LHC beam-machine interaction studies with FLUKA and DPMJET

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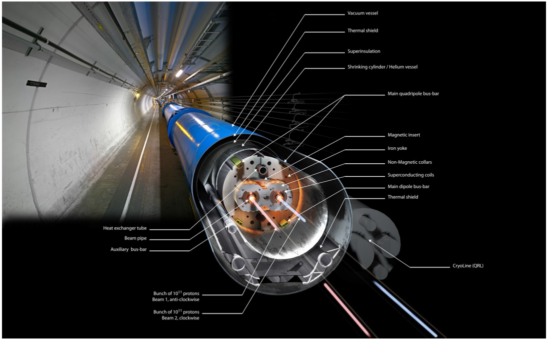
with valuable contributions from many people from the CERN-FLUKA team

80th Birthday Celebration in Honour of Professor Johannes Ranft

April 8^{th}, 2013

LHC beam-machine interaction studies: from beam losses to secondary shower description

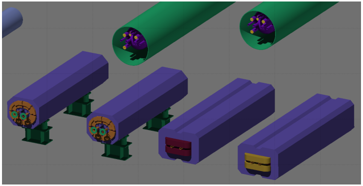


Beam losses in the LHC – both, normal and accidental ...

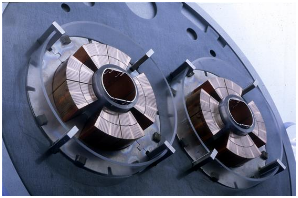
- luminosity production in experiments
- halo collimation
- injection failures
- asynchronous beam dump
- residual gas in vacuum chamber
- dust particles falling into beam
- ...

FLUKA/DPMJET regularly used at CERN to perform LHC beam-machine interaction simulations in the context of

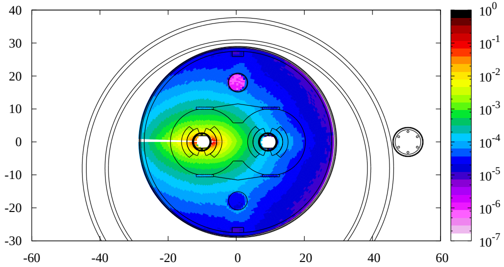
- machine protection
- collimation
- high-luminosity upgrade
- design studies
- radiation to electronics (R2E project)
- activation
- ...



Unprecedented operational conditions ...

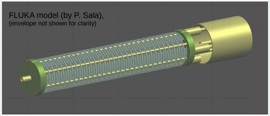


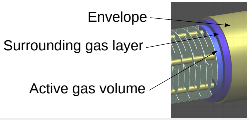
- The energy stored in a nominal LHC beam (@7TeV) is 362 MJ
- About ∼80 J/cm^3 are sufficient to induce damage in coils of a superconducting LHC magnet
- Some ∼mJ/cm^3 can lead to a magnet quench in case of fast (msec) beam losses (∼mW/cm^3 in case of steady-state losses)



Beam loss detection

- More than 3000 Beam Loss Monitors (BLMs) are mounted along the ring (ionisation chambers filled with N_2 gas)
- The monitors trigger a beam extraction request in case of critical beam losses
- Often BLM signals are the only measured quantity available when analysing loss events ... and they give absolute dose values!



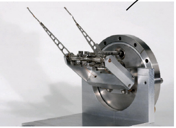


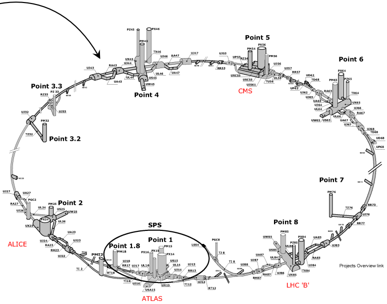
Validation I: BLM response due to losses induced by wire scanner (p@3.5 TeV)

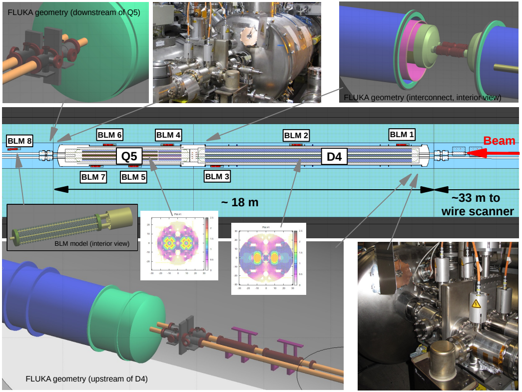
- First years of LHC operation yielded opportunity to perform validation against dose measurements
- Wire scanner test: controlled benchmarking conditions (well defined source term), allowing for an absolute comparison
  → # of impacting protons well known:

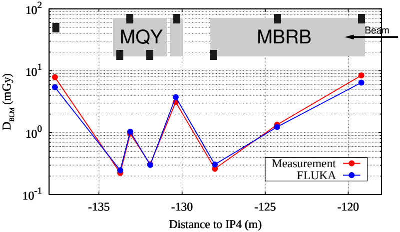
  $$N_{prot\ impact} = N_{beam} f_{LHC} d_{wire} / v_{wire}$$

- Figure bottom right: comparison of calculated and measured BLM pattern, **agreement within 30%!**



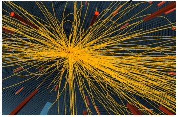


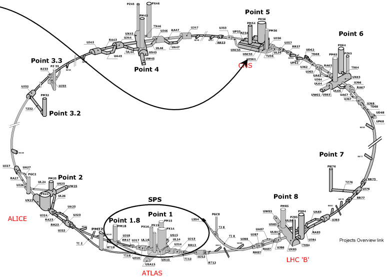


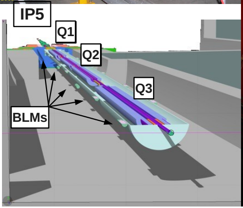


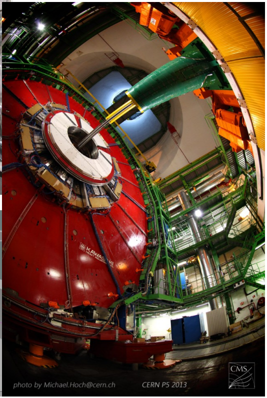
Validation II: BLM response due to collision debris from IP5 (p@3.5 TeV)

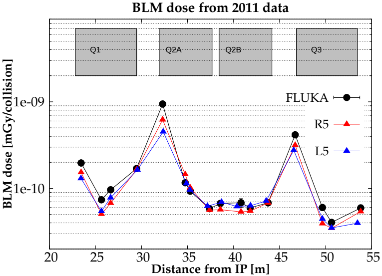
- Another validation study, this time concerning the collision debris from CMS
- Simulation of p-p collisions with DPMJET
- Figure bottom right: Comparison of calculated and measured BLM pattern along the inner triplet in IR5, **generally good agreement!**
- Note: comparison incorporates CMS luminosity measurement and 73.5 mb p-p cross-section (from TOTEM)







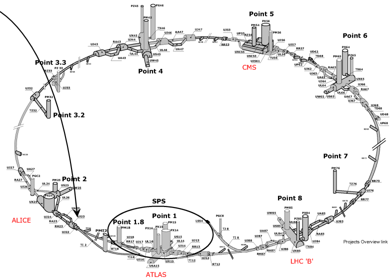


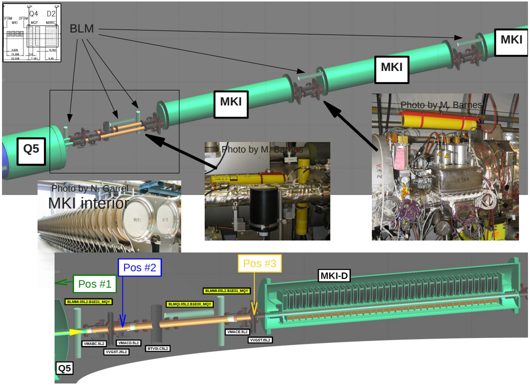


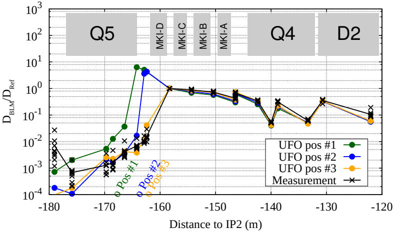
FLUKA study: L.S.Esposito et. al.

Unexpected beam losses: hunting UFOs

- Beam losses due to proton interactions with micrometer dust particles in the vacuum chamber,
  UFOs = Unidentified Falling Objects
- During past years of operation, UFOs have caused several beam dumps
- Figure bottom right: by analysing BLM pattern, FLUKA studies allowed to determine UFO locations around IR2 injection kickers (MKIs)

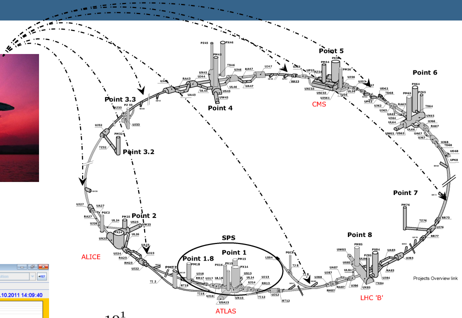


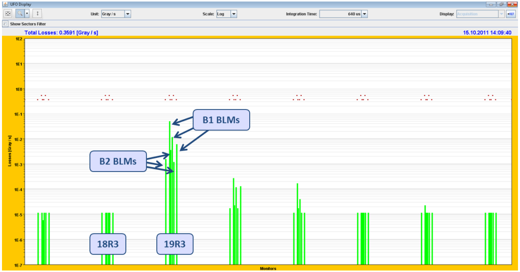


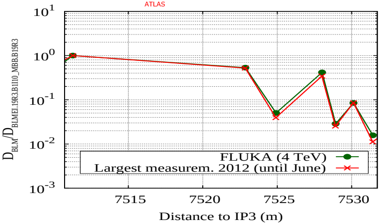


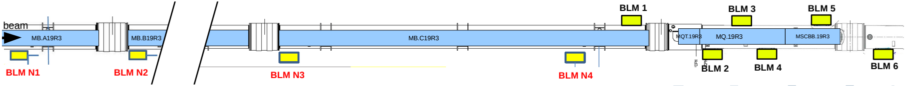
Hunting even more UFOs, this time in the LHC arcs

- UFOs can be observed all around the LHC ring
- They are expected to pose a performance limitation for post-LS1 operation (towards nominal energy)
- Arc-BLM configurations, in particular beam abort thresholds, are currently being optimised with FLUKA



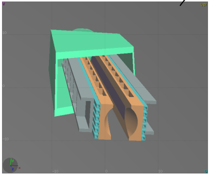


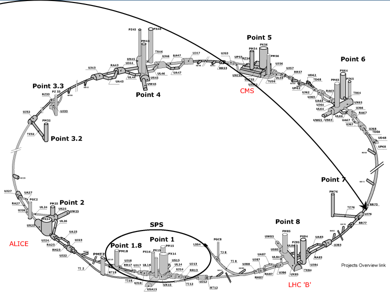


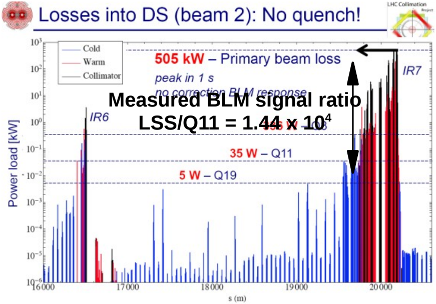


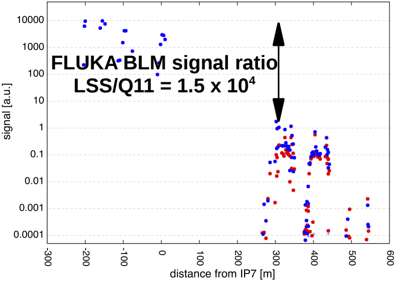
Expected losses: collimation

- Machine study: 500 kW power impacting on primary collimator (TCP) in IR7
- Corresponding FLUKA shower calculations were performed, spanning over several hundred meters (from TCPs until dispersion suppressor)
- BLM signal ratio straight section/Q11 nicely reproduced



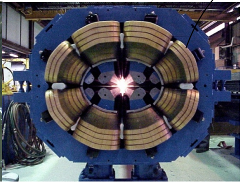


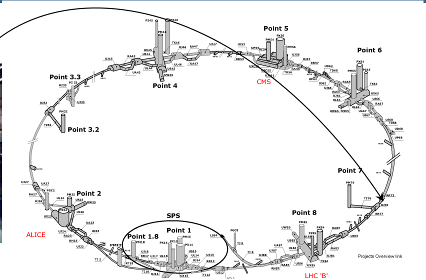


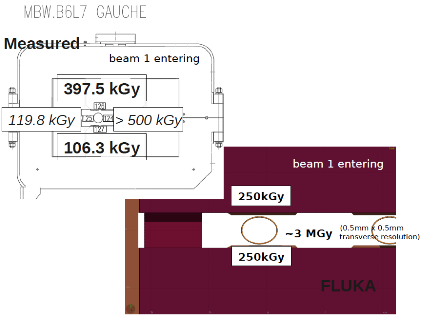


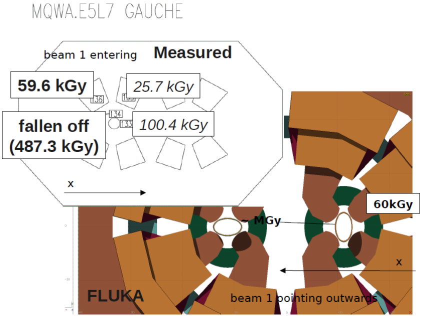
Measurements: R. Assmann et. al.

Collimation region: magnet deterioration





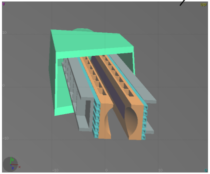


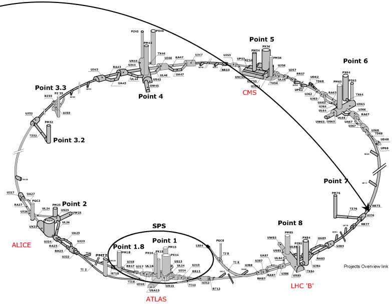


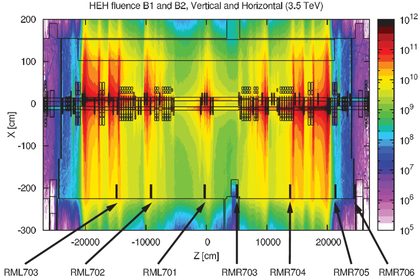
Measurements: J. Trummer et. al.

Radiation to electronics

- Radiation to electronics: single event effects always a critical issue
- FLUKA/DPMJET heavily used (here an example of IR7 is given)
- Figure below: calculated high-energy hadron fluence in the IR7 collimation region ($1/cm^2$)
- Table bottom right: comparison of measured and simulated Single Event Upsets (SEUs) througout 2010 operation







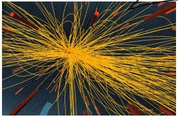
K. Roed et. al.

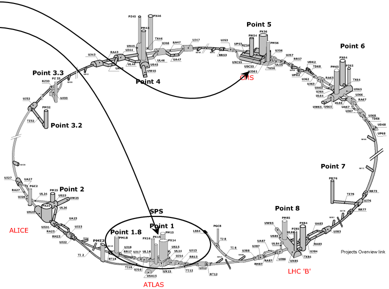
NUMBEROF SEUs MEASURED BY THE RADMONS INSTALLED IN IR7 AND COMPARED TO FLUKA PREDICTIONS FOR 2010 LHC OPERATION.

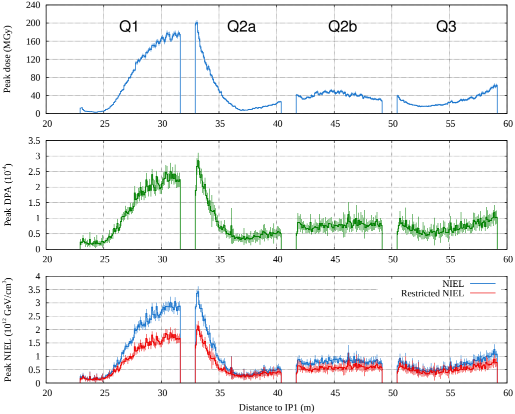
RadMon	Measured (Err [%])	FLUKA (Err [%])	F/M (Err [%])
RML703	13246 (± 1)	13800 (±19)	1.0 (±19)
RML702	4601 (± 2)	7650 (±20)	1.7 (±21)
RML701	2406 (± 2)	3590 (±20)	1.5 (±20)
RMR703	878 (± 3)	641 (±20)	0.7 (±21)
RMR704	17903 (± 1)	17600 (±20)	1.0 (±20)
RMR705	264 (± 6)	731 (±18)	2.8 (±19)
RMR706	13 (±30)	7 (±28)	0.6 (±40)

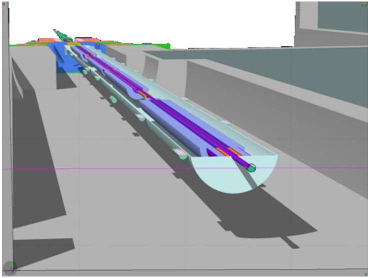
Towards high luminosity

- 7 TeV, 3000 fb^{-1}
- New inner triplet design heavily based on FLUKA studies, p-p collisions simulated by means of DPMJET
- Figure bottom left: peak dose, peak DPA and peak NIEL in the triplet coils









I think it is evident that FLUKA/DPMJET are essential simulation tools for the LHC ... a success story to be continued!

Thank you for your attention!