Calibration at Low Energy with DUNE prototypes

For PHENIICS Fest 2024

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I. Context of DUNE

1. Neutrino Physics
2. DUNE's main goals
3. DUNE's Far Detector (FD)
4. ProtoDUNEs
5. Beam

II. Low Energy at DUNE

1. DUNE's Low Energy (LE) goals
2. Calibration sources (radiologicals)
3. Selection principal

III. Results on ProtoDUNEs

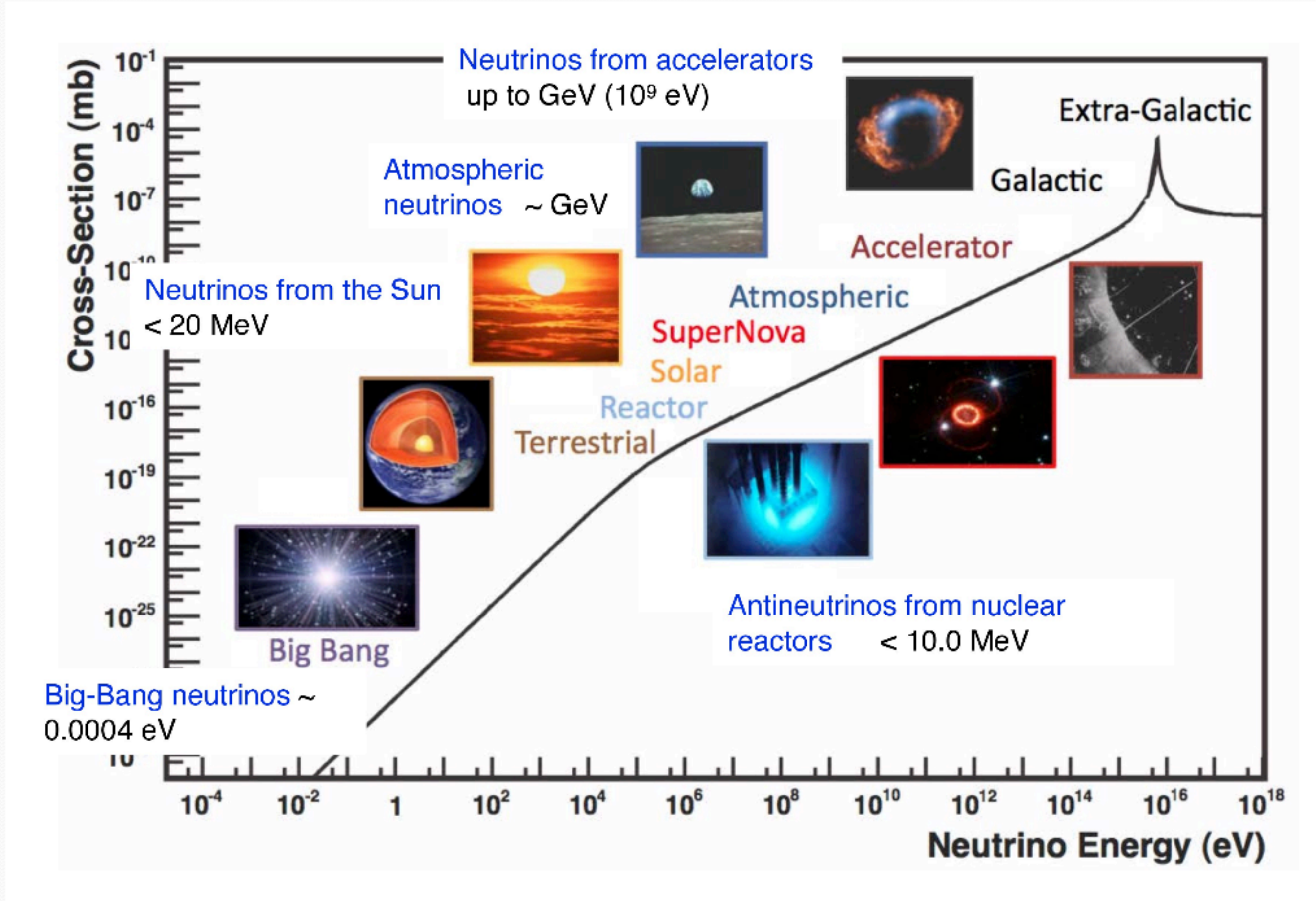
1. Efficiency on PDVD
2. Efficiency on PDHD
3. Calibration PDVD-HD

Conclusion

Context of DUNE

I.Context of DUNE

- Neutrino can be produce from very **different sources** in a **large range of energy**
  - DUNE → **Accelerator, atmospheric,** solar, SN…



I.Context of DUNE

- ν's can be produced in **3 flavours states** (ν_e , ν_μ , ν_τ) and **3 mass states** (ν_1 , ν_2 , ν_3)
- ν's can **oscillate** from one state to an other along their paths

$$P(\nu_e \to \nu_\alpha) = |\Sigma\ \mathrm{U}_{ei}\mathrm{U}^*_{\alpha i}\ e^{-i\mathrm{E}_i t}|^2_{i=1,\,2,\,3}$$

- where **U = PMNS matrix** (~CKM matrix)

$$U = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{CP}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

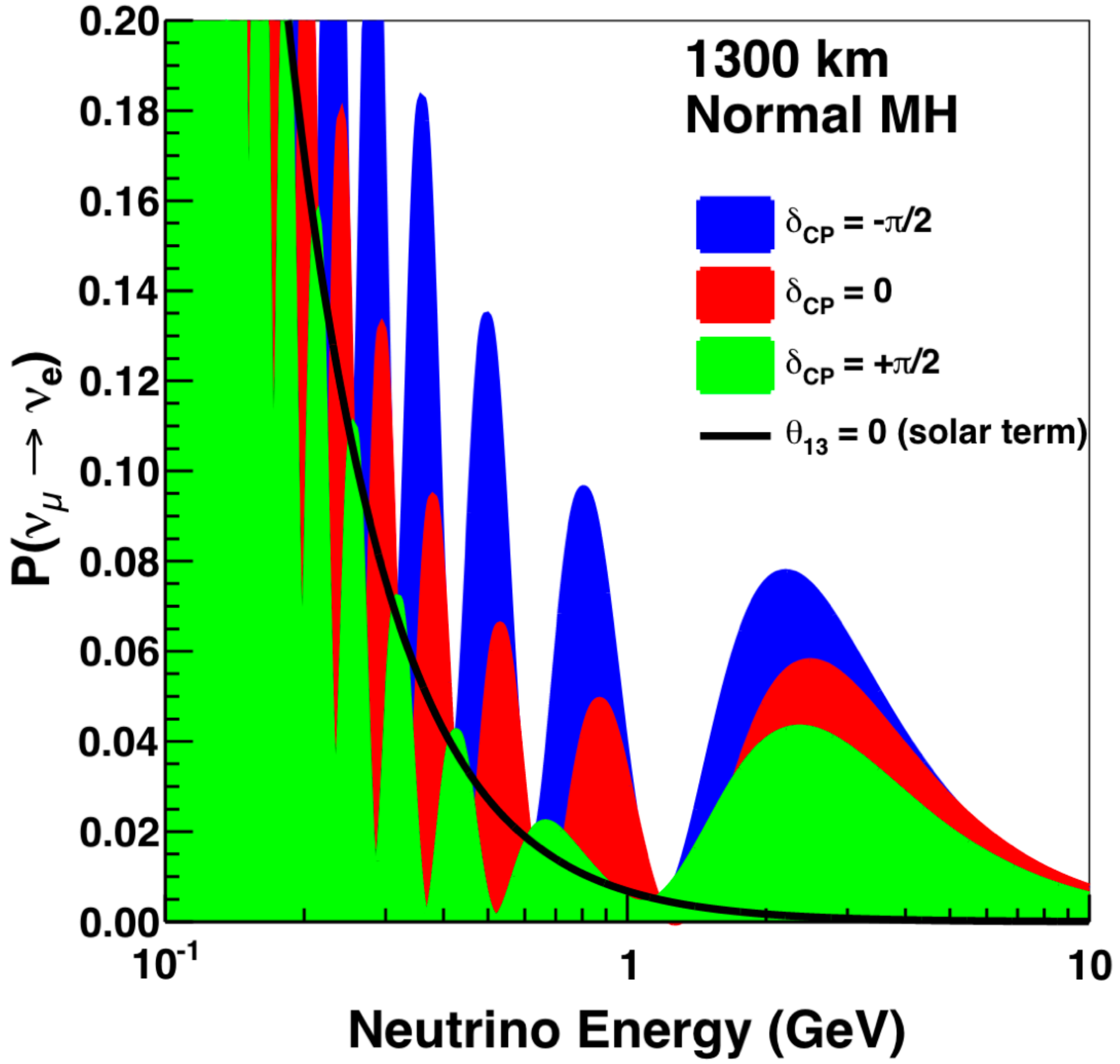
$c_{ij} \equiv \cos\theta_{ij},$

$s_{ij} \equiv \sin\theta_{ij}$

atmos+LBL(dis): $P(\nu_\mu \to \nu_\mu)$

Chooz+LBL(app): $P(\nu_e \to \nu_e)$ & $P(\nu_\mu \to \nu_e)$

solar+KamLAND: $P(\nu_e \to \nu_x)$

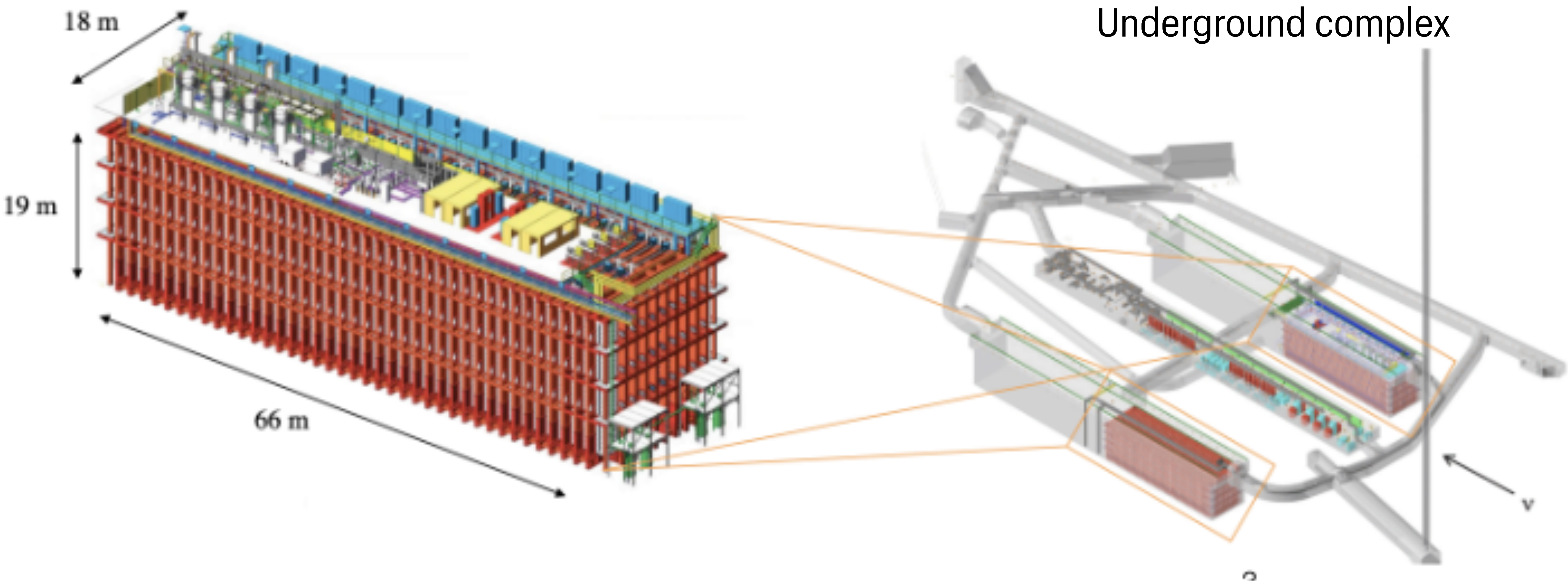


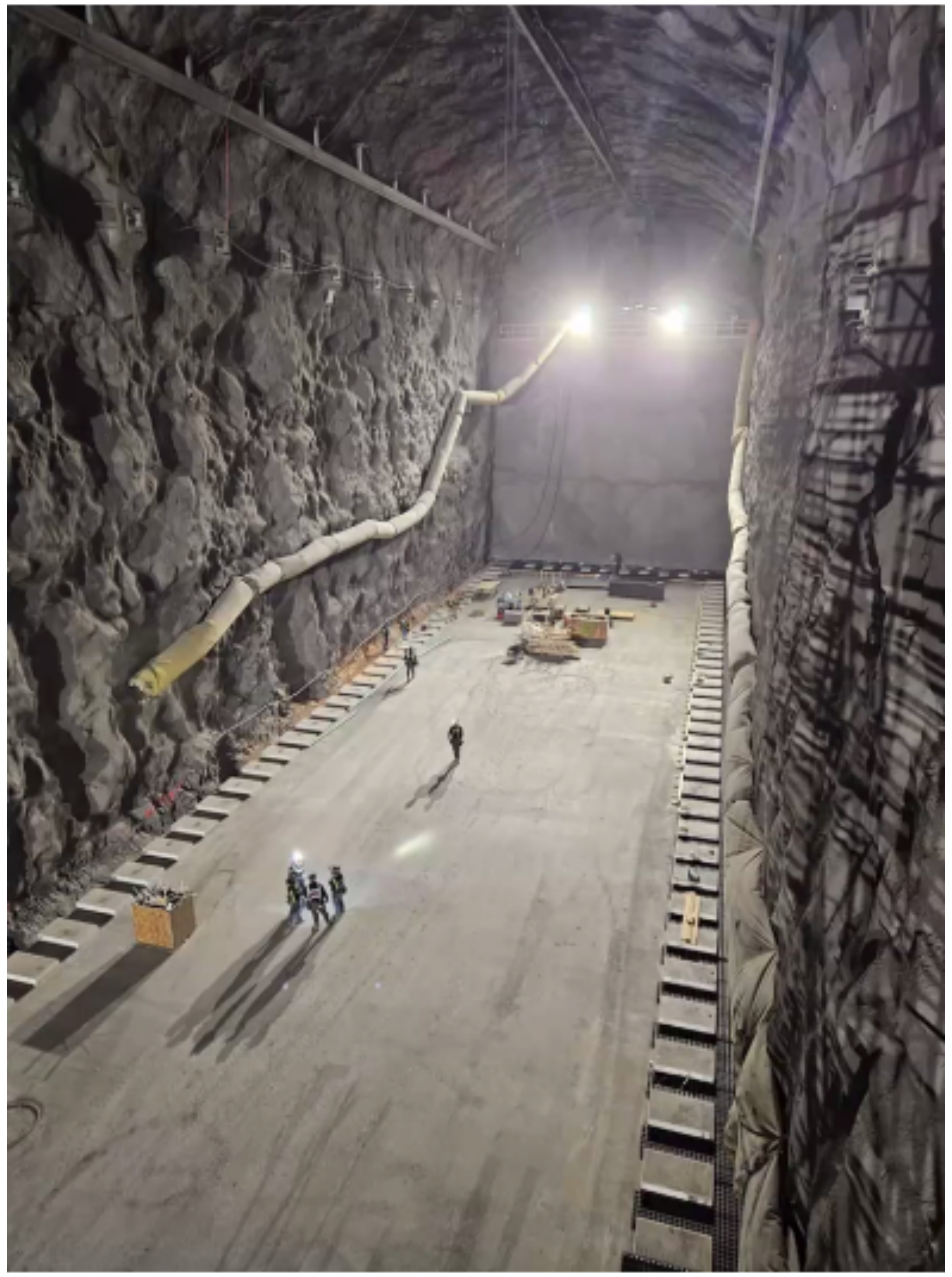
I.Context of DUNE

- DUNE is composed of three part : **Accelerator**, **Near Detector** and **Far Detector**
- Long baseline neutrino experiment → Oscillation oriented experiment
  - δ_{CP} , θ_{23} & θ_{13} measurements
  - **testing unity of PMNS matrix**
  - resolving **mass hierarchy**
  - BSM, atmospheric ν's, proton decay …

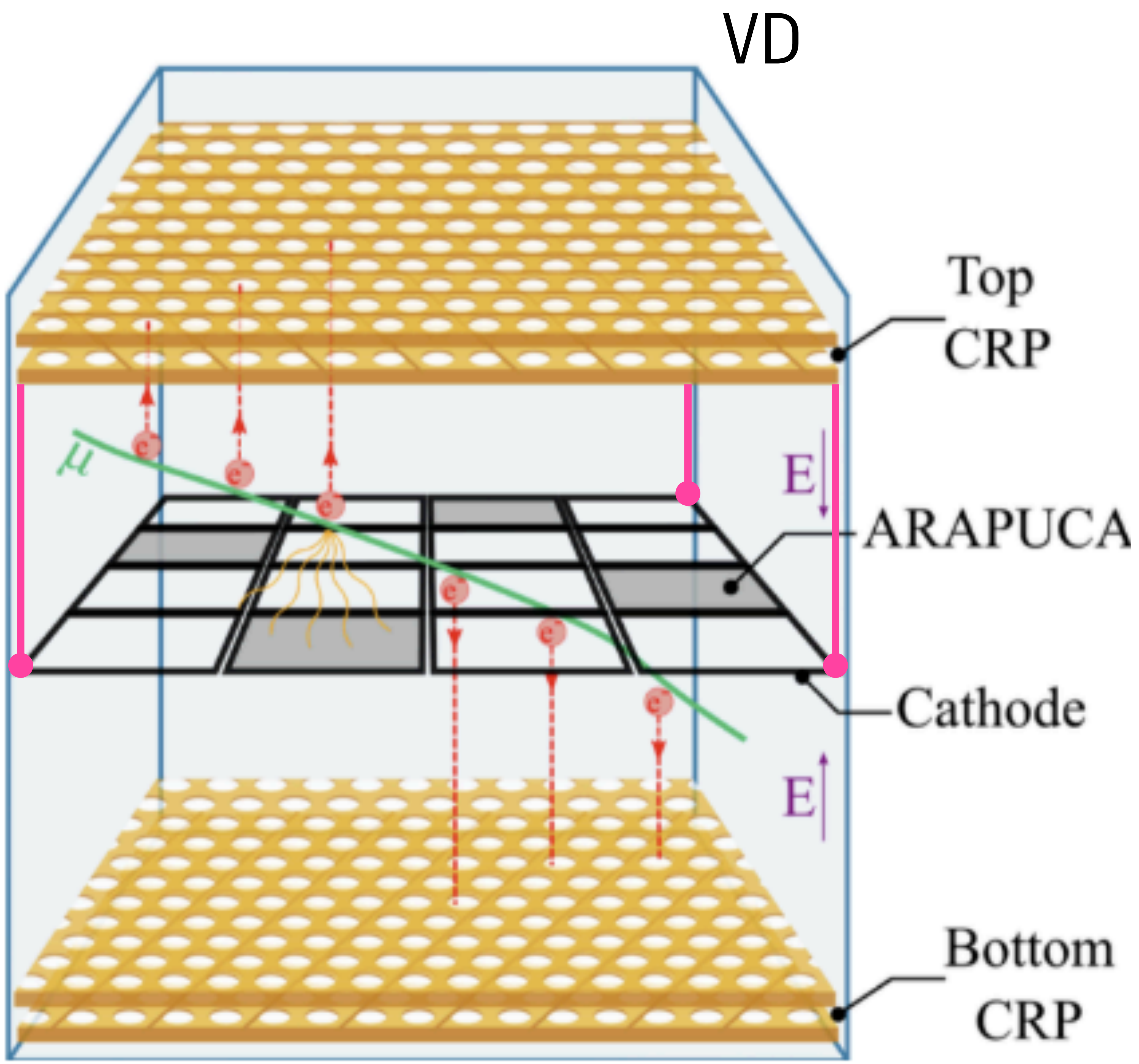
I.Context of DUNE

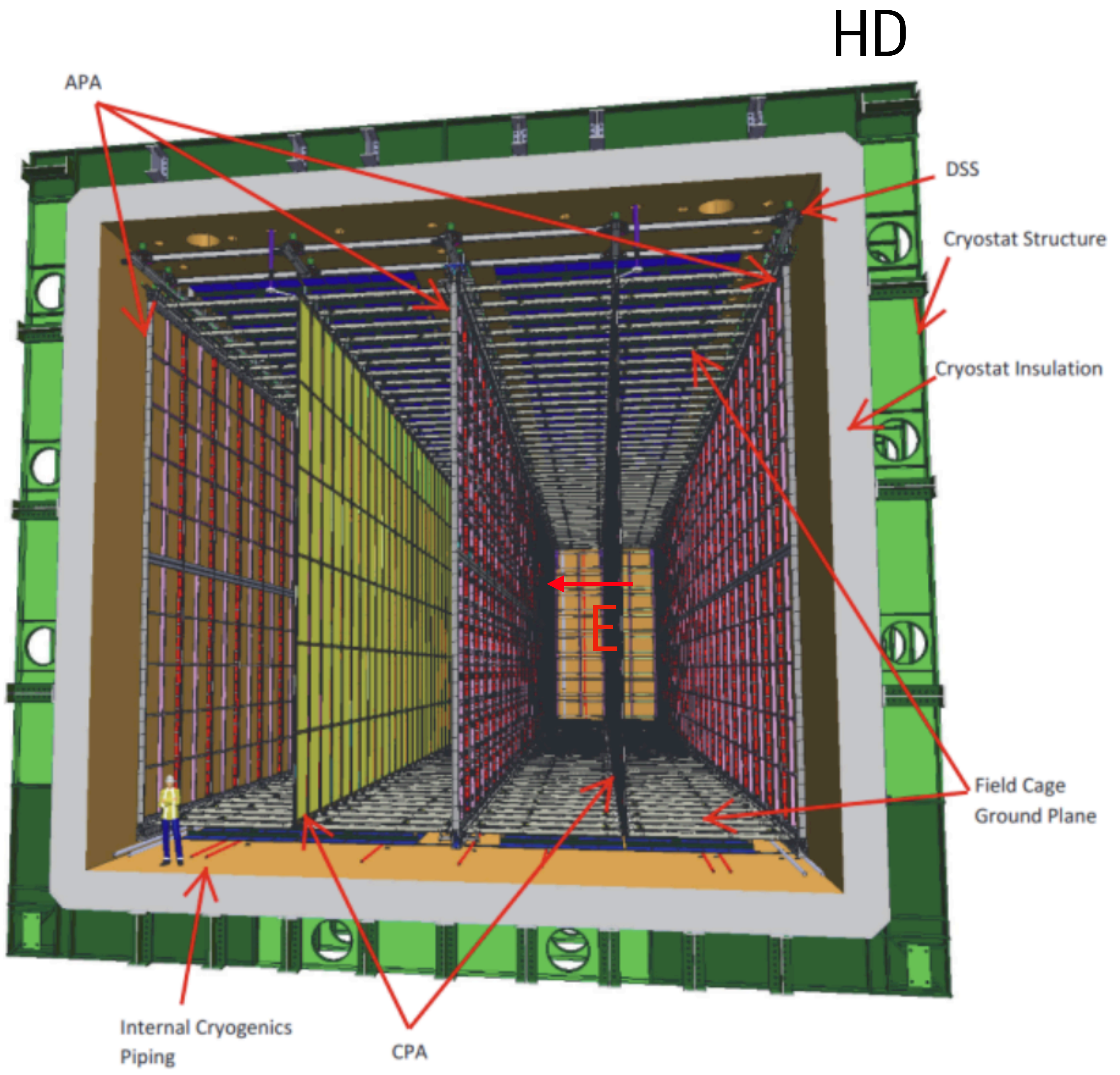
- **Far Detector** = 4 cryostats with **LArTPC based technologies** with dimensions 66m x 18m x 19m
    - Cryostats 1 & 3 → **Vertical Drift design**
    - Cryostat 2 → **Horizontal Drift design**
    - Cryostat 4 → to be defined





800 ktons of rock



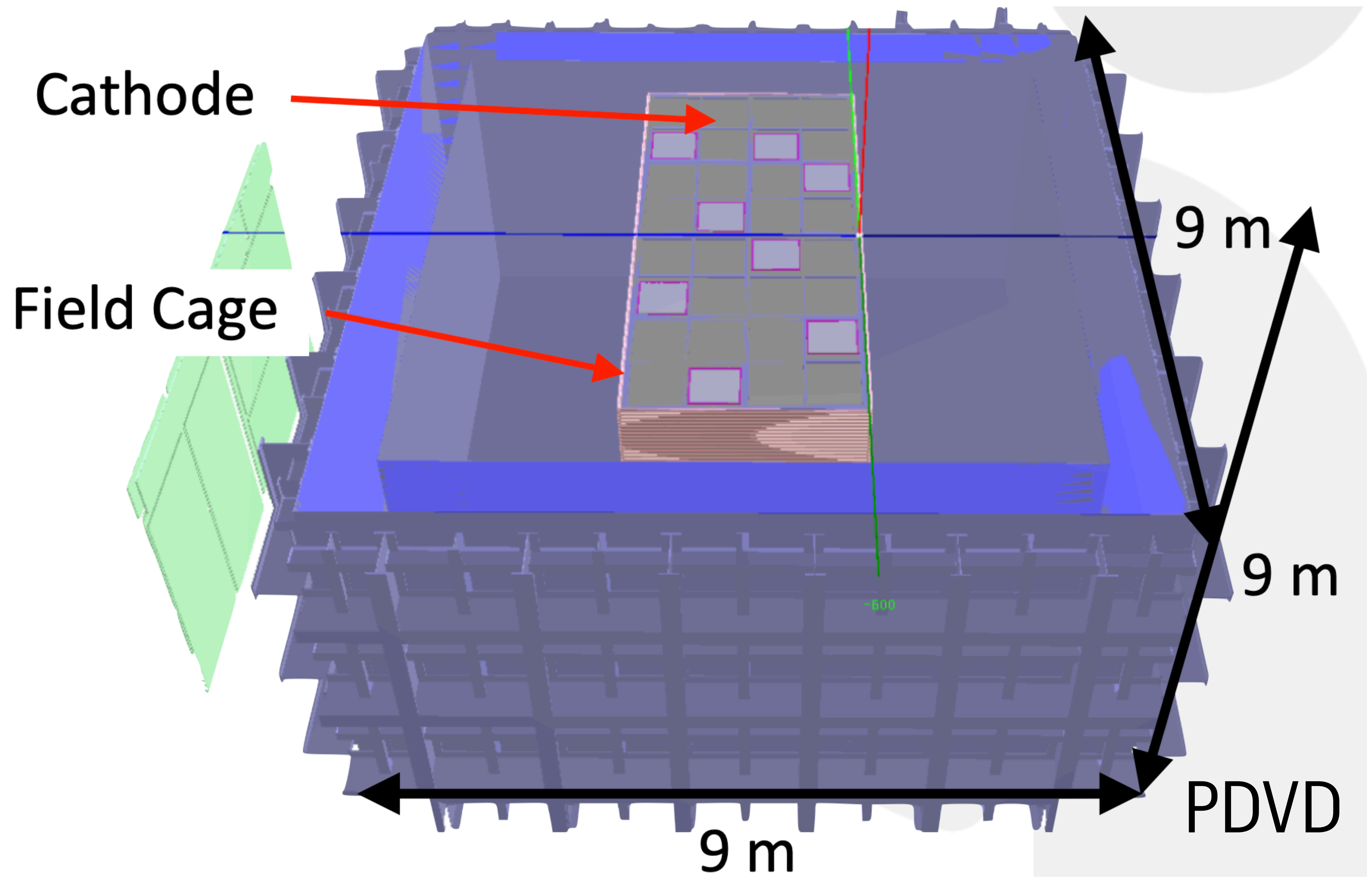


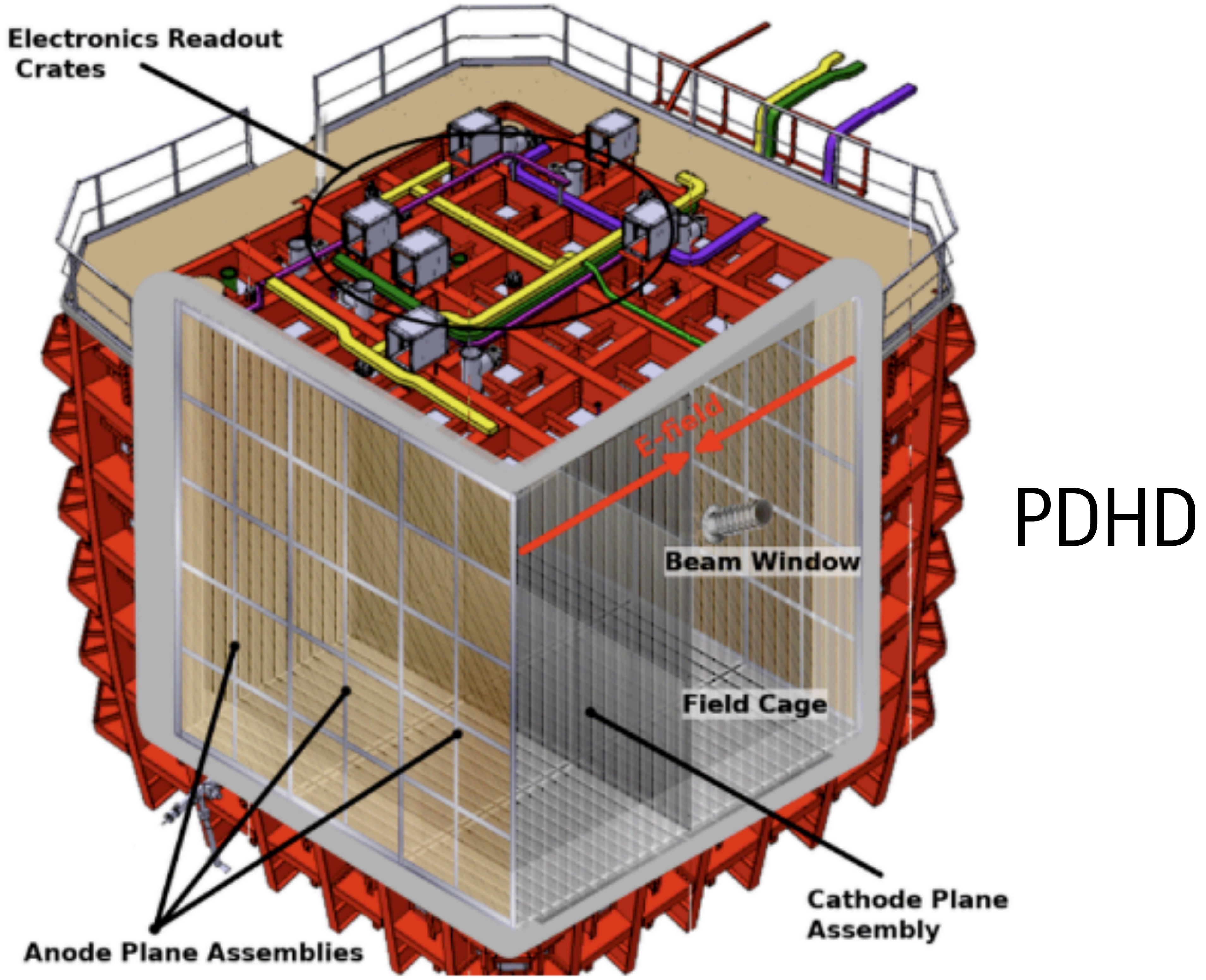
Other main topic of my thesis :
- characterisation of cables that lift the cathode

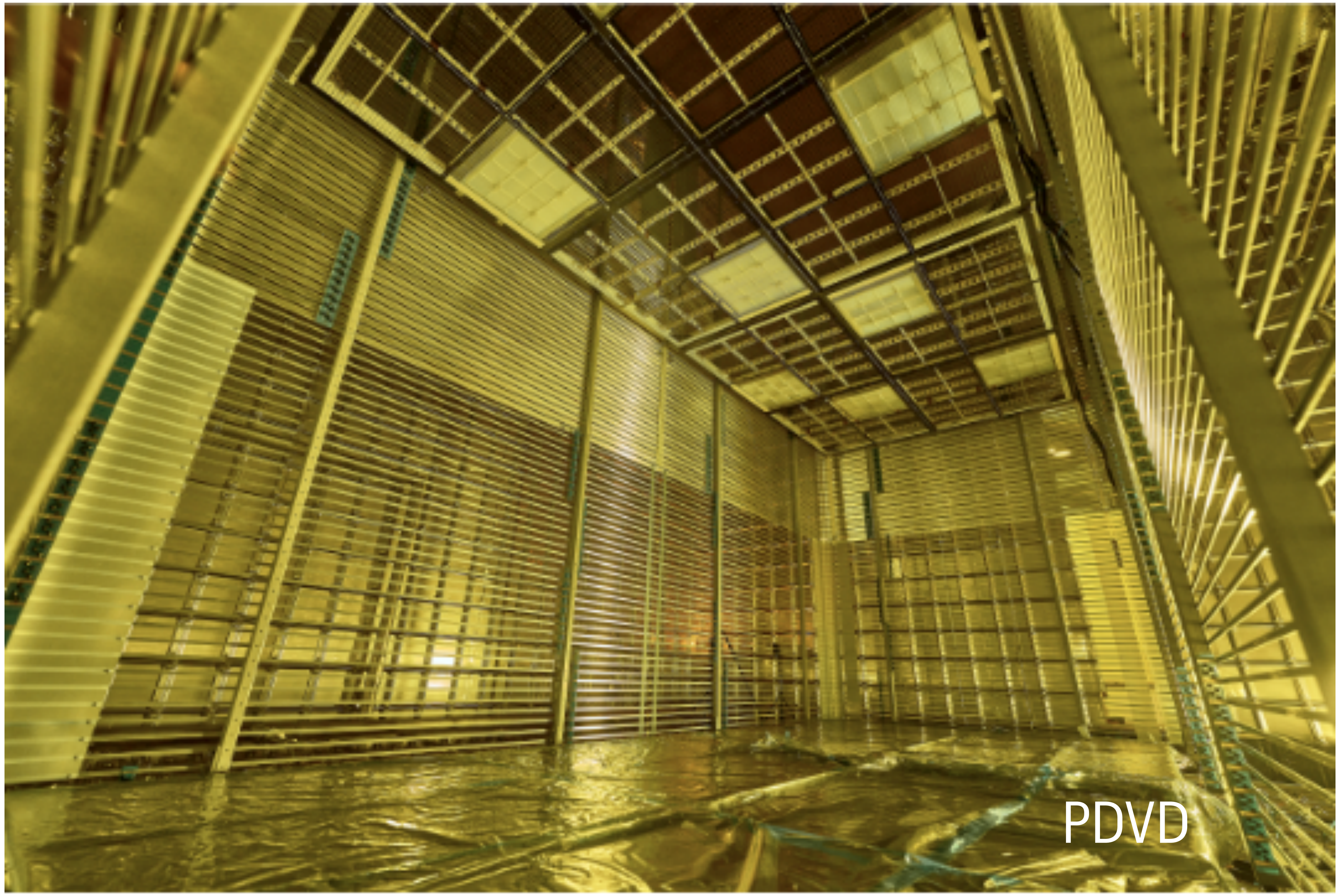
IJCLAB is producing the cathodes for VD

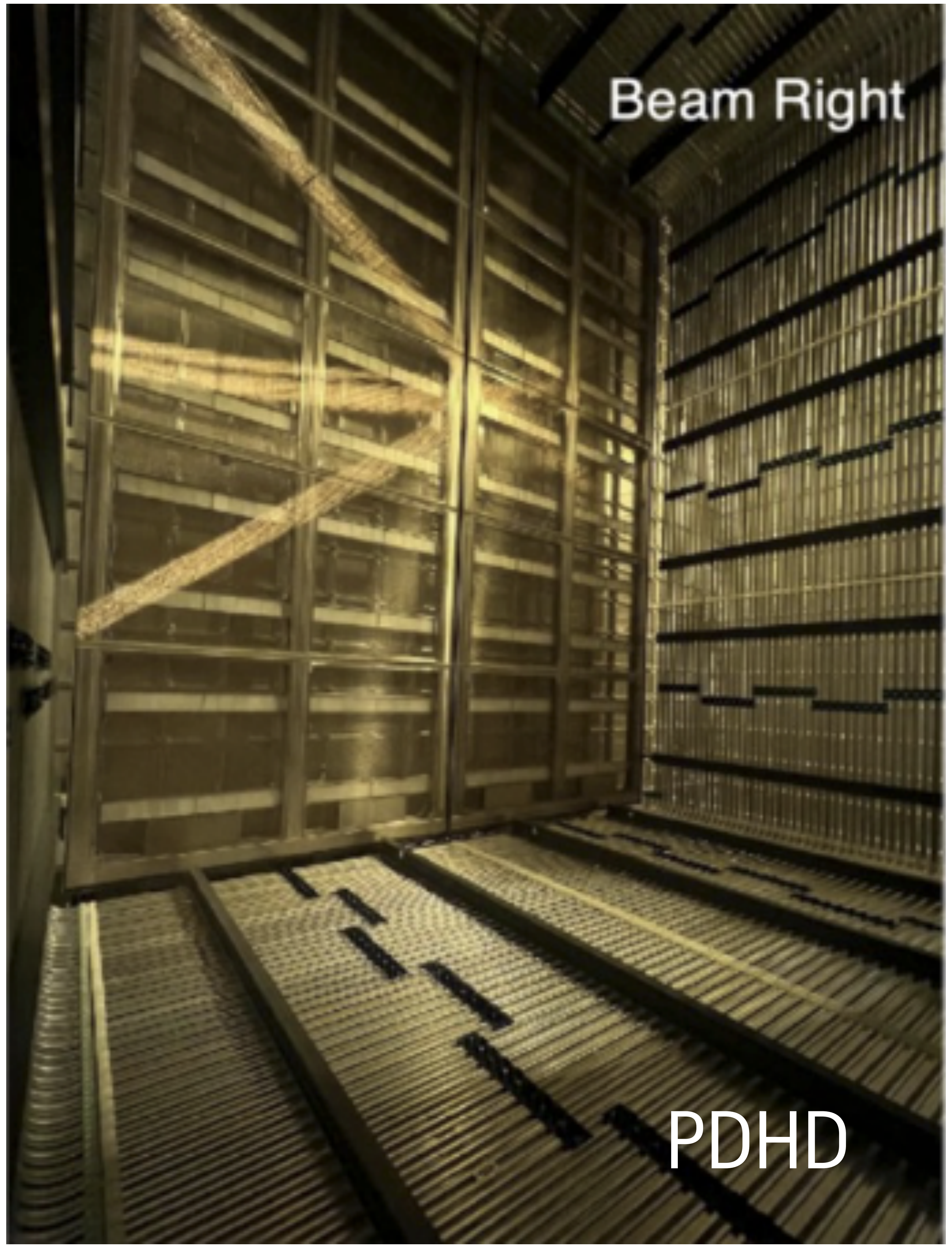
I.Context of DUNE

- 2 Prototypes @CERN on surface in 2 (9m x 9m x 9m) cryostats :
  - **ProtoDune Vertical Drift (PDVD)** → data taking in October
  - **ProtoDune Horizontal Drift (PDHD)** → data taking in May

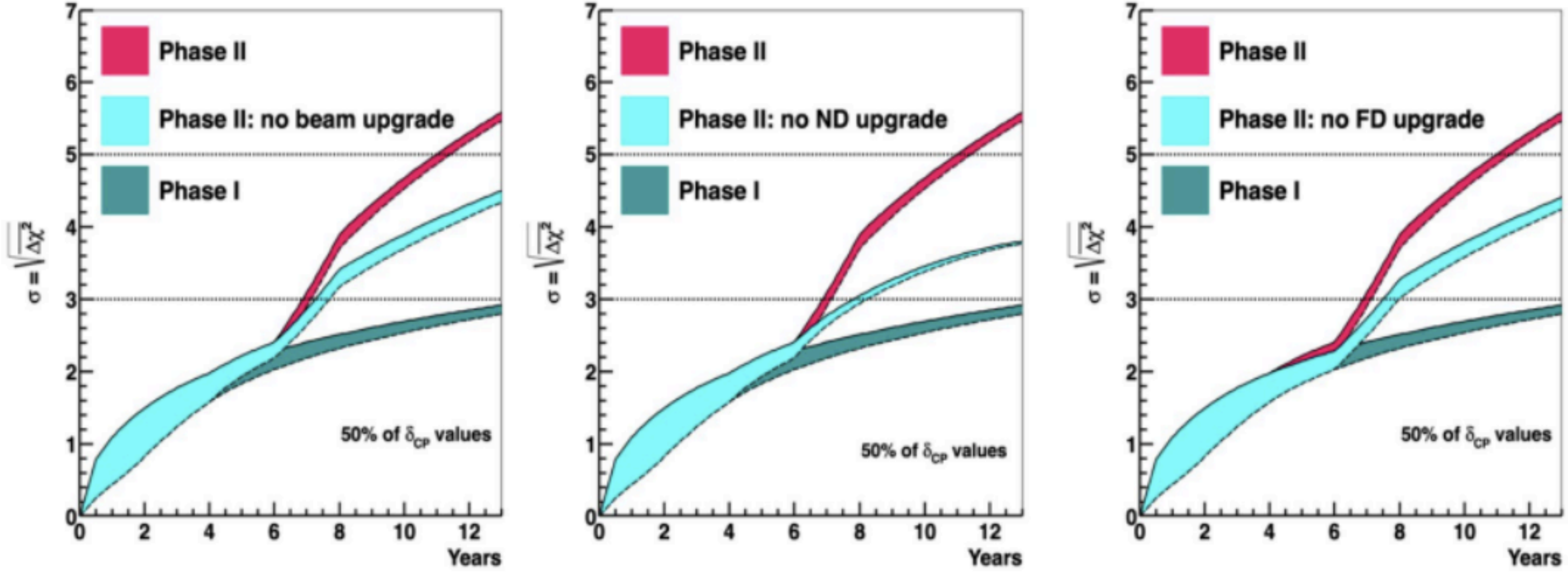





PDVD

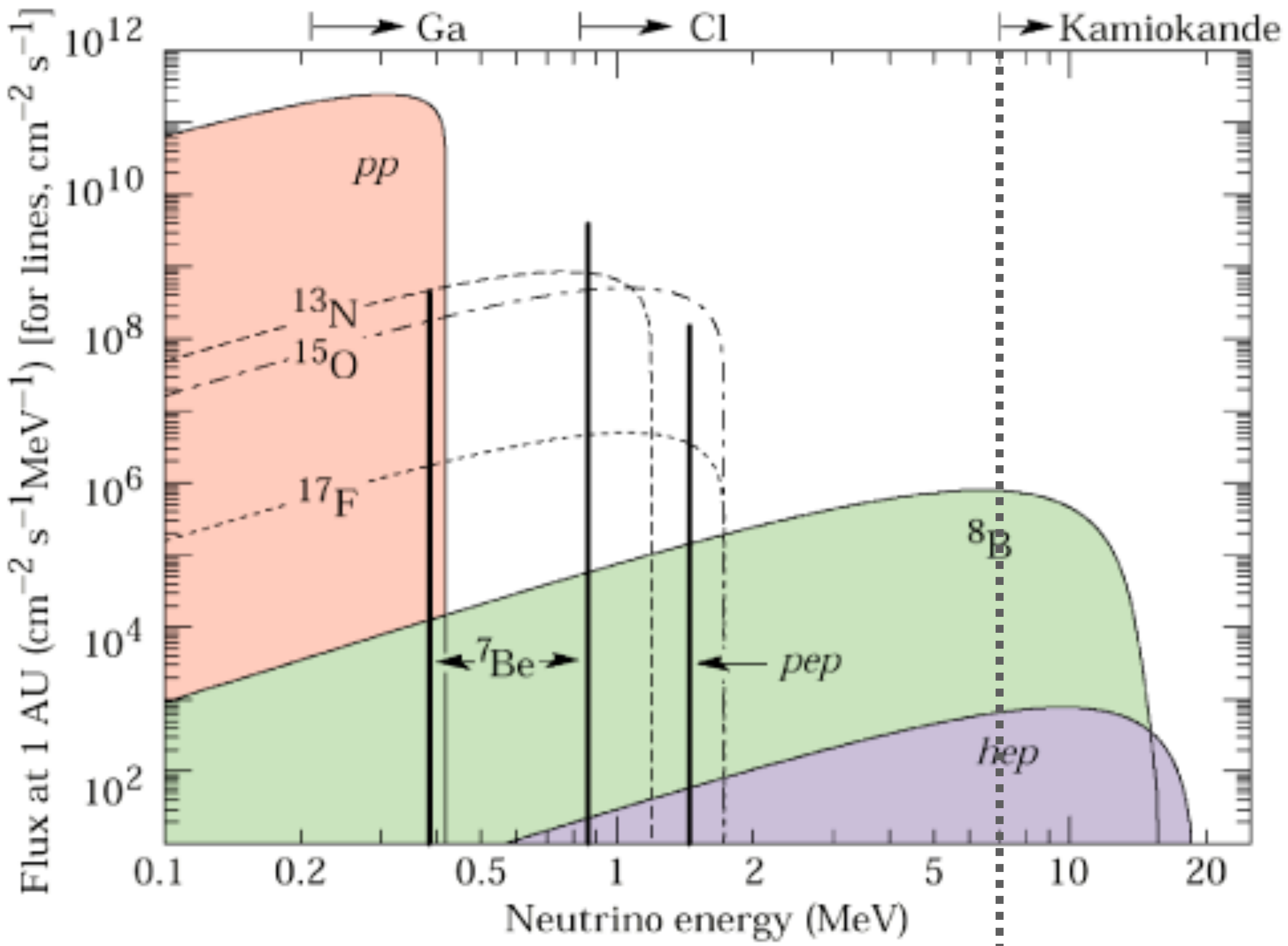

Beam Right
PDHD

- Will be last to operate (< 2MW)→ ~2031 while FD will be ready in 2029
- Need an update to reach **2.1 MW power**
- Oscillation studies will be limited by the beam power → **initial studies will focus on other physics topics**



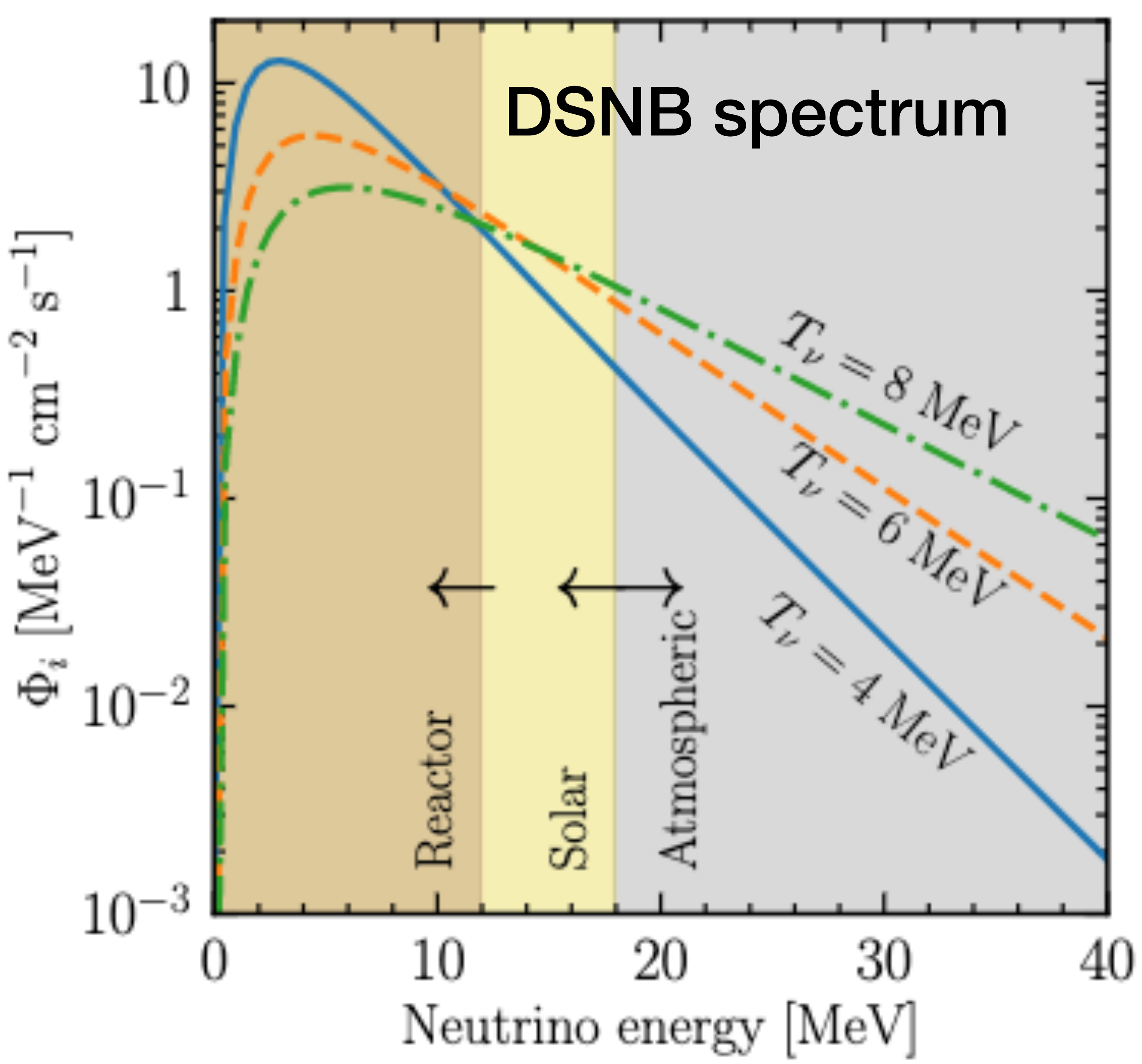
Low Energy at DUNE

- Solar neutrino's : may see **hep neutrino** for 1st time
- Supernovae :
  - **Supernovae burst**
  - Diffuse Supernovae Background (DSNB)



CC threshold for
$\nu_e + {}^{40}Ar \rightarrow {}^{40}K + e^-$

the energy spectrum of solar neutrinos.
Image reprinted from J. Bahcall, A.M. Serenelli, and S. Basu Ap. J. 621, L85 (2005)



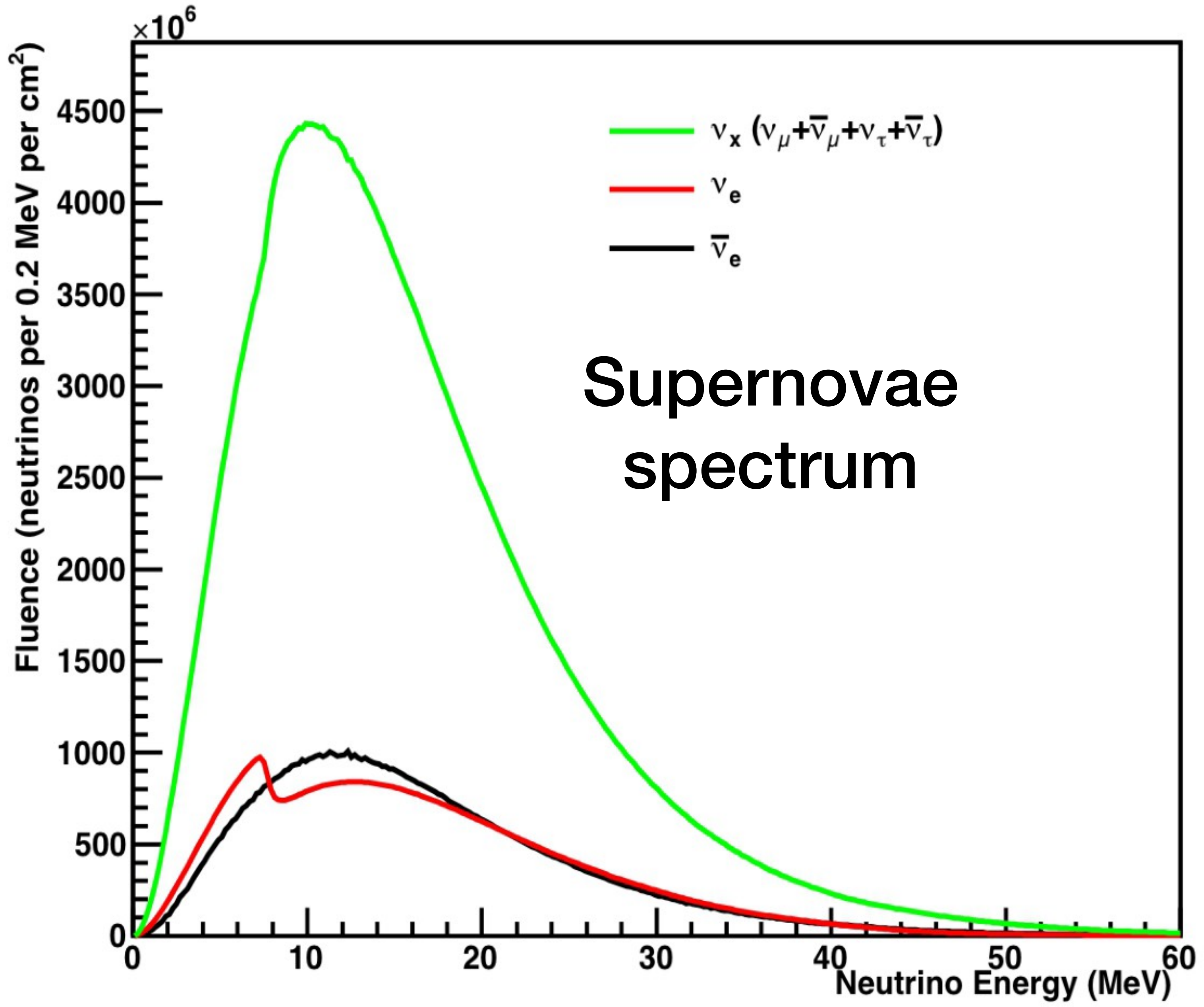
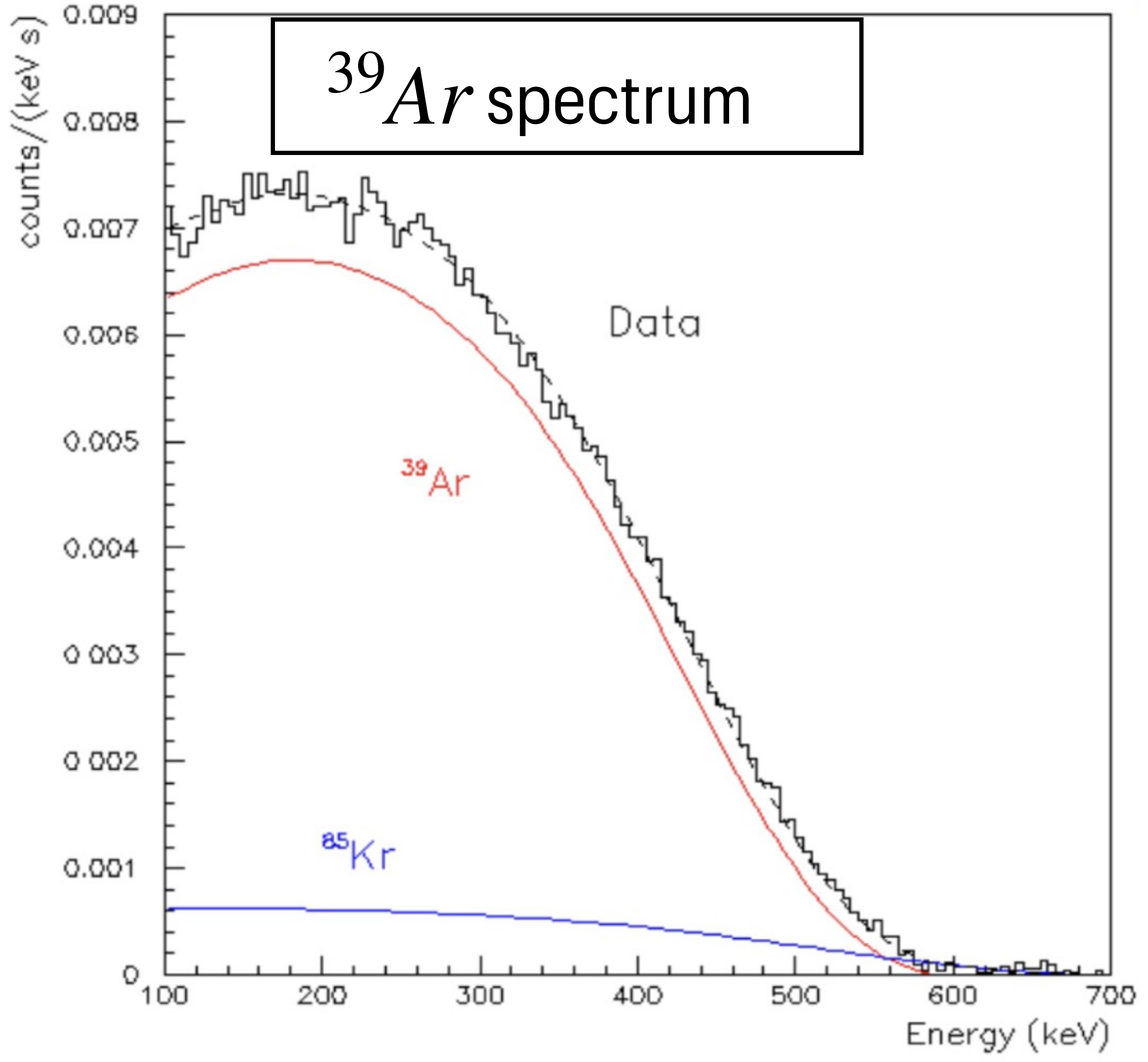


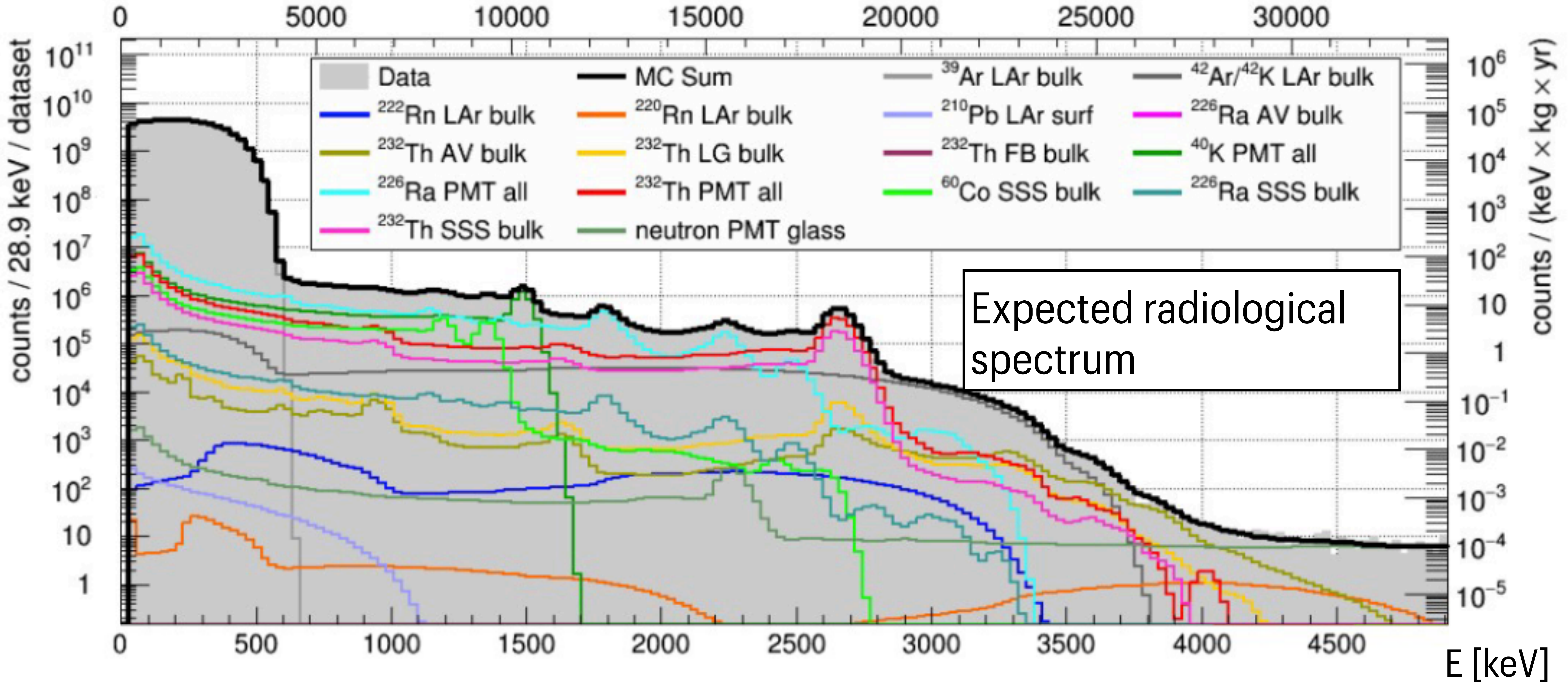
Figure from arXiv:1205.6003 [astro-ph.IM]

arXiv:2207.09632 [astro-ph.HE]

II. Low Energy at DUNE

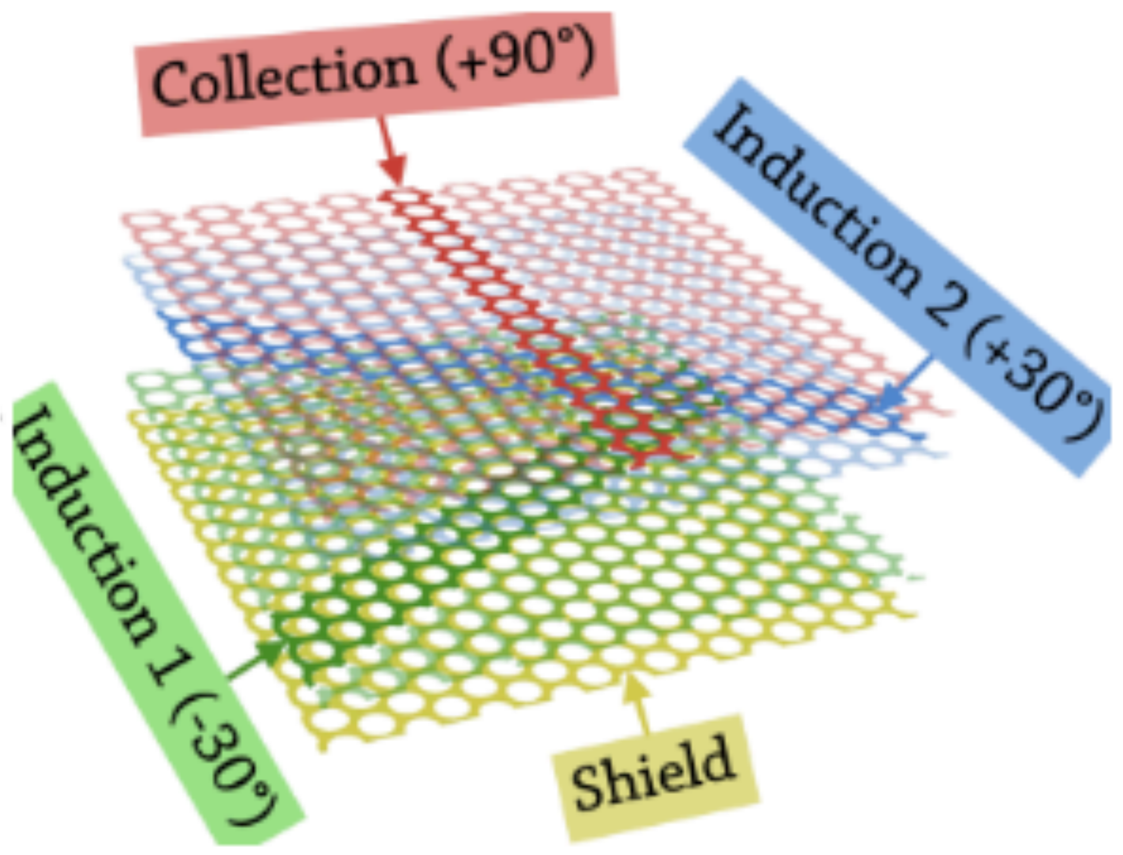
- **Cosmics** (suppressed a lot in FD)**/radiologicals** but important for prototypes (PD) @CERN
- Intern radioactivity, in LAr mainly ^{39}Ar
  - FD : ~10^7 decays/s
  - PD : ~10^5decays/s
- From detector components (cathode, photodetector …) mainly ^{42}K, ^{222}Rn chain and ^{238}U chain
- Radioactivity from the cavern rock (neutron…)
- **All these signals are point-like events**

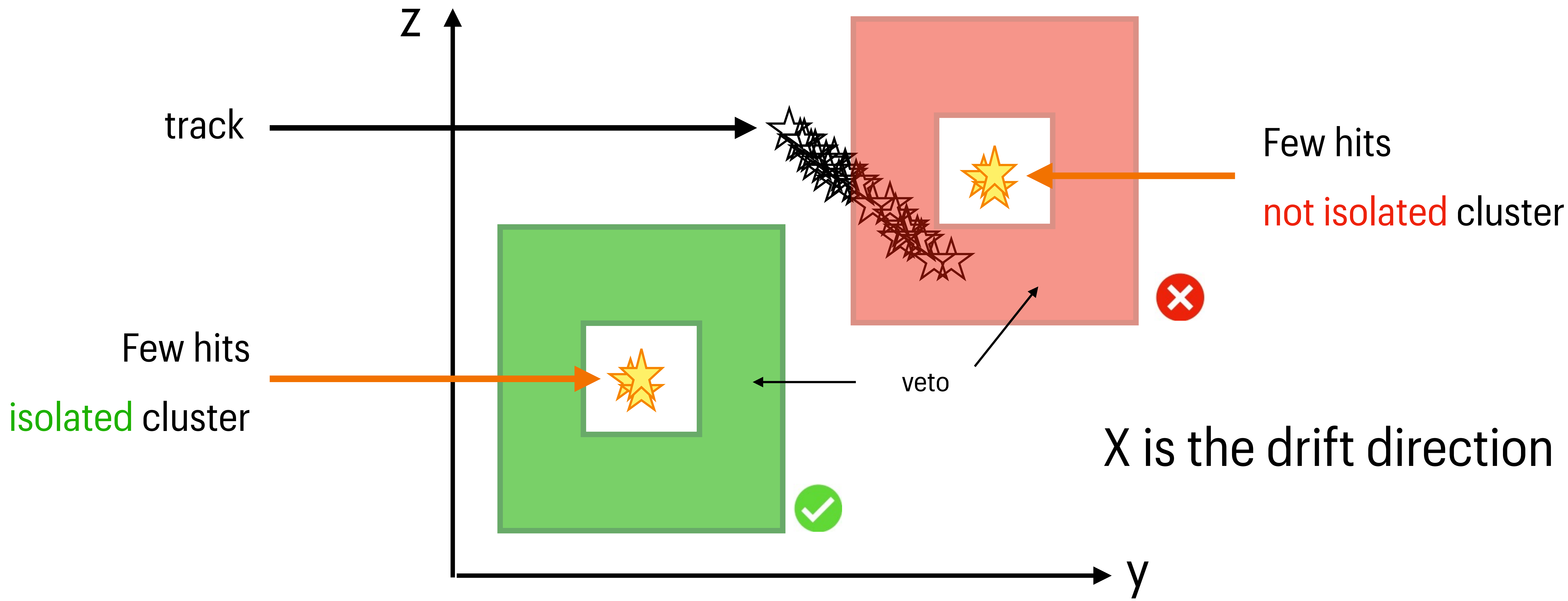




Background measurement with DEAP-3600 (3.3 tonne LAr dark matter detector at SNOLAB)

- My analysis → **Selecting this decays** (^{39}Ar, ^{42}K ...) to **calibrate the prototypes** and then to **estimate background in FD**
- Geometric selection : Low energy decays → **few hits isolated** clusters (size ~1 cm)
- Hits in coincidence (needs to be seen by 3 crossing wires) → noise rejection





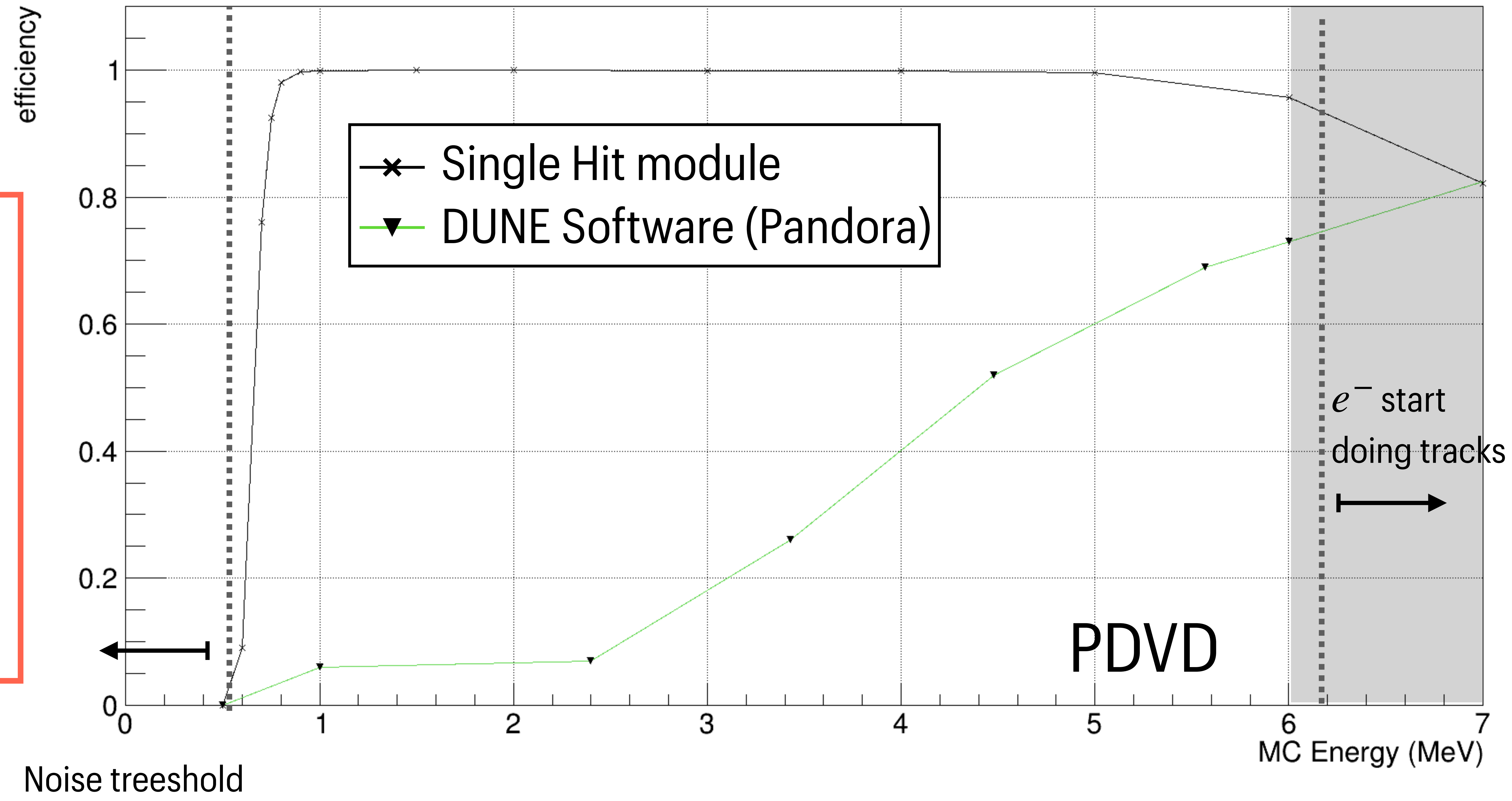
Results on ProtoDUNEs

- ~2500 e^- for a given energy E_{e^-} from 0.5 MeV to 10 MeV

$$\text{efficiency} = \frac{\sum^{N_{event}} \min(\ 1\ ,\ N_{cluster}\ )}{N_{event}}$$

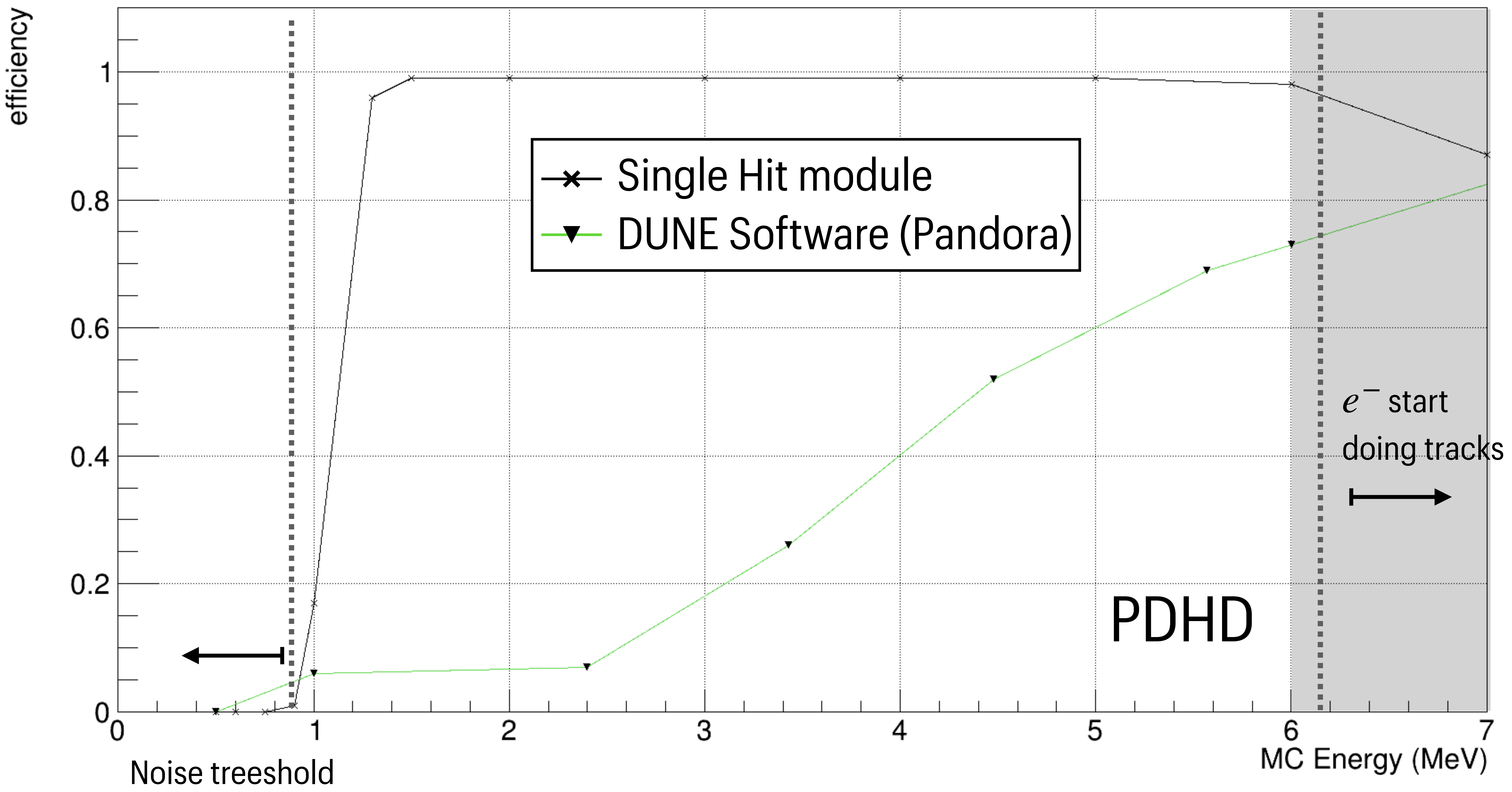
$N_{cluster} =$ Number of clusters with $(\ d < 25\text{ cm}\ )$

$d =$ distance to True MC position [cm]



- No hit reconstructed with $E_{e^-} \leq 600$ keV
- Reconstruct 99% of e^- if. 800 keV $\leq E_{e^-} \leq 5$ MeV

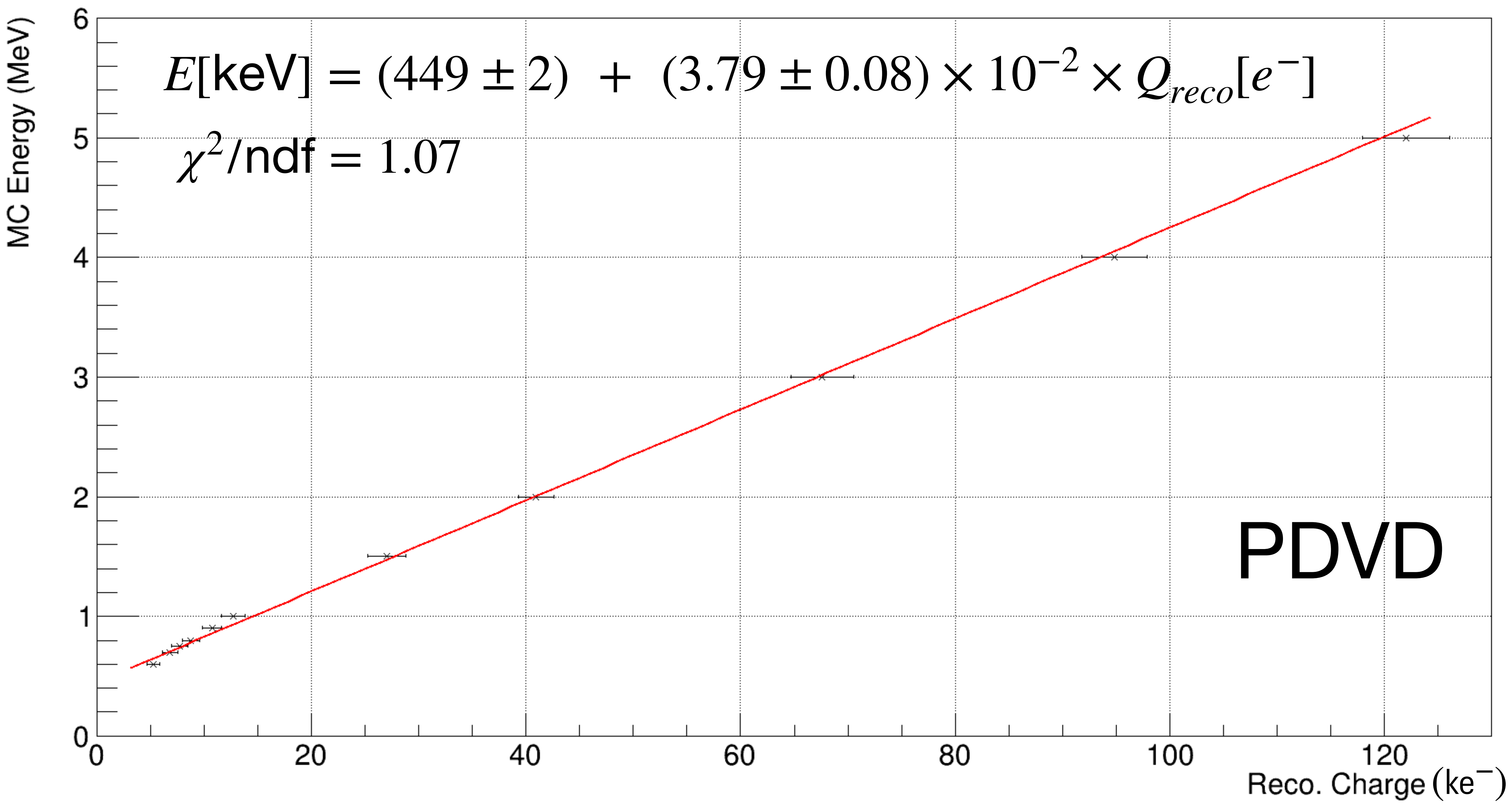
- No hit reconstructed with $E_{e^-} \leq 800$ keV
- Reconstruct 99% of e^- if. 1.3 MeV $\leq E_{e^-} \leq 5$ MeV

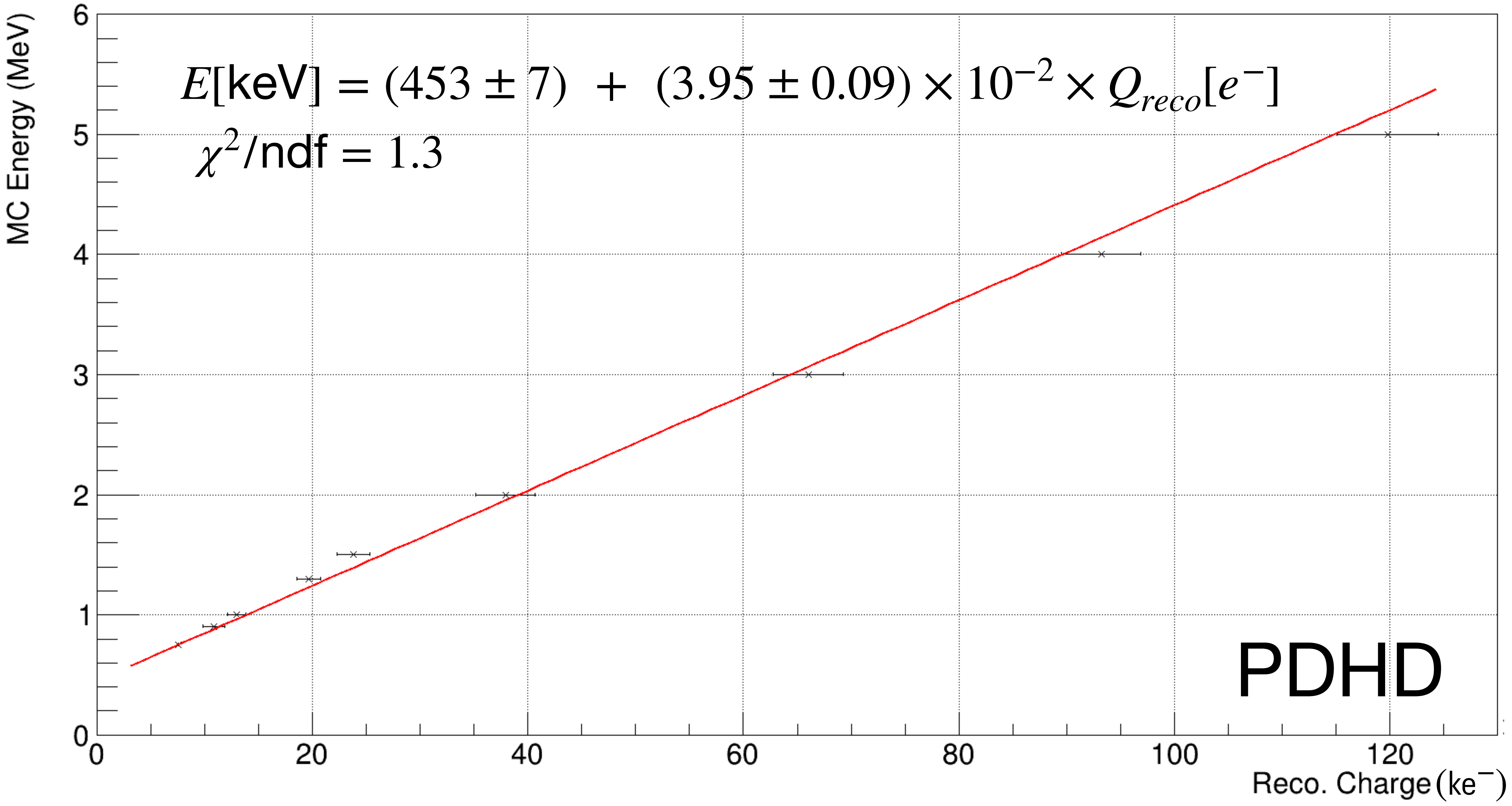


III. Results on ProtoDUNEs

- Calibration constant are compatible within the statistical errors
- understand offset ? Artefact from noise ?
- **Compatible at higher energy** (10 % error) :

$$N_{e^-}^{th}(1\,\text{GeV}) = 29.6 \times 10^6 \approx 26.3 \times 10^6 = N_{e^-}^{calib}(1\,\text{GeV})$$





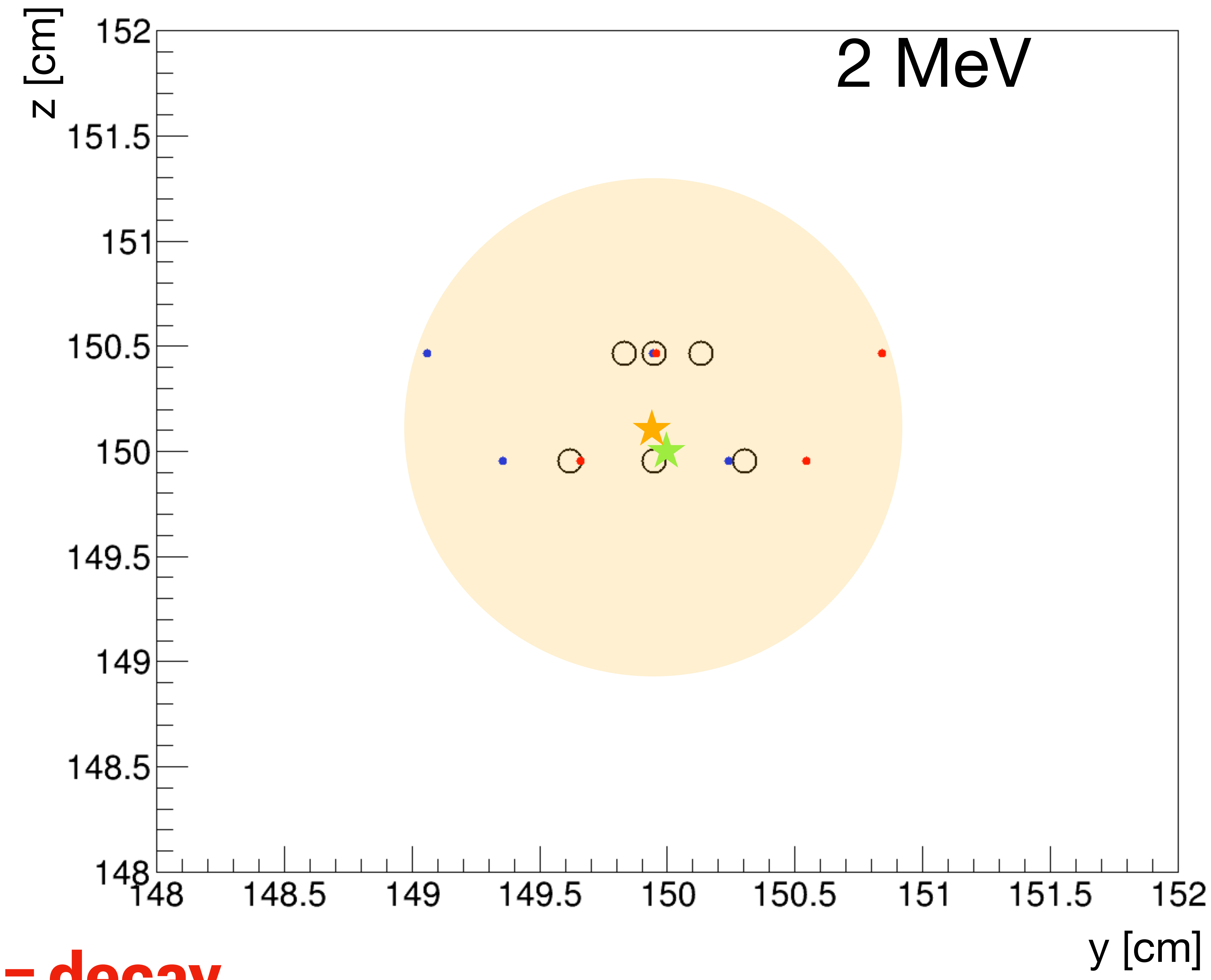
Conclusion

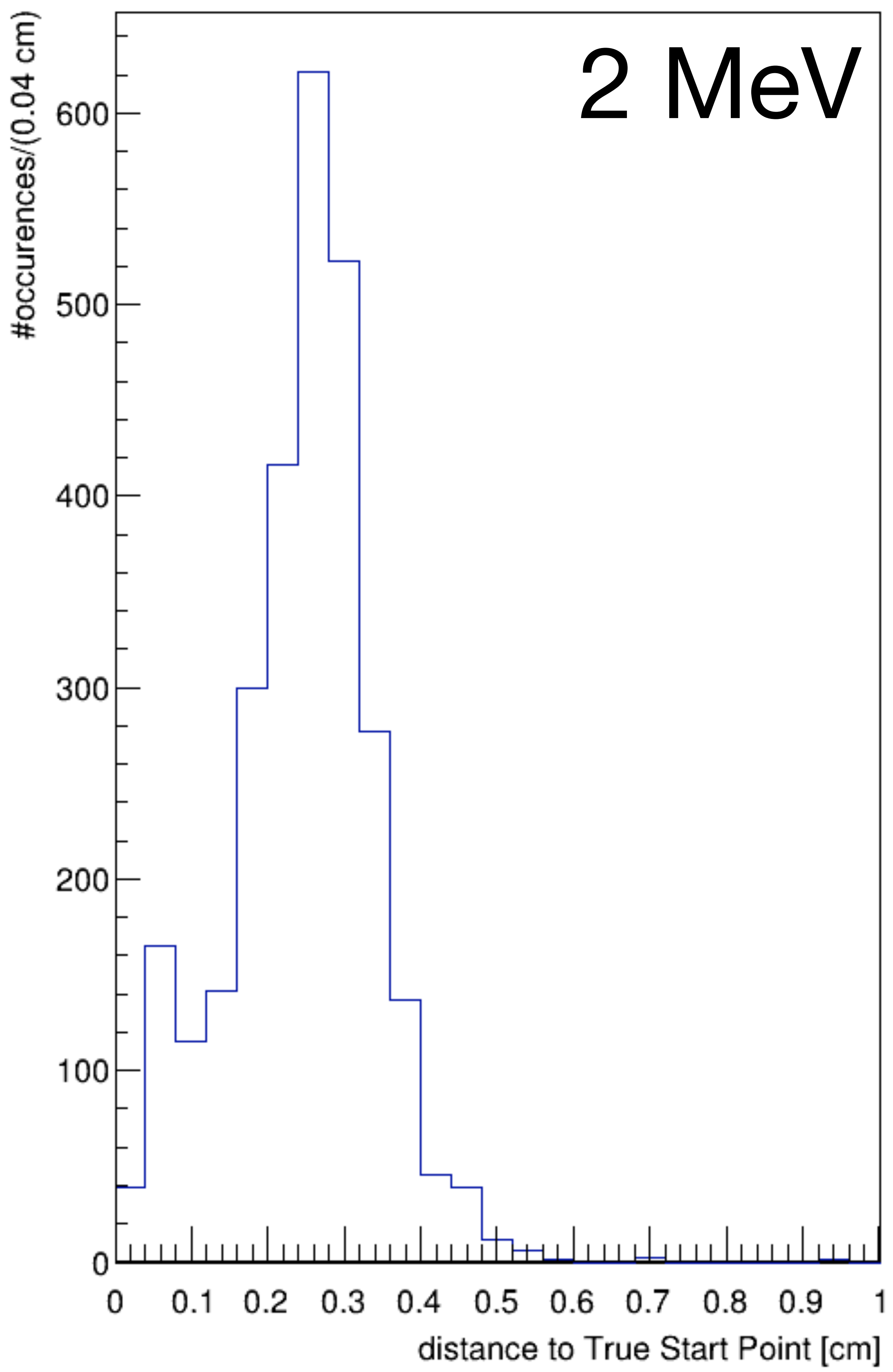
- Identification efficiency on PDVD/HD simulation : **~99% of e- in the 1-5 MeV region**
- **Capable of calibrating** both detectors at low energy
- Sharp threshold (limited by HitFinder)
- Calibration constant are compatible within the statistical errors (understand offset ? Artefact from noise ?)
- Next :
  - Apply the analysis on PDHD data in the coming months
  - Look at more realistic simulation with continuous spectrum (radiologicals + cosmics) and CALCI systems (PNS and laser data)
  - Simulation with different noise levels

Annexe

I. SingleHit module

- ★ True Start Point (Gen)
- ● Ind1/Col. Intersection
- ● Ind2/Col. Intersection
- ○ SingleHit SpacePoint
- ★ Reco. Cluster (SingleHit)





- Goal → **1 cluster = decay**
- **Cluster position is a barycentre of SpacePoint (with collection energy)**
- Spatial resolution for PDVD/HD : $R_s \lesssim 1\text{cm}$

I. DUNE's context

- **Near Detector** (ND) measurements shall be of sufficient precision to ensure that when extrapolated **to predict the FD event spectra**, the associated systematic error must not dominate the measurement precision