LHC Performance Workshop - Chamonix 2016
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CERN, Geneva, CH

Collimation Upgrade Path for HL-LHC

Stefano Redaelli, CERN, BE-ABP, on behalf of HL-WP5

Acknowledgements: R. Bruce, O. Brüning, A. Bertarelli and F. Carra for the MME team, P. Hermes, A. Lechner and FLUKA team, D. Mirarchi, J. Jowett, R. Losito, L. Rossi, A. Rossi, B. Salvachua, W. Scandale, ABP collimation team.

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New elements relevant for road map

- **Monitoring of 2015 performance**

  Operational experience at beam energy close to nominal;
  Collimation cleaning and beam losses at higher energies;
  New collimator design with integrated beam position monitors (BPMs);
  Operation of ion run with bumps to mitigate ion losses.

- **Assessment with beam of quench limits of superconducting magnets at 6.5 TeV**

  Preliminary analysis of 2015 tests now available.

- **Results of material testing and new collimator prototyping (without and with beam)**

  Can we make a jaw with novel "advanced" materials?

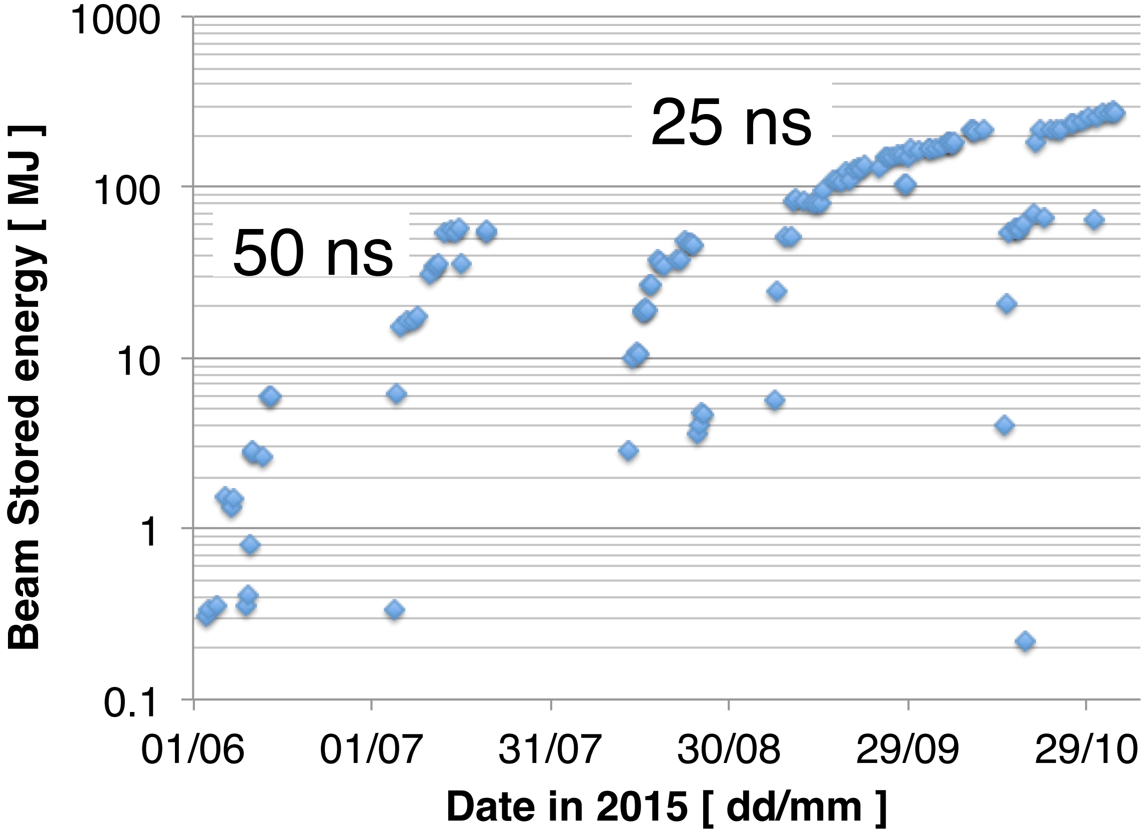
  Results of robustness tests against beam losses at HiRadMad.
  Results of radiation tests (BNL [US-LARP], GSI [EuCARD^2], Kurchatov,…

- **Results of MDs and specific studies**

  Crystal collimation, halo control.

- **Continued effort in simulations to converge on conceptual and technical solutions.**

2015 operational experience

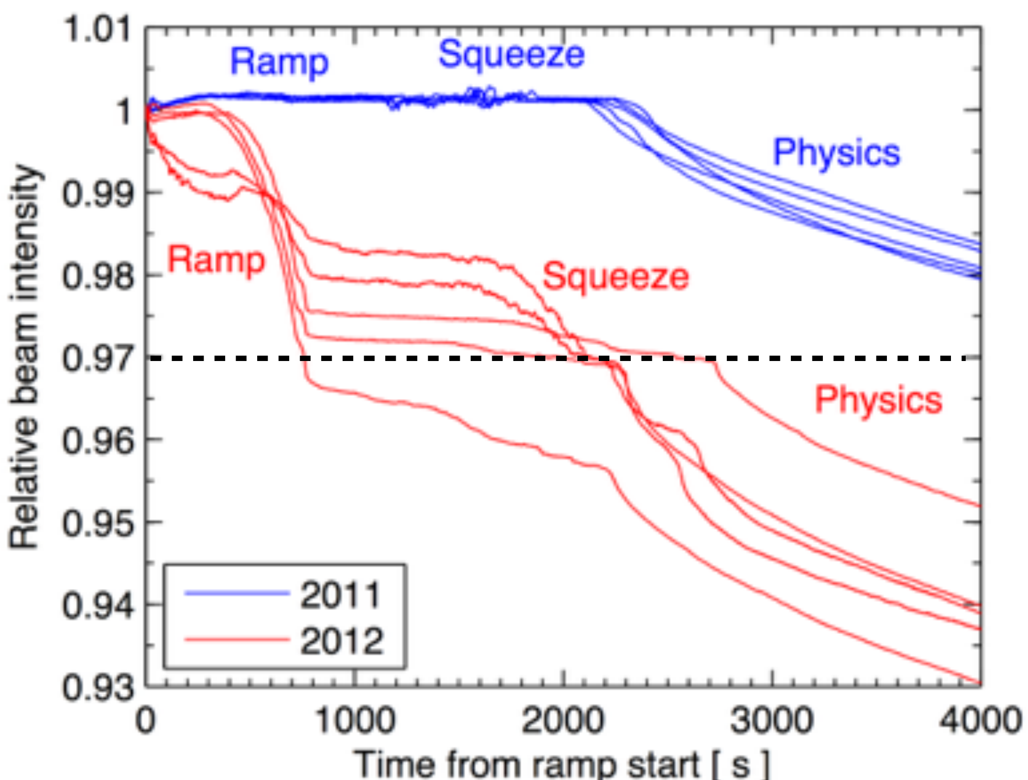


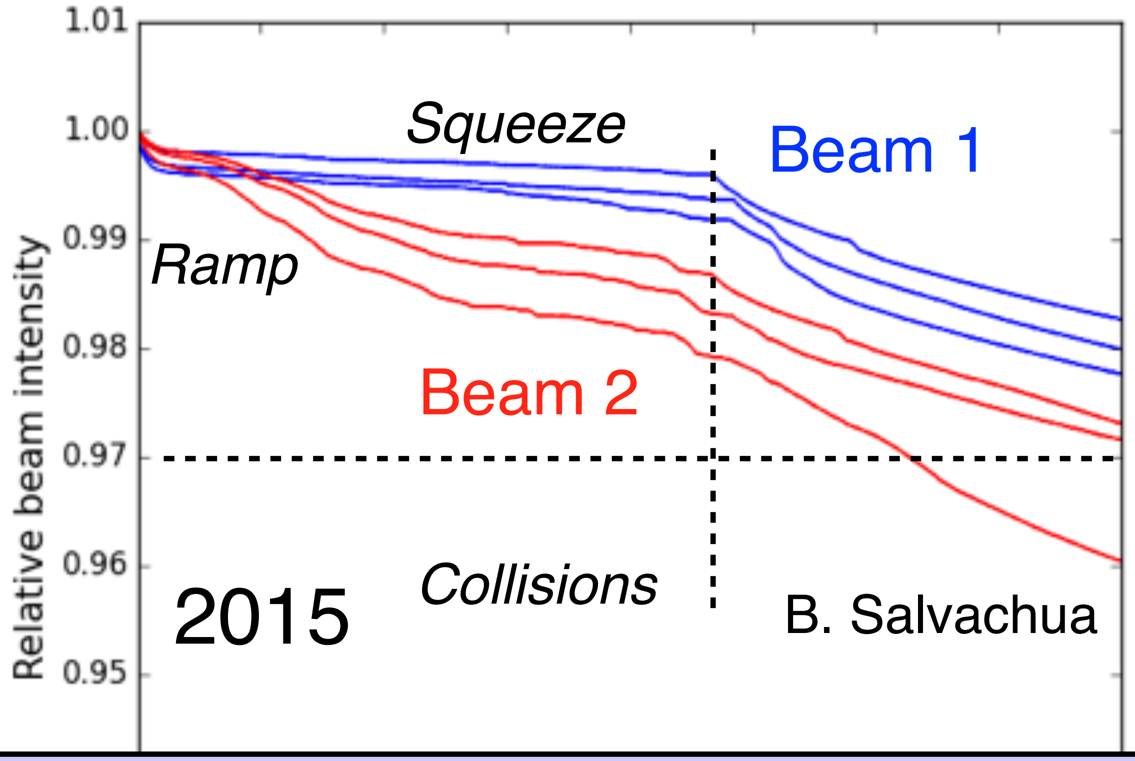
Proton stored energy up to 280 MJ.

No quenches from circulating beam losses!

BUT: Machine parameters and configuration were not yet pushed.

Can we make solid extrapolations?





Cannot consider 2015 as fully representative.
Important to continue monitoring in 2016.

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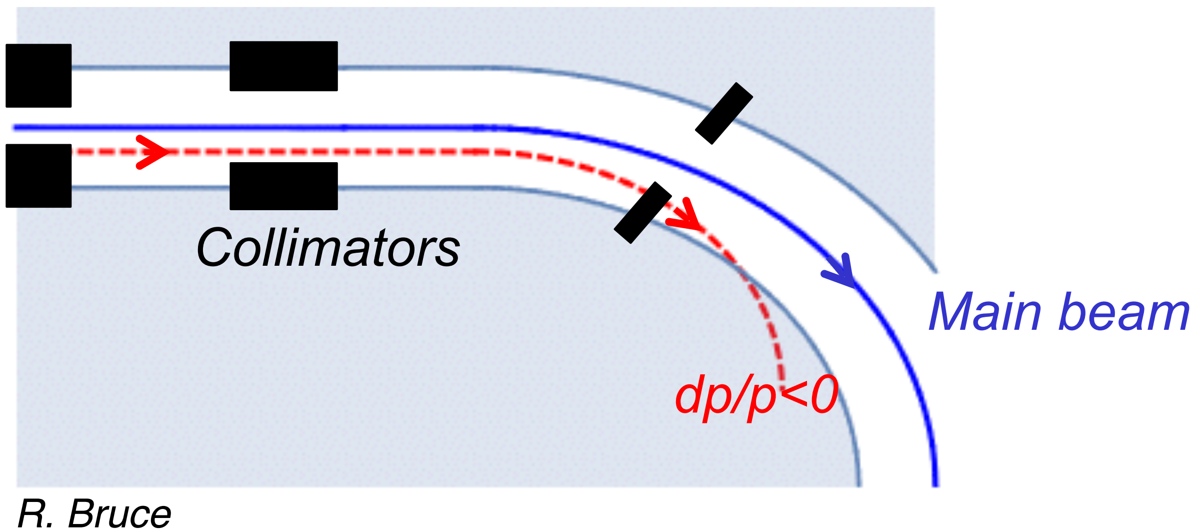
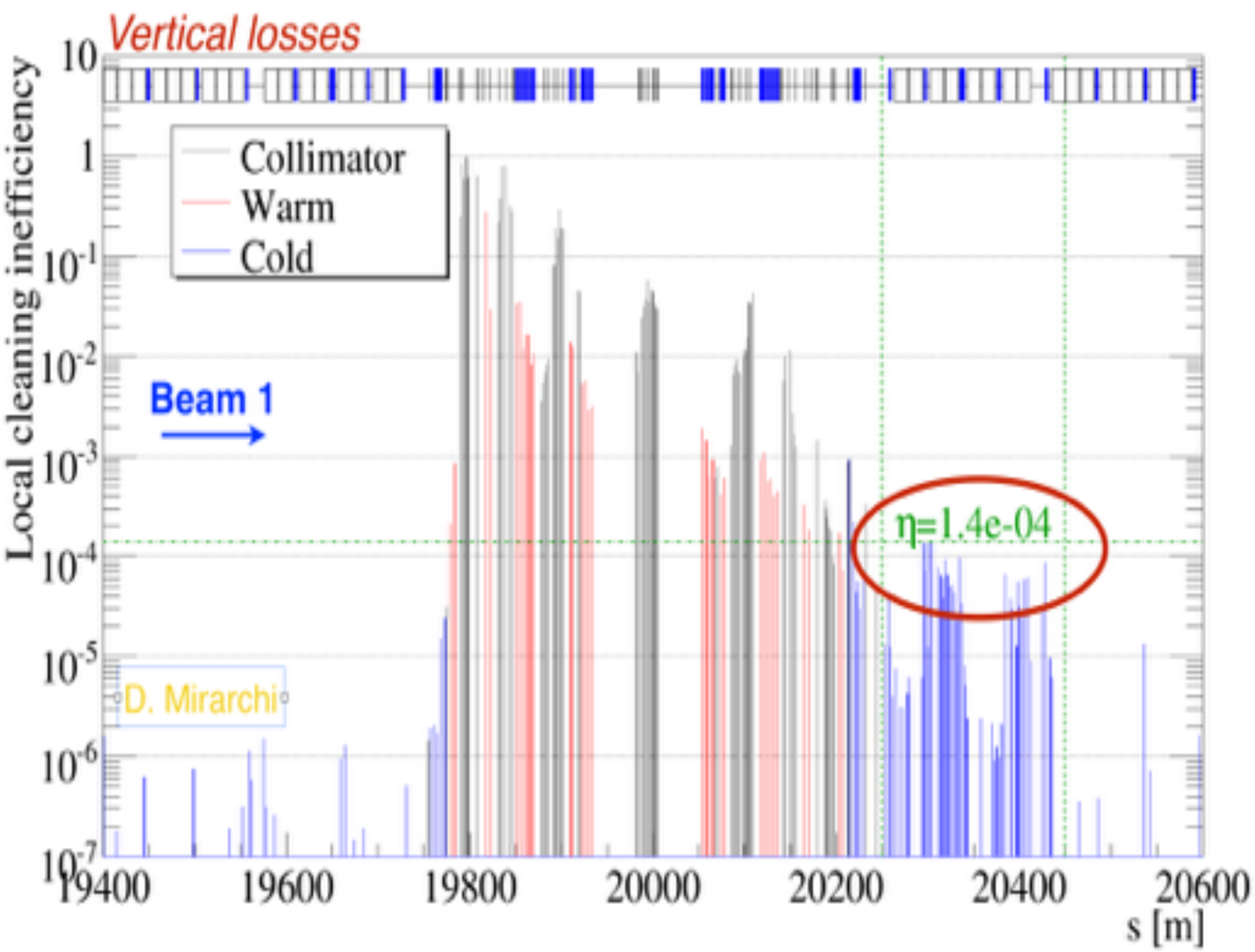
Dispersion suppressor losses





Out-scattered off-energy particles have different bending radius than main beam

Qualitatively similar behaviour in collimation insertion and experiments:

Start deviating significantly only in first bends, downstream of collimators.

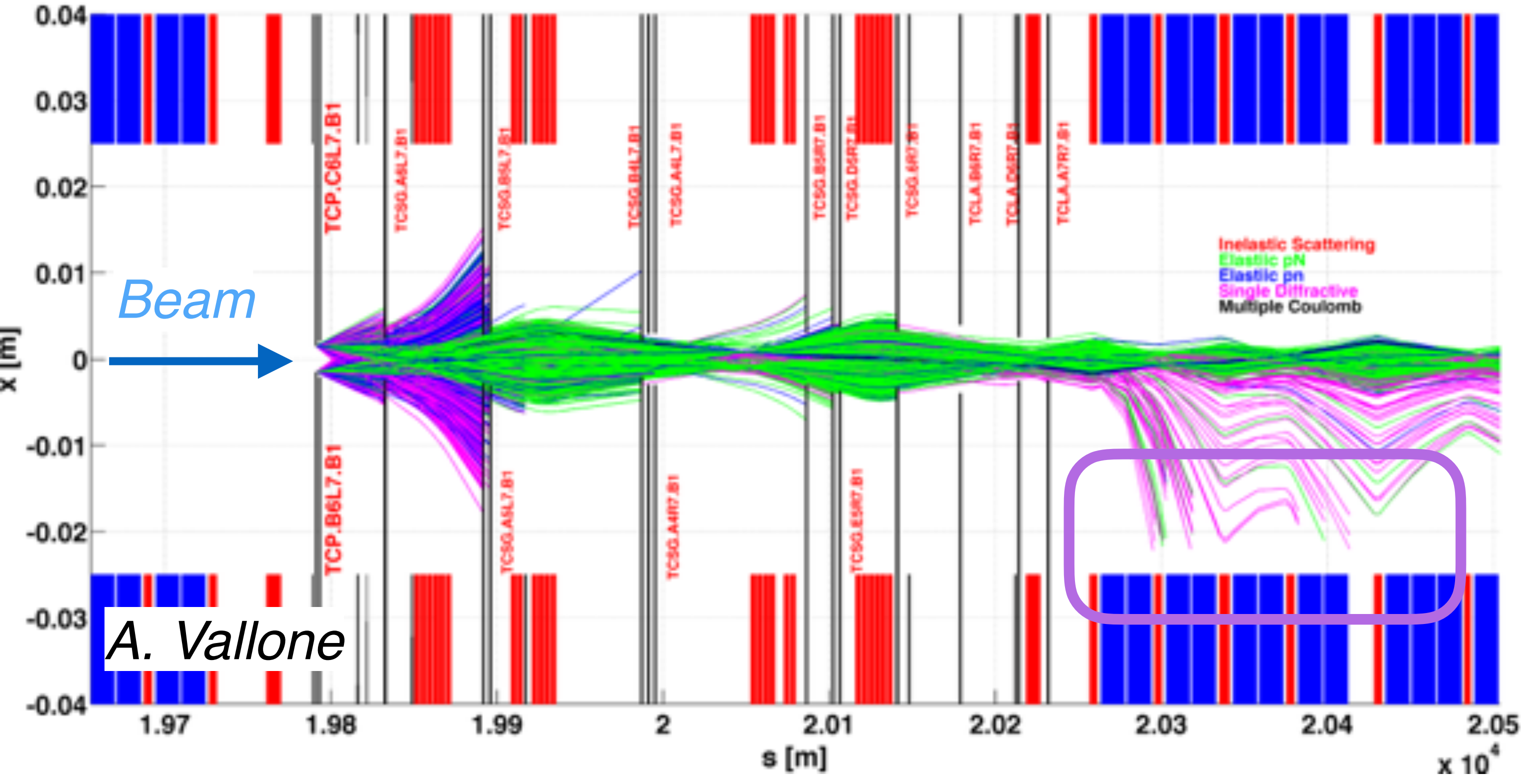
Present multi-stage system is <u>not</u> optimised to catch these dispersive losses.

<u>Idea</u>: Install new collimators (TCLD) in front of exposed magnets, where there is already separation from main beam.

Need two jaws: ion beams; better shower absorption; more precise alignment.

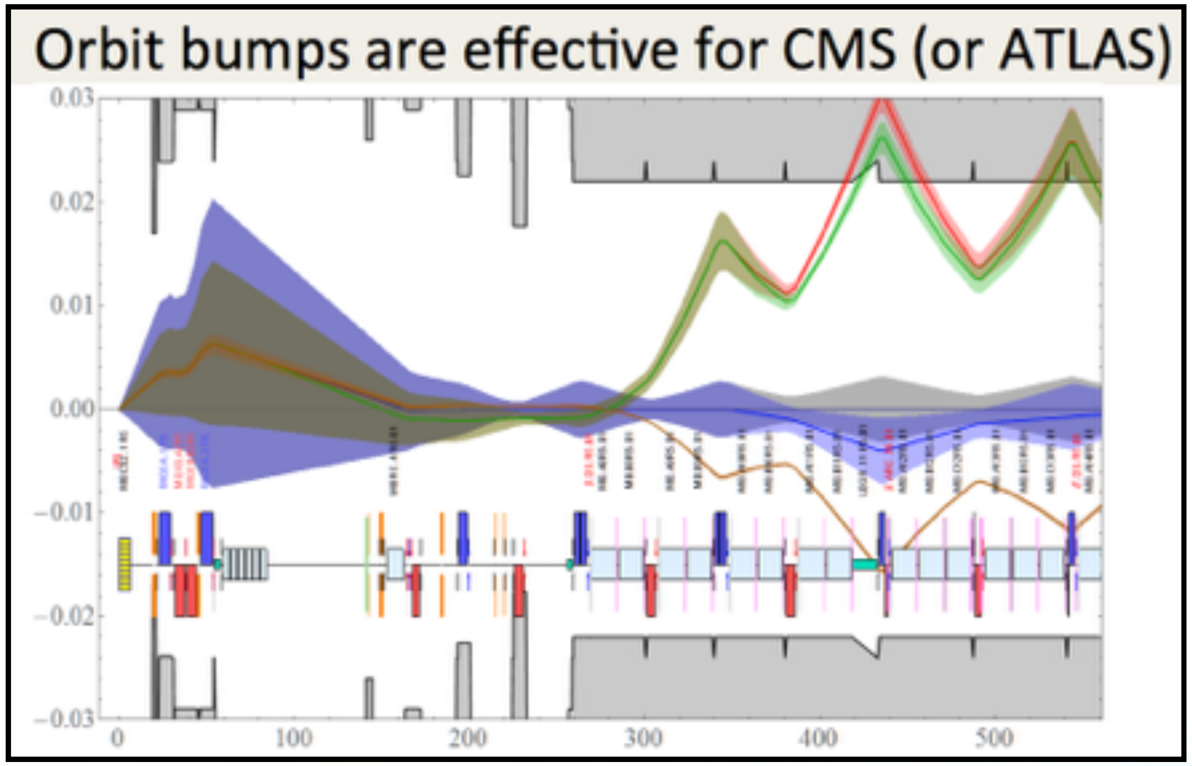
Quench tests relevant for collimation

"Collimation quench test"



Controlled beam losses: Beam particles are intercepted by the primary collimators and disposed of through the standard cleaning mechanism. As close as possible to ***operational losses***. Increase loss rates until quench dispersion suppressor magnets.

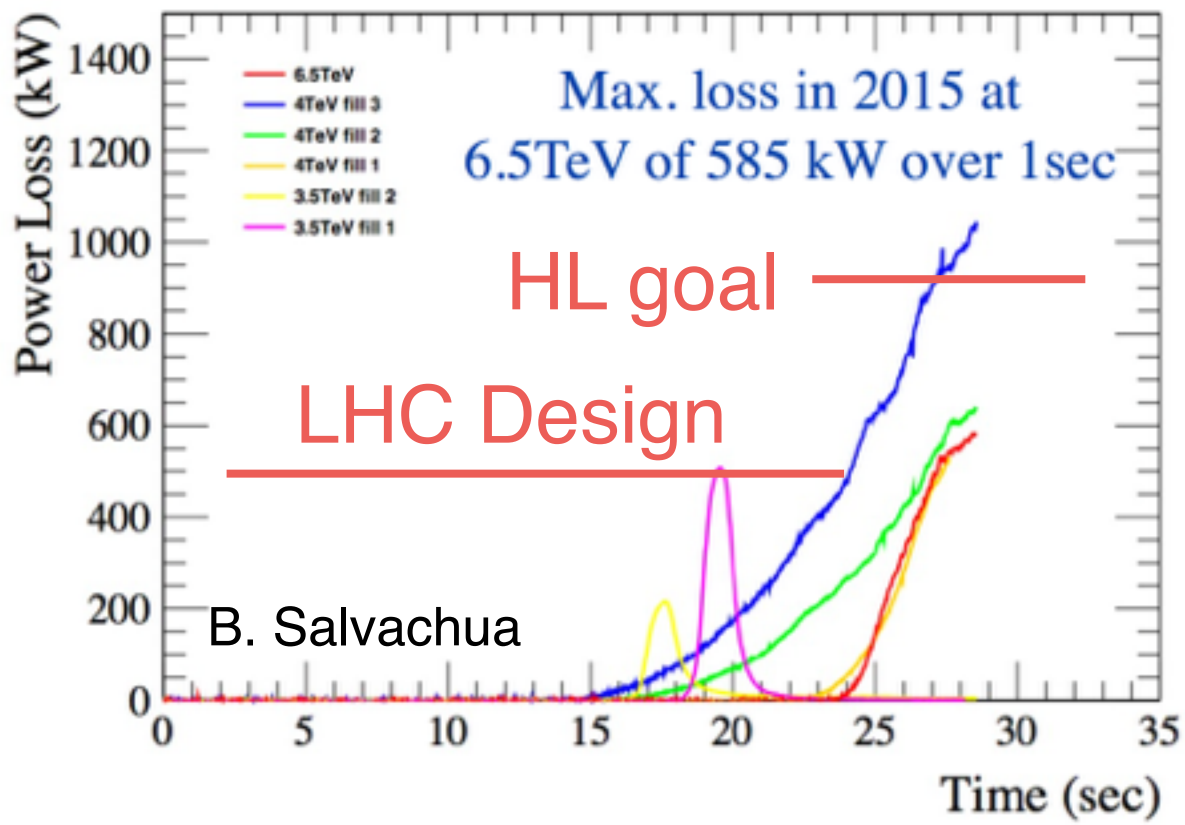
"BFPP quench test" (BFPP = Bound-Free Pair Production)



Steer secondary beams generated by the Pb-Pb collision in magnets. Increase luminosity ("levelling by offset"). Details in J. Jowett talk.

2015 quench tests and intensity reach

Primary beam losses on collimators



Summary of 6.5TeV test in 2015:

Protons:

- Max achieved was **585kW** primary beam losses.
- No quench (set lower limit)

Ions:

- Achieved **15 kW** losses.
- quench of MBB-9L7!

Intensity reach obtained scaling losses to a 0.2h lifetime at full intensity.

Predicted intensity reach for Run II (preliminary)

	Imax	*$E_b$max*	*Design*	*HL-LHC*
Protons (6.5 TeV) [lower limit, as no quench]	*> 4e14p*	***> 420 MJ***	335 MJ	630 MJ
PB ions (6.37 Z TeV)	<11.4e10Pb	**<10.8 M**		

Potentially, one crucial limitation to go to 7TeV before LS2.

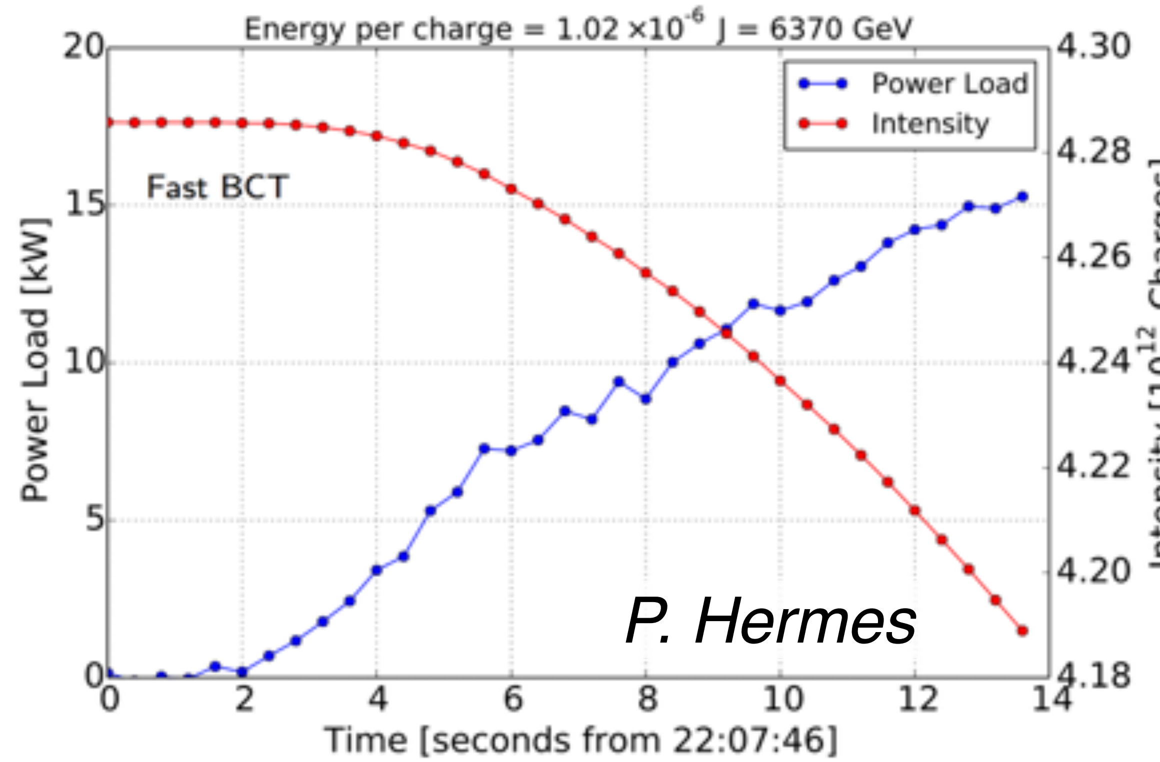
Extrapolations to 7 TeV need more inputs from quench limit team.

Uncertainties in predictions

Given estimates rely on accurate measurements of loss rates from the BCT (beam current transformers)

We did not achieve a steady loss condition.

… as close as we can get to operational loss scenarios…



Scaling to 7 TeV: quench limit versus current?

Detailed simulations are ongoing but not yet ready

Goal: estimate peak loss rates in coils. Input

- *More tricky for ions (PhD work, P. Hermes*

Given figures assume a minimum lifetin … h.

Fresh results from last week. We need a dedicated followup between the teams involved!

Collimation and ion quench teams

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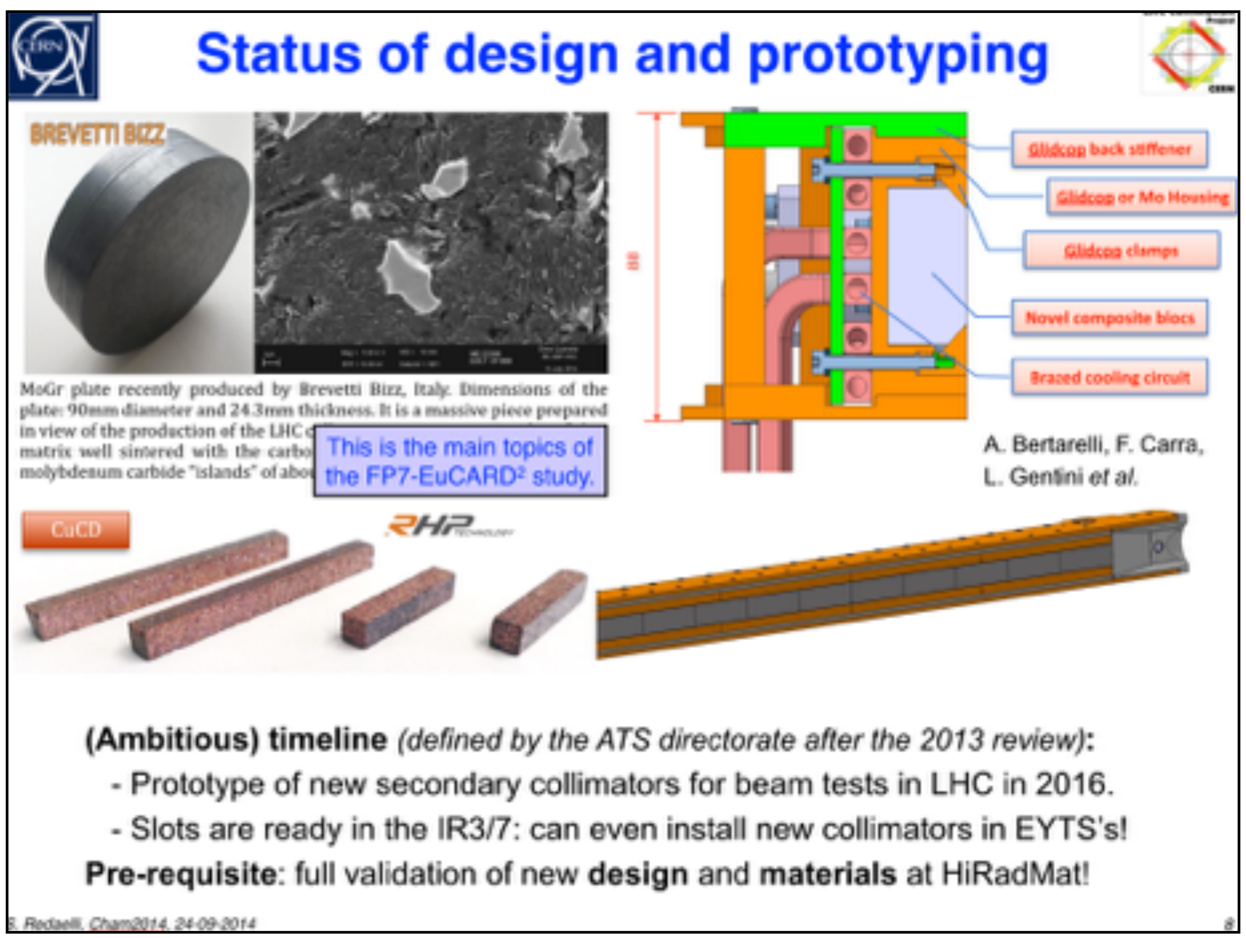
Material R&D and jaw prototyping

Cannot find one single solution that addresses conflicting requirement.
Baseline material choices:

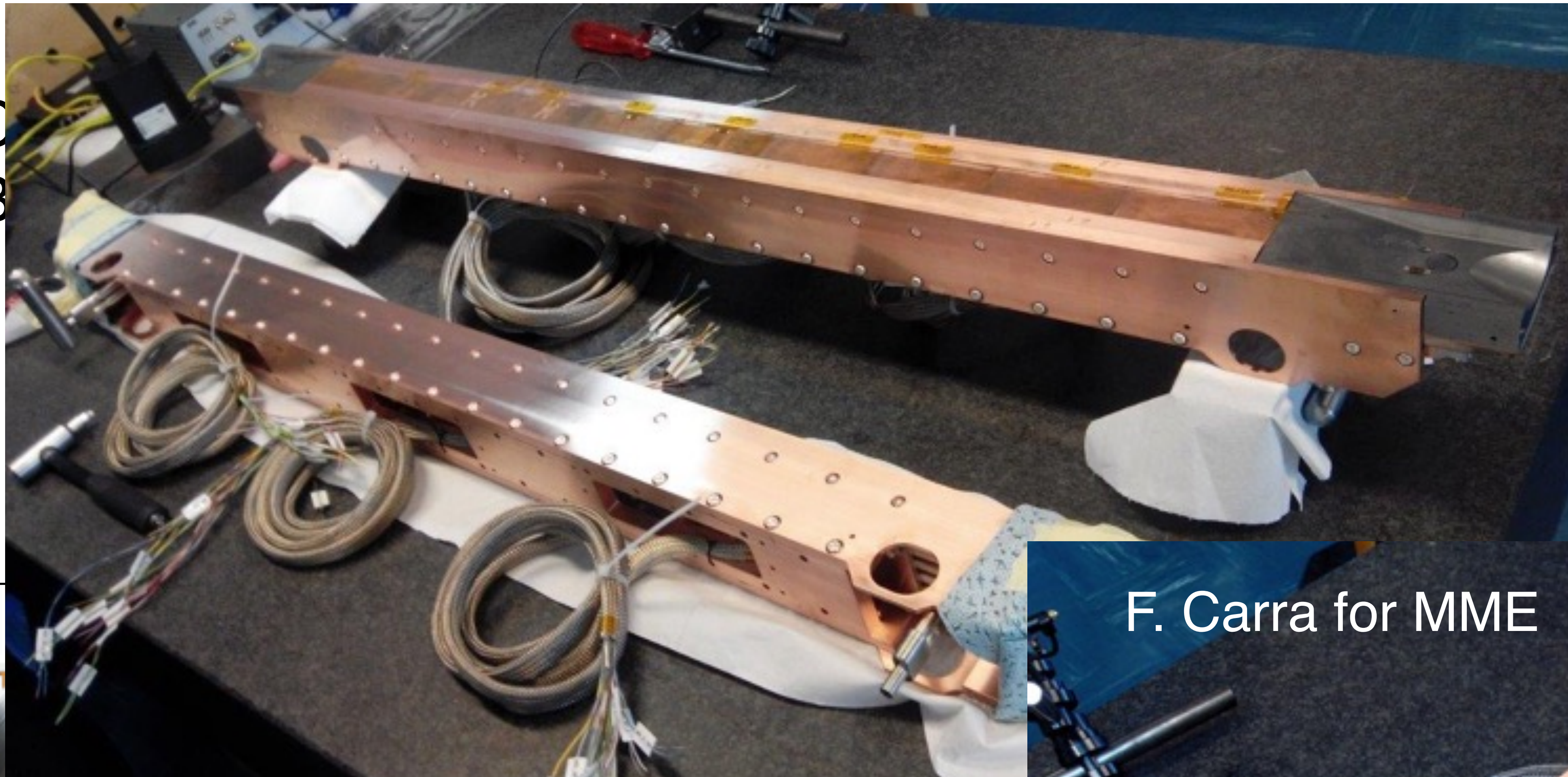
- CuCD (Copper diamond): more robust tertiaries for triplet protection
- MoGR (Molybdenum GRaphite), with Mo coated, for high robustness and reduced impedance in IR7 (secondary collimators).

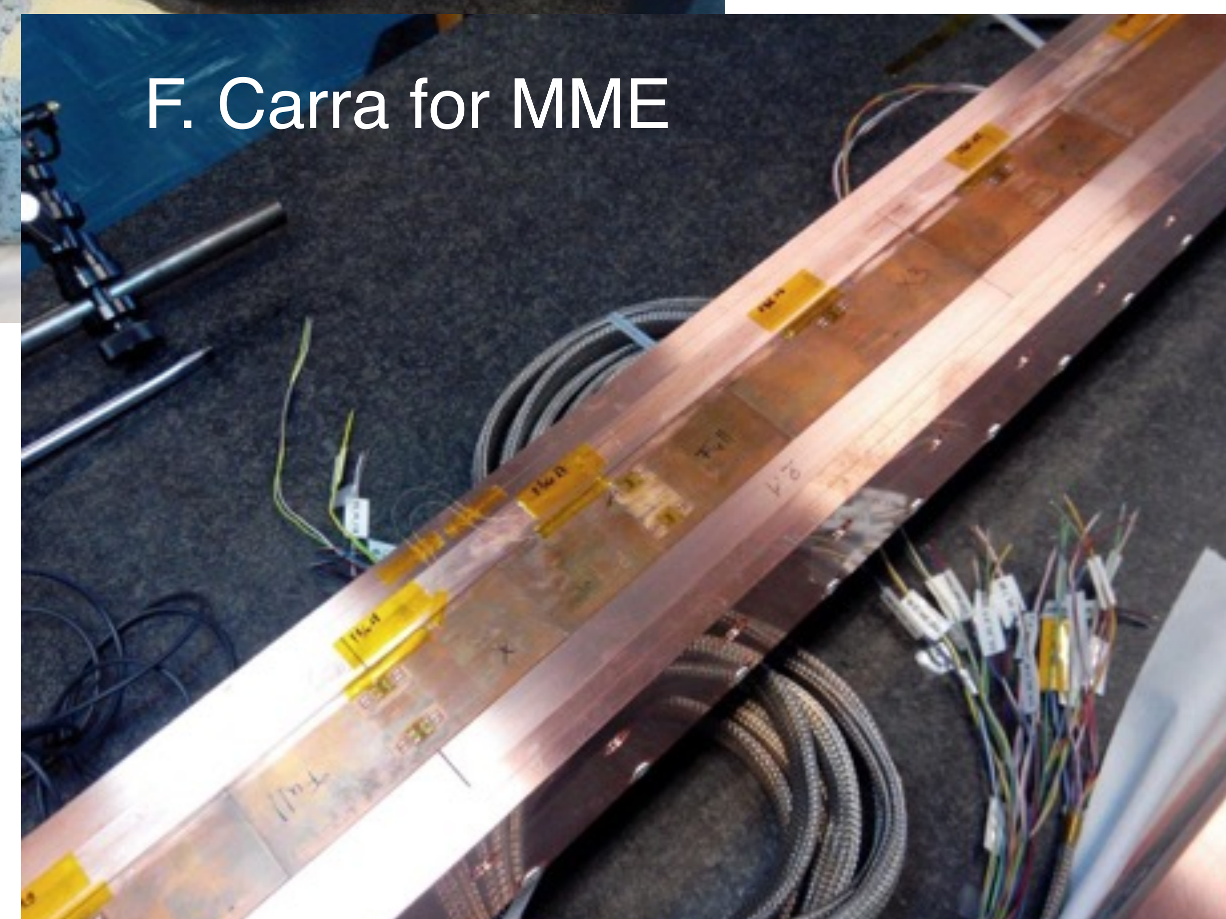


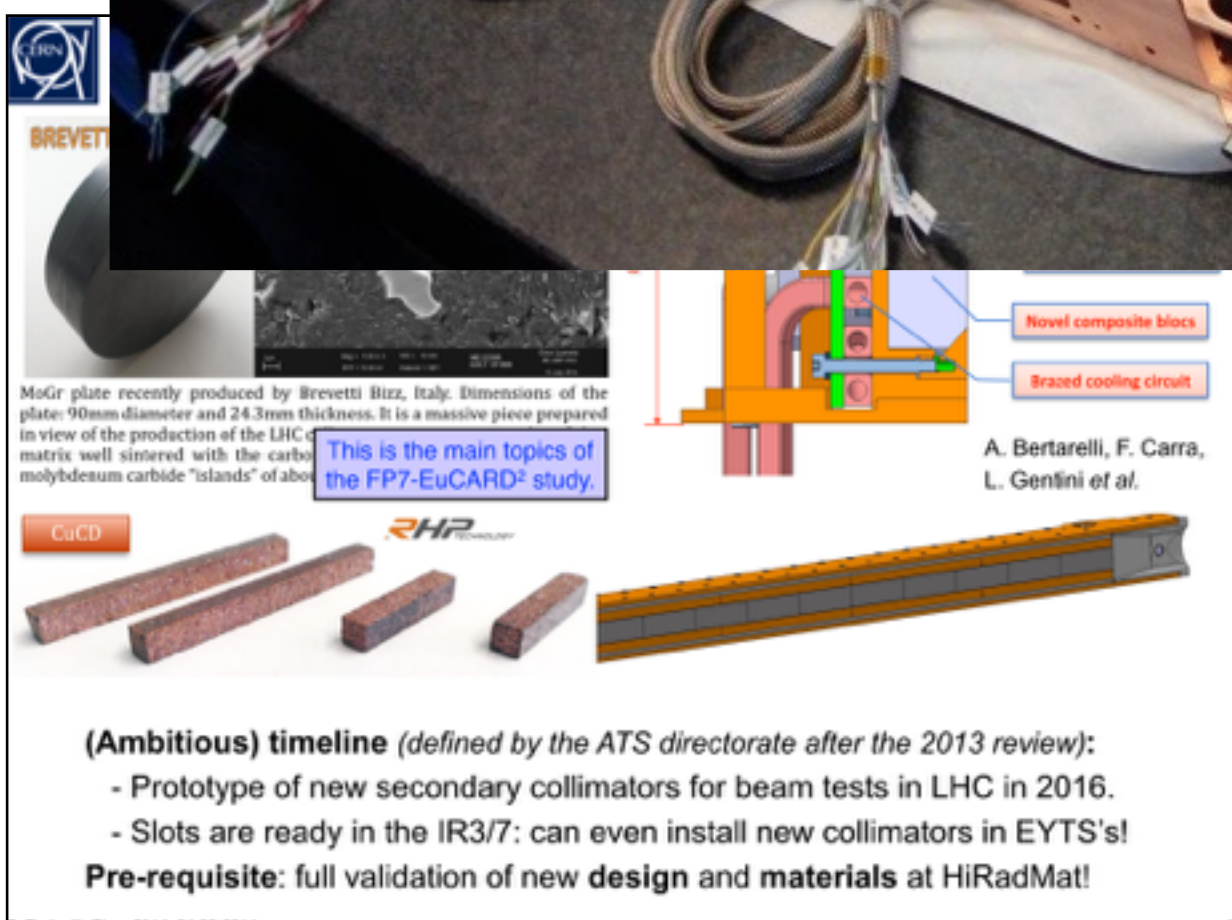
Material R&D and jaw prototyping

C requirement.
B

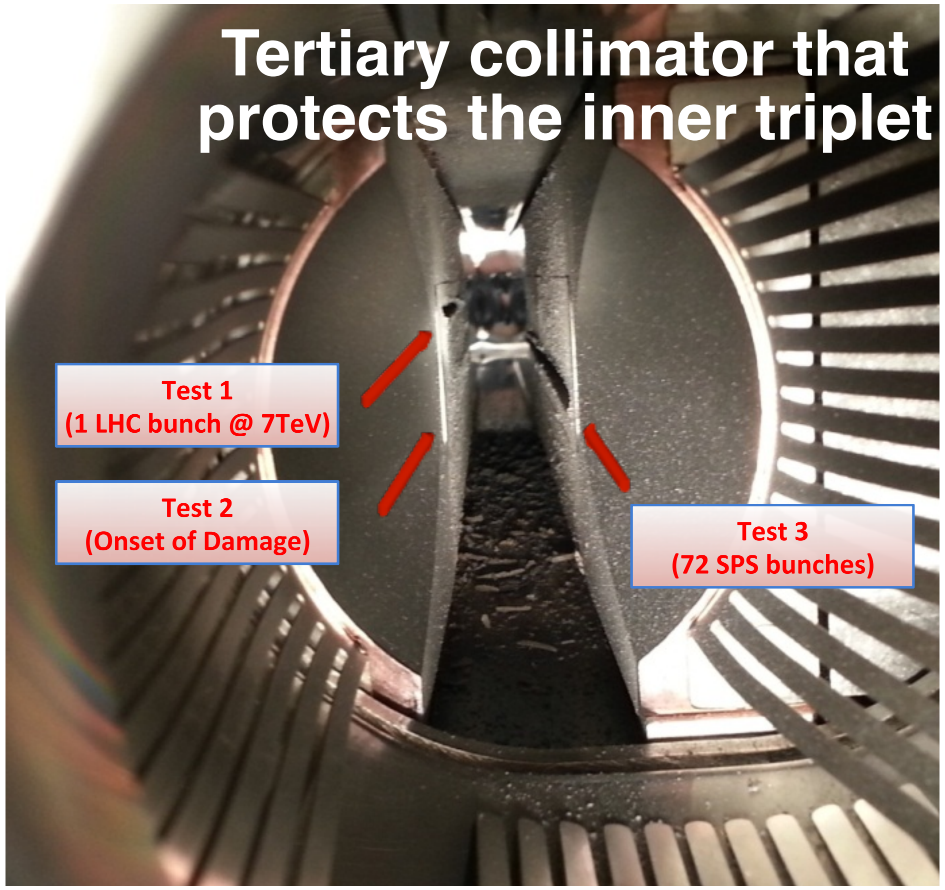
iplet protection
high robustness
ors).





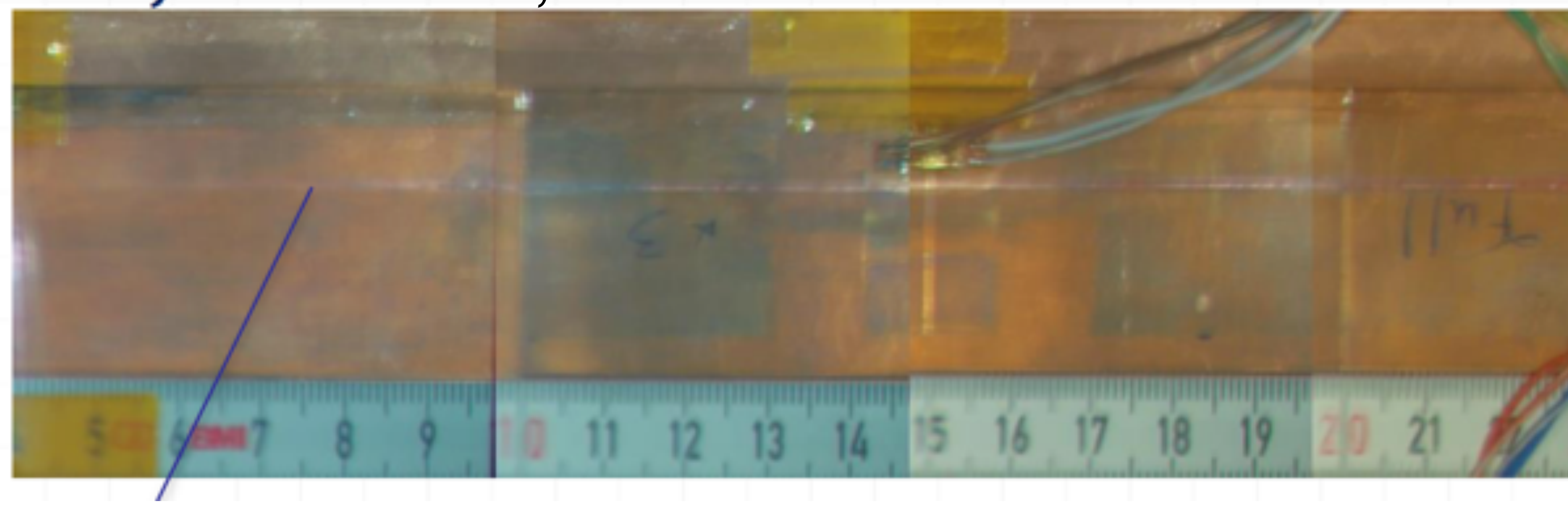


Results at HiRadMat



A. Bertarelli, F. Carra

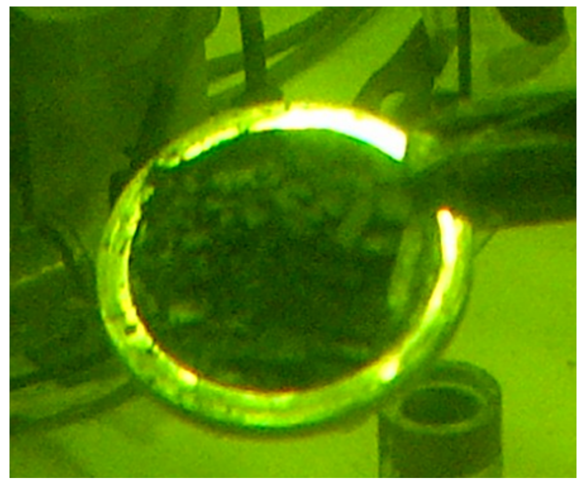
Copper Diamond: candidate tertiary collimator material, 10-15 times more robust.



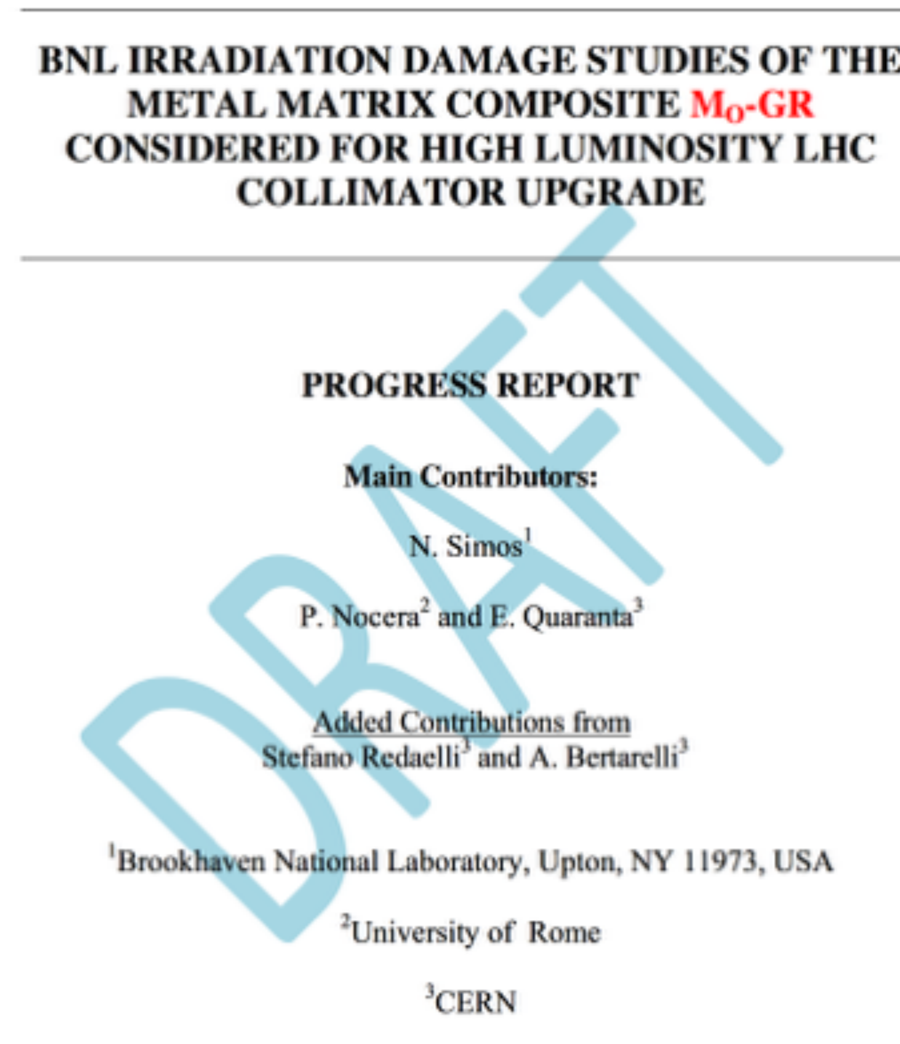
Excellent results: full MoGR jaw survived as well as CFC to impact of 288b of 1.3x1011p with σ=350µm (density beyond LIU)

Radiation tests of new materials - MoGR

Two main regimes for tests with beam: fast failures (thermo-mechanical robustness) and high radiation doses (long times).



State of Mo-GR after 1.1 10^{21} p/cm^2 FLUENCE !!!!



BNL IRRADIATION DAMAGE STUDIES OF THE METAL MATRIX COMPOSITE Mo-GR CONSIDERED FOR HIGH LUMINOSITY LHC COLLIMATOR UPGRADE

PROGRESS REPORT

Main Contributors:

N. Simos[1]

P. Nocera[2] and E. Quaranta[3]

Added Contributions from

Stefano Redaelli[3] and A. Bertarelli[3]

[1]Brookhaven National Laboratory, Upton, NY 11973, USA

[2]University of Rome

[3]CERN

DRAFT

Very high doses at BNL: some MoGR samples broke!

*Launching another set of measurements with **latest MoGR grades**. Very important for us.*

Collaboration contract for new irradiation campaign ~ready for signature. Will address onset of damage.

Is this really a showstopper?

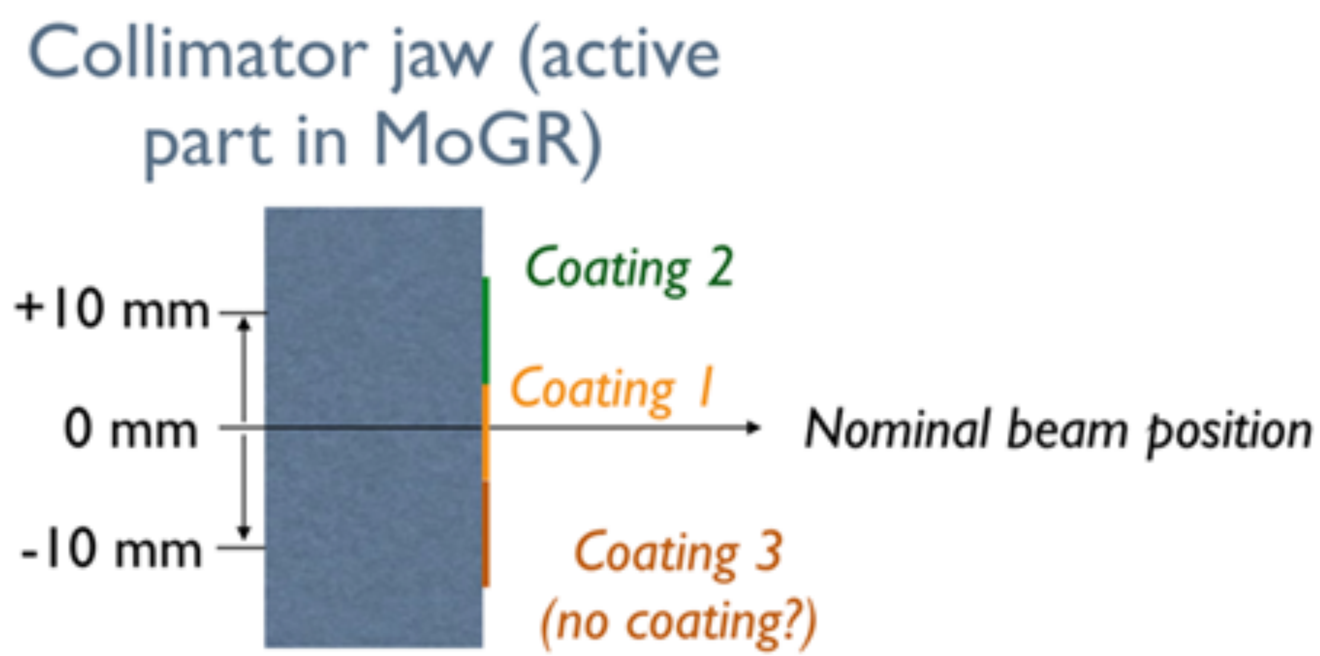
Coating for reduced impedance

Different possible implementations for coating are being explored.

Ideally, combine good robustness with high electrical conductivity.

Best impedance performance from pure Mo or Cu.

Building a prototype ready for LHC installation in the 2016 EYTS!



A. Bertarelli for MME

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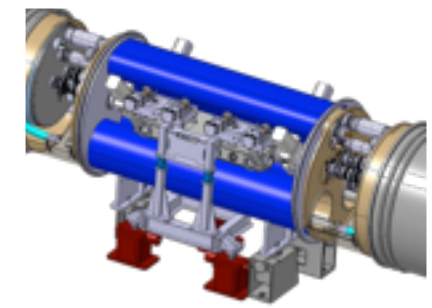
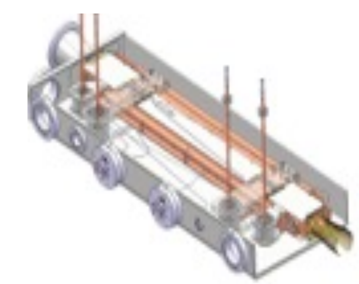
Baseline upgrades

Completely new layouts
Novel materials.
IR1+IR5, per beam:
- 4 tertiary collimators
- 3 physics debris collimators
- fixed masks

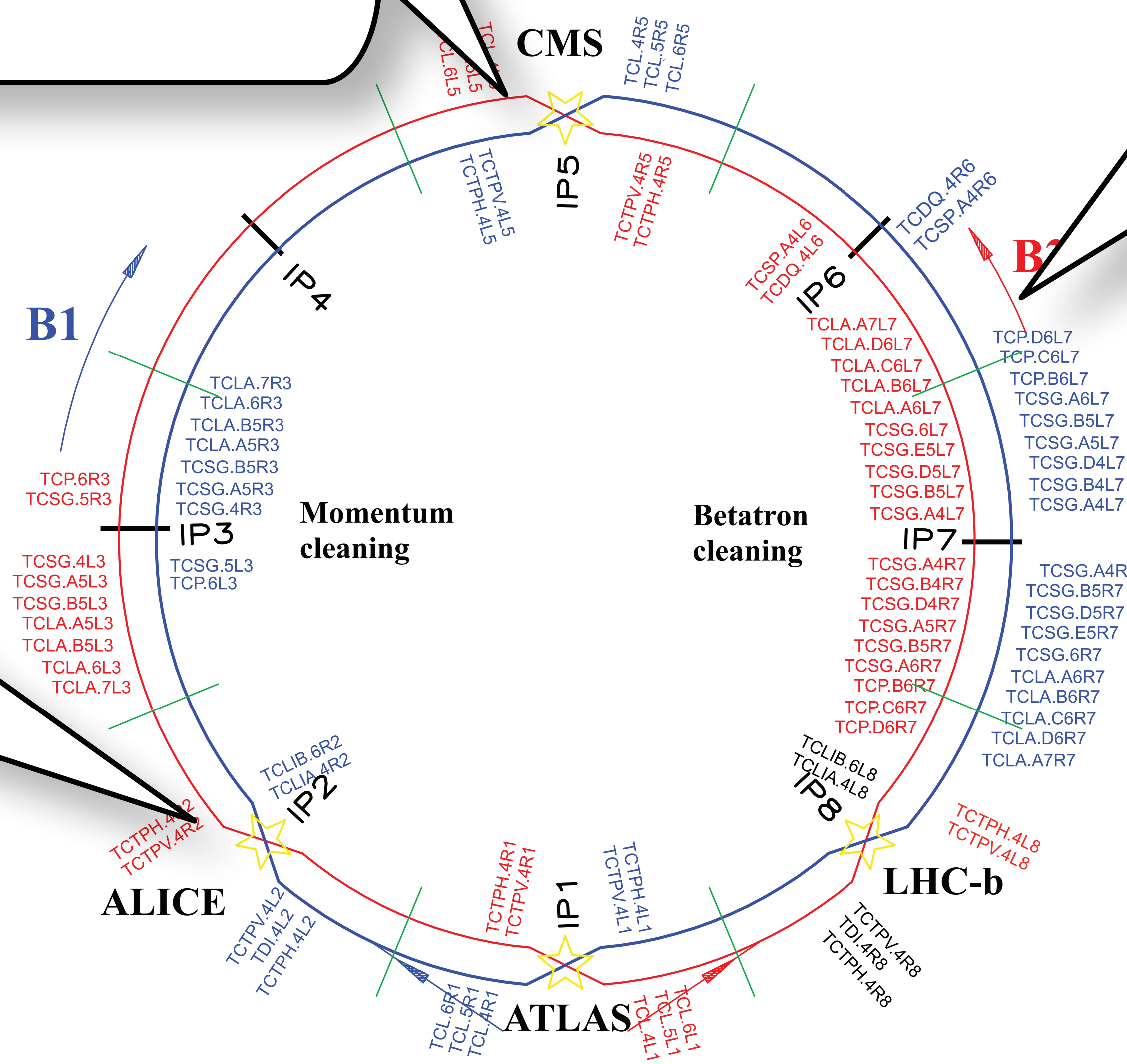
56 new collimators to be produced by LS3 in the present baseline!

Cleaning: DS coll. + 11T dipoles, 2 units per beam

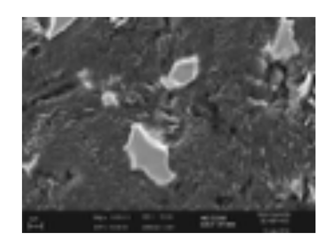


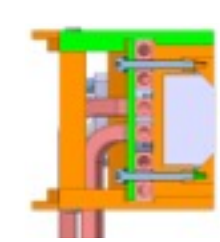


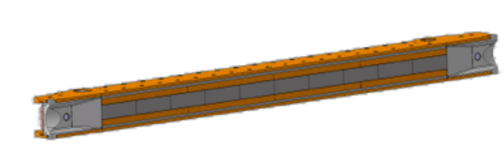
Ion physics debris:
DS collimation



Low-impedance, high robustness secondary collimators







HL baseline for DS collimation

Major collimation project review in 2013 addressed needs for cleaning upgrades beyond LS2.

- *Initially, it was though that we would be limited first in IR2, but reviewers expressed strong concerns about the scaling of IR7 performance estimates;*
- *Decided to continue with the development of 11T dipoles and collimators;*
- *Clear early on: no more than 2 units (each: 2 new dipoles) by LS2.*

Present proposal based on recent quench tests and operational experience with IR bumps:

(See also talk by J. Jowett).

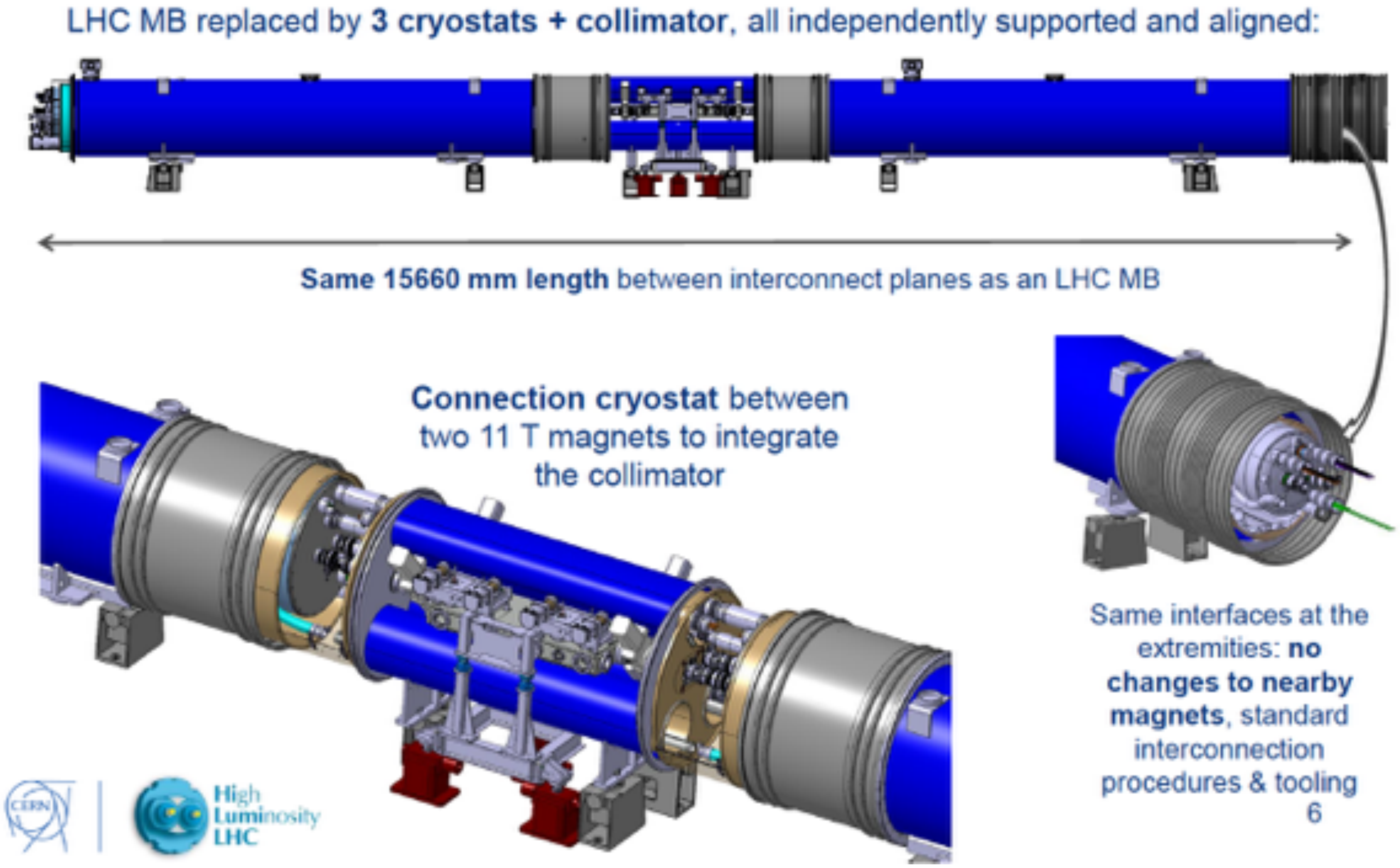
- ***2 dispersion suppressor collimators (TCLDs) around IP2, no 11T dipoles***
  Bumps to steer BFPP losses in collimators located in the connection cryostat.
- *4 TCLD + 11T dipole units needed around IR7 for HL-LHC.*
  Staged installation with 1 unit per beam in LS2 (2 collimators, 4 dipoles).
  Complete installation with 2 more full units in LS3, if needed.
- *No local dispersion suppressor collimation around IR1/5.*

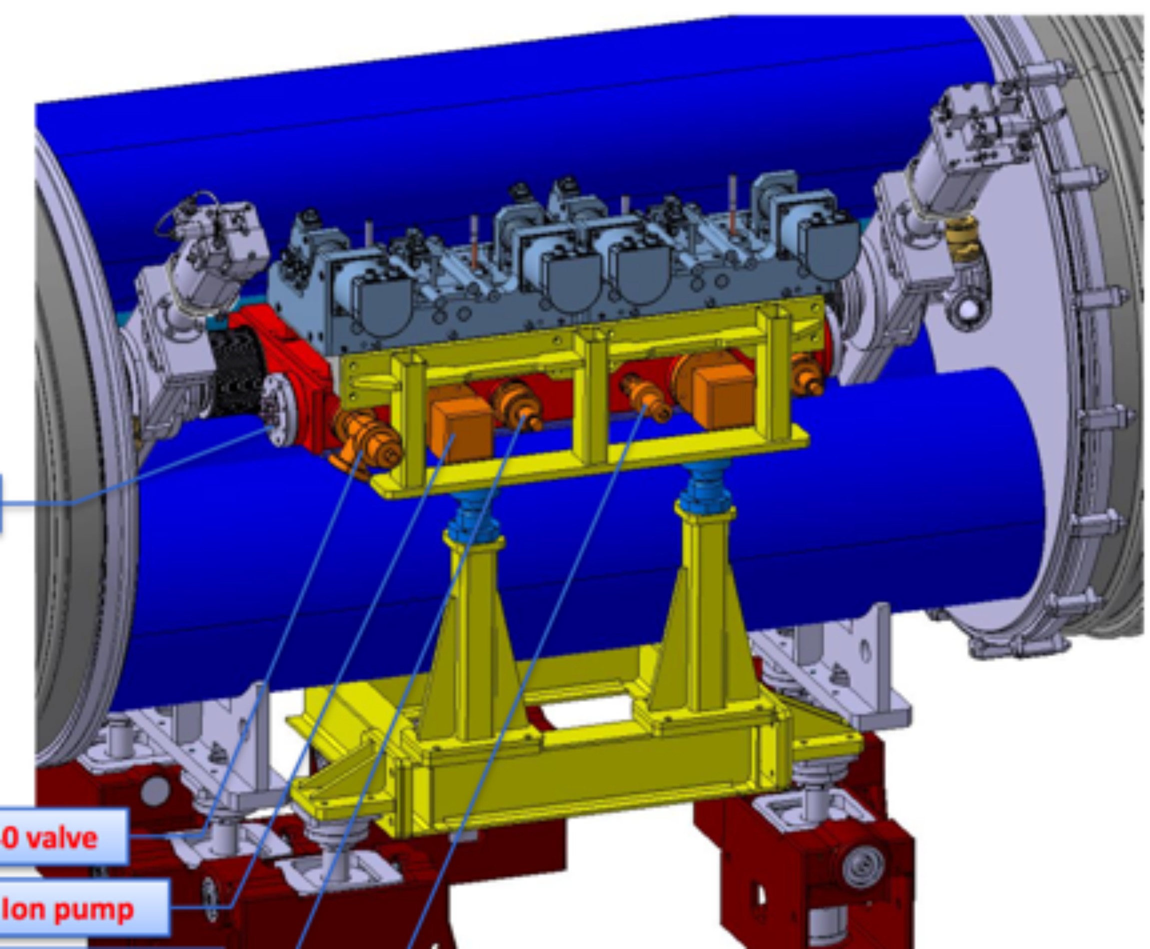
Technical solution based on 11T dipole

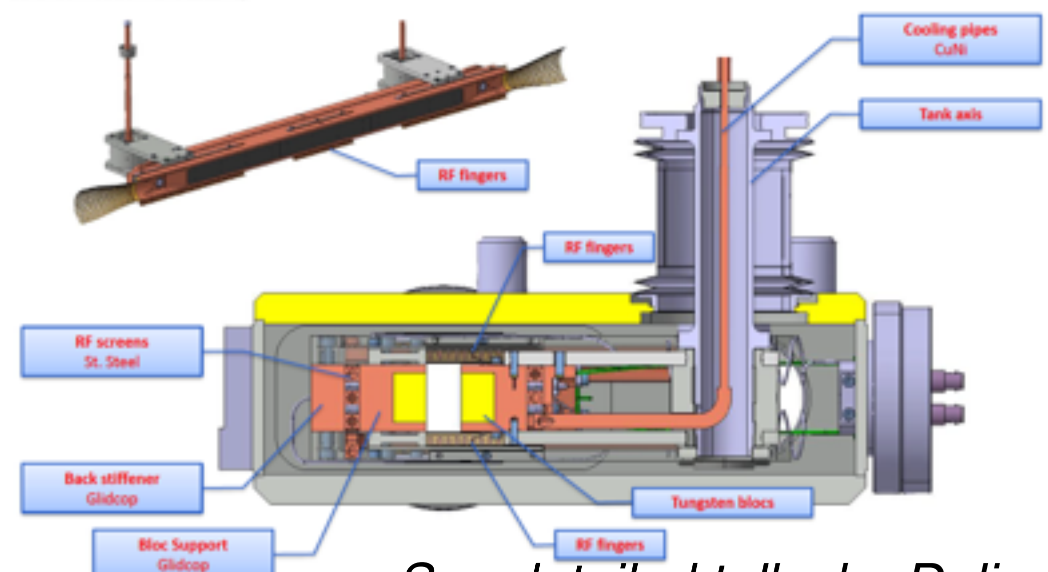
Completed a solid baseline design for a collimator active length of 60cm.

Launched the construction of a prototype in 2015.

Need to work on the integration into a connection cryostat, without 11 T dipoles around.







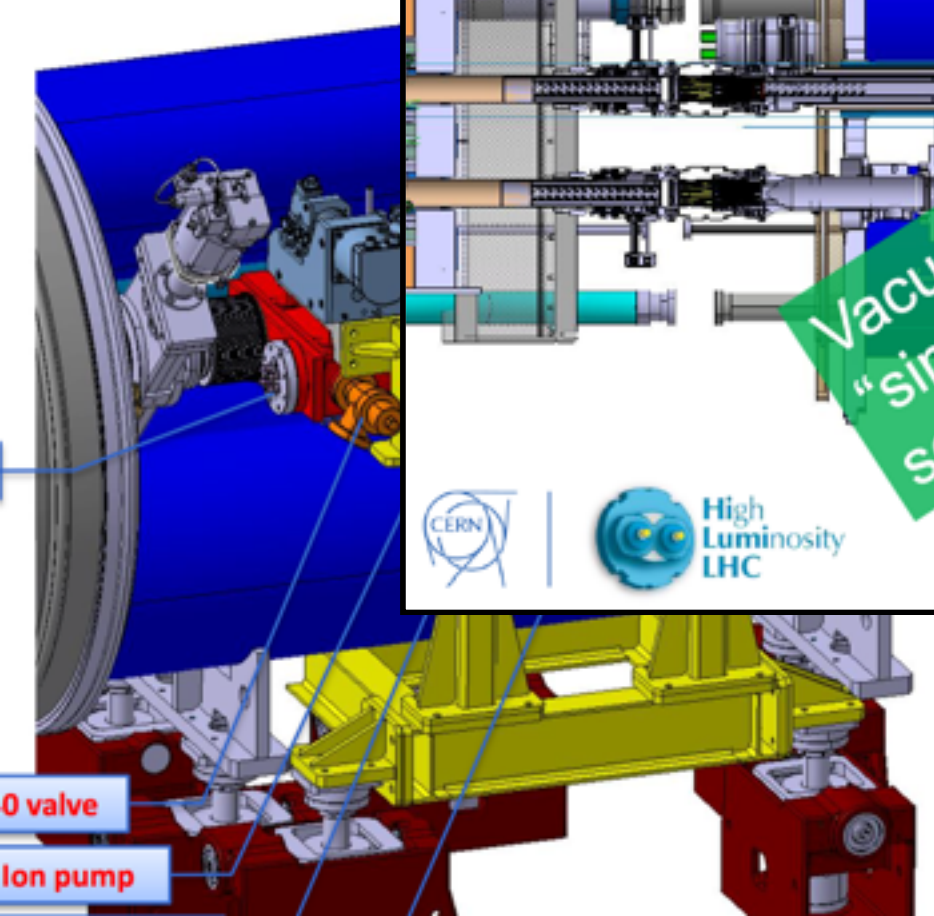
See detailed talks by Delio D. and Luca G. at last ColUSM, 18/09/2015

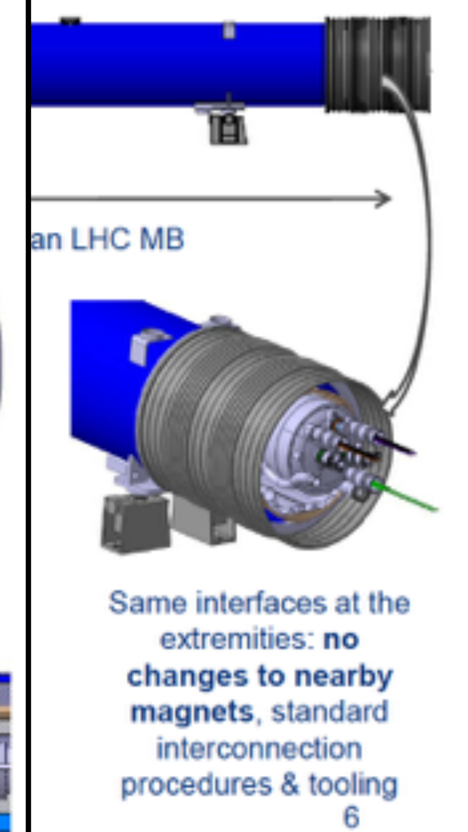
Technical solution based on 11T dipole

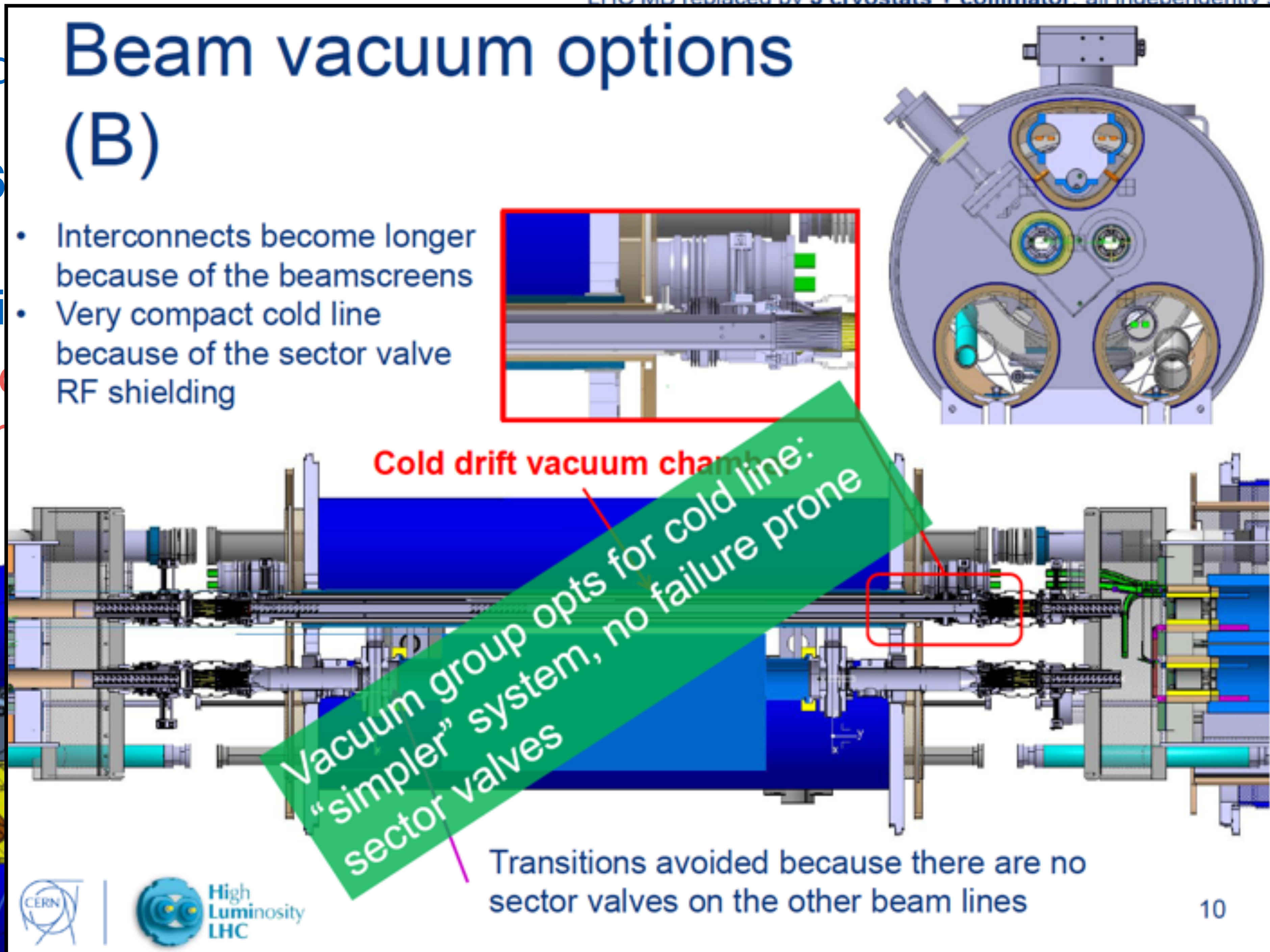
Completed design for length of 6

Launched prototype i

Need to w into a conn without 11

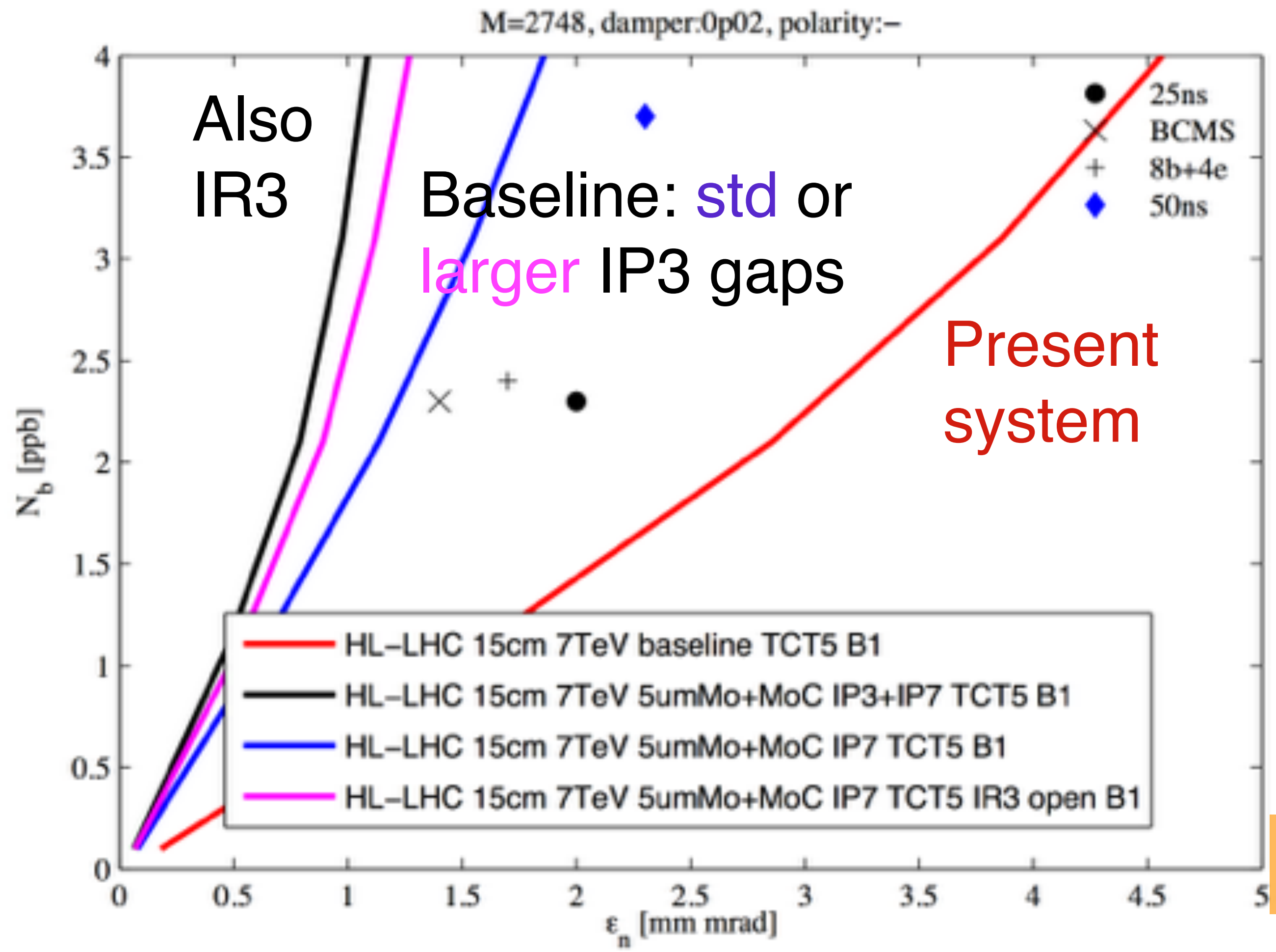






See detailed talks by Delio D. and Luca G. at last ColUSM, 18/09/2015

Collimation impedance reduction



No HL-LHC beam stable with the present carbon-based secondary collimators (TCS).
"Historical" limitation of the system addressed by changing materials of TCSs.

N. Biancacci, impedance team

BASELINE: New secondary collimators in the betatron cleaning (22 collimators). MoGR jaw coated with pure Mo. (Alternative coatings being studied.) Staged installation: 8-10 collimators in LS2.

OPTION: New TCS also for momentum cleaning (8) if need more margin.

Remark: present primary collimators changed with propose to change material to lower impedance.

Backup slides: new IR collimation for ATLAS and CMS.

Main production lines for HL

LS2 (ALICE upgrade, LIU beams available)

2 dispersion suppressor collimators (TCLD) + spare for IR2
New proposal: 2 additional TCLDs for IR7, with 11T dipoles
8-10 units of low-impedance secondary collimators (TCSPW) for IR7

LS3 (Final HL)

Complete low-impedance solution in IR7 (12-14 TCSPW units)
New tertiary collimators in IR1/5: (16 TCTPW units)
New physics debris absorbers and masks (12 TCL units + 12 masks)
Up to 4 TCLD units in IR7.

Until LS2 (prototyping and beam tests)

Prototype low-impedance collimator for LHC beam tests in 2017.
Four collimators with wires for beam-beam long range compensation.
Interventions on crystal collimation test stand - new goniometers.
Heavy involvements with beam tests outside LHC (SPS, HiRadMat, etc.)

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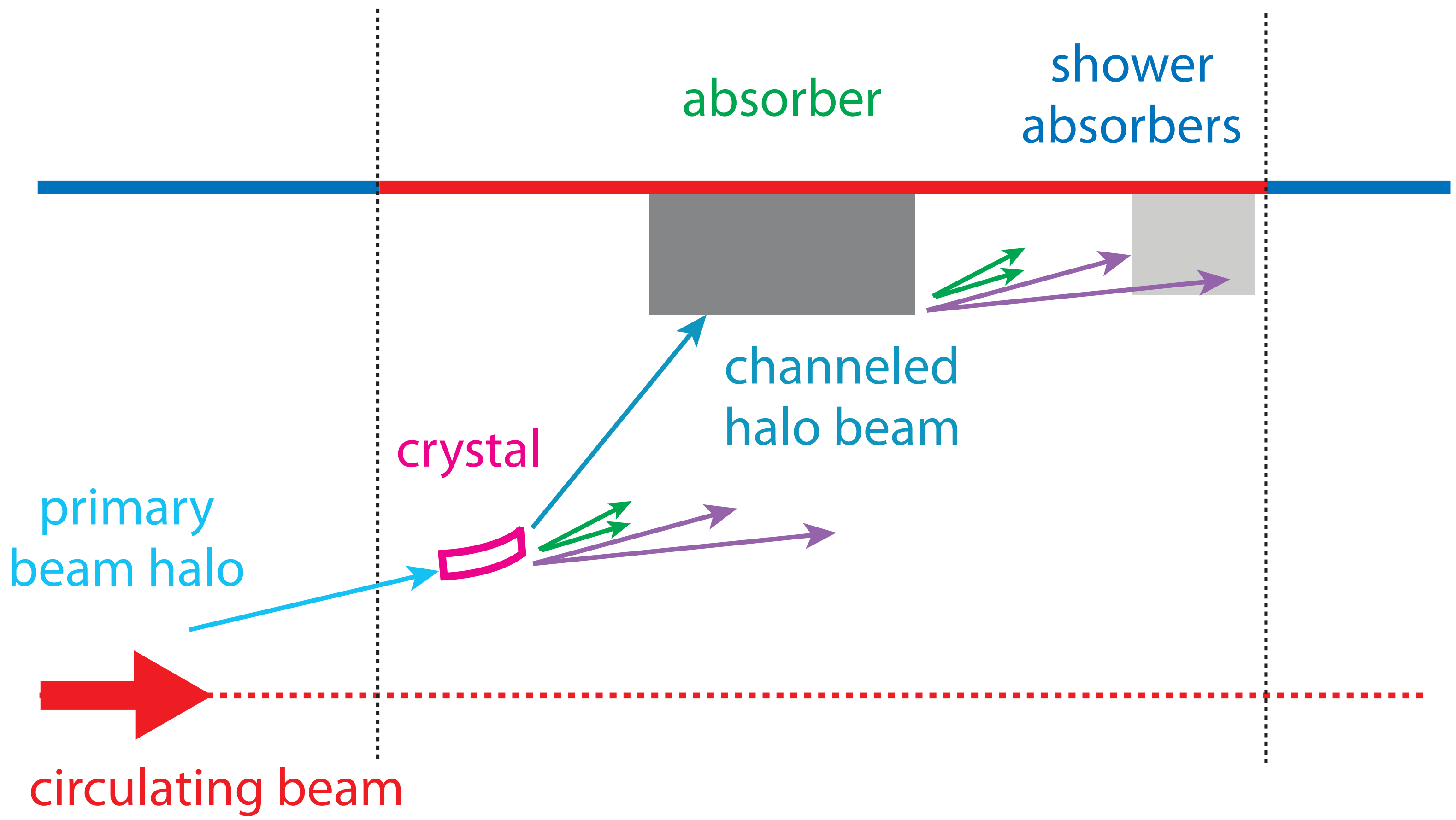
Crystal collimation concept

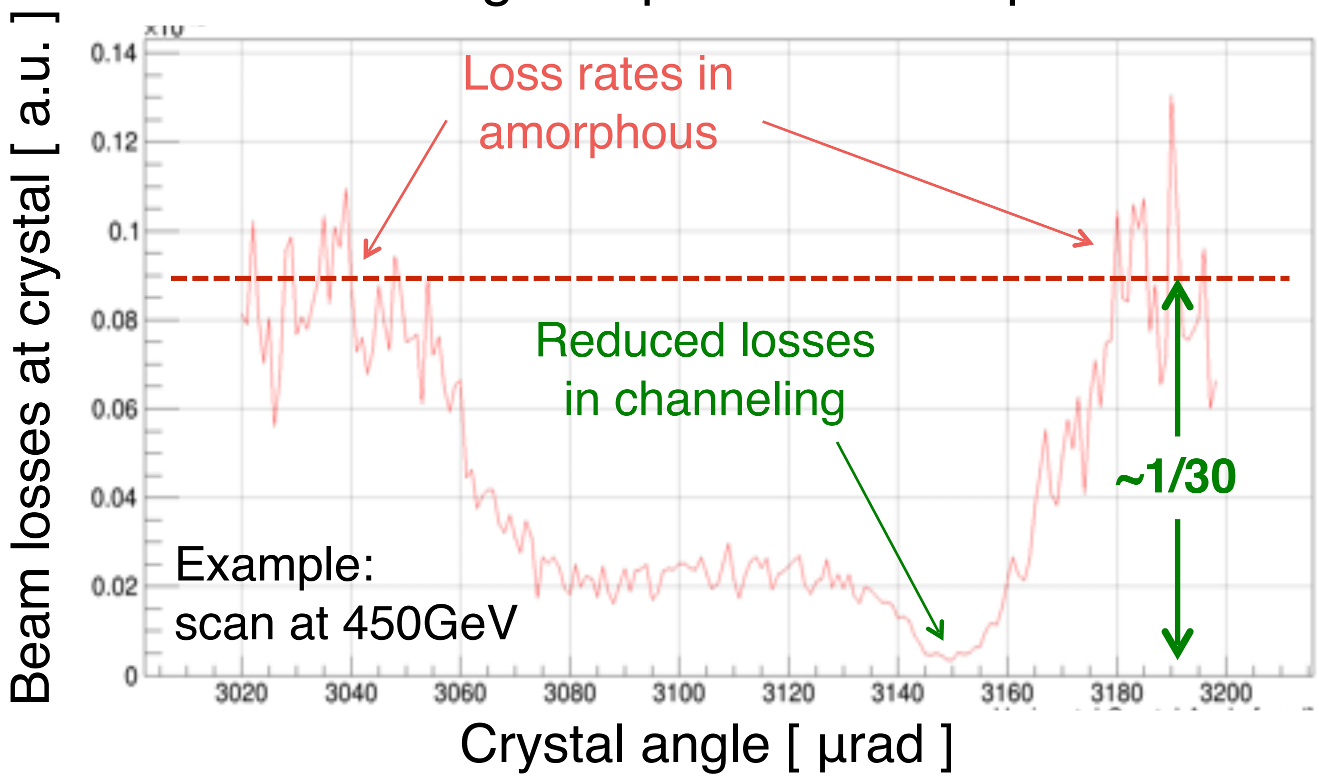


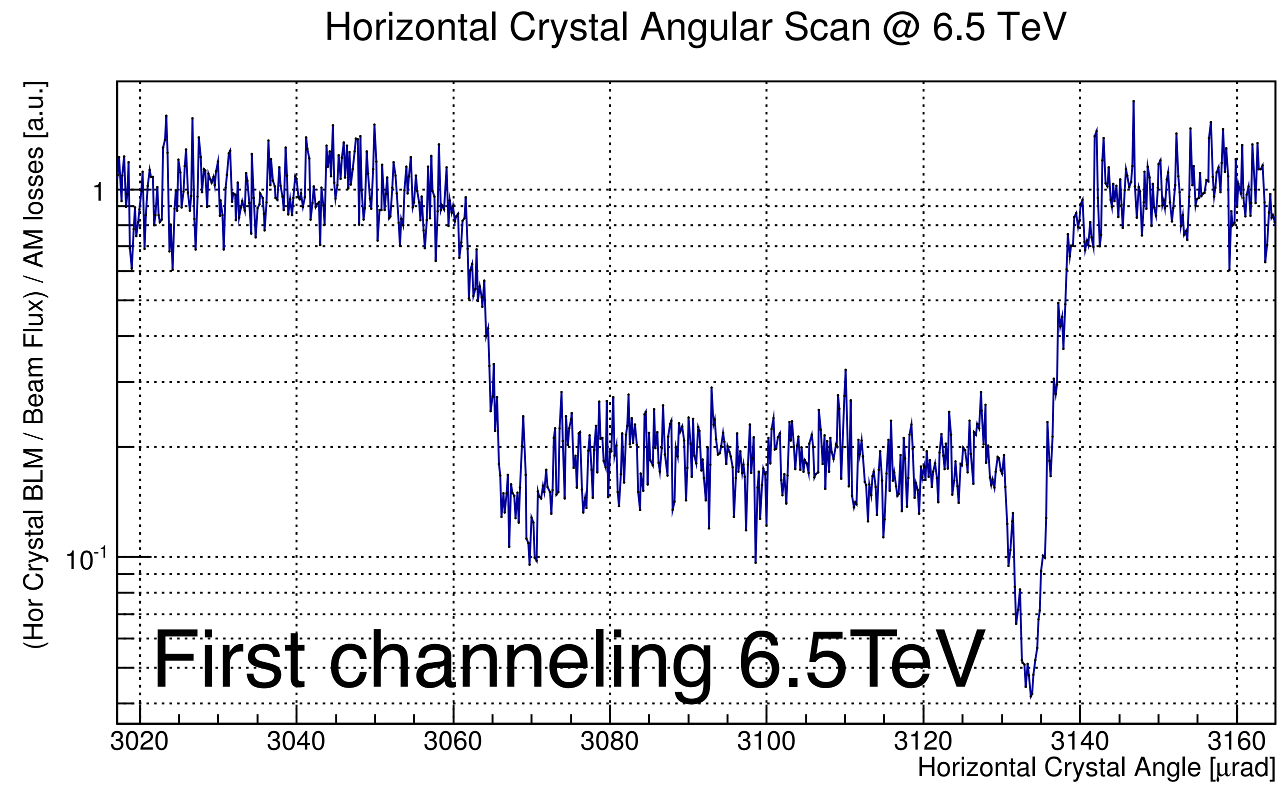
MDs in 2015 carried out with low intensities demonstrated: proton channeling at 6.5TeV; Pb channeling at 450GeV.

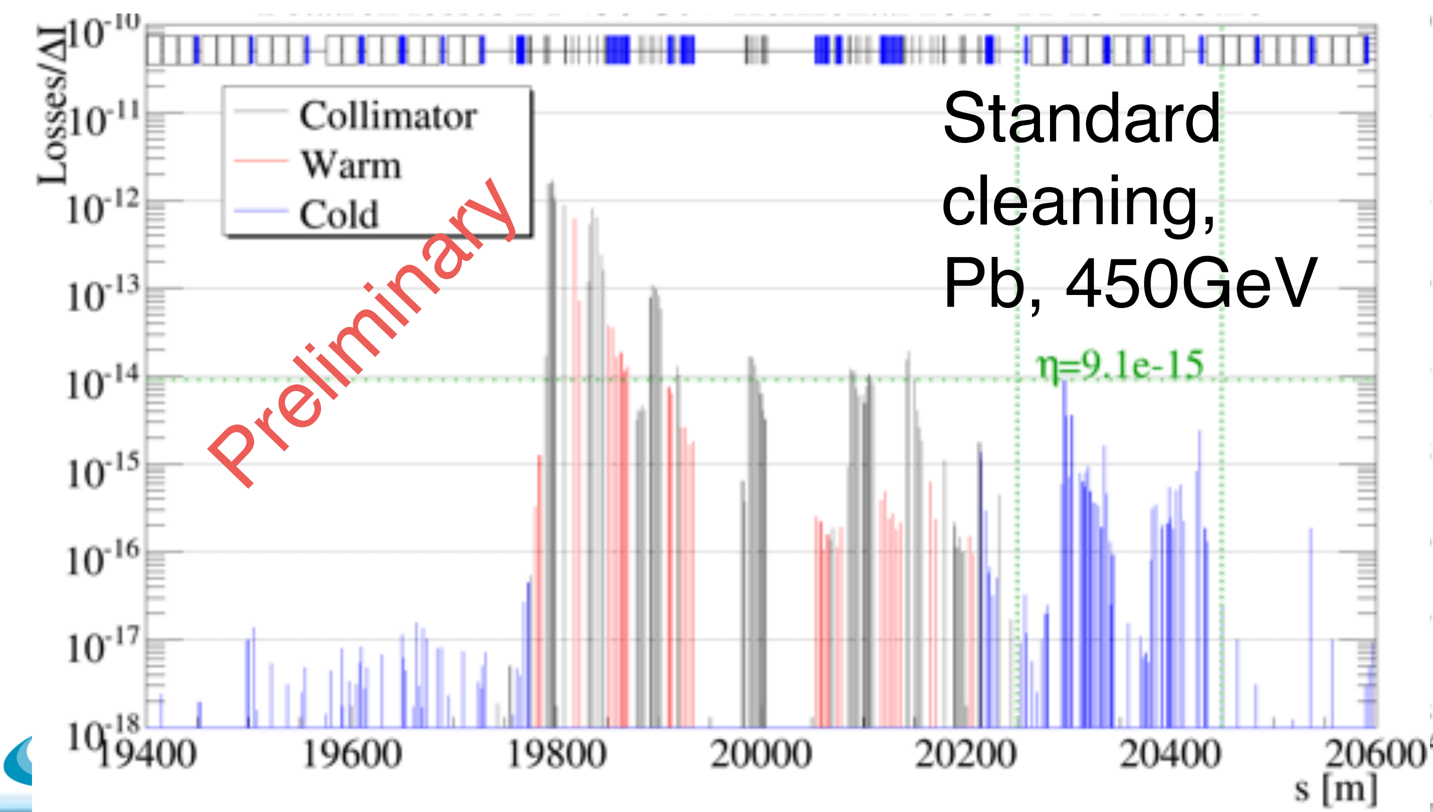
Collimation tests at LHC: collaboration with UA9 team (W. Scandale) and EN-STI.

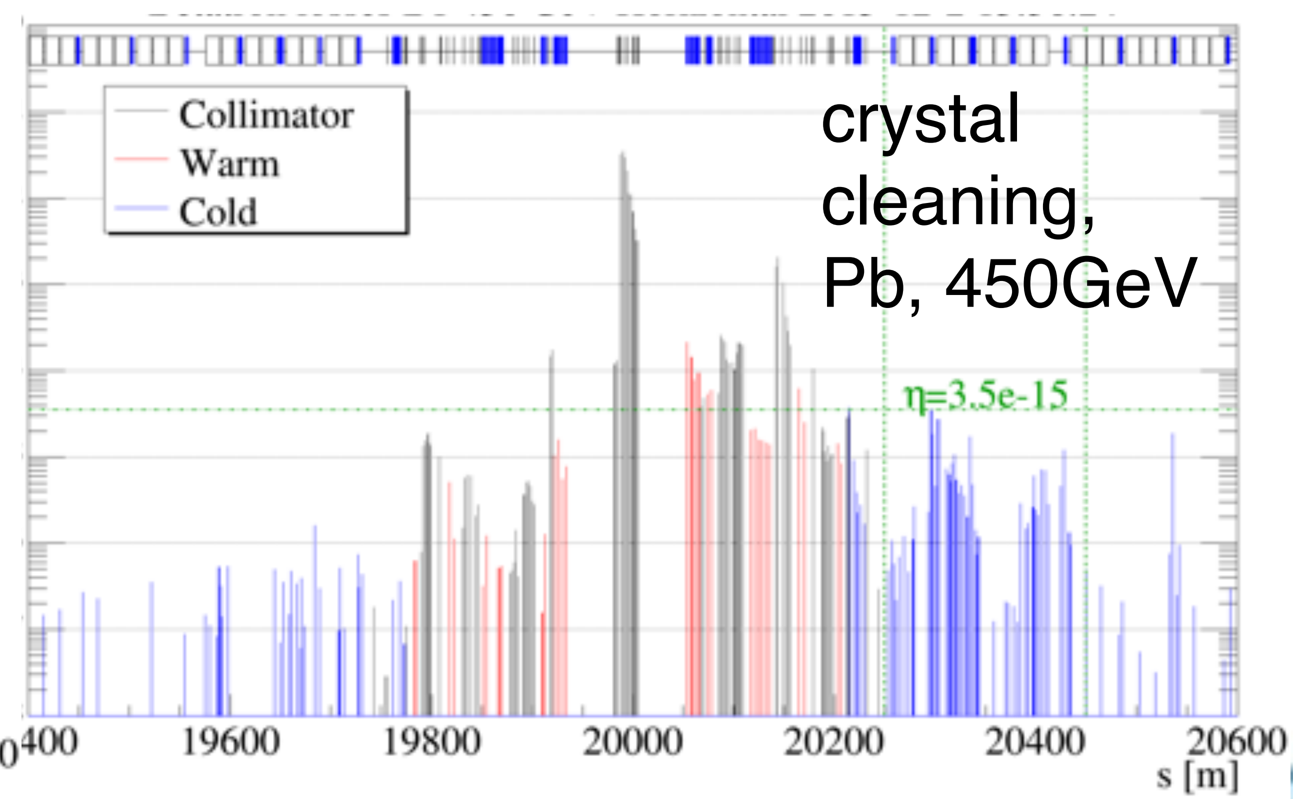
Preliminary results

Angular scan: reduction of local losses in channeling compared to amorphous.









Prospect for crystal collimation

Handling the proton stored energies will be hard:

Deploying a crystal-based system requires dismounting the present IR7 system. We do not have yet a solution.

Smaller total intensities of Pb beams are expected to be handled by the present system (<<1 kW intercepted by the secondary collimators).

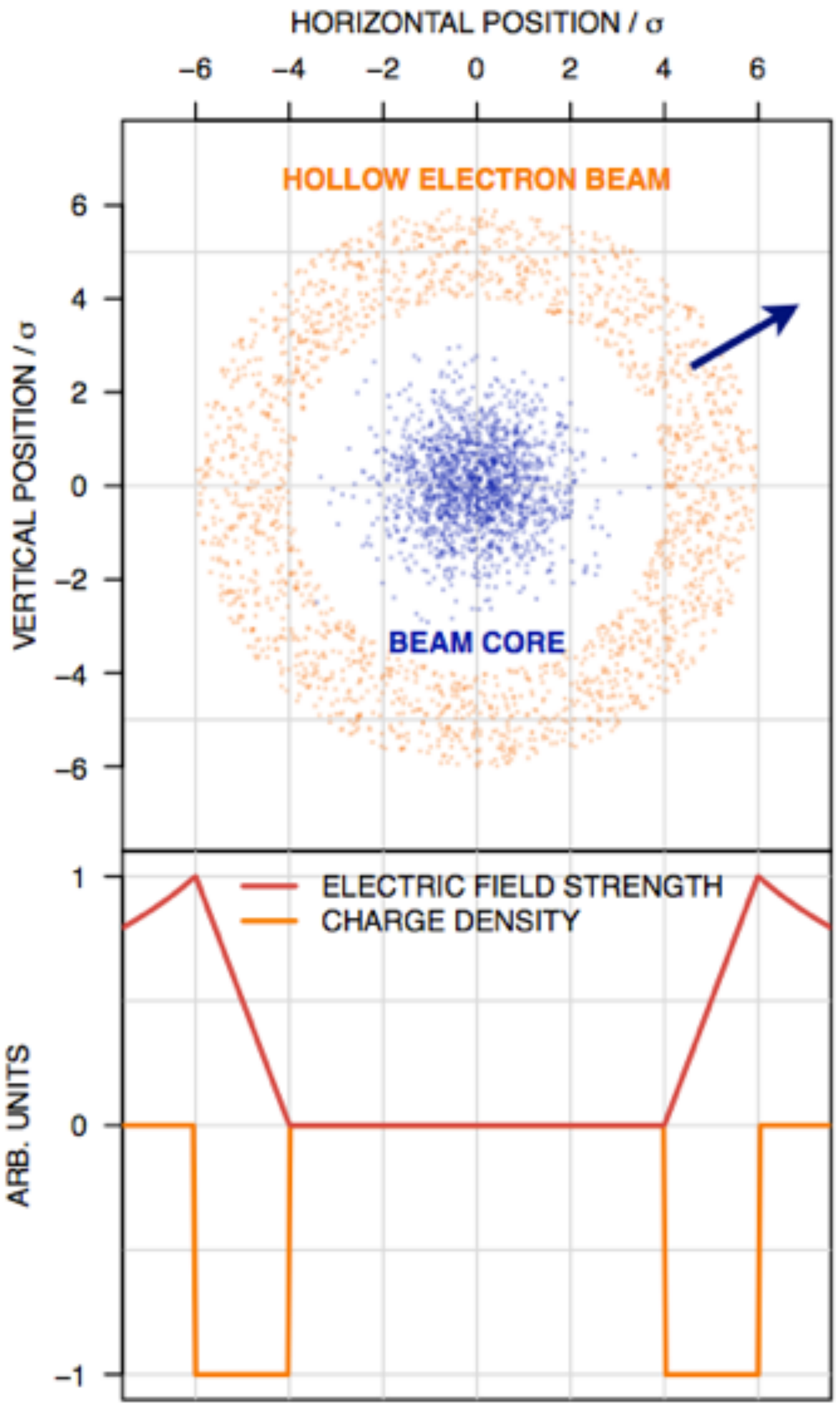
Crystal collimation could be deployed in LS2 to mitigate ion intensity limitations of the present system. Alternative to 11T dipoles. Could study in detail integration in the present system.

Still several outstanding questions to address with beam:

- Pb ions: channeling and cleaning at 6.5TeV;
- Protons: cleaning at 6.5TeV;
- Performance in dynamics machine phases (ramp, squeeze).

(1) and (2) planned for 2015 but not complete — lack of time.

Hollow e-lens beam (HEB)

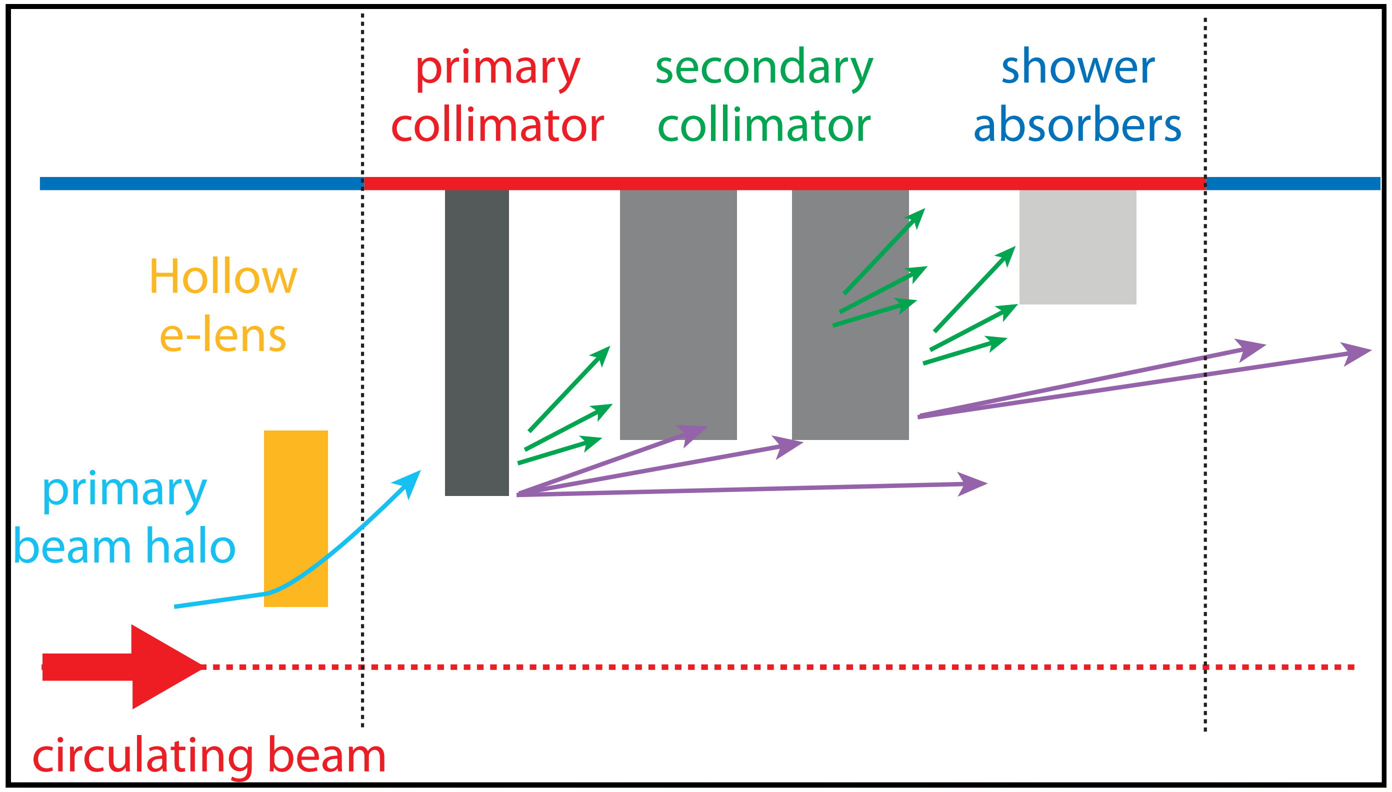


G. Stancari

Provides selective and controllable excitation of halo particles above amplitude of the r_{in}.

<u>Complementary</u> to present system and other upgrades, like crystals.

Outstanding for LHC: need modulated currents to excite halos fast enough.

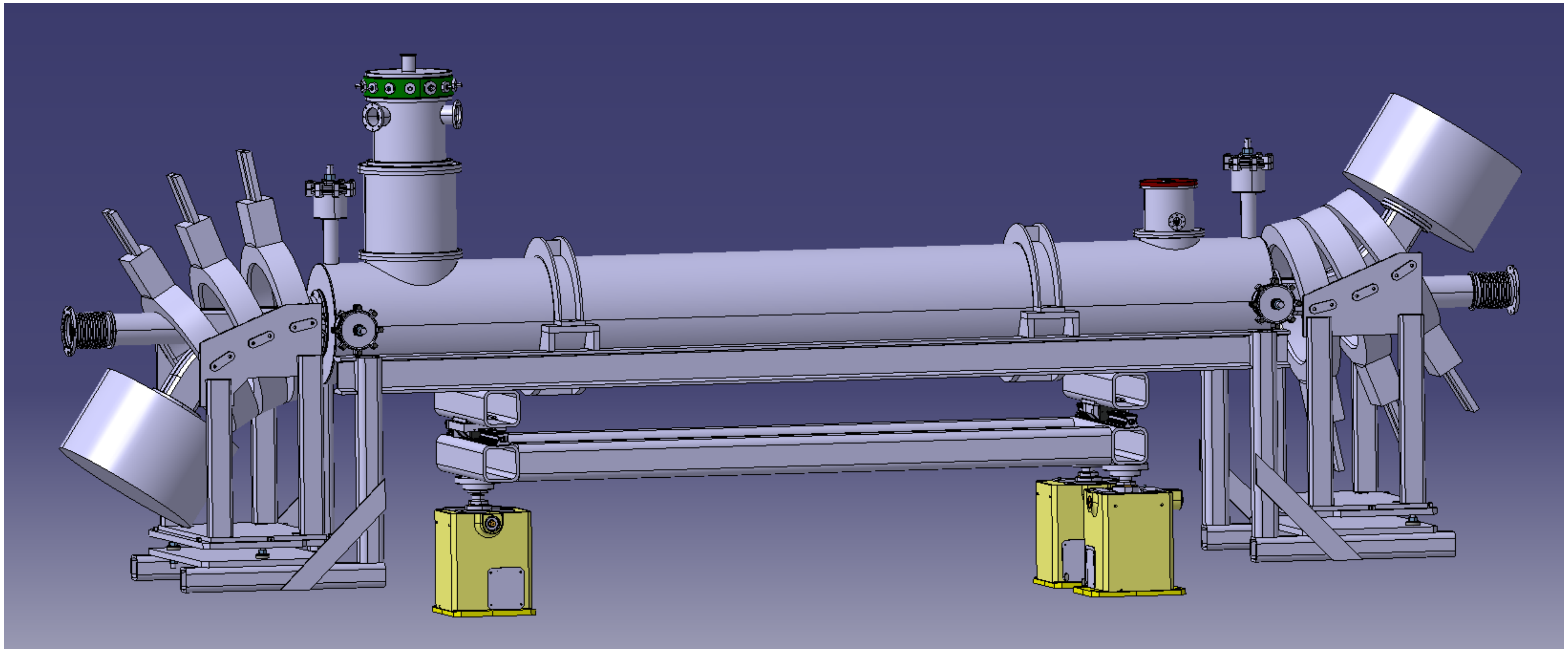


Active halo control

Goal: Control actively transverse halo above 3-4 σ. Essential in order to

- mitigate loss spikes on primary collimators with HL intensities;
- control static halo population → **fast failures of crab-cavities**.
- New: dynamic losses during vibrations/earthquakes.
  See slides J. Wennigner.

Recap.: Synergy with BE/BI effort to measure halos at the LHC and develop e-beams.



Recent news on improved designs

Plan to ship the CERN gun to FNAL to demonstrated the design e-beam current of 5 A. Strong collaboration with LARP (FNAL team + Toohig fellow).

D. Perini et al., EN/MME

EUROPEAN ORGANIZATION FOR NUCLEAR RESEARCH
CERN – ACCELERATORS AND TECHNOLOGY SECTOR

CERN-ACC-2014-0248

FERMILAB-TM-2572-APC

Conceptual design of hollow electron lenses for beam halo control in the Large Hadron Collider*

G. Stancari, V. Previtali, and A. Valishev
Fermi National Accelerator Laboratory, PO Box 500, Batavia, Illinois 60510, USA

R. Bruce, S. Redaelli, A. Rossi, and B. Salvachua Ferrando
CERN, CH-1211 Geneva 23, Switzerland
(Dated: October 30, 2014)

Conclusions

- Presented an updated collimation upgrade roadmap for HL
- Several important results achieved in the last year
  - *First results of quench tests at 6.5TeV indicate lower limits than expected.*
  - *Excellent results on novel collimation material, but coating and radiation hardness still some open question.*
  - *Good experience up to 280MJ, but loss rates might be worst in 2016.*
- Our baseline: staged implementation of HL upgrades for collimation cleaning and impedance reduction, starting in LS2
  - *Dispersion suppression upgrades in LS2: IR2 and IR7, 4 collimators + 4 11T dipoles*
  - *Staged installation of low-impedance collimator: Run III will also profit!*
- Deployment of new IR collimation solutions will happen in LS3
- Promising first results from crystal collimation
  - *Interesting alternative to ion collimation in IR7 for Run III. Not obvious for protons.*
- Evaluating the possibility to include hollow e-lens as baseline.
  - *Development has continued: built first CERN gun to be tested at FNAL.*
  - *I think that we are ready to take this decision. Wait another 6 months to see 2016?*

Key stepping stones in ~2016

Analysis of operational performance at 6.5TeV

- Losses with pushed machine configuration.

Further understanding of beam-based quench limits:

- Beam test plan — if deny needed — will be elaborated after the detailed analysis of present results is completed.
- I would like to see proton losses up to ~1MW.

Crucial prototyping of new collimator designs

Full prototype of the dispersion suppressor collimator:

new design to be tested before launching production.

LHC-ready prototype of low impedance collimator.

Expect important results on coating and radiation hardness.

Results from HL MDs: crystal collimation, halo measurements and control

Test of CERN gun for high-current hollow e-beams.

Follow with interest the development of 11 T dipoles.