BLM Thresholds for Run 3

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Acknowledgments: F.Carra, M.D'Andrea, G.H.Hemelsoet, L.Medina, M.Peryt, S.Redaelli, M.Sobieszek, H.Timko, A.Waets, J.Wenninger, D.Wollmann, C.Zamantzas

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BLM LHC System and Thresholds

Main Functionality:
Machine Protection: magnet quench protection and equipment protection in case of high beam losses.
Beam Diagnostics and Machine optimization: provide real-time beam loss measurements along the LHC

BLM signals provided in 12 different time intervals (Running Sums, RS) from 40µs to 83.9 s
BLM thresholds are implements for each of those RS and for 32 different beam energy steps or levels (EL).

Per monitor

Per family (several monitors sharing the same master thresholds)

BLM Threshold = Monitor Factor x Master Threshold[RS][EL]

Single value from 0 to 1

A matrix of 12 x 32 = 384 values

Any BLM connected to the BIS can trigger a beam dump on any running sum

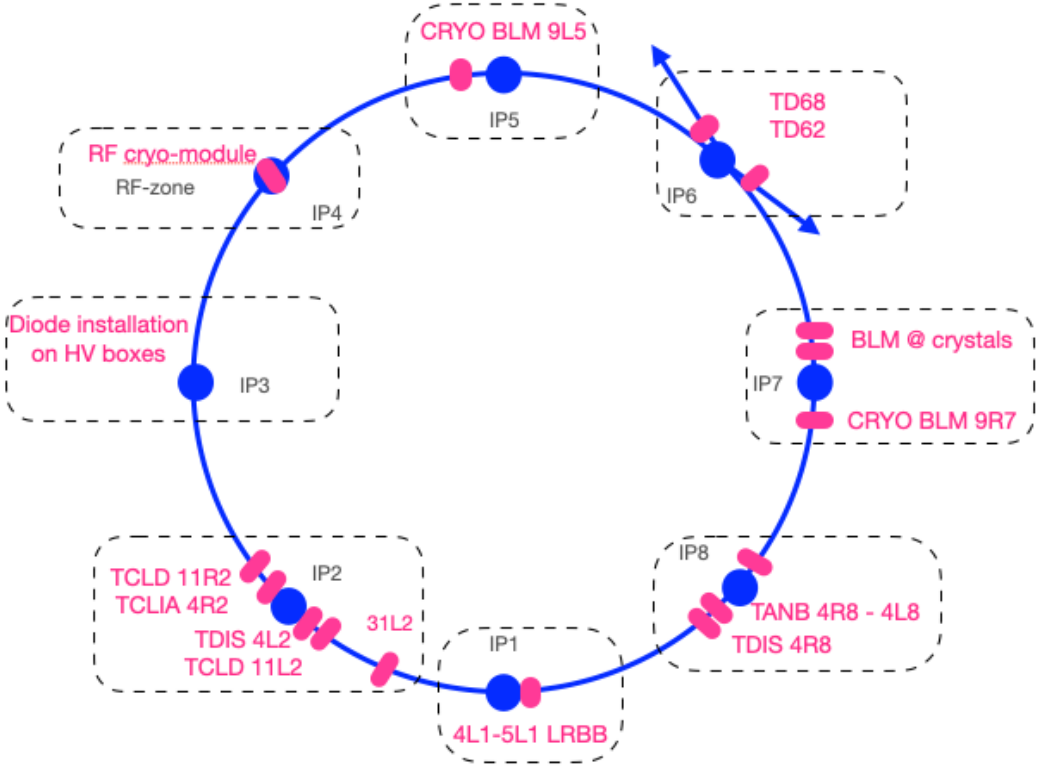
BLM system changes during LS2

Hardware | Firmware | Software

Removal and re-installation of 30 % of the BLM system due to DISMAC activities in cells 8-34 for all sectors

Modification of the system in all insertion points.

- Adding new monitors: crystal collimators
- Layout modifications on: TDIS, TCLD, MoGr Collimators…
  All changes described in this ECR: LHC-BLM-EC-0015



System after LS2

- Ionization chambers **3648 (111 with filters)**
  - connected to BIS: **3529 (71 with filters)**
  - number of BLM families: **112**
- LIC 110 and SEM 177 – not connected to BIS

BLM system changes during LS2

Hardware → Firmware → Software

Preparation for migration to the new BI processing platform:
- **Firmware** upgrade on the BLM Threshold Comparator card.
- **Firmware** upgrade on the BLM Combiner & Survey card.

→ No change on functionality or interface to the BIS

Migration from FESA2 **to FESA 3**.
Concentrators re-built, new UCAP running in parallel.
Update and merging of **BLM GUIs**, including BLM Thresholds.

→ No change on functionality but some API changes from FESA

Update of Layout and InforEAM DB

→ Update on synchronization tasks in LSA DB

Layout and InforEAM DB server was updated during LS2 and the BLM information re-shuffle.
BLM names, DCUM, Filters , status flag (connection to BIS, connection to the system, masks), electronics cards assignment, etc. About 30 fields with BLM data are synchronized to LSA after system changes.
This data is merged to final tables that include the BLM thresholds only stored in LSA.
Consistency was verified before and during the pilot run 2020.

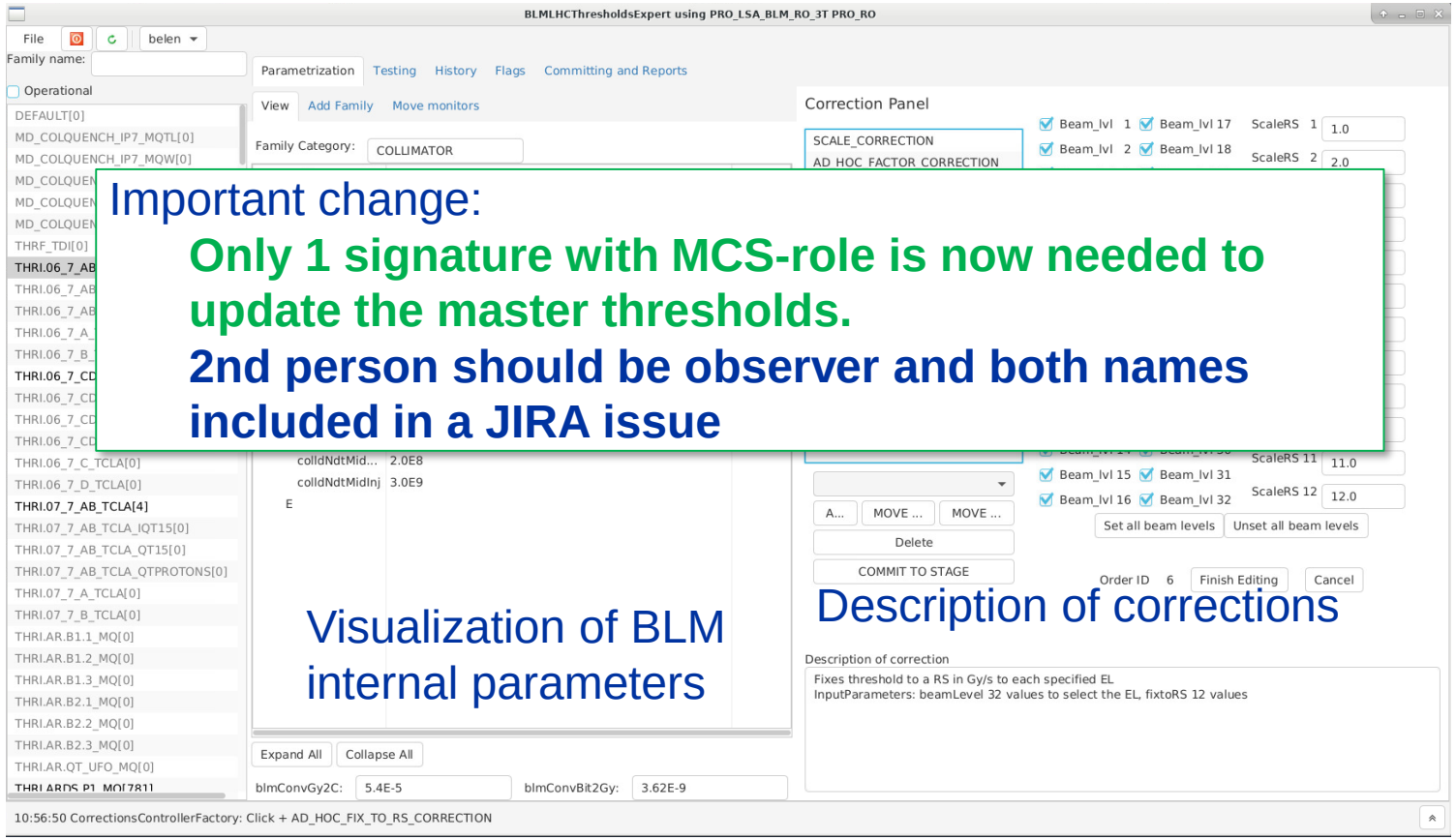
M.Peryt + M.Sobieszek

BLM system changes during LS2

G.H.Hemelsoet + BI SW

Hardware → Firmware → **Software**

Update on the BLM thresholds GUI



Important change:

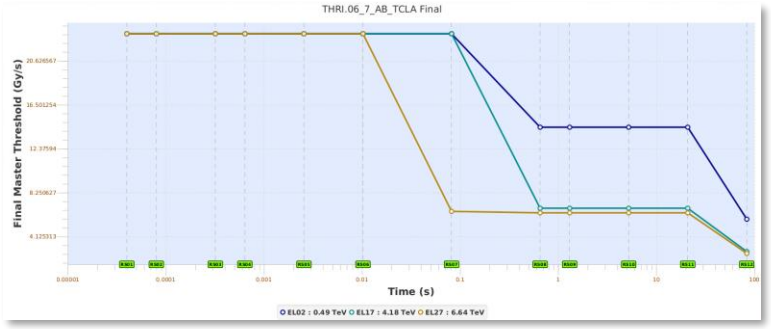
Only 1 signature with MCS-role is now needed to update the master thresholds.

2nd person should be observer and both names included in a JIRA issue

Visualization of BLM internal parameters

Description of corrections

Many improvements on the display of information, thresholds curves, changes, etc.



Committing changes to LSA DB
Generate settings and Driving
Now possible within the same application

BLM thresholds for Run 3

BLM at super conductive magnets: no update on quench limits but threshold strategy due to the expected increase of UFO rate after LS2, diode statuses and increase of energy will **be discussed in Anton's talk.**

BLM at collimators: initial damage limits and material factors used in previous runs. Many ad-hoc corrections based on measurements (the loss maps) were necessary in order to provide BLM thresholds that will allow the operation of the machine at high intensities.

During LS2 we reviewed the model of the BLM thresholds at IP7 collimators, incorporating new damage limits, better energy scale corrections, assessing new damage limits for MoGr collimators… Other collimators will follow (TCT, TCL, IP3, etc.)

BLM for injection protection: Injection Inhibit firmware will be deployed and fully commissioned in all BLM crates for 2022. However as discussed in the MPP workshop 2019 for the first year of run we will follow the **same strategy as for Run 2 of using filters and thresholds adjustments**. A work plan has been discussed at the BLMTWG to follow-up on this matter: study of beam losses, distribution of families and filters.

Beam Losses from RF voltage reduction: Analysis of beam losses during exercise of reducing RF voltage presented. Identified some BLM were threshold-to-dump reaches 60%. L.Medina and H.Timko.

Collimator BLM threshold model

Threshold Model

$$\text{Master Threshold}[RS][EL] = f_{\text{corrections}}\left(Q_{\text{BLM}}[RS][EL] \times N_{\text{p}}[RS][EL] \right)$$

$f_{\text{corrections}}(\text{thresholds}[RS][EL])$

A set of functions that allow for very flexible changes, so called ad-hoc corrections

$Q_{\text{BLM}}[RS][EL]$

Response Factor:
Expected BLM signal per proton lost
NEW from measurements!

$N_{\text{p}}[RS][EL]$

Damage limits:
Maximum number of protons allowed.
Updated values

Building the Model

Damage limits
MEASUREMENTS and SIMULATIONS

→

BLM response from loss maps
MEASUREMETNS

→

Interpolation with energy
MEASUREMENTS

Verification

→

Expected energy deposition
SIMULATION

→

Expected thermo-mechanical response
SIMULATION

Selection of new families: combine several BLMs to share the same master thresholds

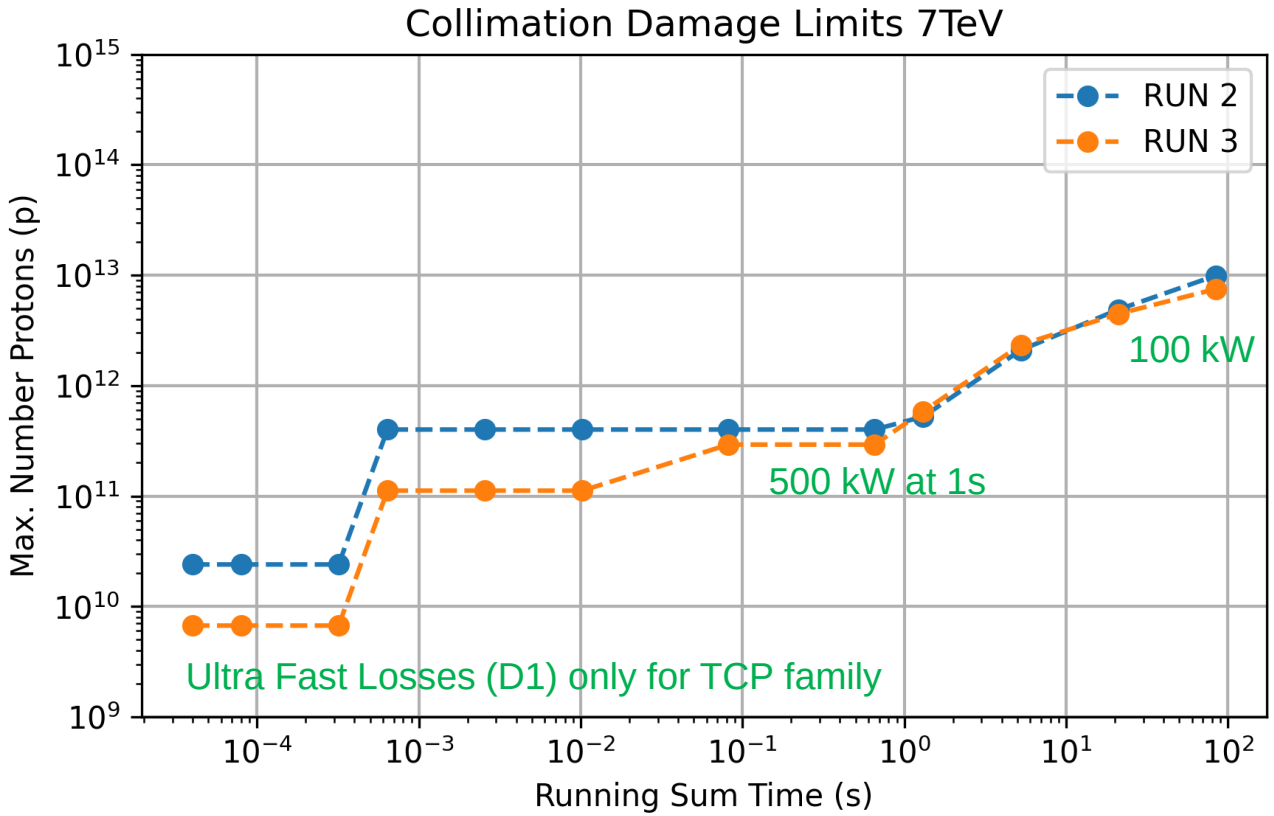
Update of damage limits

New limits summarized by F.Carra 74th BLMTWG based on Quench Test and HiRadMat results.

500kW up to 10 s

Study damage effect (fragmentation, plastic deformation, etc.) for different collimator materials.
Numerical Simulations + Experimental Test
Presented at MPP workshop 2019

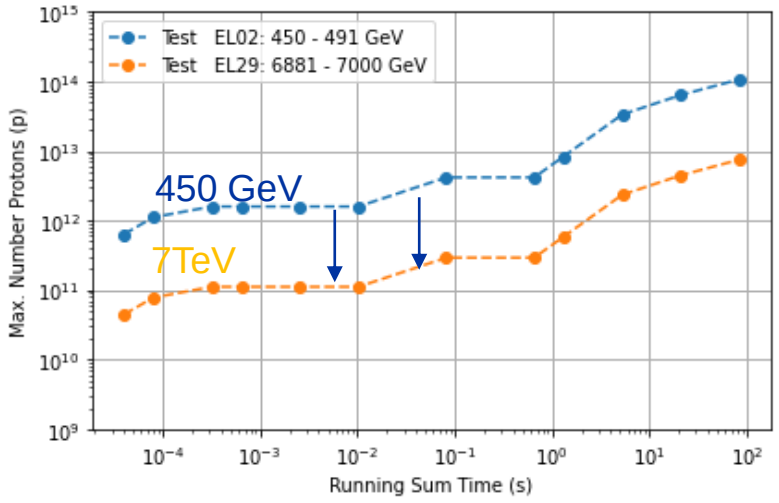
RS	Times	Max. Values
RS01 - RS06	40 µs - 0.01 s	125 kW x 1 s
RS07	0.08 s	500 kW x 1 s
RS08 - RS10	0.6 s - 5.2 s	500 kW
RS11	20.9 s	500 kW x 10 s
RS12	83 s	100 kW



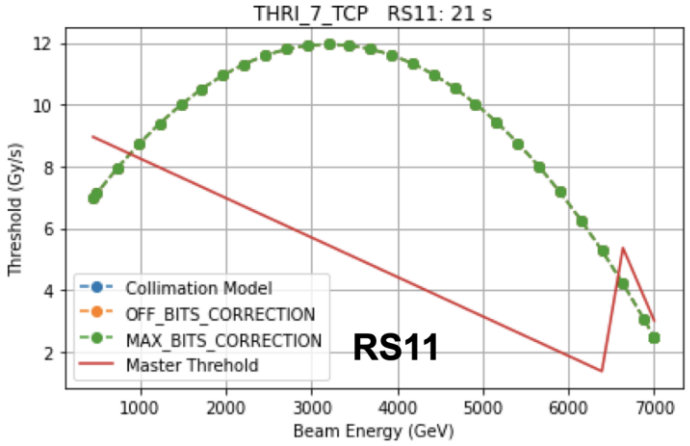
Maximum values of beam losses in the full collimation system.

Limits extrapolation with energy

How to go from max. number of protons at injection to top energy

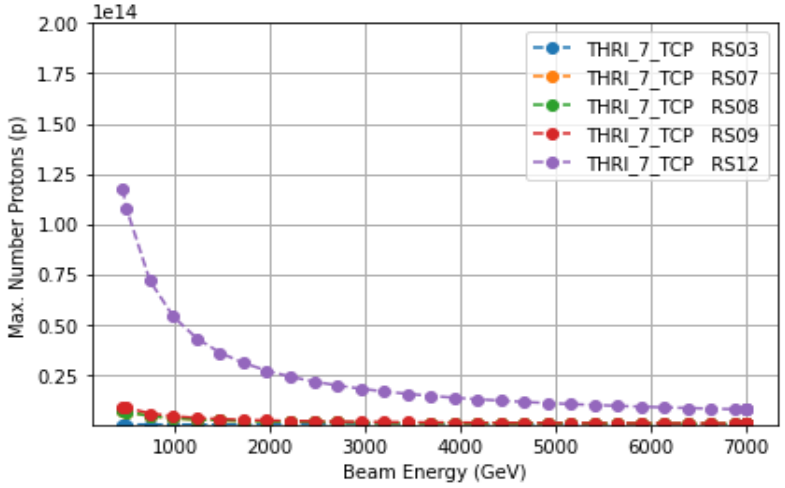


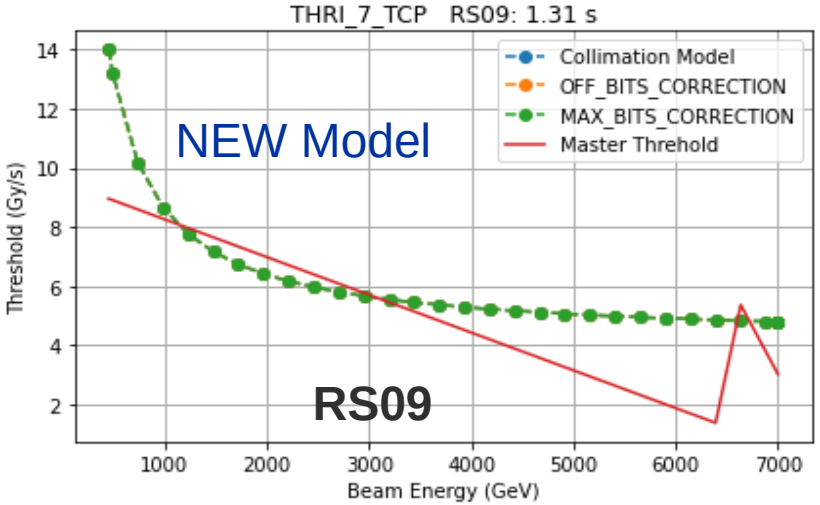
Old Model: interpolates linearly the maximum number of protons. **Creating non-physical curves** when adding different response factors for injection and top energy.



New Model: keeps the **maximum power loss constant over different energies** and calculate the equivalent number of protons.

Results in a smooth arrival to the top energy limits. **Flat top correction can minimized or even removed.**

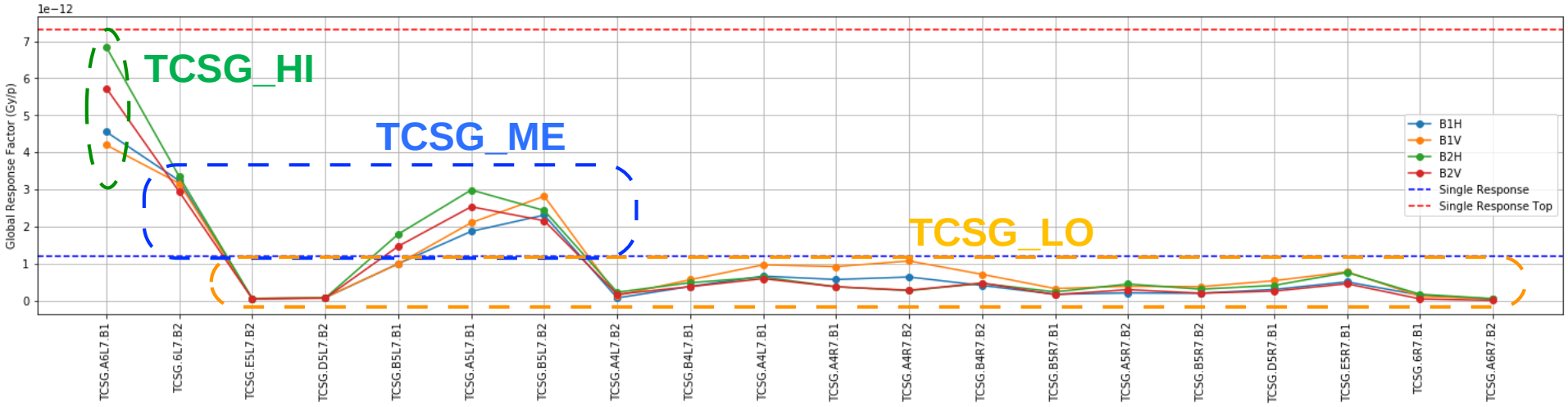




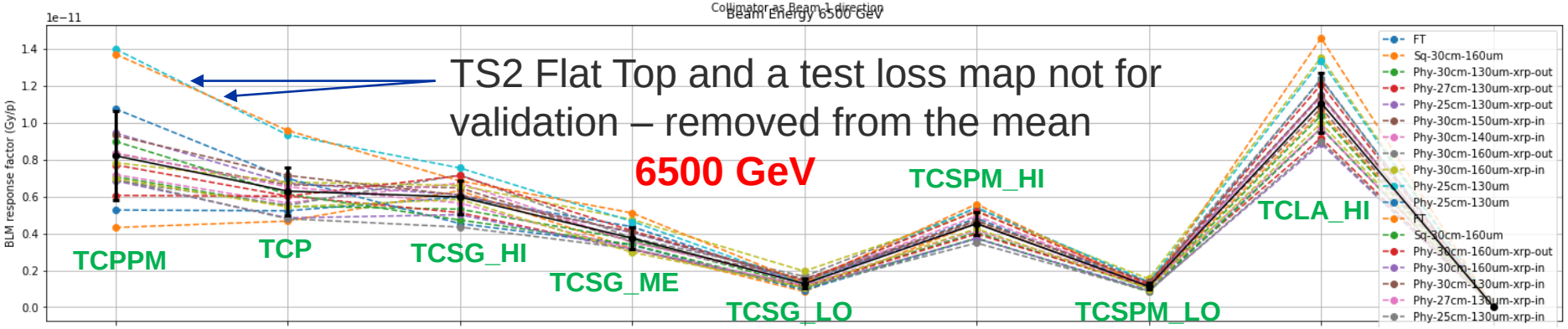
Response factors

BLM response factors is the **expected BLM signal per proton lost in the collimation system**. It is calculated from existing loss maps in Run 2 → nearly 100 loss maps analyzed to get an average response

Definition of new families: example for Secondary Collimators TCSG

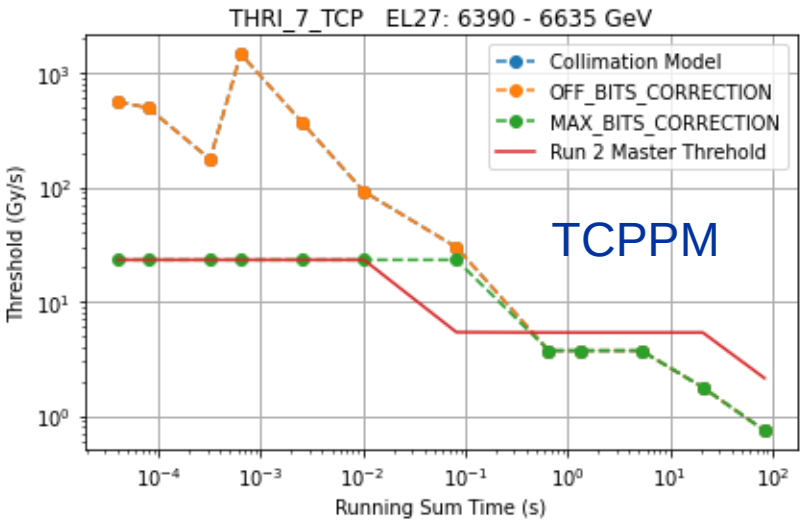


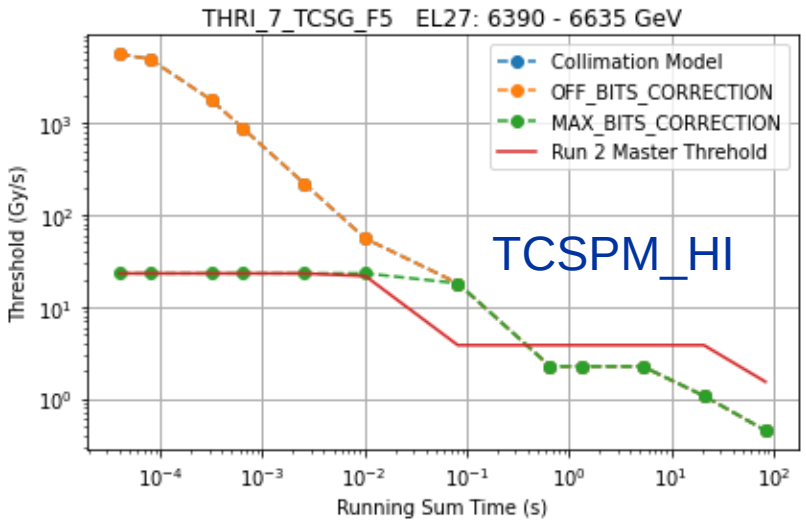
BLM response per family

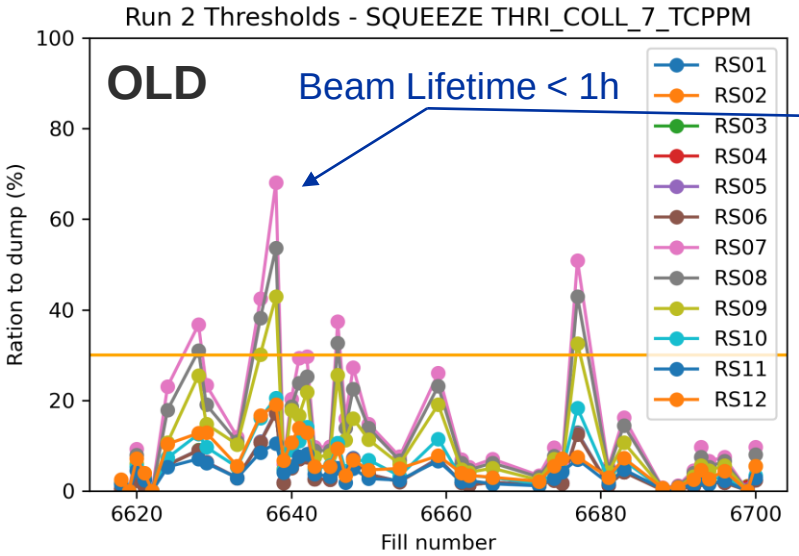


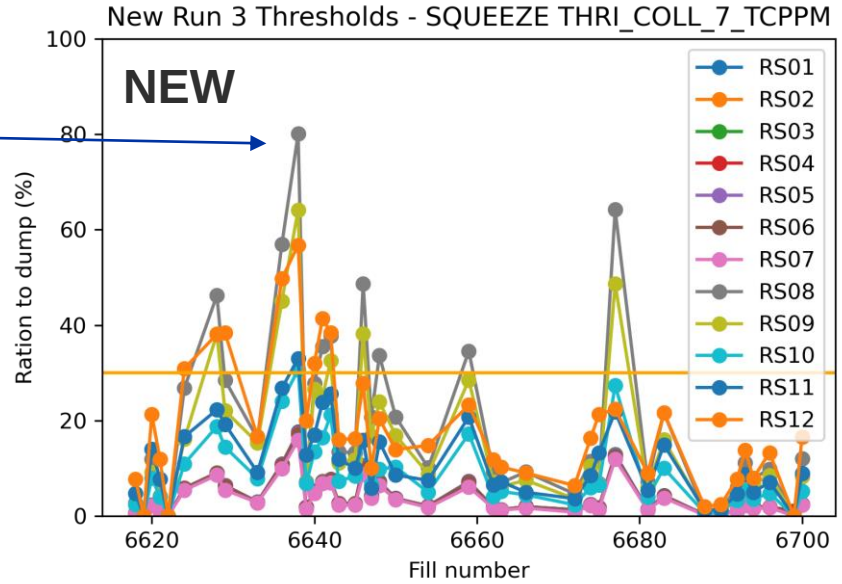
New Model Curves

New model in GREEN
Old model in RED









Verification of ratio-to-dump with Run 2 data on-going.

BLM thresholds in the machine are reduced by a Monitor Factor.

Presently running with
MF = 0.4 for Collimation Max. Loss = 200kW

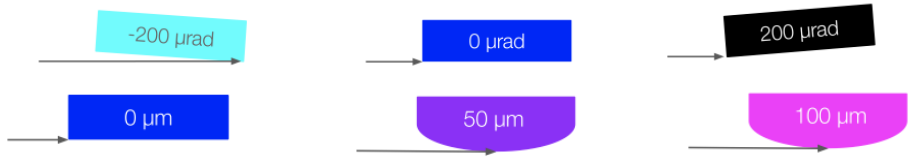
“500kW” thresholds are validated with FLUKA and thermo-mechanical simulations.

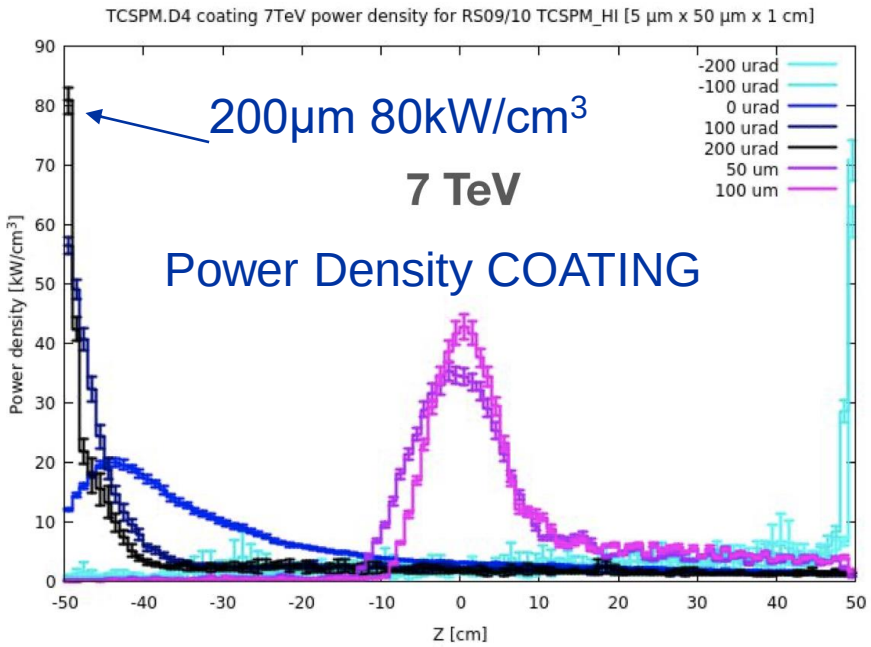
Studying the expected: maximum and average energy depositions, temperature increase, stresses, etc.

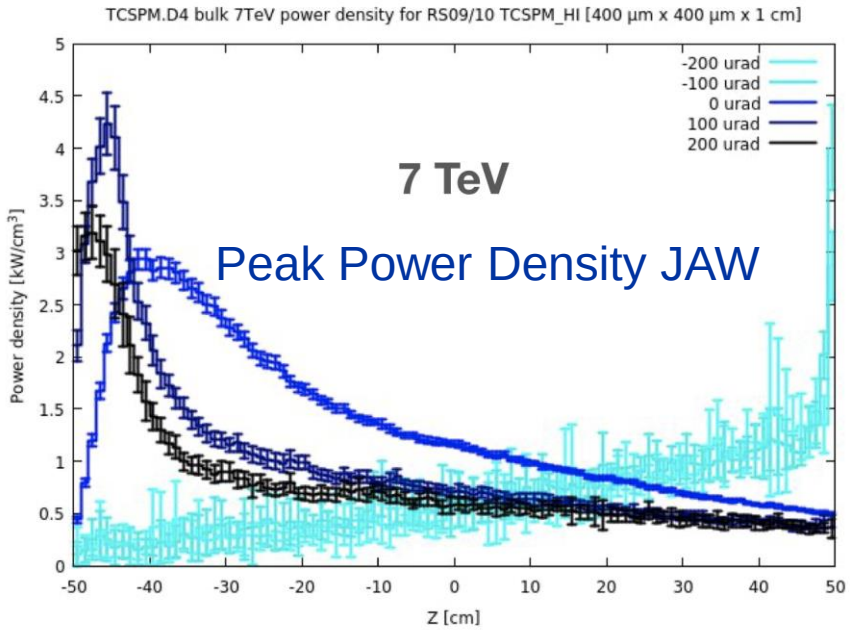
Energy deposition studies

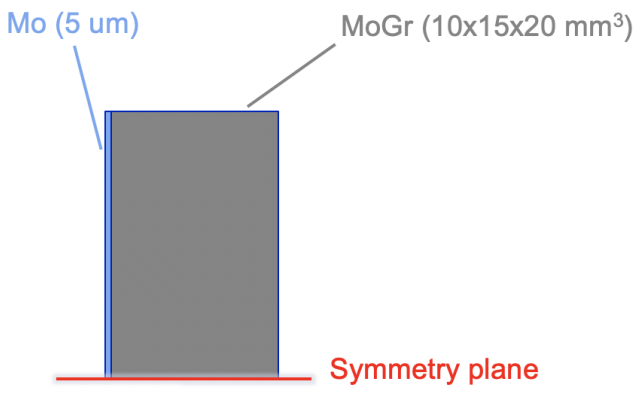
New Thresholds curves for the secondary collimators with MoGr and Mo coating were used to study the maximum energy deposition with FLUKA.

Scraping of primary losses on TCSPM.D4R7 collimator



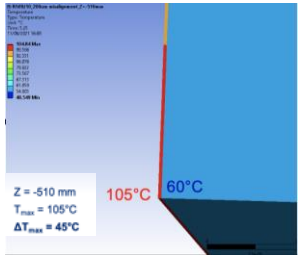






Mo Coating resistance

Thermo-mechanical simulations were done for the 0µm and 200µm jaw tilt (most extreme cases).



	200 µm misalignment	
	RS09/10	
	Z=-510mm	Z=350mm
T_{max}	105°C	**280°C**
ΔT_{max}	**45°C**	1°C

Two types of "failures" identified:

- **Carburization of the coating *f(T_{max})*→** loss in electrical conductivity, i.e. loss in impedance performance
- **Structural failure of the interface *f(T_{max} , ΔT_{max})*→** coating peel-off

Reference experimental test: **post-coating thermal treatment** to outgas the coated blocks prior to installation **T_{max}=400°C, ΔT_{max}~0 →** no carbides, no coating peel-off, good adherence.

Thermomechanical stresses studies at the interface show that the 400°C thermal treatment is more demanding than then 200µm misalignment.

None of the possible failures seem an issue, however safety factors should be consider until there is more experimental data to study the peel-off effect.

Summary

- **Outlined BLM system changes, BLM thresholds mainly affected by upgrades in DB and software changes. Tools where tested during pilot run.**
- **BLMTWG reviewing different loss scenarios and revisiting the thresholds: UFO-magnets, injection, RF, luminosity losses and Collimation.**
- **New BLM Threshold Model for collimation in IP7 being deployed for Run 3:**
  - More robust, better models, provides more physical curves and many of the empirical corrections accumulated along the past years are now incorporated in the model.
  - For longer running sums the new model provides slightly lower thresholds but it comes from solid understanding of damage limits and so far it does not seem to impose a limitation, more checks on-going.
- **Other collimators will follow the upgrade of the model.**

Back-up

Update of damage limits

New limits summarized by F.Carra 74th BLMTWG based on Quench Test and HiRadMat results.

500kW up to 10 s

Study damage effect (fragmentation, plastic deformation, etc.) for different collimator materials.
Numerical Simulations + Experimental Test
Presented at MPP workshop 2019

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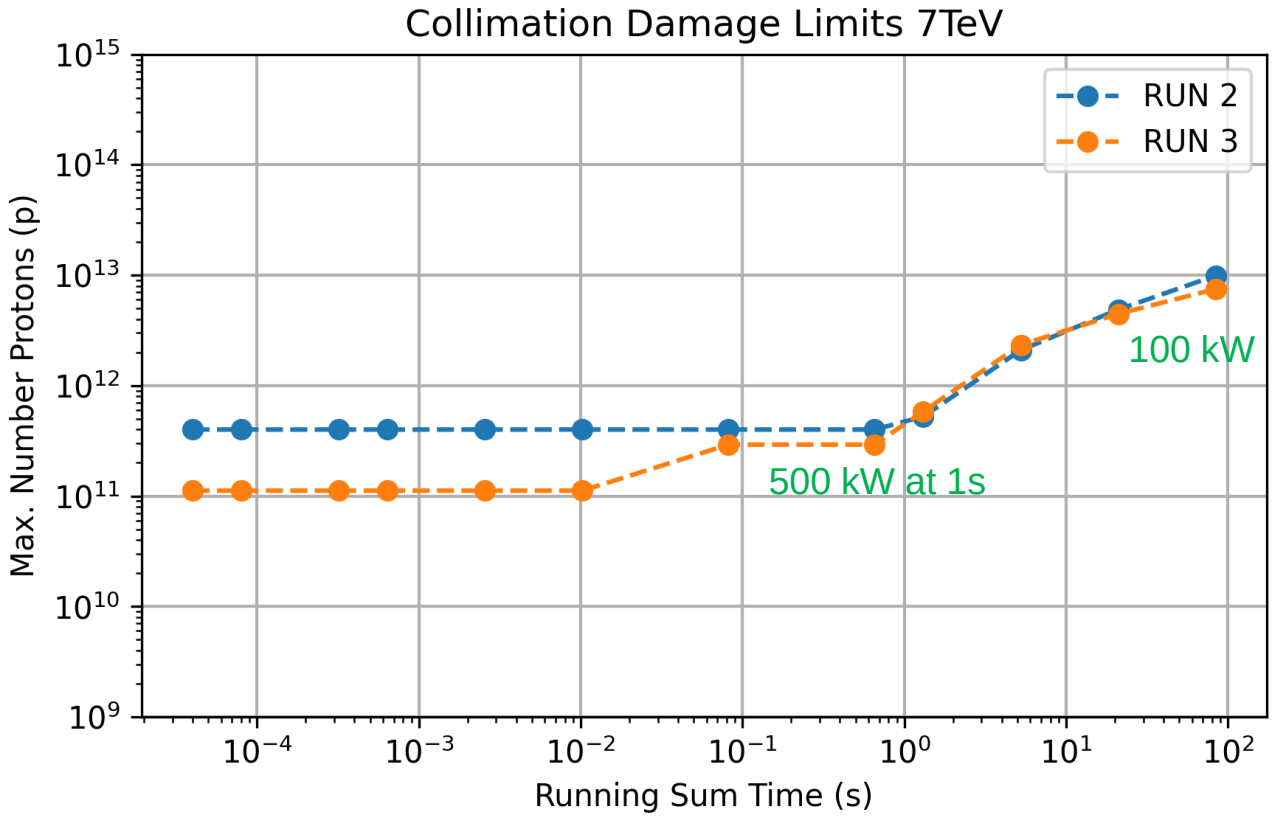


Maximum values of beam losses in the full collimation system.

Definition of BLM families

THRI_COLL_7_TCPPM
TCP.D6L7.B1
TCP.C6L7.B1
TCP.D6R7.B2
TCP.C6R7.B2

THRI_COLL_7_TCP
TCP.B6L7.B1
TCP.B6R7.B2

THRI_COLL_7_TCSG_HI
TCSG.A6L7.B1
TCSG.A6R7.B2

THRI_COLL_7_TCSG_ME
TCSG.6L7.B2
TCSG.B5L7.B1
TCSG.A5L7.B1
TCSG.B5L7.B2
TCSG.6R7.B1
TCSG.B5R7.B2
TCSG.A5R7.B2
TCSG.B5R7.B1

THRI_COLL_7_TCSG_LO
TCSG.E5L7.B2
TCSG.D5L7.B2
TCSG.A4L7.B2
TCSG.B4L7.B1
TCSG.A4L7.B1
TCSG.A4R7.B1
TCSG.A4R7.B2
TCSG.B4R7.B2
TCSG.D5R7.B1
TCSG.E5R7.B1

THRI_COLL_7_TCSPM_HI
TCSM.6L7.B2
TCSM.6R7.B1

THRI_COLL_7_TCSPM_LO
TCSPM.D4R7.B2
TCSG.D4R7.B2
TCSG.D4L7.B1
TCSM.B4L7.B1
TCSM.B4R7.B2
TCSM.E5L7.B2
TCSM.E5R7.B1

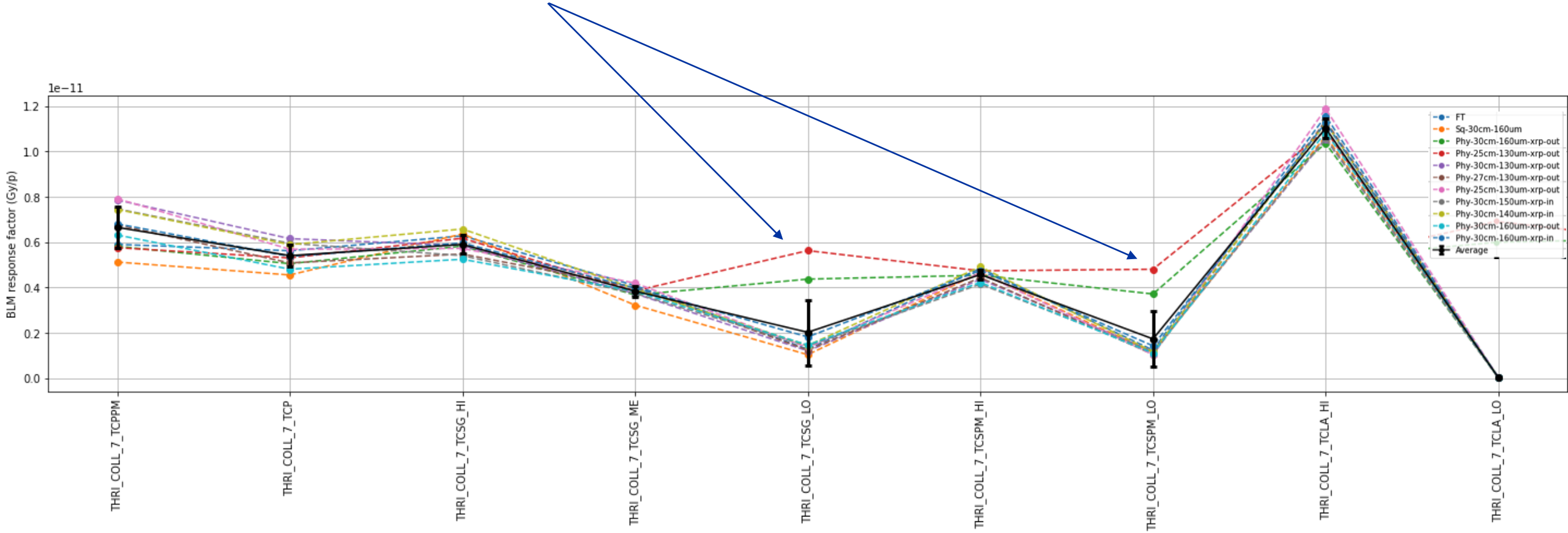
THRI_COLL_7_TCLA_HI
TCLA.B6L7.B2
TCLA.A6L7.B2
TCLA.B6R7.B1
TCLA.A6R7.B1

THRI_COLL_7_TCLA_LO
TCLA.A7L7.B2
TCLA.D6L7.B2
TCLA.C6L7.B2
TCLA.A7R7.B1
TCLA.D6R7.B1
TCLA.C6R7.B1

Based on distribution of losses from the loss map analysis, collimator materials and interlock redundancy, new collimator families are proposed for Run 3.
The response is now calculated per family.

BLM response factors: outliers

Two loss maps with collimator misalignments that have been removed from the data sample, the outliers were clearly visible in the response factor.



Summary of BLM response factors

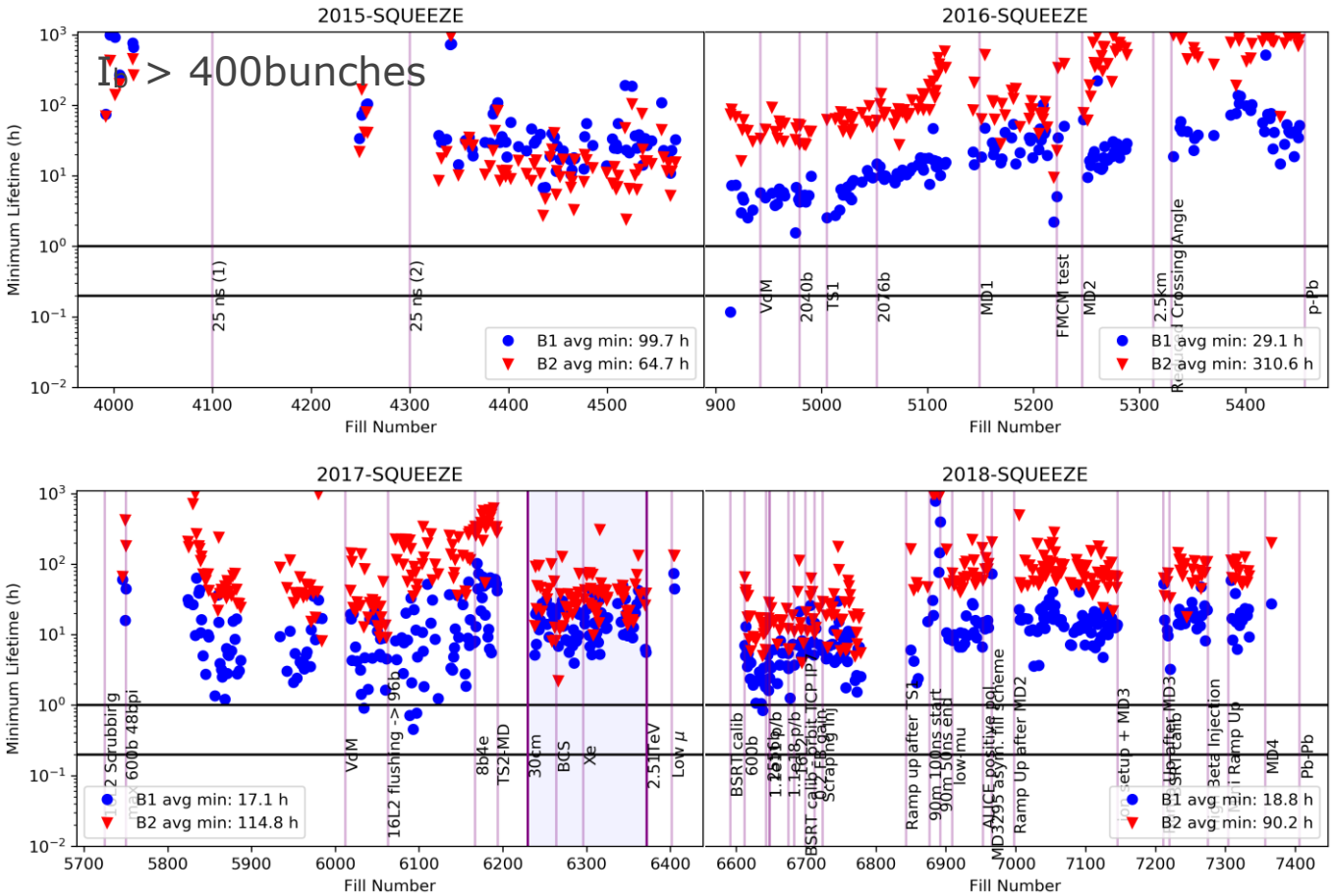
BLM response	INJECTION [pGy/p]		6500 GeV [pGy/p]	
THRI_COLL_7_TCPPM	**1.4**	**± 25%**	**7.5**	**± 20%**
THRI_COLL_7_TCP	**1.1**	**± 25%**	**5.9**	**± 13%**
THRI_COLL_7_TCSG_HI	**0.20**	**± 19%**	**5.8**	**± 15%**
THRI_COLL_7_TCSG_ME	**0.24**	**± 20%**	**3.6**	**± 14%**
THRI_COLL_7_TCSG_LO	**0.24**	**± 20%**	**1.3**	**± 22%**
THRI_COLL_7_TCSPM_HI	**0.20**	**± 30%**	**4.4**	**± 13%**
THRI_COLL_7_TCSPM_LO	**0.22**	**± 20%**	**1.1**	**± 17%**
THRI_COLL_7_TCLA_HI	**0.76**	**± 17%**	**11.0**	**± 12%**
THRI_COLL_7_TCLA_LO	**0.0043**	**± 15%**	**0.026**	**± 30%**

Pre-LS2 BLM response at the collimators was assumed to be
33.6 aC/proton →***0.62 pGy/proton***
About 10 times higher for TCP families

In addition, for the _LO families we proposed to increase the response by about 30% to add some margin to these BLM were the signal is very low.

One option is to define a minimum response factors for injection and top energy for these "LO" families :
Injection: minimum response of 0.3 pGy/p
6500TeV: minimum response of 1.5 pGy/p
This will need to be cross-checked with simulation results.

Beam Lifetime – SQUEEZE – Run 2



Beam Lifetime – ADJUST – Run 2