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

'How to maximise the HL-LHC performance'
R. De Maria

- HL experiments accept 140 events/Xing, with 1.3 mm^{-1} density
  - This is the performance limit, with physics efficiency

- 'HL-LHC baseline meets US2 target *with long fills* and exceeds it significantly *with higher pile-up limit*'

- 'LIU expected performance is close to the target but still worth improving for robustness and potentials'

'How to maximise the HL-LHC performance'
R. De Maria

- Requirements to approach 270 fb^{-1}/y - baseline
  - Lower beta* (~15-10 cm, with rebuilding IR1/5 insertions)
  - 25 ns with 1.9-2.2e11 p+/b (no ecloud in dipoles, beams stable)
  - Leveling via beta* (important to deploy in P8 in Run2)
  - Crab cavities, flat beams at IP to mitigate geometric reduction
  - Need longer fills than the 2012 average of 6h (physics efficiency!)

- Other messages
  - Beam characteristics of LIU baseline are OK for reaching US2 goals
  - Min. ~2 μm ε_{xy} 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 interesting to reduce crabbing/wire requirements

'How to maximise the HL-LHC performance'

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'
L. Rossi

- **Vast amount of work around the ring (1.2 km) for baseline**
- **Some work to be done in LS2 (DS collimators IP2/7, SC link IR7, P4 cryoplant, some collimators)**
  - Work should fit inside 18 months
- **Major part planned for LS3**
  - work should fit inside 26 months
- **Detailed shutdown plannings still to be made** – co-activities may prove to be limiting, also radiation doses to personnel (clear issue for the future)

	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

'How to implement all the HL-LHC upgrades' L. Rossi

- Other potentially beneficial systems still actively under study
  - 800 MHz and 200 MHz RF
  - 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 <u>in machine</u> to eventually aim above 3000 fb^{-1} if limitation on peak pile-up can be relaxed, e.g. to run at 7e34 $cm^{-2}s^{-1}$ (200 PU)

`Can we ever reach the HL-LHC requirements with the injectors (LIU)?` – H.Bartosik

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

`Can we ever reach the HL-LHC requirements with the injectors (LIU)?` – H.Bartosik

Scrubbing or coating? A possible strategy …

Oct.

Nov.

2014

Mar.

2015

Jun.

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

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

YES

NO

LIU-SPS Review: coating?
(after data analysis!)

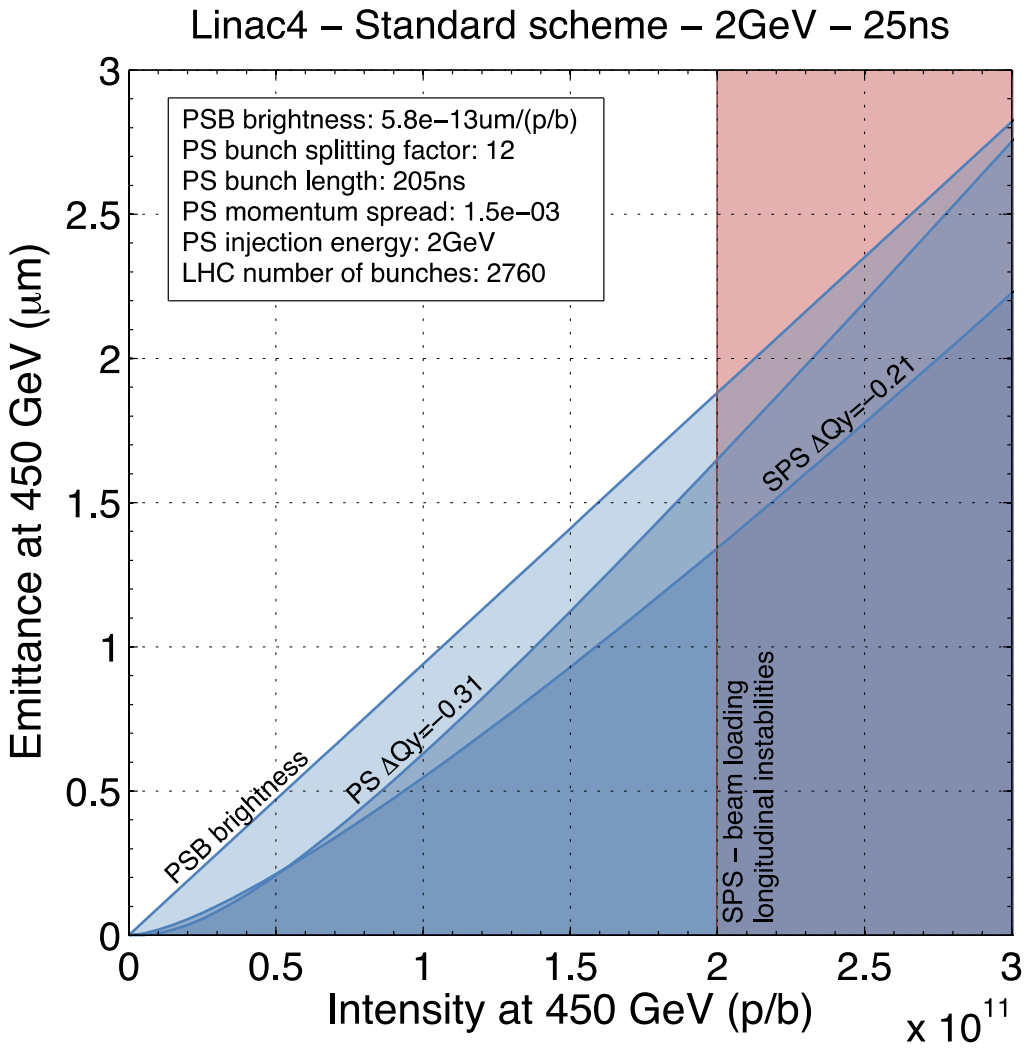
a-C coating (during LS2)

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)

`Can we ever reach the HL-LHC requirements with the injectors (LIU)?` – 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)

`*Work effort in the LHC injector complex for upgrade scenarios*` – B.Mikulec, J.B. Lallement

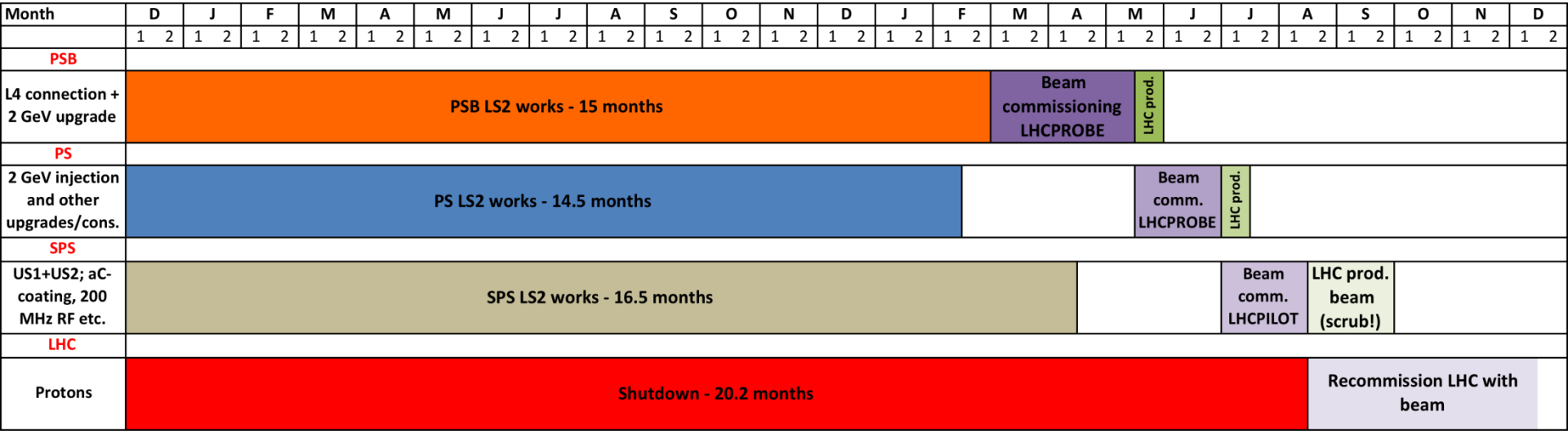
Linac4 connection to the PSB during an intermediate shutdown**:**

<u>9.2 months (LHC Pilot)</u>

All LIU upgrades during LS2**:**

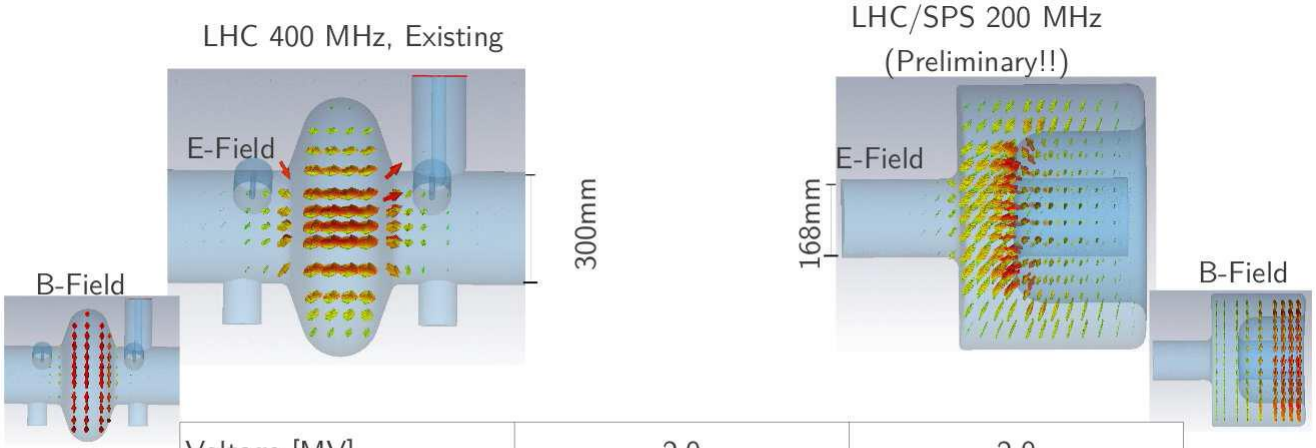
<u>20.5 months (LHC Pilot)</u>

<u>22 months (LHC Production)</u>



`HL-LHC: Exploring alternative ideas` – R.Tomas

- **Alternatives:**
  - *8b+4e from the injectors* (2.4E11 p/b) (test possible in 2014-2015):
    - ⇒ **much less e clouds than 25 ns**
    - ⇒ **much better than 50 ns (with achievable intensity of <3E11 p/b)**
  - *200 MHz main RF in LHC* (2.5E11 p/b):
    - ⇒ **larger longit. emittance from SPS / higher intensity**
    - ⇒ **less e cloud effects than with 400 MHz**
    - ⇒ **Interesting also in US2 even 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*` – R.Tomas

- **Other possibilities**:
  - *Pile-up density leveling*:
    ⇒ **Lower integrated luminosity**
  - *Pile-up density reduction with "crab-kissing"*:
    ⇒ **Potential for reduction to 0.65 mm-1 with pile-up at 140 (800 MHz?)**
  - *Coherent electron cooling*
  - *Optical stochastic cooling*

`LIU: Exploring alternative ideas` – H.Damerau

Linac4

PSB

- Faster recombination kickers PSB-PS (with 1.4 GeV)
- 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

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

Basic choices + alternatives

Additional benefit/margin

- Vertical painting Linac4 +? %
- Long. flat or hollow bunches +25 %
- Resonance compensation +? %
- Special injection optics +? %
- Long. flat or hollow bunches +25 %
- 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*` – 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 for even more RF power**

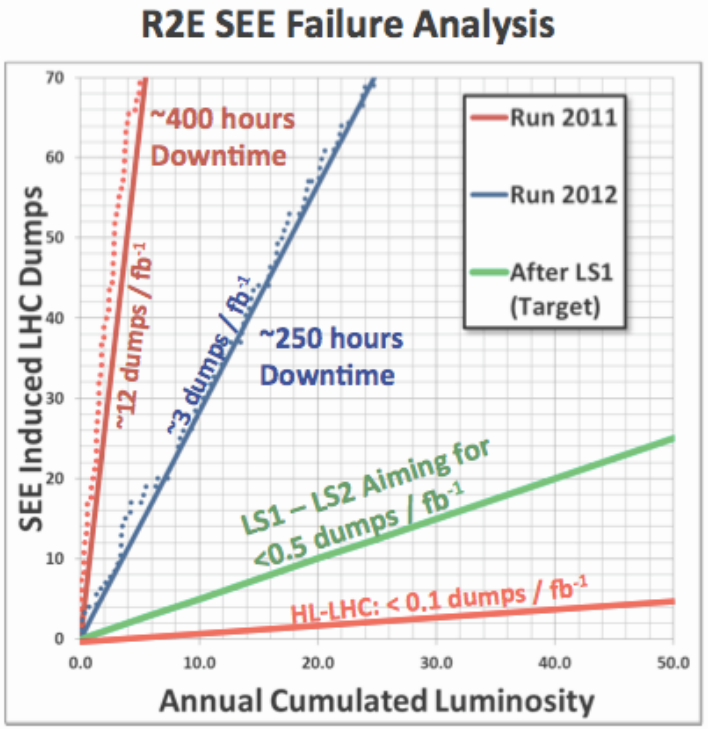
- **Interesting alternatives can be studied in injectors after LS1**
  - → **PSB: Hollow bunches**
  - → **PS: Flat or hollow bunches, special flat-bottom optics, pure batch compression, 8b+4e schemes, higher PS-SPS transfer energy**
  - → **SPS: split tunes optics, higher intensity with slightly longer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

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

'How to reach required availability' - M. Lamont

- A lot is already being done and anticipated to be done, across OP, R2E equipment groups, RP and HL-LHC project
- Availability issues to be monitored by the AWG in 'more formal' approach?

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

'How to reach required availability' - M. Lamont

- Clear message: fixing fault is only part of problem: also overheads and pain of losing fill (ramp, squeeze, in physics)…
- Number one cause of lost fills was in fact not fault related, somewhat self-inflicted:
  - 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)…

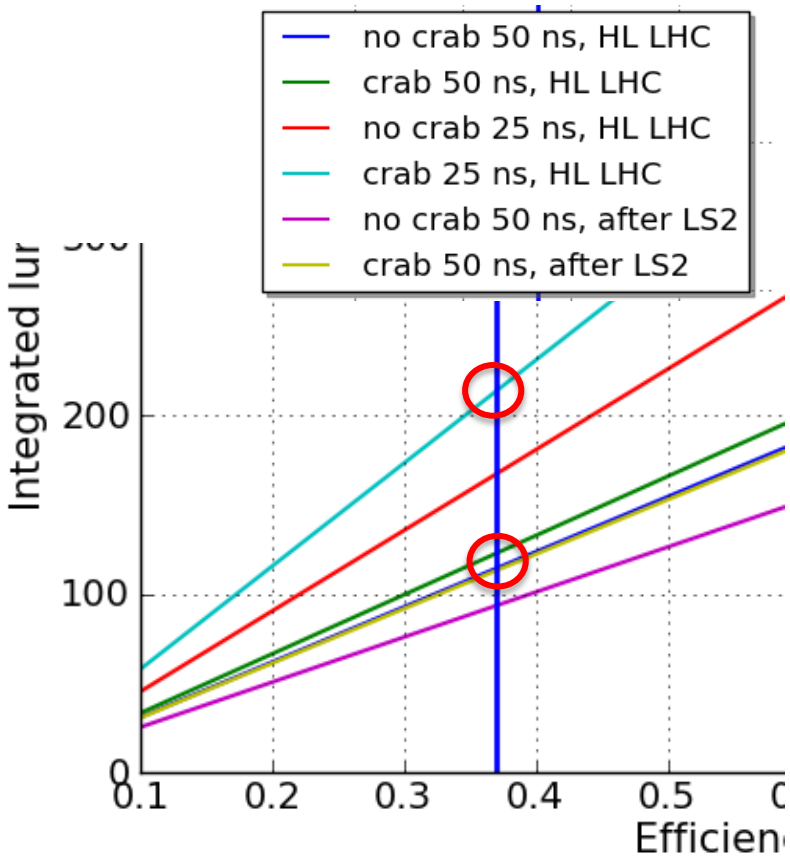
- Must keep addressing issues with individual systems and anticipate operating conditions in HL era. R2E effort remains critical.
- **BACK OFF!** Keep operational parameters 'comfortable'
- 'Run it like we mean it!' Work on the % level issues…
- Large effort will clearly be needed to keep the 2012 efficiency levels in HL-LHC era (i.e. shouldn't at this stage count on doing much better)

'50 ns backup solution' - V. Kain

- Main threat to 25 ns seems still to be ecloud….
- 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' - V. Kain

- 50 ns as alternative has following features
  - Much easier as regards ecloud
  - 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
- Intermediate schemes to be investigated: e.g. 8b-4e beam
  - More bunches than 50 ns, less e-cloud than 25 ns
- No clear-cut additional upgrades identified for 50 ns
  - Efficiency and crab cavities in LHC more important than 'stretching' injectors

Open questions…

Preliminary observation:

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

- **Experiments**
  - Operating at the largest possible pile-up is essential for >=3000 fb-1 …
  - How crucial is pile-up density? => risk of trade-off with integrated luminosity. Only point of reference is 140 peak and 1.3 mm-1. Is 200 peak acceptable with density of 0.7 mm-1? Or 170 peak and 1.0 mm-1?
- **LHC**
  - Is Availability Working Group the body to coordinate the High Availability part for HL-LHC?
  - What is decision tree for HL-LHC options? (200 MHz main RF deserves more investigation)
  - Can detailed planning for LS2 and LS3 be made for HL-LHC?
- **Injectors**
  - Planning of implementation? => Decision (esp. Linac4 connection) with adequate organization set-up asap (optimization of cabling work, minimization of beam commissioning risks…)