HiLumi HL-LHC PROJECT

LHC Collimation Project CERN

Overview of LHC conventional and advanced collimation systems

Stefano Redaelli, CERN, BE-ABP
on behalf the collimation team

Beam Dynamics meets Vacuum, Collimations, and Surfaces

CERN
X-BEAM Workshop: Beam Dynamics meets Vacuum, Collimations and Surfaces
8-10 March 2017
Karlsruhe Institute of Technology, Karlsruhe, Germany

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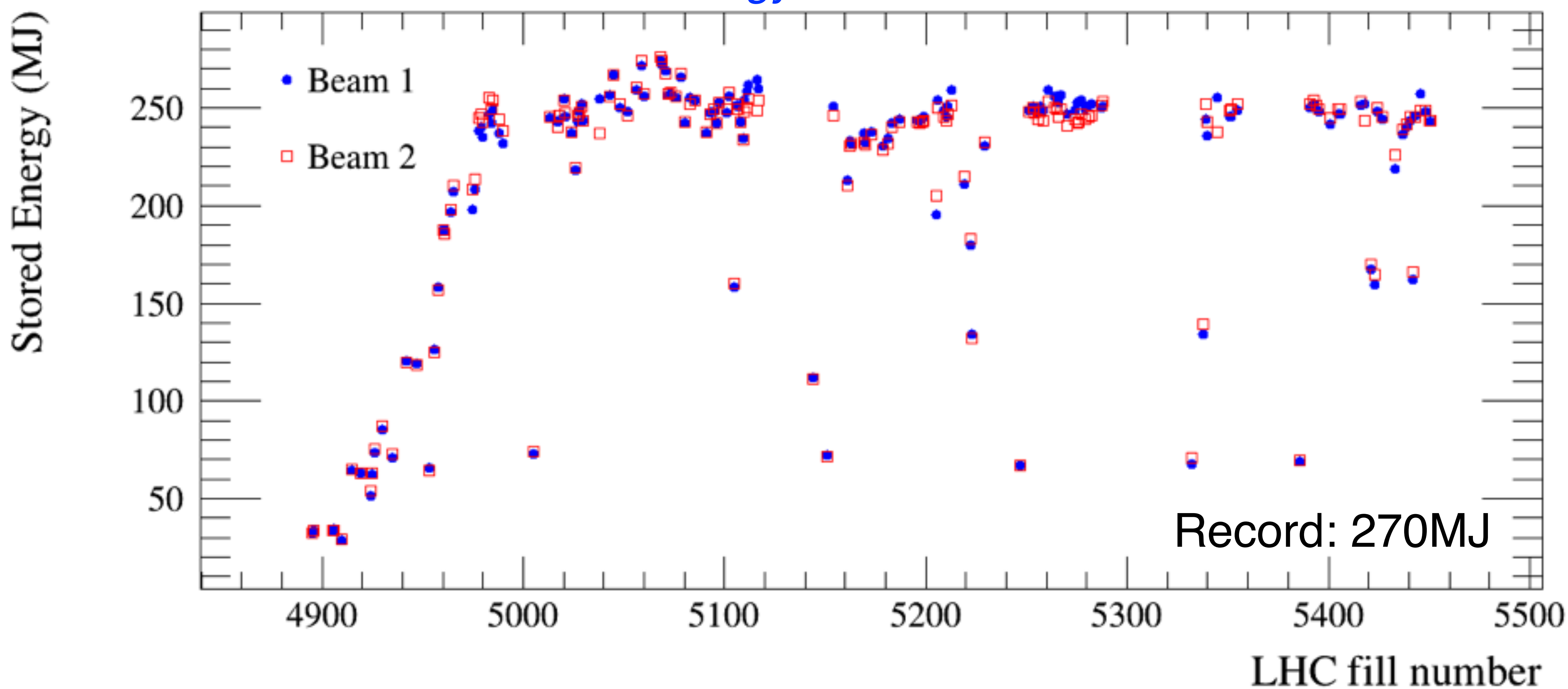
Introduction

The LHC collimation system is designed to prevent superconducting magnet quenches from losses of the 360MJ LHC proton beams

LHC stored beam energy vs time in 2016 at 6.5 TeV



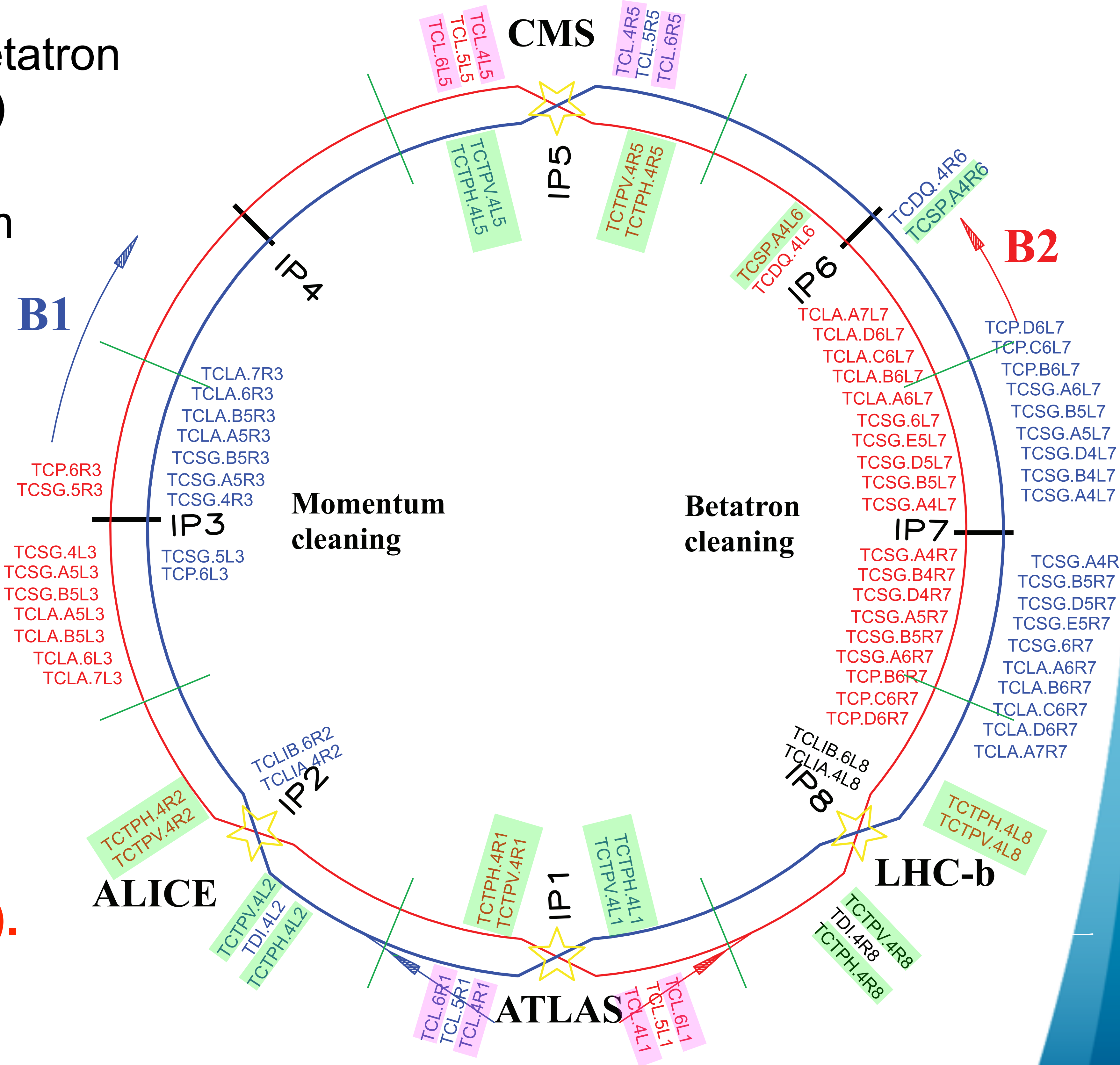
So far, no quenches from circulating beam losses at the LHC!

LHC collimation layout

Dedicated insertions for betatron (IR7) and momentum (IR3) cleaning systems.

Cleaning of incoming beam in all experiments.

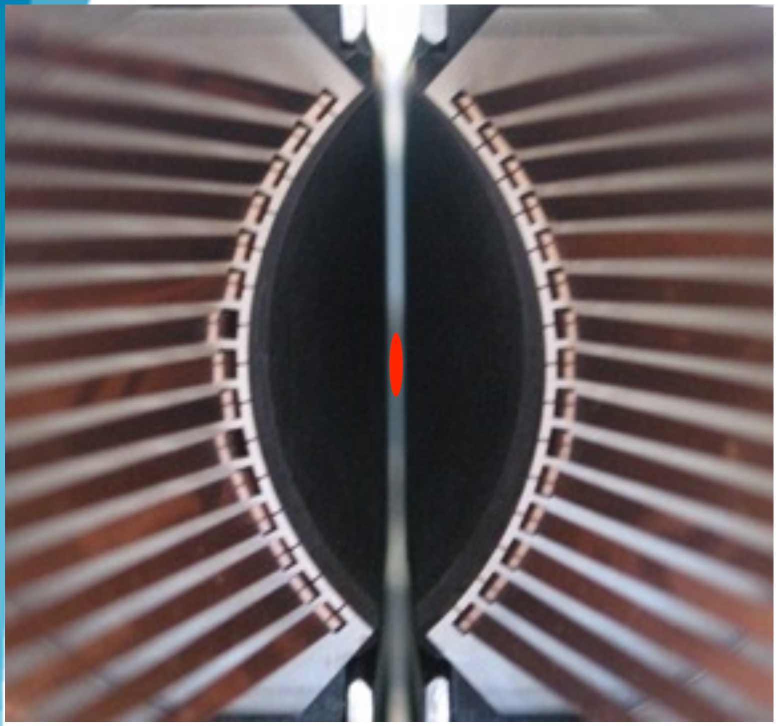
Physics debris collimation in the high-lumi IR1/5.



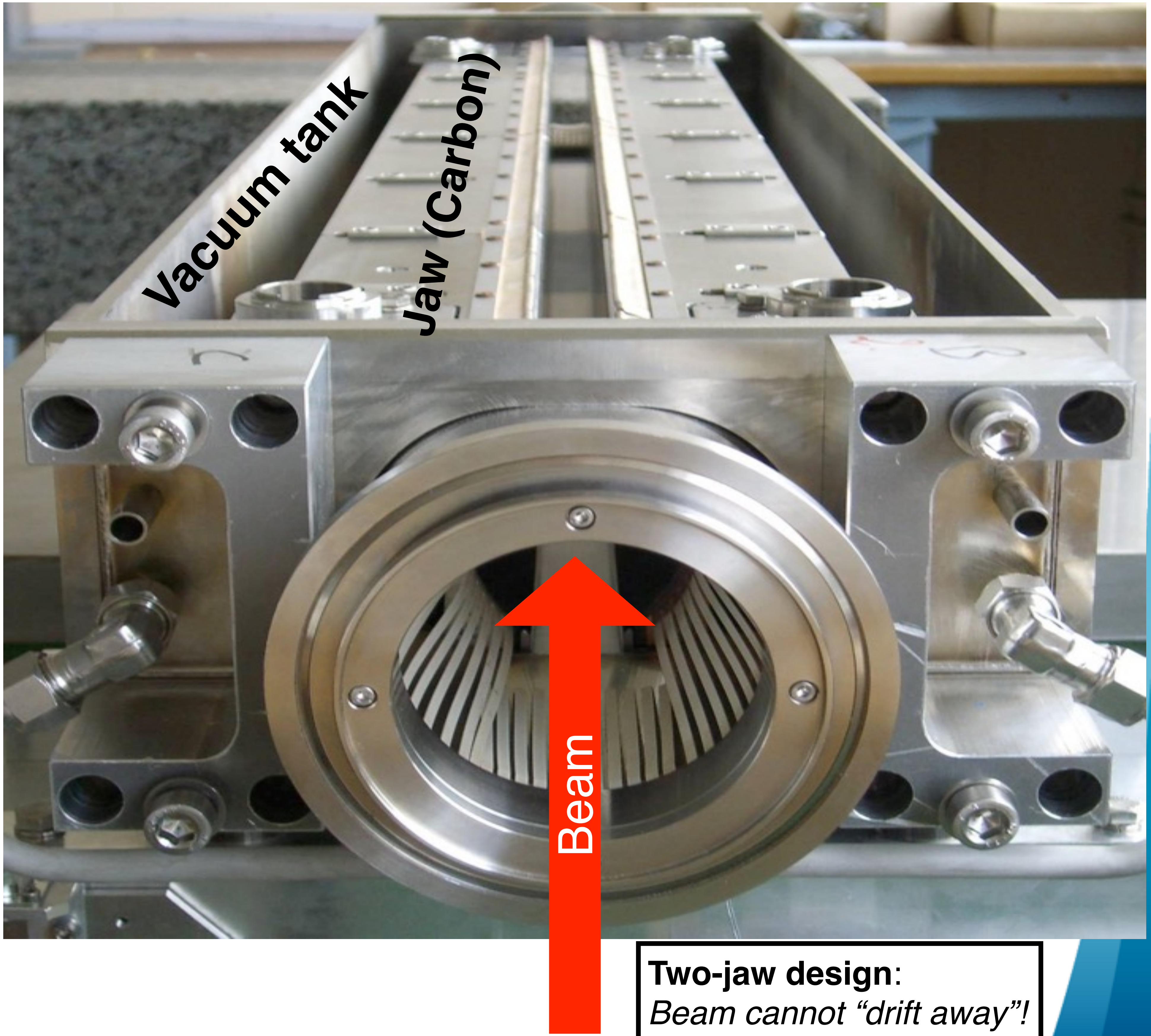
Total of 118 [was 108 in Run I] **collimators (108** [was 100] **movable).**

Collimator design and main features

What the beam sees!



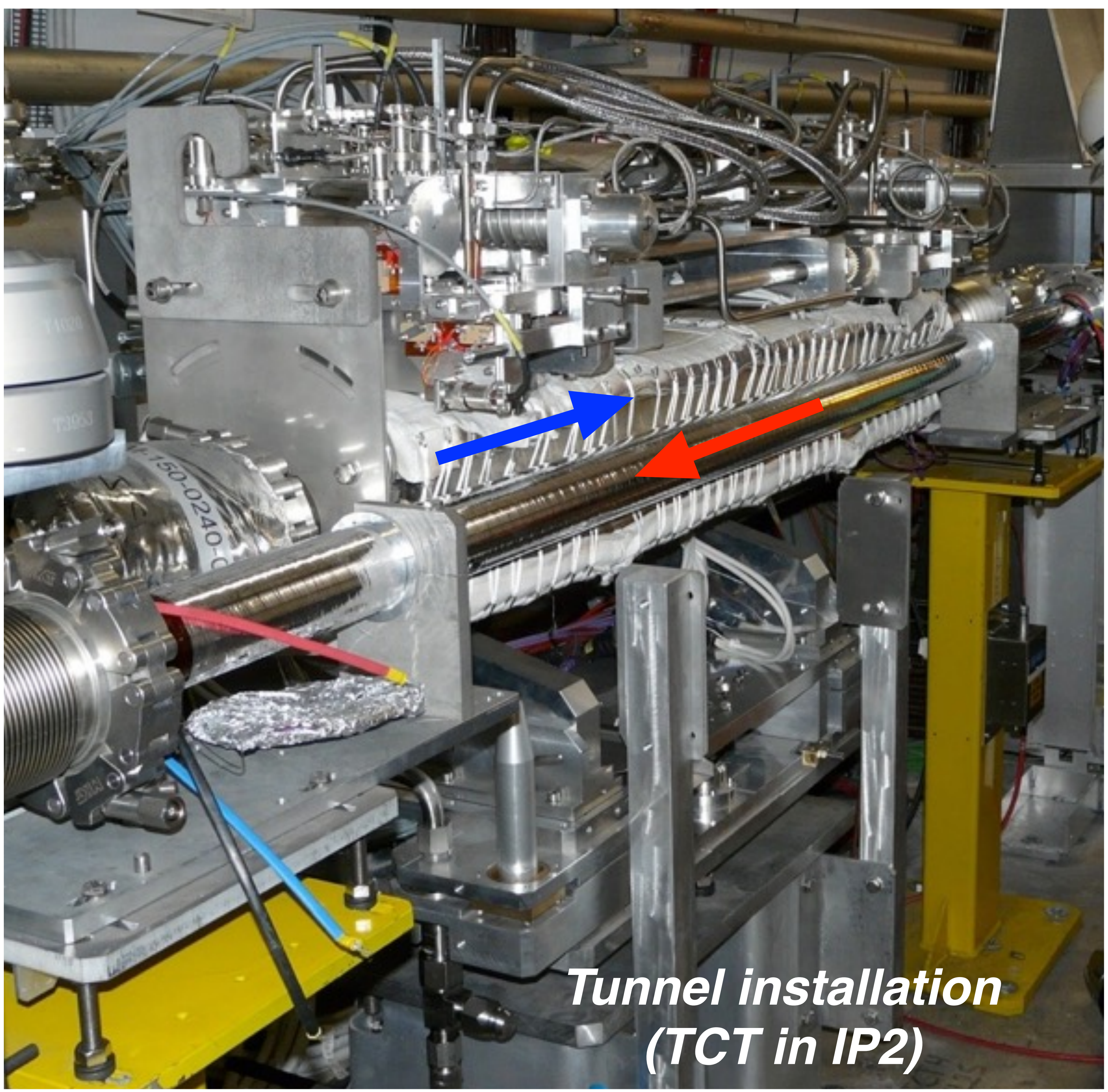
~ 2 mm

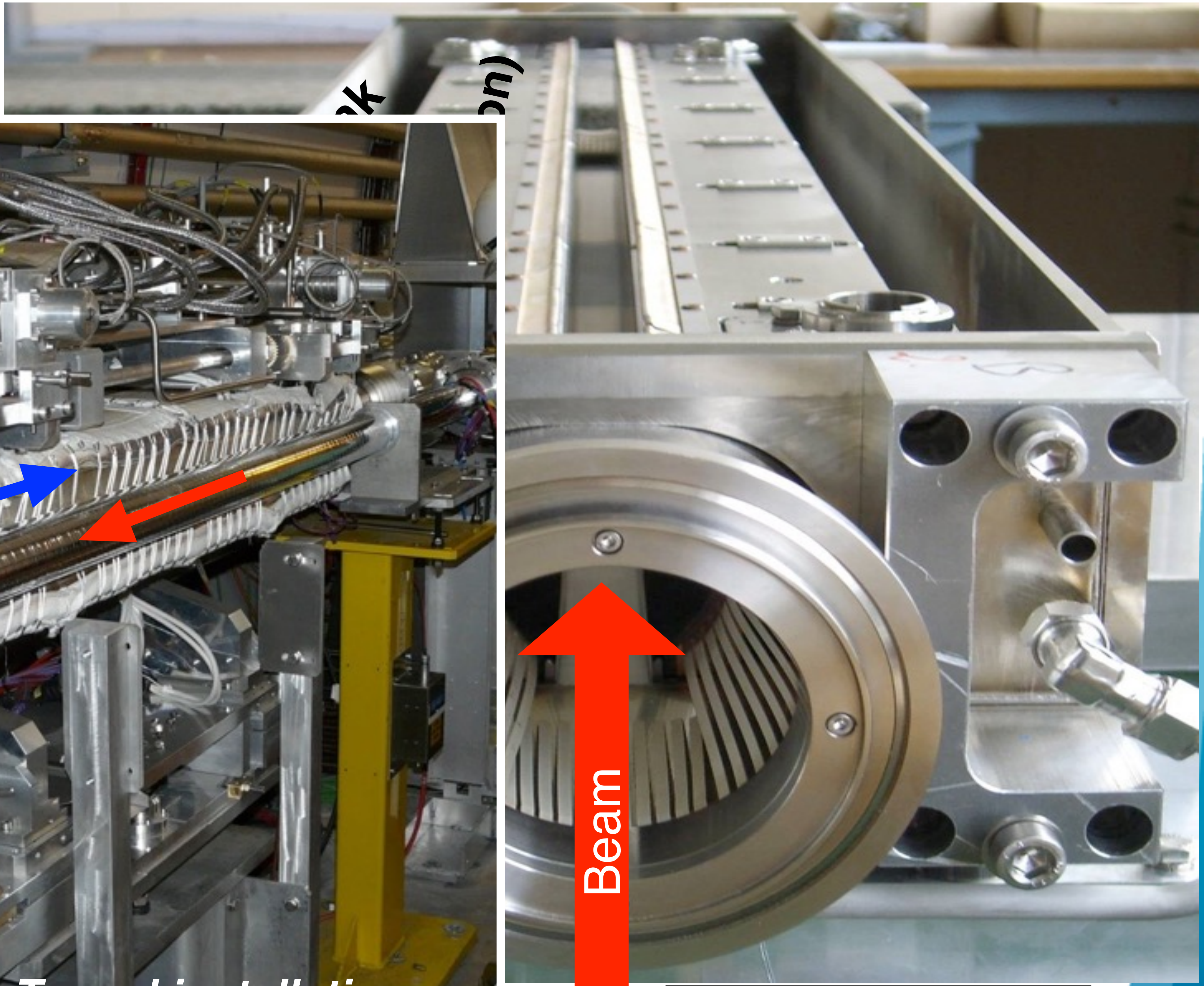


Two-jaw design:
Beam cannot "drift away"!

Collimator design and main features

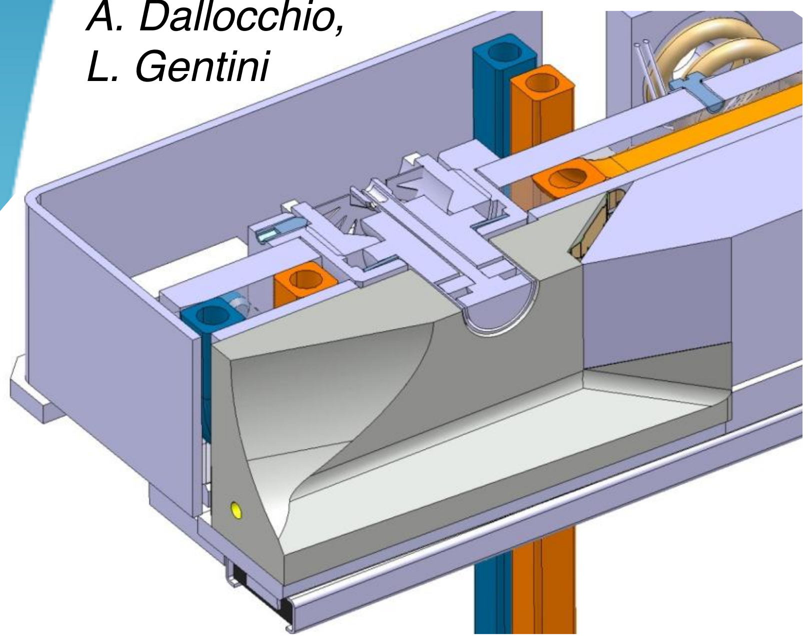
What the beam sees!

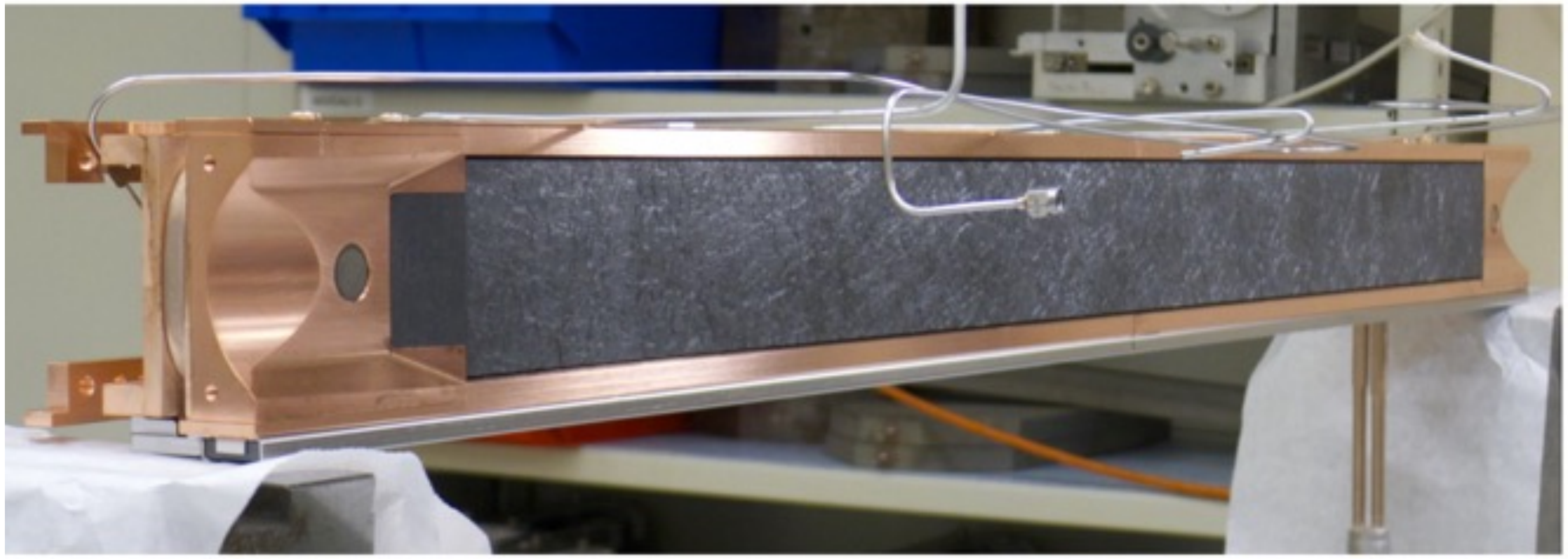




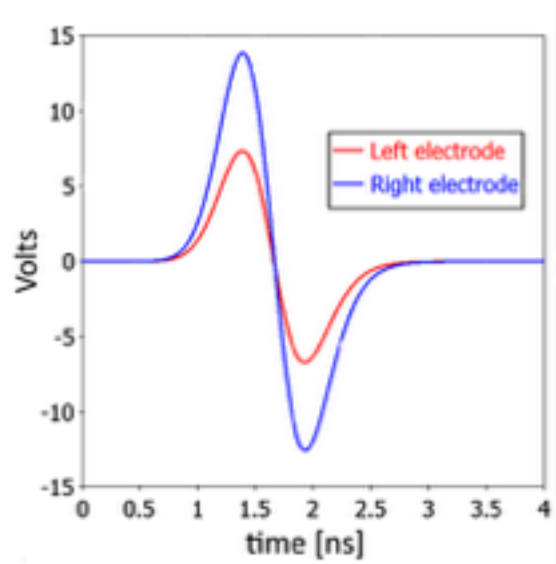
Two-jaw design:
Beam cannot "drift away"!

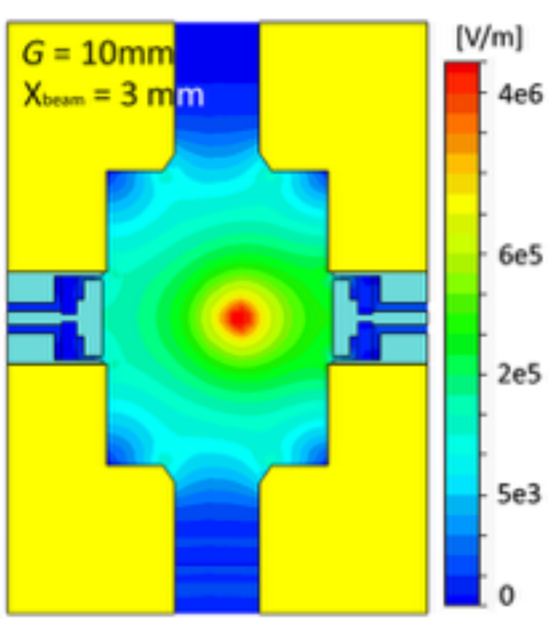
New: BPM-integrated design

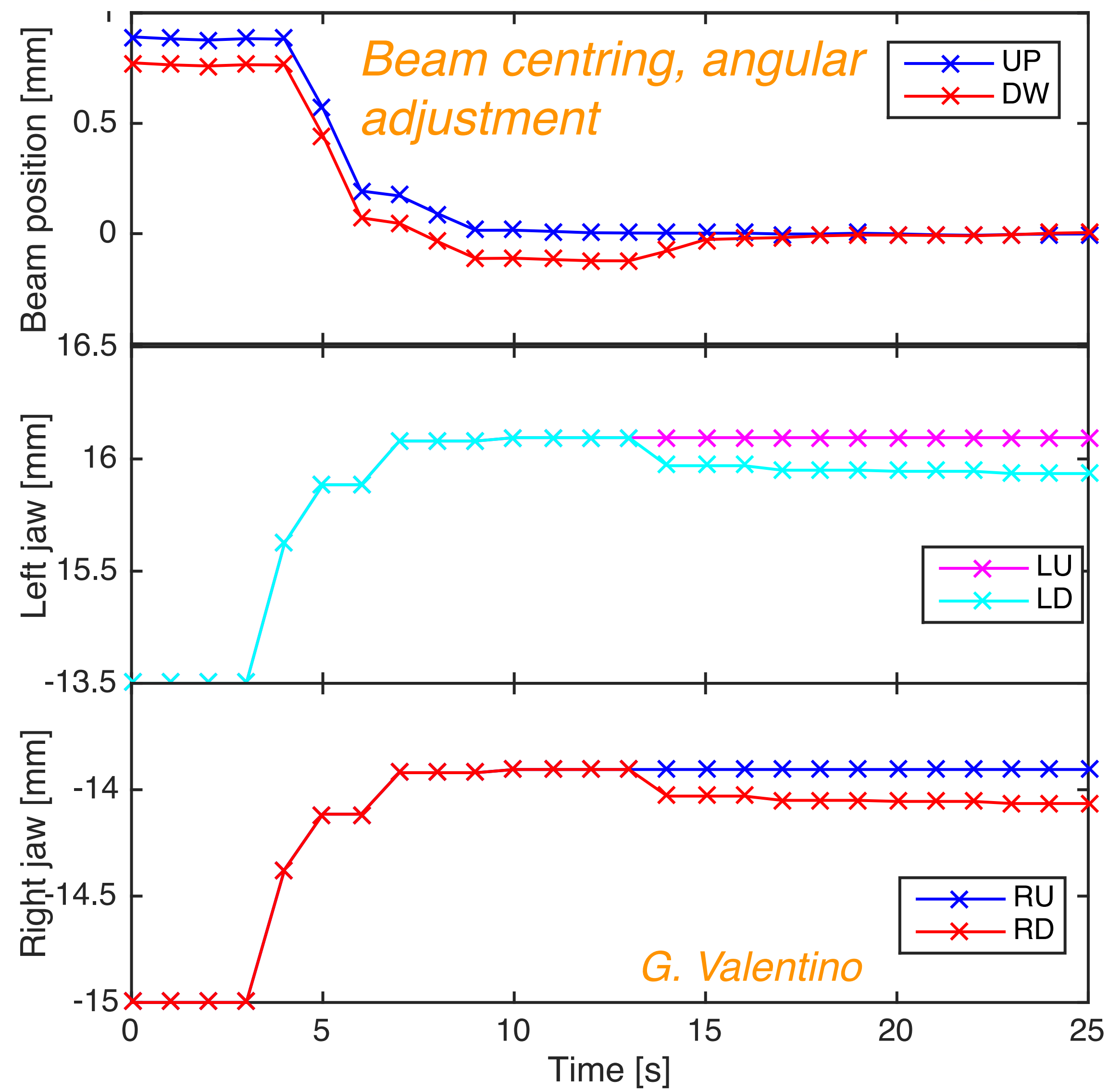




18 new BPM collimators installed around experiments in 2014 for faster alignment and orbit monitoring.







Collimator materials — inventory

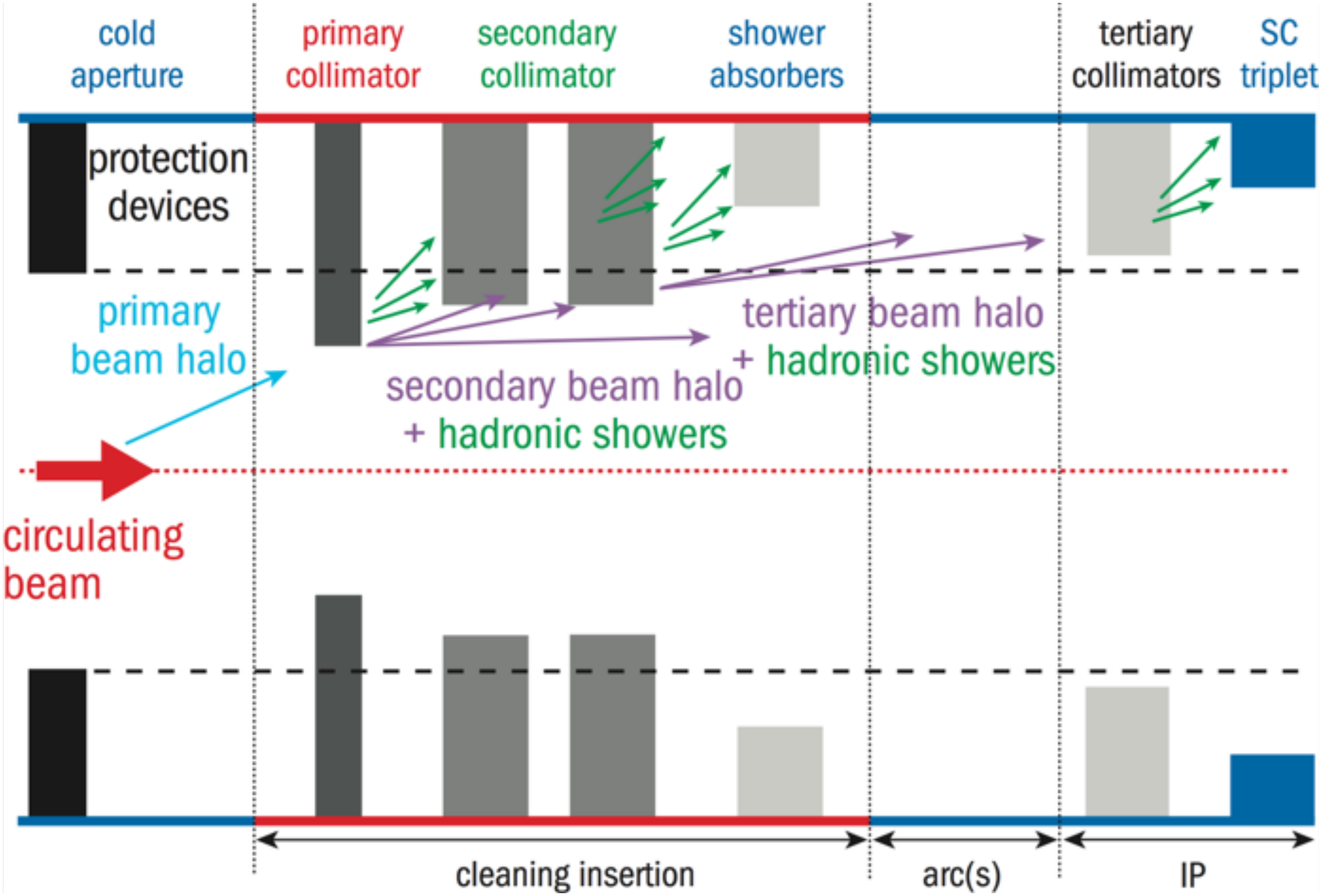
Functional type	Name	Plane	Num.	Material
Primary IR3	TCP	H	2	CFC
Secondary IR3	TCSG	H	8	CFC
Absorbers IR3	TCLA	H,V	8	Inermet180
Primary IR7	TCP	H,V,S	6	CFC
Secondary IR7	TCSG	H,V,S	22	CFC
Absorbers IR7	TCLA	H,V	10	Inermet180
Tertiary IR1/2/5/8	TCTP	H,V	16	Inermet180
Physics absorbers IR1/5	TCL	H	8	Cu
	TCL	H	4	Inermet180
Dump protection IR6	TCSP	H	2	CFC
	TCDQ	H	2	C
Passive absorbers IR3	TCAP	–	4	Inermet180
Passive absorbers IR7	TCAP	–	6	Inermet180
Inj. prot. IR2/8	TDI	V	2	hBN, Al, Cu, Be
	TCLI	V	4	Gr
	TCDD	V	1	CFC
Inj. prot. (lines)	TCDI	H,V	13	Gr

Vacuum guidelines and requirements were taken into account from initial phases of production.
Careful selection of well-qualified materials.

Bake-able to 250 deg during 24h (> 60 over 20 years)
Clean, with no traces of hydrocarbons, organic and inorganic residues
(partial pressure < 10^{-11} mbar)
Leak tight: global helium leak rate < 10^{-10} mbar.l/s
Outgassing rate 10^{-12} mbar.l/s.cm2 i.e. furnace treatment at 1000 deg
under vacuum (carbon surface, stainless steel, ferrites …)
Total outgassing rate ~ 10^{-7} mbar.l/s

V. Baglin for the vacuum team

Multi-stage cleaning — a beam dynamics topic

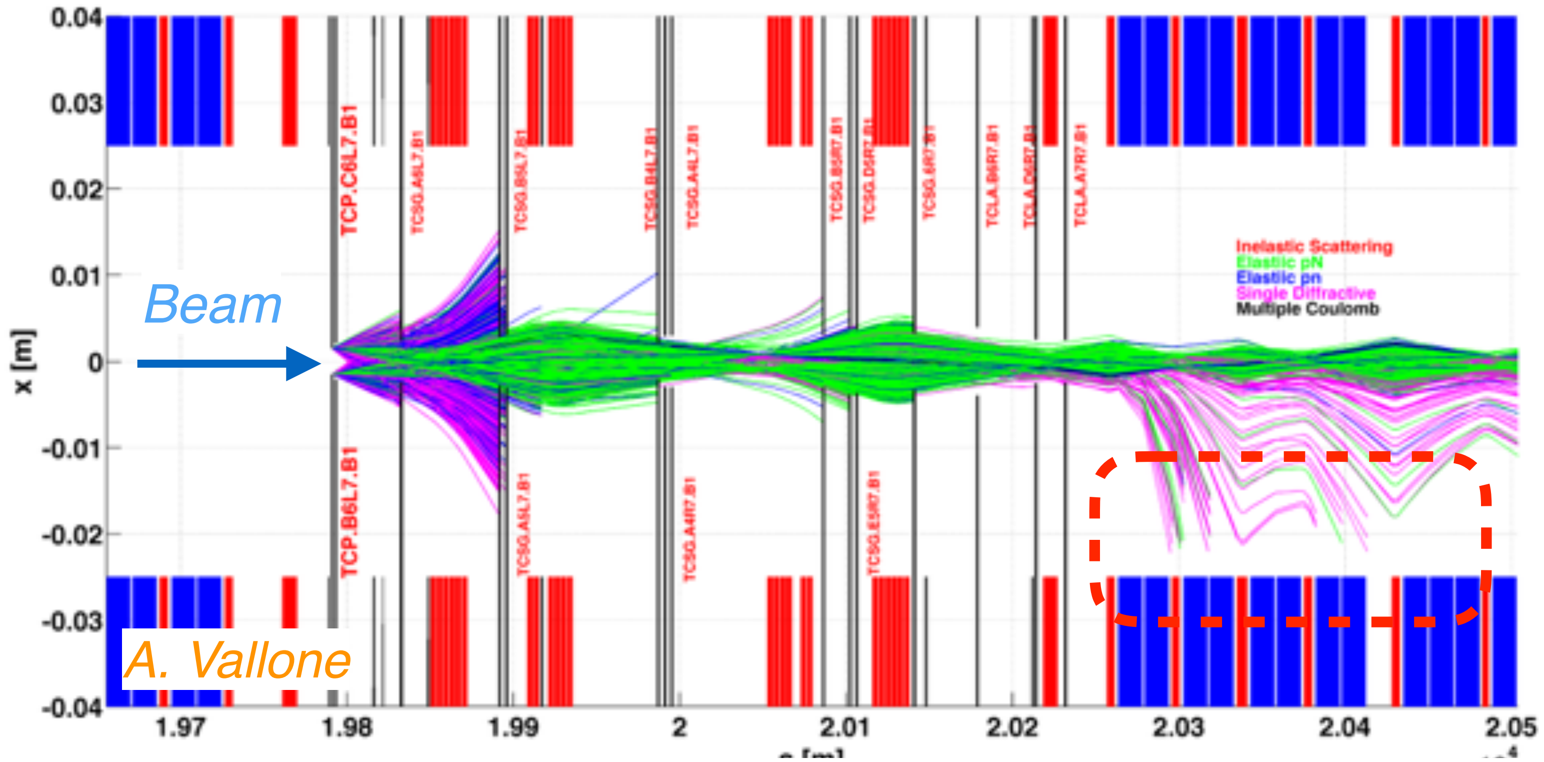


Complex beam dynamics

meets

Material science, impedance, interaction with matter, operational optimisation, …

Betatron cleaning: simulation and measurement

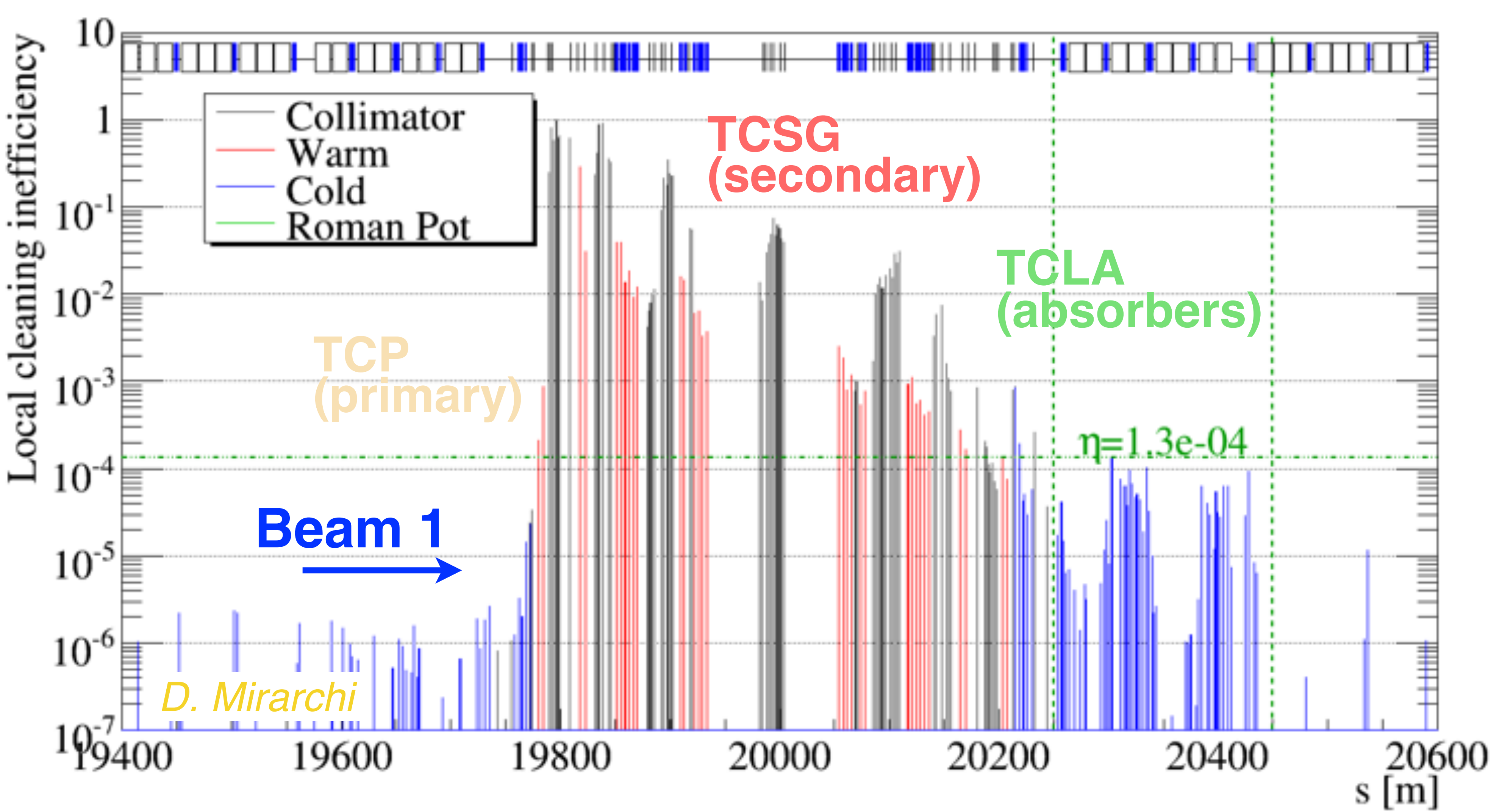


Multi-turn cleaning process "limited" by dispersive losses in the dispersion suppressors downstream of the collimation insertion.

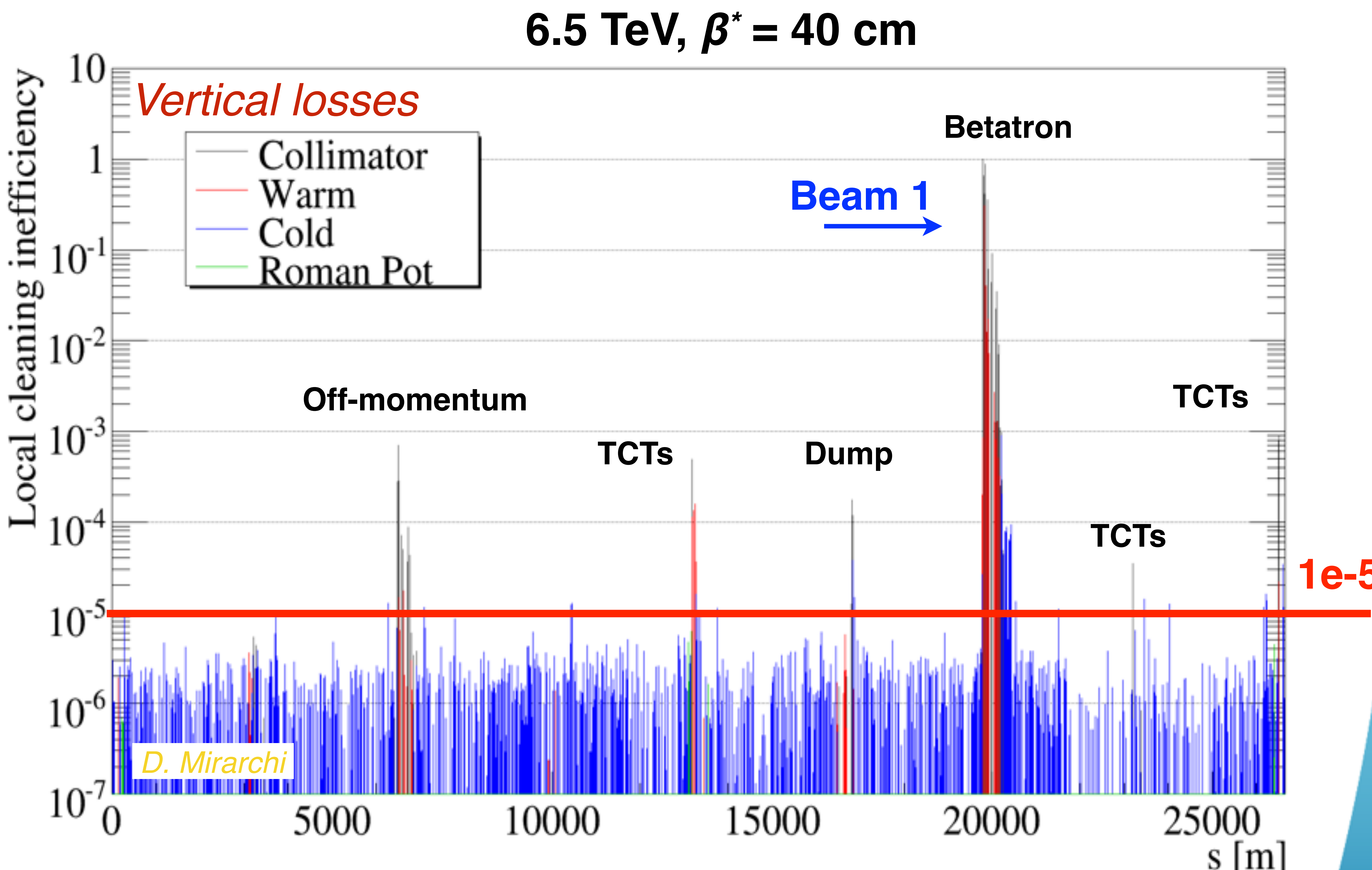
<u>Cleaning measurement</u>: controlled excitation of beams (white noise in transverse damper), then plot ratio of losses:

$\boxed{BLM_i \ / \ BLM_{TCP}}$

(BLM = beam loss monitor)



Overall cleaning performance



Excellent cleaning: highest cold losses ~ 0.0001!

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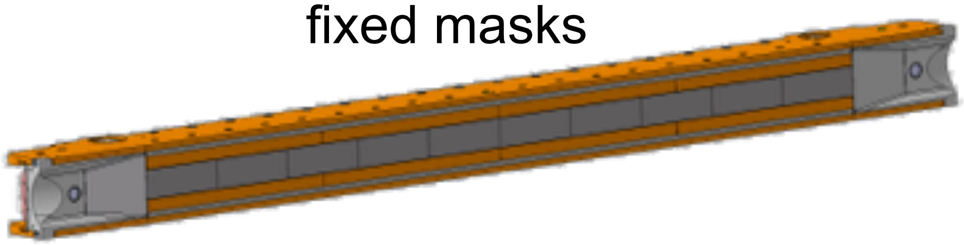
- LHC Collimation
  - Overall layout and collimator design
  - Beam cleaning performance
- **Upgrade plans for HL-LHC**
  - **New challenges for the upgrade**
  - **Crystal collimation developments**
  - **Status of hollow e-lens**
- Conclusions

HL-LHC: Scope of collimation upgrade

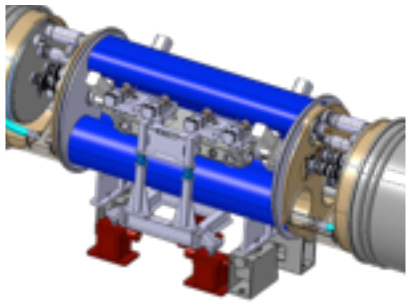
- Increased beam stored energy: 362MJ → **700MJ at 7 TeV**
  - ***Collimation cleaning*** *versus quench limits of superconducting magnets.*
  - *Machine protection constraints from **beam tail** population*
    (7 MJ above 3 sigmas even for perfect Gaussian tails!).
- Larger bunch intensity (I_b=2.2x10^{11}p) in smaller emittance (2.2 μm)
  - ***Collimation impedance*** *versus beam stability.*
  - ***Collimator robustness*** *against regular and abnormal beam losses*
    at injection as well as top energy.
- Larger p-p luminosity (1.0 x 10^{34}cm^{-2}s^{-1} → **5.0-7.5 x 10^{34}cm^{-2}s^{-1}**)
  - *Need to improve the **collimation** of **physics debris**.*
  - *Overall upgrade of the **collimation layouts** in the insertion regions.*
- Much **smaller β^*** in the collision points (55 cm → 15 cm)
  - *Cleaning and protection of high-luminosity insertions and physics background.*
- Operational efficiency is a critical for HL-LHC!
  - *Reliability of high precision devices in high radiation environment; alignment.*
- Upgraded ion performance (6 x 10^{27}cm^{-2}s^{-1}, i.e. 6 x nominal)

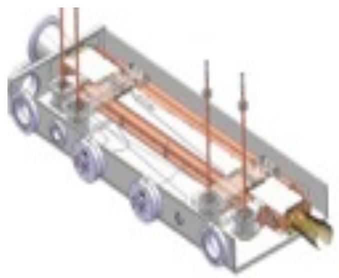
Collimation upgrade baseline

Completely new layouts
Novel materials: TCTs in CuCD
IR1+IR5, <u>per beam</u>:
- 4 tertiary collimators
- 3 physics debris collimators
- fixed masks

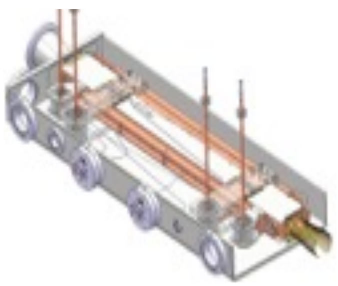


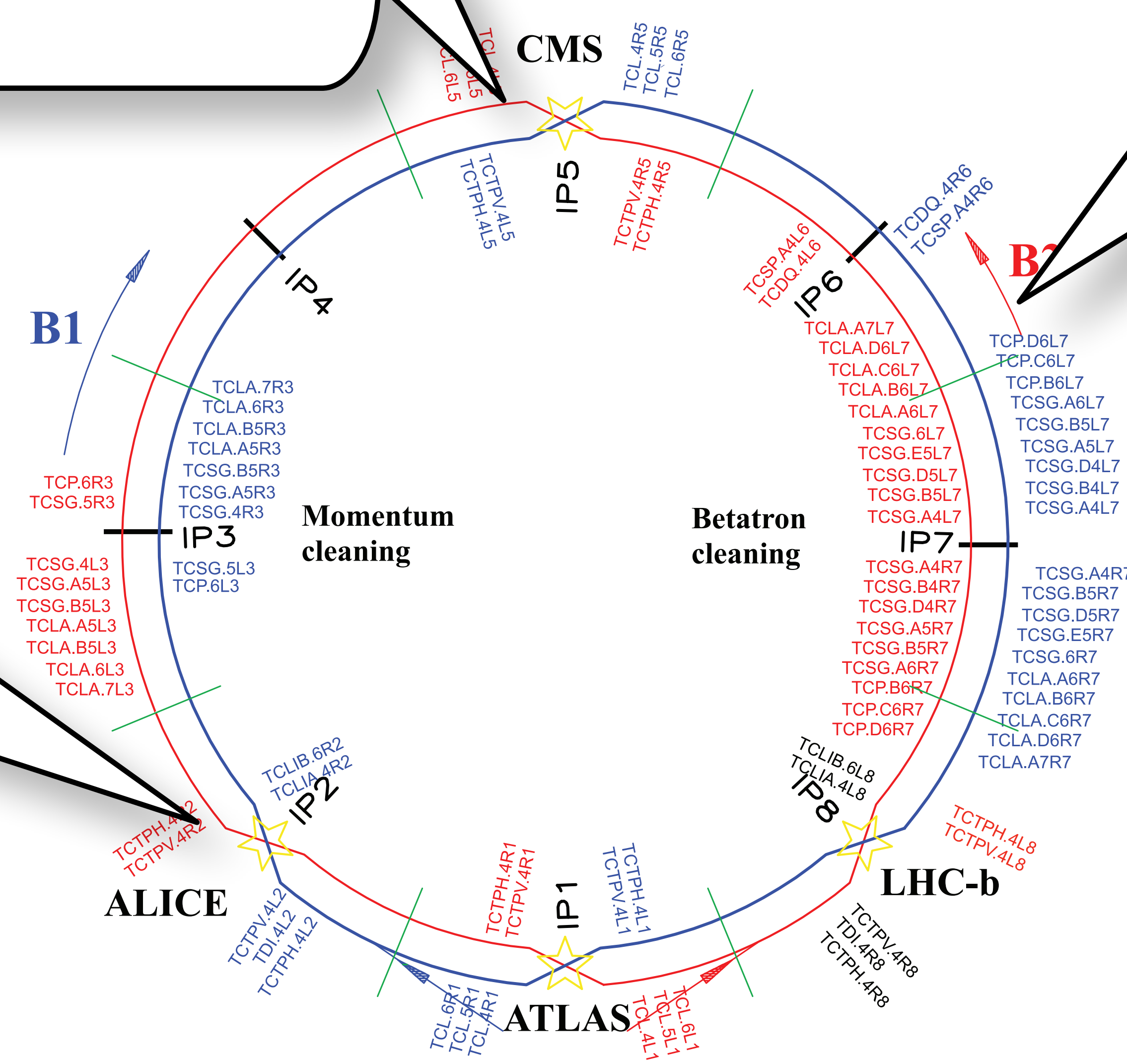
Cleaning: DS coll. + 11T dipoles, 1 unit per beam



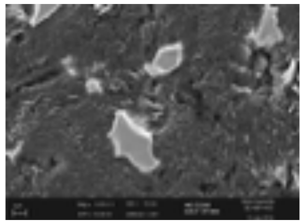


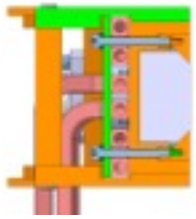
Ion physics debris: DS collimation

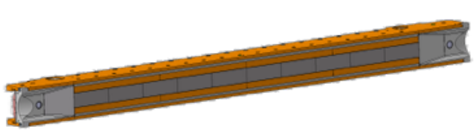




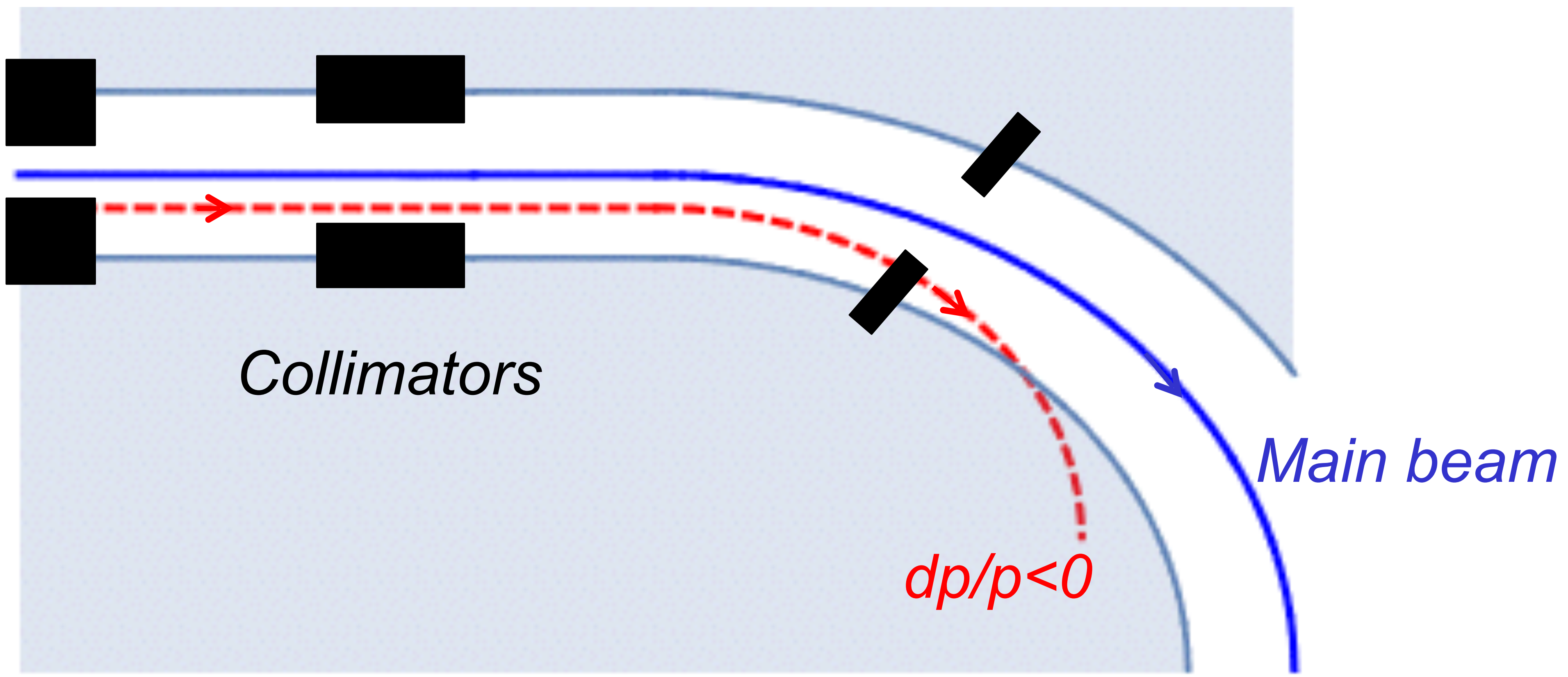
Low-impedance, high robustness secondary collimators: coated MoGr







Dispersion suppressor collimation



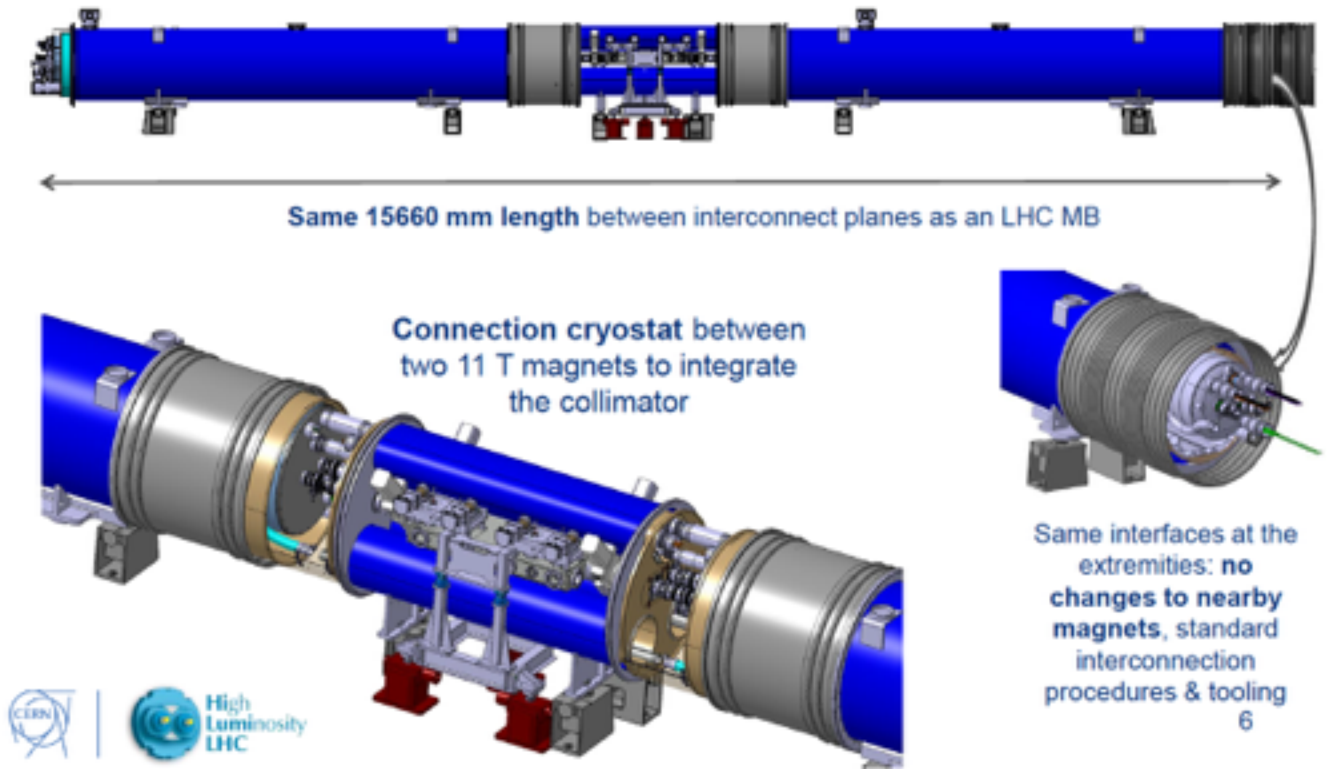
Dispersion suppressor collimation

- One standard 15 m long dipole replaced with 2 shorter 11 T dipole, making space for a warm collimator in the cold region. Installation: 2020!
- Similar solution around ALICE detector, with collimator in connection cryostat
- Cold collimator option was dismissed because of vacuum arguments

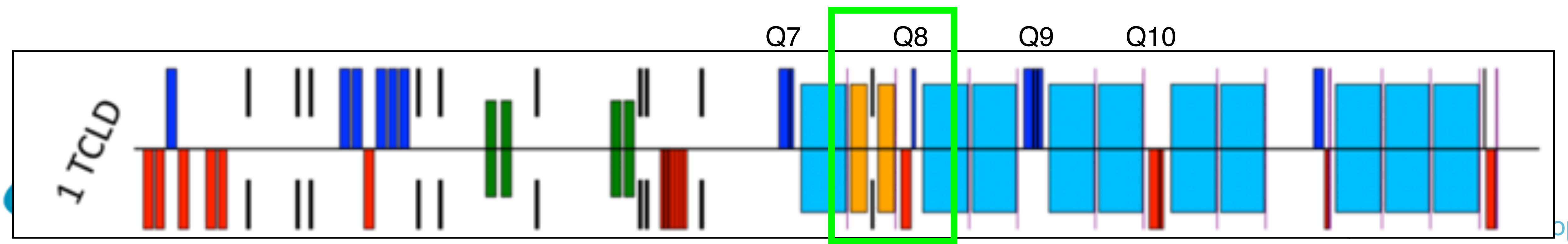
  Topics for discussion: cryo collimators for future multi-100MJ beams?

60cm active length, Tungsten alloy.

Design of “TCLD” collimator finalised: prototype under construction. Production: 4 collimator units for 2020.

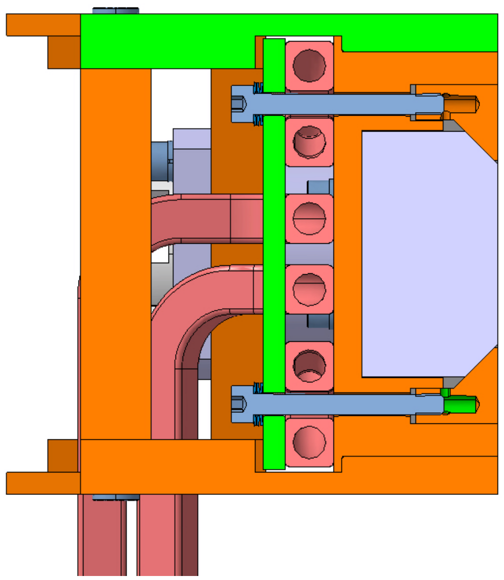


Courtesy D. Duarte.

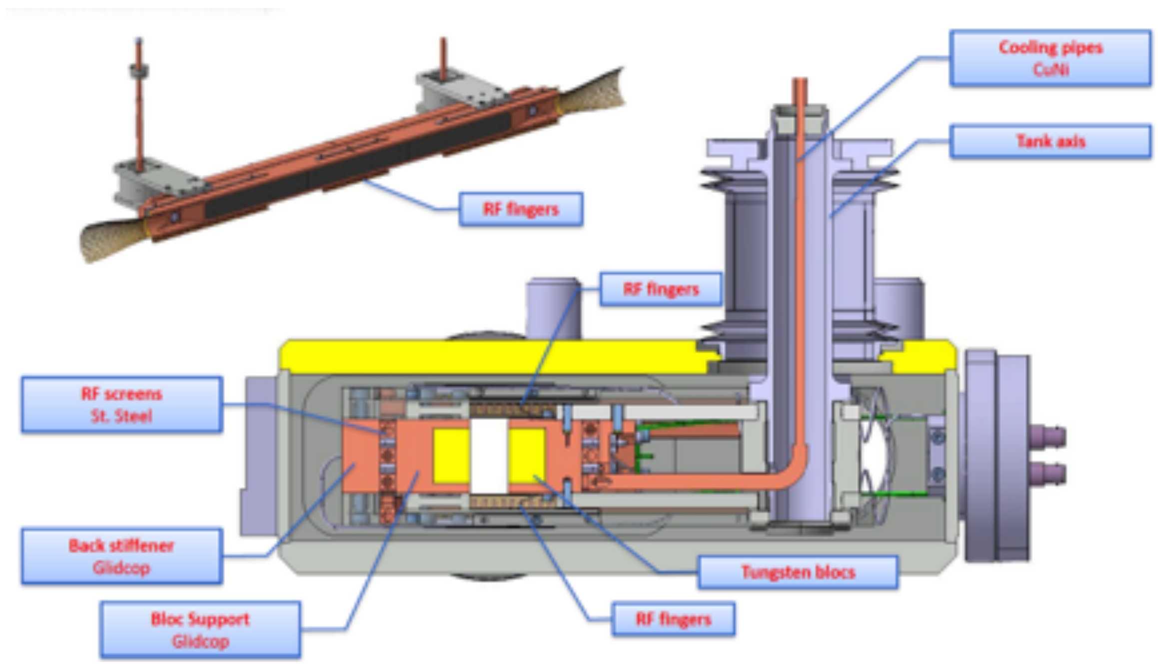


New collimator designs

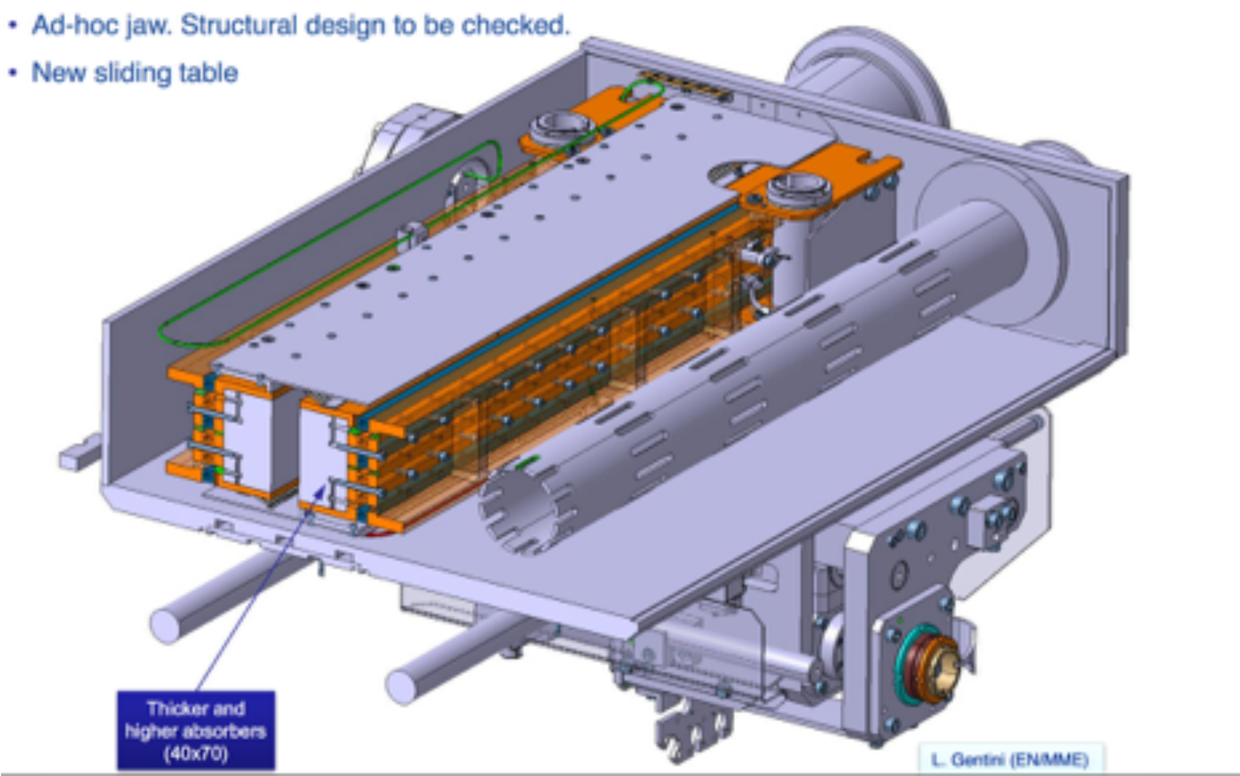
New secondary collimator jaw



TCLD for DS

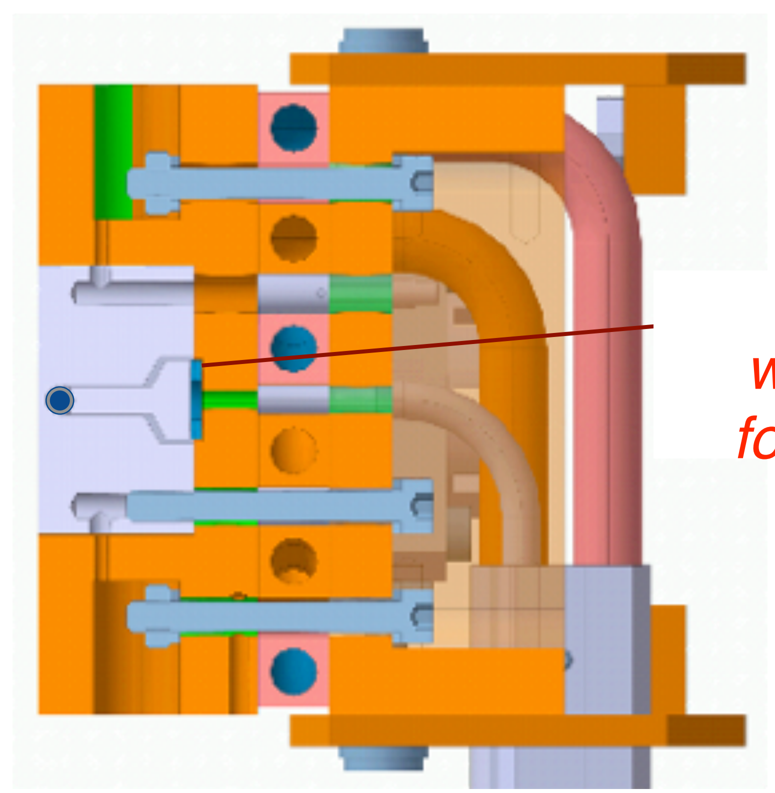


TCTX/TCLX for TAXN/D2 regions



Vacuum of second beam?

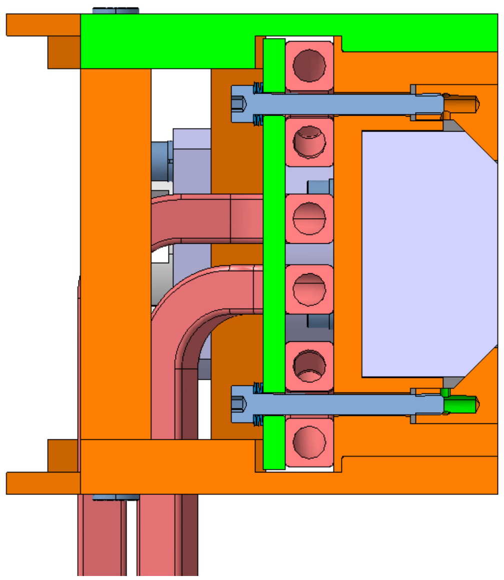
TCTPW for beam-beam compensation studies



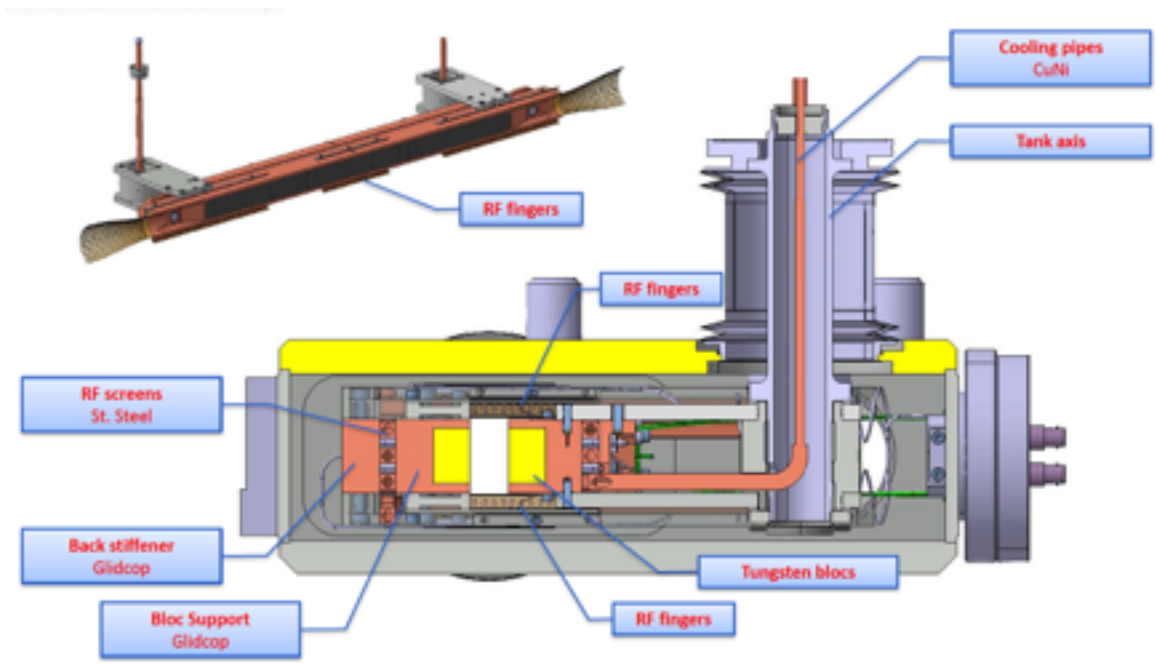
Tertiary collimator with embedded wire for long-range beam-beam MDs

New collimator designs

New secondary collimator jaw



TCLD for DS



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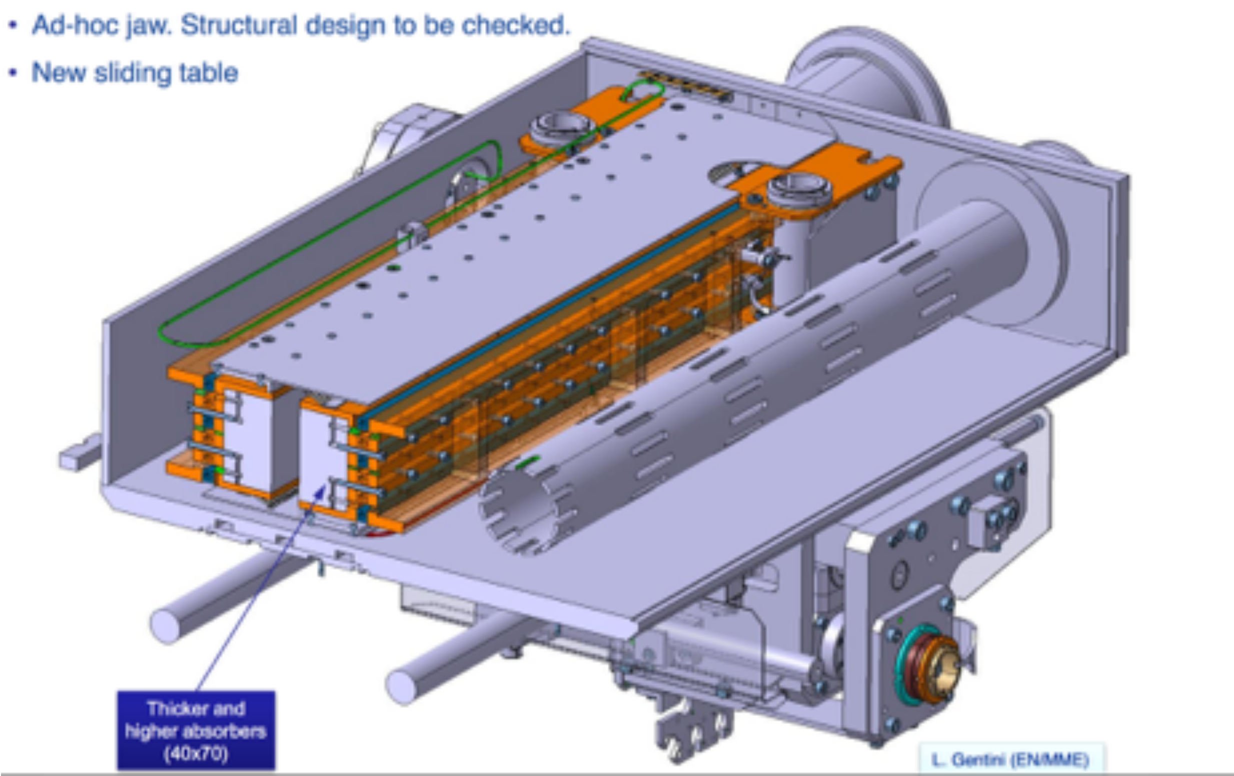
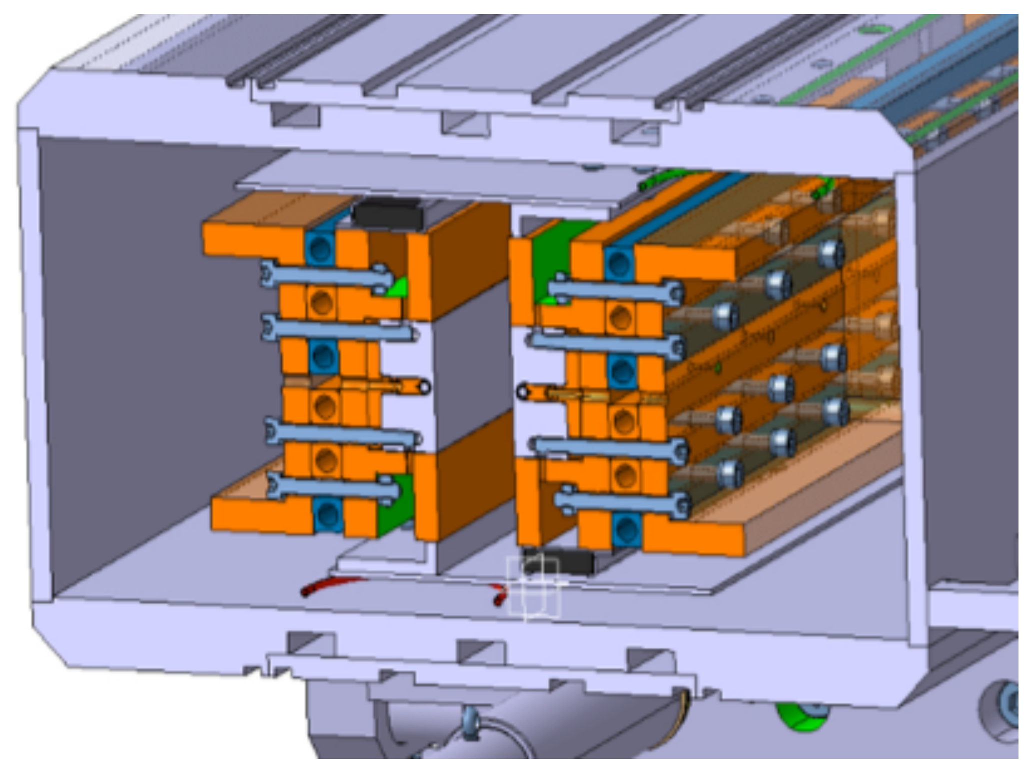


TCTPW for beam-beam compensation studies



Vacuum of second beam?

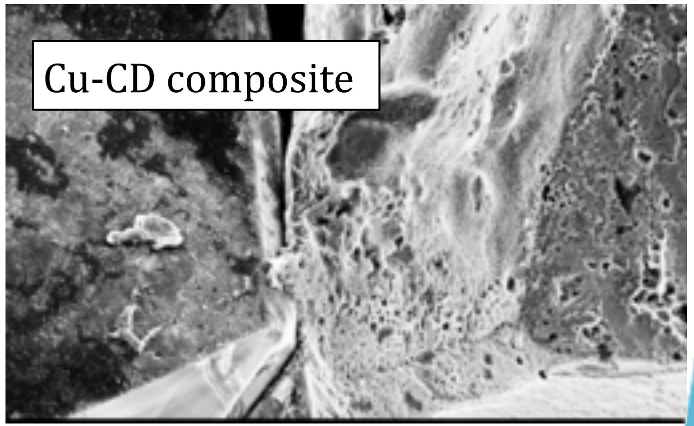
Advanced materials for future collimators

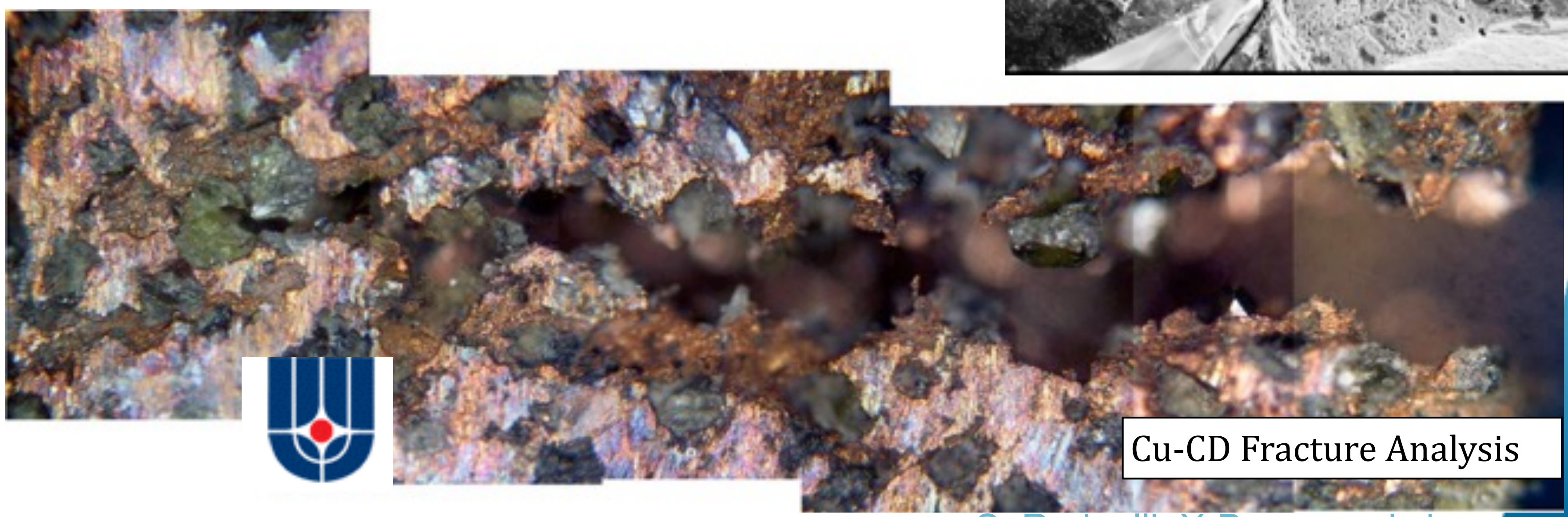
- **Scope:** more robust tertiary collimators; **low-impedance secondaries.**
  Most promising: Mo-Gr composited, with or without Mo coating.
  Copper Carbon-diamond (CuCD).
- **Our ambitious plan:**
  Build and install **12 low-impedance** collimators by **2020**!
- **Many challenges ahead (for a short time):**
  - Prototype will be installed next week in the LHC.
  - Production techniques for new materials, including coating
  - Material properties under high irradiation
  - **UHV behaviour of novel materials, with coating.**

Synergy : FCC collimation studies

Mo-Gr composite

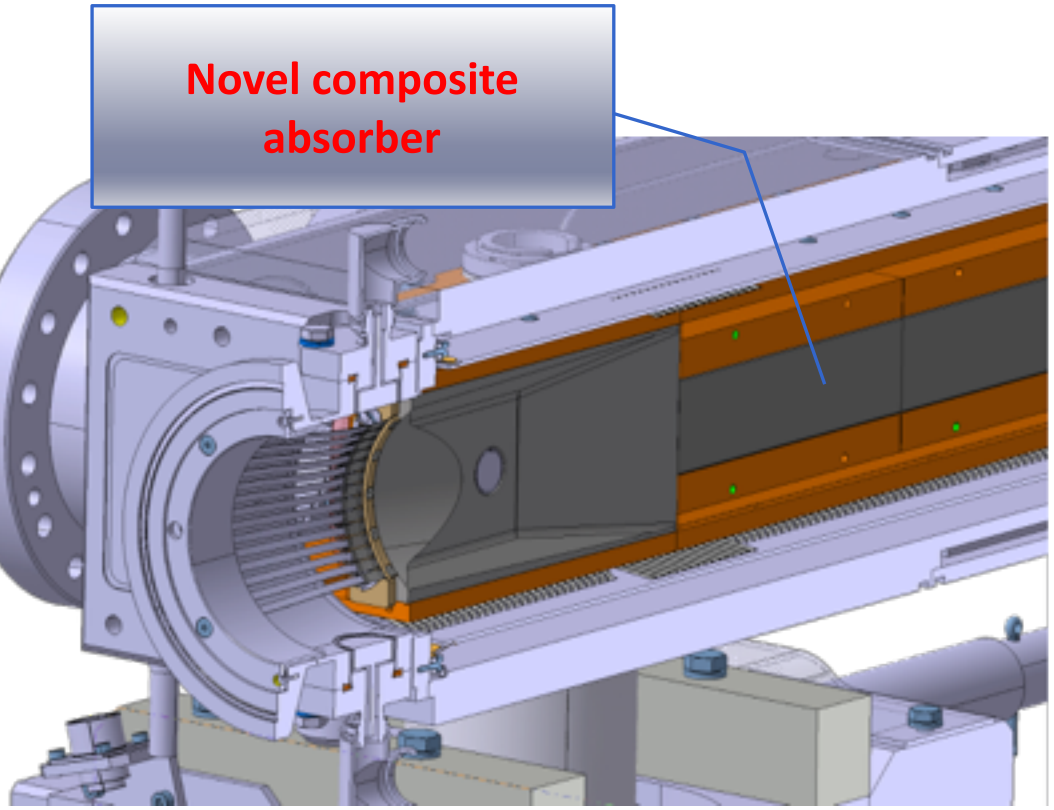
Cu-CD composite

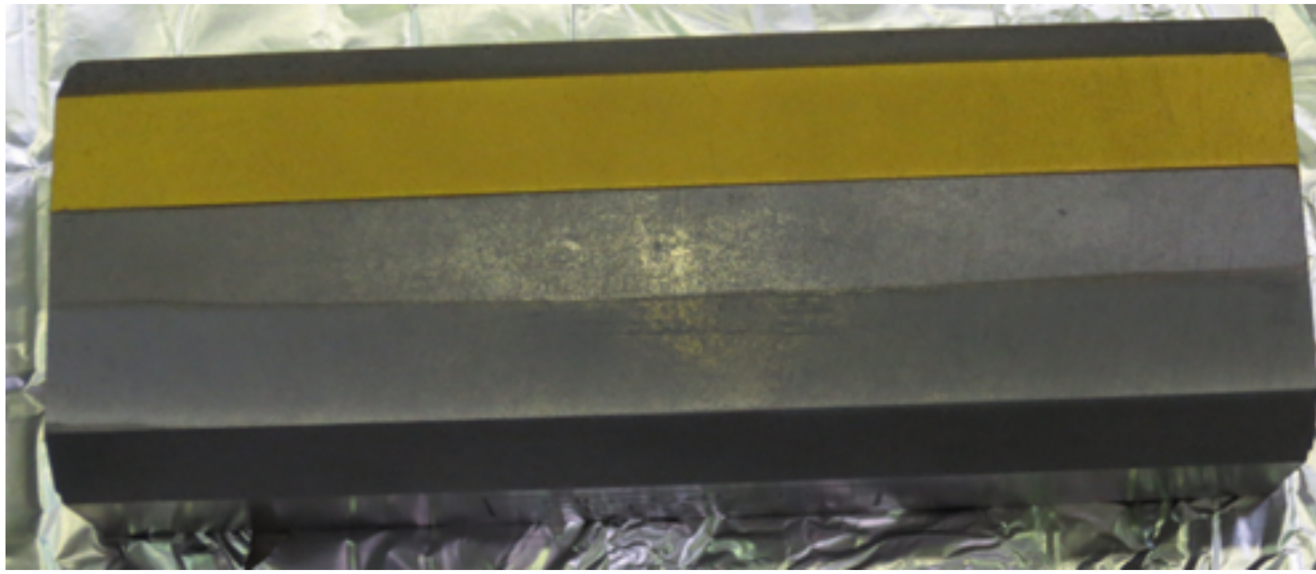




Cu-CD Fracture Analysis

Status of prototyping and vacuum





MoGr block coated with TiN (yellow top) and Mo (bottom)

Vacuum is a critical concern!
Collimator to be installed next week for beam tests in 2017.

C. Accettura, F. Carra

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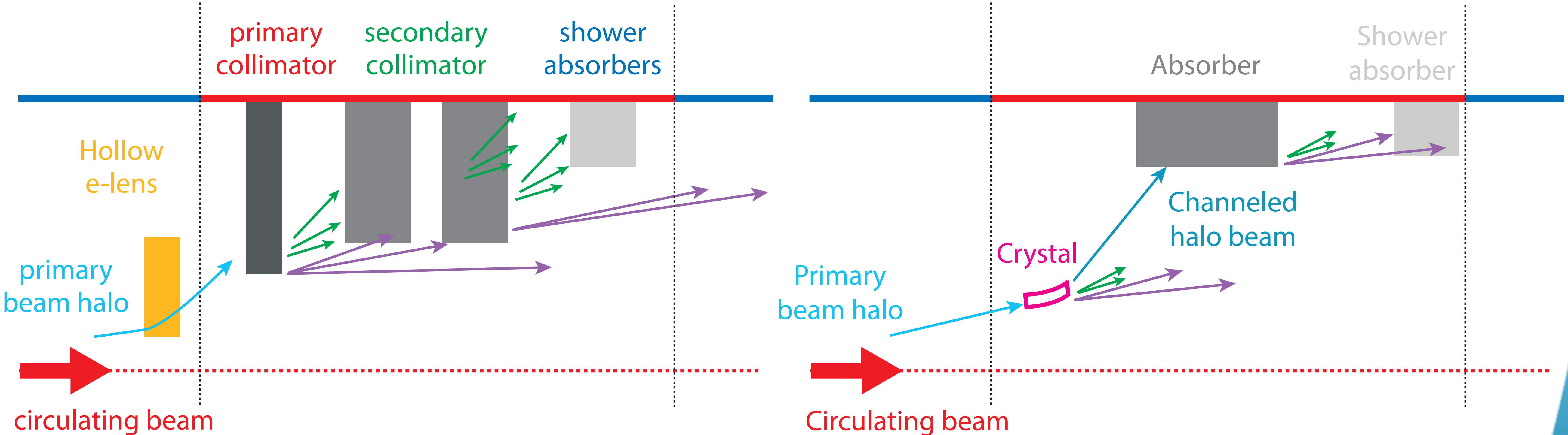
Advanced collimation studies

- Active halo control through **hollow electron-lenses**

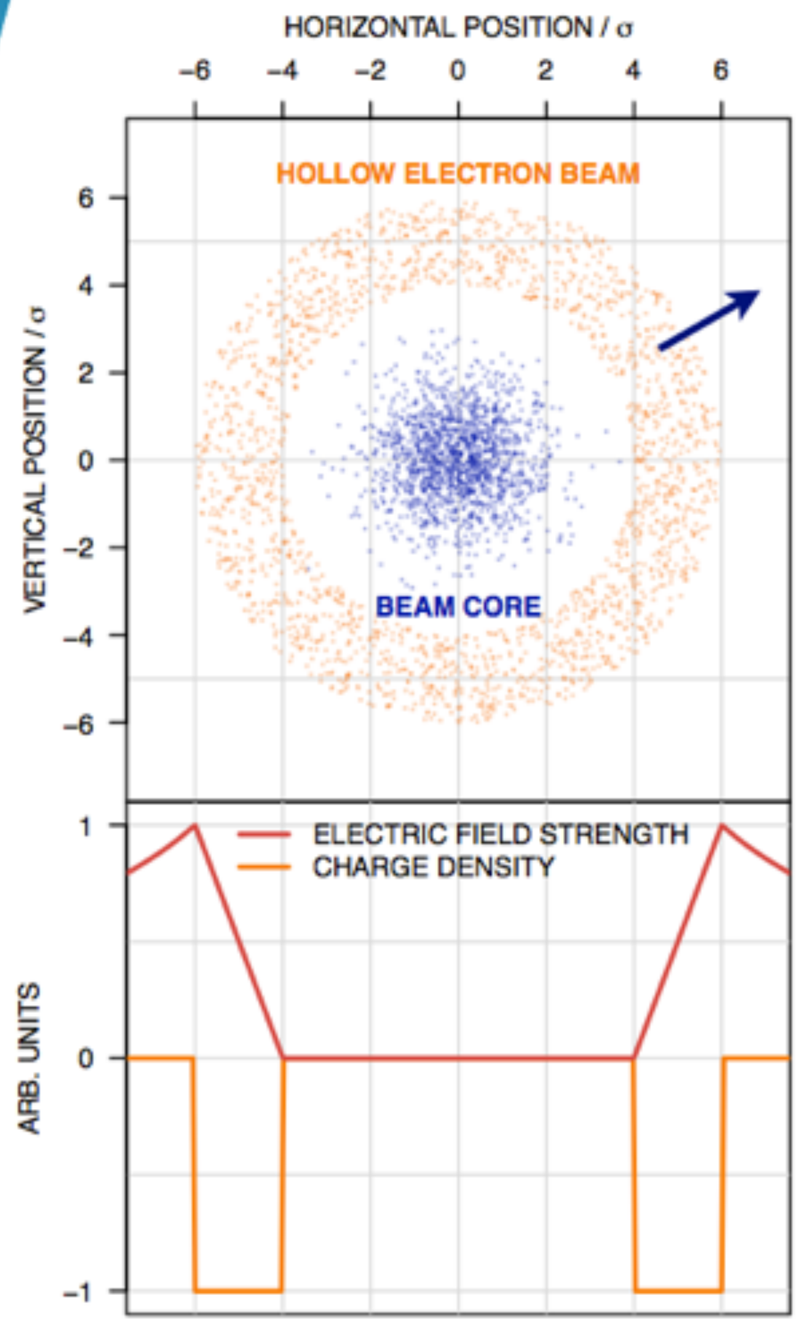
  *Recent **project review** on HEL: acknowledged the need for active halo controls at the HL-LHC and fully recommended to deploy HELs.*
  Details: https://indico.cern.ch/event/567839
  We are in the process of assessing the addition of HELs to the baseline.

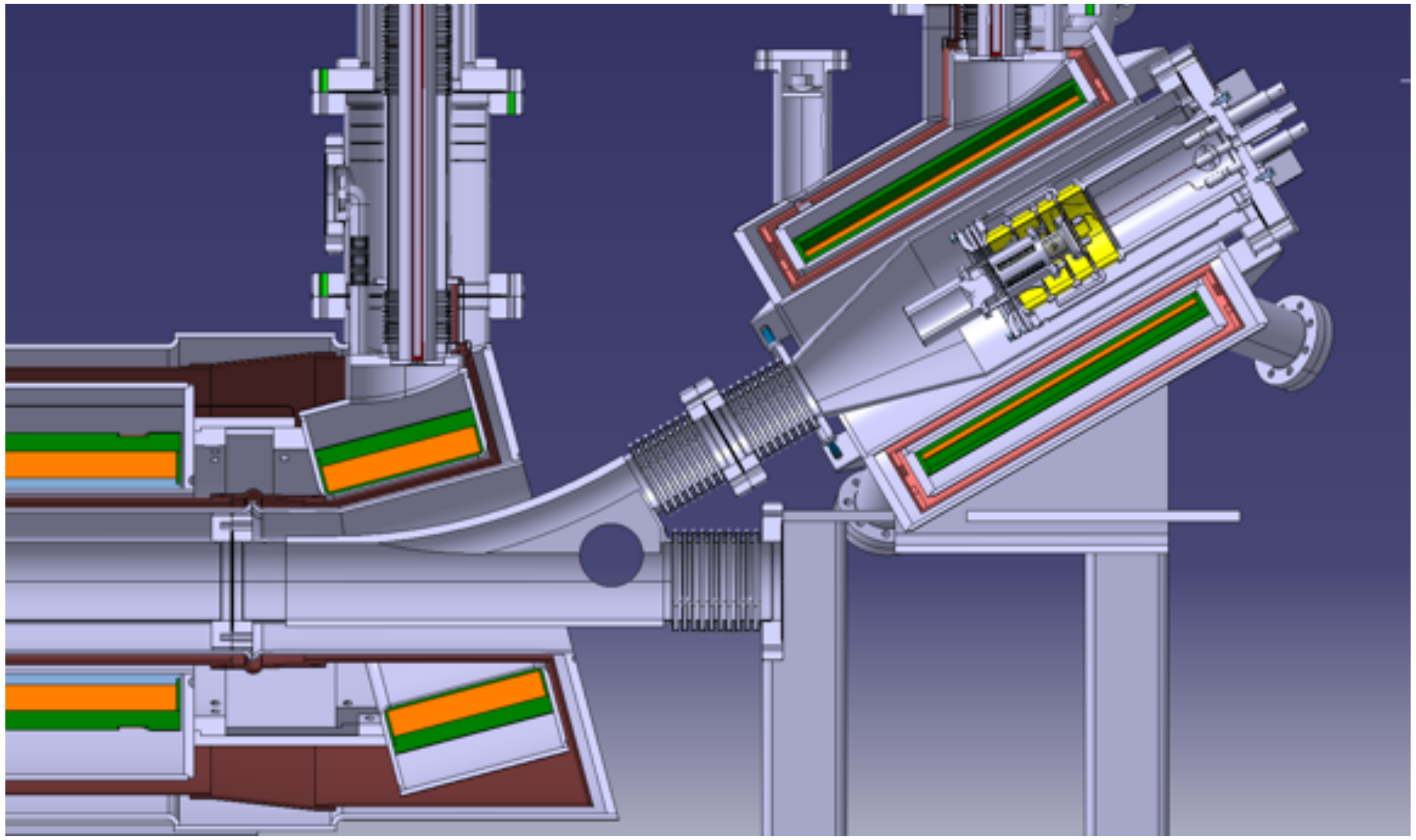
- **Crystal collimation** with bent crystals

  *Goals: improve **ion cleaning performance***
  LHC tests: first observation of channeling at 6.5 Z TeV (proton + Pb ions).



Hollow e-lens concept



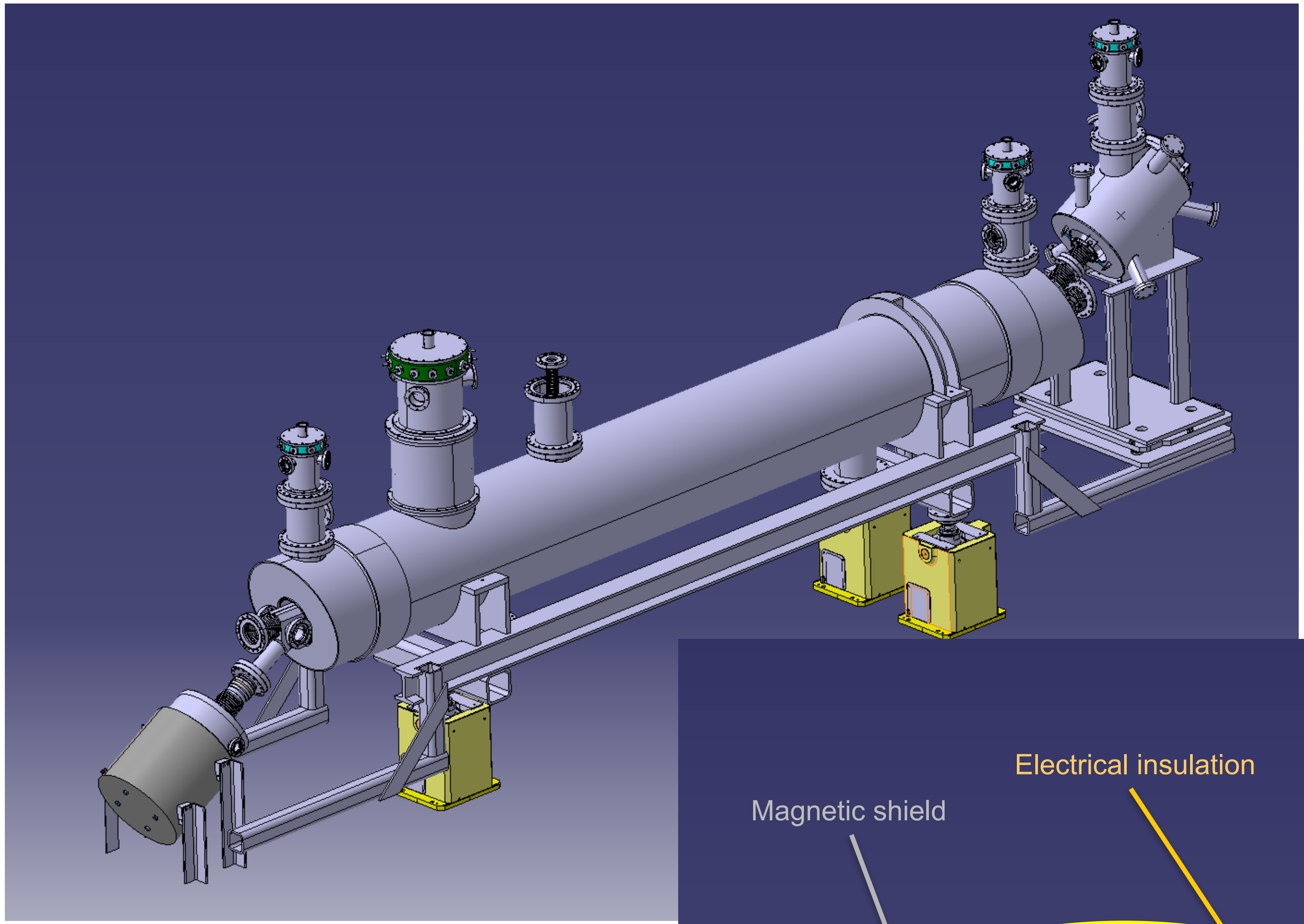


"Non-material" scraper — adds scraping functionality but particles are disposed of by the present collimation system.

Can be installed in other points than IR7, because kicks per turn are small.

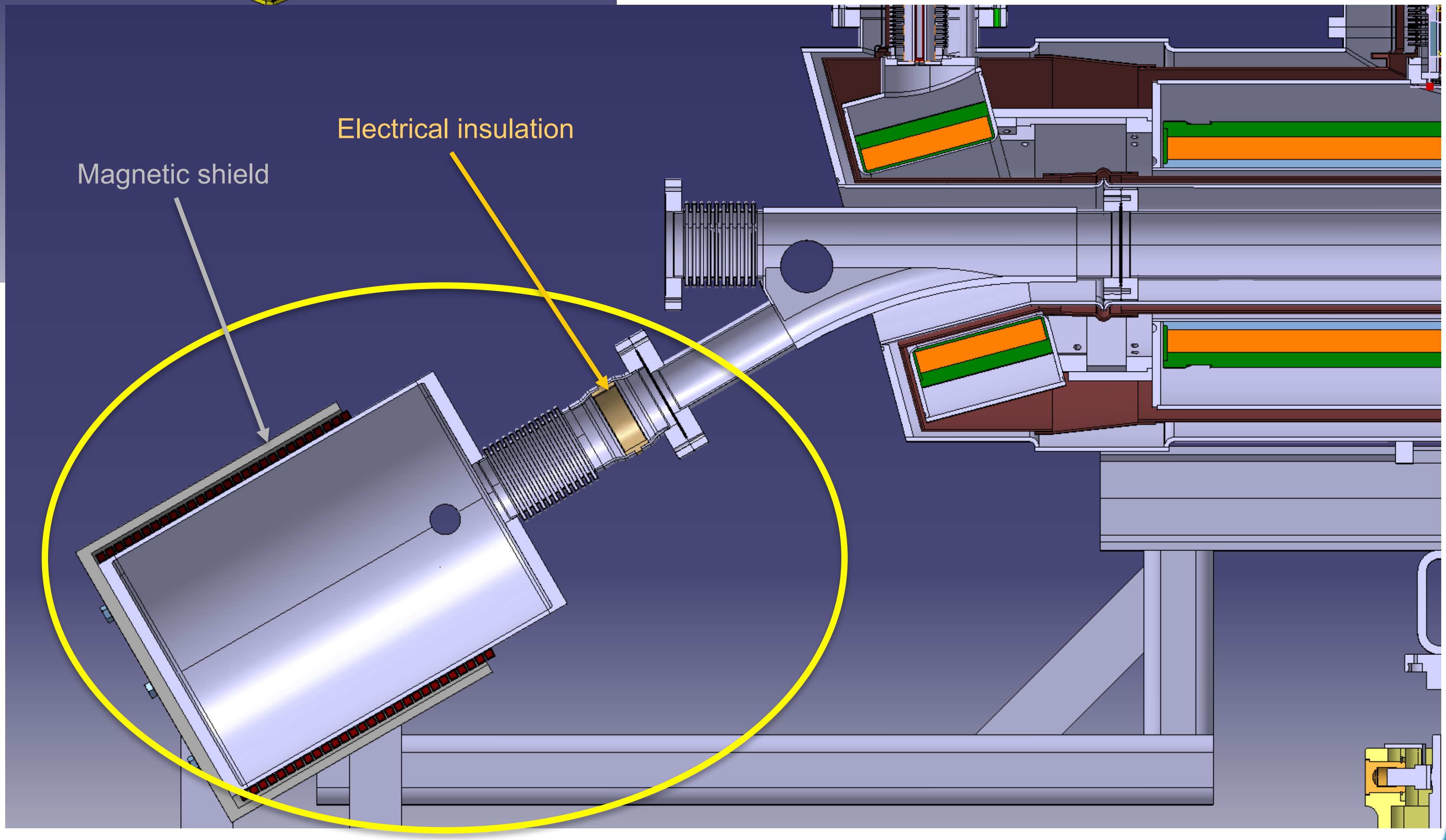
Require overlap of e- and proton beam over ~3 meters.

Hollow e-lens design



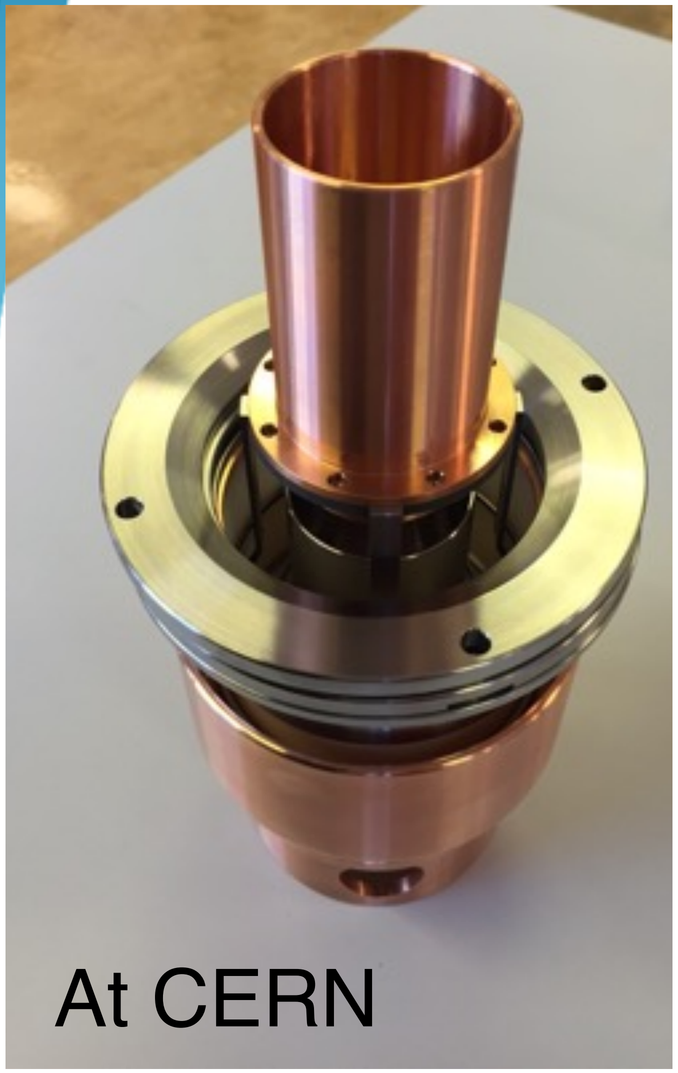
Technical design of hollow e-lens for the HL-LHC is well advanced! All key components have been addressed.

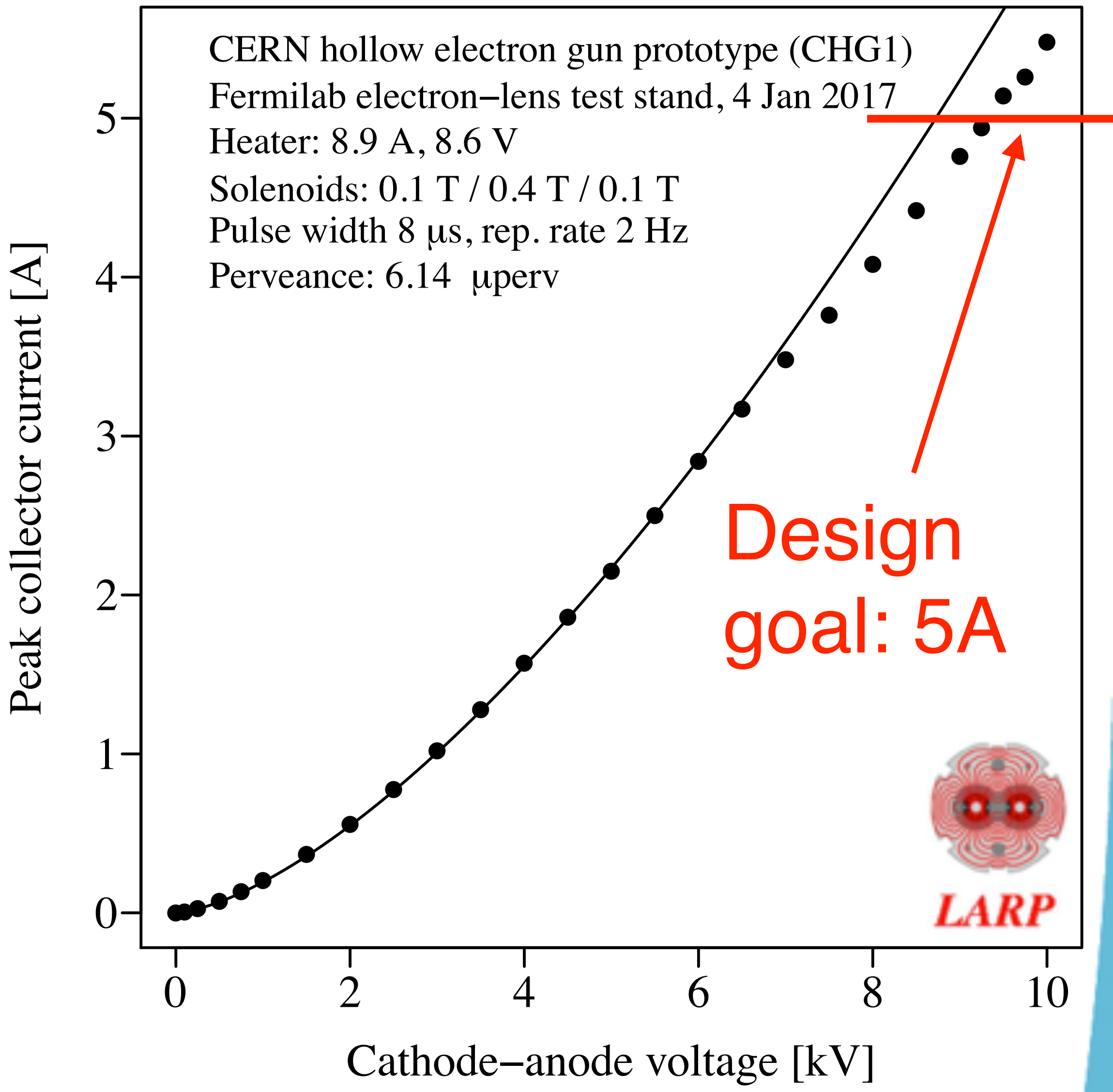
Timeline: studying a possible implementation of two lenses in 2023 (LS3)!



D. Perini

CERN electron gun





The first CERN hollow electron gun was tested in the Fermilab electron beam test-stand. Achieved output current 5.4A (new record).

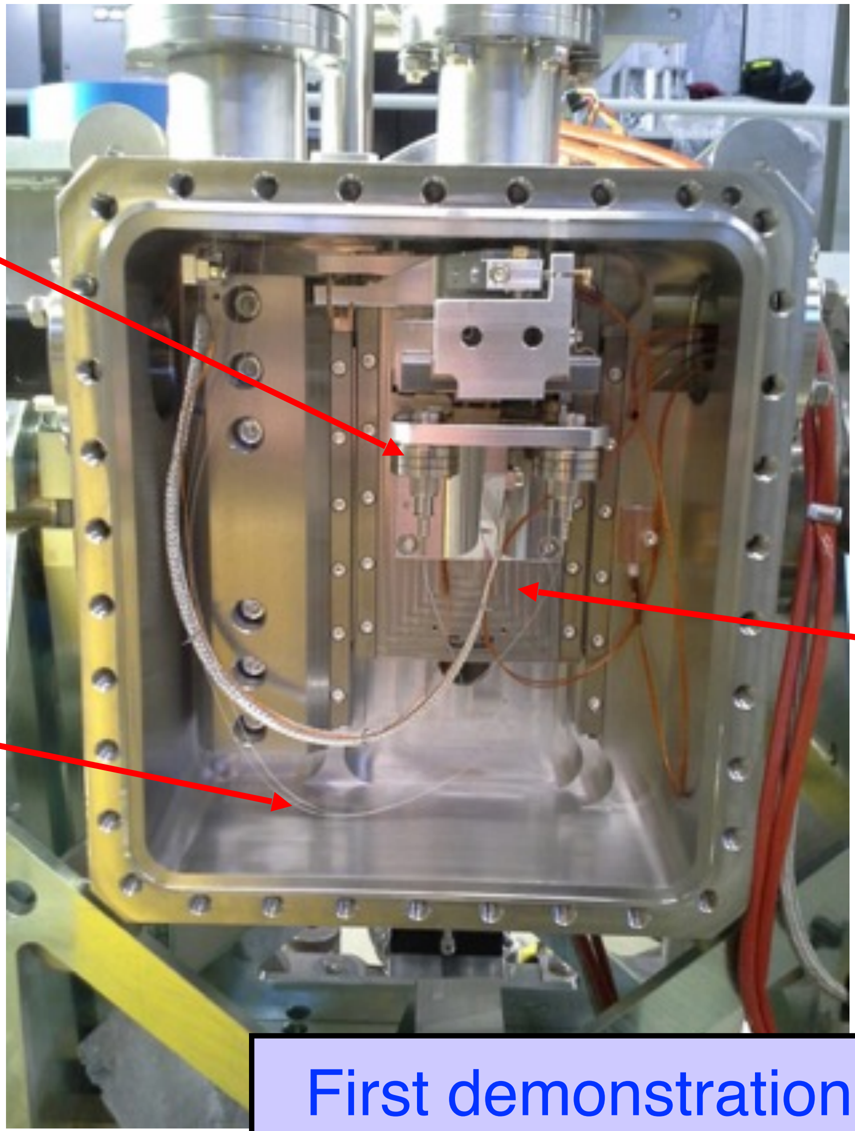
Measurements by G. Stancari (FNAL).

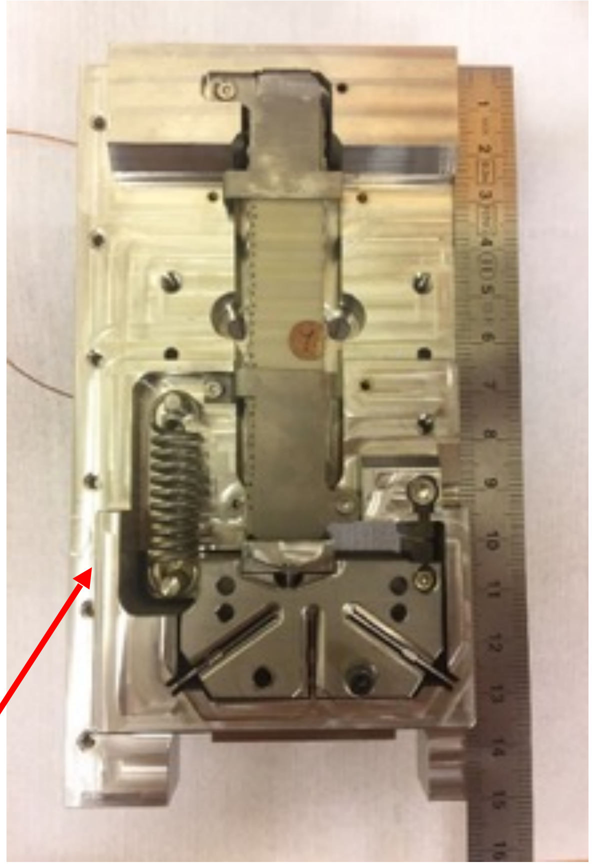
Controls R&D and development for crystals

Piezo goniometer modifications for 220˚C bakeout compatibility

Interfererometer optical heads with high temperature Ceramabond glue

High temperature, vacuum compatible optic fibres





Rotational stage with thermal expansion compensation spring assembly and custom piezo actuator with high Curie temperature, no glue and high temperature solder for electrode wires

Limiting component: Optic fibre fe… develop a 220˚C compatible versi…

First demonstration of LHC halo channeling at 6.5 TeV!
4 bent crystals in the LHC as of 2017.
Studying a 1 MJ collimator absorber for proton beams

A. Masi for the STI controls team

Conclusions

- Reviewed the LHC collimation system and the main activities planned for its HL-LHC upgrade
  - Excellent performance of present system, and further improvements needed for the upgrade.
- The collimation upgrade focused on improved **collimator impedance**, **dispersion suppressor cleaning** and **new layouts** of high-luminosity interaction regions
  - Highlighted some concerns related to vacuum aspects.
  - Presently focused on making novel materials compatible with UHV operation.
- We are pushing forward new advanced collimation concepts, not yet baseline but proceeding at full steam as R&D topics
  - Hollow e-lenses for active halo control of 700MJ beams
  - Crystal collimation, with focus on heavy ion cleaning concerns
- Several issues / points of contact with the communities at this workshop!
  - I am looking forward to discussing further!