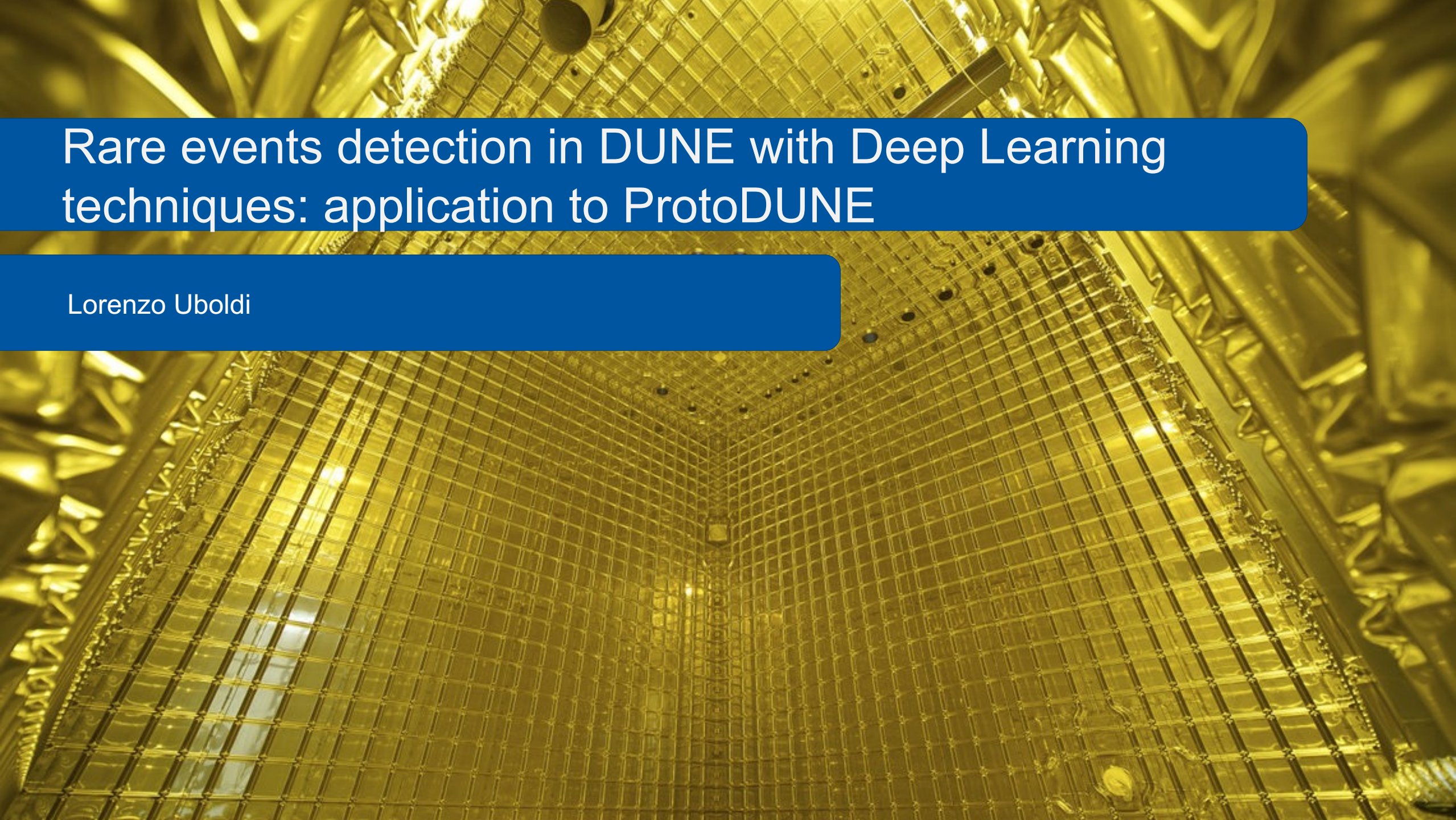


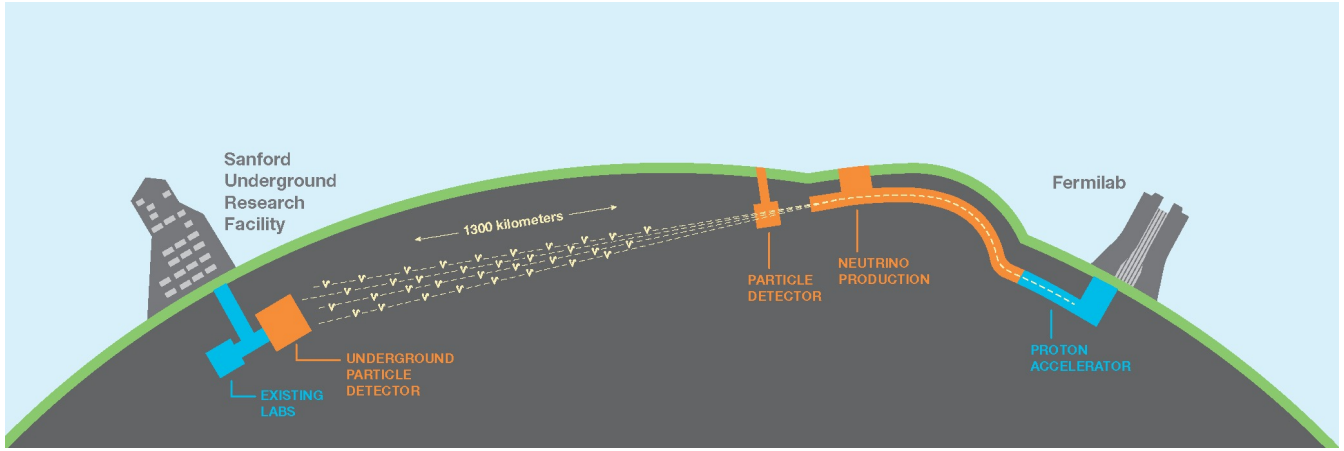
Rare events detection in DUNE with Deep Learning techniques: application to ProtoDUNE

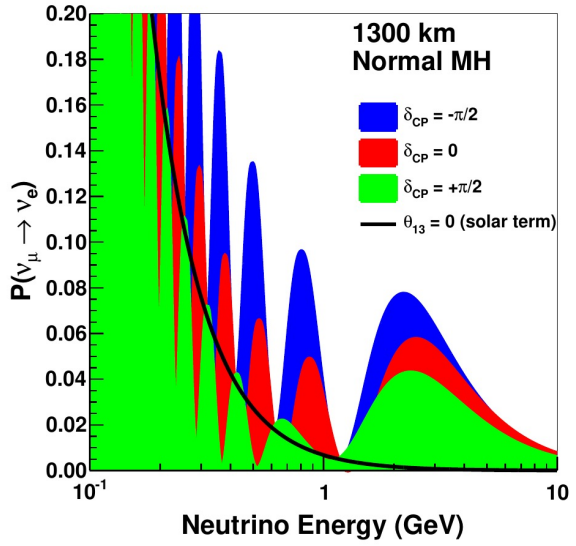
Lorenzo Uboldi

DUNE: Deep Underground Neutrino Experiment

Beam physics:

- Oscillation parameters
- CP violation
- Mass ordering



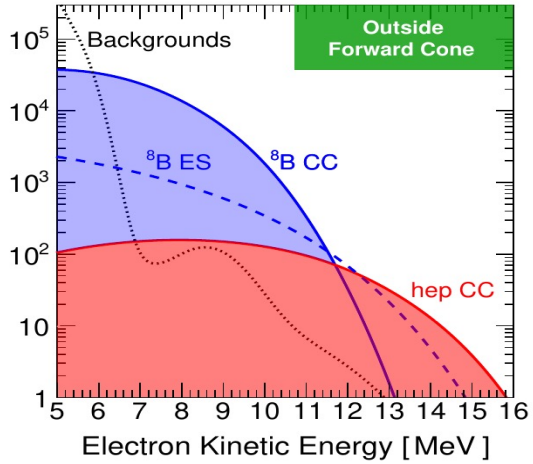


Distinctive signature

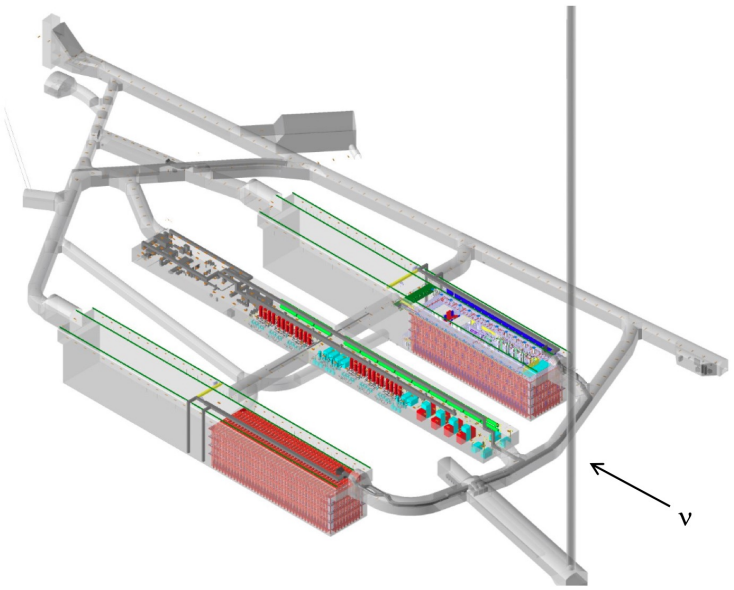
$$\nu_e + {}^{40}\mathrm{Ar} \rightarrow e^- + {}^{40}\mathrm{K}^*$$

SN burst:
1 every few decades
Neutrinos:
5 – 50 MeV for ~ 30 sec
~3000 events expected

Solar: 8B and hep

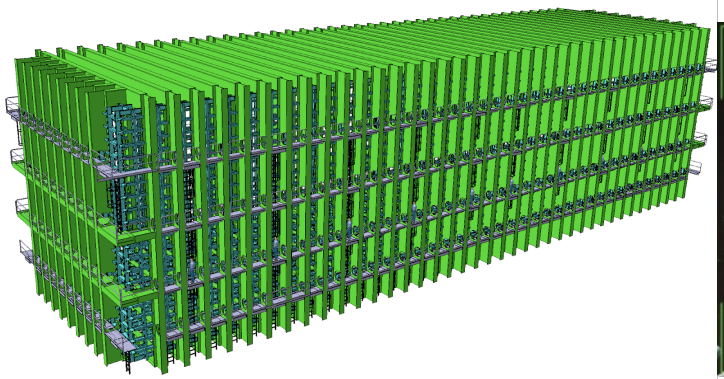


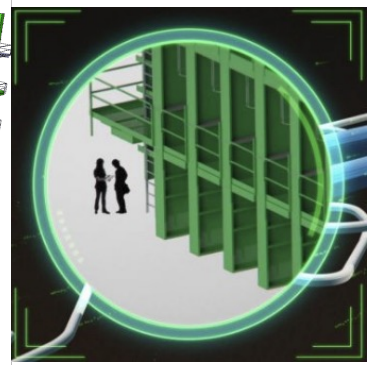
DUNE and ProtoDUNE



4 x Far Detectors:

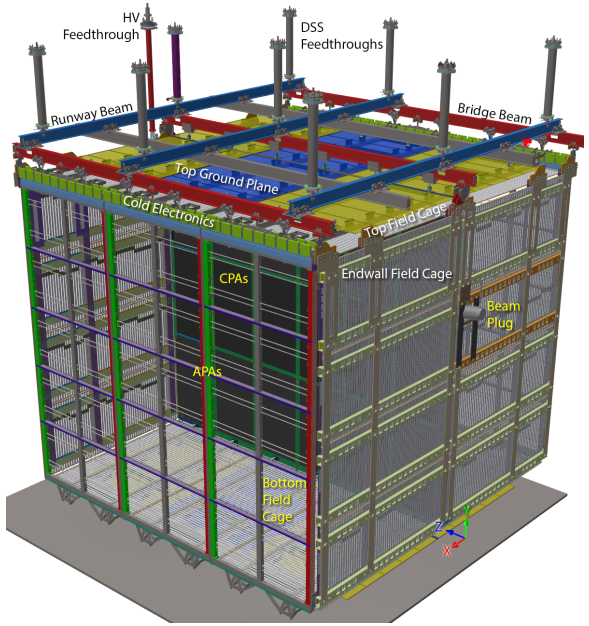
- 17 kton LAr
- 14m x 14 m x 62 m



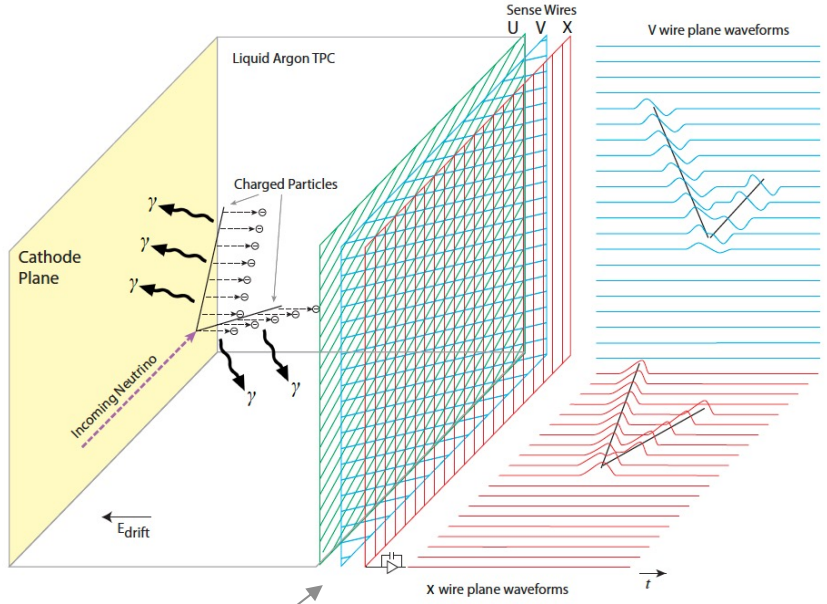


ProtoDUNE, a FD prototype at CERN:

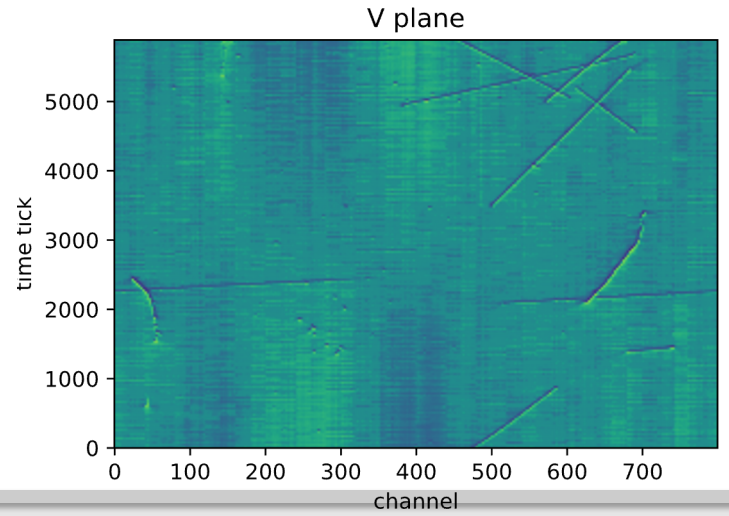
- 770 ton LAr (1/20 of DUNE FD)
- 11m x 10m x 11m



Liquid Argon Time Projection Chamber (LArTPC)

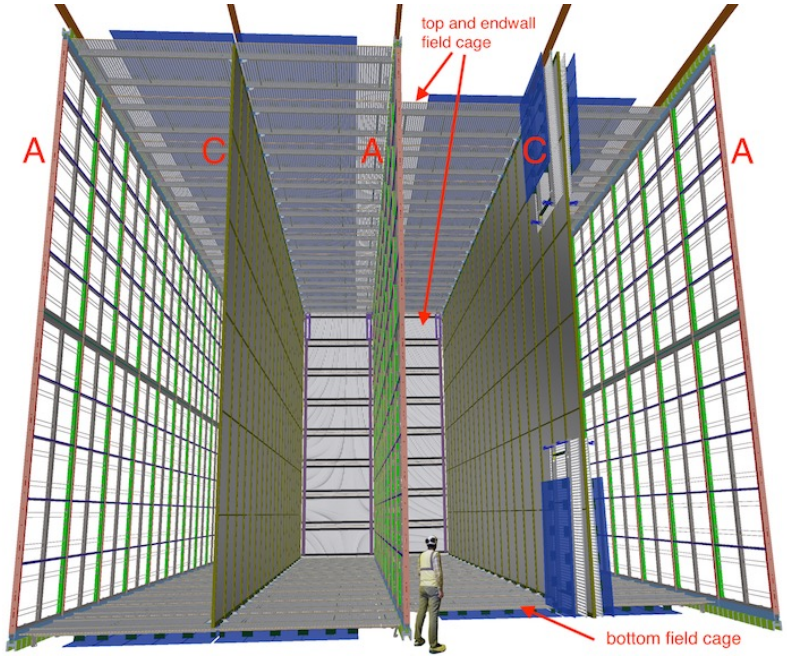


APA: anode plane assembly



Huge amount of data:

- 4 x 384000 channels
- Sampled at 2 MHz



Rare events data:

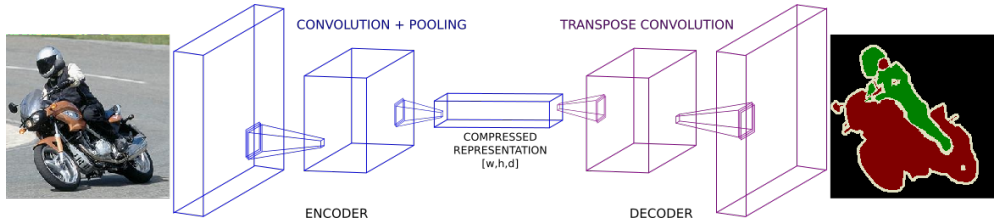
- 145 exabyte/year!
- Fermilab storage is limited to 30 petabyte/year

An online data reduction system able to keep signal is needed with high efficiency at low energy

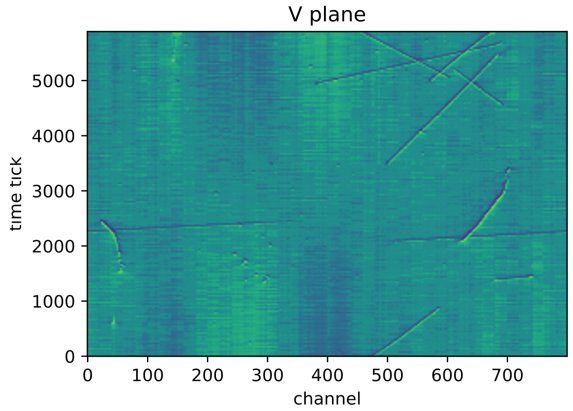
Semantic Segmentation and Deep Learning approach

Pixel-wise classification

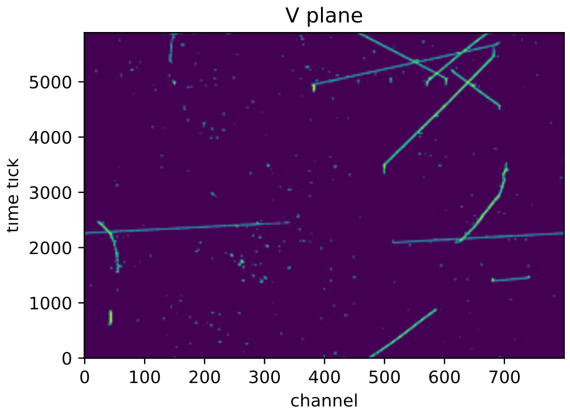
Neural network approach



LArTPC data is well suited for semantic segmentation



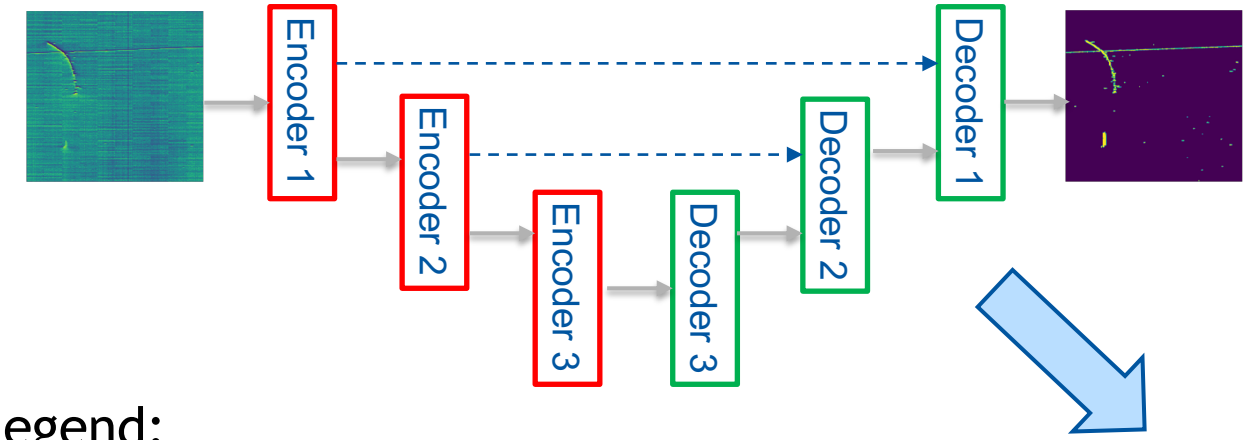
Reconstruction chain



Noise can be discarded, signal kept

Training on ProtoDUNE data

Neural Network adapted from LinkNet [1]

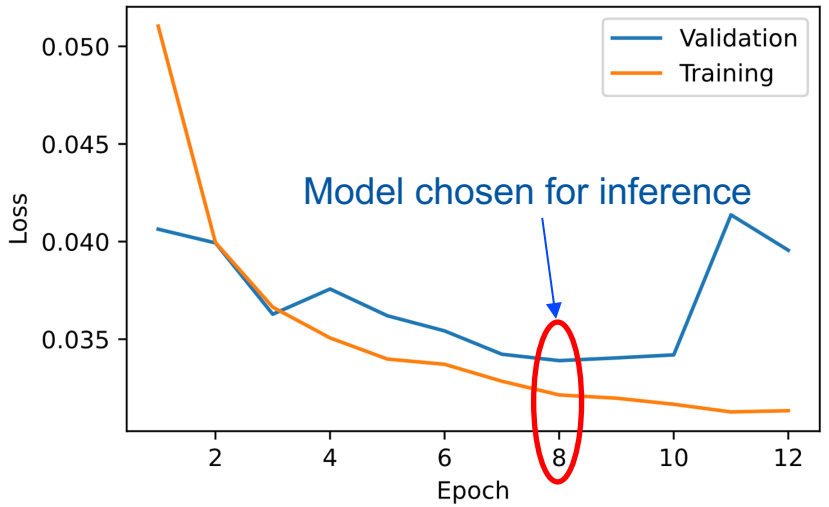


Legend:

- Encoder — convolutional residual block
- Decoder — transposed convolution
- main data flow
- skipped connection for loss convergence

	LinkNet	TinyLinkNet
Weights	11'863'562	182'353
One pass (MB)	2'169	379
GFLOPs	36.9	1.1

Trained on mixture of MC and real data with unbalanced Binary Cross Entropy loss:



- **BCE loss**: cost function to minimize during training
- **Epoch**: training iteration

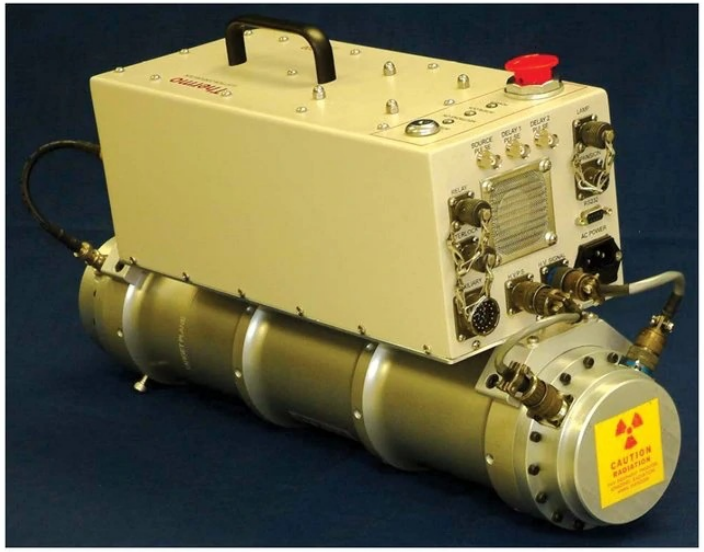
Results on real data:
- Signal lost ~ 1%
- Unnecessary data ~0.5 %

[1]: LinkNet: Exploiting encoder representations for efficient semantic segmentation, 2017 IEEE Visual Communications and Image Processing

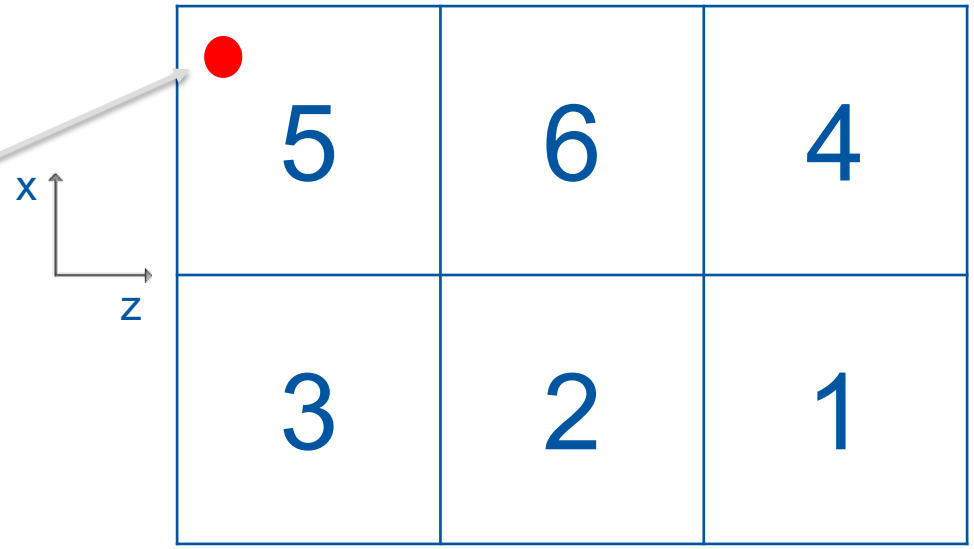
Low energy depositions

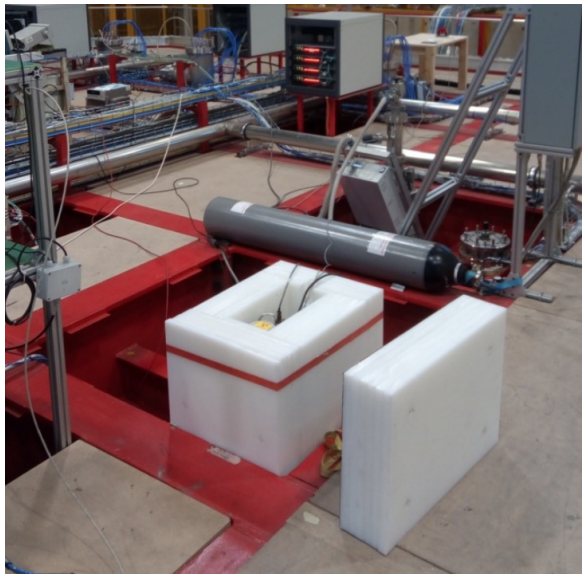
- Supernovae burst
- Solar neutrinos

→ Localized low energy depositions (MeV range) → is the network able to detect?



APA numbering

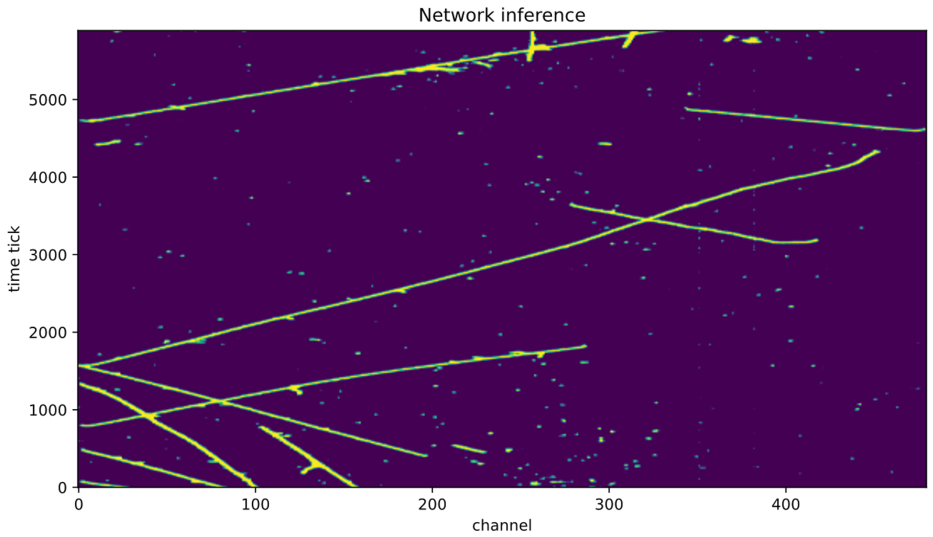




Neutrons in LAr are captured and release **6.1 MeV** via a gamma cascade → Perfect test!

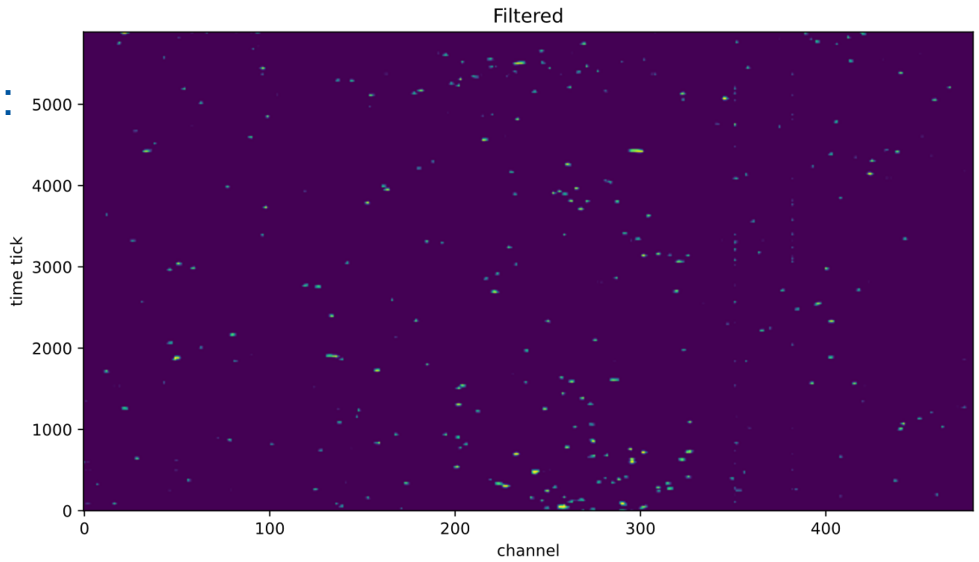
Two datasets:
- Equal number of events
- One with generator **on**
- One with generator **off**

Hits selection

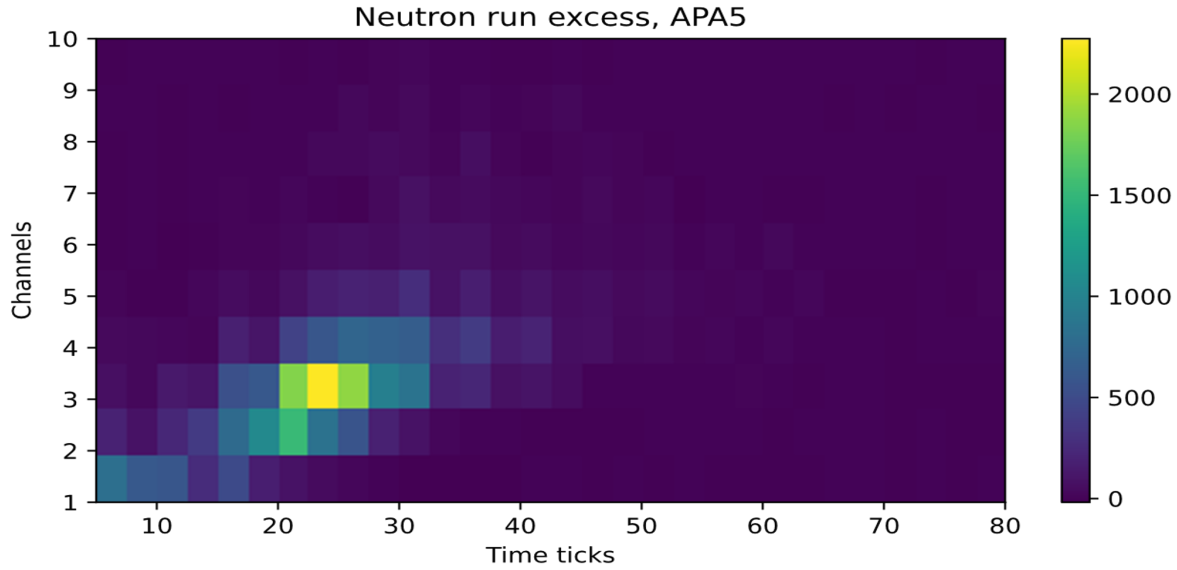


Cut tracks longer than:

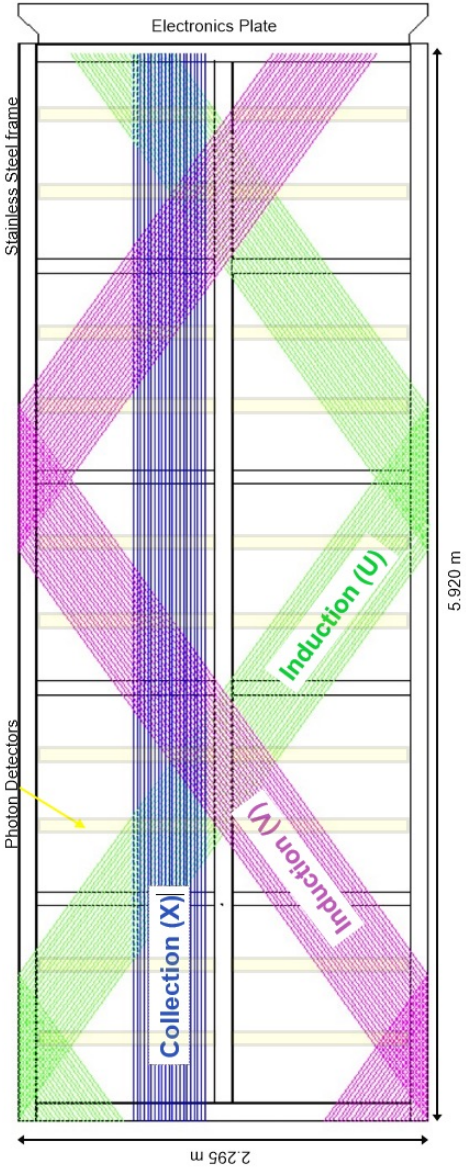
- 10 channels
- 80 time ticks



Result: neutron vs cosmic runs

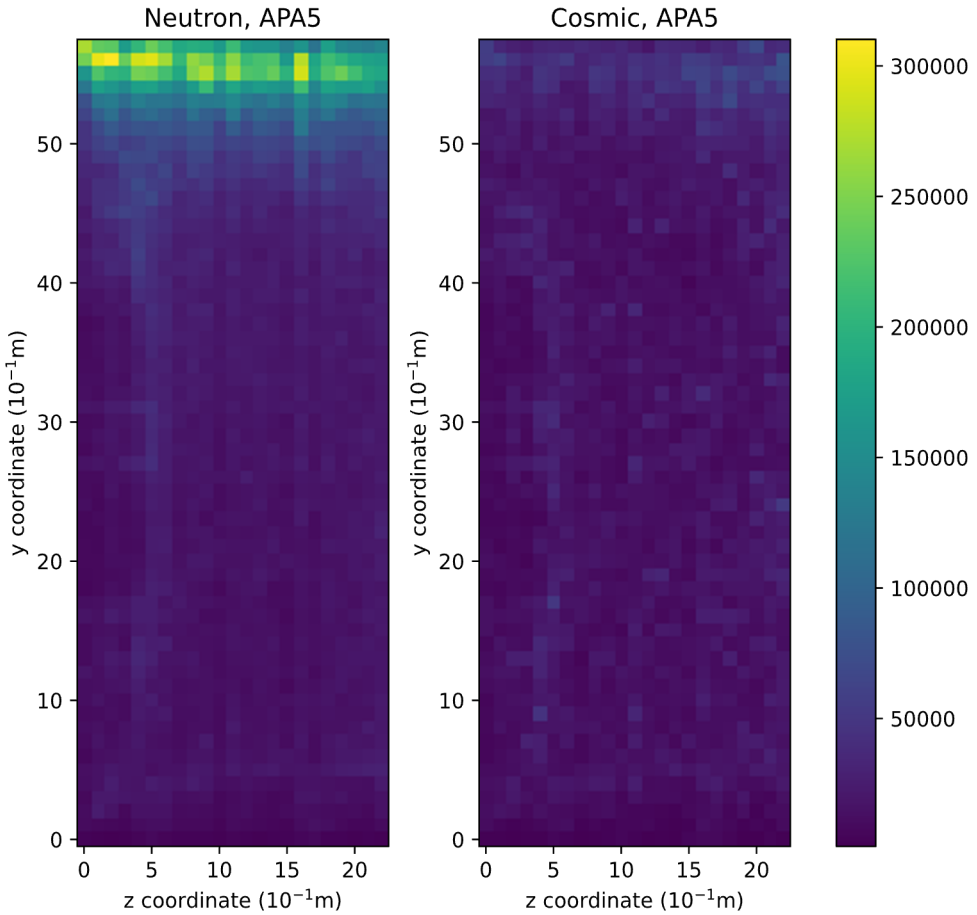


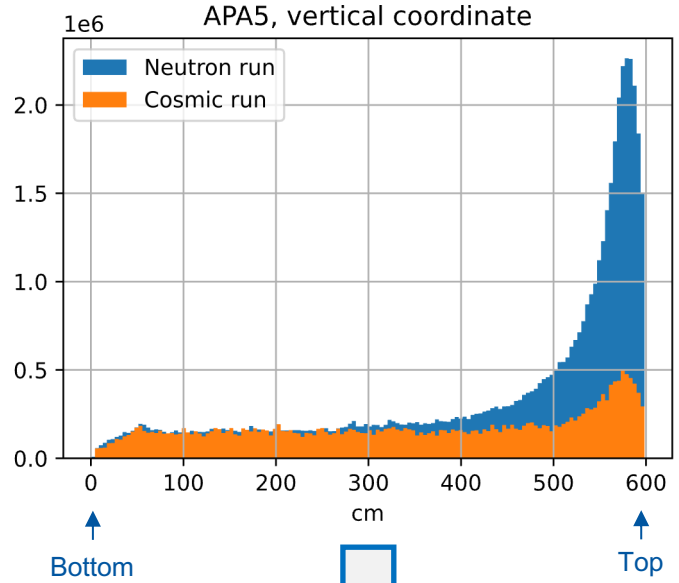
Spatial localization

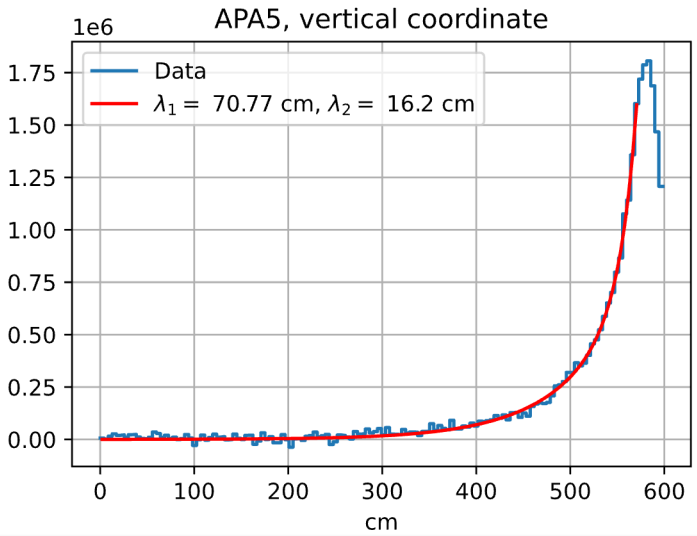


Gamma mean free path → ~ 14 cm

Neutron mean free path → ~ 80 cm



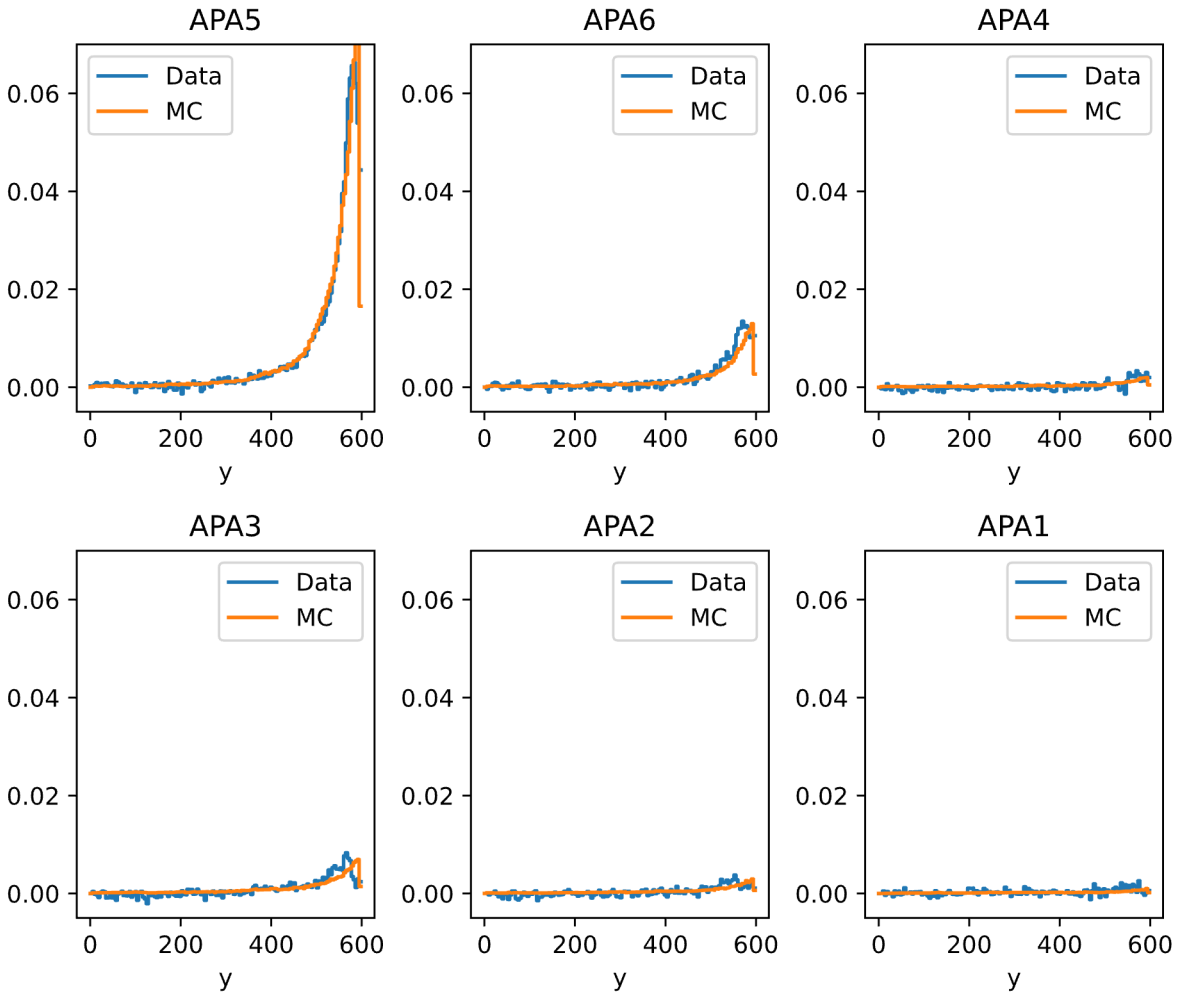




Monte Carlo comparison

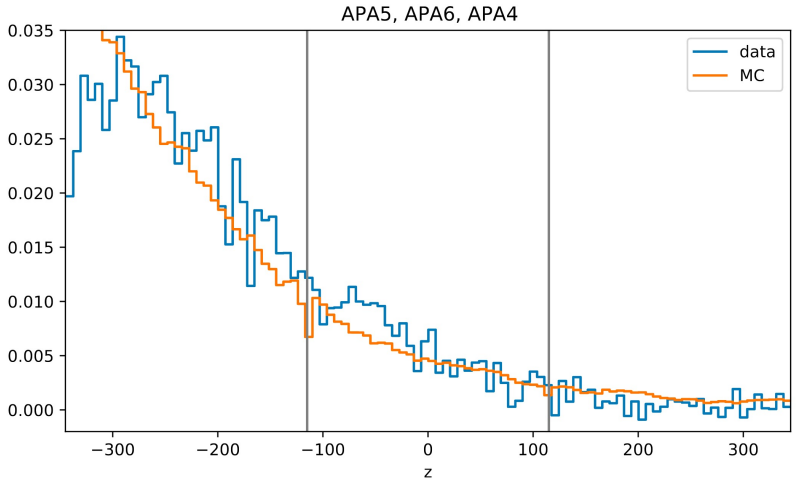
Full ProtoDUNE geometry plus the neutron gun performed with FLUKA

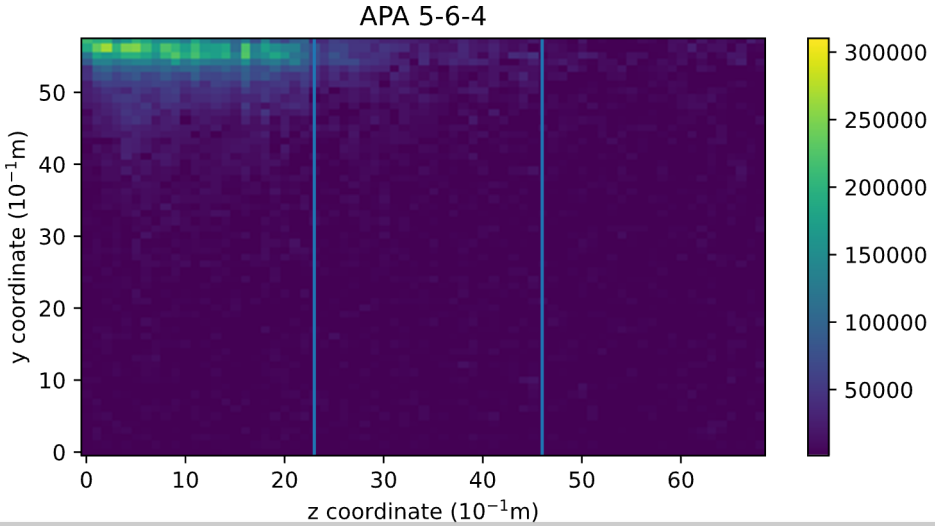
Vertical coordinate



5	6	4
3	2	1

Transversal coordinate





Conclusions

In order to perform the rare events studies DUNE data:

- We developed and adapted a semantic segmentation neural network to the DUNE requirements
- We trained it using MC and ProtoDUNE real data.
- We tested in a situation that resembles the DUNE's low energy events and we obtained very promising results
- The network is able to find neutron low energy interactions: it will be a powerful tool for the DUNE experiment.

Future developments:

- An implementation in hardware (FPGA or ASIC) for online application
- A subsequent network can be trained to perform a pre classification of the event

This project has received funding from the European's Union Horizon 2020 Research and Innovation Programme under grant agreement number 858199, 'INTENSE'