LHC Accelerator Performance & Plans

L. Ponce

On behalf of the LHC Team

BE department, OP group

Outline

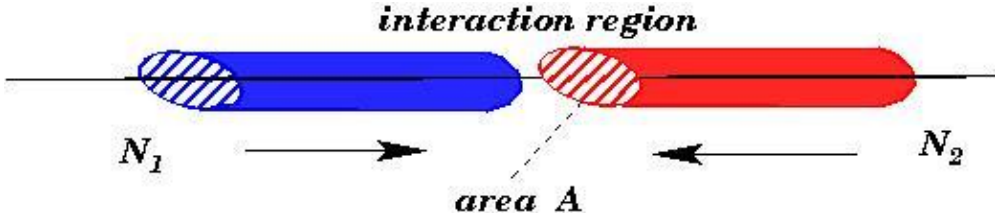
- Performance in 2012
- Main beam parameters in 2012
- High intensity issues
- Proton-Lead run
- Performance after LS1

Luminosity : collider figure of merit

- The key parameter for the experiments is the event rate dN/dt. For a physics process with *cross-section* σ it is proprotional to the collider **Luminosity *L***:

unit of L : 1/(surface × time)

$$dN/dt = L\sigma$$



- The luminosity can be expressed as (for equal particle populations and Gaussian profiles) :

$$L = \frac{kN_1N_2f}{4\pi\sigma_x^*\sigma_y^*} = \frac{kN_1N_2f\gamma}{4\pi\beta^*\varepsilon}$$

- σ^*_x, σ^*_y : *transverse rms beam sizes.*
- β^* *betatron function*
- ε *beam emittance*
- ***k*** *: number of particle packets / bunches per beam.*
- $N_{1/2}$ *: number of particles per bunch.*
  - $k \times N_{1/2}$ **: total beam intensity**
- ***f*** *: revolution frequency = 11.25 kHz.*

To maximize L we need:

- Large N, large k,
- Smallest possible β^* or ε .

⟺ ... or some optimum combination !

Chamonix: Objectives for 2012

Highest Priority

Sufficient Integrated Luminosity to

discover (or exclude) the Higgs before the Long Shutdown

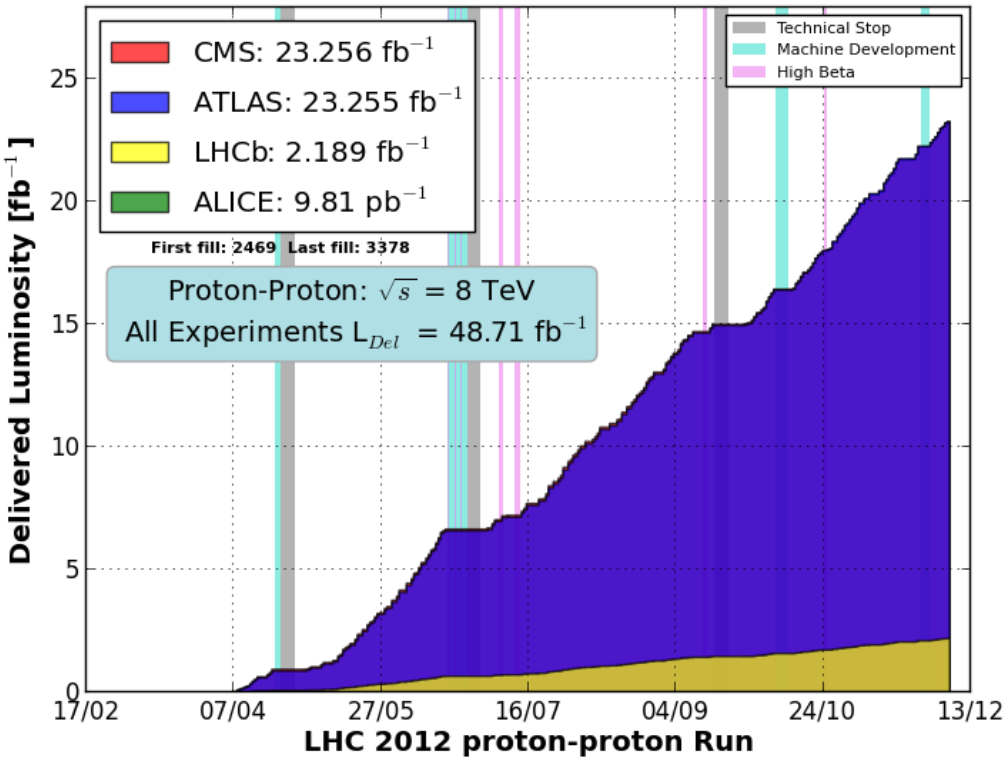
Target set at 15 fb^{-1}

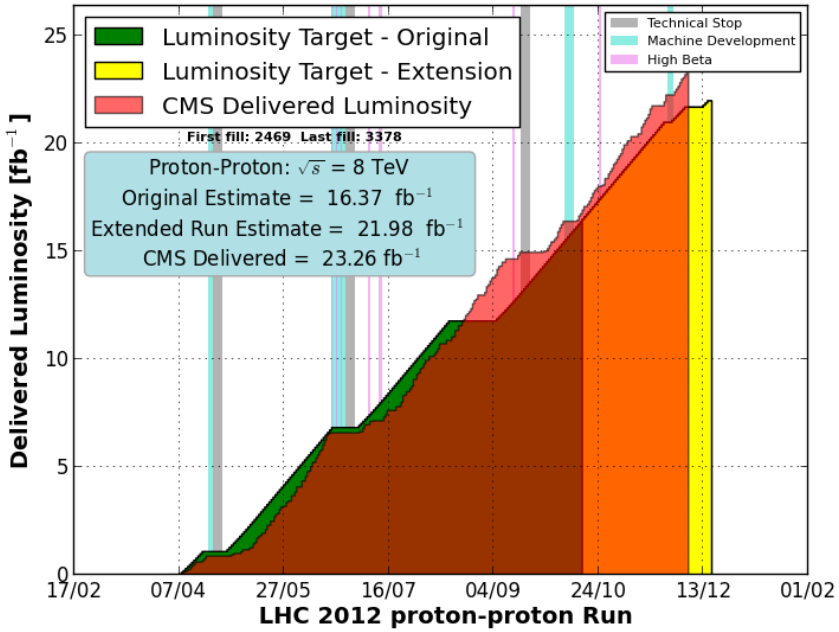
Plans

- ✓ Keep 50ns bunch spacing and 1380 bunches:
  - ➢ Increase bunch intensity (keep lowest possible emittance from injectors)
  - ➢ -> high pile up in experiments: ~35 events/crossing
- ✓ Increase beam energy: 3.5 –> 4 TeV (+15% in Luminosity)
- ✓ Reduce β* in CMS and ATLAS: 1m -> 0.6m (+60% in Luminosity)
  - ➢ Requires "Tight" collimator settings
- ✓ β* = 3m in Alice and LHCb, Tilted Crossing in LHCb,
- ✓ Satellite-main collisions in Alice

Luminosity production 2012

- 1 fb^{-1} on a good week; best week: 1.35 fb^{-1}
- Maximum integrated luminosity per day: 286 pb^{-1}
- Integrated luminosity 23.2 fb^{-1} (as of 05/12/2012)

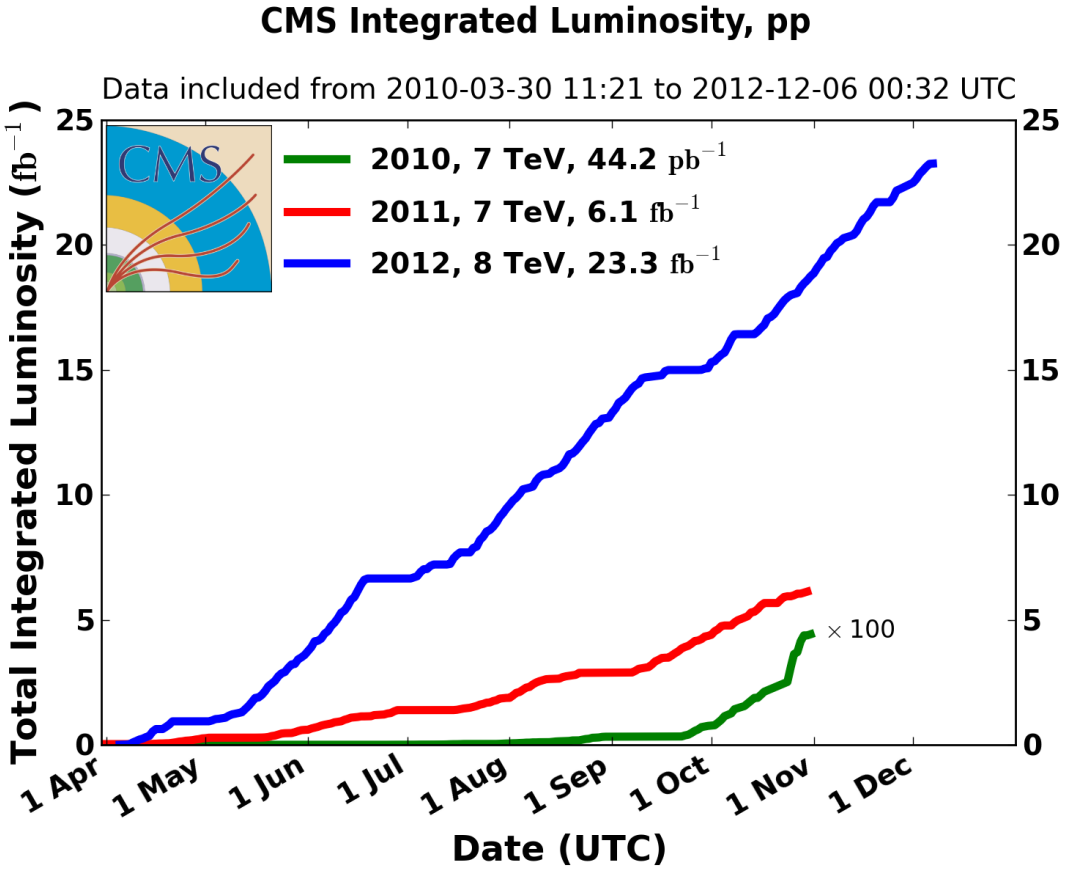


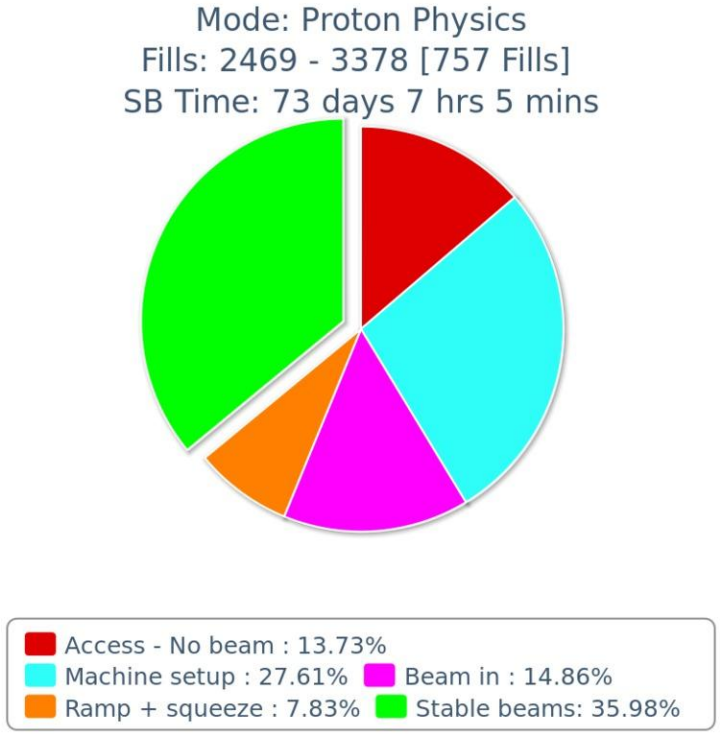


Luminosity production 2010-2012

Integrated luminosity for ATLAS/CMS reaches now ~ **28 fb^{-1}**.

- *In 2012, we spent 37% of the scheduled time delivering collisions to the experiments ('stable beams'), compared to 33% in 2011*

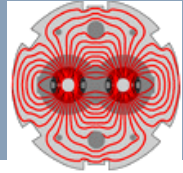




Outline

- Performance in 2012
- Main beam parameters in 2012
- High intensity issues
- Proton-Lead run
- Performance after LS1

Beam parameters: from 2011 to 2012

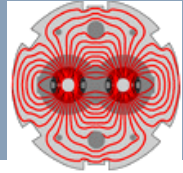


Main changes in 2012:

- *Beam energy: **4 TeV**.*
- ***Reduction of β**** ↔ *tighter collimator settings.*

Parameter	2010	2011	2012	Nominal	Constrained by
N (10^{11} p/bunch)	**1.2**	**1.5**	**1.6-1.7**	1.15	
k (no. bunches)	368	1380	1380/1374	2808	Bunch spacing
Bunch spacing (ns)	150	75 / 50	50	25	
ε (μm rad)	**2.4-4**	**1.9-2.4**	**2.2-2.5**	3.75	Injectors
β* (m)	3.5	1.5 → 1	0.6	0.55	Aperture/ tolerance
L ($cm^{-2}s^{-1}$)	**2×10^{32}**	**3.5×10^{33}**	**7.6×10^{33}**	10^{34}	
Pile-up	3	19	35	23	

Performance from injectors 2012



Design report with 25 ns:
- **1.15×10^{11} ppb**
- **Normalized emittance 3.75 microns**

Bunch spacing [ns]	Protons per bunch [ppb]	Norm. emittance H&V [microns] Exit SPS
50	1.7×10^{11}	1.8
25	1.2×10^{11}	2.7

- Emittances smaller than nominal.
- PS close to the limit of beam stability, injecting close to 1.9×10^{11} ppb into SPS.
- continuously pushing the limits

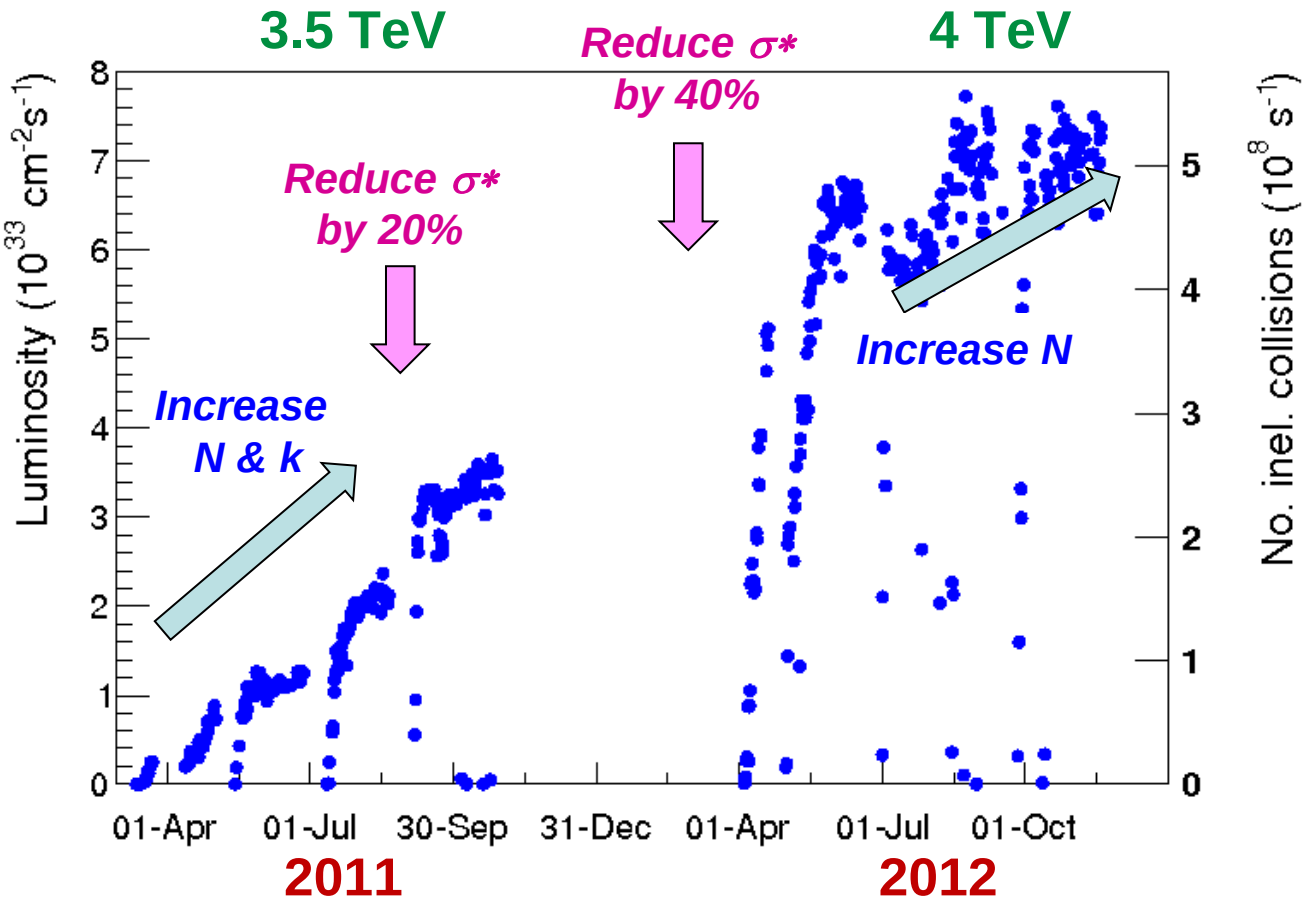
Note: importance of 50 ns in the performance so far. This at the expense of high pile-up.

Peak luminosity 2011-2012

Over the last 2 years the peak luminosity was progressively increased:

- Through the beam intensity (mainly 2011),
- Through beam size reduction at the IP.
- Record *Peak L = 7.7 ×10^{33} cm^{-2}s^{-1}*

75% of Design Luminosity @ Half design Energy and Half the number of bunches!!



Outline

- Performance in 2012
- Main beam parameters in 2012
- High intensity issues
- Proton-Lead run
- Performance after LS1

High intensity beam issues 1/2

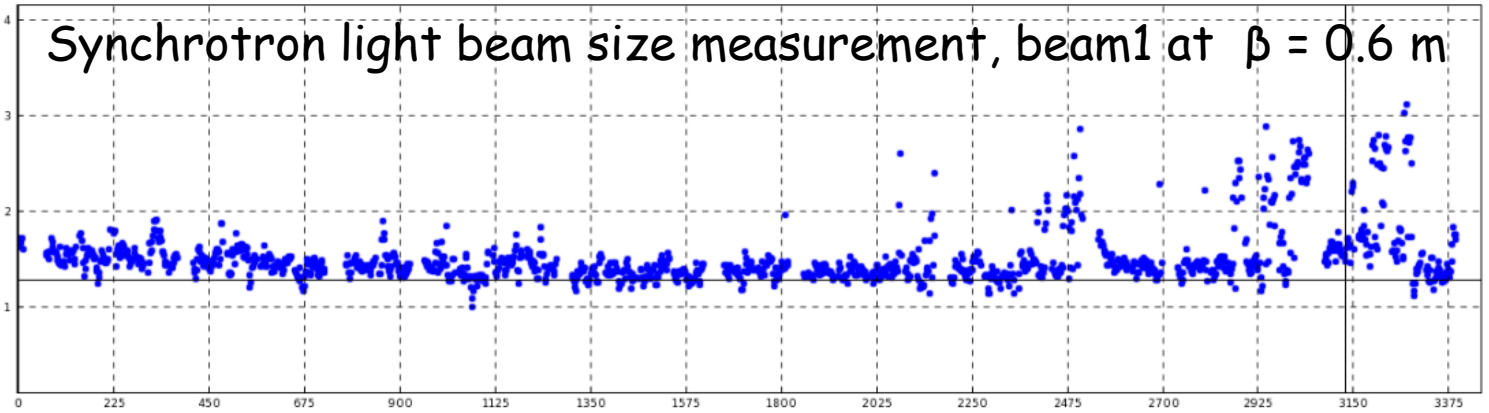
- With 50 ns bunch spacing and stored intensity of ≥ 2×10^{14} protons (1380 bunches), issues related to high intensity and tight collimators

140MJ in gaps of +1.1 mm!

- Beam instabilities leading to emittance blow-up

  important impact on machine efficiency.

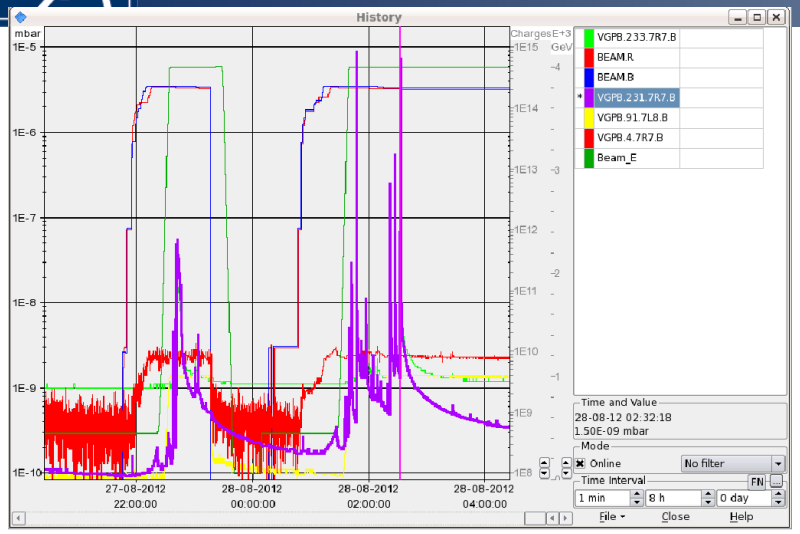
  - ***2012: Lost 30 fills due to those issues during squeeze and adjust,***
  - ***2011: Only 1 fill lost.***



Things are now under control:

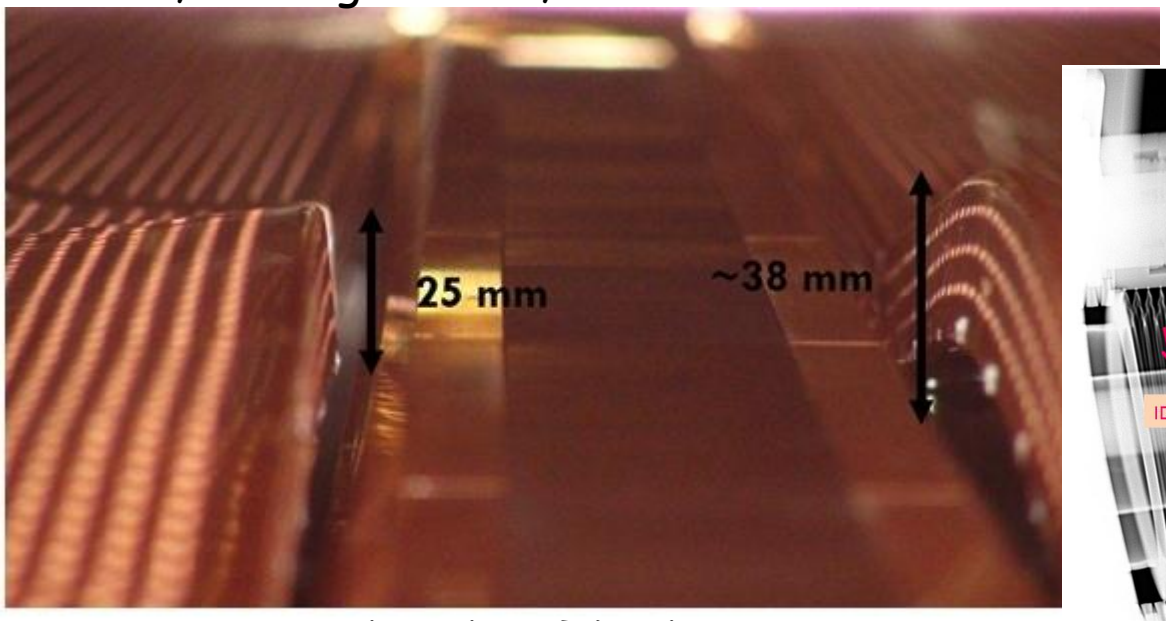
- transverse feedback, non-linear magnetic fields (sextupoles, octupoles and beam-beam), tune split...

RF Heating of Components

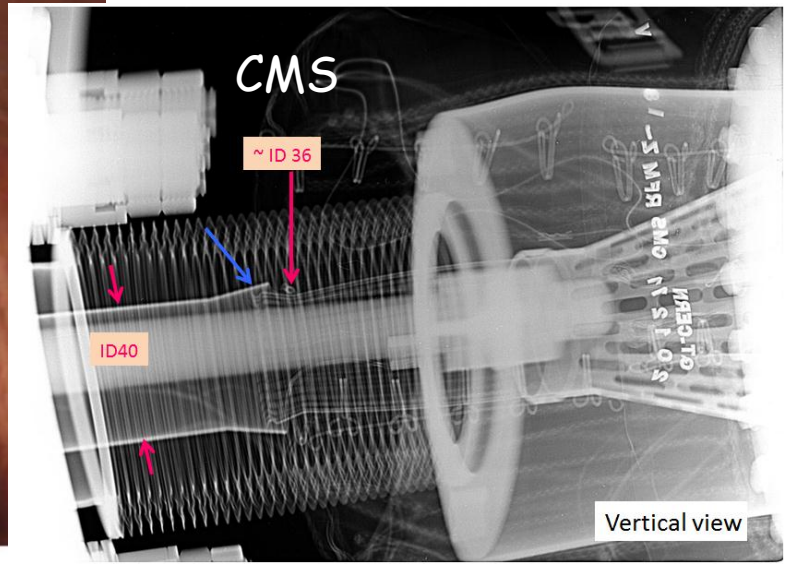


Vacuum, RF fingers 7R7, 27/8/2012

Synchrotron light monitor, removed 29/8/2012

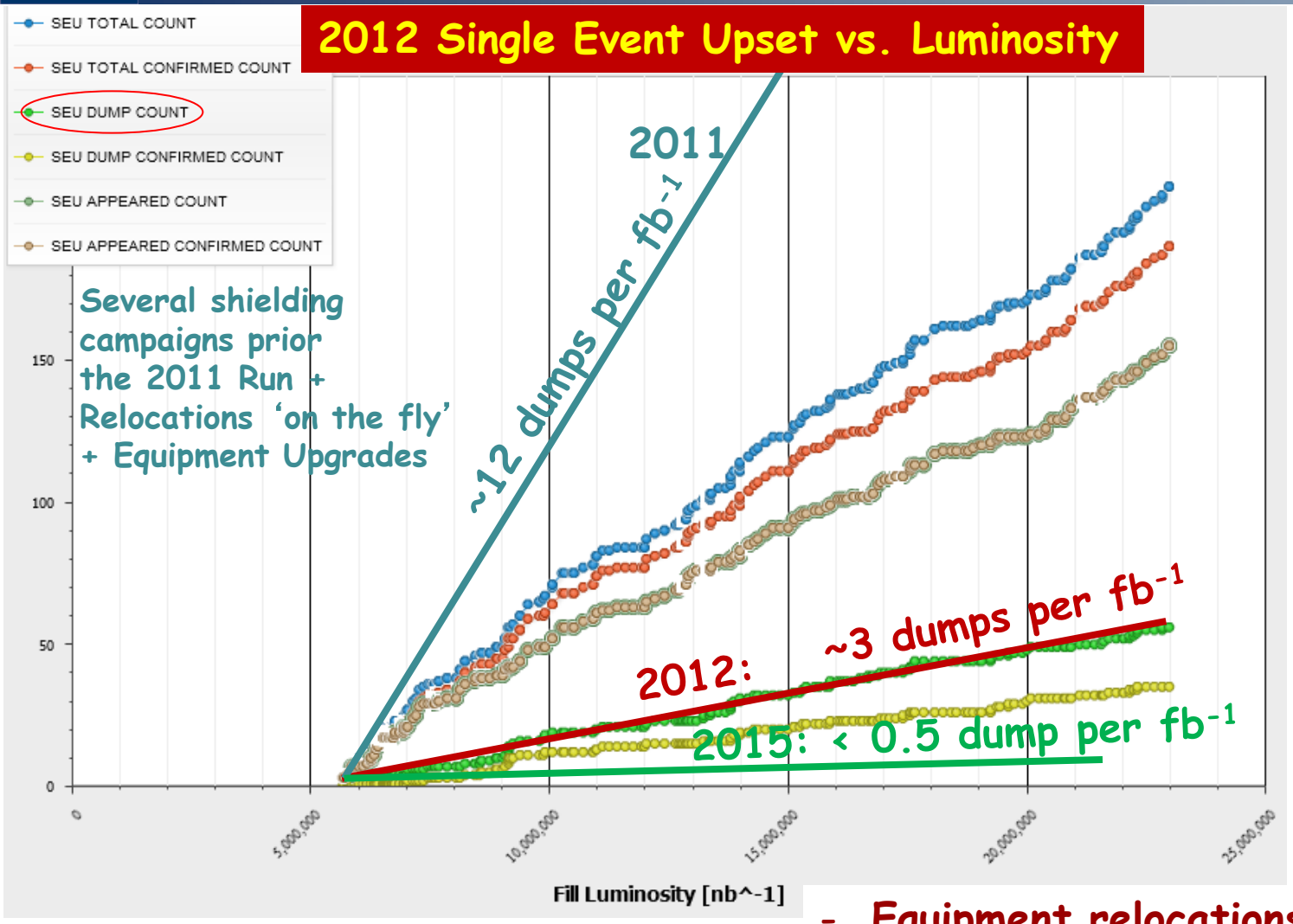


Injection absorber TDI beam screen



X-mas stop 2011/2012

Radiation affecting Electronics

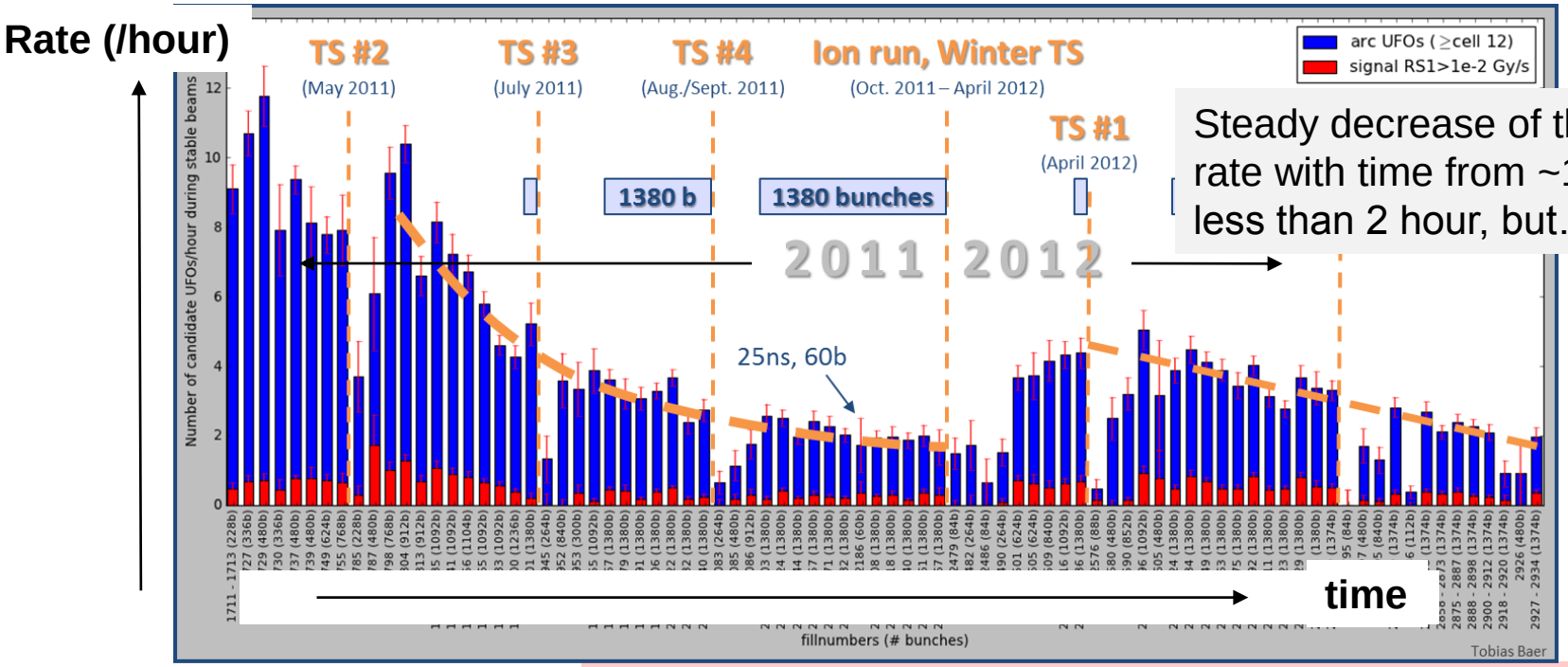


LS1

- Equipment relocations @ 4 LHC Points (>100 Racks, >60 weeks of work)
- Additional shielding
- Critical system upgrades (QPS, FGC)

“(Un)identified Falling Objects”

UFO= beam losses due to dust particles falling into the beam



Steady decrease of the UFO rate with time from ~10 / hour to less than 2 hour, but…

At 7 TeV:

20 beam dumps in 2012 (compared to 17 in 2011)

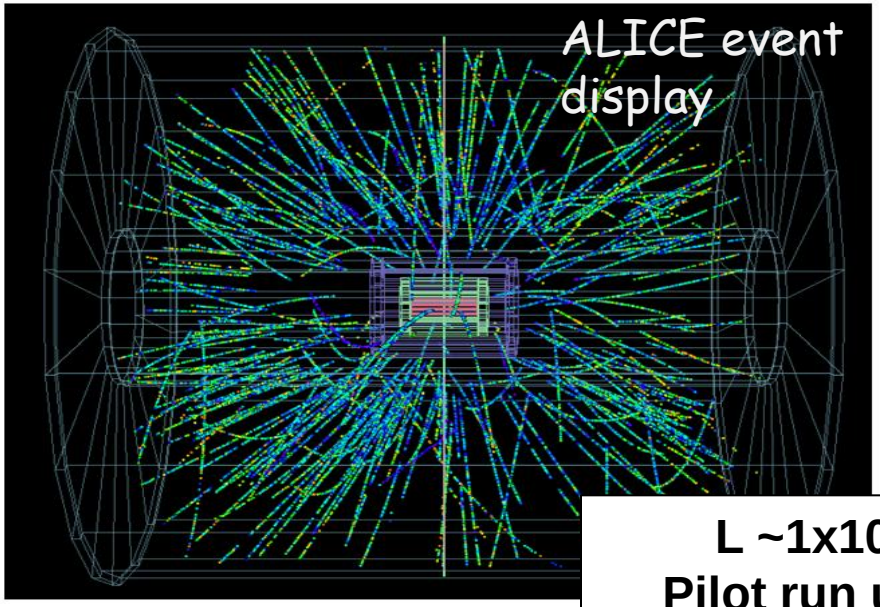
Losses induced in the magnets will increase by a factor 3 + smaller quench margin (tolerable loss will go down by a factor 5)

→ scaling the rate and amplitudes, expect at least one beam dump per DAY !! Could become a serious issue !!

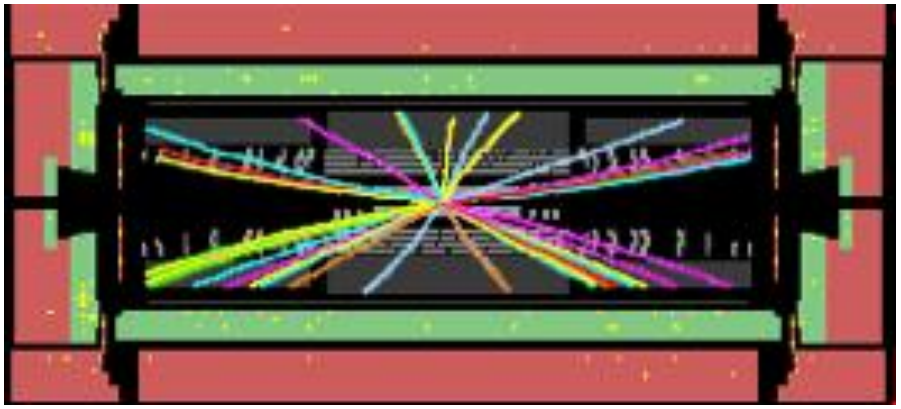
Outline

- Performance in 2012
- Main beam parameters in 2012
- High intensity issues
- Proton-Lead run
- Performance after LS1

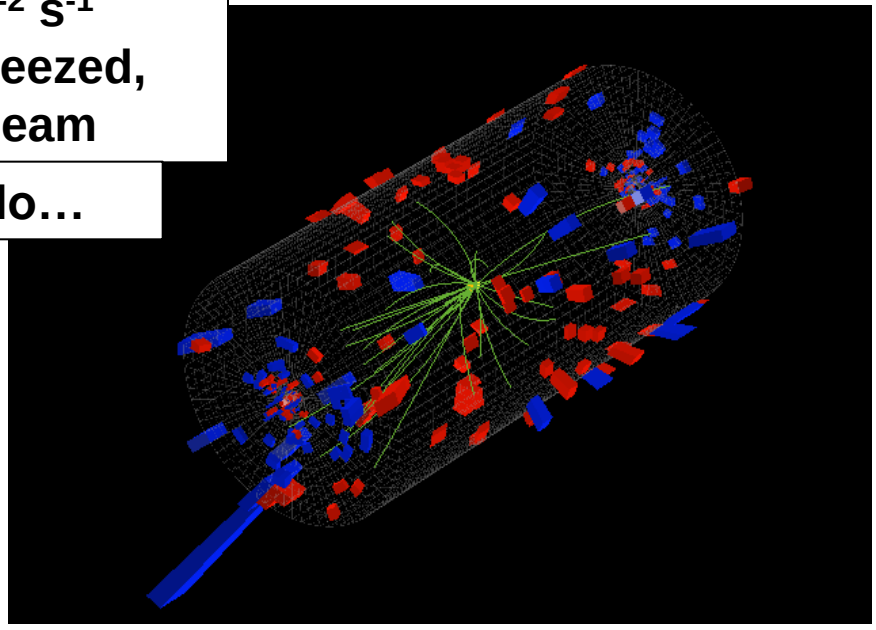
13-14 Sept – First p-Pb Collisions



ATLAS

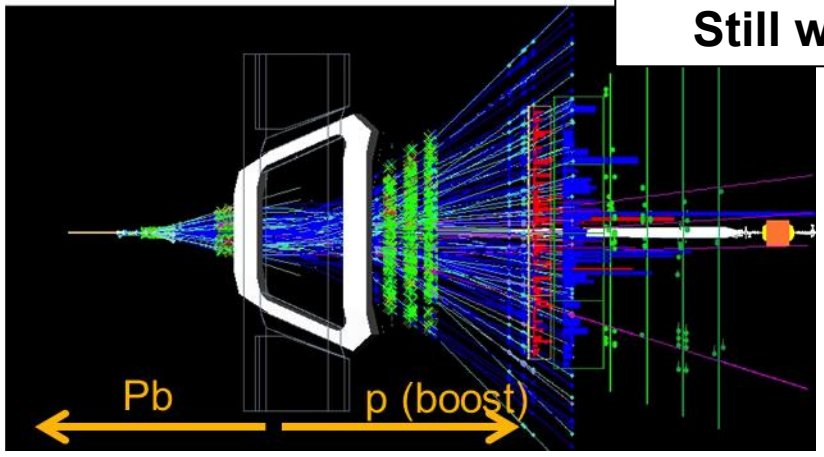


CMS

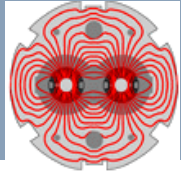


L ~1x10^{+26} cm^{-2} s^{-1}
Pilot run un-squeezed,
15 bunches/beam

Still work to do…



Proton-Lead – potential performance



- 4 weeks beginning of 2013, requested by ALICE following high Pb-Pb luminosity in 2011
- Detailed work to adapt systems, operation procedures

	Extrapolated from pilot run	All out optimism
Number of bunches	318	318
Number colliding bunches	300	300
Beta* [cm]	80	60
Pb bunch intensity	1.2×10^{8}	1.3×10^{8}
Pb emittance (H/V) [micron]	1.0/1.4	1.0/1.4
p bunch intensity	1.5×10^{10}	5×10^{10}
p emittance [micron]	1.7	1.7
Luminosity	7.07×10^{28}	3.4×10^{29}

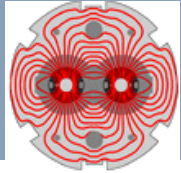
Numbers for CMS

Target integrated luminosity: 30 nb^{-1}

Outline

- Performance in 2012
- Main beam parameters in 2012
- High intensity issues
- Proton-Lead run
- Performance after LS1

Restart after LS1



Long Shutdown to prepare 7 TeV: end of March 2012 – end of 2014

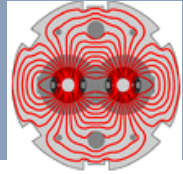
- All interconnects opened and repaired
- Several (~20) magnets changed
- Huge infrastructure works for Radiation to electronics mitigation
- New protection systems
- Lots of new controls/ software
- Etc. etc.

Essentially: restart in 2015 as a new machine

What will be the likely running conditions?

- Beam Energy? ➔ retraining the magnets
- Bunch spacing? ➔ conditions for the experiments
- What performance can we expect?

The nominal energy era



During 2008 Hardware Commissionning:

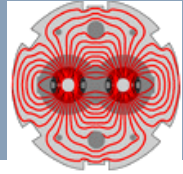
- 7 sectors reached 5 TeV without a quench
- 1 sector reached 6.6 TeV with about 30 quenches

Plan to Start LHC after LS1 at 6.5 TeV
(move slowly upwards in later years)
Will see better during the HWC Campaign mid 2014

There are new challenges waiting for us out there.

- *Magnets close to their limits,*
- *Tolerable beam loss reduced by a factor ~10-20,*
- *UFOs may degrade Machine availability*
- *And the unknown unknowns…*

50 versus 25 ns



	50 ns	25 ns
GOOD	• Lower total beam current • Higher bunch intensity • Lower emittance • Well known	• **Lower pile-up**
BAD	• **High pile-up** • Need to level but Pile-up stays high	• More long range collisions: larger crossing angle; higher beta* • Higher emittance • Electron cloud: need for scrubbing; emittance blow-up; • Higher UFO rate • Higher injected bunch train intensity • Higher total beam current

Expect to move to 25 ns because of pile up…

Post LS1 - potential performance

4 out of many possible scenarios…

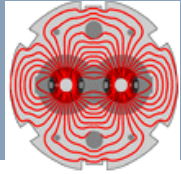
	Number of bunches	N_b LHC Flat top [10^{11} p]	Emit LHC (SPS) [mm]	Peak Lumi [10^{34} cm^{-2}s^{-1}]	~Pile-up	Int. Lumi [fb^{-1}]
25 ns	2760	1.15	3.5 (2.8)	0.92	21	24
25 ns low emit.	2320	1.15	1.9 (1.4)	1.6	43	42
50 ns	1380	1.6	2.3 (1.7)	1.7 Level 0.9	76 level 40	~45*
50 ns low emit.	1260	1.6	1.6 (1.2)	2.2	108*	…

All numbers approximate

(*) different operational model to be validated (leveling)

Int. L based on 150 days of production, 6.5 TeV, 1.1 ns bunch length, 35% efficiency.

Summary



- In the past 3 years the LHC has surpassed its goals for both peak and integrated luminosity
  - ✓ *LHC operation shown the results of excellent design, construction, and installation*
  - ✓ *Injector complex performed exceptionally*
- Stop LHC operation mid-February 2013 after a 4 weeks period with proton-Lead ion collisions.
- There are issues!
  Measures to address these for post LS1 operation are under close examination

Carrying forward a wealth of experience from operation at 3.5 and 4 TeV

Let us come back to you in December 2015 with a long list of new records