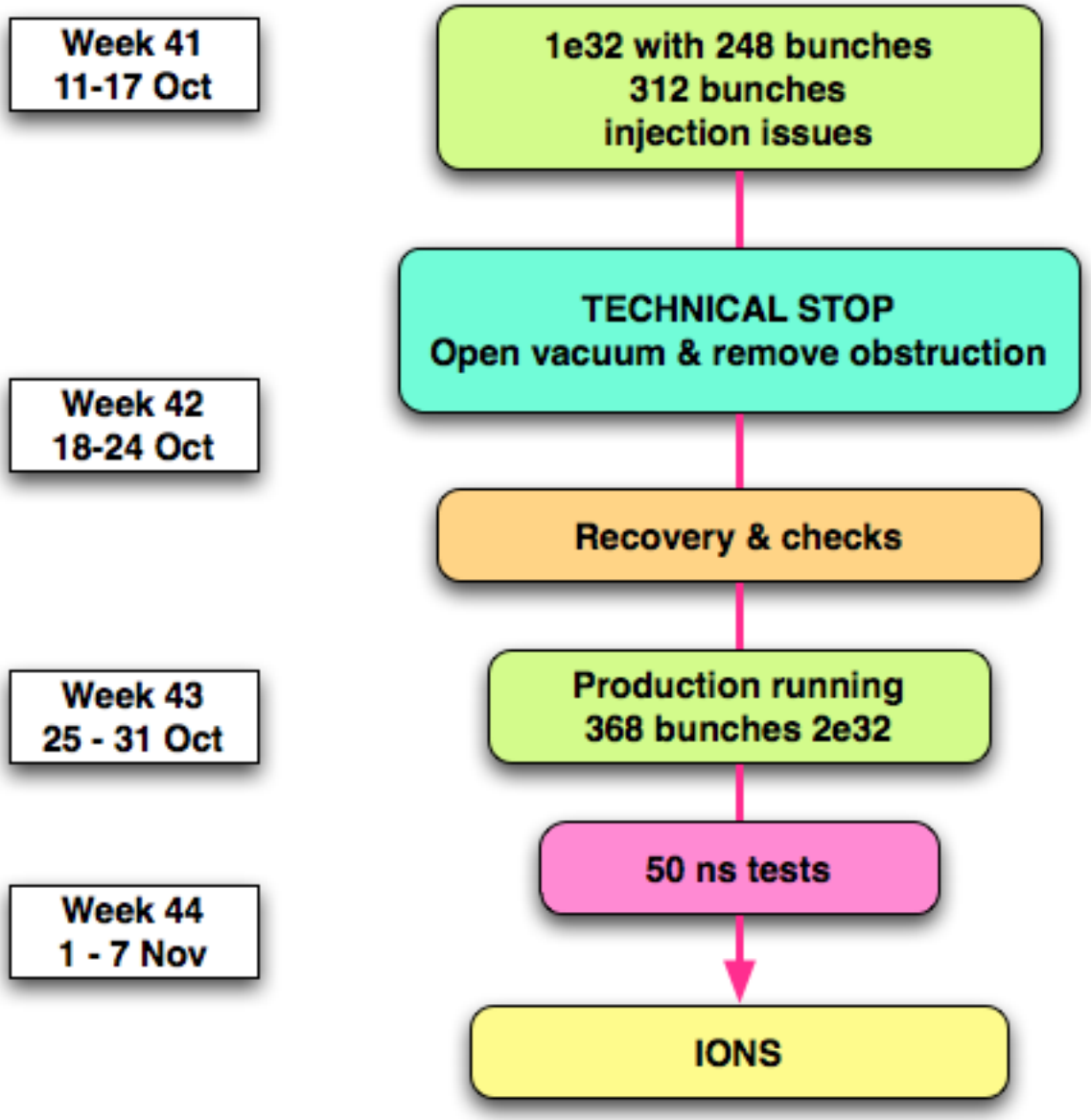
Status of LHC

Mike Lamont

on behalf of a tired and emotional LHC team

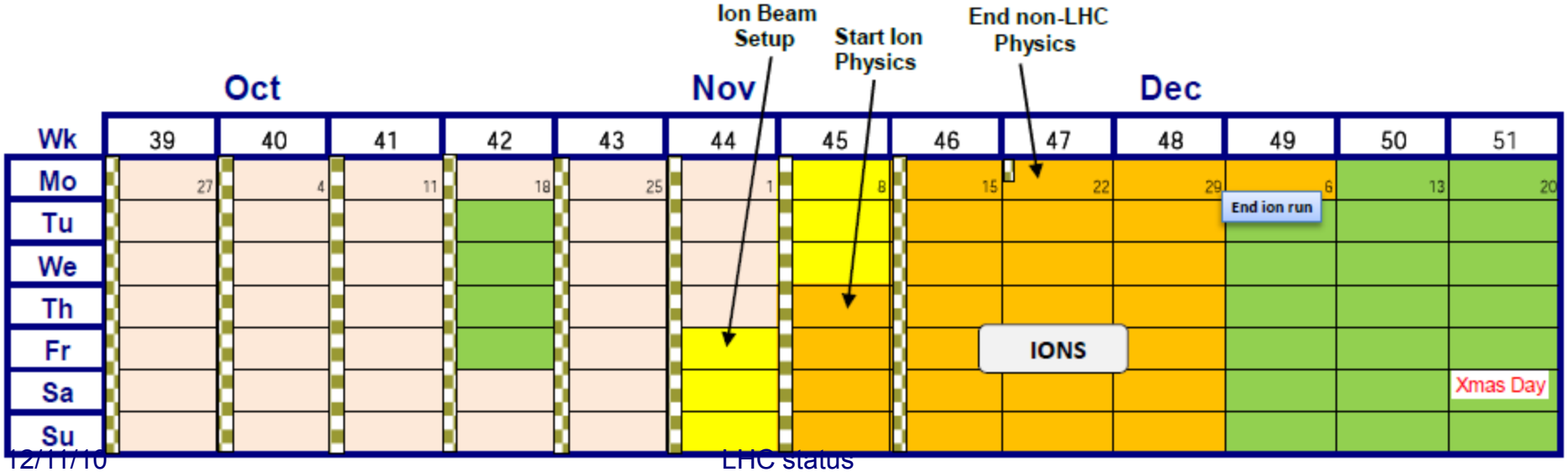
Periodic report on the status of LHC commissioning and operations.
This report will review the final achievements of the pp run, the prospects for 2011, and will provide the first assessment of the current heavy ion run

Last month or so



A month ago

- Clipped 10^{32} $cm^{-2}s^{-1}$ with 248 bunches
- Moved to 312 bunches
  - 1.3 & 1.4 10^{32} $cm^{-2}s^{-1}$ fills lost to UFOs
  - Less ambitious fill in for 9.5 hours giving 2.3 pb^{-1}
- Ongoing injection problems
  - investigations reveal obstruction in injection septa point 2
- Technical stop moved to week 42



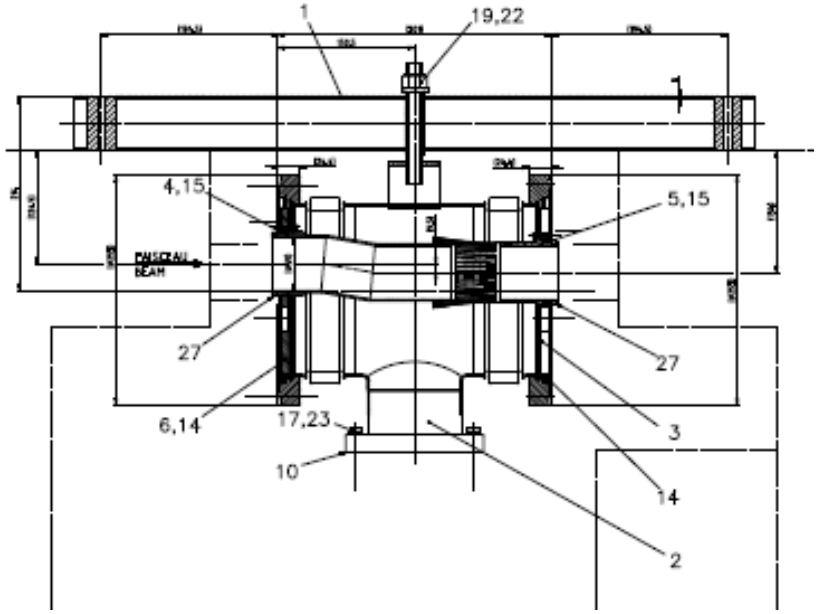
Physics before the technical stop

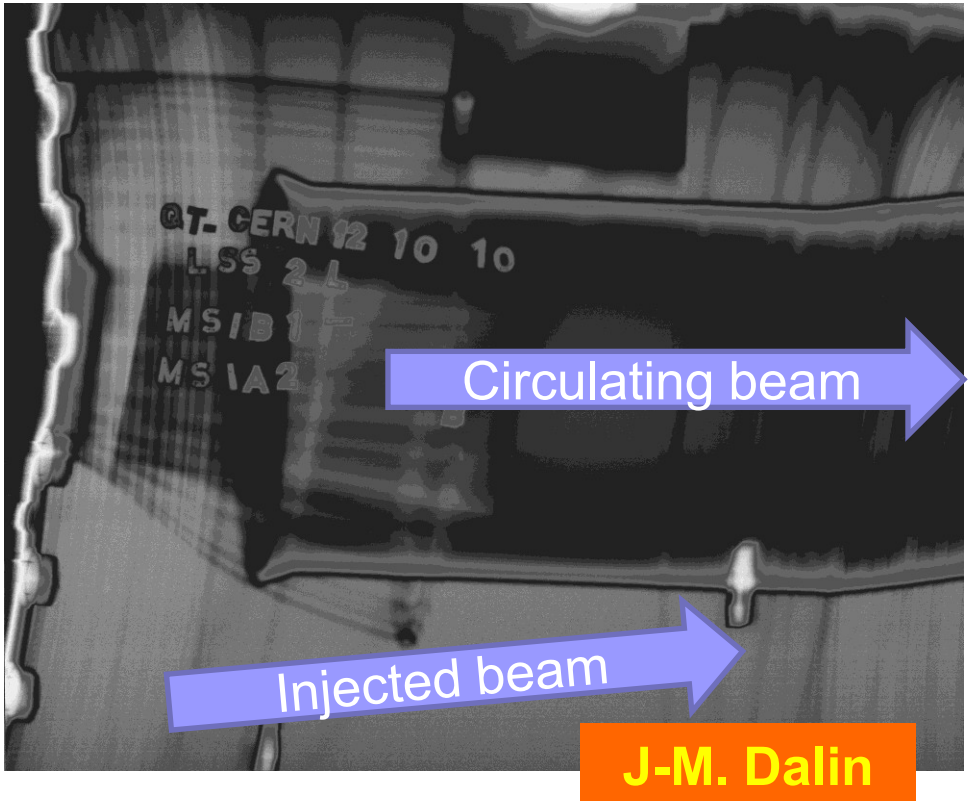
Fill	Date	# bunch	p/ bunch [10^{11}]	L_{peak} [10^{32} $cm^{-2}s^{-1}$]	Stable beams [h]	L_{int} [pb^{-1}]	Reason for dump
1418	14/10	248	1.04	**1.03**	8.5	>2.4	PC IT.R1
1422	15/10	16	0.78	**0.018**	5.5	0.03	LBDS
1424	16/10	312	1.13	**1.35**	1	0.4	**UFO** LHCb BCM
1427	16/10	312	0.89	**0.86**	9.5	2.3	OP REQUEST
1430	18/10	312	1.15	**1.48**	0.6	0.3	**UFO** Pt.4

- Typical emittances in collision 2.5 μm
  - and attempting to go lower
- Nominal bunch intensities

MSI interconnection repair

- Radiation survey and X-ray showed a clear aperture restriction at the transition between the injection septa MSIB/MSIA due to a non-conformity in the mounting of the interconnection





Conditions for injection degraded too much → decision to anticipate the week 44 TS to week 42. Injection fine after intervention.

Production running after TS

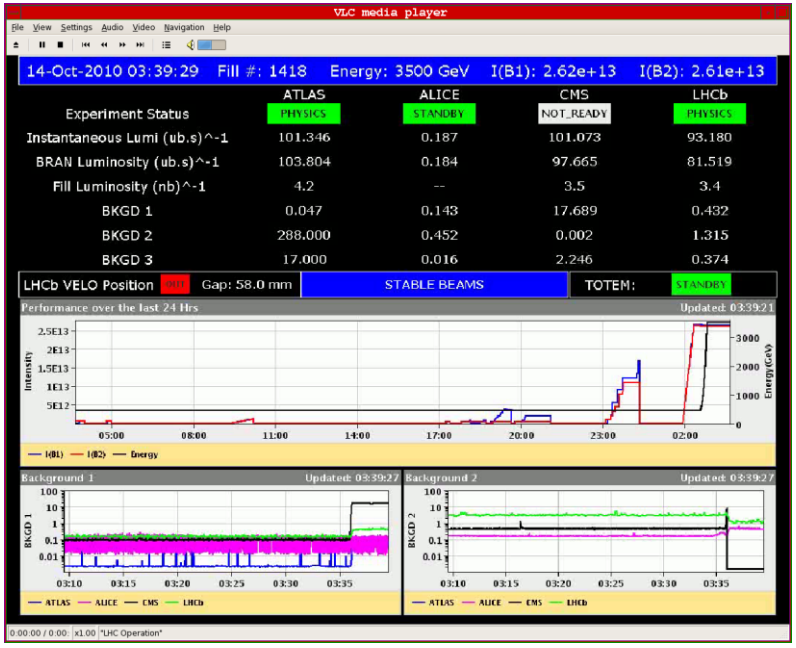
Date	#	Nb	Fill length	pb-1	Peak lumi	Lost to
Sun 24	1439	312	10h42	4.2	1.51e32	OP request
Mon 25	1440	368	11h20	6.0	2e32	EOF studies
Tue 26	1443	368	2h17	.15	2e32	UFO Q8.L5
Tue 26	1444	368	7h12	4.0	1.95e32	OP request
Thu 28	1450	368	14h32	6.3	1.8e32	OP request
Fri 29	1453	368	6h20	2.6	1.6e32	OP request
Sun 31	1459	108 (50 ns)	6h01	0.45	2.6e31	OP request
Total				**23.7**		

plus one attempt with **424 bunches**: beam dump just after arriving to 3.5 TeV. TCTH.4R8.B2 BLM in IR8 triggered on 0.6s running sum - strange loss patterns.

11:00 Friday 29th October
End proton production running for 2010

Fill 1418

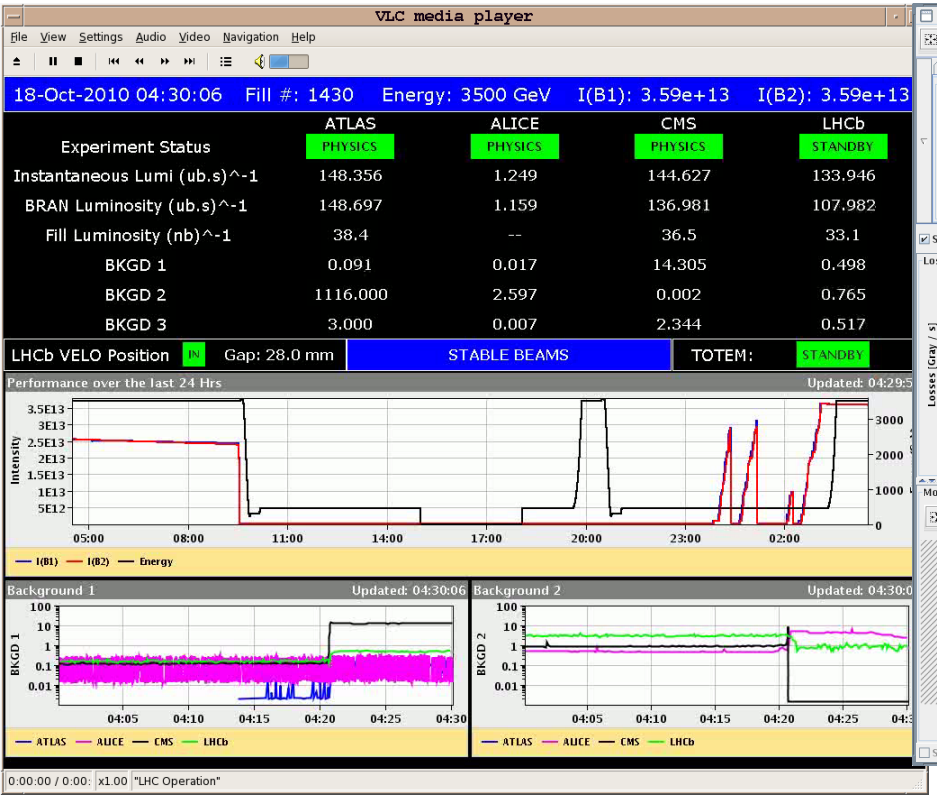
Peak luminosity	~1.03e32
Beam current	2.62/2.61 e13
Average bunch current	1.04e11
Emittance (reconstructed from lumi)	2.4 micron
Approx beam-beam tune shift	0.016
Stored beam energy	14.9 MJ

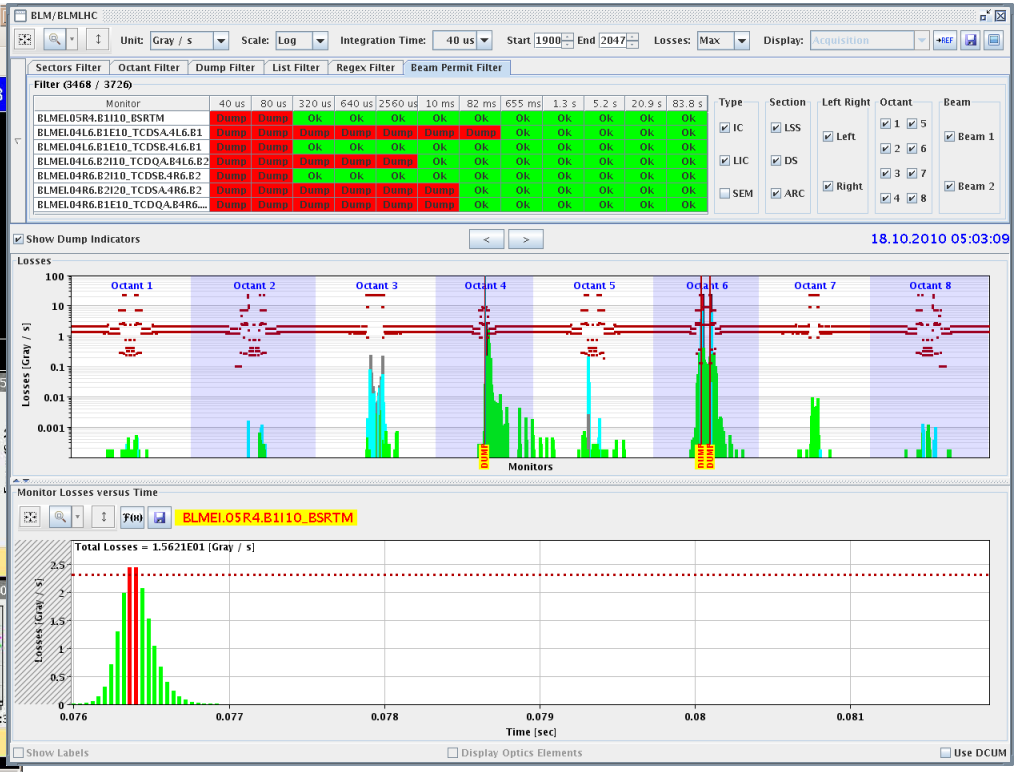


c/o Giulia Papotti, Anthony Rey in the middle of the night…

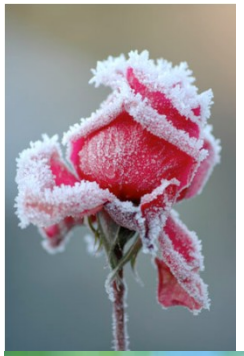
Fill 1430

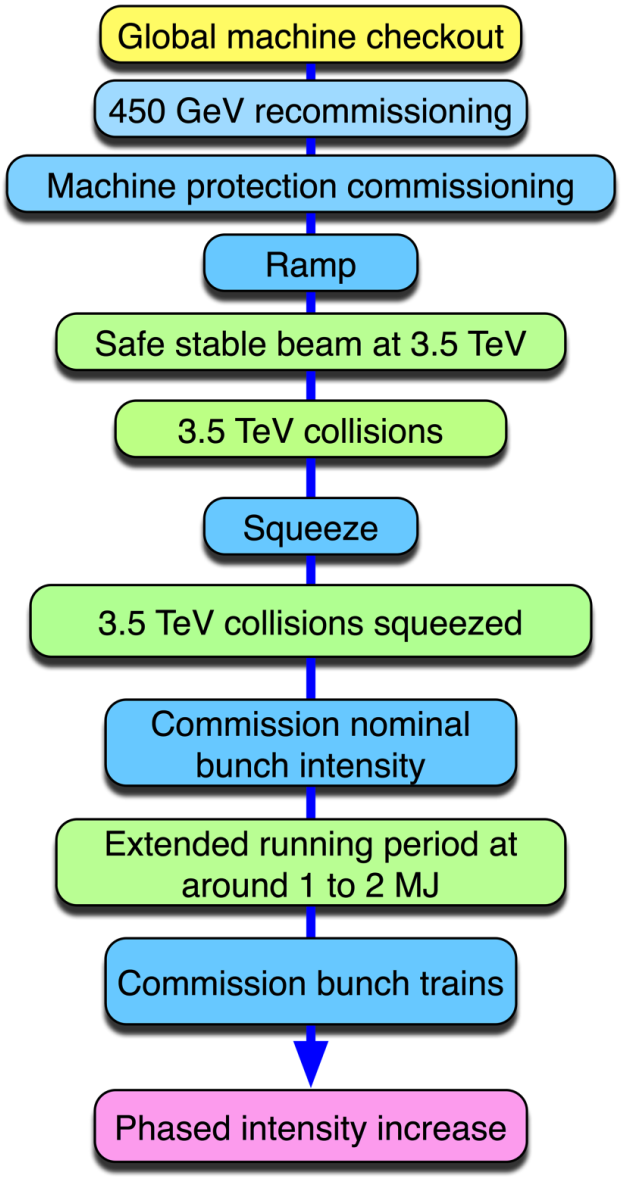
- 3.6×10^{13} p/beam in collision (~20 MJ/beam)
- $L_0 > 1.3 \times 10^{32}$ cm^{-2} s^{-1} ➔ Emittance in collision 2.4 um
- Damped by UFO event after 0.5 hour (~250 nb^{-1}). UFO event on beam 1 close to BSRT in point 4 (just above threshold)



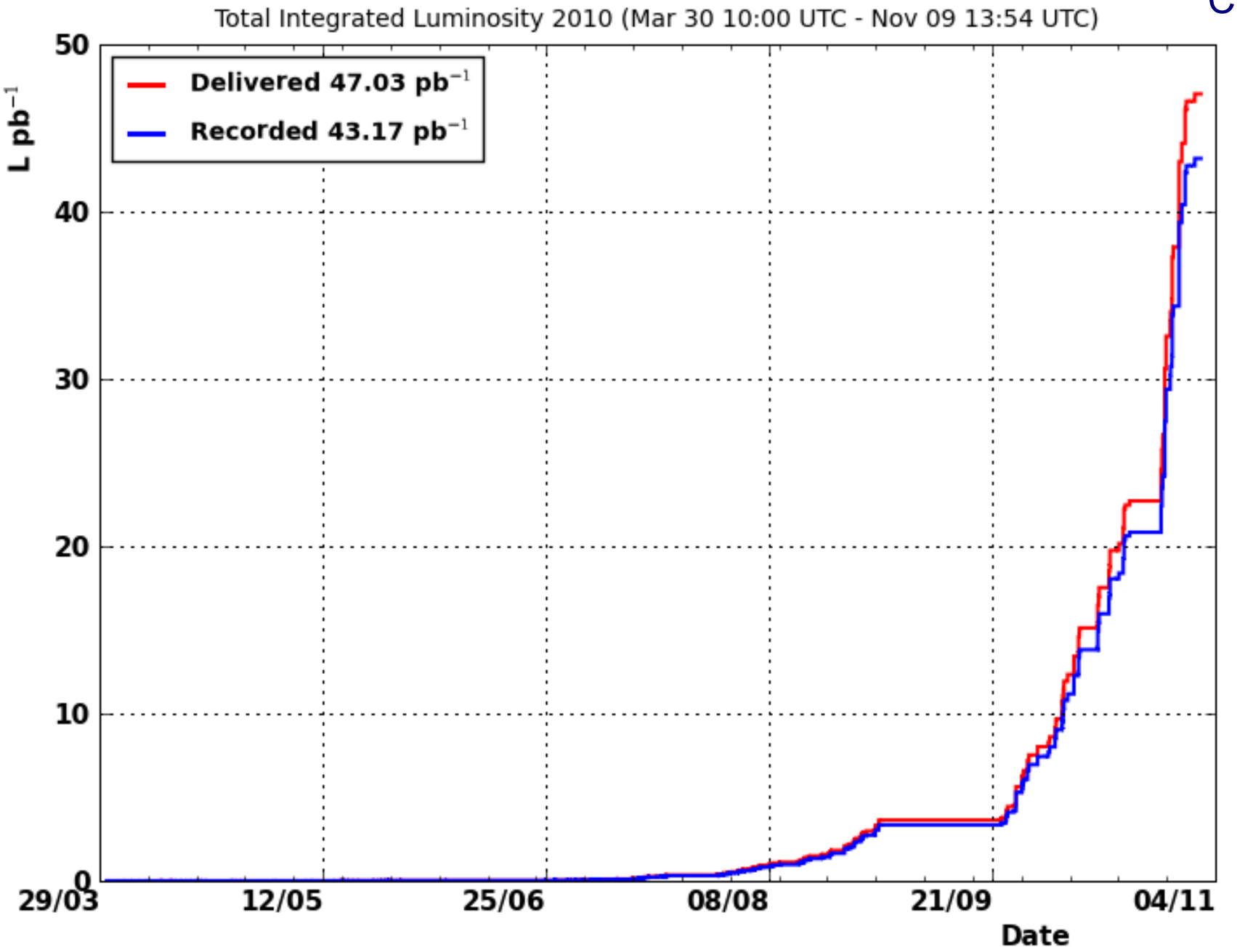


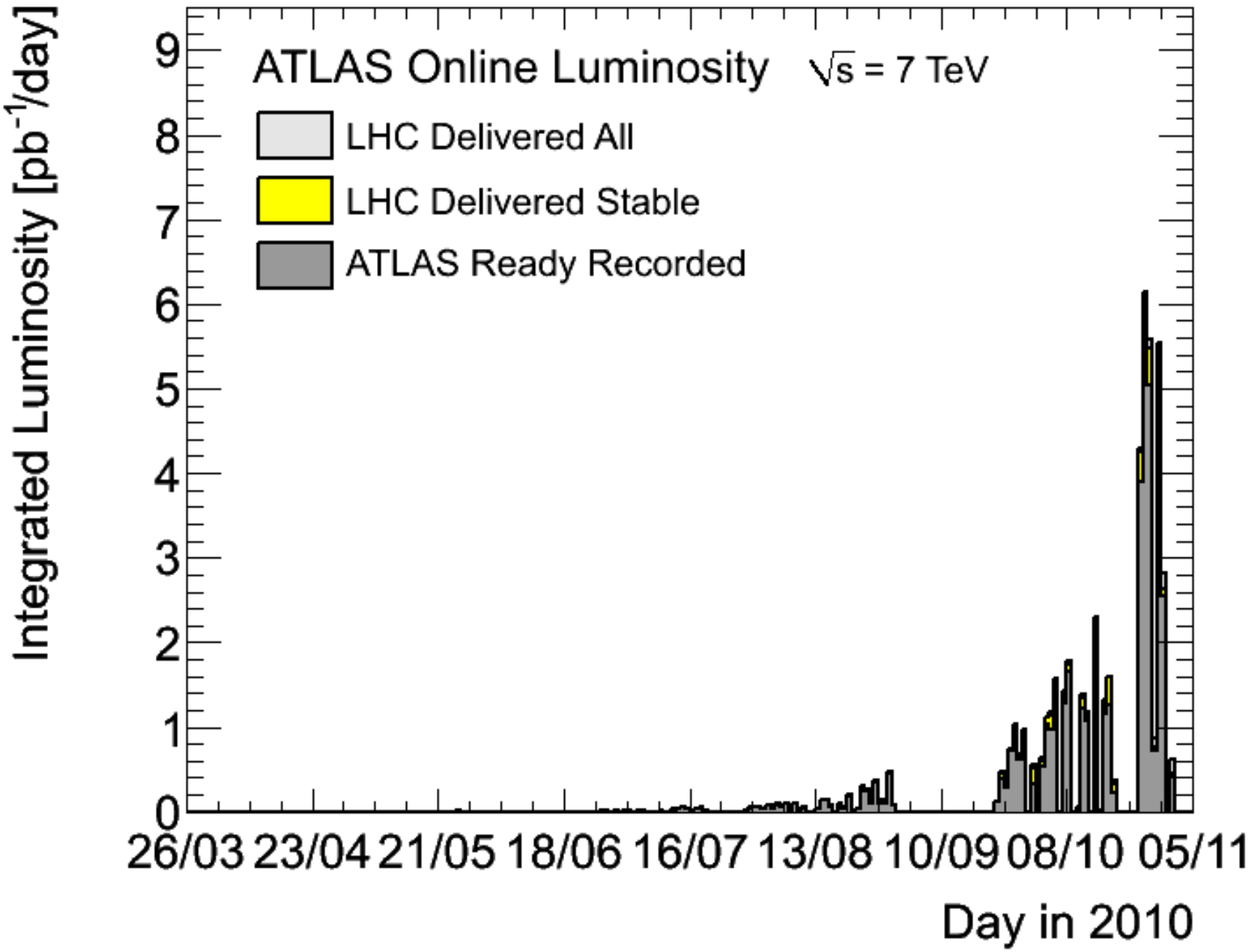
It's been a long year…



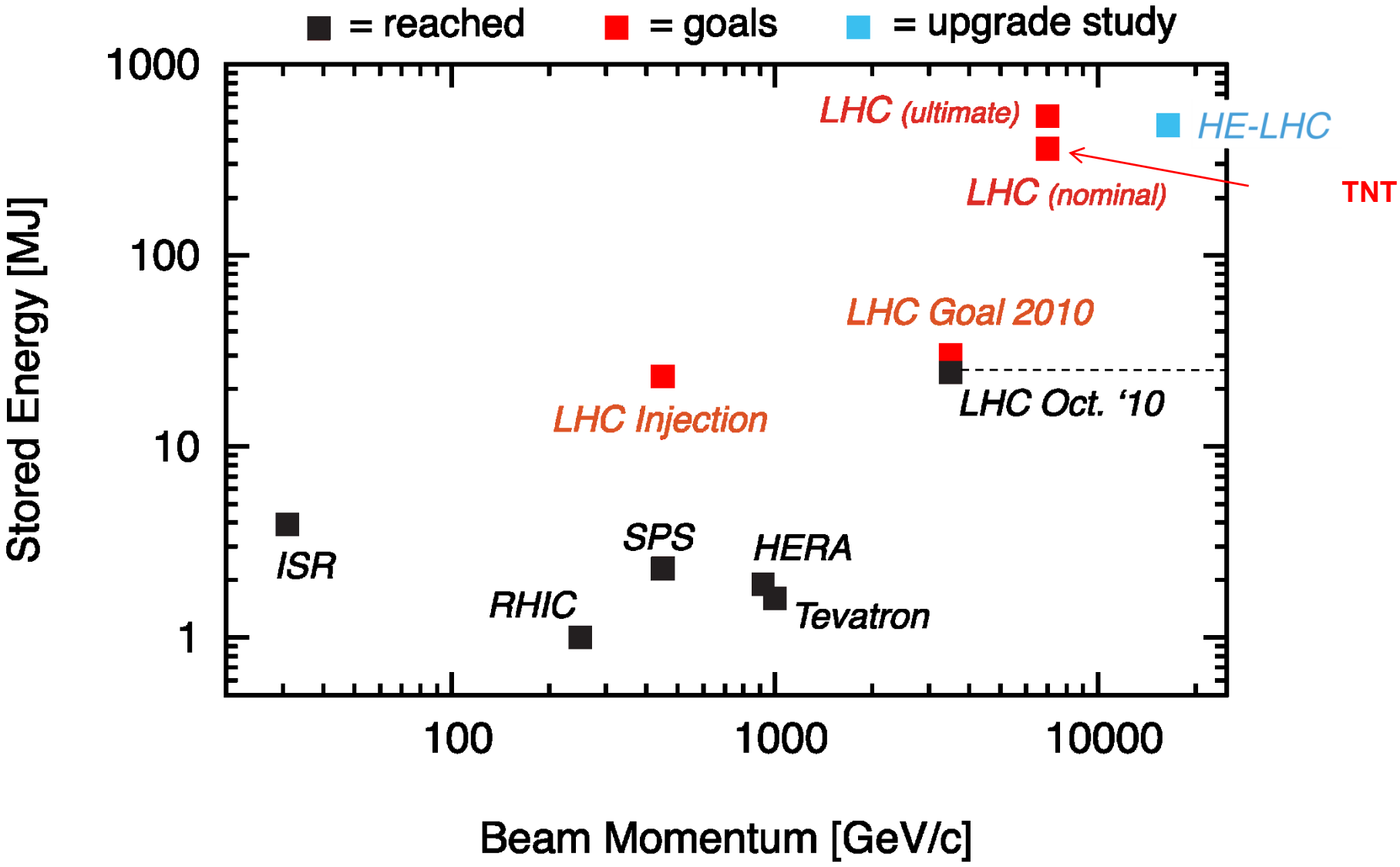


CMS


Total Integrated Luminosity 2010 (Mar 30 10:00 UTC - Nov 09 13:54 UTC)
Delivered 47.03 pb^{-1}
Recorded 43.17 pb^{-1}
L pb^{-1}
50
40
30
20
10
0
29/03
12/05
25/06
08/08
21/09
04/11
Date


ATLAS Online Luminosity
√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

Status LHC Stored Energy



2010 – main aims

- Clear priority to lay the foundations for 2011 and the delivery of 1 fb^{-1}
- Have performed a safe, phased increase in intensity with validation and a running period at each step
- Gained solid operational experience of [not faultlessly] injecting, ramping, squeezing and establishing stable beams
- Aimed for steady running at or around 1 MJ over the summer – around 3 weeks in the end
- Followed by commissioning of bunch trains and a comparatively fast ramp up in beam intensity

Surprises

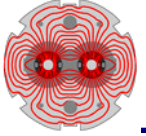
- We were never meant to run at 3.5 TeV
  - 7 TeV studied in exquisite detail
  - 3.5 TeV - bigger beams, less aperture, less attention
  - Beta* = 3.5 m
- Very good single beam lifetime
  - Vacuum – very good up to now
    - electron cloud incoming (see below)
  - Non-linearities: excellent field quality, excellent magnet model
- Can inject, ramp and squeeze with minimal beam loss
- Transverse emittance (read beam size)
  - Too small emittance from injectors
  - Ditto longitudinal plane
- Nominal+ bunch currents from injectors

Surprises

- Beam-beam
  - A lot easier than expected
  - Can collide nominal bunch intensity collisions without problems
  - Even with much lower than nominal beam sizes
  - Resolving expected problems with predicted cures (octupoles, transverse feedback)

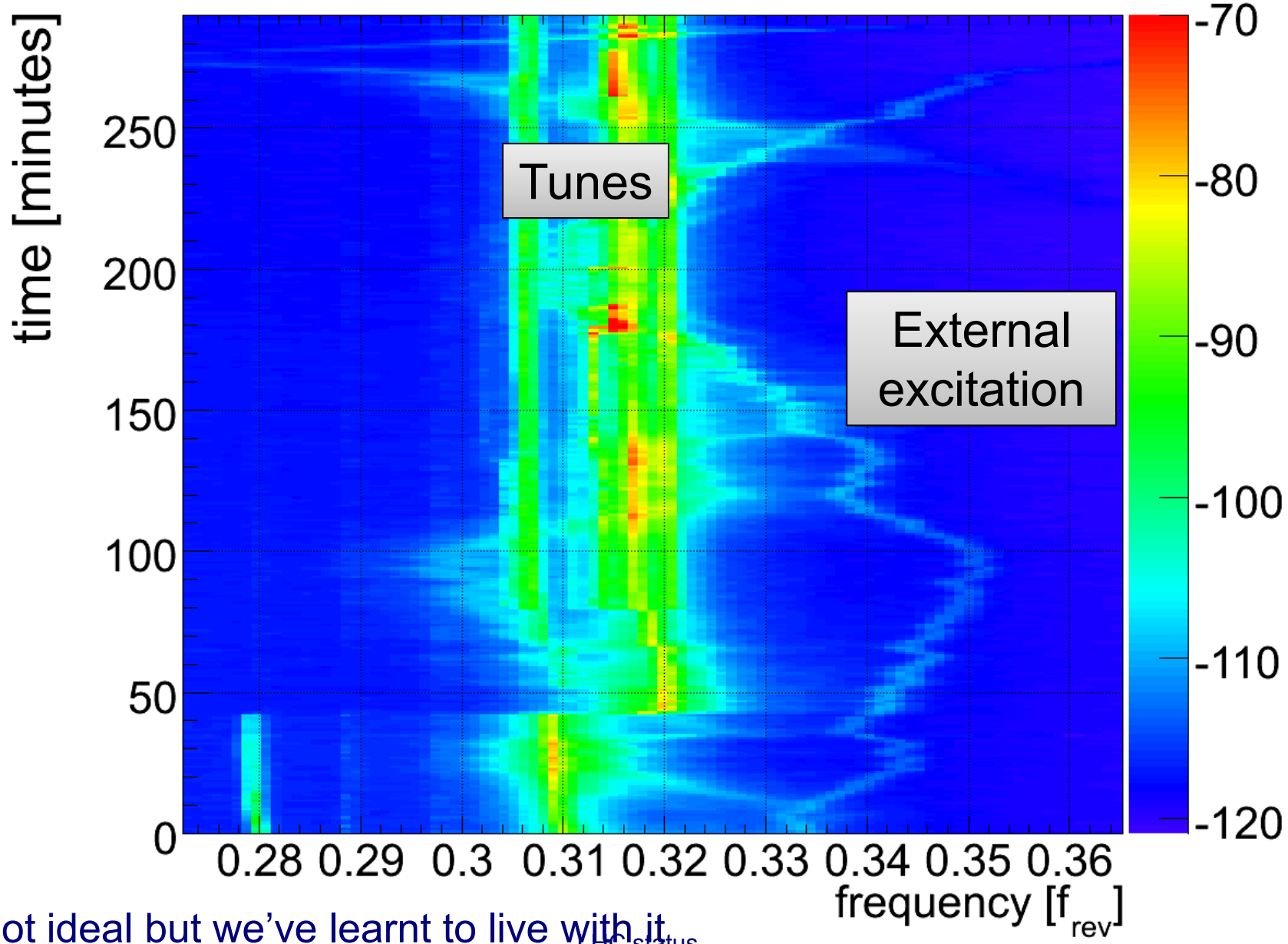
  - Still surprising…

However…



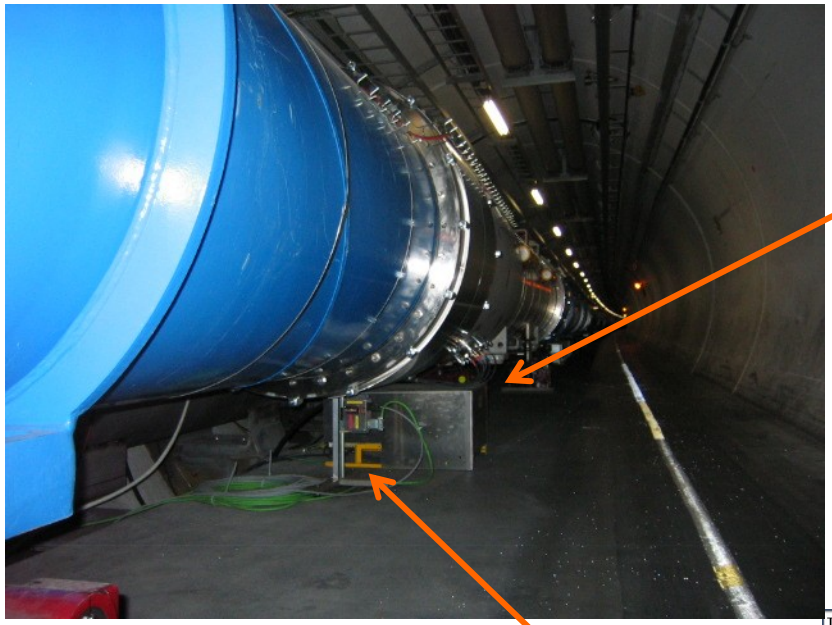
PROBLEMS, PROBLEMS

The hump - source still unknown



Not ideal but we've learnt to live with it

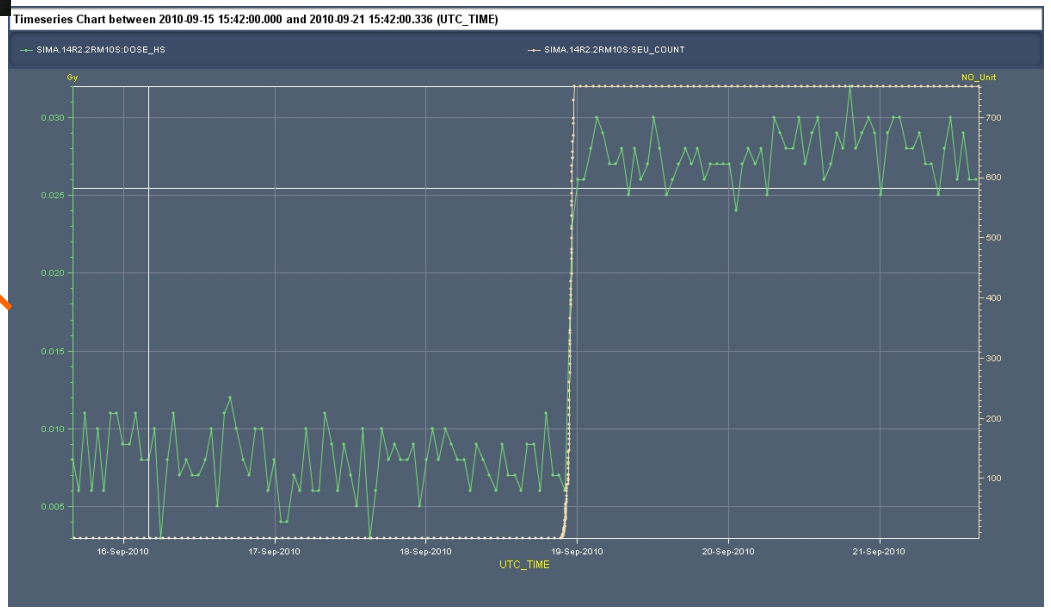
SEUs



QPS crate

SEU count (RADMON) during off momentum loss map

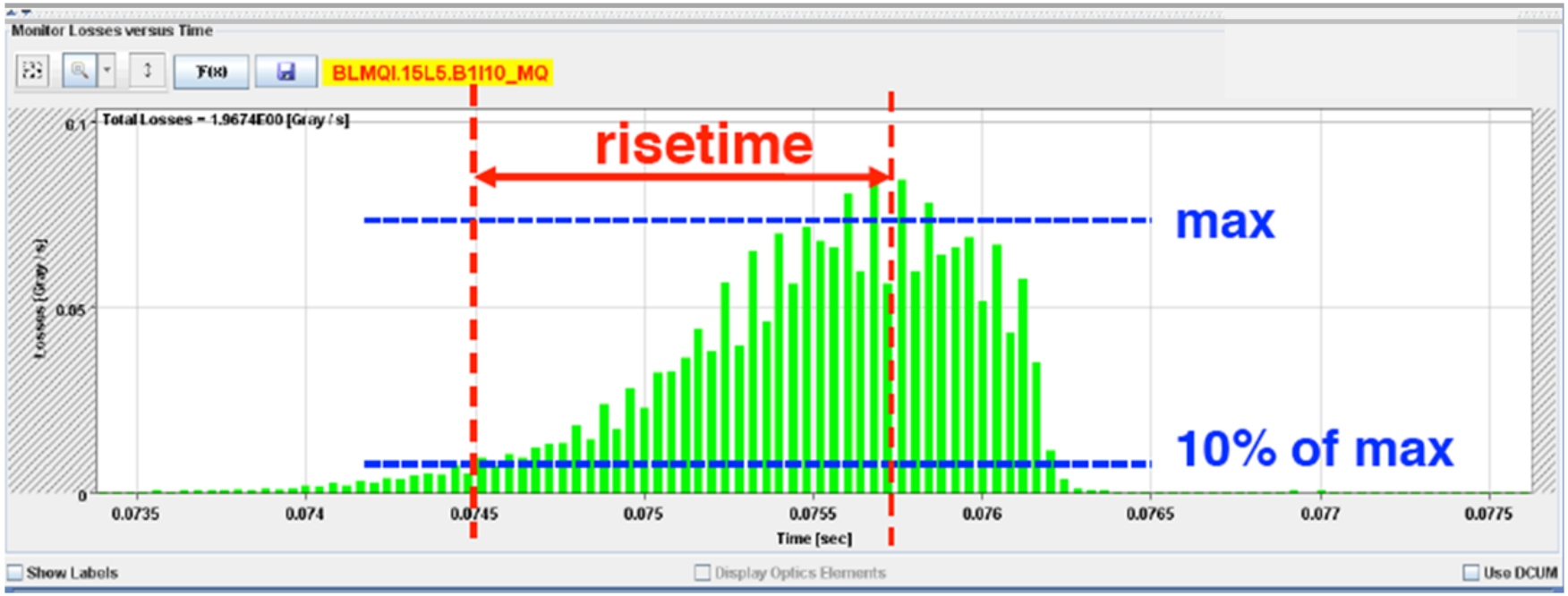
Thijs Wijnands



Not a problem at the moment but being monitored carefully

UFOs

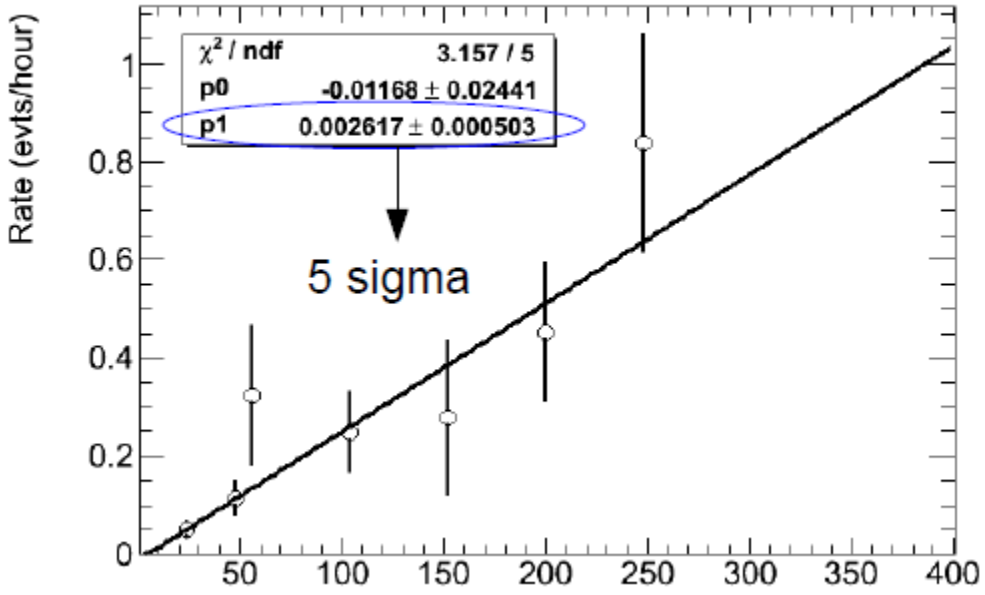
- Sudden local losses (some in the middle of the arc) have been recorded. No quench, but preventive dumps.
- Rise time partly < 1 ms.
- Potential explanation: dust particles falling into beam creating scatter losses and showers propagating downstream



UFO: intensity dependence

Beam loss monitor thresholds have been raised a the appropriate timescales

Logging data mined for events not above threshold



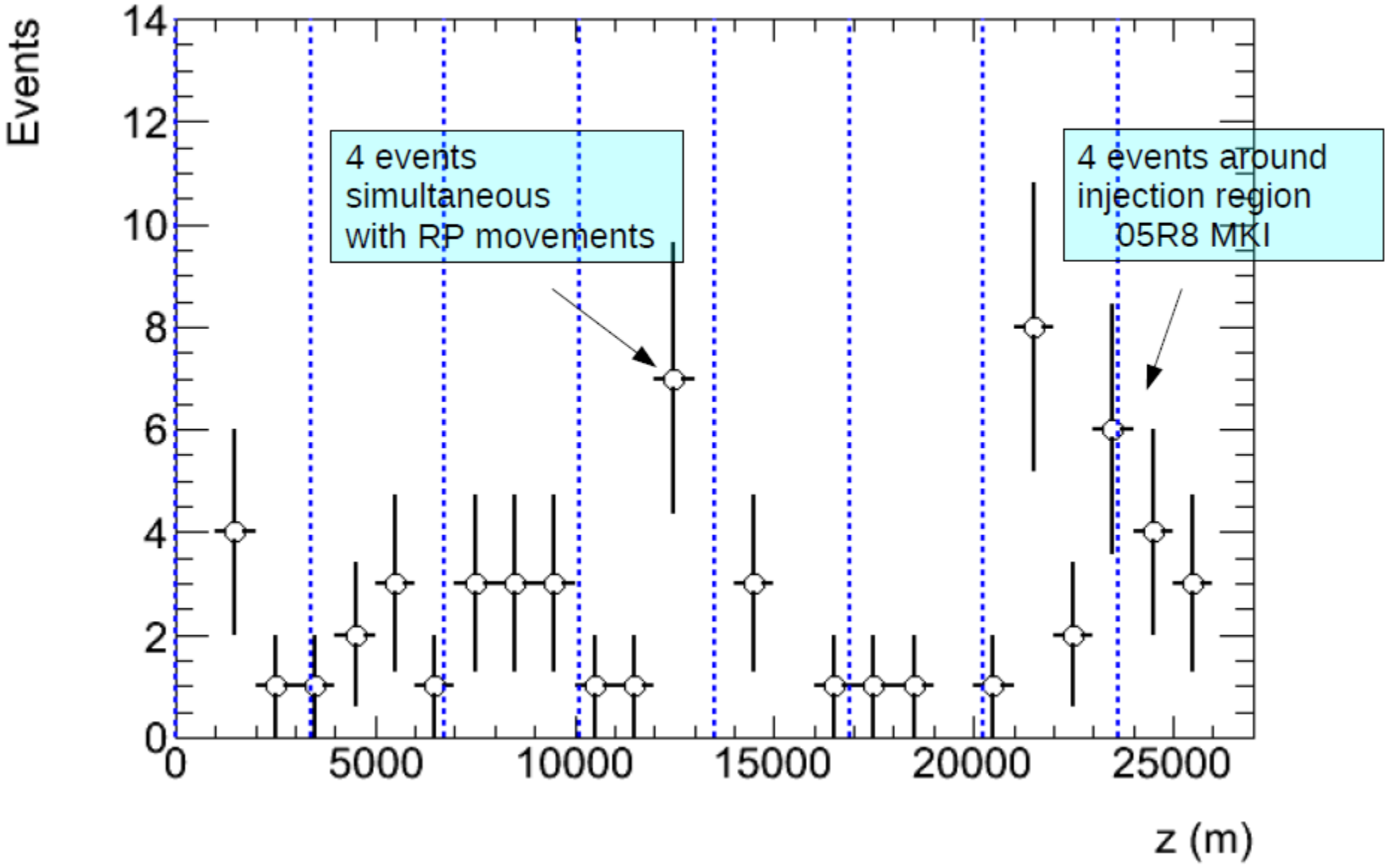
"UFO" Rate

The UFO rate seems to increase linearly with intensity:

Extrapolating
2000 Bunches => ~ 5.2 evts/hour

E. Nebot for the BLM team

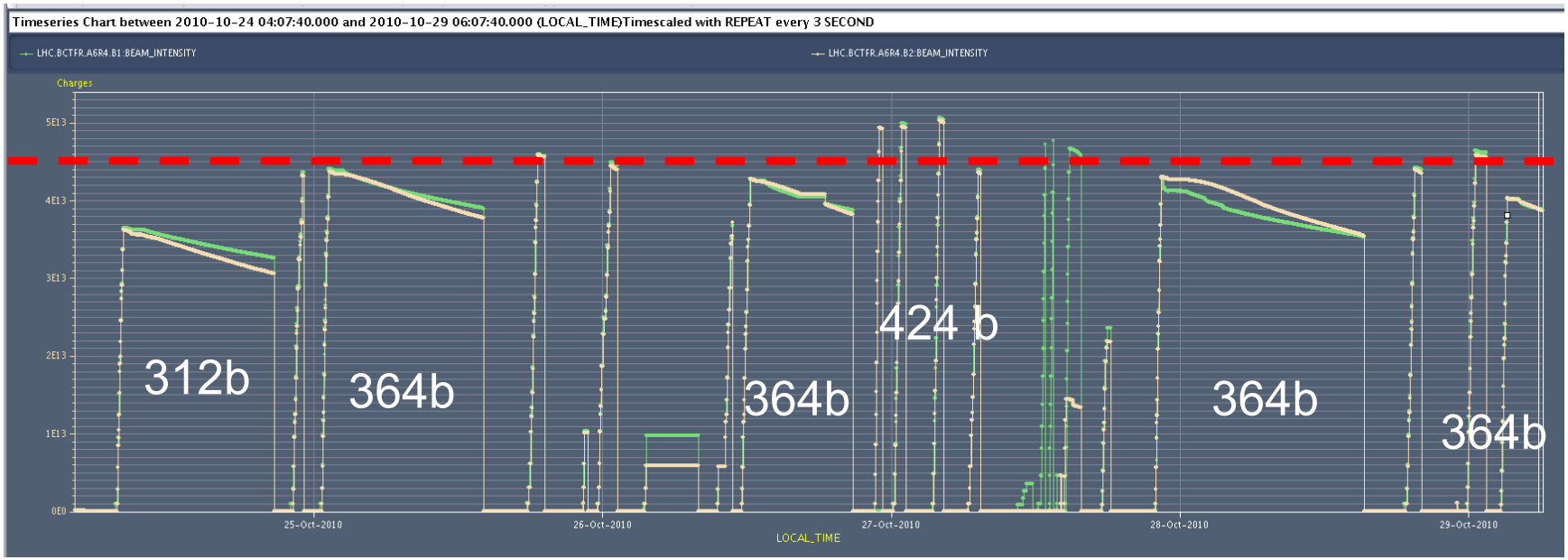
UFO: location



E. Nebot for the BLM team

Intensity Reach 150 ns

4.35e13 p (?) → to be followed…



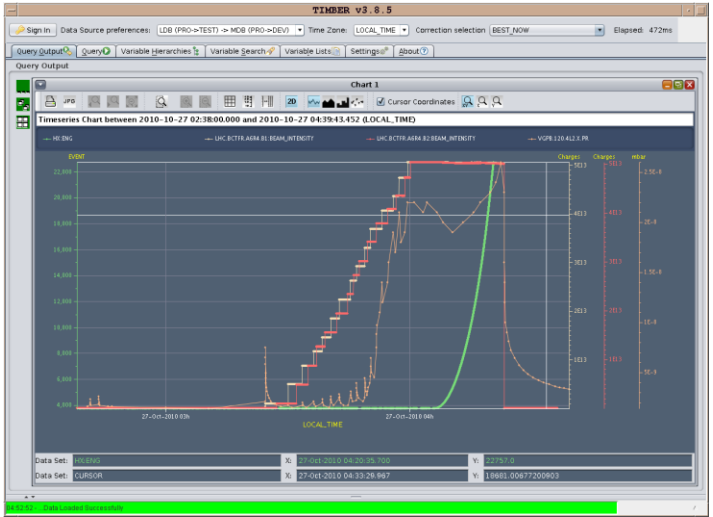
Stored energy reached at 3.5 TeV: **28.0 MJ**

Stored energy at 3.5 TeV in stable beams: **24.4 MJ**

Vacuum – a very brief history

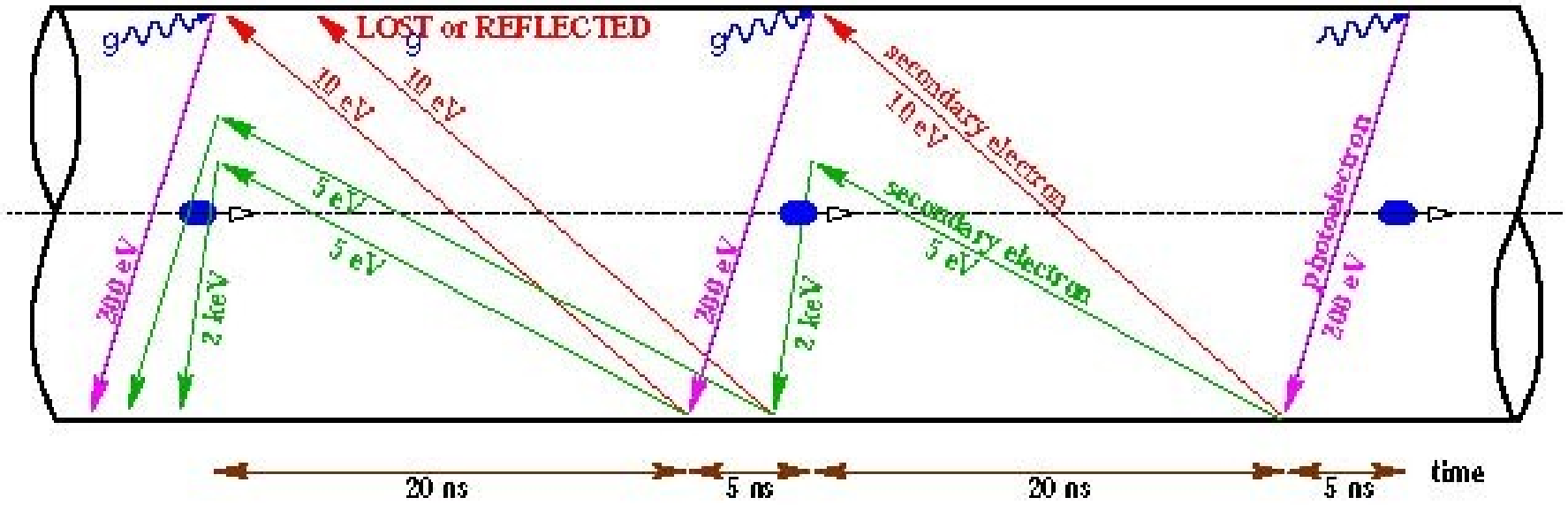
Initially

- Pressure rise seen in common beam pipe regions
- Particularly unbaked warm-cold transitions
- Two effects:
  - electron cloud driven by closely space passage of b1 and b2 bunches
  - synchrotron radiation induced desorption
- Region +/- 58 m of IP1 equipped with solenoids
  - worked well – classic cure for electron cloud
- Cleaning observed



Vacuum – move to 50 ns.

- OK with batches of 12*50 ns.
  - into stable beams with 108 bunches
  - instability noted at end of squeeze – cured with transverse feedback
- Move to batches of 24*50 ns.
  - large pressure rises kick off in warm sections – including single beam pipe
  - pressure rises in some case enough to close valves
- Scrubbing noted
  - which apparently persists



schematic of e- cloud build up in LHC arc beam pipe,

due to photoemission and secondary emission

[F. Ruggiero]

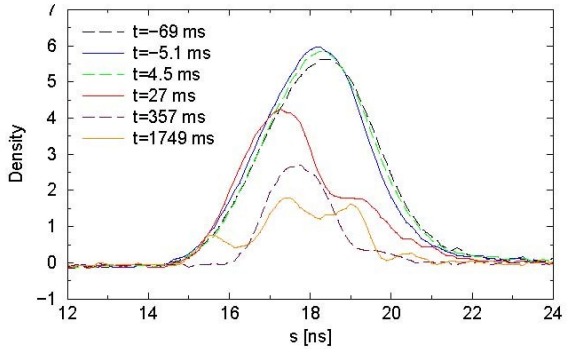
Can e- cloud be a problem for s.c. hadron ring?

Frank Zimmermann - presentation to LHC MAC 10 June 2005

RHIC

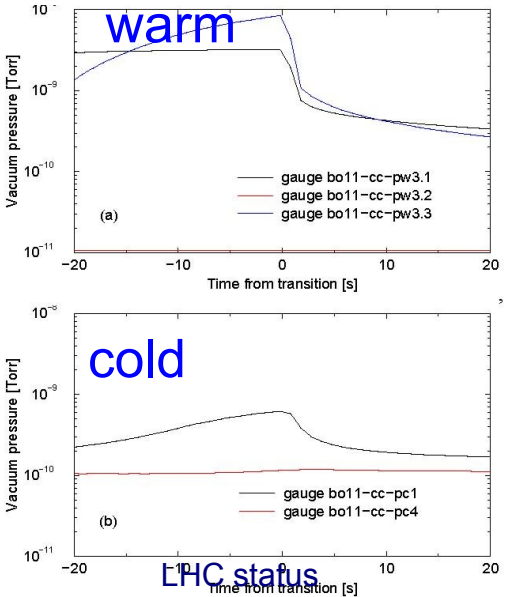
***At 108 ns bunch spacing**, electron cloud and electron-ion interactions cause **transverse instabilities, emittance growth**, and **beam loss**, along with **vacuum pressure rise and background increase**.*

*Electron cloud effects occur **both in the warm (30% of length) and cold (about 70%) regions.***

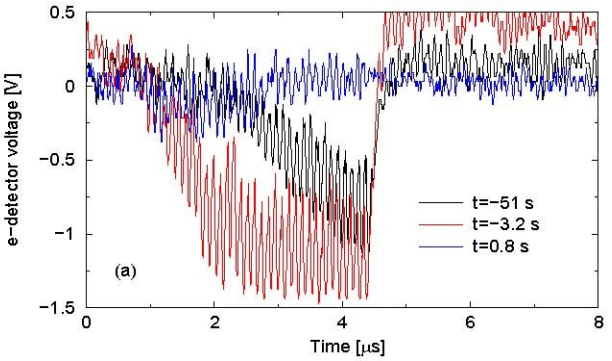


evolution of longitudinal profile during beam loss near γ_t

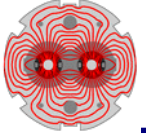
vacuum pressure rise



measured e-flux



J. Wei



electron cloud effects

- vacuum pressure rise
- single-bunch instability
  - - interplay w. impedance & beam-beam
- multi-bunch instability
- incoherent emittance growth
- heat load in cold arcs (quench)
- perturbation of beam diagnostics

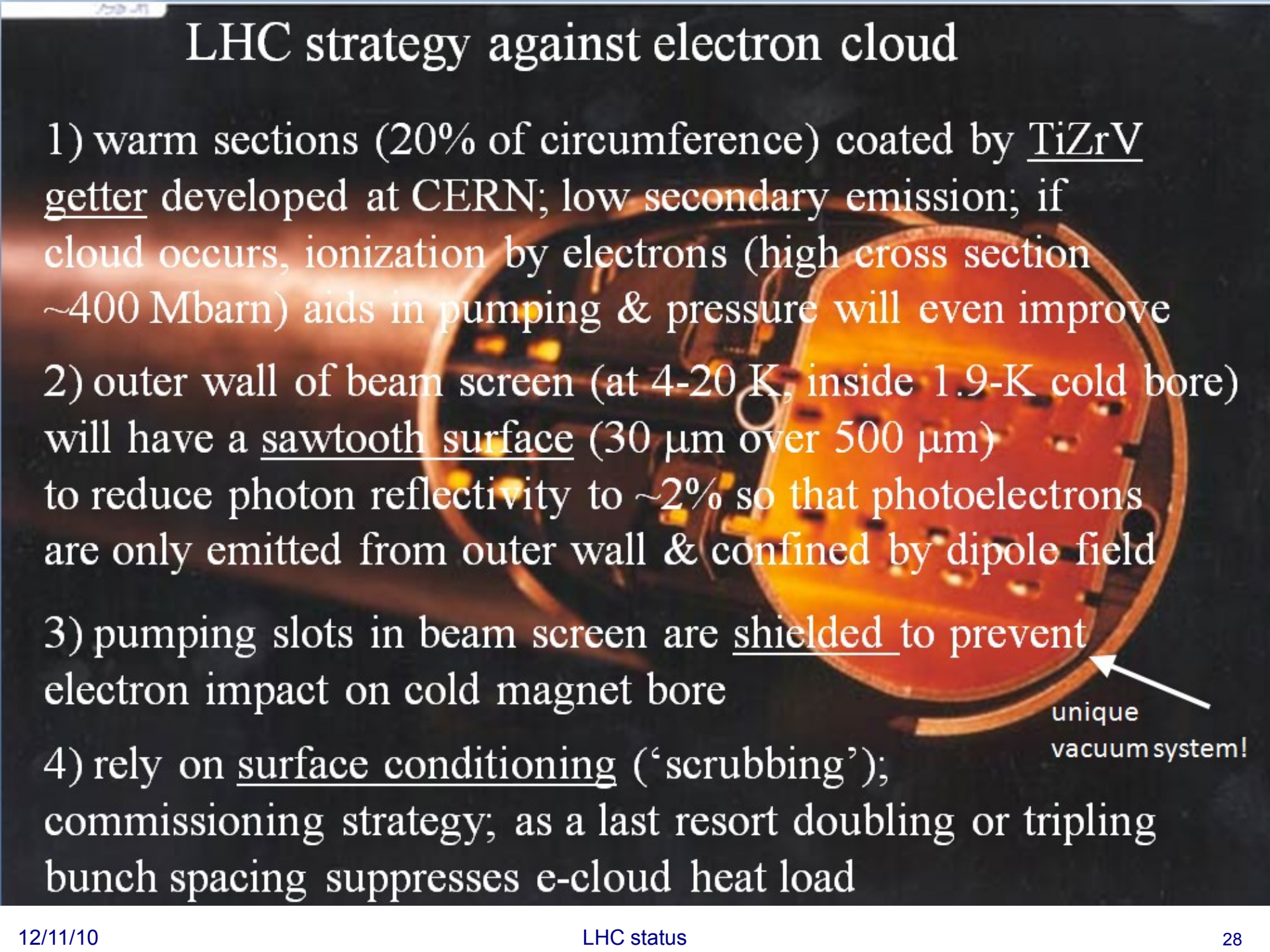
Frank Zimmermann

LHC strategy against electron cloud

1) warm sections (20% of circumference) coated by TiZrV getter developed at CERN; low secondary emission; if cloud occurs, ionization by electrons (high cross section ~400 Mbarn) aids in pumping & pressure will even improve

2) outer wall of beam screen (at 4-20 K, inside 1.9-K cold bore) will have a sawtooth surface (30 μm over 500 μm) to reduce photon reflectivity to ~2% so that photoelectrons are only emitted from outer wall & confined by dipole field

3) pumping slots in beam screen are shielded to prevent electron impact on cold magnet bore



4) rely on surface conditioning ('scrubbing'); commissioning strategy; as a last resort doubling or tripling bunch spacing suppresses e-cloud heat load

Crash program of investigations with 50 ns

Preliminary conclusions

- At 50-ns spacing strong evidence for large electron cloud build up in warm and cold sections
- Cold sections are of bigger concern
- In the arcs significant heat load due to electron cloud has been observed. Its reduction at high energy after scrubbing is not striking.
- Both heat load & instability in 3rd and 4th train indicate SEY δ_{max}~2.5 in the arcs (larger than expected) at R=0.5
- Av. e-cloud density ~6×10^{11} m^{-3} (from Q' effect)
- The evaluation of the behaviour with 75 ns beams at 450 GeV and comparison with the 50 ns beam in terms of pressure-rise heat load and beam stability is necessary

Next week: 2 to 3 days

Frank Zimmerman, Gianluigi Arduini, Miguel Jimenez, Laurent Tavian et al

Hadron Collider switches to heavy ions, tinfoilers wet pants again

Also: *Reg* hack in large-red-button LHC control room incident

By **Lewis Page** • **Get more from this author**

Posted in Physics, 8th November 2010 13:52 GMT

Particle-punishing boffins at the Large Hadron Collider - the most outrageously powerful matter-rending apparatus and largest machine of any kind assembled by the human race - have switched ammunition. The colossal superconductor massdriver cannons of the LHC are now firing "fully stripped" ultrahypervelocity lead projectiles rather than comparatively insubstantial hydrogen ones.

IONS

Acknowledgements to:

John Jowett

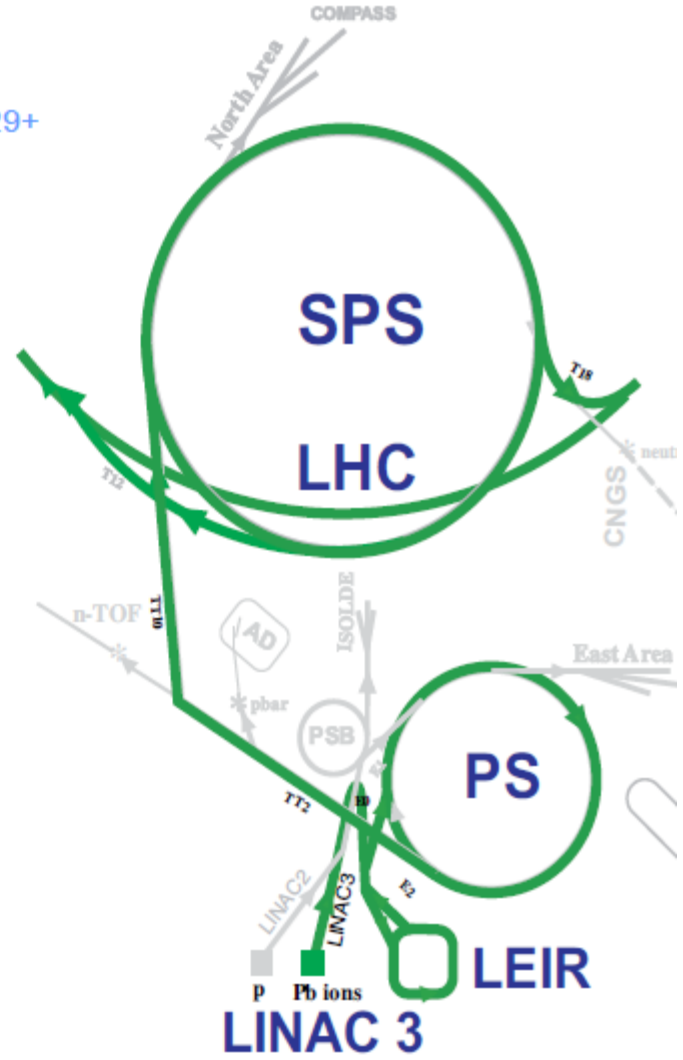
Walter Venturini

Matteo Solfaroli Camillocci

A word from our suppliers

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



Nominal ions through the chain

	ECR Source	Linac 3	LEIR	PS	SPS	LHC
Output energy	2.5 KeV/u	4.2 MeV/u	72.2 MeV/u	5.9 GeV/u	177 GeV/u	2.76 TeV/u
^{208}Pb charge state	29+	29+ → 54+	54+	54+ → 82+	82+	82+
Output Bρ [Tm]		2.12	4.80	86.7 → 57.3	1500	23350
bunches/ring		→ 1.14	2 (1/8 of PS)	4	52	592
ions/pulse	9 10^9	1.15 10^9	9 10^8	4.8 10^8	4.7 10^9	4.1 10^{10}
ions/LHC bunch	**1.1 10^{10}.**	**1.45 10^9**	**2.25 10^8**	**1.2 10^8**	**9 10^7**	**7 10^7**
bunch spacing [ns]				100	100	100
ε*(norm. rms) [μm]	0.07	0.25	0.7	1.0	1.2	1.5
ε (phys., rms) [μm]	30	2.6	1.75	0.14	0.0063	0.0005
Repetition time [s]	0.2-0.4	0.2-0.4	3.6	3.6	~50	~10'fill/ring

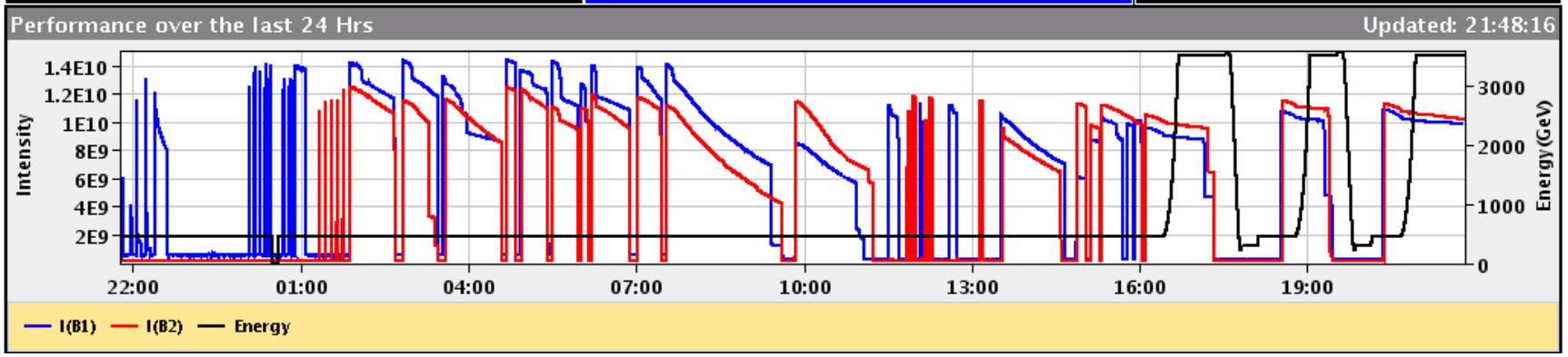
Been seeing around 1.2 x 10^8 ions per bunch – very good

Ion Commissioning: Thursday & Friday

05-Nov-2010 21:48:18 Fill #: 1473 Energy: 3500 Z GeV I(B1): 9.86e+09 I(B2): 1.02e+10

	ATLAS	ALICE	CMS	LHCb
Experiment Status	STANDBY	STANDBY	STANDBY	STANDBY
Instantaneous Lumi (ub.s)^-1	0.000	0.000	0.000	0.000
BRAN Luminosity (ub.s)^-1	0.000	0.000	0.000	0.000
Inst Lumi/CollRate Parameter	1.00e+00		0.00e+00	
BKGD 1	0.002	0.244	0.000	0.122
BKGD 2	0.000	0.000	0.000	0.407
BKGD 3	0.000	1.628	0.098	0.044

LHCb VELO Position OUT Gap: 58.0 mm | SQUEEZE | TOTEM: STANDBY



Beam 1 Inj., Circ. & Capture

Beam 2 Inj., Circ. & Capture

Optics Checks
BI Checks
Collimation Checks

First Ramp
Collimation Checks
Squeeze

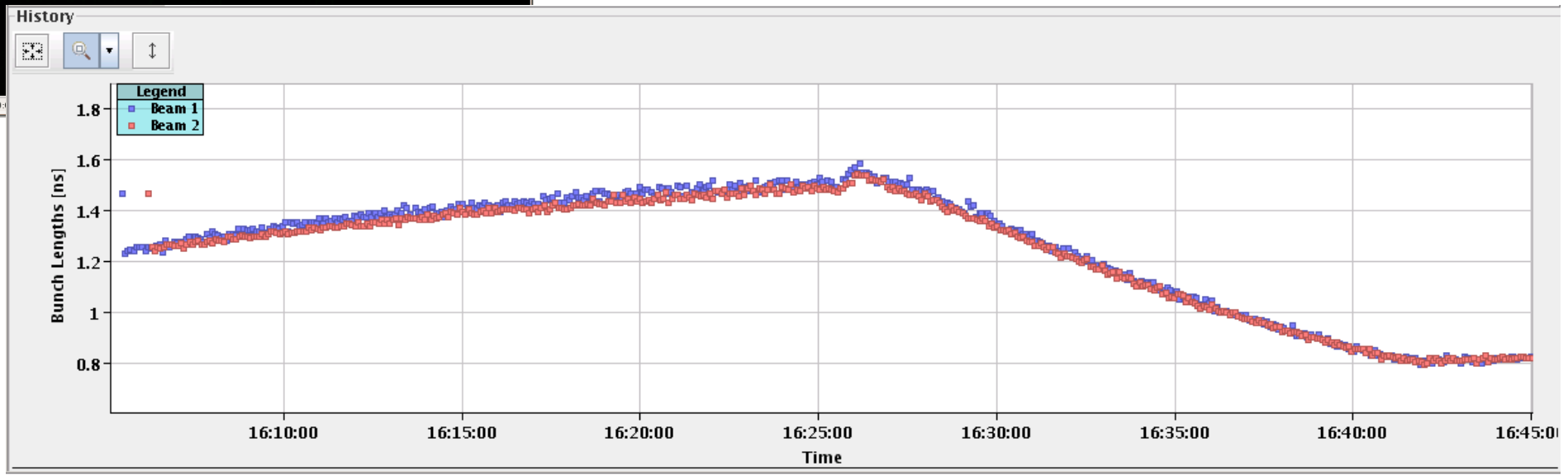
Cunning wheeze – remembering Lorentz

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

Friday afternoon: first ramp – no losses

World first: observation of synchrotron light from nuclei

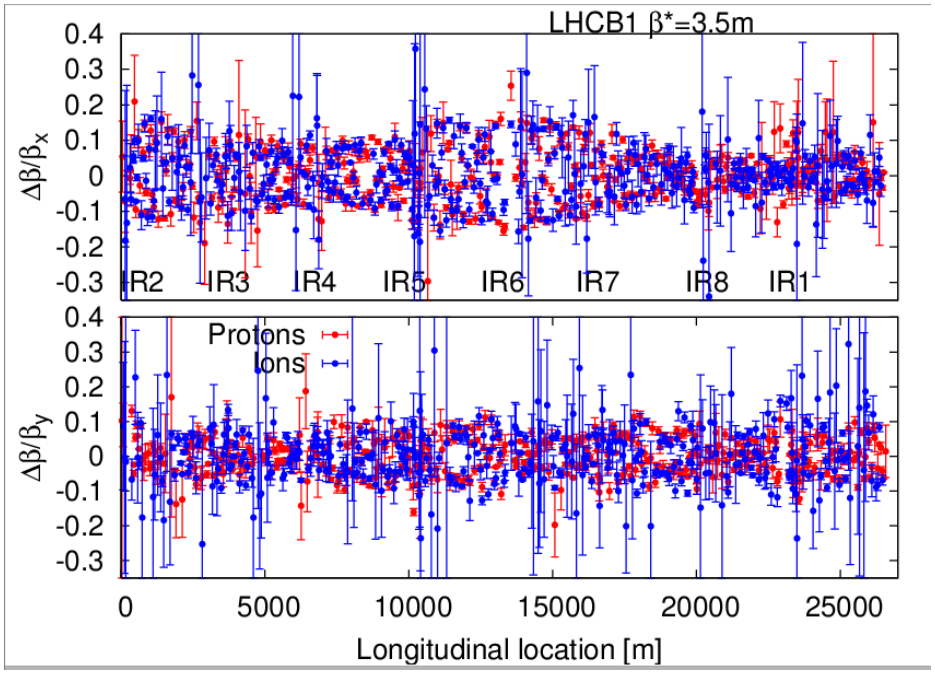
Appears around 0.55 Z TeV (later if filtered)

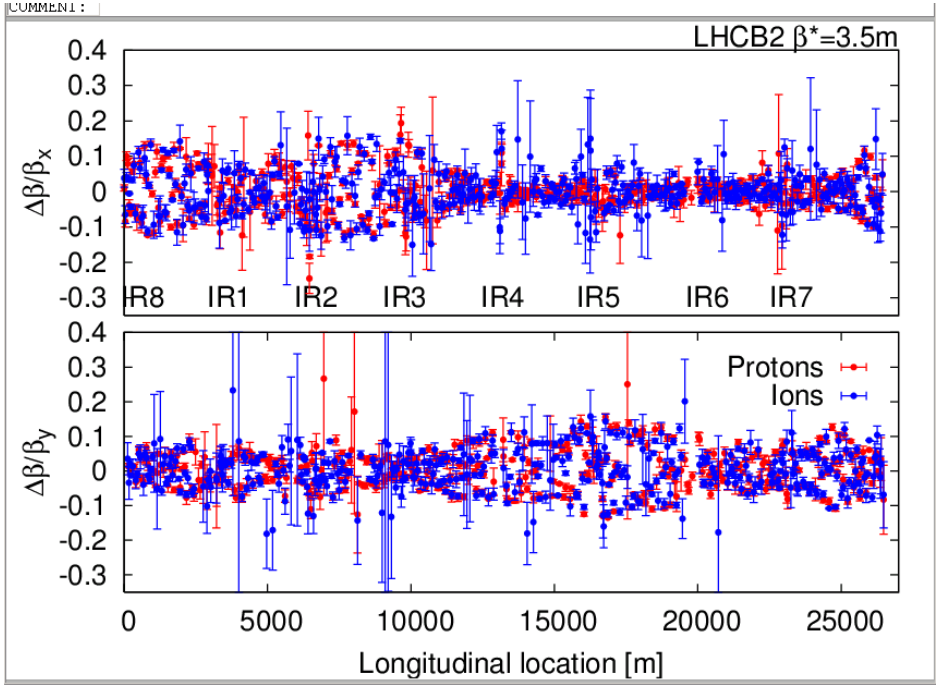


Bunch length increasing at injection (IBS), down during the ramp, increasing again at 3.5 TeV (IBS)

Optics measurements at 3.5 Z TeV, squeezed

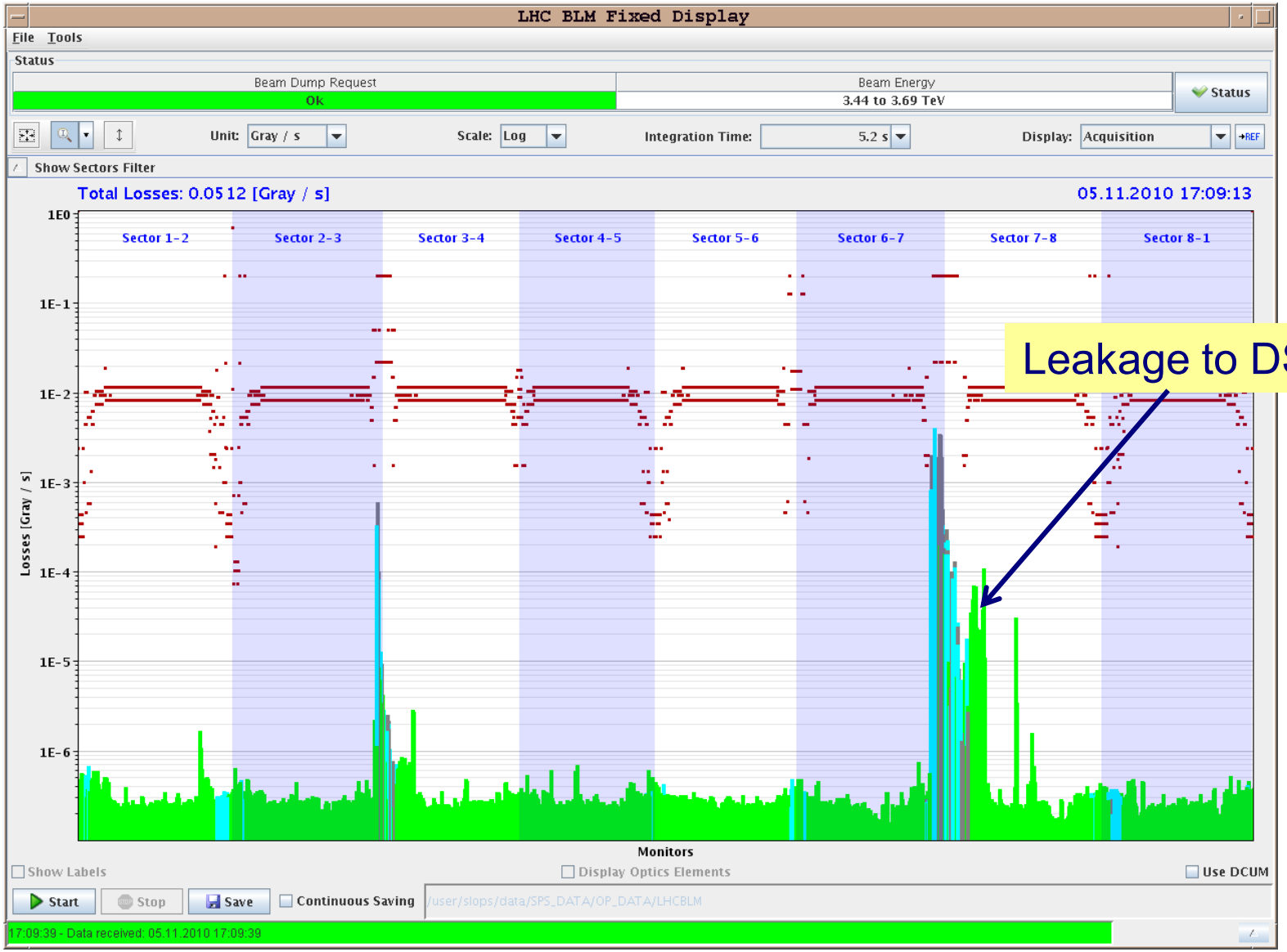
- Very similar to protons





R. Tomas et al.

Betatron loss maps – 450 GeV



Conclusions from collimation team

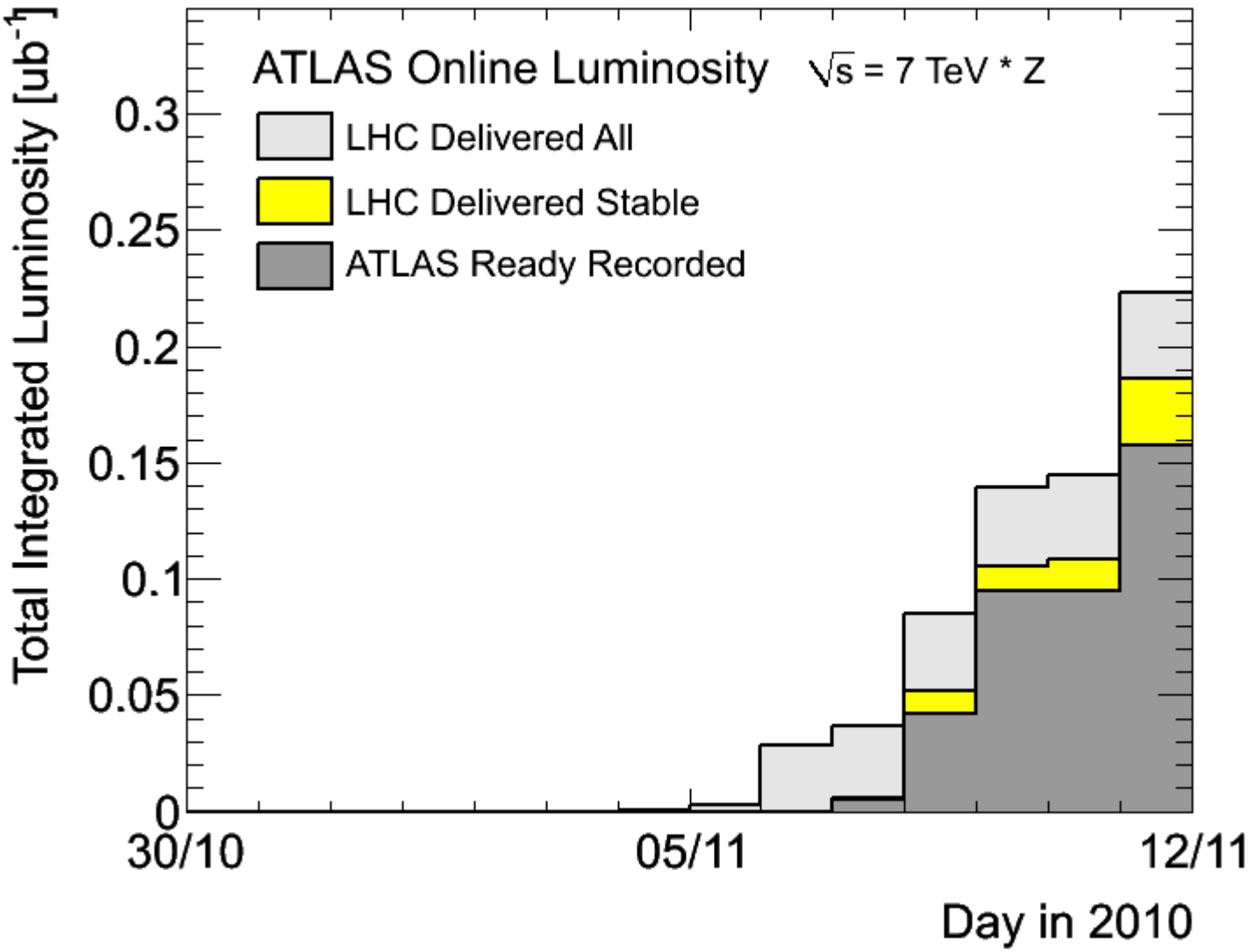
- We lose about a factor 50-100 in cleaning efficiency for ions compared to protons.
  - Expected (ion fragmentation and dissociation)
- Main losses in predicted locations, namely the dispersion suppressor magnets.
- At injection a large 10% leakage into IR1 from IR3 losses for beam 2 has been observed for positive momentum errors.
- It is not clear what ion species escapes IR3 and travels to IR1.
- To be analysed in detail.

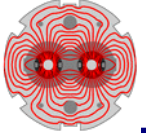
Ions - conclusions

- Very swift commissioning period leveraging proton set-up to the maximum.
  - pushing though 2 – 17 – 69 toward 120 bunches per beam
  - Peak luminosity around 6 x 10^{24} $cm^{-2}s^{-1}$ with 69 bunches
- Injectors are giving us 70% beyond design single-bunch intensity, some consequences…
  - Significant IBS growth and de-bunching at injection, seems to be in reasonable agreement with theory
- Emittance blow-up in physics is not too bad, but mostly not IBS
- Collimation of heavy ions is complicated
  - Simulations roughly right but do not show all details – need considerable effort for refinement … and counter-measures in future

John Jowett

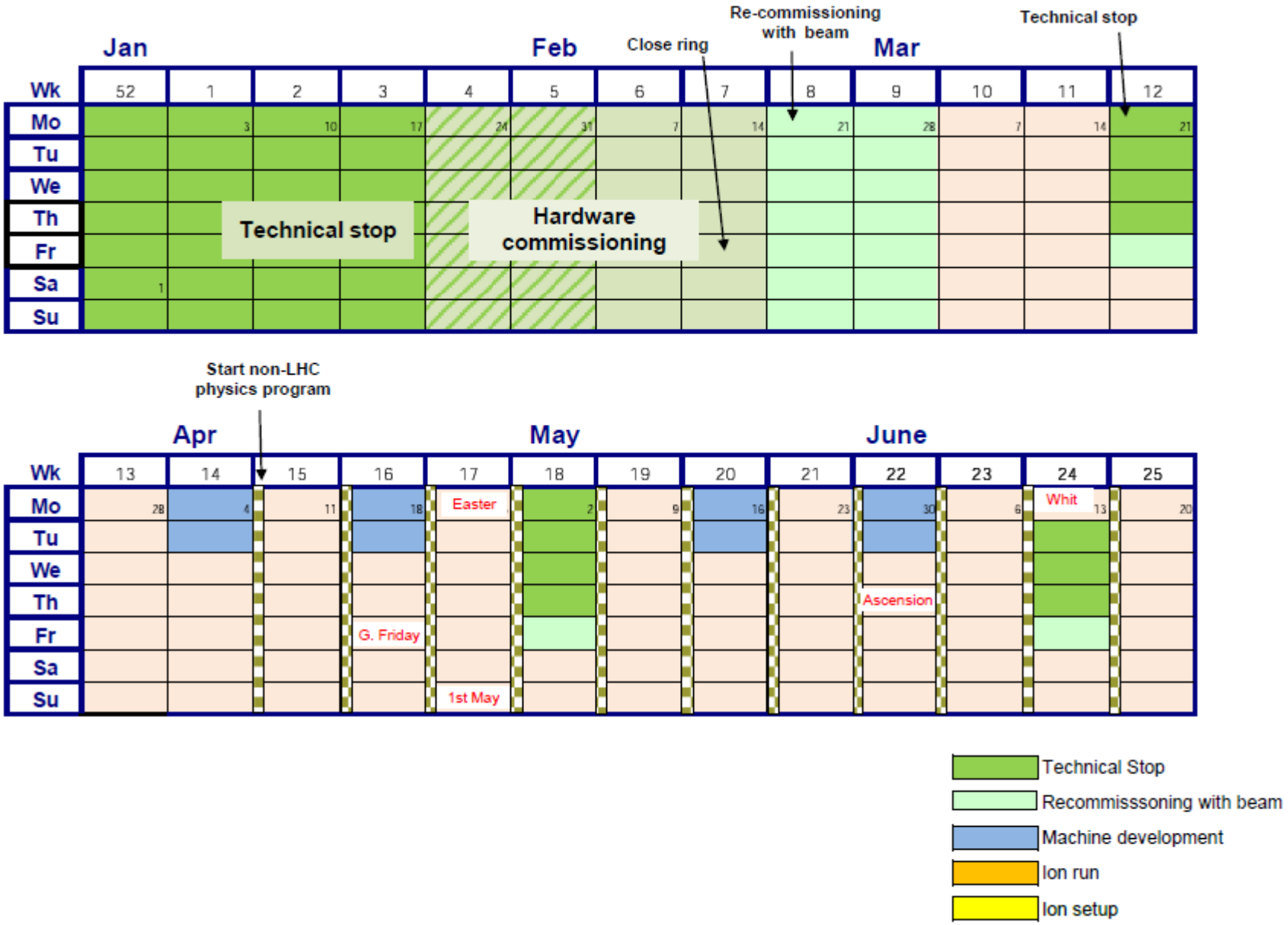
Despite some problems…



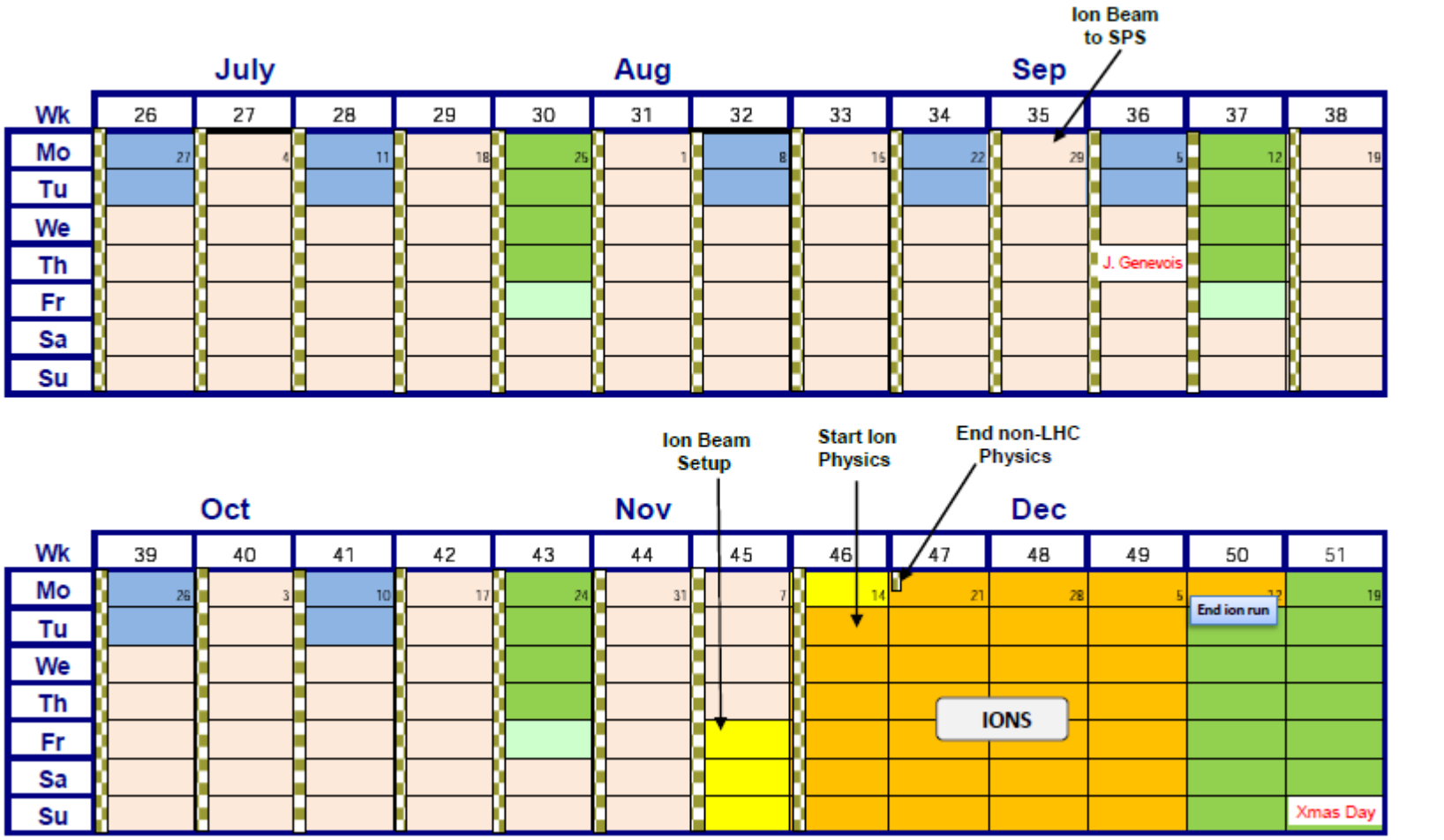


2011

Draft LHC schedule 2011 Q1 & Q2



Draft LHC schedule 2011 Q3 & Q4



2011 - summary

- Beam back around 21st February
- 2 weeks re-commissioning with beam (at least)
- 4 day technical stop every 6 weeks
- Count 1 day to recover from TS (optimistic)
- 2 days machine development every 2 weeks or so
- 4 days ions set-up
- 4 weeks ion run
- End of run – 12th December

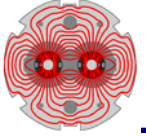
~200 days proton physics

2011: “reasonable” numbers

- 4 TeV (to be discussed at Chamonix)
- 936 bunches (75 ns)
- 3 micron emittance
- 1.2 x 10^{11} protons/bunch
- beta* = 2.5 m, nominal crossing angle
- Hubner factor 0.2

Peak luminosity	6.4 x 10^{32}
Integrated per day	11 pb^{-1}
200 days	2.2 fb^{-1}
Stored energy	72 MJ

Usual warnings apply – see problems, problems above



Ultimate reach

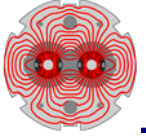
1.6 x10^{11} ppb and emittance of 2 microns at 3.5 TeV respects the robustness limits of the collimation system (equivalent to ultimate intensity)

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}
Integrated per day	38 pb^{-1}
200 days	7.6 fb^{-1}
Stored energy	134 MJ

Usual warnings particularly apply – see problems, problems above



Conclusions

The LHC team is tired and emotional.