AIDA

Advanced European Infrastructures for Detectors at Accelerators

Deliverable Report

Performance of beamline and infrastructure

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AIDA

Advanced European Infrastructures for Detectors at Accelerators

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DELIVERABLE REPORT

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Abstract:

This document presents the work done during the four years of AIDA contract at the National Laboratory of Frascati (LNF) of INFN, the Ferarra and Perugia INFN structure and the University of Bergen, to improve and characterize the DAFNE Beam Test Facility (BTF).

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TABLE OF CONTENTS

1. EXECUTIVE SUMMARY 4

2. INTRODUCTION 4

3. BTF REMOTE TROLLEY 5

4. GEM TRACKING TELESCOPE 6

5. LYSO CALORIMETER AND BEAM ENERGY SPREAD 7

6. DIAGNOSTICS AND DAQ UPGRADE 9

7. CONCLUSION 11

8. REFERENCES 11

1. EXECUTIVE SUMMARY

The activity of the Frascati Beam Test Facility (BTF) during the four years of AIDA contract, although limited by some fault of the DAFNE complex, has been successful and of satisfaction for the users coming from most of the main institutions in Europe. The sub-tasks foreseen, remote trolley table, TPC GEM beam tracking device, qualification of beam energy spread and upgrade of the DAQ system have been successfully designed, operated and are available as users' facilities.

2. INTRODUCTION

The BTF[1] user access during the 4 years of AIDA contract has been of an average of about 220 days/year, 8 days/group, 20 groups/year, selected through 2 calls/year (see http://www.lnf.infn.it/acceleratori/btf/ for details). Unfortunately, during 2011 the DAFNE accelerator complex suffered many faults that have limited the time allocated to the beam test facility. Most of test beams and experiments cancelled have been successfully recovered before the end of 2011, while all the 2012 test beam and experiments have been successfully completed, i.e. we booked 316 days of activities. After the summer shutdown (25 July- 9 Sep) the BTF is foreseen to operate until the end of November.

The activities during 2013 have been strongly limited by the long DAFNE shutdown during the first six months of the year. During 2014, the Frascati Beam Test Facility allocated about 260 days of shifts dedicated to HEP detector tests and calibration and study of electromagnetic interactions (see http://www.lnf.infn.it/acceleratori/btf/ for details).

During these years we have developed new booking procedures and access rules, optimized by the continuous feedback from the users' experiences. We focused our attention to reduce the number of steps to enroll the people in the BTF, giving the possibility for the users to take advantage of all of the services offered by the LNF. Thanks to an effective secretary service it has been possible to manage the large number of foreign users as shown in Figure 1.

We hosted two main kinds of tests:

- Test Beam of HEP detectors (single particle operation mode):

  Various detector technologies: calorimeters, scintillators, fibers, drift chambers, micro-pattern gas detectors (GEM, MSGC), RPC, diamond, silicon pixels, silicon micro-strips, fluorescence detectors, Cerenkov, RICH, etc

- High energy electromagnetic interaction experiments (high multiplicity operation mode)

  - Thermo-acoustic expansion of materials due to ionizing particles
  - Absolute air and Nitrogen fluorescence yield
  - Microwave emission from e.m. showers
  - Electron and positron channeling, parametric radiation

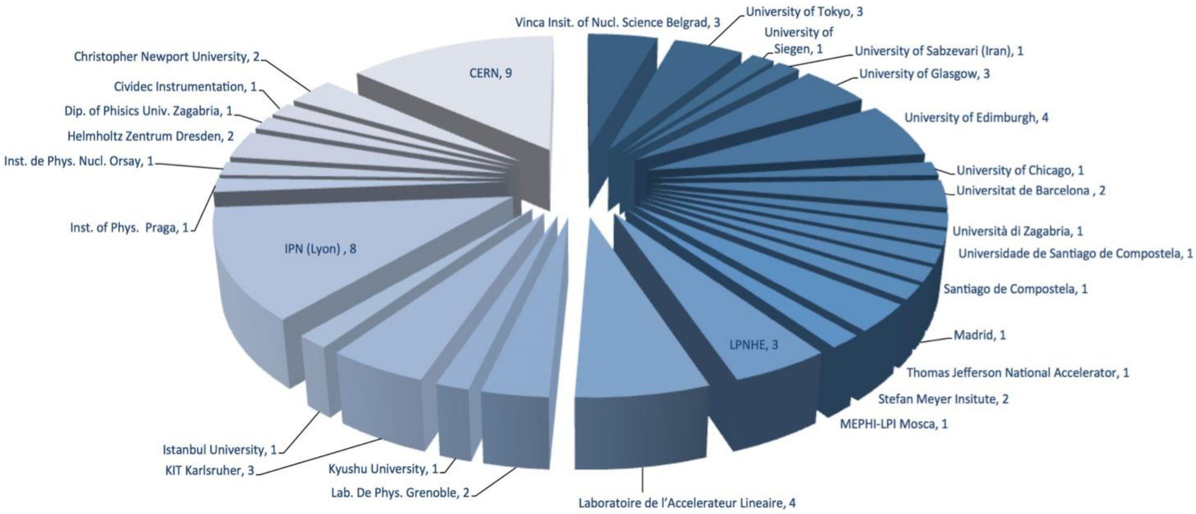

Figure 1 - Pie chart of BTF users institutions

A fraction on the beam time has also been dedicated to the achievement of the AIDA project milestones.

3. BTF REMOTE TROLLEY

A remote controlled table has been designed, tested and put into operation in spring 2011. The main parameters of the table are listed in *Table 1*. User test beam operations during the last year have shown excellent agreement with typical users requirements.

disposable area	600x600 mm^2
min height	915 mm
max height	1250 mm
horizontal excursion	1000 mm
max load	200 Kg
accuracy	< 1 mm^2

Table 1. Main parameters of the remote controlled table.

The AIDA-NOTE-2012-003 “Remote test bench equipped with service movable platform in two axis”, describing the table, is available in the AIDA database [2].

The almost four years users’ experience showed that the remote trolley is operating in a very stable, accurate and absolutely reproducible way. In case of light payload (under few kilograms), we pushed up the single axis step resolution, lowering it down to 0.1mm in same step direction of movement. It has been performed on the both axes and a complete software correction has been implemented.

4. GEM TRACKING TELESCOPE

A prototype for a 3D track system has been developed at the Frascati Laboratory. It consists of a compact TPC with 4 cm drift, and a triple GEM structure as readout system. Since 2012, the tracker system has been tested at BTF in various conditions of particle multiplicity, from single up to a thousand electrons per bunch, and at CNAO[1] with continuous proton beams. A resolution of 80 microns for a single particle has been verified, correlating data with a Medipix telescope. A test beam was performed also at CERN using a Lead Ion beam.

The final system of TPC GEM readout with a data acquisition card based on FPGA and powered up with the HVGEM module has been installed late 2013.

The assembly and test of GEM service elements (gas system, electronics, and installation systems) have been performed. The installation and test of the new software, design and implementation of a hand manageable fixed installation of the operative TPC GEM support has been completed. Test of the operative CANBUS via KVASER in the BTF virtualization system is operative.

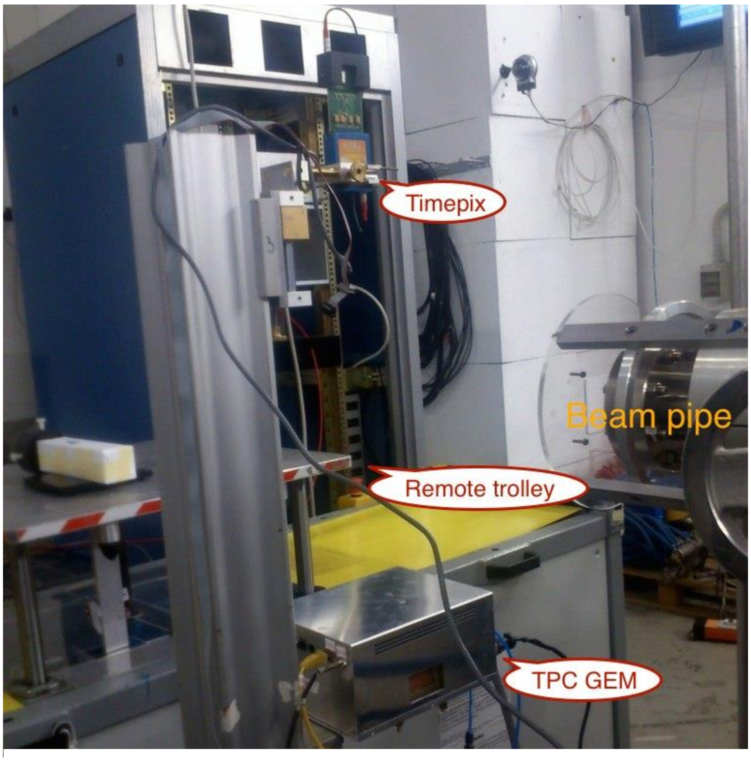

Figure 2 – Remote trolley, TPC GEM and TIMEPIX as available at the BTF facility

GEM detectors are now completely integrated in the BTF timing and DAQ with newly dedicated gas pipes for gas supply. An easy automated calibration software has been developed to improve the detectors' reliability. We are developing also a pressure/flow stabilization system to improve the HVGEM 2.0 native current measurement to cover the intermediate current range delivered.

In order to accomplish the users' need for a fast silicon transverse beam imaging, a TIMEPIX® detector with BLUEbox is integrated in the BTF timing and a DAQ is available for the users. TIMEPIX® has a square pixel size of $55\ \mu m^2$ in a 256 x 256 pixel layout for a square sensitive

[1] Italian National Centre of Oncology created with the goal of treating tumors by using protons and carbon ion particles

area of about 2 cm². The timing feature of TIMEPIX detector easily fits the BTF experimental needs. Figure 2 shows the TPC GEM and the TIMEPIX detectors installed at the BTF.

5. LYSO CALORIMETER AND BEAM ENERGY SPREAD

The LYSO calorimeter prepared as a SuperB prototype has been commissioned (INFN-Perugia/Ferrara group and University of Bergen) as a monitor for the beam energy at the BTF Facility. The prototype has been built and assembled in a mechanical structure of carbon fiber, containing 25 LYSO crystals equipped with APD's (Avalanche Photodiodes) as photodetectors. The matrix has been studied at the BTF facility with electron beams in the energy range from 100 to 500 MeV. A Monte Carlo simulation program has been developed to compare the measurements to expectation. Different and detailed aspects (geometry effect, dead material, photo-statistics of the crystals, electronics noise) have been included in the simulation.

The analysis of the data collected during the test beam has shown that there is a good agreement between the resolution obtained with the data and the Monte Carlo simulation, a resolution of about 2% is reached at energies of 500 MeV

The results of the performance of the LYSO matrix with APD's (Avalanche Photodiodes) readout have been reported at 2013 annual meeting, in particular the measured beam spread of the BTF beam line and the achieved energy resolution.

The possibility of using a read out for the LYSO crystals with SiPM's (Silicon Photomultipliers) is also under investigation: 9 LYSO crystals have been readout with 36 4x4 mm^2 SiPM's (4 per crystal) and tested at the BTF line with electrons in the energy range from 100 to 500 MeV.

The linearity of the calorimeter has been measured showing that the calorimeter is linear up to 1.4 GeV or up to 600 MeV depending on a filter applied to attenuate the light coming from the crystal to avoid saturation in the photodetectors. Energies above 500 MeV have been studied with multiple particles in the beam.

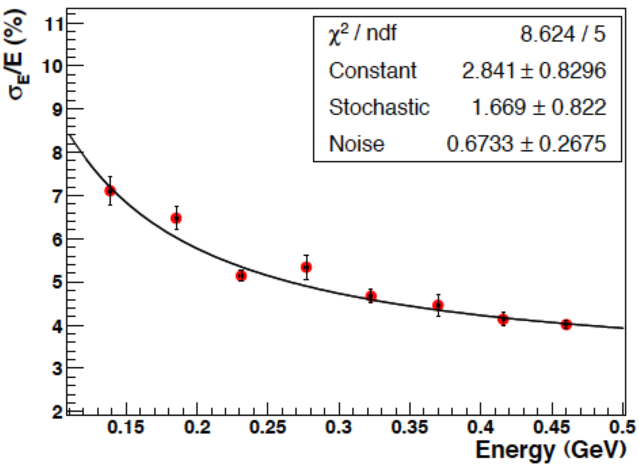

Figure 2 - Measurements of LYSO energy resolution for the characterisation of the Frascati test beam. Measurements performed with SiPM readout

The Energy resolution - figure 3 - has also been studied. In this case the tested matrix is 3x3 and not 5x5 as it was done with the APD's and a correction factor has been applied, evaluated by Monte Carlo simulation, to subtract the contribution of the leakage contribution. A good energy resolution is obtained also in this configuration, with a constant term of about 3%.

Even if the performance of the calorimeter are shown to be excellent also in this configuration, it appears that APD's readout performance is better than the one with SiPM's. This is essentially due to the fact that the LYSO produces a very large amount of light and to perform well with SiPM as photodetectors some filters have to be applied in order to avoid saturation, reducing the photo-statistics and then worsening the stochastic term of the resolution. Concerning the constant term the lateral leakage is also playing an important role. The real advantage of SiPM with respect to APD's is the very compact digital readout, which greatly simplifies the experimental setup.

In parallel the Group of UiB has built a beam radiation monitor consisting of an array of eight LYSO crystals arranged in a ring around the beam pipe to record beam radiation photons in the 100 keV energy range. Each crystal with dimensions of 0.5 cm x 0.5 cm x 4 cm is wrapped in ESR film from 3M. Each crystal is glued to a SiPM from KTEK having an active area of 0.3 cm x 0.3 cm with 12,100 20 mm x 20 mm pixels. The signal after amplification with a charge-sensitive preamp AD8000 (gain of 8.5) is recorded in a 14-bit ADC, which is read out with Labview [3-4-5-6-7].

To test for linearity and measure the energy resolution, energy spectra from five radioactive sources (^{133}Ba, ^{57}Co, ^{22}Na, ^{137}Cs and ^{60}Co) were measured.

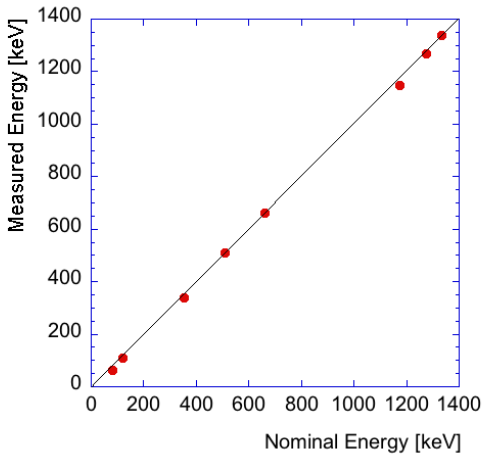

Figure 4 - Linearity measured with five sources

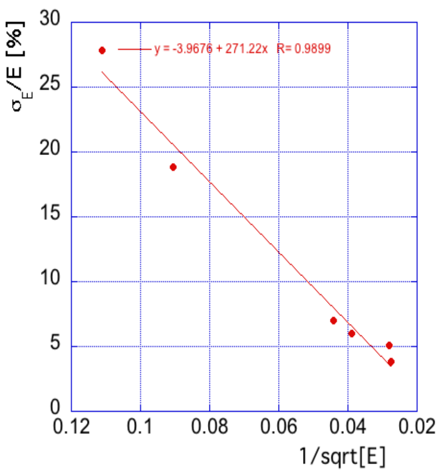

Figure 5 - Energy resolution

Figure 4 depicts the measured energies of the photon lines from the five sources as a function of the nominal energy showing that the energy scale is linear at least up to 1.33 MeV.

Figure 5 shows the energy resolution as a function of the nominal photon energy. For example, the energy resolution of the 511 keV ^{22}Na line is σ/E=7%. The lowest energy emission line (81 keV ^{133}Ba) is also clearly visible with a 20 % energy resolution Before installation, the photon counters need to be tested at KLOE. A mechanical support structure needs to be completed once the KLOE physicists have decided where to mount the counters.

6. DIAGNOSTICS AND DAQ UPGRADE

The BTF multipurpose DAQ system has been continuously updated and developed during the four years of AIDA contract in order to host new devices and develop a GUI (Graphical Users Interface) for users.

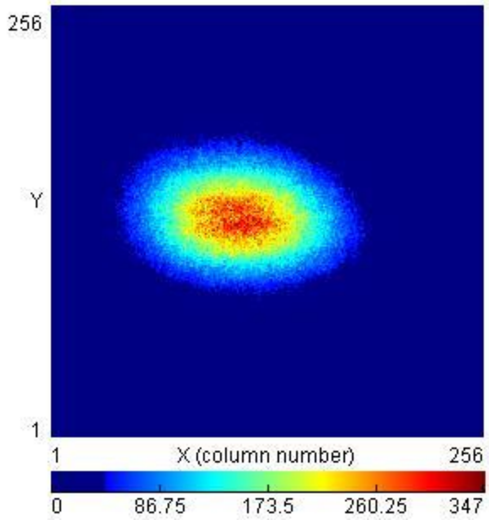

Figure 6 - BTF electron beam (average multiplicity ≈200 particles/bunch) of 450 MeV energy imaged by the MEDIPIX detector. The side of the sensor is 25 mm.

All the functionality of the GEM system (CANBUS via KVASER in HVGEM) runs temporary on virtualized environment. Studies of the co-relation among HVGEM currents and particle multiplicity has been started to obtain an independent beam current monitor over a wide range.

A MEDIPIX detector (Timepix) has been tested to increase the transverse beam detection quality (see Figure 6) and qualify the BTF calorimeters over a wide range of multiplicity. The same scheme has been also very useful to define the timing of BTF standard experimental setup.

After preliminary studies for the porting of DAQ-BTF from labview to !CHAOS[2], a new standalone DAQ-BTF written in C is under test. Next steps will be the implementation of DAQ-BTF-C in !CHAOS framework. An operative test on BTF magnets and beam transport has been performed in November 2013. The test-beam reached all the foreseen AIDA milestones.

The last step on the vacuum improvements has been performed: a safety fast valve was coupled to a gate one. The local safety system is now able to interlock vacuum at 10^{-7} mbar in a few milliseconds. The BTF vacuum system is now fully integrated in the general supervisor software, that is capable of managing all the remote monitoring and actions on interlocks and valves.

A complete new design of the BTF networking service offered to the users has been performed, in accordance to the recent developing of the DAFNE network service:

- The serial bus-controlled apparatus (I.e. BTF scrapers, HVGEM CANBUS, remote trolley table and others) have been migrated to a MOXA serial to Ethernet switches in order to standardize, via serial virtualization, the basic BTF slow control low level communications.

- The number of network switches and wireless beacons has been improved and a BTF VLAN has been developed and offered to non-LNF/INFN users. A full mapping of cables and plugs has been done and the topological distribution of the Ethernet cables and plugs will fulfill also the future users' needs. This task has been completed improving also the BTF-LNF internal network service in order to be prepared to host long term local experiments. The overall number of cables/plugs is over 50 unities.

- A BTF-dedicated DHCP server has been implemented. The BTF DHCP server is extremely efficient: the nominal integration time of the users computing machine in the BTF private subnet is now just the time to plug the Ethernet cable. We are now able to offer 100Mbit/s DHCP network as far as 1Gbit/s private links.
- After having fixed these hardware development steps, we have migrated the software in a virtual machine environment in order to strength the reliability of the software services needed by the BTF environment itself and the ones given to the users for BTF beam run-time control.
- The virtual machine subsystem (VMS) is DELL based and pushed up the BTF up-time offering a very good redundancy, it also allowed the BTF staff to perform software development during the users run-time in a common well defined environment. VMS used as computational node both for the users and the BTF staff even if it is mostly used for BTF setup and diagnostic display during users run-time. The MOXA apparatus are controlled via Ethernet drivers; TIMEPIX and HVGEM-CANBUS are directly attached to the VMS via virtual USB probes.
- A BTF live data collecting system has been developed in conjunction with the DAFNE DCS upgrades. It is based in MEMCACHED technology whose dead time is completely negligible in comparison with loop time of BTF subsystem asynchronous data chunk repetition rate. The BTF-MEMCACHED subsystem has been under stress, without failures, since more than two years.
- It has been reached the complete redundancy on BTF DAQ boards, VMIC control machine and crates. In the mean time we have doubled the NIM, VME, HV crates/boards and power supplies unities, available to be provided to the users.
- Moreover, user-friendly BTF PTU environmental sensors have been implemented, whose data is used by the users to gain a net calibration of their detectors in temperature, humidity and pressure in real time.

For the DAQ topics we have resolved problems related to the data format, maintaining the DAQ modular flexibility and we perform a good improvement in timing issues. The BTF data acquisition is working as usual in a very straightforward way, collecting and displaying data to the users via the DAFNE slow control environment. The data caching of BTF-DAQ has been doubled also on the BTF MEMCACHED server in order to permit a full collection of BTF data sources. Some improvement to the BTF-DAQ code and bug fixing allowed to stably run the system at the full LINAC repetition rate. The overall system stability is assured by the BTF internal network that reached a very good stable configuration even with the weekly stress due to different users' requirements.
Some recent upgrades in acquiring and integration of scientific instrumentation follow:

- A remote motorized linear stage equipped with heavy duty stepper motor was implemented with an accuracy of 100µm and a resolution of 0.1µm in a maximum range of 100mm; this stage has been also integrated in BTF data caching and virtual machine subsystem.

- A remote motorized rotary stage system is equipped with heavy-duty stepper motor was implemented with an accuracy of 20μrad, mostly used by users to precisely control the angular positioning of detectors (i.e. Cherenkov fiber characterization).

- The remote trolley table is working in a very stable way and showed no significant interruption (i.e. annual maintenances). In case of light payload (under few kilograms), we pushed up the single axis step resolution, lowering it down to 0.1mm in same step direction of movement. It has been performed on the both axes and a complete software bug correction has been implemented.

Both of the two linear and rotary stages, the BTF scrapers control, some vacuum probes, the remote trolley table, the environmental dose detectors and some other BTF diagnostic tools are controlled and collected in the MOXA serial-to-Ethernet BTF subsystem. This system is also used by the users, thus permitting the integration in the BTF private VLAN, removing the necessity of any standalone PC.

7. CONCLUSION

The task 8.2.2 concerning the test beam infrastructure of Frascati has been successfully completed, reaching the deliverable defined in the AIDA contract. The devices supported by the AIDA project, remote trolley and TPC GEM tracker, have been commissioned and integrated as permanent tools. These, after the integration in BTF DAQ and the development of dedicated GUI, are now fully available for BTF users after the integration in BTF DAQ and the development of dedicated GUI. The experience reported by users operating such devices has been fully positive. The qualification of the beam energy spread with the LYSO calorimeter in the energy range from 100 to 500 MeV has been successfully performed, providing an accurate result very useful for the qualification of the facility and the needs of many users.

Moreover, the users' experiences at the BTF over these four years of contract have been very positive and have gained of the continuous integration of new diagnostics, and DAQ upgrade.

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