The Mu2e Tracker

Duke University

University of Houston

University of Minnesota

York College
The City University of New York

Fermilab

Berkeley Lab
Lawrence Berkeley National Laboratory

Argonne National Laboratory

Mu2e

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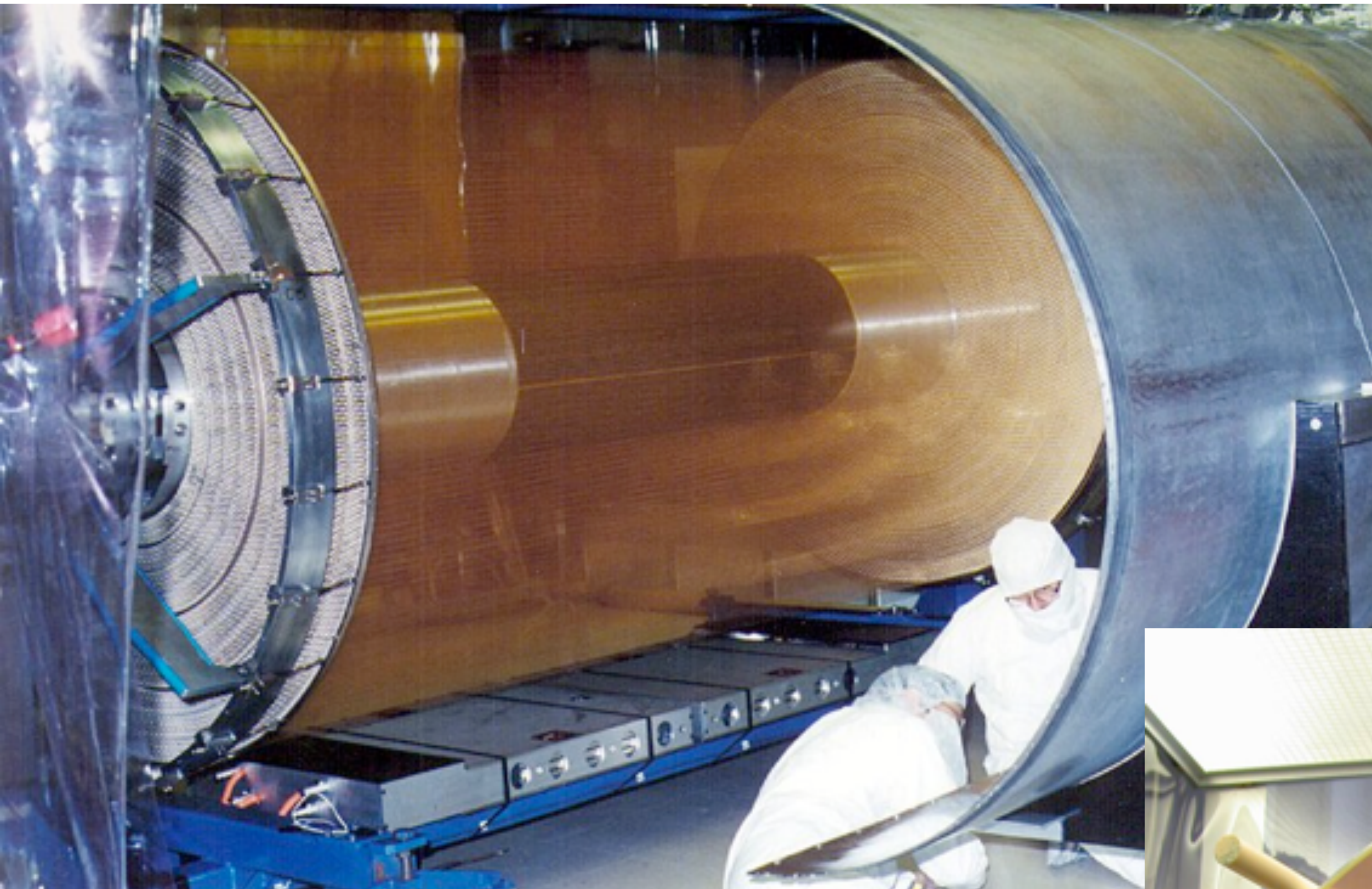
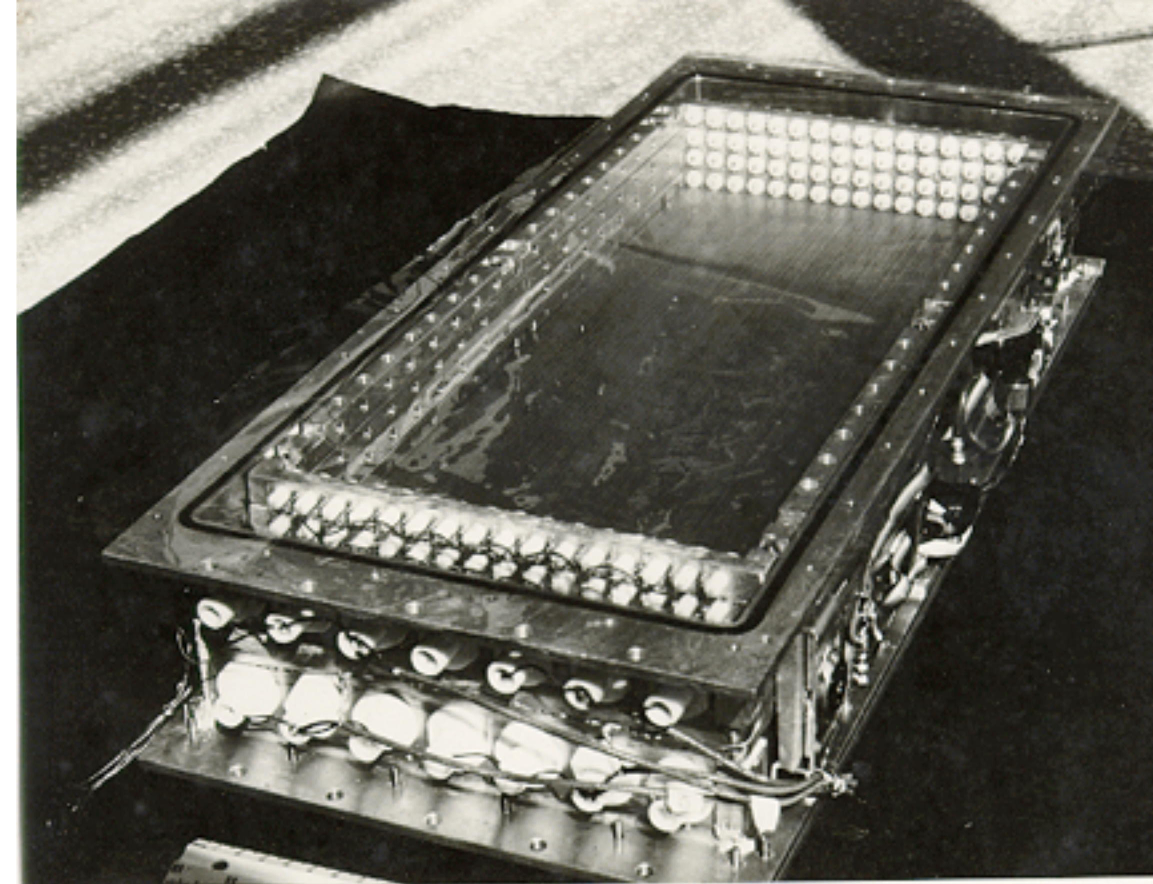
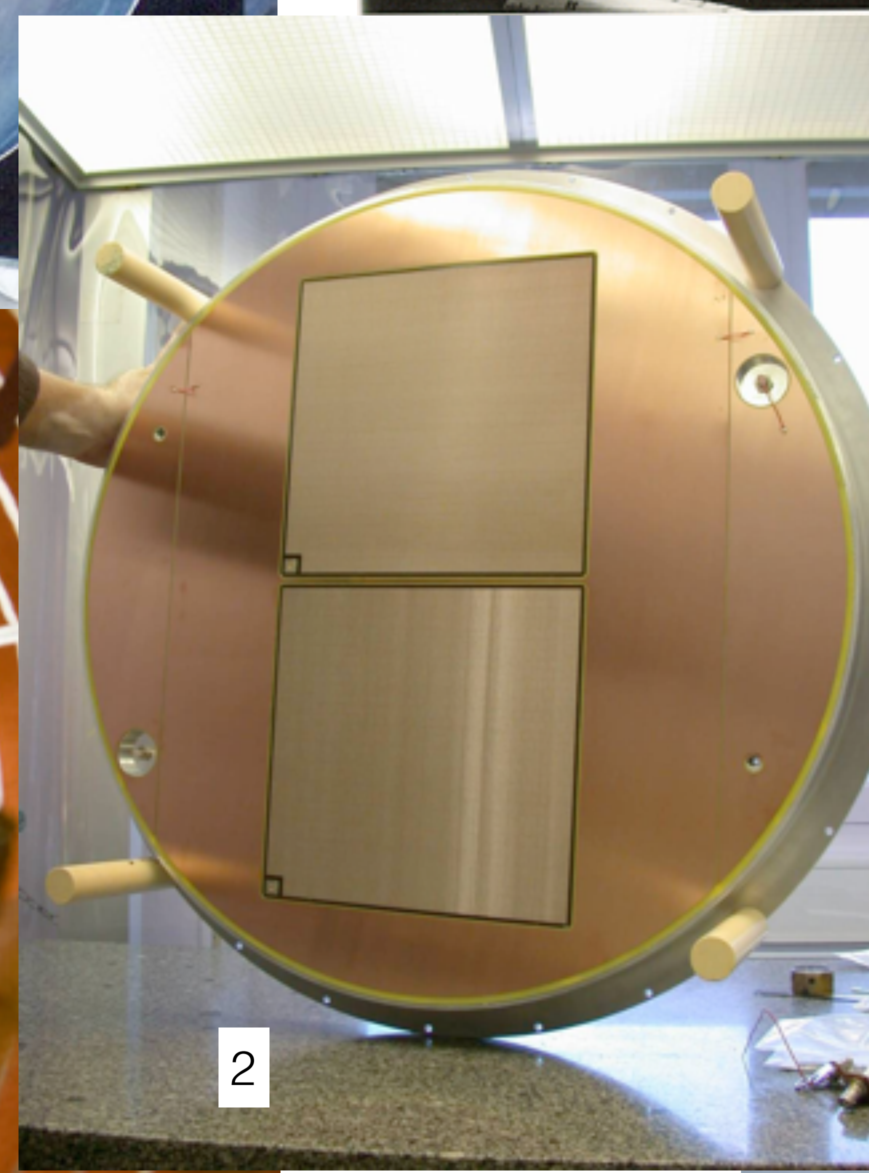
Thursday August 3rd, 2017
Summer Student Seminar
Fermilab

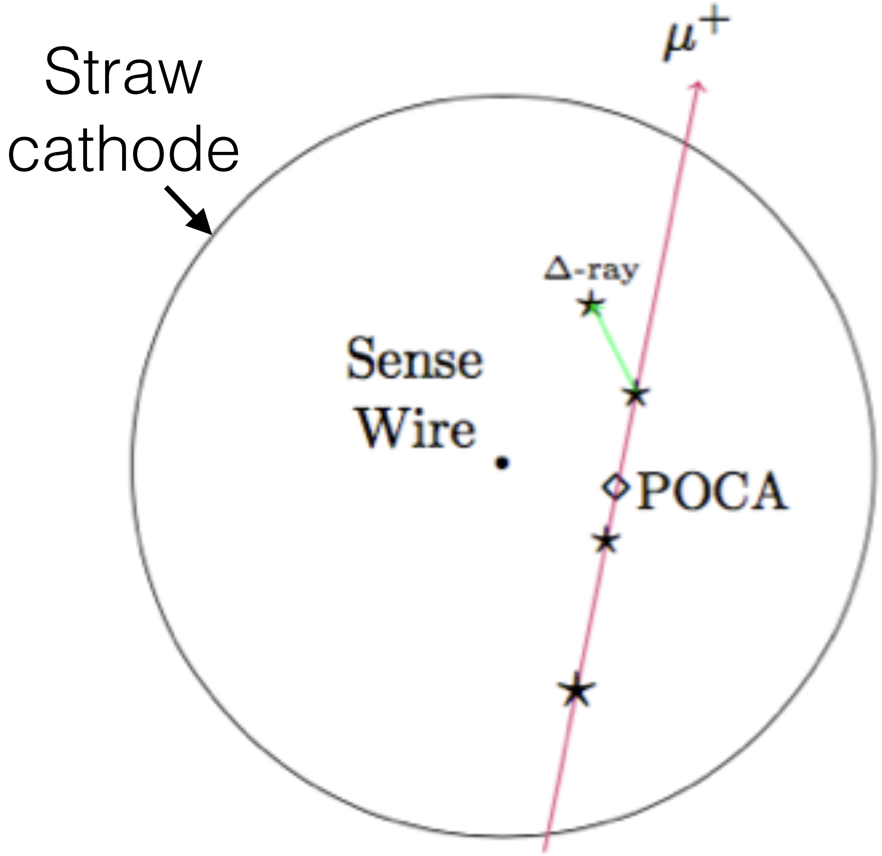
Some Gas Ionization Detectors



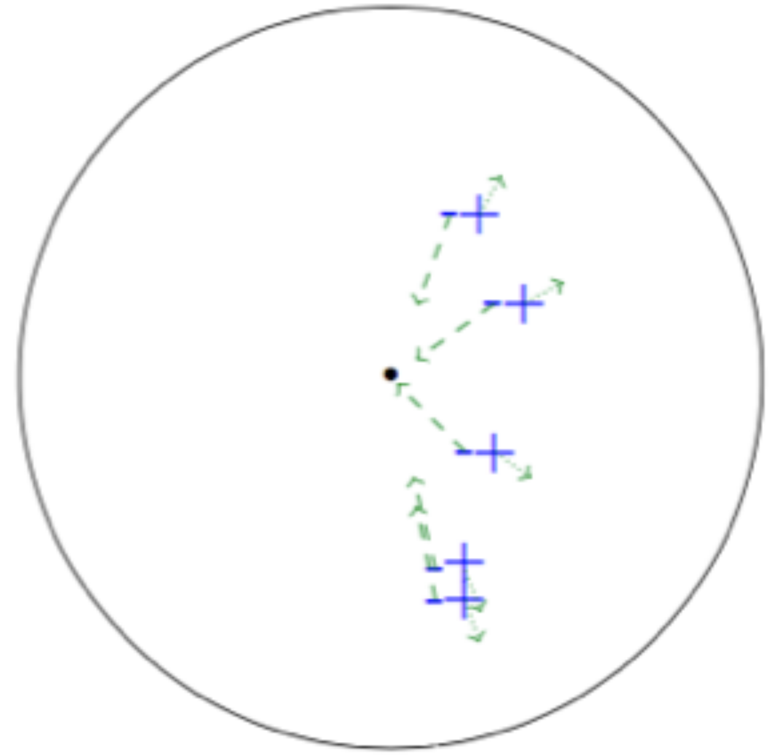




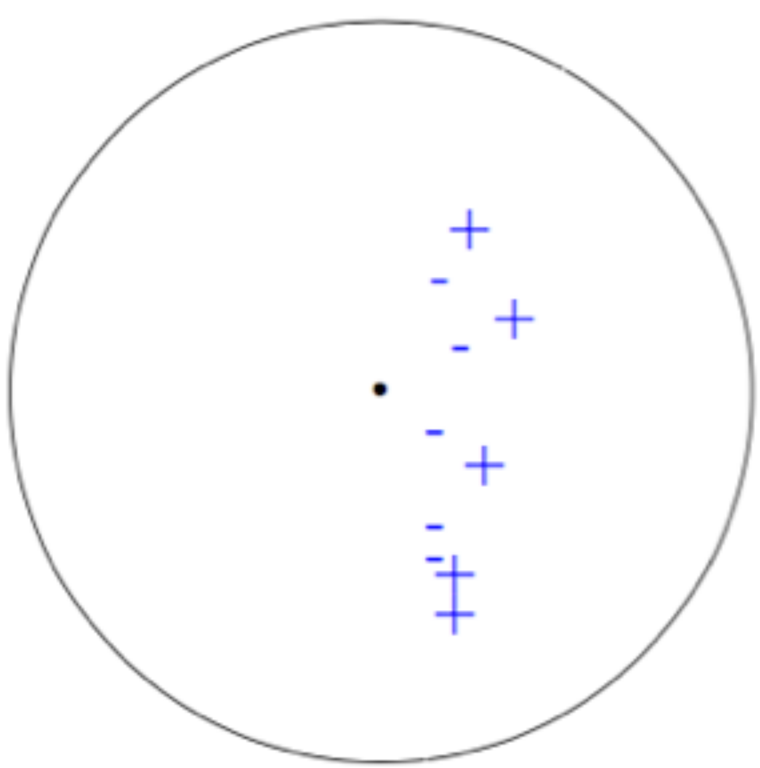
Cartoon Picture (t ~ ns)



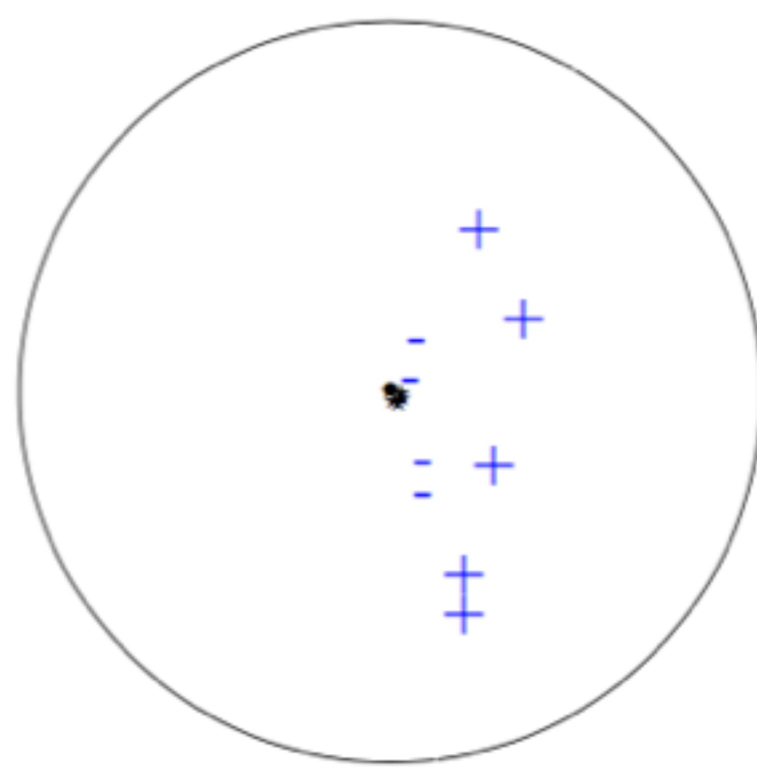
(a) Charged particle track, primary ionizations and delta-ray ($t \sim$ ns).



(b) Electrons and ion pairs created by ionization ($t \sim$ ns).



(c) Electrons drift towards the sense wire, ions are very slow by comparison ($t \sim 10\,$ns).



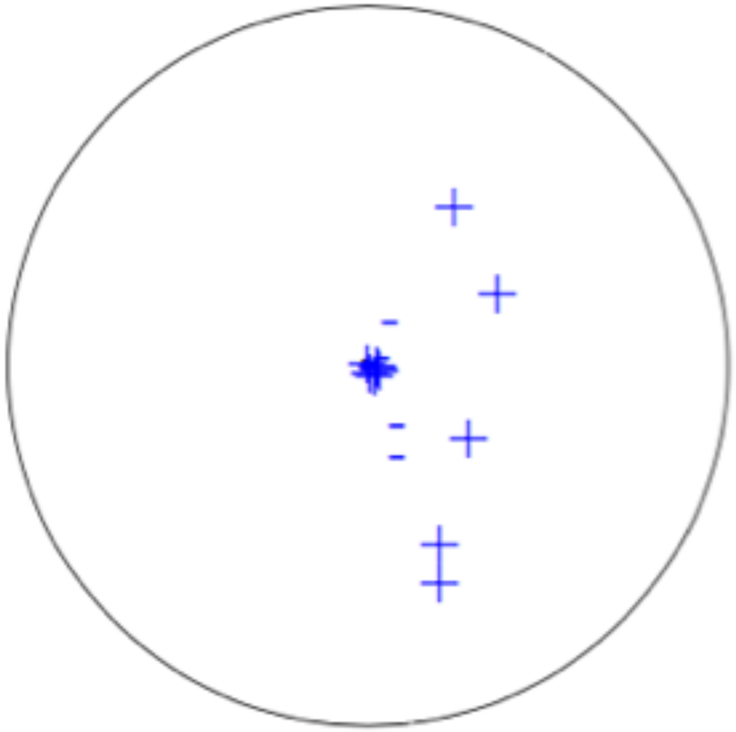
(d) Electron from the closest ionization creates an avalanche at the sense wire ($t \sim 10\,$ns).

- Strong electric field near wire

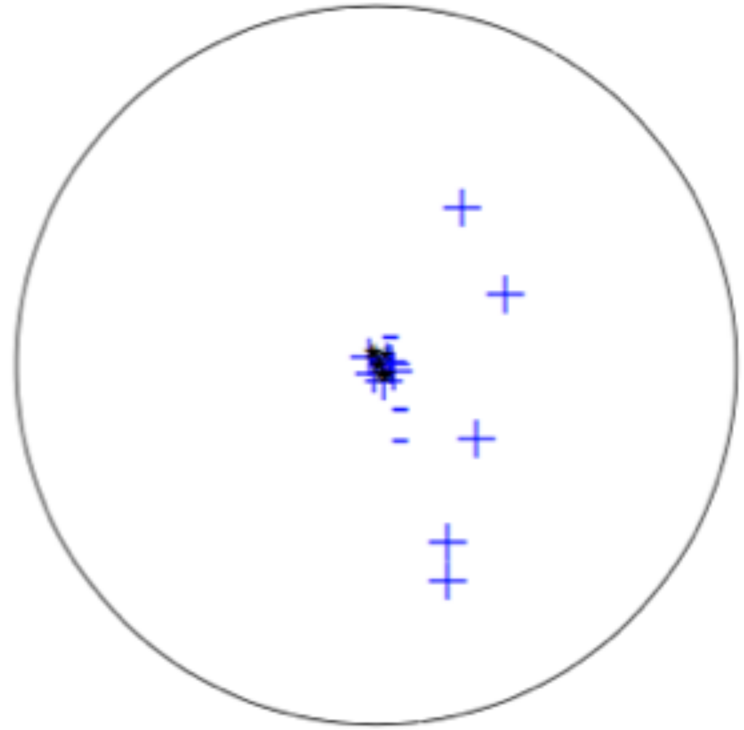
$$E = \frac{1}{r}\frac{V_0}{\ln(b/a)}$$

- Primary ionization makes 10~100 e-ion pairs/cm.
- Delta rays ionize off-track

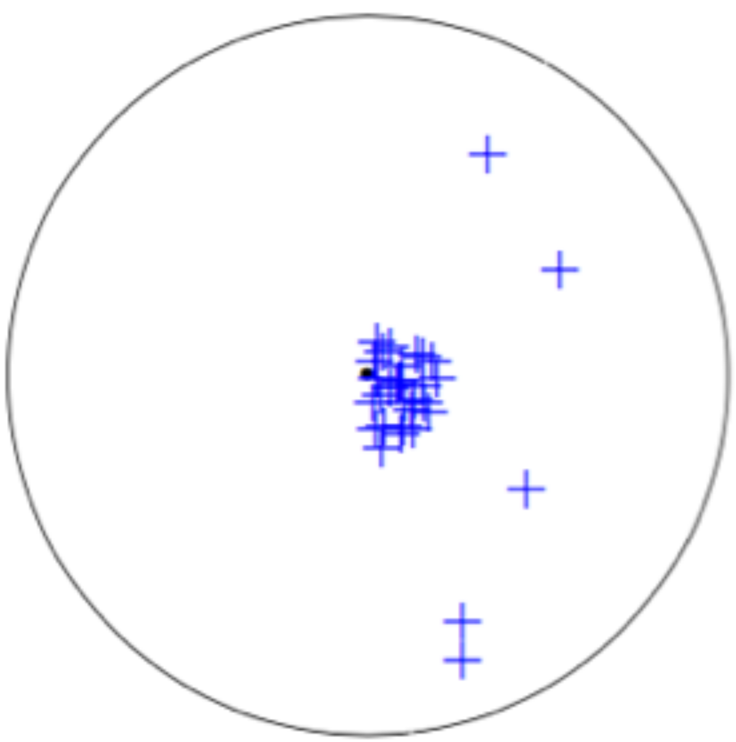
Cartoon Picture (t ->µs)



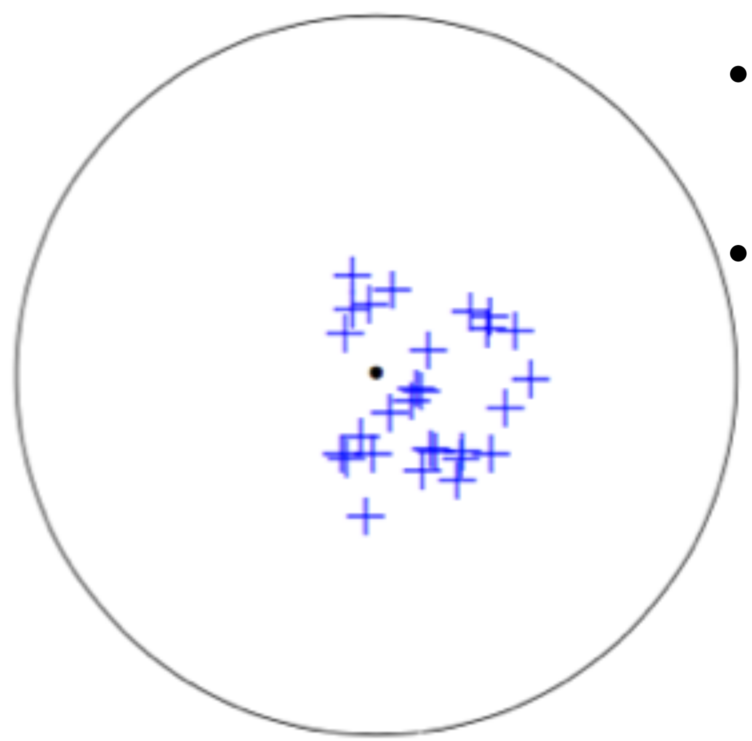
(a) Remaining electrons continue drifting, cloud of ions remains at sense wire from avalanche ($t \sim 10\,\text{ns}$).



(b) The remaining electrons also avalanche. Lots of ions are present at the sense wire ($t \sim 100\,\text{ns}$).



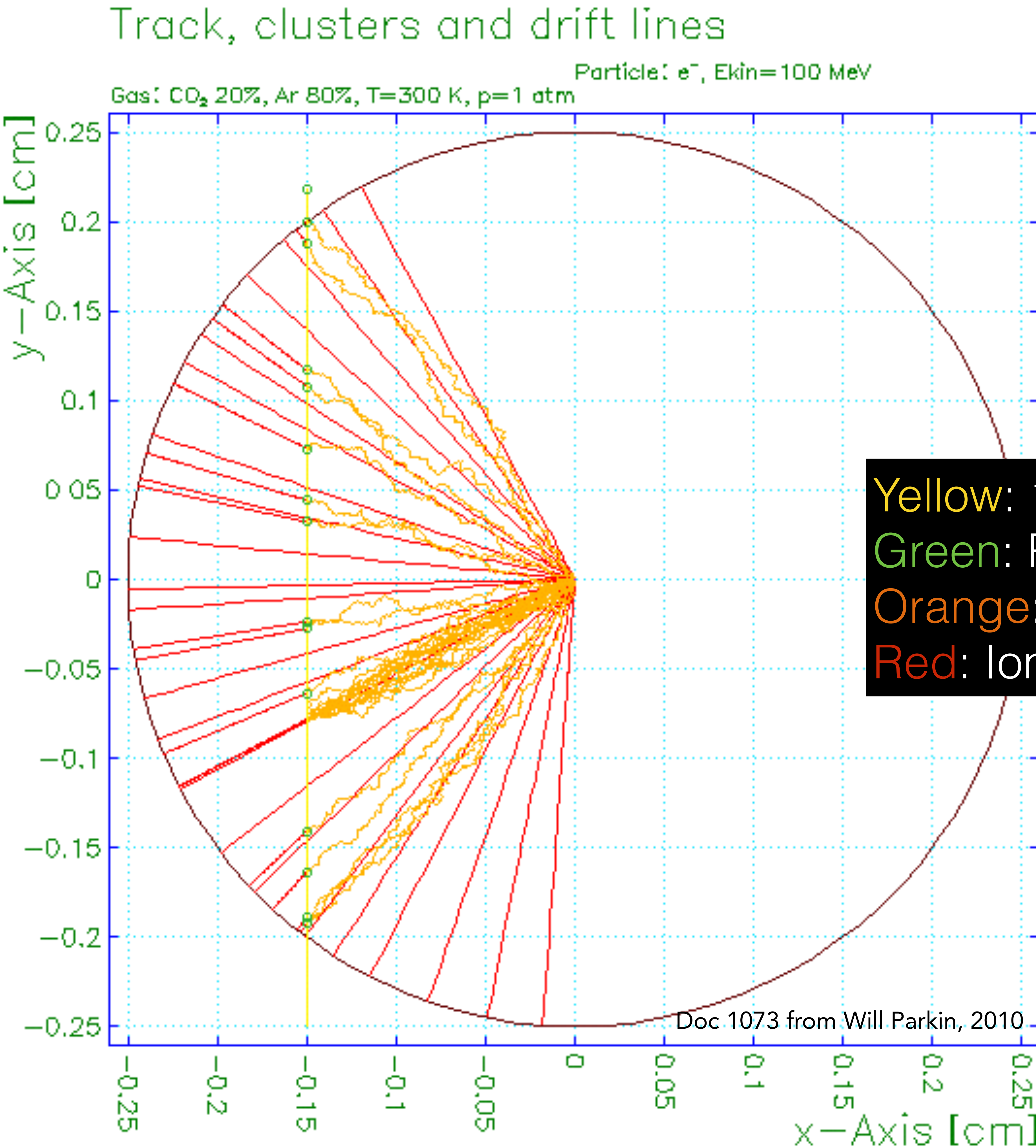
(c) Electrons are gone, ions continue slow drift towards field wires ($t \sim \mu s$).



(d) The ions continue to drift until they hit the field wires ($t \sim 10\,\mu s$).

- Avalanche multiplies electrons by ~10^5 "gas gain"
- Leftover ions called "space charge", reduce effective gas gain.
- Avalanche give ~mV signals, further amplified by readout electronics.

Visualization from Simulation



Doc 1073 from Will Parkin, 2010

Yellow: 100 MeV electron
Green: Primary ionizations
Orange: Electron drift paths
Red: Ion drift paths

Tracking

- The arrival time of the first avalanche gives us a measurement of the DOCA (distance of closest approach) of the particle to the sense wire. DOCA resolution is can be as good as ~100 μm.

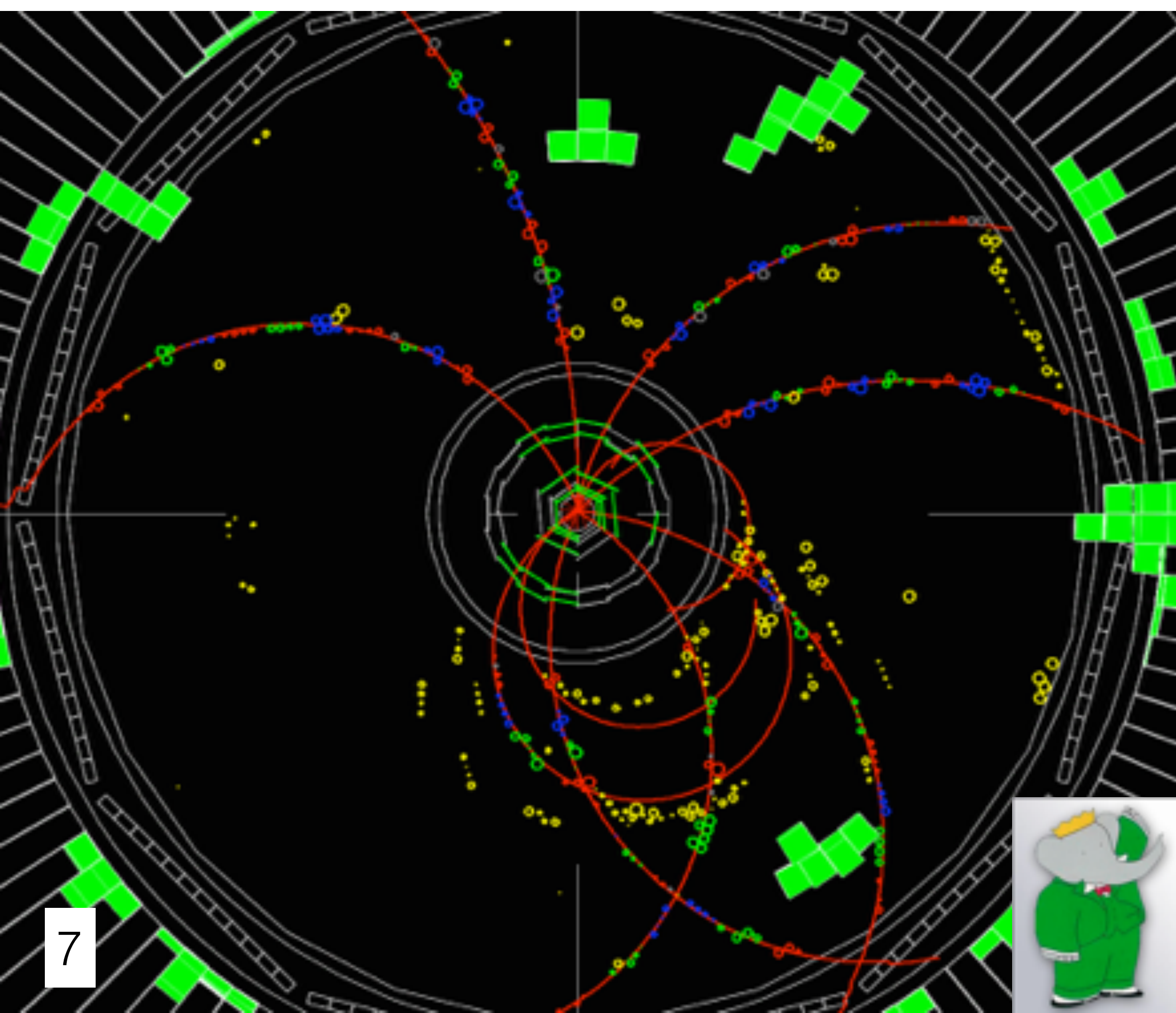
- Difference in arrival time or signal strength on both ends of a single wire gives Z-coordinate along sense wire with ~cm resolution.

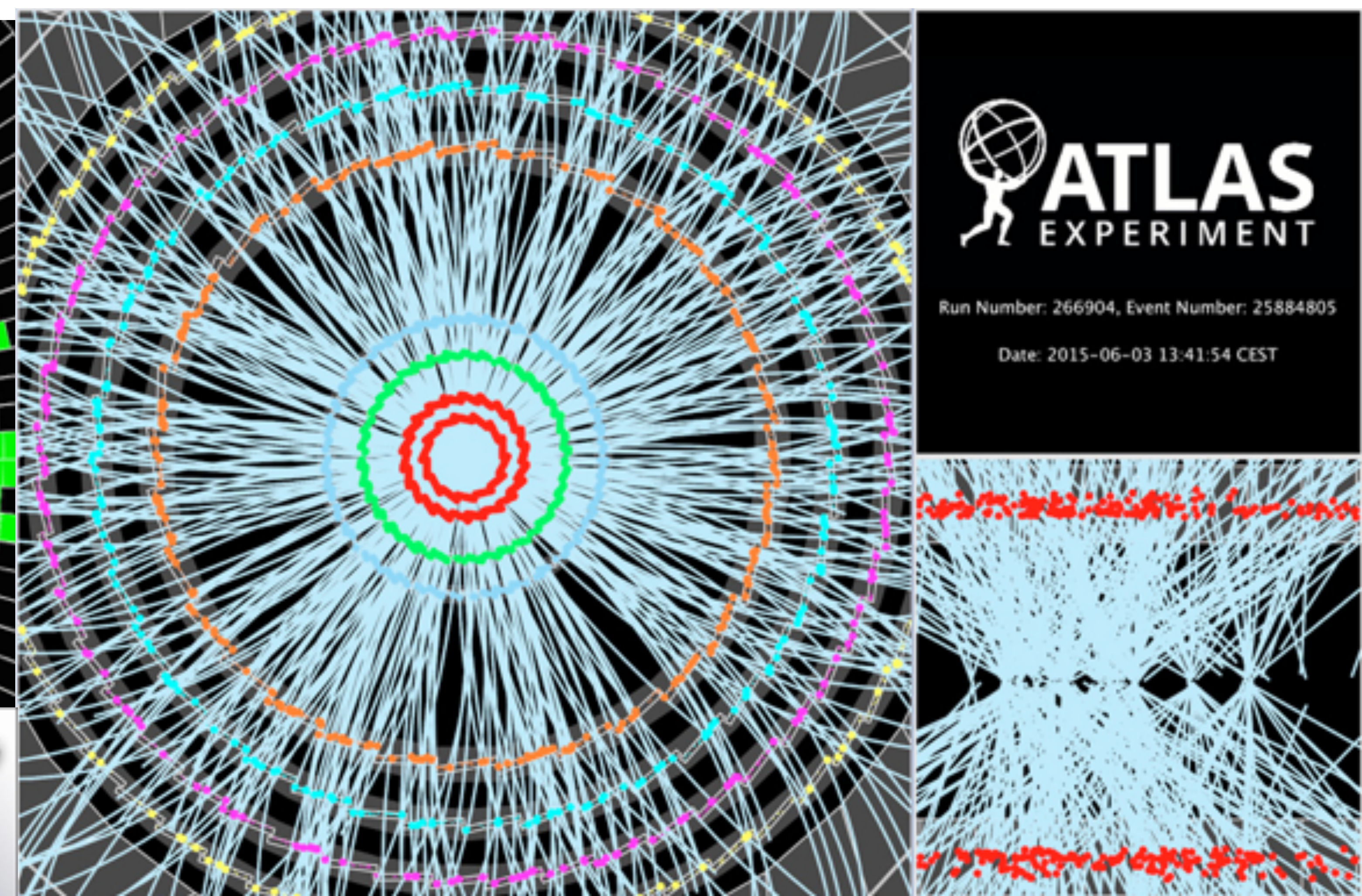
- Multiple wire hits combine to make a geometric track. With no magnetic field, it's just a straight line.

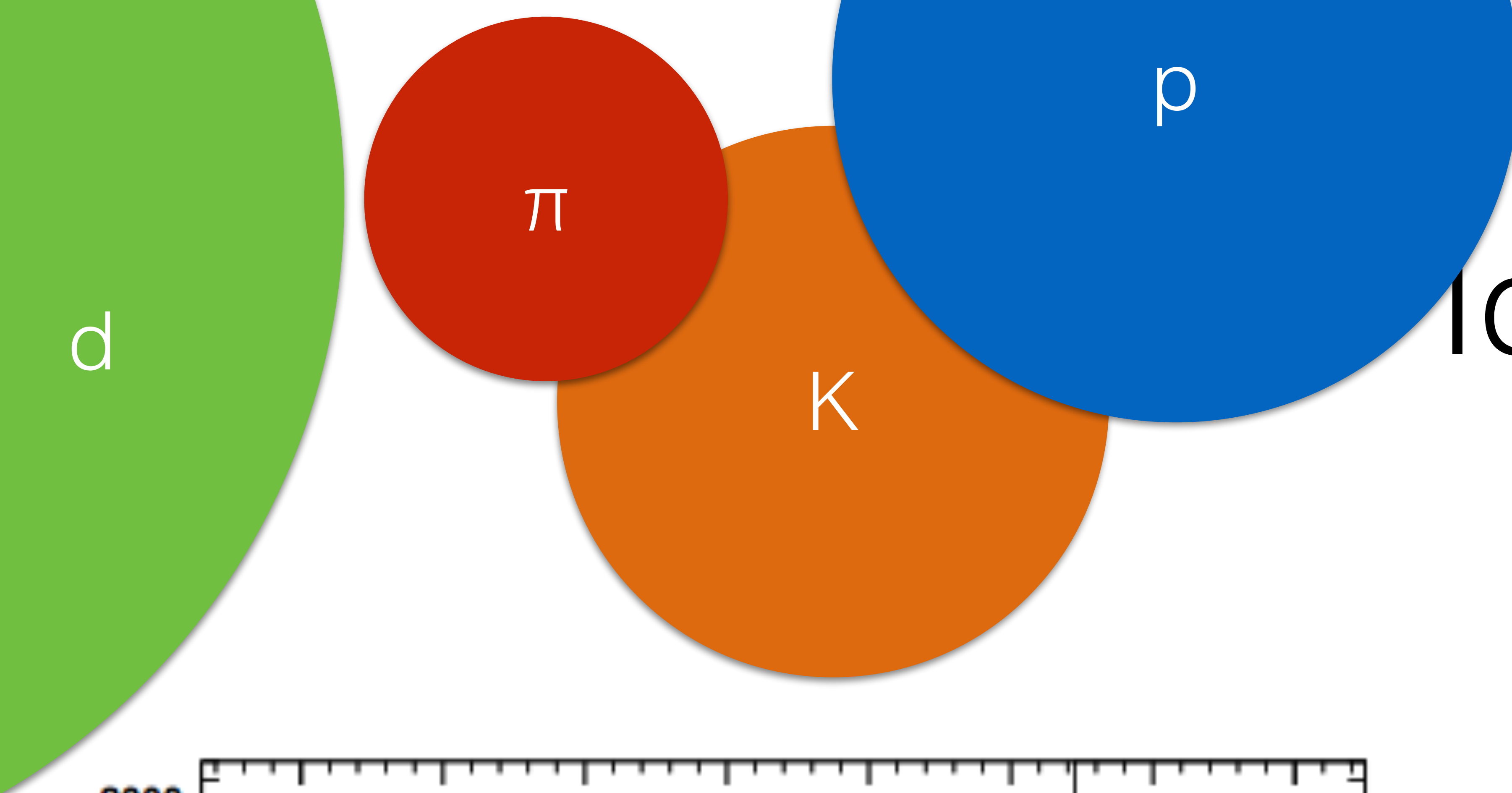
- In a magnetic field, tracks are helices because of the Lorentz force. The radius & pitch give us momentum (~100 KeV/c resolution). The handedness of the helix gives us the sign of the charge.

- Tracking algorithms are vulnerable to multiple scattering, which changes the momentum of the particle as it moves through the detector. Thus we make the detector as “transparent” as possible.

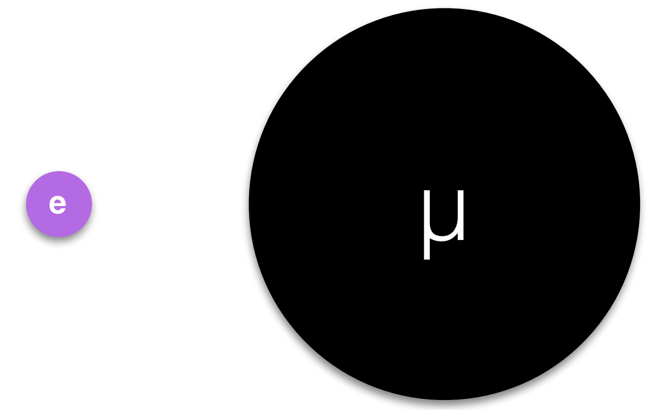
- If there are many particles in the event, correctly associating hits with tracks may be challenging.

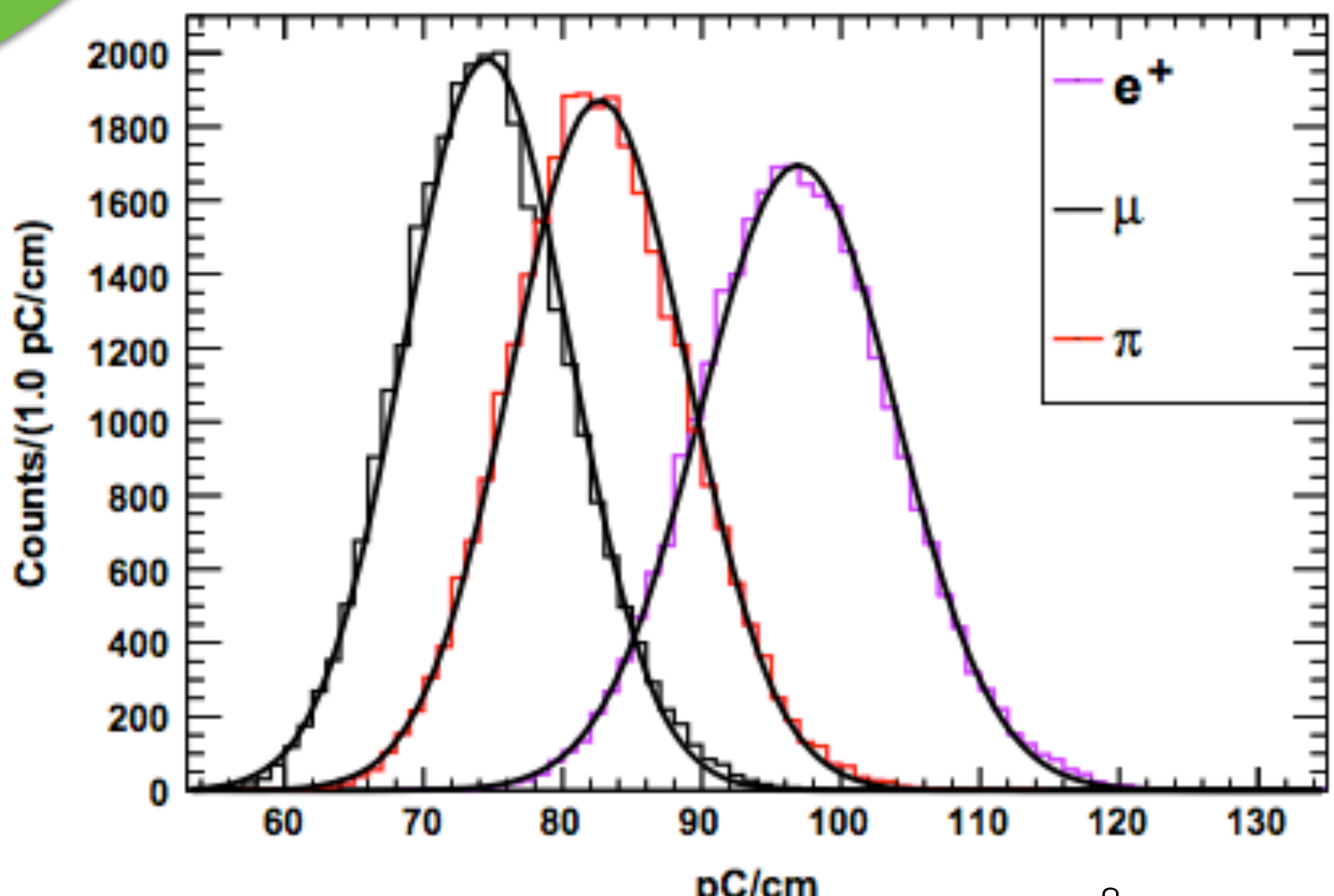






Particle Identification





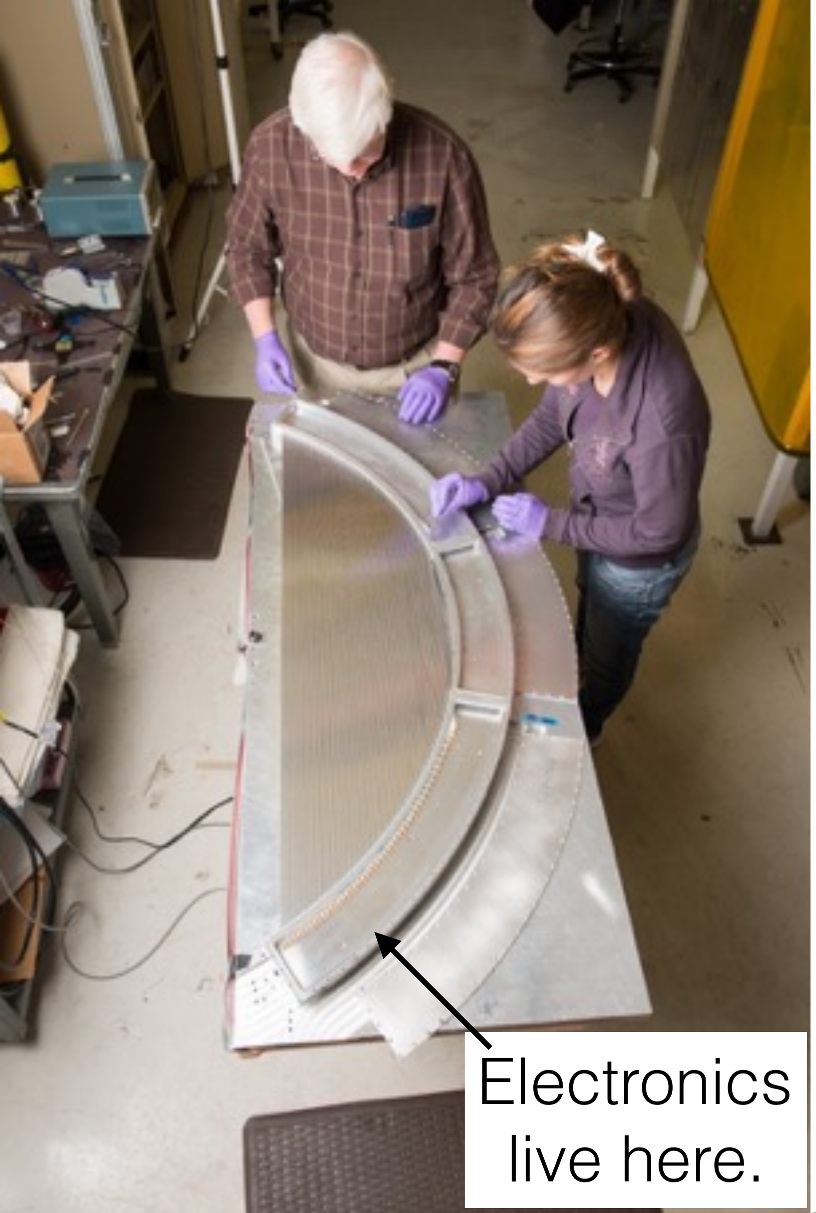
Probability of ionization depends on particle speed (~$1/\beta^2$). With momentum & charge from tracking we get the mass, i.e. the species.

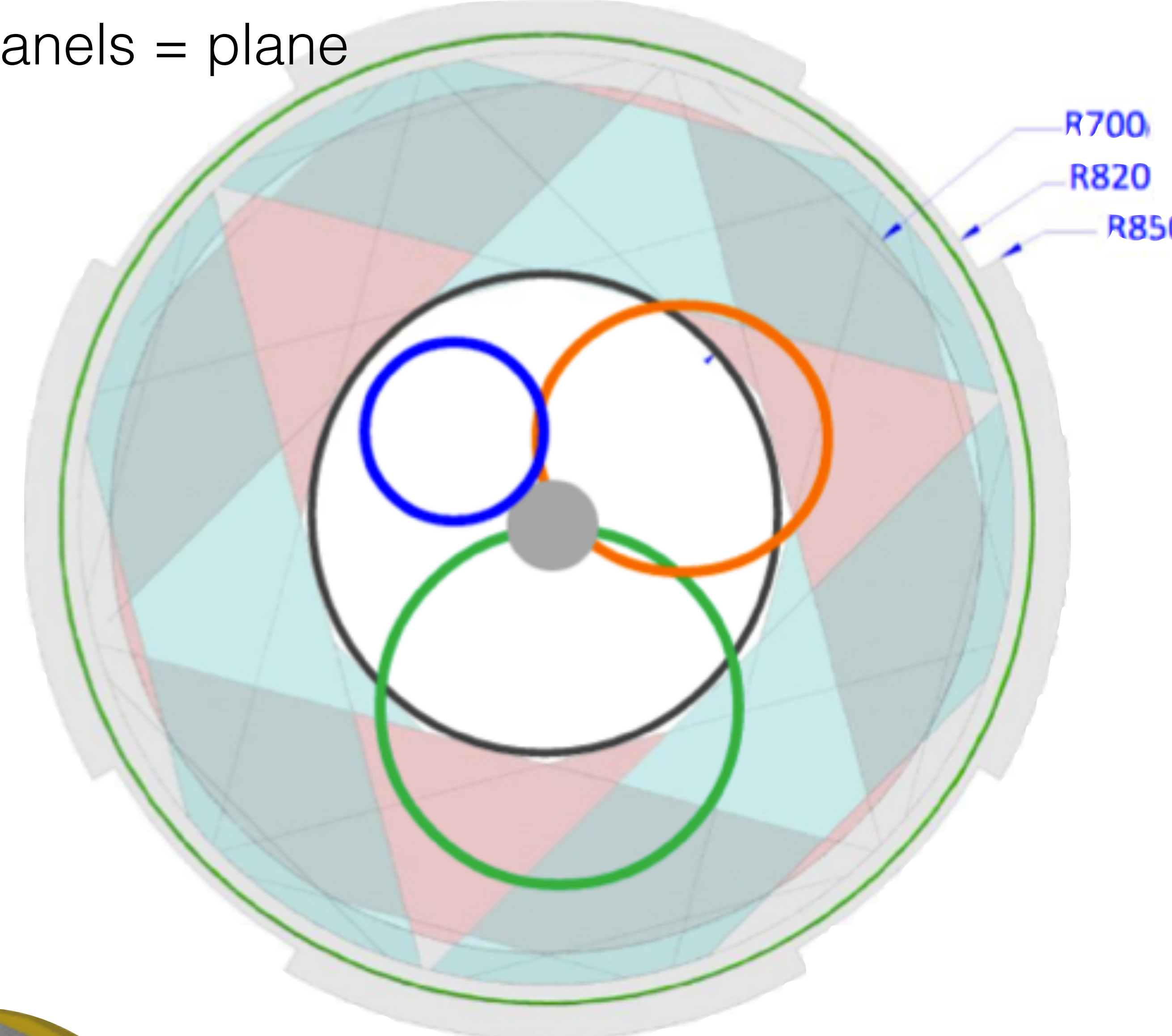
Measurement is done by integrating wire current over time.

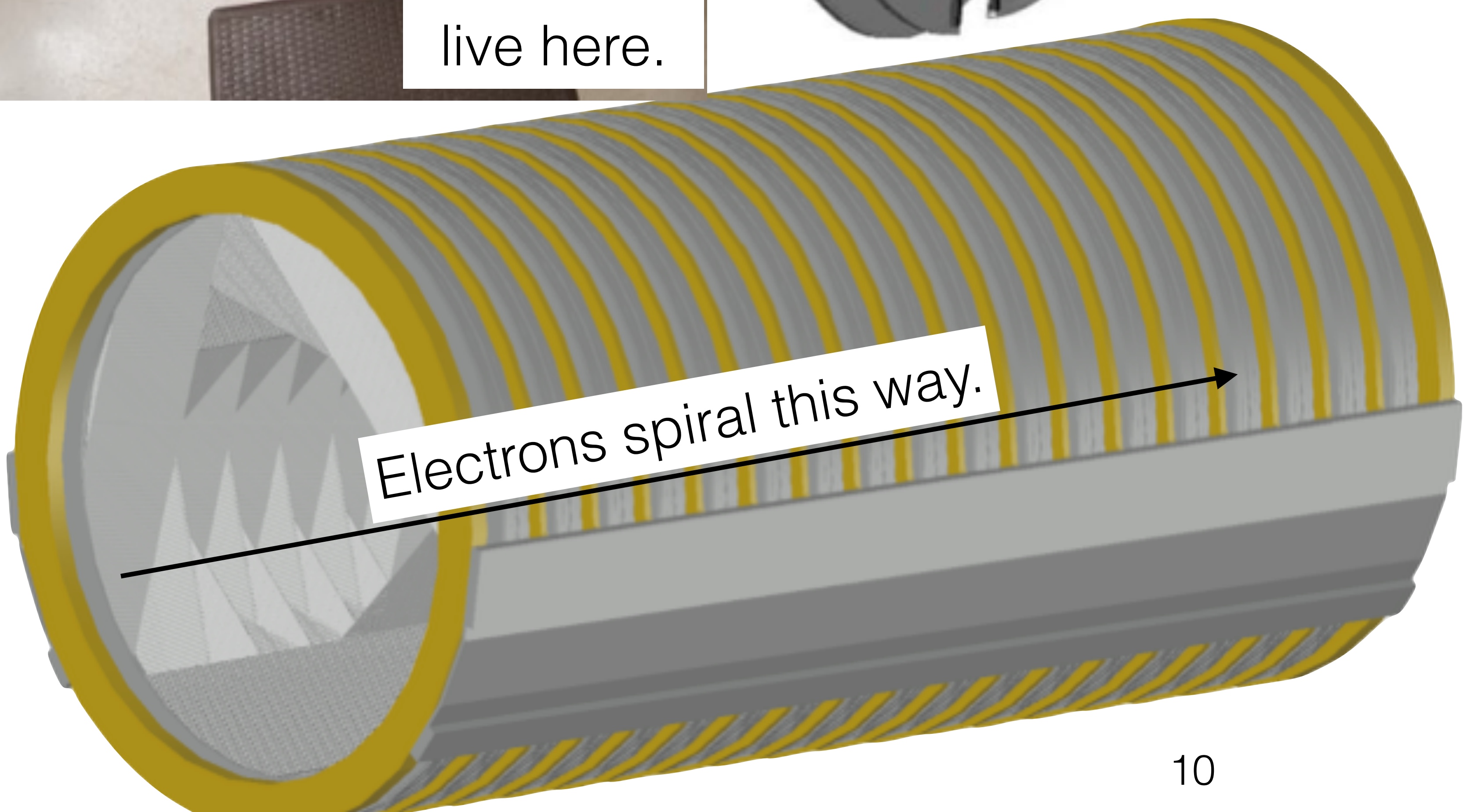
This technique is sensitive to Delta-rays, and requires careful treatment of raw data.

What about Mu2e?

- The tracker's job is to accurately track electrons with momentum > 105 MeV/c (resolution < 350 keV)
- If the track comes from the aluminum stopping target, it could be a μ->e event!
- But there are lots of other particles coming through the tracker volume: mostly muons that did not stop in the target and all those < 105 MeV/c electrons.
- During the proton flash, an unreasonable number of proton tracks go through the tracker, mostly in the middle.
- The solution: make it hollow!







Electrons from a μ->e conversion will have higher energy and will spiral through the straws (r~400 to 700mm)

99% of electrons from regular μ decays, muons, and protons will spiral in central "dead zone" r < 400 mm.

Modular construction: can replace panels or stations.

Current Status

- Small-scale and pre-production prototypes already exist & tested.
- Production prototypes to be assembled at FNAL and Minnesota this summer/fall.
- Radiation studies on electronic components ongoing (but optimistic so far).
- “Vertical slice test” to be done by end of the year.
- “Factory” to be set up & started at Minnesota in the fall/winter.

Further resources

- Panel prototype assembly on Alessandra Luca’s DPF2017 poster
- Andy Edmond’s Doc 7761 (lots about track reconstruction)
- Tracker requirements Doc 732
- Tracker geometry Doc 888
- Tracker TDR Doc 4516
- More gas ionization pedagogy in My Thesis
- F. Sauli, “Principles of Operation of Multiwire Proportional and Drift Chambers,” CERN Academic Training Lecture, 1977.