Belle II Particle Identification

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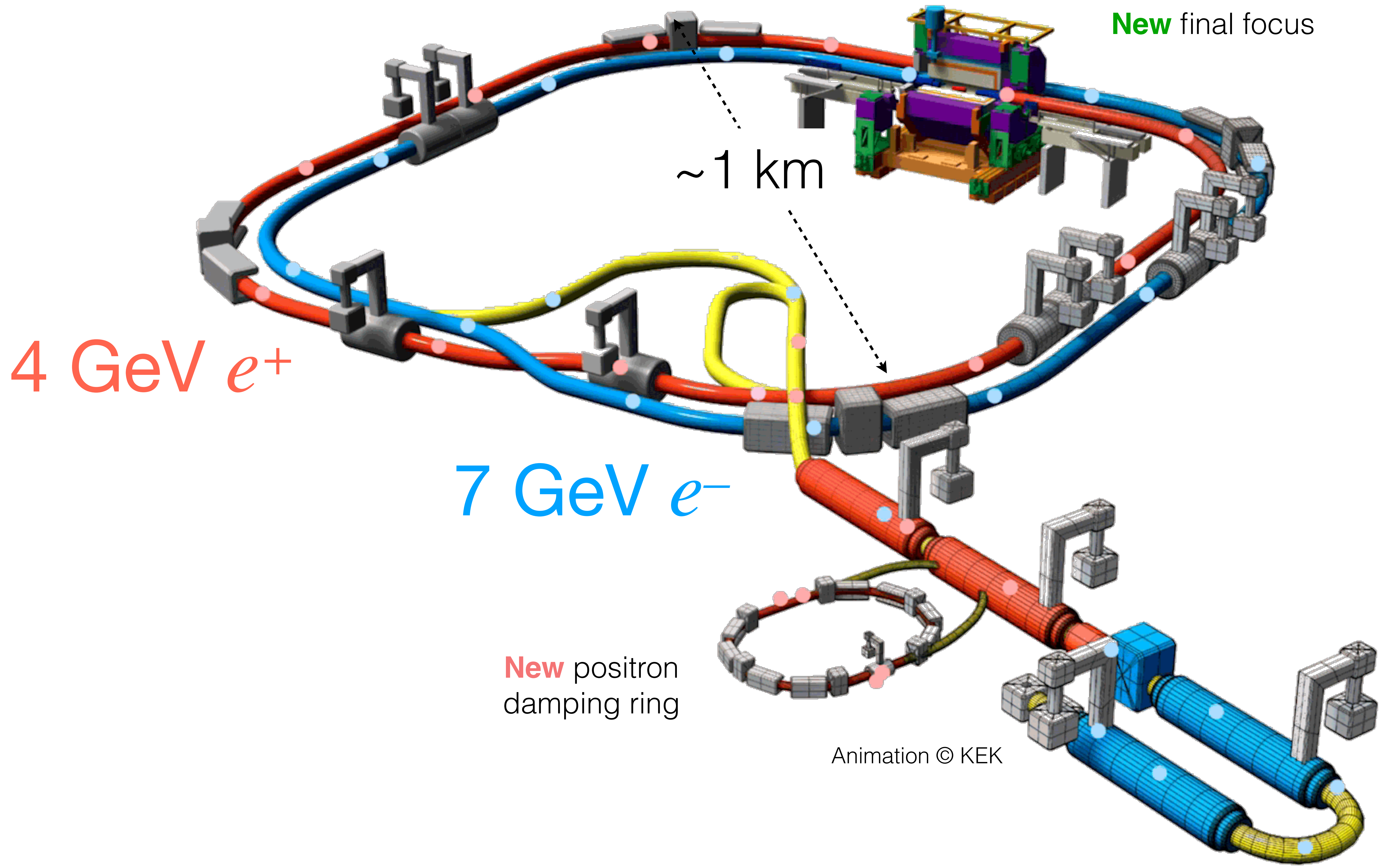
The University of Mississippi
Quarknet workshop - July 2020

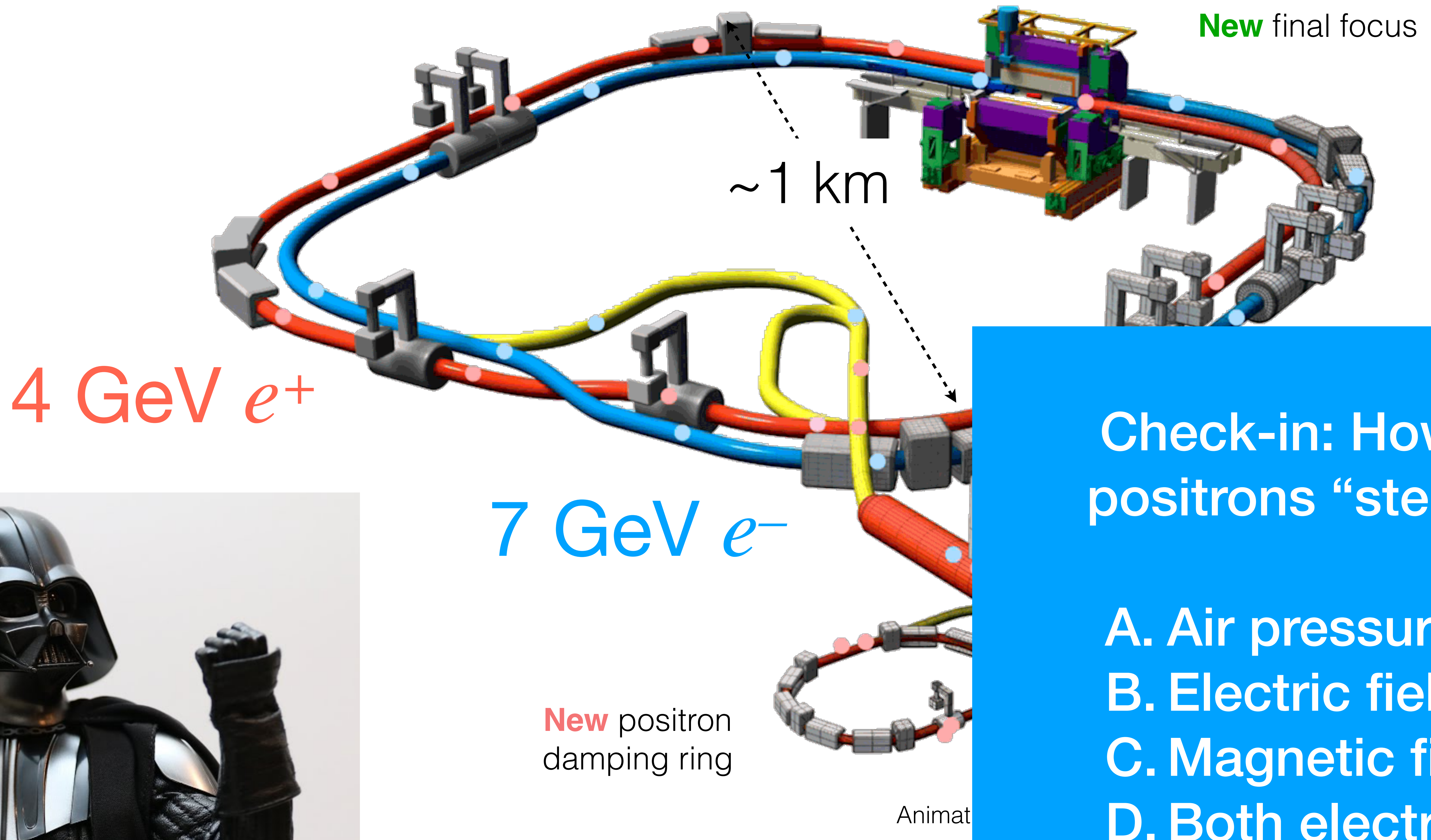

Mt. Tsukuba (877m)
SuperKEKB
Belle II
LINAC
main ring: 3km
e- (HER): 7GeV
e+ (LER): 4GeV
KEK
Tsukuba
Campus

SuperKEKB and Belle II: 2nd generation “B Factory”



$$c\bar{c},\ u\bar{u},\ d\bar{d},\ \ell^+\ell^- \leftarrow e^+e^- \rightarrow \Upsilon(\mathrm{nS}) \rightarrow B^{(*)}\bar{B}^{(*)}$$

SuperKEKB and Belle II: 2nd generation “B Factory”



Check-in: How are the electrons and positrons “steered” around the rings?

A. Air pressure
B. Electric fields
C. Magnetic fields
D. Both electric and magnetic fields
E. The Force

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A canonical $\mathbf{B\bar{B}}$ Event

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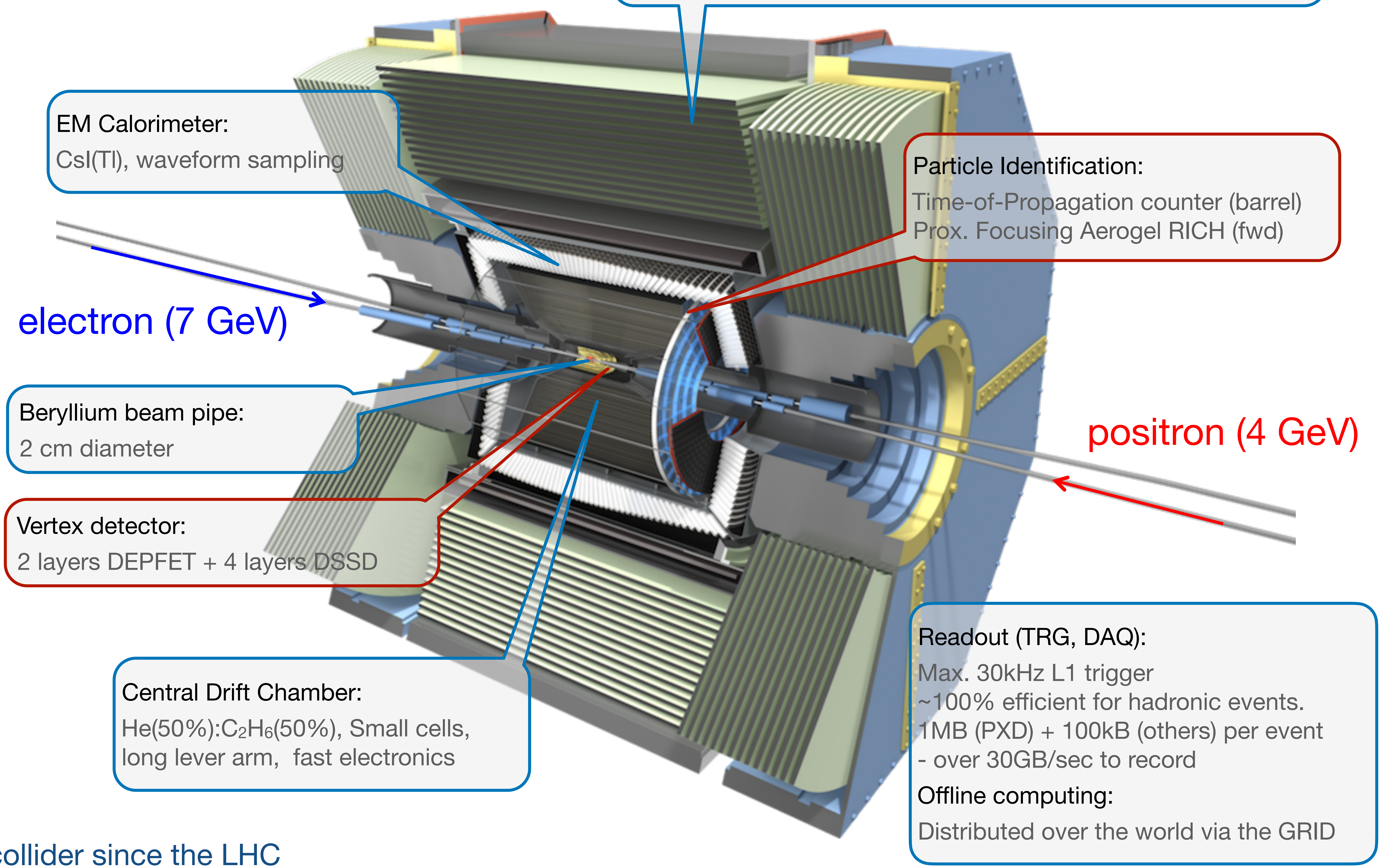
What are some features you notice in this event?

The Belle II detector



First new particle collider since the LHC
(intensity rather than energy frontier; e^+e^- rather than pp)

arXiv:1011.0352 [physics.ins-det]

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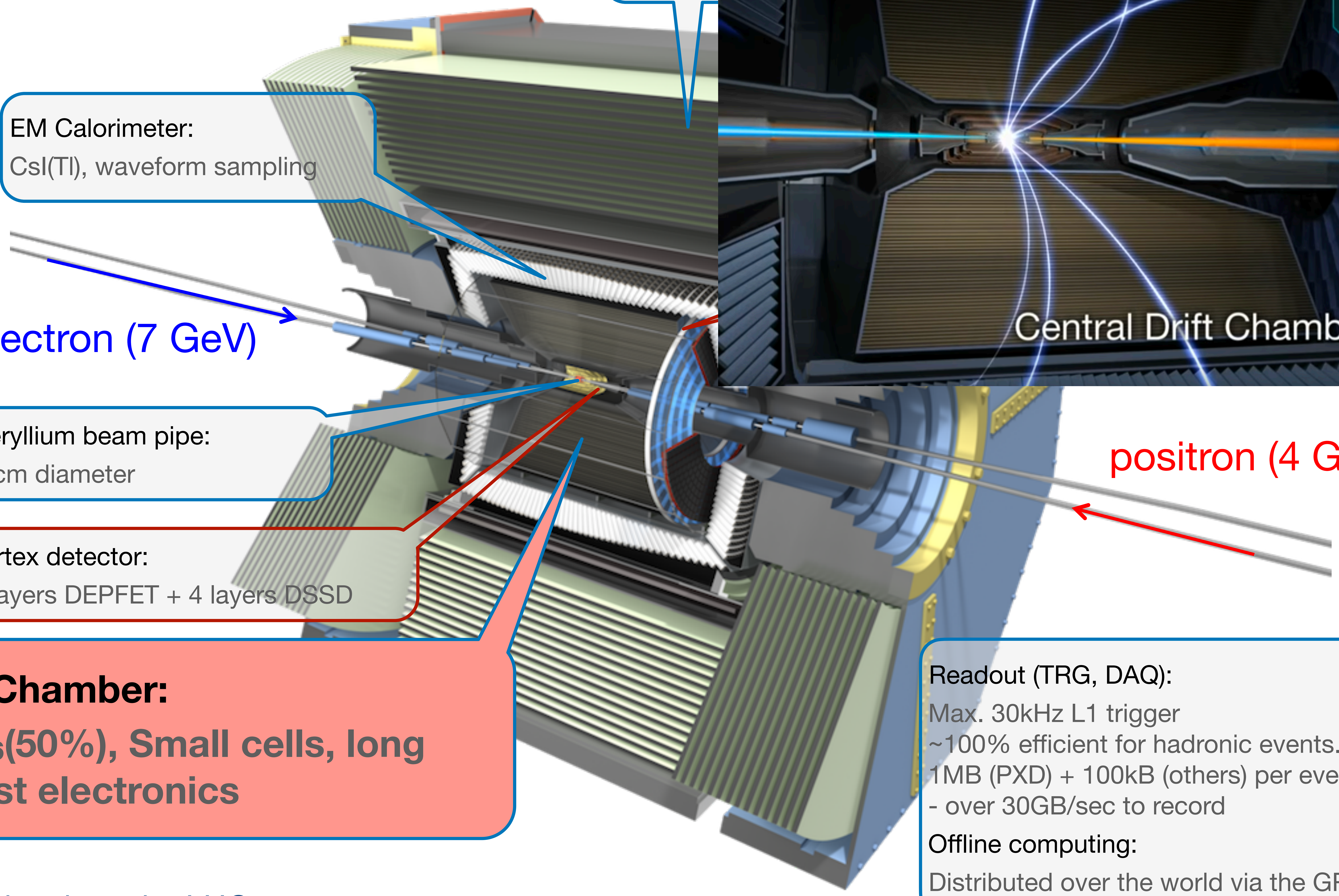

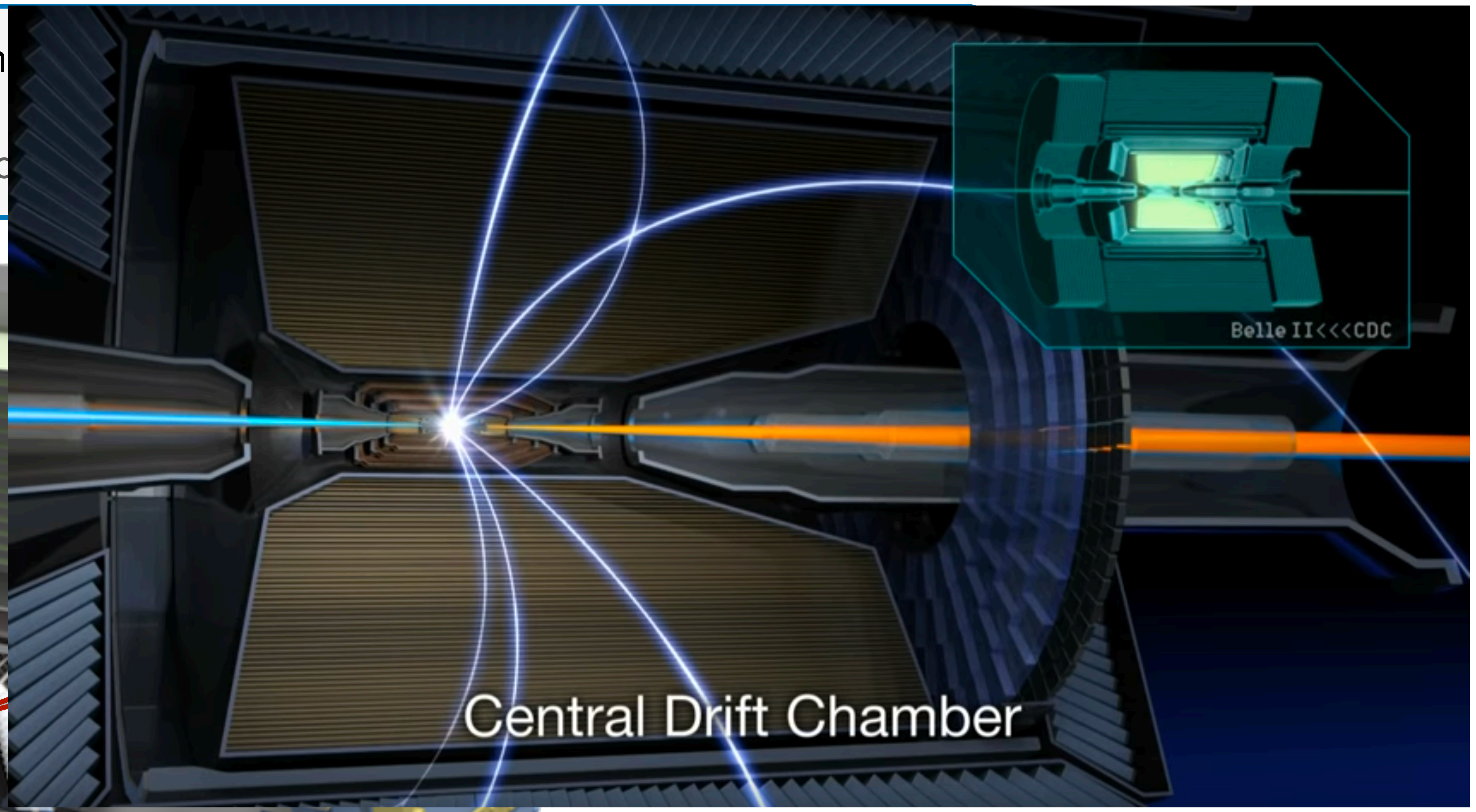

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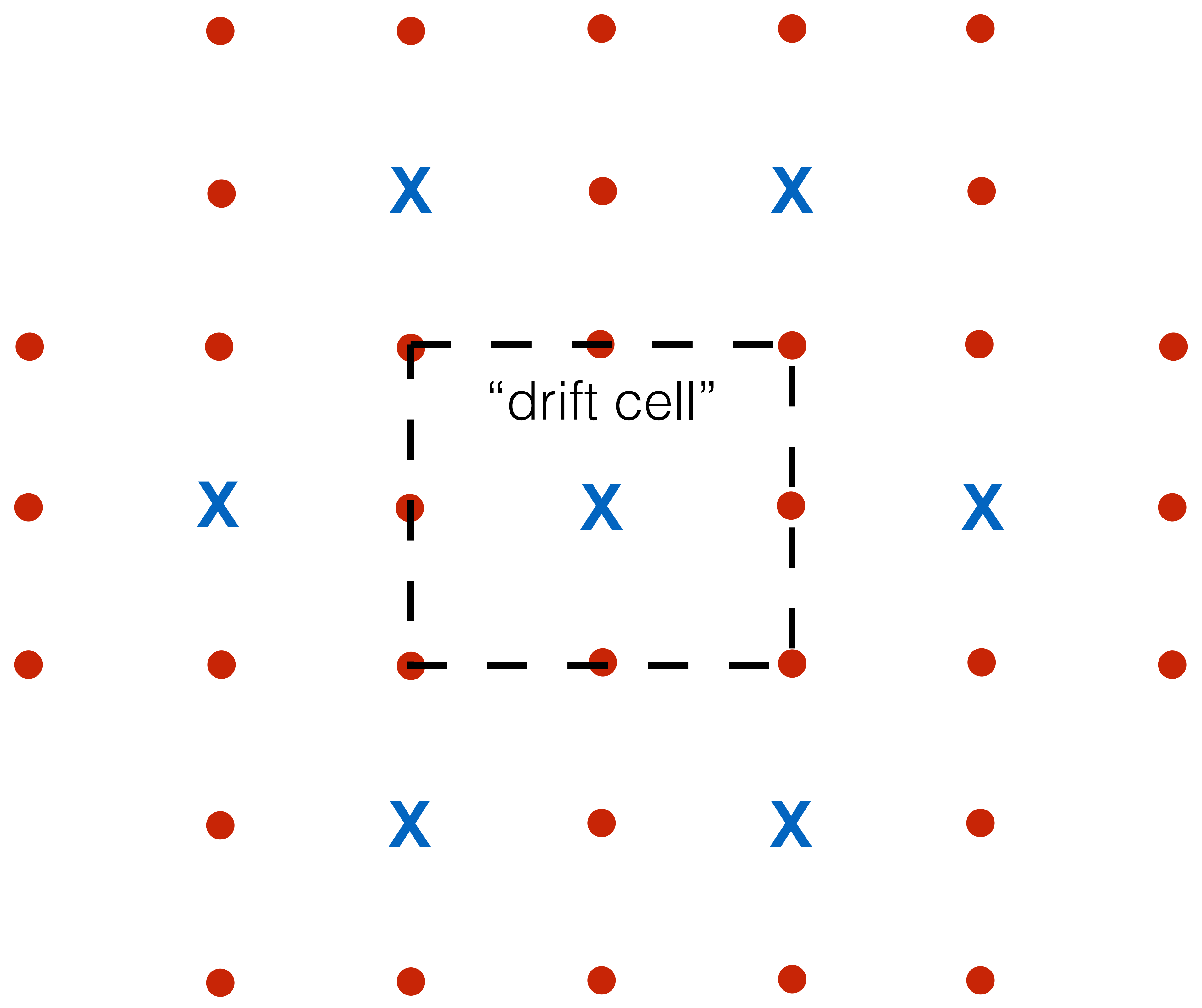
Central Drift Chamber

- CDC layers alternate between “field layers” and “sense layers”
  - Sense wires held at a large potential (anode)
  - Grounded field wires help to shape the electric field



Central Drift Chamber

$$F_B = q\vec{v} \times \vec{B}$$

B into the page

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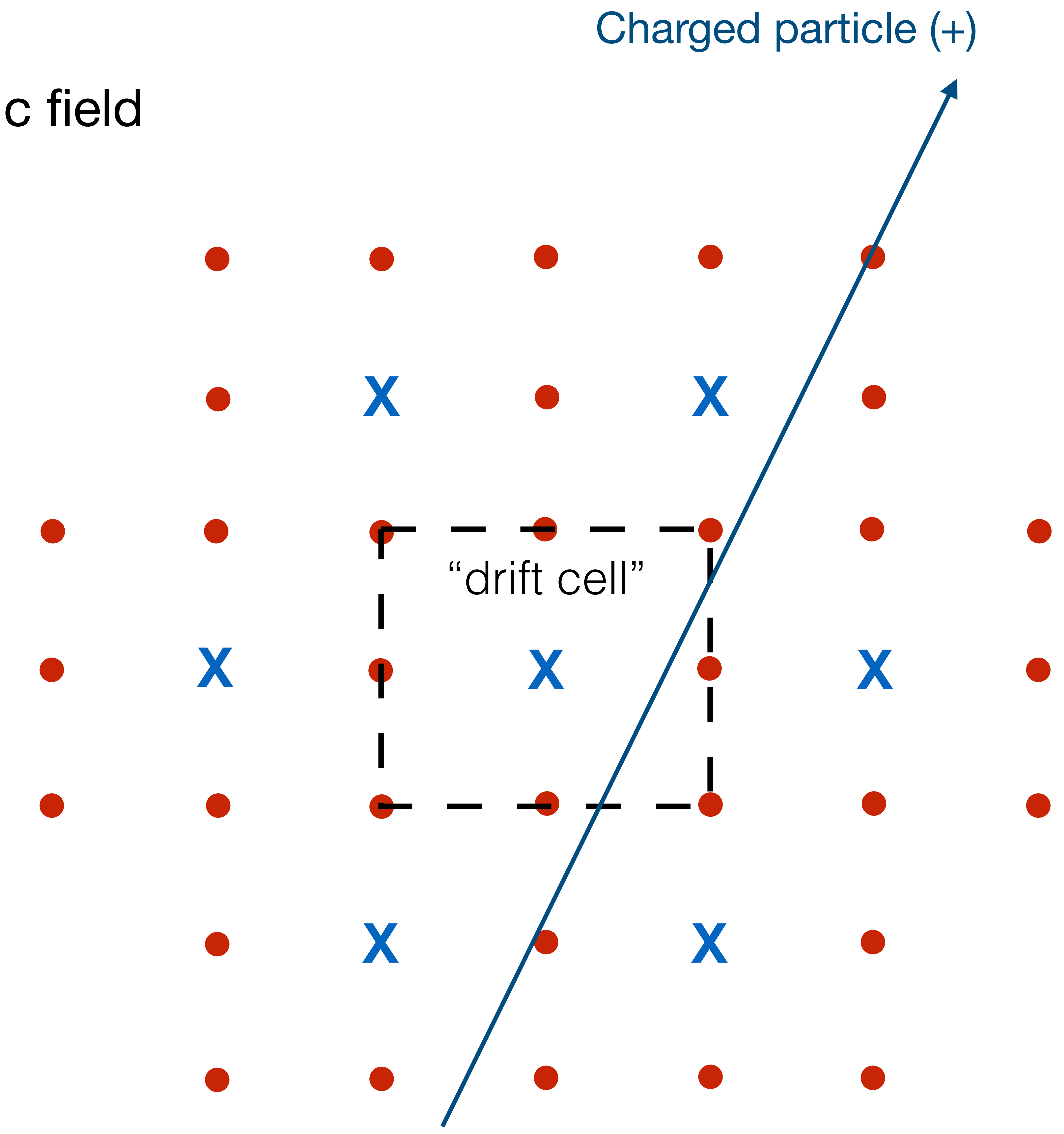

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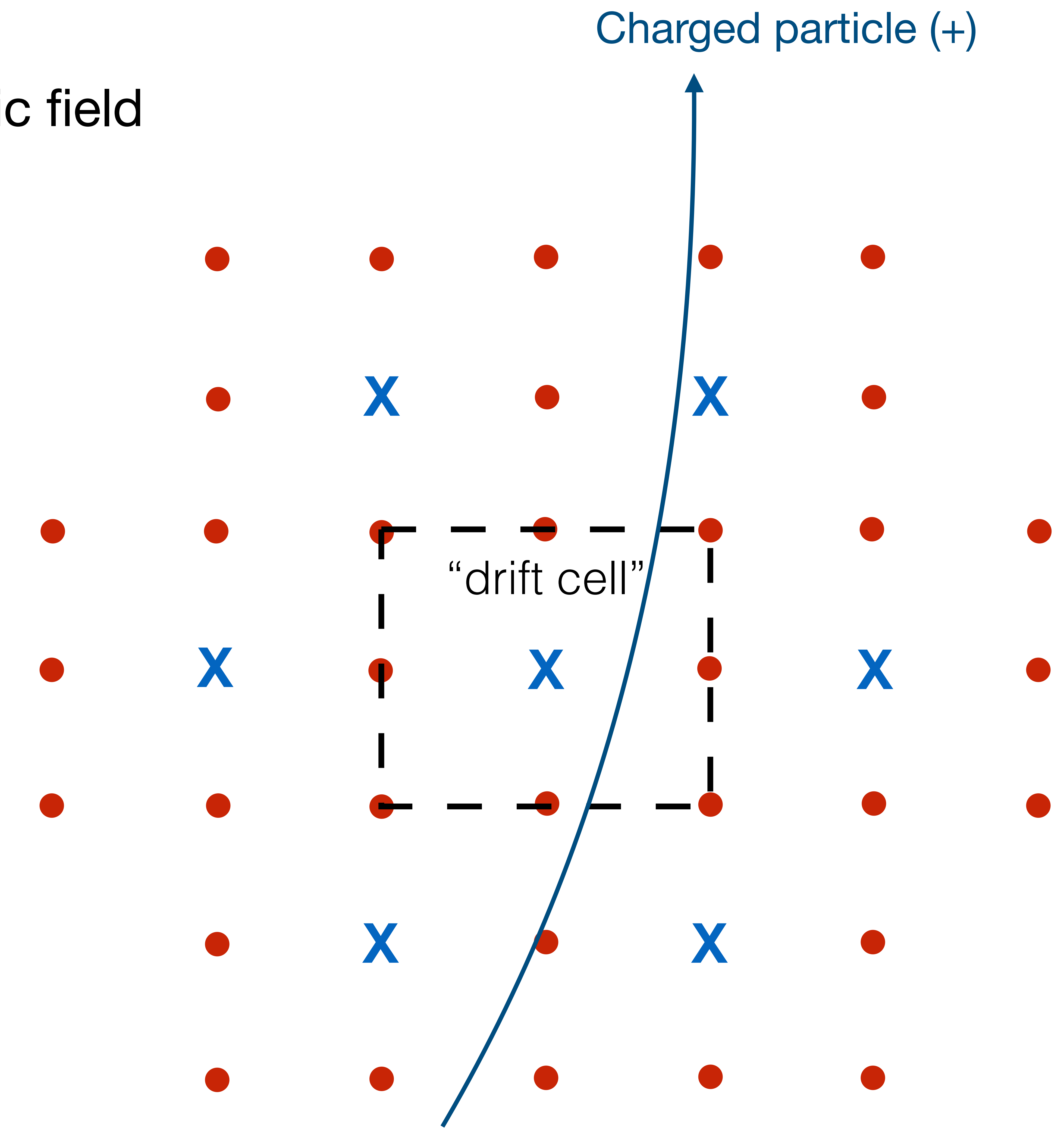

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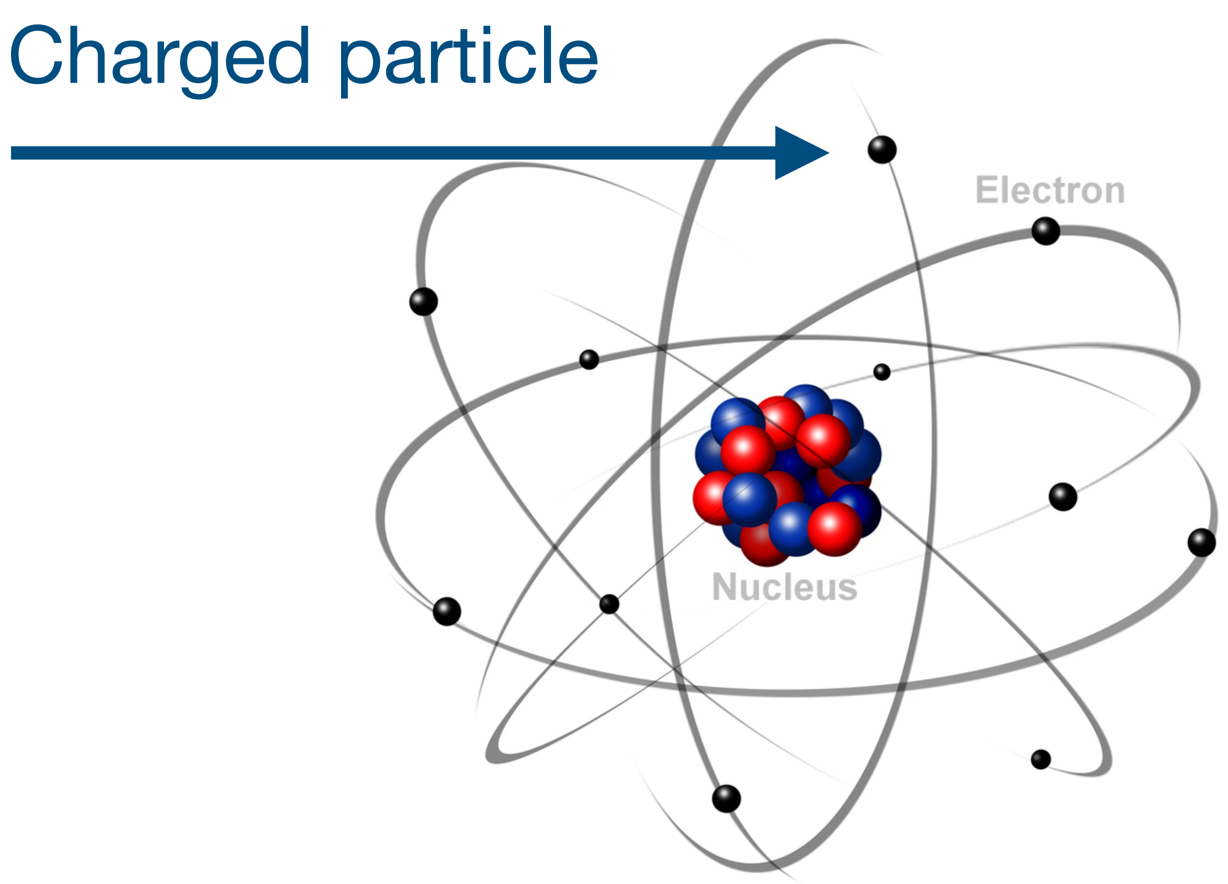

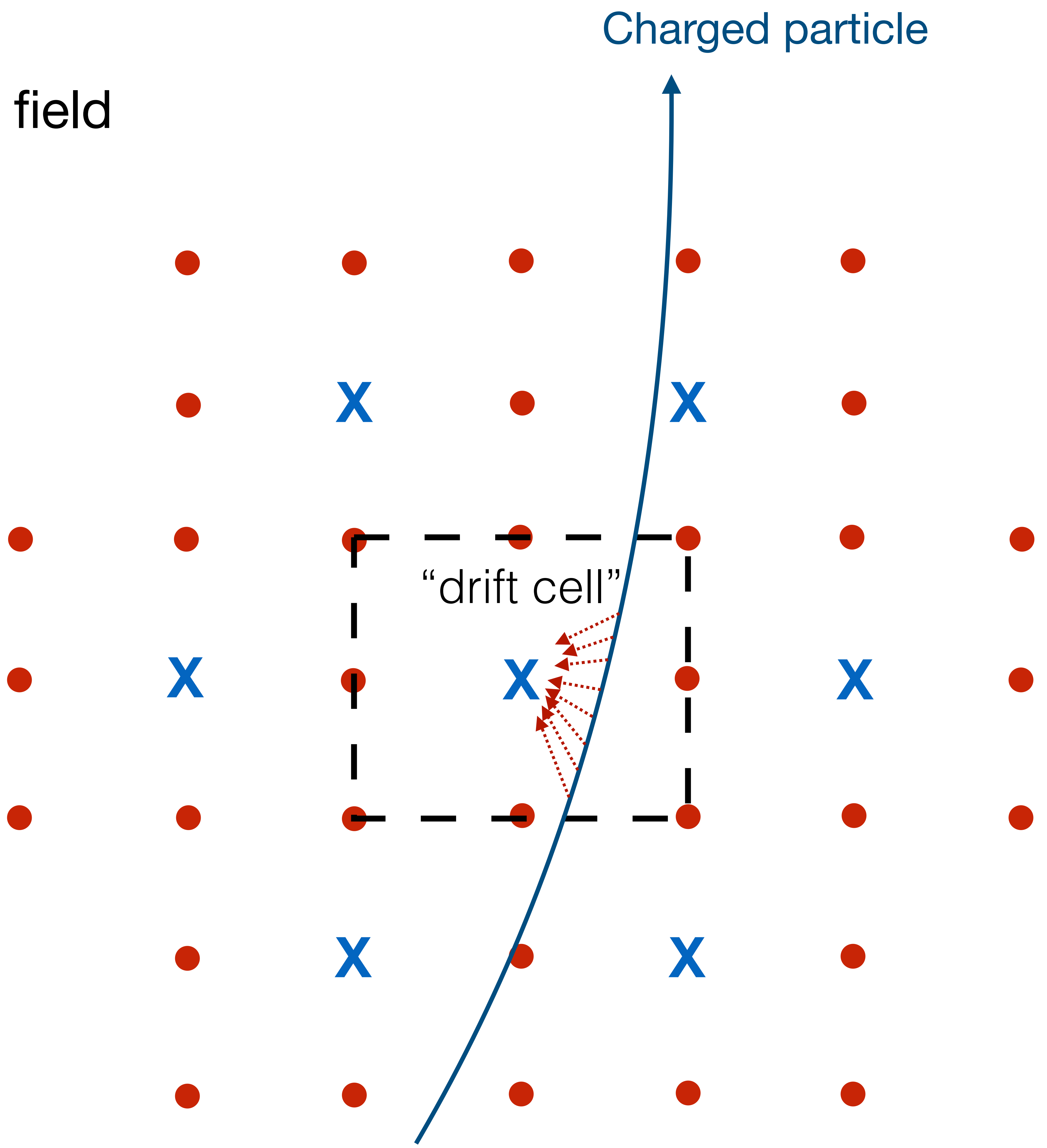

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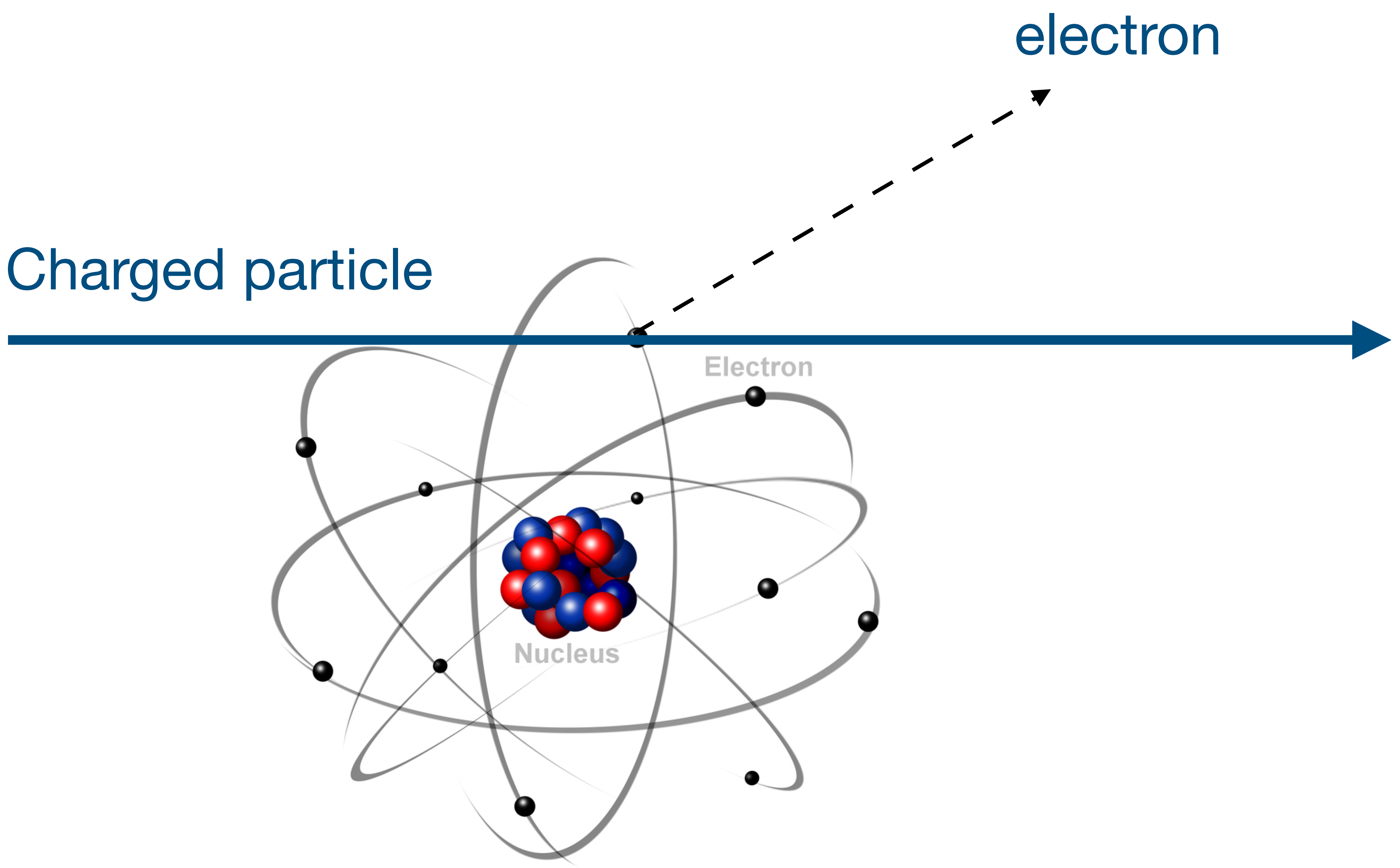

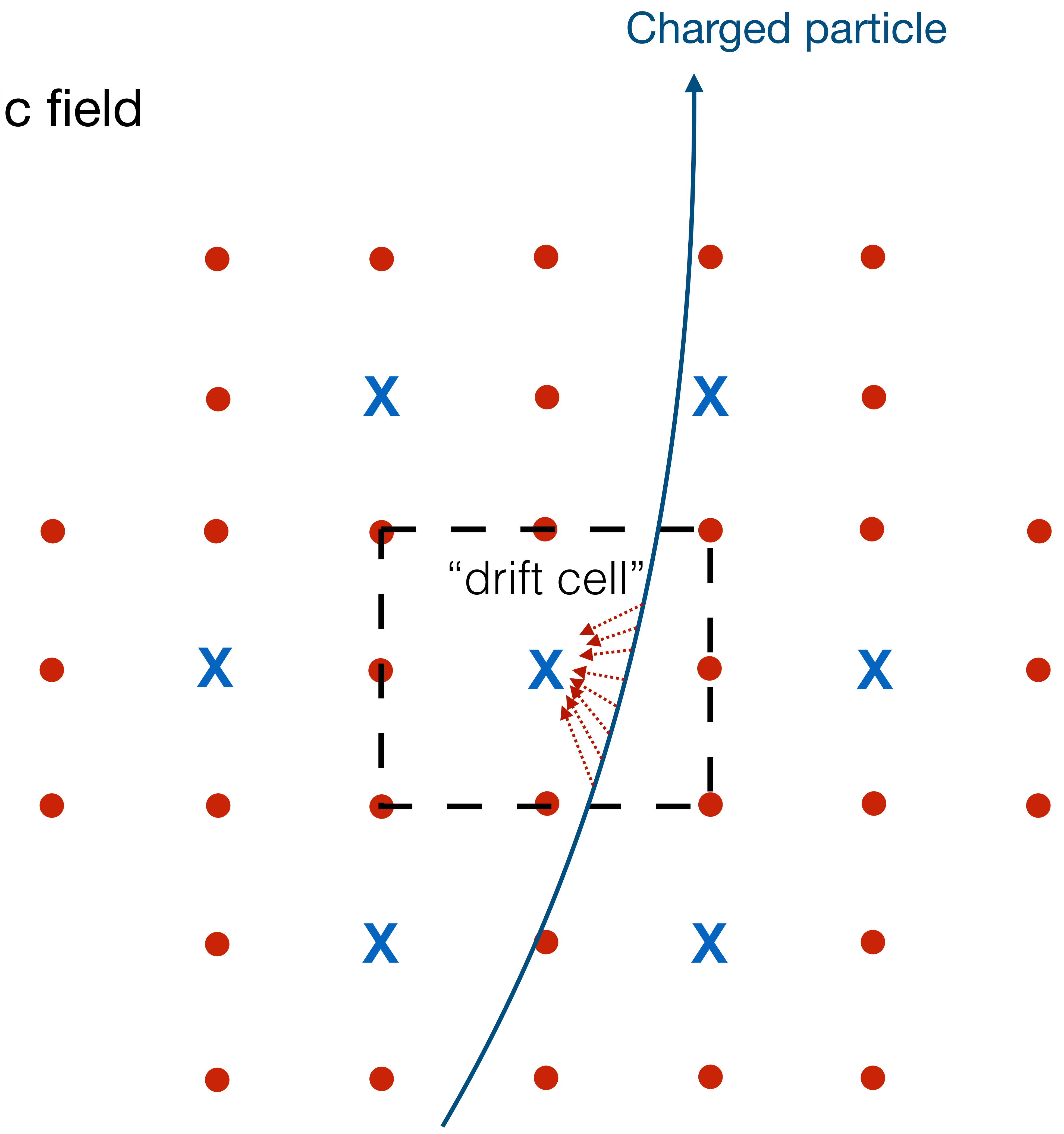

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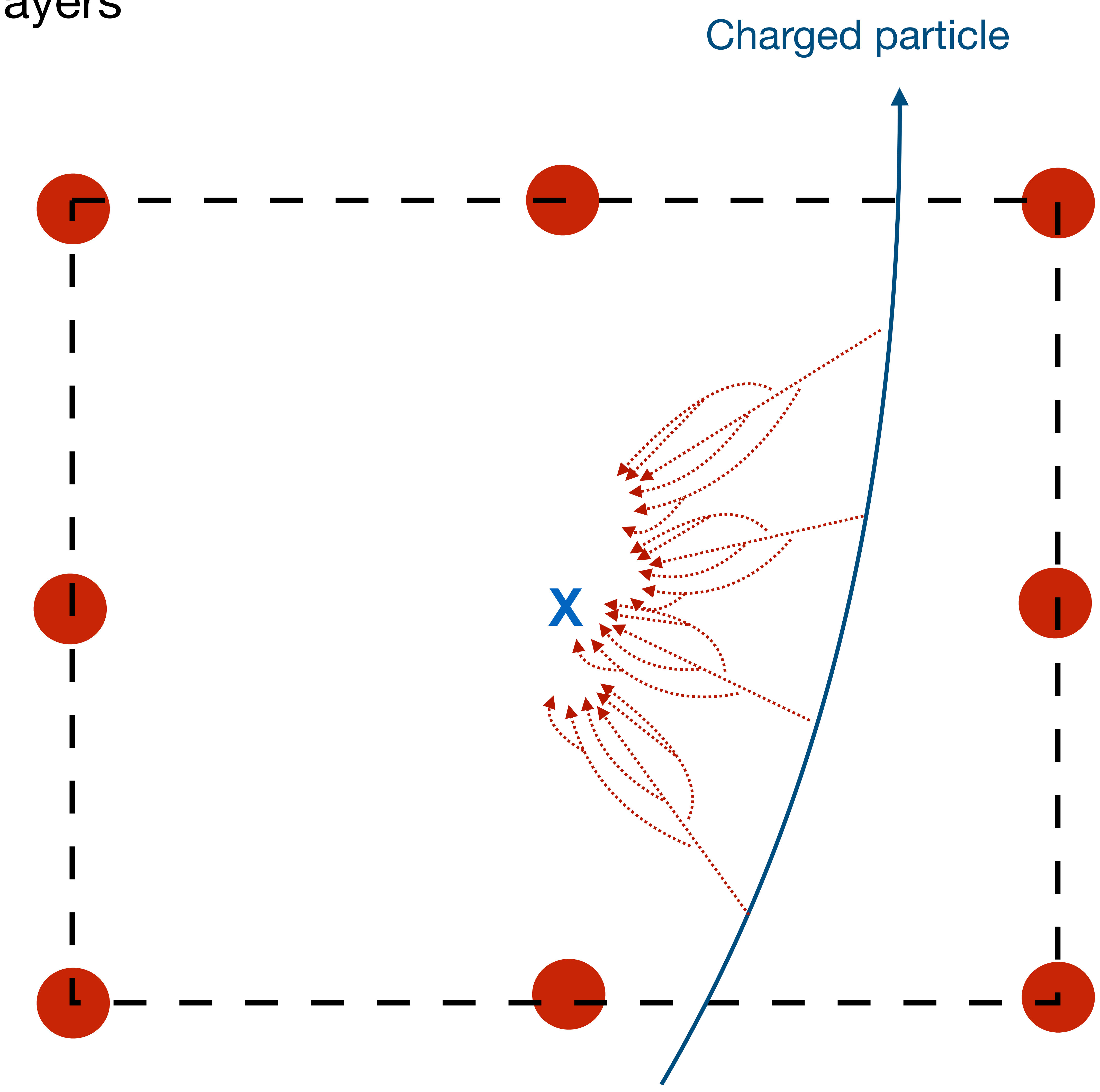
- Near the wires, the large electric field causes the electrons to gain enough energy per mean free path to ionize at the next collision



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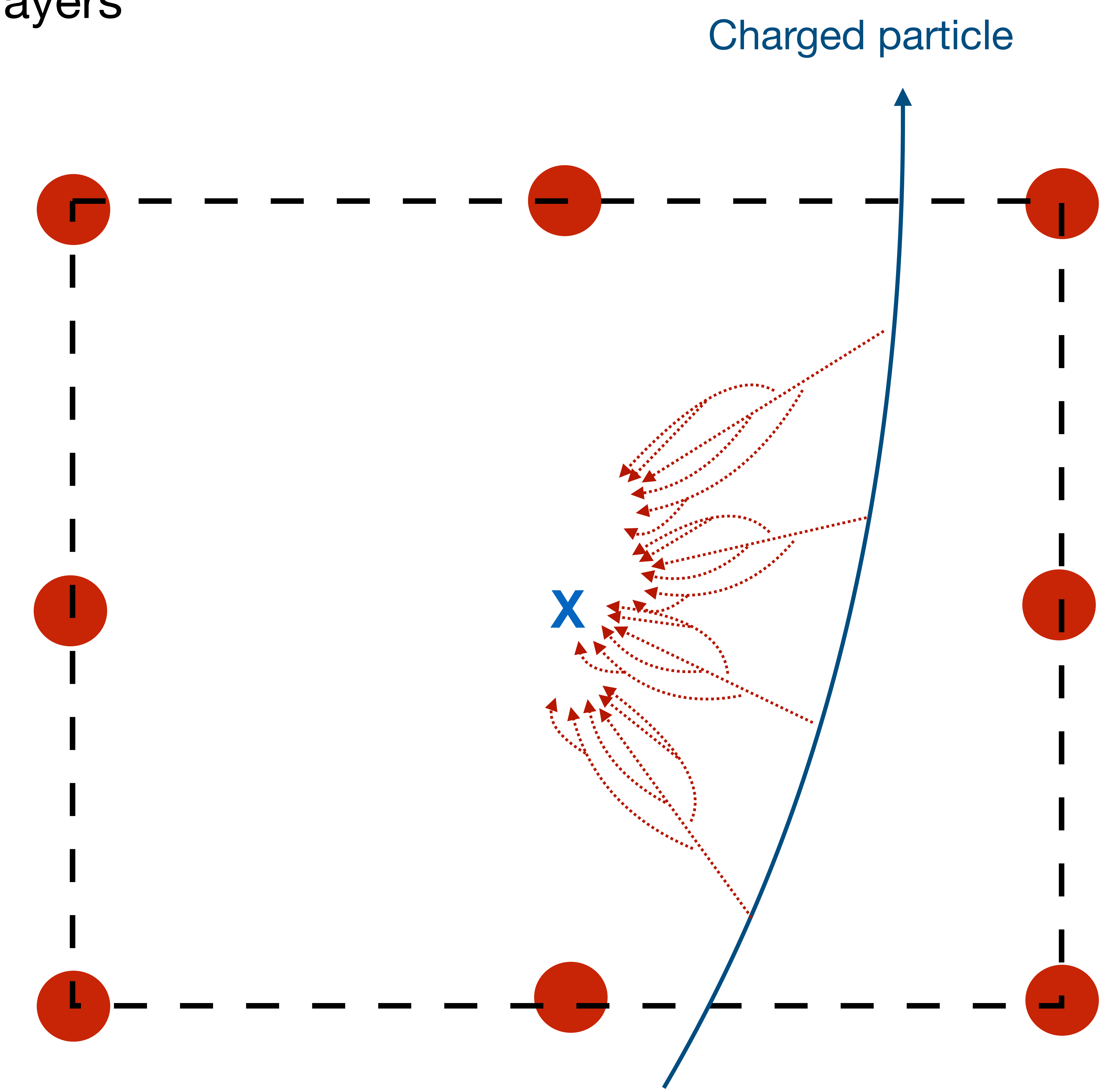

- Electrons liberated by ionization drift toward the sense wires
- Near the wires, the large electric field causes the electrons to gain enough energy per mean free path to ionize at the next collision
- Detectable signal created by avalanche of electrons near sense wires
- Location of the hit and drift time are used to determine the trajectory of the track

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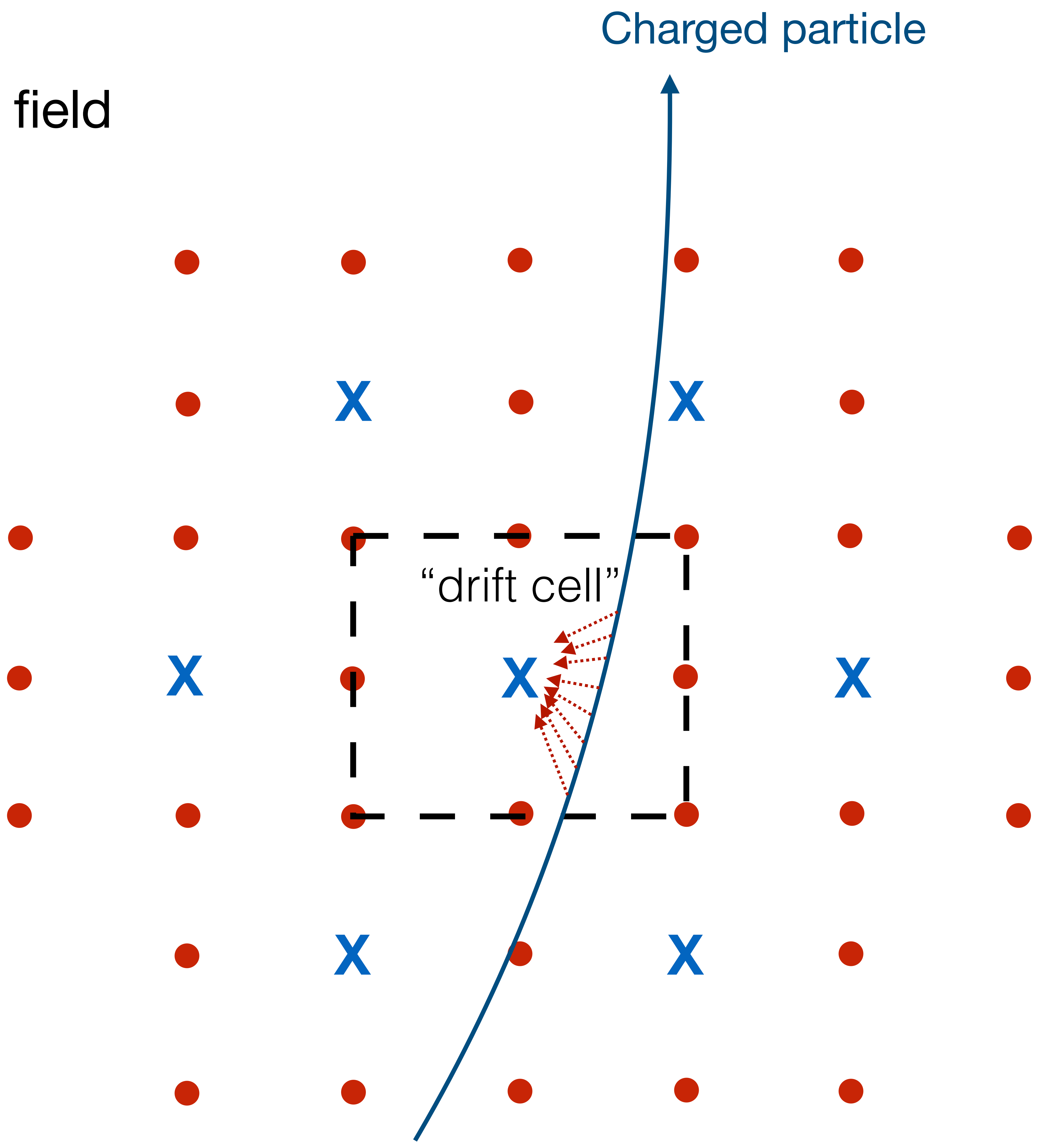
Check-in: What important feature are we missing in this picture?

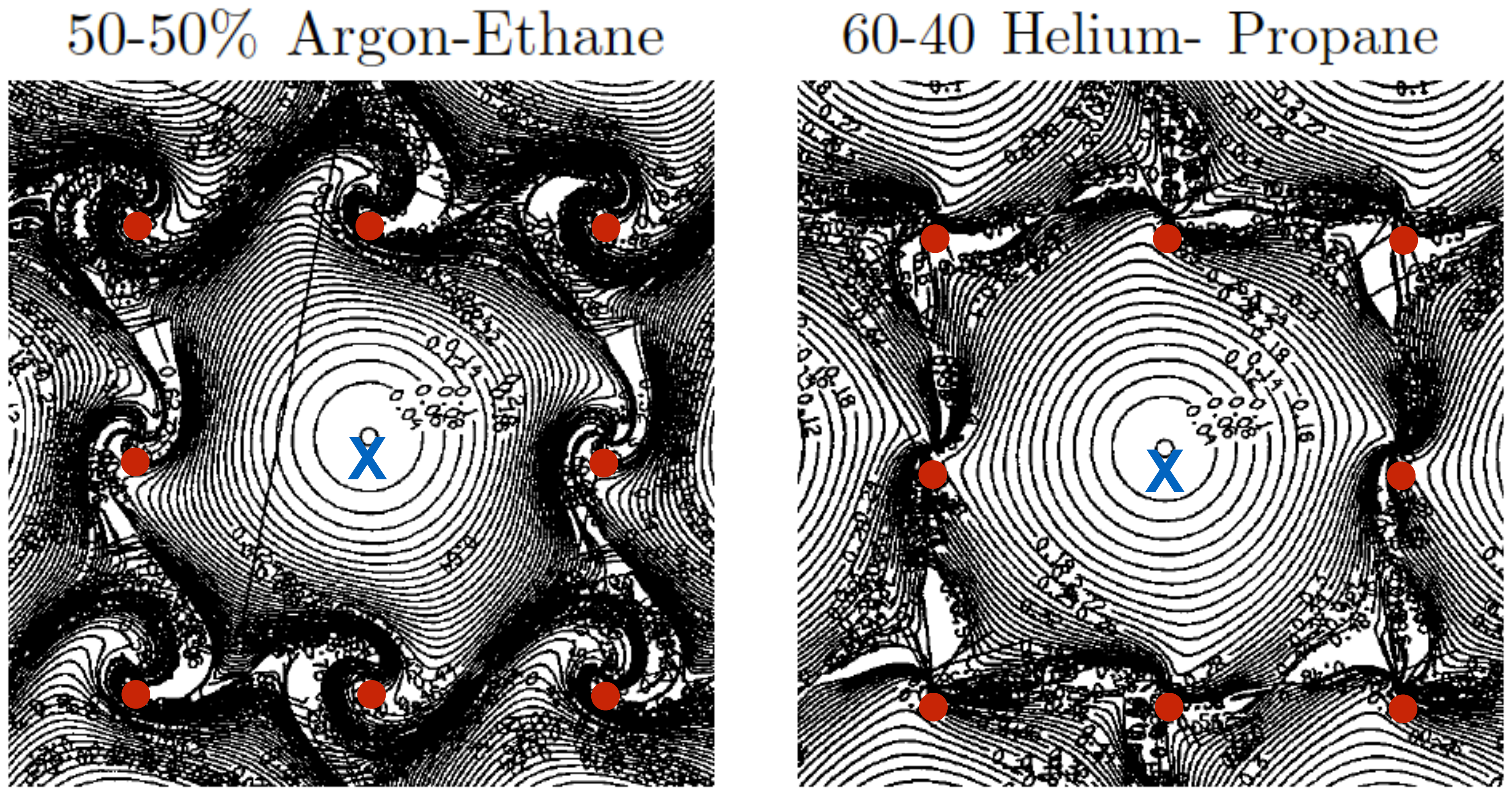
A. Air pressure
B. Electric fields
C. Magnetic fields
D. Ionization
E. The Force



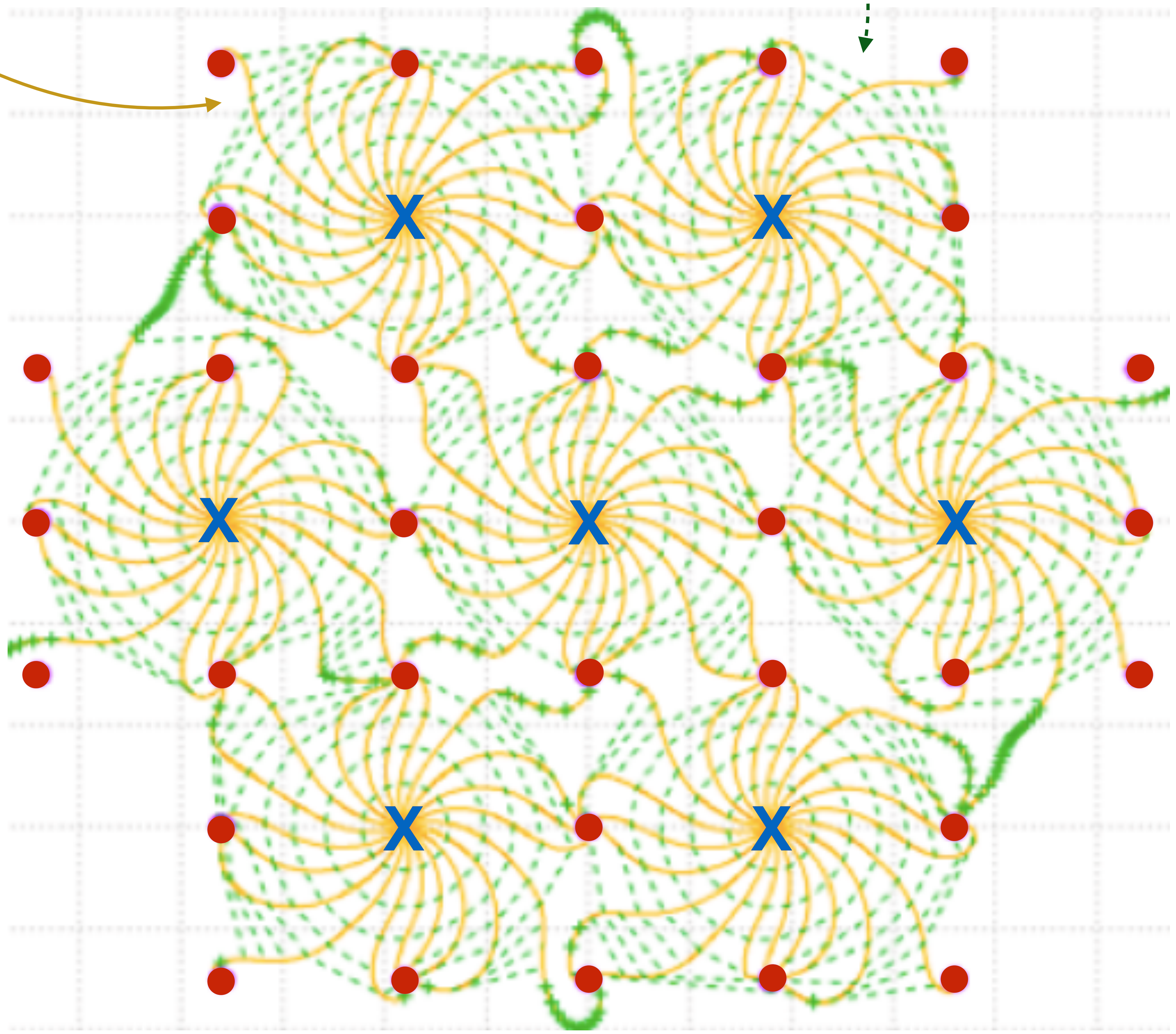
Drift cells

$$F_B = q\overrightarrow{v} \times \overrightarrow{B}$$

- Presence of magnetic field causes electron trajectories to curve
  - Changes the shape of isochrones (lines of equal drift time)
  - Lorentz Angle: angle between drift path with and without B-field
  - Also depends on the gas composition
  - Note: B-field can have a big effect on drift time!

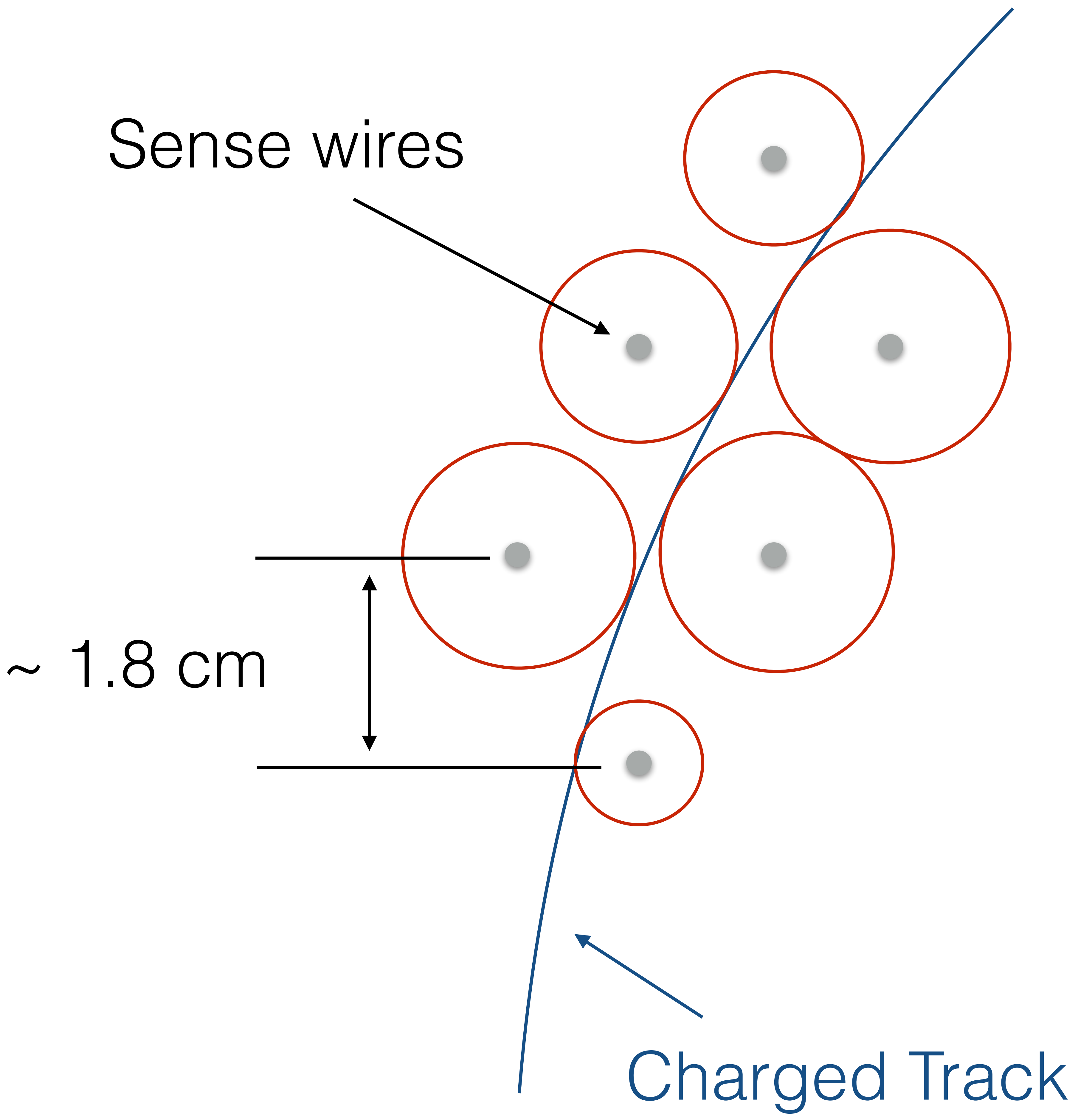


Example from CLEO



Very simplistic overview of tracking

- Localize a charged track to be on a ~135 μm resolution drift circle around wire



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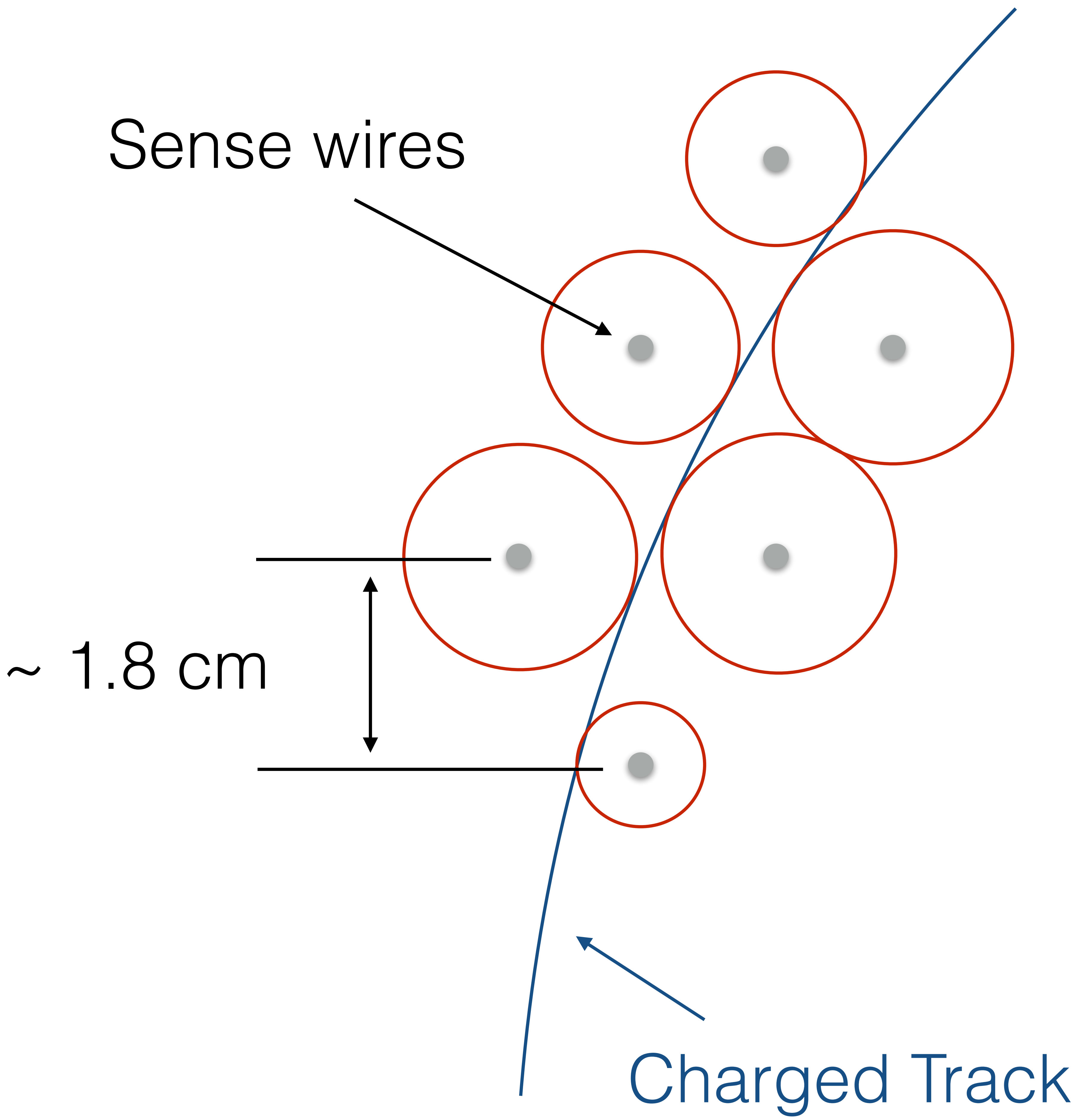

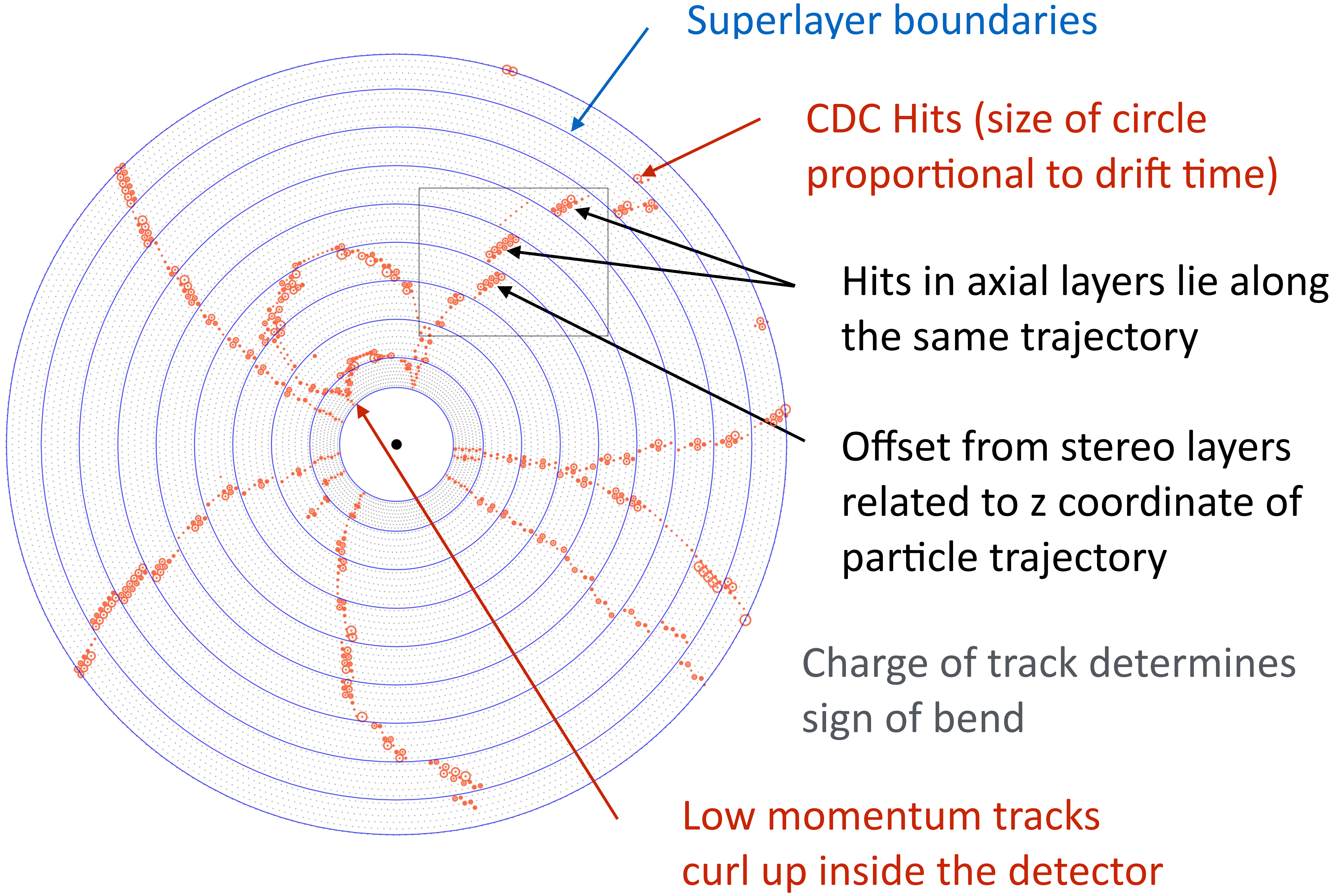

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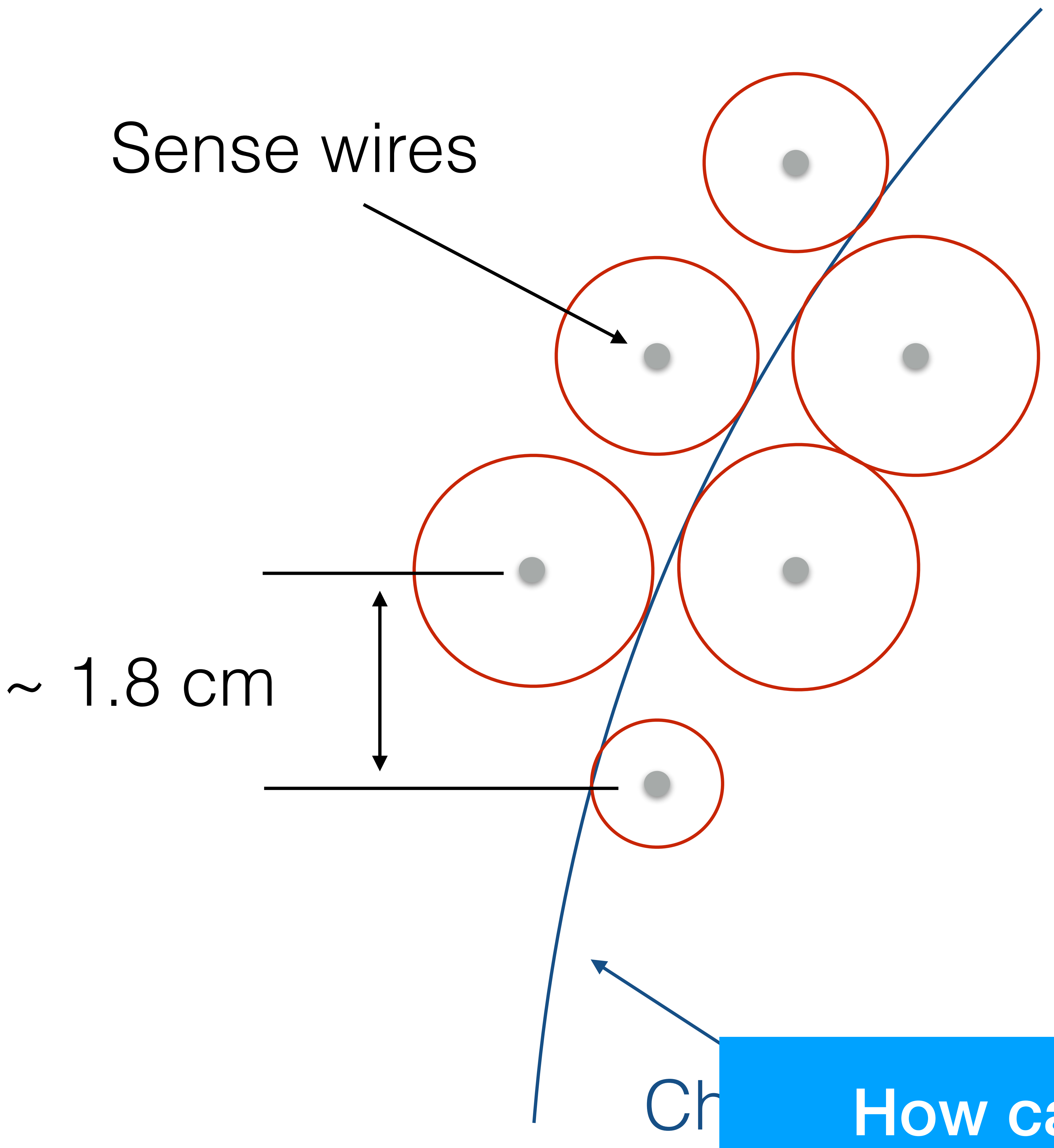

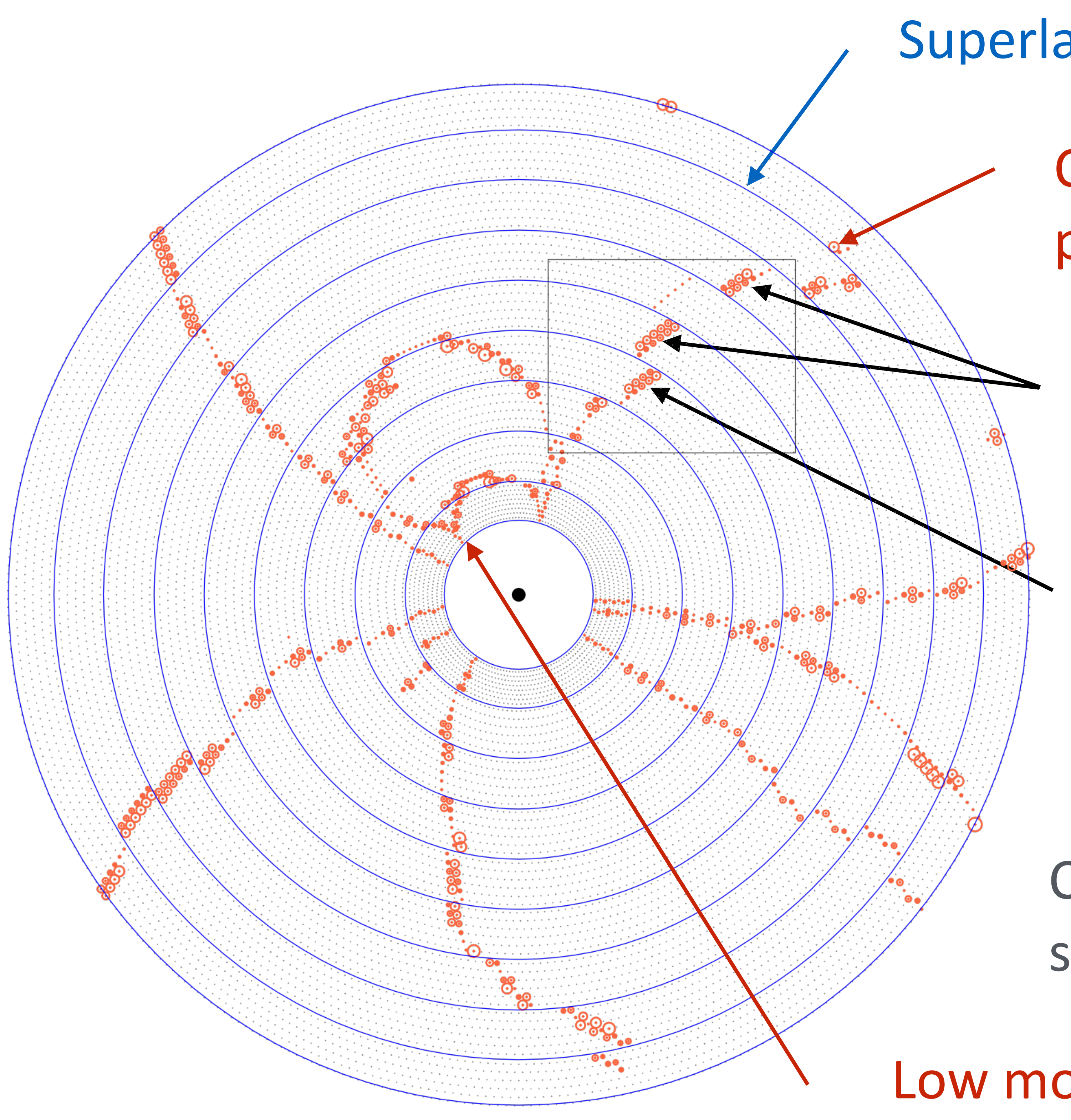

How can we use this to measure the momentum of a particle?

Particle IDentification (PID)

$$\gamma = \frac{1}{\sqrt{1-\frac{v^2}{c^2}}} = \frac{1}{\sqrt{1-\beta^2}} \qquad \beta\gamma = \frac{p}{m}$$

- Particle identification is basically measuring mass (measure both p and β simultaneously)
  - $\pi^{\pm}$: 140 MeV
  - $K^{\pm}$: 494 MeV
  - $p^{\pm}$: 938 MeV
  - $\mu^{\pm}$: 106 MeV

- All depends on the interaction
  - Specific energy loss: dE/dx
  - Time of flight (ToF)
  - Cherenkov techniques

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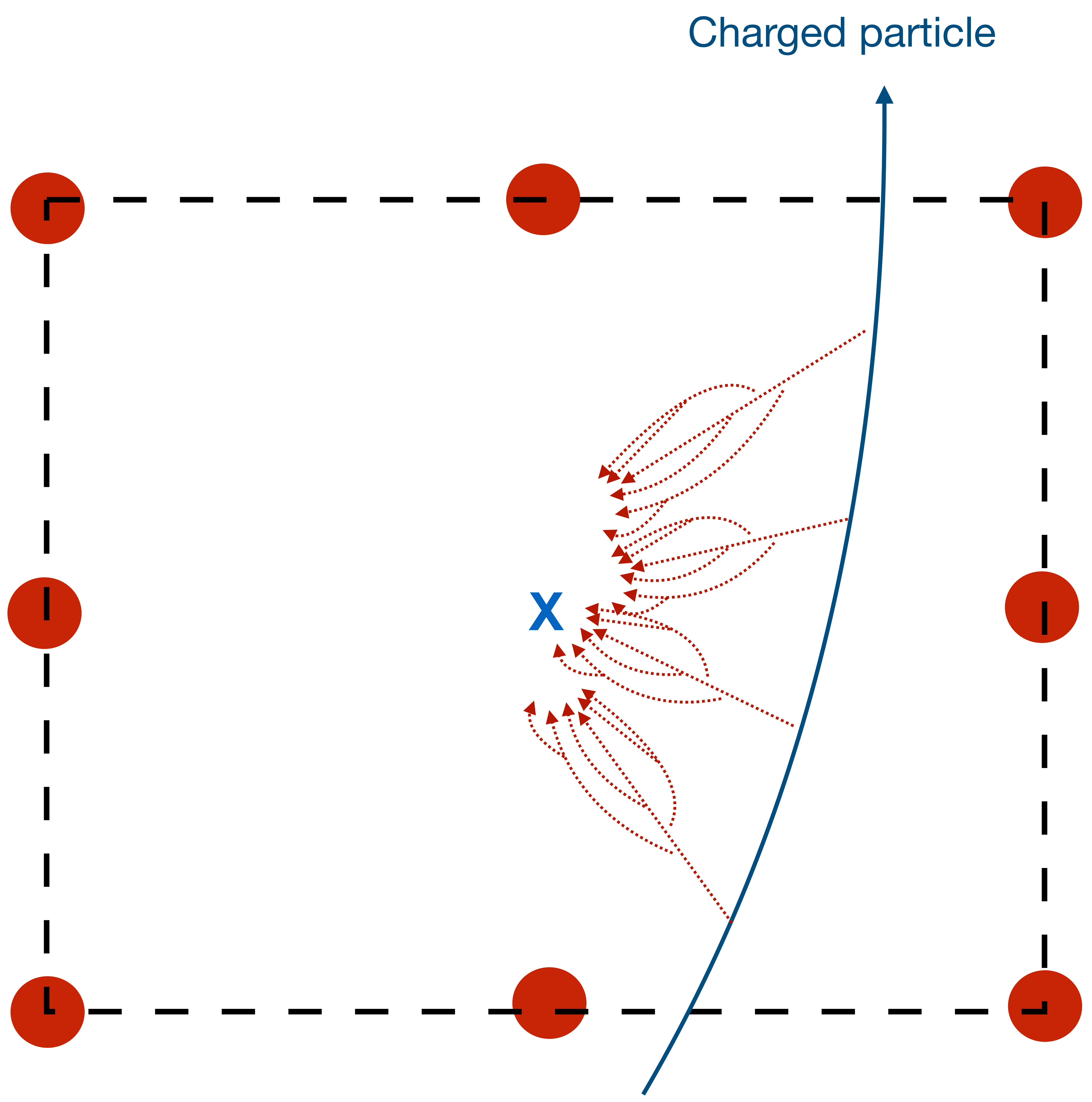
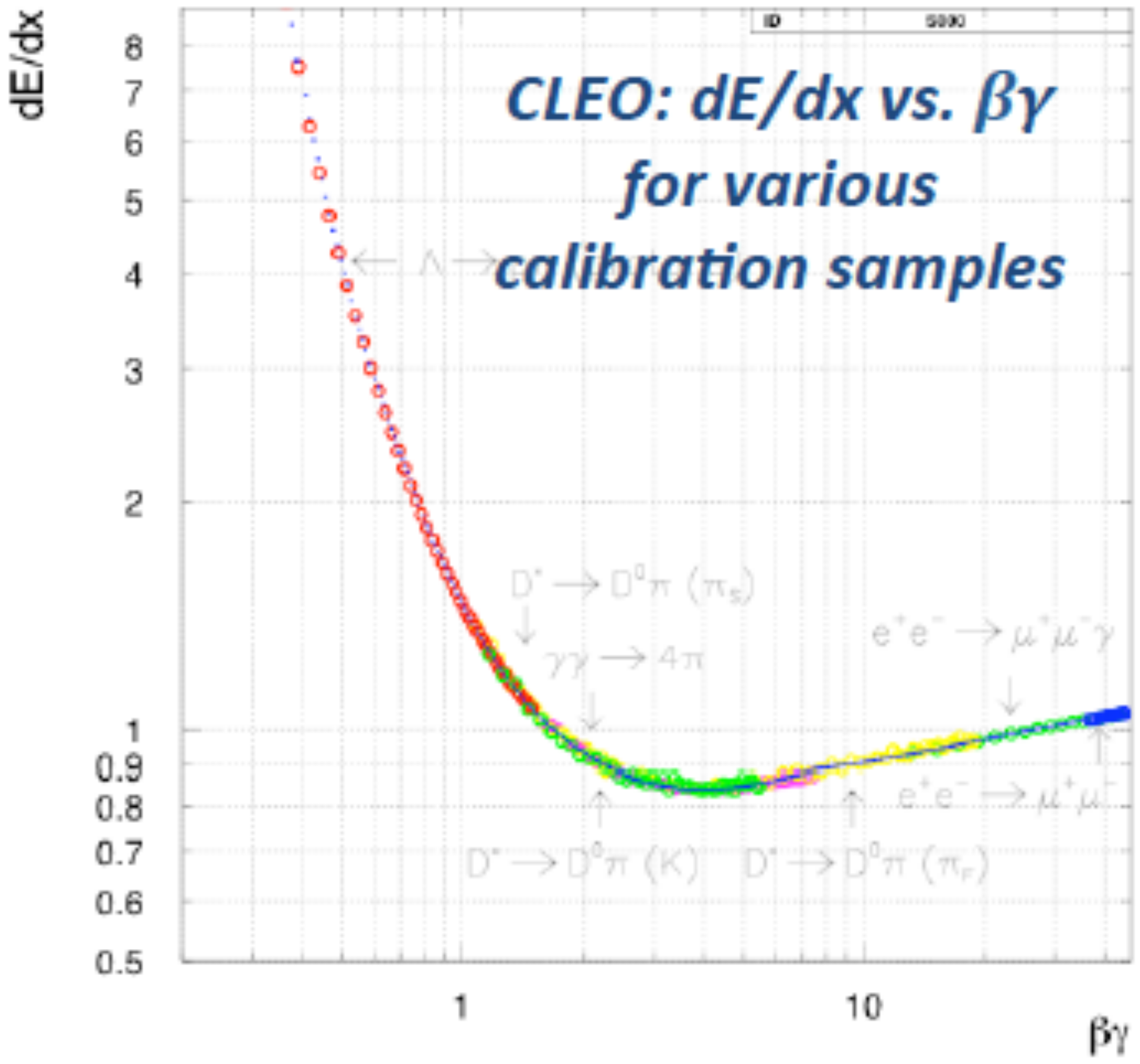


Basic philosophy

- dE/dx depends only on βγ = p/m (Bethe-Bloch formula)

Predict: What will happen if we look at momentum rather than p/m?



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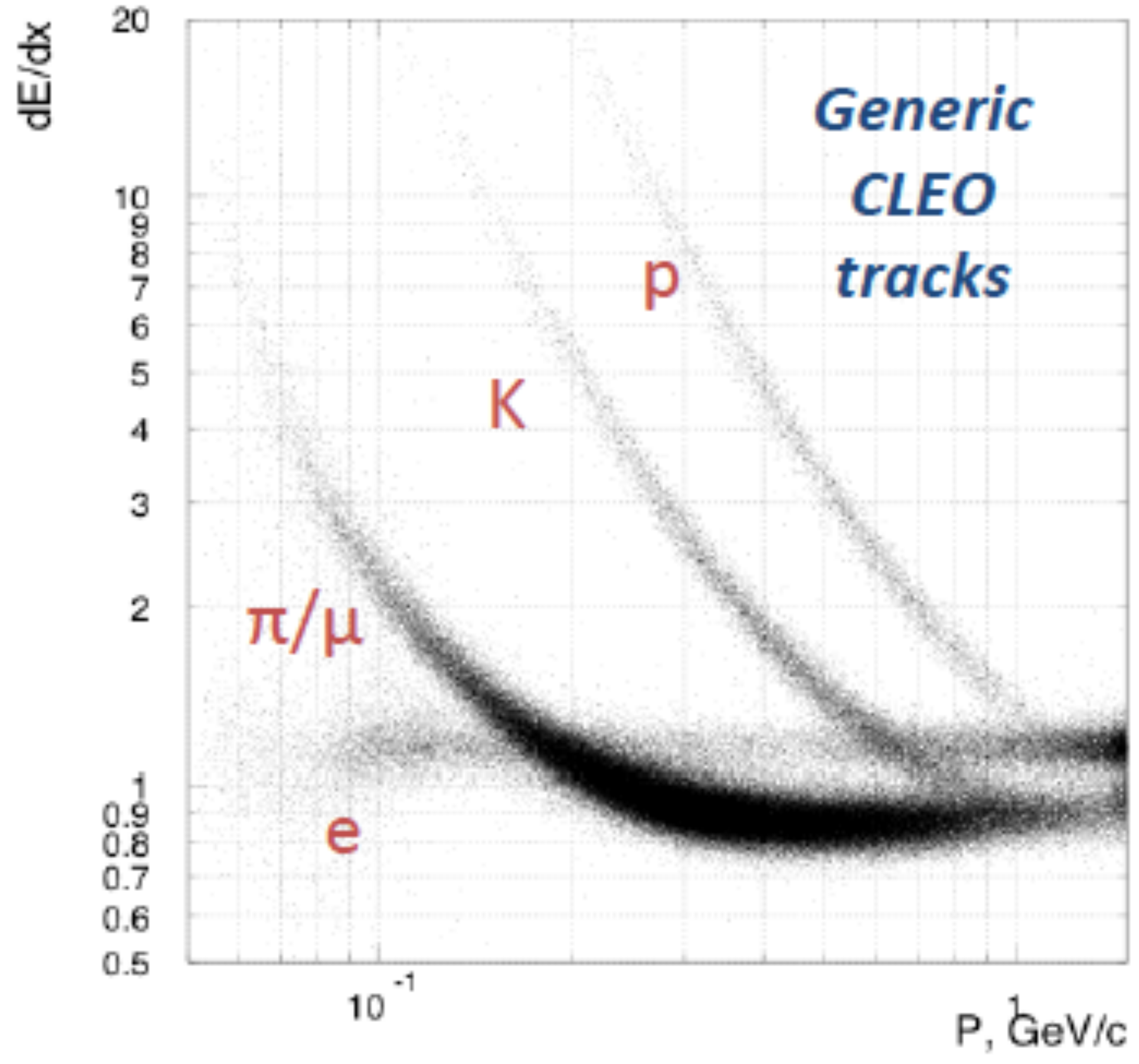
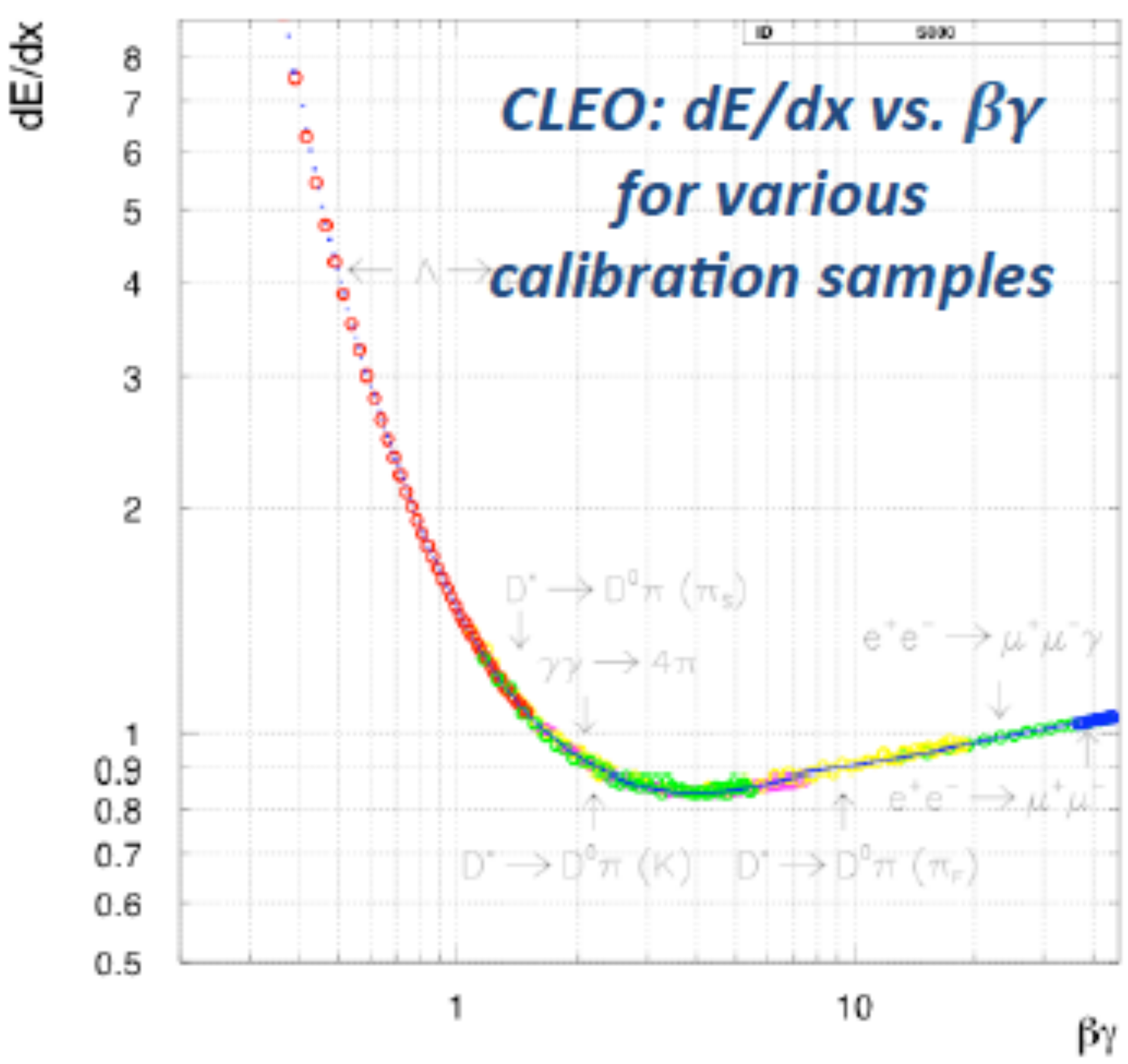
- Measuring dE/dx and the momentum allows us to predict the mass (identity) of the particle





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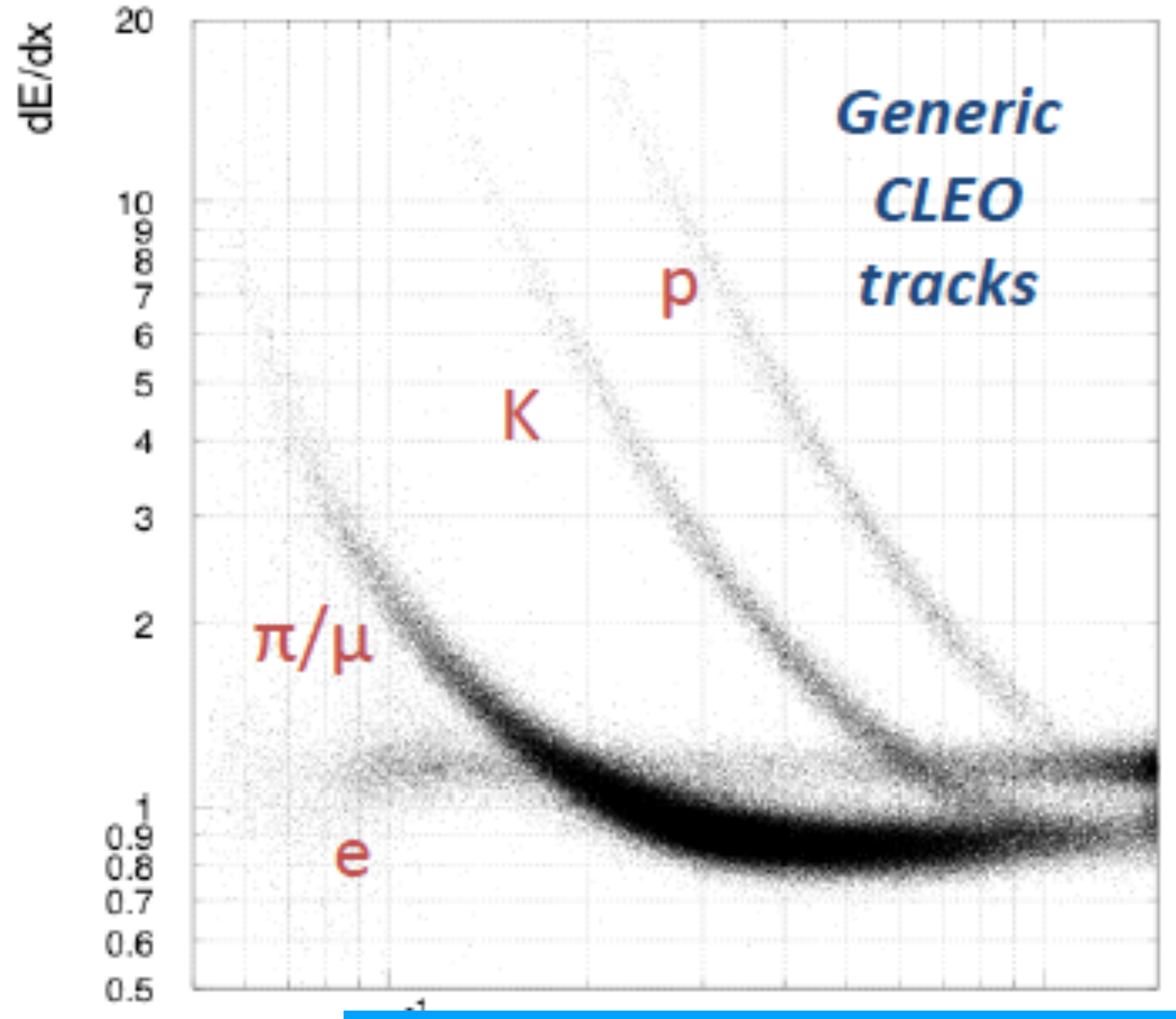
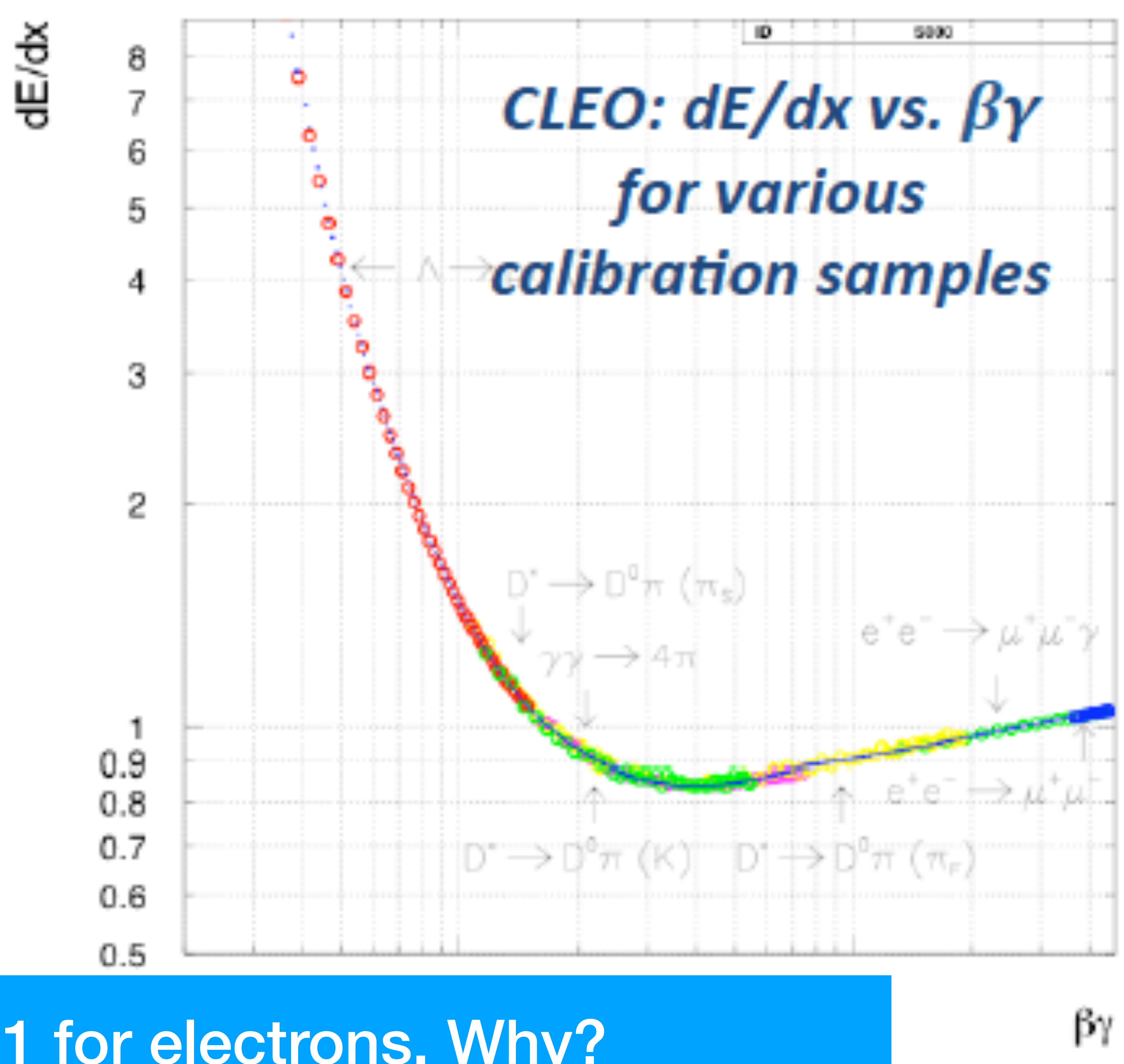
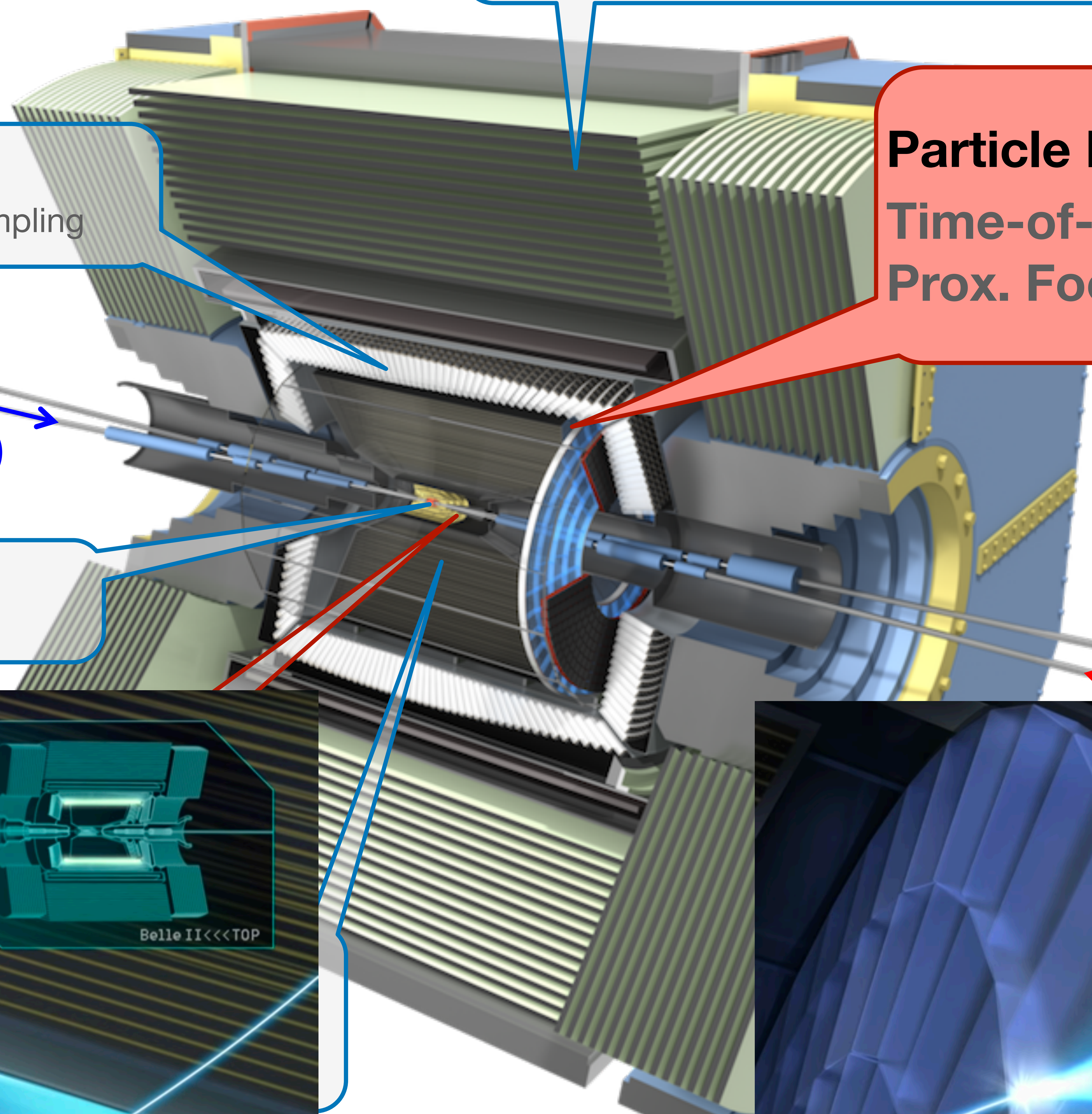
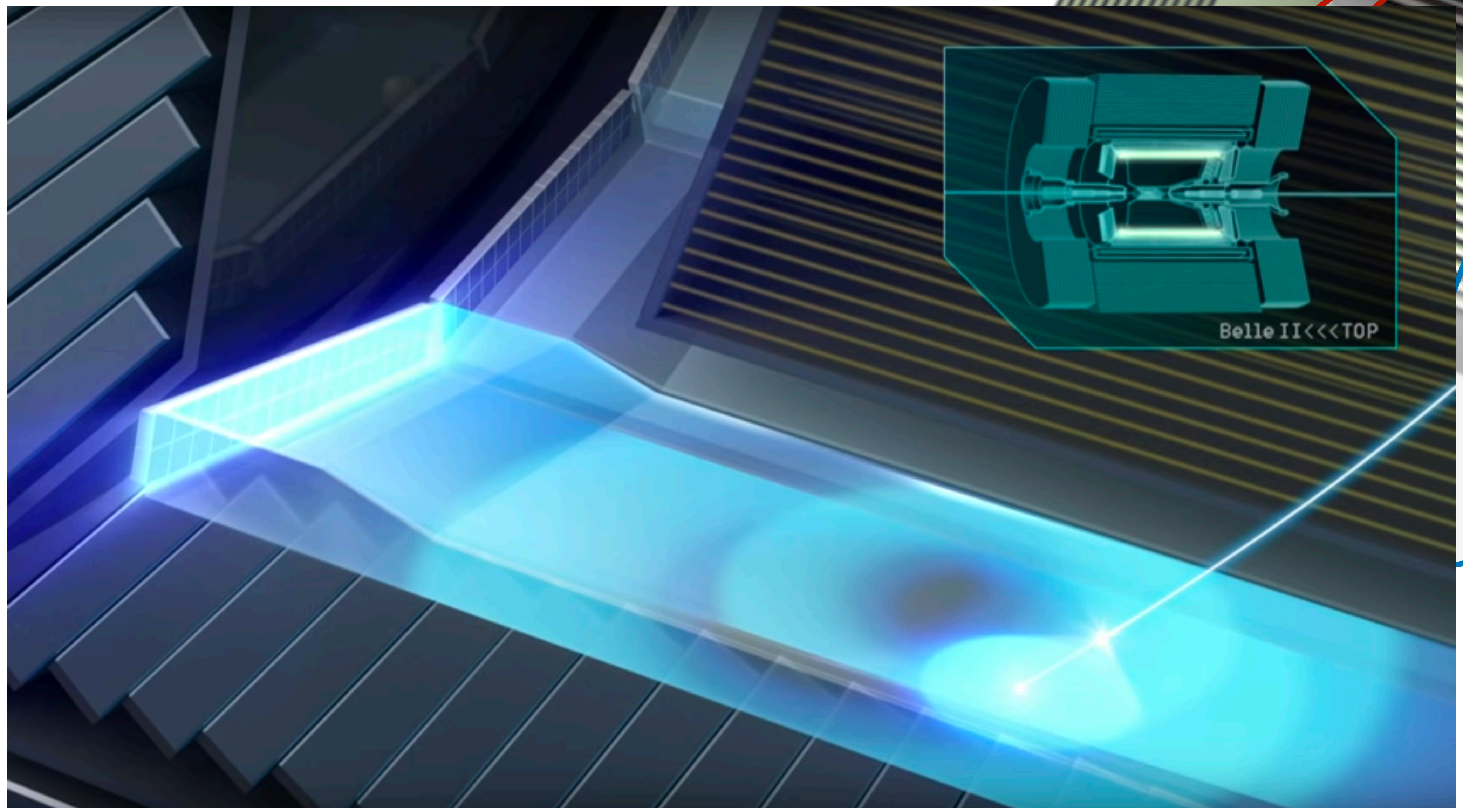


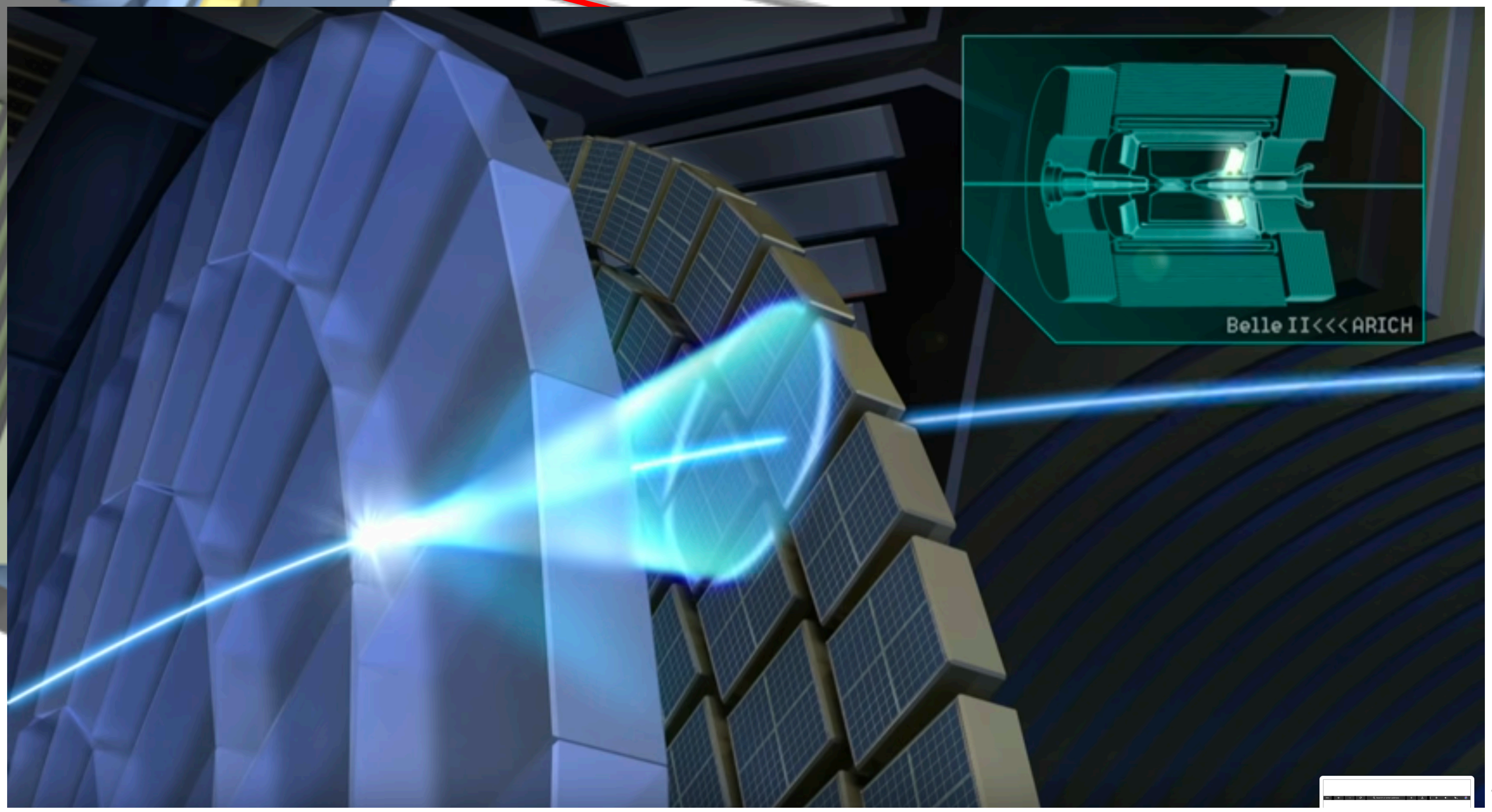


We artificially set dE/dx to 1 for electrons. Why?

The Belle II detector

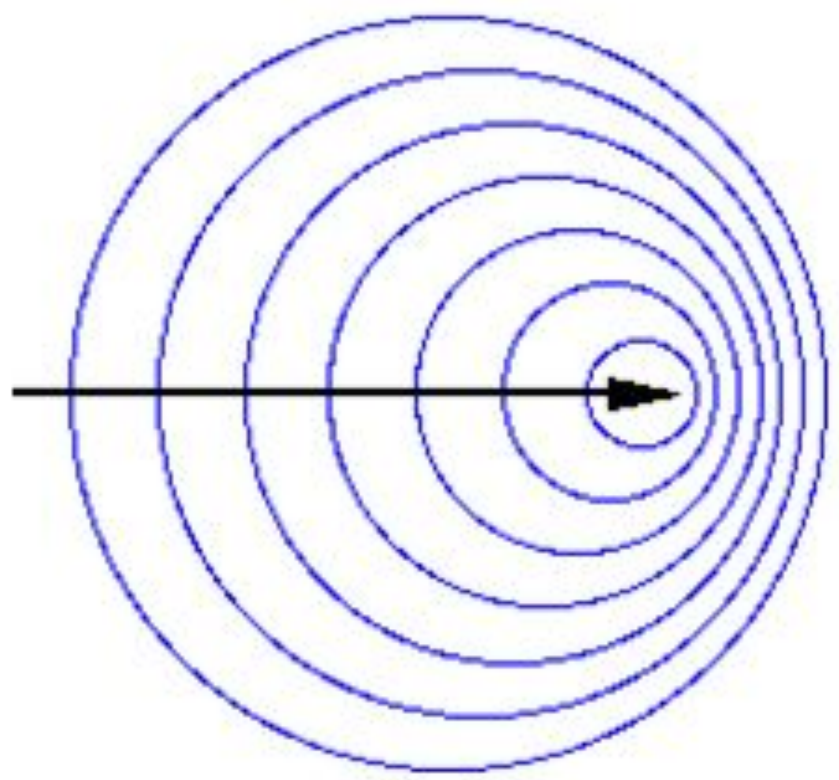






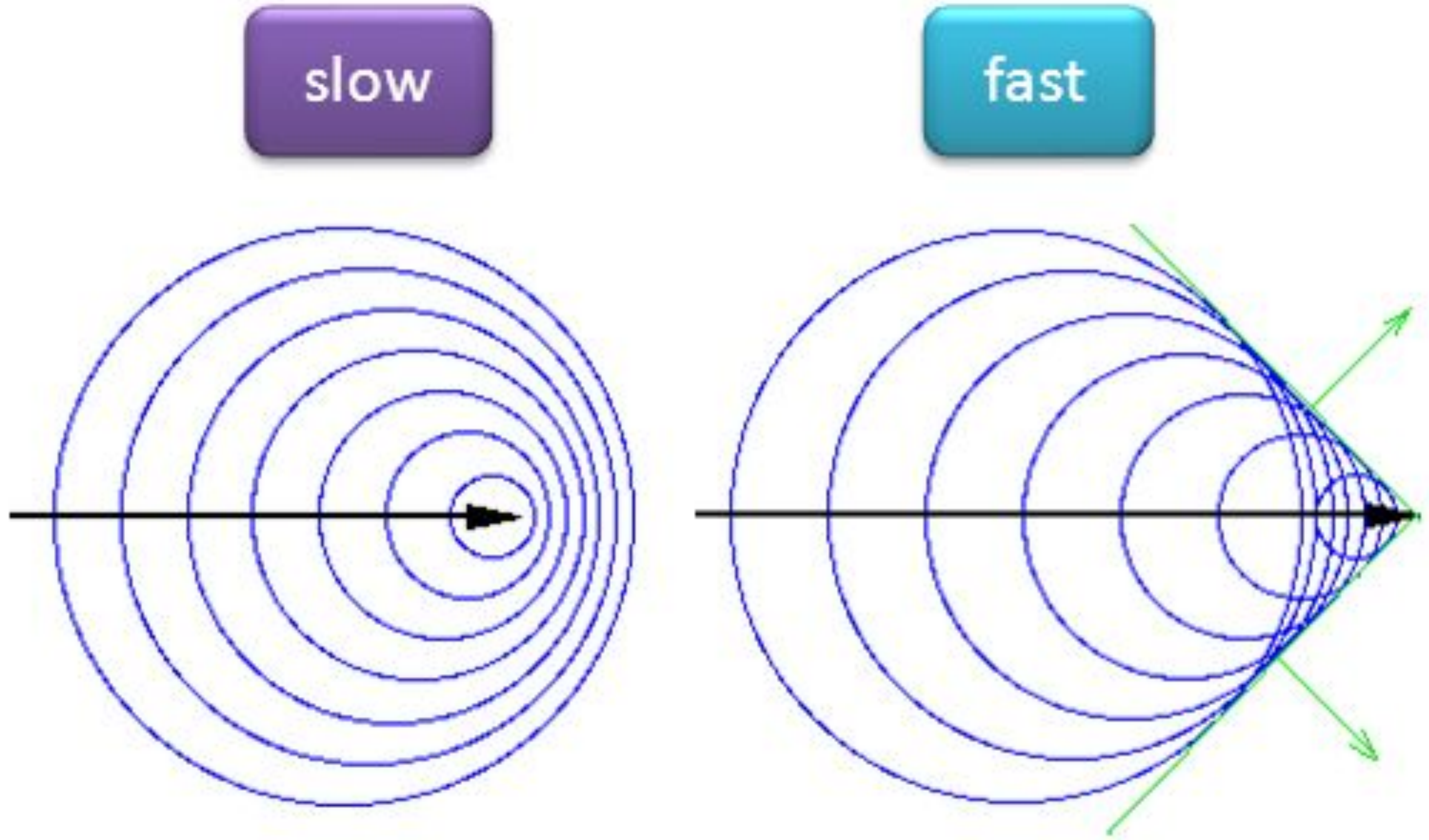
Cerenkov techniques

- Charged particle moving through a dielectric medium



Cerenkov techniques

- Charged particle moving through a dielectric medium with velocity > the propagation speed

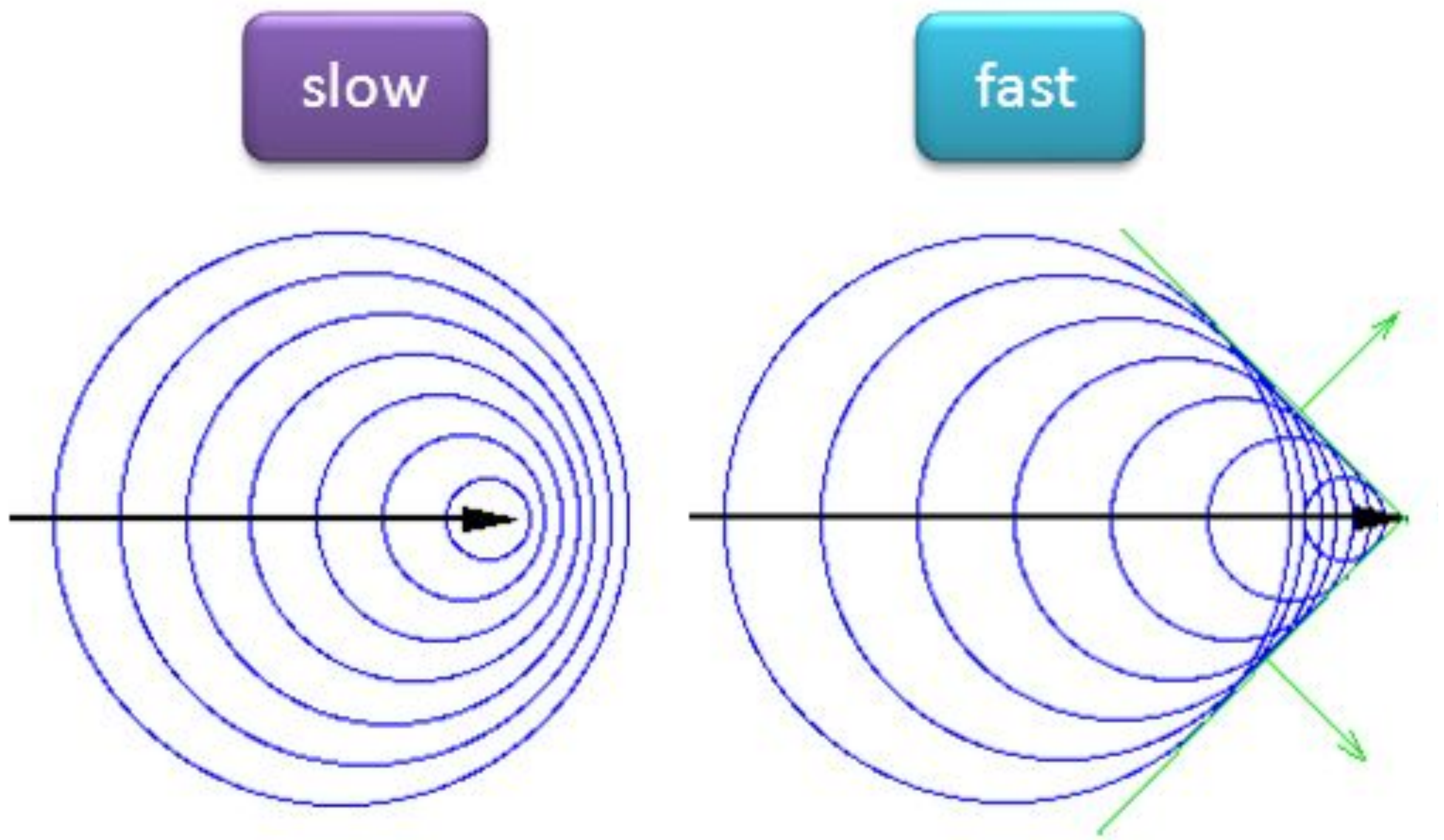


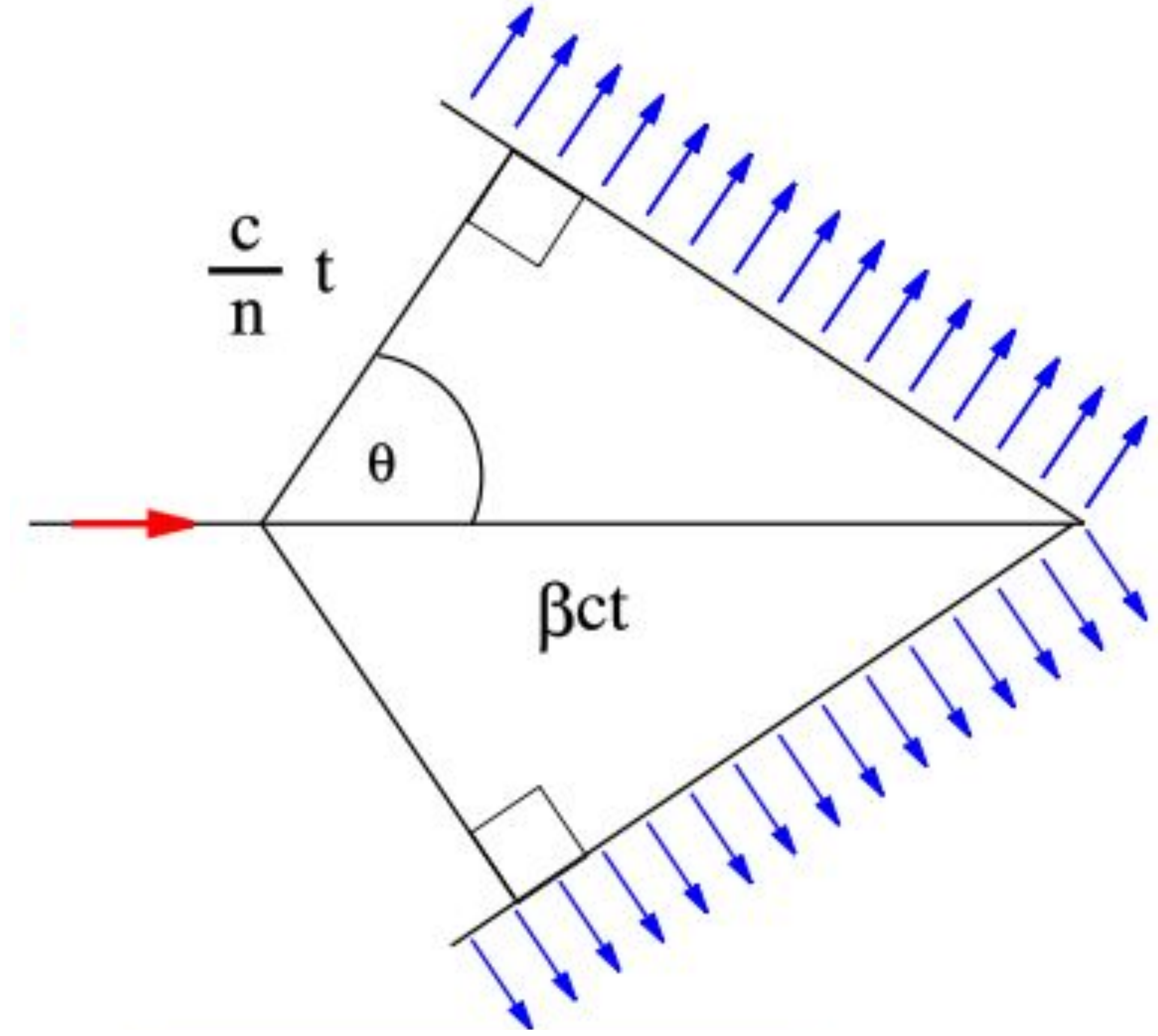
Cerenkov techniques

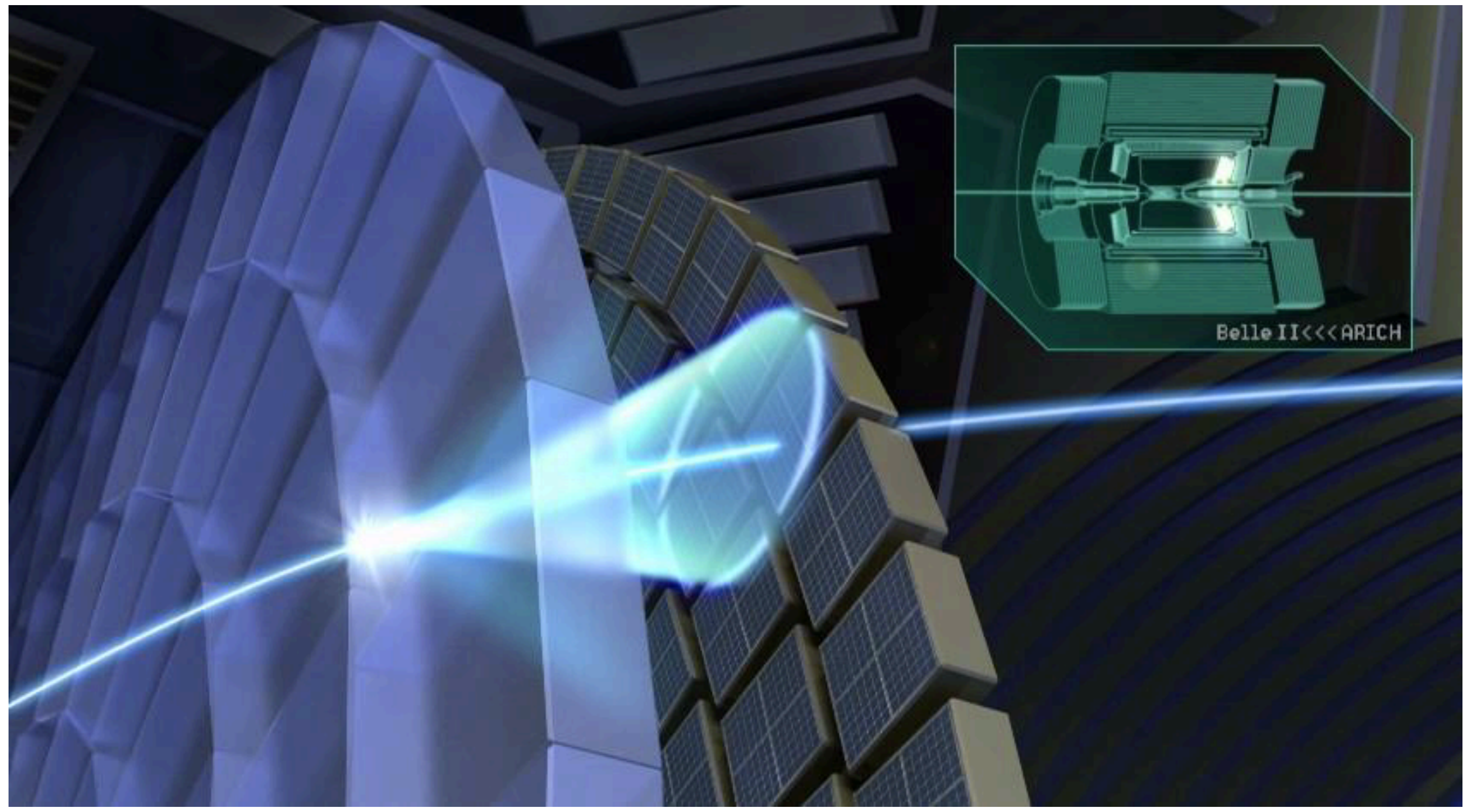
- Charged particle moving through a dielectric medium with velocity > the propagation speed of light in the medium will radiate photons (light)

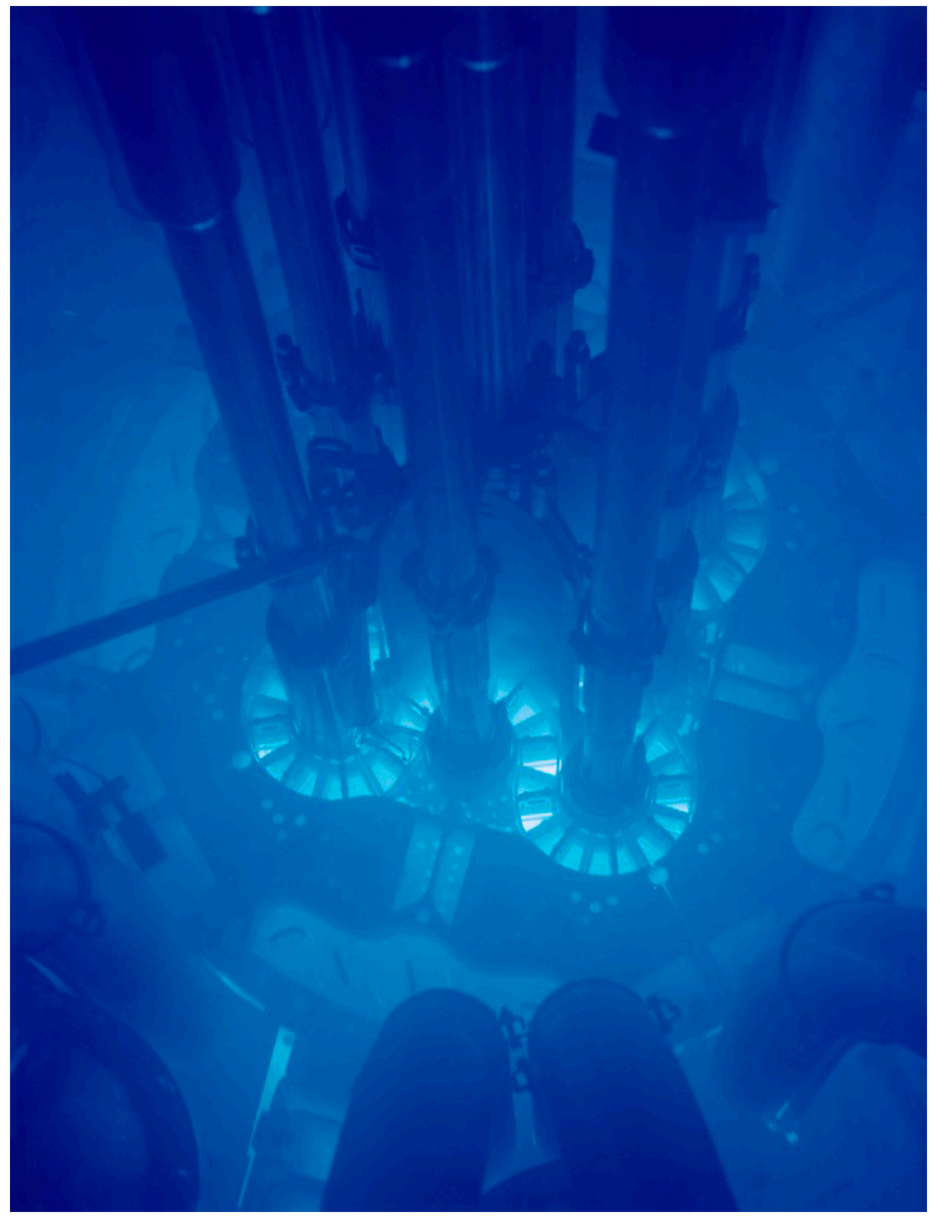
- Photons are emitted at a fixed angle: $\cos(\theta) = \frac{1}{n(\omega)\beta}$

- Emission spectrum is ~1/E: mostly in optical range









Čerenkov light in the ARICH (endcap Particle ID)

Čerenkov light in the TOP (barrel Particle ID)

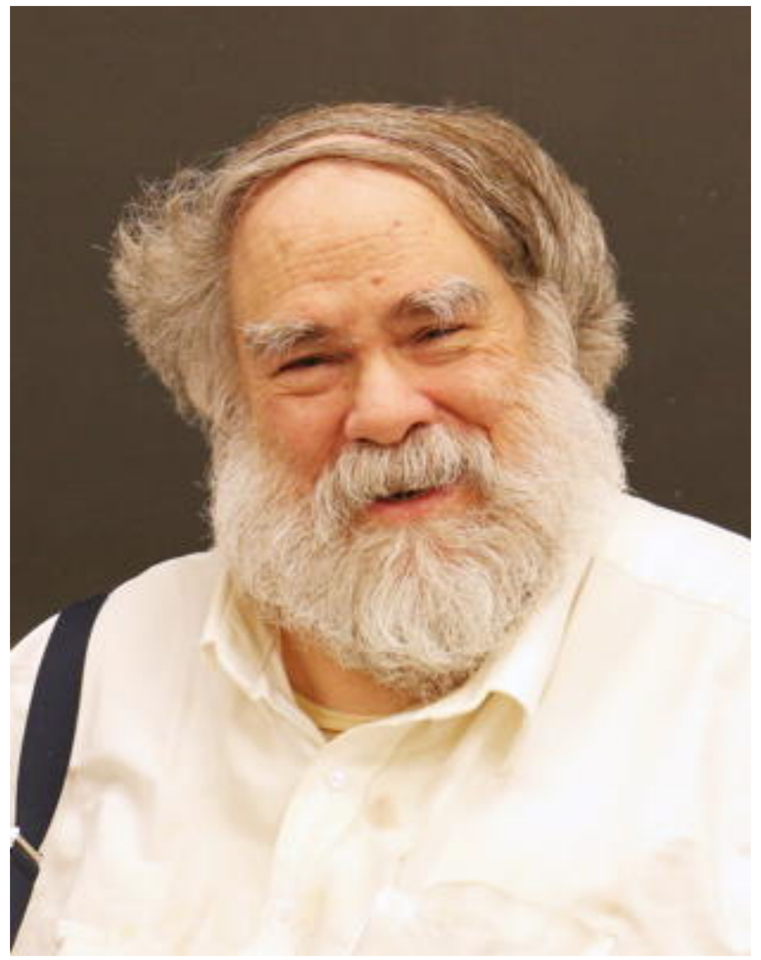
Putting it all together

Belle II @ Ole Miss

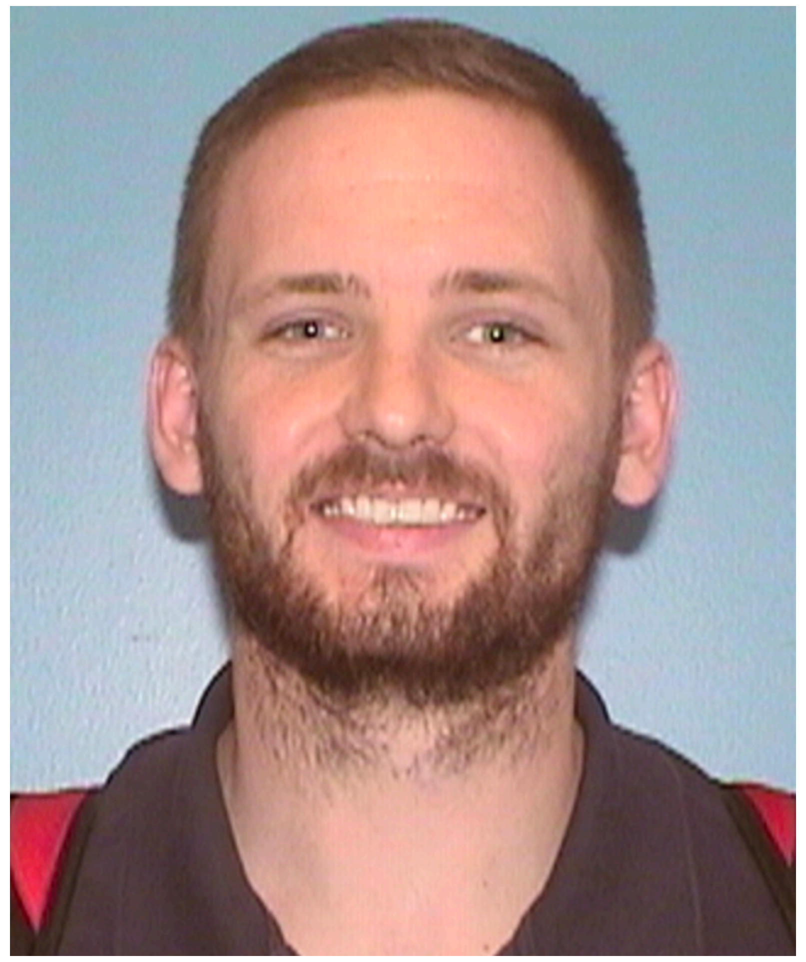

Jake Bennett


Lucien Cremaldi


Robert Kroeger


Don Summers


Saroj Pokharel


Justin Guilliams


Anil Panta


Michael Jeandron

Michel Villanueva


David Sanders