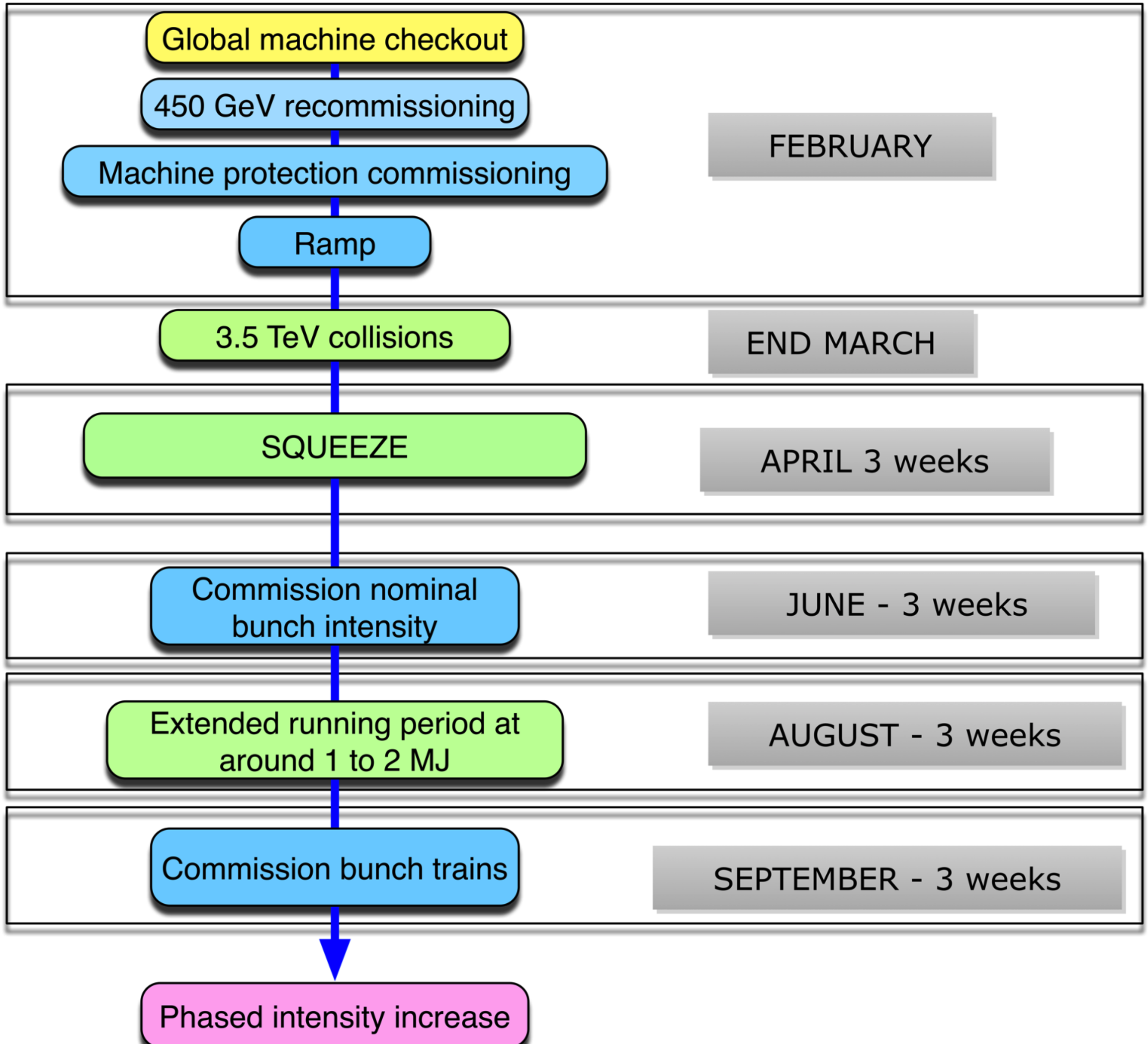
LHC status and plans for 2011

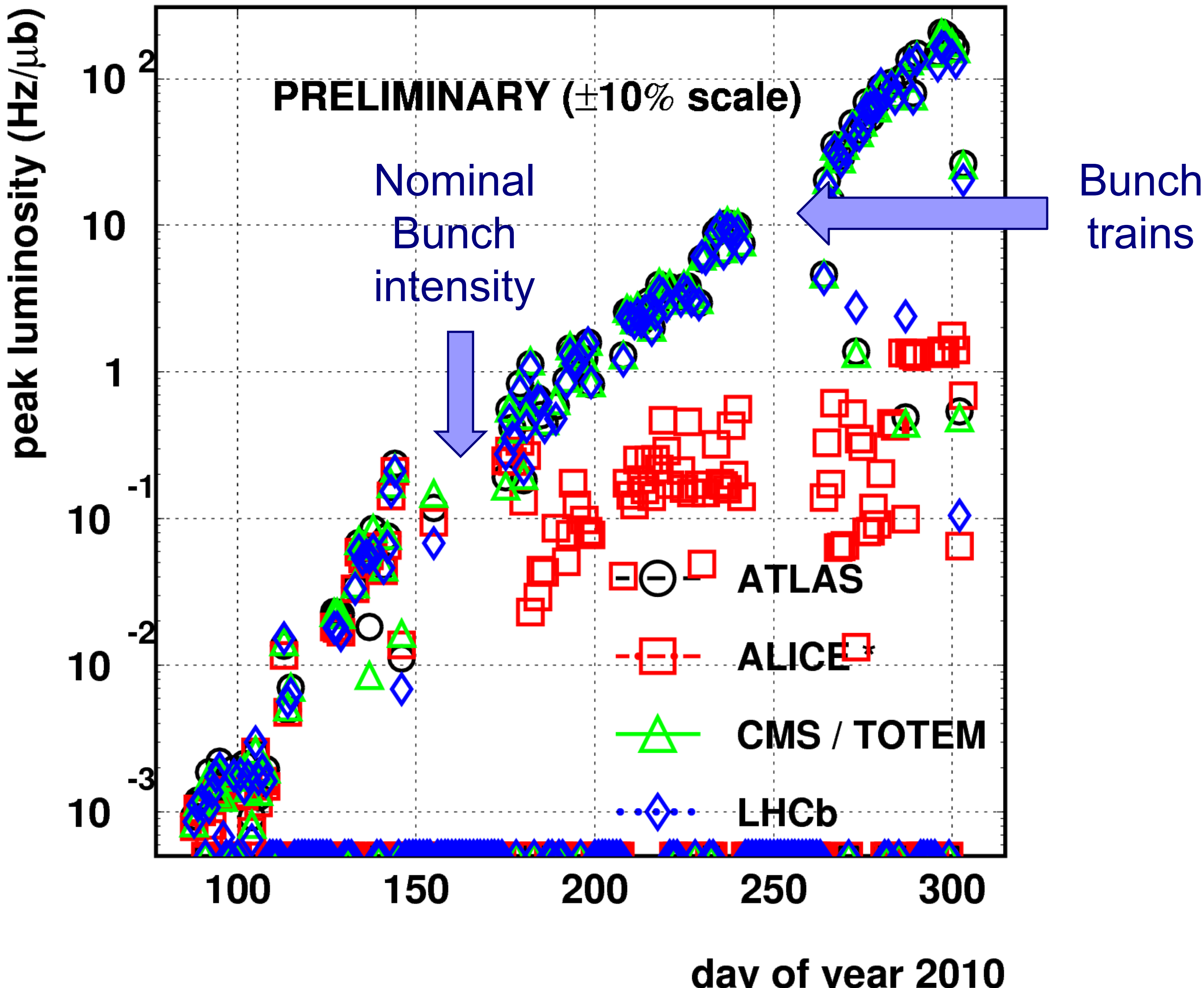
Mike Lamont
for the LHC team

2010 - a long year…



2010/11/05 08.35

LHC 2010 RUN (3.5 TeV/beam)



* ALICE : low pile-up limited since 01.07.2010

Bunch intensity - bunch spacing

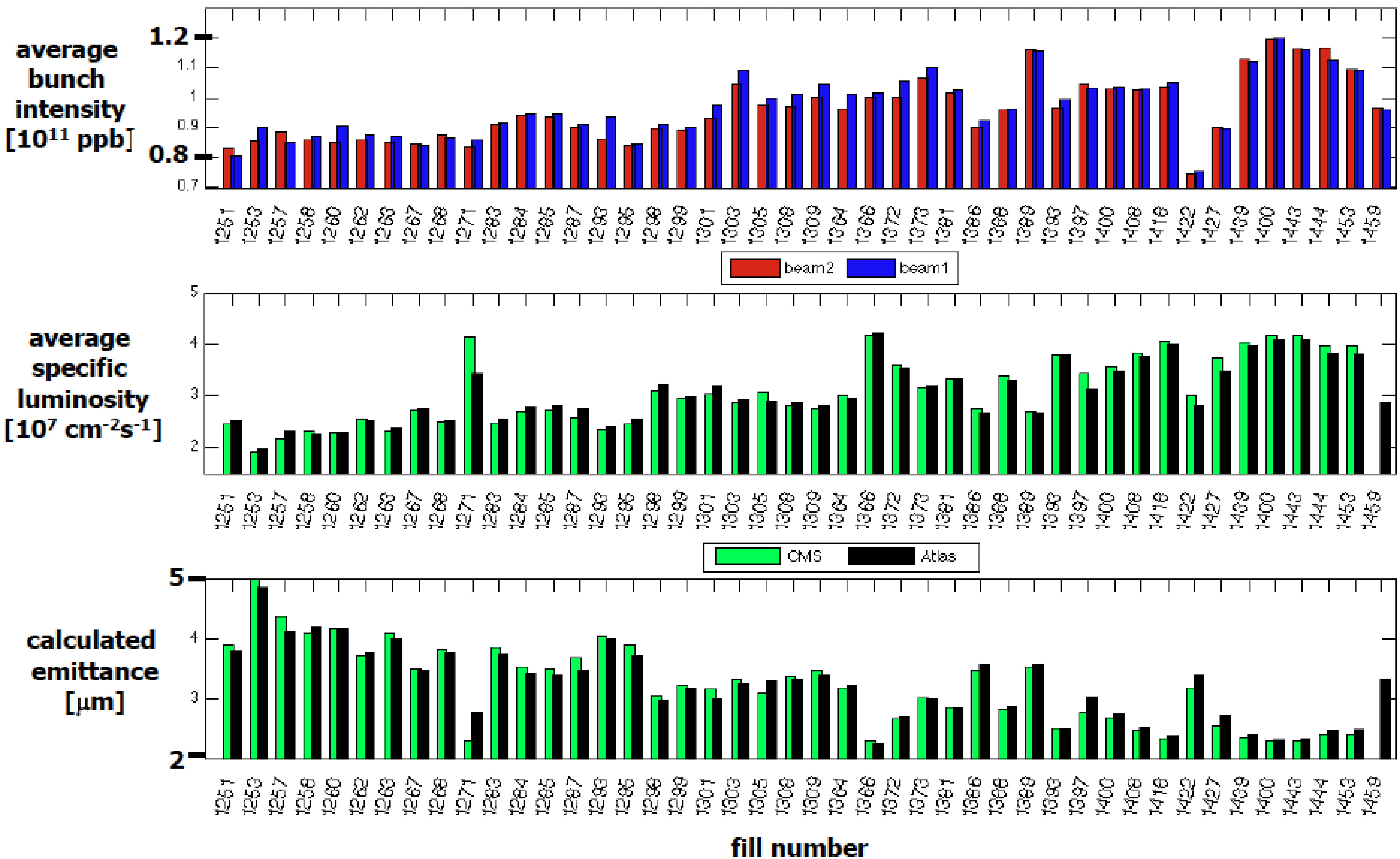
- Started low before moving to nominal bunch intensity
  - 1.15×10^{11}
  - Limit given by the predicted beam-beam limit
- Worked in 2010 with a few (~50) widely spaced bunches to start with…before moving to 150 ns bunch trains
  - Crossing angles on and pushed to 368 bunches

Beam	Np/bunch	Emittance H&V [mm.mrad]	No. of bunches from SPS
LHC150_SB	**1.1×10^{11}**	**< 2.5 (1.6)**	**1 – 4 x 12**
LHC_75_SB	1.2×10^{11}	2	1 – 4 x 24
LHC_75_DB	1.2×10^{11} (?)	1.2 (?)	1 – 4 x 24
LHC_50_SB	1.45×10^{11}	3.5	1 – 4 x 36
LHC_50_DB	1.15×10^{11} (?)	1.5 (?)	1 – 4 x 36
LHC_25_DB	1.15×10^{11}	3.6	1 – 4 x 72

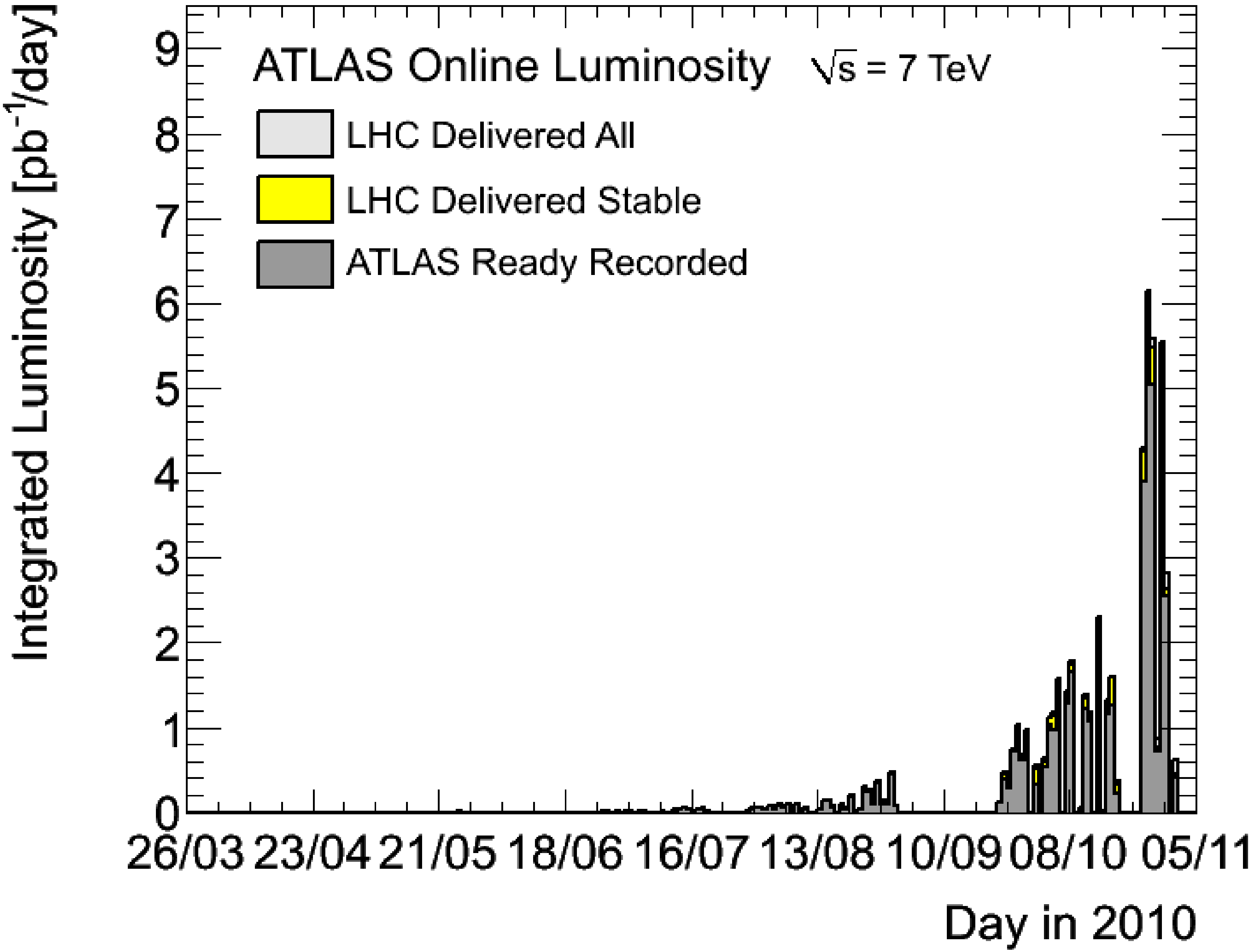
2010 parameters

	2010	Nominal
Energy [TeV]	3.5	7
beta* [m]	3.5, 3.5, 3.5, 3.5 m	0.55, 10, 0.55, 10
Emittance [microns]	**2.0 – 3.5** start of fill	3.75
Transverse beam size at IP [microns]	around 60	16.7
Bunch current	1.2e11	1.15e11
Number of bunches	368 348 collisions/IP	2808
Stored energy [MJ]	28	360
Peak luminosity [$cm^{-2}s^{-1}$]	2e32	1e34

Lumi analysis: statistics across fills



prepared by G. Trad



ATLAS Online Luminosity $\sqrt{s}$ = 7 TeV
LHC Delivered All
LHC Delivered Stable
ATLAS Ready Recorded
Integrated Luminosity [pb^{-1}/day]
0
1
2
3
4
5
6
7
8
9
26/03
23/04
21/05
18/06
16/07
13/08
10/09
08/10
05/11
Day in 2010

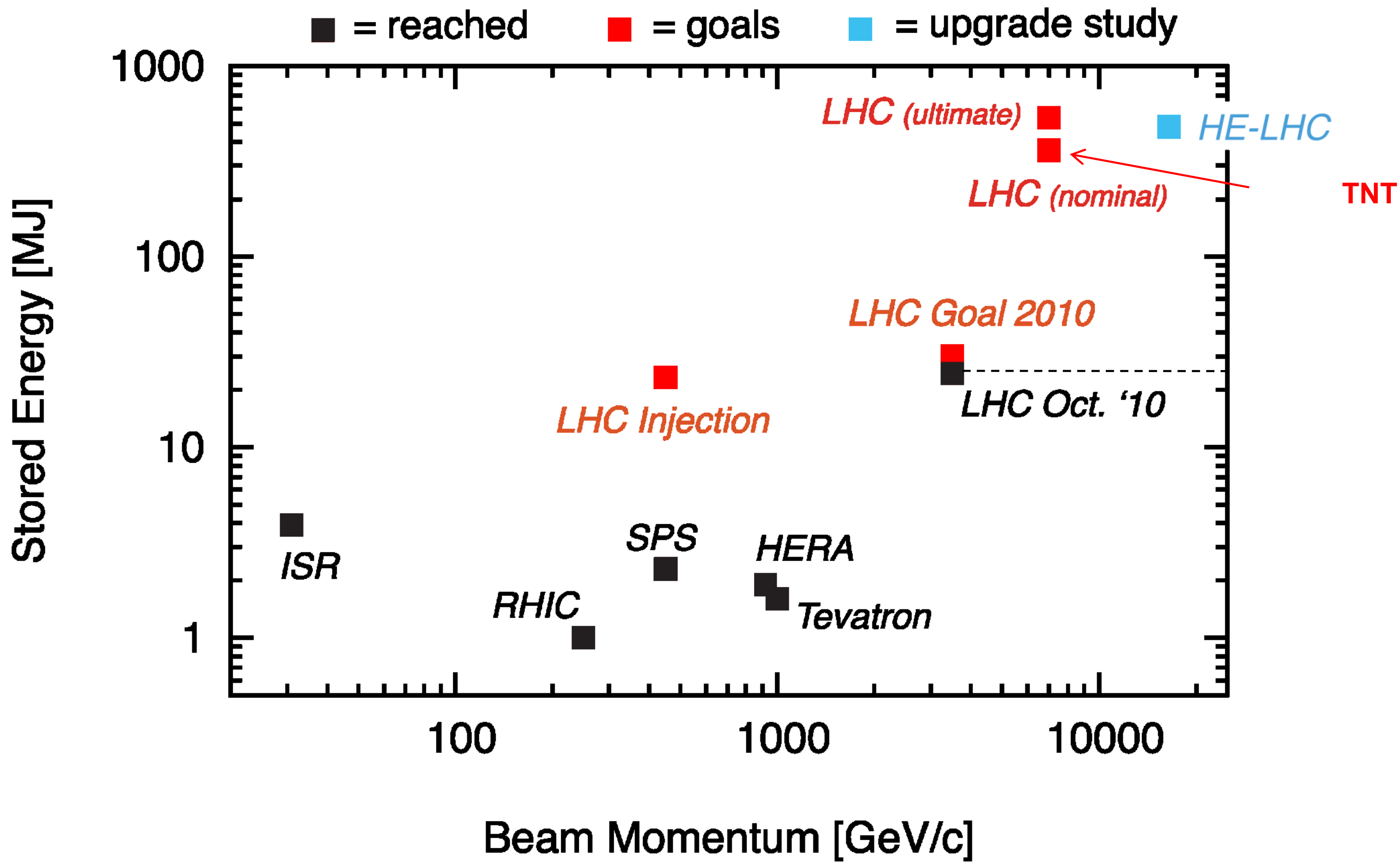
2010 - records

Peak stable luminosity delivered	2.07 x 10^{32} $cm^{-2}s^{-1}$
Maximum luminosity delivered in one fill	6.3 pb^{-1}
Maximum luminosity delivered in one day	5.98 pb^{-1}
Maximum luminosity delivered in 7 days	24.6 pb^{-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)

Courtesy Atlas

Status LHC Stored Energy

Stored energy reached at 3.5 TeV: **28.0 MJ**



Ralph Assmann

Beam-beam tune shift

- Design report

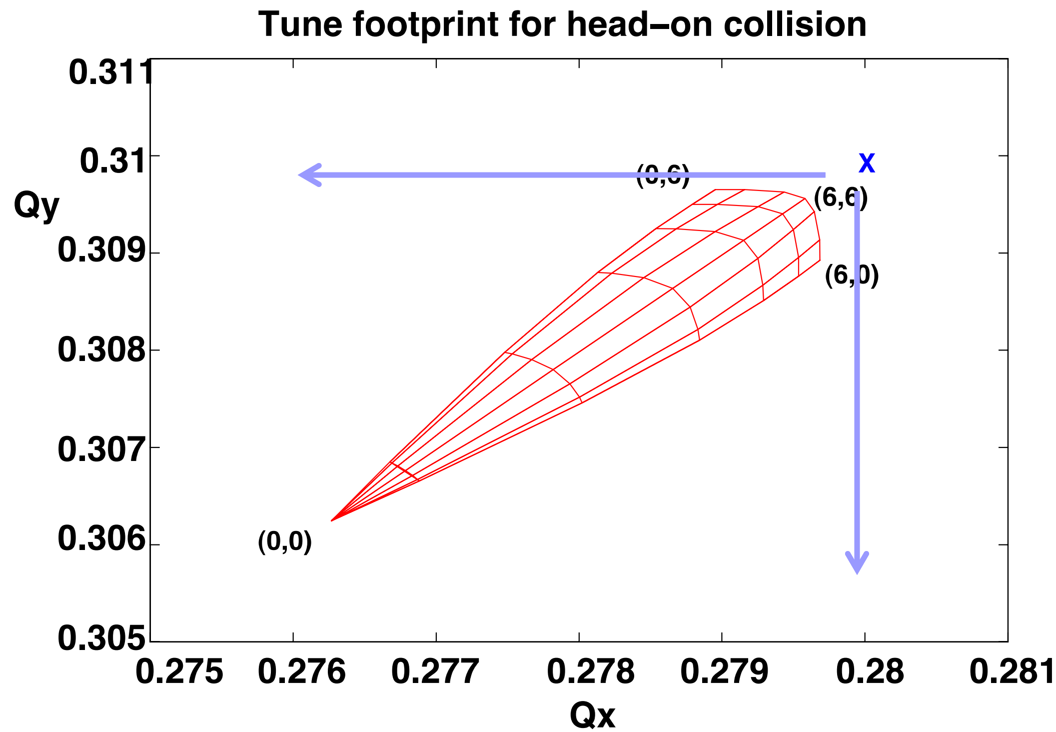
$$\Delta Q_{tot} \cong 0.015$$

$$\xi_{bb} \cong 0.005$$

- 2010

$$\Delta Q_{tot} \cong 0.02$$

$$\xi_{bb} \cong 0.007$$



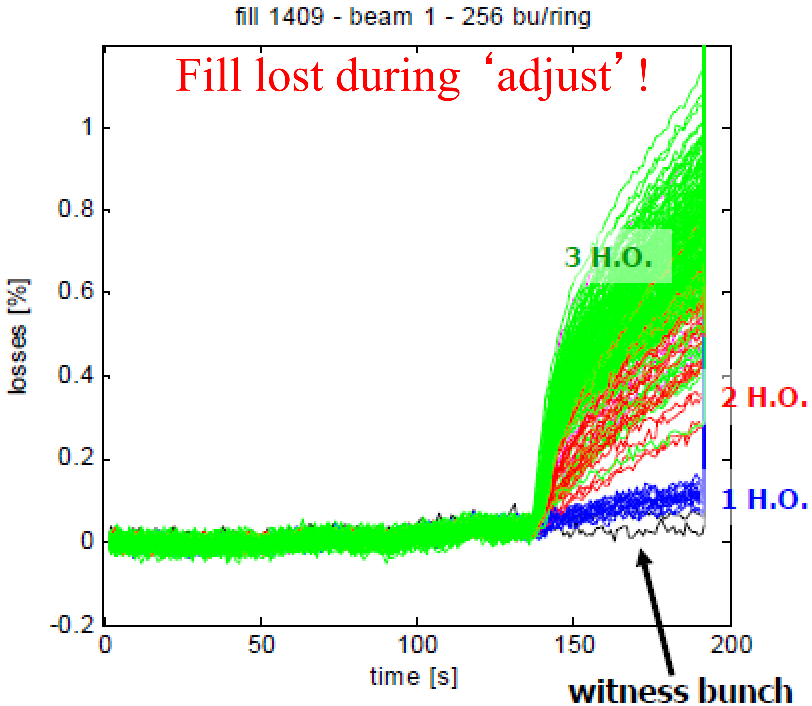
Tatiana Pieloni

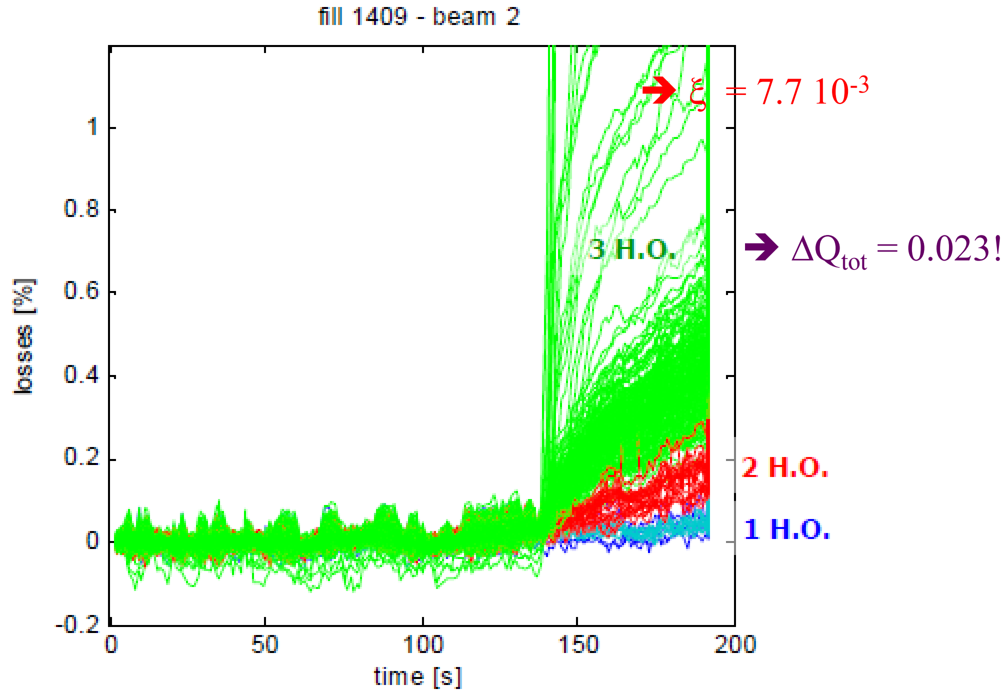
- … small lattice nonlinearities
- Measurement of maximum attainable beam-beam parameter a high priority in 2011 operation

Beam-Beam: Bunch by bunch

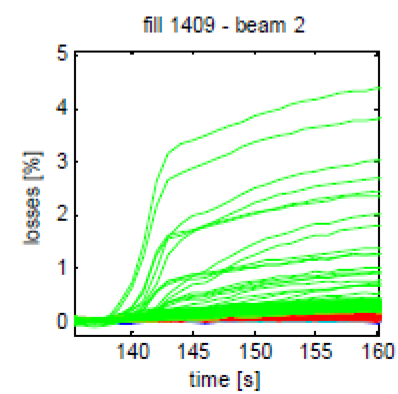
Fill 1409: 12.10.2010

ε_n = 1.6 μm; $N_b = 10^{11}$; 256 bunches





- beams dumped right after colliding (~1 minute)
- clear dependence of losses on number of H.O. collisions
- some bunches b2 lose up to 5% in the first few seconds
  - 12 out of 14 biggest losers from first 3 16-bunch injections
    - 10^{th} 11^{th} 12^{th} 13^{th} in the 16-bunch train



IPs: 1 5 2 8 - 1 5 8 - 1 5 2 - 1 5 - 2 8 - 8 - 2

giulia papotti (BE/OP/LHC)

Beam lifetime in general

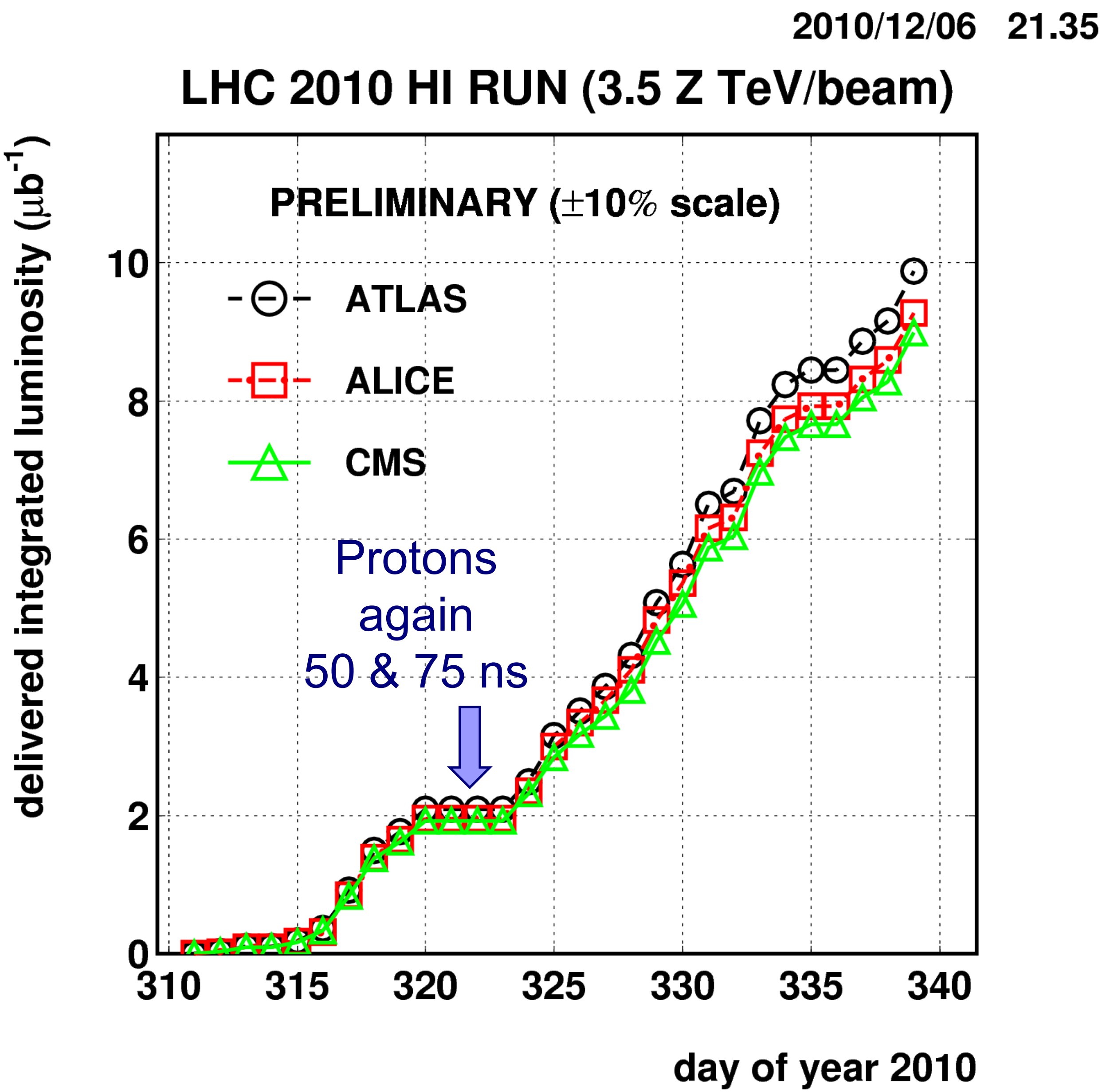
- Excellent single beam before collisions ~200 - 300 hours
- Luminosity lifetime ~15 - 20 hours
  - Reasonably well given by emittance growth and intensity decay
  - Minimal drifts in overlap – beams very stable
- Intensity lifetime ~90 hours
  - Luminosity burn, losses on collimators
- Emittance growth (x ~ 30 hours, y ~ 20 to 40 hours)
  - IBS
  - and something else – at least sometimes “the hump”

Ions - cunning wheeze – remembered Lorentz

- Used the identical magnetic machine as used for protons until the very last moment in the cycle:
  - Same ramp, squeeze to 3.5 m.
  - Kept separation and crossing angles the same
- Happily the BPMs gave similar readings for low intensity ions as those of high intensity protons
  - Same reference orbit more-or-less
  - Same collimator settings through ramp and squeeze
- Brought crossing angles to desired positions when going into collision
  - Set-up tertiary collimators in collision, validated with loss maps
  - Collided and declared stable beams

Four days from first injection to first stable beams

Ions

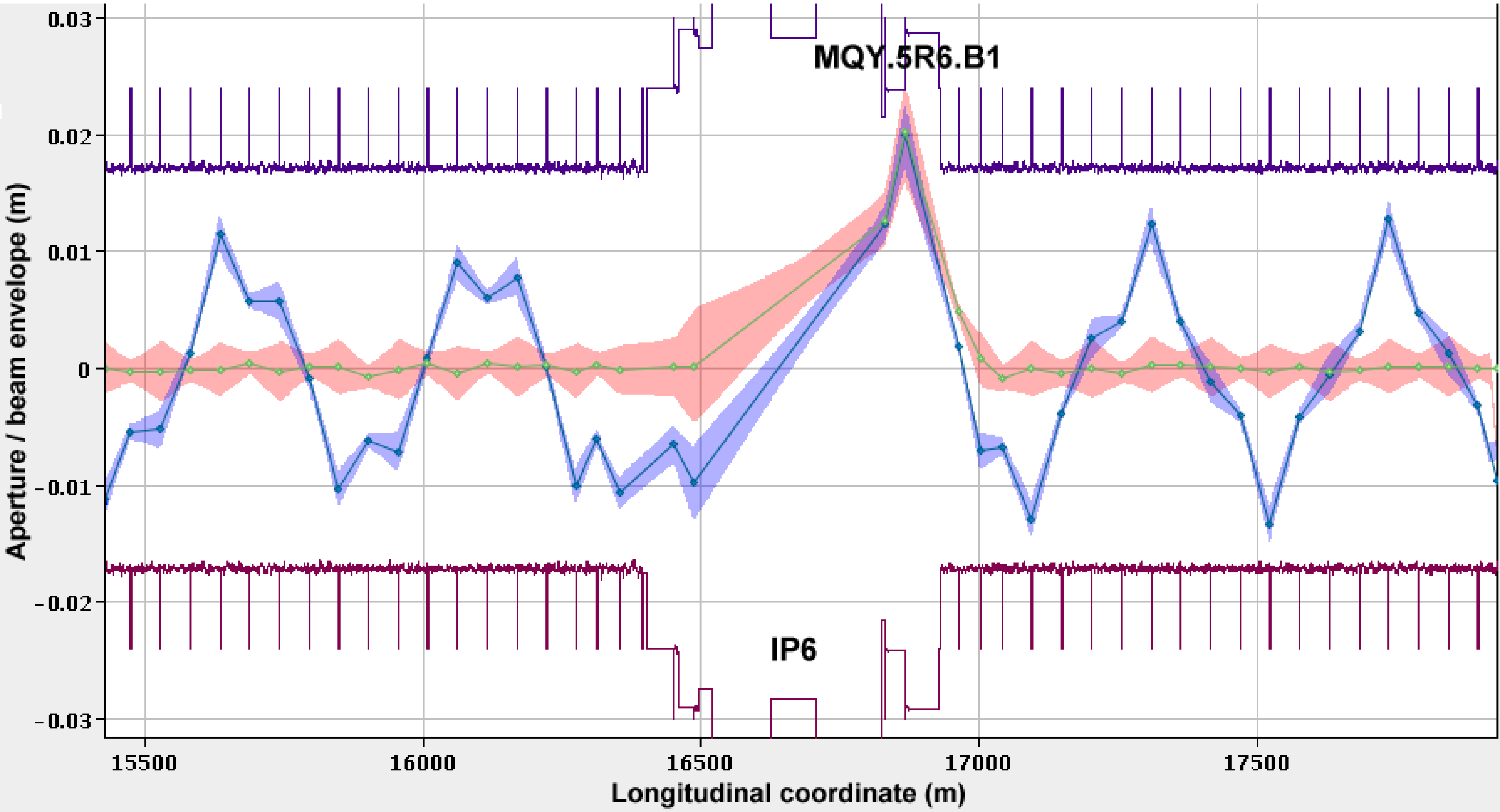


2010/12/06 21.35
LHC 2010 HI RUN (3.5 Z TeV/beam)
PRELIMINARY (±10% scale)
ATLAS
ALICE
CMS
Protons
again
50 & 75 ns
delivered integrated luminosity (μb-1)
0
2
4
6
8
10
310
315
320
325
330
335
340
day of year 2010

2010 – main aims

- Clear priority to lay the foundations for 2011 and the delivery of 1 fb^{-1}. Peak luminosity target $1x10^{32}$ $cm^{-2}s^{-1}$ ✔
- Gain solid operational experience of injecting, ramping, squeezing and establishing stable beams ✔-
- Steady running at or around 1 MJ for an extended period ✔
- Perform a safe, phased increase in intensity with validation and a running period at each step ✔

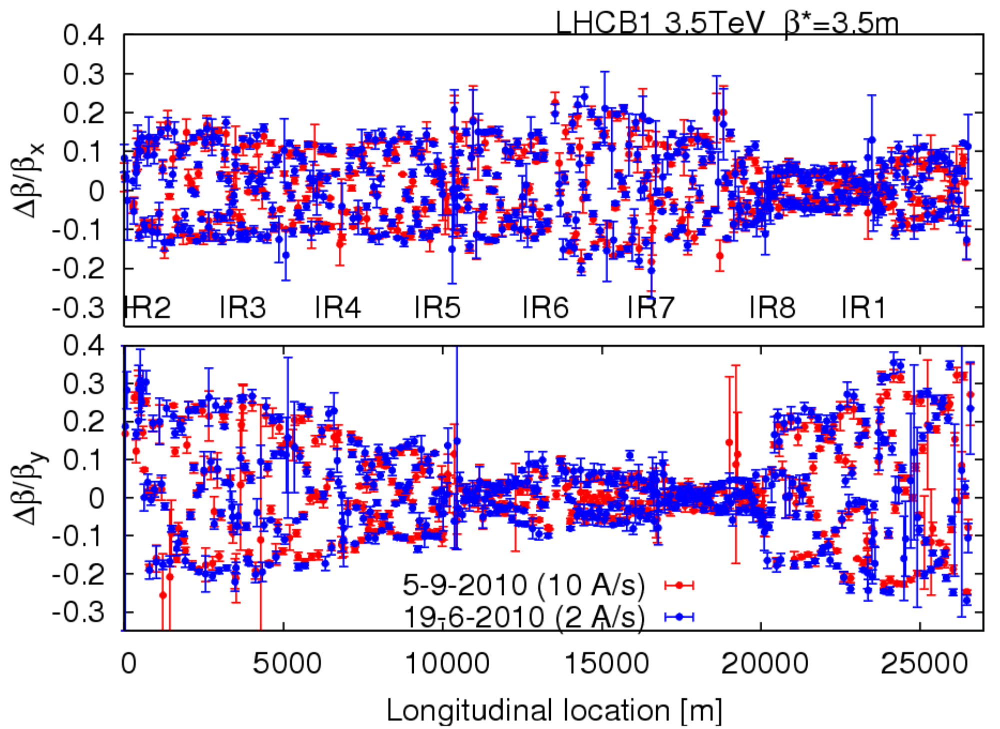
Aperture



MQY.5R6.B1
IP6
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
Aperture / beam envelope (m)
15500
16000
16500
17000
17500
Longitudinal coordinate (m)

Optics & magnetic machine

- Optics stunningly stable

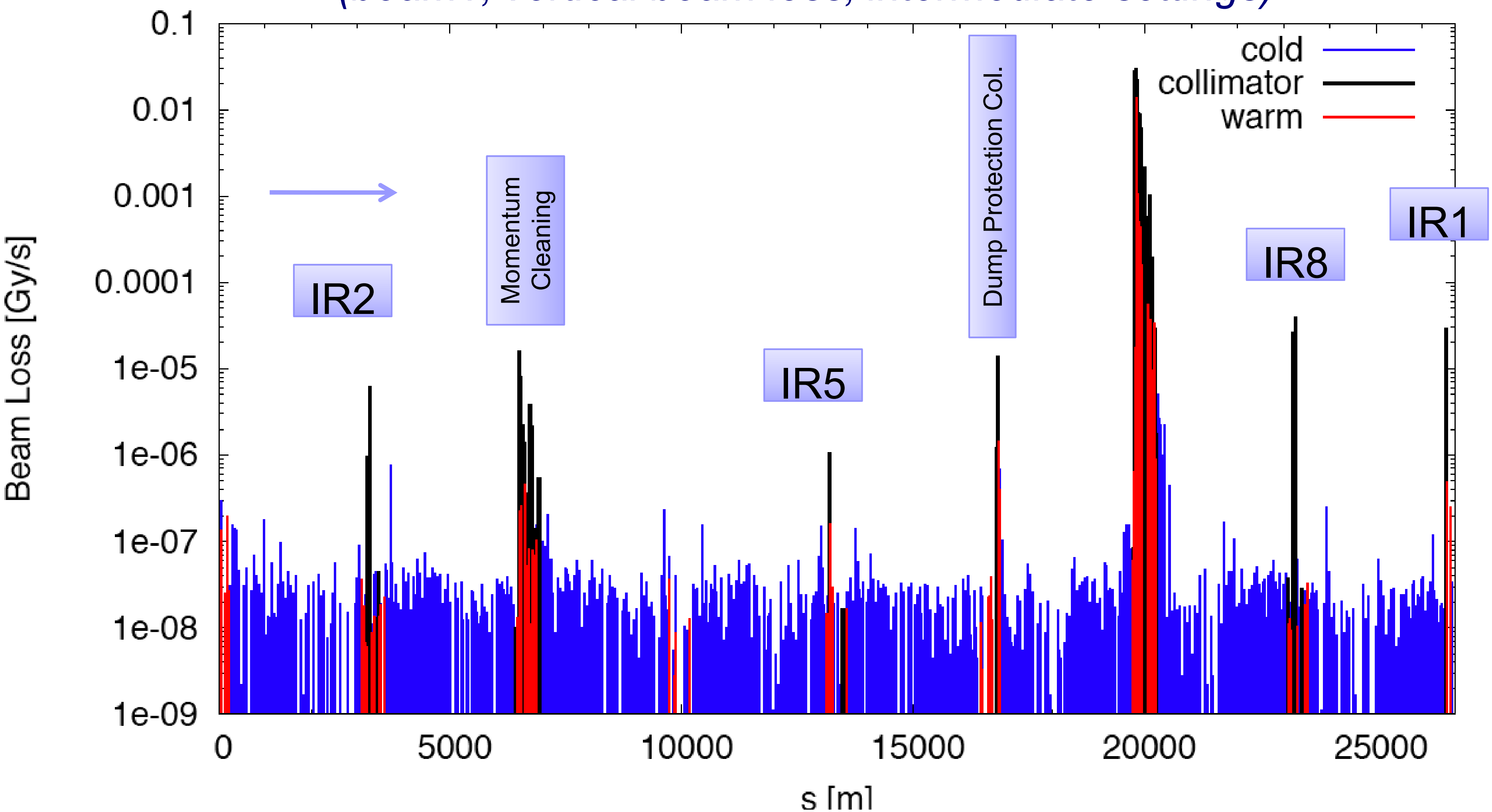


- Machine magnetically and optically well understood
  - Excellent agreement with model and machine
- Magnetically reproducible
  - Important because set-up remains valid from fill to fill

Measured Cleaning at 3.5 TeV

Making sure the hierarchy is respected

(beam1, vertical beam loss, intermediate settings)

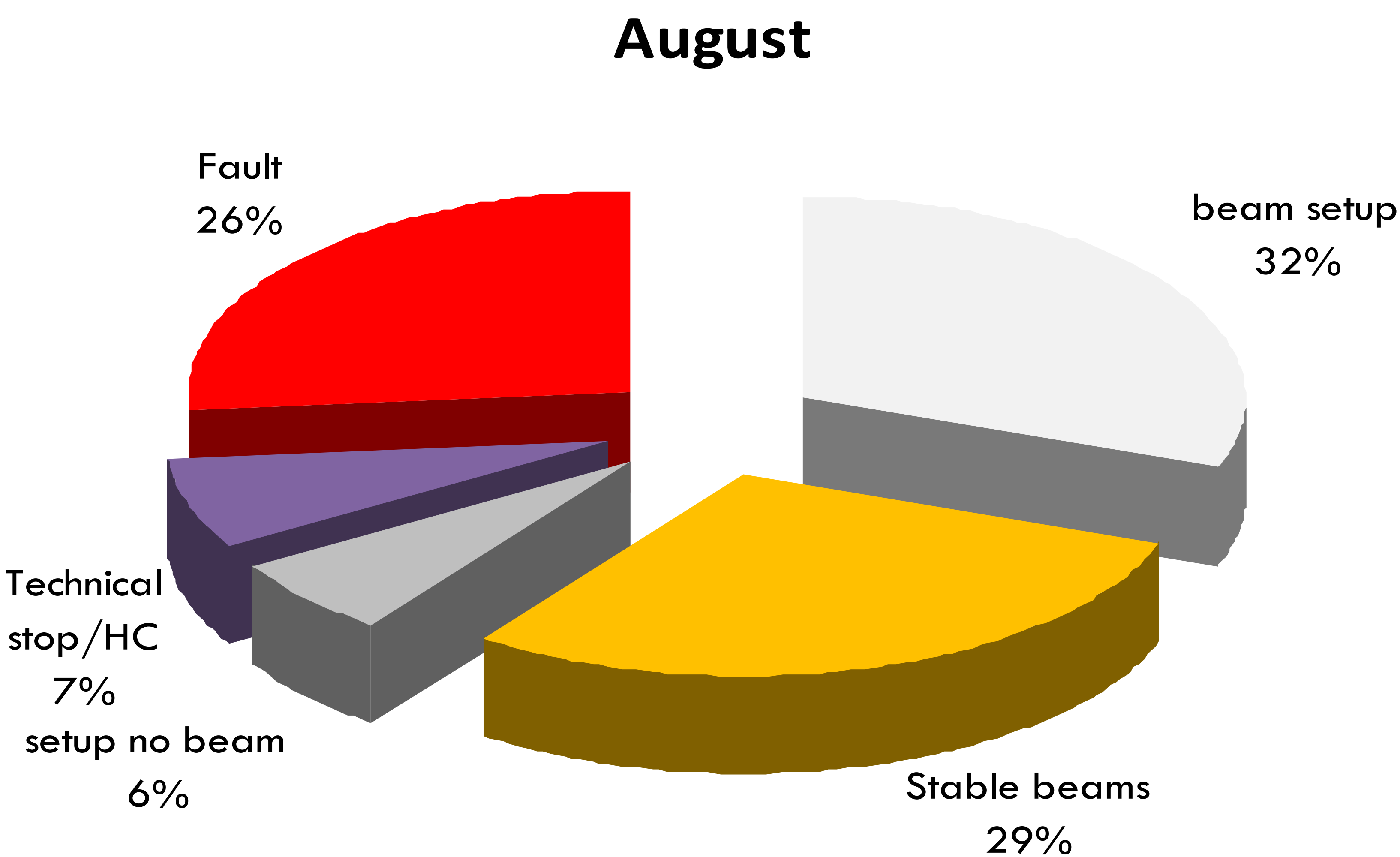


Summary

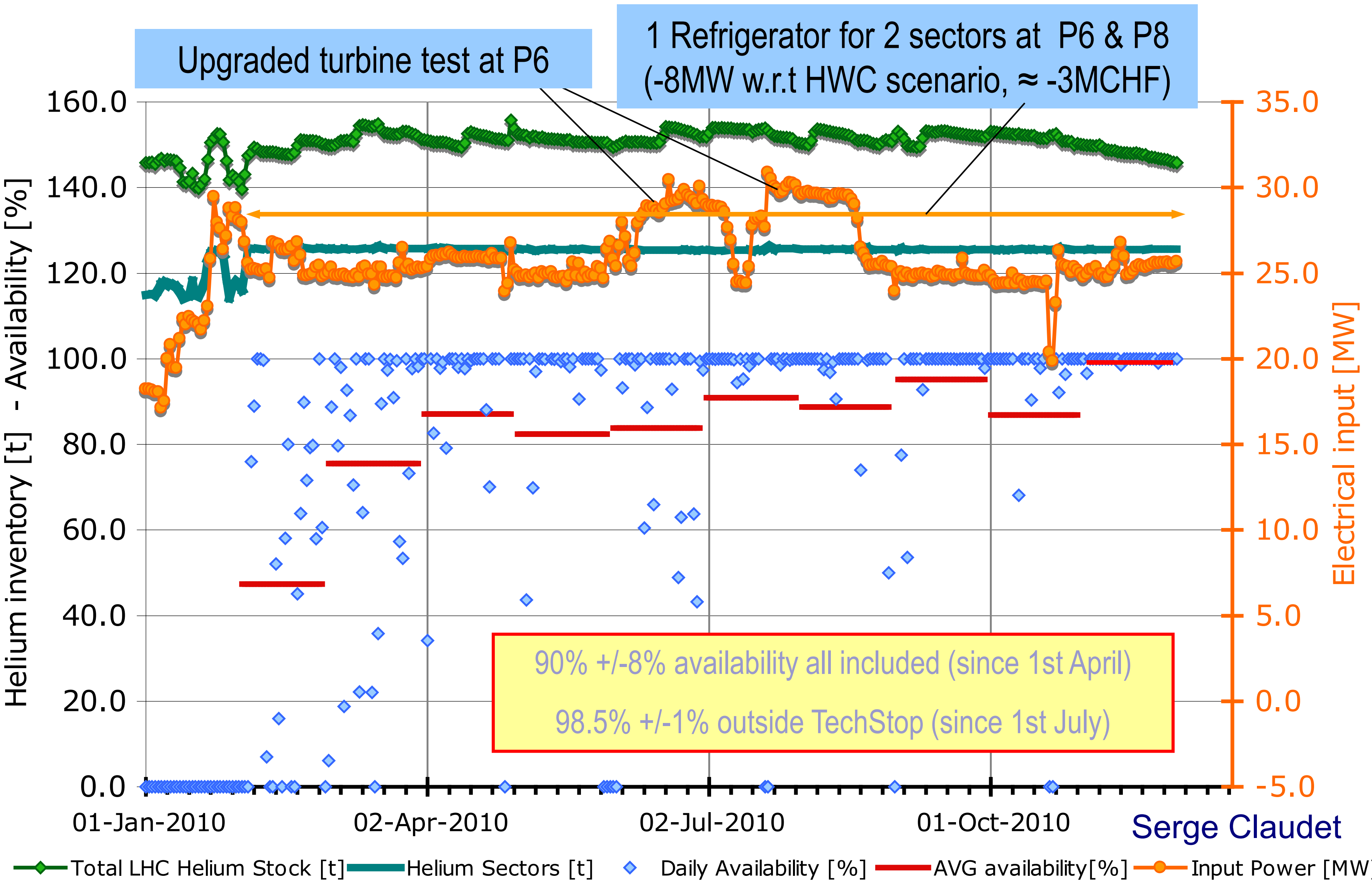
- Excellent single beam lifetime
- Ramp & squeeze essentially without loss
  - No quenches with beam above 450 GeV
  - Excellent performance of Machine Protection
- Optics close to model (and correctable)
- Excellent reproducibility
- Aperture as expected
- Better than nominal from injectors
  - Emittances, bunch intensity
- Beam-beam: can collide nominal bunch currents
  - With smaller that nominal emittances

And surprisingly good availability…

Probably the best typical month



Cryogenics - global performance monitoring

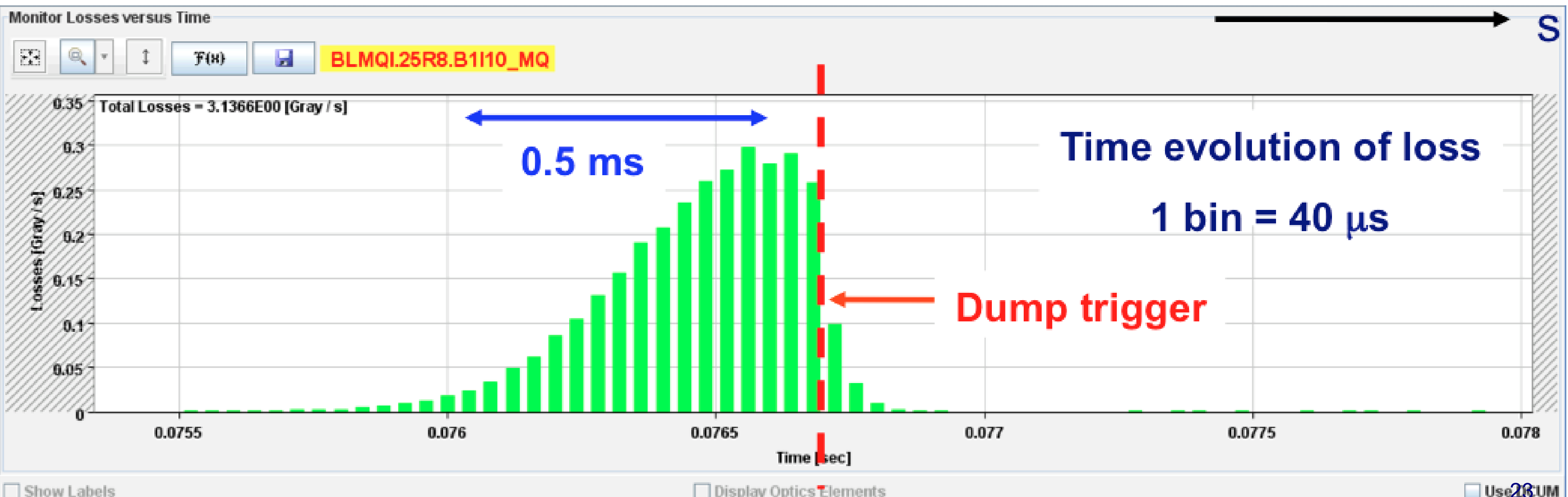


From design, implementation to operation: it works, the dream comes true !!!

PROBLEMS – TWO OF THEM

UFOs – unidentified falling objects

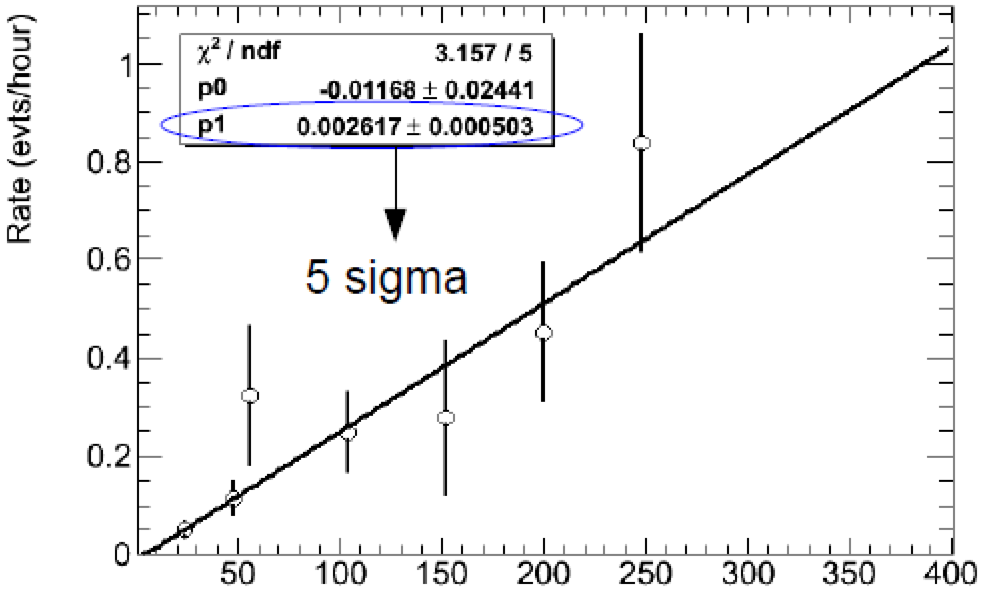
- Many sudden local losses have been recorded.
- No quench, but preventive dumps
- Rise time around of the order 1 ms.
- Potential explanation: dust particles falling into beam creating scatter losses and showers propagating downstream
- Distributed around the ring – arcs, inner triplets, IRs



UFO: intensity dependence

Beam loss monitor thresholds have been raised at the appropriate timescales

Logging data mined for events not above threshold



"UFO" Rate

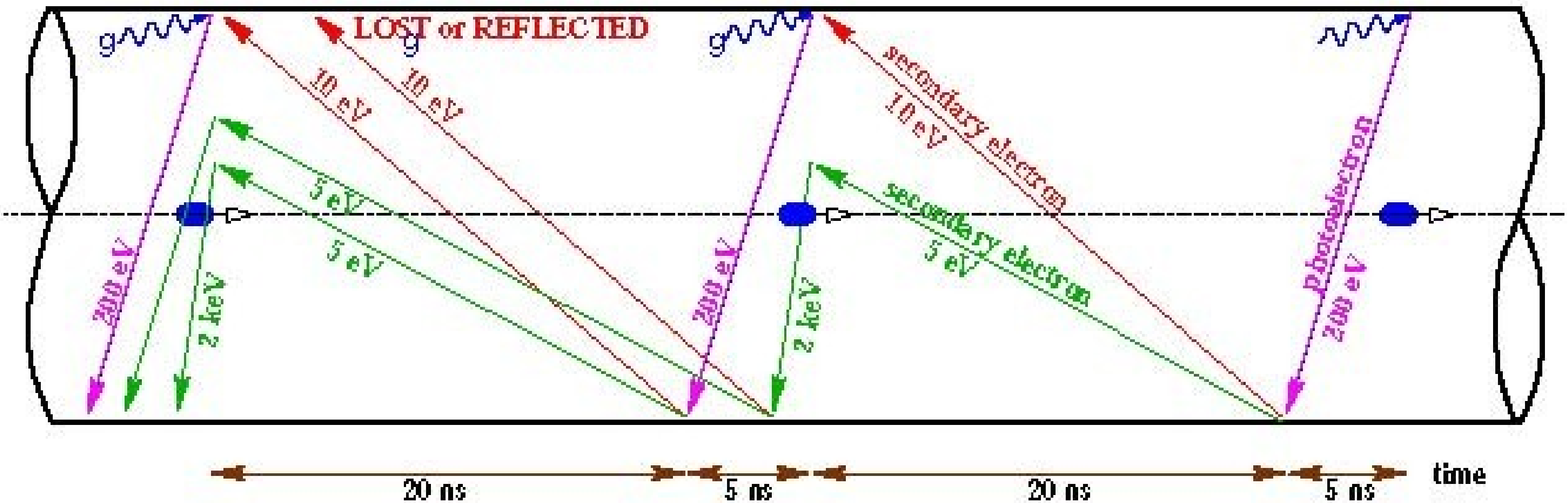
The UFO rate seems to increase linearly with intensity:

Extrapolating
2000 Bunches => ~ 5.2 evts/hour

E. Nebot for the BLM team

Electron cloud

Reflection



Secondary emission yield [SEY]

Schematic of electron cloud build up in LHC arc beam pipe due to photoemission and secondary emission [F. Ruggiero]

Electron cloud effects

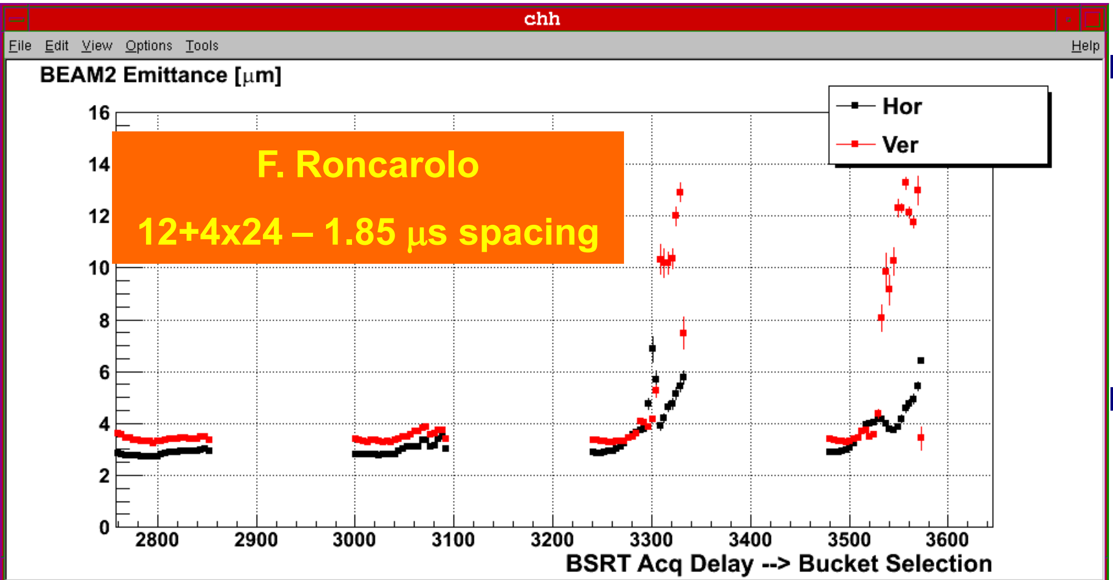
Electron cloud effects occur ***both in the warm and cold regions.***

- Vacuum pressure rise (background in experiments)
- Single-bunch instability
- Multi-bunch instability
- Interplay with impedance & beam-beam
- Incoherent emittance growth
- Heat load in cold arcs (quenches in the limit)
- Perturbation of beam diagnostics

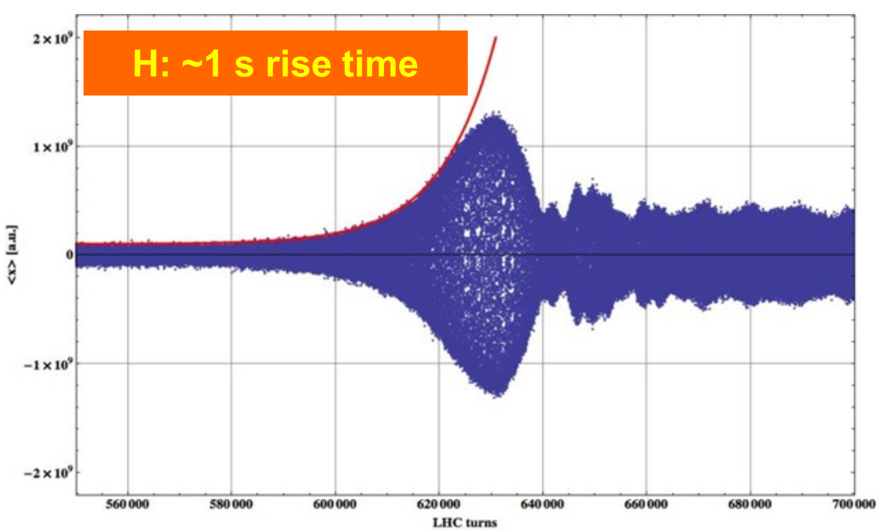
Experience in 2010

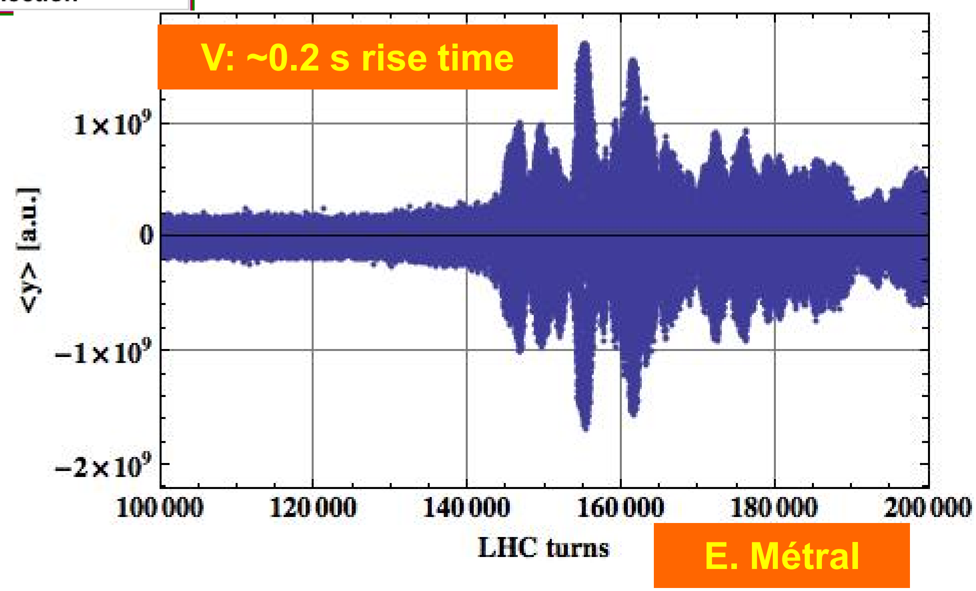
- Vacuum activity started off in regions with common beam pipe at 450 GeV as we pushed up the number of bunches with 150 ns spacing
  - Test solenoids cured problem – electron cloud
- Tried 50 ns bunch spacing
  - Things really kicked off
  - High vacuum activity in warm regions (single beam pipe)
  - Significant heat load in cold regions
  - Instabilities and beam size growth observed
  - Surface conditioning ('scrubbing') observed
    - Gas desorption rates and SEY drop
    - Time constant < 1 day
- Situation a lot cleaner with 75 ns
  - incoherent effects seen – emittance blow-up
  - 800+ bunches injected into both beams

Beam stability at 450 GeV/c (50 ns)



- Build-up of the electron cloud over more than one train leading to instabilities and emittance blow-up along the trains.
- Compatible with electron cloud instability



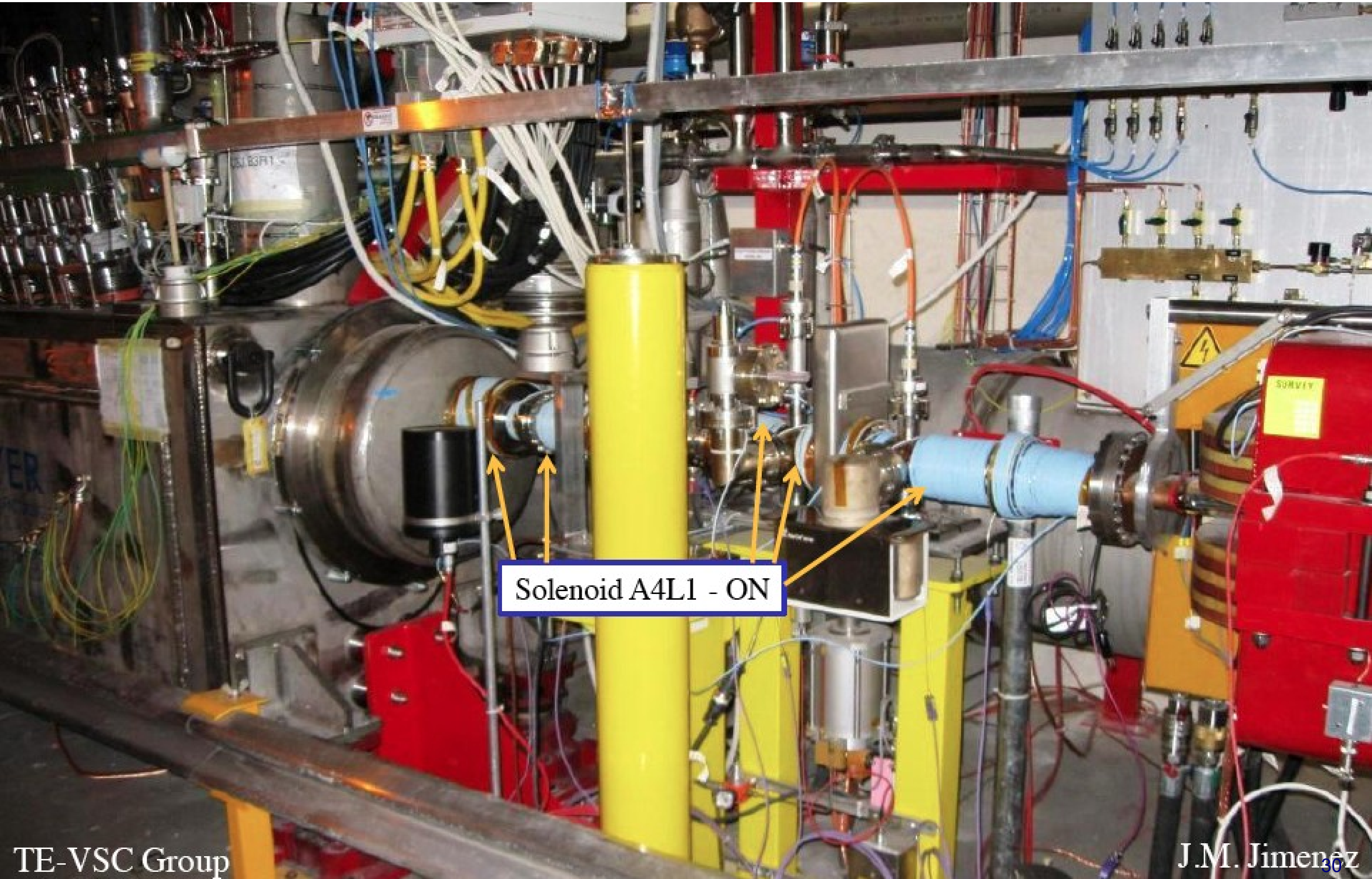


Strategy

- One week's scrubbing with 50 ns beam
  - Good for 75 ns with 1.3e11 bunch intensity
- Lots of wire is being wrapped around warm bits during the technical stop (solenoids)
- Push 75 ns to a maximum of 930 bunches
- Pushing 150 ns to a maximum of 450 bunches is a backup option
- Keep 50 ns for machine development

2010 observations are certainly due to ~ 2 < SEY < ~ 2.5, whereas 1.7 was usually the max value studied in the past

Solenoids between DFBX and D1 in IR1R



2011

Assumed beam parameters for Physics

Beam parameters	
Energy	3.5 TeV
β* : IP1 – 5 – 2 – 8	1.5 – 1.5 – 10 – 3 m for 2.5 μm
Separation (Injection)	± 2 mm
Separation (Physics)	± 0.7 mm (reduction during the ramp)
B1 ½ external crossing angles (Inj.)	± 170 μrad (all IPs)
B1 ½ external crossing angles (Phys.)	+120 μrad (IP1&5); ± 80 μrad (IP2); - 235 μrad (IP8)

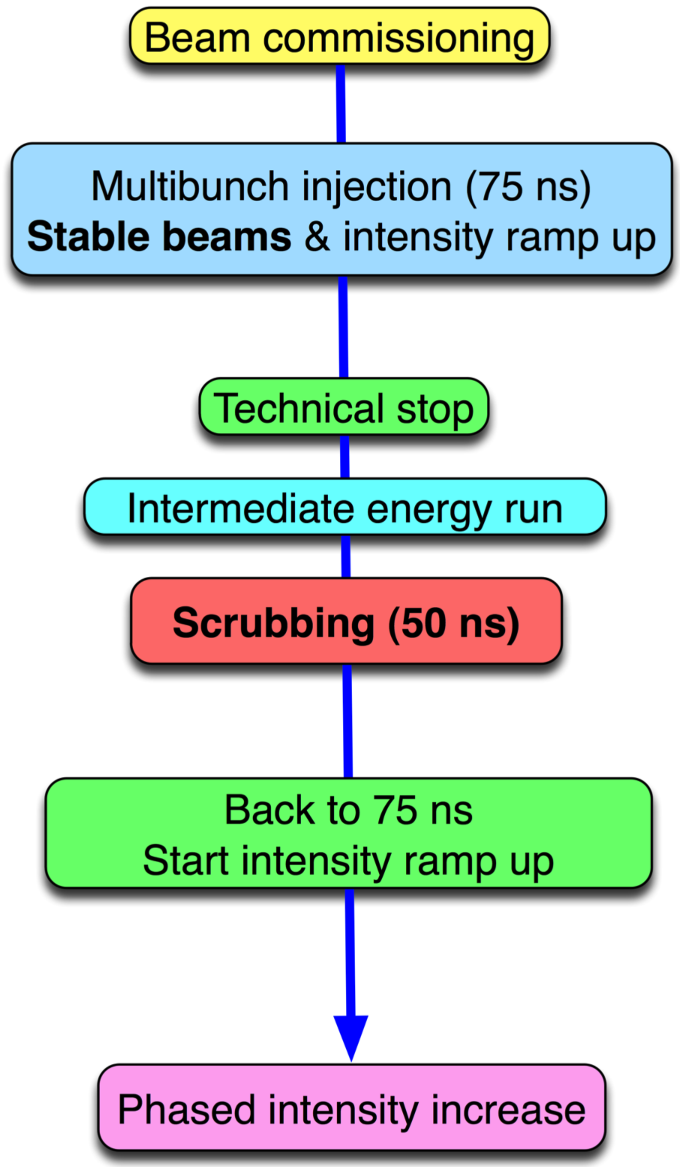
Beam parameters	150 ns	75 ns	50 ns
Bunch intensity [e11 p/b]	1.2	1.2	1.2
Normalised Emittance [μm]	2.5	2.5	2.5
Colliding bunches	368*	936	1404

Malika Meddahi

Days for Luminosity operation

PHASE	Days
Total proton operation	264
5 MDs (4 days)	- 20
6 TS (4+1 days)	- 30
Special physics runs	- 10
Commissioning	- 20 to -30
Intensity ramp up	- 30 to -40
Scrubbing run	- 10
Total High intensity	124 to 144 (135 days for integrated L)

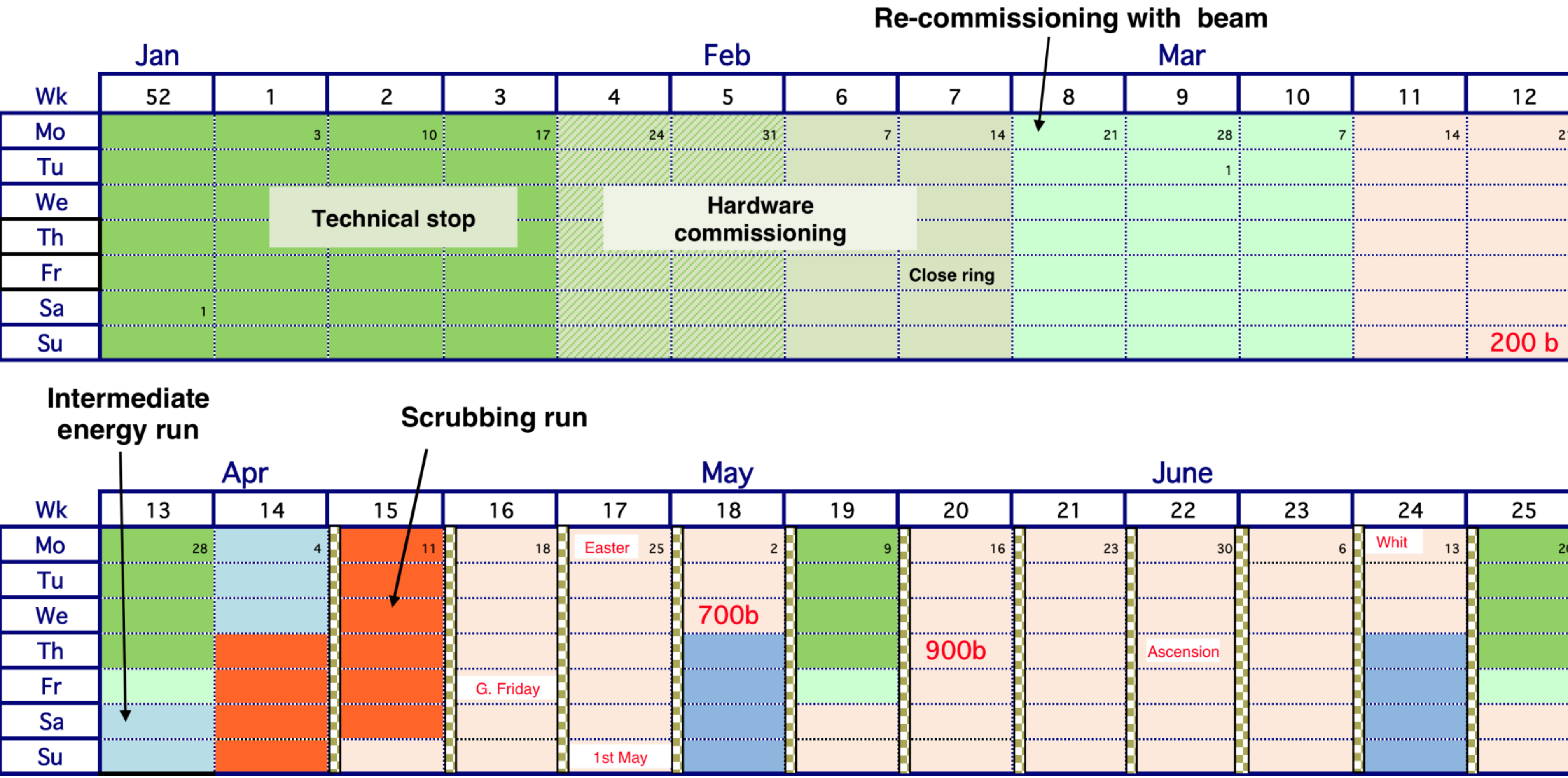
LHC 2011 - phase 1



Baseline scenario

- Beam commissioning – 3 - 4 weeks
  - Exit - stable beams with low number of bunches
- Ramp-up to ~200 bunches (75 (or 150 ns)) – 2 weeks
  - Multi-bunch injection commissioning continued
  - Stable beams
- Technical Stop – 5 days
- [Intermediate energy run – 5 days]
- Scrubbing run – 10 days including 50 ns injection comm.
- Resume 75 ns operation and increase no. bunches - 3 weeks
  - 300 – 400 – 600 – 800 – 930 - MP and OP qualification
- Physics operation 75 ns – 930 b

2011 LHC schedule Q1/Q2



Some dates to be confirmed

Estimated Peak and Integrated Luminosity

$\beta^* = 1.5$ m, 3.5 TeV

days	H.F	Comm with	Fills with	kb	Nb e11	ε μm	ξ/IP	L Hz/cm^2	Stored energy MJ	L Int fb^{-1}
160	0.3	150 ns	150 ns	368	1.2	2.5	0.006	~5.2e32	~30	~1.9
135	**0.2**	**75 ns**	**75 ns**	**936**	**1.2**	**2.5** **2** **1.8**	**0.006** **0.007** **0.008**	**~1.3e33** **~1.6e33** **~1.8e33**	**~75**	**~2.7** **~3.3** **~3.7**
125	0.15	50 ns	50 ns	1404	1.2	2.5	0.006	~2e33	~110	~2.8

Malika Meddahi

2012 - ultimate reach

1.6 x10^{11} ppb and emittance of 2 microns at 3.5 TeV respects the robustness limits of the collimation system (equivalent to ultimate intensity)

Ralph Assmann

- 4 TeV (?)
- 1400 bunches (50 ns)
- 2.5 micron emittance
- 1.5 x 10^{11} protons/bunch
- beta* = 2.0 m, nominal crossing angle
- Hubner factor 0.2

Peak luminosity	2.2 x 10^{33}
150 days	~5 fb^{-1}
Stored energy	~130 MJ

Usual warnings particularly apply – see problems, problems above

Conclusions 1/2

- Injection, ramp and squeeze fully operational
- LHC magnetic model, optics excellent
- Beam instrumentation in good shape.
- Beam cleaning and collimation works reliably with predicted efficiency.
- Machine protection reliably catches failures etc.
- Machine aperture looks good
- Performance with beam (losses, lifetimes, luminosity, emittance growth etc.) is very encouraging

Conclusions 2/2

- Machine availability is excellent – the hard work of numerous teams
- There are problems
  - UFOs somewhat worrying
  - Electron cloud well understood – measures prepared
- 2011 – another long year ahead…
  - 75 ns. bunch spacing – up to 930 bunches
  - Nominal intensities, beta* 1.5 m
  - should be good for 5 to 10 x 10^{32} $cm^{-2}s^{-1}$
  - and 1 to 3 fb^{-1}
- Will run in 2012
  - Attempt to measure splice resistance in 2011/2012 might open the way to 4 TeV or higher