EFFECTS OF ULTRAPERIPHERAL NUCLEAR COLLISIONS IN THE LHC AND THEIR ALLEVIATION

R. Bruce, S. Gilardoni, J.M. Jowett

Outline

- Electromagnetic processes in the LHC during ion operation
- Bound Free Pair Production
  - estimated effect
  - alleviation proposal
  - operational aspects
- Electromagnetic dissociation
  - estimated effect
- Conclusion

Electromagnetic processes

- During Pb^{82+} operation in the LHC, electromagnetic interactions between colliding beams take place at IP:
  - Bound Free Pair production (BFPP):

$$^{208}\mathrm{Pb}^{82+} + ^{208}\mathrm{Pb}^{82+} \xrightarrow{\gamma} ^{208}\mathrm{Pb}^{82+} + ^{208}\mathrm{Pb}^{81+} + \mathrm{e}^{+}$$

$\sigma^{\mathrm{BFPP}} \approx 281$ barn H. Meier *et al.*, Phys. Rev. A 63.032713 (2001)

  - Electromagnetic Dissociation (EMD), 1 or 2 neutrons:

$$^{208}\mathrm{Pb}^{82+} + ^{208}\mathrm{Pb}^{82+} \xrightarrow{\gamma} ^{208}\mathrm{Pb}^{82+} + ^{207}\mathrm{Pb}^{82+} + \mathrm{n}$$

$\sigma_{1\mathrm{n}}^{\mathrm{EMD}} \approx 215$ barn I.A. Pshenichnov *et al*, Phys. Rev. C 64.024903 (2001)

$\sigma_{2\mathrm{n}}^{\mathrm{EMD}} \approx 0.2\sigma^{\mathrm{BFPP}}$

Compare: σ_{hadr}=8 barn

Magnetic rigidity change

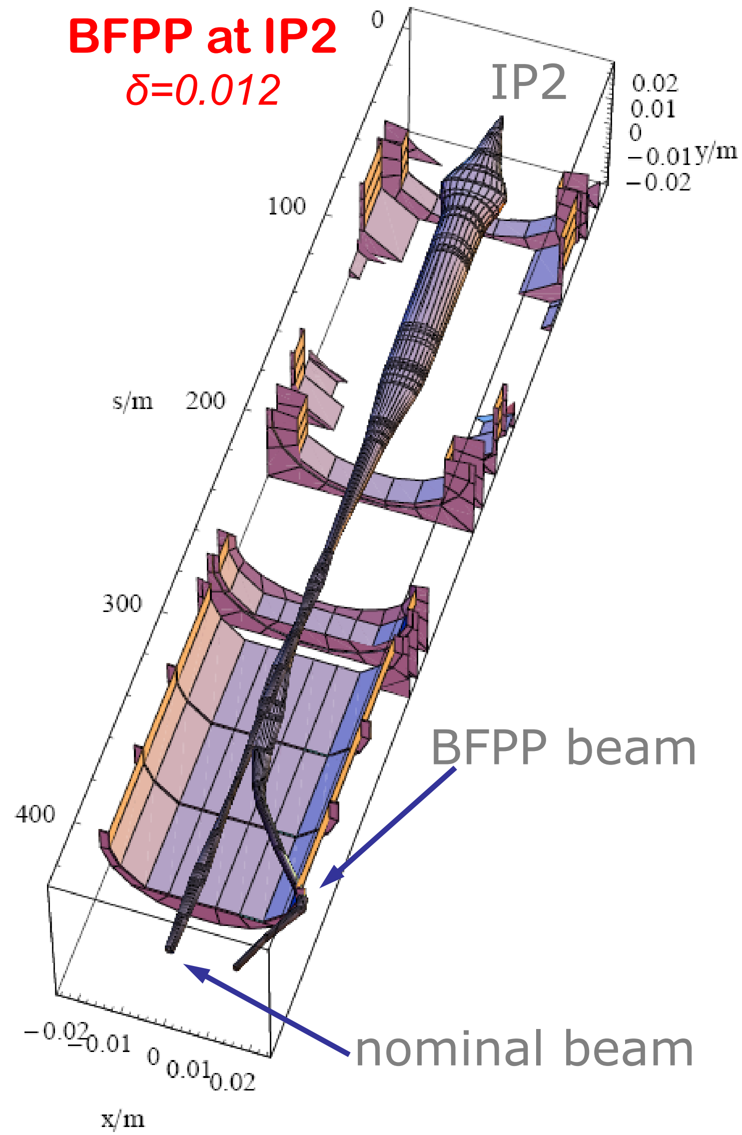
- **BFPP and EMD create ions with altered magnetic rigidity:**

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

- **These ions follow locally generated dispersion function from IP**
- **Lost in localized spot where aperture and δ satisfy**

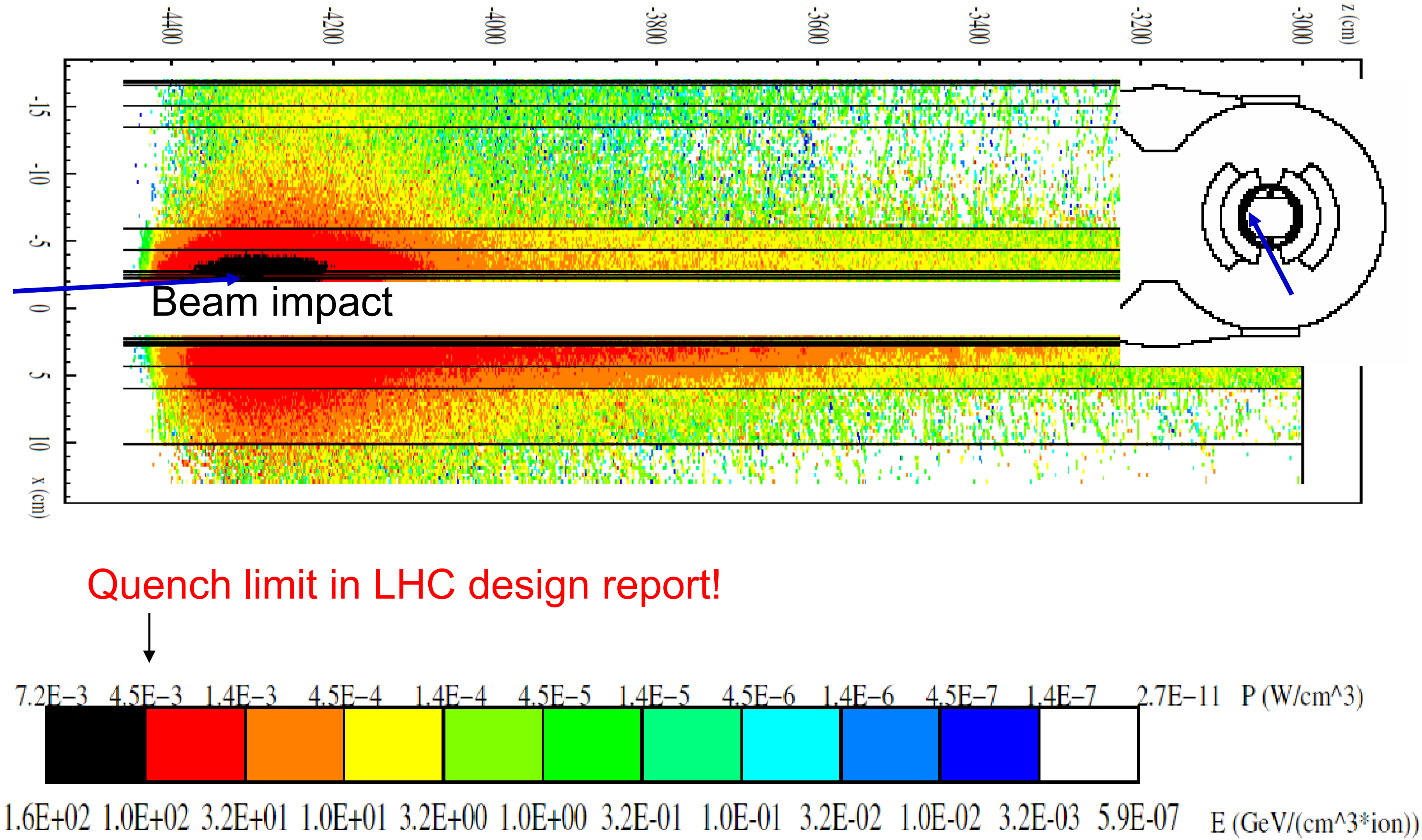
$$\delta\, d_x = A_x$$

- **Induced heating risk to quench superconducting magnets**



Effect of BFPP

- **FLUKA simulation of shower in main dipole magnet, peak luminosity**



Effect of BFPP (2)

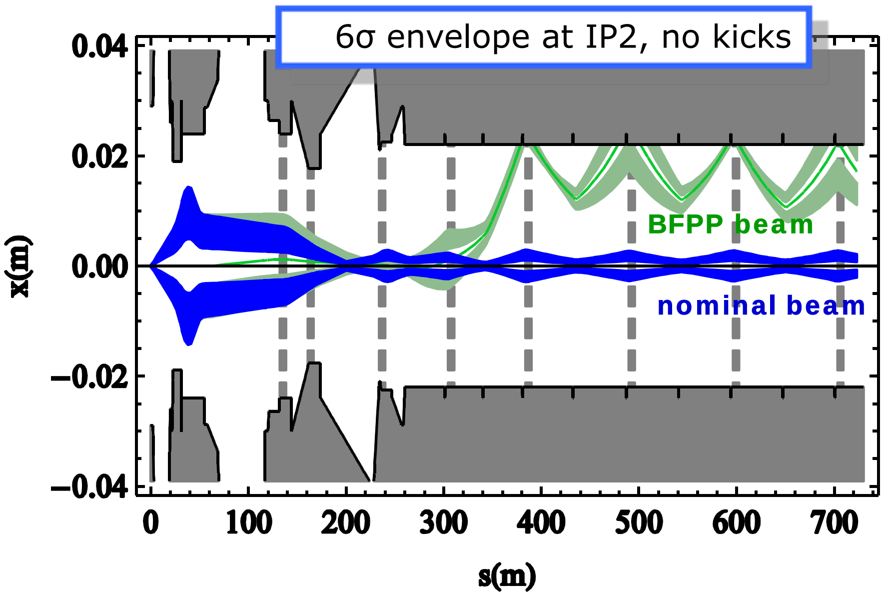
- Some other estimates of quench limit exist, indicating a factor ~2-3 higher
- However, even if they are correct the energy deposition from BFPP is at 80% of limit
- Simulation uncertainty: factor ~2
- Uncertainty in quench limit, BFPP cross section and shower simulation

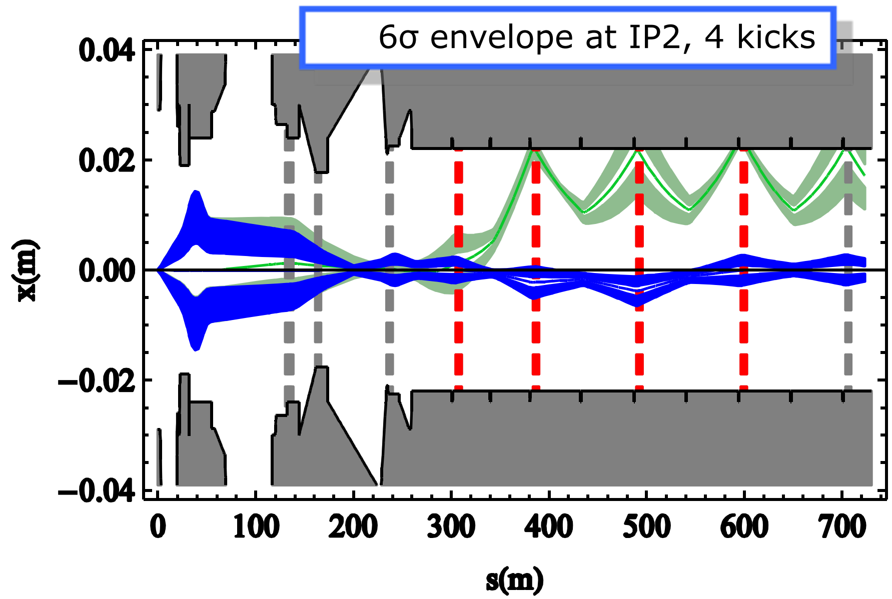
⇒ Quenches induced by the heating from BFPP losses can not be excluded!

⇒ In case these losses cause quenches, we need to introduce counter measures!

Idea: BFPP alleviation

- BFPP orbit oscillates with dispersion function
- Idea: distribute losses over several impact positions with closed orbit bumps
- Use existing orbit correctors





- Example: losses equally distributed over 3 impact position

⇒ **Maximum heat load in a single element decreases by factor 3**

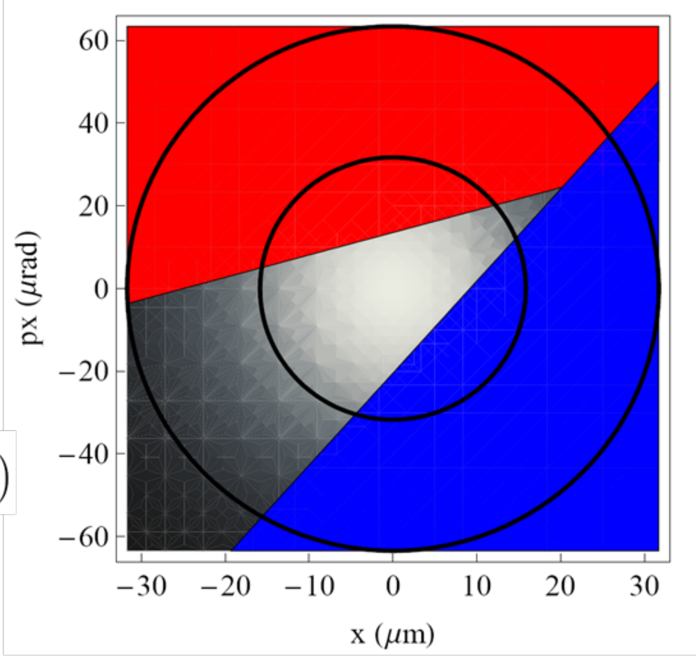
Orbit displacements

- **Each aperture limitation defines cut in initial phase space**
- **Integrated phase space population in each area = 1/3**
- **Formally, the particles lost at aperture limitation *m* contained in region**

$$R_m: \; C_m x_0 + S_m p_{x0} + x_\mathrm{B}(s_m) + \Delta_m > A_x(s_m)$$

- **Solve equation system for Δ_m:**

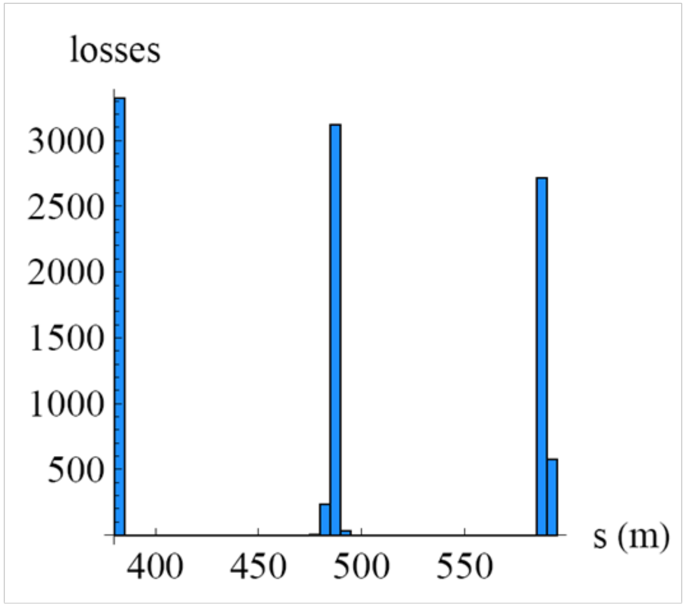
$$\iint_{R_m \cap \left(R_1^c \cup R_2^c \ldots \cup R_{m-1}^c\right)} P_\beta(x_0, p_{x0}) \; dx_0 \; dp_{x0} = 1/n, \; \forall \; m$$



Phase space at IP2

Orbit displacements (2)

- **First step analytically solvable**
- **Iteration with numeric method gives all** Δ_m
- **Once** Δ_m **are known, kicks are easily found by matching**
- **To distribute losses over *n* impact locations, we need *n+1* kicks**
- **Expected loss pattern confirmed by single particle tracking**



Operational aspects

- **Maximum deviation of nominal orbit = 3.8 mm**
- **6 σ envelope still far from aperture**
- **Beta beating of 1.7%**
- **Required corrector settings:**

s (m)	Δ (mm)	θ (μrad)	B (T)	r (%)
307.394	2.23	-17.5	0.45	14.6
386.922	4.06	-28.5	0.74	23.8
492.547		-14.4	0.52	17.7
599.444		-22.2	0.80	27.3

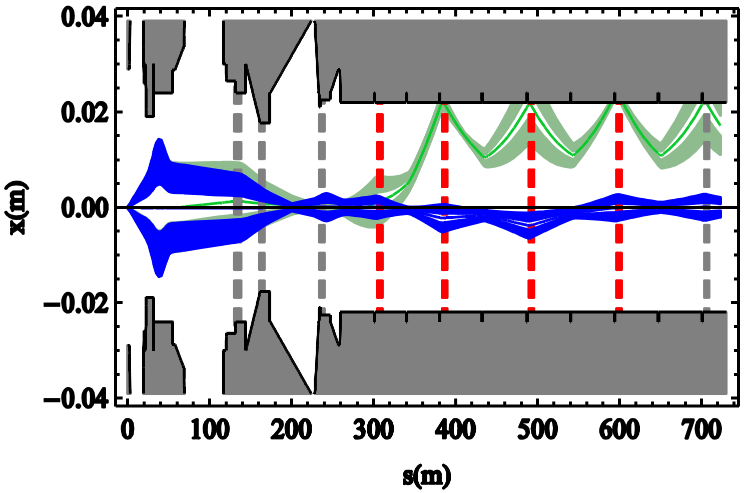
- **Adjustments of 0.1% of total strength necessary**

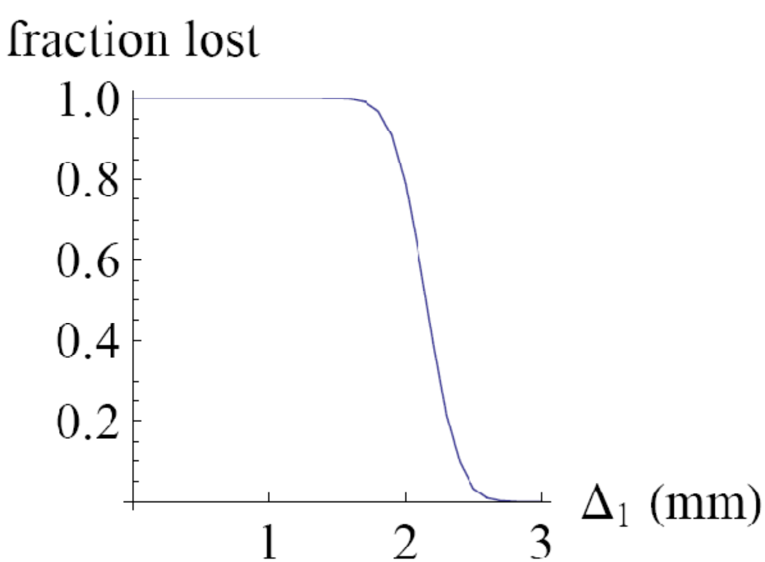
Tuning of orbit bumps

- Closed orbit in imperfect machine and aperture errors change necessary displacement
- Correctors have to be tuned around predicted value, using BLMs
- Bumps have to be introduced before full luminosity is reached
- Can be achieved by van der Meer-scan in vertical plane

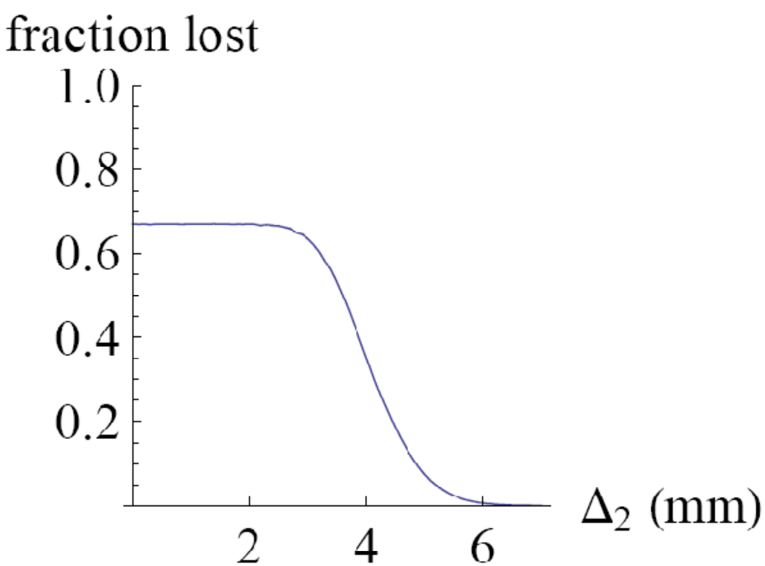
Tuning of bumps (2)

- Proposed method: start by tuning the first corrector to have 1/3 lost at first impact position, let correctors 2 and 3 follow to close the bump
- Tune second correctors to have ½ of remaining losses lost at second impact location, let correctors 3 and 4 follow to close the bump





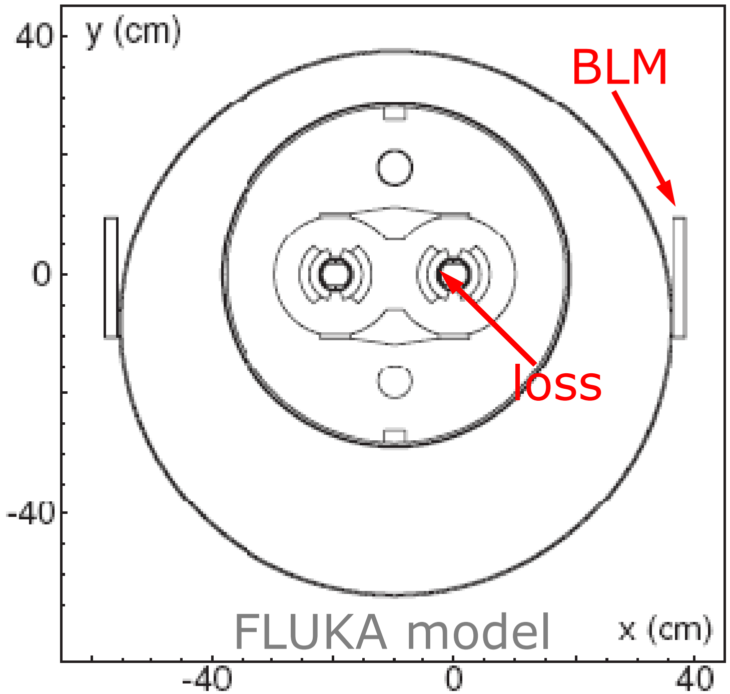
1st impact position

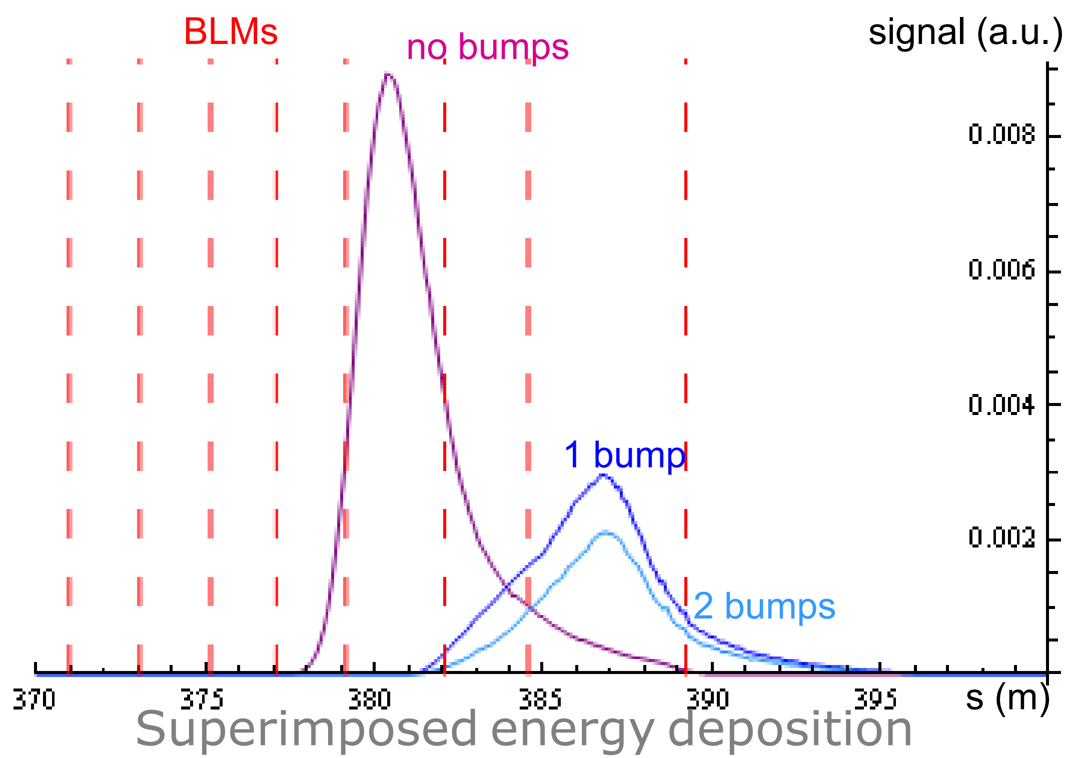


2nd impact position

Estimated BLM signals

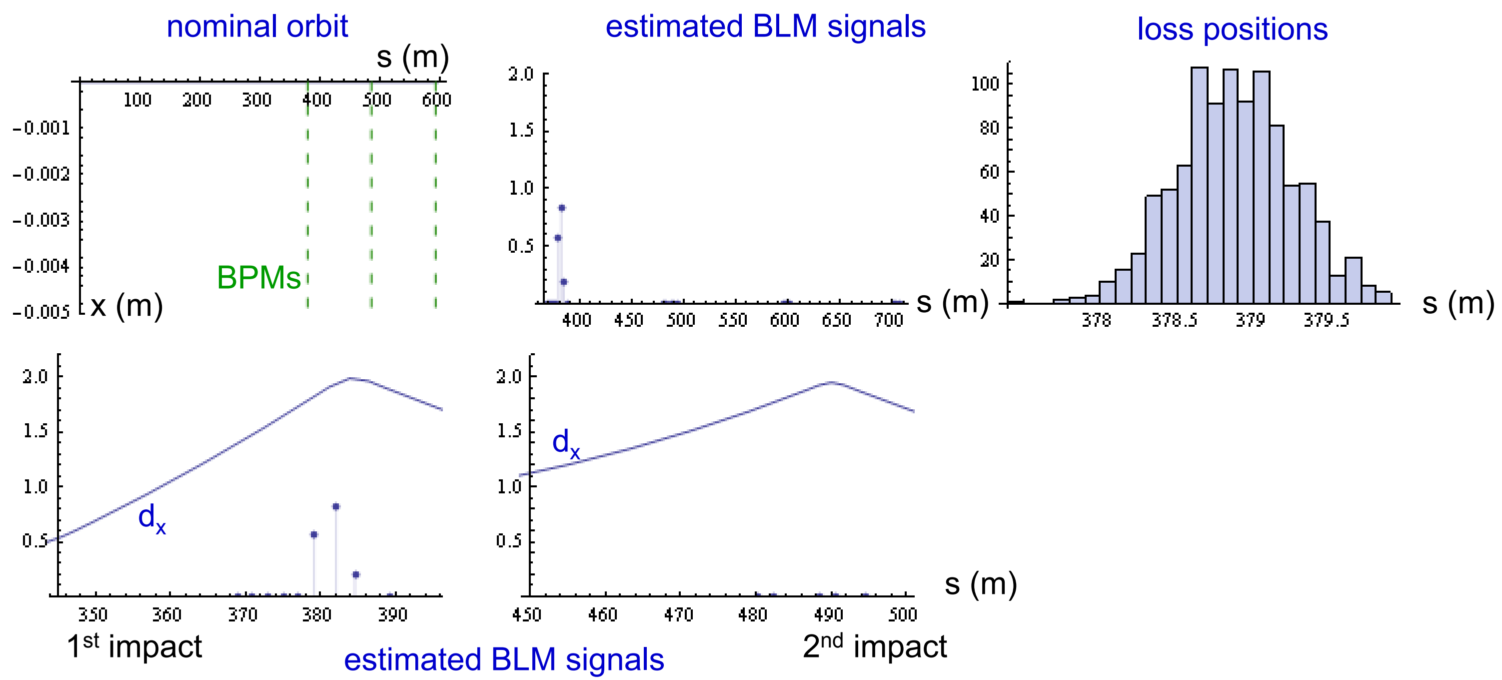
- Estimate losses at different impact positions by monitoring BLM signals
- Approximation of expected ratio between BLM signals: convolution of BLM signal from pencil beam as simulated by FLUKA and impact positions from tracking





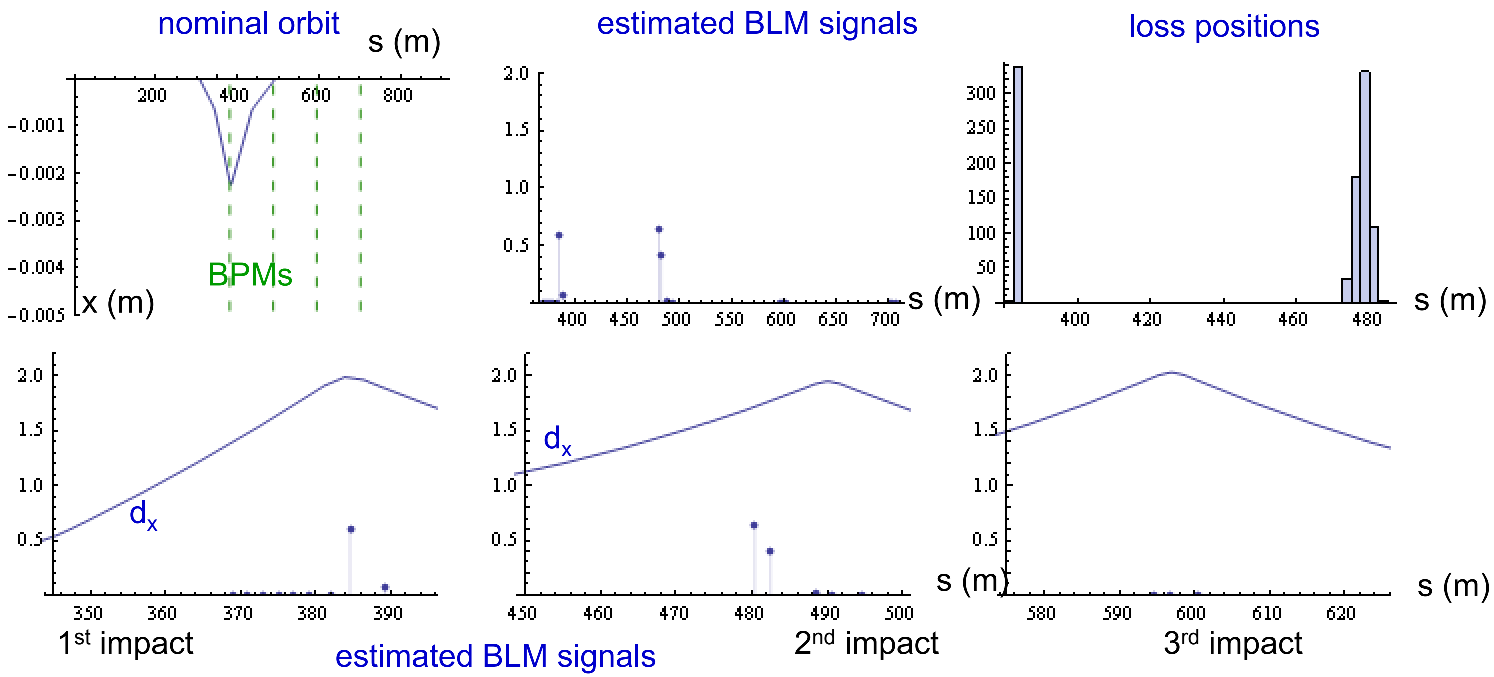
Example: Tuning first bump

- Tuning in steps of ~1.3 % of total corrector strength
- Steps of ~0.1% could be necessary for fine-tuning



Example: Tuning second bump

- Tuning in steps of ~1.8% of total corrector strength
- Steps of ~0.1% could be necessary for fine-tuning



- Due to uncertainties, we can not hope to reach exactly 1/3 at each impact position
- More bumps might be needed to compensate

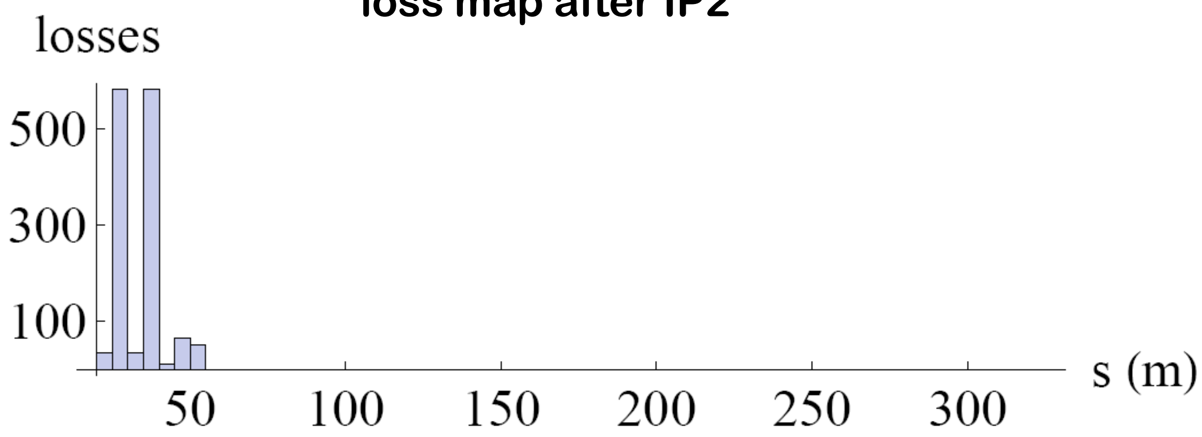
Outline

- Electromagnetic processes in the LHC
- BFPP
  - estimated effect
  - alleviation proposal
  - operational aspects
- Electromagnetic dissociation
  - estimated effect
- Conclusion

1-neutron EMD

- δ= -0.0048 is still inside momentum aperture
- These particles can make a full turn and should be intercepted by collimation system
- Tracking with ICOSIM from each IP:
  - 99% of EMD particles lost in collimators
  - remaining 1% impose no risk of quenching

loss map after IP2



2-neutron EMD

- δ= -0.0096 is outside momentum aperture
- Particles lost in a well-defined spot on the other side of the vacuum chamber
- Cross section significantly lower:
  $\sigma_{2n}^{EMD} \approx 0.2\sigma^{BFPP}$
- 5 times lower heating power than BFPP
- Should pose no danger of quenching

Conclusion

- Ions affected by EMD are very unlikely to be dangerous
- Ions affected by BFPP risk to quench magnets
- We propose distributing the losses in several magnets with orbit bumps
- Operational procedure for tuning the bumps proposed
- Future work: detailed FLUKA simulations of estimated BLM signals for increased accuracy