Calibration with Argon39 in ProtoDUNE and DUNE

universite PARIS-SACLAY

DEEP UNDERGROUND NEUTRINO EXPERIMENT

A. Introduction to DUNE

a. Brief context

b. The Vertical-Drift (VD)

c. The prototypes : Module-0 and ColdBox

B. Needs for Calibration

a. The Space Charge effect

b. The Charge Quenching

c. The Electron Lifetime

C. A Natural Source of Calibration : Ar^{39} Beta decay

a. The signal

b. What can we extract ?

- Energy spectrum
- Waveforms

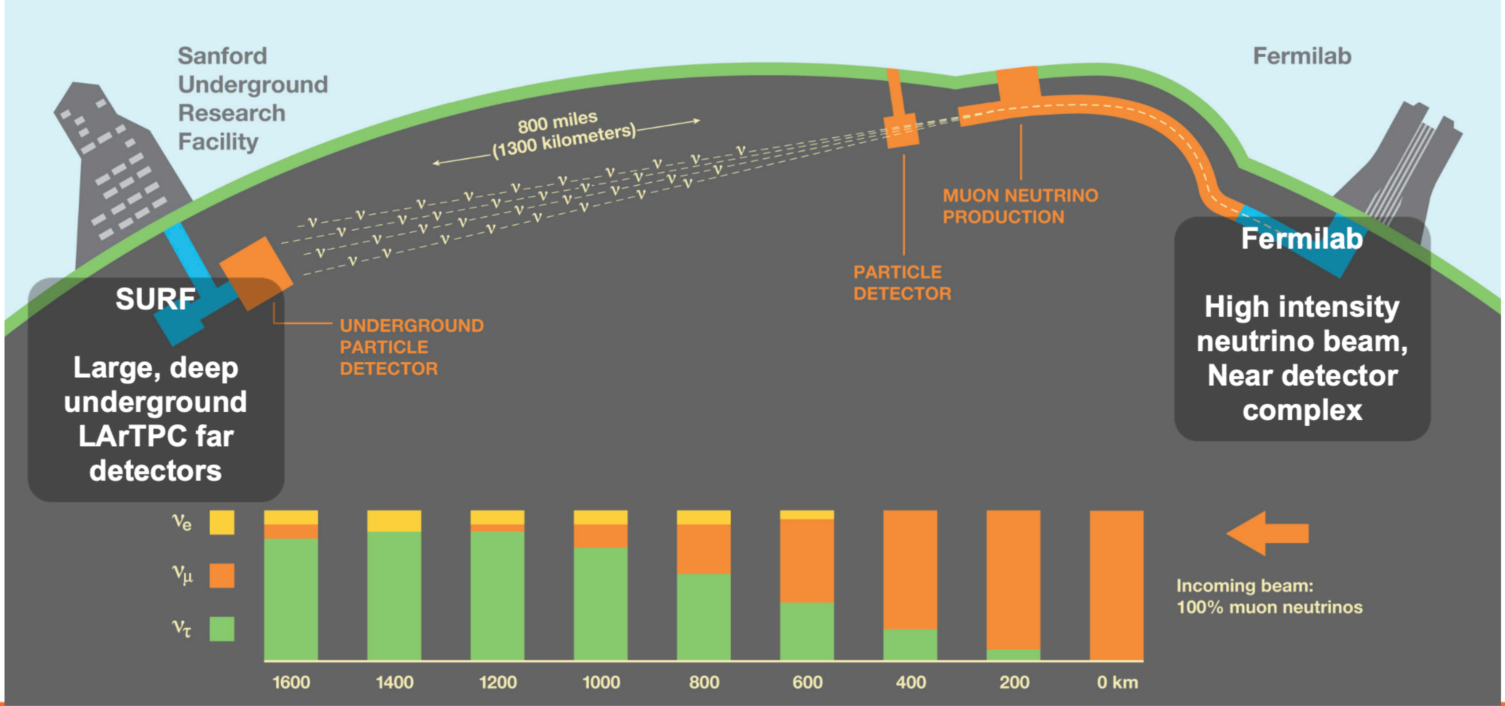
c. Selection principle

d. Preliminary results

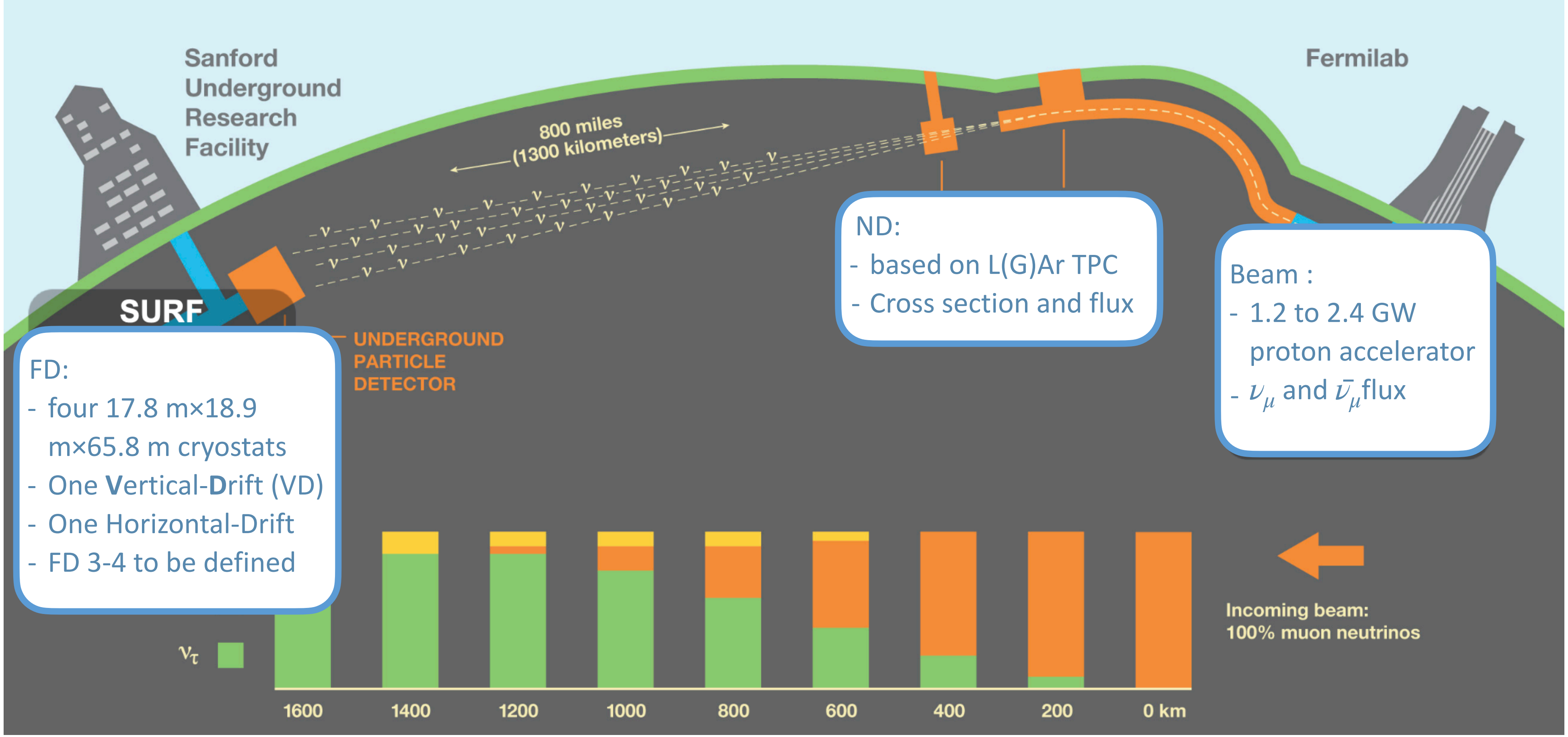
D. Outcomes and Conclusion

A. Introduction to DUNE

- Long Baseline neutrino experiment based on **L**iquid **Ar**gon **T**ime **P**rojection **C**hamber (LAr-TPC) technology.
- Composed of 3 parts : the Beam, the **N**ear **D**etector (ND) and the **F**ar **D**etector(FD)
- DUNE aims to characterize few of the neutrinos' parameters: δ_{CP} , θ_{23} , θ_{13}, unity of PMNS matrix, mass hierarchy
- And also study some **B**eyond **S**tandard-**M**odel or astrophysical phenomena like proton decay or Supernova.



Introduction to DUNE

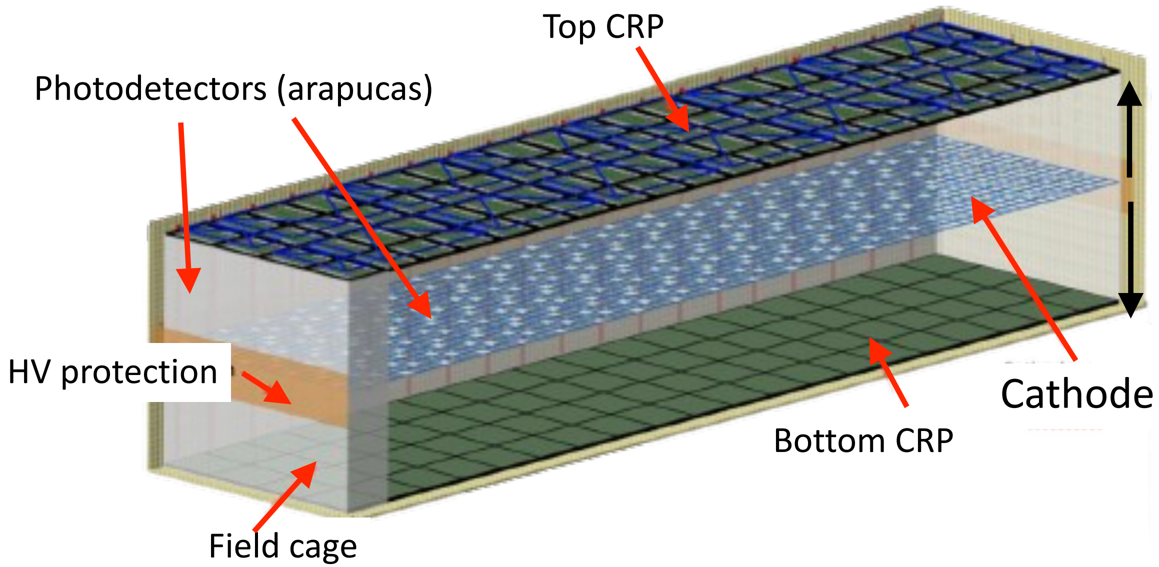


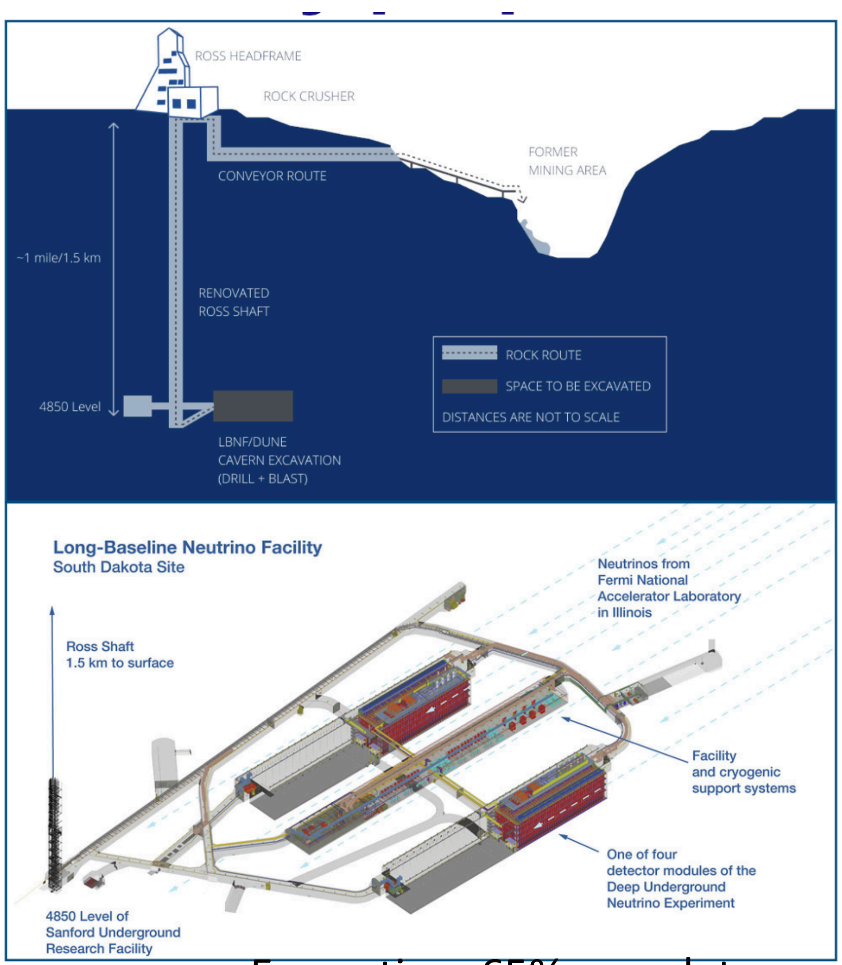
FD:
- four 17.8 m×18.9 m×65.8 m cryostats
- One **V**ertical-**D**rift (VD)
- One Horizontal-Drift
- FD 3-4 to be defined

ND:
- based on L(G)Ar TPC
- Cross section and flux

Beam :
- 1.2 to 2.4 GW proton accelerator
- ν_μ and $\bar{\nu}_\mu$ flux

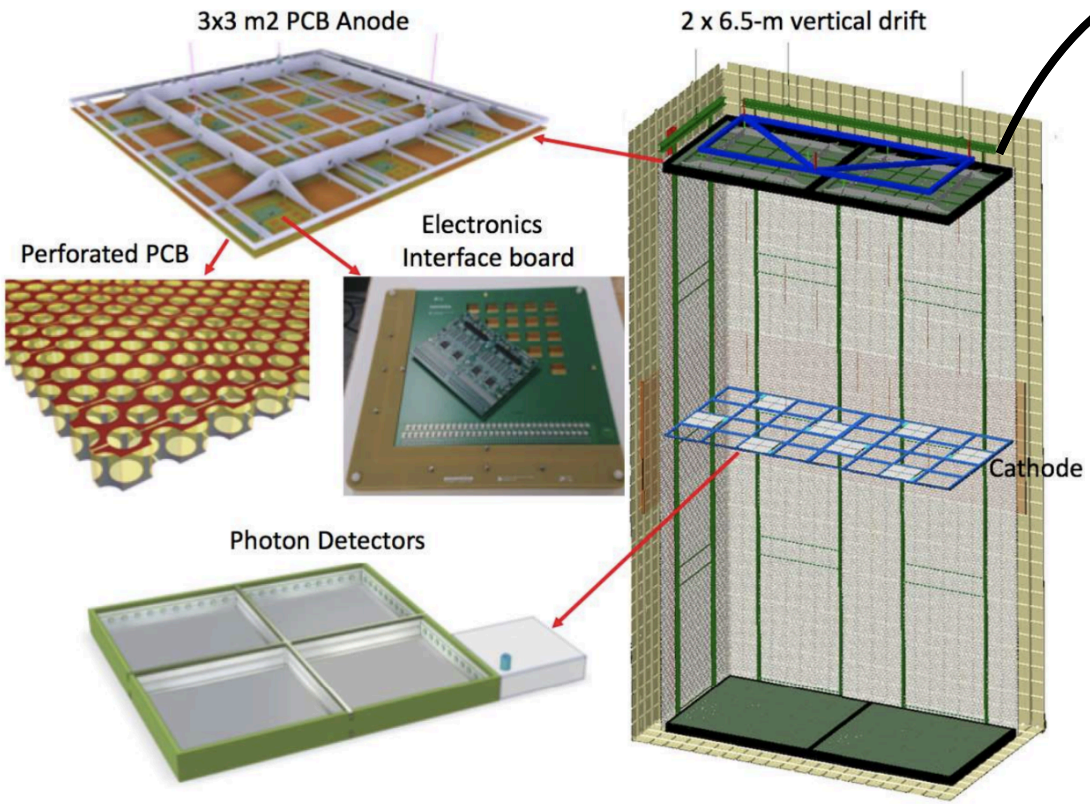
- One of the FD cryostat
- Double TPC with drift field of 450 V/cm for an active volume of ~15 kton
- IJCLab contributions:
    - Cathodes
    - Top electronics feedthroughs

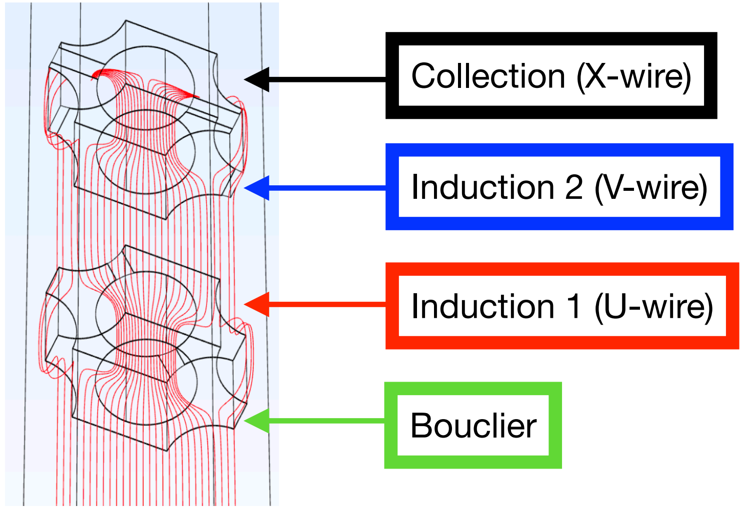


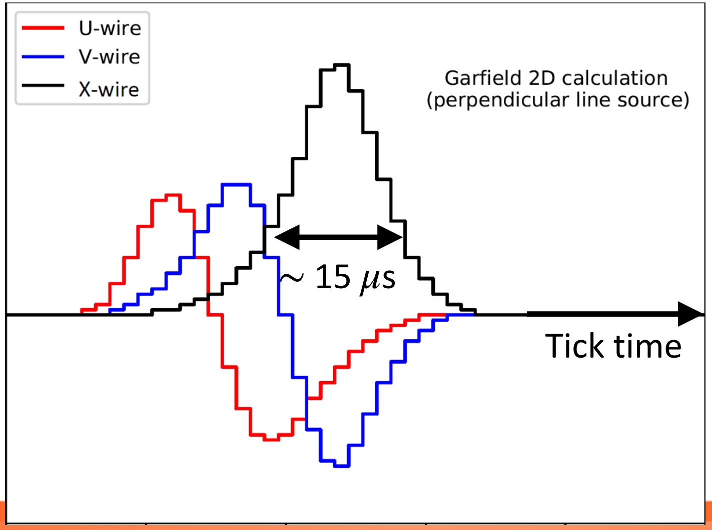


Excavation: 65% complete

Charge Readout electronic

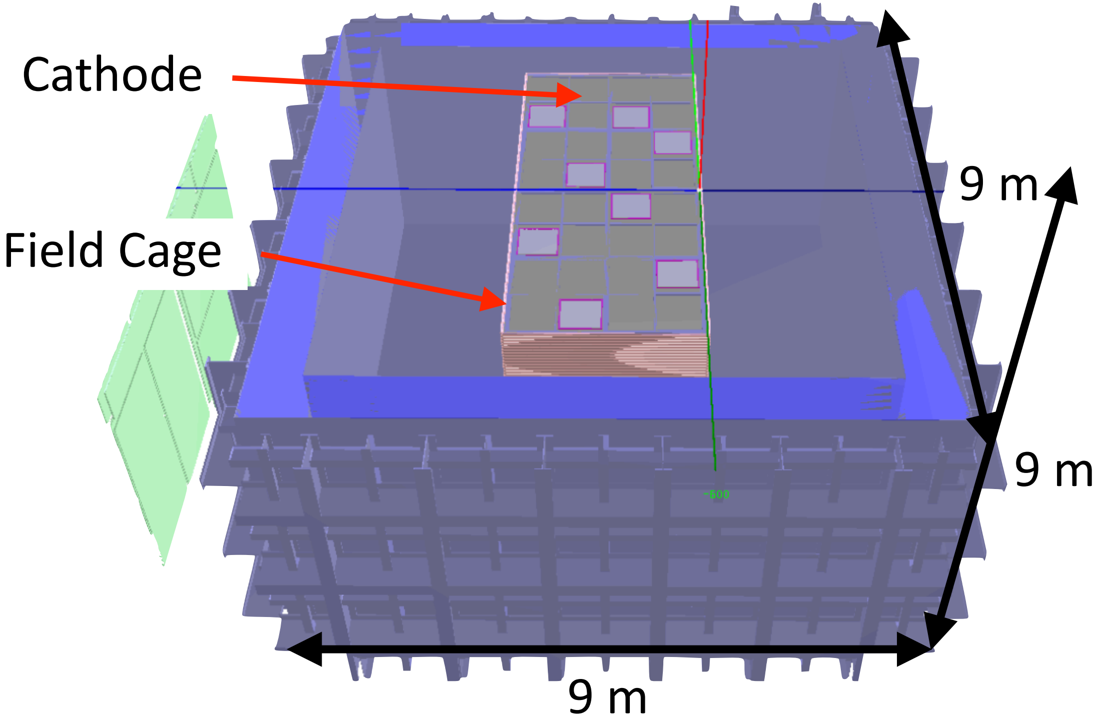






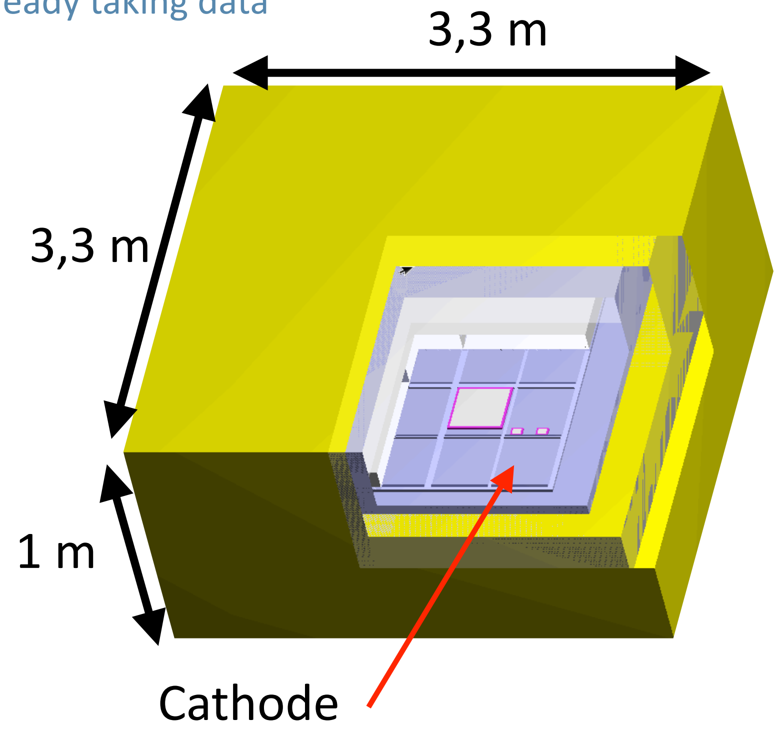
Module-0

- True design prototype
- Drift length: 3.38 m, effective volume: 3.375 m x 6 m x 6.76 m
- Will take data during the fall



ColdBox

- Prototype used mainly for structural and electronics tests
- Drift length ~ 20 cm, effective volume 3 m x 3 m x 0.2 m
- Already taking data

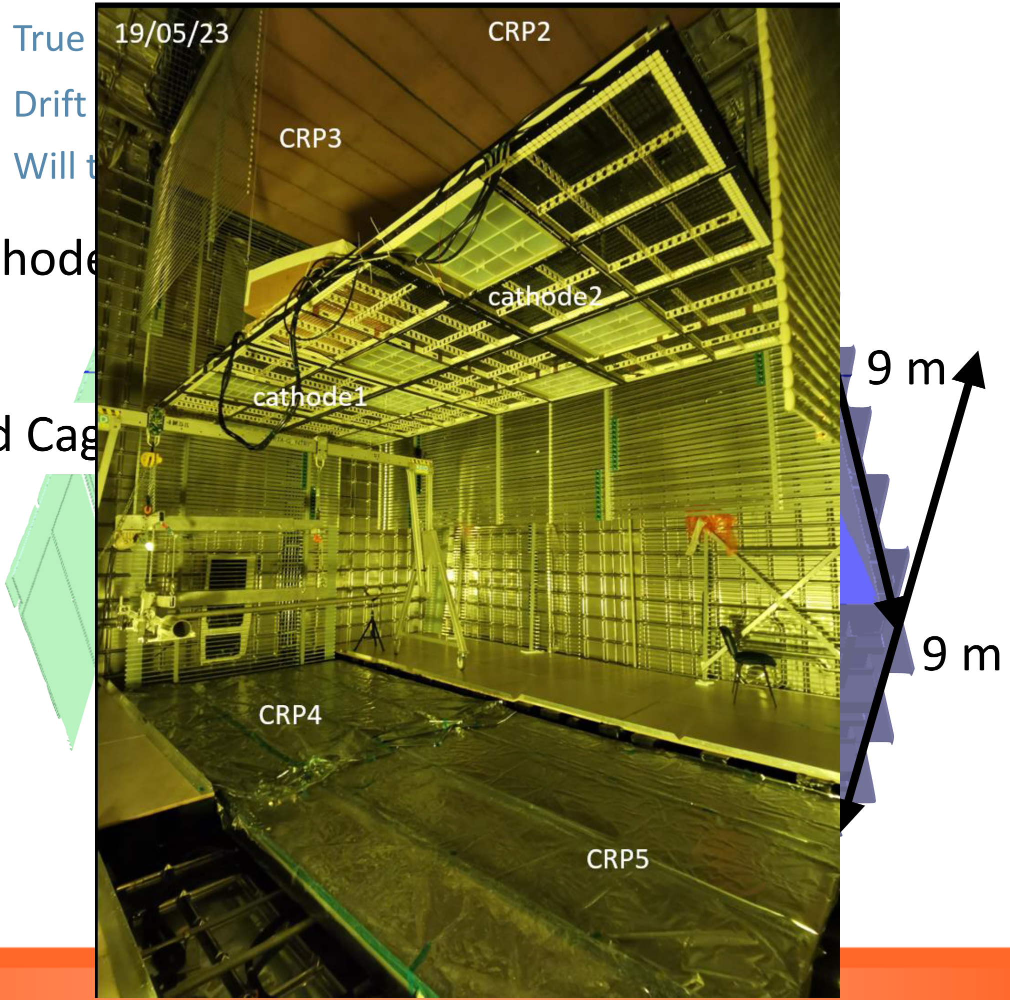


Module-0

- True
- Drift
- Will t

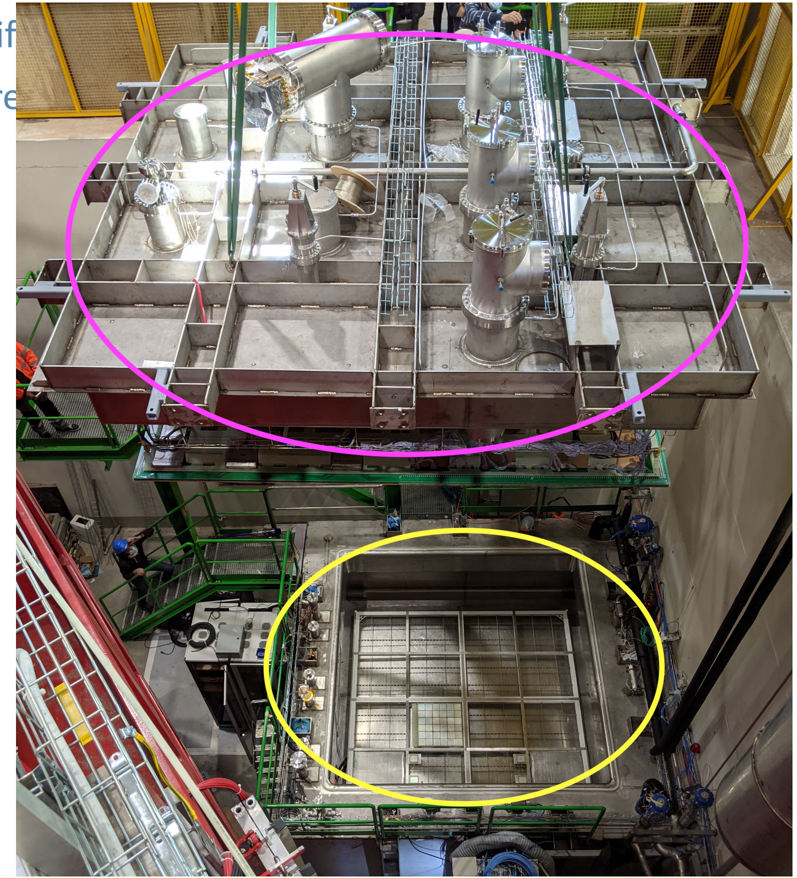
Cathode

Field Cag



ColdBox

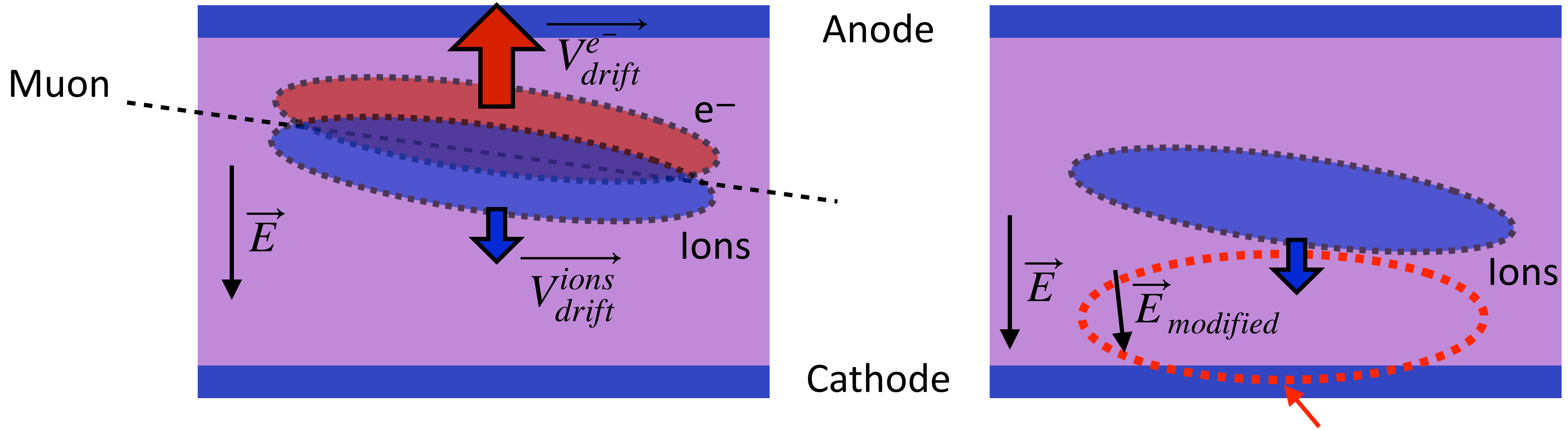
- Prototype used mainly for structural and electronics tests
- Drif
- Alre



B. Needs for Calibration

There are several detector effects that are relevant during the production of ionisation electrons and their drift towards the anode. These effects must be known and quantified in order to correctly understand the response of our detector

- **Space charge effect:** the **modification of drift field** in detector volume due to build-up of **slow moving argon ions** that are produced from **cosmic rays**



All the events that happen under the ion cloud
don't see the true electric field (which can be modified up to 10-20%)

- This effect **is relevant only for surface detectors** ie it must be quantified for Module-0 but will be negligible for VD : at 1500 m underground we receive $\sim$ 5 cosmic/ m^3/ day, **ie** $\sim$ **1400 cosmic for 1/2 hour run in VD.**

- **Charge Quenching:** effect characterised by the recombination factor ***R***, which is the fraction of ionization charge that remains after prompt recombinaison with associated argon ions.
- ***R*** describes the efficiency in converting dE/dx into dQ/dx
- We use the **modified Box Model** but we can also use Birks Model

$$R = \frac{dQ/dx}{dE/dx} = \frac{ln(\alpha + \frac{\beta \times dE/dx}{E_{field}\ \rho})}{\frac{\beta \times dE/dx}{E_{field}\ \rho}}$$

$$E = \Gamma \frac{I}{R} Q$$

α = Box model parameter

ρ = liquid Argon density

$\beta = 0.212$ (kV/cm)(g/cm^2)

E_{field} = electric field

E = Energy in keV

Γ = electronic conversion factor in electron/ADC.tick

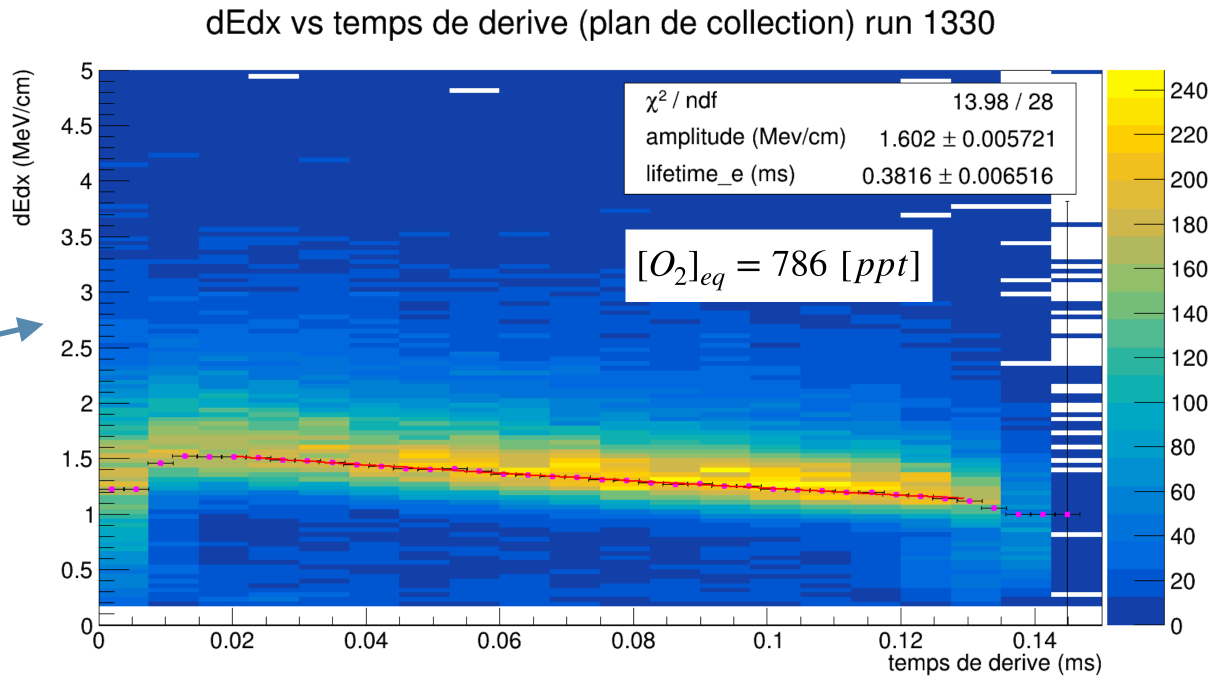
I = ionization energy = 23.6 eV

Q = collected charge in ADC.tick

- **Electron lifetime (τ_e):** quantifies the attachment of drifting ionisation electrons to electronegative impurities such as oxygen or water in the argon
- Well characterised with muons because we can plot the MIP (Minimum Ionisation Particle) with respect with drift distance (distance to the anode)
- In practice we want $\tau_e \gtrsim 5 \times \tau_{drift}$ with $\tau_{drift} \simeq 4.3$ ms for VD and $\tau_{drift} \simeq 2.1$ ms for Module-0 (and 0.1 ms for ColdBox)

$$\tau_e \text{ [ms]} \approx 300/[O_2]_{eq} \text{ [ppt]}$$

Obtained with ColdBox Data
The electron lifetime is not quite good because the ColdBox has been opened and closed several times for various test and the drift distance is only 0.2 m.
LAr purity will be better in Module-0

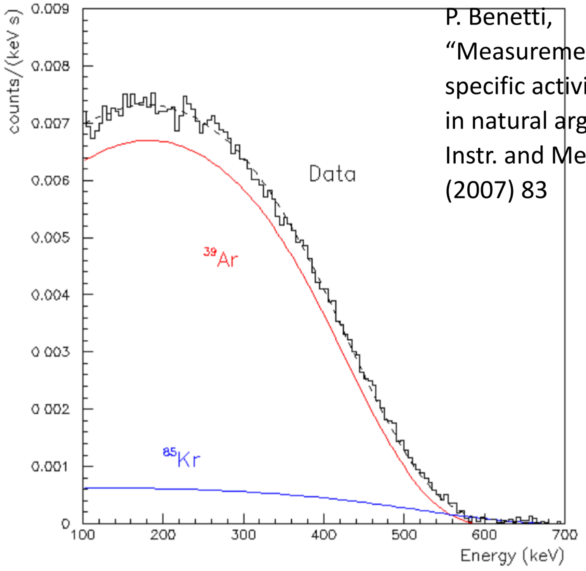


A Natural Source of Calibration : Ar^{39} Beta decay

Point-like event

$$\bar{X}_0 = \frac{1}{\rho\sigma} \approx \text{few nm}$$

Ar^{39}



P. Benetti, "Measurement of the specific activity of Ar-39 in natural argon," Nucl. Instr. and Meth.A 574, (2007) 83

Activity: 1 Bq/kg

ie: - $\sim 2 \times 10^7$ decay/s for VD

- $\sim 8 \times 10^4$ decay/s for Module-0

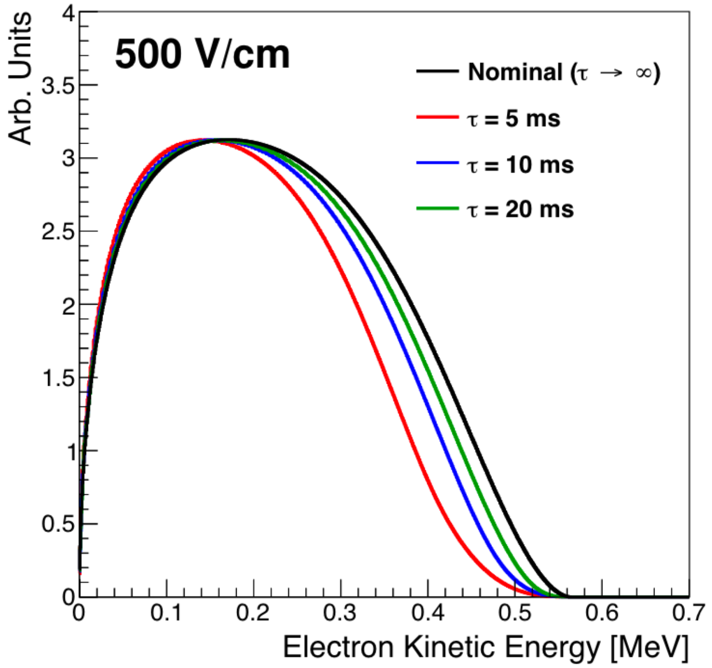
- $\sim 3 \times 10^3$ decay/s for ColdBox

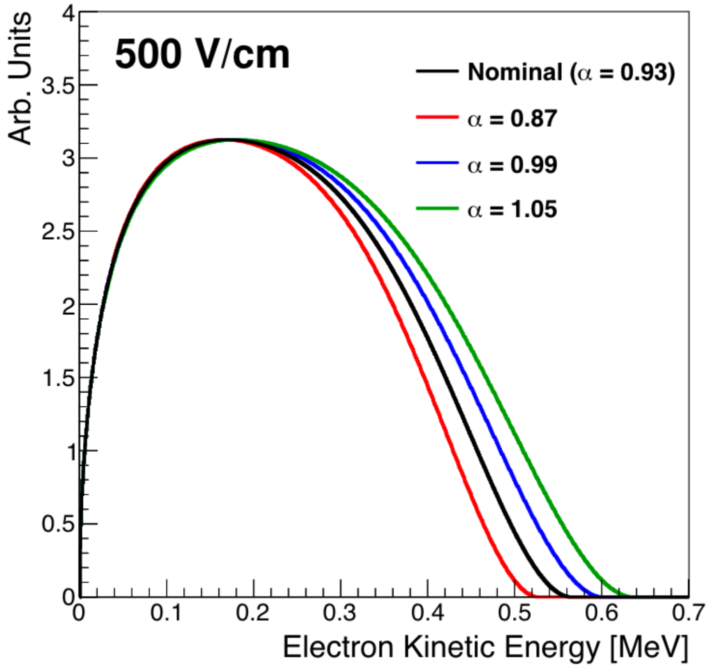
Low Energy event

Good for MeV scale

SuperNova Neutrinos

- From the **energy spectrum** we can extract the Recombinaison factor and the electron lifetime
- Even if we can't know the position in the drift direction (no light emitted during the decay) the fact that t**he decays are uniformly distributed in the TPC volume** gives us a sensibility to the purity of the argon.

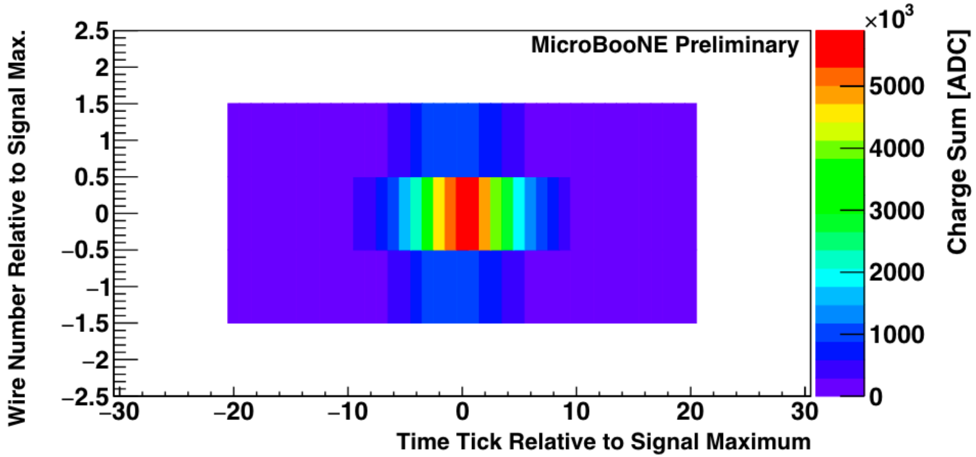


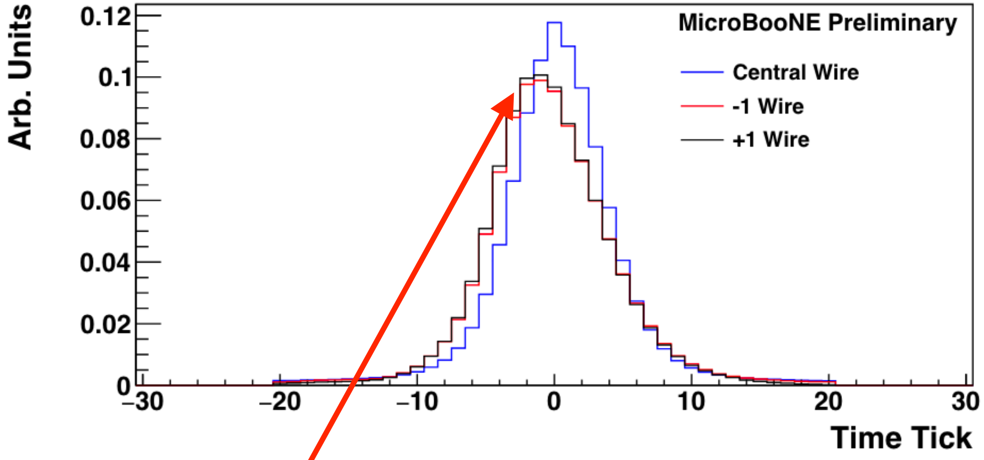


MicroBooNE Collaboration. « Study of Reconstructed ^{39}Ar Beta Decays at the MicroBooNE Detector », 29 juin 2018. https://doi.org/10.2172/1573057.

- From the **waveform** we can extract the strip/wire to strip/wire response variation and so extract electric field distortion near the anode for example.
- It is also possible to observe the effect of the diffusion by studying the dependency to our spatial selection criteria (see next slide)

MicroBooNE Collaboration. « Study of Reconstructed ^{39}Ar Beta Decays at the MicroBooNE Detector », 29 juin 2018. https://doi.org/10.2172/1573057.

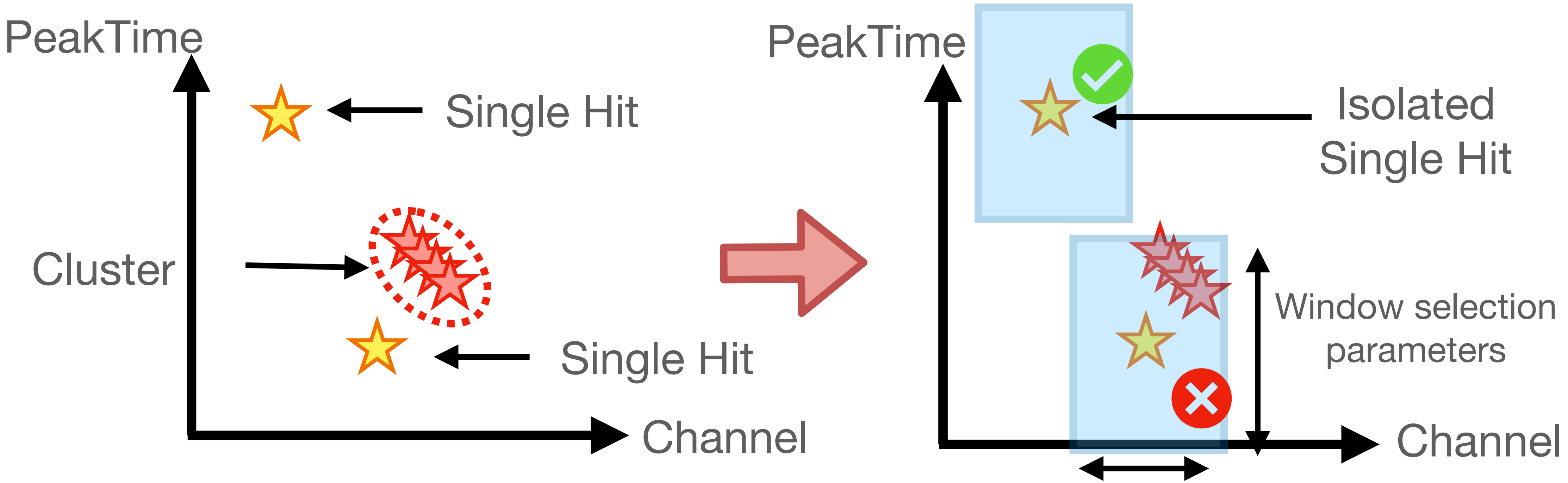




Induction effect on wire neighbour on the collection plan

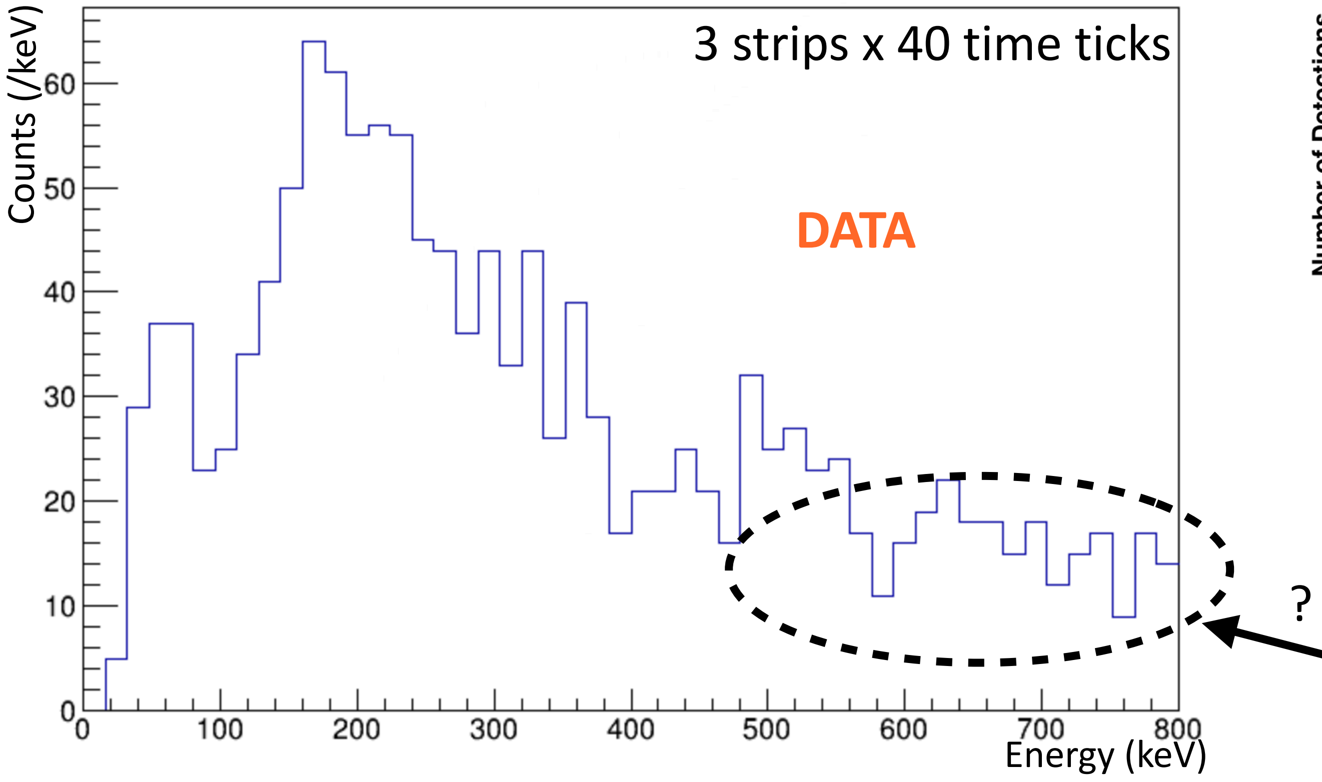
Selection principle

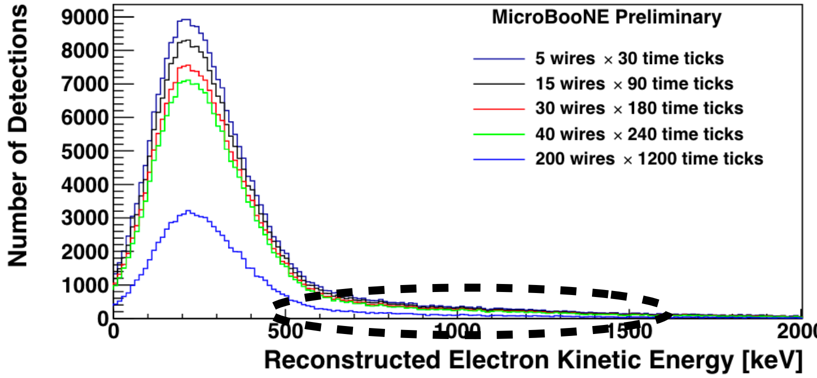
- We want to select **isolated single** hit.
- **Single** = alone in its own cluster
- **Isolated** = no other hits in window of 40 time ticks by 3 strips ie in a **15 mm x 15 mm square**



- From a ColdBox run after applying the selection algorithm we manage to see some potential Ar39 candidates

MicroBooNE Collaboration. « Study of Reconstructed ^{39}Ar Beta Decays at the MicroBooNE Detector », 29 juin 2018. https://doi.org/10.2172/1573057.

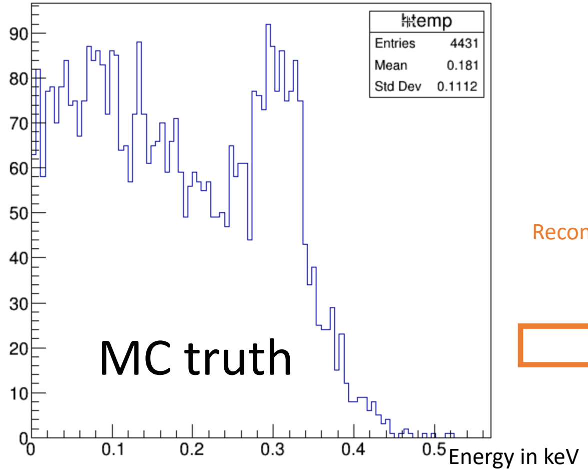


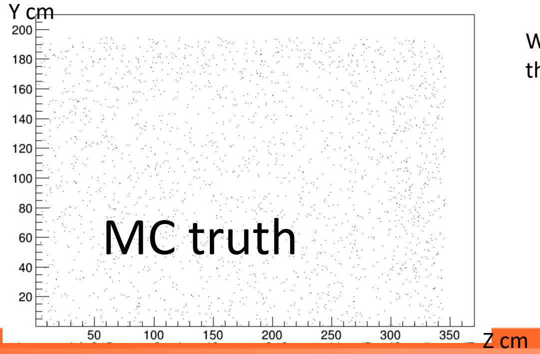


High energy tail due to cosmogenic and high energy radiological sources (Th, U)

Preliminary results 2/3

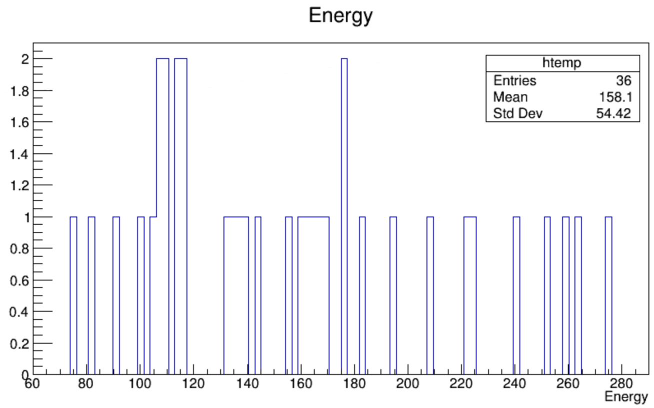
- Simulation with **LArSoft** on the ColdBox
- We manage to see some energy deposition but the reconstruction is not optimal for low energy events but I'm working on a new dedicated code to select this type of events

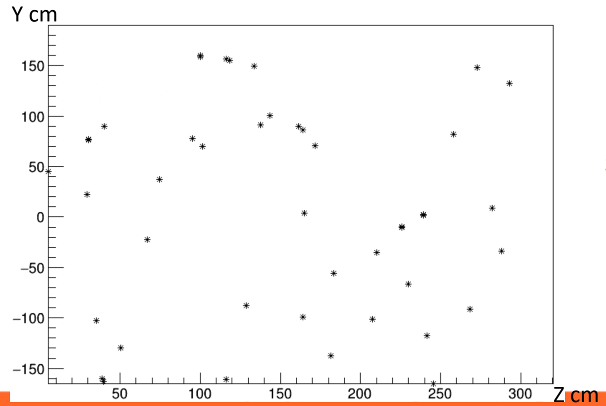




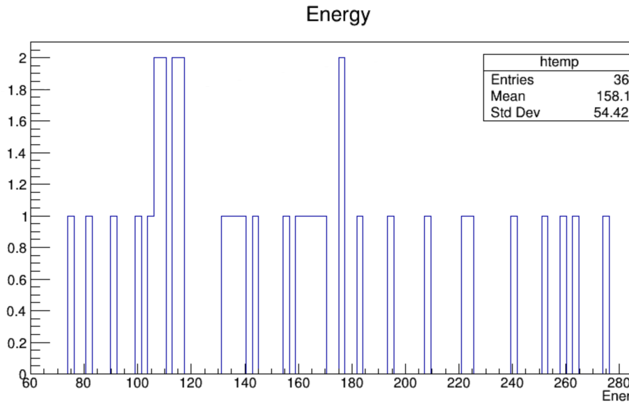
Reconstruction

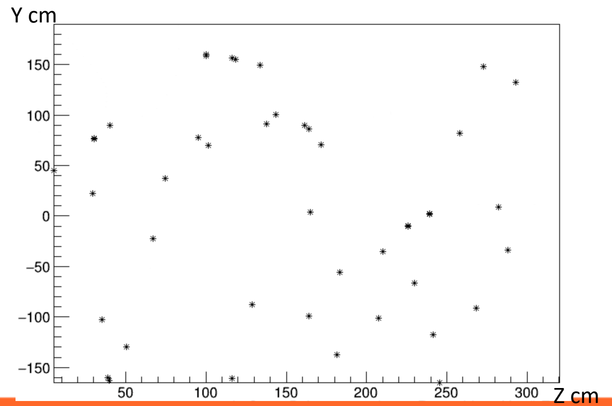
Where do we lost the signals ?



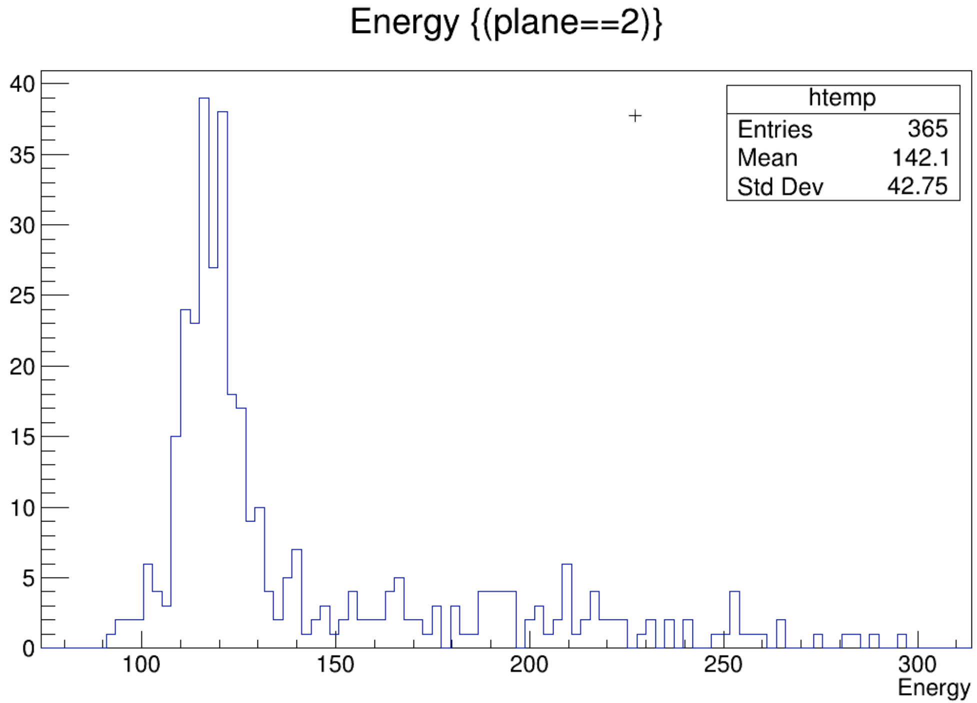


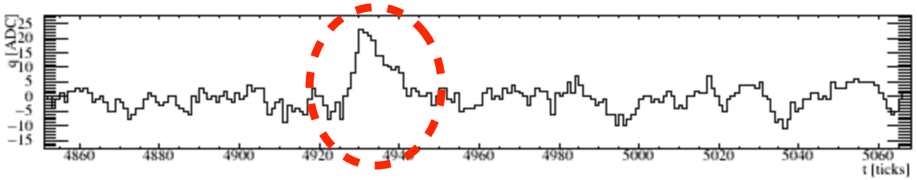
Selection Efficiency: 100%





- At the level of the hits without taking into account the spatial reconstruction we manage to have this spectrum with more statistic and the same efficiency for our selection algorithm





The energy is not well calibrated

Conclusion and Outcomes

- The analysis of Ar^{39} decay will be very useful for Module-0
- Hints for Ar^{39} decay signals in ColdBox prototype data
- Analysis under development to optimize the low energy single hit traces in order to compare the energy spectra from data and simulation
- Plan to directly use the waveforms for the selection and look at the spatial component after
- Need to evaluate the energy resolution by selecting empty events

- For the futur, this calibration must be crossed with other approaches (Stopping muons and Michel electrons for example) to reduce the bias