Collimation status and layout for IR1 and IR5

R. Bruce, S. Redaelli

on behalf of the WP5 team

Many contributors…

- ***CERN*** : A. Bertarelli, F. Carra, F. Cerutti, L. Esposito, P. Hermes, J. Jowett, A. Lechner, D. Mirarchi, E. Quaranta, A. Rossi, B. Salvachua, W. Scandale, M. Schaumann, E. Skordis, G. Steele, G. Valentino
- ***Royal Holloway, University of London***: S. Gibson, H. Garcia-Morales, R. Kwee-Hinzmann, L. Nevay
- ***SLAC :*** T. Markiewicz
- ***University of Huddersfield:*** R. J. Barlow, H. Rafique, A. Toader
- ***University of Manchester and Cockcroft Institute***: R.B. Appleby, J. Molson, M. Serluca

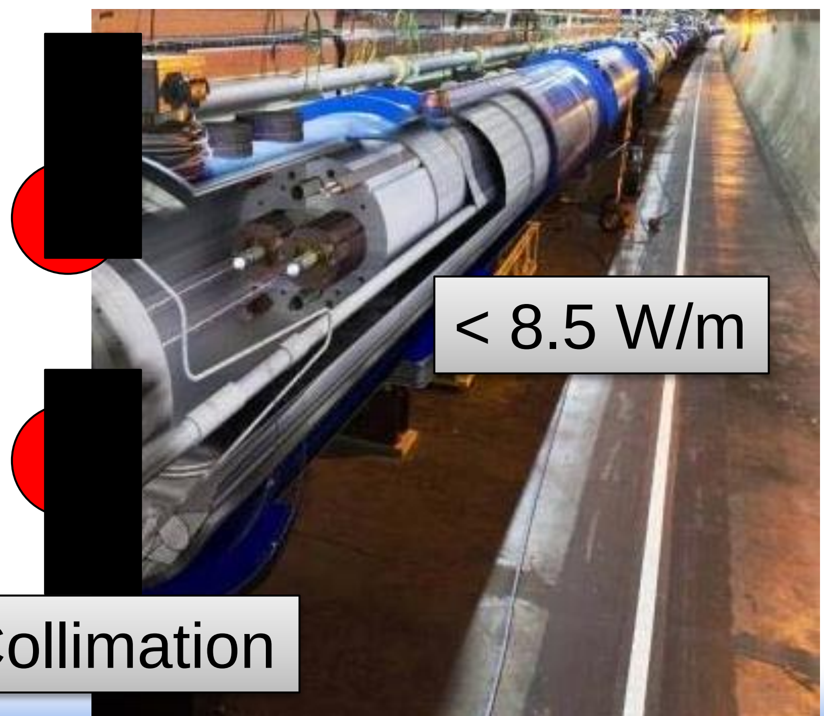
- Team members who recently left: L. Lari, A. Marsili

Outline

- Introduction: Collimation in the present LHC
- Challenges for HL-LHC
- Proposed collimator layout
  - IR7
  - IR1/5 incoming beam
  - IR1/5 outgoing beam
  - Outgoing beam for heavy-ion operation: IR2, IR1, IR5
- Summary

Introduction

- Very high stored energy in LHC (nominal: 362 MJ, HL: 675 MJ). Maximum specified loss rate from nominal beam was 500 kW, while design quench limit was 8.5 W/m.
- Need a very efficient collimation system to intercept unavoidable beam losses that otherwise might quench superconducting magnets!

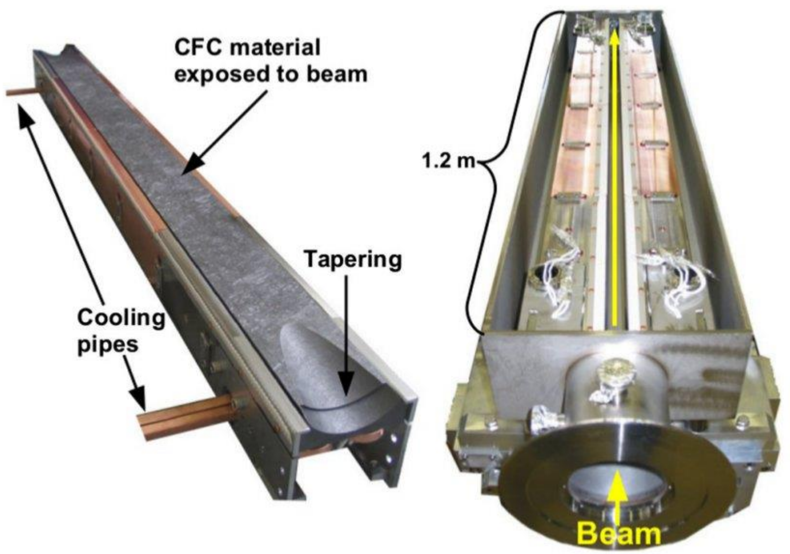


Challenge of *nominal* LHC

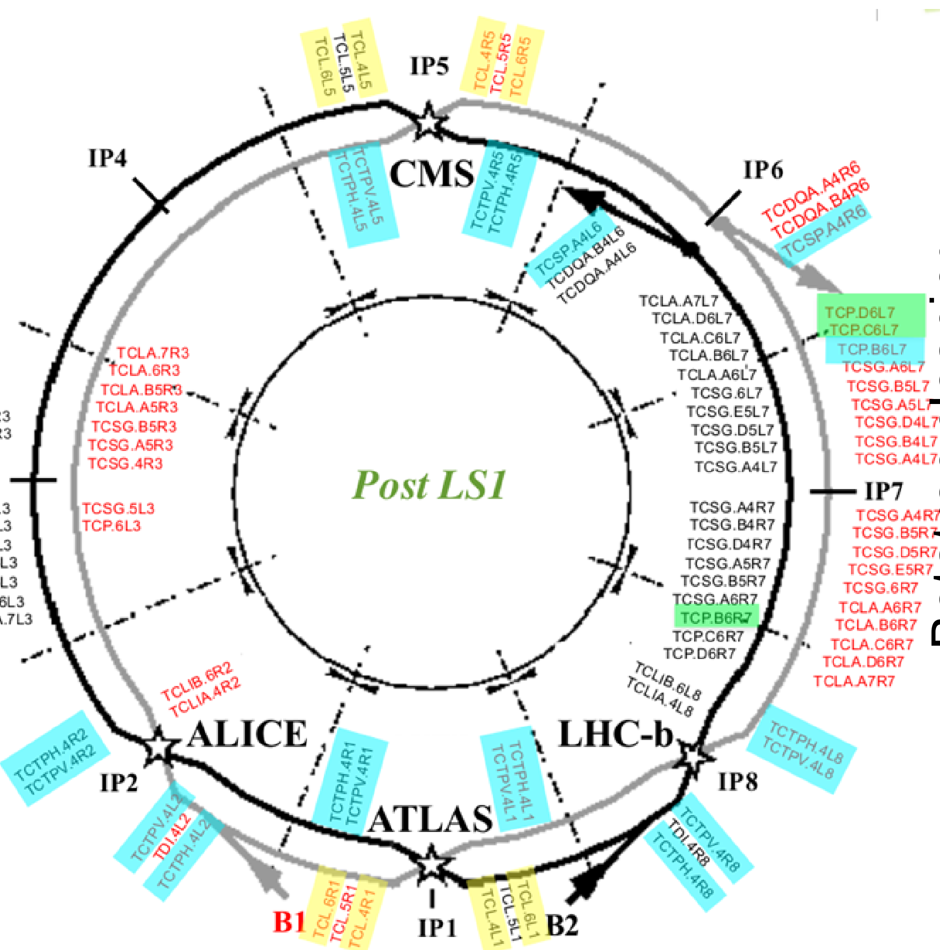
500 kW

LHC collimation system

- LHC Run 2 collimation system: > 100 movable devices
- Betatron cleaning: IR7, momentum cleaning: IR3

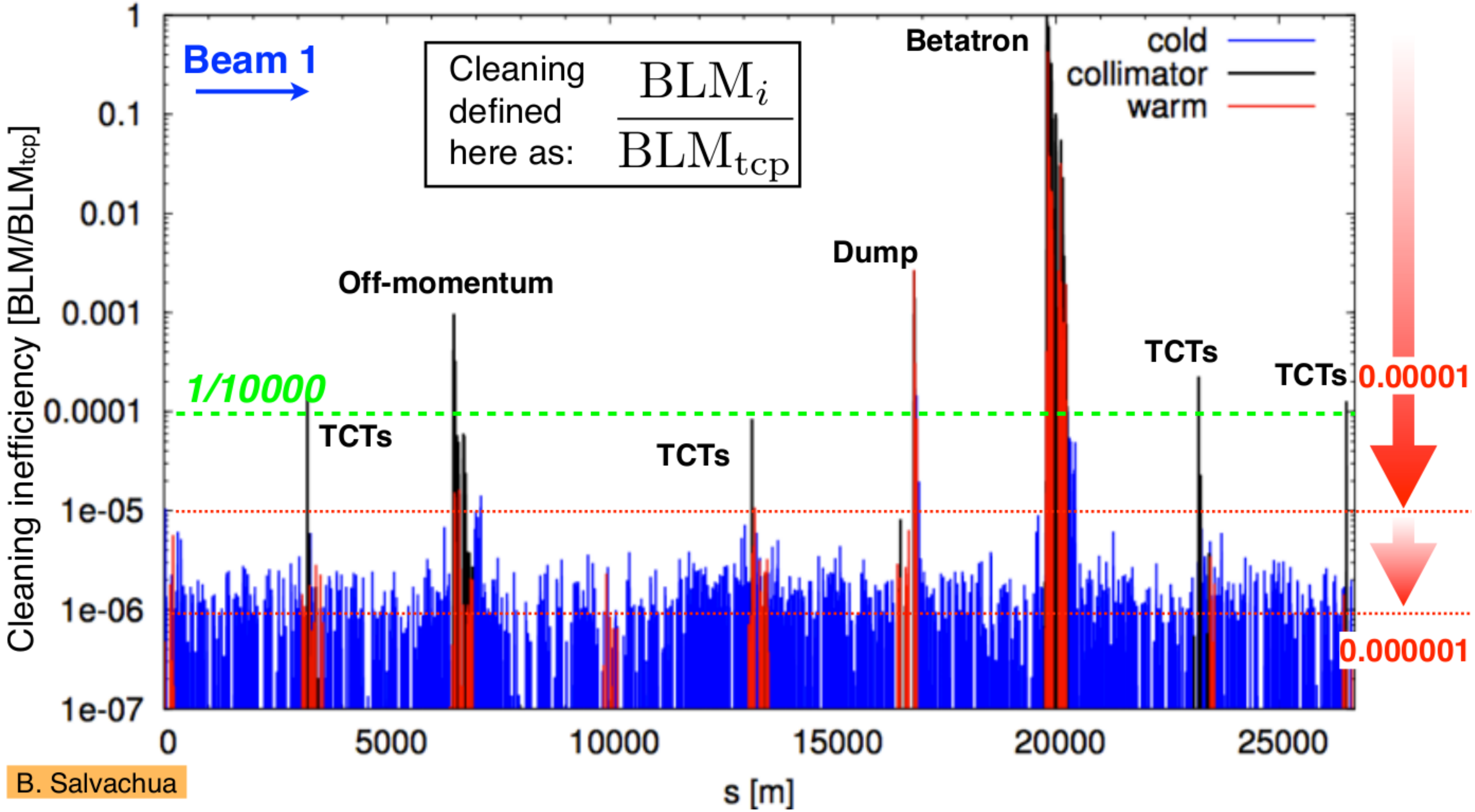


Momentum cleaning



Betatron cleaning

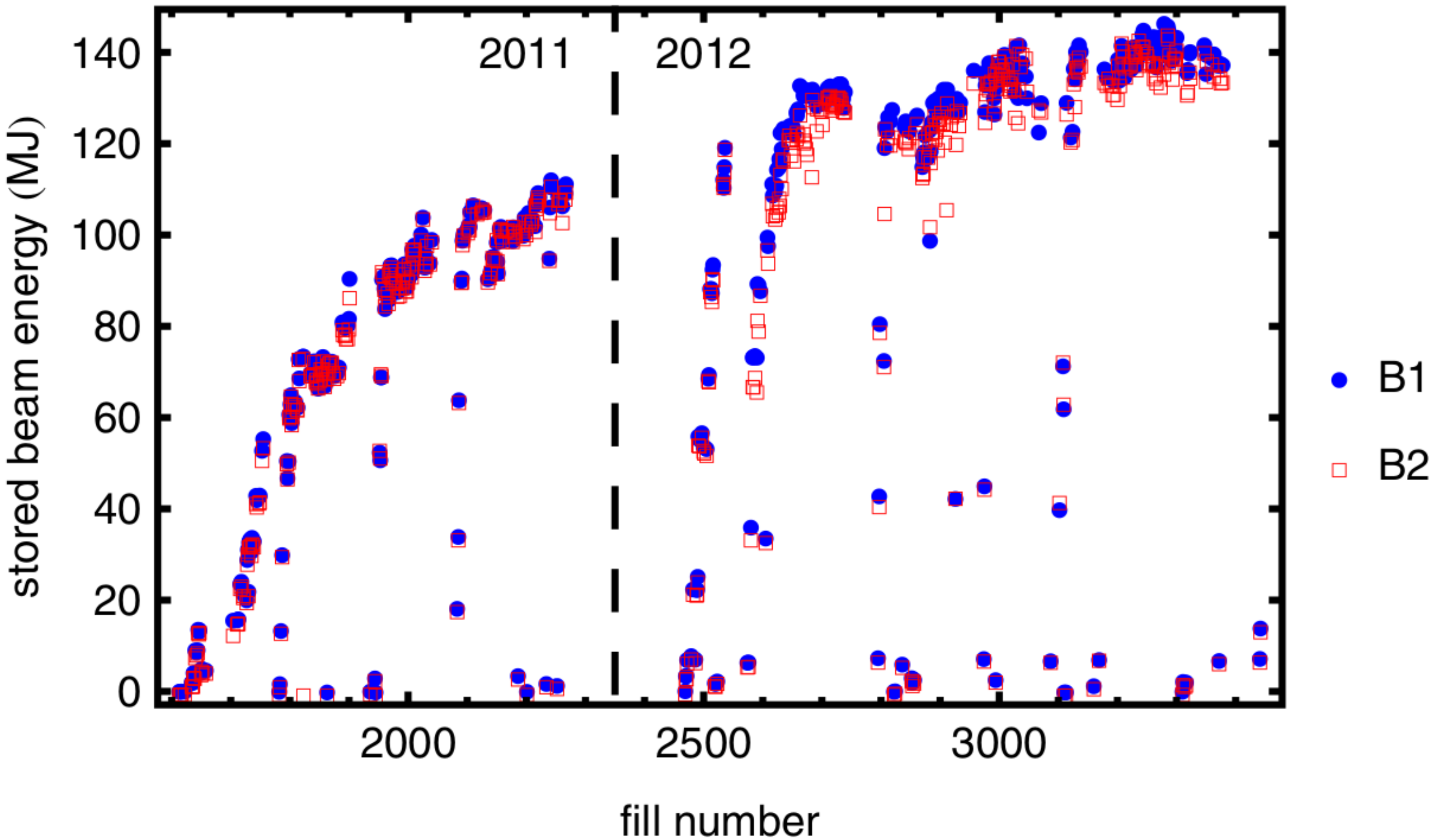
Achieved performance in Run 1



- Highest losses in cold magnets: factor ~10^4 lower than losses on the primary collimator

Stored energy in Run 1

- Routinely stored ~140 MJ beams over hours
- No quenches with circulating beam



Challenges for HL

- Collimation working very well in Run 1. Why upgrade?
- Higher stored energy *(nom: 362 MJ -> HL: 675 MJ)* =>
  - For given beam lifetime, higher loss rates on collimators and cold magnets but same quench and damage limits
- Different IR optics and layout =>
  - Potentially new aperture bottlenecks that need local protection
- Higher luminosity =>
  - Higher fluxes of physics debris (protons and heavy ions)
- Higher bunch intensity *(nom: 1.15e11 -> HL: 2.2e11)* =>
  - Worse beam stability for same collimator openings - impedance
- In addition: radiation, wear etc.

HL collimation upgrades

- Several upgrades studied to meet the challenges
- Today: not all upgrades discussed. Focus on major **layout changes**
- Topics **not** covered in today's talk:
  - Low-impedance collimators
  - More robust collimators
  - Operational efficiency, setup time
  - Mechanical and radiation wear
  - Advanced collimation concepts under study (not yet part of HL baseline): active halo control, crystals, rotatable collimator design

Outline

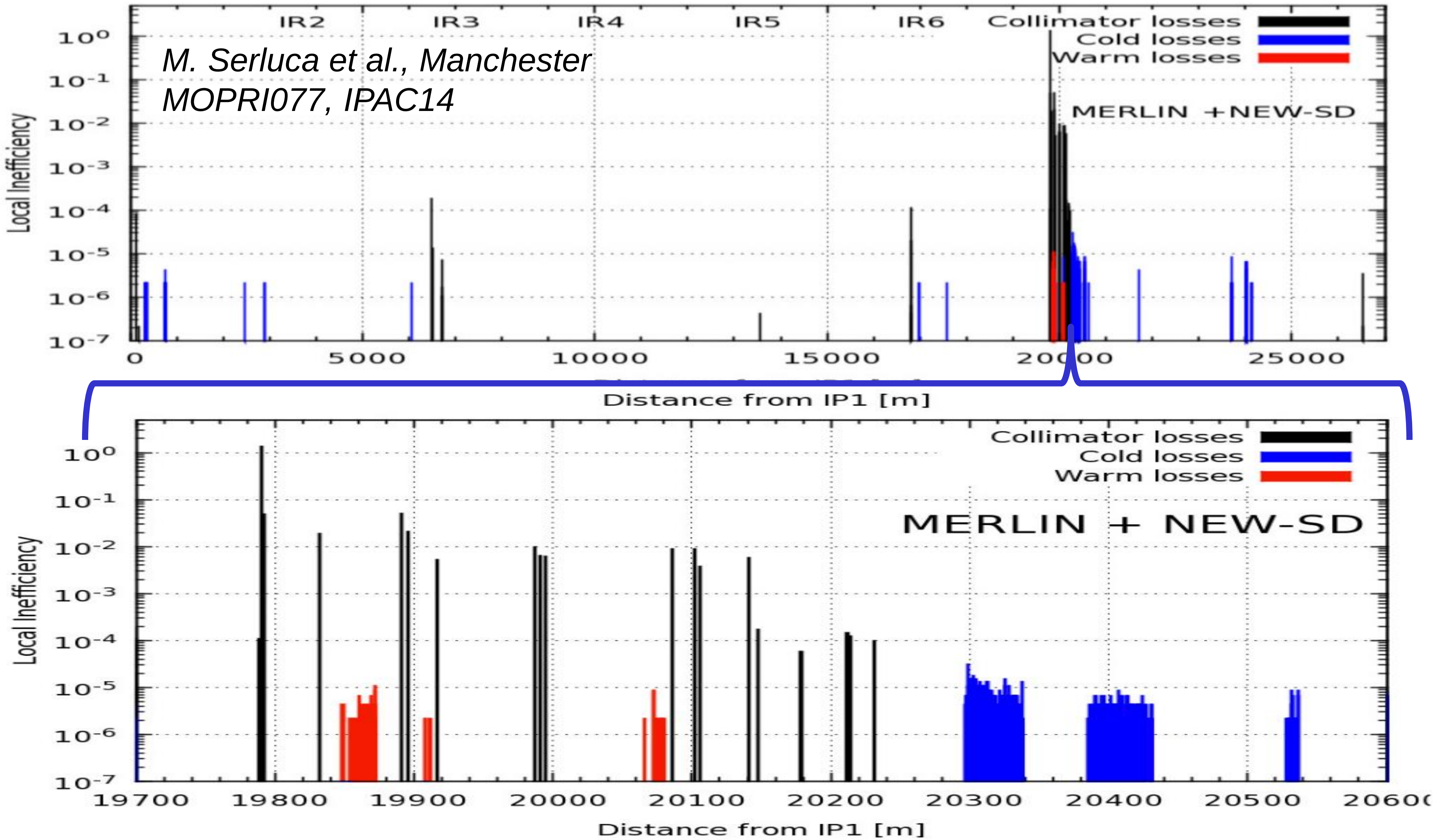
- Introduction: Collimation in the present LHC
- Challenges for HL-LHC
- Proposed collimator layout
  - IR7
  - IR1/5 incoming beam
  - IR1/5 outgoing beam
  - Outgoing beam for heavy-ion operation: IR2, IR1, IR5
- Summary

IR7 limitation, Run 1

- Location in ring with highest cold beam-cleaning losses in Run 1: IR7 DS
- To cope with higher primary loss rates: decrease leakage to DS
- IR7 DS expected to be limiting loss location also in HL-LHC

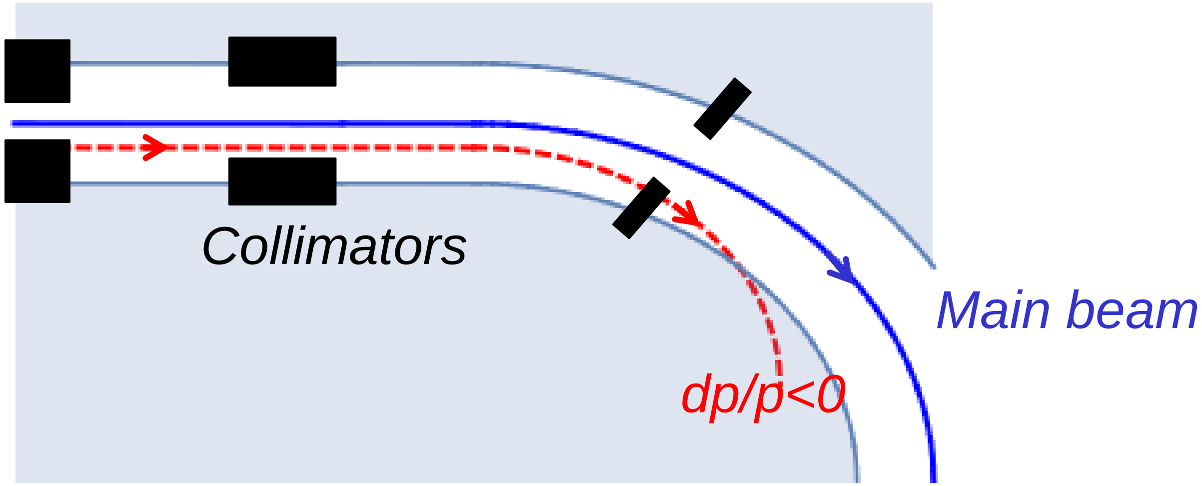
IR7 limitation for HL

- Example: pre-squeeze simulated with MERLIN (M. Serluca et al.)



DS collimators

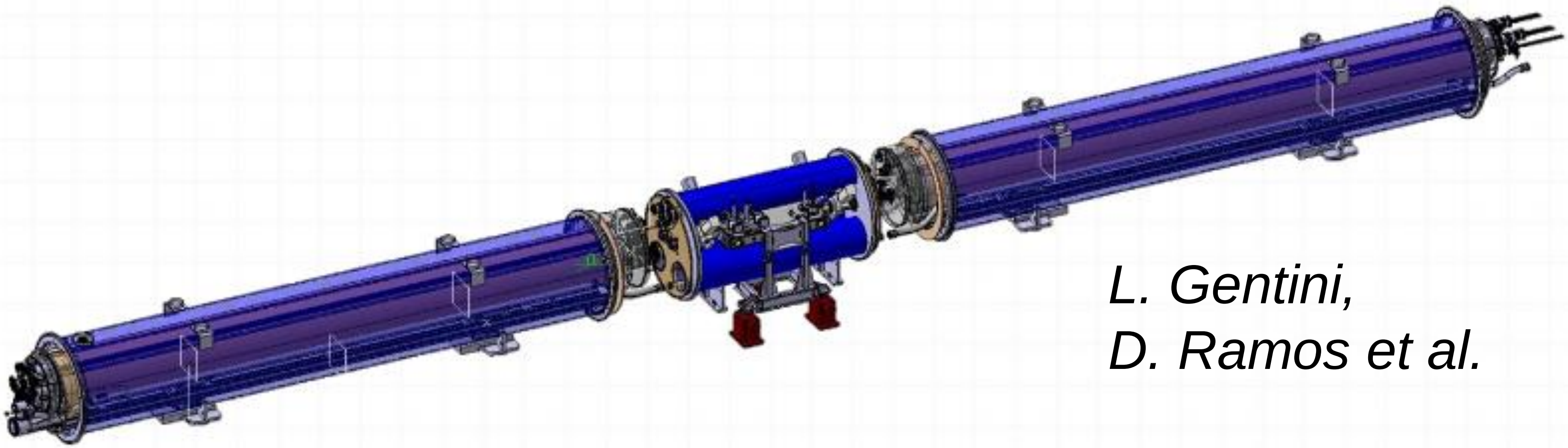
- Out-scattered off-energy protons have different bending radius than main beam



- Start deviating significantly only in first bends, downstream of collimators
- Idea: Install new collimators (TCLD) in front of exposed magnets, where there is already separation from main beam

Design of TCLDs

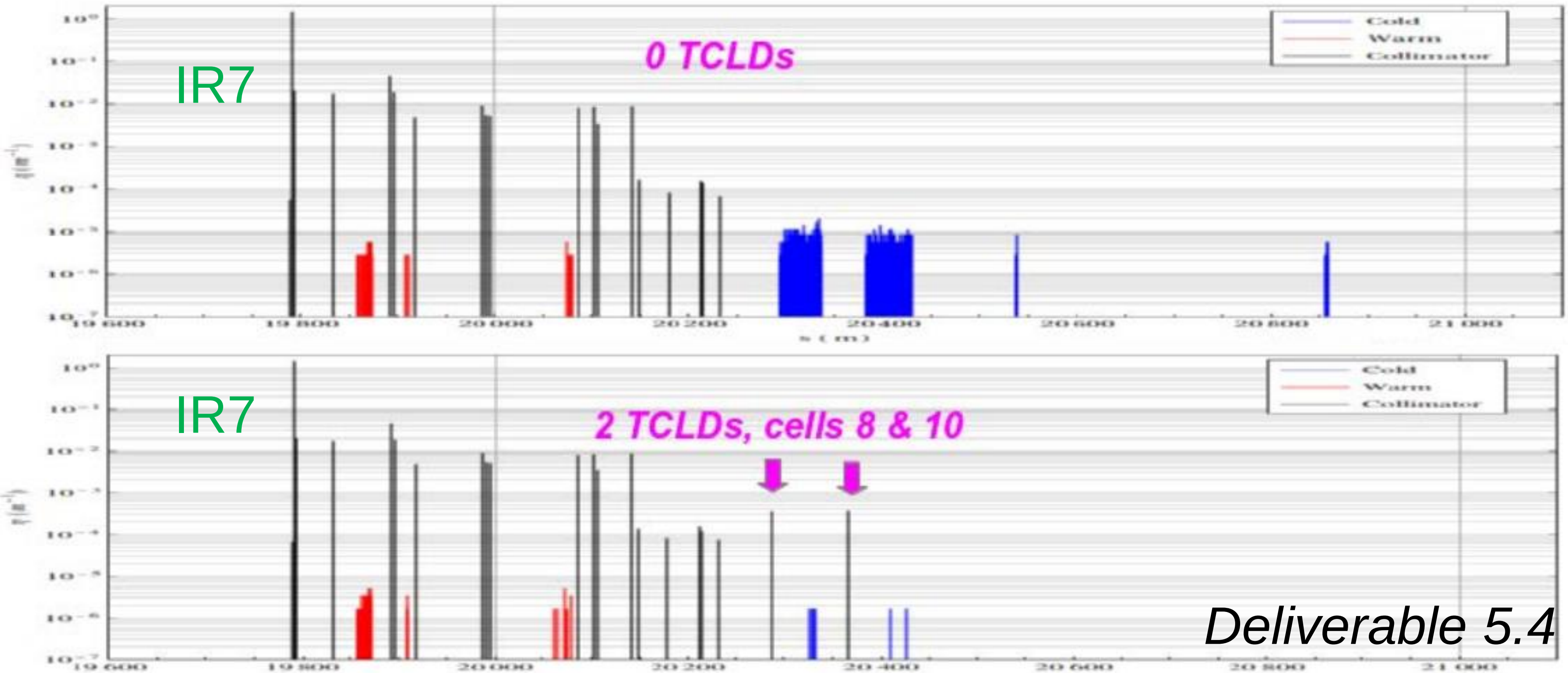
- Integration: Replace main dipole by two 11T dipoles (WP11) and TCLD (WP5) in between
- Mechanical design and integration under study
- More details: Talk F. Carra



L. Gentini,
D. Ramos et al.

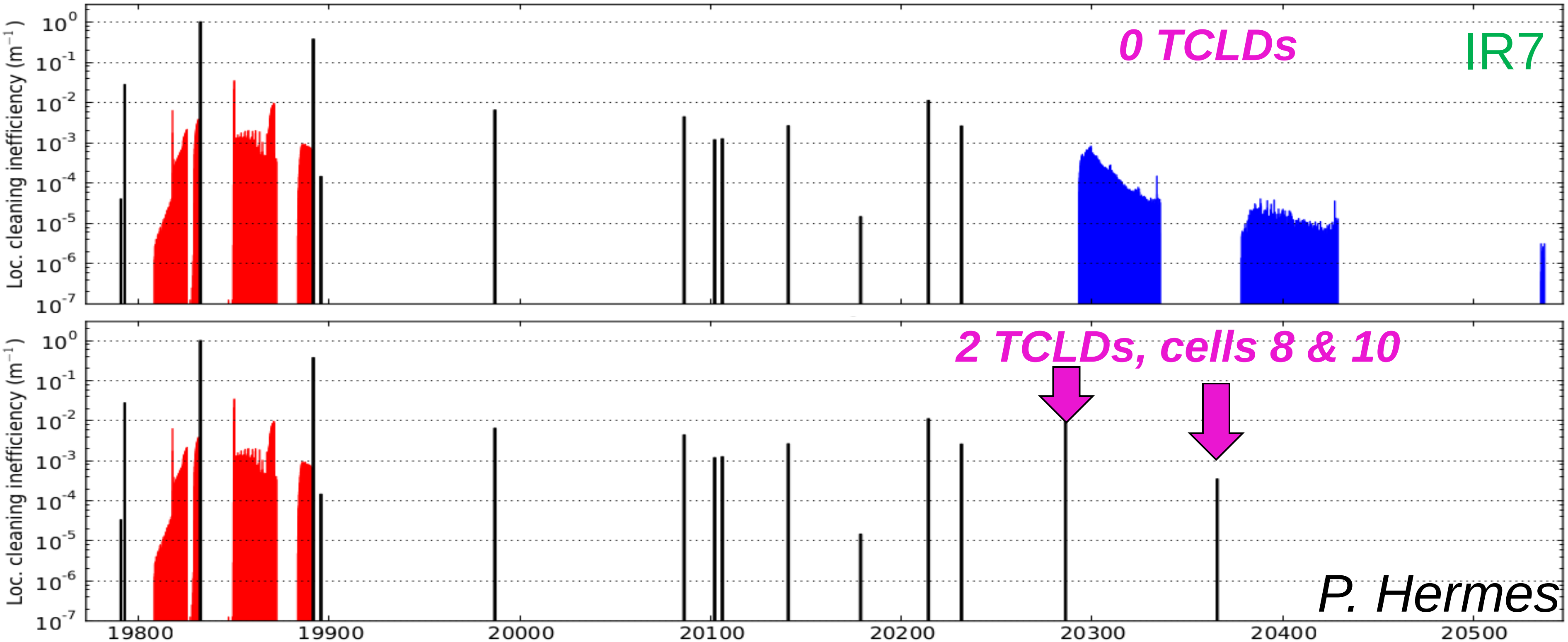
Performance with DS collimators

- Simulations SixTrack + FLUKA with 2 TCLDs in cells 8 and 10 (0.8 m W jaws): Gain factor ~10 in peak power in superconductors
- Final decision for installation should be based on Run 2 experience



IR7 DS collimation for heavy ions

- Heavy-ion collimation: nuclear fragmentation in primary collimator creates ions with changed magnetic rigidity. Lost in DS
- *Preliminary simulation*: 2 TCLDs alleviate all losses for Pb^{82+}
- To be re-confirmed: Improved simulation code under development



Outline

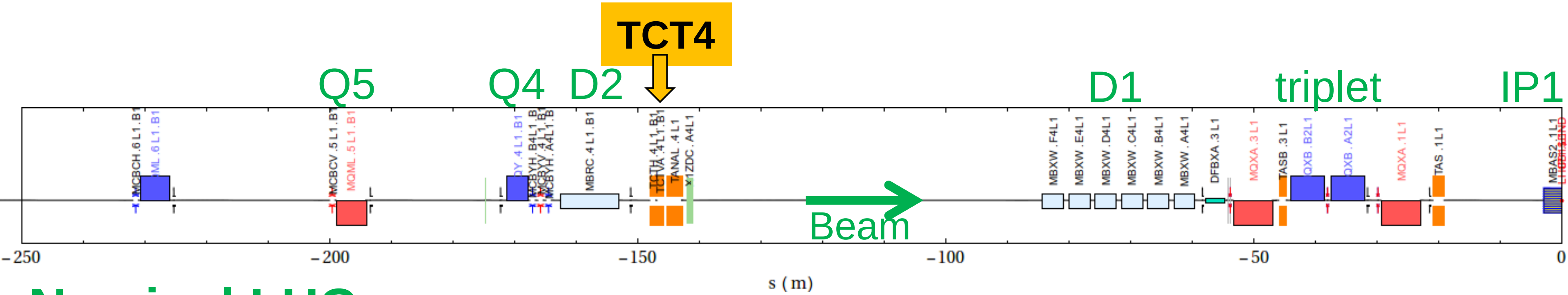
- Introduction: Collimation in the present LHC
- Challenges for HL-LHC
- Proposed collimator layout
  - IR7
  - IR1/5 incoming beam
  - IR1/5 outgoing beam
  - Outgoing beam for heavy-ion operation: IR2, IR1, IR5
- Summary

Incoming beam, IR1/5

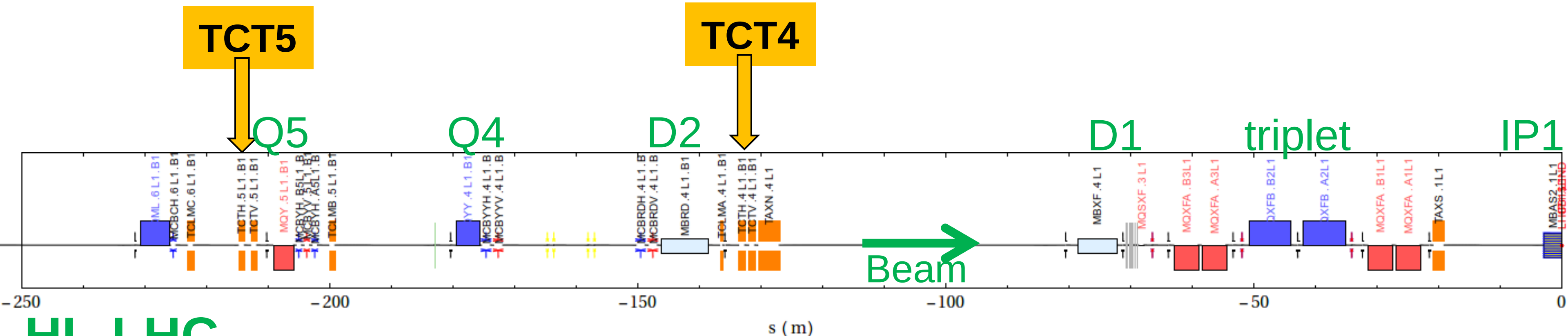
- Presently: pair of horizontal / vertical tertiary collimators (TCT) in cell 4 protects triplet (global aperture bottleneck) against
  - Cleaning losses
  - Fast losses during asynchronous beam dumps
- HL: potentially new bottlenecks in Q4/Q5, upstream of present TCT
  - Could be exposed to both cleaning losses and fast losses during asynchronous dumps
- Solution: Introduce additional TCT in cell 5

IR1/5 layout, incoming beam

- Proposal: add TCT5 in front of Q5, in space of missing dipole



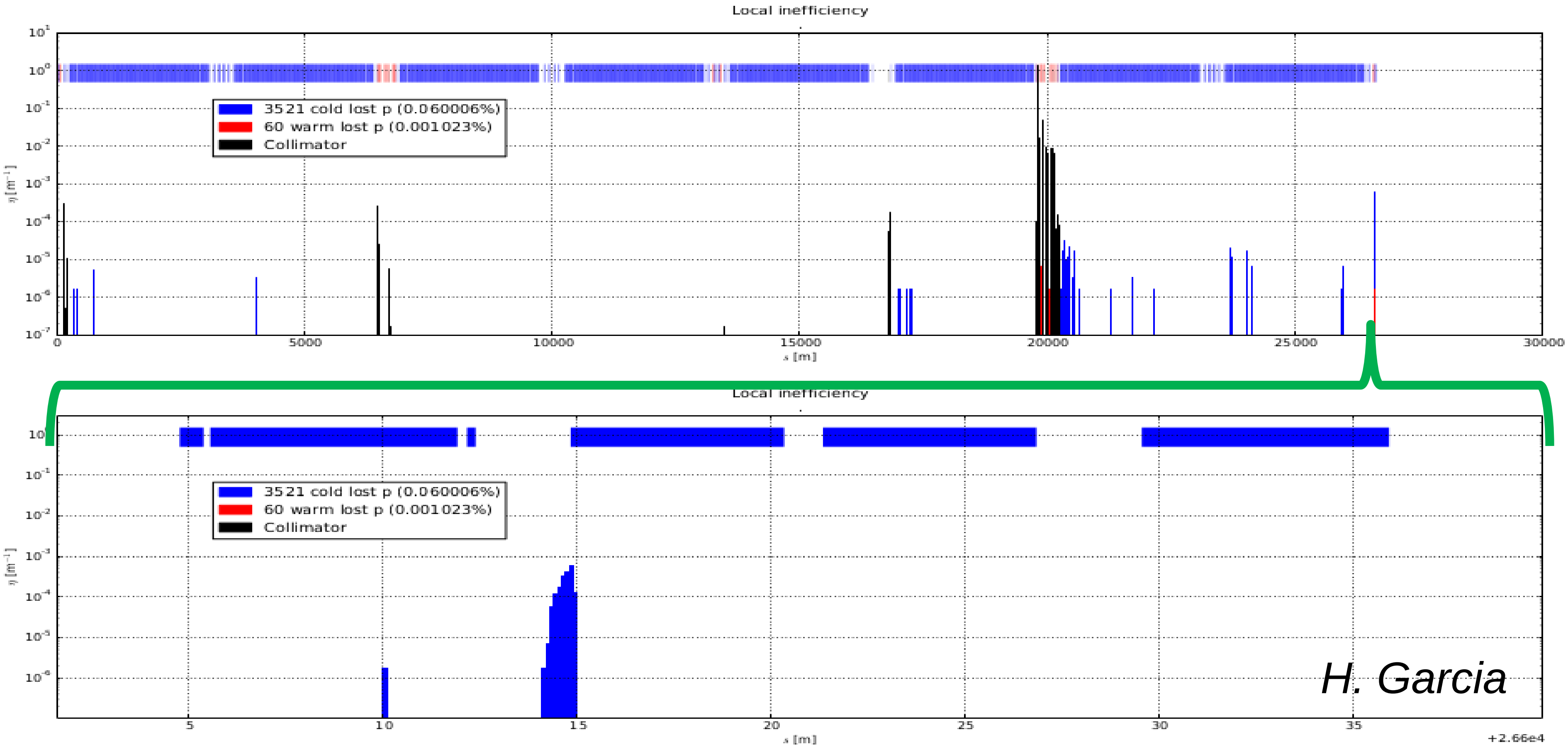
Nominal LHC



HL-LHC

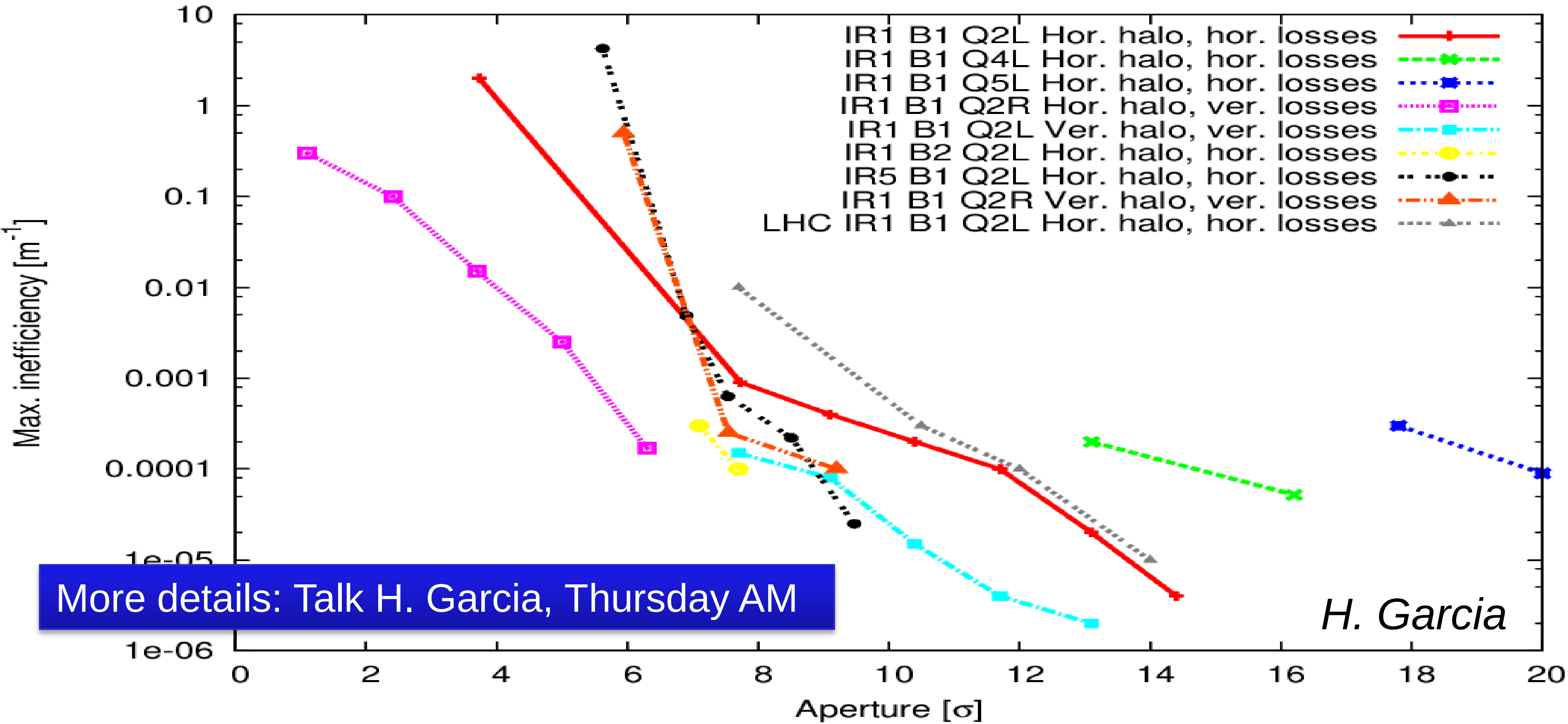
Cleaning simulations

- To quantify need for upgrade: Simulating with SixTrack beam cleaning in HL *without TCTs* (*H. Garcia, Royal Holloway*)
- Vary aperture of magnets in experimental IRs, study IR losses



Cleaning losses in triplets and Q4/Q5 *without* TCTs

- Cleaning simulations with variations of IR magnet apertures
- With imperfections, apertures down to 12 σ allowed
- Simulated losses at A>12 σ: possible need of TCTs for cleaning

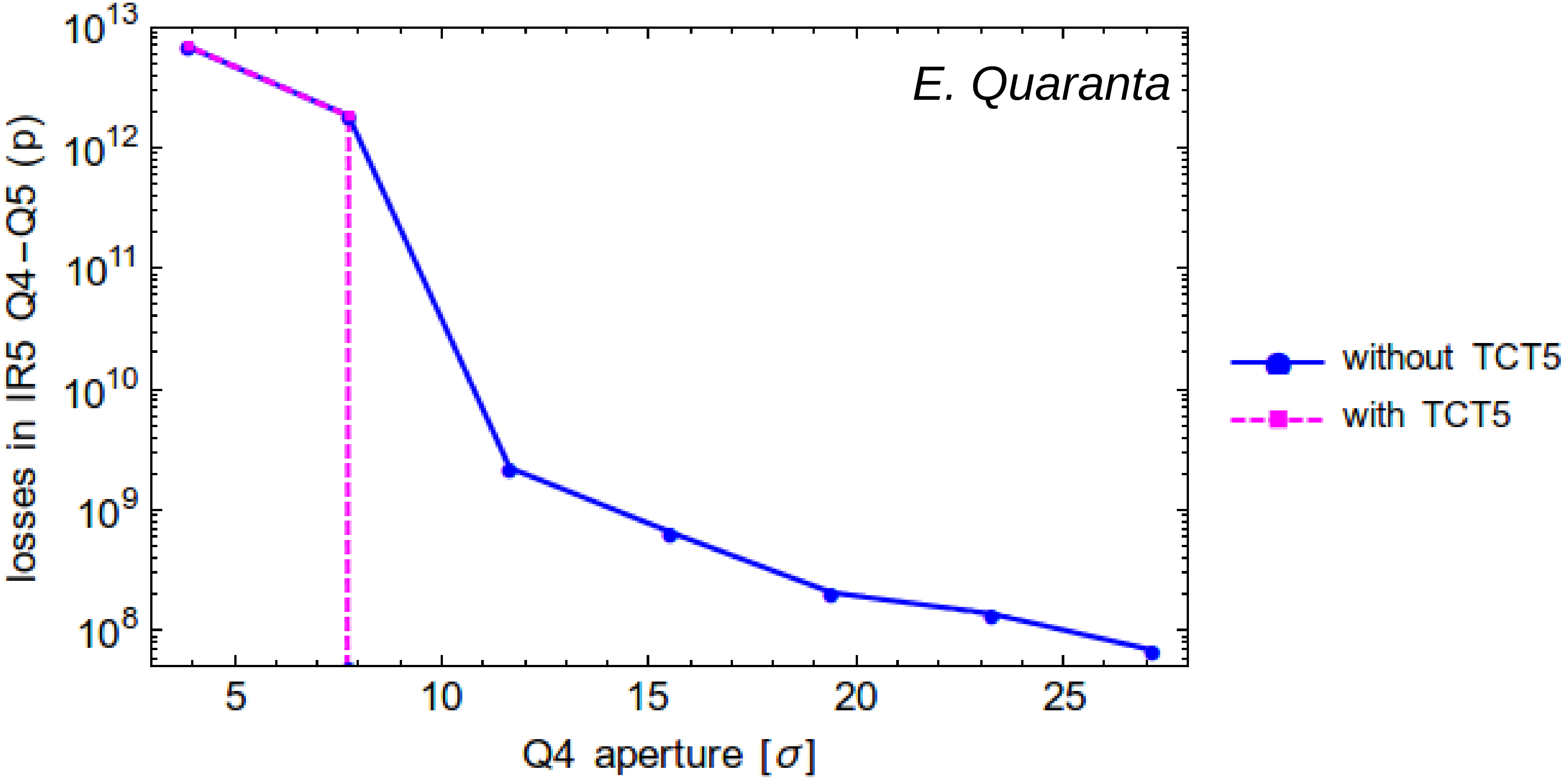


More details: Talk H. Garcia, Thursday AM

IR losses during asynchronous dumps

- Asynchronous beam dump: fast one-turn failure where one or several bunches could be kicked directly onto the aperture and cause damage
- Examine IR aperture losses during asynchronous beam dumps
  - Simulation with SixTrack, with and without TCTs (*E. Quaranta, CERN*)
  - Take most critical failure mode: single-module pre-fire
  - Sum hits on IR apertures over all impacting bunches
  - Normalize by HL-LHC bunch population 2.2e11
  - Sensitivity study of aperture in Q4/Q5 (upstream of present TCT)

Asynchronous dump with TCT5



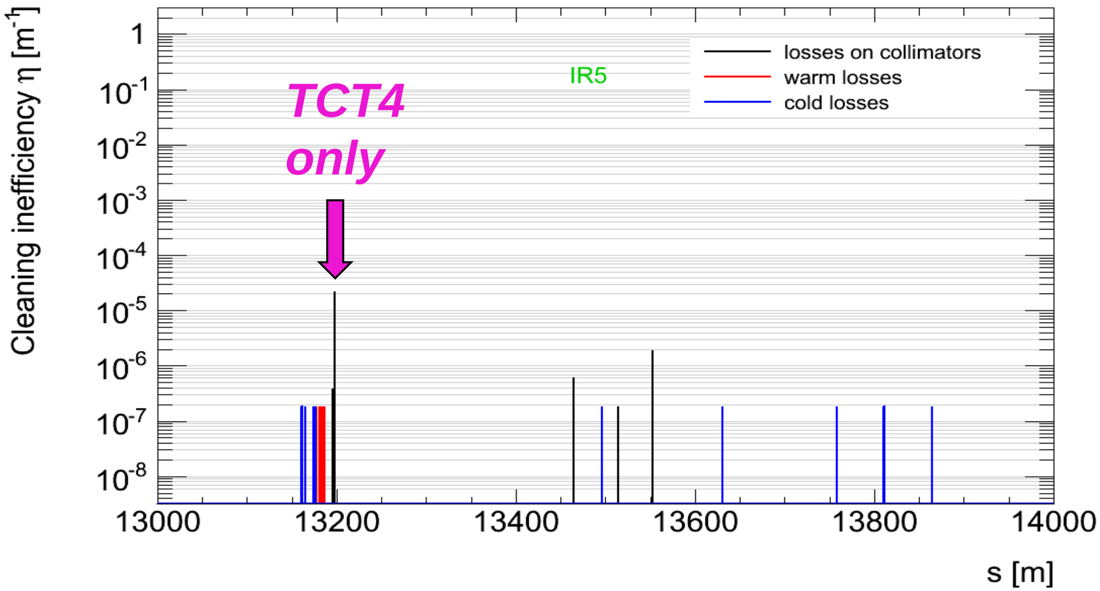
- Even at the nominal aperture, impacts seen at Q4/Q5 and triplet
  - Possibly enough to quench at 7 TeV
- TCT5 efficiently blocks all aperture losses if inside the aperture

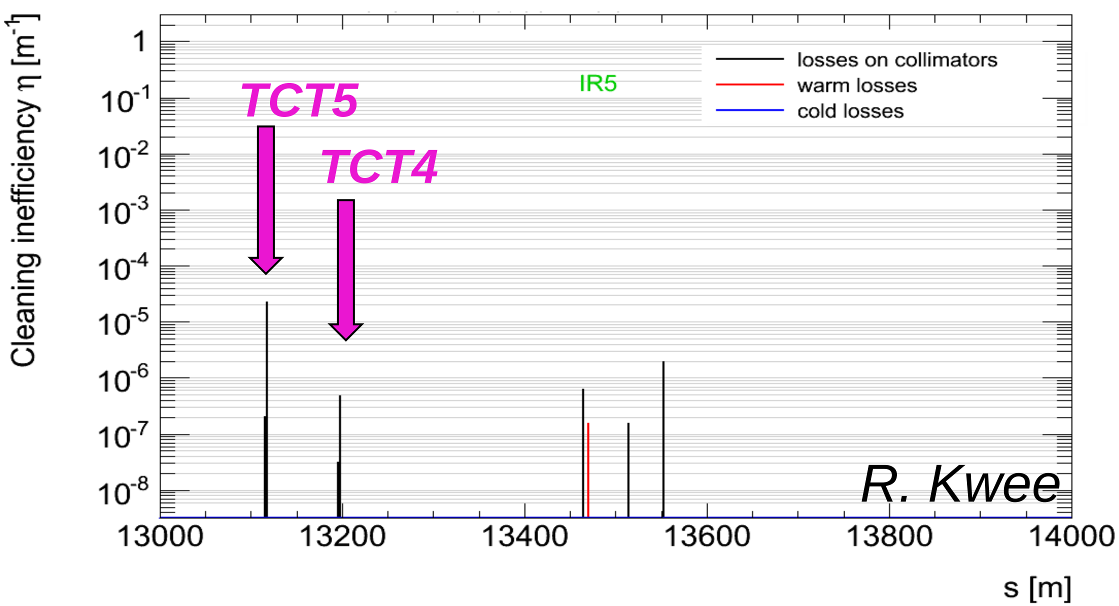
IR collimation on incoming beam

- Cleaning losses without TCTs:
  - No cleaning losses on perfect aperture
  - With imperfect apertures, losses appear also at > 12σ
- Asynchronous beam dumps without TCTs:
  - Losses on triplet and Q4/Q5 aperture even with perfect aperture, possibly enough to quench
- **Local protection needed.** Propose to add TCT in front of Q5 for increased protection

Background reduction with TCT5?

- Additional advantage: Potentially lower experimental background
- TCT5 (further from experiment) takes over losses from TCT4 (*R. Kwee, Royal Holloway*)
- Shower calculations planned to quantify effect





Outline

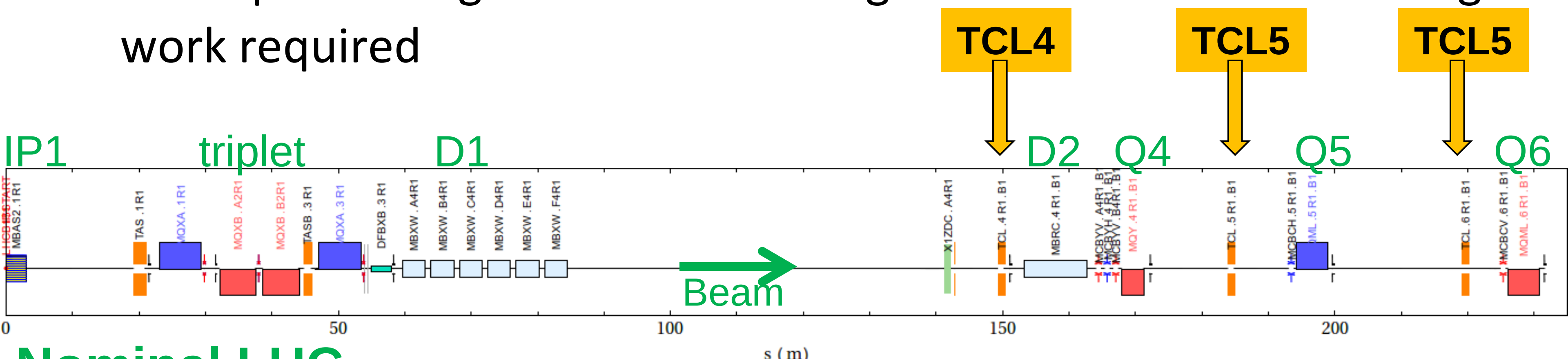
- Introduction: Collimation in the present LHC
- Challenges for HL-LHC
- Proposed collimator layout
  - IR7
  - IR1/5 incoming beam
  - IR1/5 outgoing beam
  - Outgoing beam for heavy-ion operation: IR2, IR1, IR5
- Summary

Outgoing beam IR1/5

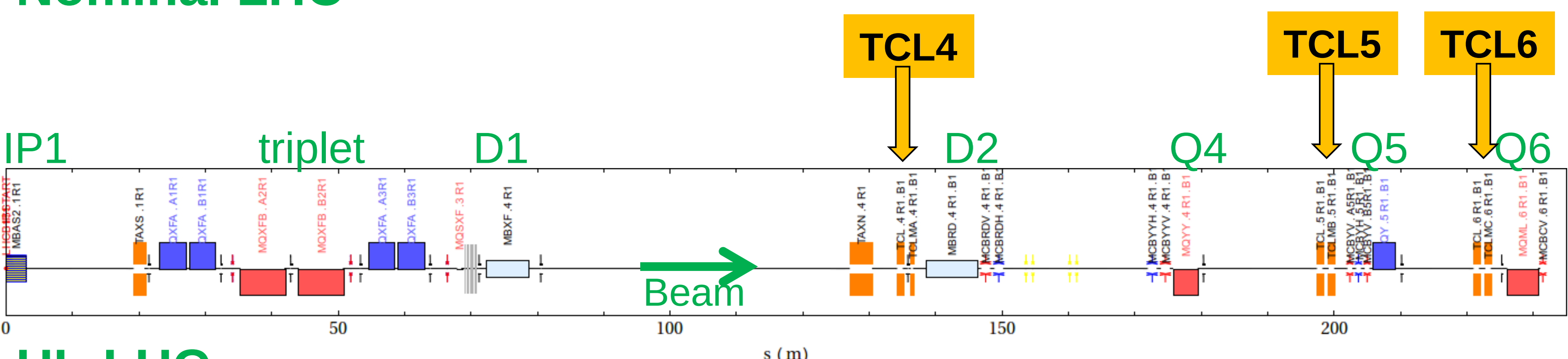
- Present layout (upgraded in LS1) : 3 collimators (TCLs) in cells 4,5,6 to intercept physics debris
- To assess protection of magnets in HL: FLUKA simulations of energy deposition from physics debris (L. Esposito et al., CERN, collaboration WP10 and WP2)
- Present layout with added fixed masks seems to give sufficient protection for high-luminosity proton operation. Under study in WP10/WP2/WP5:
  - Some integration issues
  - Possibility to change TCL design and have thicker jaws – increase protection and remove fixed mask to gain space
  - More details: talk L. Esposito, Thursday AM

Layout: Outgoing beam IR1/5

- Same collimators as for Run II, but some longitudinal shifts
- Conceptual design with known integration issues. Detailed design work required



Nominal LHC



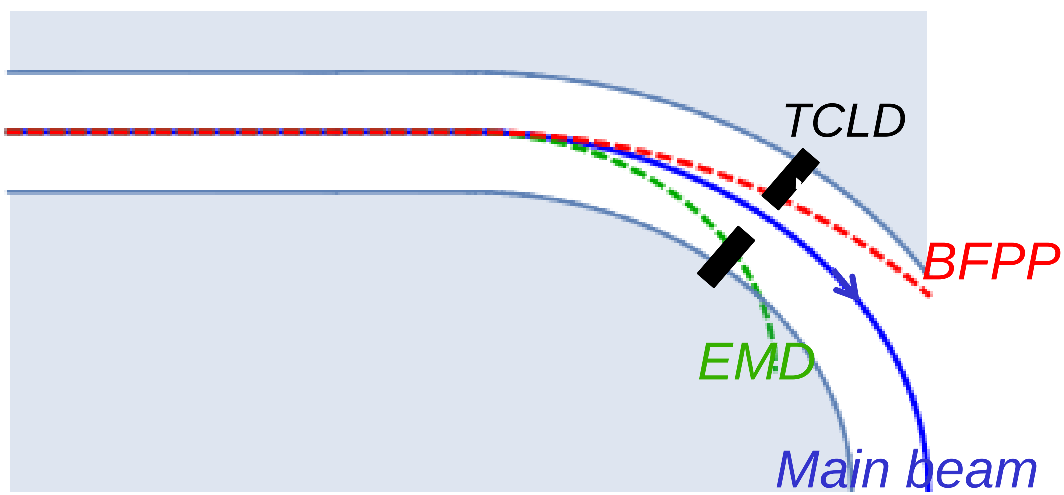
HL-LHC

Outline

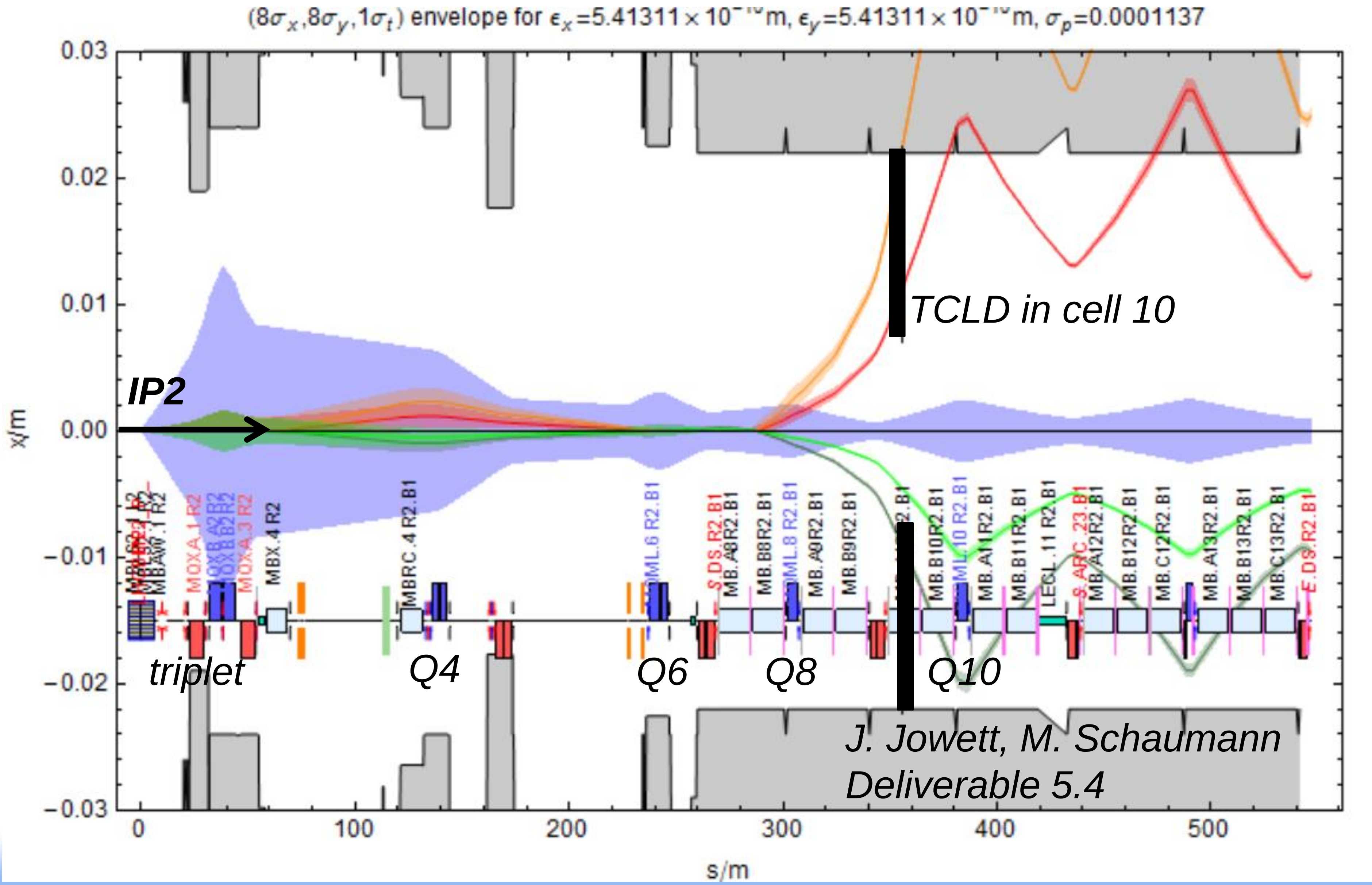
- Introduction: Collimation in the present LHC
- Challenges for HL-LHC
- Proposed collimator layout
  - IR7
  - IR1/5 incoming beam
  - IR1/5 outgoing beam
  - Outgoing beam for heavy-ion operation: IR2, IR1, IR5
- Summary

Outgoing beam, heavy ions

- During Pb^{82+} heavy-ion collisions, large cross section for:
  - Bound-free pair production (BFPP) : electron acquired by outgoing ion(s)
  - Electromagnetic dissociation (EMD): Loss of 1 or 2 neutrons (dominant)
- Changed ratio charge / mass gives different bending radius
  - Losses on aperture when bending starts in DS. Analogue to IR7
- At upgraded ALICE Pb-Pb luminosity 6e27$cm^{-2}s^{-1}$, estimated heat load > quench limit (deliv. 5.3)
- Power density reduced by factor ~100 with TCLD => no quench expected

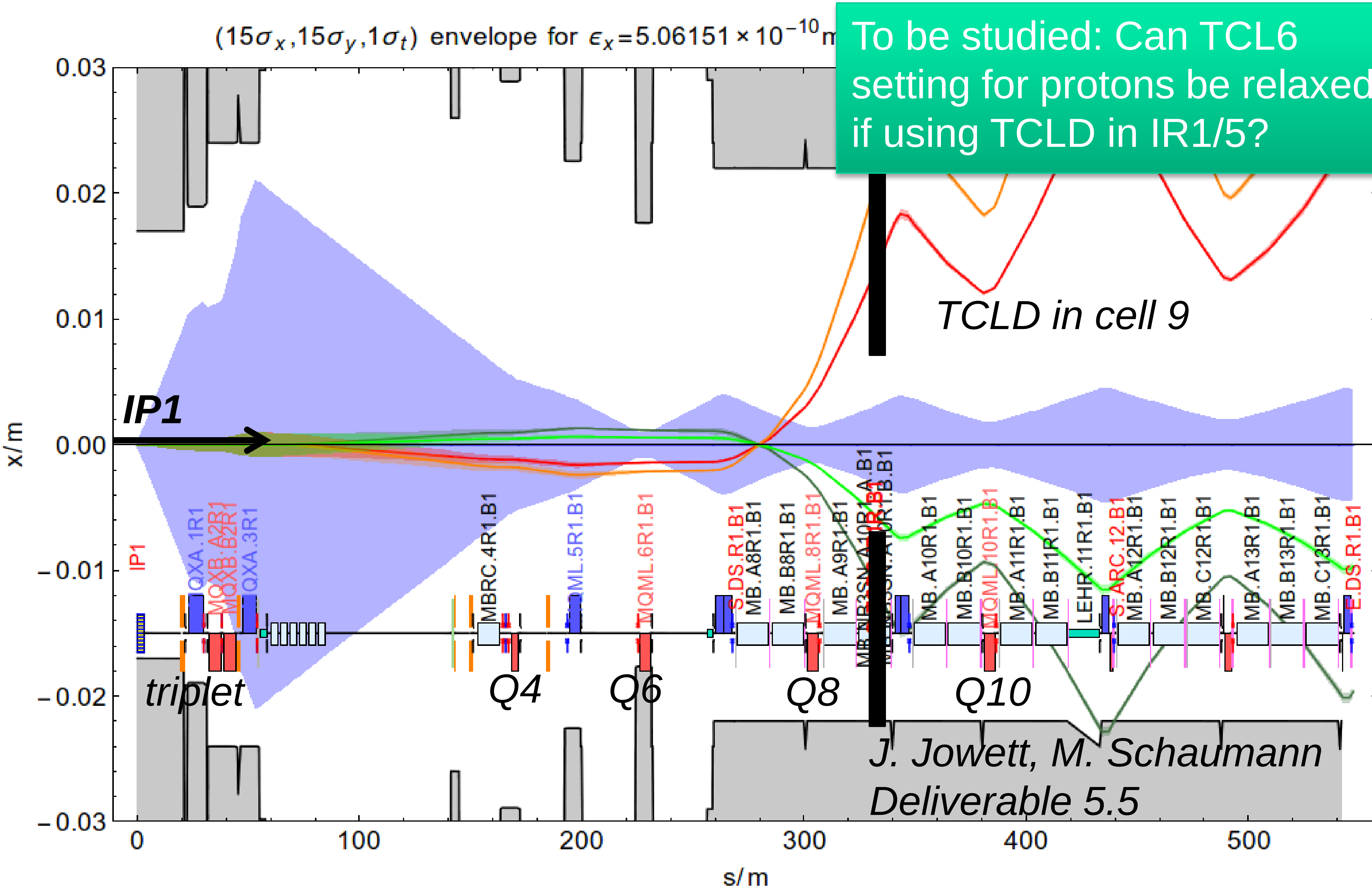


Outgoing beam, IR2, Pb^{82+} ions



Outgoing beam, IR1/5, Pb^{82+} ions

To be studied: Can TCL6 setting for protons be relaxed if using TCLD in IR1/5?



Outline

- Introduction: Collimation in the present LHC
- Challenges for HL-LHC
- Proposed collimator layout
  - IR7
  - IR1/5 incoming beam
  - IR1/5 outgoing beam
  - Outgoing beam for heavy-ion operation: IR2, IR1, IR5
- Summary

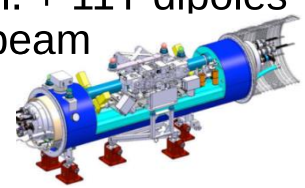
Summary of major layout changes

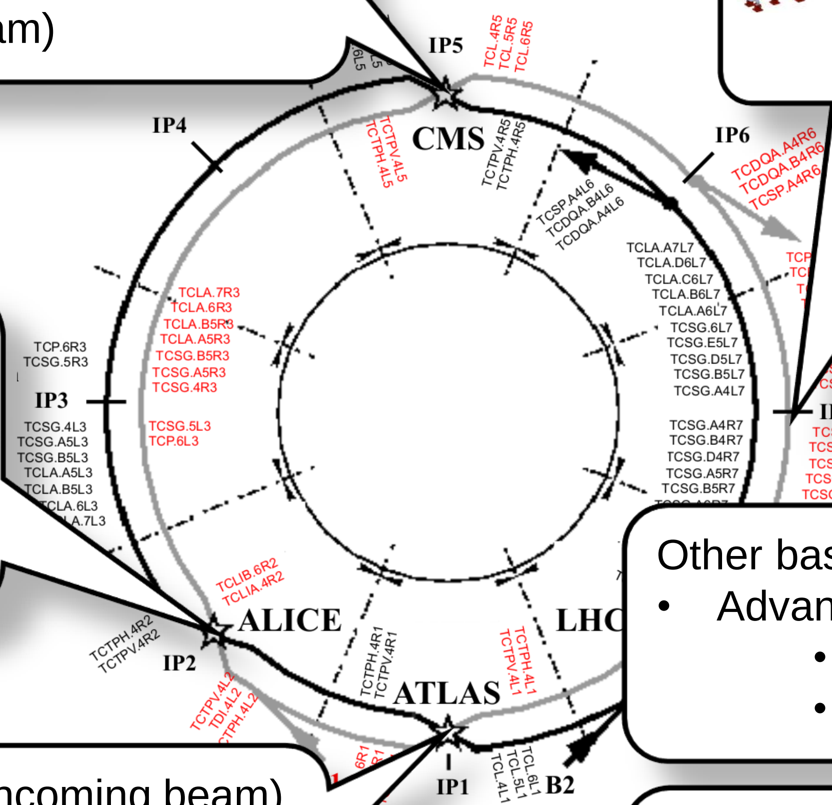
TCT5 (1 on each incoming beam)

Ion physics debris: DS coll. + 11T dipoles (1 per beam)

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

Ion physics debris:
DS coll. + 11T dipoles
1 per beam





Final decision on installation to be taken based on Run 2 experience

Other baseline upgrades:

- Advanced materials
  - Better TCT robustness
  - Better impedance

TCT5 (1 on each incoming beam)

Ion physics debris: DS coll. + 11T dipoles (1 per beam)

Advanced additional studies:

- Halo control (hollow e-lens etc)
- Crystal collimation
- Rotatory collimator design

Backup

Losses vs aperture reduction

- Cold cleaning losses start appearing at reductions >5mm