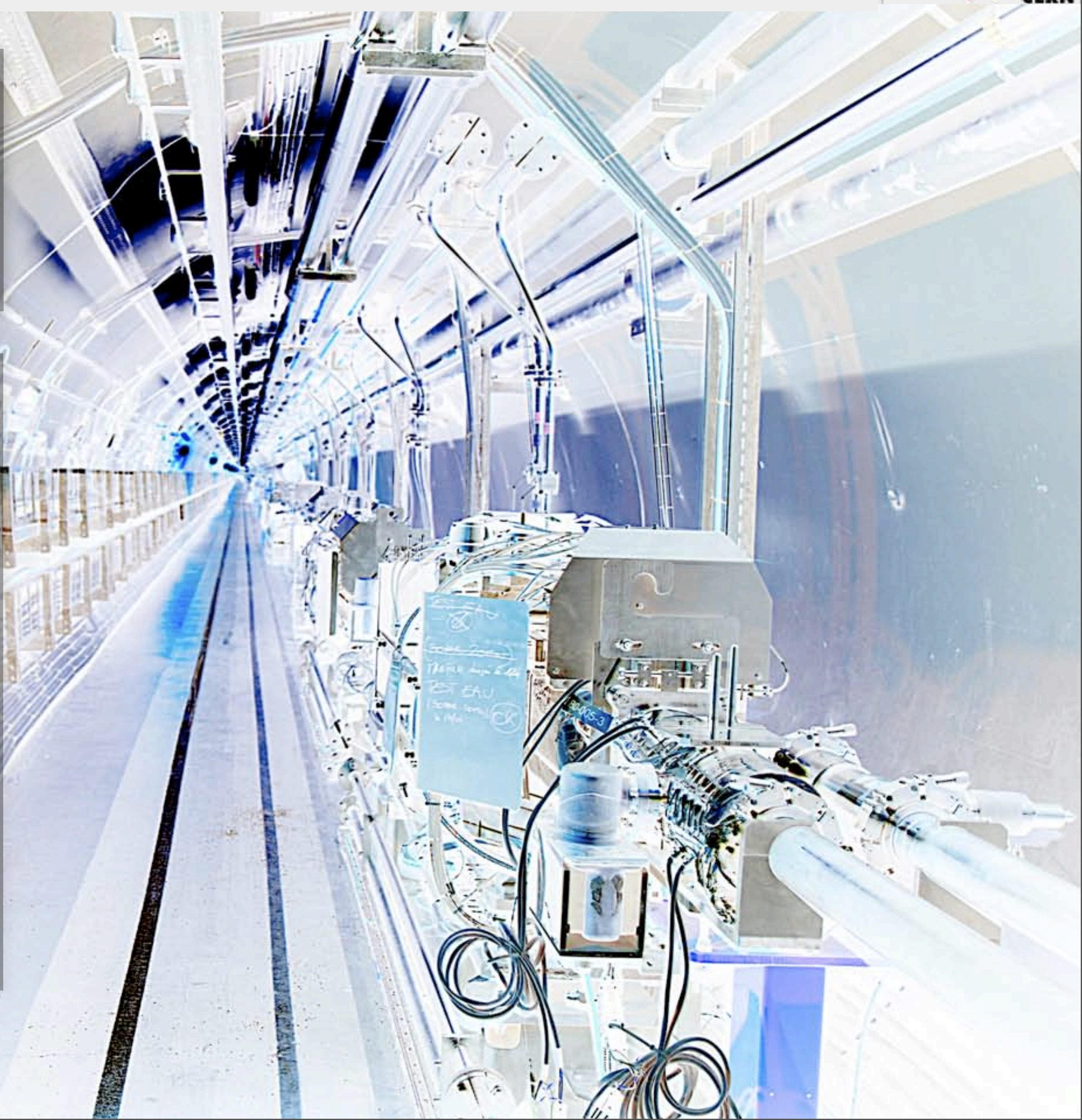
Status LHC Collimation Phase I and Phase II Plans

R. Assmann, CERN/AB
27/10/2008
for the Collimation Project
LARP CM11



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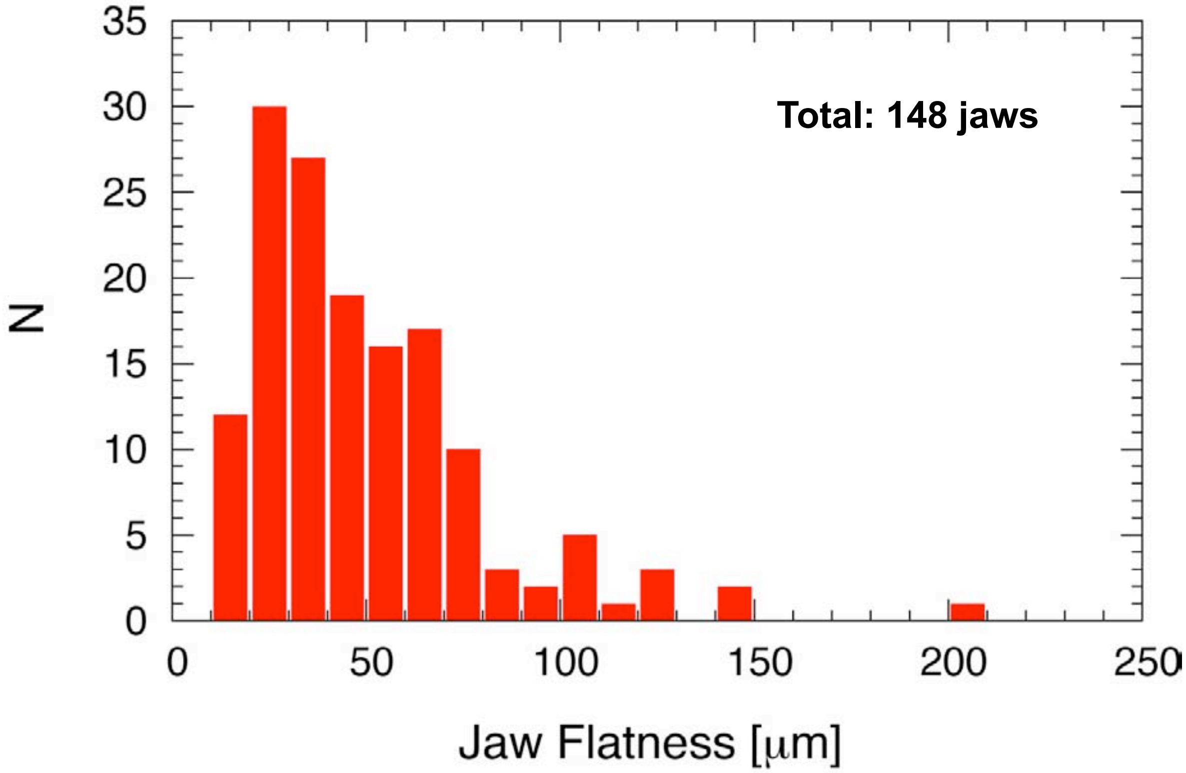
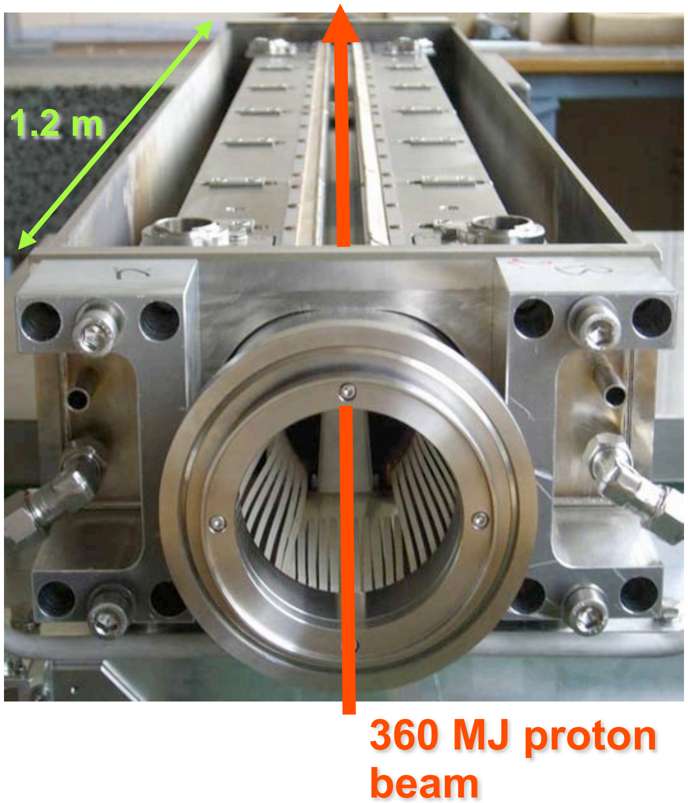
V. Previtali, S. Redaelli,
T. Weiler, AB/BDI (R. Jones
et al) and many others

Phase I Status

- Production of **130 collimators and absorbers** for the LHC essentially finished (industrial production of 110 collimators is 100% complete, 5 collimators still in CERN production).
- Installation for the 2008 LHC run with beam:
  - **88 collimators for up to 10 times stored energy of the Tevatron.**
  - **Preparations (cables, water, base supports) for 144 collimators** (phase I, II, III).
- Shutdown 2008/9:
  - Complete Phase I with installation of **22 additional collimators**.
  - Preventive **work on mechanical piece** (roller cage) to ensure 20 year lifetime of most radioactive collimators (potentially affected by material weakness in early series production).
  - Prepare remote survey and handling tools for collimation (not discussed here).
- Additional collimators for high luminosity and spares.

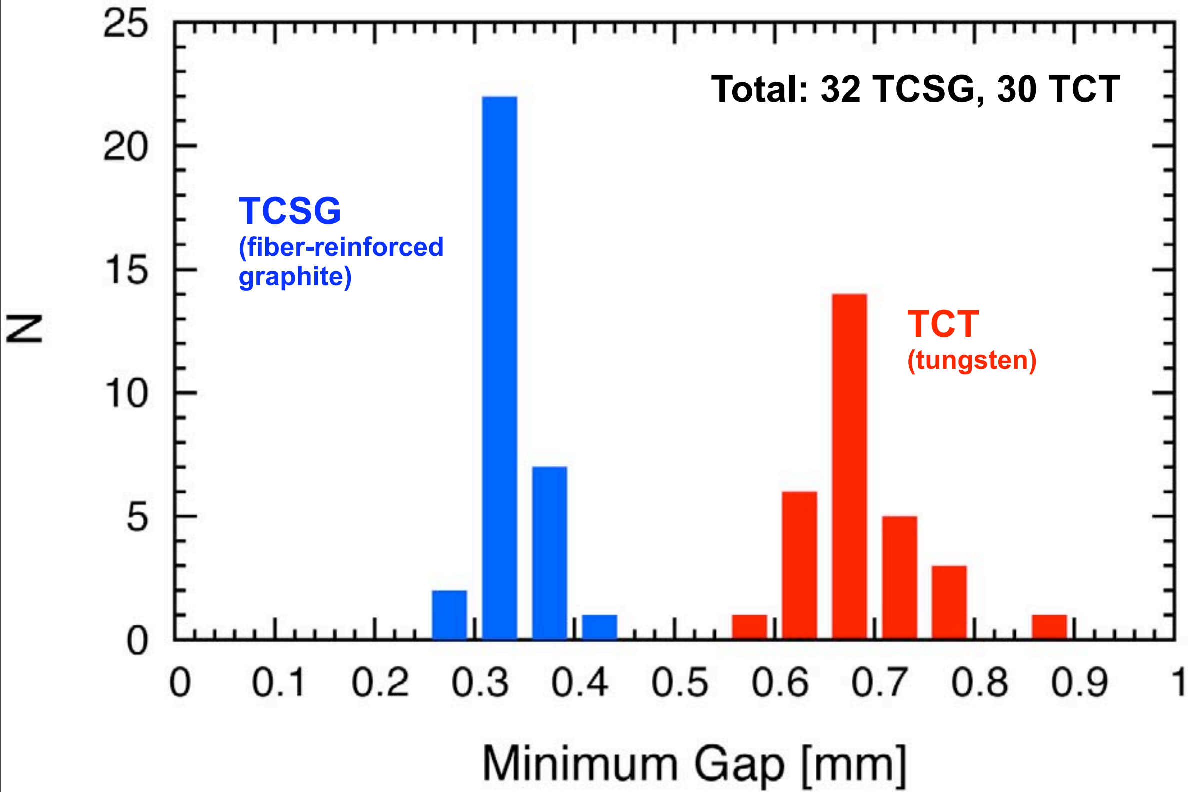
Jaw Flatness (Ring & TL)

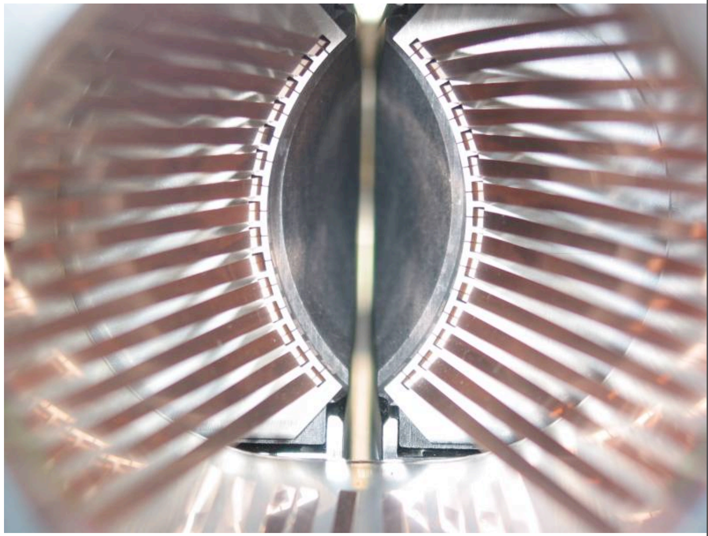




Flatness better than many feared. Out of tolerance collimators were placed in locations with more relaxed tolerances, meaning larger beta (limited sorting). Enough collimators for tightest places (40 μm).

Minimum Collimation Gap (Ring)



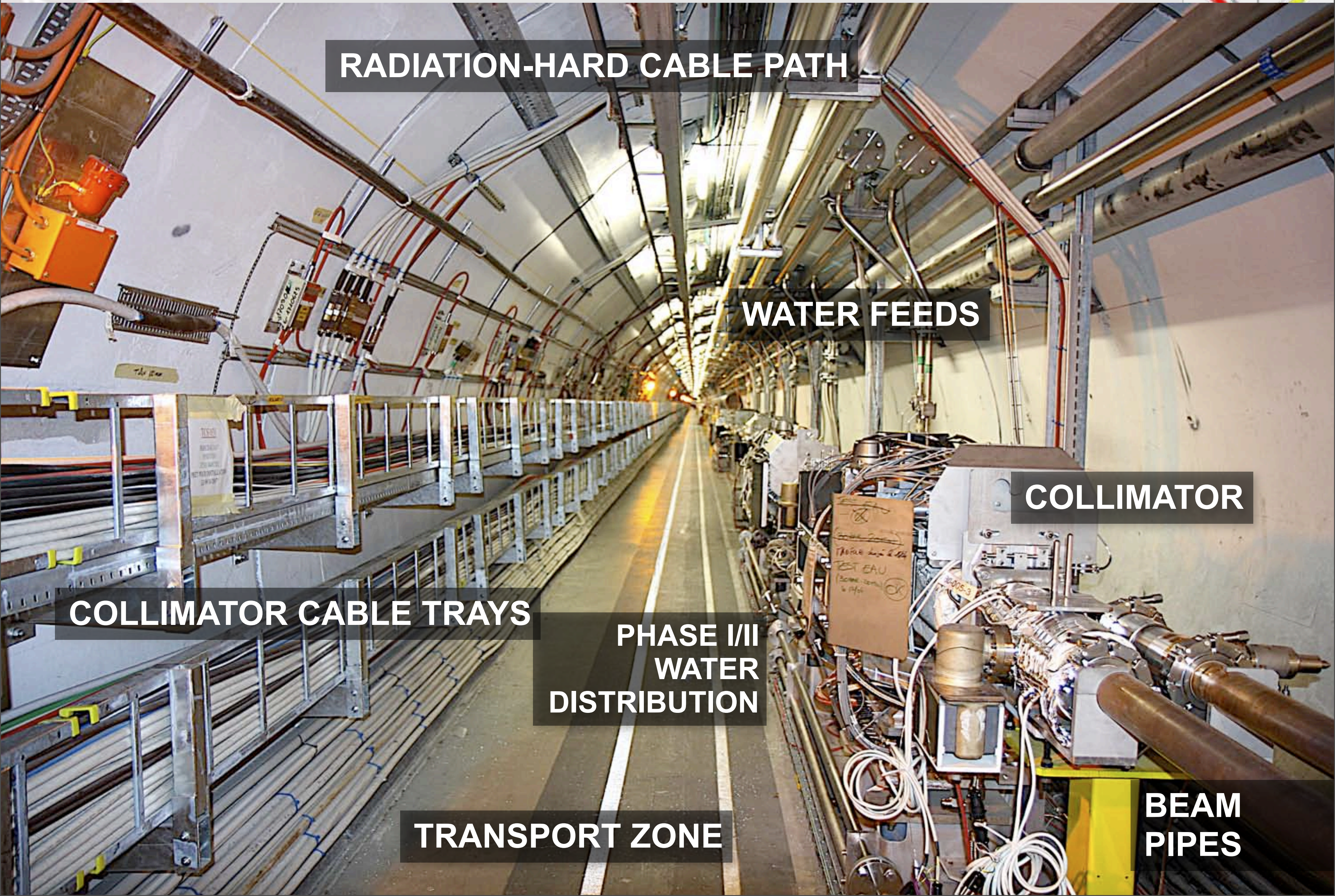


High precision collimators produced adequate for LHC conditions!

Note: No time to discuss here production problems with a few CERN collimators.

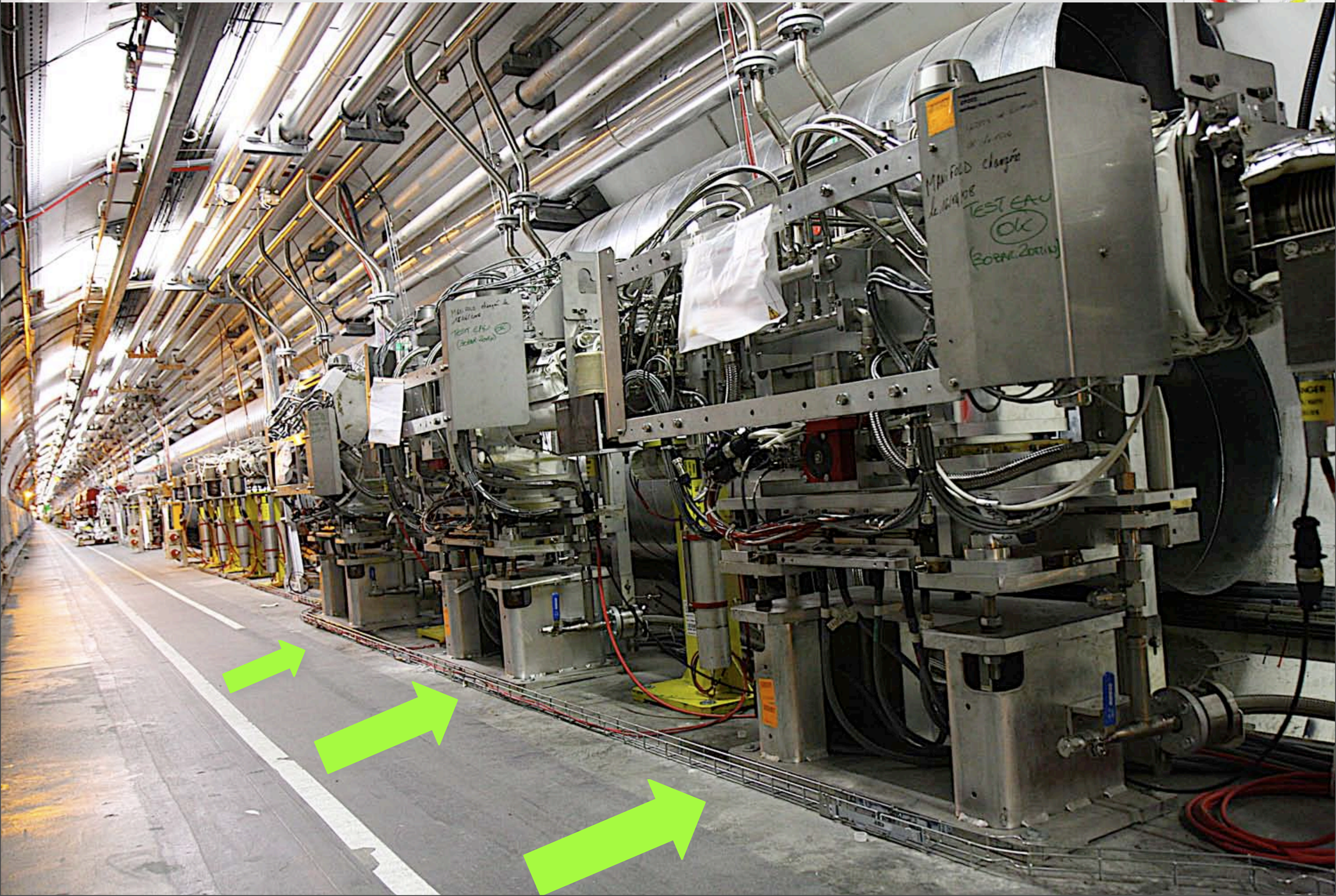
Important: **Readiness for 2008 run and parameters is ensured.**

Cleaning Insertion IR7

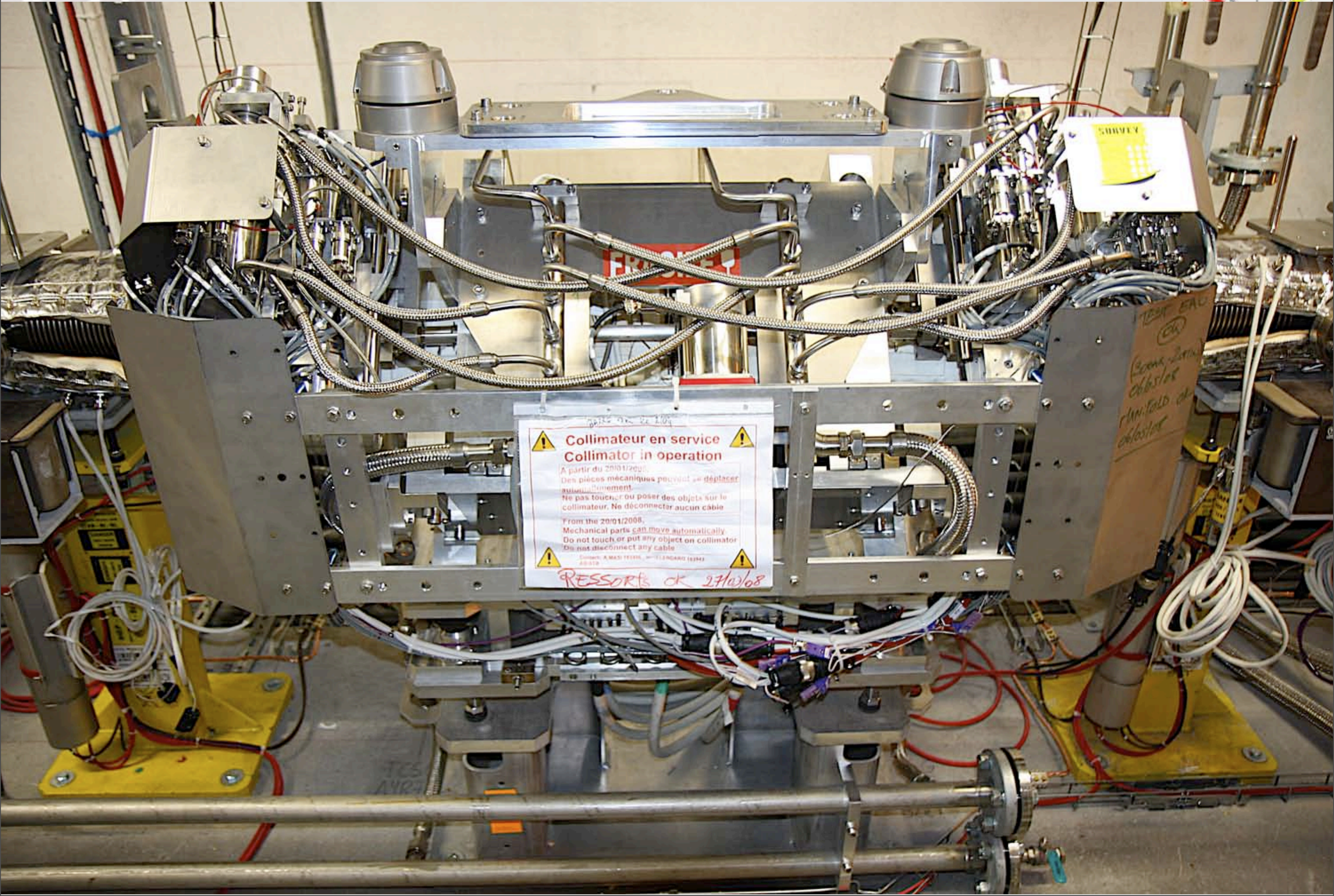


LHC Collimation Project

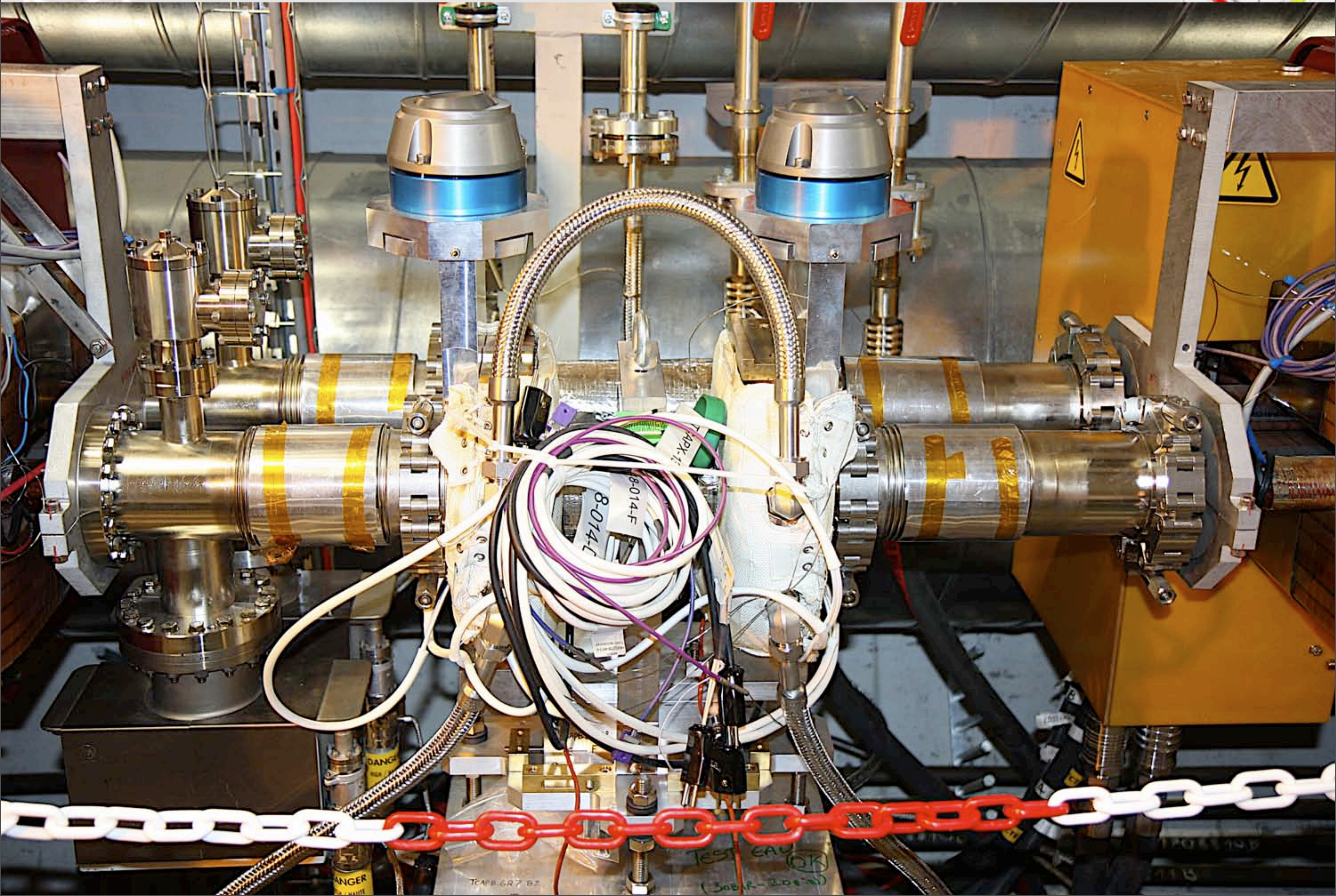
3 Primary Collimators of Phase I



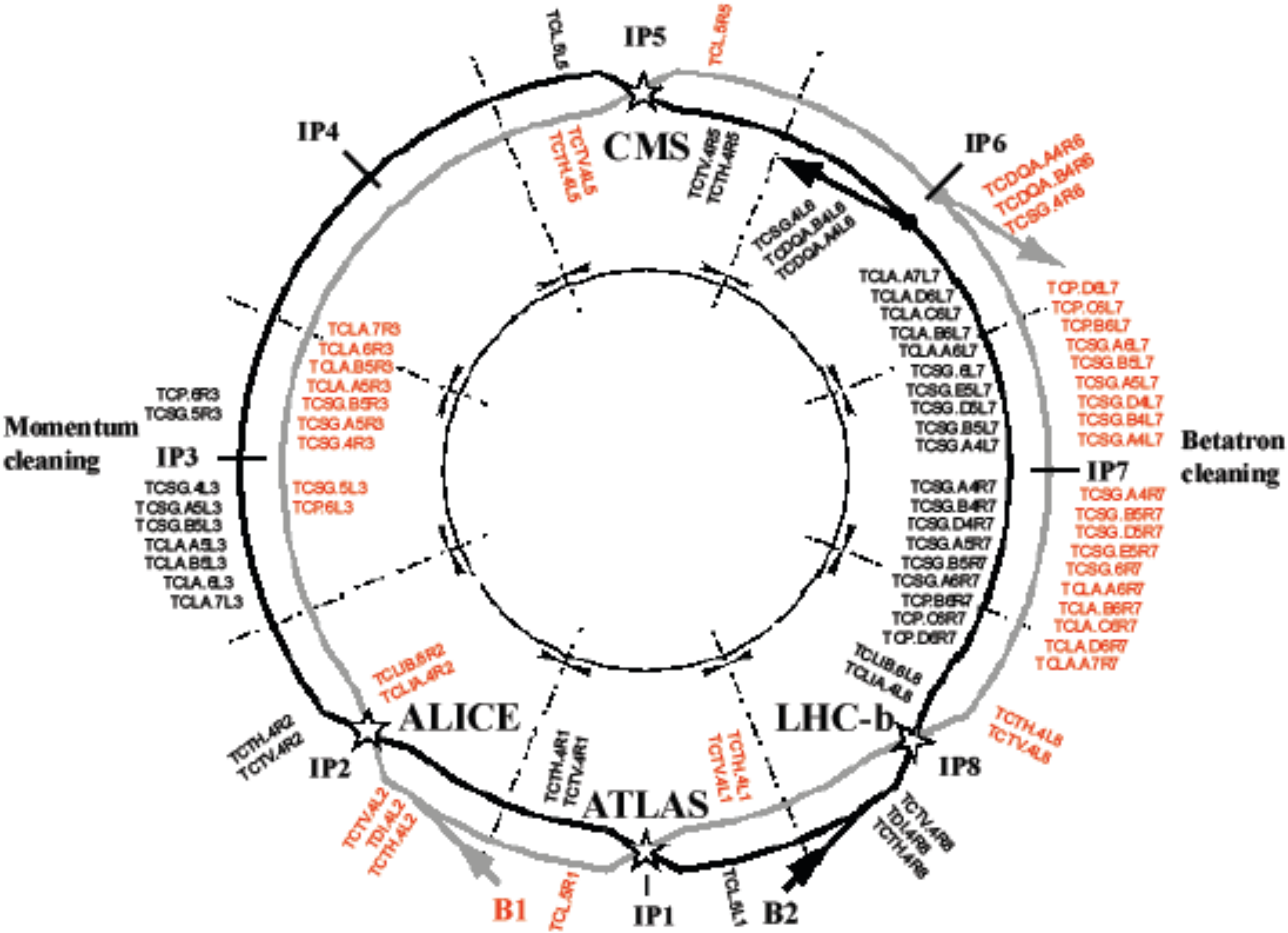
Side View Phase I Collimator



Phase I Passive Absorber TCAPA



First Beam Day: 10 Sep 2008



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CMS
TCL.6L5
TCL.5R5
TCTV.4L5
TCTH.4L5
TCTV.4R5
TCTH.4R5
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IP6
TCDQA.A4R6
TCDQA.B4R6
TCSG.4R6
TCSG.4L6
TCDQA.B4L6
TCDQA.A4L6
TCLA.A7L7
TCLA.D6L7
TCLA.C6L7
TCLA.B6L7
TCLA.A6L7
TCSG.6L7
TCSG.E5L7
TCSG.D5L7
TCSG.B5L7
TCSG.A4L7
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TCP.C6L7
TCP.B6L7
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TCSG.D4L7
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TCSG.A4L7
Betatron
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TCSG.B5R7
TCSG.A6R7
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TCP.D6R7
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TCLA.D6R7
TCLA.A7R7
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TCLA.7R3
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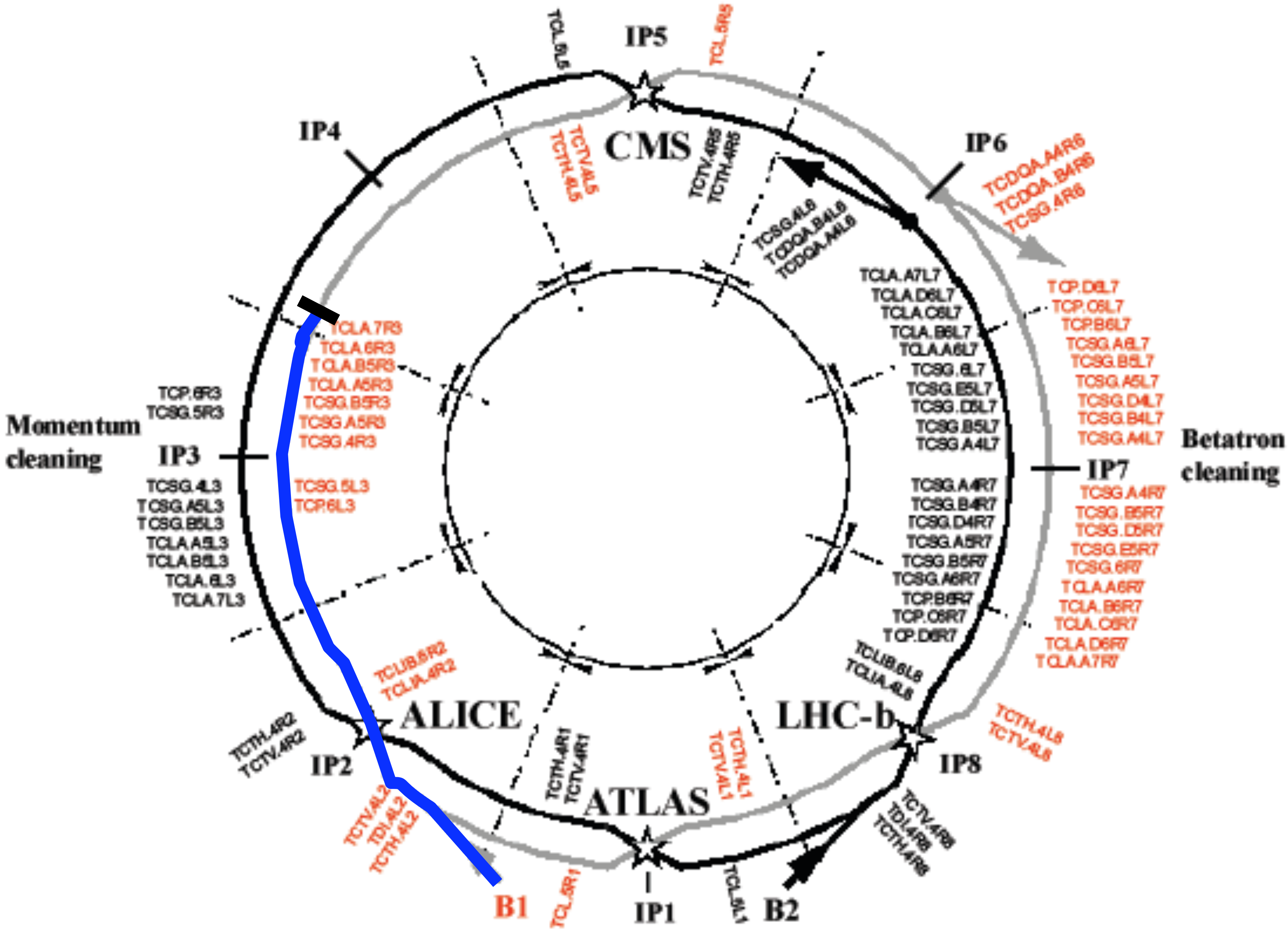
TCP.6L3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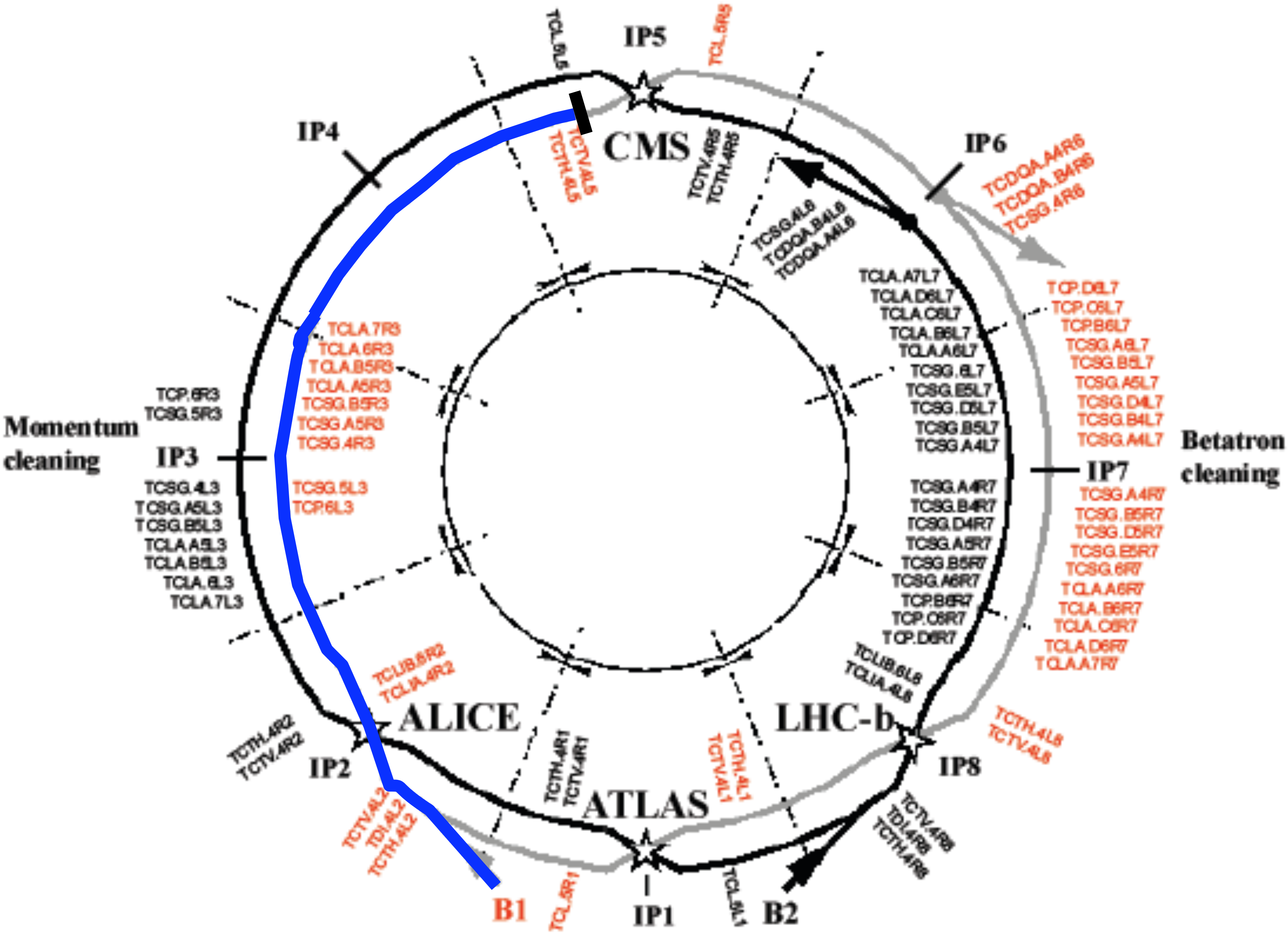
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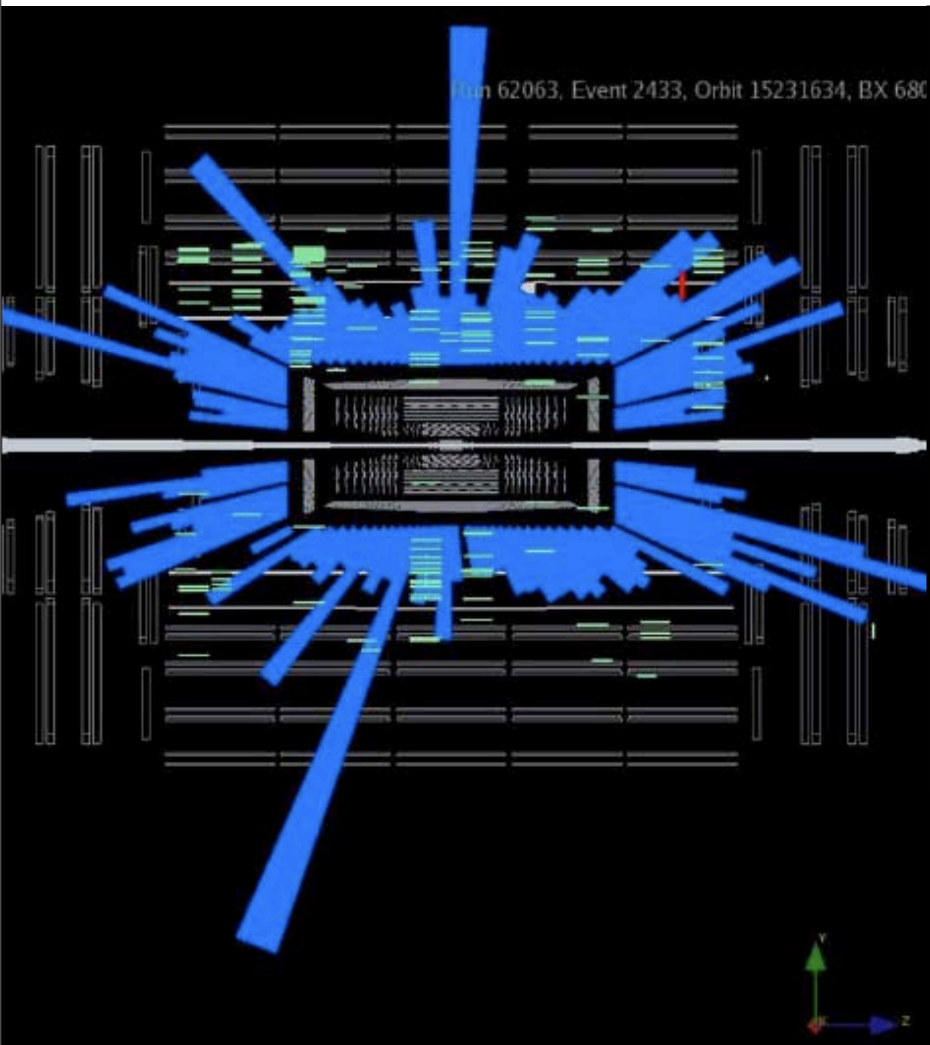
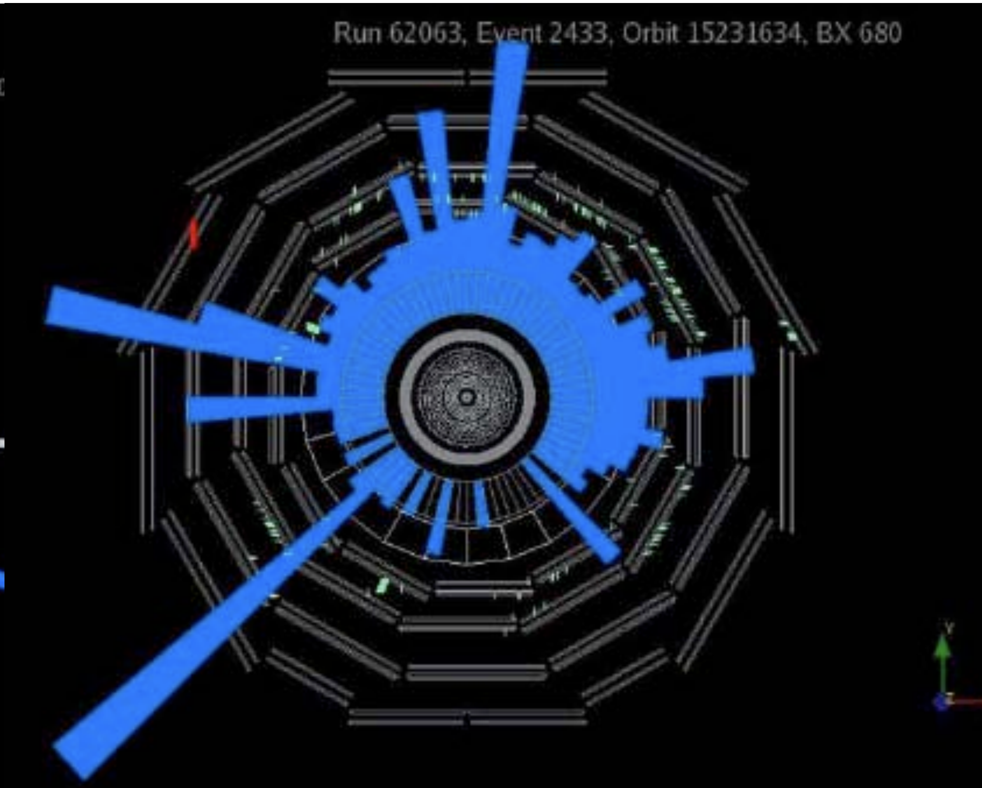
TCP.6L3

Tertiary Collimator “Splash” Events



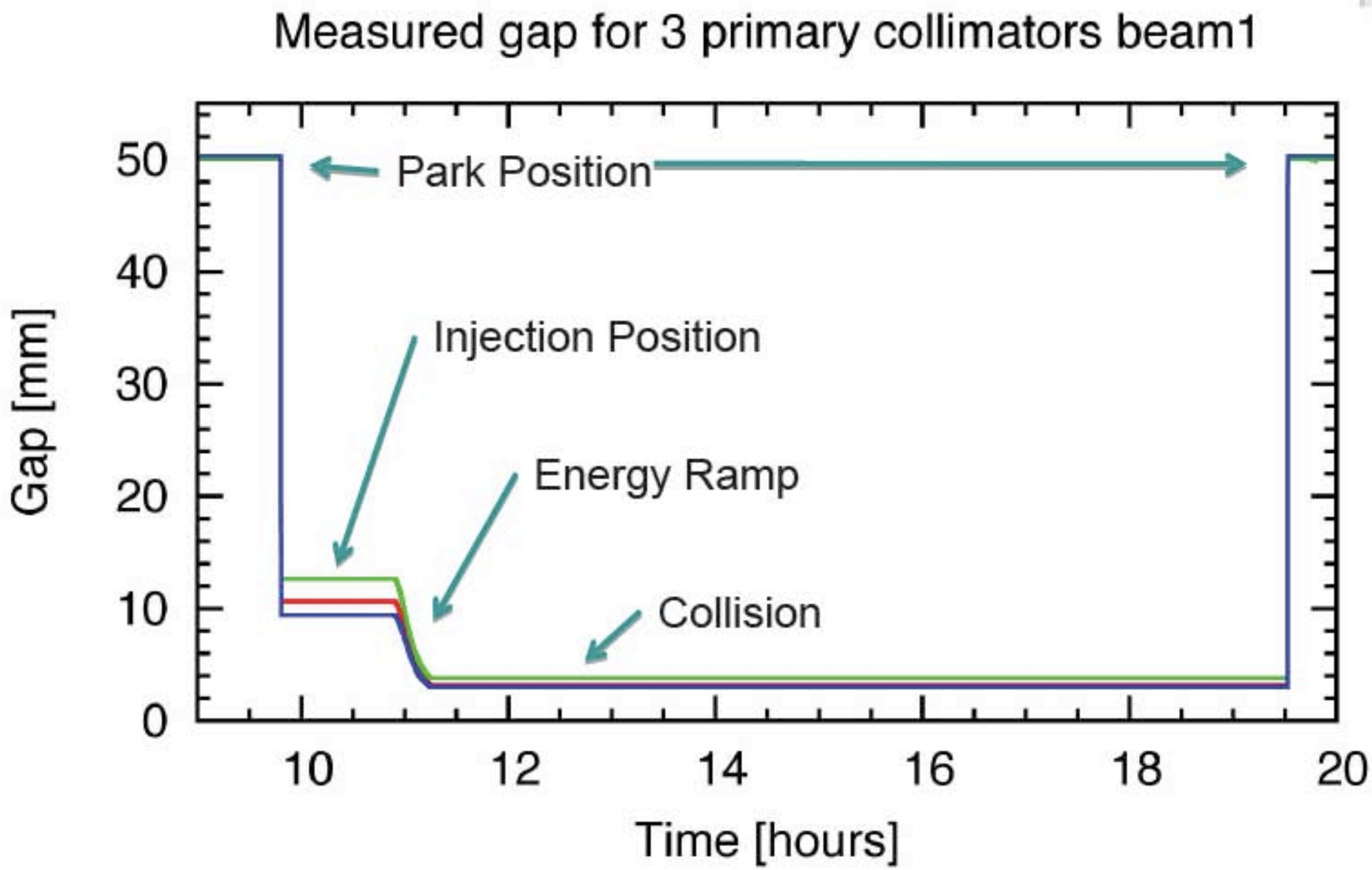


CMS view of beam hitting collimator

Performance Highlights

- Collimators **used very successfully as stoppers and fixed targets** during September 10 first beam day (collimator events) and earlier injection tests. Unforeseen but entertaining use of tertiary collimators at experiments…
- Machine **protection functionality completely checked** (interlocks from temperature and position sensors activated by violating limits). Few residual sensor issues identified. **System was fully safe** (ready for higher intensities/energies).
- **No opportunity to set up with beam as collimators.**
- Collimators kept operational since August, except **IR3 collimators** which were **switched off after incident in 3-4**. All 18 collimators in IR3 fully OK.
- Used time after incident to perform **reproducibility test over 10 days with all 28 collimators in IR7**.

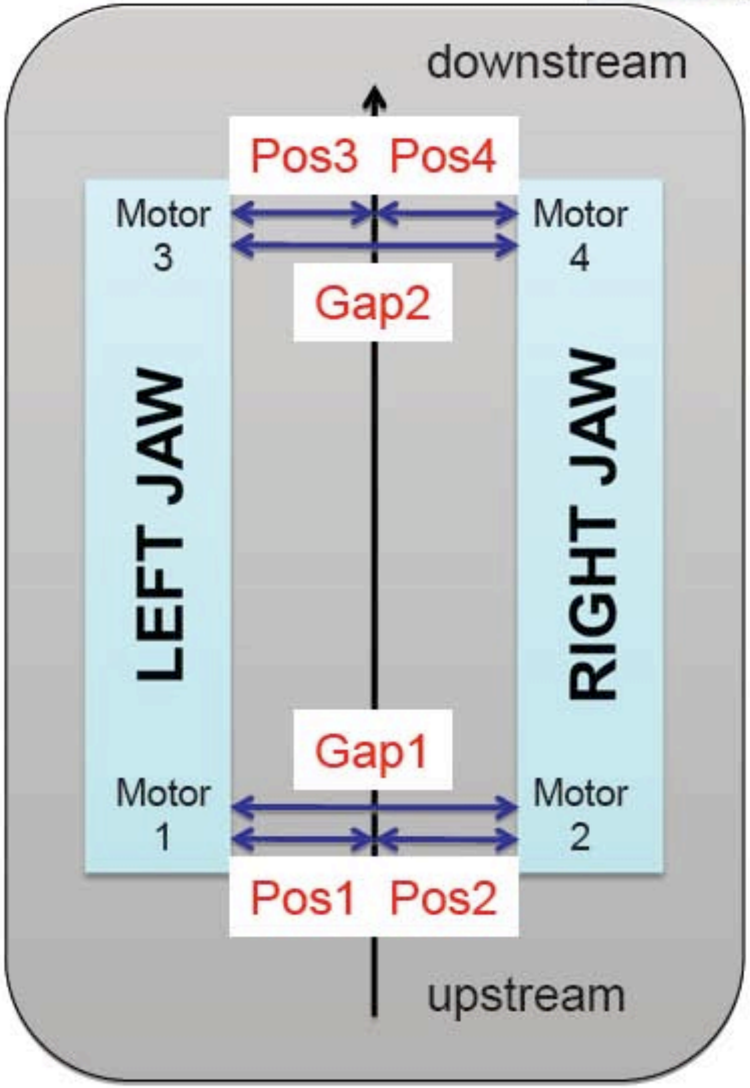
Nominal Collimator Cycle



Real functions for 28 collimators generated in collimator control. **Executed by operation crew on shift (thanks!).**

Test Procedure

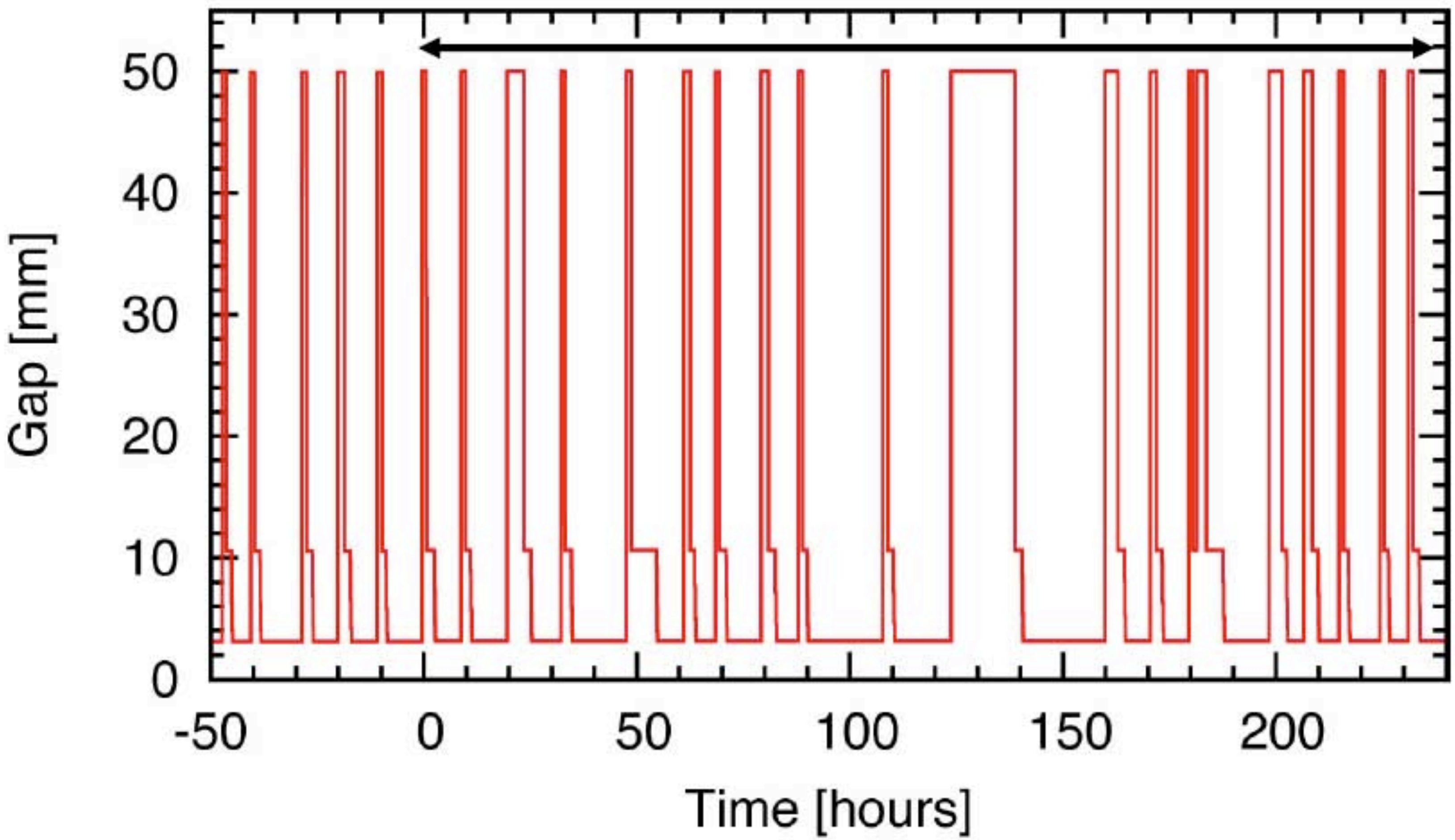
- Each collimator has 6 position sensors: **4 jaw corners and 2 gaps measured independently**.
- Redundancy for 6 sensors and 4 DOF.
- **Stepping motors are driven through the collimator cycle without any feedback from measured positions.**
- Position monitoring implemented completely independent (safety) and used for measuring the jaw position and the gaps.
- Jaw positions used for operational interlocks (time driven).
- Gap sensors used for independent MP interlock (energy driven).
- **How well do we control collimators?**



Top view for horizontal collimator.

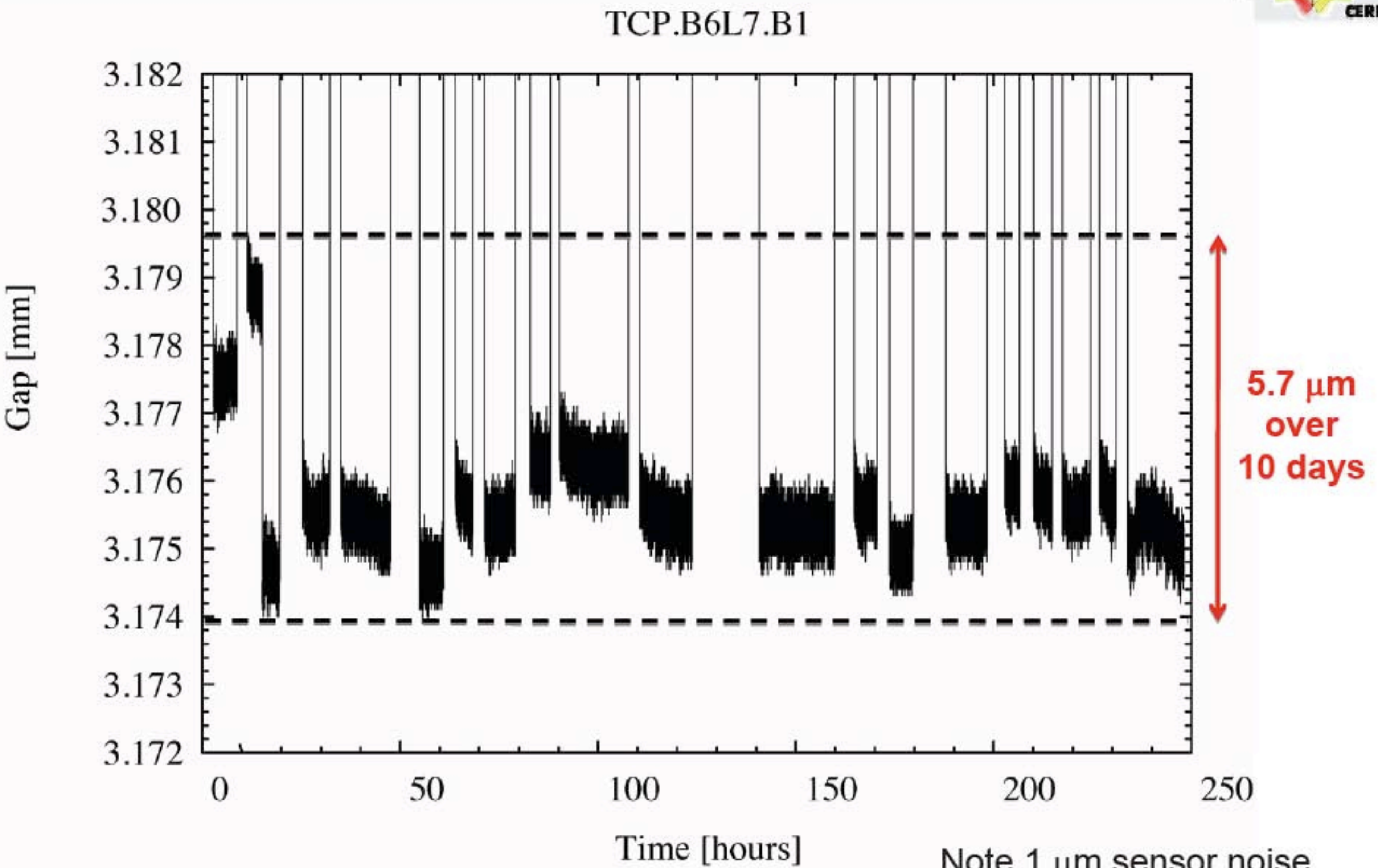
Reproducibility Run

TCP.B6L7.B1



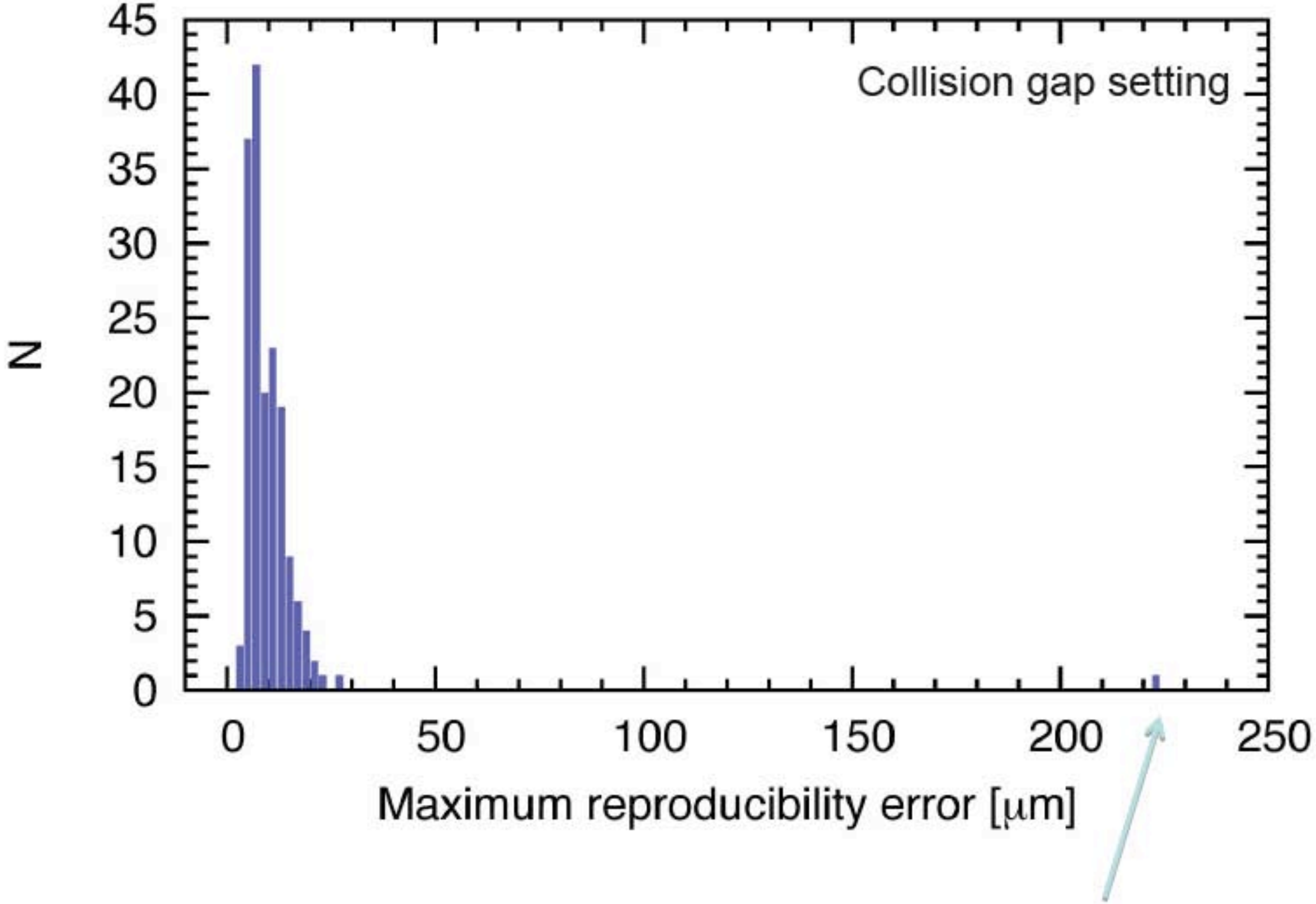
Analyzing 19 cycles after T=0 (reset of collimator sensor calibrations).

Zoom into Collision Gaps



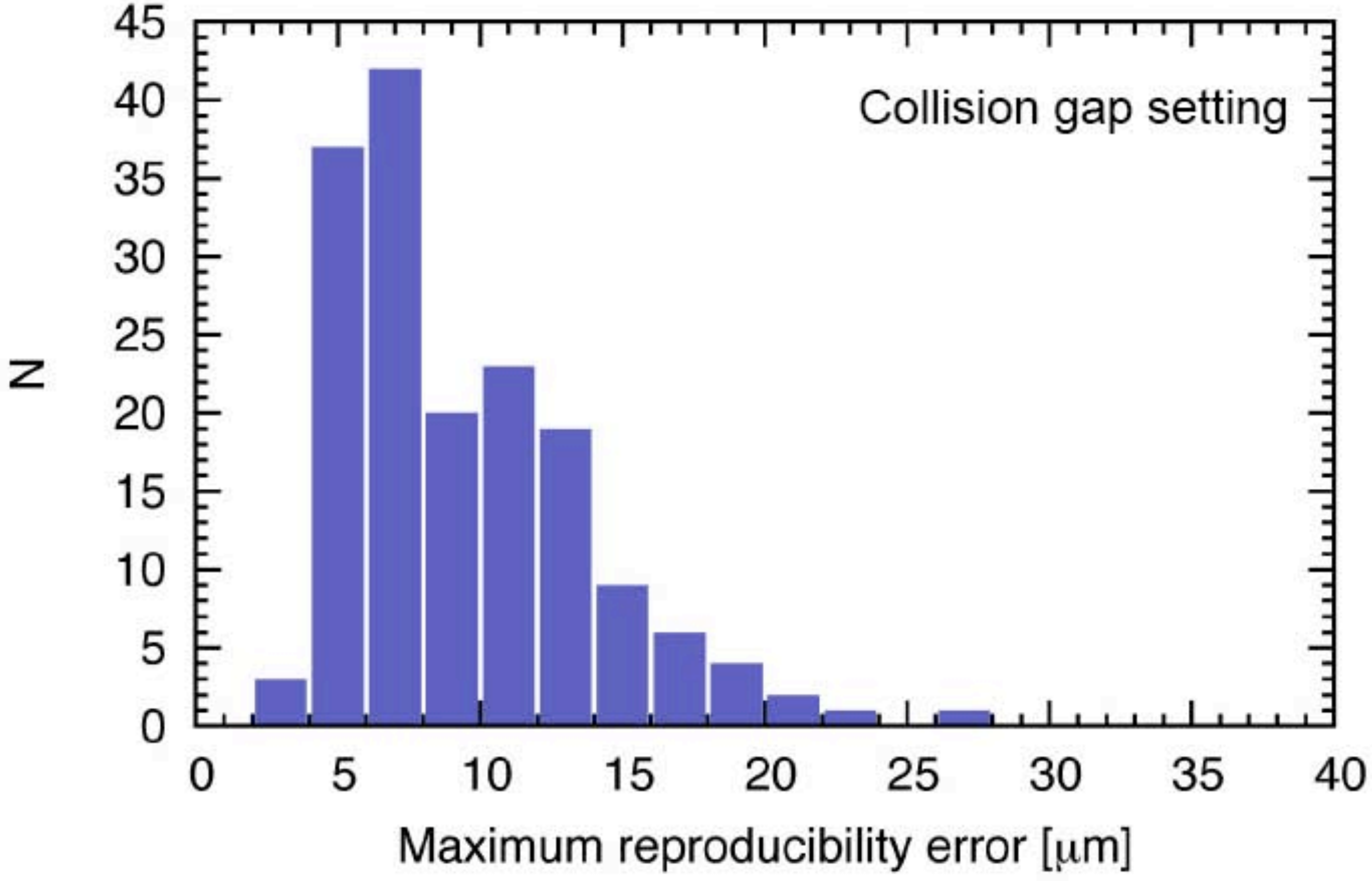
Note 1 μm sensor noise.

Reproducibility IR7 collimators in 10 days



168 position sensors for 28 collimators. Only 1 sensor above 30 μm!

Reproducibility IR7 collimators in 10 days



Includes mechanical, motor and sensor stability! Specification is surpassed: major success for all involved! Possible to control at **better than 30 μm level**!

Also: Includes collimators with Inox cages which work fine (to be replaced)!

Commissioning Preparations

ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE

Laboratoire de Physique des Acceleratour et des Particules

Commissioning Scenarios and Tests for the LHC Collimation system

Thèse de Doctorat

présentée à la Section de Physique de la Faculté des Sciences de Base de l'École Polytechnique Fédérale de Lausanne pour l'obtention du grade de Docteur ès Sciences

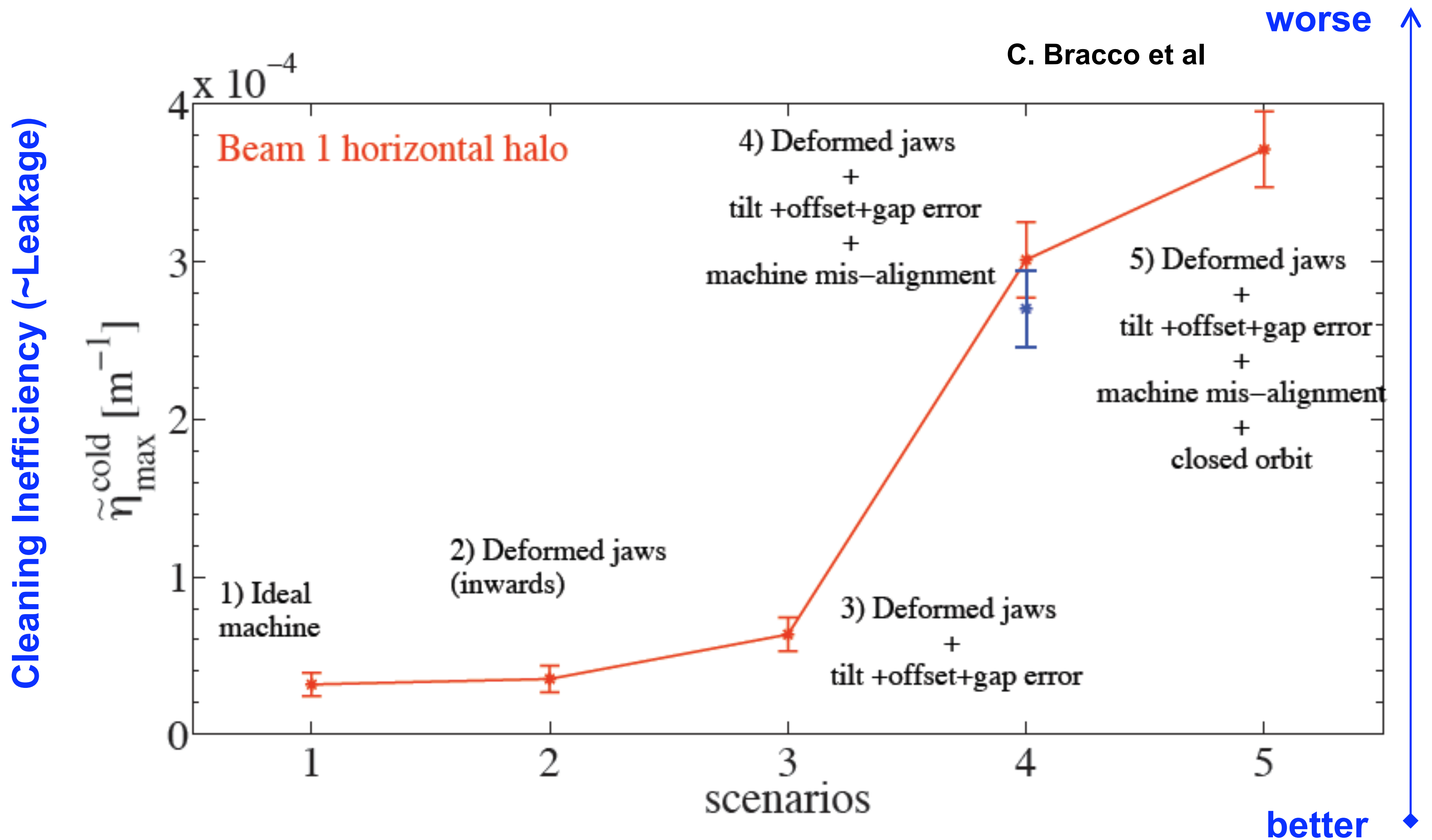
par

Chiara Bracco

A few examples from Chiara's thesis for 7 TeV commissioning

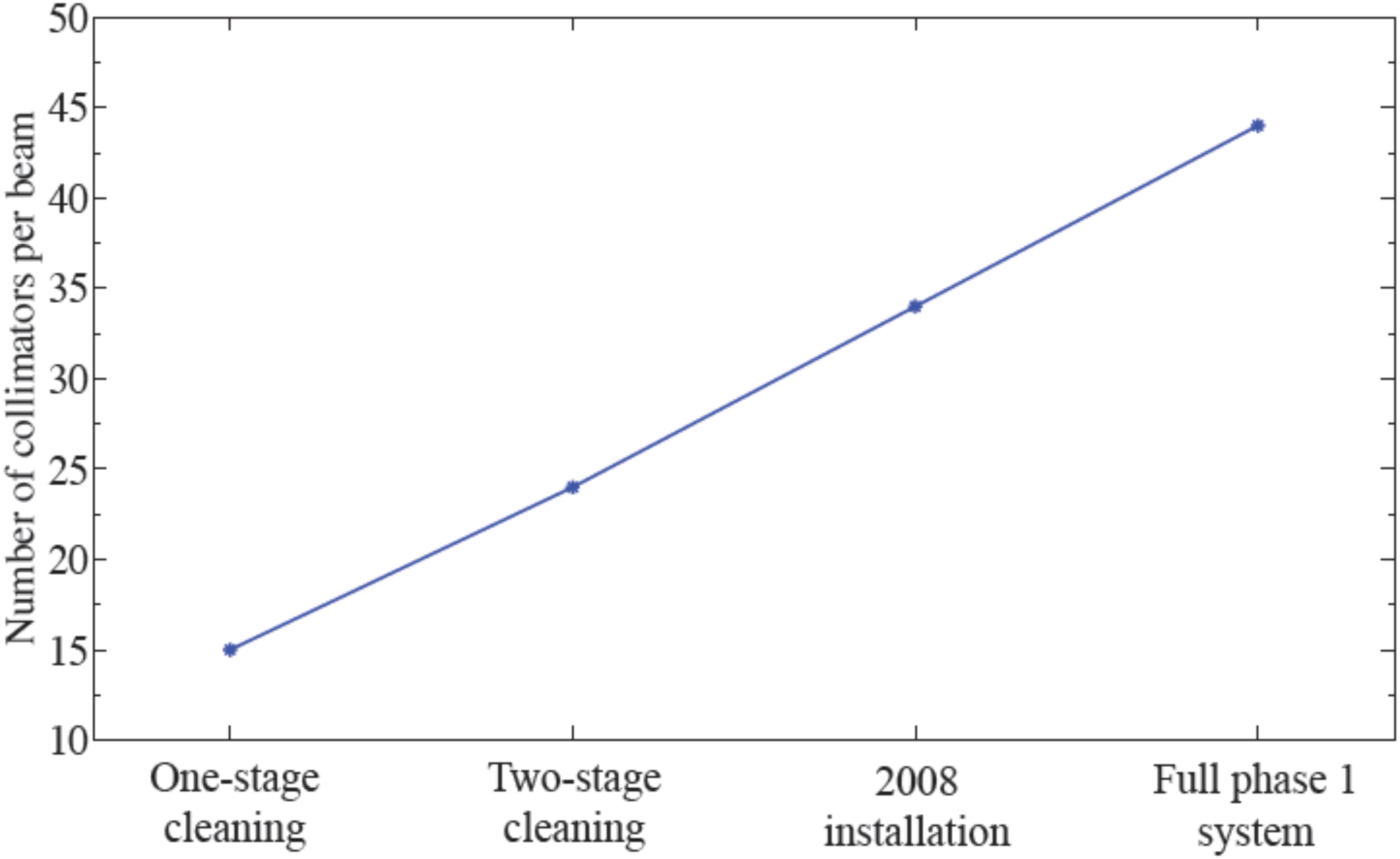
Impact of Realistic Imperfections

C. Bracco et al



4 Setup Stages of LHC Collimation

C. Bracco et al



45

15

Beam Time Required for Setup
(per Beam)

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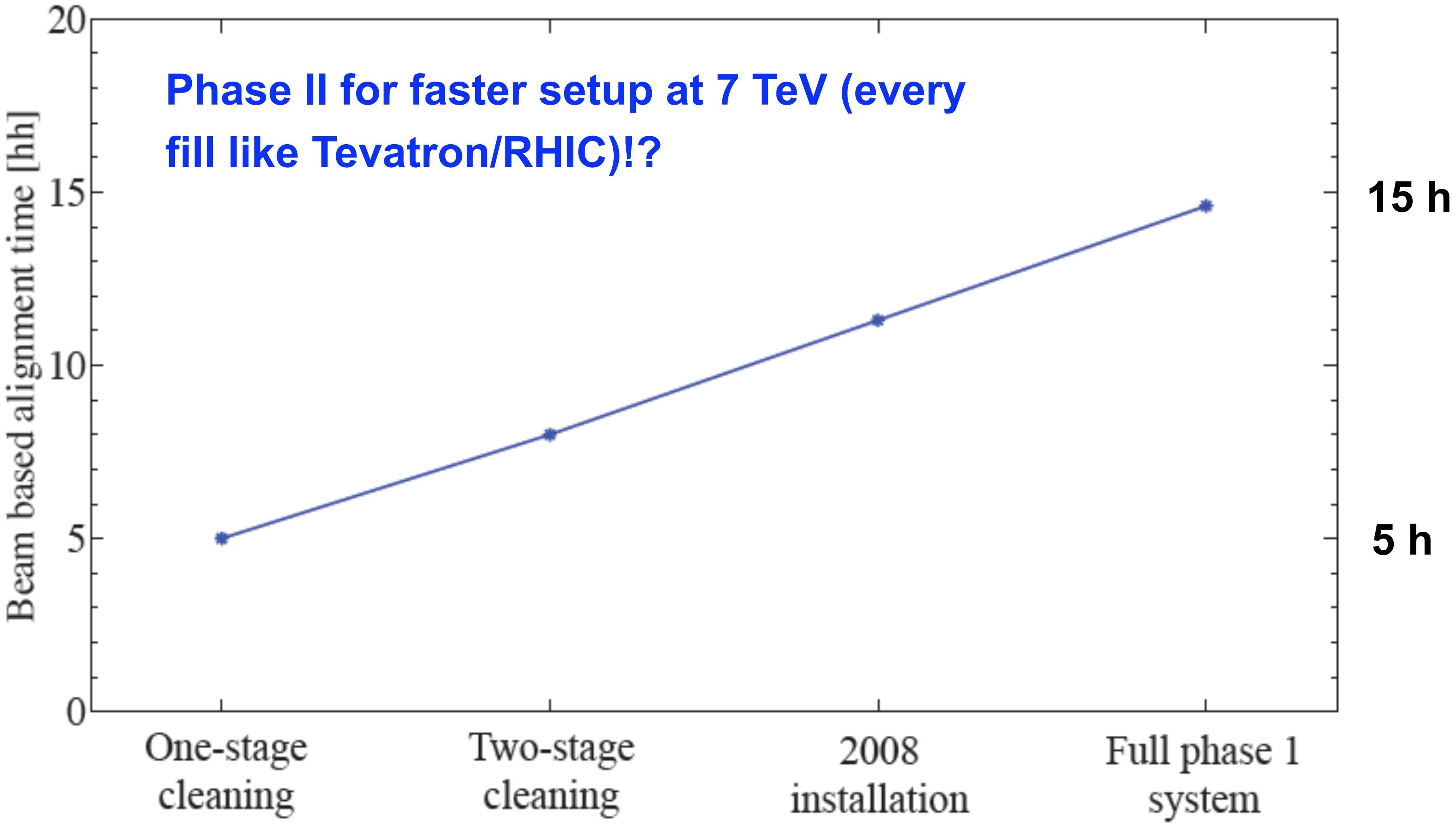

Performance Evolution

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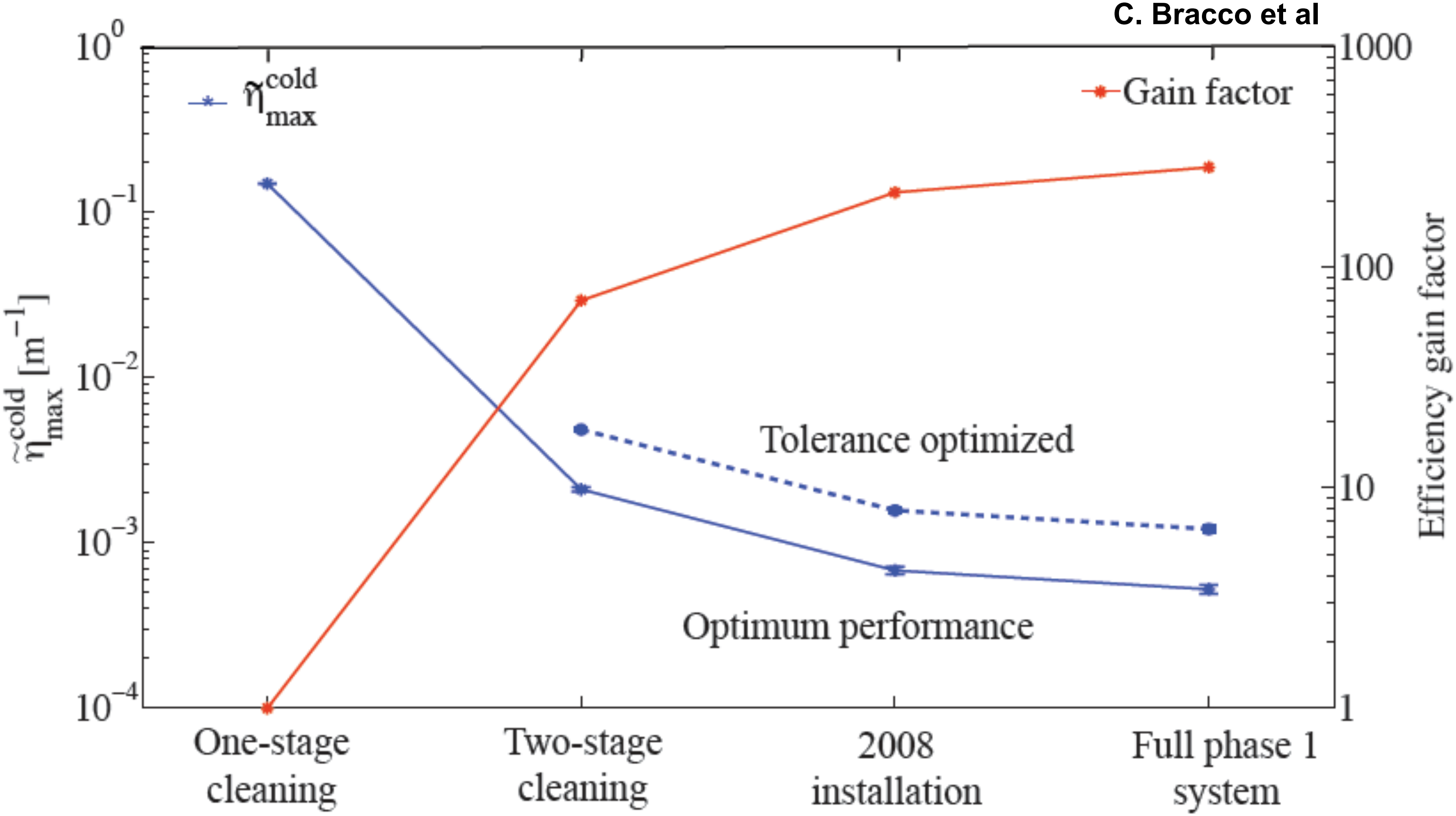

Collimator Setup Tolerance

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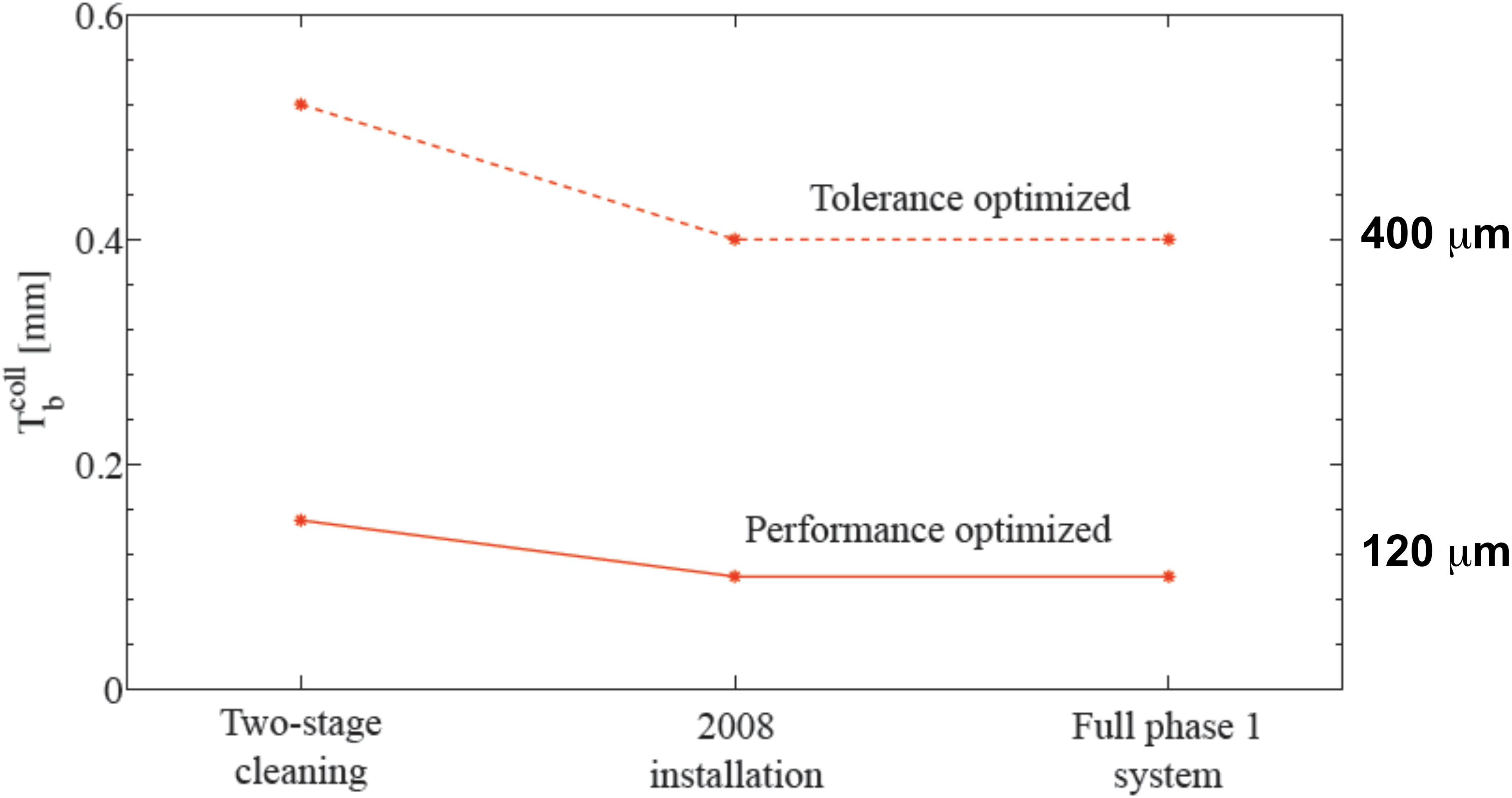

LHC Transient Orbit Tolerance

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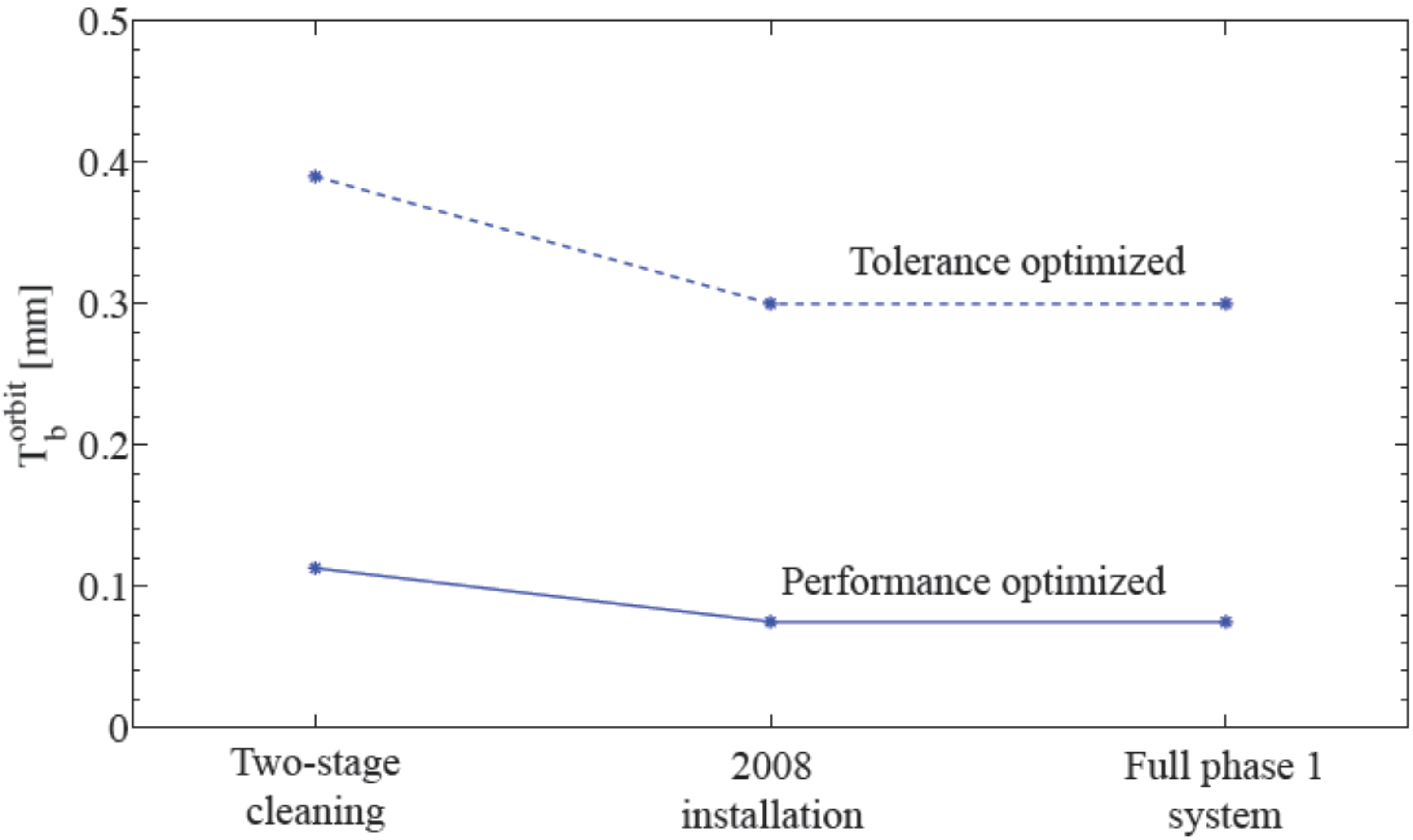
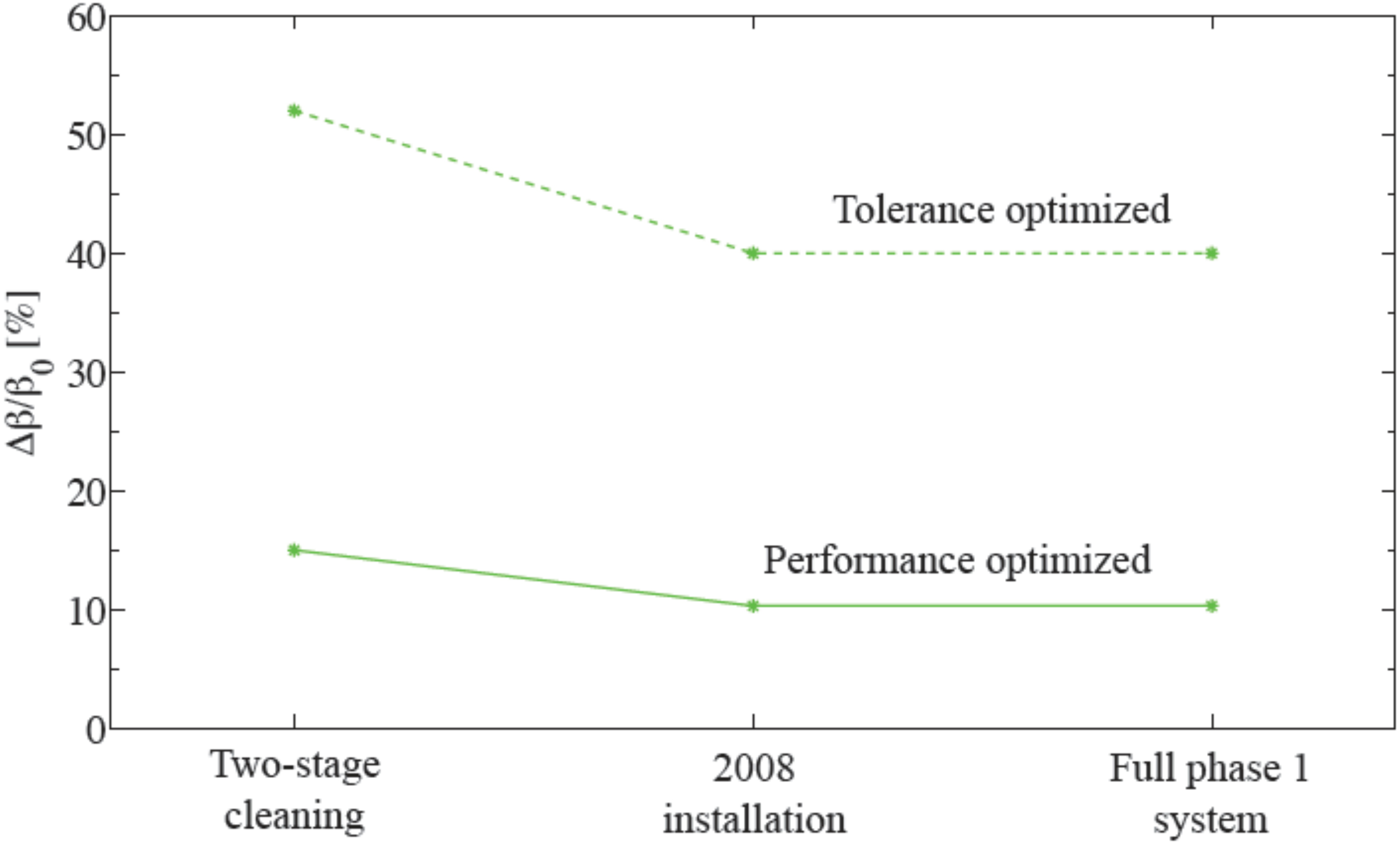


300 μm

80 μm

LHC Transient Beta Beat Tolerance

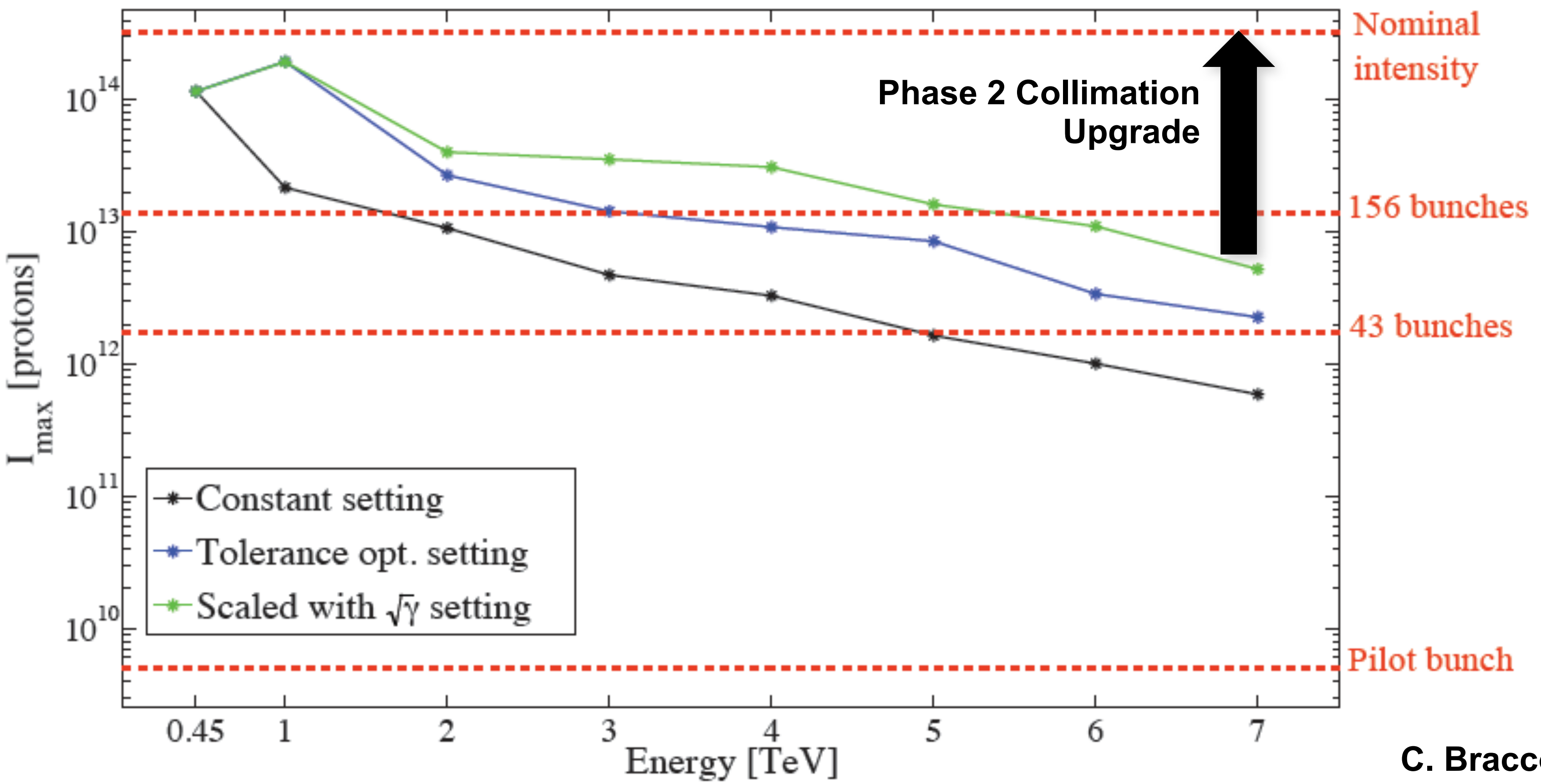
C. Bracco et al



40 %

10 %

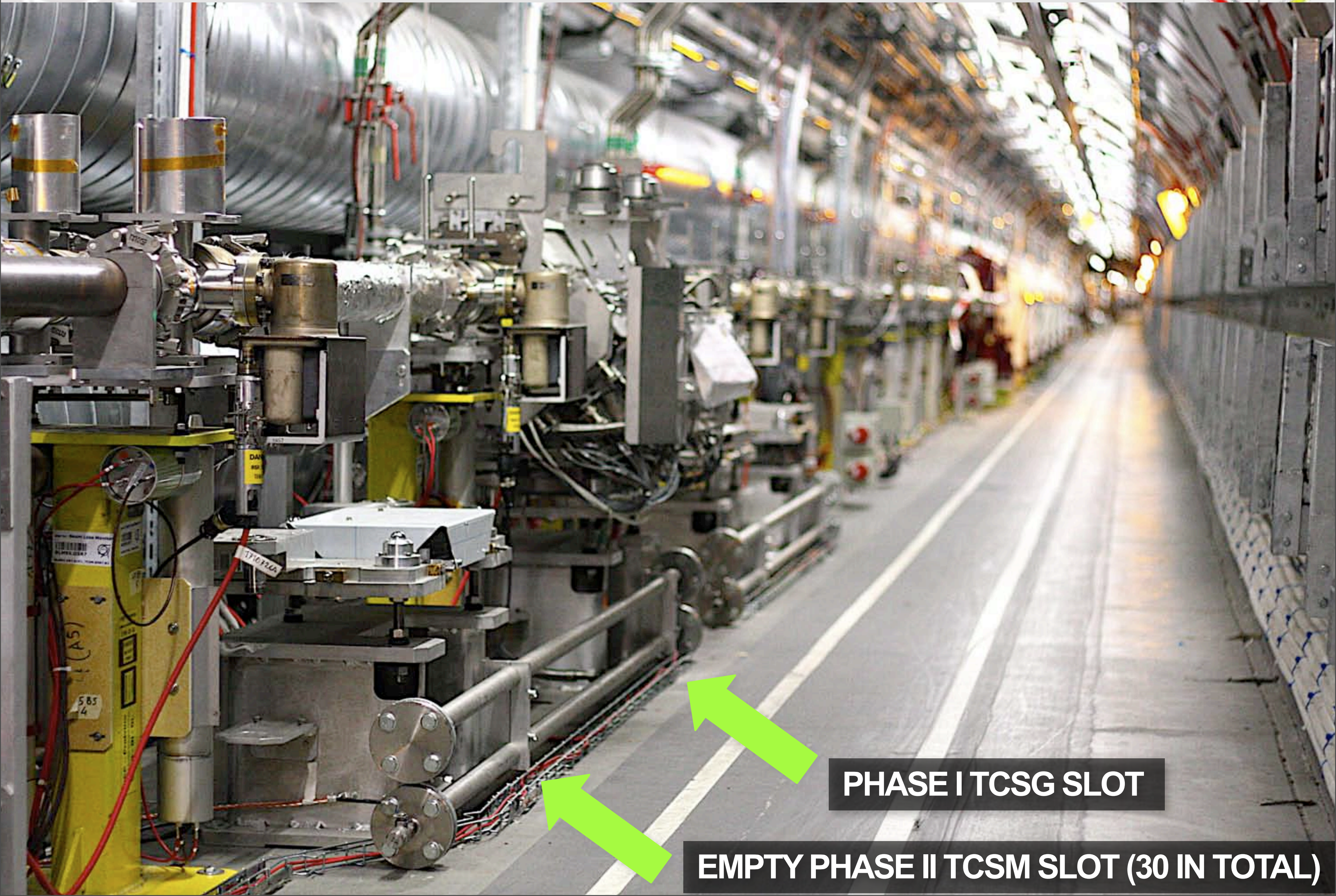
Intensity Reach versus Beam Energy
(with Multiple Imperfections)



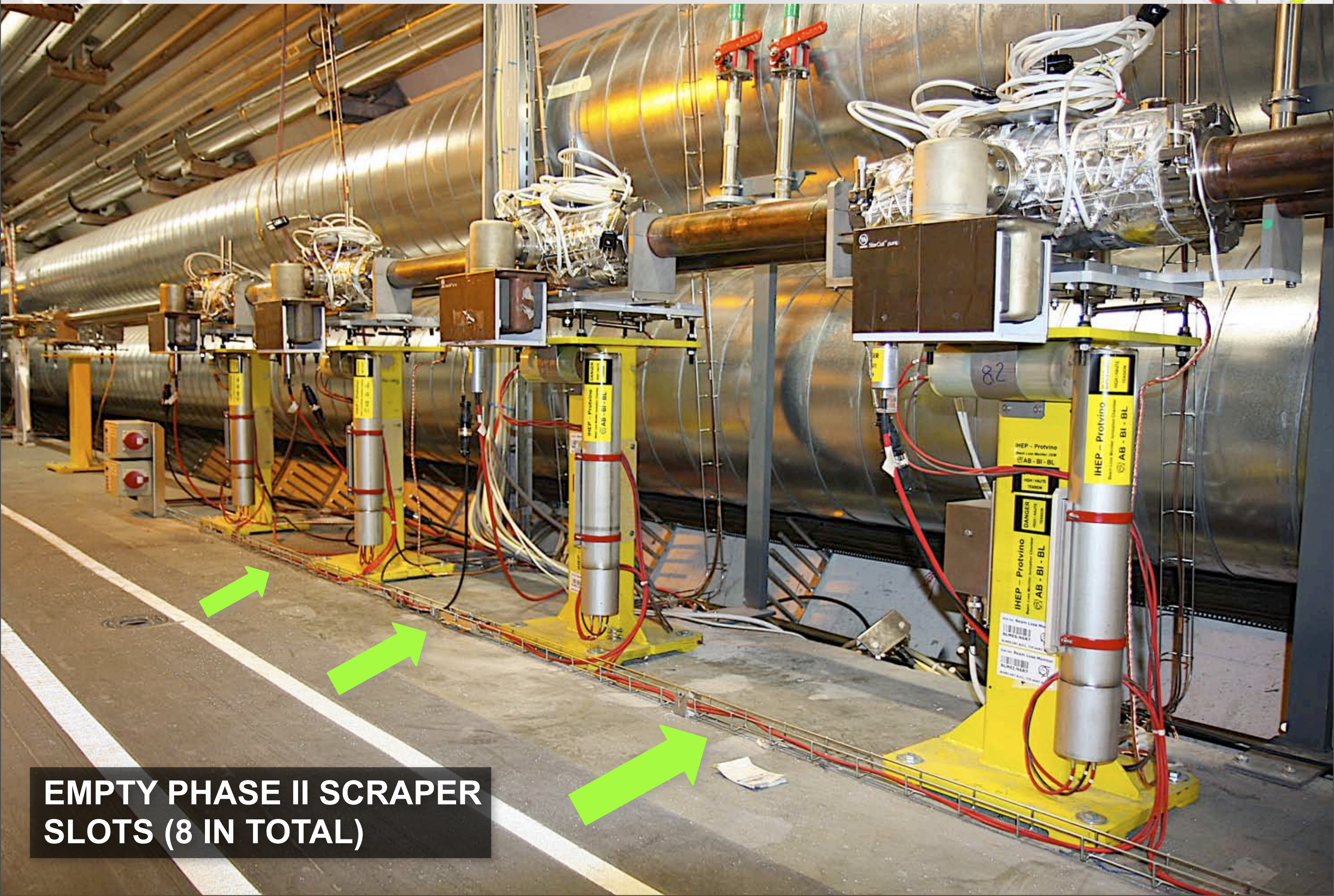
C. Bracco et al

- ➔ All simulations **predict need for phase II collimation upgrade!**
- ➔ **Phase 2 collimation effort** put in place (white paper, new initiative).

Phase II Secondary Collimator Slots



Phase II Beam Scraper Slots



The Phase 2 Path

- Due to LHC extrapolation in stored energy and predicted limitations in phase 1 system:
  The LHC collimation system was conceived and approved during its redesign in 2003 always as a staged system.
- Phase 1 collimators will stay in the machine and will be complemented by additional phase 2 collimators.
- Significant resources were invested to prepare the phase 2 system upgrade to the maximum extent.
- **Phase 2 does not need to respect the same constraints as the phase 1 system.**
- The challenge we put to ourselves: **Improve at least by factor 10 beyond phase 1!**

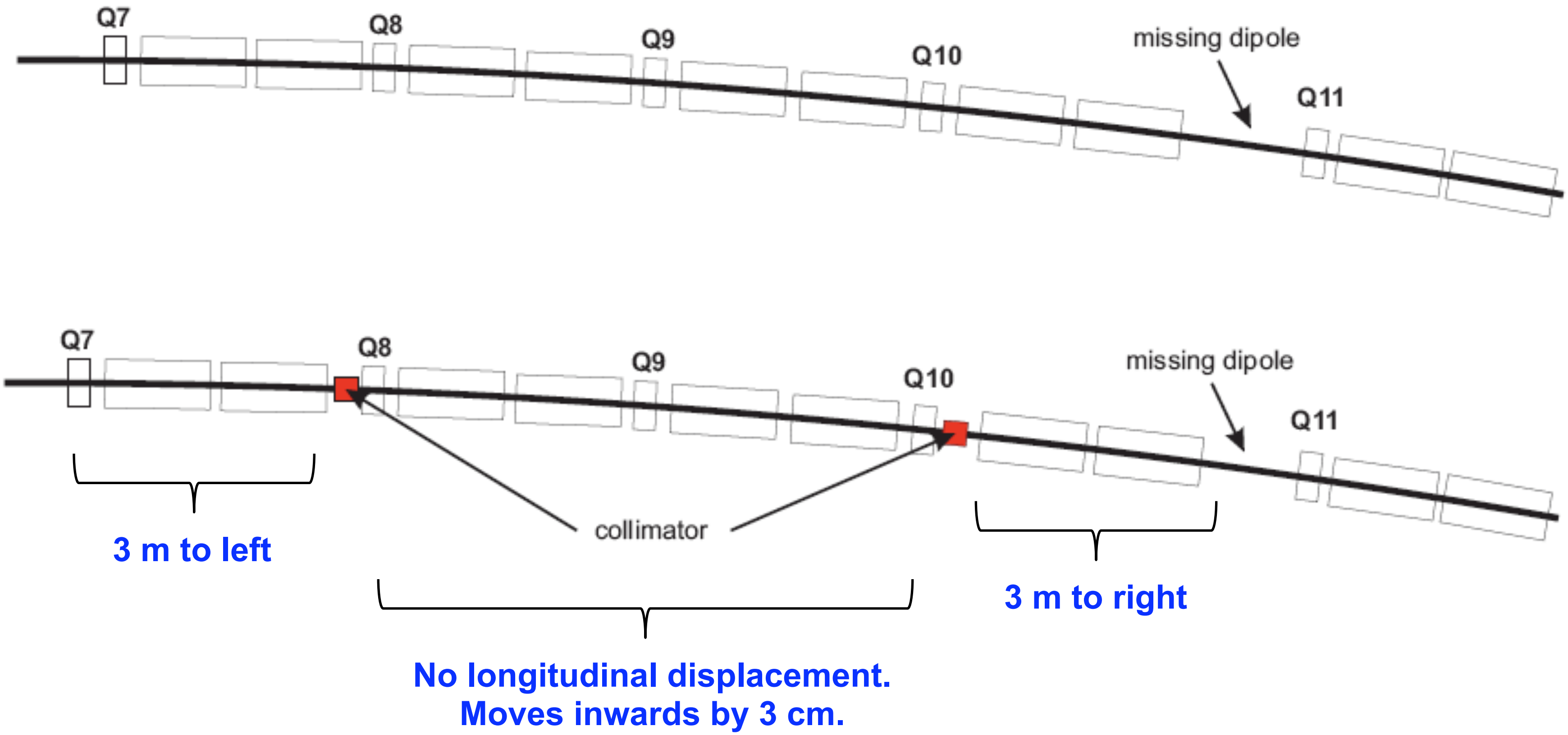
Phase 2 Collimation Efforts

- Phase 2 collimation project on R&D has been included into the white paper:
  - We set up project structure in January 2008. Key persons in place. Work packages agreed.
  - Two lines: (1) Upgrade of collimation and improved hardware. (2) Preparation of beam test stand for test of advanced collimators.
  - Review in February 2008 to take first decisions.
- US effort (LARP, SLAC) is ongoing and we are well connectet. First basic prototype results shown at EPAC08 ➔ Tom et al.
- FP7 request EUCARD with collimation work package:
  - Makes available significant additional resources (enhancing white paper money).
  - Remember: Advanced collimation resources through FP7 (cryogenic collimators, crystal collimation, e-beam scraper, …).

Improving Collimation Function

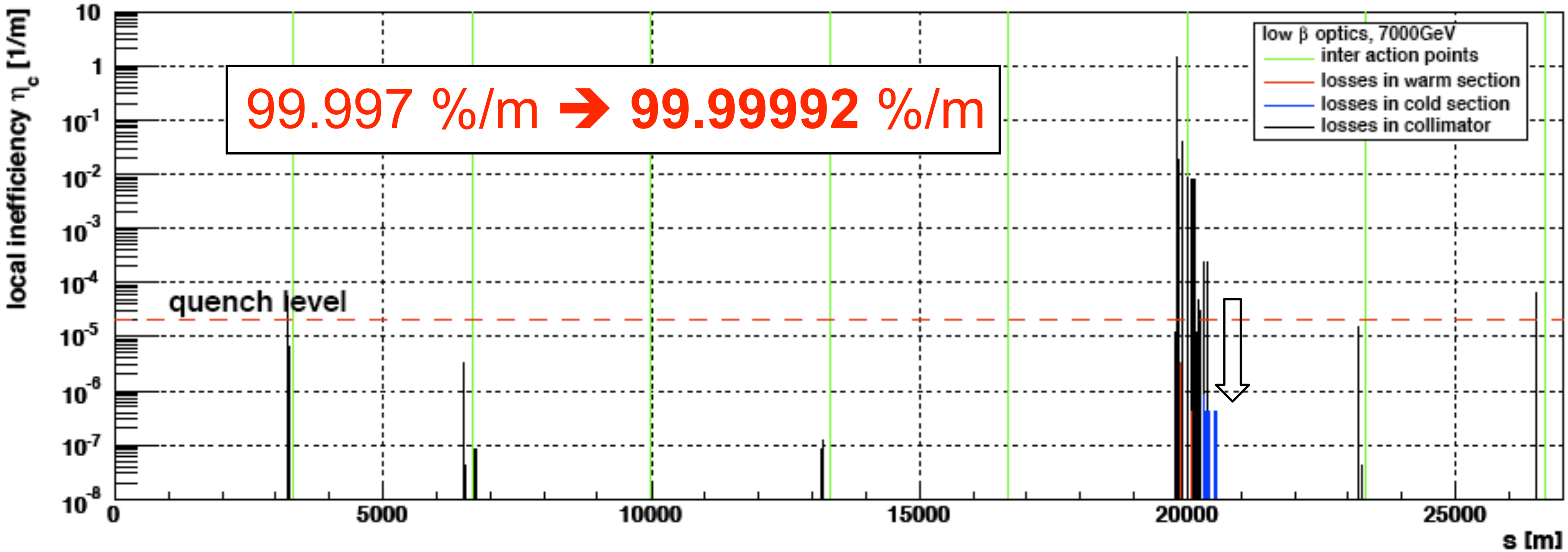
- Phase 2 primary and secondary collimators (TCSM):
  - Reduce number of off-momentum particles produced (losses in dispersion suppressor) with other materials.
  - Improve radiation-hardness and limit radiation damage to jaw surface with better jaw material (stability of thermal and electrical conductivities, better vacuum, less dust, …).
  - In jaw diagnostics for faster and more accurate set-up of collimators, possibly re-optimizing settings every fill at high intensity.
- Collimation in super-conducting dispersion suppressors:
  - Install collimators into SC area, just before loss locations to catch off-momentum particles before they get lost in SC magnets.
  - Might be beneficial to install around all IR's, for sure in IR3 and IR7.
  - Elegant use for space left by missing dipoles!
- Scrapers…

Change in Layout of DS



Layout and optics checked with MADX. No problem for the optics and survey seen. Optics change (move of Q7) small even without optics rematch. More careful work is required. Note, that impact on infrastructure was not checked yet!

Proton Collimation Efficiency with Phase 2 Cu Collimators and Cryogenic Collimators

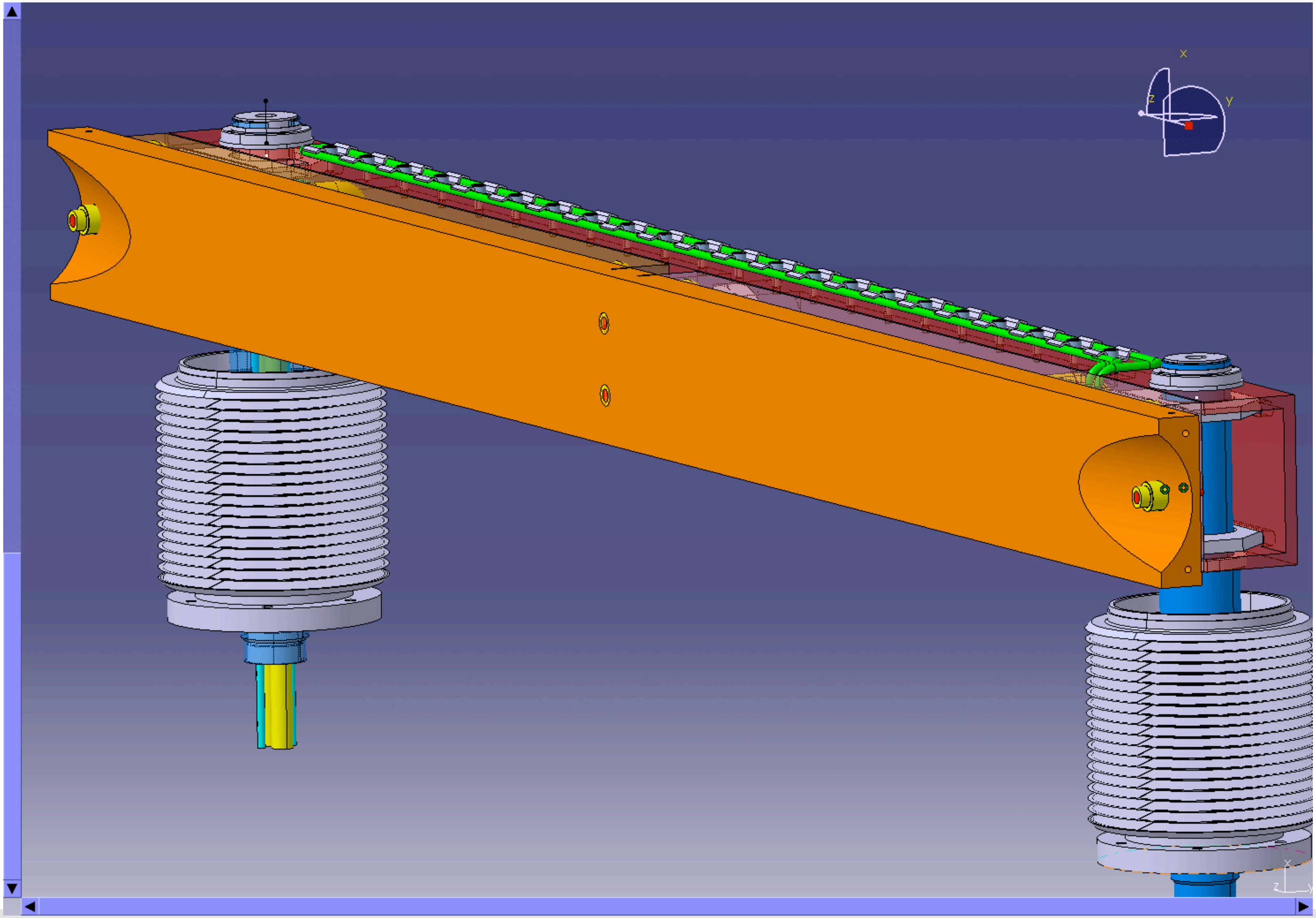


Inefficiency reduces by factor 30 (good for nominal intensity). Lower losses in the experimental collimators (background). Should also work for ions.

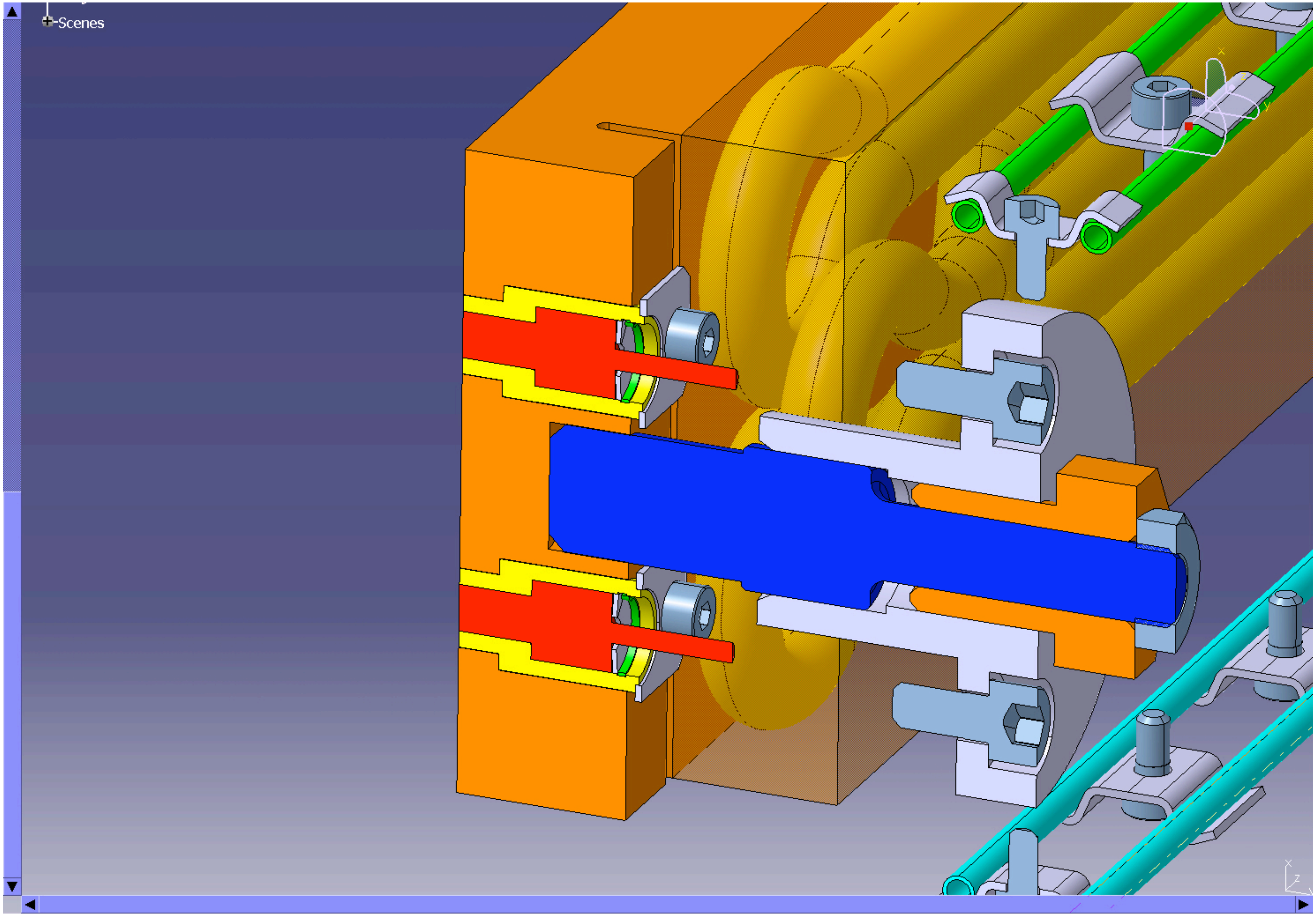
Caution: Further studies must show real feasibility of this proposal (energy deposition, heat load, integration, cryogenics, beam2, …). Just a concept at this point.

Cryogenic collimators will be studied as part of FP7 with GSI in Germany.

Engineering Design CERN Prototype



Electrode in CERN Design



Phase II CERN Collimator TCSM

- So far working on a second generation phase I collimator: implement all improvements we are aware off based on experience with phase I design, construction and operation.
- Innovation is in following areas:
  - Advanced jaw materials, including new composite materials (e.g. Cu – diamond with EPFL), coatings, foils. Effects on efficiency, impedance, radiation hardness, vacuum, etc.
  - Jaw flatness control.
  - In-jaw instrumentation (BPM, ionization, loss, …).
  - Improved robustness of mechanical movement system.
- We plan for 1-2 prototypes of different phase II secondary collimators at CERN. These will be alternatives to the LARP phase II design.
- Can have different types at different locations (different exposure to beam loss, beam heating, accidents). LARP into accident-exposed locations!?

Phase II Cryogenic Collimator

- Cryogenic collimators would protect the LHC dispersion suppressors against off-momentum losses (single-diffractive scattering in collimators, dissociation and fragmentation in collimators or from collisions).
- Can provide a very strong gain in cleaning efficiency (factor 30?).
- Cleaning efficiency can be used to increase gaps (after triplet upgrade with large aperture) and reduce impedance. Detailed study ongoing.
- GSI has to build cryogenic collimators for the FAIR project. CERN-GSI collaboration on developing this technology and prototypes together.
- **Must be shown in beam tests to work as expected.**
- Requires modification of the SC dispersion suppressors IR3, IR7, …
- Additional applications:
  - Solve ion luminosity limit with cryogenic collimators around experimental insertions.

Phase II Crystal Collimator

- Crystal collimators would complement primary collimators. Would need 4 per beam.
- Promises big improvement in cleaning efficiency. Solve ion limitations if dissociation and fragmentation is suppressed in crystal?
- At the moment an **experimental method in basic R&D state**. Crystal-based collimation must be shown to work reliably with stored beam and diffusive beam losses ➔ Tevatron and SPS experiments.
- Many questions remain to be addressed for the LHC. Most important:
  - Where to dump the extracted halo load (up to 1 MW)?
  - Machine protection issues if crystal extracts full beam.
  - …
- See EPAC06 paper by R. Assmann, S. Redaelli, W. Scandale

Phase II Scraper

- Originally, the phase I system was agreed to include 8 beam scrapers.
- These should allow to scrape beam tails until 3-4 σ at the start of a physics fill (like Tevatron and RHIC). Less sensitivity to beam tails and less spiky beam loss (background) behavior.
- Detailed studies were done but no powerful scraper design was identified. Most powerful scrapers found were the existing phase I primary collimators, however, limited to about 5-6 σ.
- Phase I scrapers were abandoned for construction in 2007 and moved into phase II. Experience shows that dedicated scrapers are important!
- Work must resume at some point. First ideas:
  - **Hollow e-beam lens scraper** (V. Shiltsev). Started some study with J. Smith.
  - **Fast rotating scraper** (sawing the beam, spreading the heat load).

Comment on LARP for Collimation

- CERN is not developing any concept similar to rotating collimators. We fully rely on LARP/SLAC commitment.
- Decision on hardware production and way to improve the LHC collimation system (~2010/11) taking into account:
  - **Experience with LHC beam** (beam loss, quenches, collimation efficiency). Already seen LHC beam-induced quench with 2e9 protons at 450 GeV.
  - **Results from phase II collimator beam testing** (before and in LHC).
  - **Results from cryogenic collimator development** (CERN, GSI, …).
  - **Results from advanced collimation concepts** (crystals, e-beam lens, …).
- Good to foresee a collimator production project in APL for later decisions:
  - Produce phase II secondary collimators.
  - Produce scrapers, crystal collimators, e-beam lens scrapers, collimators needed for triplet upgrades, …
  - Likely several improvements needed: share work load between CERN/US…

LHC Collimation Timeline

- Timelines are shifting, as we couple ourselves to LHC beam experience.
- Present view, to be refined in February 2009 review:
  - **February 2009**: First phase II project decisions. Design work on TCSM ongoing at LARP and CERN.
  - **April 2009**: Start of FP7 project on collimation ➔ Start of development for cryogenic collimator and LHC crystal collimator.
  - **2009-2010**: Laboratory tests on TCSM collimator prototypes.
  - **2010-2011**: Beam tests of TCSM and cryogenic collimators.
  - **2011/12**: Production and installation of phase II collimation upgrade.
  - **2012/13**: Readiness for nominal and higher intensities from collimation side.
- It is clear that this is a challenging time scale. The beam experience will accelerate or decelerate this effort.