What can be learned during Run II for Run III and HL-LHC runs

Presented by R. De Maria

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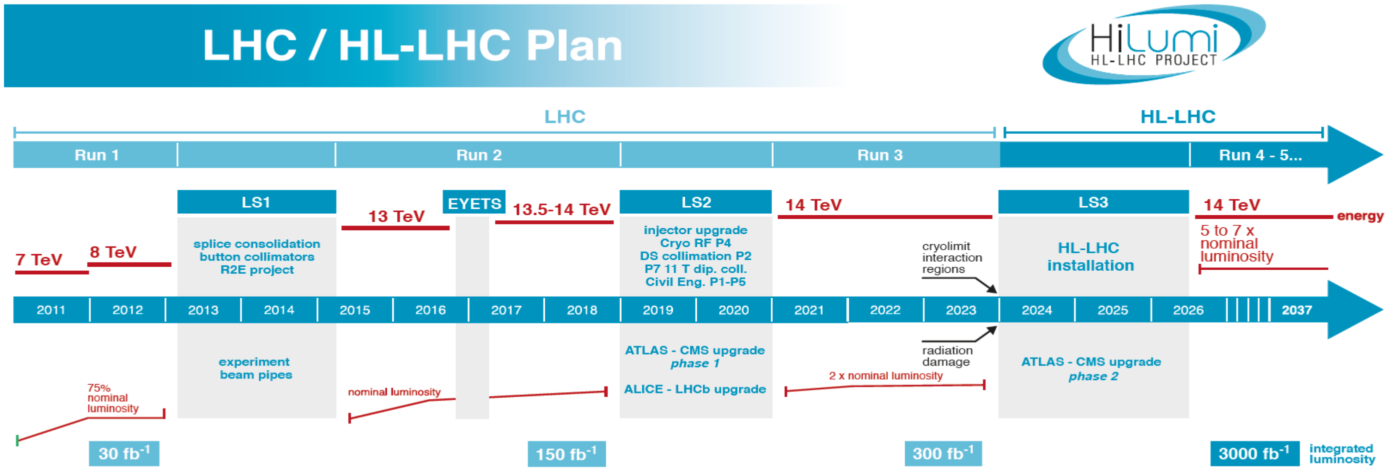
Evian Workshop - 2016

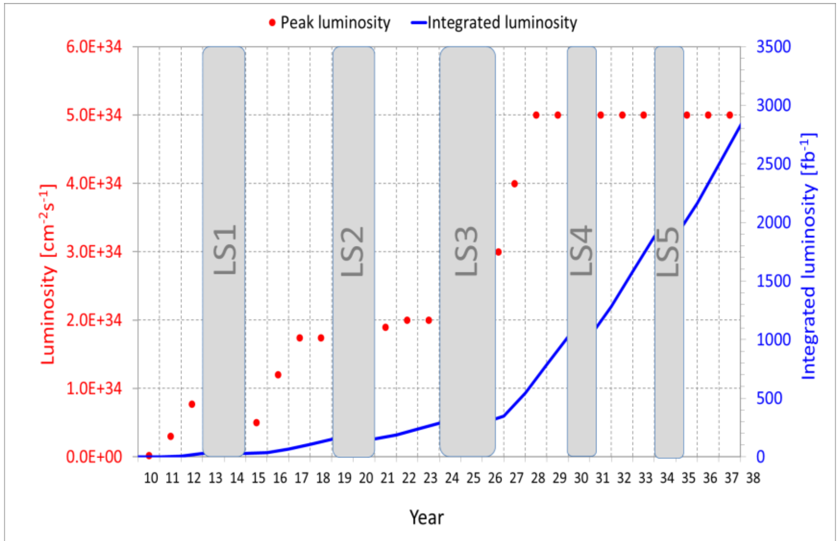
Run III

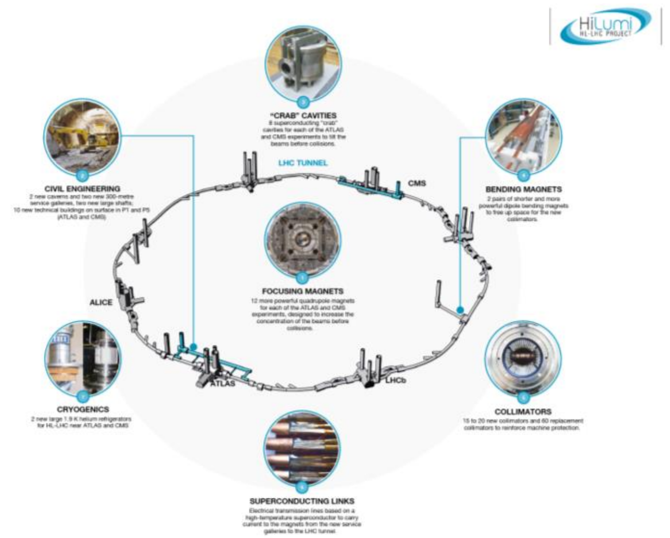


Run III: 3 years following LS2

1. Integrate as much luminosity to reach the end of the lifetime of the triplet (≥300 fb^{-1})
   - Reach pile-up limit or cryogenic luminosity limit, maximize peak luminosity and bunch population.
2. Use LIU beams in the LHC as soon as are ready.
   - Prove emittance preservation and bunch population increase, understand the limitation from e-cloud that may impact HL-LHC.

HL-LHC





After LS4, proton physics days increase from standard 160 days to 200 and after LS5 to 220

HL-LHC: mid 2026 to end 2039 after LS4

- Reach ≥ 3000 fb^{-1} by
  - Maximize availability, levelled luminosity per bunch, number of bunches, bunch population, brightness.
  - Crab-cavities to alleviate geometric reduction factor to small β* and long bunches and pile-up density.

Injector Brightness and LHC Filling Schemes

Production scheme	ppb [10^{11}]	ε [μm]	Inj.	BPI	Colliding 1,5/2/8
Standard	1.3→2.3	2.8→2.1	13	288	2748/2494/2572
BCMS	1.3→2.3	2.5→1.7	20	144	2544/2205/2308
			12	288	2736/2258/2378
8b+4e STD	1.6→2.5	2.4→2.1	13	144	*1960/1163/1806**
8b+4e BCMS	1.6→2.5	1.2→1.8	20	96	*1696/1470/1538**
80b	1.3→2.3	1.3→2.1	14	240	2732/2476/2549
			12	320	2800/2246/2606
50 ns	1.8	1.8	13	144	1374/1247/1286
Single	>3.0	>1.5	n/a	1	n/a

RunII → HL-LHC

*scaling

Smooth transition in Run III between Run II parameters and HL-LHC ones.

Variety of production schemes important also for accessing in Run II some areas of the parameter space for dedicated studies.

H. Bartosik, G. Iadarola, X. Buffat, C. Schwick

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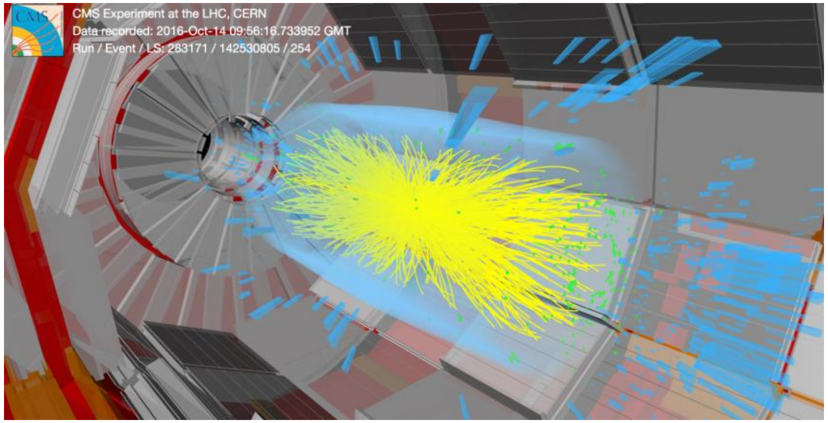
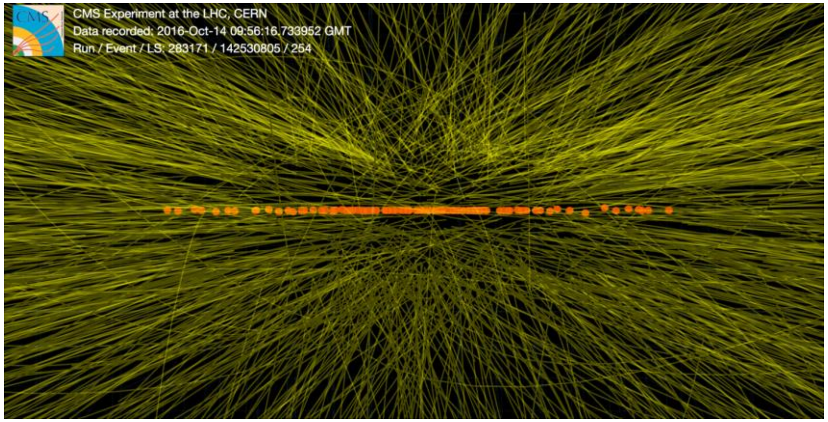
Luminosity Limits





Preference for high pile-up test:

- single bunch
- trains with 25 ns structure
  - Can a short 8b+4e BCMS train with reduced crossing angle and β* be useful
- Will always a short non-colliding train be needed for the experiment, can they at least collide?
- Luminosity signals important for operation and analysis. Any improvement possible in accuracy and speed?

HL-LHC relies on 140 to 200 event per crossing

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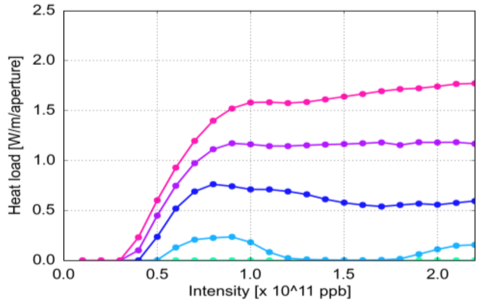
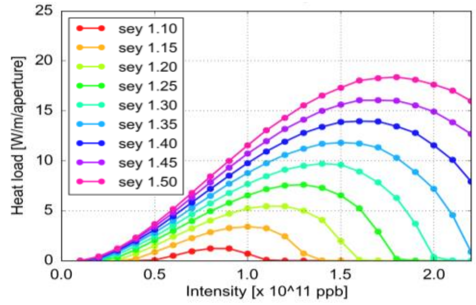
E-cloud uncertainties





Can low SEY achieved in reasonable time?
What is the surface model that will representative for heat load with bunch population and long trains?

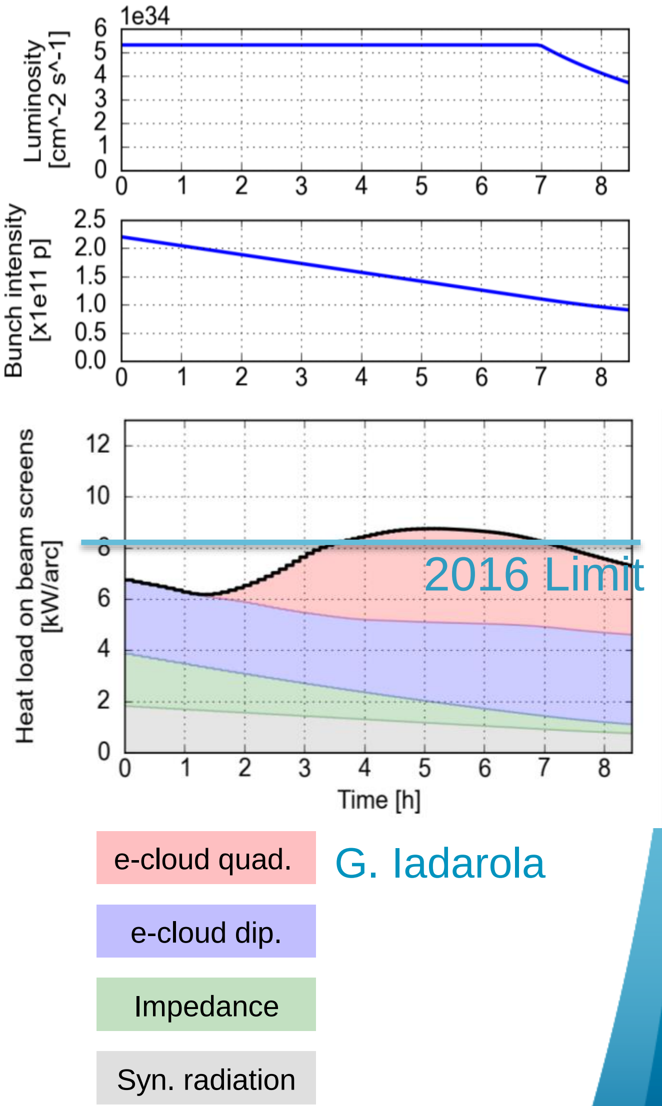
Today's heat loads in sector 12, 23, 81 may not compatible with HL-LHC depending on the behavior of the surface.
A saturation of scrubbing have been observed during 2016.

In Run II:

- Due to limits in beam current only scrubbing efficiency on can be studied
  - nominal trains and hybrid scheme important to show whether faster scrubbing is possible
  - Instabilities threshold with e-cloud has and can be studied.

In Run III with LIU beams:

- Learning scalings and scrubbing with intensity finally possible and HL-LHC scenario could start to be validate.
  - Scrubbing with high possible current and long trains.
  - Comparisons filling schemes options will be conclusive.



G. Iadarola

Beam-Beam HO effects

Beam-beam effects are a potential unknown when higher tune shift (with LIU beam) is coupled with additional noise (crab cavity and tune ripple).

- Beam-beam studies:
  - sensitivity to noise driven by crab cavity, power converter ripple, ground motion
  - correlation DA with measured observables
  - interplay with ADT: mitigate the effect of noise without adding more
  - interplay with optics and collimation (dynamic beta-beating)
  - flat optics and reduce overlap due to coupling
  - study head-on (2 IP-only needed) without crossing angle
  - study mitigation with levelling by offset also in IR1/5
- Instabilities:
  - measure Landau damping with long range and offset collision (BTF)
  - mode coupling instability of colliding beams (scenarios with large synchro-betatron coupling are being studied without crab cavity)

X. Buffat

Collimation Settings

Collimator	2017b	HL-LHC
TCP IR7	**5.0**	**5.7**
TCSG IR7	**6.5**	**7.7**
TCLA IR7	10	10
TCP IR3	15	15
TCLA IR3	18	18
TCSG IR6	20	20
TCDQ IR6	**7.3**	**9.0**
TCT IR1/5	**7.5**	**10.9**
Protected Ap. IR1/5	**8.5**	**12.3**
TCT IR8	15	15
Protected Ap. IR8	16	17
Protected Ap. Arc*	18	18

*Arc bottlenecks not measured

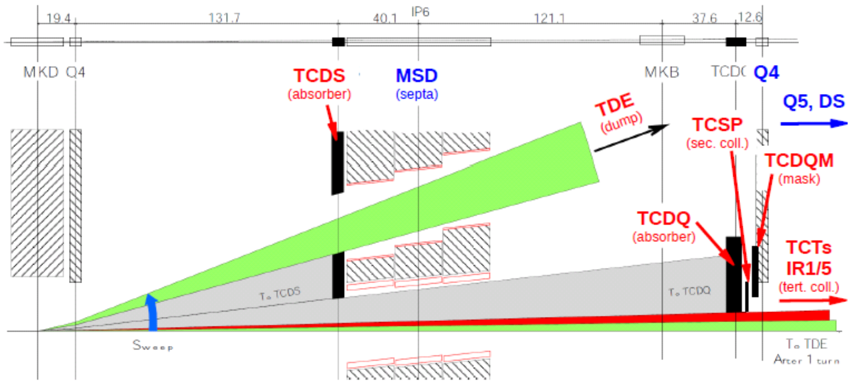
Run III should approach HL-LHC ones as soon as LIU beams will be available in Run III.

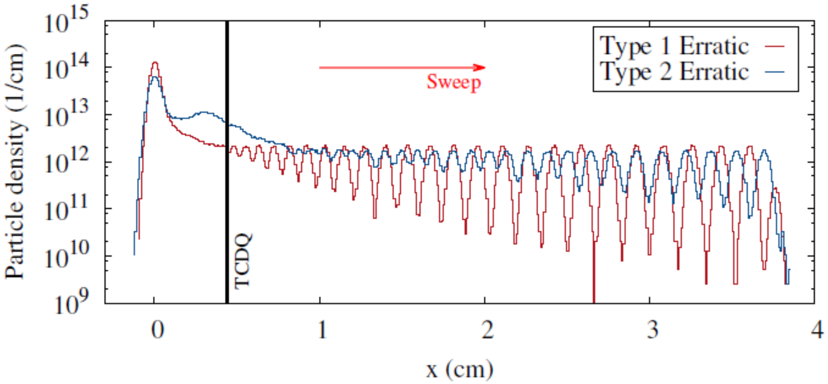
The present HL-LHC collimation baseline is solid with new materials

Ongoing studies to apply LHC improvements in HL-LHC:

- Impedance limits for TCP and TCS retraction:
  - confirm impedance reduction with newly installed collimators
  - impact in Run III if LIU beam are available
- Confirm MKD-TCT tolerances with next run.
  - Studies for even tighter TCT.
- Tighter TCDQ for HL-LHC despite damage limit and increased beam current to gain aperture from points above?
- Study protected aperture in new location that might become bottleneck in the HL-LHC: Arcs, IR8.
- Confirm expected losses in the DS and mitigation with cold collimators.
- Confirm issues related to loss spike and potential gain from e-lens.
- Crystal collimation, halo scraping, active halo control,…

Protecting devices





Studies to prepare LIU beams after LS2 and HL-LHC:

- TDE robustness: preventing MKB failures, study new material for the TDE
- Investigate TCDQ gap limits due to damage with new optics and settings strategies (end the ramp with the gap needed for the lowest β*)
- Reduce orbit interlock tolerance for instance using BPM in use TCDSP to mitigate optics constraints in IR6.

C. Bracco, A. Lechner

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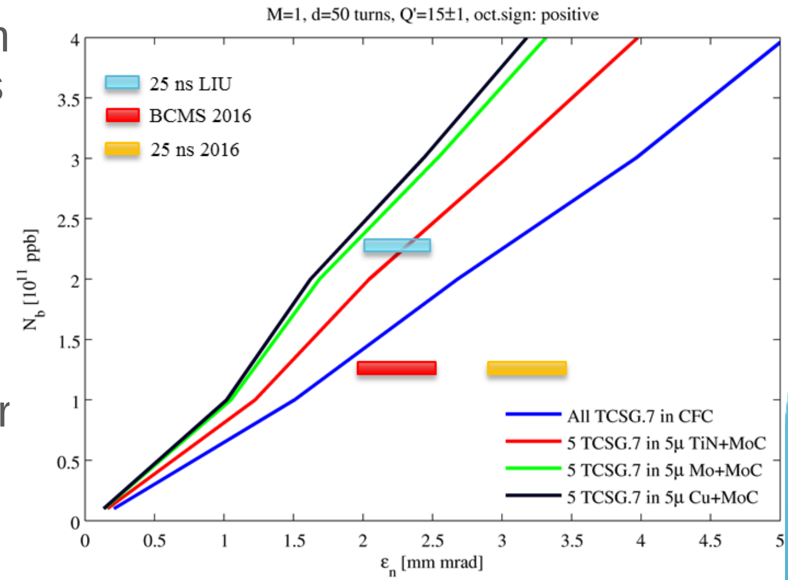
Impedance

1.4 times HL-LHC single bunch brightness has already been achieved with LOF = 560 A.

Parameter	*LHC*	HL-LHC	LHC 2016	Delta [%]
Energy [TeV]	*7*	7	6.5	- 7
Bunch population [10^{11}]	*1.15*	2.2	**1.9**	- 14
Transv. emittance [μm]	*3.75*	2.5	**1.5**	- 40
Brightness [10^{11} / μm]	*0.31*	0.88	1.27	**+ 44**

Factor 4.1!

- Why is the beam sometimes still unstable during th adjust process (role of the TOTEM bump / process or other changes e.g. 470 A vs about 300 A prediction)?
- Use 8b+4e with full trains to confirm achieved brightness in multibunch and no-elcloud.
- Confirm the impedance model with closer TCSG.
- The machine needs to be linearised at low β* befor introducing again the required nonlinearities
- Continue the checks for impedance model at injection.
- Study Q" as additional stabilizing mechanism less sensitive to transverse distributions.



E. Metral, N. Biancacci

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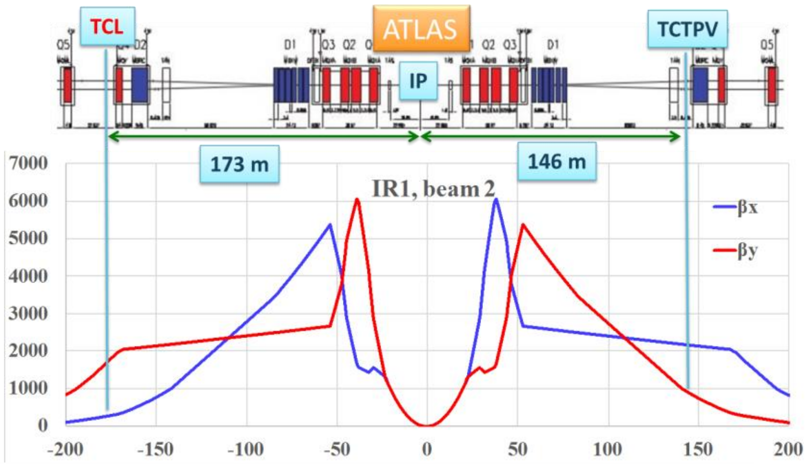
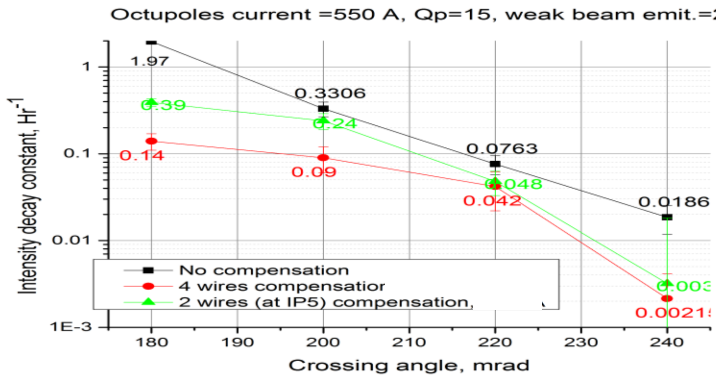
Beam-Beam Long Range Effect

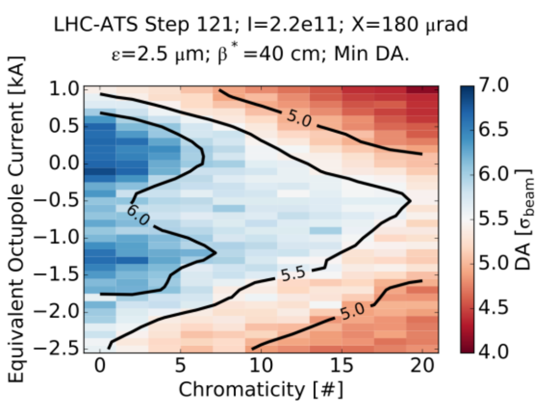
Reducing crossing angle brings
- luminosity
- reduce pile-up density
- more and more useful without crab cavities
- and increase triplet lifetime

Objectives:
- find minimum crossing angle compatible with good lifetime
- Investigate potential of flat optics and strong-pacman





A.Patapenka, S. Valishev et al.

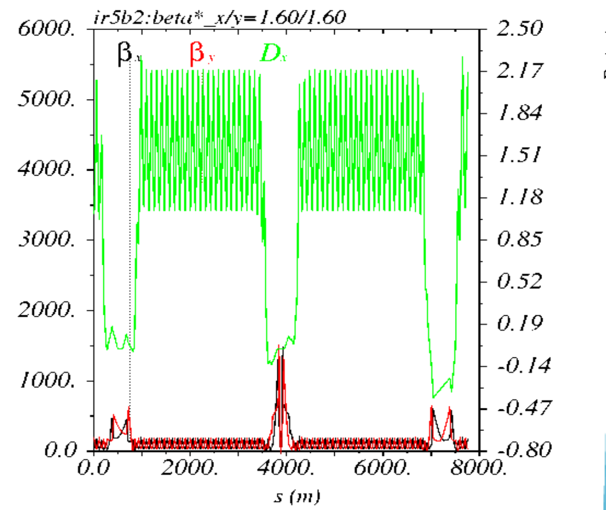


D. Pellegrini

Main lines of study:
- Long range wire compensation
- Octupole compensation

ATS Dev. & MD plan for 2017/2018

	ATS 2017	ATS MD	HL-LHC
β* final	33 cm	10 cm	20 cm to 10 cm
β* pre-squeeze	40 cm	40 cm	50 cm
β peak	7.2 km	24 km	16 km to 32 km
Crossing Angle	340 µrad	0 µrad	≤590 µrad
Aperture	8.5 σ	~7 σ	≤12.3 σ with orbit bumps
Telescope	1.2	4	2.5 to 5



- Development and experimental validation of **flat telescopic optics**

→ ultimately 60/15 cm starting from 60 cm pre-squeezed optics

→ synergy with the BBLR wire compensation to be established

- Experimental study of **LR beam-beam compensation with octupoles and telescopic optics** (and HL-LHC running scenario with MO<0)

→ e.g. 30/30 cm starting from 1.2 m pre-squeezed optics, or using the above flat optics.

S. Fartoukh

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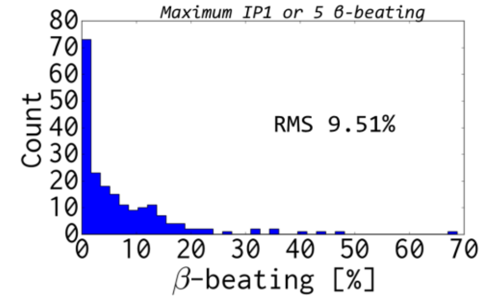
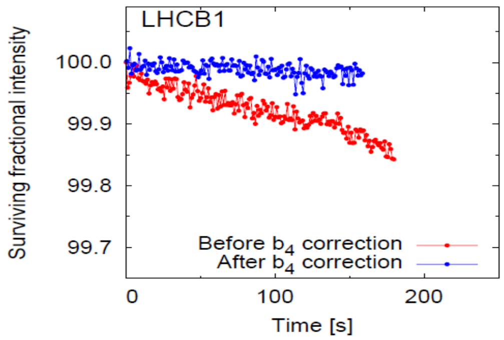
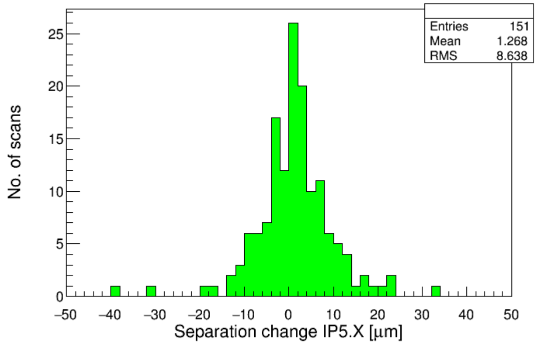
Orbit and Optics control

- Optics control:
  - IP optics control at very low β*: important to reduce aperture tolerances too.
- Non-linear optics and control
  - Effectiveness and control of non linear correction.
  - With low β* study triplet and D1 field quality sensitivities, identify unacceptable field quality for new HL magnets.
- Orbit feedback and control and β* levelling (OP)
  - master orbit feedback at the IP (σ =7 → 5 μm)
  - orbit gymnastic compatible 2 additional fixed point around the IP (needed with crab cavities)
  - understand how to perform IP re-alignment with or without motorized triplet alignment (lesson to learn for the HLLHC).
  - implement β* levelling in “stable” beams:



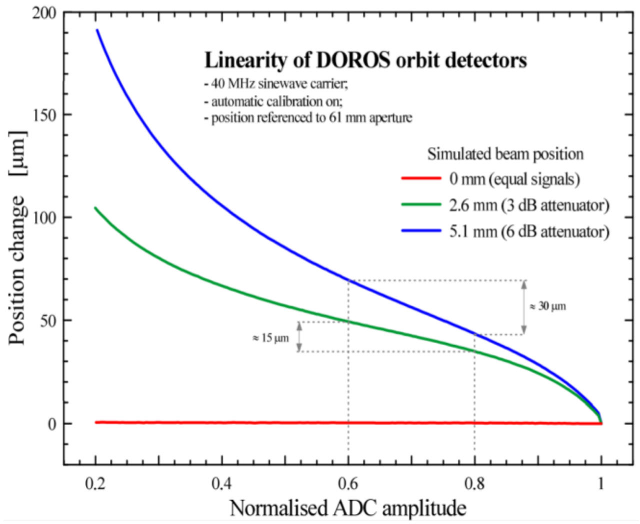




J. Coello, E. Maclean, R. Tomas, M. Giovannozzi, J. Wenninger

Instrumentation and measurements

- Beam position monitor:
  - Precision and reproducibility in the triplet for IP orbit control (~2 μm with DOROS) to be compatible with HL-LHC IP beam size (7 to 5 μm).
  - “synchronous orbit” to avoid Beam 1/Beam 2 cross talk: solved in HL-LHC but not in Run III.
  - Gain linearity for measuring β for amplitude data to avoid or complement k-modulation in the triplet (1% “capture” mode).



- Profile measurement:
  - The development of the Beam Gas Vertex detector for continuous emittance measurement through the cycle
  - The development of Beam halo monitoring using SR coronagraph
- Instabilities and multi-bunch diagnostic:
  - Consolidating the beam instability monitoring system in view of higher bunch intensity after LS2
- Beam loss:
  - With higher peak luminosity, can we already see if collision debris limit the measurements of beam losses in IR?

M. Gasior, G. Trad, T. Levefre

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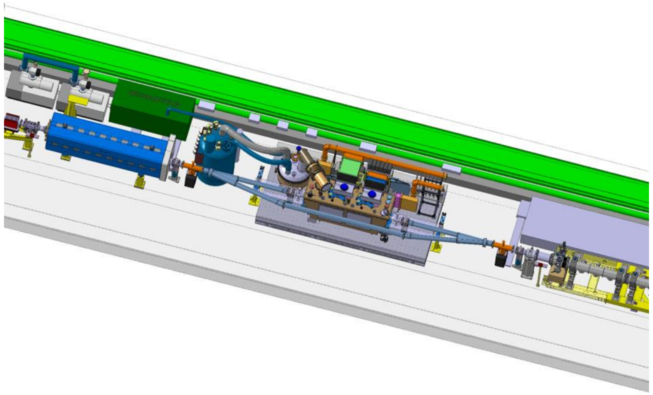
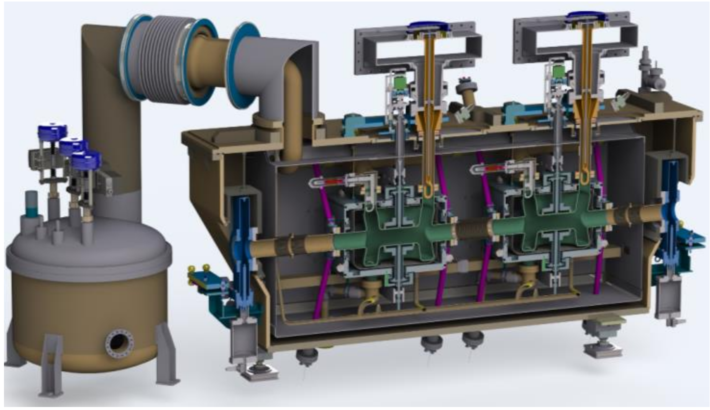
Crab cavities

Crab cavities sensibly reduce impact of crossing angle and long bunches on luminosity and pile-up density. One of the pillar of HL-LHC.





SPS-LSS6 dedicated test stand for beam tests in 2018:

- Operation of such type of cavities in high current and high energy CW (proton) circular machines has never been done!
- Ultra-precise control of cavity voltage and phase guarantee.
- Guarantee the operation of cavities with a trip rate significantly below the LHC availability
- Emittance growth, machine protection, RF non-linearity, instabilities where proton beam tests are the only conclusive answer.

R. Calaga

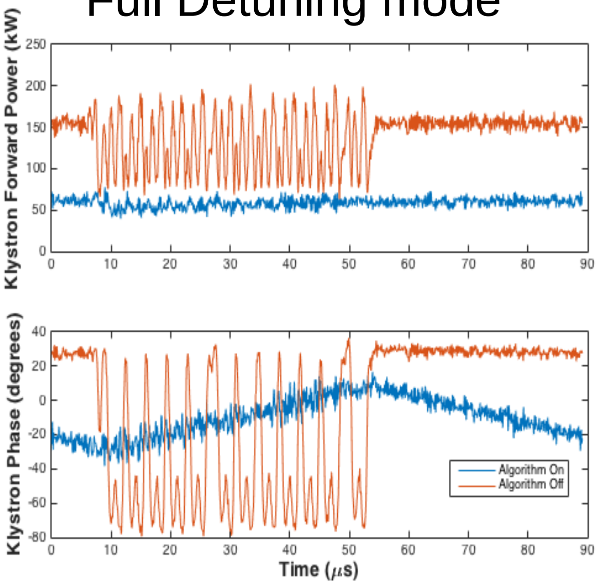
RF studies

Baseline HL-LHC relies on:

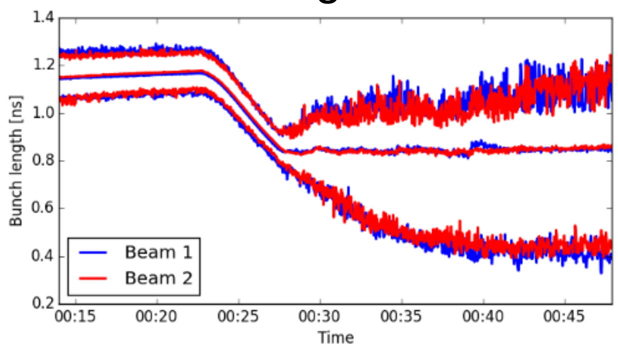
- Full detuning mode with 16 MV
  - When we will start full detuning mode with 16 MV?
  - Potential performance improvement already with present run.
- Emittance blow-up and stabilization measures
  - understand better the controlled longitudinal blow-up for higher intensities and/or smaller bunch lengths
  - studies of coupled-bunch instability threshold for full nominal beam with HL-LHC bunch length, but smaller longitudinal emittance

In Run III and HL-LHC do we need to minimize bunch length for performance or maximize for e-cloud.

Full Detuning mode



Bunch length bifurcation



P. Baudrenghien, E. Shaposhnikova, H. Timko

Main area of studies and validation

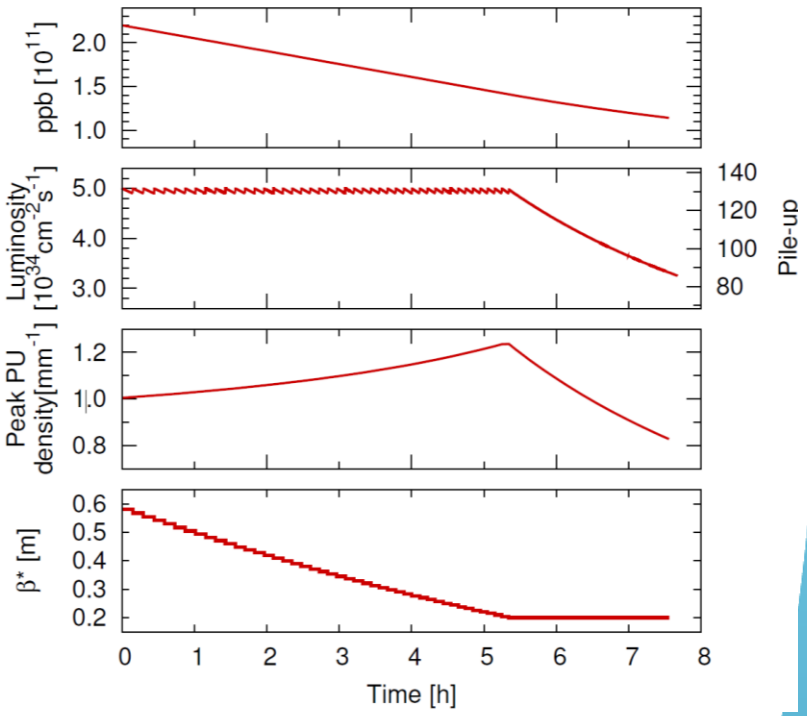
Run III

- Learn to use LIU beams
- E-cloud control
- Flat β* potential
- Master levelling

HL-LHC

- Scrubbing effectiveness and scaling of heat-load with bunch population
- Levelling scenarios (in particular beta*)
- Operation of the crab cavities with high intensity and brightness beams
- Halo control
- Head-on and long range limitations
- Nominal RF at 16 MV
- New field quality from new magnets
- Alternatives (round vs flat, crab availability, wire, e-lens, 200 MHz)

HL-LHC fill



Machine studies essential to validate performance figures and anticipate issues.