Operational aspects of a hollow electron lens at HL-LHC

R. Bruce

based on material from, and discussions with:

J. Coello de Portugal, M. Fitterer, M. Giovannozzi, G. Mazzacano, S. Redaelli, B. Salvant, R. Tomas, J. Wagner, D. Wollmann, C. Zanoni

Hollow electron lens review 19/10/2017

Introduction

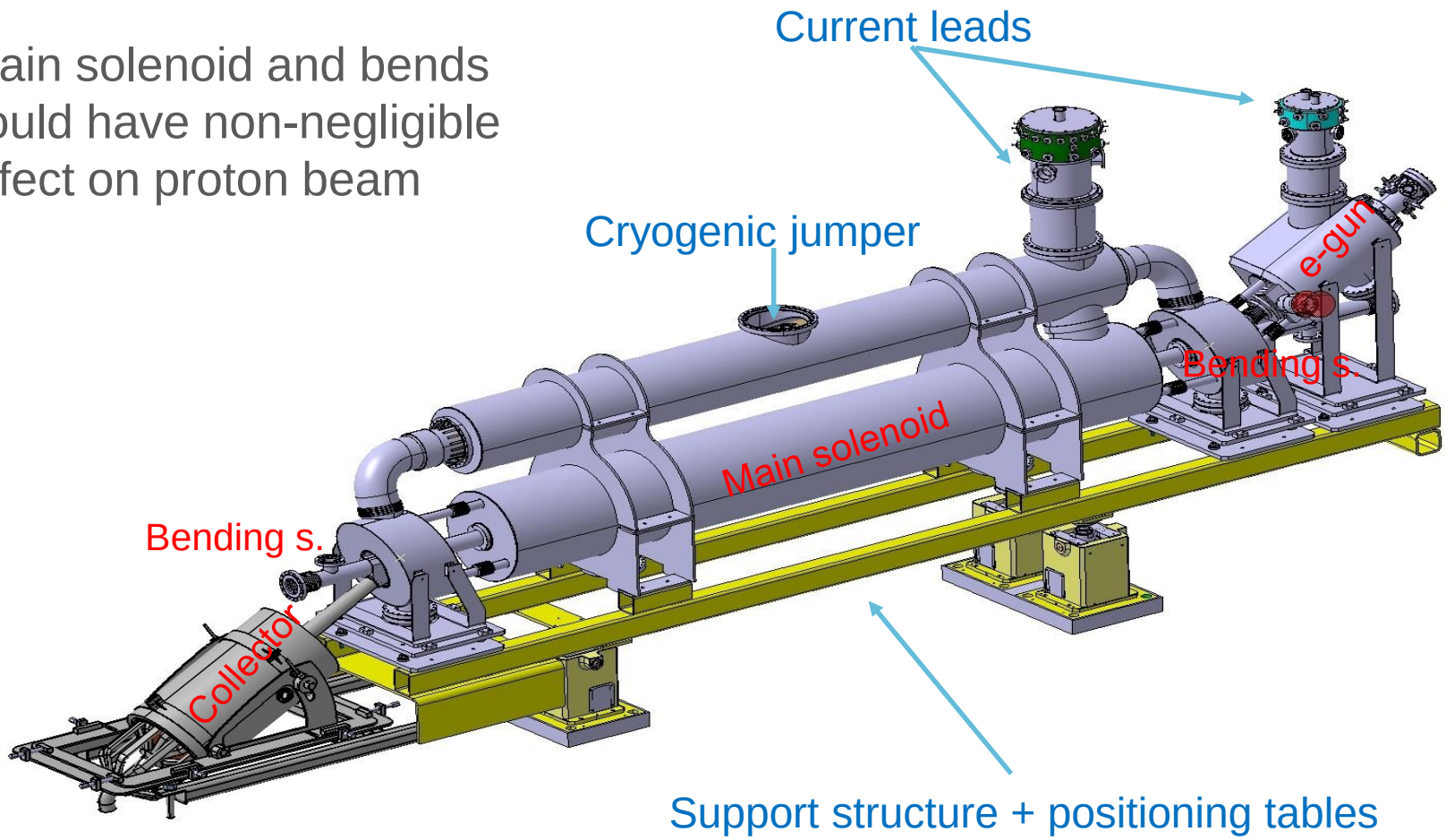
- Apart from a cleaned halo, what will be the impact on HL-LHC operation if the hollow electron lens is installed?
- Outline of this talk:
  - Aperture
  - Effect of solenoids
  - Impedance
  - Effect on proton beam core from electron beam
  - Operation without tails
  - Hollow electron lens failures

Aperture

- Round beam pipe of 80 mm radius foreseen in electron lens
  - No reduction with respect to present beam pipe
- No issue in terms of available aperture for the circulating beam
- Maybe even an aperture reduction is possible. To be studied

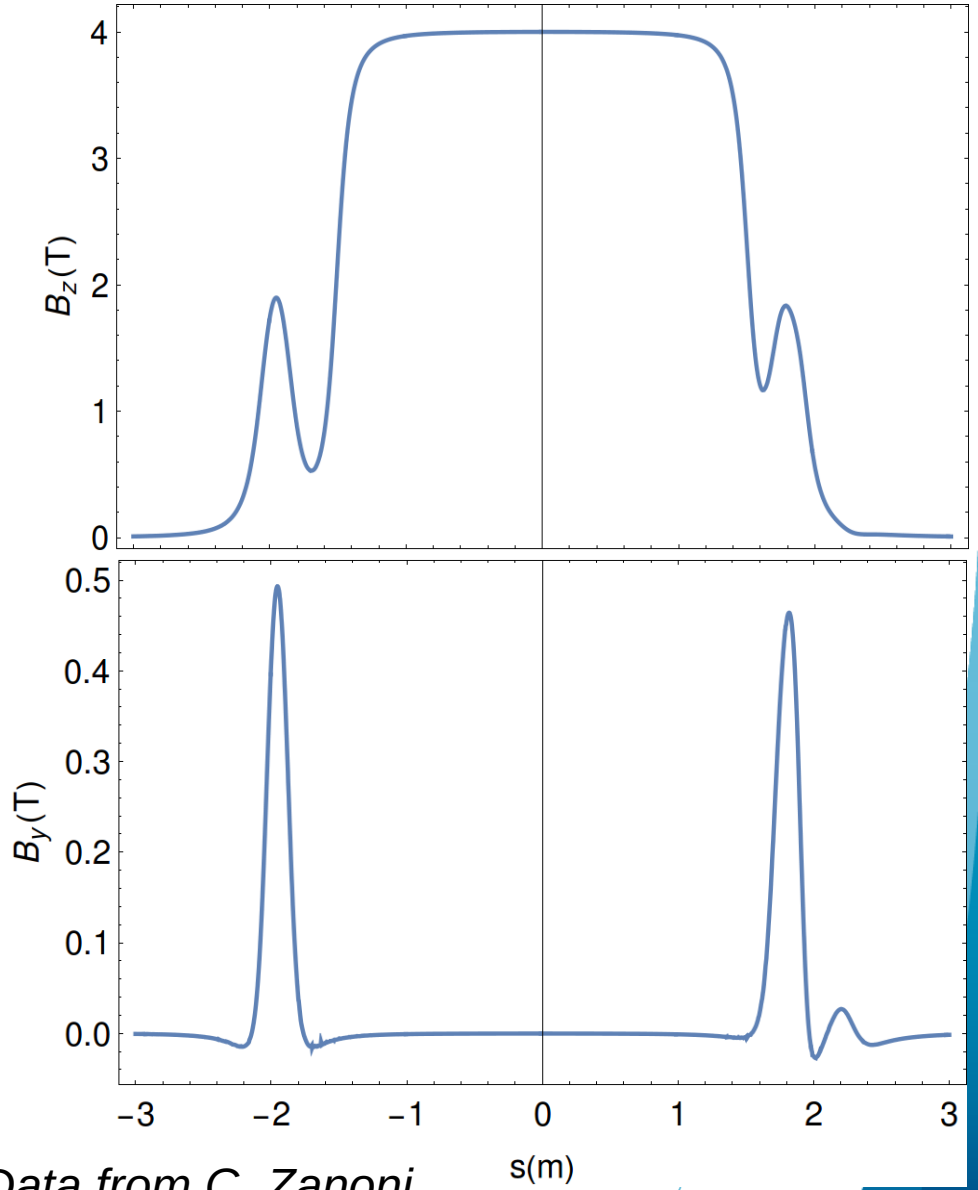
Effect from solenoids

- Main solenoid and bends could have non-negligible effect on proton beam



Magnetic fields acting on beam

- Longitudinally
  - main solenoid has 4T field over 3 m
  - The bends have field up to 2T
- Transversally
  - Up to 0.5 T vertical field
  - Negligible horizontal field
- Other beam
  - Small field leaking to the other beam.
  - Magnetic shielding can be added around pipe

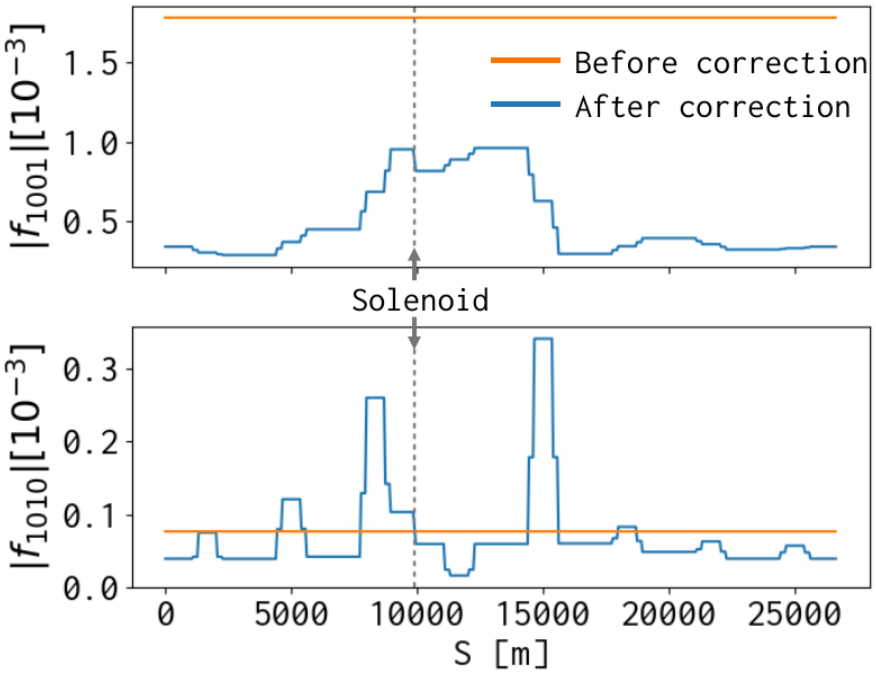


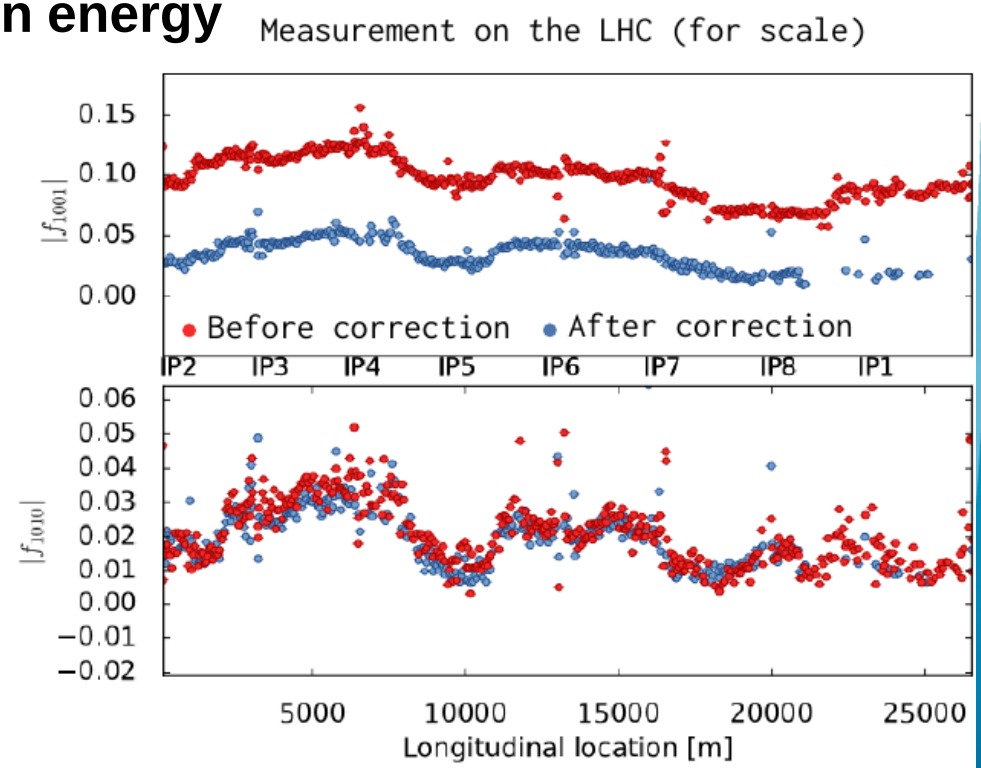
Data from C. Zanoni

Studies on solenoid coupling: Injection

- Effect of linear coupling from solenoidal fields studied, pessimistically assuming 6T field
  - Full details: HSS section meeting 11/10/2017
- Much smaller than measured coupling in the LHC

Injection energy





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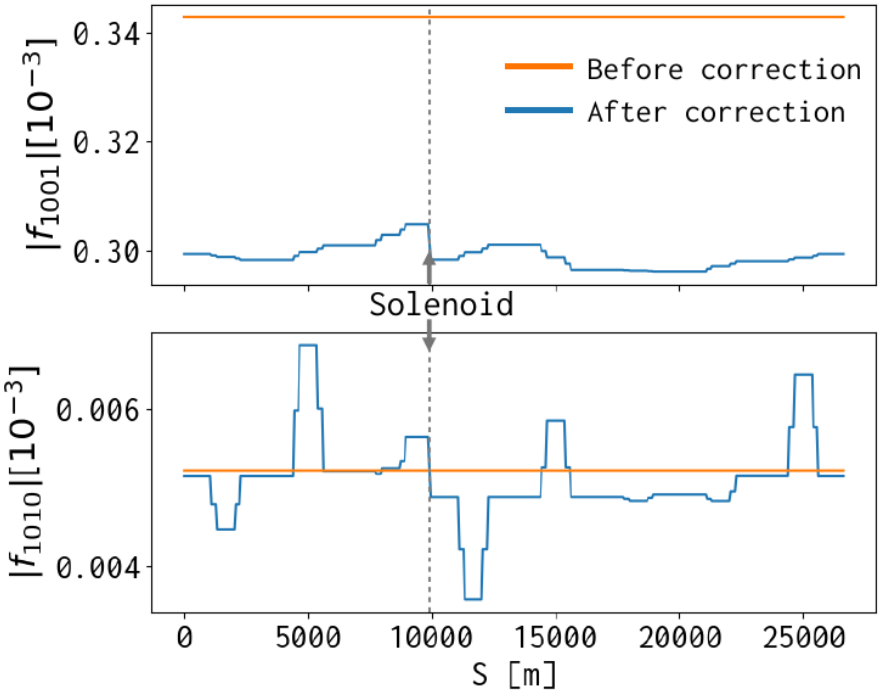
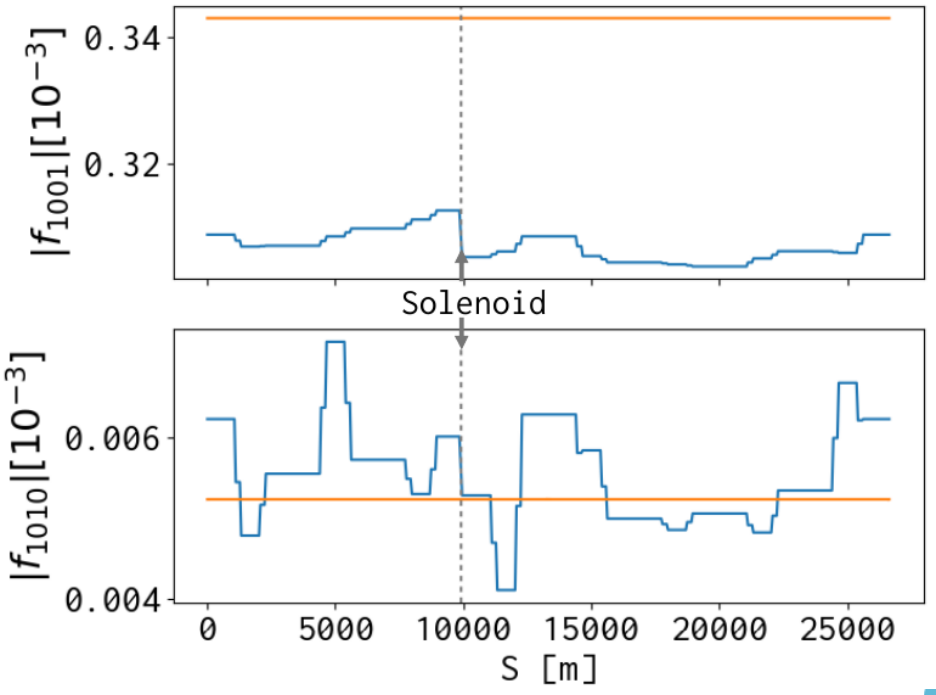
Studies on solenoid coupling: 7 TeV

7 TeV, flat top



7 TeV, β*=15 cm



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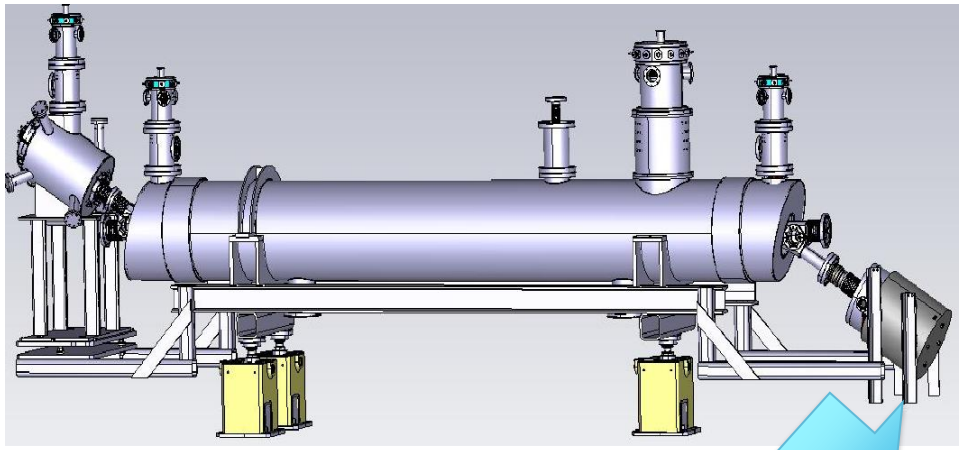
- Conclusion on solenoid coupling: negligible

Transverse dipole component

- S-shape of e-lens conceived so that the effect on the proton beam core from the two electron beam crossings cancels out
- With this shape, kicks from bending solenoids add up
- Effect on orbit and mitigations under study
  - Local correction?
  - Fallback solution: Ramping of solenoids with beam energy => smaller kick at injection
- In case of quench, missing dipole kick could cause losses => needs interlocking
- Effect of fringe fields still to be studied (both for transverse and solenoidal fields)

Impedance calculations

- Impedance calculations on pipe performed using CST Particle Studio
  - Full details: talk G. Mazzacano in HL-LHC WP2 meeting 13/10/2017



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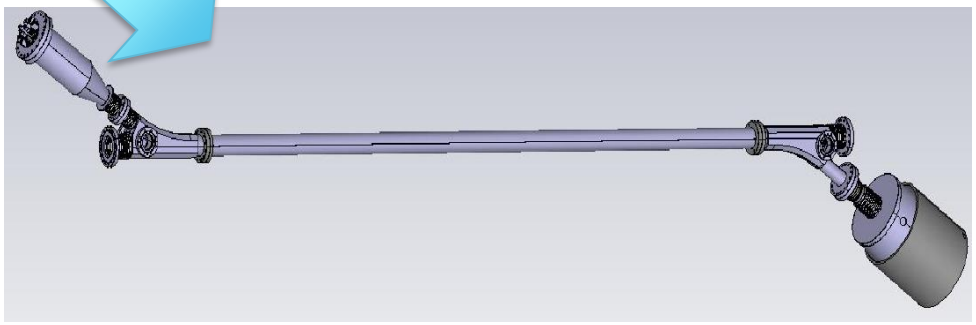
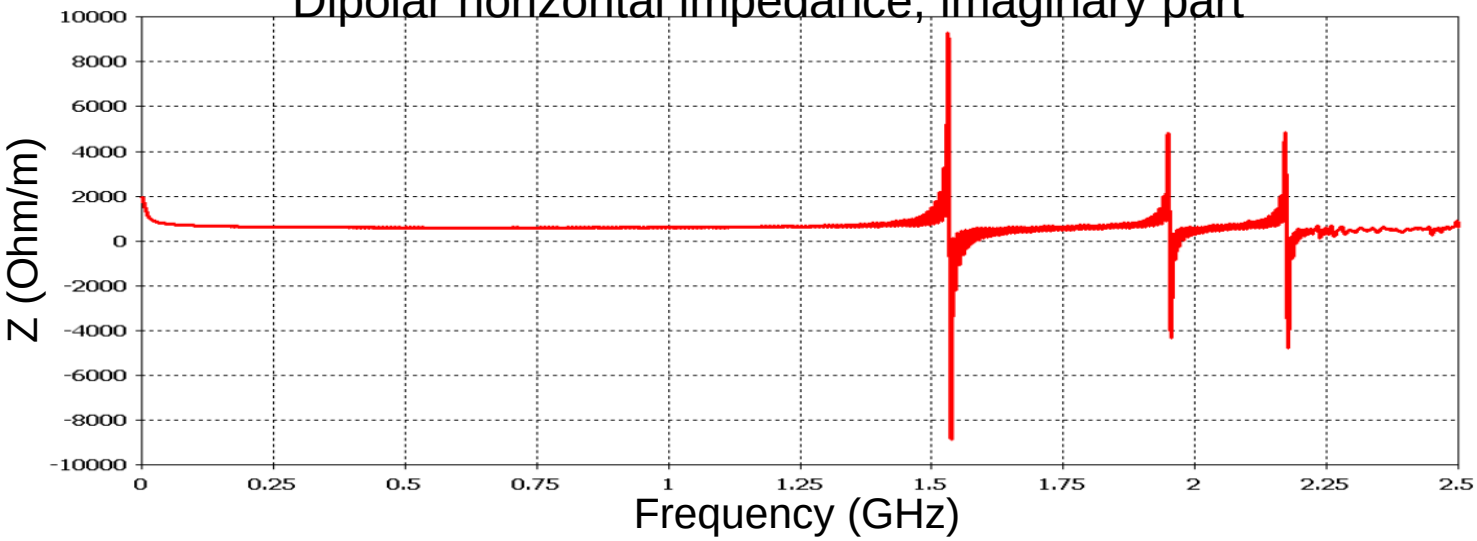
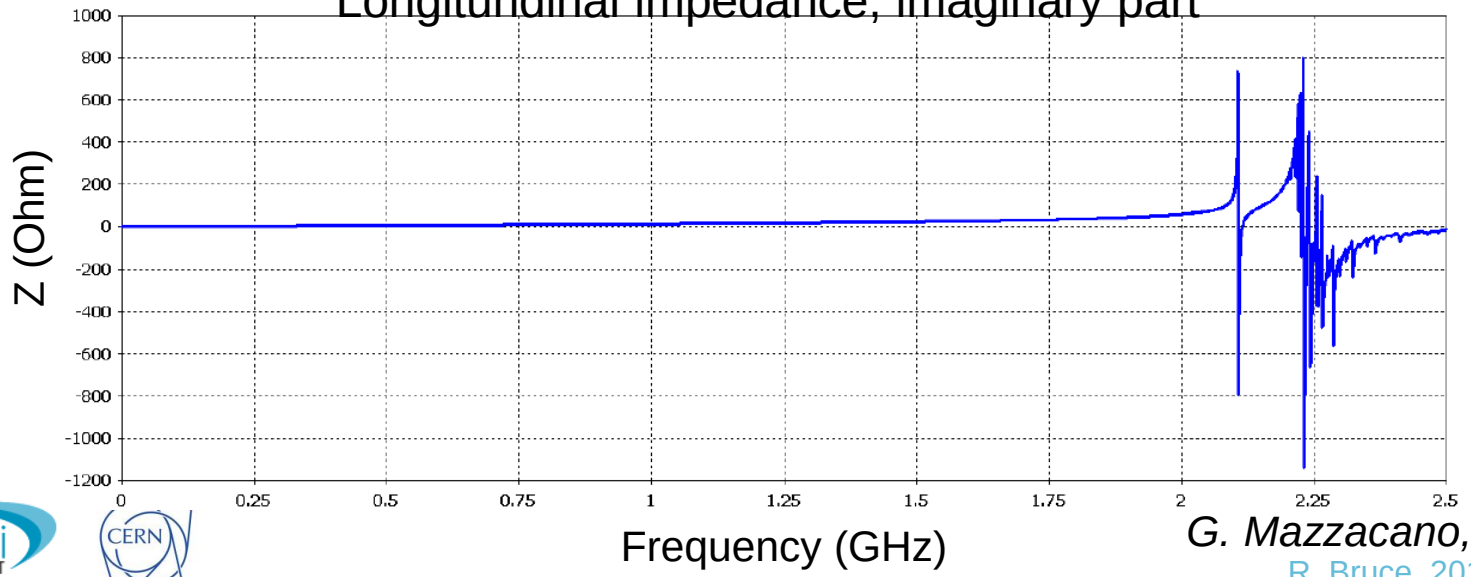


Example results: impedance vs frequency

Dipolar horizontal impedance, imaginary part



Longitundinal impedance, imaginary part



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Comparison to total LHC impedance

G. Mazzacano, B.Salvant

	Electron Lens	Total LHC Impedance
Longitudinal imaginary	$\frac{Z(f)}{n(f)} = 0.021\ \mathrm{m}\Omega$	$\frac{Z(f)}{n(f)} = 90\ \mathrm{m}\Omega$
Dipolar horizontal imaginary	$Z_{trans} = 600\ \Omega/m * \frac{\beta_x}{70}$	$Z_{trans} = 2\ \mathrm{M}\Omega/m$
Dipolar vertical imaginary	$Z_{trans} = 700\ \Omega/m * \frac{\beta_y}{70}$	$Z_{trans} = 2\ \mathrm{M}\Omega/m$

β at e-lens *(J. Wagner)*

Configuration	Beam	Energy [GeV]	β^* [m]	β_x [m]	β_y [m]
Injection and end of ramp	1	450 – 7000	6	231.30	213.31
	2	450 – 7000	6	281.49	262.49
Collision round 50cm	1	7000	0.50	231.60	212.54
	2	7000	0.50	281.37	263.23
Collision round 15cm	1	7000	0.15	198.20	213.08
	2	7000	0.15	283.46	264.21

Conclusion on impedance

- The studied design of the electron lens shows good performance. Impedance is small (permil level) compared to total LHC impedance budget
- Some recent design changes have not yet been studied for impedance
  - Work ongoing
  - No issue expected

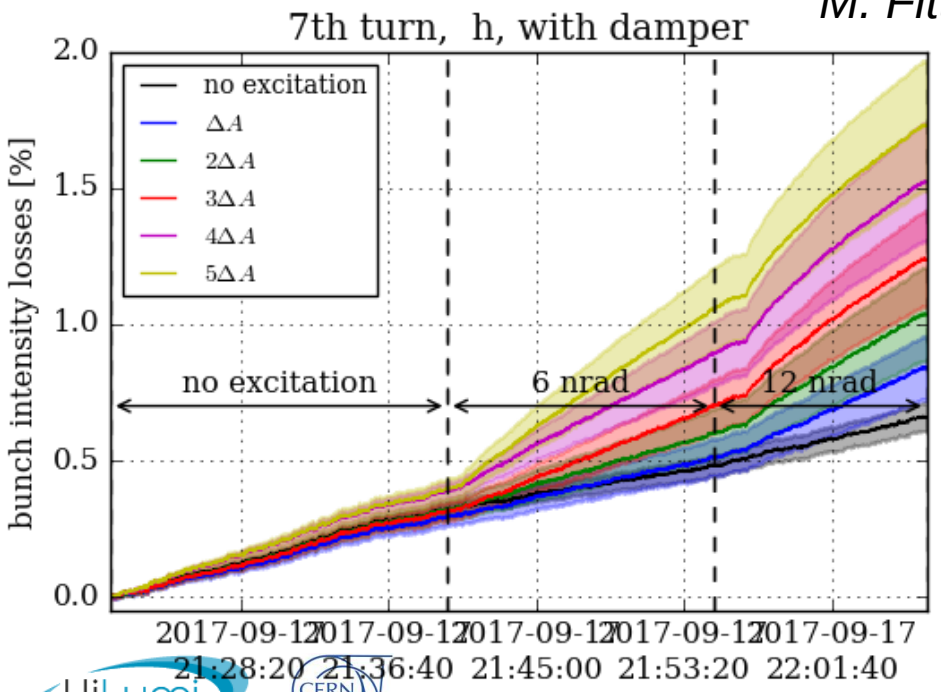
Effect on proton core from electron beam bends

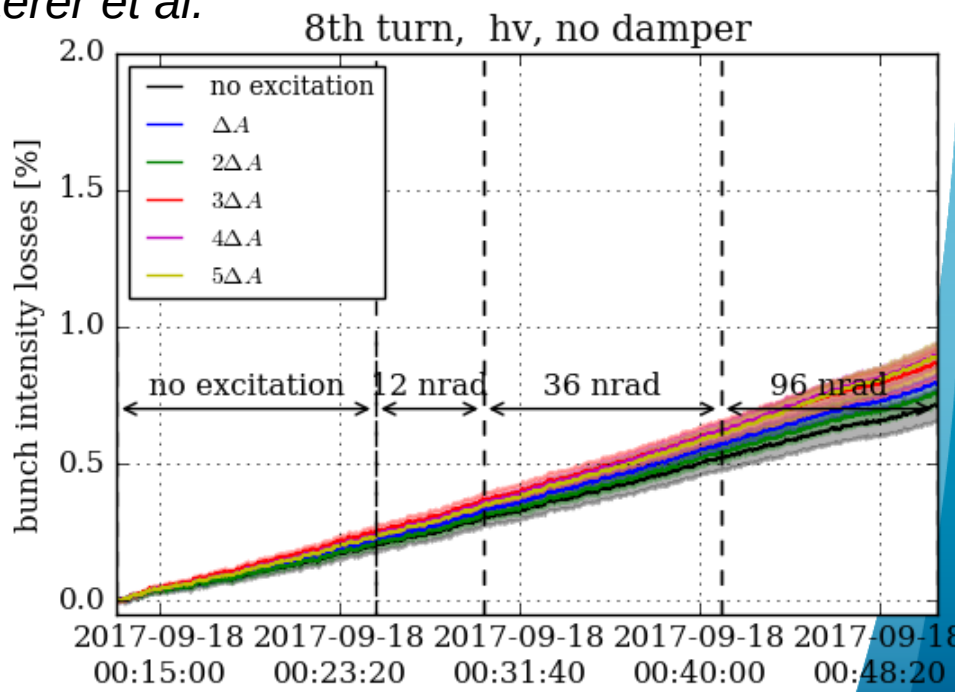
- For ideal radially symmetric hollow electron lens with an S-shaped geometry, effect on core cancels
- Imperfections on the bends or electron beam profile => non-zero kick at the center of the beam
  - Negligible in continuous mode, but could be important if the hollow electron lens is pulsed
- Effect studied in simulations and experiments in 2016 (*CERN-ACC-NOTE-2017-0037*) and in 2017 (analysis ongoing) – *M. Fitterer et al.*
  - Transverse damper (ADT) simulates kick from e-beam

Results: effect on proton beam core

- For some pulsing patterns of the hollow electron lens, emittance growth and losses are observed, while other pulsing patterns show no effect on proton beam core
- Choice of pulsing pattern during operation important
- Studies ongoing

M. Fitterer et al.





Cross-talk electrons and protons

- Previous proton beam core considerations for single bunches
- To be studied: Can one proton bunch perturb the e-beam in a way that it affects the next proton bunch?

Operation without tails

- In case of a fast beam movement, losses from tails would trigger beam dump before losses from core
- If tails are depleted by hollow e-lens, risk to hit directly core and have faster rise of losses
- Mitigation: leave some witness bunches with untouched halo
  - E-lens response time sufficient for acting train by train
  - Might need to review BLM thresholds
- ALICE plans proton operation around 3 months per year during HL-LHC
  - Relies presently on colliding halo in the two beams through separation levelling
  - To be checked: compatibility of ALICE operation with depleted tails

What if the hollow electron lens doesn't work?

- Failure modes should be studied in detail and proper interlocks put in place
  - Example: quench of solenoid
- If halo cleaning is strictly needed, e.g. for crab cavity failures, we cannot operate without it
  - Good halo monitor needed, which can be interlocked
- If halo cleaning is needed to mitigate loss spikes: risk more beam dumps in the absence of e-lens
- If halo cleaning turns out not to be strictly needed, interlocks should be designed so that LHC can operate without it
  - Impedance and aperture OK => The hollow electron lens is transparent for the machine if turned off.

Conclusions

- Studied impact on HL-LHC operation from the hollow electron lens
- Solenoids: coupling negligible. Effect on orbit and fringe fields to be studied, but no showstopper expected
- Impedance: Well within spec. Latest design still to be studied, but no showstopper expected
- Aperture: no reduction of beam stay clear
- Effect on core from electron beam: pulsing mode has to be optimized for machine configuration
- Operation without tails: Need to leave witness bunches from machine protection
- The hollow electron lens is transparent for the machine if turned off. Detailed interlock strategy to be defined – no showstopper expected.

Conclusions

- In conclusion, hollow e-lens seems to be a benign device for operation, although some points remain to be studied

Thanks for your attention