, more than 200 kW of klystron forward power would be required for beam currents above nominal. An alternative scheme has been proposed; it tolerates phase modulation of the cavity field due to transient beam loading by the beam gaps while adjusting the voltage phase set point accordingly, bunch per bunch.

This scheme would allow the present ACS system to deal with beam currents of up to 1.1 A, compatible with the HiLumi-LHC upgrade. The scheme was thoroughly validated in MDs through 2012; Figure 8 shows the average klystron forward power during an MD Fill: A 6-bunch batch is injected at 11:40, a 144-bunch batch at 11:43, and then more batches are injected to reach 654 bunches total (50 ns spacing). The adaptive algorithm is switched on at 12:00 and the klystron forward power is reduced in a matter of seconds.

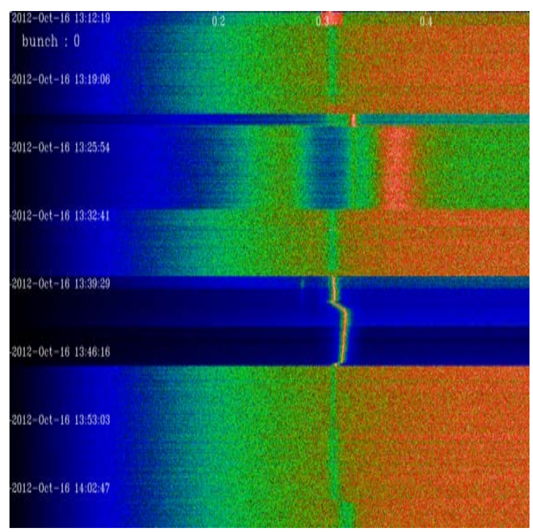



**Figure 9: Extraction of the tune with the ADT, tune (abscissa) vs. time (ordinate). The blue band indicates operation at low damper gain, where the tune appears as a peak, while with high damper gain, it appears as a notch.**

## Proton-lead collisions

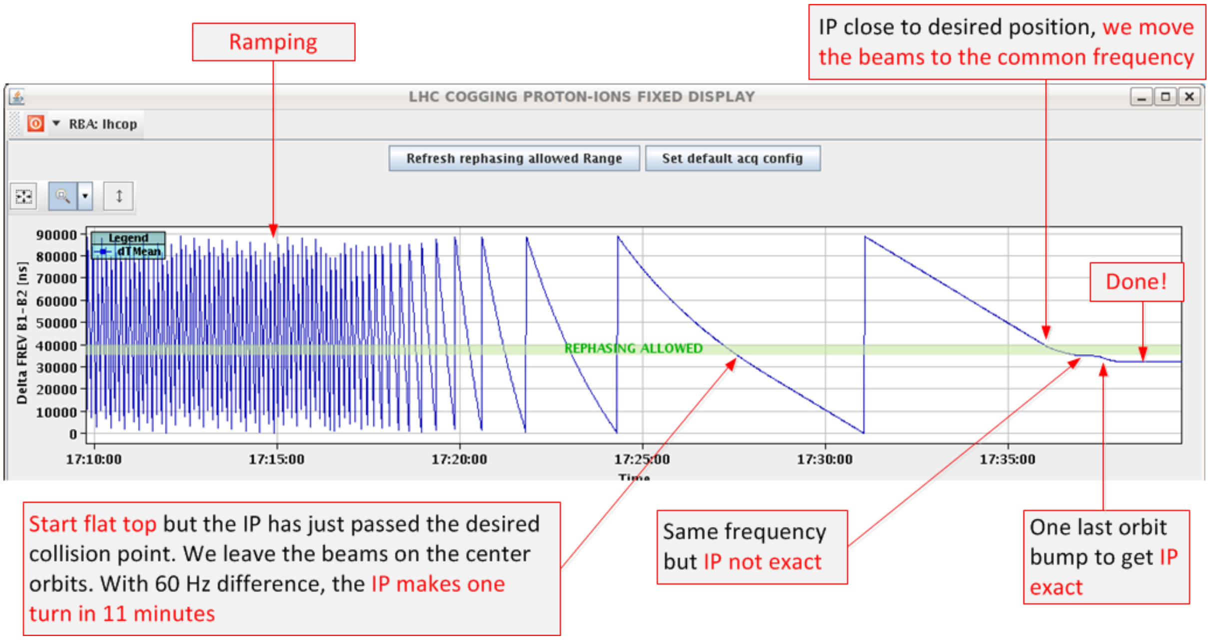



**Figure 10: Time Interval between the passage of reference bunch zero of both beams during ramping and rephasing.**

Preparing for the physics run scheduled in early 2013, the p-Pb pilot physics fill took place in 2012. The two LHC rings see identical dipole fields and, to keep the orbit centred, the RF frequencies must be different at injection. At 450 GeV p-equivalent, the capture frequency is 400.788860 MHz for p and 400.784200 MHz for Pb. Acceleration proceeds with independent frequencies. As the Pb become more relativistic, the frequency difference reduces down to 60 Hz only at 4 TeV. On the flat top, the two rings are smoothly brought to the same frequency, resulting in a +0.3 mm average orbit offset of the p ring and −0.3 mm offset of Pb ring. Following this, the two rings are locked, but the *Encounter Point* is not in the detector yet; reference buckets “0” can actually encounter anywhere in the 27 km long ring. The two rings are then gently cogged to achieve crossing in the detector. This takes 11 minutes maximum. Figure 8shows the complete process from the start of the ramp. It shows the Time Interval between the passage in an RF pick-up of reference bunch zero of both beams. The full rephasing procedure takes 15 minutes maximum after reaching 4 TeV.

## Higher-brightness beams for the LHC

Following preliminary tests with higher-brightness beam variants in 2011, new hardware was developed and installed in the low-level RF system to remove limitations related to double-batch injection on h = 9 and to the operation of the RF loops with more harmonics along the cycle. A first test fill in the LHC with a higher-brightness 50 ns variant from the PS took place in August, mainly to check the behaviour of the collider with a small transverse emittance beam.

After verification of the batch compression scheme and with the new hardware in place, significantly more complicated RF manipulations became possible. The so-called BCMS scheme (Batch Compression, bunch Merging and triple Splitting) was demonstrated (see Figure 11) in second test fill of the LHC early in December. Again, 4+4 bunches are injected into h = 9 from the PSB, but batch compression proceeds to h = 14. Following bunch merging to 4 bunches on h = 7, each bunch is triple-split to yield 12 bunches on h = 21. Thanks to the new low-level hardware, the radial and beam phase loops operated at five different harmonics ( $h = 9, 11, 13, 7, 21$) during these manipulations. Trialled at 1.4 GeV (kinetic), the BCMS scheme was later set up on an intermediate flat-top at 2.5 GeV to avoid longitudinal acceptance limitations. Compared with the nominal LHC beam variant, the splitting ratio in the PS is halved with the potential of a commensurate gain in beam brightness. The LHC test fill with the 50 ns BCMS beam (24 bunches per PS batch) produced about 1.5 times more luminosity per bunch crossing with respect to the nominal beam. At the very end of the 2012 run, the 25 ns BCMS variant – with fully twice the brightness of the classical 25 ns beam – was taken by the LHC and brought to collision. This led to the decision to adopt the 25 ns BCMS variant as the baseline for luminosity production after LS1.

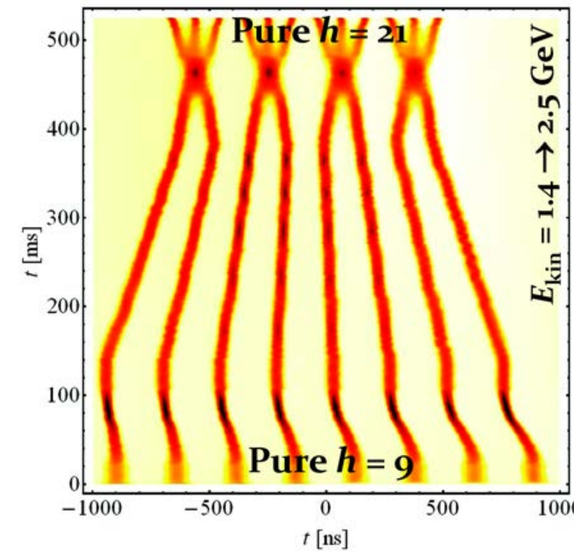



Figure 11: Measured bunch profiles during the BCMS RF manipulation following acceleration on *h*=9 to an intermediate flat-top at 2.5 GeV

# High Luminosity LHC (HL-LHC) – LHC Upgrade

## BE-ABP Group

The LHC upgrade studies progressed considerably in 2012 in the context of the HiLumi Design study. In this framework, the Work-Package (WP) 2 responsible for the beam dynamics and performance of the HL-LHC project had three key main objectives which were all successfully reached. The first one was to define a few possible sets of optics (β*, crossing angle) and beam parameters (emittance, bunch spacing, bunch charge). 2012 marked the end of the first series of validation tests with beam of the ATS optics, where β* in the range of 12-14 cm was achieved and measured at IP1 and IP5 in a dedicated machine experiment. The second key objective of WP2 was to develop a baseline layout for the HL-LHC, including a complete set of specifications for the new equipment, in terms of strength, length and mechanical acceptance. The third key objective of WP2 was to start the analysis of this optics in terms of long-term stability (so-called dynamic aperture) and deduce from this analysis first specifications for the field quality of the new magnets. In the HiLumi-WP5, devoted to collimator upgrades for the HL-LHC era with emphasis on the IR collimation, first cleaning simulations were performed using the baseline ATS optics. Potential issues with the collimation cleaning performance, associated to the large arc beta-functions as required by the ATS scheme, were identified and mitigation measures are being studied. Advanced collimation concepts for the future have been considered, too. The research on new collimator materials has also continued with high priority: operational scenarios for impedance calculations with new collimators were defined and studied. Important beam tests on candidate materials for future collimators were carried out at the HiRadMat facility.

## BE-BI Group

### Cryogenic Beam Loss Monitors

The LHC magnets close to the Interaction Points are exposed to high radiation levels due to collision debris. With the present configuration of the installed ionisation chambers used for beam loss monitoring in this region, the ability to measure the energy deposition in the coil is limited, as the debris masks the real beam loss signal. This is a critical issue for LHC machine protection in the HL-LHC era. The option of placing detectors inside the cold mass close to the coils is therefore actively being investigated. The advantage is that the signal measured by the detector then corresponds to the amount of energy actually deposited in the superconducting coil. The detectors currently under investigation are:

- Single crystal chemical vapour deposition (CVD) diamond with a thickness of 500 µm, an active area of 22 mm2 and gold as metallisation material
- P+-n-n+ silicon wafers with a thickness of 280 µm, an active area of 23 mm2 and aluminium as metallisation material

In liquid helium, the major downside of silicon compared to diamond disappears as the leakage current for silicon is below 100 pA at 400 V. The experiments performed in 2012 in the East Area of the PS allowed the effects of radiation on the sensitivity of these detectors to be evaluated at cold for the first time. Prototypes will now be installed on the cold mass of some of the existing LHC magnets during LS1, allowing further investigations to be carried out.

## BE-RF Group

### LHC Crab Cavities

Crab cavities (CCs) are now part of the baseline for future LHC. On the hardware side, a large international effort on superconducting CCs led by the BE-RF group has significantly advanced the technology development. The first CC prototypes with ultra-compact dimensions were successfully tested both at CERN and in the US. One cavity surpassed the nominal voltage by factor of 2 with the two others showing promising results, expected to reach similar performance in subsequent tests. A test of CCs in a two-cavity cryomodule in the SPS is in preparation – a dedicated Engineering Meeting took place at FNAL in December. The preliminary RF powering and control system is defined both for the SPS tests and the final LHC configuration. Several RF and beam dynamics simulations to estimate desired and undesired effects of the CCs were performed and tolerances were defined. Measurement set-up for the cavity prototypes is under fabrication. Work has progressed on the integration of the CCs with the 400 MHz system. The need for a strong short-delay feedback to reduce the cavity impedance at the fundamental frequency calls for a location of the transmitters in a gallery running parallel to the tunnel. Assuming that the beam can be centered within 1 mm, a 50 kW transmitter linked to the cavity via a circulator is sufficient. As a mitigation to possible particle losses following a single cavity failure, a feedback coupling crabbing and un-crabbing cavities around the IP has been proposed.

An operational scenario was studied, making the cavities transparent to the beam during filling and ramping, and gently bringing them in operation at flat top.

# LHC injector chain (Linac 2, Linac3, PSB, LEIR, PS, SPS, Experimental Areas and Associated Facilities)

## BE-ABP Group

The ABP group has contributed to the performance follow-up of the proton and ion beams in the injectors for the LHC and for fixed target physics and in particular has conducted machine studies aimed at reducing beam losses and identifying and eliminating sources of transverse emittance blow-up. After a challenging commissioning period LINAC2 started up in time to deliver protons. The operational period was very calm, with 99.2% uptime and a total of 4.7 1020 protons delivered to the PSB in 2012. At LINAC3, the timing and the power converter front ends had been renovated during the winter shutdown which made the start-up more difficult than usual. Over the year steady tuning of source and Linac improved the intensity and stability, such that, towards the end of the year, the Linac tuning in combination with LEIR allowed the combined accelerators to reach the nominal intensity for LHC ions (4.5 108 Pb54+ ions per bunch out of LEIR). The LHC beam performance in the injectors has greatly benefited from the implementation of the Q20 optics studied and the excellent results obtained with the BCMS scheme raise the hope for well for above-nominal performance of the LHC already for the start-up after LS1.

The mitigation of the irradiation of the extraction septum in SS16 requires the installation of a dummy septum in SS15. The design of the extraction trajectories for the new layout has been followed up by intense activities of beam-based measurements to ensure that the proposed scheme is viable. A side effect of these studies has been the reduction of beam losses on several beams.

## BE-BI Group

### PS Complex SEM-grids

Secondary emission monitors (SEM) are the workhorses used for tuning the transverse properties of the larger beams in the transfer lines of the CPS complex. The control electronics of these devices was last renovated in the 1970’s and now starts to show problems related to their age. A renovation program was therefore started a few years ago with the aim of replacing the whole control electronics. In 2012 a prototype of this system was successfully tested on LINAC3, LEIR and at the LINAC4 test-stand in order to validate the design before launching the large-scale production. At the end of LS1 the aim is to have all CPS SEM systems equipped with new electronics. In order to fully integrate these systems, new SEM control and acquisition software is being developed, offering additional functionalities to operational applications.

## PSB Injection trajectory

The present 40-year-old beam trajectory measurement system of the Linac2 to PS Booster transfer-line is undergoing an upgrade program to prepare it for use with Linac4. Prior to replacing all 20 magnetic type pick-ups and their electronics, the new prototype BPM system was tested and commissioned with 50 MeV proton beams. This used the same electronics and software foreseen for the Linac4 system. High-resolution beam position, intensity and phase measurements were successfully performed with this prototype (see Fig. 12), qualifying it for use both in the transfer line to the PSB and in Linac4. The new electronics chain does not require head amplifiers in the tunnel leading to higher reliability and easier maintenance. Based on these results the decision has been taken to replace the entire transfer line BPM system with this new development during LS1.

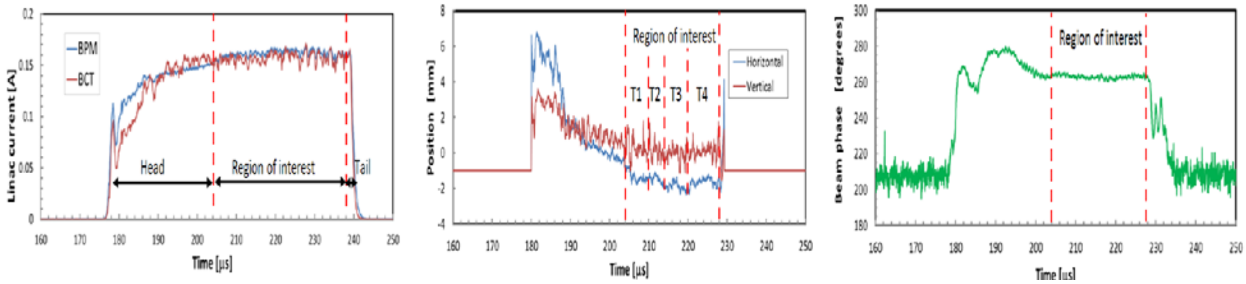



**Figure 12: Linac2 BPM results Left: overlaid BPM and BCT intensity readings. Middle: Beam positions for each of the 4 PSB rings. Right: Beam phase.**

## DC BCT for SPS Safety

The demands for operational flexibility in the exploitation of accelerators at CERN could lead to the presence of ions for the North Area and high intensity protons within the same SPS super cycle. When the North area is prepared for ions, the possibility that an intense proton bunch could be extracted represents a significant hazard to people working in the primary experimental areas. Protecting against this eventuality, an instrumented safety interlock was requested which inhibits the slow extraction if the beam intensity in the SPS is above 2E11 charges. This is based on two new DC Beam Current Transformers (DCCT) installed in LSS5 of the SPS during 2012. The redundant systems deliver two status signals to the SPS Interlock System; one indicating if the beam is above or below the threshold intensity and the other linked to the availability and status of the DCCTs (Fig. 13). Functional reliability testing has been carried out throughout the year and the complete safety interlock should be active after LS1.

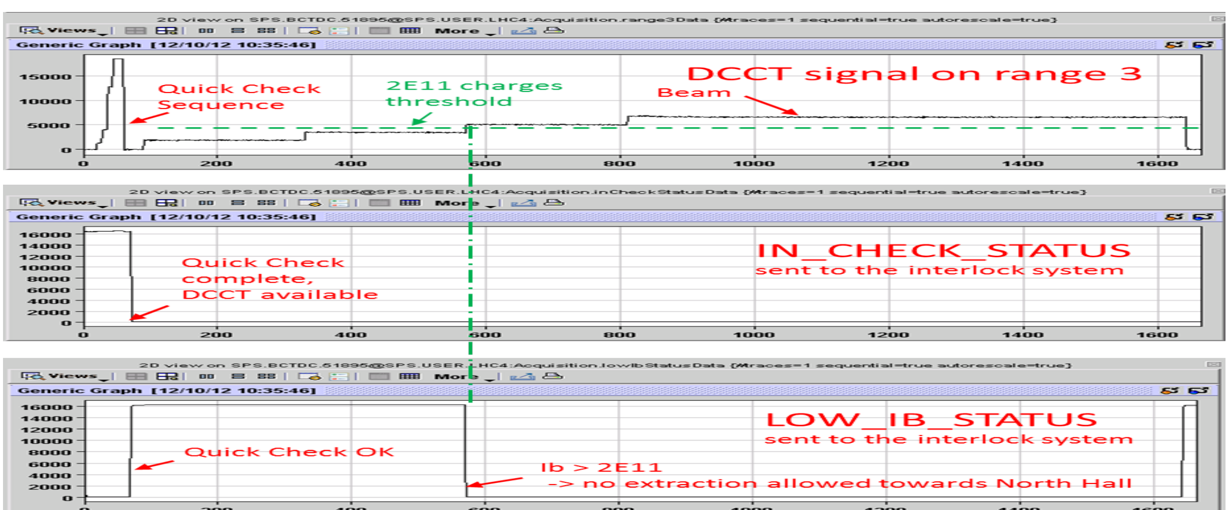



**Figure 13: Signals and interlock status bits from the new SPS DCCTs.**

## SPS Experimental Areas

After the successful deployment of GEM profile monitors on the Antiproton Decelerator (AD), the BI-EA section investigated the possibility of replacing the multi-wire proportional chambers (MWPC) in the SPS experimental areas with a GEM-type detector. Some 80 MWPCs are used for transverse profile measurement and energy spectroscopy in the experimental areas of the SPS. On these high energy experimental beam lines the intensities are much lower than in AD, requiring higher gains, while issues related to multiple scattering and annihilation are not present. With this in mind, it was possible to give priority to the robustness of the detector, producing an industrial design with low cost and maintenance needs. A ‘big’ (200x200mm) triple-GEM chamber was developed and tested towards the end of the 2012 run. The first measurements from a ‘big’ GEM prototype can be seen in Fig. 14 and show very promising results for the complete replacement of MWPC’s in the years to come.

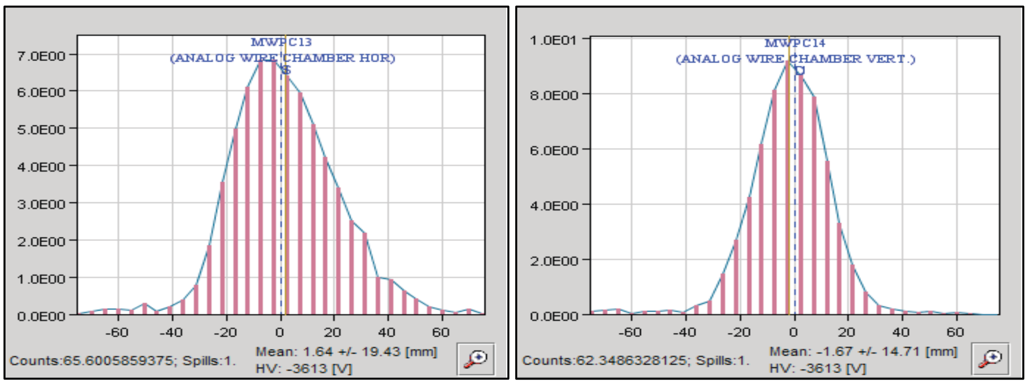



**Figure 14: Transverse profiles measured on a ‘big’ XGEM.065.057 in the M2/COMPASS line**

# BE-CO Group

## Renovation of the CERN injectors complex control system

In 2012 a complete renovation of the CERN injectors complex control system was started, based on new hardware and software solutions. The development of the new LINUX-based Front-end software architecture (FESA3) and hardware boards based on the VMEBus64x and PCIe standards progressed as planned. In parallel, a joint effort was made by all groups from the BE, TE and EN departments to finalize the roadmap and technical details for the renovation of about 350 front-end systems that will take place during the LS1 period. The hardware components provided by several major European hardware manufacturers were successfully tested and integrated into the CERN control system environment. All these efforts will permit in 2013 to start what is considered as the biggest injectors complex control system upgrade program since more than 15 years.

## The Software Interlock System (SIS)

The SIS system was deployed on the CPS and the PSB accelerators.  In the second half of the year the CTF renovation and PS/PSB Stray Field Compensation implementations were started with LN4 to follow. In the scope of the ACCOR project, it was agreed that SIS would be the solution to replace the COMPAR GM devices in all accelerators. This will be done during LS1.

### The Fixed Display Framework (FDF)

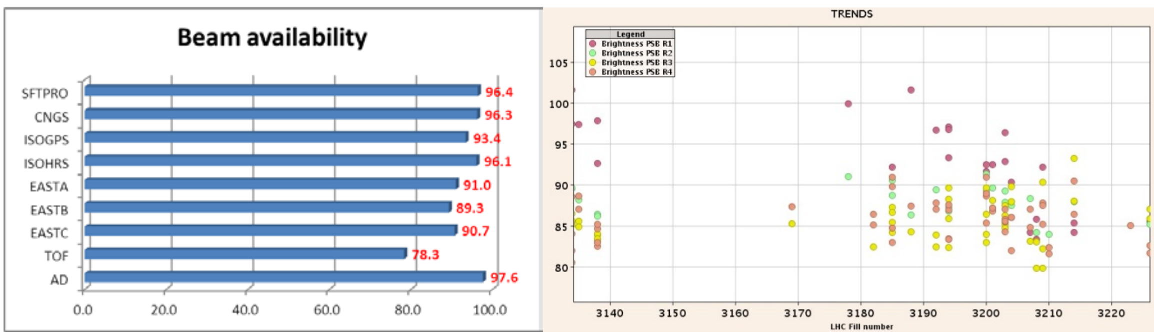
In 2012, as part of the controls consolidation of the SPS page1, several improvements were implemented:

- The BCT3/4 signal is modified per LSA cycle;
- Logbook comments can be sent to Vistars;
- An automatic LARGER swapping mechanism ;
- A new crate for the OASIS scope providing the magnetic cycle.

## BE-OP Group

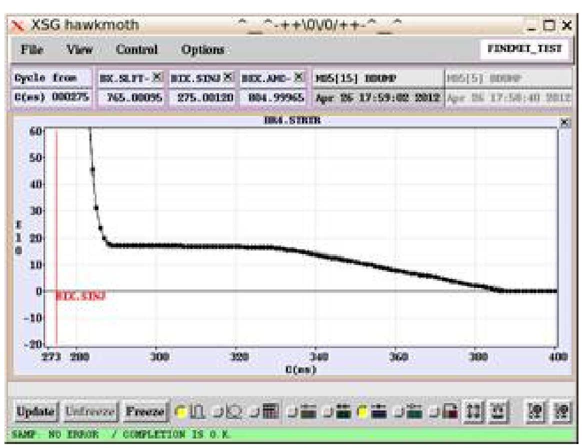
### PSB

The Booster has served for another year as one of the backbone accelerators of the LHC proton injector chain and of CERN’s fixed target physics program. For the LHC type beams, an automatic logging was put in place to record the brilliance of the beams extracted from the PSB. Beams were delivered to the LHC with highest availability and quality, and in excess of the original specifications. For the fixed target program, the Booster has delivered beams to its experimental facility – ISOLDE – and to the downstream synchrotrons.




**Left: beam availability for the fixed target users. Values for TOF and EAST are underestimated for technical reasons. Right: logged beam brilliance for LHC beams in the PSB.**

In the frame of the LHC Injectors Upgrade Project, machine development sessions were held and new hardware was tested. A highlight was the capture and acceleration of beam with the new Finemet RF cavities on 26 April 2012.




**First beam captured and accelerated with the new RF system. The picture shows intensity as a function of time along the PSB cycle.**

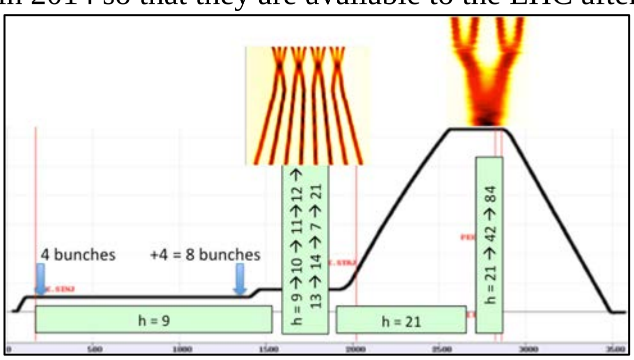
2012 was also the year of the 40th anniversary of the PSB. The event was commemorated with articles in the CERN Courier and the Bulletin, and a festive colloquium was held with speakers from the early days of the PSB.

## PS

After a short winter stop, during which only urgent maintenance work was done, the PS started setting up with beam during the last week of February. Throughout the preceding hardware test period the TE-EPC team successfully tested some degraded modes of POPS that will allow continuing to run with POPS under certain scenarios when some parts of POPS are out of order, using the redundancy that has been built in.

The beams required for the LHC, nTOF and CNGS were fully available during the second week of March.

The PS working point control is normally done with the low energy quadrupoles up to about 3.5 GeV after which the PFWs take over until the beam is extracted. As a feasibility test the nTOF working point was setup not using the low energy quadruples, but by using the PFWs from injection onwards. Since the test was successful the nTOF beam was produced successfully during the whole of 2012 in this configuration, providing a valuable input for the LHC injector upgrade project. Later in the year a similar and also successful test was made with the LHC production beam and transverse beam profile measurements did not show any sign of blow-up, which was considered a potential issue, hence providing more valuable input for the LIU project.
Throughout the 2012 run many machine development studies were performed, on various subjects, mainly in view of the LHC injector upgrade. For these studies the PS operations team prepared many different beams with often very specific beam characteristics. Most of these concerned space charge related studies and the preparation of the new production scheme of the LHC beams. The latter uses rather complex RF manipulations such as batch compression, bunch merging and bunch splitting, with the aim to increase the beam brightness, hence the luminosity produced in the LHC. Towards the end of the run the LHC successfully injected and accelerated the beams produced with this new scheme, as a test. The aim is to make these beams operational in the injector complex in 2014 so that they are available to the LHC after LS1.




nTOF and CNGS both made an early start and profited from an extension of the run at the end of the year. In January 2012 the integrated intensity for the 2012 nTOF run was estimated at 1.55x1019 p.o.t. However thanks to the good machine availability, the run extension and the good machine performance 1.9x1019 protons could be accumulated on the nTOF target, about 23% more than anticipated.

## SPS

Never was the SPS sending so many different beams to so many users as it did during the long and successful run in 2012.The production beam to the LHC reached brightness levels never obtained before (1.7 x1011 p/bunch with an emittance < 1.8 micron). This performance was partly due to the new Q20 optics, which became the standard operational optics since September 2012. Towards the end of the year, the SPS prepared the ion beam and the 200 ns proton beam for the LHC Pb-p operation, which was required immediately after the Christmas holidays. A special beam was set up for CNGS, using a 100 ns bunch train, in order to perform time of flight measurements. For the standard run we accumulated 3.84x1019 protons during what turned out to be the final year for CNGS. In spite of some vacuum leaks in the heavily corroded splitter area of TT20, the fixed target proton run finished with an honourable 80% of beam availability. In 2012, COMPASS resumed production and the SPS was sending again 2.5 1013 protons on the T6 target. Towards the end of 2012, Pb-ions were sent to the north area targets to create heavy ion fragments for NA61. For this experiment, the ions had to be accelerated and extracted at three different energies. The HiRadMat facility was heavily used in 2012. About a dozen experiments used the whole pallet of available proton beams in the SPS in order to hammer, melt, evaporate or explode different material.

It was an exciting and successful year indeed, but the SPS started to show also some signs of aging and fatigue. The corrosion in TT20 was already mentioned, but the SPS suffered also from more and more missing monitors, cracks in TT10, flooding in BA2/LSS2 and failing high voltage cables. SPS will be refurbished during LS1, and, after some surgery she will come back in 2014.

## BE-RF Group

### PSB

For the digital LLRF system, progress was significant through 2012: Many megabytes of source code have been written and validated for both operation and laboratory tests. Effort has been dedicated to the development of software tools for the management of the memory map and for the generation of automatic drivers ("Cheburashka"). Python scripts were devised for interactive or automatic test in the laboratory of the hardware boards. The PSB will restart in 2014 with 5 operational DLLRF systems, one for each ring plus one for "ring 0", which will be interfaced to both ferrite and Finemet HLRF systems and could control the beam in any of the four PSB rings, in parallel with normal operation; this "ring 0" system will be used for special MDs or for validating new features. The 5 Finemet® cavities installed in ring 4 were integrated with the cavity controllers and the new LLRF system (including gap relay control, amplitude and phase loop, adjustment of phase relative to C02 cavity) and very successfully tested in June – with 8 injected turns, 6 A of beam (or $4.6 \cdot 10^{12}$ protons) were successfully accelerated.

### PS

The 50 ns production beam for LHC physics was optimized throughout the run and yielded a bunch intensity of up to $1.9 \cdot 10^{11}$ ppb regularly extracted from the PS.

### SPS

Also the SPS RF systems demonstrated high reliability and performance, thanks to experienced, committed staff and – for the high power systems – a strict "two tested spares for every component" policy. This policy pays off: 2012 had the best fault statistics over the last 10 years.
Longitudinal stability of the high intensity proton beam in the SPS is achieved by Landau damping, using a fourth harmonic (800 MHz, TWC800) RF system operated in bunch shortening mode. There is presently no compensation for the transient beam loading in these cavities. The

LLRF regulates the amplitude/phase in the middle of the 8 μs long proton batch. The travelling cavity filling time is 320 ns and transient beam loading therefore distorts the RF field in the head of the batch. This makes for an inaccurate phasing of the harmonic voltage with the fundamental. It also results in a varying synchrotron frequency along the batch. As longitudinal blow-up is achieved by injecting phase noise around the calculated zero-amplitude synchrotron frequency, the spread results in a varying longitudinal emittance along the batch at transfer into the LHC. A new LLRF is being designed. It includes One-Turn Delay feedback, feed-forward, longitudinal damper acting via the cavity field (dipole and quadrupole mode) and longitudinal blow-up (via phase or amplitude excitation).

The high-power RF system for the TWC800 is being upgraded to an IOT based system; after successful Factory Acceptance Test in 2011, we received our first pre-series transmitter. Then 2012 was marked by its long and difficult test phase: we observed a very strange phenomenon: The system was unstable after several hours of operation. We found out that all trips of the new system were correlated with the time of the day as indicated in Figure 15. After careful analysis, the system trips turned out to be due to insufficient protection of the transmitter against incoming RF from an LLRF generator (a typical EMC problem). We changed the LLRF generator and we were able to perform several tests of more than 1'000 hours without a single fault. The series production as so been launched in late 2012.

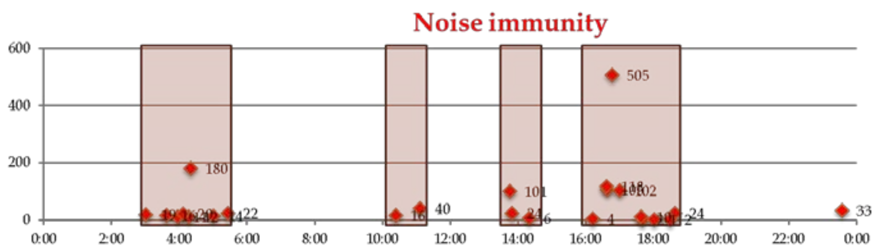



**Figure 15: Correlation of 800 MHz IOT system trips with the time of the day**

The 200 MHz amplifier upgrade project has equally made good progress: Market Surveys for the drivers and finals have been launched in early 2012. 17 companies qualified for the drivers, 7 for the finals. Technical specifications took account of the problems encountered with the 800 MHz IOT systems as well as the experience gained with the 1 kW SSPAs for HIE-Isolde. The new BAF3 building studies have been validated. The infrastructure has been approved by all involved. Even if we do not know yet which amplifiers will be selected (Diacrode®, SSPA or tetrode), the overall external envelope has been defined, and the amplifiers suppliers will have propose compatible solutions.

### LEIR

In the 2012-2013 ion run, a special effort was dedicated to optimising the LEIR machine so as to produce the ion intensity required by the NOMINAL beam. Thanks to several MDs, which targeted also an optimisation of the various LLRF parameters, an intensity of exceeding the $5 \cdot 10^{10}$ charges required by the NOMINAL scheme was provided, within the limits of the longitudinal emittance allowed by the PS machine and the subsequent accelerators chain.

### Hadron Linacs

Operation of the hadron linacs did not see any major disturbances in 2012. On the contrary, despite the prolonged running periods, the downtime due to RF related faults for Linac2 was at a record low of less than 3 hours, while there was zero downtime for Linac3. A result that can be clearly attributed to the expertise of the RF technicians and their preventive maintenance efforts that now pay off. At REX the upgrade of the 202 MHz, 130 kW has started, which will be completed in 2014 with the goal of adapting the RF system to the increased operational demands in the coming years (HIE-ISOLDE phase 1).

### Ions

During the LHC Pb-Pb run in 2011, the bunch intensity was very uneven along the batch injected into the LHC. In addition to other causes, RF noise was contributing much to the problem. Instigations without Pb beam were conducted in 2012 and the source was identified as the 500 MHz reference clock used in the Master DDS. During the p-Pb run, this clock was replaced by a commercial 500 MHz OCXO (Oven-Compensated Crystal Oscillator) with observed improvement to the intensity lifetime along the 39.6 s long Pb filling time.

# LHC Injector Upgrade

## BE-ABP Group

### PS Booster Upgrade

The study of the beam dynamics implication of the H- injection at 160 MeV from LINAC4 in the presence of high space charge tune spreads has been pursued. Emphasis has been put on understanding the performance and limitations of the existing codes and in particular of the PTC-ORBIT code in collaboration with KEK, in the collection of experimental data for benchmarking purposes and in the simulation of the beam injection and low energy part of the ramp. The impact on losses and emittance blow-up of some of the hardware choices proposed for the injection layout (e.g. replacement of two main bending magnets with shorter ones to allow for more space in the injection area, and Inconel vacuum chamber for the chicane magnets) have been investigated. The studies did not evidence any showstopper for these two possible options so far. The accuracy of the evaluation of the space charge effects relies on the availability of a detailed magnetic model for the PSB main magnets. This information is not available but can be inferred from beam measurements. The measurements and their analysis have started in 2012 and have allowed to validate the instrumentation requirements (turn-by-turn orbit acquisition should be made available in 2014) and the measurement methods and to get the first measurements of the quadrupolar errors and magnet misalignments for all the four PSB rings.

### PS Upgrade

The beams required for the LHC Upgrade are characterized by an extremely high brightness and therefore are subject to space charge effects also in the PS machine even after an increase of the injection energy from 1.4 to 2 GeV as proposed in the frame of the LIU project. Differently from the PSB the beam in the PS remains at injection energy for a longer period (1.2 s compared to few ms in the PSB) and for that reason space charge effects have to be studied over much longer time scales. The tools required for such studies are being evaluated and preliminary simulations have been performed with PTC-ORBIT to determine short term effects. High priority has been given to experimental studies to collect sufficient information for benchmarking purposes. The modelling of the magnets of the PS at 1.4 and 2 GeV is well advanced and it has profited of the studies and methods applied for the implementation of the Multi-Turn Extraction in the PS and for the optics measurements and correction in the LHC. This has permitted to estimate and compensate some harmful third order resonances with the use of skew sextupoles. These elements have been installed in the ring during the Winter Stop and the resonance compensation tests will be performed at the beginning of 2013. Significant effort has been put on the commissioning and performance analysis of the PS transverse feedback in collaboration with the RF group: it has been demonstrated that the machine can be operated with low chromaticity and no coupling at injection and that the onset of the high energy instability (attributed to electron cloud effects) observed with LHC 25 ns beams can be delayed so that it will not occur before extraction. The impedance model started to be developed and promising results of transverse impedance localization around the ring were obtained. This will help us identifying the major contributors and proposing mitigation measures for future high-intensity and/or high-brightness operation. A significant step forward in the quest towards higher brightness has been achieved with the setting-up of the LHC beams with the so-called Batch Compression, Merging and Splitting (BCMS) scheme in collaboration with the RF group. This has almost doubled the brightness of the LHC beams (with both 25 and 50 ns spacing) at PS extraction (at the expense of a smaller number of bunches). These beams have been delivered to the LHC for dedicated physics runs allowing increasing the specific luminosity per bunch by more than 30%.

## SPS Upgrade

The low gamma transition optics (Q20) has been put in operation since September 2012 after a thorough commissioning of all the LHC operational beams. The transition has been completely transparent for LHC operation and it has resulted in a net increase of the brightness of the LHC beams delivered by the SPS by almost 20% also seen at LHC injection. However, a persistent blow-up in the LHC from injection to collision has not yet allowed to profit of this brightness increase for physics operation (see Fig. 16). The origin of the emittance blow-up in the LHC is under investigation. The implementation of the Q20 optics has opened the way to studies for high brightness beams in the SPS and LHC (similar to those planned for the High Luminosity Upgrade) at least with single bunch beams and was used also for the ion beams acceleration in the SPS during the proton-ion run in 2013. The impedance model was also further improved with simulation studies of the kicker magnets to an unprecedented level of detail of their geometry.


**Figure 16: Brightness of the beam at SPS extraction (crosses), at LHC injection with nominal optics (triangles) and with Q20 optics (diamonds) and at the LHC in collision (circles). For the LHC data: Beam 1 is indicated with full labels and Beam 2 with empty labels.**

# BE-BI Group

## PS Ghost and Satellite Detection

The presence and desired control of satellite and ghost bunches for the LHC physics runs have implied systematic longitudinal beam intensity analysis in the LHC injector chain. In the PS, an existing wall current monitor (WCM) was used to study such parasitic particles. The beam intensity signal was acquired with a sampling frequency of 8GHz and different data algorithms were applied to differentiate nominal bunches from particles situated outside of these main bunch populations. During cycles in the PS with LHC-type beams (50ns spacing), software was put in place to continuously acquire 5 consecutive turns at the PS flat-top (80000 samples). The studies were beneficial in demonstrating the overall limitations in both the detector and its electronics and showed that averaging over several hundred turns is required to reach the expected intensity resolution. Development for a new wall current monitor was therefore started in 2012 for installation during LS1 along with improved analogue front-end electronics and a high bandwidth, high sampling rate acquisition system.

## SPS Orbit and Trajectory system upgrade

New front-end electronics and low-level software are being developed for the SPS Multiple Orbit POsition System (MOPOS). Analogue signals from each shoe-box pick-up electrode are split into three parallel detection chains with different input filters and gain stages to cover the large intensity range and beam patterns available in the SPS. A schematic overview can be seen in Fig. 17.

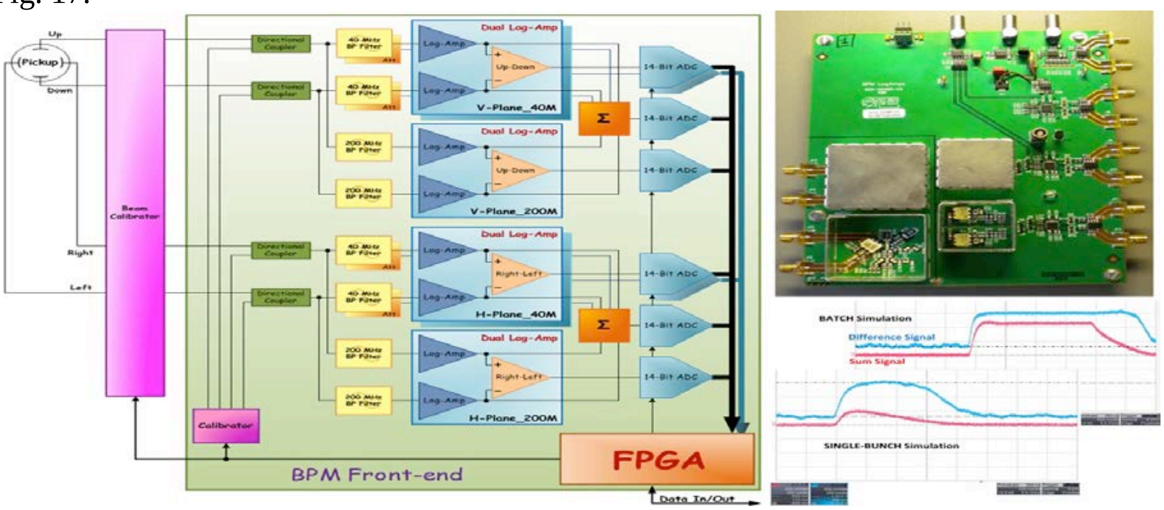



**Figure 17: Layout of the new MOPOS front-end (Left). Picture of a first PCB prototype (Top Right). Simulation of the expected intensity and position signals (Bottom Right).**

A first prototype was assembled and tested on the SPS under different beam conditions, including single bunch and 25ns and 50ns LHC bunch trains with both proton and ion beams. The overall accuracy of the system was estimated using local orbit bumps and found to be as expected. The system is now being optimised and a pre-series produced to equip part of the SPS during LS1 to allow testing in parallel with the operational system once beam is back.

# LINAC 4:

## BE-ABP Group

The volume H- ion source and extraction system were designed, produced and installed at the 3 MeV test stand, which also required modifications to the high voltage system, including multiple pulsed high voltage electrodes, vacuum system, hydrogen gas injection and RF matching network. The electron-beam dump (the performance limitation of the previous unit) was successfully tested by dumping a 2 A electron beam extracted from the - 45 kV platform of the source. The intensity of H- ions was very low, but with a polarity inversion it was shown that a proton beam was also available for RFQ commissioning if necessary. The dynamics of the pulsed hydrogen injection could be simulated and validated experimentally. A systematic investigation of the wear processes leading to ion source life time limitation was published. The design of a cesiated surface prototype was advanced to a level permitting simulation. In collaboration with the KEIO (Japan) and Orsay (France) universities, particle-in-cell simulations of the main plasma (at reduced plasma density) and of the expansion of the nominal plasma leading to beam formation in the extraction region (at nominal density) were achieved for the volume and surface sources geometries. In the LINAC4 tunnel, the Faraday cage and racks were installed in preparation for a second installation of a source dedicated to beam testing in the LINAC4 tunnel. The procurement of the Permanent Magnet Quadrupoles (PMQ) for the Drift Tube Linac (DTL) had been completed by November 2012, with all of the 70 quadrupoles necessary for the tank 2 and tank 3 both delivered to CERN, and passed the qualification process. The quadrupoles inside the drift tubes have gradients up to 25 T/m, are 80 mm, have an external diameter of 60 mm and were produced by a new European supplier (Elytt).

A new determination of the underground geodetic reference network including the 5 removable survey pillars along the main Linac tunnel and the transfer line tunnel has been accomplished. The source and LEBT have been aligned and the marking out for the jack installation have been done for the diagnostic line positions and the machine components. A complete metrology of the first Cell-Coupled Drift Tube Linac (CCDTL) module has been done in Russia (BINP, Novosibirsk) in June 2012 in order to prepare several metrology measurements that are necessary at CERN for the CCDTL assembly and the PMQ alignments. The DTL segment metrology measurements with laser tracker have also started.

## BE-BI Group

### 3 MeV Test-Stand Preparation

2012 was a busy year for preparing the 3 MeV test-stand. The BI Group was particularly involved in the setup and hardware commissioning of a diagnostics bench installed in two stages; first at the exit of the RFQ and then after the chopper line. The diagnostics bench is equipped with: 2 beam current transformers (BCTs) measuring the beam intensity as well as losses in the beam line between the 2 transformers; a slit/grid emittance meter with a complex mechanical slit construction to absorb the high temperature load expected from the 3 MeV beam; a wire grid made from 40 µm carbon wires; a spectrometer line with a wire grid measuring the energy spread of the beam; 3 beam position monitors (BPMs) measuring the beam position and deduced time of flight between 2 selected BPMs; a longitudinal bunch shape monitor (BSM) designed and constructed by the Institute of Nuclear Research, Moscow; a transverse and longitudinal "halo" monitor for characterizing the H- distribution after chopping. All systems were successfully installed and commissioned to be ready for testing with beam in 2013.

## BE-RF Group

2012 saw the completion of the Linac4 RFQ and the start of assembly of the two subsequent accelerating structures. The first segment of the Drift Tube Linac (DTL) was completely assembled with drift tubes and is confirmed to be leak-tight (cf. Figure 18). The remaining segments are foreseen to follow during 2013 and 2014 and high-power tests of a first complete tank are scheduled for early 2014. During November 2012, a team of technicians from BINP, Novosibirsk, assembled the first 2 modules (out of 7) of the Cell-Coupled DTL, which were subsequently vacuum-tested and prepared for high-power conditioning (cf. Figure 19). The high-power tests of the first module have started and will continue in 2013, which will also see the completion of the CCDTL assembly as well as the conditioning of most of the 7 modules.
The coaxial cables returning measurements to the LLRF (cavity antenna, waveguide couplers) and sending signals to the klystrons (RF drive) have been installed in 2012. All cables were tested via TDR, with their end shorted and terminated. The reference line has also been installed with all the couplers. Each transmitter (klystron or tetrode) has a LLRF system in private VME crate installed in the Faraday Case on the surface. All VME crates, partially with custom-designed boards, have been installed and with CPUs linked to the network. These control all RF systems, including the chopper and the RFQ tuner.

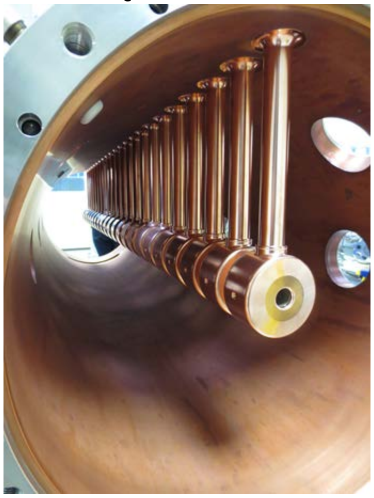


**Figure 18: First segment of Linac4 DTL with drift tubes.**

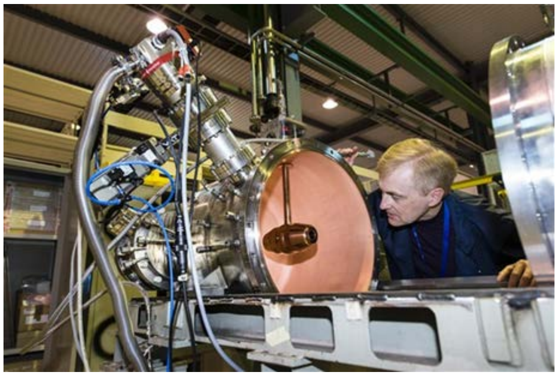


**Figure 19: Assembly of first Linac4 CCDTL module in SM18.**

# Neutrino Factory Studies

## BE-ABP Group

### LAGUNA-LBNO Studies

The contribution to the LAGUNA-LBNO study has started with the design of a High Power Proton Synchrotron. Two preliminary versions of the lattice (one for a maximum energy of 50 GeV and the other for a maximum energy of 75 GeV) based on negative momentum-compaction optics (similarly to that proposed for the PS2 study) and on a three-fold symmetry have been proposed. A conceptual design of the collimation system is being worked out.

### EUROnu Project

The group has coordinated and contributed to the design of a Beta Beam facility and has contributed to the design of the front-end of a Neutrino Factory in the frame of the European FP7 project EUROnu which ended in August 2012. The work consisted in doing final experimentation, analysing and summarizing the findings from four years of work. And last but not least, to propose methods and procedures for estimating the cost of the different facilities as well as possible and weighing this to the physics reach and to setting up a ranking of the three possible options. Relevant for the costing exercise were new physics results that came out in March 2012 and transformed the design of all the facilities, from a very versatile and rather expensive design to a more targeted design with reduced parameter-space. The complete costing of the Beta Beam facility was done together with the other two EUROnu facilities to arrive at an analysis that could be used for a comparison of the facilities. A recommendation to the European Strategy from EUROnu was to promote the Neutrino factory as the facility of choice, but that the Superbeam could do very well with a considerably smaller cost.

# Medical Related Experiments

## BE-ABP Group

### A Facility for bio-medical experiments with LEIR "Bio-LEIR"

The Low Energy Ion Ring LEIR has to be maintained and operated for the LHC and SPS ion physics programs, but is not fully used. Upgrades and modifications to allow for additional experiments on radiobiology and other studies of interest for hadron therapy centres have been further investigated. The motivation is that for a modest additional investment, light ion beams can be provided to users. A first design of the slow-extraction and of the transfer lines from the extraction to two target stations has been produced and it is being documented.

## BE-OP Group

### MedAustron

MedAustron is a facility for light-ion cancer treatment and research in Wiener Neustadt, Austria. The partnership between CERN and the EBG MedAustron company concerns the development and production of a synchrotron based accelerator complex. The project started under CERN guidance in 2008 and has hosted so far more than 50 EBG MedAustron employees in the BE-OP-MED section with the goal to acquire all relevant knowledge, to build and procure the required components and subsystems. 2012 marked the successful completion of the MedAustron injector test stand operation at CERN. The aim was to qualify the injector's beam with the first of three ECR ion sources, part of the low-energy beam transfer line with beam diagnostics and a newly developed Radio-Frequency Quadrupole (RFQ). Test stand operation finished in December 2012 with the achievement of the nominal proton and carbon beam performances at RFQ exit. With the completion of the MedAustron building in Wiener Neustadt in October 2012, installation of the particle accelerator started with the placement of accelerator infrastructure and support systems, vacuum equipment, the first batch of power converters, all IT and control system equipment as well as the on-site verification of the machine protection system. The majority of control system components was remotely installed, configured and operated from CERN to ensure readiness for accelerator commissioning. Magnet acceptance tests and magnetic measurements will continue at CERN until 2014, before magnets are shipped to Austria for installation, following the established production schedule. The production and testing of the synchrotron RF system that is based on CERN's recent developments for the PS Booster, will be completed by the end of 2013. These are the remaining activities to be carried out at CERN in the successful CERN/MedAustron technology transfer project. Design and development of all particle accelerator components, control system and operation concepts have been completed within the established project schedule from 2008 to 2013. With these achievements the focus shifts to accelerator commissioning carried out on-site in Wiener Neustadt and marks the completion of a successful knowledge-transfer project at CERN.

# AD/ELENA

## BE-ABP Group

Over the year, the technical design has progressed. Integration studies are well advanced and show that enough space is available for the different components to be installed. Various required new magnets are in the technical design stage and a bending magnet prototype, aiming at verifying field quality with very low magnet strengths, is under construction. The optics of the AD to ELENA transfer line has been refined and first modifications of the first part of this line, used as well to bring antiprotons from the AD to experiments, will be implemented during LS1. Optics solutions for all the electrostatic transfer lines from ELENA to experiments exist and electrostatic focusing and deflection elements are in the design stage. A Technical Design Report describing the machine is expected by the first half of 2013.

# BE-OP Group

## AD

A relatively trouble-free start-up in April permitted careful setting-up of the AD machine. As well as performing machine studies, a significant amount of time was spent at low energies where setting-up is slow and where parameters for beam-cooling are especially important for good efficiencies in both the AD and at the experiments. As a result, emittances of the extracted beam remained small throughout the run and previously observed degradations needing re-tuning could be avoided. Further studies included reduction of longitudinal emittances in view of optimizing design and operation of the transfer line from AD to ELENA as well as establishing correct optics models for the present transfer lines to the experiments.

At the end of the run, the AD had totalled 5360 hours of physics with a beam availability of 90% and with an AD machine availability of 95% - all these being new records.
On the experimental side, much progress was made including:

• Commissioning of several new experimental set-ups:
  - ALPHA2: start-up and running-in of a new apparatus which includes a separate antiproton catching/accumulation trap as well as a trap for antihydrogen formation and laser spectroscopy.
  - ATRAP1: Installation of a new experiment aimed at studies of the magnetic moment of (1) trapped antiproton. First measurements results are already at hand with a precision of 10-6.
  - ATRAP2: Tests and debugging of new apparatus aimed at antihydrogen spectroscopy
  - AEGIS: First successful antiproton trapping, continuing installation of main components including the 5T solenoid and detectors. This experiment will perform gravitational studies on ultra-low energy antihydrogen.

• Progress at ASACUSA: antihydrogen beams from the CUSP trap have been observed for the first time.

• End of ACE: The 2 last dedicated runs were done to complete the program of medical studies with antiprotons and live cells.

# BE-RF Group

The ELENA RF work package includes the design, development and deployment of the HLRF and LLRF systems, In addition, the RF work package includes the design, development and deployment of a longitudinal diagnostic system providing the beam phase information to the low-level RF system, the intensity measurement for bunched and debunched beams and the measurement of $\Delta p/p$ for debunched beams to assess the electron cooling performance.
Much progress was made on the definition of the ELENA cycle, harmonics and voltages required. On the longitudinal diagnostics side, the baseline system for providing the required beam parameters and signals was defined as based upon two ultra-low-noise AC beam transformers.

# REX/ISOLDE/HIE-ISOLDE:

## BE-ABP Group

REX-ISOLDE experienced a smooth and in general problem free, but very dense, year of operation. The running of the machine, using stable beams, was extended to the middle of February 2013 in order to accommodate HIE-ISOLDE related beam developments, such as transverse and longitudinal emittance measurements, RF-phasing tests, and validation of beam diagnostics equipment aimed for HIE-ISOLDE. Preparatory tests for the TSR@ISOLDE were also performed and it could be demonstrated that very low mass-to-charge ratios, down to A/Z = 2, can be accepted and accelerated by the Linac. This is of major importance as the ring, and its physics programme, request highly charged ions. With three new elements (He, K and Ti) and 15 new radioactive isotopes being delivered for physics during 2012, REX-ISOLDE has now broken the 100 isotope wall and can list in total 33 different accelerated elements. The new experimental setups which were used for the first time during 2012 will broaden the physics reach of REX-ISOLDE further. In addition, at the autumn INTC meeting an impressive 31 new letters of intent for REX/HIE-ISOLDE experiments were received, most of them triggered by the higher beam energies available in the future. This is promising and assures an equally dense experimental programme also after LS1. In the frame of the HIE ISOLDE Linac monitoring project, a new HBCAM camera development has started in collaboration with Brandeis University and very promising results have been obtained. In parallel, series of tests began to validate new types of multidirectional retro reflective targets for super conducting RF cavities and solenoids. The first results show satisfying geometrical performances as well as a good compatibility with vacuum. After the HIE-ISOLDE upgrade, the physics interest at REX could be further invigorated by the installation of a storage ring, and the feasibility of using the Heidelberg Storage Ring TSR, moved and installed at CERN, has been studied (TSR@HIE-ISOLDE). The REX low-energy section turns out to be very well suited, and in fact vital, for the injection into the ring as the ions have to be stored for approximately a second in the Penning trap between each injection batch. Most of the interesting physics reach of such a facility could be made with the present REXEBIS charge breeder, but in order to reach the very highly charged ions that would be required in some cases, a new highly performing EBIS (Electron Beam Ion Source) would be needed.

## BE-BI Group

### Diagnostic Boxes

The development of beam instrumentation for the HIE-ISOLDE REX upgrade is advancing well. A new diagnostic box (see Fig. 20) capable of measuring the beam current, profile and position was designed in collaboration with the Spanish company “AVS”. This new device contains a Faraday cup and a scanning blade with a V-shaped slit and can be complemented by solid state detectors, collimating masks and stripper foils as needed along the Linac and its transfer lines. A prototype was tested at the present REX facility where it was shown that the initial Faraday cup design was far from optimal. Extensive simulation work was therefore carried out in order improve the design within the very tight space constraints imposed by the intertank region of the HIE-ISOLDE superconducting cavities.

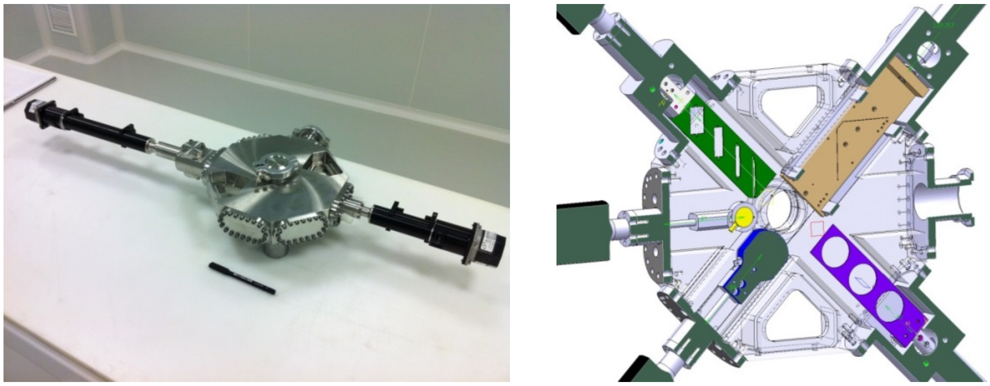


**Figure 20: The HIE-ISOLDE REX diagnostic box: prototype (left), 3D model internal view (right).**

## BE-OP Group

### ISOLDE and REX

2012 was a very successful year for ISOLDE. Thanks to an extended running period (37 weeks) a new record of 529 shifts (8h) of radioactive beam was reached, beating the previous record established in 2011. The number of shifts per day also increased. These impressive statistics were achieved despite some major problems with the target handling robots and GPS front-end, showing all the potential and flexibility of the ISOLDE machine and the professionalism of the ISOLDE team and support groups.

| Delivered | 2012 | 2011 |
|---|---|---|
| Protons | 11.5e19 | 8.05e19 |
| All shifts (IS+LOI+MD) | 529 | 463.5 |
| Shifts for IS exp | 416 | 313.5 |
| Shifts for LOIs | 15.5 | 16 |
| REX shifts (IS +LOI) | 221.5 | 190.5 |
| Average IS shifts/day | 1.61 | 1.55 |

**ISOLDE statistics 2012**

REX delivered 221.5 shifts of post-accelerated radioactive beam in 2012 (as compared to 190.5 in 2011). The running period was extended with stable beam to the middle of February 2013 to perform important HIE-ISOLDE related tests, such as emittance measurements, RF phasing, stripping foil and beam diagnostics tests. Some preparatory studies for the TSR@ISOLDE project were also performed. The possibility of injecting and accelerating light beams of A/q =2 in the REX linac was demonstrated and the fast extraction from the REXEBIS down to 30 us was investigated, both aspects essential for the operation of the storage ring at ISOLDE. The technical aspects of installing the Heidelberg Test Storage Ring after ISOLDE are under evaluation by a CERN team.

With three new elements (He, K and Ti) and 15 new isotopes in 2012, in total 33 elements and more than 100 isotopes have been post-accelerated at REX. This year a challenging 6He beam was delivered, the lightest isotope to be charge-bred at REX so far.

A number of remarkable physics achievements also took place in 2012 at ISOLDE. Precision mass-measurements of neutron rich Ca isotopes were performed at ISOLTRAP using conventional and multi-reflection time of flight spectrometry. The first spin-polarized beams with a post-accelerated beam were obtained at REX using a tilted foil technique and beta-NMR resonance setup for detection. Moreover, for the first time radioactive ions have been studied with beta-NMR in a liquid medium. This new technique pioneered at ISOLDE is particularly promising for biochemistry.

Some major upgrades and consolidation of ISOLDE will take place during LS1. Besides the installation of the first stage of HIE-ISOLDE, which will start operation in 2015, the target handling robots will be replaced. A new building housing solid-state physics and lasers labs will be built to replace several smaller buildings at the back of ISOLDE, making space for a future storage ring hall. Civil engineering work will also start for the future MEDICIS facility; an installation dedicated to the production of isotopes of medical interest which makes use of the unused proton beam behind the ISOLDE targets.

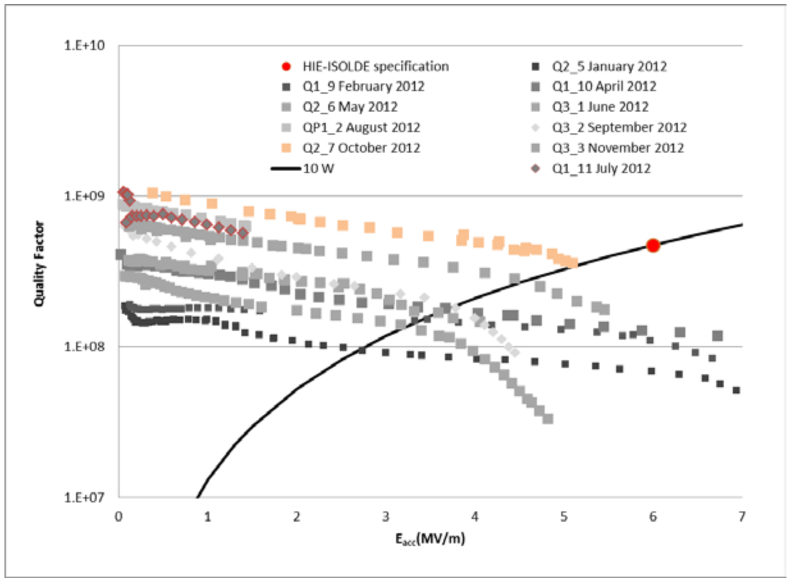
## BE-RF Group

REX, the Isolde post-accelerator, had a record number of 12 runs and a record 190 shifts of delivered radioactive ion beams. This was the first year that the 7-gap cavities were running with the 3 refurbished tuners and there were no more RF interruptions due to failure of these units. The only major RF problem was the failure of the 9-gap amplifier in August, because of which, one run had to be cancelled.

During 2012 the cavity development for HIE-ISOLDE progressed at sustained speed. At the end of 2011 a test cavity had reached the design accelerating field of 6 MV/m for the first time, but the $Q$ value was still well below the required $5 \cdot 10^8$. Constant work, focused to adapt the bias diode sputtering technology to the HIE-ISOLDE cavity, led gradually to higher cavity performances. A total of 9 test cavities were produced and cold-tested in SM18, where an effective turnaround of 3 weeks was reached for the whole loop from substrate to RF test. Increasing bake-out temperatures and sputtering rate was clearly beneficial, although more process parameters had to be changed at once for rapid progress. Towards the end of the year, increasing the film thickness by 25% produced a substantial breakthrough and a test cavity reached 5 MV/m at 10 W. This level of performance, albeit still below the specification, would be already enough to accelerate all the ISOLDE radioactive species up to $5.3\ \mathrm{MeV}/u$; thus allowing to meet all the physics requirements of the first phase of the project (using 2 cryomodules with 5 high beta cavities in each).

At the end of the year the remaining issues on the coating side ($Q$ switches, low sputtering rate on the high magnetic field region, and bad surface quality on the high electric filed region) were identified, and a work plan was laid down towards solving them

Evolution of prototype cavity performance in 2012




# SURVEY FOR ALIGNMENT

## LHC

During the technical stop of January, the vertical and horizontal positions of all the components of sector 78 were re-measured using different technologies. The vertical movement observed since the LEP period had a reduced amplitude this year. 29 magnets were realigned in the V-plane and 31 in the H-plane. Following layout modifications in Long Straight Section (LSS) 2, some collimators and two Zero Degree Calorimeters (X2ZDC) were realigned. For the first time, the collimators of the LSS7 were measured with a remote survey train and the differences with respect to the standard measurements were in the range of 0.2 mm at 1 sigma, as expected. The fiducialisation and cartography of the 18 magnets to be installed in the tunnel during LS1 were done including 2 Short Straight Sections (SSS) measured also with the “geo-magnetic mole”. The 80 strain gauges designed to perform remote repositioning of the low beta triplets safely together with their associated electronics, acquisition systems have been tested, and half of them have been installed and calibrated in-situ during the technical stops. Taking into account the increasing level of radiation in the area and the limited access near the triplet during the technical stops, remote control stations have been designed to validate remotely Hydrostatic Levelling Sensors (HLS) and Wire Positioning Sensors (WPS) installed on the low beta quadrupoles. The prototypes of both stations have been validated with success and all the components are under procurement to be installed during LS1.

### SPS Complex

A measurement of the vertical position of the quadrupoles of the TI2 has been realised and 44 magnets were realigned consequently. The same operation was done for TI8 and 20 magnets were realigned. The quadrupoles at the bottom of the TI8 were also measured in the horizontal plane and some important displacements, in the range of 2 mm, were done. This proves once again the instability of this area. In the SPS, some dipoles and quadrupoles were exchanged, the fiducialisation measurements of the SPS quadrupoles being now done by the SU team. In the North area of the SPS, all the components of the K12 beam line have been aligned including the experimental area NA62. A beam was sent in October and arrived successfully at the end.

### LHC Experiments

The activity has been shared between the future upgrades and LS1 preparatory works on one hand and the alignments in the caverns during the Technical Stops on the other hand. Geometrical controls have been done in surface halls for the ATLAS new beam pipe tooling and IBL insertion tests in the full scale mock-up area, for the CMS YE4 new endcap disk assembly tests and for the ALICE DCAL rails. In addition the ATLAS open/close monitoring system project has been started. During the Technical Stops the geodetic networks were partially updated in ALICE, ATLAS and CMS and the periodic cavern stability controls done for the last two. In ATLAS the surveys related to the detector opening and closing have been done for the mobile parts in addition to the follow-up of the C side EE Muon Chambers installation. In CMS, PLT installation tests and HF were surveyed as well as the influence of the magnetic field on HF position. In ALICE the new TRD modules and the deformations of the beam pipe, detector supports and TPC were measured as well as the Muon Tracking Chambers after repair. In LHCb, the beam pipe position has been controlled under vacuum and at atmospheric pressure. RICH, Calorimeters and Muon detectors were surveyed and a position monitoring of the IT and OT tracking stations were performed with and without magnetic field.

### Non-LHC Experiment

COMPASS: After the geometrical follow-up of the new RPD camera assembly in the clean room, the alignment of the new upstream zone configuration was performed including the RPD and LH2 Target. In addition some twenty detectors of the experiment have been re-aligned.

### Geodesy

The link from the surface network to the underground one has been realised around the BA4 of the SPS. The results have shown an expected inconsistency in the range of 16 mm. All the data necessary for the calculation of the distance between CERN and Opera have been post-processed with the Bernese Software. For CLIC, a number of hardware updates to improve the performance of the Deflectometre Prototype were started, together with the necessary changes to the associated control software.

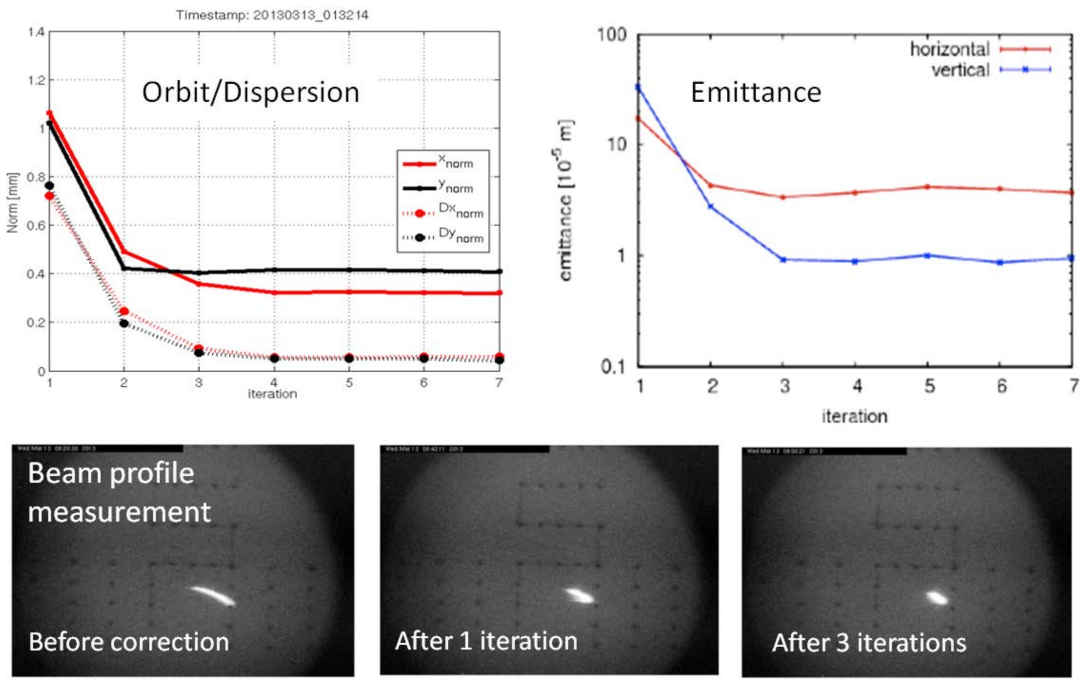
# CTF3/CLIC:

## BE-ABP Group

In 2012, the CLIC Conceptual Design Report (CDR) was published, including a “CLIC study summary” describing possible implementation stages for CLIC, costing and objectives and work-plan for post-CDR phase (2012-16). Documents submitted as inputs by the CLIC study to the European Strategy process and the equivalent process in the US, Snowmass 2013 were derived from this volume. The staging scenario is being further developed taking into account the discovery of the Higgs-like boson and the results of the CDR study, by re-optimizing the CLIC parameters and design for a staged implementation starting from 350 GeV. Several options for cost and power saving were identified. Substantial reductions of the project cost and of the power consumption are expected from the study. Studies to improve the performance and/or relax tolerances in several sub-systems continued as well. A proposal for a common Final Focus design between CLIC and ILC, based on the former, has also been put forward. A study on the potential use of the SPS as a e+e- damping ring has shown that by adapting its optics and adding a few meters of superconducting wiggler, nominal CLIC emittances could be reached (although with damping times longer than needed in CLIC). An interesting working point consistent with ILC requirements was also identified. A growing activity this year was the participation to beam tests in collaborating laboratories. Three commissioners were provided during a few months to ATF2 at KEK, contributing to the excellent results obtained (the vertical beam size went down from 150 nm to 60 nm, approaching the goal of 40 nm). In collaboration with LAPP-Annecy, ground motion sensors of the type used for CLIC were installed in ATF2, with the aim to check the correlation of ground motion to beam jitter (the main outstanding issue) and eventually use this information to build a beam feedback. One highlight of last year was the experiment of beam-based dispersion free steering performed at the FACET facility at SLAC. The automatic steering software developed at CERN was used to accurately measure kick response and dispersion in a section of the FACET Linac (part of the old SLC), then build up from this information a machine model to calculate the steering corrections needed to optimize orbit and dispersion. The corrections were then applied and the process was iterated. After a few iterations, the orbit oscillations and dispersion were minimized, and the beam emittance reduced in both planes to a level below the normal operation values, in excellent agreement with expectations.

CTF3 activities progressed by establishing routine operation for drive beam combination factor 8 and consolidating beam stability and repeatability with the implementation of new feedbacks, which stabilize RF phases in the injector and beam energy. A new optics with low momentum compaction was implemented in the end-of-Linac chicane, shortening the bunches delivered to the CLIC Experimental Area (CLEX) to about 12 ps FWHM and reducing the drive beam phase jitter by more than an order of magnitude. This achievement is essential for achieving next year the CLIC phase stability requirements using a feed-forward system designed to further reduce the jitter by a factor 10. The feed-forward system is being implemented in CTF3 in collaboration with INFN-Frascati and Oxford University. The transfer line to CLEX is being modified to install two kickers and its optics readapted. The fast amplifiers and feed-forward electronics are under preparation at Oxford, while the phase monitors from Frascati were tested with beam in CTF3, demonstrating the required performances. Thanks to the advances in drive beam production and delivery to CLEX, the deceleration measured in the Test Beam Line (TBL) went from 25% to 35%, approaching the 2013 target of 40%. The agreement with the final energy and power production expectations for a 22 A beam, is also very good, and the beam deceleration process is well controlled, with no measurable losses.

On the Two Beam Modules setup, the short range strategy of alignment for CLIC has been validated through cross-check measurements by different instrumentations at better than 15 μm. The control of the alignment of the components and their associated supports under different conditions of temperature and ventilation is under way. Comparison tests between oWPS and cWPS sensors have shown that the performances of both types of sensors are comparable. The first compact cam movers have been assembled and tested along one degree of freedom, showing a repeatability of displacement below 1 µm over the whole stroke of the mover (± 5 mm). A system based on a laser beam reference and sensors consisting of a shutter closed to observe the beam speckles indirectly via a CCD camera, is under development. First tests performed on short distance show that the concept is promising.




**FACET experiment results: reduction of dispersion and orbit amplitude (top left) and of the horizontal and vertical emittance as a function of the iteration steps (top right), and corresponding evolution of the beam profile (lower row).**

## BE-BI Group

### CTF3/CLIC Beam Instrumentation

A device to measure short bunch lengths based on the use of ultra-short laser pulses and electro-optical (EO) crystals was developed and installed in 2012 on the Califes beam line at CTF3 allowing the system to be commissioned with beam. Fig. 21 shows an example of a streak camera image with both electrons and laser photons. First electro-optical signals have been observed and bunch length measurements using EO spectral decoding are expected to be available by the end of 2013.

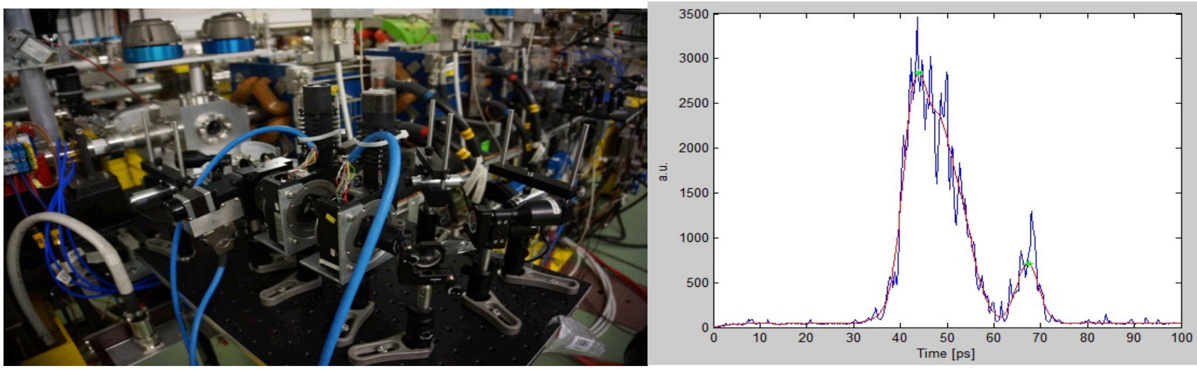



**Figure 21: (Left) Electro-optical set-up installed on the Califes beam line at CTF3. (Right) Overlaid longitudinal profile of the electron and the laser beam as measured by a streak camera**

Prototypes of CLIC Beam Position Monitors (BPMs) designed in collaboration with Fermilab (US) and RHUL (UK) were installed on CTF3 and tested with beam. A strip-line BPM was designed for the drive beam to provide a simple and robust BPM, which could be built in large quantities (>10000), and can operate in the vicinity of very high power Power Extraction and Transfer Structure (PETS) working at 12GHz. The first beam signals have not shown any degradation due to the presence of the high electro-magnetic field generated by the PETS. This encouraging result must however be confirmed by a precise analysis of the BPM resolution and of the noise and background level under different beam conditions.

Prototype RF cavity BPMs designed for the CLIC main beam and working at 15GHz was also installed and tested extensively with beam. These are expected to provide a beam position measurement with 50nm resolution and a time resolution better than 50ns. The BPM characteristics are in good agreement with simulations, but the ultimate resolution of the BPM has yet to be assessed. An improved set-up with 3 consecutive monitors is in preparation to measure the resolution of a cavity BPM on CTF3.

## BE-RF Group

### X-band RF structures

One of the highest priorities for the RF structure development program of the CLIC study is to increase the number of testing slots for high-gradient accelerating structures. 100 MV/m range performances have been shown in the few structures which could be tested, but more statistics are needed in order to better understand how long linacs composed of such structures would perform. Three klystron-based test stands are planned at CERN to increase testing capability and in 2012 the first, Xbox-1, was successfully commissioned and operated routinely by the end of the year. Approximately 50 MW of peak power was delivered to a prototype accelerating structure with a repetition rate of 50 Hz – the result of a genuine joint effort of many! For the next step in expanding testing capability, a location was found to house XBox-2 and significant progress was made in preparing hardware for it.

With the challenge of achieving accelerating gradient mostly under control, the CLIC study is actively investigating other applications beyond linear colliders which might benefit from our high-gradient technology. For example, the yearly meeting which originally focused on CLIC RF structures now gathers together representatives from many types of accelerators including FELs, medical linacs and Compton sources.

### CLIC Modules

The design and integration of the CLIC module was finalized for the CDR. The assembly of the first prototype module in building 169 was completed in September 2012 after intensive qualification tests of the alignment and positioning systems. The cooling and heating systems allowing for assessing the CLIC operating conditions and the overall thermo-mechanical behaviour have been implemented and validated, including the associated data acquisition and control system. For the fabrication of these modules a rigorous QA system was set up to manage the procurement and the traceability of the few thousands components.

### CTF3 Experiments and status

The CTF3 run in 2012 was focused on optimizing the beam quality for the experiments in CLEX. The beam stability was improved by adding multiple feedbacks. The emittance growth was studied and optimized by improving the orbits in the. Beam base alignment procedures were tested for both linac and combiner ring. Factors 4 and 8 combined beams were routinely used for experiments in the test beam line (TBL) and the two beam test stand. TBL was equipped in 2012 with 13 PETS structures allowing for the first time an energy extraction of more than 30% from the drive beam. The maximum 12 GHz power produced was 720 MW with a beam current of 21 A.

# SPL

## BE-RF Group

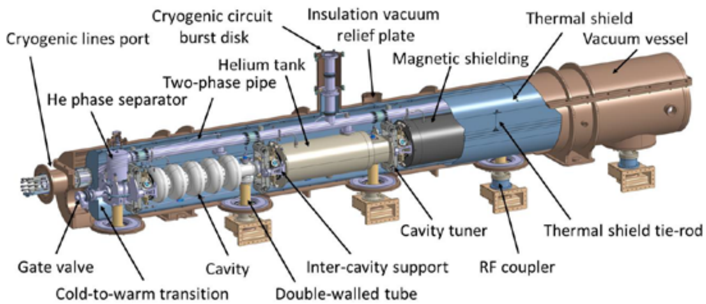
The SPL R&D program focuses on the construction and testing of a 4-cavity cryo-module that contains most of the features of the foreseen 8-cavity “full” cryo-module, which is the baseline for the high-energy section of the SPL.

In 2012 the procedures for measuring and tuning half-cells and dumb-bells were established and successfully applied to a five-cell copper prototype of the SPL beta=1 cavities. The 2 completed copper prototypes were also used to refine machining procedures before the start of the Nb cavity production at Research Instruments. A first mono-cell prototype Nb cavity was completed and electro-polished at a newly established EP facility at CERN. This first prototype qualified the manufacturing techniques, validated the EP set-up and re-established the CERN procedures for vertical cold testing of superconducting cavities in the 700 MHz range.

Two power couplers were developed for use on the SPL cavities: i) a cylindrical window type, and ii) a coaxial window type. Both types have been successfully high-power tested in travelling wave mode up to full power and in full reflection mode. The couplers are also used for mechanically supporting the cavities inside the cryo-module, a principle that is being verified by a mock-up, designed in 2012 and to be tested in 2013. The design of the cryo-module itself is completed and the specifications for tendering are in preparation.

Apart from the infrastructure upgrades in SM18 (cleanroom upgrade, 2K He supply consolidation, 704 MHz RF test stand for full cryo-module, upgrade of vertical test stands), the SPL R&D program also advanced on new diagnostics for SC cavities such as an optical measurement bench and quench detection systems via 2nd sound measurements with OSTs or via temperature mapping.

As a common platform for information exchange between ESS and CERN and also other institutions involved in high-power SC linac projects, ESS and CERN are organizing a yearly workshop called SLHIPP (Open Collaboration Meeting on Superconducting Linacs for High Power Proton Linacs). The 2012 event took place in Catania on 3-4 May.




**The SPL four-cavity cryo-module**

# COLLIMATION PROJECT:

**BE-ABP Group**

A safe operation was ensured in all conditions during the 4 TeV run in 2012. No quench of superconducting magnets was experienced with stored beam energies up to 140 MJ. In 2012, tighter collimator settings were deployed for a β* reach of 60 cm at 4 TeV. These settings ensured a cleaning efficiency above 99.99%, improving by about a factor 5 the performance of the year 2011. This was maintained throughout the year with one single collimator alignment campaign in IR3/6/7. Some 15 alignment campaigns were nevertheless needed in the experimental regions to optimize the tertiary collimators and match the different configurations required by the experiments. The tools for collimator alignment were further improved, achieving alignment times below 2 minutes per collimator. The collimation upgrade strategy during LS1, representing a first step of the improvements planned for the HL-LHC, has been worked out. The improvements consist of: replacements of 18 collimators with new BPM-based design; addition of passive absorbers in IR3; addition of physics debris absorbers in high-luminosity insertions; vacuum layout improvements in IR8.

# Future machines and EuCARD

In 2012 EuCARD-AccNet-EuroLumi launched brainstorming on higher-energy pp colliders (HE-LHC/VHE-LHC), on TLEP as an alternative to linear colliders, with large future potential thanks to its long circular tunnel; and on ERL-based $\gamma\gamma$ colliders – SAPPHiRE, which could be realized by a simple reconfiguration of the LHeC, further widening the scope of this facility. LEP3 and TLEP are two recently proposed circular Higgs factories in the LHC tunnel and in a new 80-100 km tunnel, respectively. TLEP offers the better performance and it could share the tunnel with a later very-high-energy LHC (VHE-LHC), which would provide proton-proton collisions at 100 TeV c.m. The combination of TLEP and VHE-LHC represents a long-term strategy for accelerator-based high-energy physics. The LHeC is designed to collide a new 60 GeV energy electron beam, from a 3-pass energy-recovery linac, with the 7 TeV energy LHC proton beam. At the nominal target ep luminosity of 1033 cm−2s−1, the LHeC would produce a few 1000 Higgs bosons per year. In 2012, an increase to 1.6-2.2×1034 cm−2s−1 was proposed, based on a combination of improvements.

### LHC Electron Cloud and EuCARD

In June 2012, EuCARD-AccNet organized and co-sponsored the workshop ECLOUD12 and the CERN Low Emittance Ring (LER) study. At ECLOUD12 for the first time colleagues from the space-craft community participated, namely from VALSPACE, ONERA, MIT, ICMM-CSIC, and EPFL Lausanne. 2012 was devoted to the preparation and follow-up of the progress of the LHC electron-cloud scrubbing with 25-ns bunch spacing and the benchmarking of new diagnostics tools like synchronous phase shift. The scrubbing run showed an unexpected saturation, with still significant heat load and apparently little further scrubbing at both injection and top energy. Residual electron cloud inside the quadrupole magnets is one of the possible explanations put forward. Several other studies have been performed in the PS and SPS machines to prepare the future operation with 25 ns. For the first time in 2012, the nominal LHC beam in the SPS has been produced without any detrimental signs of electron-cloud, revealing a positive scrubbing effect over the last few years. However, when the intensity was slightly increased, the beam quality was rapidly degraded due to electron-cloud. Finally, experimental and simulation studies on a wide-band feedback for electron-cloud instabilities continued in collaboration with US-LARP, leading to very promising results.

# InCA/LSA Project

## BE-CO Group

In addition to providing a stable service for the LHC, SPS, CPS and PSB accelerators, in 2012 the efforts of the LSA/InCA team were focused on deployment of the system for REX and ISOLDE. The team also started to prepare for deployment for the AD machine planned for 2014, preparations that will continue during LS1.

# Cross Departmental Activities

## BE-ASR Group

The Administration, Safety and Resources (ASR) group is mandated to provide overall assistance to the department, to each individual group and to each and every member of the personnel in the department in the smoothest and most unobtrusive way while being careful at the same time to minimize the inevitable overhead associated with administrative work, resources planning and control, and Safety.

Specific responsibilities, mainly concerning human resources, have been mandated to the BE-ASR group leader, by delegation of the department head. Such departmental representation is hence ensured in staff selection committees, the contract review board, and the Standing Concertation sub-group dealing with modifications of the Staff Rules & Regulations, Administrative Circulars and Operational Circulars.

In order to overview all resources – human and financial – within the medium term period, the ASR group leader has also the responsibility of Deputy Departmental Planning Officer (DDPO).

### The BE Newsletter

The success of the BE Newsletter, introduced in 2011, was confirmed by a survey launched in February 2012. The activity was therefore pursued to provide information of general interest to the BE community, with the publication of three newsletters during 2012. The content varies widely from scientific and technical to practical, social and safety information. The management, compilation of all contributions and final editorial work is in the hands of BE-ASR.

### Administration & Secretariats – BE-ASR-AS

The Administration and Secretariats team is tasked with ensuring an effective and high quality administrative assistance for Group Leaders and Section Leaders, as well as providing an administrative support for all categories of personnel for a wide range of activities. The team of seven group secretaries (including for MedAustron) and departmental support in the Central Secretariat (DAO, DDAO) is geographically split between the Meyrin and Prévessin parts of the CERN site and located in different buildings. The recurring activities of the assistants start from the welcoming of new arrivals (151 in 2012), ensuring that appropriate space and furniture is made available, as well as the management and follow-up of contract extensions, transfers, detachments, contract terminations and departure formalities. Of particular importance also is the coordination of selection committees for Fellows as well as Doctoral, Technical and Summer students. At department level the central secretariat is also involved in the follow-up of induction interviews, mid- and end-probation reports, the coordination of the MARS exercise as well as all actions related to advancement, promotion and awards of staff members within the Department, treatment and monthly control of overtime, shift and stand-by duty. In the groups the secretaries assist the CERN personnel with arranging official travel and calculation of reimbursements, treatment of reimbursements of education fees, management of subsistence fees, control of absences and third party claims. The secretaries also provide assistance with the administrative organization of events and conferences (e.g. IEFC and "Evian" workshops, ECLOUD'12, COOL'13 preparation), the creation and update of group websites and documentation systems and the coordination of visits onsite, especially in the CCC.

The Departmental Administrative Officer (DAO) collaborates proactively and continuously with the HR department and the Legal Service to streamline and improve the administrative procedures, making sure to implement correctly and efficiently the revisions of administrative circulars and contributing to the pragmatic documentation of the CERNAdmin e-guide.

### Resources & Logistics – BE-ASR-RL

The main tasks of the Resources and Logistics team are to provide assistance to the Departmental Planning Officer (DPO) and his deputy (DDPO) on budgetary and financial matters, and to the Departmental Space Manager (DSM) for space and storage management, follow-up of small works and related logistics. The *financial and budget related activities* concern primarily monitoring and reporting on material budgets for all BE Groups and projects, monitoring and follow-up of the invoices and yearly accruals, maintenance of budget codes and signature rights. In close collaboration with the DDPO and DG-RPC-EUT, a major effort has been put on the administrative management of European co-funded projects in the Department (10+), in terms of staff allocation (i.e. HR costing) and material expenditures on EU-funded budget codes and the CERN-funded "matching" codes.

The activities of *space management* continued to be time-consuming and complex in nature. The two modular buildings on the CERN Meyrin and Prévessin sites were installed, equipped, and occupied by personnel, involving many movements and transports. The latter requires supervision of the planning and follow-up of the *small works* in offices, labs and workshops, as well as space optimization. As many of the required services are provided by the GS department, constructive communication with these teams and their managers is essential in order to react to unforeseen events and delays. The works to remove the wooden panels and furniture, infested by woodworms in buildings 6, 8, 9 and 10 have started with a one-year delay and have not been completed yet.

Beyond the normal space issues in a large department, specific actions took place:

- Establish list of critical needs related to LS1 in collaboration with all space managers;
- Find office space for RP technicians, cohabiting with BE honorary members;
- Accommodate space for the new MedAustron RF-cavity test stand;

Mandated by the Department Head, the Space Manager actively collaborates in the *Groupe de Travail sur le Partage de l'Espace* (GTPE) on global discussions related to space policy, guidelines, mandate and objectives of the GTPE as well as in Master Plan Users Committee, and in *GTPE for Works*.

The departmental *logistics* includes the management of keys and cylinders (478 requests), management of the departmental car fleet, the departmental inventory of equipment, the monitoring of the use of telephones, management of photocopiers and office and workshop furniture. Car-sharing solutions are strongly promoted and some specific solutions are being implemented in order to optimise the resources for transport. Due to the gradual increase of people and vehicles on site and the diminishing parking space during civil works, the section liaises with the GS Department to address the difficulties of mobility encountered by the staff. Following new rules and CERN-wide policy on a list of obligatory inventoried equipment, a new application prototype for the inventory was put in place by the end of the year.

On September 1st, the role of the Departmental Training Officer (DTO), was “outsourced” to a staff member in BE-RF and the role of his deputy was “insourced” by the BE-ASR-AS section leader. With the new *Learning & Development Policy* that was elaborated and approved during 2012, and a renewed team – including the new management of the HR-LD group –, motivating dynamics have been created. Language courses tailored to the specific needs and constraints of the members of the Department has been provided with positive feedback from the attendants.

Since 2010, The Department Head has put in place yearly BE Workshops, which consists of a 3-day residential forum to create dialog between staff members within BE and the Departmental Management. All members of the top BE management attend, alongside 11 members of staff selected by the Department Head. As a follow-up to the discussions and suggestions made at the 2012 Workshop, a tailored BE Project link persons mandate and training were put in place, to assist people holding these roles with the bi-directional flow of information between the Project and the Group.

### Safety Unit – BE-ASR-SU

The BE-Safety Unit comprises eight members in 2012: seven staff and one fellow. A staff member from BE-BI joined us in January as deputy RSO (30%). Two colleagues achieved recognition for their health and safety skills and knowledge by passing the NEBOSH *International General Certificate on Occupational Health and Safety*.

The Safety Unit has acquired new competencies in the field of *risk analysis* and organised in this domain a two-day training entitled “Méthodes d'analyse de risques : prévention des accidents et exploitation du retour d'expérience” at CERN, with invited members of other departments.

The Safety unit is also committed in the establishment of the *CERN Crisis Team* through our Nuclear Safety Officer. The goal is to set up a crisis organization to react and manage a crisis.

### Safety of Personnel

The effort to improve Safety *communication* in the department was pursued this year. The departmental Safety web site is regularly updated with Safety Tips. Short targeted Safety messages are sent to the whole department, for example on the use of bikes in the dark. Together with the HSE Unit, the Safety Unit organised the second edition of the *World Day for Safety and Health at Work*. This year’s emphasis was on electrical hazards and ergonomics at the workplace. Approximately 350 persons stopped at the stands that were set up at the restaurants, with the active participation of HSE, the Medical Service and the Fire Brigade. Two articles and three Safety columns were published in the *BE Newsletter*. The Safety Unit continues to contribute in this task which consists of informing on subjects which are of interest to all BE staff. The main topic concerned the readiness for LS1, providing mainly information on new regulations regarding personal protection equipment (PPE), and safety trainings.

The Safety officers continue to maintain frequent and positive *communication with the TSOs*: regular meetings are organised in order to share experiences and provide them with information that could make their tasks easier. Part of the departmental Safety web site is dedicated to useful information concerning the function of TSOs. The HSE objectives are communicated to the TSOs and actions to achieve them are discussed altogether.

The Safety unit has started updating the *BE Department Safety Plan*, putting emphasis on areas of specific risks in the BE Department.

Preparation of new *training courses* was a significant task in 2012. The update and improvement of the on-line course LHC level 4 on SIR was finalised. A survey was launched in order to receive feed-back about safety training needs from the entire department (25% of our target audience responded). Since October 2012, the numbers of BE members trained as first aiders and to the use of self-rescue mask are followed up in view of LS1. Finally, proposals were made to HSE-SEE, DGS-RP and GS-FB in the review of their courses (review level 1, 2, 3; course on PS complex and training for emergency guides).

Due to the recent French decree on operations on electrical installations, the Safety Unit proposes an implementation of the revised *Electrical Habilitation* requirements in the accelerators. The proposal consists in defining a safe passage in all machines (emergency exit path). Access to machines will then be controlled automatically on a SIR access module course. Any work on equipment of the machines will be controlled by IMPACT procedure and will require Electrical training, “consignations” or supervision by a person with the correct “habilitation”. The proposal is being validated by the HSE Unit.

As requested in the first HSE objective for BE “Limit the number of accidents/incidents at work” the Safety Unit continued to emphasise on the *reporting of incidents and accidents*. Four types of accidents were reported: slips, trips and falls, commuting accidents and manipulation. There were overall 271 accidents at CERN in 2012. For BE, the figures remain stable: 22 this year versus 23 last year. However, the increase in commuting accidents is worrying with more accident reports in 2012: (2011: 50% bike, 50% car; 2012: 21% bike, 79% car).

The Safety Unit, in collaboration with the EN Department, finished a register of all the areas in the LHC where *emergency sign or instructions* are missing and therefore should be placed. New up-to- date signs will be put in place during LS1. The Safety Unit took an active part in the establishment of new guidelines concerning *evacuation*. Three evacuation drills were organized where the Safety Unit participated as observers or co-ordinators. (Buildings 5, 33 and CMS cavern).

Following the planning established by HSE concerning *building inspections*, 37 out of 66 buildings were inspected. The inspections have not identified any major lack of compliance with rules and standards. The Safety Unit supports the TSOs during the inspections.

Concerning the second HSE objective for BE to improve chemical hazard identification and control, our Safety Officers have launched a large campaign to identify *chemical products* stored on the CERN premises. A simplified form was sent to TSOs and additional support is provided when needed.

On the third HSE objective for BE, our team continued to work on a CERN wide action to improve *machine-tools*. It is the BE DSO’s responsibility to guarantee the conformity of such machines. 75% of BE machine tools are inspected and 13% are compliant. It has been decided that the EN Department will take care of the corrective actions on behalf of the departments. The validity of *gas bottles* was checked successfully by the groups after providing the necessary information on how to read the labels on the bottles.

Last but not least, a total of 851 LHC *access requests* have been treated this year.

### Laser Safety

The Laser Safety Officer of the Department maintains the inventory of all dangerous lasers in the Accelerator and Technology sector. 17 laser installations were inspected in 2012 out of the 30 lasers operated in the sector. The A&T LSO is including the TSO's in the procedure for identification and registration of new lasers. The Laser Safety Officer contributed to the updating and improvement of the *Laser Safety training* and gave part of the course which took place in December.

### Safety of Installations

The development of a *quality assurance plan* has continued this year. It consists of maintenance and intervention procedures on *equipment that are particularly important for safety (EIS)*, or related to safety. The aim is to provide a well-documented methodology for the groups concerned to implement it. The register of EIS for all beam facilities has been fully completed. Labels to identify the EIS on site are available from the Safety Unit and are deployed around CERN. An identification sheet grouping all the relevant information of an EIS has been standardized and is ready to be used by the equipment owners. The Safety Unit still ranks as a driver in encouraging the establishment of *Safety Files*. Our role is either to edit safety files (LHC, PS, PSB, and Linac4) or to give advice and assistance to others. A validated template helps the authors and ensures a coherent Safety documentation for all beam facilities (EDMS 1162935). Moreover, our team created and leads the "Safety Folders' Editors Club" where every editor can ask for help and share his/her experience. Our team took part in the installation and testing of the Beam Imminent Warning (BIW) in the North area where each of the 30 experimental zones have been equipped with red flashing lights indicating that the zone is, or being closed.

The BE RSO and his deputy collaborated with RP and studied possible changes to *radiation shielding* around accelerators in particular, to guarantee the visitor's safety. The RSO was asked to study the procedures concerning *shielding installations* in order to find the best way to identify and control their status. All shielding installations will be traced in the future.

A survey was made to establish a list of potential activated *waste generated during LS1* and to prepare temporary storage for activated materials.

Most members of our unit are committed in the three *Complex Safety Advisory Panels (CSAP)*, (for LHC, SPS and PS), for which we also provide two scientific secretaries. These panels are composed of members from all technical departments, report to the EIFC & LMC and recommended action in matters of safe operation of CERN Accelerators Complexes. They also advise the Complex Manager in matters of safe operation of a given Complex.

Safety officers hold weekly *Beam Safety Panels* every week. Any subject concerning Radioprotection, Access or operational issues can be raised and resolved during these meetings.

Safety agents in the different departments collaborate in order to avoid safety aspects of cross-departmental activities being overlooked. A memo was written to insist on the *interdepartmental collaboration* whereby several departments contribute to "and have responsibility for " activities in the beam and experimental areas. (EDMS 1151087)

As suggested by the ASN, the Safety Unit specified the functionalities of a system allowing the *reporting of deviations in matters of Safety* in the accelerator and experimental facilities. (EDMS 1161842). The main objectives are to collect the deviations through a unique system and to allow the collect analysis of statistics. Based on these statistics, actions could be decided, put in place and their efficiency checked. The proposed system will also allow the full management of a deviation in a formalized way (i.e. Validation, Analysis, Decision of actions, Implementation of actions, and finally Verification and closing). A dedicated website as well as a public e-mail address (Safety-Deviations@espace.cern.ch) were put in place, to the satisfaction of the ASN.

Concerning *Safety documentation*, various procedures were updated or implemented this year, among which should be noted:

- Predefined reaction to level 3 alarms and incidents / accidents for the LHC machine. (EDMS 1154191)
- Procédure tests de validation fonctionnelle (dits tests DSO) du système de sûreté d'accès. (EDMS 1146640).

## BE-BI Group

### Controls renovation project

Certain VME control and acquisition boards developed by BE-BI have shown not to be 100% compatible with the new Intel based CPUs provided by BE/CO. The amount of work required to re-develop these BI modules is considerable and a VME adapter board (VMA) was therefore designed and tested to allow circumventing these problems with no changes to the low-level software. The final version of the VMA is now under production and it is expected that the VMA will allow several BI systems to be consolidated during LS1.

## BE-CO Group

### Development tools

In 2012, CO introduced a tool called "SDC" to distribute carefully pre-configured Eclipse Development Environment on Windows or Linux to over 150 Java and C++ developers in the accelerator sector. This drastically simplifies the task of keeping the development tools up to date and push new configurations or Eclipse versions synchronously to all developers.

In 2012, Bamboo, a "continuous integration" system became increasingly popular among software developers. By the end of the year, over 500 software packages (each one corresponding to a C/C++ library or a Java jar file) were configured in this system. Every time a developer of a package commits new code to the central source code repository, Bamboo automatically compiles the whole package, and executes unit tests to validate the change. Subsequently, all dependent packages are compiled and tested in the right order to make sure the original change did not break any of them. With an average of 200 commits per day, each triggering a cascaded compile-test cycle, this creates an important work load, for which we installed eight back-end servers in 2012.

In 2012, the CO Testbed became an important corner stone of the development process. It is a replication of the core of the control system "in the lab", with all different types of Front-end hardware and all versions of operating system used in operations.

## Smooth upgrades

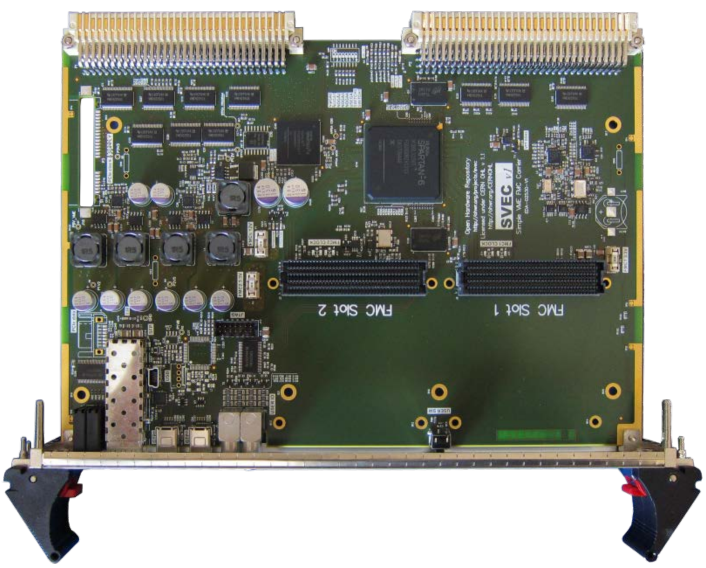
An important goal of the Controls Group in 2012 was to strive for smooth upgrades of the accelerator controls system during the Technical Stops (TS). We provided new tools to support smooth upgrades. For instance, the new Dependency Analysis plugin for Eclipse helps Java software developers to plan software upgrades and make sure they are backward-compatible.

In 2012, we rolled out a new version of the Linux OS (SLC6 64bit) on the consoles. This was a massive and successful upgrade campaign of around 250 consoles not only in the CCC, but also in many technical buildings and local control rooms around the accelerator complex.

Later in the year, a new version of 64bit Linux was prepared for general deployment in LS1 for the new Front-end hardware such as the MENA20 CPUs.

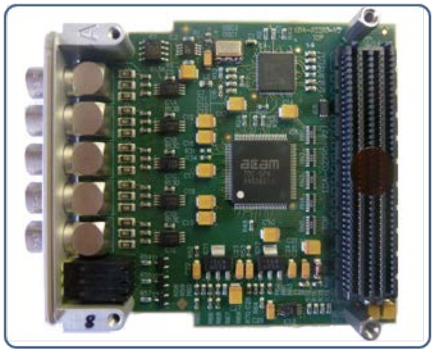
## Hardware and driver developments

Two of the most important hardware developments in 2012 were the SVEC and TDC FMC boards. The SVEC is a VME64x board with two FMC sockets, a Spartan-6 FPGA memory and an SFP socket for connecting to the outside world using a Gb/s link such as White Rabbit. After going through two revisions and a price enquiry process, a series of boards was successfully received at CERN and work got underway to develop gateware and driver support for three mezzanine types: ADC, TDC and the fine delay generator. The SVEC board is currently available for purchase in the catalogues of two commercial companies.




**The SVEC board, a carrier for two FPGA Mezzanine Cards (FMC)**

The TDC FMC is a VITA 57 mezzanine board with a Time to Digital Converter capable of time-stamping 5 TTL inputs with sub-nanosecond precision. It is built around an ACAM TDC-GPX chip, and it is currently available for purchase from a commercial company.



**The Time to Digital Converter (TDC) FMC**

Work on Linux device driver support progressed for the three mezzanine types (ADC, TDC and fine delay) on the two supported carriers (PCIe and VME64x). In terms of work completed in 2012, one of the highlights was the deployment of a new set of drivers to support the IP-Octal mezzanines for RS232, RS422 and RS485 communication from VME and PCI hosts. The PCI versions were successfully upstreamed to the official Linux kernel.

### Control Room Infrastructure

22 Proliant Blades and 3 new ProLiants were installed or upgraded in 2012 for BE/CO, TS/CV, QPS and Cryogenics. The disk space has been doubled for the Disaster Recovery Plan (DRP) that is deployed on the Meyrin site (old TCR). 52 PVSS servers were migrated and updated to our latest standards.

The control room of NA62 has been installed to the BE/CO standards.

### DIAMON and LASER

Since July 2012, the new DIAMON-2 infrastructure based on the common BE-GS C2MON platform has been made available to operations and to our users.

Several new features like the synoptic panels (user created views animated by monitored data elements) and the history player (possibility to “replay” events recorded in the database) are now fully available.

The new CLIC agent is now in operation in about 1,500 machines on 4 different platforms (SLC6, SLC5, Windows, LynxOS).

### Controls Middleware (CMW), Tracing and JMS

The ZeroMQ communication library was chosen as a replacement for CORBA. Since Q3-2012, a major development effort has been undertaken to provide a new major version of the CMW core library, i.e. RDA3, based on the ZeroMQ transport layer.

The BE/CO Log & Tracing service played an important role in 2012. It helped significantly to improve the overall diagnostic capabilities of the middleware infrastructure and delivered important runtime events (logs, errors, exceptions) for the ACET project. Further improvements and extensions were implemented in several layers: C/C++ log library, JMS brokers & Camel converters and Tracing GUI.

Our JMS (Java Messaging Service) messaging infrastructure saw deployment of 10 new brokers in 2012 and it achieved 99.999% availability in 2012 (50’ downtime out of 102,240 hours). There are now 40 brokers deployed and a constant message load of 2,200 msg/sec is observed, resulting in 2.5TByte/day of data exchanged in the JMS infrastructure.

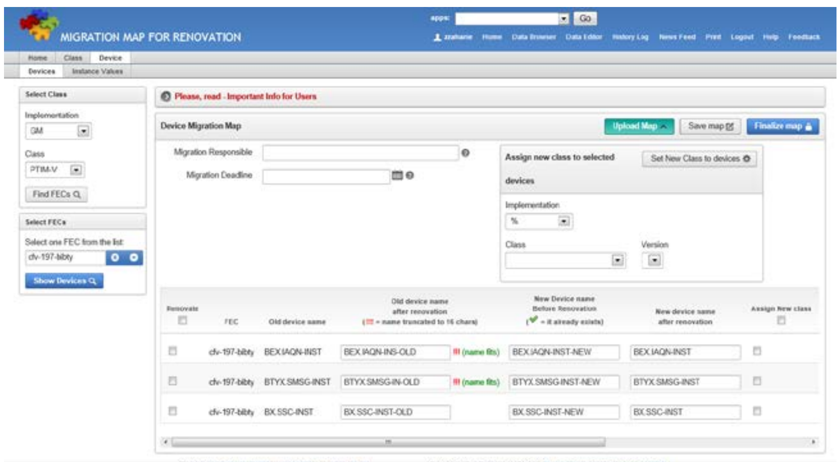
## Virtualization

A standard virtual machine (VM) running either SLC6 or Win7, is now based on a 64-bit architecture, has 4 cores and up to 4Gb of RAM. All standard BE-CO software tools are installed by default on all VMs. By the end of 2012, the BE-CO group had deployed 200 SLC6 and 100 Windows7 VMs.

## Controls Configuration Service

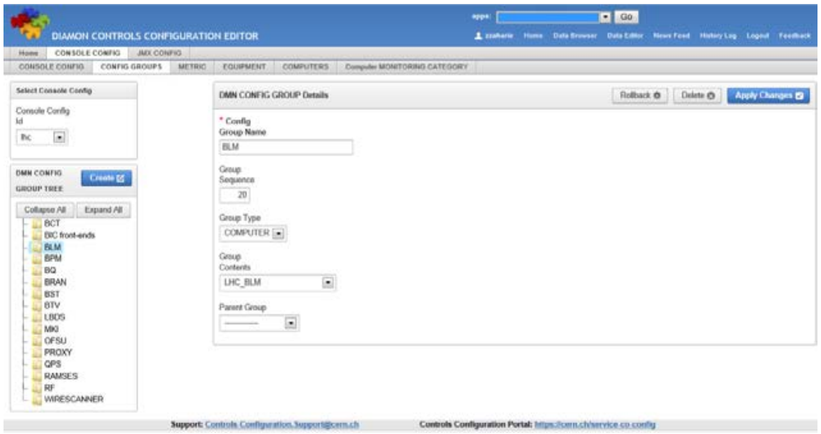
Several major developments are outlined below.

- The Safe Machine Parameters configurations were integrated into the Controls Configuration service. User interfaces and APIs were provided for the needs of the Machine Protection team in the TE Department.
- In 2012 the intensive work for the renovation of the configurations of the controls system started to provide dedicated functionalities (processes and interfaces) supporting the ACCOR project.




- The design and development tools, related to the Controls device models, were made fully data driven. The FESA-3 configurations were integrated into the Central Configuration Service and in September 2012 a preliminary version was released and tested in LEIR.

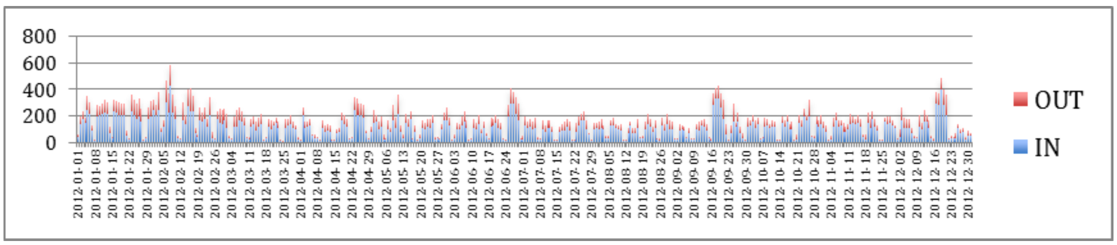
- A lot of effort was put into providing the configuration capabilities as well as the integration and streamlining of the configuration data flow to the DIAMON server. A special set-up to test the configurations of the DIAMON agents for the front-end computers in the PS-Complex was put in place. A first version of a new DIAMON Configuration Editor was provided, homogeneously integrated into the suite of interactive Controls Configuration interfaces.



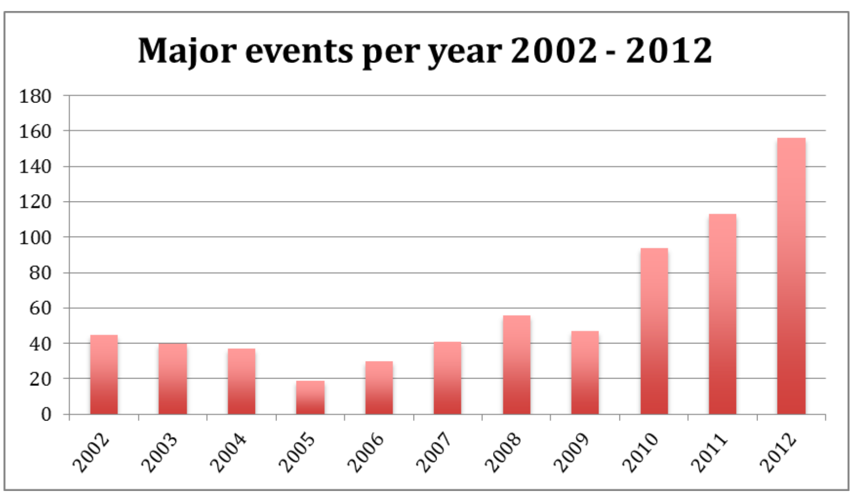

**BE-OP Group**

## Technical Infrastructure

2012 was another year of uneven work load for the technical infrastructure operators with calmer periods during LHC operation and busy periods during the technical stops. A total of 58316 calls made and received by TI with peaks around 400 calls per day during technical stops. A second operator is allocated to TI operation for these periods to help handle the work load.




The number of major events continues its steady progression. In 2012 we counted a record 151 events. Electrical glitches alone counted for 36 events including perturbations on the Swiss and French power grids and local thunderstorms, causing the LHC FMCMs to trigger. The machine protection group is preparing the LHC power supplies to become more resilient to small electrical perturbation after LS1.

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