BLM thresholds for post-LS1 LHC operation: UFOs and orbit bumps in the arcs and straight sections

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Workshop on Beam-Induced Quenches

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Contents

Transient beam losses due to dust particles in the arcs

UFOs ("Unidentified Falling Objects") in the LHC arcs:

- # of beam dumps decreased from 5 in 2010 to 2 in 2011 and to 1 in 2012
- reduction can mainly be attributed to a fivefold increase of BLM thresholds, starting from mid-2011
- however: situation will be more challenging after LS1 due to (nearly) twice as high magnet currents and higher stored beam energies

At 6.5 TeV, do UFOs have the potential to quench an arc magnet?

- Considering the experience from Run I, from Quench tests and from FLUKA and QP3 simulations, the answer is: yes

Would have the largest UFOs@3.5/4 TeV in Run I quenched an arc magnet if the beam would not have been dumped?

- Not sure, probably not ...

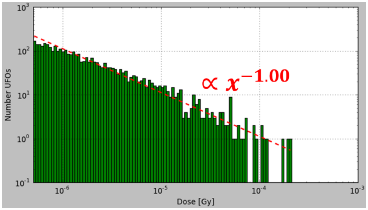


Figure (courtesy by T. Baer, Chamonix workshop 2012): histogram of integrated beam loss signals for 4513 arc UFOs ($\geq$cell 12) at 3.5 TeV (2011).

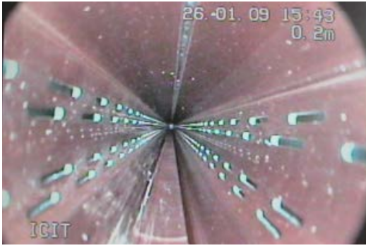


Figure (courtesy by C. Garion, LMC # 170, Oct 2013): MB beam screen interior – endoscopy inspections in LS1.

Installation of additional BLMs in cell 19R3 (Feb 2012)

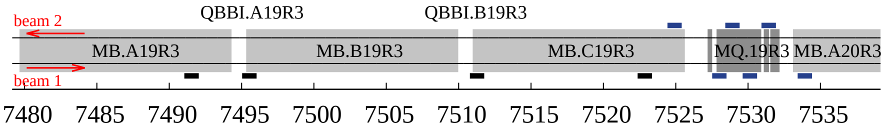


Illustration: Standard BLM installation (blue) and additional mobile BLMs on Beam 1 (black).

Photos: Mobile BLMs installed in cell 19R3 in Feb. 2012 (pictures by courtesy of R. Tissier and S. Grishin.).

- The reason for selecting cell 19R3 was the large number of beam-dust particle interactions which were registered in this cell (beam 1) during 2011 operation at 3.5 TeV
- The mobile installation is the only means to determine the spatial distribution of beam-dust particle interactions in an arc cell
- Relied on measurements collected in 2012 + simulations to conclude for post-LS1 BLM reconfiguration and threshold settings

Largest BLM signals measured in 19R3 due to beam-dust particle interactions@4 TeV

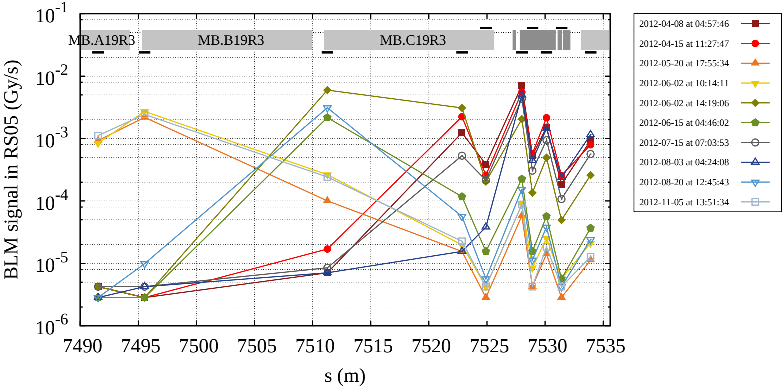


Figure: Ten largest BLM signals (RS05) and corresponding BLM pattern registered in cell 19R3 during 2012 operation due to interactions of the circulating beam (B1) with dust particles in the vacuum chamber. The RS05 offset level due to the applied offset current is 4.24×10^{-6} Gy/s. Beam direction is from the left to the right.

- Some of the dust particle-induced loss events show differing BLM signatures while others shared a resembling BLM pattern.
- The characteristics of the different pattern indicate that the liberation of dust particles into the beam is not localized but spread out across the cell.

Comparison of the BLM pattern measured in cell 19R3 with simulations

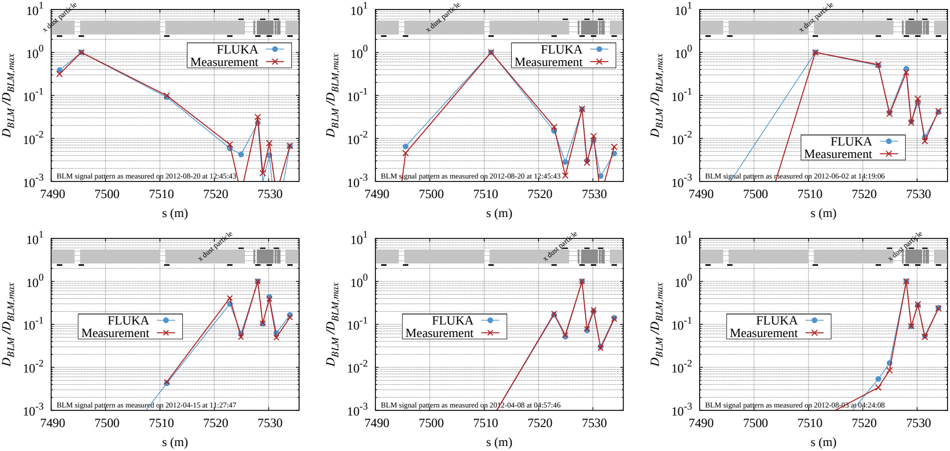


Figure: Comparison of BLM signals simulated with FLUKA against BLM pattern measured in cell 19R4 during 4 TeV proton operation. All pattern are normalized the respective maximum signal. Measured pattern are offset corrected.

Summary of observations in cell 19R3

- **Spatial distribution within cell**
  - Dust particle locations seem more or less evenly distributed in the cell
    - → statistics limited, but 19R3 is still assumed to be more or less representative wrt spatial distribution
  - Largest events in 19R3 originate very likely from interactions within MBs (and not the interconnects)
  - Pre-LS1 standard BLM configuration in arcs was inefficient to detect dust particle-induced losses due to the absence of BLMs on MBs
    - → for the same number of interactions BLM signals showed large variation depending on dust particle location (nearly two orders of magntitude)
    - → triggered BLM relocation during LS1 (see also next slides)
- **Amplitude**
  - FLUKA vs measurements: $1\text{–}4\times10^{6}$ inelastic nuclear proton-dust particle interactions for largest events in 19R3
  - *Events registered in 19R3 were however not among the largest compared to other arc cells*
    - → For largest events (beam dumped), number of interactions until beam abort estimated as $\sim5\times10^{7}\text{–}10^{8}$

Contents

New BLM positions in arc cells

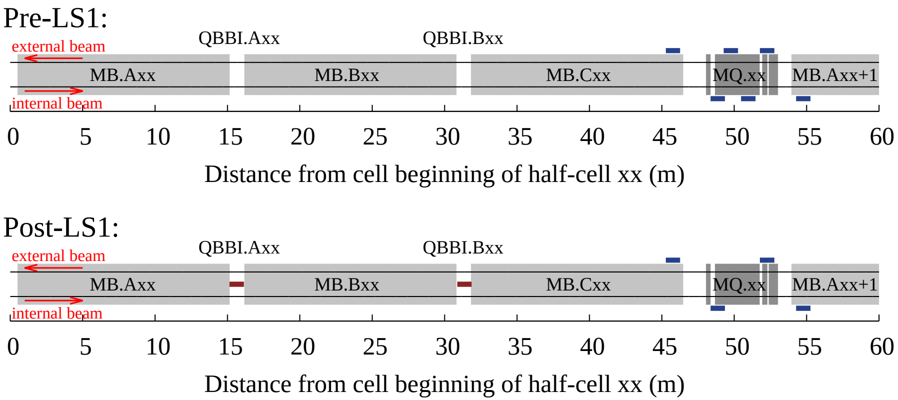


Illustration: Illustration of the pre- and post-LS1 BLM configuration for an arbitrary arc half-cell located on the right of an interaction point and with Beam 1 as the internal beam. BLMs installed on the horizontal plane outside of magnet cryostats are indicated in blue, while BLMs installed above MB-MB interconnects are marked in red.

- BLMs vertically above MB-MB interconnects are about a factor 3 less sensitive to UFO losses than corresponding horizontal BLMs after interconnects, but with the benefit of covering both beams.

How do the redistributed BLMs detect UFO-induced losses and orbit bumps?

UFOs: BLM coverage for different dust particle positions $D_{BLM}^{QL} = \frac{D_{BLM}^{p} \times QL}{\varepsilon^{p}}$

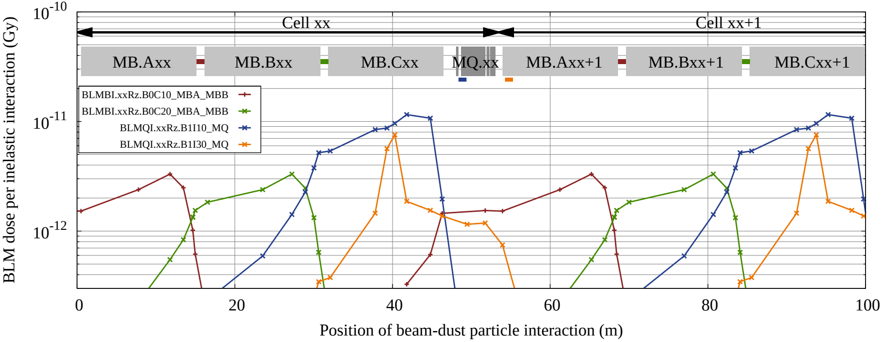
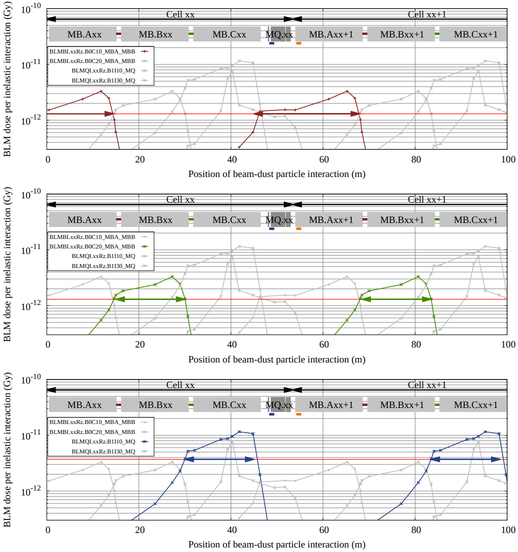


Figure: Dependency of BLM signals on the dust particle position in the Beam 1 vacuum chamber as predicted by particle shower simulations (for protons at 7 TeV). Results apply to an arbitrary arc cell located on the right of an interaction point, with Beam 1 as the internal beam and the MQ focussing on the horizontal plane. Signals of BLMs on the other beam are not shown. All signals are expressed per inelastic proton-nucleus interaction. The beam direction is from the left to the right.

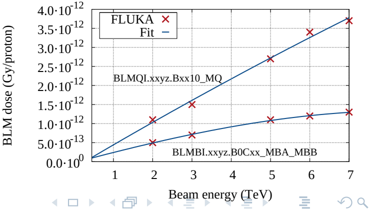
UFOs: BLM coverage for different dust particle positions

$$D^{QL}_{BLM} = \frac{D^{p}_{BLM} \times QL}{\varepsilon^{p}}$$



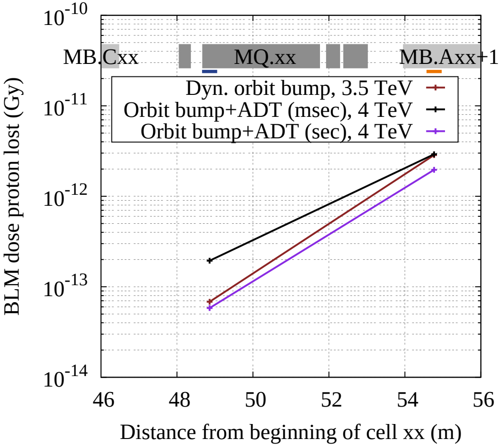
Detecting UFOs:

- Entire cell can be covered by three BLMs
  - The first vertical BLM covers the first MB, but also the upstream short straight section
  - The second vertical BLM covers the central MB
  - The BLM after the MB-MQ interconnect covers the third MB
  - The BLM after the MQ-MB interconnect is redundant
- For the other beam, the two vertical BLMs swap their role (hence their threshold should be identical)



Orbit bump: BLM coverage for vert./horiz. orbit bumps in MQ

$$D^{QL}_{BLM} = \frac{D^{P}_{BLM} \times QL}{\varepsilon^{P}}$$



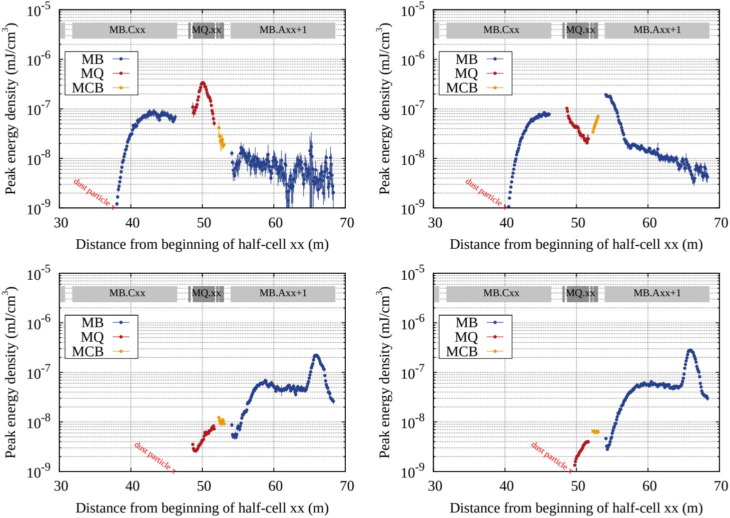
Detecting orbit bumps:

- Contrary to UFOs, losses due orbit bumps are concentrated around the MQ
- Contrary to UFOs, orbit bumps are
  - ○ mainly detected by BLM after the MQ-MB interconnect
  - ○ but less by BLM after the MB-MQ interconnect

Expected energy density?

UFOs: peak energy (@7 TeV) vs position of dust particle

$$D^{QL}_{BLM} = \frac{D^{p}_{BLM} \times QL}{\varepsilon^{p}}$$



Horizontal aperture curvature: peak due to neutral particles

(mainly γ's from decaying π^0 as well as neutrons)

Figure: Peak energy density ϵ_p in magnet coils due to proton-dust particle interactions in the MQ or in the MB directly upstream of the MQ, assuming a beam energy of 7 TeV. All distributions are per inelastic proton-nucleus collision. Beam direction is from the left to the right.

UFOs: peak energy density vs beam energy

$$D_{BLM}^{QL} = \frac{D_{BLM}^{p} \times QL}{\varepsilon^{p}}$$

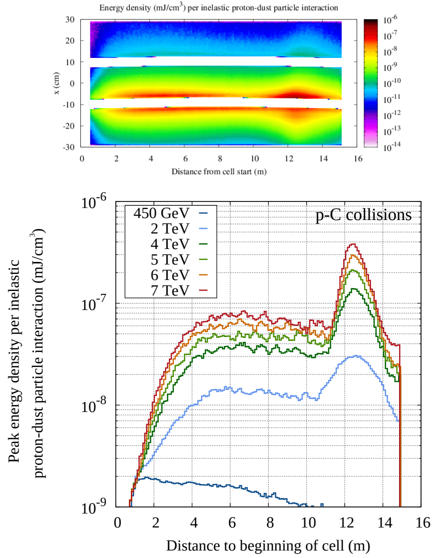
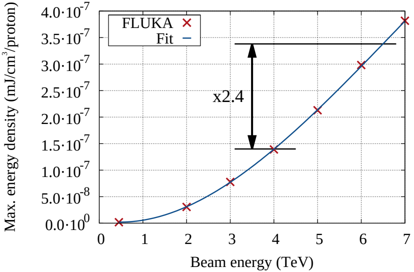


Figure: Peak energy density in MB coils per proton–dust particle interaction for different beam energies. The dust particle is assumed to be composed of carbon.

Limiting case: peak in MB (if BLMs cover for UFOs in MBs, then they also cover for MQs!)



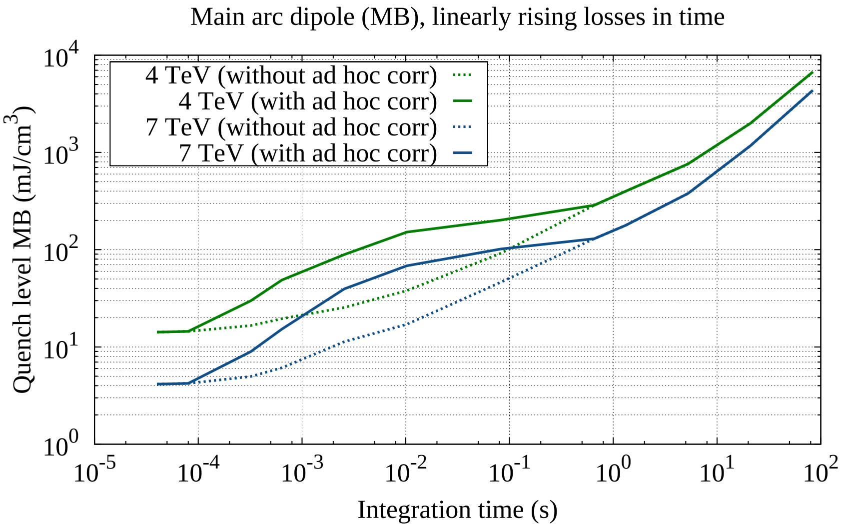
What maximum energy densities can we expect at 6.5 TeV?

- Evidently depends on number of interactions and hence on dust particle dynamics, composition, size, ...
- Assuming $\sim 10^8$ (like we estimated for 4 TeV) then we can end up with a few 10 mJ/cm^3 (→quench possible)

Expected quench levels?

UFOs: Quench levels of MBs $D_{BLM}^{QL} \times AdHoc = \frac{D_{BLM}^{p} \times QL}{\varepsilon^{p}} \times AdHoc$

Quench levels (QP3) without and with ad-hoc correction[†]:

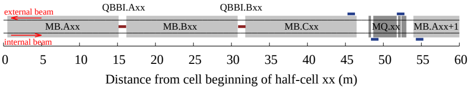


[†] *Correction accounts for less conservative model of the quench level in the UFO time range (experience from quench test).*

Contents

1. Detecting UFO-induced losses in the arcs: a brief recap of Run I (cell 19R3)
2. Post-LS1 BLM configuration in the arcs and ingredients for new thresholds
3. Post-LS1 thresholds for arc BLMs
4. Summary and outlook for straight sections

Proposal of strategy for post-LS1 arc thresholds



Three BLM families:

- BLMs above MB-MB interconnect (both on B1/B2)
- BLMs upstream of MQ (one on B1/one on B2)
- BLMs downstream of MQ (one on B1/one on B2)

Loss scenarios:

- BLMs above MB-MB interconnect: Dust particles
- BLMs at MQ: see table on the right
  - Both MQ families set to the same thresholds (separate families = retain flexibility for later)
- *Previously considered scenario of enhanced losses at interconnects neglected*

BLMs at MQ:

	RS01-RS0?	**RS0?-RS12**
<4 TeV	Orbit bump	Orbit bump
≥4 TeV	UFOs	Gas leak† / Orbit bump?††

† *Thresholds can be derived from UFO-like losses.*

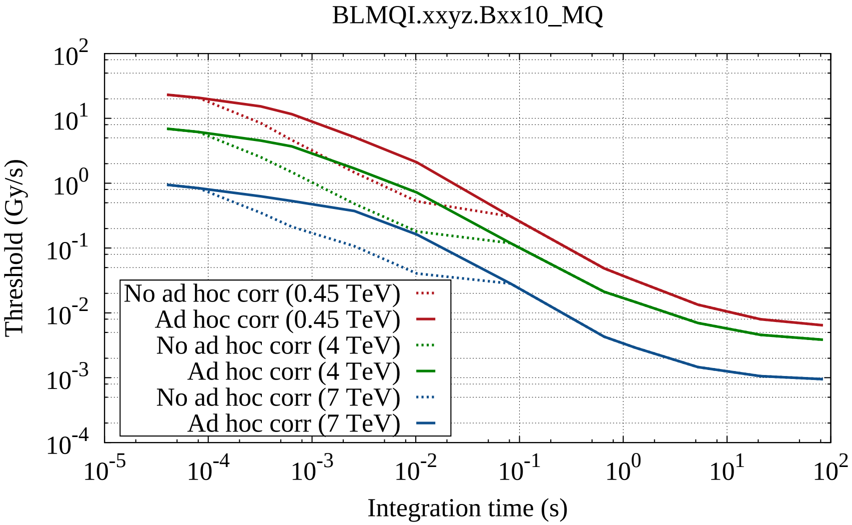
†† *Not (yet) considered in the presented thresholds.*

BLMs above MB-MB interconnect (B1&B2)	BLMs on MQ (B1)	BLMs on MQ (B2)
BLMBI.*xxyz*.B0C10_MBA_MBB BLMBI.*xxyz*.B0C20_MBA_MBB	BLMQI.*xxyz*.B1I10_MQ BLMQI.*xxyz*.B1I30_MQ	BLMQI.*xxyz*.B2E10_MQ BLMQI.*xxyz*.B2E30_MQ

BLM names in same colour = same BLM family.
Naming convention: C. Zamantzas and S. Grishin, “LHC BLM System - Expert Name Convention Additions”, MPP, 16/05/2014.

Resulting thresholds: BLMQI.xxyz.Bxx10_MQ (UFOs+orbit bump) $D_{BLM}^{QL} \times AdHoc$

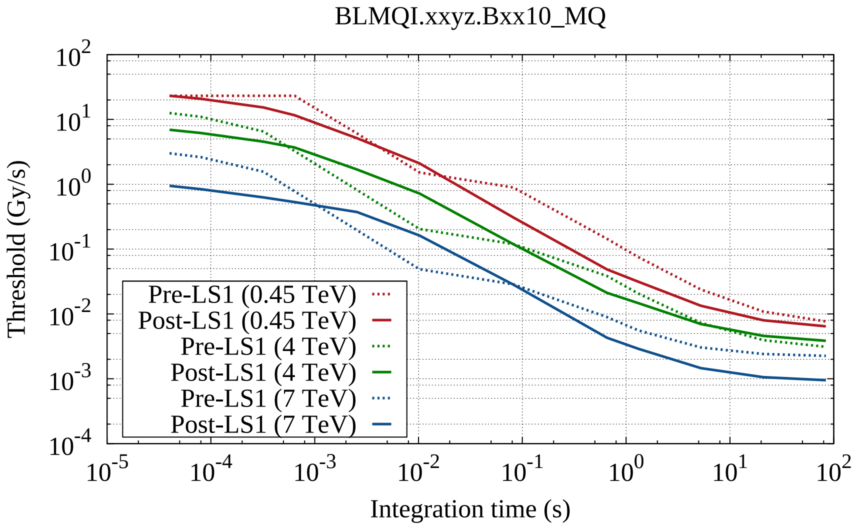
Post-LS1 thresholds without and with ad-hoc correction[†]:



[†] *Correction accounts for less conservative model of the quench level in the UFO time range (experience from quench test).*

Resulting thresholds: BLMQI.xxyz.Bxx10_MQ (UFOs+orbit bump) $D_{BLM}^{QL} \times AdHoc$

Comparison pre- vs post-LS1 thresholds:



Contents

Summary and concluding remarks for the arcs (and DS)

Newly proposed thresholds for the arcs:

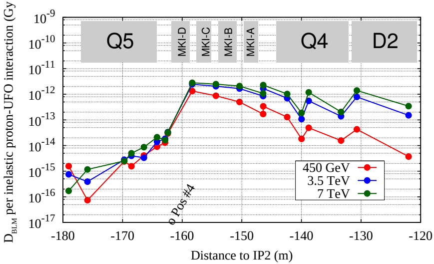
- Incorporate different loss scenarios depending on energy and running sum: orbit bumps+UFOs(+gas leak)
    - The presented thresholds were based on vertical dynamic orbit bump (from 2011 quench test), but are planned to be updated using the steady-state orbit bump (2013 quench test) since it is more conservative (factor ∼2)
- Are based on the best current knowledge of BLM response, energy deposition in coils (both from FLUKA) and quench limits (from QP3, with ad-hoc correction to account for outcome of quench tests)
- Not intended to be conservative for UFOs, i.e. applied thresholds are proposed to be at the presently assumed quench limit

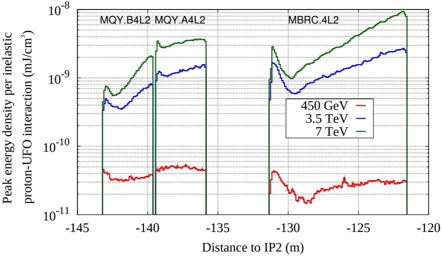
Proposal for DS:

- Quadrupole BLMs and BLMs above MB-MB interconnects
    - same as in the arcs
- Horizontal BLMs on MBs
    - set for ion runs, with sufficient play in monitor factor to rise thresholds for proton runs

Outlook for the straight sections

- Q4–Q6: same stratety proposed as for arc quadrupoles (UFOs above 4 TeV+orbit bump below 4 TeV)
  - Contrary to arc MQ-BLMs, the BLMs at SS MQs don't have to protect also dipoles
- Similar for Q3, with corrections for debris in long running sums
- D1/D2: UFOs
- Taking into accound experience from MKI UFOs (see figures on the right)





BACKUP

Recap of BLM threshold formula

BLM signal at quench

$$D_{BLM}^{QL}(E,t) = \frac{D_{BLM}^{p}(E,t) \times QL(E,t)}{\varepsilon^{p}(E,t)} \qquad [Gy] = \frac{[Gy/p] \times [mJ/cm^3]}{[mJ/cm^3/p]}$$

D_{BLM}^{QL} = BLM signal at quench level
D_{BLM}^{p} = BLM signal per proton lost
QL = Quench level
ε^{p} = Peak energy density in coils per proton lost

$$MasterThreshold(E,t) = \mathrm{N} \times D_{BLM}^{QL}(E,t) \times AdHoc(t)$$

$$AppliedThreshold(E,t) = MonitorFactor \times MasterThreshold(E,t)$$

Reference: B. Auchmann, "Strategy for new BLM thresholds in arcs and DS", MPP, 27/06/2014.