The WA105 project : a prototype of double phase liquid argon TPC for the Long Baseline neutrino oscillation experiment DUνE

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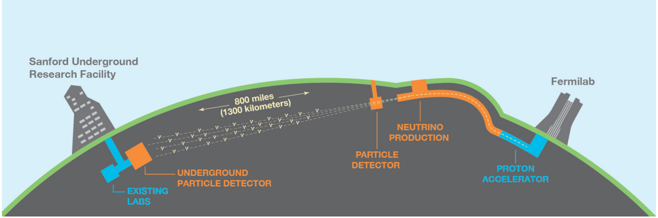
Introduction

- WA105 : R&D project to test DUνE's detector technology
- Following decades of research on the Time Projection Chamber (TPC) Technology

The DUνE experiment

The DUνE experiment



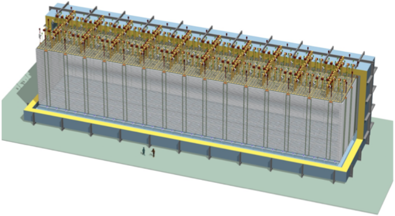
Objectives

- Measure the CP violation phase in the PMNS matrix
- Determine neutrino mass ordering
- Measurements of proton life time
- Study of atmospheric and supernova neutrinos

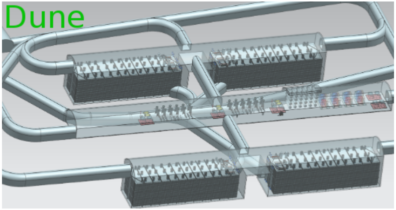
When, how, where?

- Around 2026
- From Fermilab to Sanford
- Will measure the oscillation probability $P(\nu_\mu \to \nu_e)$ at 1300km and 2GeV

Sanford far detector:



- 10kT liquid argon TPC

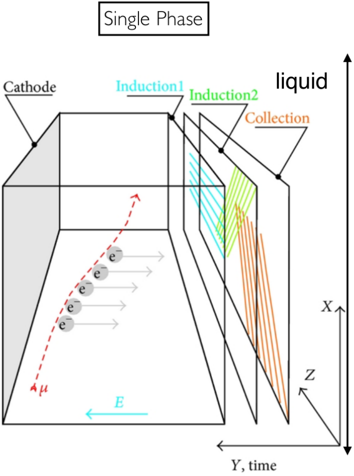


- 4 modules = 40kT (one module at the beginning, 3 will be added afterwards)

Detector: R&D

The Liquid Argon TPC (LArTPC) technology

The Liquid Argon TPC (LArTPC) technology

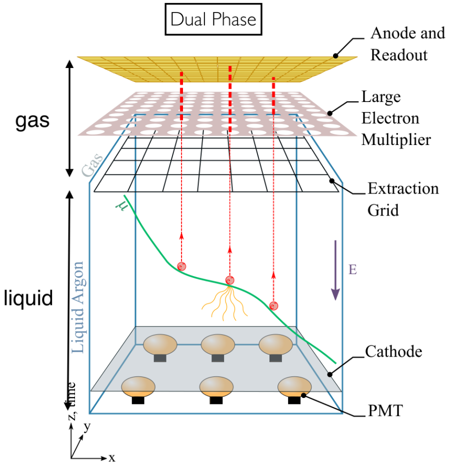


- 3D tracks reconstruction
- Measure $\frac{dE}{dx}$

Benefits of the liquid argon:

- High density (required for neutrino experiments)
- Does not absorb ionization electrons (if no impurities, mostly O_2) $\Rightarrow$ allows for big volumes
- Small electron diffusion ($\sigma \sim mm$ after a few meters drift)
- Liquid : a lot of ionization ($\sim$ 7000 electrons/mm after recombinaison)

Double Phase Liquid Argon TPC (DLArTPC)

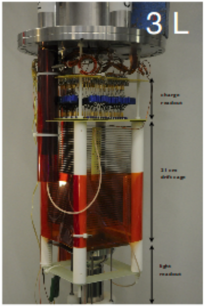


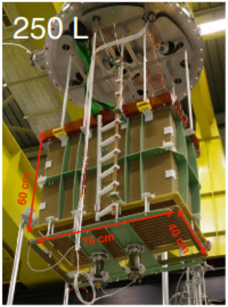
Amplification of charges in gas:

- Allows bigger drift lengths
- Adjustable gain
- Good S/B $\rightarrow$ low energy threshold ($\sim 10 MeV$)

State of the art of double phase TPC

- Technology validated at low scales (3L and 250L)
- Gain > 90
- Drift length $< 1m$





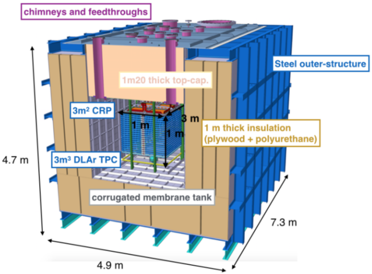
2007 ~ 2014

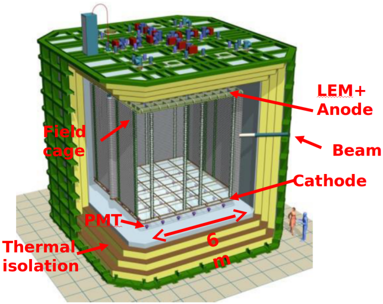
Need one more R&D step to reach DUνE's 10kT scales

The WA105 project

The WA105 project

A two-steps project

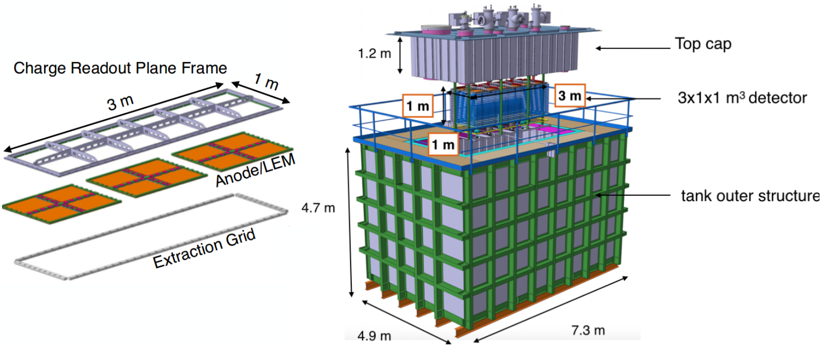




- TPC of $3 \times 1 \times 1 m^3$ active volume (5T active, 25T in total)
- CERN, 2014–2017
- Detects cosmic muons (first tracks in June 2017)

- TPC of $6 \times 6 \times 6 m^3$ (300 tonnes)
- CERN, 2016–2019
- Will detect cosmic muons and charged particles from CERN's beam

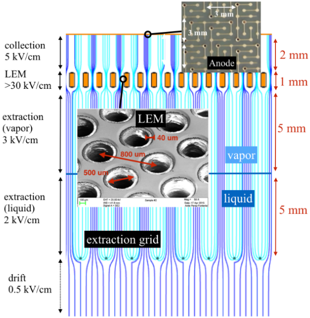
The 3 × 1 × 1 prototype

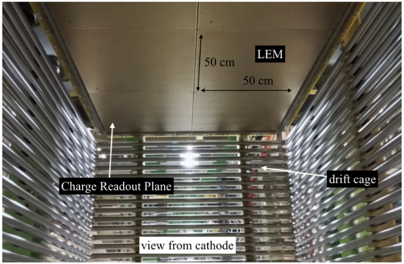


Objectives:

- test amplification and lecture of charges on surfaces of several meters square
- Validate technology choices for the 6 × 6 × 6 construction

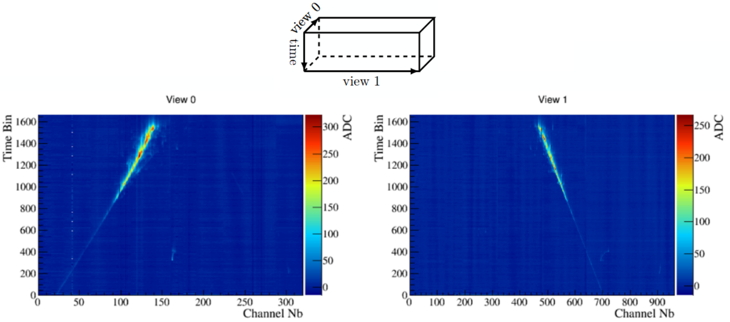
The charge readout plane (CRP)





- Extraction of charges from liquid to gas : electric field $\sim 2kV/cm$
- Amplification in gas through the Large Electron Multipliers (LEM) : electric field $> 30kV/cm$
- Gathered at anode by an induction field of 2kV/cm
- Segmented anode (pitch of $\sim 3mm$), separated x and y views

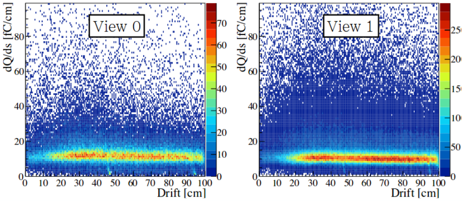
First tracks in June

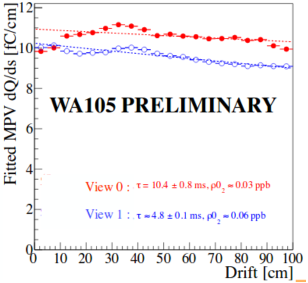


- A high voltage problem on the extraction grid forbade us from reaching nominal voltages, but the principle of DLArTPC with a CRP of a few m^3 works.
- Currently running and being analyzed

First results

Evaluation of liquid argon purity





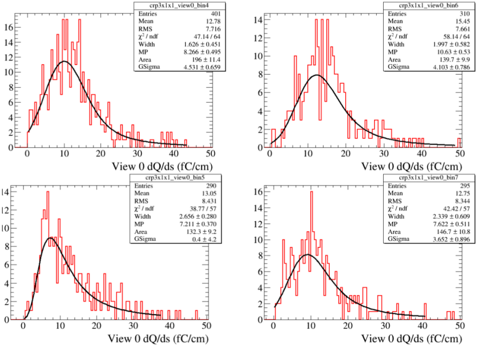
Small variations of $\frac{dQ}{ds}$ vs drift distance: $\Rightarrow$ good argon purity ($\rho(O_2) \simeq 0.06 ppb$).

First results

Evaluation of LEMs gain

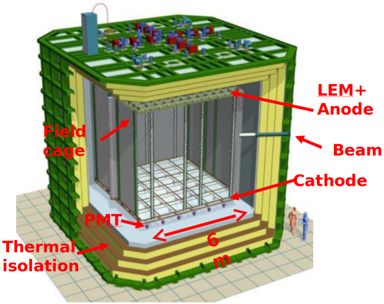
$$< \frac{dQ}{ds} >_{measured} = f_{share} \times Gain \times f_{extr} \times \frac{dQ}{ds}_{MIP} \times f_{ind} \simeq 13 fC/cm$$

- $f_{share} = 0.5$: charges shared between x and y
- $f_{extr} = 0.42$: liquid-gas extraction efficiency (see slide 31)
- $\frac{dQ}{ds}_{MIP} = 10 fC/cm$
- $f_{ind} = 0.33$: induction efficiency (see slide 35)
- $\Rightarrow Gain \simeq 19$ at 28kV/cm



Results are still preliminary, finer analysis is to come.

The $6 \times 6 \times 6m^3$ demonstrator



Objectives

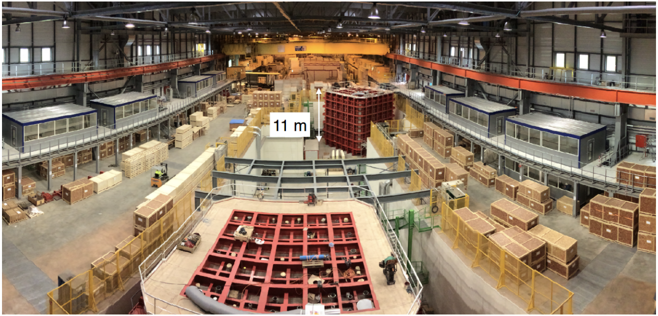
- Test the cryostat and the drift cage at bigger scales
- Study long drift lengths
- Test very high voltages (300kV)
- Test construction method, which is as close as possible to the one that will be used in DUνE
- Test and enhance analysis software

- $6 \times 6 \times 6$ results can be extrapolated to 10kT DUνE's scales
- Under construction at CERN, cryostat finished

In competition

Single phase vs double phase

- The first module of DUνE's 10kT will be single phase. For the 3 other modules, WA0105 is in competition with a single phase demonstrator of similar volume
- Forefront: single phase demonstrator. Background: WA105 demonstrator

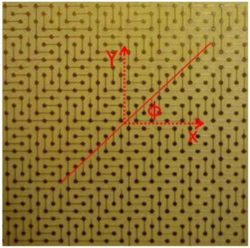


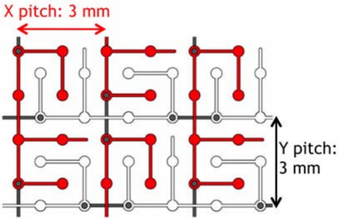
The role of Irfu

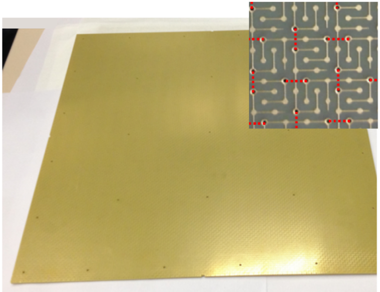
The role of Irfu

- Take part in the commissioning (done) and analyze the performance of the $3 \times 1 \times 1$ (under way)
- Design, order and caracterize the LEMs and anodes for the $6 \times 6 \times 6$ (under way)

The anodes

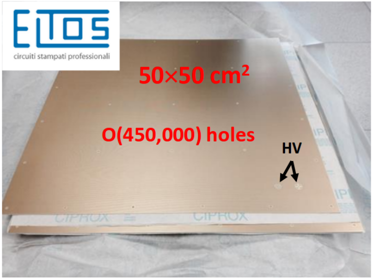


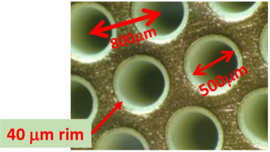




- 4 layers, 3.4 mm thick in total
- Electric continuity tested by manufacturer

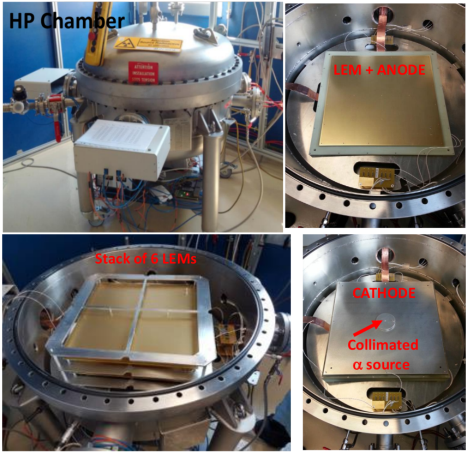
The LEMs





- 1 mm thick
- $75\mu m$ of copper on each side
- 450 000 holes where the electrons will be amplified
- Electric field $> 30kV/cm$

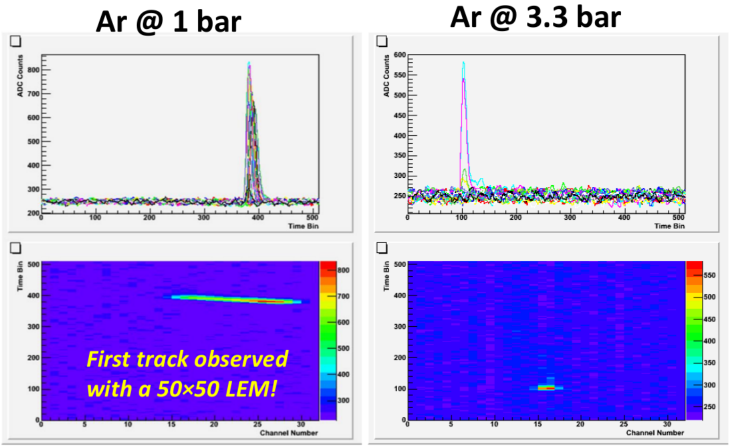
Testing the LEMs at Saclay



- High pressure chamber (3.3 bar) filled with argon to reach same density than WA105
- Can test voltage stability of 6 LEMs at a time
- Can contain a pair anode+LEM with a source (Americium) to measure gain
- Exploited since last year on several LEM geometries

Tracks seen the the chamber

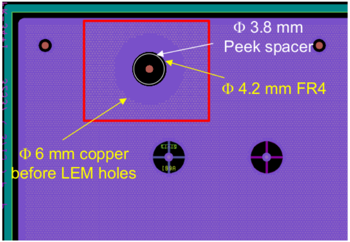
^{241}Am α tracks



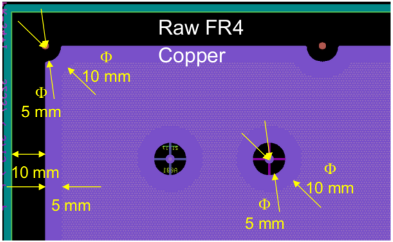
New design

During the tests, we noticed that the design chose for the $6 \times 6 \times 6$ (left) could not go higher than 3200V. We have been able to determine than higher dead zones allowed for a higher limit, and created a new design (right) that can reach 3500V.

CFR-34 LEM production design

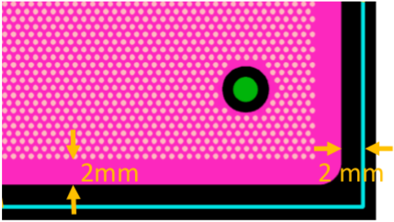


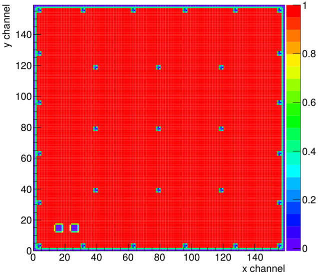
Proposed « conservative » design



My thesis work

Dead zones (old design, new one is still in study)





- Dead zones : 2 mm without copper on borders
- plus 2 mm without holes
- Screws to fix to the CRP
- High voltage connectors

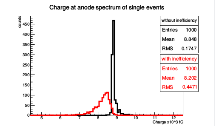
- Simulation of dead zones impact on the electron probability to reach an amplification region, done with software ANSYS (finite elements to simulate the field) and GarField (C++, simulates drift and avalanche)
- Implemented in WA105's analysis software

Effect of deas zones on particles

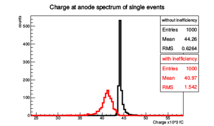
Example of electrons

Simulation of charged particles (here, electrons) going through the $3 \times 1 \times 1$

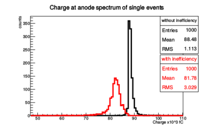
- In black : without taking dead zones into account
- In red : with the dead zones taken into account
- $\Rightarrow$ Dead zones make resolution poorer, in addition to lowering the collected charge



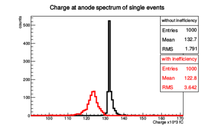
$0.2 GeV/c$



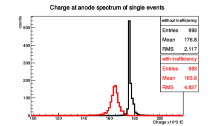
$1 GeV/c$



$2 GeV/c$



$3 GeV/c$



$4 GeV/c$

The gain

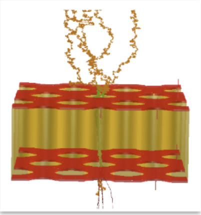
Townsend Avalanche

gas density

amplification length

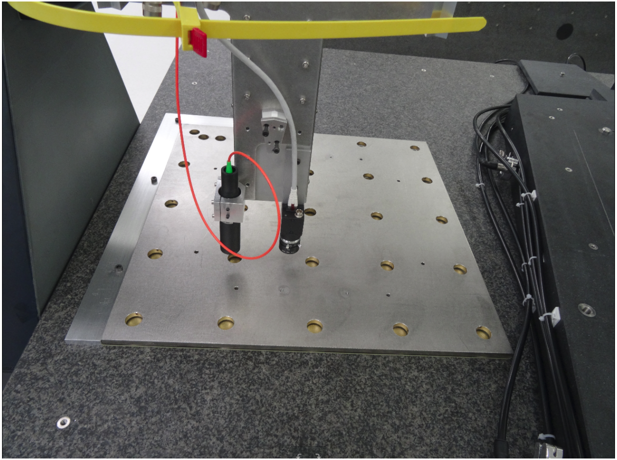
$$G_{eff} = Te^{\alpha x} = Te^{A\rho x e^{-B\rho/E}}$$

electric field inside the LEM hole



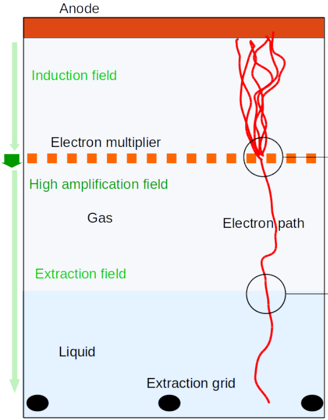
- LEM thickness must be as uniform as possible, the gain depends exponentially on it

Measure LEM thickness



Micrometric optical measurement in clean room to determine the LEMs' thickness uniformity (results expected next week)

Simulation of charge collection efficiency



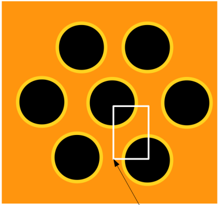
Probabilité qu'un électron sortant du LEM arrive bien à l'anode ?

Probabilité que l'électron soit bien extrait du liquide vers le gaz ?

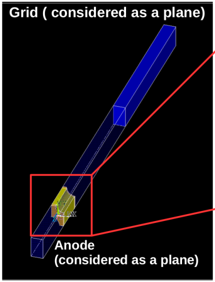
Simulated with ANSYS et GarField

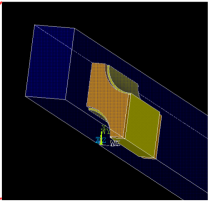
Simulation of charge collection efficiency

1st step : simulate electric field with ANSYS



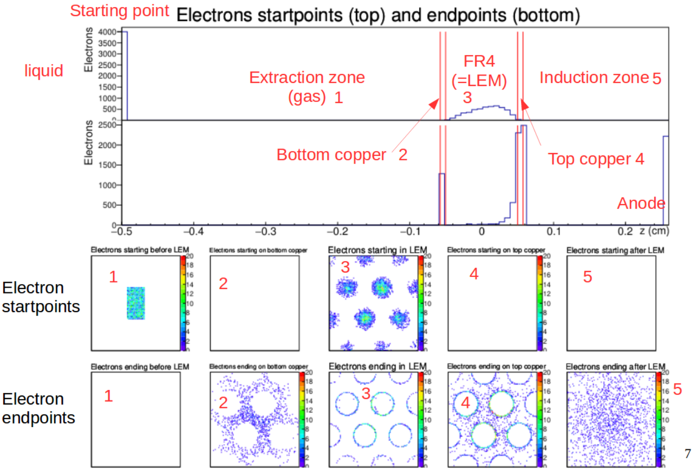
Base element in ANSYS simulation

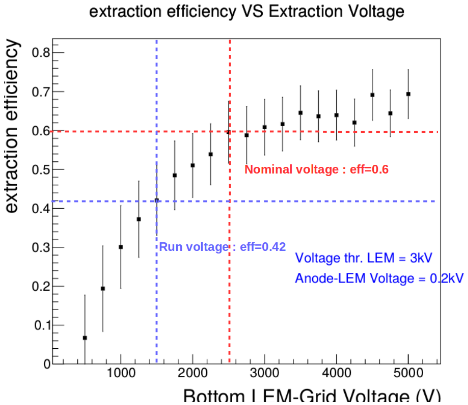




Symmetry conditions on border
give full hexagonal geometry

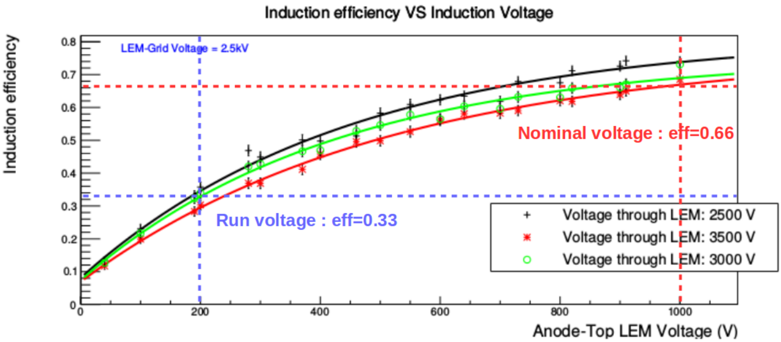
2nd step: generate and drift electrons toward LEM with GarField





Probability for an electron arriving at the extraction grid to reach an amplification zone. Loss can be electrons staying in the liquid, or arriving on the LEM without going through the holes.

Simulation of charge collection efficiency



Probability for an electron leaving the LEM to reach the anode. Loss due to electron going back toward the LEM.

Conclusion

Liquid argon TPC = very performant for neutrino detection. Gives a 3D image of their interactions. The double phase version works with surface of several meters square.

Short term : Detailed exploitation and study of $3 \times 1 \times 1$ data: purity, uniformity of gain, scintillation light, compare to simulations... Recent data, still a lot to do!
Average term : Exploitation of $6 \times 6 \times 6$ and validation of technology at bigger scales
Long term : DUνE!

Thank you!

Backup

Property	Liquid Argon
Density (g/cm3)	1.4
Radiation length (cm)	14
Interaction length (cm)	83.6
dE/dx mip (MeV/cm)	2.1
We (eV) @ E=∞	23.6
Wγ (eV) @ E=0	20
Refractive index (visible)	1.24
Cerenkov angle	36°
Cerenkov $d^2N/dEdx$ (β=1)	≈ 130 eV^{-1} cm^{-1}
Muon Cerenkov threshold	140 MeV/c
Boiling point @ 1 bar	87 K