Chamonix 2012
Sessions 3 & 4
Strategy for 2012

Chairs:

Jörg Wenninger & Oliver Brüning

Scientific secretaries:

Rogelio Tomás & Laurette Ponce

Sessions 3 & 4 - Strategy for 2012

- Experiments expectations, plans and constraints – B. Gorini
- Turn-around improvements – S. Redaelli
- Performance reach of the injector complex – R. Steerenberg
- Running the RF at higher energy and intensity – P. Baudrenghien
- Transverse damper – W. Hoefle
- R2E failure rates expectations – M. Brugger
- Beam Energy in the LHC for 2012 – A. Siemko
- Optics Options for the 2012 proton run – M. Giovannozzi
- Collimator Settings and Performance – R. Bruce
- Performance Reach in the LHC for 2012 – G. Arduini
- MD Plans for 2012 – R. Assmann
- Ions in 2012 – J. Jowett

Change in personnel

The CERN management could not find any other brilliant 20-fingered physicist

So it went for two “standard” ones

Emilio

Benedetto

Machine parameters

- β* configuration:
  - ATLAS and CMS: as small as possible.
  - LHCb: 3m - no change wrt 2011.
    - Compatible with the inclined crossing.
    - Provides a factor >= 2 for leveling.
  - Alice: from 10m to 3m.
    - Allow satellite-main filling scheme with natural satellites.
- Bunch length:
  - Increasing bunch length by up to ~10% would be acceptable
    - Recommendation: fix the ideal length before the start of physics and keep it stable

Spacing and pileup in 2012

- Experiments support **50 ns separation as a default scenario.**
  - **Provide as much integrated luminosity as possible (>= 15 fb-1).**
  - **Request to provide 5 fb-1 for ICHEP (→ for first week of June).**

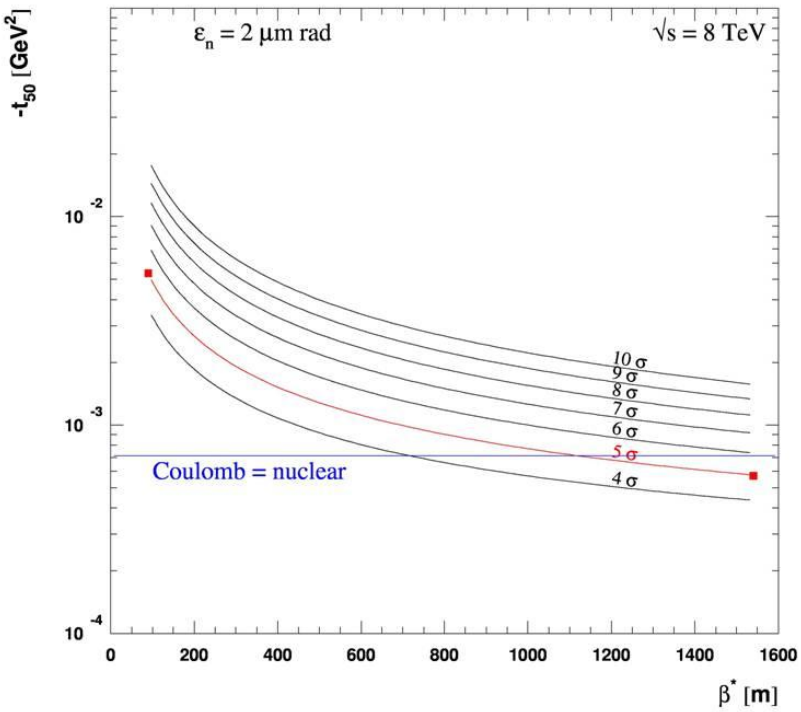
- No real show-stopper expected up to peak pileup of 30 **but:**
  - Detailed analyses still ongoing: if hard limits are identified, will need to investigate ways to cap the pile-up (lower bunch charge, lumi-leveling), even at the expense of some luminosity
  - For the longer term 25 ns remains the preferred scenario
    - Plan sufficient MDs to establish 25 ns feasibility
- ATLAS requests 10h of low pile up with a total of 10 million events.

Heavy ions

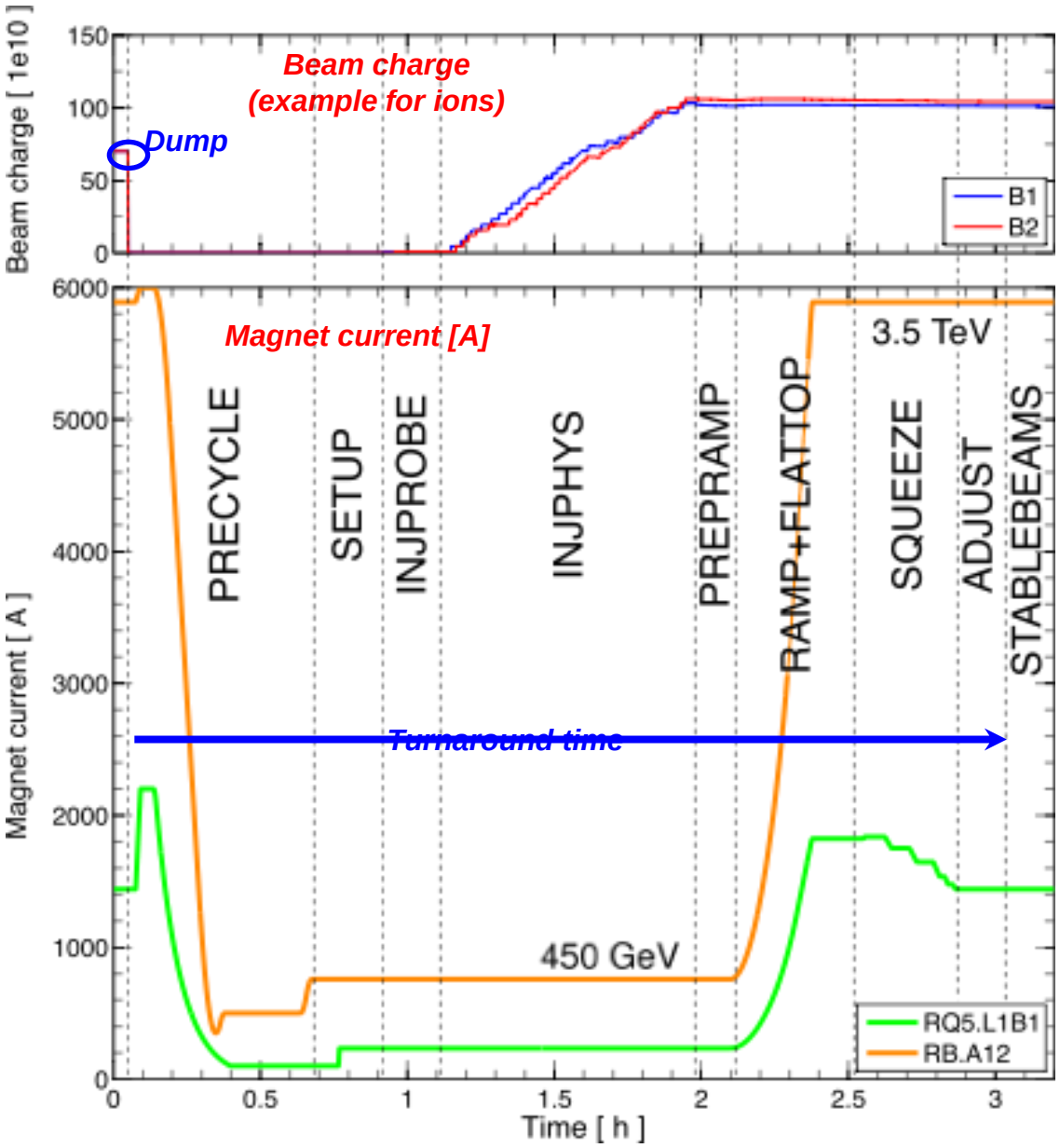
- The default plan for 2012 is to take data with p-Pb collisions only
  - ALICE requests both p-Pb and Pb-p beam setups.
  - Still unclear if ALICE will also need polarity reversals for both setups
- Energy of p-Pb
  - Most likely the request will be to run at equivalent proton energy of 3.5 TeV, but 4 TeV is still being considered
- Beam optics
  - Target is smallest β* for ALICE, ATLAS and CMS
- LHCb will also join the run for the p-Pb part
  - β* most likely 3m, filling schemes to be defined.
- Luminosity target for 2012
  - Expected luminosity ~3x1028 cm-2s-1
  - Integrated L of 30 nb-1 is a realistic target

High beta

- Two physics goals
  - Diffractive physics at β*=90m (mainly TOTEM)
  - Highest β* to approach Coulomb interference region for elastic scattering
- Only one physics run can be supported within the present schedule
  - Tentative proposal is to go for a mixed setup with 90m in IP5 and 500m in IP1



Recap.: operational cycle

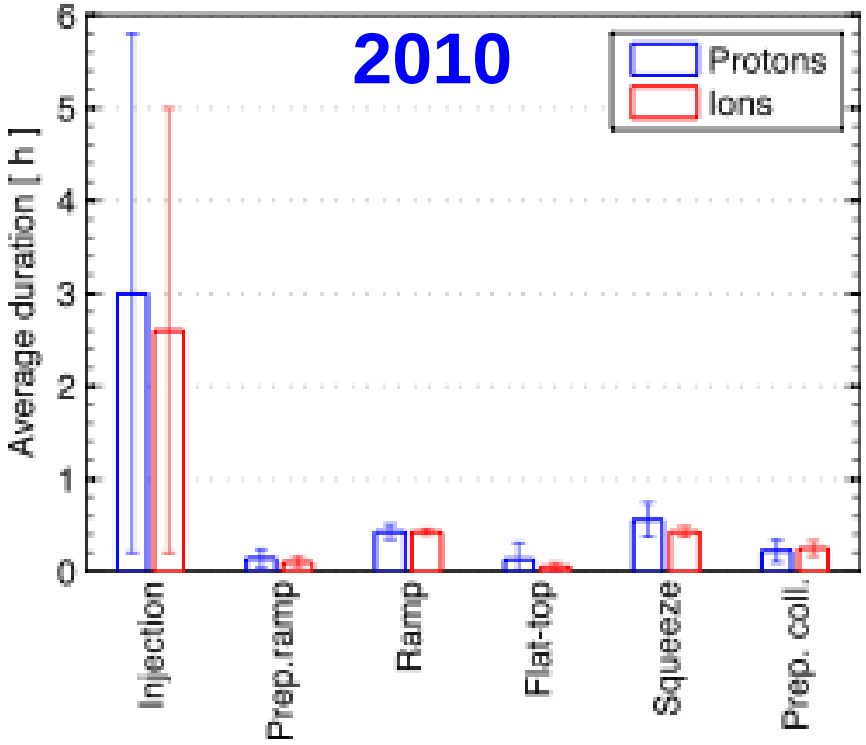


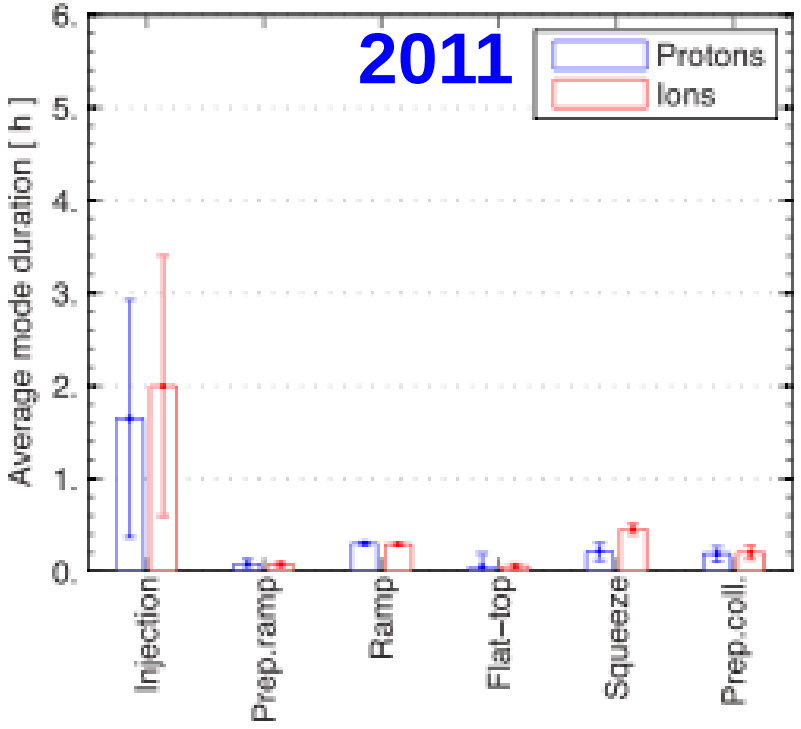
Time-functions *for settings of*
(1) ramp,
(2) squeeze(s),
(3) collisions,
(4) pre-cycle (without beam).

Discrete *("actual") settings for:*
(1) injection,
(2) prepare ramp,
(3) flat-top,
(4) adjust (end of squeeze),
(5) stable beams.

Remark:
Machine recovery after dump at top energy full yin the shade of the precycle → analysis starts from injection

Comparison 2010-2011 by mode (I)





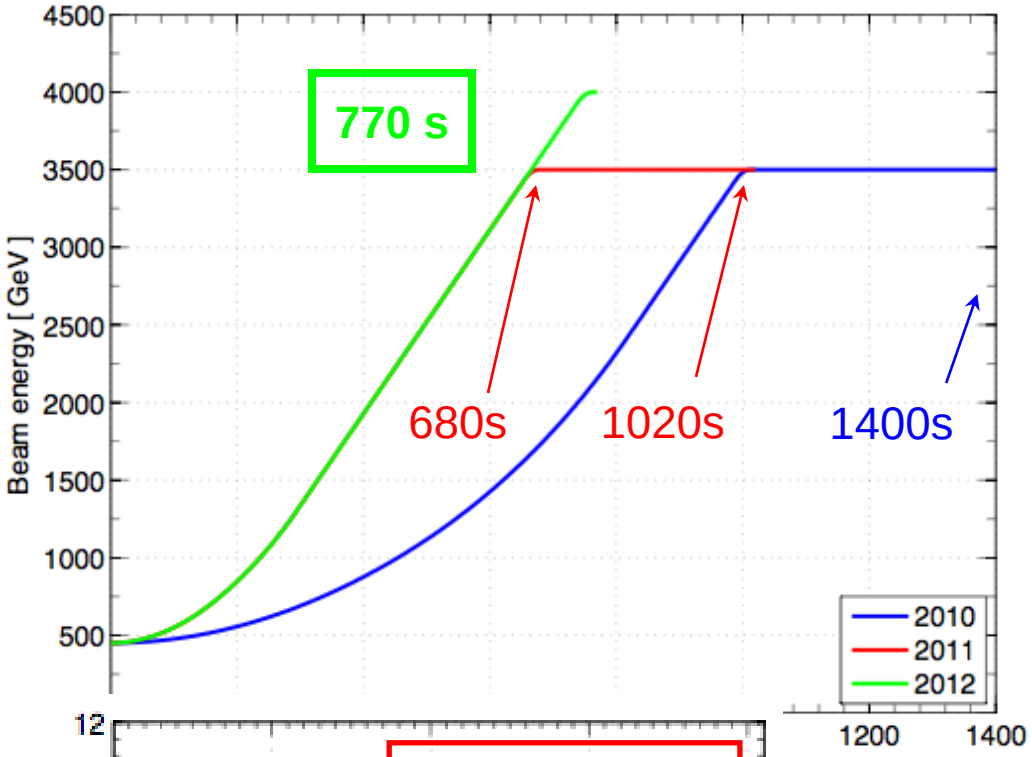
1. **Injection still drives the time to go back in physics**
2. **Nevertheless, the process was improved in 2011!**

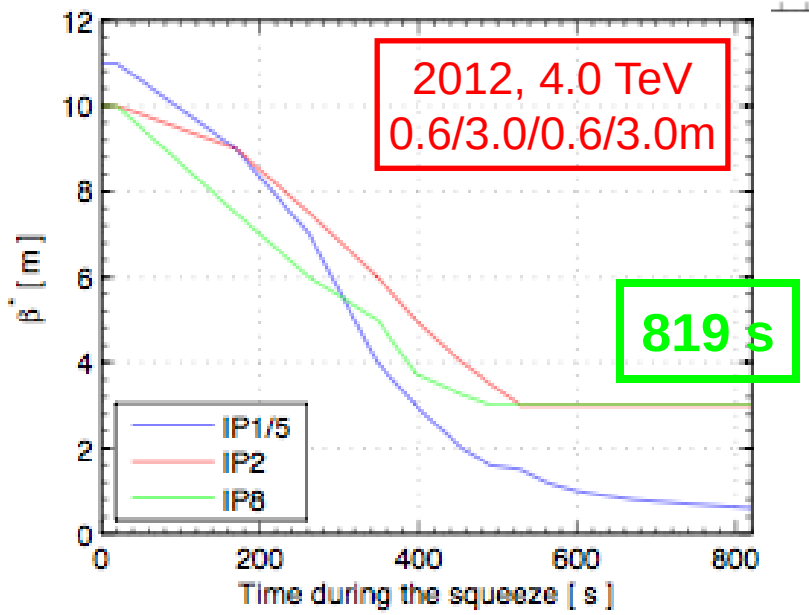
   On average we gained 1.4h with respect to 2010 (larger n_b)!

2010: averages over last ~30 fills; 2011: all proton fills since mid-May

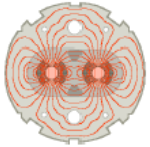
Ramp to 4 TeV & Squeeze in 2012

- Same optics and dipole parameters as 2011 give ramp duration of 770 s (4 TeV)
- Remove decay *plateau* at top energy
  - Move Q' correction from lattice sextupoles to spool correctors.
- Squeeze in 819 s (4 TeV, 0.6/3.0/0.6/3m)
- Improved feed-forward strategies





2012 parameter table (protons)



Parameter	Value at 450 GeV	Value at top energy
Energy [GeV]	450	**4000**
$\beta^*_{IP1/5}$ [m]	11.0	**0.6**
β^*_{IP2} [m]	10.0	**3.0**
β^*_{IP8} [m]	10.0	3.0
Parallel separation [mm]	2.0	**0.67**
Crossing angle IP1/5 [μrad]	170	**145**
Crossing angle IP2 [μrad]	170	**90^+**
Crossing angle IP8 [μrad]	170 (H)	**100 (V)**
Ramp duration [s]	2010: 1020	→ **770**
Squeeze duration [s]	2010: 548 (1.0 m)	→ **819** (0.6 m)
Collision BP duration [s]	2010: 56	→ **56**

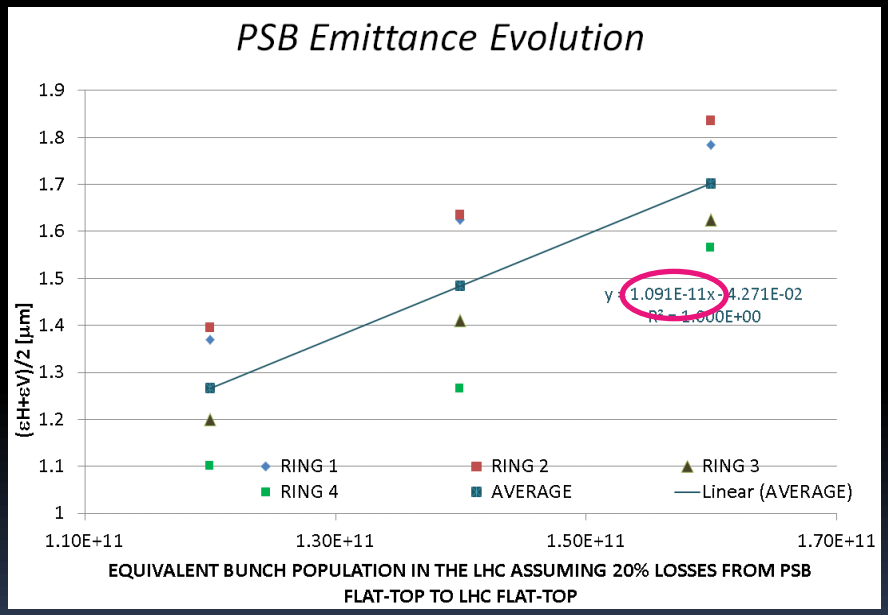
Injector performance in 2011

	Final Operationally Produced Characteristics 2011										
	PSB extraction				PS extraction			SPS extraction			
	Ip / ring [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb batches	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	ε_{longit} [eVs]	nb bunches
LHC25 (DB)	16	2.5	2	4 + 2	1.3	2.5	72	1.1 5	3.5	0.7	1 - 4 x 72
LHC50 (SB)	24	3.5	1	3 x 2	1.75	3.5	36	1.45	3.5	≤ 0.8	1 - 4 x 36
LHC50 (DB)	10	1.4	2	4 + 2	1.6	1.6	36	**1.5**	**1.9**	≤ 0.8	1 - 4 x 36

- Once the double batch 50 ns beam was taken by the LHC the performance was pushed throughout the injector chain:
  - Gradual intensity increases resulted in ~30% more than anticipated
  - Keeping the transverse emittances as small as possible (+27%)
- The 25 ns beam was for the first time produced within nominal specifications.

Possible gains

- Performance of the 4 booster rings is not the same !
- Since the PS beam is assembled from 2 PSB cycles using 4+2 rings, we could move to a 3+3 rings scheme and use the best rings !
- A schema with 3 injections 2+2+2 rings could be tested, but possible issues with beam stability at injection in the PS & even longer SPS cycles. Requires setup of completely new cycles.

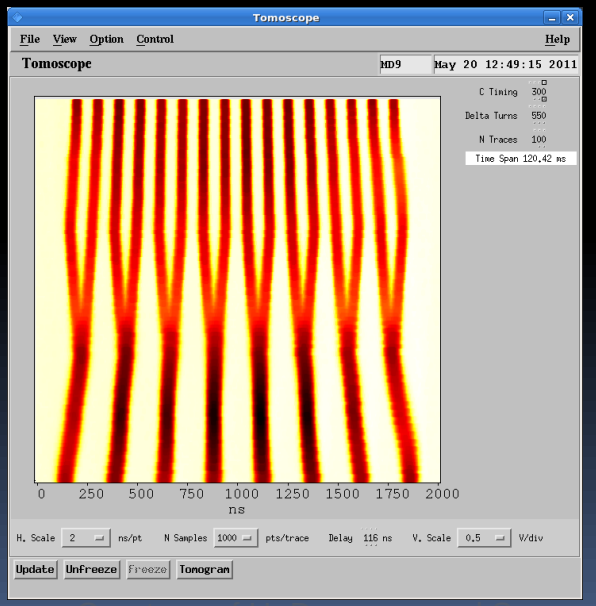


Courtesy of PSB team

Diagnostic and solution to be assessed prior to LS1

More advanced ideas

- A batch compression scheme, presented at Chamonix 2011:
  - Smaller transverse emittances for similar intensities.
  - Based on harmonic 9 at PS injection followed by batch compression and splitting.
  - Will become available to the PS and SPS later in 2012.
- LHC can most likely not profit from this new scheme before the end of the 2012 run
  - But tests in the fall not excluded !



Courtesy of H. Damerau and S. Hancock

Tentative 2012 Injector Performance

- It will be a slow process of small increases and careful adjustments.

	Tentative Operational Characteristics 2012										
	PSB extraction				PS extraction			SPS extraction			
	Ip / ring [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb batches	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	nb bunches	Ip / bunch [x10^{11}]	ε_h and ε_v [mm · mrad] 1σ, norm.	ε_{longit} [eVs]	nb bunches
LHC25 (DB)	16	2.5	2	4 + 2	1.3	2.5	72	1.1 5	3.5	0.7	1 - 4 x 72
LHC50 (DB)	11	1.6	2	4 + 2	1.8	1.9	36	**1.6**	**2**	≤ 0.8	1 - 4 x 36

- Might already not be compatible with SPS NA operation
  - No NA physics during preparation, filling and MD's ?

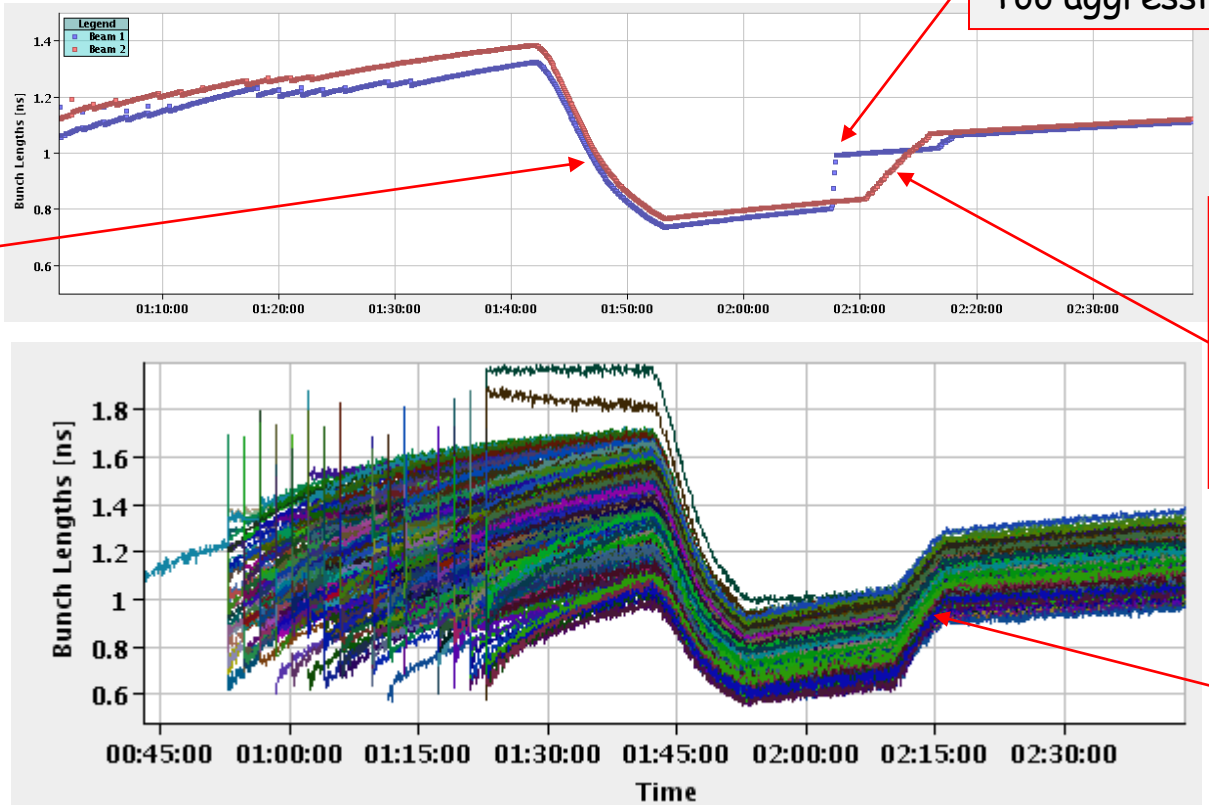
RF : new longitudinal blow up

- The first trial of the new blow-up, with Ions at 3.5 z TeV was very conclusive: regular bunch lengthening, equal for all bunches

First trial with B1. Too aggressive!

Ramping without blow up

Reduced noise power tried with B2. Very smooth and linear effect without feedback from bunch length



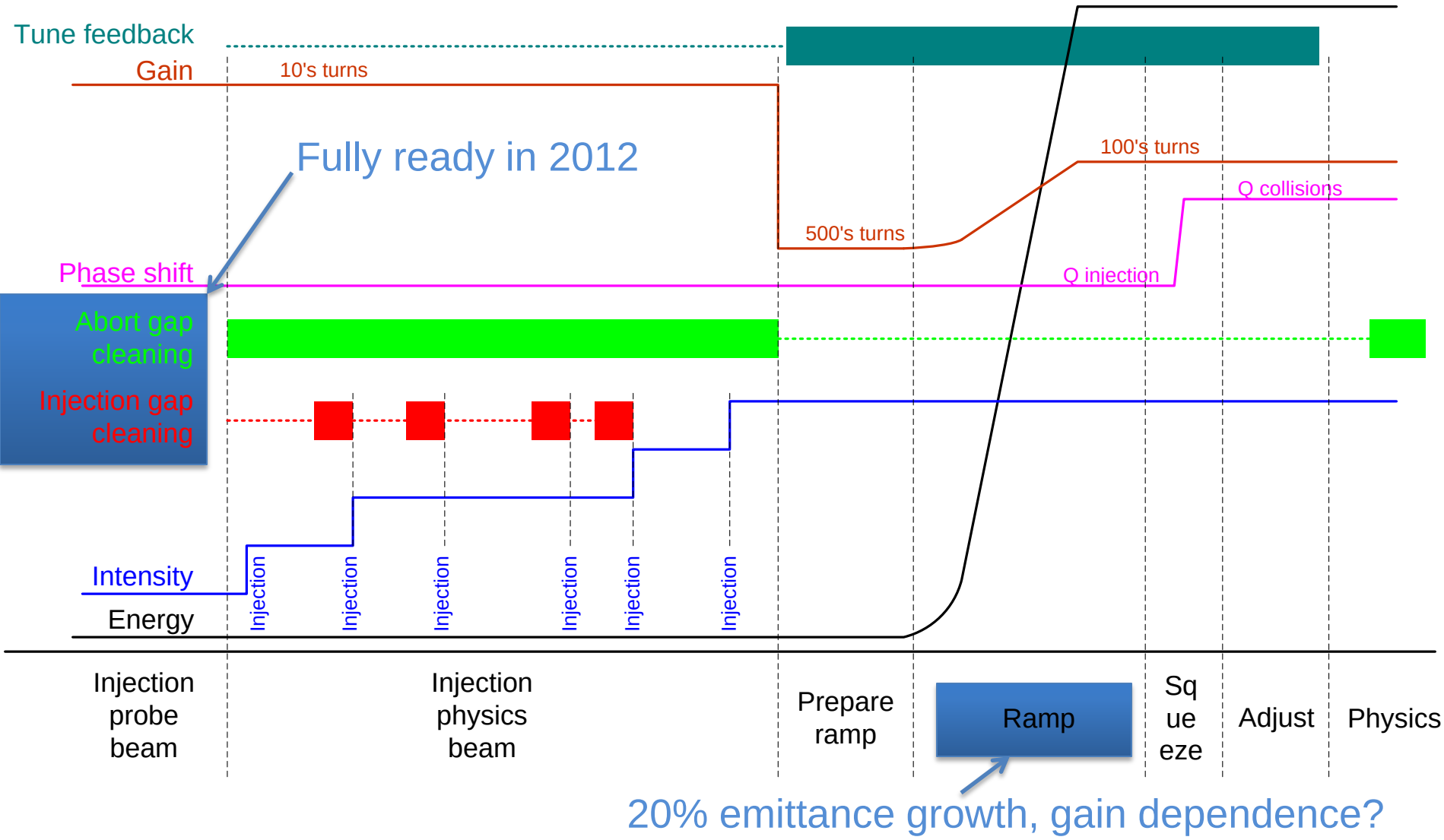
Same effect on all 358 bunches

Bunch length mean (top) and b-by-b Beam 2 (bottom), 358 bunches

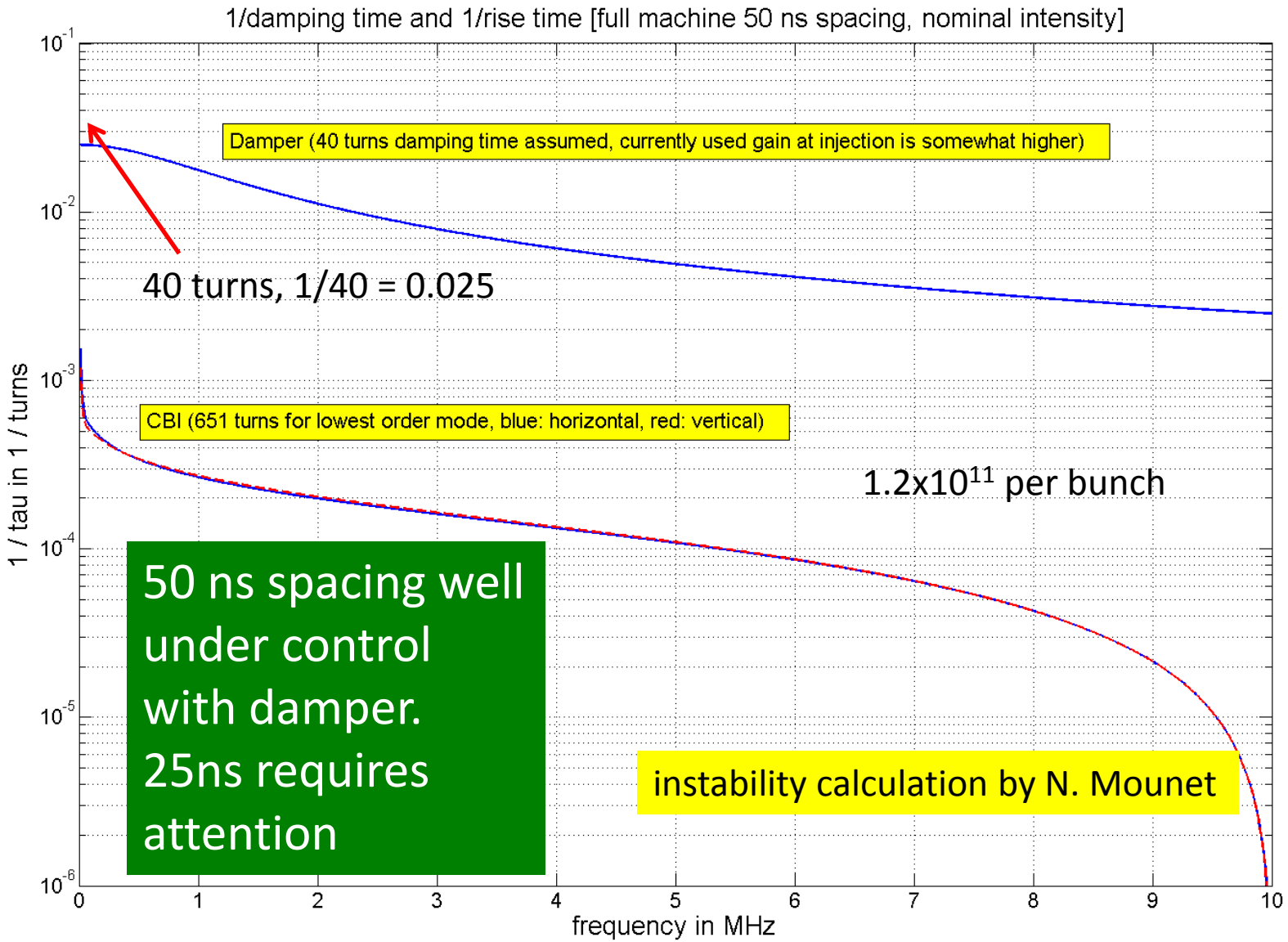
RF : higher beam energy and intensity

- In 2012 the RF group plans the following upgrades
  - Further reduction of capture losses with the longitudinal damper.
  - Modification of the blow-up method.
  - Batch per batch blow-up at injection → reduces transverse emittance blowup by IBS (~10% in 30 minutes!)
- Thanks to the longitudinal blow-up, the stability is independent on the energy. Operation at 4 TeV should not cause problems.
- RF has not seen the single bunch int. limit, circulated 3E11 ppb.
- RF can deal with nominal total intensity (2808b, 25 ns, 1.1E11) .
- Increasing bunch length helps for heating effects but in collision is limited to 1.4ns (dependence on beta*).

ADT through the cycle



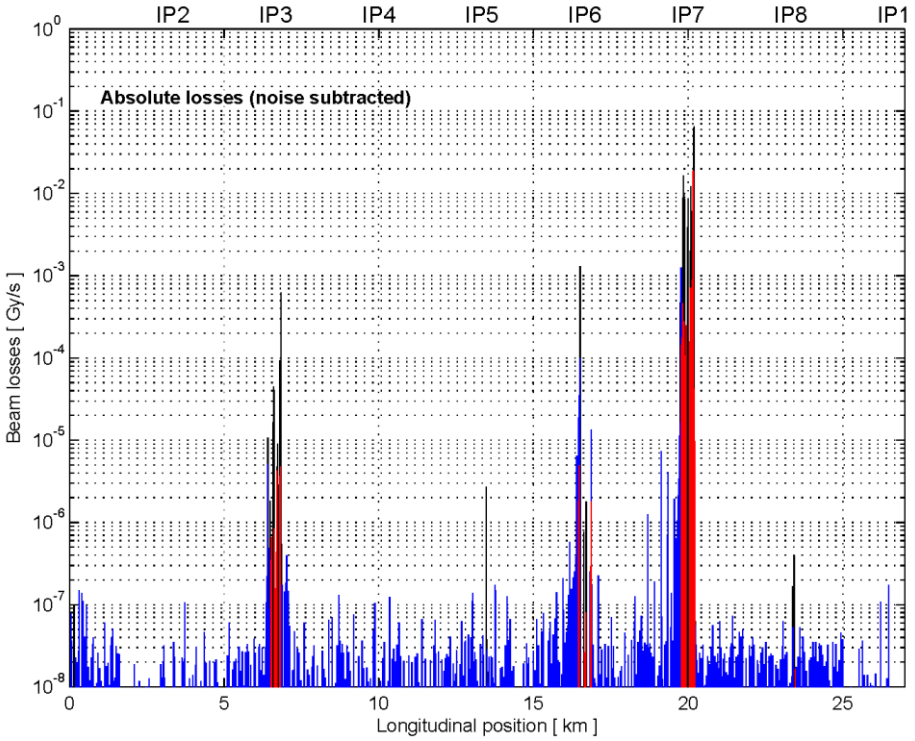
ADT with 50 ns spacing



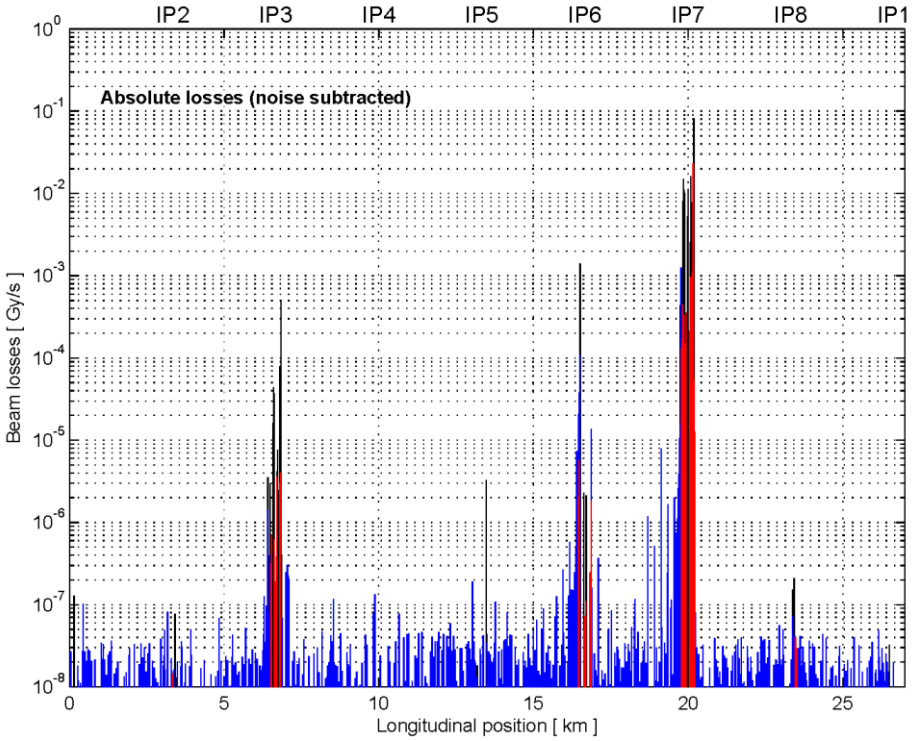
Bunch excitation and loss maps

- Loss maps with ADT blow up validated in MD in 2011.
  >> to be made operational during startup of 2012.
  >> large gain in time for loss maps.

damper (ADT blow-up) loss map



3rd order resonance



R2E expectations for 2012

Affected Equipment Group	LHC Critical Areas	2011 #ofDumps	2011 #ofFailures	Estimated Downtime (partl. in shadow)	2011 Avoided SEE Dumps	2012 Expected Dumps (No Additional Mitigation)	2012 Estimated Dumps (With Mitigation)
QPS	Tunnel, UJs/RRs	23	140	~60 hours	150	69	~20
Cryogenics	UJs	25	48	~250 hours	~25	75	1-2
Power-Converters	Tunnel, UJs/RRs, UAs	13	15	~30 hours	few (FGC)	39	10-20
Collimation Control	UJs (P1/5)	6	8	~20 hours	-	18	7
B/P/WIC	UJs, US85	3	4	~15 hours	1-2	9	0
Access	UJs	-	~4-8	~10 hours	-	-	
EN/EL	UJ56, US85	2	3	~15 hours	-	6	~1
	Totals	**72**	**~220**	**~400h**	**~180**	**216**	**~30-50**

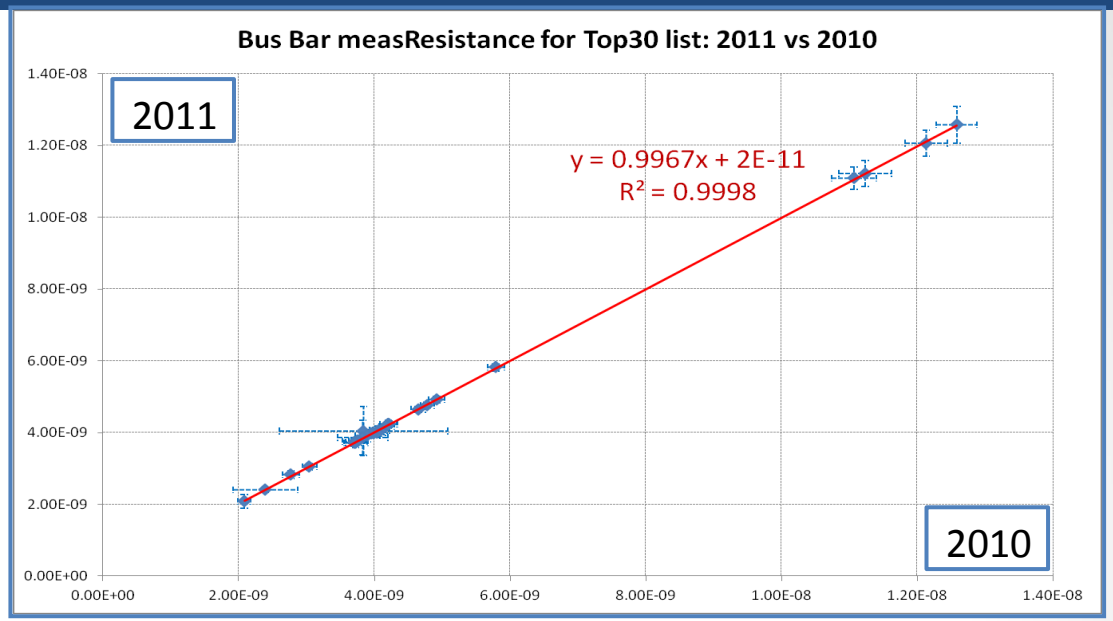
- xMas-Mitigation crucial: patch, shielding, relocat.
- Patches to continue during 2012
- Particular emphasis (analysis) of 'new' failures

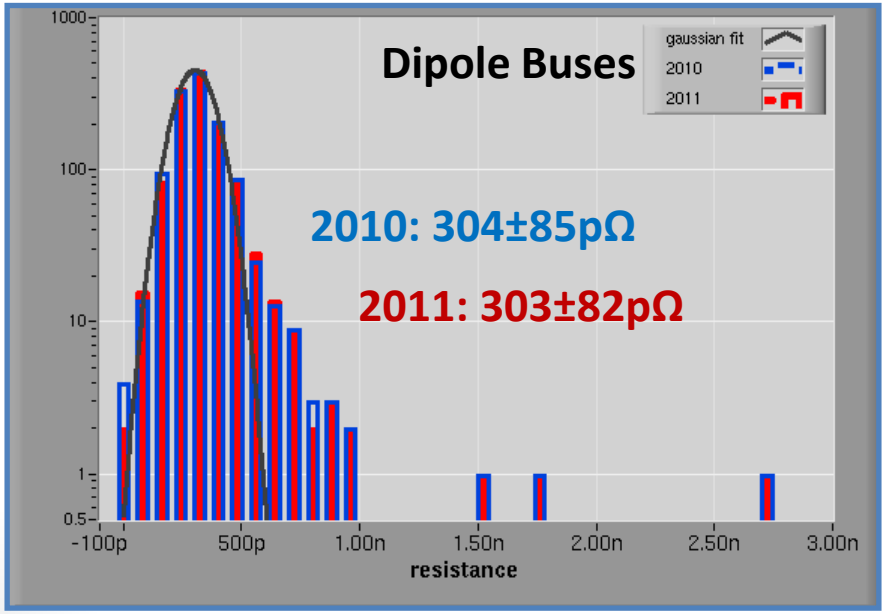
Status of SC cable splice resistances in LHC

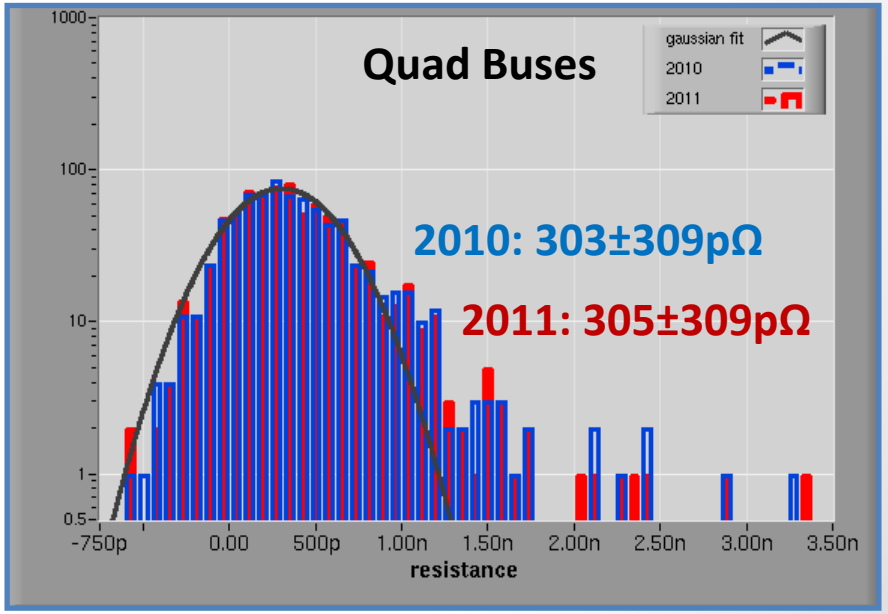
NO CHANGES OBSERVED! ☺

Top 30 list: $R_{spl,max}$>1.2nΩ

$R_{spl,max} = R_{segment} - (n-1)\cdot R_{spl,average}$

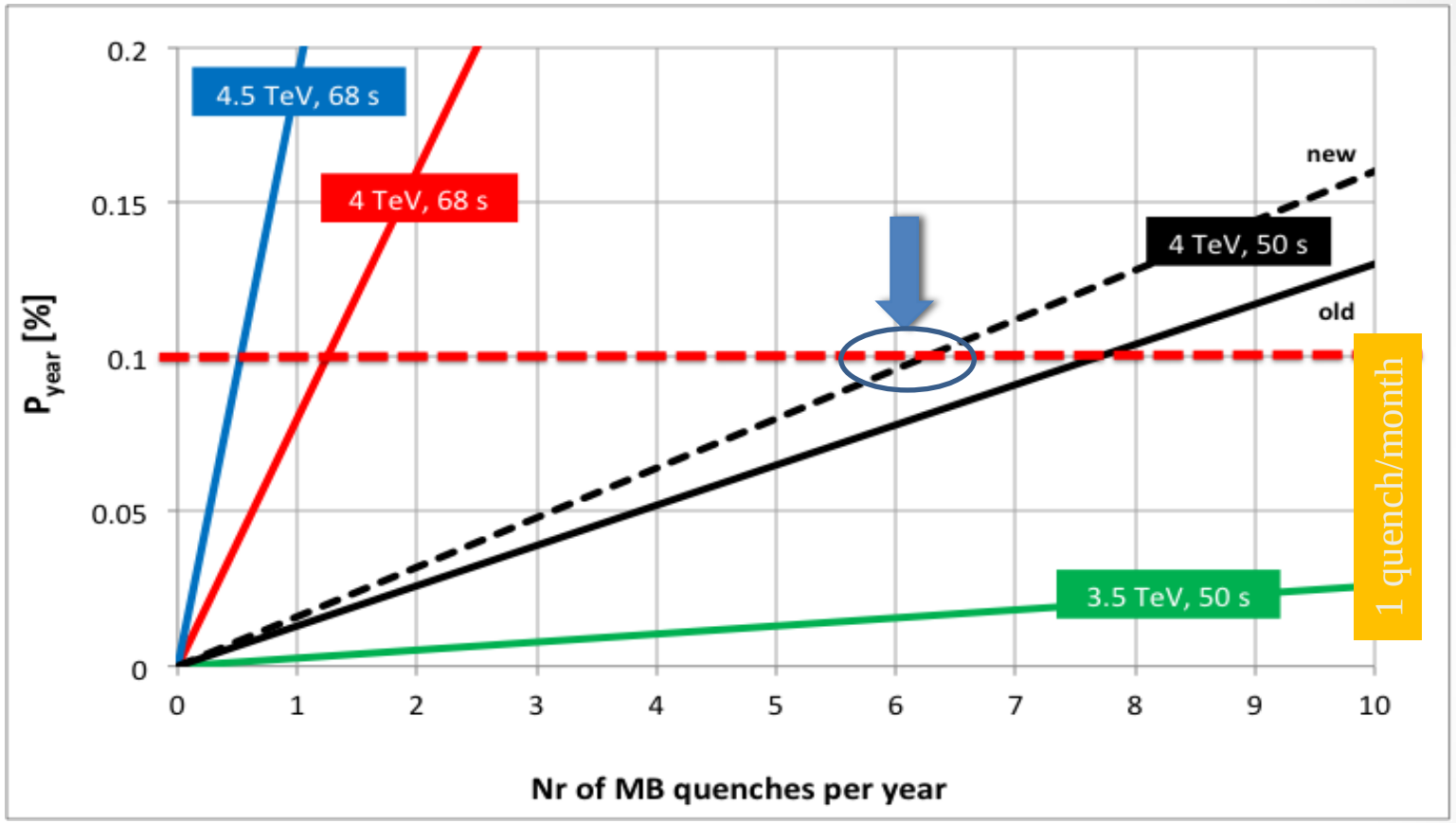






(*) $R_{spl,max} = R_{segment} - (n-1)\cdot R_{spl,average}$

What is the envisaged maximum beam energy?



- If during 2012 the number of high current quenches stays below 5-6 then we have the same probability of burn-out as during 3.5 TeV run in 2011 with 40 quench limit

No show-stoppers from equipment point of view to operate LHC in 2012 at maximum beam energy of up to 4.00 TeV

Proposed configurations 50 ns & 25 ns:

Key assumption	50 ns	ATLAS	Alice	CMS	LHCb
Quadratic sum of tolerances	Beta* (m)	0.60	3	0.60	3
	|half cross angle| (μrad)	145	90	145	230-250
Linear sum of tolerances	Beta* (m)	0.70	3	0.70	3
	|half cross angle| (μrad)	134	90	134	230-250
Fall back solution	Beta* (m)	0.90	3	0.90	3
	|half cross angle| (μrad)	118	90	120	230-250
Valid for any configuration	|half parallel separation| (mm)	0.65	0.65	0.65	0.65

Key assumption	25 ns	ATLAS/CMS
Quadratic sum of tolerances	Beta* (m)	0.80
	|half cross angle| (μrad)	192
Valid for any configuration	|half parallel separation| (mm)	0.65

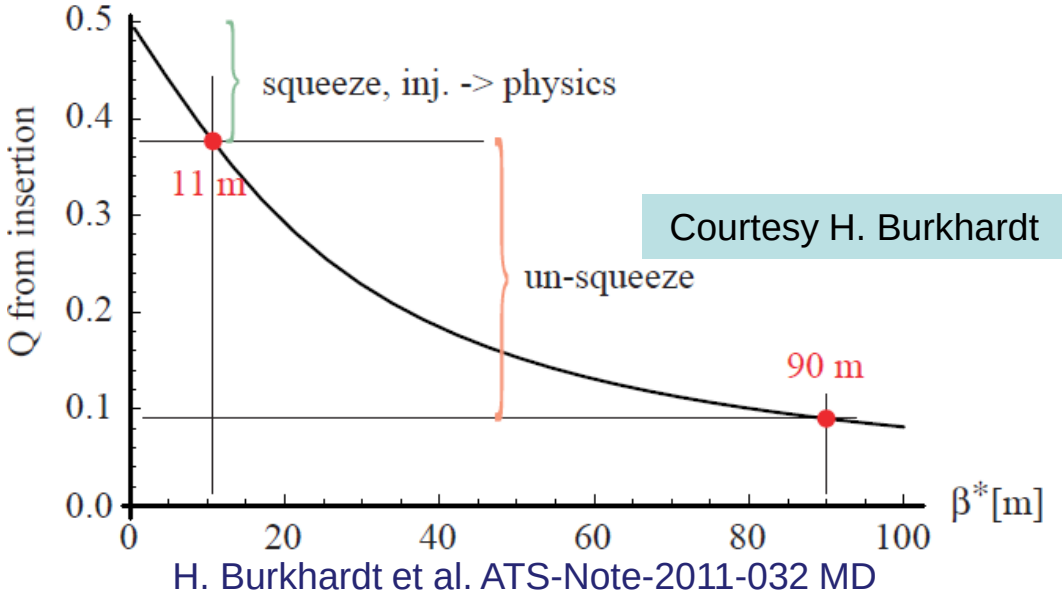
Top energy - IV

- Comparison of performance reach for various options at 4 TeV (again focusing on ATLAS and CMS).

Parameter	Unit	50 ns			25 ns
Half crossing angle IP1/5	μrad	118.00	134.00	145.00	192.00
Beta * IP1/5	m	0.90	0.70	0.60	0.80
Total number of bunches		1380	1380	1380	2760
Bunch intensity (10^{11})		1.50	1.50	1.50	1.15
Normalised transverse emittance	μm	2.50	2.50	2.50	3.50
Protons per beam (10^{14})		2.07	2.07	2.07	3.17
Current per beam	mA	372.43	372.43	372.43	571.07
Stored energy per beam	MJ	132.69	132.69	132.69	203.46
RMS bunch length	cm	9.40	9.40	9.40	10.10
Beam size IP1/5	mm	0.023	0.020	0.019	0.026
Geometric factor IP1/5		0.901	0.849	0.809	0.797
Number of colliding pairs in IP1/5		1331	1331	1331	2662
Luminosity in IP1/5 (10^{33})	$cm^{-2}\ s^{-1}$	4.57	5.54	6.16	3.82
Events per crossing IP1/5 (76 mbarn)		23.22	28.15	31.29	10.0

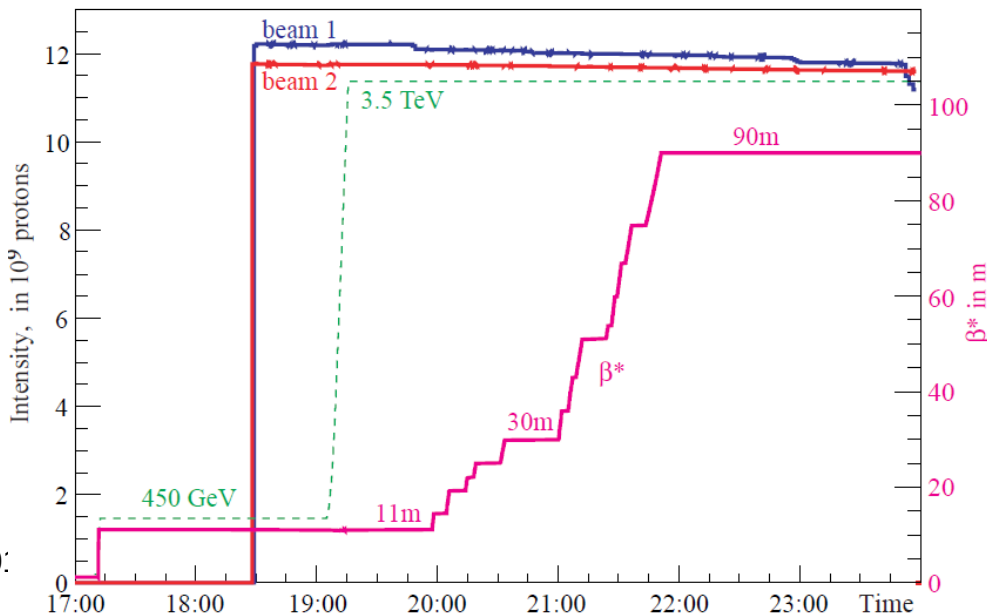
High-beta optics (target, IP1 β*=500m)

- Different regime with respect to the standard squeeze optics.
- Challenges:
  - Optics:
    - Aperture
    - Tune compensation
      - Using QF/QD
      - Using QTF/QTD
      - Re-matching other IRs
    - Separation
      - Only parallel separation possible
  - Hardware:
    - Special use of MQX
    - Strong powering imbalance of IR quadrupoles: request for additional cables issued.
- 90 m is first (**successful**) step!



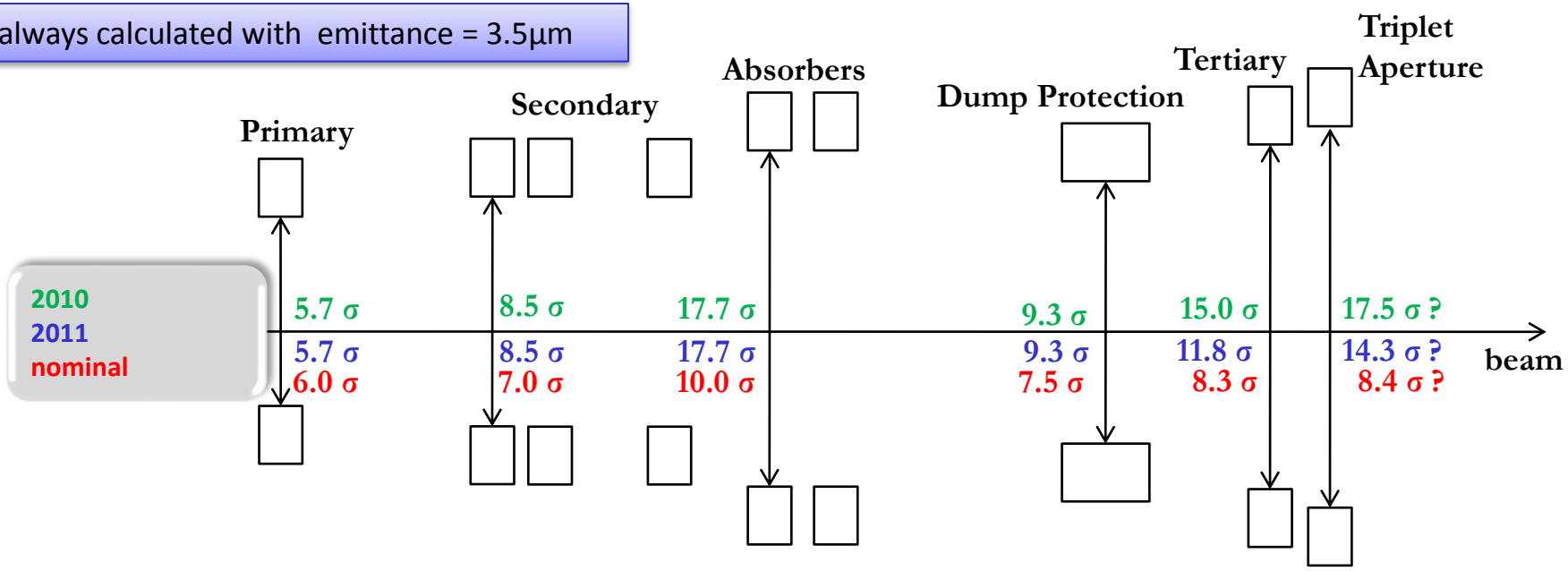
Courtesy H. Burkhardt

H. Burkhardt et al. ATS-Note-2011-032 MD



Importance of collimation for performance

σ always calculated with emittance = 3.5μm



- Collimation system defines minimum aperture that can be protected
- Therefore, limit on β* from collimation (beam blows up in triplet in squeeze)
- Inefficiency (leakage fraction) in cold region depends on collimation system
- Together with the beam lifetime and the quench limit, the collimation system thus defines the maximum allowed intensity

See early predictions: R. Assmann Chamonix 2002

How tight?

Norway

Iberian peninsula

Intermediate settings (2011): ~3.1 mm gap of primary collimator

Tight settings: ~2.2 mm gap of primary collimator

Tight settings summary

- Advantages:
  - Protection of a smaller triplet aperture => more squeeze in β*
  - Better efficiency => higher intensity reach
  - Maintain full protection and operational margin for van der Meer scans
  - Gain experience for 7 TeV
    - Tight gap of TCP in mm similar to nominal gap at 7 TeV, while secondary collimators are further retracted. **Tight settings at 3.5 TeV in mm = relaxed settings at 7 TeV**.
    - Sooner or later we have to use (at least) these settings in mm to reach nominal. Problematic for 7 TeV if tight settings can not be used now
- Detrimental effects:
  - Beam losses in ramp and squeeze caused by orbit variations (solution underway)
  - Impedance and beam-beam effects (cure proposed)
  - We give up a little margin between primary and secondary collimator

Proposal for collimator settings and β*, 50 ns

- Tight settings, square margin:
  - primary collimator stays at 4σ 3.5 TeV position in mm, but using σ at 4 TeV for margins in IR7 and IR6-IR7
- These settings work only if we assume
  - Beam losses in ramp and squeeze mitigated
  - Instabilities observed with tight settings alleviated
    - Larger beam-beam separations needed?
  - We have the same excellent aperture (to be re-measured)
- Must be demonstrated operationally!
- ~50% higher lumi and pile-up than 2011

	3.5 TeV	4 TeV	7 TeV
gamma	3730	4263	7461
TCP 7	4.0	4.3	5.7
TCSG 7	6.0	6.3	7.7
TCLA 7	8.0	8.3	9.7
TCSG 6	6.8	7.1	8.5
TCDQ 6	7.3	7.6	9.0
TCT	8.5	9.0	10.4
aperture	9.9	10.5	12.3
Φ (μrad)	155	145	126
β* (m)	0.6	0.6	0.45

Fall-back solution in case linear addition of errors margins must be used or larger crossing angle needed:
Tight settings, β *=0.7 m

Fall-back solution in case of unexpected problems with tight settings:
intermediate settings, linear margins, β *=0.9 m

Our analysis concerns only collimation limit on β*
For optics considerations, see talk M. Giovannozzi

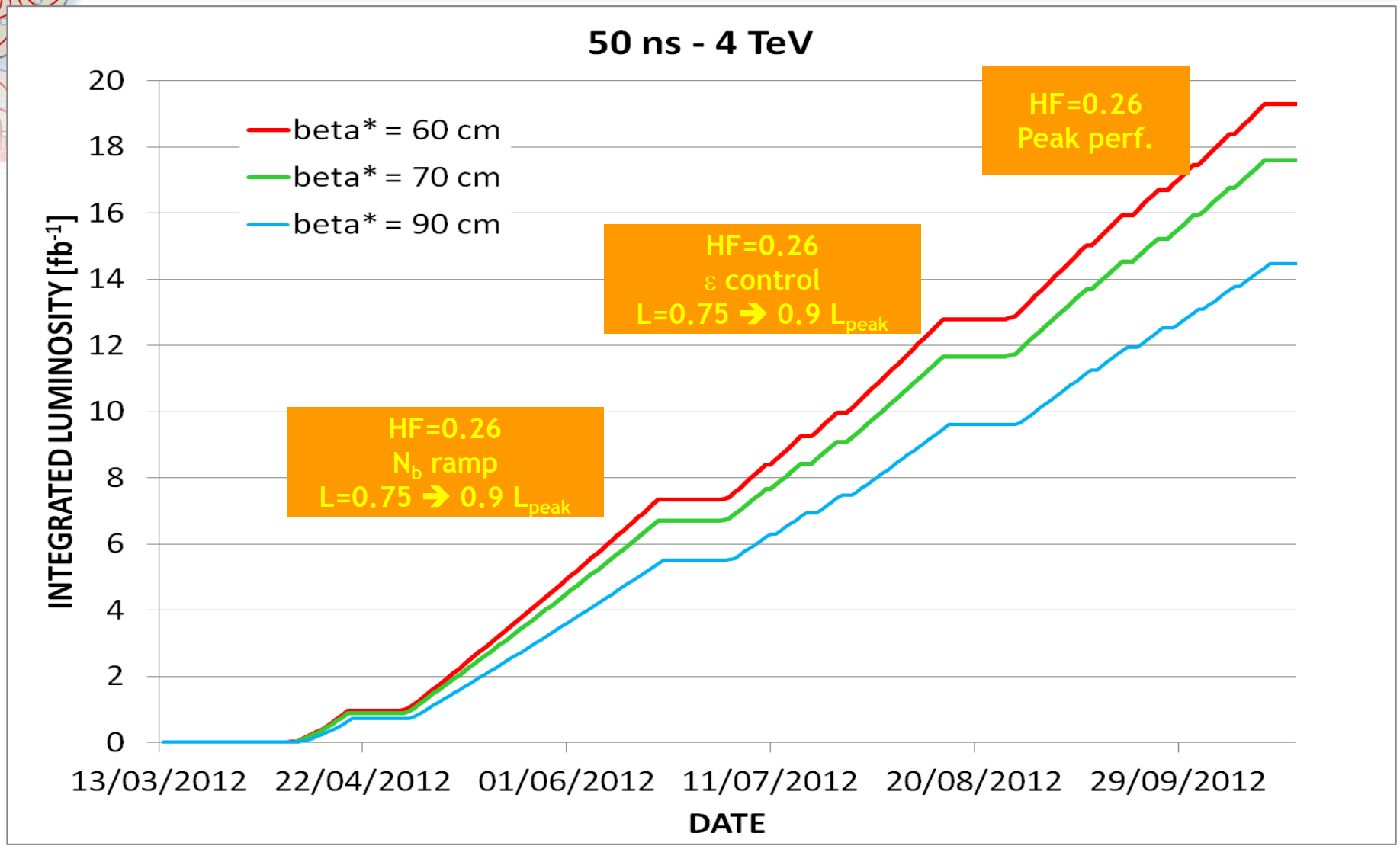
2012 proton run – 50 ns

- Assumptions:
  - 147 days of physics
  - 22 days of MDs
  - 21 days of commissioning with beam (small number of bunches)
  - 20 days of Technical stops
  - 6 (2x3) days of recovery after Technical Stops
  - 8 days of special physics runs
  - 3 day of scrubbing with 25 ns beam including setting-up and 1 day of contingency. To be planned as soon as possible before serious intensity ramp-up.

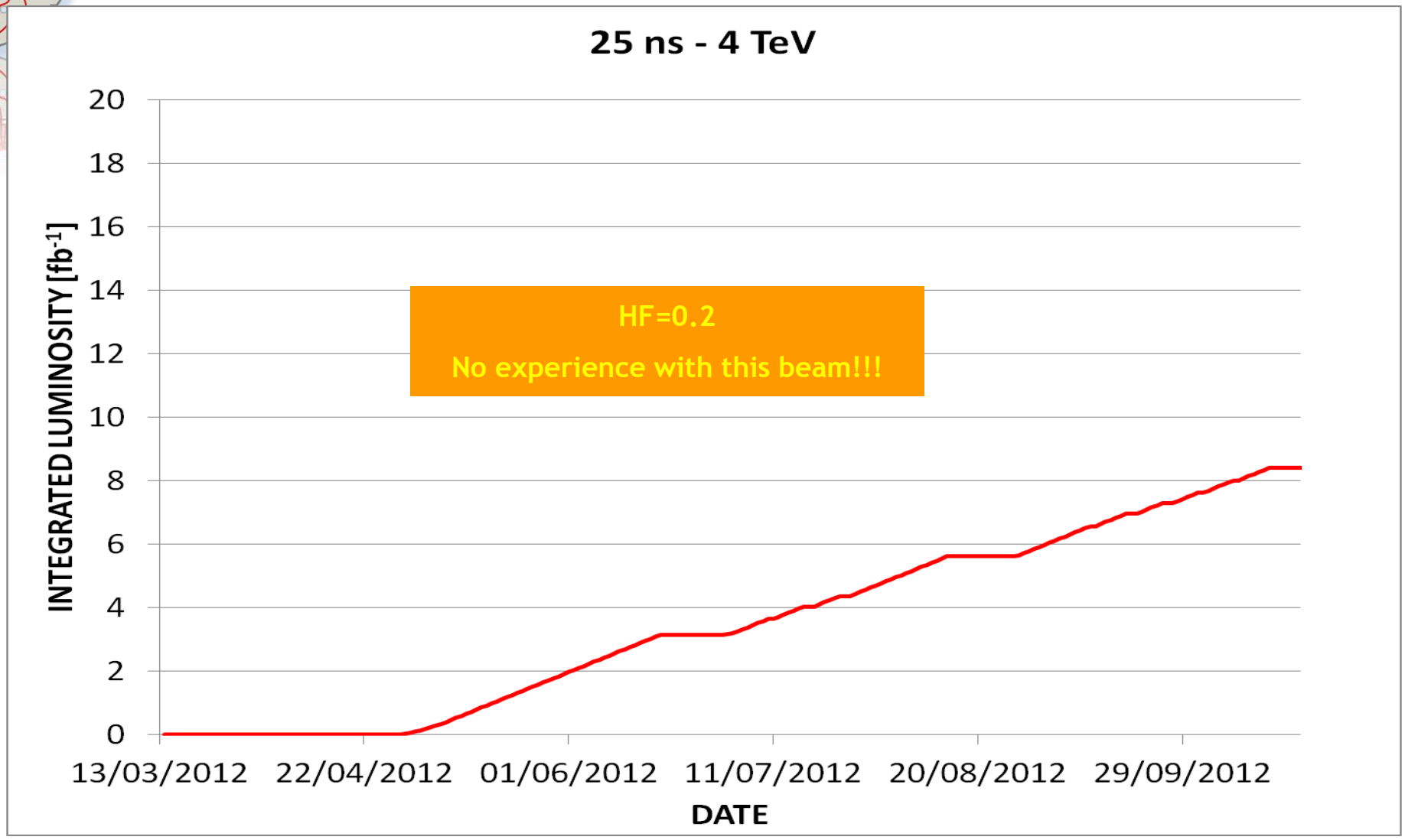
- Intensity ramp up as discussed in Evian (for 50 ns):
  - 48-84-264-624: 3 fills and 6 hours of Stable Beams (assumed 25% SB time)
  - 840-1092-1380: 3 fills and 20 hours of Stable beams (assumed 28% SB time)

  ➔ 2 weeks for validation of maximum number of bunches

50 ns – 4 TeV – very optimistic



25 ns -4 TeV


25 ns - 4 TeV
INTEGRATED LUMINOSITY [fb-1]
20
18
16
14
12
10
8
6
4
2
0
HF=0.2
No experience with this beam!!!
13/03/2012
22/04/2012
01/06/2012
11/07/2012
20/08/2012
29/09/2012
DATE

Summary

	$\int Ldt/L_{peak}$/Pile-Up @ 3.5 TeV [$fb^{-1}/10^{33}$ $cm^{-2}s^{-1}$/e.p.c.]	$\int Ldt/L_{peak}$/Pile-Up @ 4 TeV [$fb^{-1}/10^{33}$ $cm^{-2}s^{-1}$/e.p.c.]
50 ns - β^*=0.6 m	14.3-17/6.0/29	16.2-19.3/6.8/35
50 ns - β^*=0.7 m	12.8-15.3/5.4/27	14.7-17.6/6.2/31
50 ns - β^*=0.9 m	10.7-12.8/4.5/22	12.1-14.5/5.1/26
25 ns - β^*=0.8 m	-	8.3/3.8/10

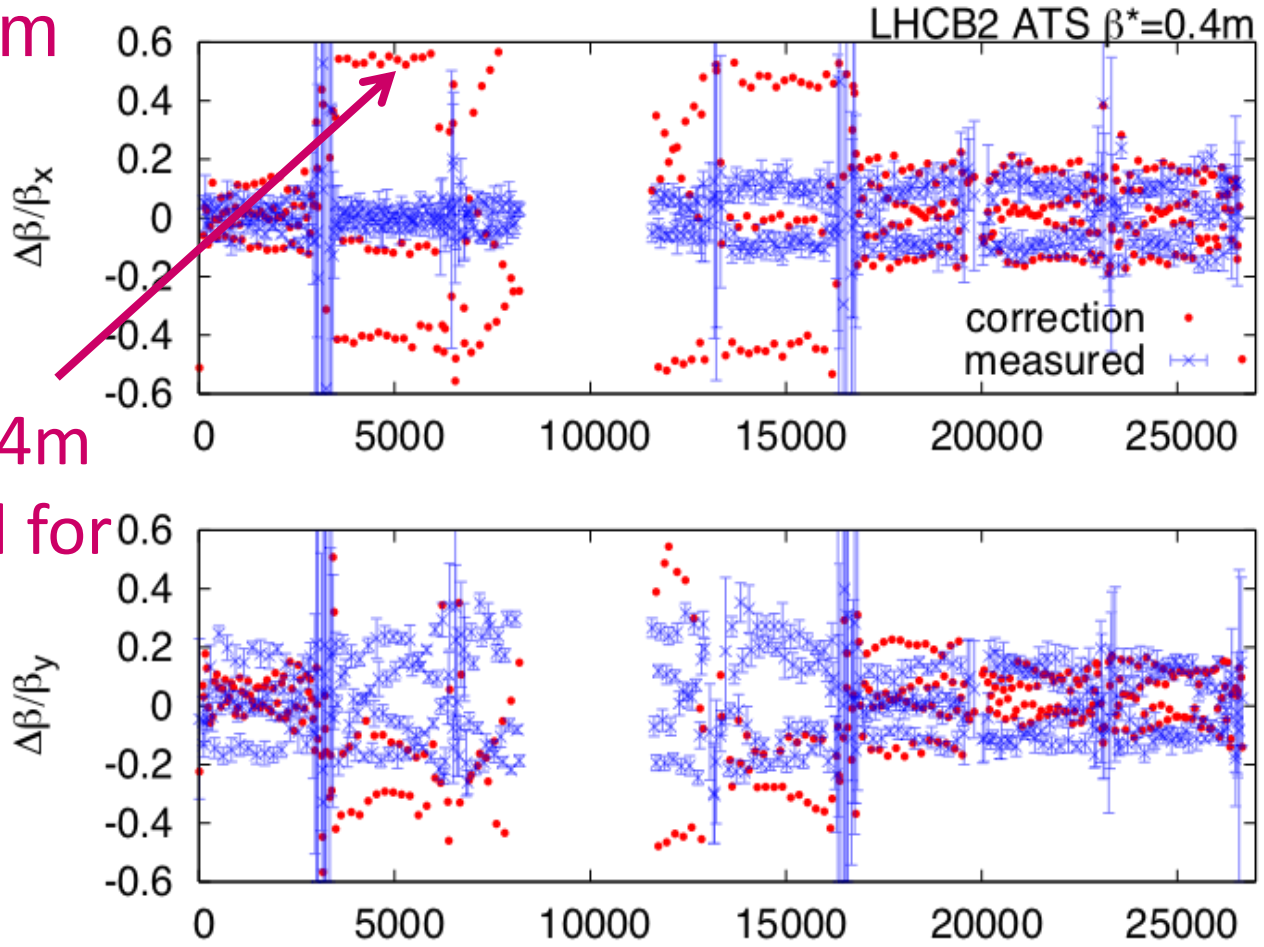
- For LHCb, assuming $<HF_{LHCb}>=0.3$ and $L_{level}= 0.4x10^{33}$ $cm^{-2}s^{-1}$ Expected Integrated luminosity:
  - ➔ ~1.5 fb^{-1} for 50 ns operation (147 days of physics)
  - ➔ close to 1.4 fb^{-1} for 25 ns operation (137 days of physics)

Long fills are certainly better for LHCb…

Steve's question regarding β*=0.6m

- Should we take conservative path (changing the parameters adiabatically) or should we «go for bust»?
- Some input from β-beating:

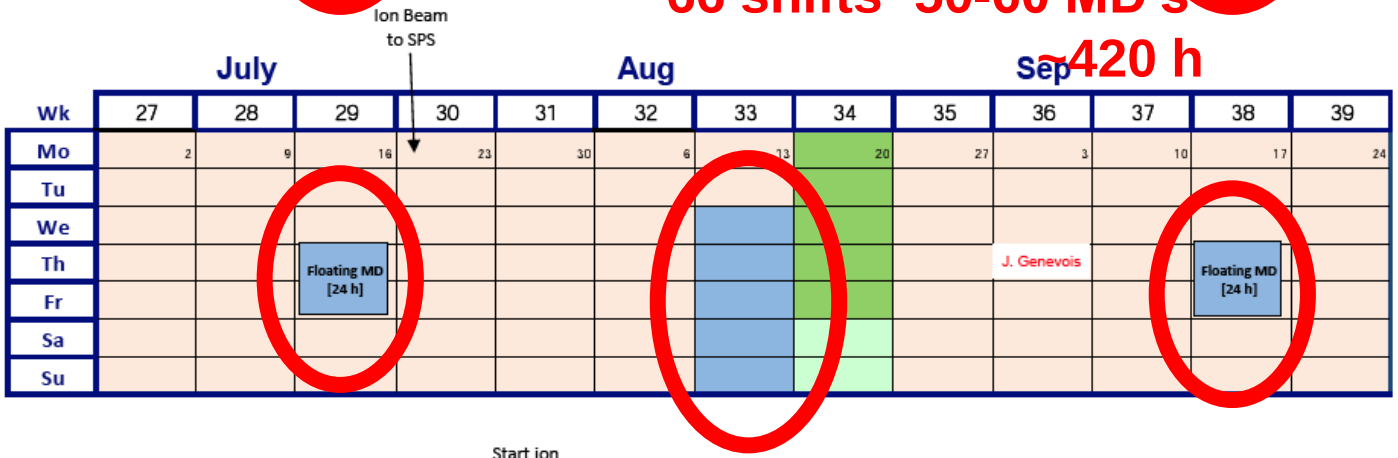
No satisfactory correction at β*=0.4m (ATS MD) was found for Beam 2

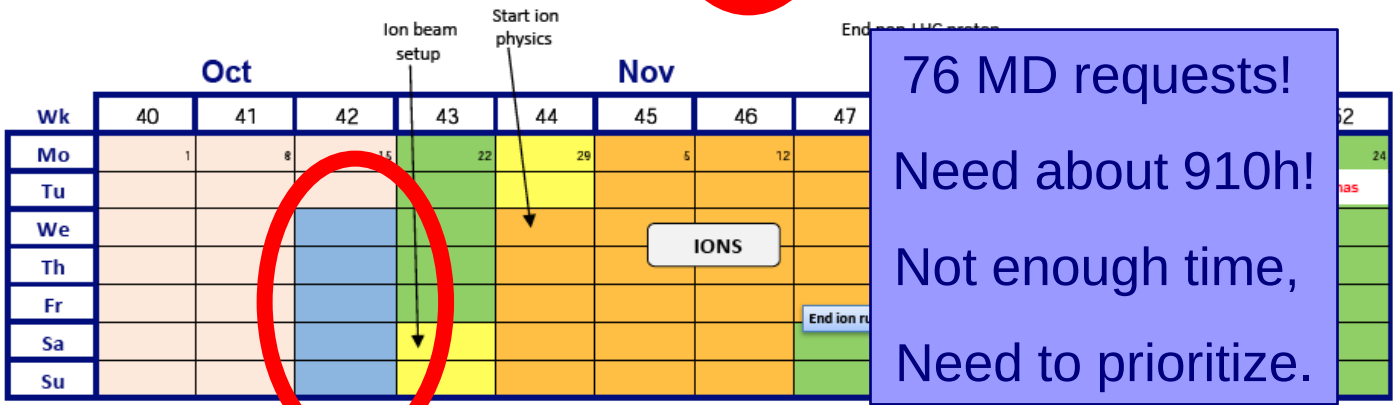


LHC MD schedule & requests for 2012

66 shifts~50-60 MD's

~420 h





76 MD requests!

Need about 910h!

Not enough time,

Need to prioritize.

Summary MD Plans (for discussion)

Operation & Physics: 9 major MD goals proposed.

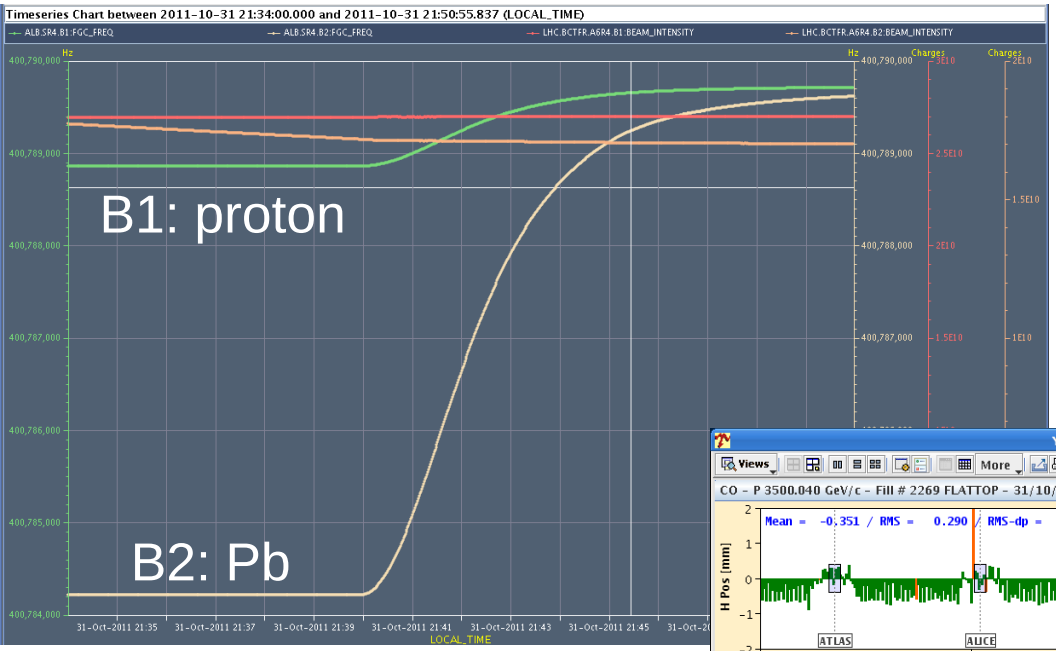
1. Understand **beam heating** effects around the LHC ring.
2. Understand & optimize **transverse emittance growth.**
3. Demonstrate RF setup for **proton-lead physics.**
4. Establish an LHC optics with a **beta* of 500 m**.
5. Understand and optimize **longitudinal beam dynamics** in LHC.
6. Establish **automatic and very fast collimator setup.**
7. Calibrate and optimize LHC **beam instrumentation.**
8. Compatibility **tune and ADT.**
9. **Equalize beta*** in ATLAS and CMS.

Future running: 7 major MD goals proposed.

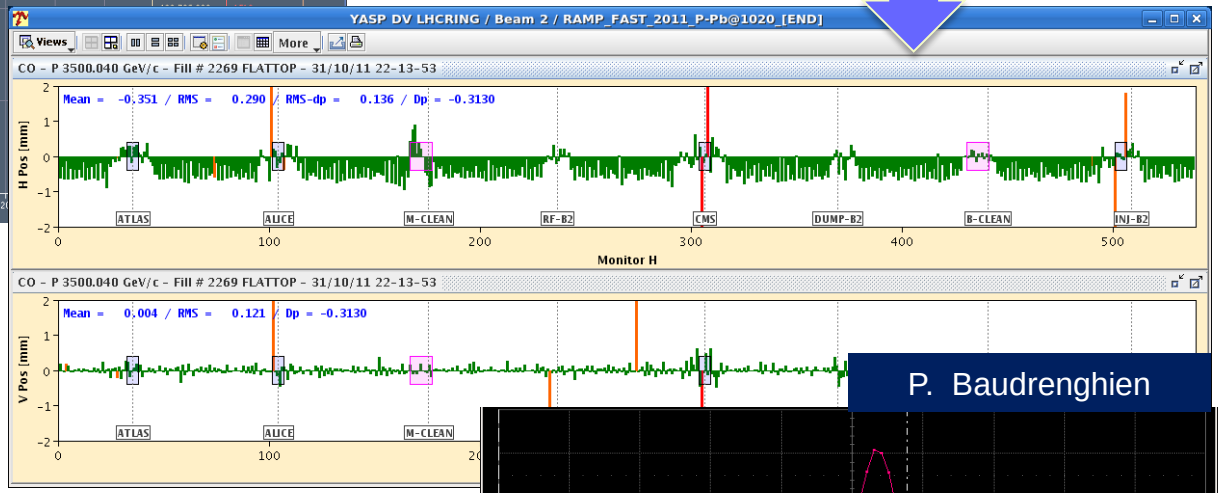
1. Characterize future **operation with 25ns.**
2. Quantify required tolerances for **non-linearities** in LHC.
3. Show feasibility **very small beta* / very high pile-up.**
4. Verify and check the **transverse impedance** limits of the LHC.
5. Show feasibility of **flat beam optics** in the LHC.
6. Establish benefits of the **½ integer tune working point.**
7. Study and improve LHC **injection limitations.**

Reduced priority MD's: 7 goals. To be scheduled as time allows.

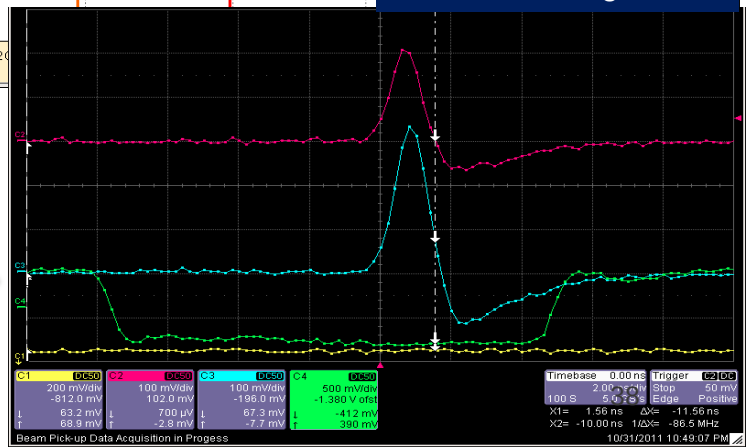
p-Pb RF: New rephasing and cogging procedure



At top energy, f_{RF}(B1) = 400.789715 MHz and f_{RF}(B2) = 400.789639 MHz. Locking RF frequencies together imposes offsets of the central trajectories. We chose to get approximately the mean RF frequency, implying that the momentum offset would be ~ $\pm 3\times10^{-4}$



P. Baudrenghien



The final frequency was f_{RF} = 400.789685 MHz. After locking the two RF systems together, we used **ATLAS BPTX for the cogging**. The initial shift between buckets 1 of each beam was 19 μs (~9 km). Total time for the `cogging operation` was about 30 min.

p-Pb feasibility test, Part 1, 16h on 31/10/2011

- Several hours setup (timing, many details…)
- Stored 4 Pb bunches (first of year) in presence of 304 p bunches (~10% nominal intensity) at injection
  - Lifetime no worse for presence of p bunches
  - Emittance blow-up, does not appear to be worse than for Pb alone
- Dumped and re-injected 4 fresh Pb
  - Still OK
- Ramped 2 Pb and 2 p bunches, good lifetime
- Re-phased RF (cogging) to move bunches 1 encounter point 9 km back to ATLAS, *no losses*

P-Pb feasibility test, Part 2

- Scheduled for 16-17 Nov 2011, plan was:
  - Ramp many p and some Pb bunches
    - We have NOT demonstrated this
  - Pilot physics fill with moderate no. of bunches
    - Would have clarified potential of detectors
- Cancelled because of leak in PS proton injection septum
  - Continuing with protons = risk of major leak and ~ 1 week of LHC down time (could have happened in p-p!).
- So … we are basing a physics programme with a complex new operating mode on a single MD
  - OK, but please tolerate a certain uncertainty in luminosity predictions!
- Strong motivation to do Part 2 in Aug-Sep 2012!

2012 strategy in numbers

4 TeV $\beta^*=0.6m \rightarrow 0.7m \rightarrow 0.9m$

50 ns $\int Ldt = 5\ fb^{-1}$ in June

$\int Ldt = 15\text{-}19\ fb^{-1}$ Dumps=30-50

Pile-Up=26-35

LHCb $\int Ldt = 1.5\ fb^{-1}$

$L_{peak}=5\text{-}6.8\ 10^{33}\ cm^{-2}s^{-1}$

TCP gap=2.2mm

SPS $\varepsilon = 2\ \mu m$

IP1 $\beta^*=500m$

SPS $N_p = 1.6\ 10^{11}$

p-Pb: 3.5 TeV or 4 TeV

$\int Ldt = 15\text{-}23\ nb^{-1}$

$\beta^*=(0.6,0.6,0.6,3)m$