Quench-preventing beam abort thresholds in Beam Loss Monitors (MB case)

THE CERN ACCELERATOR SCHOOL
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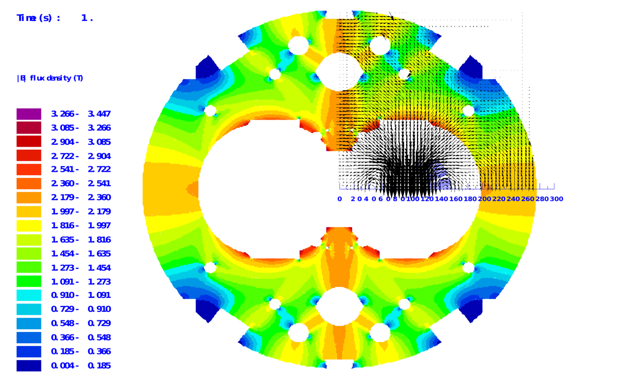
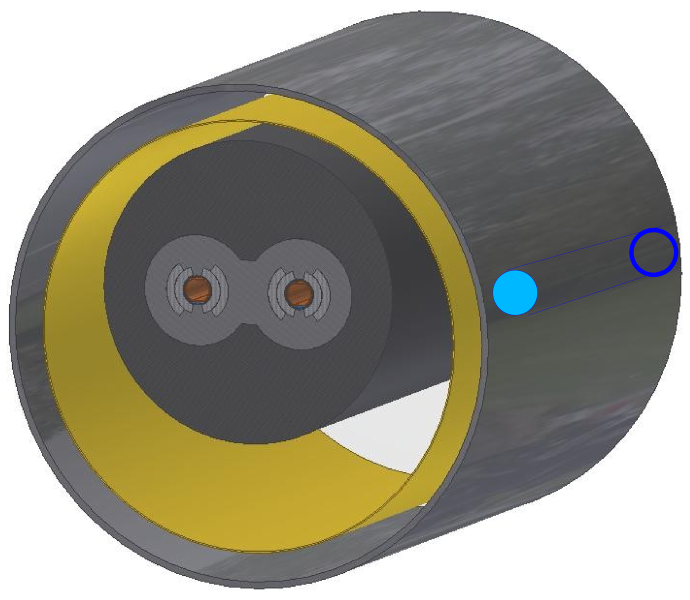
Abstract: *The goal of this study is to investigate the shower development in the Main Dipole magnet due to the losses of the LHC beam and a subsequent signal in Beam Loss detectors located outside the cryostat. This signal is related to the energy deposited in the magnet coil. The signal corresponding to beam loss which deposits energy equal to the stability margin of the coil is the beam abort threshold. The results of the Monte Carlo analysis are compared with the first beam-induced quench of LHC main dipole.*

Geant4 geometry and ROXIE field

Geant4 has been chosen
(a lot of irradiation studies are done with FLUKA)
energy cut: 0.5mm
in this study only losses without significant leak of particles on interconnections
scored: Energy deposition E_D
and particle flux outside Cryostat



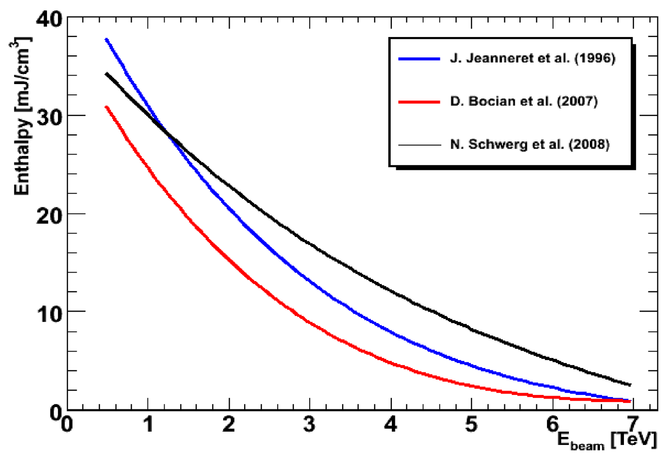
ROXIE 2D magnetic field map with smooth transition at the coil endings



Beam Loss Monitors (BLMs) are simulated as a long tubes and every particle entering the tube is registered.

The energy deposit in the coil is simulated in bins ds=5 cm, dφ=4 deg, dr=0.5 cm
the bins were tuned to fit the cascade shape

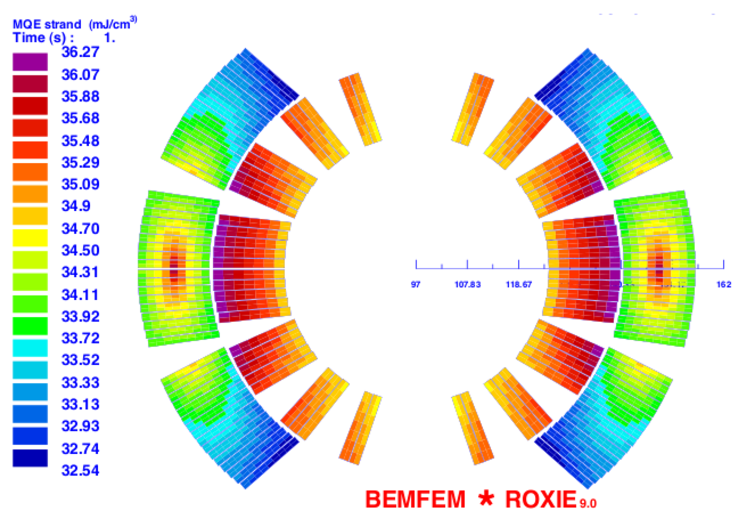
Cable stability margin



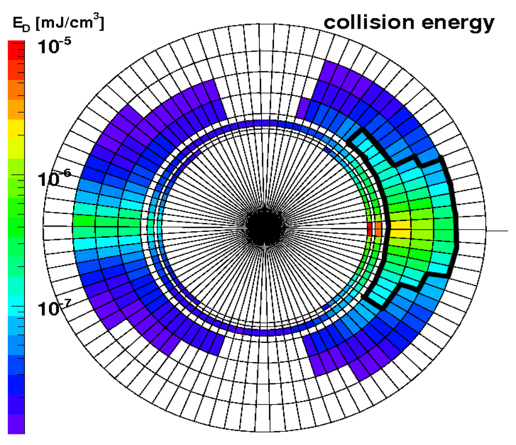
- For transient losses the amount of heat which can be absorbed by the coil is not affected by heat transfer.
- Nevertheless different calculations show different results, mainly due to different assumptions about the coil composition and value of local magnetic field

The Cable stability margin from ROXIE for injection MB current:

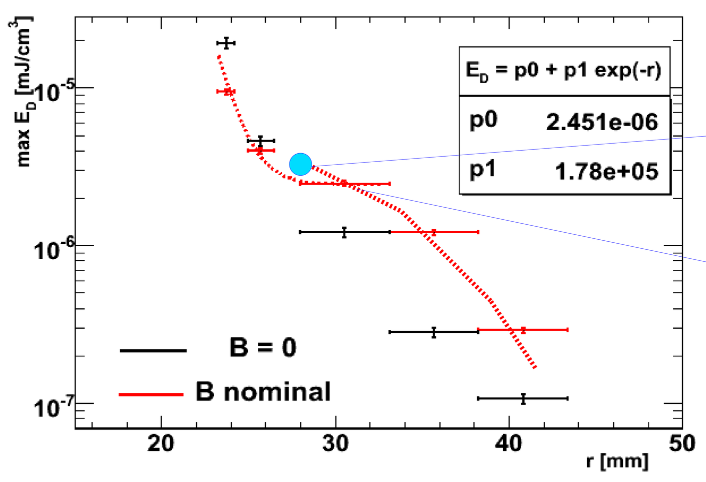
For steady-state losses models and measurements are ready.
For medium-duration losses see for instance:
Cryogenics 46:481-493,2006
LHC Project Report 994
and many others

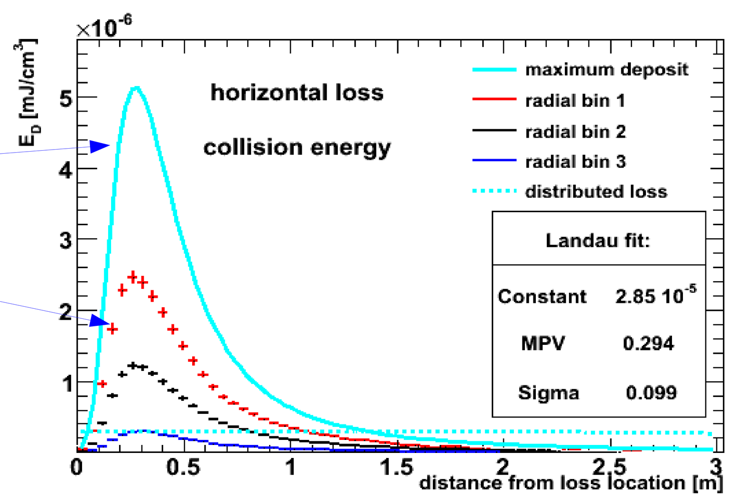


Energy deposition in the coil

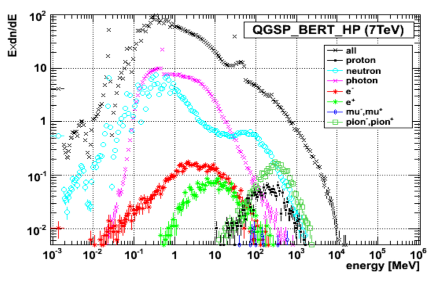


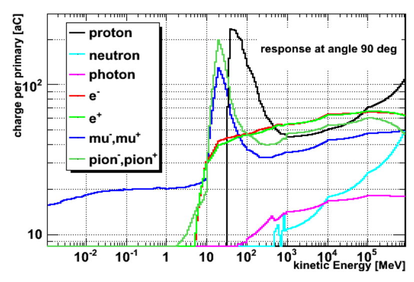
The energy deposition due to single proton is well established.
Maximum in the inner-most layer.
Concentration of energy due to magnetic field.
The maximum energy deposition raises from $1.36\ 10^{-7}$ mJ/cm³/proton for 450 GeV to $5.05\ 10^{-6}$ mJ/cm³/proton for 7 TeV (point losses) (37 times)



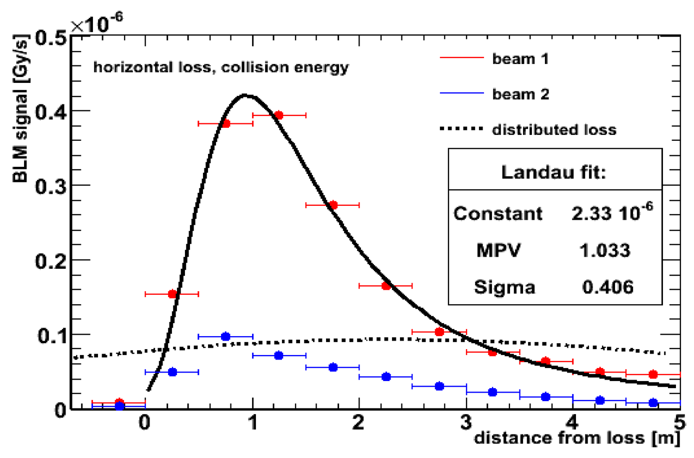


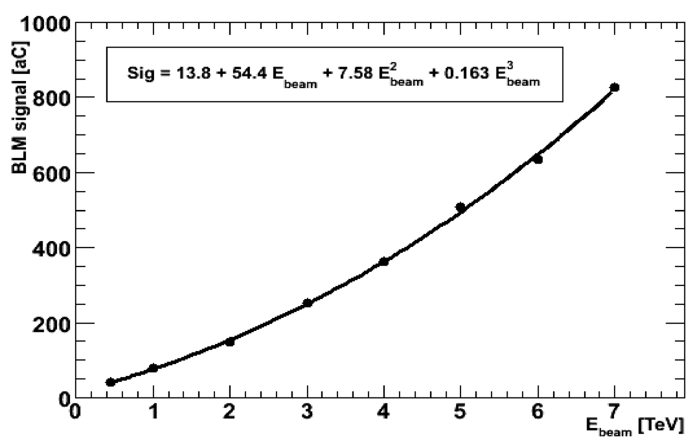
Signals in BLMs





- Spectra and angle of particles hitting the BLM are registered
- Spectra are multiplied by e response function (M. Stocker thesis)
- Result is a charge deposited in the BLM, typically about 40 aC for injection energy and almost 1000 aC for collision energy
- Geant4 simulation of the shower tail, where BLMs are placed, is not as acurate as simulation of energy deposition (20-40% error)
- The signal maximum is about 1 meter after the loss location
- Shape of the signal in case of point-like loss cab be fitted with Landau with Sigma of about 0.4 m (horizontal loss) or 0.5 meters (vertical loss)
- Detectors on the opposite beam detect signal 4 to 6 times lower
- In case of distributed losses signal is about 5 times lower

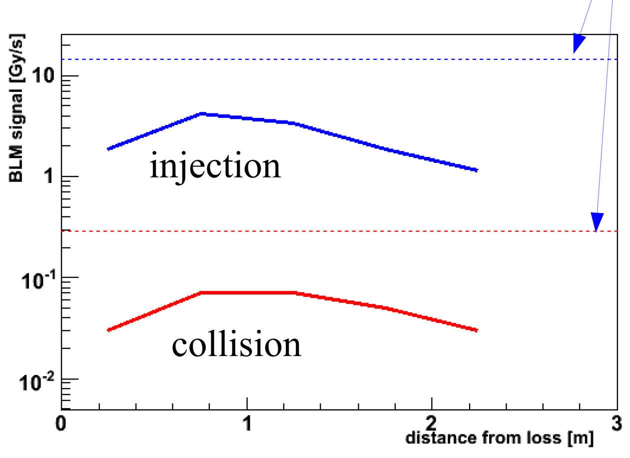




Quench-preventing thresholds

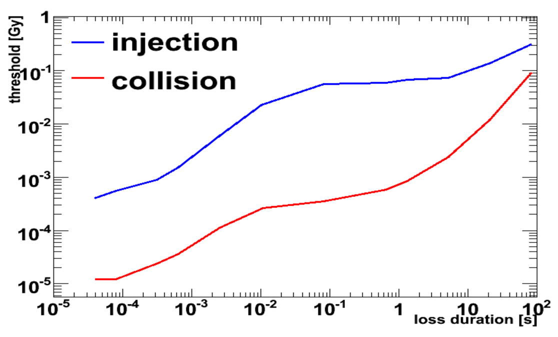
Threshold: $D\ [Gy] = C_{C\rightarrow Gy}\ Q_{BLM}\ [C]\ H_{cable}[mJ/cm^3]/E_D[mJ/cm^3]$
typically the thresholds are given in Gy/s for various integration times

distributed losses



- Thresholds for distributed losses are about 4-5 times higher then for point losses – this is because the signal outside cryostat is 4-5 times more spread then the deposited energy distribution in the coil
- The threshold value changes by factor 50 between injection and collision energy
- Time-behavior of the thresholds is a complicated issue, treated for instance in LHC Note 44 (J.B. Jeanneret et al)

Error estimation is ongoing. Roughly:
- H_{cable} knowledge about 20-50%
- E_D knowledge about 50%
- Q_{BLM} estimation error > 50%

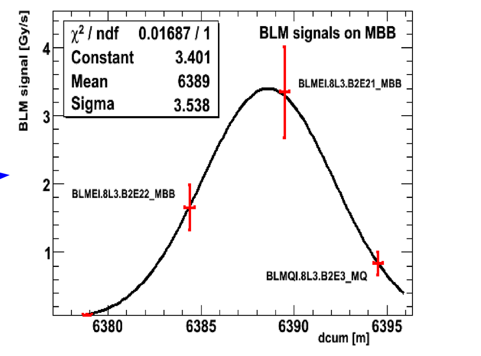


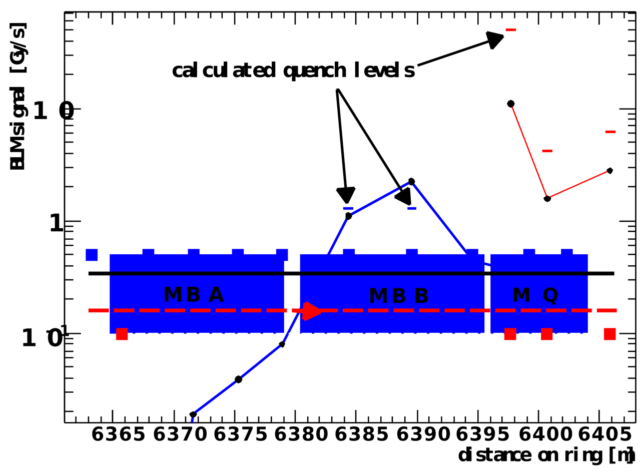
First quench

First LHC injection test, August 8th-10th 2008.
On the August 9th, at 2:19 in the morning during the aperture scan a whole beam ($4\cdot10^9$ protons) was accidentally steered to the MB magnet (cell 8L3).
Magnet quenched and data from BLM system has been recorded.
Magnet self-healed – the quench very close to the quench level.

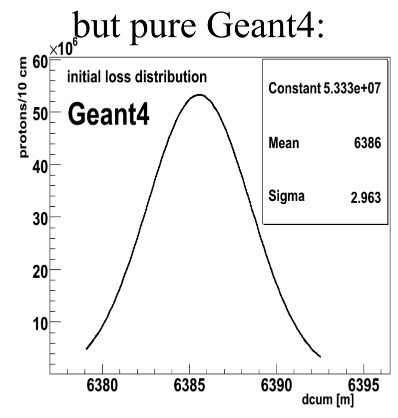
monitor name	dcum [m]	signal [Gy/s] 40 μs	signal [Gy/s] 80 μs	$\frac{Dose80\ \mu s}{Dose40\ \mu s}$
BLMEI.8L3.B2E3_MBB	6378.91	< 0.005	< 0.003	-
BLMEI.8L3.B2E22_MBB	6384.37	1.105	0.822	1.49
BLMEI.8L3.B2E21_MBB	6389.57	2.234	1.670	1.50
BLMQI.7L3.B2E3_MQ	6394.56	0.438	0.418	1.91
BLMQI.7L3.B1I3_MQ	6397.70	11.13	9.211	1.66

if using this correction...

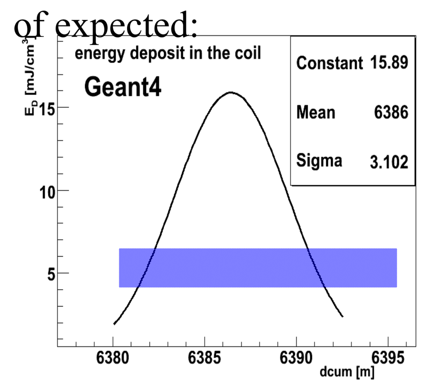




but pure Geant4:



suggested maximum E_D is half of expected:



Conclusions

The initial settings of quench-preventing thresholds for the LHC cold magnets has been done, based on work of many people:
- simulation of the BLM response function
- simulations, calculations and measurements of the Quench Margin of the magnet coils
- simulations of proton interactions and shower development inside the magnet (this work, FLUKA simulations)

The first beam-induced quench(es) of MB magnet provided interesting data, which validate the simulations and could help to determine the systematic difference between simulations and reality.

Acknowledgments:
The Geant4 geometry of this magnet has been programmed mainly by Agnieszka Priebe.
The work is at the end of a long chain of thresholds simulations, among many references see:
- Jeanneret J.B. et al. LHC Project Note 44 (1996)
- A. Arauzo LHC Project Note 238 (dispersion supressor)
- E. Gschwendtner, L. Ponce, R. Bruce and others

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