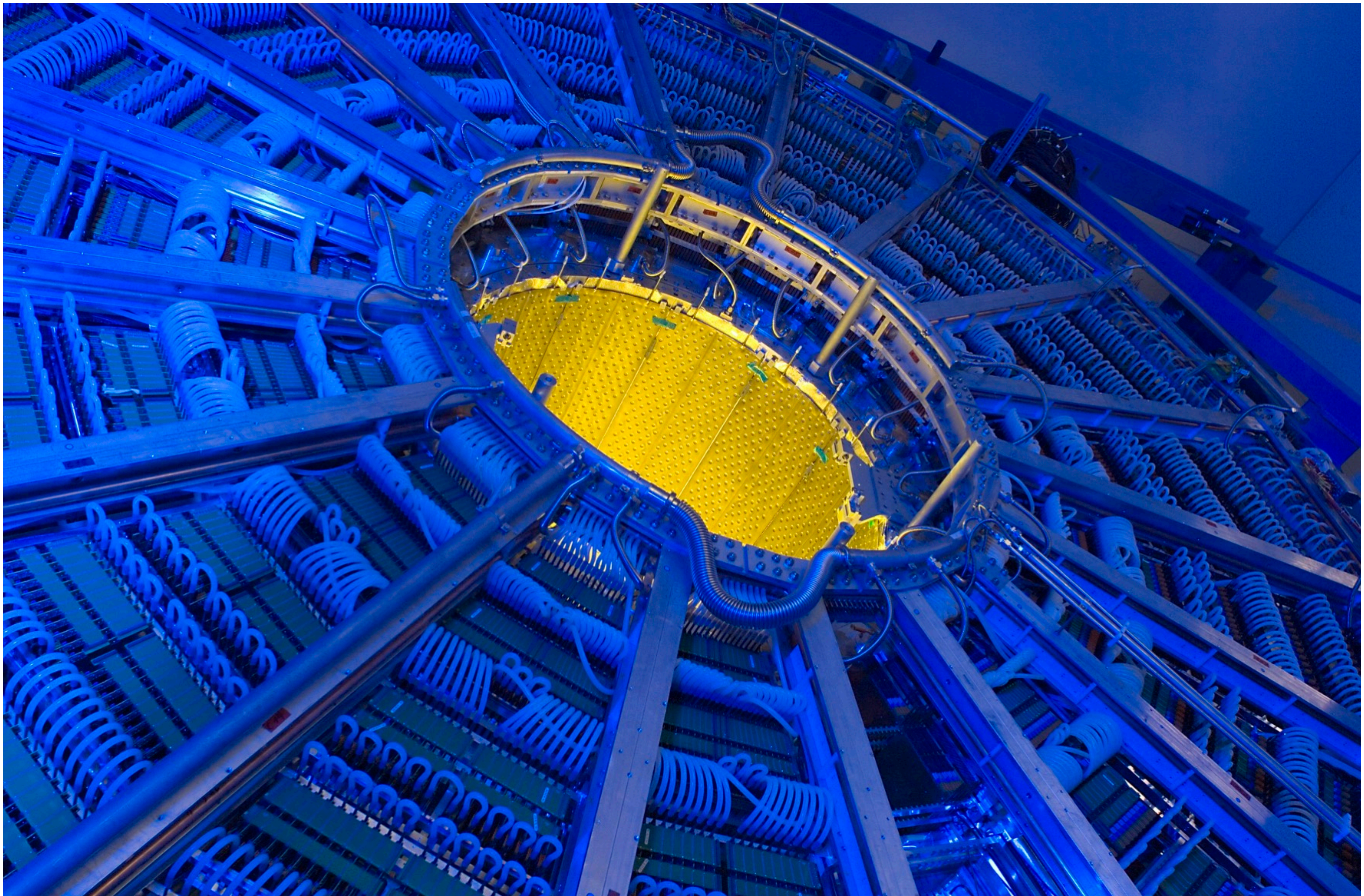
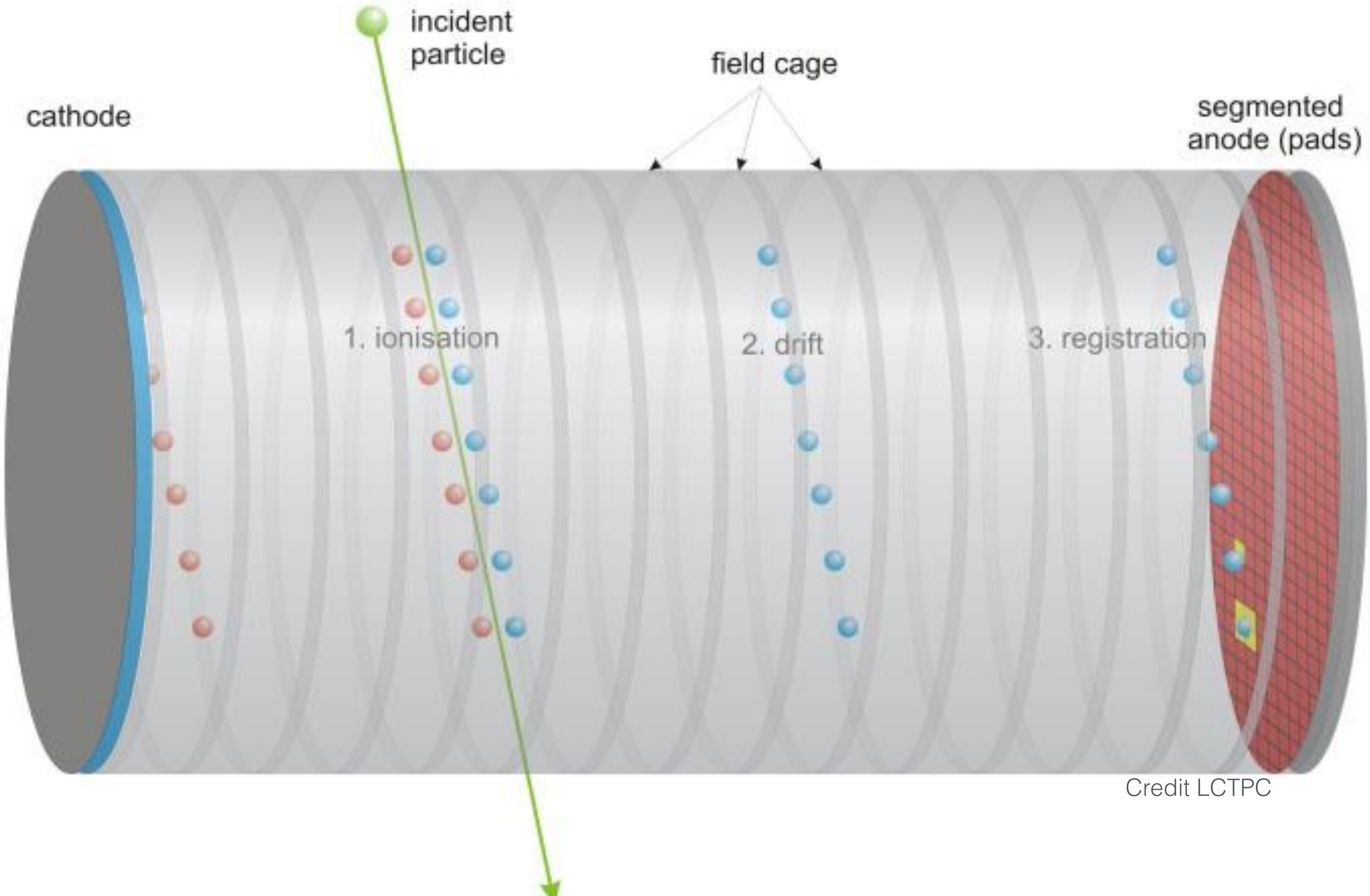
Time Projection Chambers



What is a TPC?

- Cylindrical Field Cage
  - Uniform Electric and Magnetic Fields
- Multi-Wire Proportional Chamber
  - HV wires cause avalanche of ionization
- Large gas-filled detection volumes
- Cathode pads for position resolution
  - Electronic output supplement wire readout

What is a TPC?



Credit LCTPC

The First TPC

- Created by David R. Nygen at LBL in 1976
- First Used in PEP-4 detector at SLAC for e^+e^- collisions

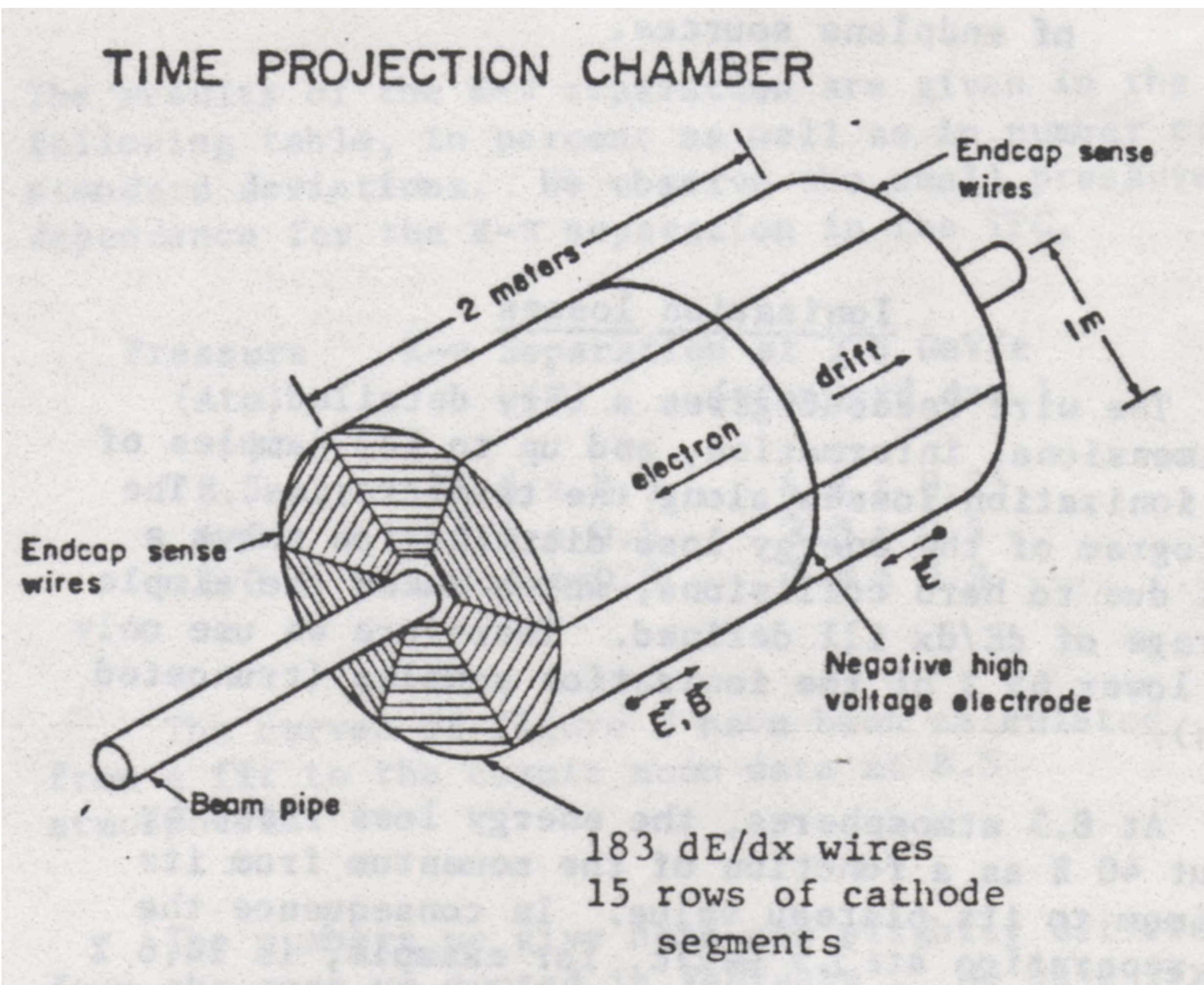
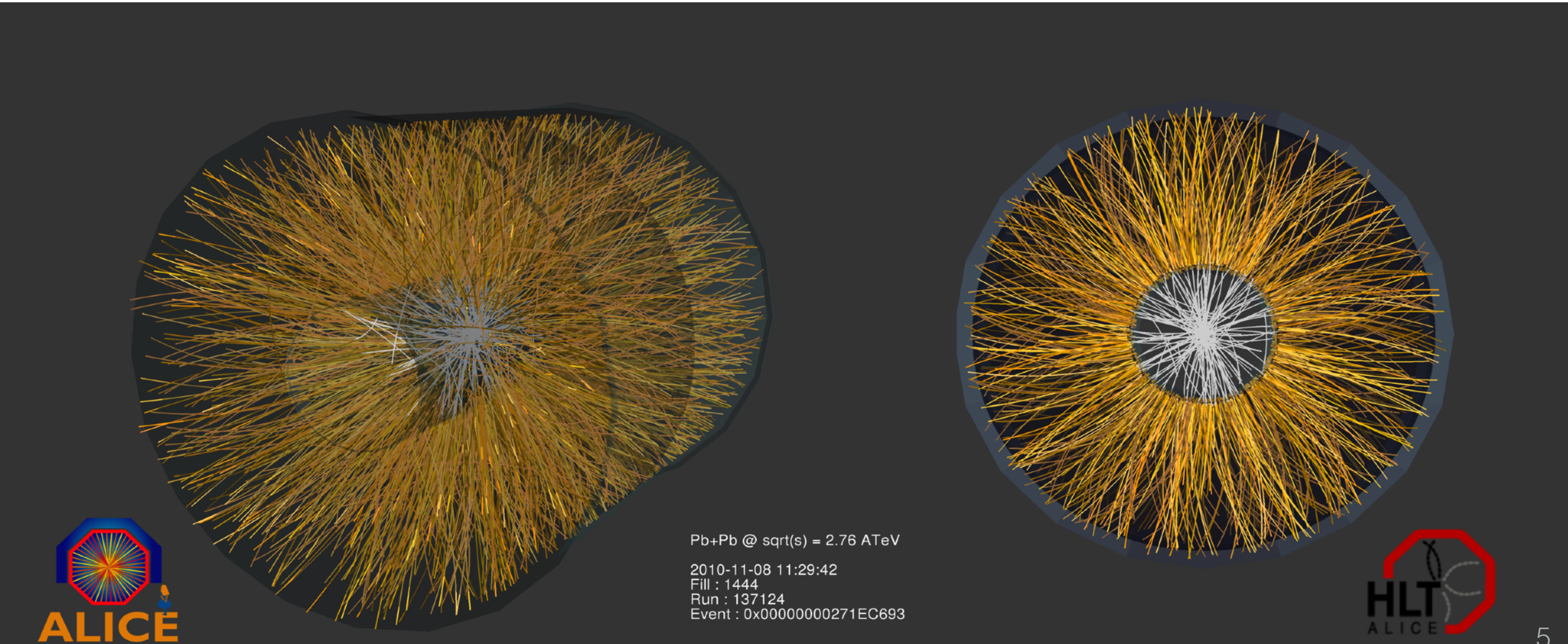


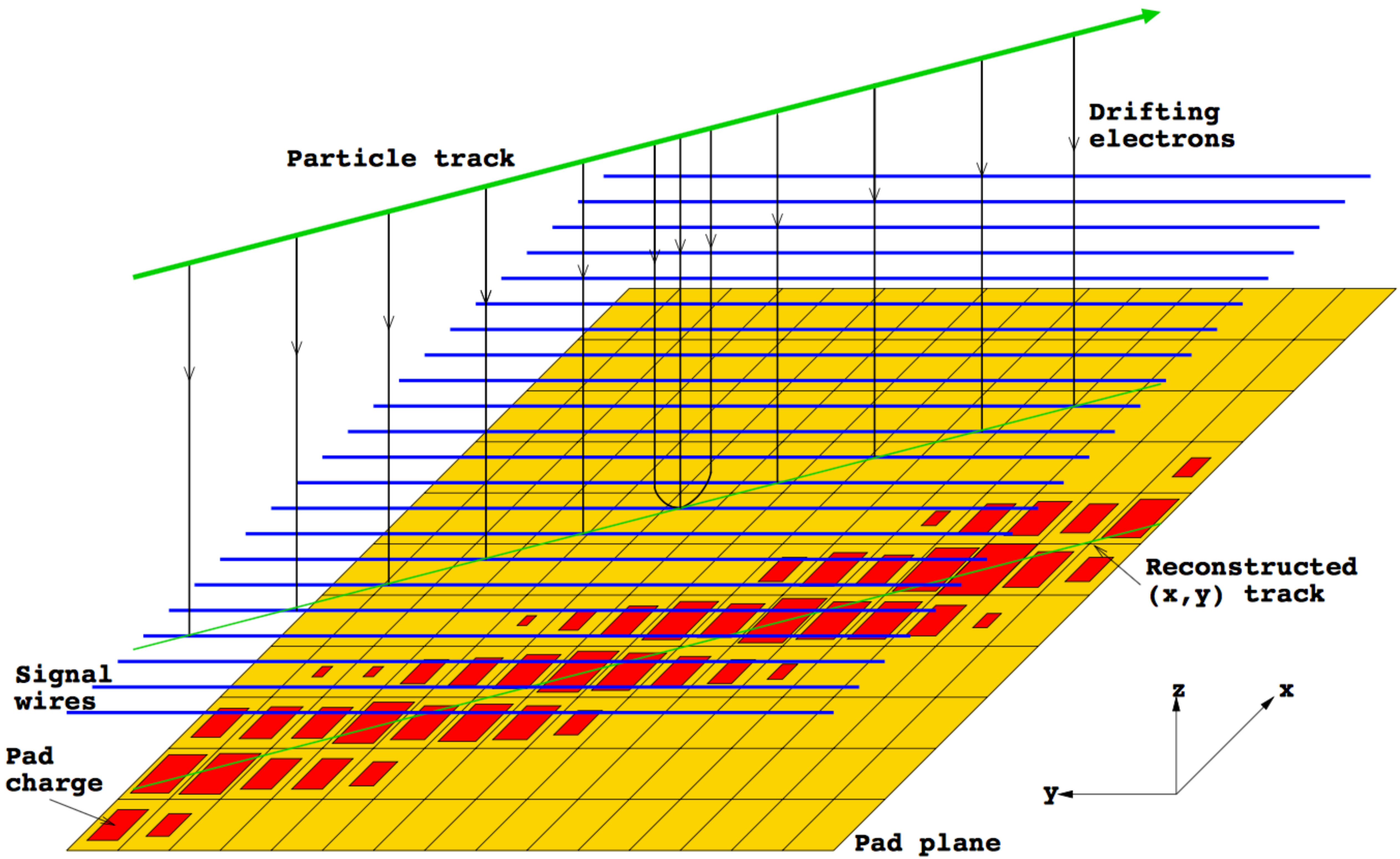
Fig. 1. A schematic drawing of the TPC

Who Cares?

- 3D track reconstruction
- Less material -> less multiple scattering
- Easier patter recognition
- Particle ID from momentum and energy measurements



Track Reconstruction



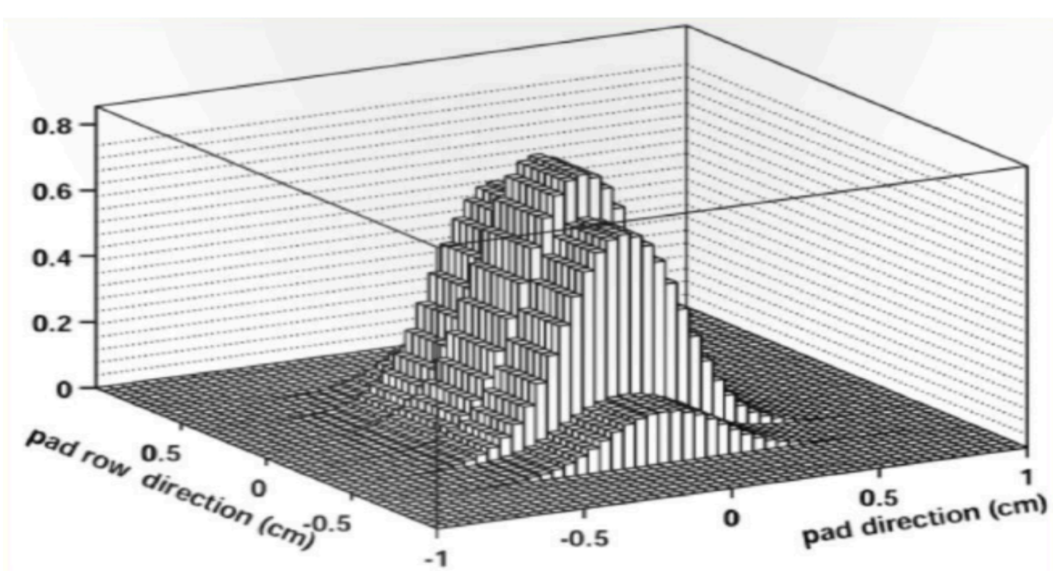
Credit Thompson, MIT 2002

X-Y Position Resolution

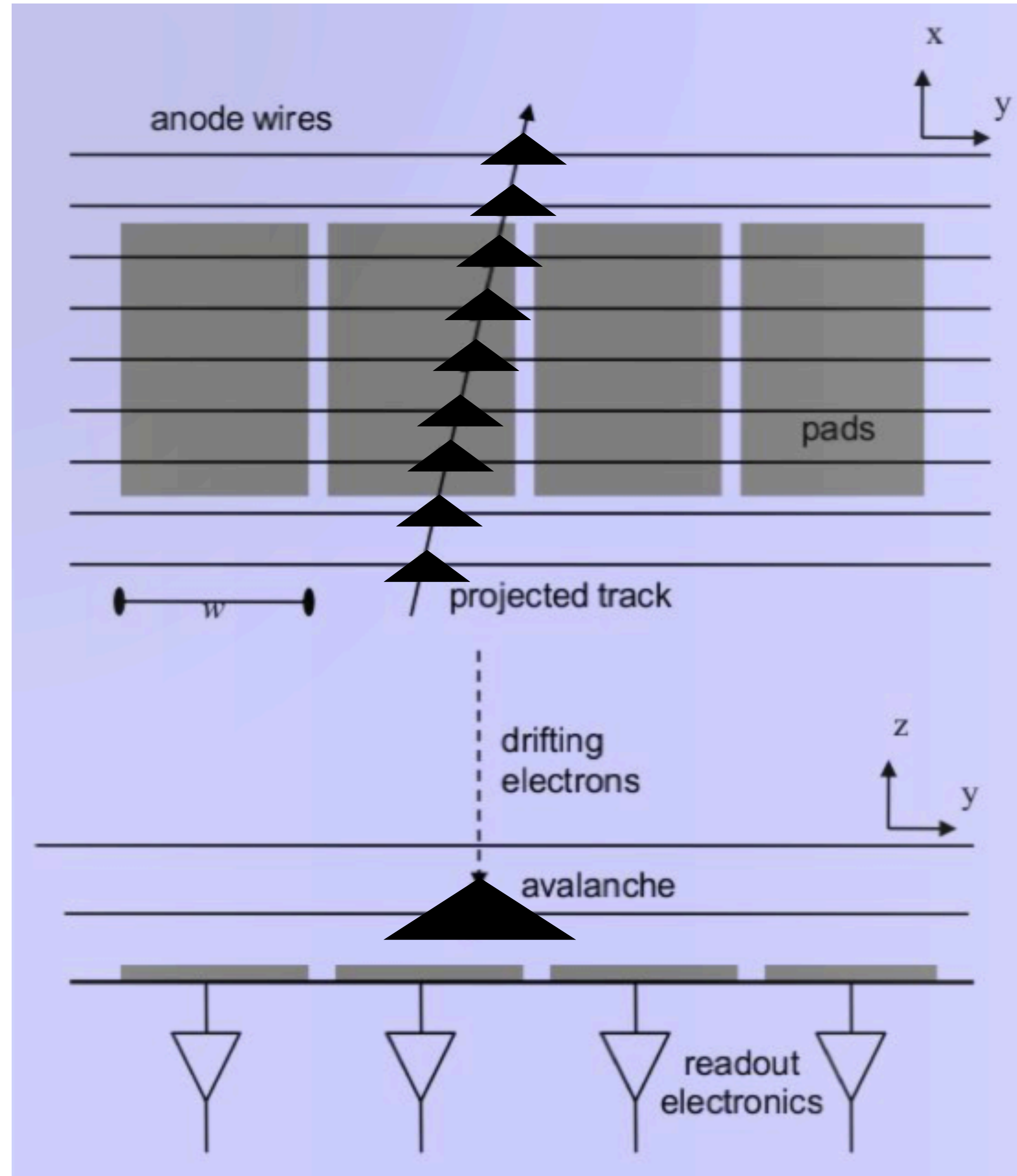
If the avalanche can be measured from at least 2 cathode pads, then the ΔY (or ΔX) << *w*

The pulse height ratio of the two signals can find the position with the pad response function ***P_0***

$$A_1/A_2 = P_0(\lambda)/P_0(\lambda - w)$$



C. Lippman Univ. Pargue 2005



C. Lippman Univ. Pargue 2005

XY is Easy. Z is Hard

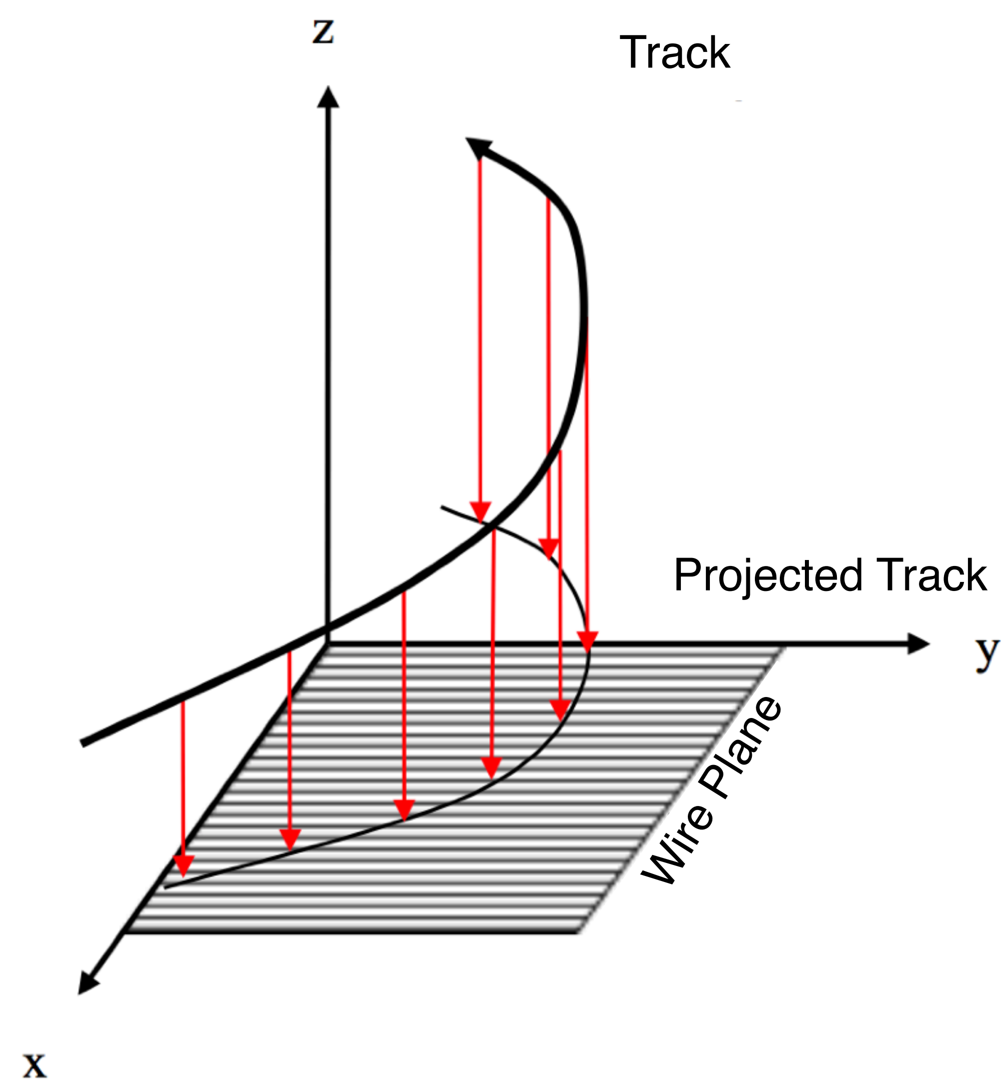
The Z coordinate is found from drift time T and the drift velocity, $\vec{\nu_d}$

Particle mobility $\mu = \frac{e\tau}{m}$

Drift time τ

Cyclotron Frequency

$$w = \frac{eB}{mc}$$



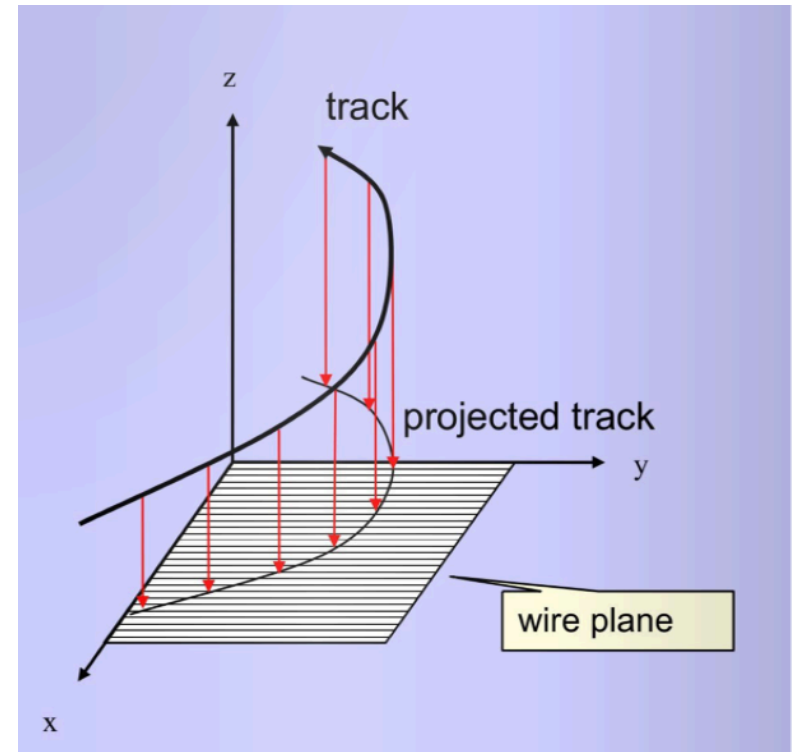
$$\vec{\nu_d} = \frac{\mu}{1+(w\tau)^2}\left(\frac{\vec{E}\times\vec{B}}{|\vec{B}|} + (w\tau)^2\frac{(\vec{E}\cdot\vec{B})\vec{B}}{|\vec{B}|^2}\right)$$

Diffusion in the Z direction

What happens when the E and B fields are not parallel?

Mechanical/electrical imperfections

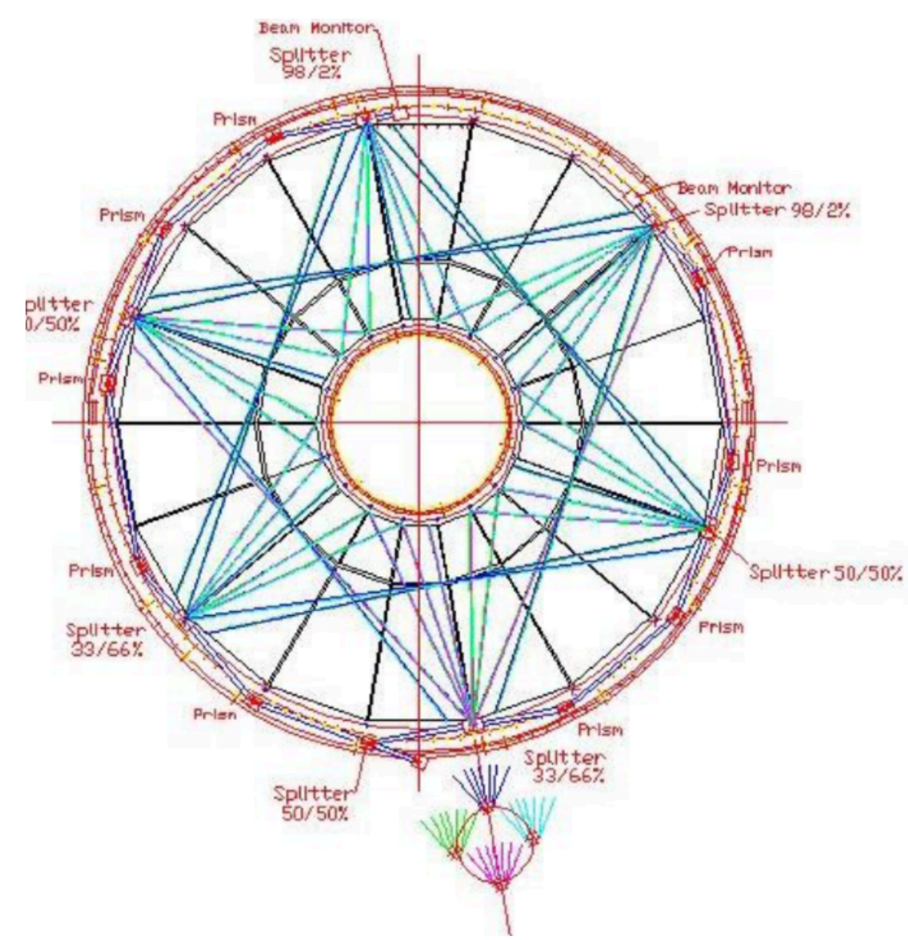
Temperature fluctuations and $\vec{\nu_d}$



<u>UV Laser Calibration</u>

Create tracks in planes of constant Z

Measure the response of the TPC to several hundred laser tracks



Wire Planes

Cathode Wire Grid

Anode Wire Grid

-Can provide timing information

-Avalanche portion of TPC

Gating Wire Grid

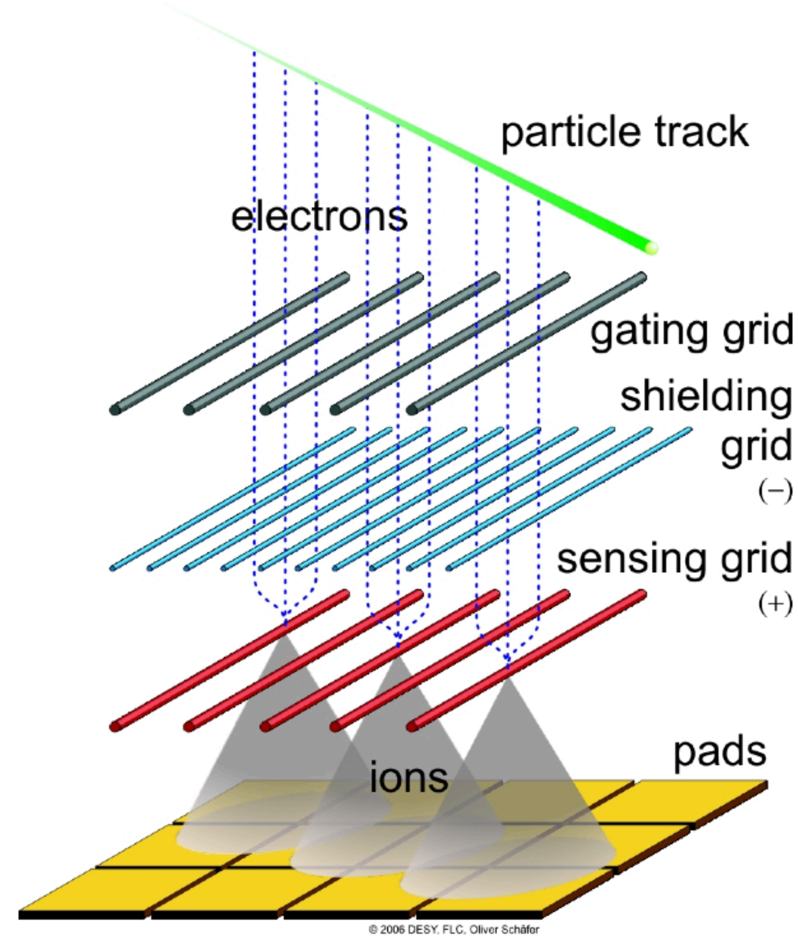
-Open Gate Mode: All wires are held at V_G

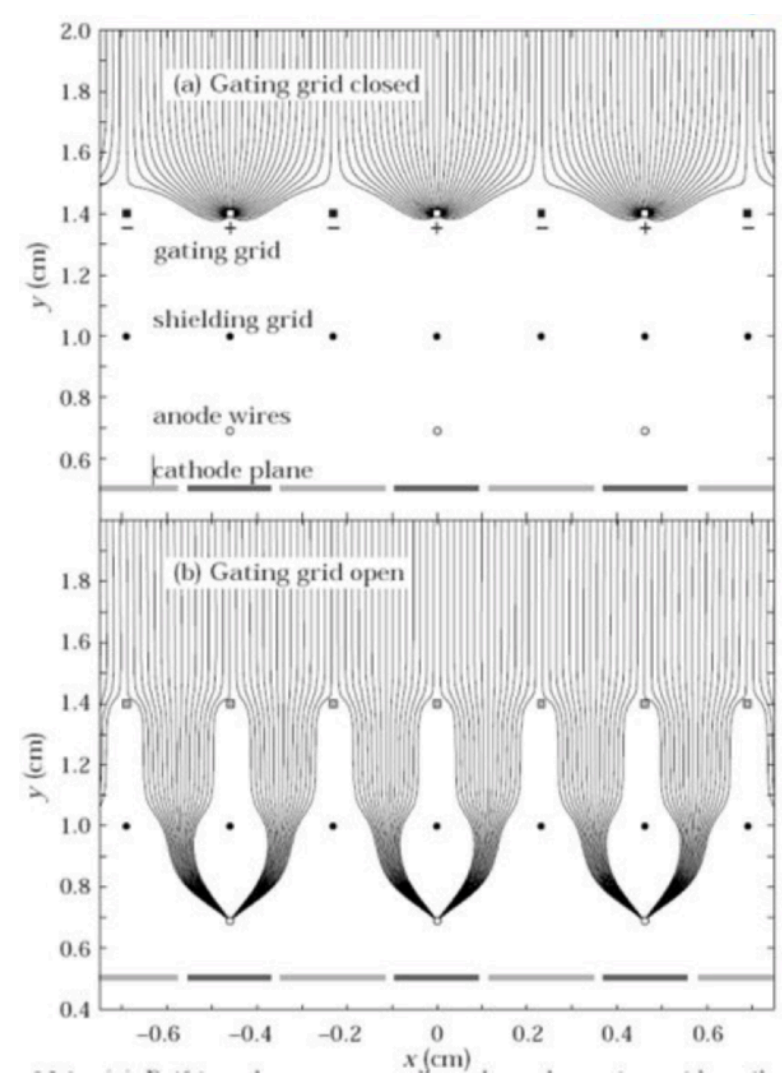
-Closed Gate Mode: All wires alternate with +/- Vg

-Trigger dependent

-Prevents stray electron from avalanche

-Prevent Ion Back-flow





dE/dX and PID

Bethe Formula: “Stopping Power Formula"

$$-\left\langle \frac{dE}{dx} \right\rangle = \frac{4\pi}{m_e c^2} \frac{n z^2}{\beta^2} \left(\frac{e^2}{4\pi\varepsilon_0} \right)^2 \left[\ln \left(\frac{2 m_e c^2 \beta^2}{I \cdot (1-\beta^2)} \right) - \beta^2 \right]$$

Parametrized and fit to data

$$-\left\langle \frac{dE}{dx} \right\rangle = K z^2 \frac{Z}{A} \frac{1}{\beta^2} \left[\ln \left(\frac{2 m_e c^2 \beta^2}{I \cdot (1-\beta^2)} \right) - \beta^2 - \frac{\delta}{2} \right]$$

density effect term δ

Combine with energy actually deposited in pads
+ Calibration

Choosing a Gas/Liquid

Transverse position resolution: Low $\vec{\nu_d}$

Minimize event overlap: High $\vec{\nu_d}$

Low space charge distortions: Low Z

Low gas gain → low primary ionization: High Z

Several other constraints…

A single, magic gas/liquid doesn't exist

Ar, Ne, CO_2, CH_4, N_2

DUNE

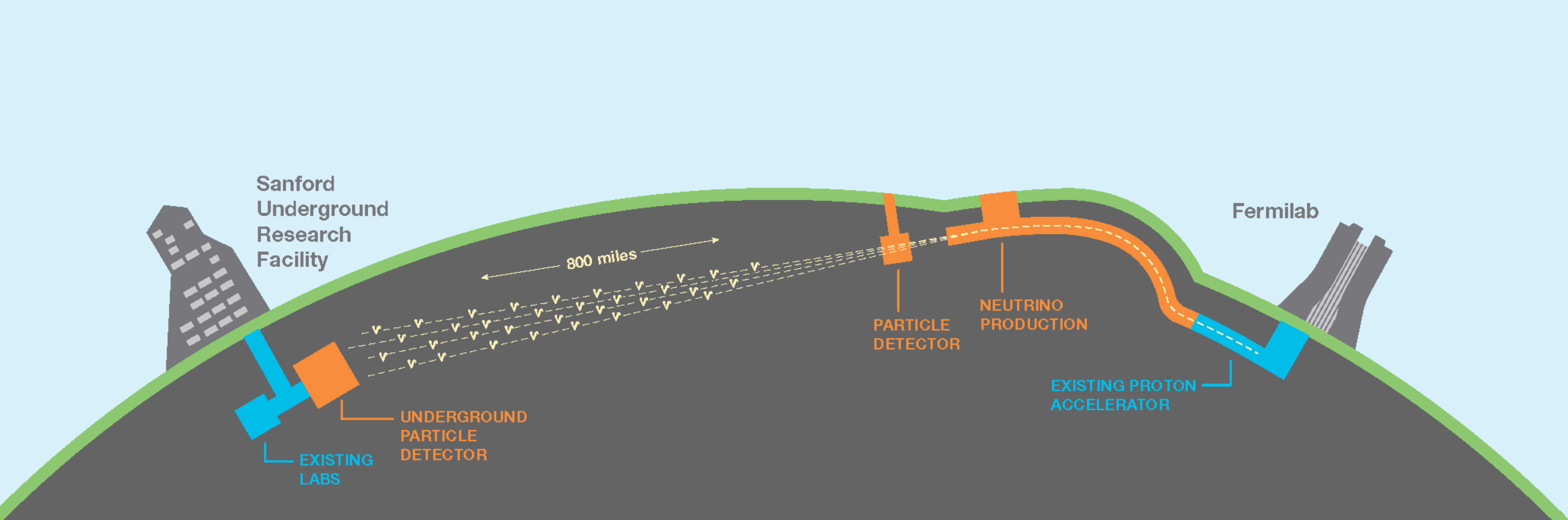
Precise determination of the mass hierarchy

Neutrino-antineutrino asymmetry (CP violation)

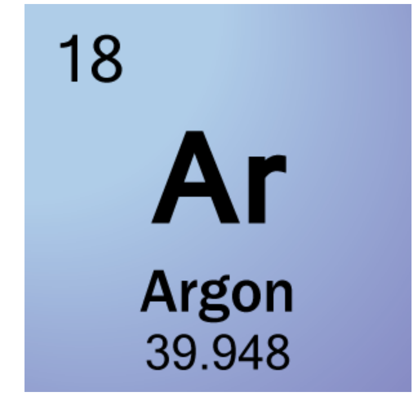
Upper bound of proton lifetime

ν_e flux from a core-collapse supernova

4 Liquid Argon TPCs with fiducial volume of 10 kT



Why Argon?



- Gain
  - Minimum Ionizing particle produces 55,000 electrons for every centimeter traversed

- Scintillation
  - 80,000 photons per centimeter
  - Light and charge information are used to distinguish candidate interactions from background

- Supernova-relevant interactions in Argon

Channel	Events “Livermore” model	Events “GKVM” model
$\nu_e + ^{40}\mathrm{Ar} \rightarrow e^- + ^{40}\mathrm{K}^*$	2720	3350
$\overline{\nu}_e + ^{40}\mathrm{Ar} \rightarrow e^+ + ^{40}\mathrm{Cl}^*$	230	160
$\nu_x + e^- \rightarrow \nu_x + e^-$	350	260
Total	3300	3770

ALICE

Heavy Ion Collisions at CERN

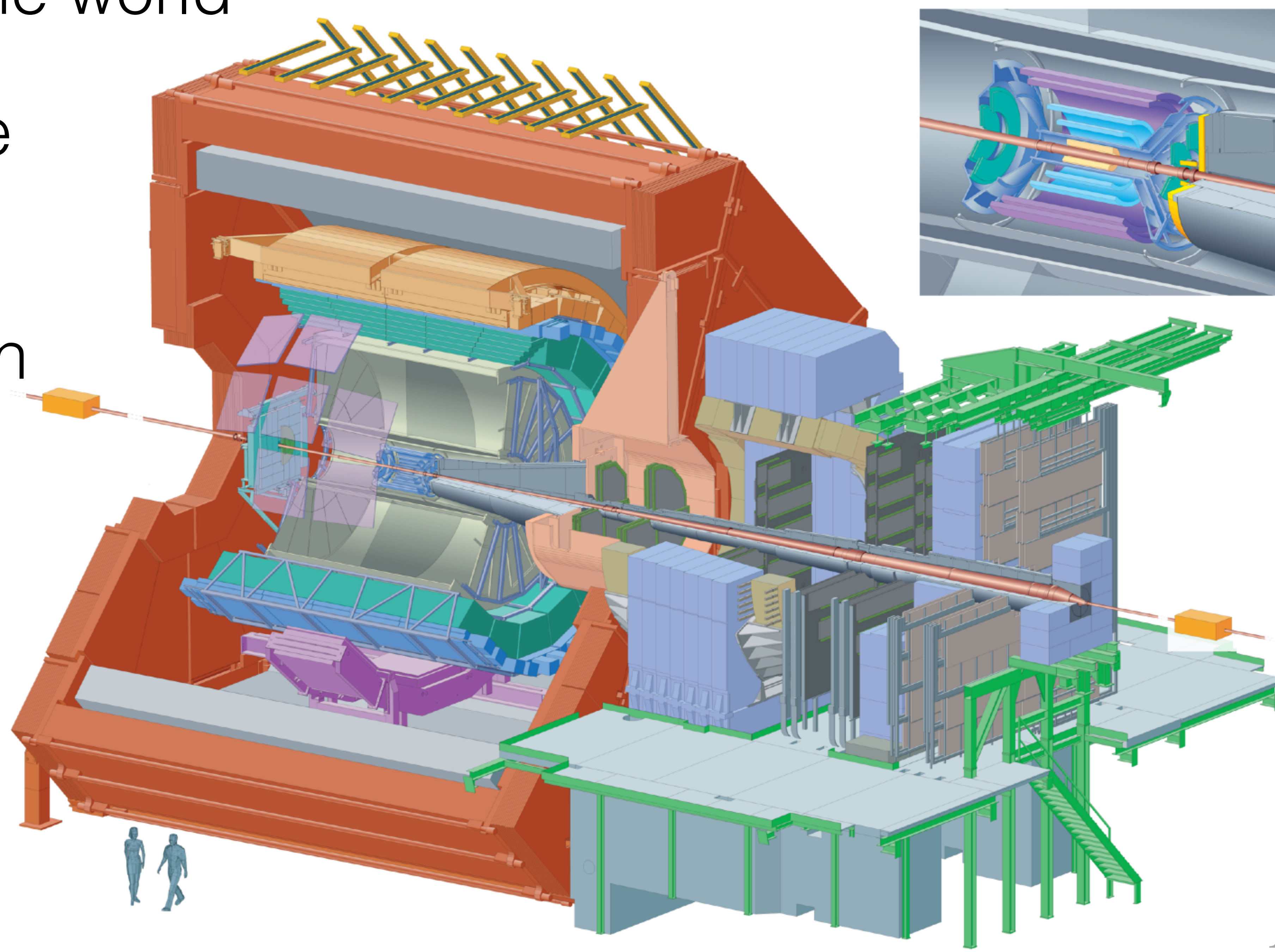
Largest TPC in the world

$NeCO_2N_2$ Volume

Uses higher position resolution silicon tracking

TPC is still vital for functionality

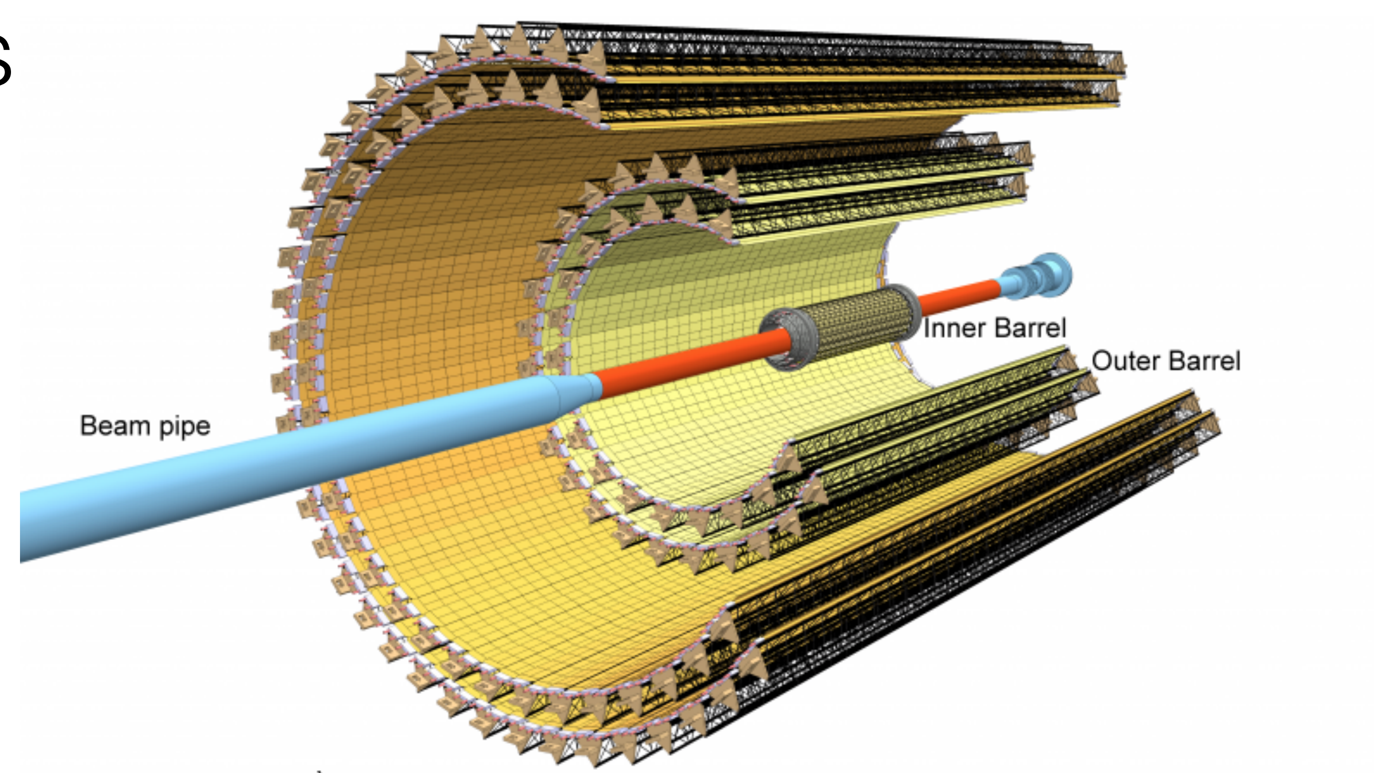
400V/cm, 0.5T



QGP Probes and Tracking

- QGP is a strongly coupled system dominated by the strong nuclear force
- Short lived "heavy" particles propagate unobstructed
- Use tracking to locate impact parameter
- The Inner Tracking System (ITS) consists of six cylindrical layers of silicon detectors

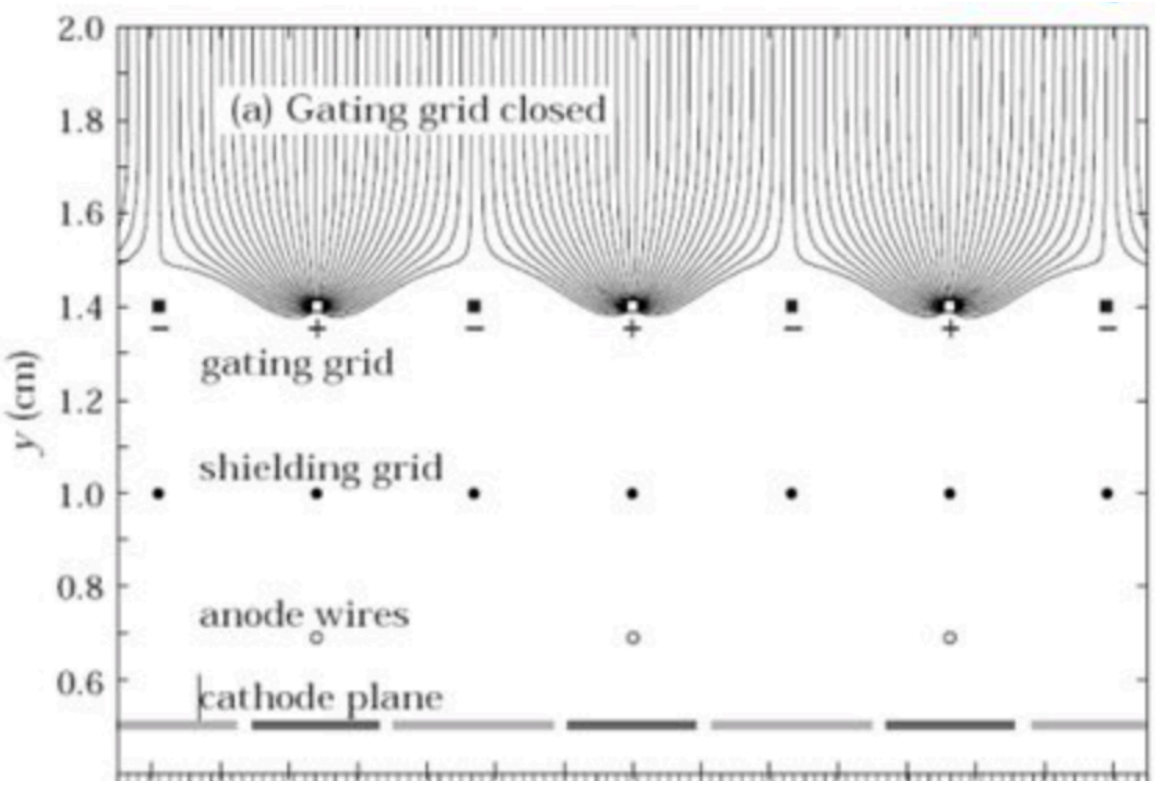
Better Understanding of QCD



Improve Gas Based TPCs

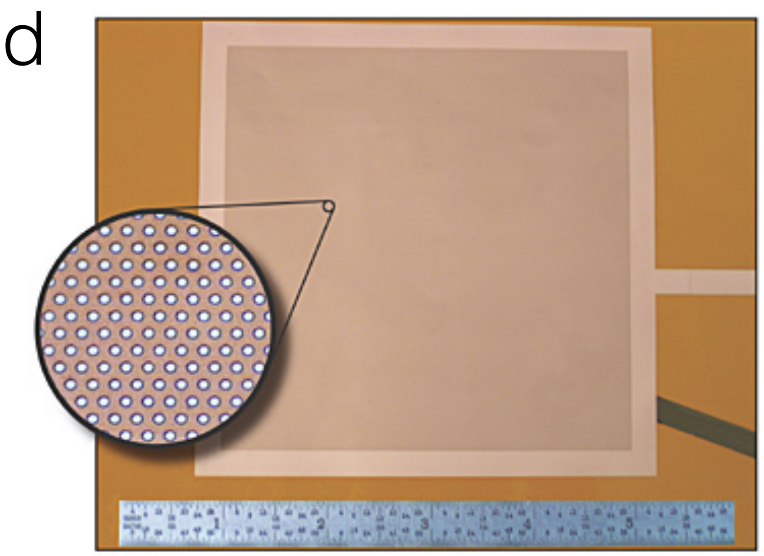
Ion Back-Flow

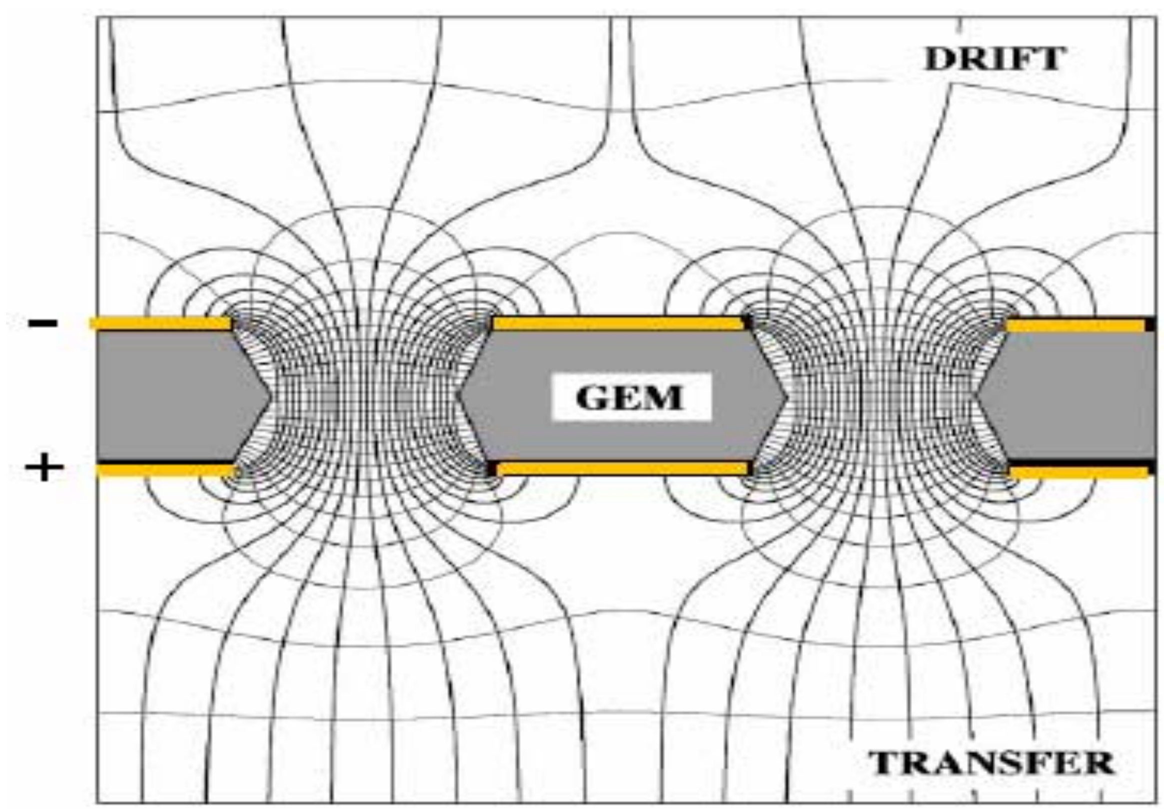
- Not completely solved by gating grid
- Stray Ions -> space charges



Gas Electron Multipliers(GEMs)

- Greatly reduce back-flow
- Don't need a trigger or pulse
- Ions absorbed on the upper side foil
- Can be stacked





Conclusion

3D track reconstruction, PID, and momentum

Vital components of nuclear and neutrino physics

GEMs are a promising improvement to gas-based TPCs

While high event multiplicity experiments may switch to silicon, no foreseeable replacement in neutrino and dark matter experiments