Session 3
Performance Improving Consolidation and Upgrade scenario 1

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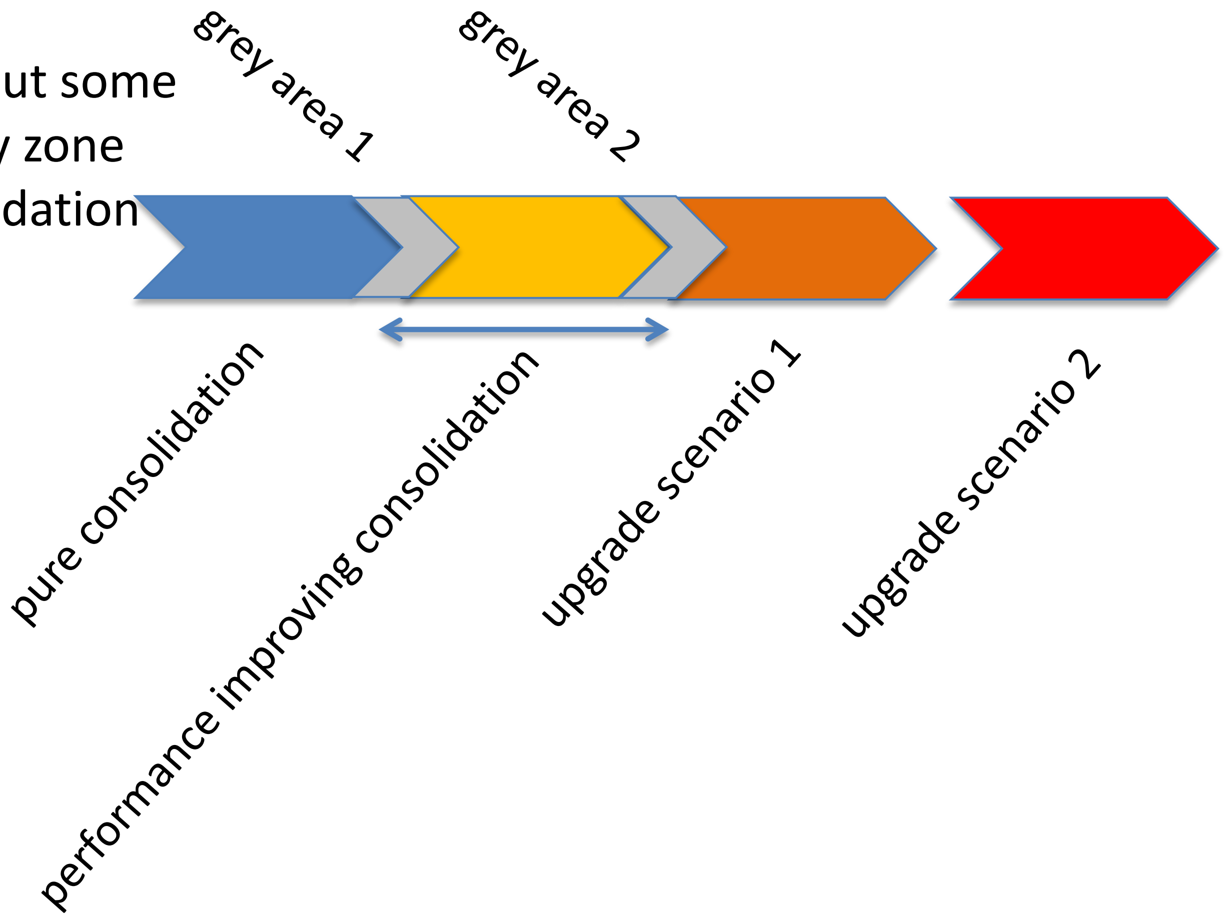
Thanks to all speakers and contributors

PICs in the injectors: What are we talking about? - K. Hanke

PERFORMANCE IMPROVING CONSOLIDATION:

Replacement or upgrade of a system justified by consolidation but with the goal of improving performance

Clear definition but some overlaps and grey zone with pure consolidation and US 1 and 2.



In short

- **Time drivers and minimum single block**

  LIU-PSB: minimum single block **12 m**

  LIU-PS: minimum single block **3 m**

  LIU-SPS: minimum single block **6 m**

  => all time estimates depend strongly on available resources (manpower)

  => consequent amount of work to be done in parallel for all machine

  => to be considered with the Cons, maintenance, upgrade preparatory work

- **Cost of PICs**

  LIU-PSB: 50 MCHF (essentially LIU-PSB budget[1] without the Linac4 part)

  LIU-PS: 16 MCHF (80% of total budget 20 MCHF[2])

  LIU-SPS: 23 MCHF (30% of total budget 77 MCF)

[1]: total budget 60.8 MCHF

[2]: baseline 20 MCHF, with all options 32 MCHF

- **PICs are mandatory and must be fully implemented in LS2 in the injectors regardless of which upgrade scenario is chosen**

PICs: what do we gain in beam performance? – Gianluigi Arduini

PIC @ 6.5 TeV (Pile-up limit at 140)

	Lev. time [h]	Opt. Fill length **2012 6h**	η_{6h}/η_{opt} [%] **Goal <50%**	ϕ_{6h}/ϕ_{opt} [%] **2012 36%**	Int. Lumi for η=50% for 6h /opt. fill length **Goal > 70 fb^{-1}**	Max. Mean Pile-up density/Pile-up [ev./mm]/[ev./xing] **<1.3/<140**
BCMS – 40/20	-	6.5	37/37	25/26	93/94	0.97/84
Standard - 40/20	-	7.3	40/40	27/28	87/88	0.79/69
BCMS – 50/25	-	6.8	39/39	26/27	89/89	0.77/78
Standard – 50/25	-	7.6	43/42	28/30	82/83	0.63/64

- The luminosity target can be reached with 40/20 optics
- BCMS: slightly higher performance but more sensitive than standard scheme to additive sources of emittance blow-up
- 50/25 optics provides margin in aperture and offers a reduction of the pile-up density below 0.7 events/mm
- Key questions and studies required in Run 2 have been sketched - Understanding and Control of the additive sources of blow-up; Confirmation of the feasibility of β*-levelling as a possible solution for IP8; Confirmation of the feasibility of scrubbing the dipoles down to SEY=1.3-1.4 possibly with dedicated beams; Full understanding of the stability limits for single and two-beams

Which beams in the injectors fulfil HL-LHC Upgrade Scenario 1 goals? Simone Gilardoni

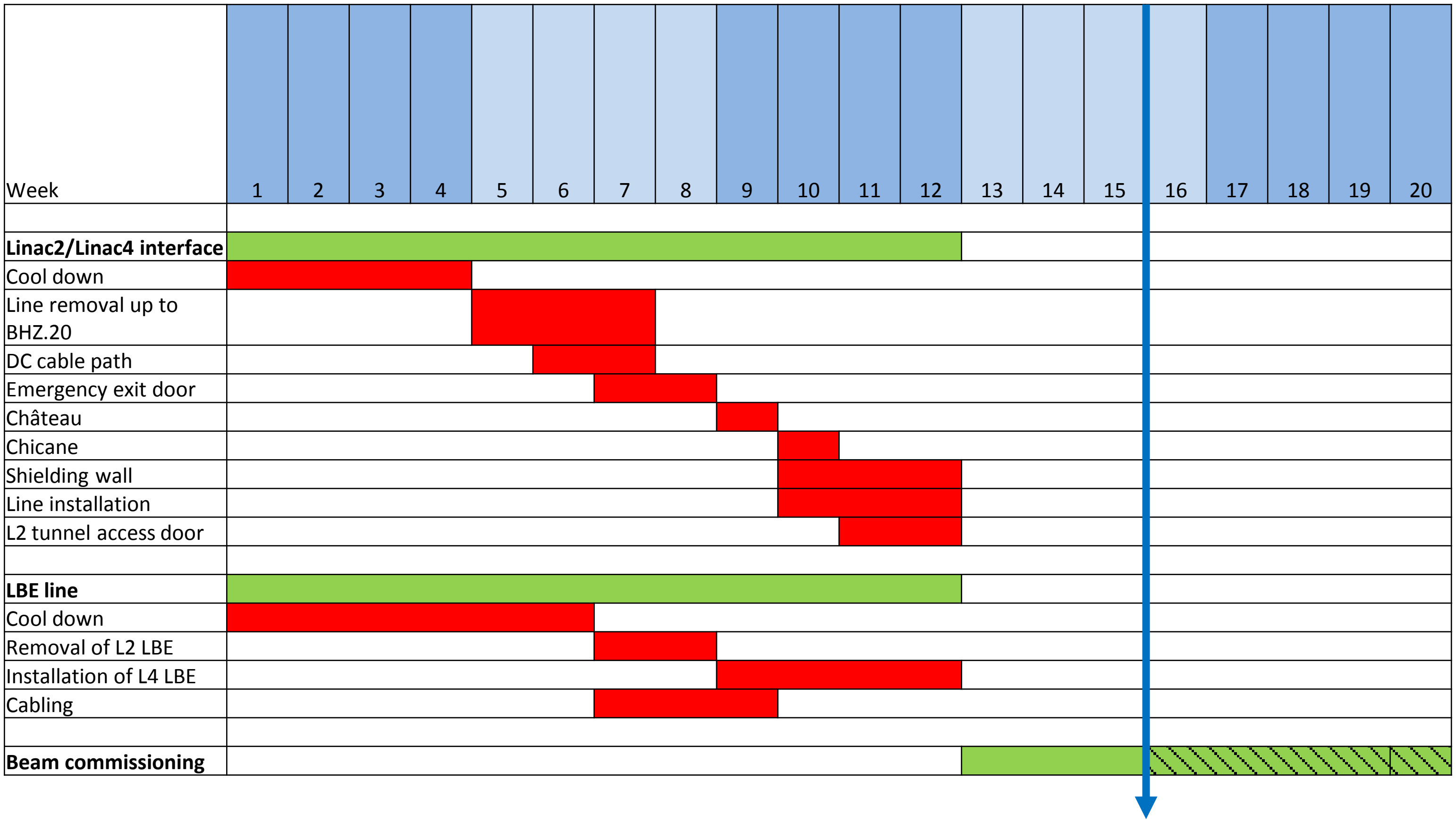
	Ib(10^{11})	ε (μm 1σ norm)	
US1 requirements (LHC collision/**injection Baseline**)	1.5/**1.58**	1.5/1.25	LHC
US1 requirements (LHC collision/injection Alternate)	1.2/1.26	1/0.83	
US1 NEW requirements (LHC collision/injection Alternate)	**> 1.45e11**	**> 1.8**	
Linac4 + 2 GeV + SPS LLRF upgrade US1 (PS Standard scheme – 72 bchs)	**1.45**	1.37	LIU at SPS extraction
Linac4 + 2 GeV + full SPS upgrade (PS Standard scheme – 72 bchs)	**2.0**	**1.88**	
Linac4 + 2 GeV + SPS LLRF upgrade (PS BCMS scheme – 48 bchs)	**1.45**	0.91	
Linac4 + 2 GeV + full SPS upgrade (PS BCMS scheme – 48 bchs)	**2.0**	**1.37**	

Large bunch intensity in LHC more important than low emittances

200 MHz RF Upgrade necessary to match the preferred requirements of LHC-US1 with unchanged longitudinal parameters at LHC injection.

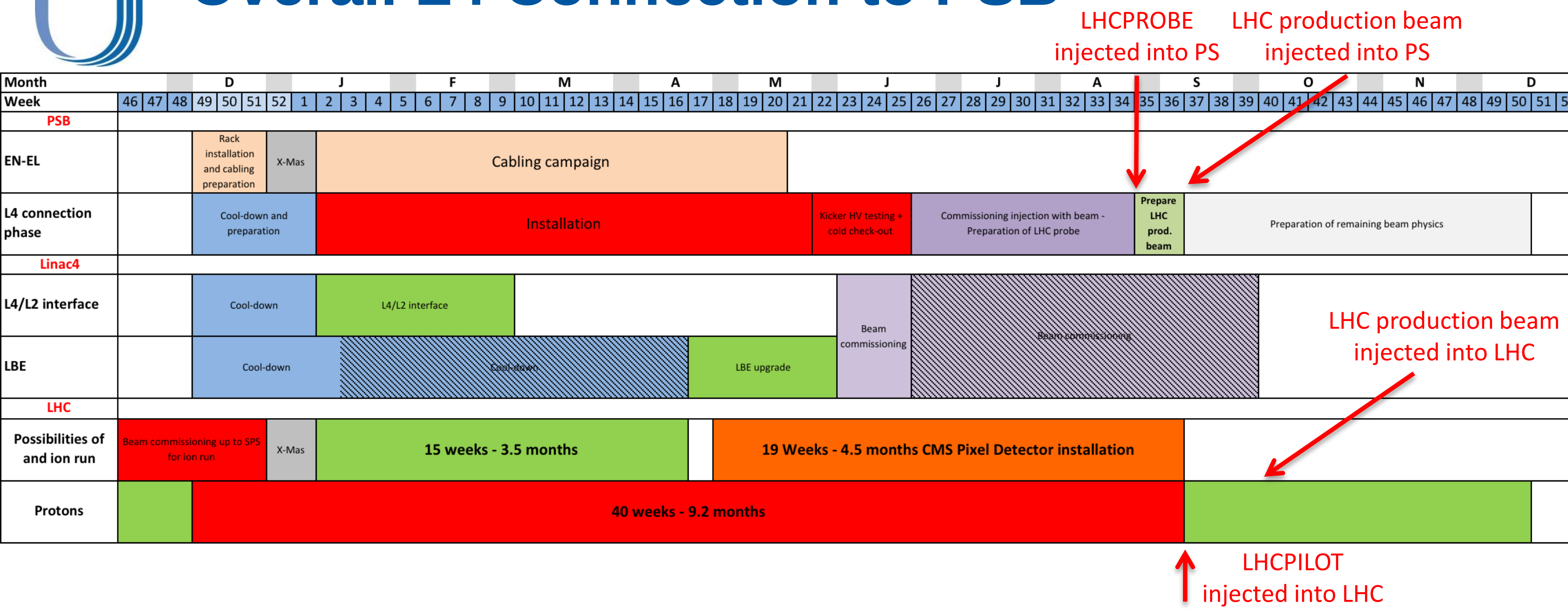
LIU US1 ≣ LIU US2

Work Effort in the LHC Injector Complex, Including Linac4 Connection, for the Upgrade Scenarios – Jean-Baptiste Lallement, Bettina Mikulec



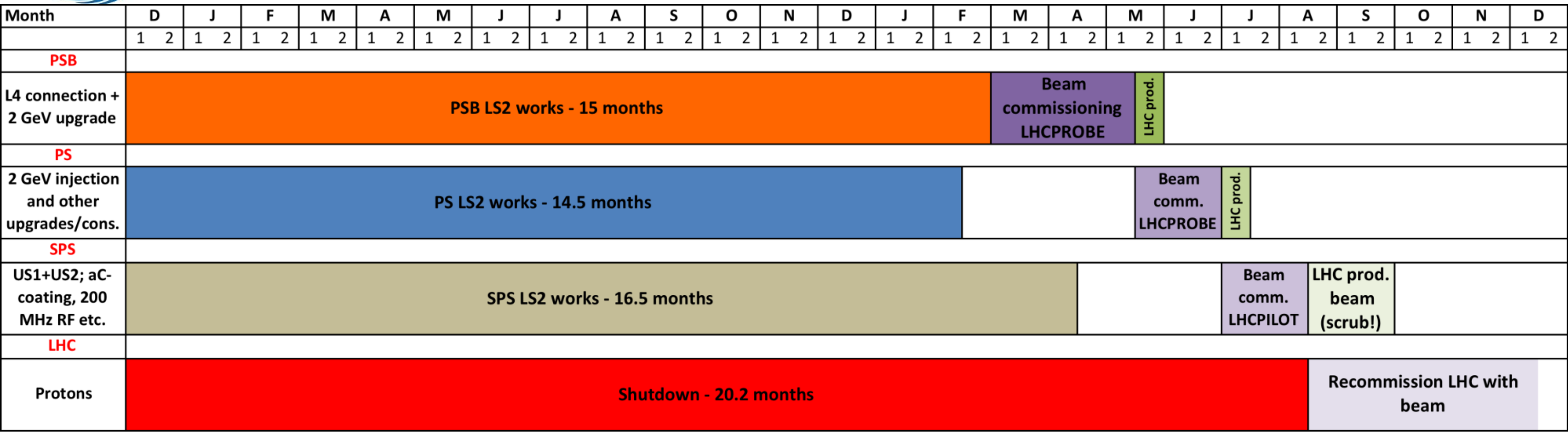
Linac4 : 15 weeks to deliver a beam to the PSB

Overall L4 Connection to PSB



- Duration for the Linac4 connection to the PSB: 9.2 months
  - Deliverable: LHC production beam injected into PS; coincides with injection of LHCPILOT beam into the LHC
  - Other physics beams to follow at an estimated rate of ~2/week
- First beam to the PS after 9 months
- Ion run and CMS pixel detector installation in parallel?
  - Ion beam commissioning in LHC ion injector chain end of 2016 in parallel to p run
  - LHC ion run of up to 3.5 month after X-mas
  - CMS pixel detector installation: 4.5 months
  - Could other activities profit? (NA61/SHINE etc.)

LIU LS2 Planning



LS2:

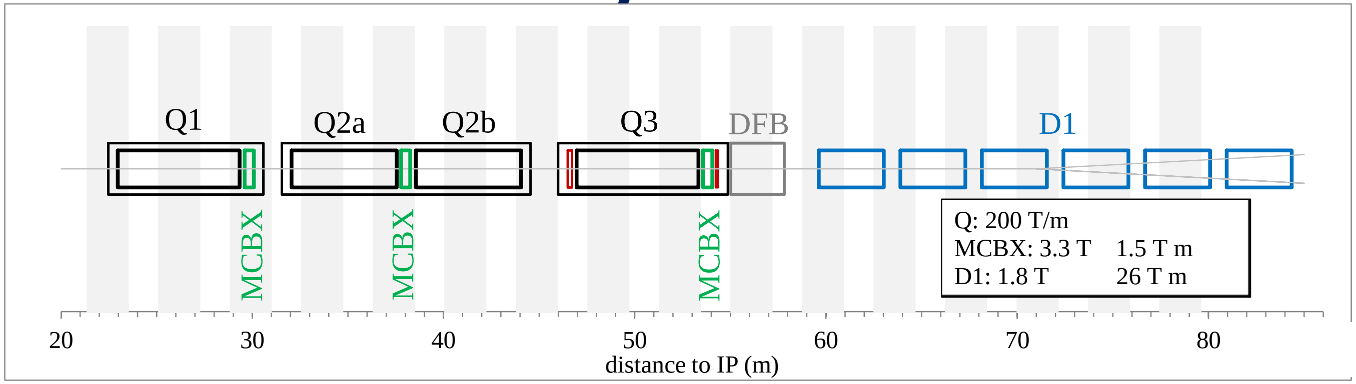
- Time line driven by PSB activities (impressive cabling work to be performed -> coherent scheduling in progress taking into account the overall requests needed for other projects)
  - ➢ PSB first beam (LHCPROBE) to the PS: **after 17.5 months**
  - ➢ PS ready for beam from PSB already **after 14.5 months** **-> need to gain 3 m in PSB**
  - ➢ SPS ready for beam from PS: **after 16.5 months**

→ **First injection of LHCPILOT into the LHC: after ~20.5 months**

→ **Minimum time for injection of LHC production beam into the LHC: after ~22 months** (scrubbing!)

Layouts

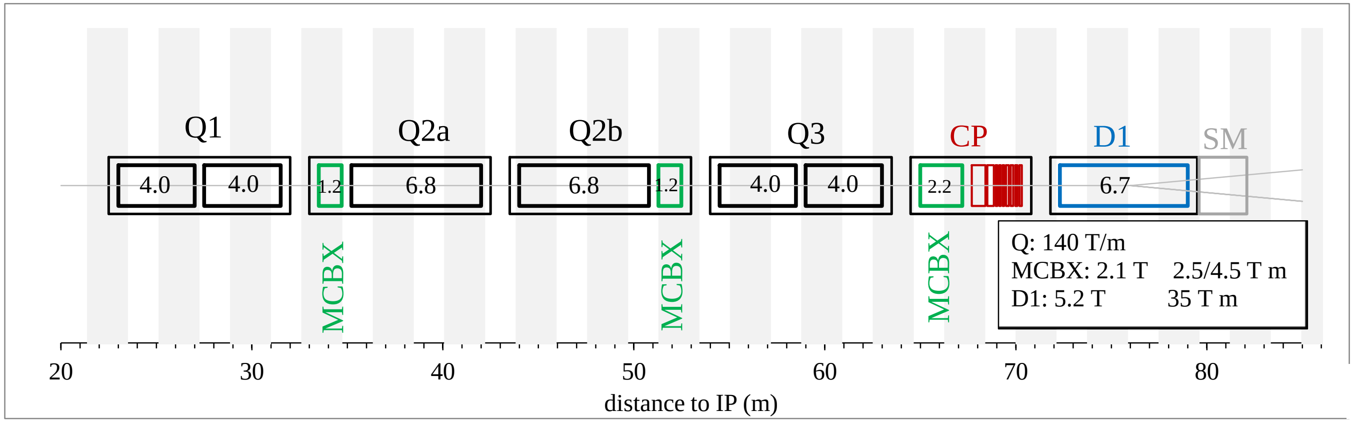
From P. Fessia



LHC

[E. Todesco]

Aperture ~twice the LHC baseline (70 mm to 150 mm), but more compact triplet layout thanks to Nb_3Sn and superconductive D1



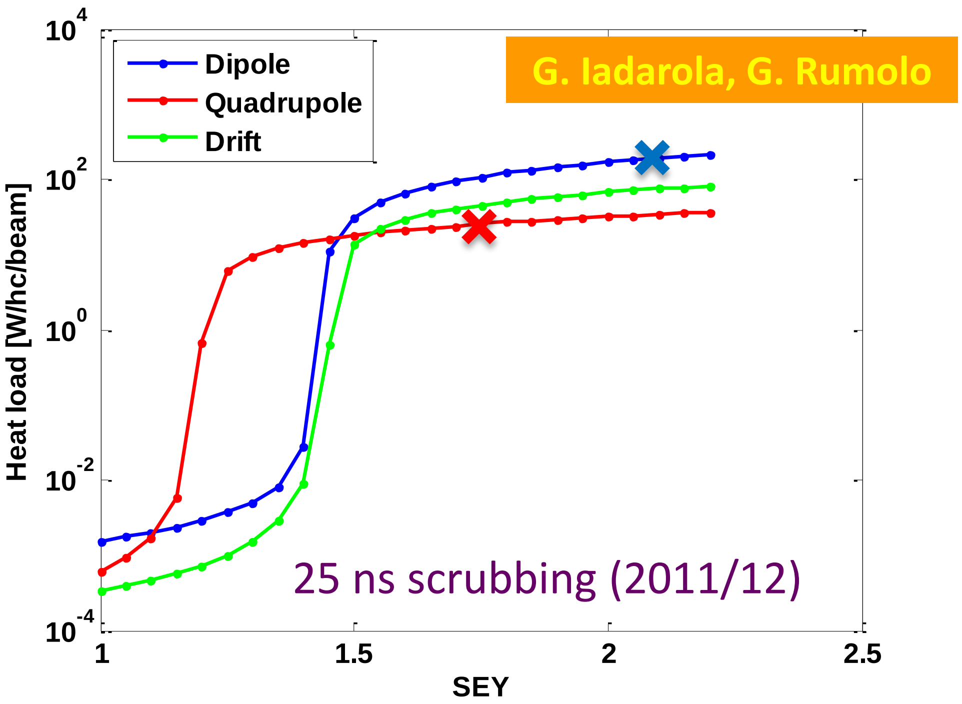
HL LHC

[E. Todesco]

From . G. Arduini

Implications & Assumptions (e-cloud)

- Control of the blow-up due to e-cloud via scrubbing at 450 GeV
  - Emittance blow-up occurs when electron cloud activity in the dipoles
  - SEY reduction in the dipoles at 450 GeV with 25 ns scrubbing run. Need margin for small emittance/shorter bunch ➔ doublet beams being considered and LS1 interventions to increase cryo-margin at injection (SAM and Sector 34)

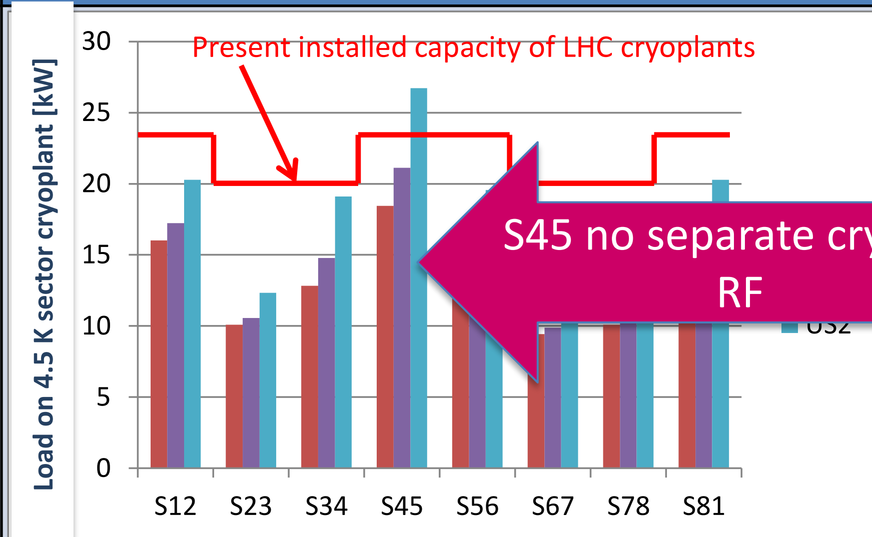


- Expect heat load in the quadrupoles due to the lower threshold SEY ➔ cryo upgrade (c/o P. Fessia)
- HL-LHC triplets/D1 will have e-cloud countermeasures implemented (aC coatings and possibly clearing electrodes)

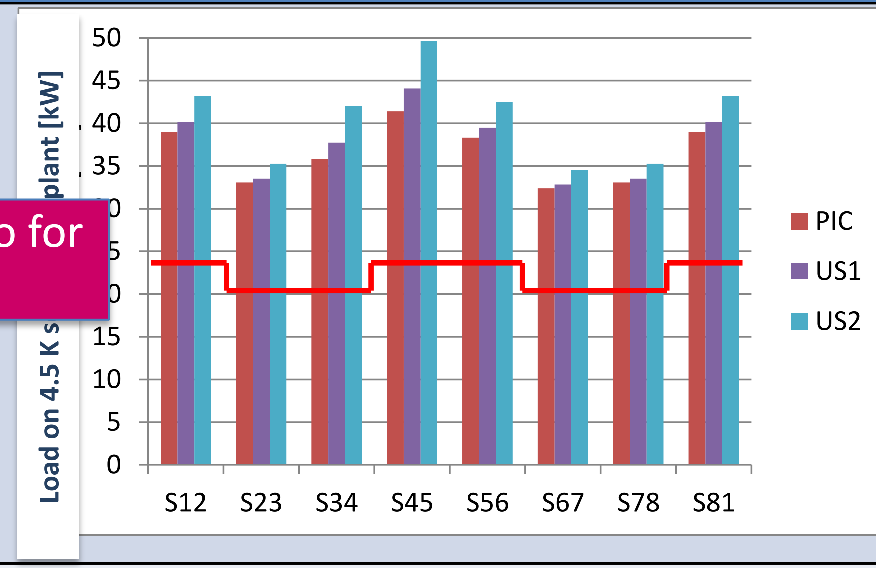
Total load per sector 4.6-20K range

TODAY

4.6-20 K e-cloud Dipole off

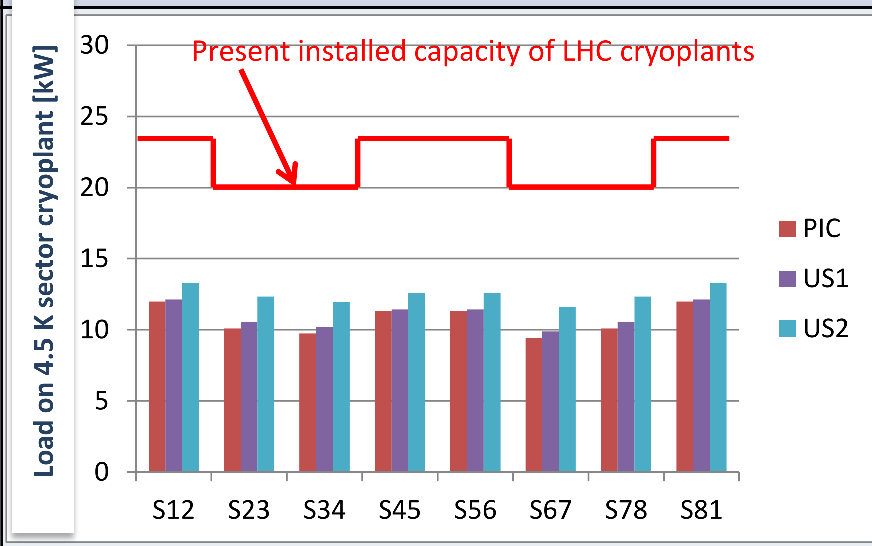


4.6-20 K e-cloud Dipole on

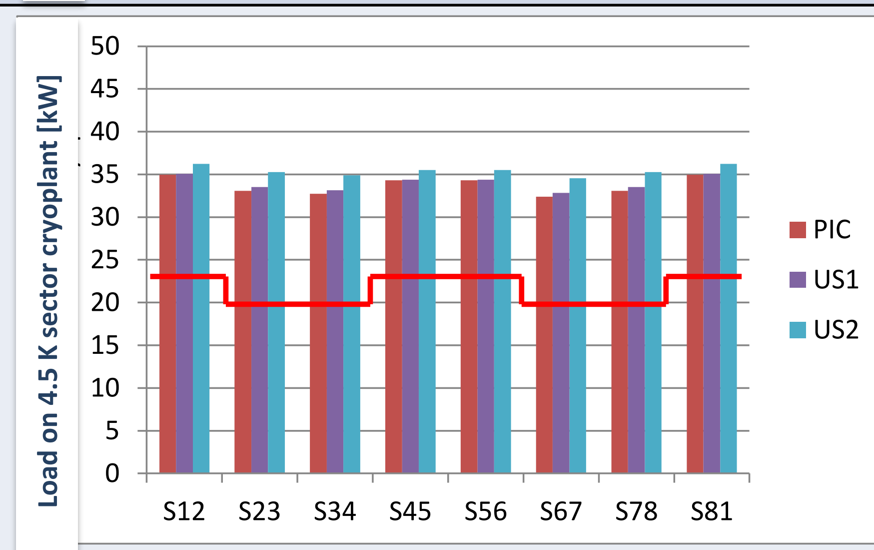


+ IP4 + IP1 + IP5

4.6-20 K e-cloud Dipole off



4.6-20 K e-cloud Dipole on



From P. Fessia

[L. Tavian]

Conclusions

From P. Fessia

- PIC actions
  - Concern practically all the sectors of the machine
  - The are spread between the 1st long technical stop after LS1 and LS3
- Interaction region interventions in IP 1 and 5 provide safe operation for 2025->2035 years and the required luminosity capacity (See G. Arduini talk)
- Collimation interventions push down the whole machine impedance providing more robust collimators and ensure safe ion run in IP2. Remark: the collimator lifetime is being analysed in this moment. Possible intervention on secondaries could be necessary to provide reliable exploitation after LS2
- Beam diagnostic interventions provide the necessary diagnostic capacity, with hardware compatible with the higher radiation dose
- Sc links provide a solution to radiation electronic issues for the Power converters, but also contribute in reducing collective dose, interventions time and reduce risk of SEE
- Cryoplant at point 4 provides flexibility in the management of the RF interventions and eliminate the 1st machine bottleneck in term of cooling capacity. All cryo installation have to be performed with a long term view from the installation/integration perspective (foresee for future needs)
- High radiation dose point call for radiation management and possible reconfiguration to provide the best as possible reliability and access conditions. Radiation tolerant electronic development (including R&D and testing) will affect several equipment groups (costs, resources)

HL-LHC Assumptions for US1:

From. O. Bruning

- -New triplet magnets (PIC) -> smaller than nominal β^* reach
- -No new magnets or movements in the matching section
- -No Crab Cavities
- -Long Range Beam-Beam wire compensators at a position of ca. 10 sigma resulting in a required beam separation of 10 sigma (question was raised why we assume LRBB wires for US1 but not for US2 and if compatible with CS).
- -160 days of operation for physics production; -Beam energy = 6.5 TeV
- -25ns scheme using BCMS -> 2593 bunches
- -5% intensity loss from SPS extraction to LHC collisions
- -Cases 1: 20% emittance blow-up from SPS extraction to LHC collisions (the question was raised if this is a realistic assumption for small emittance beams)
- -Other Cases: emittances between 1.8 and 2 micrometer (between 50% and 75% blow up from SPS extraction to LHC collisions wrt LIU expectations)

Summary of LIU Performance: [Simone Gilardoni]

	LHC collision		SPS extraction	
Classical Scheme	**Int/b**	**Emitt* (µrad)**	**Int/b**	**Emitt* (µrad)**
~~US1 Baseline~~	~~1.50E+11~~	~~1.5~~	~~1.58E+11~~	~~1.25~~
~~US1 low emit.~~	~~1.20E+11~~	~~1~~	~~1.26E+11~~	~~0.83~~
US1 LIU SPS LLRF 200 MHz upgrade	1.38E+11	1.64	1.45E+11	1.37
US1 LIU SPS 200 MHz full upgrade	1.90E+11	2.26	2.00E+11	1.88
BCMS				
~~US1 Baseline with BCMS~~	~~1.50E+11~~	~~1.5~~	~~1.58E+11~~	~~1.25~~
~~US1 low emittance with BCMS~~	~~1.20E+11~~	~~1~~	~~1.26E+11~~	~~0.83~~
US1 LIU SPS LLRF 200 MHz upgrade	1.38E+11	1.09	1.45E+11	0.91
US1 LIU SPS 200 MHz full upgrade	1.90E+11	1.64	2.00E+11	1.37

- BCBMS ➔ 2592 bunches for trains of 48 bunches
  following presentation by John Jowett @ LIU Technical meeting
  and Christian Carli's Chamonix 2011 presentatio
- Last lines refer to SPS upgrade with RF Power upgrade [ca. 25MCHF]

➔ Following analysis based on evaluation of non-crossed out cases and with variations of the beam emittance

From. O. Bruning

Large β & SPS RF Power Upgrade: Case 3b

- -US1 flat beams; SPS with new LLRF system **and withthe RF power upgrade**
- -N at collisions = 1.9 10^{11}ppb
- -n = 2508 colliding pairs in IR1 and IR5 (revised BCMS filling scheme)
- -normalized emittance = 2.80 micrometer (> 70% blow-up wrt SPS extraction)
- -flat beams with beta* = 0.5m / 0.25m
- -beam separation of 10sigma -> crossing angle of 310 microrad
- -IBS growth rates of ca. 22h horizontally and 25h longitudinally (scaled)
- -Peak Luminosity = 5 10^34 cm^-2s^-1
- -No Leveling time; Lumi decay time = 6 h; Turnaround time = 3 hours
- -Total fill length (leveling + decay + turnaround) = 9h
- -Integrated Lumi per fill =0.71 fb^{-1}; Lumi per year for perfect operation = 304fb^{-1}
- -Required efficiency for achieving 170fb^-1 per year = 56%

==> Case 3b could reach the US1 goals but is challenging in terms of efficiency.

From. O. Bruning

+MS Upgrade for US1: Case 4

- -US1 flat beams; SPS with new LLRF system and with the RF power upgrade
- -N at collisions = 1.9 10^{11}ppb
- -n = 2508 colliding pairs in IR1 and IR5 (revised BCMS filling scheme)
- -normalized emittance = 2.65 micrometer (> 70% blow-up wrt SPS extraction)
- -flat beams with beta* = 0.4m / 0.1m
- -beam separation of 10sigma -> crossing angle of 310 microrad
- -IBS growth rates of ca. 22h horizontally and 25h longitudinally (scaled)
- -Peak Luminosity = 8 10^{34} cm^{-2} s^{-1}
- -Leveling time = 2.9 h; Lumi decay time = 4 h; Turnaround time = 3 hours
- -Total fill length (leveling + decay + turnaround) = 9.9h
- -Integrated Lumi per fill =1.06 fb^{-1}; Lumi per year for perfect operation = 413fb^{-1}
- -Required efficiency for achieving 170fb^-1 per year = 41%

==> Case 4 could easily reach the US1 goals and is OK from the IBS point of view.
20% L-int increase wrt Case 3b (requiring essentially TAS and TAN upgrades)

From. O. Bruning

From E. Todesco

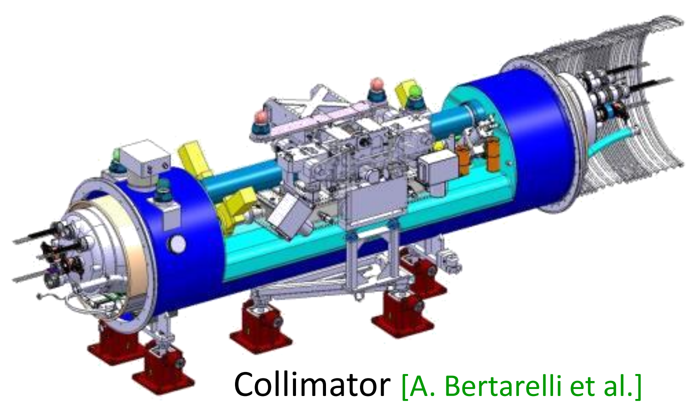
- The plan for collimation in the next years is strongly dependent on the first results of operation at 7 TeV

[S. Redaelli]

  - So it is difficult to make a guess, but we must have a baseline

- With these caveat, for US1 we foresee installation of additional collimators in IR7 – IR1 – IR5
  - 11 T technology used to make space
  - 10 units needed: 20 magnets (5.5 m long) plus 10 collimators
  - Same hardware used in IP2 for the PIC – cost ~65 MChf

11 T dipole [M. Karppinen, S. Zlobin et al.]



Collimator [A. Bertarelli et al.]

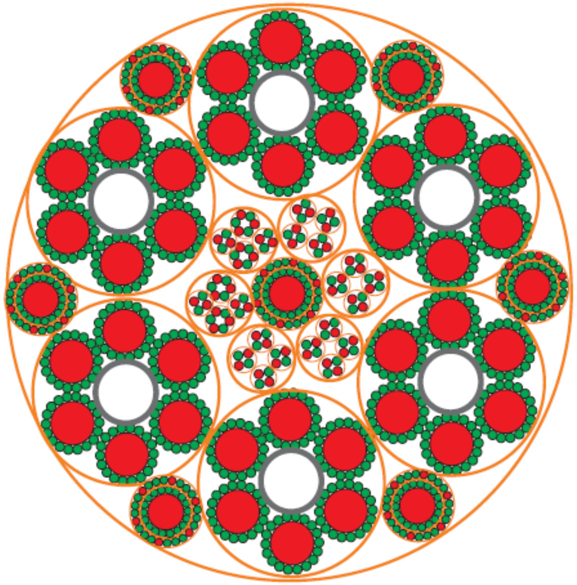
From E. Todesco

- Aim: move power converters of matching sections from tunnel to surface

Superconducting Links at P1 and P5
Matching Sections and Arc

- **Two Superconducting Links** per point – from surface to underground areas – for powering of **MSs**
- **Two Superconducting Links** per point – from surface to underground areas – for powering of **arcs**
- Need for **civil engineering** to be verified
- R&D Combined with development of system for Triplets
  → Test of **full system** (DFB and SC Link) in **2015**
- Installation in LHC during **LS3** (**2022**) or **LS2** (**2018**)
- Procurement of **series** to be started by end **2015** for integration during LS2

A. Ballarino, October 2012



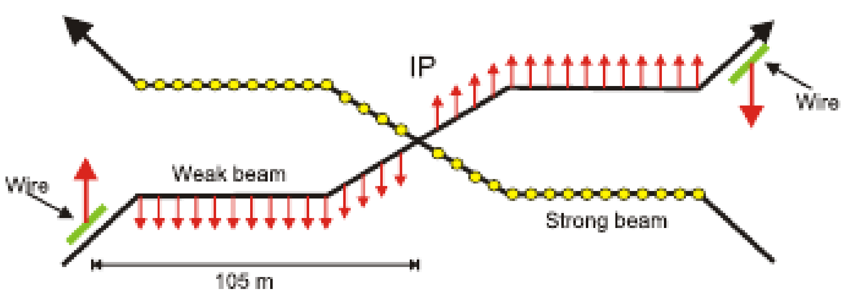
Cross-section of link for triplets
[A. Ballarino]

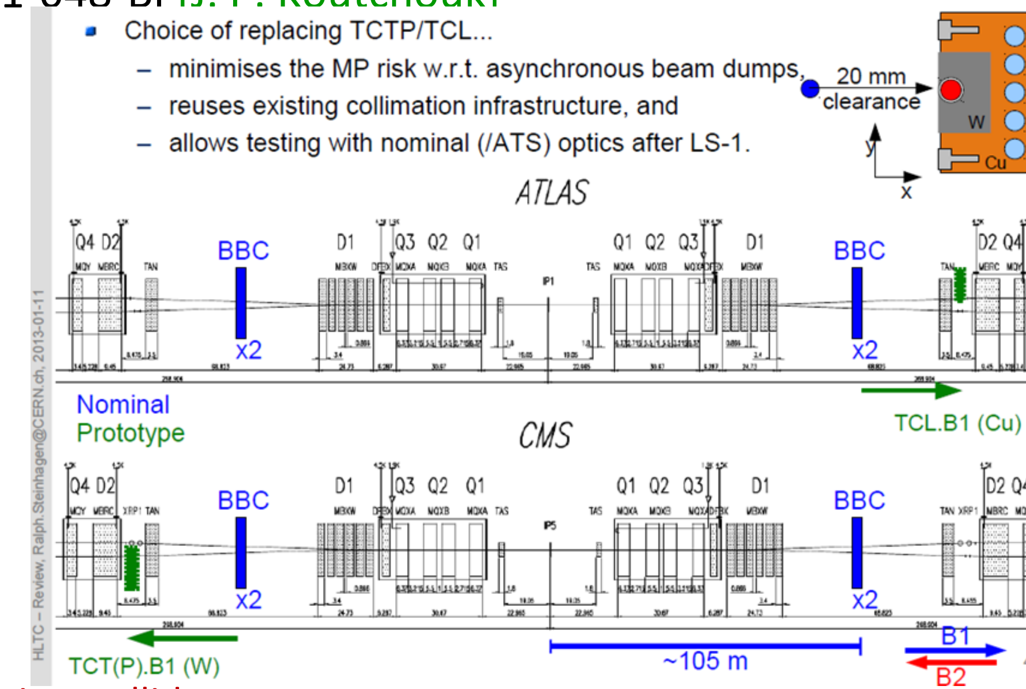
- Synergy with triplet sc link
- Technology: possibly MgB_2
- Cost: ~20 MChf

BEAM BEAM LONG RANGE WIRE COMPENSATOR

From E. Todesco

- Idea: use a current to cancel the longe range beam-beam effect and close crossing angle
- Initial proposal based on CERN-SL-2001-048-BI [J. P. Koutchouk]





- Experimented on RHIC and SPS, but not yet in a collider
  - In RHIC: you can spoil a beam with this
  - In SPS: a wire can compensate another wire
- A proof of principle in the LHC is needed