MEASUREMENTS OF HEAVY ION BEAM LOSSES FROM COLLIMATION

R. Bruce

CERN - AB/ABP, Geneva, Switzerland
also at MAX-lab, Lund University, Sweden

R. Assmann, G. Bellodi, C. Bracco, H.H. Braun, S. Gilardoni, E.B. Holzer, J.M. Jowett, S. Redaelli, T. Weiler, C. Zamantzas
CERN

Outline

- Introduction and motivation: Collimation of ions
- Simulation tools
- Experimental setup
- Results: comparison between measurement and simulation
- Conclusion

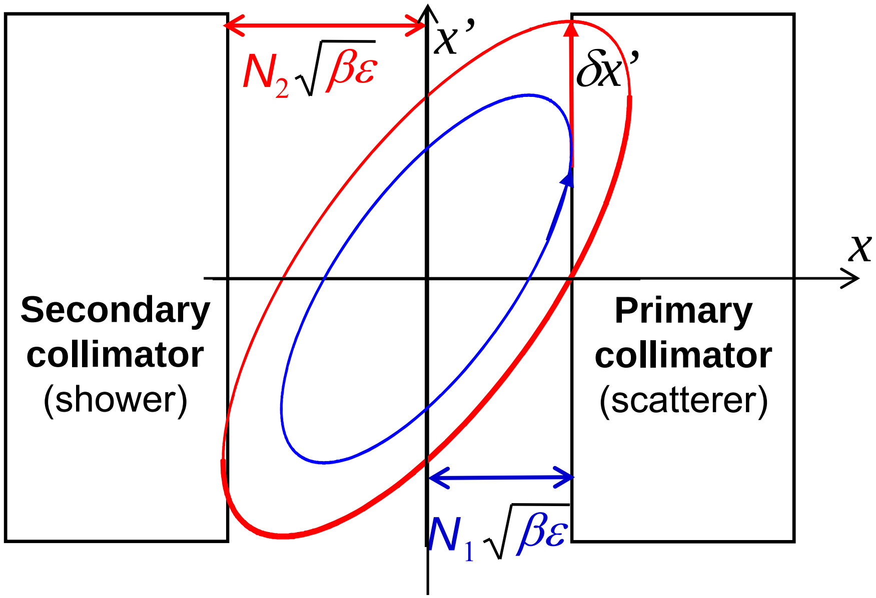
LHC operation with Pb^{82+} ions

The LHC will run ~1 month/year with heavy ions.

	$^{208}Pb^{82+}$ ions	Protons
Energy per nucleon	2.76 TeV	7 TeV
Number of bunches	592	2808
Particles per bunch	7×10^7	1.15×10^{11}
Bunch spacing	100 ns	25 ns
Peak luminosity	10^{27} cm^{-2} s^{-1}	10^{34} cm^{-2} s^{-1}
Stored energy per beam	3.81 MJ	350 MJ

- Because of the high stored beam energy, efficient collimation is necessary for machine protection to avoid quenches
- Collimation system optimized for proton operation
- Although beam power is 100 times less in the LHC Pb^{82+} beam, the collimation inefficiency is a factor 40 higher than for protons

Collimation of ions



Necessary condition to hit secondary collimator:

$$\delta x' > \sqrt{\frac{\left(N_2^2 - N_1^2\right)\varepsilon_N}{\gamma_{REL}\beta_{TWISS}}},$$

Ions in the LHC: $\delta x' > 7\,\mu\text{rad}$

RMS MCS angle of 2.76 A TeV Pb^{82+} ions on graphite: 4.7 μ rad/$m^{1/2}$

⇒ 2 m of collimator needed to give necessary kick

Nuclear interaction length of 2.76 A TeV Pb^{82+} ions on graphite: 2.5 cm
(compare protons: 38 cm)
Electromagnetic dissociation length: 19 cm

Ions are likely to undergo nuclear fragmentation before the necessary angle is obtained!

Collimation of ions (2)

Large probability for fragmentation in primary collimator

⇒ Production of isotopes (Pb_{207}, Pb_{206}, Tl_{203} etc) with different Z/A ratio (different rigidity) that are not intercepted by secondary collimator, assuming the same collimation optics as for protons.

$$\delta = \frac{Z_0}{A_0}\frac{A}{Z}(1+\delta_{\mathrm{kin}}) - 1$$

Fragments follow the locally generated dispersion.

May be lost downstream, causing heat deposition in superconducting magnets.

The ICOSIM program

Optical tracking

•Linear + leading order in chromatic effects, thin sextupoles.

•MAD-X optics files and aperture tables

Particle-matter interaction in collimator

•FLUKA (A. Fasso, A. Ferrari, J. Ranft, P. Sala et al). Used for the SPS study

•Fragmentation cross-sections from RELDIS & ABRATION/ABLATION routines (Igor Pshenichnov) + crude Monte Carlo of MSC and ionization. Faster, but less accurate. Used for previous LHC studies

Output

•Impact coordinates

•Collimation efficiencies

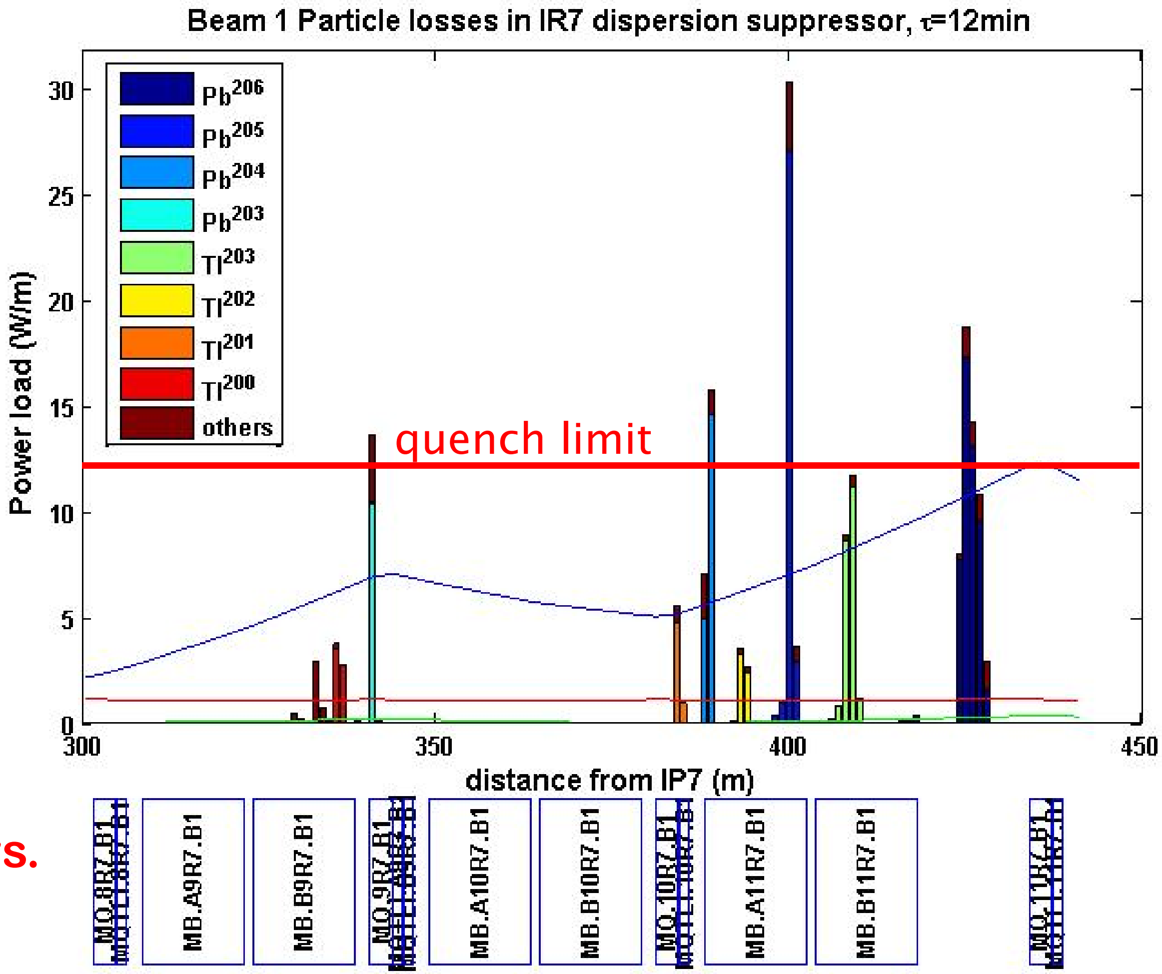
(For more details, see H. Braun et al in EPAC04)

Results for the LHC

- Nominal LHC ion luminosity may be limited due to quenches induced by fragments

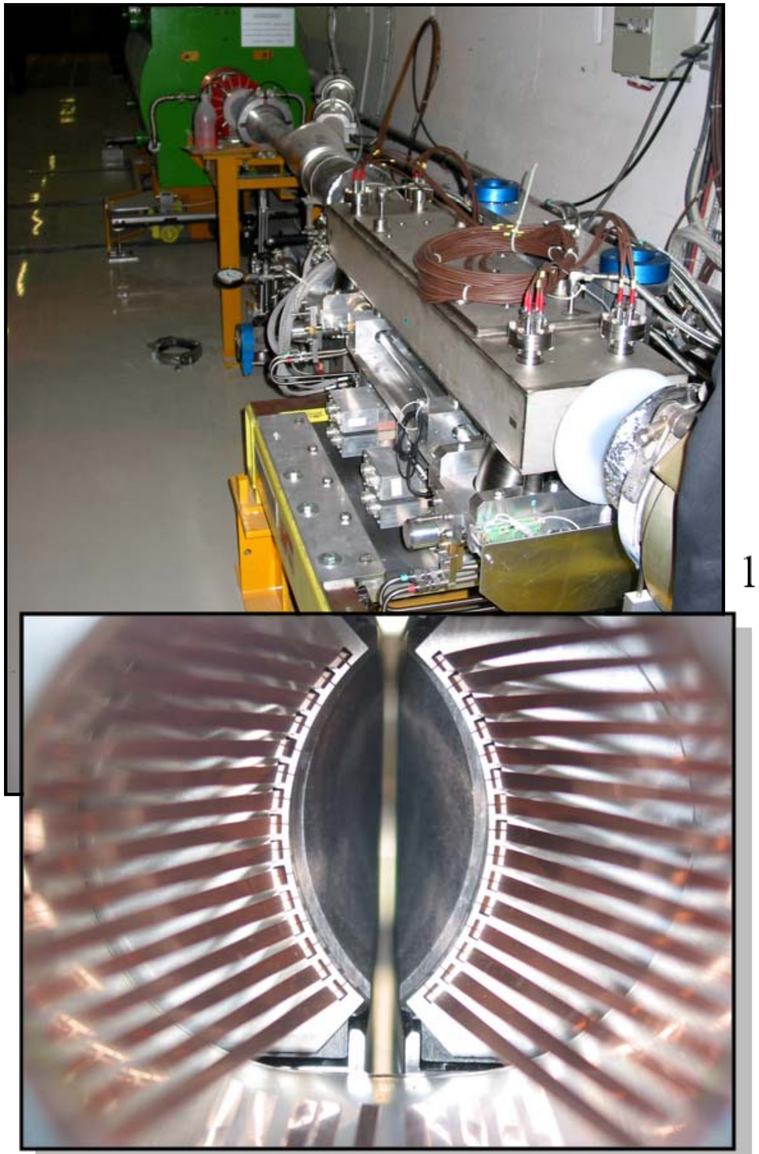
- Uncertainties:
  - Quench limit
  - Fragmentation cross sections
  - Impact distribution on collimator
  - Presumed beam lifetime

Benchmark of simulation vs. data needed to confirm predicted behaviour and quantify uncertainties (except quench limit)

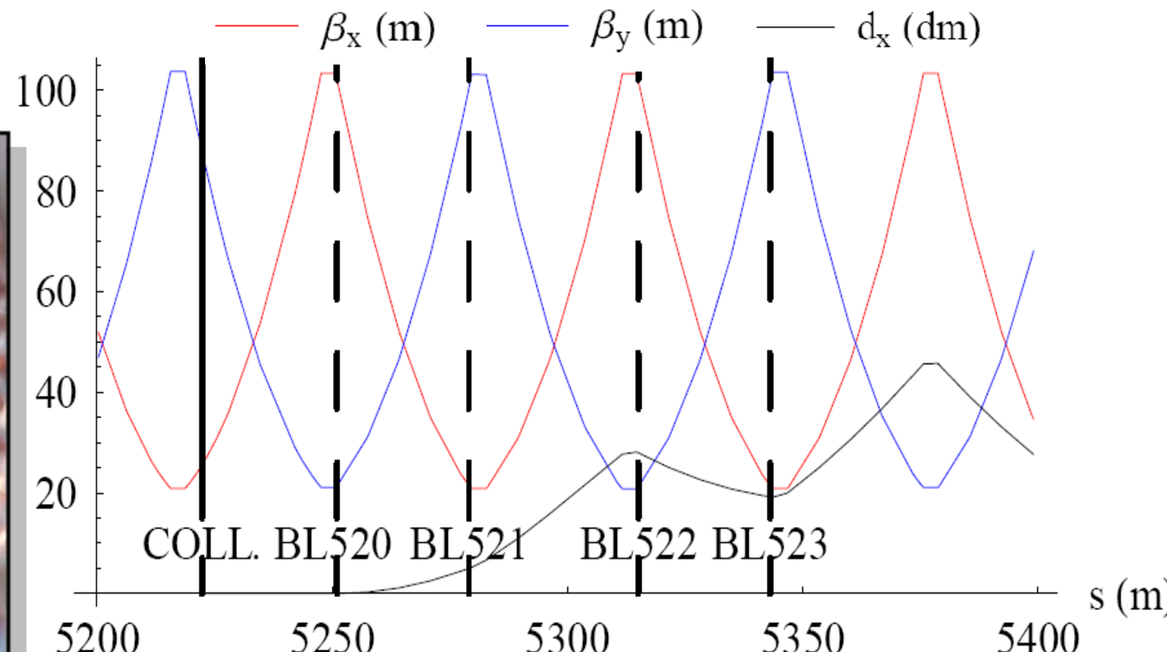


Dispersion suppressor after IR7
12 minute beam lifetime assumed

SPS experiment

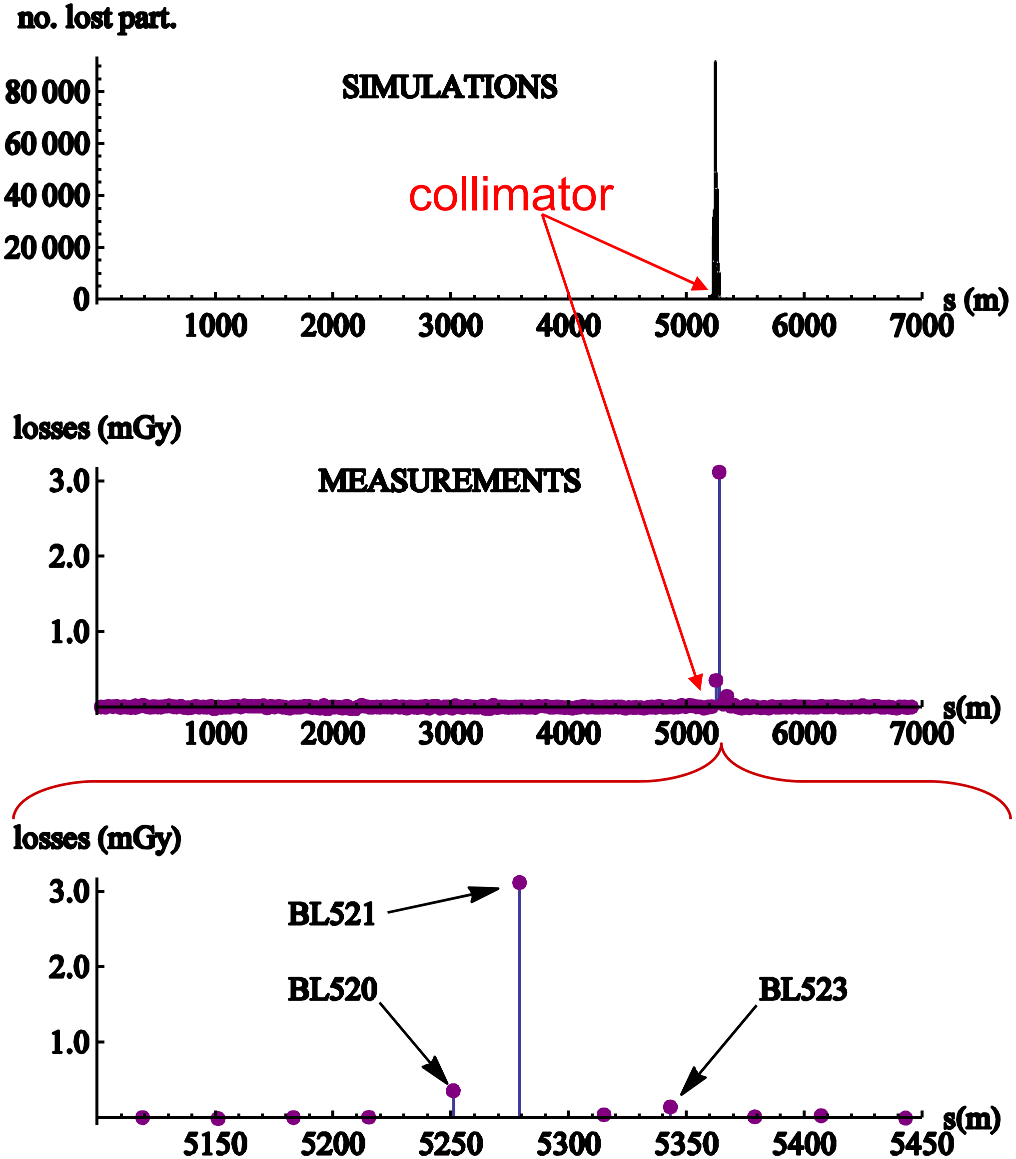


- LHC secondary collimator prototype installed in SPS (2 independent carbon jaws in hor. plane)
- Jaws moved in and out during Pb^{82+} ion operation to create losses, typical steps 0.1-1 mm
- Losses measured by 216 BLMs (ionization chambers) around the ring
- 106.4 GeV/nucleon coasting Pb^{82+} beam
- 270 GeV coasting proton beam for comparison



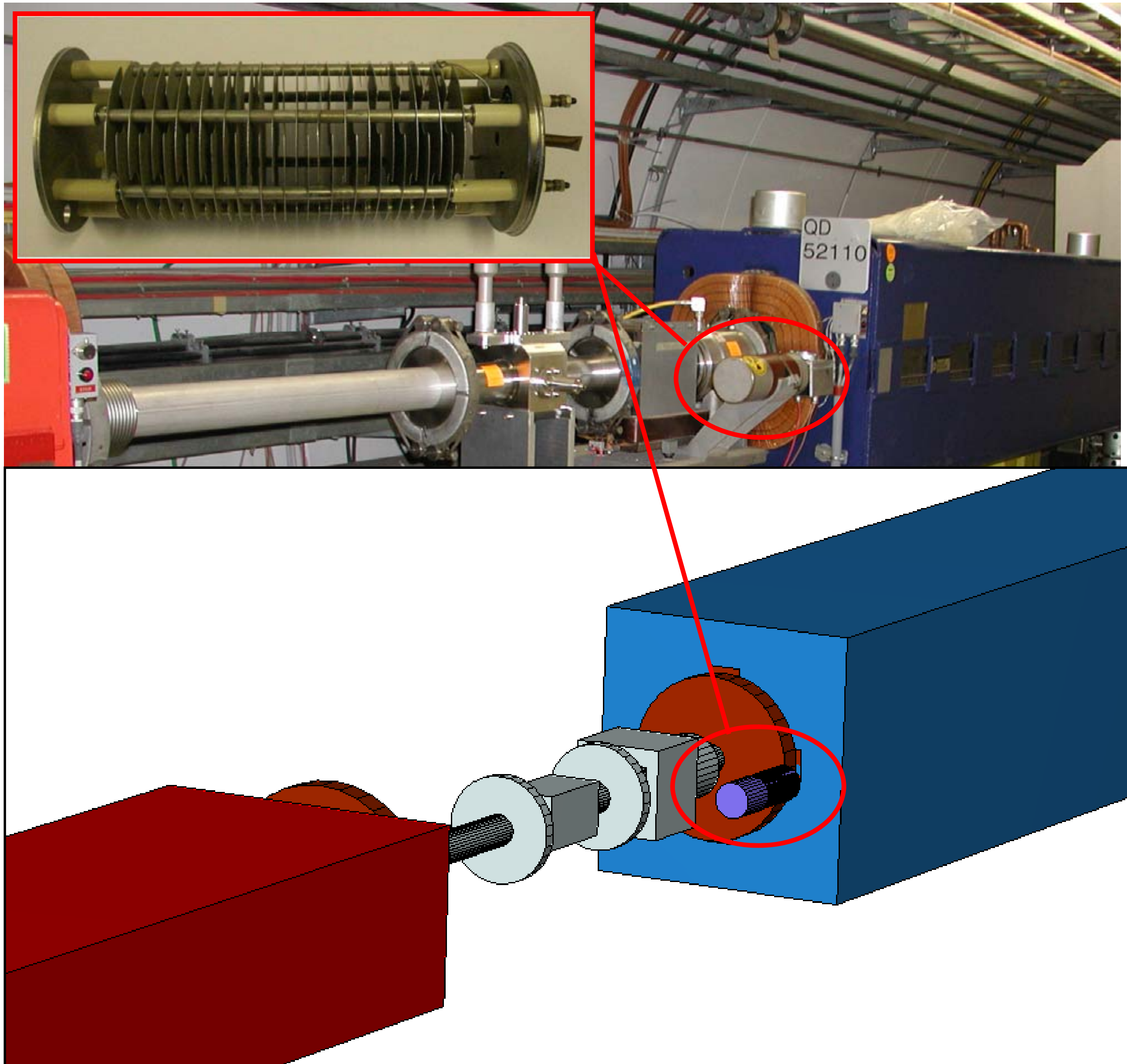
Qualitative comparison

- Simulated impact positions plotted with 5 m binning
- One main loss location, just downstream of collimator
- Background (loss map without movement) subtracted
- Good agreement qualitatively – main loss peak well reproduced
- Studying closest BLMs quantitatively



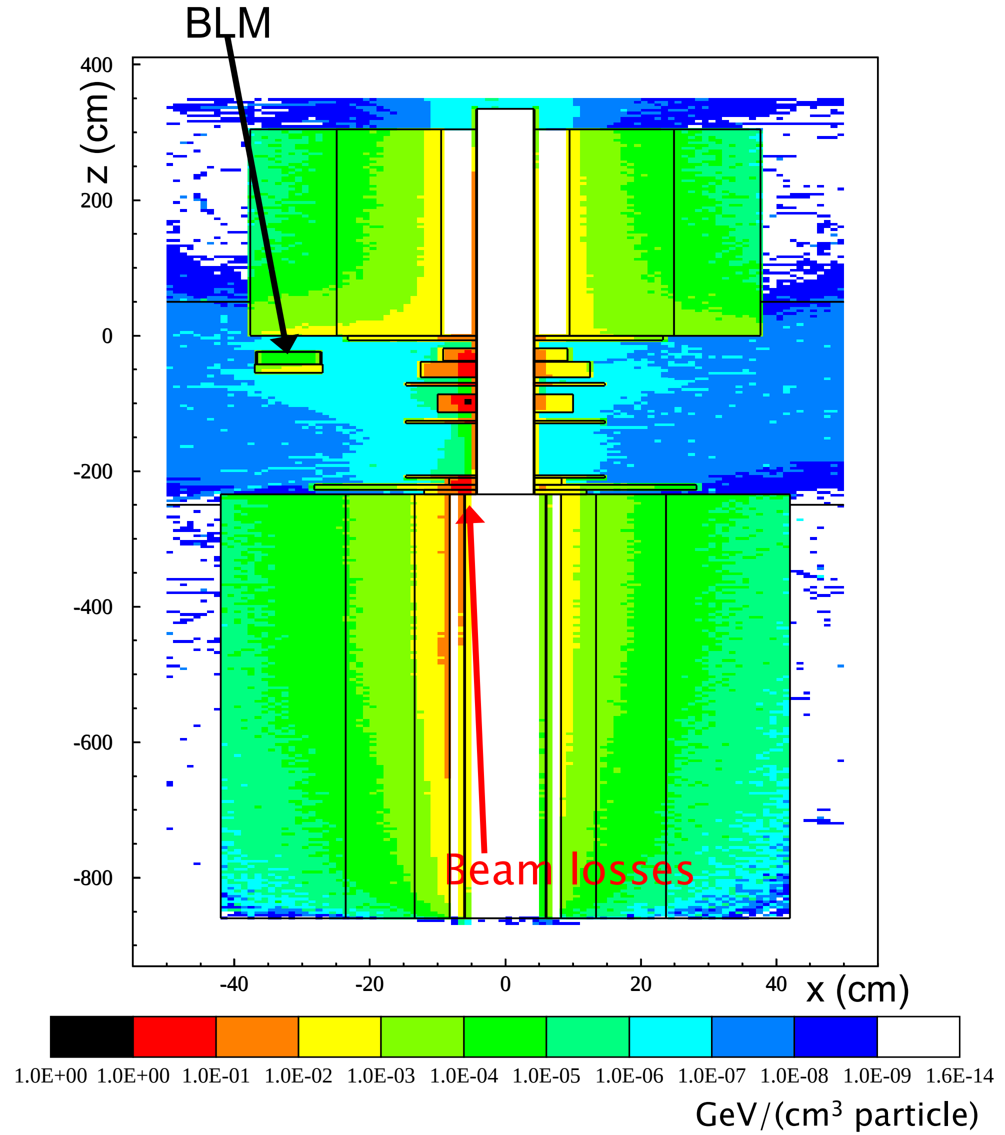
Quantitative comparison

- Considering not only impact location, but absolute BLM signal
- Particle-matter interaction of losses in geometry taken into account
- 3D geometry around each BLM implemented in FLUKA



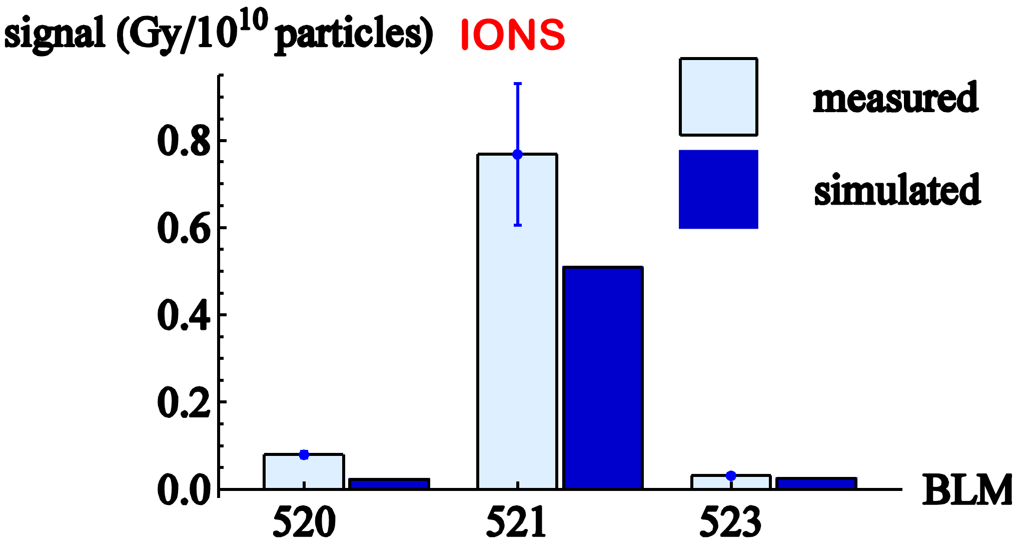
Quantitative comparison (2)

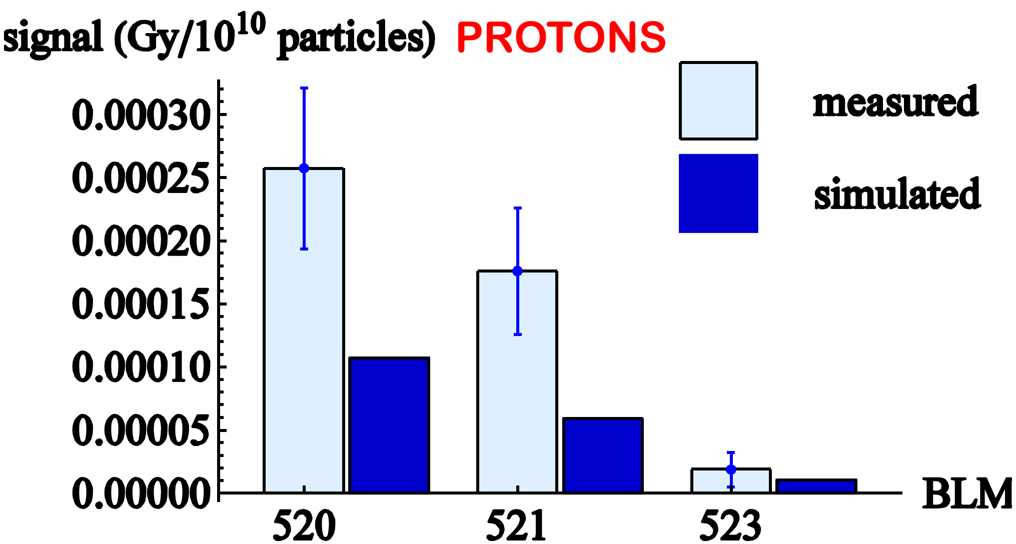
- **Impact coordinates from tracking fed as starting conditions into FLUKA**
- **Energy deposition in BLM gas scored**
- **Simulating the BLMs closest to the collimator with the strongest signal (520, 521,523)**
- **Both Pb^{82+} ions and protons simulated**



Results

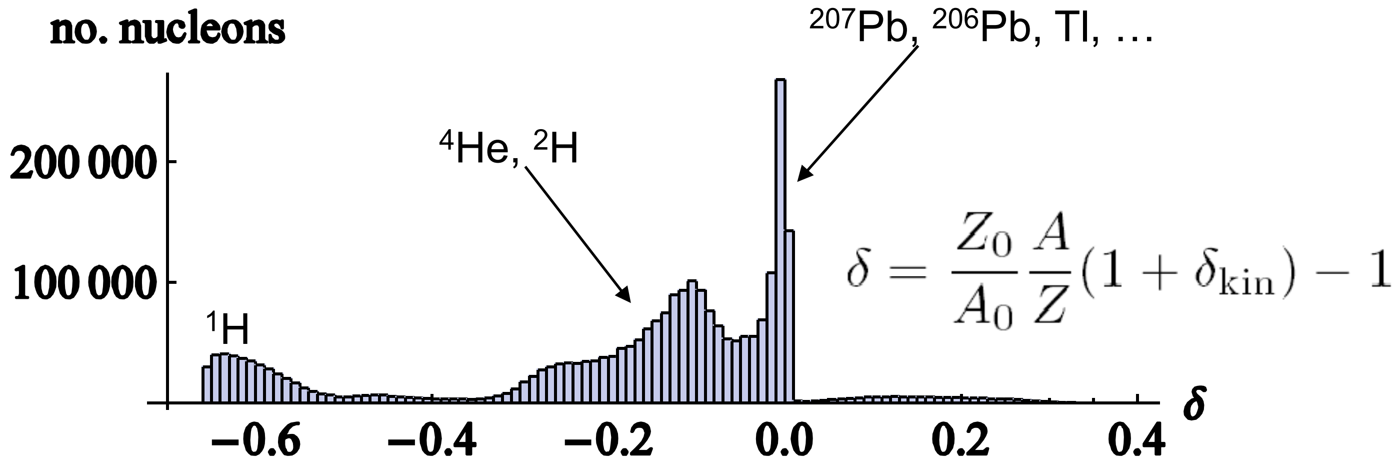
- Qualitative difference ions-protons
- Ions lost due to dispersion, protons due to large angles
- Negligible ion losses predicted and simulated at BL522
- Good agreement within estimated errors

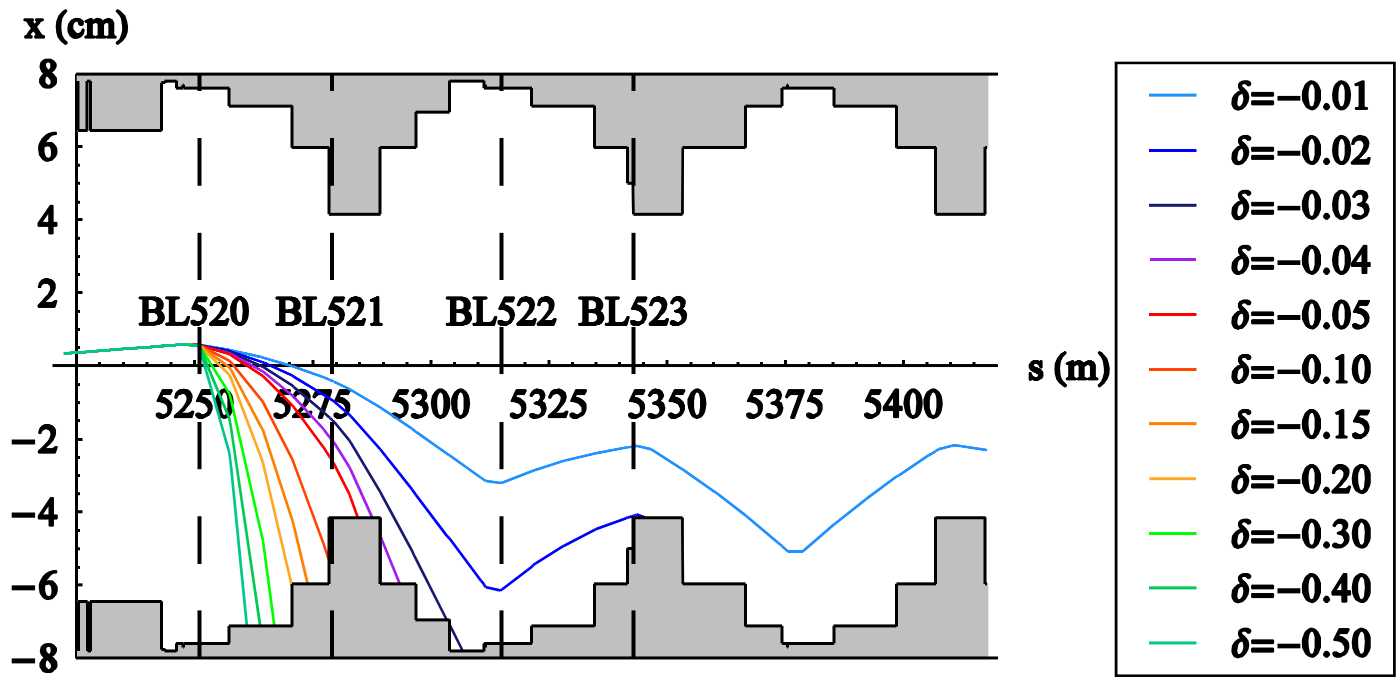




Dispersive ion orbits

- Aperture limitations cut out different parts of spectrum
- Wide range of fragments lost close to BL521
- Isotopes close to ^{208}Pb lost at BL523, close to LHC situation





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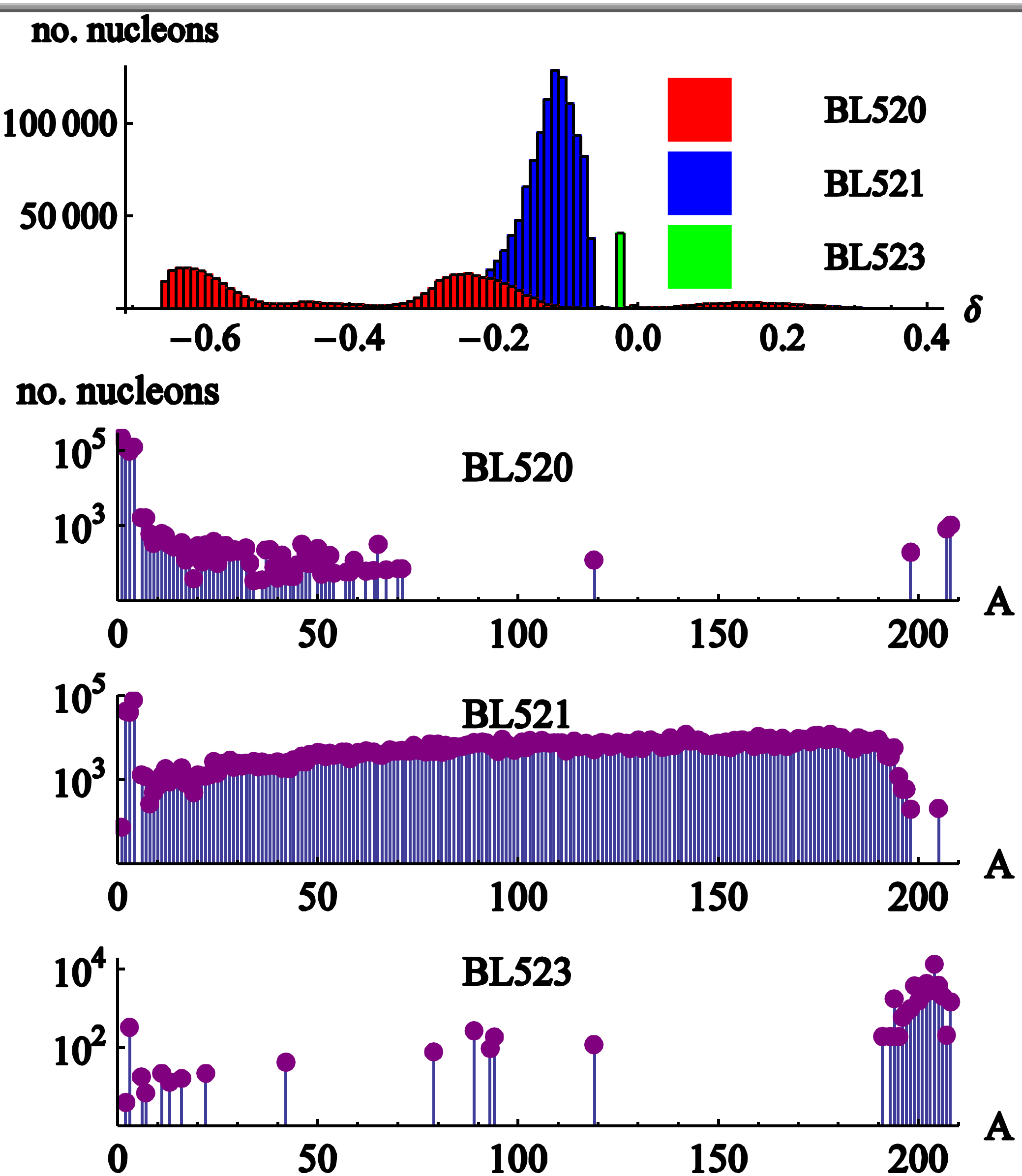

Conclusion

- Collimation efficiency during Pb^{82+} operation of LHC predicted to be lower than ultimately required because of fragmentation processes

- Collimation experiment confirms qualitatively different loss patterns for ions (dispersive) and protons (angular)

- Simulations with ICOSIM + FLUKA reproduce measurements within estimated uncertainties, not only in terms of loss positions but also in absolute BLM signals

- Future work: remedies for LHC ion collimation (magnetized collimator, cold collimators, crystal collimator, rematching optics, non-linear collimation, extra high-Z spoilers)

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- M. Jonker, Machine operators

Extra slide – normalization of BLMs

- **FLUKA output given in GeV/cm^3/particle, converted to Gy**
- **Simulated BLM signal normalized to number of lost particles from beam by:**

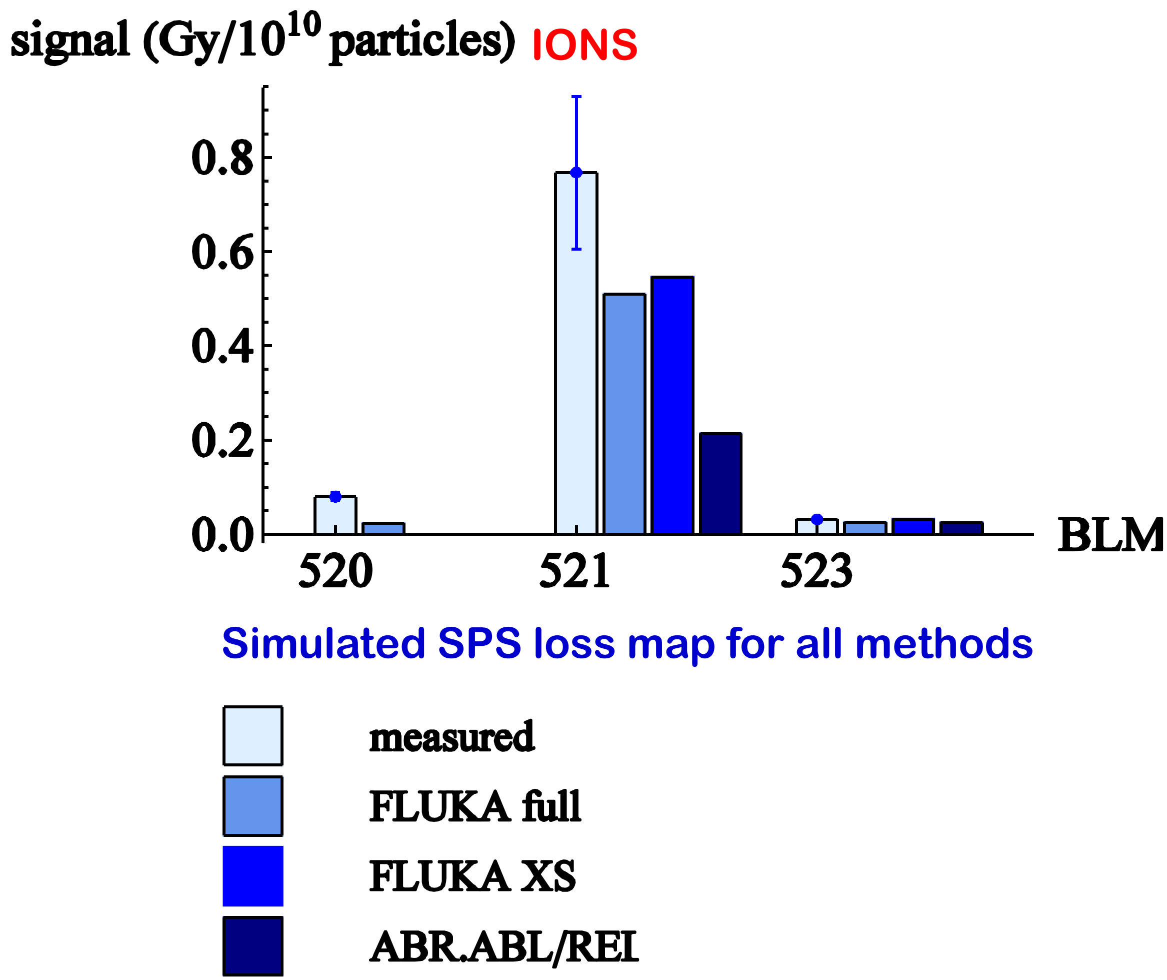
$$sim.norm.signal = \underbrace{\frac{sim.signal}{imp.particle}}_{\text{FLUKA}} \times \underbrace{\frac{imp.particles}{lost.sim.prim.part.}}_{\text{ICOSIM}} \times 10^{10}\ particles.$$

- **Measured BLM signal normalized by:**

$$meas.norm.signal = \frac{\overbrace{meas.signal}^{\text{BLM measurement}}}{\underbrace{meas.lost.prim.part.}_{\text{BCT measurement}}} \times 10^{10}\ particles.$$

Extra slide – Cross section method

- Simplified Monte Carlo in collimator used for LHC simulations
- Tabulated cross sections from FLUKA or ABR.ABL./RE.
- Ionization from Bethe-Bloch
- MCS with Gaussian approximation
- Only heaviest fragment tracked
- Not suitable if light ions are important
- Important benchmark for the LHC



Simulated SPS loss map for all methods

Extra slide – Spectrum of particles

- BLM signal caused not caused by lost ions directly, only by secondary shower particles at low energy
- Spectrum of particles causing the signal