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B. Auchmann for the BLM Thresholds Working Group

BLM Threshold Strategy (vis-a-vis UFOs and Quenches)

with substantial contributions by T. Baer, R. Bruce, F. Cerutti, B. Dehning, L. Esposito, E.B. Holzer, A. Lechner, O. Picha, S. Redaelli, M. Sapinski, N. Shetty, E. Skordis, and others.

Overview

- Reminder of post-LS1 UFO prognostics
- BLM thresholds for the UFO scenario in the arcs
  - Energy deposition
  - BLM signal
  - Quench level
- Other post-LS1 BLM threshold strategies
  - Cold magnets
  - Warm magnets
  - Collimators

For more on the topic, see presentations at the *2014 Workshop on Beam-Induced Quenches*, September 15-16 at CERN, http://indico.cern.ch/event/BIQ2014.

Reminder of UFOs in MKIs

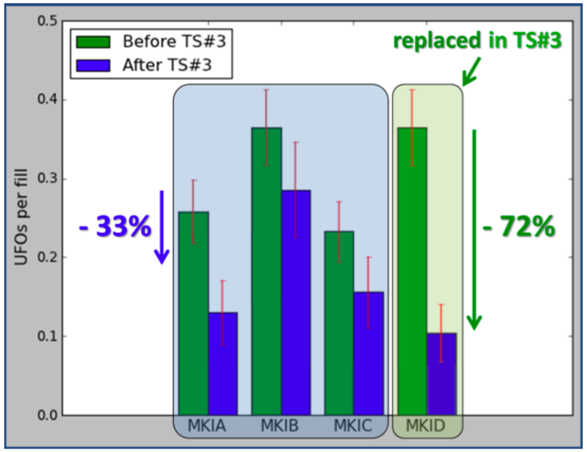
Monday morning talk on LBDS and Kickers after LS1 by W. Bartmann.

Mitigation to reduce UFO activity in the MKIs:

- improved cleaning procedures ➔ reduction of dust particles by factor 20-40;
- installation of additional screen conductors to reduce peak voltages by factor 7 ➔ further reduction of particle-detachment from ceramic tubes.

Efficiency of the measures was proven with test installation during the 3rd technical stop in 2012.

➔ MKI UFOs are not expected to be the limiting Issue at 6.5 TeV.



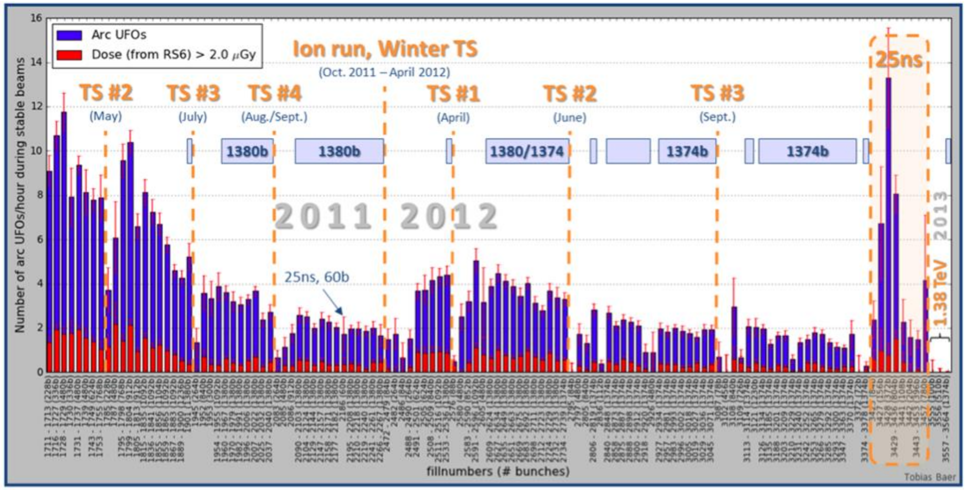
Reminder of UFO Problematic in the Arcs

As beam energy goes from 4 TeV to 6.5 TeV:

- **energy-deposition per proton-particle collision increases** ~2.4x;
- **quench level decreases** 2-3x; NB: Values updated wrt. T. Baer, CERN-THESIS-2013-233
- average UFO duration decreases due to smaller beam sizes;

Other effects after LS1:

- deconditioning due to warm-up and openings;
- more BLM triggers due to monitor re-location;
- possible quenches from UFO losses shorter than MPS reaction time;
- increased UFO rate (at least initially) for 25 ns bunch spacing;
- new confidence through SMACC that quenches at 6.5 TeV are not catastrophic, albeit undesirable.



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In short, after LS1, in the arcs

- **UFO-induced quenches and/or BLM triggers in the arcs are expected**;
- no mitigation was possible to reduce UFO activity;
- nonetheless the situation can be substantially improved through:
  - the **relocation of BLMs for 100% coverage** of SC magnets,
  - and a **refinement of BLM thresholds to avoid unnecessary triggers and quenches**.

BLM Threshold Formula

The assumed signal at quench is composed of three input factors:

$$\mathrm{BLMSignal@Quench}(E,t) = \frac{\mathrm{BLMResponse}(E,t) * \mathrm{QuenchLevel}(E,t)}{\mathrm{EnergyDeposit}(E,t)}$$

$$\mathrm{Gy} = \frac{\mathrm{Gy/p} * \mathrm{mJ/cm^3}}{\mathrm{mJ/(cm^3 p)}}$$

The $\mathrm{MasterThreshold}$ is a multiple of the $\mathrm{BLMSignal@Quench}$.

$$\mathrm{MasterThreshold}(E,t) = N * \mathrm{BLMSignal@Quench}(E,t) * \mathrm{AdHoc}(E,t)$$

The $\mathrm{AppliedThreshold}$ is set with the $\mathrm{MonitorFactor}$ (0…1].

$$\mathrm{AppliedThreshold}(E,t) = \mathrm{MonitorFactor} * \mathrm{MasterThreshold}(E,t)$$

The factor N shall ensure safety from damage while providing flexibility and room for corrections via the $\mathrm{MonitorFactor}$.

- 2009 Startup for cold magnets: N = 3, $\mathrm{MonitorFactor}$ = 0.1.

$$\text{BLMSignal@Quench}(E,t) = \frac{\text{BLMResponse}(E,t) * \text{QuenchLevel}(E,t)}{\text{EnergyDeposit}(E,t)}$$

UFO loss scenario EnergyDeposit

EnergyDeposit for p-C collision at the beginning of an MB.

Maximum of the deposition is due to neutral particles and MB sagitta.

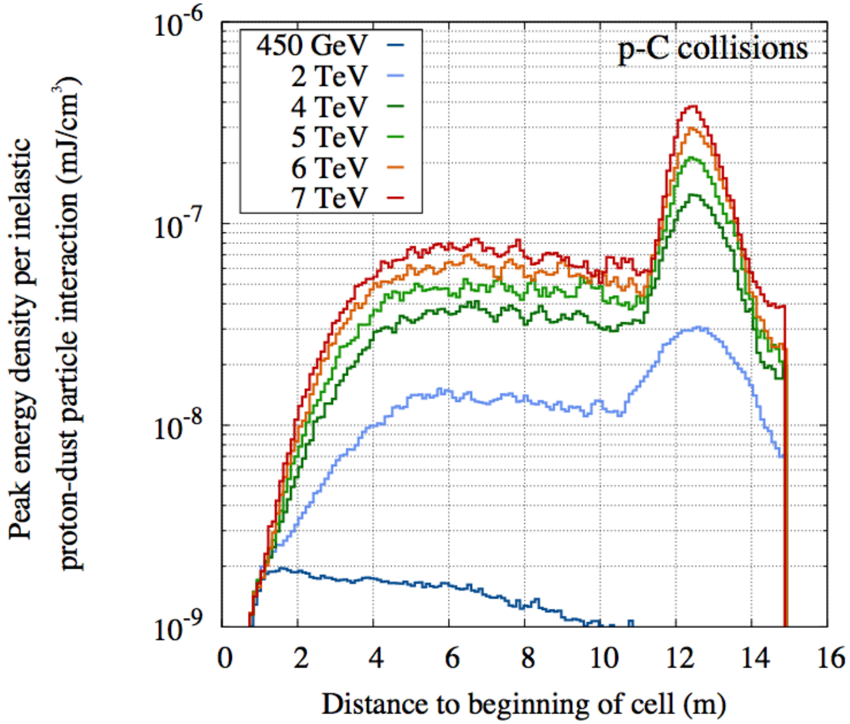
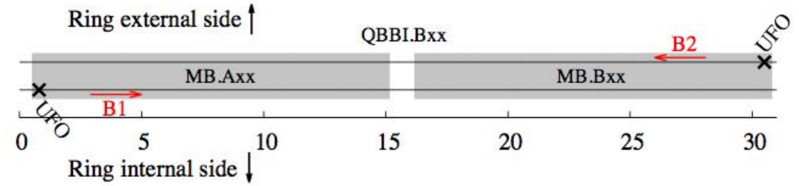
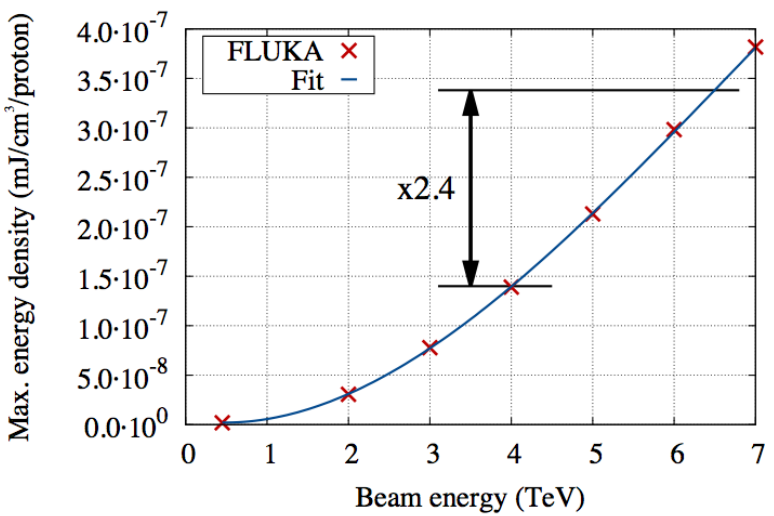


Figure: Peak energy density in MB coils per proton–dust particle interaction for different beam energies. The dust particle is assumed to be composed of carbon.



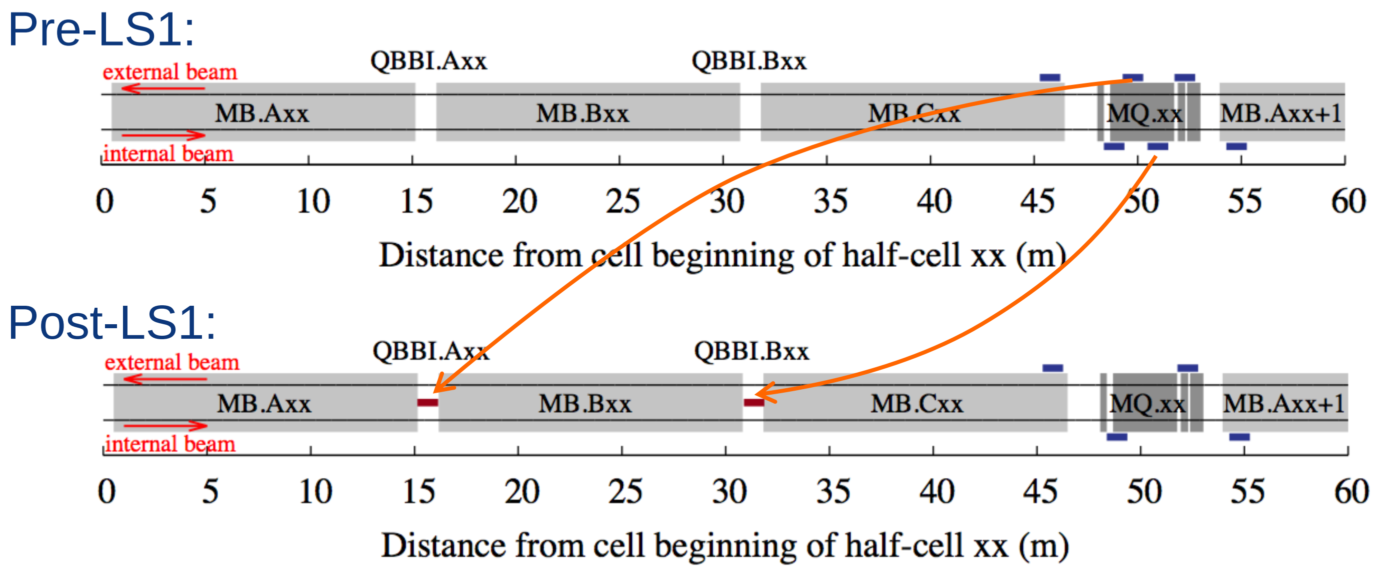


$$\text{BLMSignal@Quench}(E,t) = \frac{\text{BLMResponse}(E,t) * \text{QuenchLevel}(E,t)}{\text{EnergyDeposit}(E,t)}$$

UFO loss scenario BLMResponse

BLMs moved from centre of MQ to position above MB-MB interconnects.

Vertical position about 3x less sensitive to UFO losses than horizontal, but covering both beams.

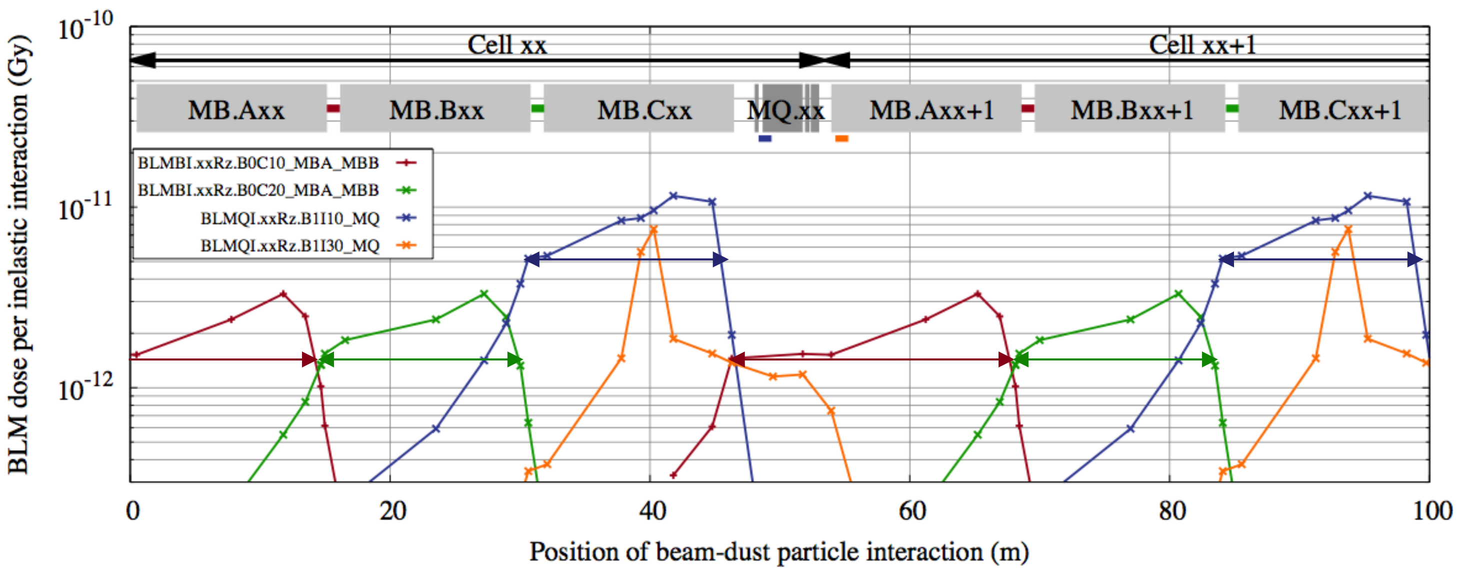


$$\mathrm{BLMSignal@Quench}(E,t) = \frac{\mathrm{BLMResponse}(E,t) * \mathrm{QuenchLevel}(E,t)}{\mathrm{EnergyDeposit}(E,t)}$$

UFO loss scenario BLMResponse

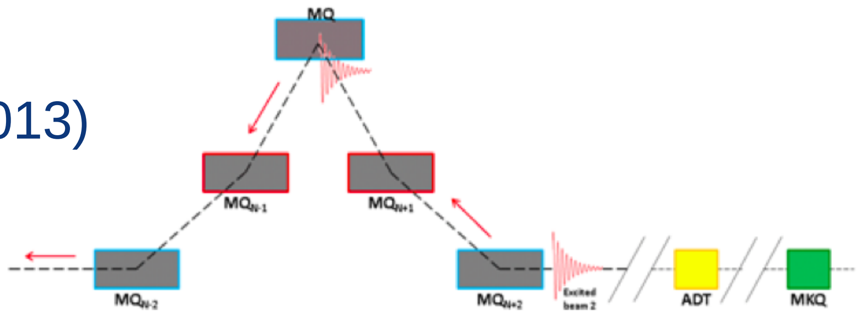
FLUKA study of p-C collision; BLMResponse as a function U.F.O. location.

The installation of BLMs on MB-MB interconnects increases the sensitivity at the beginning of the cell by a factor 30 ➔ 100% coverage can be achieved.



$$\mathrm{BLMSignal@Quench}(E,t) = \frac{\mathrm{BLMResponse}(E,t) * \mathrm{QuenchLevel}(E,t)}{\mathrm{EnergyDeposit}(E,t)}$$

Testing the QuenchLevel

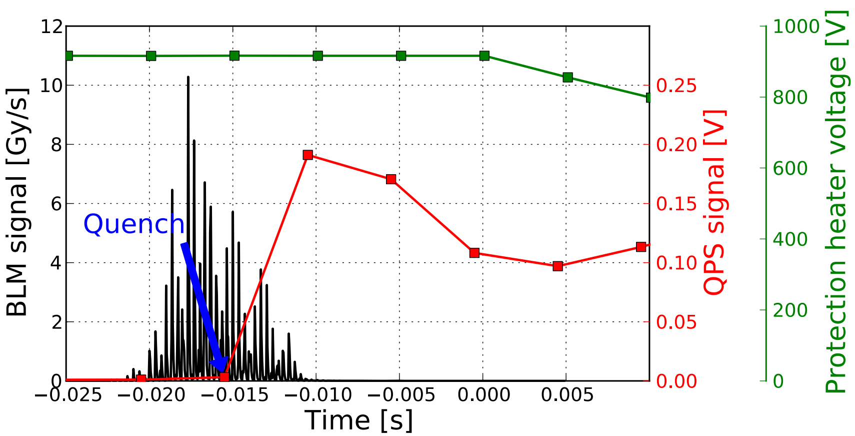


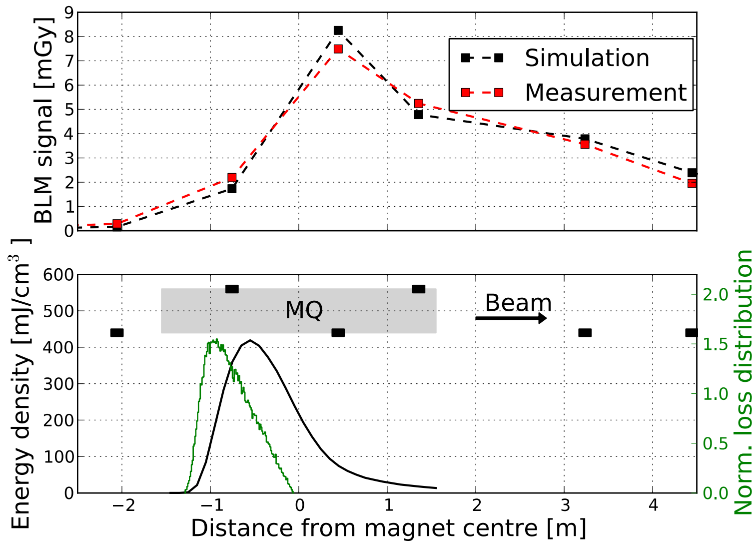
Fast orbit-bump quench test (15/02/2013)

Millisecond-losses induced by combined orbit bump, MKI kick, and coherent ADT excitation.

After ~10 ms a quench occurred **4x above QP3 quench-level estimate**.

The model's lower estimate may be due to μs substructure of loss pulse.





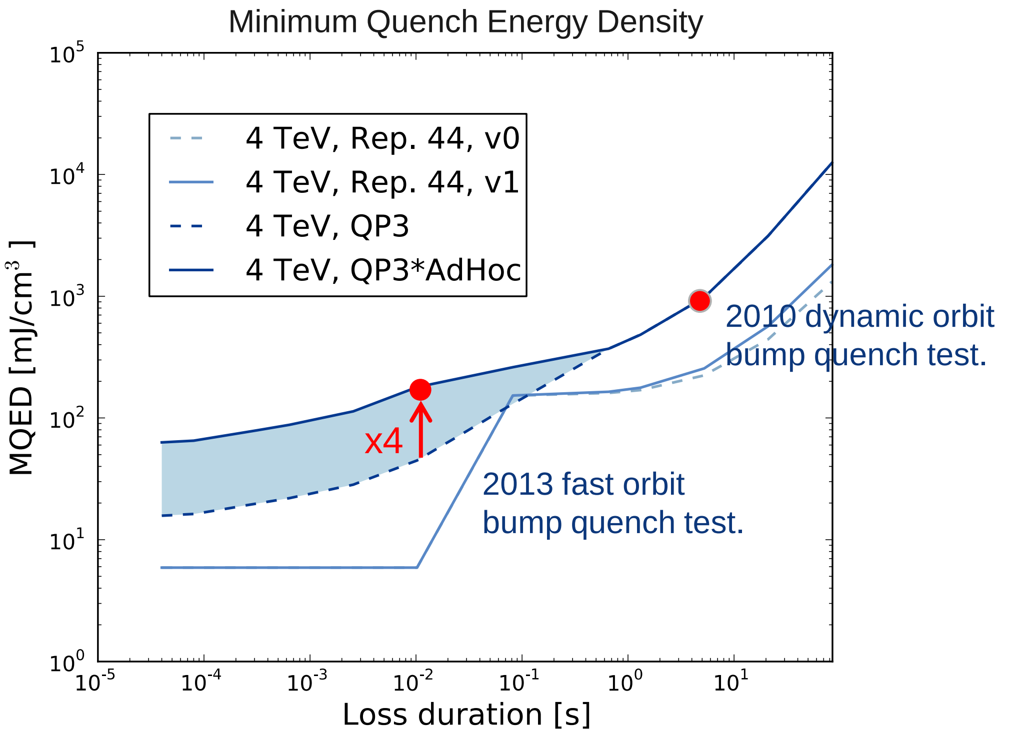
$$\text{MasterThreshold}(E,t) = N * \text{BLMSignal@Quench}(E,t) * \text{AdHoc}(t)$$

Applying AdHoc factor to QuenchLevel

Outcome of the orbit-bump quench test: Factor 4 higher quench level in the 10-millisecond time range and possibly below.

We propose to start after LS1 with an optimistic correction of electro-thermal model between 40 μs and 10 ms.

2008 strong-kick event validated quench level.

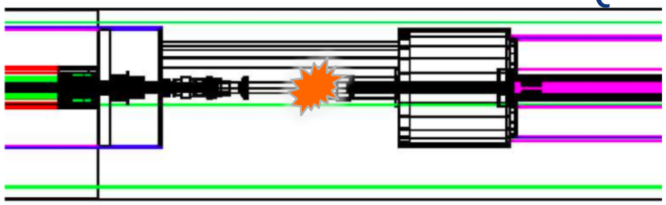


$$\mathrm{BLMSignal@Quench}(E,t) = \frac{\mathrm{BLMResponse}(E,t) * \mathrm{QuenchLevel}(E,t)}{\mathrm{EnergyDeposit}(E,t)}$$

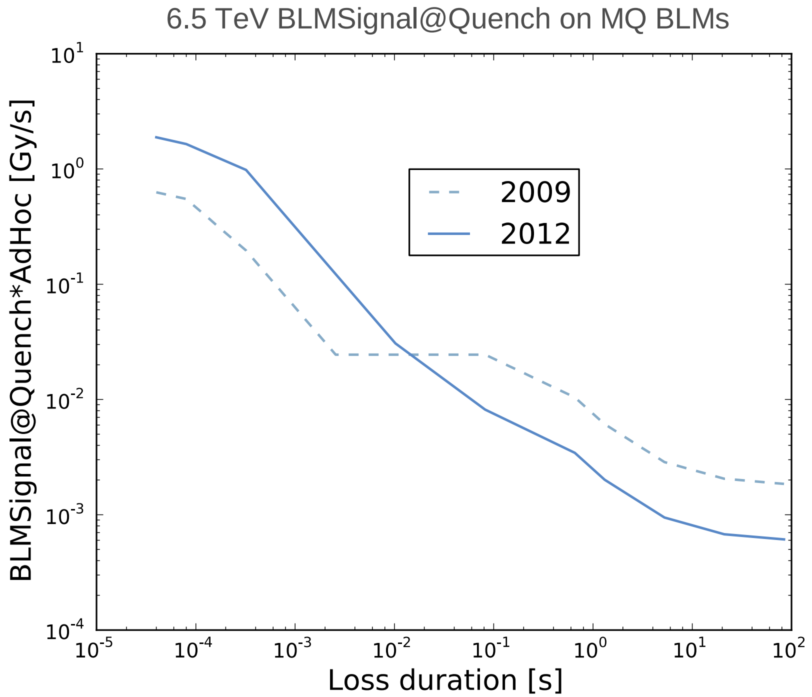
Arc thresholds

The initial beam-loss scenario were on losses in the MB-MQ interconnects.

It was adjusted several times based on UFO observations and quench tests.



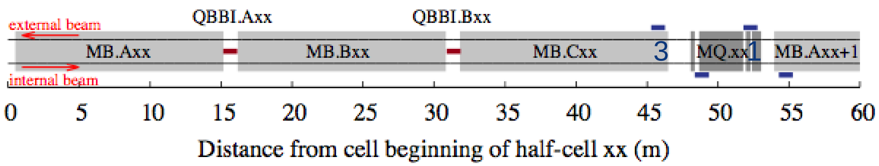
C. Kurfürst, CERN-THESIS-2010-070



B. Auchmann, LHC Performance Workshop (Chamonix 2014)

$$\mathrm{BLMSignal@Quench}(E,t) = \frac{\mathrm{BLMResponse}(E,t) * \mathrm{QuenchLevel}(E,t)}{\mathrm{EnergyDeposit}(E,t)}$$

Arc thresholds

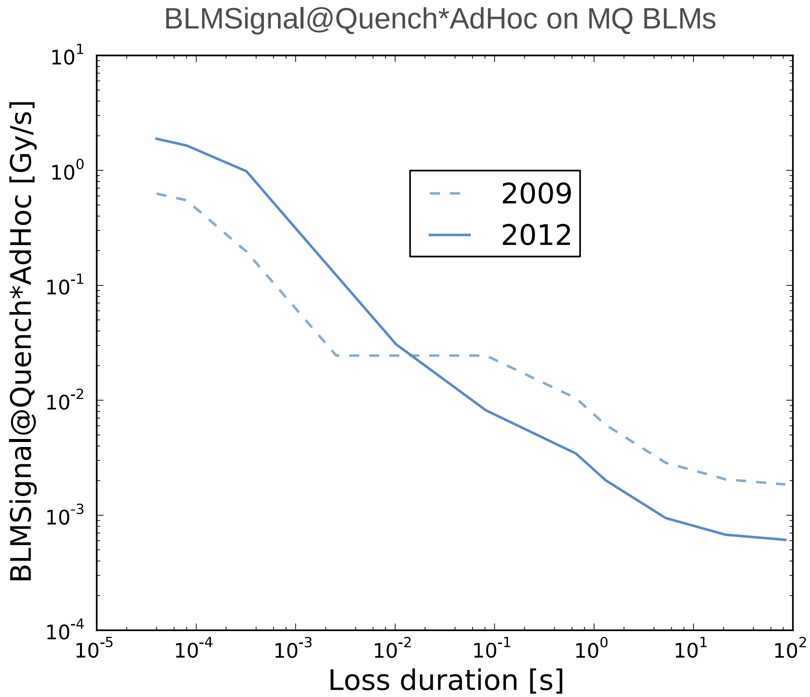


After LS1 we foresee

- UFO scenario on **MB-MB** interconnects;
- UFO and orbit-bump scenarios on **MQs**:
  - Position 1 is sensitive for UFOs;
  - Position 3 is sensitive for orbit bumps.

Beam-loss scenarios for MQ BLMs.

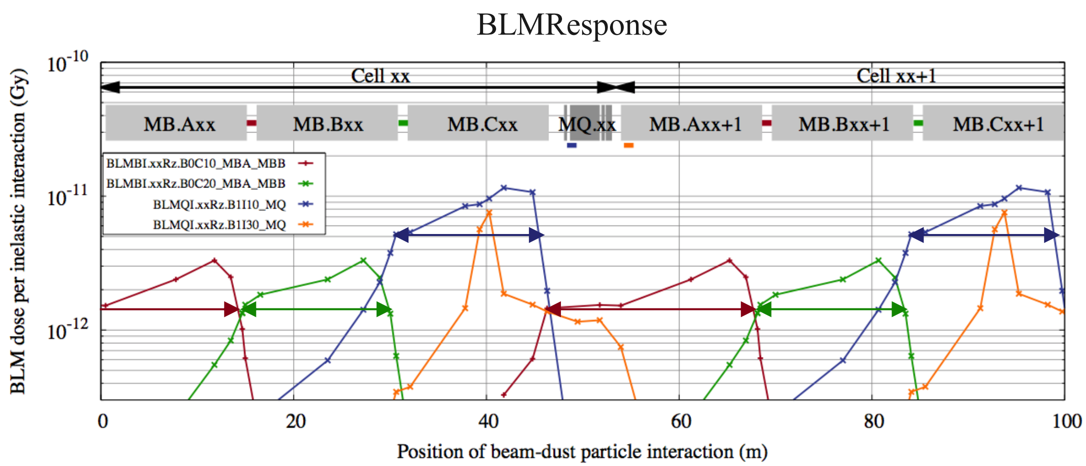
MQ BLMs	40 µs – 80 ms	80 ms – 80 s
450 GeV – 4 TeV	Orbit Bump	Orbit Bump
4 TeV – 6.5 TeV	UFO	Orbit Bump



NB: the higher QuenchLevel is almost completely outweighed by the lower BLMResponse/EnergyDeposit ratio of the UFO scenario wrt. the interconnect-loss scenario.

Arc-UFO BLM Strategy

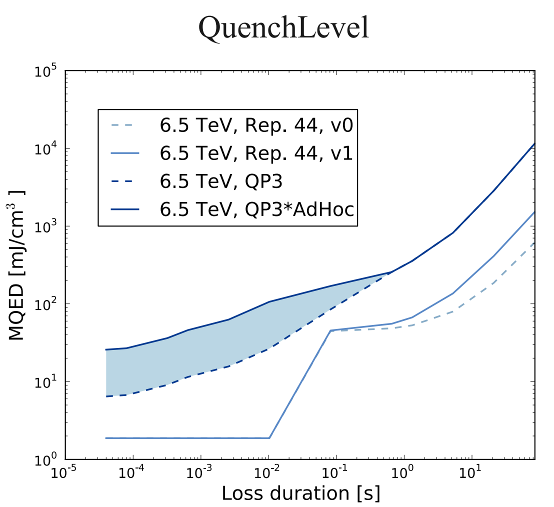
- We use FLUKA models and optimistic quench levels to define thresholds.
- Thresholds are set for 100% coverage of the arcs.
- Ratios of BLM-signals and FLUKA model will allow for localization of UFOs.



- Absolute BLM signals will allow to estimate the energy deposition in coils.

$$\mathrm{DepositedEnergy} = \frac{\mathrm{BLMSignal(t) * EnergyDeposit(E,t)}}{\mathrm{BLMResponse}(E,t)}$$

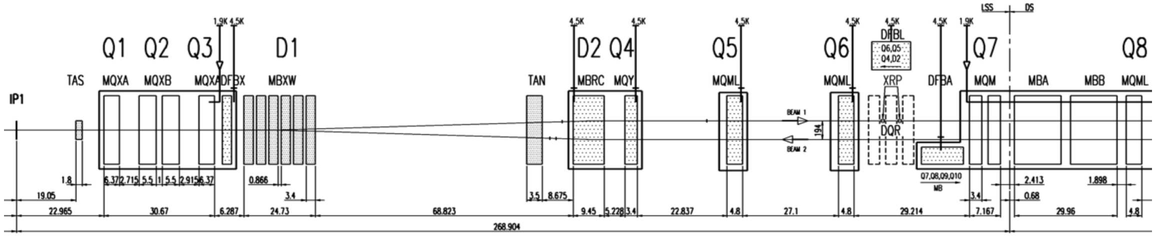
- ➔ We can obtain efficiently upper and lower bounds on quench levels, and optimize the BLM thresholds.
- For this purpose, $N = 10$ and $\mathrm{Monitorfactor} = 0.1$ set the $\mathrm{AppliedThreshold}$ to the predicted $\mathrm{BLMSignal@Quench}$.



Thresholds on Other Cold Magnets

DS magnets will be set for UFO and orbit-bump scenarios, as in the arcs.

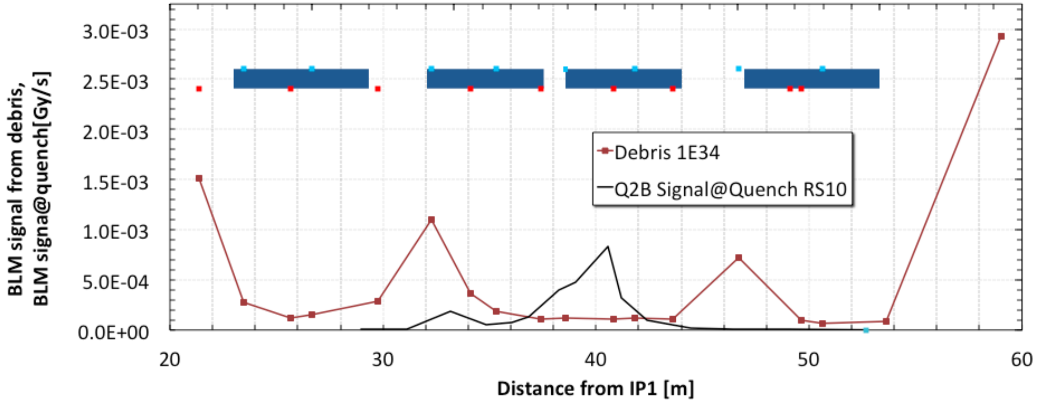
Thresholds on separation dipoles will be set using the UFO scenario.



IPQs and Triplets will be set for UFOs and orbit bumps, similar to MQs.

Triplet BLM thresholds have to ensure that physics debris (different loss scenario!) will not dump the beam. Thresholds will be kept safely above debris.

Physics Debris vs. BLMSignal@Quench for Orbit Bump in RS10



B. Auchmann, LHC Performance Workshop (Chamonix 2014)

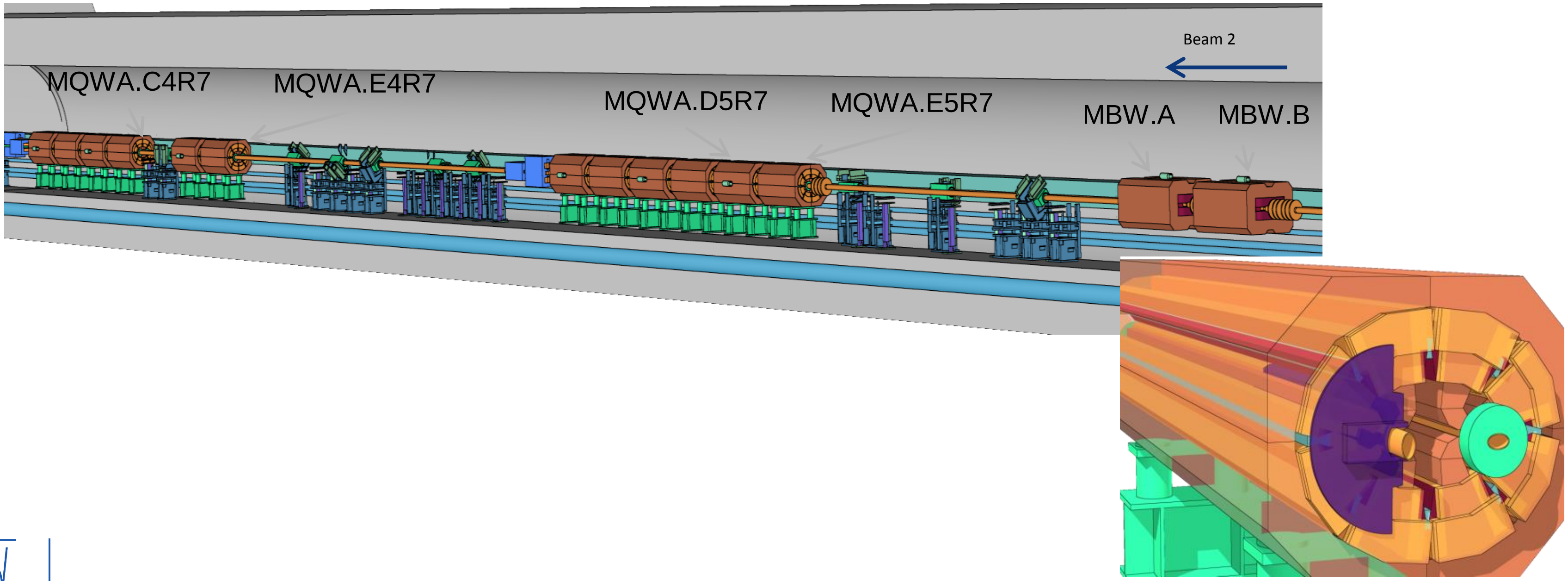
Thresholds on Warm Magnets

New shielding has been installed on MQWs in IR3 and IR7 during LS1.

BLM dose is used offline in conjunction RadMon counts to monitor the integrated dose.

A new FLUKA model will be used to set BLM thresholds protecting

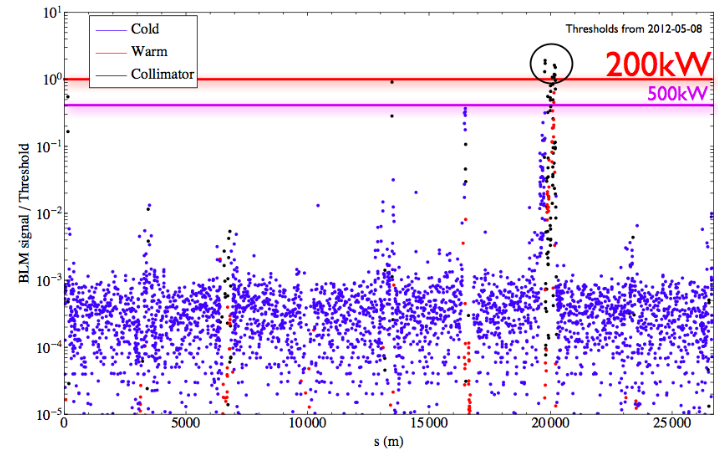
- the vacuum tube from damage,
- the coil from over-heating.

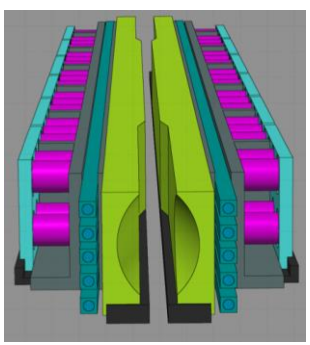


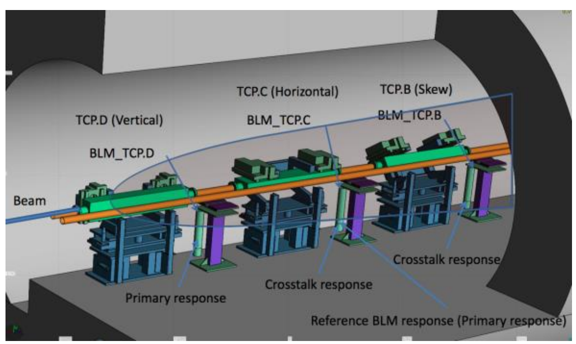
Thresholds on Collimators

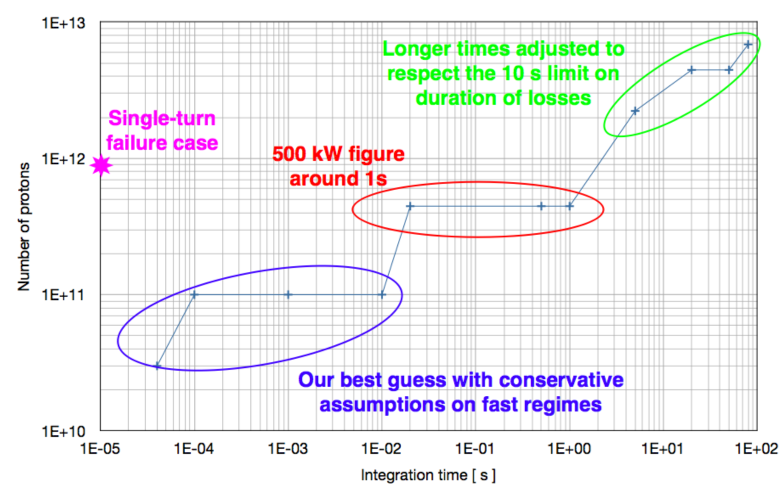
Thresholds on collimators will be set based on

- loss-maps that are scaled up to 500 kW primary losses on the TCPs;
- updated damage levels of collimators based on material and geometry;
- FLUKA models of energy-deposition in collimators and BLM signals;
- experience with cross-talk between monitors on adjacent collimators.





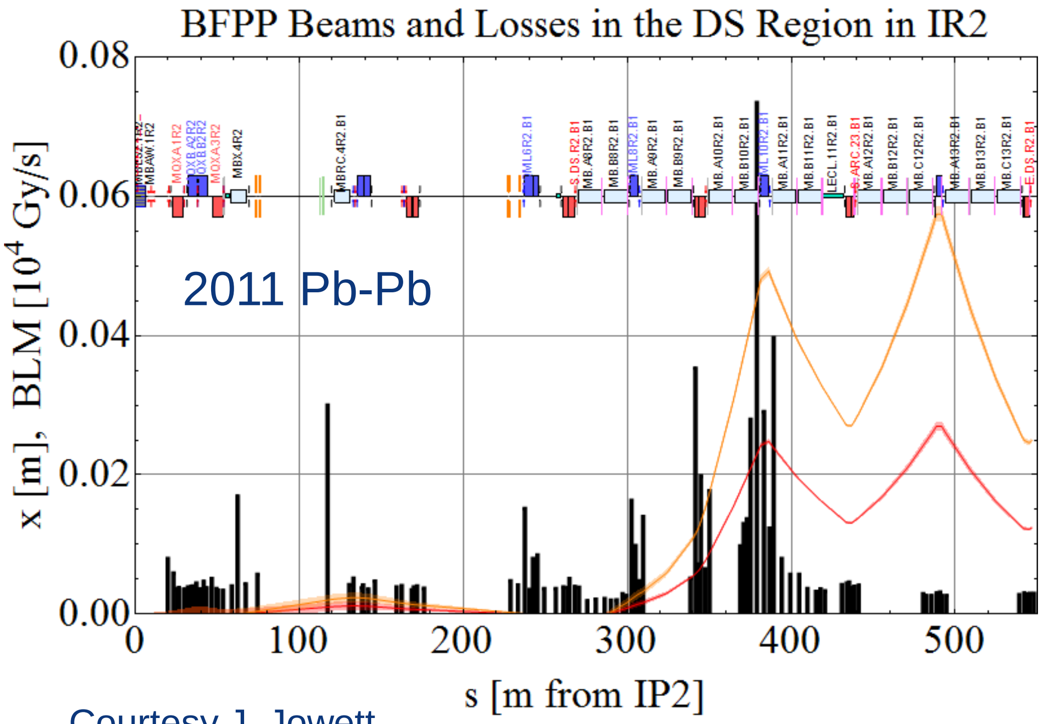




S. Redaelli, BIQ2014, 16/09/2014

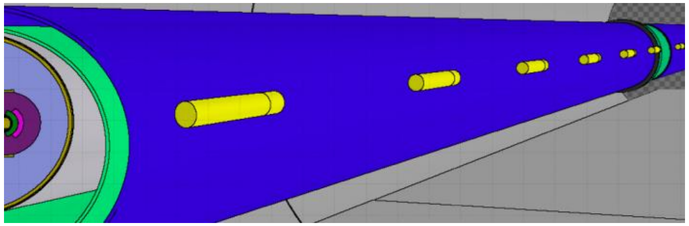
Thresholds for Ion Operation

Secondary ion beams from IPs and collimation led to very localized losses.
Additional BLMs on DS dipoles will be used to protect MBs from this scenario.



Courtesy J. Jowett

FLUKA model of DS dipole



Conclusion

- **New BLM positions** in the arcs and **FLUKA models** will allow **to localize and quantify UFOs**.
- Quench tests provide grounds for **optimistic** assumptions on **quench levels**.
- **Efficient tuning of BLM thresholds** is possible – **some UFO-induced quenches are to be expected**.
- Strategies for cold magnets, warm magnets, and collimators were discussed in detail at BIQ workshop. They are based on improved models and updated loss scenarios.
- Detailed verification of all updated thresholds against “proven” 4 TeV thresholds will be carried out.
- Tools for the offline monitoring of BLM signals vs. thresholds as well as signals vs. noise around the ring exist and will be deployed during Run 2. The goal is a proactive detection of potential limitations for operation.
- Future quench tests to validate quench levels further are desirable.

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