Low Energy Calibration in DUNE's Far Detector prototypes

Emile Lavaut on behalf of the DUNE collaboration

Context of DUNE

- DUNE is composed of three parts : **Accelerator**, **Near Detector** and **Far Detector**
- **Low Energy (LE) Neutrino Physics (~few MeV) :** Solar neutrino, Supernova, Diffuse Supernova Background
- For **LE** the **Far Detector** is very well suited:
  - Huge volume (4 modules of 17 kt of Liquid Argon each): good statistics
  - Underground: good cosmics suppression
  - Spatial and angular resolution (Supernova Pointing)

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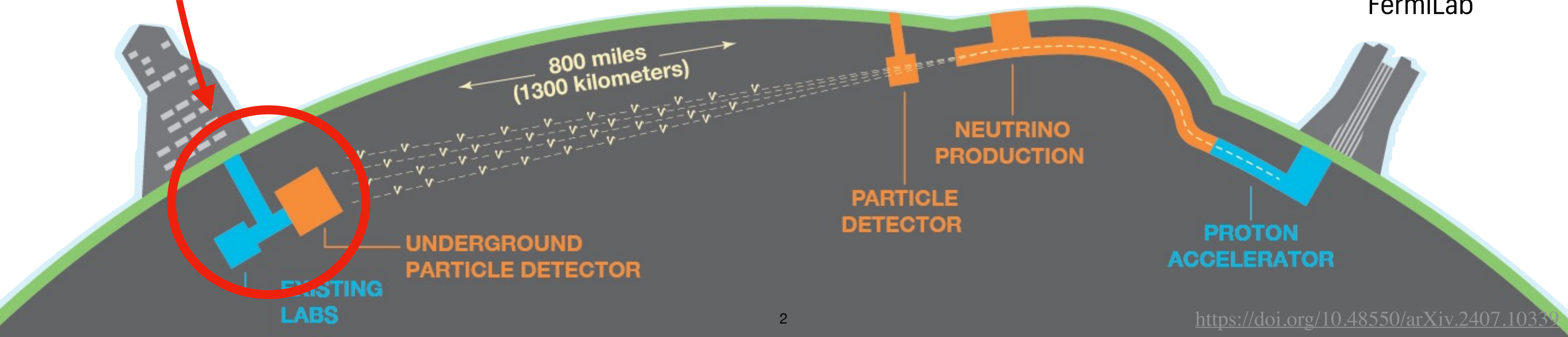
FermiLab

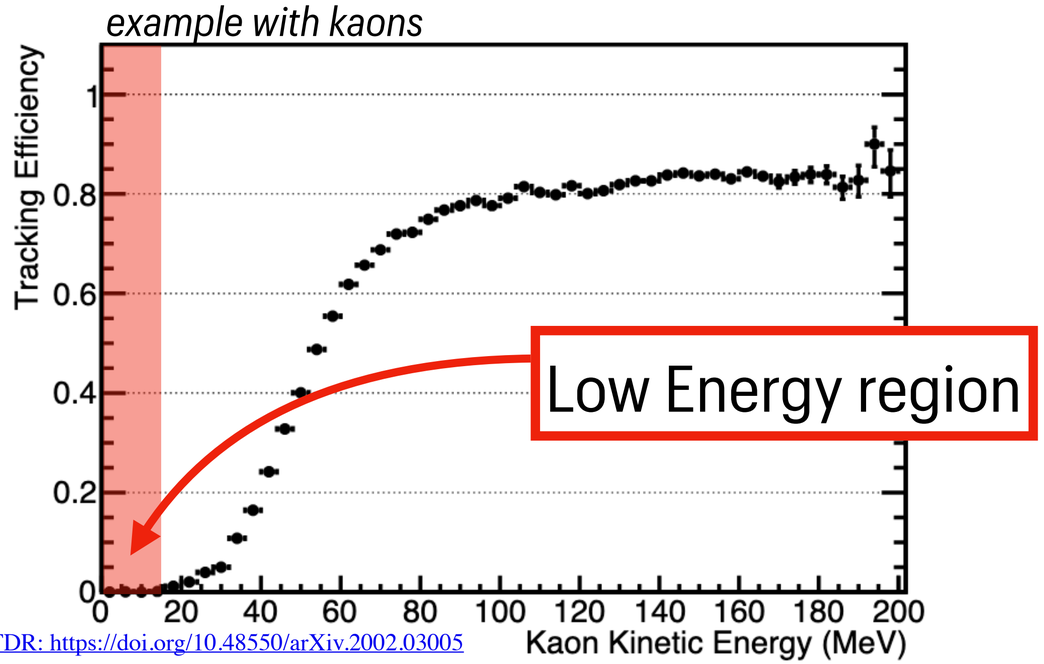


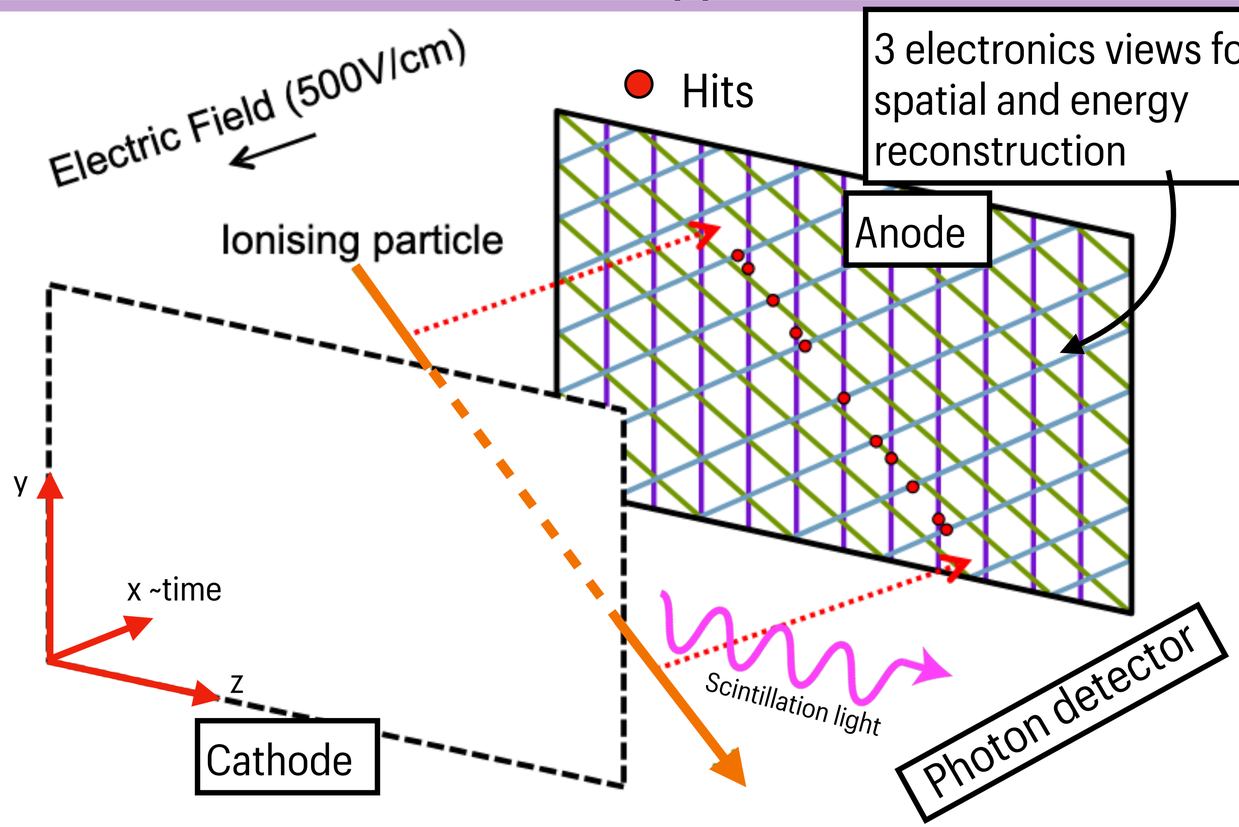
https://doi.org/10.48550/arXiv.2407.10339

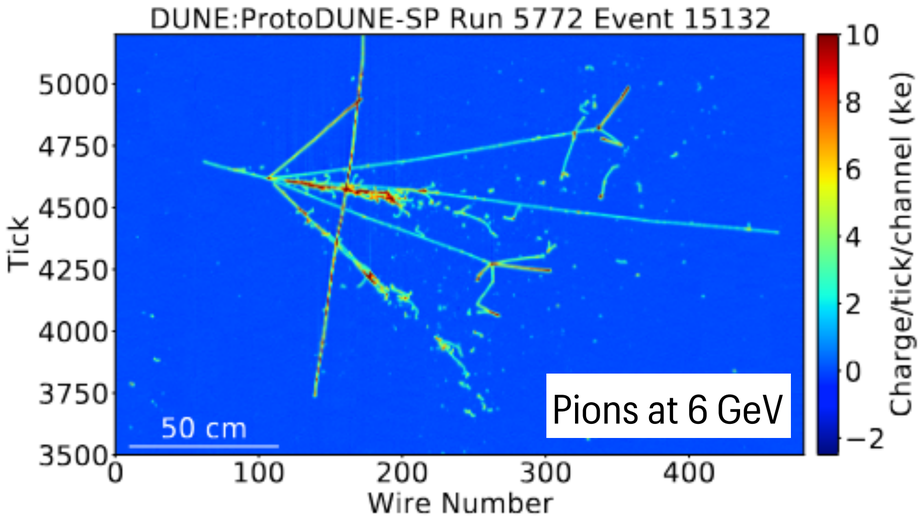
Context of DUNE

DUNE's Prototypes: the ProtoDUNE's

- Far Detector: **Liquid Argon TPC**
- **Default reconstruction/PID (Particle Identification) suboptimal for MeV signals**
- 2 Prototypes currently @CERN **on surface**: ProtoDUNE Vertical Drift (PDVD) and ProtoDUNE Horizontal Drift **(PDHD)**
- **PDHD took data from May to October 2024**





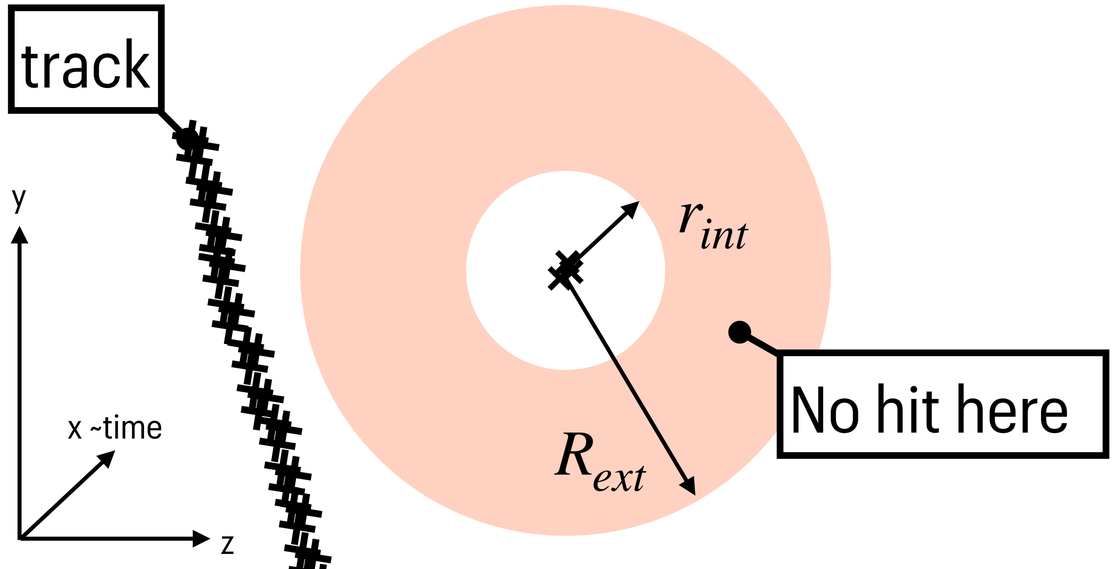


DUNE TDR: https://doi.org/10.48550/arXiv.2002.03005

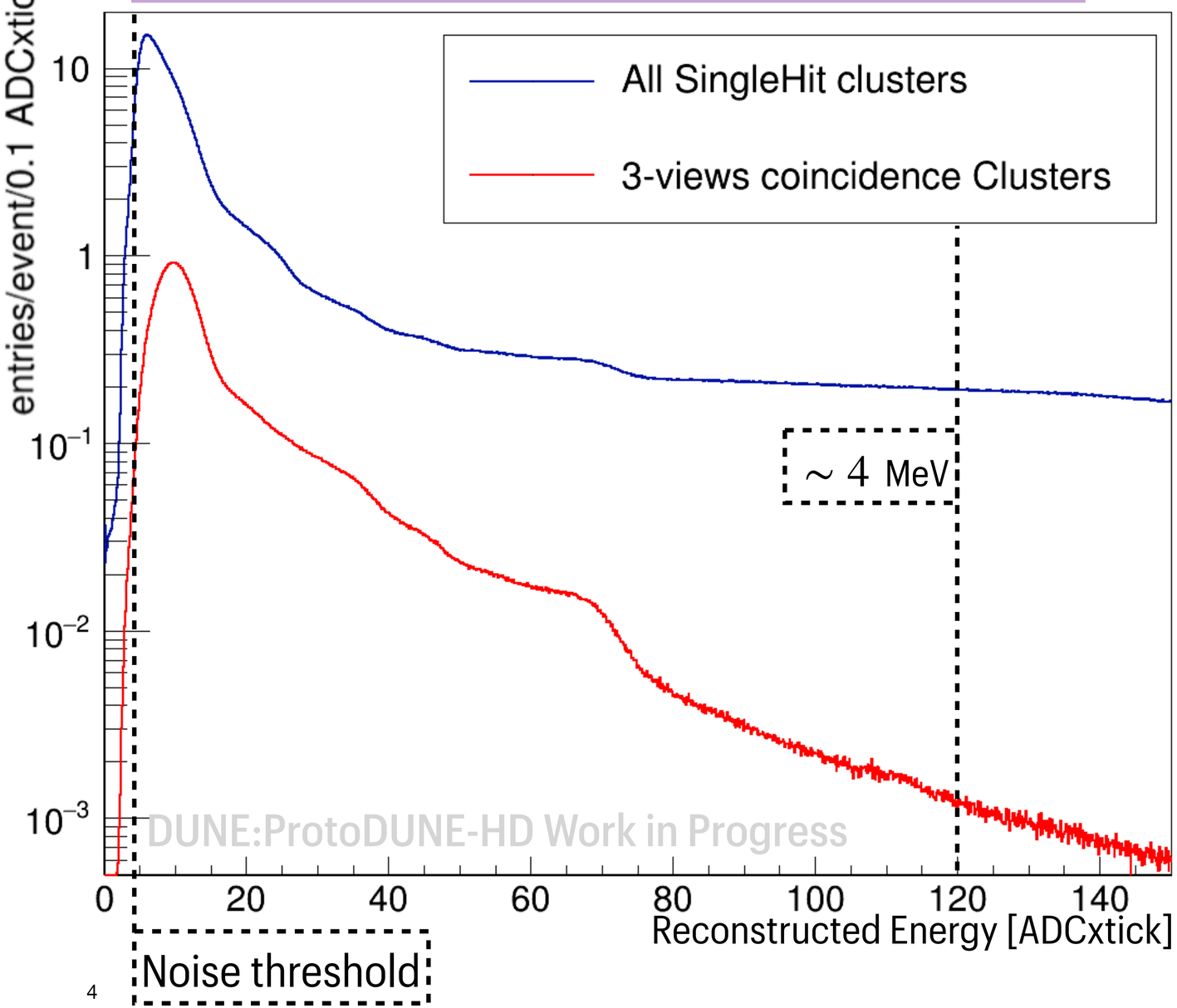
ProtoDUNE-HD calibration

Few MeV SingleHit spectrum

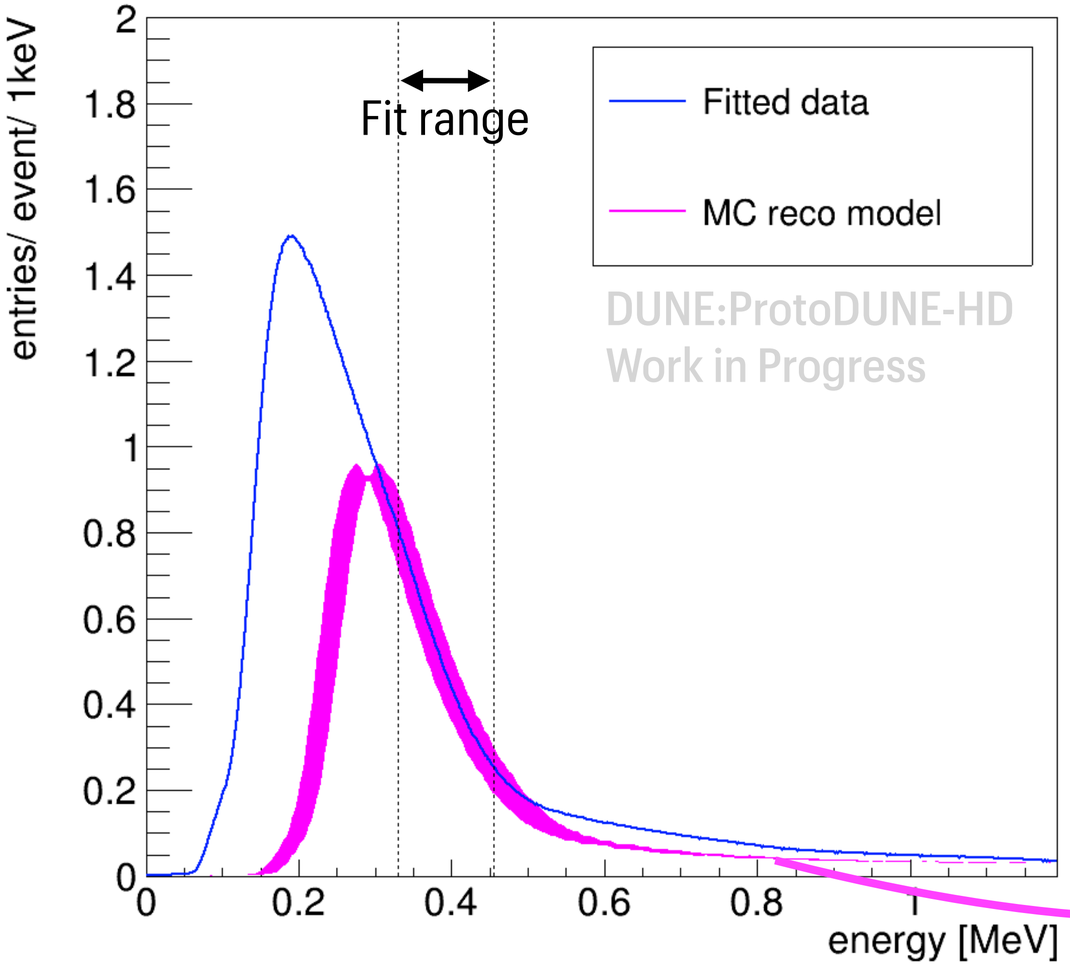
- Use radiologicals for calibration:
  - $^{39}\mathrm{Ar}$ in volume
  - Natural contribution from detector components ($^{232}\mathrm{Th}$,$^{238}\mathrm{U}$ chains)
  - additional $^{207}\mathrm{Bi}$ source
- Made a **dedicated analysis tool** to reconstruct **isolated hits** position and energy and make **LE clusters**



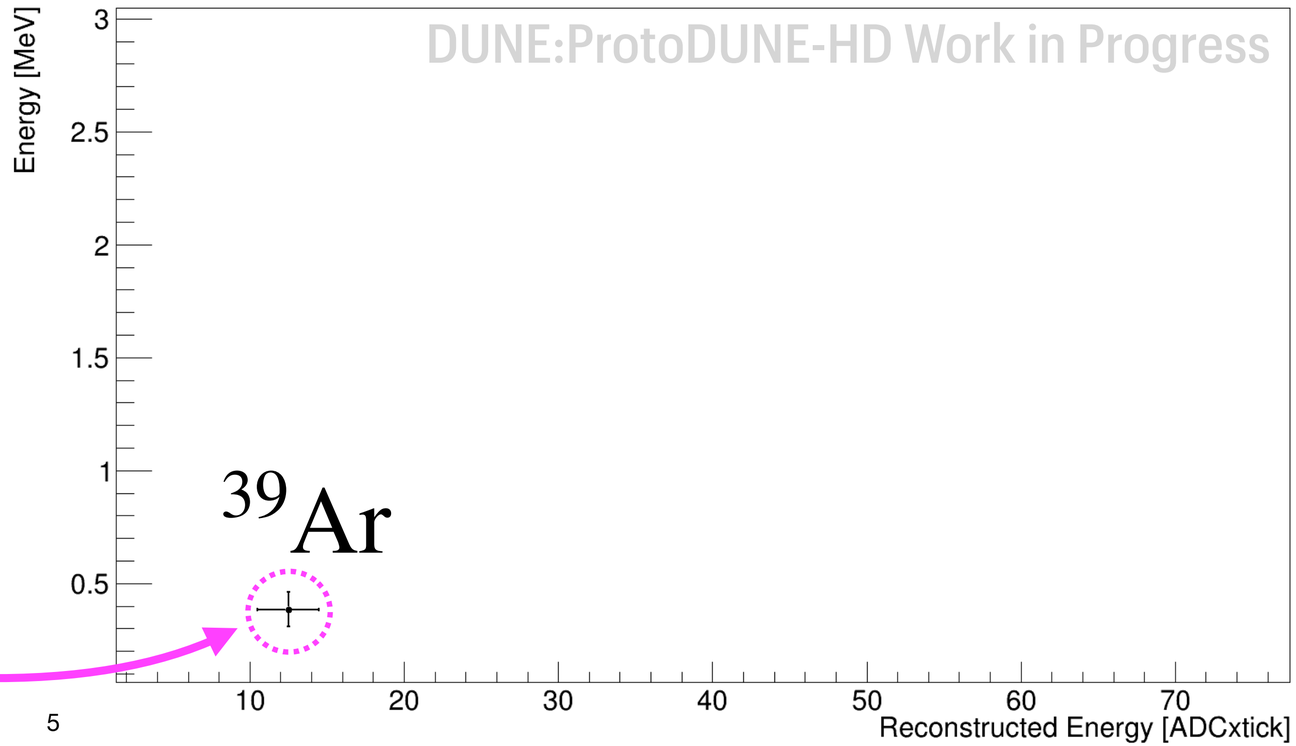
Challenging because signal near noise level



- **Identification of the peak as ^{39}Ar**
- **Official DUNE Monte Carlo**: cosmics + ^{39}Ar + 1 GeV electron beam + ^{85}Kr + ^{222}Rn
- Fit ^{39}Ar end of spectrum region → [10.5 , 14.5] ADCxticks



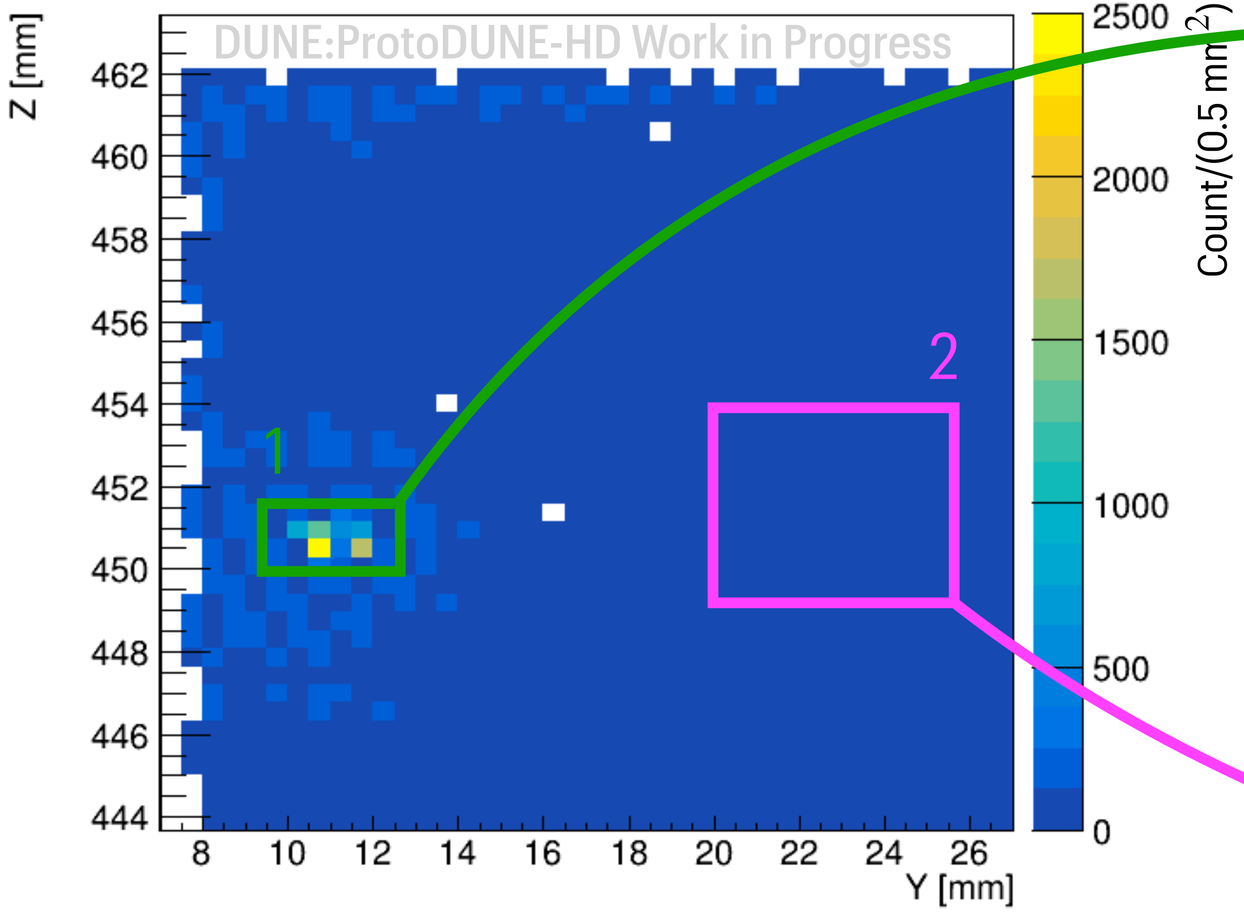
- c_A is the fitted calibration factor in MeV/ADC/ticks
- we find $c_A = 0.031 \pm 0.001$



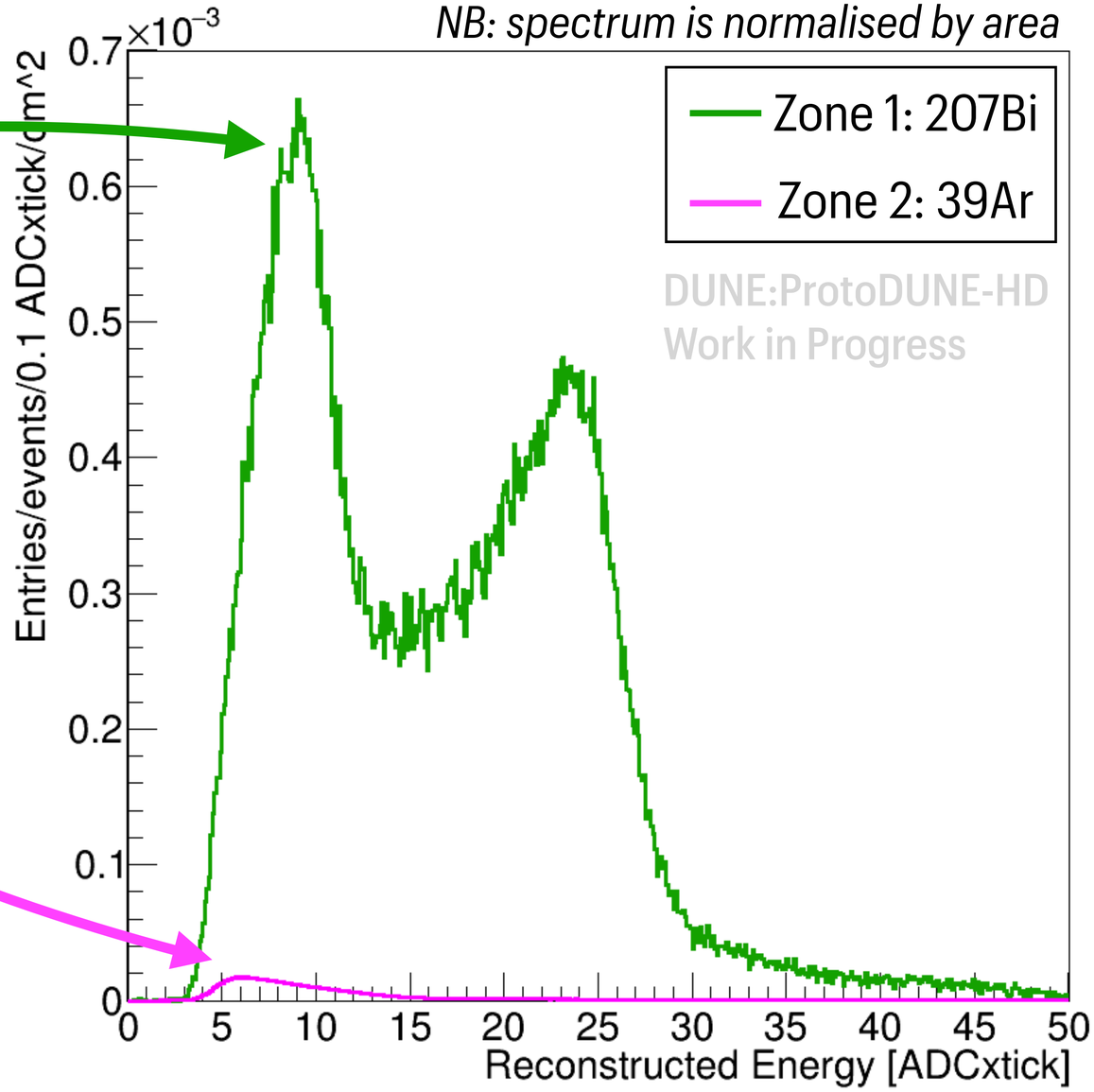
ProtoDUNE-HD calibration

^{207}Bi energy range

- For calibration purpose a source of ^{207}Bi has been added in PDHD
- Position is reconstructed **at the cm level**



NB: spectrum is normalised by area

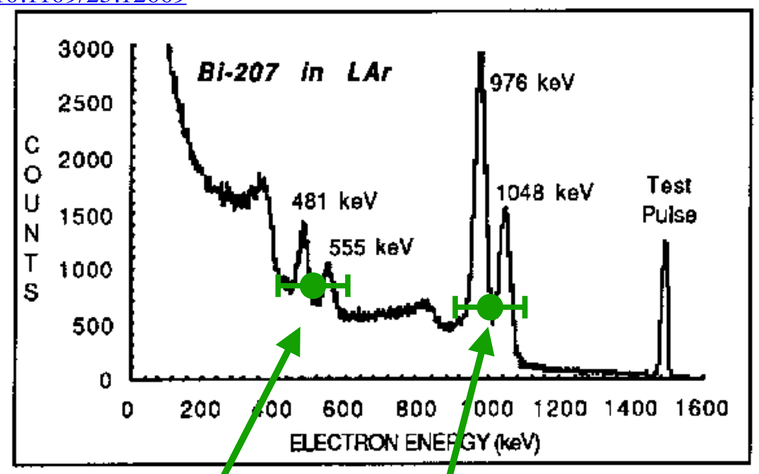


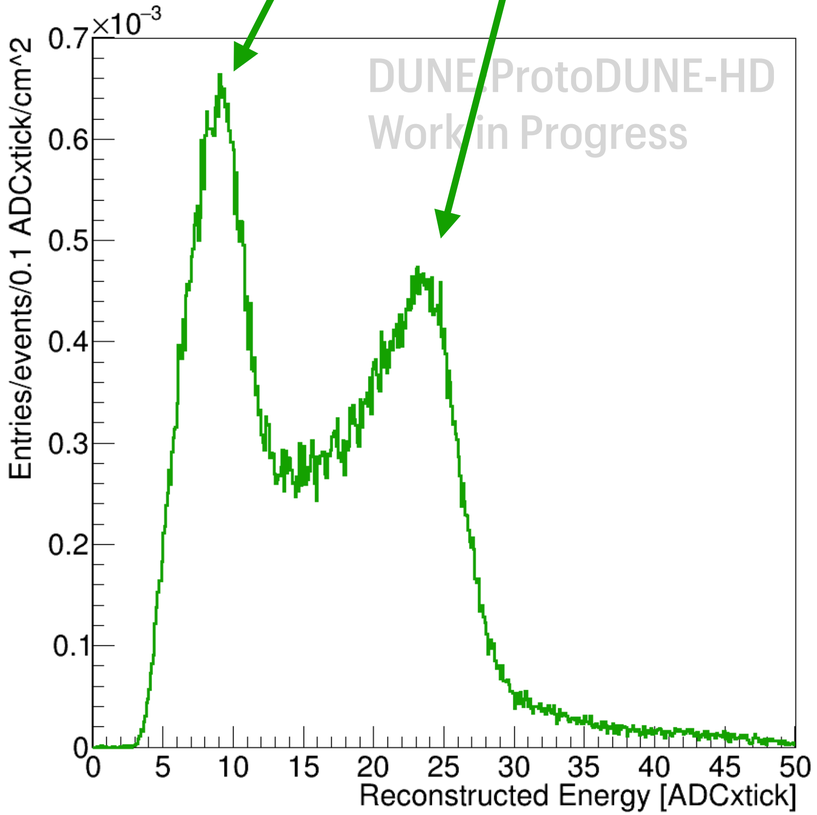
Fiducialization allows us to clearly identify ^{207}Bi

ProtoDUNE-HD calibration

^{207}Bi energy range

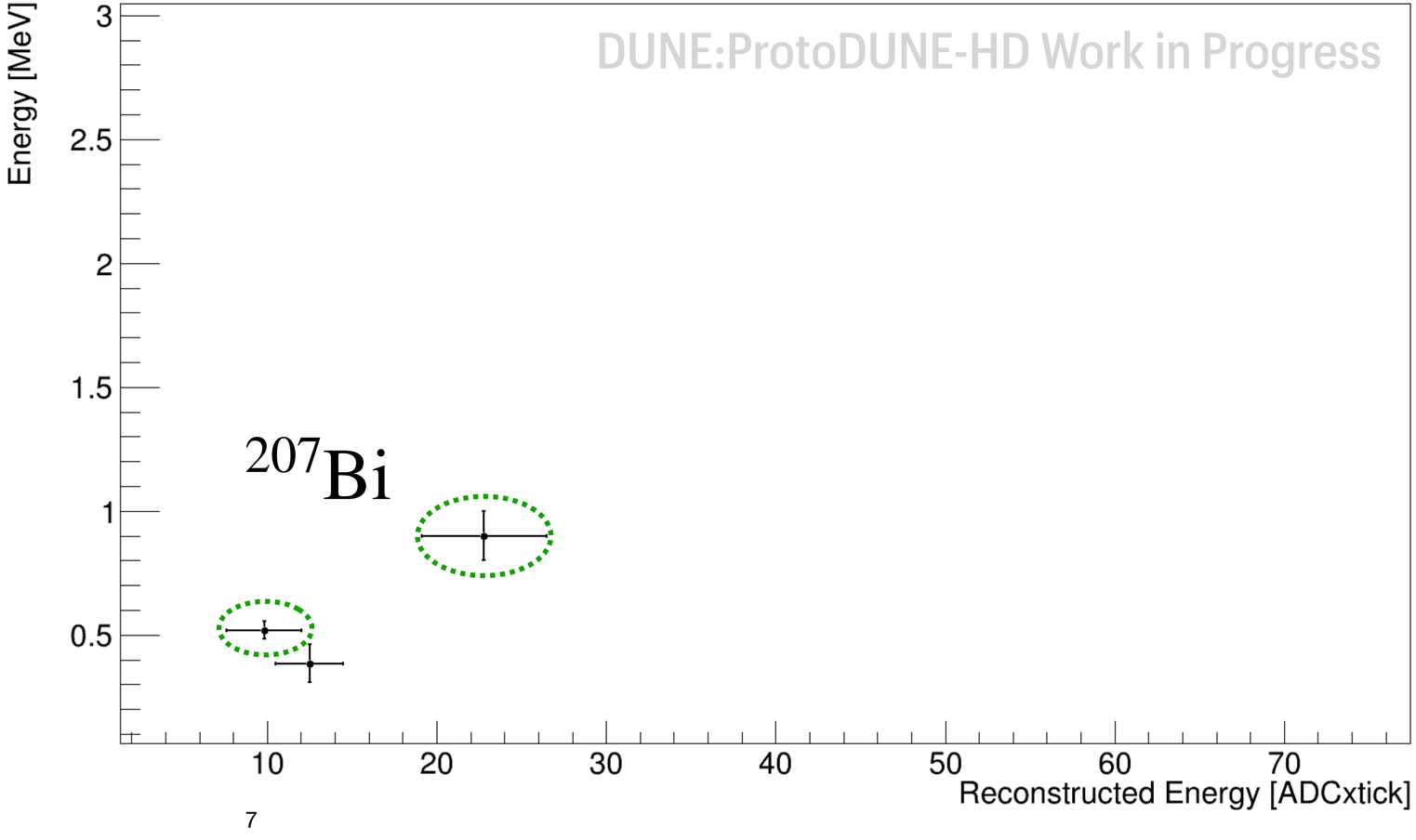
DOI:10.1109/23.12669





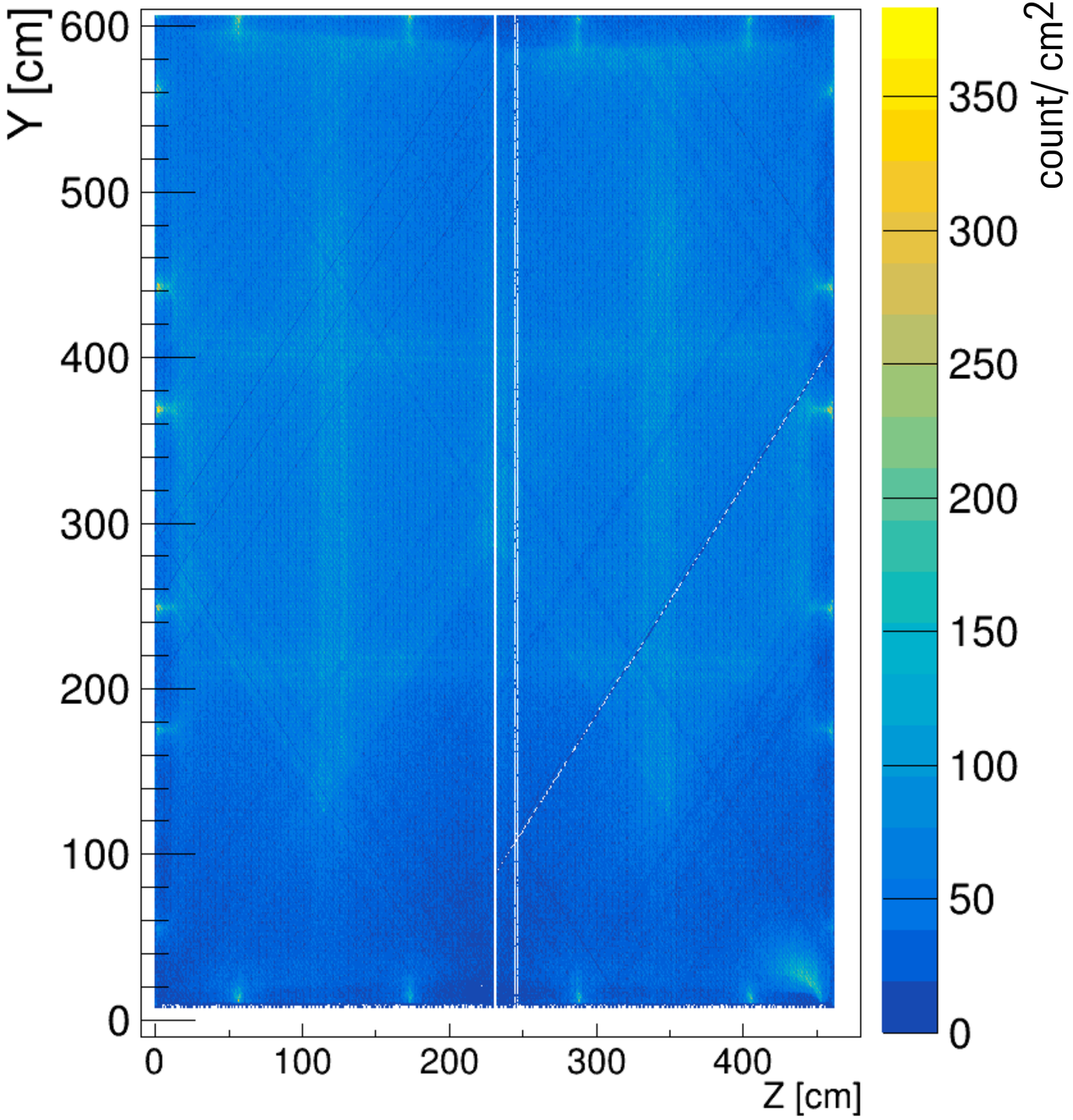
- ^{207}Bi is complex source (several gamma rays and conversion electrons)

- **Identification of two electrons peaks**

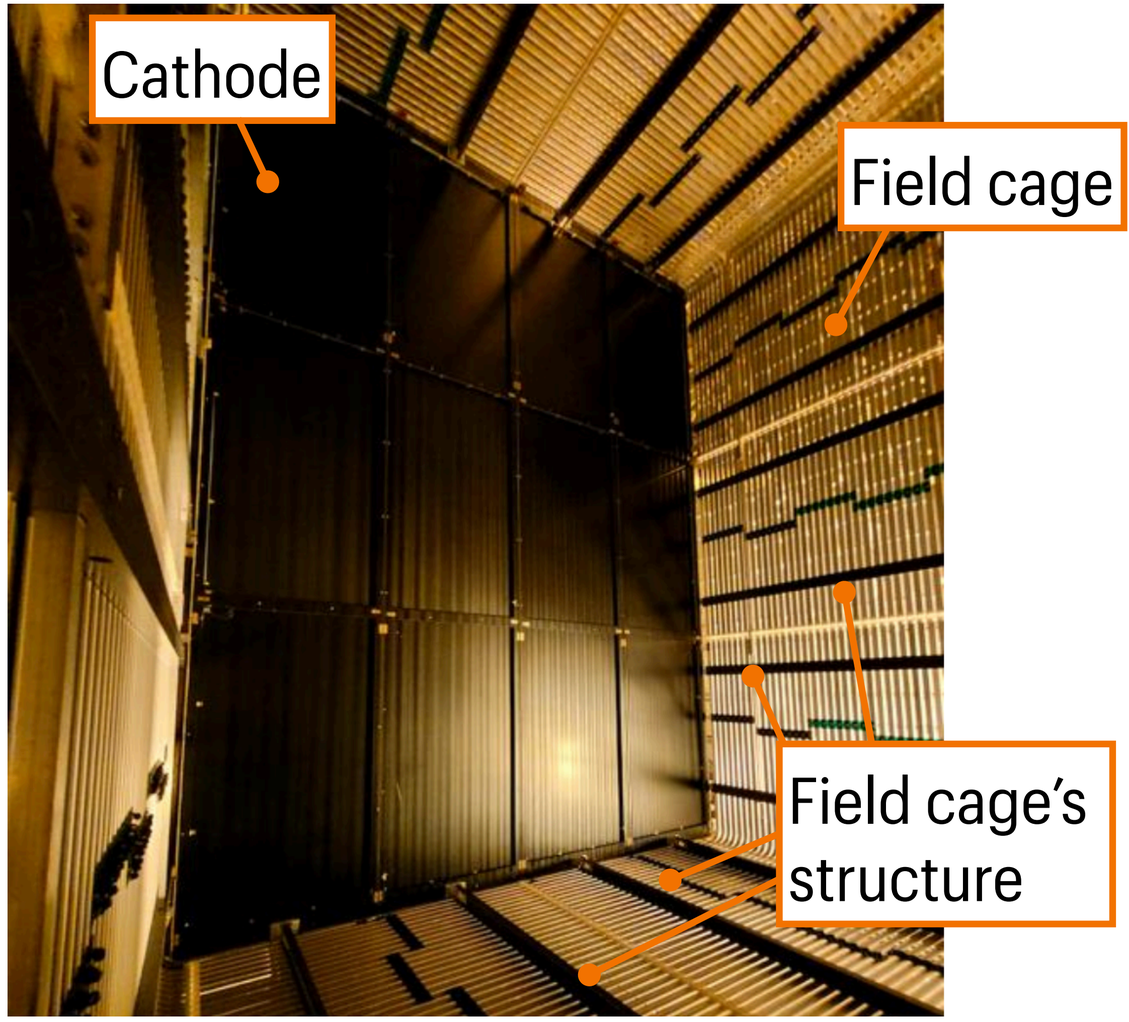


ProtoDUNE-HD calibration

^{232}Th energy range



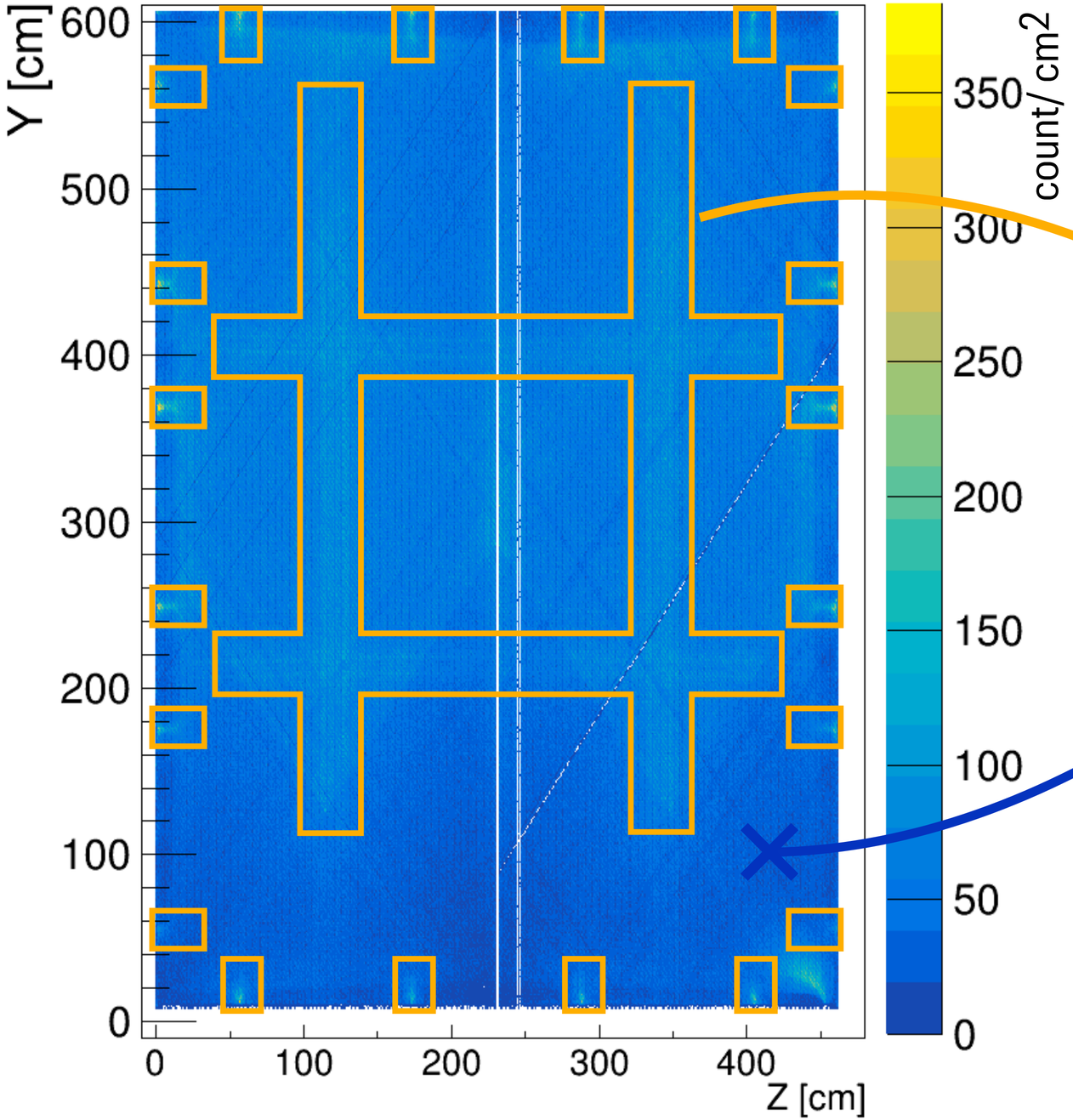
- We recognize **cathode and field cage structure**



Picture of the inside of ProtoDUNE-HD detector

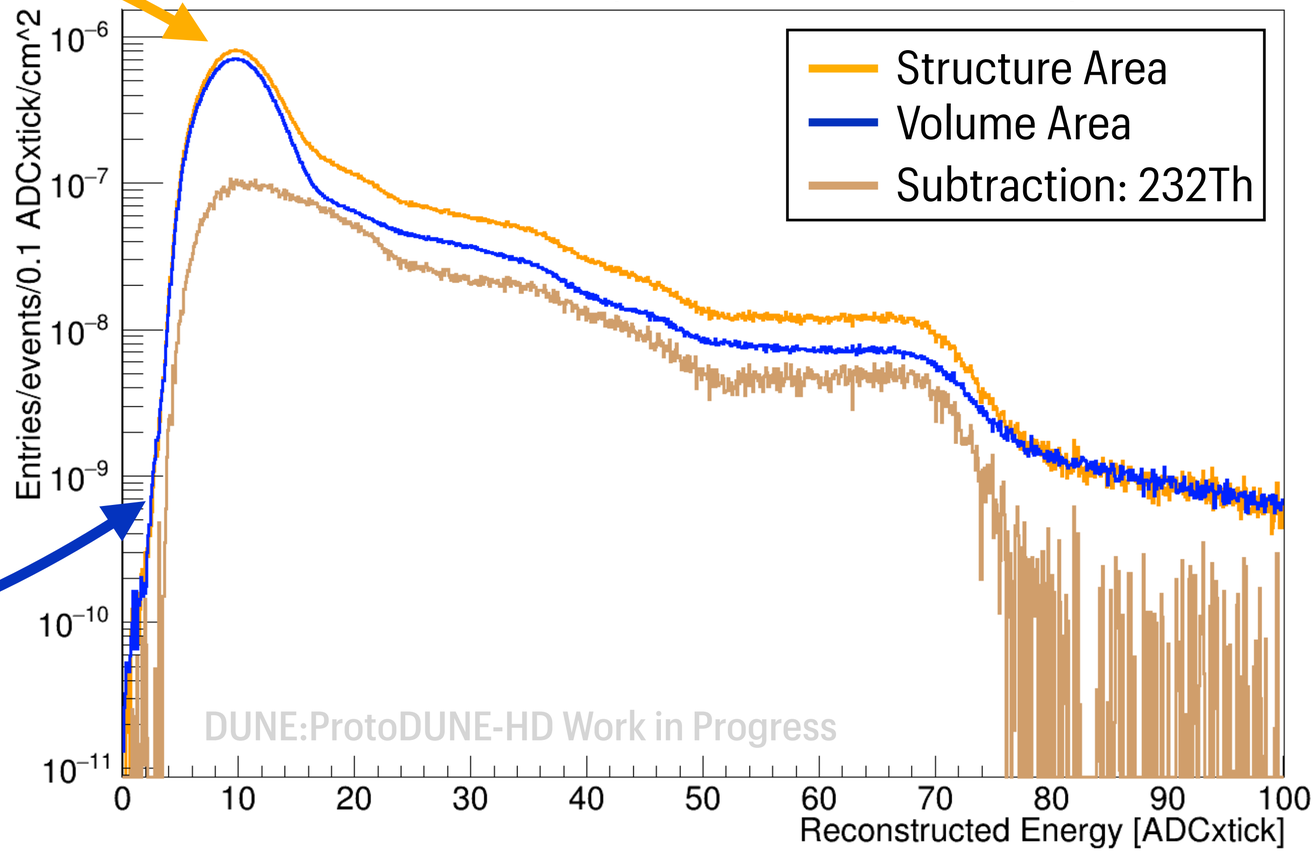
ProtoDUNE-HD calibration

^{232}Th energy range



- ^{232}Th is a well known natural radioactive component with a prominent **2.6 MeV gamma line** from ^{208}Tl decay

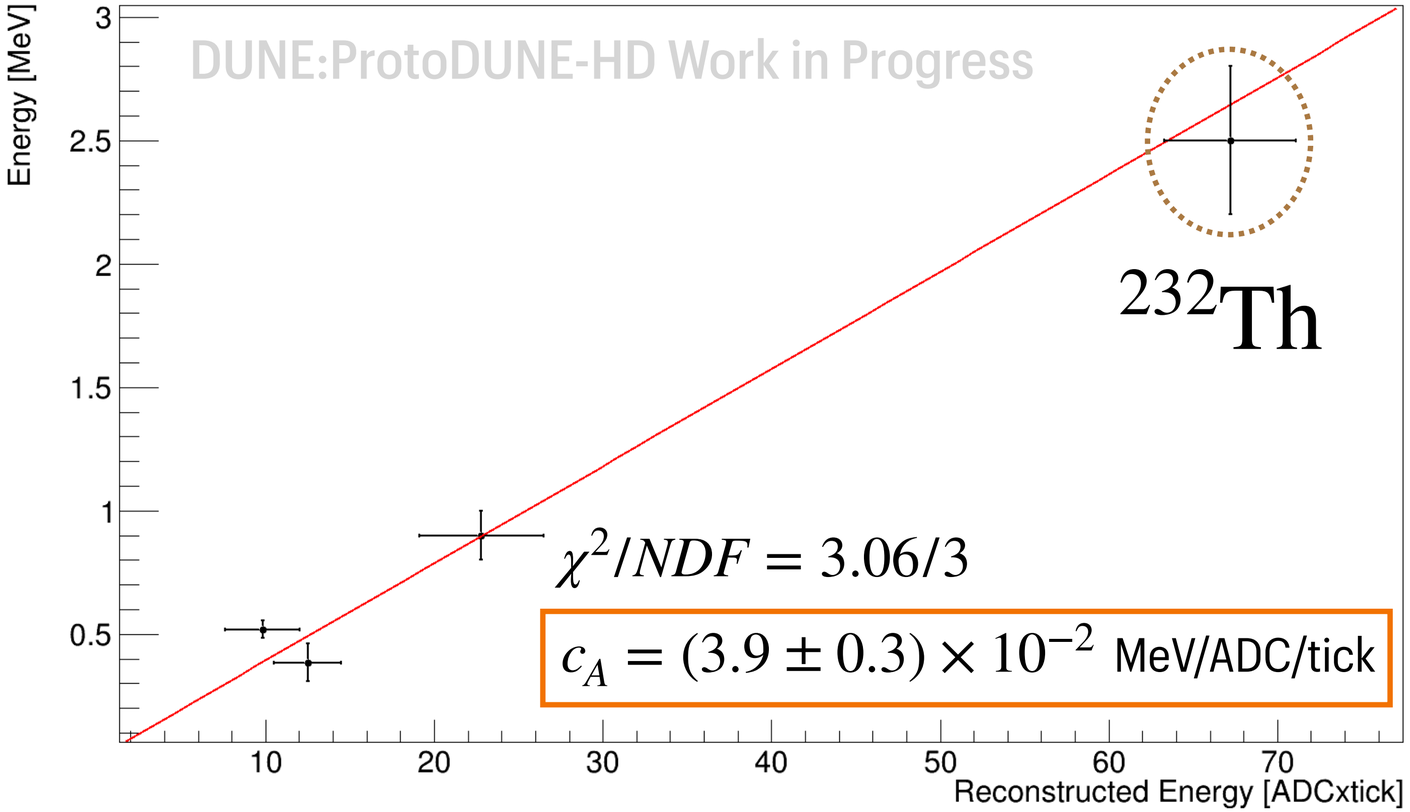
NB: spectrum is normalised by area



Consistent with literature: MicroBoone https://doi.org/10.1103/PhysRevD.111.032005

ProtoDUNE-HD calibration

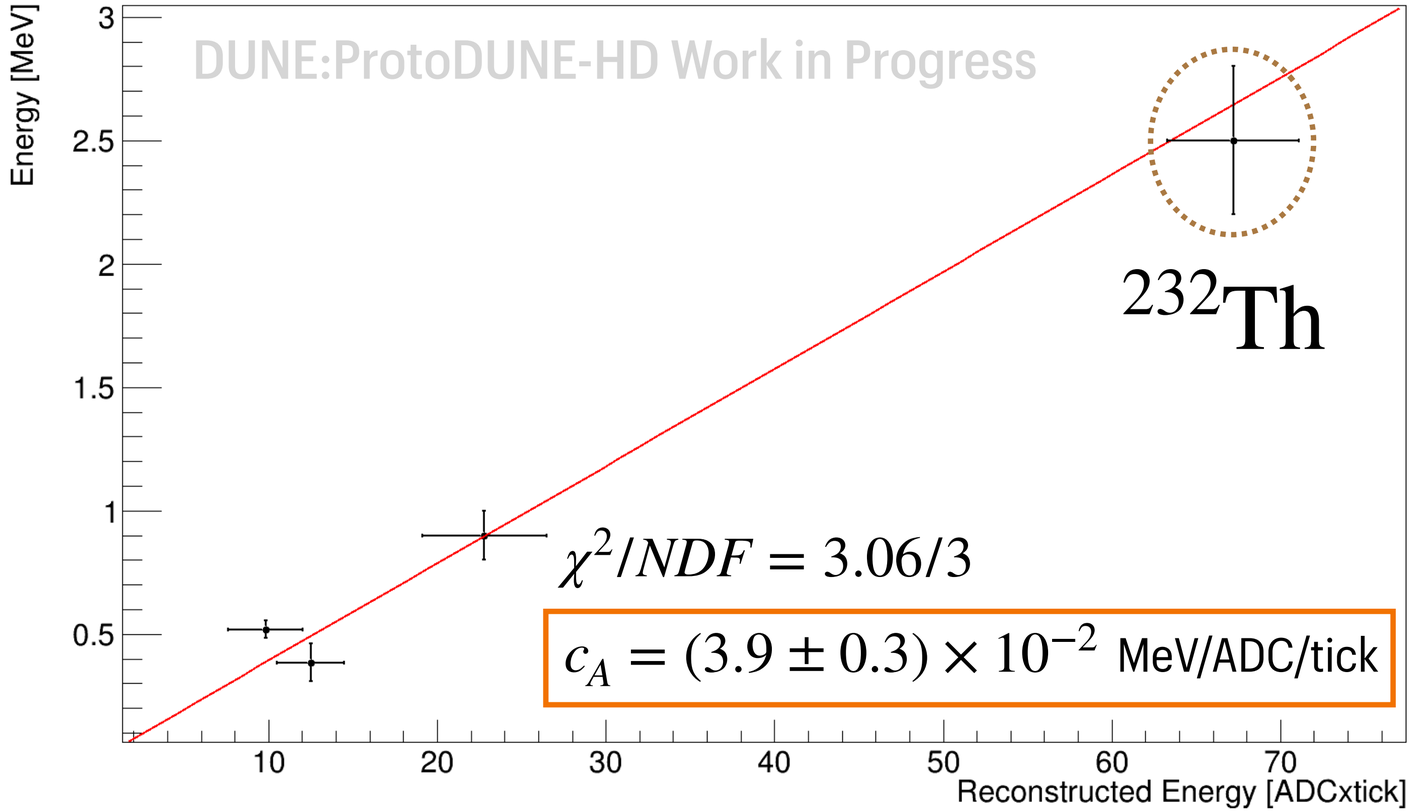
Calibration factor and recombination



- Calibration factor is consistent with higher energy:

  $c_A^{\mathrm{HE}} \approx 0.036$ MeV/ADC/tick

- From calibration **we can compute the recombination R :**



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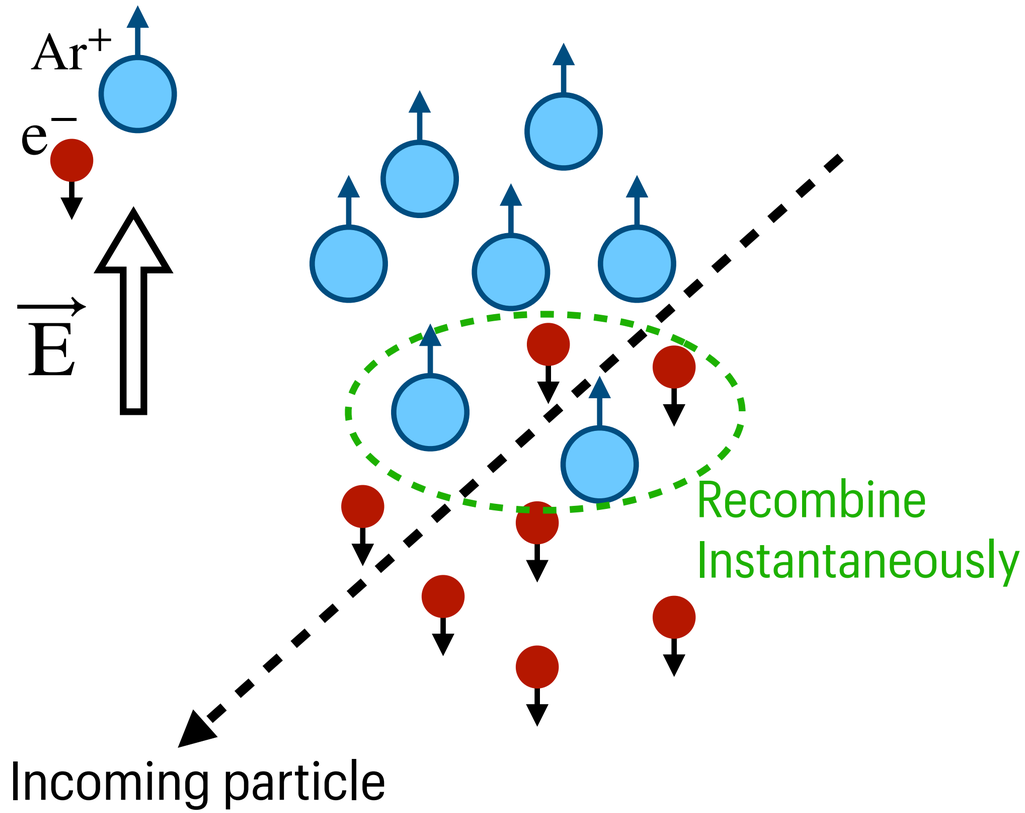
- Important features of LArTPC is recombination R:

$$\mathrm{R} = \frac{\mathrm{E}_{\mathrm{visible}}\ [\mathrm{MeV}]}{\mathrm{E}_{\mathrm{true\ deposited}}\ [\mathrm{MeV}]}$$



ProtoDUNE-HD calibration

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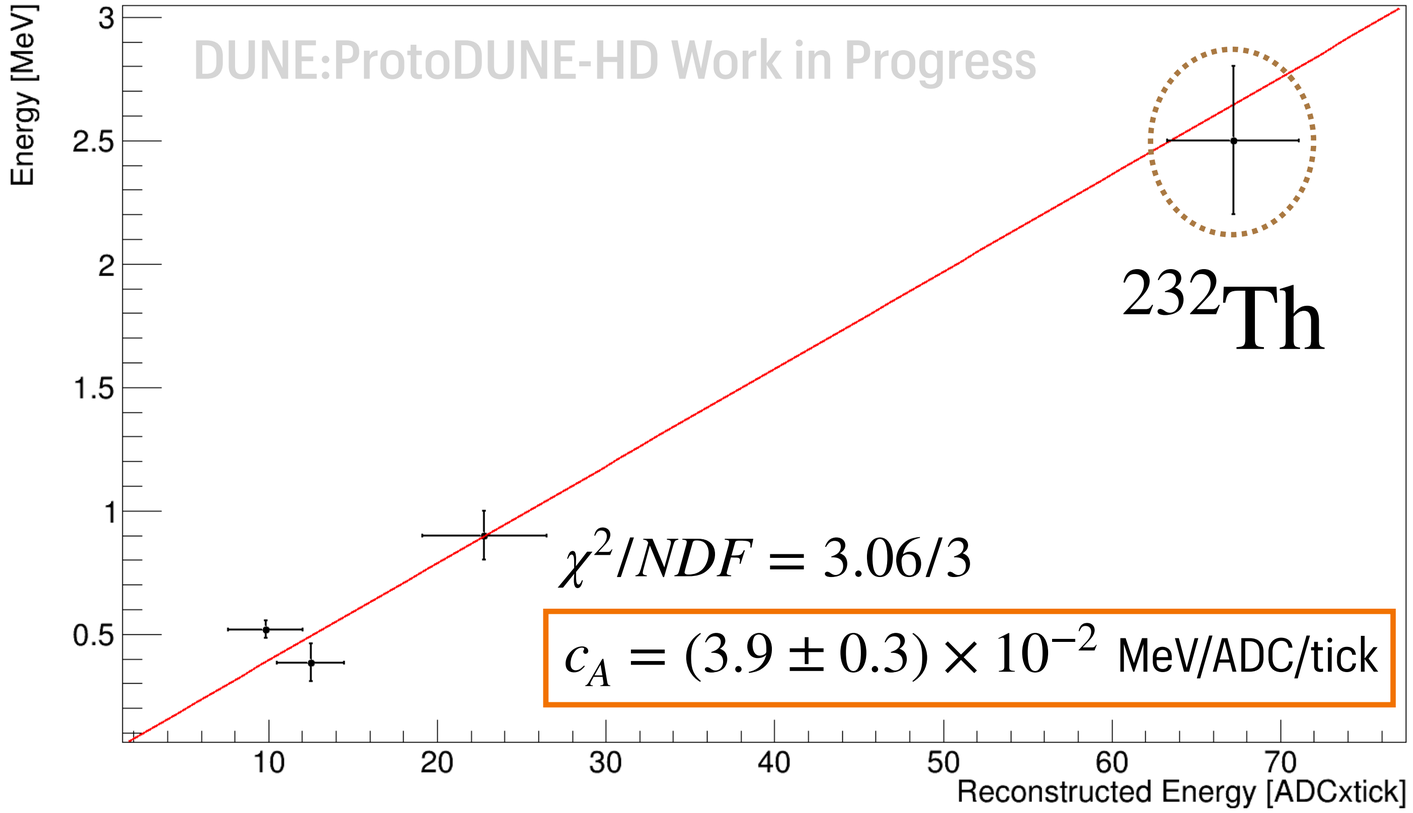

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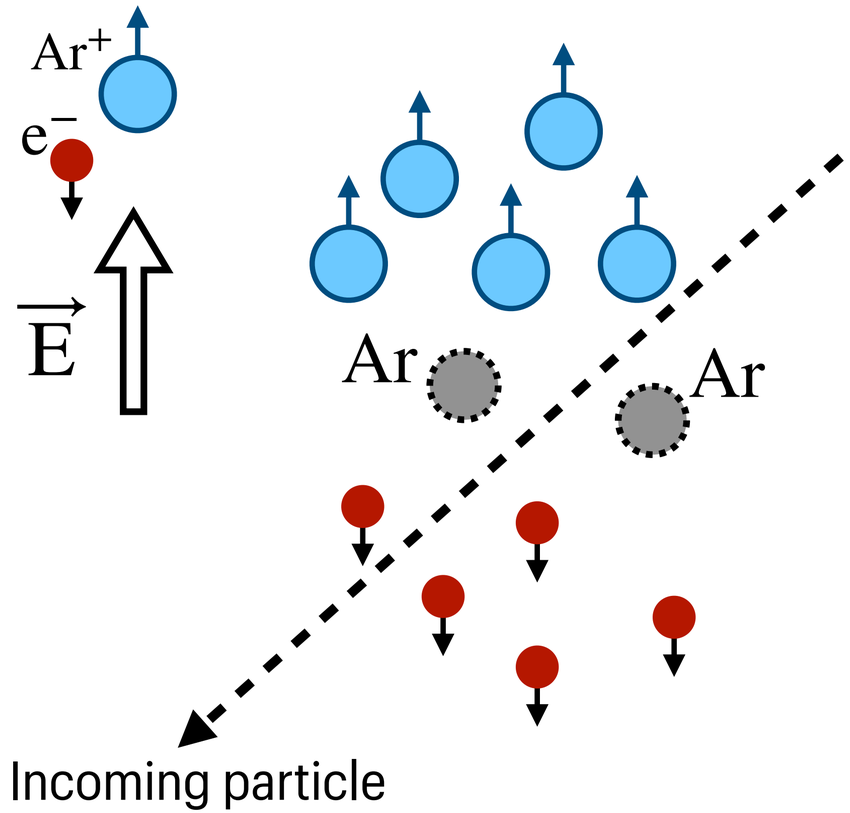

ProtoDUNE-HD calibration

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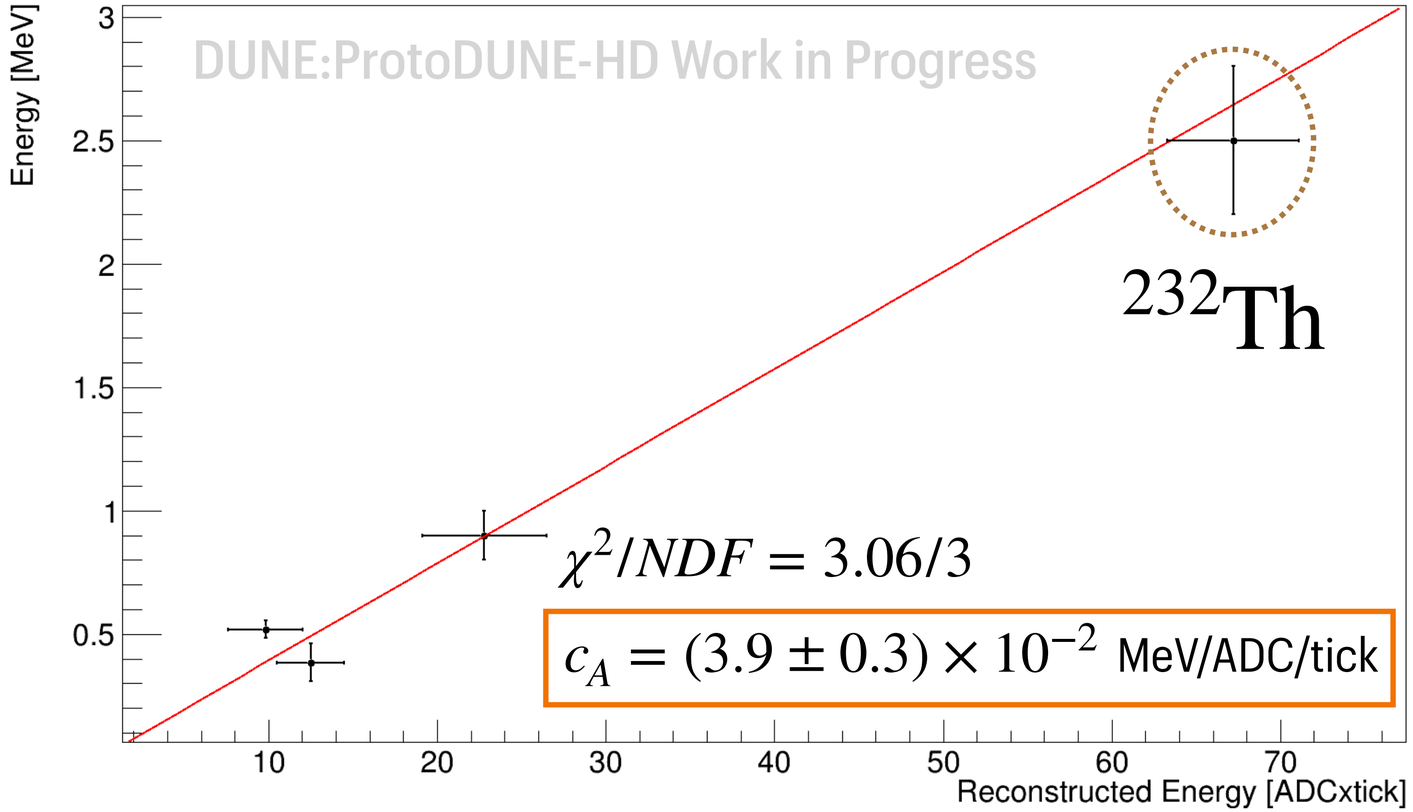

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$$\mathrm{R} = \frac{\mathrm{E}_{\mathrm{visible}}\ [\mathrm{MeV}]}{\mathrm{E}_{\mathrm{true\ deposited}}\ [\mathrm{MeV}]}$$

- Predicted with Modified Box Model at higher energy but **not well tuned at MeV scale**

$$\mathrm{R} = \frac{W_{ions}}{g_e \times c_A} = 0.60 \pm 0.05$$

- **Value compatible with other experiments** and error of the same order of magnitude

CONCLUSION

- **Developed an analysis tool for the collaboration available in DUNE's software**

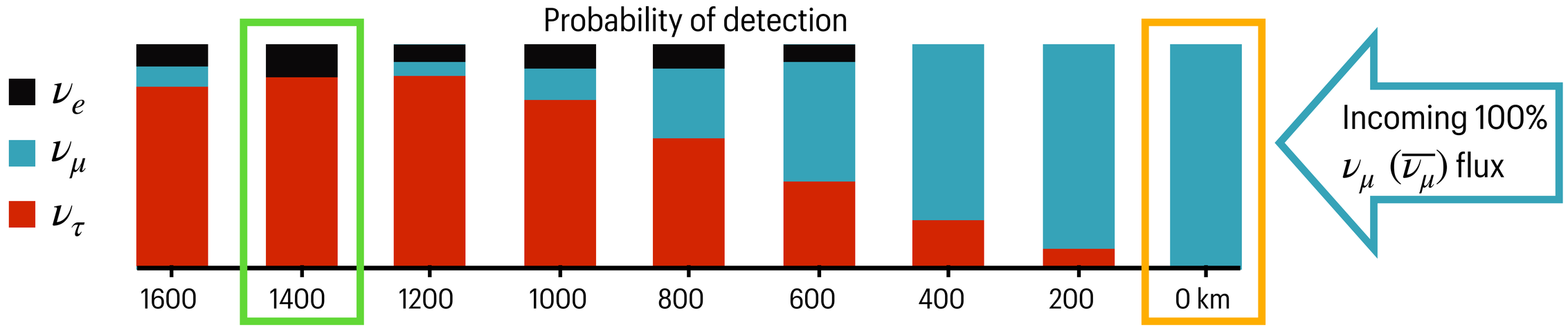
- **Very good spatial resolution:** cm level (Bi source, field cage structure)
- **Shown that MeV scale physics is possible for ProtoDUNE-HD (DUNE Far Detector ?)**

- Several radiological sources identified → **used for first calibration at low energy made on PDHD data**
- Find **recombination** value consistent with other experiments at low energy

- First comparison with MC made, building a new refined MC model for PDHD
- Waiting for PDVD data and Far Detector background simulation to make the same analysis

Annexe

- DUNE is composed of three parts : **Far Detector**, **Near Detector** and **Accelerator**



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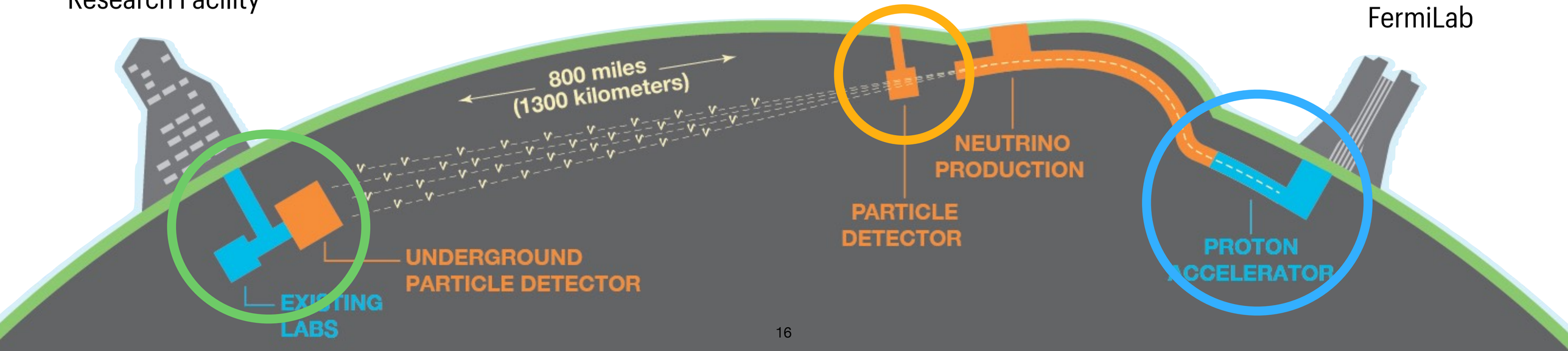
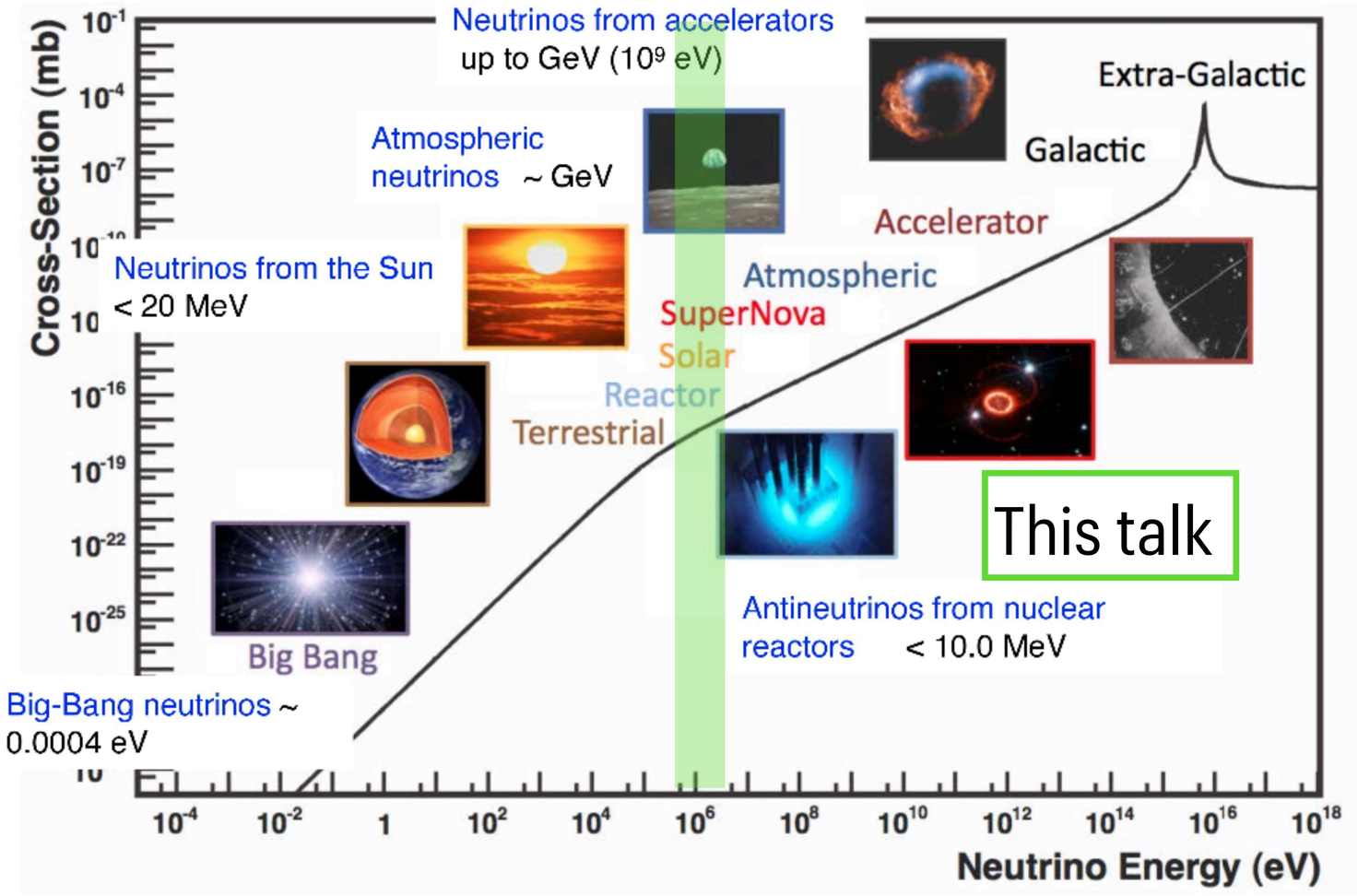


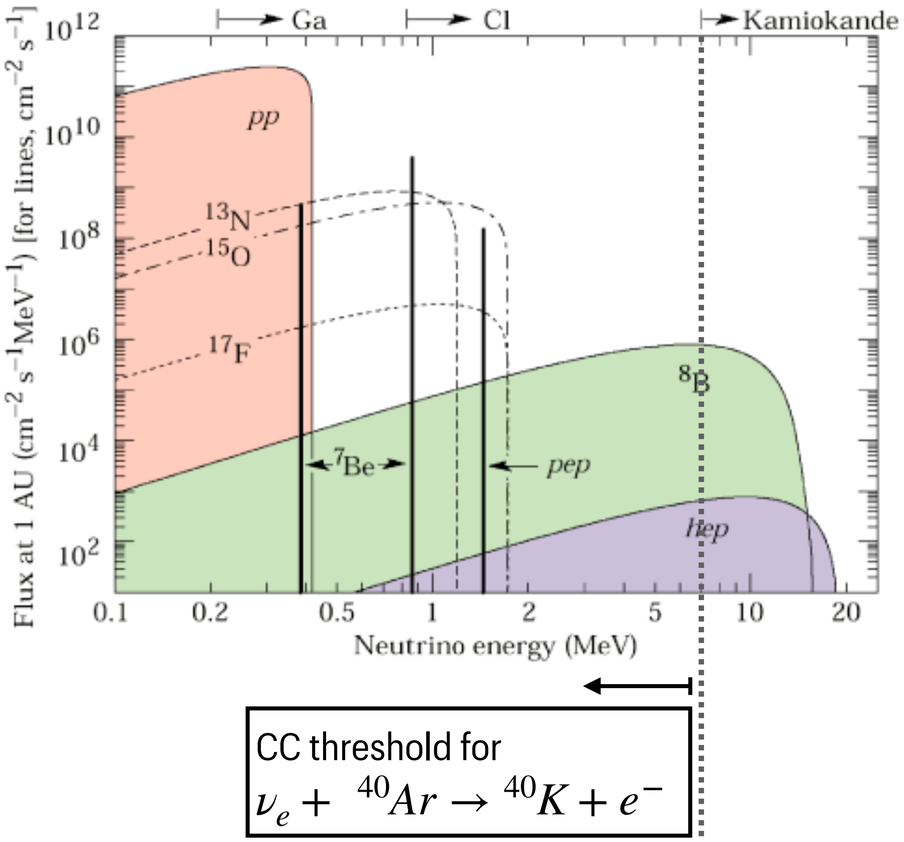
- Neutrino can be produced from very **different sources** in a **large range of energy**
- DUNE → **Low Energy physics:** neutrino at ~MeV

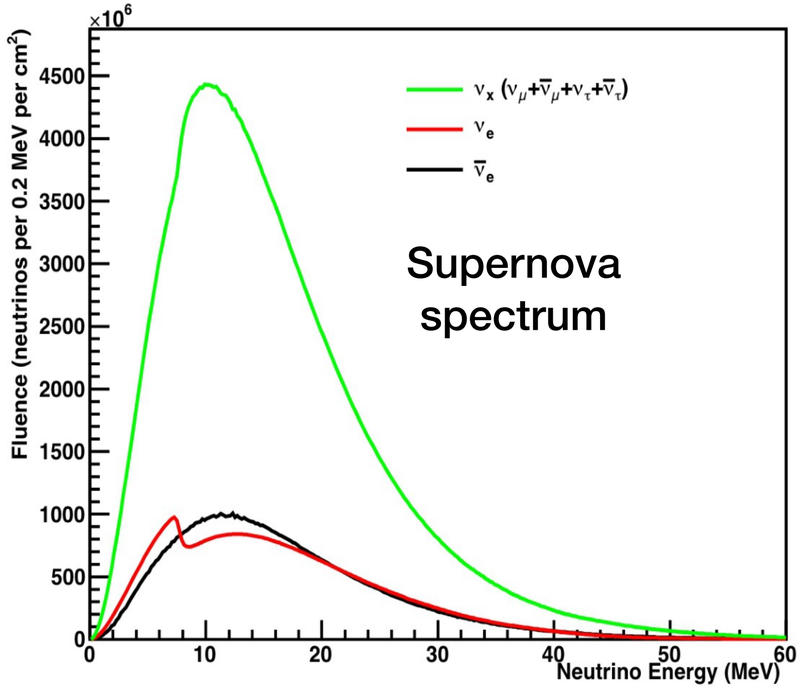
Physics aim :

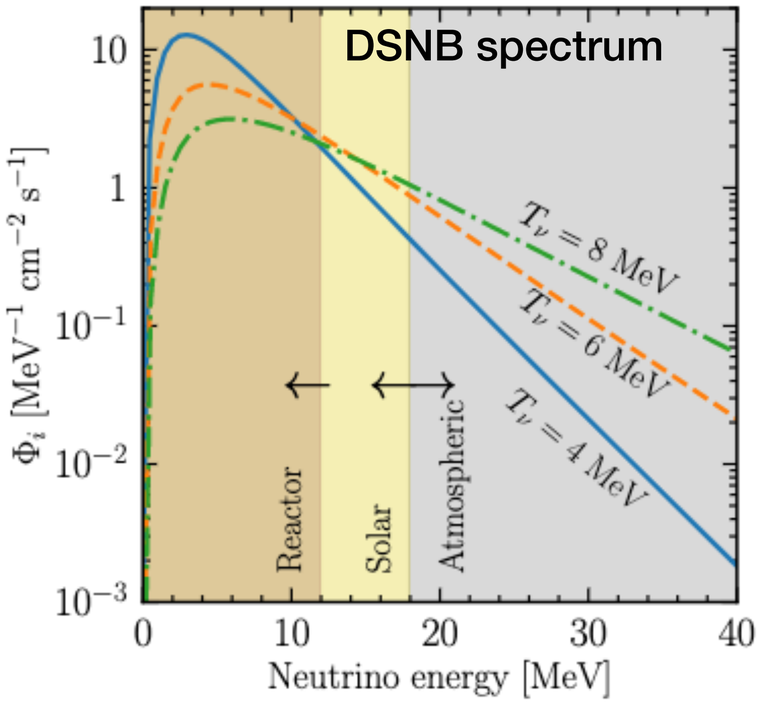
- HEP neutrino from the Sun
- Supernova (SN)
- Diffuse SuperNova Background

See next slide









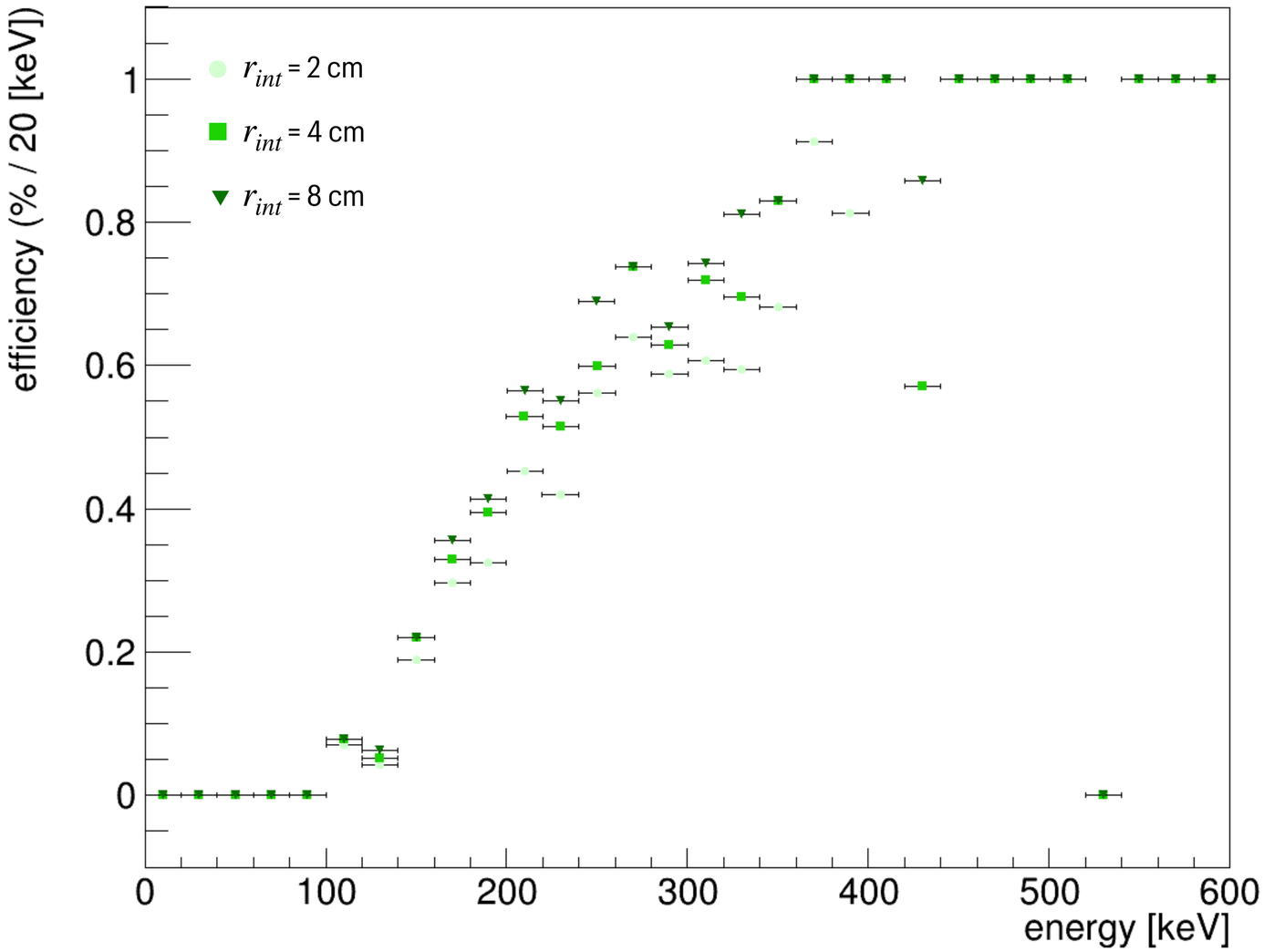
- **Challenging range of energy** with lower cross-section and more sensitive to detector or reconstruction effects like background or noise level.

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

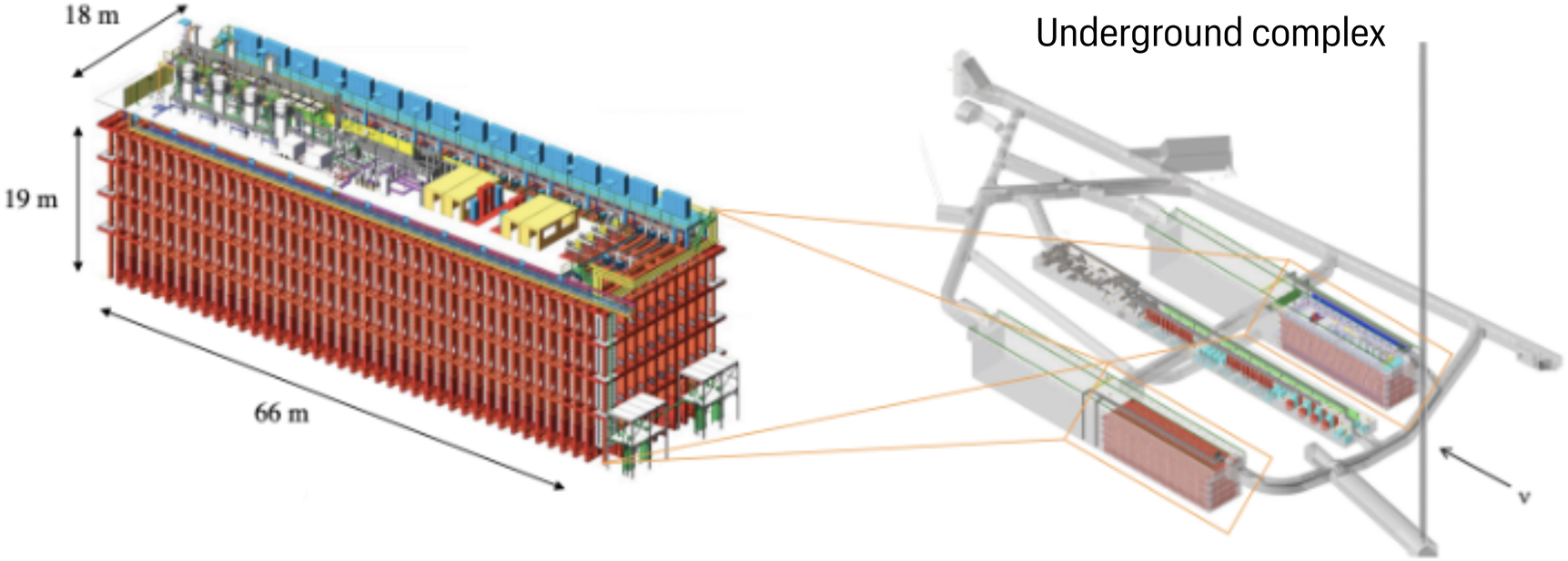
arXiv:2207.09632 [astro-ph.HE]
Figure from arXiv:1205.6003 [astro-ph.IM]

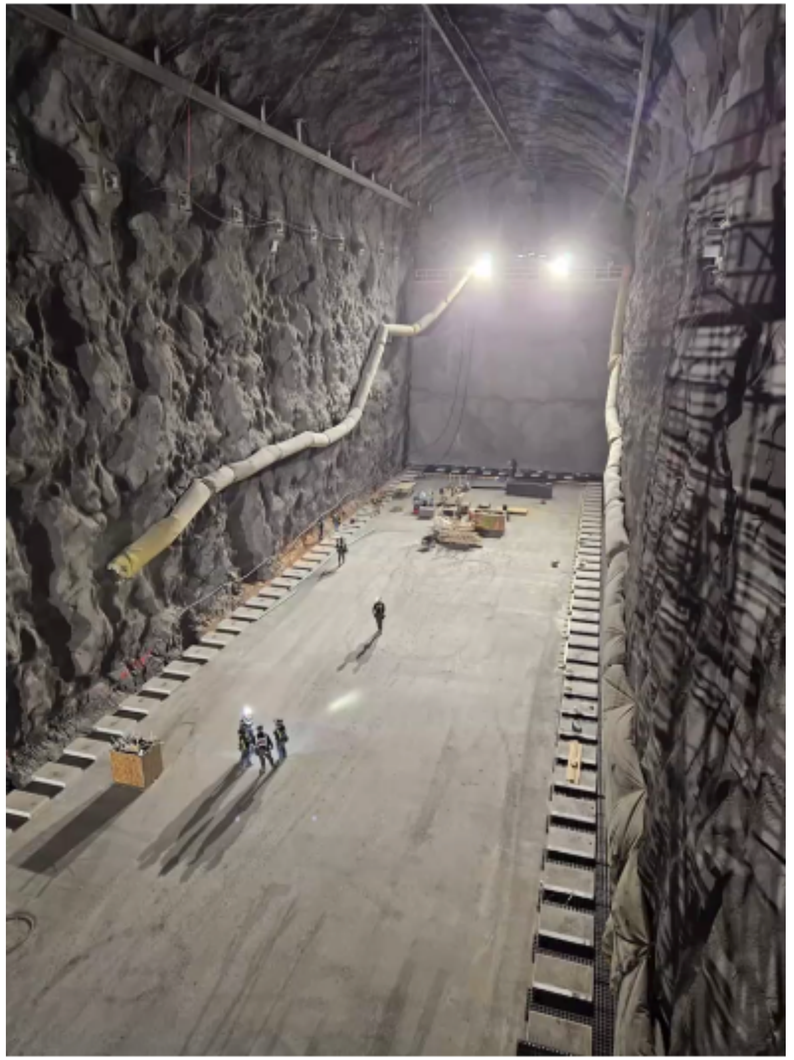
Efficiency

- **Mean efficiency: ~40 % for 39Ar (MC)**
- i.e. decays with < 3 hits and < 1 MeV
- The SingleHit analysis tool improves the LE events reconstruction, down to ~200 keV

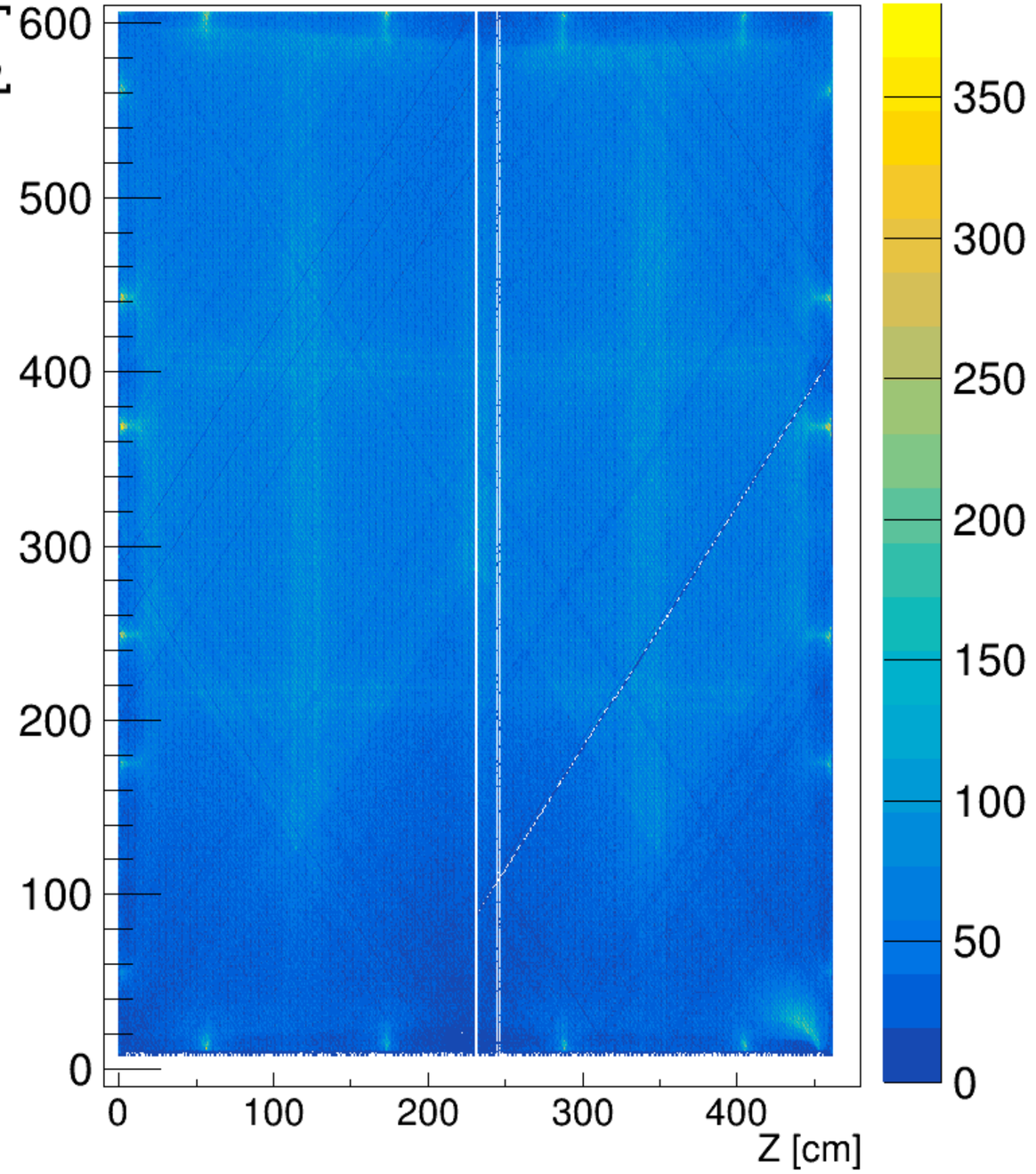


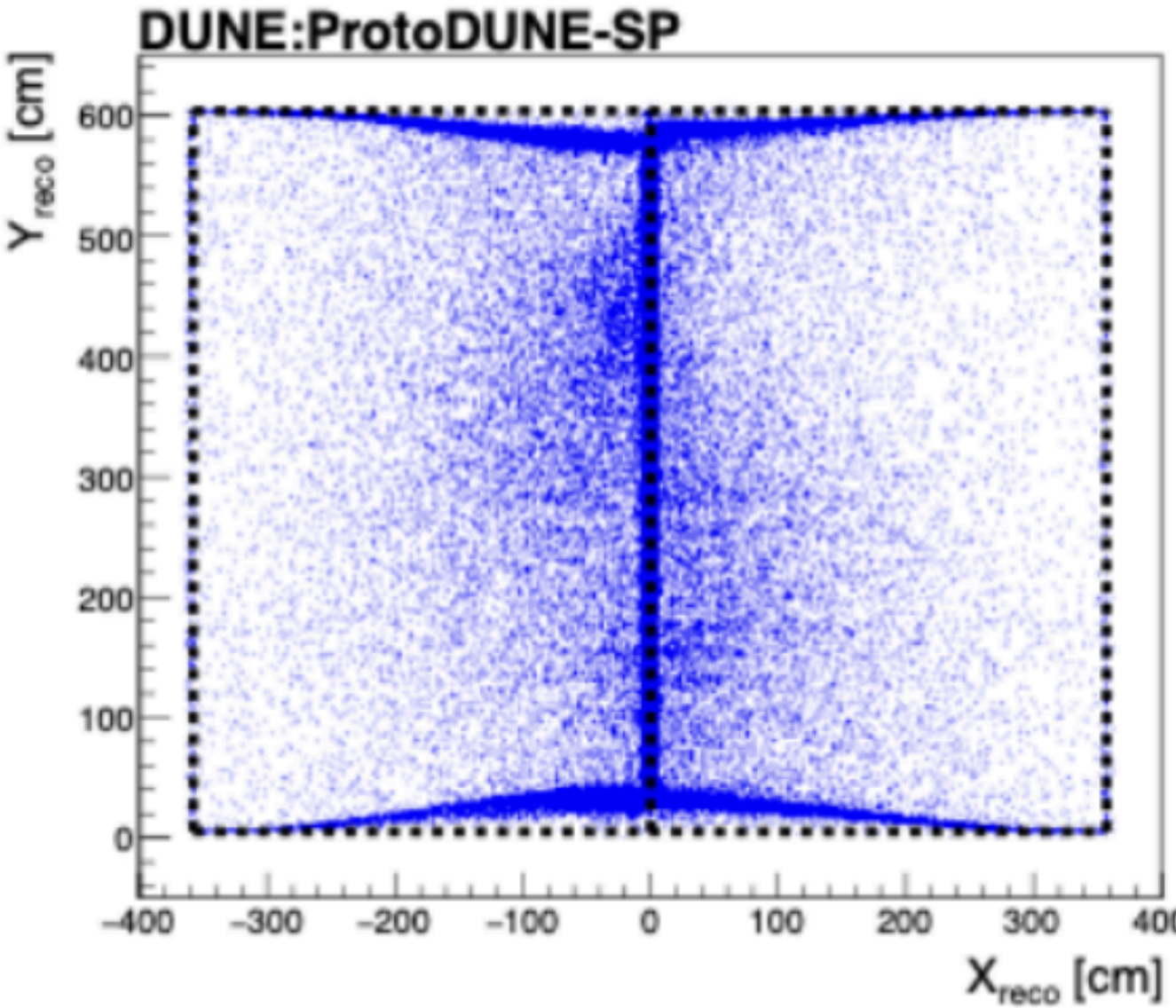
- **Far Detector** = 4 cryostats with **LArTPC based technologies** with dimensions 66m x 18m x 19m
  - Cryostats 1 → **Vertical Drift** (IJCLAB contribution)
  - Cryostat 2 → **Horizontal Drift**
  - Cryostat 3 → modified **Vertical Drift**
  - Cryostat 4 → to be defined





800 ktons of rock extracted


600
500
400
300
200
100
0
0
100
200
300
400
Z [cm]
350
300
250
200
150
100
50
0


DUNE:ProtoDUNE-SP
Y reco [cm]
600
500
400
300
200
100
0
−400
−300
−200
−100
0
100
200
300
X reco [cm]

Data set	Particle		Topic	$\mathscr{R}$ at 0.5 kV/cm
3 ton	Stopping	μ, p	$\mathscr{R}_{3t}$ vs. $\frac{dE}{dx}$ 3 $\mathscr{E}$ values	mip: 0.70 ± 0.02
Scalettar[3]	^{113}Sn source	364 keV e^-	$\mathscr{R}_S$ vs. $\mathscr{E}$	0.58 ± 0.01
	^{241}Am source	5.64 MeV α	$\mathscr{R}_\alpha$ vs. $\mathscr{E}$	$0.014 \pm ?$
Aprile[4]	^{207}Bi source	976 keV e^-	$\mathscr{R}_A$ vs. $\mathscr{E}$	0.64 ± 0.05
T600	Stopping	μ	$\mathscr{R}_{T600}$ vs. $\frac{dE}{dx}$	mip: 0.71 ± 0.04

From: Study of electron recombination in liquid argon with the ICARUS TPC