Beam-Induced Quench workshop, BIQ2014
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CERN, Geneva, Switzerland

Collimation BLM threshold strategy

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on behalf of the collimation project team
Acknowledgements: B. Auchmann, B. Holzer, FLUKA team
Initial inputs: R. Assmann, M. Sapinski

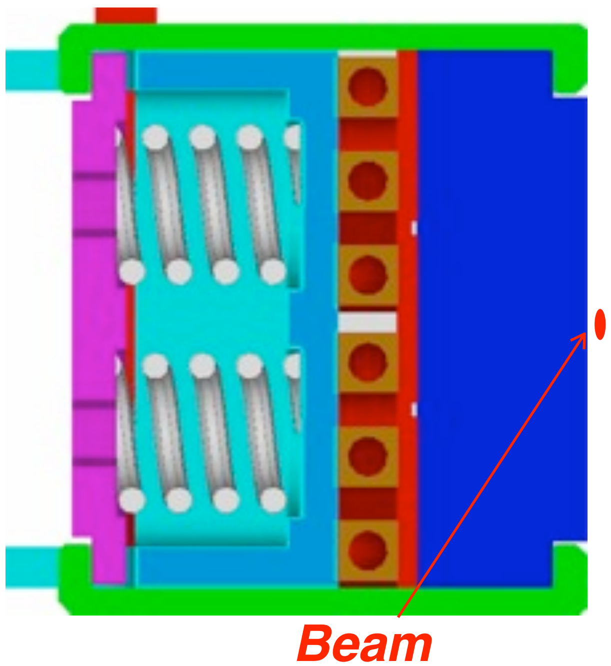
Outline

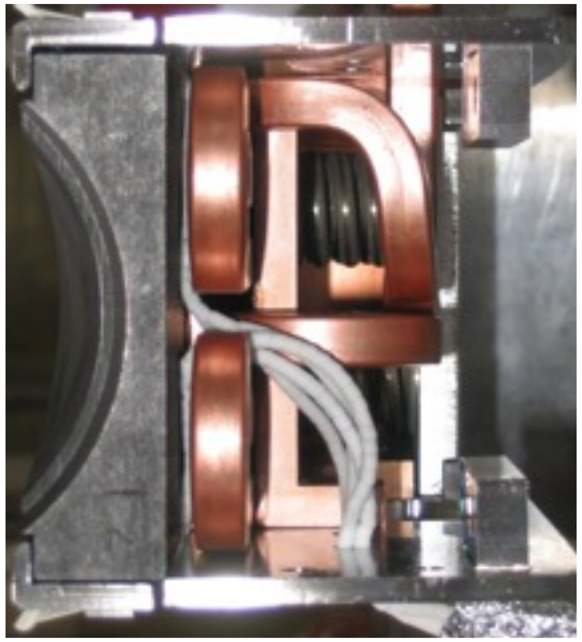
- Introduction
- Collimation layout and designs
- Run I threshold strategy
- 2015 strategy and improvements
- Conclusions

Introduction

Collimators are amongst the **most robust LHC components**

- *Ok for injection failure of 288x1.15x10^{11}p at 450GeV: tested in TT40 (2004/2006)*
- *Ok for up to 8 nominal bunches at 7 TeV (simulations for pessimistic conditions)*
- *Designed to allow operation with steady losses up to **500 kW** (in IR7)!*





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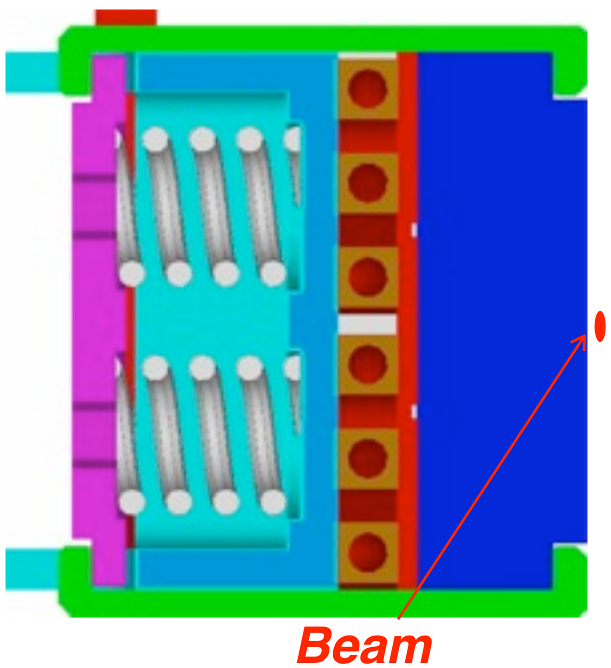

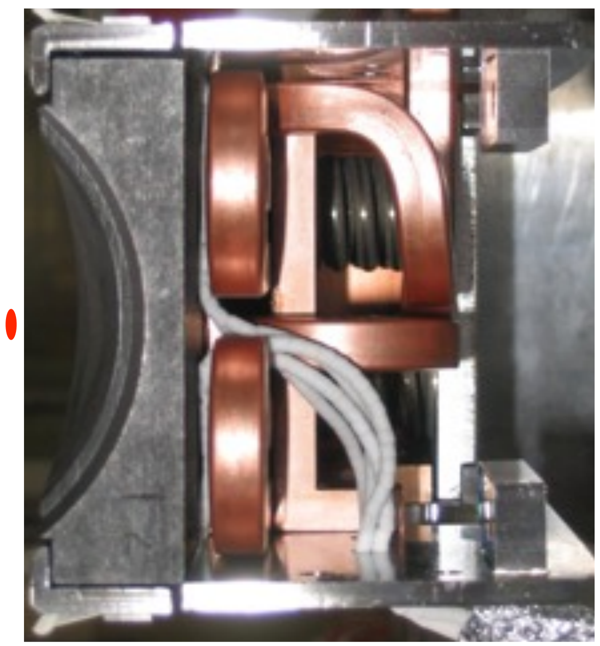

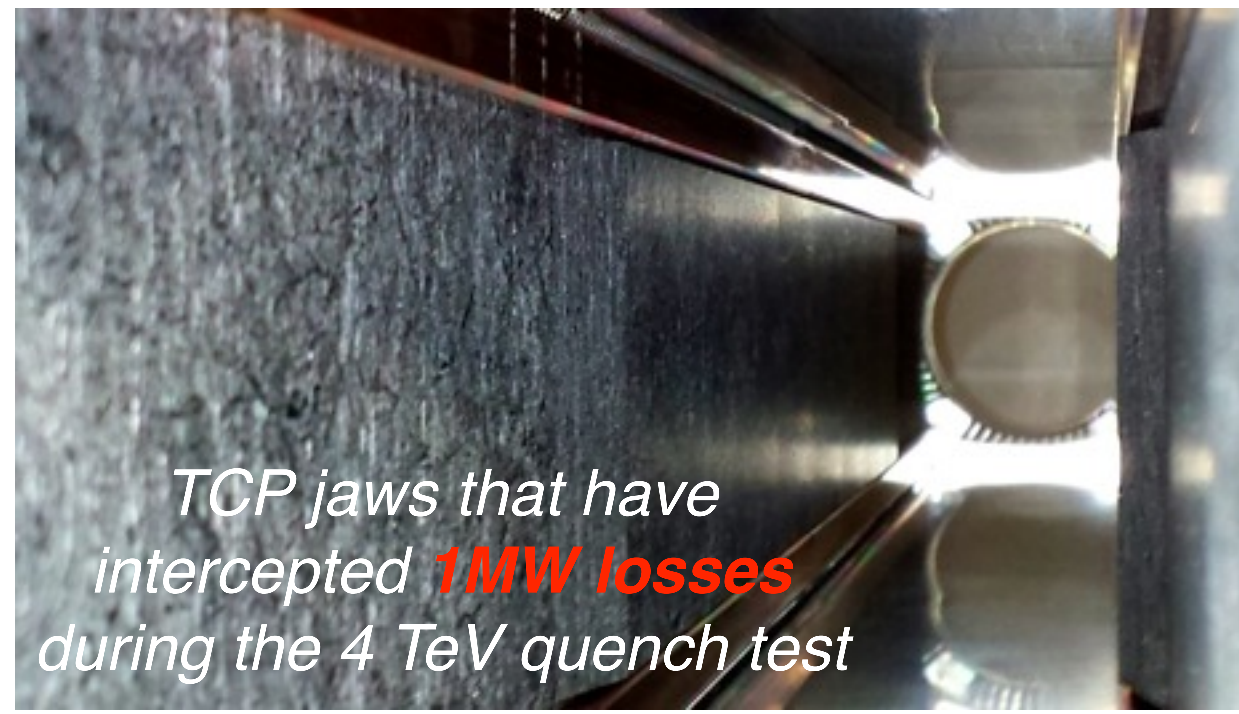

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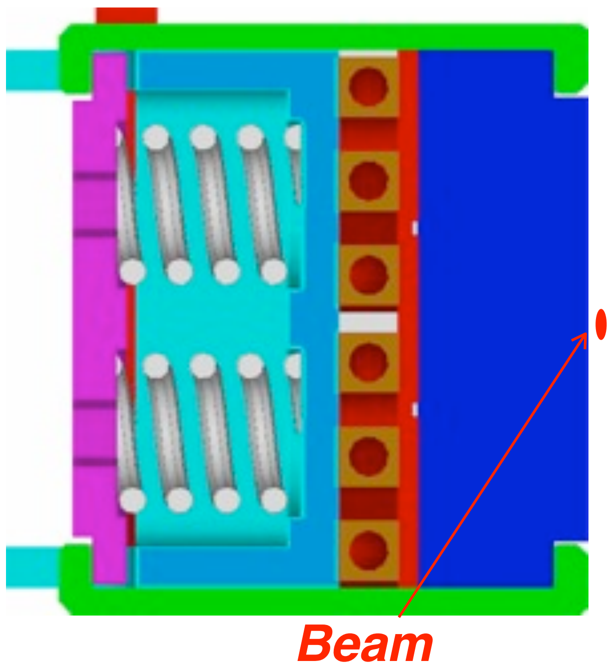

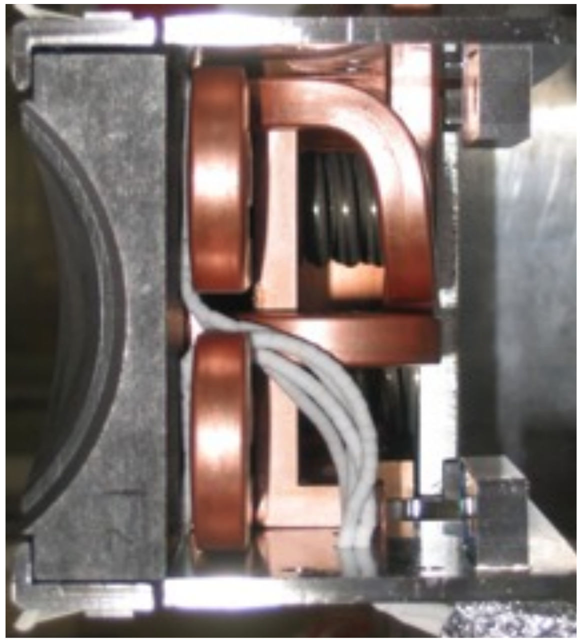

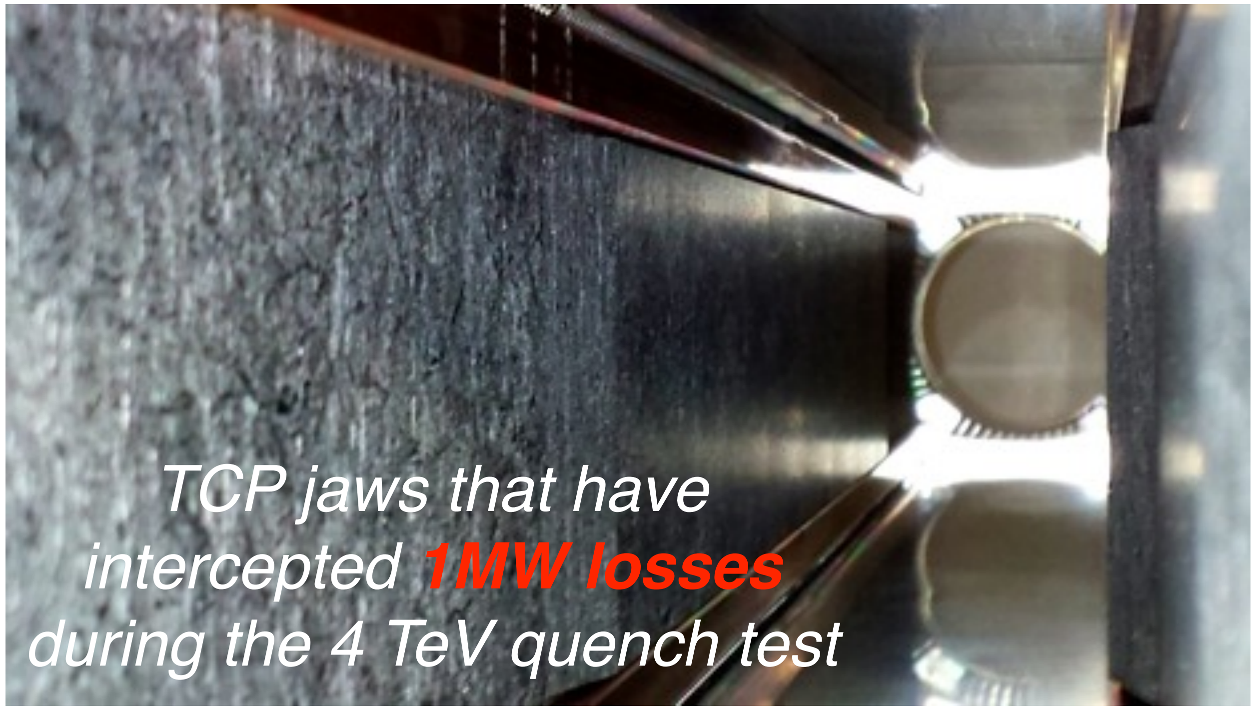

Why we need BLM protection thresholds for collimators:

- *Collimators are very high-precision devices. Their functionality can be jeopardized even in absence of apparent damage of robust jaw materials (e.g., plastic deformation compromising the 40 µm flatness);*
- *LHC metallic collimators are be more easily damaged by the beam;*
- *"Operational (OP) thresholds": largest losses at collimators*
  → *collimators are "ideal" locations to detect early on undesired loss conditions.*

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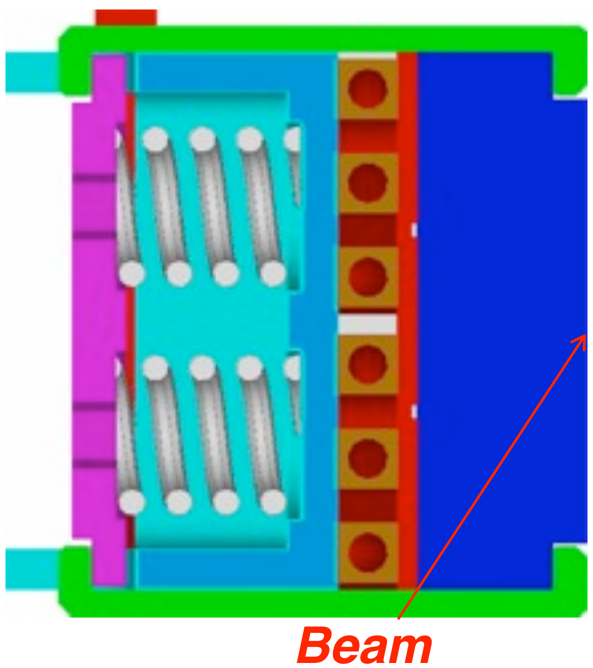

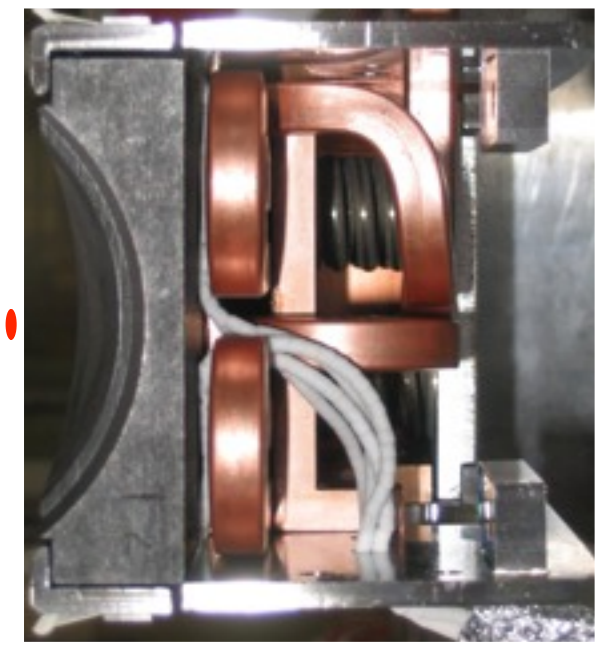

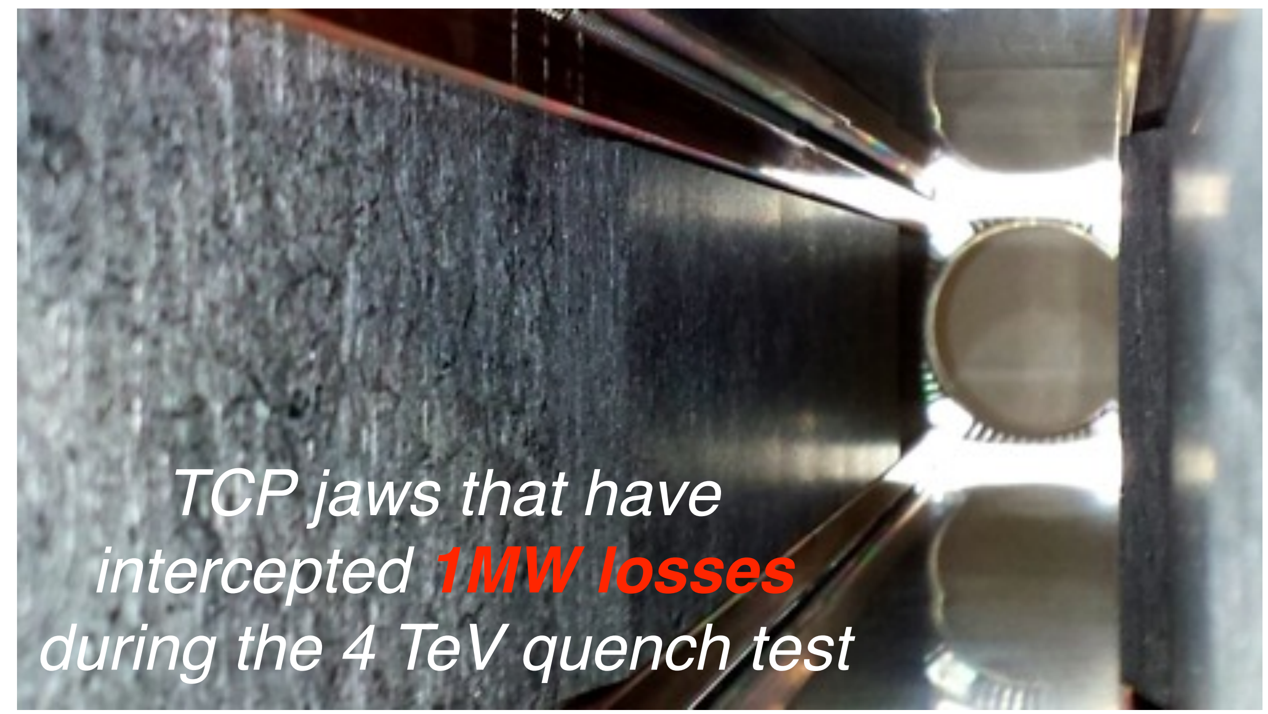

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- *"Operational (OP) threshold*
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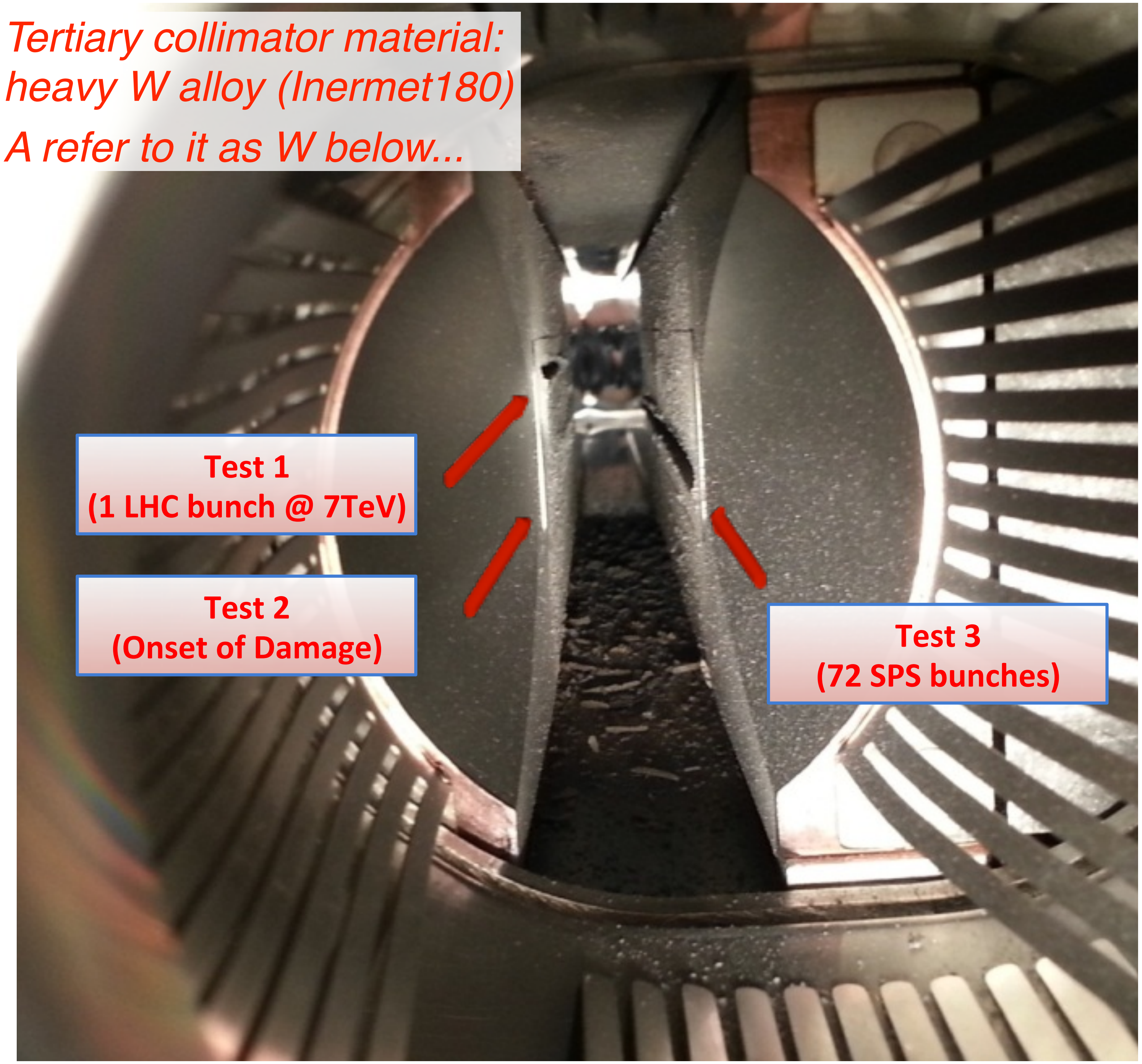
*Definition of **collimation BLM strategy** combines:*
- protection of individual collimator devices;
- "operational optimized" thresholds.

Beam can damage collimators...



Controlled beam test at the CERN HiRadMat facility: 440 GeV SPS beams simulating the effect of single-turn failures at the LHC. Tested a inermet180 (W) tertiary collimator.

"Test 1"→ Equivalent to one single LHC bunch at 7 TeV

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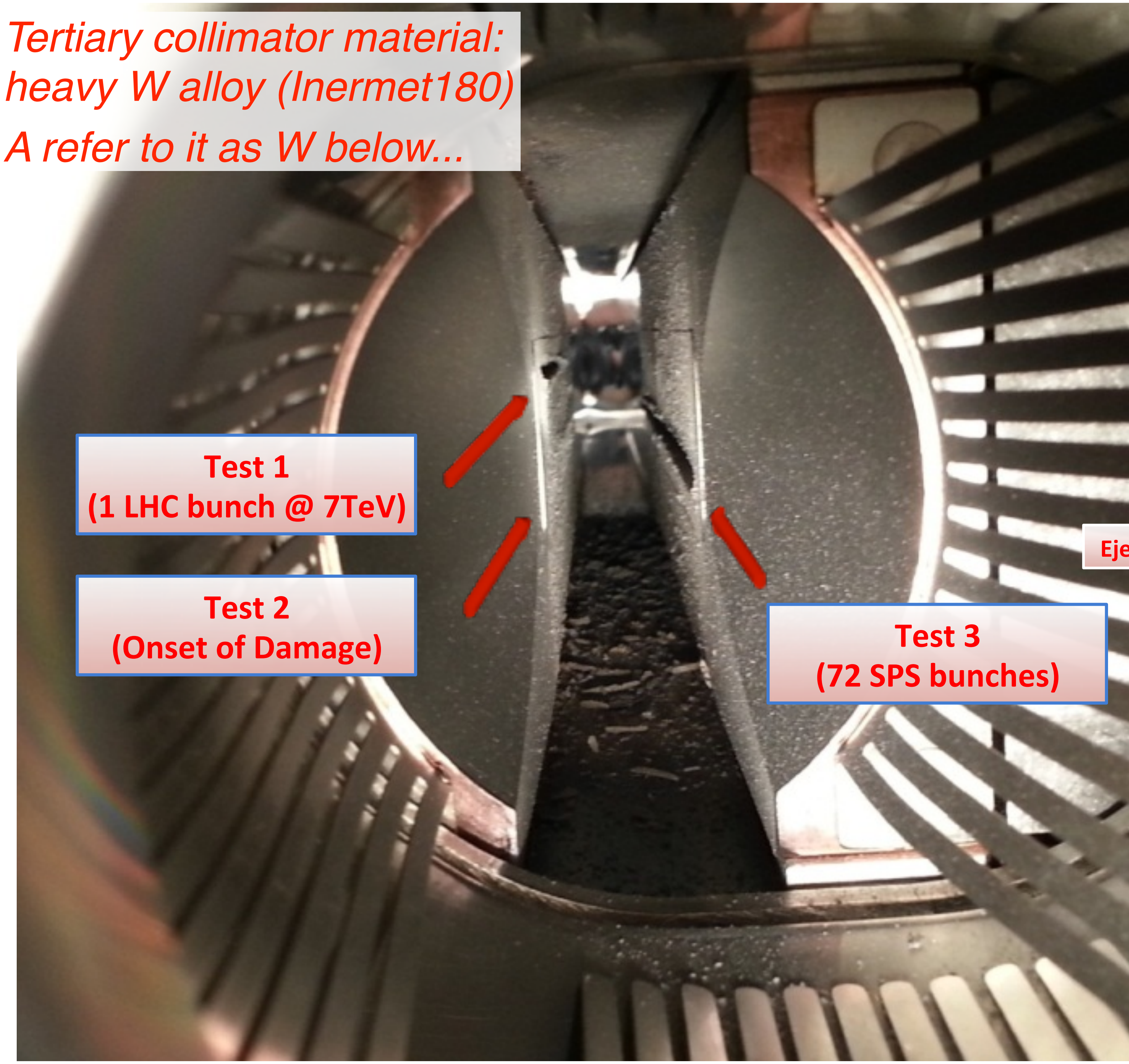

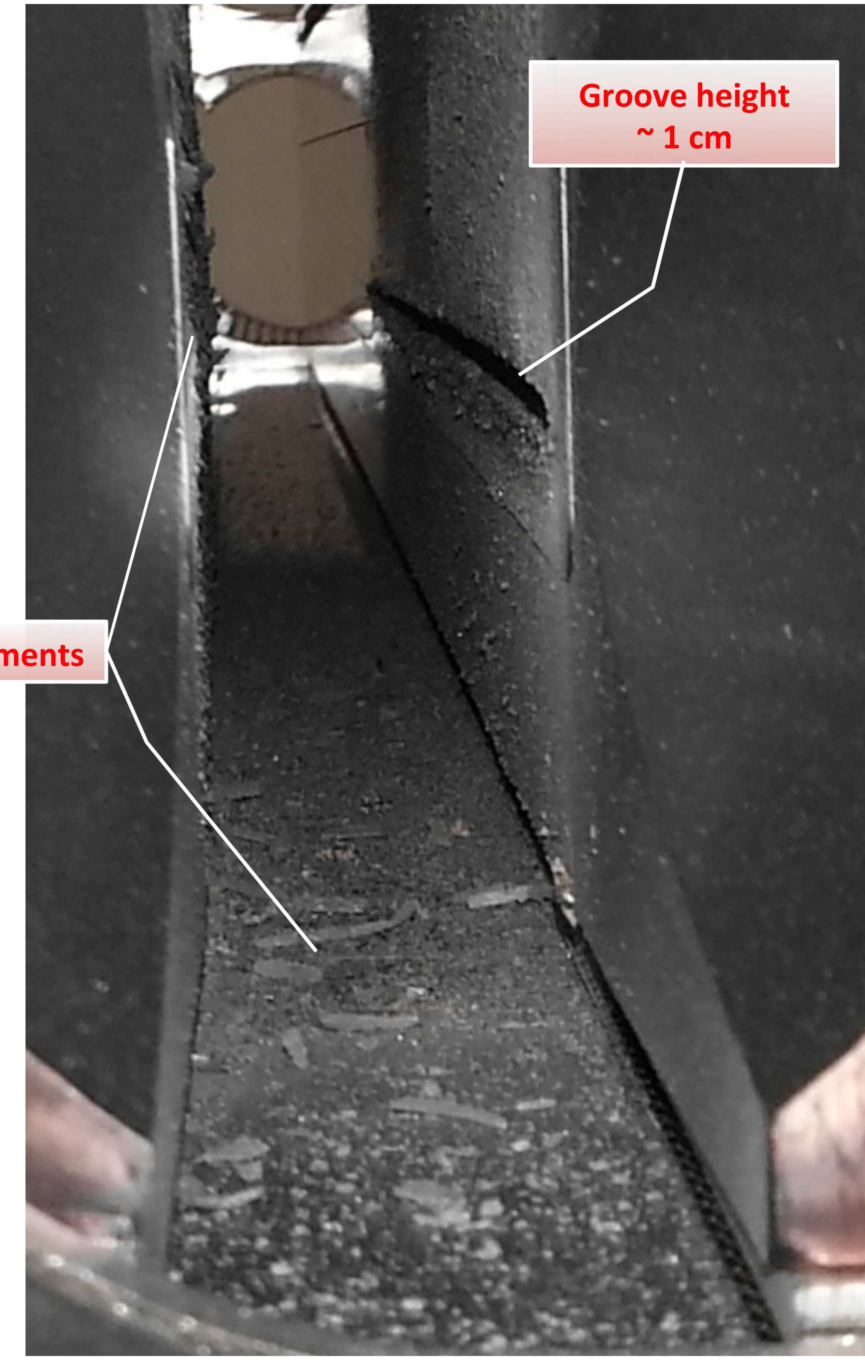

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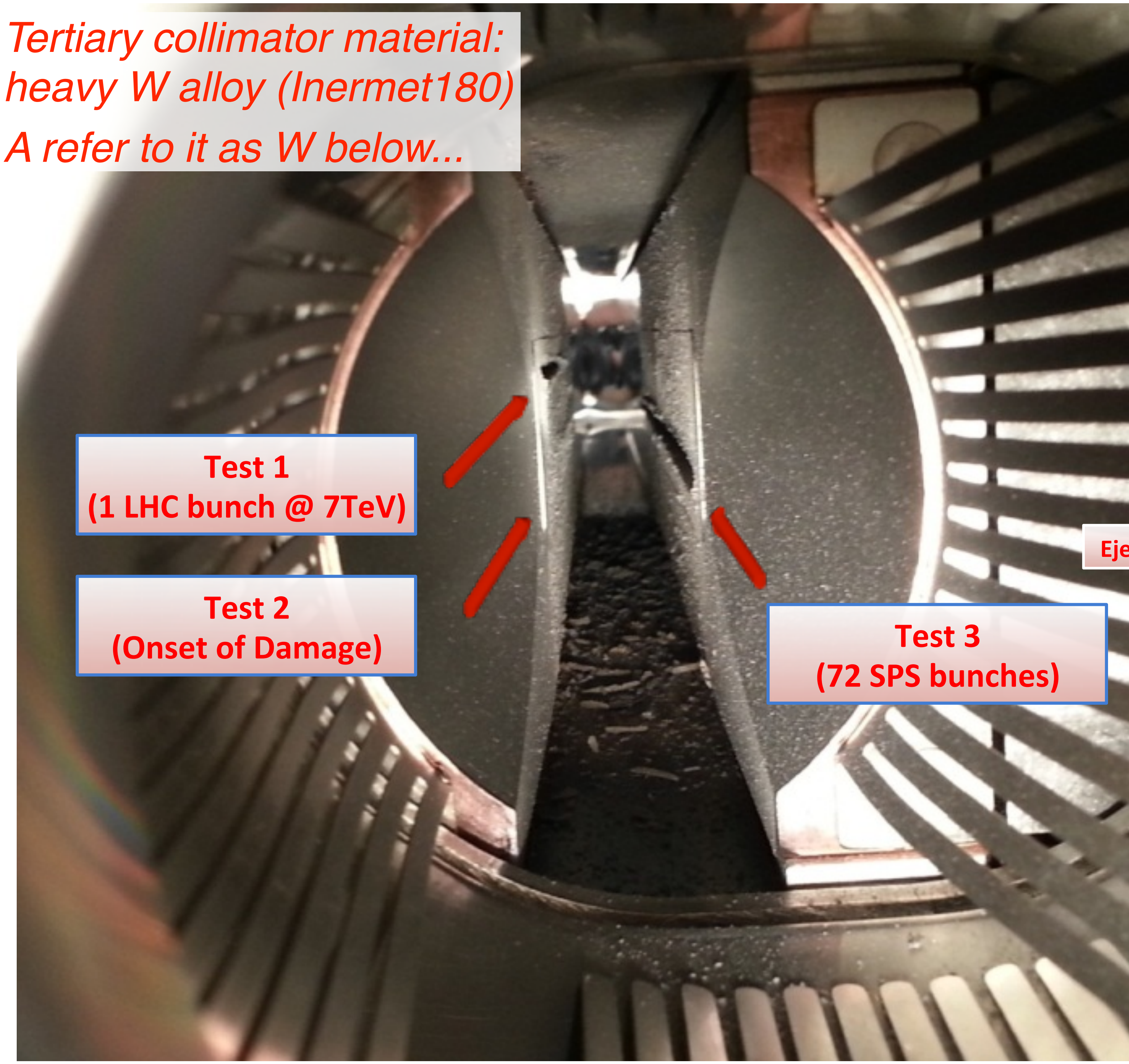
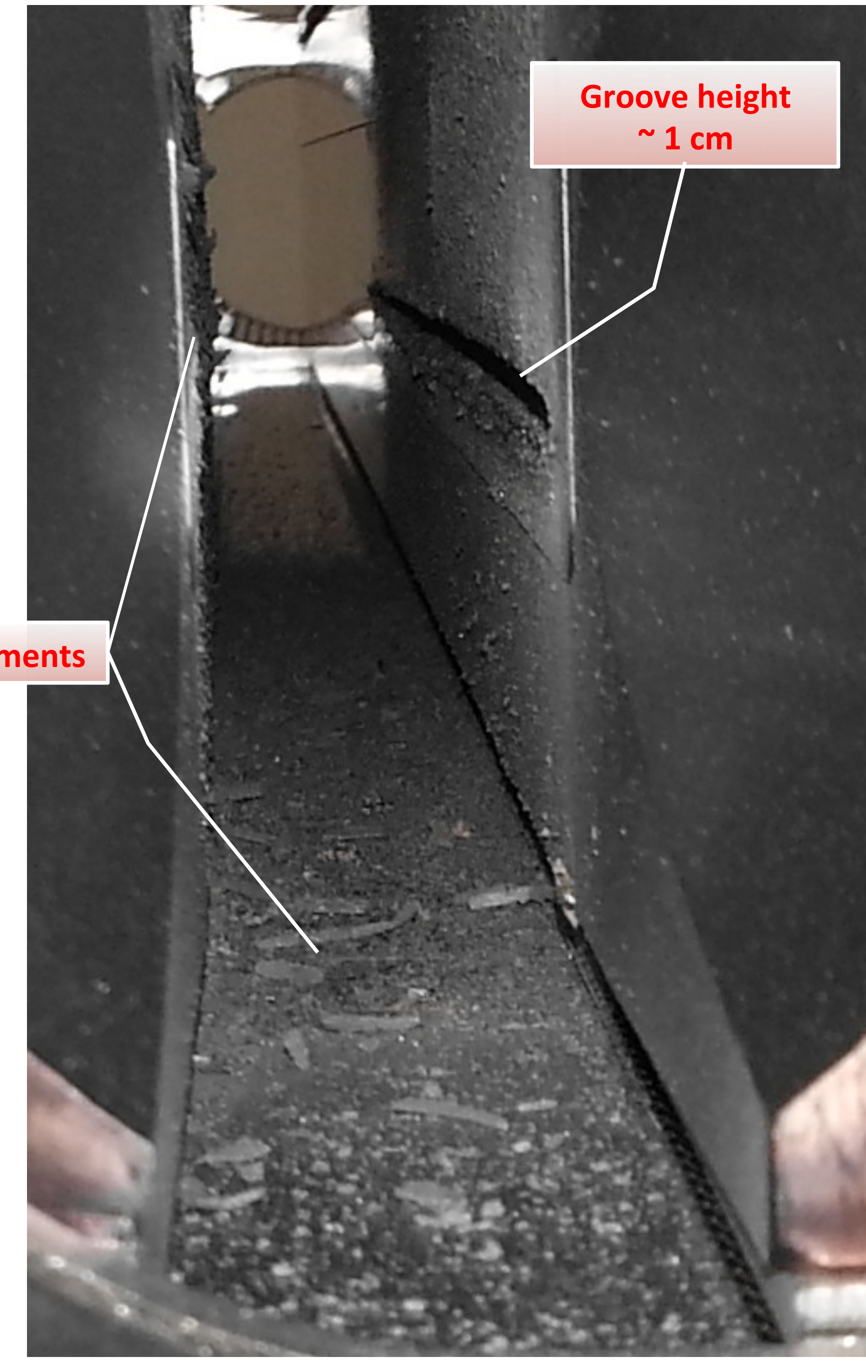
Tertiary collimator material:
heavy W alloy (Inermet180)

A refer to it as W below...



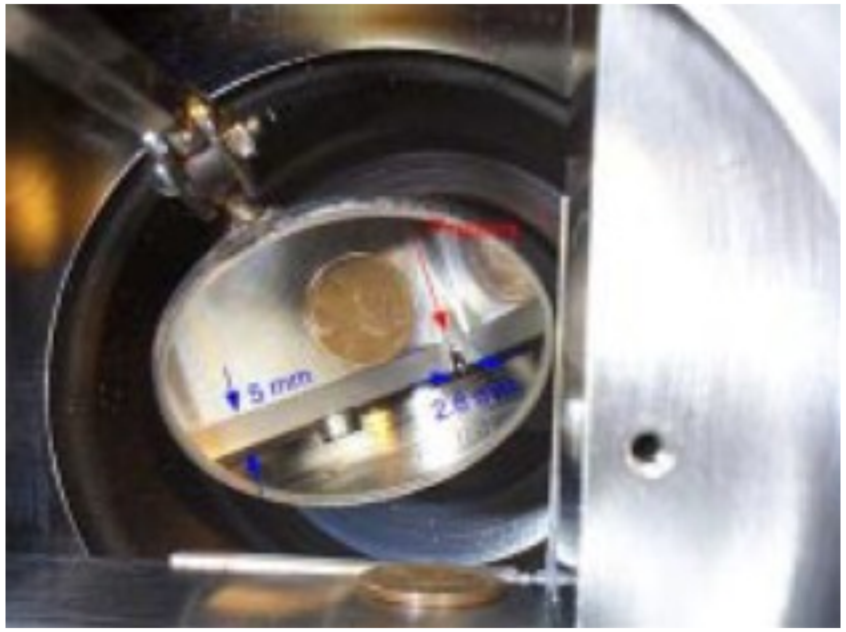


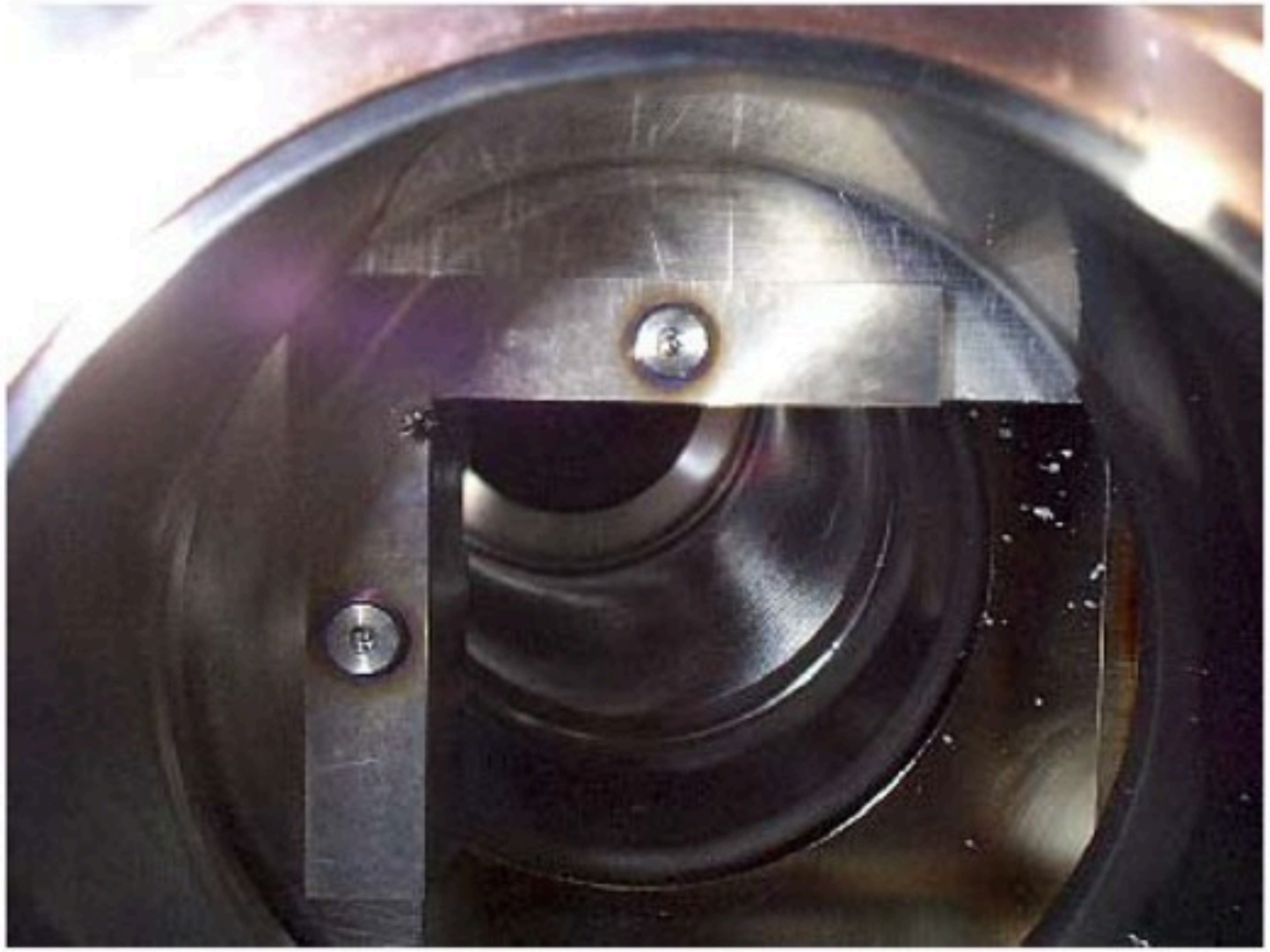
Controlled beam test at the CERN HiRadMat facility: 440 G
effect of single-turn failures at the LHC. Tested a inermet18

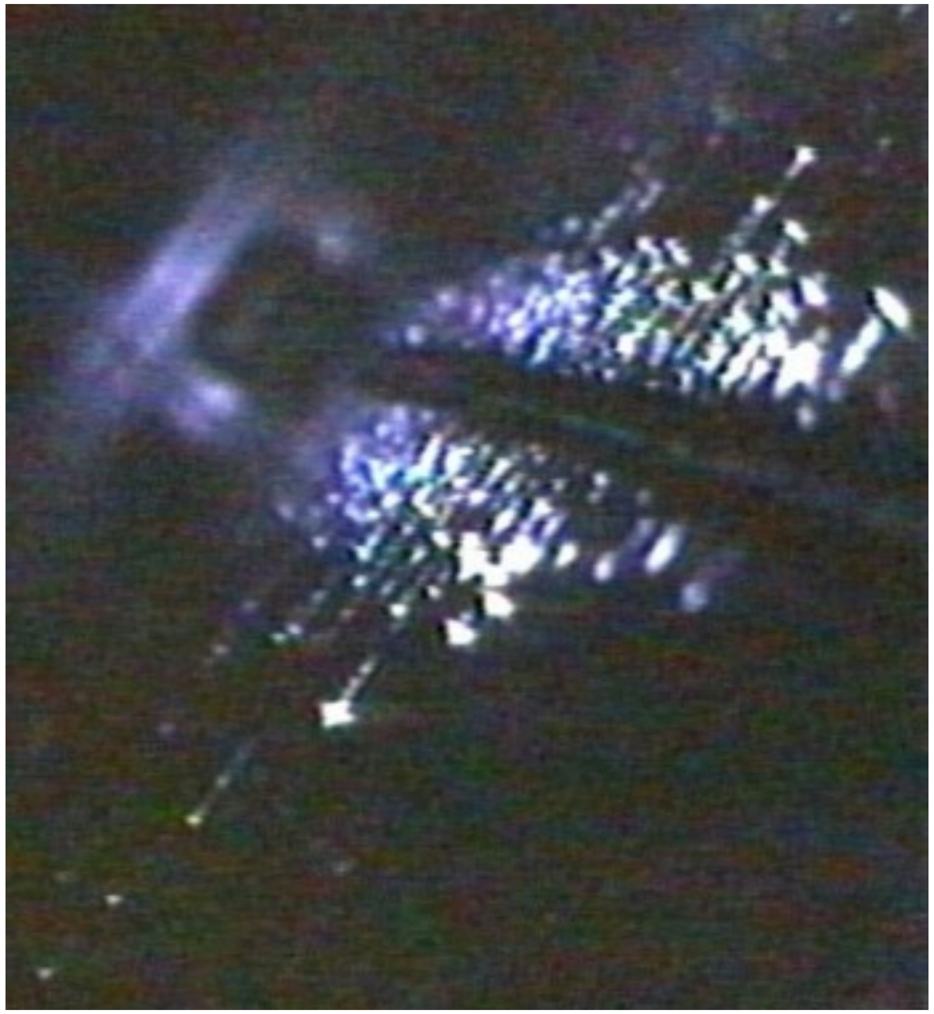
"Test 1"→ Equivalent to one single LHC

Recap.: BLM cannot protect against single-turn failures!

Examples from the Tevatron



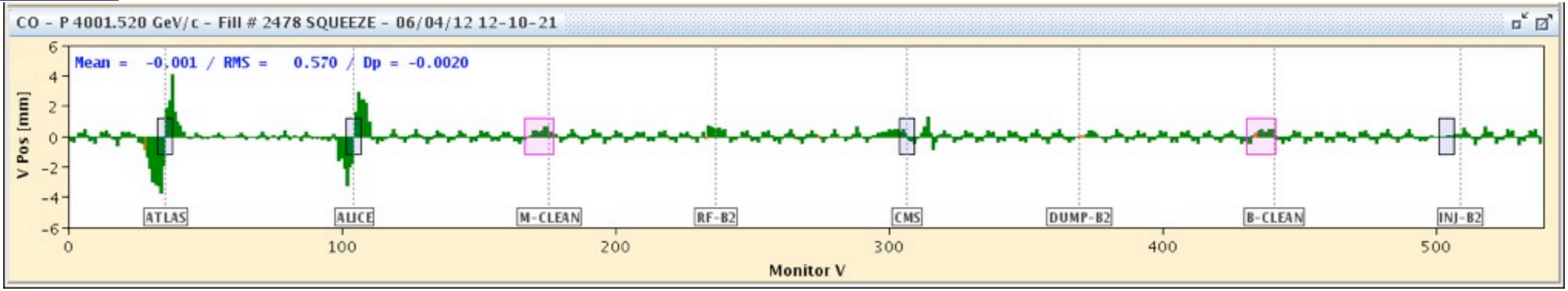




“Famous” Dec. 2003 event: see details in FERMILAB-FN-751 (Jun. 2004).

After a dipole quench (caused by Roman pot insertion), an orbit drift sent the beam into primary scatterer, then secondary collimator.

TCT losses at the LHC



Fill 2478 (April 6th, 2012), dumped during the squeeze.
Vertical orbit reference feedback was flattened at the squeeze end.
Beam current ~ 1.1×10^{13}p at 4 TeV; ~7 MJ stored

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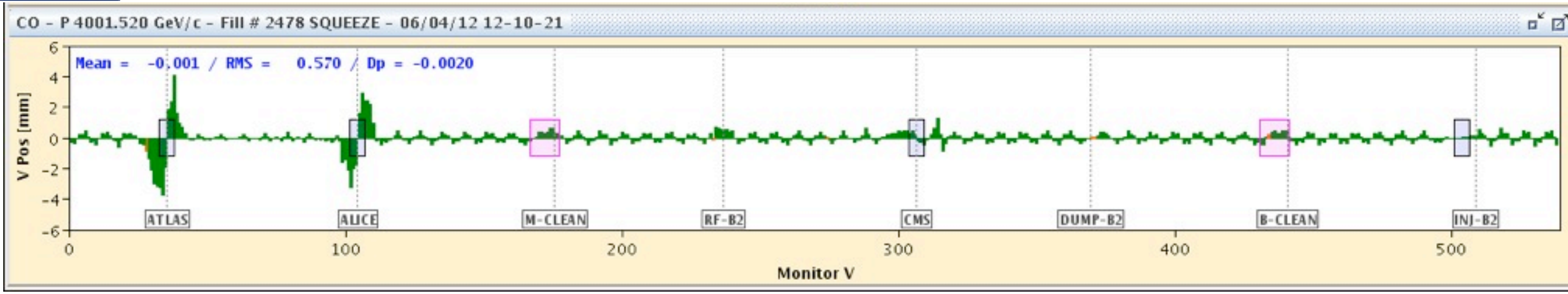

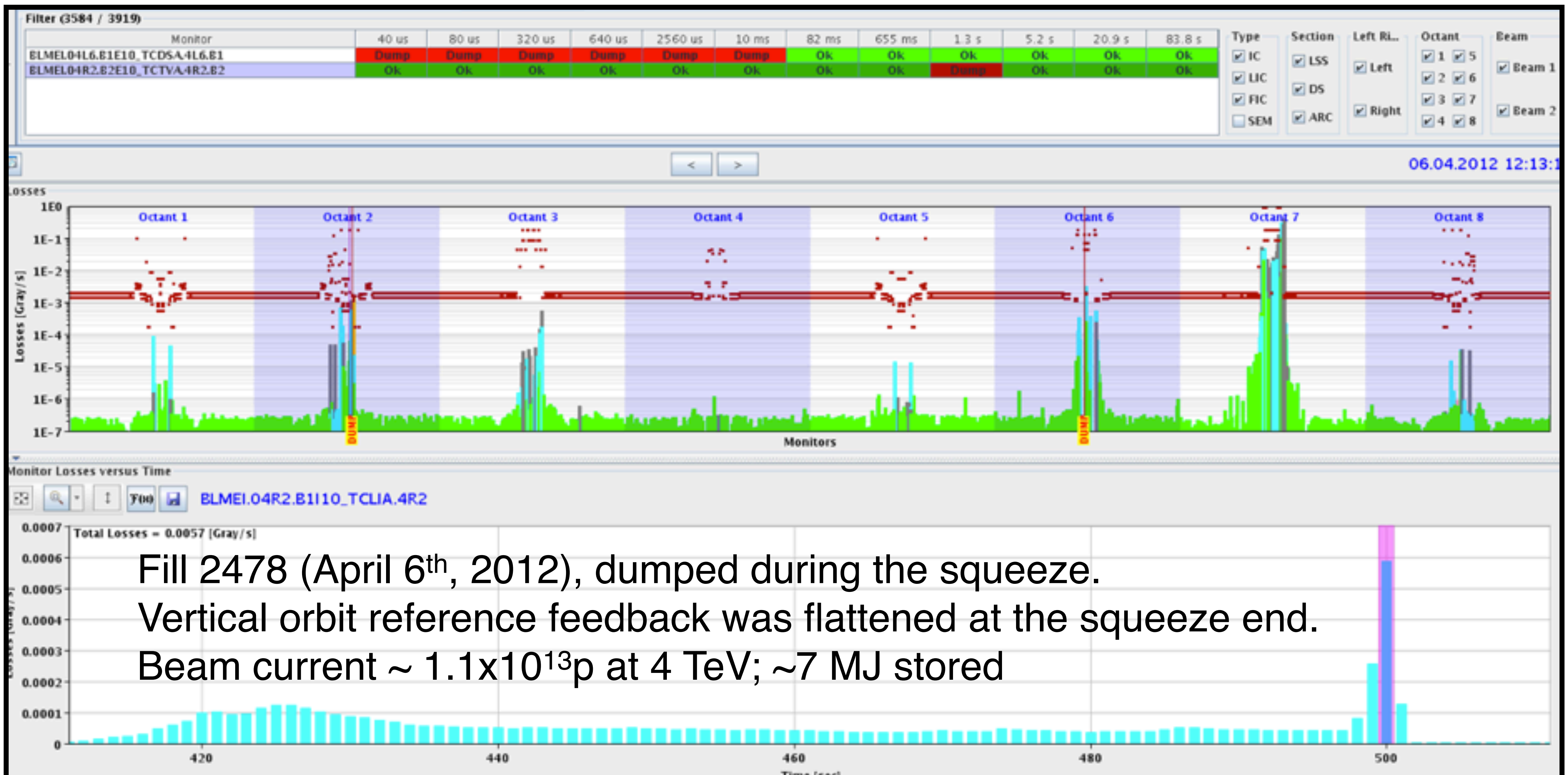

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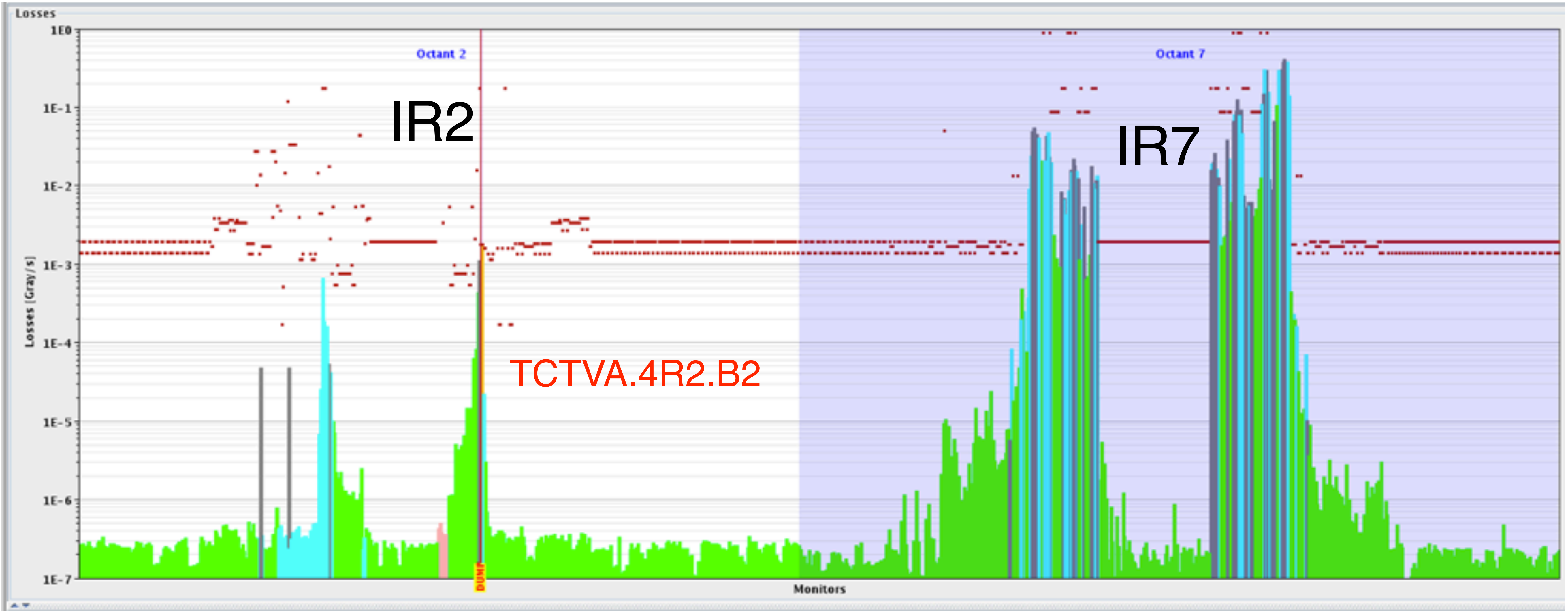
Zoom in IR2 / IR7



The beam did not quite "touch" yet the metallic collimator: beam dump occurred with primary losses still under control in IR7!
The problem was amplified by a setting error in the TCT, but similar issues can happen any time in case of local orbit "structures" build-up.

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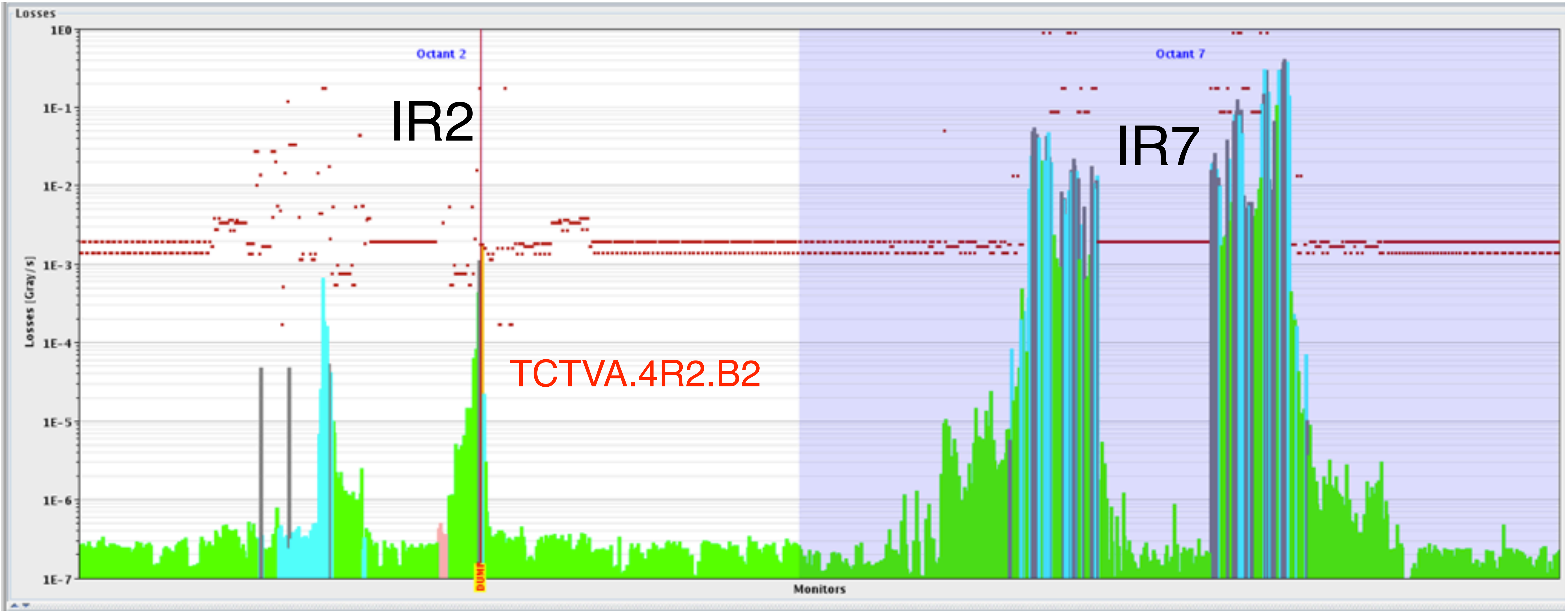

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The collimator BLM might be the last line of defense to prevent collimator damage!

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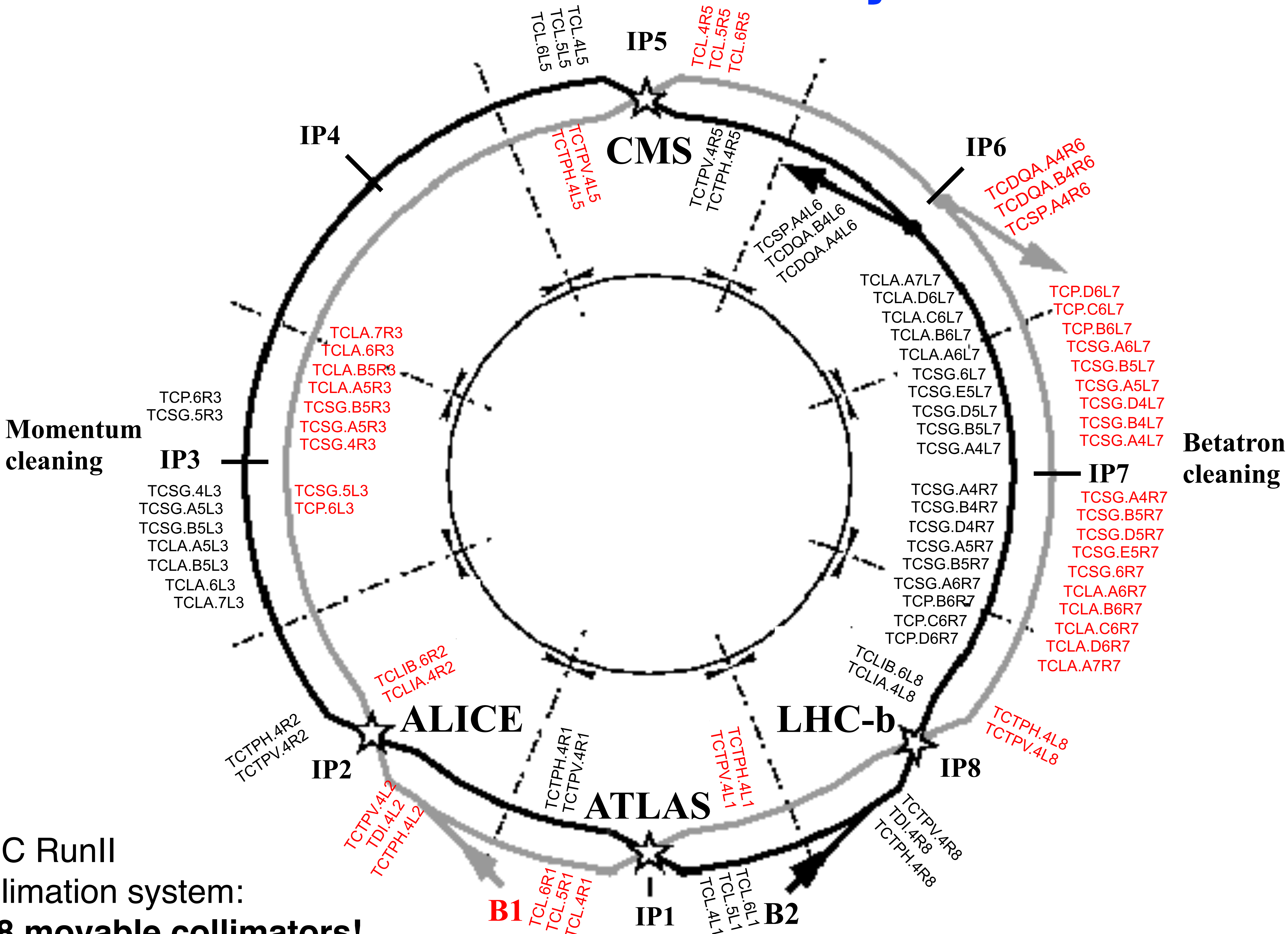
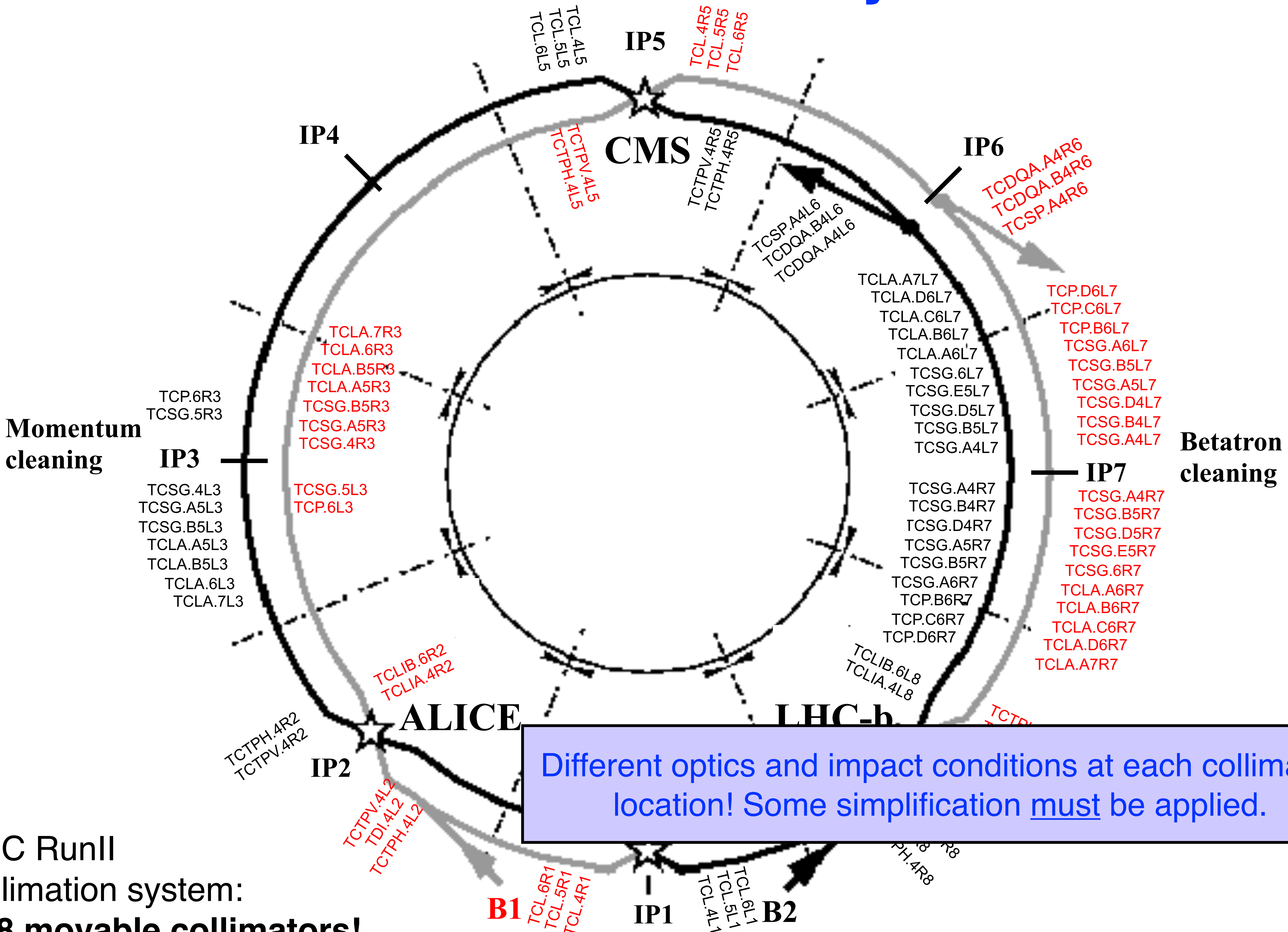
2015 collimation layout



LHC RunII
collimation system:
108 movable collimators!

2015 collimation layout



Different optics and impact conditions at each collimator location! Some simplification must be applied.

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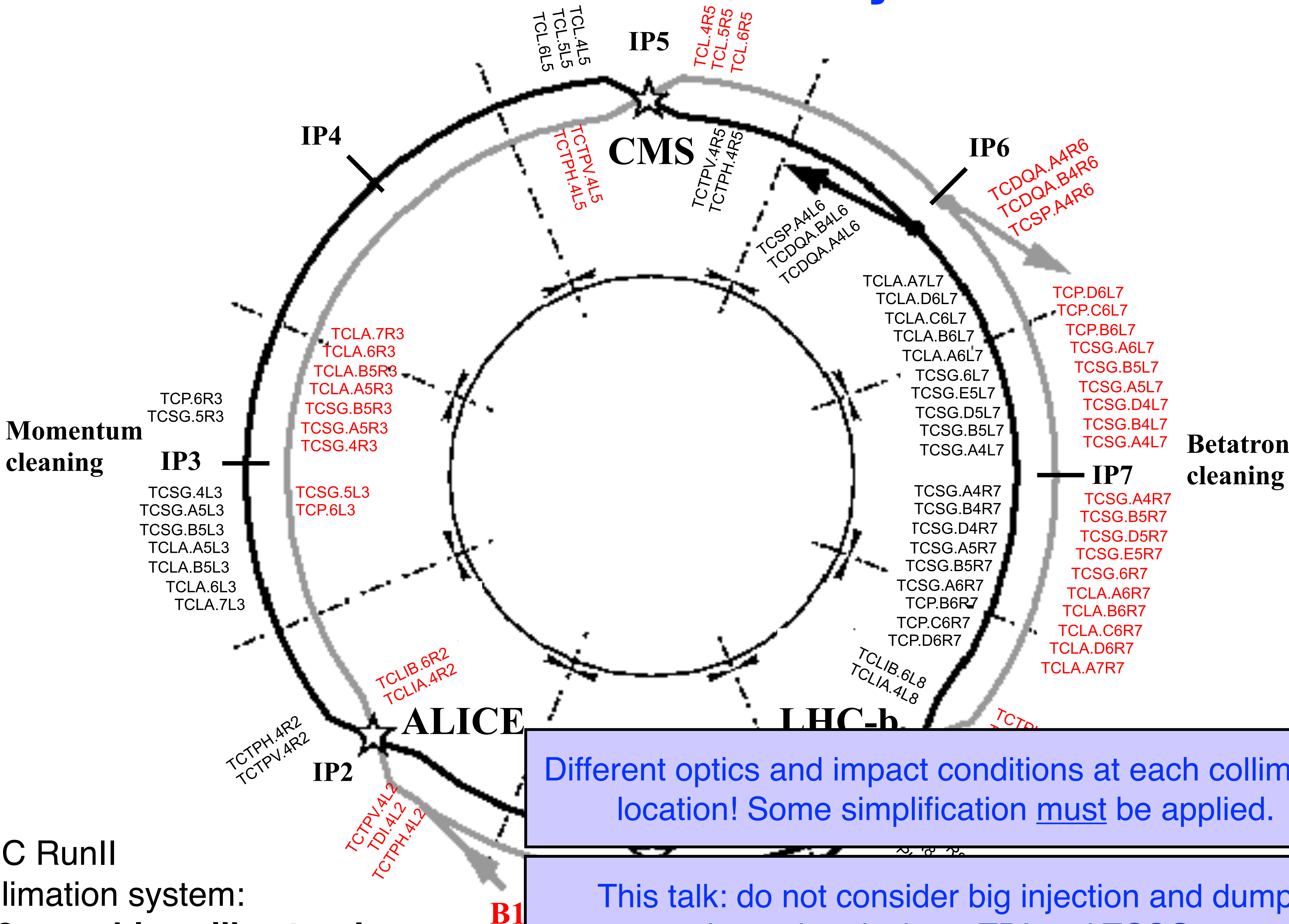

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This talk: do not consider big injection and dump absorption devices, TDI and TCSQ.

LHC RunII collimation system:
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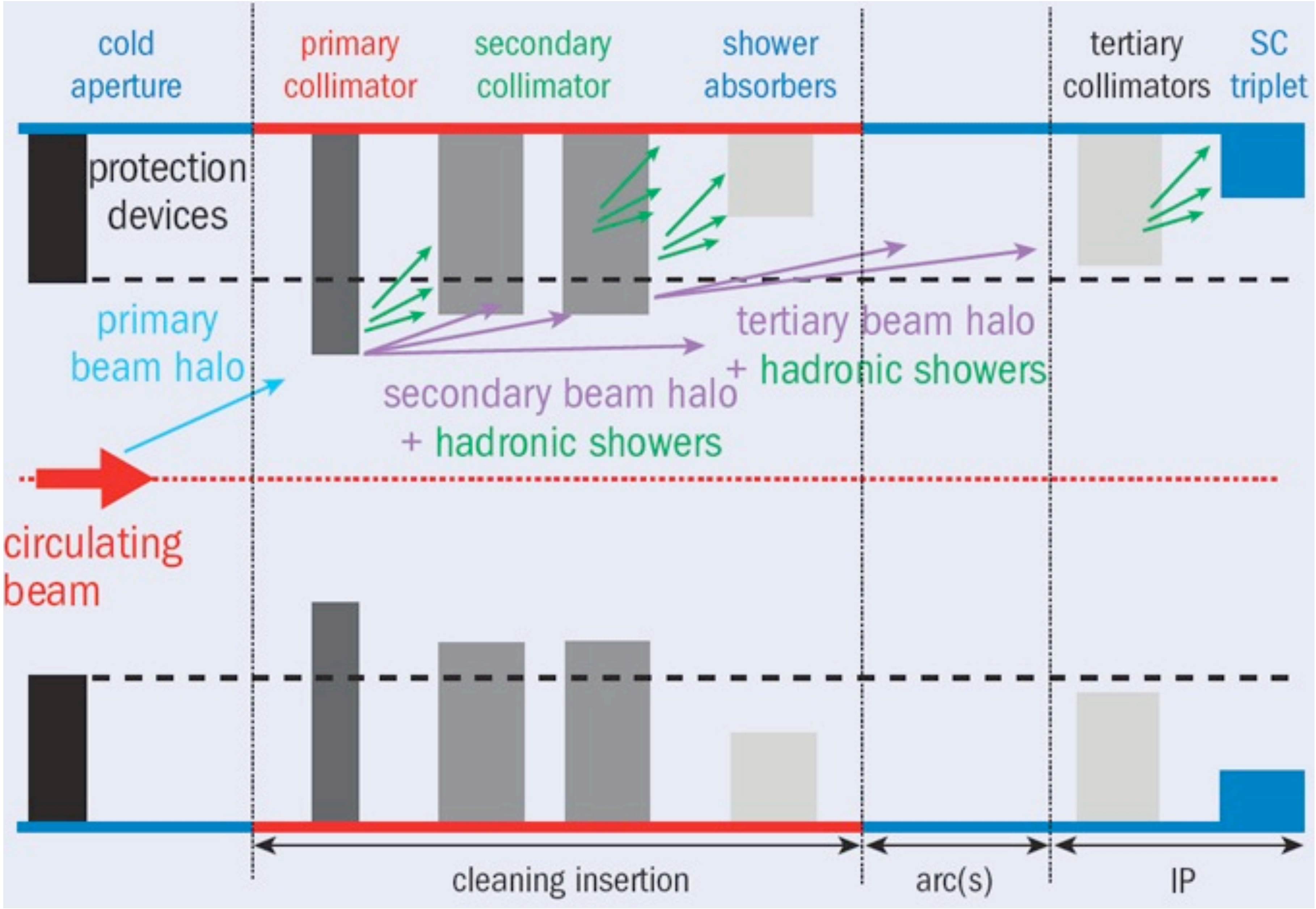
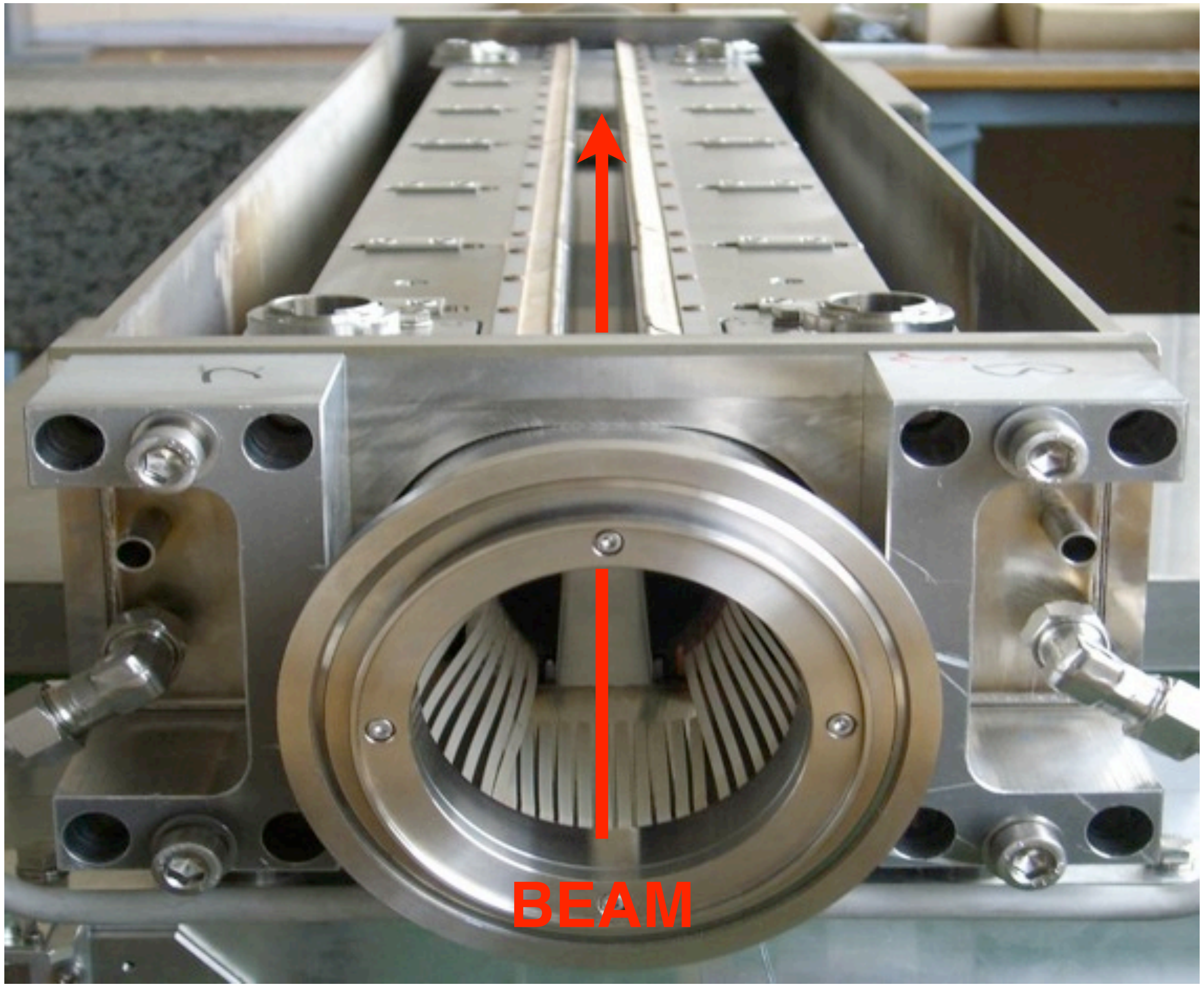
Recap. of multi-stage collimation

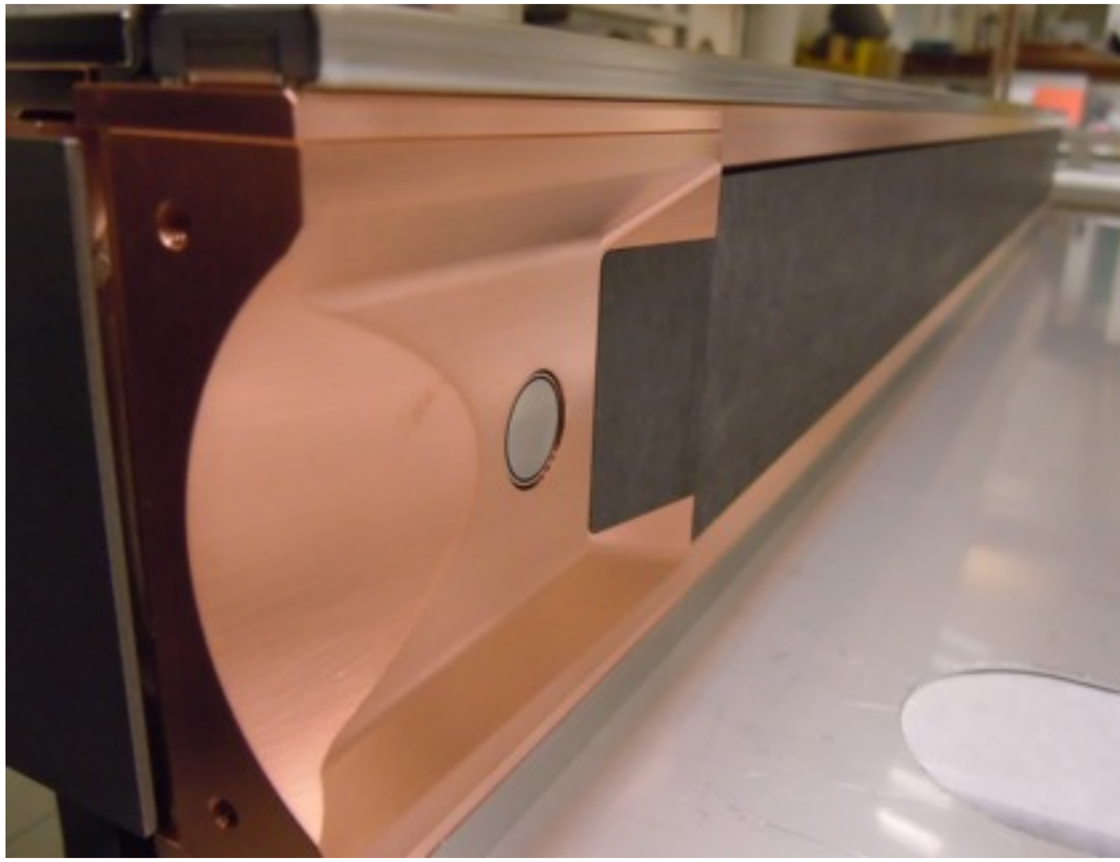


Only robust collimators (primary and secondary stage) are within the envelope of passive machine protection. These are the ones designed to withstand asynchronous dumps (up to 8 bunches at 7 TeV)!

Collimator designs



CFC jaw with BPM



Several designs and materials to fulfill different requirements around the ring...

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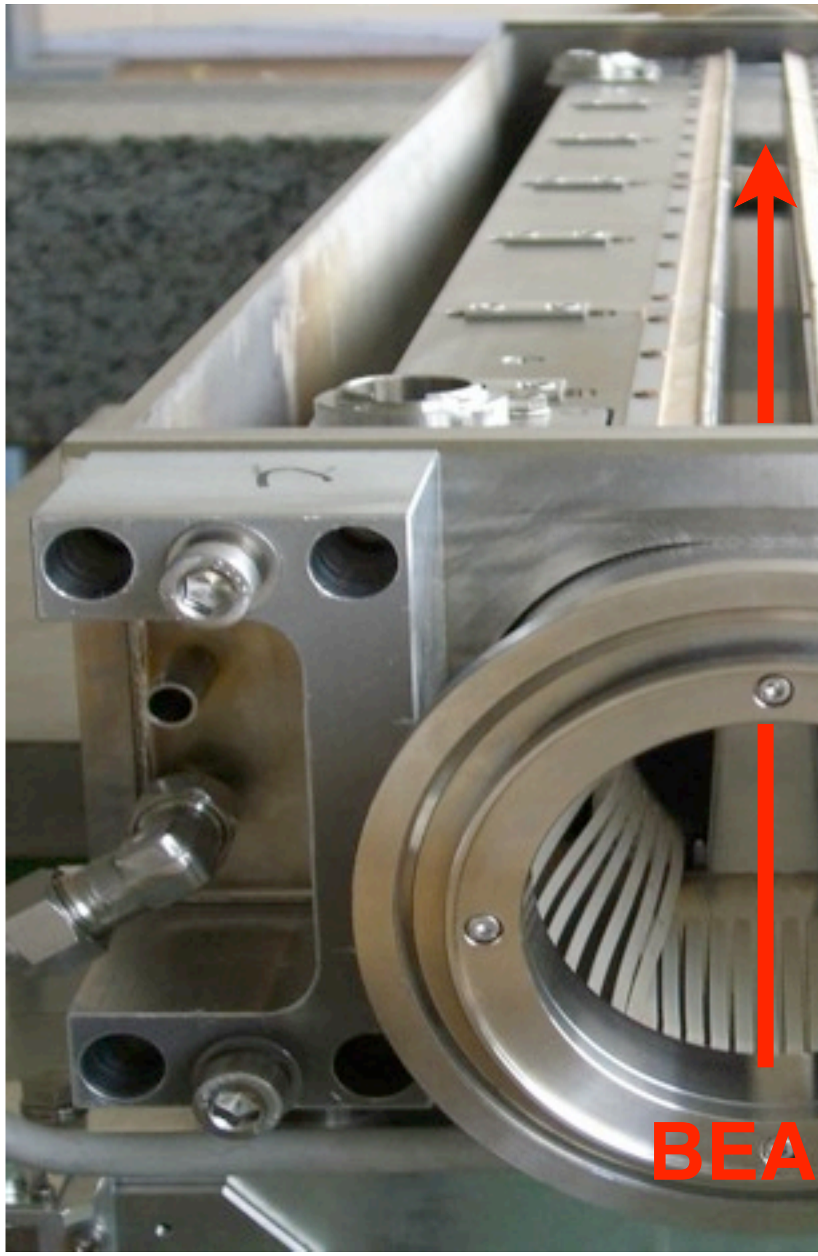

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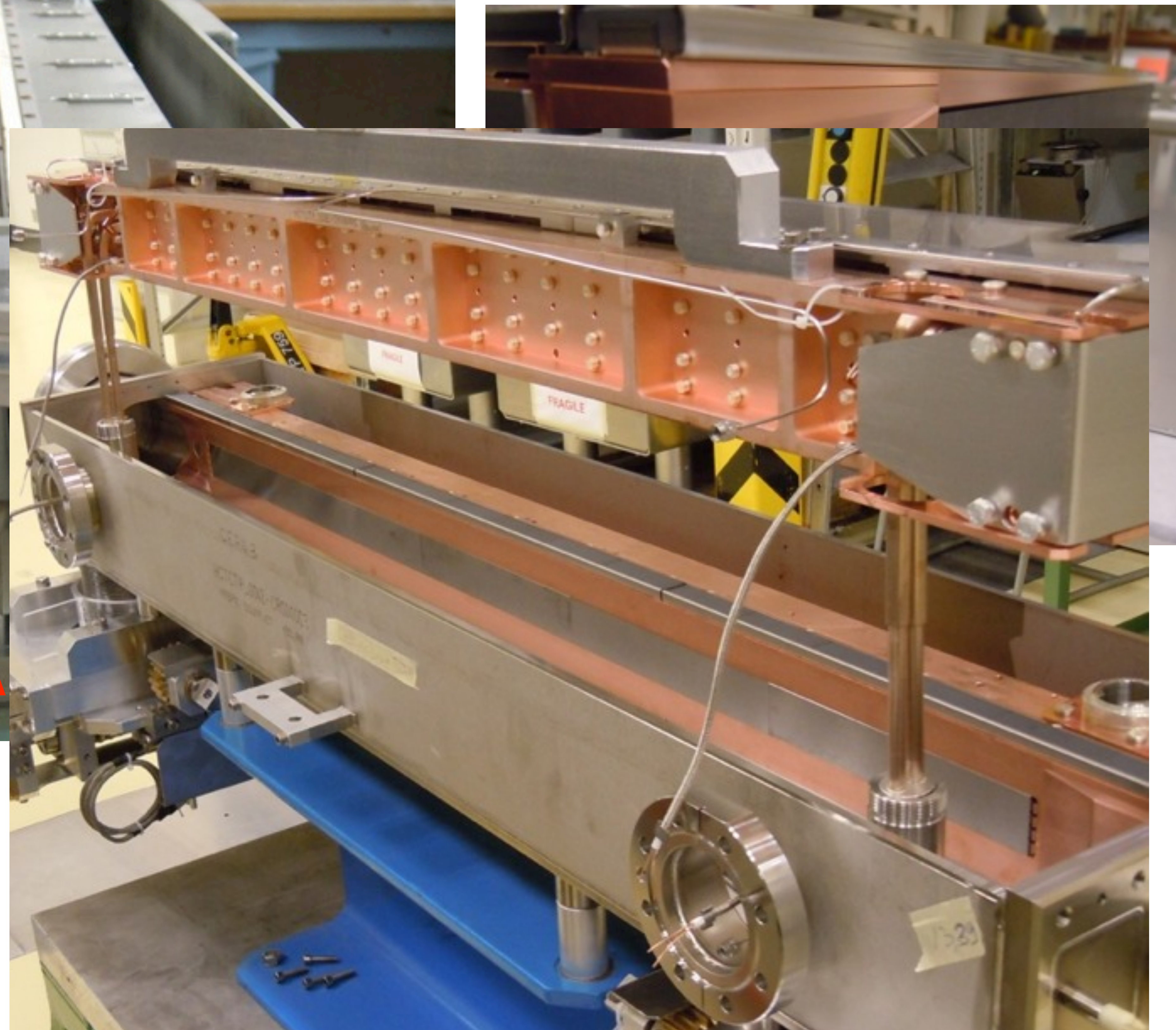

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Ring collimator families for 2015

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TCSG	“TCSG”	1.0	CFC	3/7	--	30
TCSP	“TCSP”	1.0	CFC	6	yes	2
TCLA	“TCLA”	1.0	W	3/7	--	18
TCL6	“TCLA”	1.0	W	1/5	--	4
TCL4/5	“TCLP”	1.0	Cu	1/5	--	8
TCTP	“TCTP”	1.0	W	1/2/5/8	yes	16
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We have > 7 different designs for ring collimators (material, length...).

Jaw materials: CFC, Tungsten alloy, Copper (Gr in InjProt collimators).

CFC and W design: variants with and without BPMs integrated.

Still 2-in-1 collimator design for auxiliary injection protection.

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BLM families for protection levels

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TCSG_THR	TCSG IR3/7 + TCLI IR2/8	CFC/1m	34
TCSP_THR	*TCSP IR6*	*CFC/1m/BPM*	*2*
TCLA_THR	TCLA IR3/7 + TCL6 IR1/5	W/1m	22
TCTP_THR	*TCTP IR1/2/5/8*	*W/1m/BPM*	*16*
TCL-Cu_THR	TCL IR1/5	Cu/1m	8

Assume same BLM family for CFC 2-in-1 design as for single-beam collimator.

Presently studying if the presence of the BPM changes significantly the collimator robustness for the two cases in CFC and Tungsten.

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We might need a "finer" granularity in addition to this functional definition of families. (e.g., change a sub-set of secondaries).

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- **Overall approach**: start rather <u>conservative</u> (tighter thresholds than needed) and relax punctually based on operational needs.

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- **Rationale at startup of Run I:**
  1. Start from threshold definition for primary collimators at 7 TeV; (well defined and studied impact scenarios of losses)
  2. Factor 10 lower thresholds for secondary collimators;
  3. Factors 200 and 2000 lower for Cu and W, respectively.

  [Assumed same signal to BPM per proton on jaw, for all designs!]

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- **Some considerations** (note that limits are given in number of protons)
  - Primary beam losses rely on collimation hierarchy *(500 kW loss case assumed primary losses on the TCPs).*
  - Factor for TCSG takes into account that losses would take place further downstream in the cleaning insertion.
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- **Adjustments of values then followed operational experience...**

Design loss rates

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	1.6×10^{13}	1200
Top energy	cont	1.0	0.8×10^{11}	97
	10	0.2	4.3×10^{11}	487

R. Assmann et al., Chap. 18 of LHC Design Report

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Two regimes studied in great detail for collimator protection:

- Losses around 1s and above. Concern: collimation permanent deformation.

→ *design value: withstand drops of beam lifetime to 0.2 h, i.e. giving 500kW. can be tolerated **up to 10s***

- Single-turn failures (not relevant for BLM thresholds!). Concern: jaw damage.

→ *Full injection train of 288 bunches (fast injection failures)*

→ *Up to 8 bunches at 7 TeV (asynch. dump with single-MKD pre-firing+re-trigger)*

TCP threshold plot 2008

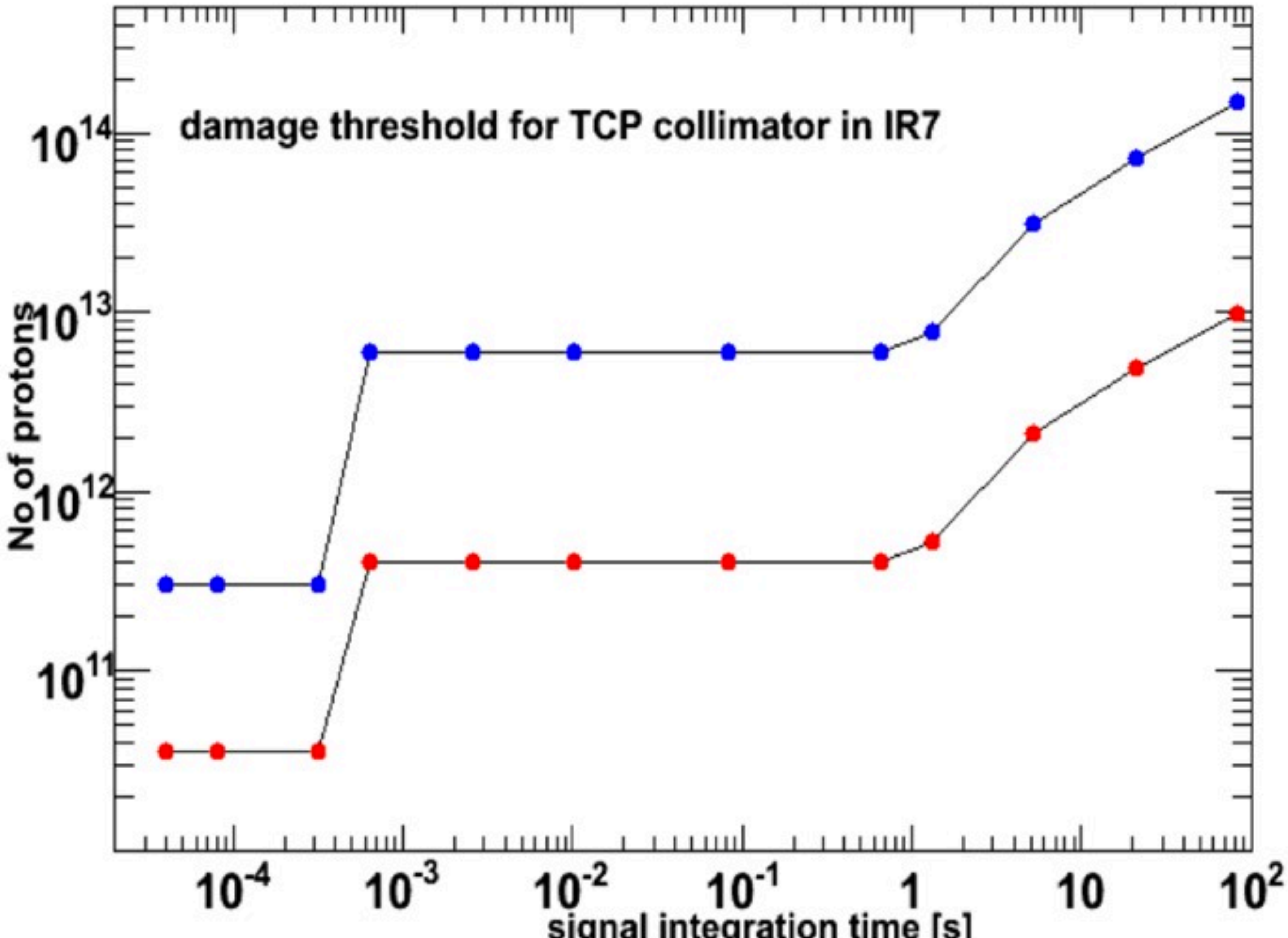
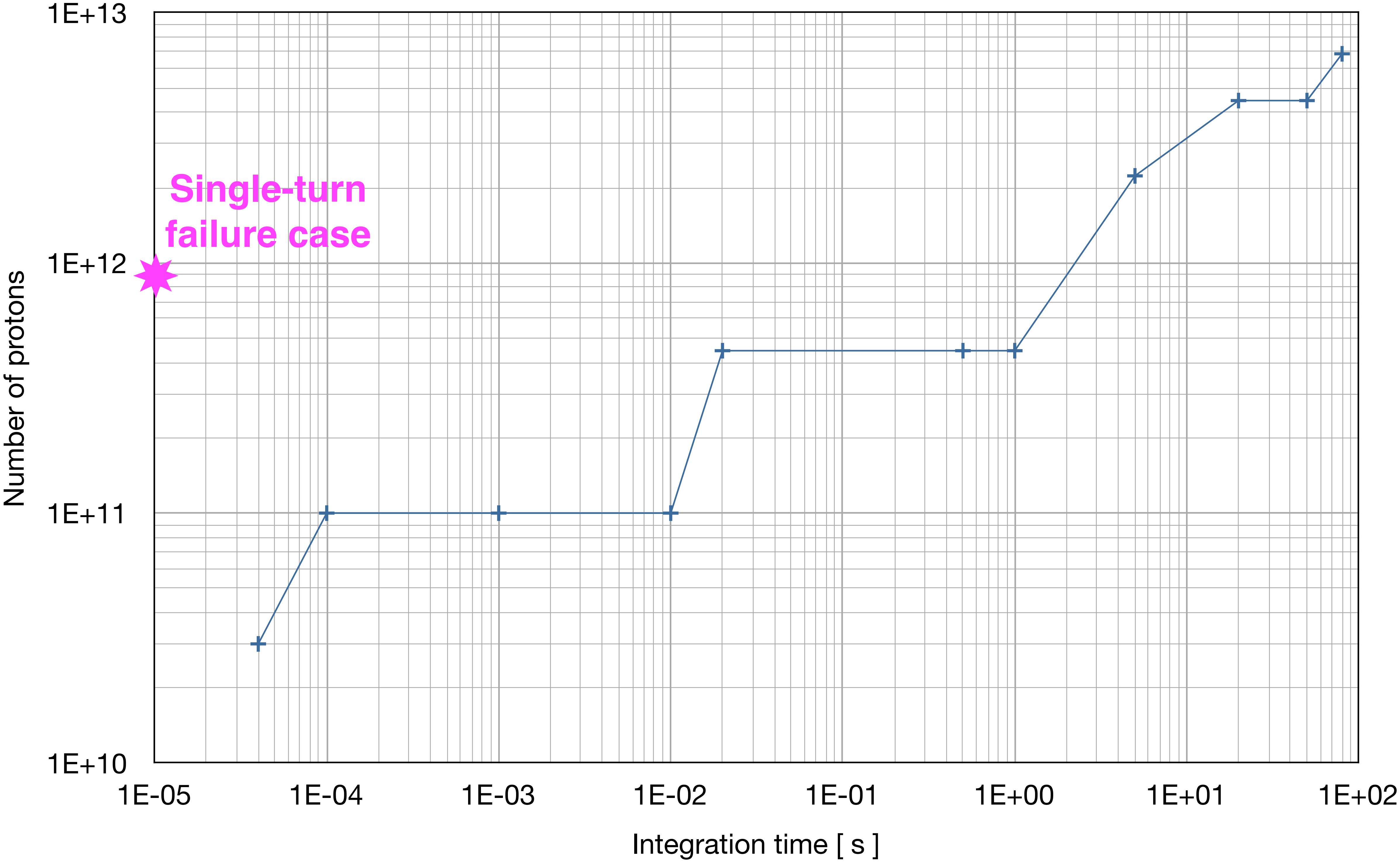


Illustration 3: Time evolution of thresholds for TCP collimator for injection (blue dots) and collision (red dots) beam energy.

M. Sapinski et al., EDMS 995569

Updated protection limits for TCP



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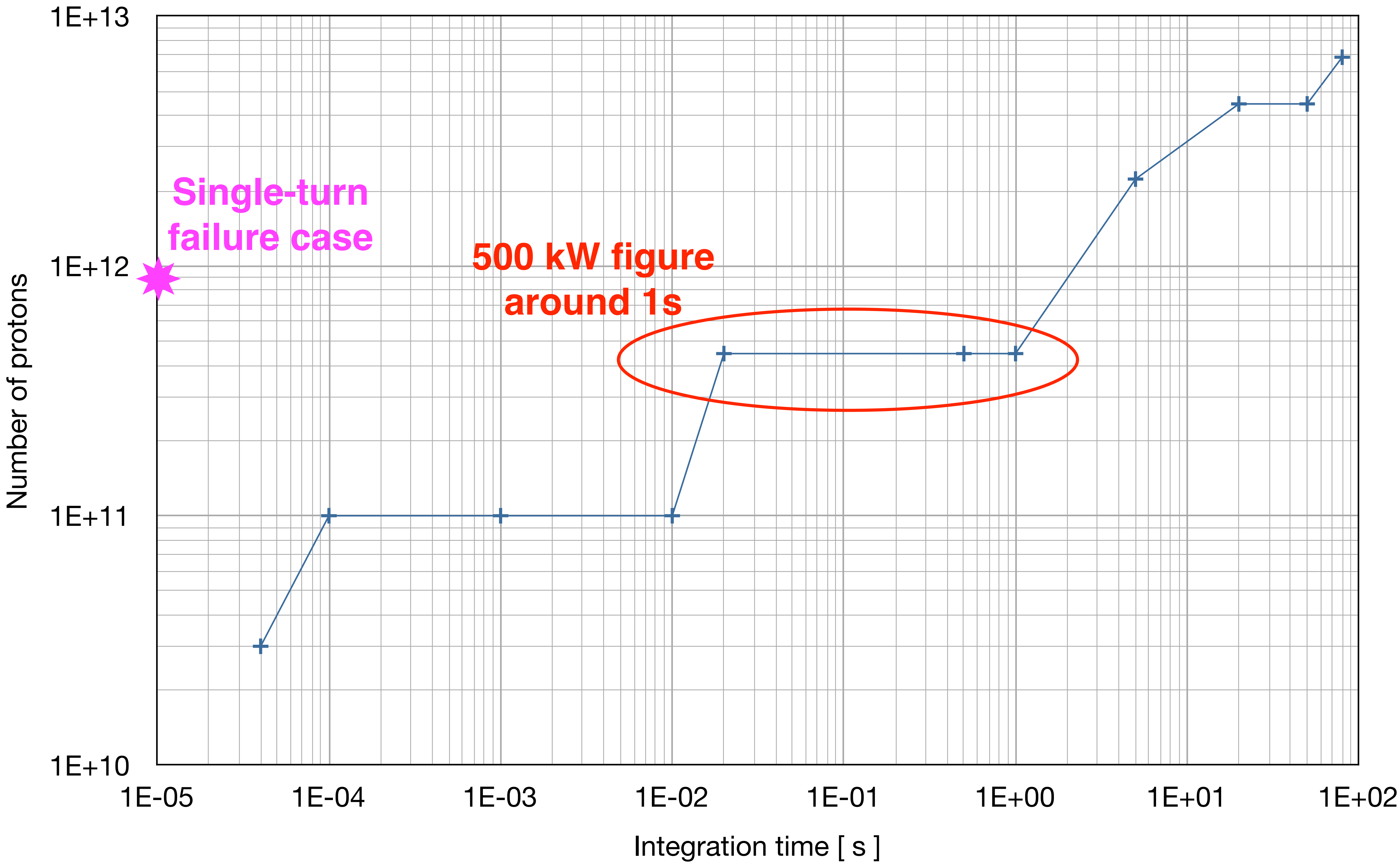

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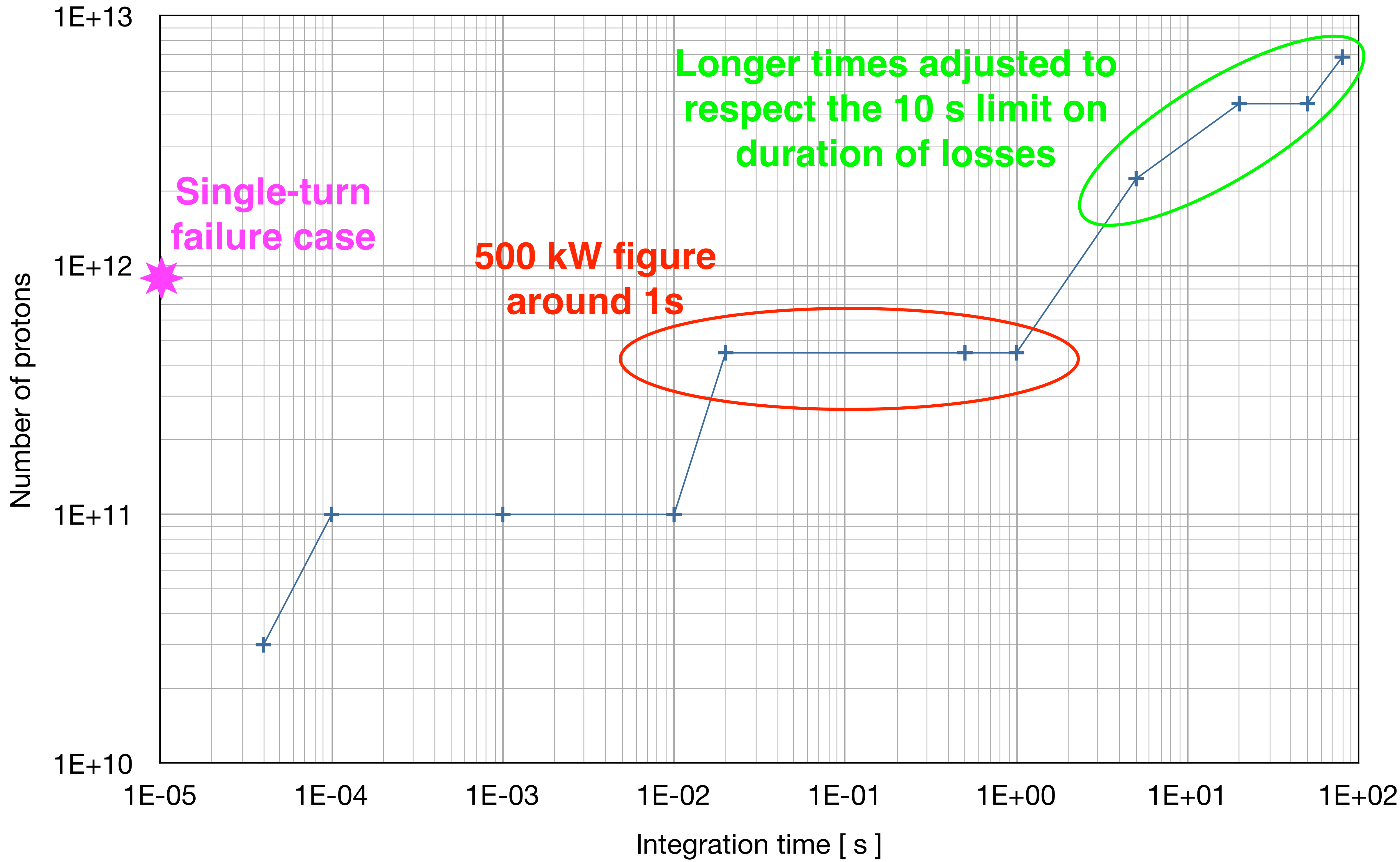

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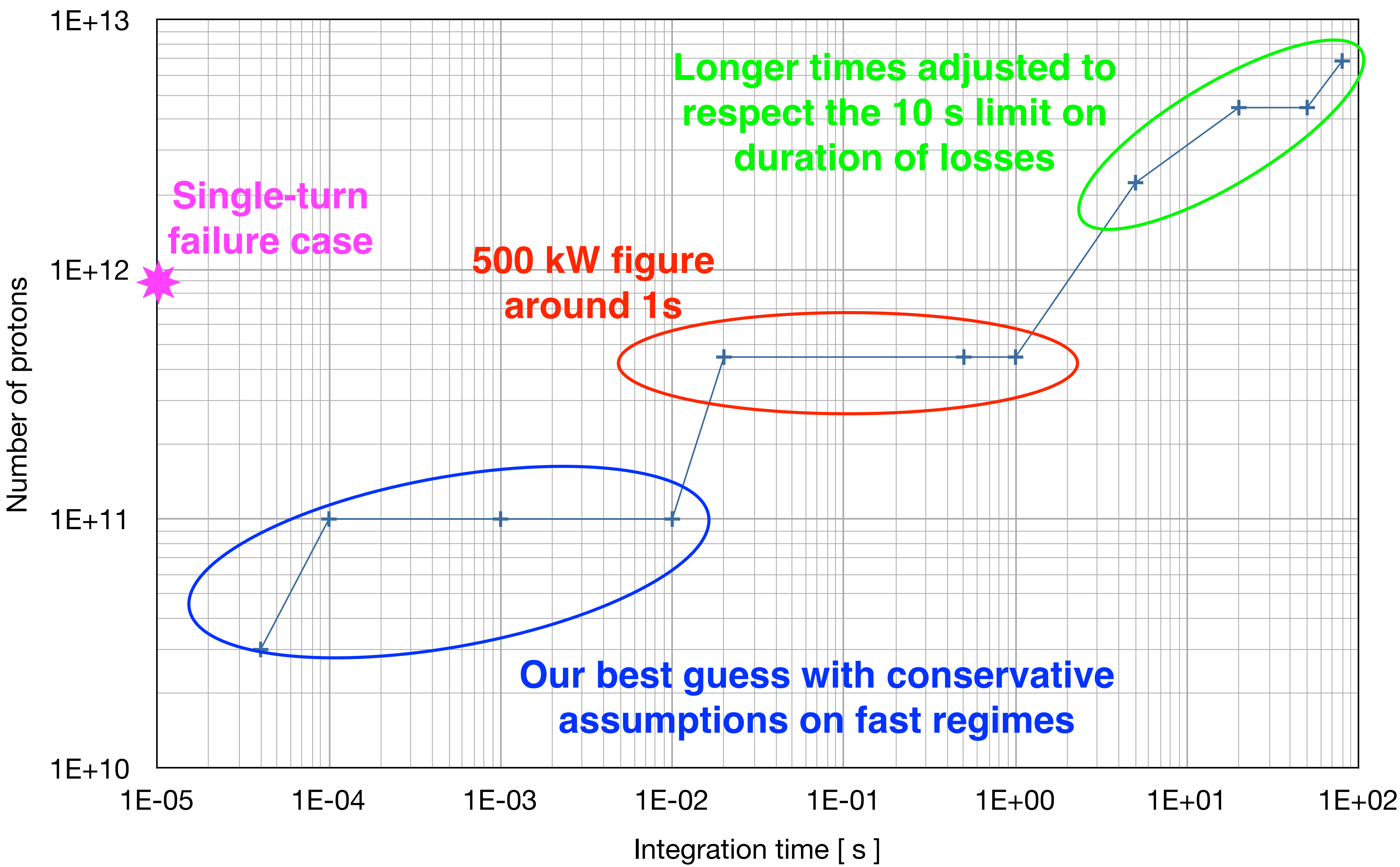

Changes applied during Run I

Different reasons for changing throughout the years. Strategy was to address operational issues/limitations as they came along...

☑ **Cross-talk between beams**

- TCLA's of one beam seeing losses from the TCP of the other beam

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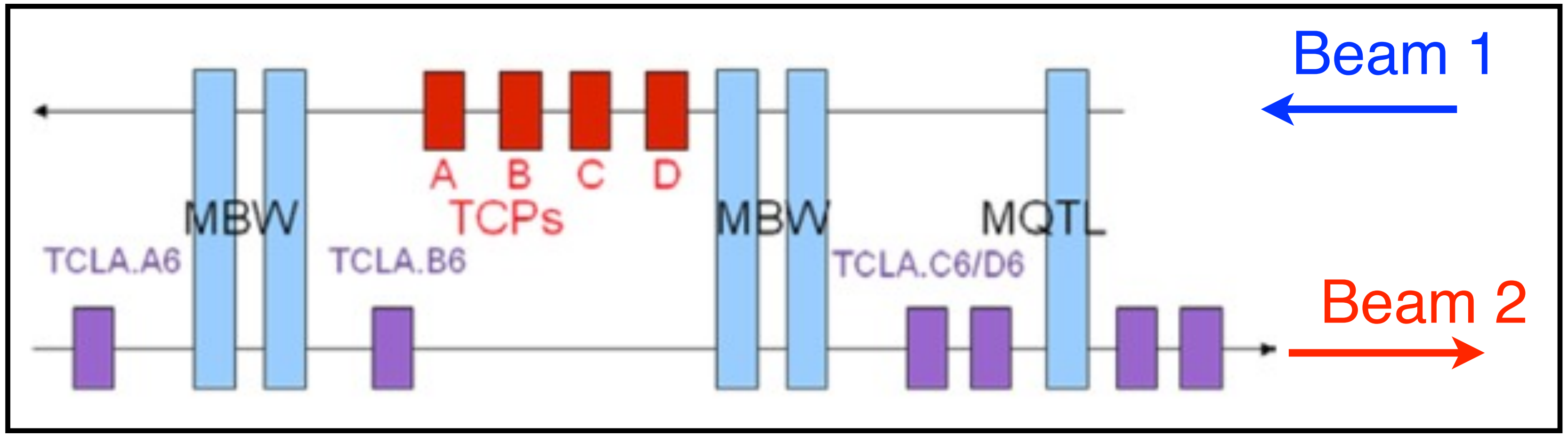

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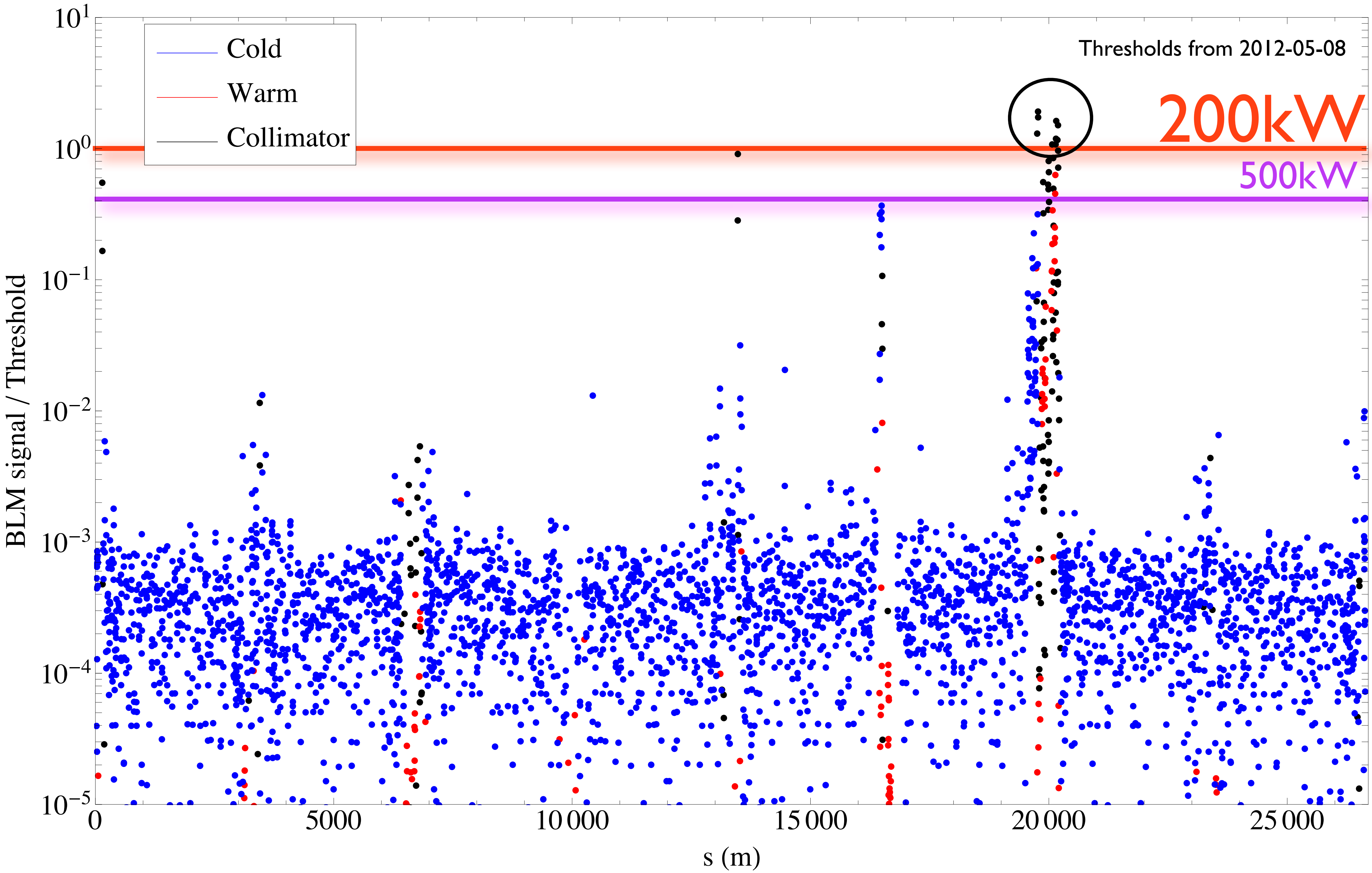
- ☑ **Cross-talk between beams**
  - *- TCLA's of one beam seeing losses from the TCP of the other beam*
    → could profit from redundant layout: BLM's of TCLA downstream
- ☑ Operational losses for given cleaning hierarchy
  - *- Set of secondary collimators were changed (cross-talk)*
  - *- Interventions on longer running sums (no issues for protection)*
  - *- Fast thresholds of W collimators during alignment (hierarchy violated)*
- ☑ **IR3/7 thresholds set in physics units of primary beam losses**
  - *- IR3 and IR7 thresholds scaled by factor from loss maps and normalized to 200 kW losses at 4 TeV (master table: 500kW).*
- ☑ Ions: increased losses in the dispersion suppressor magnets.

Changes documented in 7 engineering change requests. **Not easy** to re-construct all the required information... (work on-going).

“kW thresholds” for beam losses



Idea: adjust collimator thresholds based on **measured loss maps**. BLM thresholds are re-scaled starting from loss maps to achieve a desired loss rated.
→ empirically identify the minimum set of BLM that needs to be changed in order to allow a maximum “desired” beam loss rate, for a given collimation hierarchy.

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- Start-up thresholds to be re-calculated using the new figures for TCP's:
  - *Updated number of allowed limit of impacting protons;*
  - *Propose to apply different conversion factors from different jaw materials;*
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  - *This can be done in the first months of commissioning, when we do not expect yet limitations because of low intensities, and applied when we see limitations.*
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Comments:

"Inverse" strategy compare to Run I for points (3-4) and (2)!

Need to work out "ultimate" thresholds limits that we do not want to exceed!

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  If quench limits are as expected, collimator protection dumps before quenching!
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  Achieved 1 MW losses in 2012 quench test for controlled time profiles of losses!
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- Need to **quantify** the **present safety margins** in order to be ready in case of operational requests to relax thresholds.

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- When enough operational experience is accumulated, we will address the possibility to operate safely with **1 MW losses**!