First Results of the Compensation of the Beam-Beam Effect with DC Wires in the LHC

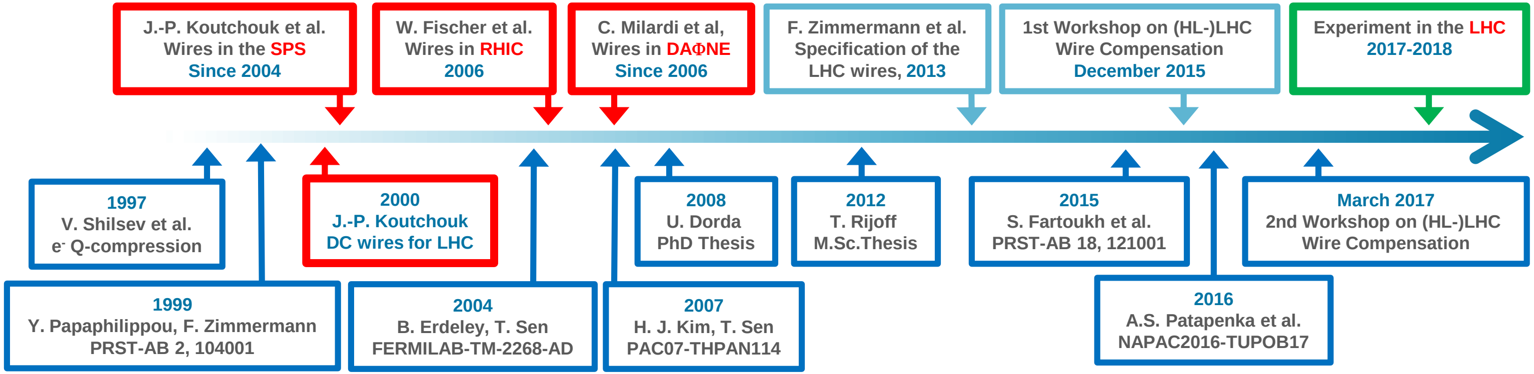
G. Sterbini, S. Fartoukh, N. Karastathis, Y. Papaphilippou,
A. Poyet, A. Rossi and K. Skoufaris on behalf of the
HL-LHC wire compensation team.

IPAC19, Melbourne, 22nd May 2019

Outlook

- Introduction on the wire compensation.
- Experimental constraints and optimization of the wires settings.
- Experimental objectives and results.
- Benchmarking with simulations.
- Next steps and summary.

Historical background

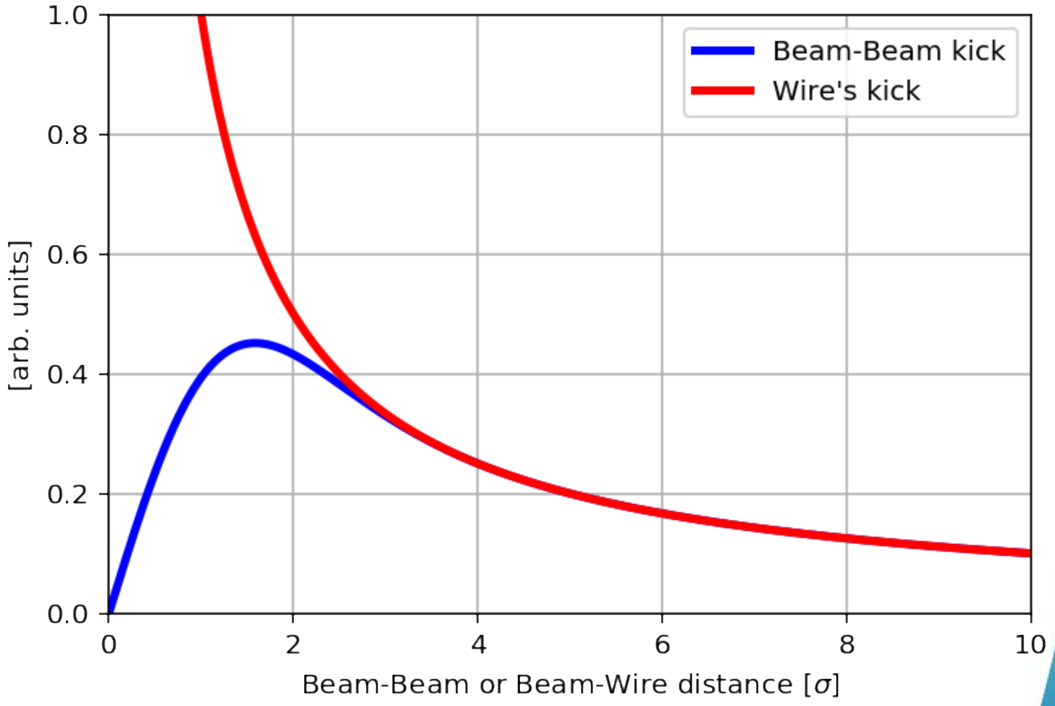


- DC wire proposed for LHC by J.-P. Koutchouk in 2000.
- Experimental tests of DC wires in SPS, RHIC and DAΦNE. Long range compensation never demonstrated in hadron collider with operational configurations → need for direct experiments in LHC.

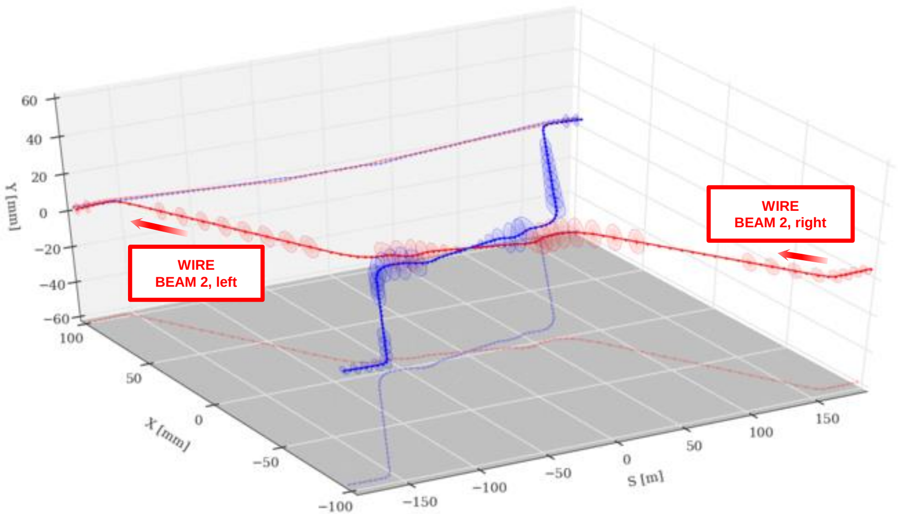
The wire compensation principle I

1. The electromagnetic kick of the long-range beam-beam effect is similar to the one given by a DC wire.

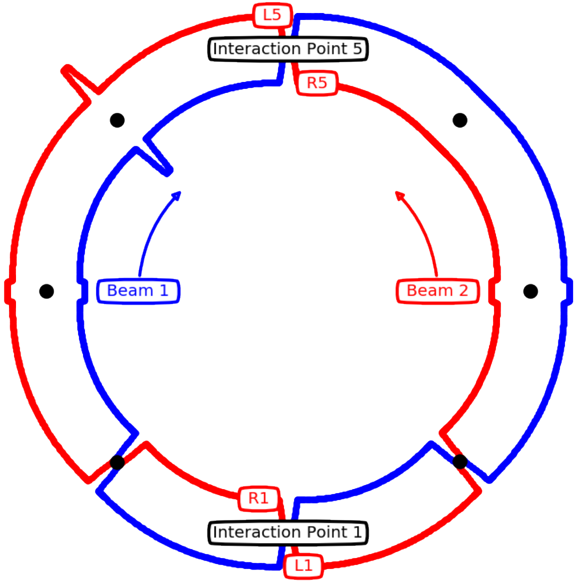
2. Analogy of the wire field with standard multipole magnets → Resonant Driving Terms compensation [S. Fartoukh et al., PRST-AB **18**, 121001]



The wire compensation principle II



The DC wire compensation

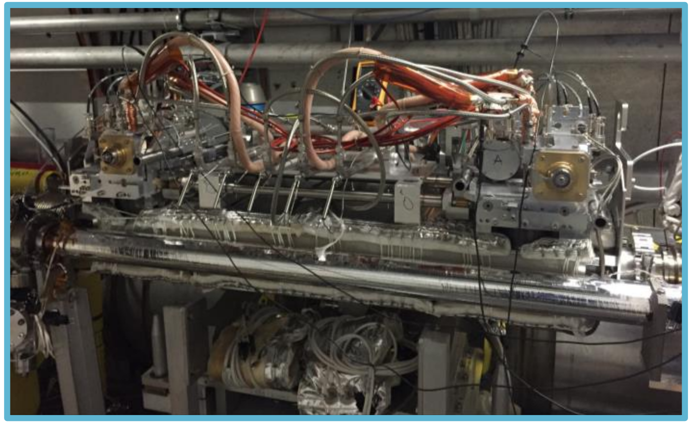


Layout of the wire installation

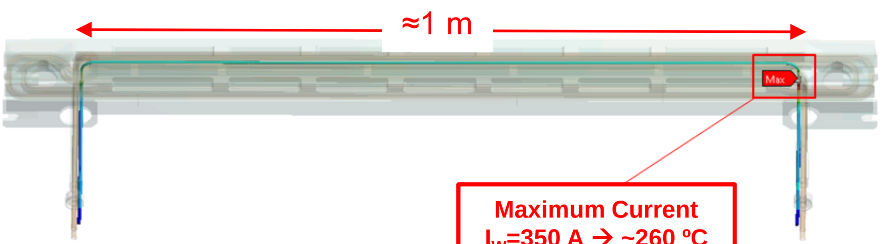
- **Since 2018 four wire demonstrators have been installed in LHC (B2, IR1+IR5)** with the aim to explore the potential of the wires in HiLumi HL-LHC PROJECT (L. Rossi, **MOYPLM3**).

Wire-in-collimator demonstrator

- LHC wire demonstrators are embedded in the jaw of operational tertiary collimators.
- **1-m long Cu wire of 2.48 mm diameter capable to carry up to 350 A.**

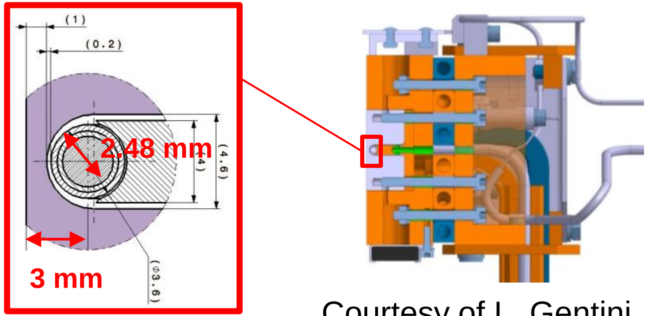


Top view



Courtesy of F. Carra

Front view



Courtesy of L. Gentini

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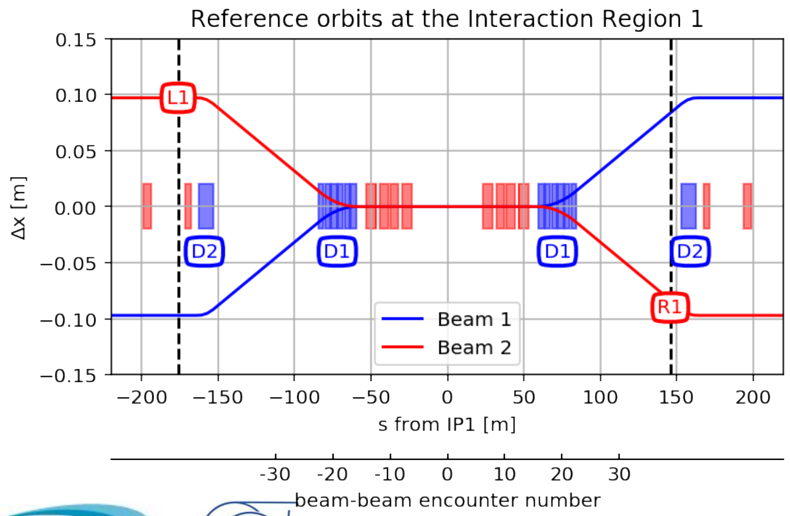
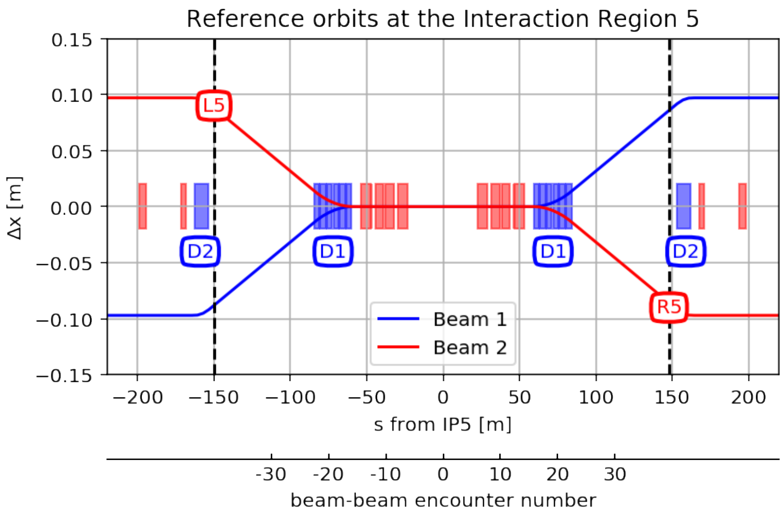
Longitudinal position of the wires

- The longitudinal position of the wires was determined by the present position of the collimators and the integration constraints.
- Symmetric position in the IR5.

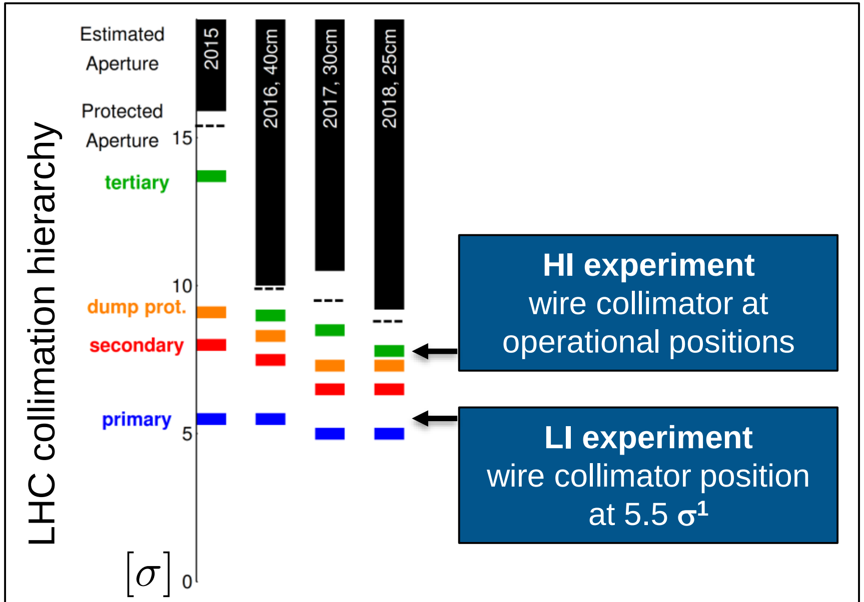
Wire demonstrator	s from the Interaction Point [m]
L1, collimator not-used in operation	**-176.17**
R1, tertiary collimator	**145.94**
L5, IP debris collimator	**-150,03**
R5, tertiary collimator	**147.94**





Transverse positions of the wires

- The wire are installed in the crossing plane of the Interaction Region, i.e.,
  - vertical in IR1,
  - horizontal in IR5.
- Given the constraints of the LHC collimation hierarchy, two classes of experiments were performed
  1. **LI**: **Low Intensity** experiment (only 2 bunches in Beam 2) with wire-collimator just in the shadow of the primary collimators
  2. **HI**: **High-Intensity** experiment (bunch trains in Beam 2) with wire-collimator at the operational position.



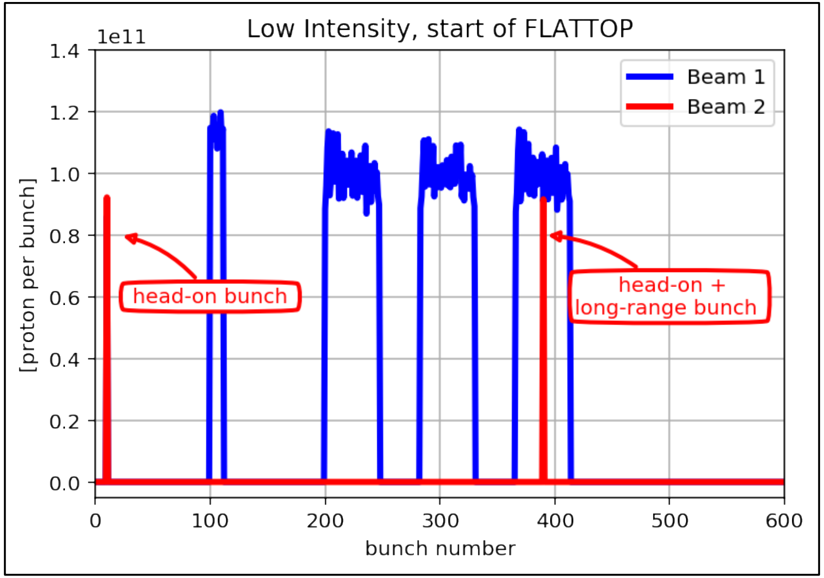
Courtesy of R. Bruce

Wire demonstrator	LI experiment	HI experiment
	beam-wire distance [mm]	
L1	**-7.41**	not powered
R1	**7.42**	**9.83**
L5	**-7.15**	not powered
R5	**8.24**	**11.10**

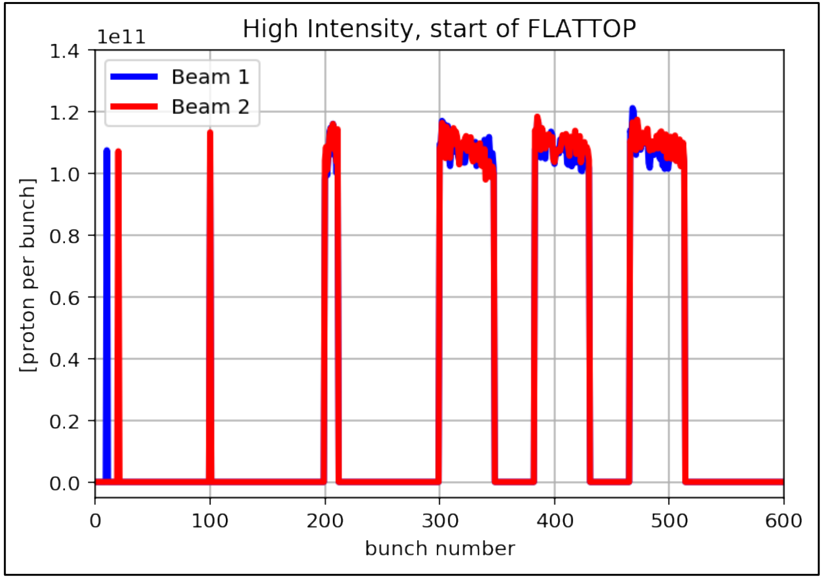
[1] An ε_n=3.5 mm mrad assumed.

Filling schemes and beam-beam encounters

Low Intensity experiment



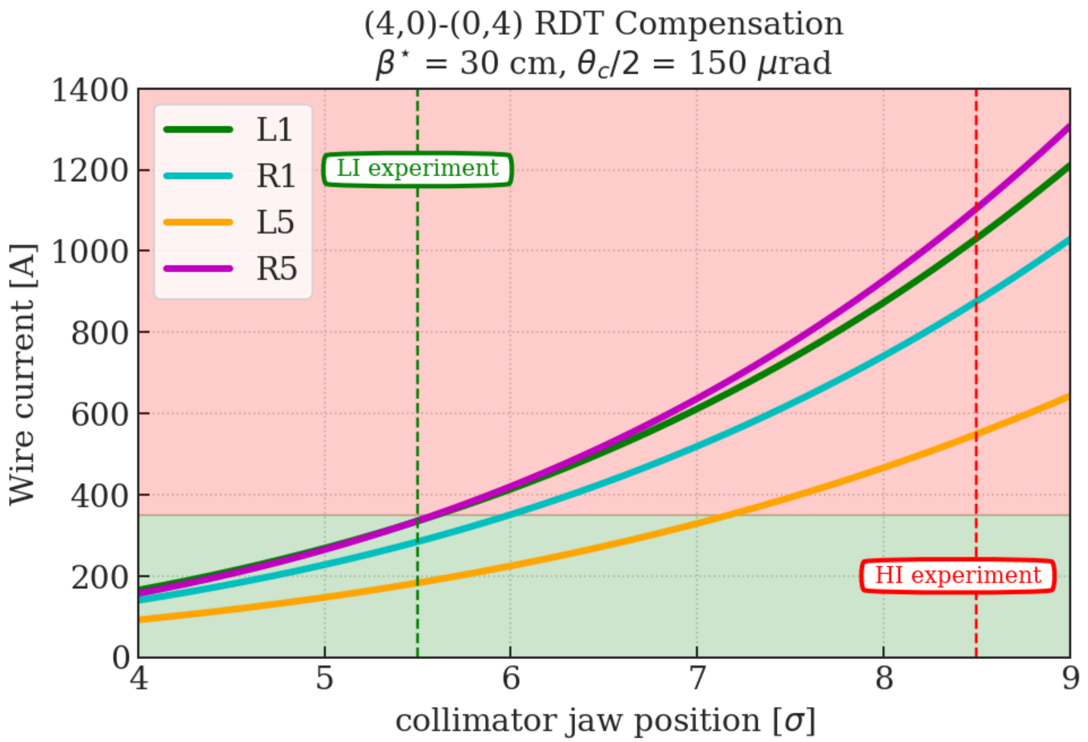
High Intensity experiment



- In the **LI experiment** the first bunch of B2 see only two head-on's (in IP1 and IP5) and the second bunch experiences head-on and long-range encounters.
- In the **HI experiment** we 3 trains with beam-beam interactions as during operation.

Wire current settings I

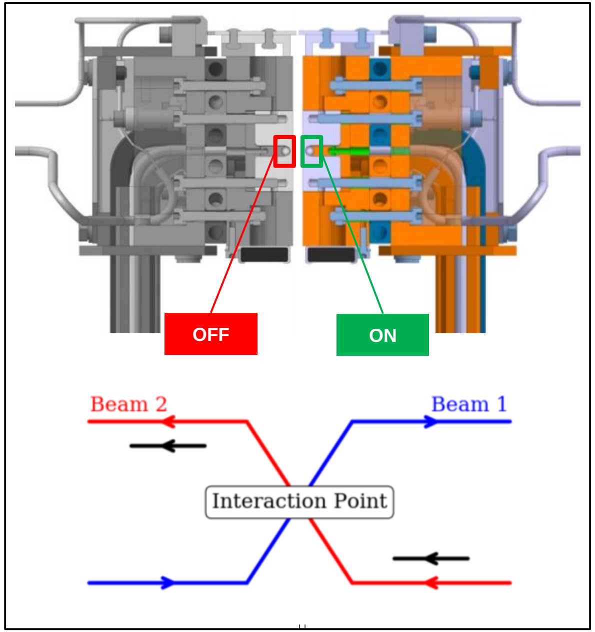
- The experimental setup allowed to minimize only two Resonance Driving Terms.
- We set the wire currents to compensate the **(4,0) and (0,4) RDT**: first order amplitude detuning.
- For the HI experiment, due the larger beam-wire distance, the current for the compensation is not compatible with the standard wire configuration.



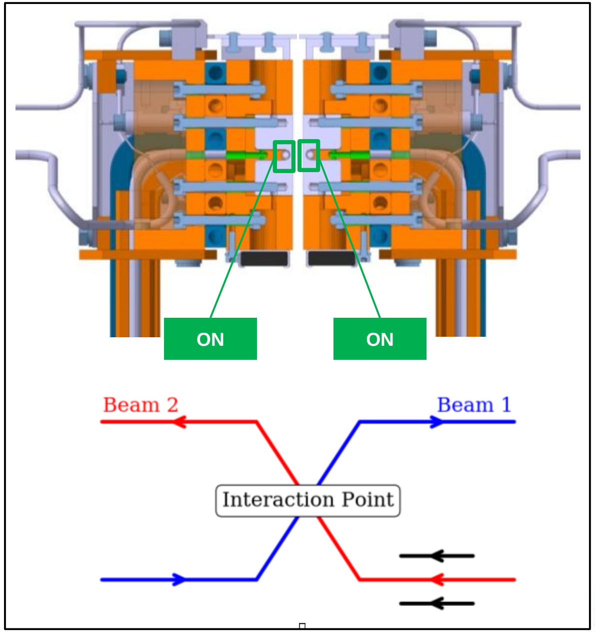
Wire current settings II

- In the wire-collimator, both jaws house a wire.
- In the **LI experiment** only the wire of one single jaw was powered.
- For the **HI experiments** the wires of both jaws where powered: this allowed to double the integrated strength of the quadrupolar, octupolar, etc., components.

LI experiment



HI experiment



Wire demonstrator	LI experiment	HI experiment
	Current [A]	
L1	350 x 1	not powered
R1	320 x 1	350 x 2
L5	190 x 1	not powered
R5	340 x 1	350 x 2

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Objectives of the experiments

- **Prove a beneficial effect of the wire demonstrators** in a regime dominated by long-range beam-beam effect. The compensation should not degrade the lifetime of the head-on bunches.

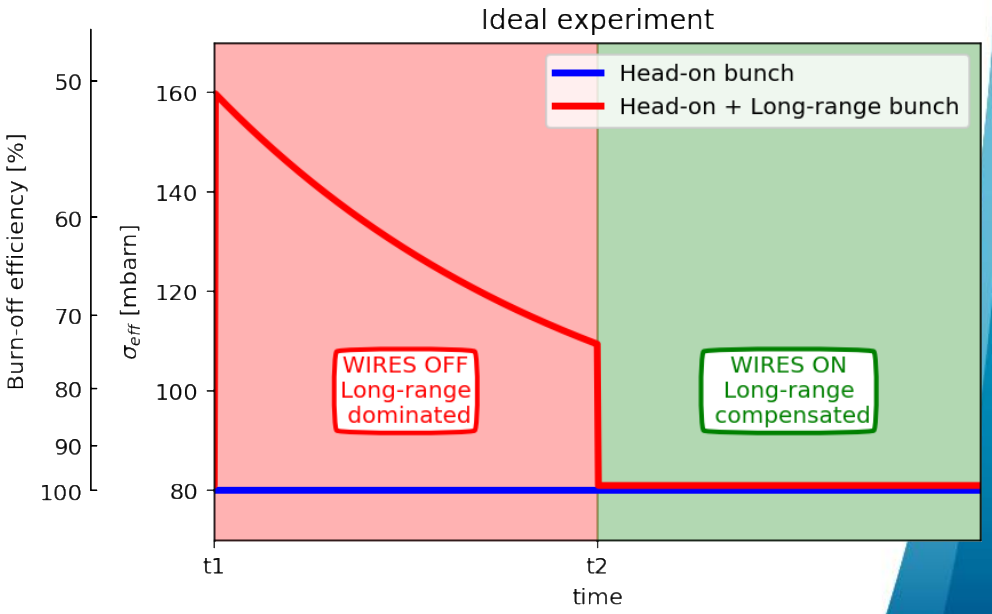
- We need to guarantee the beam-wire alignment and that the linear effects of the wire (orbit and tunes) are compensated with feedforwards.

- The main observables are the beam losses, its lifetime and the **bunch effective cross-section** (σ_{eff})..

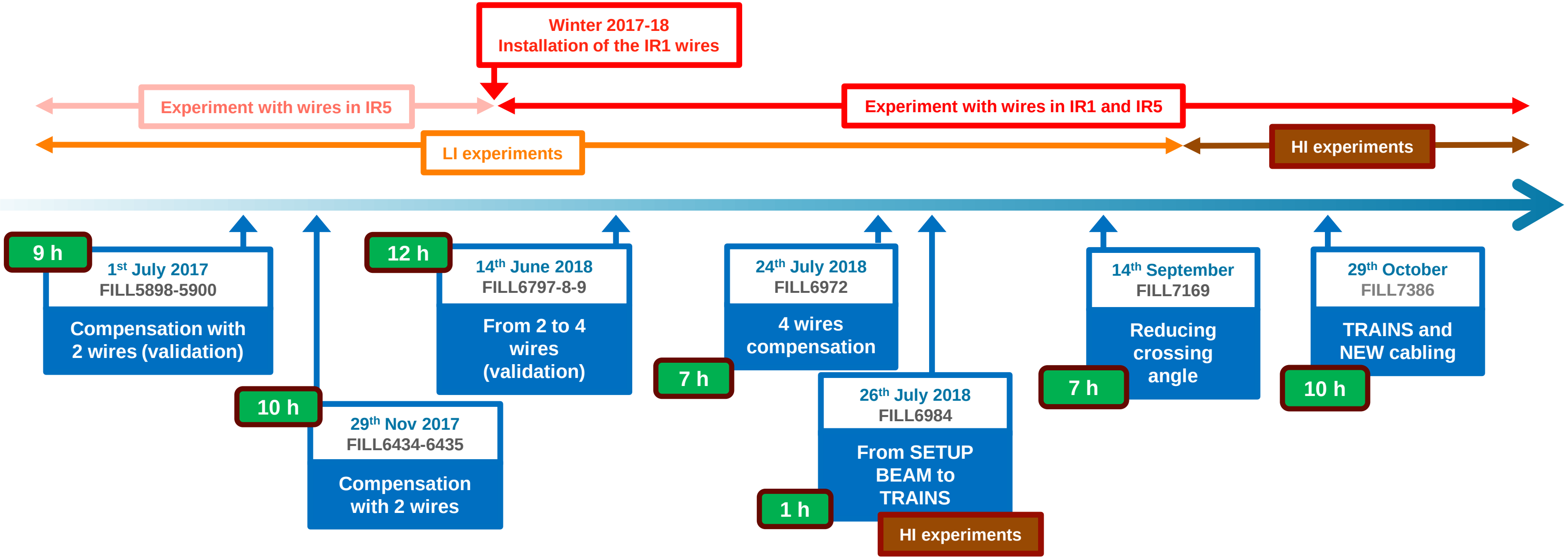
$$\sigma_{EFF} = -\frac{1}{\sum_{IP} L_{IP}} \frac{dN}{dt}$$

Instantaneous luminosity

Intensity loss-rate

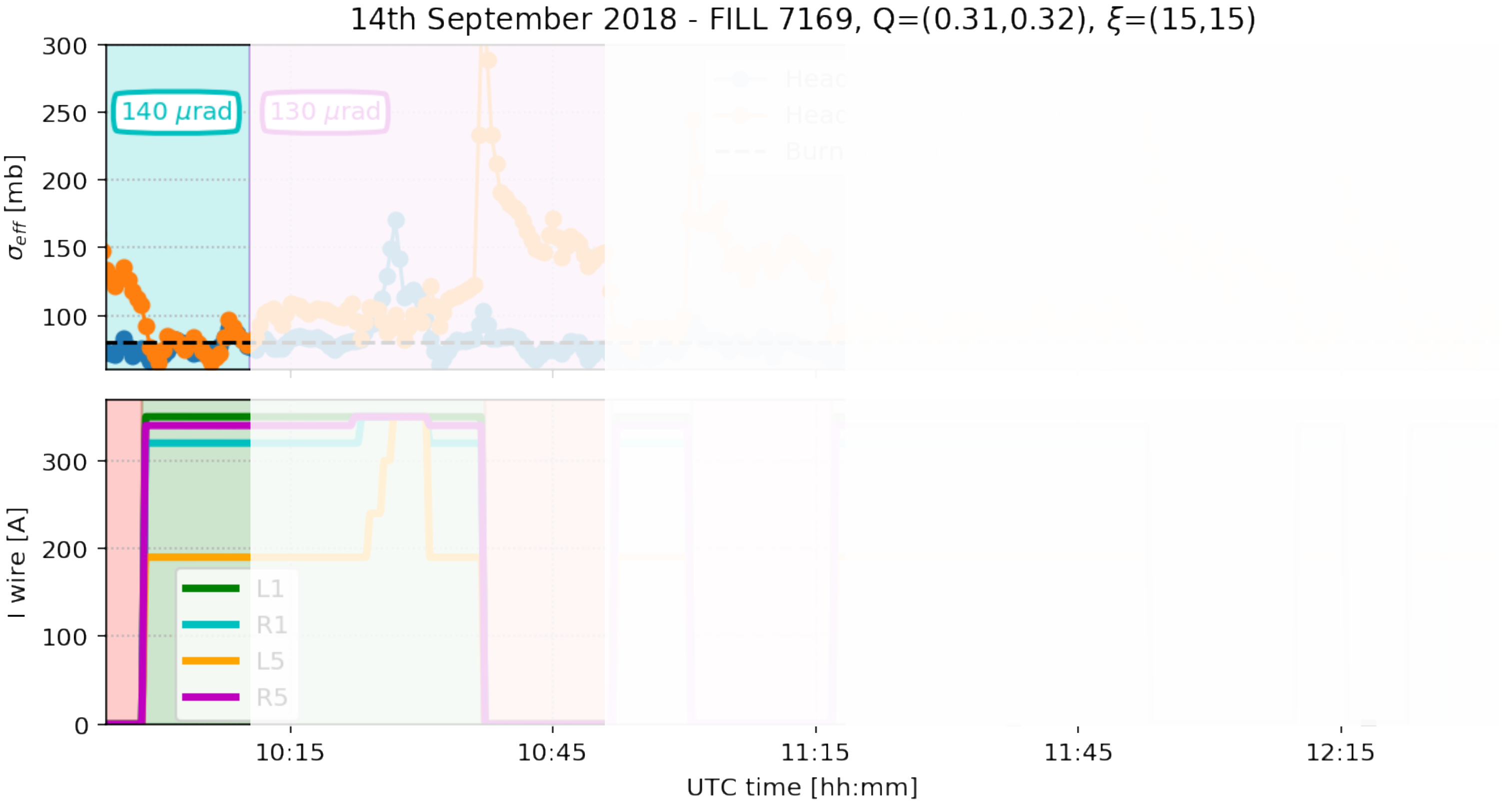


The experimental campaign



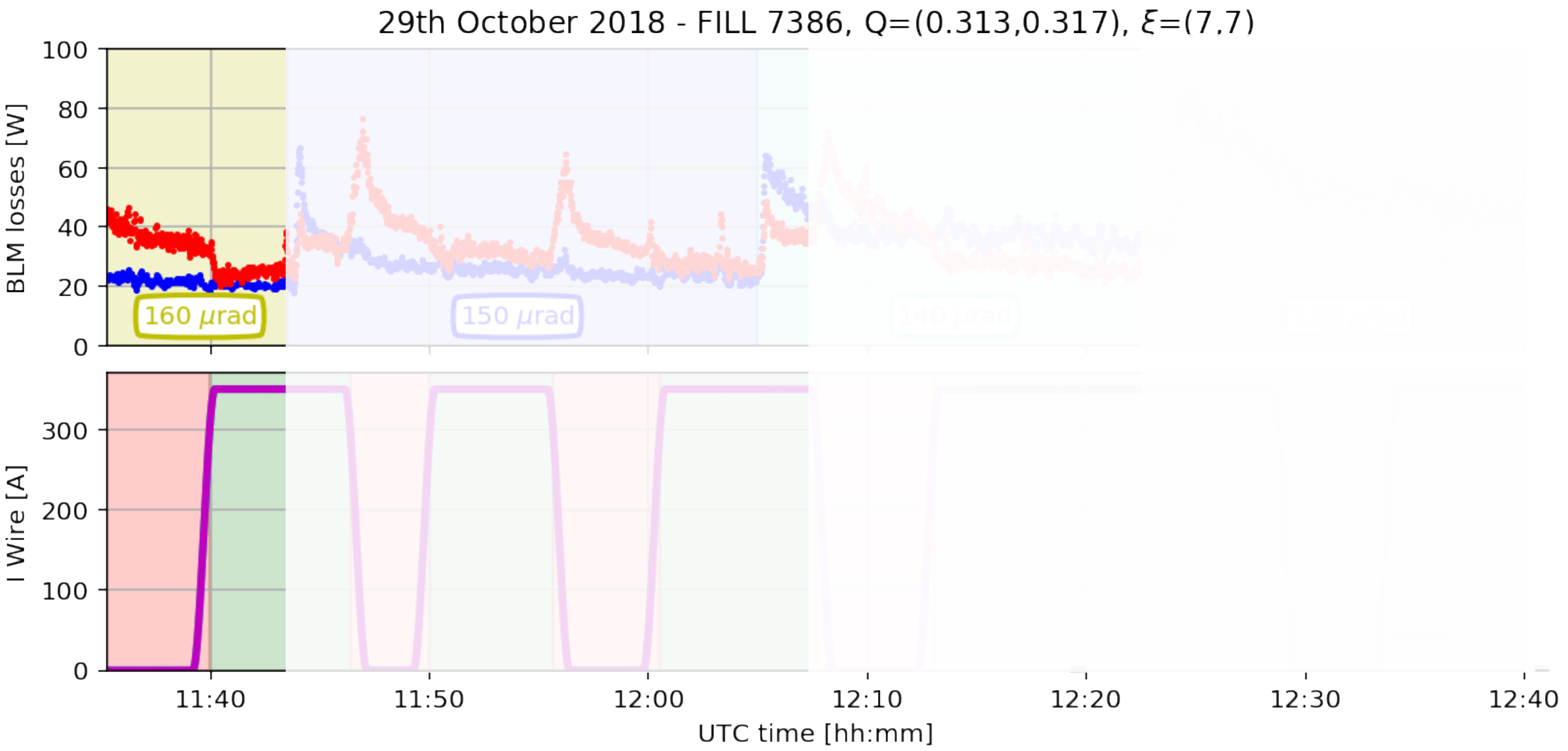
- A rich experimental campaign was performed during the last 2 years: the compensation effect was systematically observed.

Low-Intensity experiment



- **Almost full compensation, even at reduced crossing angle, for regular bunch whereas head-on bunch not degraded.**

HI experiment (operational conditions)



- **Compensation provides a reduction of B2 losses of ~20%.**

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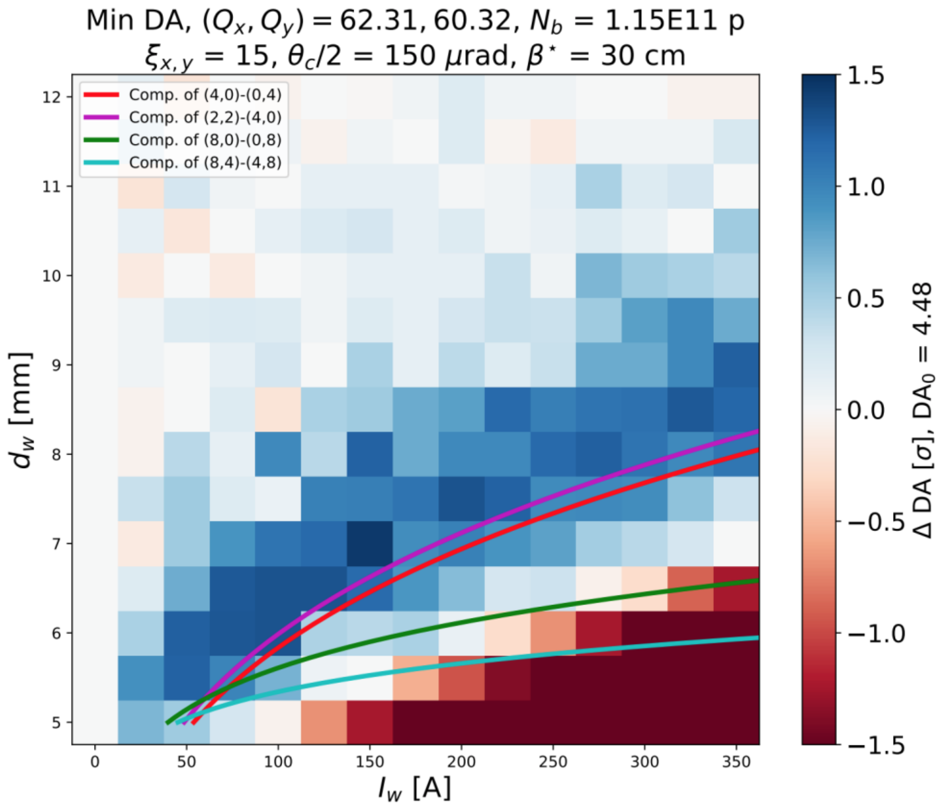
Simulations of the LHC experiments

A. Poyet
MOPMP052

- The experimental configuration was simulated using Dynamic Aperture (**DA**) tracking.
- Correlation between DA and beam lifetime was studied in D. Pellegrini et al., Incoherent beam-beam effects and lifetime optimization, 8th LHC Operation Evian Workshop, 2018.
- Simulations show a large compensation area corresponding to the (4,0)-(0,4) RDT minimization. A clear effect on the compensation is also visible by parametric studies on the tunes space.



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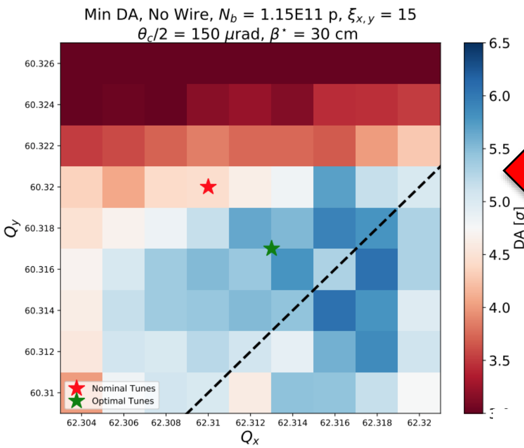
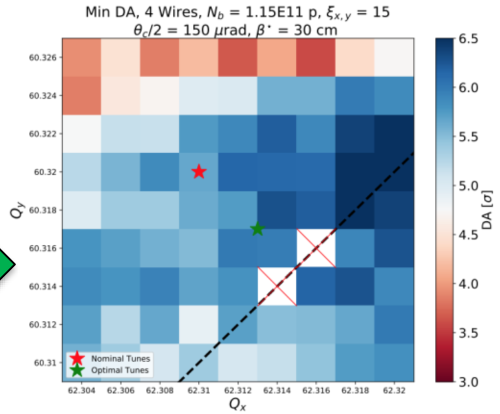


Wire compensation OFF

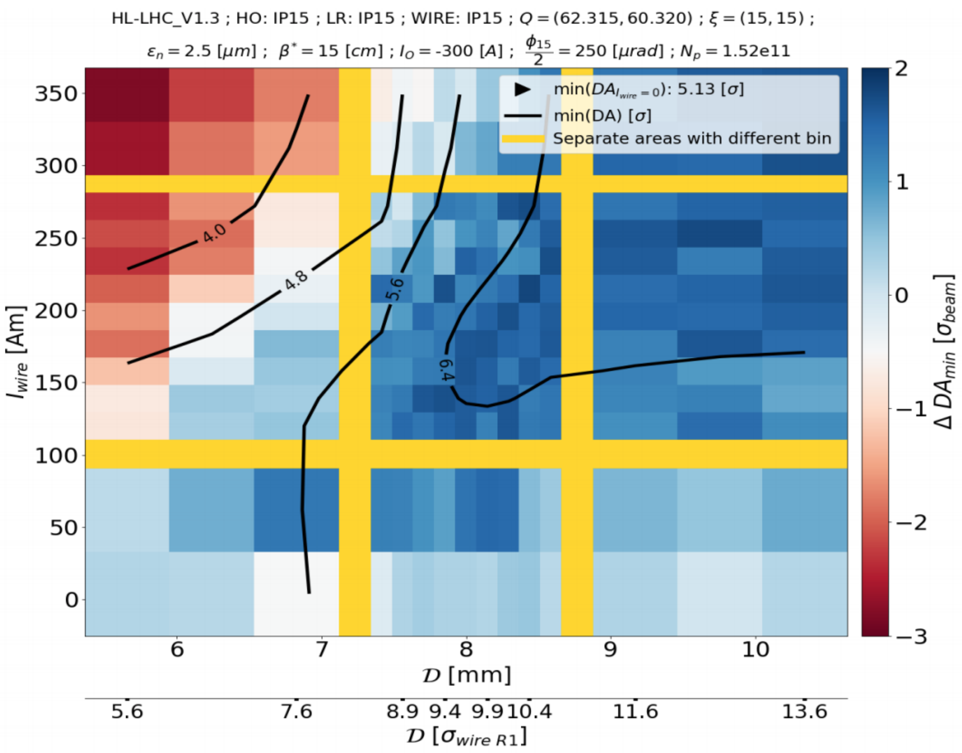
Wire compensation ON



Simulations of the HL-LHC case

K. Skoufaris
MOPMP053

- A systematic numerical study was performed for the HL-LHC scenarios (focusing on round optics).
- In the HL-LHC (round optics), up to 2 σ_{beam} in DA can be gained with the wire compensation. The results suggest the possibility to trade-off beam-wire distance with wire current.
- A significant improvement in the tunes space was observed also in this case.



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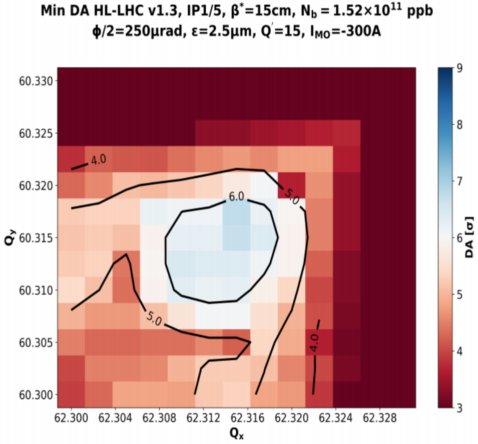
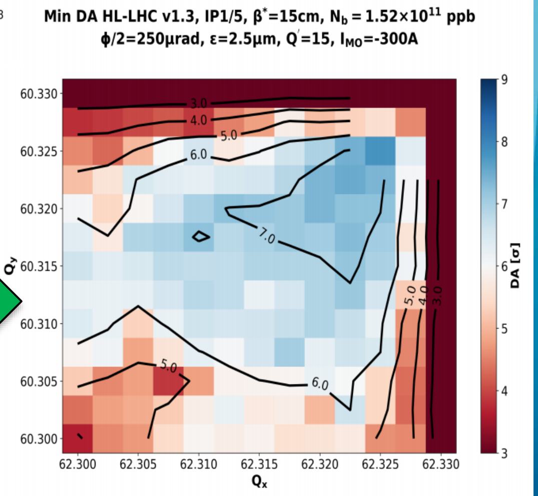


Wire compensation OFF



Wire compensation ON

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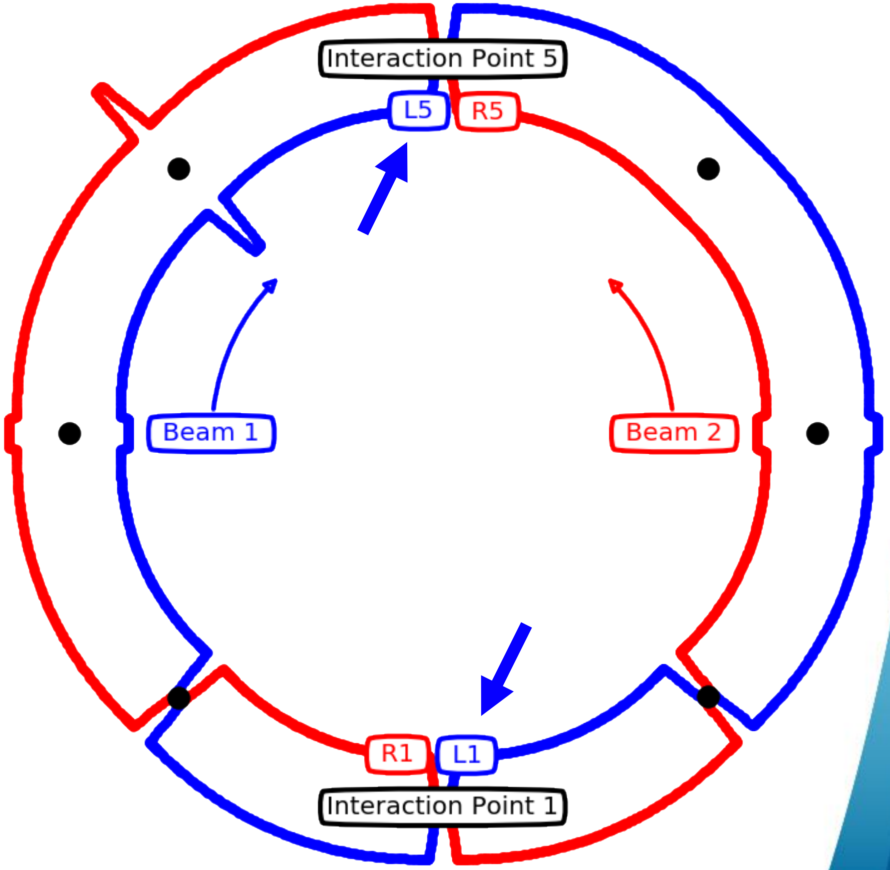
Next steps and proposals

- Following these encouraging results, it was proposed
  - **to use the wires routinely** during the next LHC operation period in the High-Intensity configuration
  - **to equip also the Beam 1** with wires by moving two wire demonstrators (L1 and L5) from Beam 2 to Beam 1.

- First iterations for a **HL-LHC wire design are on-going**.



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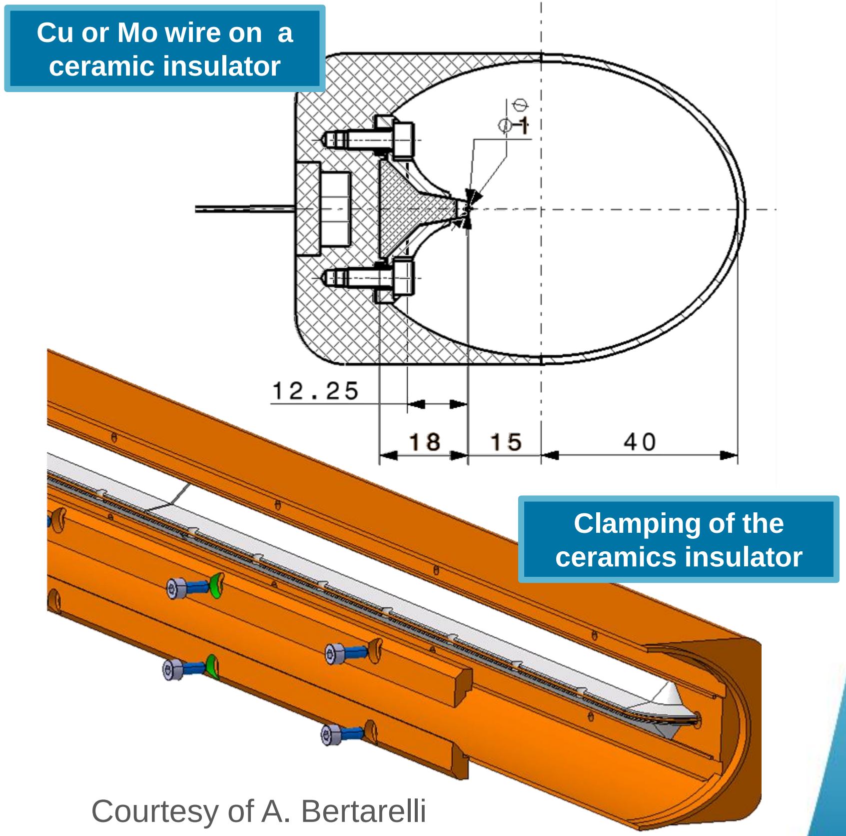


Courtesy of A. Bertarelli
[8th HL-LHC CM]

Summary

- In 2017-18 a rich measurements campaign was performed to explore the potential of the wire compensation for HL-LHC. For the first time in a hadron collider, the positive effect of the compensation was systematically observed in operational-like conditions. Following these results we proposed to use the wire demonstrators operationally for the next LHC run.
- Simulation results are consistent with measurement and the explored scenarios confirm the wire potential for HL-LHC. It can relax the HL-LHC operation in several directions (crossing angle reach, aperture increase and beta* reach, triplet irradiation and available tune space).
- First iterations for a HL-LHC wire design are on-going. Our next objective is to prepare a proposal for a technical review.

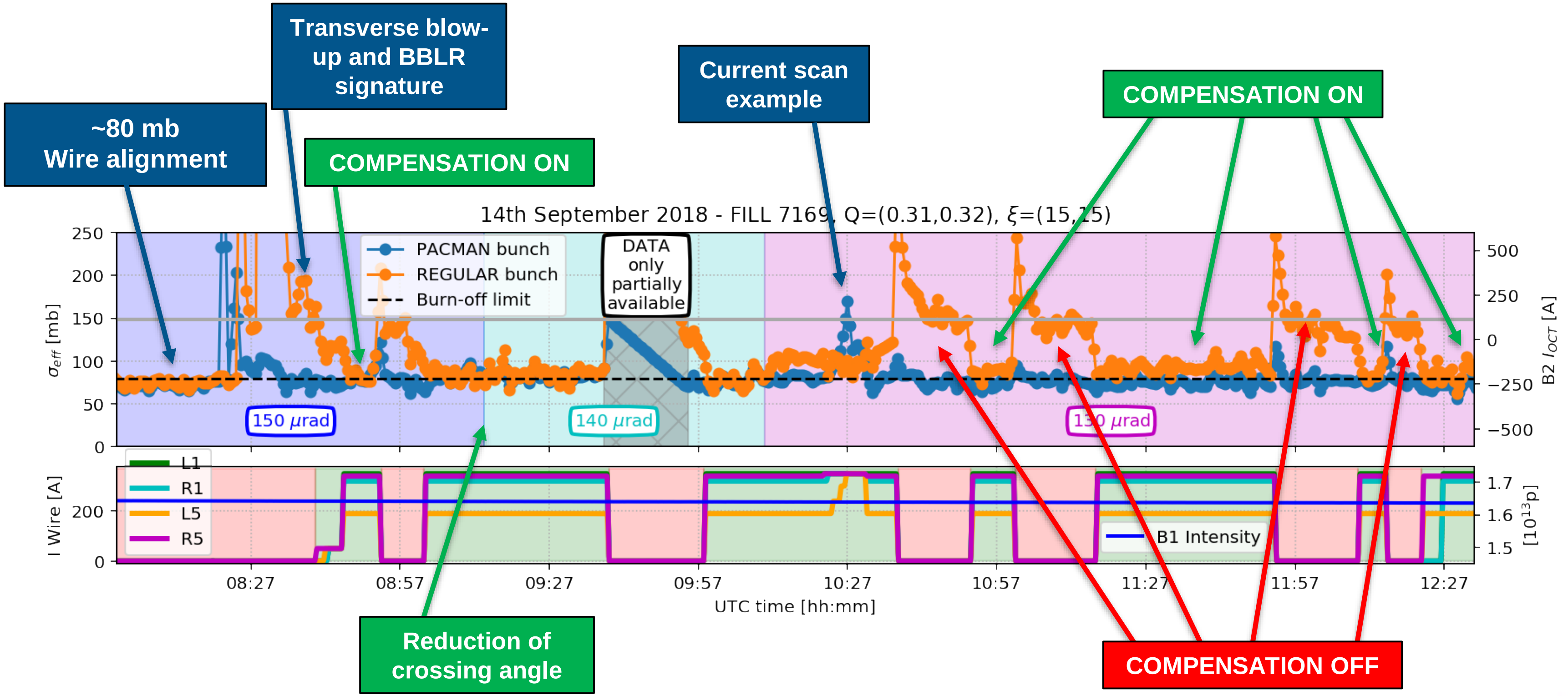
Thank you for the attention.

On behalf of the HL-LHC wire compensation team

D. Amorim, G. Arduini, H. Bartosik, A. Bertarelli, R. Bruce, X. Buffat, L. Carver, C. Castro, G. Cattenoz, E. Effinger, S. Fartoukh, M. Fitterer, N. Fuster, M. Gasior, M. Gonzales, A. Gorzawski, G.-H. Hemelsoet, M. Hostettler, G. Iadarola, R. Jones, D. Kaltchev, K. Karastatis, S. Kostoglou, I. Lamas Garcia, T. Levens, A. Levichev, L. E. Medina, D. Mirarchi, J. Olexa, S. Papadopoulou, Y. Papaphilippou, D. Pellegrini, M. Pojer, L. Poncet, A. Poyet, S. Redaelli, A. Rossi, B. Salvachua, H. Schmickler, F. Schmidt, K. Skoufaris, M. Solfaroli, G. Sterbini, R. Tomas, G. Trad, A. Valishev, D. Valuch, J. Wenninger, C. Xu, C. Zamantzas, P. Zisopoulos and all participants to the design, production and commissioning of the wire compensator demonstrators.

BACKUP SLIDES

Low-Intensity experiment



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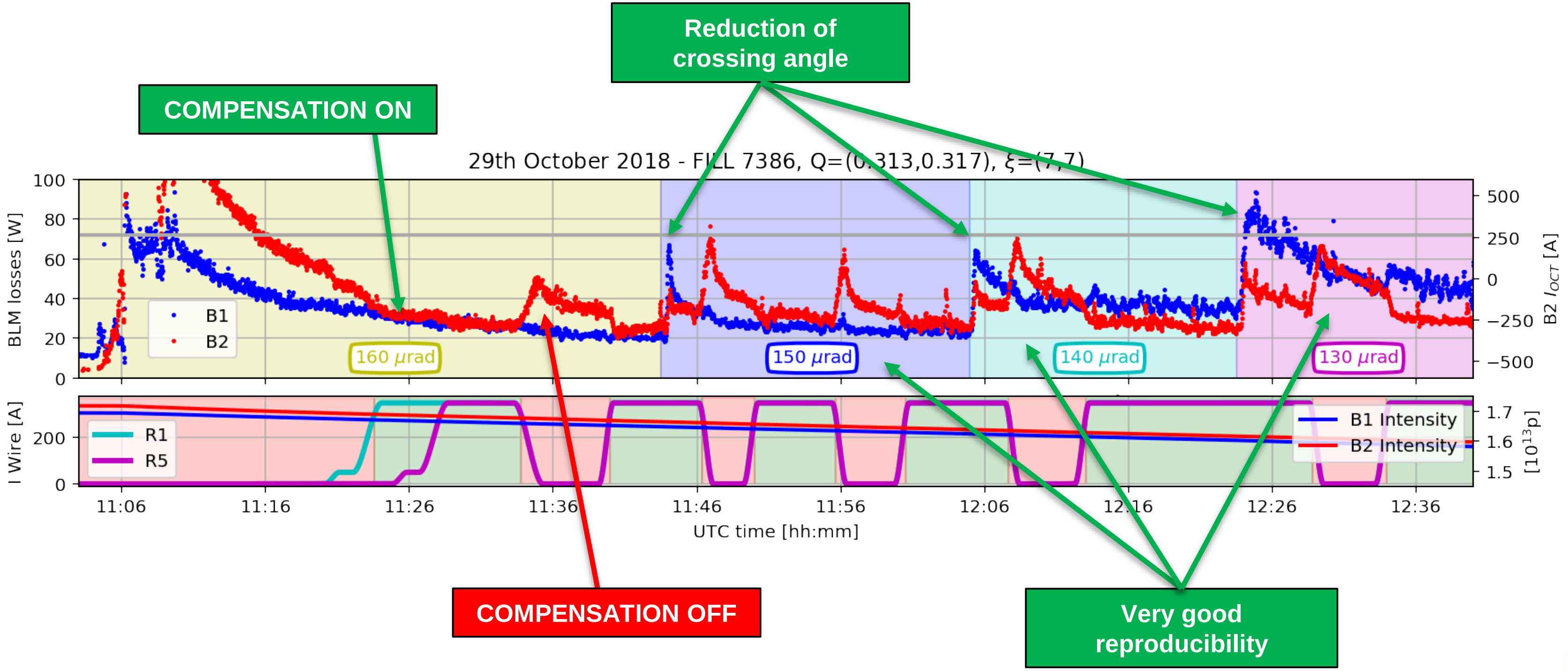

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