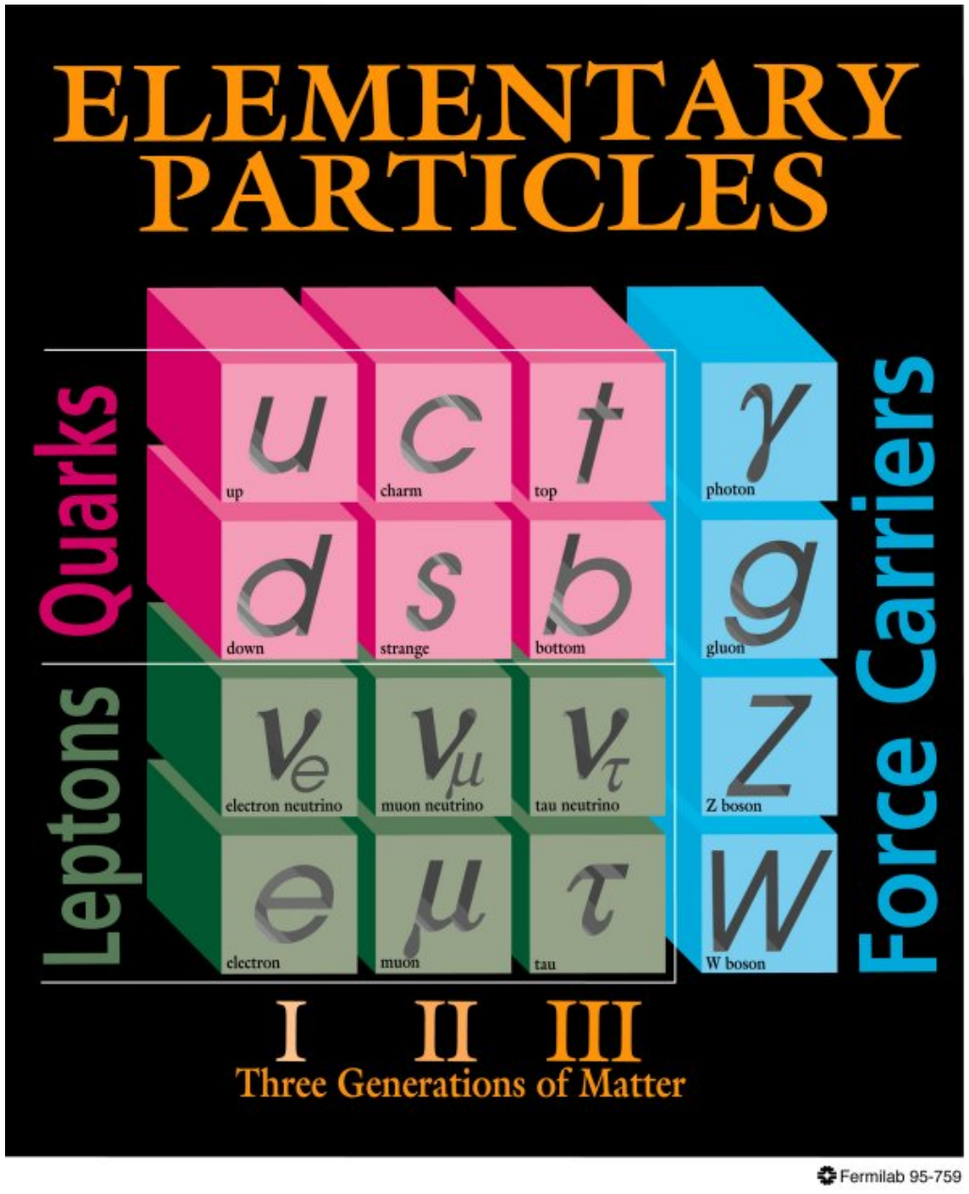
Introduction to LArTPC for Neutrino Detection

Yichen Li

8/18/21

What is neutrino?

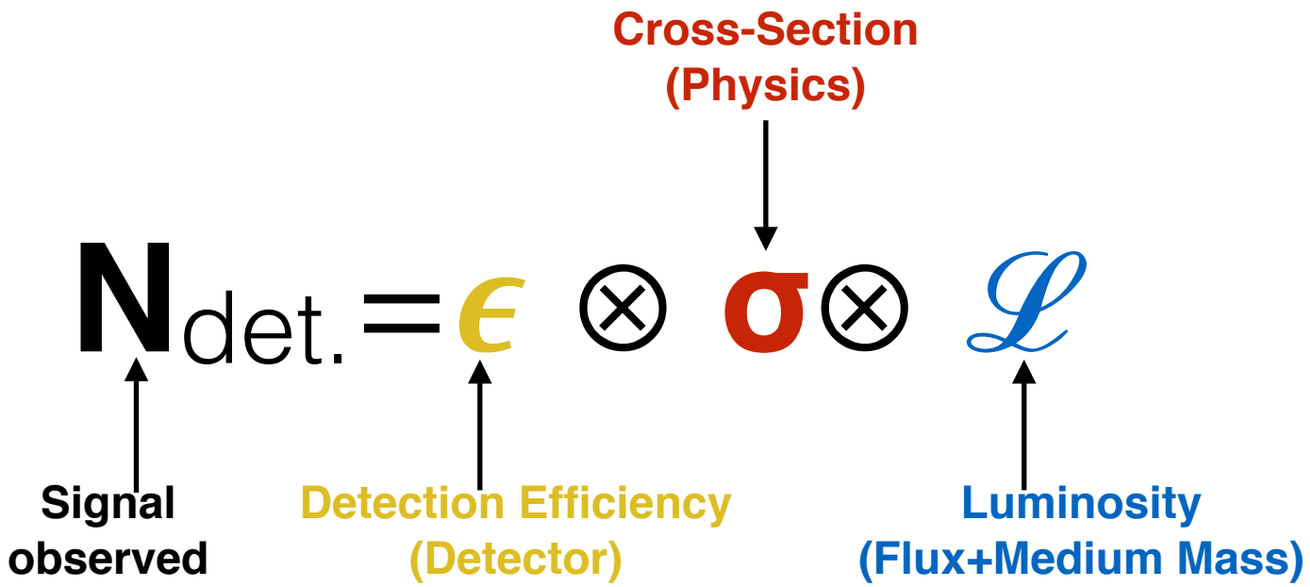


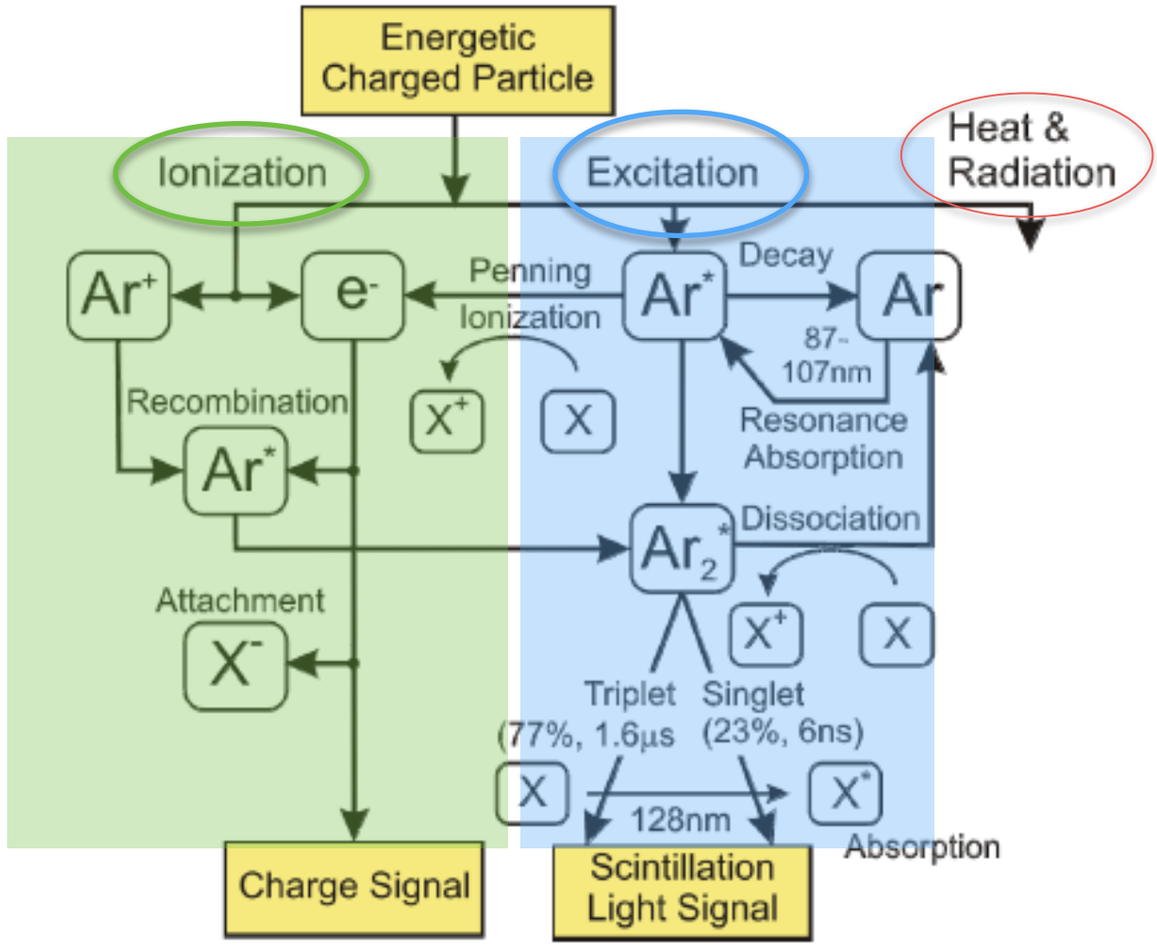
Interaction	Mediators	Relative Strength	Range (m)
Strong	**g**	**10^{38}**	**10^{-15}**
E&M	**γ**	**10^{36}**	**?**
Weak	**W, Z**	**10^{25}**	**10^{-18}**
Gravitation	gravitons	1	?

Neutrinos are fundamental particles in the standard model!
They interact through weak interaction

Experimental Detection of Neutrino Interactions

- In general, the requirements for neutrino detection is to get data with sufficient statistics to study physics
- HEP experiments are indirect measurement
  - The particle of interest is too small to be visible
  - The particles are detected via the interactions with the detector medium
    - Charge and Light signals





Requirements for Neutrino Detector

- **Big/Massive**
  - Guarantee sufficient number of events with small cross-section of neutrino interactions
- **Resolution**
  - Sufficiently precise to extract physics information
- **Fast**
  - Precisely determine event time and reject background
- **Affordable**
  - Economically feasible to built a large scale detector
- **Versatile**
  - Capable of detecting multiple types of interactions/particles

Why Liquid Argon?

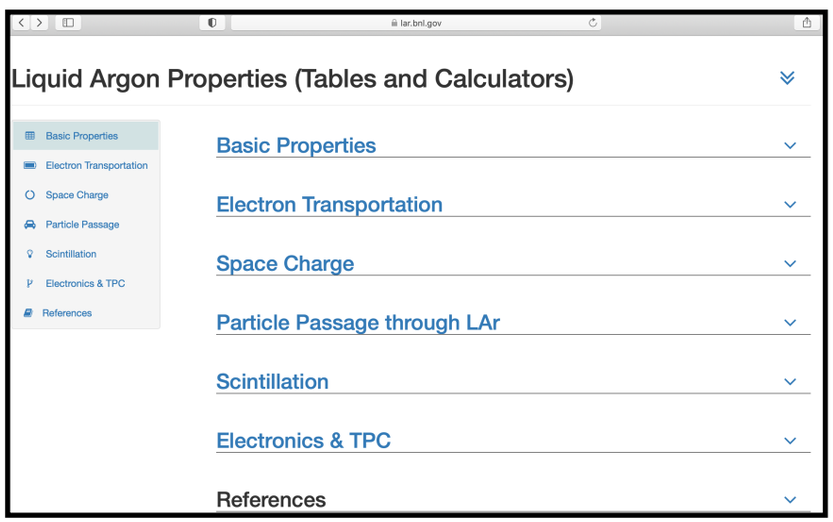
- Large number of ionization electrons production and scintillation light yield
- If the purity is high (<0.1 ppb) Ionized charges can drift through long distance
- Dense to provide a large mass for neutrino interactions
- High dielectric strength to hold high voltage to drift electrons
- Argon is abundant in the air(~1% of atmosphere), byproduct of liquid oxygen and liquid nitrogen production, low production cost

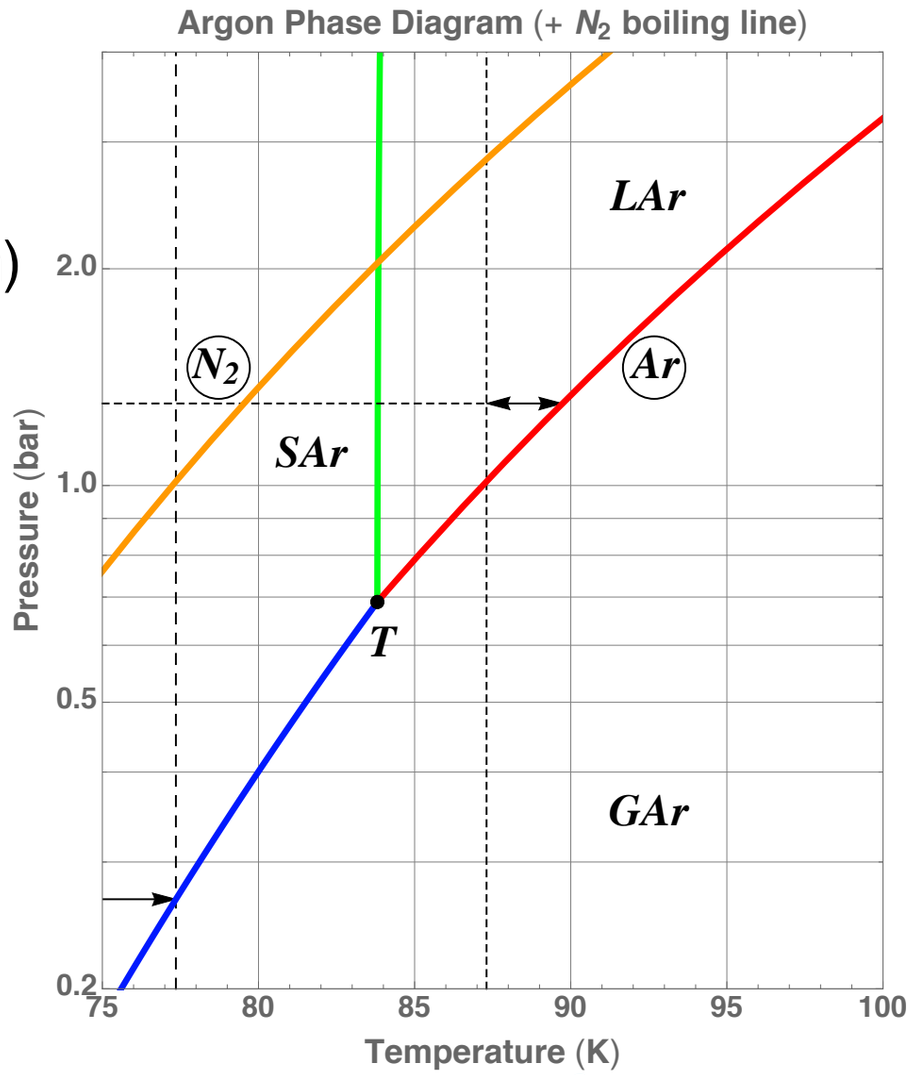
Atomic Number	2	10	18	36	54
Boiling Point [K] @ 1atm	4.2	27.1	87.3	120	165
Density [g/cm	0.125	1.2	1.4	2.4	3
Radiation Length [cm]	755.2	24	14	4.9	2.8
dE/dx [MeV/cm]	0.24	1.4	2.1	3	3.8
Scintillation [γ/MeV]	19,000	30,000	40,000	25,000	42,000
Scintillation λ [nm]	80	78	128	150	175
Cost ($/kg)	52	330	5	330	1200

From: Mitch Soderberg

LAr Properties

- Thermal properties
  - Normal boiling point at 1atm: 87.3K—>matches pressurized LN2 temperature for condensing
  - Triple point temperature: 83.8K
- Signal generations
  - W-value for ionization: 23.6 eV/pair
  - W-value for scintillation: 19.5 eV/photon
- Electron transportation properties:
  - Electron drift velocity ~ 1.6mm/us at 0.5kV/cm (3580 mph)
  - Electron drift velocity depends on LAr temperature
- Most information and homework:
  https://lar.bnl.gov/properties/

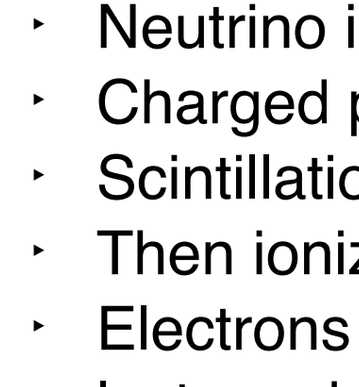


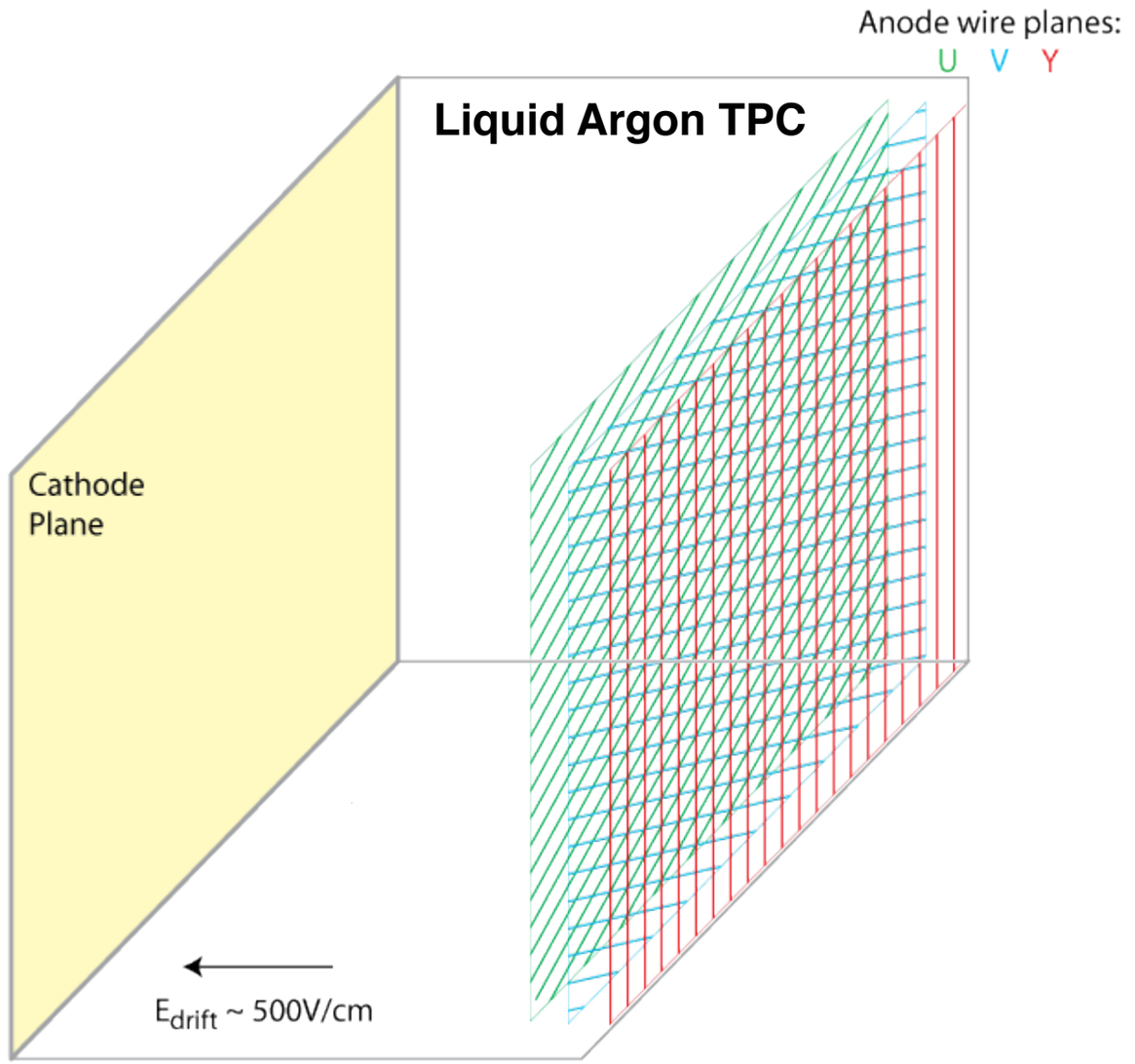


Brookhaven National Laboratory

The Principle of LArTPC Detector

- Neutrino interaction with Ar
- Charged particle tracks ionized Ar atom.
- Scintillation Light (~ns) is detected by photo detector at the same time.
- Then ionized electrons are drifted to the anode plane(~ms in time, ~meters in space).
- Electrons near the wires are collected first and electrons far from the wires are collected last, so drift coordinate information is converted into electron drift time(time is projected)
- Calorimetry information is extracted from wire pulse characteristics.





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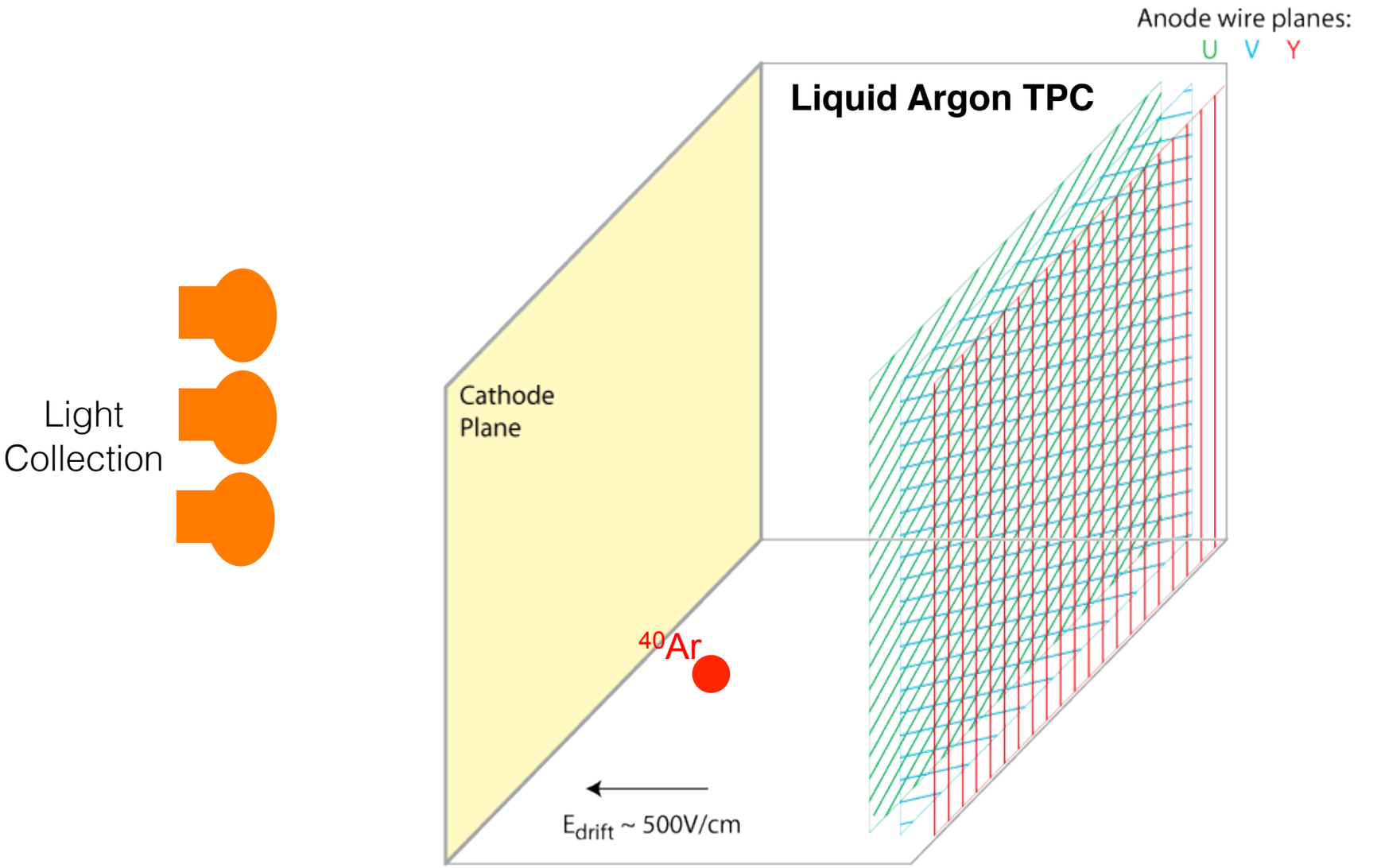

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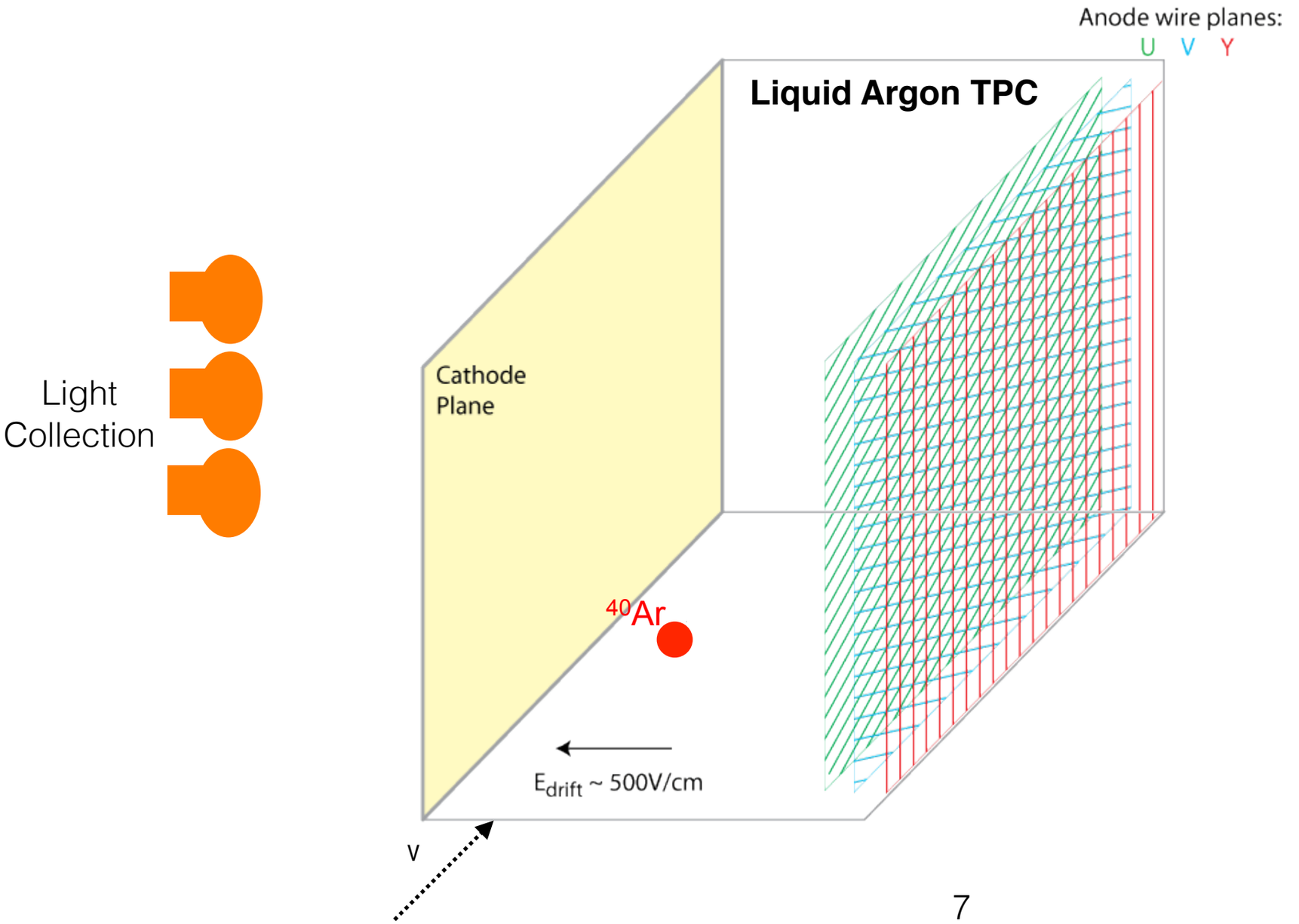

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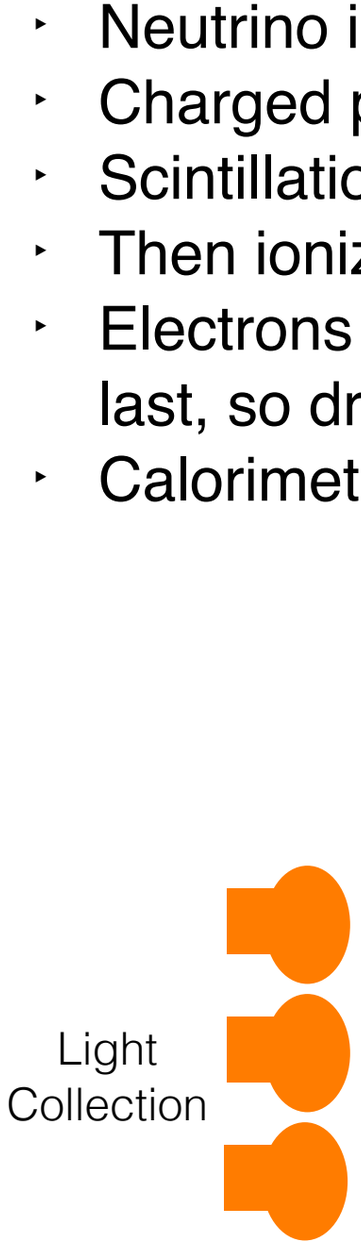

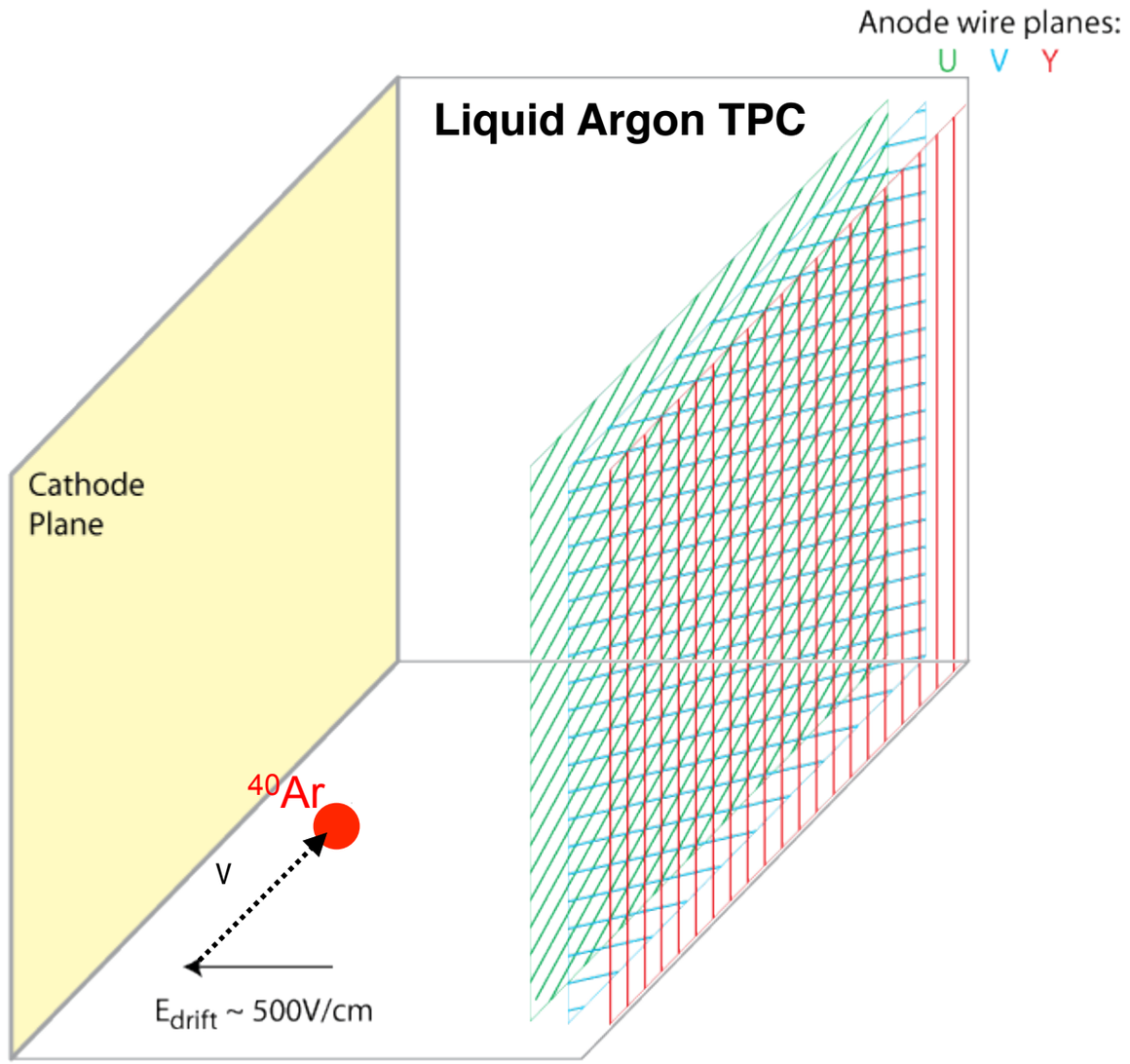

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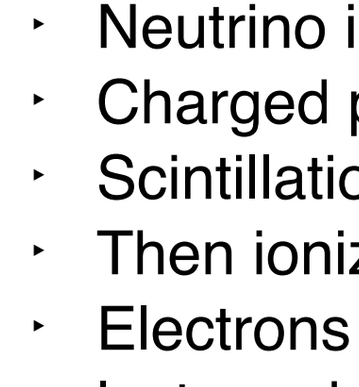

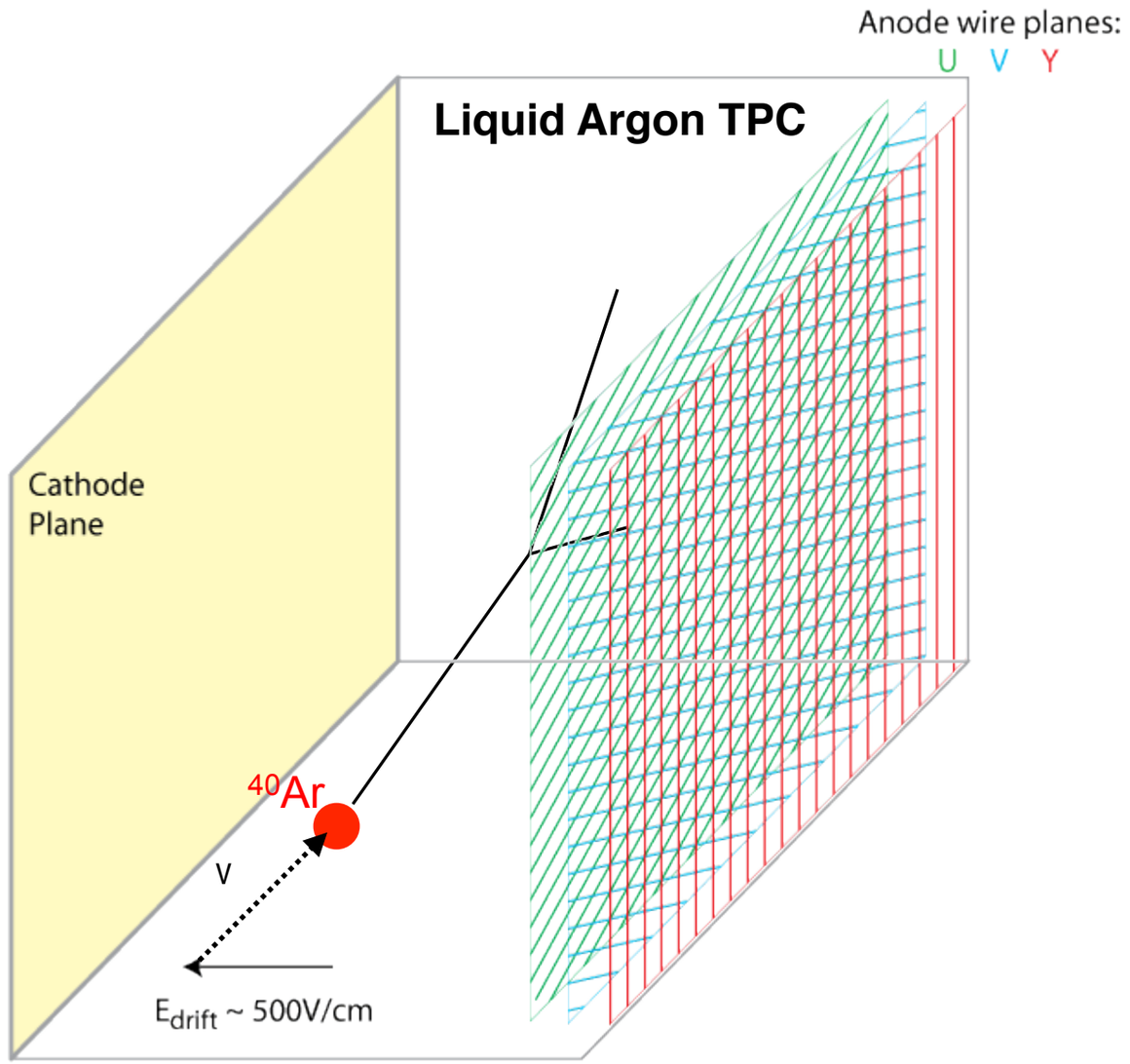

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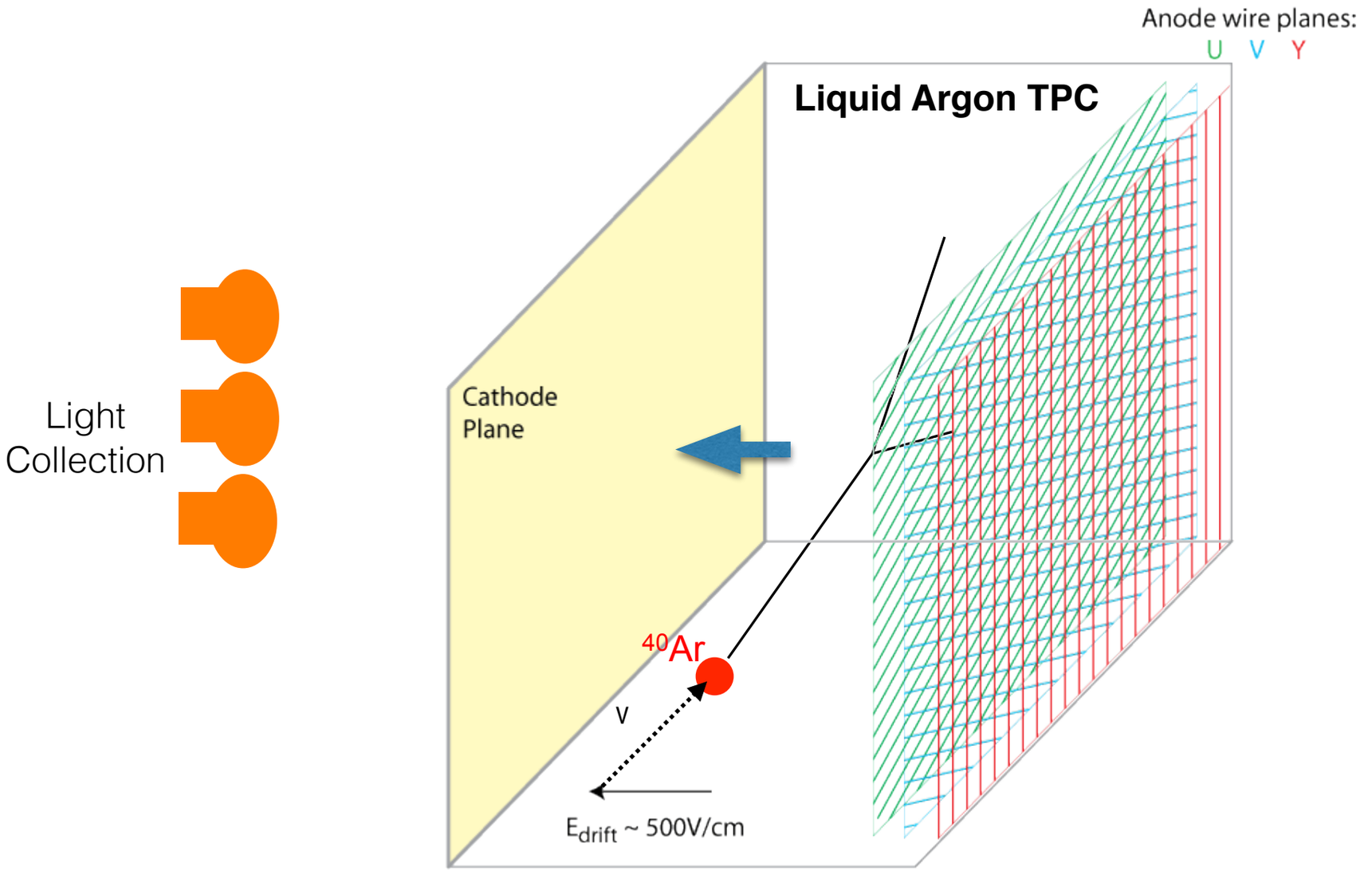

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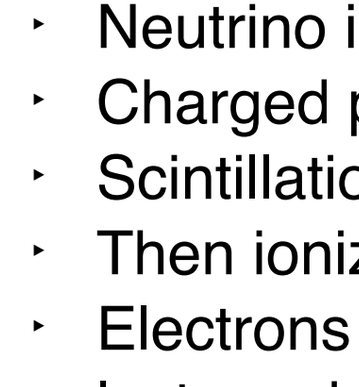

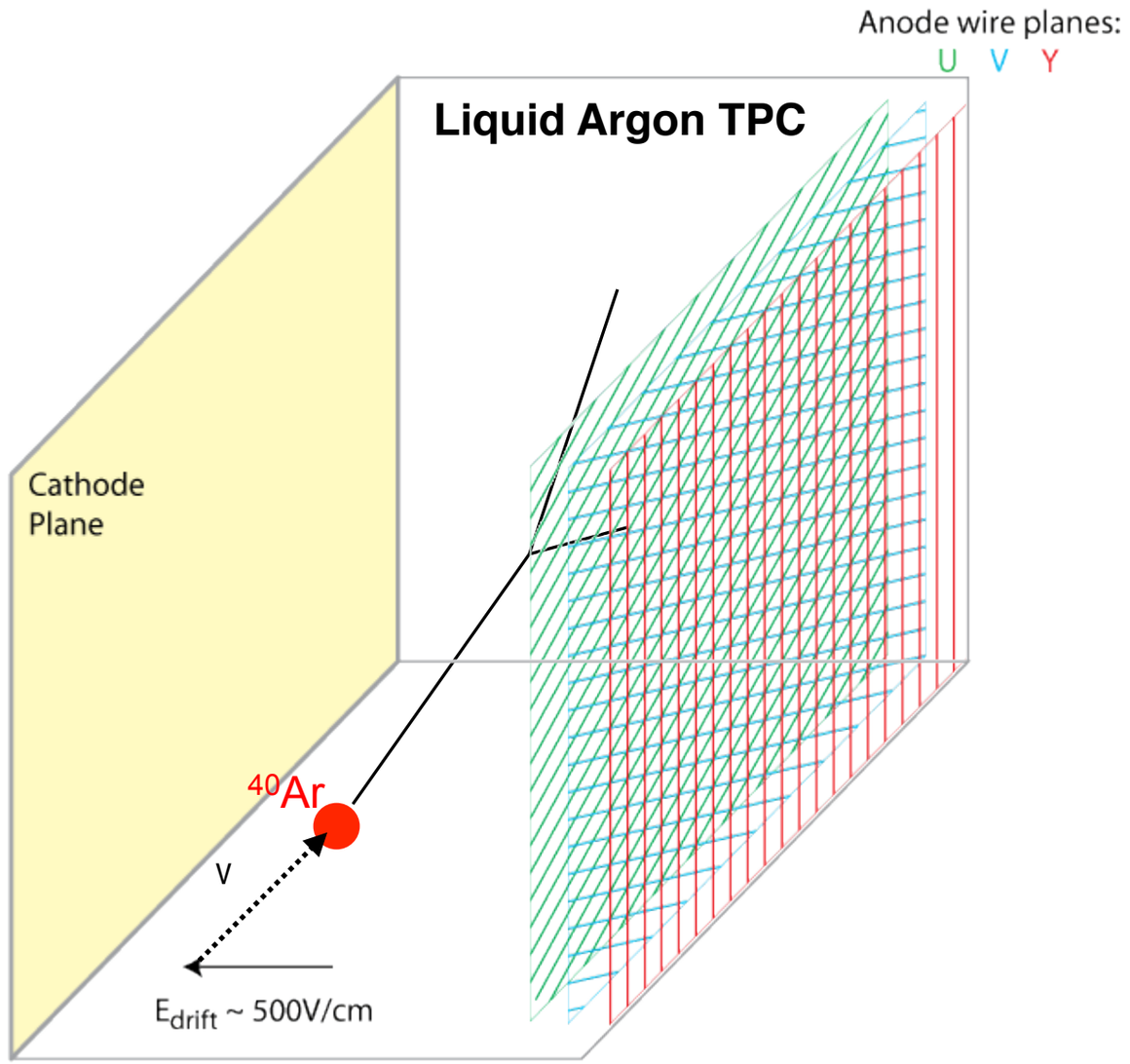

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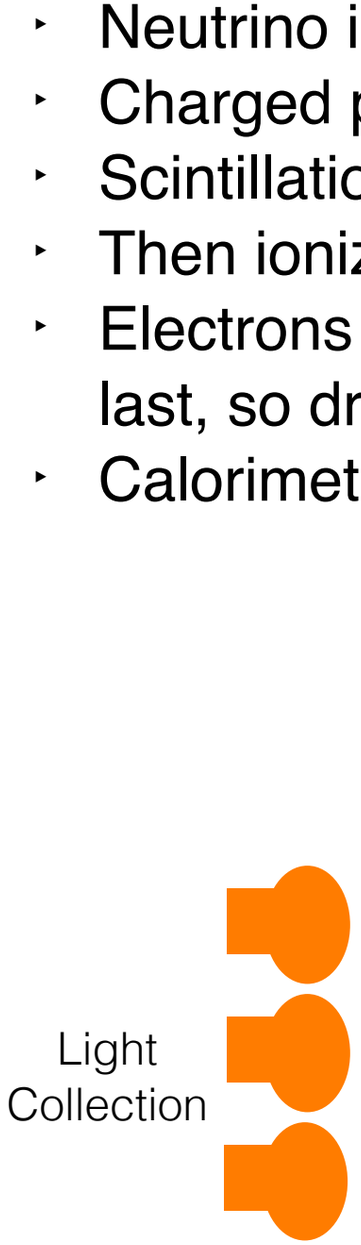

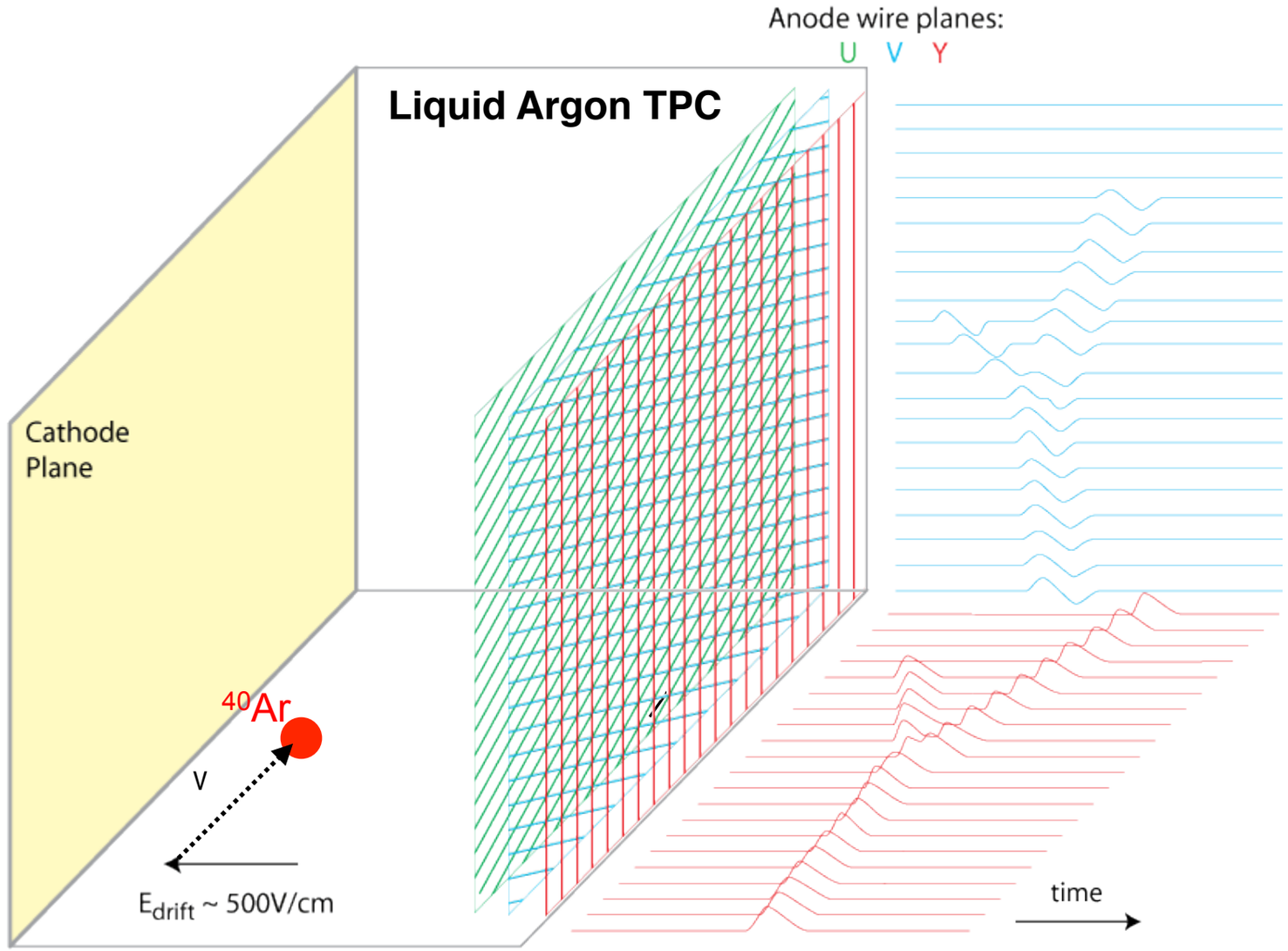

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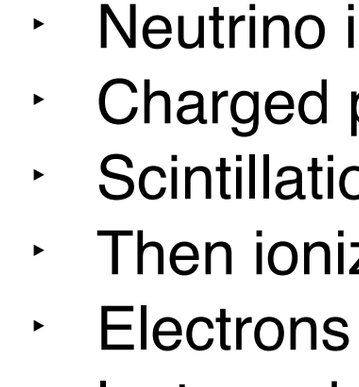

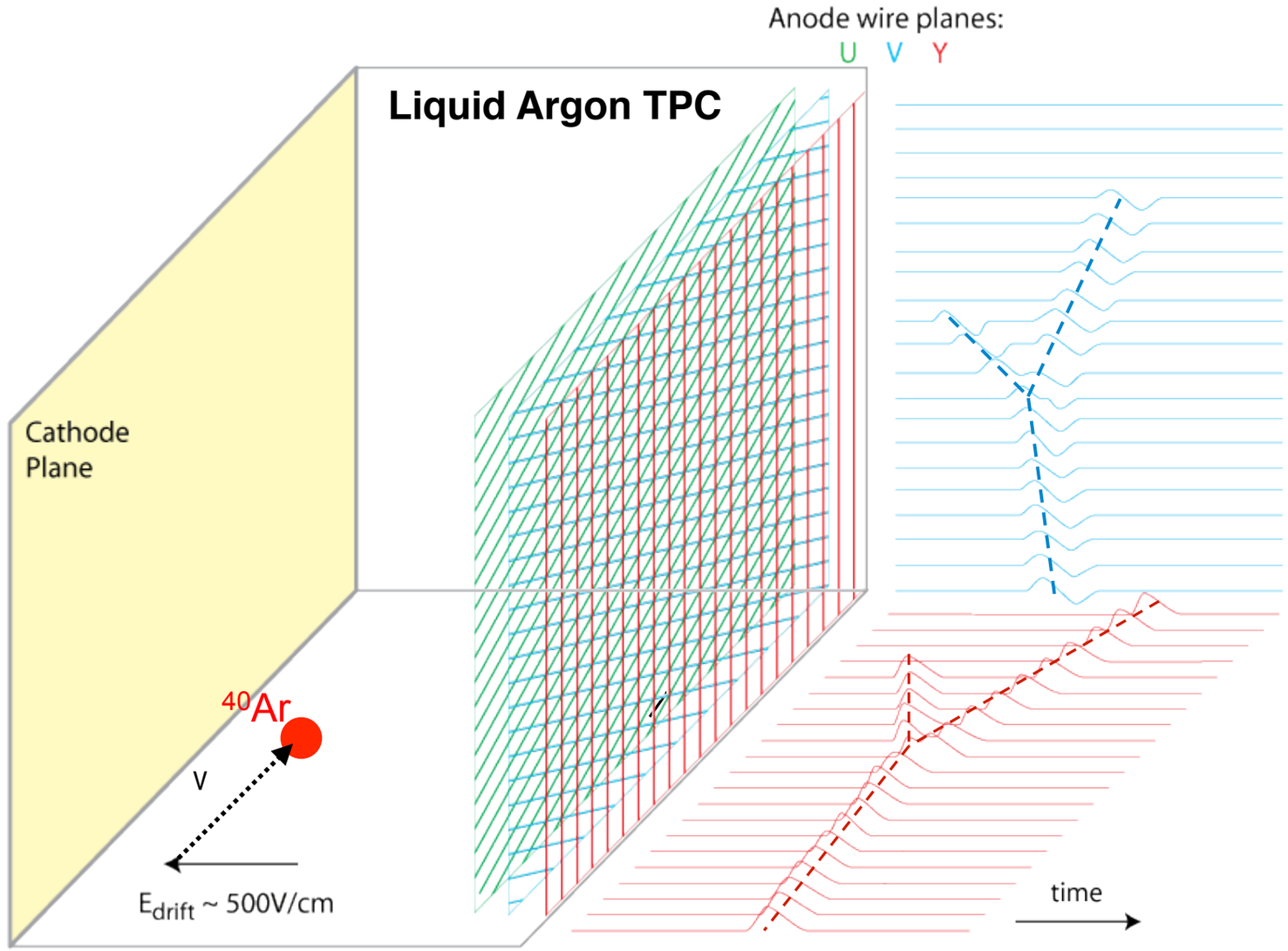

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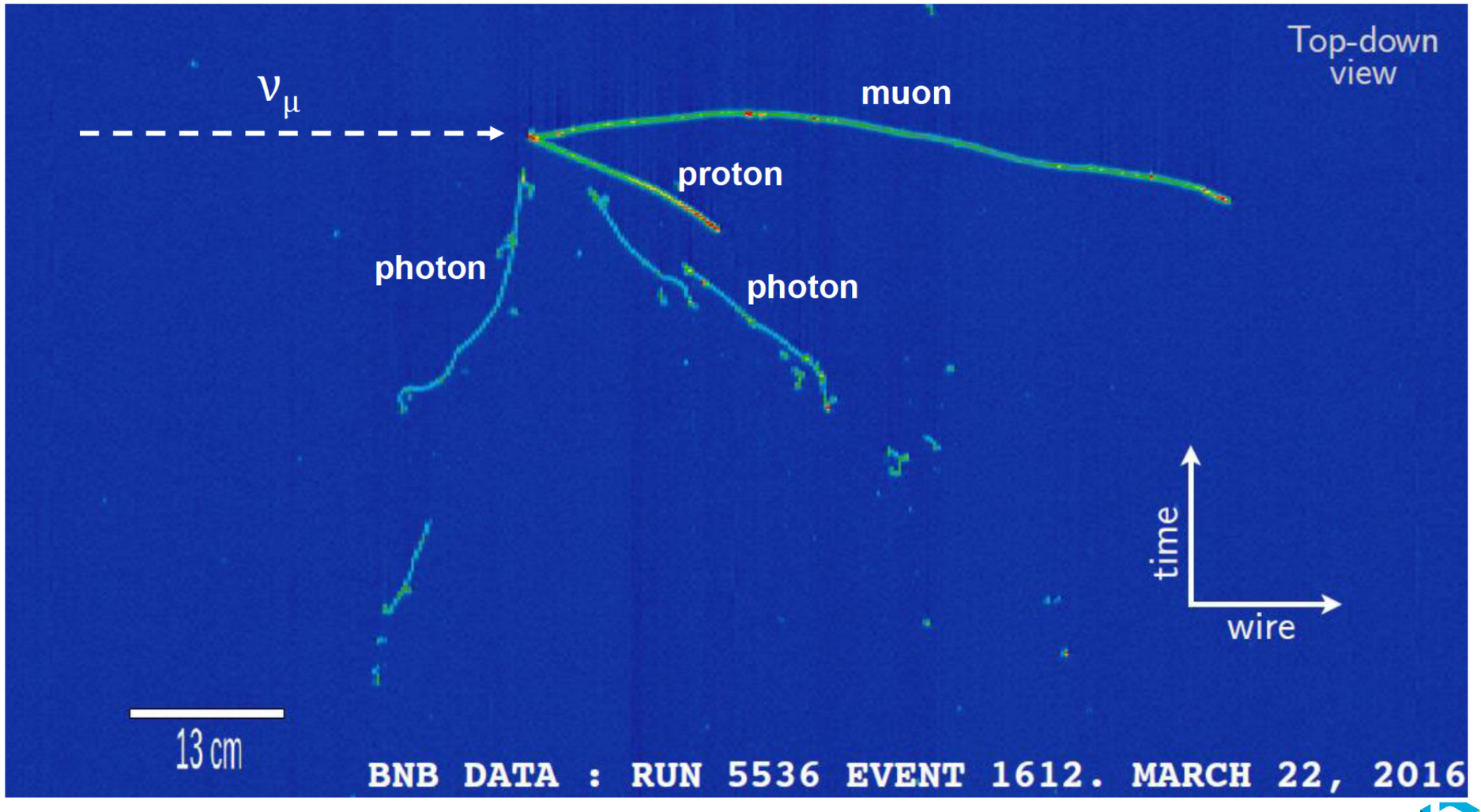
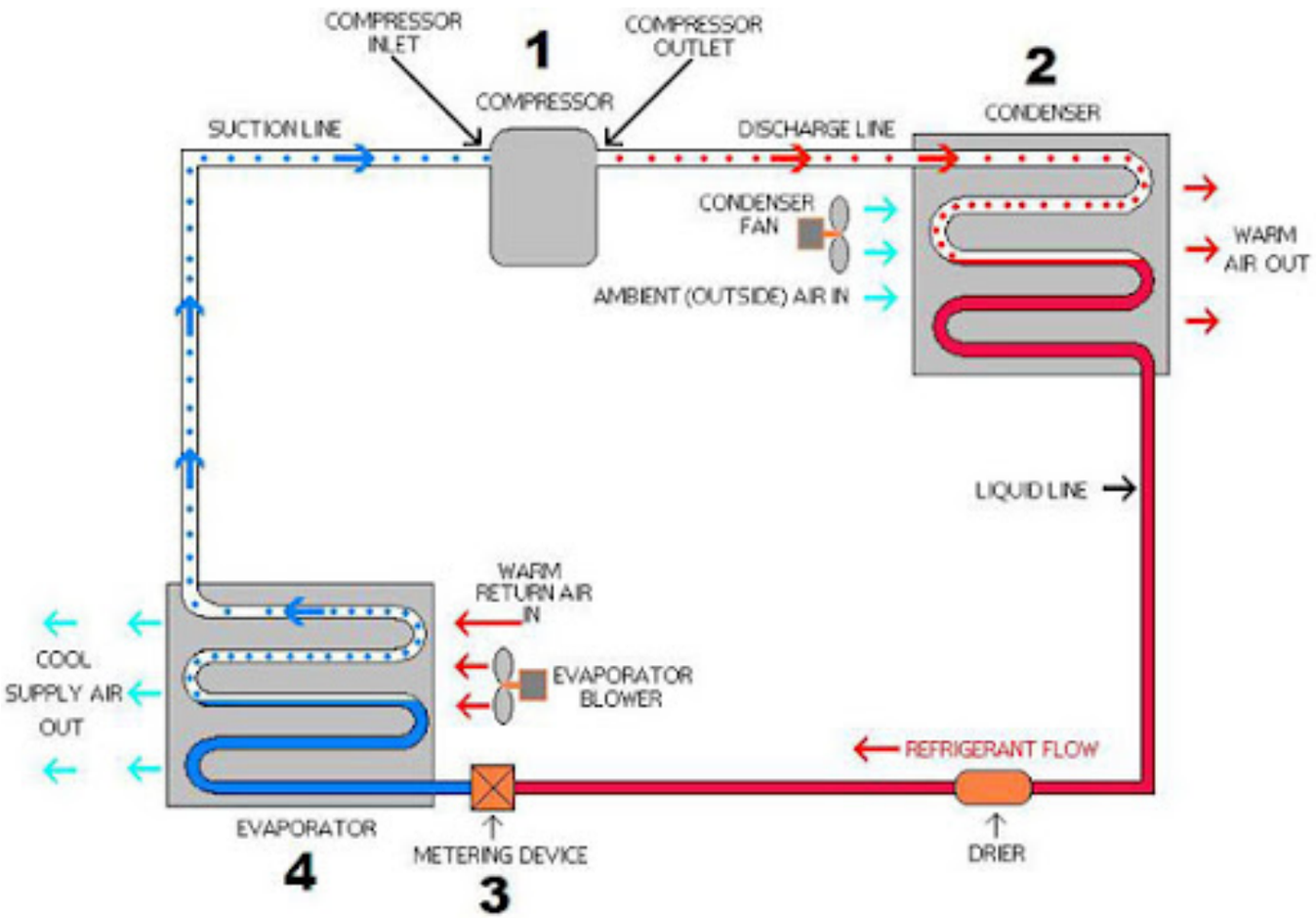
Technical Challenges of LArTPC

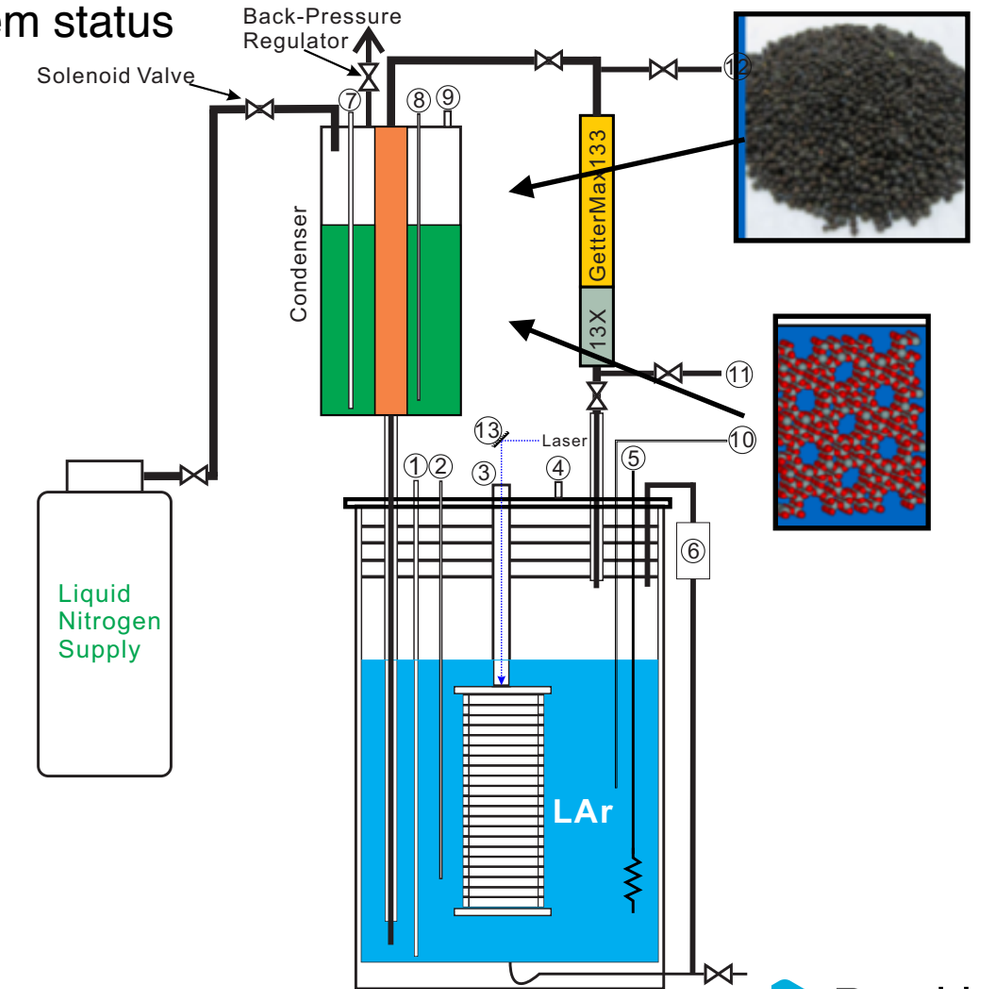
- Ultra high purity is required to minimize electron loss:
  - Common electronegative impurities are Oxygen and Water
  - Impurity concentration < 10s of part-per-trillion level is required for LArTPC.
- Cold electronics to minimize noise. Cryogenic condition is challenging for the electronics
- Breakdown with HV: ~10^2 kV HV required for electron drift. Breakdown mechanism not fully understood for LAr
- Space charge effect for surface detector.



LArTPC Cryogenic System

- LArTPC cryogenic system is actually a large refrigerator at very **low** temperature!
  - LAr evaporates needs to be condensed to maintain the stable operation
  - Sufficient condensing power
  - Good insulation quality
- Achieve desired purity level by passing argon through filters containing molecular sieve (to remove water) and copper based catalyst(to remove oxygen)
- Detector components must also be properly chosen to minimize contaminations
- Continuous recirculation necessary to reach/maintain high purity
- Control system operates the cryogenic system, monitoring system status





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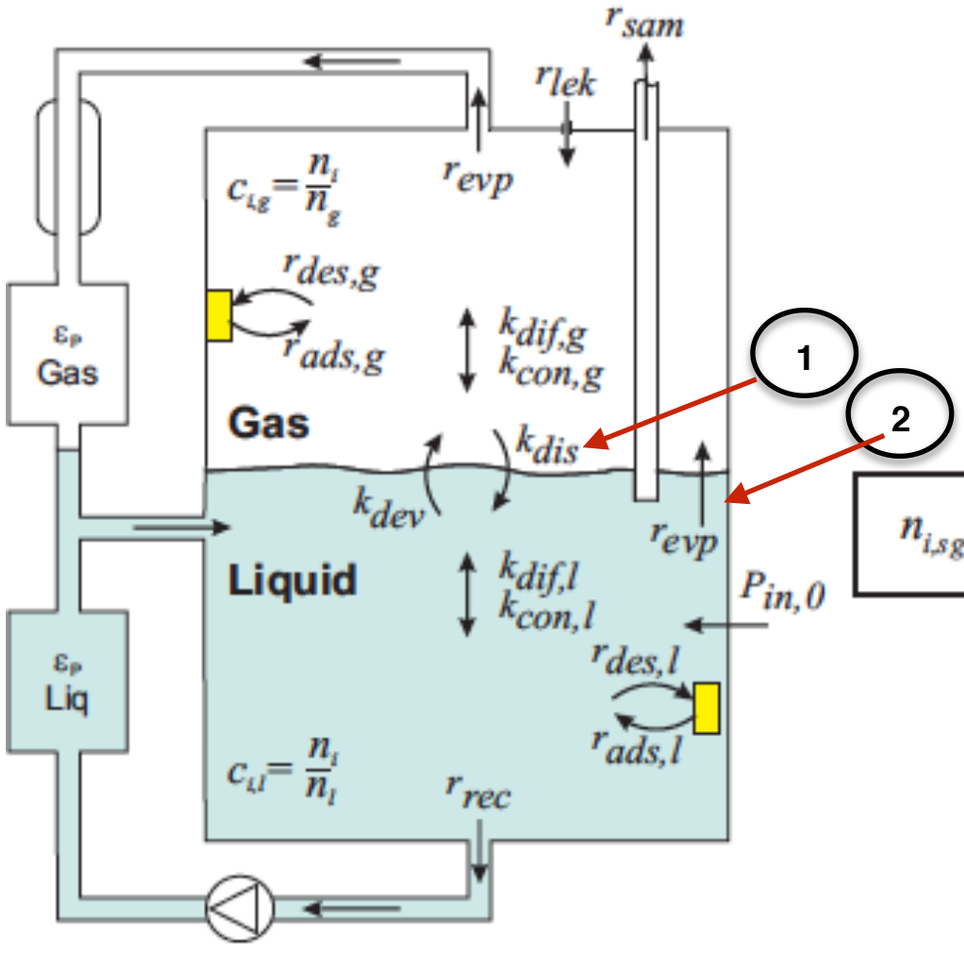
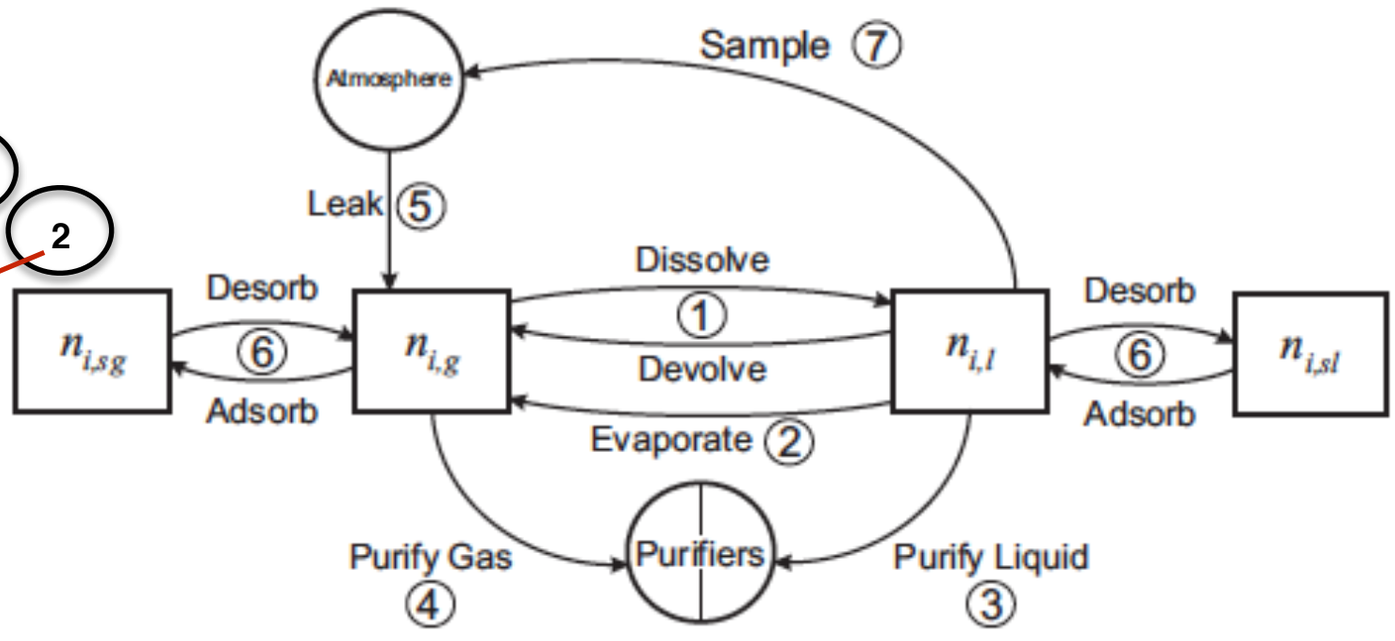
Impurity in LArTPC

- Impurities in LAr attenuate the signals
- They come from the leak, outgassing and residual impurities in the supply LAr
- Commercial LAr typically contains ~ppm impurity, LArTPC requires <1ppb
- Purification required to achieve the required purity level
- A quantitative kinetic model of impurity distribution is constructed

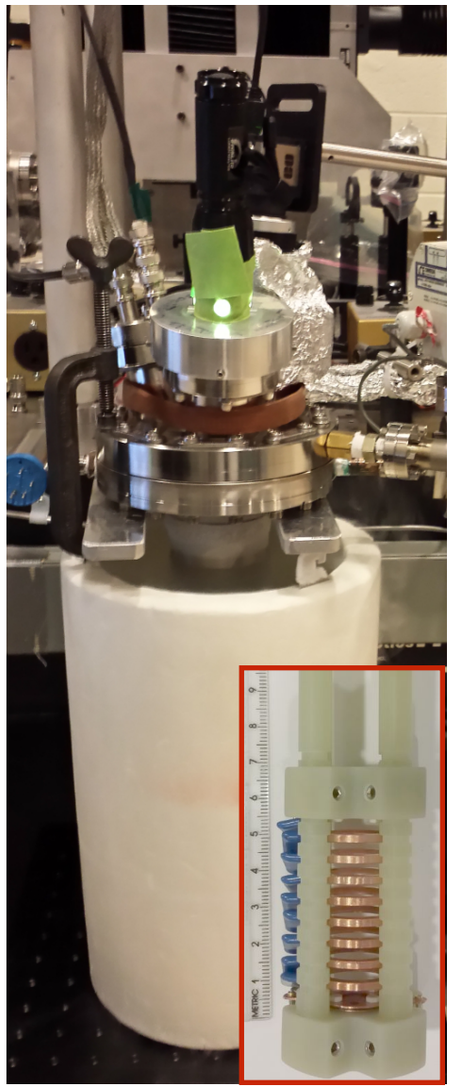


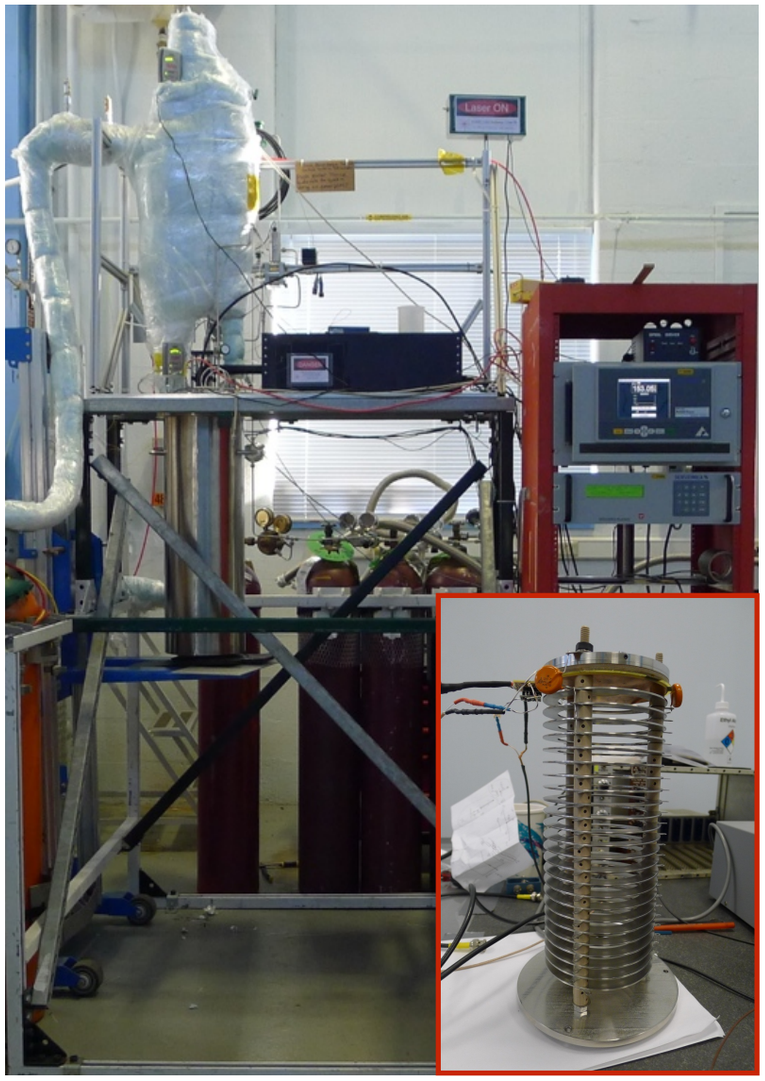


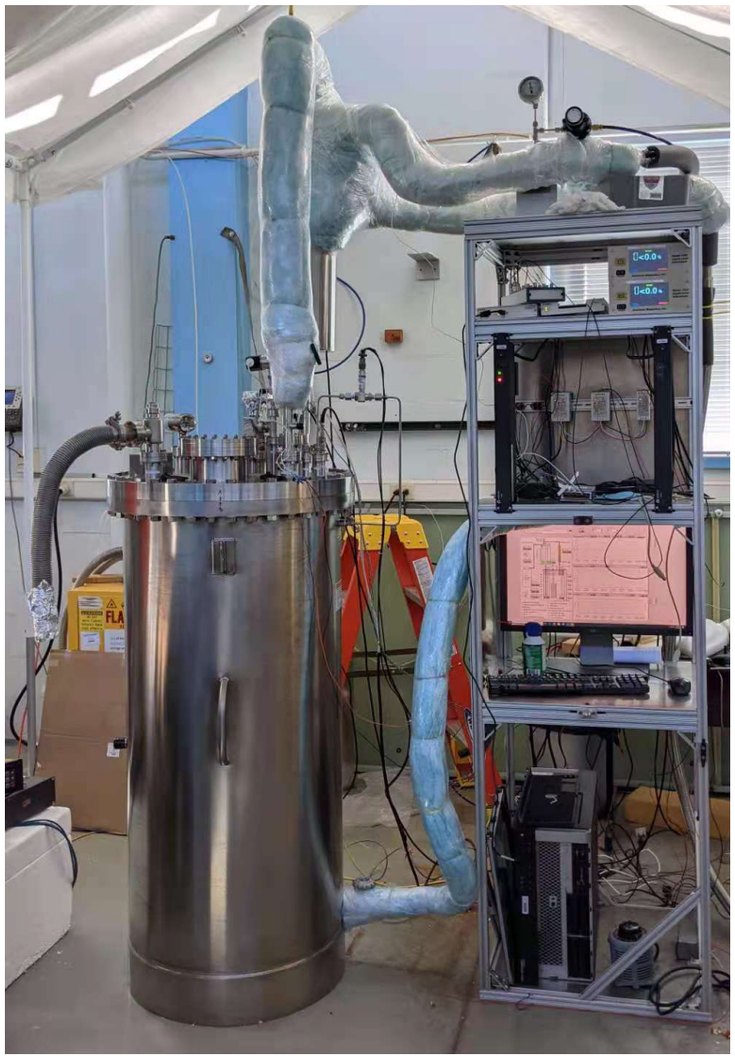
Reading assignment: NIM, A 1010 (2021) 165491

LAr R&D Experimental Setup at BNL

- 2L test stand is cooled by LN_2+Dry ice bath and LAr is formed by liquefying purified commercial GAr
- 20L test stand is an upgraded and improved apparatus with LAr circulation and GAr purification
- The 260L Test Stand LAr Field Calibration System (LArFCS) is commissioning
- Only gas purification is implemented in out local setup
  - Also added liquid purification in the LAr filling line







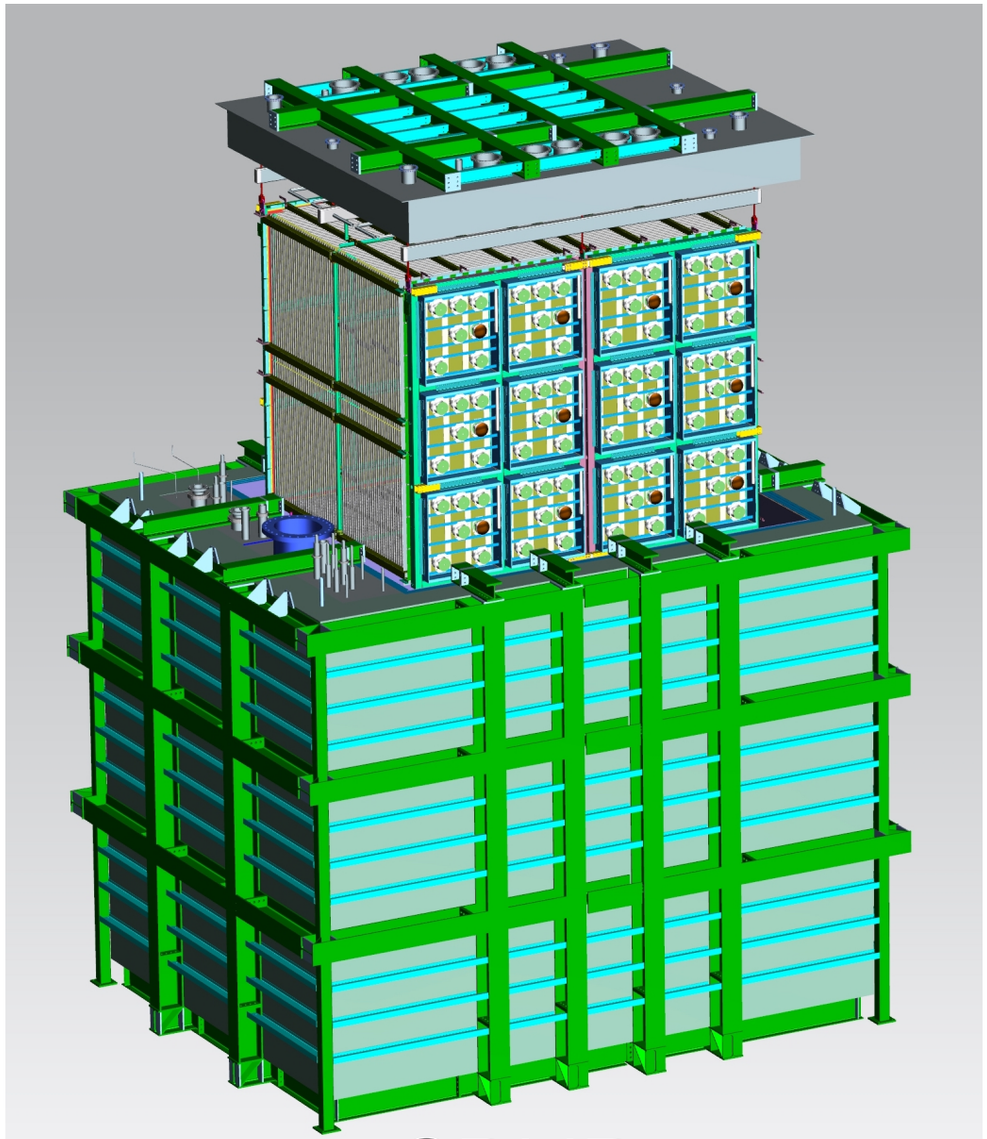
2 L Test Stand

20 L Test Stand

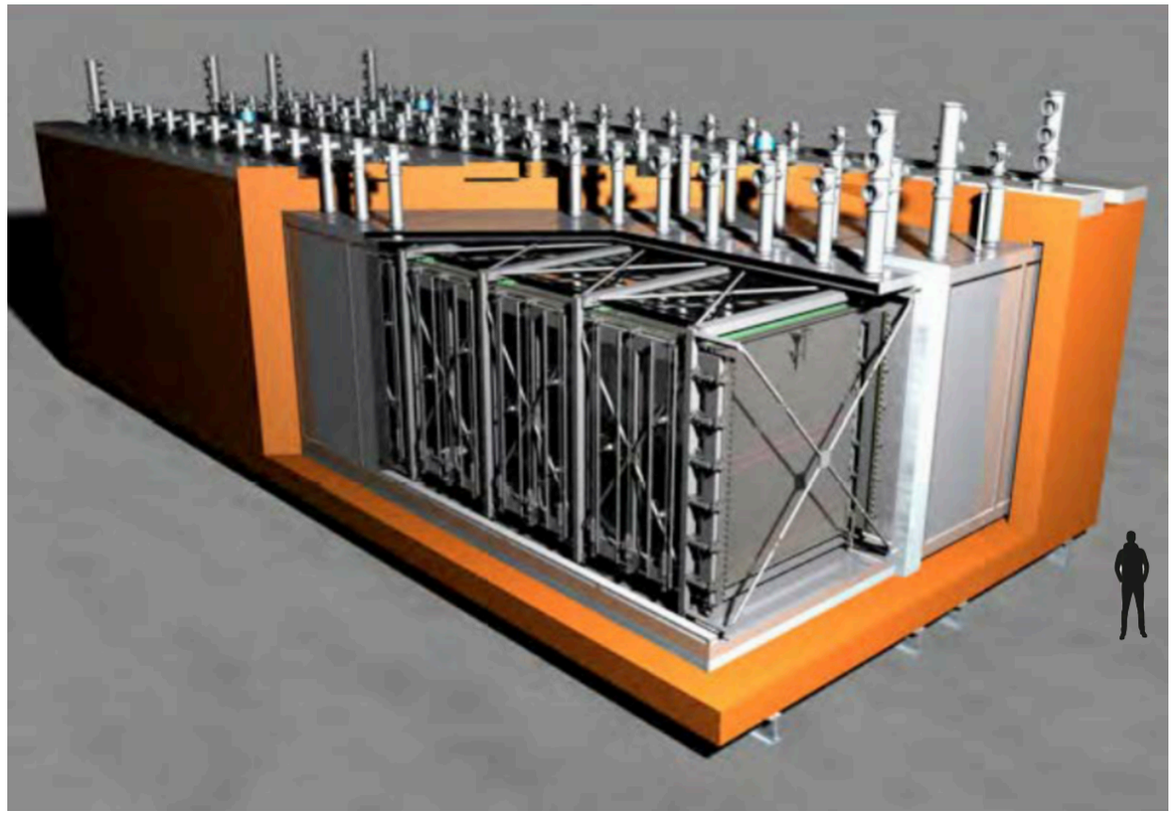
260L LArFCS

SBND and ICARUS at Fermilab

- LAr LArTPC experiments on beam line can go up to the scale of 10^2 + tons
- The cryogenic operation principle and requirements are similar to the small test stand
- SBND and ICARUS at Fermilab will be shown after my lab tour



SBND



ICARUS