DRAFT!

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

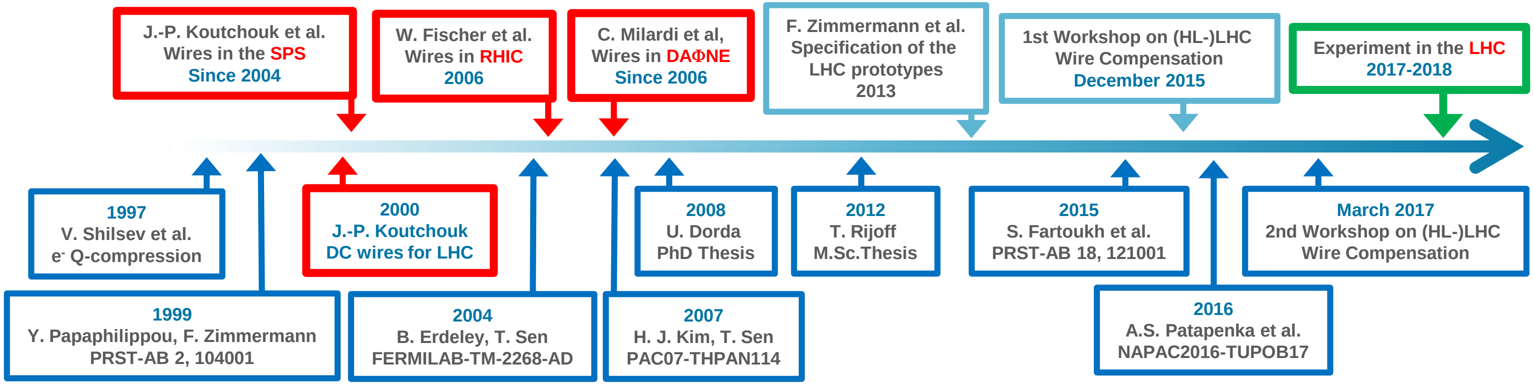
G. Sterbini, S. Fartoukh, N. Karastathis, Y. Papaphilippou, A. Poyet, A. Rossi and K. Skoufaris on behalf of the wire compensation team.

IPAC19, Melbourne, 22nd May 2019

Outlook

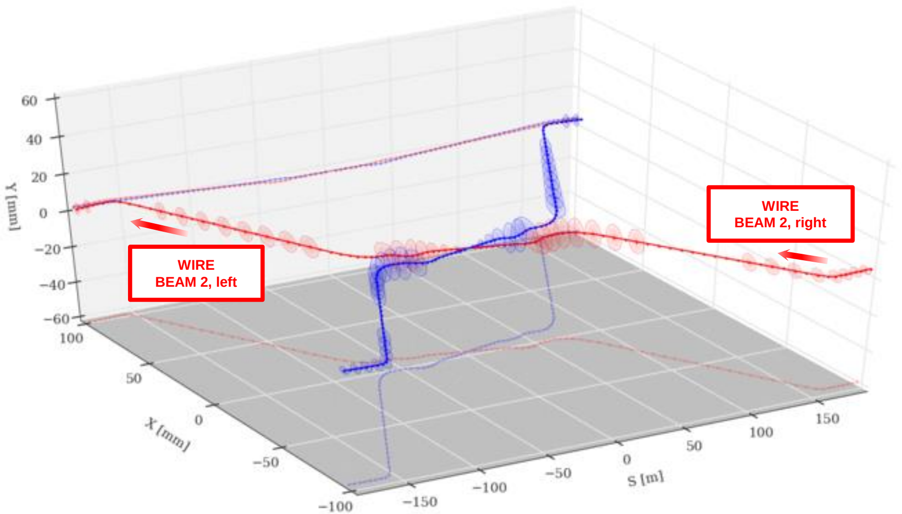
- Introduction on the wire compensation.
- Experimental constraints and optimization of the wires settings.
- Experimental objectives and results.
- Benchmarking with simulations.
- Next steps and summary.

Historical background

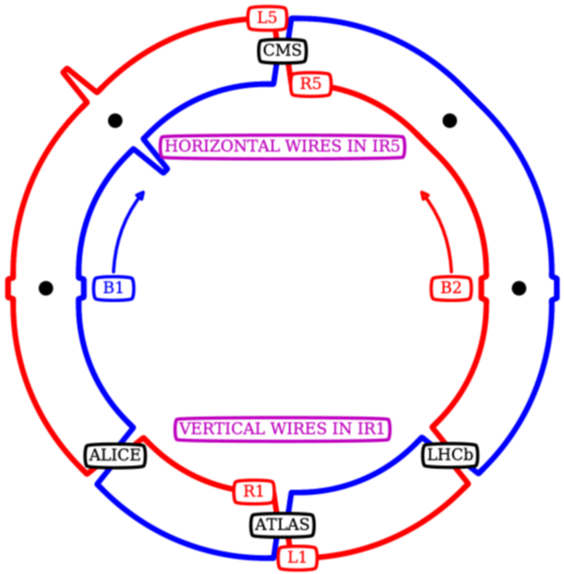


- DC wire proposed for LHC by J.-P. Koutchouk in 2000.
- Experimental tests of DC wires in SPS, RHIC and DAΦNE. Never tested in hadron colliders with operational configurations
- → need for direct experiments in LHC.

The wire compensation principle



The DC wire compensation

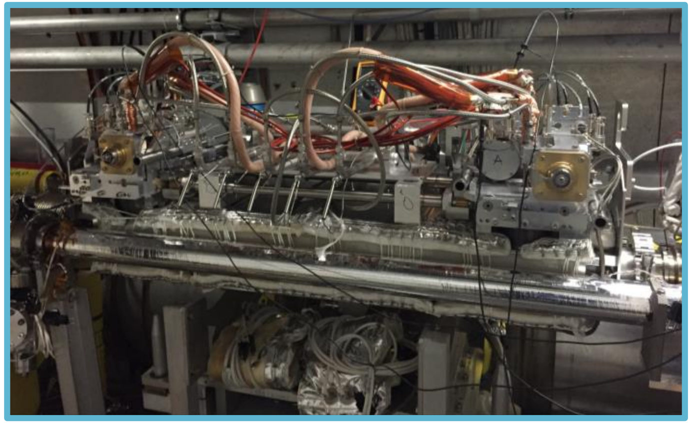


Layout of the wire installation

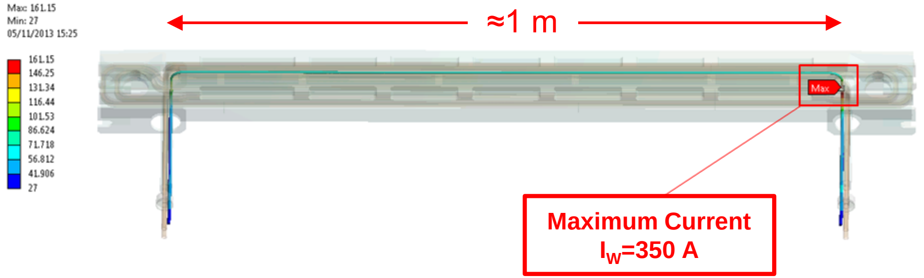
- **Since 2018 four wire prototypes are installed in LHC (B2, IR1+IR5)** with the aim to explore the potential of the wires for HL-LHC (see L. Rossi, **MOYPLM3**).

Wire-in-collimator prototype

- LHC wires prototypes 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.**

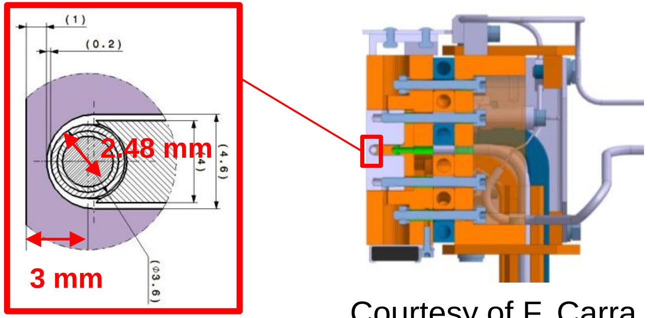


Top view



Courtesy of F. Carra

Front view



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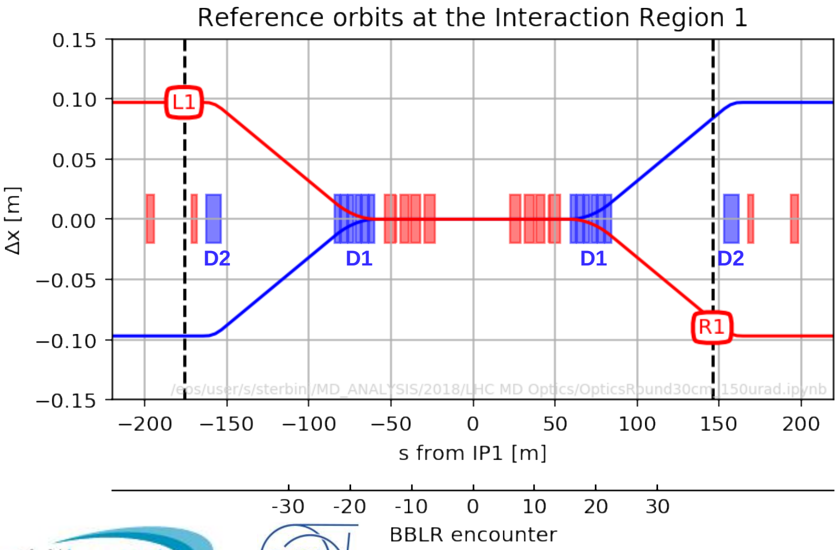
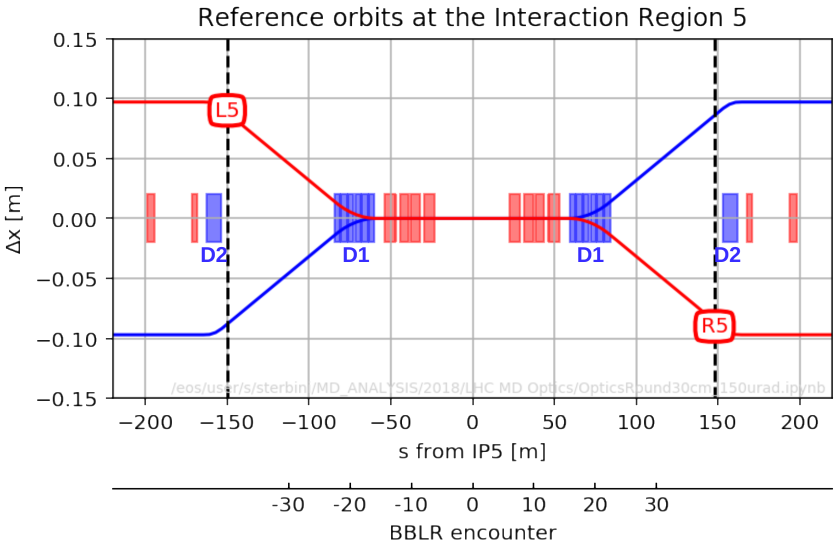
Longitudinal position of the wires

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

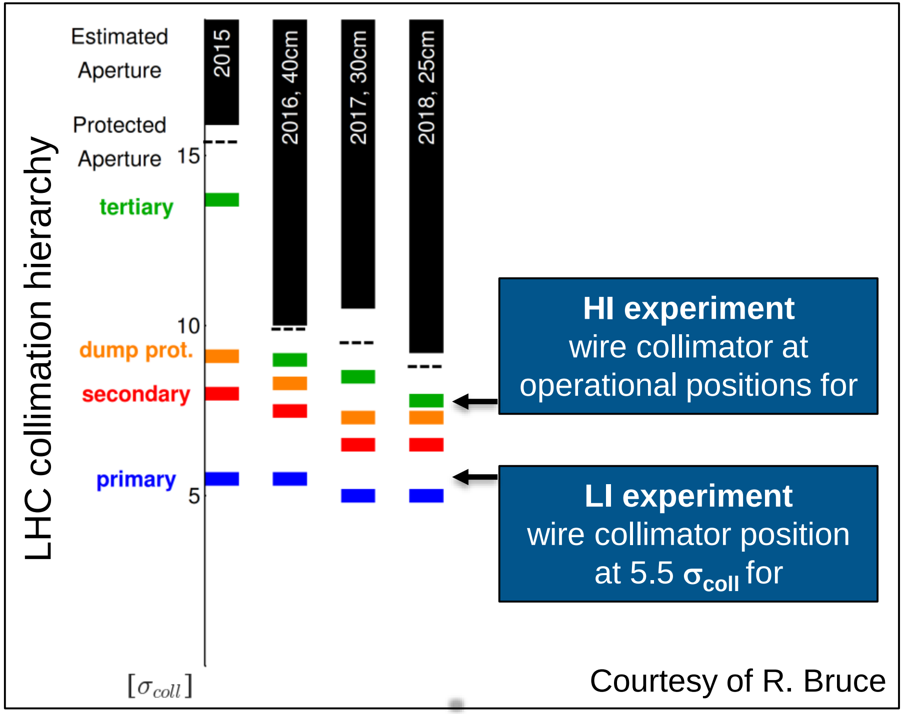
Wire prototype	s from IP [m]
L1, not-used in operation	-176.17
R1, tertiary collimator	145.94
L5, IP debris collimator	-150.03
R5, tertiary collimator	147.94





Transverse positions of the wires

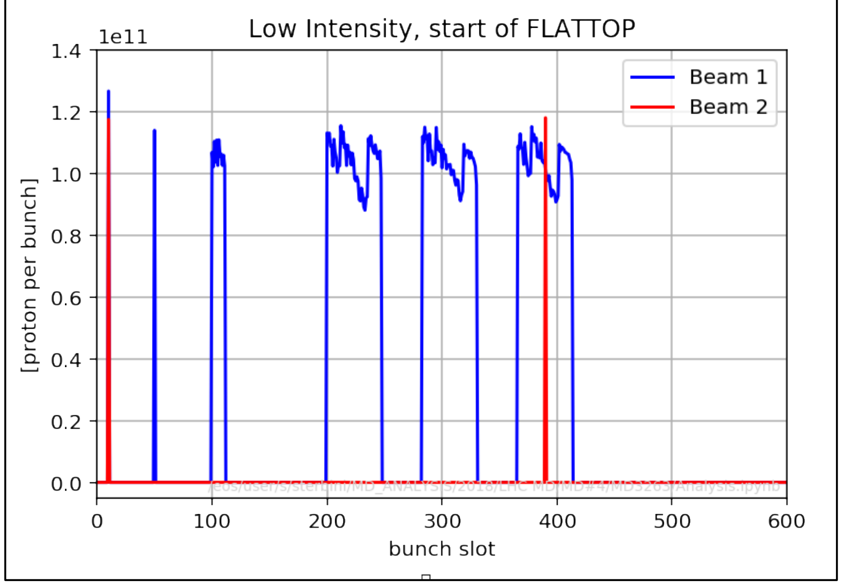
- The wire are installed in the crossing plane of the Interaction Region, i.e.,
  - vertical in IR1,
  - horizontal in IR5.
- Given the constraints of the LHC collimation hierarchy, two classes of experiments were performed
  1. **LI**: **Low Intensity** experiment (only 2 bunches in Beam 2) with wire-collimator 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 (tertiary)



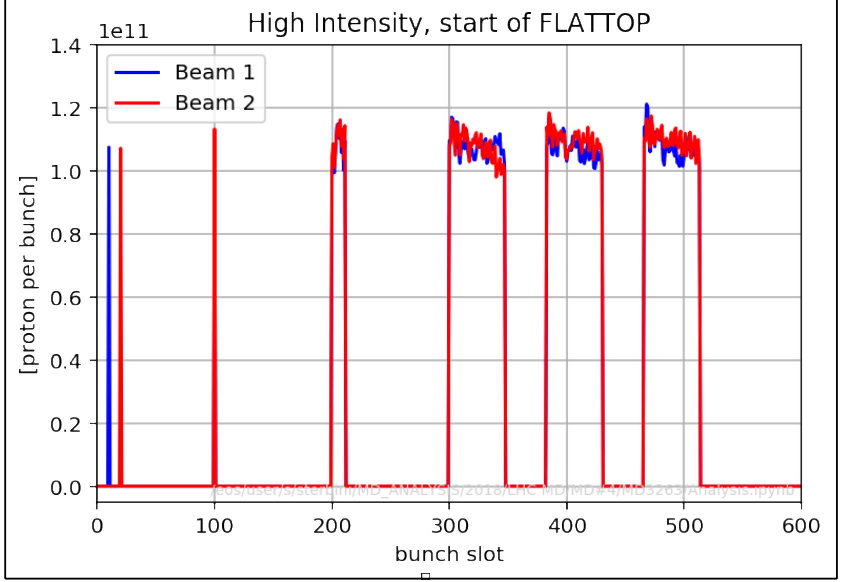
Wire prototype	LI experiment	HI experiment
L1	-7.41 mm	not used
R1	7.42 mm	9.83 mm
L5	-7.15 mm	not used
R5	8.24 mm	11.10 mm

Filling schemes and beam-beam encounters

LI experiment



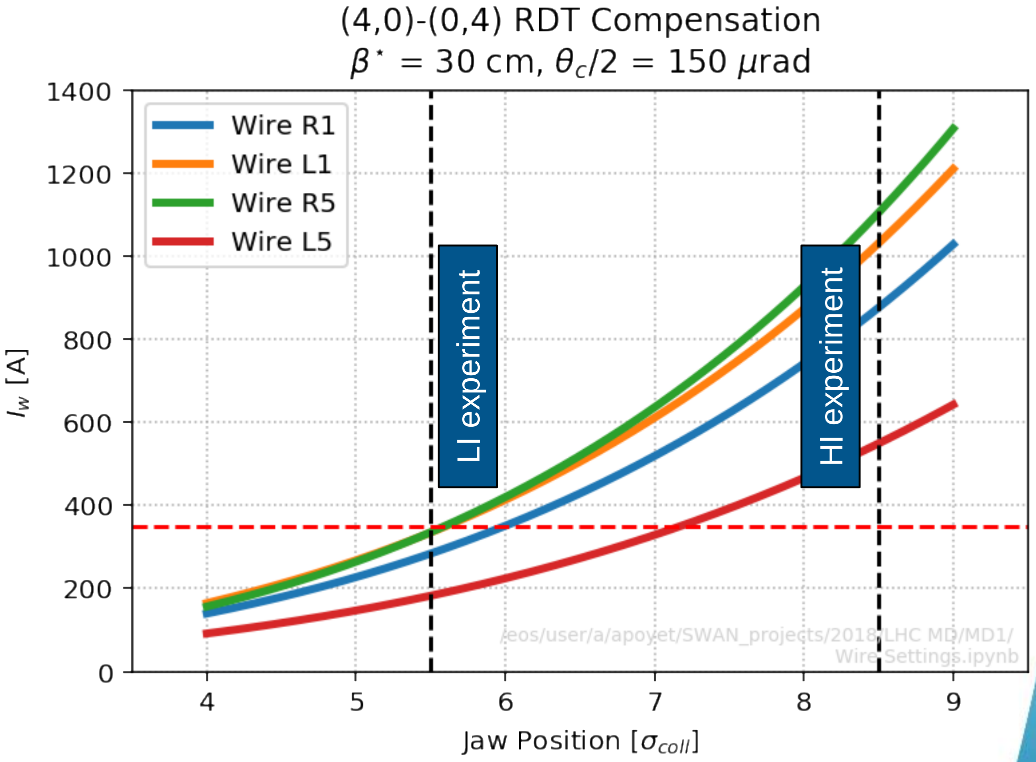
HI experiment



- 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 have the complete distribution of PACMAN bunches in IR1/5.

Wire current settings I

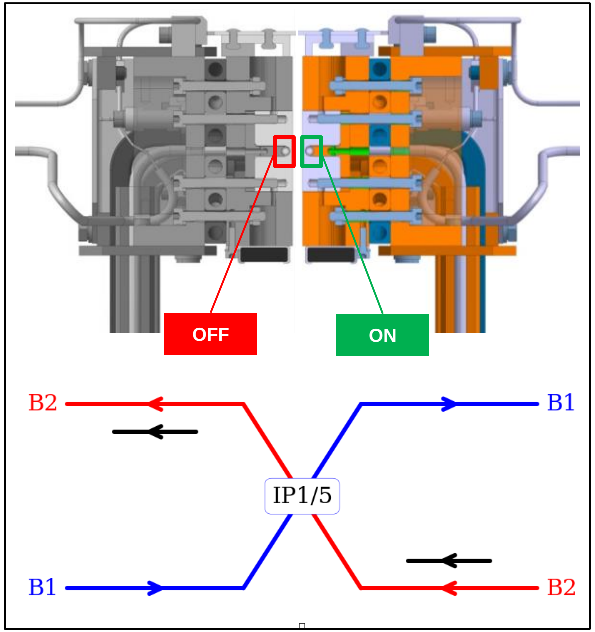
- The experimental setup allowed to minimize only two Resonance Driving Terms [S. Fartoukh et al. PRST-AB 18, 121001].
- We set the wire currents to compensate the **(4,0) and (0,4) RDT**: first order amplitude detuning.
- For the HI experiment, due the larger beam-wire distance, the current for the compensation is not compatible with the standard wire configuration.



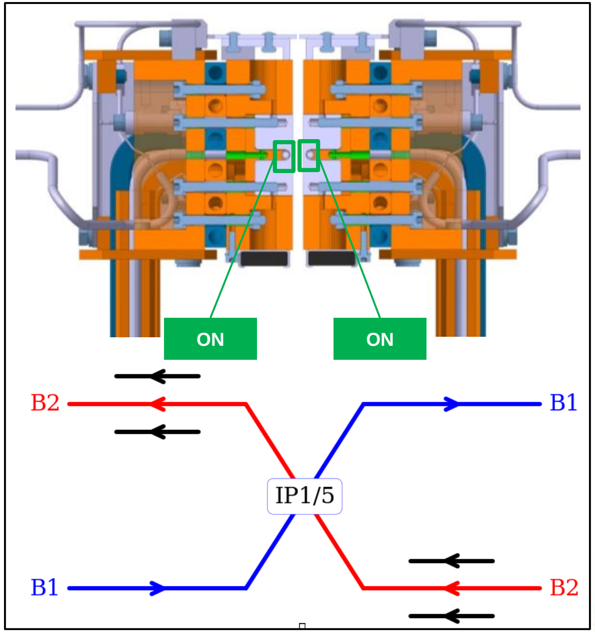
Wire current settings II

- 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 prototype	LI experiment	HI experiment
L1, not-used in operation	350×1 A	not used
R1, tertiary collimator	320×1 A	350×2 A
L5, IP debris collimator	190×1 A	not used
R5, tertiary collimator	340×1 A	350×2 A

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Objectives of the experiments

- **Prove an beneficial effect of the wires prototypes** in a regime dominated by long-range beam-beam effect. The compensation should not degrade the lifetime of the PACMAN bunches.

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

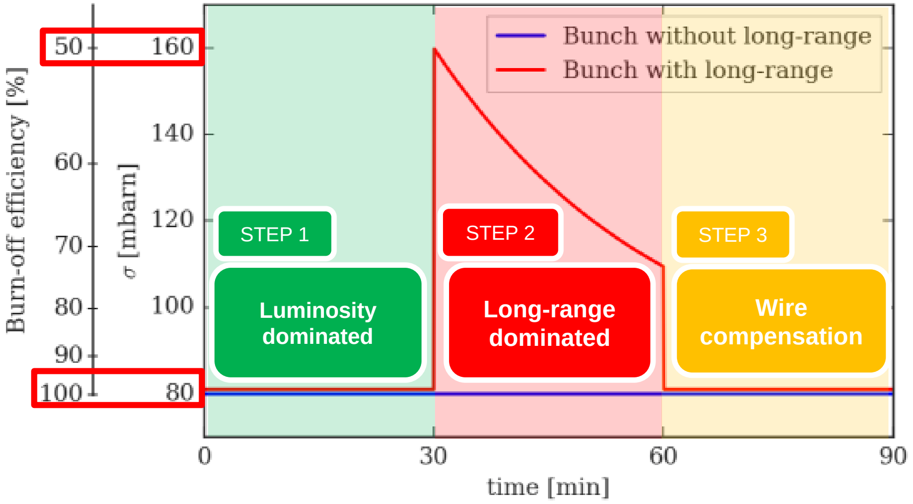
- Our observables are the bunch effective cross-section (σ_{eff}), the beam losses and the beam lifetime.

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

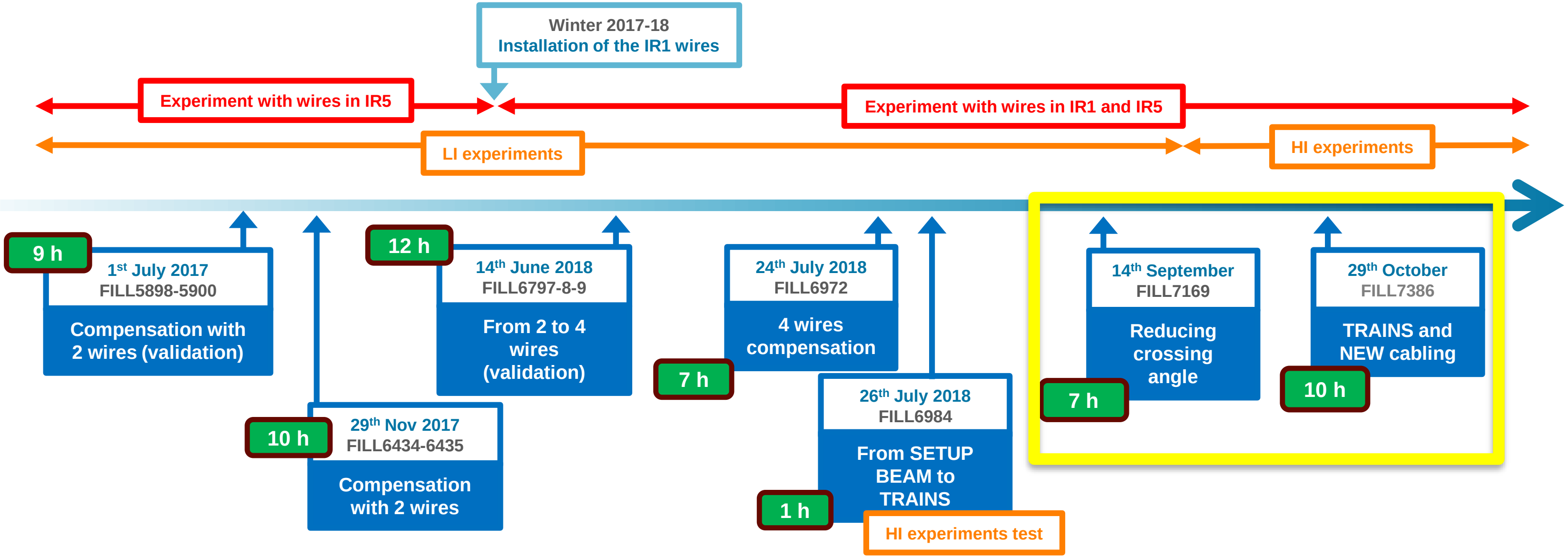
Instantaneous luminosity

Intensity loss-rate

The IDEAL compensation

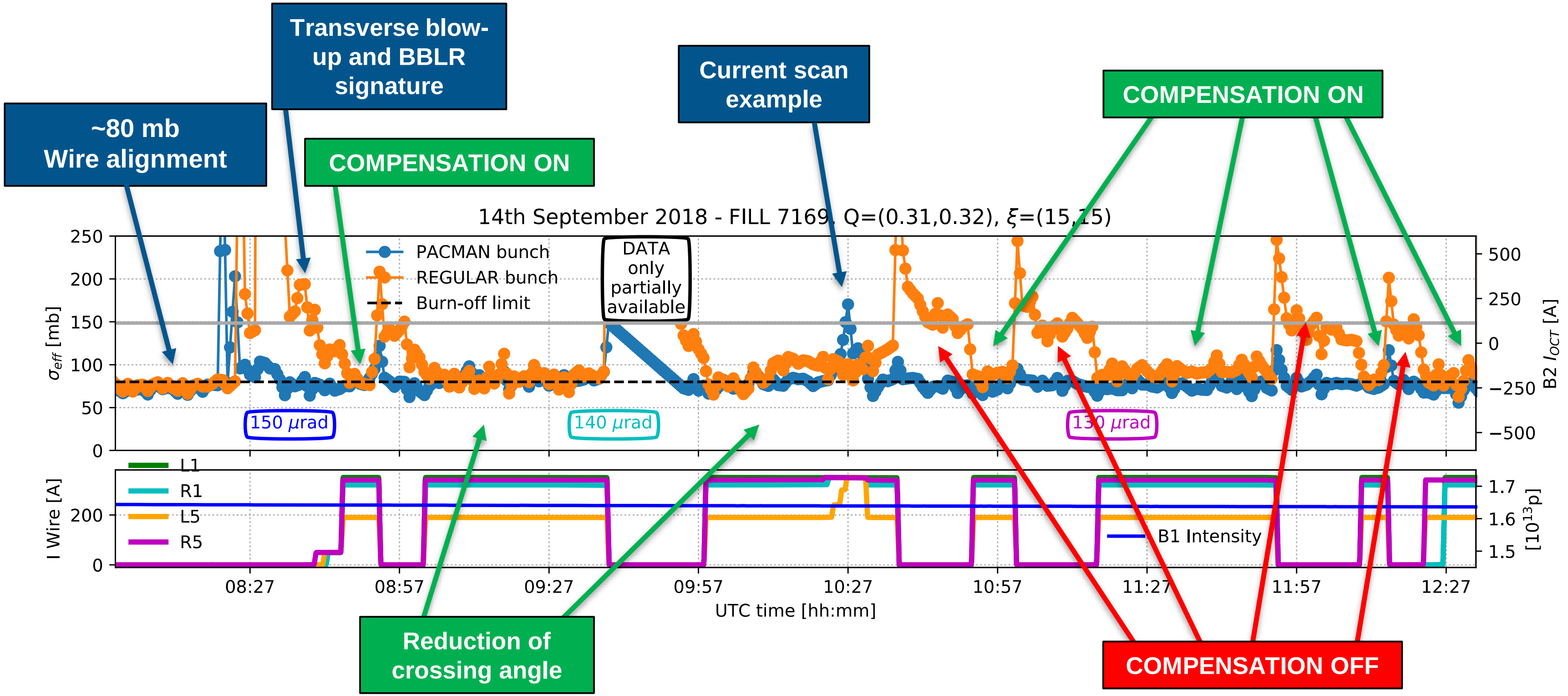


The experimental campaign



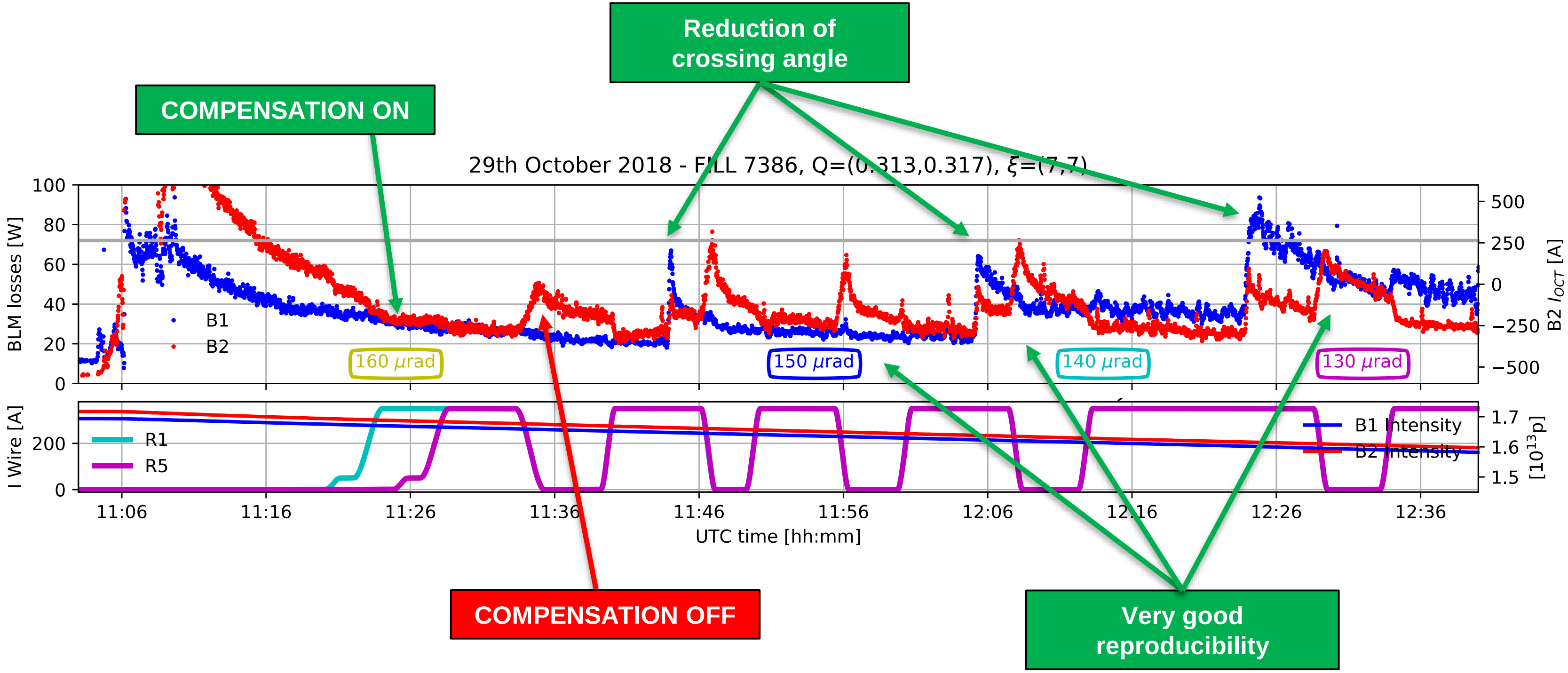
- A rich experimental campaign was performed during the last 2 years: the compensation effect was systematically observed.

Low-Intensity experiment



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

HI experiment (operational conditions)



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

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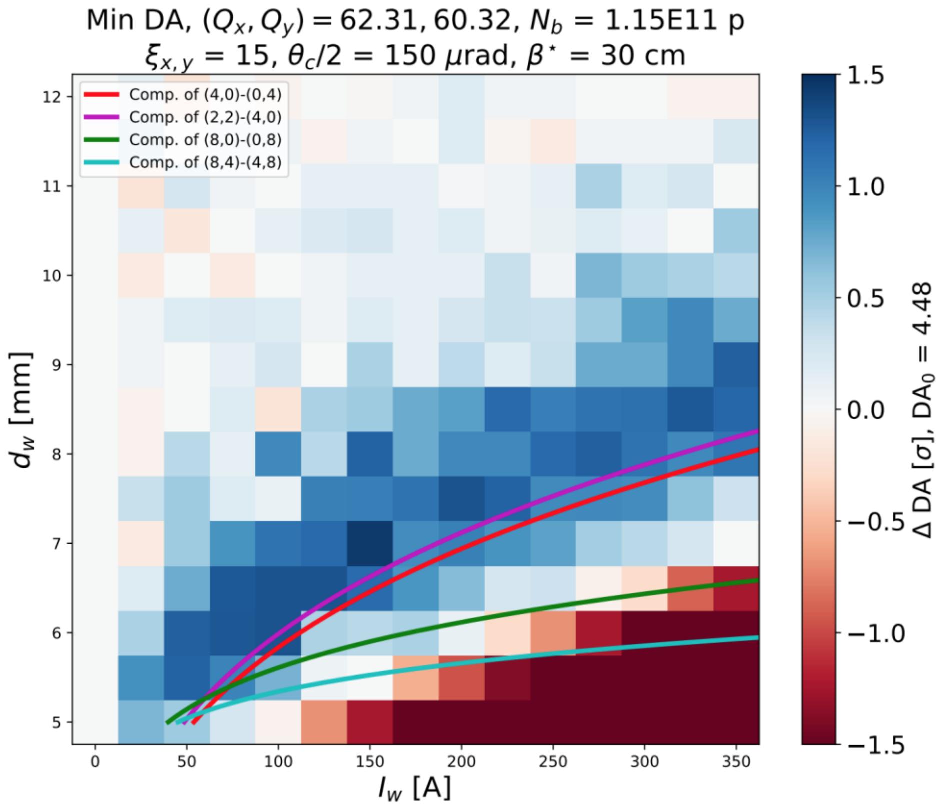
Simulations of the LHC experiments

A. Poyet
MOPMP052

- The configuration of the LI experiment was simulated with numerical tracking and the machine Dynamic Aperture (**DA**) was observed.

- 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 plane.



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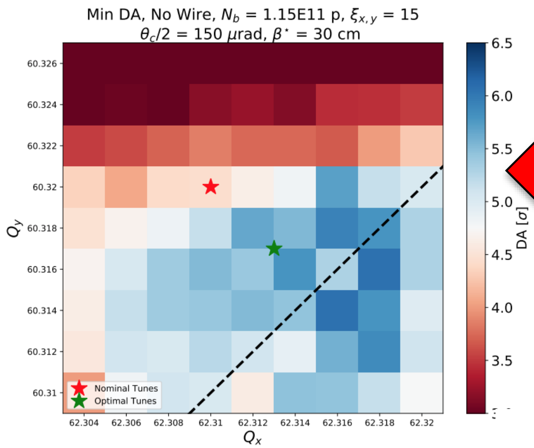
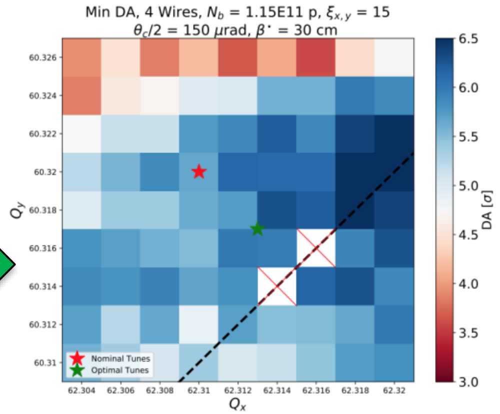


Wire compensation OFF



Wire compensation ON

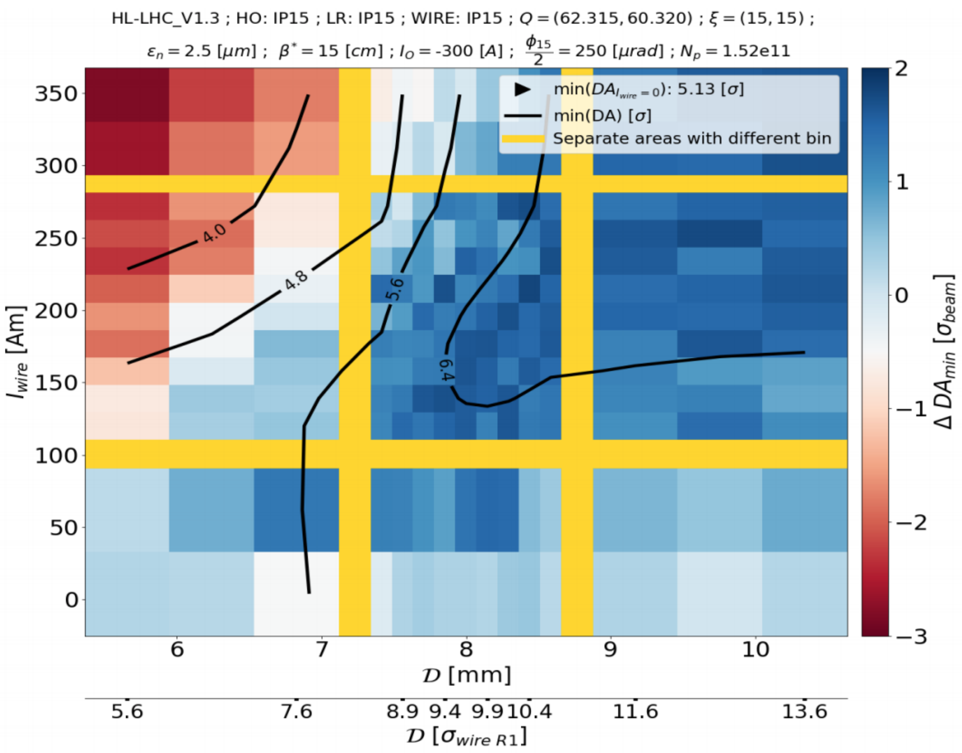
Simulations of the HL-LHC case

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 plane was observed also in this case.



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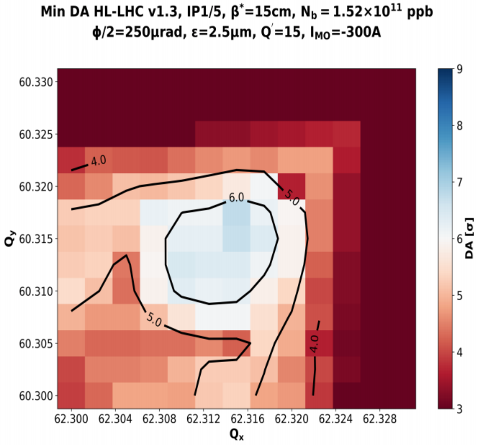
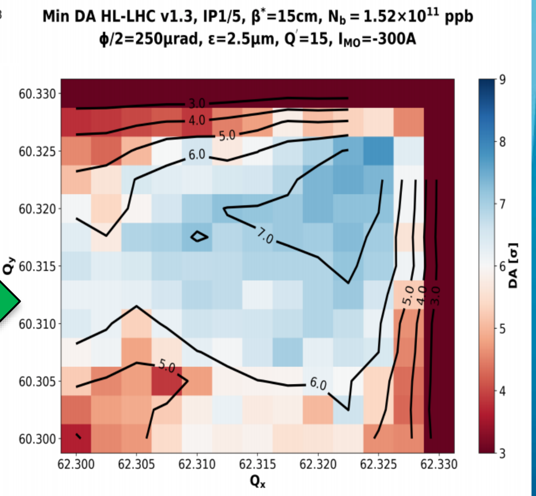


Wire compensation OFF



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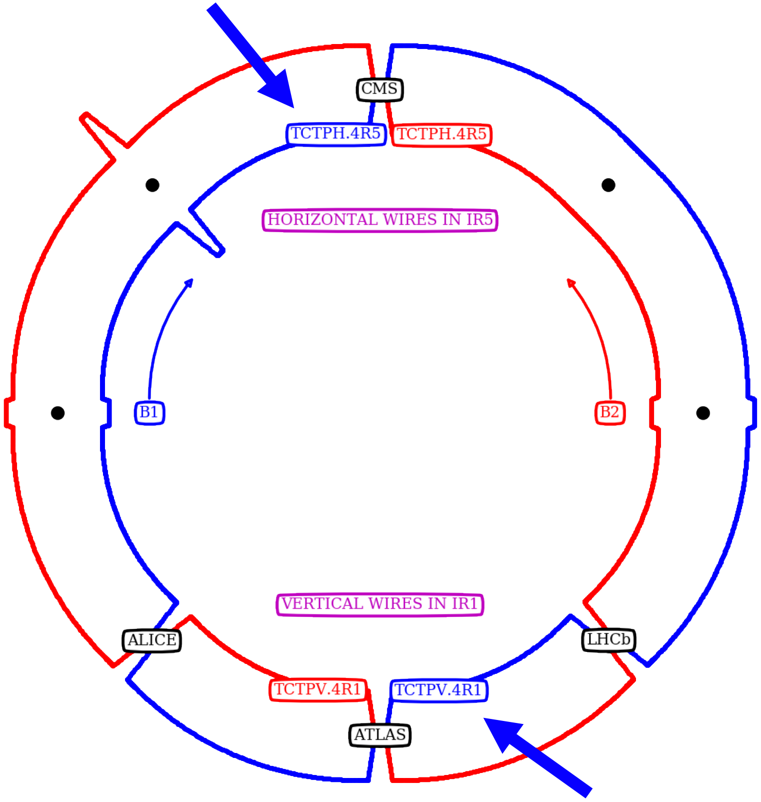
Next steps and proposals

- 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 prototypes (L1 and L5) from Beam 2 to Beam 1.

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



/eos/user/s/sterbini/MD_ANALYSIS/2018/LHC MD Optics/OpticsInjection.ipynb

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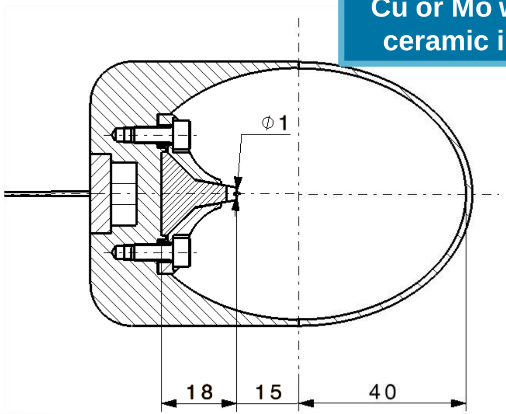
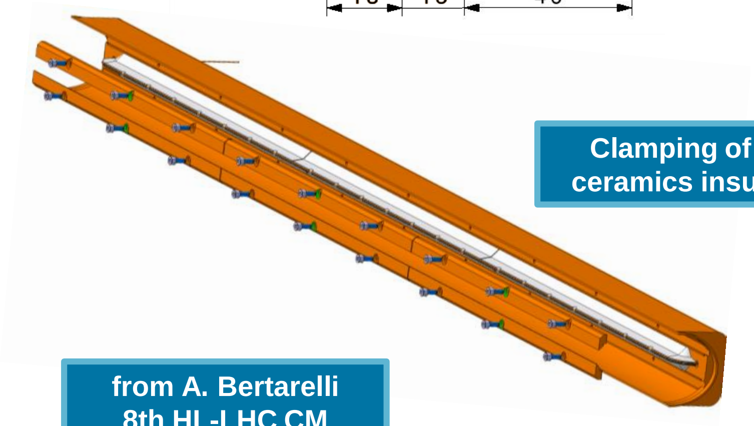
Cu or Mo wire on a ceramic insulator





Clamping of the ceramics insulator

from A. Bertarelli 8th HL-LHC CM

Summary

- In 2017-18 a rich measurements program was performed to explore the potential of the wire compensation in HL-LHC. Within the constraints of a sub-optimal setup, a positive effect of the compensation was systematically observed even with reduced crossing angle and in operational-like conditions. Following this results we proposed to use them operationally for the next LHC run.

- Simulations 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 (beam intensity reach, crossing angle/triplet irradiation and available tune space).

- First iterations for a HL-LHC wire design are on-going and the next objective is to prepare a proposal for a technical review.

Thank you for the attention.

On behalf of the 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 prototypes.