LHC Status Report (mainly proton-proton)

S. Myers
(presented by J.M. Jowett)
Precision Physics at the LHC, Paris
18th December 2010

Topics

- Performance with Protons
- Protons in 2011
  - 150ns or 75ns or 50ns?
  - Issues
  - Proposed Strategy
  - Rough Estimates of performance Range
- Future
  - HL-LHC
  - HE-LHC

reminder

Decided Scenario 2010-2011

Following the technical discussions in Chamonix (Jan 2010) the CERN management and the LHC experiments decided

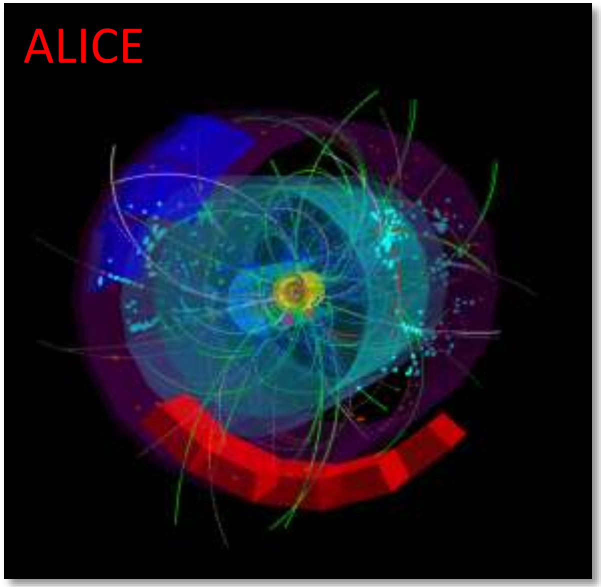
- Run at 3.5 TeV/beam with a goal of an integrated luminosity of around 1fb^{-1} by end 2011
  - Implies reaching a peak luminosity of 10^{32} in 2010
- Then consolidate the whole machine for 7TeV/beam (during a shutdown in 2012)
- From 2013 onwards LHC will be capable of maximum energies and luminosities

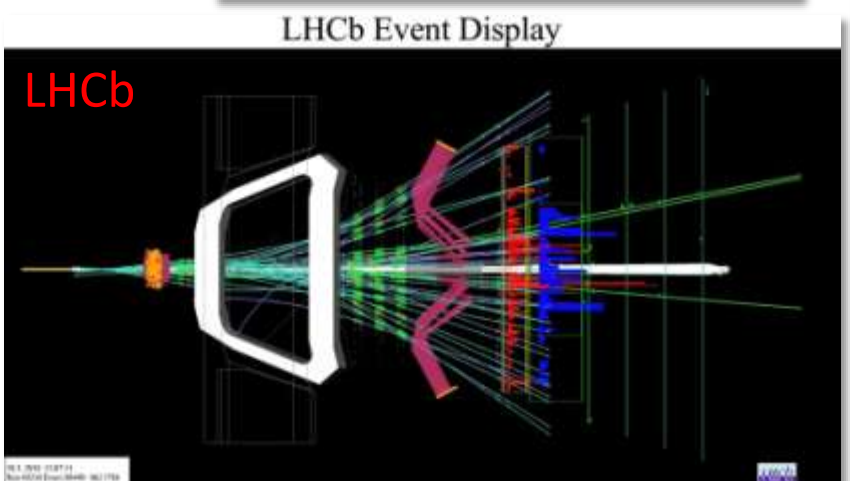
Primary Goal for 2010

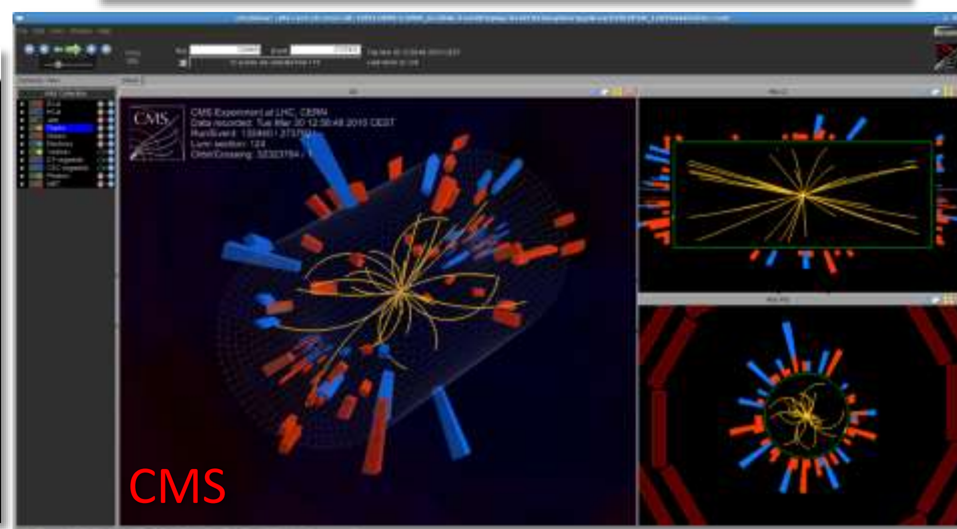
Performance with Protons

- Start up
  1. Low intensity/bunch running
  2. High Intensity/bunch running
  3. High bunch intensity and bunch trains

LHC: First collisions at 7 TeV on 30 March 2010







First Running Period (low bunch intensity)

calculated

Event	TeV	OEF	β*	Nb	Ib	Itot	MJ	Nc	Peak luminosity	Date
1	3.5	0.2	10	2	1.00E+10	2.0E+10	0.0113	1	8.9E+26	30 March 2010
2	3.5	0.2	10	2	2.00E+10	4.0E+10	0.0226	1	3.6E+27	02 April 2010
3	3.5	0.2	2	2	2.00E+10	4.0E+10	0.0226	1	1.8E+28	10 April 2010
4	3.5	0.2	2	4	2.00E+10	8.0E+10	0.0452	2	3.6E+28	19 April 2010
5	3.5	0.2	2	6	2.00E+10	1.2E+11	0.0678	4	7.1E+28	15 May 2010
6	3.5	0.2	2	13	2.60E+10	3.4E+11	0.1910	8	2.4E+29	22 May 2010

> Seven Orders of magnitude below design

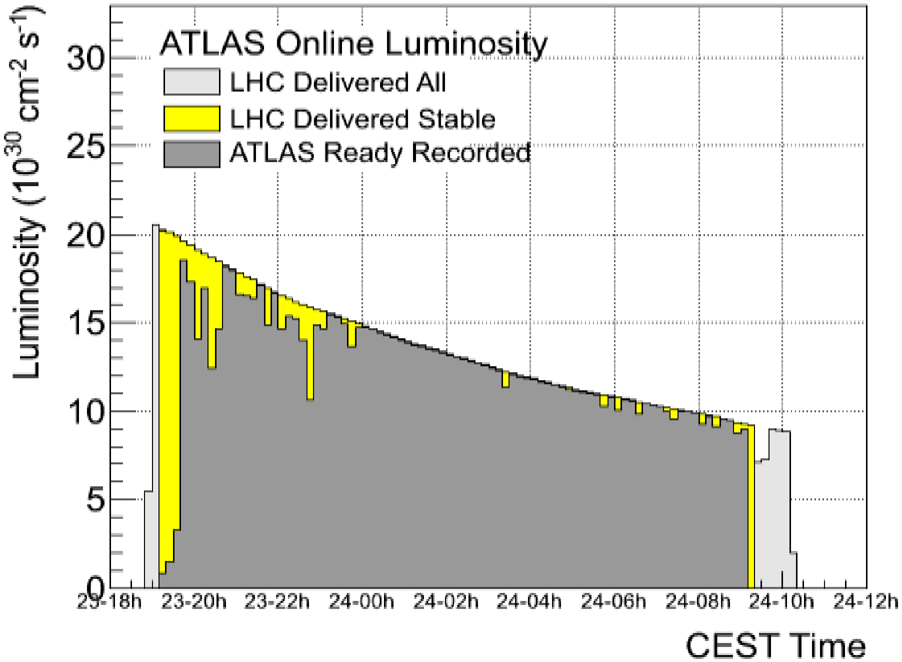
At this point, just ahead of the ICHEP, Paris, (based on collisions at 450 GeV with 1.1e11 ppb) we decided to change mode of operation to high bunch intensity

Second Running Period (High bunch Intensity)

calculated

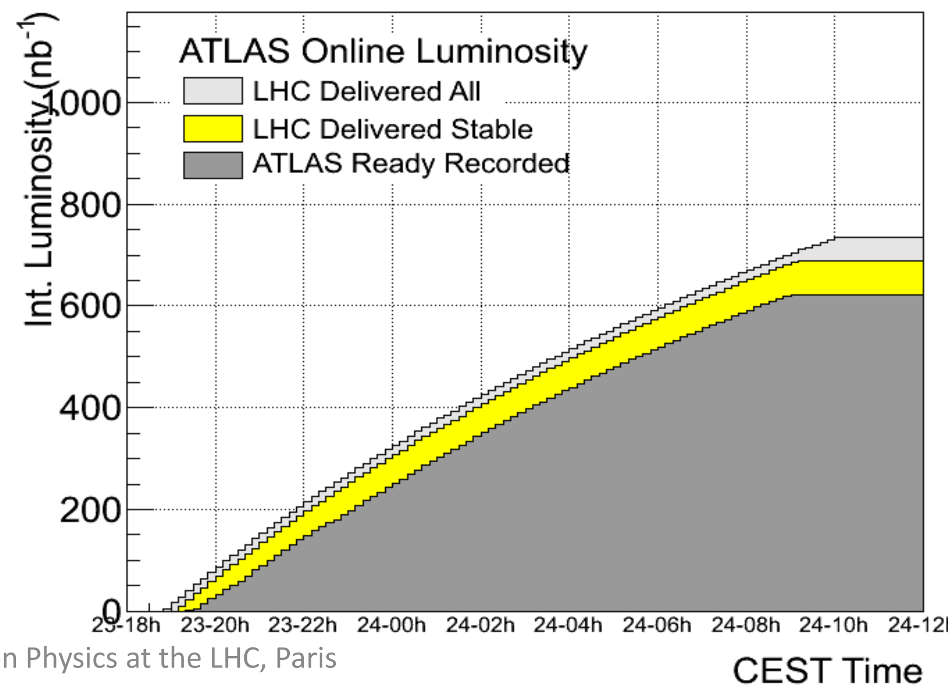
Event	TeV	OEF	β*	Nb	Ib	Itot	MJ	Nc	Peak luminosity	Date
1	3.5	0.2	10	2	1.00E+10	2.0E+10	0.0113	1	8.9E+26	30 March 2010
2	3.5	0.2	10	2	2.00E+10	4.0E+10	0.0226	1	3.6E+27	02 April 2010
3	3.5	0.2	2	2	2.00E+10	4.0E+10	0.0226	1	1.8E+28	10 April 2010
4	3.5	0.2	2	4	2.00E+10	8.0E+10	0.0452	2	3.6E+28	19 April 2010
5	3.5	0.2	2	6	2.00E+10	1.2E+11	0.0678	4	7.1E+28	15 May 2010
6	3.5	0.2	2	13	2.60E+10	3.4E+11	0.1910	8	2.4E+29	22 May 2010
7	3.5	0.2	3.5	3	1.10E+11	3.3E+11	0.1865	2	6.1E+29	26 June 2010
8	3.5	0.2	3.5	6	1.00E+11	6.0E+11	0.3391	4	1.0E+30	02 July 2010
9	3.5	0.2	3.5	8	9.00E+10	7.2E+11	0.4069	6	1.2E+30	12 July 2010
10	3.5	0.2	3.5	13	9.00E+10	1.2E+12	0.6612	8	1.6E+30	15 July 2010
11	3.5	0.2	3.5	25	1.00E+11	2.5E+12	1.4129	16	4.1E+30	30 July 2010
12	3.5	0.2	3.5	48	1.00E+11	4.8E+12	2.7127	36	9.1E+30	19 August 2010

Maximum reached is 10.7×10^{30} $cm^{-2}s^{-1}$



23 September 2010
48 bunches; bunch trains

This was a “turning point” fill as it showed that a head-on beam-beam tune shift of ~.02 total was possible (cf design of .01)

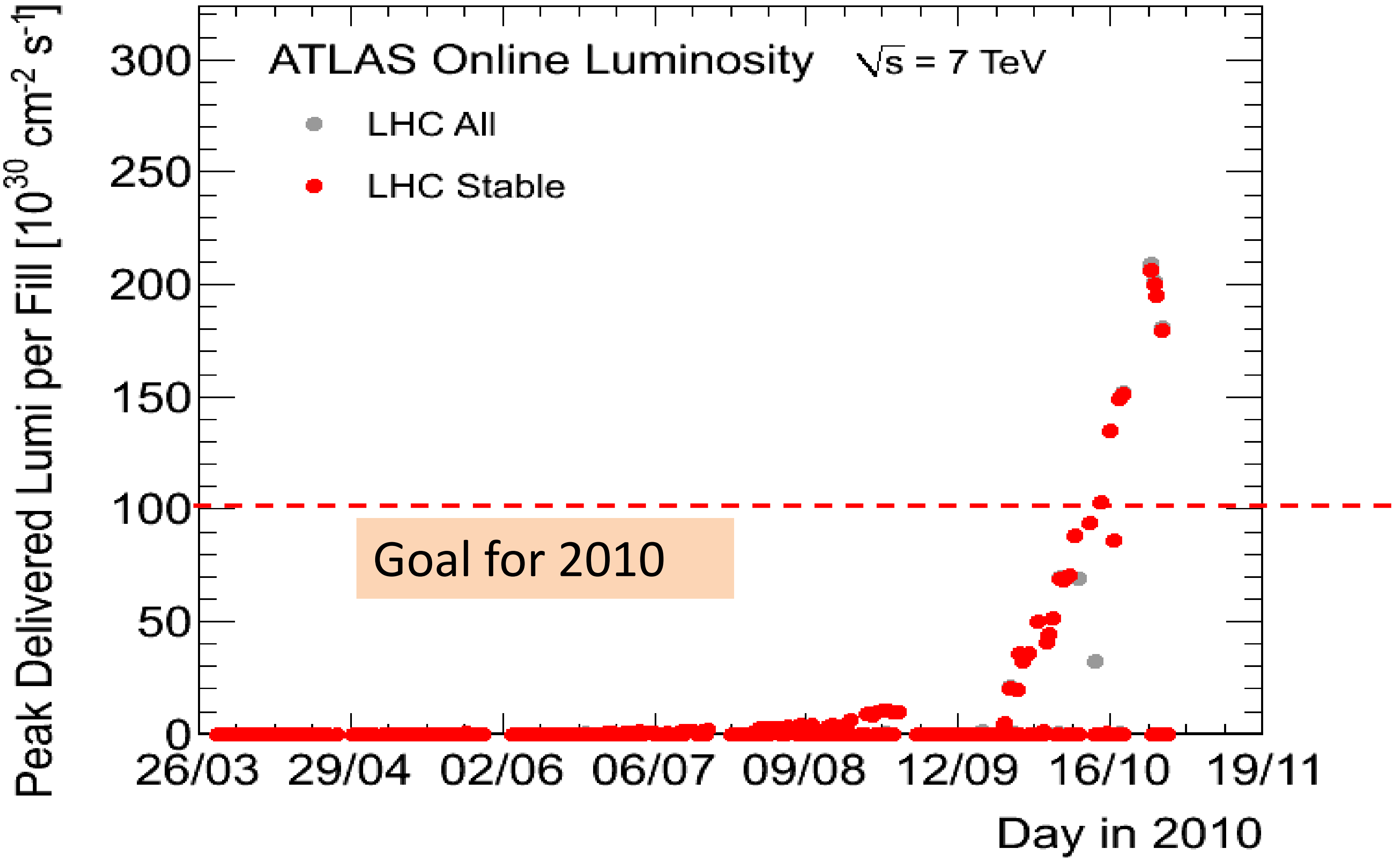


Running with Bunch Trains (Parameters)

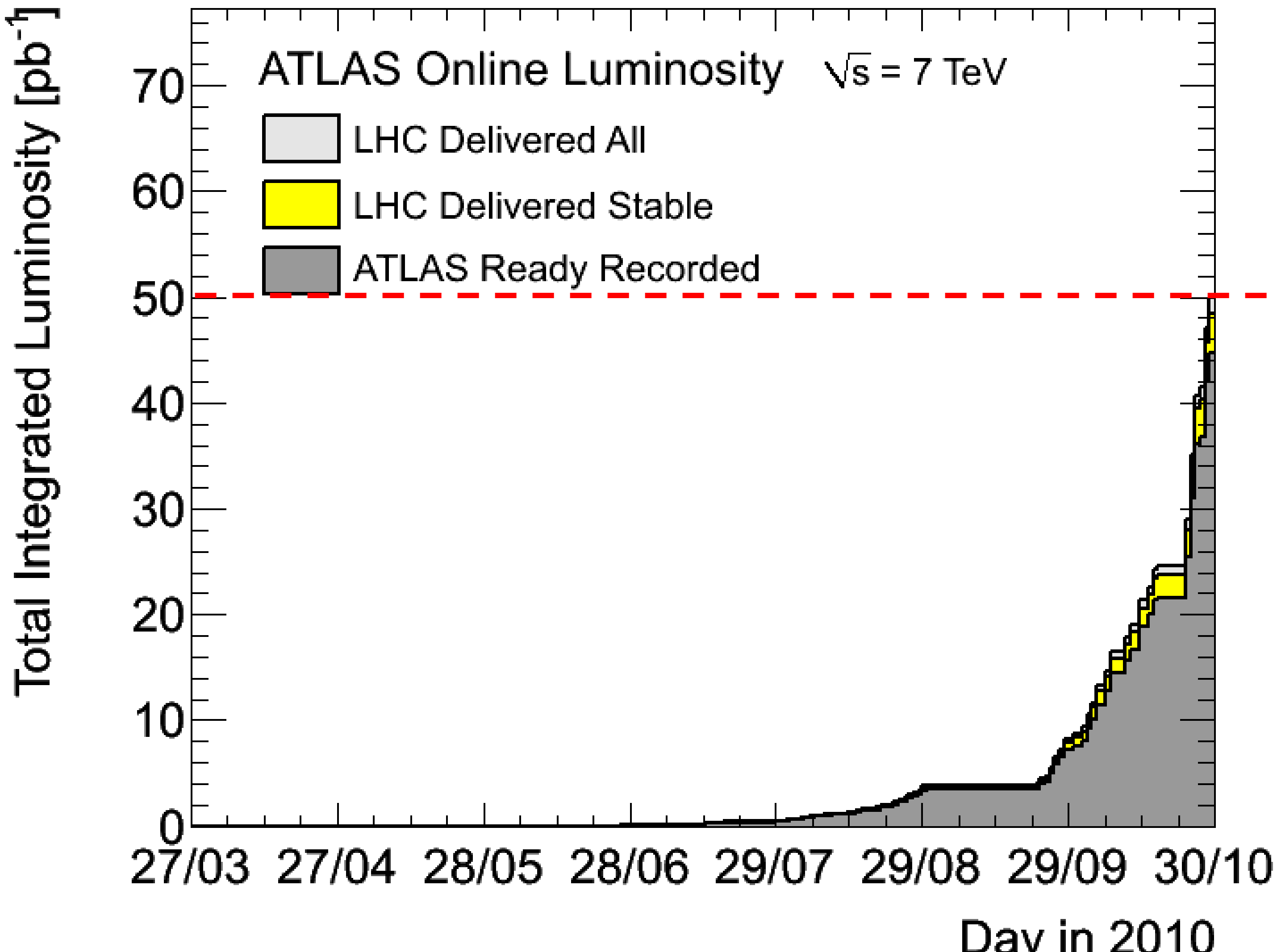
Nb	Ib	MJ	Nc	Peak luminosity (design parameters)	Maximum luminosity (measured)	Pile up (from measured Lumi)	Date
56	1.10E+11	3.5	47	1.203E+31	2.000E+31	1.9054	23/09/2010
104	1.10E+11	6.5	93	2.381E+31	3.500E+31	1.7955	25/09/2010
152	1.10E+11	9.4	140	3.584E+31	5.000E+31	1.7550	29/09/2010
204	1.10E+11	12.7	186	4.762E+31	7.000E+31	1.8307	04/10/2010
248	1.10E+11	15.4	233	5.965E+31	1.030E+32	2.2158	14/10/2010
312	1.10E+11	19.4	295	7.552E+31	1.500E+32	2.5650	16/10/2010
368	1.15E+11	23.9	348	9.737E+31	2.050E+32	2.9721	25/10/2010

Performance Improvement by a factor of 200,000 in 7 months:

Peak Luminosity



28/10/2010 (approaching 50pb-1)



2010 – proton records

Peak stable luminosity delivered	$2.07 \times 10^{32}\ cm^{-2}s^{-1}$
Maximum luminosity delivered in one fill	$6304.61\ nb^{-1}$
Maximum luminosity delivered in one day	$5983.78\ nb^{-1}$
Maximum luminosity delivered in 7 days	$24637\ nb^{-1}$
Maximum colliding bunches	348
Maximum average events per bunch crossing	3.78
Longest time in Stable Beams for one fill	30.3 hours
Longest time in Stable Beams for one day	22.8 hours (94.9%)
Longest time in Stable Beams for 7 days	69.9 hours (41.6%)
Fastest turnaround to Stable Beams	3.66 hours (protons)

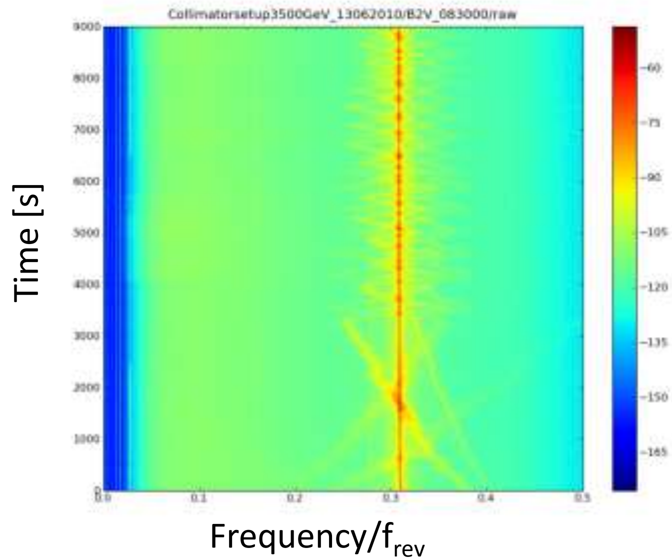
Obstacles that had to be dealt with

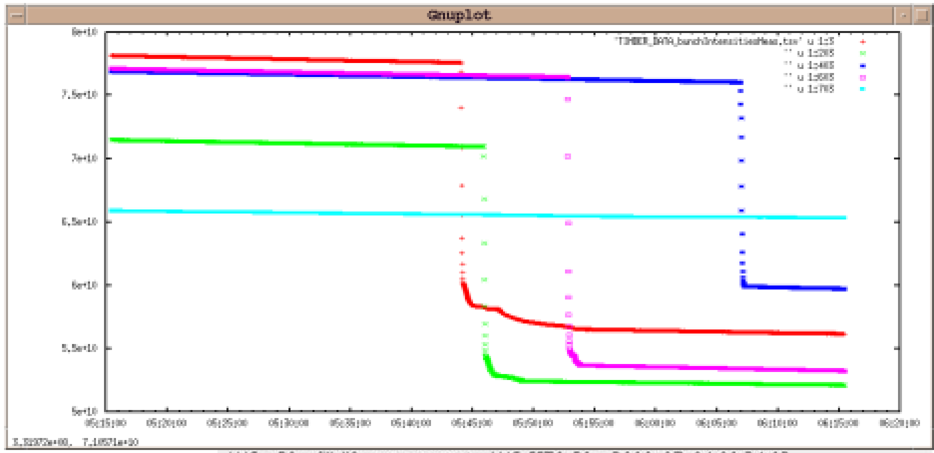
- Machine protection
  - Fear of MJs
  - Setting up time for the protection system
- UFOs (or whatever it is!)

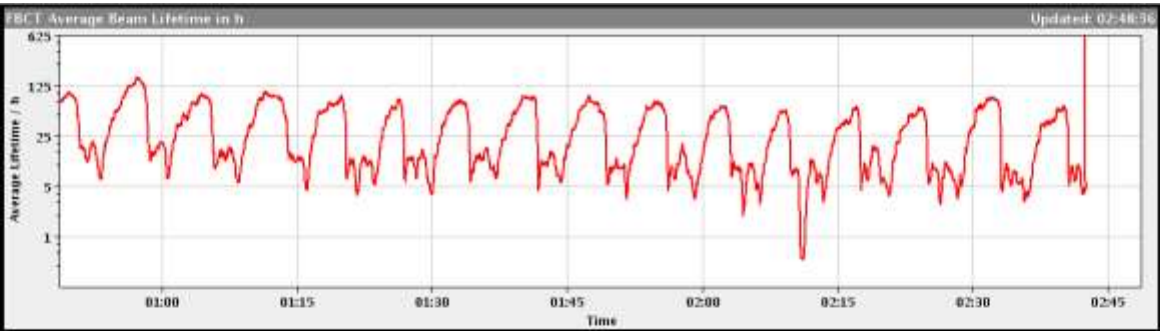
- The "Hump"
  - Oscillating fields , strength and frequency changing, blowing up emittance (esp. Beam 2 vertical) for protons and ions. Source not found yet.
- Injection sensitivity B1 (chamber installed wrong way around 2 years ago!!)

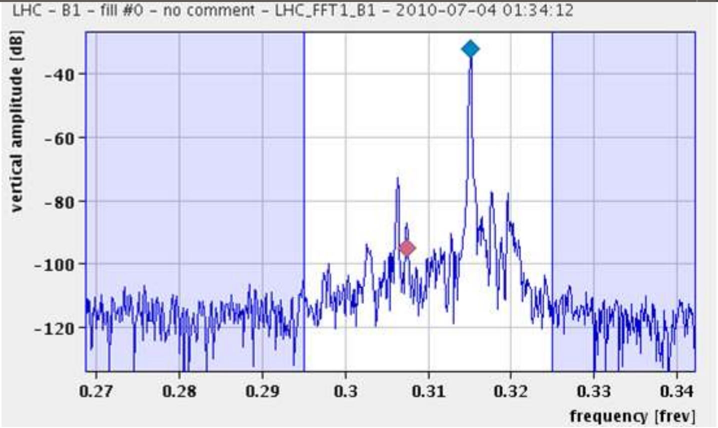
Open issues

- The so-called “hump”: leading to emittance blow-up and low lifetime in beam 2
- Beam-beam coherent effects leading to selective losses in bunches mostly during luminosity scans









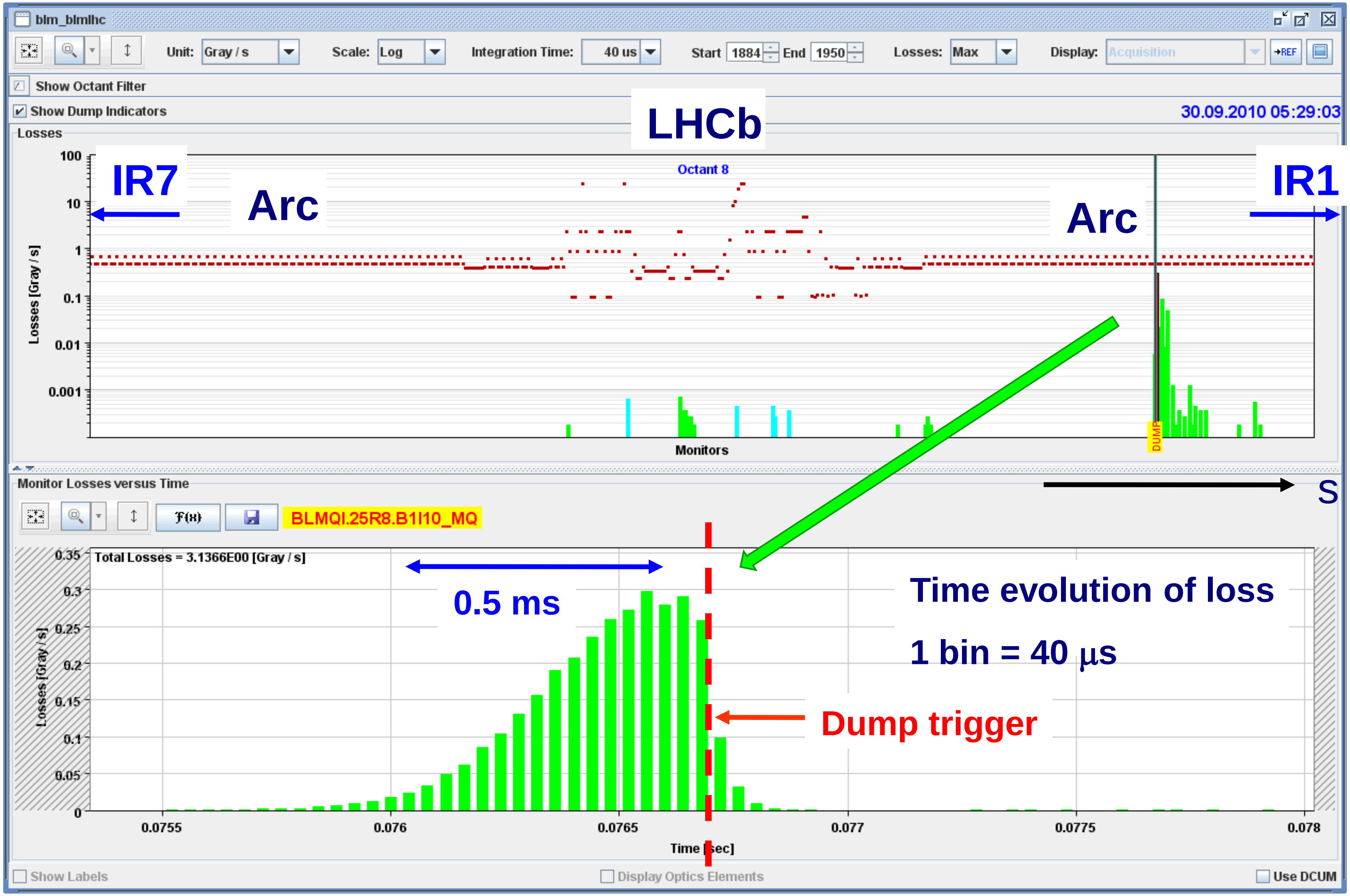
G. Arduini

UFOs

- UFO dependencies:
  - ➔ rate proportional to total beam current (# bunches)
  - ➔ occurrence in all locations
  - ➔ most UFOS occur below BLM threshold
  - ➔ no UFOs observed at injection (even with 680 bunches)

UFOs: Unidentified Falling Objects

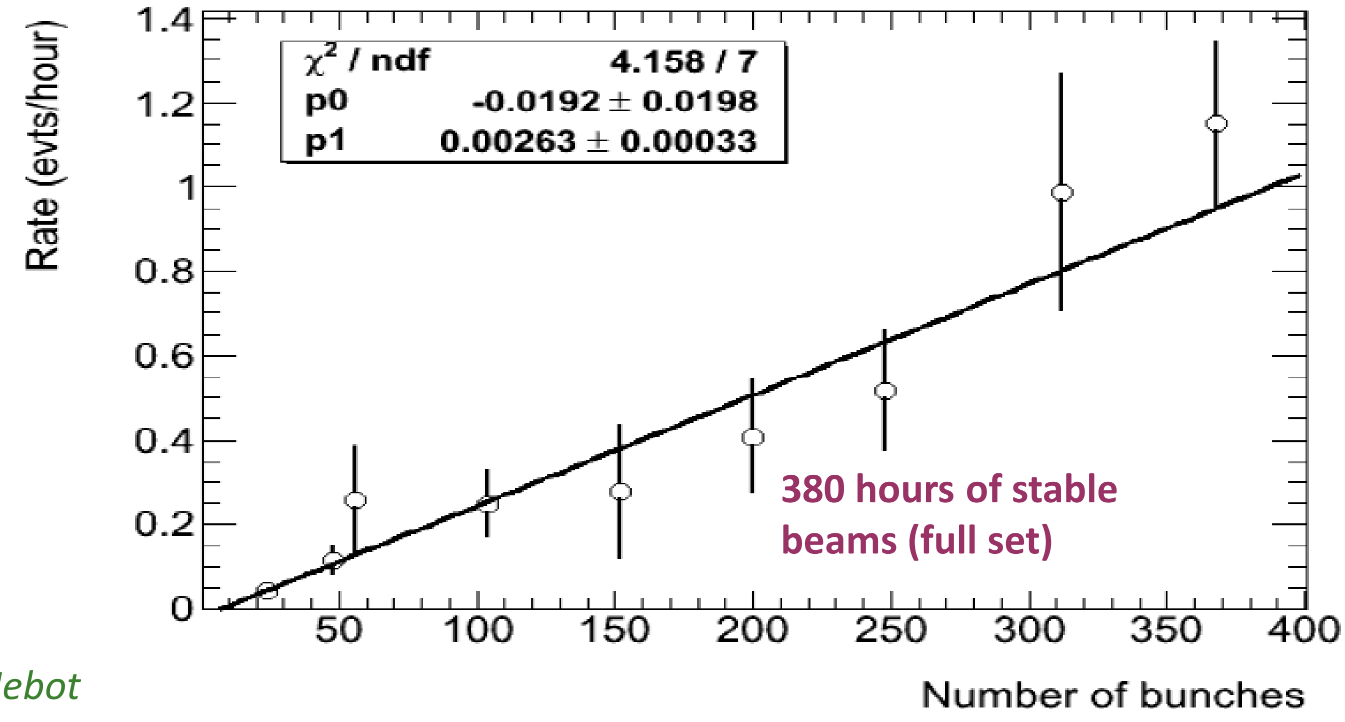
Beam loss monitor post-mortem



J Wenninger @ LMC 1.12.10

UFOs

- UFO dump count now 18.
  - ***UFOs have reappeared despite threshold increase.***
  - *2 UFO dumps triggered by exp. BCMs (LHCb, ALICE) and not by machine BLMs.*
- UFO rate at ~ 1 event/hour with 360 bunches at 3.5 TeV.
  - *Rate essentially proportional to intensity.*



E. Nebot

2010 Ion Run

The "Early Ion Scheme" was "invented" in Chamonix 2003 (8 years ago)!

The basic machine parameters are similar

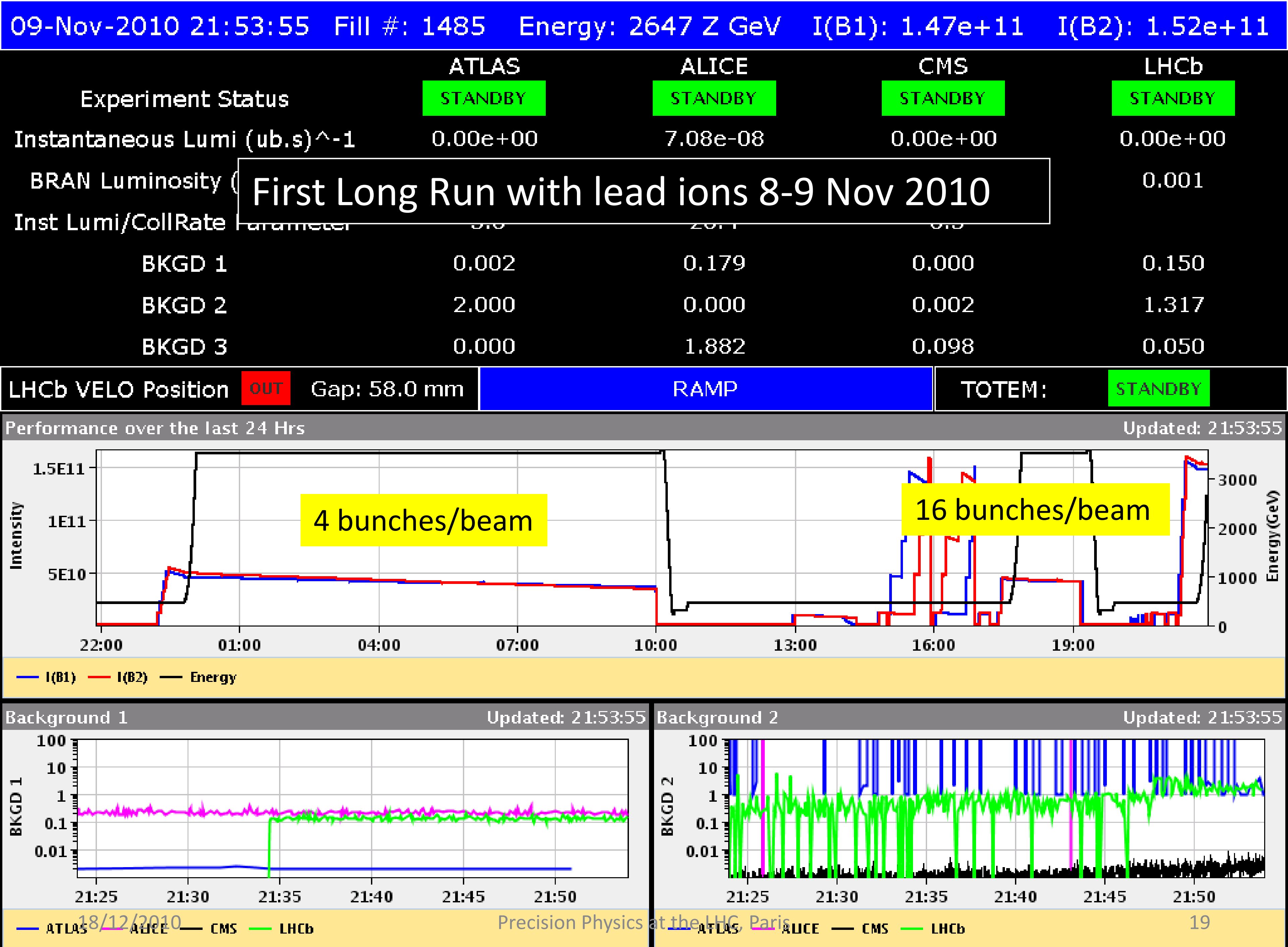
- *But the collimation system needed some setting up*
- *The behavior of the beam instrumentation was critical – the low intensities make life more difficult*

Expectations

- *Peak Luminosity ~10^{+25} cm^{-2} s^{-1}*
- *Integrated Luminosity ~3-10 μb^{-1}*
- *But each collision looks pretty impressive!*

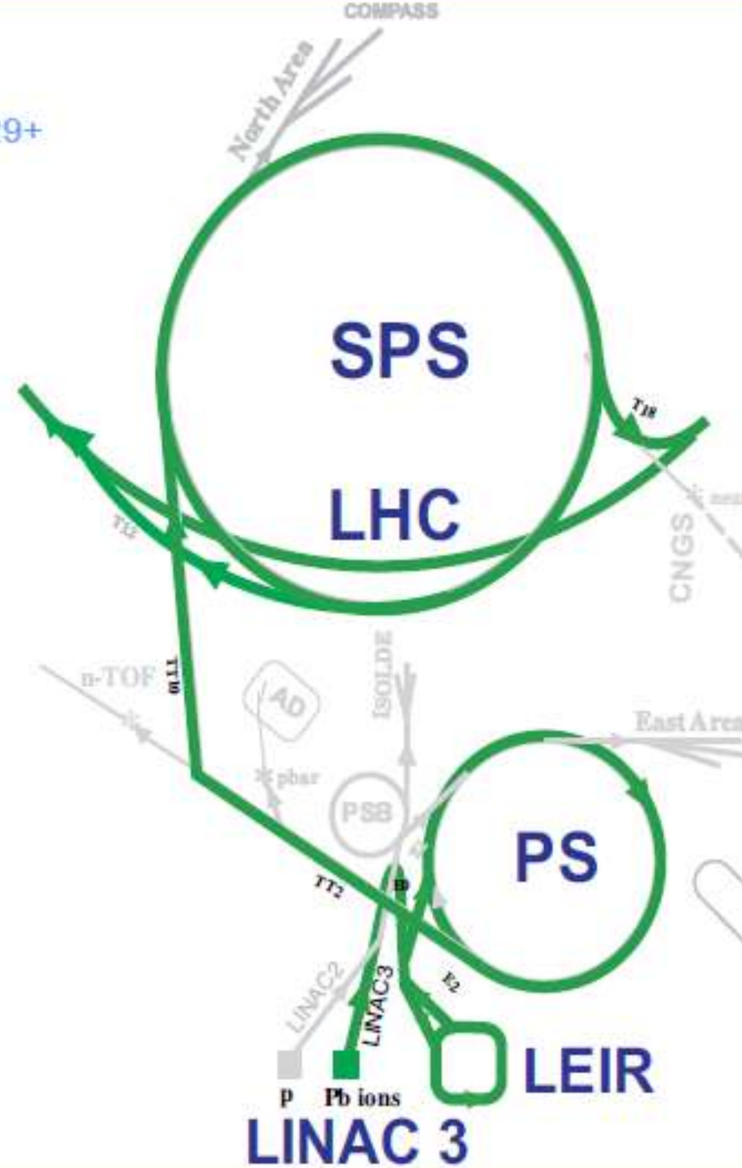
The "Early Ion Scheme" allowed an impressively fast change from protons to ions…. 3 days!

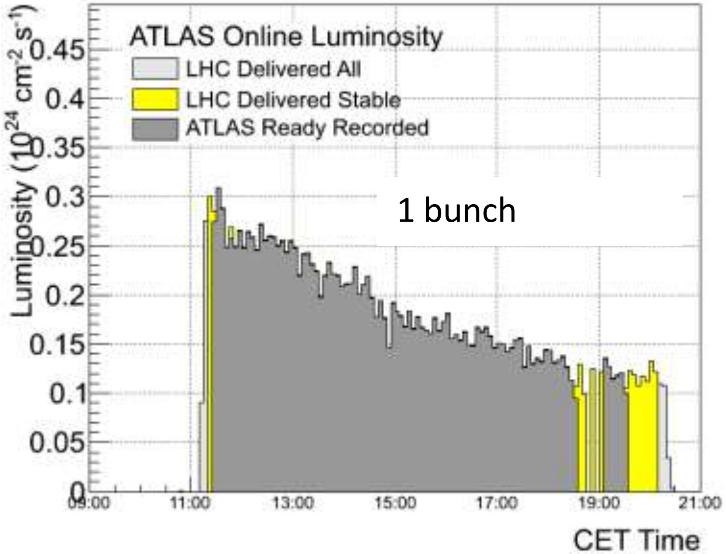
First Long Run with lead ions 8-9 Nov 2010

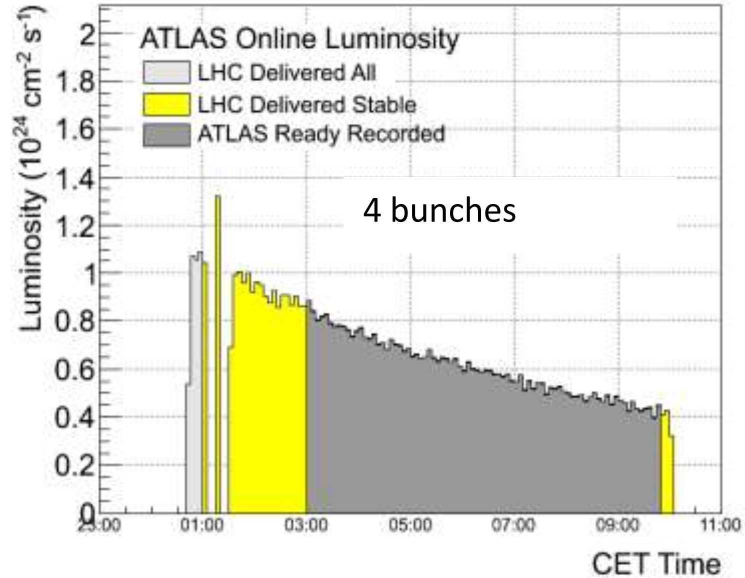


Lead ion injector chain

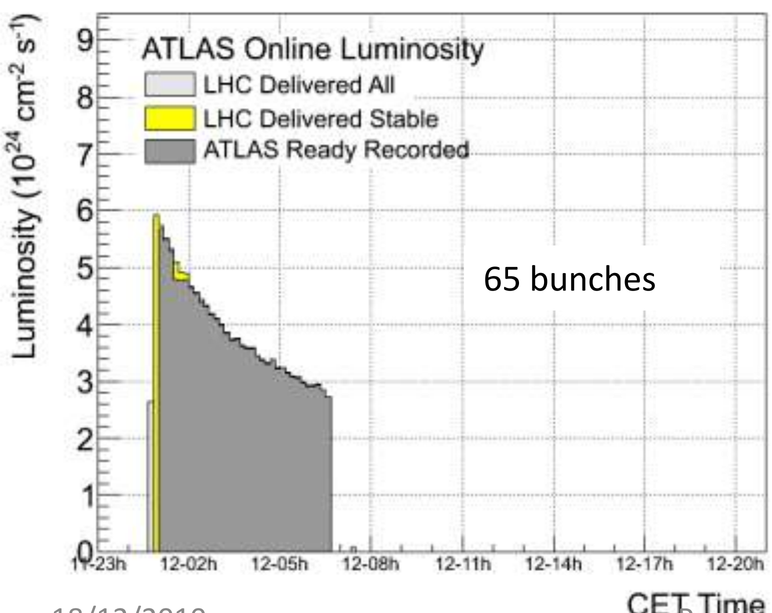
- ECR ion source (2005)
  - Provide highest possible intensity of Pb^{29+}
- RFQ + Linac 3
  - Adapt to LEIR injection energy
  - strip to Pb^{54+}
- LEIR (2005)
  - Accumulate and cool Linac 3 beam
  - Prepare bunch structure for PS
- PS (2006)
  - Define LHC bunch structure
  - Strip to Pb^{82+}
- SPS (2007)
  - Define filling scheme

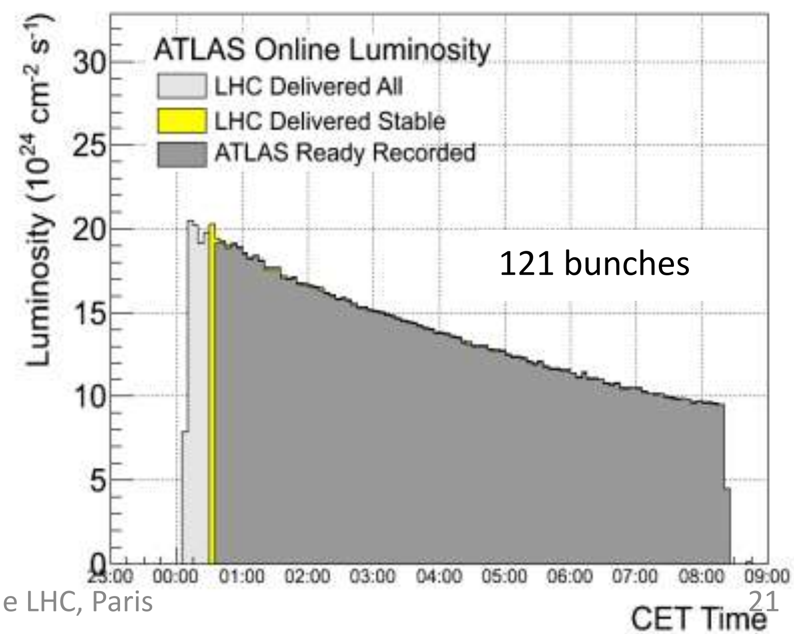




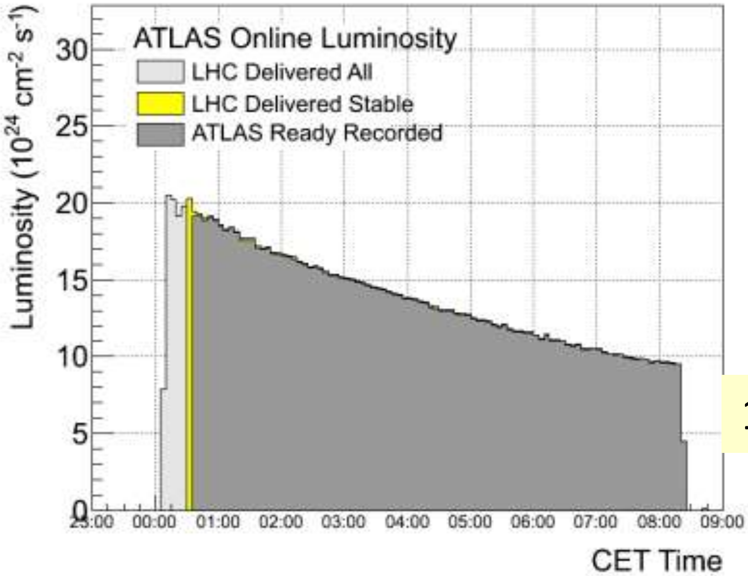


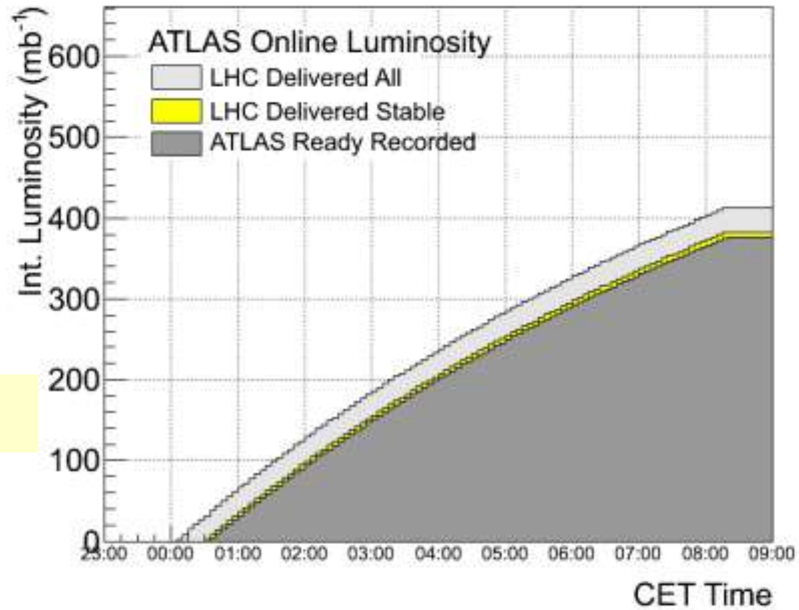
Ramping up the number of ion bunches





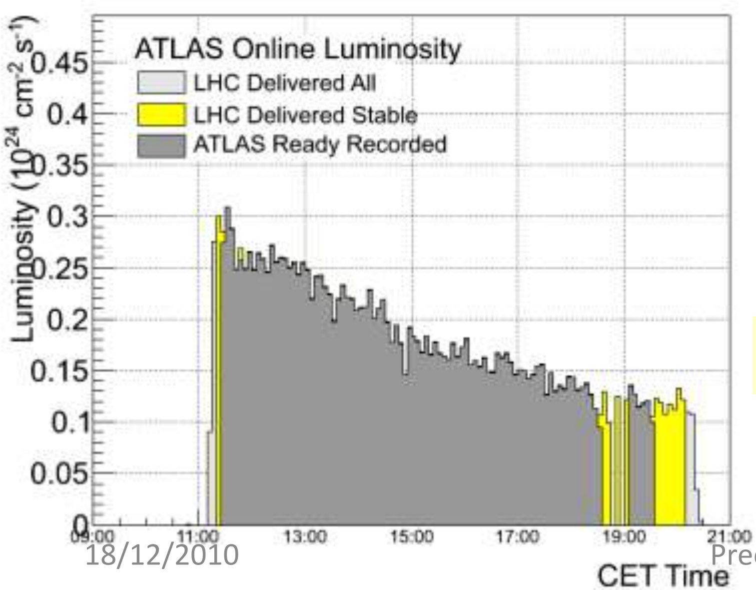
6 days of ion operation (x 100 increase)

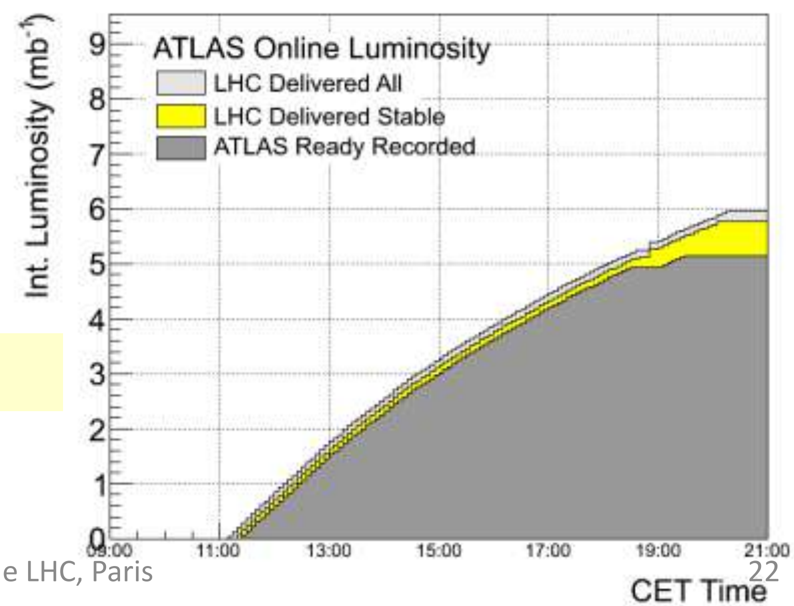




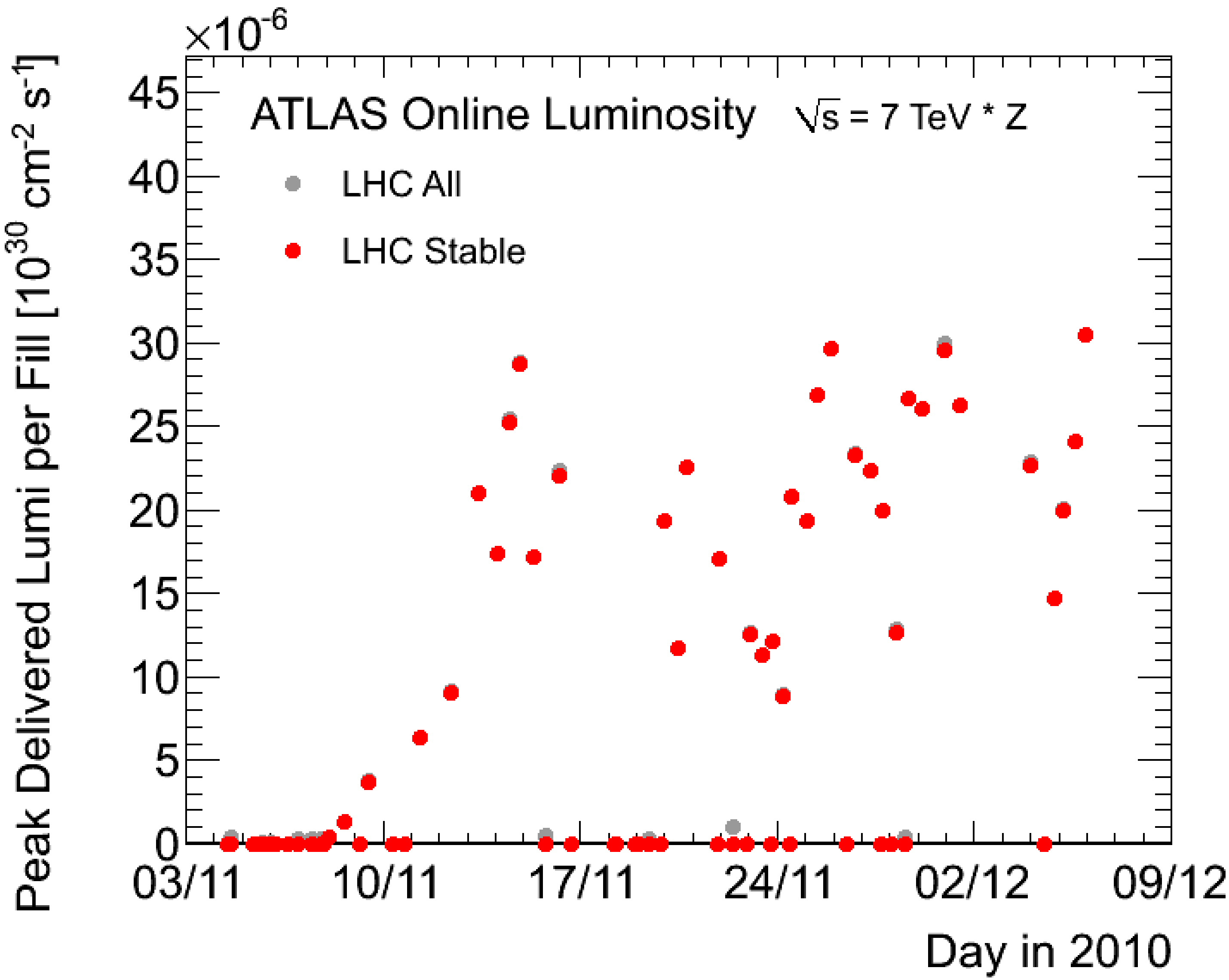
14 Nov

8 Nov

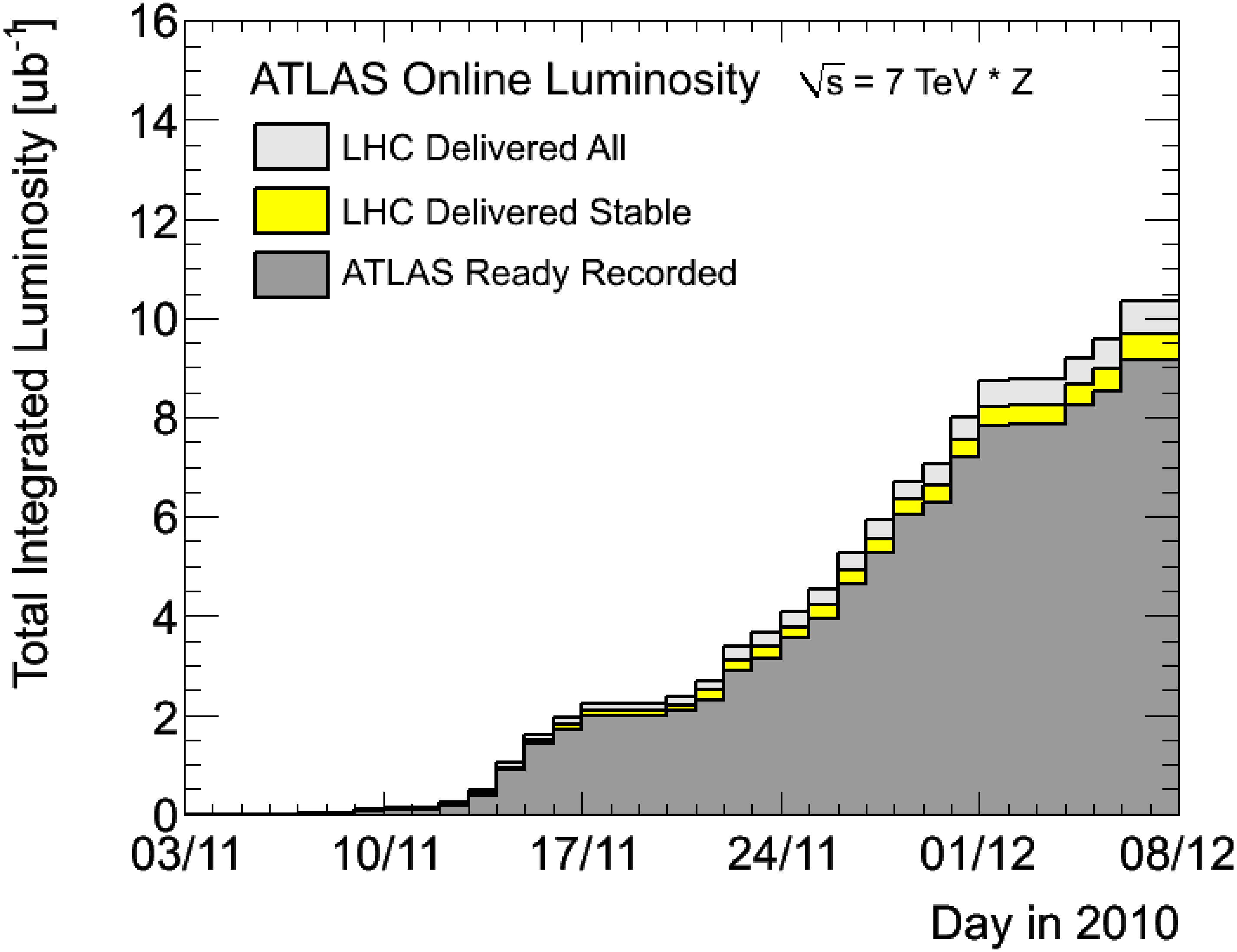




Evolution of the Peak Luminosity with lead Ions



Integrated Luminosity with lead Ions



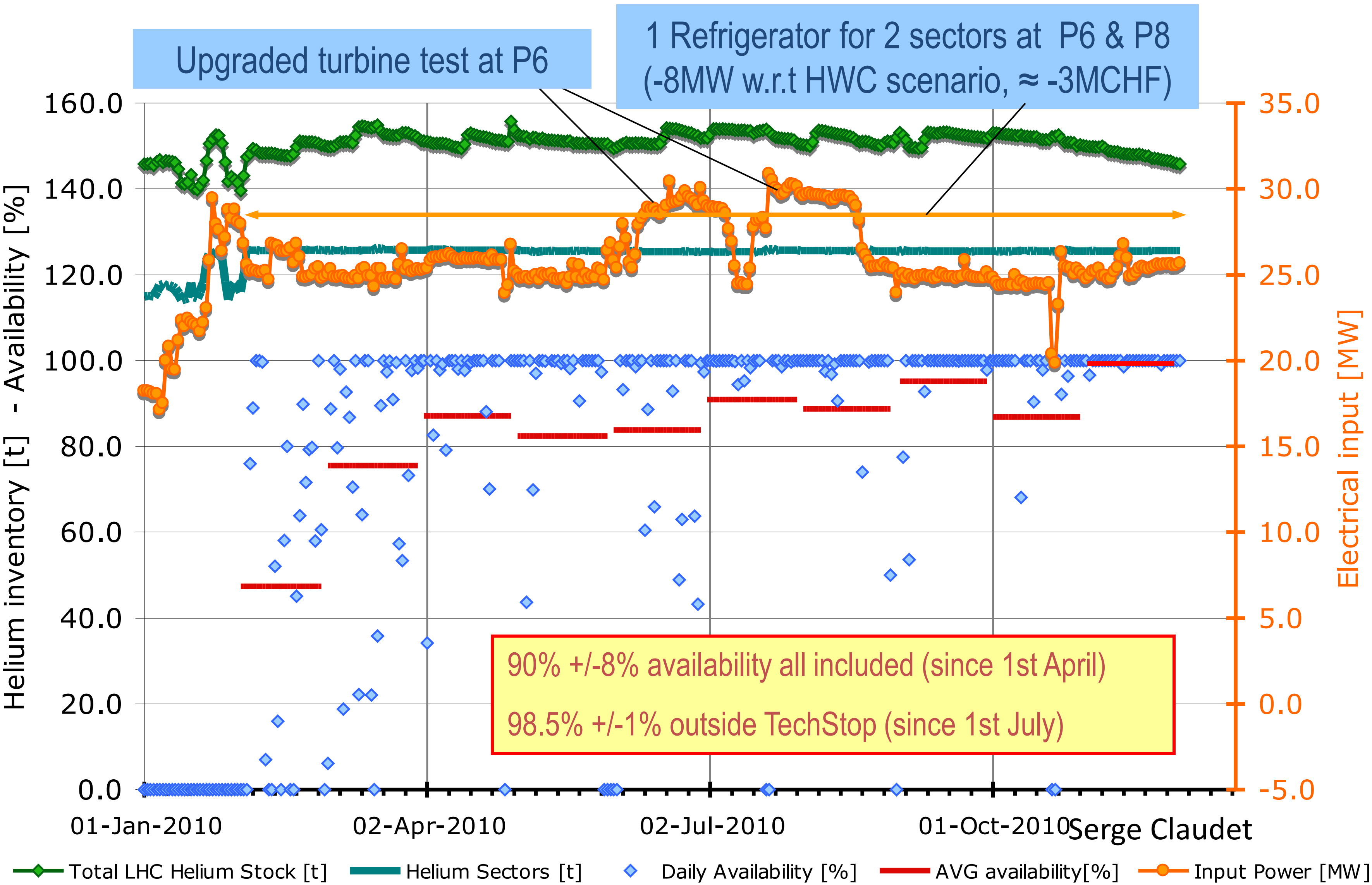
Summary: What did we learn in 2010

- LHC is magnetically very reproducible on a month to month time scale
- Head on beam-beam limit higher than foreseen
- Aperture better than foreseen
- Not a single magnet quench due to beam
- Careful increase of the number of bunches OK
- Electron cloud and vacuum
- Machine protection
  - Set up is long
  - Quench levels for fast and slow losses need to be optimised
  - UFOs

Why did it all work so well!

- Magnet Field Quality
  - Care during magnet production
  - Magnet sorting during installation
  - Magnet modelling (FIDEL)
  - Alignment of the magnets
- Power converters
- Applications software
- Beam Instrumentation working from day 1
- (n)QPS and Machine protection
- Cryogenics system performance
- Preparation
  - Hardware commissioning
  - Beam testing through many years in many accelerators
  - Dry runs and machine check-out
- Experienced people who got their training on LEP
- Injectors performance
- A great operations crew ably led by Mike Lamont

Example of one large system:Cryogenics



Serge Claudet

From design, implementation to operation: it works, the dream comes true !!!

Plus the others!

- Controls
- Feedbacks
- Collimation
- Machine protection
- RF
- LBDS
- Injection
- Optics, ABP
- MP3, QPS, piquets, support, Access, TI

PLUS of course! Time

3 – 4 years delay helped enormously.

(The time was well spent in preparing for the operation of the machine)

The machine (as well as the detectors) was in

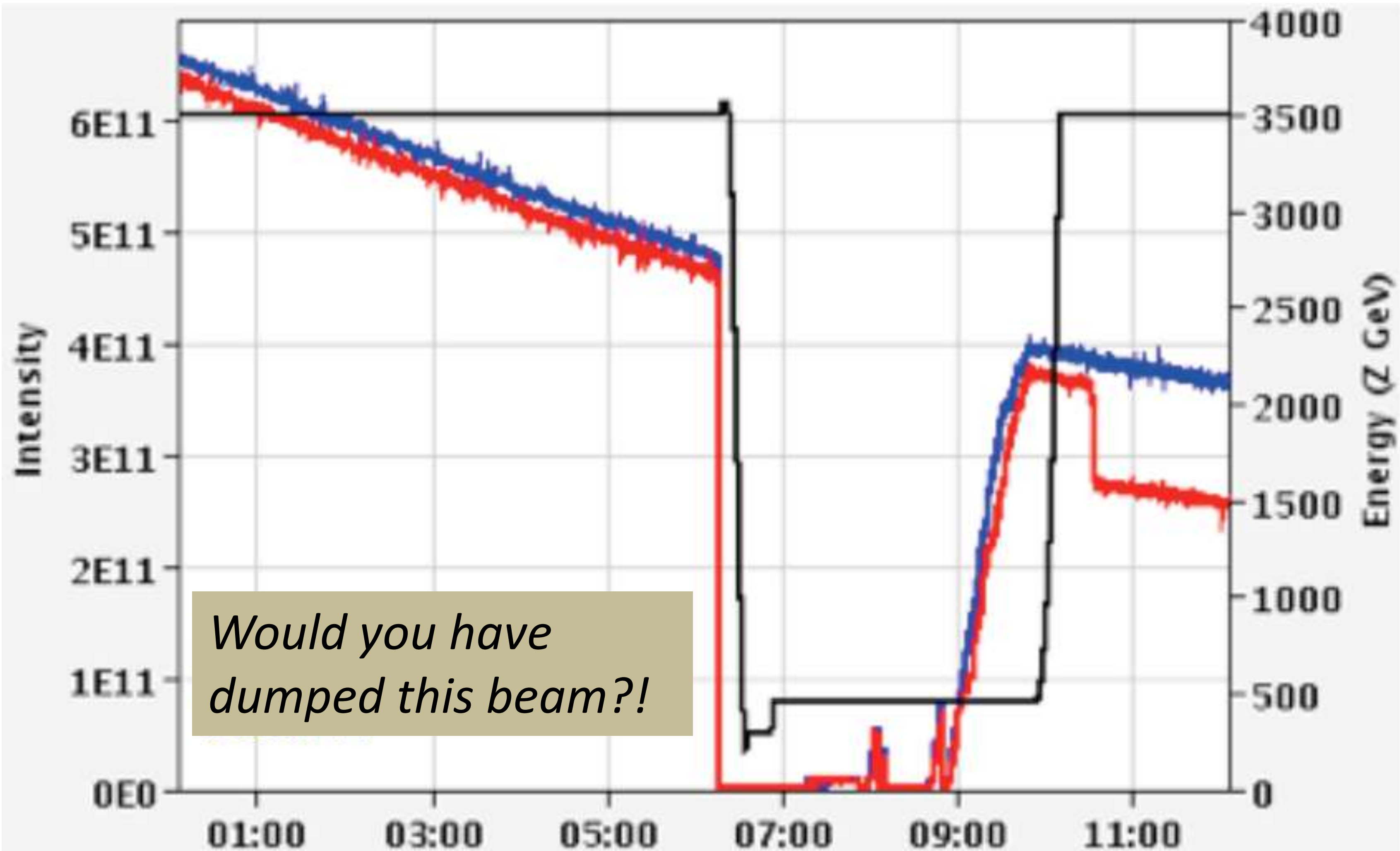
“An unprecedented state of readiness”

Teamwork

And most importantly

With many and varied interpretations

Mistakes were made!



Topics

- Performance with Protons
- Performance with Ions
- Protons in 2011
  - 150ns or 75ns or X ns?
  - 900 bunches or 450 bunches
  - Issues
  - Proposed Strategy
  - Rough Estimates of performance Range

Electron Cloud

Peak Luminosity Range

- I assume
  - 4TeV per beam (not given)
  - Max. Head on beam beam shift .008(cf .0035 design)
    - Separating beams in LHCb?
  - Emittance: 2.0urad possibly down to 1.5 with 150ns (cf 3.75 design)
    - Nb = 1.2e11 and 1.1e11 with lower emittance
  - β* = 2.0m and possibly 1.5

Year	TeV	β*	Nb	Ib	MJ	Emittance	luminosity	Beam beam Shift	Pile up
2010	3.50	3.50	368	1.18E+11	24.5	2.2	2.05E+32	0.0173	3.0
2011	4.00	2.00	450	1.20E+11	34.9	2.0	6.04E+32	0.0194	7.2
2011	4.00	2.00	900	1.20E+11	69.8	2.0	1.21E+33	0.0194	7.2
2011	4.00	1.50	450	1.20E+11	34.9	2.0	8.06E+32	0.0194	9.6
2011	4.00	1.50	900	1.20E+11	69.8	2.0	1.61E+33	0.0194	9.6
2011	4.00	1.50	450	1.10E+11	32.0	1.5	9.03E+32	0.0237	10.7

Possible Issues with 900 bunches (75ns)

- Electron Cloud

  Vacuum runaway, heat load on cryo, beam instabilities

  - Is Cleaning at 450GeV good for 3.5/4TeV?
    - Synchrotron radiation
  - Scrubbing will need 50ns (25ns?)
- UFOs (Or is it something else?)
  - Why is there an energy dependence (?no UFOs at 450GeV)
- Beam-beam (long range)
- Machine Protection (~100MJ)
- Single Event Upsets (SEUs)

Not Given: 75ns is our choice, but we need a fallback

Present Thinking on Strategy for 2011

Proposal will come from Chamonix

Decide on beam and optics parameters, E,β*,crossing angle, emittance, Nb

Chamonix

Commission LHC with new optics parameters, loss maps, MP etc

Start with 150nS

2 weeks ?

Re-establish 2010 Collisions (150ns) with new configuration

Physics up to 450 Bunches (200,300,400,450)

2 weeks ?

Switch to 75nS

Beam Scrubbing at 450GeV for 900 bunches (75ns) using 50ns beams

1 weeks ?

Attempt Physics with up to 900 Bunches (2 weeks) , (200,400,600,800, 900)

? 2 weeks

Decide on 150ns or 75ns for rest of 2010

Beam beam studies

Decision 450/900 bunches?

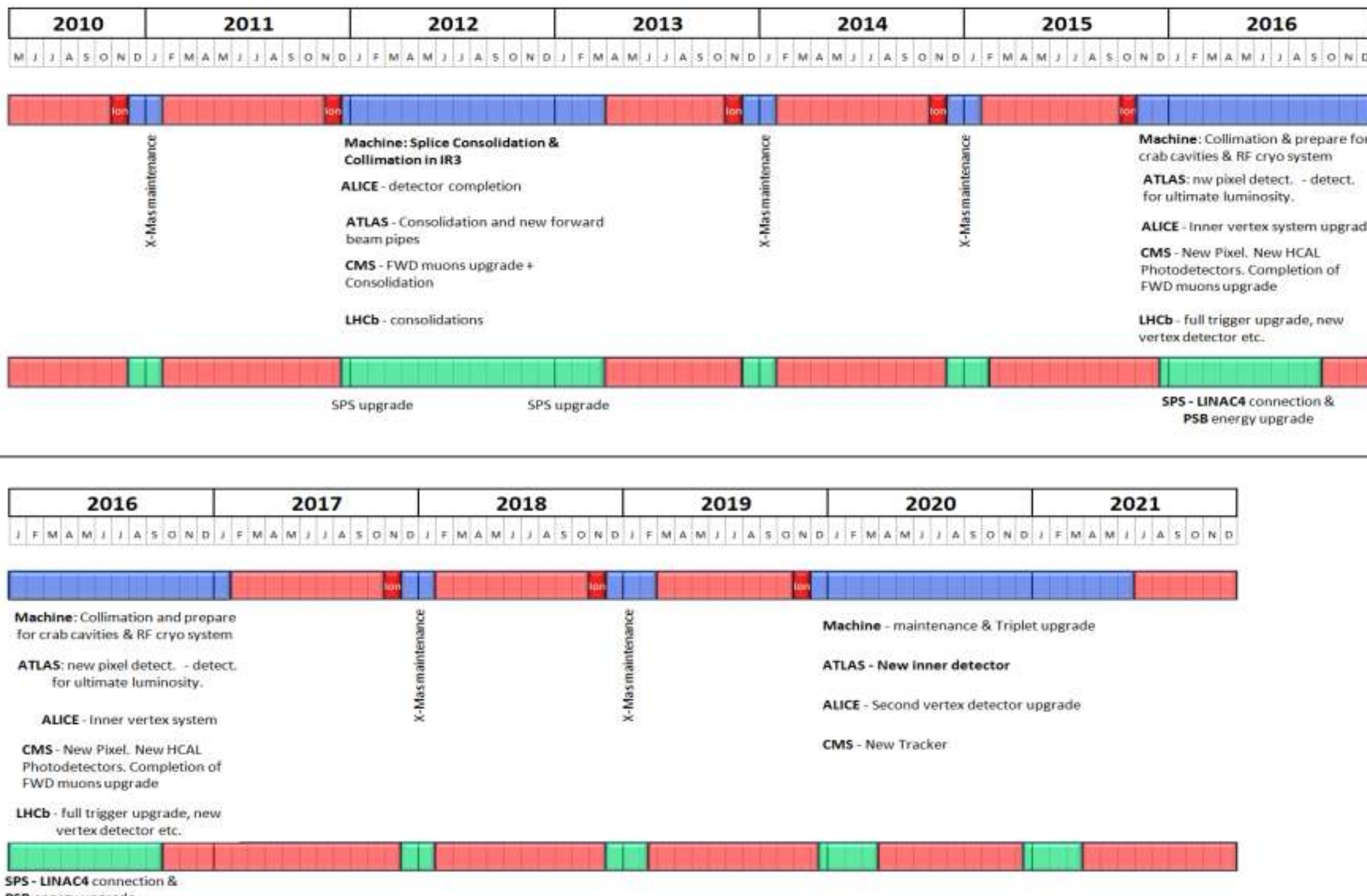
Range of Integrated Luminosity

Goal is still $1fb^{-1}$

236 Days total

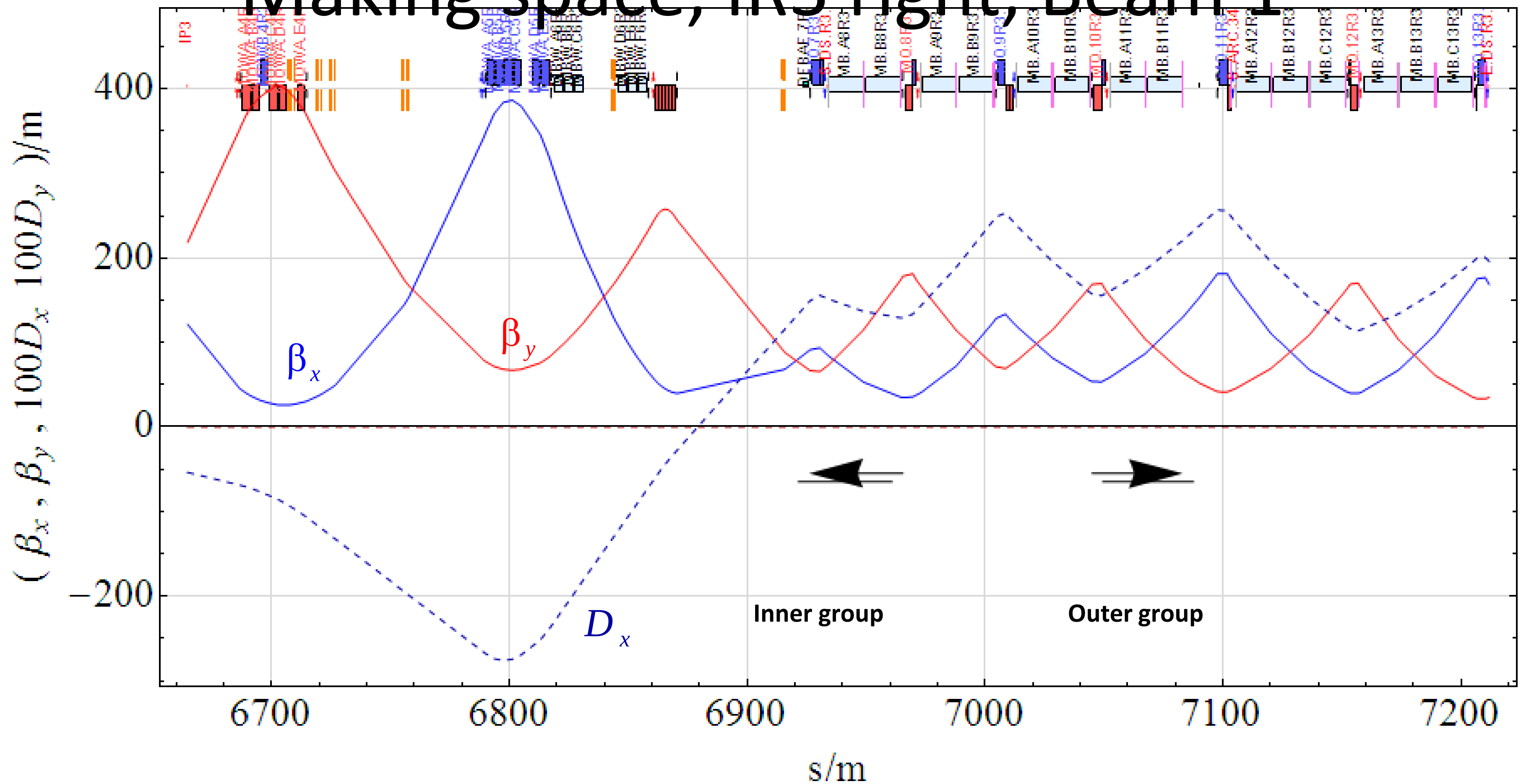
Mode of Operation	TeV	OEF	β*	[illegible]	Ib	MJ	Emittance	luminosity	pb-1 per day	Days	Integrated (fb-1)
2010	3.50	0.20	[illegible]	368	1.18E+11	24.5	2.2	2.05E+32	3.5	194.0	0.7
HWC	4.00	0.00	2.00	0	0.00E+00	0.0	2.0			28.0	0.00
recommissioning	4.00	0.00	2.00	0	0.00E+00	0.0	2.0			14.0	0.00
redo 150ns, 450 b	4.00	0.20	2.00	450	1.20E+11	34.9	2.0		0.0	14.0	0.00
scrubbing	4.00	0.00	2.00	900			2.0		0.0	7.0	0.00
up to 900 bunches	4.00	0.10	2.00	900	1.20E+11	69.8	2.0		0.0	14.0	0.00
Physics with 450	4.00	0.20	2.00	450	1.20E+11	34.9	2.0	6.04E+32	10.4	159.0	1.66
Physics with 900	4.00	0.20	2.00	900	1.20E+11	69.8	2.0	1.21E+33	20.9	159.0	3.32
Physics with 450	4.00	0.20	1.50	450	1.20E+11	34.9	2.0	8.06E+32	13.9	159.0	2.21
Physics with 900	4.00	0.20	1.50	900	1.20E+11	69.8	2.0	1.61E+33	27.8	159.0	4.43
Physics with 450	4.00	0.20	1.50	450	1.10E+11	32.0	1.5	9.03E+32	15.6	159.0	2.48

The 10 year technical Plan



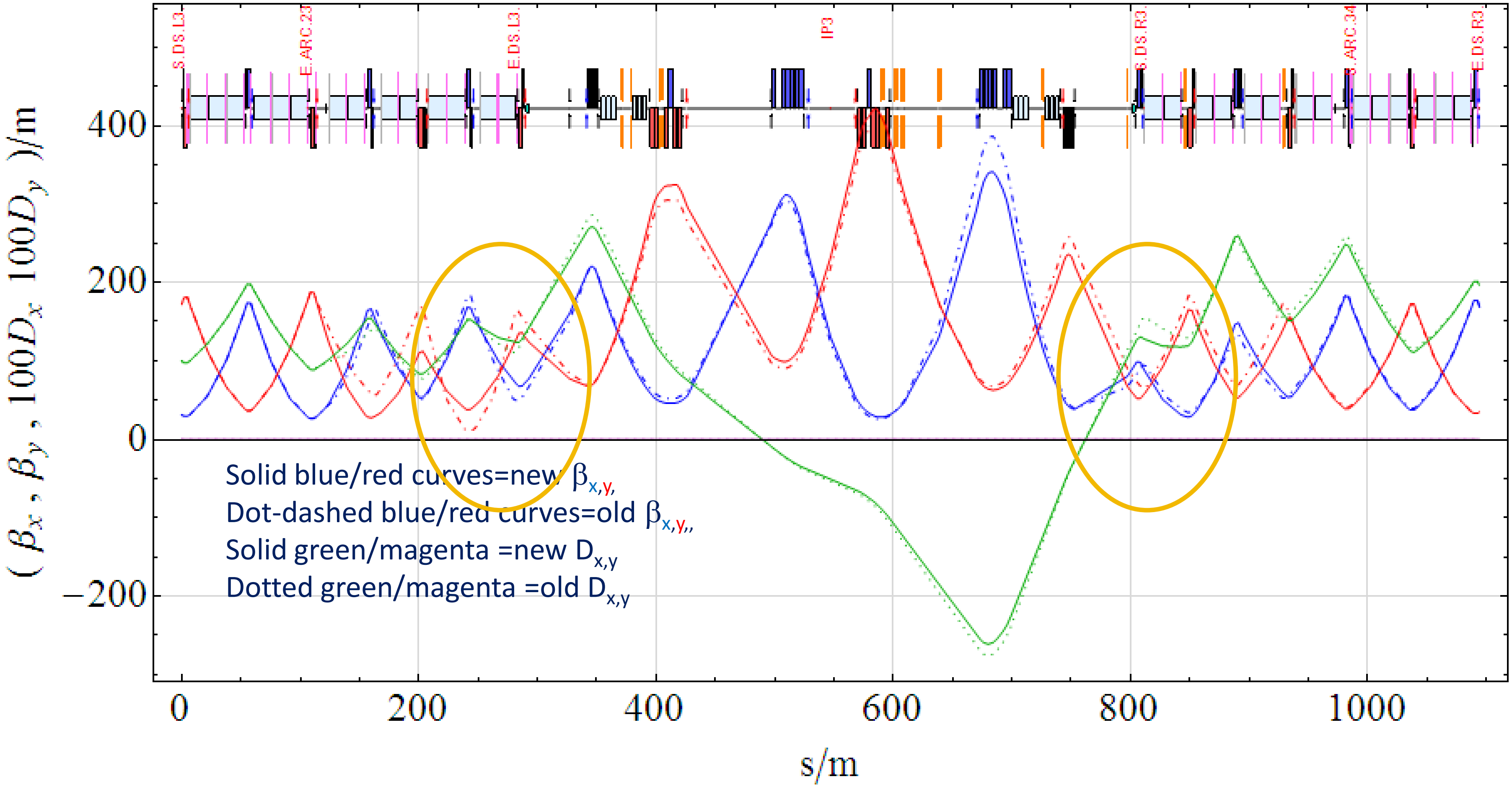
Luminosity Upgrade

Making space, IR3 right, Beam 1



Move outer group of elements 4.5 m away from IP into missing dipole space.
Move inner group of elements 4.5 m towards IP to (roughly) compensate change in geometry.
Similarly on left of IP3.

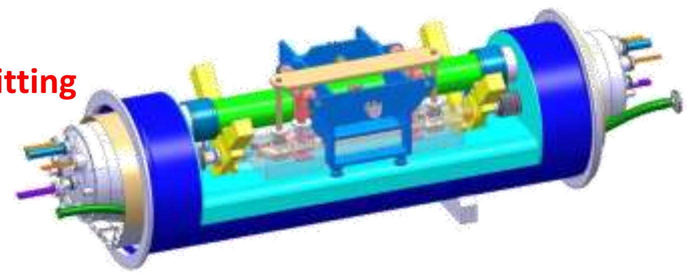
Rematch of IR3, Beam 1

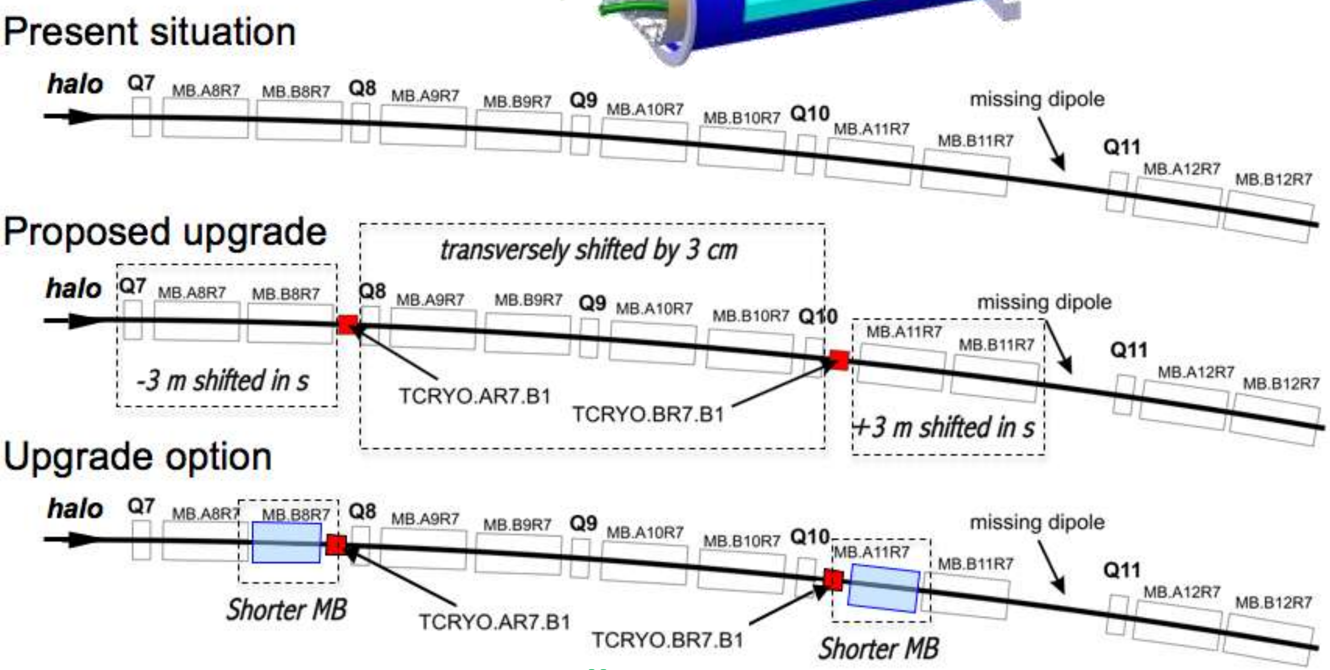


Perfect match – same transfer matrix over IR3 - so can be used in modular way with all existing LHC optics configurations.
Adjusted β-function peaks (many iterations) to avoid loss of mechanical aperture.
Optics in central (warm) part is close (not identical) to old optics.

First action of HL-LHC: 11 T LHC dipole Make room for collimation beyond P3

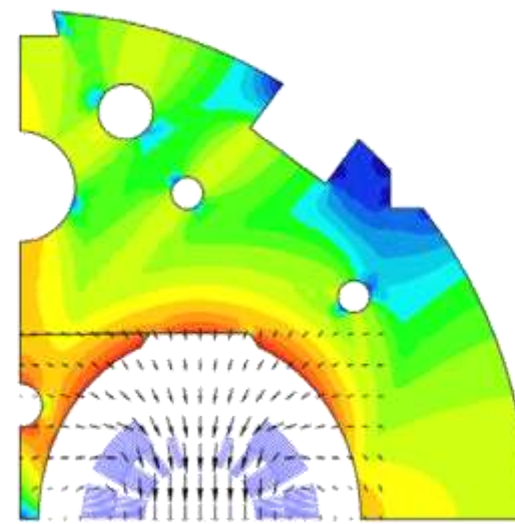
A warm collimator sitting on a cold by-pass





Here cryocollimators could be accomodate

In 2012-13 we plan to move 28 cold equipments
Later on this will be avoided, but an alternative solution is studied in HL-LHC:
A 11T LHC MB (twin) Collaboration with Fermilab



Upgrades: Foreword

New Studies were launched more than one year ago

- Performance Aim
  - To maximize the useful integrated luminosity over the lifetime of the LHC
- Targets set by the detectors are:
  3000fb^{-1} (on tape) by the end of the life of the LHC
  → 250-300fb^{-1} per year in the second decade of running the LHC

- Goals
  - Check the coherence of the presently considered upgrades wrt
    - accelerator performance limitations,
    - Detector needs,
    - manpower resources and,
    - shutdown planning including detectors

Luminosity Upgrade Scenario

- For LHC high luminosities, the luminosity lifetime becomes comparable with the turn round time $\Rightarrow$ Low efficiency
- Preliminary estimates show that the useful integrated luminosity is greater with
  - a peak luminosity of 5×10^{34} cm^{-2} s^{-1} and a longer luminosity lifetime (by luminosity levelling)
  - than with 10^{35} and a luminosity lifetime of a few hours
- Luminosity Levelling by
  - Beta*, crossing angle, crab cavities, and bunch length

Detector physicists have indicated that their detector upgrades are significantly influenced by the choice between peak luminosities of 5×10^{34} and 10^{35}.

- Pile up events
- Radiation effects

Hardware for the Upgrade

- New high field insertion quadrupoles
- Upgraded cryo system for IP1 and IP5
- Upgrade of the intensity in the Injector Chain
- Crab Cavities to take advantage of the small beta*
- Single Event Upsets
  - SC links to allow power converters to be moved to surface
- Misc
    - Upgrade some correctors
    - Re-commissioning DS quads at higher gradient
    - Change of New Q5/Q4 (larger aperture), with new stronger corrector orbit, displacements of few magnets
    - Larger aperture D2

Reduction of β^*

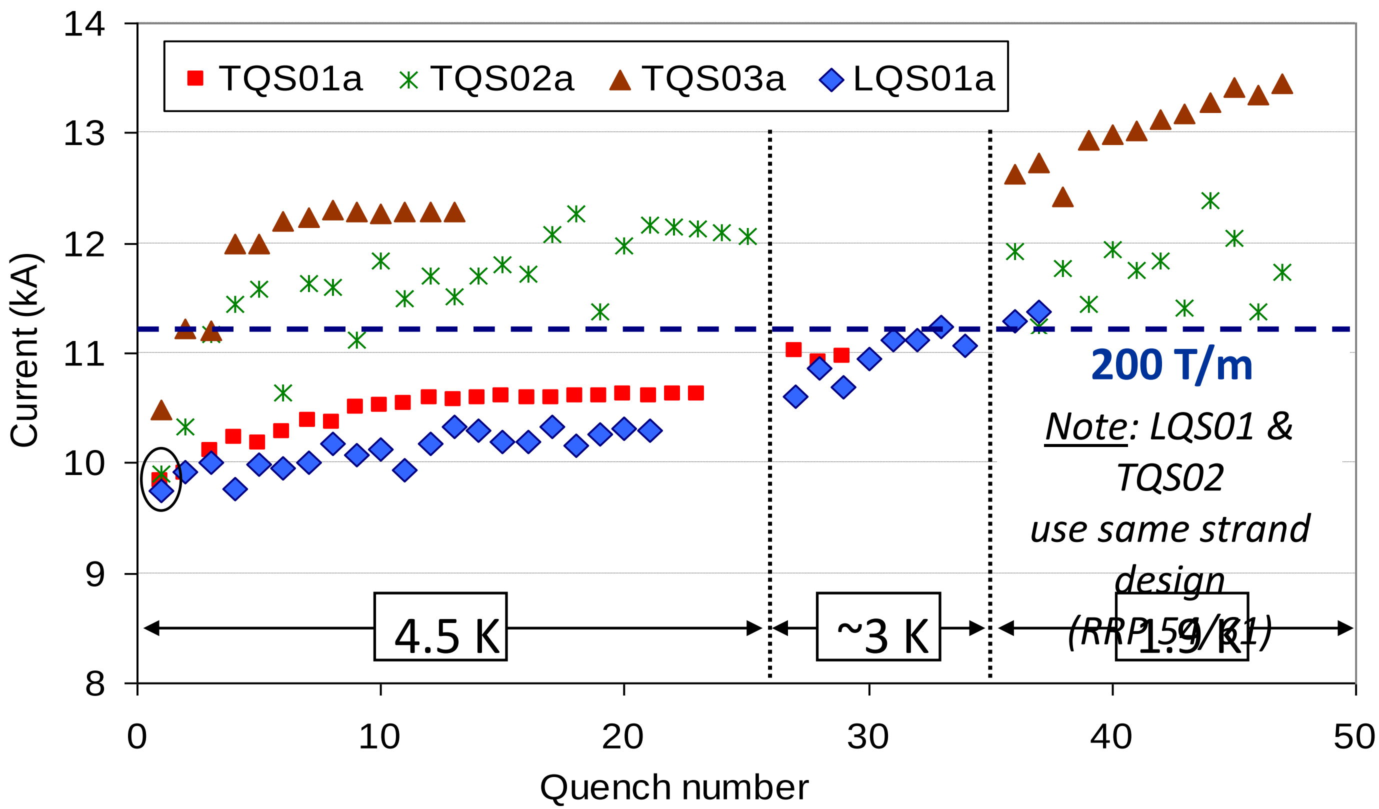
- **High Gradient/Large Aperture Quads, with B_{peak} 13-15 T**. **US-LARP engaged to produce demonstration prototype by 2013. Then Construction by 2018** (a prudent assumption)
- β^* down to 22 cm with a improvement **factor ~2.5** in luminosity, **if coupled with** a mechanism to compensate the geometrical reduction (e.g. crab cavities)
- If we can find a way to correct the chromatic aberrations, β^* down to 10-12 cm could be envisaged

The main ingredient of the upgrade IR Quads

- **High Gradient/Large Aperture Quads, with B_{peak} 13-15 T.** Higher field quadrupoles translate in **higher gradient/shorter length** or larger aperture/same length or a mix . **US-LARP engaged to produce proof by 2013. Construction is 1 year more than Nb-Ti : by 2018** is a prudent assumption. β^* as small as 22 cm are possible with a **factor ~2.5** in luminosity by itself, **if coupled with a mechanism to compensate the geometrical reduction.** If a new way of correcting chromatic aberration could be found, **β^* as small as 10-12 cm can be eventually envisaged.**

HF Nb_3Sn Quad

- Nb_3Sn is becoming a reality (first LQ long -3.6 m – quad 90 mm)
- This year we expect a second LQ **and a 1 m long - 120 mm** aperture model
- In 3 years: 4-6 m long magnets, 120 mm ap., G=180-200 T/m



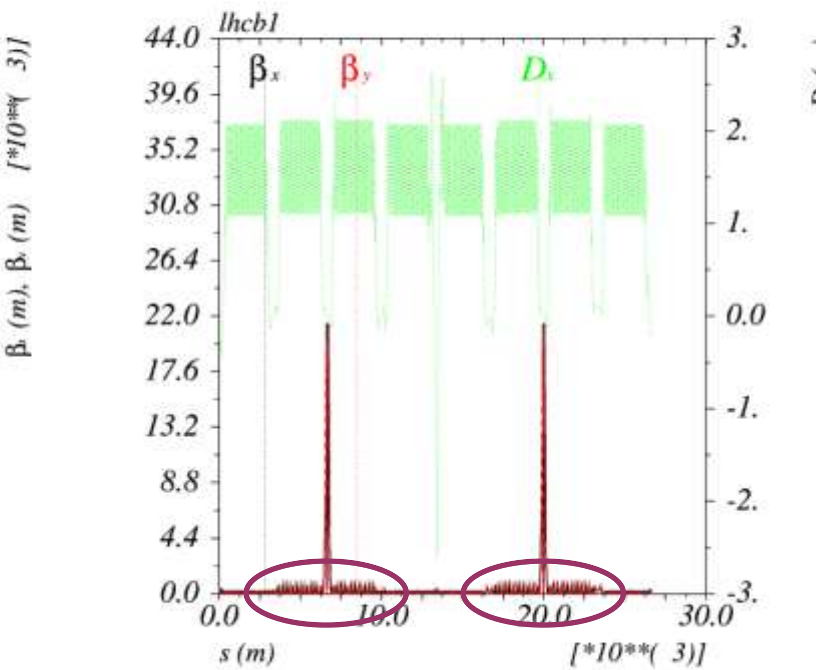
An "Achromatic Telescopic Squeezing" (ATS) scheme for the HL-LHC

→ Creating beta-beating bumps in the arcs (LMC-26/07/2010 & sLHCPR0049/50)

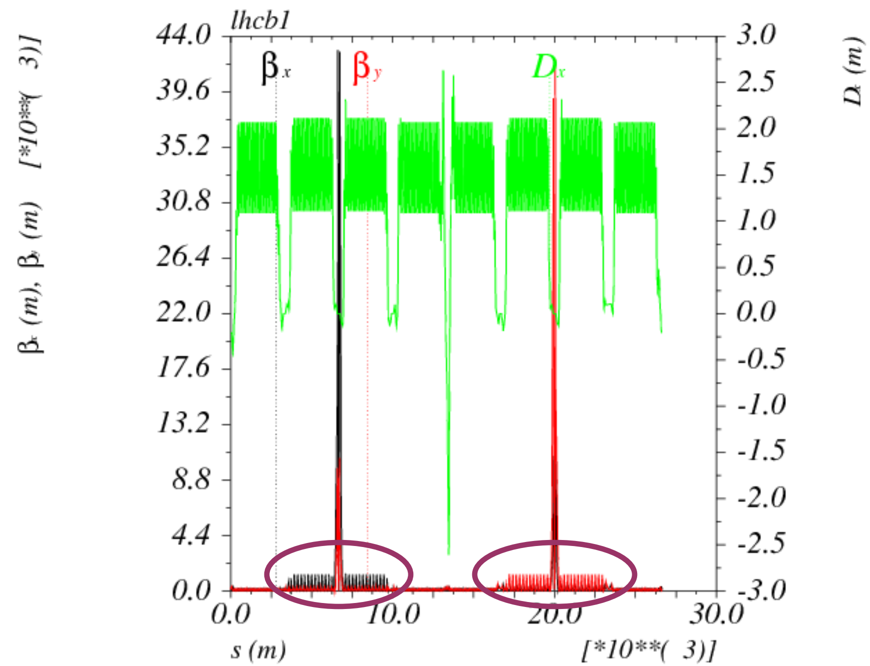
1) To perform the squeeze (below β*=50-60cm)

2) To remove any chromatic limit (Q', Q",.., off-momentum β-beat, spurious $D_{x,y}$ from X-angle)

3) To preserve the optics flexibility in the low-beta IRs



Round collision optics:
$\beta^*_{x/y}$ = 15 cm/15 cm at IP1 and IP5
→ Preferred optics if crab-cavities available

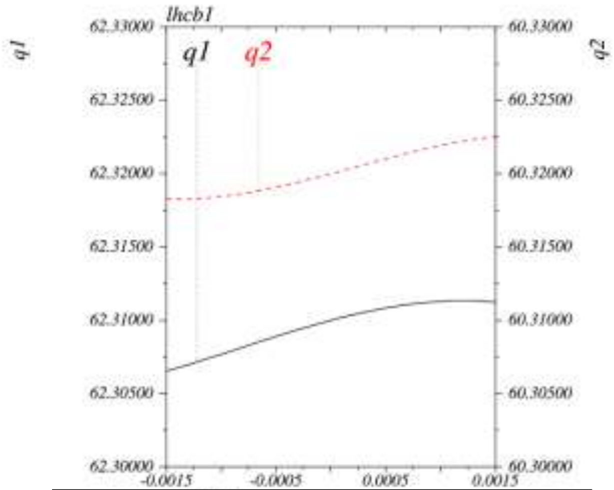


"Alternated" flat collision optics:
$\beta^*_{x/y}$ = 7.5 cm/30 cm at IP1 (V crossing)
$\beta^*_{x/y}$ = 30 cm/7.5 cm at IP5 (H crossing)
→ Back-up optics w/o crab-cavities

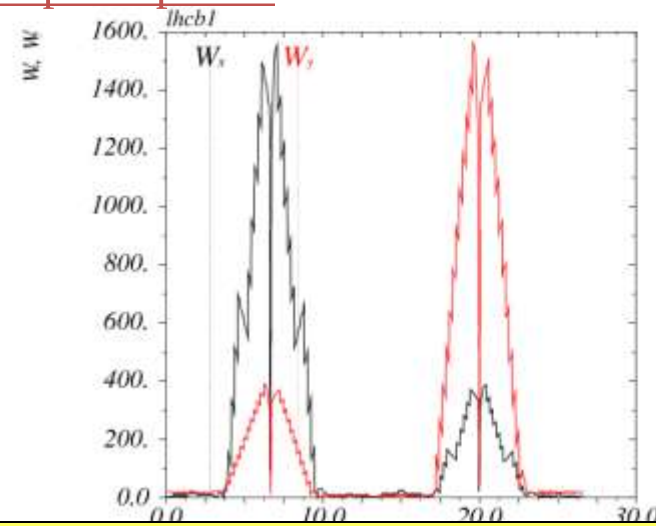
S. Fartoukh

…With a series of fundamental chromatic properties (illustration given for the flat optics)

1) Chromatic correction using only one sector of sextupoles per IT

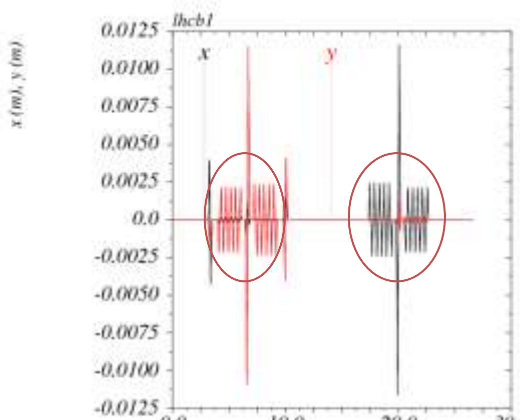


Tune vs δp (+/- 0.0015 window)



Montague functions (W=1000 ⇔ Δβ/β=100% at δ=0.001)

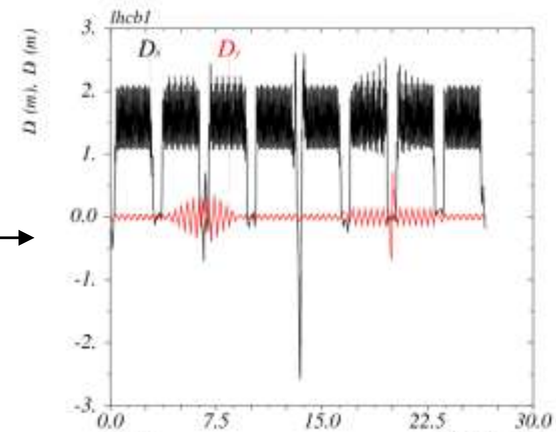
2) Correction of the spurious dispersion induced by the crossing-angles in IR1 and IR5



Closed orbit with X-scheme

→Dispersion controlled within ~50cm in the IT (residual from IR2 and IR8) thanks to 2.5 mm orbit bumps induced in sectors 81/12/45/56

→ Would reach ~10 m w/o correction!



H and V dispersion

S. Fartoukh

Performance vs β* (w/o crab-cavity)

$$\mathcal{L}(\beta^*) \propto \frac{N_b^2}{\varepsilon} \times \overbrace{\frac{1}{\sqrt{\beta_x^*}\sqrt{1+\left(\frac{\theta_c \sigma_z}{2\beta_x^*}\right)^2}}}^{\text{Sensitivity to } \beta^* \text{ in the crossing plane}} \times \overbrace{\frac{1}{\sqrt{\beta_y^*}}}^{\text{Sensitivity to } \beta^* \text{ in the non-crossing plane}} \times \overbrace{H_A}^{H_A \sim 1 \text{ (no hour-glass effect for } \beta^*_{x,y} > \sigma_z)}$$

- **<u>Round beam optics</u>** ($\beta^*_x = \beta^*_y$)

→ The lumi saturates without crab-cavity :

$$\mathcal{L}(\beta^*) \overbrace{\propto}^{\beta_x^* \equiv \beta_y^* \to 0} \frac{1}{\theta_c \sigma_z}$$

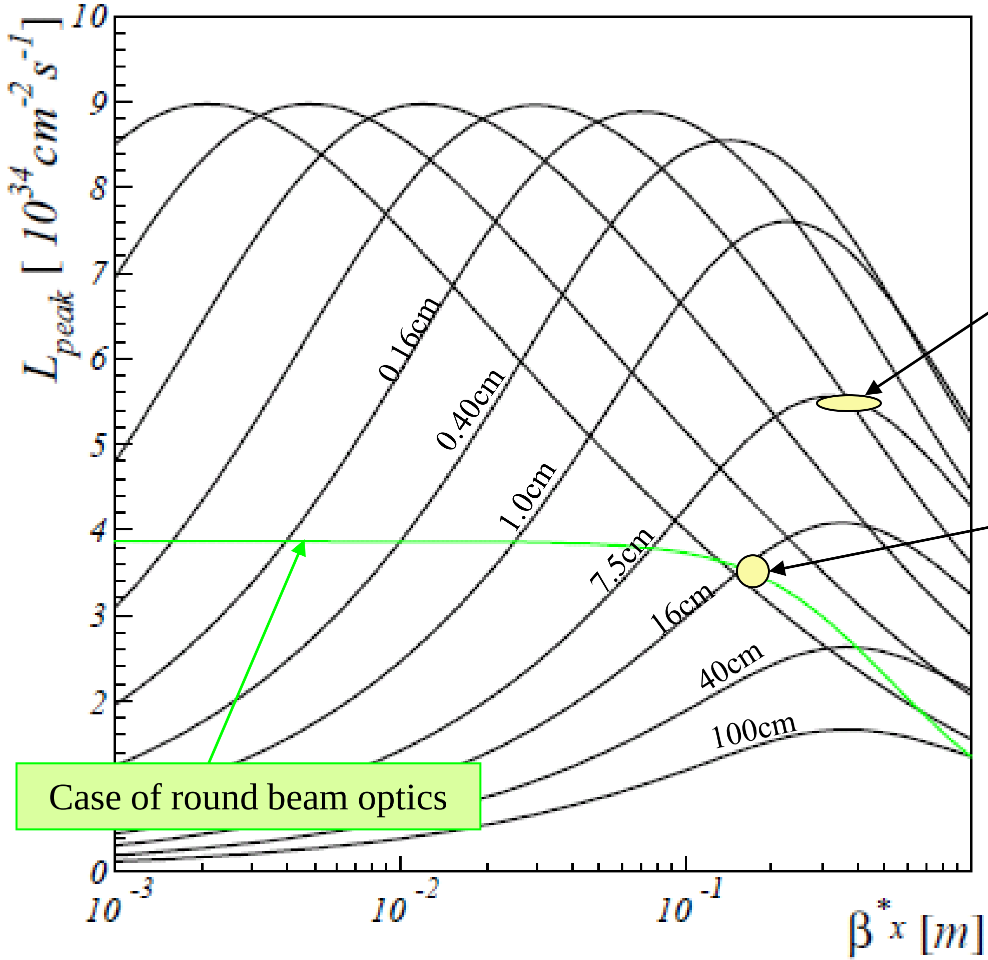
- <u>Flat beam optics</u> ($\beta^*_x \neq \beta^*_y$)

→ Is optimal fixing β* in the crossing plane to

$$\beta_x^* \equiv \frac{\theta_c \sigma_z}{2} \approx 30-35\,\mathbf{cm}$$

→ Continue to increase when decreasing β* in the other plane (and then saturates due to the hour-glass effect at very small β*)

Lumi v.s. β* in the Xing plane (with hour-glass effect) for different values of β* in the other plane:
→ Calculations done for 25ns, nominal emittance and bunch length, ultimate intensity (no crab.)



Example of flat optics:
β* =30 cm in the crossing-plane
β* = σ_z =7.5 cm in the other plane
Θ_c = 10σ in the plane of biggest β*
→ Peak lumi ~5.6 $10^{34}cm^{-2}s^{-1}$

"Equivalent" round optics:
β* =15 cm in both plane
Θ_c = 10σ
→ Peak lumi ~3.5 $10^{34}cm^{-2}s^{-1}$

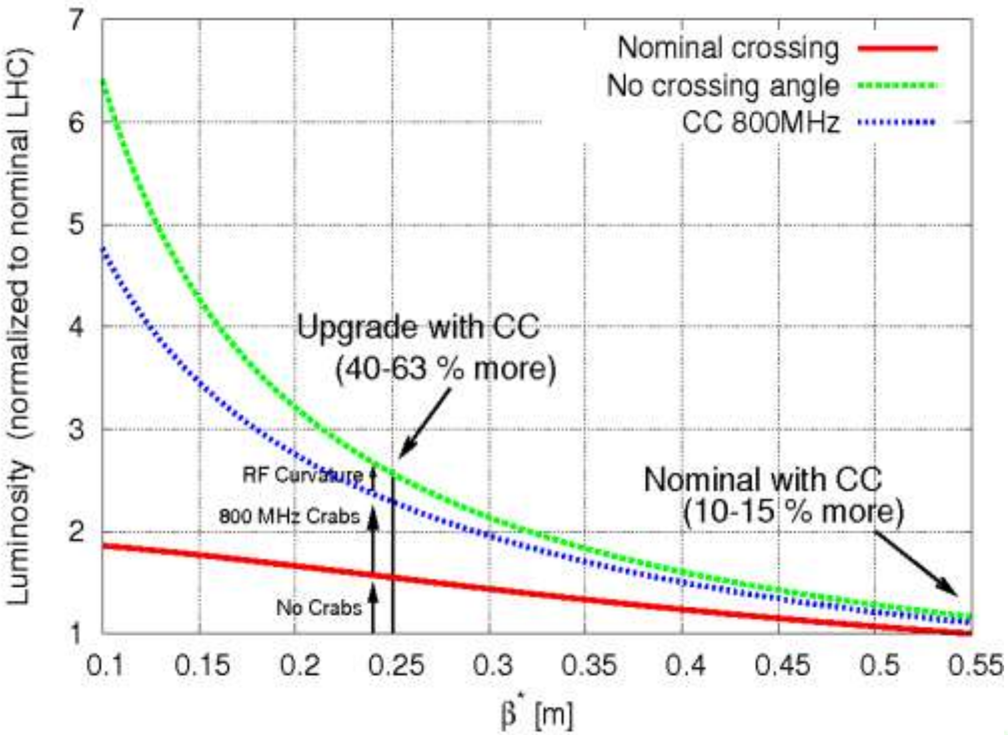
1. The "virtual" performance of the two optics becomes equivalent with crab-cavity (~8-9E34),
2. In all cases the two options requires to push β* well beyond the Phase I limit!

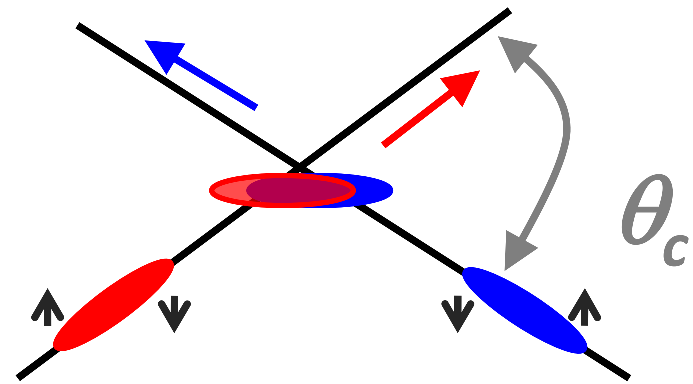
S. Fartoukh

RF Crab cavities

- **Crab Cavities**: this is the best candidate for exploiting small β^* (for β^* around nominal only +15%). However Crab Cavities have not yet been validated for LHC , not even conceptually: **the issue of machine protection is being addressed with priority.**
  - Global Scheme. 1 cavity in IP4, Proof on LHC, good for 1 X-ing.
  - Local scheme; 1 cavity per IP side. (**local doglegs ?)**

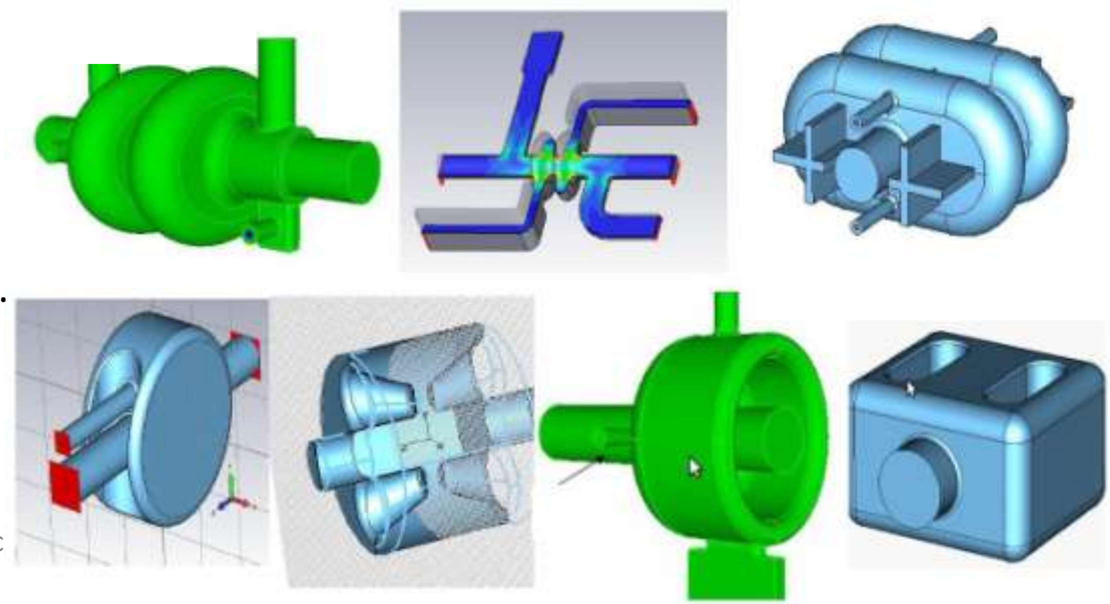
Crab Cavities





Elliptical 800 MHz not far from being designed. Require 400 mm beam-beam

400 MHz small cavity under conceptual study, they can (?) fit in 194 mm beam-beam. Required for final solution



Design Study Scope and Milestones

- A consistent design to reach 5 10^{34} with levelling, allowing LHC to reach the goal of 1000 fb^{-1} by 2025
  - Exploring in detail a coherent approach to all aspects of the upgrade, both in terms of hardware and LHC operation
  - Produce by end 2013 a PDR (Preliminary Design Report) **for approval by the CERN Council**
  - Producing by end of 2014/mid- 2015 a TDR (Technical Design Report) for the upgrade including a realistic estimate of the the maximum luminosity

HL-LHC Conclusions

- The ultimate luminosity targets set by the detectors are:
    - 3000fb^{-1} (on tape) by the end of the life of the LHC
    - → 250-300fb^{-1} per year in the second decade of running the LHC
- The Upgrades needed to attack these goals are
    - a newly defined HL-LHC which involves
        - luminosity levelling at ~5-6x $10^{34}cm^{-2}s^{-1}$ (crab cavities etc…)
        - At least one major upgrade of the high luminosity insertions
    - SPS performance improvements to remove the bottleneck
    - Aggressive consolidation of the existing injector chain for availability reasons
    - Performance improvement of the injector chain to allow HL-LHC beam conditions

First Thoughts on an Energy Upgrade

Very Long Term Objectives: Higher Energy LHC

Preliminary HE-LHC - parameter...

Very preliminary with large error bars

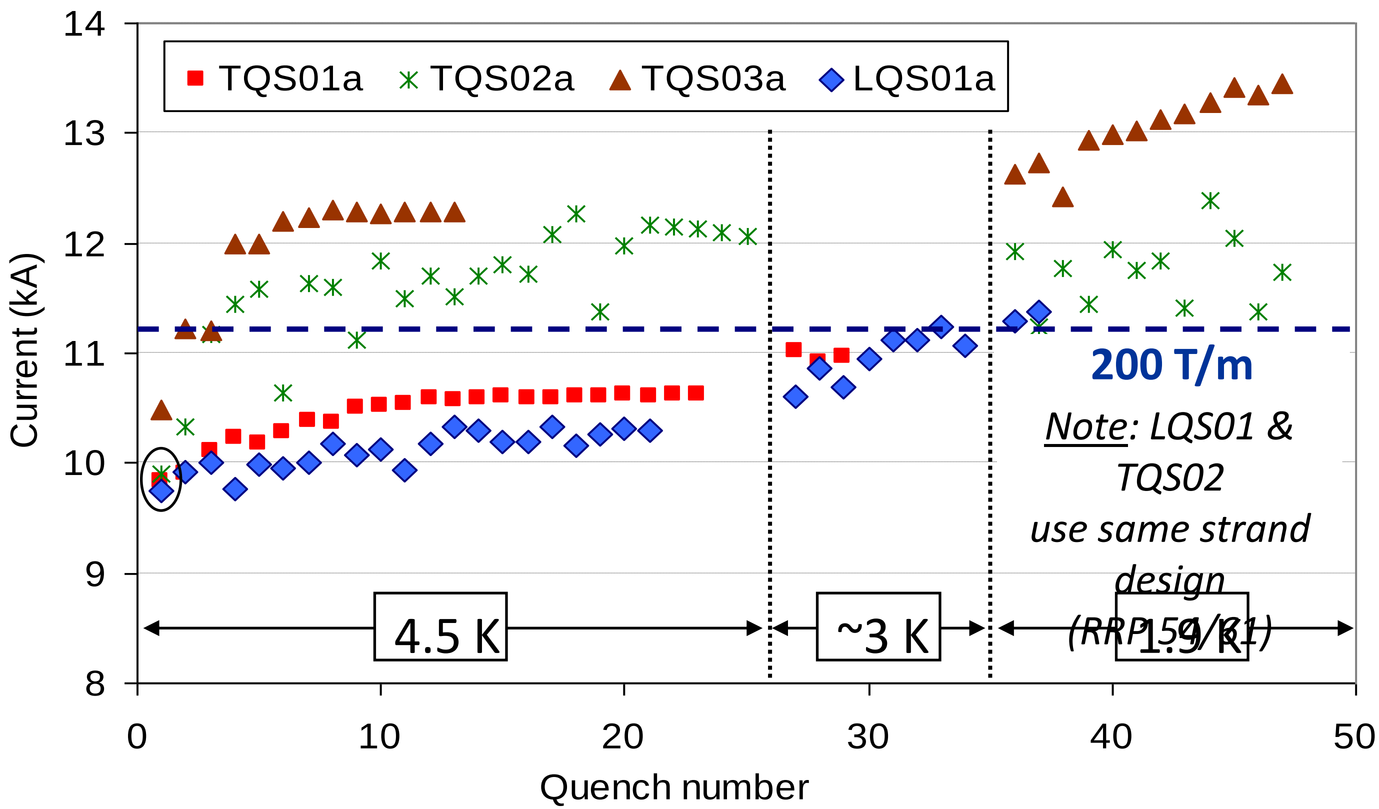
	nom...	HE-LHC
beam energy [TeV]	[illegible]	16.5
dipole field [T]	[illegible]	20
dipole coil aperture [mm]	[illegible]	40-45
#bunches / beam	[illegible]	1404
bunch population [10^{11}]	[illegible]	1.29
initial transverse normalized em... [μm]	...5	3.75 (x), 1.84 (y)
number of IPs contributi...	3	2
maximum total bea...	0.01	0.01
IP beta function ...	0.55	1.0 (x), 0.43 (y)
full crossing ...	285 (9.5 $\sigma_{x,y}$)	175 (12 σ_{x0})
stored b...	362	479
SR p...	3.6	62.3
longitu... ...amping time [h]	12.9	0.98
events pe...	19	76
peak lumin... ... $cm^{-2}s^{-1}$]	1.0	2.0
beam lifetime ...]	46	13
integrated luminosity over 10 h [fb^{-1}]	0.3	0.5

HE-LHC – main issues and R&D

- ***high-field 20-T dipole*** *magnets based on Nb_3Sn, Nb_3Al, and HTS*
- ***high-gradient quadrupole magnets*** *for arc and IR*
- ***fast cycling SC magnets*** *for 1-TeV injector*
- ***emittance control*** *in regime of strong SR damping and IBS*
- *cryogenic handling of* ***SR heat load*** *(first analysis; looks manageable)*
- *dynamic* ***vacuum***

HF Nb_3Sn Quad

- Nb_3Sn is becoming a reality (first LQ long -3.6 m – quad 90 mm)
- This year we expect a second LQ **and a 1 m long - 120 mm** aperture model
- In 3 years: 4-6 m long magnets, 120 mm ap., G=180-200 T/m



Acknowledgements

It has been a very impressive year for the LHC with protons and lead ions (and also for all the other CERN accelerators).

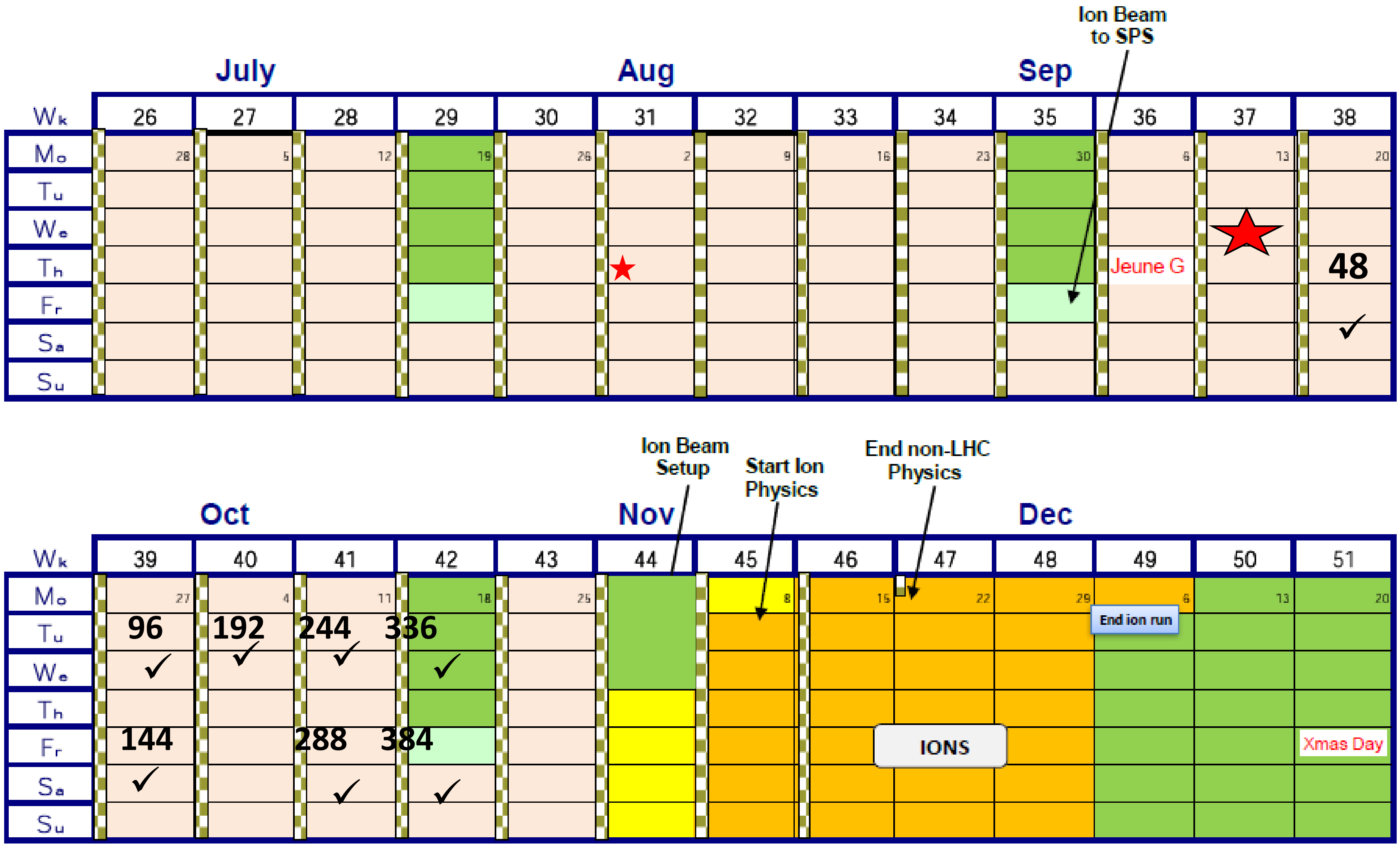
The superb progress and performance of the LHC machine and its injectors is due to the excellence, hard work and dedication of the CERN staff and due to the help we received from our international collaborators.

It is a great personal pleasure to acknowledge the success of this great team.

Thank You for your attention

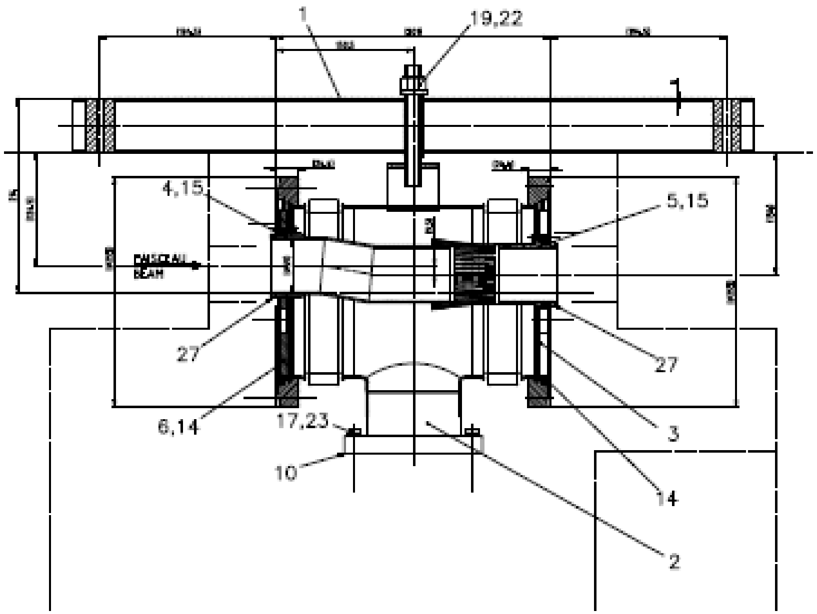
SPARES

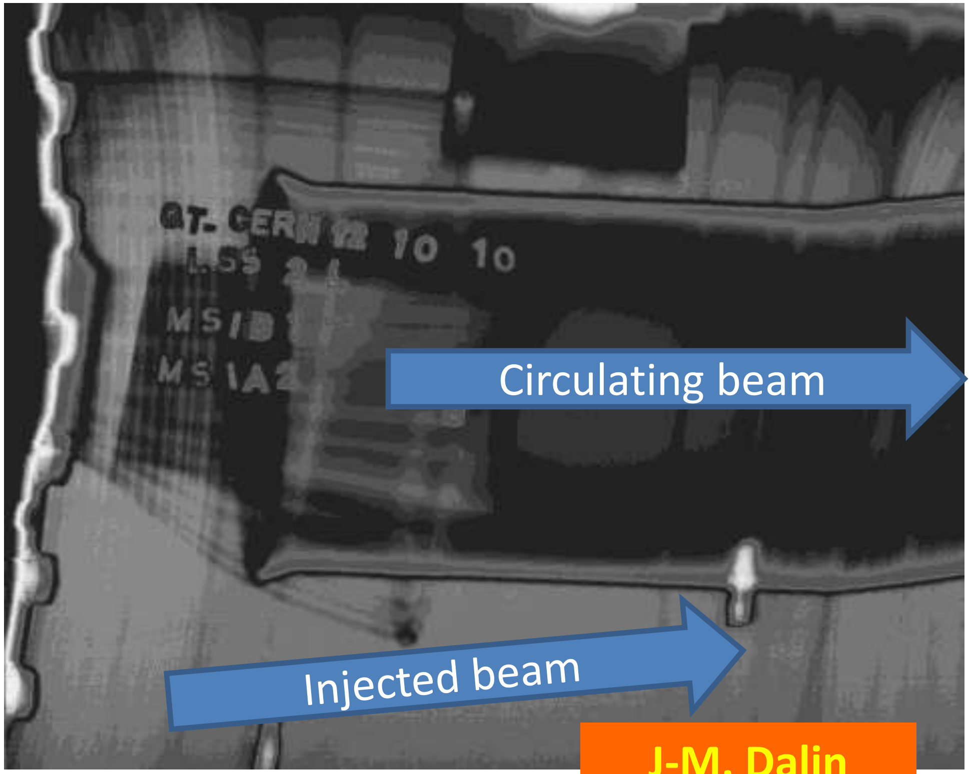
Aggressive Schedule



Injection losses B1

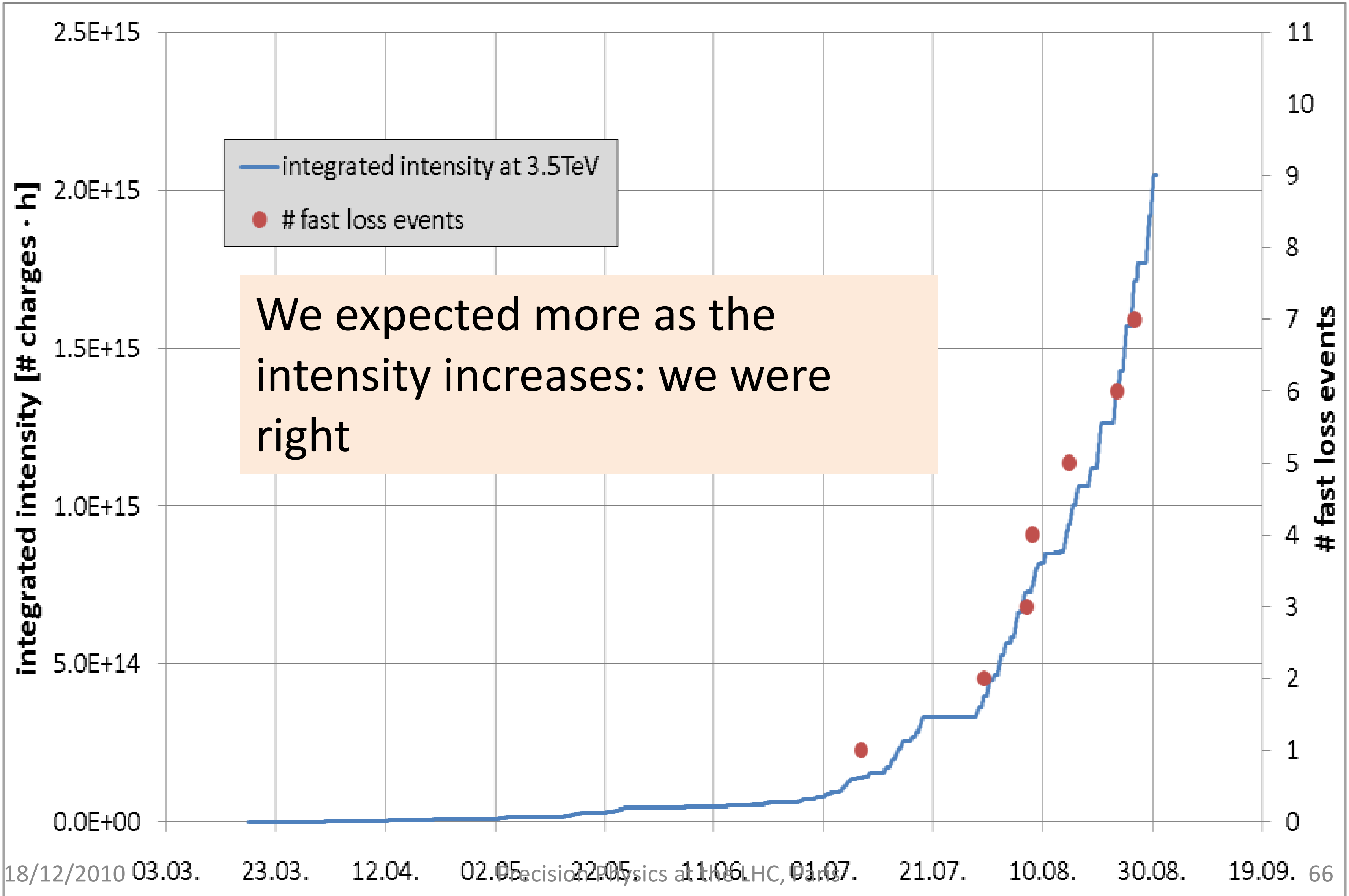
- Radiation survey and X-ray (Tue 12/10) have evidenced a clear aperture restriction at the transition between the injection septa MSIB/MSIA due to a non-conformity in the mounting of the interconnection



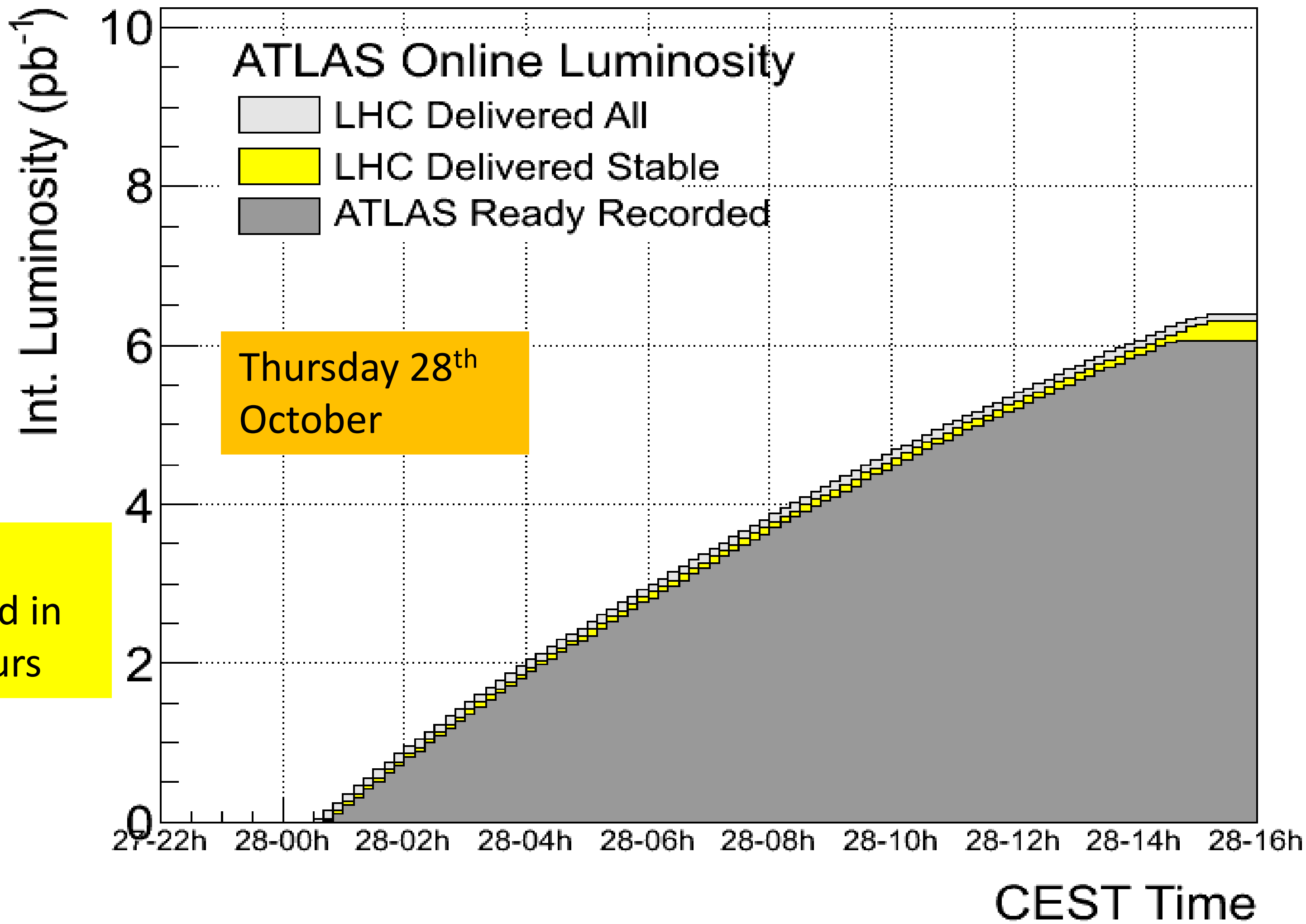


J-M. Dalin

Not the peak luminosity!!!
Correlation of Number of fast Losses with beam Intensity



Highest Integrated Luminosity Fill so Far



Thursday 28th October

6.3pb-1 delivered in 14.5 hours

Measured 450 GeV Aperture

Beam / plane	Limiting element	Aperture [σ]
Beam 1 H	Q6.R2	12.5
Beam 1 V	Q4.L6	13.5
Beam 2 H	Q5.R6	14.0
Beam 2 V	Q4.R6	13.0

- Predicted aperture bottlenecks in triplets (n1=7) do not exist.
- “Measured” n1 = 10 – 12 (on-momentum) instead design n1 = 7
- “We discover the performance gold mine of aperture”