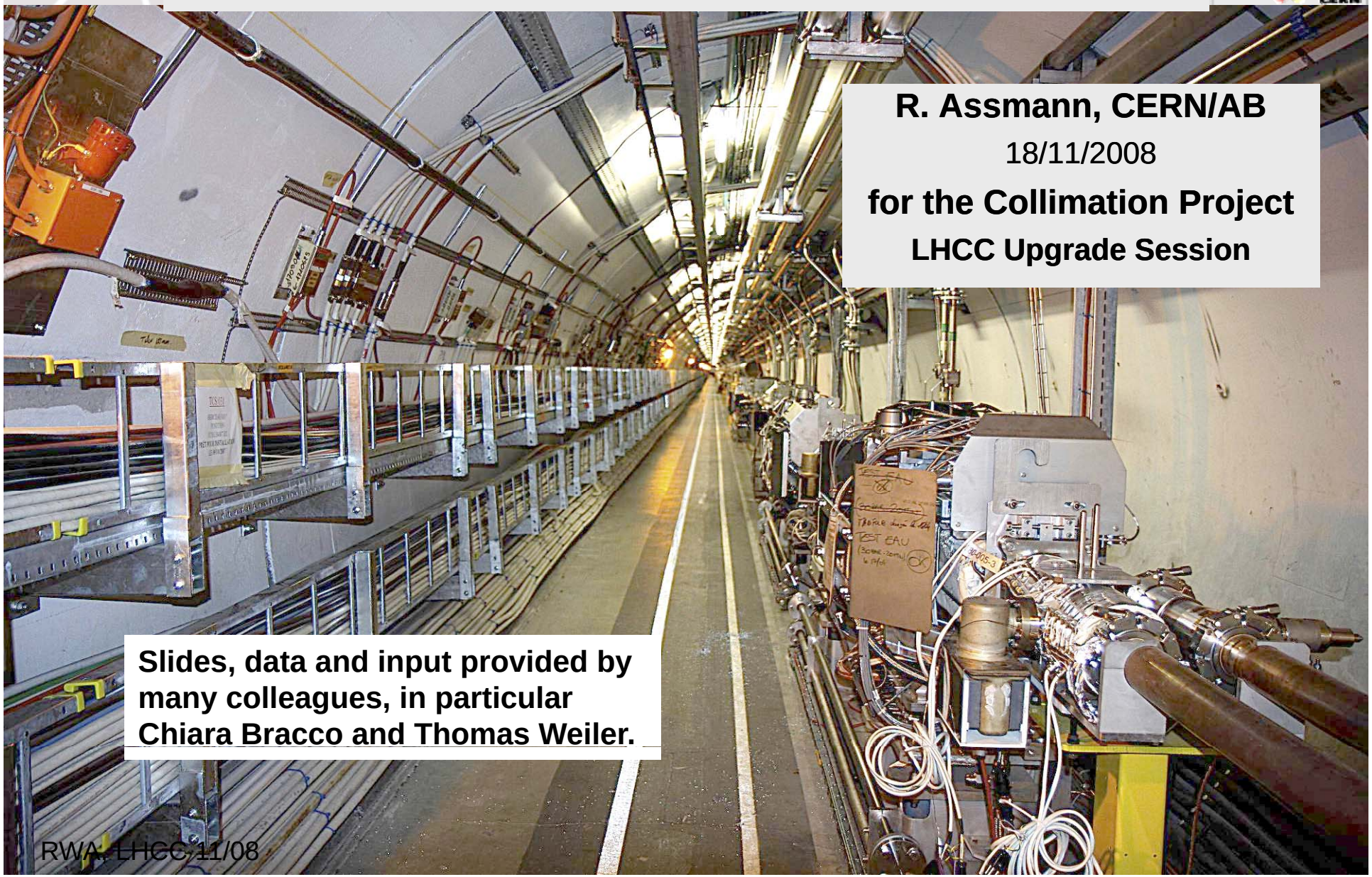
Collimation Upgrade Issues for the Experimental Insertions



R. Assmann, CERN/AB

18/11/2008

for the Collimation Project

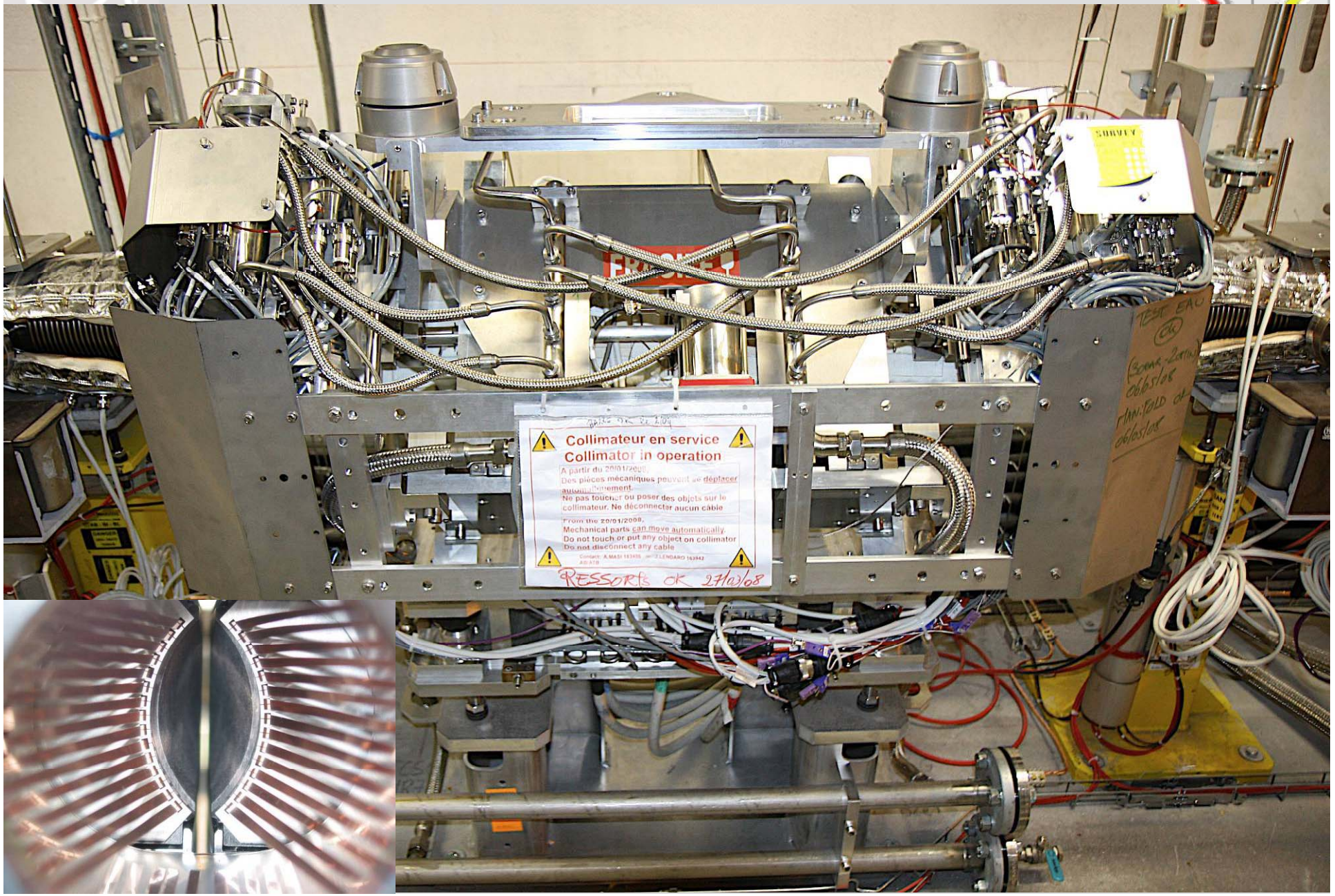
LHCC Upgrade Session

Slides, data and input provided by many colleagues, in particular Chiara Bracco and Thomas Weiler.

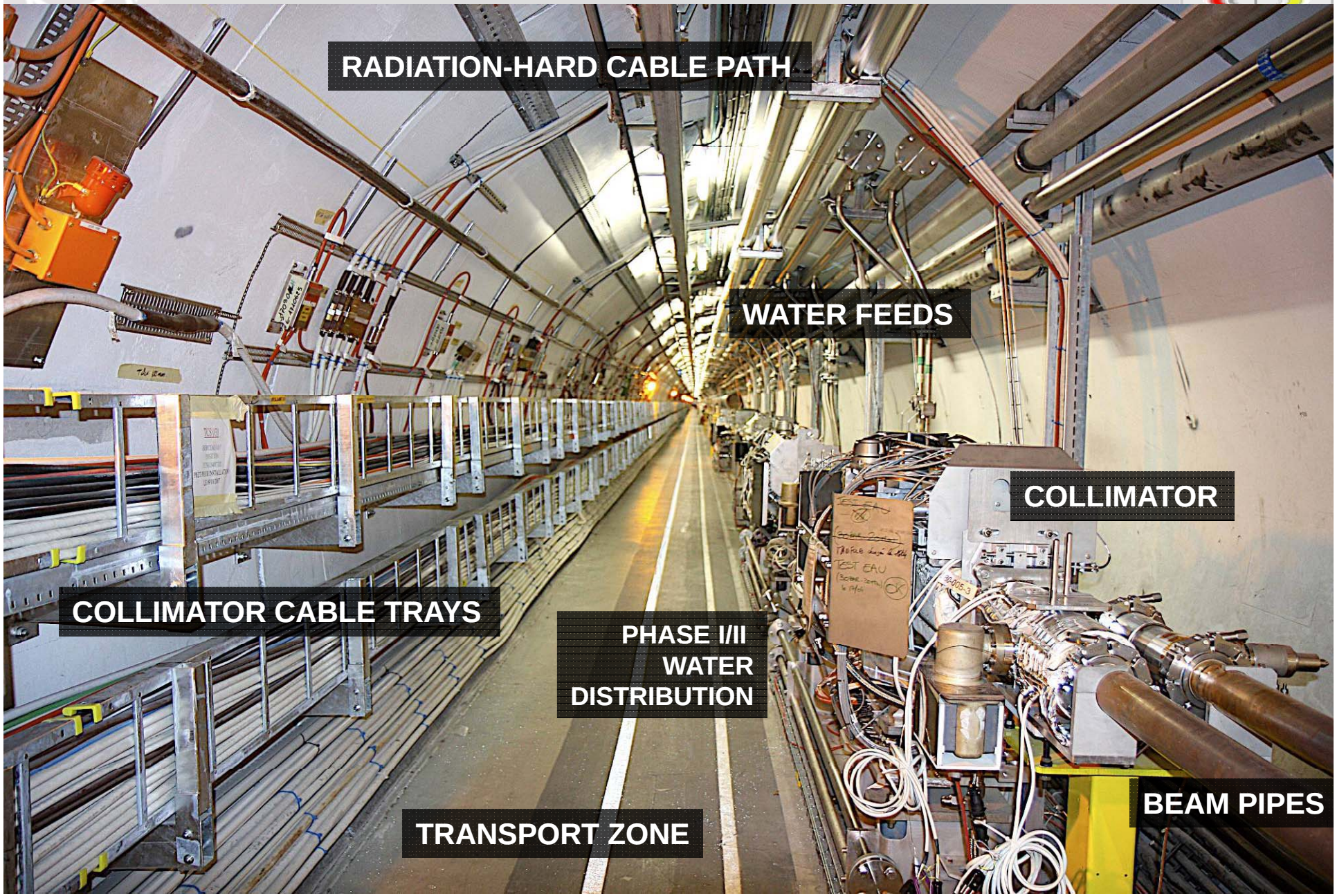
Constraints Collimation Phase I

- Strict constraints imposed in 2003 for phase 1 system:
  - Availability of working collimation system for LHC beam start-up
  - Robustness against LHC beam (avoid catastrophic problems)
  - Radiation handling (access for later improvements)
  - No modifications to SC areas (due to short time and problems with QRL)
- Compromises accepted:
  - Limited advanced features (e.g. no pick-ups in jaws).
  - Risk due to radiation damage for fiber-reinforced graphite (electical + thermal conductivity changes, dust, swelling, …). Kurchatov data shows factor 4-5 changes with irradiation in various important parameters.
  - Steep increase in machine impedance due to collimators.
  - Excellent cleaning efficiency, however, insufficient for nominal intensity.

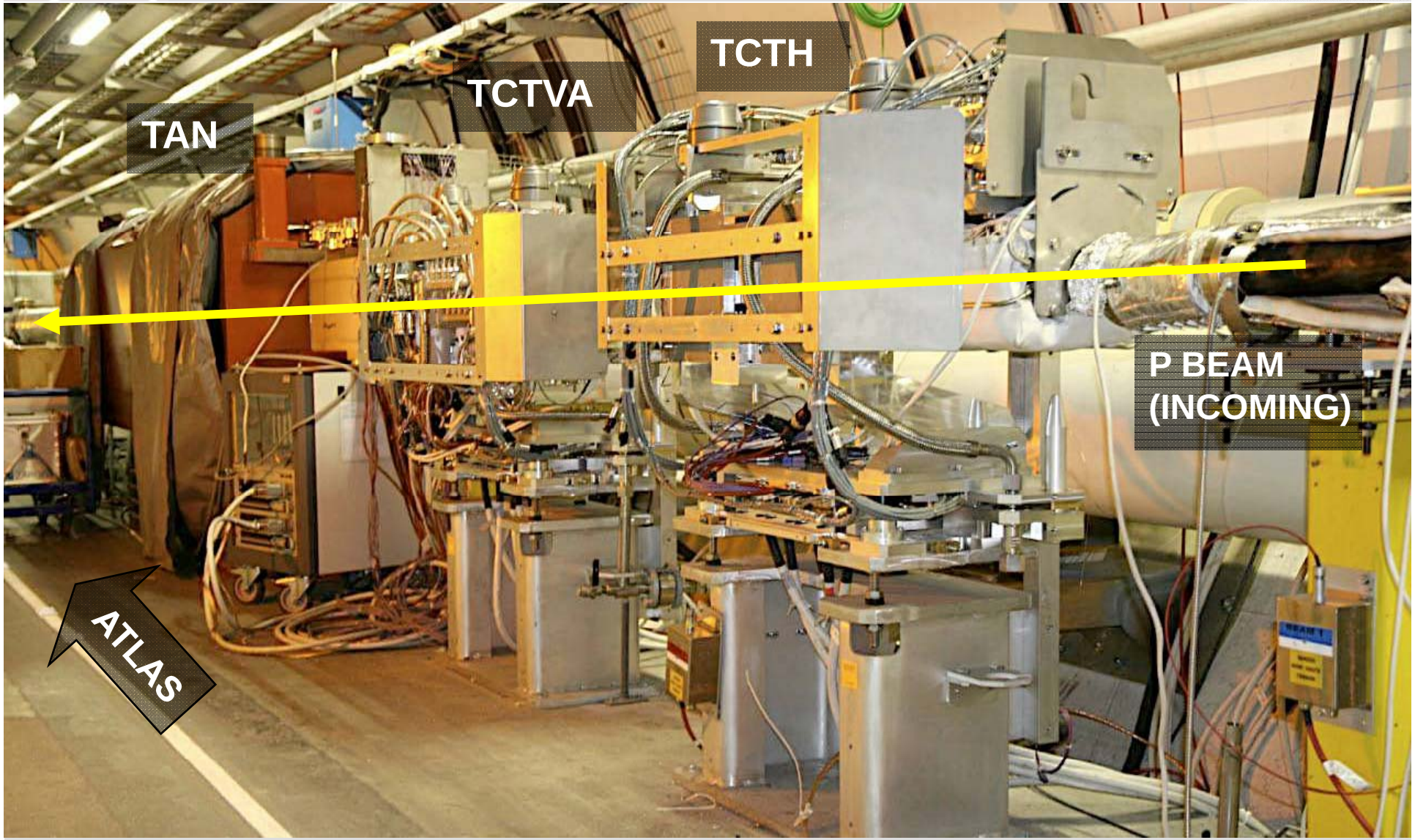
Side View Phase I Collimator

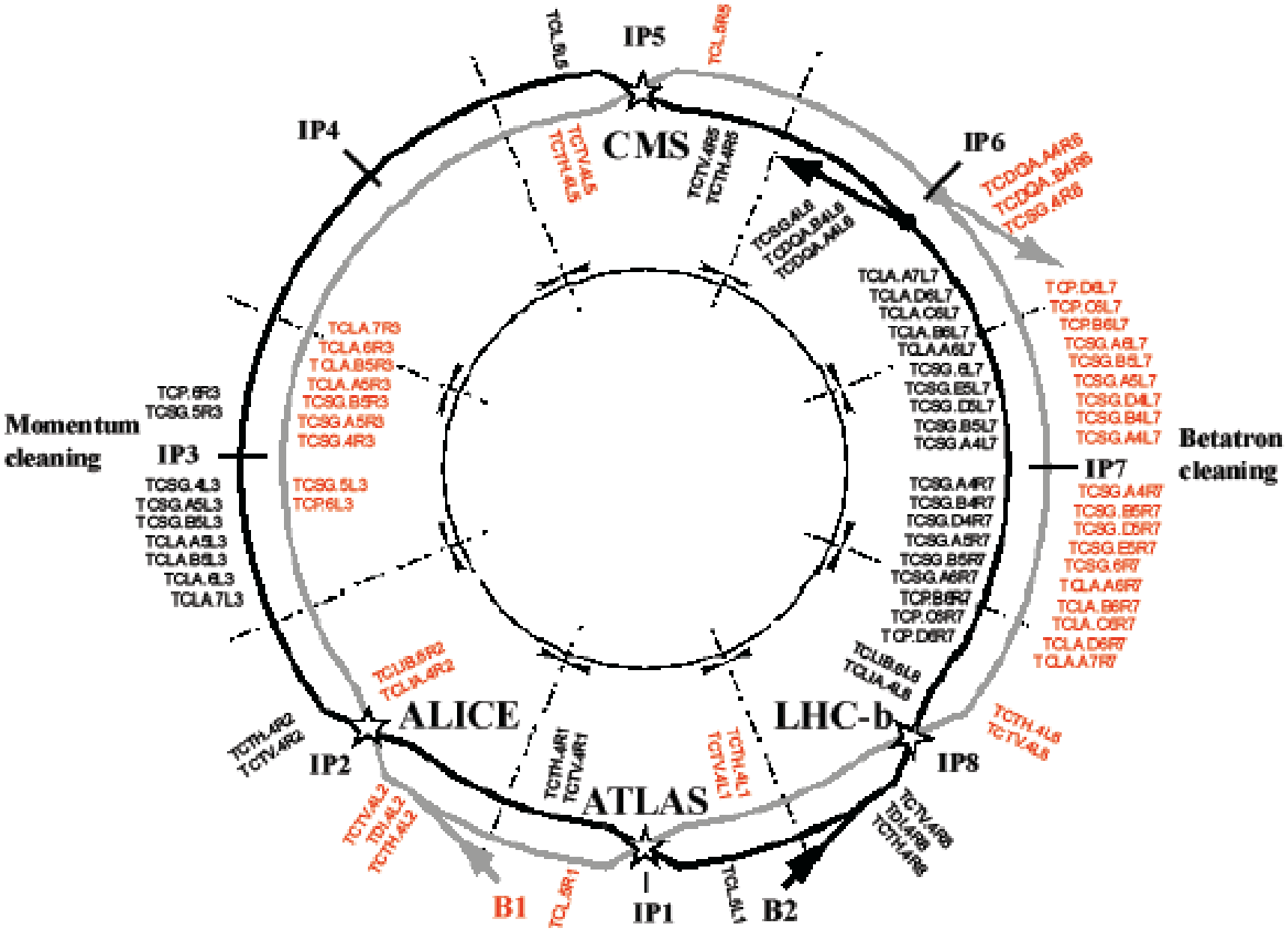


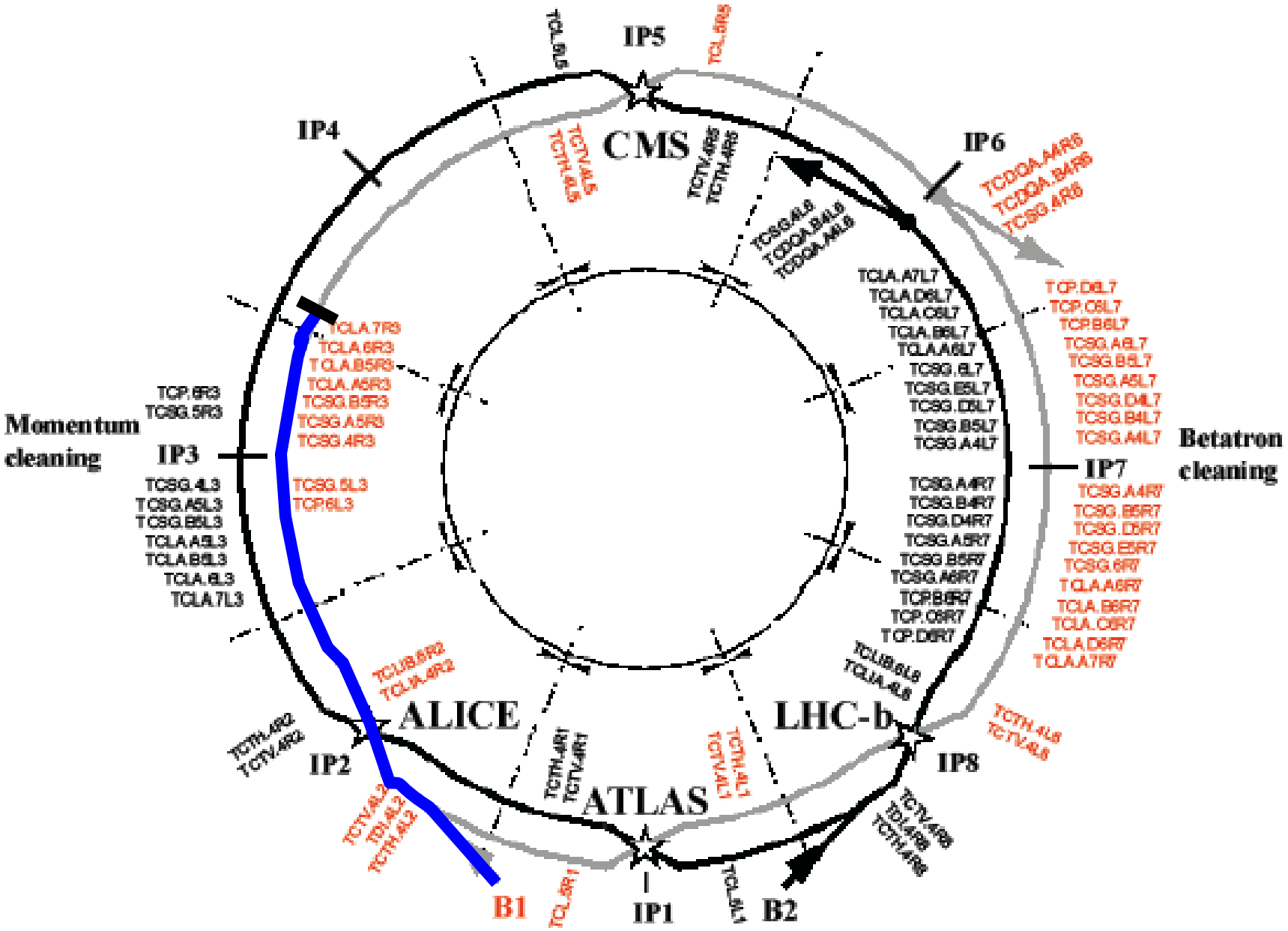
Cleaning Insertion IR7

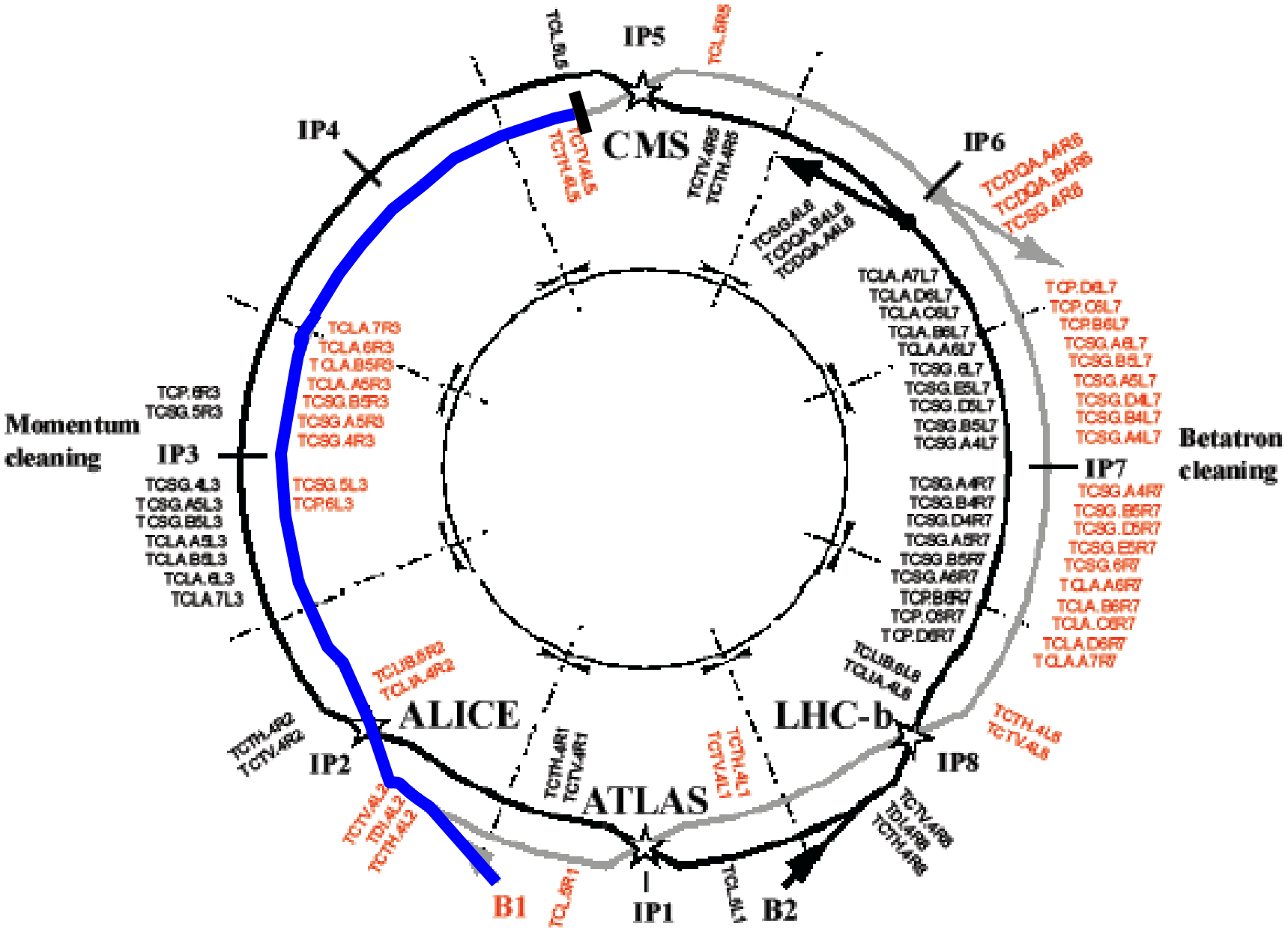


IR1 Tertiary Collimation (W Jaws)

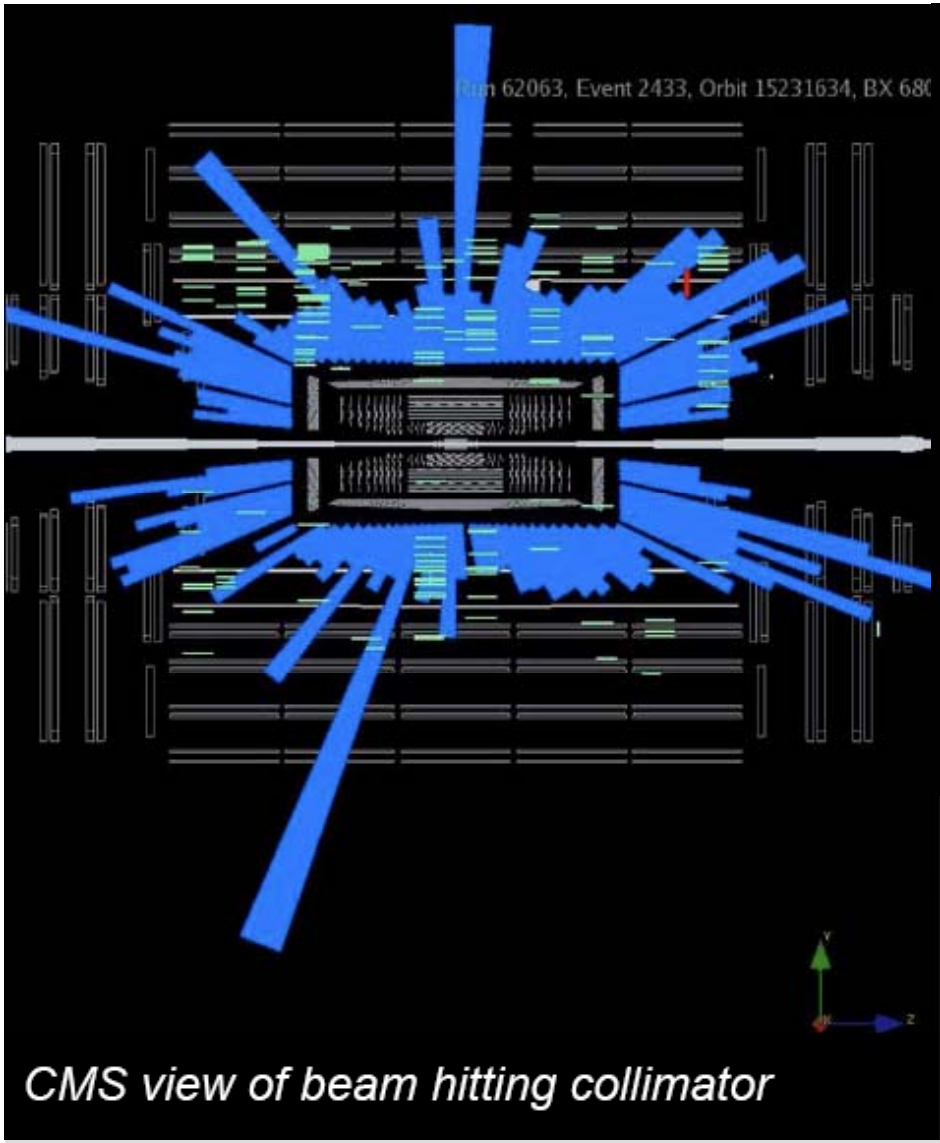



IP5
CMS
IP4
IP6
Momentum cleaning
IP3
IP7
Betatron cleaning
ALICE
LHC-b
IP2
IP8
ATLAS
B1
IP1
B2
TCL.6L5
TCL.6R5
TCTV.4L5
TCTH.4L5
TCTV.4R5
TCTH.4R5
TCSG.4L5
TCDQA.B4L5
TCDQA.A4L5
TCDQA.A4R6
TCDQA.B4R6
TCSG.4R6
TCLA.7R3
TCLA.6R3
TCLA.B5R3
TCLA.A5R3
TCSG.B5R3
TCSG.A5R3
TCSG.4R3
TCP.6R3
TCSG.5R3
TCSG.5L3
TCP.6L3
TCSG.4L3
TCSG.A5L3
TCSG.B5L3
TCLA.A5L3
TCLA.B5L3
TCLA.6L3
TCLA.7L3
TCLA.A7L7
TCLA.D6L7
TCLA.C6L7
TCLA.B6L7
TCLA.A6L7
TCSG.6L7
TCSG.B5L7
TCSG.D5L7
TCSG.B5L7
TCSG.A4L7
TCP.D6L7
TCP.C6L7
TCP.B6L7
TCSG.A6L7
TCSG.B5L7
TCSG.A5L7
TCSG.D4L7
TCSG.B4L7
TCSG.A4L7
TCSG.A4R7
TCSG.B4R7
TCSG.D4R7
TCSG.A5R7
TCSG.B5R7
TCSG.A6R7
TCP.B6R7
TCP.C6R7
TCP.D6R7
TCSG.A4R7
TCSG.B5R7
TCSG.D5R7
TCSG.E5R7
TCSG.6R7
TCLA.A6R7
TCLA.B6R7
TCLA.C6R7
TCLA.D6R7
TCLA.A7R7
TCLIB.6L2
TCLIA.4R2
TCTH.4R2
TCTV.4R2
TCTV.4L2
TDI.4L2
TCTH.4L2
TCL.5R1
TCTH.4R1
TCTV.4R1
TCTH.4L1
TCTV.4L1
TCL.5L1
TCLIB.6L8
TCLIA.4L8
TCTH.4L8
TCTV.4L8
TCTV.4R8
TDI.4R8
TCTH.4R8

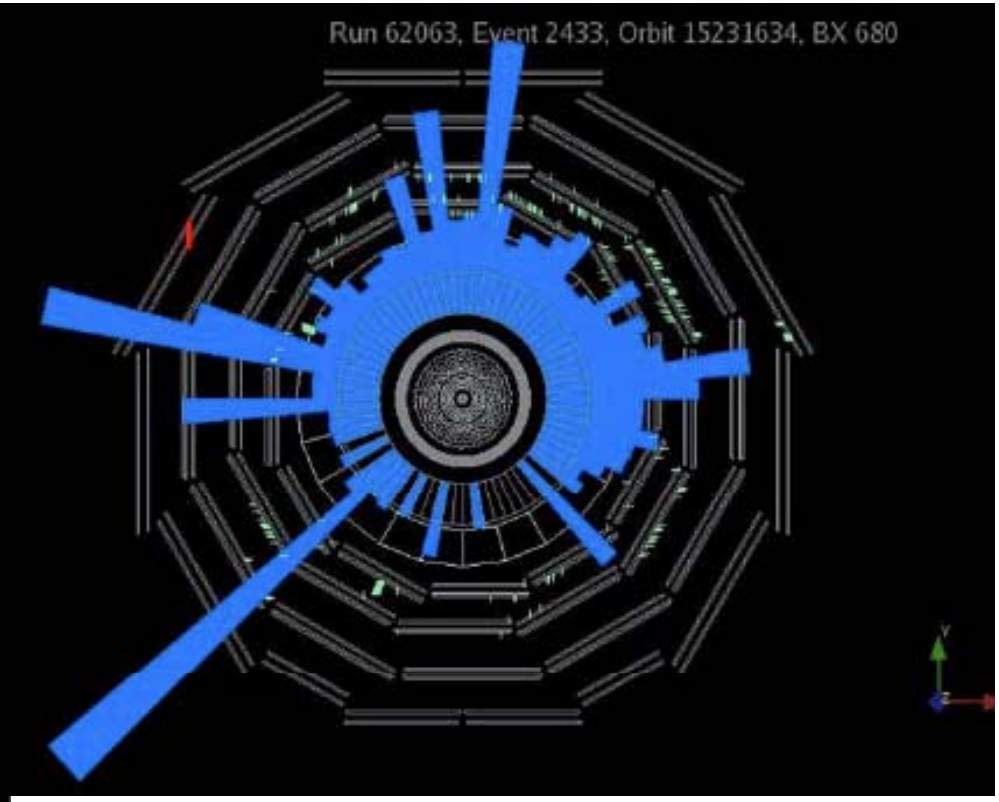

IP5
CMS
IP4
IP6
Momentum cleaning
IP3
IP7
Betatron cleaning
ALICE
LHC-b
IP2
IP8
ATLAS
IP1
B1
B2
TCLA.7R3
TCLA.6R3
TCLA.B5R3
TCLA.A5R3
TCSG.B5R3
TCSG.A5R3
TCSG.4R3
TCSG.5L3
TCP.6L3
TCSG.4L3
TCSG.A5L3
TCSG.B5L3
TCLA.A5L3
TCLA.B5L3
TCLA.6L3
TCLA.7L3
TCP.6R3
TCSG.5R3
TCLA.A7L7
TCLA.D6L7
TCLA.C6L7
TCLA.B6L7
TCLA.A6L7
TCSG.6L7
TCSG.E5L7
TCSG.D5L7
TCSG.B5L7
TCSG.A4L7
TCSG.A4R7
TCSG.B4R7
TCSG.D4R7
TCSG.A5R7
TCSG.B5R7
TCSG.A6R7
TCP.B6R7
TCP.C6R7
TCP.D6R7
TCP.D6L7
TCP.C6L7
TCP.B6L7
TCSG.A6L7
TCSG.B5L7
TCSG.A5L7
TCSG.D4L7
TCSG.B4L7
TCSG.A4L7
TCSG.A4R7
TCSG.B5R7
TCSG.D5R7
TCSG.E5R7
TCSG.6R7
TCLA.A6R7
TCLA.B6R7
TCLA.C6R7
TCLA.D6R7
TCLA.A7R7
TCLIB.6L2
TCLIA.4R2
TCTH.4R2
TCTV.4R2
TCTV.4L2
TDI.4L2
TCTH.4L2
TCL.5R1
TCTH.4R1
TCTV.4R1
TCTH.4L1
TCTV.4L1
TCLIB.6L8
TCLIA.4L8
TCTH.4L8
TCTV.4L8
TCTV.4R8
TDI.4R8
TCTH.4R8
TCL.4L1
TCDQA.A4R6
TCDQA.B4R6
TCSG.4R6
TCSG.4L6
TCDQA.B4L6
TCDQA.A4L6
TCL.6R5
TCL.6L5
TCTV.4R5
TCTH.4R5
TCTV.4L5
TCTH.4L5


IP5
CMS
IP4
IP6
IP7
Betatron cleaning
Momentum cleaning
IP3
IP2
ALICE
LHC-b
IP8
ATLAS
IP1
B1
B2
TCL.6R5
TCL.5R1
TCL.4L1
TCP.6R3
TCSG.5R3
TCSG.4L3
TCSG.A5L3
TCSG.B5L3
TCLA.A5L3
TCLA.B5L3
TCLA.6L3
TCLA.7L3
TCLA.7R3
TCLA.6R3
TCLA.B5R3
TCLA.A5R3
TCSG.B5R3
TCSG.A5R3
TCSG.4R3
TCSG.5L3
TCP.6L3
TCLIB.6R2
TCLIA.4R2
TCTH.4R2
TCTV.4R2
TCTV.4L2
TDI.4L2
TCTH.4L2
TCTH.4R1
TCTV.4R1
TCTH.4L1
TCTV.4L1
TCLIB.6L5
TCLIA.4L5
TCTH.4L5
TCTV.4L5
TCTV.4R5
TCTH.4R5
TCSG.4L5
TCDQA.B4L5
TCDQA.A4L5
TCDQA.A4R6
TCDQA.B4R6
TCSG.4R6
TCTV.4R6
TDI.4R6
TCTH.4R6
TCLA.A7L7
TCLA.D6L7
TCLA.C5L7
TCLA.B6L7
TCLA.A5L7
TCSG.6L7
TCSG.B5L7
TCSG.D5L7
TCSG.B4L7
TCSG.A4L7
TCSG.A4R7
TCSG.B4R7
TCSG.D4R7
TCSG.A5R7
TCSG.B5R7
TCSG.A6R7
TCP.B6R7
TCP.C6R7
TCP.D6R7
TCLIB.6L5
TCLIA.4L5
TCP.D6L7
TCP.C6L7
TCP.B6L7
TCSG.A6L7
TCSG.B5L7
TCSG.A5L7
TCSG.D4L7
TCSG.B4L7
TCSG.A4L7
TCSG.A4R7
TCSG.B5R7
TCSG.D5R7
TCSG.E5R7
TCSG.6R7
TCLA.A6R7
TCLA.B6R7
TCLA.C6R7
TCLA.D6R7
TCLA.A7R7

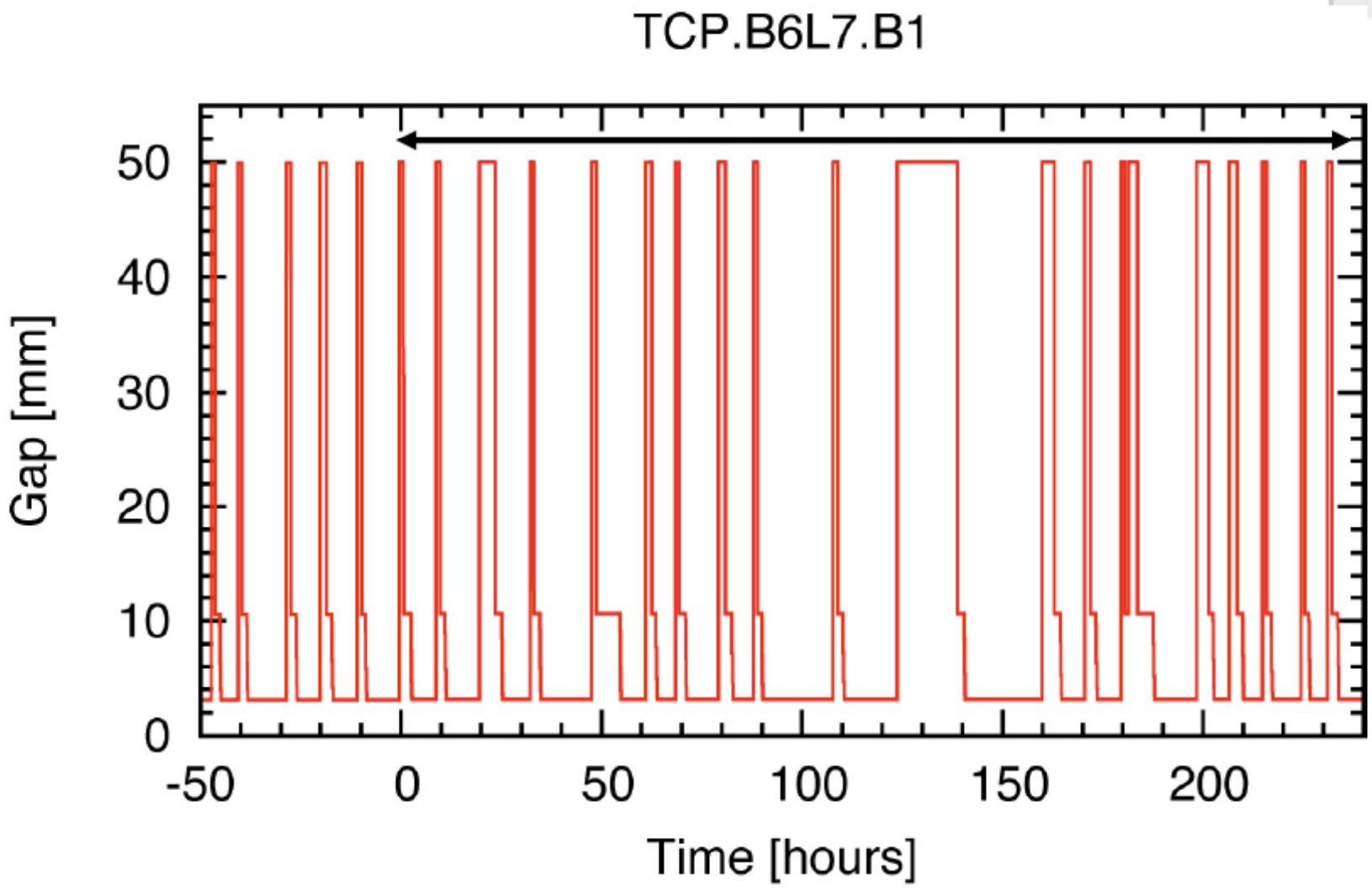
Tertiary Collimator Events (1m W)



CMS view of beam hitting collimator

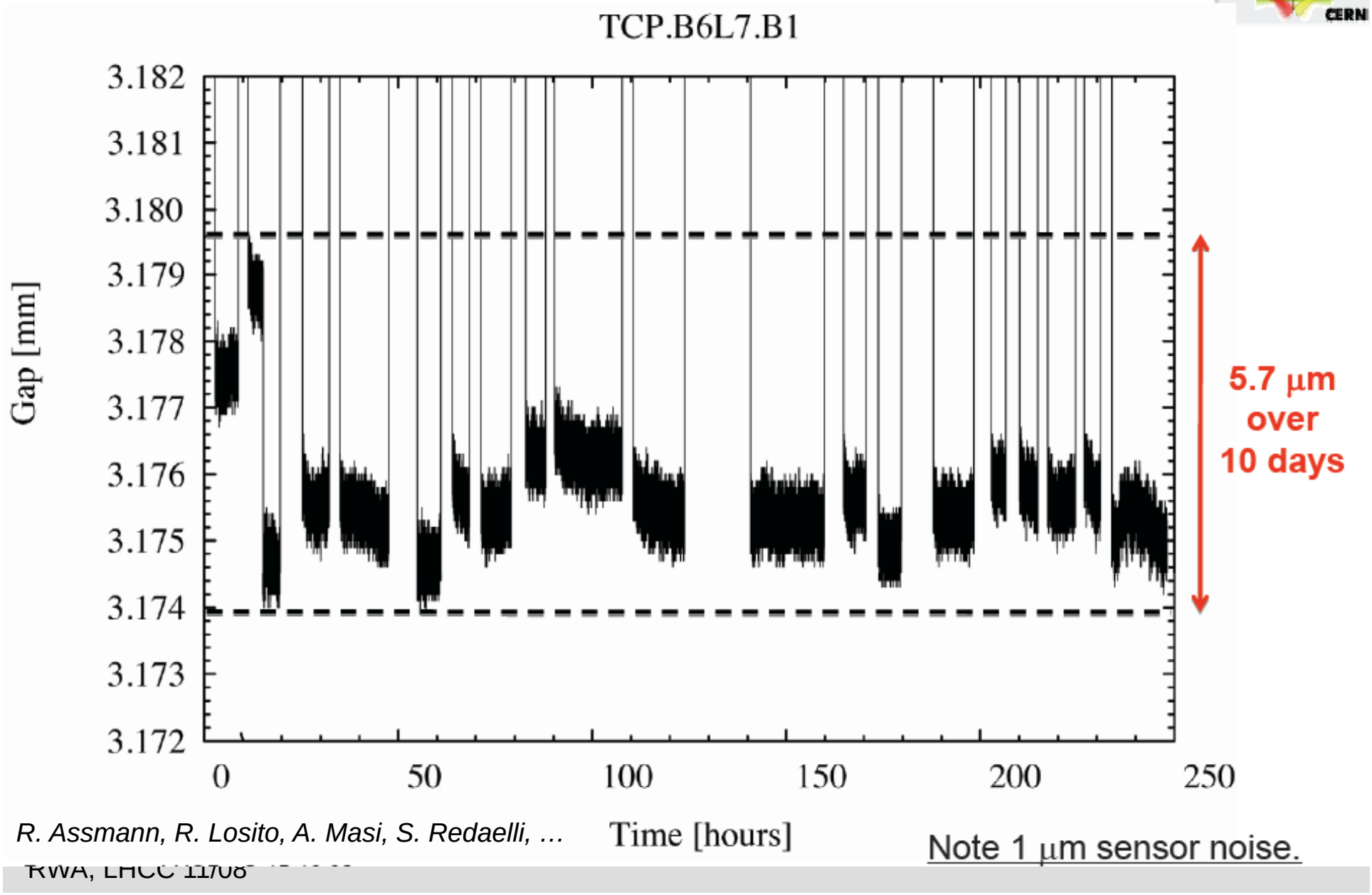


Reproducibility Run



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

Zoom into Collision Gaps



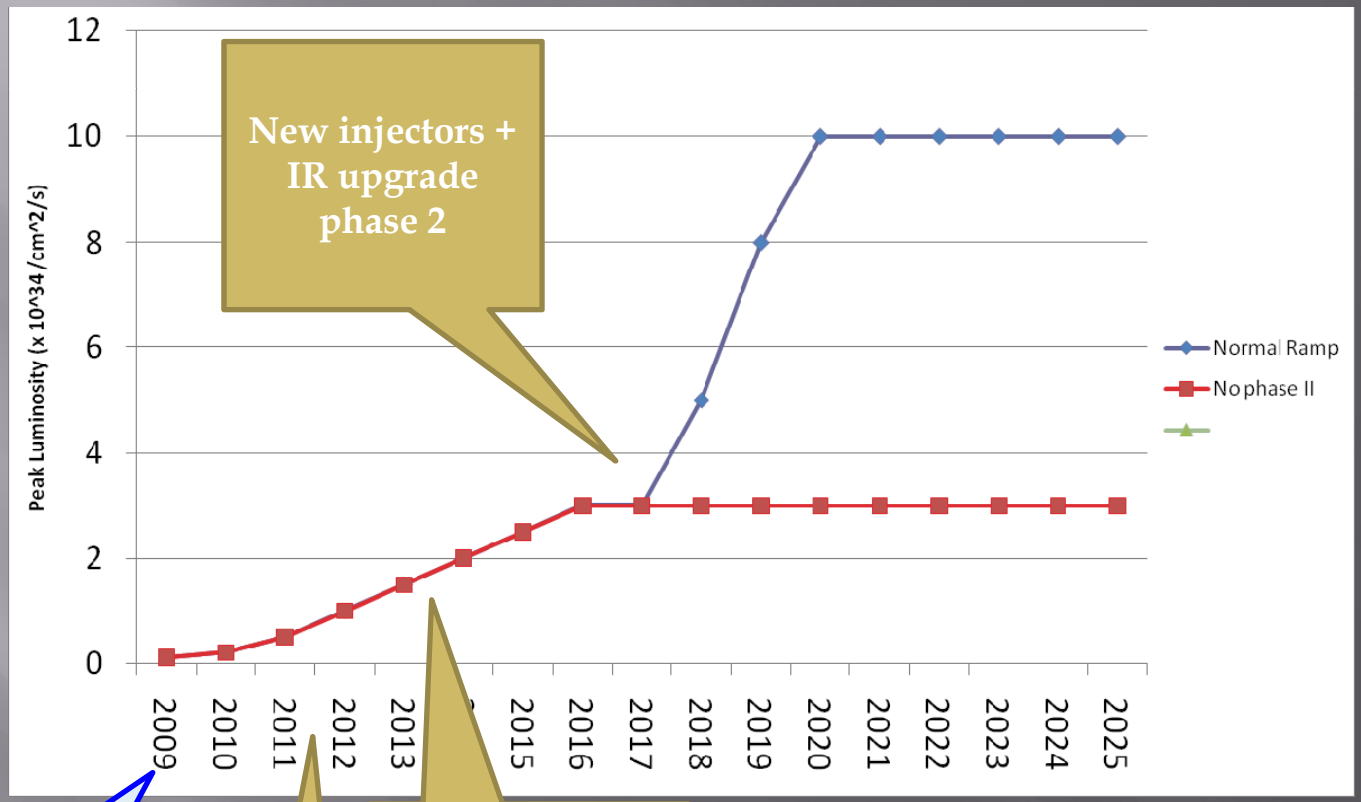
R. Assmann, R. Losito, A. Masi, S. Redaelli, …

Note 1 μm sensor noise.

Predicted Limits of LHC Collimation Phase 1

- **Cleaning efficiency (require > 99.995%/m):**
  - Ideal performance reach: 40% of nominal LHC intensity
    (factor 100 better cleaning than Tevatron/HERA)
  - With imperfections: loose up to factor 11 in performance
    (factor 10 better cleaning than Tevatron/HERA)
  - Imperfections must be minimized and special setup routines are being developed.
  - Upgrade of collimation required ➔ **phase 2**.
- **Impedance:**
  - Beam stability limit: 40% of nominal beam intensity
- Other possible limitations:
  - Collimator lifetime with radiation damage
- Note: Significant uncertainties in predictions! Many input parameters!

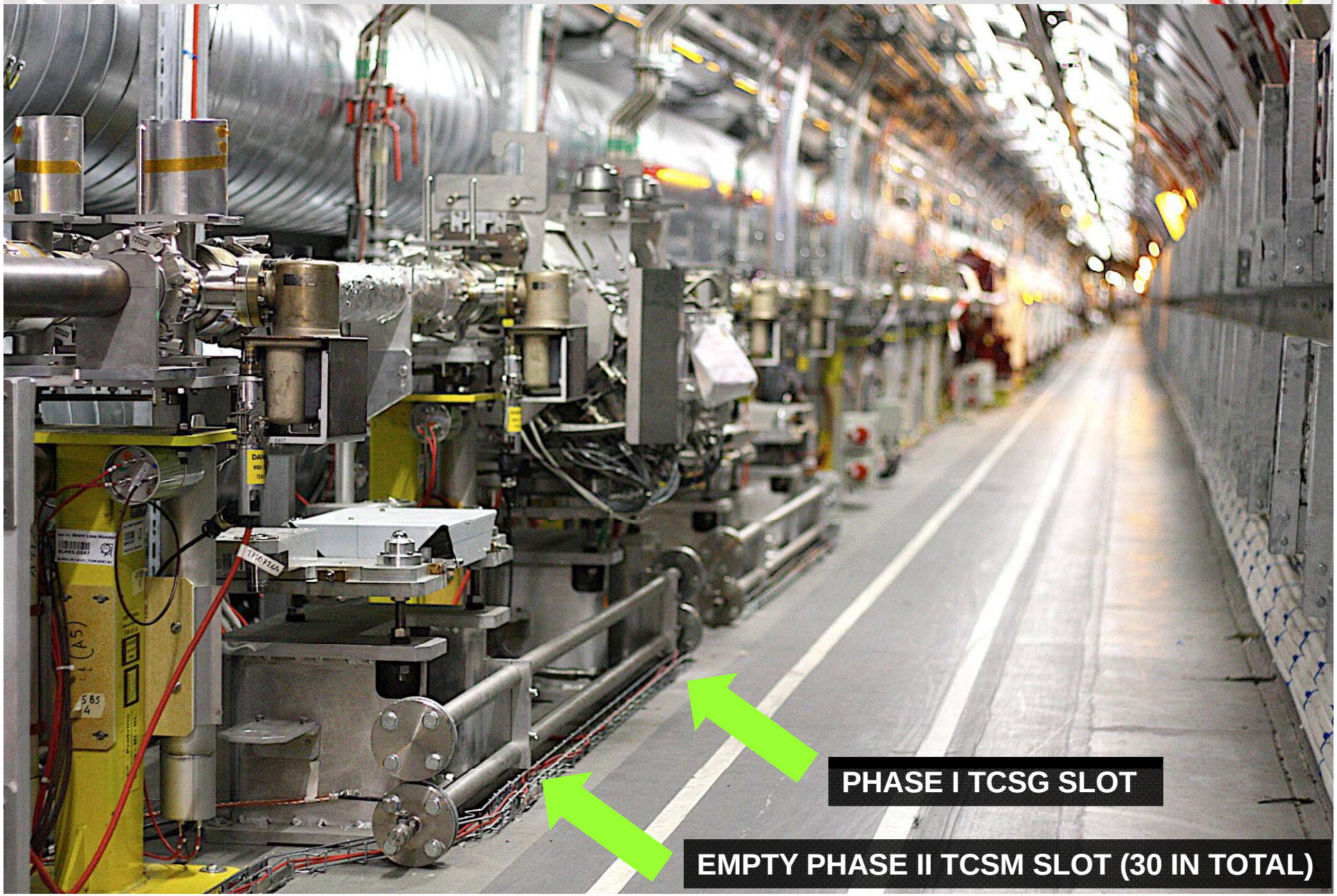
Peak luminosity…



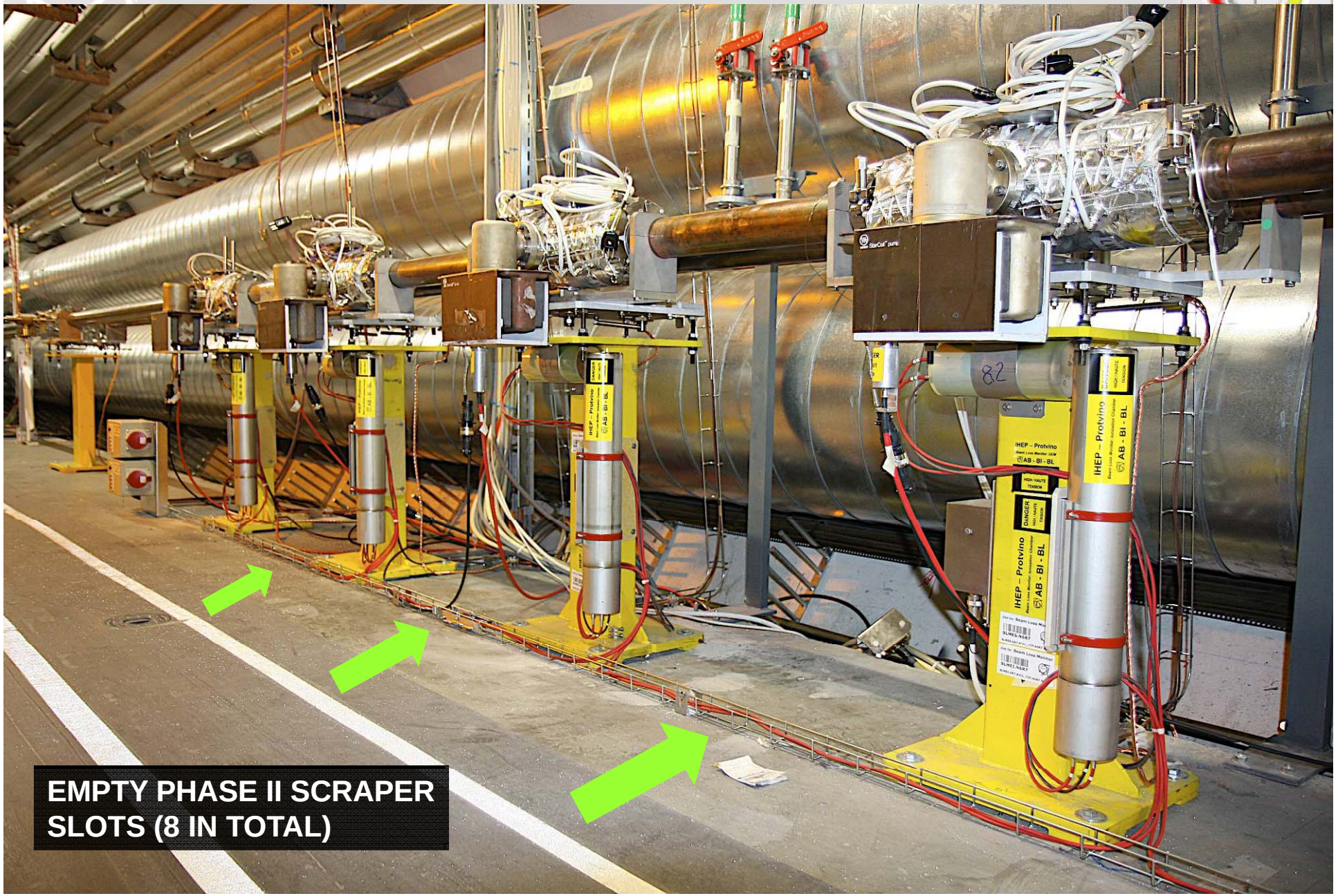
The Collimation Phase II

- 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 II Secondary Collimator Slots



Phase II Beam Scraper Slots

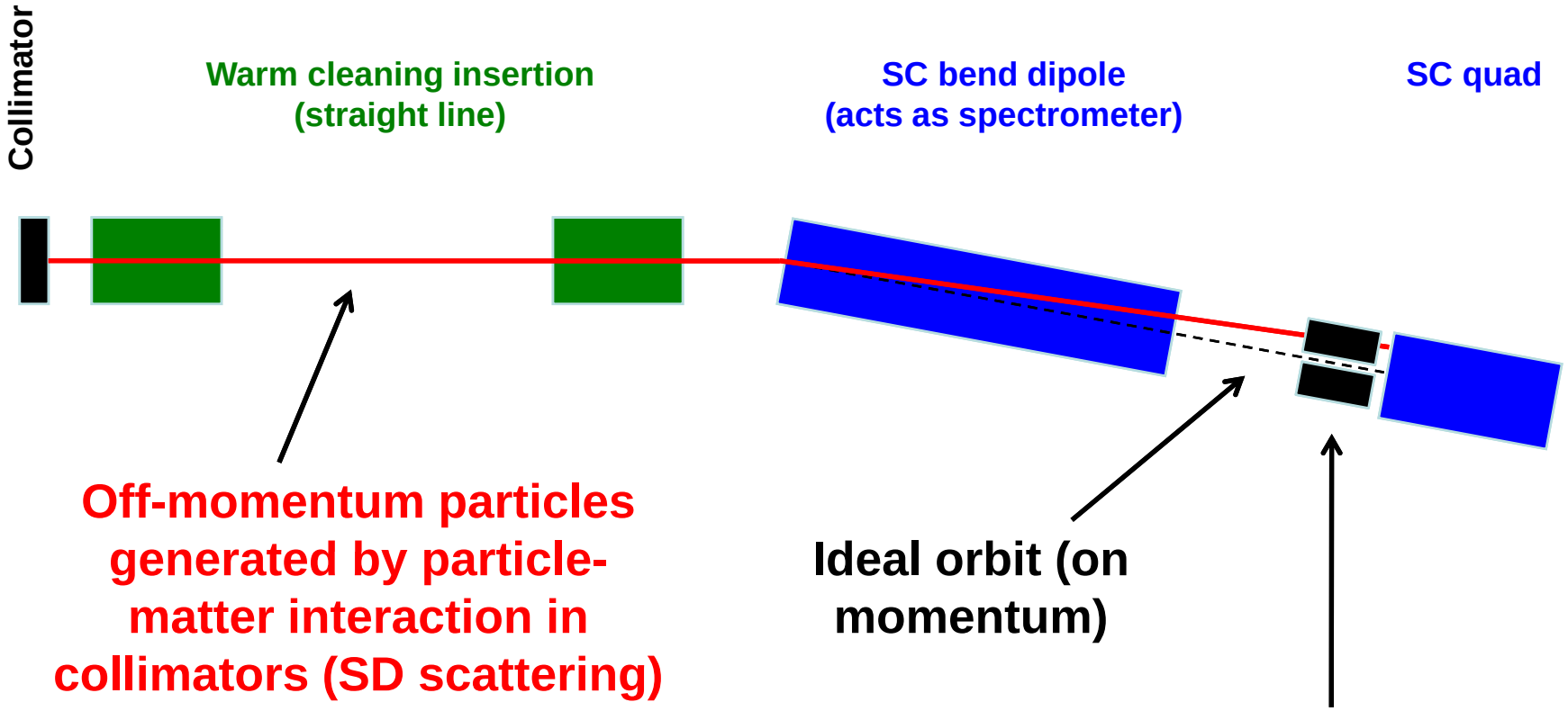


EMPTY PHASE II SCRAPER SLOTS (8 IN TOTAL)

Phase II Collimation Project

- 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 2009 to take first decisions.
- US effort (LARP, SLAC) is ongoing. First basic prototype results shown at EPAC08.
- FP7 request EUCARD with collimation work package:
  - Makes available significant additional resources (enhancing white paper money).
  - Remember: Advanced collimation resources through FP7 (cryogenic collimators with GSI, crystal collimation, e-beam scraper, …).

Schematic Solution Efficiency



+ metallic phase 2 collimators in IR3 and IR7

Prediction Beam 1 Halo (H) Losses in Experimental Insertions

preliminary

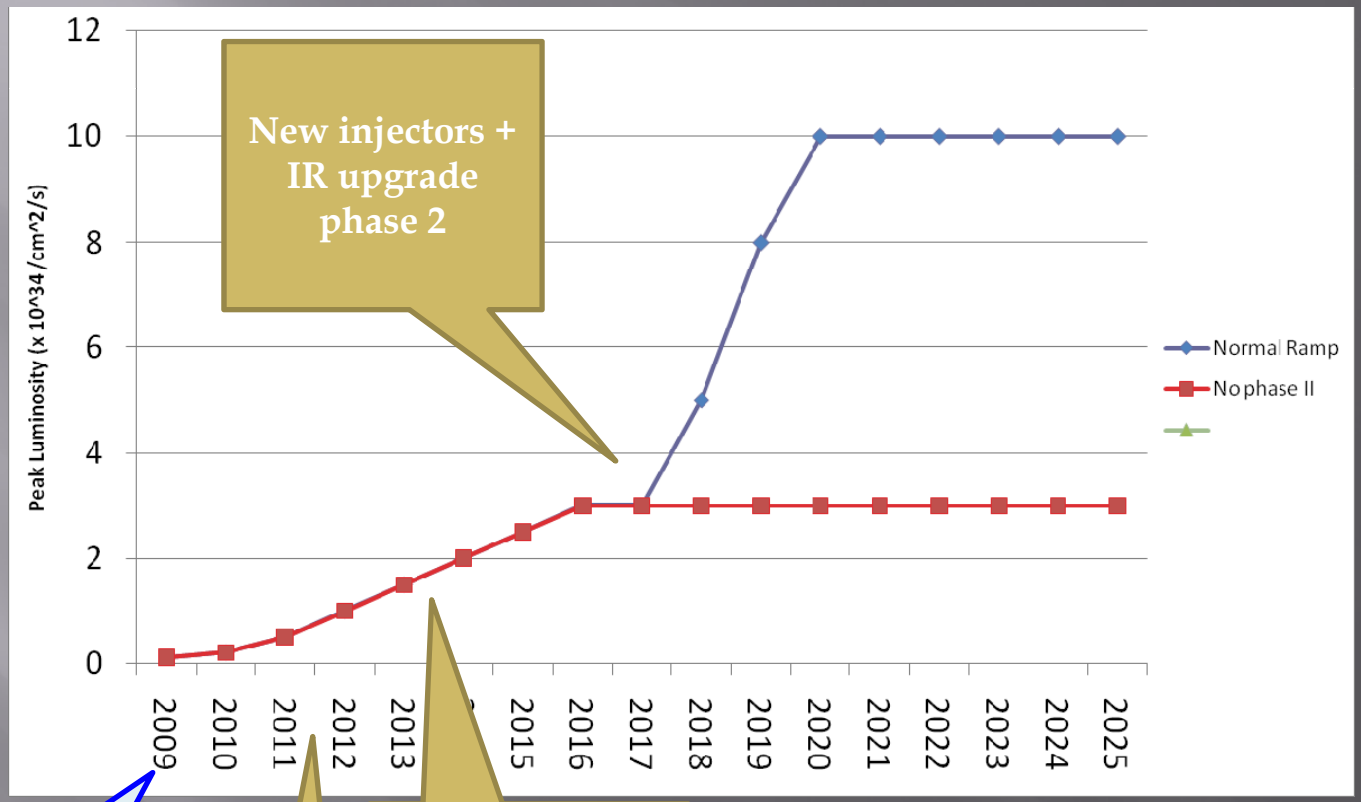
IR	Phase I (perfect)	Phase I (imperfect)	Phase II
IR1	**4.9×10^{-4}**	1.0×10^{-3}	**7.7×10^{-6}**
IR2	1.3×10^{-4}	2.1×10^{-4}	2.2×10^{-6}
IR5	**6.5×10^{-6}**	5.7×10^{-5}	**2.9×10^{-6}**
IR8	3.0×10^{-4}	7.5×10^{-4}	5.6×10^{-5}

- Numbers show fraction of overall loss that is intercepted at horizontal tertiary collimators in the various insertions (collimation halo load).
- Phase 2 collimation upgrade reduces losses in IR's by a factor up to 60!
- Beam 2 has opposite direction ➔ more losses in IR5 and less in IR1!

LHC Phase II 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 (with GSI).
  - **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.

Peak luminosity…



Consequences from Phase I Triplet Upgrade

- Under responsibility of Ranko Ostojic. Work ongoing. Review panel met on 1 Aug 2008 to discuss the main findings of the conceptual design review for the LHC Insertion Upgrade Phase-I.
- Triplet aperture: **70 mm** ➔ **120 mm**
- D1: room temperature ➔ super-conducting
- "Modifications to the warm sections, in particular of the TAN and installation of additional collimators and other protection equipment can be delayed to a later normal shutdown, ...".
- After the phase I triplet upgrade we will have the same tertiary collimation. **Losses can still be very different:** Combination of collimation halo (collimation settings), optics and detailed aperture variation.
- **Loss studies and background studies must be redone** (collimators can be opened, potential losses before D2 or at TAN, more passing through triplet, change of loss distribution between experiments, …).

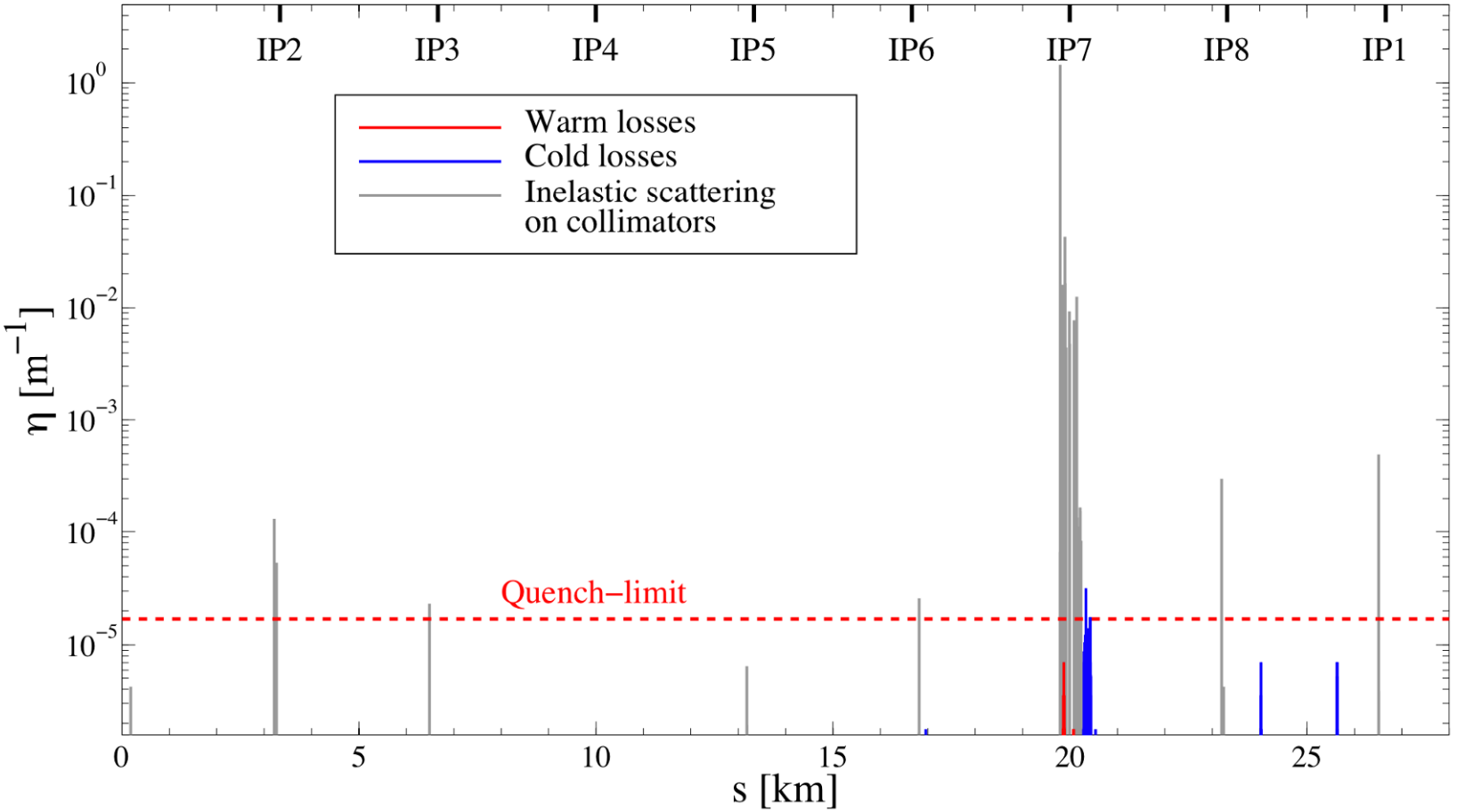
Required Beam Loss Studies for Phase I Triplet Upgrade

- Full agreement that detailed loss studies must be performed in order to qualify the performance of any new insertion layout.
- Important workload, but we know about HERA problems with beam losses and background after the IR upgrade.
- For example, **procedure for experimental beam pipe**:
  - Phase I triplet project: Define study optics and aperture model for phase I IR upgrade.
  - Experiments: Define required range of β^* for each IR after upgrade (need for high β^* optics?).
  - Machine: Determine maximum beam size (optics), required normalized gap (collimation) and required machine margins (optics, beam-beam, …). This gives minimum acceptable beam pipe aperture.
  - Experiments: Propose baseline for experimental beam pipe.
  - Machine & experiments: Qualify beam loss and aperture with new baseline.

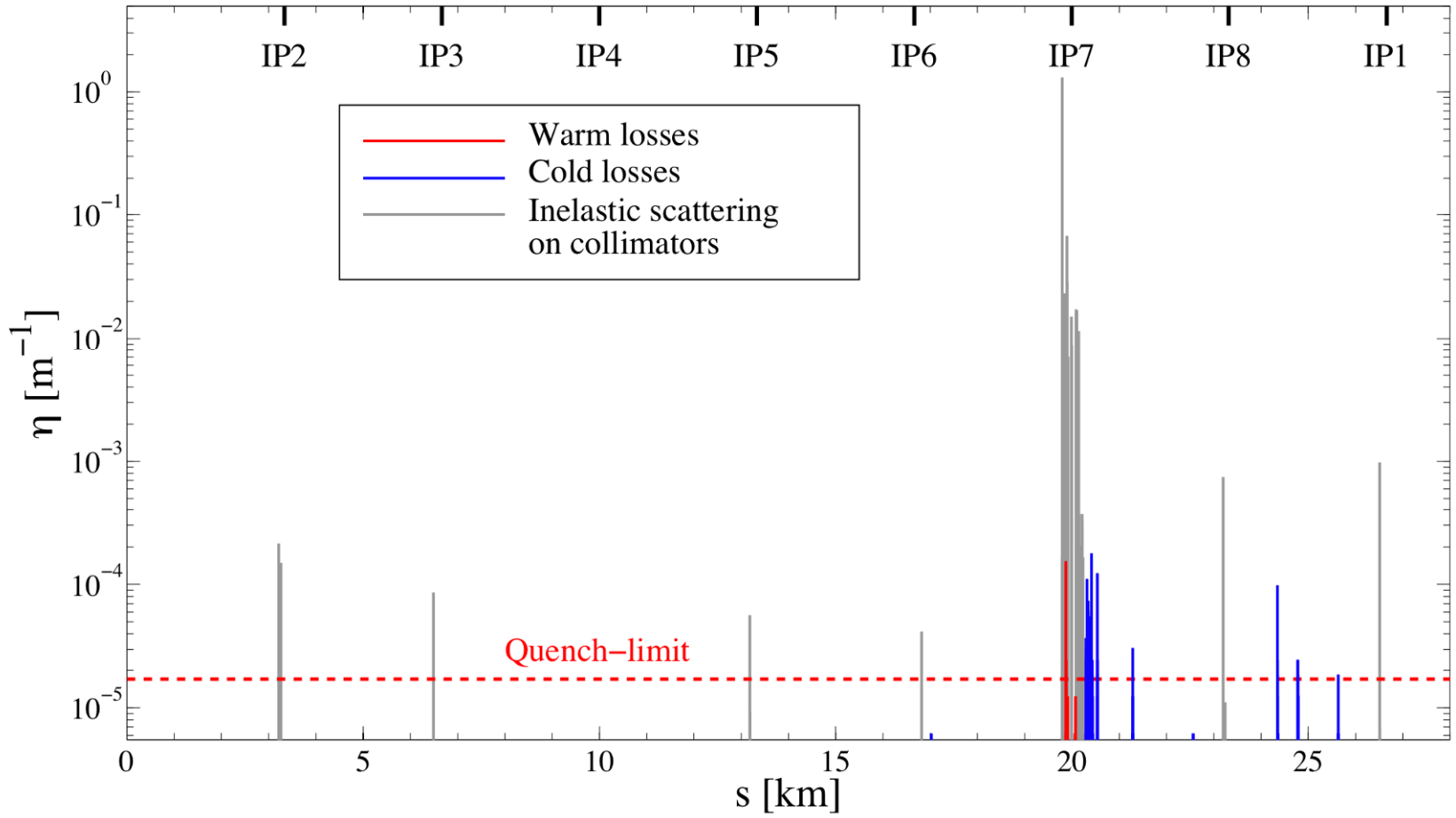
Conclusion

- Collimation upgrade studies are ongoing, supported through white paper project on “collimation phase II”, US LARP and in the future through FP7.
- Focus is put on improving the cleaning systems in IR3 and IR7. A solution for improving cleaning efficiency by factor >10 has been worked out from accelerator physics and is being studied.
- This solution reduces overall halo load around the ring, for example a factor 60 is gained for beam 1 halo load in IR1. All IR’s catch less than 10^{-5} of total halo after phase II collimation upgrade.
- Phase I triplet upgrade: No tertiary collimation upgrade foreseen after phase I triplet upgrade. Nevertheless, change of aperture and optics imposes redoing beam loss and background studies.
- Procedure is proposed to arrive at baseline for experimental beam pipe and insertion, which can then be qualified for beam loss and background.
- *Other collimation upgrades being discussed: ions, more cryogenic coll., …*

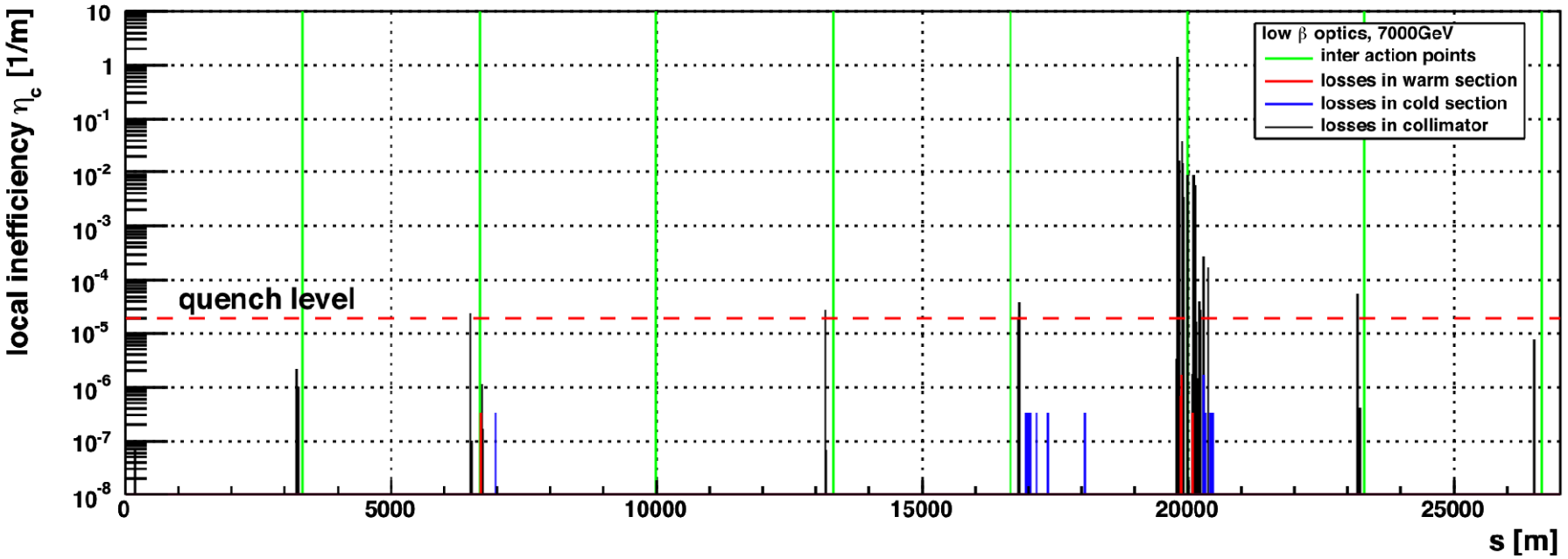
Beam 1 H Halo Loss Map (nominal)



Beam 1 H Halo Loss Map (imperfect)



Beam 1 H Halo Loss Map (nominal)



Beam 2 H Halo Loss Map (nominal)