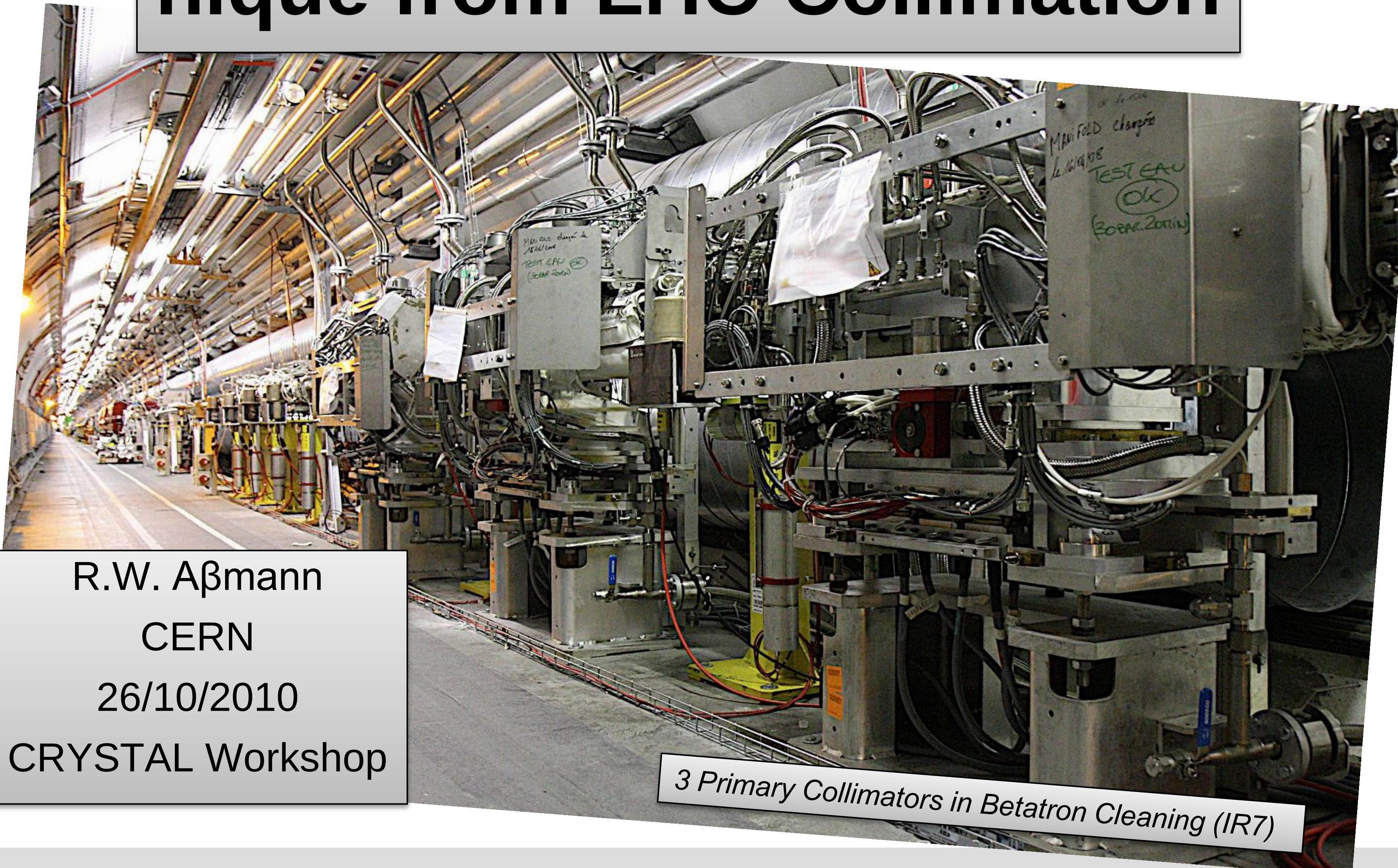
View on Bent Crystal Technique from LHC Collimation



3 Primary Collimators in Betatron Cleaning (IR7)

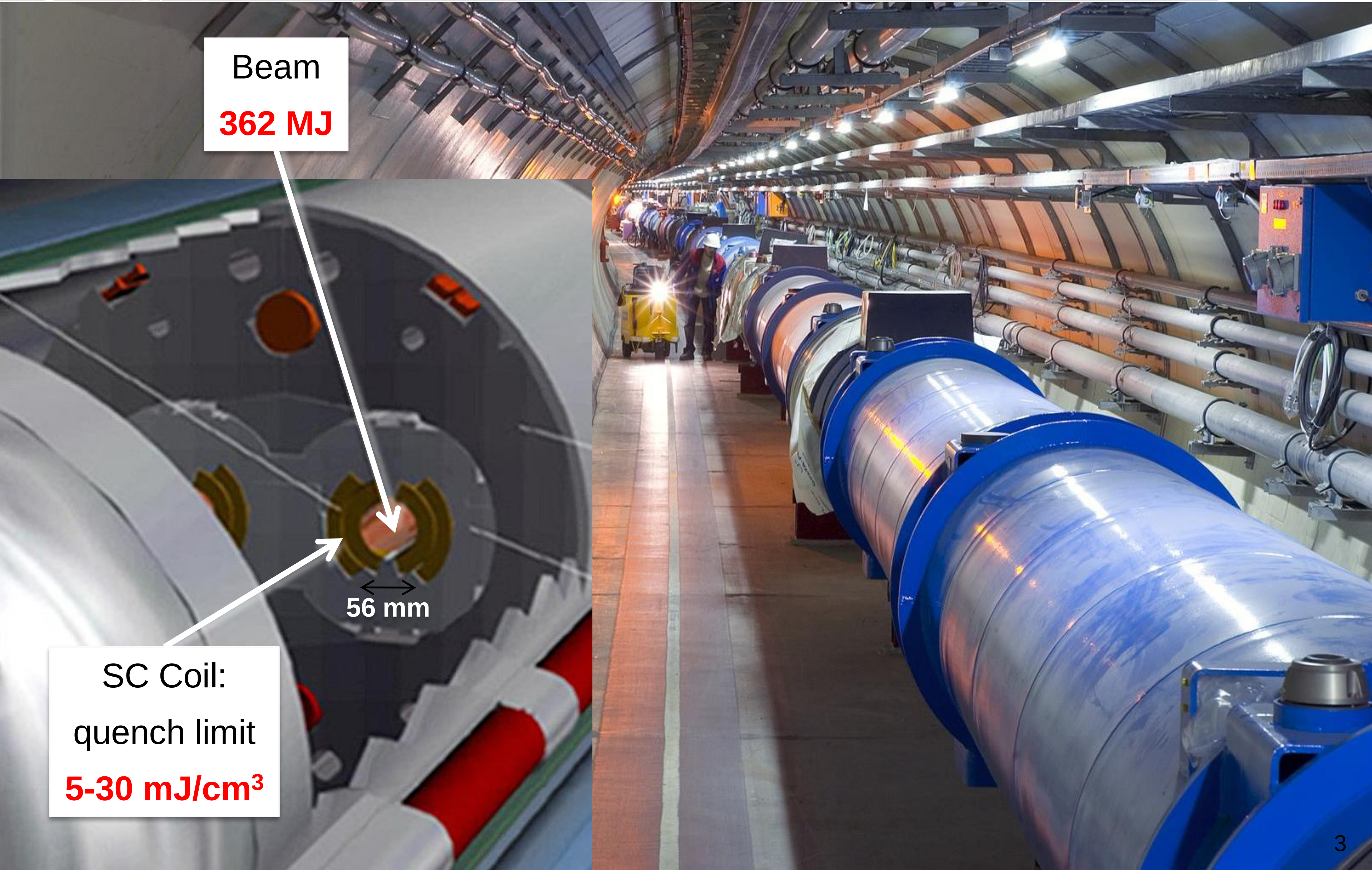
R.W. Aβmann
CERN
26/10/2010
CRYSTAL Workshop

Where We Are With LHC Collimation

- LHC: Ideally no power lost (protons stored with infinite lifetime).
- Collimators are the LHC defense against unavoidable losses:
  - Irregular fast losses and failures: Passive protection.
  - Slow losses: Cleaning and absorption of losses in super-conducting environment.
  - Radiation: Managed by collimators.
  - Particle physics background: Minimized.
- Specified **7 TeV** peak beam losses (maximum allowed loss):
  - Slow: 0.1% of beam per s for 10 s **0.5 MW**
  - Transient: 5×10^{-5} of beam in ~10 turns (~1 ms) **20 MW**
  - Accidental: up to 1 MJ in 200 ns into 0.2 mm^2 **5 TW**

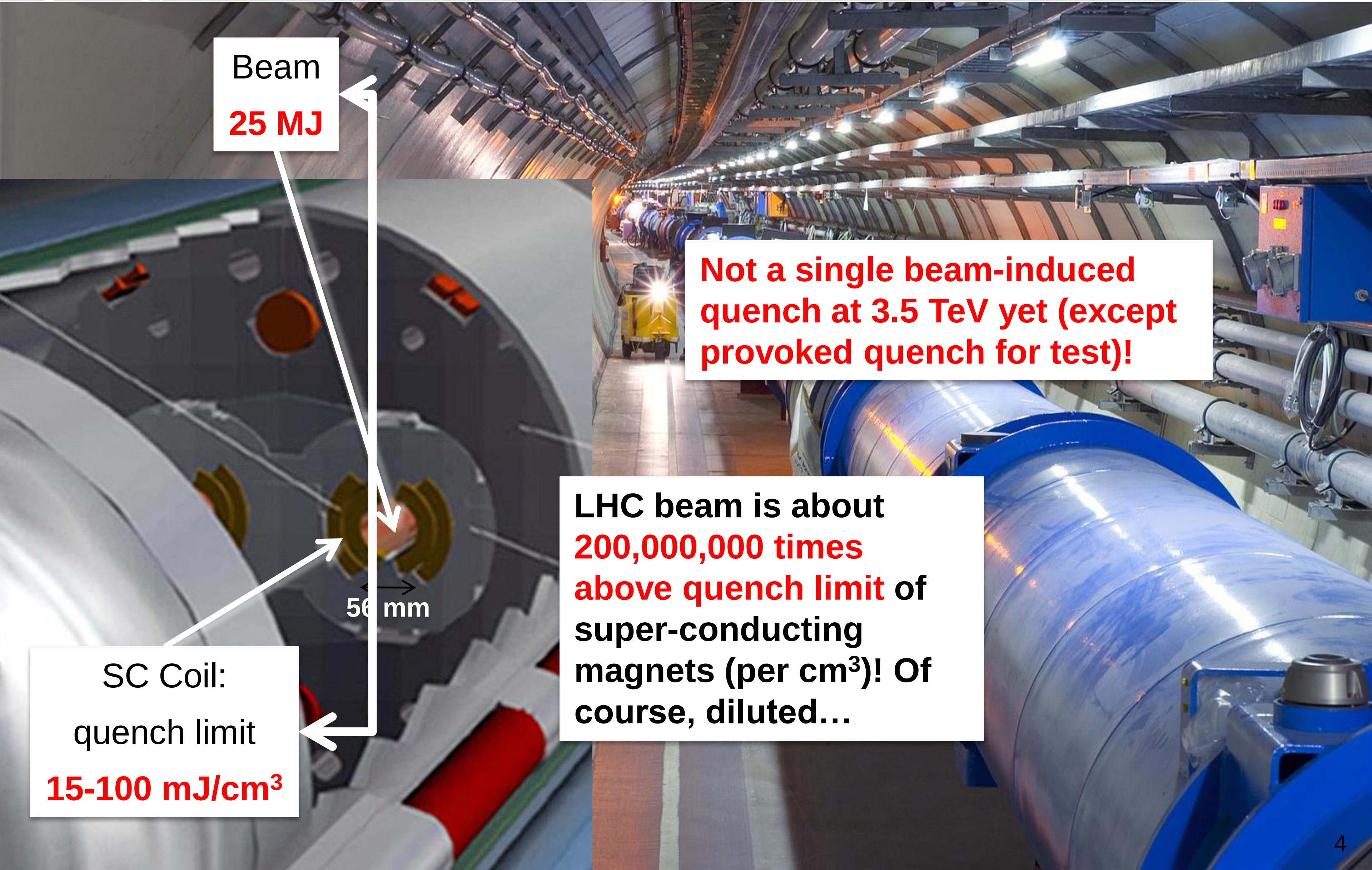
Quench Limit of LHC Super-Conducting Magnets

Nominal design at 7 TeV



Quench Limit of LHC Super-Conducting Magnets

Situation at 3.5 TeV (on September 26, 2010)

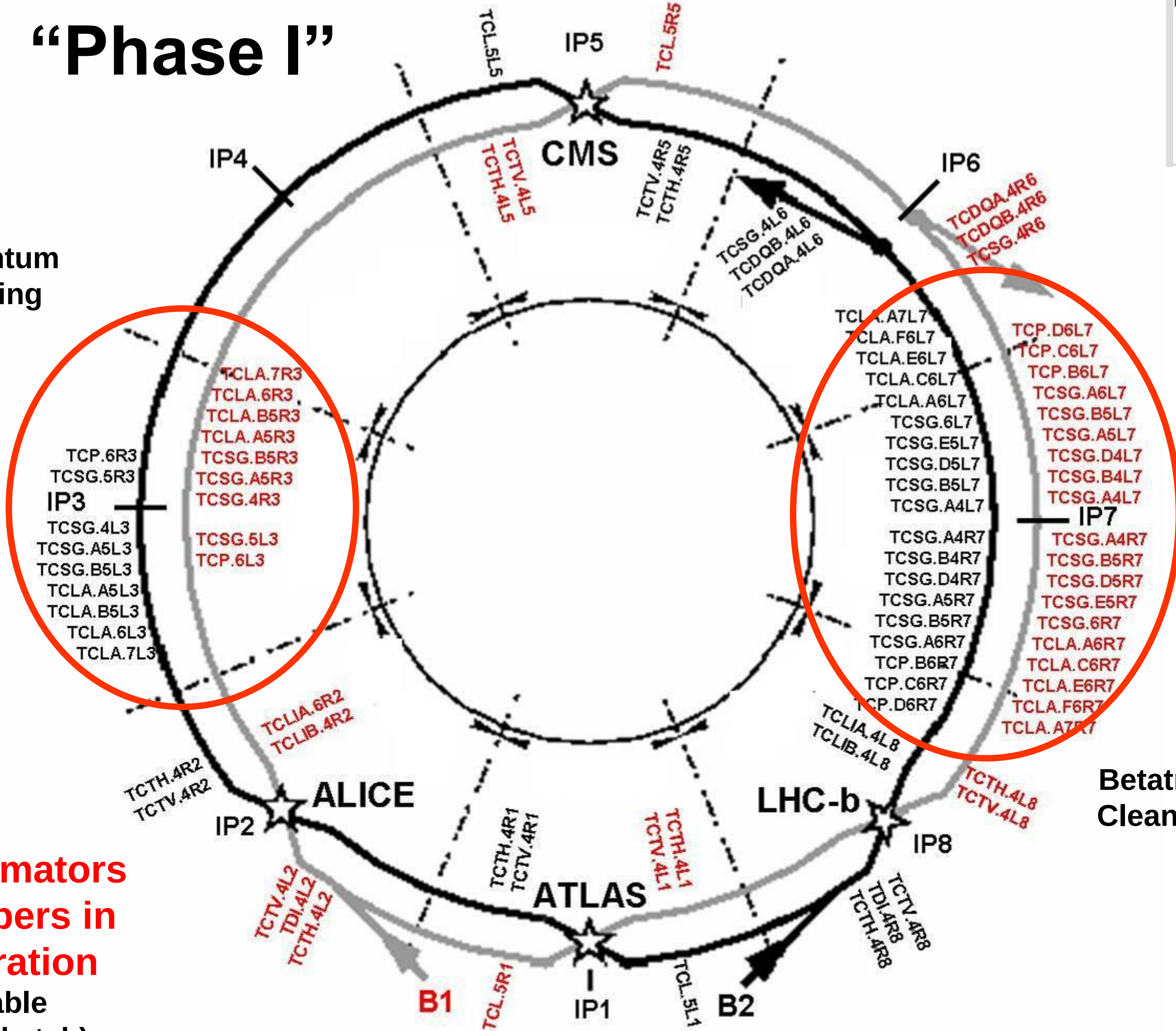


Intensity Frontier at LHC: Role of Collimation

- All other SC proton colliders had an important number of beam-induced quenches while pushing up to the MJ regime.
- LHC reached 3 times the world record in stored energy per beam within 6 months and without a beam-induced quench with stored beam.
- How was this achieved?
  - Highly efficient, 4 stage collimation system in the LHC.
  - Tight collimation all through injection, ramp, squeeze and collision.
  - Catches safely all losses that occur while intensity is increased.
  - This includes “normal” losses (scattering, emittance growth, diffusion, …) and losses with equipment failures.

"Phase I"

Momentum Cleaning



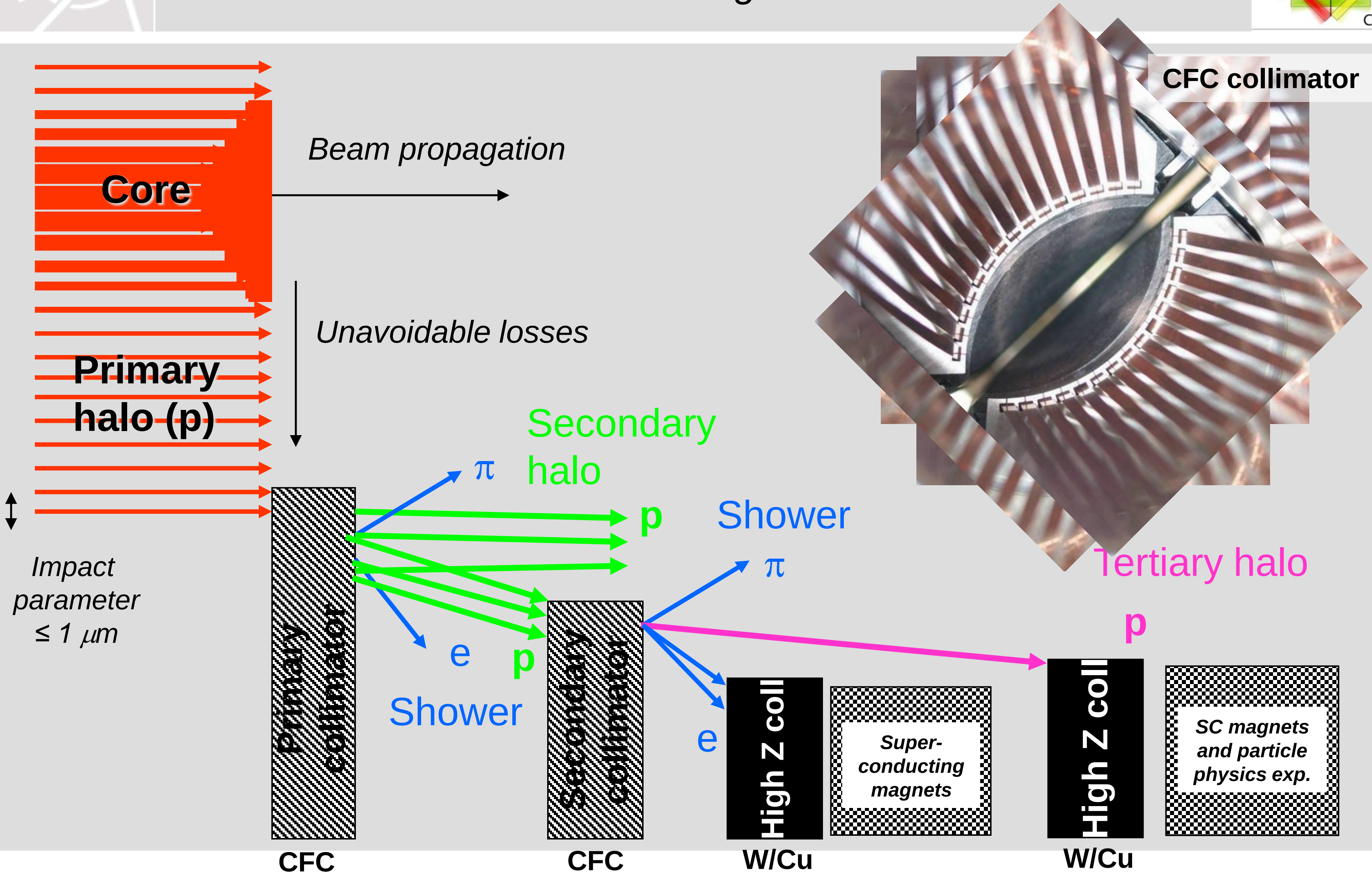
Betatron Cleaning

108 collimators & absorbers in 1st generation

(only movable shown in sketch)

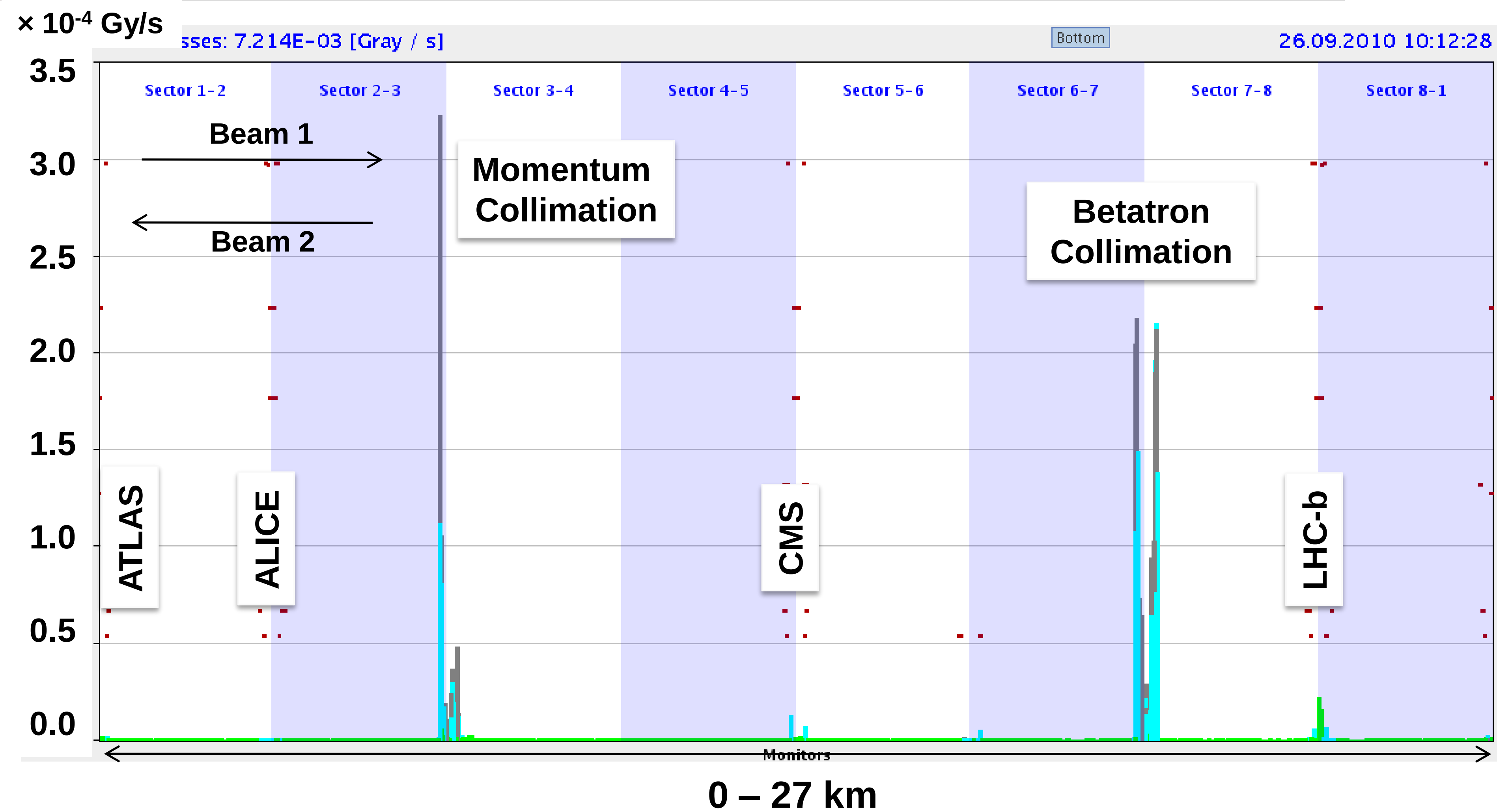
Multi-Stage Cleaning & Protection

3-4 Stages



Losses Around the Ring

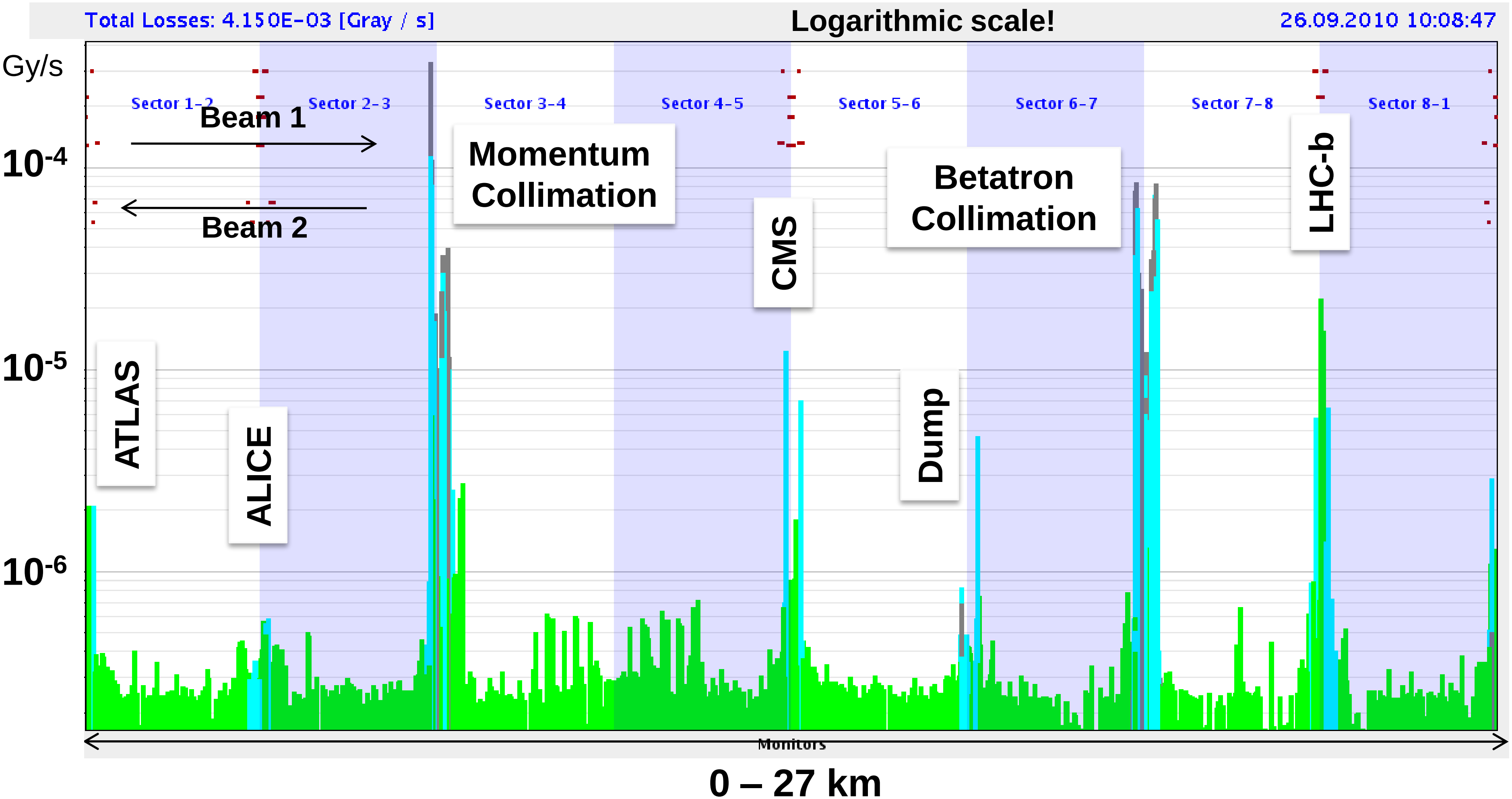
(3.5 TeV, End Fill 26.9.2010, τ > 75 h)



Essentially all losses at collimators → No beam dump or quench!

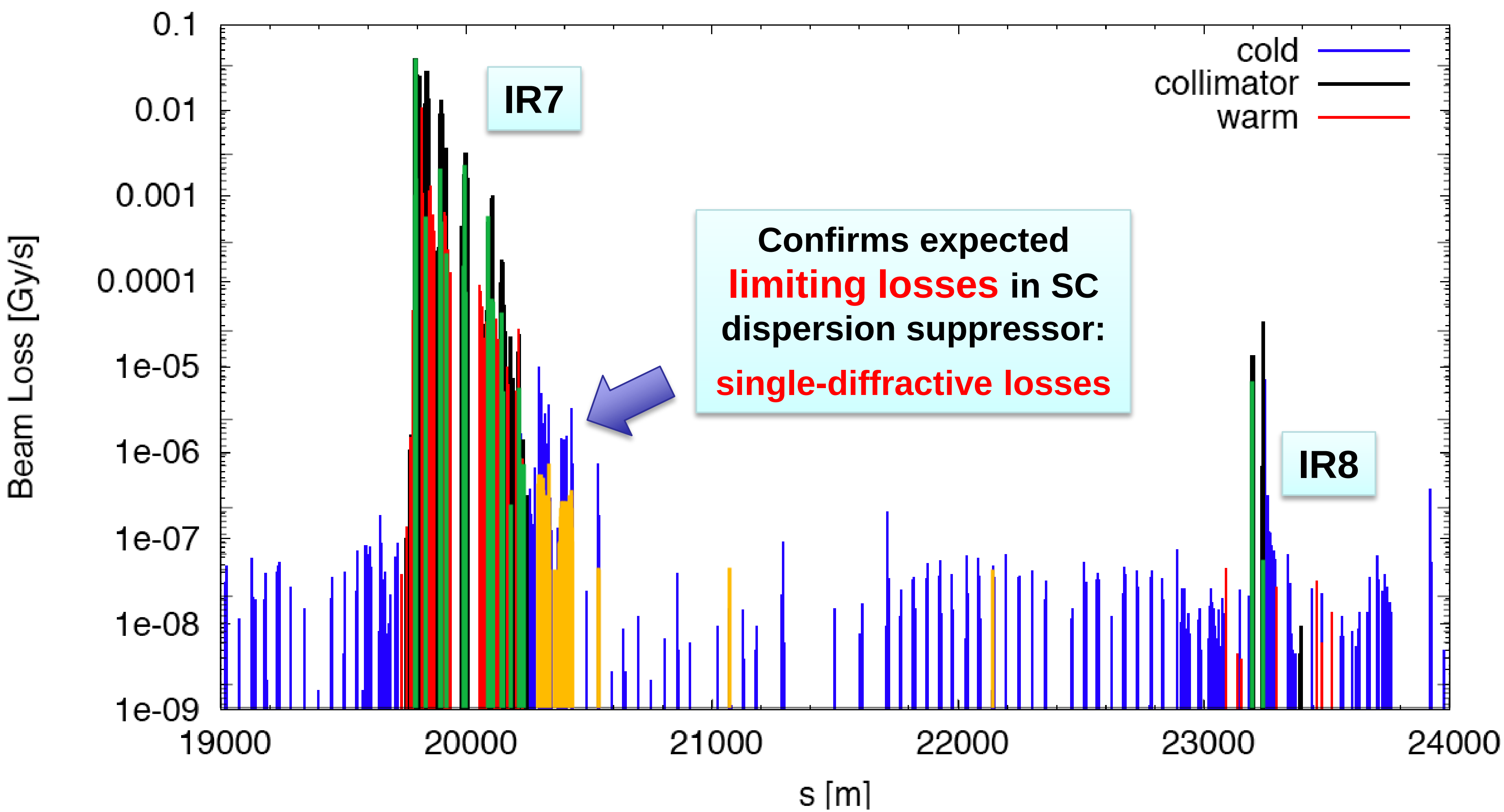
Losses Around the Ring

(3.5 TeV, End Fill 26.9.2010, τ > 75 h)

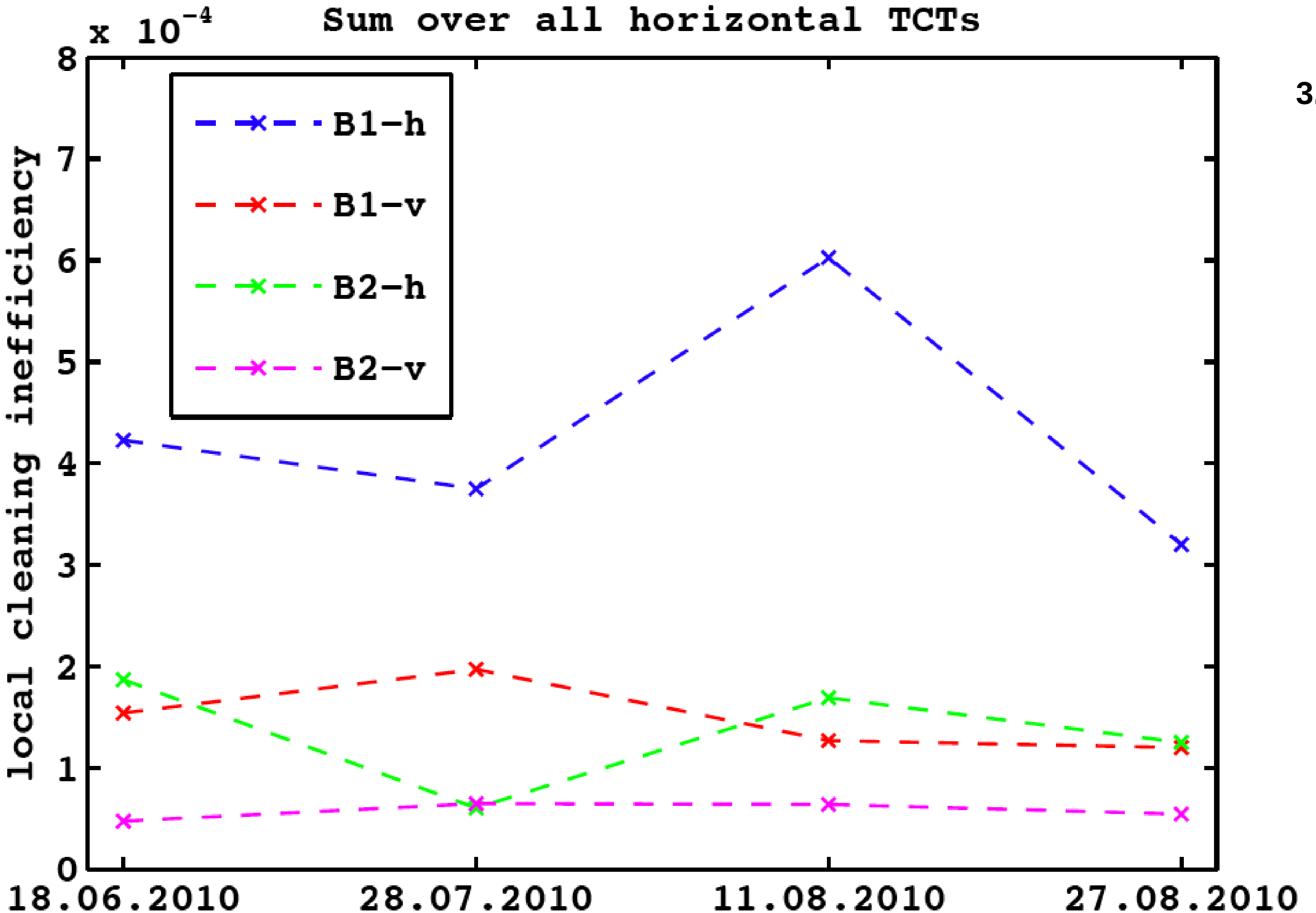


→ *Details can be seen in logarithmic scale!*

Meas. & Sim. Cleaning at 3.5 TeV
(beam1, vertical beam loss, intermediate settings)



Betatron Cleaning: Stability Over 10 Weeks



3.5 TeV

Where Do Bent Crystals Fit In?

- Installed LHC collimation delivers very nice performance, consistent with predictions.
- Beam is very stable in the LHC → might provide more performance reach than predicted. To be discussed in Chamonix.
- An LHC collimation upgrade is being prepared for gaining another factor 10 in performance. Urgency to be discussed in Chamonix.
- **Bent crystals on paper should provide another factor 20 improvement.** Note fundamental change in concept with crystals:
  - Now: 500 kW losses are sprayed over ~250 m. Diluted energy is then absorbed at the end of the cleaning insertions.
  - With crystals: 500 kW losses will be extracted to one point. Requires halo beam dump. Will impact energy deposition and radiation impact in cleaning insertions.
- Bent Crystal can enhance collimation efficiency.

Our Studies on LHC Collimation Enhanced with Crystals

- In parallel to our other work we performed over the years various studies on LHC collimation with crystals.
  - **Optics study for a possible crystal-based collimation system for the LHC.**
    R. Assmann, S. Redaelli, W. Scandale, (CERN). CERN-LHC-PROJECT-REPORT-918. 2006.
  - **Beam Loss Predictions for the UA9 Crystal Collimation Experiment.**
    V.P. Previtali, R. Assmann, S. Redaelli (CERN), I. A. Yazynin (IHEP Protvino). PAC09.
  - **Simulations of Crystal Collimation for the LHC.**
    V.P. Previtali, R. Assmann, S. Redaelli (CERN), I. A. Yazynin (IHEP Protvino). PAC09.
  - **Performance Evaluation of a Crystal-Enhanced Collimation System for the LHC.**
    V.P. Previtali. Thèse EPFL, no 4794 (2010).

Possible Concept

- The papers listed describe boundary conditions and possibility to use bent crystals for LHC collimation in detail. Here sketch of use for collimation:
  - Bent crystals can only be installed close to primary collimators in IR7 and IR3. In total 8 locations where channeling must be obtained and maintained.
  - Will then have 3 stage cleaning enhanced with crystal channeling.
  - As the possible locations have $\alpha \neq 0$, cr… at top energy where beam di…
  - If …ing, crystals would act as short primary collimators.
  - If channeling, crystals would extract the beam halo to a dedicated beam halo dump.
  - Dedicated beam halo dumps for H, V, skew, off-momentum halo must be integrated, preferably one for several planes. Secondary collimators are not suitable as halo dumps (have low Z, CFC material).
  - Survival of downstream equipment must be shown, probably requiring additional passive absorbers.

An LHC installation is a major investment!

Central Condition

(for Details See 2006/2009 Studies)

- Crystals extract the beam halo.
- The beam halo must be safely transported to a halo dump.
- Two conditions:
  - **Halo kick should be large enough to separate the halo from the beam and to catch the extracted halo downstream.**
  - **Halo kick should be small enough that extracted halo travels safely** (without losses) through the beamline elements between crystal and halo dump (e.g. MBW and MQW).
- We studied this trade-off in 2006 and 2009. See Valentina's talk. Resulting channeling angle for LHC: **40-50 μrad** (if same angle used for H and V).
- Needs to be refined with imperfections…
- The according crystals need to be qualified in SPS first.

Towards an LHC Installation I
(view from LHC collimation)

1. Full exploitation of the 120 GeV SPS experiment UA9 (when achieved?):
   a) Show expected improvement (factor 20 in far away losses, i.e. more than factor 2 which was obtained in 2009).
   b) Show stability with higher intensities: efficient channeling with up to 3e13 p at 120 GeV (1e11p in 2009).
   c) Test with higher energy (270 GeV).
   d) Qualify crystals for LHC.
2. Low intensity test setup in LHC (2013/14?):
   a) Extrapolation to LHC too far (e.g. 120 GeV to 7 TeV) → Test required.
   b) Based on complete SPS results propose LHC test system.
   c) Install at least 4 crystals to test 1 beam (H, V, skew, off-momentum).
   d) Identify or install halo dumps. Use collimators as low intensity halo dump?
   e) Requires full integration with LHC collimation.
   f) Outcome: Prove low intensity crystal collimation at 7 TeV.

Towards an LHC Installation II
(view from LHC collimation)

3. High intensity test setup in LHC (2016 or integrated with earlier low intensity test?):
   a) Install at least 4 crystals to test 1 beam (H, V, skew, off-momentum).
   b) Design, produce and install dedicated halo dumps for high intensity beams in IR3 and IR7.
   c) Design, produce and install any required additional passive absorbers for protecting the warm magnets.
   d) Requires full integration with LHC collimation.
   e) Outcome: Prove crystal collimation of 100 MJ beams at 7 TeV.
4. Production setup in LHC (~2020, in time for HL-LHC upgrade):
   a) Equip all 8 locations of primary collimators.
   b) Install final halo dumps and passive absorbers for both beams.
   c) Commission for LHC operation.

Conclusion

- Crystal-enhanced collimation is a promising path to improved collimation efficiency.
- The need for better collimation efficiency in the LHC is being assessed next Chamonix meeting (1st generation of LHC collimation performs very well and LHC beam is very stable).
- A more conventional collimation upgrade will provide a factor 5-10 improvement in collimation efficiency for 2013 and 2016.
- Bent crystals can offer another factor 20 (on paper) and some improvements have been shown in SPS. I think this should be pursued.
- **After full exploitation of the SPS experiment (intensity, energy) the technique should be tested in the LHC.**
- Full integration with the existing LHC collimation system is required.
- A possible path to an LHC production system for 2020 has been outlined.