FLUKA Simulations for Assessing Thresholds of BLMs Around the LHC Triplet Magnets

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Outline

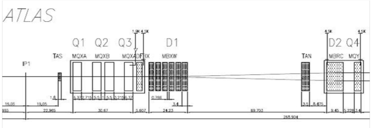
The *Inner Triplet*

The *inner triplet* [1]

A string of three superconducting quadrupoles (Q1-Q3) installed on both sides of every Interaction Point (IP) of the Large Hadron Collider (LHC);

Aim

The final squeeze of beams before collision.



But. . .

. . . being so close to the IP, it is subject to the collision debris.
Even if it is well protected, abnormal beam losses might occur.

Considered Quench Limits

Effect of Energy Deposition in Superconducting Coils

increase the coil temperature, with a possible risk of **quench** (i.e. the sudden transition from superconducting to normal conducting state).

Quench Limit

Energy required to locally increase the temperature of the coil up to the quench. It sets the upper **threshold to the allowed losses**.

Superfluid Helium

An important **asset** is its **high thermal conductivity**. The **time scale** of the loss is thus relevant for identifing the proper quench limit to be used.

fast transient losses

i.e. **below** 100 μs

- the heat has no time to leak to superfluid Helium;
- the quench limit is calculated as enthalpy limit for a **dry cable**;
- *considered* value (ROXIE [2]): **1.2 mJ/cm^3** LHC Project Report 44 [3]: 0.8 mJ/cm^3;

steady-state losses

i.e. **above** 100 μs

- the heat has time to **spread** over a certain volume of cable (**thermal equilibrium volume**);
- the **cryogenic system** actually removes the heat;
- *considered* value: **12 mW/cm^3** (compatible with [4]);

The BLM System [5]

Aim

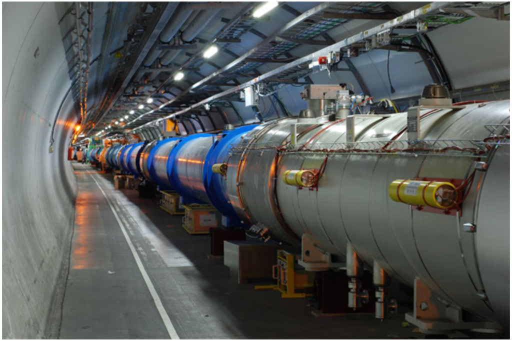
Identify possible losses that may lead the magnets to quench, and trigger a beam dump signal;

Method

Detecting abnormal radiation field intensities around the accelerator.

Assessment of Thresholds

A quite delicate subject: BLMs should allow the safe and reliable operation of the machine, i.e. they should **prevent magnet quench** as well as **avoid unnecessary beam dumps**.



Integration time

Twelve signal integration times, between **40 μs** and **84 s**.

FLUKA Simulations

Aim

Relate the energy deposited in the superconducting coil of the *inner triplet* to the signal read by BLMs all around: **assessment of the signal thresholds**.

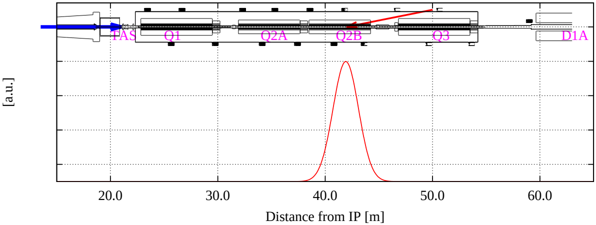
FLUKA simulations of the *Inner Triplet* presently installed on the right side of Point 1 of LHC (ATLAS). Considered scenarios:

pp-collision debris

- $L_0 = \mathbf{10^{34}\ cm^{-2}\ s^{-1}}$ [1];
- **80 mb** as pp inelastic cross section at 14 GeV centre-of-mass energy;

direct losses in Q2B (MQXB.2BR1)

7.0 TeV protons on Q2B magnet, due to wrong settings of collimators (tracking simulation);



For other scenarios: EDMS doc in preparation.

FLUKA Simulations - Statistical Uncertainty

Typical Values

- <5% on peak energy deposition in the coils;
- <10% on BLM signals;

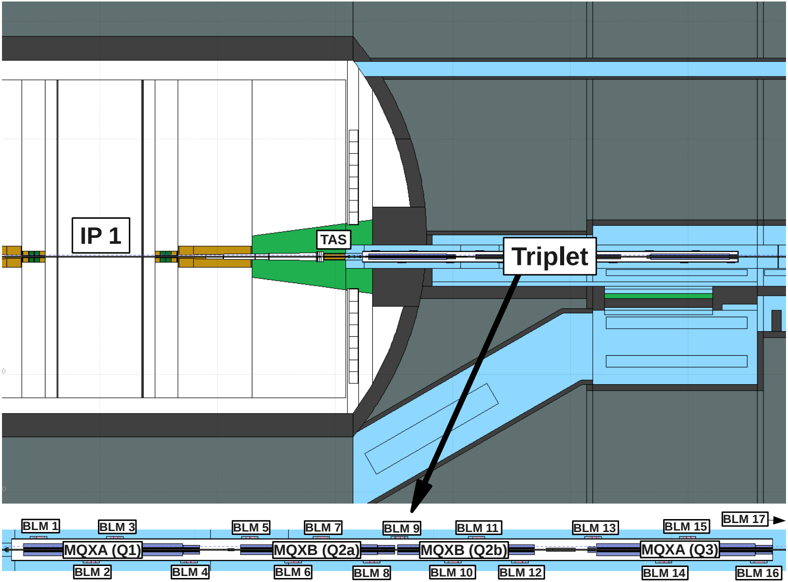
Unavoidable Sources of Uncertainty

- material and geometry implementation;
- strong dependence on a very small angular range of the reaction products;
- extrapolation of cross sections for the primary events;
- interaction modeling;

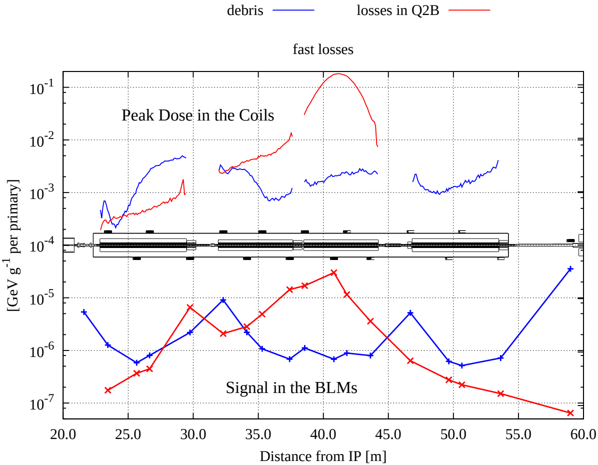
Numbers

Many ancillary elements (like interconnects, flanges, valves. . .) were not included in the FLUKA geometries at the stage of this work; still they can affect the estimation of the BLM response; thus, the collection of numbers here reported as a support for the conclusions is not intended to be taken literally;

Fluka Geometry



Patterns



For *each* scenario...

...the dose to the coils and the signal in the BLMs have the **same qualitative behaviour**;

Q2B Losses

Maxima are quite distinct, but the **gradient** between the two is much larger than for debris;

Reliability

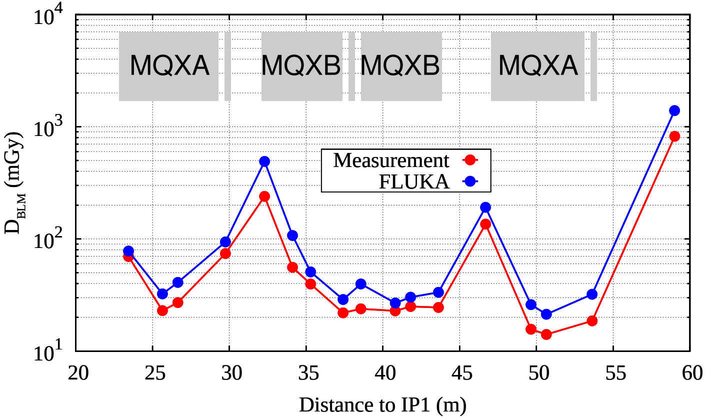


Figure: Measurement: pp collisions in IP1, 28th Oct 2010, fill 1450 (stable beams); Number of bunches: 364; Integrated luminosity: 6255.71 nb^{-1} @ 3.5 TeV

Reasons for the Discrepancy

- uncertainty in the measurement of the integrated luminosity;
- material and geometry implementation (missing details, e.g. interconnects);

Reliability (II)

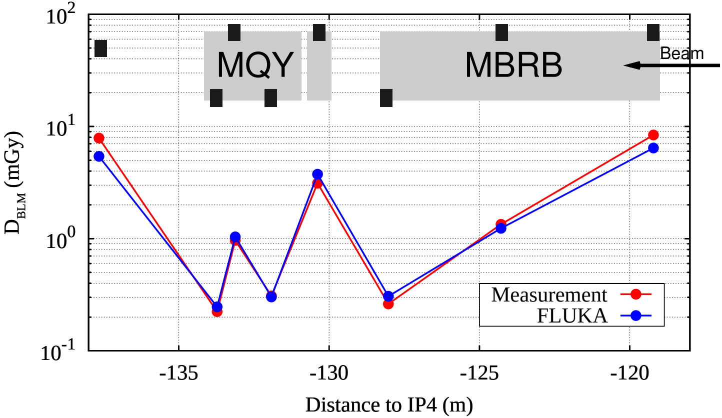
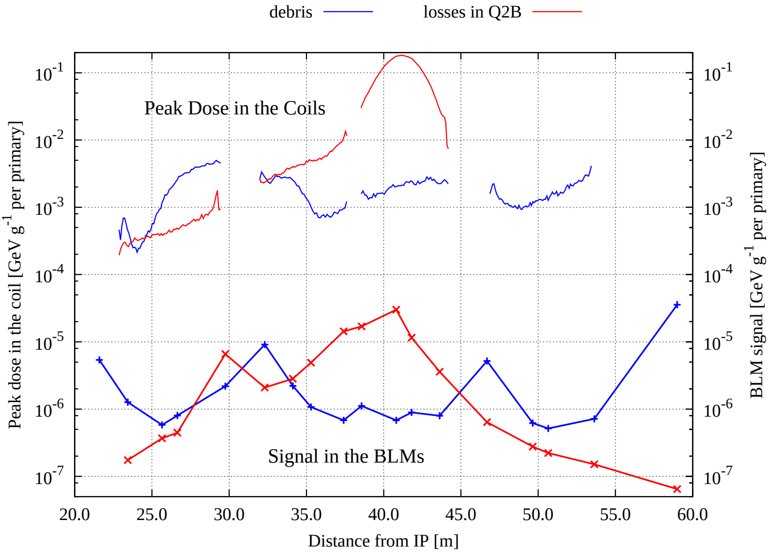


Figure: Measurement: beam wire scanning in IR4, about 32 m upstream MBRB.4L4 @ 3.5 TeV; scanning speed: 25 cm/s; MD on the 1^{st} Nov 2010

Very good agreement

- better control of normalisation coefficients;
- much more detailed geometry;

Fast Losses: Signals **per Primary Event**



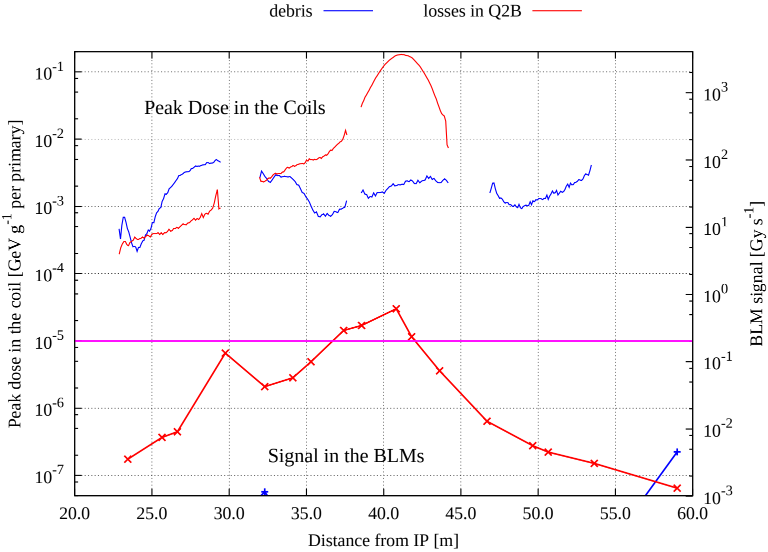
pp-collision debris

3.2 10^4 collisions in 40 μs;

direct losses in Q2B

allowed losses: **5.1 10^6** protons;

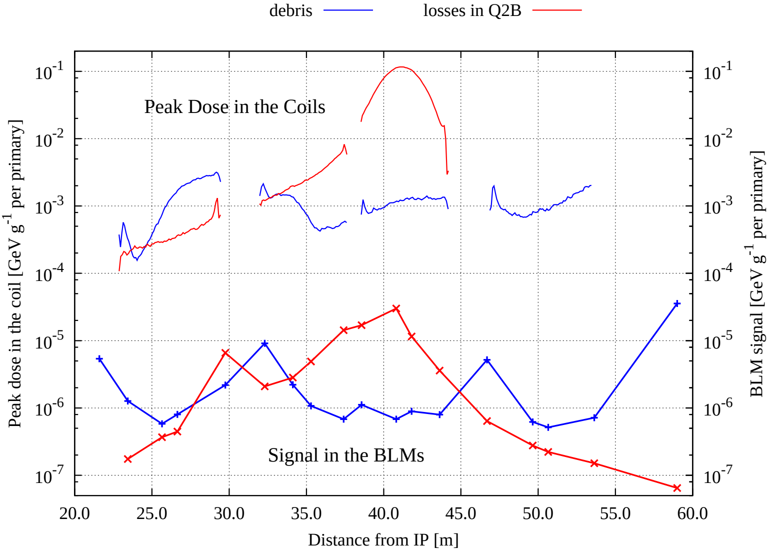
Fast Losses: Signals **Integrated over 40 μs**



After normalisation…

…the signal due to the debris is far below the one due to lost protons!

Steady-State Losses: Signals **per Primary Event**



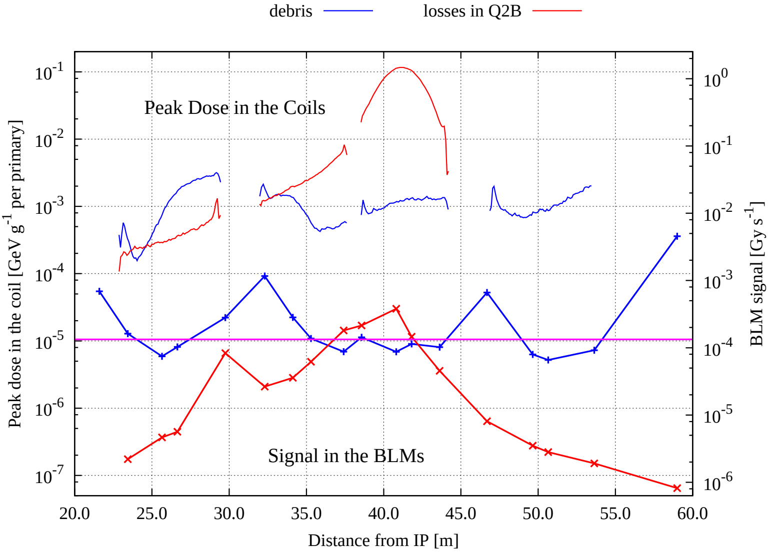
pp-collision debris

8 10^8 collisions per second.

direct losses in Q2B

allowed losses: **7.9 10**^{7} protons per second;

Steady-State Losses: **Final** Signals



After normalisation…

…the signal due to the loss can't be distinguished from the one due to the debris!

Conclusions I

Fast Transient Losses (over 40 μs)

The BLMs placed close to the loss location would be able to prevent the magnet quench.

Steady-State Losses

The signals from direct losses do not stand out against those produced by the collision debris.

Coexistence of Results

The two scenarios (debris vs losses in Q2B) were **separately** analysed, but during operation, they might actually coexist: even if digits may change, the final conclusions do not.

Possible Long Term Solutions

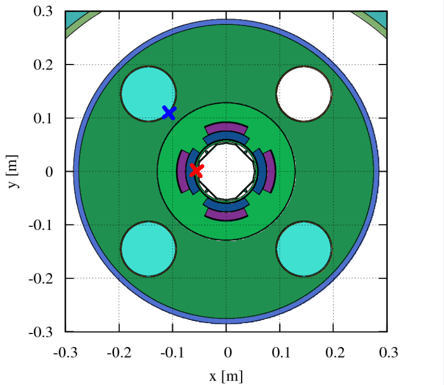
- “topological threshold”: the beam dump signal is triggered when the longitudinal profile of the BLMs signal changes in **shape**;
- detectors **close to the coils**: the measured dose is more directly linked to the dose actually received by the coils.

These strategies might be particularly important for the upgrade of the LHC towards higher values of luminosity.

New Positions of BLMs

The Closer to the Coils, the Better

- higher intensity of the signal;
- signal better follows the longitudinal pattern of the peak in the coil;



Upgrade Parameters

- peak luminosity: **5 $\mathbf{L_0}$**;
- Nb_3Sn superconducting cable (about **35 mW $\mathbf{cm^{-3}}$**);

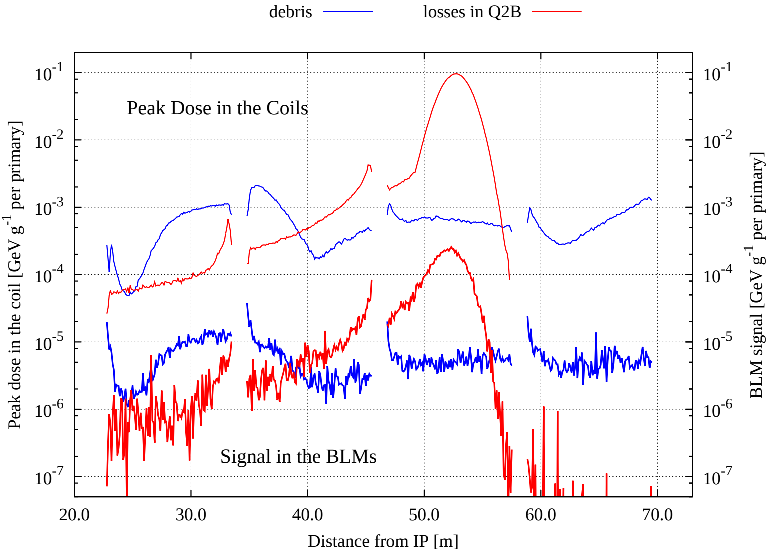
Four Holes

- one for the heat exchanger;
- the others for not breaking the quadrupole symmetry. Good location for the new BLMs.

FLUKA Estimation

No design or location of the new BLMs (at that moment): estimation of the signal via the dose inside the yoke (blue cross).

Steady-State Losses: Signals **per Primary Event**



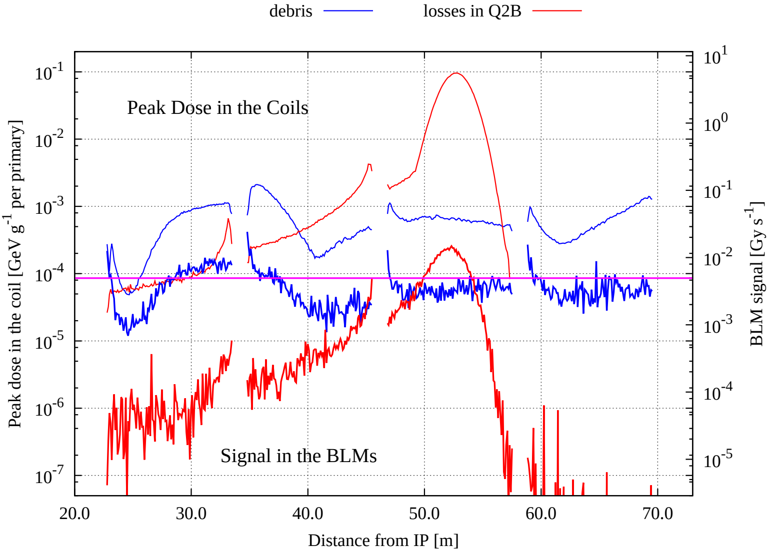
pp-collision debris

4 10^9 collisions per second.

direct losses in Q2B

allowed losses: **3.6 10^8** protons per second;

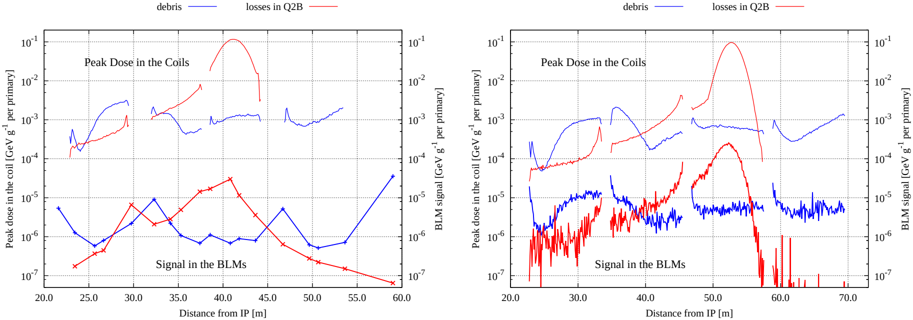
Steady-State Losses: **Final** Signals



After normalisation. . .

. . . the signal due to the loss can be better distinguished from the one due to the debris.

Final Conclusions



Fast Transient Losses (over 40 μs)

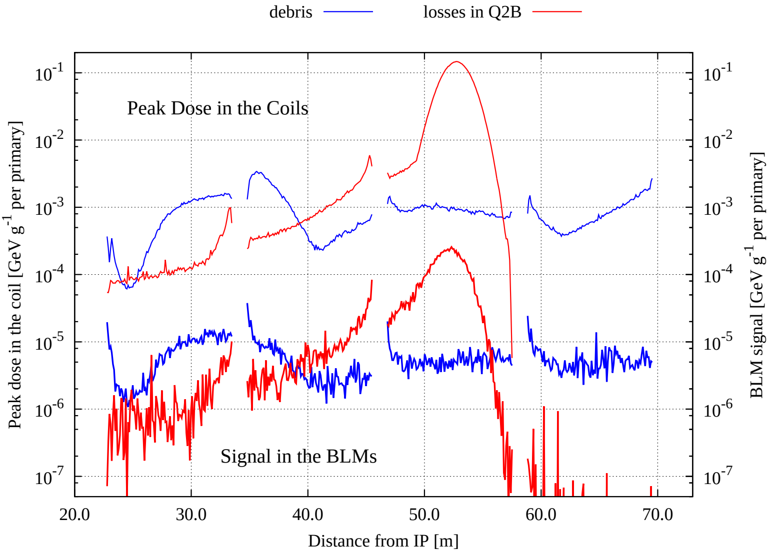
The BLMs placed close to the loss location would be able to prevent the magnet quench; thresholds can thus be assessed.

Steady-State Losses

The insertion of monitors inside the magnet yoke closer to the coils permits to better see the signal induced by the abnormal loss.

Spare Slides

Fast Losses (Upgrade): Signals **per Primary Event**



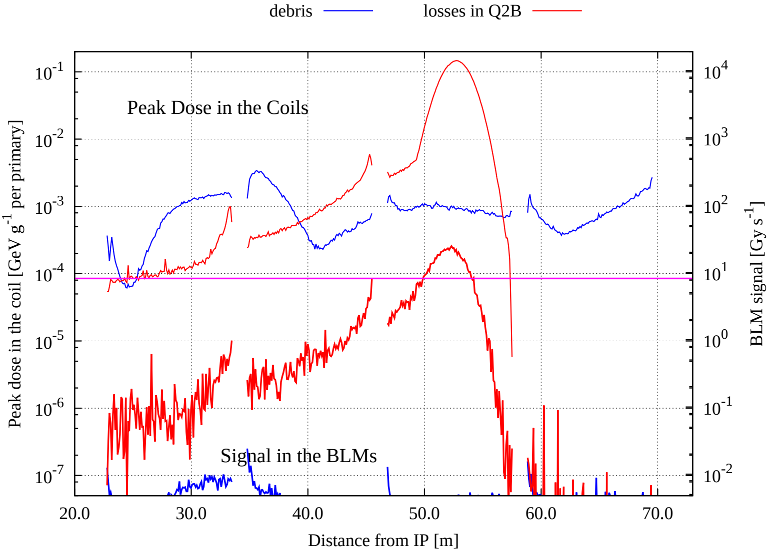
pp-collision debris

1.6 10^5 collisions in 40 μs;

direct losses in Q2B

allowed losses: **2.4 10^7** protons;

Fast Losses (Upgrade): Signals **Integrated over 40 μs**



After normalisation. . .

. . . the signal due to the debris is far below the one due to lost protons!

[1] “LHC Design Report, Vol. I The LHC main ring”, CERN-2004-003, June 2004;

[2] “ROXIE: Routine for the Optimization of Magnet X-Sections, Inverse Field Calculation and Coil End Design”, Proceedings of the 1^{st} International Roxie Users Meeting and Workshop, CERN, Geneva, March 16^{th}–18^{th} 1998, S. Russenschuck eds., CERN yellow report 99-01, 1999;

[3] J.B. Jeanneret, D. Leroy, L. Oberli, T. Trenkler, “Quench Levels and Transient Beam Losses in LHC Magnets”, LHC Project Report 044, 1996;

[4] N.V. Mokhov, I.L. Rakhno, J.S. Kerby, J.B. Strait, “Protecting LHC IP1/IP5 Components Against Radiation Resulting from Colliding Beam Interactions”, LHC Project Report 633, 2003;

[5] for an overview of the LHC BLM system see `http://cern.ch/blm`;