2nd Joint HiLumi LHC-LARP Annual Meeting
INFN, Laboratori Nazionali di Frascati
Frascati, Italy, November 14th-16th, 2012

LHC Collimation Status and Plans

Stefano Redaelli, CERN, BE-ABP
on behalf of the LHC Collimation Project and HiLumi WP5

CERN

SEVENTH FRAMEWORK PROGRAMME

High Luminosity LHC

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.

LHC Collimation Project CERN

Outline

- Introduction
- LHC collimation status
- Collimation after LS1
- HiLumi-WP5 activities
- Conclusions

Introduction

Crucial role of collimation for the future LHC performance:

- *Cleaning performance might determine the maximum beam intensity;*
- *Collimators define the machine impedance at high energy;*
- *The collimation hierarchy determines that β^* reach;*
- *Collimator setup has an impact on the operational efficiency;*
- *Role in the radiation optimization and machine protection.*

The re-design of the collimation system has therefore been integral part of the design study for HL-LHC since the early phase.

Different studies and ongoing programs:

- CERN LHC Collimation project:
  Overall responsibility of LHC collimation, including operation, performance monitoring and optimization, remote handling, improvements of present system, ...
- FP7 HiLumi WP5:
  Design of collimation in the interaction regions, upgrade for cleaning.
- FP7 EuCARD/EuCARD2:
  New materials and new collimator design concepts.
- Strong and long-standing external collaborations:
  US-LARP, HIEP, Kurchatov, Fermilab (energy deposition),...

Goals of collimation upgrades

Collimation upgrade studies comprise different aspects:

- Improve the **cleaning performance** in cold regions
  - *- Highest losses: dispersion suppressors of IR3/7 and experimental IR1/2/5*
- Improve the **impedance** and **robustness**
  - *- State-of-the-art new material and new designs for secondary collimator jaws*
  - *- Compatibility with failure cases and improved robustness at critical locations (TCTs)*
- Enhance the **operational efficiency** / machine protection aspects
  - *- **Improve the beta* reach** and and flexibility of IR configuration*
  - *- Faster and more accurate collimator alignment*
- Improve the **collimator layouts** in the experimental regions
  - *- Better cleaning of incoming beam and outgoing physics products*
- Optimize location and distributions of losses
  - *- Improve lifetime of warm magnets*
  - *- Confine losses in dedicated regions, optimize doses to equipment/personnel*
- Be ready to replace **collimators** if they break or age
  - *- The hardware is designed for 10 y lifetime*
- Achieve **remote handling** in high ra
  - *- Quick collimator replacement in hottest*
- New injection / dump collimation →

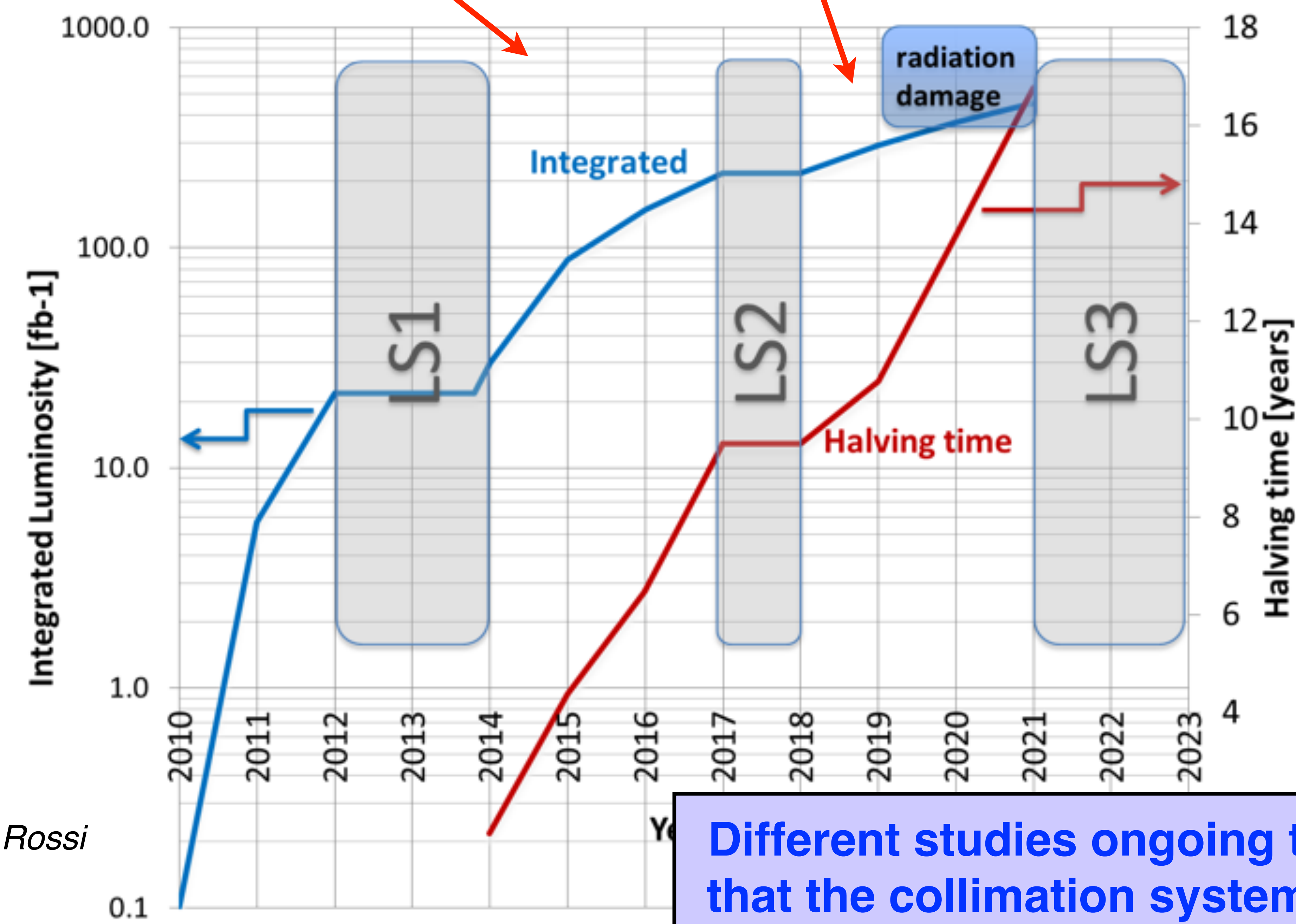
First step: understand the possible limitations of LHC performance from the collimation.

HL-LHC timeline

~ Nominal energy and Luminosity

Double the LHC luminosity

~ 3000 fb^{-1}!



L. Rossi

Different studies ongoing to ensure that the collimation system is ready for the different HL phases!

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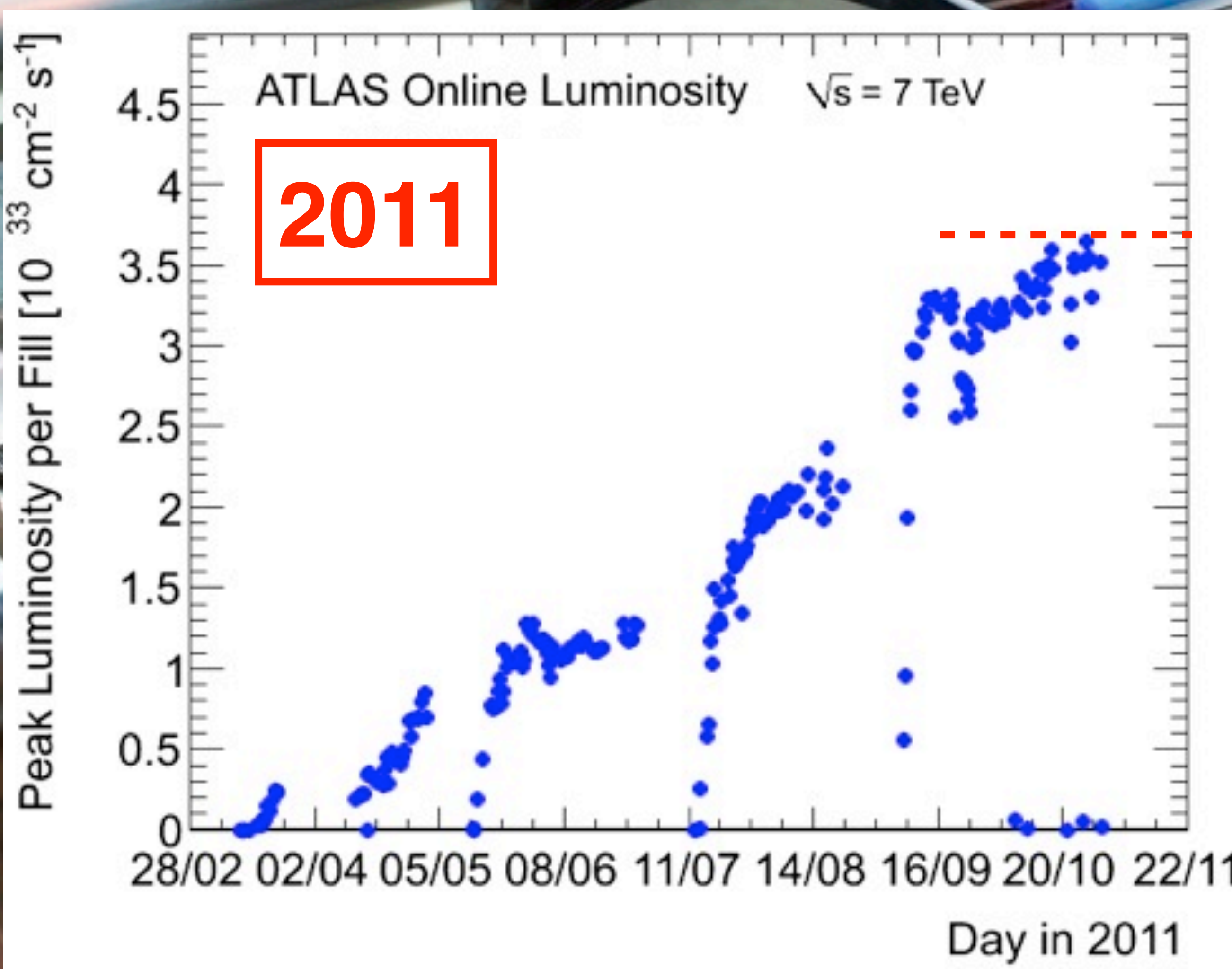
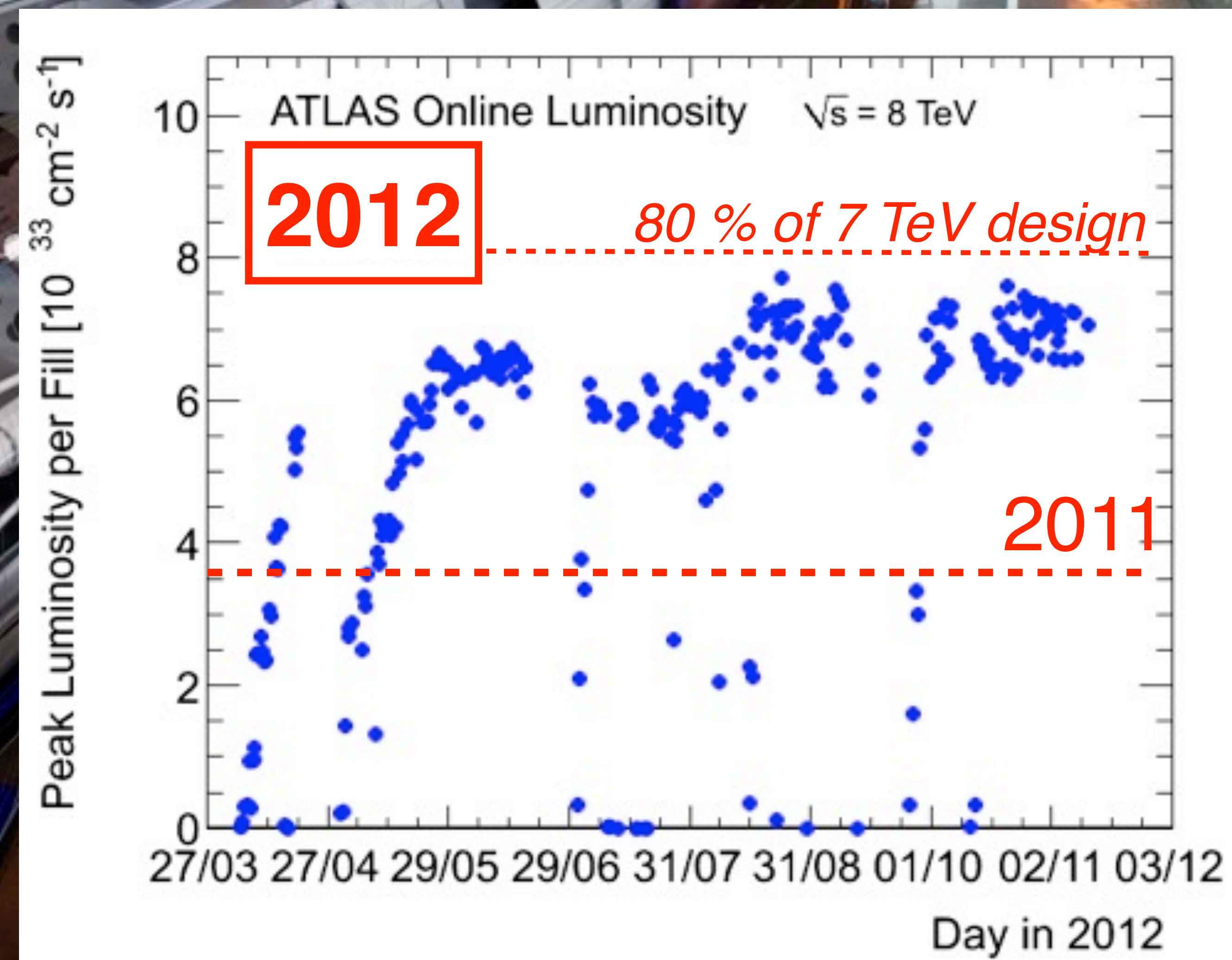
LHC performance

2011 : 3.5 TeV, $\beta^* = 1.0$ m, ~110 MJ (1380 bunches at 50 ns)

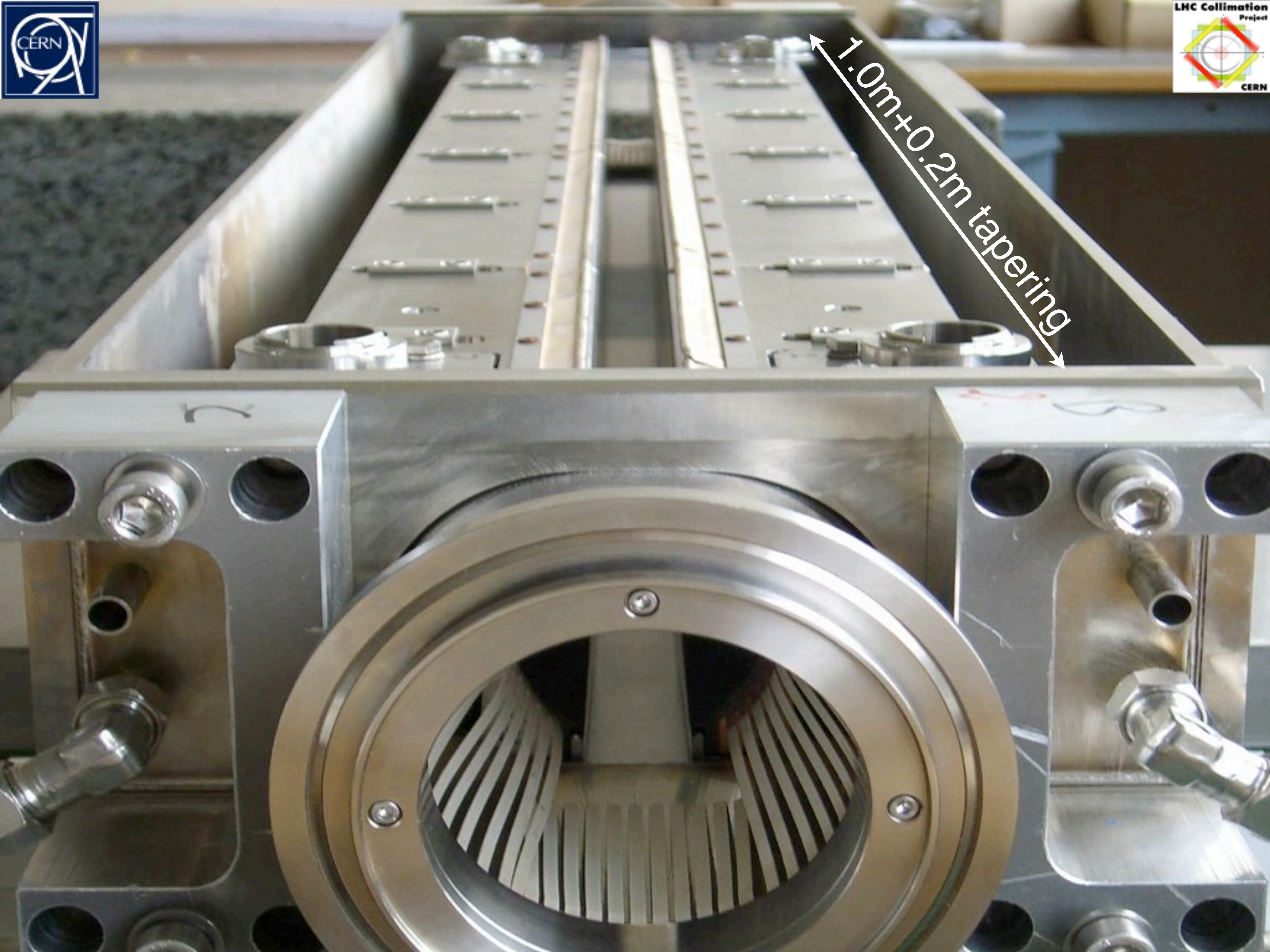
2012 : 4.0 TeV, $\beta^* = 0.6$ m, ~140 MJ (1380 bunches at 50 ns)





No quench with circulating beam, with stored energies up to 70 times of previous state-of-the-art!

The collimator system performance is a crucial ingredient in this achievement!


1.0m+0.2m tapering

Requirements to handle 360 MJ

Main collimation challenges:

- **High stored energy**: Collimators needed in **all phases** *(inj., ramp, squeeze, physics);* Function-driven controls of jaw positions mandatory; **Robustness** and **cleaning efficiency**; Big and **distributed** system (100 collimators).
- **Small gaps**: Mechanical **precision**, **reproducibility** (< 20 microns); Constraints on orbit/optics **reproducibility**; Machine **impedance** and beam instabilities.
- **Collimator hierarchy**: Collimators determine the LHC ***β^** reach**.
- **Machine protection**: Redundant **interlocks** of collimator jaw positions and gaps.
- **High-radiation environ.**: **Radiation**-hard components (HW + SW); Challenging remote **handling**, design for quick installation.

Parameter		Unit	Specification
Jaw material			CFC
Jaw length	TCS TCP	cm cm	100 60
Jaw tapering		cm	10 + 10
Jaw cross section		mm²	65 × 25
Jaw resistivity		μΩm	≤ 10
Surface roughness		μm	≤ 1.6
Jaw flatness error		**μm**	**≤ 40**

Heat load	kW	≤ 7
Jaw temperature	°C	≤ 50
Bake-out temp.	°C	250
Minimal gap	**mm**	**≤ 0.5**
Maximal gap	mm	≥ 58
Jaw position control	μm	≤ 10
Jaw angle control	μrad	≤ 15
Reproducibility	**μm**	**≤ 20**

R. Assmann et al. (2003)

A "staged" approach was adopted to cope with conflicting requirements.

LHC collimation layout

Two warm cleaning insertions

IR3: Momentum cleaning
- 1 primary (H)
- 4 secondary (H,S)
- 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) per beam

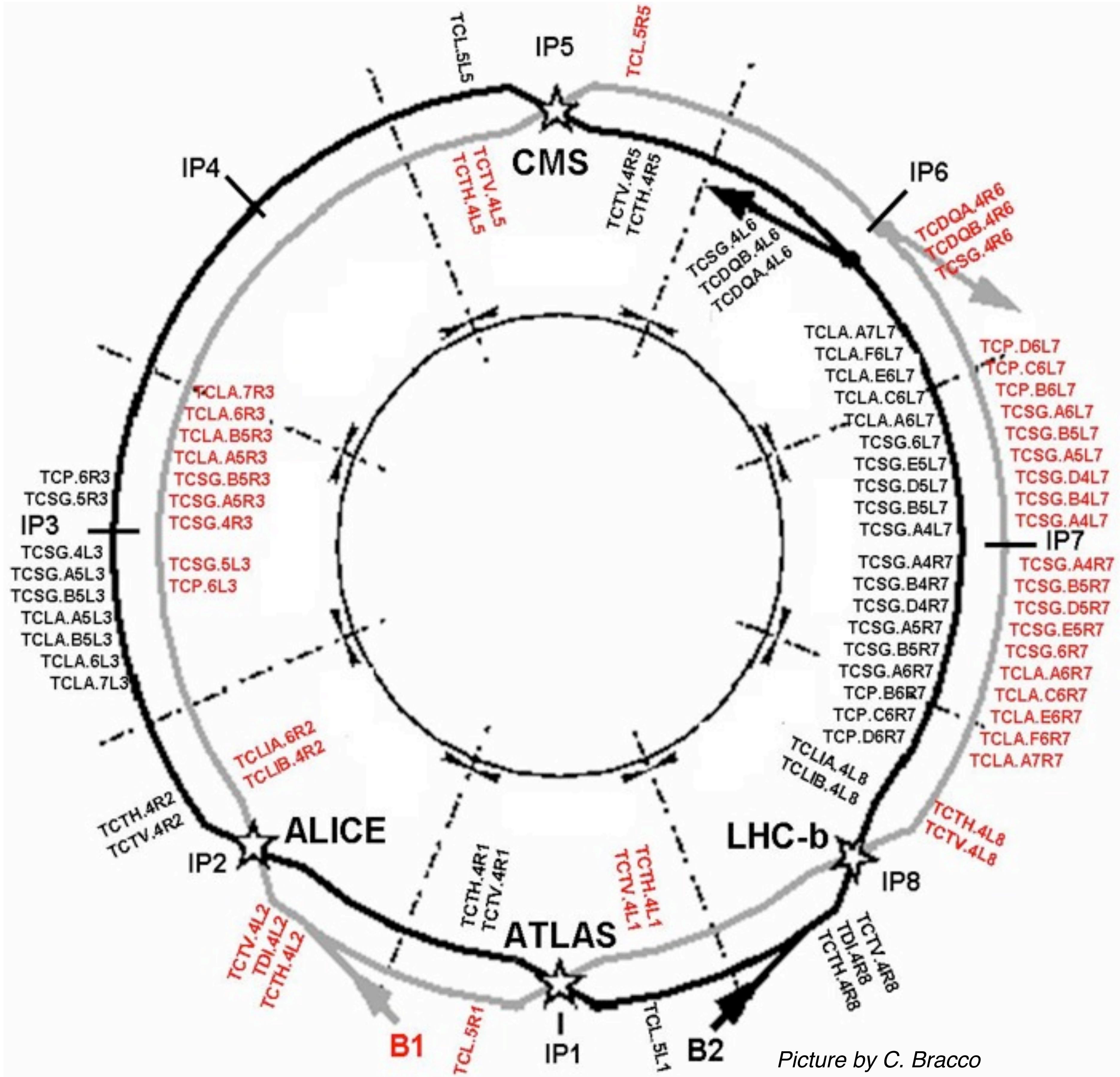
Physics debris absorption

2 TCL (1 per beam in IR1/5)

8 passive absorbers for warm magnets in IR3/7.

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

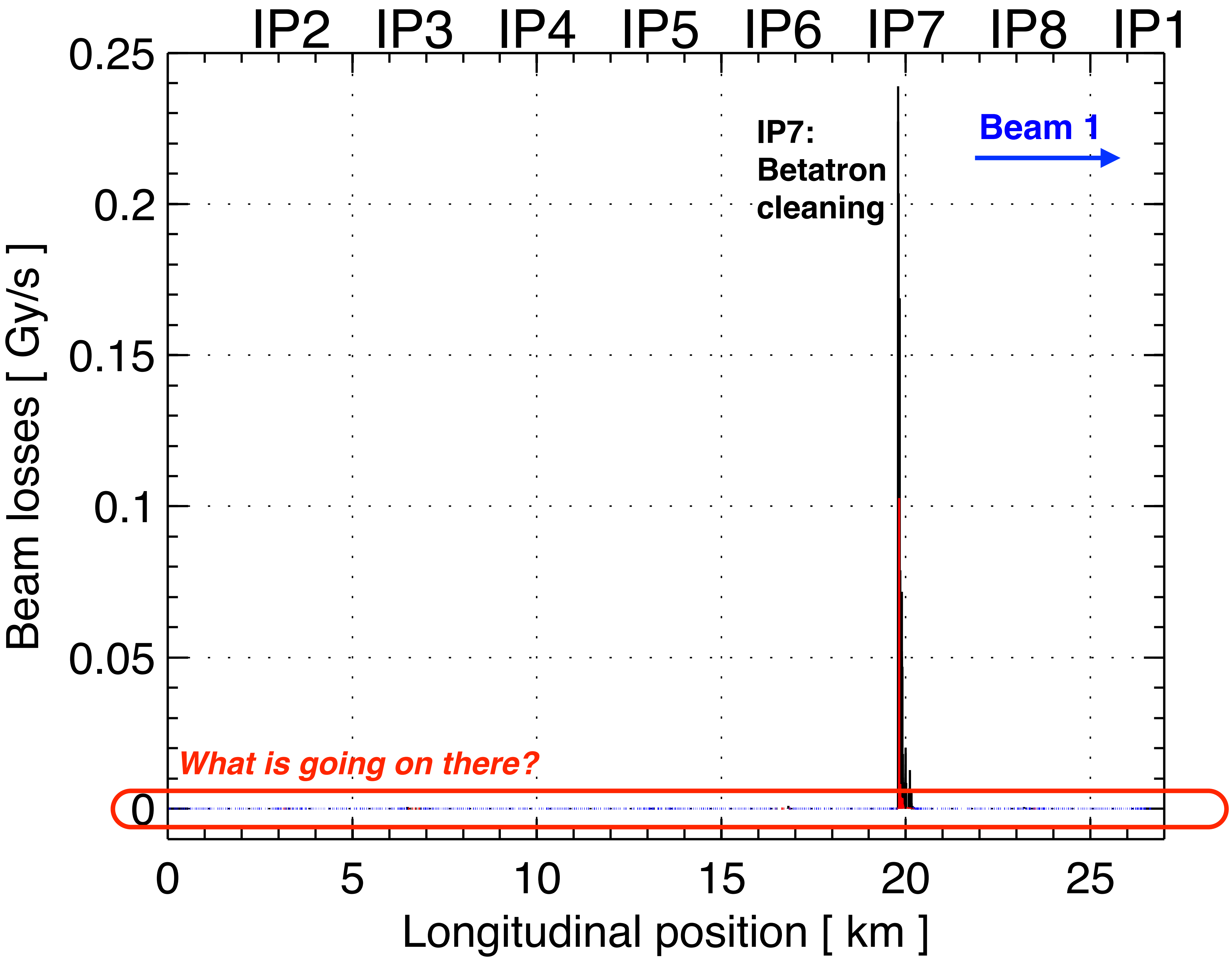
Total of 108 collimators (100 movable).



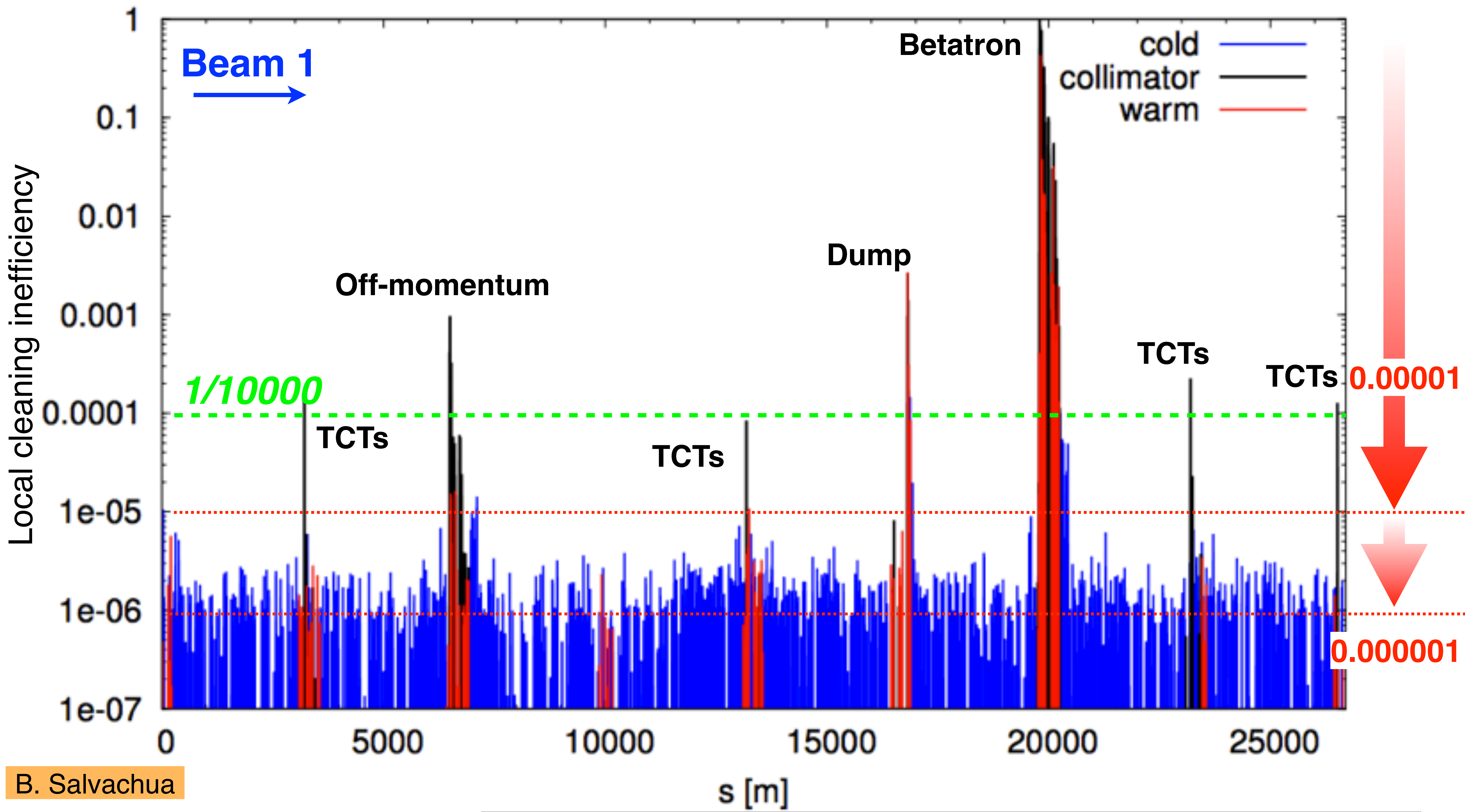
Picture by C. Bracco

Collimation cleaning

3600 beam loss monitors (BLMs) along the 27 km during a loss map



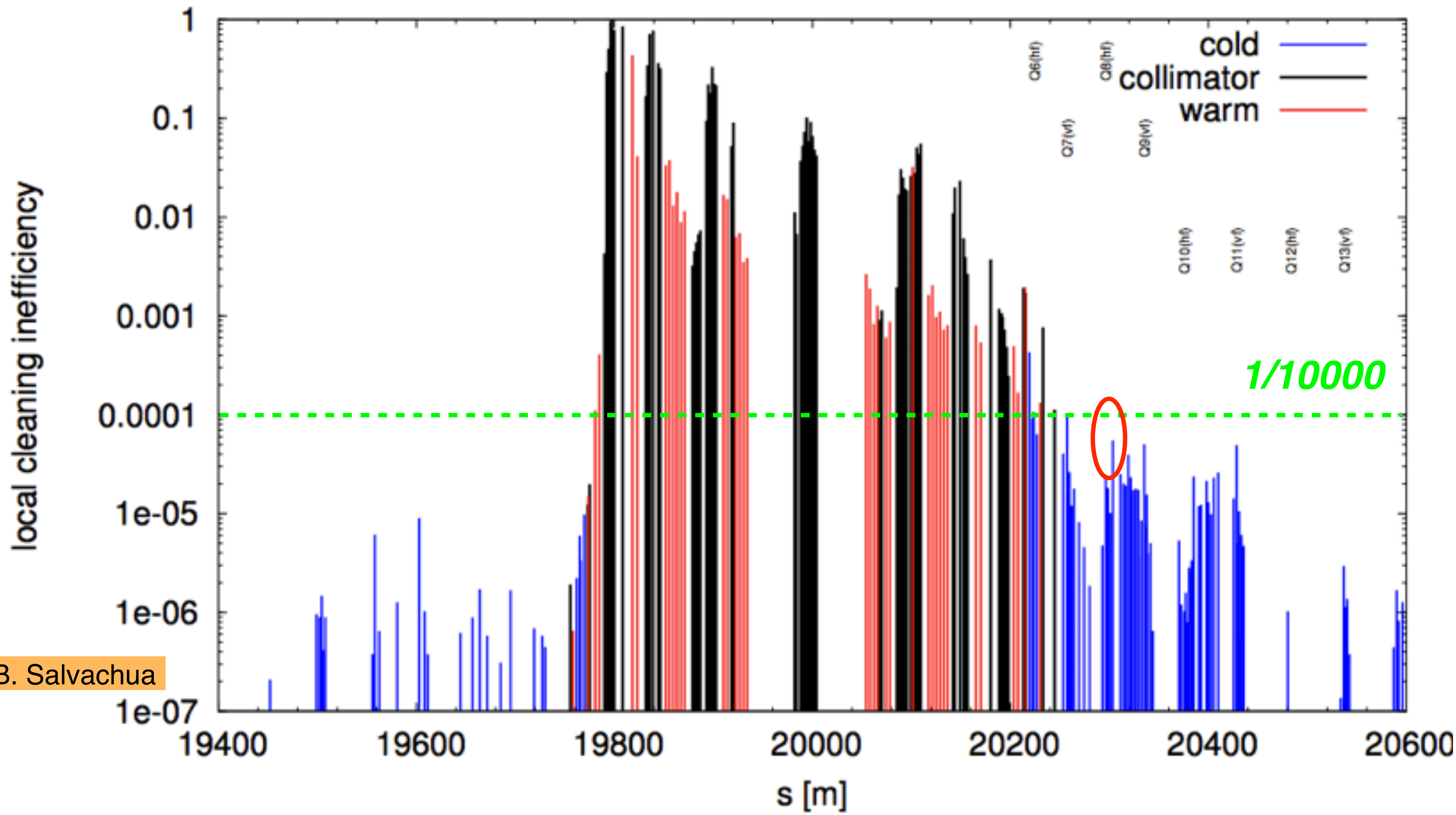
Collimation cleaning: 4.0 TeV, β^*=0.6 m



B. Salvachua

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

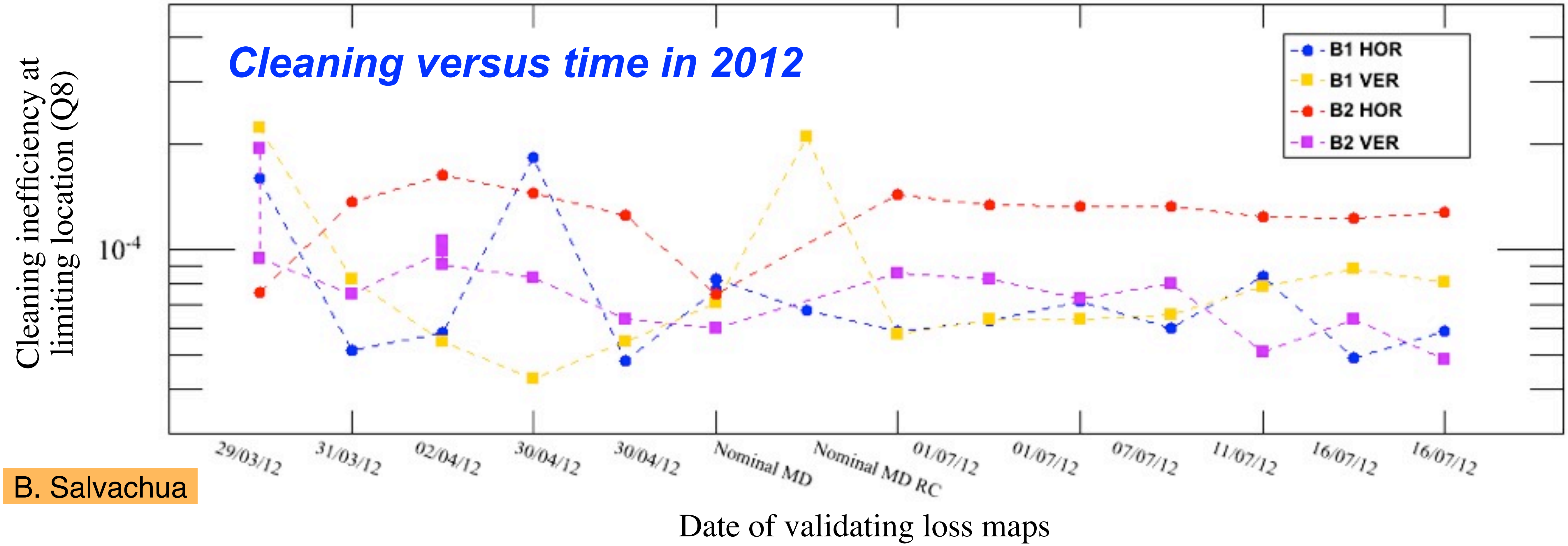
Losses in IR7: 4.0 TeV, β^*=0.6 m



B. Salvachua

<u>Critical location</u> (both beams): losses in the dispersion suppressor (Q8) from <u>single diffractive</u> interactions with the primary collimators.
With squeezed beams: tertiary collimators (TCTs) protect locally the triplets.

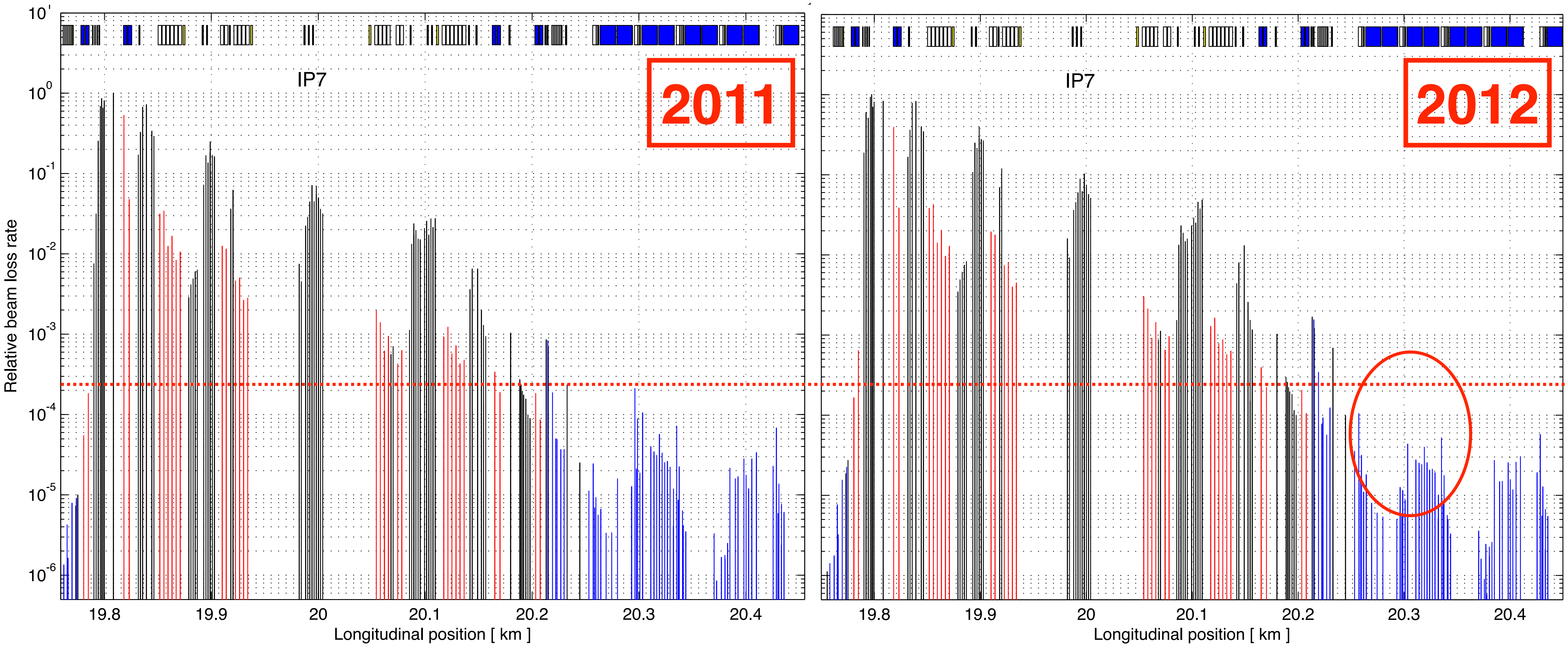
Stability of cleaning performance



B. Salvachua

- **Excellent stability** of cleaning performance observed!
- Achieved with **only 1 alignment per year** in IR3/6/7 (2x30 collimators).
- Operational strategy: **Unfrequent alignments** and **regular validation campaigns** for the collimator cleaning and hierarchy (loss maps)
  Monitoring of standard physics fills + periodic dedicated loss maps
- New alignments are needed for **new physics configurations**
  Changes optics or orbit, Van der Meer scans, spectrometer polarity, ...

Comparison: 2011 vs 2012



The local cleaning in the IR7 DS's was improved by a **factor ~5** compared to 2011, thanks to the deployment of collimator **"tight" settings**.

(TCP settings equivalent to 7 TeV nominal gaps).

Drawbacks: we are now dealing with **larger losses** in standard operation: **tail removal** during ramp and beam instabilities from **larger impedance**!

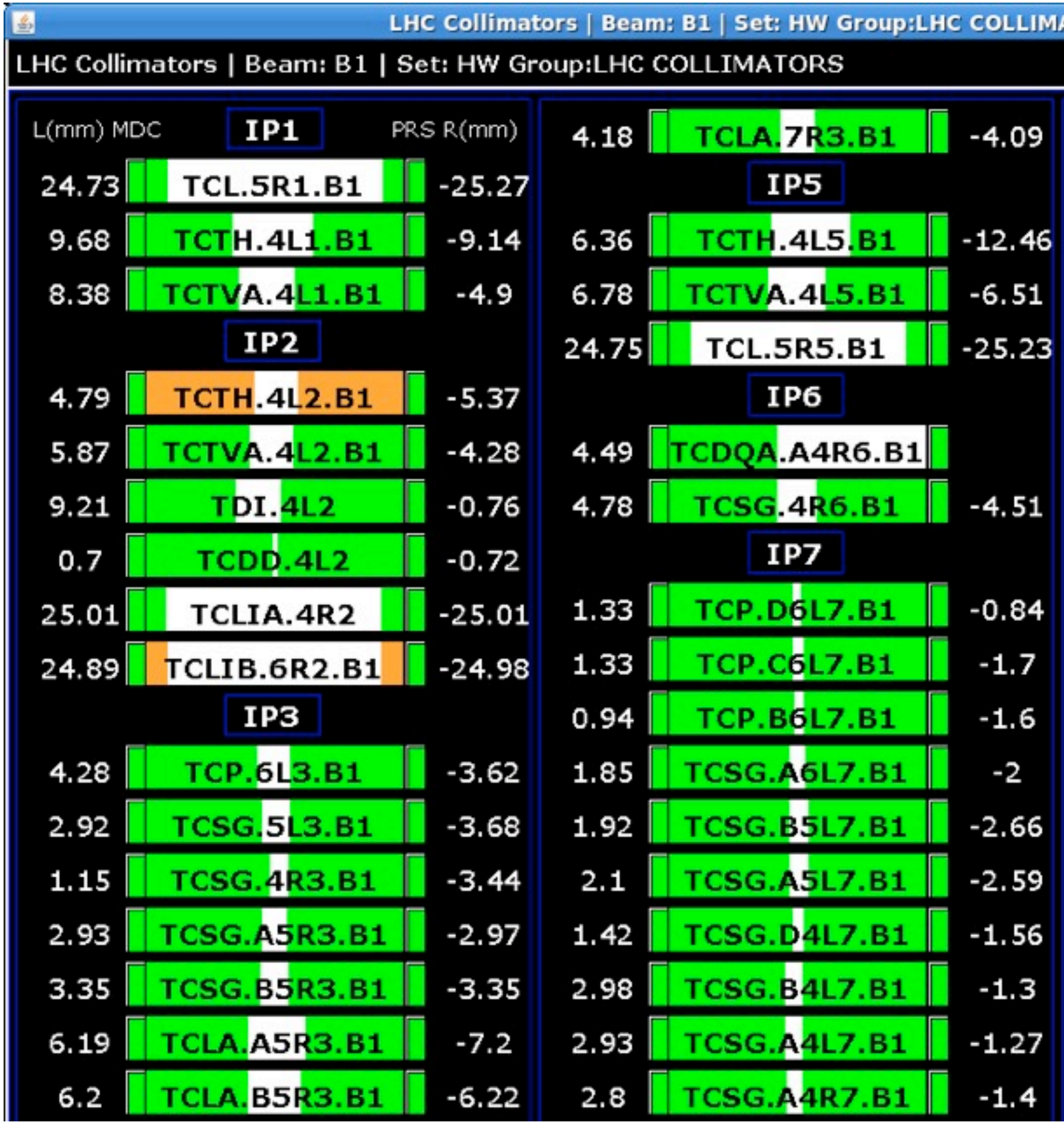
4 TeV physics settings in millimeters

LHC Collimators | Beam: B1 | Set: HW Group:LHC COLLIMATORS

LHC Collimators | Beam: B1 | Set: HW Group:LHC COLLIMATORS 29-03-2012 18:05:27

IP	L(mm) MDC	Collimator	PRS R(mm)
IP1	24.73	TCL.5R1.B1	-25.27
	9.68	TCTH.4L1.B1	-9.14
	8.38	TCTVA.4L1.B1	-4.9
IP2	4.79	TCTH.4L2.B1	-5.37
	5.87	TCTVA.4L2.B1	-4.28
	9.21	TDI.4L2	-0.76
	0.7	TCDD.4L2	-0.72
	25.01	TCLIA.4R2	-25.01
	24.89	TCLIB.6R2.B1	-24.98
IP3	4.28	TCP.6L3.B1	-3.62
	2.92	TCSG.5L3.B1	-3.68
	1.15	TCSG.4R3.B1	-3.44
	2.93	TCSG.A5R3.B1	-2.97
	3.35	TCSG.B5R3.B1	-3.35
	6.19	TCLA.A5R3.B1	-7.2
	6.2	TCLA.B5R3.B1	-6.22
	4.18	TCLA.7R3.B1	-4.09
IP5	6.36	TCTH.4L5.B1	-12.46
	6.78	TCTVA.4L5.B1	-6.51
	24.75	TCL.5R5.B1	-25.23
IP6	4.49	TCDQA.A4R6.B1	
	4.78	TCSG.4R6.B1	-4.51
IP7	1.33	TCP.D6L7.B1	-0.84
	1.33	TCP.C6L7.B1	-1.7
	0.94	TCP.B6L7.B1	-1.6
	1.85	TCSG.A6L7.B1	-2
	1.92	TCSG.B5L7.B1	-2.66
	2.1	TCSG.A5L7.B1	-2.59
	1.42	TCSG.D4L7.B1	-1.56
	2.98	TCSG.B4L7.B1	-1.3
	2.93	TCSG.A4L7.B1	-1.27
	2.8	TCSG.A4R7.B1	-1.4
	2.22	TCSG.D5R7.B1	-2.67
	2.49	TCSG.E5R7.B1	-2.4
	3.08	TCSG.6R7.B1	-3.54
	2.01	TCLA.A6R7.B1	-1.34
	2.66	TCLA.B6R7.B1	-3.36
	4.37	TCLA.C6R7.B1	-1.48
	1.7	TCLA.D6R7.B1	-2.14
	1.5	TCLA.A7R7.B1	-2.32
IP8	8.54	TCTH.4L8.B1	-1.66
	5.38	TCTVB.4L8	-5.4
TI2	1.06	TCDIV.20607	-2.72
	4.45	TCDIV.29012	-0.48
	3.49	TCDIH.29050	-4.36
	2.55	TCDIH.29205	-2.45
	5.7	TCDIV.29234	-0.54
	3.49	TCDIH.29465	-2.34
	9.44	TCDIV.29509	-3.7

4 TeV physics settings in millimeters



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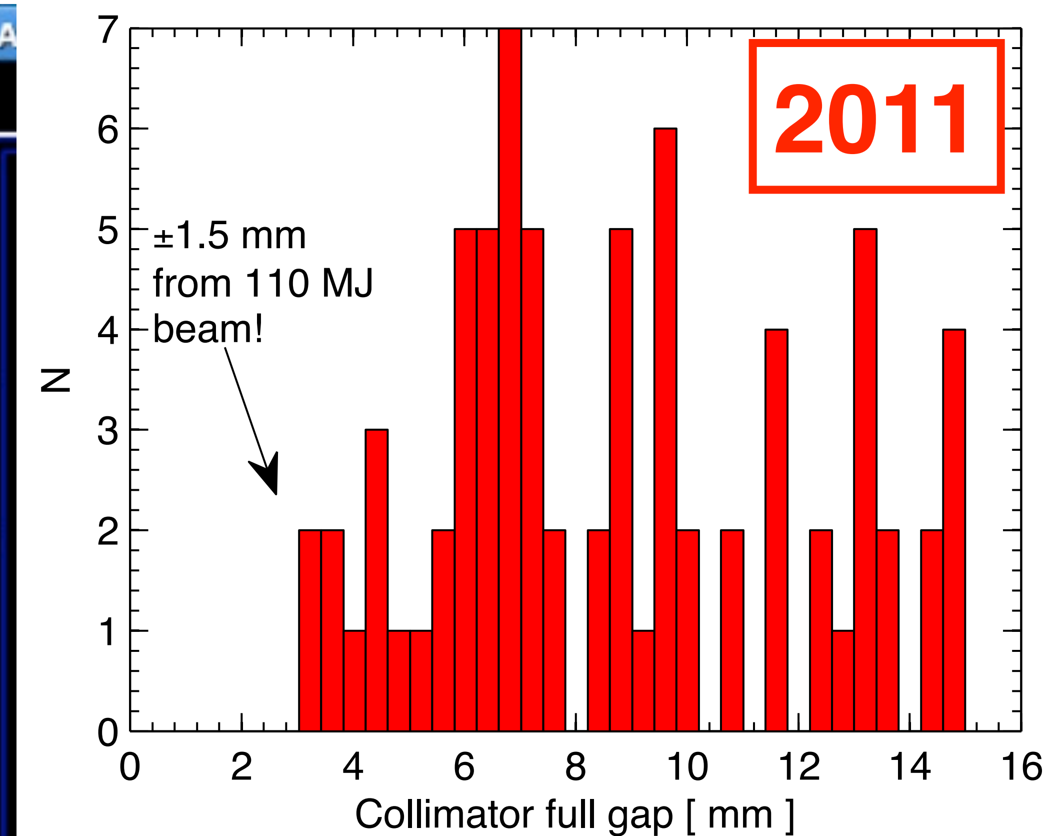
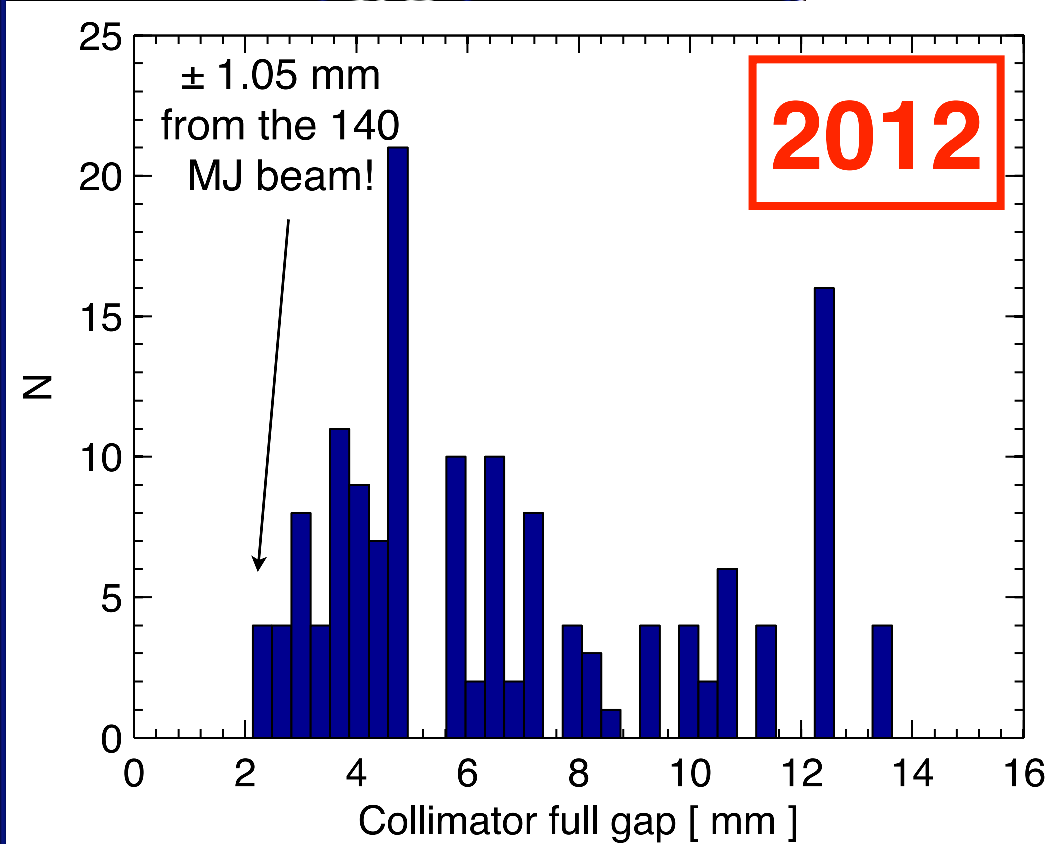
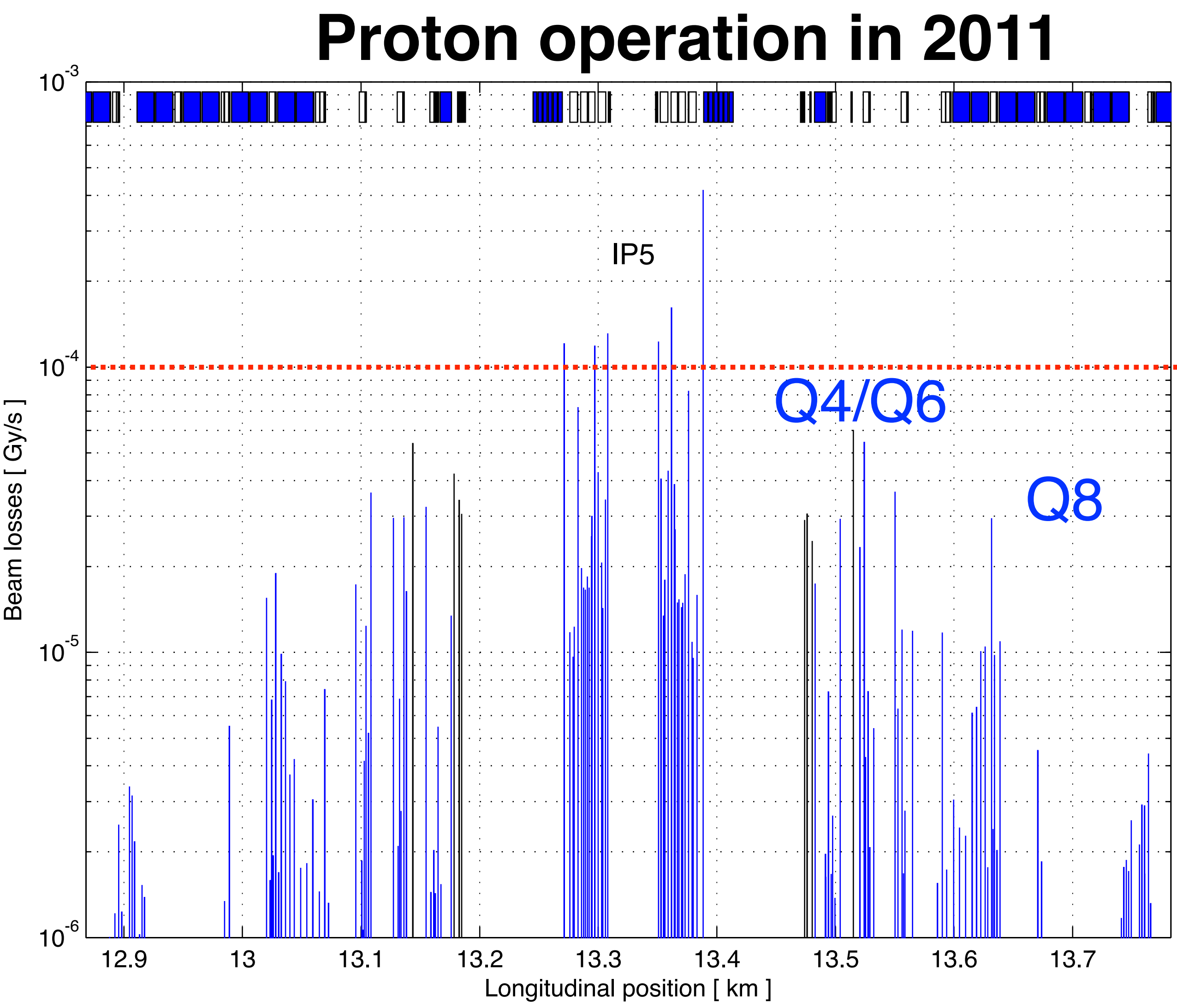
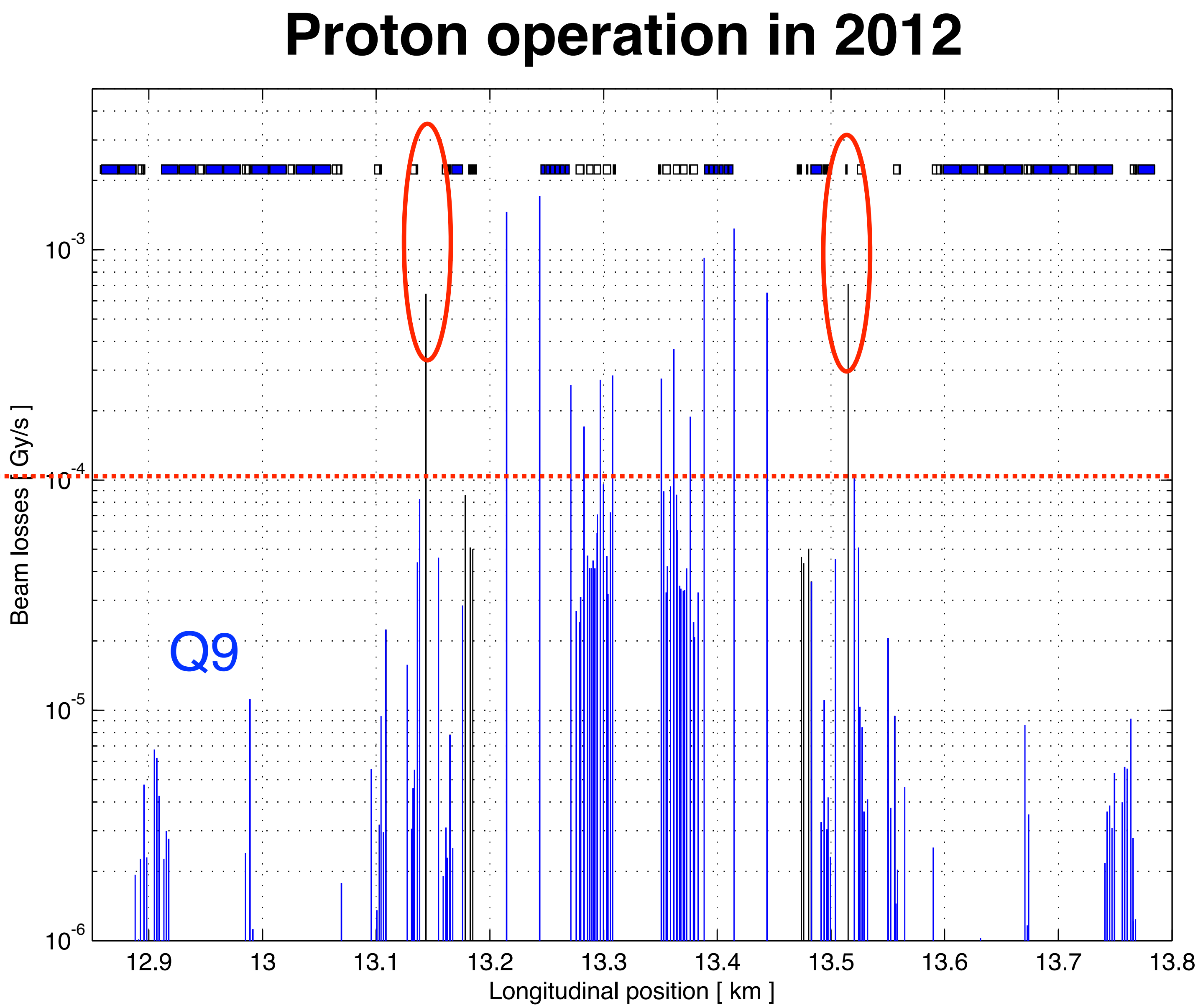




Losses from luminosity debris



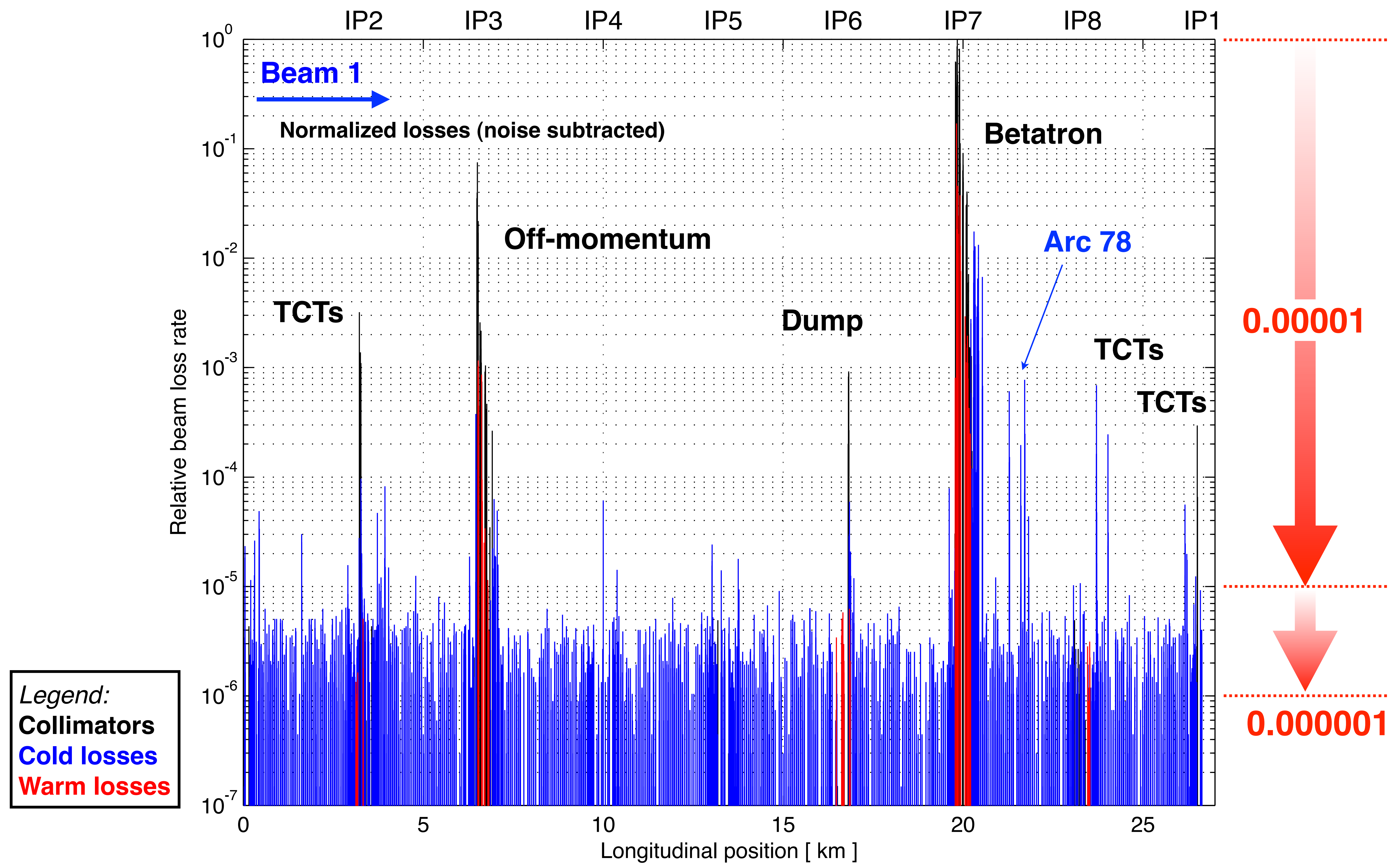


Ongoing program (beam measurements + tracking and energy deposition simulations) to understand the present losses from luminosity debris!

What can we do with the existing physics debris collimators (TCLs) to protect matching sections and dispersion suppressors?

➙ *feedback on layout of experimental regions already for LS1 (see next talks).*

Lead ion beam at 3.5 TeV (2011)



See next talk by J. Jowett

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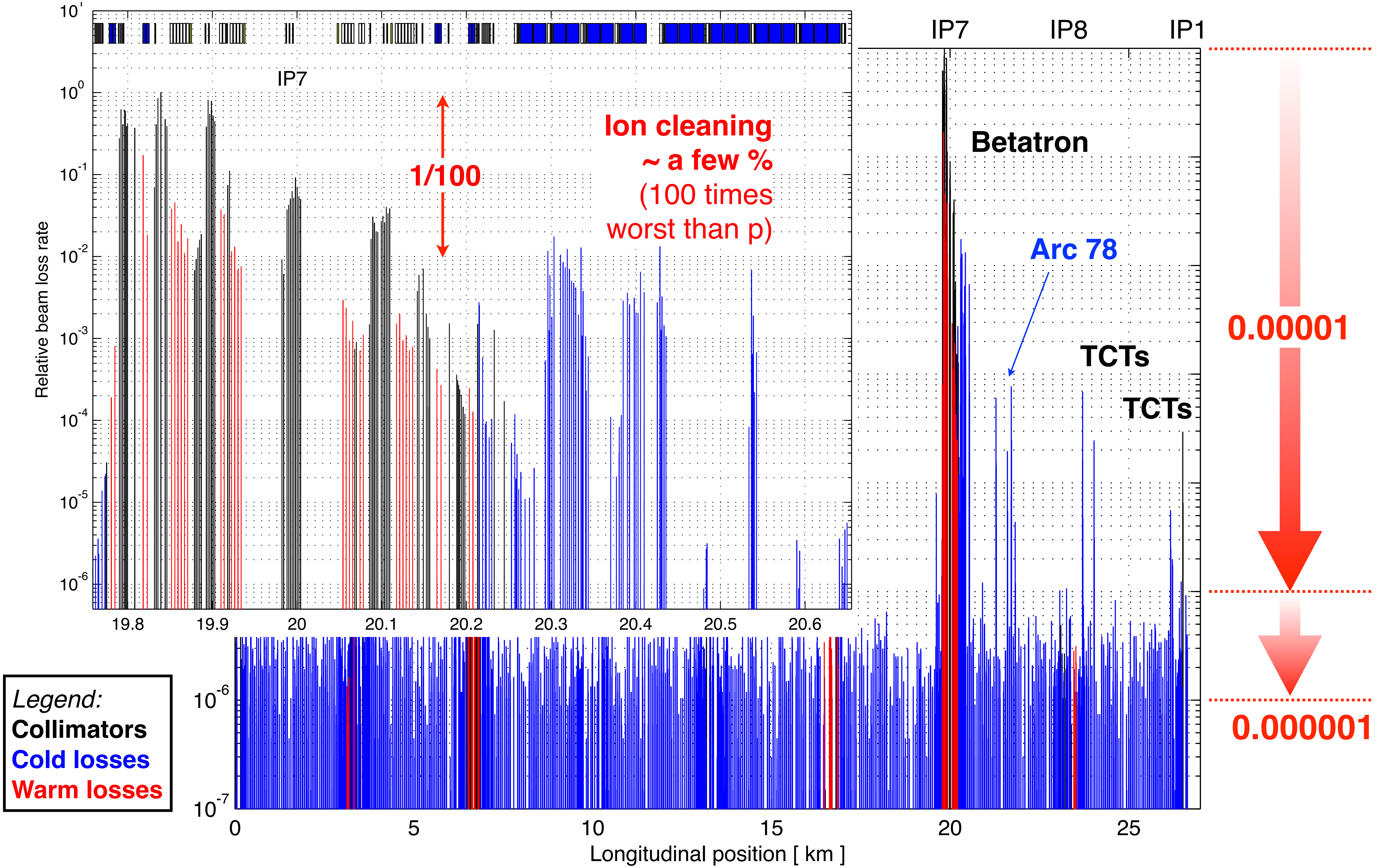

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Collimation operational experience

- **Very good performance** of the collimation system so far (up to 140MJ):
  - *- Validated all critical design choices (HW, SW, interlocking, ...);*
  - *- Cleaning close to simulations and ok for operation after LS1;*
  - *- We learned that we can rely on the machine stability!*
  - *- Established and improved semi-automatic alignment tools;*
  - ***- Performance estimates based on 2011 quench tests - to be reviewed after 2012 run Analysis of losses + quench tests at 4 TeV in Feb. 2013.***
- The present LHC collimation **cannot protect** the cold dispersion suppressors.
  - *- Critical locations with present layout: IR7, IR1/5, IR2 (ions).*
  - *- Investigations ongoing on limitations from quench and magnet lifetime.*

HiLumi

- The collimators determine the **LHC impedance**
  - *- Rich program on "dream" materials and new collimator concepts.*

Starts already in LS1

- Collimation alignments and validation of new setting are **time-consuming**.
- The **operation flexibility** in the experimental regions (VdM scans, spectrometer polarity changes, β* leveling, ...) is affected by collimation constraints.
- The ***β**** **reach** is determined by collimation constraints: retraction between beam dump and horizontal TCTs which are not robust.
- Collimator handling in **radiation environment** will be challenging.

New collimators with integrated BPMs

- **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.

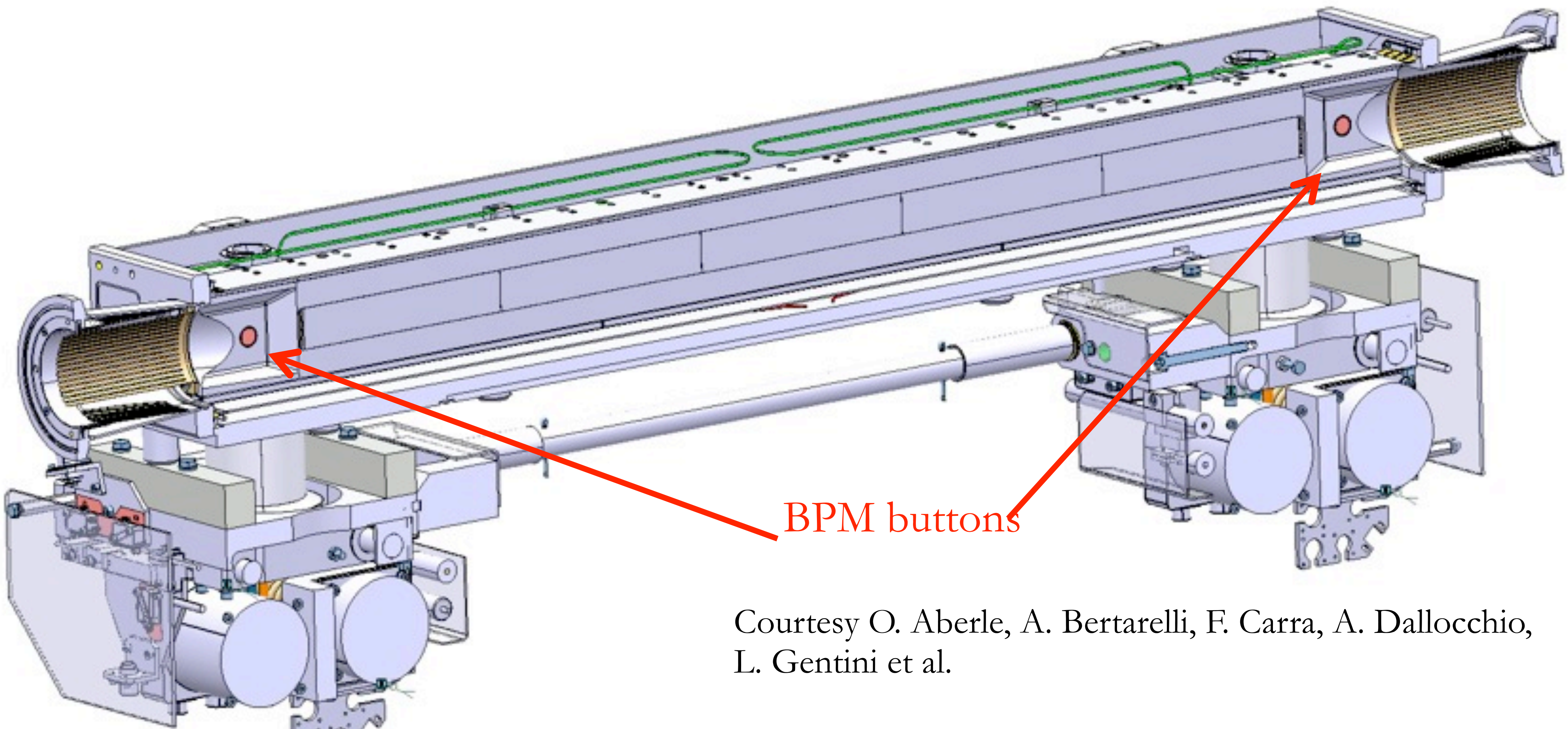
  ➙ *Drastically reduced setup time => more flexibility in IR configurations*

  ➙ *Reduced orbit margins in cleaning hierarchy => more room to squeeze β*: ≥* ***35 cm (R. Bruce)***

- Solid experimental validation of this concept from SPS beam tests (2010-2012)
- These new collimators **replace the existing collimators** *(minor vacuum layout changes in IR8)*

  ➙ No changes of the present layout, improved collimator setup in all IRs.

- Other improvements are foreseen in different IRs: warm magnet protection, **TCL layout IR1/5**



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

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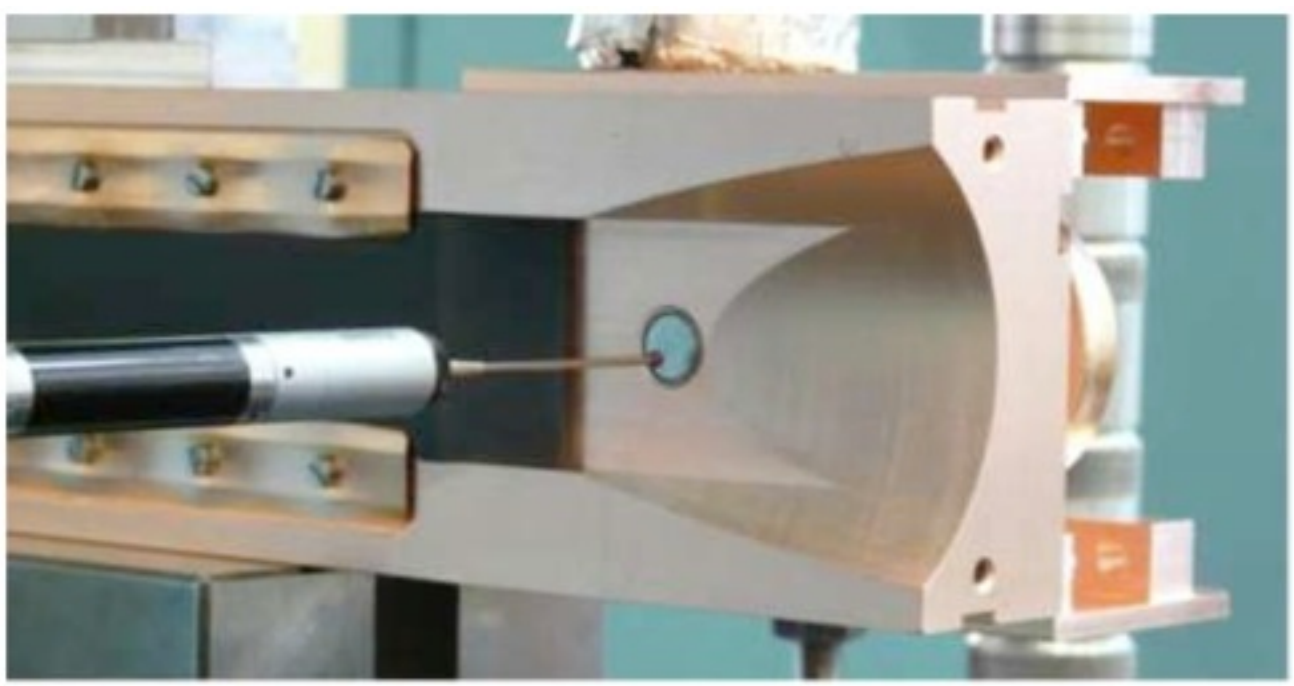
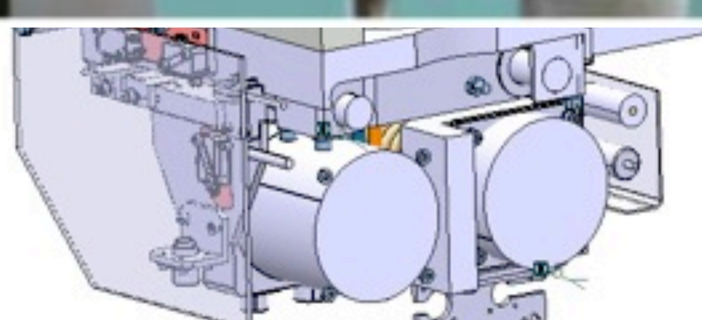
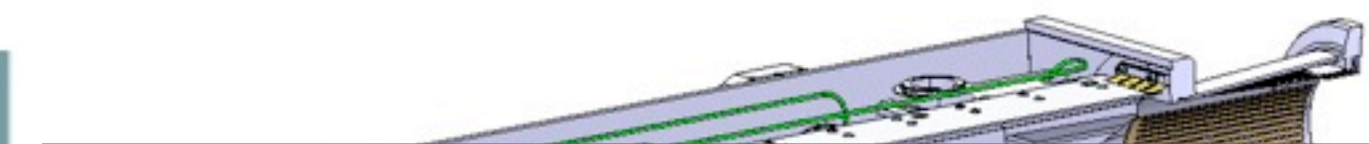
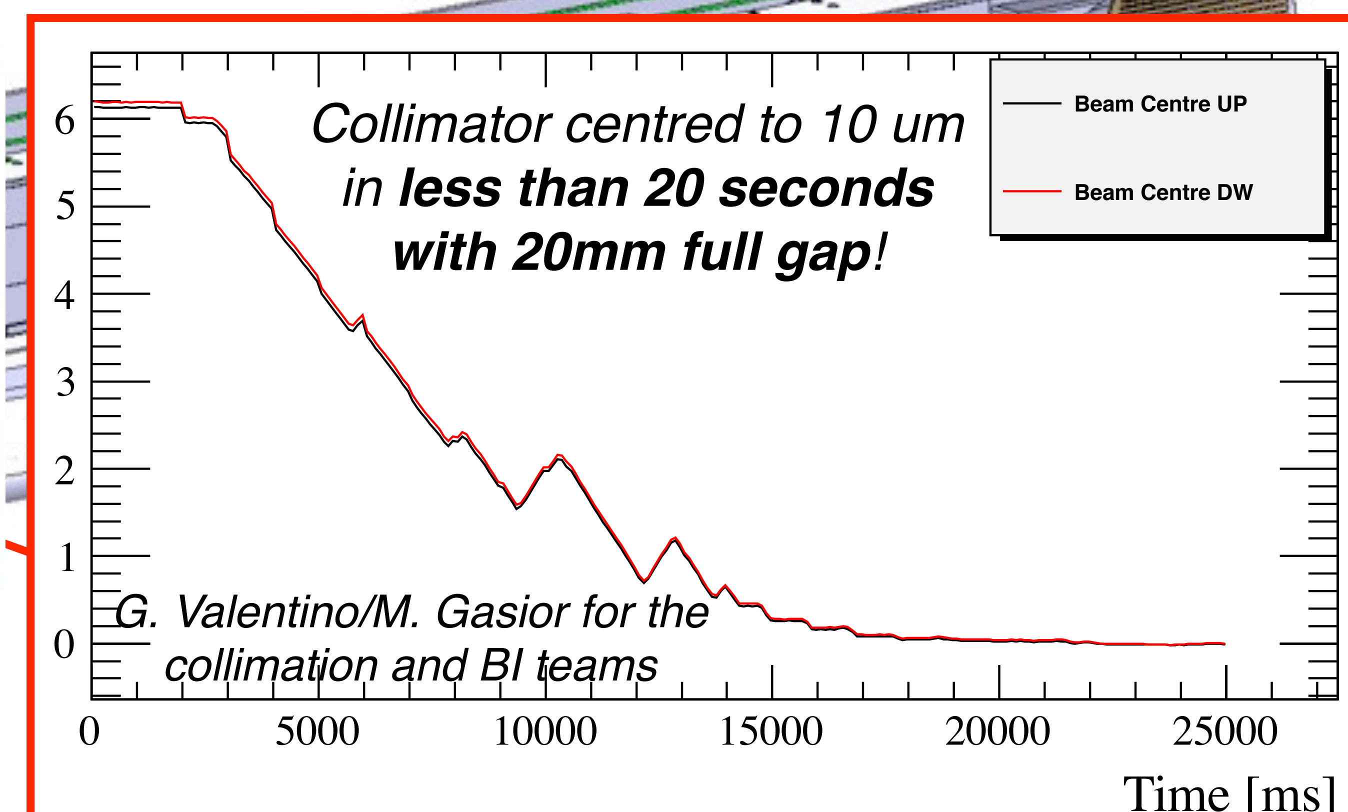








Intensity reach from collimation cleaning

The performance reach does not only depend on the collimation cleaning!

Minimum (assumed) beam lifetime

Quench limit of SC magnets

Collimation cleaning at limiting cold location

LHC total intensity reach from collimation:

$$N_{\text{tot}} = \frac{\tau R_q}{\tilde{\eta}_c}$$

Preliminary 7 TeV performance estimate based on ACHIEVED loss rates at 3.5 TeV
(500 kW for protons, 27 kW for ions)

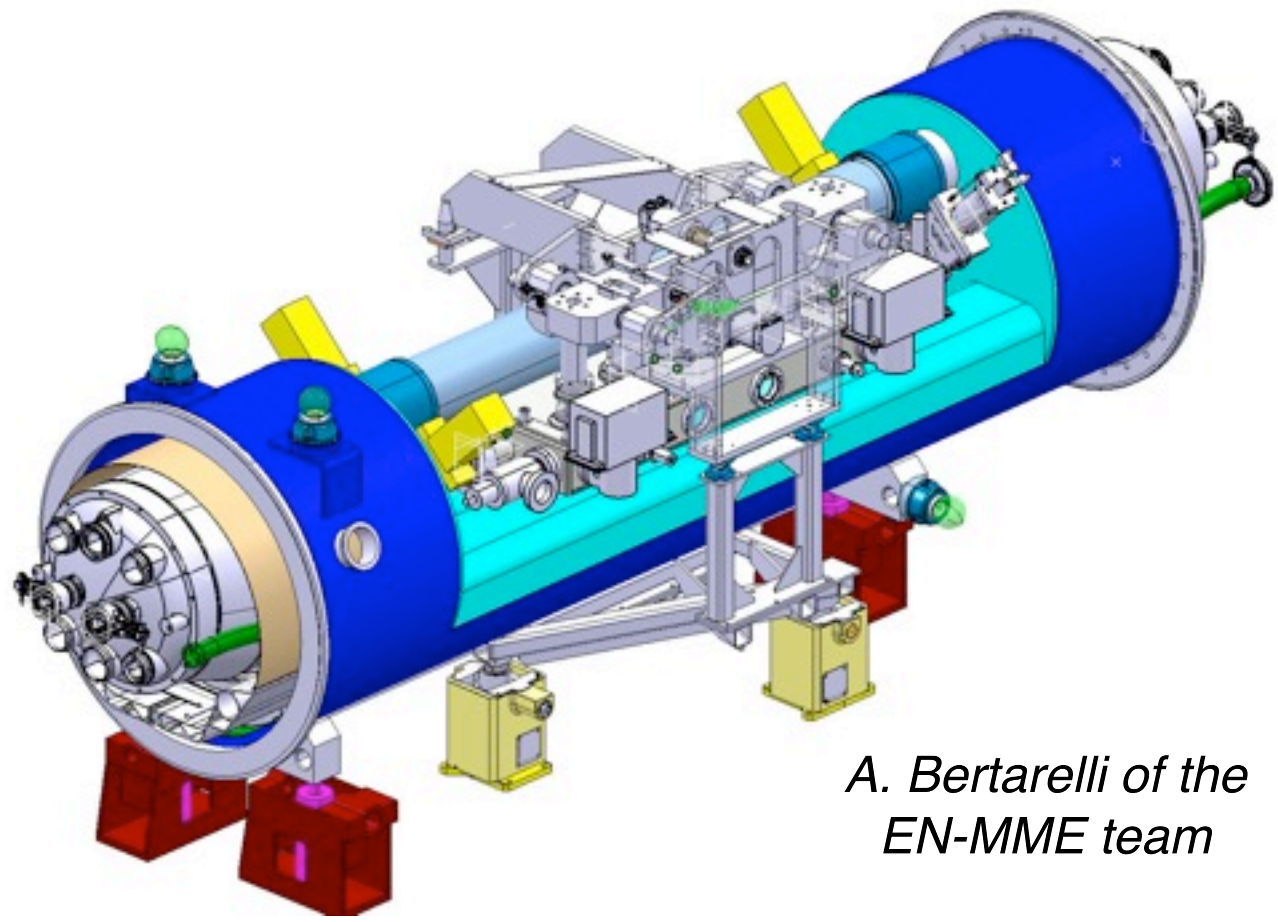
→

Protons: > 1.5 x nomin
Ions: 5-25 x n
Ions (L debri

Caveats/assumptions:
- So far, we did NOT quench → Figures for
- It is assumed that the **lifetime** will be t ... **nd smaller β***
- The losses were achieved only during
- There are uncertainties on **quench limit** ... **ing** performance at **larger E**

It is **crucial** to continue **investigations** on **quench limits** and to **monitor** the other relevant **parameters** in **2012**!

DS upgrade in cleaning insertions



A. Bertarelli of the EN-MME team

(1) Catch local losses in the dispersion suppressor (DS): two DS collimators per beam

- Layout change of the DS: moving dipoles to create space;
- New design of warm collimators.

(2) Combine momentum/betatron cleaning in IP3 by adding 5 vertical collimators per beam

- Standard technology of Phase I.
- Essentially using existing slots.
- New production chain for building the missing collimators.

Details: Review of DS work, July 2010:
http://indico.cern.ch/conferenceDisplay.py?confId=100156

DS upgrade in cleaning insertions

(1) Catch local losses in the dispersion suppressor (DS): two DS collim... er beam

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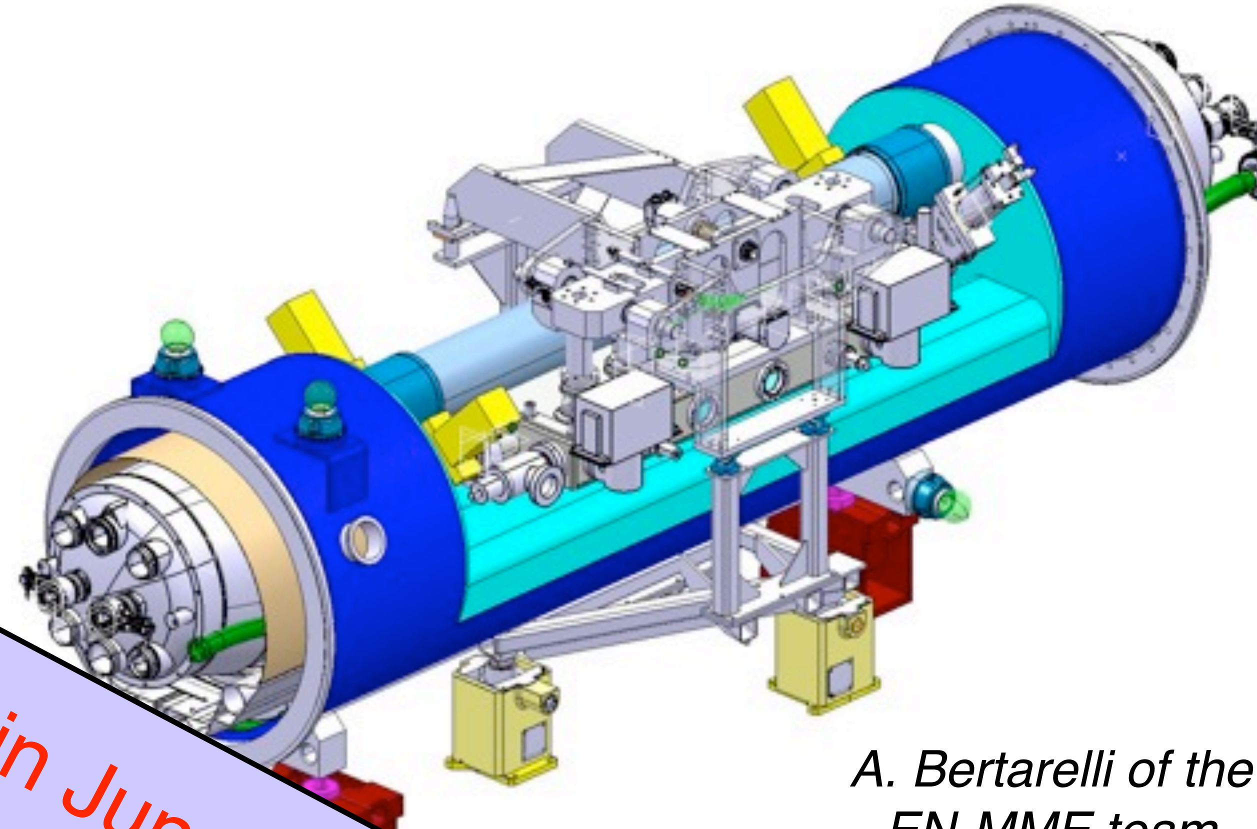


A. Bertarelli of the EN-MME team

External review in June 2011 → DS in the cleaning insertions **postponed**: real needs will be addressed by the first experience at 7 TeV.

The important work on warm "cold collimator" is not lost → concept coupled with the 11 T dipole! Prototyping has continued.

https://indico.cern.ch/conferenceDisplay.py?confId=155408#2011-10-05

Details: Review of DS w... ...0:

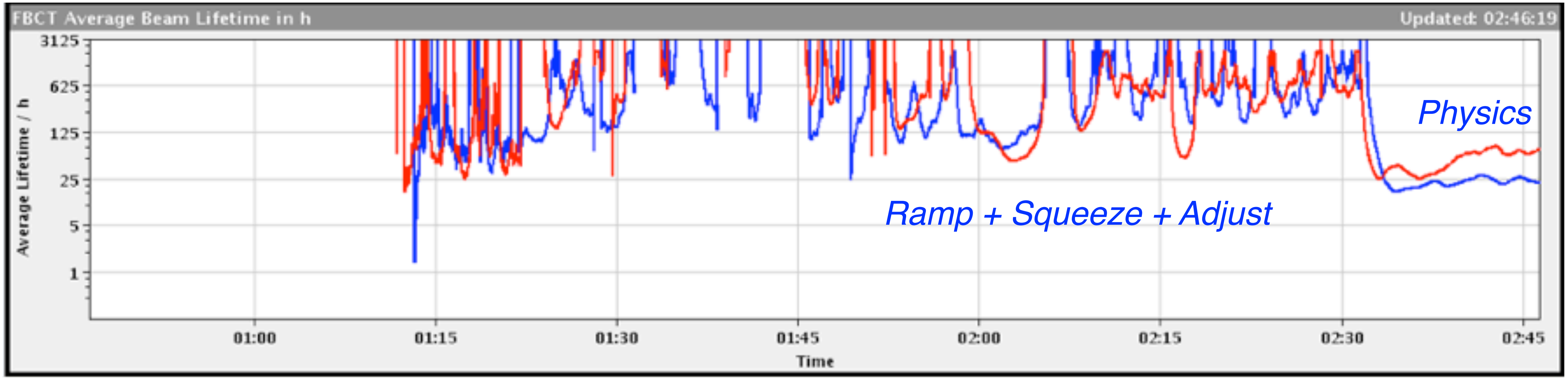
http://indico.cern.ch/conferenceDis... ...?confId=100156

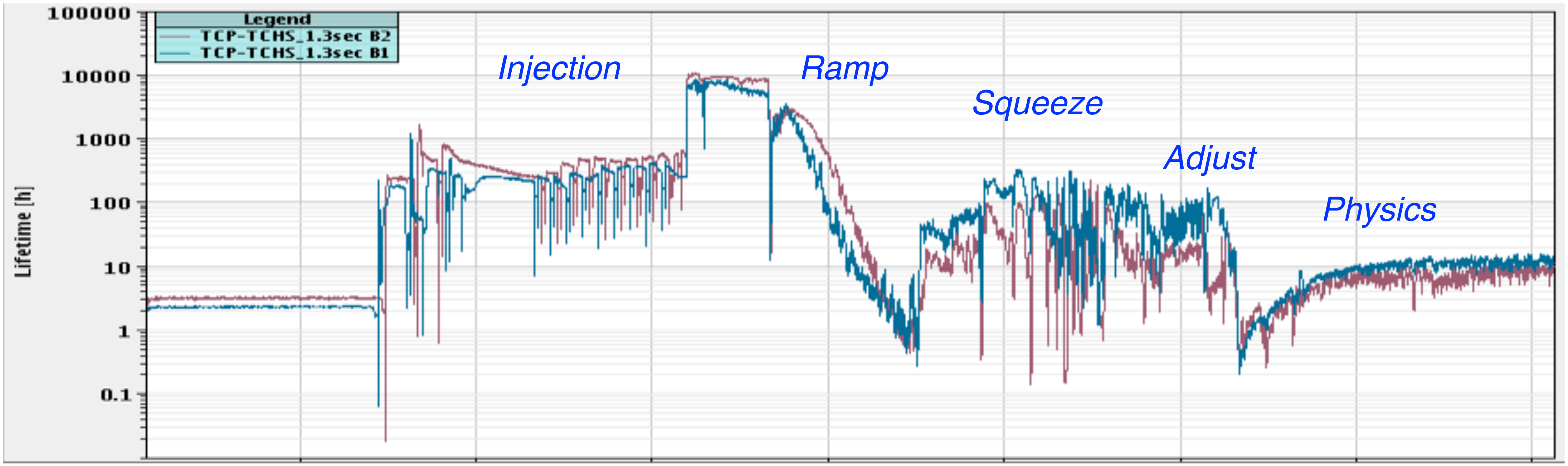
Prototyping of cryostat by-pass

D. Duarte Ramos

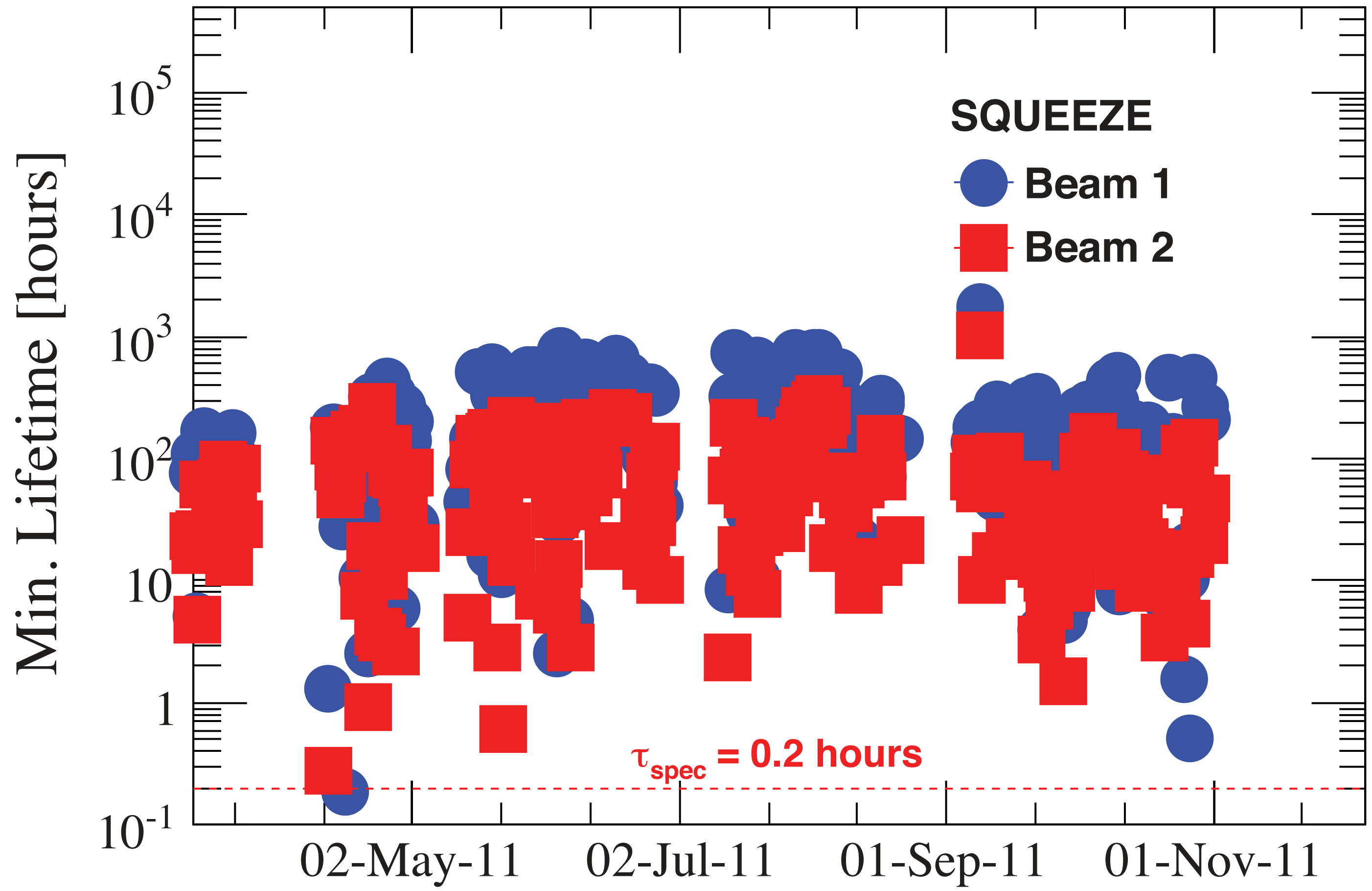
Lifetime during LHC operational cycle

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

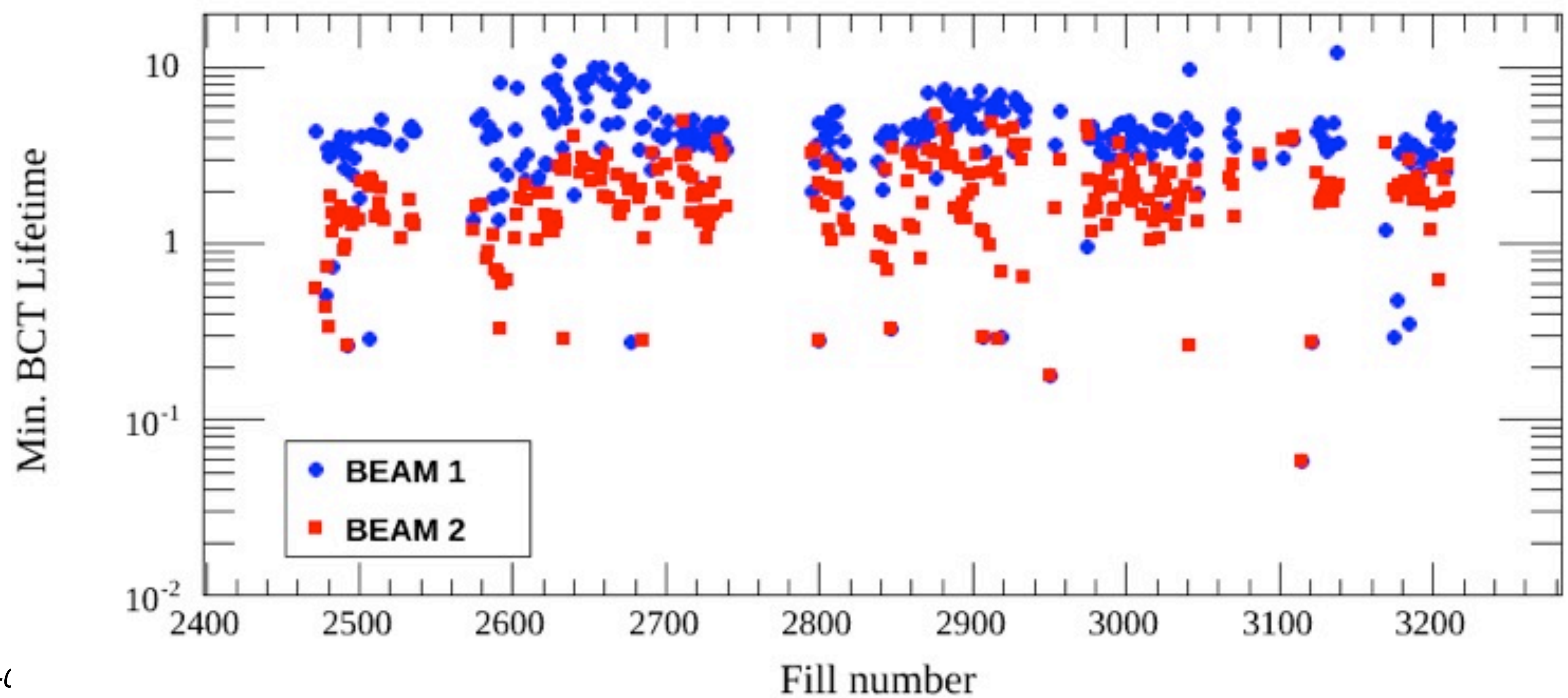




Example: squeeze losses 2011/2012



2012 operational experience is being reviewed. Quench tests in Feb. 2013 will provide required inputs for more reliable performance reach estimates.



B. Salvachua

Outline

- Introduction
- LHC collimation status
- Collimation after LS1
- **HiLumi-WP5 activities and beyond**
- Conclusions

HiLumi WP5 tasks

WP 5.1: Coordination & Communication

– To coordinate and schedule work package tasks
– To monitor work progress and inform the project management and work package participants
– To follow up the WP budget and use of resources
– To prepare internal and deliverable reports

WP 5.2: IR Simulations of Halo Loss

– Assess locations and magnitudes of halo loss in the IR's for various upgrade scenarios (includes crab cavities, ATS, ...).
– Assess impact of imperfections.

WP 5.3: IR Simulations of Energy Deposition

– Assess locations and magnitudes of energy deposition in the IR's for various upgrade scenarios.
– Assess impact of imperfections.

WP 5.4: Design of IR Collimation

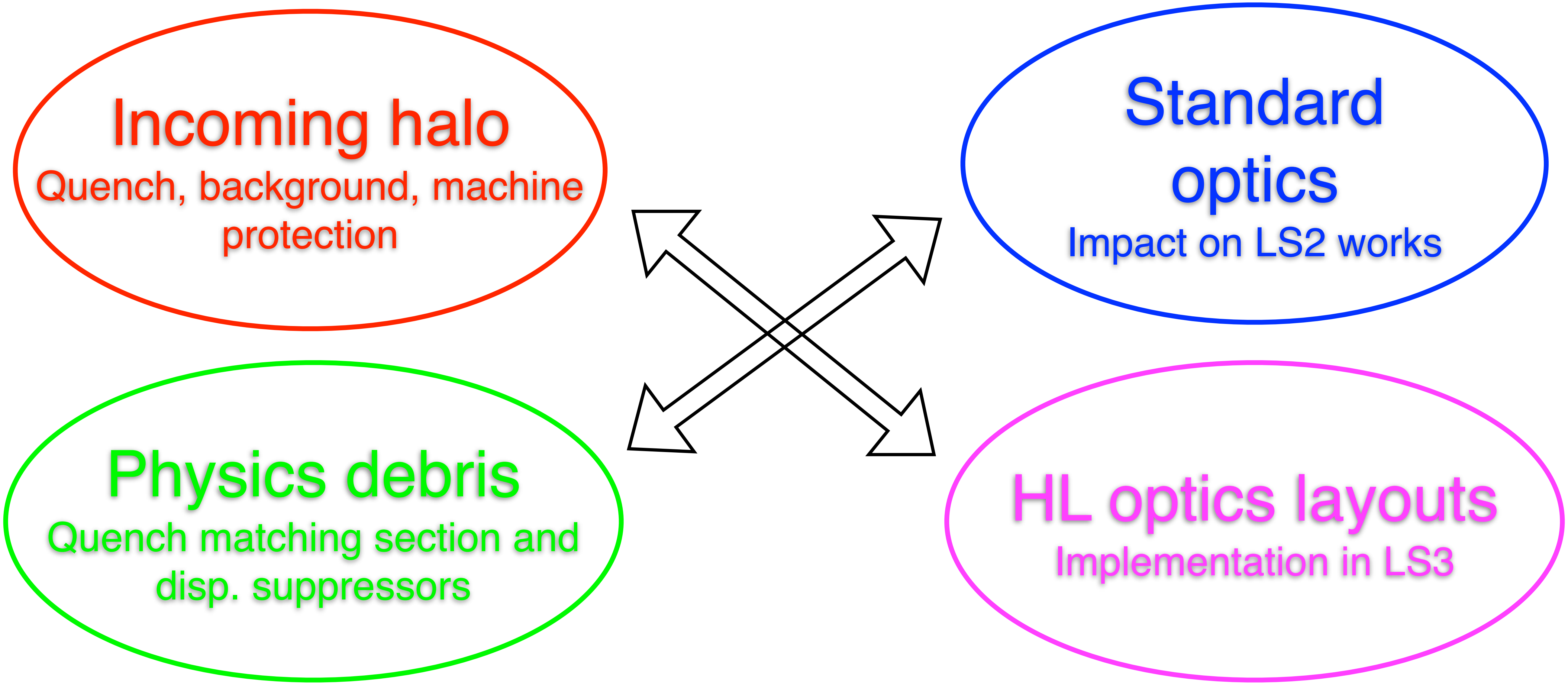
– Study required collimation to keep losses at the same level or below before the upgrade.
– Integration of collimators, new layout and optics.
– Feed-forward to simulation WP's.

Deliverables

- **M12**: Set up of models and implementation of upgrade optics.
- **M24**: Assessment of beam halo losses in various upgrade scenarios (includes crab cavities, ATS, …).
- **M36**: Definition of new IR collimation solution.
- **M42**: Verification of new IR collimation solution in simulations. Possible iteration in design.
- **M48**: Final report.

Focus of studies must clearly be based on the observed system limitations!

Required simulation environment



- **Setup for proton and ion simulations**
- **Primary goal: Do we need dispersion suppressor collimations in LS2?**
- **Complementary simulation setups:**
  Tracking (Sixtrack, Merlin) and detailed energy deposition (FLUKA).
- Collimation limitations for the **LHC β* reach**.
- **Strong link to LHC operation/MD studies**: benchmarking and code validation

Agendas of WP5 collimation sessions

Collimation status and plans	*Dr. Stefano REDAELLI*	*Aula Div.Acc. (Bldg 2), INFN Frascati*	15:00 - 15:30
Collimators for high heavy ion luminosity	*Dr. John JOWETT*	*Aula Div.Acc. (Bldg 2), INFN Frascati*	15:30 - 15:50
Simulations of HL halo loss and IR losses	*Dr. Aurelien MARSILI*	*Aula Div.Acc. (Bldg 2), INFN Frascati*	15:50 - 16:10
Energy depositions studies for TCLs in IR1/5	*Dr. Luigi Salvatore ESPOSITO*	*Aula Div.Acc. (Bldg 2), INFN Frascati*	16:10 - 16:30
Coffee break		*Aula Div.Acc. (Bldg 2), INFN Frascati*	16:30 - 17:00
Collimation after LS1: cleaning and β* reach	*Dr. Roderik BRUCE*	*Aula Div.Acc. (Bldg 2), INFN Frascati*	17:00 - 17:30
Status of HL loss simulations with Merlin	*Dr. Maurizio SERLUCA*	*Aula Div.Acc. (Bldg 2), INFN Frascati*	17:30 - 18:00
HL collimation studies in Valencia	*Dr. Angeles FAUS-GOLFE*	*Aula Div.Acc. (Bldg 2), INFN Frascati*	18:00 - 18:30

Key features of the upgrade optics and layout possibly impacting on collimation (20+5)	*Dr. Riccardo DE MARIA*	*Aula B. Touschek (Bldg 36), INFN Frascati*	16:00 - 16:25
First collimation results with the baseline 15 cm ATS optics (20+5)	*Dr. Aurelien MARSILI*	*Aula B. Touschek (Bldg 36), INFN Frascati*	16:25 - 16:50
Prioritized action list	*Dr. Stefano REDAELLI et al.*	*Aula B. Touschek (Bldg 36), INFN Frascati*	16:50 - 17:00
General discussion		*Aula B. Touschek (Bldg 36), INFN Frascati*	17:00 - 17:30

Second session on Thu. morning

- **US-LARP collimation activities**
  - Status of SLAC RC collimator.
  - Tevatron hollow e-lens usage at CERN.
  - New proposal on material irradiation studies at BNL.
- **Material studies at CERN**
  - FP7 activities within EuCARD and EuCARD2.
- **Status of crystal studies for collimation**:
  - UA9 status and options for beam tests at the LHC.

Status of SLAC RC collimator (20+5)	*Dr. Thomas MARKIEWICZ*
Auletta B-1 (Bldg 36), INFN Frascati	09:00 - 09:25
Hollow e-lens at CERN (20+5)	*Dr. Giulio STANCARI*
Auletta B-1 (Bldg 36), INFN Frascati	09:25 - 09:50
Status of LHC material studies and proposal for irradiation tests at BNL (20+5, remote)	*Dr. Alessandro BERTARELLI*
Auletta B-1 (Bldg 36), INFN Frascati	09:50 - 10:15
Plans for crystal tests at the SPS and LHC (20+5)	*Dr. Daniele MIRARCHI*
Auletta B-1 (Bldg 36), INFN Frascati	10:15 - 10:40
Discussion	
Auletta B-1 (Bldg 36), INFN Frascati	10:40 - 11:00

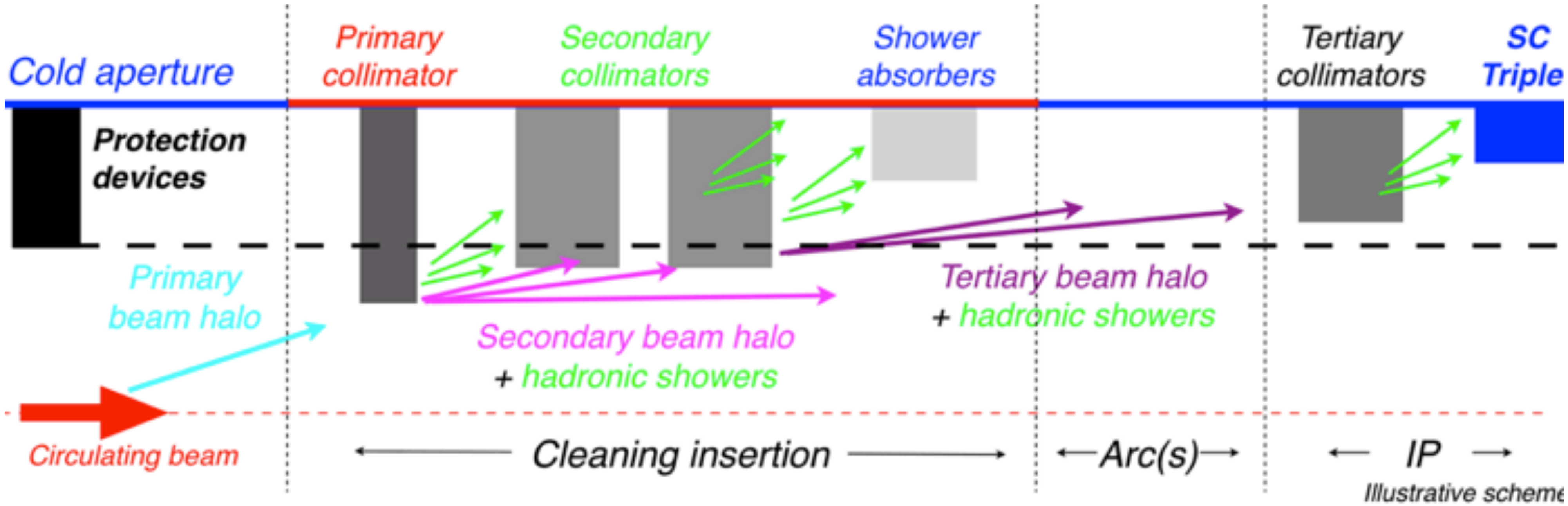
Conclusions

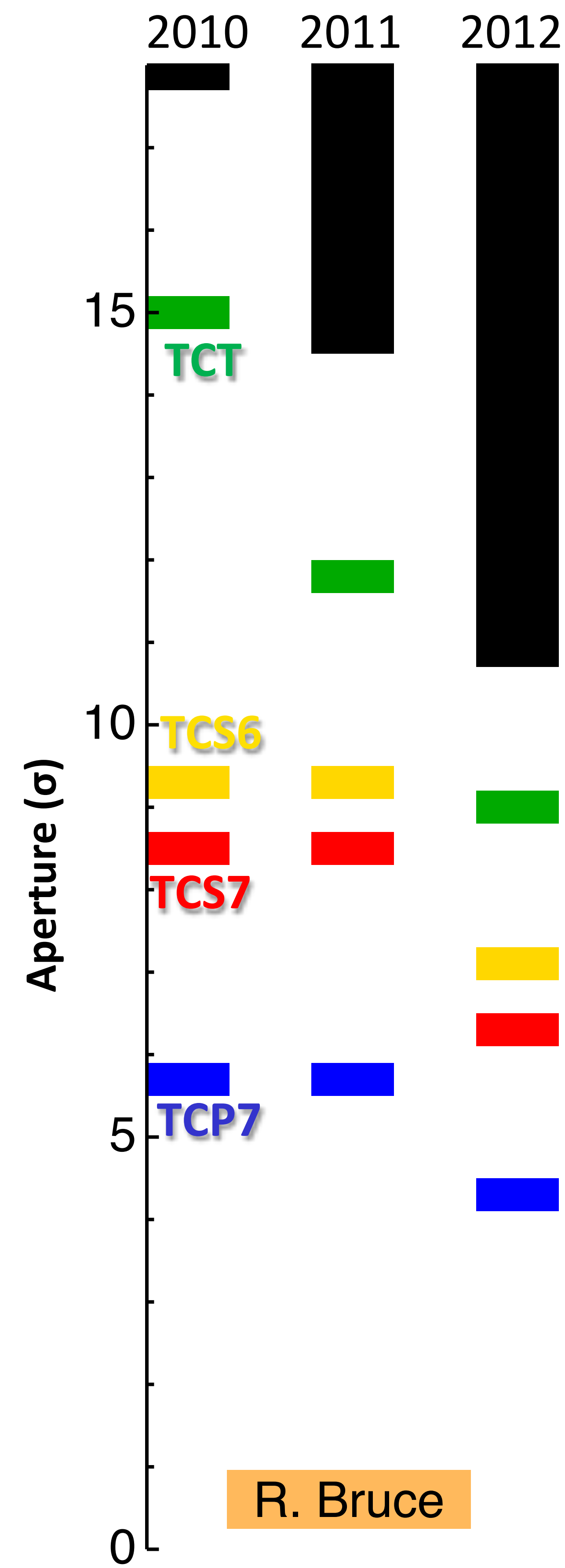
- The performance of the **LHC collimation system** was reviewed.
  - *- Considered runs of 2010/11/12, with focus on the 2012 operation (up to 7.7x10^{33} $cm^{-2}s^{-1}$).*
- The LHC and its collimation system **work well** (~140 MJ, up to 4 TeV)
  - *- Cleaning inefficiency below a few 0.0001, stable during one whole run.*
  - *- Improved semi-automatic alignment tools were deployed.*
  - *- Tighter collimator settings allowed a* ***β^*=60cm*** *(we are now at 77% of 7TeV design lumi).*
- Collimation system upgrades are already taking place in LS1 to address some of the observed limitations!
- The path for the HL-LHC will be addressed by a **project review** in spring 2012.
  - *- Full review of 2012 operational experience and system limitations;*
  - *- basic decisions on the road maps for dispersion suppressor collimators.*
  - *- System improvements for implementation in 2018 and 2021 (LS2 and LS3) will be finalized after first experience at ~7 TeV (2015).*
- The Hi-Lumi WP5 scope was reviewed. These activities proceeded well in this first year. More work ahead will provide essential inputs!

Reserve slides

Collimation hierarchy and β* reach

LHC multi-stage collimation



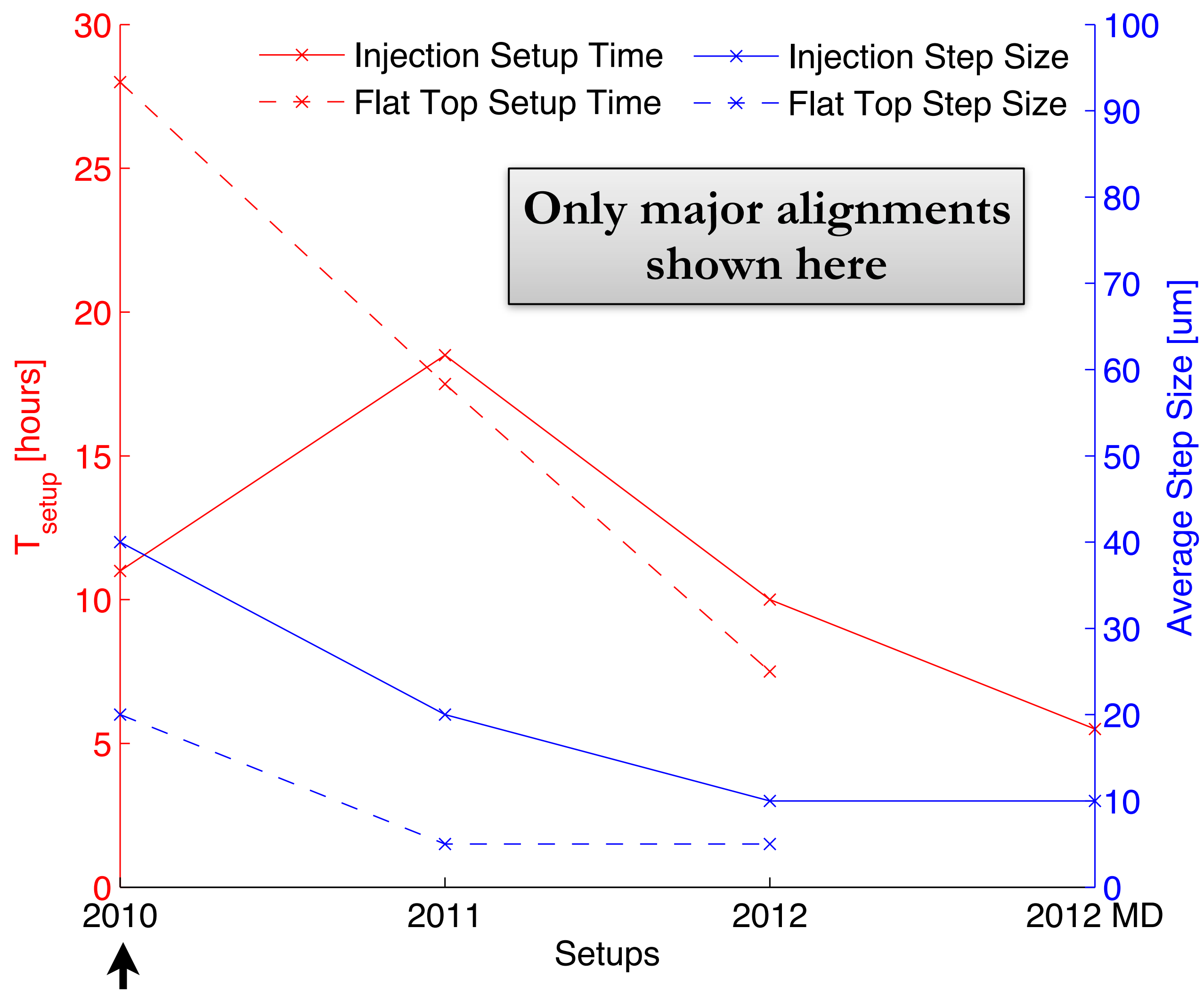


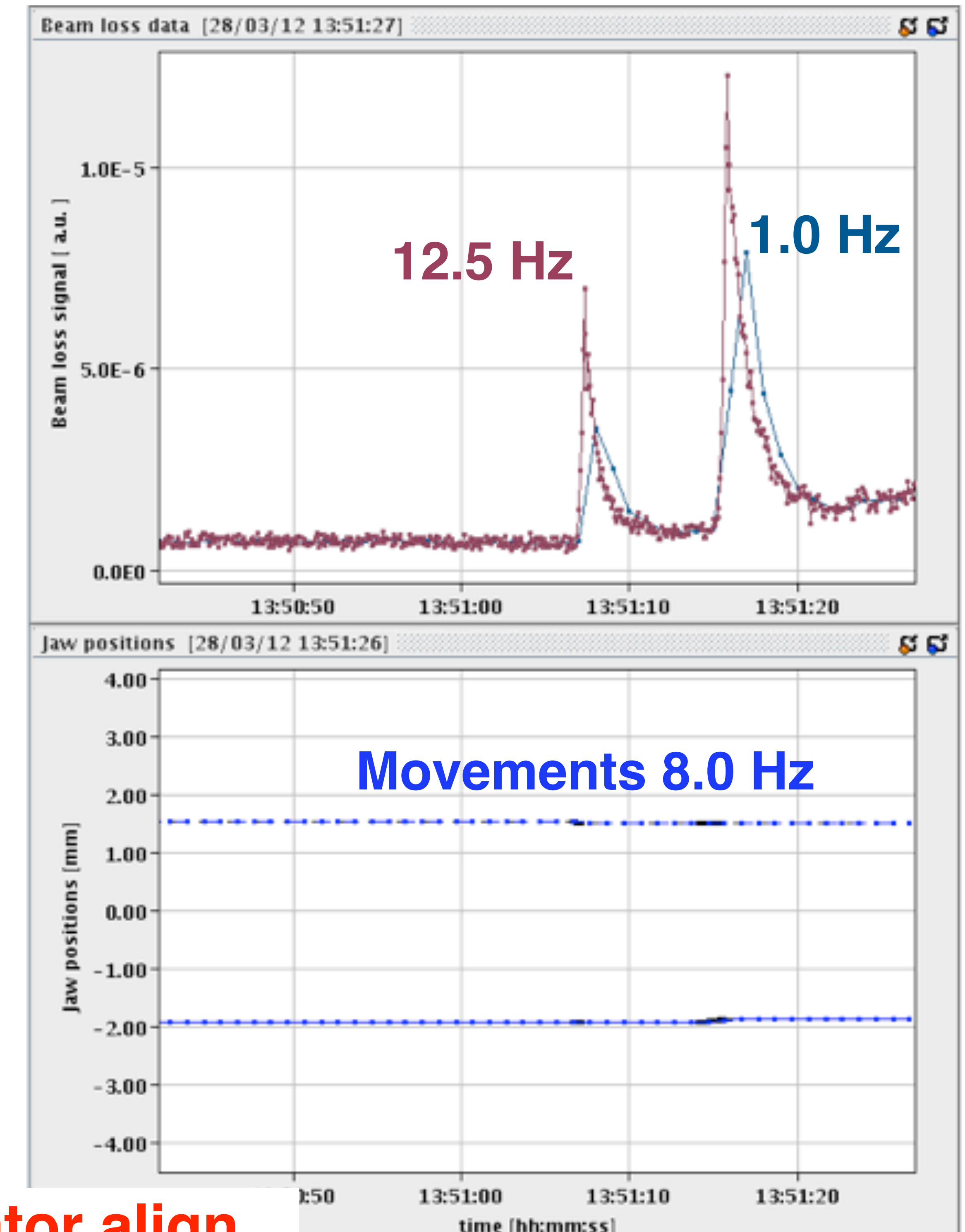
- **Tight settings** established in **2012** after thorough validation in 2011 *(monitoring of standard fills + dedicated MD)*
- Important **advantages**:
  - Improved β^* reach **60 cm**: 40-50% gain in luminosity reach!
  - Better cleaning!
  - Still "relaxed" orbit margins (1 alignment per year!)
  - Gain operational experience with small 7 TeV gaps (in mm)
- **Drawbacks**:
  - Larger losses in operation *(talks: R. Schmidt MOI1A01, and L. Ponce TU03C01)*
  - Increased **impedance** → instabilities *(See B. Salvant, WEO1A02)*

Collimator alignment

2012 commissioning: alignment campaigns

Setup Type	Injection	Flat Top	Squeezed	Colliding
Date	21/03	29/03	31/03	30/03
N. of coll.	86	80	16	20



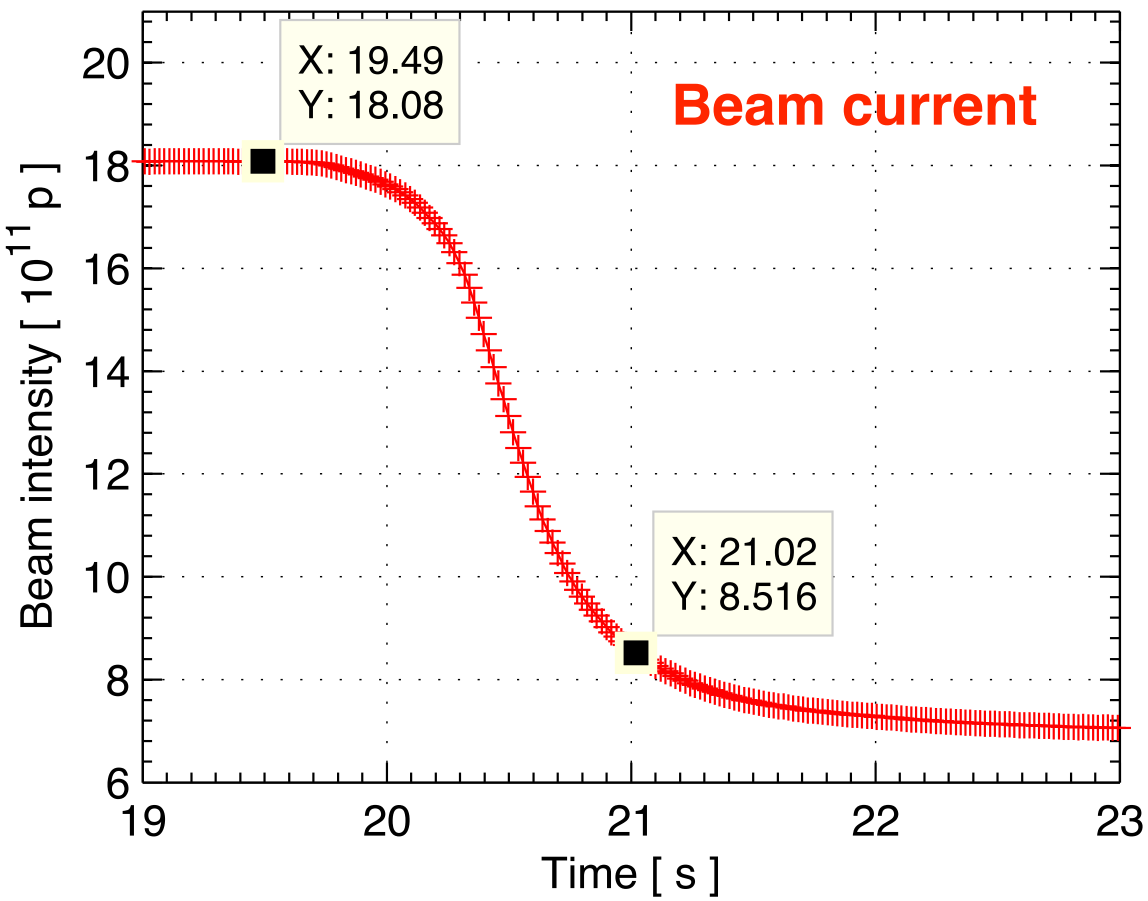


Number of dump triggered during collimator align.

	2010 (Manual)	2011 (1 Hz)	2012 (8 Hz)
Num. of dumps	1 (inj) + 4 (3.5TeV)	2 + 0	0 + 0

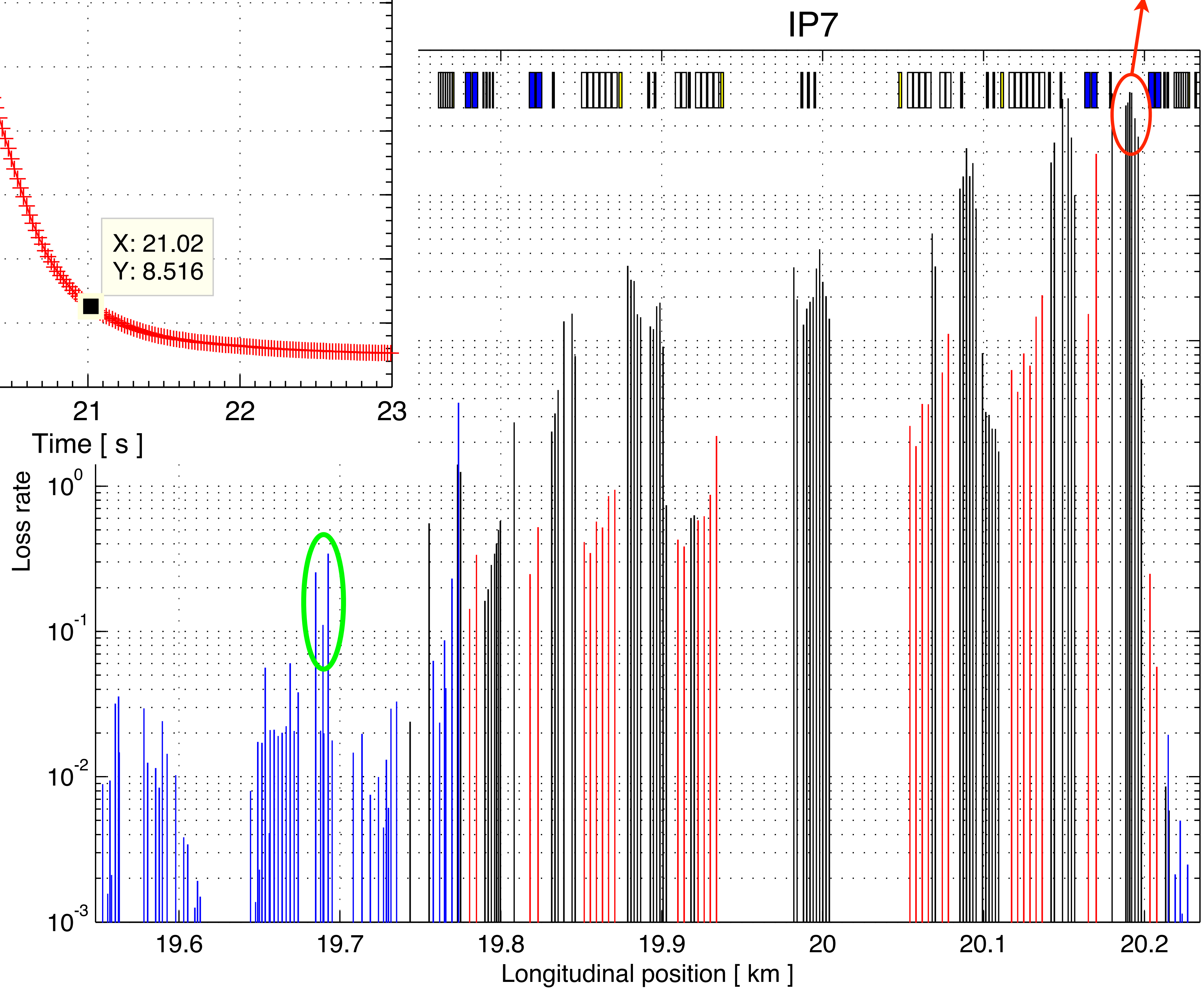
Ph.D. work of G. Valentino
See a recent ICAP paper + MPO246

Handling large beam losses



500 kW primary losses on the TCP at 3.5 TeV!

Beam2



LHC collimation system could handle 500 kW losses in a superconducting machine!

Poster MPO245

Example: settings reproducibility

Reproducib
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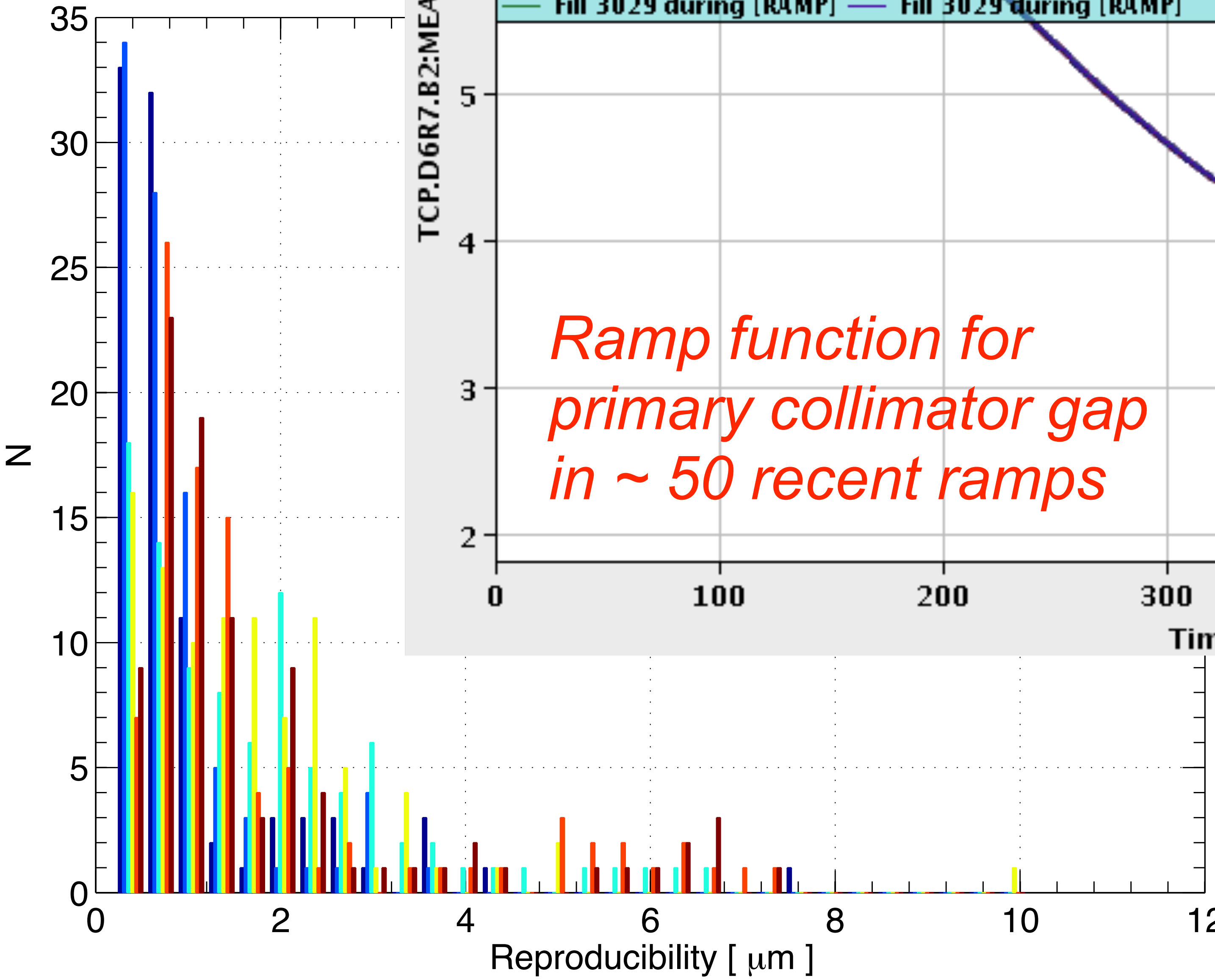
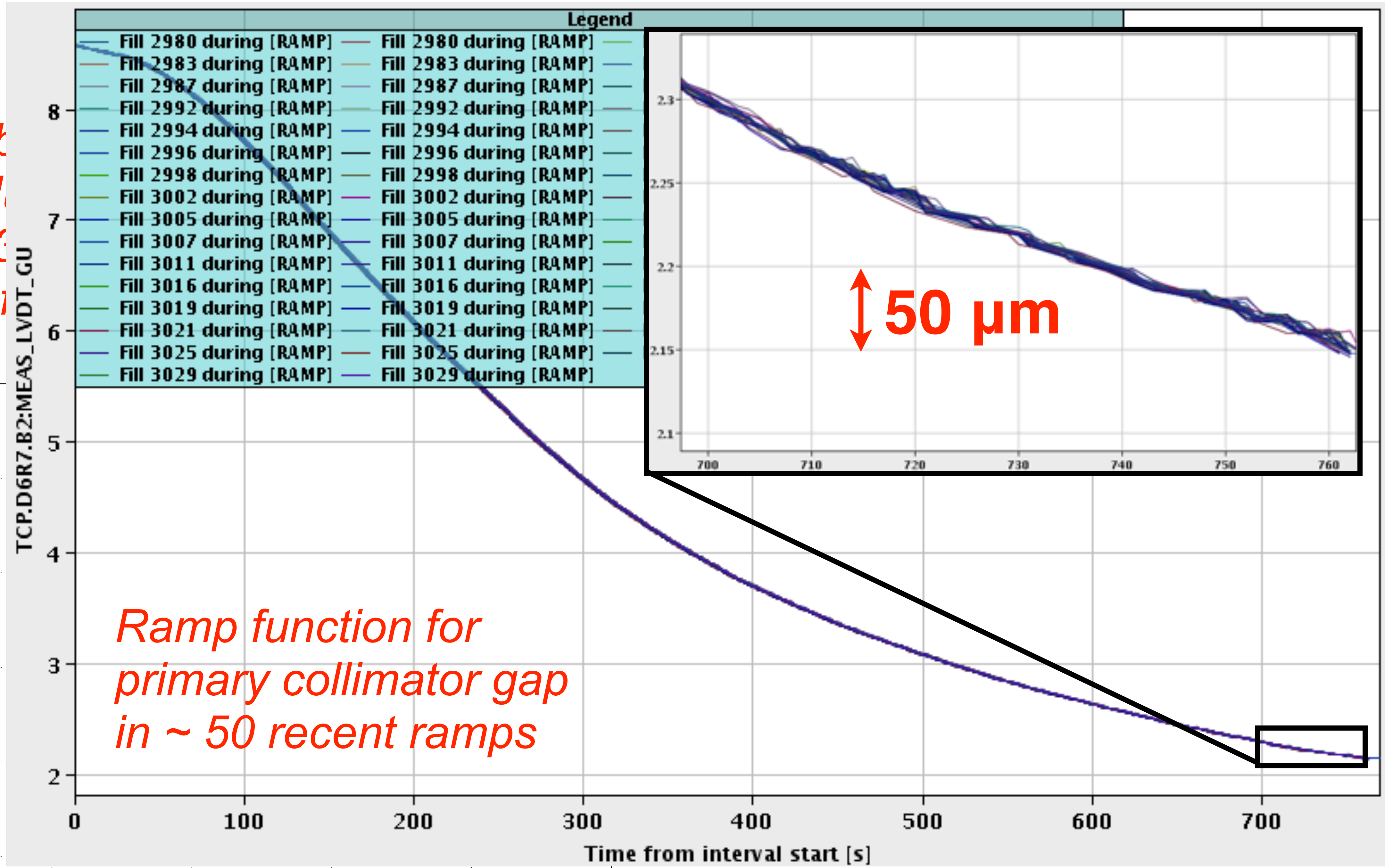




Caveat:
System is somewhat affected by power cuts (e.g. from storms): errors go up to < 20-30µm

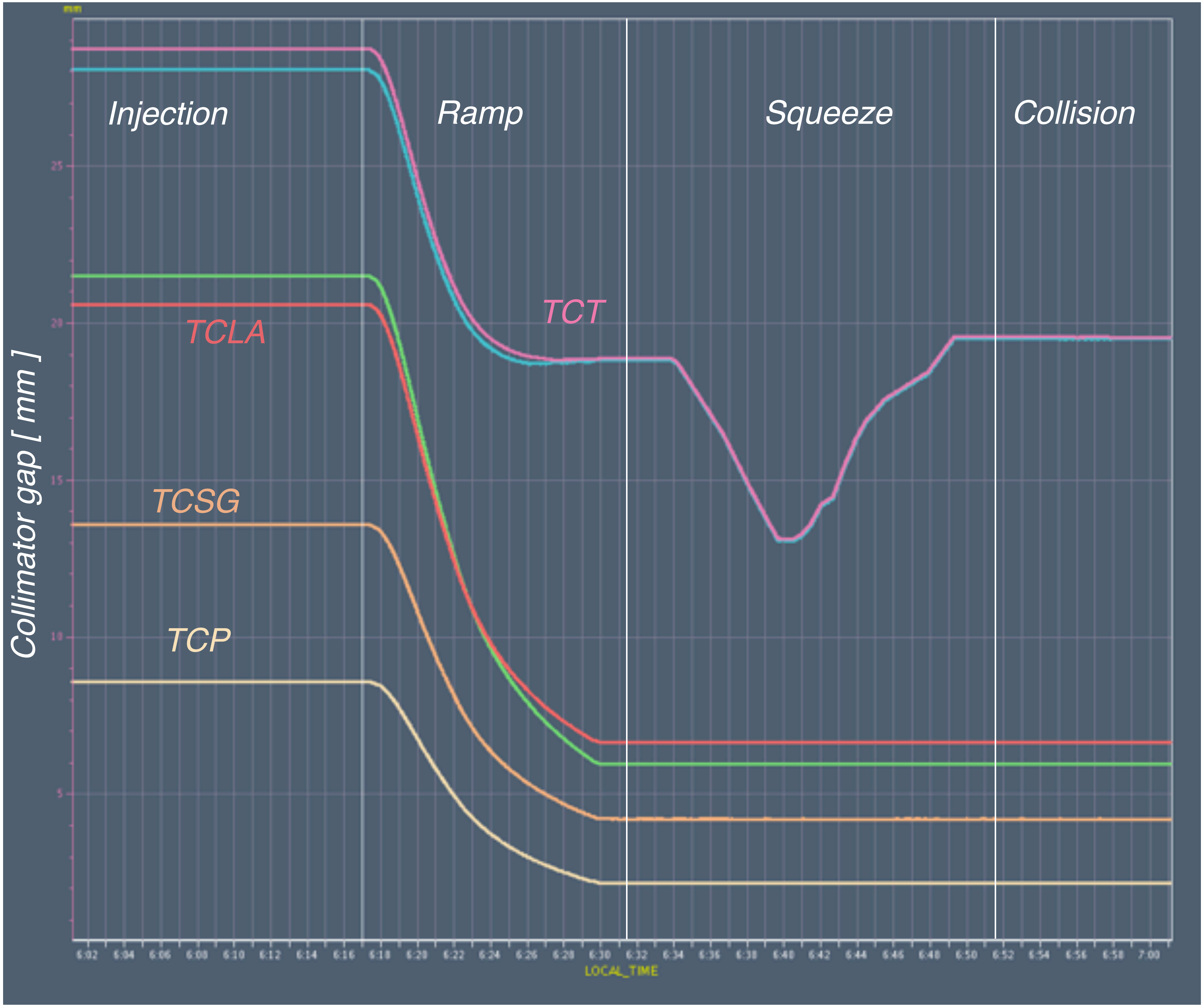
2012 collimator setting table

Parameter	Unit	Plane	Type	Set 1	Set 2	Set 3	Set 4
				Injection	Top energy	Squeezed	Collision
Energy	[GeV]	n.a.	n.a.	450	4000	4000	4000
β^* in IR1/5	[m]	n.a.	n.a.	11.0	11.0	0.6	0.6
β^* in IR2	[m]	n.a.	n.a.	10.0	10.0	3.0	3.0
β^* in IR8	[m]	n.a.	n.a.	10.0	10.0	3.0	3.0
Crossing angle IR1/5	[μrad]	n.a.	n.a.	170	145	145	145
Crossing angle IR8	[μrad]	n.a.	n.a.	170	220 (H)	220 (H)	100 (V)
Crossing angle IR2	[μrad]	n.a.	n.a.	170	90	90	90
Beam separation	[mm]	n.a.	n.a.	2.0	0.65	0.65	0.0
Primary cut IR7	[σ]	H,V,S	TCP	5.7	4.3	4.3	4.3
Secondary cut IR7	[σ]	H,V,S	TCSG	6.7	6.3	6.3	6.3
Quartiary cut IR7	[σ]	H,V	TCLA	10.0	8.3	8.3	8.3
Primary cut IR3	[σ]	H	TCP	8.0	12.0	12.0	12.0
Secondary cut IR3	[σ]	H	TCSG	9.3	15.6	15.6	15.6
Quartiary cut IR3	[σ]	H,V	TCLA	10.0	17.6	17.6	17.6
Tertiary cut IR1/5	[σ]	H,V	TCT	13.0	26.0	9.0	9.0
Tertiary cut IR2/8	[σ]	H,V	TCT	13.0	26.0	12.0	12.0
Physics debris collimators	[σ]	H	TCL	out	out	out	10.0
Primary protection IR6	[σ]	H	TCSG	7.0	7.1	7.1	7.1
Secondary protection IR6	[σ]	H	TCDQ	8.0	7.6	7.6	7.6

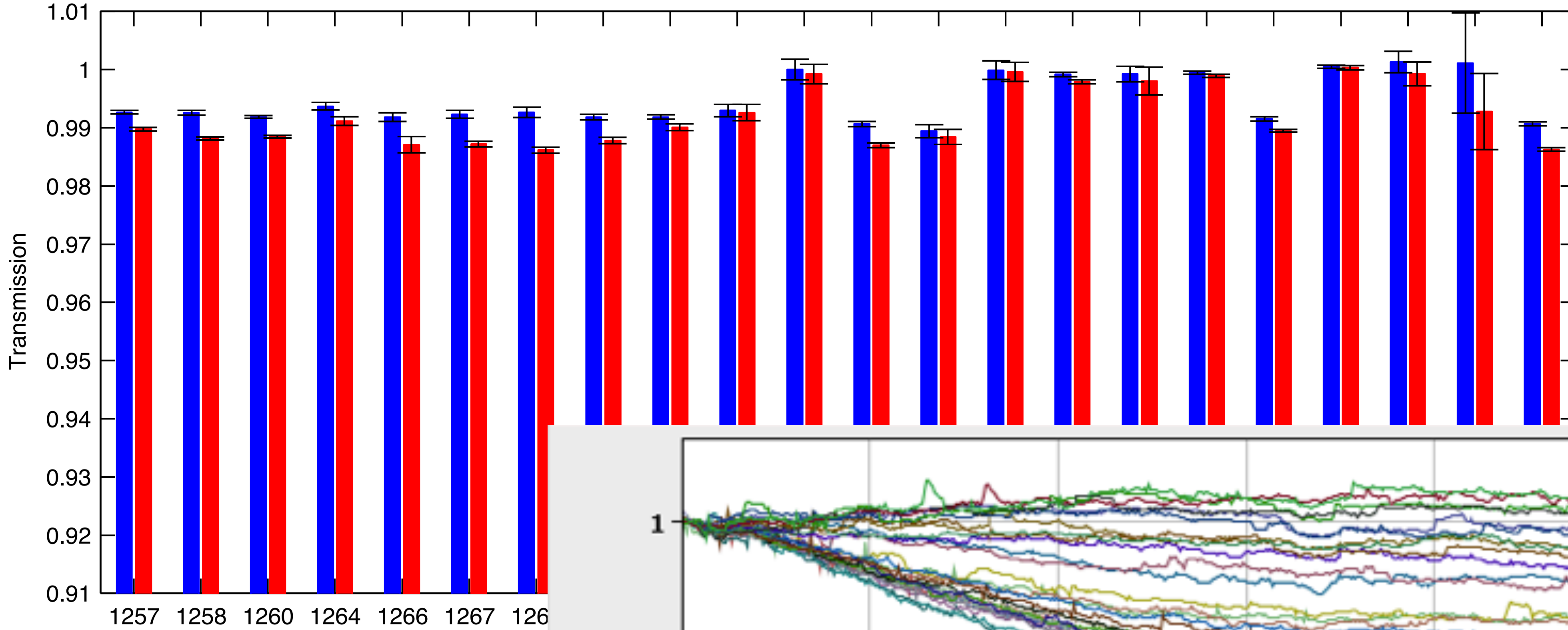
4 sets of beam-based settings, smooth transition between different sets.

Each setting set must be validated by loss maps.

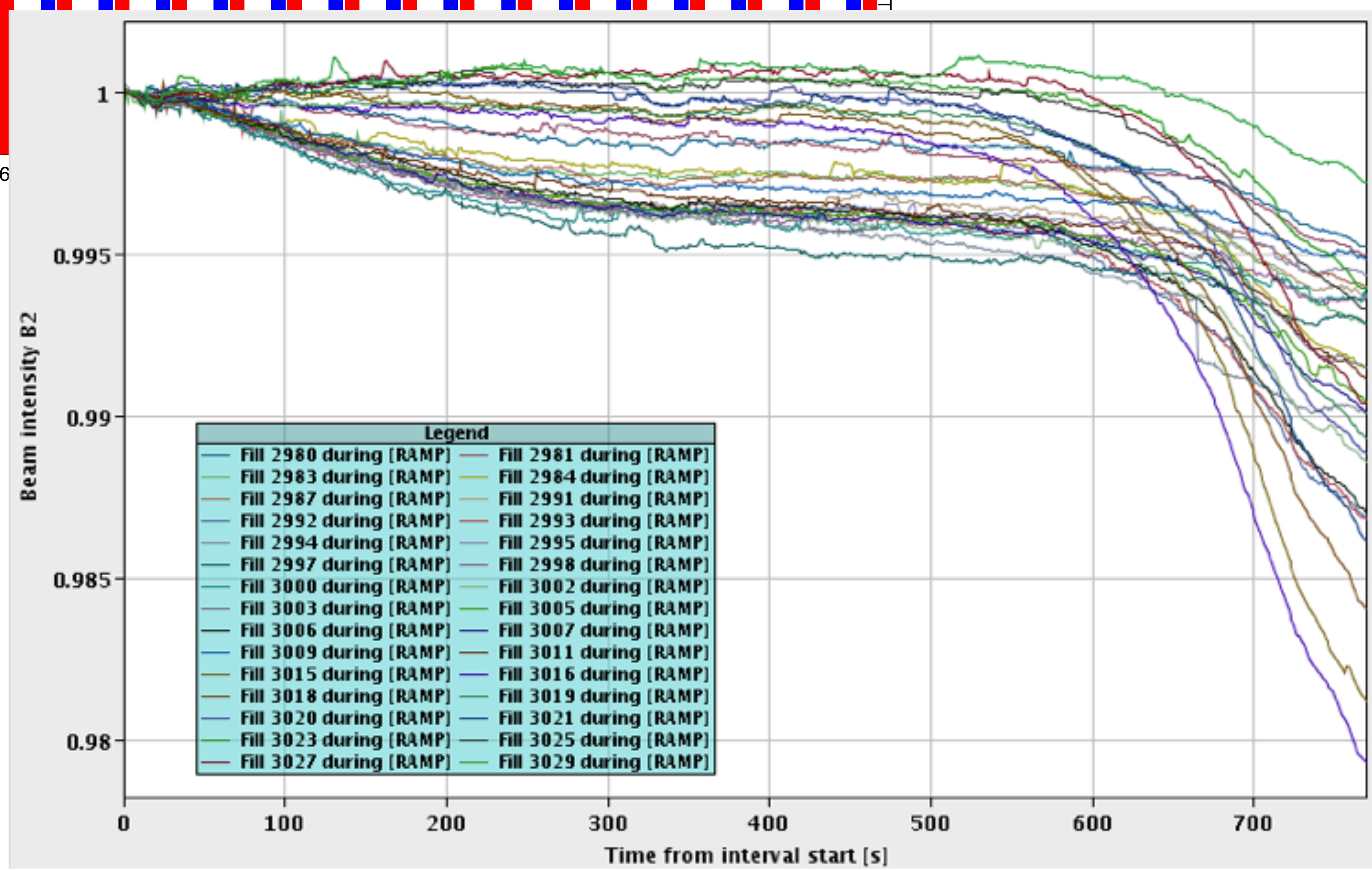
Collimator gaps during the OP cycle



Ramp losses in 2012



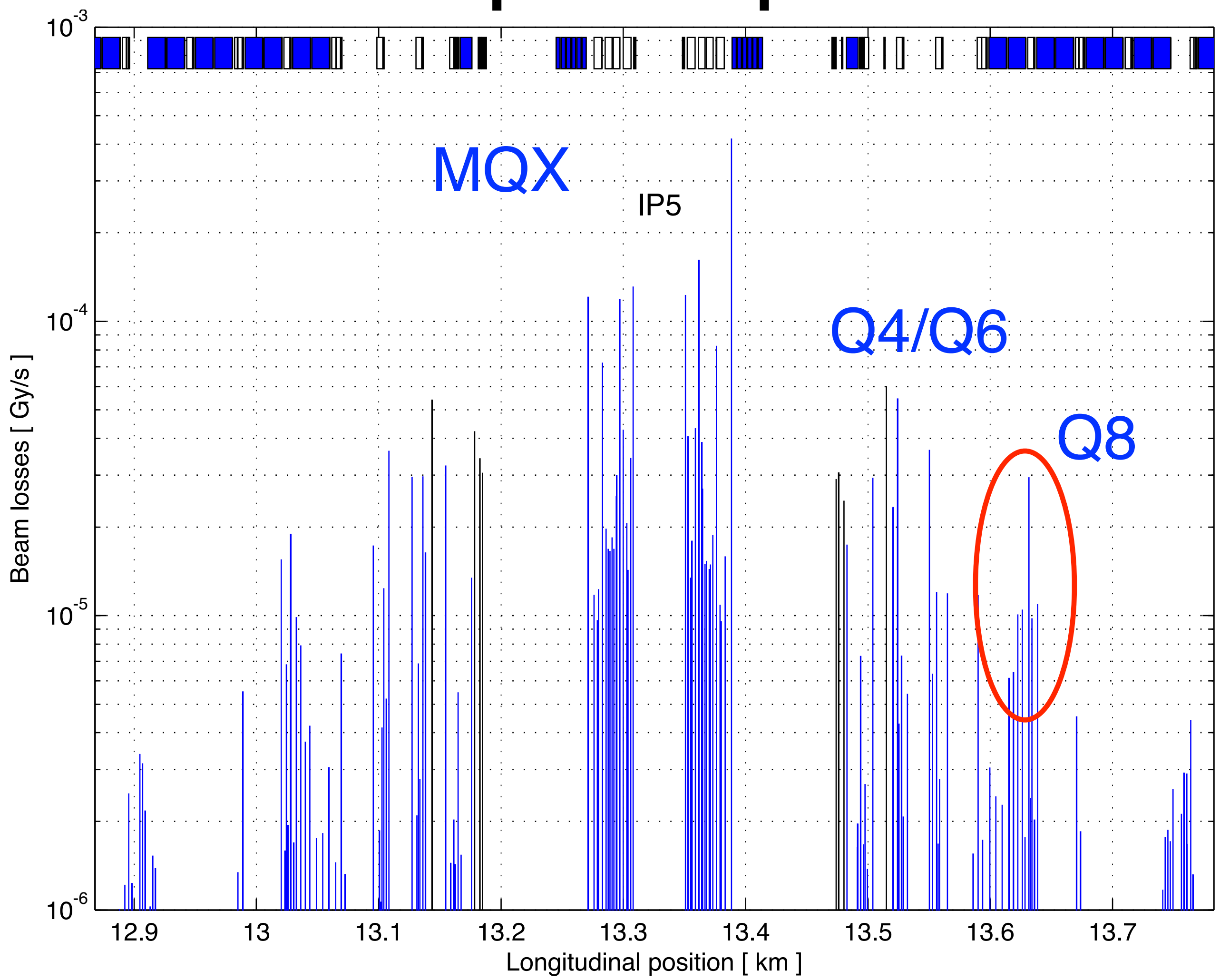
Typical intensity transmission during the 4.5 TeV ramp (2010/2011), relaxed collimator settings



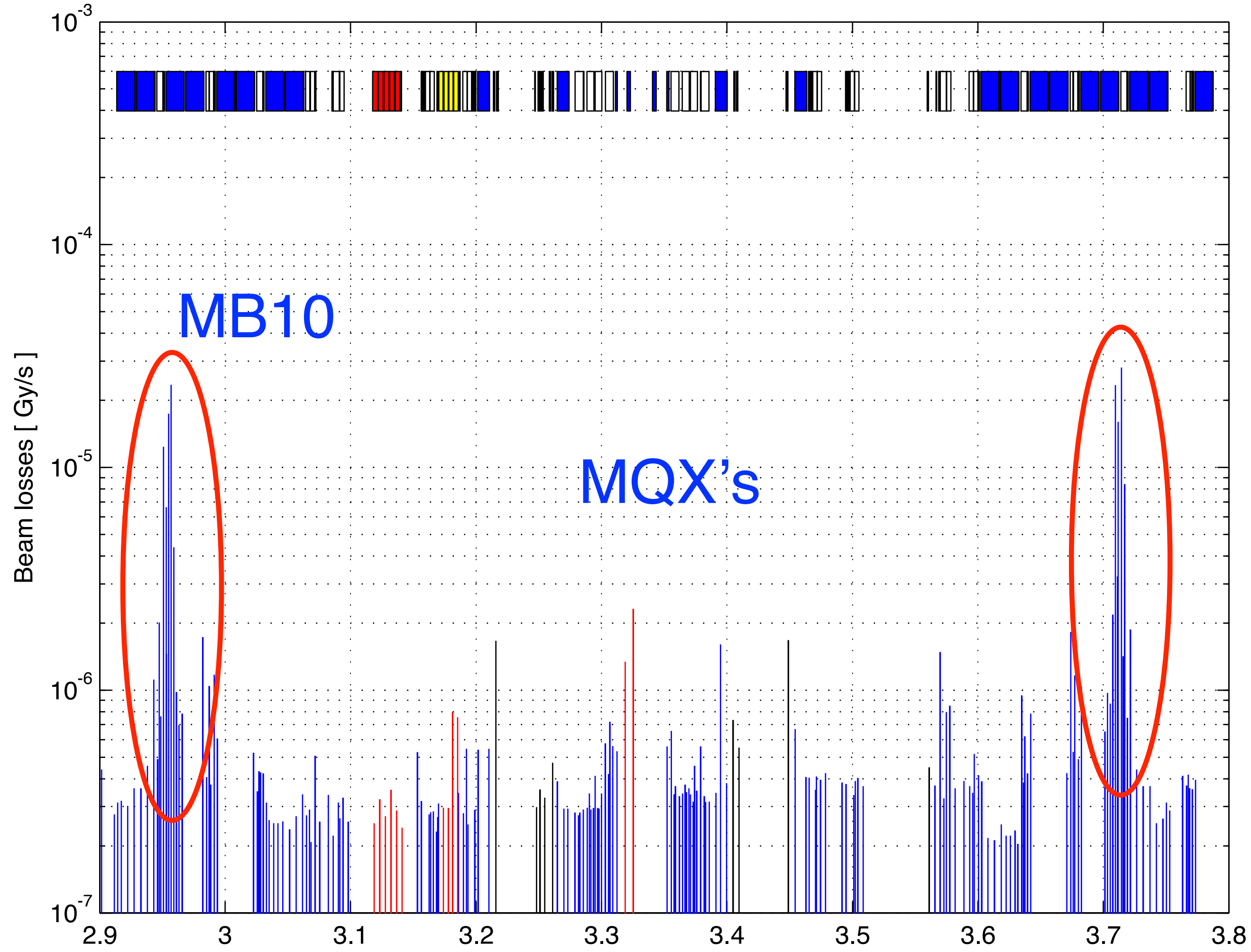
Transmission during the energy ramp in recent physics fills at 4 TeV, tight collimator settings.

Losses in experimental regions

IP5: proton operation



IP2: Ion operation

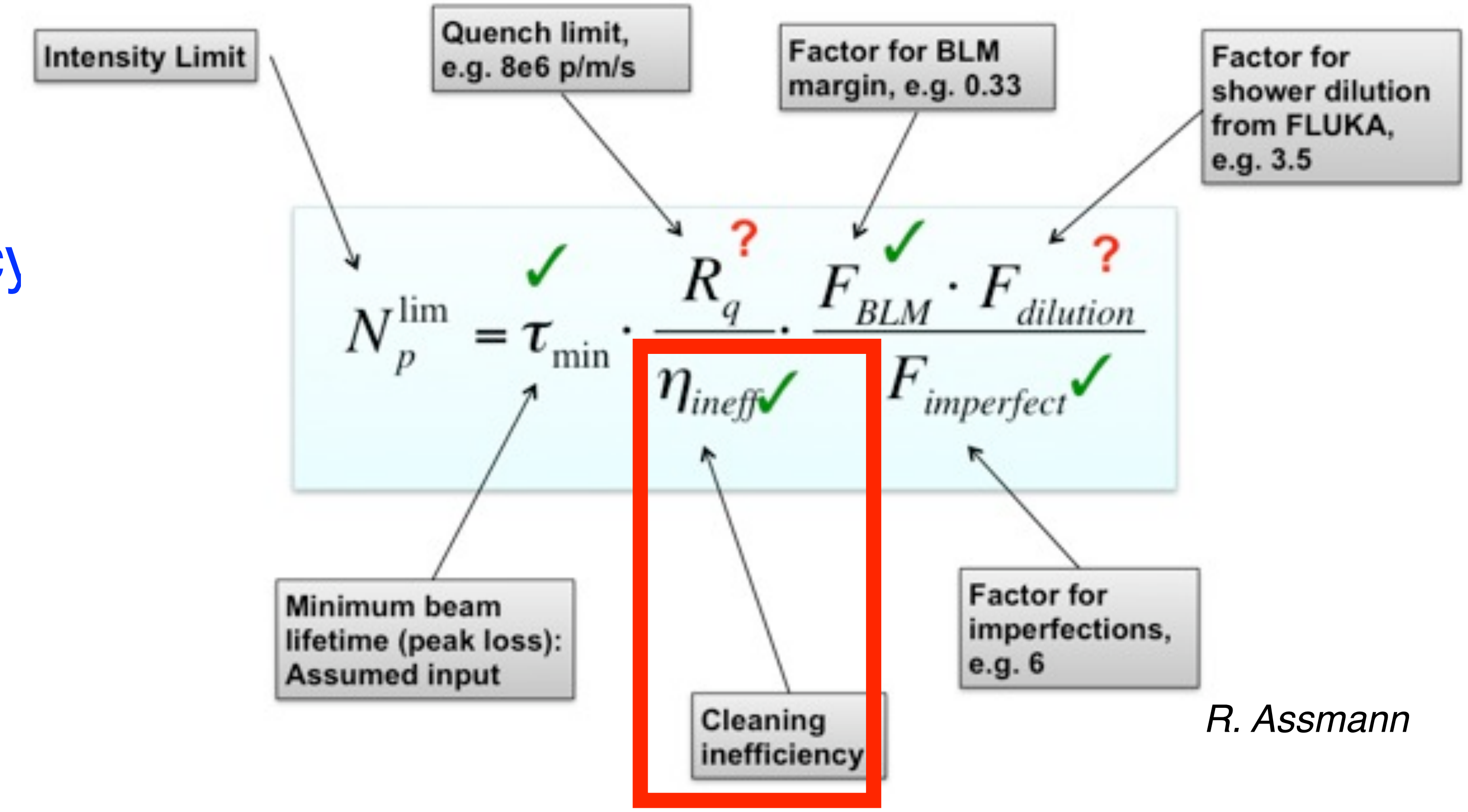


- **Continuous** losses in the dispersion suppressors of experimental regions during physics production
- Different loss locations for proton and ion beams in different IRs
- Local radiation caused by losses affected already the LHC operation!
- Can be cured satisfactorily only by local collimators in the DS
- Even if we would not quench, the magnet lifetime might become a concern

Design loss assumptions

Performance reach depends on:

- Collimation cleaning inefficiency
- Total beam intensity;
- Peak minimum lifetime;
- Quench limit of magnets;
- Loss dilution length.



R. Assmann

Our design specification:

Mode	T [s]	τ [h]	R_{loss} [p/s]	P_{loss} [kW]
Injection	cont.	1.0	0.8×10^{11}	6
	10	0.1	8.6×10^{11}	63
Ramp	≈ 1	0.006	1.5×10^{13}	1200
Collision	cont.	1.0	0.8×10^{11}	97
	10	0.2	4.3×10^{11}	487

This figures are being revised based on the beam experience