Bound Free Pair Production in RHIC and LHC

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Outline

- Bound Free Pair Production
- Measurements in RHIC
- Monitoring losses in the LHC
- Conclusion

Bound Free Pair Production (BFPP)

- EM process, takes place at the IP in ultra-peripheral heavy ion collisions (large impact parameters)
- e^+e^- pair created by the field between the colliding nuclei
- As opposed to free pair production, the electron is created in an atomic shell of one of the ions
- Schematic of reaction:

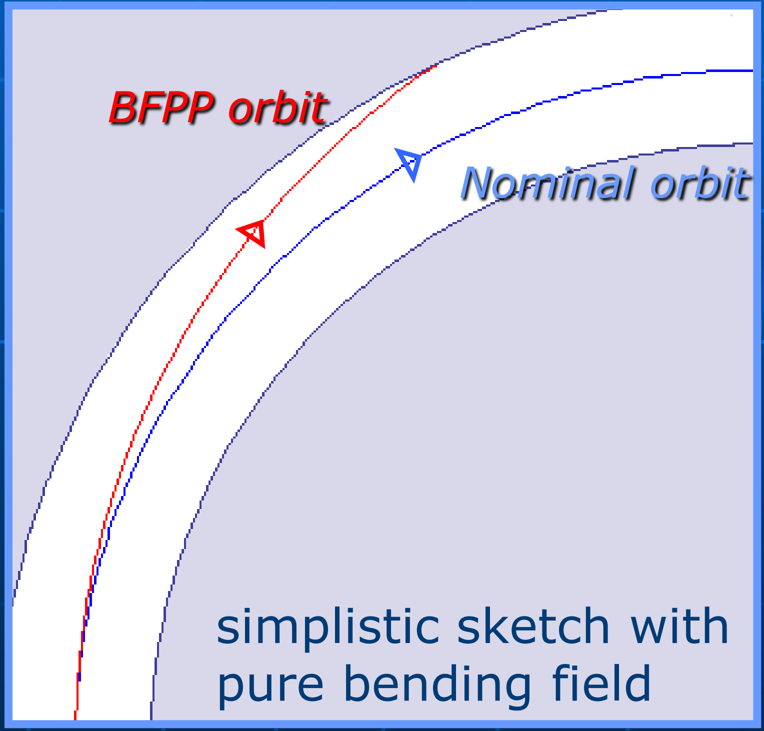
$$Z_1 + Z_2 \xrightarrow{\gamma} (Z_1 + e^-)_{1s_{1/2},\ldots} + Z_2 + e^+$$

Features of BFPP

- Affected particles emerge at a very small angle to the main beam (small transverse recoil)
- However, fractional deviation of the magnetic rigidity

$$\delta = 1/(Z-1)$$

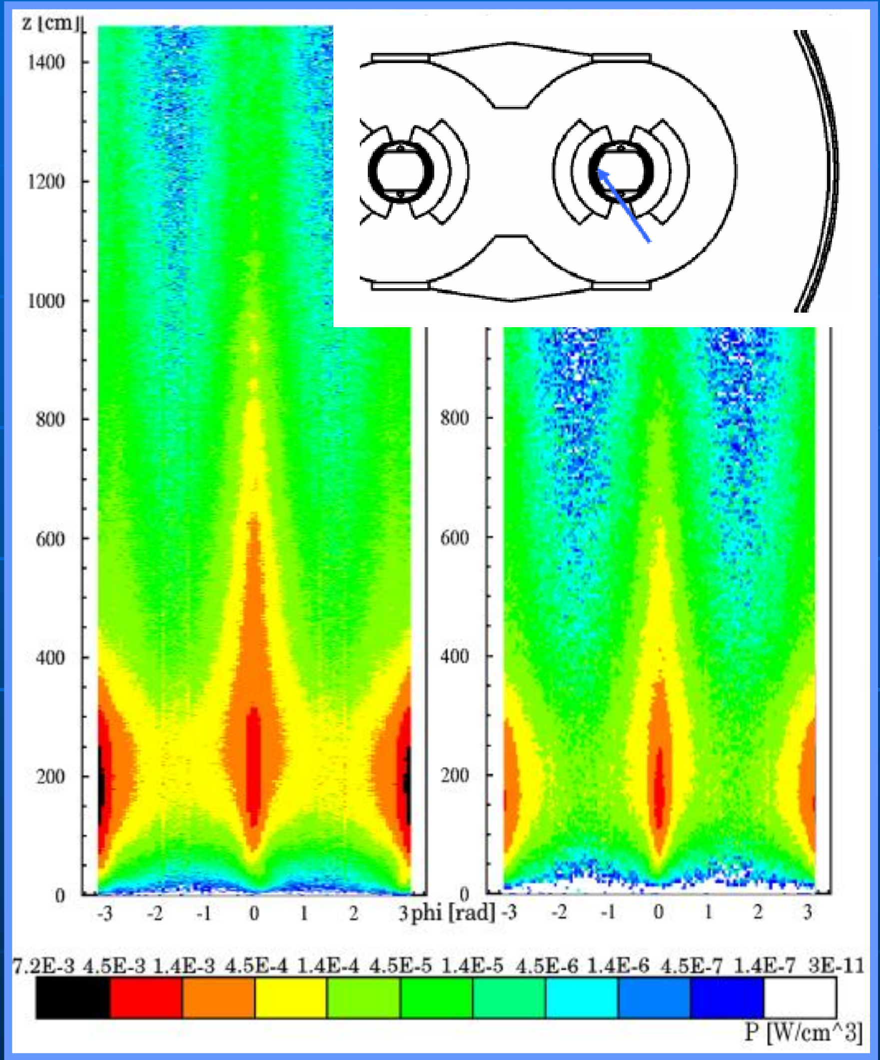
- BFPP particles follow the locally generated dispersion function from the IP
- Contributes to luminosity decay *(Gould LBNL Report LBL-18593; Balz et al, Phys. Rev. E 54:4233)*
- Might be lost in a well-defined spot – could possibly quench magnets *(Klein, Nucl. Inst. Meth. A 459:51; Jowett et al, TPPB029 EPAC03, Jowett Chamonix 03)*



- Loss rate given by $L\sigma$

BFPP in the LHC

- σ=281 Barn for Pb^{82+} operation at 2.76 TeV/nucleon, 281 kHz loss rate (*Meier et al, Phys. Rev. A 63:032713*)
- Hadronic cross section = 8 barn
- BFPP beam at IP2 lost in disp. suppressor dipole
- 25 W heating power
- Simulations: magnets are not likely to quench due to BFPP beam losses
- However, quench still possible within estimated uncertainties
  - Quench limit, Monte Carlo, BFPP cross section
- Good understanding (=benchmark) needed!



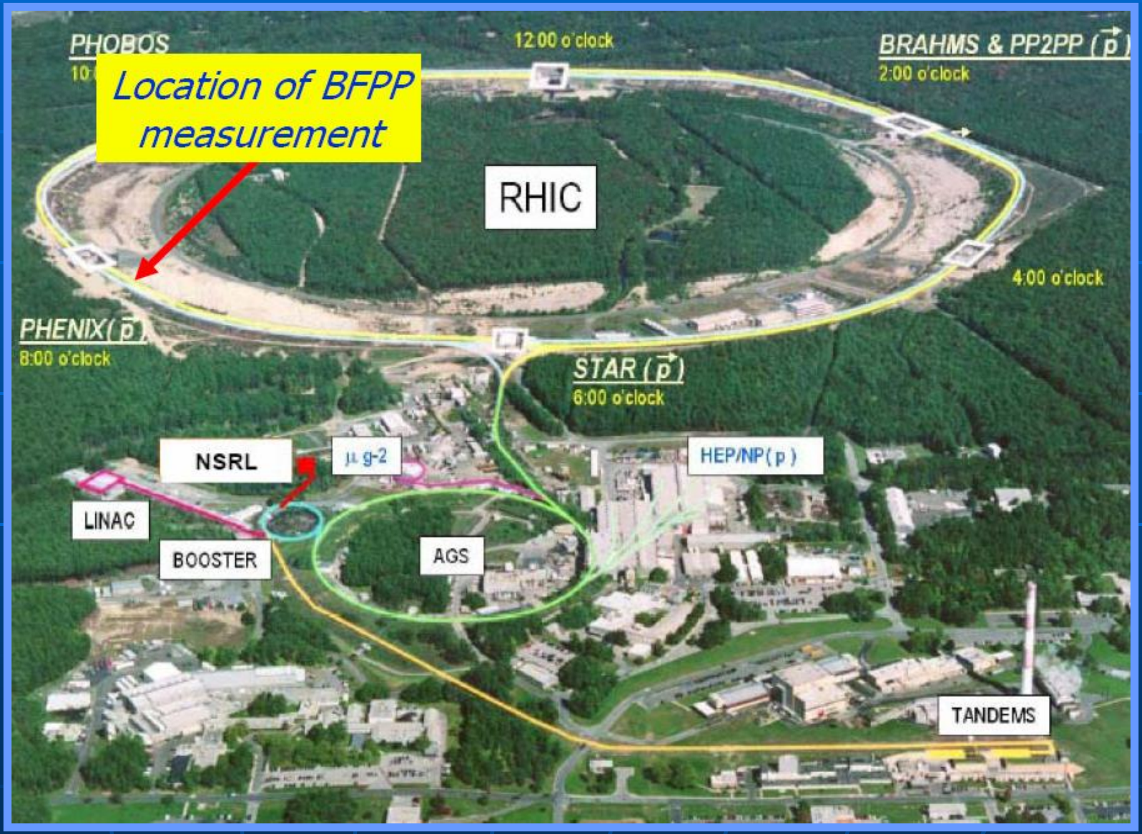
R. Bruce, S. Gilardoni, J.M. Jowett. Bfpp losses and quench limit for lhc magnets. *LHC Project Note 379, CERN, 2006.*

Outline

- Bound Free Pair Production
- Measurements in RHIC
  (R. Bruce et al, Phys. Rev. Letters 99:144801, 2007)
  - cross section, impact point
  - experimental setup
  - measured results, comparison with simulation
- Monitoring losses in the LHC
- Conclusion

RHIC accelerator complex

- Two storage rings called "blue" and "yellow", circumference 3.8 km
- Four experiments: STAR, PHENIX, BRAHMS, PHOBOS
- Collides mainly Au^{79+} ions at 100 GeV/nucleon, but has also operated with several other species
- BFPP experiments performed with Cu^{29+} at 100 GeV/nucleon



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BFPP at RHIC

	σ_{BFPP} (barn)	$L/10^{27}$ ($\mathrm{cm}^{-2}\mathrm{s}^{-1}$)	BFPP rate (kHz)	$\delta(\%)$
LHC Pb-Pb 2759 GeV/nucleon	281	1	281	1.2
RHIC Au-Au 100 GeV/nucleon	114	3	342	1.3
RHIC Cu-Cu 100 GeV/nucleon	0.2	20	4	3.6
RHIC Cu-Cu 31 GeV/nucleon	0.08	1	0.08	3.6

- During Au^{79+} operation, δ too small to form spot
- Cu^{29+} operation at RHIC provides a good opportunity to measure BFPP
- Low rate $\Longrightarrow$ no risk for magnet quenches (4 mW heating power, 25 W in the LHC)

Cross section

- Interpolating data in *Meier et al* gives $\sigma \approx 0.2$ barn

$$\sigma_i \approx Z_1^5 Z_2^2 \left(A_i \log \gamma_{\rm cm} + B_i\right)$$

$$\sigma_{\rm BFPP} = \sum_i \sigma_i$$

- Recent calculation gives $\sigma = 0.19$ barn
(Aste arXiv:0710.4305v2)

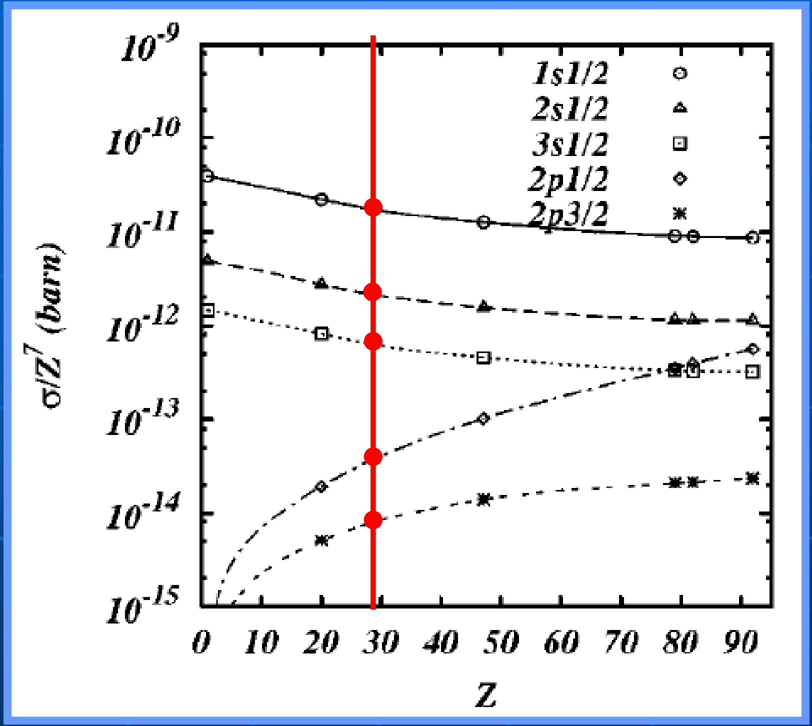
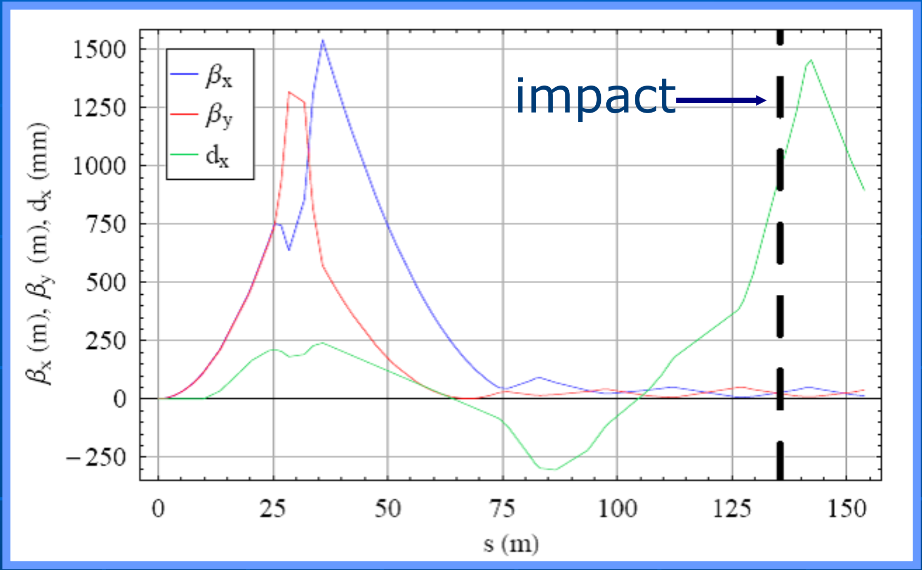
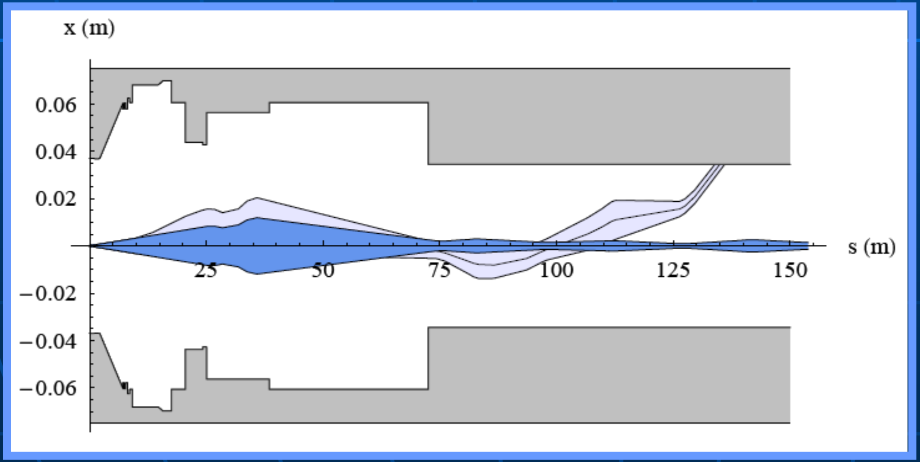


figure from Meier et al, Phys. Rev. A 63:032713

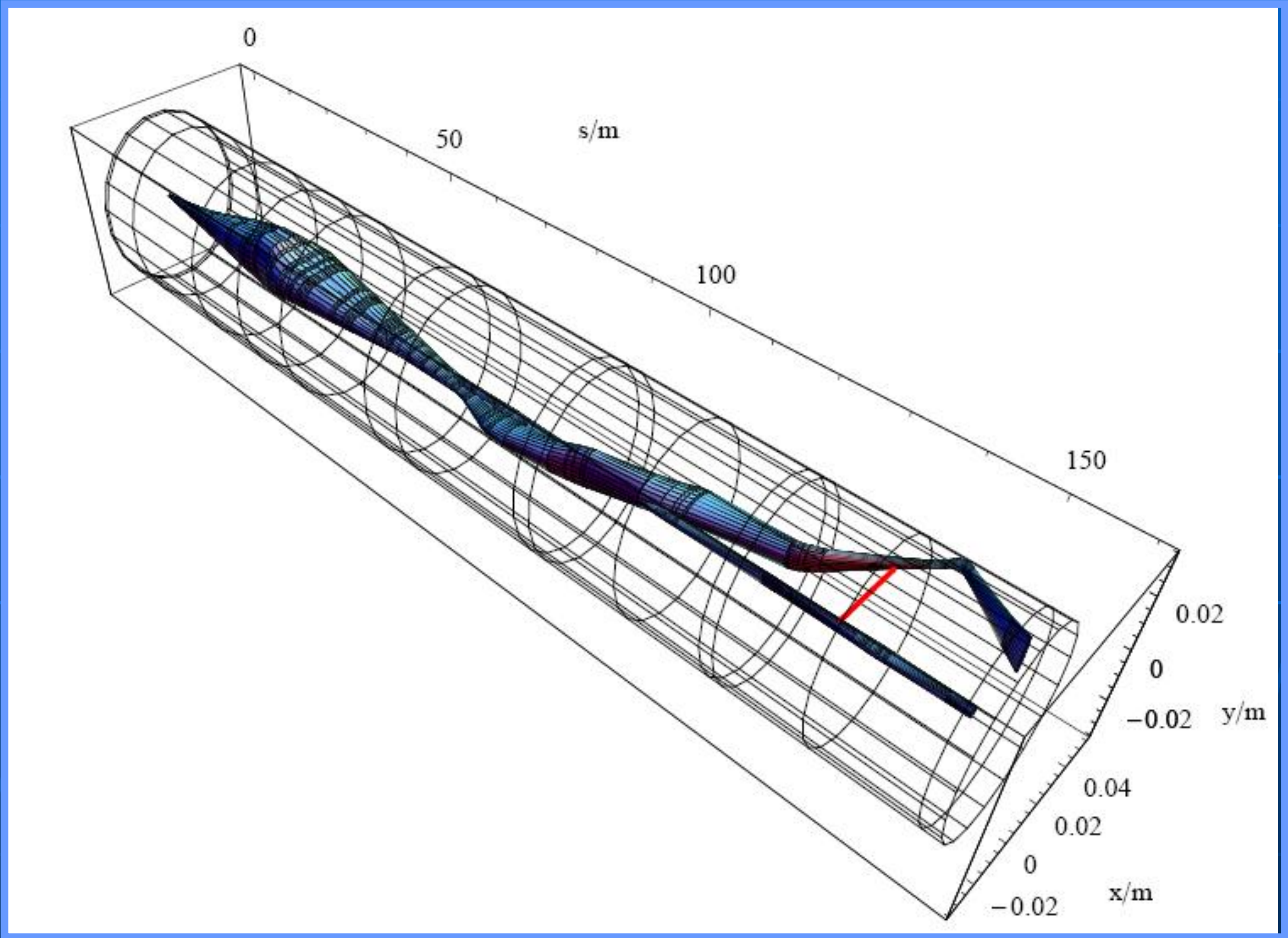
Impact point at RHIC

- Optics functions calculated by MAD-X
- Gives impact at 135.5 m from the PHENIX IP

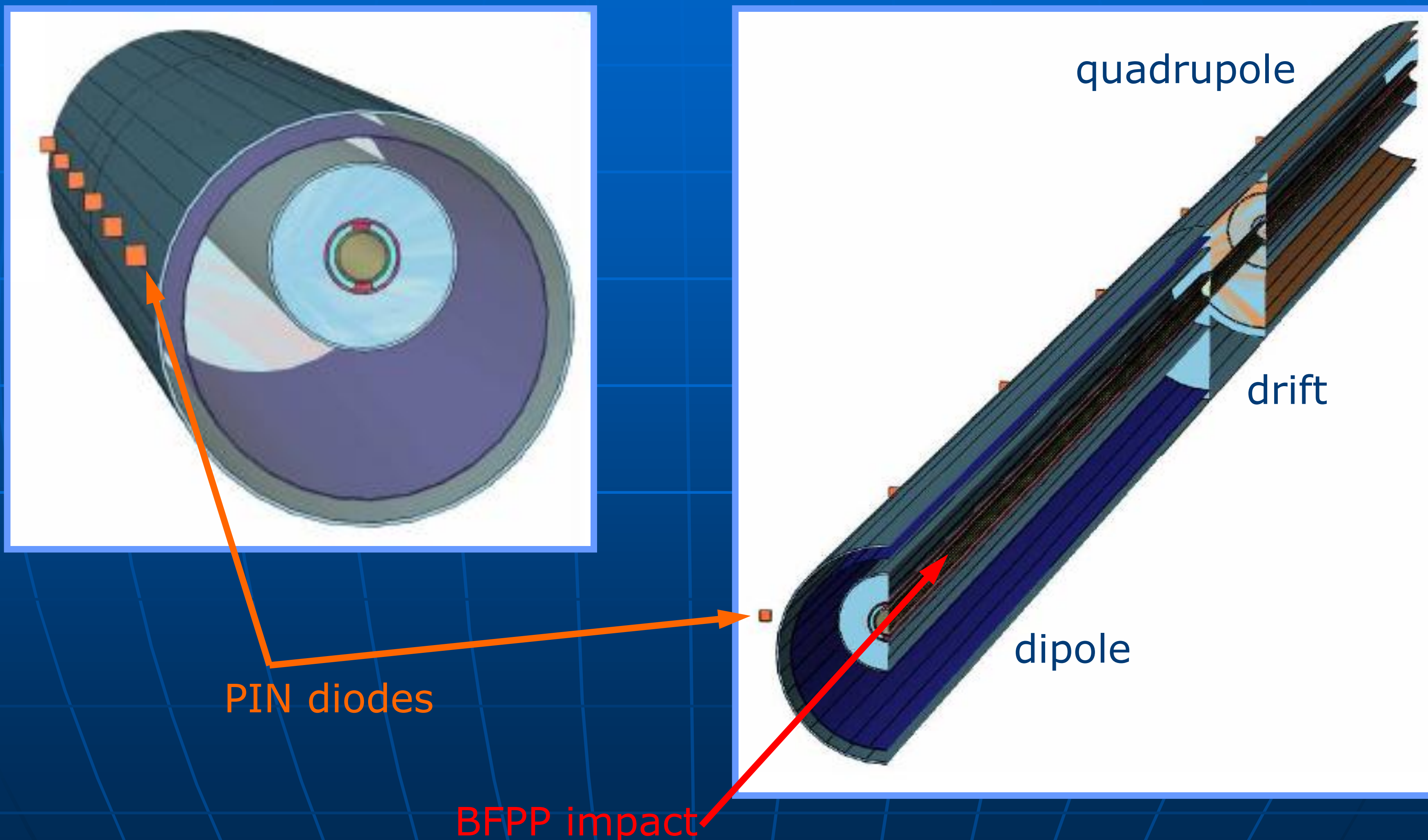




Impact point (continued)

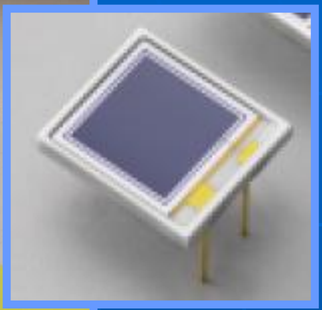


Elements around impact point



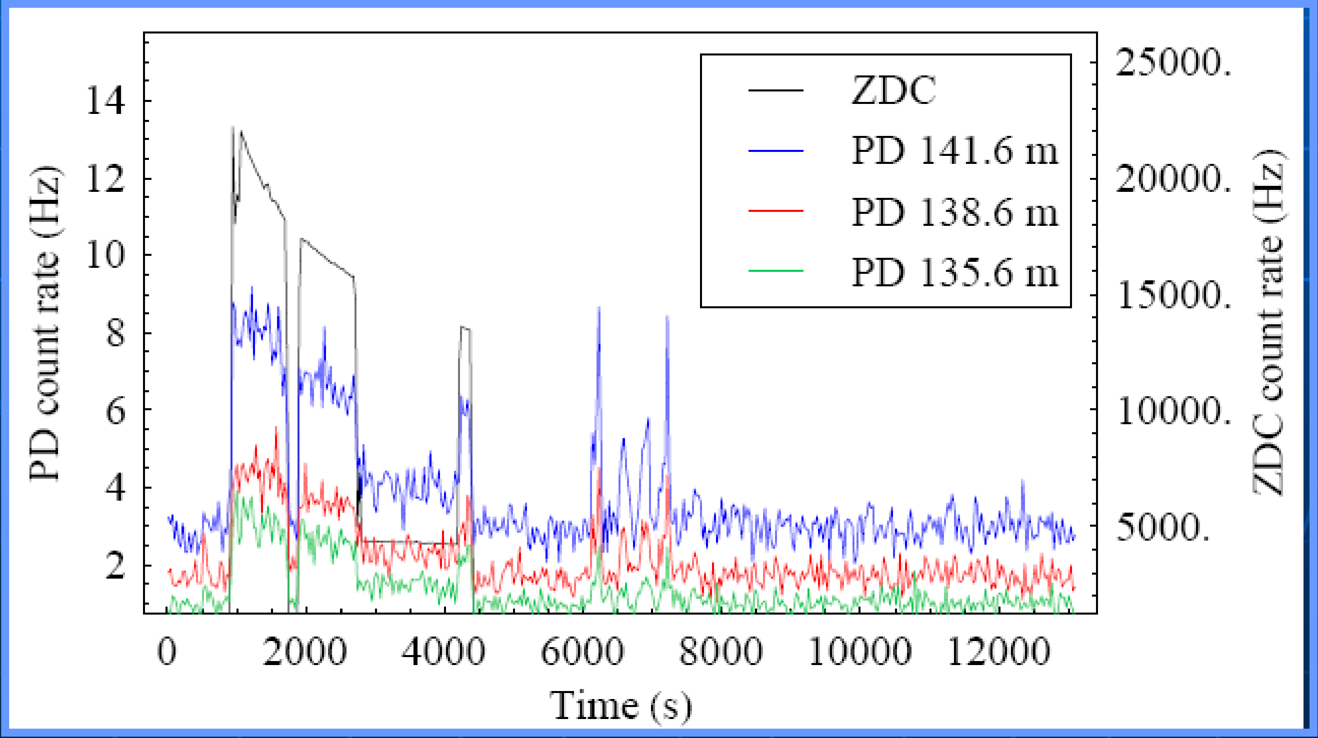
Experimental setup

- PIN diodes (PDs), Hamamatsu S3590, mounted on the outside of the magnets around expected impact point
- Silicon detector, sensitive to passage of MIPs
- Digitally counting number of particles
- PDs with 3 m spacing (wide conf.)
- later moved to 0.5 m spacing around observed max (close conf.)



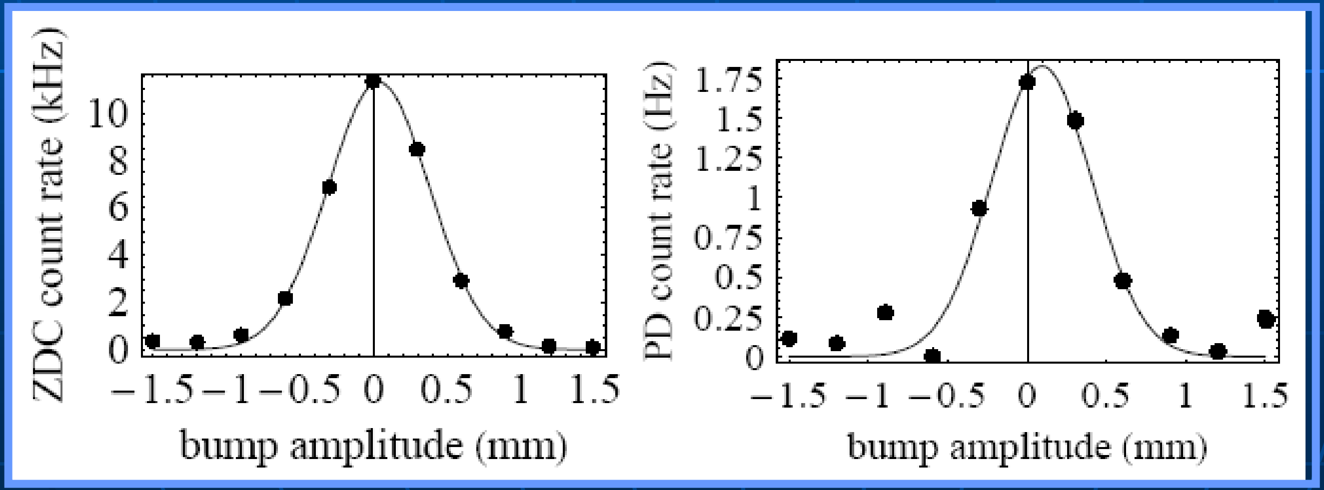
Measured signals

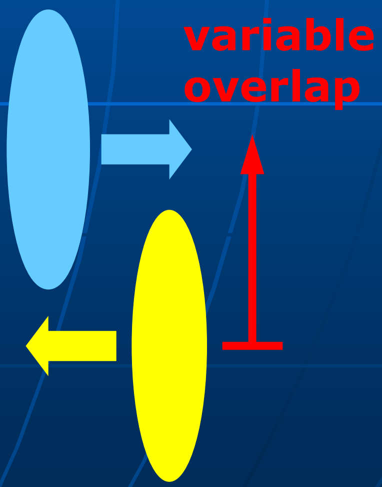
- Measured PD signals well correlated with luminosity (proportional to ZDC) and localized along *s*
- Maximum in wide configuration found at 141.6 m from the IP, and at 140.5 m in the close configuration
- Signals measured in the range between 0 and 20 Hz



van der Meer scan

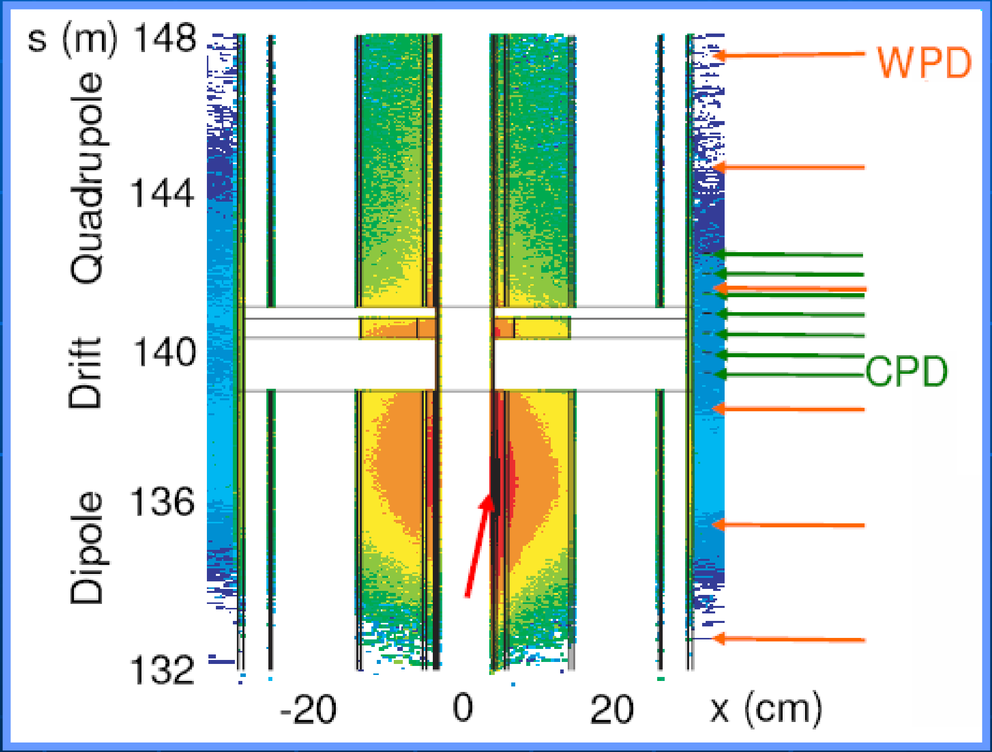
- orbits scanned transversely across each other at the IP by means of a variable orbit bump
- luminosity and PD signal recorded as a function of orbit bump amplitude
- Good correlation found
- Very unlikely that PD signals are caused by anything else than BFPP





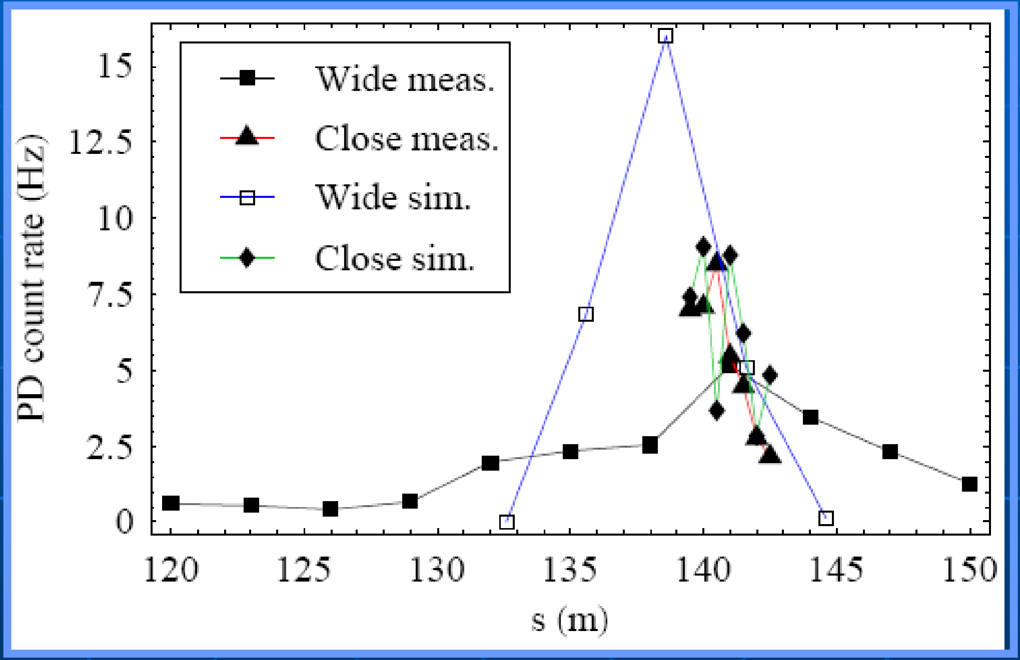
Shower simulations

- Ensembles of BFPP particles tracked until loss from the IP assuming a Gaussian distribution in betatron amplitudes
- Impact coordinates and momenta from MAD-X tracking recorded, fed as starting conditions to Monte-Carlo simulation of shower with FLUKA
- 3D geometry of magnets around impact implemented, including dipole field
- simulated PD signals recorded



Comparison of simulations and measurements

- Qualitatively good agreement
- Magnitude of signals correct within a factor 2
- However, maximum signal found 1.9 m later in *s* in measurements



measured signals averaged and normalized to typical luminosity of 9.1 x 10^{27} cm^{-2} s^{-1}

Error sources

- Uncertainty in closed on-momentum orbit
  - real orbit during measurements not well known, limited data available
  - Least squares fit to Beam Pos. Monitor data attempted using measured quad. displacements and corrector strengths
  - not successful, unless large displacements (~1mm) of quadrupole magnets allowed, then several possible fits
  - Estimated orbit error can move BFPP impact point 2m
- Pollution by other losses, e.g. collimation
  - cleanest data sets in the beginning of stores used
- Relatively few events (0-20 Hz)
- 0.01 MIPs entering PD per lost BFPP ion from shower simulation has a large uncertainty
- PD counting efficiency

Summary of measurements

- First measurements ever of beam losses caused by BFPP

- Losses localized along s around predicted impact point
- High correlation with luminosity
- Agreement with simulations when taking into account estimated uncertainties

⇒ shows presence of beam losses caused by BFPP

- Unfortunately, uncertainties too large to make a meaningful estimate of the cross section

Reference: R. Bruce et al, Phys. Rev. Letters 99:144801 (2007)

Outline

- Introduction
- Bound Free Pair Production
- Measurements at RHIC
- Monitoring losses the LHC
  (LHC Project Note 402)
  - Beam loss monitor thresholds (general ion losses)
  - Monitor positions to survey BFPP losses
- Conclusion

Motivation

- Measurements show BFPP losses present in RHIC
- Earlier studies predict that BFPP induced heating brings magnets very near quench limit

⇒ these losses must be closely monitored in the LHC

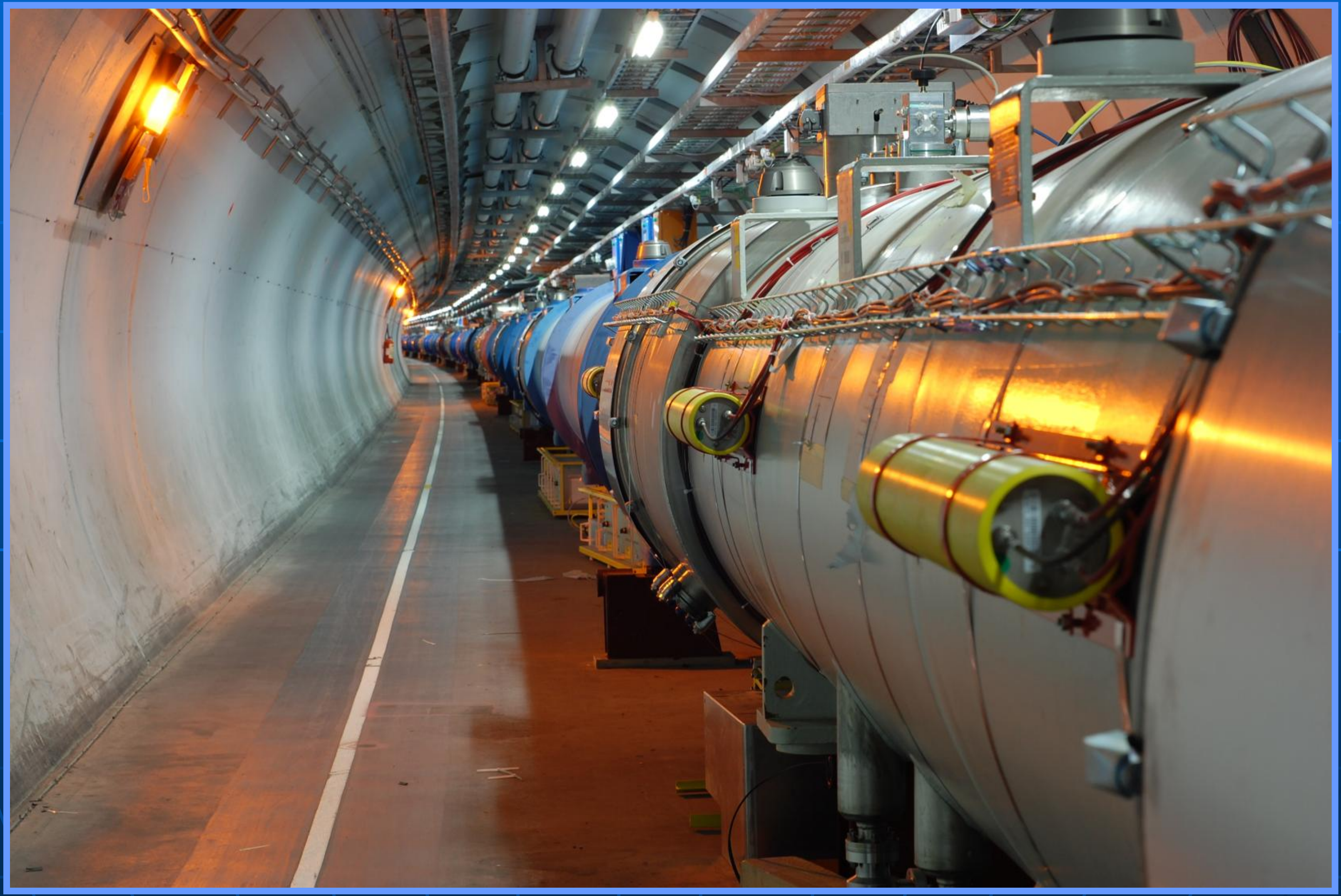
- Question: Is the present beam loss monitor (BLM) system, designed for proton operation, sufficient?
  - type of monitor, threshold for beam emergency extraction
  - positions of monitors

Present BLM system

- Ionization chambers, 50cm long, filled with N_2
- Detect secondary charged particles emerging outside the cryostat

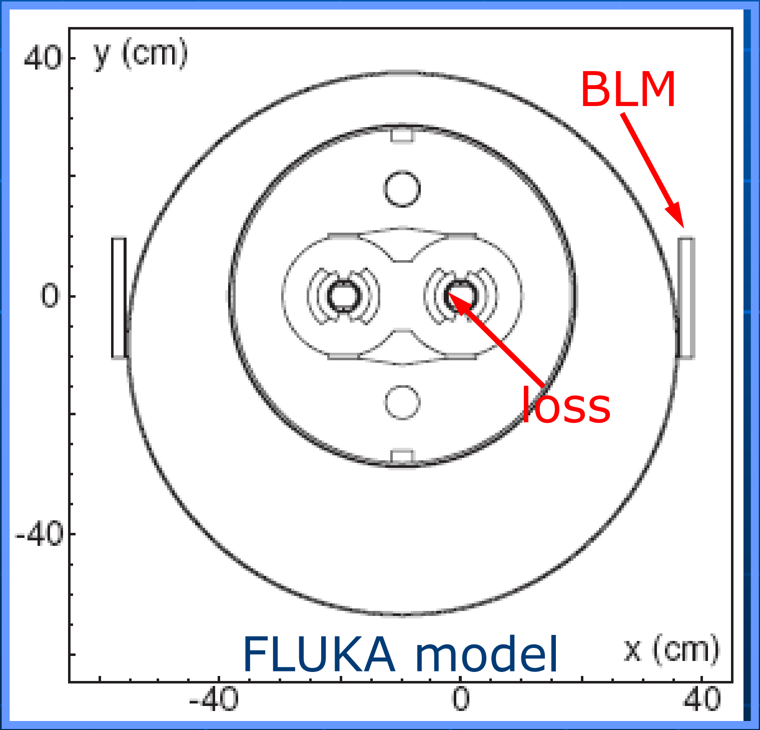
- Monitors foreseen at expected proton loss locations (mainly quadrupoles)
- Ratio between temperature in superconductors and BLM signal simulated for protons
- This ratio determines the beam abort threshold

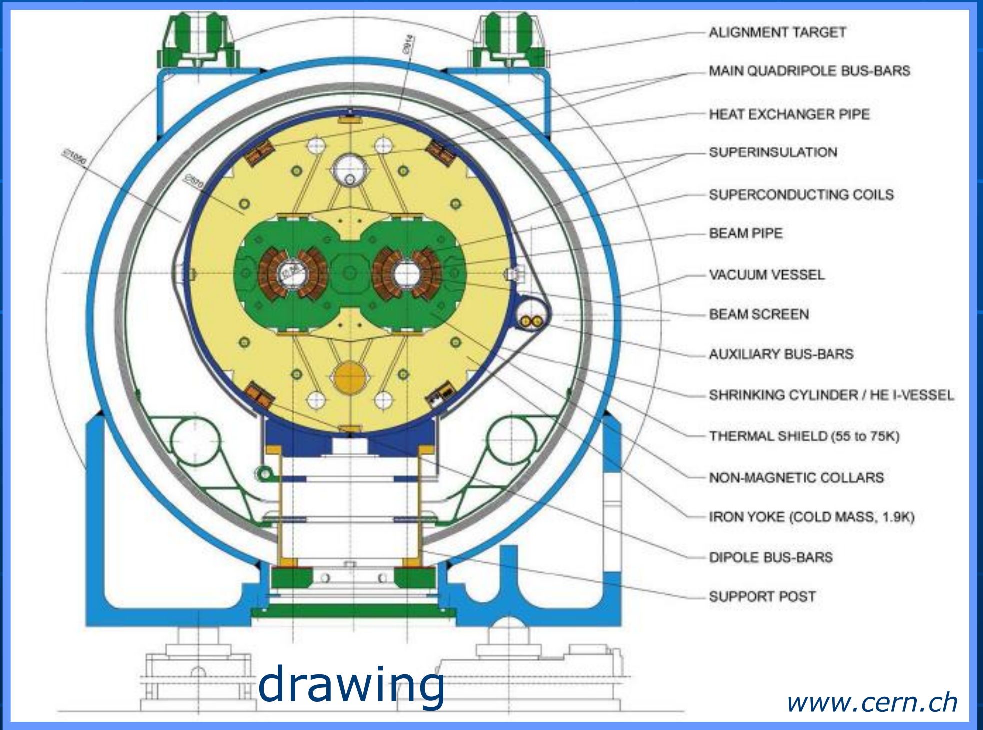
Present BLM system (2)



Ion shower simulation

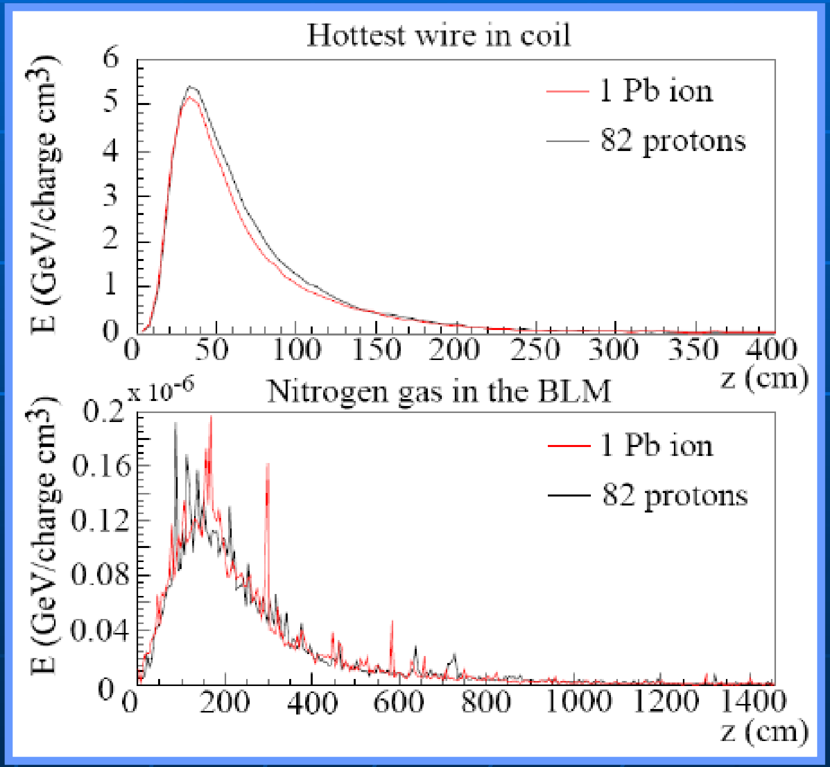
- Simulated ratio between energy deposition in superconducting coil and simplified BLM in FLUKA
- 3D model of an LHC dipole (including magn. field):





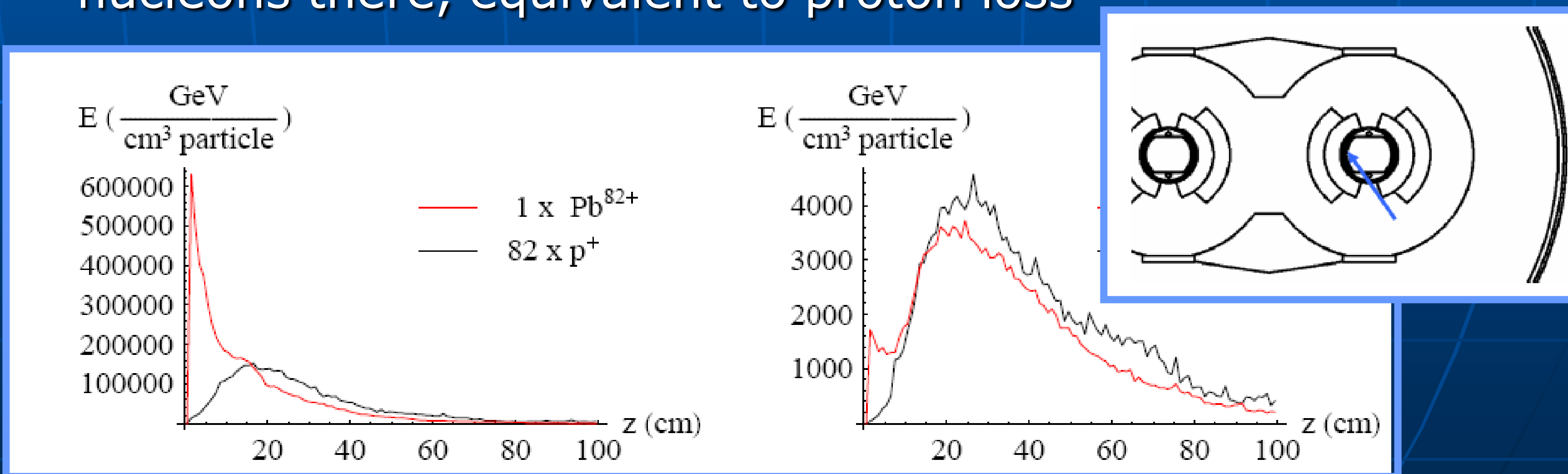
Results

- Generic loss represented by a "pencil beam" of Pb^{82+} ions and protons at LHC energy
- General loss can be represented by a super-position of pencil beams
- Results show similar ratio for the two species
- The same thresholds for dumping the beam can be used



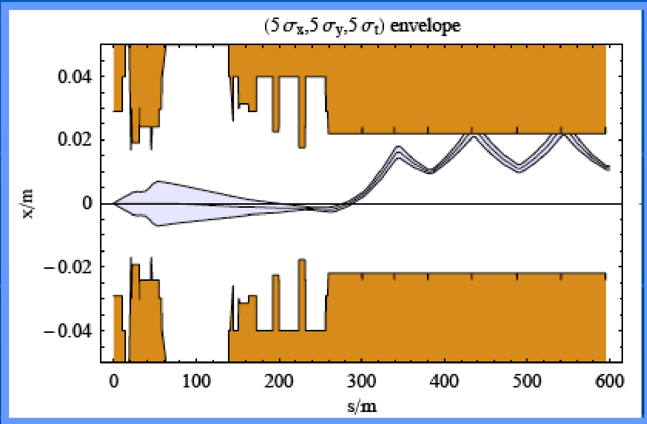
Why?

- Although Pb^{82+} ions have larger ionization cross section (~82^2), the hadr. shower dominates energy deposition
- clear difference in a thin slice around trace of lost particle
- Superconductors shielded by beam screen
- FLUKA simulations show that ions fragment fully before reaching the superconductors $\Longrightarrow$ shower from independent nucleons there, equivalent to proton loss

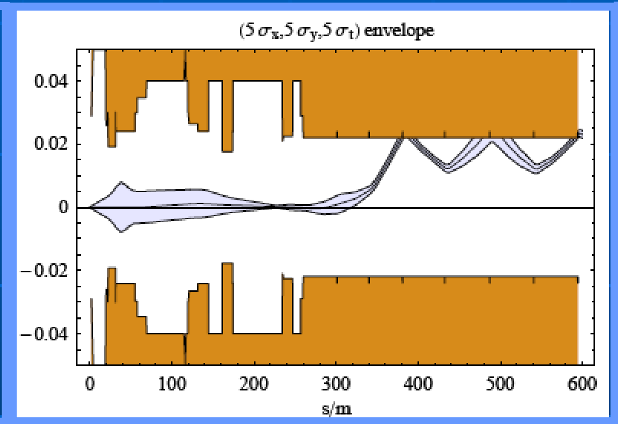


Tracking of BFPP ions in the LHC

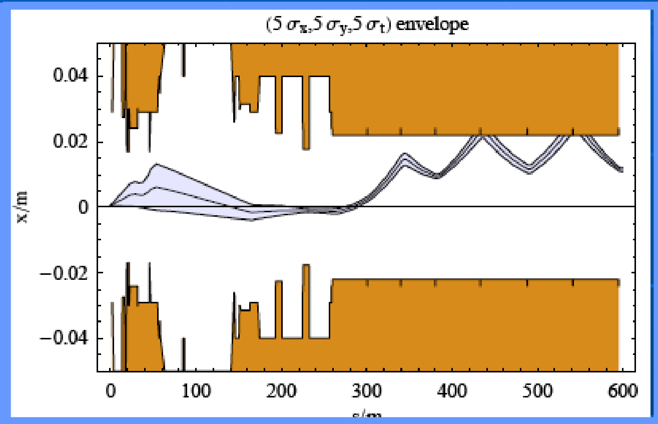
- BFPP ions tracked with MAD-X from every IP that might collide ions



ATLAS



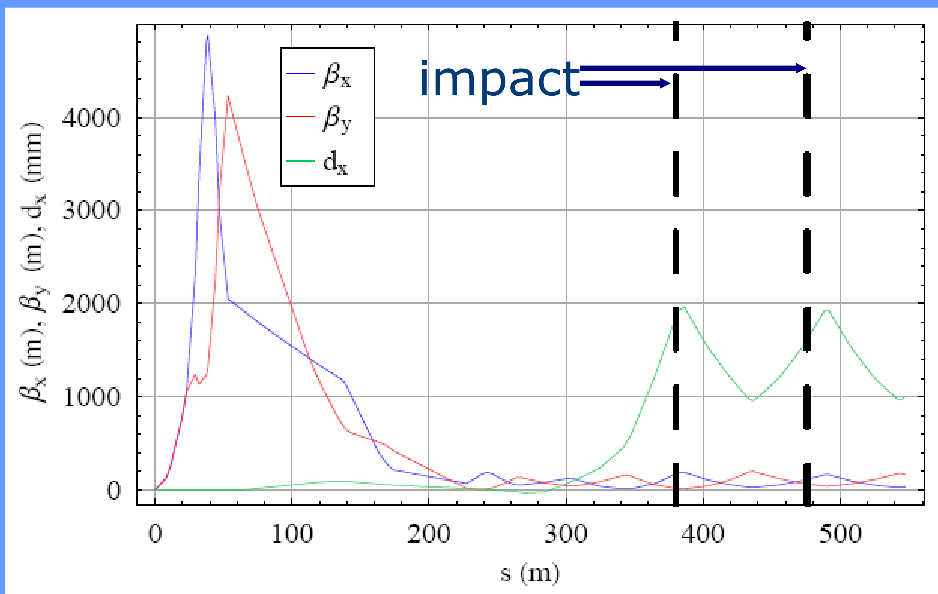
ALICE



CMS

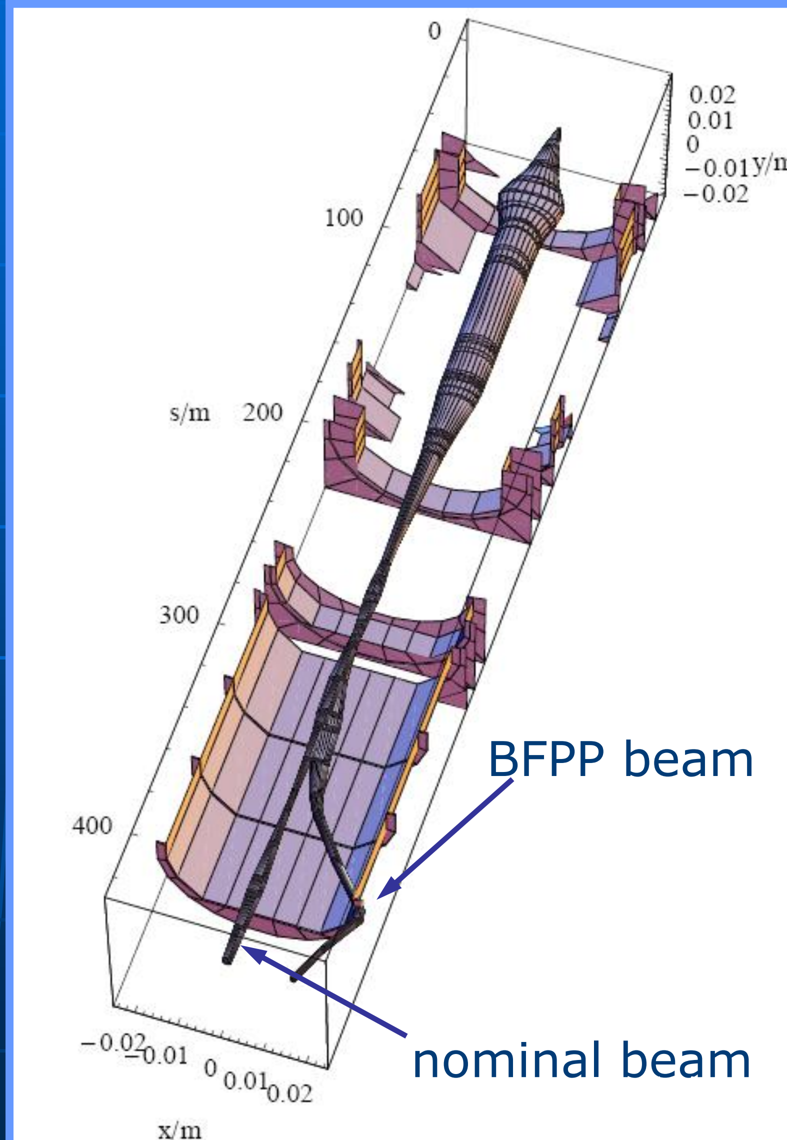
- BFPP orbit oscillating with the dispersion function
- Fraction of the beam might be lost further downstream
- Could be used to spread out the heat load

Tracking of BFPP ions in the LHC



optics from ALICE

orbits from ALICE:



Monitor positions

- BFPP losses occur mainly in dipoles, where no BLM coverage is foreseen
- Sensitivity study shows that the impact point can move several metres, as in RHIC
- Proposed scheme with additional monitors for both beams downstream of ALICE, ATLAS and CMS
- Tight spacing between monitors of 1.5 m to ensure detection

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Conclusions

- Measurements in RHIC show good evidence for the presence of beam losses caused by BFPP
- Simulations of losses agree with measurements within estimated error bars
- At the LHC, BFPP losses need to be closely monitored
- Positions of additional BLMs for this purpose are calculated
- The same beam abort thresholds as for protons can be used
- Future work: alleviation of BFPP in the LHC (orbit bump?)

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