Queen Mary University of London

Science and Engineering

Radiation Detectors (SPA 6309)

Lecture 5

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Last revised 3 February 2020

What is this lecture about?

- The principles of detection of ionising radiation
  - Interaction of charged and neutral particles with matter
  - Gaseous sensors
  - Semiconductor sensors
  - Scintillators
- Sensor systems used in particle and nuclear physics
  - Calorimeters
  - Tracking detectors
  - Neutrino detectors

Key points from previous lecture

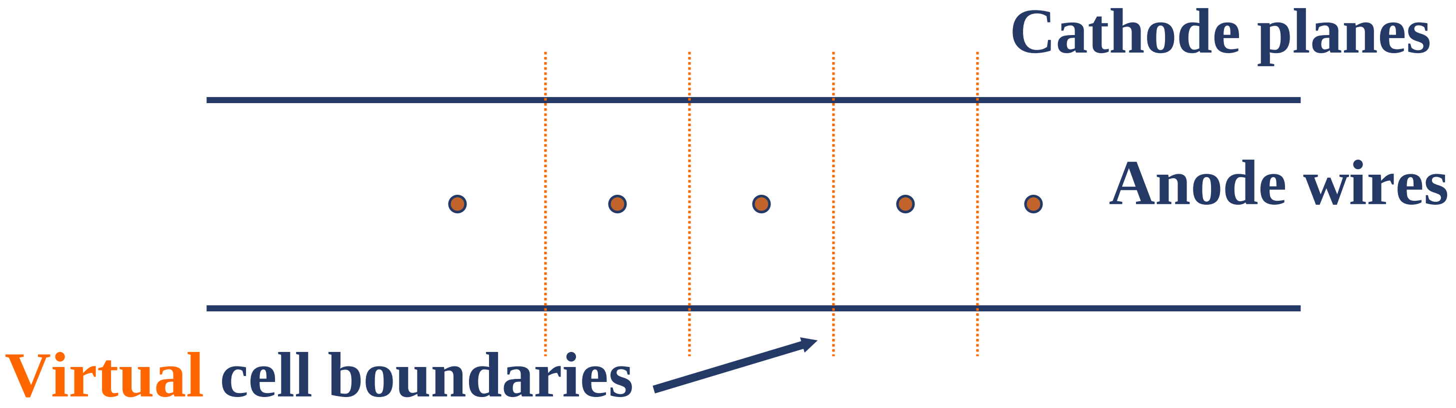
- The interactions of neutrons and Cherenkov effect
- Neutrons
  - High energy can cause fission
  - Intermediate energy, main scattering
  - Thermal neutrons ~ 25 meV (milli electron volts) very slow, liable to capture.
- Cherenkov
  - A velocity threshold below which no photons emitted
  - Very weak effect (can neglect as a cause of energy loss), intensity varies as λ^{-2}

Key points from previous lecture

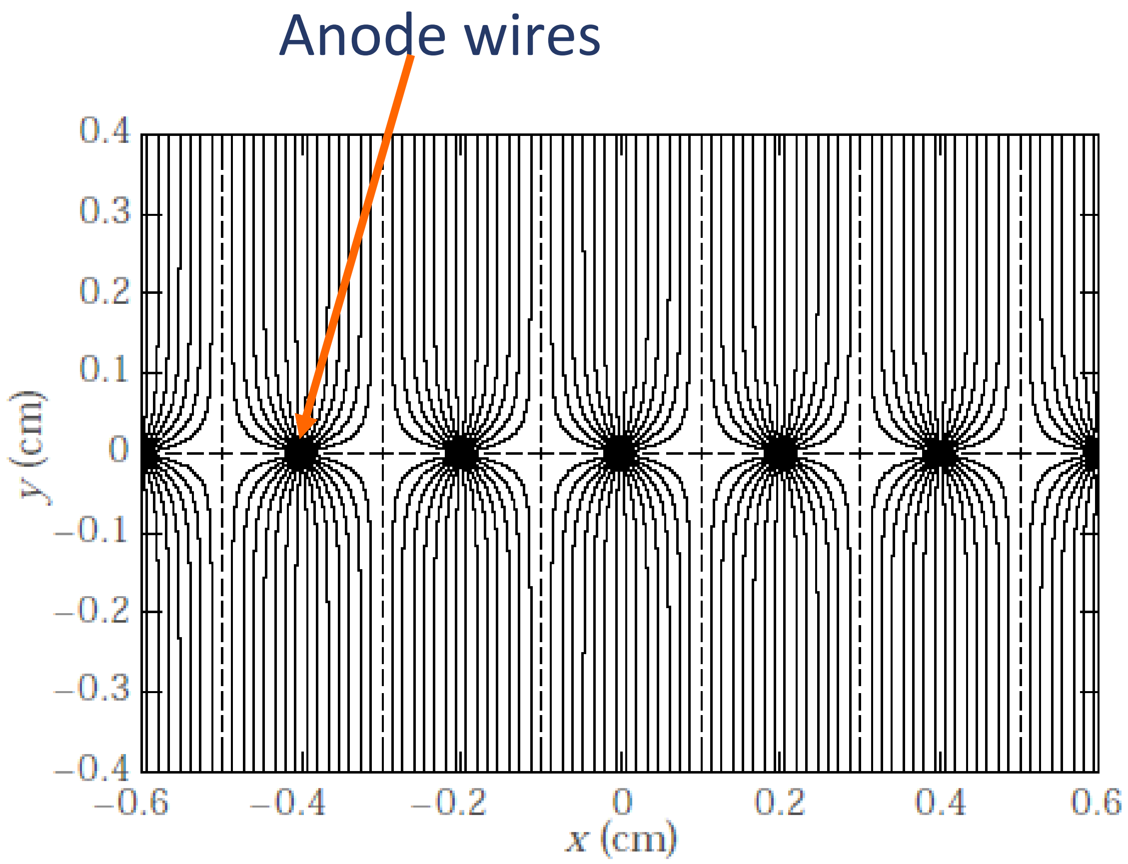
- The ionization of gasses and the proportional/Geiger counter
- Gases
  - Ionisation requires ~ 30 eV per ion-pair.
  - Electrons drift in an electric field about 1000 times faster than positive ions.
  - Electrons can cause impact ionisation in regions of high field strength.
- Proportional Counter
  - Almost all the signal is due to the movement of the positive ions.
  - Highly asymmetric energy loss (Landau-Vavilov distribution) in “thin” absorbers.
  - Geiger plateau, very large signal, long “dead time”, still used for radiation protection.

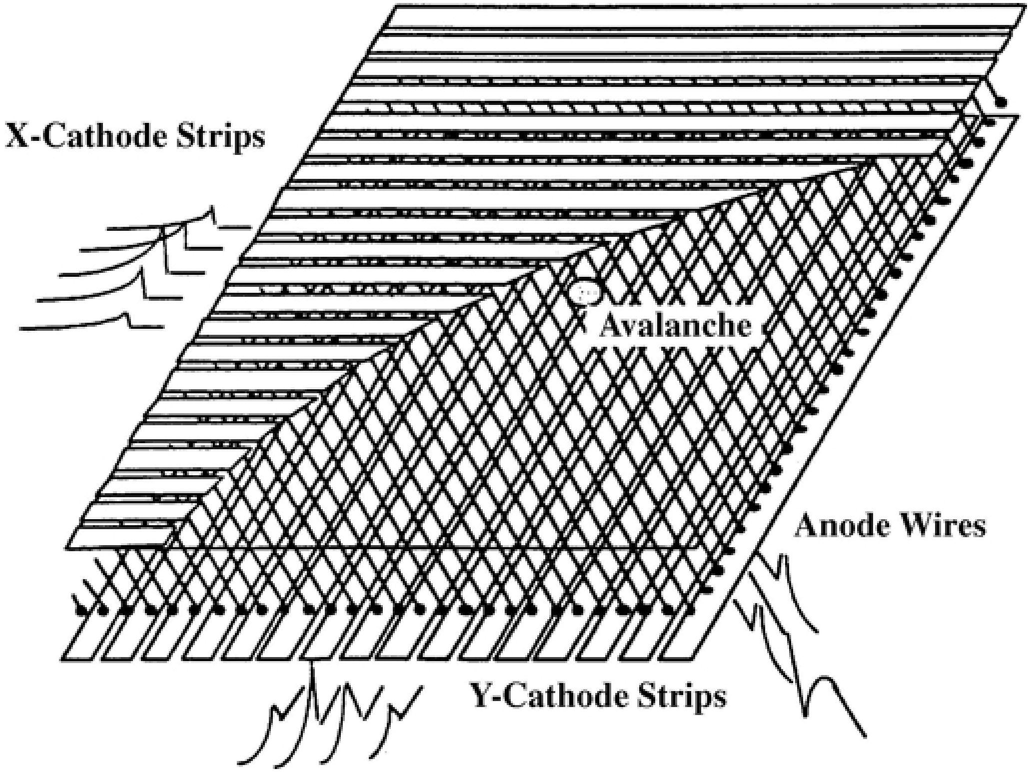
Multi-wire proportional counter

- Multi-wire proportional counters (MWPC) collect deposited charge in a large number of electrically isolated cells – position resolution
- By using planes of MWPC with orthogonal (and often diagonal) wire planes you get 2D hit resolution.



MWPC

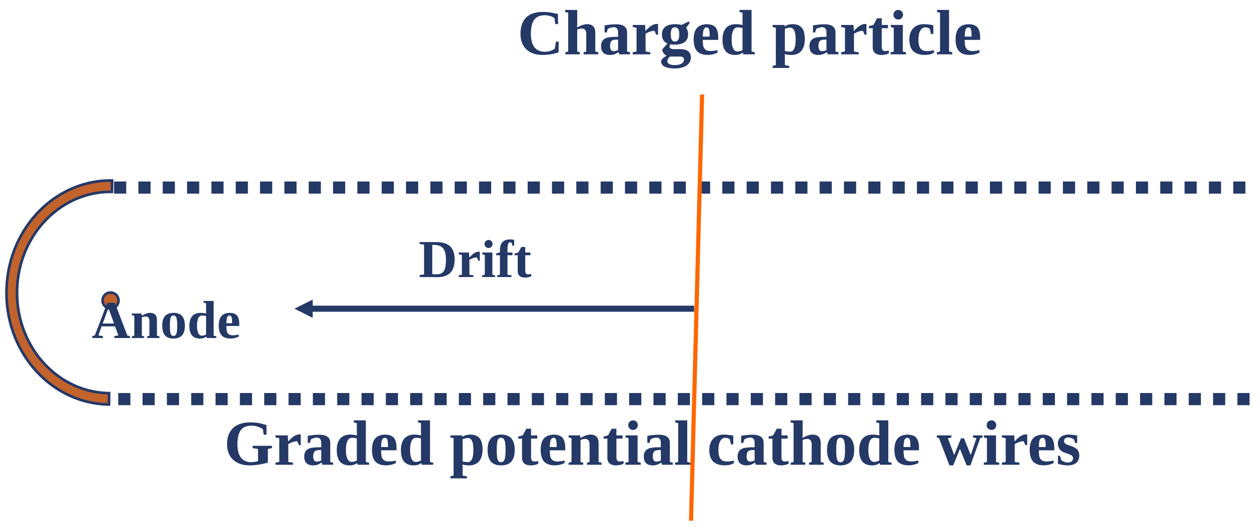




2D position sensing using induced charges on cathode plane strips.

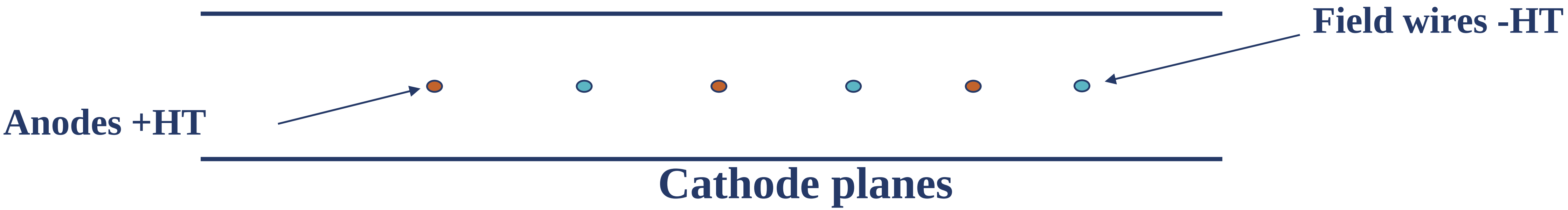
Drift Chamber (Concept)

- In principle, since the electrons travel at a constant mean velocity, measuring this drift time gives spatial information.
- Could use a modified proportional counter with a long drift region.
- This design does not scale well (long drift times, very high voltages, but see Time Projection Chamber)



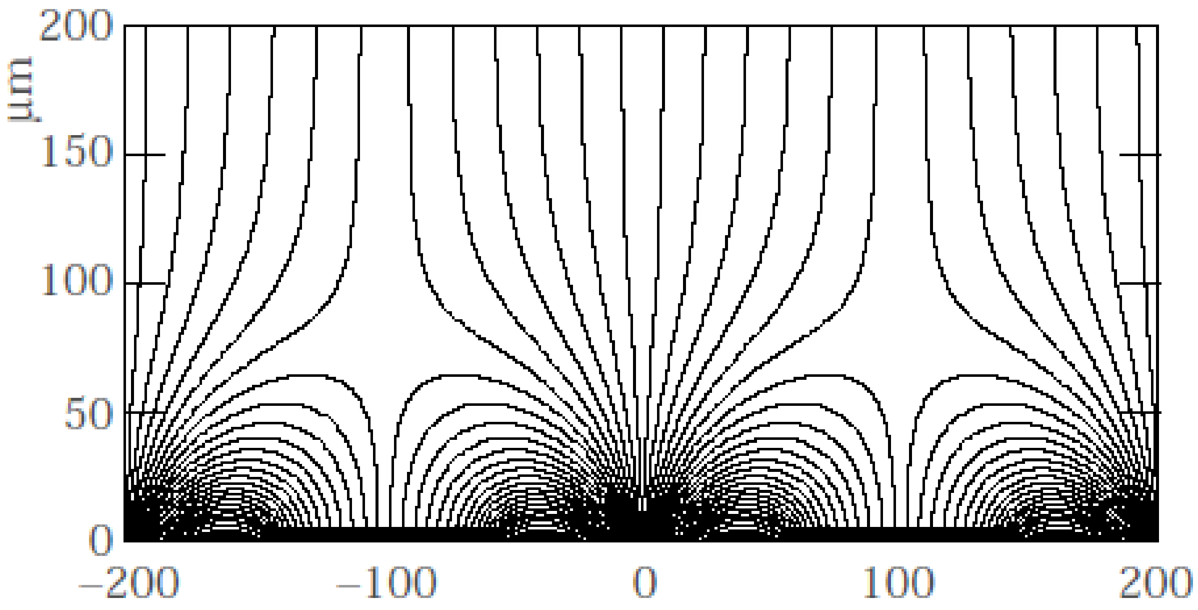
Drift Chamber (practical, obsolete)

- The clever trick is to use the same structure as a MWPC but to avoid the significant field non-uniformities (low field between anodes) which would ruin the resolution.
- Instead of having all anode wires, a drift chamber alternates anode wires with *field* wires. These are thick and help maintain the electric field in the critical region.
- Localisation accuracy is limited by
  - Spread in original position of ionisation (delta-rays)
  - Stability of drift velocity
  - Dispersion due to diffusion
  - Localisation of order 20 μm is achievable for a drift distance of 1 cm.

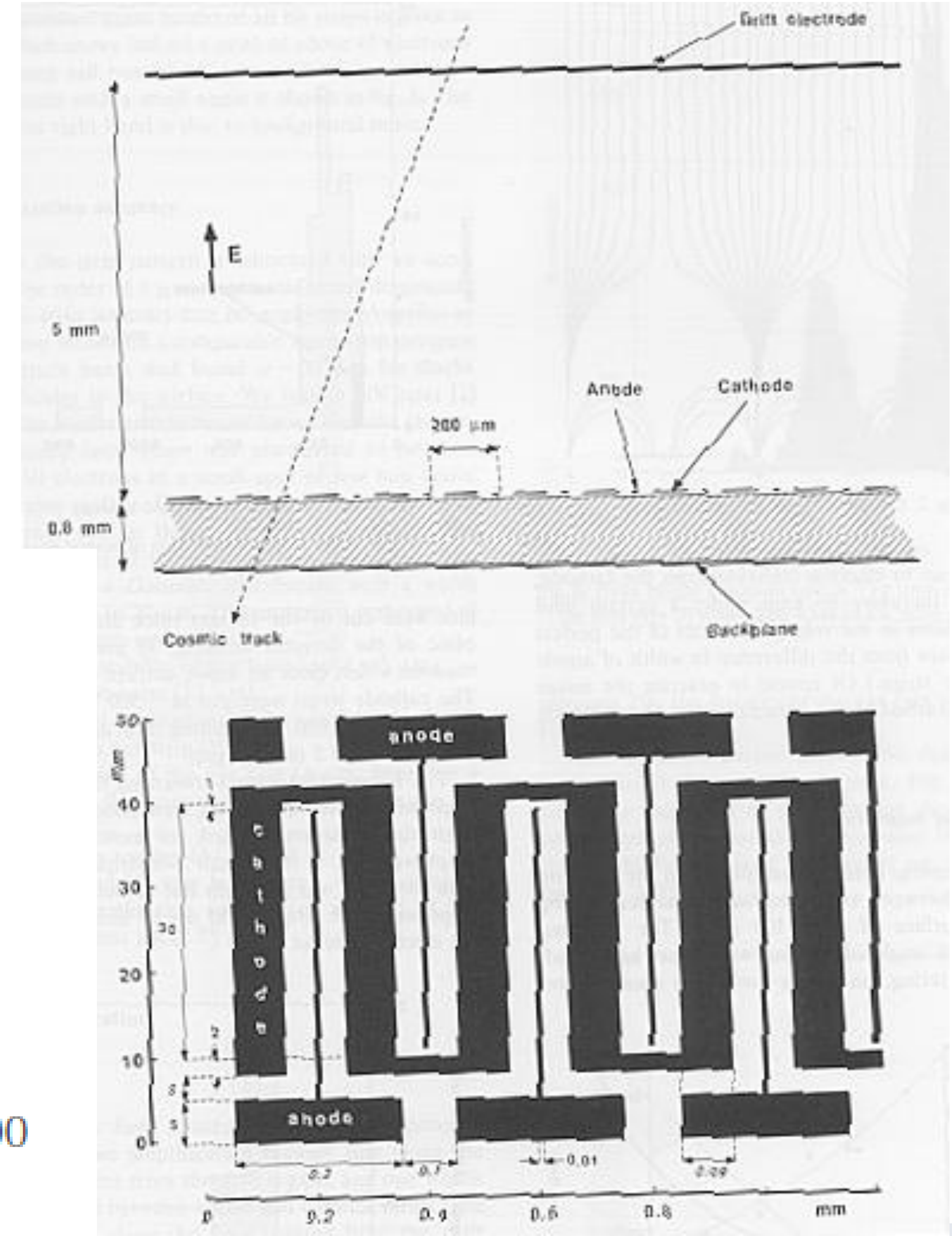


Drift Chamber (practical, modern)

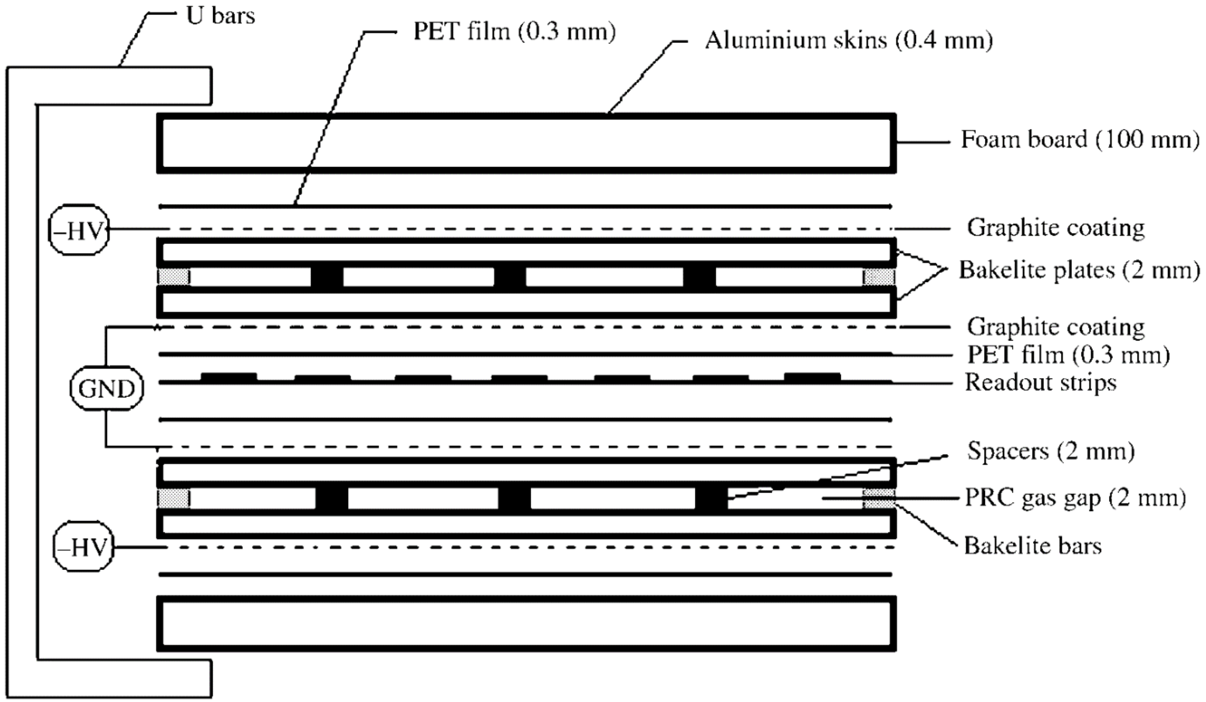
Figure (from *NIM A* **310** p89) shows a gas microstrip detector.

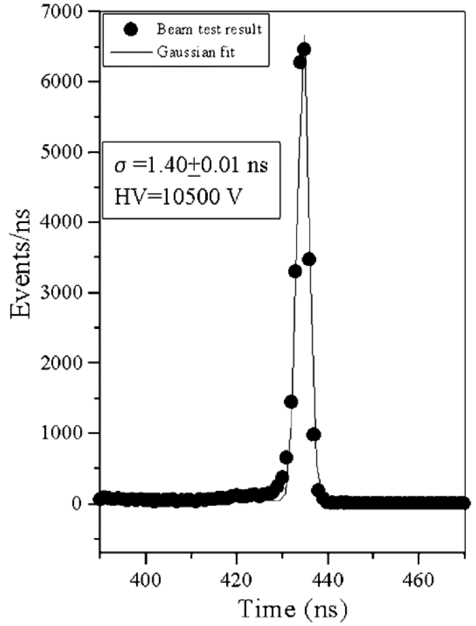


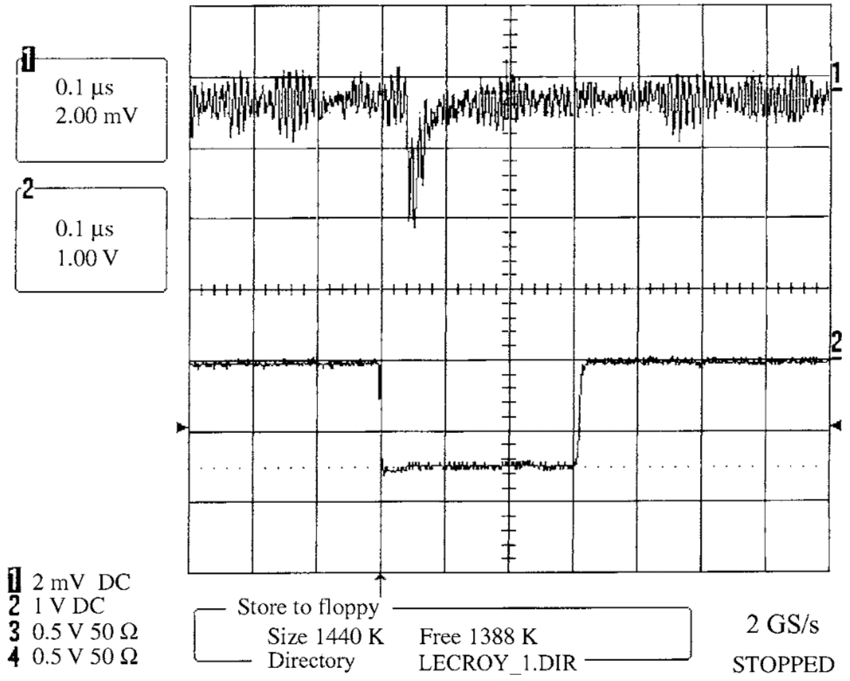
Electric field map



Resistive Plate Chamber (RPC)







Gas mixture of 95% $C_2H_2F_4$ + 5% i-C_4H_{10}

J. Phys. G: Nucl. Part. Phys. **26** (2000) 1291

NIM A **518** (2004) 86–90

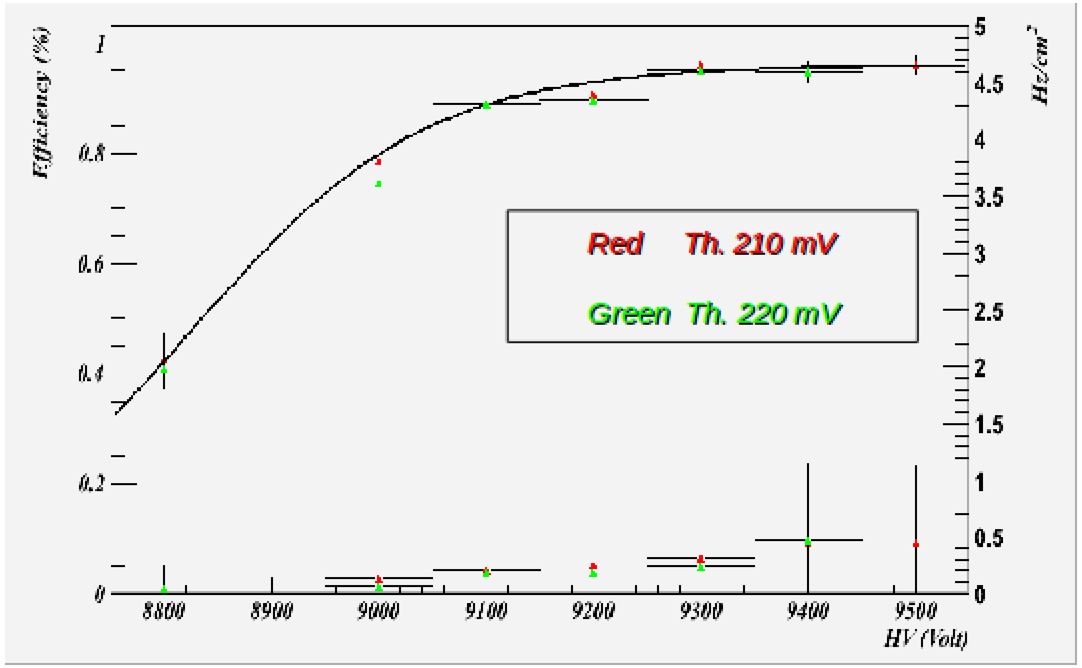
Bakelite

Still widely manufactured, even in the UK.

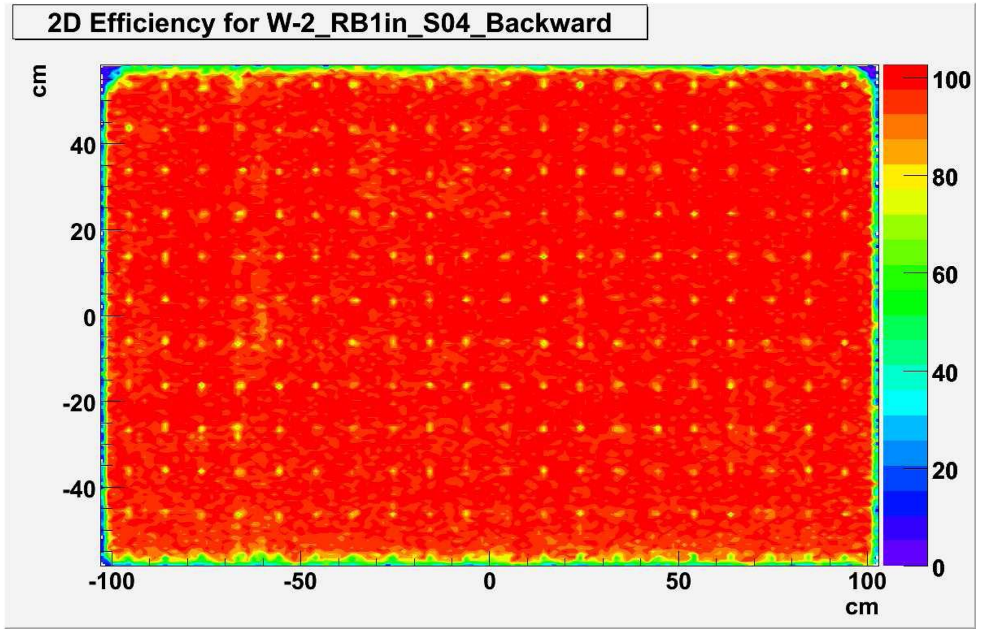
http://www.cylexplastics.co.uk/products/thermosetting-plastics/bakelite.html

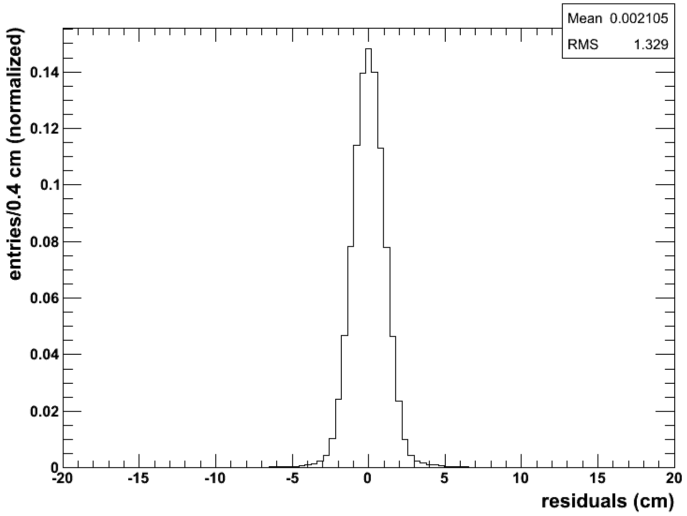
Ericsson telephone, picture by Holger Elgaard

RPC in CMS at the LHC



Efficiency as function of HV

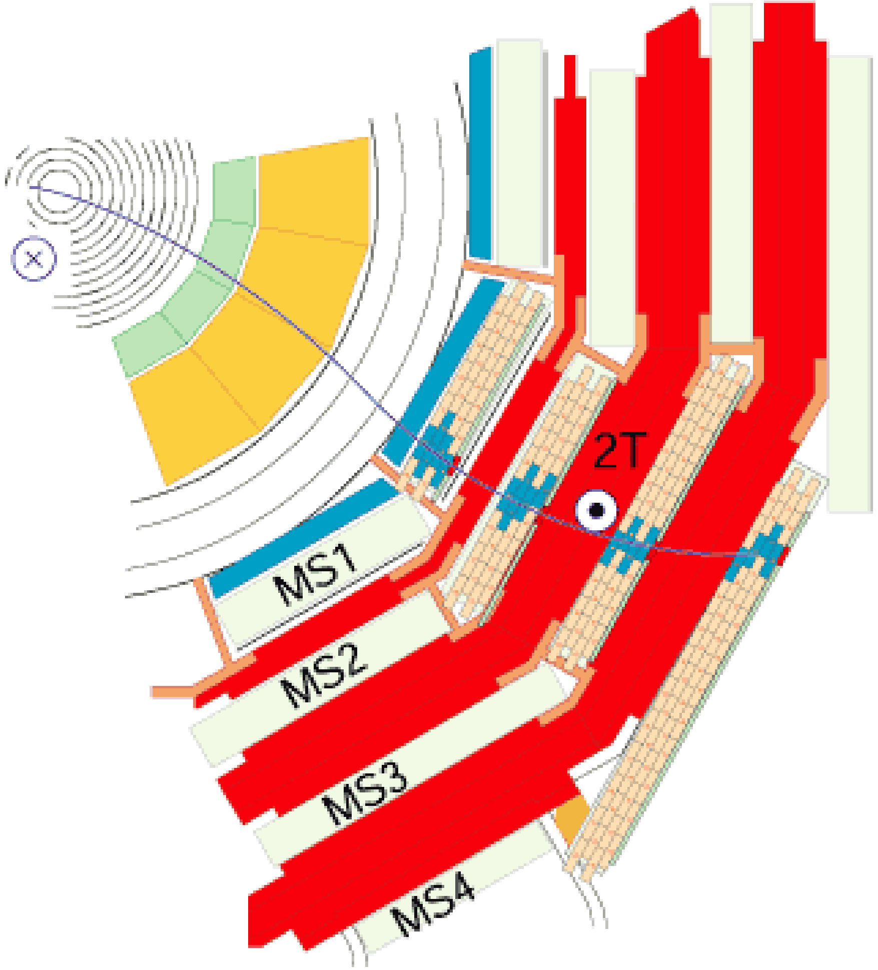




Camilo Andres Carrillo Montoya
CMS CR - 2010/070

Spatial Resolution

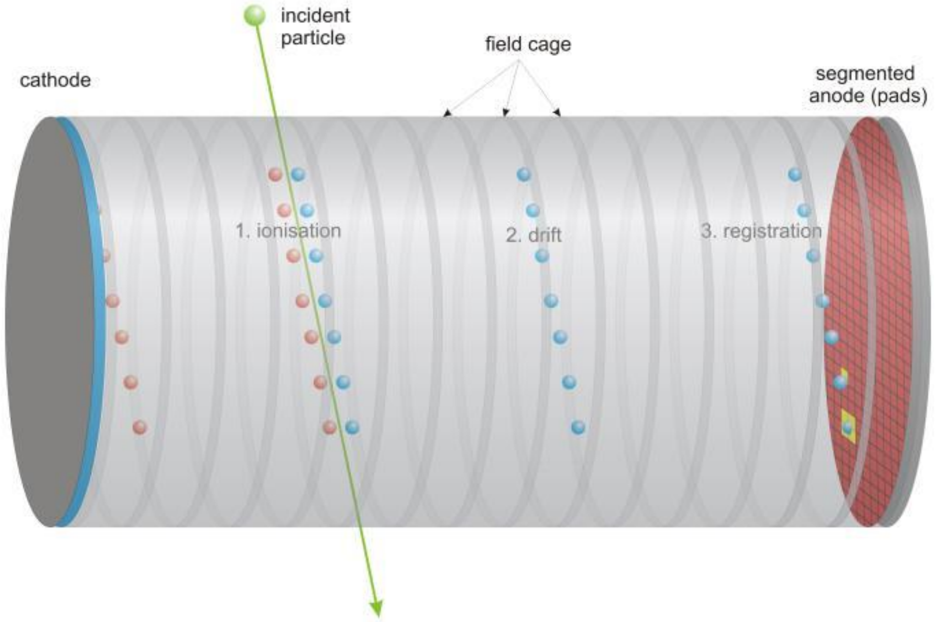
RPC in CMS



Huge system! ~ 3000 m^2 and 100 k channels

Time Projection Chamber (TPC)

A giant drift chamber, using 2D spatial plus time-of-drift information to give a truly 3D picture particle tracks. Need a trigger signal to start the timing clock.



For the precision timing need a very uniform field and very high (graded) voltages.

Use gas multiplication to provide gain at the anode. Use of Micromegas and other new approaches replacing traditional wires.

Note: this approach also works with drifting in liquid noble gases (Ar, Kr, Xe)

ALICE TPC

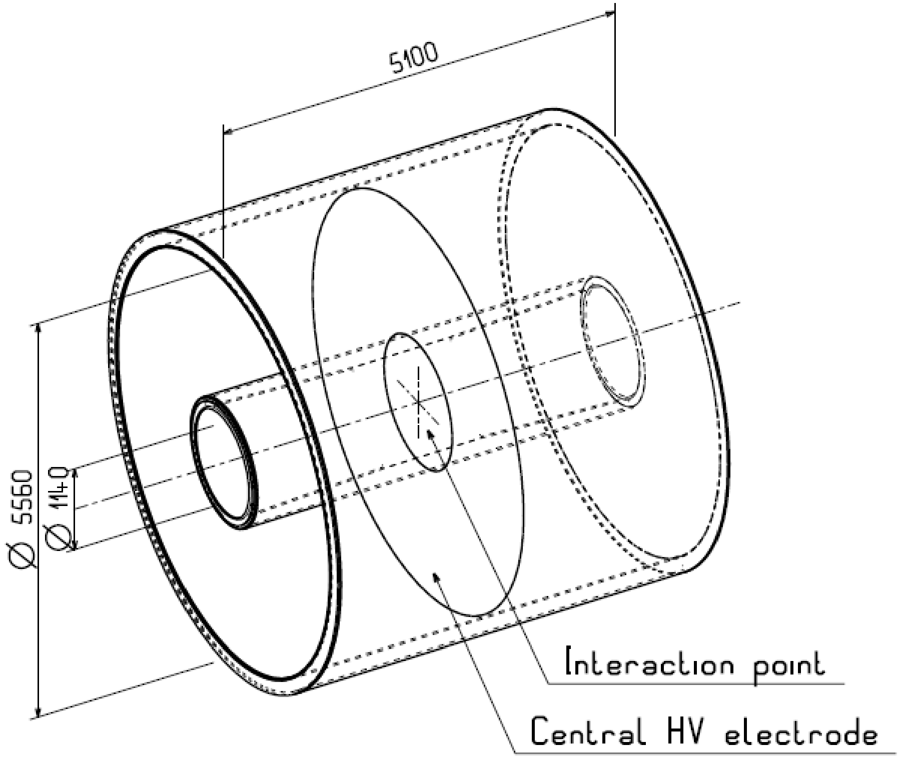


Figure 3.1: Conceptual view of the TPC field cage.

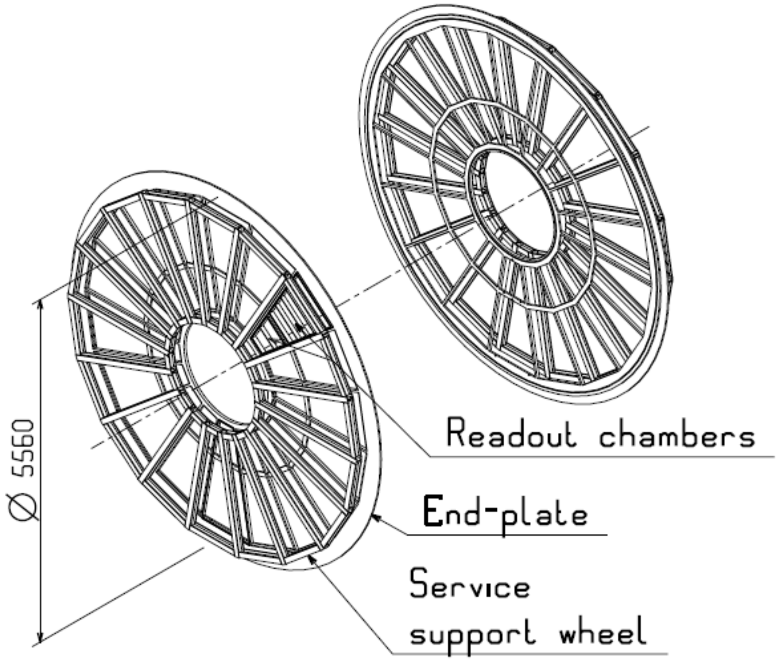
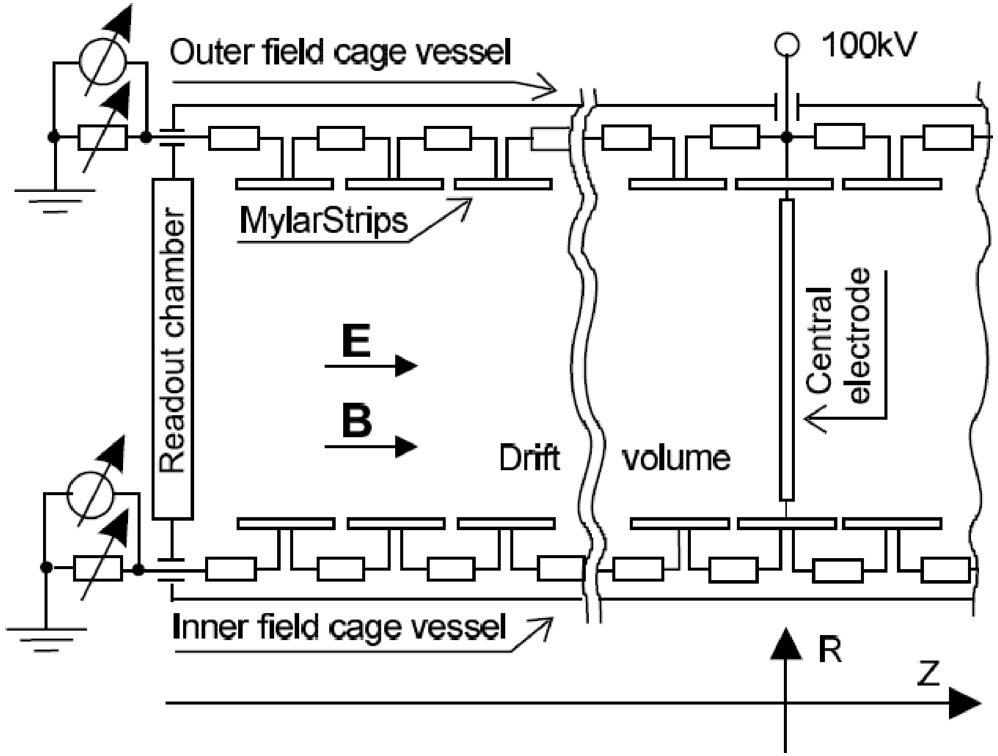
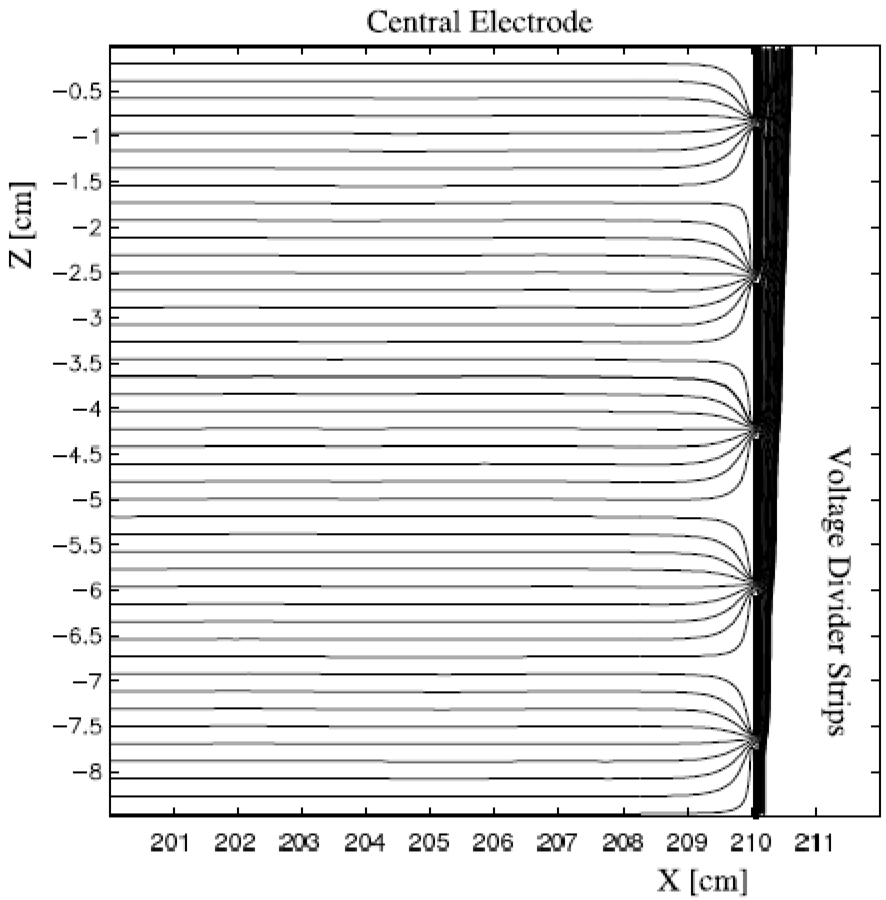


Figure 3.8: Design of the end-plate and the service support wheel.

ALICE TPC



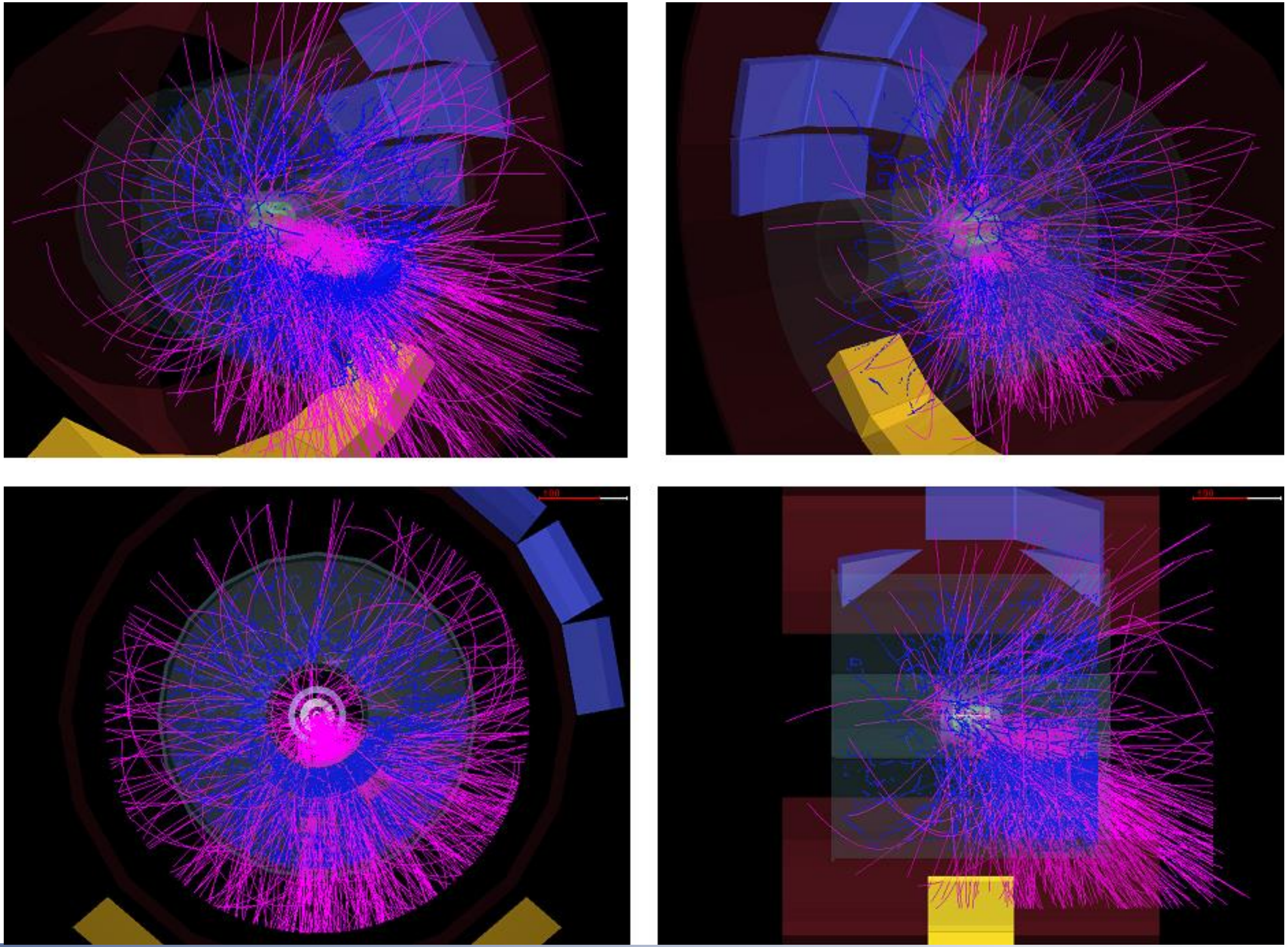
Outer field cage vessel
100kV
MylarStrips
Readout chamber
E
B
Drift
volume
Central electrode
Inner field cage vessel
R
Z



Central Electrode
Z [cm]
−0.5
−1
−1.5
−2
−2.5
−3
−3.5
−4
−4.5
−5
−5.5
−6
−6.5
−7
−7.5
−8
201
202
203
204
205
206
207
208
209
210
211
X [cm]
Voltage Divider Strips

ALICE TPC

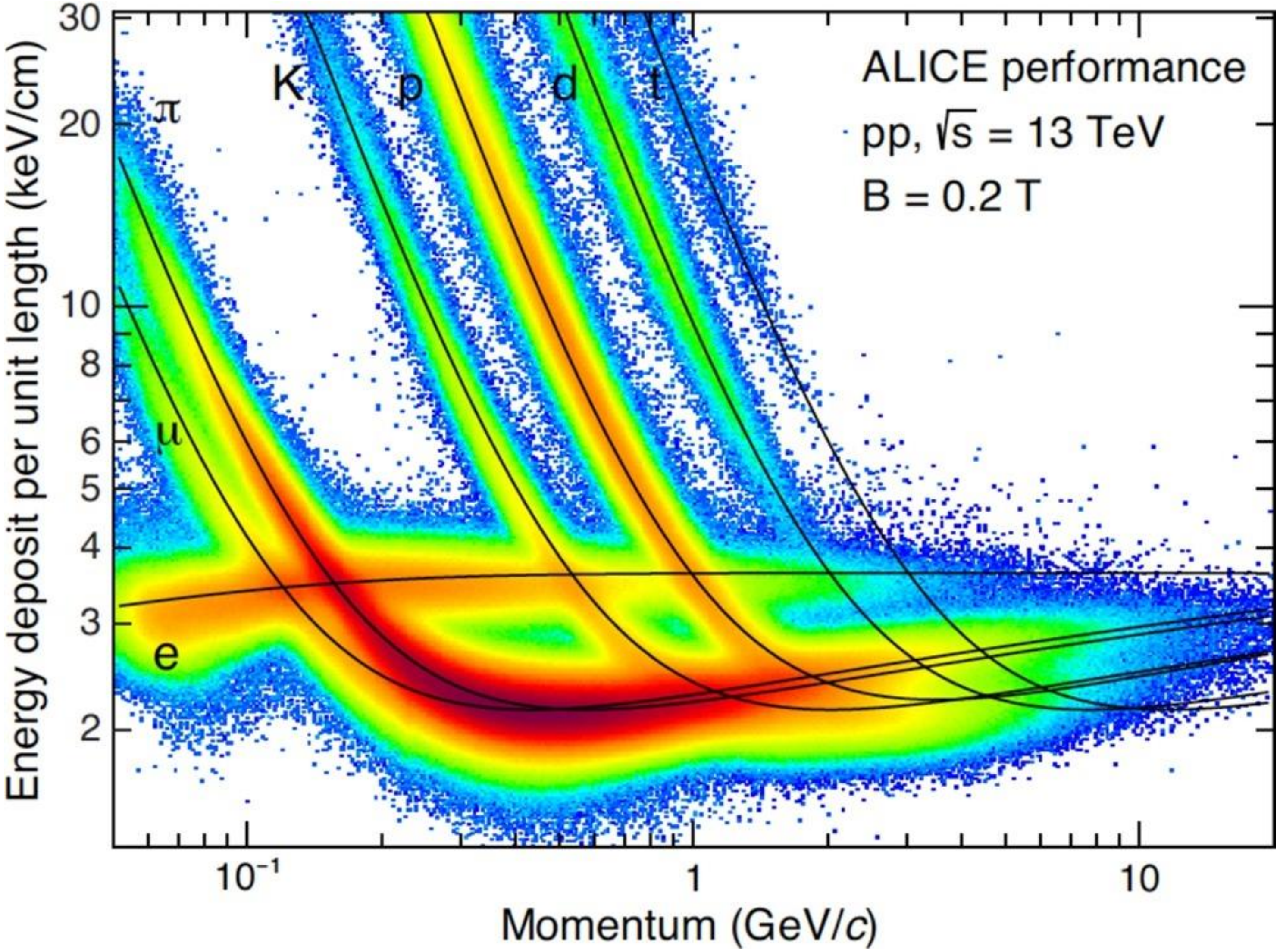
Cosmic ray shower



ALICE TPC

"Loosely-bound objects produced in nuclear collisions at the LHC" *Nuclear Physics A* **987** (2019) pp 144-201

https://doi.org/10.1016/j.nuclphysa.2019.02.006



Liquid argon TPC

Liquid argon (LAr) can also be ionised and then have long drift distances for electrons. Thus a large and massive (100 tonne +) detector can be built – neutrino physics. Lar also *scintillates* providing a fast light pulse (clock start) which is critical for TPC operation.

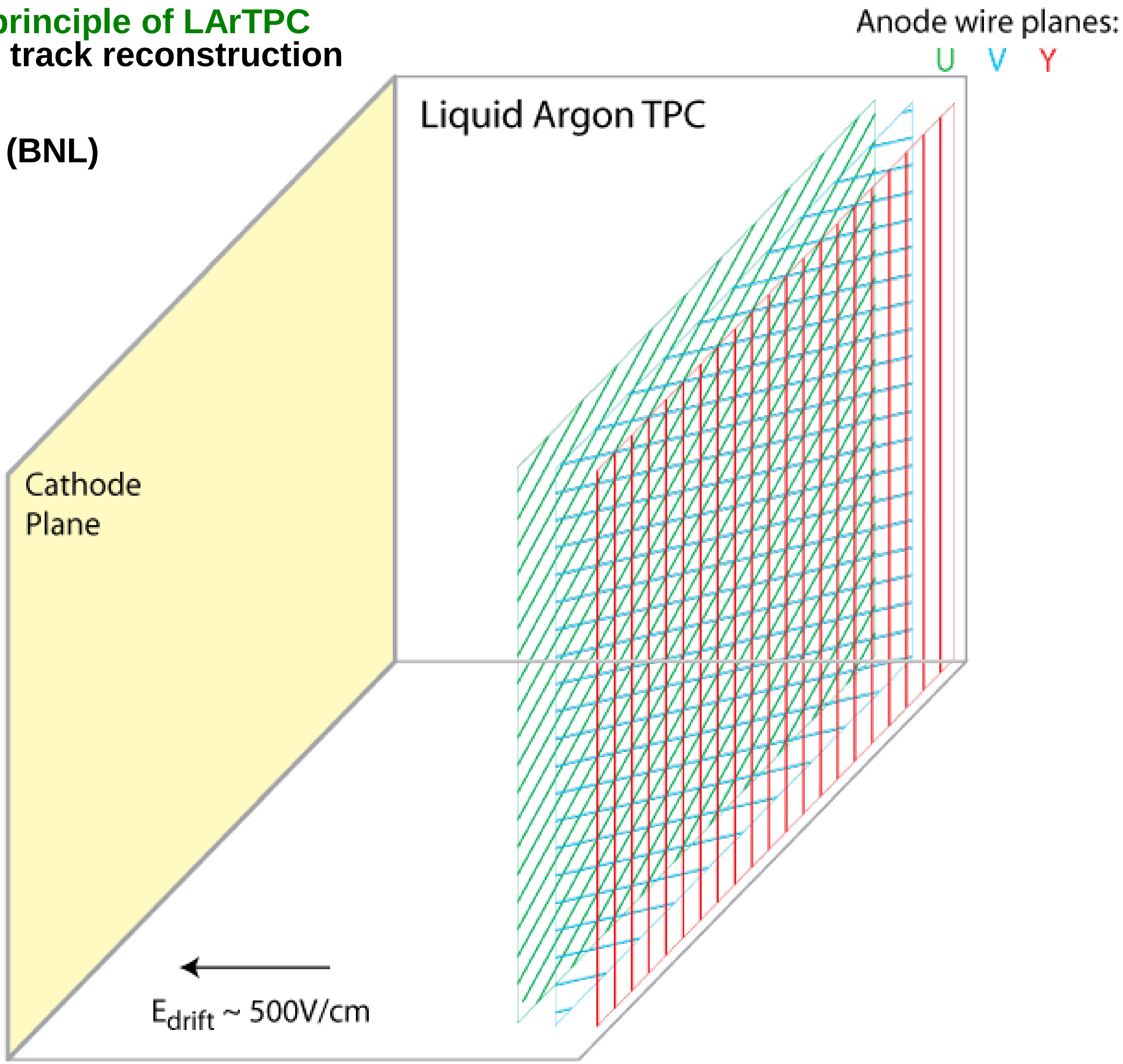
A number of these have been/are being built

MicroBooNE (170 ton) at FermiLab: https://microboone.fnal.gov/
Short Baseline Near Detector (112 ton) at FermiLab: https://sbn-nd.fnal.gov/
Deep Underground Neutrino Experiment (~ 68 k ton) at Sanford Laboratory: https://www.dunescience.org/

Liquid Argon Time Projection Chamber (LArTPC)

The principle of LArTPC
- 3D track reconstruction

Bo Yu (BNL)



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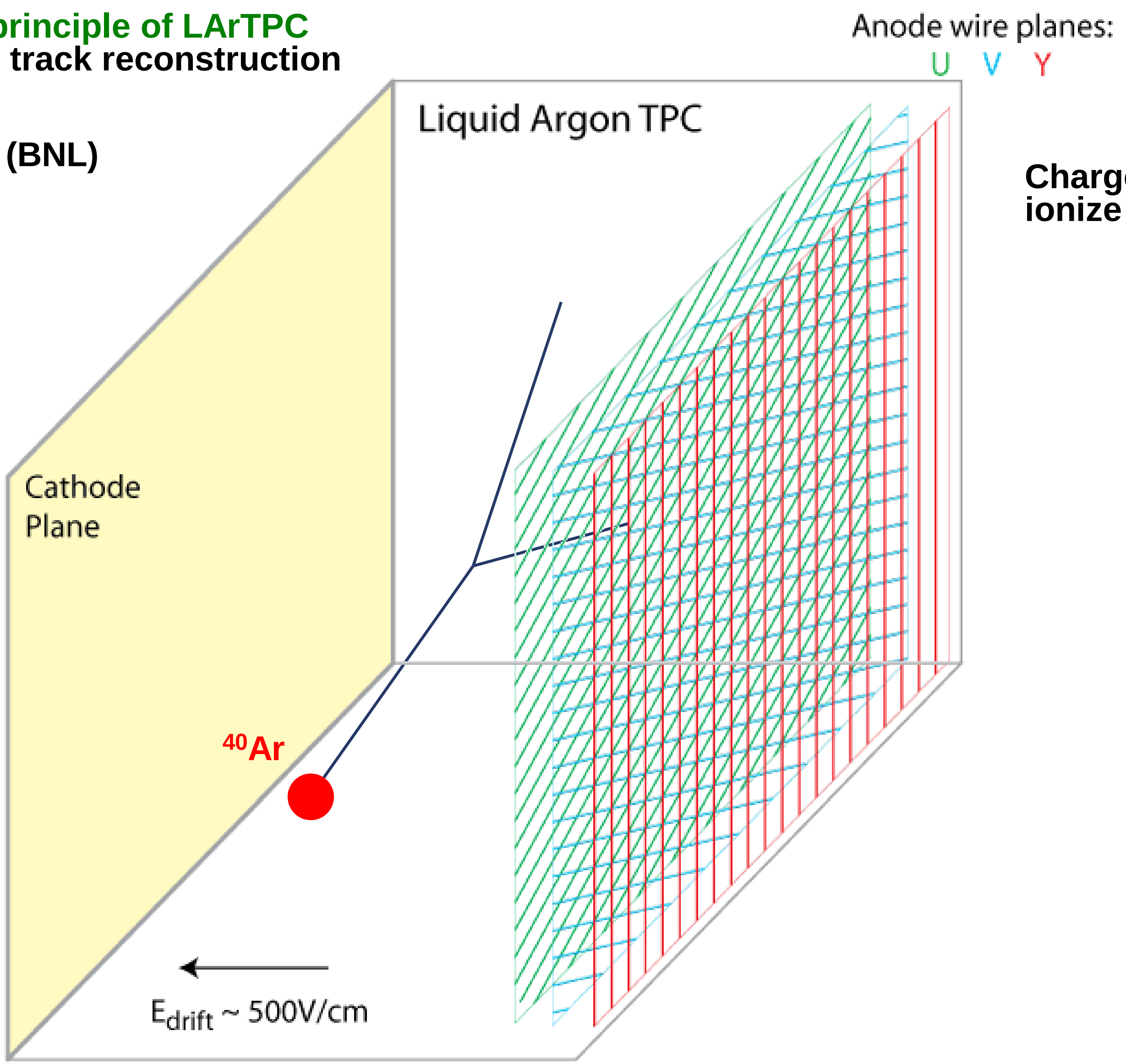

Charged particle tracks ionize Argon atoms

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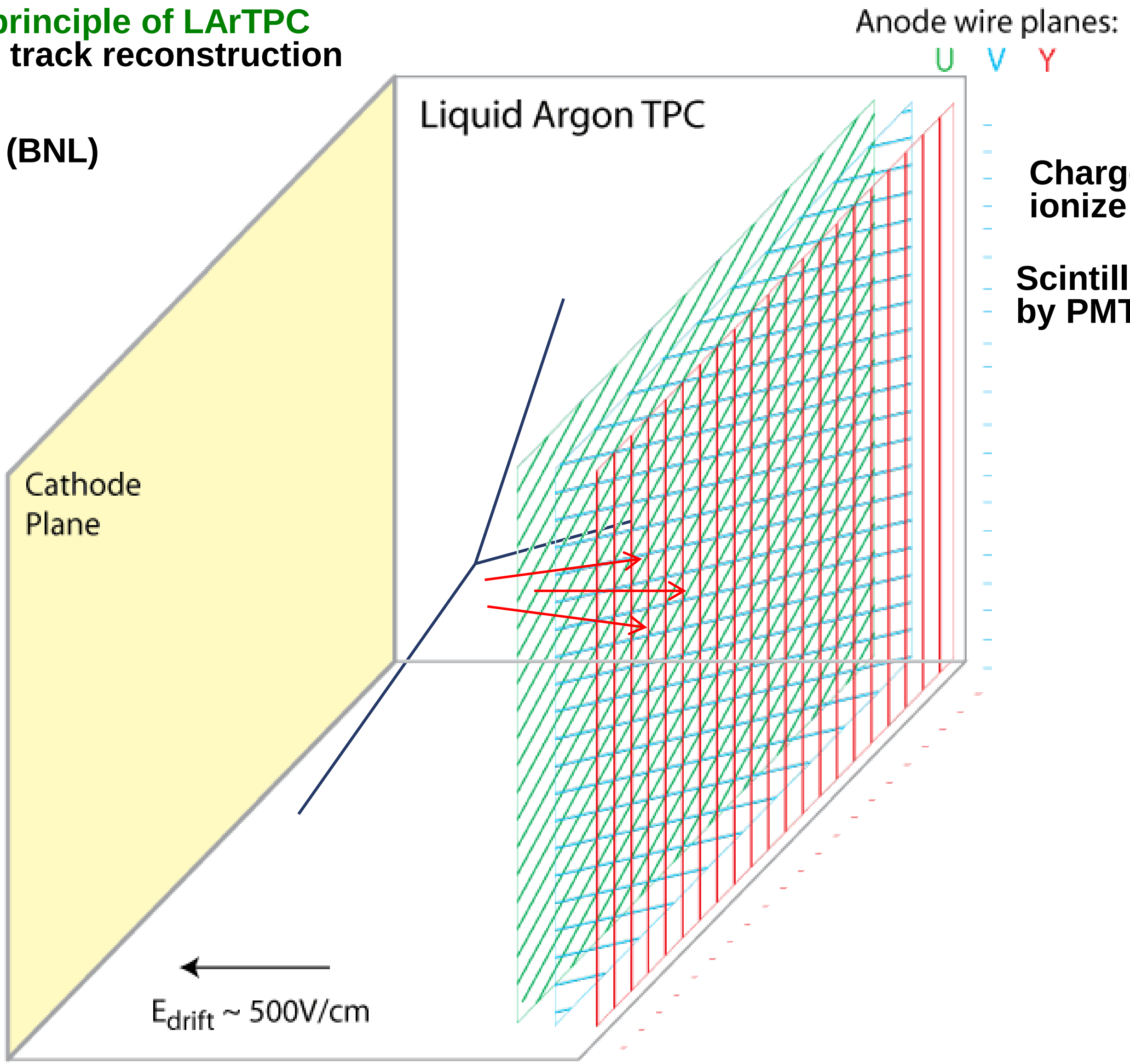
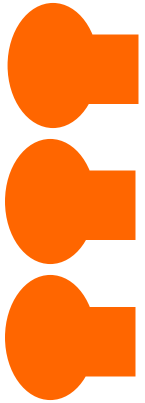


Charged particle tracks ionize Argon atoms

Scintillation light (~ns) is detected by PMTs at same time



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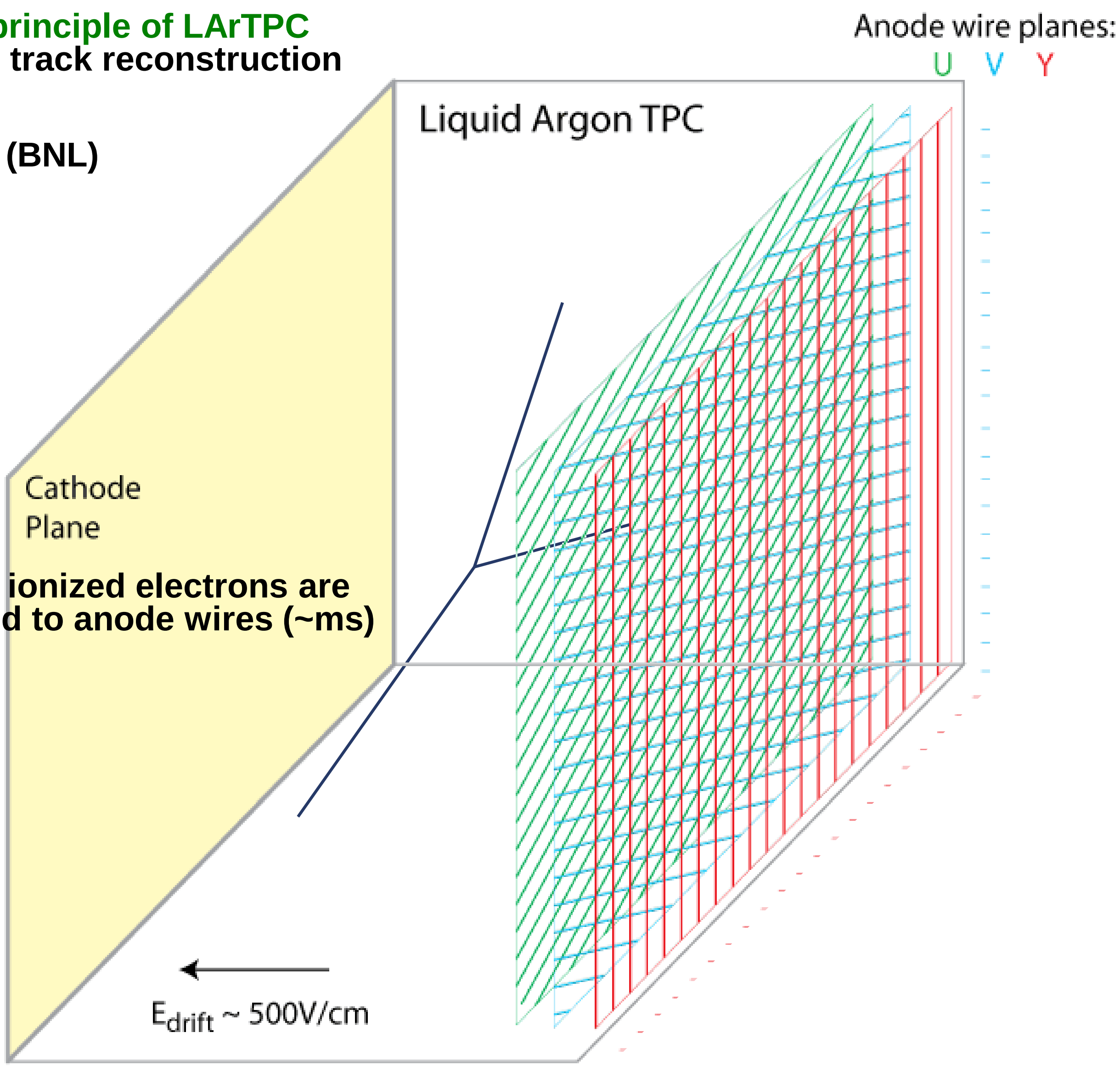

Then ionized electrons are drifted to anode wires (~ms)

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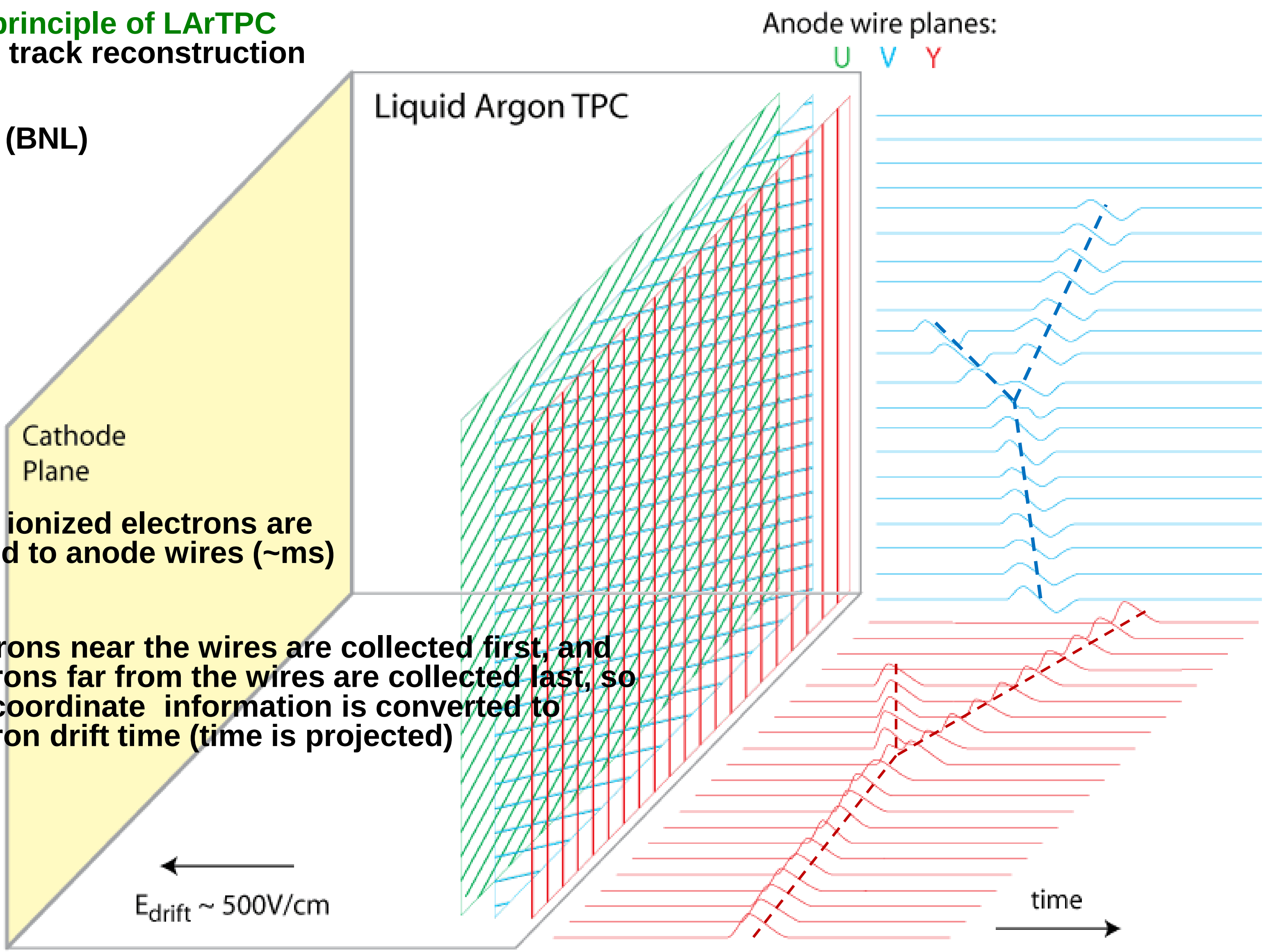
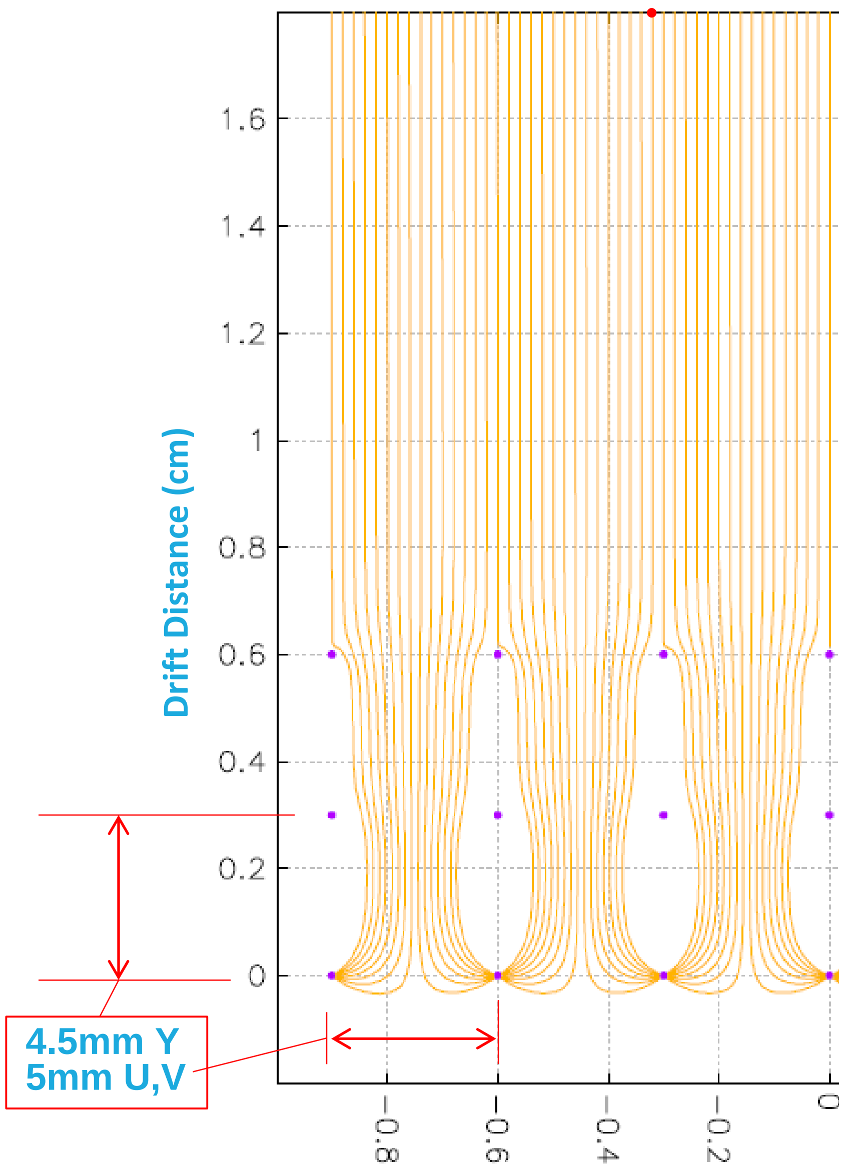


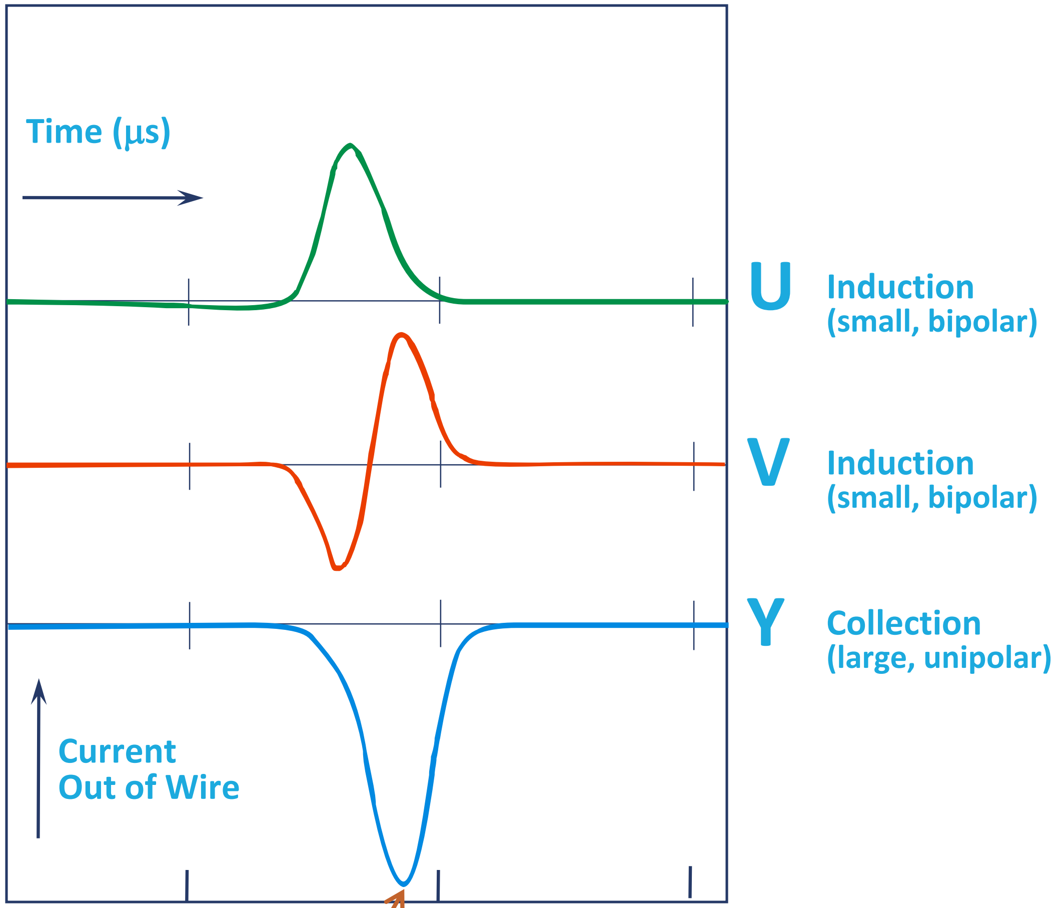
Then ionized electrons are drifted to anode wires (~ms)

Electrons near the wires are collected first, and electrons far from the wires are collected last, so drift coordinate information is converted to electron drift time (time is projected)

Charge Signal Formation

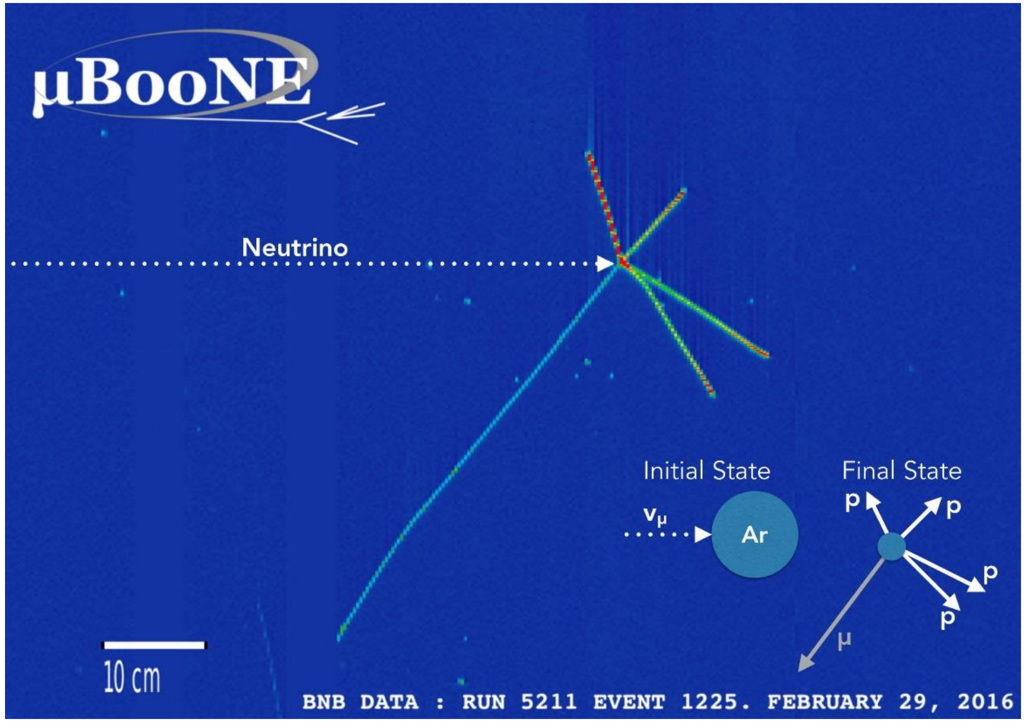
Bo Yu (BNL)

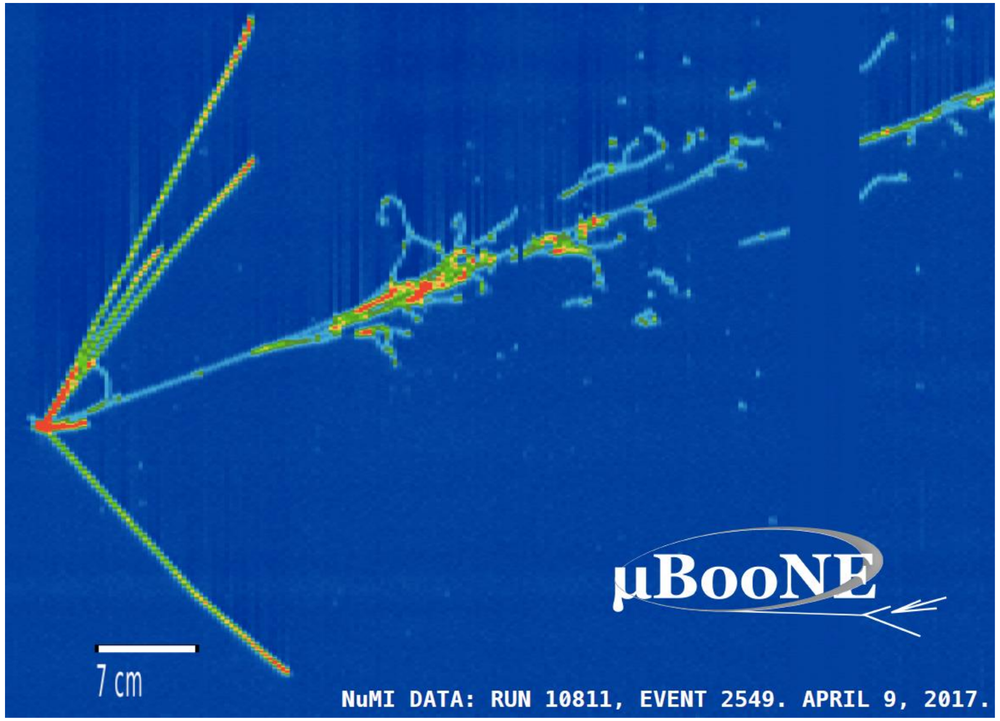




ArgoNeuT
1 MIP peak ~ 26 ADC counts
Noise rms ~ 1 ADC count

Actual TPC data from MicroBooNE





https://microboone-exp.fnal.gov/public/approved_plots/Event_Displays.html