Quench test with LHC wire scanner: FLUKA simulations

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Valuable input by T. Baer, M. Sapinski and A Verweij

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Beam wire scan: Quench test

Beam Wire Scanner (BWS.5L4.B2)

- Wire material: Carbon
- Wire diameter d_W: 30μm
- Position: left of IR4, ≈32 m upstream of MBRB.5L4 (D4)

Quench test – last scan (01/11/2010, 14:40)

- Beam energy: 3.5 TeV
- Horizontal scanning at 5 cm/s
- Dipole (MBRB) quenched
- For details, see presentation given at MPP, 12/11/2010.

Simulation work

Why

- analyse a **known** beam loss event in order to benchmark against real measurements the shower development description provided by FLUKA (on which we rely for energy deposition/particle fluence studies in many regions of the LHC, i.e. collimation and experimental insertions)
- in particular, test the code reliability up to the LHC beam energy

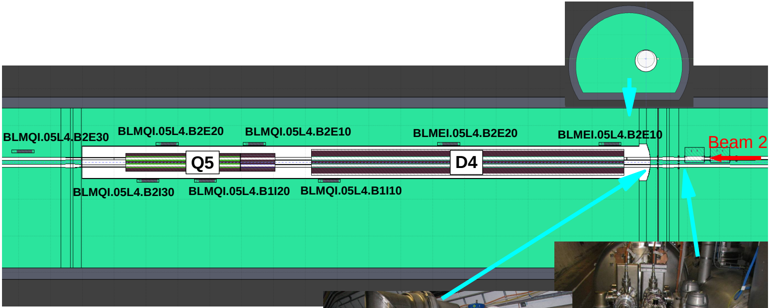
How

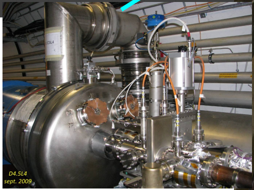
- compare the relative pattern of the BLM response along the most impacted magnet string
- compare absolute dose (i.e. collected charge) values

Issues

- normalization assessment (how many beam protons through the wire?) impacting the absolute comparison
- role of complex geometry details impacting also the relative comparison

FLUKA geometry: Magnets and BLMs



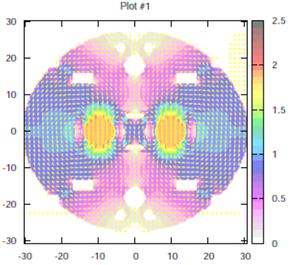


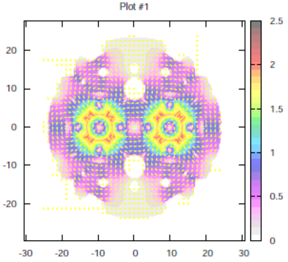
- Complex layout
- Unavoidable simplification in simulation
- Massive materials modeled!!

FLUKA geometry: Magnetic field maps

MBRB.5L4 (D4) and MQY.5L4 (Q5): Magnetic field maps applied

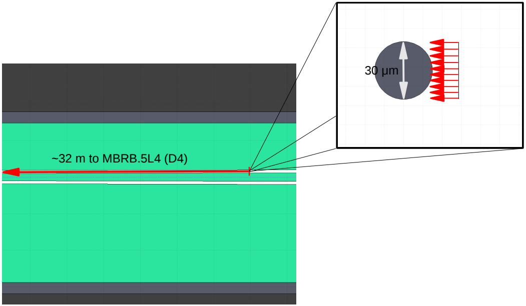
Magnetic fields in Tesla





Thanks to A. Verweij for providing the field maps.

FLUKA geometry: BWS



- Static wire position at nominal beam center
- Only protons simulated which imping on the wire
- Biasing of inelastic interactions in wire

Normalization factor

Simulation: per proton impinging on the wire $\rightarrow$ scaling required.

The total number of protons traversing the wire throughout the entire scanning process can be calculated as

$$N_W = \int_{-\infty}^{\infty} n(t)\mathrm{d}t, \quad (1)$$

where $n(t)\mathrm{d}t$ denotes the number of protons impinging on the wire in the time interval between t and $t + \mathrm{d}t$.

Normalization factor

Considering a normalized beam profile $g(x)$,

$$\int_{-\infty}^{\infty} g(x')\mathrm{d}x' = 1, \tag{2}$$

$n(t)$ can be expressed as

$$n(t) = N_b N_p f_{LHC} \int_{x(t)}^{x(t)+d_W} g(x')\mathrm{d}x', \tag{3}$$

where N_b refers to the **number of bunches**, N_p indicates the **number of protons per bunch**, f_{LHC} is the **LHC revolution frequency**, $x(t)$ represents the **wire position** at time t, and d_W is the **wire thickness**.

Normalization factor

Model solution: Supposing the wire moves with constant velocity v_W, $x(t)$ can simply be expressed as $v_W t$. Inserting Equation (3) into (1) one hence obtains

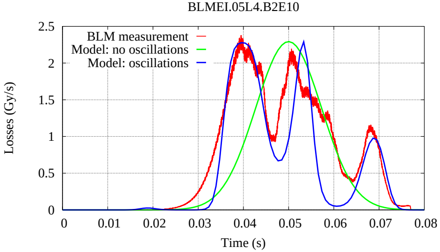
$$N_W = N_b N_p \frac{f_{LHC}}{v_W} d_W. \quad (4)$$

Assuming $N_b = 131$, $N_p = 1.15 \times 10^{11}$, $v_W = 5$ cm/s, $f_{LHC} = 11245$ Hz and $d_W = 0.003$ cm, Equation (4) yields $N_W = 1.016 \times 10^{14}$.

Uncertainties

Uncertainties in normalization factor

- **Time pattern:** can be qualitatively explained by means of wire oscillations (i.e. by inserting $x(t) = v_W t + A \cdot sin(2\pi t/T + \phi)$ into Equation (3))



Absolut comparison!

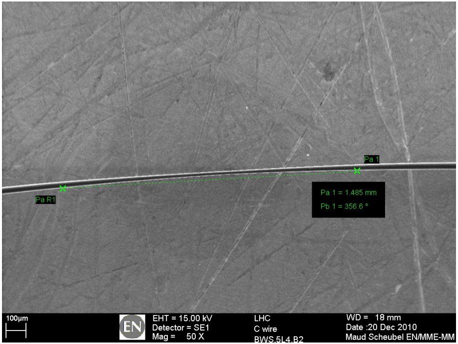
Assumed parameters:
$A = 500\ \mu$m, $T = 21$ msec

Oscillations cause limited variation of integral (few %).

Uncertainties

Uncertainties in normalization factor (cont.)

- **Wire thickness:** wire thickness observed after scan was $\approx 17\mu$m (see photo by M. Scheubel from EN/MME)



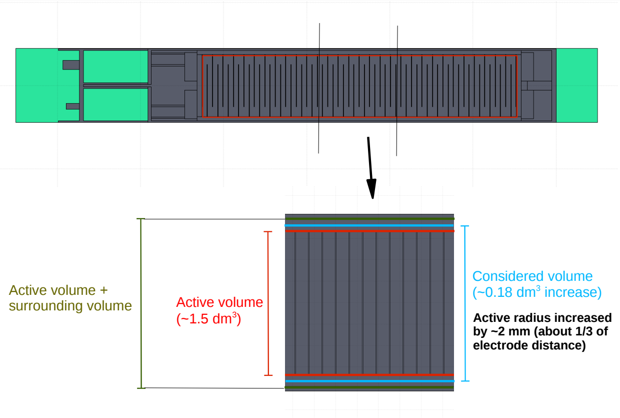
Time evolution of wire thickness throughout scan? Density and mass evolution?

Few 10% variation of integral.

Uncertainties

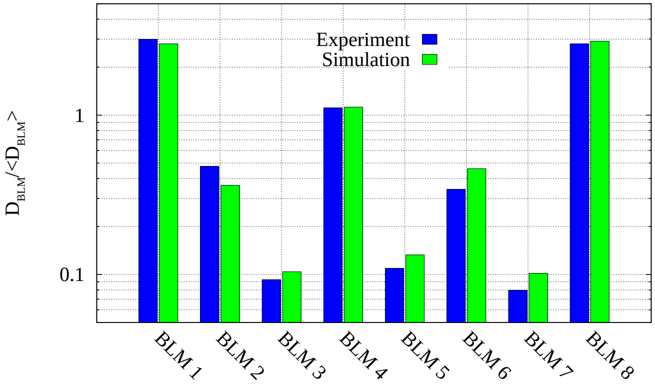
Further uncertainties

- **Active volume:** Increase of 12% assumed to account for charges collected from surrounding gas volume.



Integrated dose in BLMs

BLM time-integrated dose expressed as a fraction of the mean dose over all considered BLMs:



Integrated dose in BLMs

Comparison of measured and simulated time-integrated BLM dose values.

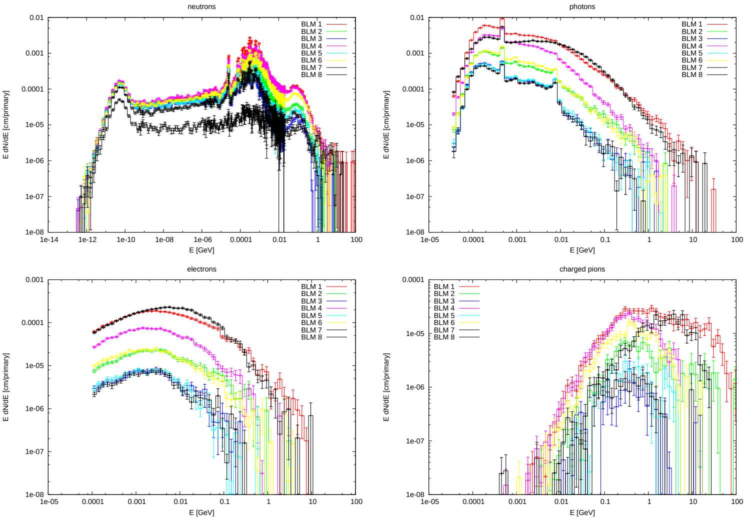
Detector	Beam	Integrated dose D (mGy)		
		Experiment	Simulation	Sim./Exp.·100
BLM 1	2	53.3	42.4 ±2.3%	79.7[1]
BLM 2	2	8.50	5.41 ±4.3%	63.7[2]
BLM 3	1	1.66	1.56 ±6.9%	94.2
BLM 4	2	19.8	16.9 ±3.3%	85.1
BLM 5	1	1.95	1.96 ±7.3%	100.4
BLM 6	2	6.12	6.83 ±4.8%	111.5
BLM 7	1	1.42	1.54 ±7.0%	108.3
BLM 8	2	50.1	43.4 ±3.0%	86.6

(Specified uncertainties represent the statistical error).

[1] Geometry details upstream of D4 (flanges, vacuum vessel end cup, stripline coupler ...) proved to be important for the 1st BLM response, implying a 25% increase.

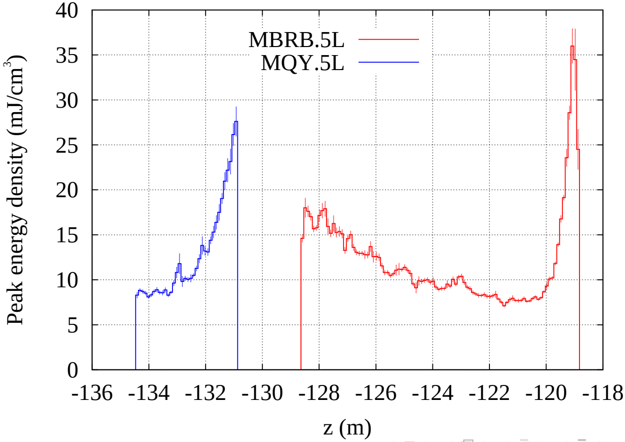
[2] Material in the vicinity of the 2nd BLM still missing!

BLM spectra


neutrons
photons
electrons
charged pions
BLM 1
BLM 2
BLM 3
BLM 4
BLM 5
BLM 6
BLM 7
BLM 8
E dN/dE [cm/primary]
E [GeV]

Peak energy density in MBRB (D4) and MQY (Q5) coils

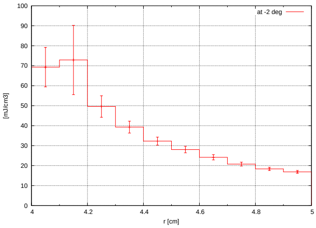
Time-integrated (≈40 msec) peak energy density.

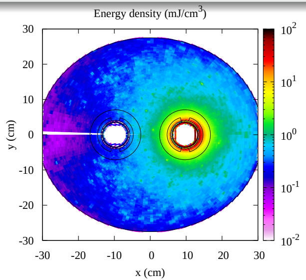


Energy density in MBRB (D4)

Time-integrated (≈40 msec) energy density at the longitudinal position of the peak in the coils (i.e. at the beginning of the magnetic length).

- Radial profile in coil (left)
- Two-dimensional energy density map (right)





Conclusions & Perspectives

- longitudinal pattern – spanning over signal variations up to a factor of 30 – remarkably well reproduced (some geometry details still not implemented explain local underestimation)
- quite reasonable absolute agreement with measured signals (normalization can be optimized)

Simulation benchmark in (almost) controlled conditions proves the reliability of Monte Carlo for predicting beam-machine interaction effects.

Provided that relevant geometry details are accurately implemented!

This applies to the whole LHC context, where the reproduction of the BLM response turns out to be critically depending on the source term reliability and the accurate machine element description.

How do we move towards UFO investigation?