The 6th International Conference - Channeling 2014
Charged & Neutral Particles Channeling Phenomena
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Goals and Plans for the Crystal Collimation Test at the Large Hadron Collider

Stefano Redaelli, CERN, BE-ABP
on behalf of the Collimation Project and the UA9 teams

The HiLumi LHC Design Study is included in the High Luminosity LHC project and is partly funded by the European Commission within the Framework Programme 7 Capacities Specific Programme, Grant Agreement 284404.

Outline

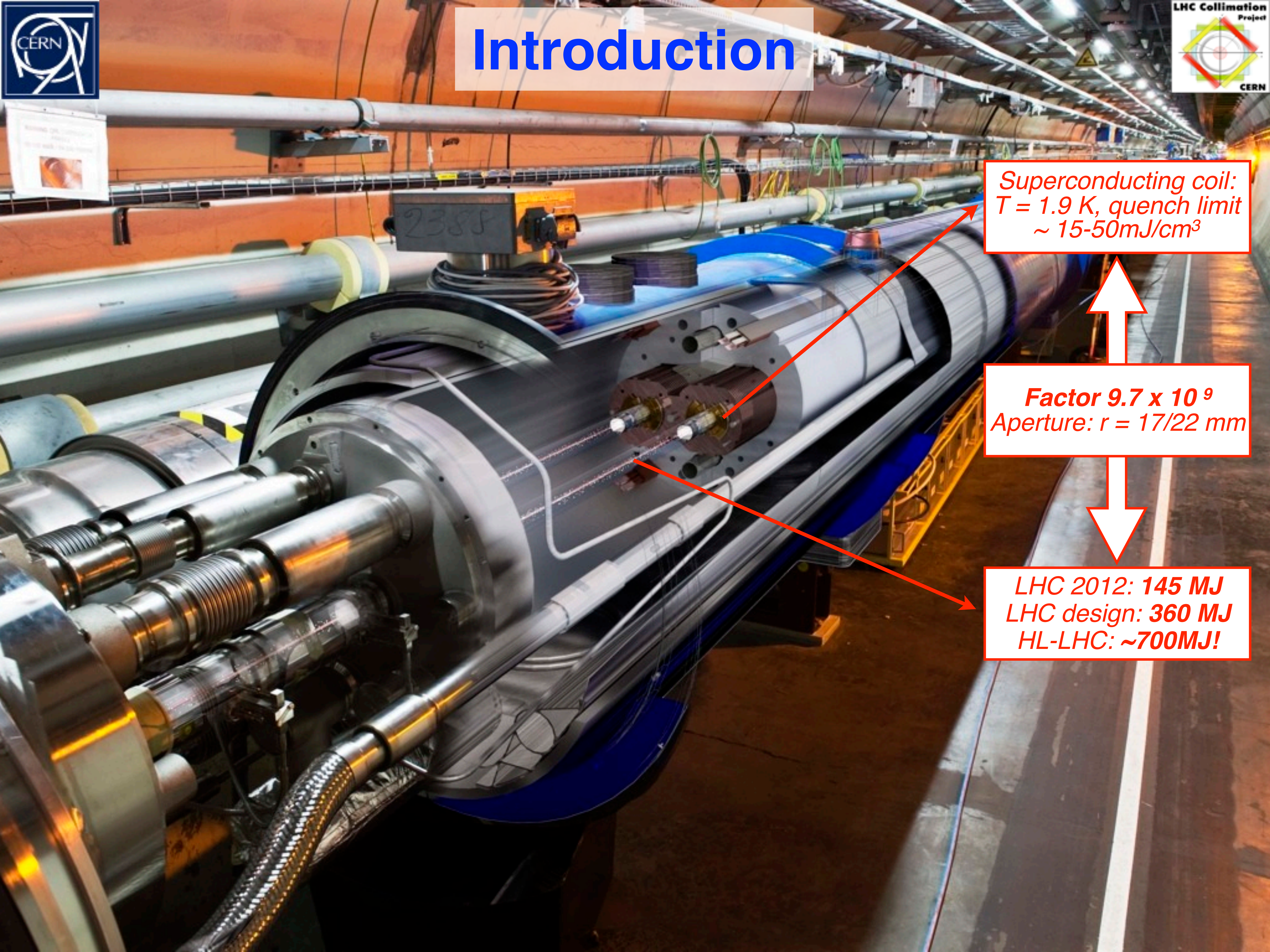
- Introduction
- LHC beam collimation
- Crystal collimation
- Layouts for beam tests
- Plans for 2015
- Conclusions

Acknowledgements

This talk is given on behalf of the members of
the LHC collimation team
the UA9 collaboration

Special thanks to
Walter Scandale
Daniele Mirarchi

Introduction



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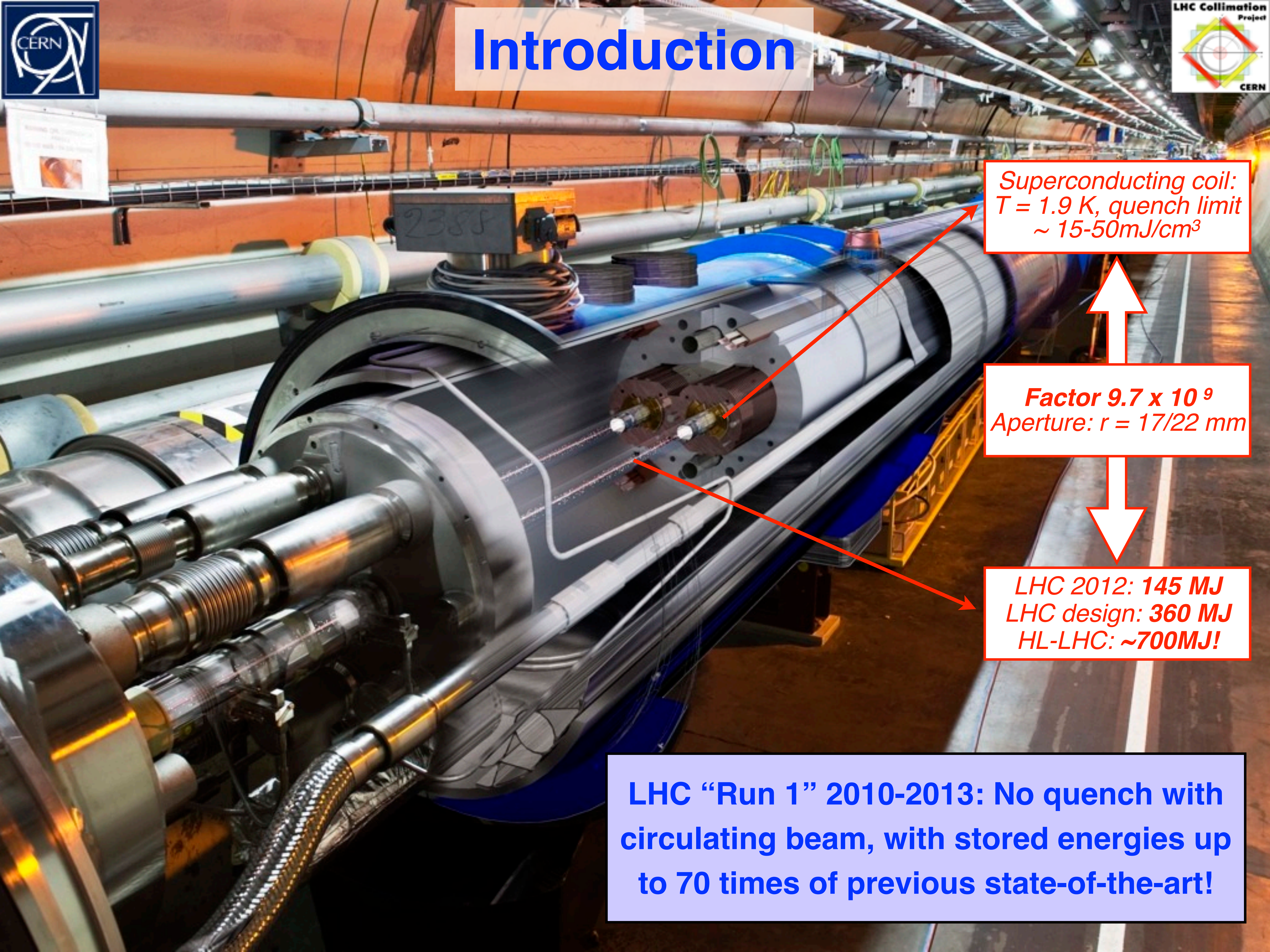

LHC "Run 1" 2010-2013: No quench with circulating beam, with stored energies up to 70 times of previous state-of-the-art!

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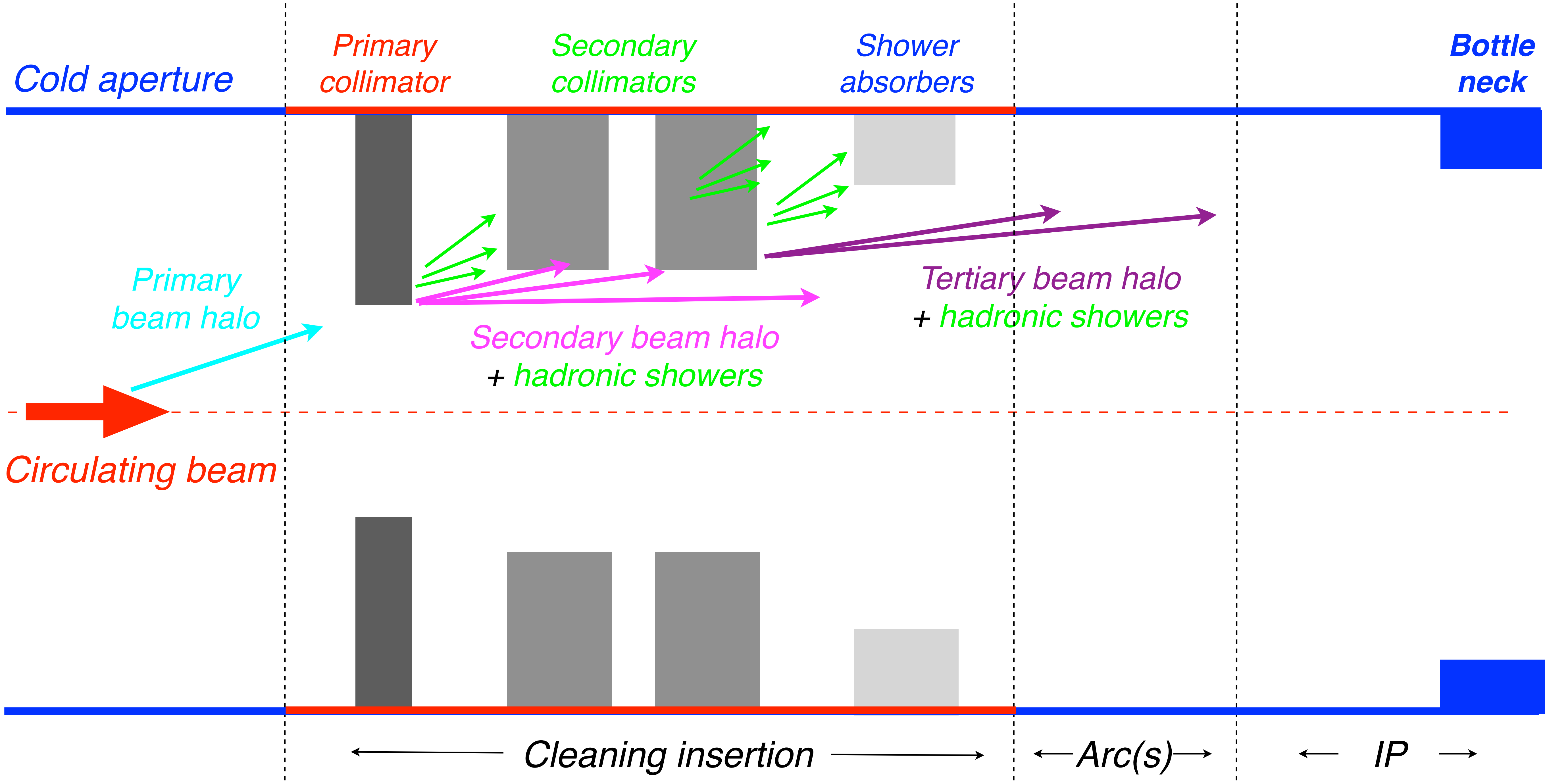
LHC multi-stage collimation



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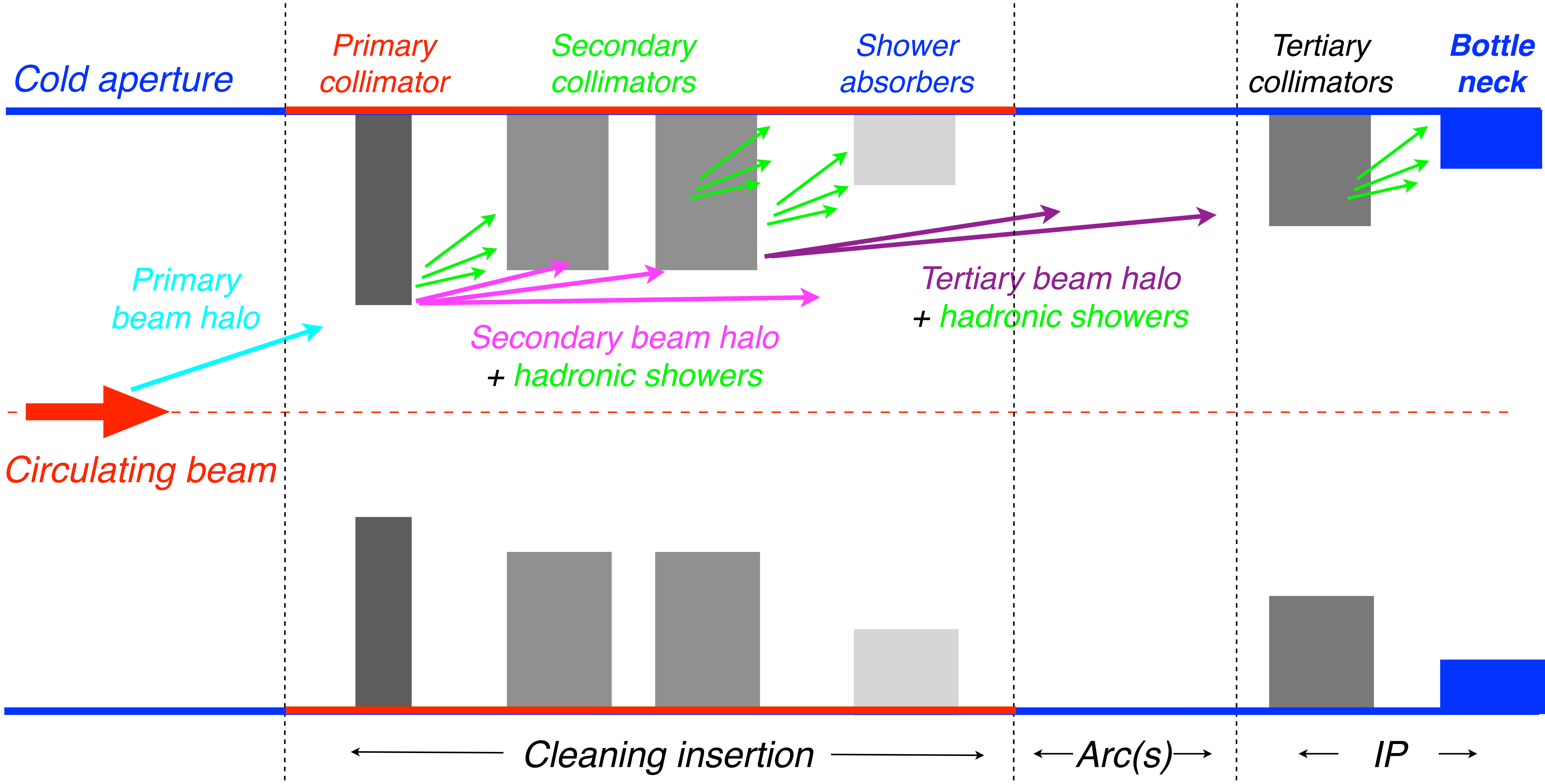

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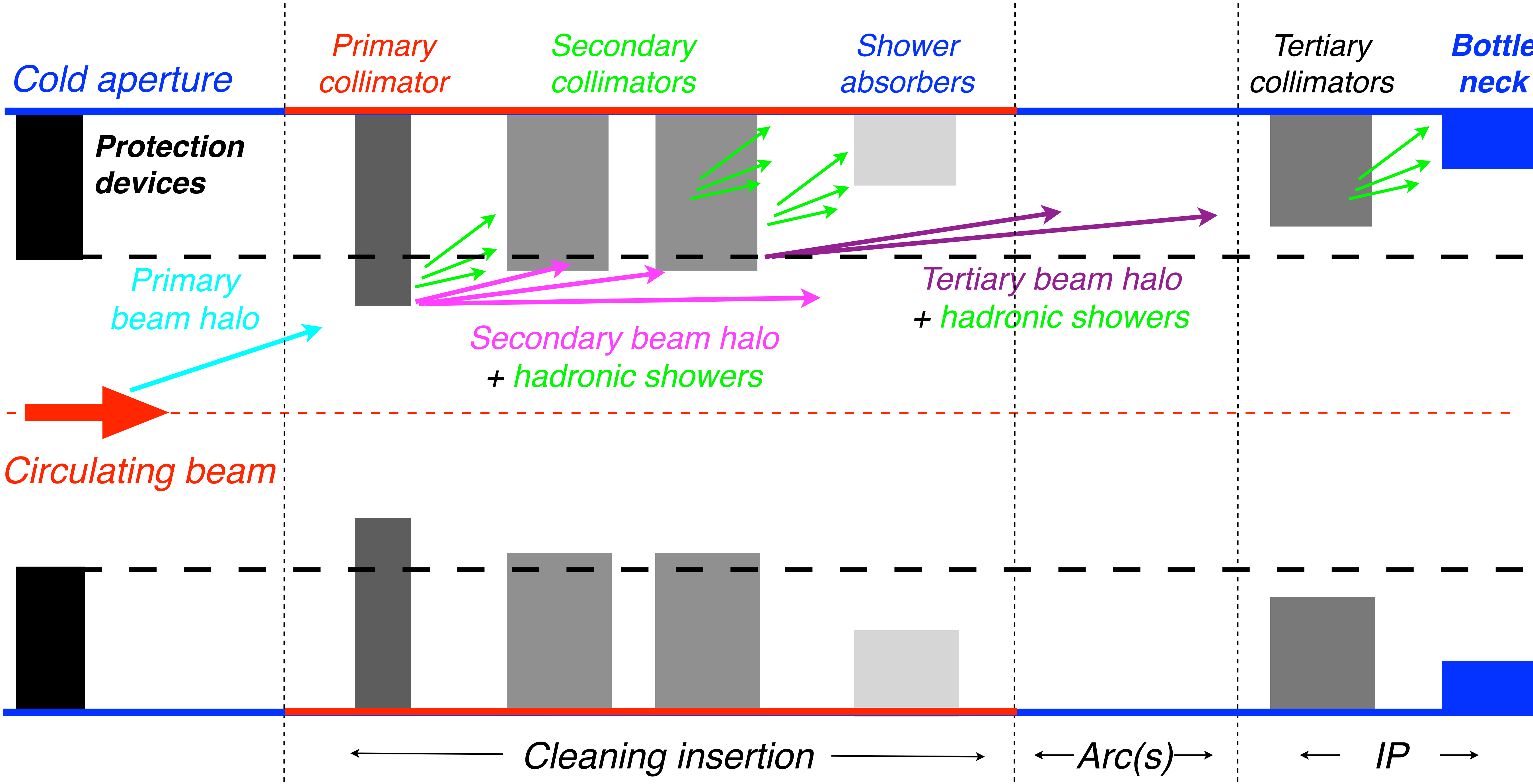

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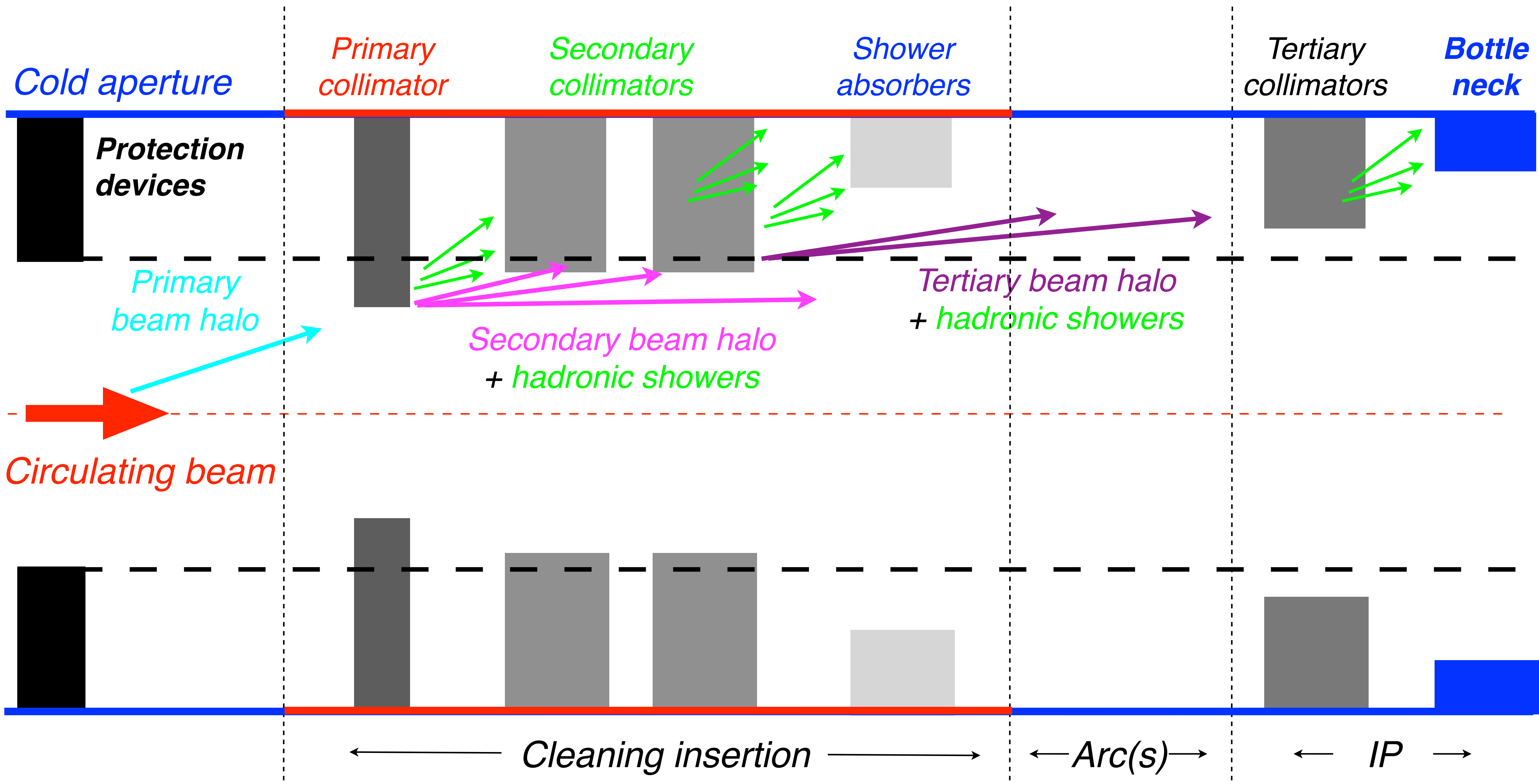


Including protection devices, a **5-stage cleaning** in required!

The system performance relies on achieving the well-defined **hierarchy** between collimator families and machine aperture.

Collimation layout for the LHC Run II

Two warm cleaning insertions, 3 collimation planes

- **IR3: Momentum cleaning**
  - **1 primary (H)**
  - **4 secondary (H)**
  - **4 shower abs. (H,V)**
- **IR7: Betatron cleaning**
  - **3 primary (H,V,S)**
  - **11 secondary (H,V,S)**
  - **5 shower abs. (H,V)**

Local cleaning at triplets

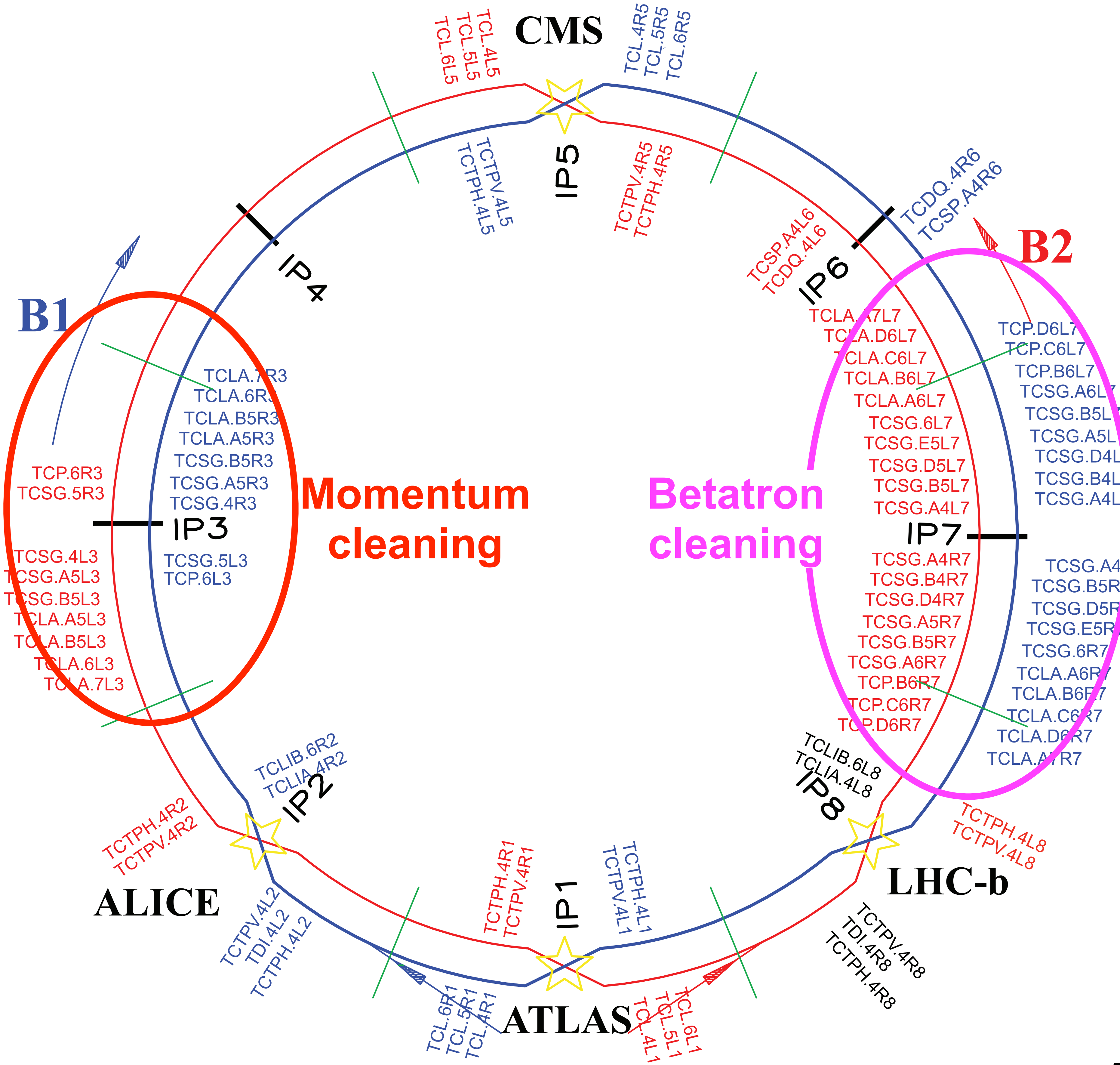
- **8 tertiary (2 per IP)**

Passive absorbers for warm magnets

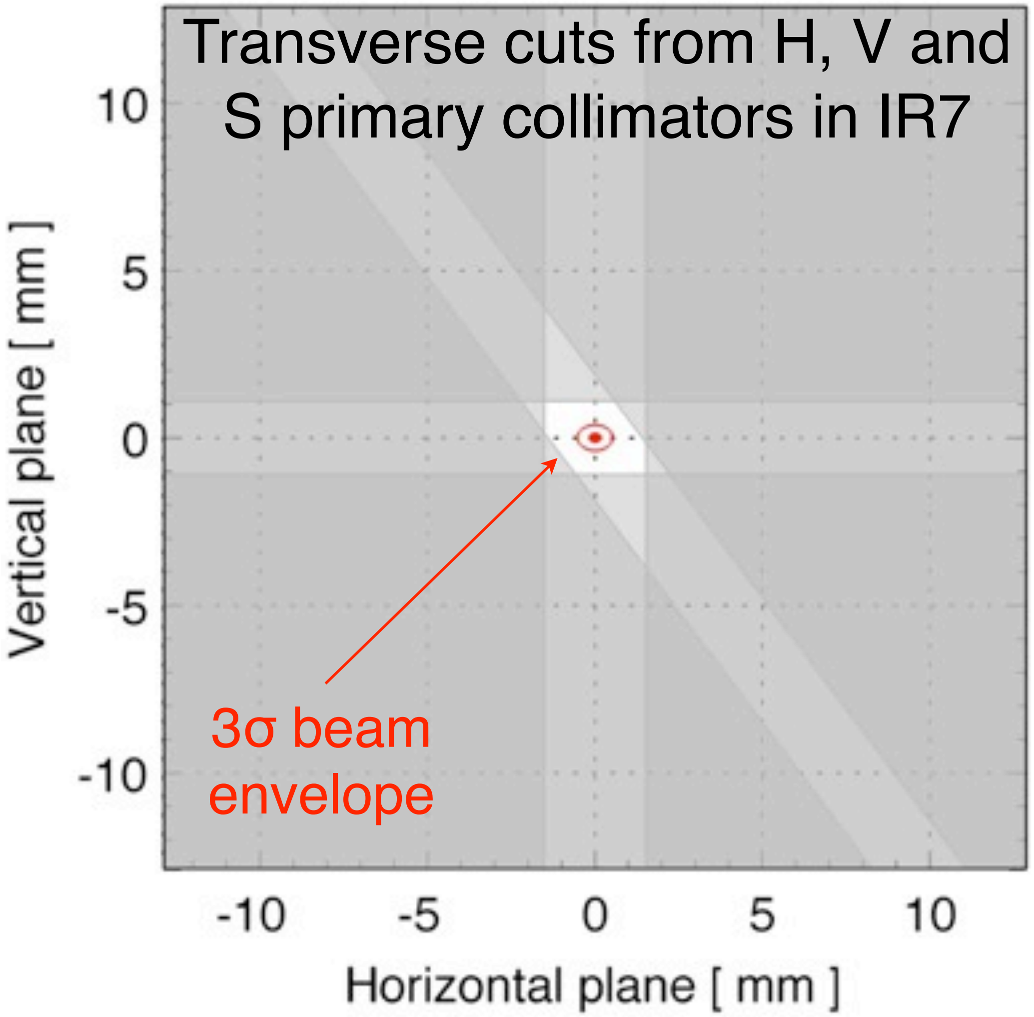
Physics debris absorbers

Transfer lines (13 collimators)
Injection and dump protection (10)

Total of 118 collimators (108 movable). Two jaws (4 motors) per collimator!



Collimator gaps in 2012



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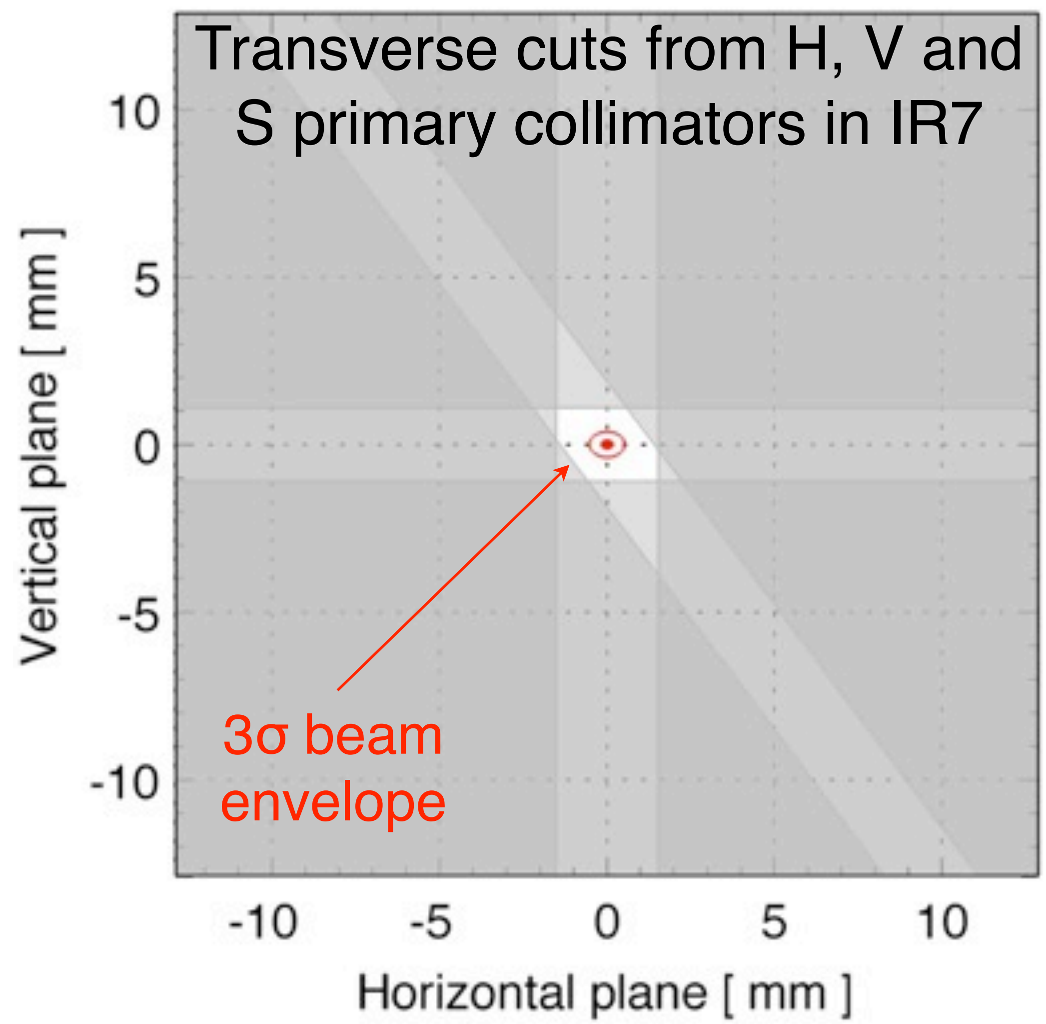

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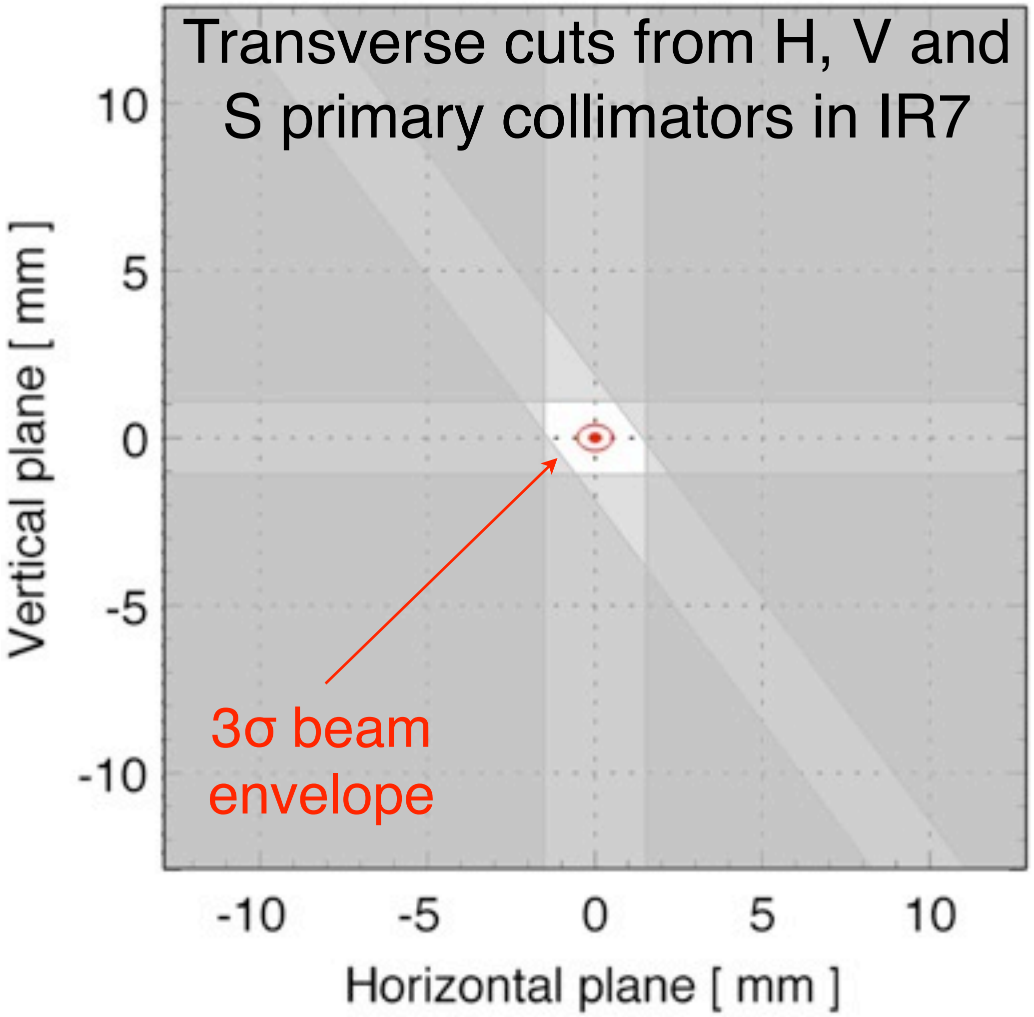

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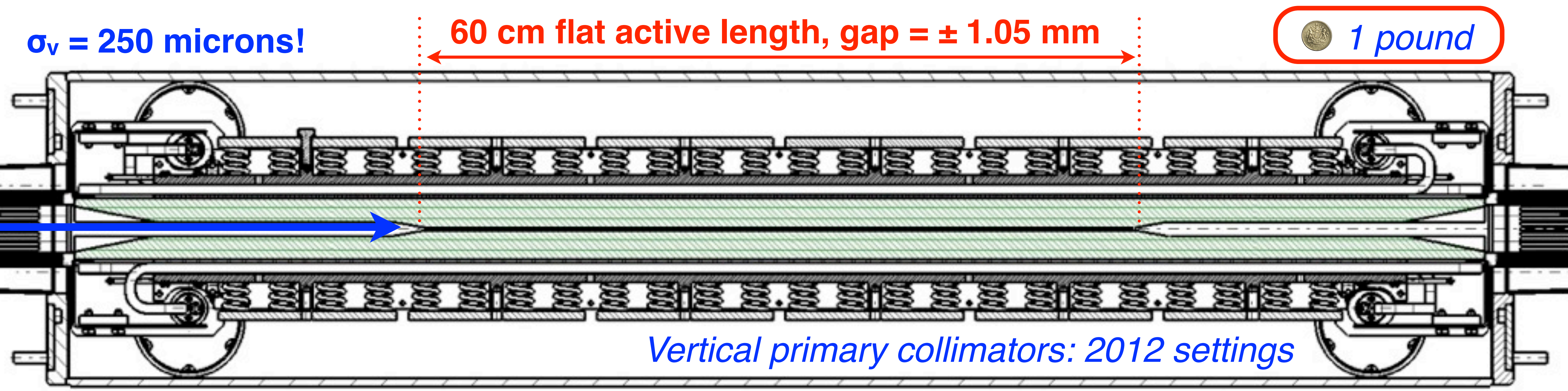
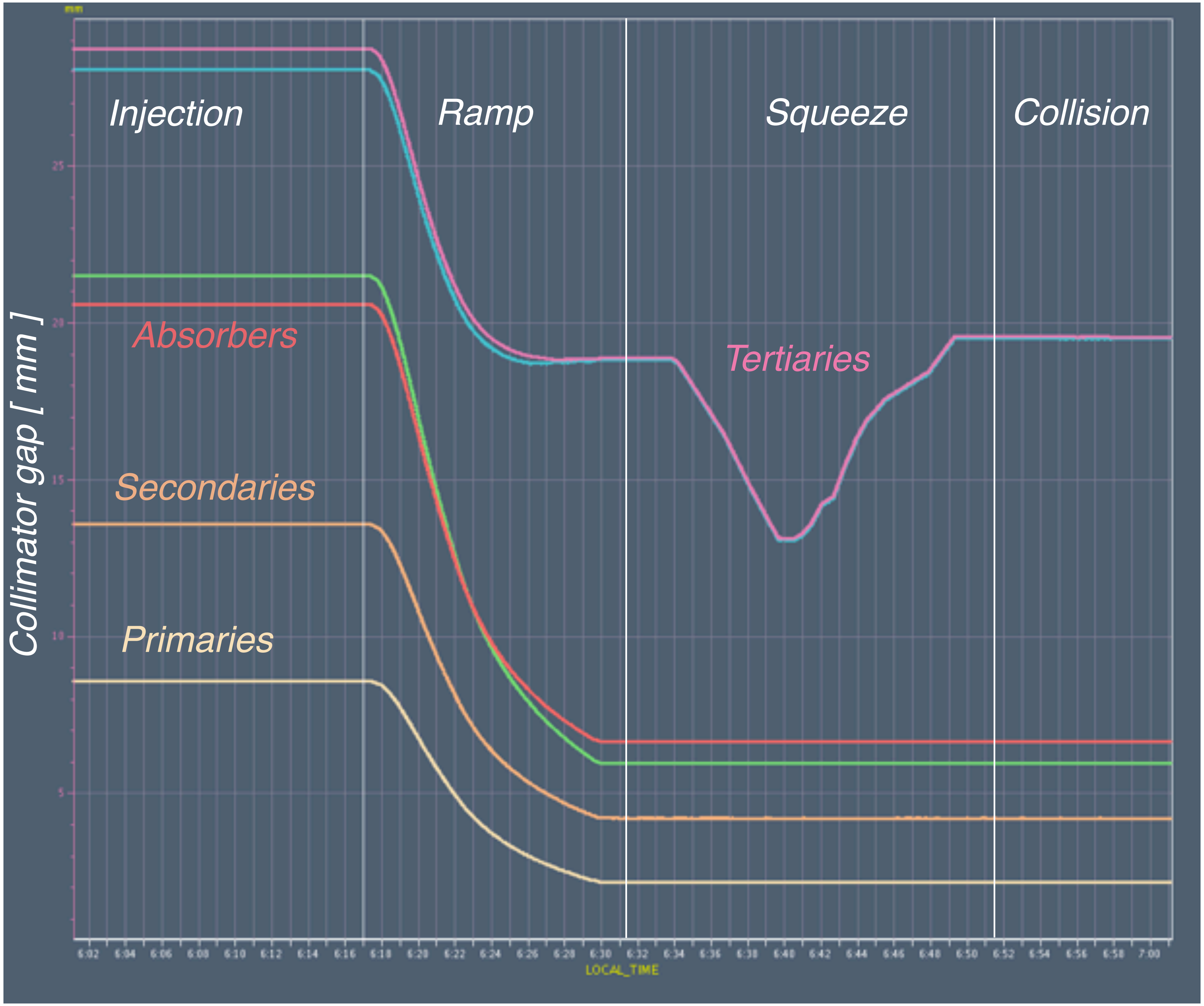
σ_V = 250 microns!



Collimator movements in operation



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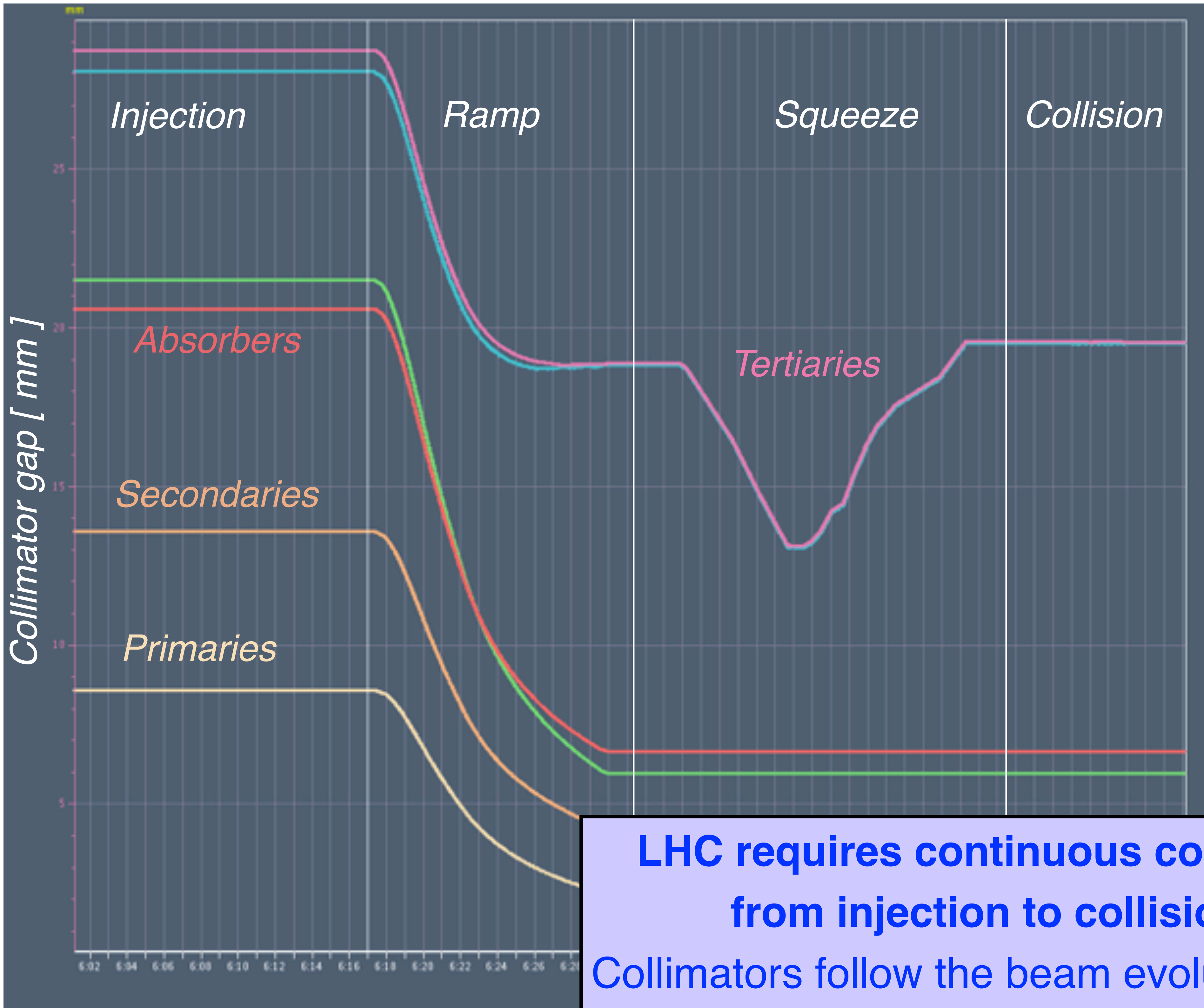
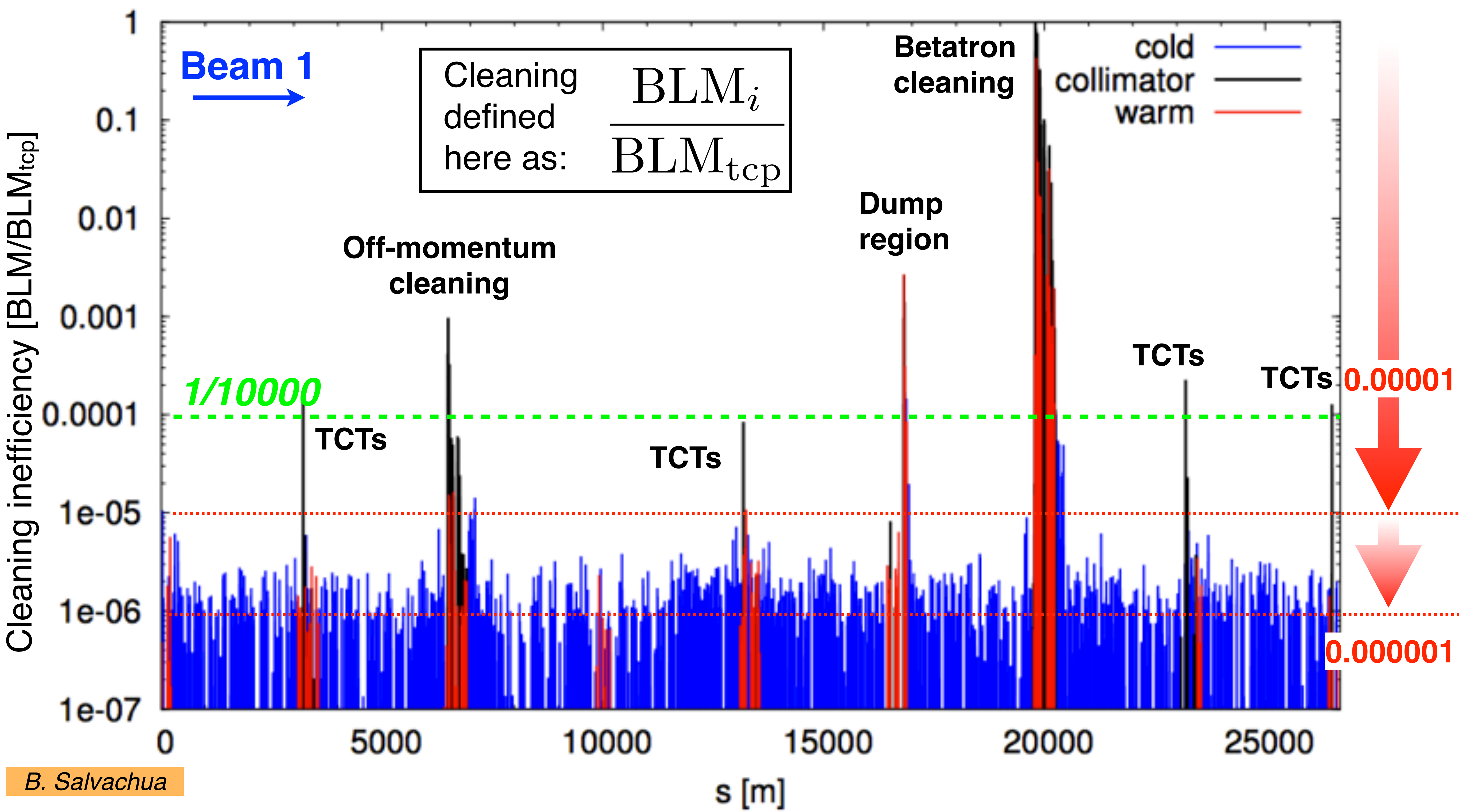


LHC requires continuous collimation from injection to collisions!
Collimators follow the beam evolution during energy and optics changes.

Collimation cleaning at 4 TeV (β^*=60cm)



B. Salvachua

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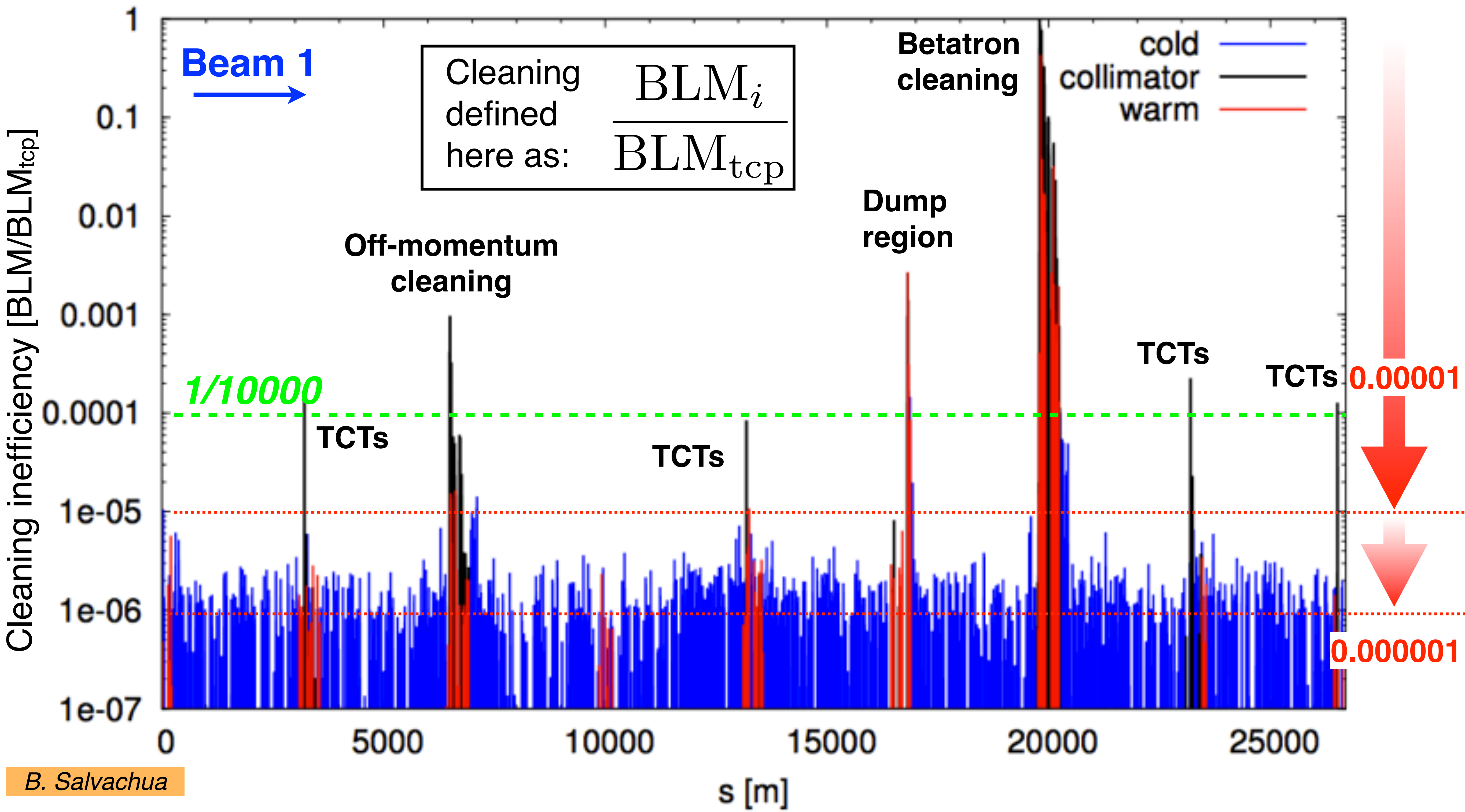

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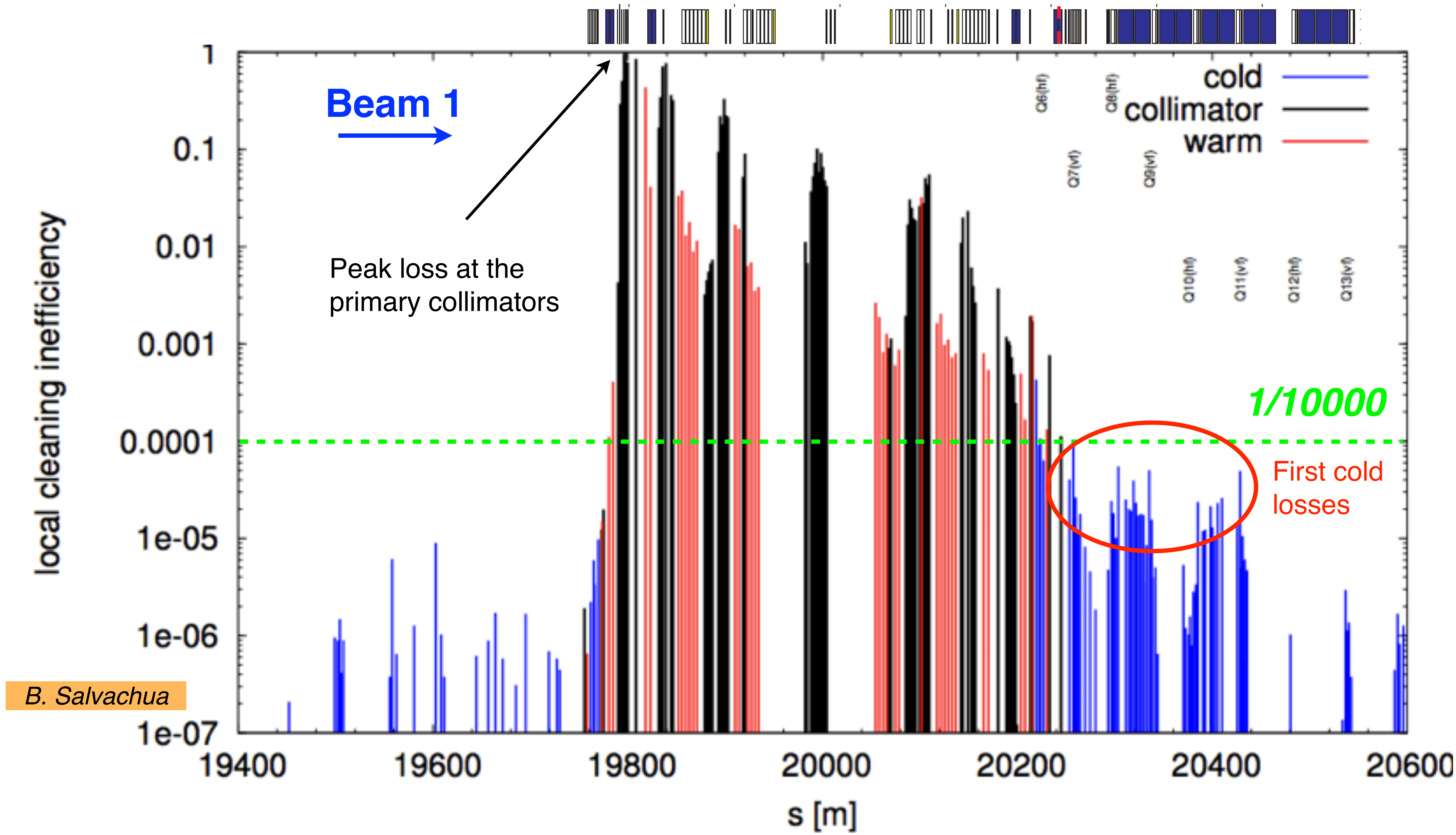
Highest COLD loss location: efficiency of > 99.99% !
Most of the ring actually > 99.999%

Collimation cleaning in IR7



Critical locations (both beams): losses in the dispersion suppressors around (Q8) from single diffractive interactions with the primary collimators.
No other major cleaning limitations observed around the ring with present optics.

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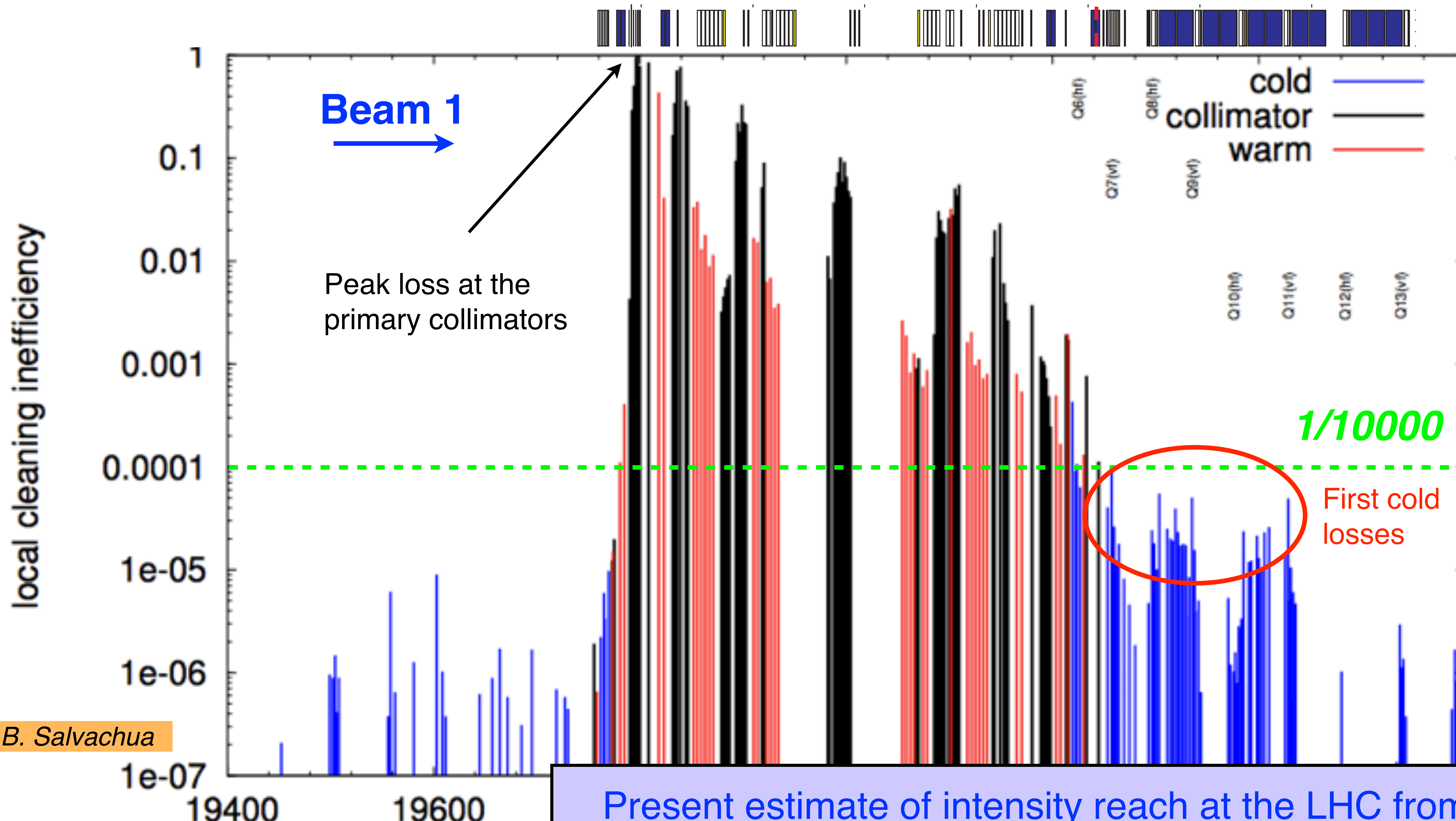

B. Salvachua

Present estimate of intensity reach at the LHC from betatron cleaning: at 6.5TeV can reach **3x-6x the nominal LHC intensity**. Margins reduced for HL-LHC. Depending on quench limit, we might have no issue!

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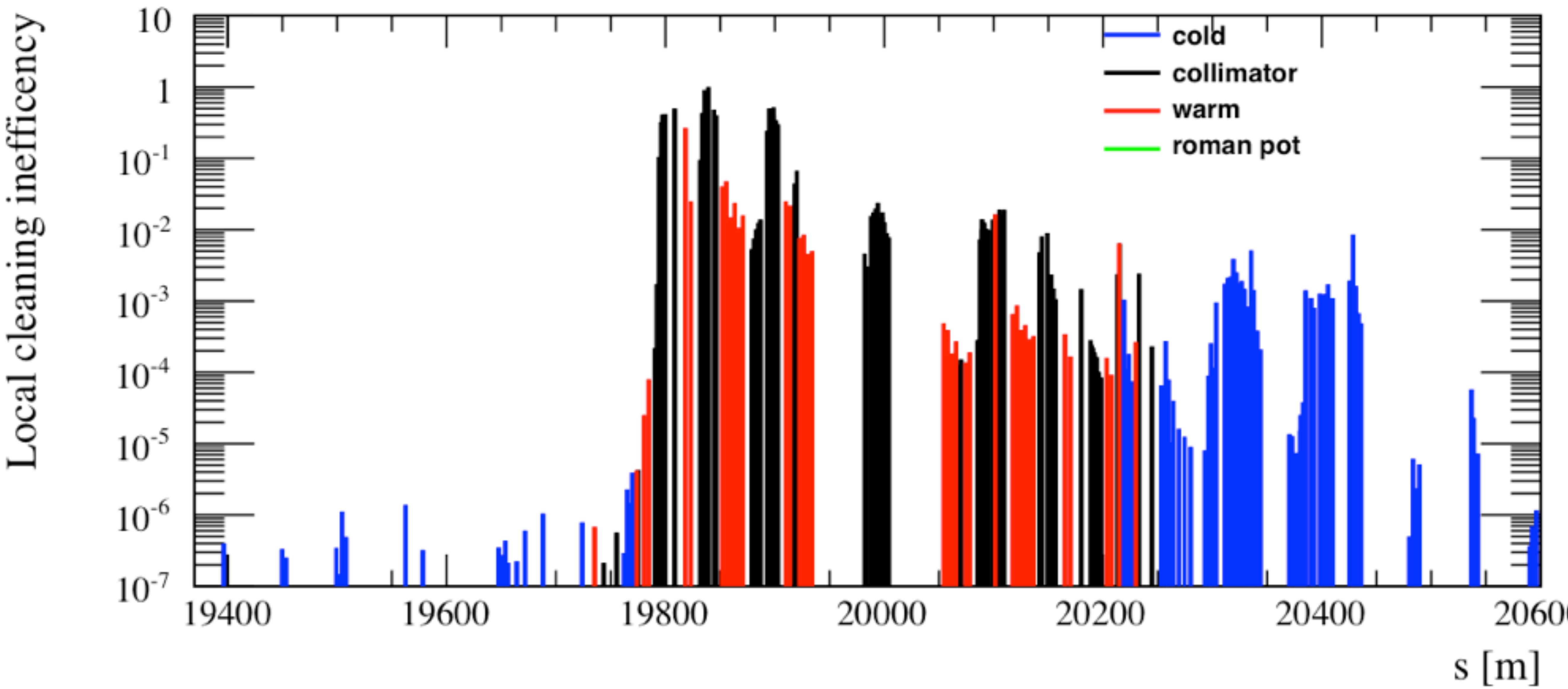
Betatron cleaning for Pb ion beams



Betatron cleaning of a few percent: **factor ~100 worst** than for protons.

Limiting location still the **dispersion suppressor**, but different loss distribution than for protons: ion beams from dissociation and fragmentation at the primary collimators are lost at specific locations.

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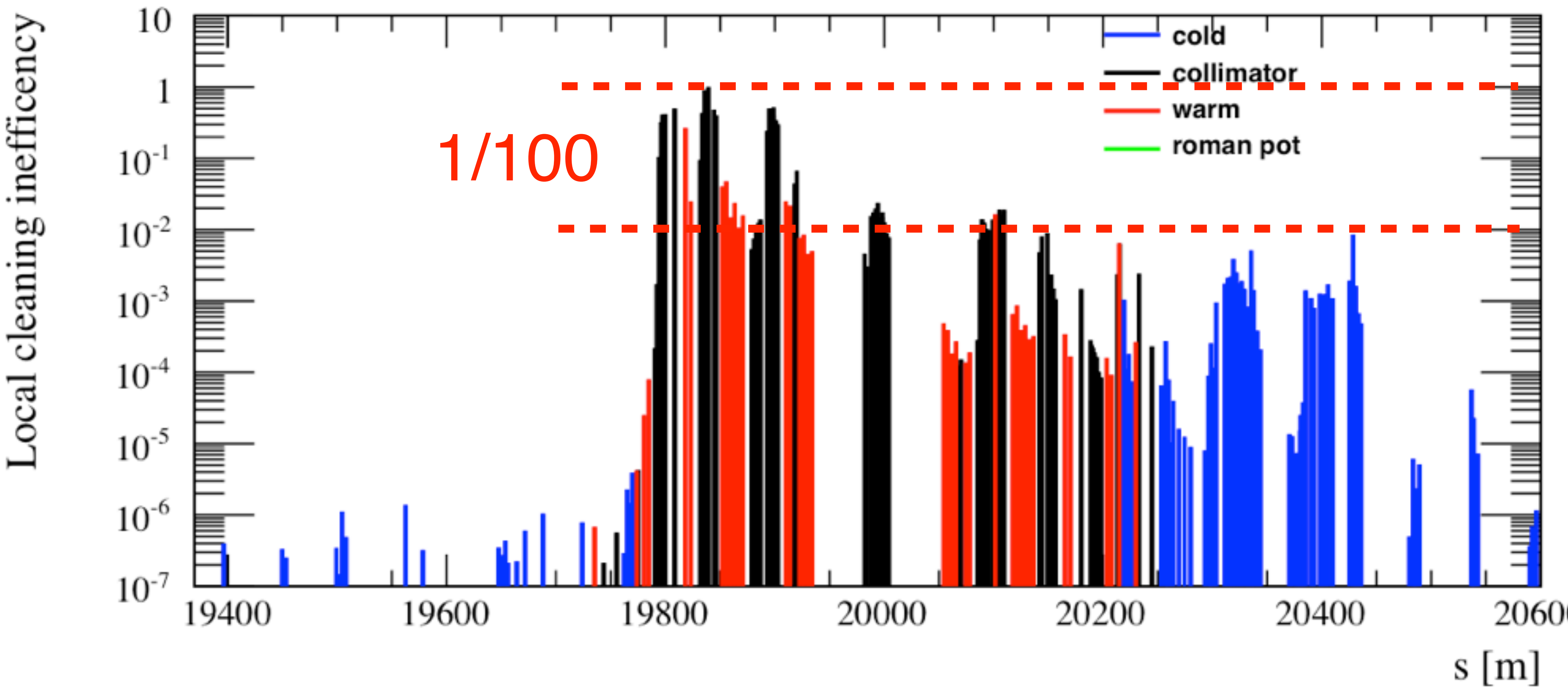

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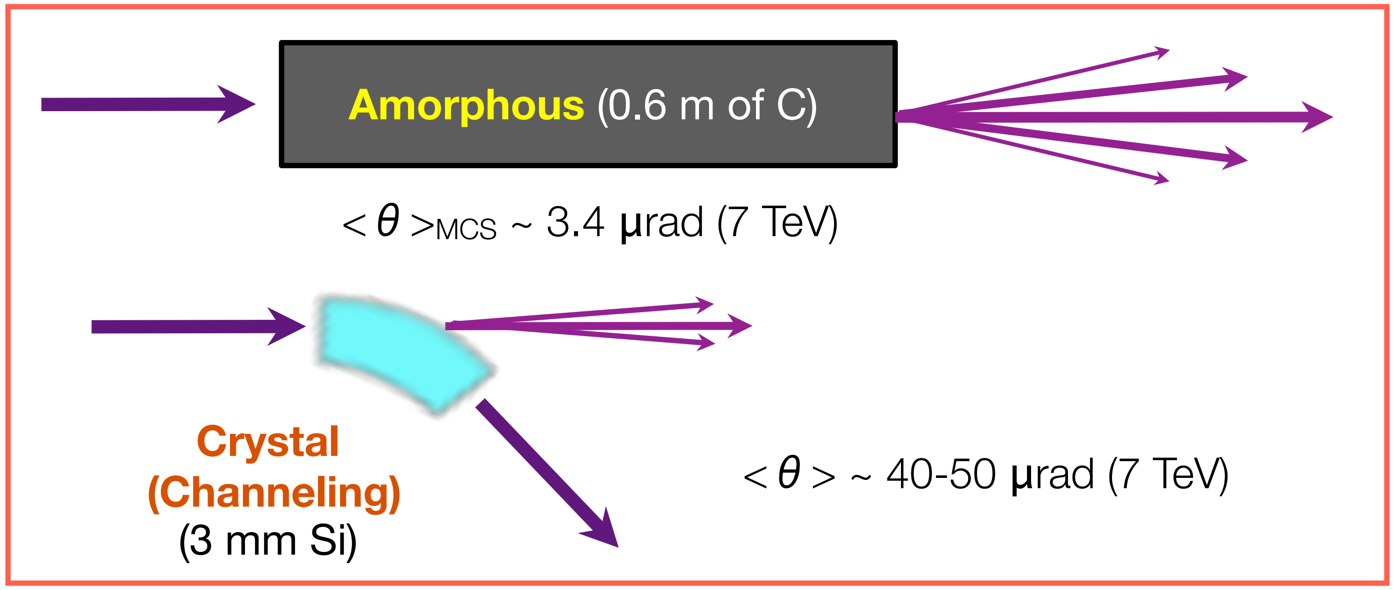
Concept of crystal collimation (i)



Bent crystals allow bending high-energy particles trapped between lattice planes.

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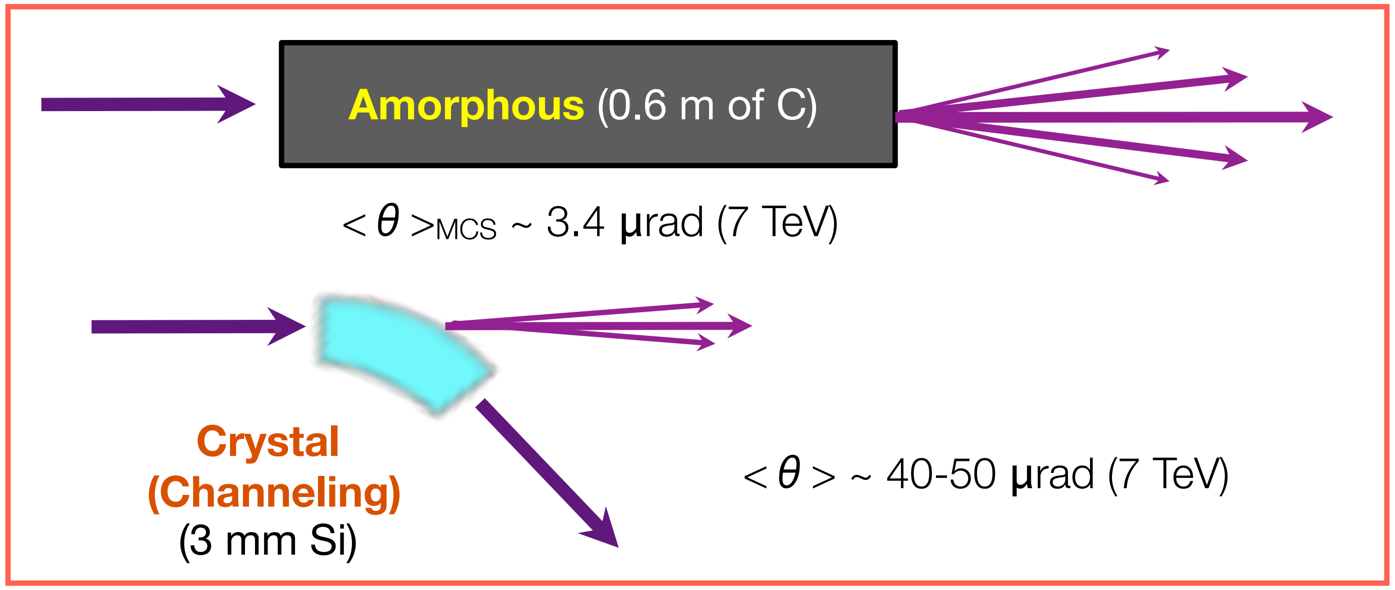

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Application for **hadron beam collimation**:

Crystals might be used as primary collimators to **exploit large angles** (~50μrad) and the **reduced change of beam rigidity** (diffractive events and ion dissociation/fragmentation).

Challenges for the LHC:

- small angular acceptance;
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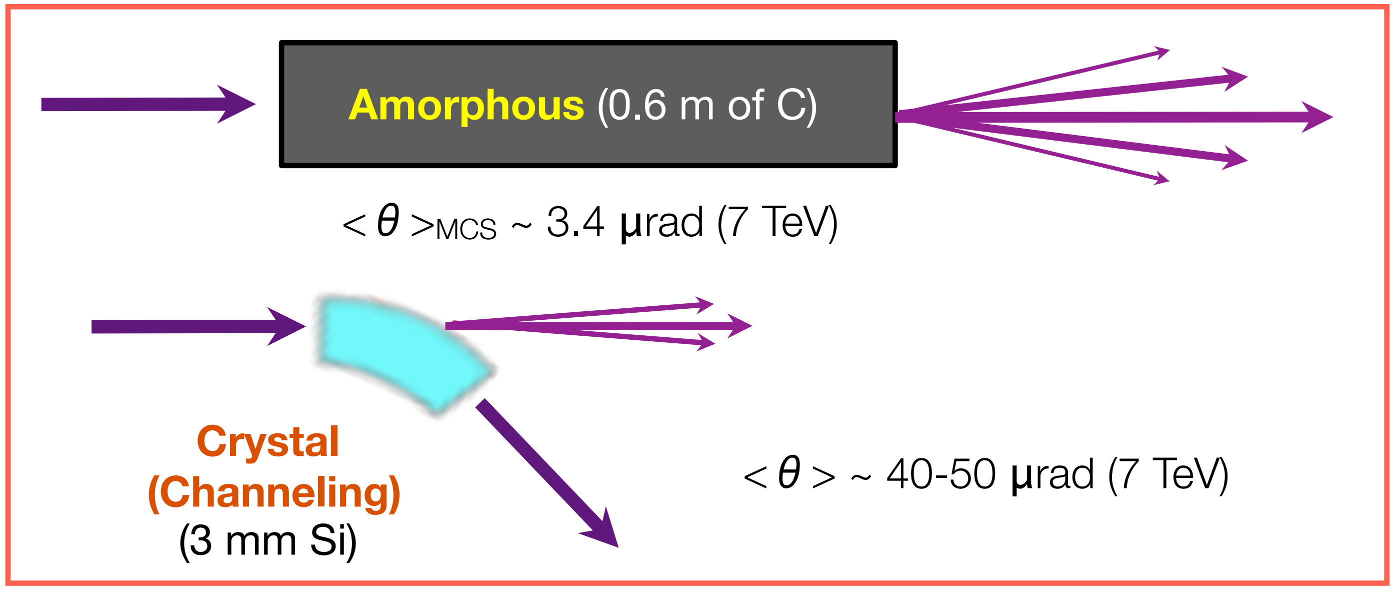

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Solid experimental validation at the SPS from UA9 experiment (starting in 2009), at beam energies up to 270 GeV (proton and ion beams).
(less positive results in other machines like RHIC and Tevatron...)

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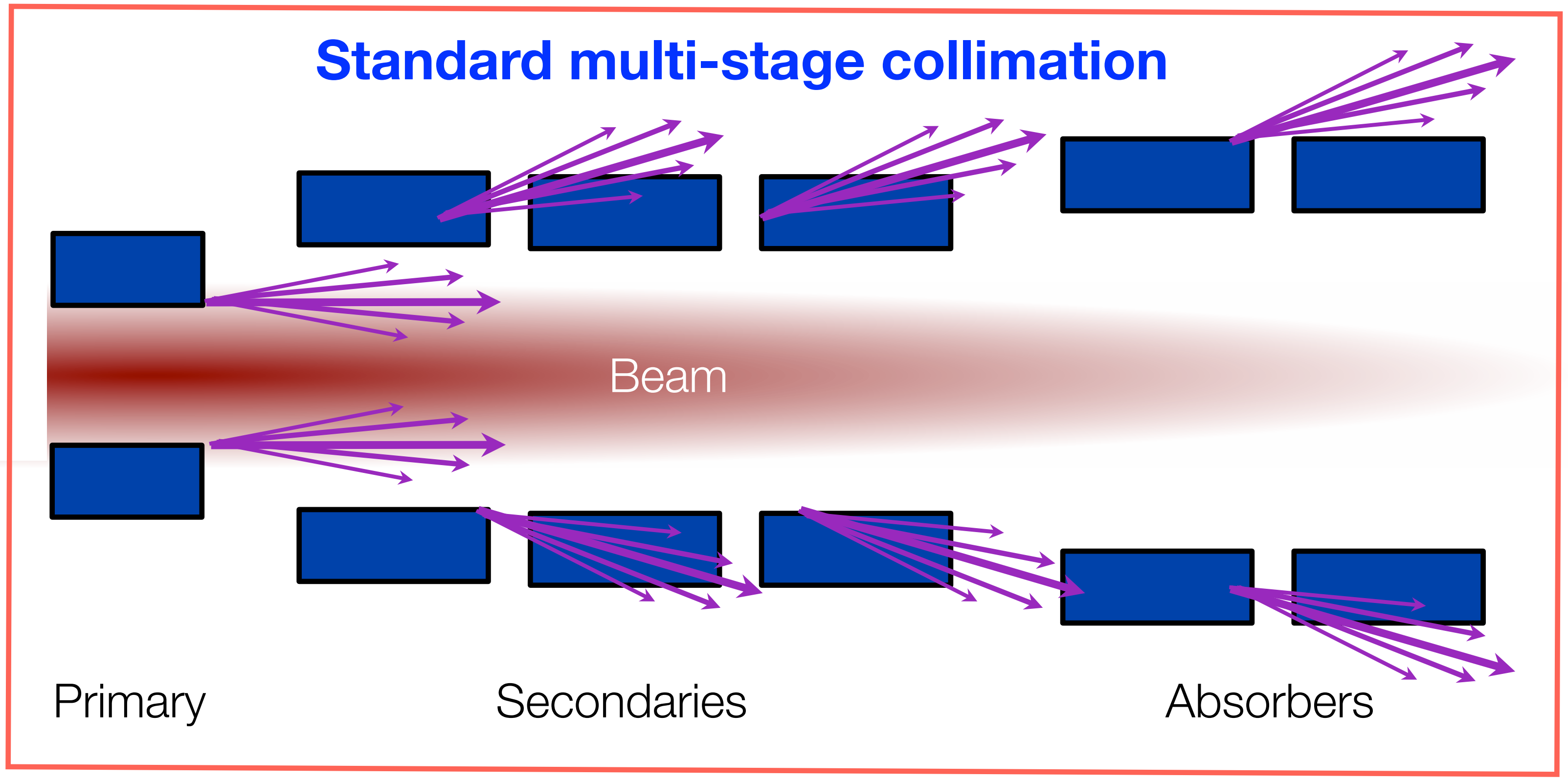

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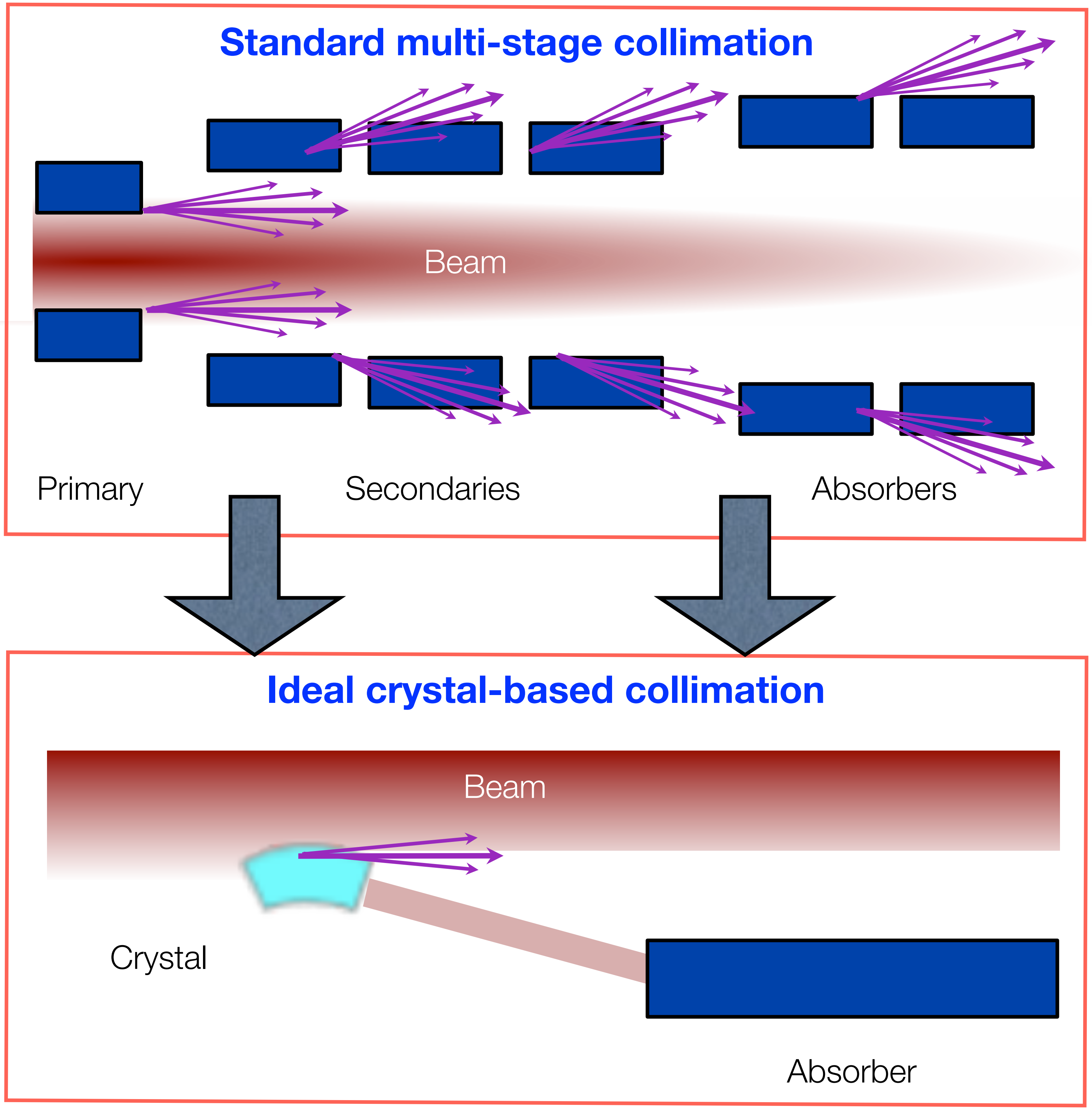

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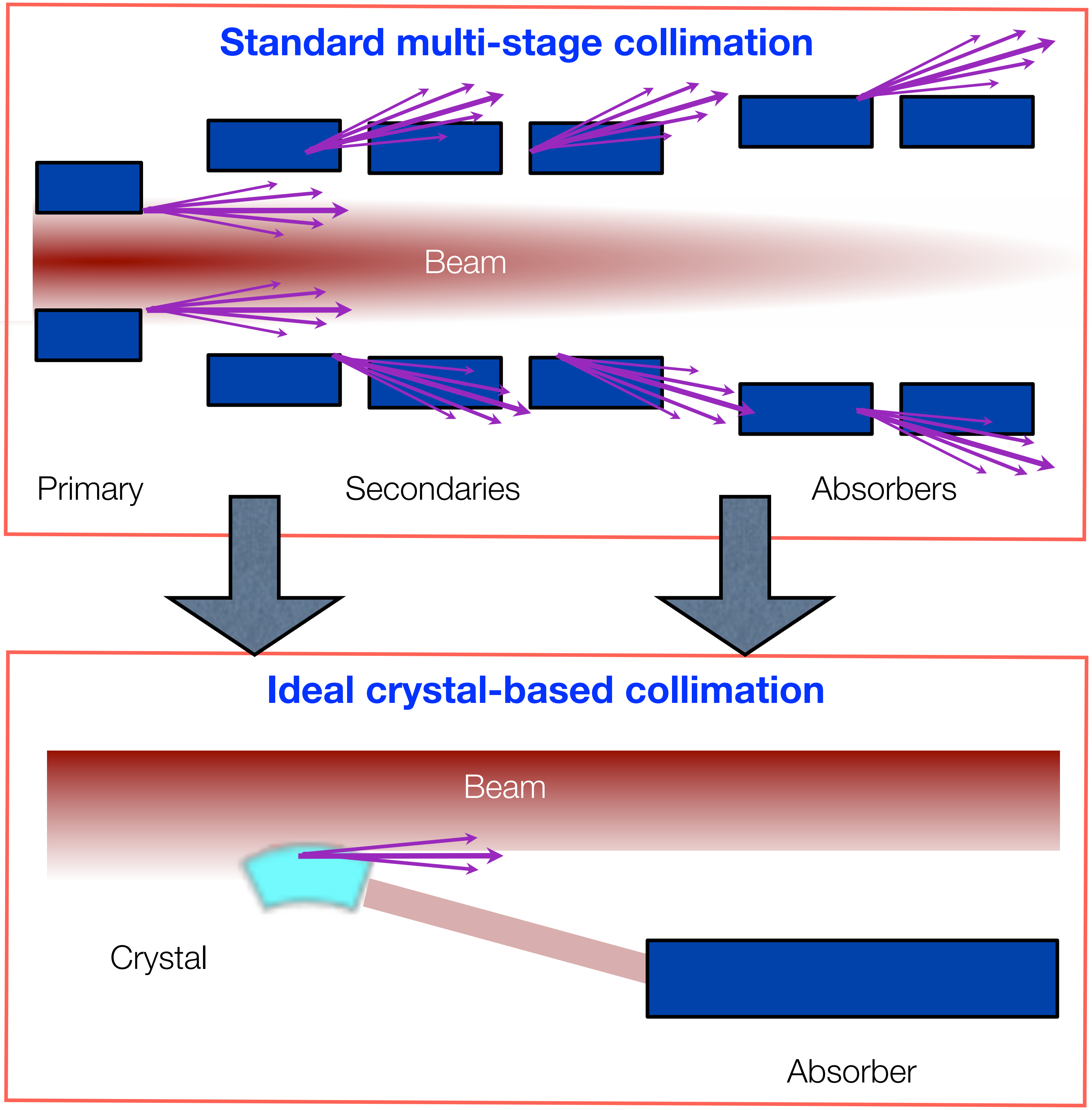

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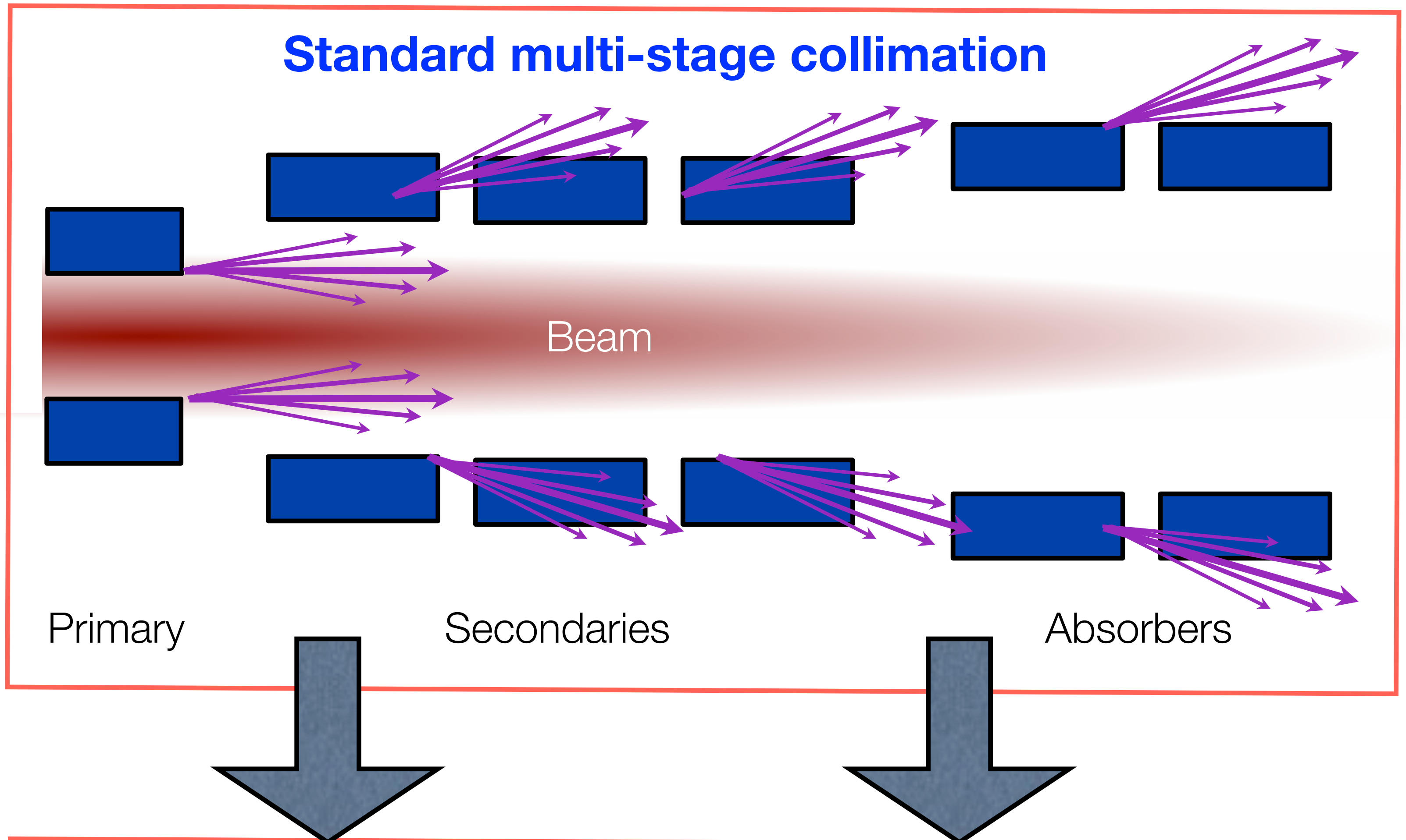

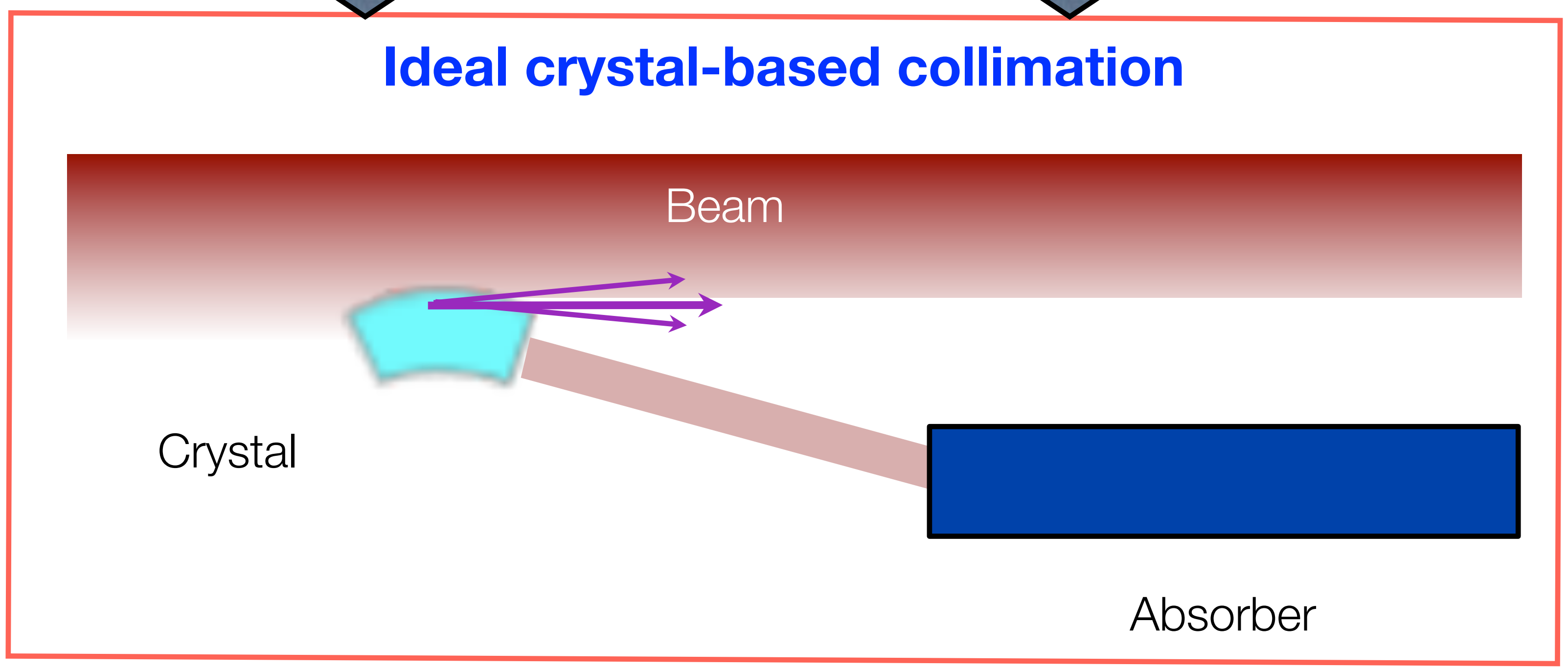

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Can this really work at the LHC?

Beam tests deemed necessary before relying on crystal collimation...

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In parallel: need to address high-energy challenge (0.5-1.0 MW losses in single absorber)

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Crystal layout design in IR7

Recent development, in addition to the years of experience from UA9:

- **Improved tools** to identify suitable candidate layouts (semi-analytical analysis of channeled beam trajectories).
- **Setup complete tracking simulations to predict loss maps**
  - Important to address cleaning performance taking into account layout constraints and leakage from collimators used as absorbers.
- Worked on an **improved crystal routine** for tracking studies.
- Conceived set of setting for the whole collimation system (~50 collimators) to achieve

PhD thesis work by D. Mirarchi (see his talk later)

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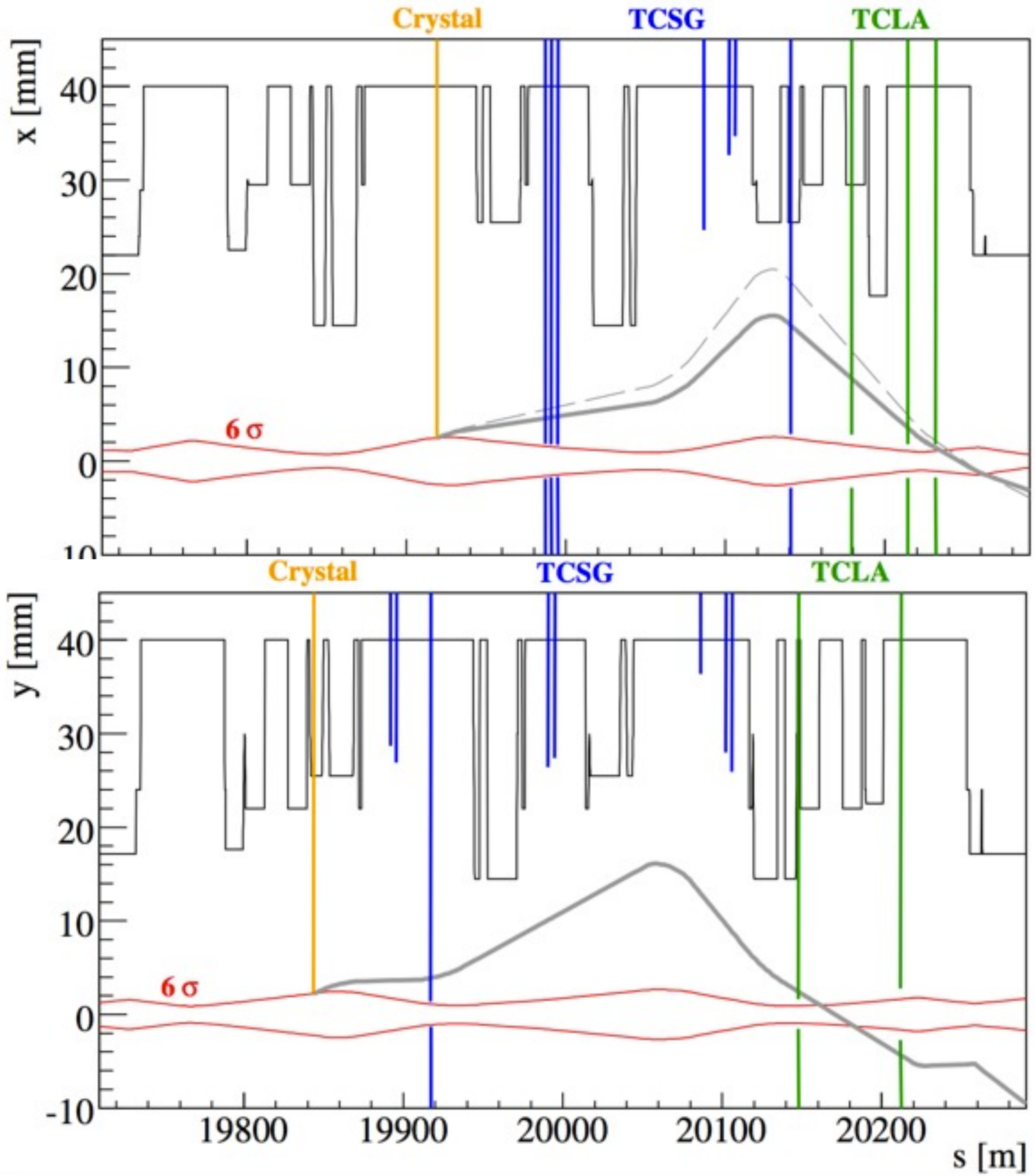

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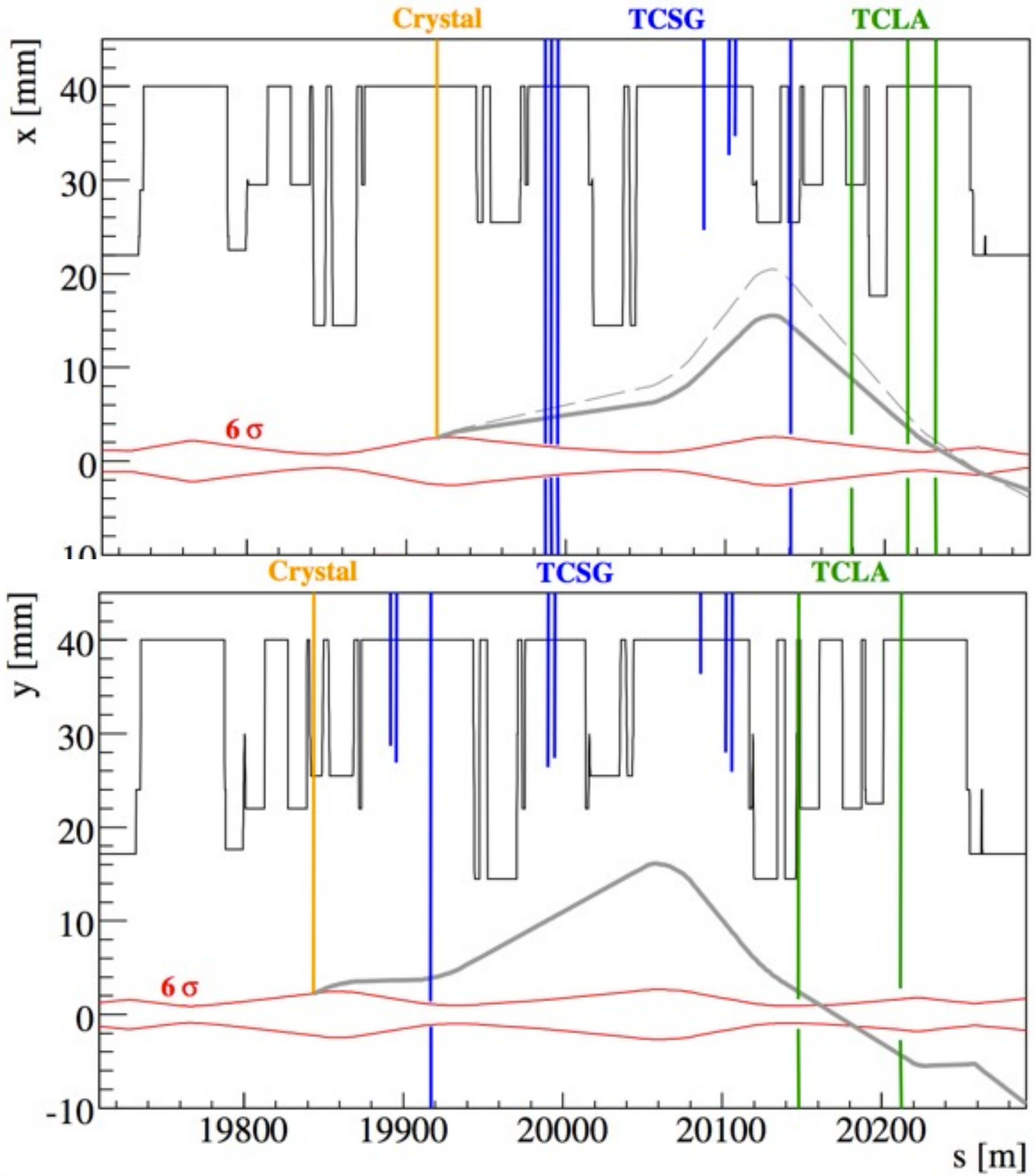

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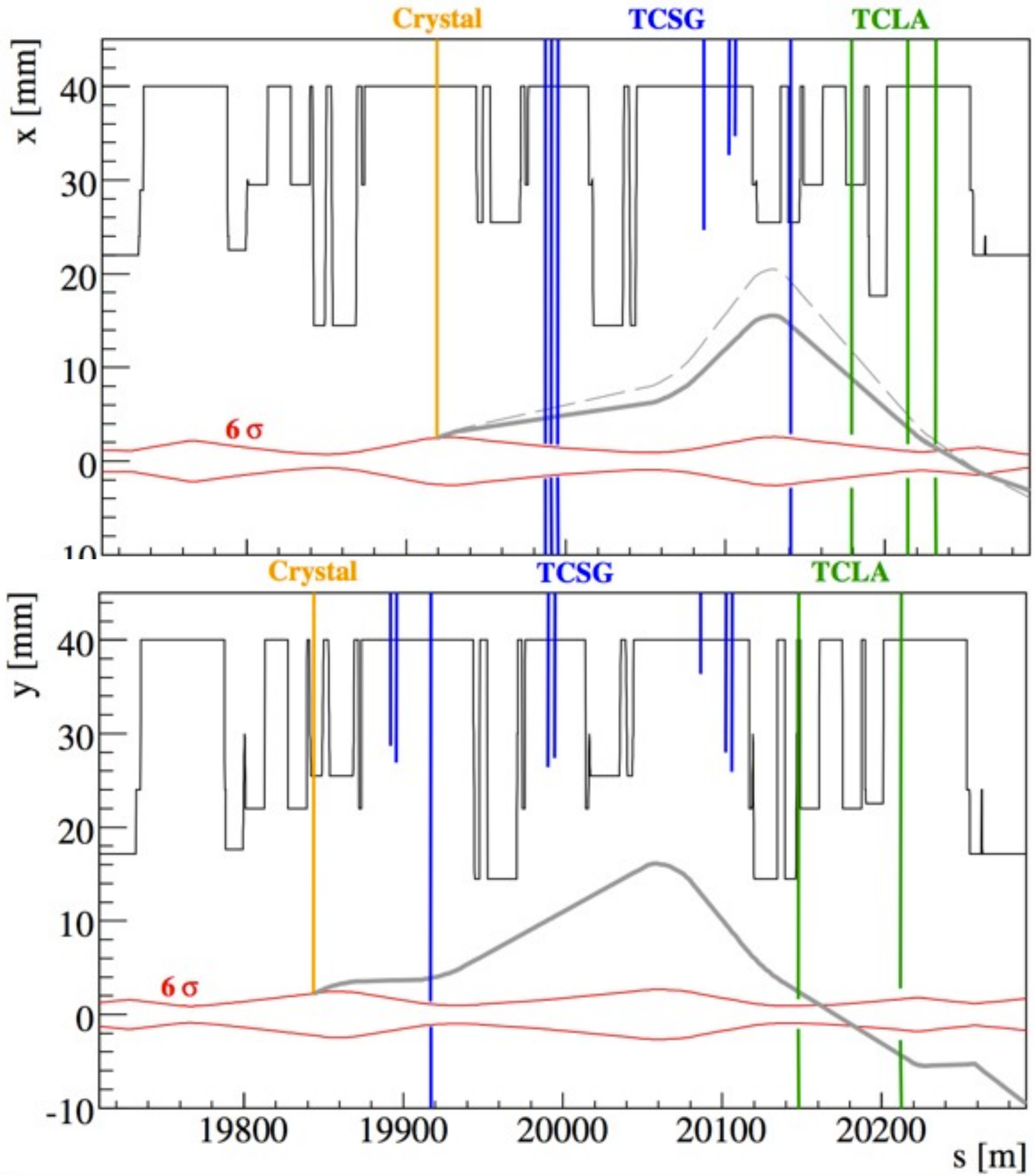

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Optics changes are very **costly** in terms of commissioning **time** at the LHC!

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→ *direct comparison of cleaning performance against present collimation.*

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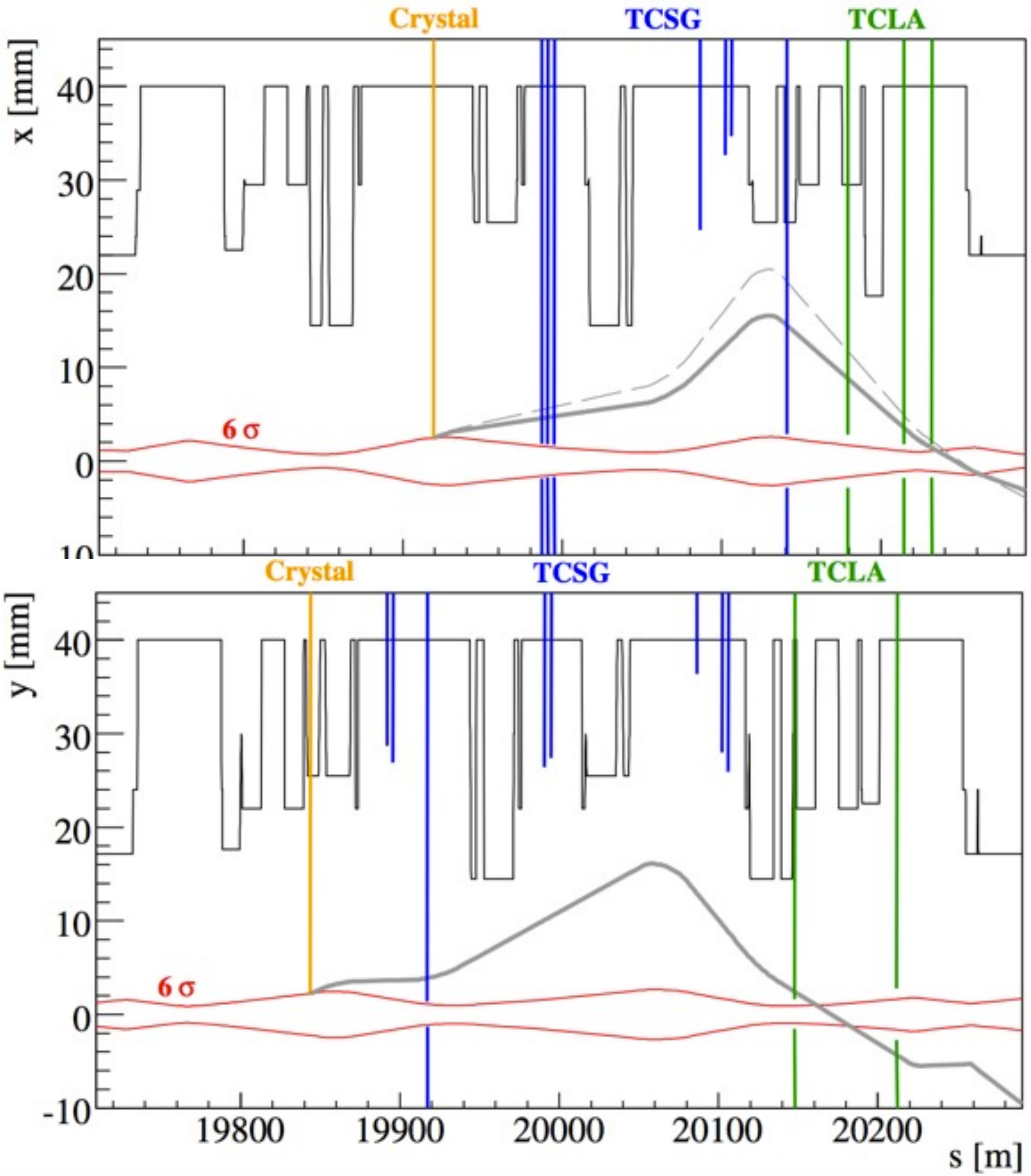

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→ *direct comparison of cleaning performance against present collimation.*

Rely on **existing collimation** system to catch the secondary beams
→ ***only compatible with low-intensity beams.***

Key layout features

Collimation plane	Bending [μrad]	Length [mm]	Material	Bending planes
Hor.	50	4	Si	110
Ver.	50	4	Si	111

Key layout features

- Initial installation (carried out in April 2014):
  - Two goniometers on beam 1 only (horizontal + vertical)
  - Preparation of infrastructure for additional detectors
  - Improved beam instrumentation (fast diamond loss monitors)

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- Initial installation (carried out in April 2014):
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  - Improved beam instrumentation (fast diamond loss monitors)
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- Possibility to improve cleaning relies on 5 other absorber collimators.

  A Carbon-based collimator is used to intercept the beam: not enough absorption for cleaning!

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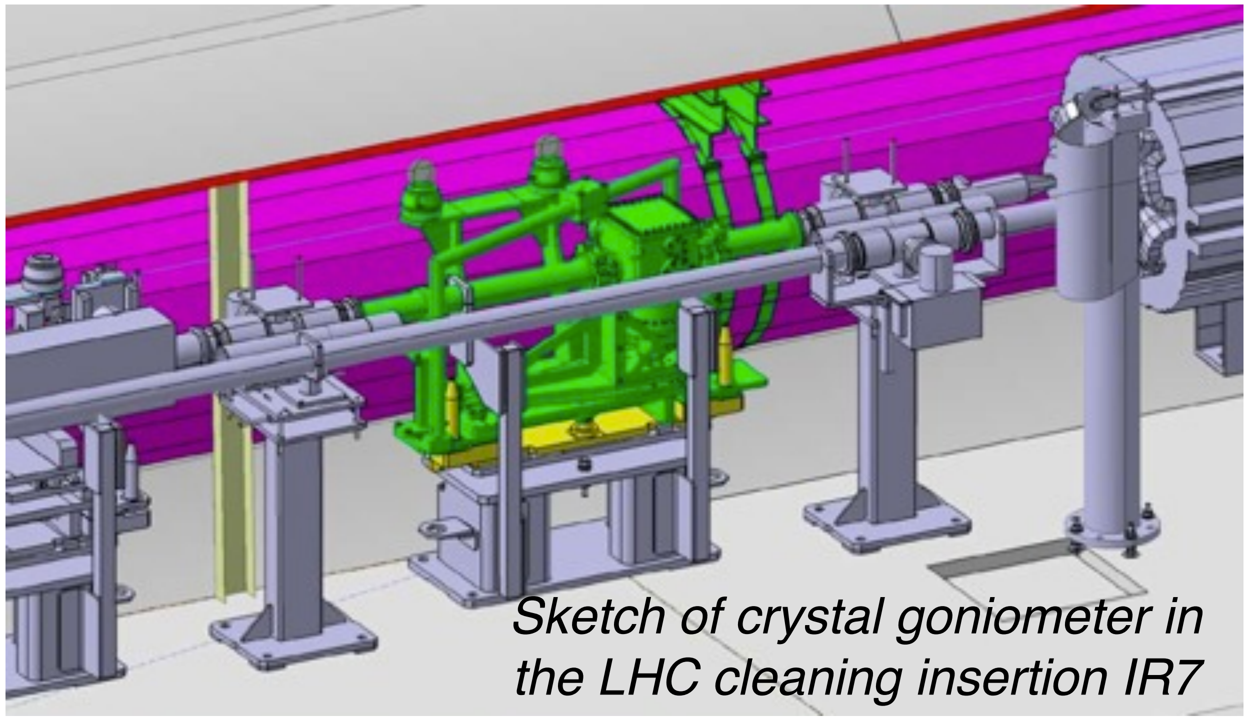
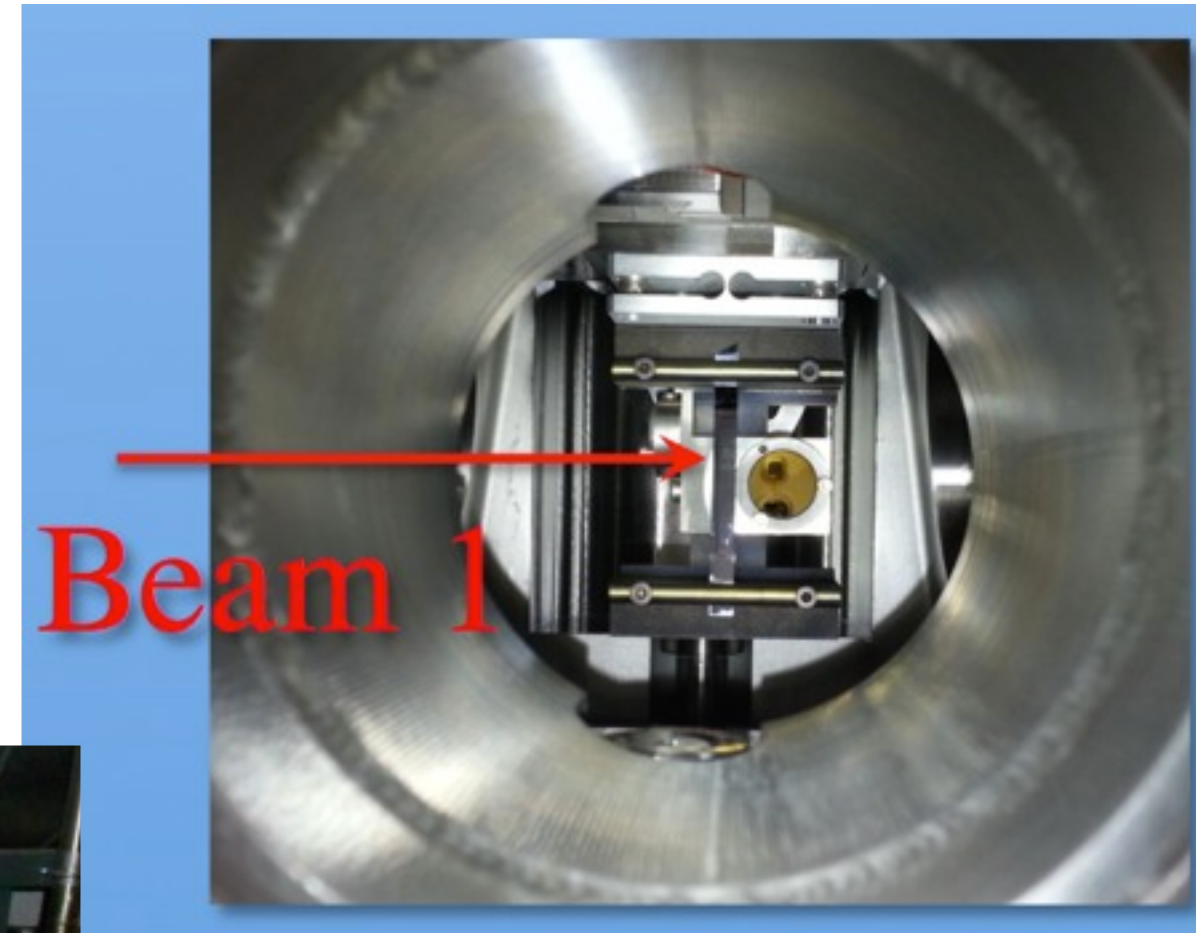
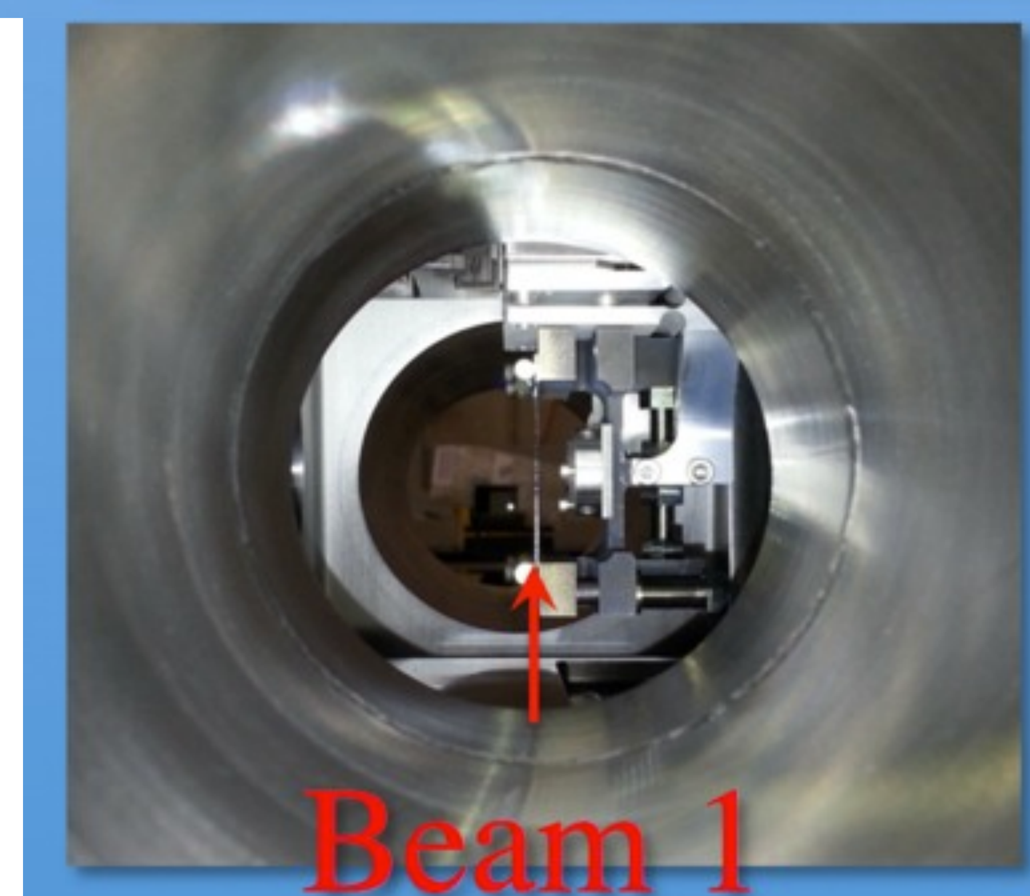
Installation status



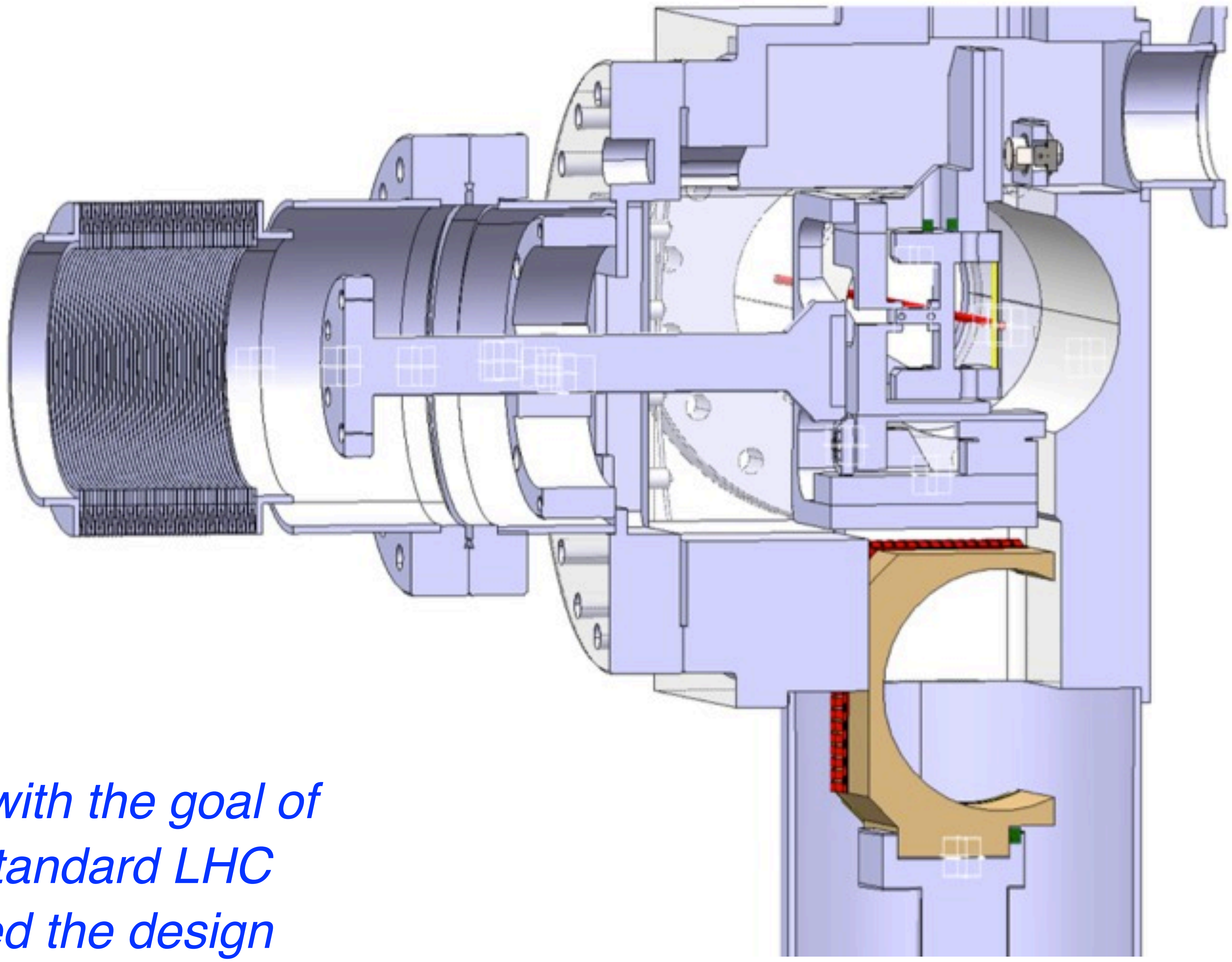
Sketch of crystal goniometer in the LHC cleaning insertion IR7





Goniometer design concept

Design derived from some LHC beam instrumentation: with high intensity beams, a 'C' vacuum chamber "hides" the goniometer (only moved in beam for dedicated beam tests).

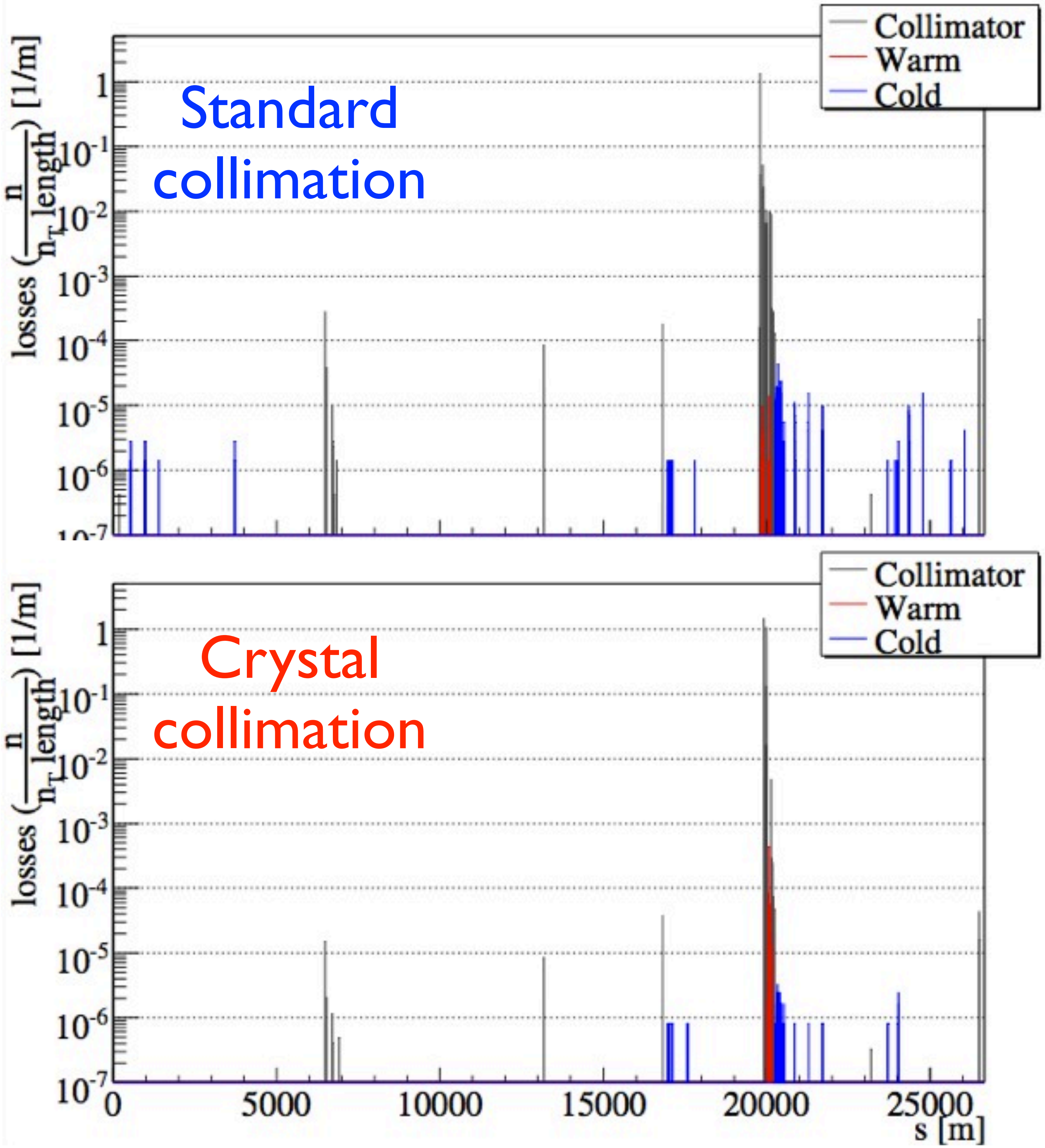


We designed the hardware with the goal of being "transparent" for the standard LHC operation. This also simplified the design versus impedance and vacuum constraints!

Courtesy W. Scandale, A. Masi

Dedicated talk by A Masi in this session!

Expected crystal collimation cleaning



See talk later by D. Mirarchi for complete simulation setup.

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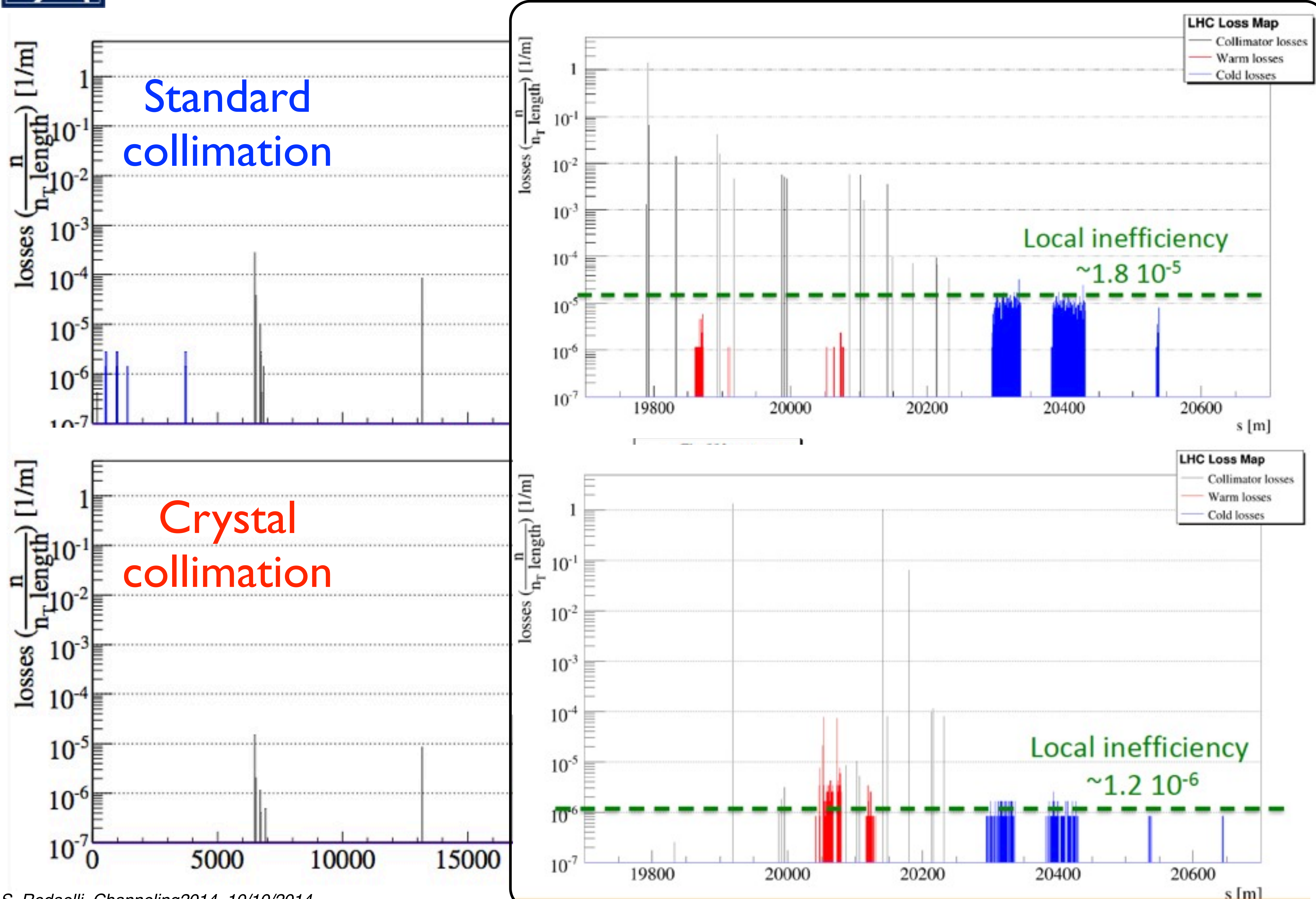
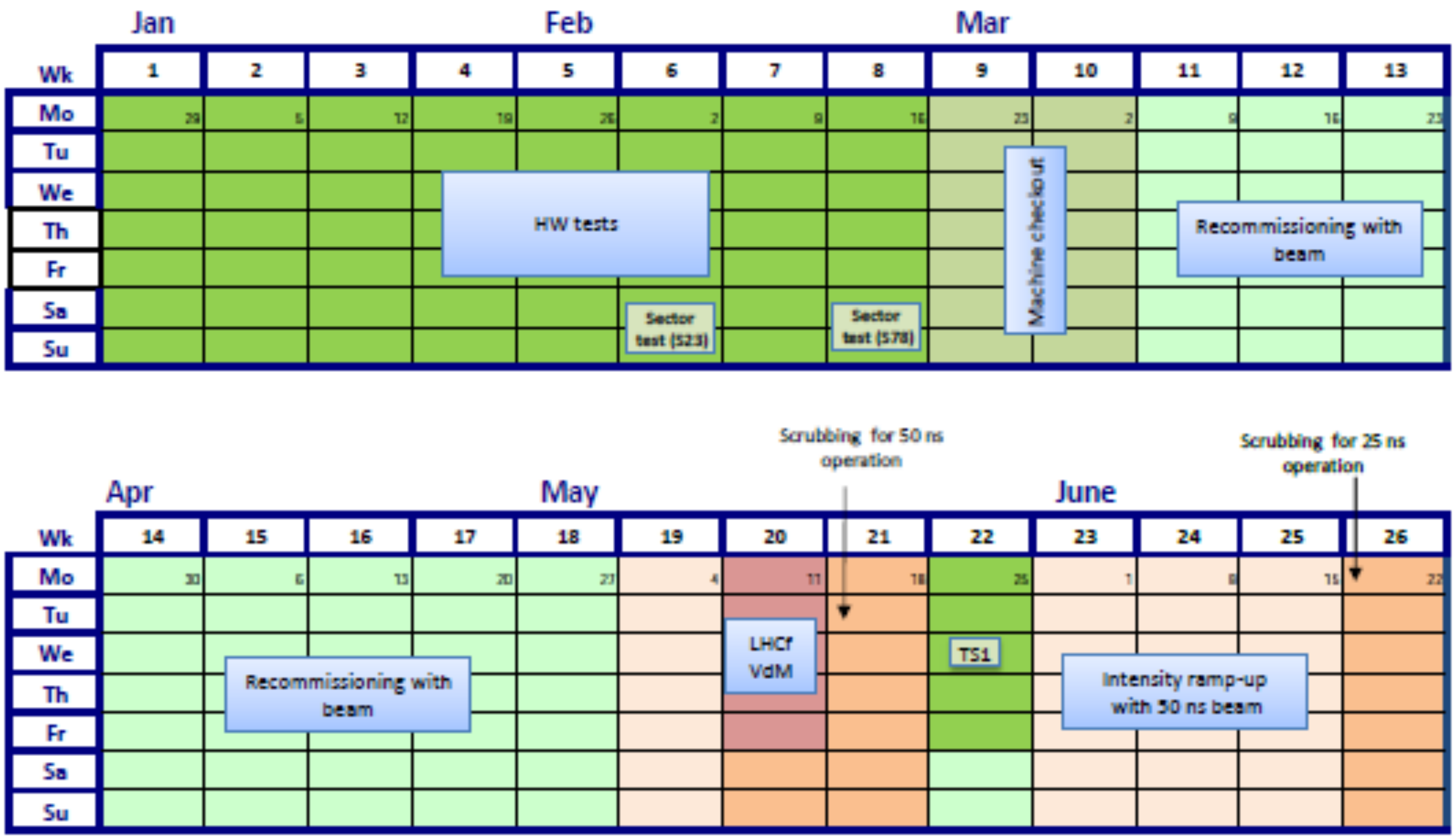


Outline

- Introduction
- LHC beam collimation
- Crystal collimation
- Layouts for beam tests
- **Plans for 2015**
- Conclusions

Baseline 2015 schedule (i)



Commissioning strategy recently discussed at the ***"Chamonix" LHC Performance Workshop*** *(Sep. 22nd-25th).*

Start of beam commissioning: ***March 2015***

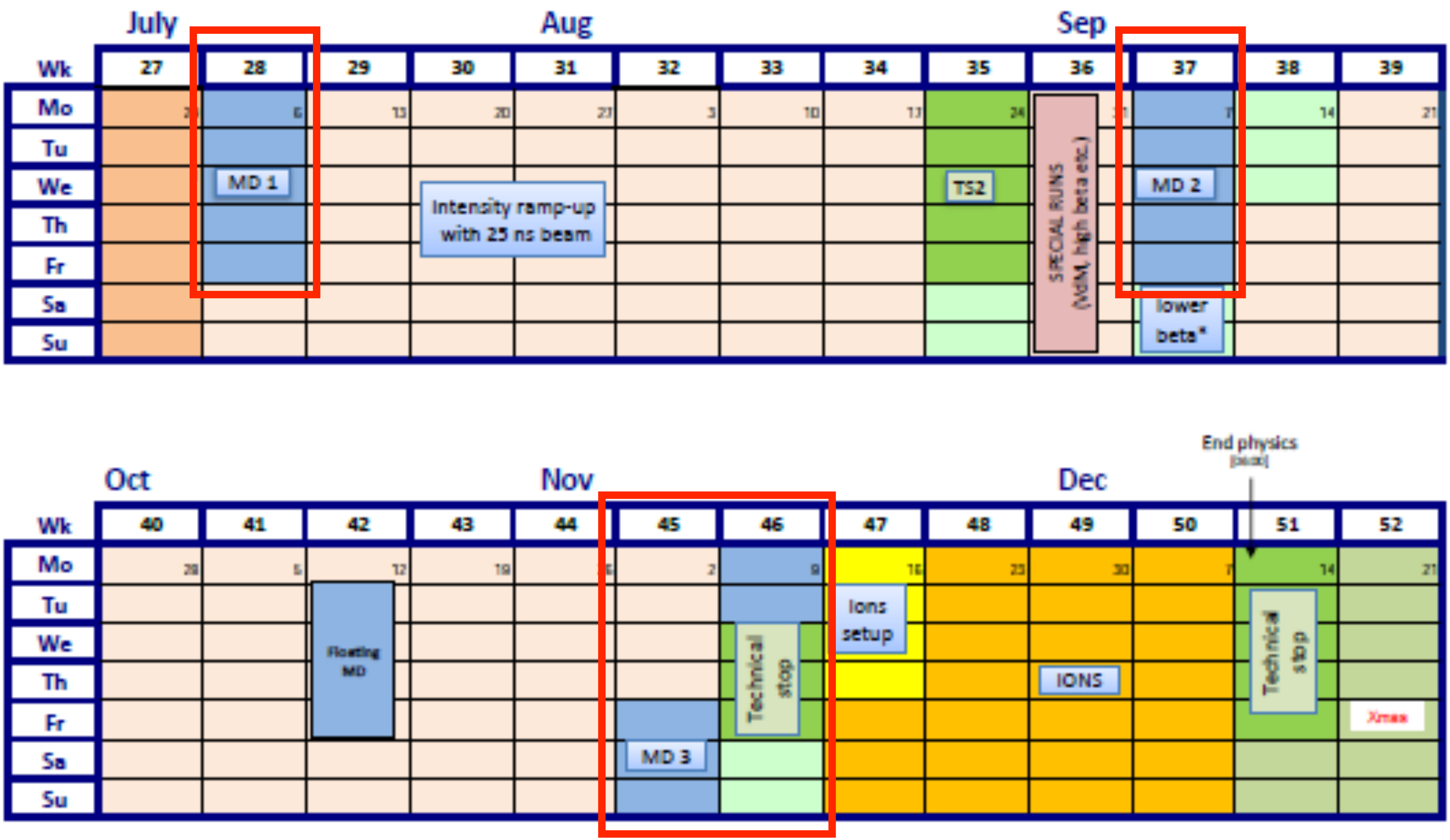
M. Lamont, J. Wenninger,

- The main strategy for 2015 is to concentrate on 6.5 TeV and 25 ns beam to reduce complexity:
  - Relaxed β* of 80 cm for the startup
  - Plan a change of β* later during the run.

→ Necessary beam time to be allocated to understand the LHC after the 2 year stop!

Explore in 2015, produce in 2016 !

Baseline 2015 schedule (ii)



MD = Machine Development → beam studies for various purposes (immediate performance improvement, long-term developments, test new concepts, ...)

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Very ambitious program!
Cannot effort hardware and software debugging during LHC beam time!

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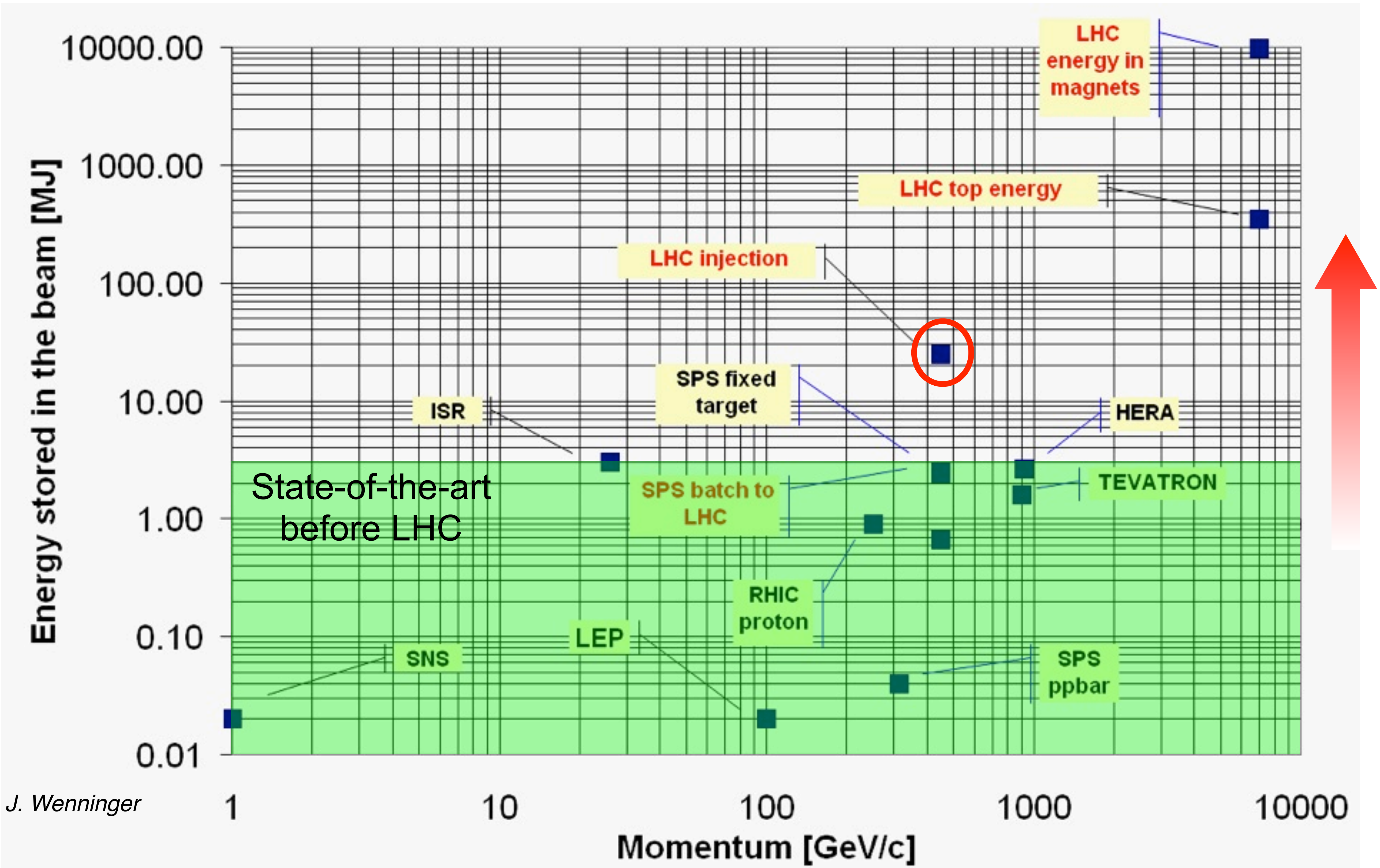
- Looking forward to seeing channeled and collimated beam in 2015!

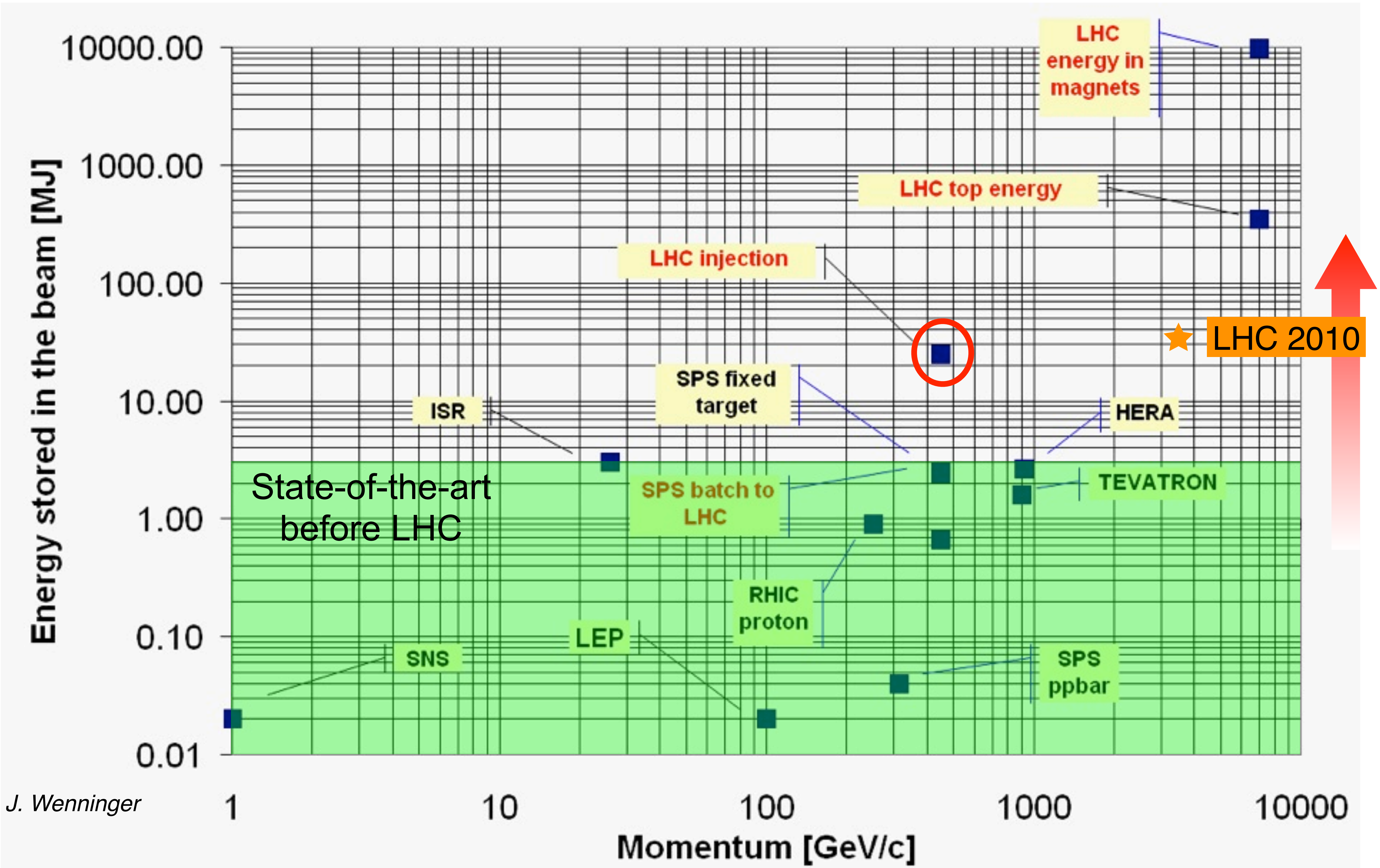
Reserve slides

The LHC stored energy challenge



J. Wenninger

The LHC stored energy challenge



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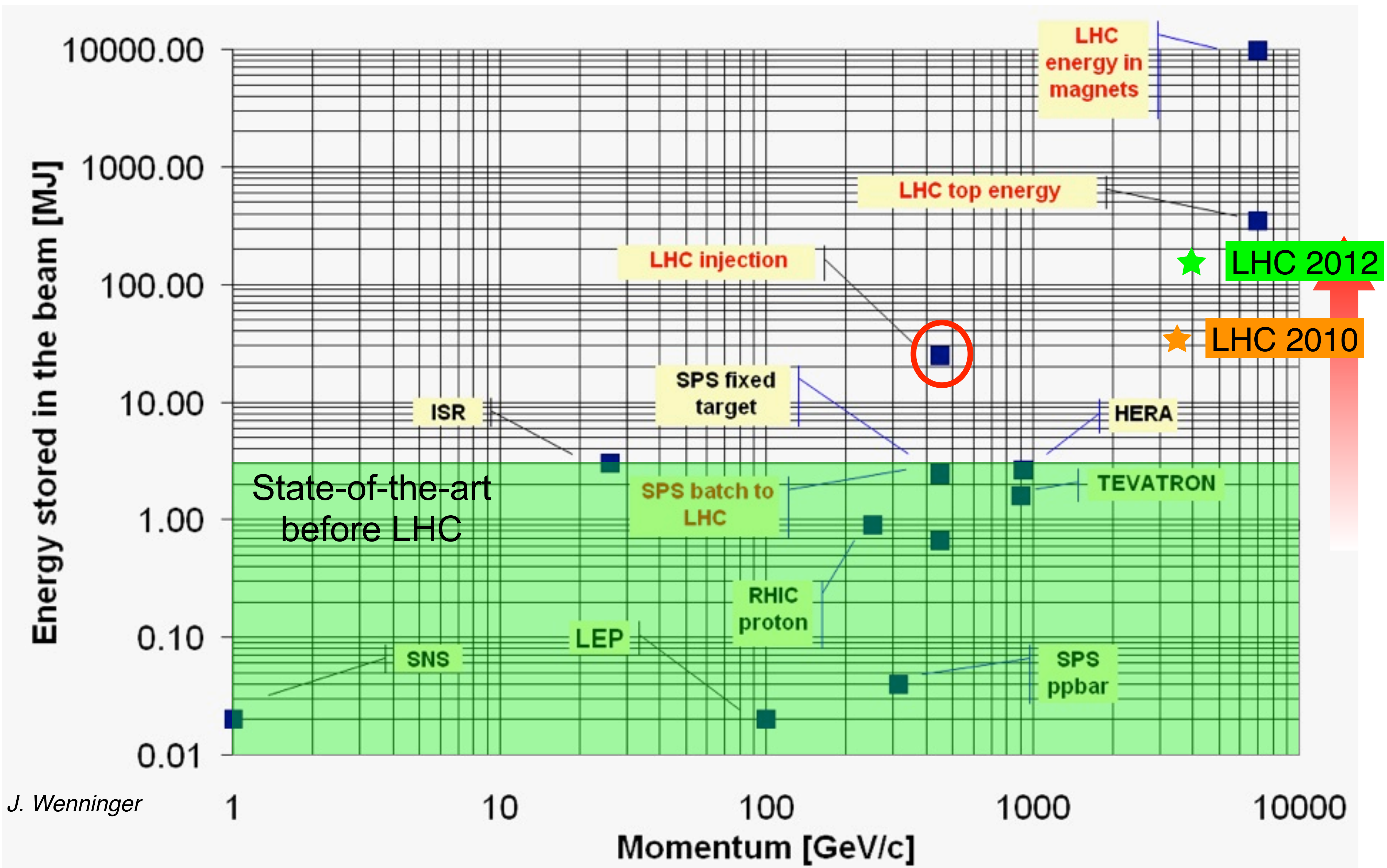

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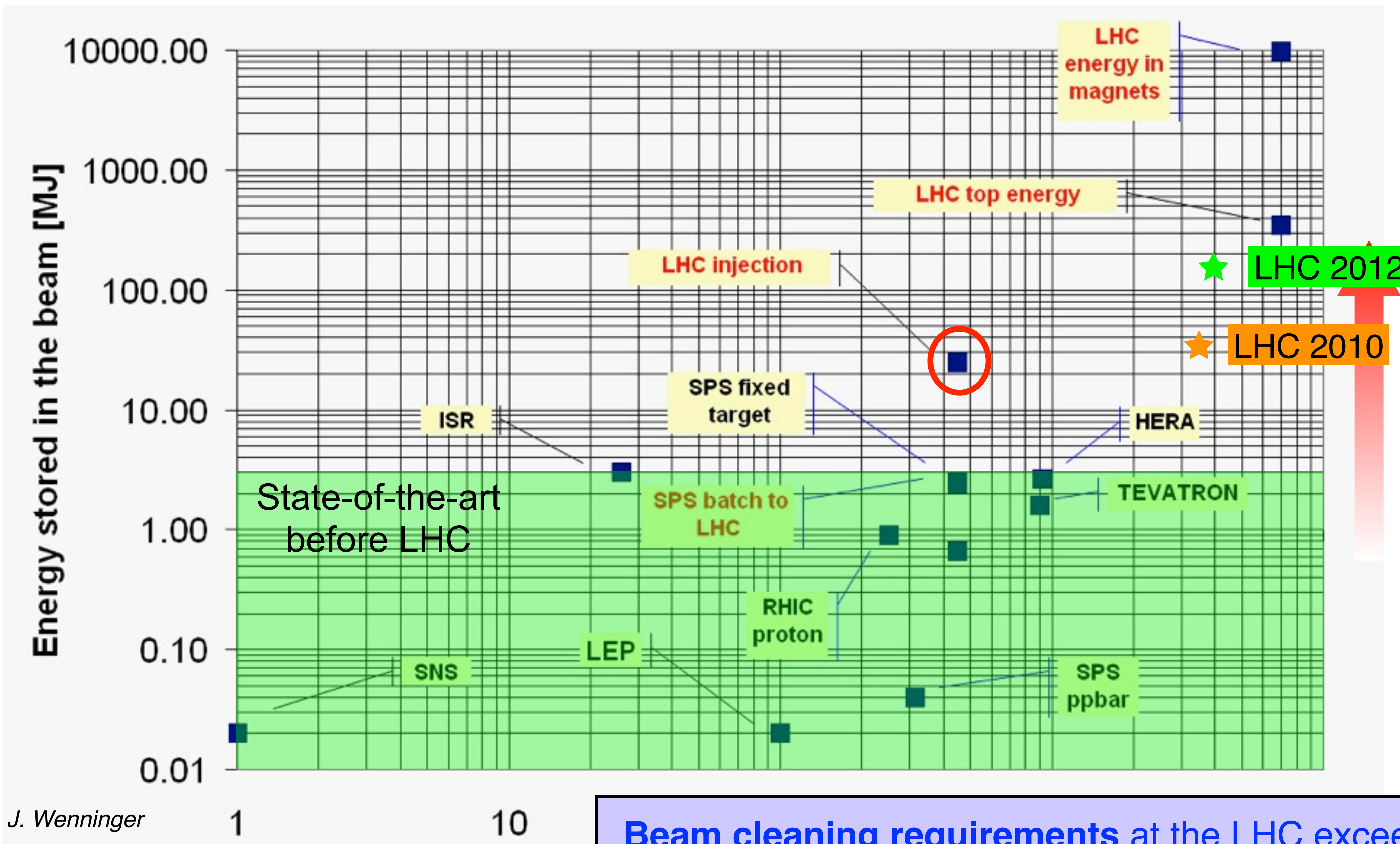

J. Wenninger

Beam cleaning requirements at the LHC exceed previous machines by orders of magnitude!

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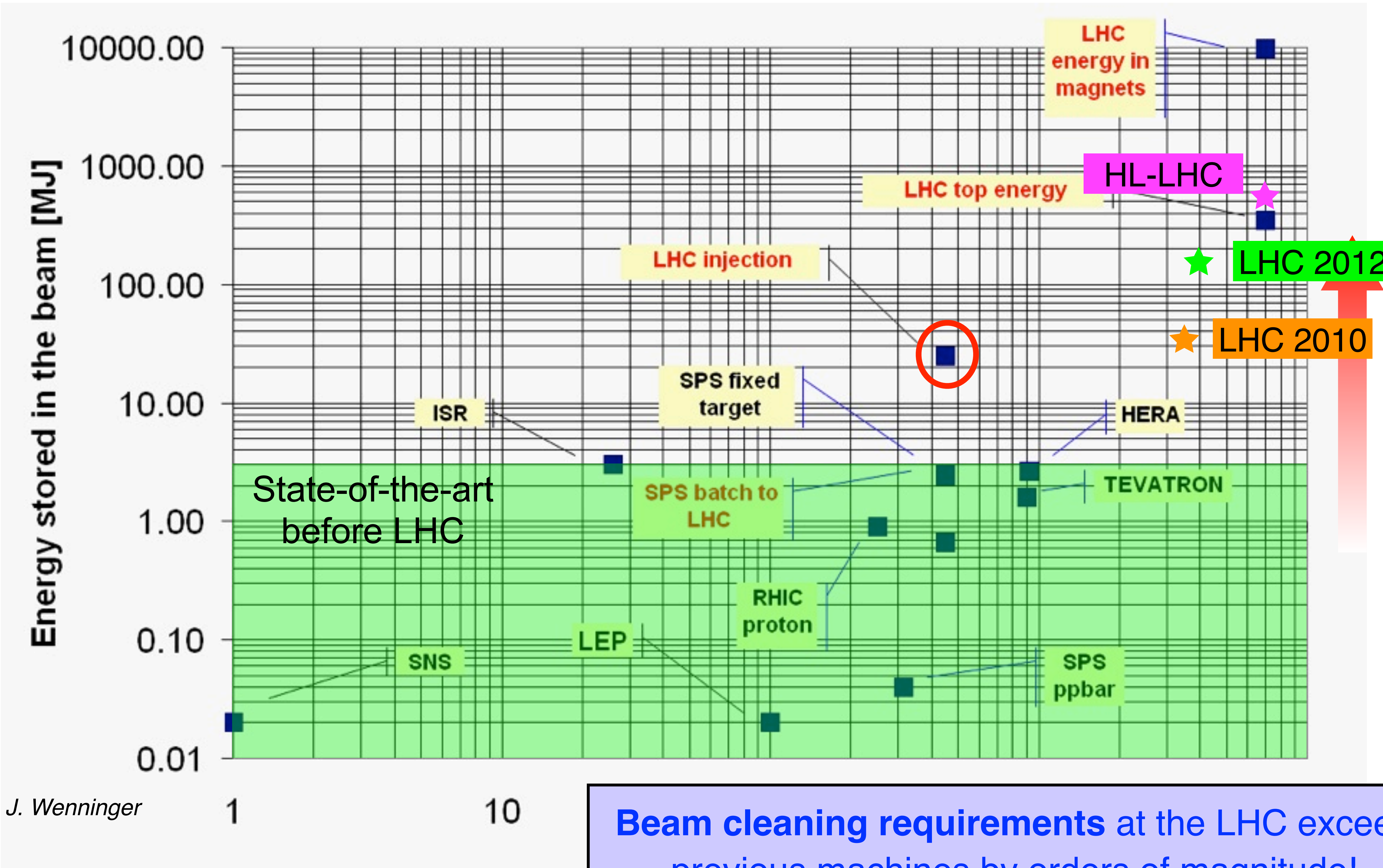

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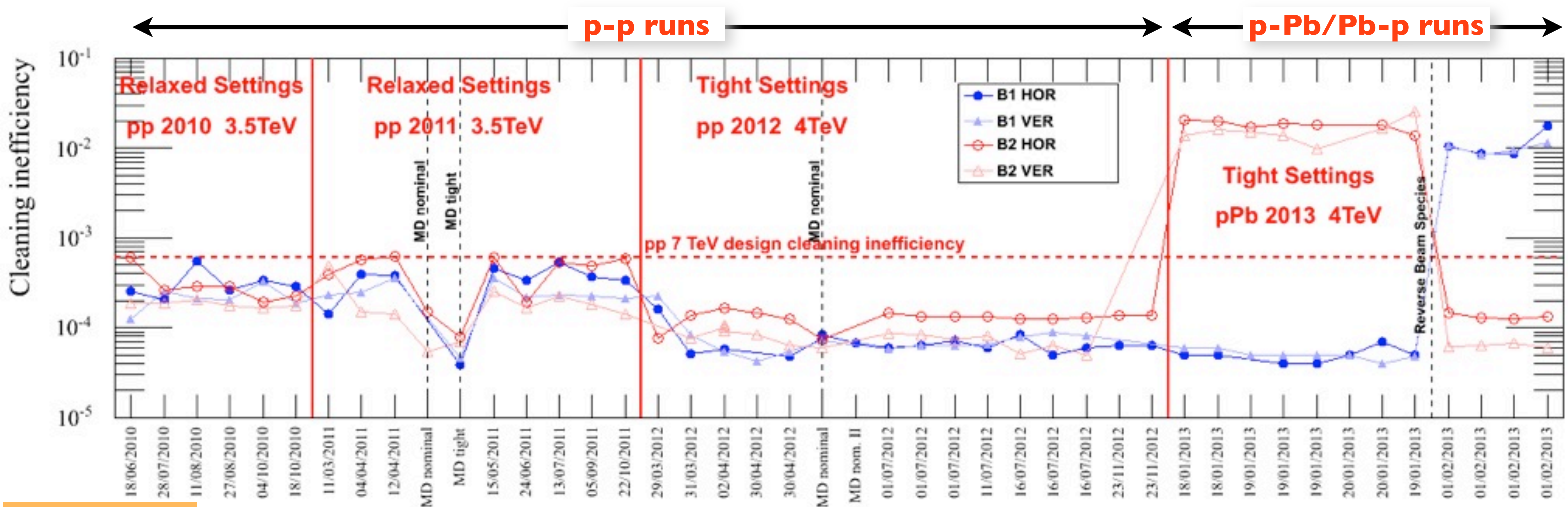
Stability of cleaning



B. Salvachua

- Excellent stability achieved with 1 alignment per year in IR3/6/7 (2x30 devices).
- New alignments are only repeated for **new physics configurations**
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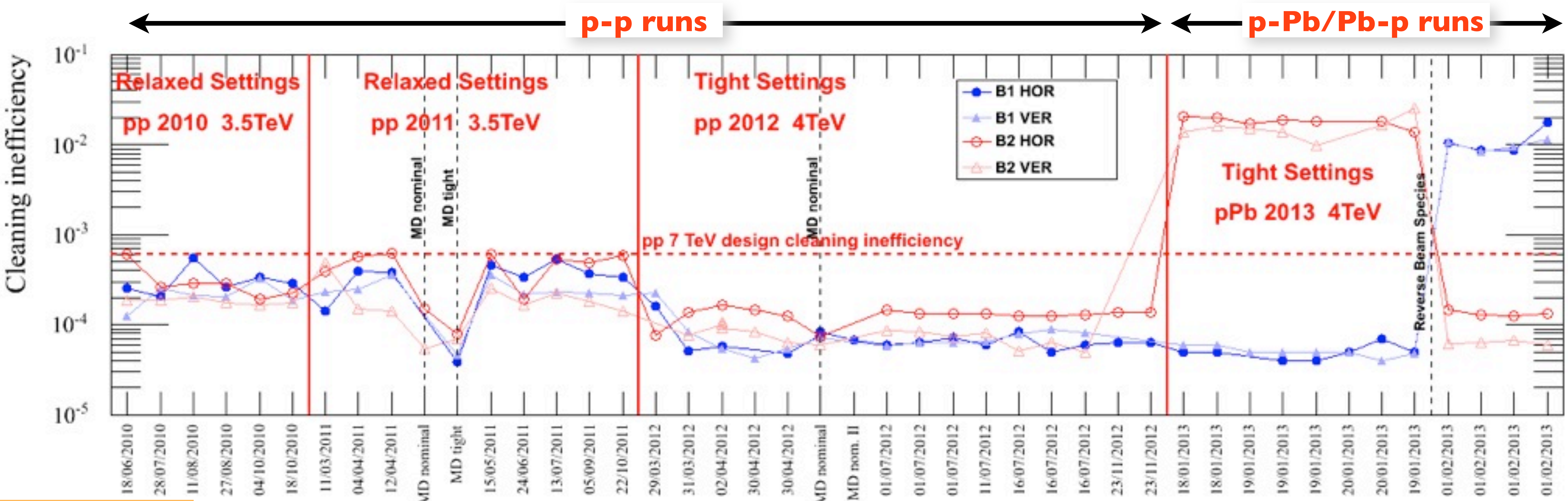

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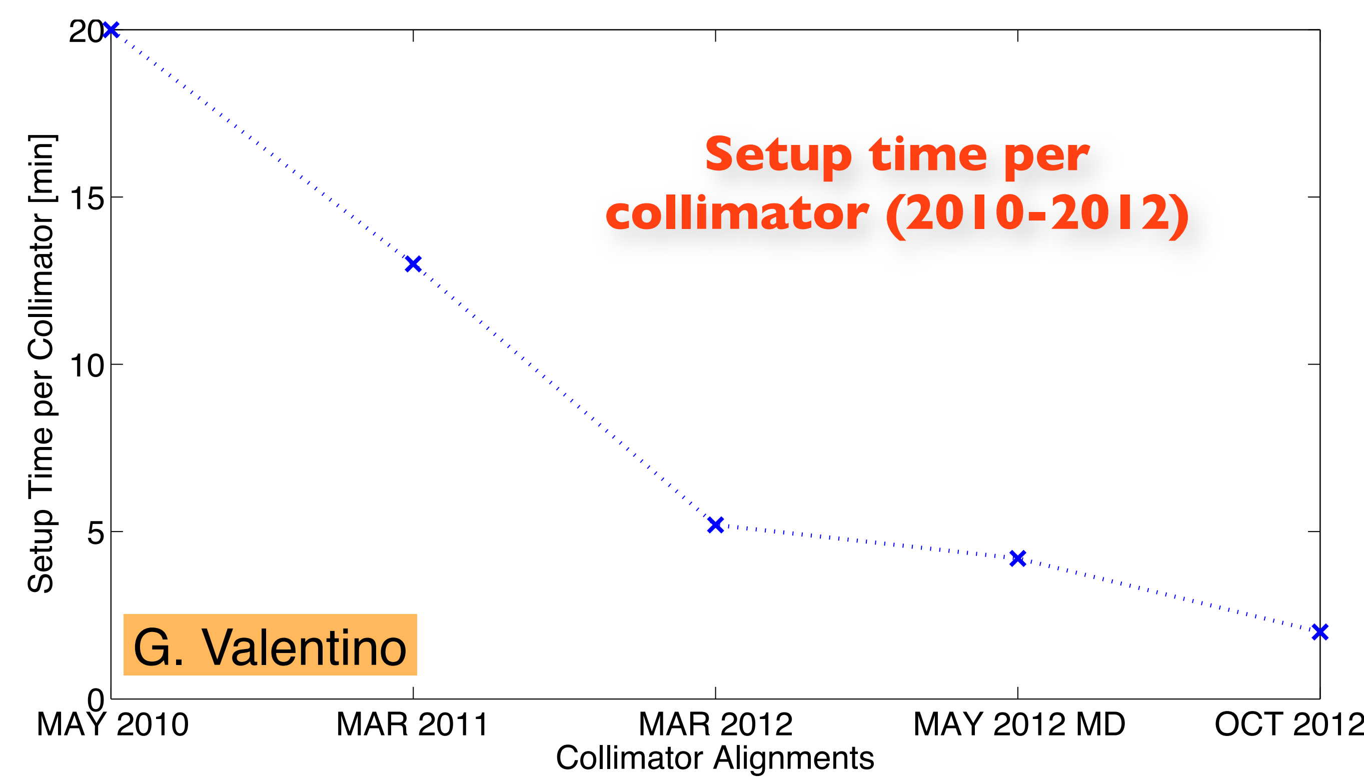
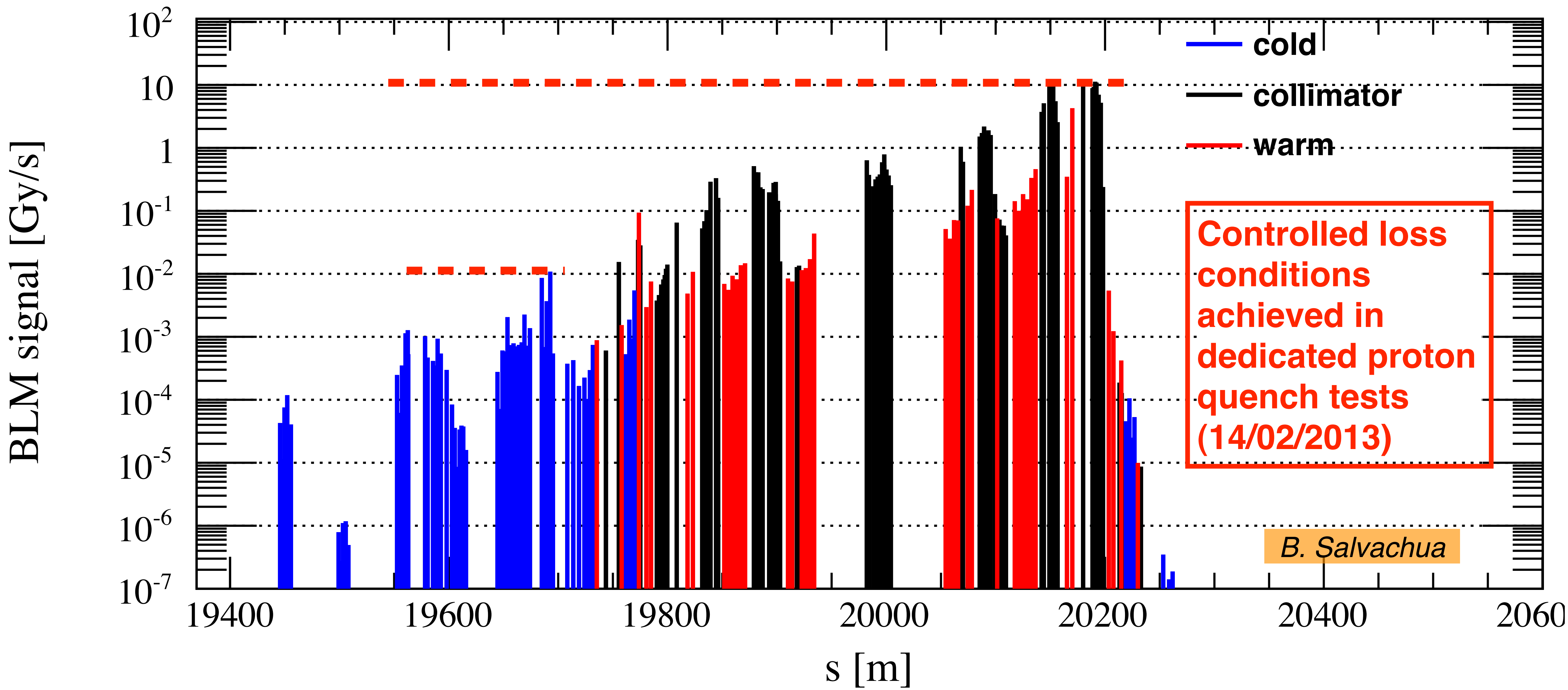


Handling 1 MW beam losses at 4 TeV!



Controlled beam excitation over several seconds: **Peak>1MW on TCP!**
Worsened cleaning by relaxing collimator settings.

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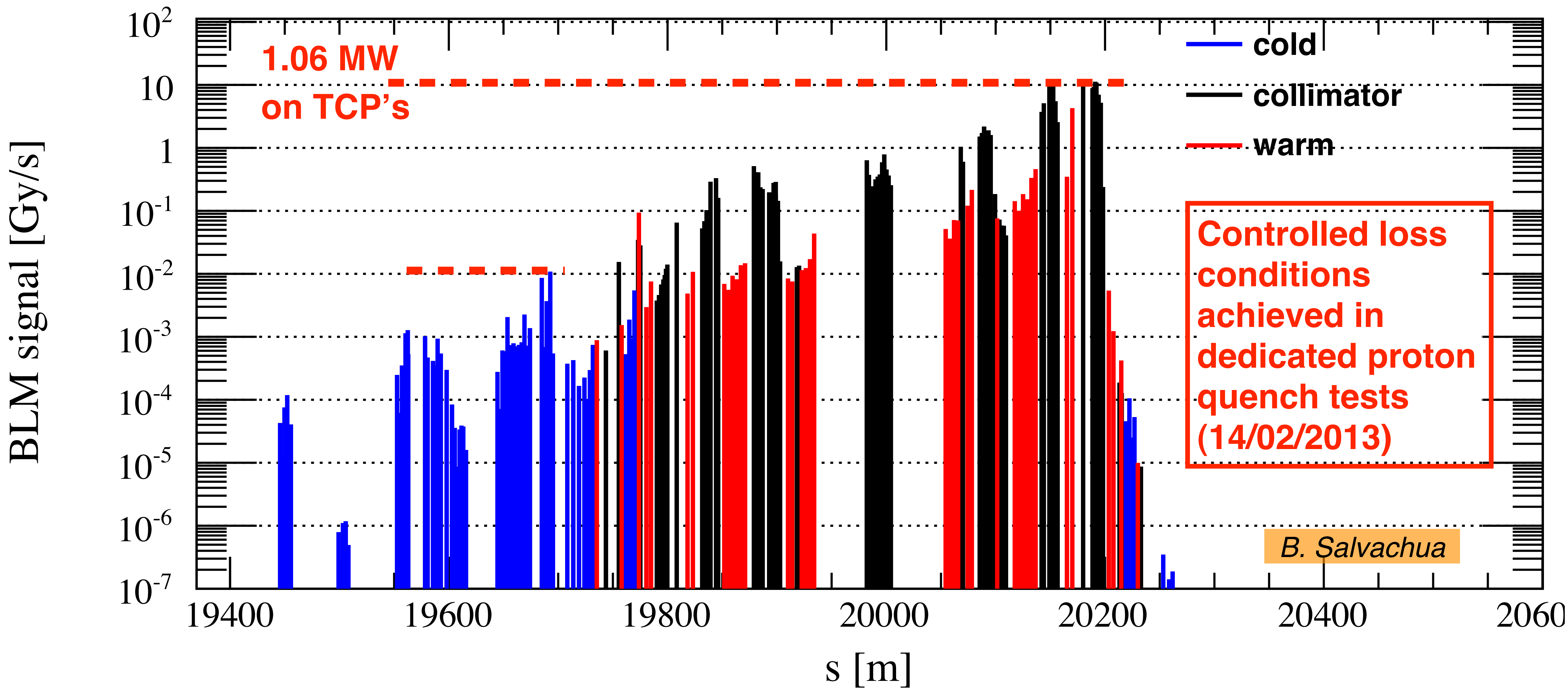

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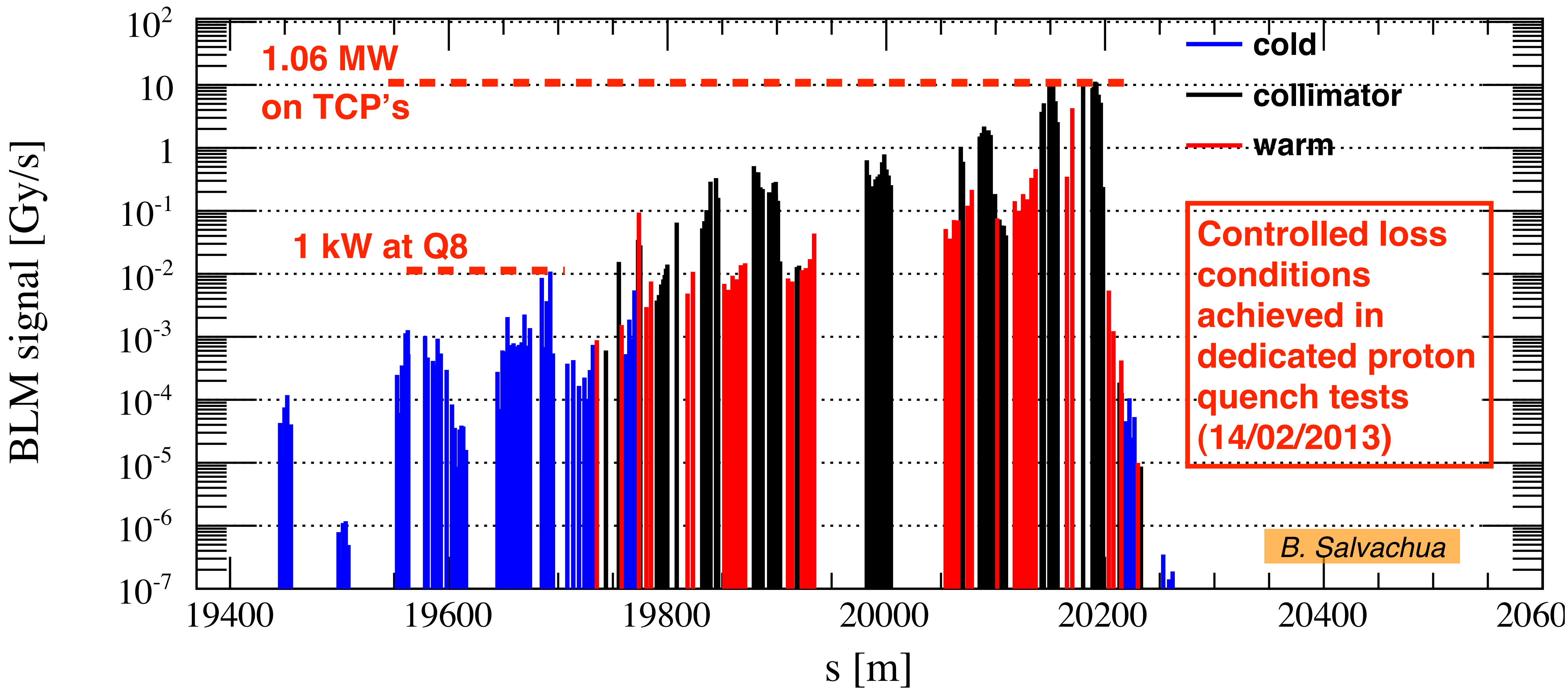

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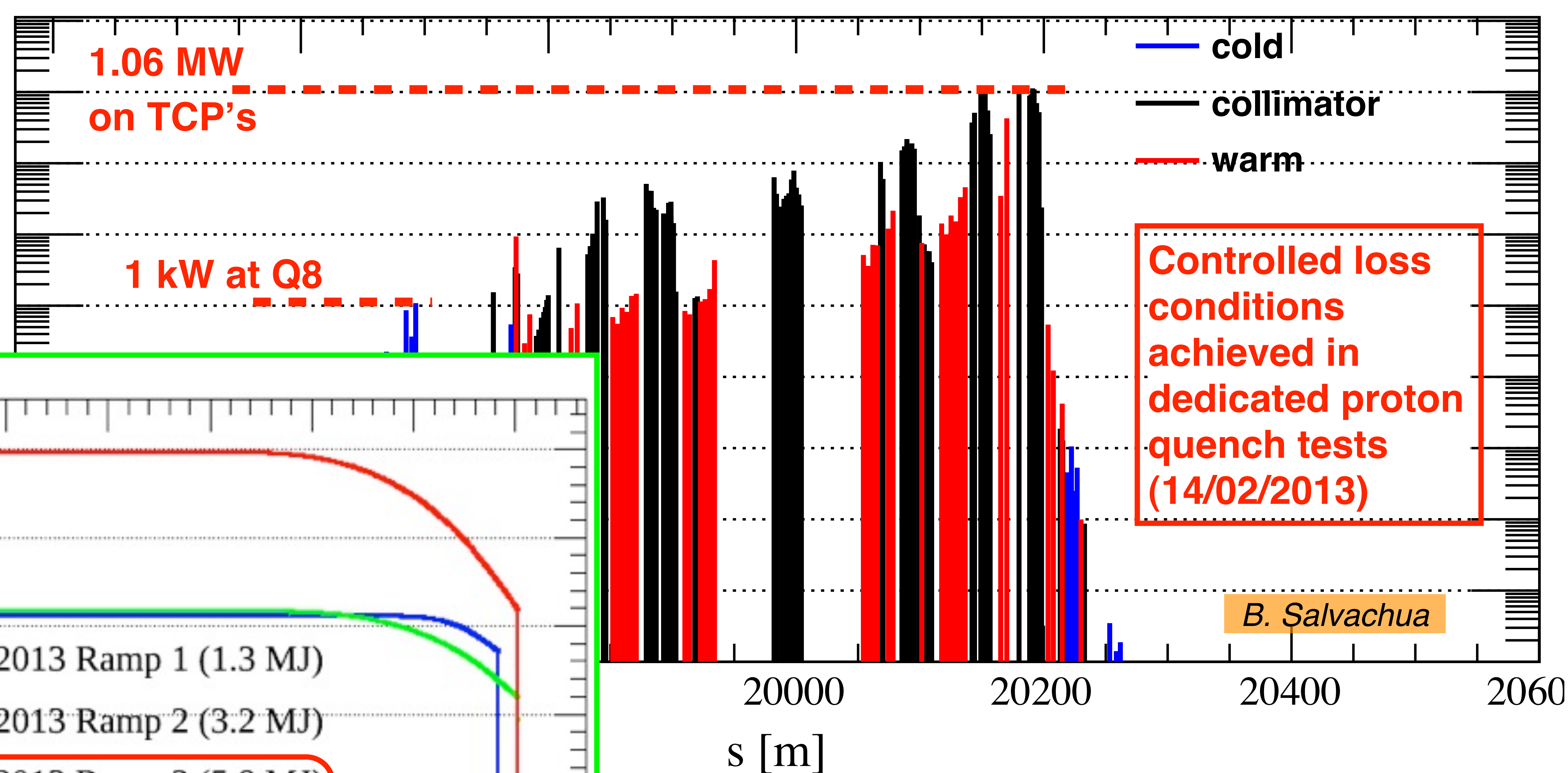

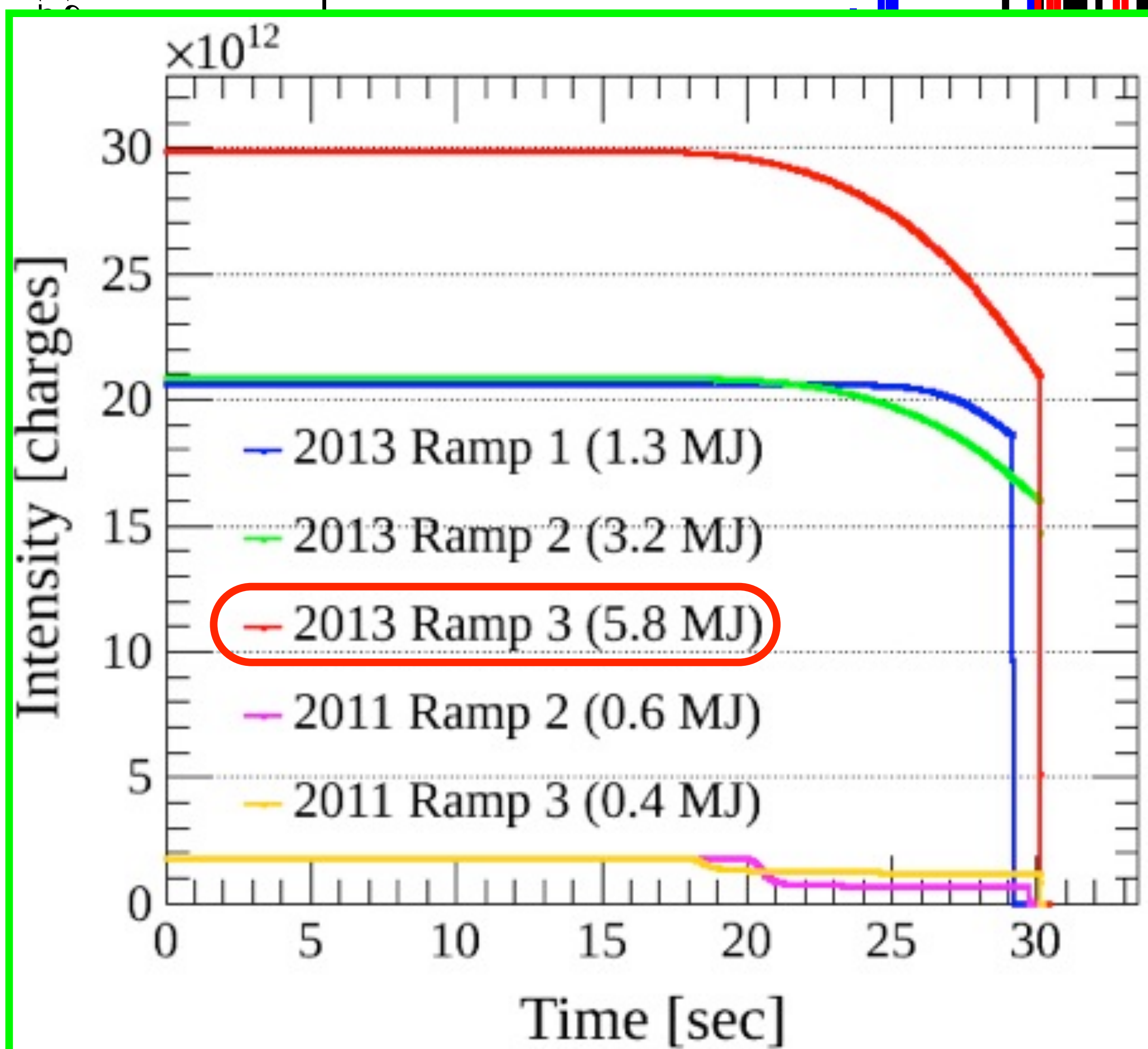

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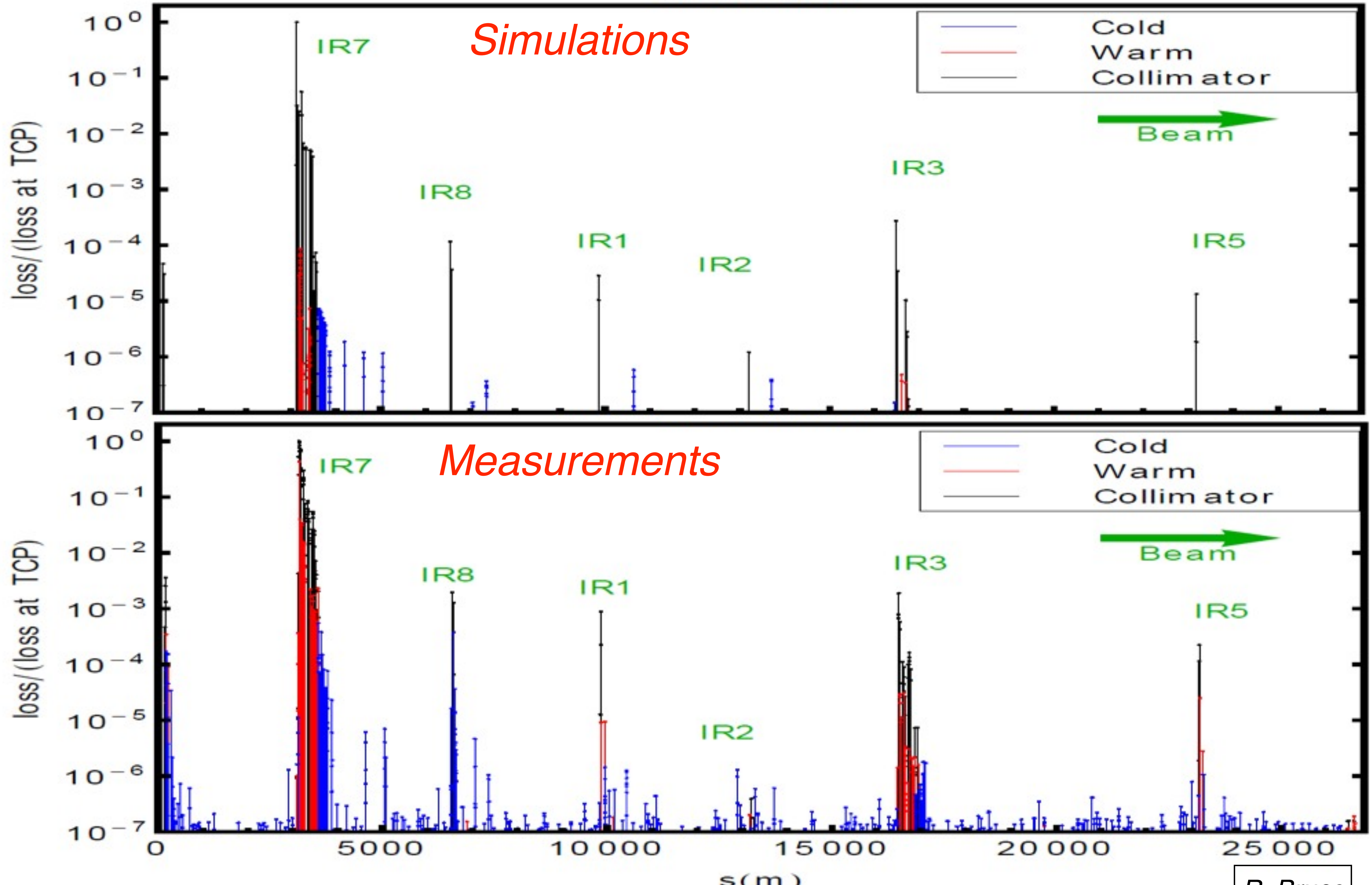
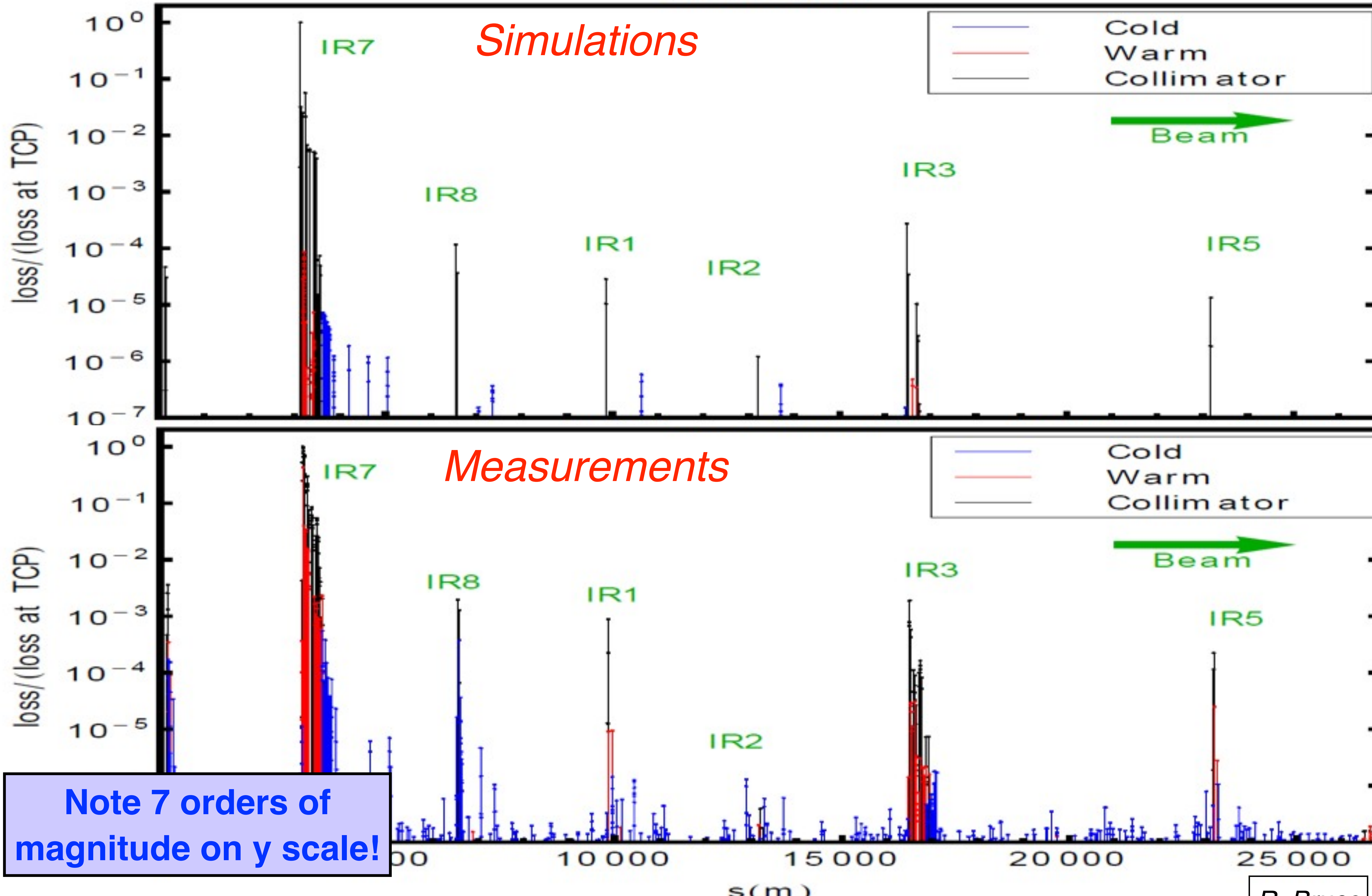


R. Bruce

Understanding of LHC beam losses



Note 7 orders of magnitude on y scale!

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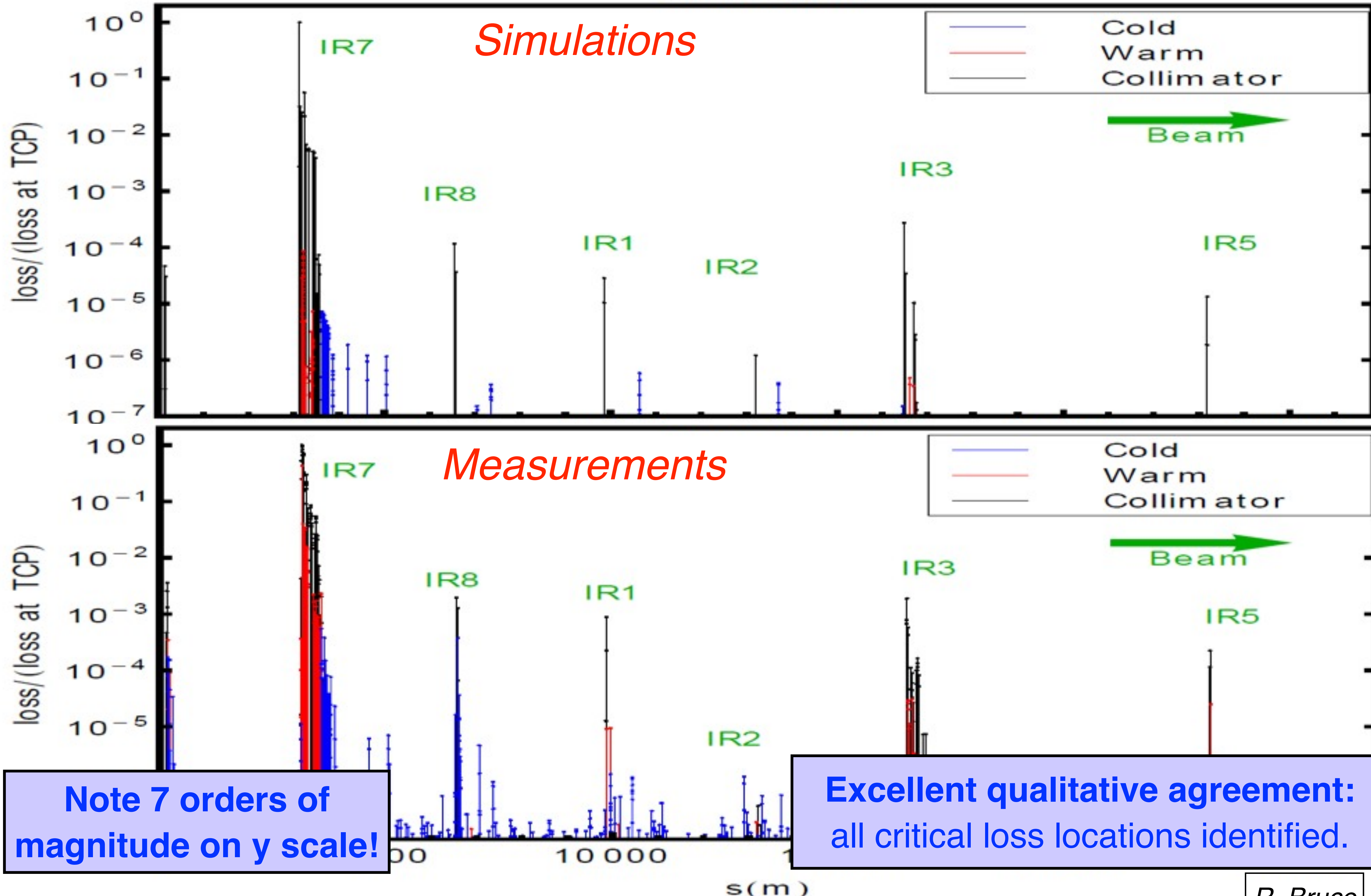

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Excellent qualitative agreement: all critical loss locations identified.

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  Same limitations apply for IR1 and IR5 that have less priority for ion runs.
- No additional limitations in IR1/5 until LS3 from physics debris thanks to the use of 3 TCL collimators.
  Expect the same result for HiLumi, but need to prove this with final IR layouts.
  Backup slide in case more details are needed. See also talk by L.Esposito.

LS1 collimation activities

- **16 Tungsten TCTs** in all IRs and the **2 Carbon TCSGs in IR6** will be replaced by new collimators with **integrated BPMs**.

  Gain: can align the collimator jaw without “touching” the beam ➙ no dedicated low-intensity fills.

  ➙ *Drastically reduced setup time => more flexibility in IR configurations*

  ➙ *Reduced orbit margins in cleaning hierarchy => more room to squeeze β*: ≥ ~**30 cm (R. Bruce)***

  ➙ *Improved monitoring of local orbit and interlocking strategy*

- Updated **TCL layouts in IR1/5** for physics debris absorption

  ➙ *Add 1-2 TCL collimator per beam. Expected to be compatible with HL proton luminosity.*

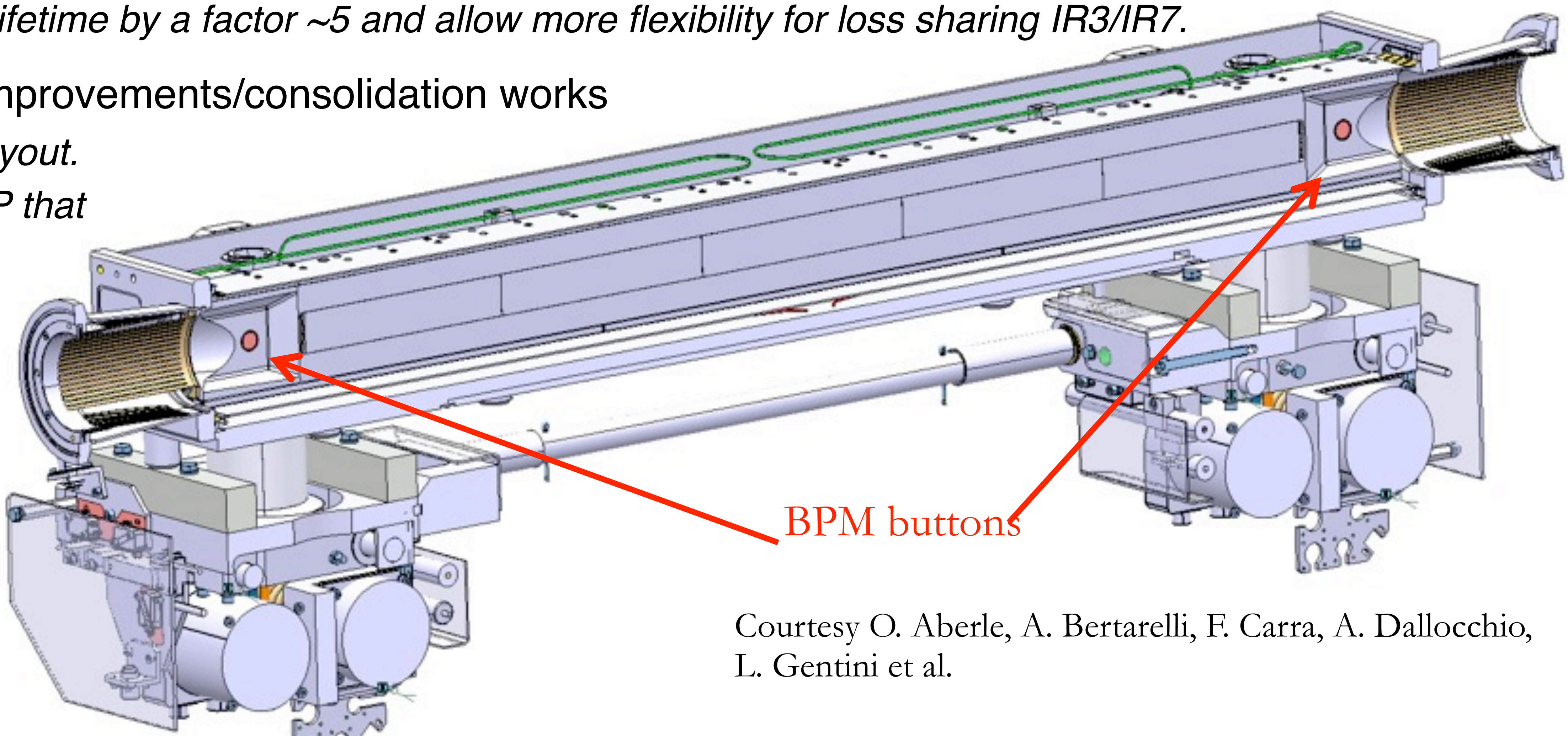
- Improve protection of warm MQW magnets in IR3 by adding **passive absorbers**

  ➙ *Improve lifetime by a factor ~5 and allow more flexibility for loss sharing IR3/IR7.*

- Other smaller improvements/consolidation works

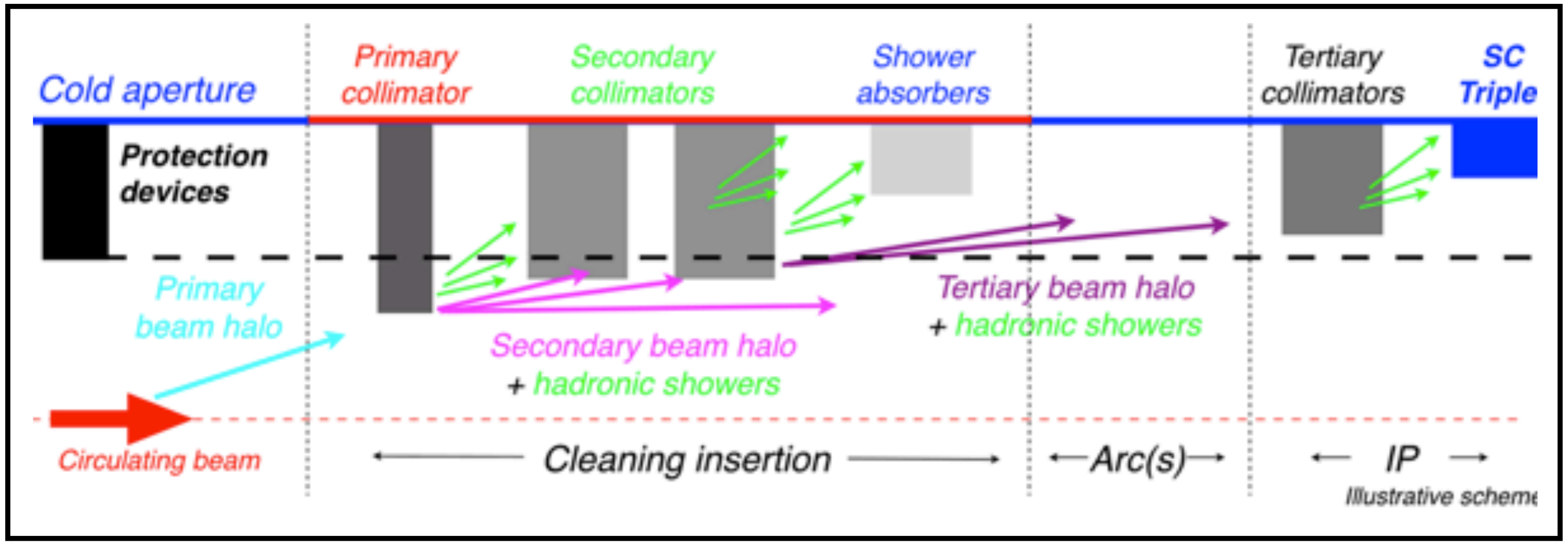
  ➙ *IR8 vacuum layout.*

  ➙ *Replace a TCP that was heating.*



Courtesy O. Aberle, A. Bertarelli, F. Carra, A. Dallocchio, L. Gentini et al.

Collimator hierarchy and β^* reach

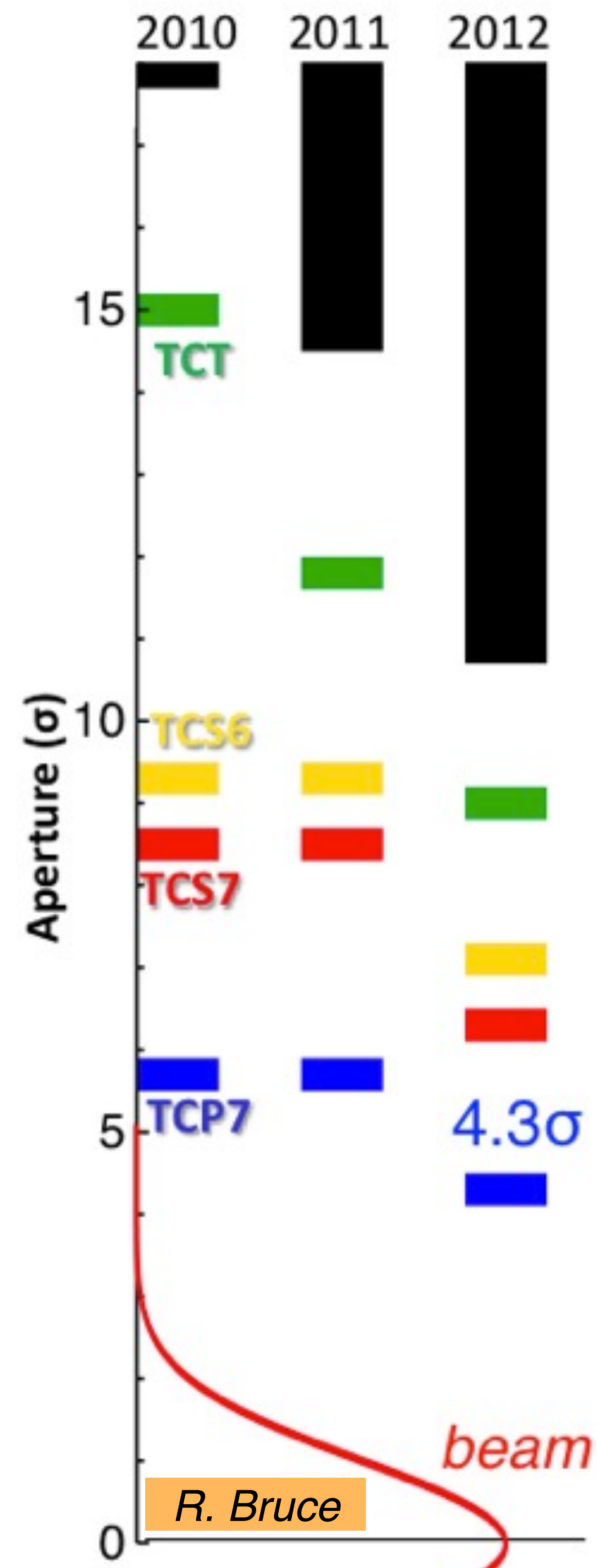


- Closing down the collimators reduces the (normalized) triplet aperture that we can protect ➙ can fit a smaller β^*:

$$\beta^* \propto \frac{1}{N_{\mathrm{mqx}}\sigma_{\mathrm{mqx}}}$$

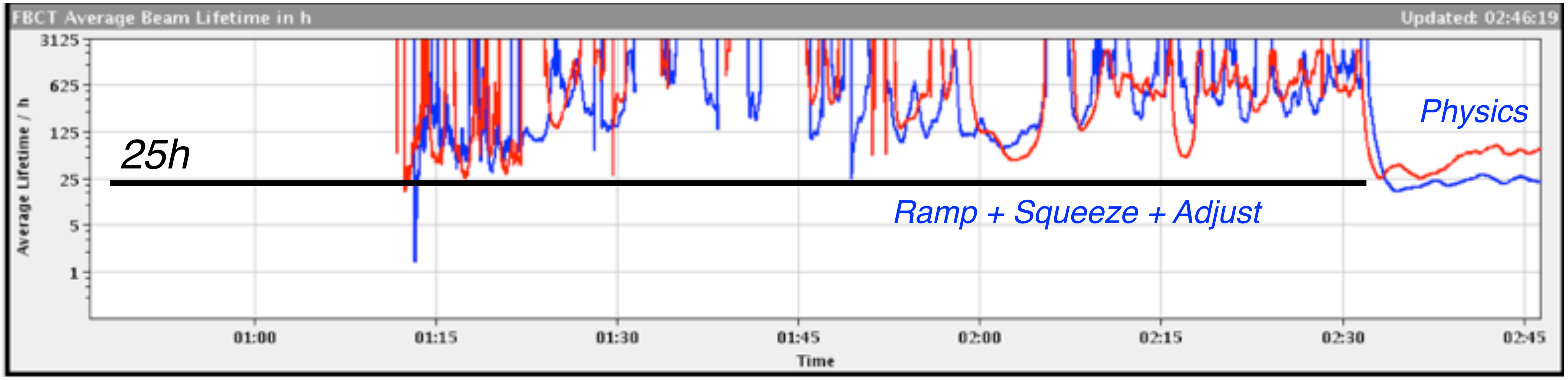
$$N_{\mathrm{mqx}} > N_{\mathrm{tct}} > N_{\mathrm{tcdq}} > N_{\mathrm{tcsg}} > N_{\mathrm{tcp}}$$

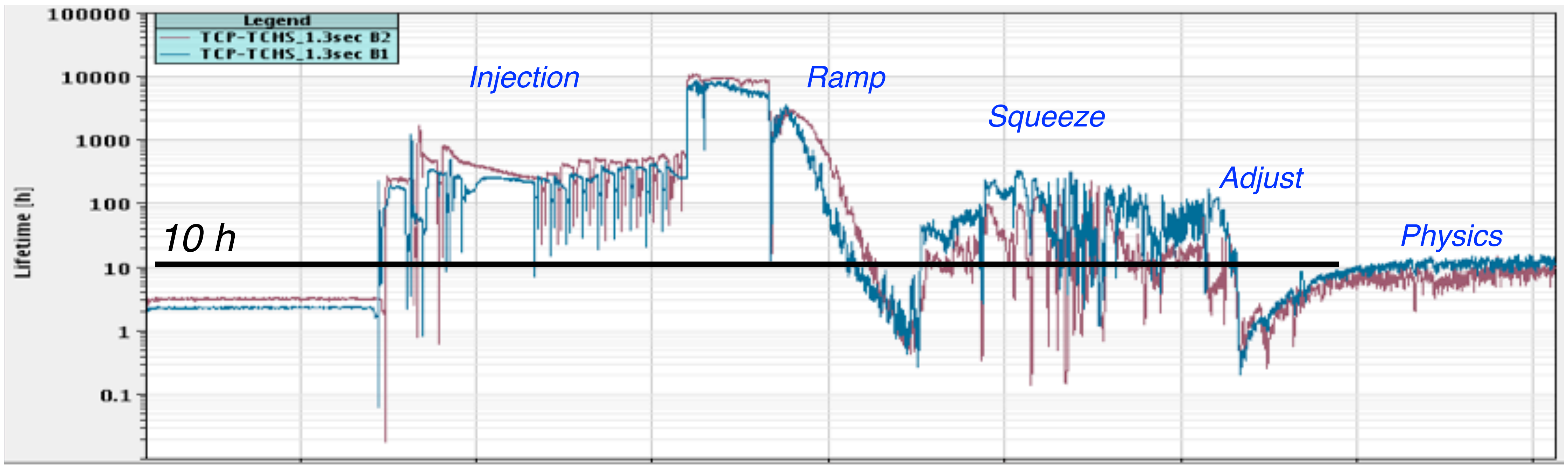
- Setting hierarchy was tightened after gaining **operational experience** and confidence in the machine (optics/orbit stability, beam lifetime, cleaning requirements, ...)
- Started with "relaxed" settings (easier commissioning, less challenging tolerance set), then achieved at 4 TeV gaps in mm equivalent to the design 7TeV goal ➙ ***β** = 60 cm!**
- **Improve cleaning** performance but **reduce lifetime**!



Lifetime during OP cycle

Couple of illustrative examples taken randomly from the LHC elogbook...





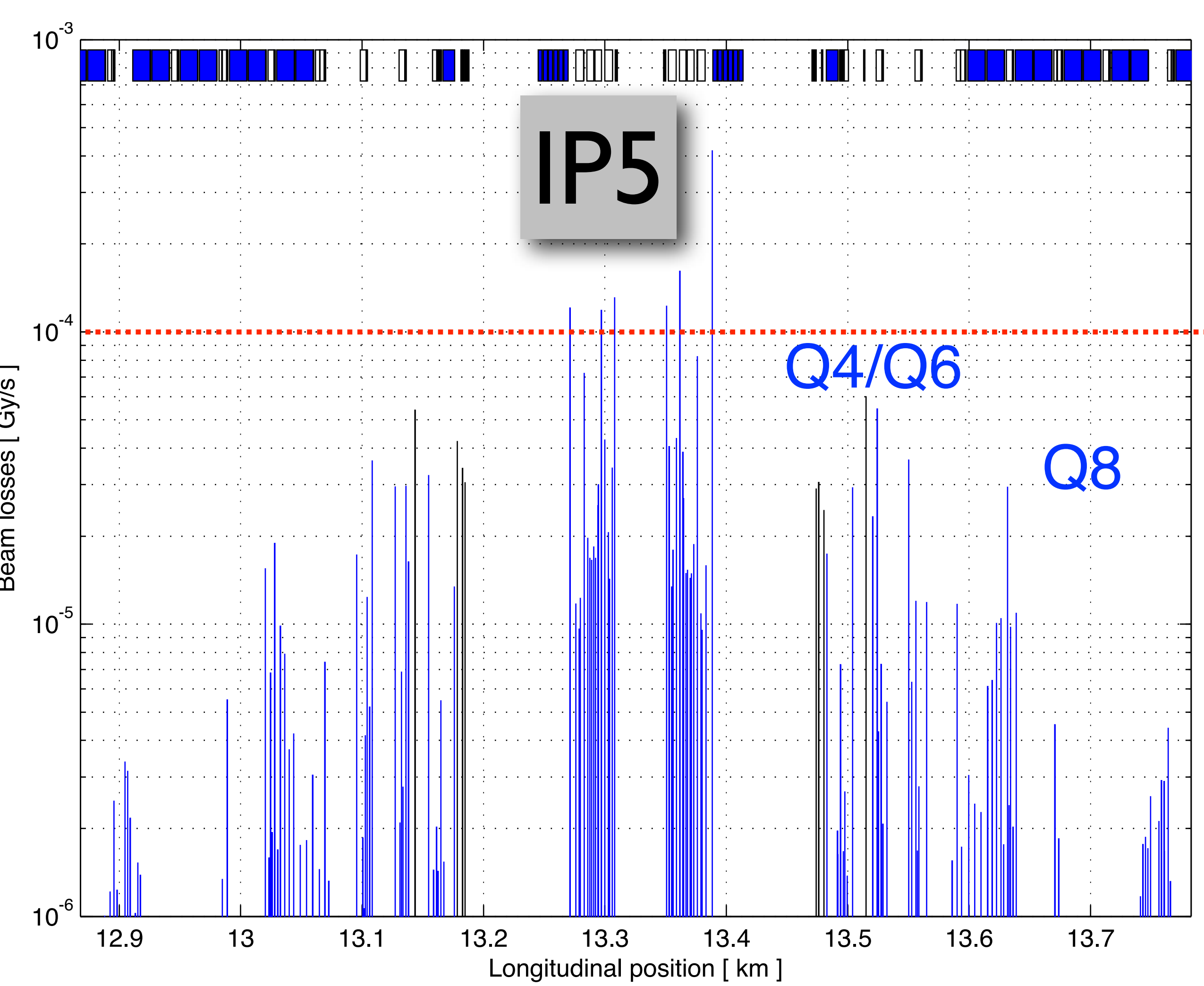
Will this be a serious issue after LS1?
Detailed analysis of quench tests will provide improved estimates.
Needs of possible scraping methods (hollow e-lens or similar) are being studied.
Can always open the collimators, at the **cost of larger β^***.

Losses from luminosity debris

- In 2012, we have started using the TCL collimators in IP1 and IP5 that catch **physics debris**.
- Set to 10σ since the start of the run.
- We have performed TCLs scans to understand the impact on reducing the losses and the load to the magnets. At 10σ measured losses at Q8 reduced by a factor of 50!

Significant improvement of SEU's in IR1 and IR5

Proton operation in 2011



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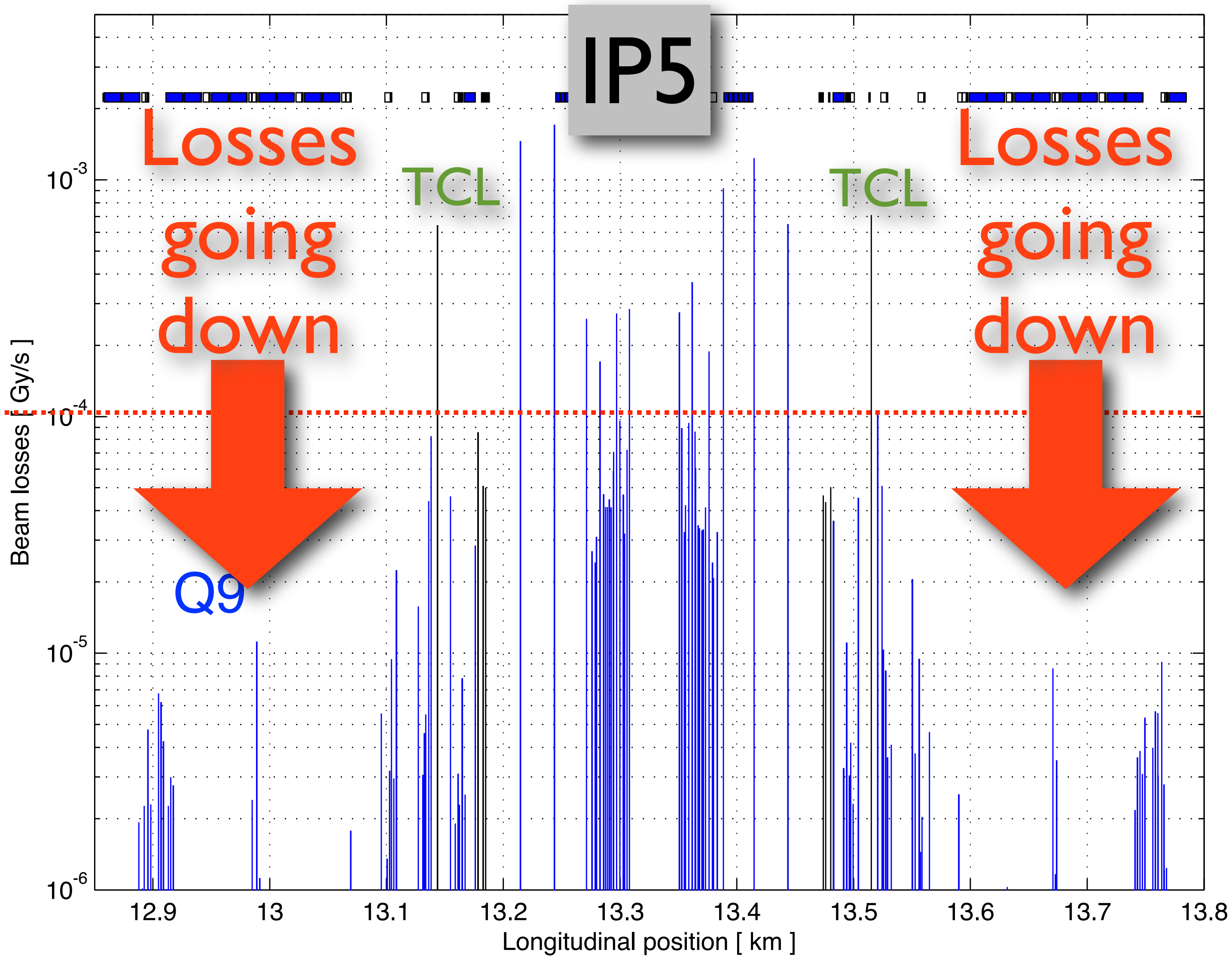
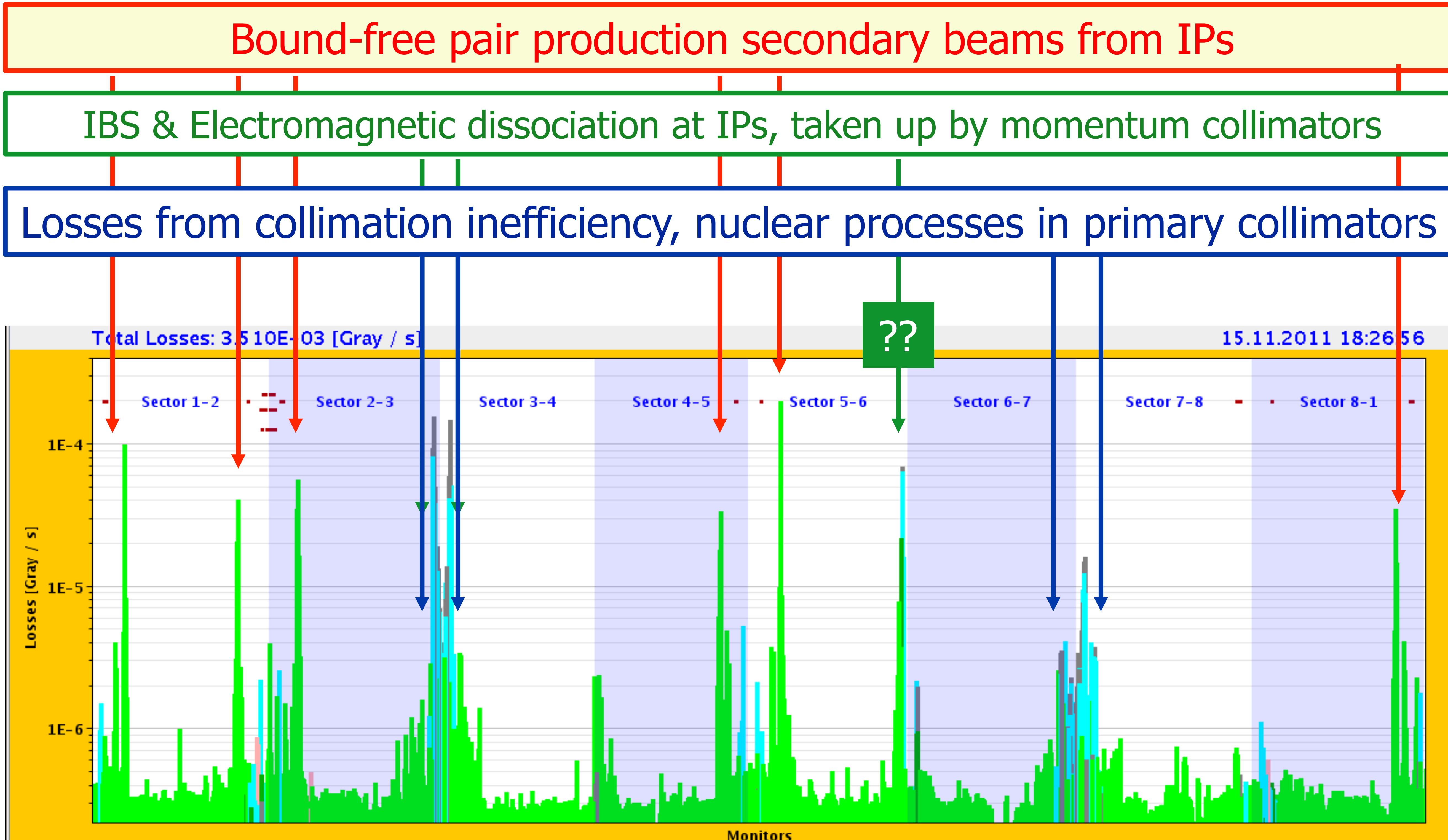
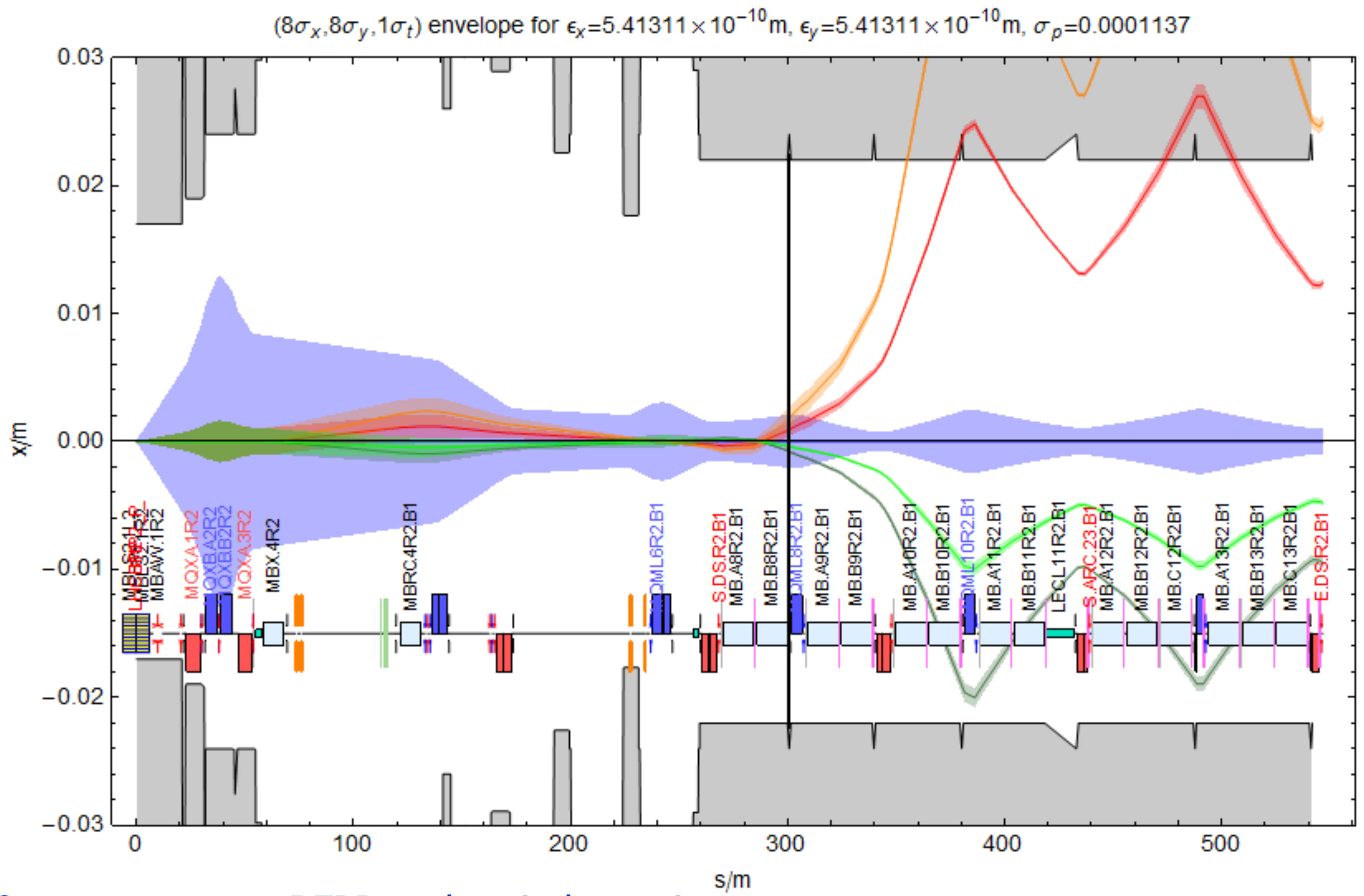


3.5 TeV losses with Pb-Pb collisions



J. Jowett

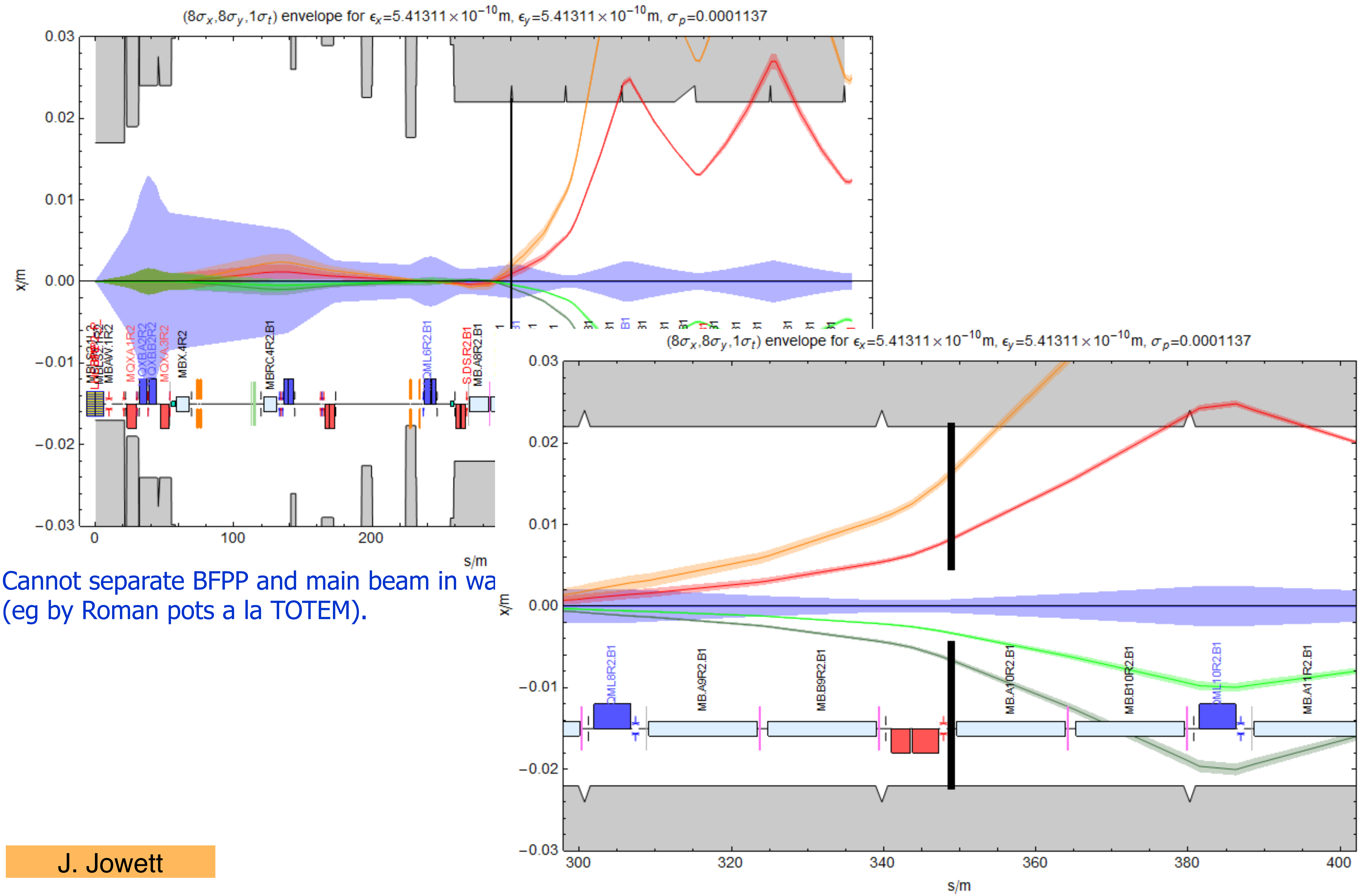
Secondary beam at the IR2 DS



Cannot separate BFPP and main beam in warm area
(eg by Roman pots a la TOTEM).

J. Jowett

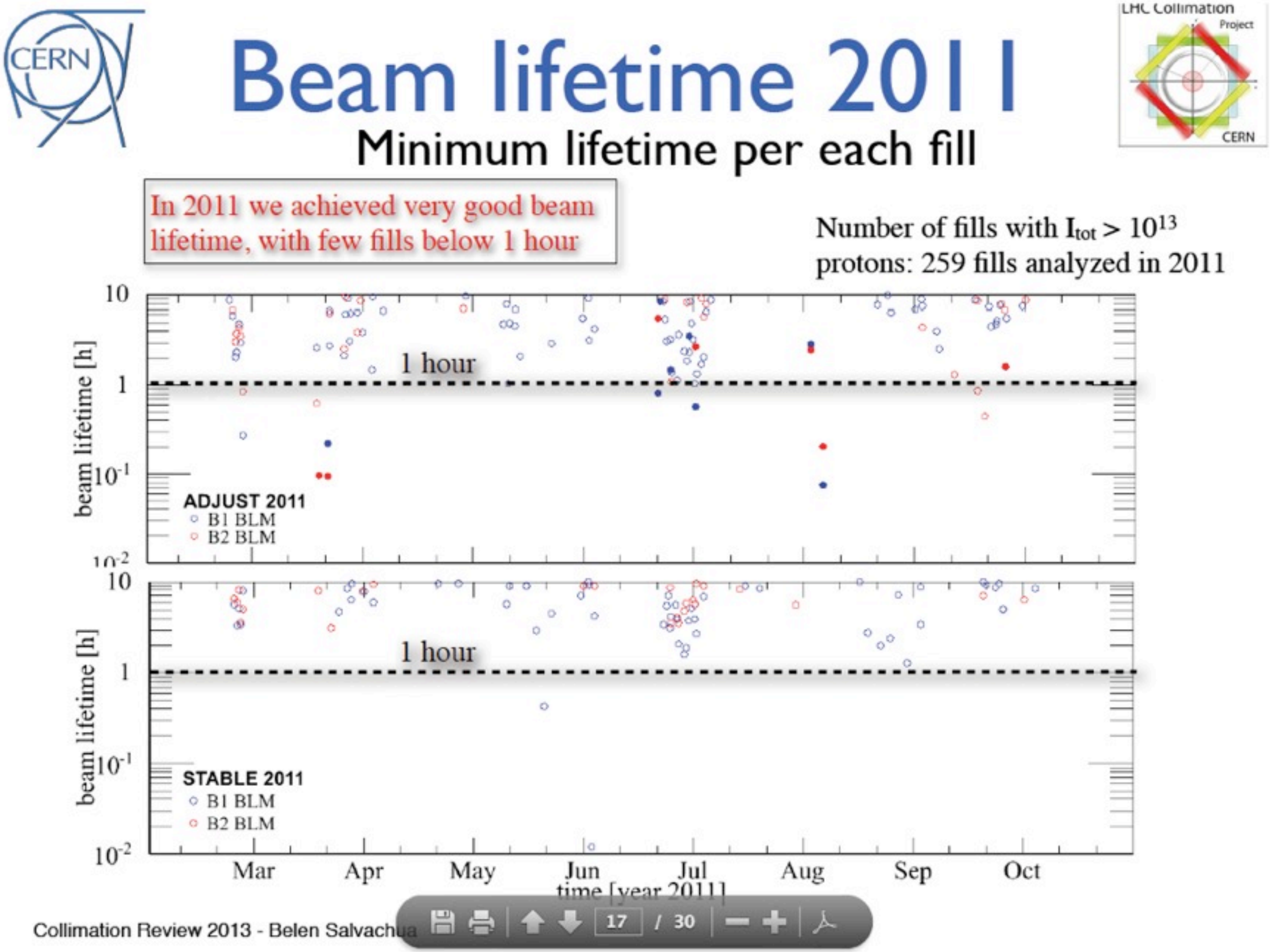
Secondary beam at the IR2 DS



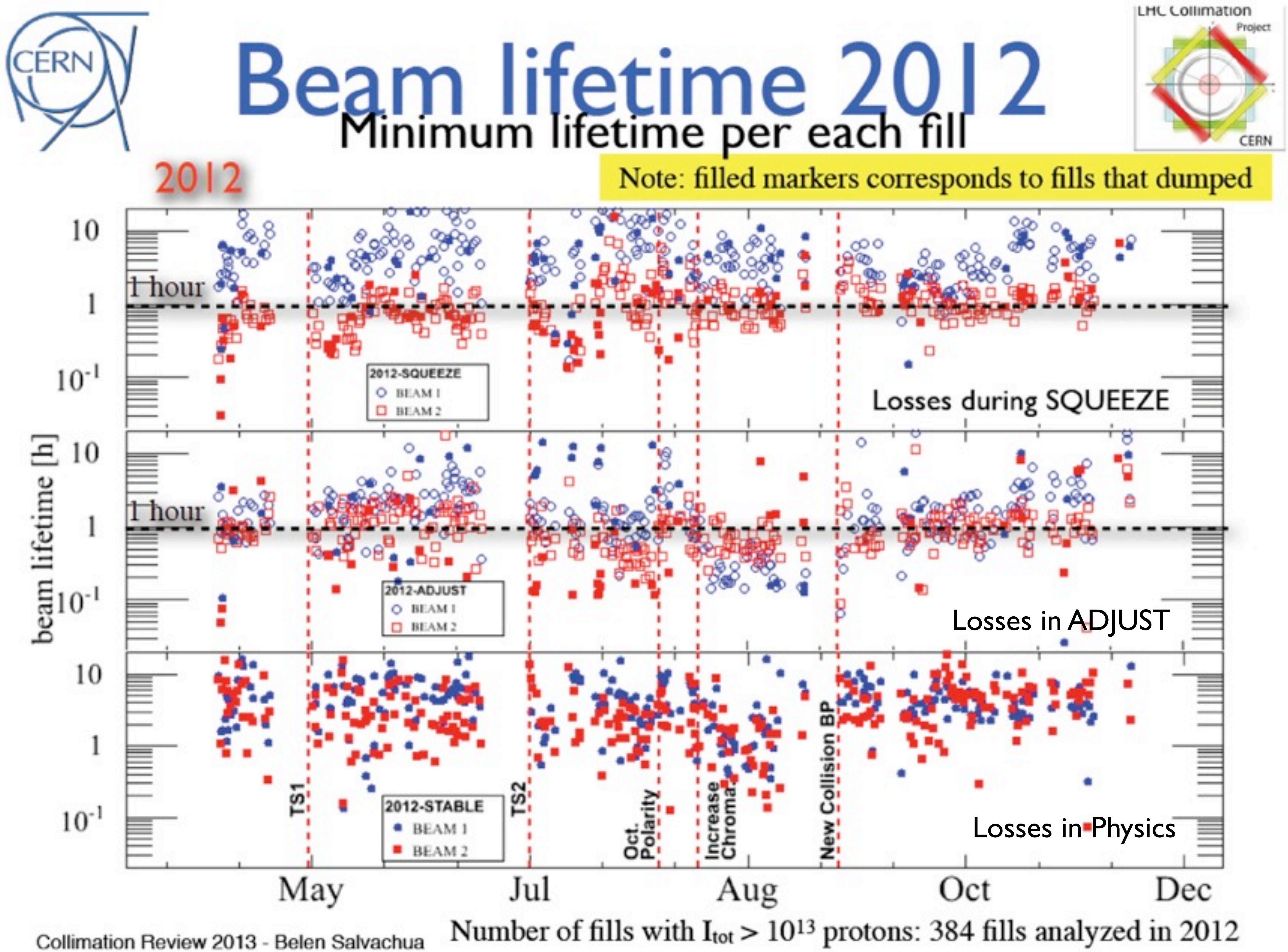
Cannot separate BFPP and main beam in wa
(eg by Roman pots a la TOTEM).

J. Jowett

Lifetime analysis (ii)



Lifetime analysis (i)



Minimum beam lifetime in 2012

Beam intensity versus time

$$I(t) = I_0 \cdot e^{-\frac{t}{\tau_b}}$$

Beam lifetime gives the loss rate on collimators. Cleaning η gives the peak losses in magnets.
Collimator design: 500 KW!

Minimum (assumed) beam lifetime

Quench limit of SC magnets

$$N_{\mathrm{tot}} = \frac{\tau_b R_q}{\tilde{\eta}_c}$$

Collimation cleaning at limiting cold location

Minimum beam lifetime in 2012

Beam intensity versus time

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Beam lifetime gives the loss rate on collimators. Cleaning η gives the peak losses in magnets.
Collimator design: 500 KW!

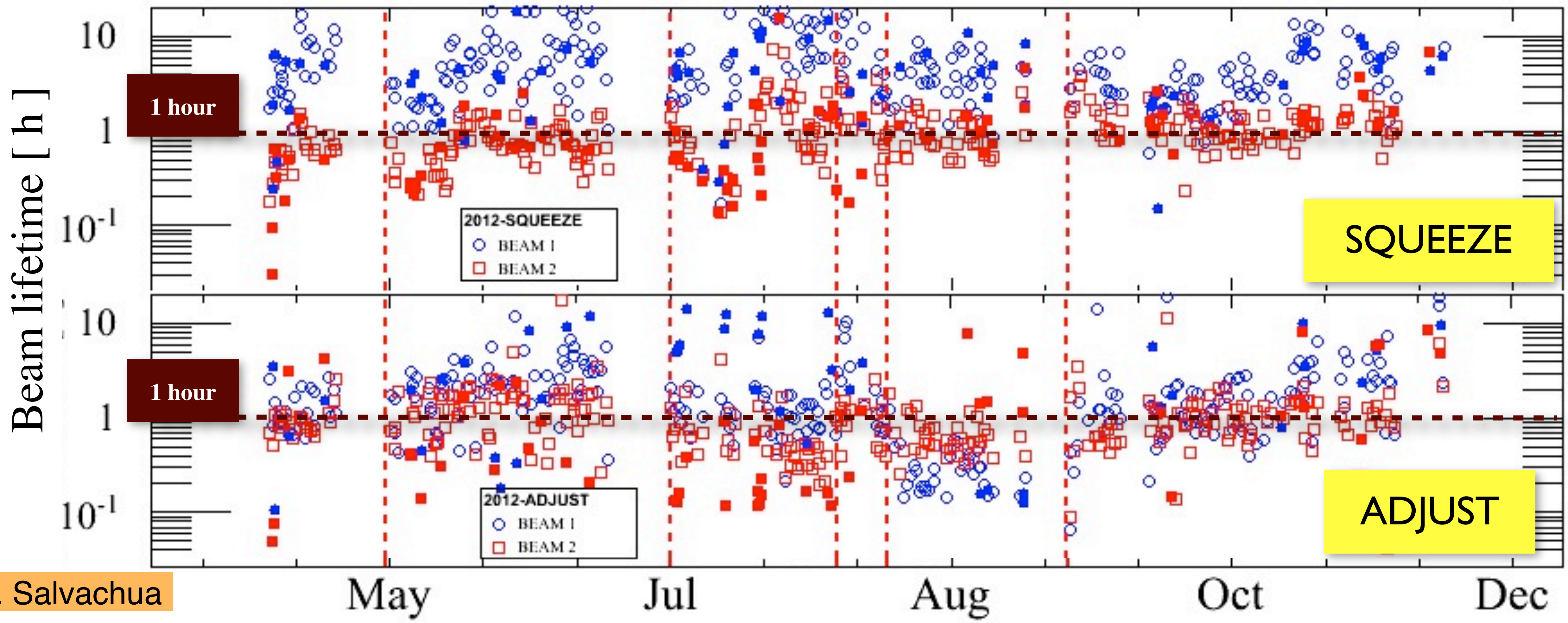
Minimum (assumed) beam lifetime

Quench limit of SC magnets

$$N_{\rm tot} = \frac{\tau_b R_q}{\tilde{\eta}_c}$$

Collimation cleaning at limiting cold location

2012: Minimum lifetime with gaps equiv. to 7 TeV: 0.2 - 1 hour



B. Salvachua

See talk by E. Métral: to what extend this depends on collimators?