Performance Reach in the LHC for 2012

G. Arduini

Acknowledgements: R. Bruce, S. Gilardoni, M. Giovannozzi, W. Herr, G. Iadarola, J. Jowett, V. Kain, M. Lamont, E. Métral, G. Rumolo, R. Steerenberg, J. Wenninger, LHC Machine Coordinators

Outline

- I will cover mostly the high luminosity experiments. ALICE and LHCb please accept my apologies

- Review of 2011
- Summary of the expected parameter range for peak luminosity for 50 and 25 ns
- Estimate of the possible integrated performance for 50 and 25 ns
- Summary & Conclusions

2011 peak performance – 50 ns

Momentum [TeV/c]	3.5
Beta* [m]	1.0/10/1.0/3.0
ε^*[μm] at start of fill for max. bunch intensity	2.6
Max. Bunch Population [10^{11} p]	1.49
Max. Number of bunches	1380
Max. Number of colliding pairs	1331/0/1331/1320
Bunch length [ns]	1.25
Max. Beam Current [A]/population[10^{14} p]	0.37 / 2.05
Max. Stored energy [MJ]	115
Peak luminosity [10^{33} $cm^{-2}s^{-1}$] in IP1/5/8	3.6/3.6/0.4
Half External Crossing angle IP1/2/5/8 [μrad]	120/80/120/250
Beam-beam tune shift (start fill)/IP	~0.007
Min. beam-beam separation (σ) $d_{sep\sigma}$	9.3
Maximum Average pile-up at IP1/5/8	17/17/2

Again on Hübner factor….

$$HF_i = \frac{\int_0^{\Delta T_i} L dt}{L_{peak,i}\,\Delta T_i}$$

- This is a “sliding” Hübner factor of the i-th successful fill with peak luminosity $L_{peak,I}$ and Δt_i is the time between the end of the $(i-1)_{th}$ stable beam period and the end of the i_{th} one. This takes into account of the fraction of time spent in stable beams and the luminosity lifetime

- For 5 periods of the run 2011 estimated:

$$HF_{peak} = \frac{\sum_i \int_0^{\Delta T_i} L dt}{Max(L_{peak,i}) \sum_i \Delta T_i}$$

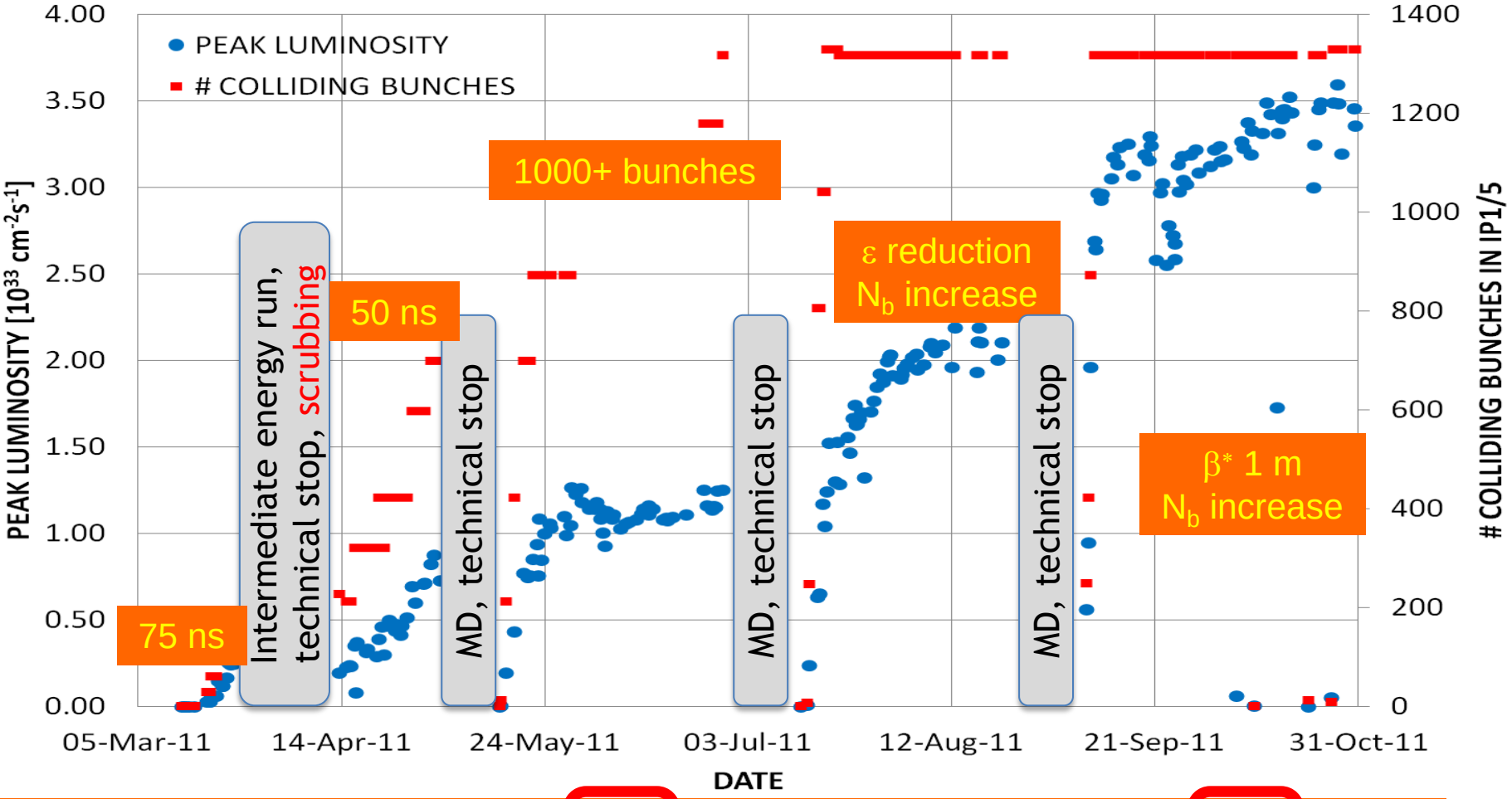
$$< HF_i >= \frac{\sum_i HF_i}{N}$$

Some notion of ramp-up built-in in the factor

No notion of ramp-up built-in in the factor

$$< HF_{LHCb} >= \frac{\sum_i \int_0^{\Delta T_i} L_{LHCb} dt}{L_{levelling} \sum_i \Delta T_i}$$

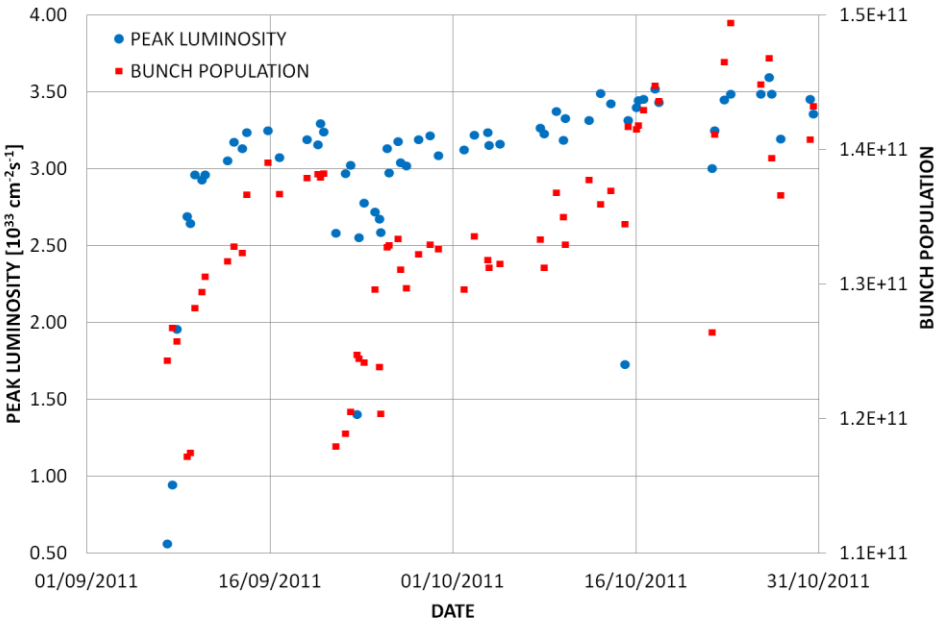
2011



SB [%]	32.8	29.2	29.1	32.8
HF_{peak}	0.14	0.19	0.15	0.2
$\langle HF_i \rangle$	0.32	0.26	0.26	0.26
$\langle HF_{LHCb} \rangle$				0.31

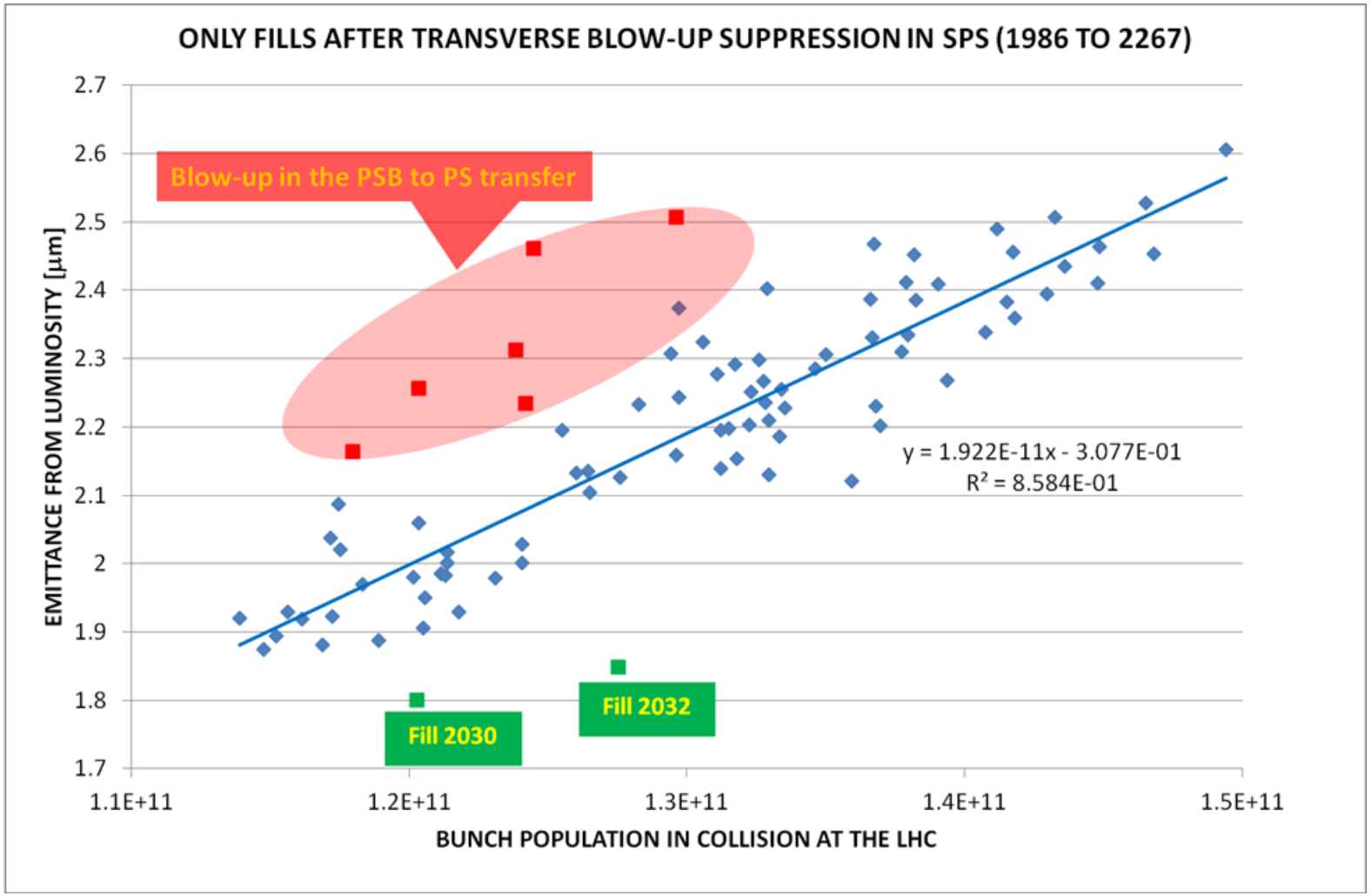
Last period β*=1 m

- Most representative for the comparison with 2012:
  - New β* (although more relaxed)
  - After initial ramp-up, constant number of bunches
  - Natural ε* provided by the injectors (no transverse blow-up in the SPS)
  - Constant β*
  - "Adiabatic" increase of the bunch intensity from 1.2 to 1.5×10^{11} p/b in ~1.5 months
  - Period with highest intensity and luminosity (UFO and SEE)
  - Mitigation measures for SEE in place



HF_{peak}=0.2
$\langle HF_i \rangle$=0.26
SB time=32.8%
$L_{peak}=3.6 \times 10^{33}$ cm^{-2}s^{-1}
$\int$ Ldt~3 fb^{-1}
Δt~47.6 days

Performance in collision



Injector and LHC ε preservation (c/o V. Kain, R. Steerenberg)

- 50 ns
  - Got up to 1.6×10^{11} p/b with 2 μm emittance at SPS extraction ➔ caveat: could lose reproducibility
  - Extrapolation of present behaviour ➔ 1.6×10^{11} p/b in collision with 2.7-2.8 μm ➔ 35-40% blow-up
- 25 ns
  - Expect 1.15×10^{11} p/b with >3 μm emittance at SPS extraction
  - Extrapolation of present behaviour ➔ 1.15×10^{11} p/b in collision with >3.7 μm (nominal emittance)
- 50 ns
  - Hope to understand and mitigate blow-up at injection (longitudinal blow-up reducing IBS blow-up, mostly H) during ramp and squeeze in the course of the run ➔ In the following assumed 2.5 μm and 3.5 μm in collision for the maximum bunch intensity for 50 and 25 ns for the estimation of the peak performance

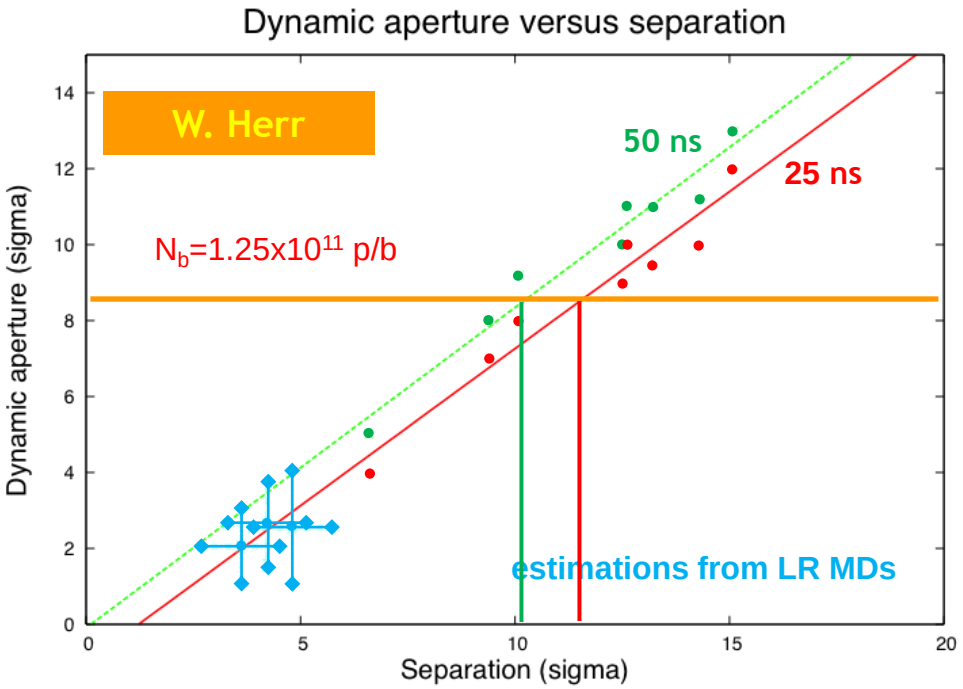
Beam-Beam (c/o W. Herr)

- In all the proposed scenarios $\Delta Q_{head\text{-}on} \sim N_b/\varepsilon^*$ is smaller or equal to 2011 values and no hard limits observed so far

- 25 ns spaced beams have ~twice (120) the number of LR as compared to 50 ns beams (64)

- To get same dynamic aperture as for 50 ns ➔ 25 ns requires ~20 % more LR beam-beam separation (for the same N_b – pessimistic) in σ!

LHC-Project-Note 416



β* reach (c/o R. Bruce)

	Θ_{cross} [μrad] @ 3.5 TeV	Θ_{cross} [μrad] @ 4 TeV	Comments
50 ns - β*=0.6 m	155	145	Tight collimator settings – errors in quadrature
50 ns - β*=0.7 m	143	134	Tight collimator settings – linear error sum
50 ns - β*=0.9 m	126	118	Intermediate settings – linear error sum

- For 25 ns (consider only 4 TeV here) ➔ in the optimistic case that we consider tight collimator settings (primaries at 4.3 beam σ) ➔ β*=0.8 m achievable with 190 μrad half crossing angle providing ~12 σ (rather conservative) separation for long range encounters

Impedance effects (c/o E. Métral)

- Operation with tight collimator settings: most critical 50 ns with 1.6×10^{11} p/b
  - Need control of chromaticity down to <1 unit
  - Back-up: octupoles at >450 A but this might have impact on lifetime
  - No show stopper expected

- Main issues:
  - TDI beam screen heating ➔ need to open the gaps to parking position (110 mm) as soon as injection is stopped ➔ hindrance for the scrubbing run
  - MKI heating ➔ impact on turn-around

- Possible bunch length increase and bunch shape tailoring (c/o P. Baudrenghien):
  - Might reduce TDI heating, expect marginal effect for MKI
  - 10% increase (up to 1.35) acceptable by the experiments (longer luminous region)
  - Reduces the peak luminosity by additional ~3%

$$L \propto \frac{1}{\sqrt{\beta^* \frac{\varepsilon^*}{\beta\gamma} + \frac{\sigma_z^2 \theta^2}{4}}}$$

  - Overall impact of bunch lengthening: gain in heating/stability vs. loss in luminosity, luminosity lifetime to be assessed in its globality

Vacuum and Scrubbing (c/o V. Baglin, G. Rumolo)

- Vacuum activity observed in 2011 after scrubbing in LSS2/5/8 related to non-conform RF fingers ➔ actions being taken

- Operation with 50 ns at 4 TeV requires:
  - SEY< 2.1 in the arcs
  - SEY<1.6 in the uncoated/unbaked straight sections
  - This is were we got at the end of the scrubbing run in April (5 days with 50 ns beam) even lower with the 25ns beams tests

- Operation with 25 ns at 4 TeV requires:
  - SEY<1.35 in the arcs
  - SEY<1.2 in the uncoated/unbaked straight sections

Vacuum and Scrubbing - 50 ns operation

- Arcs were kept below 80 K and care is going to be taken to cool down the magnet preventing condensation in the beam screens ➔ hope to find SEY as at the end of 2011 ➔ to be confirmed

- Straight sections opened in point 2/5/8 ➔ expect high vacuum activity during start-up with high intensity ➔ cleaning with 50 ns beams will take ~15 h of beam time at high intensity ➔ few hours with 25 ns beam

- 1 day of scrubbing with 25 ns beam (trains of 72 bunches) for 50 ns operation preceded by 1 day of setting-up:
  - Allow verifying the conditions of the machine (in particular the arcs) after the Christmas stop ➔ important for future operation at 25 ns
  - Create clean conditions for operation with 50 ns beams with intensities above those reached in 2011
  - Conditioning for UFOs?

Scrubbing – 25 ns operation

How much machine time:

- At least 20 hours of beam time starting with at least 2100 bunches circulating and going to ~2800 bunches
- During the MD 25 ns (after 3 MDs) 2 h of beam time at maximum current required in total ~14 h of machine time (slowed down by losses and dumps due to LSS6 BPMs, MKI vacuum activity, etc…). Scrubbing Hübner Factor=0.14. Machine availability was close to 100 %. TDI was kept IN all the time. We should not do it in 2012.
- At least 140 hours = 6 days of machine time without setting-up (of injections up to 288 bunches) and intensity ramp-up to 2800 bunches (not done so far)
- 1 day setting-up of 25 ns beam (72 bunches) + 2 shifts commissioning per injection step (144-216-288) ➔ 3 days
- 2 days for operation/scrubbing at 3.5-4 TeV with increasing number of bunches to validate operation at high energy.
- Total of 11 days with very good machine availability and no contingency

2012 expected peak performance – 50 ns – 4 TeV

Beta* [m]	0.6/3.0/0.6/3.0	0.7/3.0/0.7/3.0	0.9/3.0/0.9/3.0
ε^*[μm] at start of fill for max. bunch intensity	2.5		
Max. Bunch Population [10^{11} p]	1.6		
Max. Number of bunches	1380		
Max. Number of colliding pairs	1331/0/1331/1320		
Bunch length (4 σ)[ns]/ (r.m.s.) [cm]	1.35/10.1		
Max. Beam Current [A]/population[10^{14} p]	0.4 / 2.2		
Max. Stored energy [MJ]	142		
Peak luminosity [10^{33} cm^{-2}s^{-1}] in IP1/5/8	6.8/6.8/0.4	6.2/6.2/0.4	5.1/5.1/0.4
Half External Crossing angle IP1/2/5/8 [μrad]	145/90/145/250	134/90/134/250	118/90/118/250
Beam-beam tune shift (start fill)/IP	0.007		
Min. beam-beam separation (σ) $d_{sep\sigma}$	9.3		
Maximum Average pile-up at IP1/5/8	35/35/2	31/31/2	26/26/2

2012 expected peak performance – 50 ns – 3.5 TeV

Beta* [m]	0.6/3.0/0.6/3.0	0.7/3.0/0.7/3.0	0.9/3.0/0.9/3.0
ε^*[μm] at start of fill for max. bunch intensity	2.5		
Max. Bunch Population [10^{11} p]	1.6		
Max. Number of bunches	1380		
Max. Number of colliding pairs	1331/0/1331/1320		
Bunch length (4 σ)[ns]/ (r.m.s.) [cm]	1.35/10.1		
Max. Beam Current [A]/population[10^{14} p]	0.4 / 2.2		
Max. Stored energy [MJ]	124		
Peak luminosity [10^{33} cm^{-2}s^{-1}] in IP1/5/8	6.0/6.0/0.4	5.4/5.4/0.4	4.5/4.5/0.4
Half External Crossing angle IP1/2/5/8 [μrad]	155/90/155/250	143/90/143/250	126/90/126/250
Beam-beam tune shift (start fill)/IP	0.007		
Min. beam-beam separation (σ) $d_{sep\sigma}$	9.3		
Maximum Average pile-up at IP1/5/8	29/29/2	27/27/2	22/22/2

2012 expected (peak) performance – 25 ns – 4 TeV

Beta* [m]	0.8/3.0/0.8/3.0
ε^*[μm] at start of fill for max. bunch intensity	3.5
Max. Bunch Population [10^{11} p]	1.15
Max. Number of bunches	2760
Max. Number of colliding pairs IP1/5	2662/0/2662/2640
Bunch length (4 σ)[ns]/ (r.m.s.) [cm]	1.35/10.1
Max. Beam Current [A]/population[10^{14} p]	0.57 / 3.2
Max. Stored energy [MJ]	203
Peak luminosity [10^{33} cm^{-2}s^{-1}] in IP1/5	3.8/3.8
Half External Crossing angle IP1/5 [μrad]	190
Beam-beam tune shift (start fill)/IP	~0.0032
Min. beam-beam separation (σ) $d_{sep\sigma}$	12
Maximum Average pile-up at IP1/5/8	10/10/1

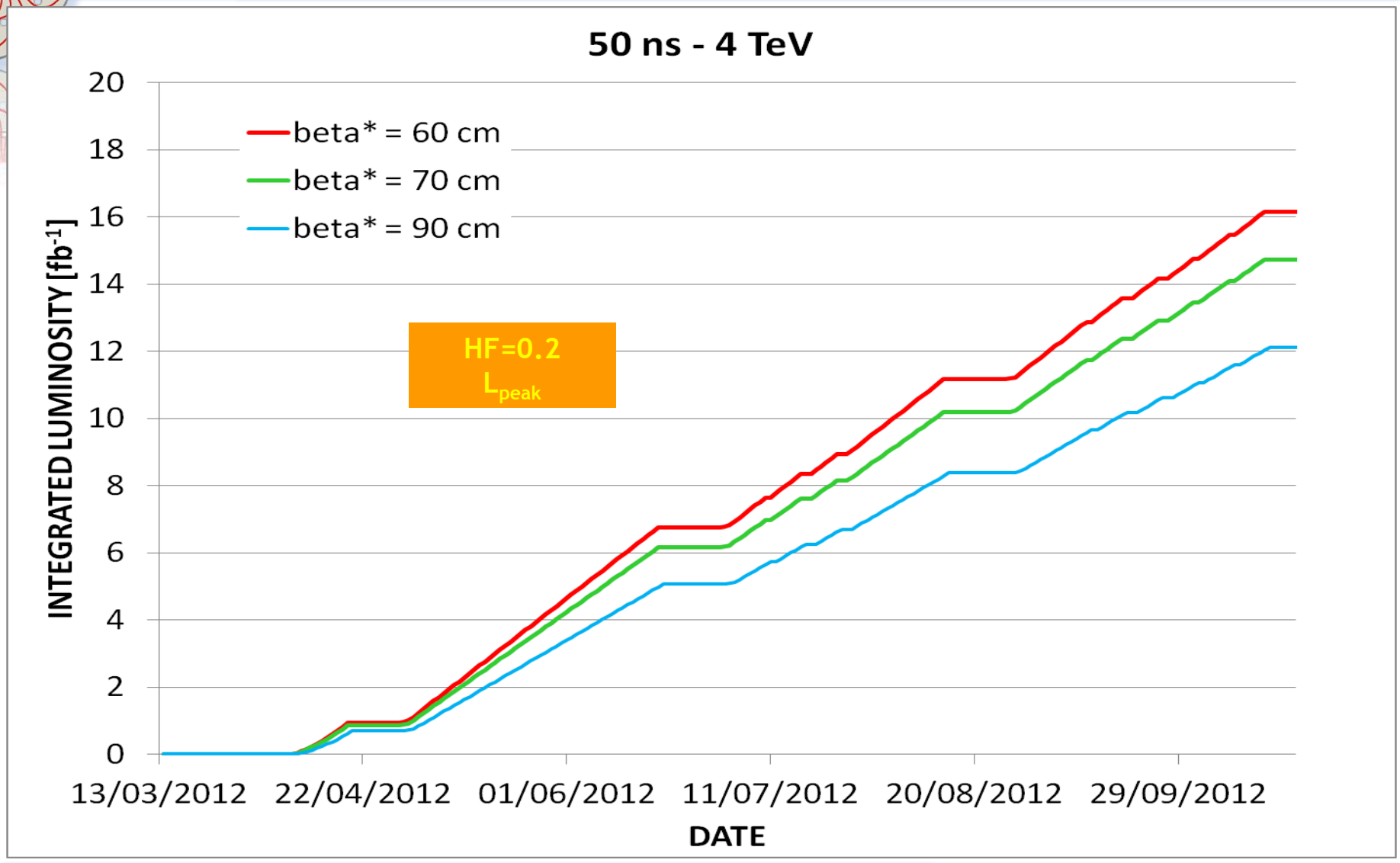
2012 proton run – 50 ns

- 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.

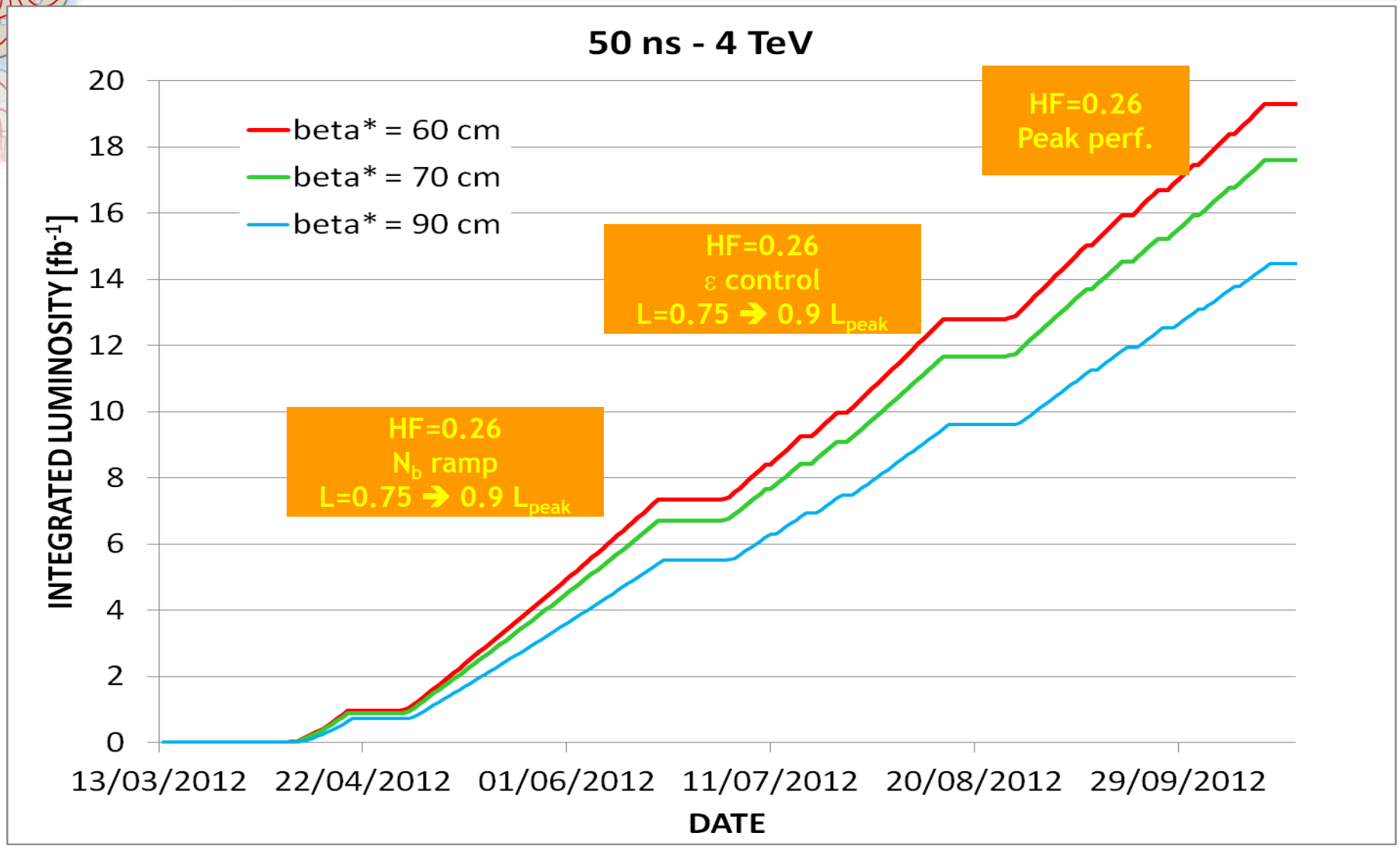
- Intensity ramp up as discussed in Evian (for 50 ns):
  - 48-84-264-624: 3 fills and 6 hours of Stable Beams (assumed 25% SB time)
  - 840-1092-1380: 3 fills and 20 hours of Stable beams (assumed 28% SB time)

  ➔ 2 weeks for validation of maximum number of bunches

50 ns - 4 TeV


50 ns - 4 TeV
beta* = 60 cm
beta* = 70 cm
beta* = 90 cm
HF=0.2
L_{peak}
INTEGRATED LUMINOSITY [fb^{-1}]
0
2
4
6
8
10
12
14
16
18
20
13/03/2012
22/04/2012
01/06/2012
11/07/2012
20/08/2012
29/09/2012
DATE

50 ns – 4 TeV – very optimistic

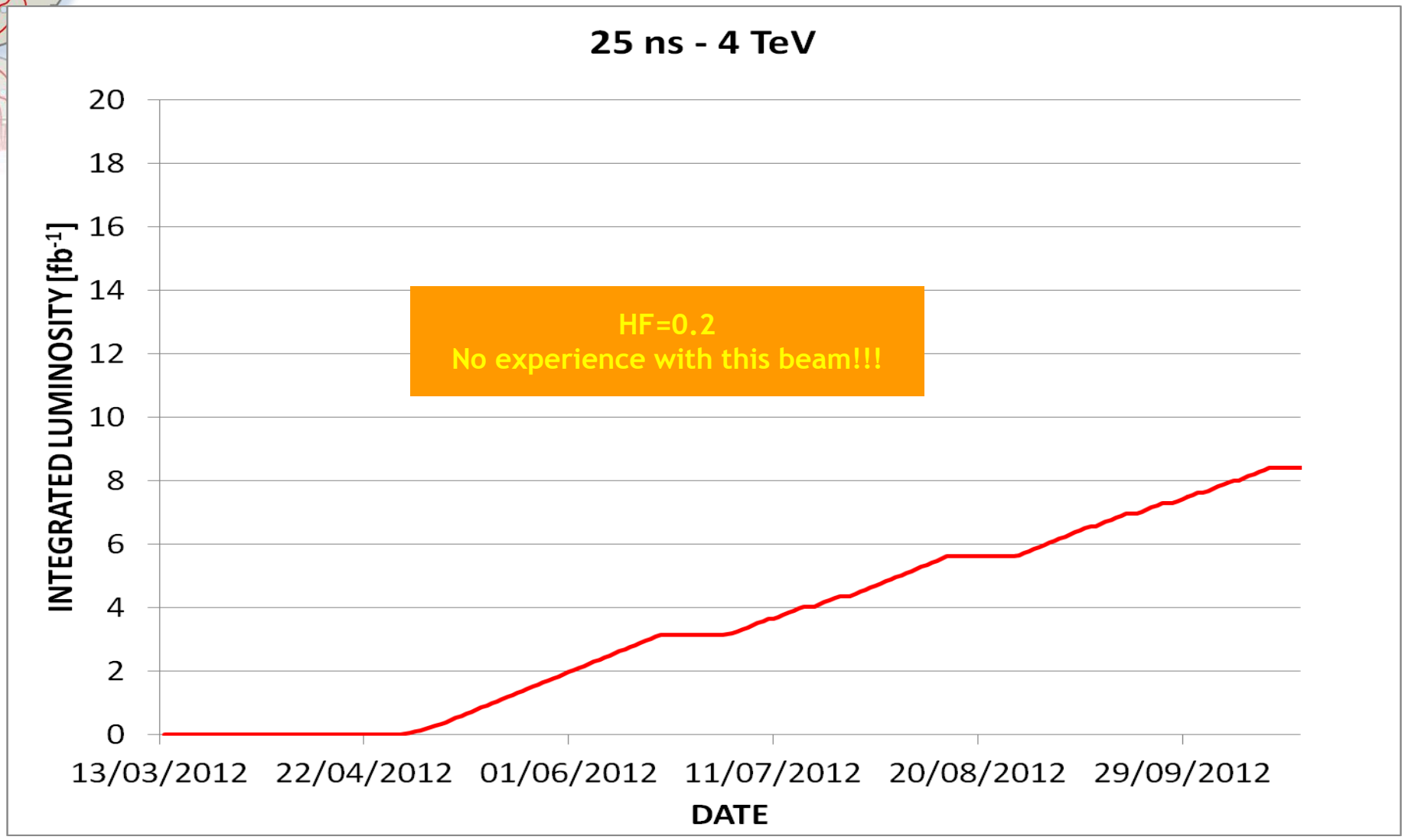


2012 proton run – 25 ns

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

- Intensity ramp up: assumed same ramp-up rate as for 50 ns (very optimistic!! As the final total current is higher!)

25 ns


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…

50 ns vs. 25 ns

- 50 ns provides clearly higher integrated luminosity than 25 ns
- Longer scrubbing period for 25 ns reduces significantly the in for the Summer conference
- Pile-up is certainly an issue for 50 ns but the flexibility of leveling can be used (should work)
- 25 ns is a new mode of operation with more unknowns and likely surprises
- 25 ns requires larger current with more potential stress on equipment and collimation
- Operation at tight settings with nominal emittance has been optimistically assumed for 25 ns
- Intensity ramp-up rate for 25 ns optimistically assumed to be the same as for 50 ns

- I do not see arguments to go to 25 ns this year.

Caveats

- Higher number based on tight collimator settings assumed to work without major problems. It will imply tight control of machine parameters (orbit,chromaticity, etc.).

- Realistic ramp-up phase in number of bunches and luminosity. Assumption of operation at peak with HF=0.26 assumes mastering high intensity and blow-up in the whole chain before the last third of the run. Should be considered as upper limit.

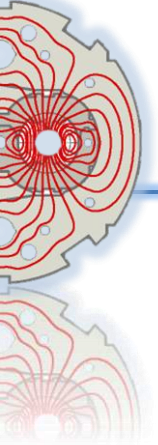
- Assumed that 4 TeV will not reserve significantly more surprises than 3.5 TeV (UFO, SEU, …..) and will not imply additional commissioning time.

Conclusions

- 15 fb^{-1} feasible ➔ heavily relies on tight collimator settings and 4 TeV. No space for rethink.

- 20 fb^{-1} seems out of reach even for a very optimistic scenario. Approaching it requires 60 cm β^* ➔ Start with that.

- In spite of the (I still consider) optimistic scrubbing plan 25 ns cannot compete with 50 ns operation. A mini-scrubbing run at 25 ns before intensity ramp-up with 50 ns would give important input for future operation at 25 ns (model and cool-down procedure validation) and would allow fast intensity ramp-up.



2011 proton run

Item	Days
Total proton operation	264
5 MDs (4 days)	- 20
6 TS (4+1 days)	- 30
Special requests	- 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)

M. Meddahi - Chamonix 2011

- What we did:
  - 167.8 days of physics (including intensity ramp-up with 75-50 ns)
  - 20 days of MDs
  - 21 days of commissioning with beam
  - 23 days of Technical stops
  - 5 days of recovery after Technical Stops
  - 10.5 days of special physics runs (1.38 TeV, VdM, high pile-up, 90 m optics)
  - 10 days of 50 ns injection set-up (2) and scrubbing (8) ➔ we got effectively 5 days
  - 3.8 days of 25 ns tests (2) and ion optics pre-commissioning (1.8)
  - 0.5 days of additional planned stops (VIPs, strike)