LHC Machine Status Report
LHCC, November 2010

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LHC Operations

On behalf of the LHC commissioning team
and drawing on material from many sources

LHC Machine Status Report

150ns operation

50ns running

Ions

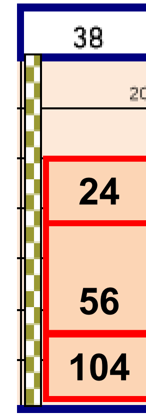
2011

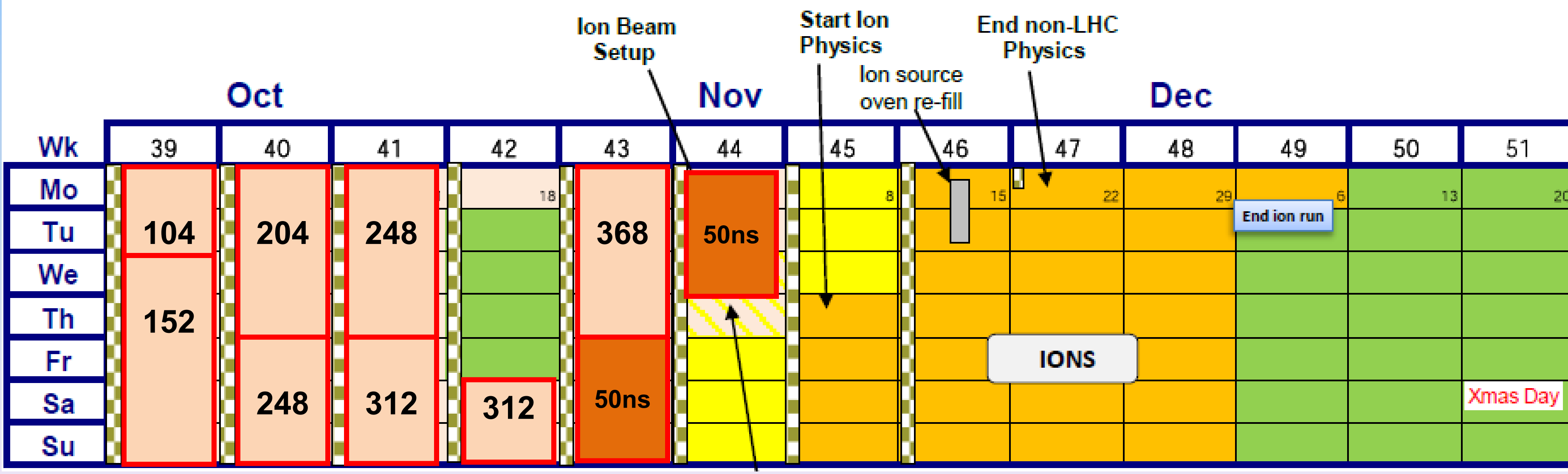
Bunch train commissioning - reminder

- First 3 weeks of September (covered at last LHCC)
- Key things addressed (then or later)
  - Operation with crossing angles all through the cycle
    - Aperture (non) issues
    - Collimation setting up and qualification (loss maps - lengthy)
  - Injection of multiple bunches
    - Injection protection devices
    - Injection of unsafe beams
  - Operation with higher beam intensities
    - Implications for beam instrumentation
    - Implications for vacuum
  - Beam dump
    - Abort gap keeper
    - More and more beam to dump (protection devices)

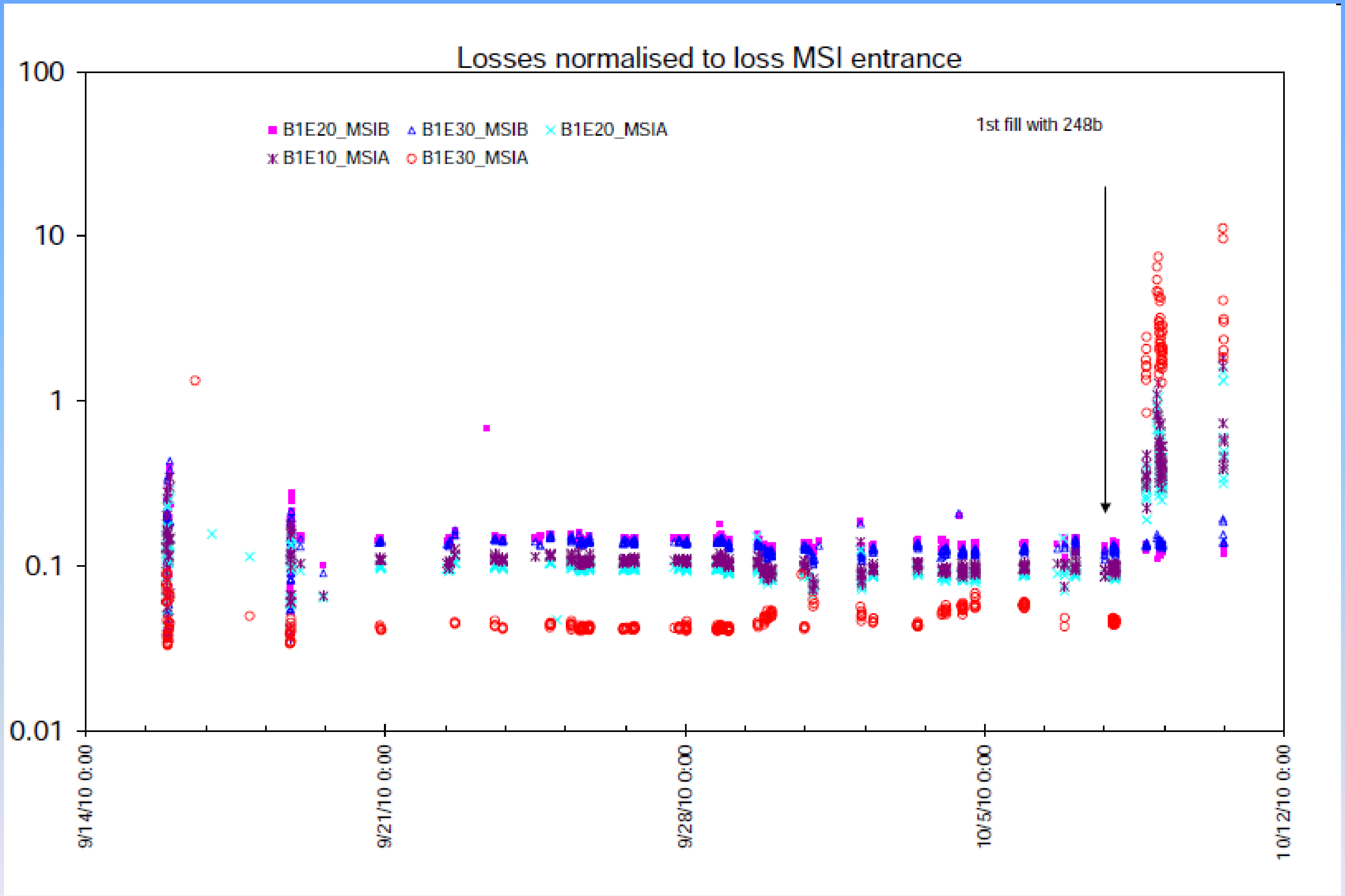
150ns bunch train running , 22/09 to 29/10

- Strategy (all with ~nominal bunch intensities)
  - Started with 24 on 24 (September 22)
  - Moved to 56 on 56 after 1 fill (September 23)
  - Incremental increase thereafter
    - After 3 fills and 20 hours, add ~ 50 bunches per beam
- Technical stop of week 44 advanced to week 42 (injection IR2)



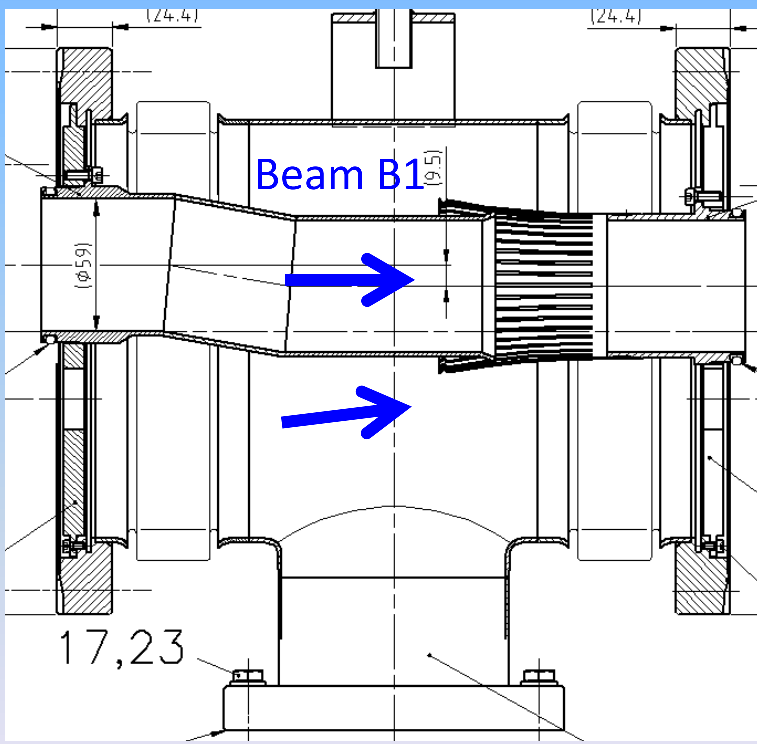


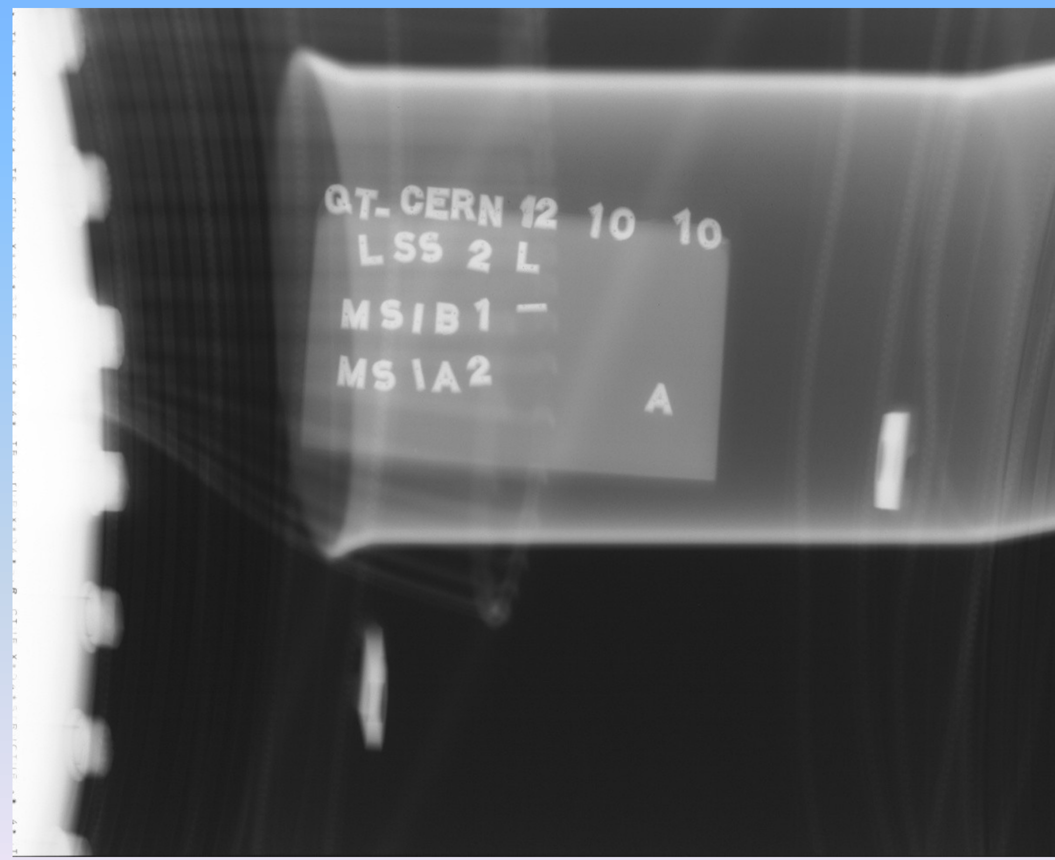
Increased losses observed in P2: started Oct 8th



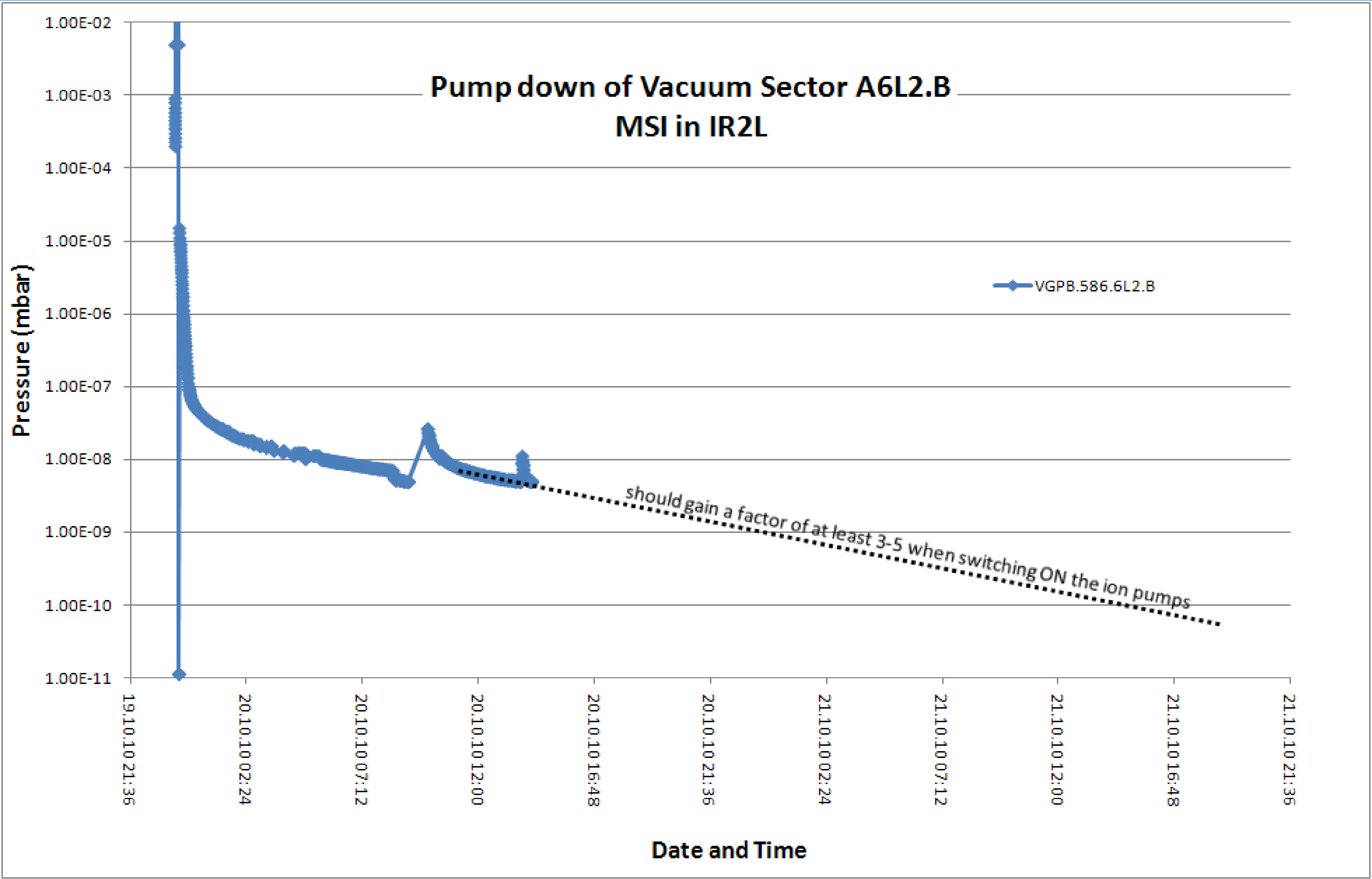
RF inserts between MSIA and MSIB septa

- At first able to steer around aperture restriction
- Eventually ran out of margin – badly aligned insert





Intervened October 19th (technical stop early)



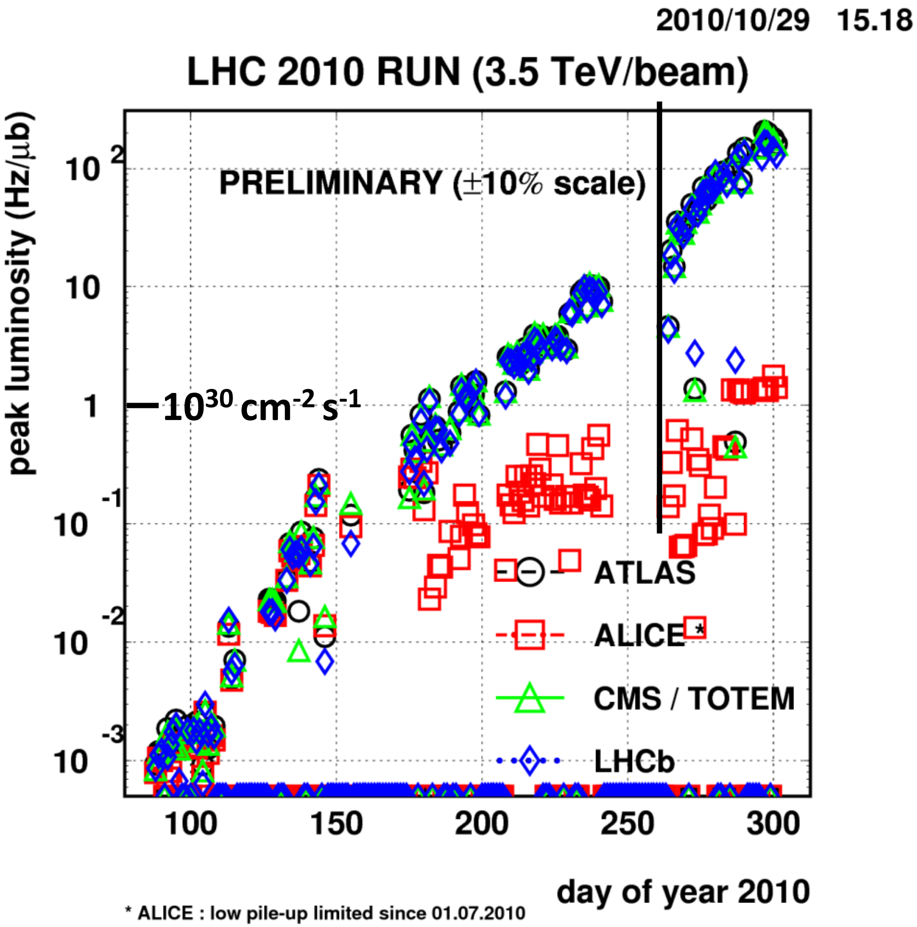
150ns bunch train performance, 22/09 to 29/10

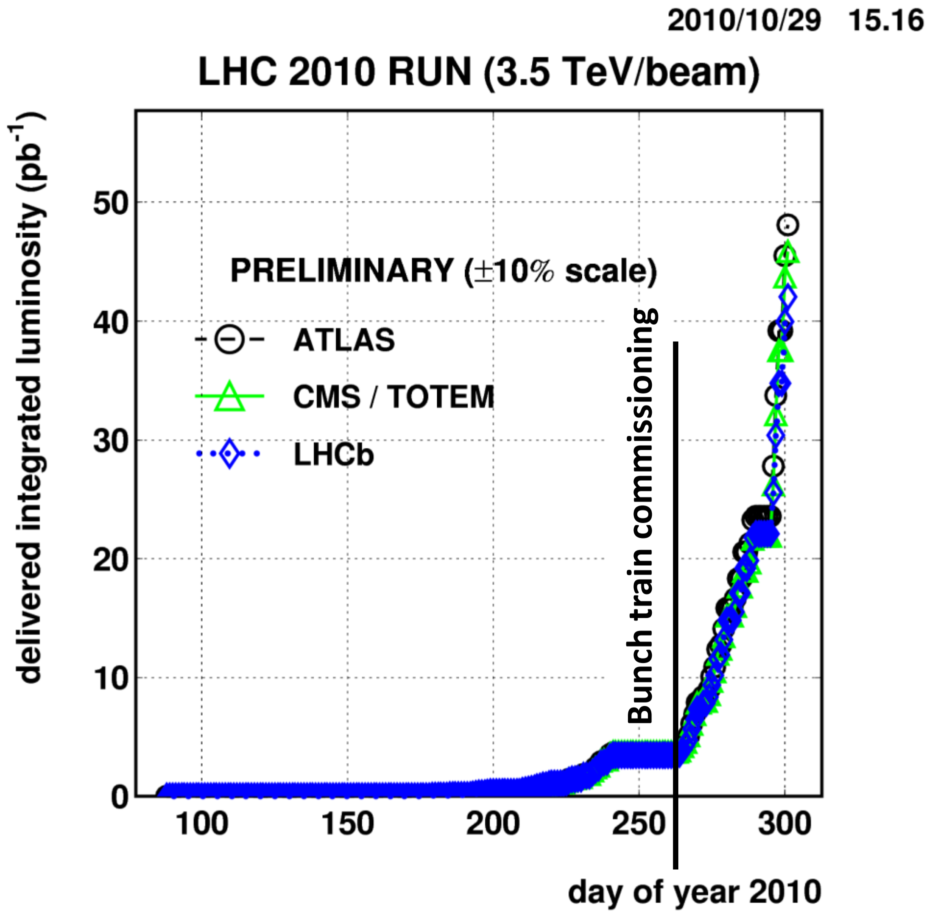
Energy	TeV	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
Bunch intensity	1.E+10	10.0	10.0	10.5	10.3	10.0	10.6	11.5	12.2
Bunches per beam		24	56	104	152	204	248	312	368
Colliding in 1 5 8		16	47	93	140	186	233	295	348
Emittance	µm	3.30	2.20	2.80	2.90	2.60	2.40	2.60	2.40
β*	m	3.50	3.50	3.50	3.50	3.50	3.50	3.50	3.50
Luminosity 1 & 5	cm^{-2} s^{-1}	4.6E+30	2.0E+31	3.5E+31	4.8E+31	6.8E+31	1.0E+32	1.4E+32	2.1E+32
Event rate / Xing	Hz	1.5	2.3	2.0	1.8	2.0	2.4	2.6	3.2
BBTS / Xing		0.0037	0.0055	0.0046	0.0043	0.0047	0.0054	0.0054	0.0062
BBTS for 3 Xing		0.0111	0.0166	0.0137	0.0130	0.0141	0.0161	0.0162	0.0187
Protons		2.4E+12	5.6E+12	1.1E+13	1.6E+13	2.0E+13	2.6E+13	3.6E+13	4.5E+13
% nominal		0.7	1.7	3.4	4.8	6.2	8.1	11.1	13.9
Current	mA	4.3	10.1	19.6	28.1	36.0	47.1	64.8	81.0
Stored energy	MJ	1.3	3.1	6.1	8.7	11.2	14.7	20.2	25.2
			1366						

Luminosity evolution 2010

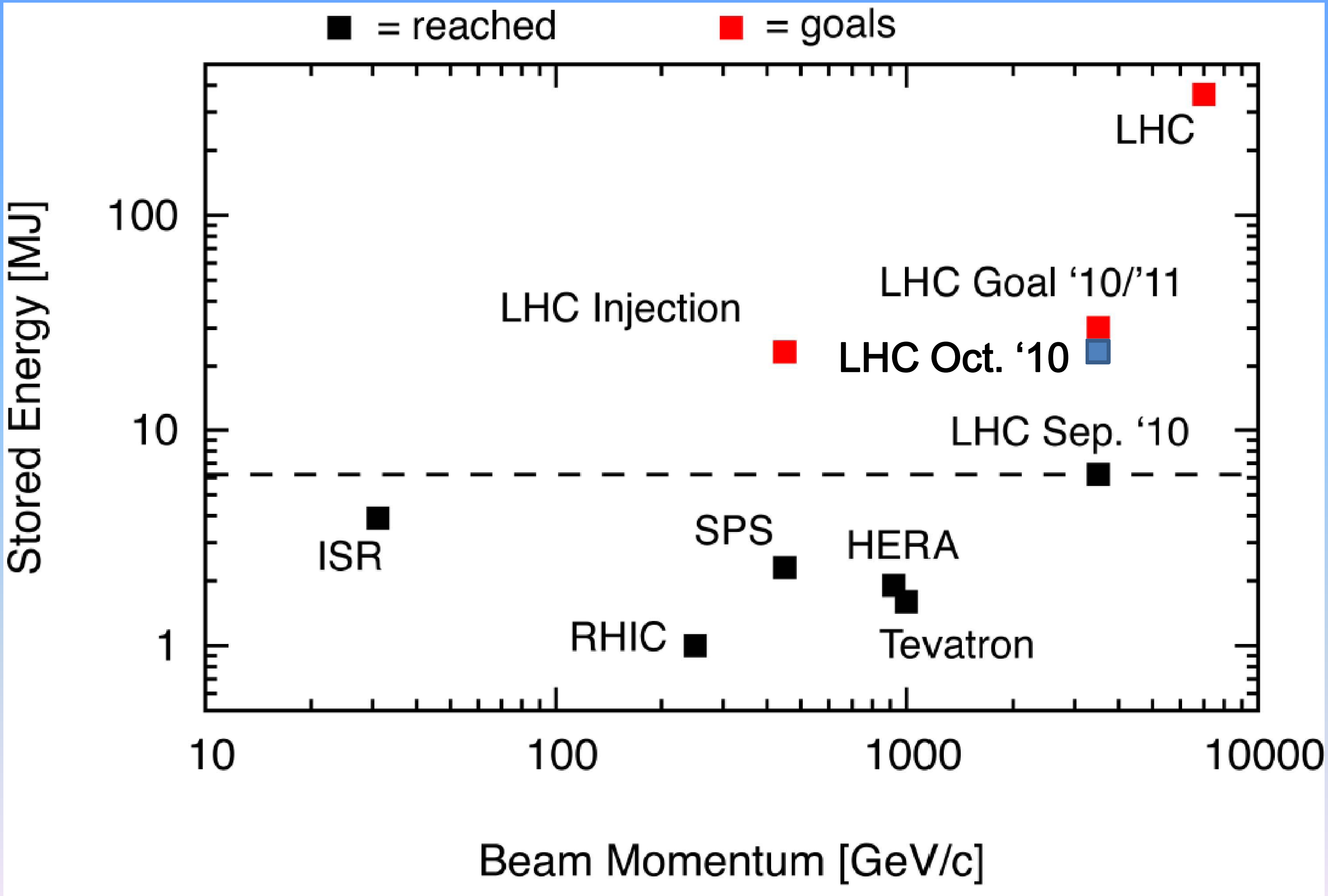
5 orders of magnitude in ~200 days

~50 pb^{-1} delivered, half of it in the last week !





LHC now on its own in terms of stored energy

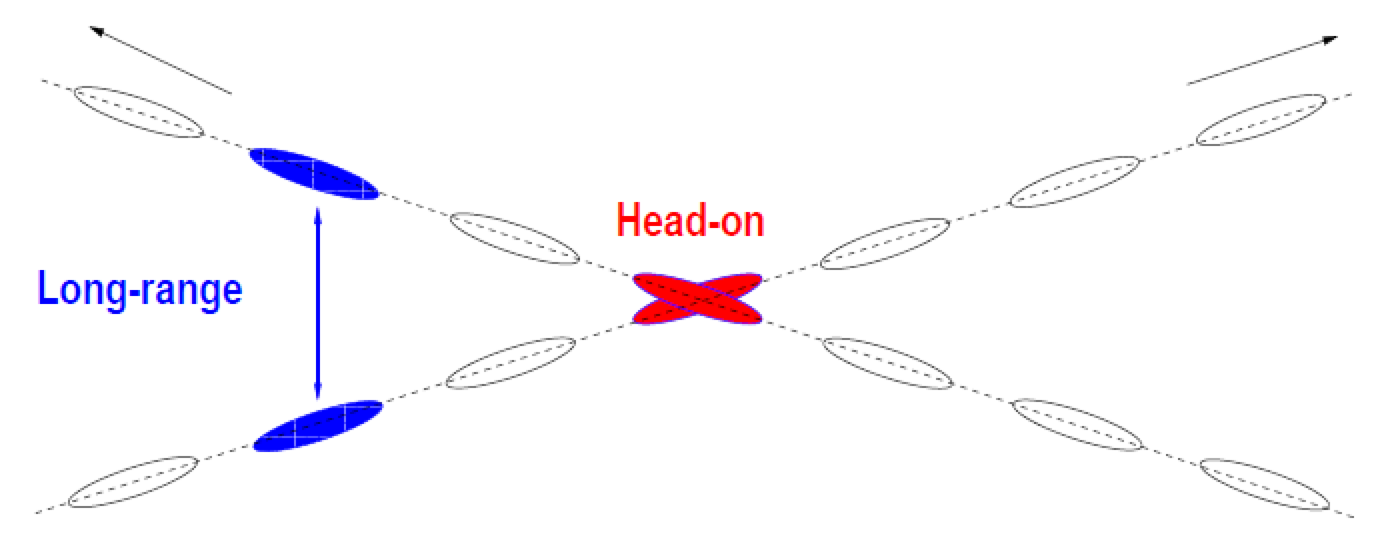


Key points

- Achievements
  - Bunch intensities ~ nominal throughout
  - Can collide small emittance bunches
  - Carefully increased number of bunches from 24 to 368
    - Inject, ramp, squeeze, collide and all that this entails
  - Stable beam operation with 25MJ per beam

- Food for thought for 2011++
  - Beam-beam effects with crossing angles
  - Behaviour of the vacuum system
  - UFOs
  - Did we reach an intensity limit ?

Beam-beam effects with crossing angles



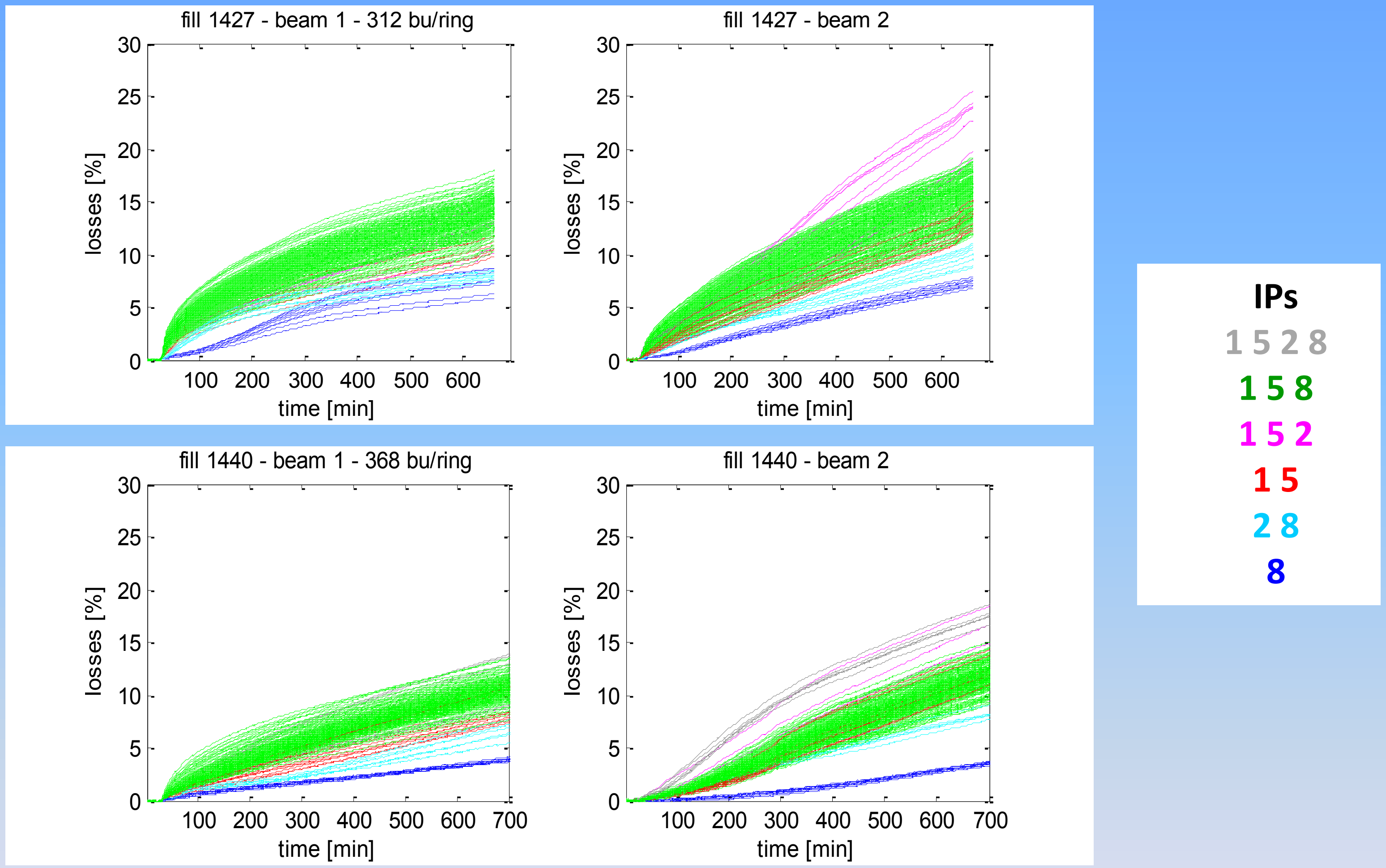
Both head-on and long-range beam-beam interactions

- Head-on tune shifts depend (mostly) on
  - Number of particles per bunch N
  - Normalised emittance ε_n
- Long range tune shifts depend on
  - Number of particles per bunch N
  - Normalised emittance ε_n
  - Beta function at the IP β^*
  - Crossing angle θ_c
  - Bunch length σ_z

$$\Delta Q_{ho} \propto \frac{N}{\epsilon_n}$$

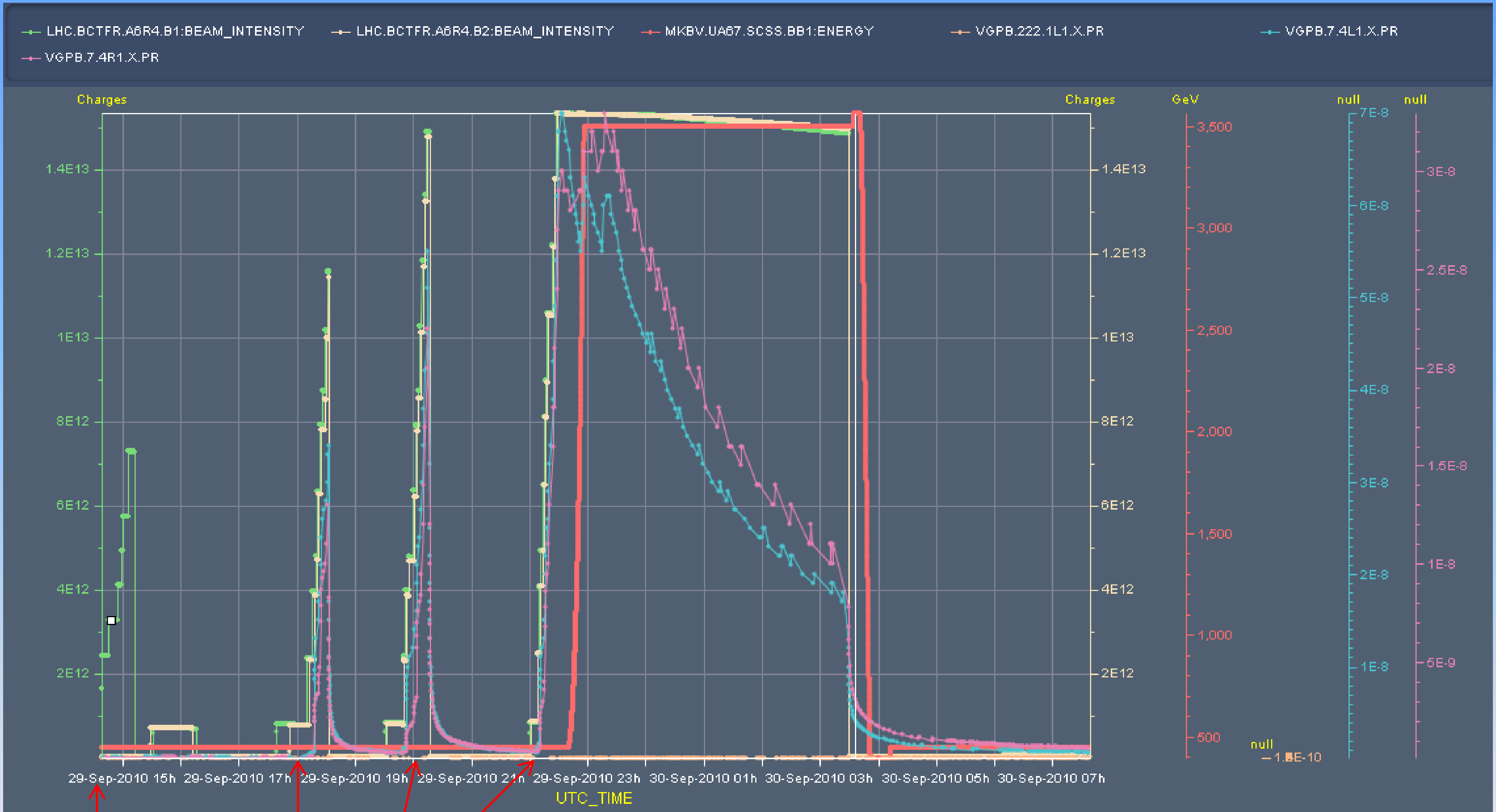
$$\Delta Q_{lr} \propto \frac{N}{d_{sep}^2} \cdot n_{lr} = \frac{N \cdot \epsilon_n}{\alpha^2 \cdot \beta^* \cdot \gamma} \cdot n_{lr}$$

Bunch intensity loss evolution through the fill



Clear differences between different bunches/beams
Correlates with number of collisions; analysis ongoing

Vacuum - Fill 1381 (First fill with 152 bunches)

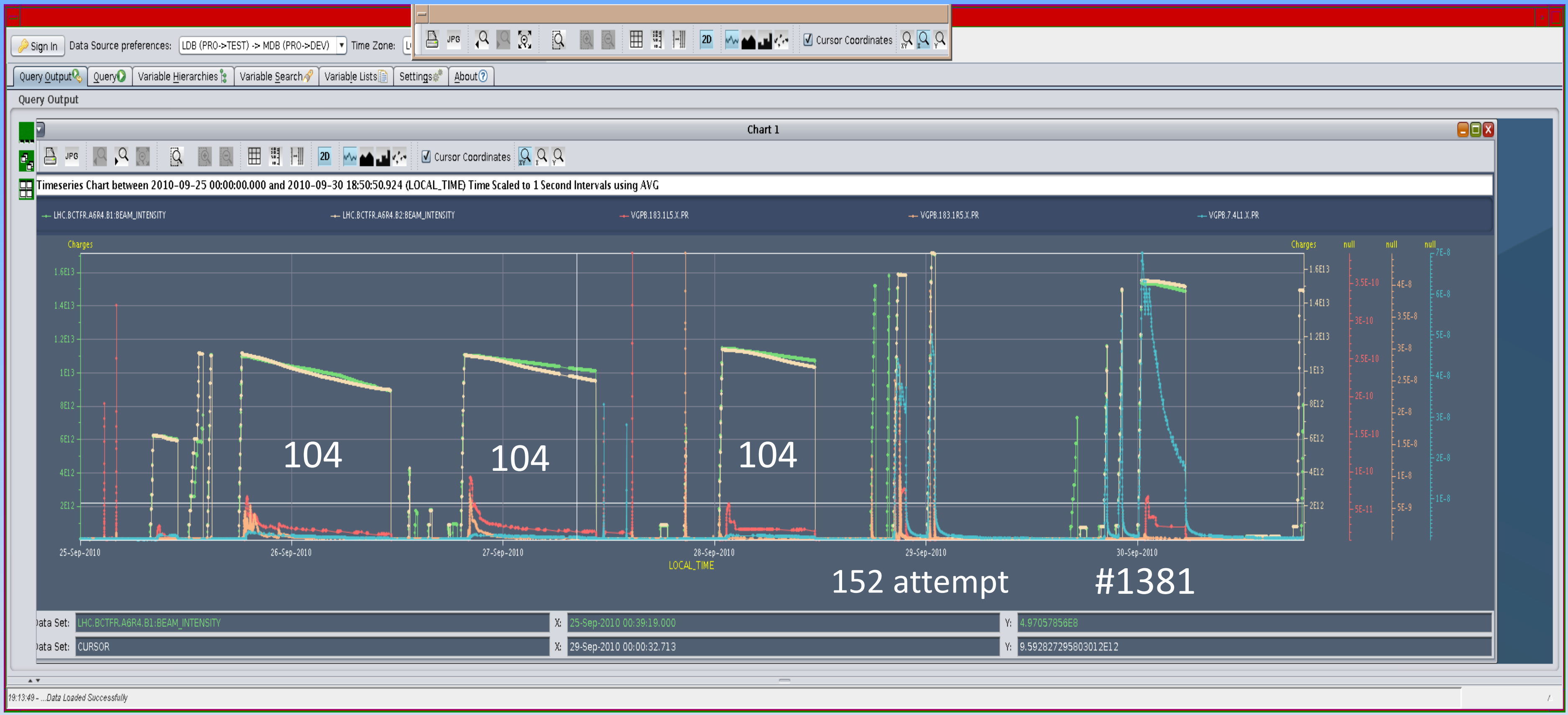


Beam 1 only
8+8

Beam 1+2
8+8

Note spikes during injection tests when B1 AND B2 are injected

Vacuum - Bunch trains and vacuum around IR1



Gradual degradation seen with the benefit of hindsight from Friday September 29th

Vacuum - summary of observations

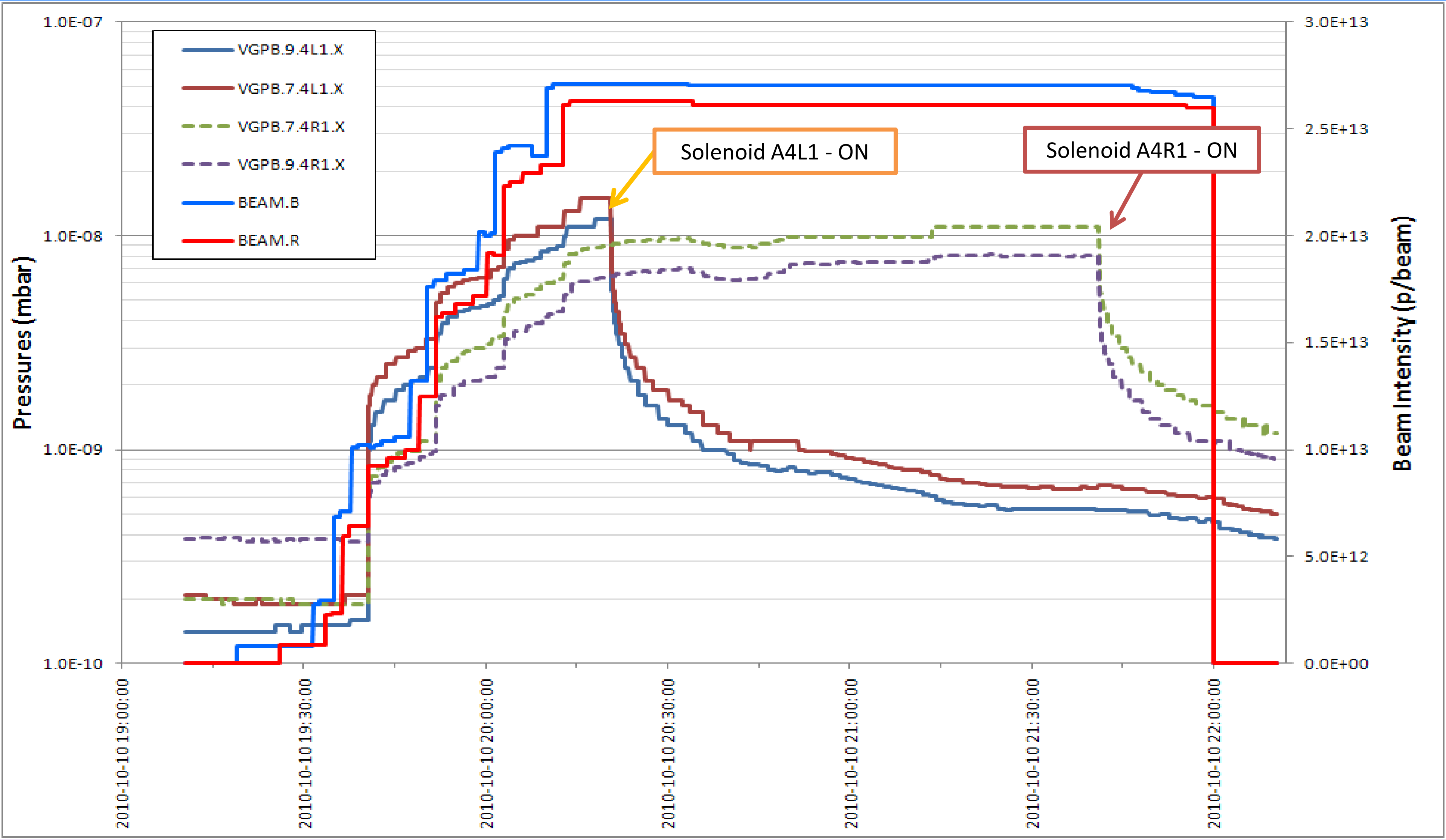
- In the LSS (Long Straight Sections)
  - Pressure rises in the pipes **with 1 circulating beam** explained by Synchrotron Radiation
    - Dependant only from the energy and total intensity
  - Pressure rises in the pipes **with 2 circulating beams** cumulates different effects:
    - SR induced by D1 or D2 bending magnets
    - HOM effects linked to the bunch length variations during the ramp
    - Electron stimulated desorption (Electron cloud) – Threshold effect

- Bigger effects observed in the Cold/Warm transition of the Inner triplets on Q3/DFBX side for ATLAS and D1 side for Alice and LHCb
  - Nothing in CMS, could be explained by the wake fields from the solenoid

- Vacuum cleaning will be very effective to reduce the pressure rises
  - Except in case of important water coverage – case of cold/warm transitions

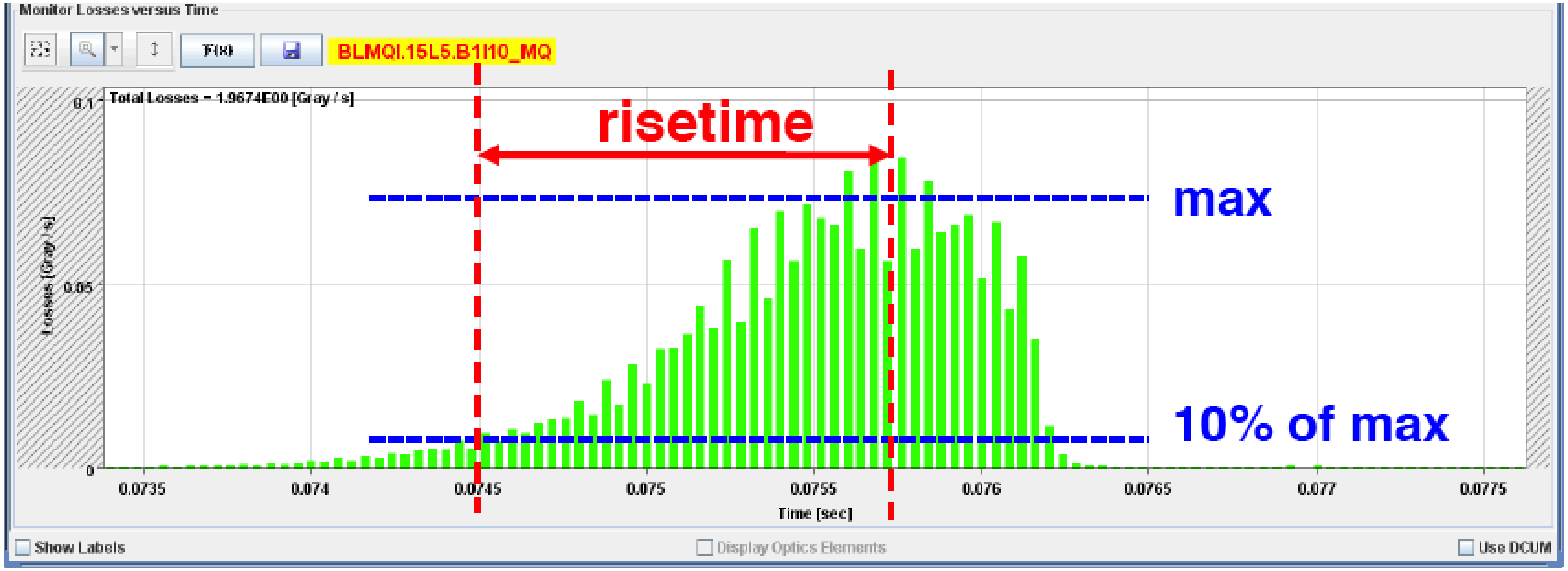
- TE-VSC Group recommends to continue increasing number of bunches
  - No risk for the vacuum system
  - Temperature diagnostics and solenoids installed (IR1)

Vacuum - effect of solenoids on pressure IR1

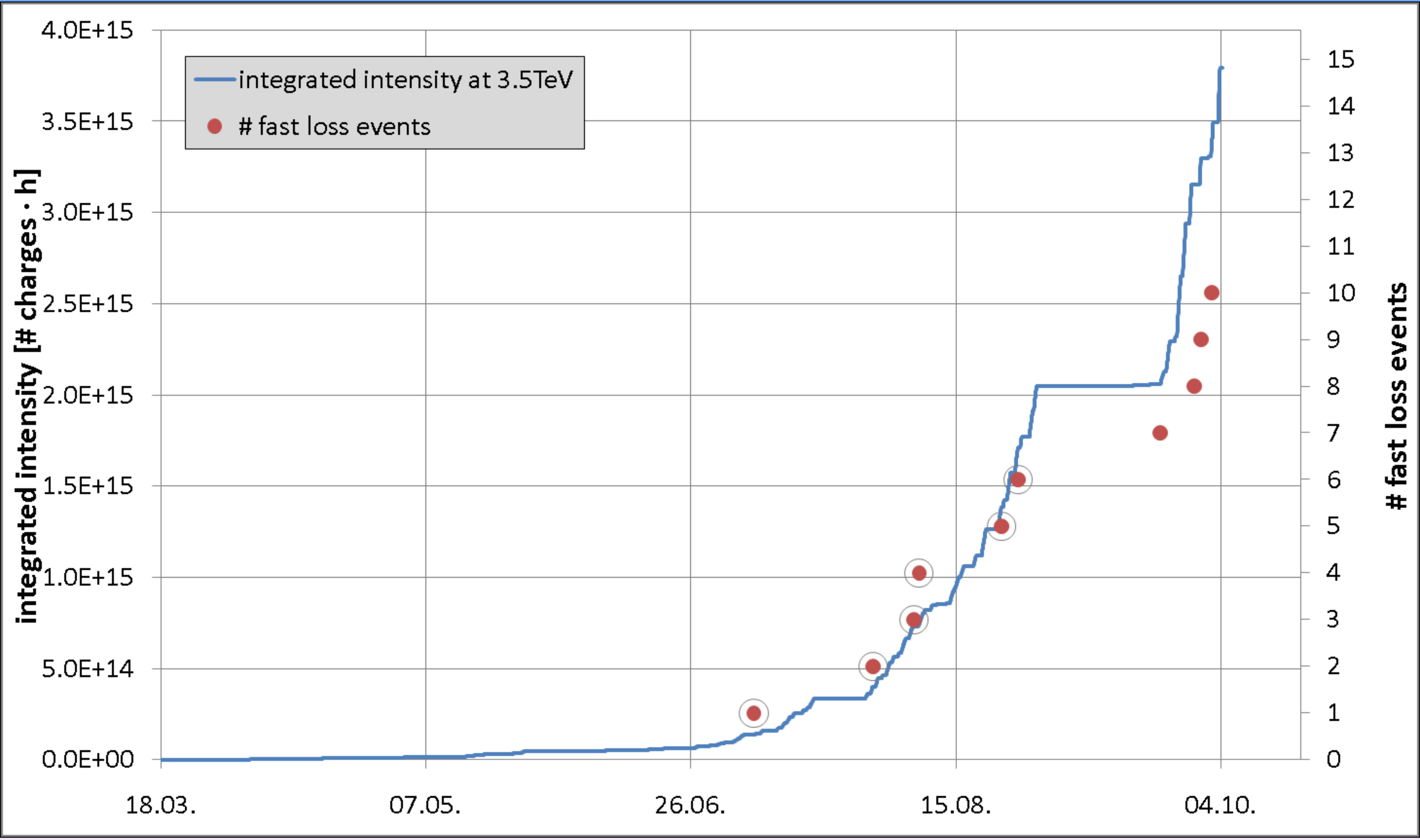


UFO - Unidentified Falling Object (fast local loss)

- Sudden local losses
- No quench, but preventive beam dump
- Rise time on the ms scale
- Working explanation: dust particles falling into beam creating scatter losses and showers propagating downstream



UFO - Worrying trend through the summer



Mitigated by change of BLM threshold

- UFO dump rate has gone down significantly since we increased the thresholds at SC elements (except triplets) by a factor 3.
  - *12 UFOs before change of threshold.*
  - *But there are still coming at a steady rate (see E. Nebot del Busto).*
  - *No quench with UFOs.*

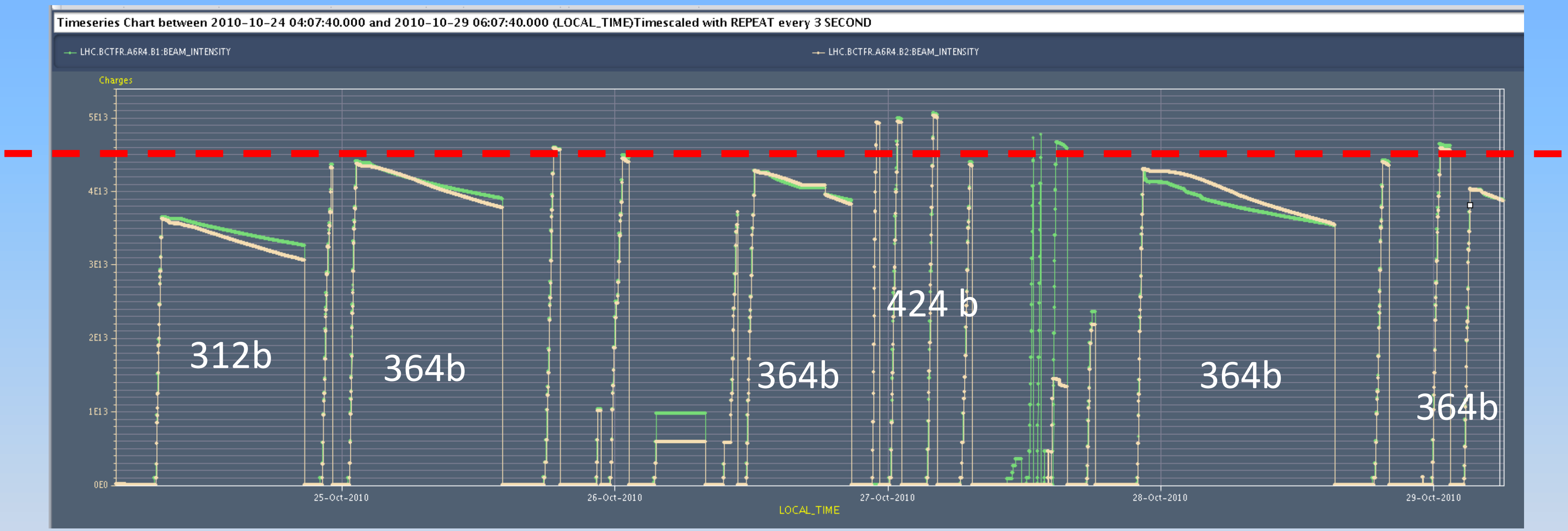
- 2 UFOs since threshold change:
  - *UFO near LHCb leading to dump by LHCb – not the LHC BLMs.*
  - *Ultra-fast and somehow non-standard UFO at BSRT.*

- Even though the UFO rate seems to be under control now, UFOs will become a problem if we ever increase the energy since the quench and BLM thresholds will come down again (factor 2-3 !).

- To be looked at/understood
  - UFO mechanism
  - Possible cleaning by beam
  - Actions for 2012 stop

Did we reach the intensity limit for 150ns ?

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: **25.2 MJ**

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150ns operation

50ns running

Ions

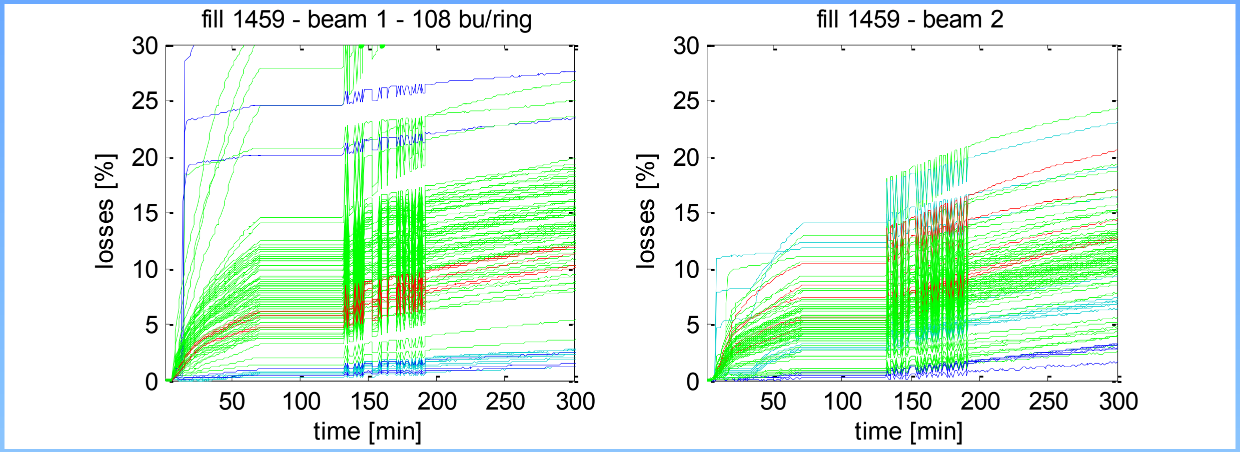
2011

50ns run (29/10 to 04/11)

- Motivation (in view of effects seen during 150ns operation)
  - Exploration of physics conditions with 50ns spacing
  - Injection and capture efficiency
  - Behaviour of Beam Instrumentation and RF and damper systems
  - Behaviour of vacuum system

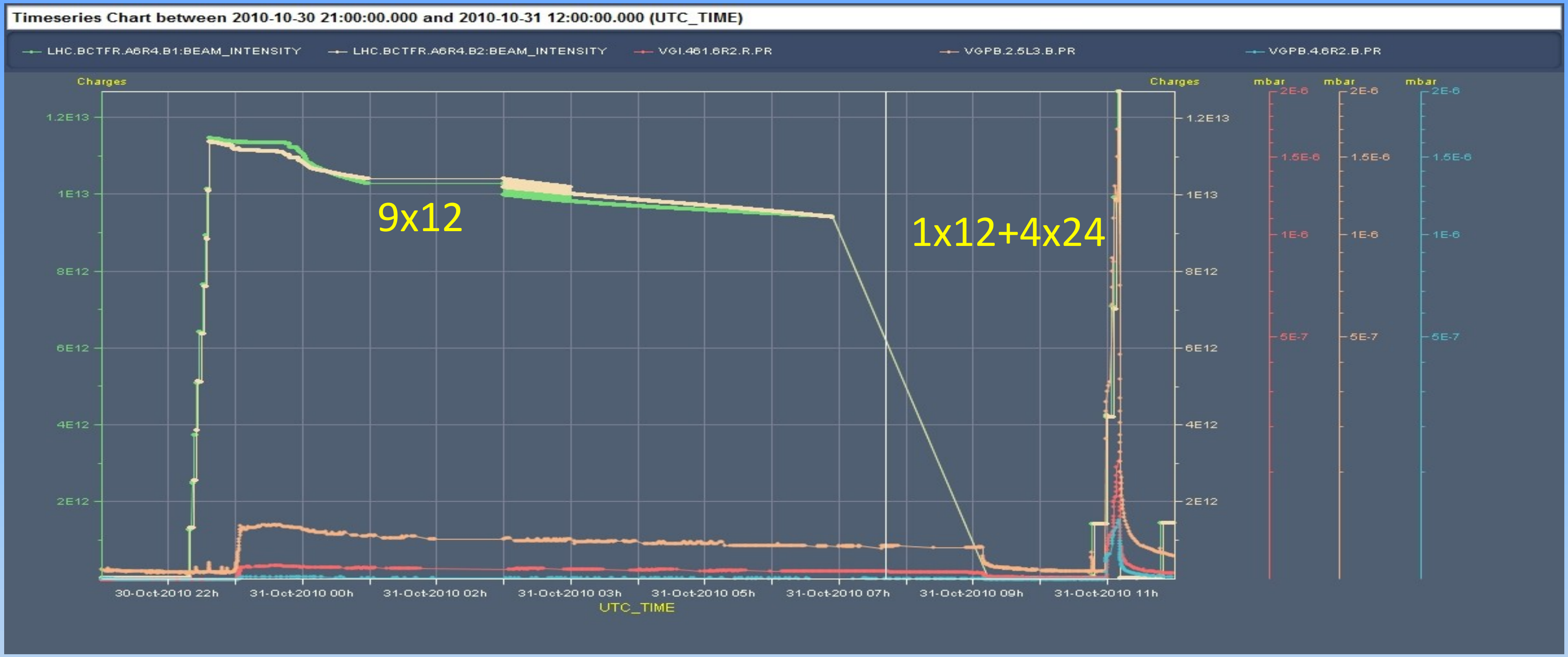
- Planning adapted as observations were made
  - Injection and capture of trains of 12
  - Physics fill with 9x12 bunches + end of fill beam-beam studies
  - Large increase in vacuum pressure when injecting trains of 24 bunches
  - Beam stability at injection
  - Systematic measurements of pressure rise in the straight sections and heat load in the arcs for different filling patterns to provide input for simulations and guide predictions:
    - Dependence on bunch intensity
    - Dependence on bunch train length
    - Dependence on bunch train spacing
  - Measurements for the characterization of the scrubbing

Physics fill with 9 x 12 bunches



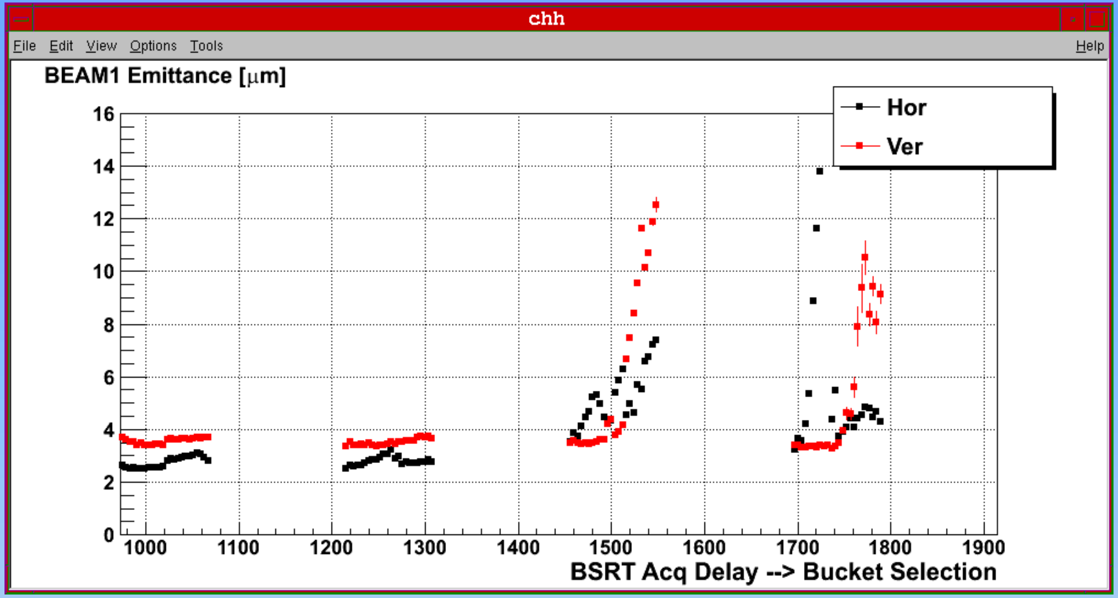
- Characterized by
  - Large bunch to bunch intensity spread
  - More losses when going in collision as compared to 150 ns
  - Beam unstable at the end of the squeeze (blow-up, tails?)
  - Bigger spread, due to the larger spread in intensity
  - Some patterns of the losses identified, more detailed study ongoing
  - Peak luminosity ~ 2.7 10^{31} cm^{-2} s^{-1} (450 nb^{-1} in 5 h)
  - Initial emittance from luminosity ~3 um (starting from 2-2.5 μm at inj)

Pressure rises with trains of 24 bunches



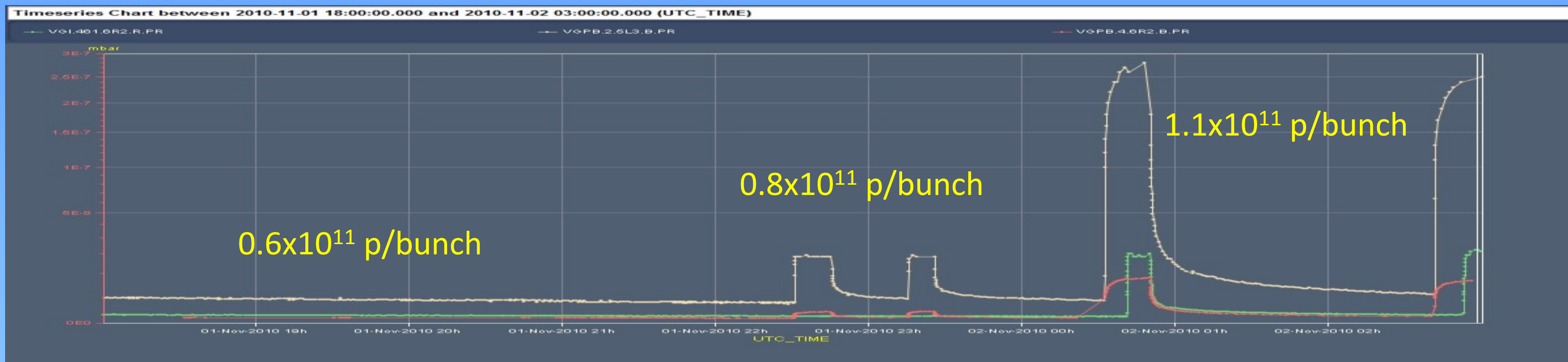
- Vacuum Interlock due to pressure increase on the penning gauges VGPB.773.6L7.R on the cold-warm transition of the Q6L7.R. Beams circulating in different vacuum chambers
- Unexpected for this number of bunches

Beam stability at injection

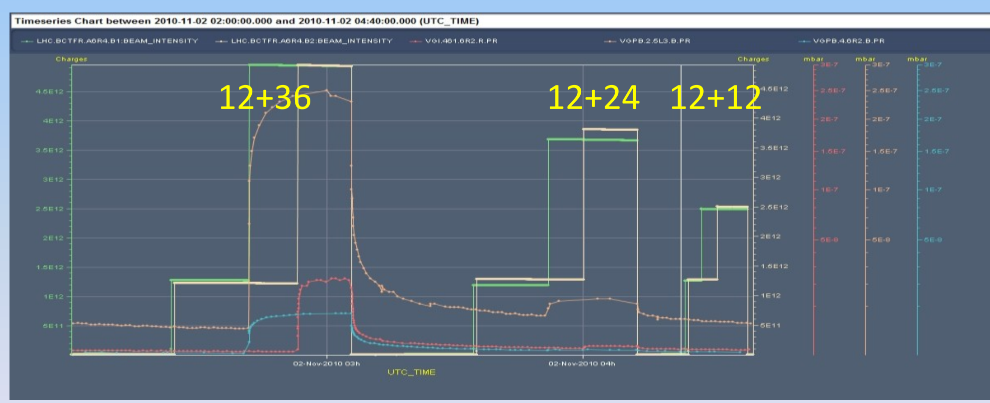


- 12 bunches + 4 trains of 24 bunches spaced by 1.85 µs
- Build-up of the electron cloud over more than one train leading to instabilities and emittance blow-up along the trains
- Consistent with preliminary results of simulations for SEY~2.5

Dependence on bunch intensity and train length

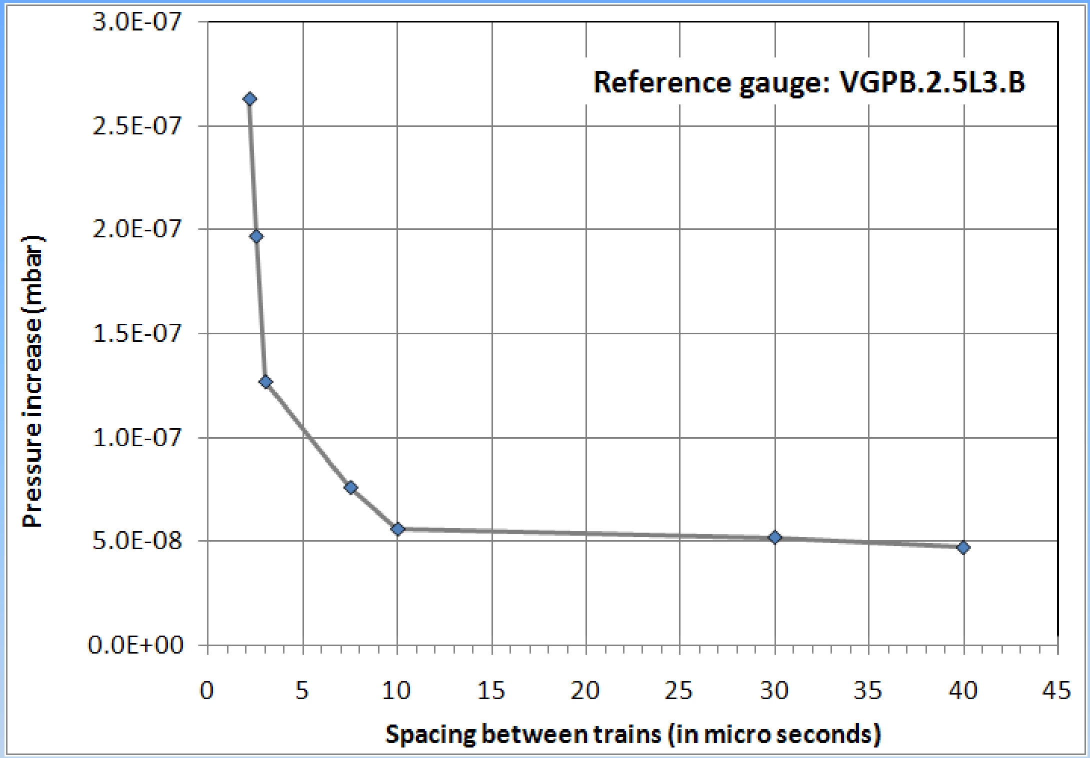


Threshold effect, starts between 0.6 and 0.8 10^{11} protons per bunch



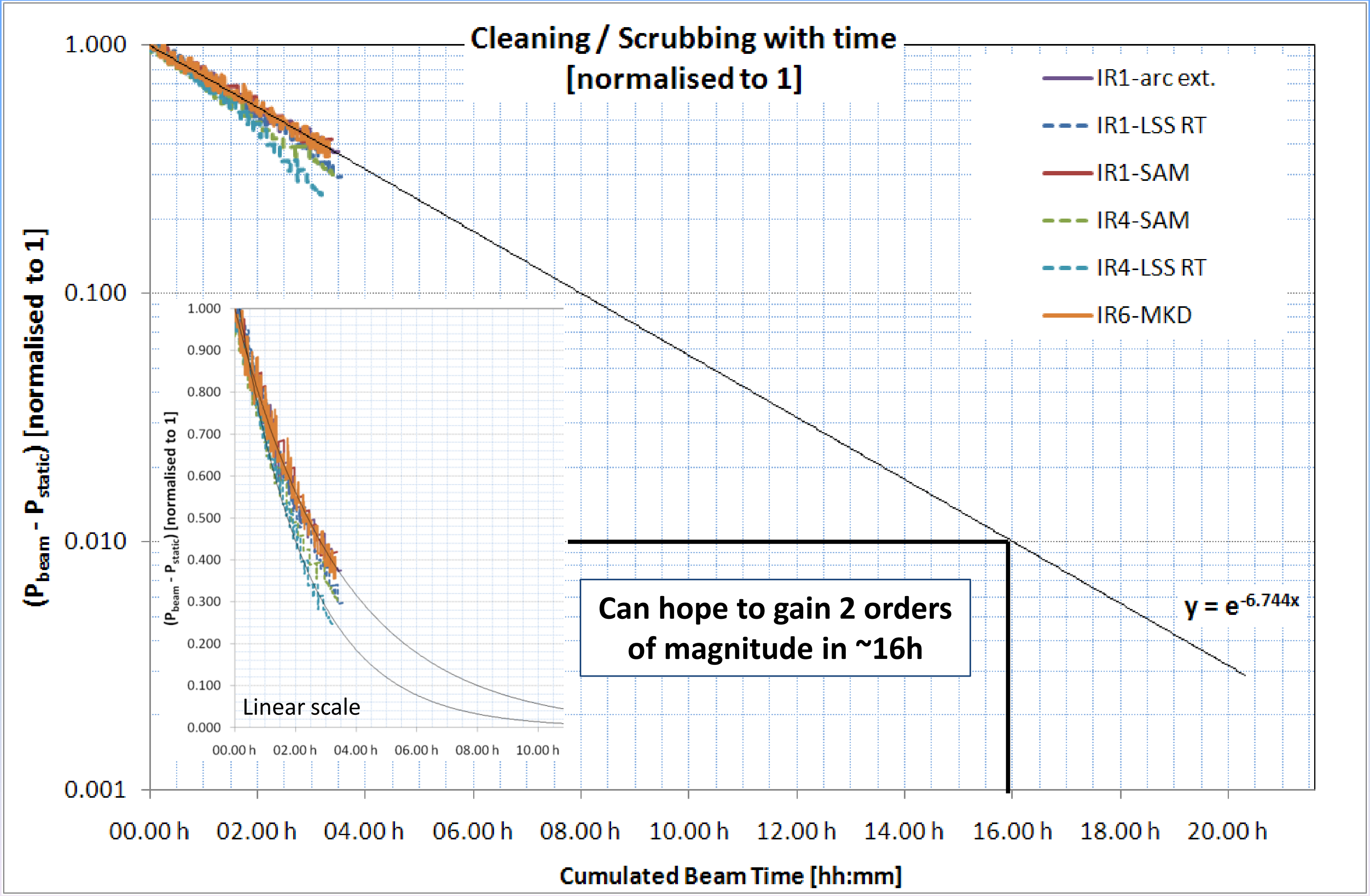
OK for trains of 12, not for trains of 24, worse for trains of 36

Dependence on spacing between trains



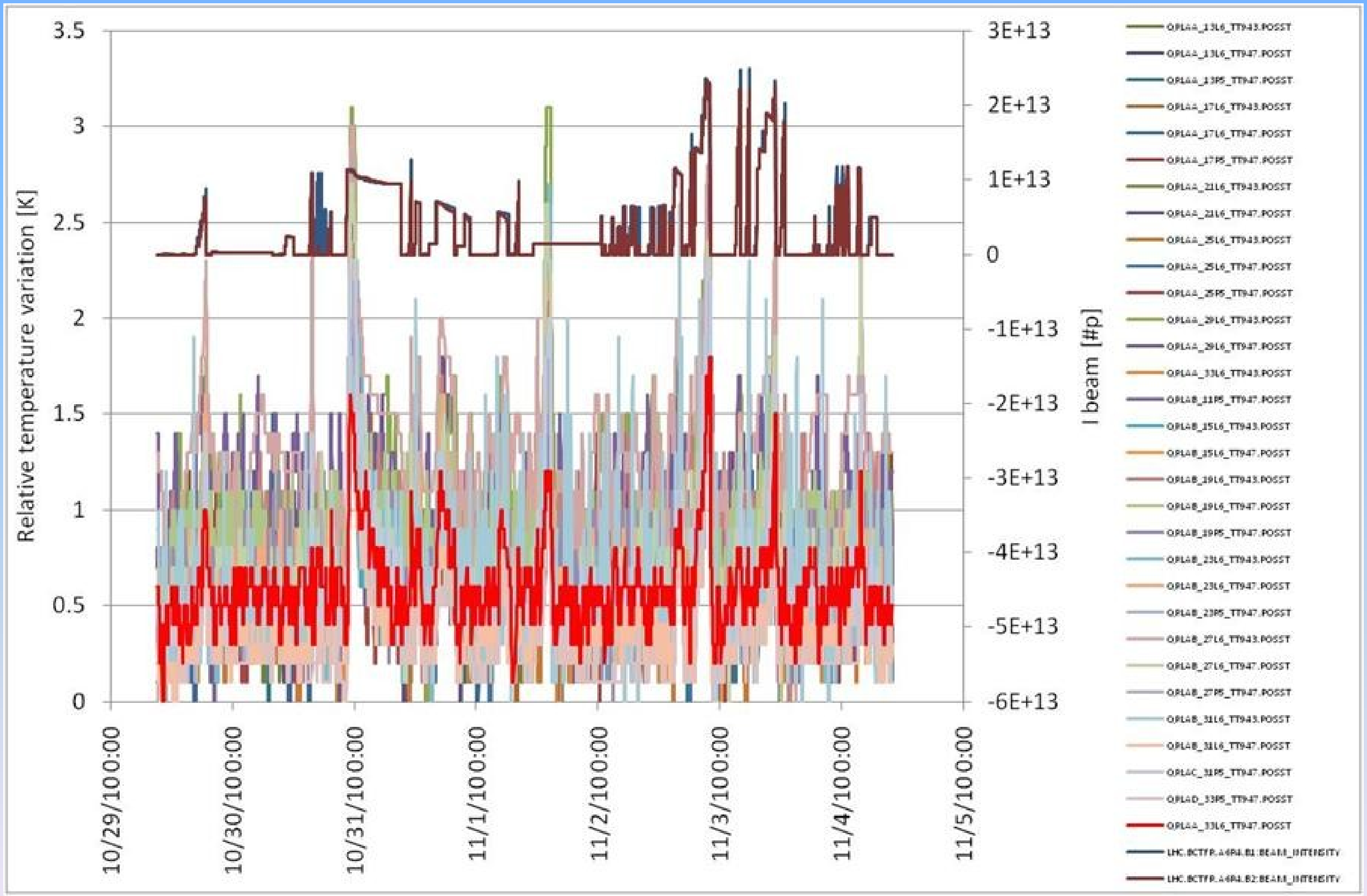
- Measurement made with 2 trains of 24 bunches
- Crosstalk between bunch trains starts at 10 μs
- Increases very quickly below 3 μs bunch train spacing

Scrubbing in the LSS



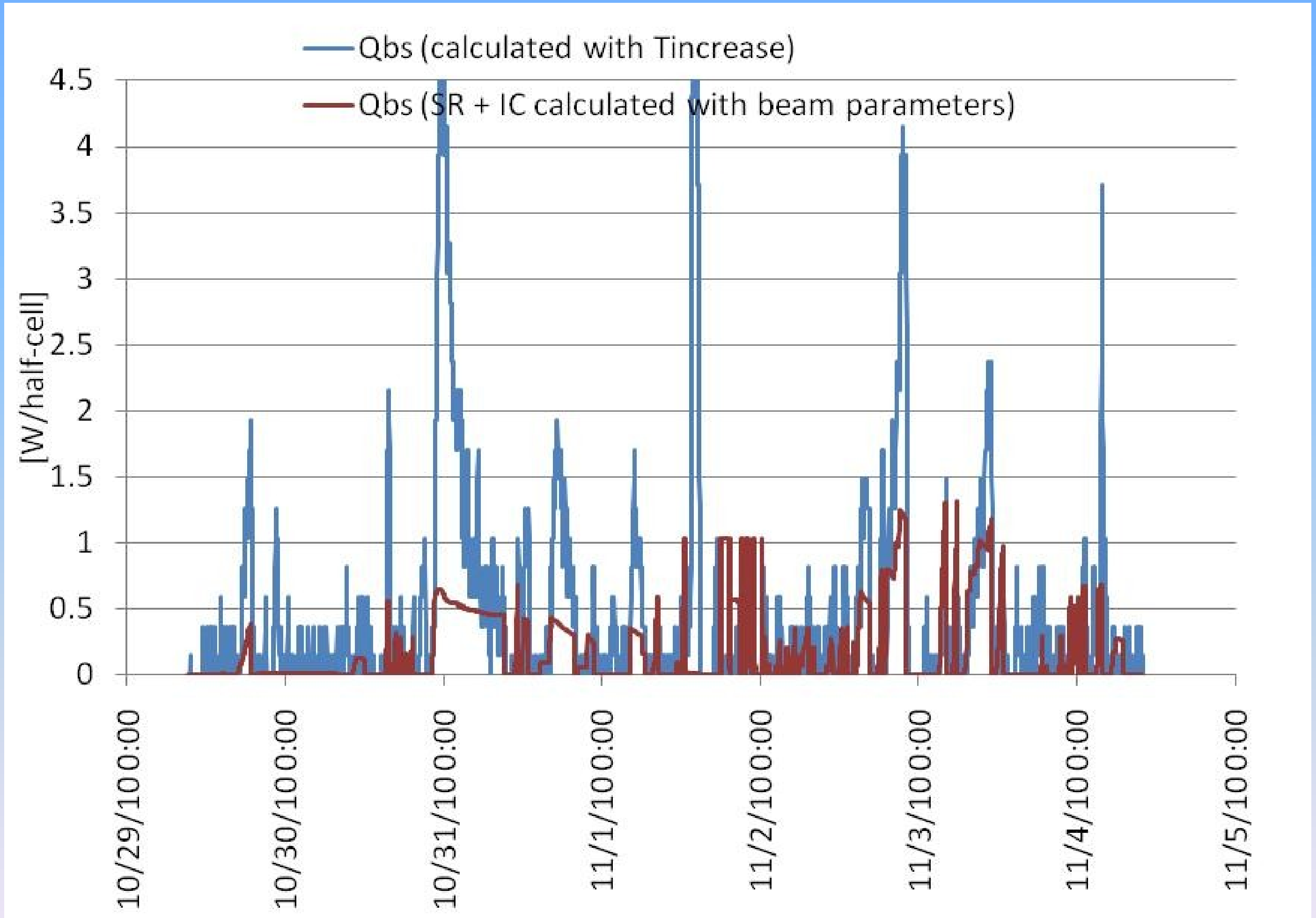
Heat load on beam screens

- Observed temperature increases on the beam screens in all the arcs in correspondence with 50 ns beam injection



Heat load on beam screen in 33L6

- Heat load dominated by sources other than Synch. Light and Image Currents on the beam screens → Electron-Cloud



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150ns operation

50ns running

Ions

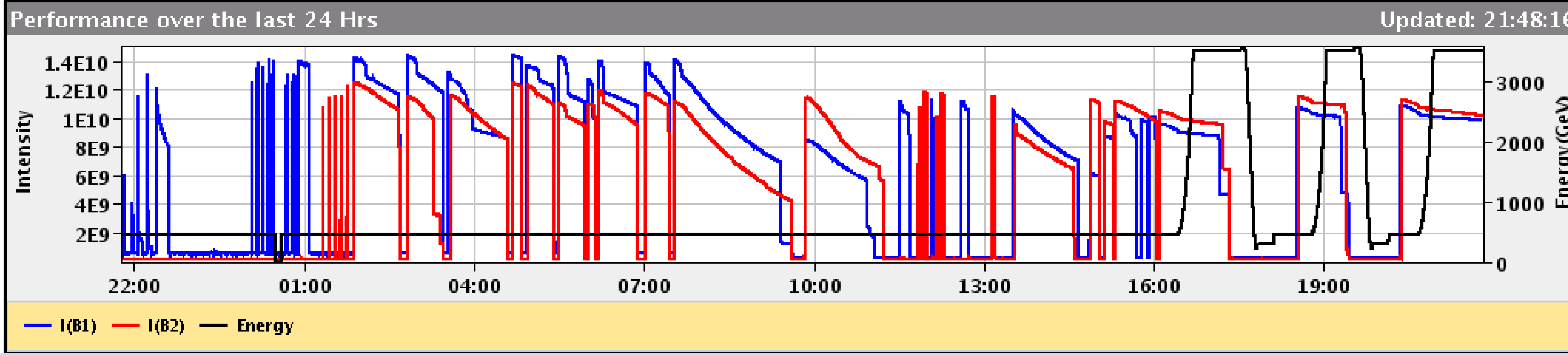
2011

Ion Commissioning: First 24h from Nov 4th !

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

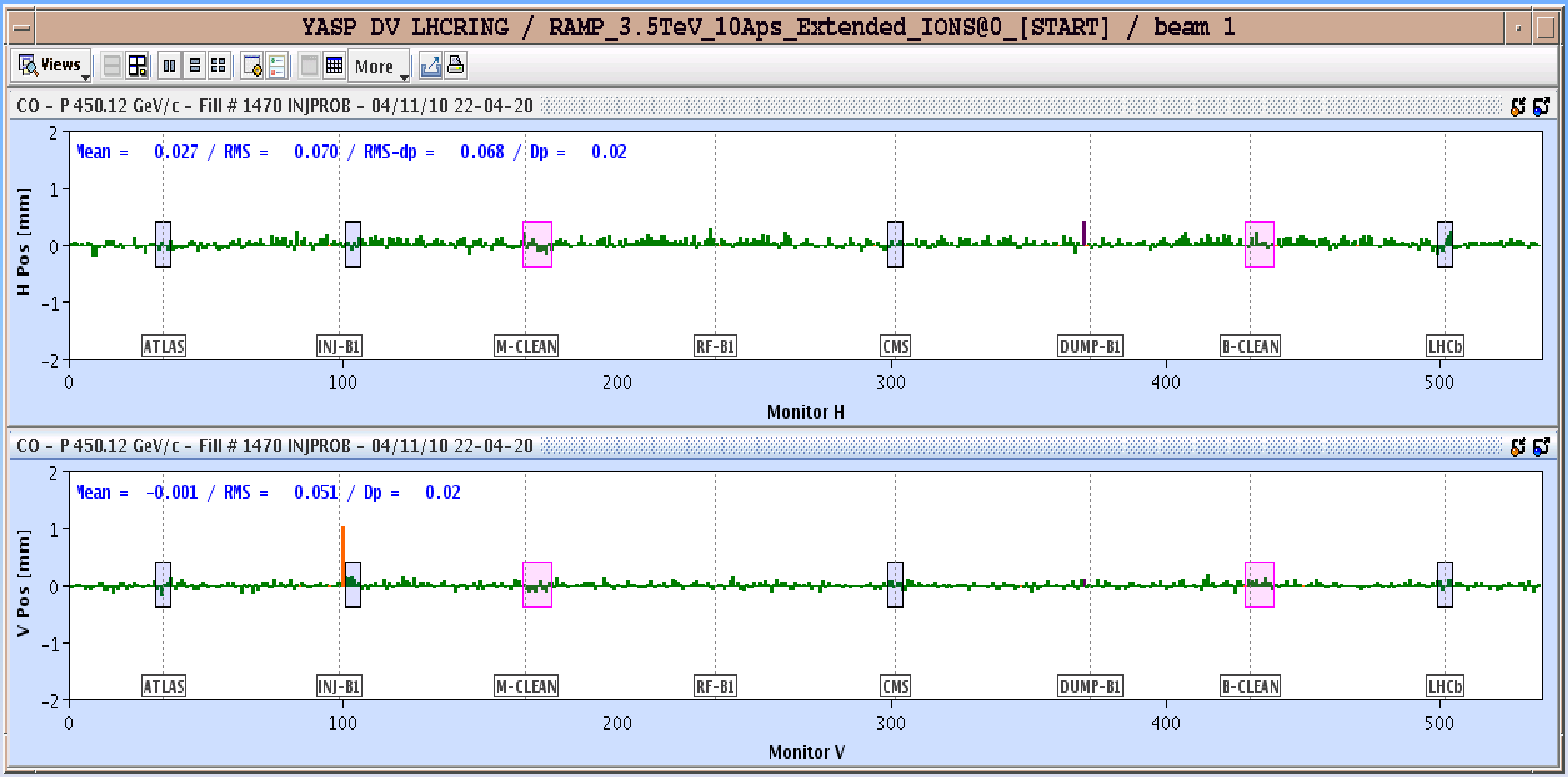
	ATLAS	ALICE	CMS	LHCb
Experiment Status	STANDBY	STANDBY	STANDBY	STANDBY
Instantaneous Lumi (ub.s)^-1	0.000	0.000	0.000	0.000
BRAN Luminosity (ub.s)^-1	0.000	0.000	0.000	0.000
Inst Lumi/CollRate Parameter	1.00e+00		0.00e+00	
BKGD 1	0.002	0.244	0.000	0.122
BKGD 2	0.000	0.000	0.000	0.407
BKGD 3	0.000	1.628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

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

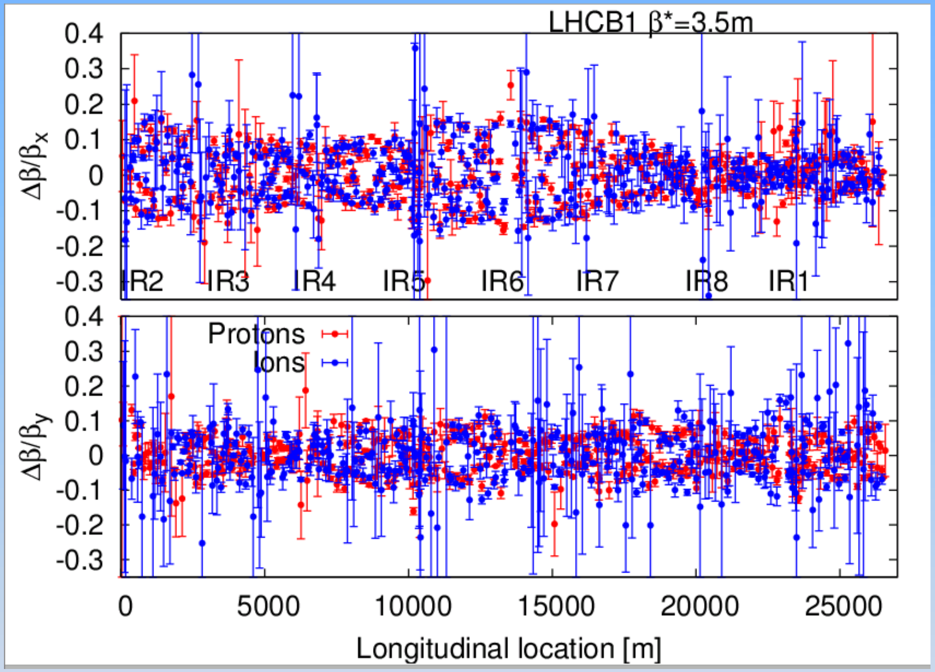


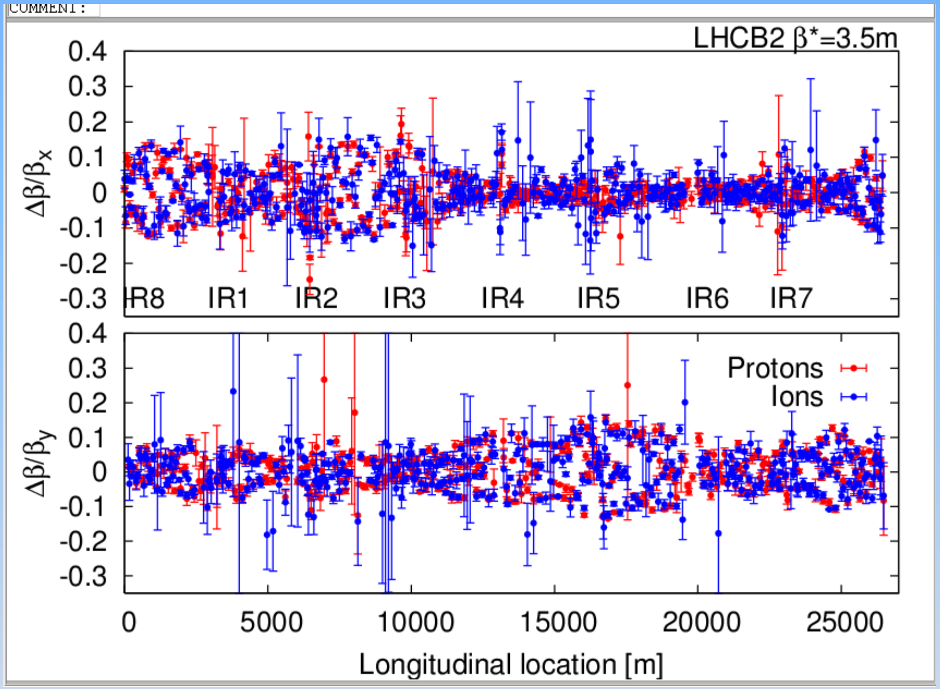
Beam 1 Inj., Circ. & Capture	Beam 2 Inj., Circ. & Capture	Optics Checks BI Checks Collimation Checks	First Ramp Collimation Checks Squeeze

Pb orbit compared to p orbit – no steering !

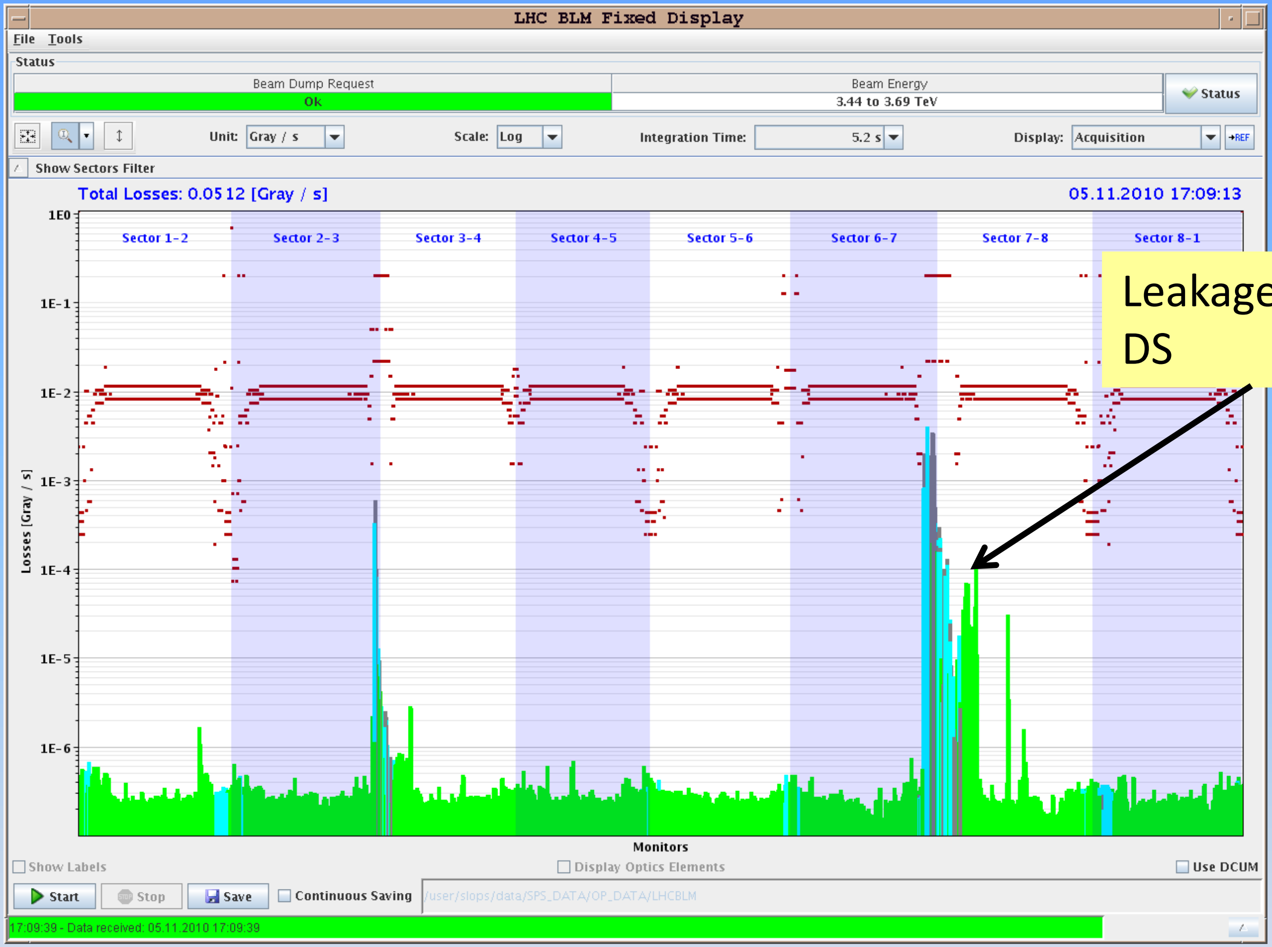


Optics comparison at 3.5 GeV 3.5 m





Collimation checks (loss maps)



- Lose about a factor 50-100 in cleaning efficiency for ions cf protons
  - Expected (ion fragmentation and dissociation)
- Main losses in predicted locations, namely the dispersion suppressors

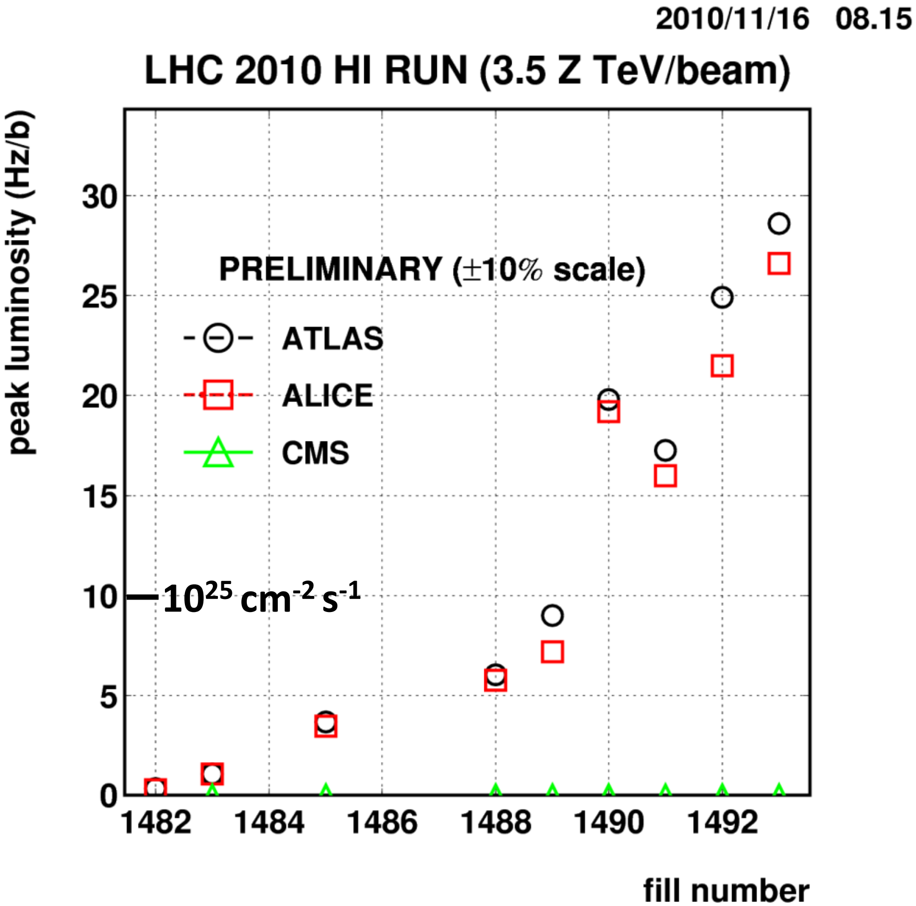
First stable beams (2 bunches per beam)

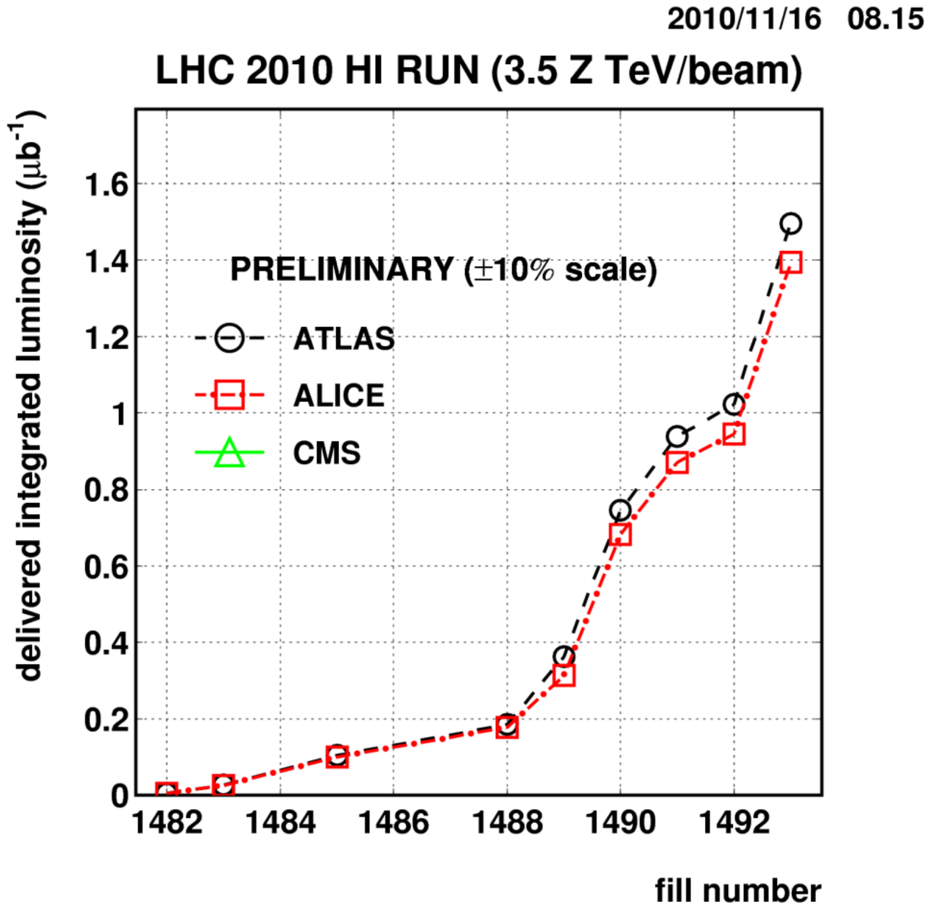
Characteristics and Evolution

- Injectors are giving us 70% beyond design single-bunch intensity of 7 10^7 ions/bunch, which is wonderful, but has consequences…
  - Significant IBS growth and debunching at injection, seems to be in reasonable agreement with theory
- Emittances at injection around 1-2 µm (with Pb gamma!).
- Emittances on flat top 1.5-3 µm
- Emittance blow-up in physics is not too bad, but mostly not IBS

Date	Bunches	Colliding IR2	Luminosity
November 8	2	1	3 10^{23}
November 9	5	4	5 10^{23}
November 9	17	16	3.5 10^{24}
November 13	69	66	9 10^{24}
November 14	121	114	2 10^{25}
November 15	121	114	2.8 10^{25}

Luminosity evolution (not quite up to date)





Single Event Upset (SEU)

- Primary ion beam losses are intercepted at the collimators
- Several features contribute to more severe ion loss problems
  - Nuclear physics: Ion dissociation and fragmentation reduce cleaning efficiency by factor ~100 when compared to protons (predicted since years, now confirmed).
    - Collimation upgrade (DS collimators) will solve this.
  - Ion beam lifetimes factor ~3-6 lower than for proton beams
    - Not yet understood
- Effects are clearly seen in Radmon monitors
- And in the equipment!
  - "QPS OK" lost on Q9.L7, communication to quench detector → Single Event Upset ("SEU"). Upgraded firmware in dispersion suppressors of LSS7 on Saturday
  - "QPS OK" lost on Q9.R7 and Q9.L7, FIP communication → SEU? No work-around available at the moment

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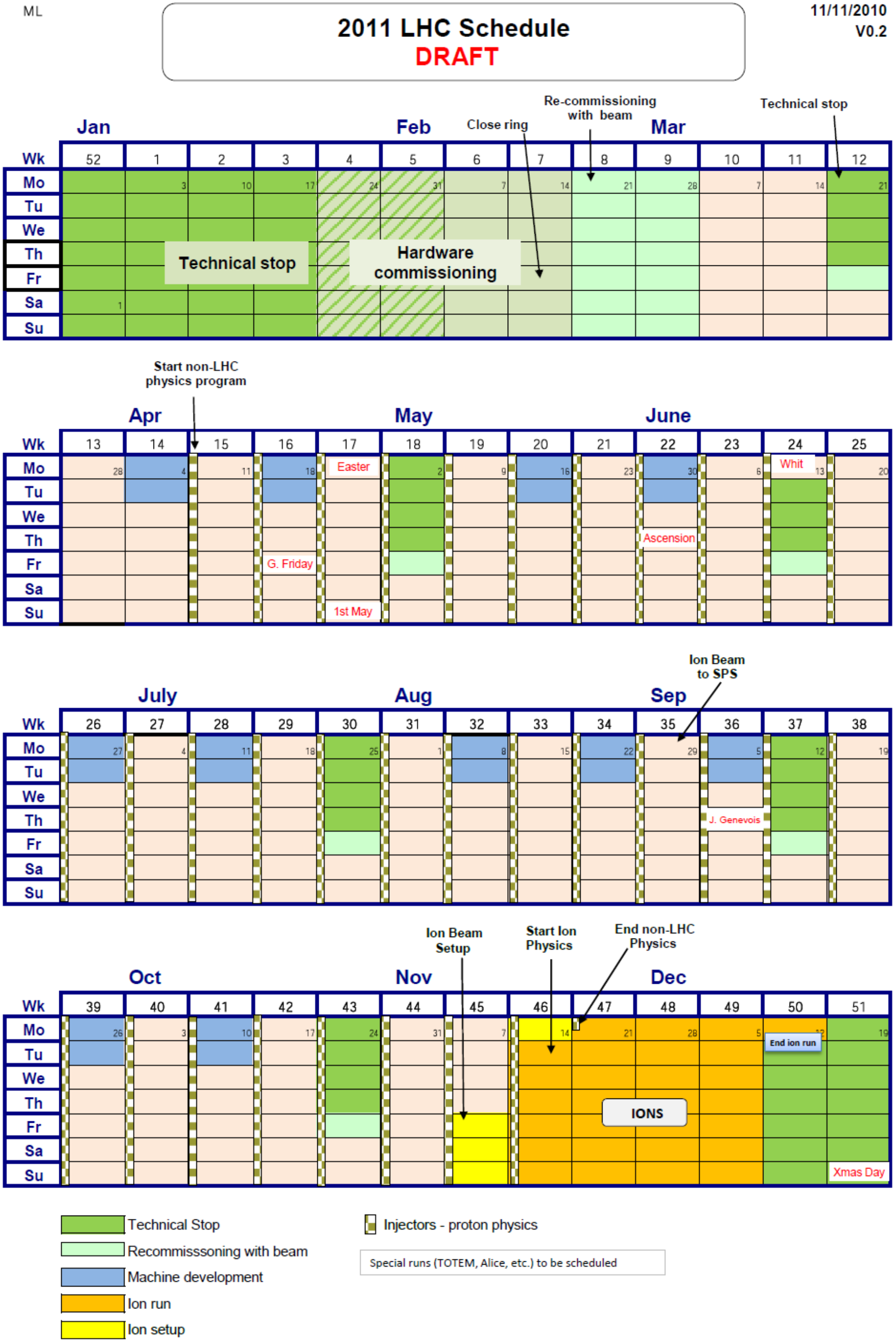

2011

- 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
- 1.2×10^{11} protons/bunch
- beta* = 2.5 m, nominal crossing angle

Peak luminosity	6.4×10^{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

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

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

Summary

- Bunch train operation with 150ns was a big success
  - Bunch intensity ~ nominal
  - Normalised emittance ε_n in collision ~ 2.5 µm
  - Maximum bunches/colliding 1 & 5 368/348
  - Peak luminosity ~ 2 10^{32} cm^{-2} s^{-1}
  - Delivered luminosity ~ 50 pb^{-1}
  - Plenty of interesting data
  - A few interesting (intensity-related) effects
- 50ns run
  - Very useful few days
  - Should allow definition of strategy for 2011 (together with ongoing studies)
- Ion run
  - Very fast switch from p to Pb
  - Quickly up to nominal performance for 2010
- Full debriefing and more at forthcoming workshops
  - Evian (December 7 - 9)
  - Chamonix (January 24 – 28)