ATLAS experiment + sMDT

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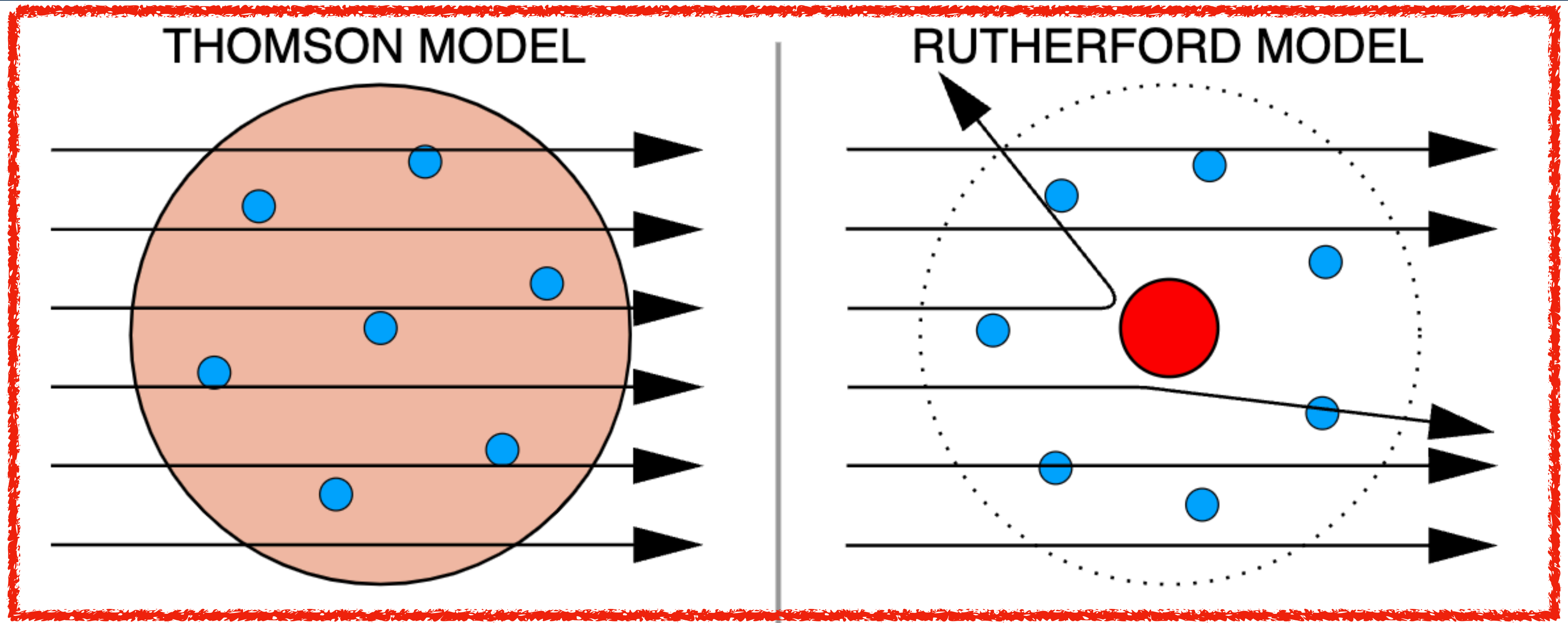
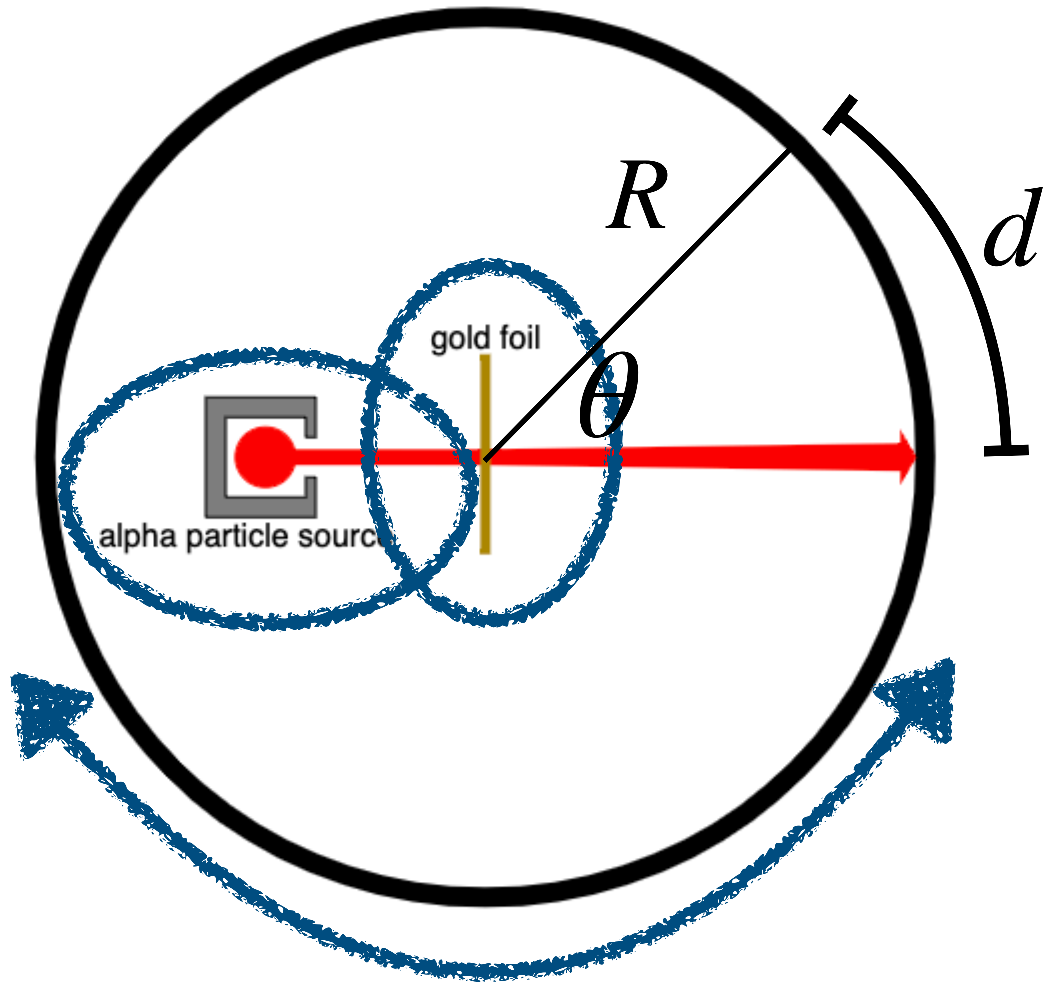
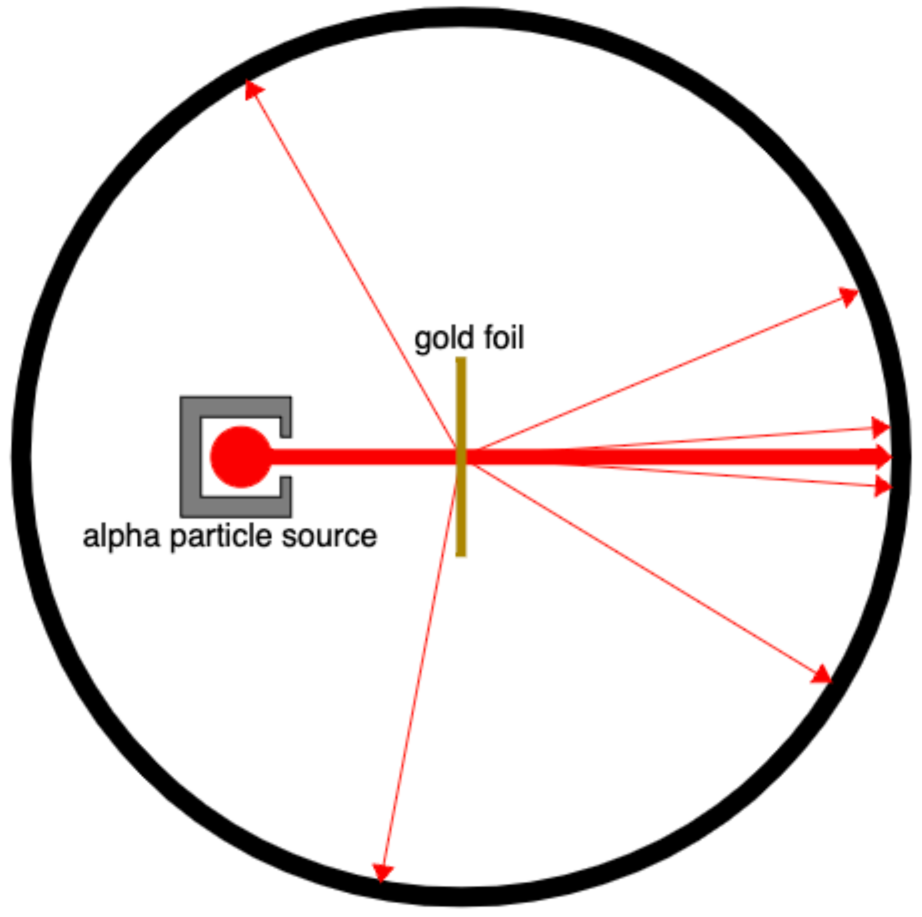
Methodology of Subatomic Physics

- **One of the first modern particle physics experiments led to the discovery of the atomic nucleus.**
  - This is an illustrative example to recall as the experimental techniques and theoretical concepts become complex.
- **The main features of a particle physics experiment:**
  - Source of energetic particles: alpha particles from radioactive isotope
  - An interaction: fixed target of gold foil
  - A detector: phosphorescent screen
  - An observable: Angular deflection $|\theta| = d/R$
  - Two alternative hypotheses: Charge is distributed evenly (Thomson) or concentrated in a dense nucleus (Rutherford)
    - Critically, the two hypotheses must describe a different expected *distribution of the observable!!*



Top-down view of a tabletop

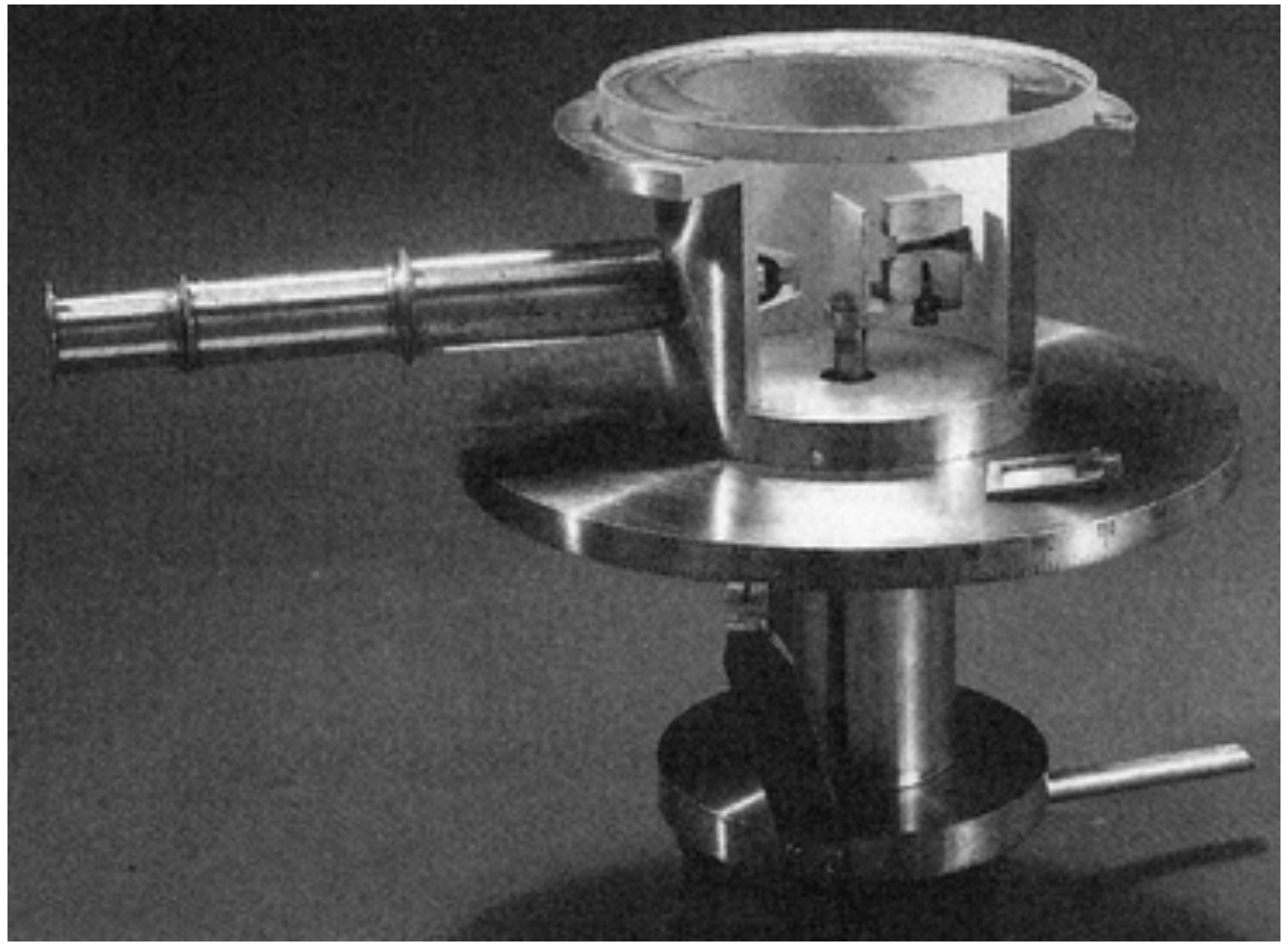


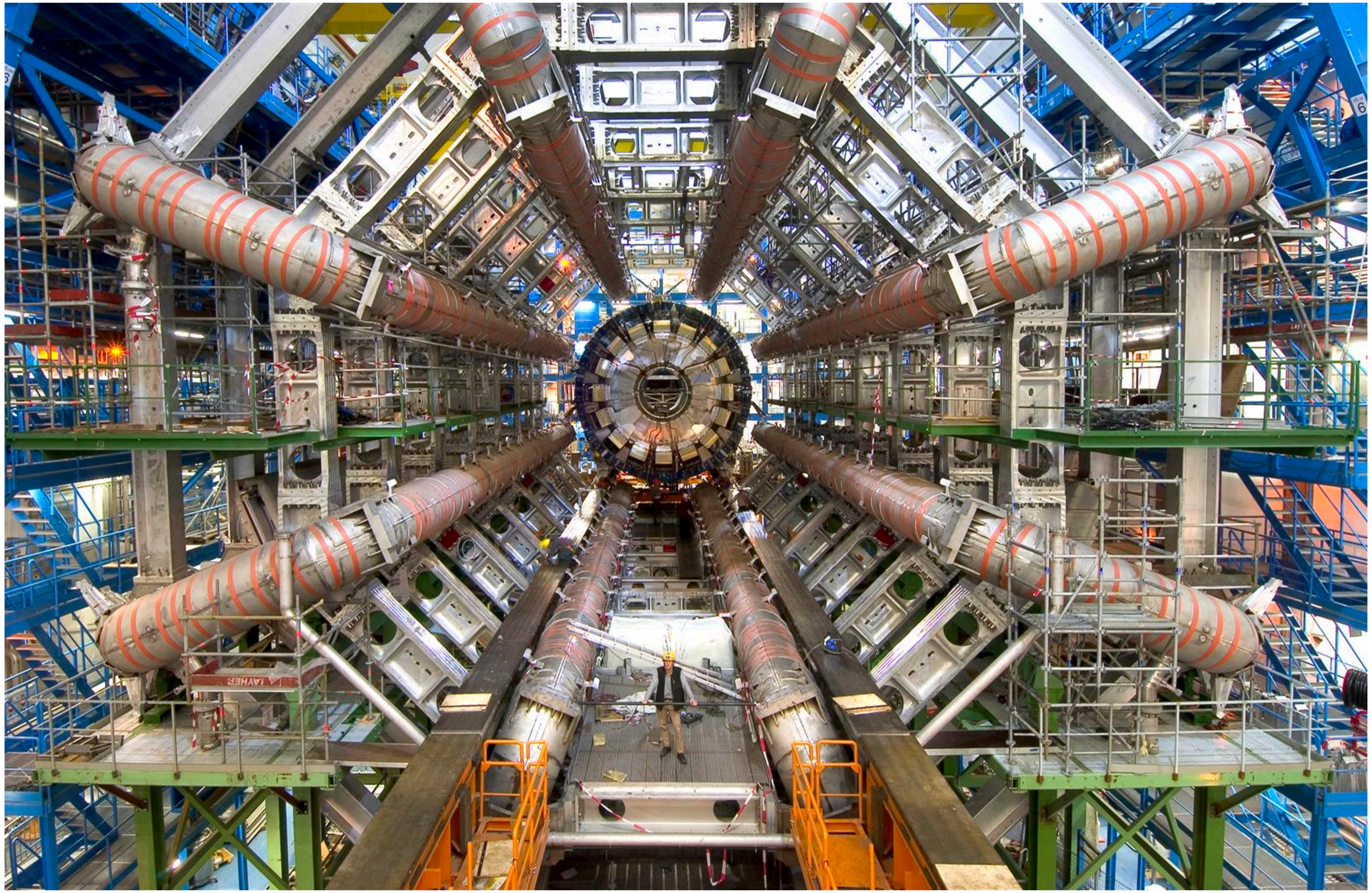


observed result

Methodology of Subatomic Physics

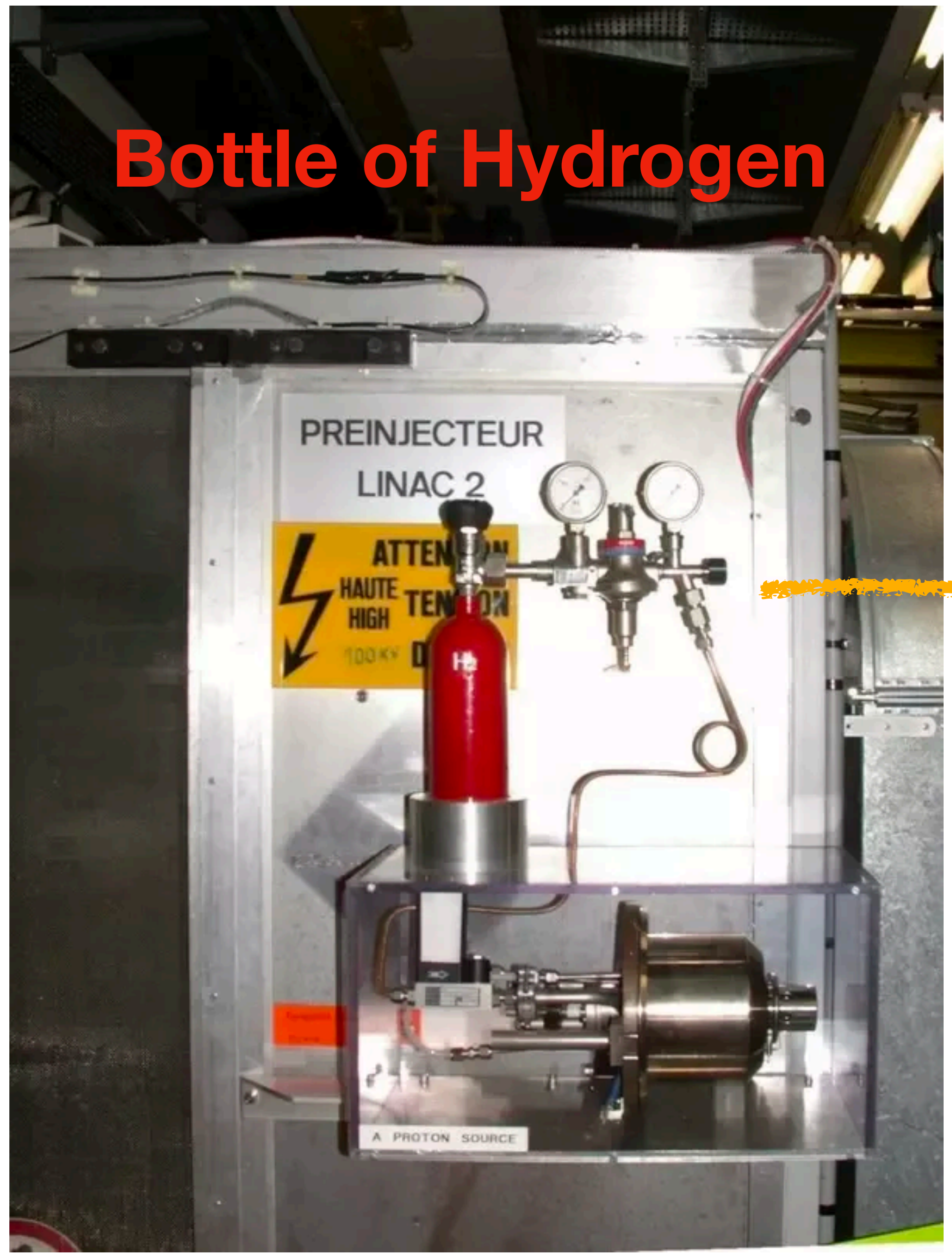
How, and for that matter, *why*, do the experiments go from looking like this…



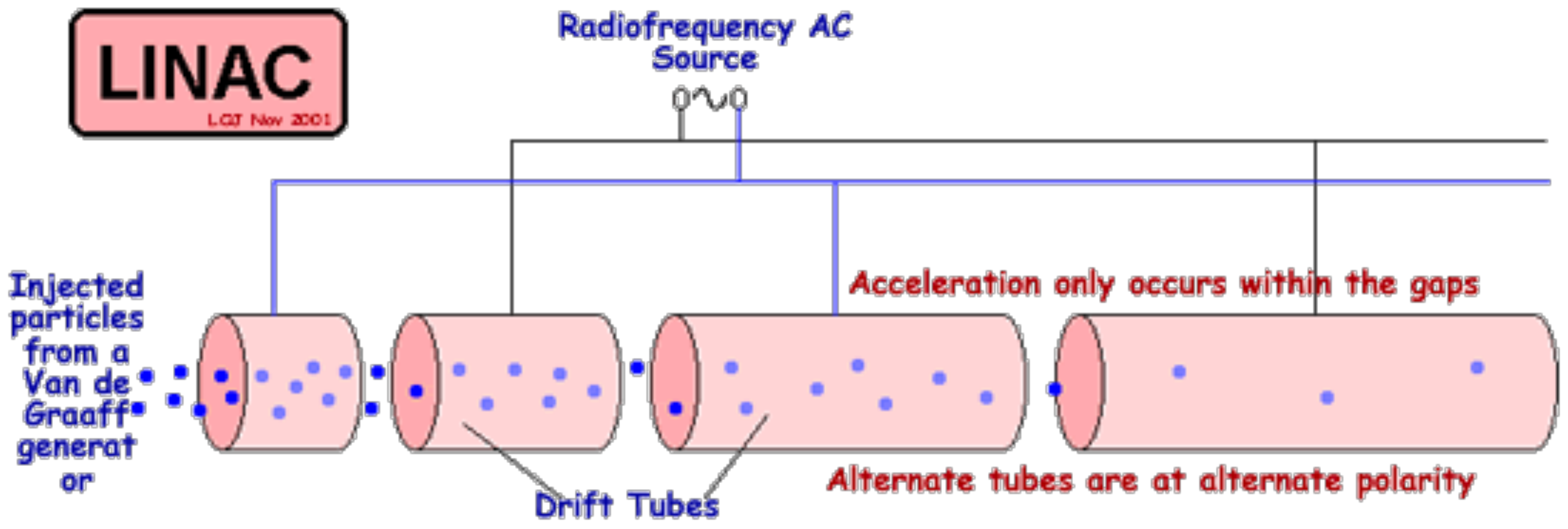


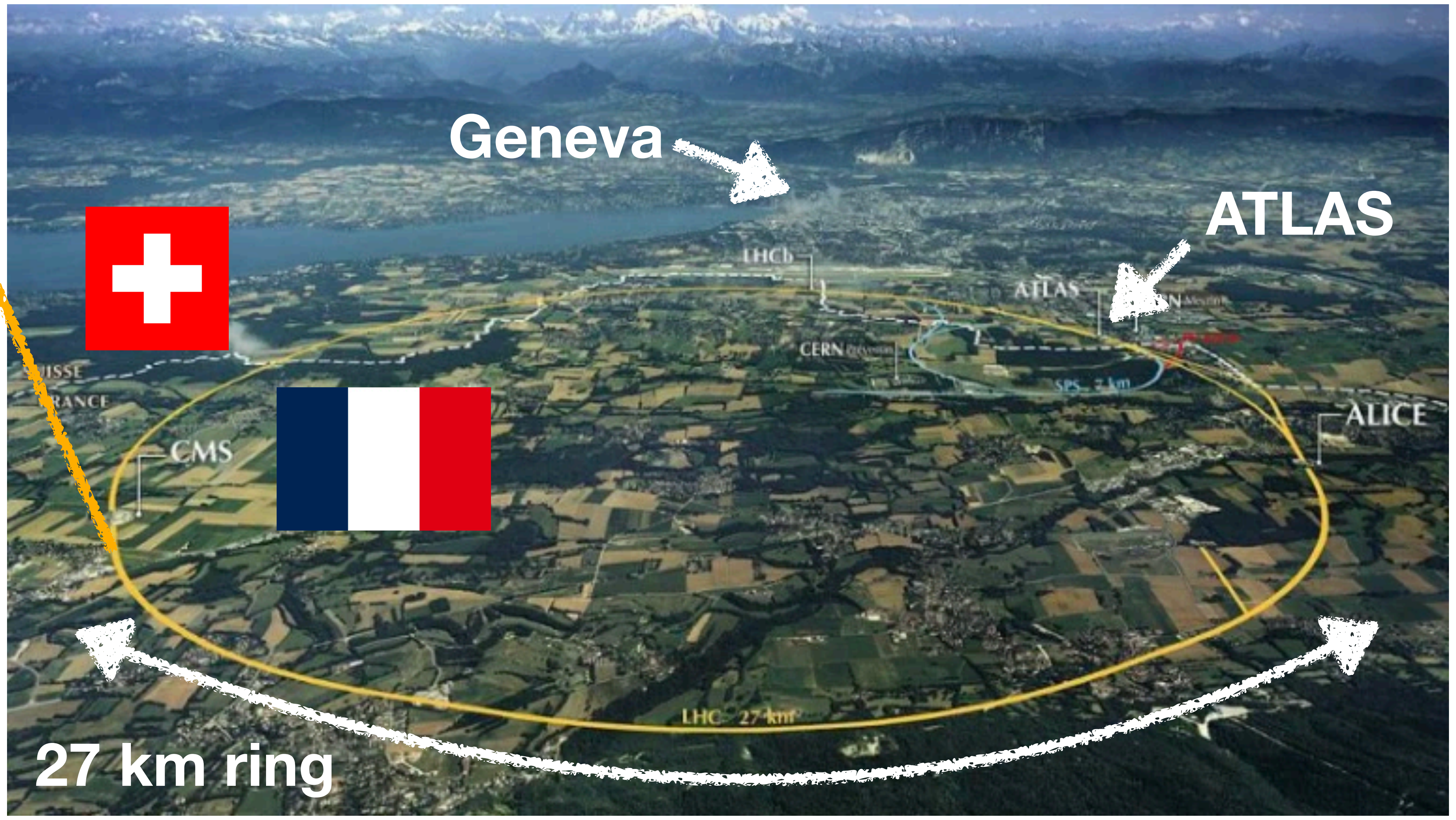
…to this?

The Large Hadron Collider



Several successive boosters, synchrotrons





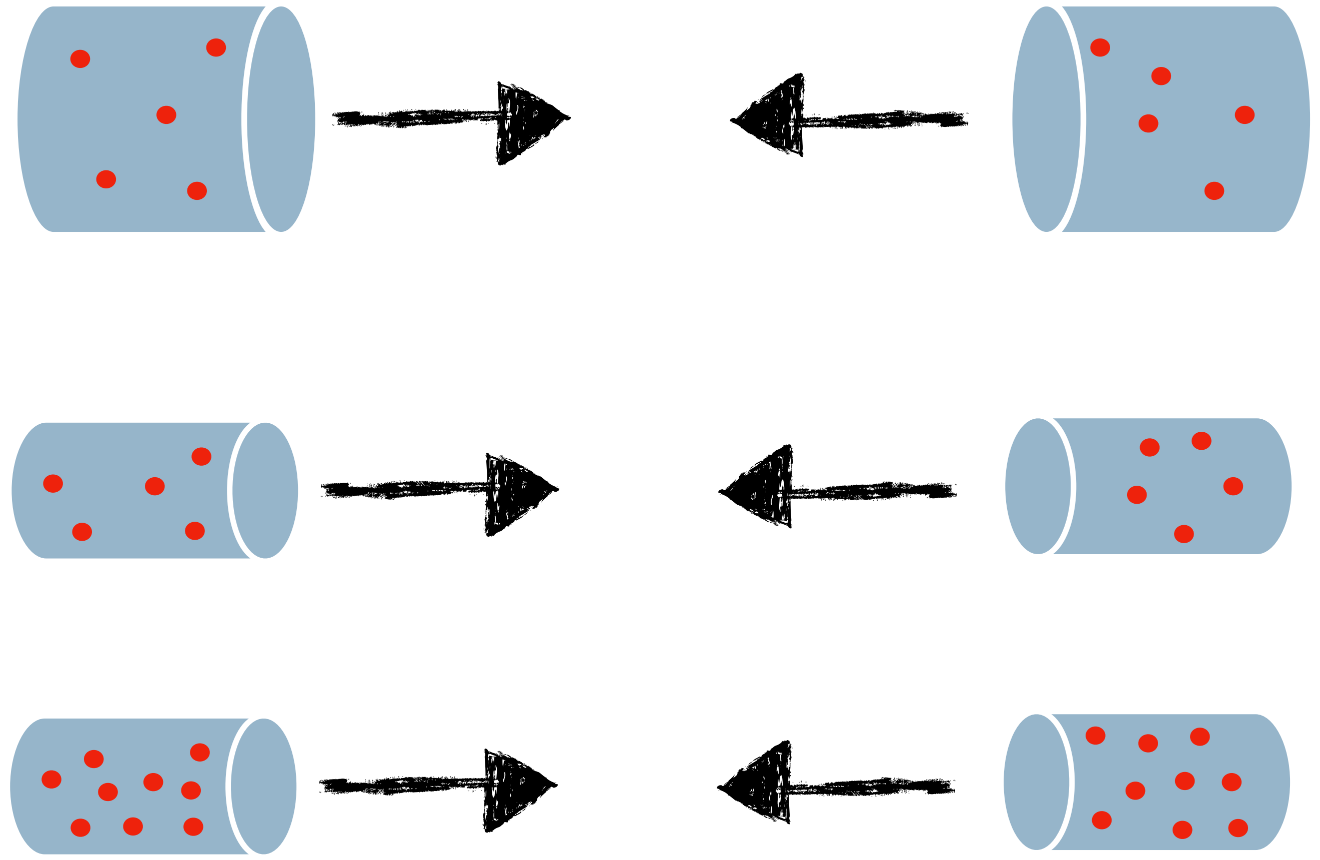
Protons circulate both directions and collide at $\sqrt{s} = 13$ TeV

- *Luminosity* refers to how many collisions we produce: either *instantaneous* or *integrated* over time

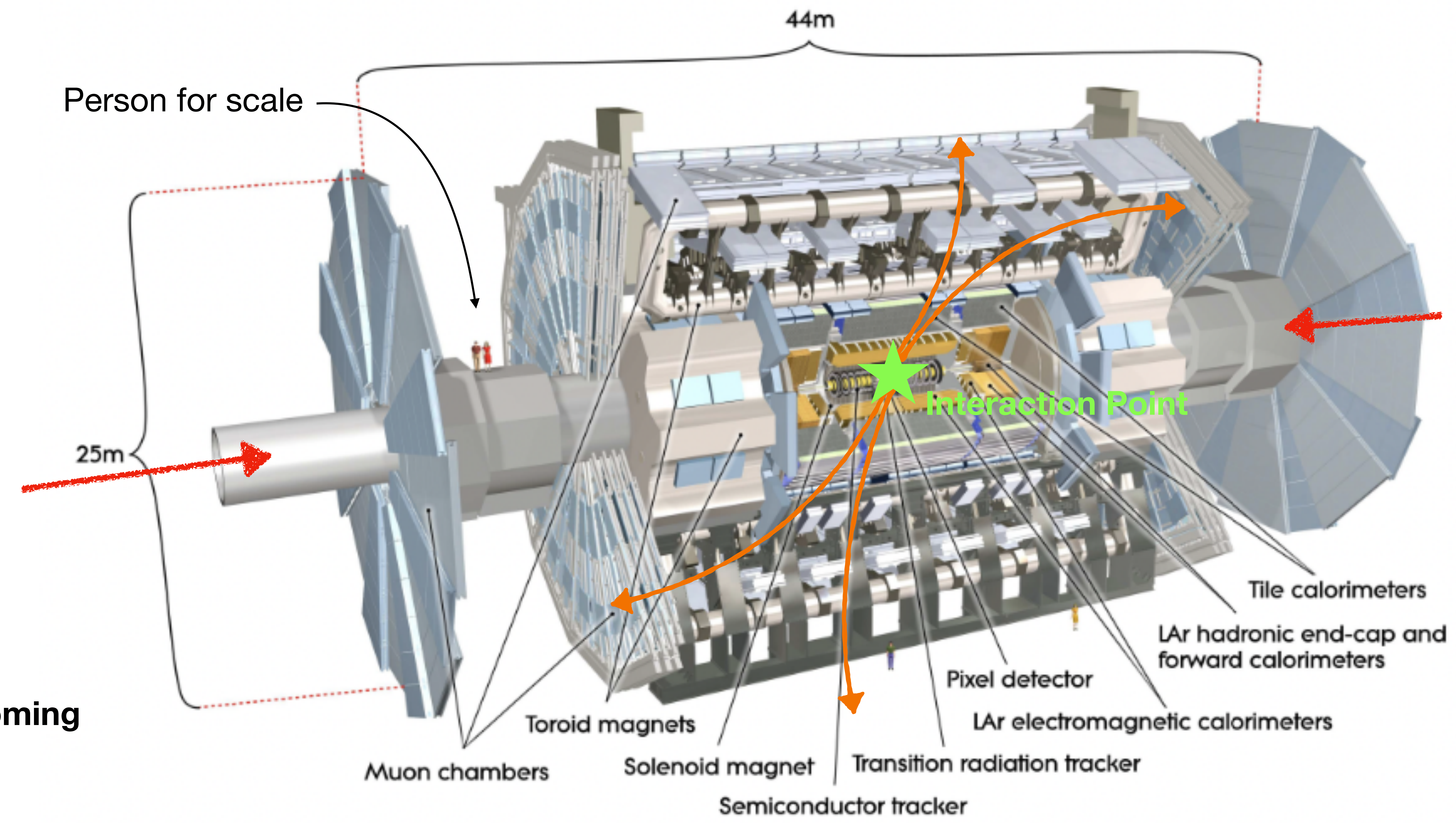
Low lumi

Higher lumi

Highest lumi



The ATLAS Detector



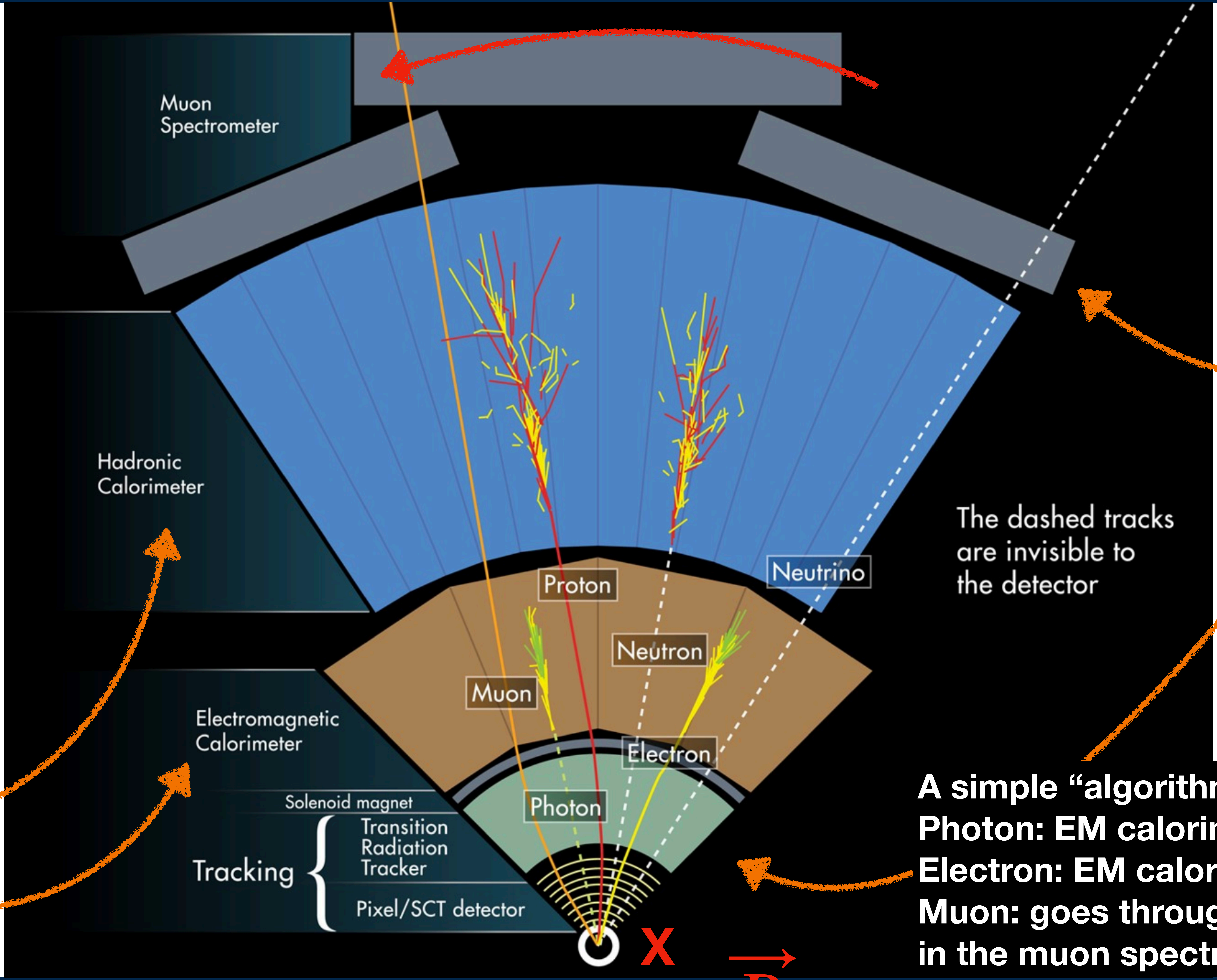
LHC Proton beam
6.5 TeV

We search for 4 leptons coming
From a Higgs boson

The ATLAS Detector

Detectors are made of an *ensemble* of ground state particles.
When an energetic particle passes through, it excites the detector
- Ionize a gas
- Create electron-hole pairs
- Produce light

<u>Calorimeters:</u>
- Destructive
- Initiate a "shower" of child particles, only some of which are visible to the detector
- Calculate energy via sampling+calibration
- In ATLAS:
  - Hadronic Calorimeter
  - EM Calorimeter



<u>Tracking Detectors:</u>
- Non-destructive
- Sample trajectory of a particle
- Calculate momentum via bend in magnetic field
- In ATLAS:
  - Muon Spectrometer
  - Inner Detector

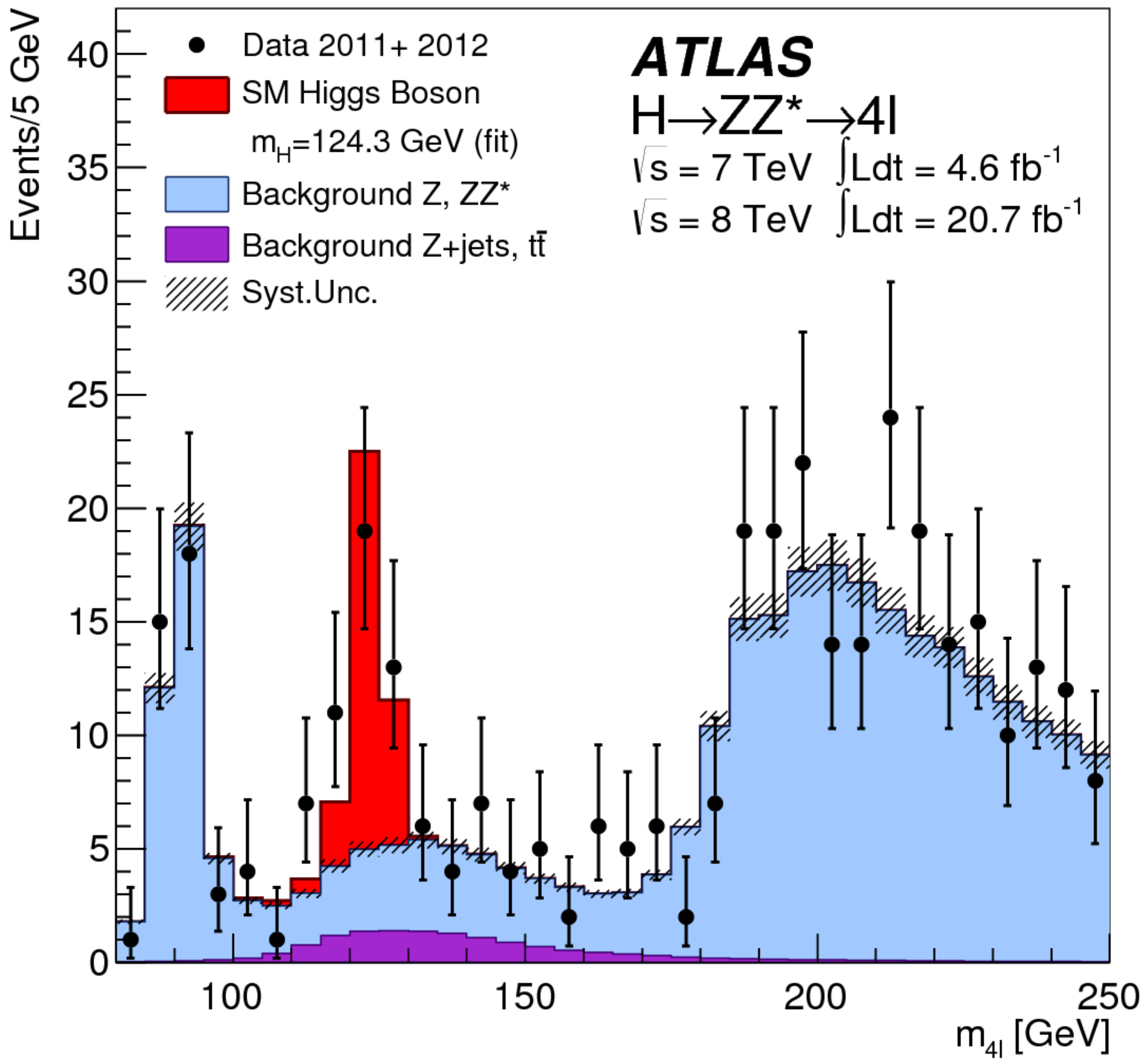
A simple "algorithm" to identify particles:
Photon: EM calorimeter cluster, no track
Electron: EM calorimeter cluster + track
Muon: goes through calorimeters and bends in the muon spectrometer

Discovery of the Higgs Boson

- **Using the ATLAS and CMS detectors, a new particle was discovered in 2012.**

- **We smash protons together and each time record the 4-lepton mass**

- **There is a sharp peak near 125 GeV because the mass of the Higgs boson is 125 GeV**



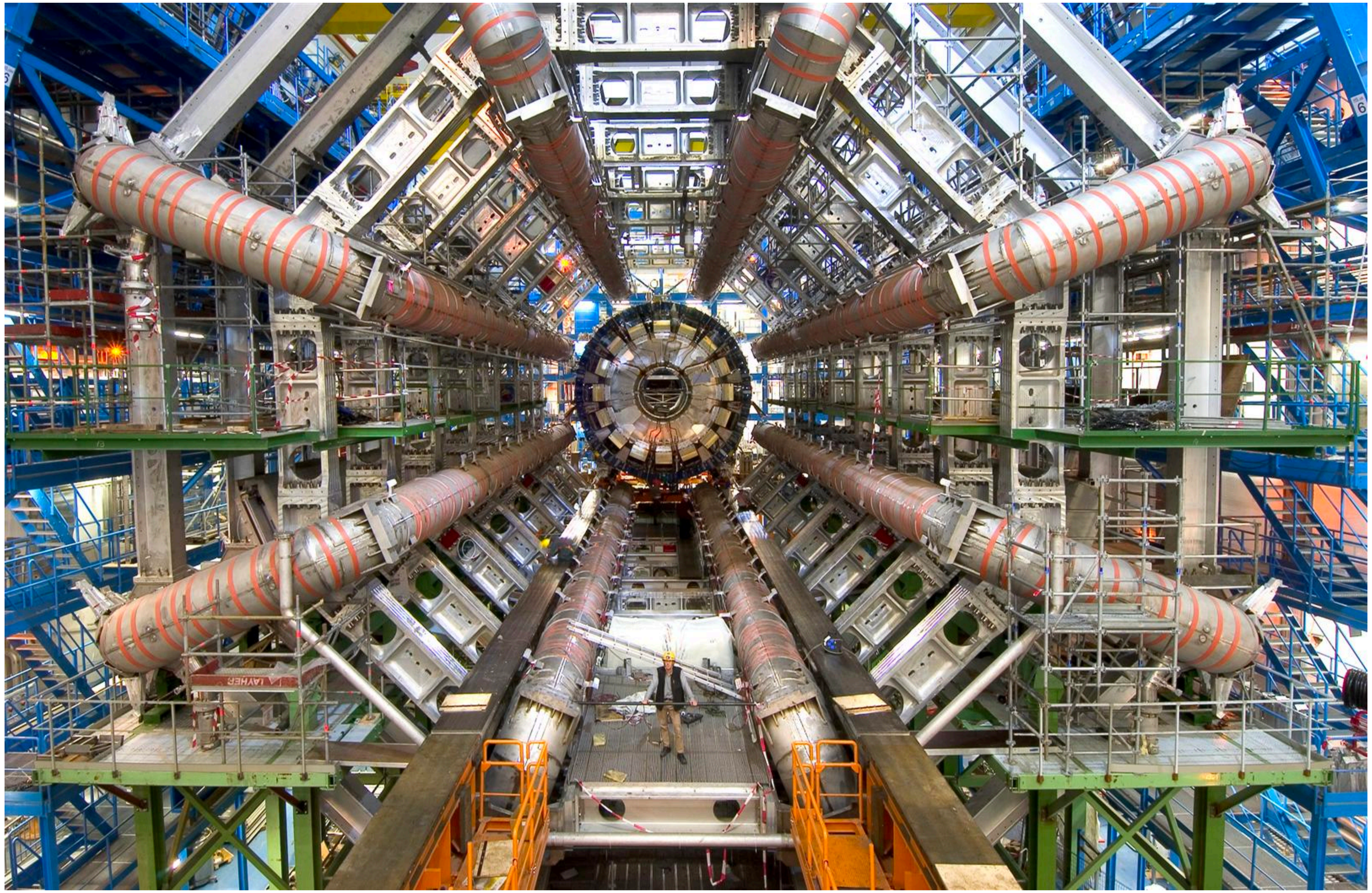
So, why did experiments get so big?

- To study nature at the smallest scales, we use the highest possible energy

$$\lambda = \frac{h}{p}$$

- Larger energy allows us to produce massive fundamental particles. For example, a pair of top quarks which has 175 times as much energy as the two initial protons colliding.

- Larger energy usually means a bigger detector. High energy muons bend in a magnetic field. Larger detector means more precise measurement of muon bend



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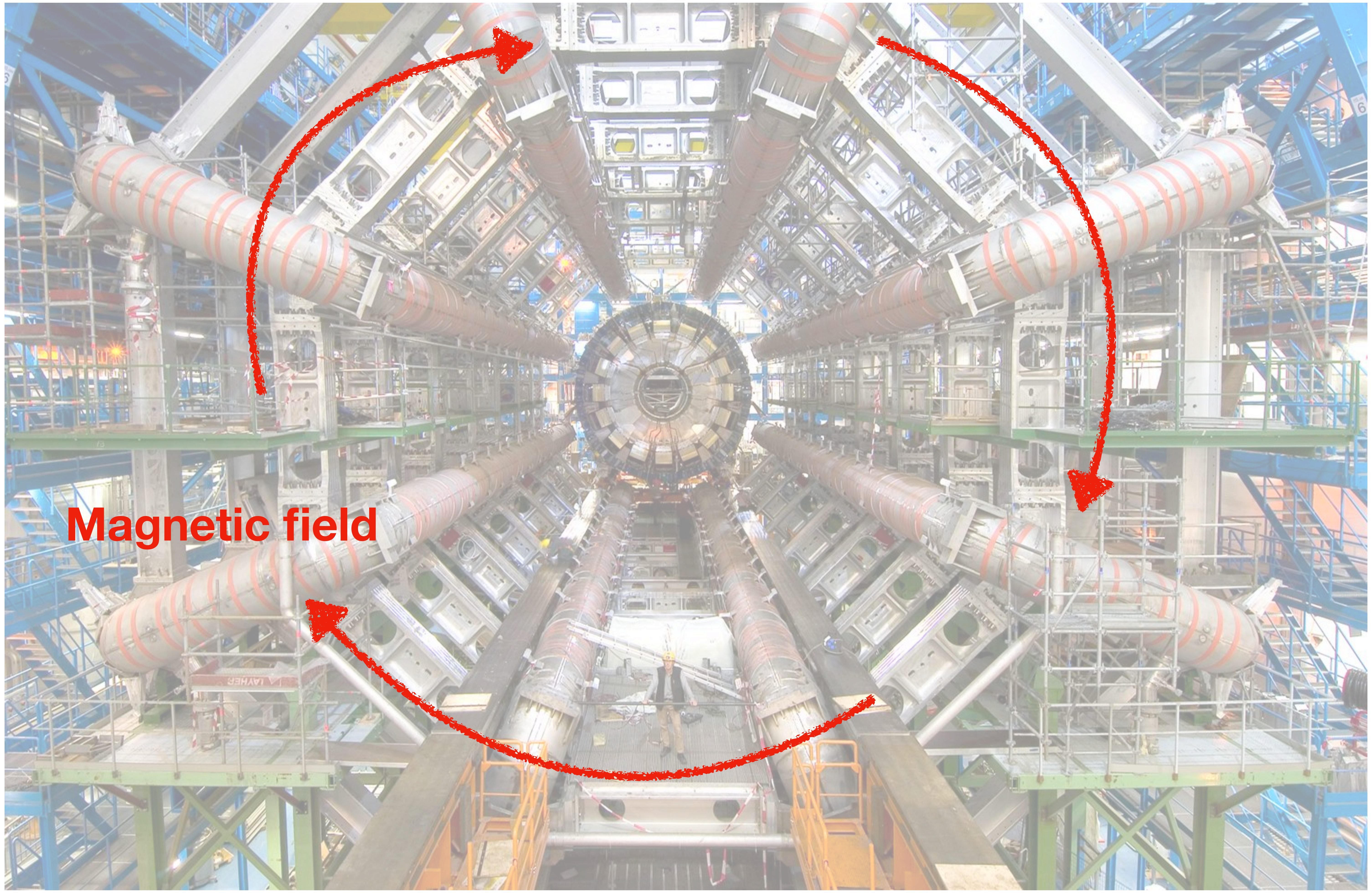
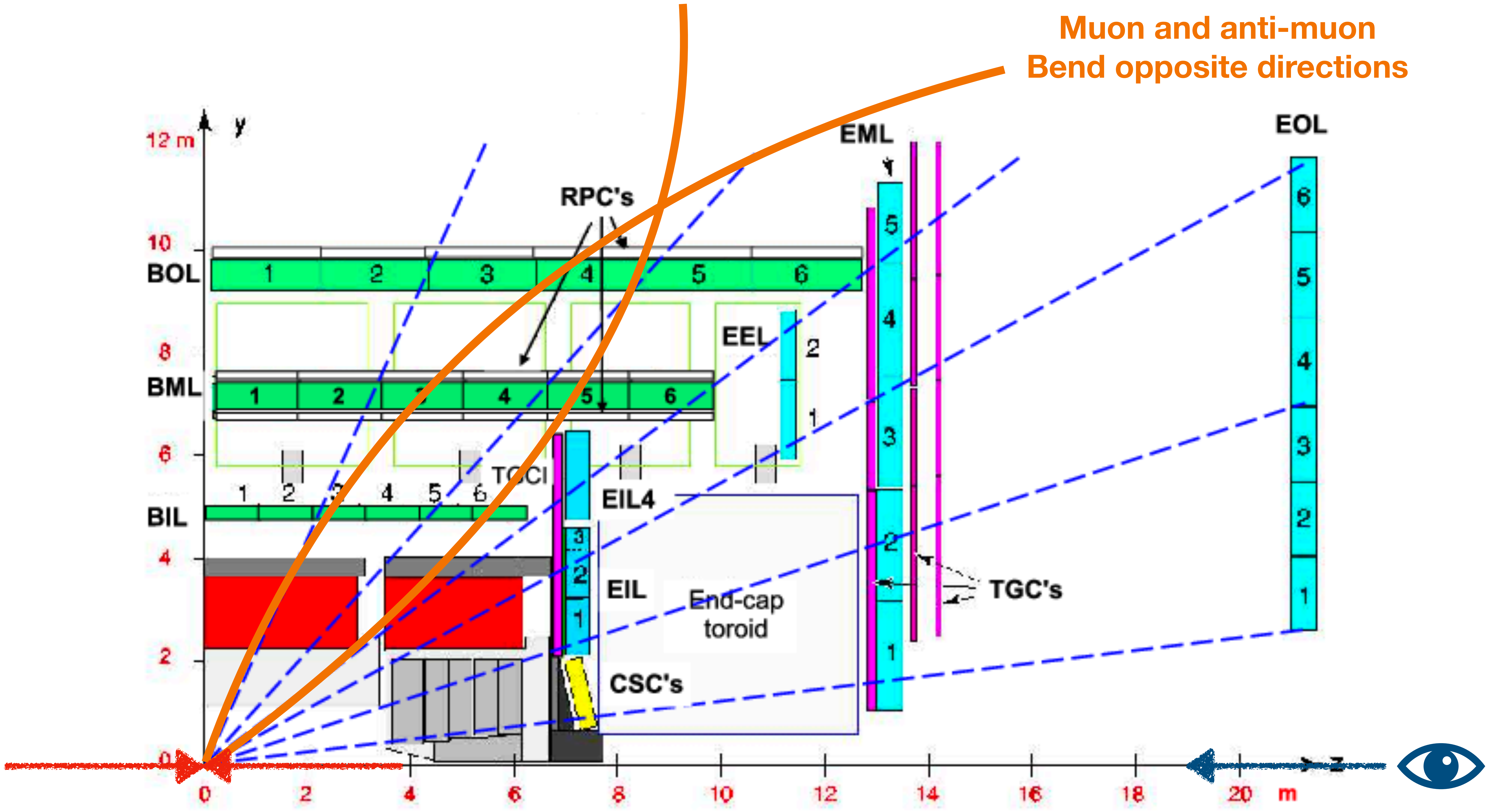


Detecting muons



Colliding LHC proton beams

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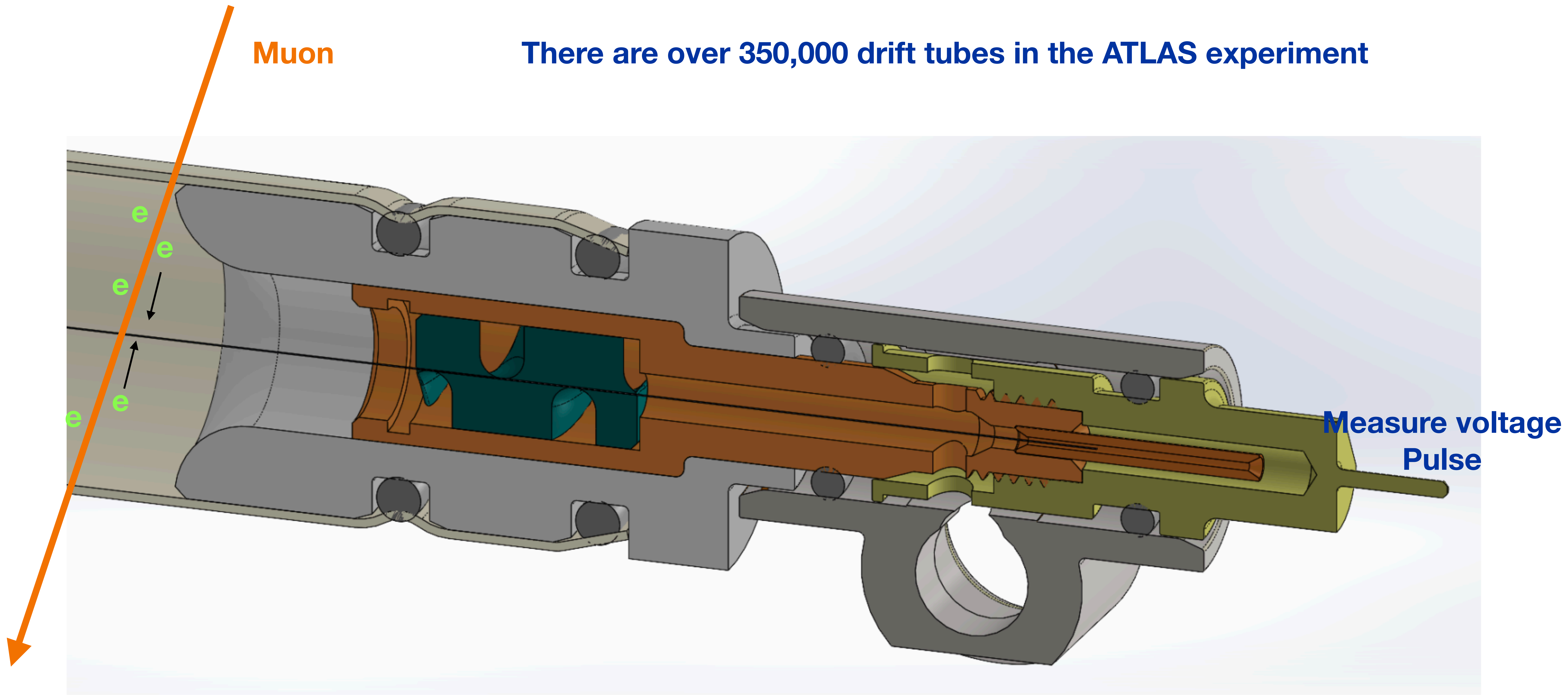
Drift tube

There are over 350,000 drift tubes in the ATLAS experiment



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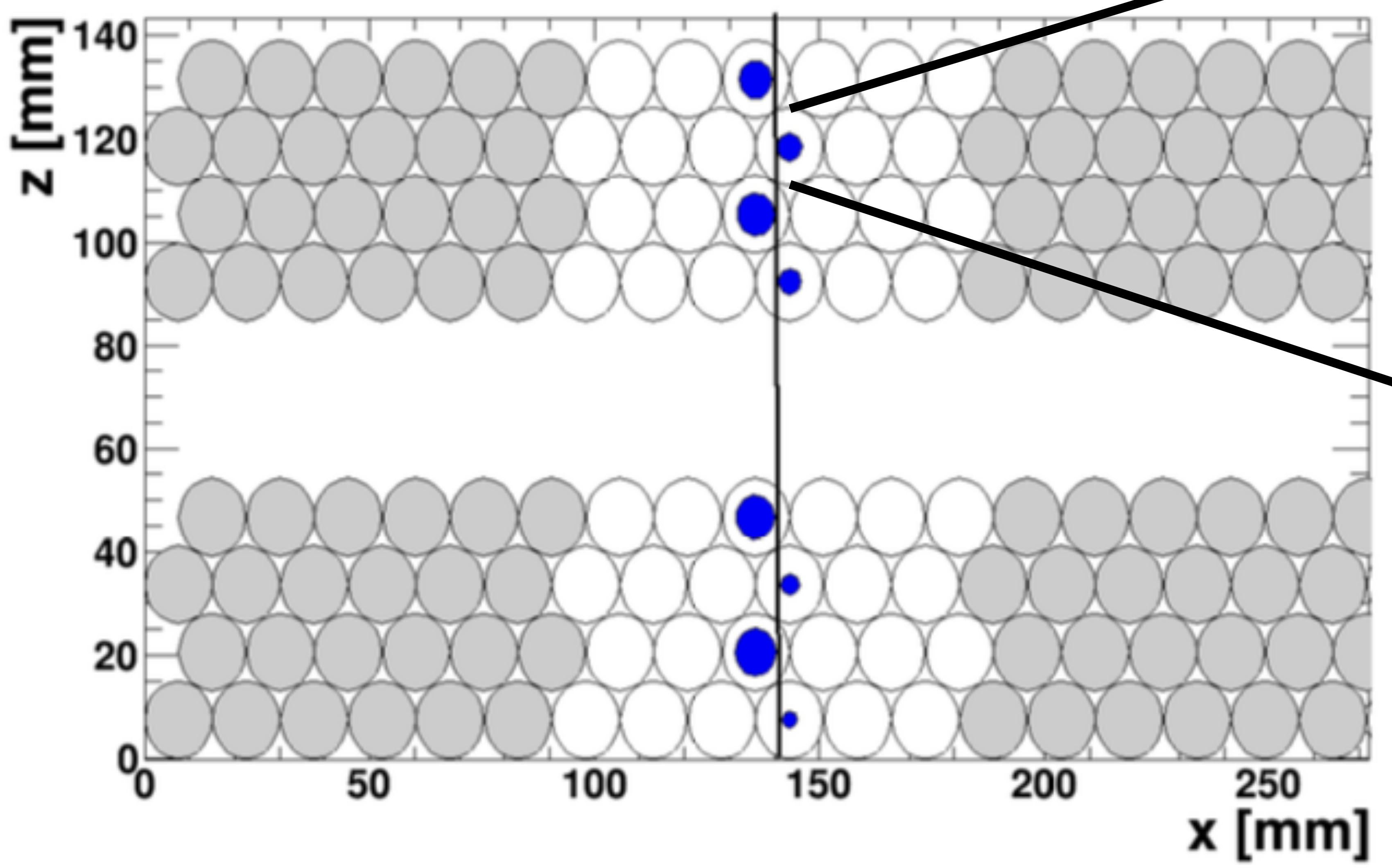
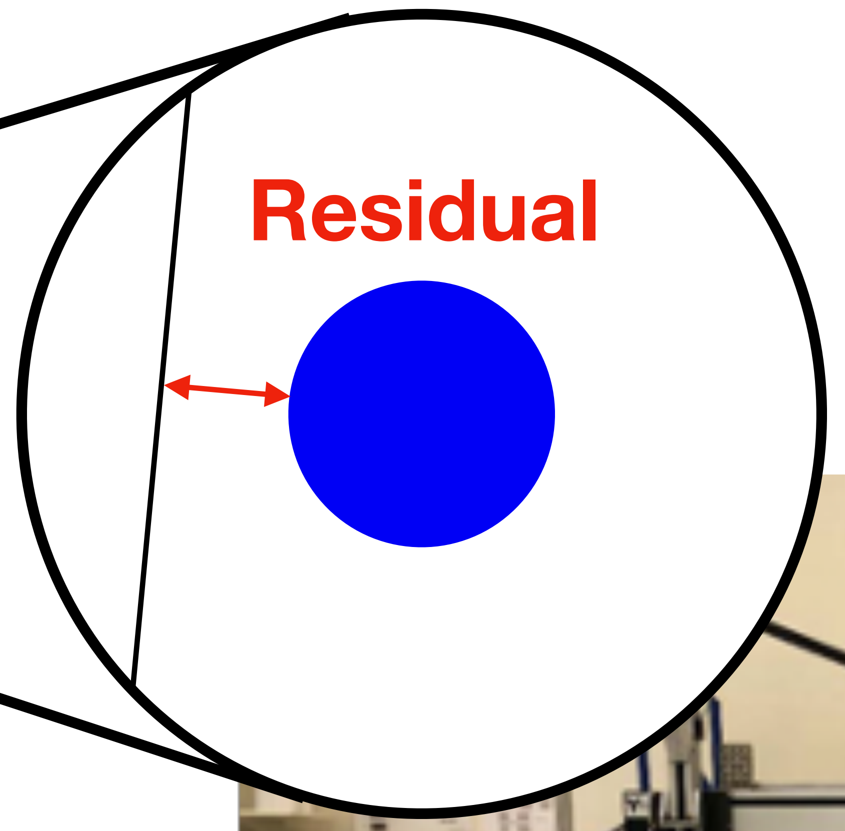
Tracking Detector for ATLAS Upgrade

- **Fifty drift chambers are assembled at Michigan and shipped to CERN**
  - Room for more trigger detectors means more trigger efficiency, which leads to better searches for new particles.

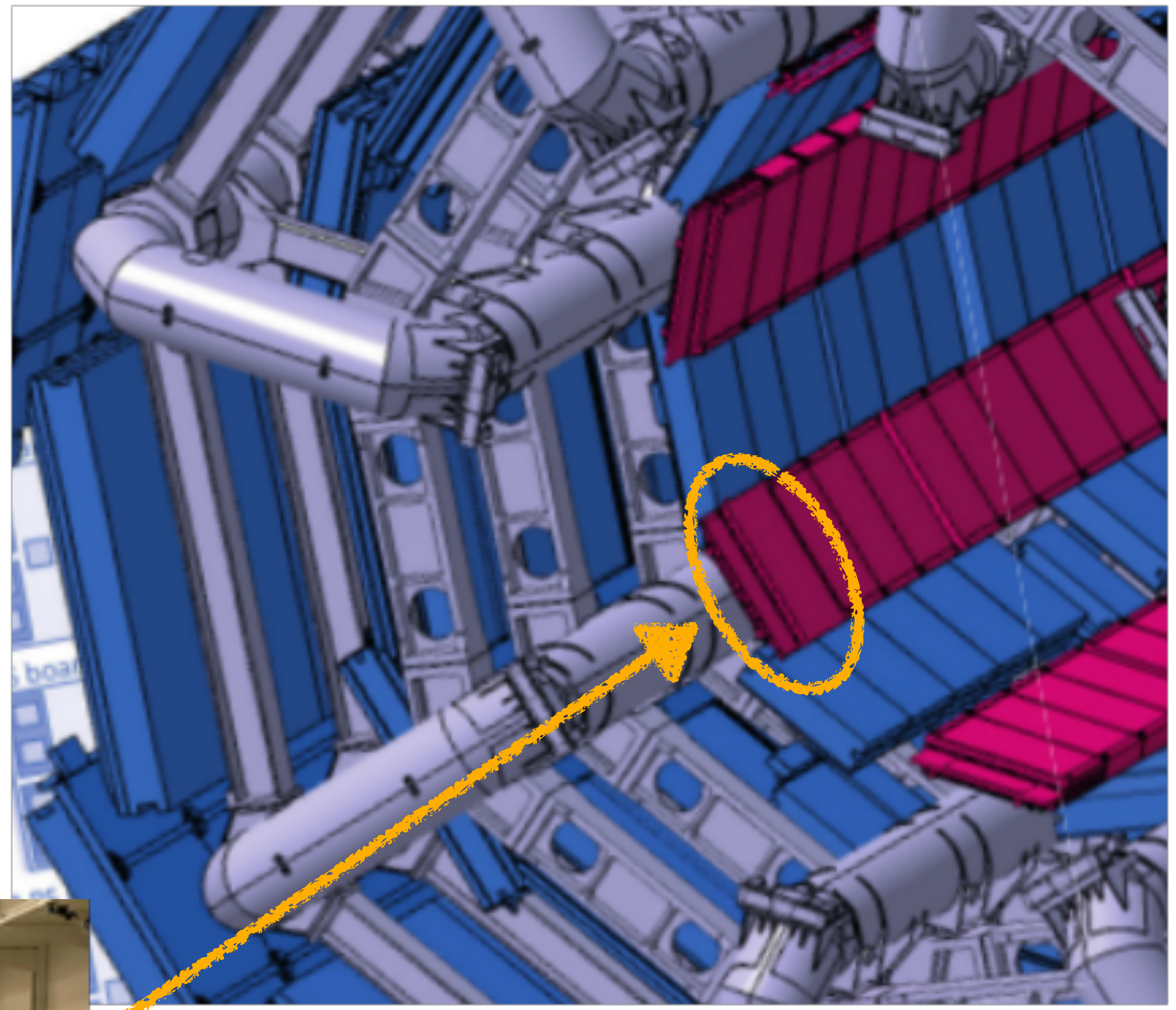
- **Tracking is performed by measuring the time for ionization electrons to drift to a wire in the center of the tube. This is used to determine the radii of tangent circles.**
  - Newly assembled chambers must meet strict requirements on tracking before they are installed in the ATLAS detector.



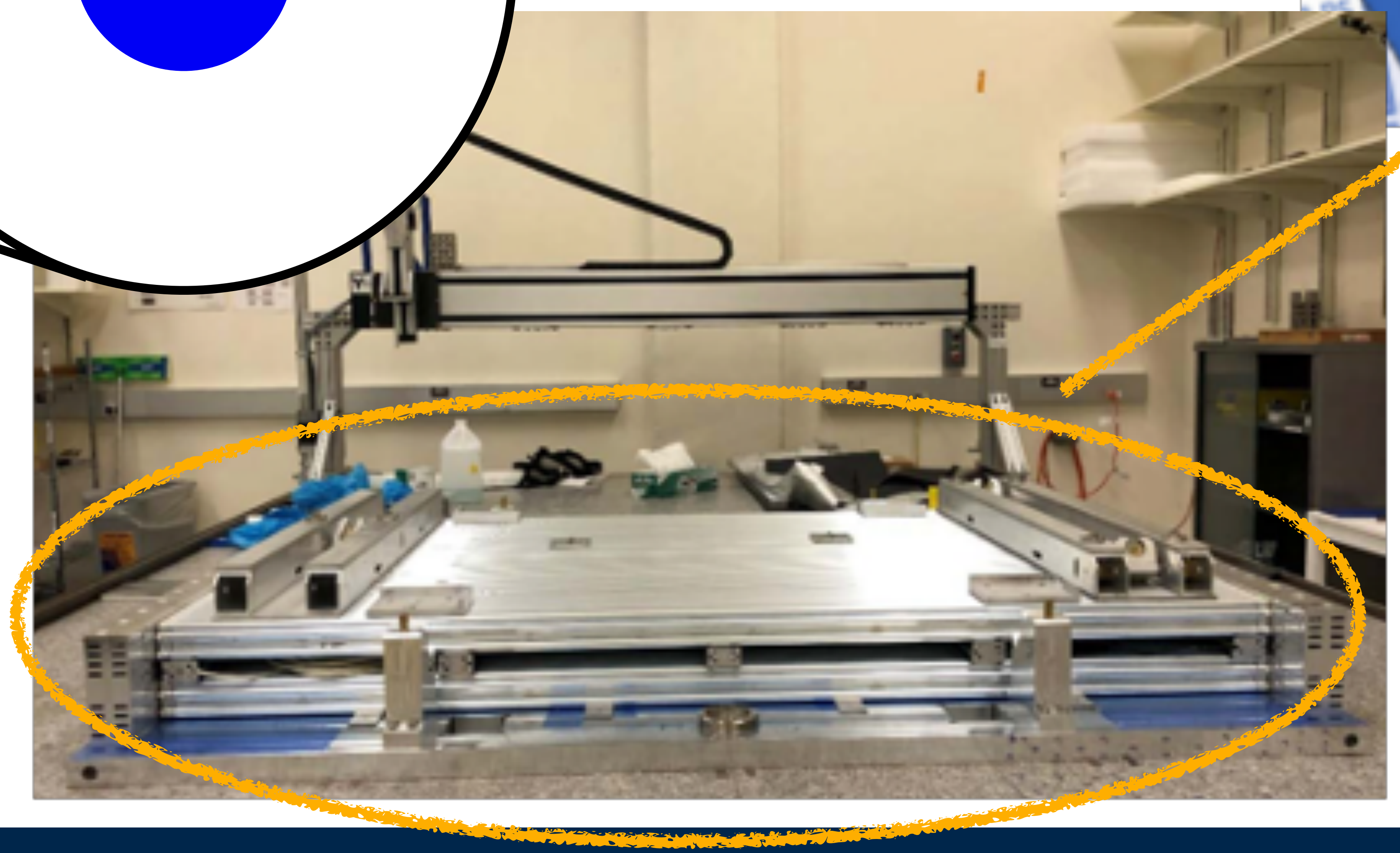


Tracking in a drift chamber

Diagram of the muon system with calorimeters removed

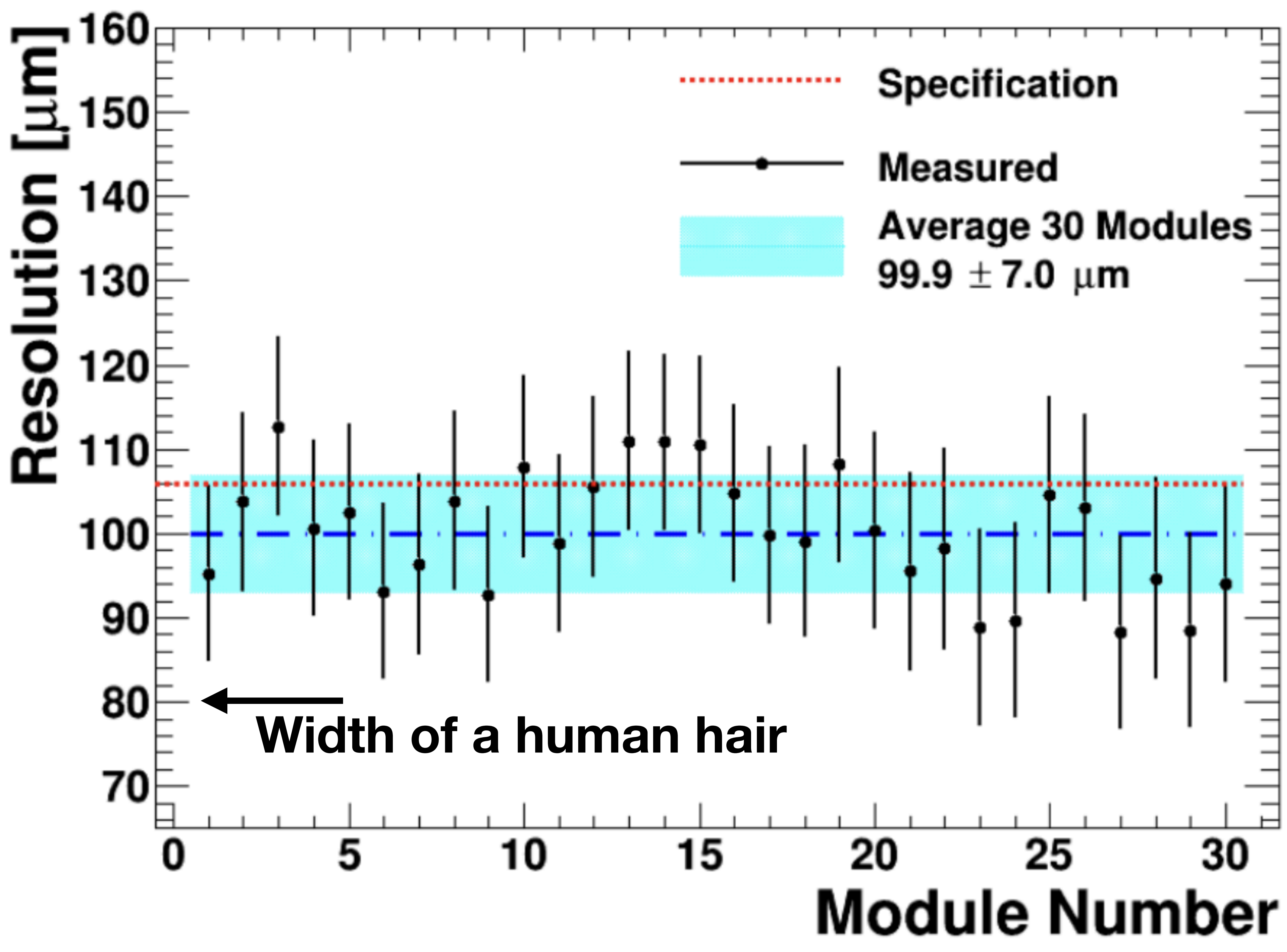


Smaller chambers will create room for more trigger detectors



One chamber under assembly
In Ann Arbor
Tubes are 1.6m in length

Drift Chamber Test Results



- **Resolution specification is 106 μm**
  - Observed resolution is $99.9 \pm 7.0\mu$m. We achieved the goal!
  - Precision of the detector determines how well muon momentum is measured