

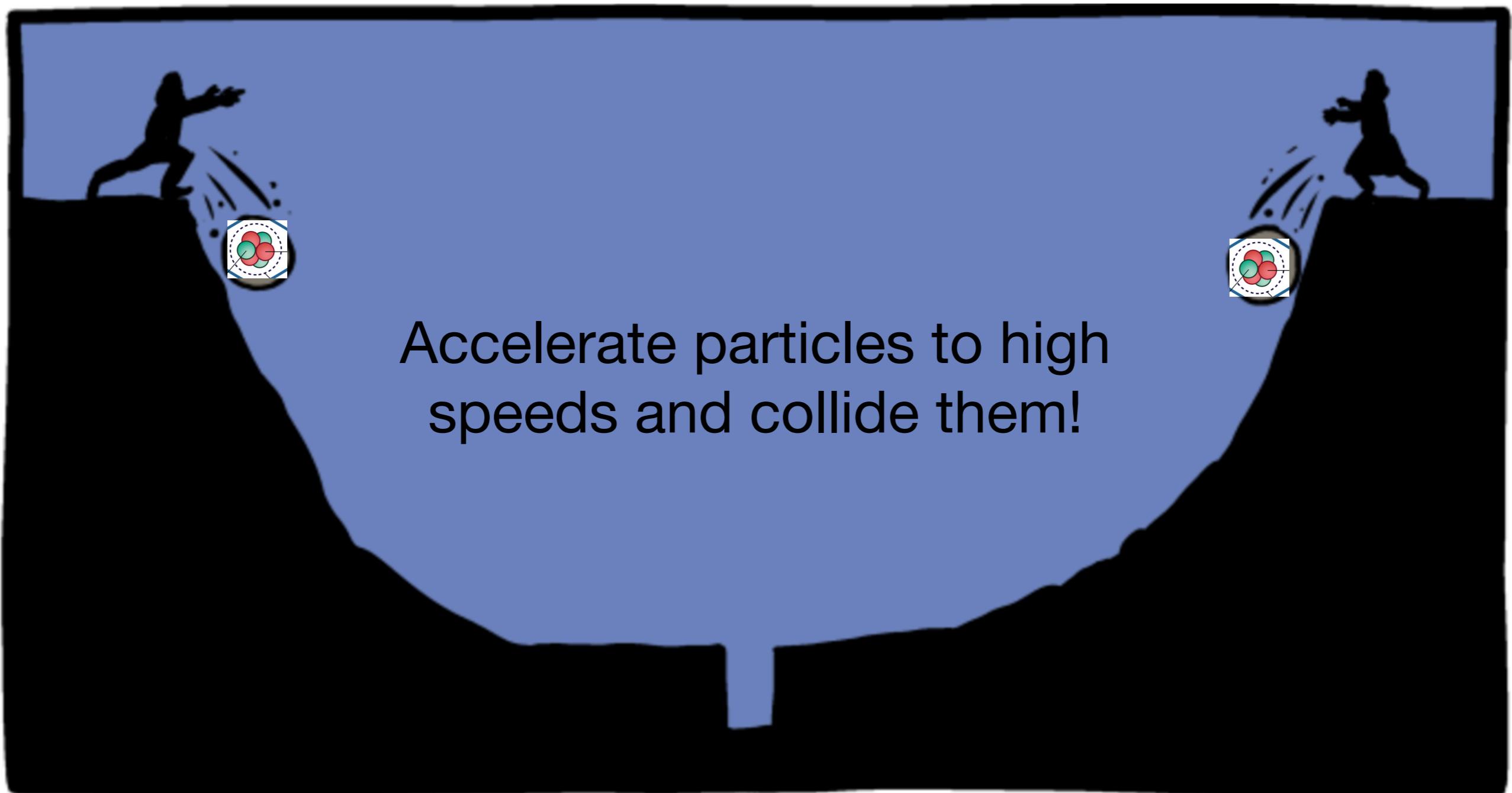
Let's Smash The Proton!

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(they/them)

School of Science and Math at Vanderbilt
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Day 2 - Units and Kinematics

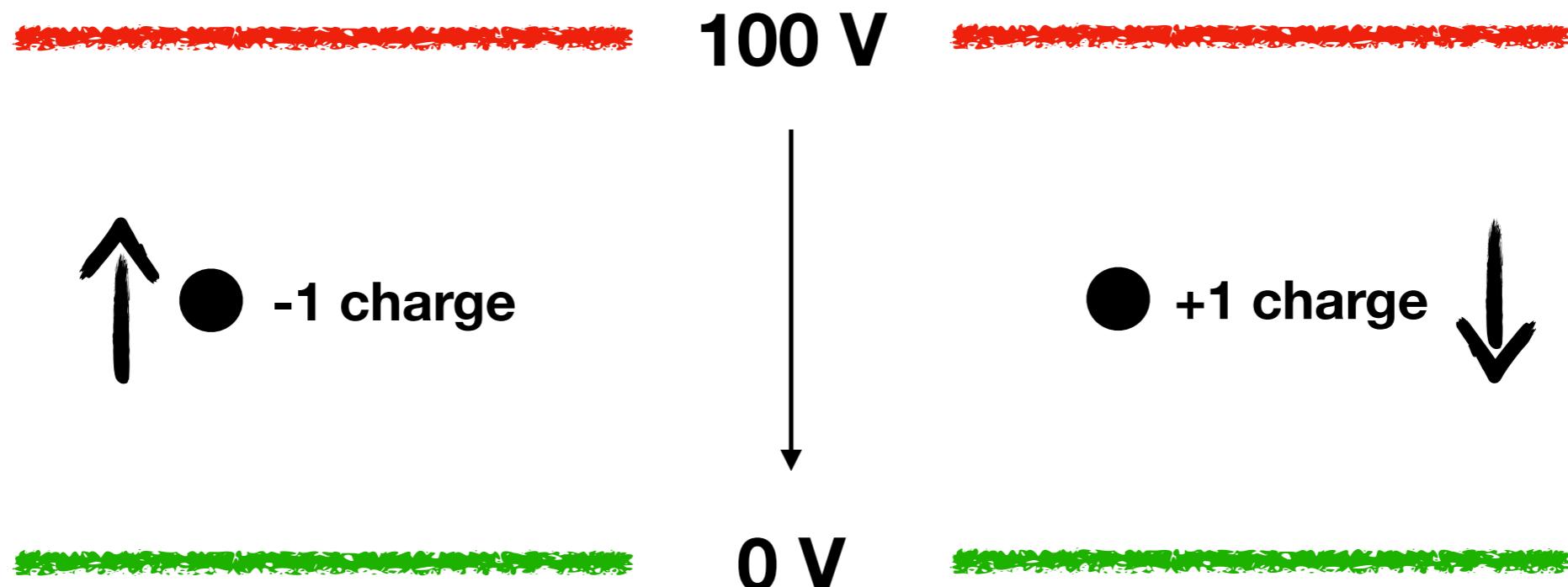
Particle Colliders



<https://www.smbc-comics.com/comic/2014-11-25>

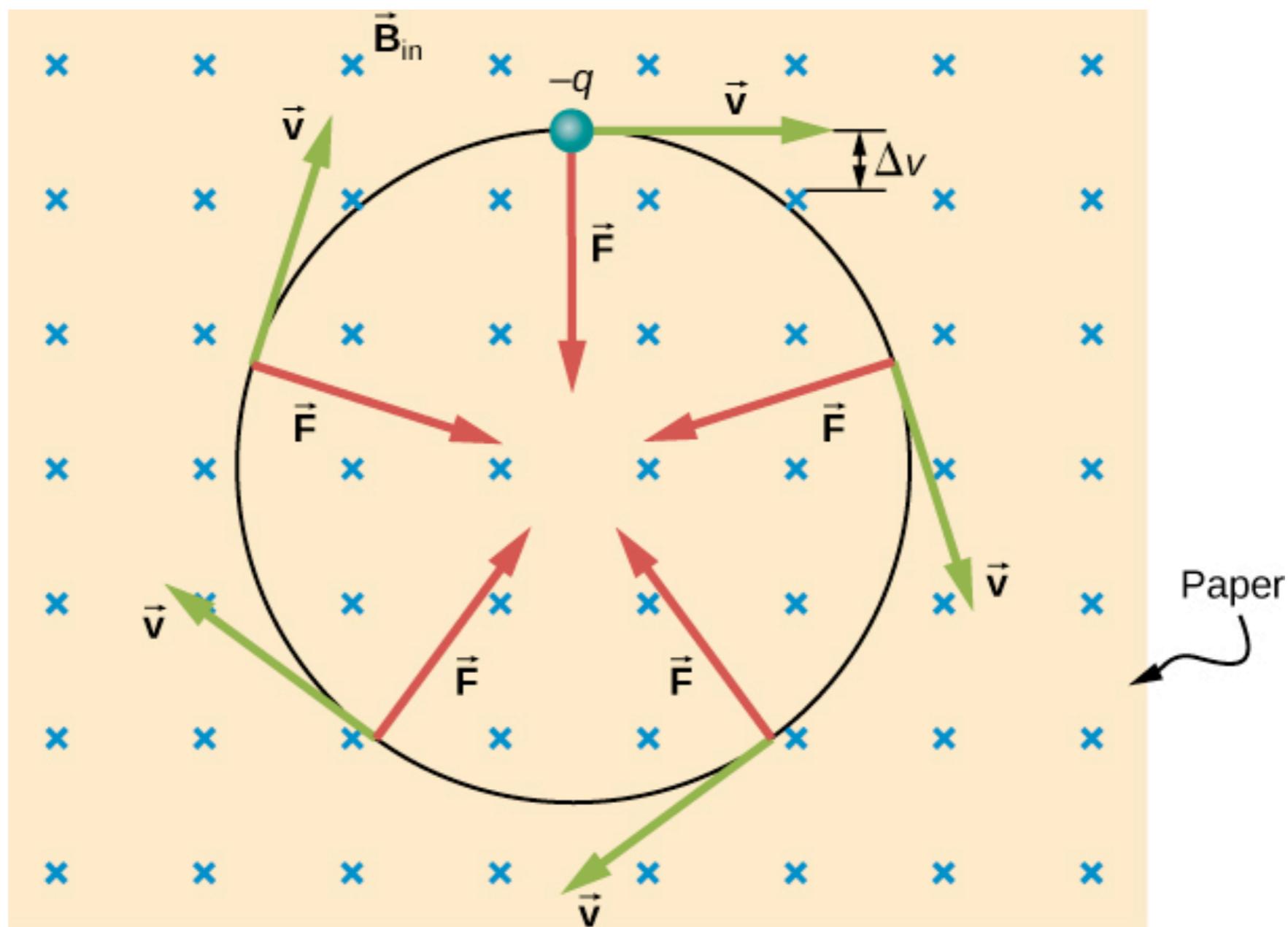
How to accelerate charged objects?

- We use the electric field!



How to turn particles?

- We use the magnetic field!



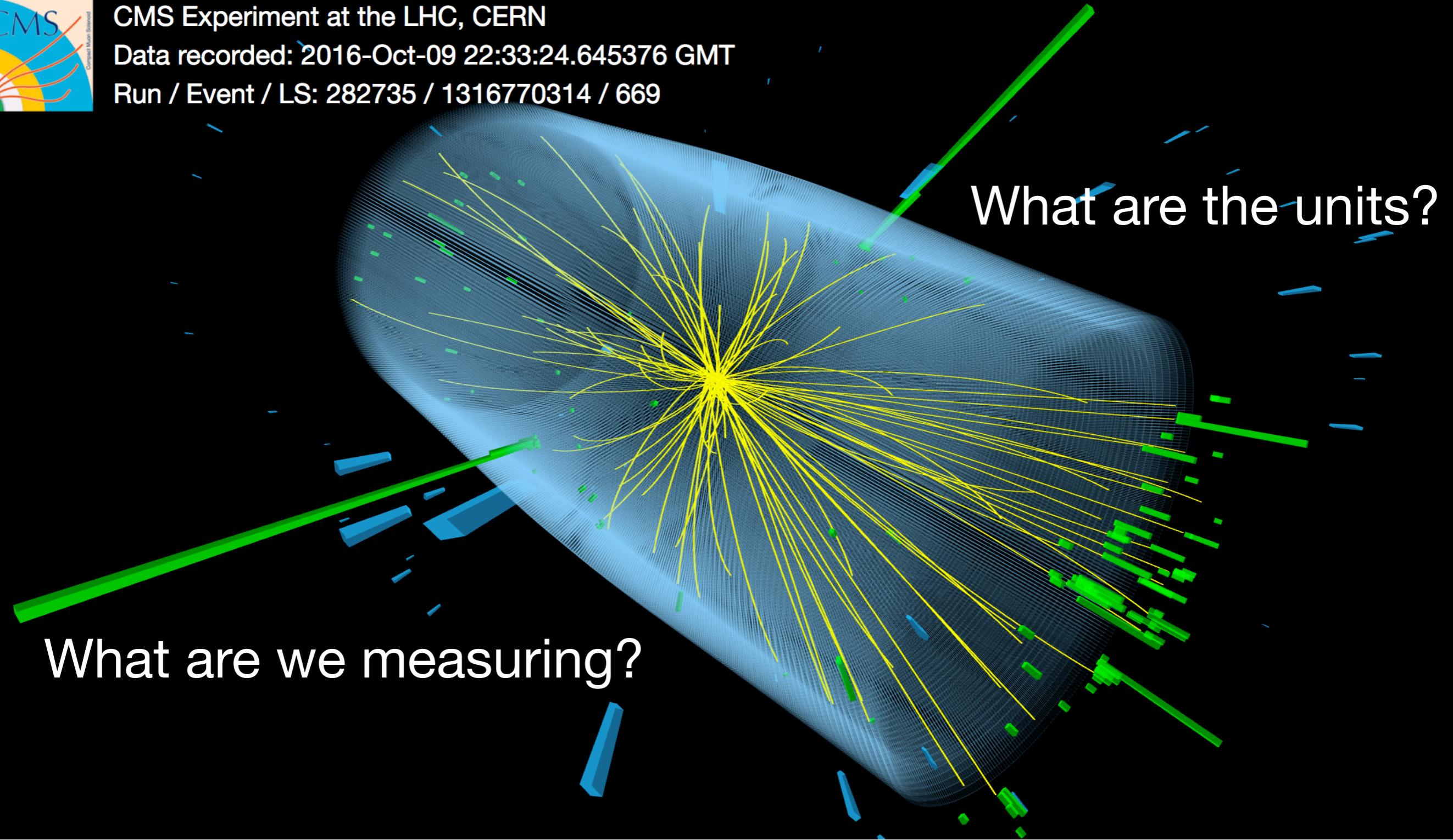
Topic of the day

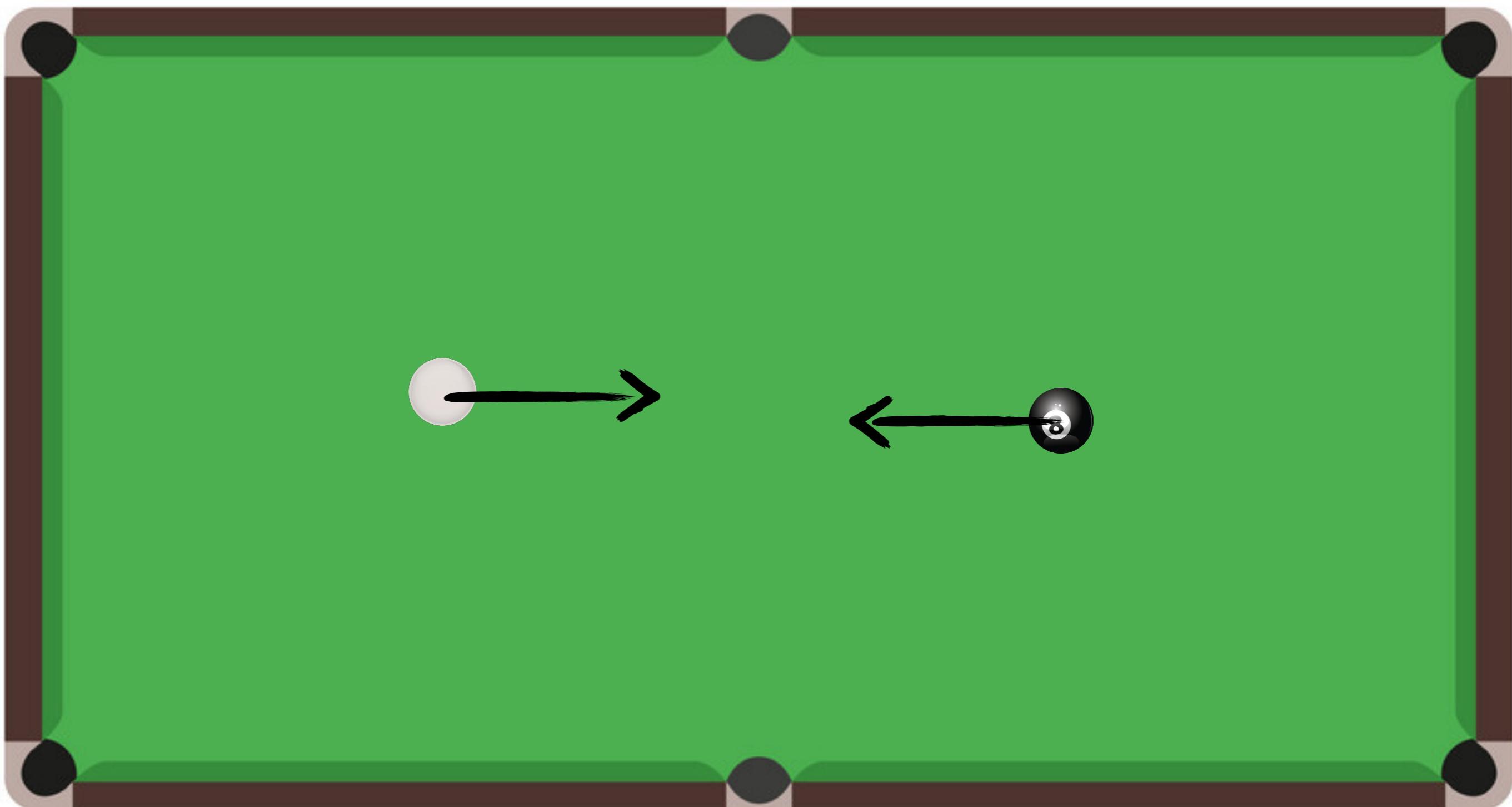


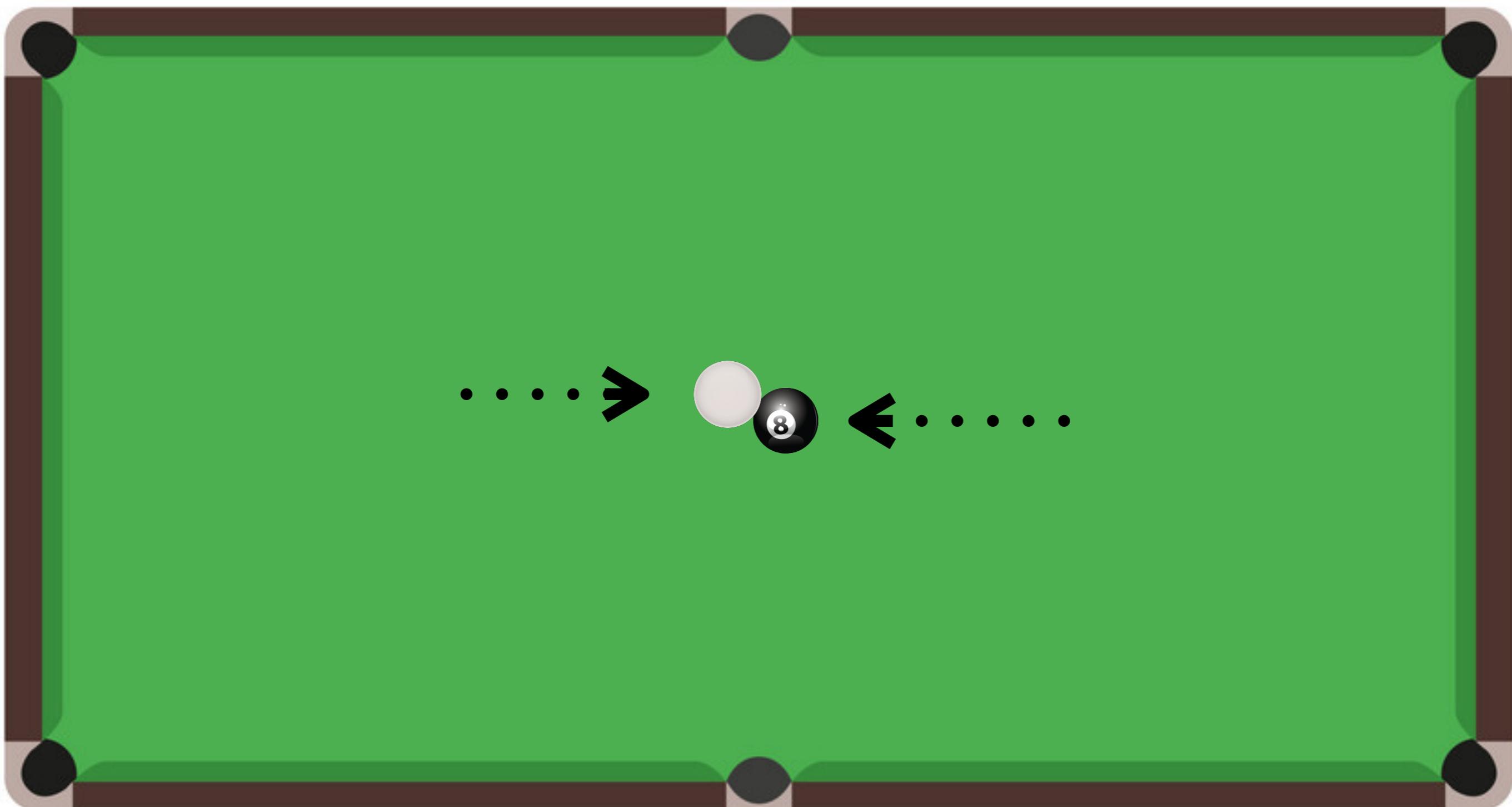
CMS Experiment at the LHC, CERN

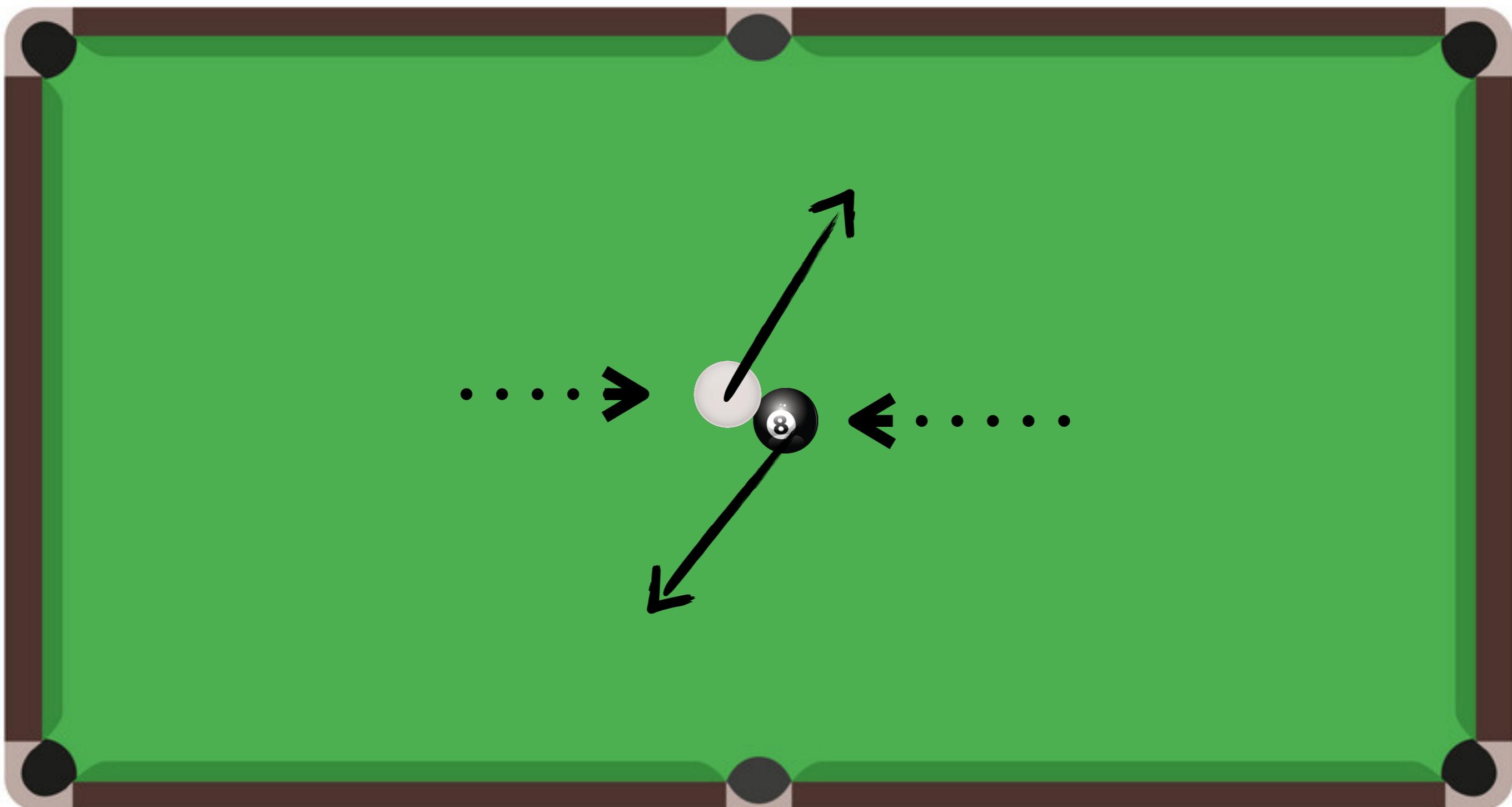
Data recorded: 2016-Oct-09 22:33:24.645376 GMT

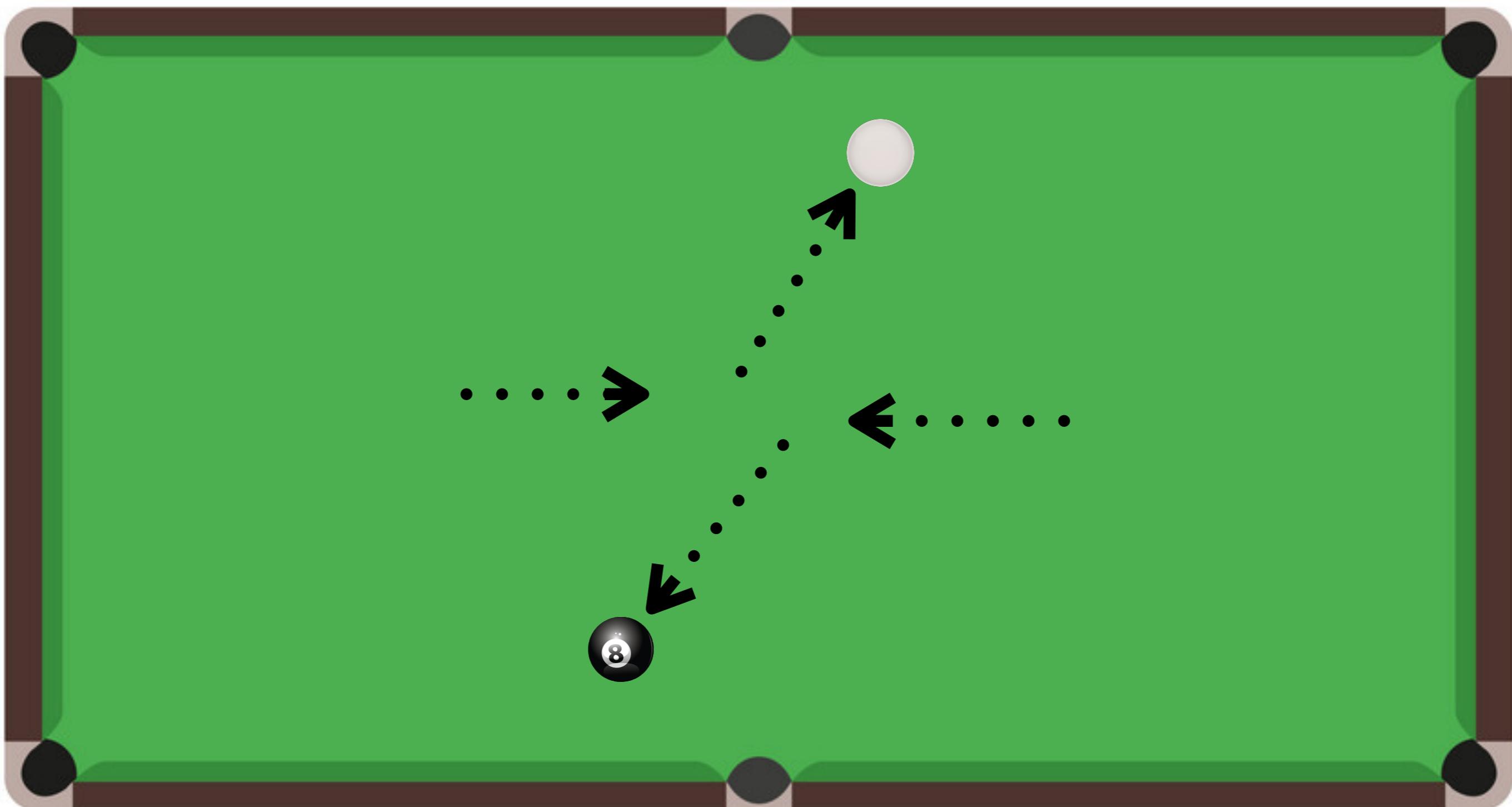
Run / Event / LS: 282735 / 1316770314 / 669

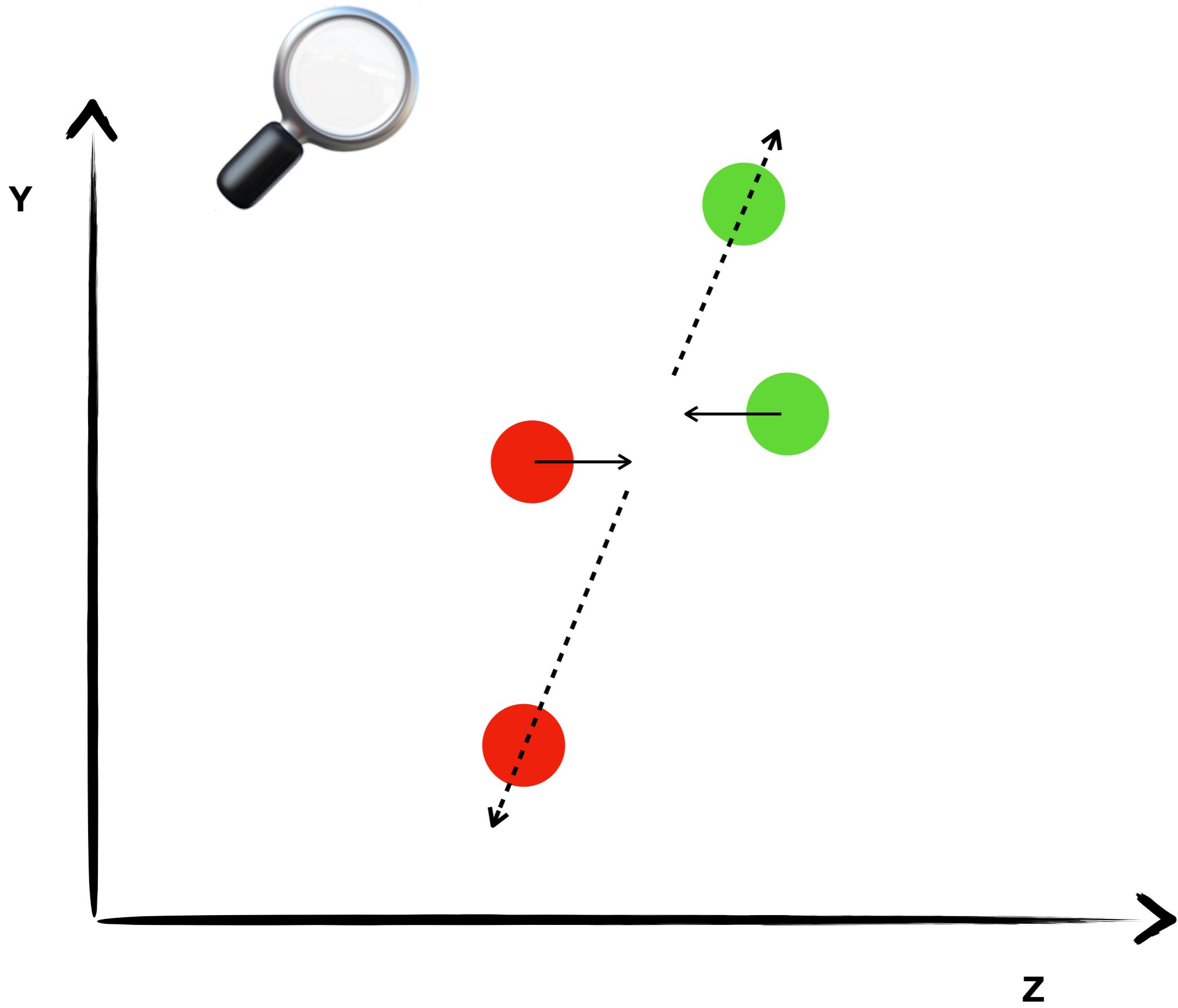






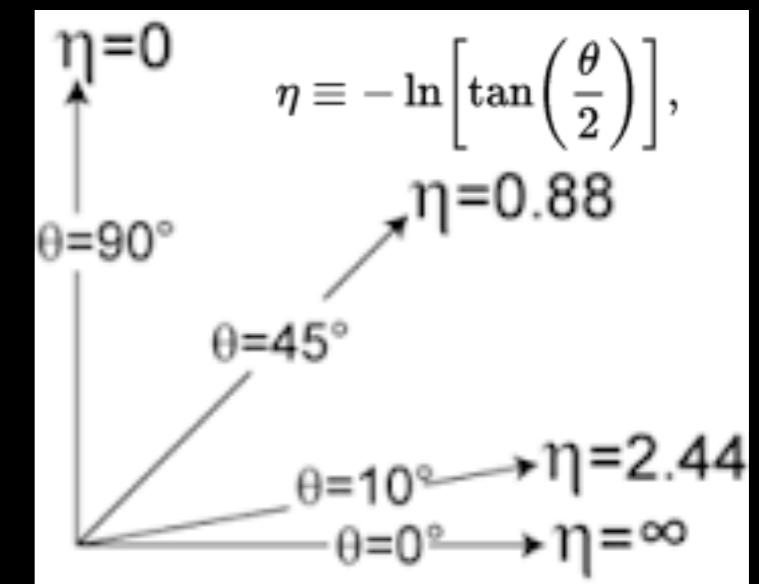
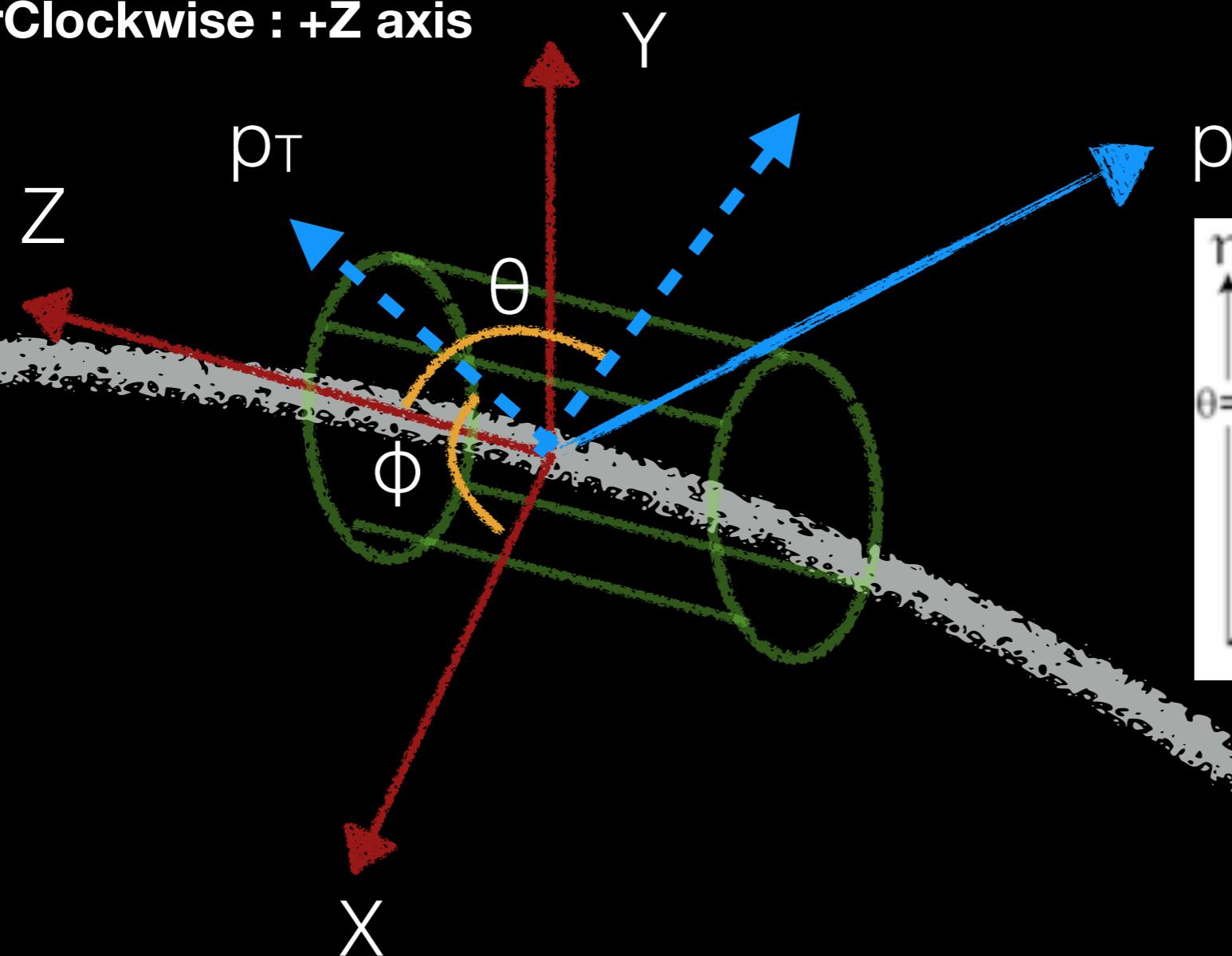






Axis and Variables

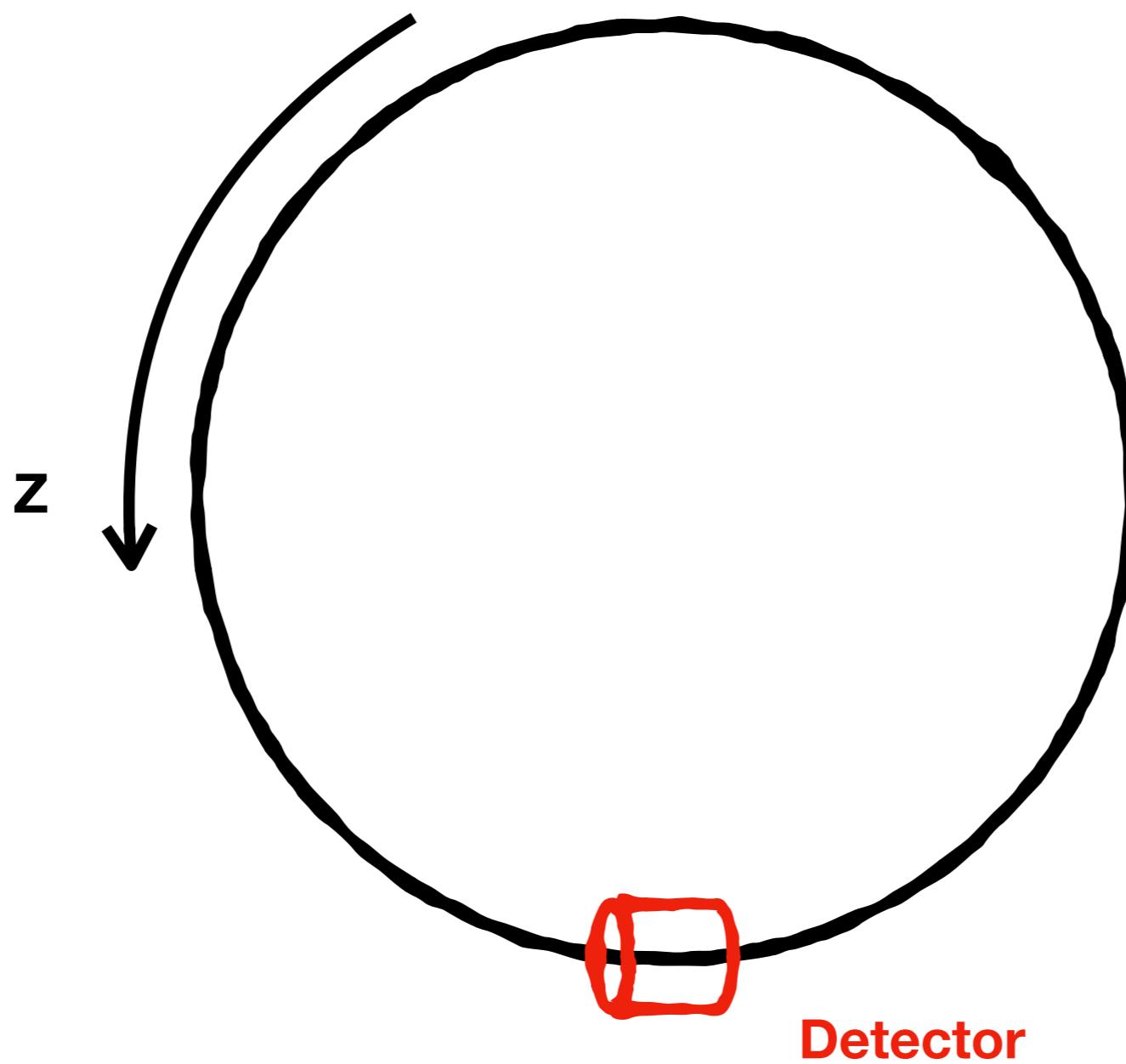
CounterClockwise : +Z axis



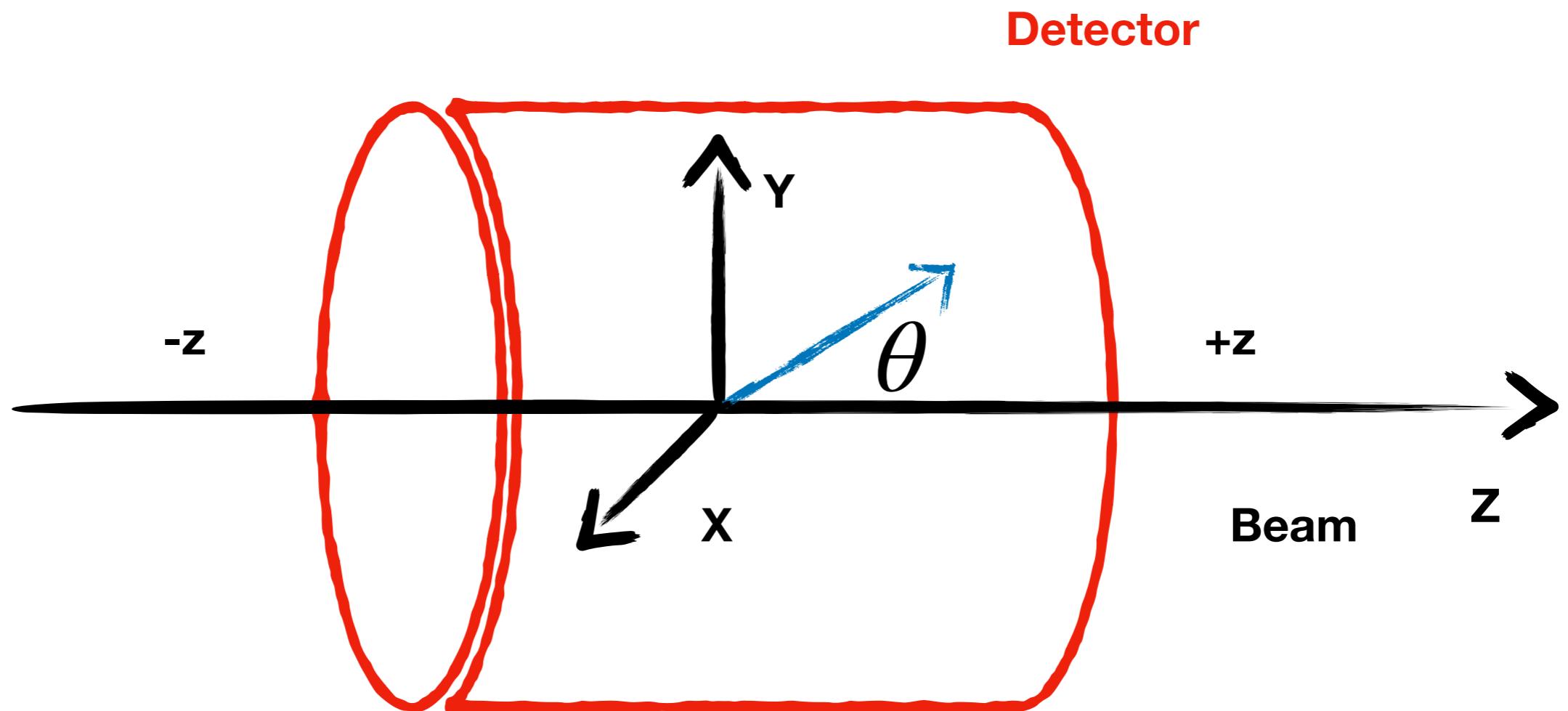
X-Y : Transverse Plane

Y-Z : Longitudinal Plane

Collisions axes

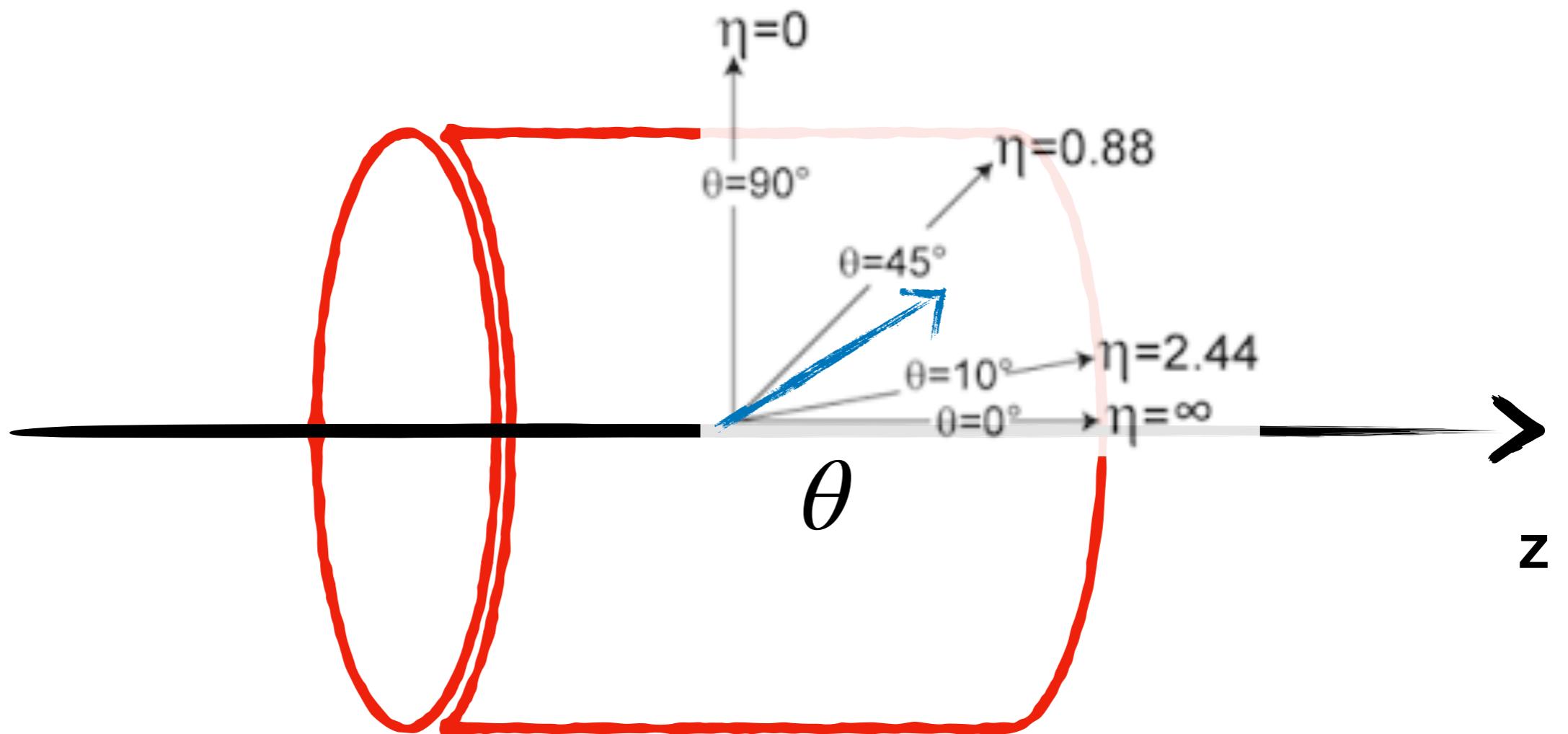


Collisions axes



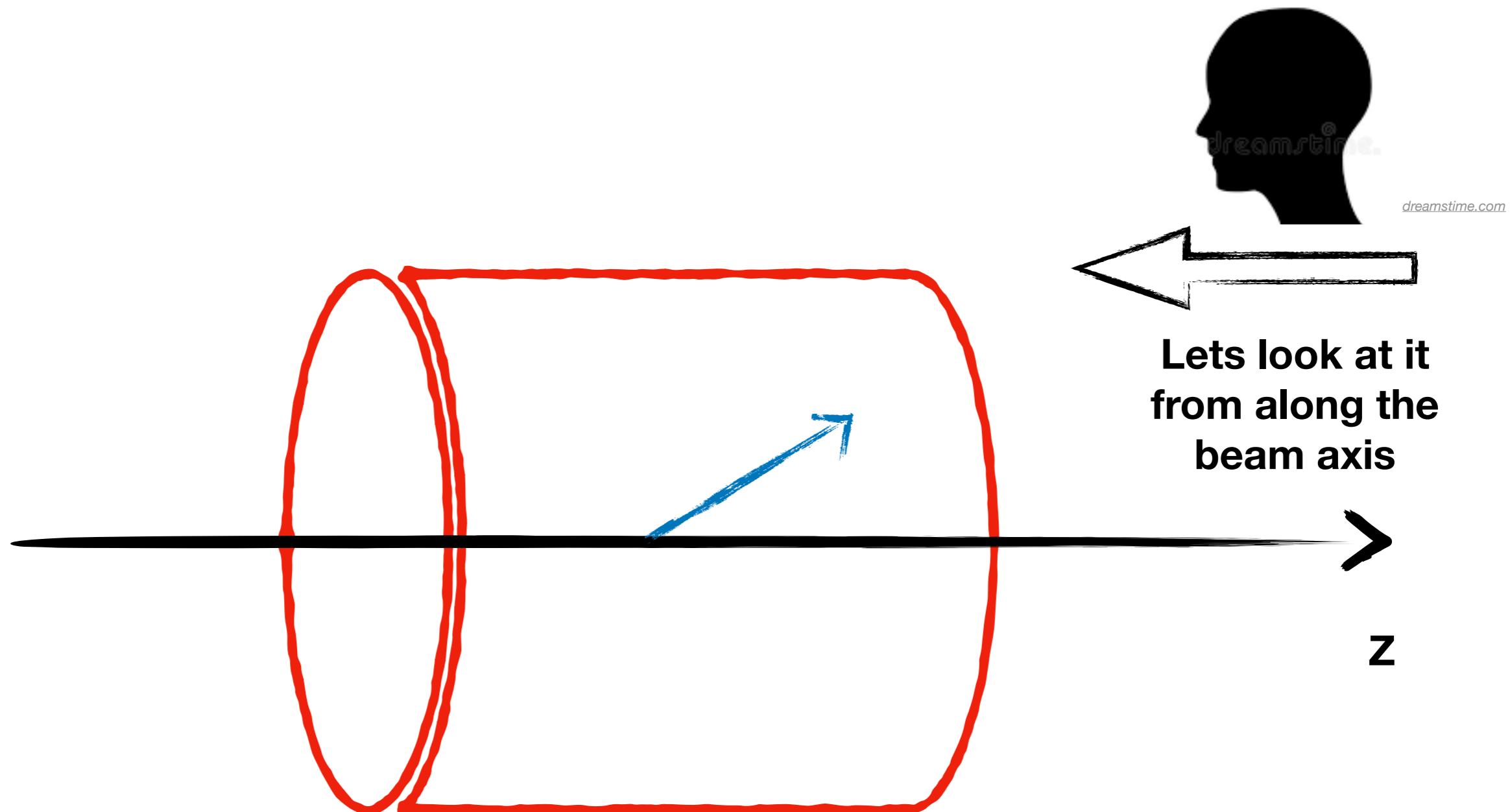
$$\vec{p} = (p_x, p_y, p_z, E)$$

Collisions axes

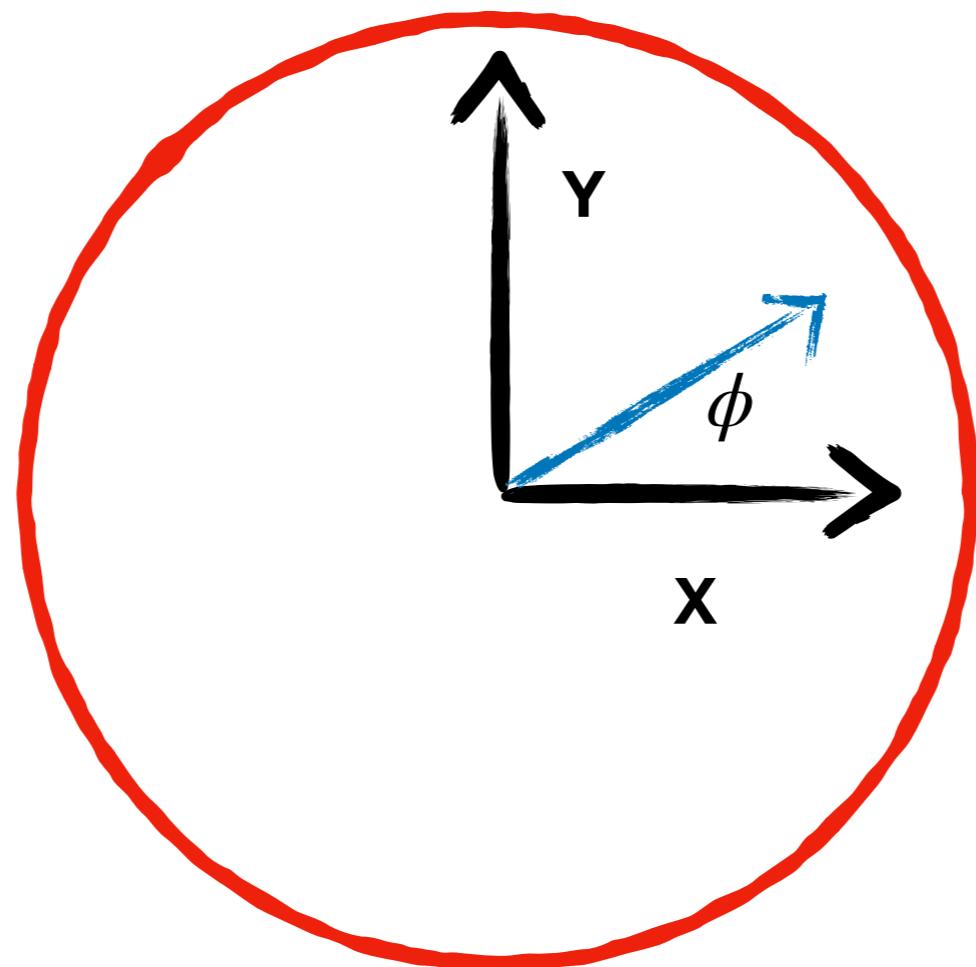


Pseudorapidity η in the longitudinal plane

Collisions axes



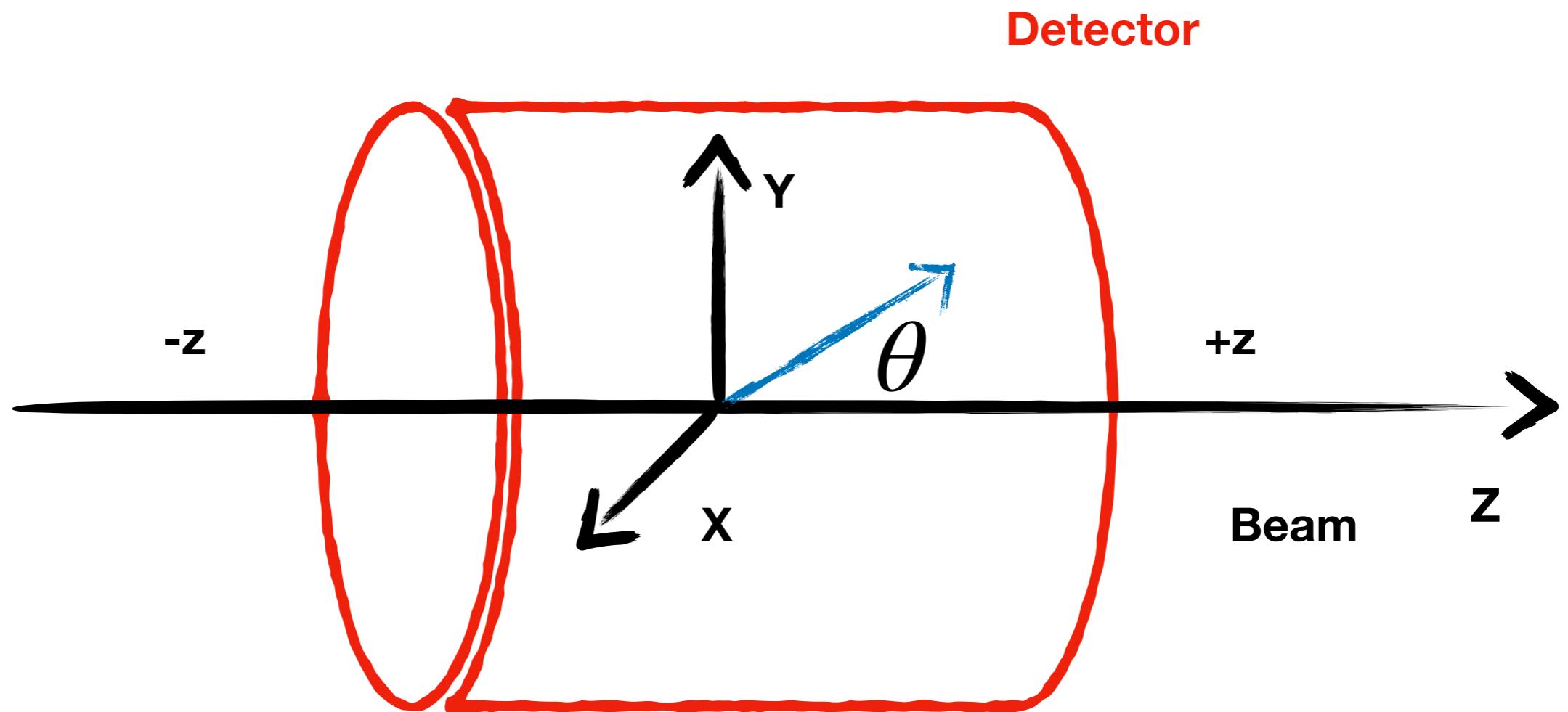
Collisions axes



Beams are going in
and out of the screen

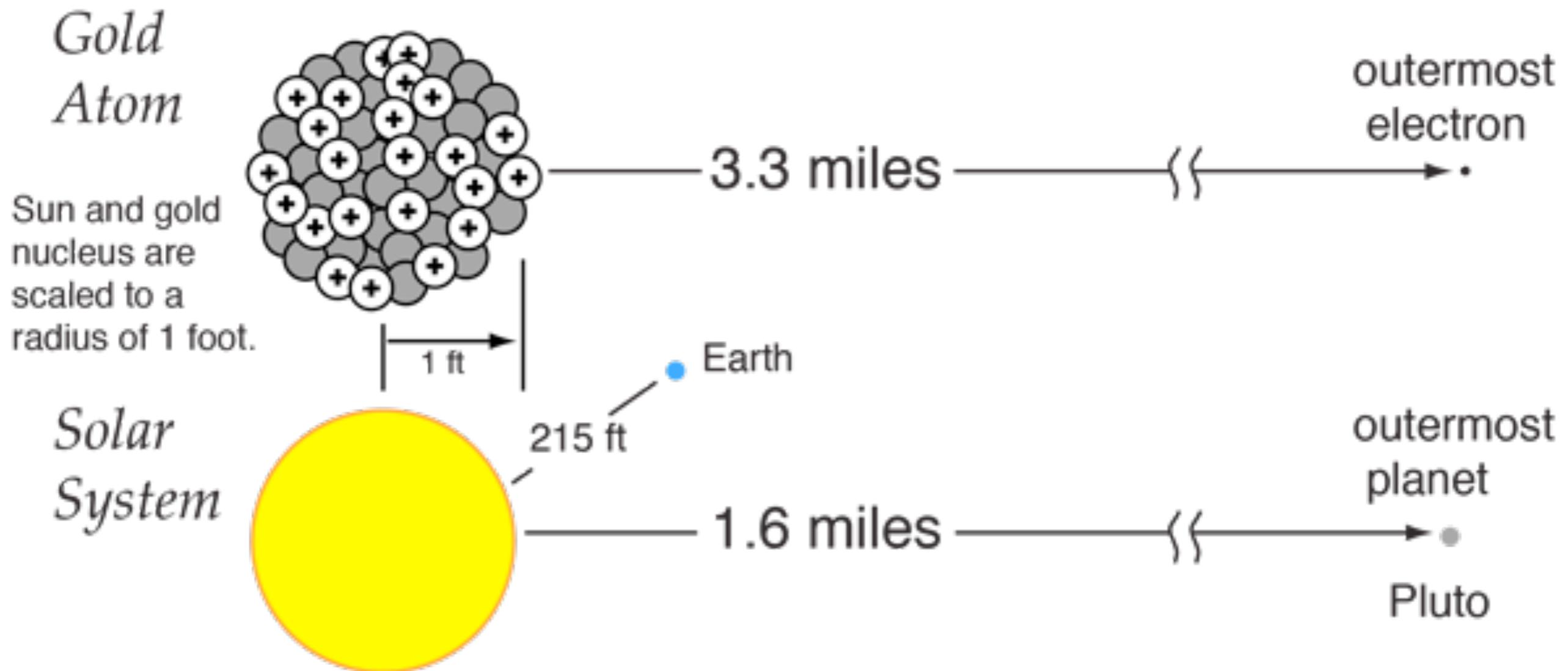
Azimuthal angle in the transverse plane

Collisions axes



$$\vec{p} = (p_T, \eta, \phi, M)$$

UNITS



Our normal units of grams/pounds, meters, joules etc.. don't make sense
Need specific units designed for high energy physics

UNITS

Lets introduce the electron volt (eV):

Energy of e- after accelerating through 1V potential field.

Energy = (mass)(length)²/(time)²

Energy/velocity = (mass)(length)/(time) - units of
momentum

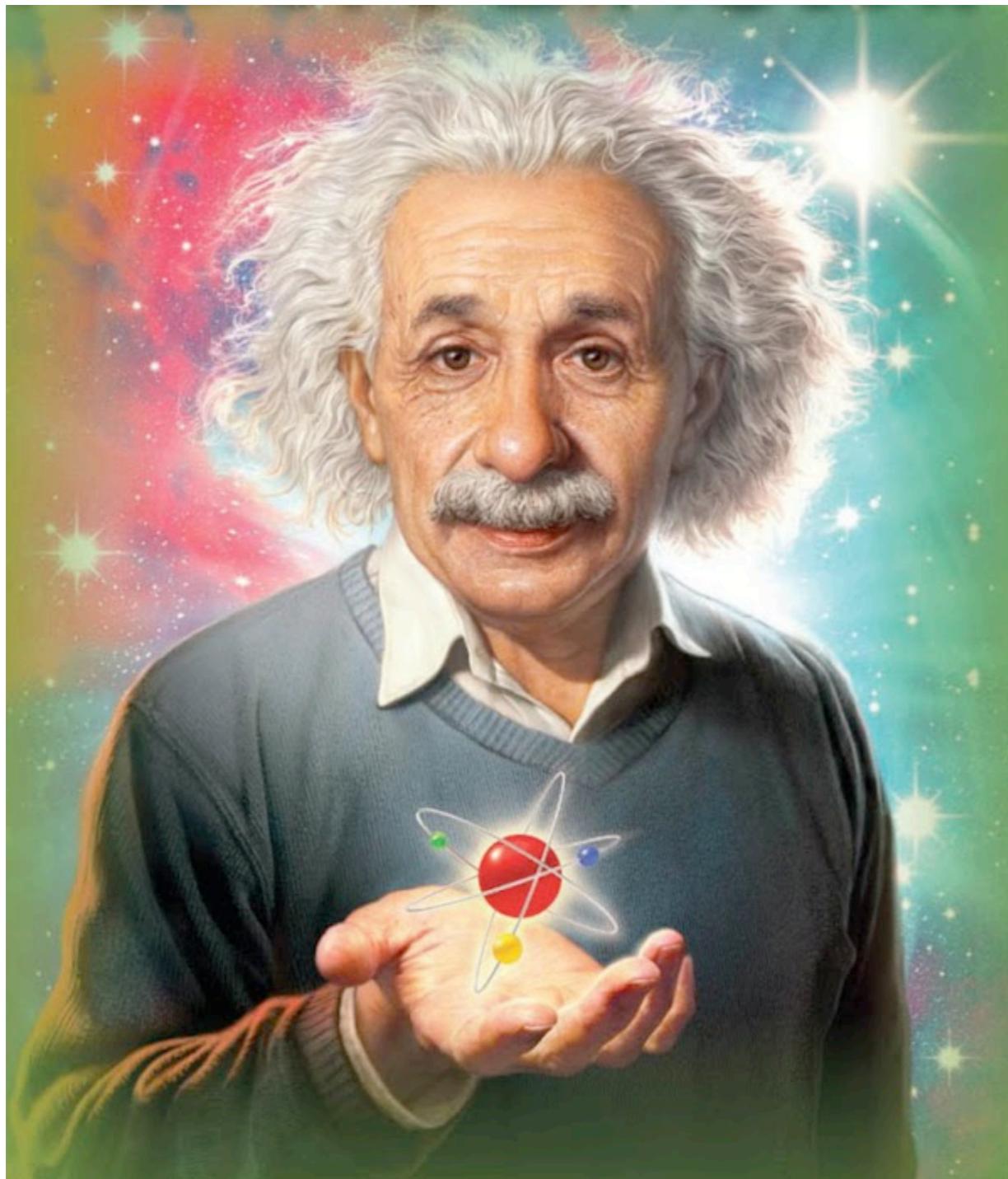
Momentum/velocity = mass

Energy: 1 eV = $1.602176487 \times 10^{-19}$ J

Momentum: 1 eV/c = 5.36×10^{-28} kgm/s

Mass: 1 eV/c² = 1.783×10^{-36} kg (e- 511 keV/c² ~ 10^{-30} kg)

Need Einstein's help here



- Energy and mass are related
- So for particles at rest
 $E = mc^2$
- Objects are also traveling very fast
- Generally assume that speed of light is 1 and use the units of GeV/c for momentum and GeV/c^2 for mass

Activity



- Lets high-five our neighbor!
- How much energy did we just generate in GeV?

Activity

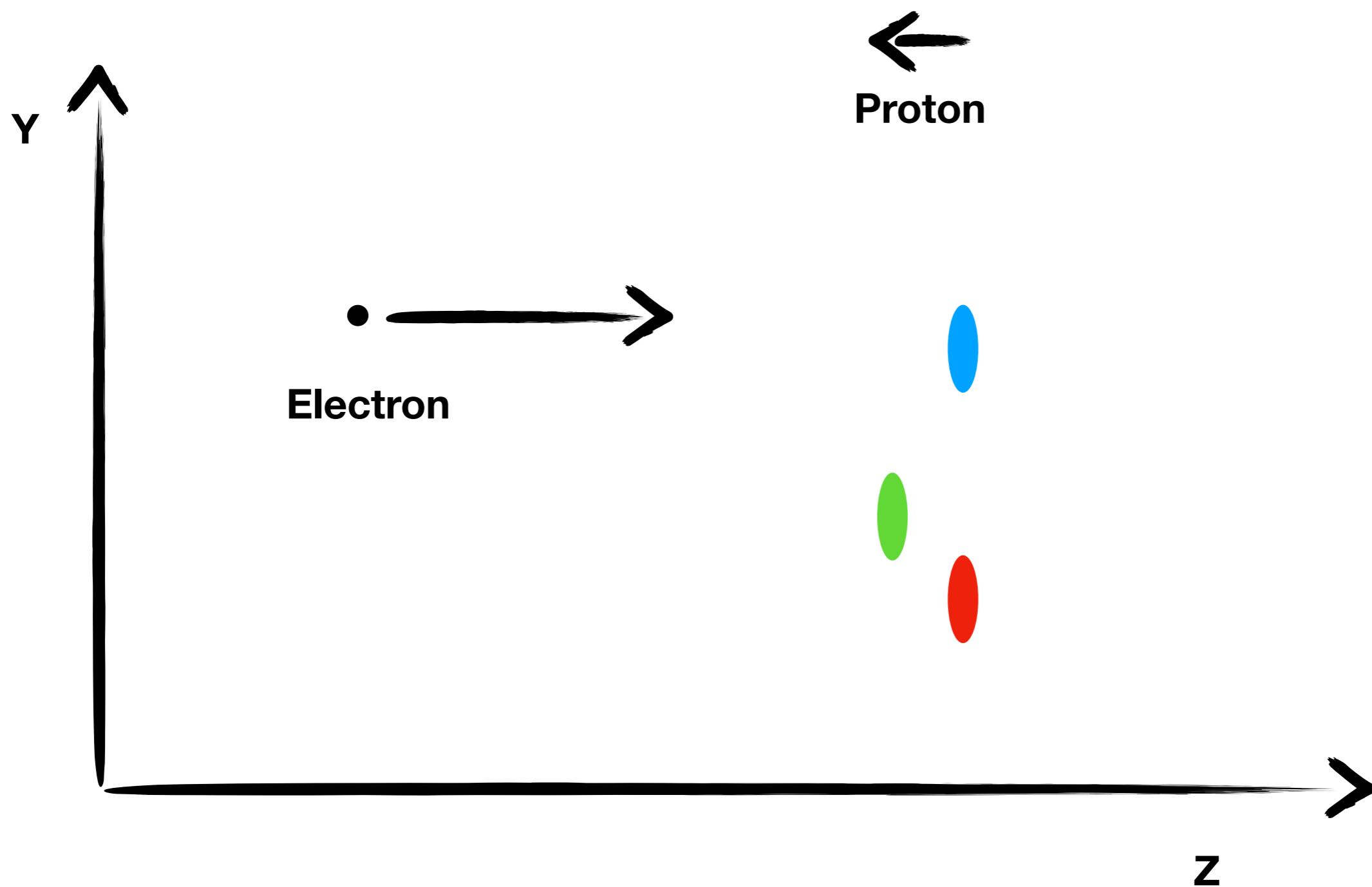


- Lets high-five our neighbor!
- How much energy did we just generate in GeV?

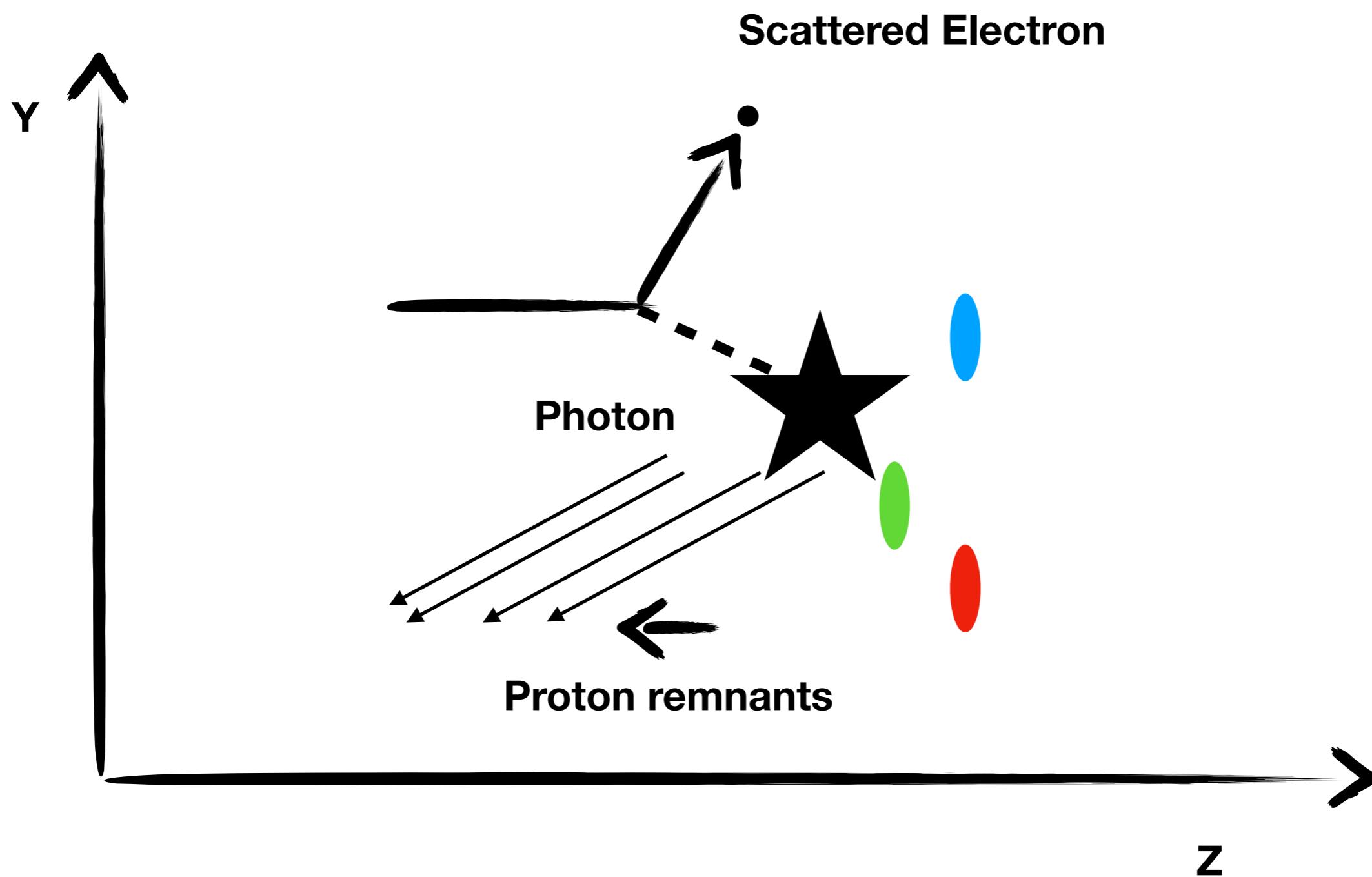
Roughly 10^9 GeV over a relatively large area!

($1 \text{ TeV} = 1 \text{ million million eV} = 1.6 \times 10^{-7} \text{ J} = \text{K.E. of flying mosquito}$)

Electron Proton Collisions

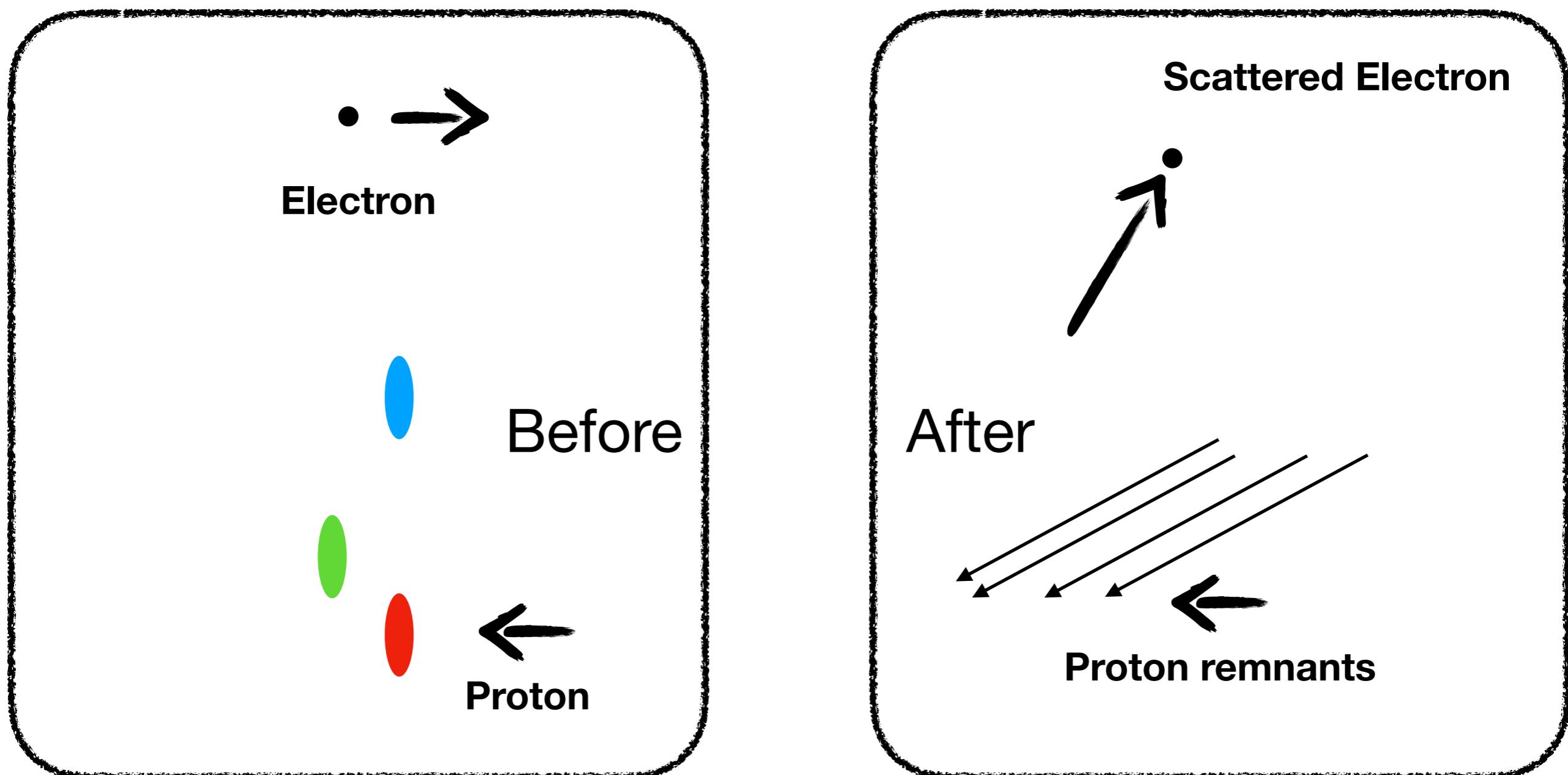


Electron Proton Collisions



Energy/Momentum Conservation

Fundamental constraint of nature





Lets run our own simulations! - to the jupyter notebooks