RLIUP 29 – 30 October 2013

Session 4 Summary

"Upgrade Scenario 2 and alternatives"

R. Garoby , B. Goddard

Agenda

1. ***How to maximize the HL-LHC performance (HL-LHC)? -*** R. De Maria
2. ***Can we ever reach the HL-LHC requirements with the injectors (LIU)?***
   - H. Bartosik
3. ***How to implement all the HL-LHC upgrades (HL-LHC)? -*** L. Rossi
4. ***HL-LHC: Exploring alternative ideas -*** R. Tomas
5. ***LIU: Exploring alternative ideas -*** H. Damerau
6. ***How to reach the required availability of LHC to reach the required level?***
   - M. Lamont
7. ***50 ns back-up scenario -*** V. Kain

+ from Session 3:

Work effort in the LHC injector complex for upgrade scenarios

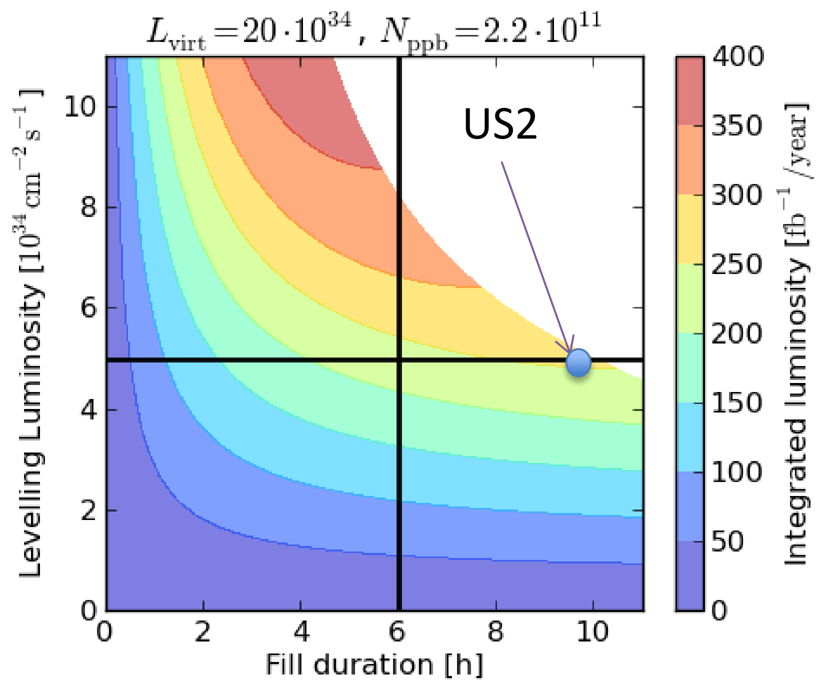
- B. Mikulec & J. B. Lallement

How to maximise the HL-LHC performance [1/3]

R. De Maria

- HL experiments accept 140 events/crossing, with 1.3 mm^{-1} density (performance limit with impact on efficiency)

- ***Long fills (>6 h) and high pile-up (>140)*** are key ingredients for US2 integrated luminosity target.



- Main challenges besides e-cloud: effective leveling method and good reliability.

How to maximise the HL-LHC performance [2/3]

R. De Maria

- Requirements to approach 270 fb^{-1}/y - baseline
  - Maximum bunch population ($\Rightarrow$ reduced collimators impedance etc.)
  - 25 ns with 1.9-2.2$\times 10^{11}$ p+/b (no e-cloud issues, beams stable)
  - Minimum β^* (~15-10 cm, with rebuilding IR1/5 insertions)
  - Leveling via β^* (important to deploy in P8 during Run2)
  - Crab cavities, flat beams at IP to mitigate geometric reduction
  - Need longer fills than the 2012 average of 6h.

- Other messages
  - Beam characteristics of LIU baseline are OK for reaching US2 goals
  - Min. ε_{xy}~2 μm in collision (1.6 μm from SPS for 40% LHC blowup)
  - Handle on pile-up density with crab-kissing, long/flattened bunches
  - Flat beams at IP and wire interesting to reduce crabbing requirements and opening to the kissing scheme

How to maximise the HL-LHC performance [3/3]

R. De Maria

Performance at 6.5 TeV

	$N_{b\ coll}$ [10^{11}]	$\varepsilon^*_{n\ coll}$ [μm]	Min β^* (xing / sep) [cm]	Xing angle [μrad]	# Coll. Bunches IP1,5	L_{peak} [10^{34} cm^{-2}s^{-1}]	L_{lev} [10^{34} cm^{-2}s^{-1}]	Lev. time [h]	Opt. Fill length [h]	η_{6h} [%]	η_{opt} [%]	Avg. Peak-pile-up density [ev./mm]
RLIUP2	*1.5*	*1.3*[6]	*15/15*	*366*	*2592*	*17.6*	*4.8*	*4.4*	*5.8*	*64.6*	*64.6*	*0.88*
LIU-BCMS	*1.9*	*1.65*[6]	*13.5/13.5*[3]	*420*	*2592*	*21.7*	*4.8*	*6.3*	*7.5*	*61.0*	*58.4*	*0.94*
LIU-STD	*1.9*	*2.26*	*14.5/14.5*[3]	*474*	*2736*	*15.8*	*5.06*	*5.3*	*6.9*	*58.2*	*57.5*	*0.97*
HL-Flat	**2.2**	**2.5**	**30/0.075**[1]	**348**[2]**/*550***	**2736**	**17.2**	**5.06**	**6.5**	**8.0**	**57.8**	**54.5**	**1.05**
HL-Round	**2.2**	**2.5**	**15/15**	**490**[2]**/*590***	**2736**	**18.7**	**5.06**	**6.8**	**8.2**	**57.8**	**54.0**	**1.05**
LIU-BCMS	*1.9*	*1.65*	*13.5/13.5*[3]	*420*	*2592*	*21.7*	*6.87*[5]	*4.3*	*6.2*	*52.2*	*52.2*	*1.34*
HL-Round	*2.2*	*2.5*	*15/15*[3]	*490*	*2736*	*17.2*	*7.24*[5]	*5.4*	*7.3*	*48.8*	*48.4*	*1.37*
HL-SRound	*2.2*	*2.5*	*10/10*[4]	*600*	*2736*	*18.7*	*7.24*[5]	*4.4*	*6.7*	*47.7*	*46.4*	*1.55*

1) compatible with crab kissing scheme (S. Fartoukh).
2) BBLR wire compensator assumed to allow 10σ.
3) β^* could be reduced to 14.5 and 13.5 cm at constant aperture.
4) Ultimate collimation settings.
5) Pile-up limit at 200 event/ crossing.
6) 30% blow-up from IBS makes 1.85 um is more likely

How to implement all the HL-LHC upgrades [1/2]

L. Rossi

- **Vast amount of work around a significant fraction of the ring (1.2 km). New triplets and deep changes in IP1 and 5.**
- **Some work to be done in LS2 (DS collimators in IP2/7, horizontal SC links in IR7, additional cryoplant in P4, some reduced impedance collimators)**
  - Work should fit inside 18 months
- **Major part planned for LS3**
  - work should fit inside 26 months
- **Detailed shutdowns plannings required to handle massive c**o-activities and radiation doses to personnel.

	remaining dose radiation enhancement factor w.r.t. June 2013 (6 months of cooling after RUN I)
LS2 (2019)	3.4
LS3 (2022)	4.3
PIC (2035)	7
US1(2035)	15
US2(2035)	22.7

- **Total cost (material):** 810 MCHF

How to implement all the HL-LHC upgrades [2/2]

L. Rossi

- Other potentially beneficial systems actively under study
  - 800 MHz (additional) and 200 MHz (new main) RF systems
  - Hollow e-lens
  - LRBB wire compensator
  - Crystal collimation
- Design Study finished by 2015 with TDR.
- «All hardware more robust for 3000 fb^{-1} than it is today for 300 fb^{-1}».
- Clear interest to establish margins in the machine to eventually reach above 3000 fb^{-1} if limitation on peak pile-up can be relaxed, e.g. to run at 7×10^{34} $cm^{-2}s^{-1}$ (200 pile-up).

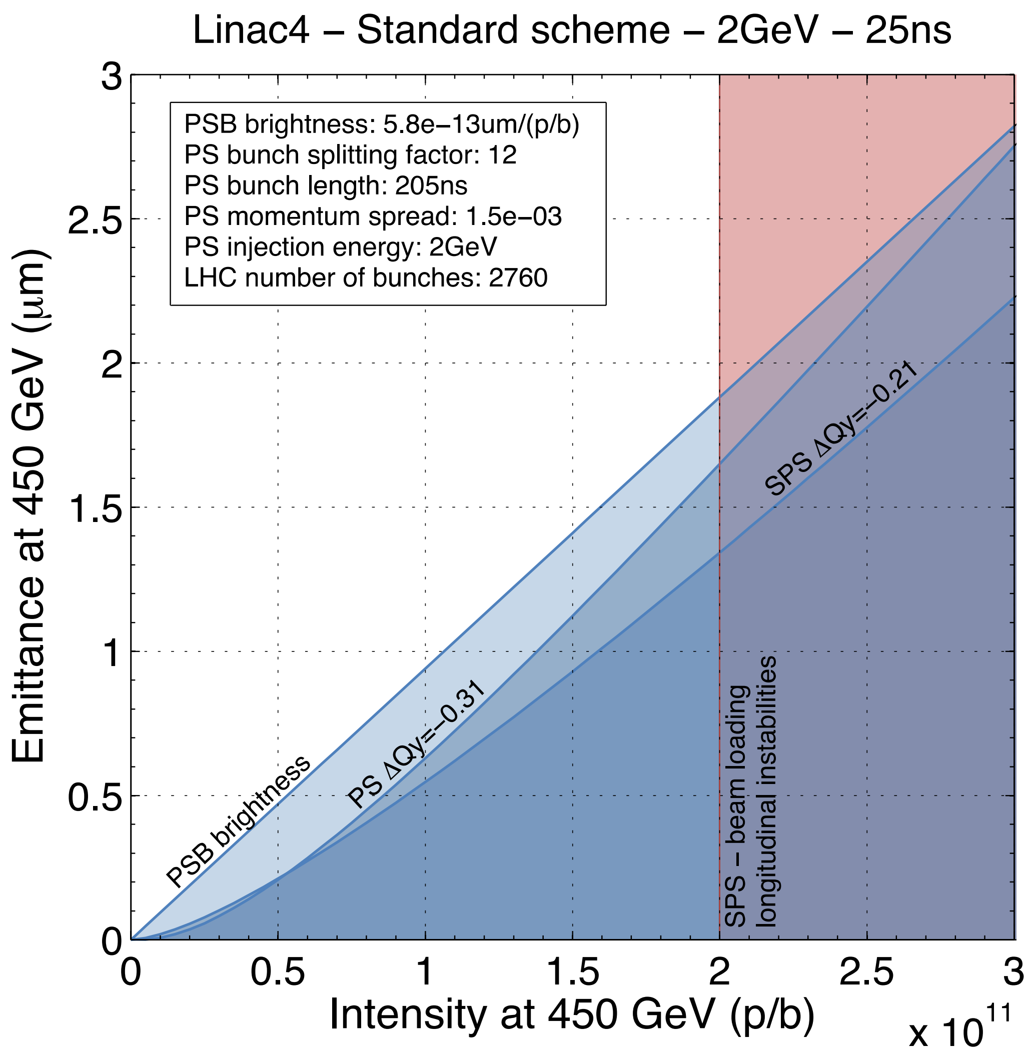
Can we ever reach the HL-LHC requirements with the injectors (LIU)? [1/3]

H.Bartosik

- **~Yes**... **<u>with the full LIU work programme</u>**:
  - All PICs + Linac4
  - All upgrades for PSB, PS (2 GeV + RF) and SPS (esp. 200 MHz high power RF upgrade)
  - SPS e-cloud mitigation

Can we ever reach the HL-LHC requirements with the injectors (LIU)? [2/3]

H.Bartosik



- **LIU upgrades**
  - SPS 200 MHz upgrade
  - SPS e-cloud mitigation
  - PSB-PS transfer at 2 GeV
- **Limitations standard scheme**
  - SPS: longitudinal instabilities + beam loading
  - PSB: brightness
- **Performance reach**
  - 2.0×10^{11} p/b in 1.88µm (@ 450GeV)
  - 1.9×10^{11} p/b in 2.26µm (in collision)

Can we ever reach the HL-LHC requirements with the injectors (LIU)? [3/3]

H.Bartosik

SPS e-clouds: scrubbing or coating? A possible strategy …

2014: Oct. – Nov.

SCRUBBING RUN I (2 weeks)
beams: nominal intensity
Goal: recover the 2012 performance
Risk: mixed with machine start-up

2015: Mar.

SCRUBBING RUN II (2 weeks)
beams: 2e11 p/b, scrubbing beam, …
Scrubbing successful for high intensity?

YES → Jun.: LIU-SPS Review: coating? (after data analysis!)

NO → a-C coating (during LS2)

a-C coating (during LS2)

Scrubbing qualification: No degradation for 2e11 p/b with 4x72 bunches and 6x48 bunches

Results from the 4 coated half cells

Simulations for higher brightness beams (from Linac4)

Work effort in the LHC injector complex for upgrade scenarios

B.Mikulec, J.B. Lallement

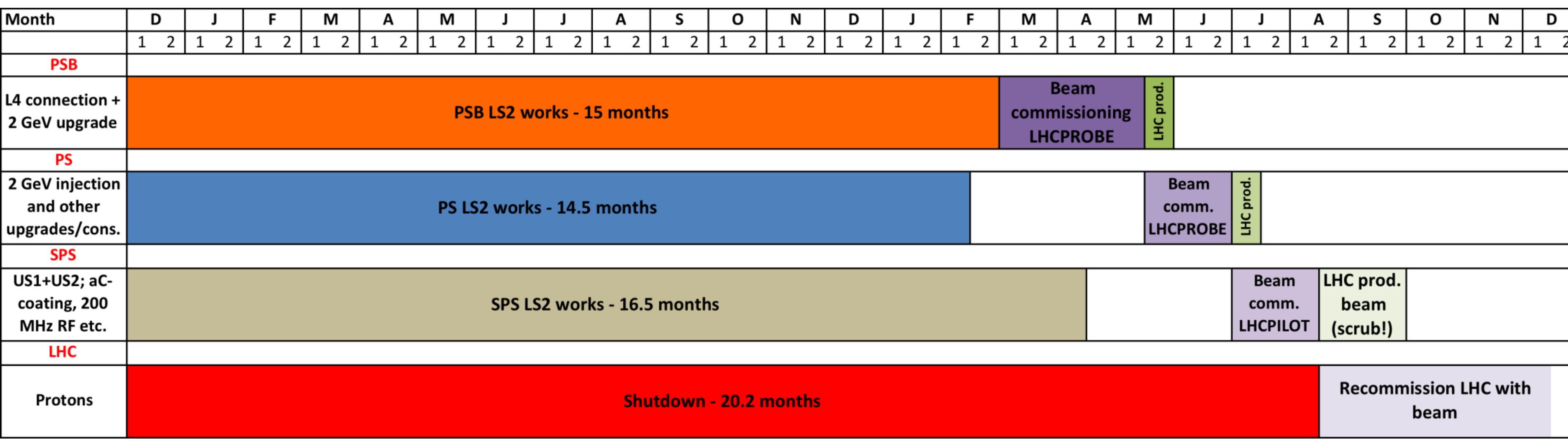
Linac4 connection to the PSB during an intermediate shutdown:

9.2 months (LHC Pilot)

All LIU upgrades during LS2:

20.5 months (LHC Pilot)

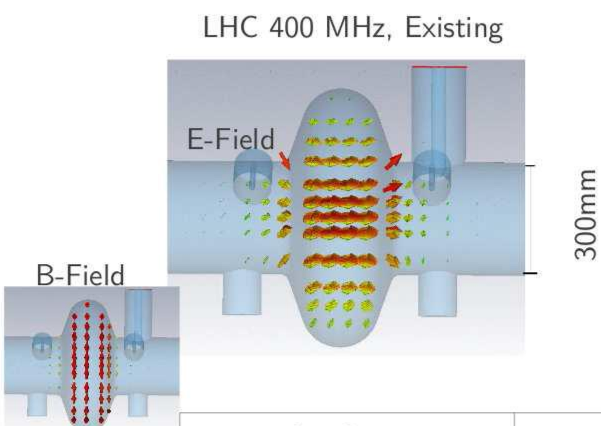
22 months (LHC Production)

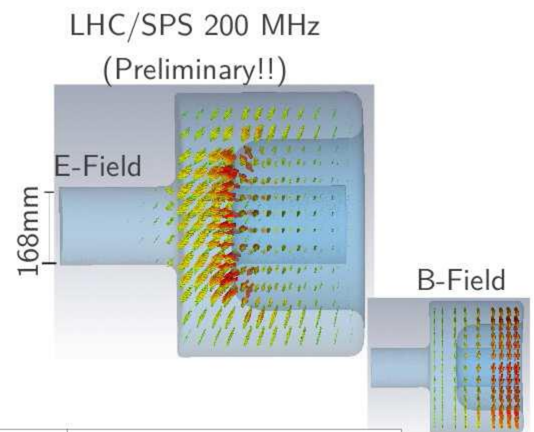


HL-LHC: Exploring alternative ideas [1/2]

R.Tomas

- **Alternatives:**
  - *8b+4e from the injectors* (2.4×10^{11} p/b) (test possible in 2014-2015):
    - ⇒ **much less e clouds than 25 ns**
    - ⇒ **much better luminosity than 50 ns (with achievable intensity of <3E11 p/b)**
  - *200 MHz main RF in LHC* ($\sim2.5\times10^{11}$ p/b):
    - ⇒ **larger longitudinal emittance / higher intensity from SPS**
    - ⇒ **less e cloud effects and less heating than with 400 MHz**
    - ⇒ **interesting also in US2 with or without crab cavity**





Voltage [MV]	2.0	2.0
Frequency [MHz]	**400.7**	**200.3**
Cavity Envelope [mm]	344	284

HL-LHC: Exploring alternative ideas [2/2]

R.Tomas

- **Other possibilities**:
  - *Pile-up density levelling*:
    - ⇒ **Lower integrated luminosity.**
  - *Pile-up density reduction with "crab-kissing"*:
    - ⇒ **Potential for reduction to 0.65 mm^{-1} with pile-up at 140 (with 800 MHz).**
  - *Coherent electron cooling*
    - *Promising performance / challenging hardware / never demonstrated.*
  - *Optical stochastic cooling*
    - *Marginal improvement / never demonstrated.*

LIU: Exploring alternative ideas [1/2]

H.Damerau

	Basic choices + alternatives	Additional possibilities
Linac4		• Vertical painting Linac4 +? %
PSB	• Faster recombination kickers PSB-PS (with 1.4 GeV)	• Long. flat or hollow bunches +25 %
	• 2.0 GeV at PSB→PS transfer	
PS	• Double-batch or *h*=5 single-batch injection • 3-split, BCMS, BCS or PBC (pure batch comp.) • 8b+4e together with 3-split or BCMS	• Resonance compensation +? % • Special injection optics +? % • Long. flat or hollow bunches +25 %
SPS	• SPS RF upgrade: 4×3+2×4 • More RF power plants: 4×2+4×3 or 10×2 • Relaxed ε_l with 200 MHz in LHC	• 28 GeV at PS→SPS transfer +15 % • Split tunes optics +5 % • Special injection optics +? %

Baseline | Beam studies before LS1 | Beam studies possible after LS1 | Needs hardware

LIU: Exploring alternative ideas [2/2]

H.Damerau

- **No magic alternative to Linac4 + 2.0 GeV + SPS RF upgrade**
- **Large number of schemes to increase intensity and brightness from injectors**
  - → **Linac4+PSB+PS may push SPS to space charge limit**
- **Longitudinally larger bunches in SPS possible together with RF upgrade**
- **Limited reach of brute-force approach installing even more RF power**

- **Interesting alternatives can be studied in injectors after LS1**
  - → **PSB: Hollow bunches**
  - → **PS: Flat or hollow bunches, special flat-bottom optics, pure batch compression, 8b+4e schemes, higher PS-SPS transfer energy**
  - → **SPS: split tunes optics, higher intensity with slightly longer bunches**

- **Combinations of alternatives keep flexibility of injector complex to react to requests from LHC: short-, micro-, 8b+4e-batches**

How to reach the required availability? [1/3]

M. Lamont

A lot is already being done and anticipated to be done, across OP, R2E equipment groups, RP and HL-LHC project

Availability – e.g. cryogenics

- 95% in 2012-13, including MDs and physics.
- Baseline target for HL-LHC era: 95 % with all facilities operational + 3 additional.

Fault overhead

- Better diagnostics
- Less tunnel interventions
  - Remote resets, redundancy, remote inspection
  - Stuff on surface, 21st century technology
- Faster interventions
  - TIM radiation surveys, visual inspections etc.

Faults

- More rigorous preventive maintenance – technical stops to allow said.
- Sustained, well-planned consolidation of injectors
- Plant redundancy e.g. back-up cooling pumps, fully reliable UPS
- Updated design for reliability, targeted rad-tol, robust, redundant system upgrades given experience and testing

Operational efficiency

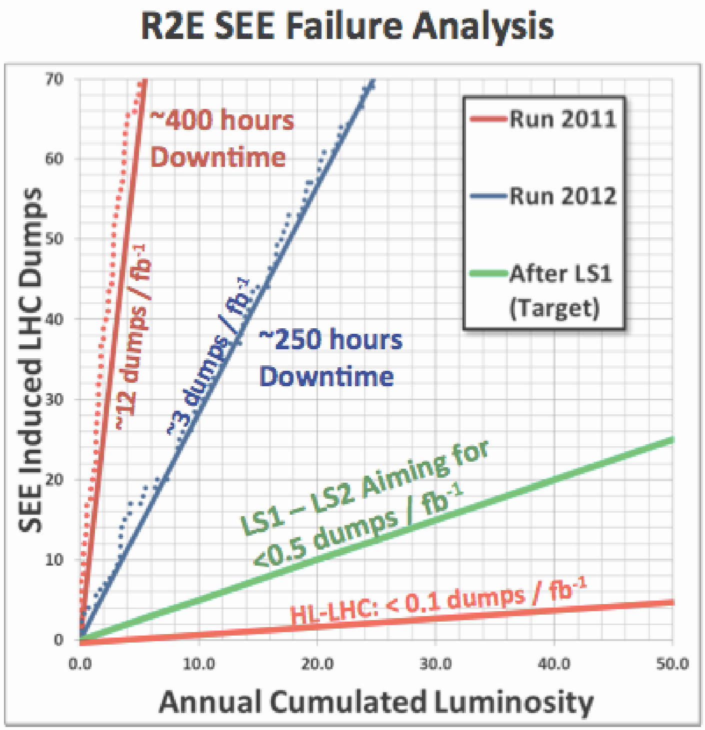
- Fully and robustly establish all necessary procedures required in HL era
- Optimized BLM thresholds completely
- Compress the cycle: e.g. Combined ramp & squeeze, etc.
- More efficient and fully optimized set-up
- Upgraded system performance: e.g. 2Q triplet power supplies

How to reach the required availability? [2/3]

M. Lamont

- Availability issues to be monitored by the AWG in 'more formal' approach?
- Injectors must be reliable!
- R2E must be mastered.

LHC R2E: Past/Present/Future



- **2008-2011**
  - Analyze and mitigate all safety relevant cases and limit global impact
- **2011-2012**
  - Focus on long downtimes and shielding
- **LS1 (2013/2014)**
  - Final relocation and shielding
- **LS1-LS2 (2015-2018)**
  - Tunnel equipment and power converters

At least X100 improvement needed!!

Courtesy Markus Brugger

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How to reach the required availability? [3/3]

M. Lamont

- Clear message: fixing fault is only part of problem: also overheads and pain of losing fill (ramp, squeeze, in physics)…
- Number 1 cause of lost fills was in fact not fault related, somewhat self-inflicted: e.g. Tight collimator settings, bunch intensity…
- Number 2 & 3 (QPS and power converters)
  - Huge distributed systems
  - Significant fraction to Single Event Effects (10% of total dumps)…
- Must keep addressing issues with individual systems and anticipate operating conditions in HL era. R2E effort remains critical.
- **BACK OFF!** Keep operational parameters ‘comfortable’
- ‘Run it like we mean it!’ Work on the % level issues…
- Large effort will clearly be needed to keep the 2012 efficiency levels in HL-LHC era (i.e. shouldn’t at this stage count on doing much better)

Workshop on **"Machine Availability and Dependability for post LS1 LHC” – CERN, 28/11/2013,** https://indico.cern.ch/conferenceDisplay.py?ovw=True&confId=277684

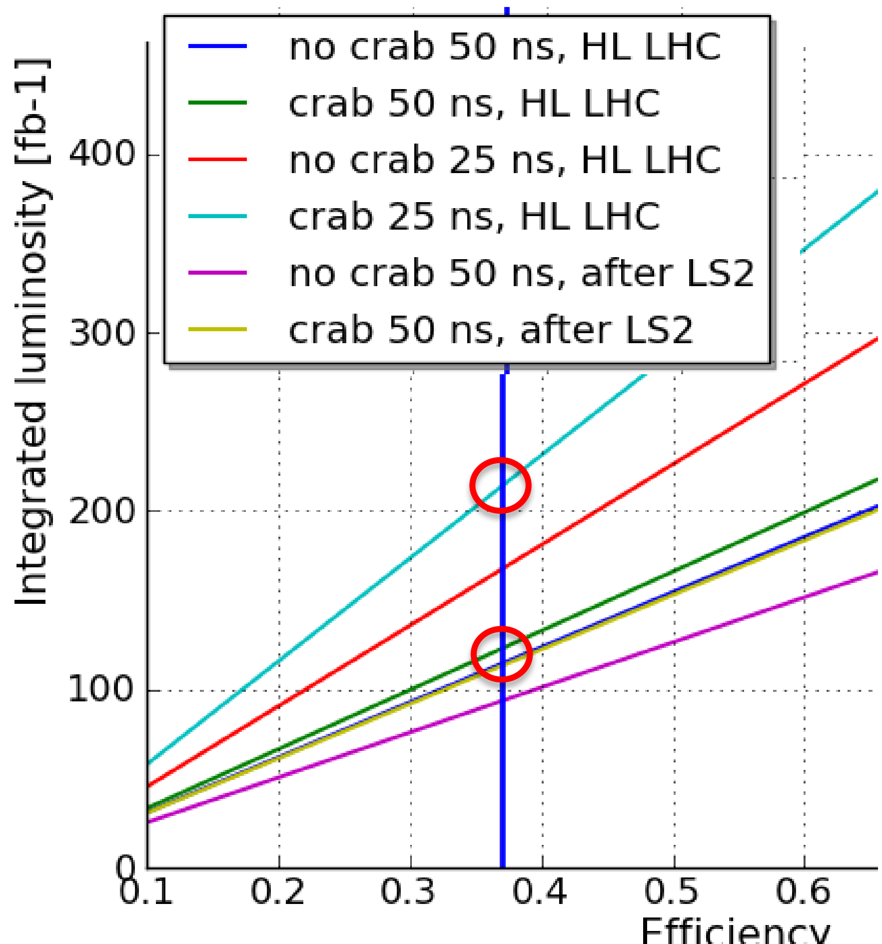
50 ns backup solution[1/2]

V. Kain

- Main threat to 25 ns seems still to be e-cloud….
- Performance essentially 50% of 25 ns reach (as 25 ns can already run at pile-up limit for average fill length)

Résumé of 25 ns possible issues

- Machine protection: probably solvable
- Heating: similar for 25 ns and 50 ns
- UFOs: to be seen in LHC run 2
- Beam-beam: most certainly under control
- Possible only real threat: e-cloud



50 ns backup solution[2/2]

V. Kain

- **50 ns main features:**
  - Much easier as regards e-cloud
  - Beam heating similar to 25 ns
  - Instabilities could be more problematic
  - Injectors can 'saturate' LHC with expected performance (again pile-up and physics efficiency are the limits)
  - Less integrated luminosity: ~50 % of 25 ns performance
- **Other schemes to be investigated:**
  - 8b+4e (short term): 33% more bunches than 50 ns
  - **Micro-batches (short term): improved LRBB situation**
  - **200 MHz main RF in LHC (long term): nominal nb of bunches**
  - **?**

My additions

- **No clear-cut additional upgrades identified for 50 ns**
  - Efficiency and crab cavities in LHC more important than 'stretching' injectors
  - Cures/mitigations might be needed to stabilize the beam: unknown today.

Open questions…

3000 fb^{-1} in ~2035 ⇒ Operation at 270 fb^{-1}/year immediately after LS3 (2024)!

Crucial importance of fill duration >6 h/pile-up >140/early availability of upgrades.

– **Experiments**
  - Operating at the largest possible pile-up is essential for reaching 3000 fb^{-1}
  - How crucial is pile-up density? Risk of trade-off with integrated luminosity.

– **LHC**
  - Realistic expectation with present assumptions is ~220 fb^{-1}/year.
  - Efficiency/high availability (=longer fills) is key for going further: need to organize accordingly (Is the AWG enough?).
  - Importance of progress on HL-LHC options (including 200 MHz as main RF) and need for decision tree.
  - More detailed planning necessary for HL-LHC during LS2 and LS3.

– **Injectors**
  - Planning? => Decision with organization set-up asap (coordination of activities, optimization of cabling work, minimization of beam commissioning risks…).