BLM Thresholds

Eva Barbara Holzer for the BLM team

LHC Machine Protection External Review

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CERN

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BLM AUDITS

BLM Audit June 2008

"Generally, the auditors found that the design and implementation of the BLM electronics and the threshold management is sound, complete, straight-forward, and, in particular, conform to the requirement of high inherent level of safety, reliability and availability.

… the **initial determination** of the **threshold values** is **very critical**. Despite the large number of sophisticated simulations, **dedicated measurement runs** and a subsequent and iterative **adaptation of the threshold values** during the early running of the LHC must be conducted.

Furthermore, although the auditors agree on the data driven approach, which manages all threshold values centrally in an Oracle database, **concern** has been the **management of the threshold values** themselves. The current **procedures** are found **incomplete** (partially since still under development), and adequate **protections against tempering or human errors are missing**."

BLM Audit Follow-up July 2009

"Most of the remaining, open recommendations are pending implementation during 2009. Of those, the Board would like to express particular concern about the **lacking procedures for changing threshold and configuration values** in the Master and Stage tables. This includes the **lack of software tools to detect erroneous values** as well as to **identify locations with too many disabled BLMs**."

Since then:

- Procedures → (mostly) finished
- Software tools to detect wrong values → improvement, a few still to be done, but often not possible to determine by software what is right or wrong
- Location with too many disabled BLMs → implemented in LSA DB (but actually no BLM was disabled so far)

DEFINITIONS

Definition - Master threshold and Applied threshold

- Give OP team certain tuning freedom on thresholds
  - Master thresholds:
    - Maximum thresholds which can be applied
    - Safety requirement:

Master thresholds < 10 * ‘damage level’ for integration times ≤ 100ms
(integration times > 100ms: also covered by QPS + cryogenic system)

  - Applied thresholds = Master thresholds * monitor factor (MF)
    - MF ≤ 1 (enforced in LSA DB)
  - MF set individually for **each monitor**
  - MCS_BLM_expert role (limited number of people) allowed to change MF

Typically: thresholds set in conservative way at the start-up of LHC → need of interventions

Families and Monitors

- Family definition: monitors with the same master thresholds
  - Similar/same:
    - Elements
    - Monitor location
    - Loss scenario
  - Between 1 and 360 monitors in one family

	# Families	# Monitors
Ionization Chambers (IC) – 99 monitors not connected to BIS (dump line, element not installed, measurement only)	122	3592
SEM – none connected to BIS	22	289
Total	***144***	***3881***

Cold Magnet Thresholds

Cold Magnets – Simulations and Measurements

Thresholds set by simulations

- Loss shape (geometry, time)
- Beam loss → Energy deposition in coil and signal in BLM
- Quench margin

$$T_{\text{hreshold}} = \underbrace{S_{BLM}(E_b)}_{\text{BLM signal}} \cdot \underbrace{\Delta Q\,(E_b,t)}_{\text{quench margin}} \,/\, \underbrace{E_D\,(E_b,t)}_{\text{energy deposited in coil}}$$

and by measurements

- Verification with beam only for:
  - MB transient loss and
  - ms range MQY (wire scan)
- Verification of steady state quench margin with heater inside beam pipe for
  - MQ, MB and MQM

Simulation Energy Distribution Coil – LHC Project Note 422

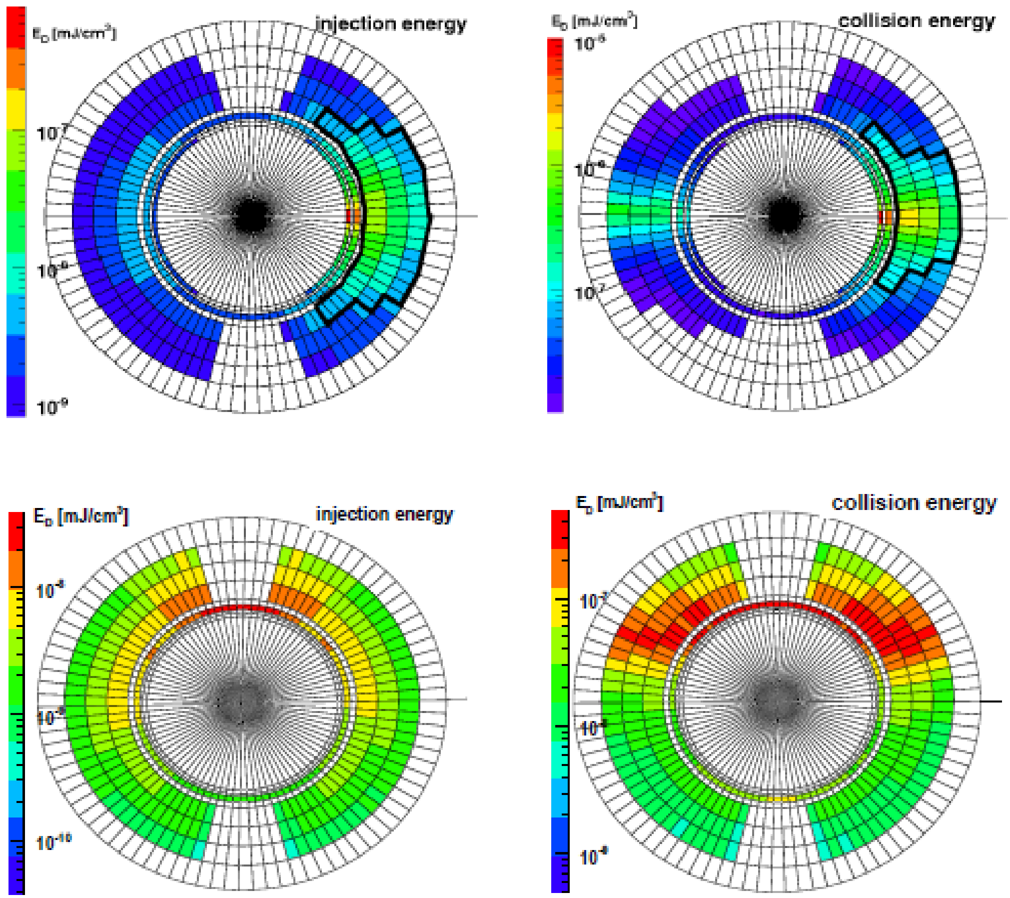


Figure 4: *Cross section through the region of MB internal coil with maximum energy deposition (per proton, for pointlike loss) for injection and collision beam energies. Upper plots show horizontal loss and areas marked contain 90% of the energy deposition in the cross section of the right coil. Down plots show vertical loss and in this case the energy deposition in beam screen is not shown.*

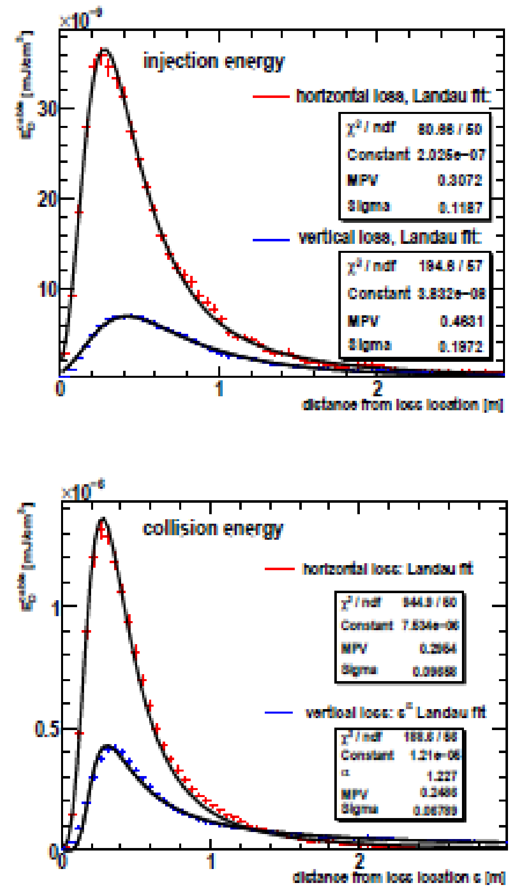


Figure 9: *Energy density distribution per impacting proton for the most exposed azimuth in the thermal equilibrium volume of the inner coil. The shape of the distribution is the same as in case of* E_D^{max}.

Simulation BLM Signal – LHC Project Note 422

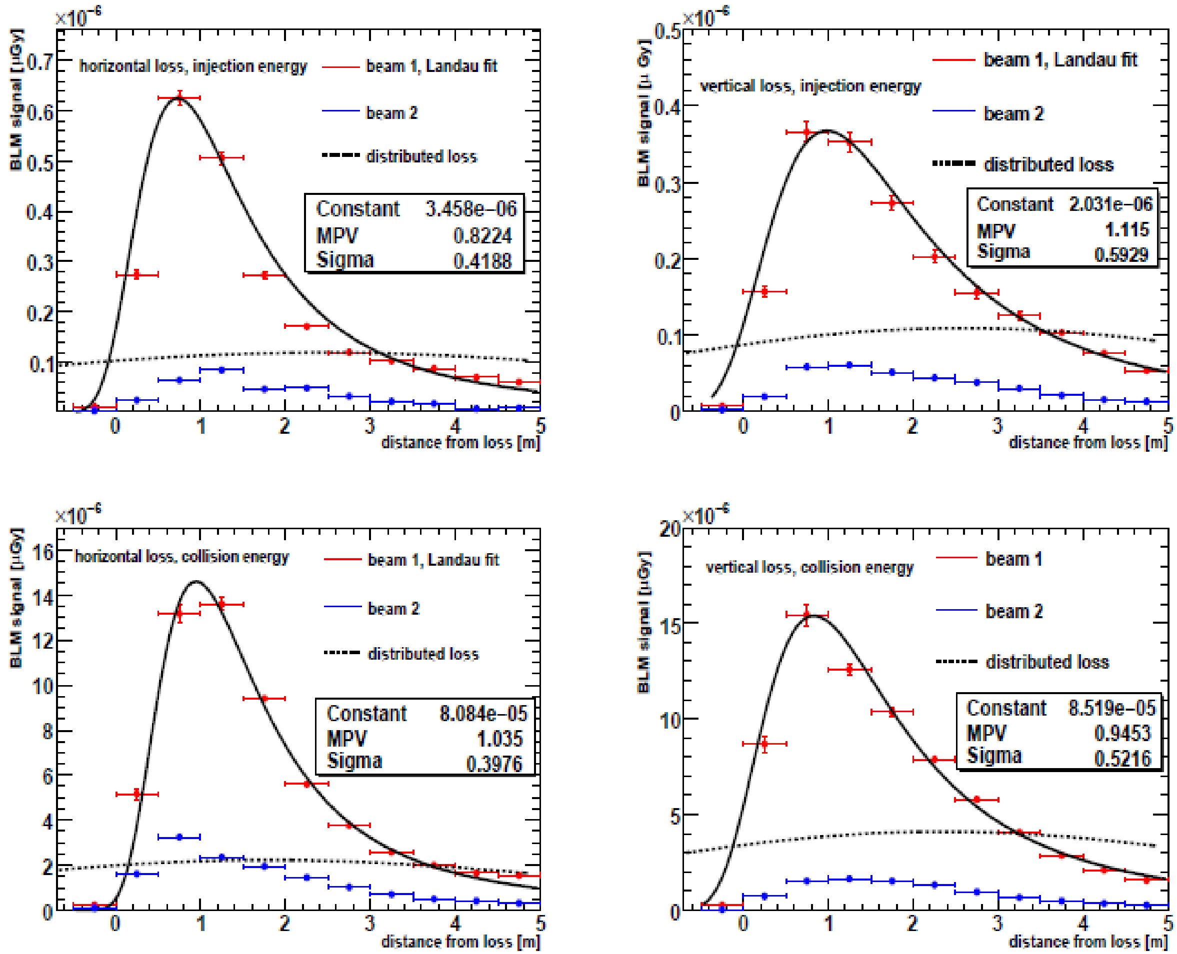
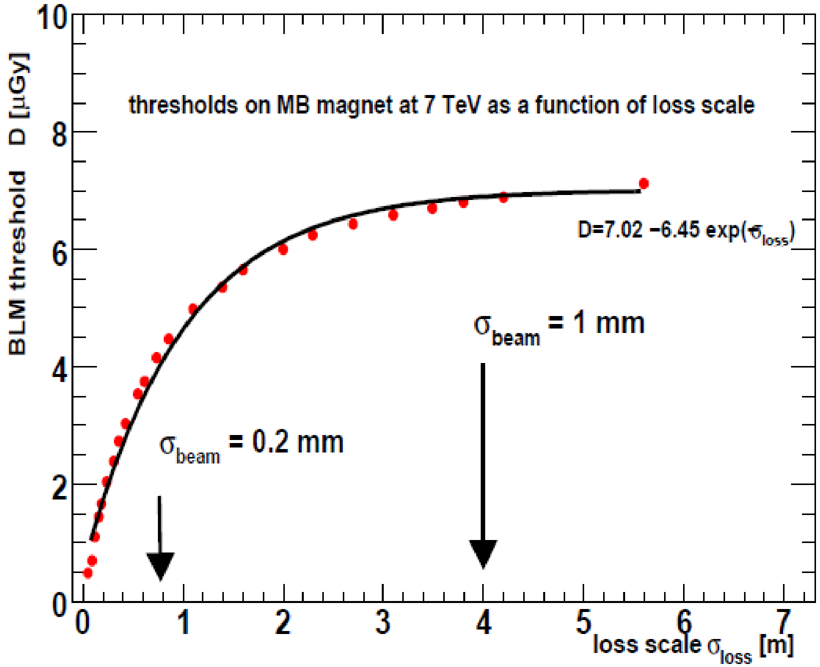


Figure 17: *Signal per impacting proton in BLM cylinders along the cryostat as a function of distance from the loss location. Left upper plot: injection beam, horizontal loss (outwards the magnet center). Right upper plot: injection beam,vertical loss . Row below: for collision energy.*

Longitudinal Loss Length Dependence - LHC Project Note 422



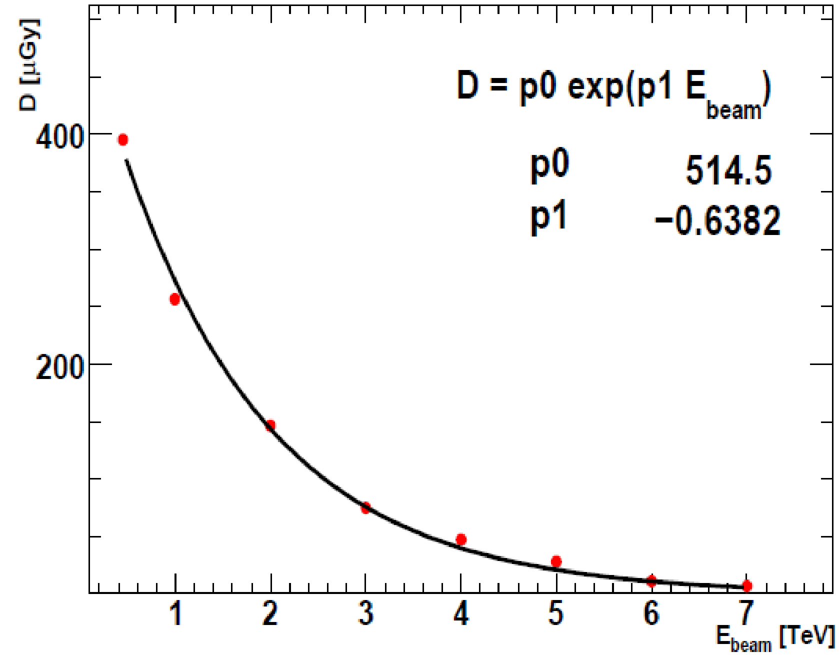


Figure 20: *Left plot: illustration of the dependency of the threshold value at collision energy from the scale of the loss distribution. Shrinking the transverse beam size from 1 to 0.2 mm leads to thresholds decrease by 50%. Fitting the dependency with assymptotic functions give values between 7 and 8 µGy for losses distributed over a distance more then 4 meters. Right plot: threshold on the MB magnet as a function of the beam energy.*

Cold Magnets

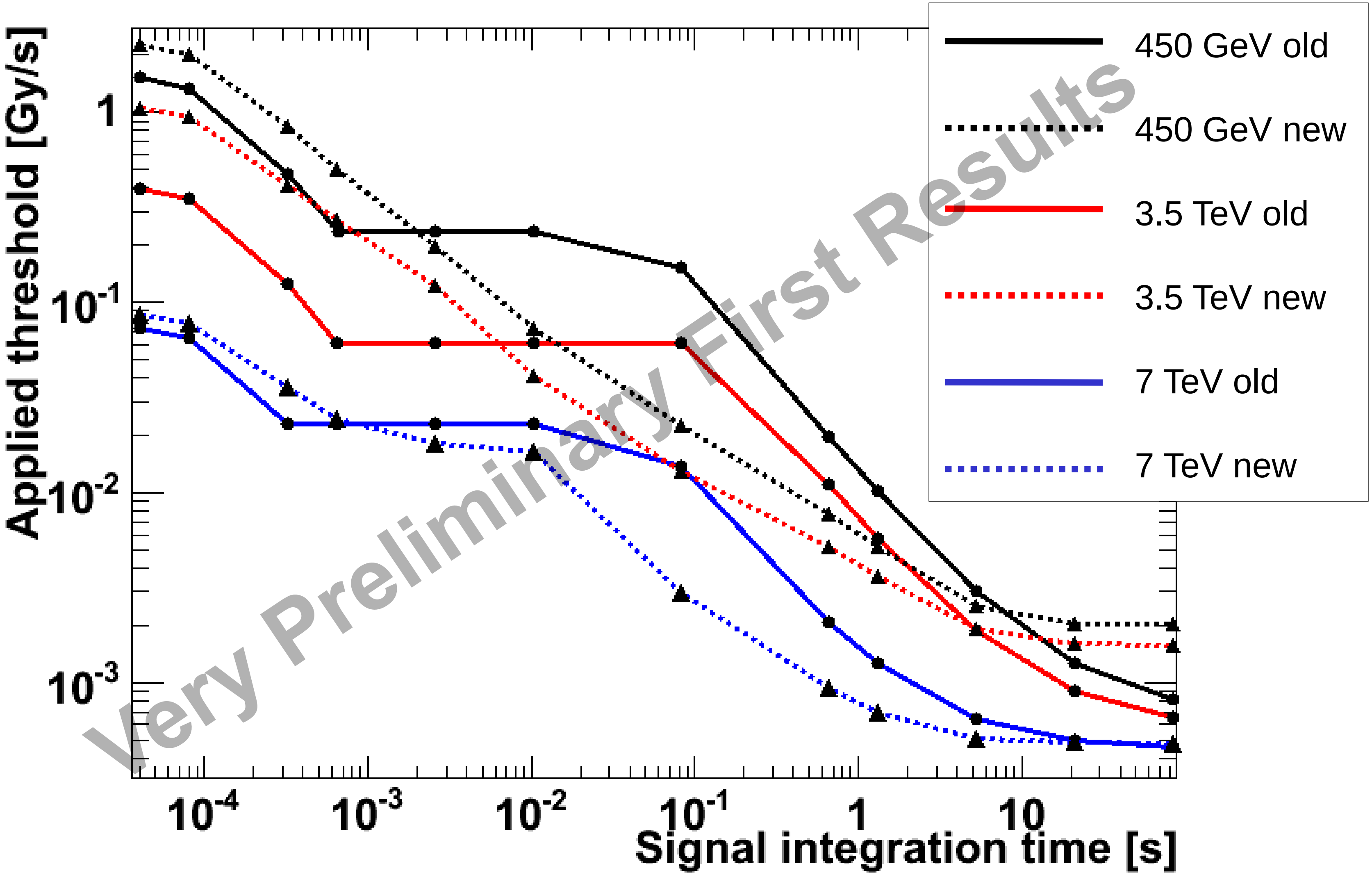
- Standard for cold magnets: MF = 0.1
  - Applied thresholds = 0.3 * ‘best to our knowledge quench levels’
  - Master thresholds = 3 * ‘best to our knowledge quench levels’
  - Short losses: about (at least) a factor of 100 between estimated quench and damage levels → safety requirement fulfilled

	# Monitors	Simulations beam loss → energy deposition magnet and BLM	Beam measurements	Heater test of steady state quench margin
MQ (2361) MB (239)	**2600**	GEANT4	Yes – transient loss Yes – transient loss	Yes Yes
Triplets: MQXA (80) MQXB (64)	**144**	FLUKA	no	
All other cold	**493**	no (scaled by their respective enthalpy for transient loss)	MQY ms range - yes all other - no	MQM – yes All other - no

Quench Margin Simulations

- Energy deposition → quench margin
  - Current model:
    - Transient losses: Calculated cable enthalpy (LHC quench events → BLM thresholds accurate to factor 1.5 NOTE 422 → corrected)
    - Steady state heat flow modeled (measurement of heat flow and quench with internal heater)
    - Transition between transient and steady state in steps and linear interpolation:
      - Heat flow along cable
      - Heat flow to He
  - Future use QP3 code (Arjan Verweij) – tuned to reproduce measurements
    - Includes all physics processes with proper time
    - Results: quench margin for all integration times without interpolation steps

Model Comparison



Accuracy of Thresholds - MB

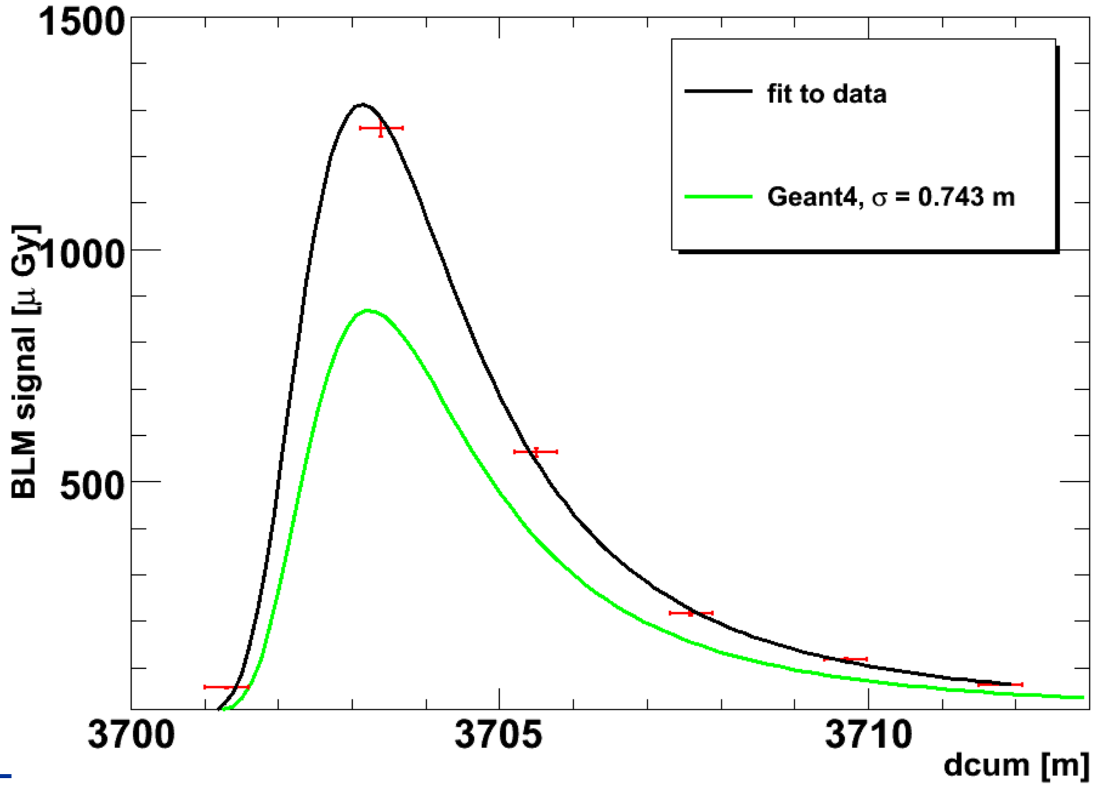
- All quenches so far on MB (all injected beam). Most likely loss location with circulating beam are the quadrupoles.
- 2 quenches in 2008 (injected beams): signals in BLMs could be reproduced by GEANT4 simulations to a factor of 1.5

  → thresholds raised

  by ≈50%

Analysis of second quench

LHC Project Note 422



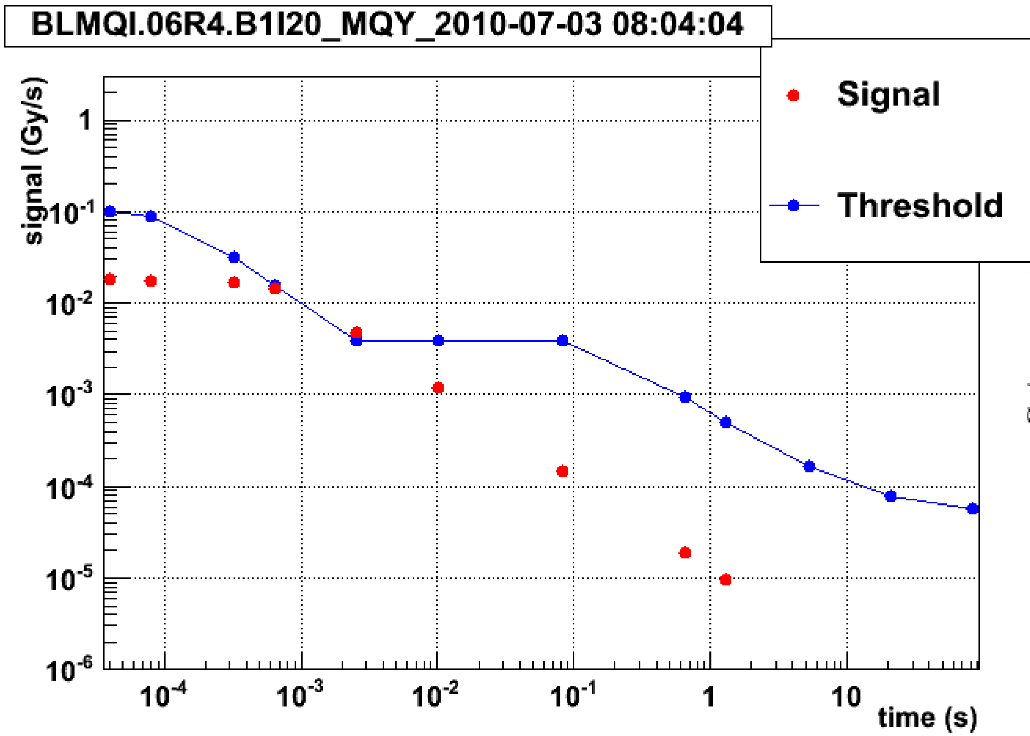
Quench Level Beam Tests

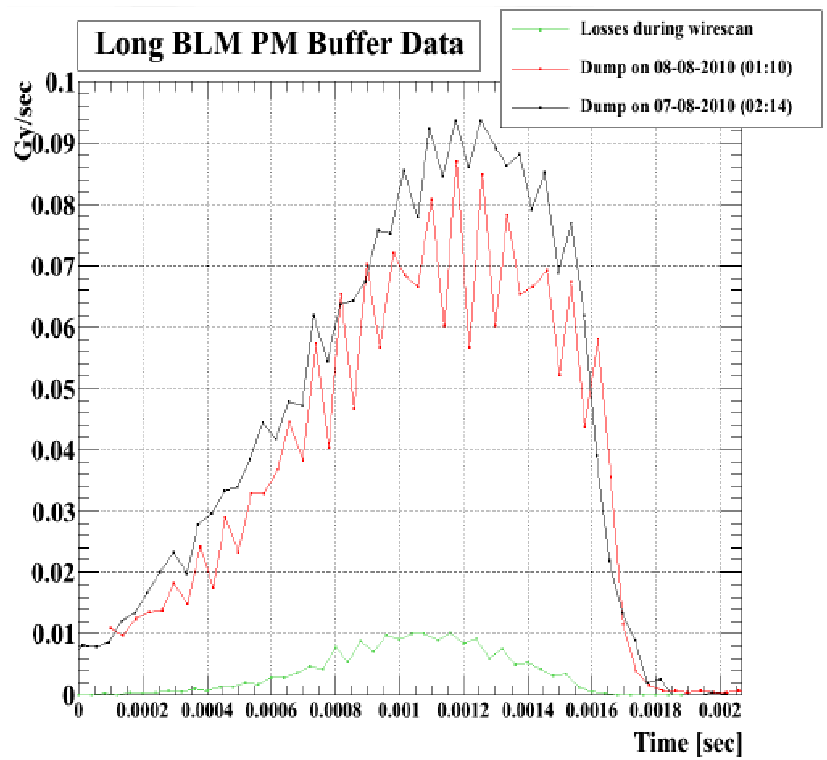
Beam Tests – Transient and Steady State Thresholds

- Beam tests: provoke either a quench, or better, a 'recovering quench' on different magnets at different energies.
    - Transient loss: Injected beam – detect with special version of nQPS
    - Steady state: Circulating beams – detect with magnet temperature monitors

Beam Tests – ms Range Thresholds

- Test thresholds in ms loss range using the wire scanner





GEANT4 Simulation of Wire Scanner

- Wire breaking after:
  - up to about 25% of nominal intensity at 450 GeV
  - 7% of nominal intensity at 7 TeV (difference mainly due to beam size)

- Magnet quench:
  - Around/below nominal intensity at 450 GeV
  - 2% of nominal intensity at 7 TeV
  - New simulations (ongoing): 50 nominal bunches at 3.5 TeV

Collimator and Warm Element Thresholds

COLLIMATOR THRESHOLDS

- Standard Collimator thresholds: MF = 1.0 (dynamic range)
  - **95** Ionization Chambers
  - Extensive simulations (protons → collimator heating and damage)
  - FLUKA simulations and beam measurements (protons → BLM signal)
  - Thresholds defined according to operational scenario
  - Mostly far below damage level (see exception)

WARM ELEMENT THRESHOLDS

- Warm elements: MF = 0.1
  - Roman pot thresholds defined by simulations
    - Verification with beam needed
  - MSD simulated, but error found. New results expected soon.
  - All other warm elements either
    - same thresholds as MSD (even though different geometry): MQW, MBWMD, BSRTM (total **94**) or
    - 23 Gy/s for all integration times and energies: MBW, MKI, MKD, (absorbers: TAN, TCD, TCAP) – total **34**
- Short term plan for warm elements – but signal in BLM / lost proton?

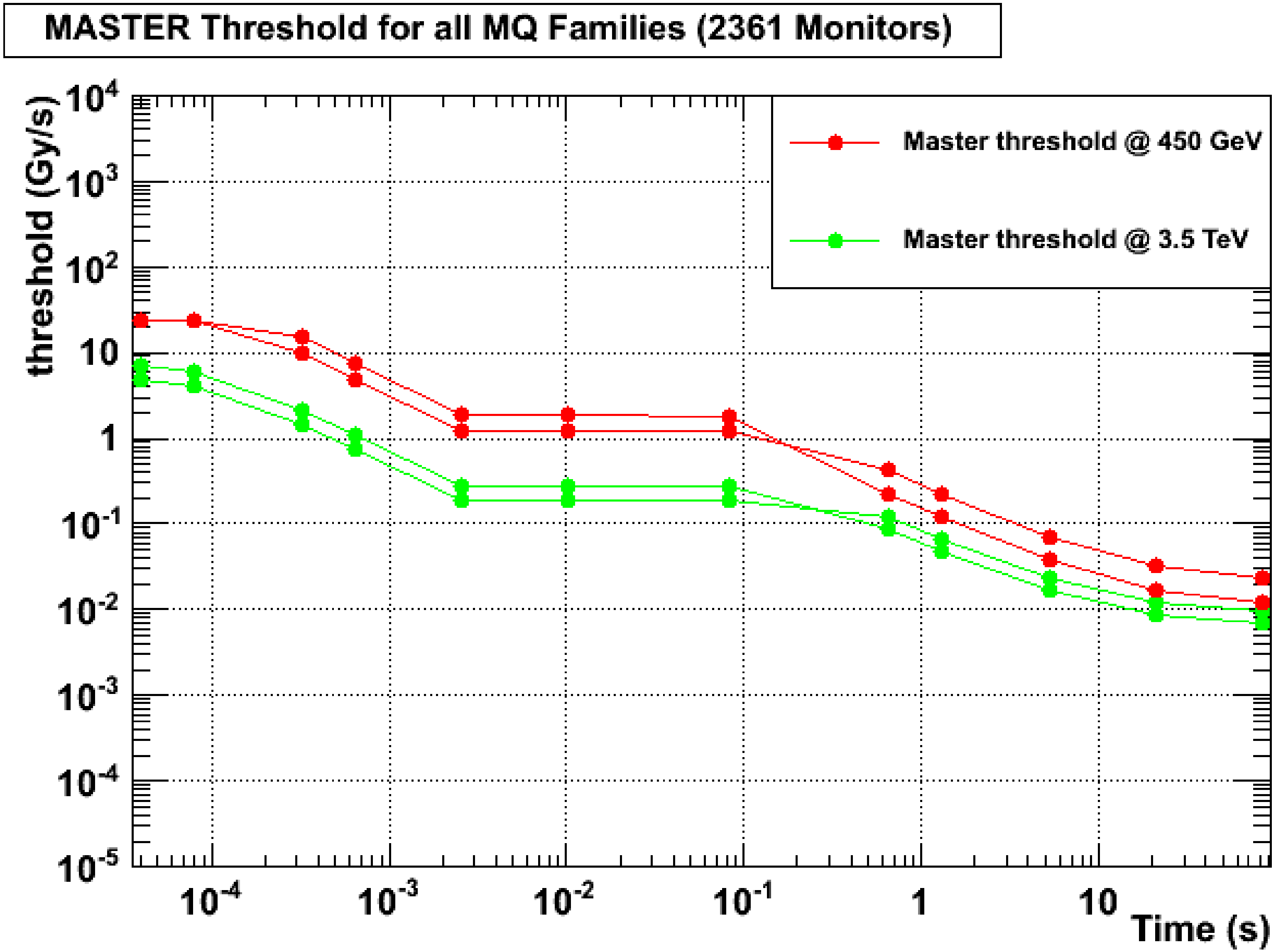
	Transient losses number of protons in 40us	Steady state number of protons in 89s
450 GeV	1E12 (factor 5 below melting in test measurements, V. Kain PAC'05)	1E11 protons/second (based on experience)
7 TeV	1E10 (scaled from 450 GeV)	1E9 protons/second

REGULAR AND/OR AUTOMATED TESTS

Master Threshold Tests

- Thresholds have to stay below max. electronics limit
  - Limit verified by measurement, enforced in LSA (tested) and 'expert threshold application' (tested)
- Family thresholds correctly set?
  - Done: Manual verification
  - tbd: crosscheck of models, plausibility check between families
  - tbd automatic search of changes:
    - 'LSA master threshold readout' (→ see plot, now manually)
    - 'LSA flag readout'
    - 'Measurement/Logging DB applied threshold and flag readout'
- Threshold calculation correct (code: THRC++)?
  - Done: manual comparison old to new thresholds, LSA master thresholds test
  - Future project (1-2 years): calculation in LSA DB (based on functions and parameters in DB)

‘LSA master threshold readout’



Other Safety Relevant Parameters/Flags

- Monitor (correct expert name) is in wrong family?
  - Done: manual LSA master thresholds test
- Monitor correct expert name?
  - tbd: manual (partly done) – less safety critical

- Safety Relevant DB Parameters/Flags
  - Connected to BIS – (now: double signature) → SW test needed
  - Maskable: can be safety issue (now: double signature) →SW test needed
  - RC filter installed – can be a safety issue (no flag at the moment, tested with beam) → flag is for display and Post Mortem interpretation, no SW test possible, no HW test possible
  - Cable connected: not safety issue
  - Conversion factor (IC/SEM): not safety issue up to now
  - HW test parameters (→ see B. Dehning's talk)

- Are all mistakes found in the past addressed by a test? → yes, either already existing or planned for future
- How is the safety critical functionality of the software tested? → only manually at the moment
  - → Define the list of safety critical functionalities to be tested before a new SW release

SYSTEM CHANGES

Reasons for Changes since Jan 2010

- Dynamic range (filters installed, MF & Master threshold changed)
- Showers from outside:
  - Collimation regions: Compromises to allow collimation and testing of cleaning performance:
    - Deviate from local protection scheme
    - Damage to certain collimators cannot be excluded by BLM (4 TCLAs in IP7 and possibly 8 TCLAs in IP3).
    - Protection based on collimator hierarchy, position interlocks, temperature interlocks
  - Injection regions: Losses from injection line collimators and from over-injection (pilot dumped on TDI in ring)
    - Compromises to allow injection:
      - Quench of 8 cold magnets (24 BLMs) at injection energy cannot be excluded by BLM (damage protection ensured)
    - First shielding installed last weeks technical stop (TI2: TCDIH.29205) – more shielding planned

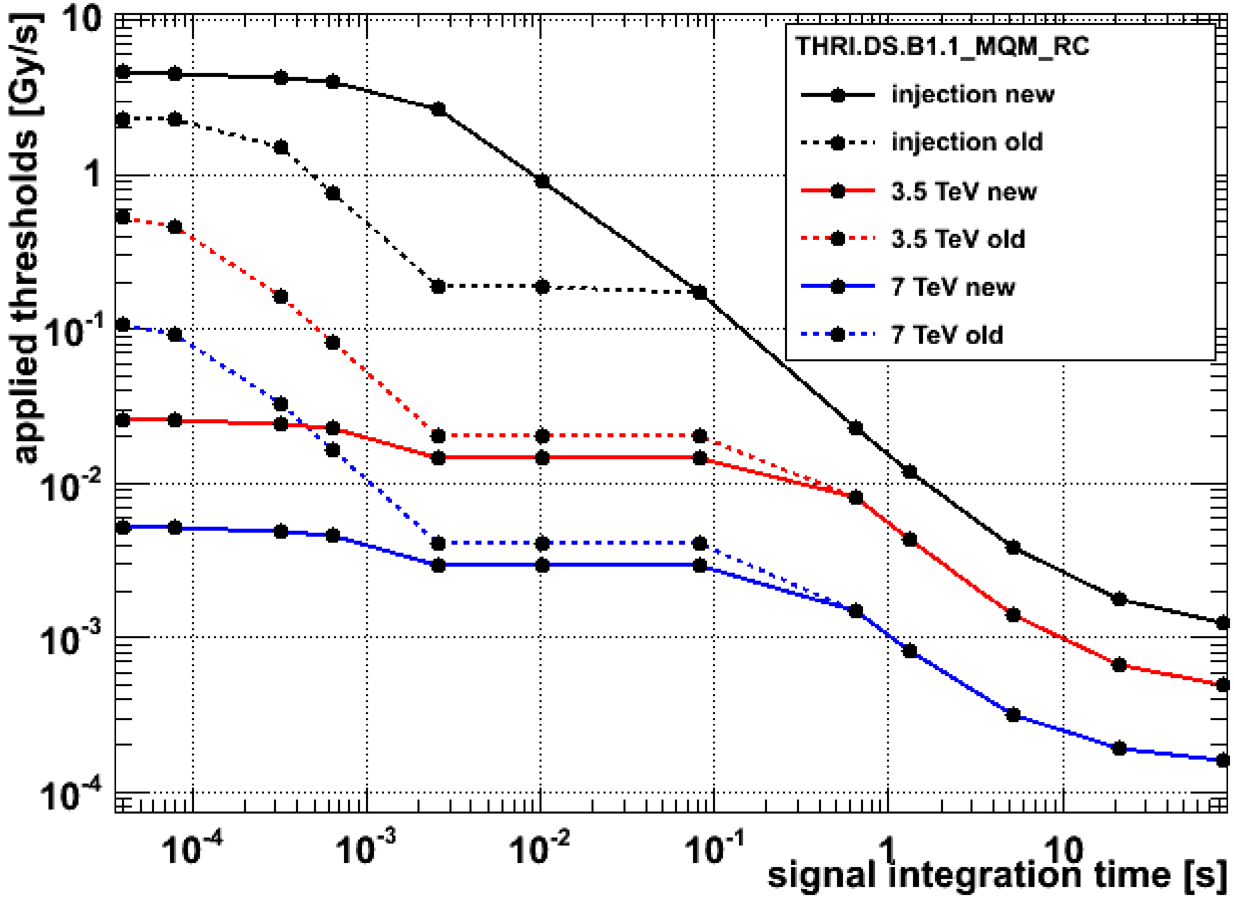
Requested Changes since January 2010

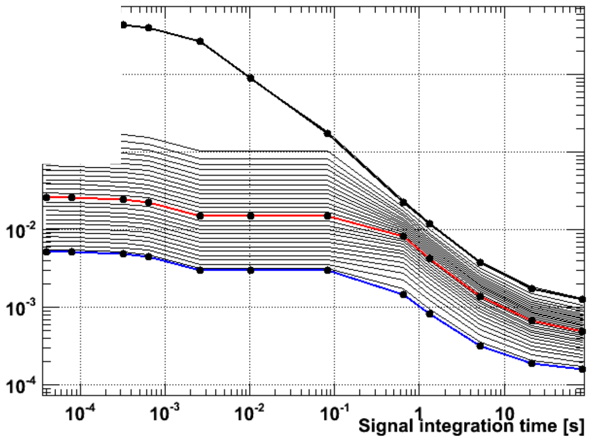
- EDMS: LHC-BLM-ECR documents

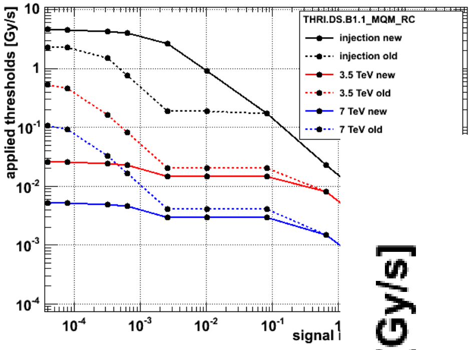
	# Monitors	# Families
HW changes since January 2010	***67***	
RC delay filter installation	64	19
New monitors	3	2
Requested Threshold changes	***97***	
New Families since January 2010	***73***	***25***
RC signal delay filters	64	19
Over-injection losses	7	4
Injection losses (but no RC filter)	2	2

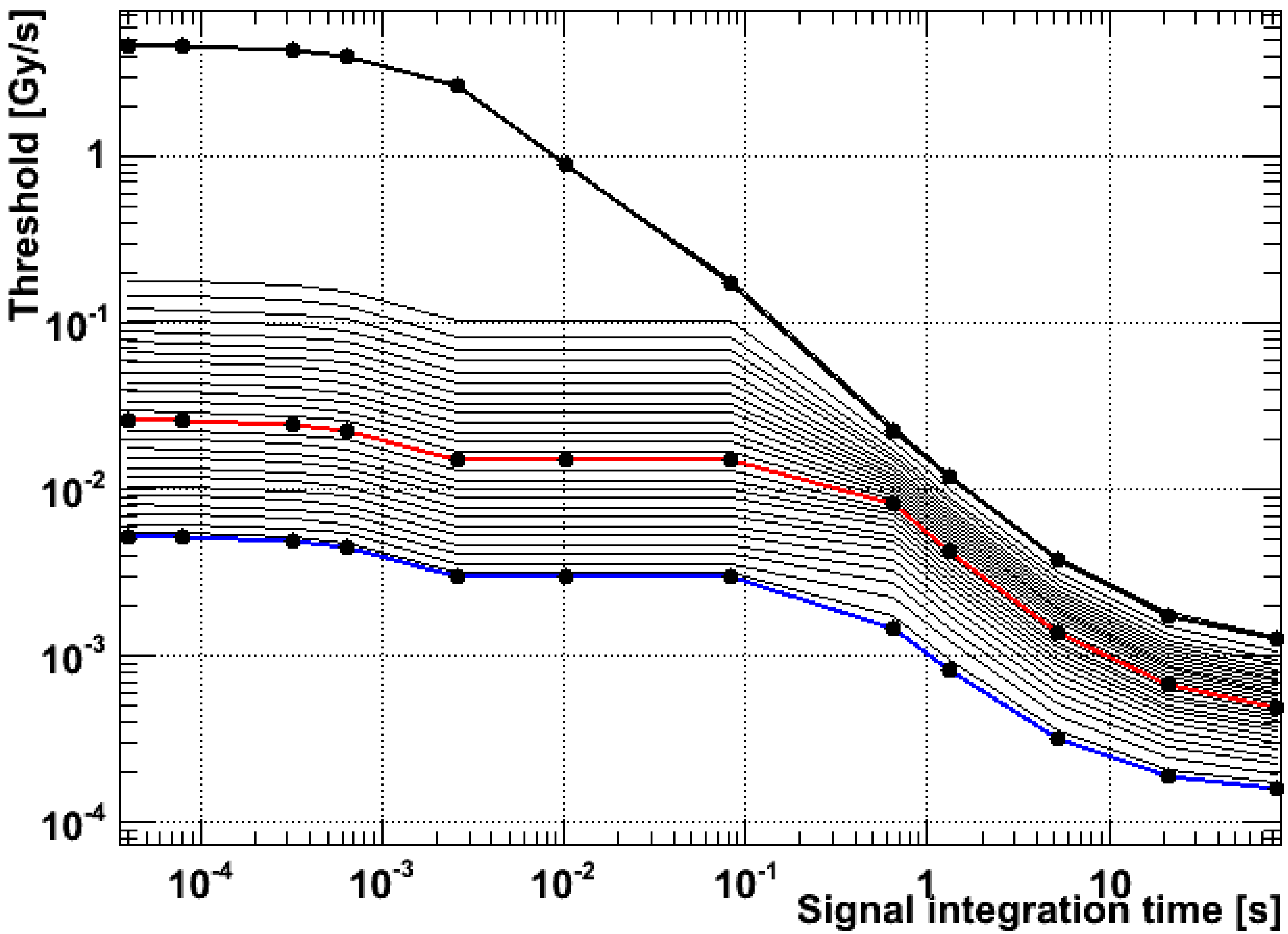
Procedures for interventions (example: threshold change)

- Request
- Proposal from BLM (verified by two BLM experts) → plots comparing old/new applied thresholds
- Proposal distributed for comments - description of change and implications – ideally already the Engineering Change Request (ECR) document
- Approval requested from (1 out of a list of 2-3 people per system):
  - MPP representative
  - Requestor system responsible
  - Responsible of all other systems concerned (if any)
  - BLM responsible


10
1
10^{-1}
10^{-2}
10^{-3}
10^{-4}
applied thresholds [Gy/s]
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
signal integration time [s]
THRI.DS.B1.1_MQM_RC
injection new
injection old
3.5 TeV new
3.5 TeV old
7 TeV new
7 TeV old


10^{-2}
10^{-3}
10^{-4}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
10
Signal integration time [s]


THRI.DS.B1.1_MQM_RC
injection new
injection old
3.5 TeV new
3.5 TeV old
7 TeV new
7 TeV old
applied thresholds [Gy/s]
signal


Threshold [Gy/s]
Signal integration time [s]

Procedures for interventions (example: threshold change)

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Deployment of changes (example: threshold change)

- LSA DB: 'threshold expert application', 2 BLM experts signature required
- Future: threshold expert application to produce before/after plot for master thresholds and applied thresholds for verification during installation
- … drive to HW, HW tests (by HW expert)
- After deployment:
  - Online display: visual verification of changed 450 GeV applied thresholds
  - Manually check history of LSA DB changes (make sure that only the foreseen families had been changed)
- Future test on **all** monitors:
  - 'LSA master threshold readout' (now: visual → see plot, future: automatic search of changes)
  - 'LSA flag readout' (connected to BIS, maskable, RC delay filter) – visual and automatic search of changes
  - 'Measurement/Logging DB applied threshold and flag readout' – visual and automatic search of changes

Concluding Remarks

- Operational experience:
  - No avoidable quenched passed BLM protection (injection quench can not be protected)
  - No big deviation detected for protection thresholds - beam test needed
  - Few human manipulation errors → now SW enforced and/or covered by tests
  - Certain uncertainties in threshold definition (but normally conservative approach)
  - No need to disable monitors so far
  - Losses always seen by several monitors (certain protection redundancy)
- 30 MJ:
  - For BLM system no differences expected for higher intensity – the critical step is set-up beam to above
  - Shielding of injection losses required (HW changes?)