European Coordination for Accelerator Research and Development

PUBLICATION

LHC Status & Plan before HL-LHC

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LHC Status & Plan before HL-LHC

Frank Zimmermann, CERN/BE

“Higgs & Beyond” Conference

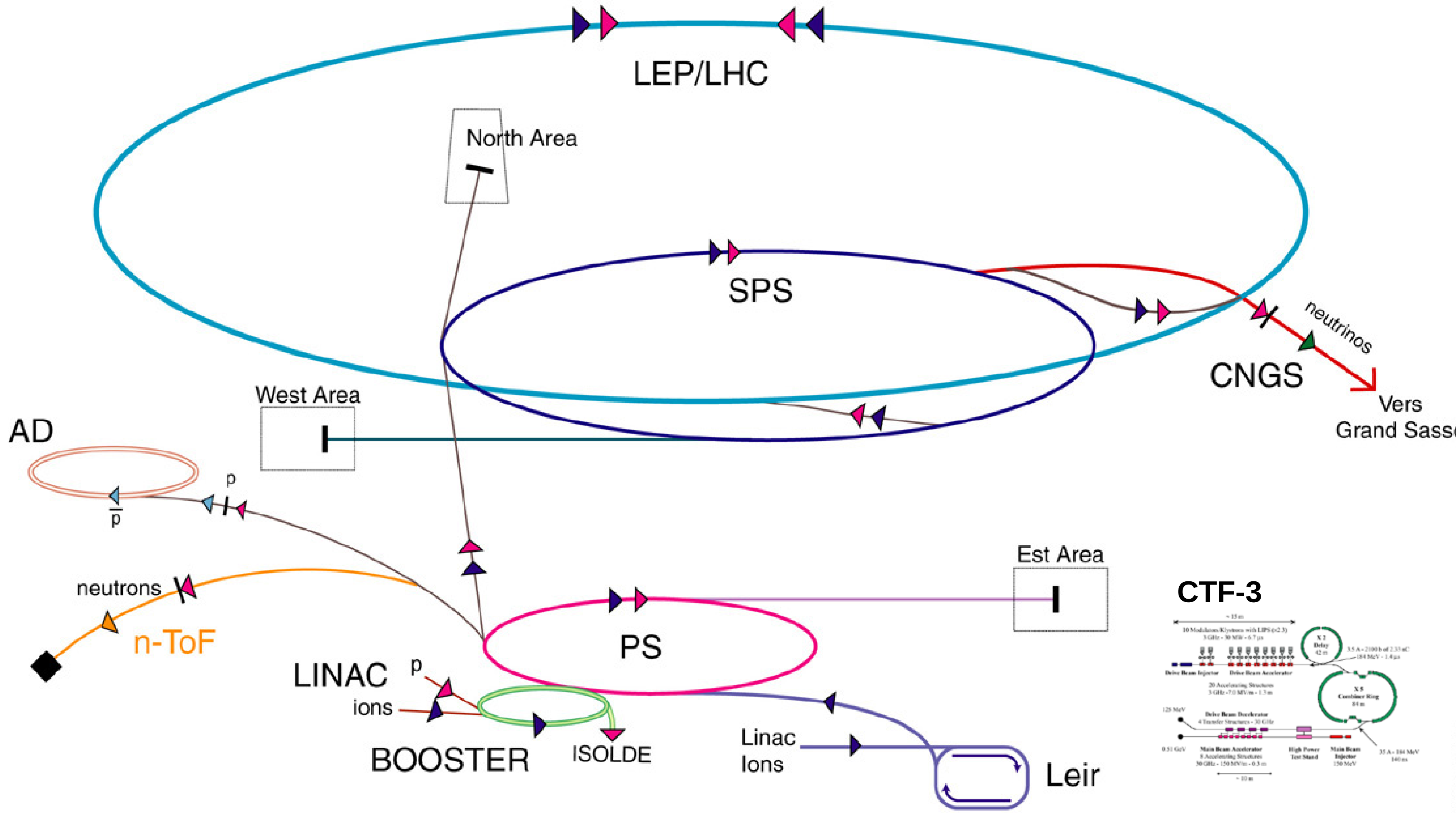
Tohoku University, Sendai

5 June 2013

thanks to Mike Lamont & Ray Veness

*Work supported by the **European Commission** under the FP7 Research Infrastructures project **EuCARD**, grant agreement no.~227579*

Accelerator chain of CERN (operating or approved projects)



p (proton)
ion
neutrons

p̄ (antiproton)
proton/antiproton conversion
neutrinos

AD Antiproton Decelerator
PS Proton Synchrotron
SPS Super Proton Synchrotron

LHC Large Hadron Collider
n-ToF Neutrons Time of Flight
CNGS Cern Neutrinos Grand Sasso

CERN AC _ HF205_ V05/09/2001

short LHC history

1983 *LEP Note 440* - S. Myers and W. Schnell propose
twin-ring *pp* collider in LEP tunnel w 9-T dipoles

1991 CERN Council: LHC approval in principle

1992 EoI, LoI of experiments

1993 SSC termination

1994 CERN Council: LHC approval

1995-98 cooperation w.Japan,India,Russia,Canada,&US

2000 LEP completion

2006 last s.c. dipole delivered

2008 first beam

2010 first collisions at 3.5 TeV beam energy

2015 collisions at ~design energy (plan)

>30 years

LHC 1

ps

LEP Note 440

11.4.1983

PRELIMINARY PERFORMANCE ESTIMATES FOR A LEP PROTON COLLIDER

S. Myers and W. Schnell

ps

LEP Note 440
11.4.1983

PRELIMINARY PERFORMANCE ESTIMATES FOR A LEP PROTON COLLIDER

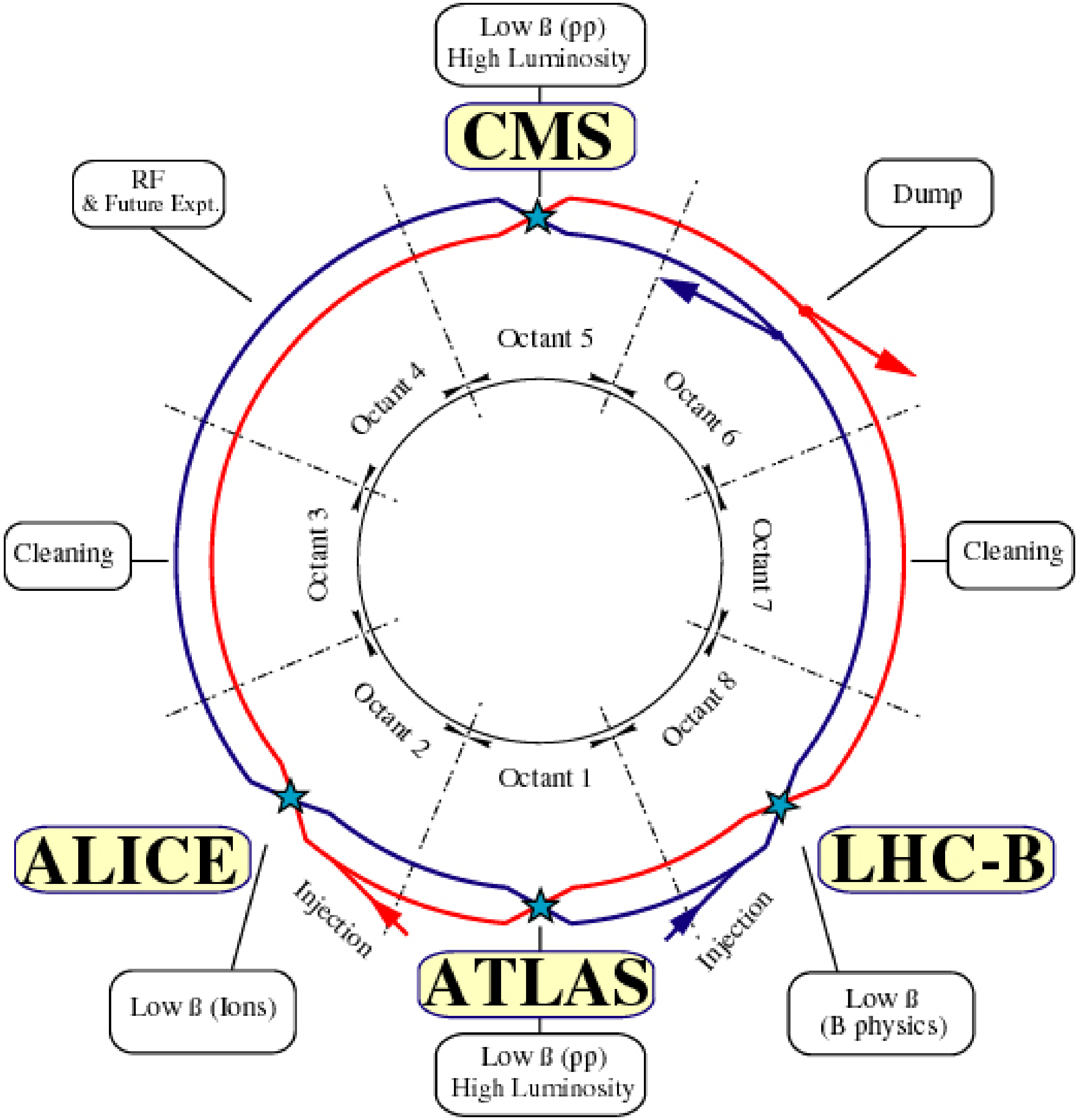
S. Myers and W. Schnell

1. Introduction

This analysis was stimulated by news from the United States where very large $p\bar{p}$ and pp colliders are actively being studied at the moment. Indeed, a first look at the basic performance limitations of possible $p\bar{p}$ or pp rings in the LEP tunnel seems overdue, however far off in the future a possible start of such a p-LEP project may yet be in time. What we shall discuss is, in fact, rather obvious, but such a discussion has, to the best of our knowledge, not been presented so far.

We shall not address any detailed design questions but shall give basic equations and make a few plausible assumptions for the purpose of illustration. Thus, we shall assume throughout that the maximum energy per beam is 8 TeV (corresponding to a little over 9 T bending field in very advanced superconducting magnets) and that injection is at 0.4 TeV. The ring circumference is, of course that of LEP, namely 26,659 m. It should be clear from this requirement of "Ten Tesla Magnets" alone that such a project is not for the near future and that it should not be attempted before the technology is ready.

LHC: highest energy *pp*, *AA*, and *pA* collider



design parameters

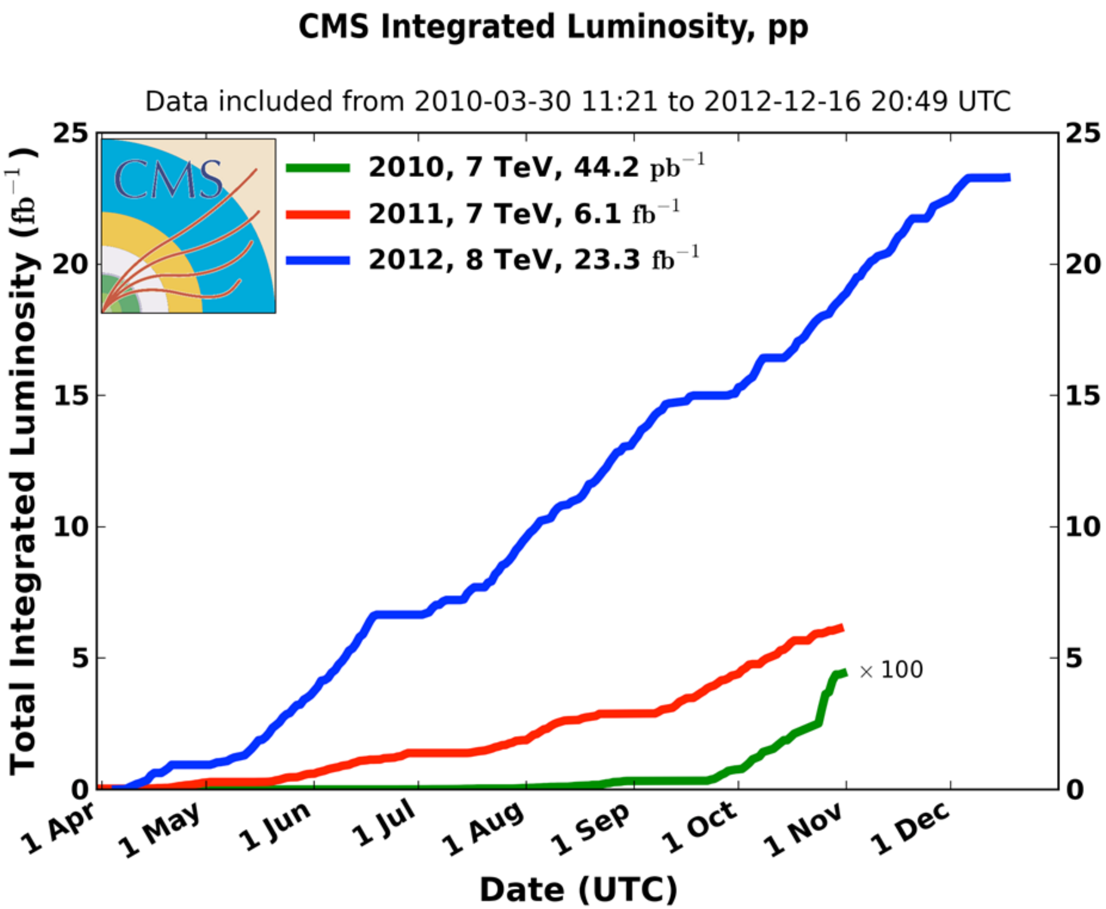
c.m. energy = 14 TeV (*p*)
luminosity $=10^{34}$ $cm^{-2}s^{-1}$

1.15×10^{11} p/bunch
2808 bunches/beam

360 MJ/beam

$\gamma\varepsilon=3.75$ μm
$\beta^*=0.55$ m
$\theta_c=285$ μrad
$\sigma_z=7.55$ cm
$\sigma^*=16.6$μm

integrated *pp* luminosity 2010-12

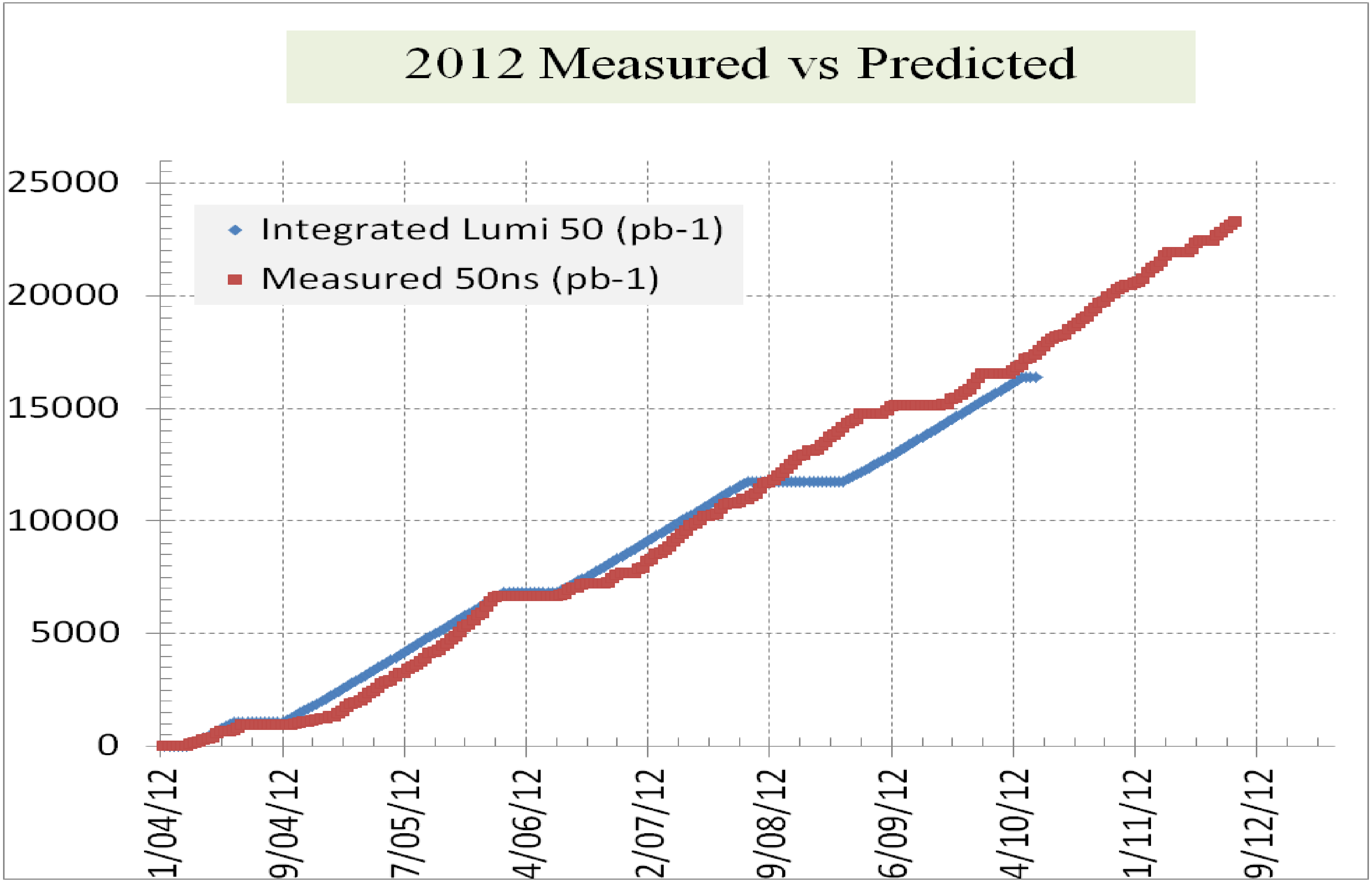


- 2010: **0.04 fb^{-1}**
  - 7 TeV CoM
  - Commissioning
- 2011: **6.1 fb^{-1}**
  - 7 TeV CoM
  - Exploring the limits
- 2012: **23.3 fb^{-1}**
  - 8 TeV CoM
  - Production

M. Lamont, IPAC'13

Steve Myers, CMAC

2012

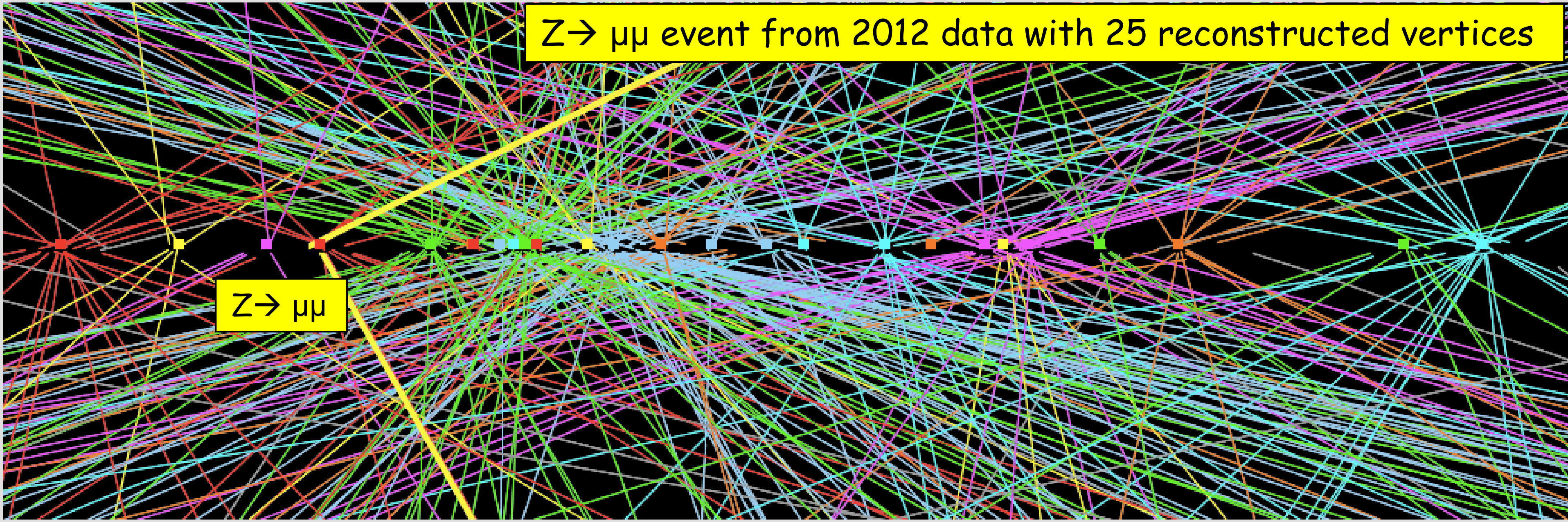


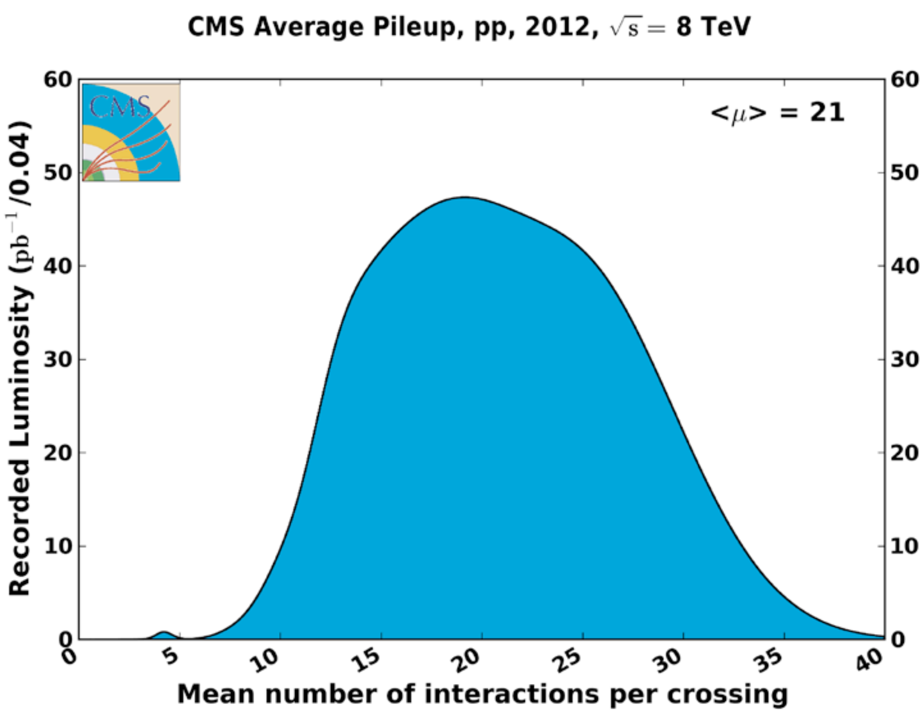
peak performance through the years

	2010	2011	2012	Nominal
bunch spacing [ns]	150	50	50	25
no. of bunches	368	1380	1380	2808
beta* [m] ATLAS and CMS	3.5	1.0	0.6	0.55
max. **bunch intensity** [protons/bunch]	1.2×10^{11}	1.45×10^{11}	1.7×10^{11}	1.15×10^{11}
normalized **emittance** [mm-mrad]	~2.0	~2.4	~2.5	3.75
peak luminosity [$cm^{-2}s^{-1}$]	2.1×10^{32}	3.7×10^{33}	7.7×10^{33}	1.0×10^{34}

>2x design when scaled to 7 TeV

M. Lamont, IPAC'13



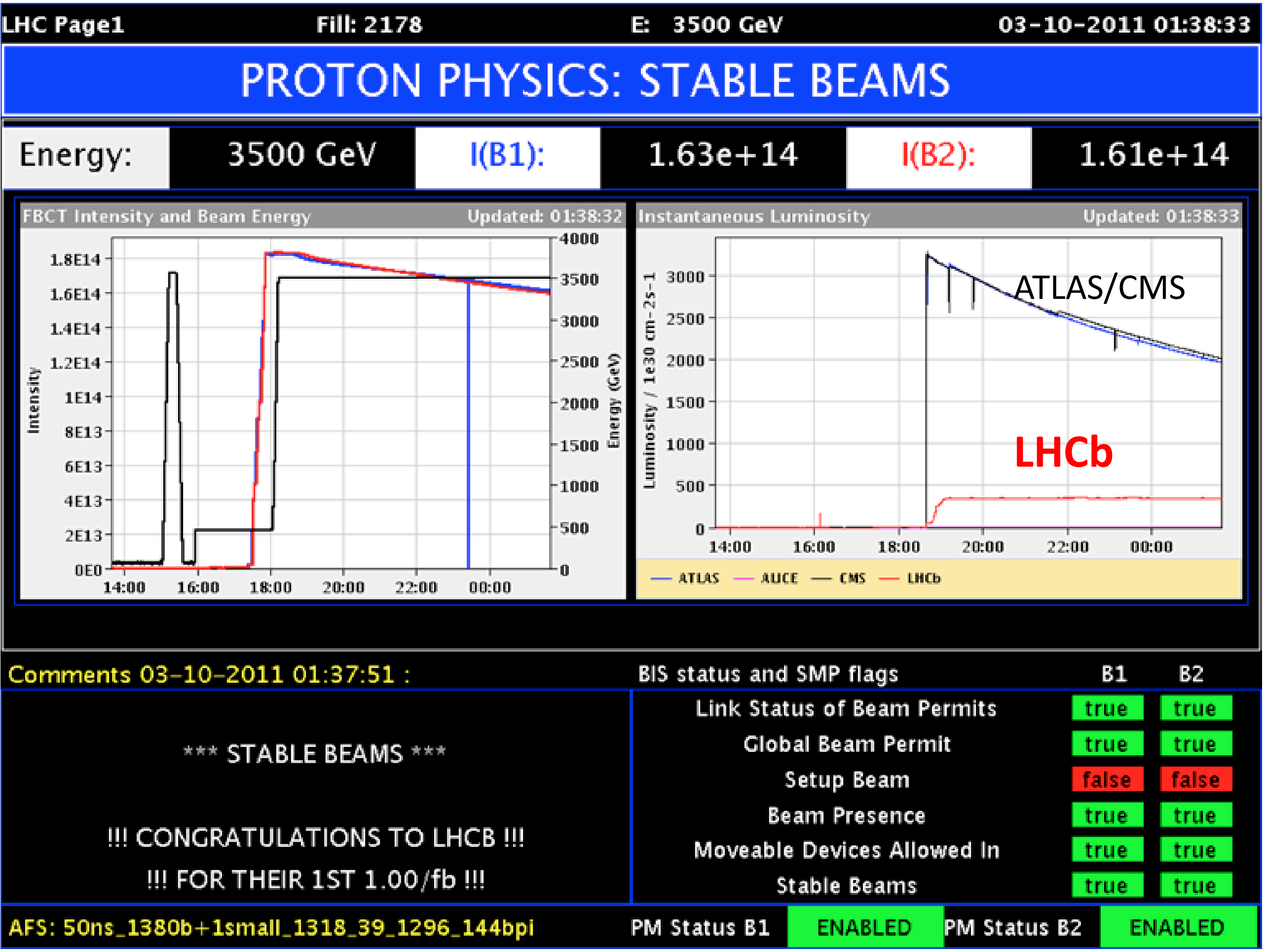


pile up
will increase
at higher energy

experiments
request
25 ns
operation
in 2015

M. Lamont, IPAC'13

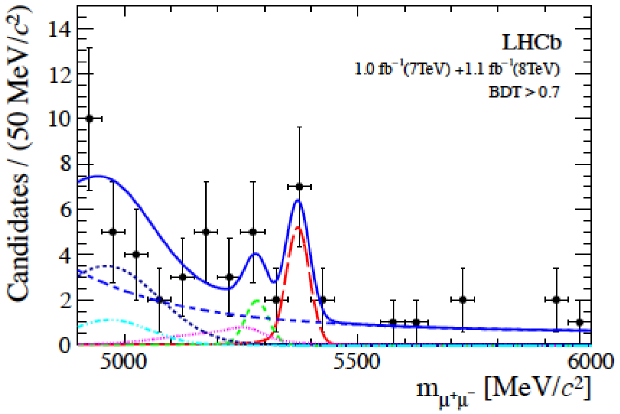
LHCb



luminosity levelling at around 4e32 $cm^{-2}s^{-1}$ via transverse separation (with a tilted crossing angle)

not completely trivial!

first evidence for the decay $B_s \to \mu^+ \mu^-$



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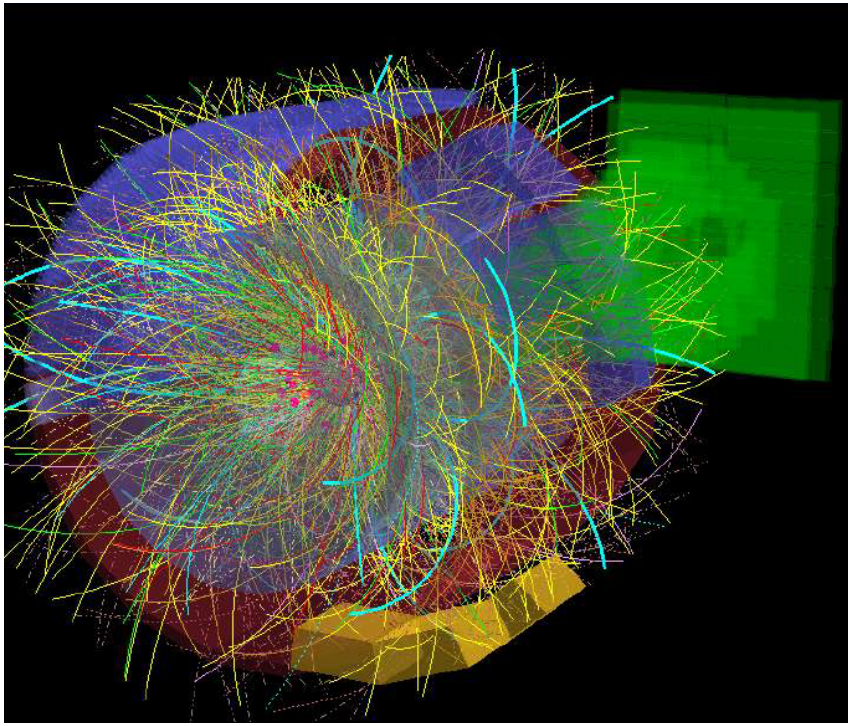
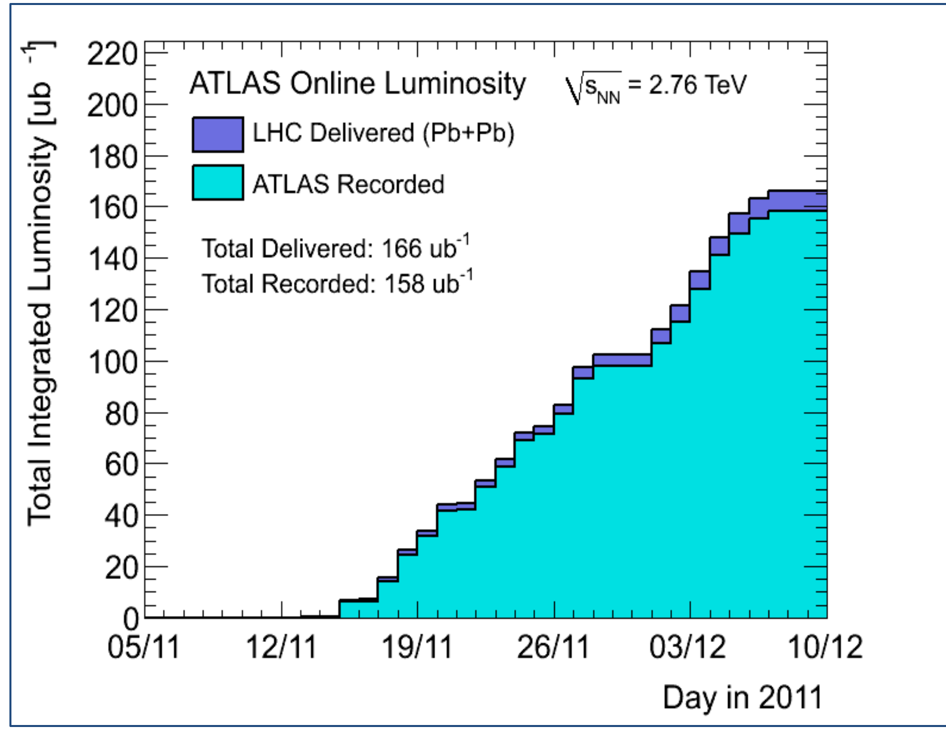
Pb-Pb

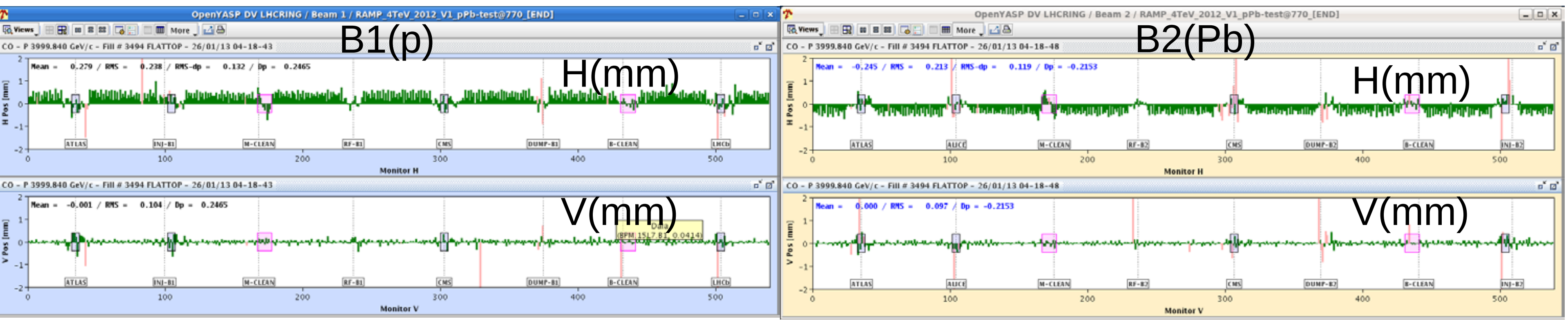




- good performance from the injectors - bunch intensity and emittance
- preparation, Lorentz' law: impressively quick switch from protons to ions
- peak luminosity around 5 x 10^{26} $cm^{-2}s^{-1}$ at 3.5Z TeV (2011) – nearly twice design when scaled to 6.5Z TeV

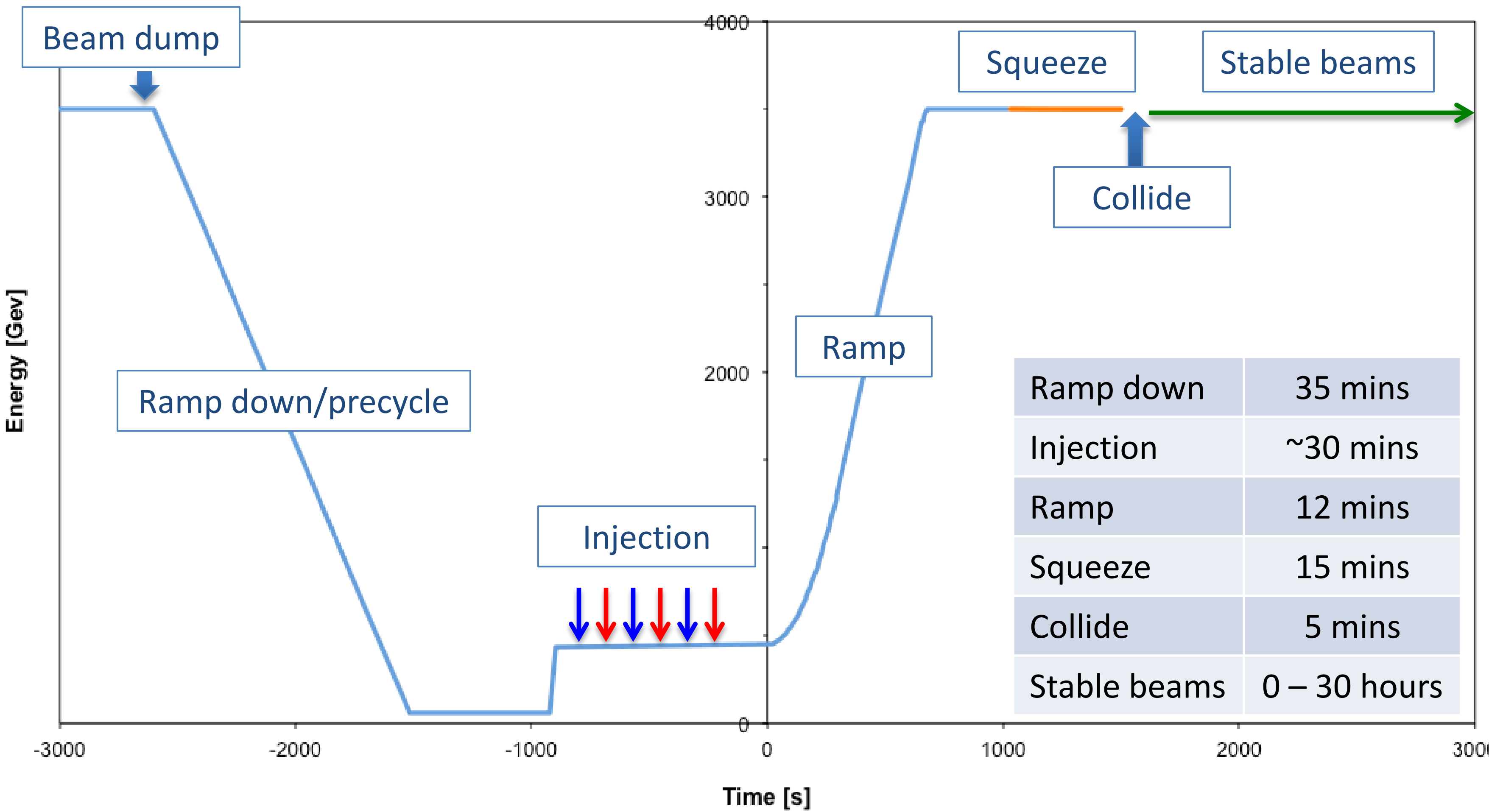
proton-lead

- beautiful result in early 2013
- final integrated luminosity above experiments’ request of 30 nb^{-1}
- injectors: average number of ions per bunch was ~$1.4x10^8$ at start of stable beams, i.e. around twice the nominal intensity



beam orbits at top energy with RF frequencies locked to Beam 1

operational cycle



Ramp down	35 mins
Injection	~30 mins
Ramp	12 mins
Squeeze	15 mins
Collide	5 mins
Stable beams	0 – 30 hours

turn around 2 to 3 hours on a good day

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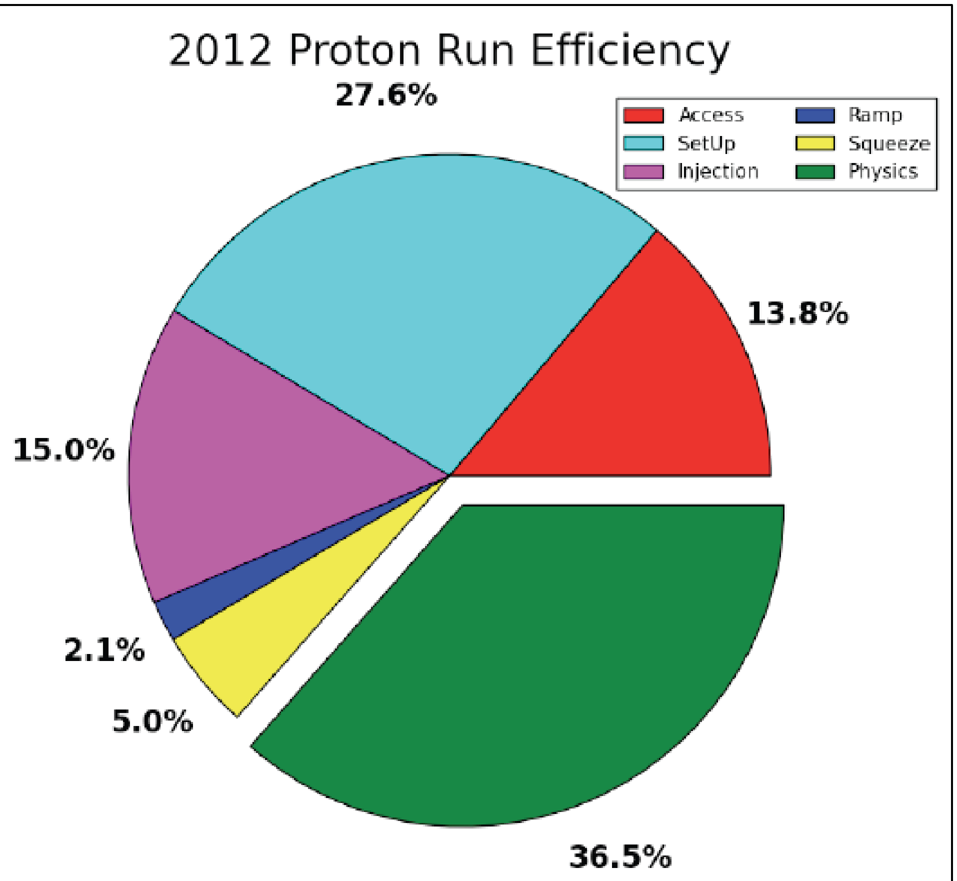
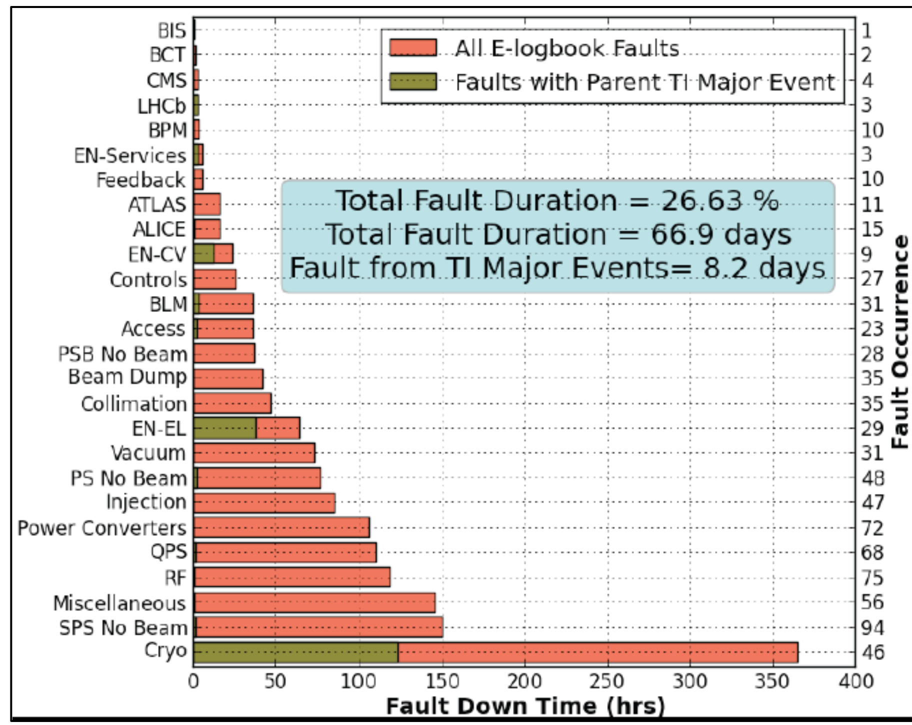
availability

- There are a lot of things that can go wrong – it’s always a battle
- Pretty good availability considering the complexity and principles of operation



SB Time: 73.2 days Total Time: 200.5 days



Cryogenics availability in 2012: 93.7%

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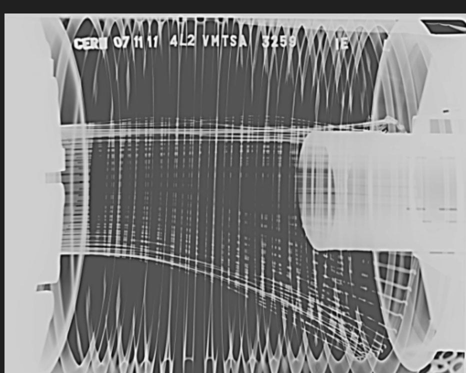
some issues in 2011-12 operation

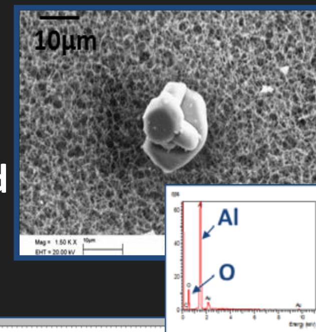
Beam induced heating

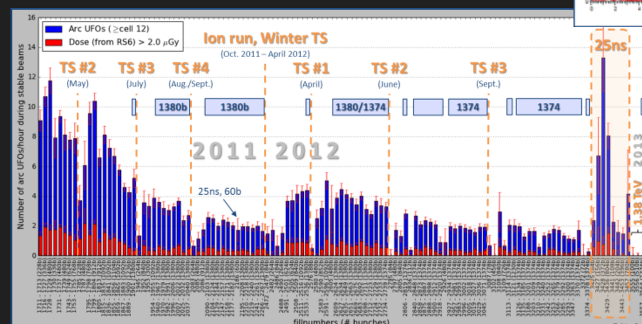
- Local non-conformities (design, installation)
  - injection protection devices
  - sync. Light mirrors
  - vacuum assemblies

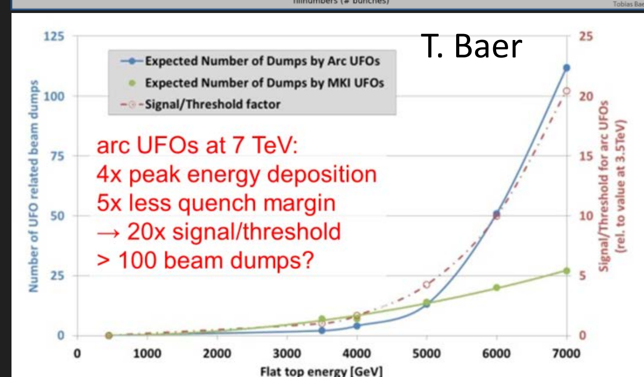


UFOs

- 20 dumps in 2012
- time scale 50-200 μs
- conditioning observed
- worry about 6.5 TeV and 25 ns spacing

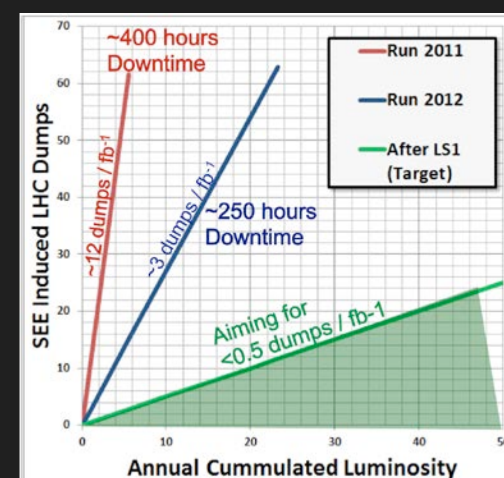






Radiation to electronics

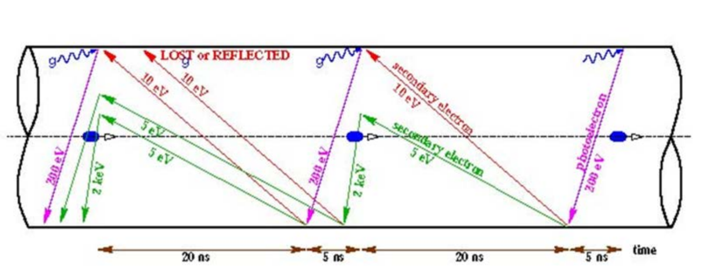
- concerted program of mitigation measures (shielding, relocation…)
- premature dump rate down from $12/fb^{-1}$ in 2011 to $3/fb^{-1}$ in 2012



another issue in 2011-12 operation

Electron cloud

- beam induced multipactoring process, depending on secondary emission yield
- LHC strategy based on surface conditioning (scrubbing runs)
- worry about 25 ns (more conditioning needed) and 6.5 TeV (photoelectrons)



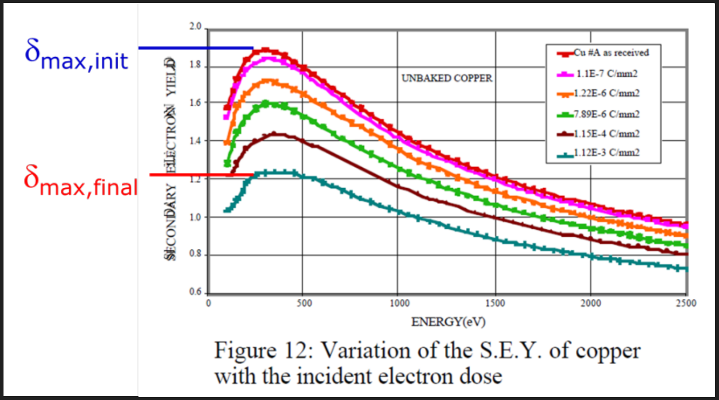
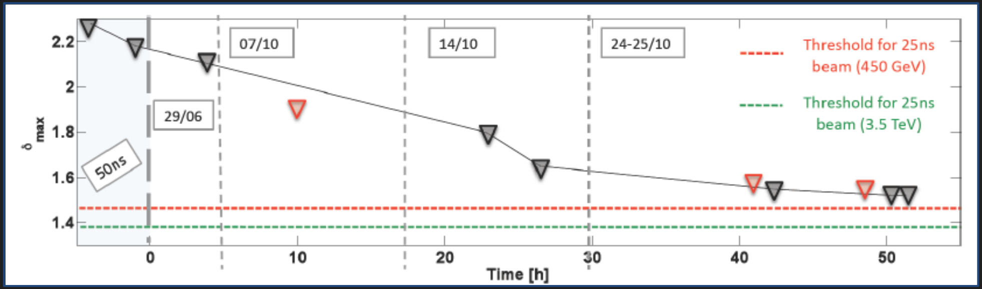
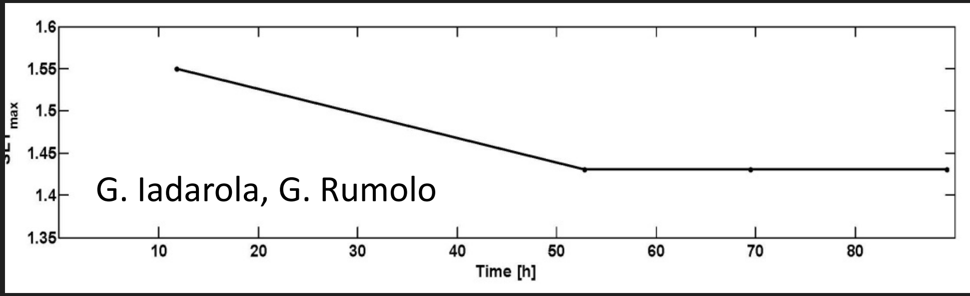


Figure 12: Variation of the S.E.Y. of copper with the incident electron dose

25-ns scrubbing in 2011 – decrease of SEY

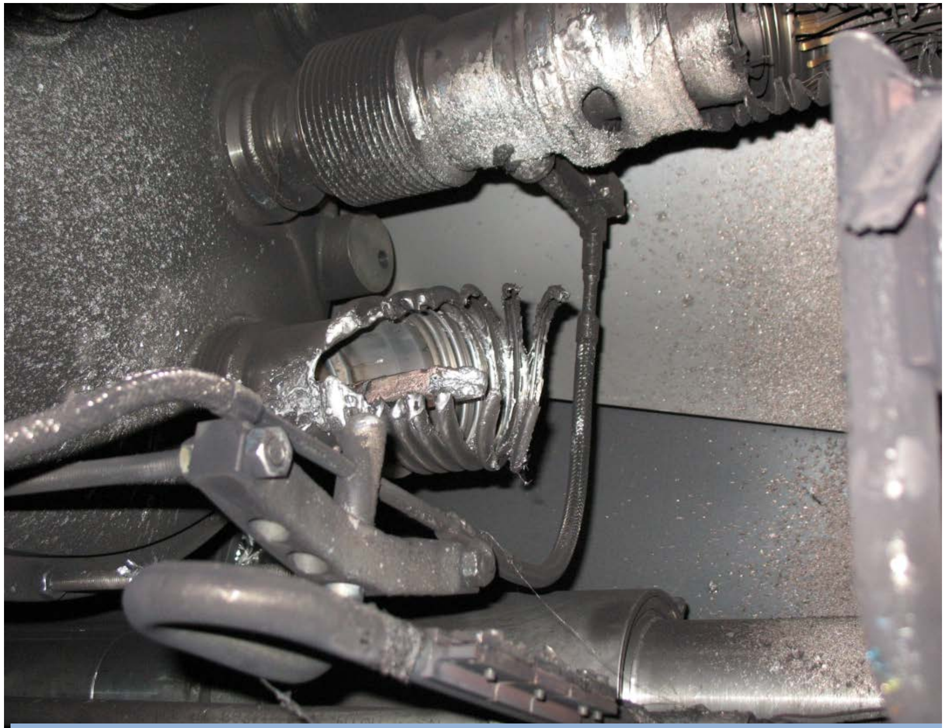


25-ns scrubbing in 2012 – conditioning stop?

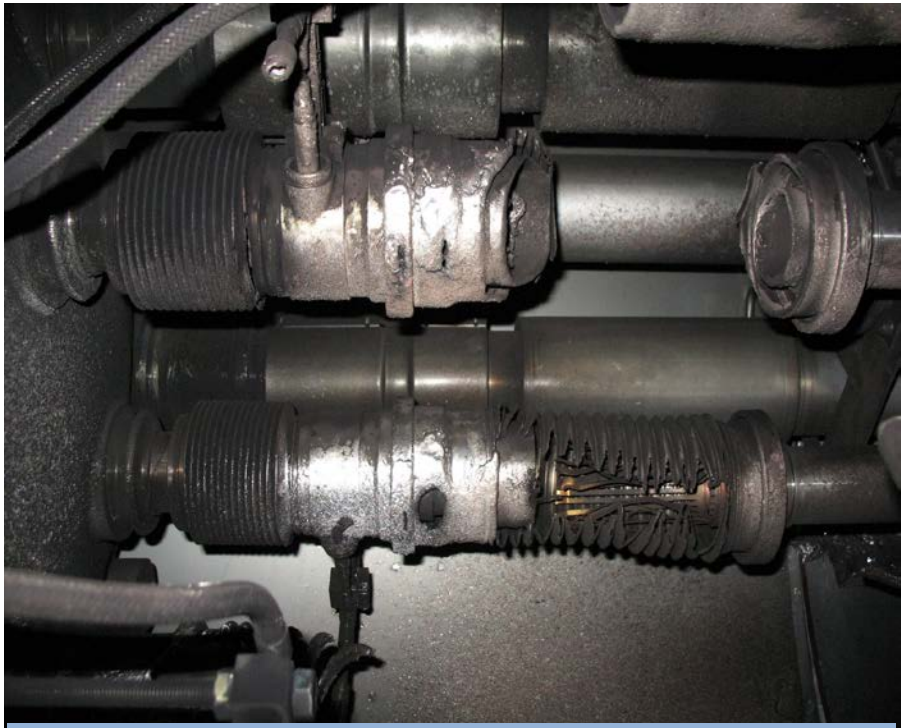


since mid February 2013,
LHC is stopped for
Long Shutdown 1 (LS1)

2008 “incident”

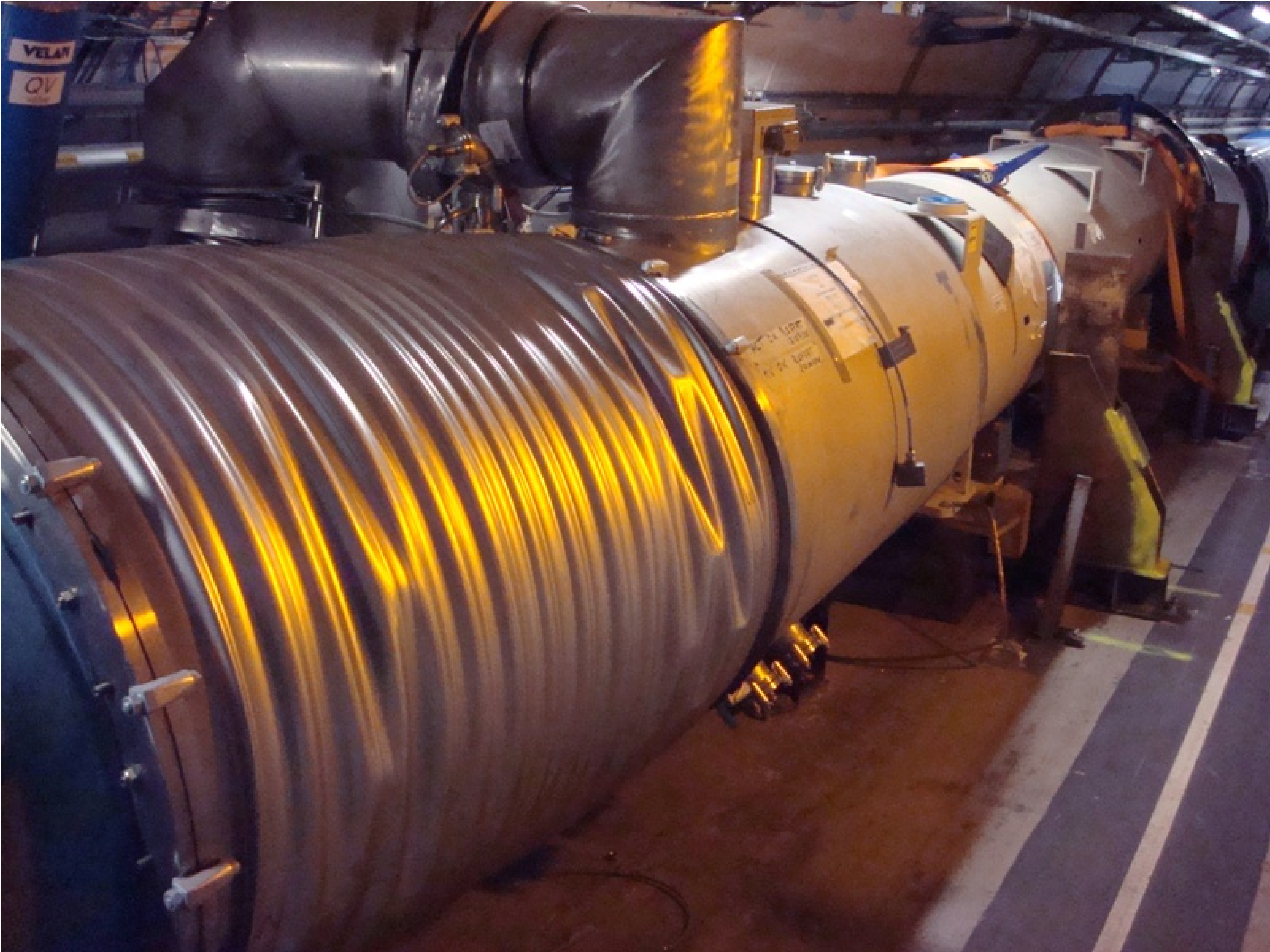


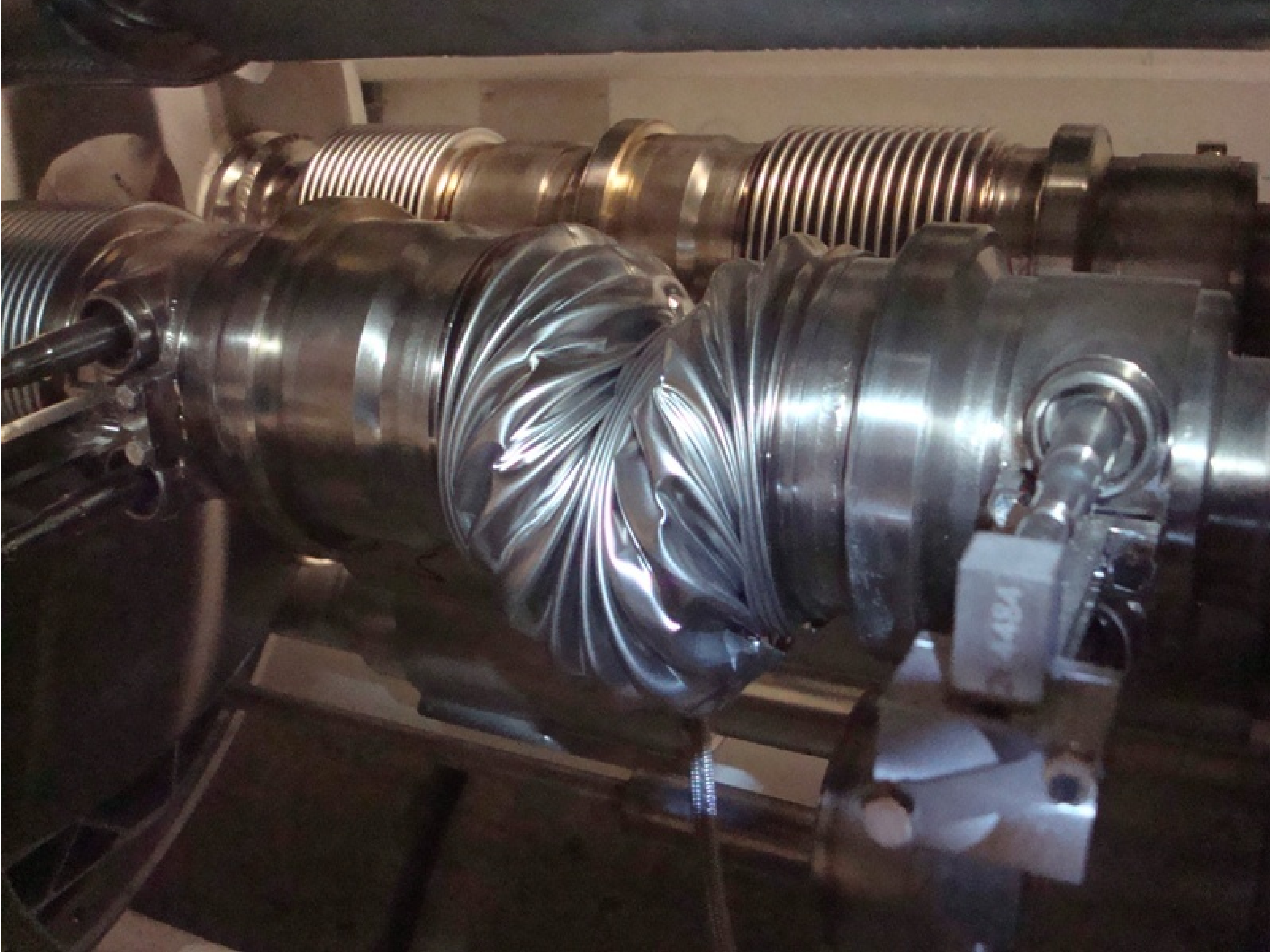
A faulty bus-bar (SC splice) in a magnet interconnect failed, leading to an electric arc which dissipated some 275 MJ



This burnt through beam vacuum and cryogenic lines, rapidly releasing ~2 tons of liquid helium into the vacuum enclosure

R. Veness


VELAN
QV



LS1 motivation

after incident, partial consolidation in 2009 & different problem of imperfect *Cu* stabilizer continuity discovered

in 2010-12 LHC operated at 7 & 8 TeV c.m. beam energy to avoid any risk

presently: Long Shutdown 1 (LS1) ~2 yr to prepare LHC for 13-14 TeV c.m., detector upgrades in parallel

The main 2013-14 LHC consolidations

1695 Openings and final reclosures of the interconnections

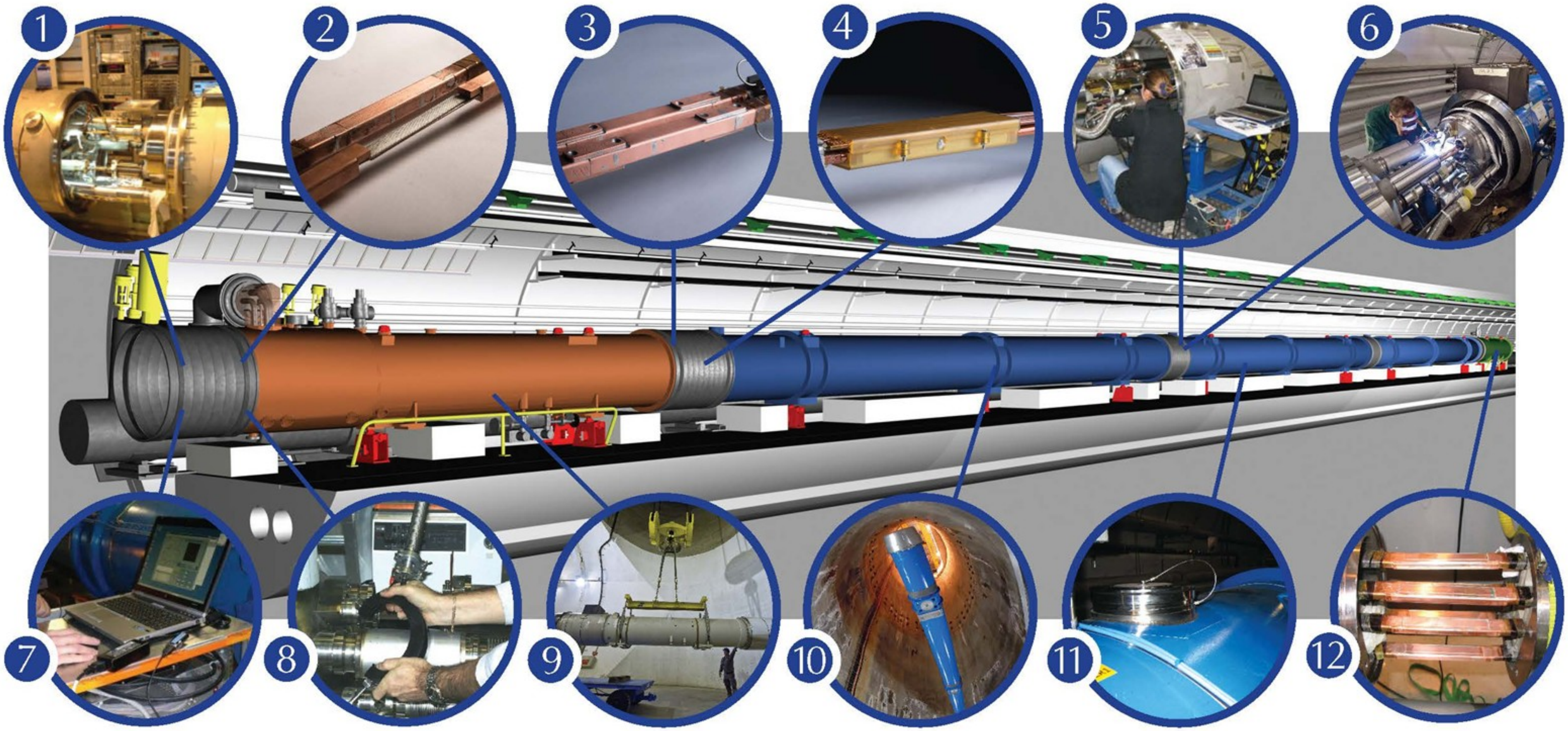
Complete reconstruction of 1500 of these splices

Consolidation of the 10170 13kA splices, installing 27 000 shunts

Installation of 5000 consolidated electrical insulation systems

300 000 electrical resistance measurements

10170 orbital welding of stainless steel lines



18 000 electrical Quality Assurance tests

10170 leak tightness tests

4 quadrupole magnets to be replaced

15 dipole magnets to be replaced

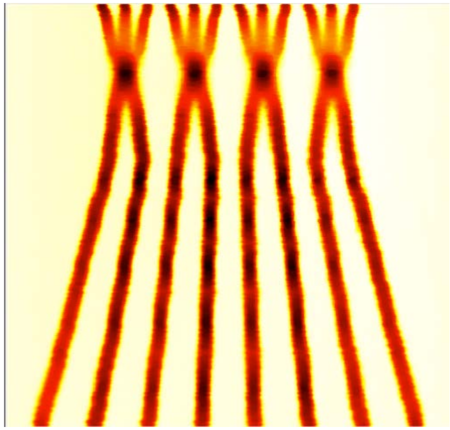
Installation of 612 pressure relief devices to bring the total to 1344

Consolidation of the 13 kA circuits in the 16 main electrical feedboxes

2015 – post LS1

- energy: 6.5 TeV (magnet retraining)
- bunch spacing: 25 ns
  - pile-up considerations
- injectors potentially able to offer nominal intensity with even lower emittance

BCMS = Batch Compression and Merging and Splitting



	Number of bunches	Ib LHC FT[1e11]	Emit LHC [um]	Peak Lumi [$cm^{-2}s^{-1}$]	~Pile-up	Int. Lumi per year [fb^{-1}]
25 ns low emit	2520	1.15	1.9	**1.7e34**	52	~45

expected maximum luminosity from inner triplet heat load (collisions debris) 1.7×10^{34} $cm^{-2}s^{-1}$ ±20%

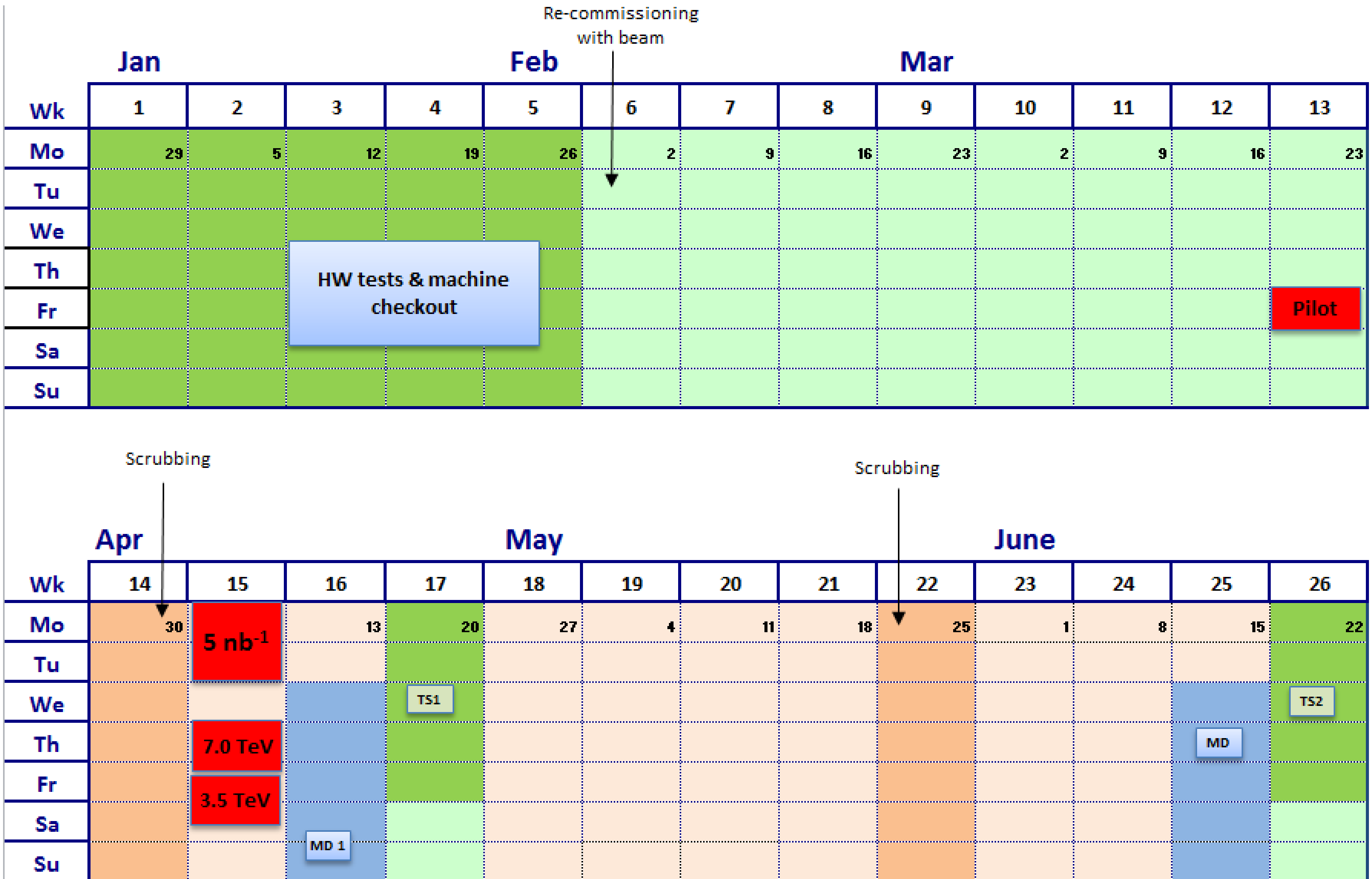
uncertainties for 2015:

- electron cloud
- UFOs

both get more difficult at 25 ns & at higher energy

- energy (limited by retraining)

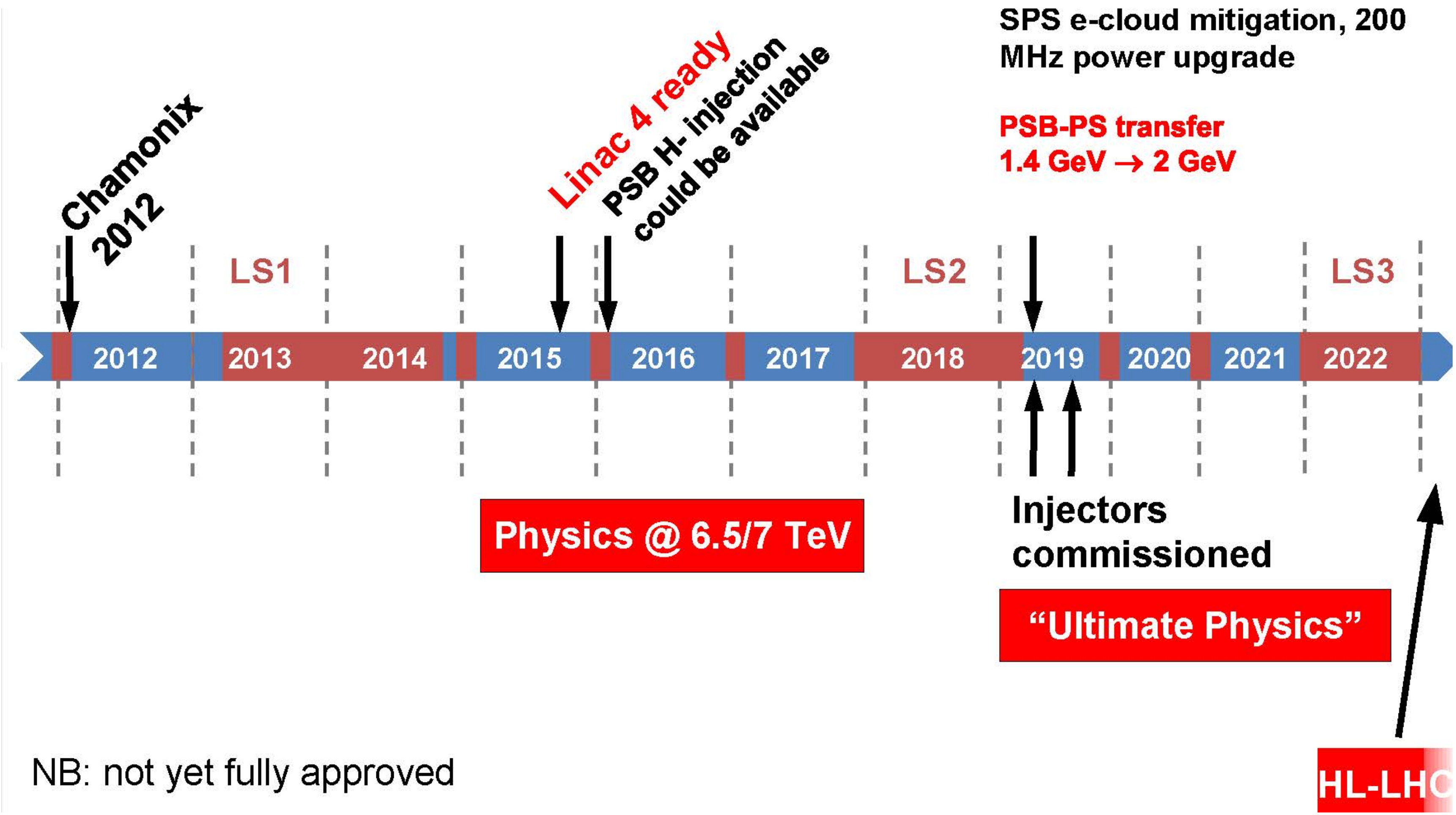
draft 2015 schedule



22-05-13 Mike Lamont

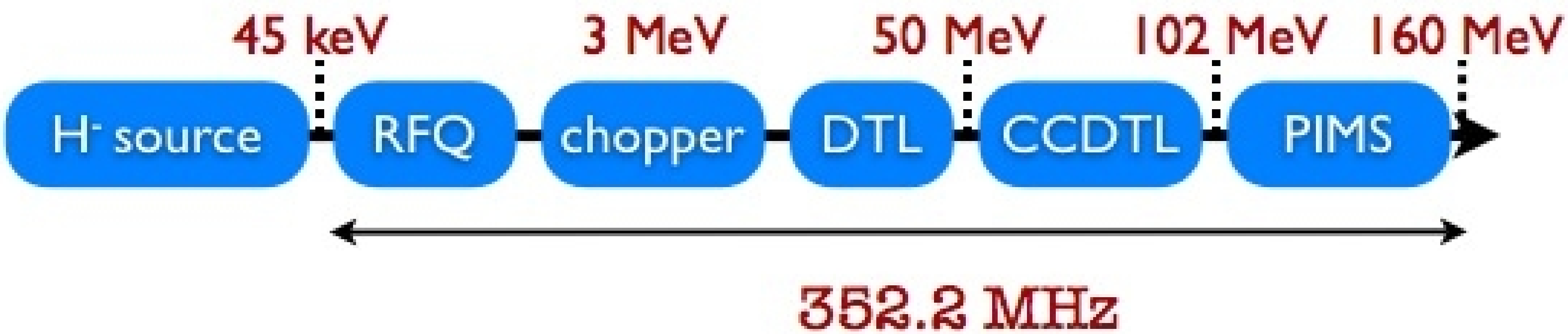
in red beam time requested by LHCf

example LHC time line – next ten years



Ralph Steinhagen, ICHEP2012

Linac4 (160 MeV H^- instead of 50-MeV p)



Linac4 could double the beam brightness injected into the booster, but there may be other bottlenecks downstream (e.g. PS injection)

plan until 2021 & beyond to be reviewed and defined later in 2013

30 September – 4 October 2013
ECFA workshop on LHC detector upgrades

8-10 October 2013
review of LHC and Injector upgrade plans “RLIUP”, a.k.a. “mini-Chamonix” at CERN

RLIUP discussion elements

next long shutdowns LS2 & LS3 – needs & dates

regular Christmas stops (13 weeks?)

"LS1.5" for CMS – 4.5 months in 2016/17?

- exchange of CMS pixel tracker

extended 3-months ion run in 2016?

connecting Linac4 (6-7 months) during ion run & LS1.5?

400/fb by 2021?

conclusions - 2010 to 2012

"reasonably good performance from commissioning through run I"

- 2 years 3 months from first collisions to Higgs

foundations laid for run II

Mike Lamont
IPAC'13

conclusions – from 2015 to 2022

in 2015 LHC will operate close to design energy with peak luminosity likely to exceed the design

new performance limits will be encountered (e.g. triplet cooling limit)

baseline for 2015 is 25 ns, but uncertainties with regard to e-cloud and UFOs; backup option: 50 ns with leveling (pile up)

plans & schedules for injection upgrade and longer shutdowns until ~2022 will be reviewed this fall

thanks