# Vertex reconstruction using the Photo Detection System

DUNE France Analysis Workshop
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16/11/2023

# DUNE low energy group

Laura Paulucci (UFABC) → leading the Supernova (SN) neutrino simulations production

Franciole Marinho (ITA) → developed the improvements for the clustering algorithm discussed in this talk

Ajib Paudel (Fermilab), Ariel Cohen & Jaime Dawson (APC) → working on the neutrino signal analysis for the Photo Detection System (PDS) vertex reconstruction for SN neutrinos

# Supernova (SN)

Supernova explosion:

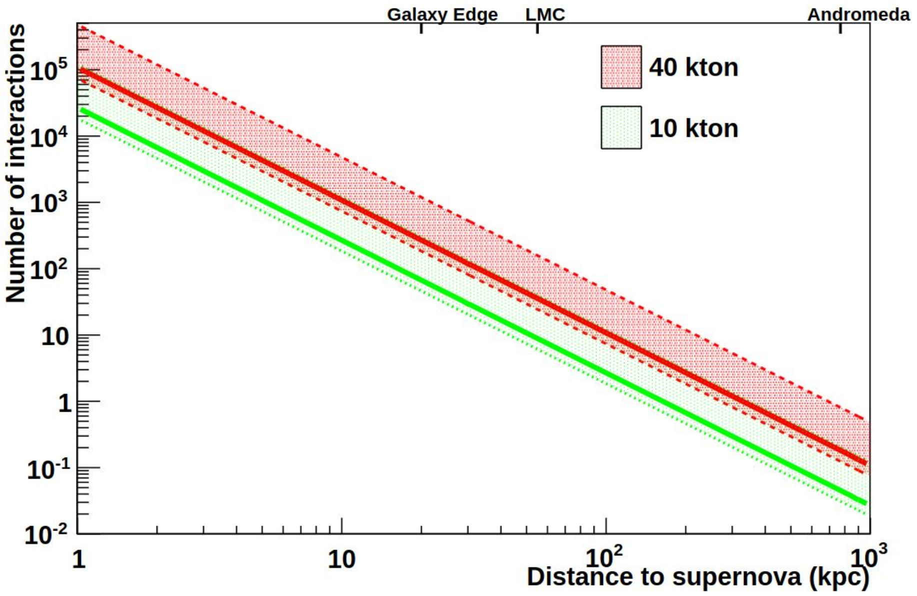
⟶ Low energy neutrinos of all flavors are emitted

DUNE → sensitivity of 10 - few tens of MeV →CC interactions produce short electron tracks in LAr

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

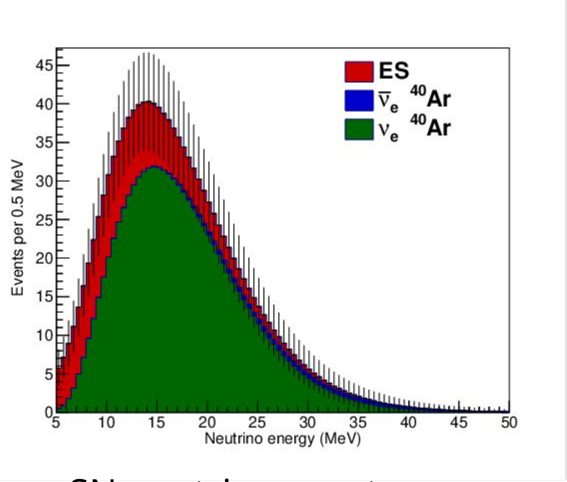
Also, deexcitation gammas product of K* allow for a unique way of tagging interactions

# What DUNE can do: directionality




Number of expected interactions as a function of SN distance

- **<u>Main objective</u>**: SN localization
- Neutrinos arrive before light signal
- Gives astronomers a chance to see the complete SN light curve!




SN neutrino spectrum

# Simulation and reconstruction

# Simulation software

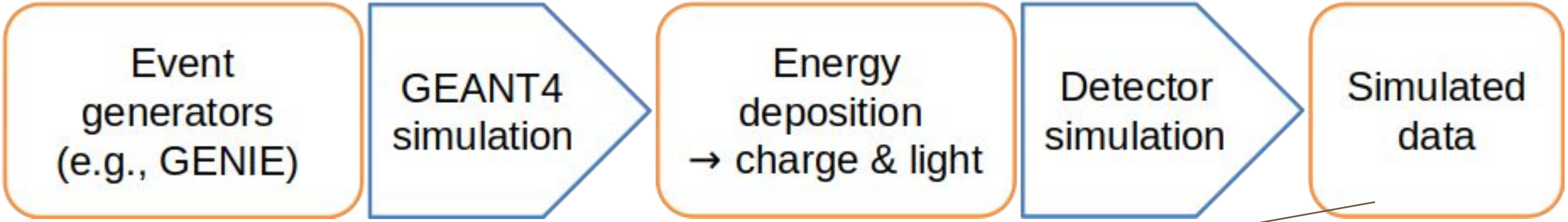
Liquid Argon Software (*LarSoft)* to produce the simulations

Github link →
https://github.com/DUNE/dunesw/tree/develop/fcl/dunefdvd

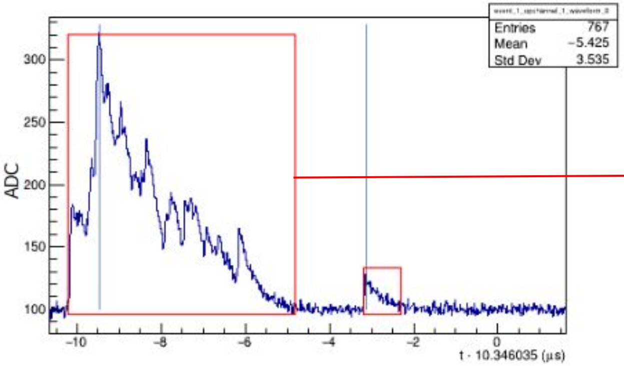
↓

Contains all the .fcl files required to run a
neutrino + LAr interaction events

# Scintillation light simulation



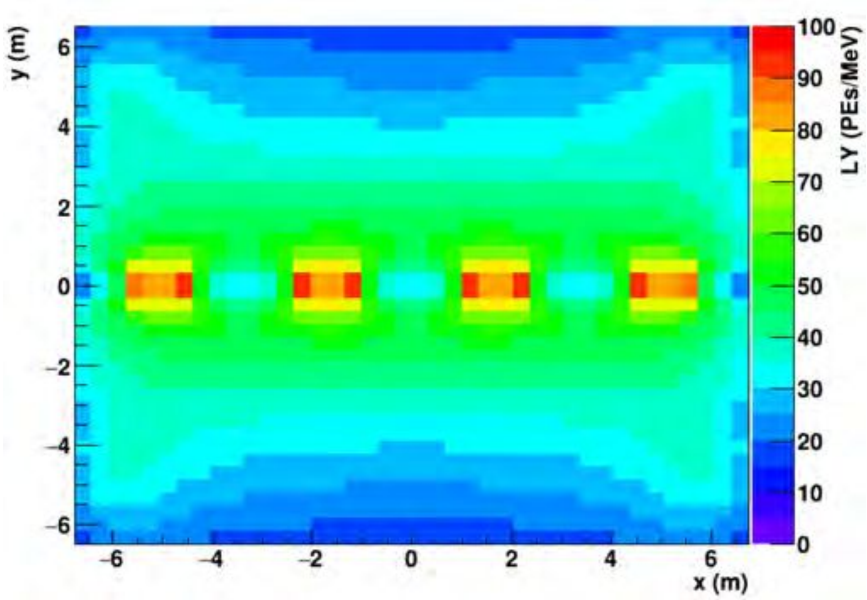

Example of an optical waveform




**hit finding:**
searches for peaks on individual waveforms channel-by-channel, identifying the time and the total amount of PEs

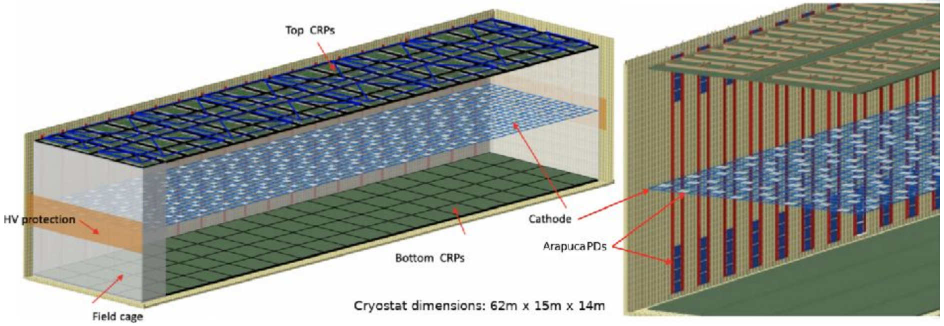
# Light yield

The **light yield (LY)** is defined as the amount of PEs obtained per unit of energy (usually MeV) → LY = PE/MeV




Xe doped (10 ppm) LAr LY → <LY> ~ 39 PEs/MeV

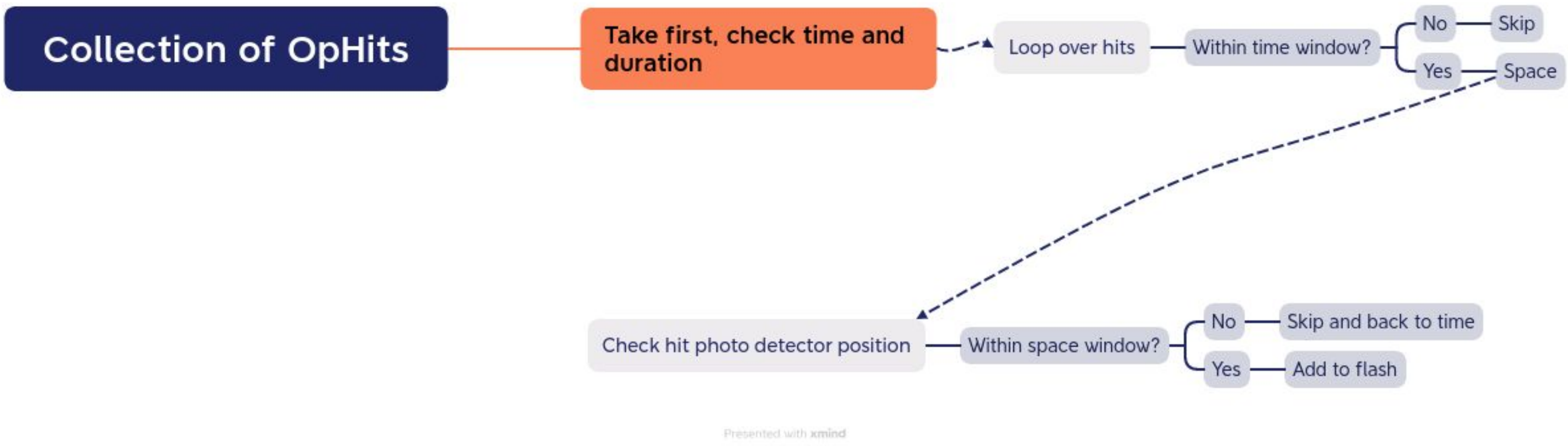
<LY> expected for DUNE > 20 PEs/MeV



# Clustering for position reconstruction

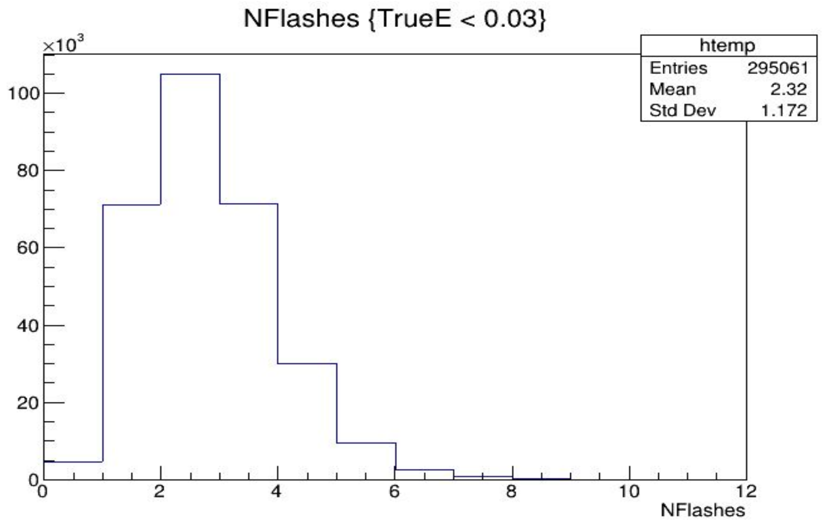
- Objective: generate *flashes* → clusterings of optical hits related in time and space
- With these flashes, we can perform a position reconstruction for the true event
- PDS reconstruction + TPC reconstruction →great imaging capabilities
- The PDS system also provides a good tool for triggering (can see DUNE TDR), and calorimetry (can see talk https://agenda.infn.it/event/33107/contributions/205130/attachments/112095/160096/NeutrinoTelescope23_brunetti.pdf)

# Creating flashes: how does it work?



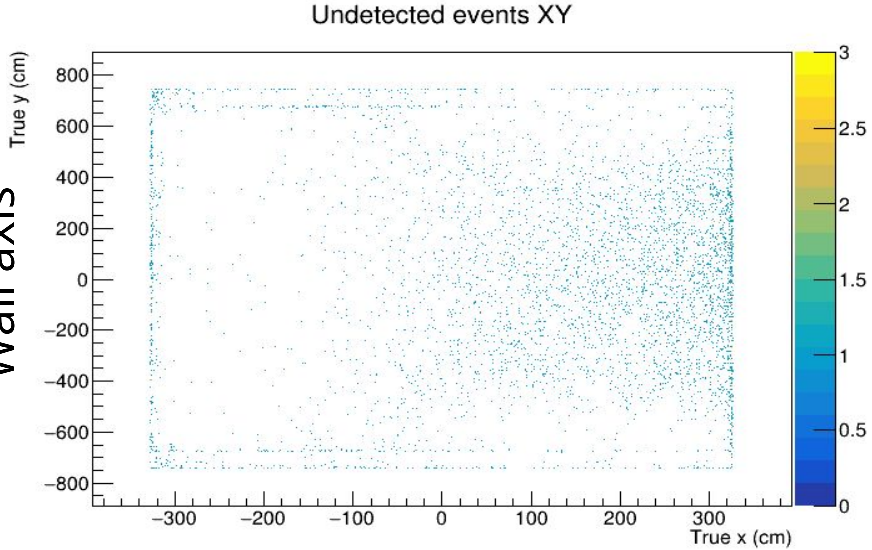
# #Flashes

- 4-30 MeV SN nues with a flat spectrum
- <LY> ~ 32 PEs/MeV




- The mean #flashes is ~2.32. Since all the hits come from a single signal event, ideally this value would be ~ 1
- Amount of 0 flashes is ~ 1.6 %

# Undetected points



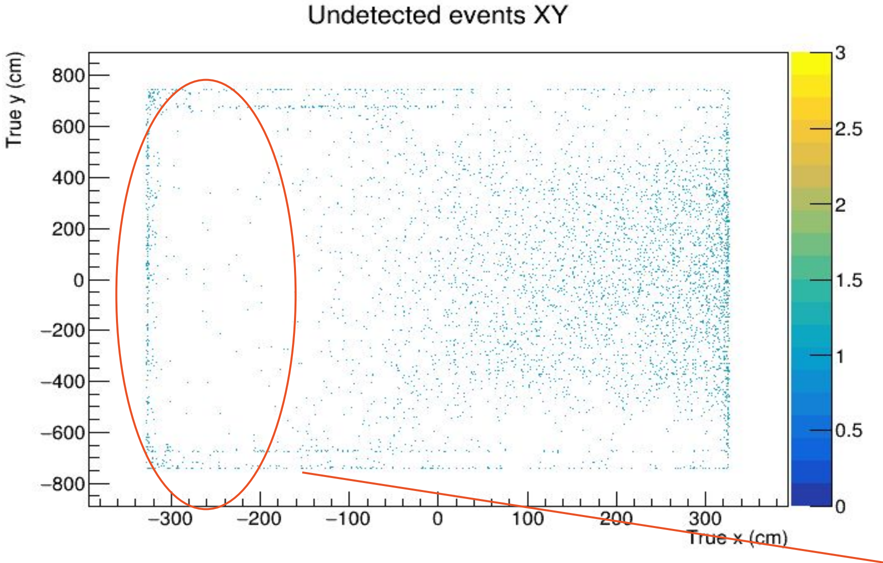

Top volume simulated

Wall axis

Drift axis

1. Amount of 0 flashes ~1.6%
2. Most of the undetected point occur further away from the cathode and the walls

# Undetected points



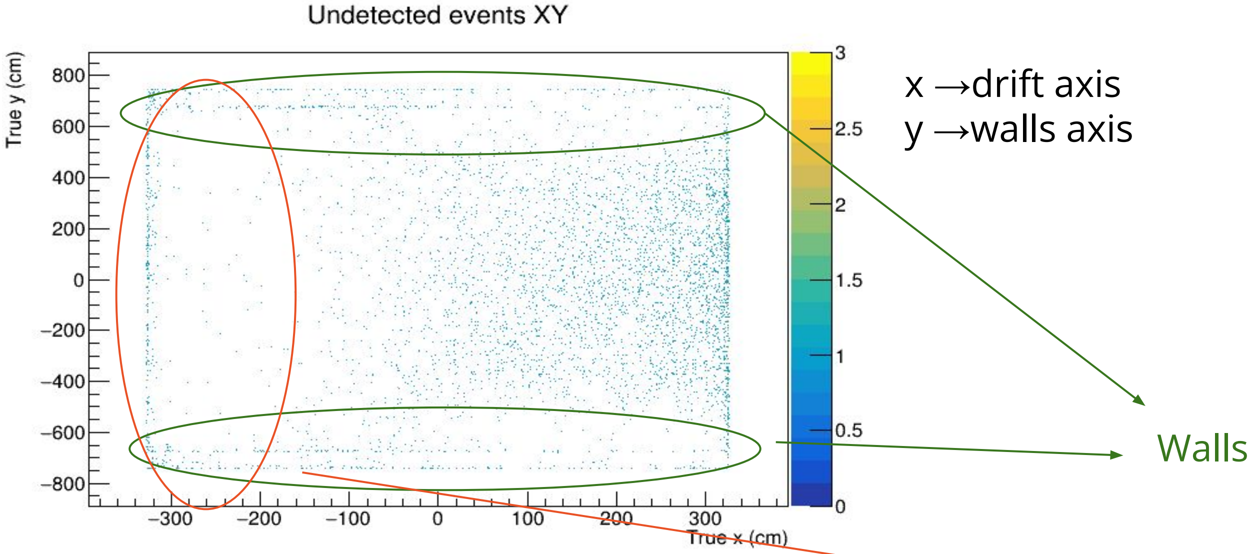

x →drift axis
y →walls axis

Top volume simulated

Cathode

1. Amount of 0 flashes ~1.6%
2. Most of the undetected point occur further away from the cathode and the walls

# Undetected points

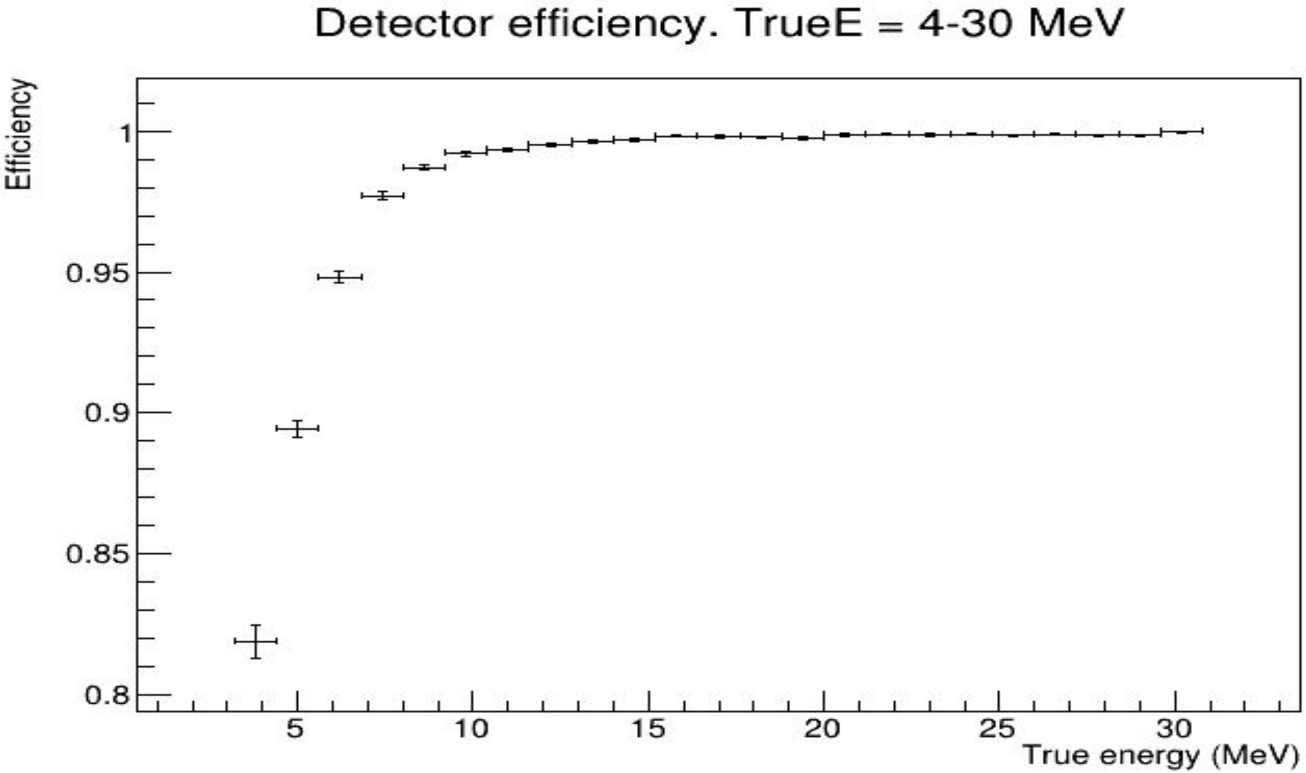



x →drift axis
y →walls axis

Top volume simulated

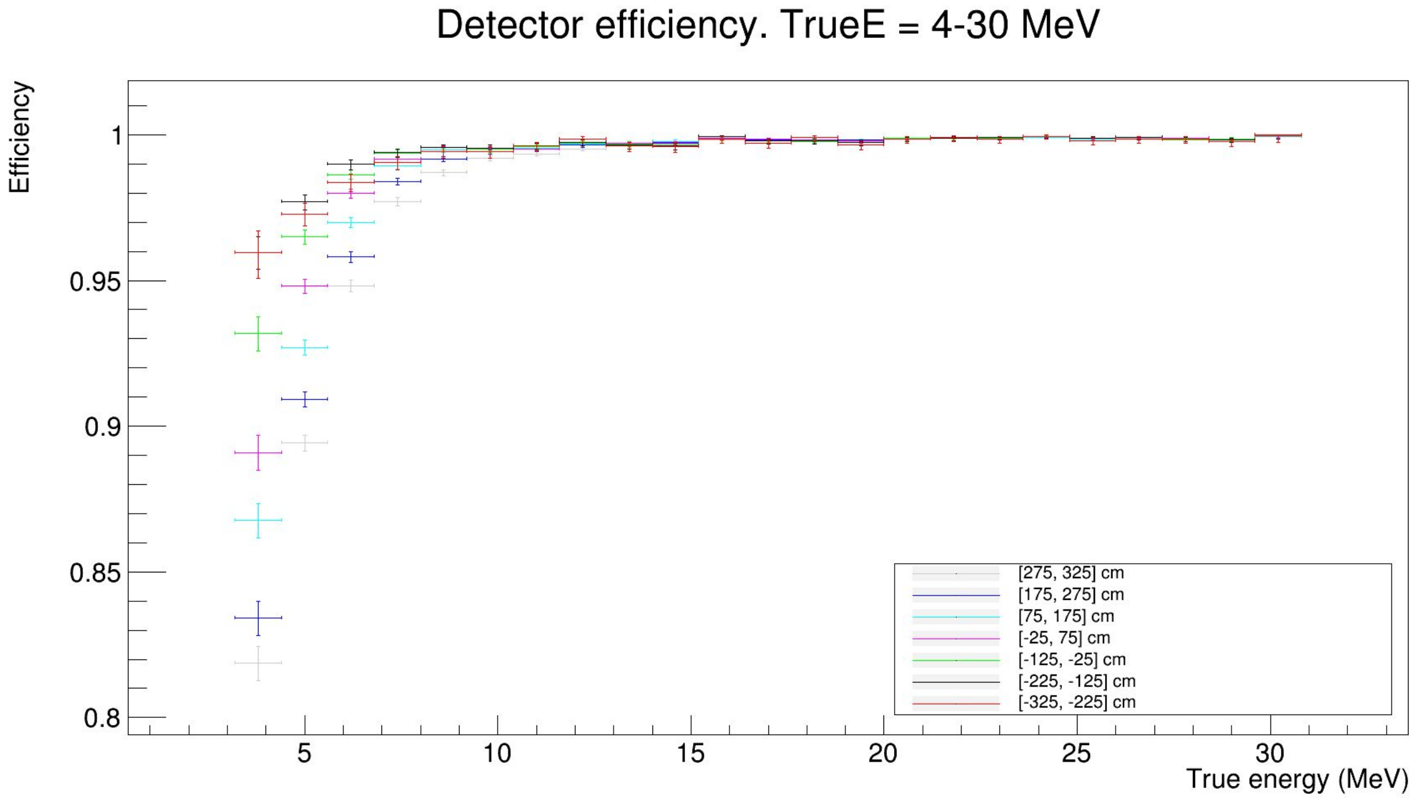
1. Amount of 0 flashes ~1.6%
2. Most of the undetected point occur further away from the cathode and the walls

# Detector efficiency



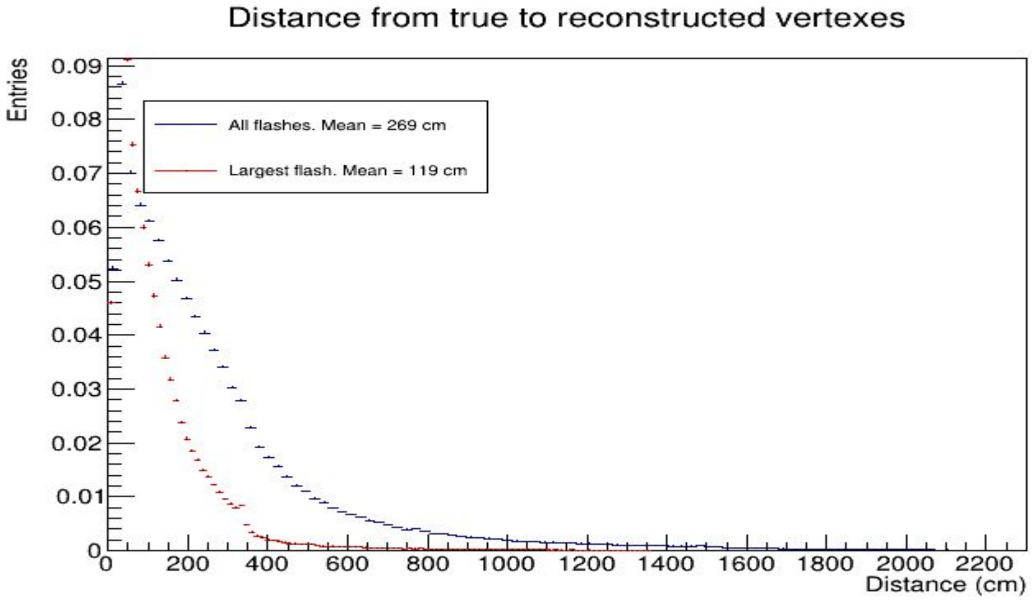

*Deff = #events with at least 1 flash/All events*

# Detector efficiency




- Made 1m cuts in the drift axis
- Strong geometrical effect, specially for lower energy neutrinos

# Spatial resolution




- Resolution for *all* flashes (blue), and the *largest* flash (red).
- Flashes with lower amount of PEs have a worse reconstruction

# Signal + background

# Background model

| Component | Activity (mBq/cm$^3$) |
|---|---|
| $^{39}$Ar in LAr | 1.41 |
| $^{42}$Ar and $^{42}$K in LAr | 0.128 $\times 10^{-3}$ |
| $^{85}$Kr in LAr | 0.16 |
| $^{222}$Rn chain in LAr | 1.395 $\times 10^{-3}$ |
| $^{40}$K in cathode | 9.1 |
| $^{238}$U chain in cathode | 0.113 |
| $^{60}$Co in anode | 0.361 |
| $^{238}$U chain in anode | 95 |
| $^{222}$Rn chain in PDS | 0.021 |
| External neutrons (rocks, concrete walls, etc) | 7.6 $\times 10^{-3}$ |
| Cavern gammas | 64 |

The two bigger points of interest are:

1. Low energy, lots of events: mainly Ar39/Ar42 (Ar 39 is generated at a rate of 1/Ls, which with 17 kt of LAr would produce ~ 10^{10} particles of 2 MeV each.
2. High energy, fewer events: mainly neutrons, which capture producing a ~6.1 MeV gamma shower.

# Signal + background simulation

**Signal**

- SN nue
- 5-30 MeV energy spectrum
- Entire simulation extends through +- 4 ms (determined by the electron drift time), with the signal is located at **T=0**.

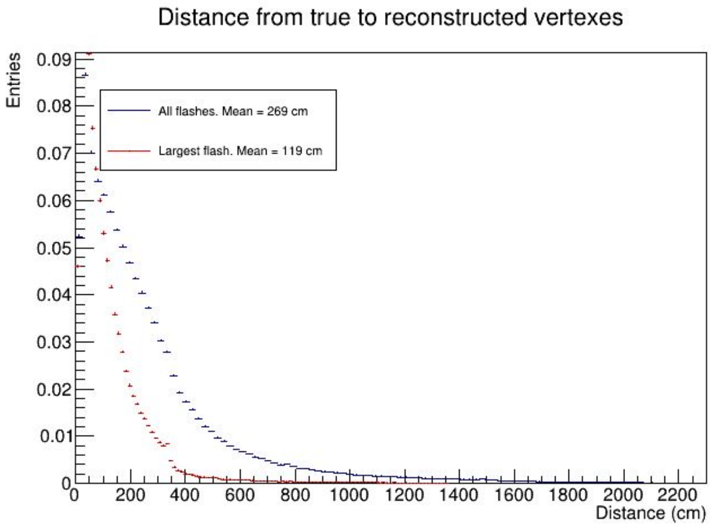
**Background**

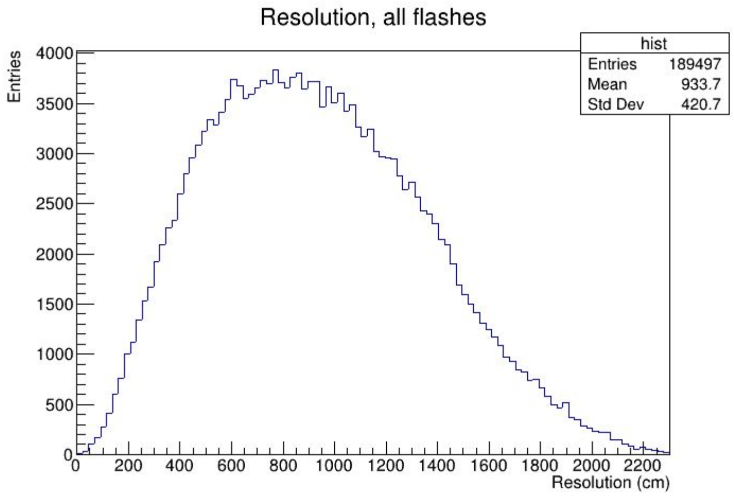
- Background extends throughout the *entire* detector, and also throughout the *entire* time window **T = +- 4 ms.**

# Resolution comparison

Background →more light across the detector and throughout the entire time window (+- 4 ms considering TPC drift) →more flashes

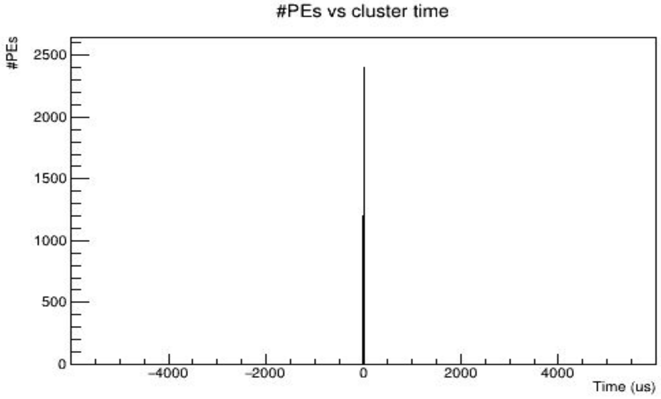
For example, looking at the spatial resolution:



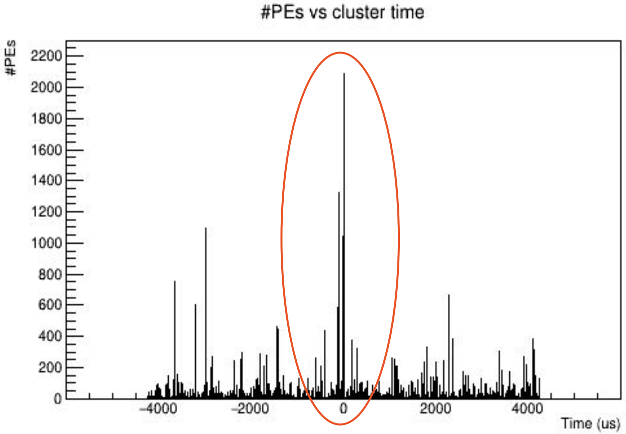



# #PEs vs time, near X-Arapuca

30 MeV nue signal only




30 MeV nue signal plus background

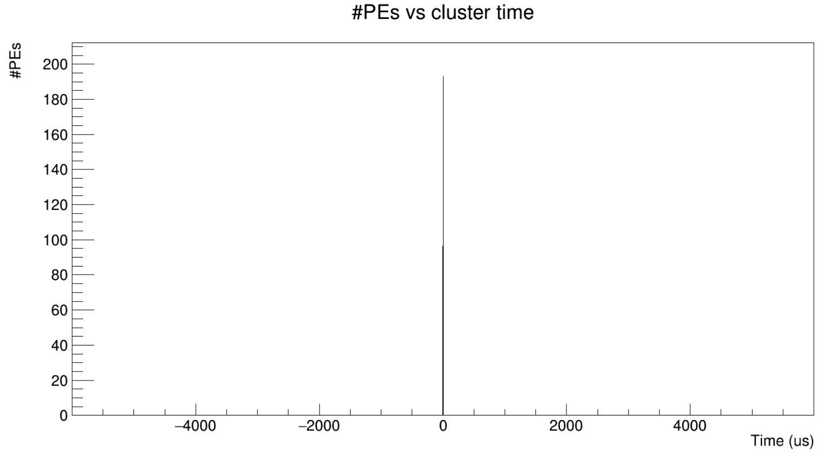



Neutrino signal is higher than background when close to an X-Arapuca

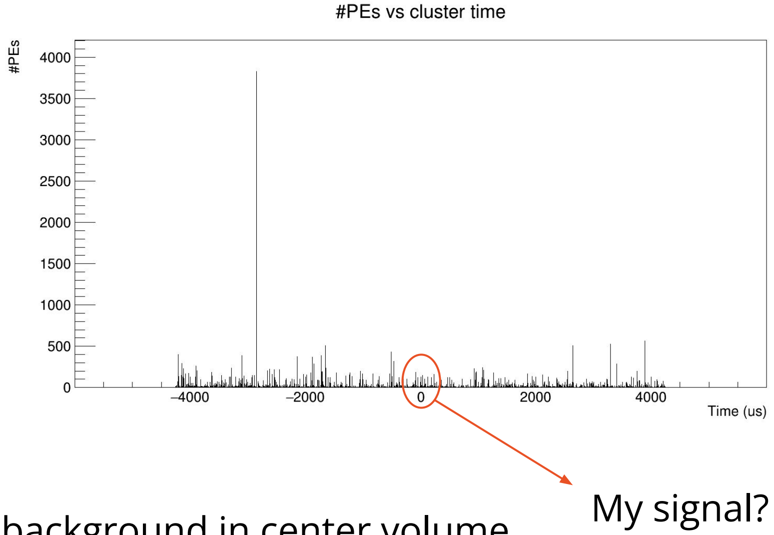
My signal

# #PEs vs time, center volume

30 MeV nue signal only

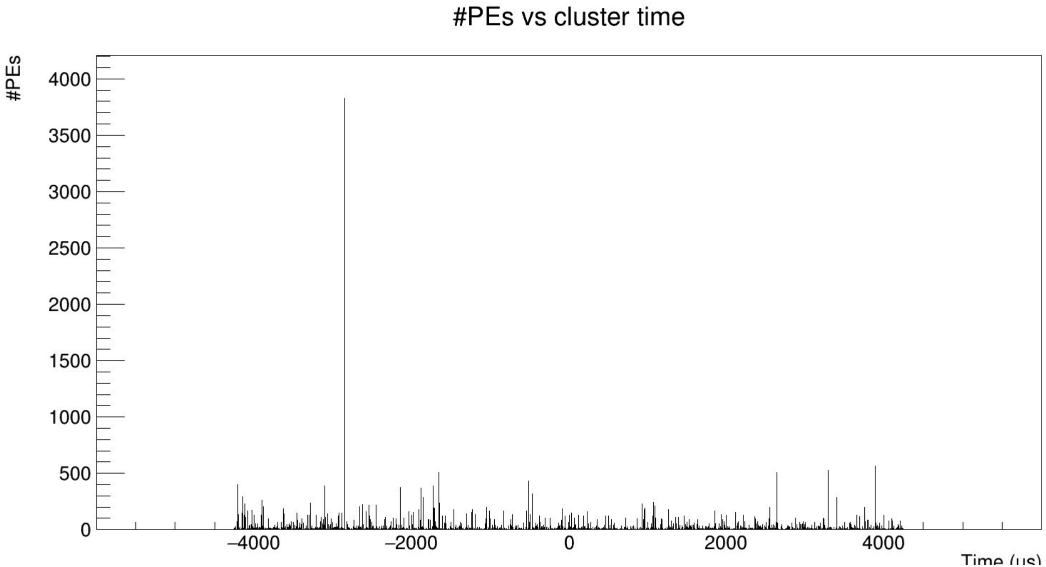



30 MeV nue signal plus background




The neutrino signal strength is comparable to the background in center volume

# What is the plan?



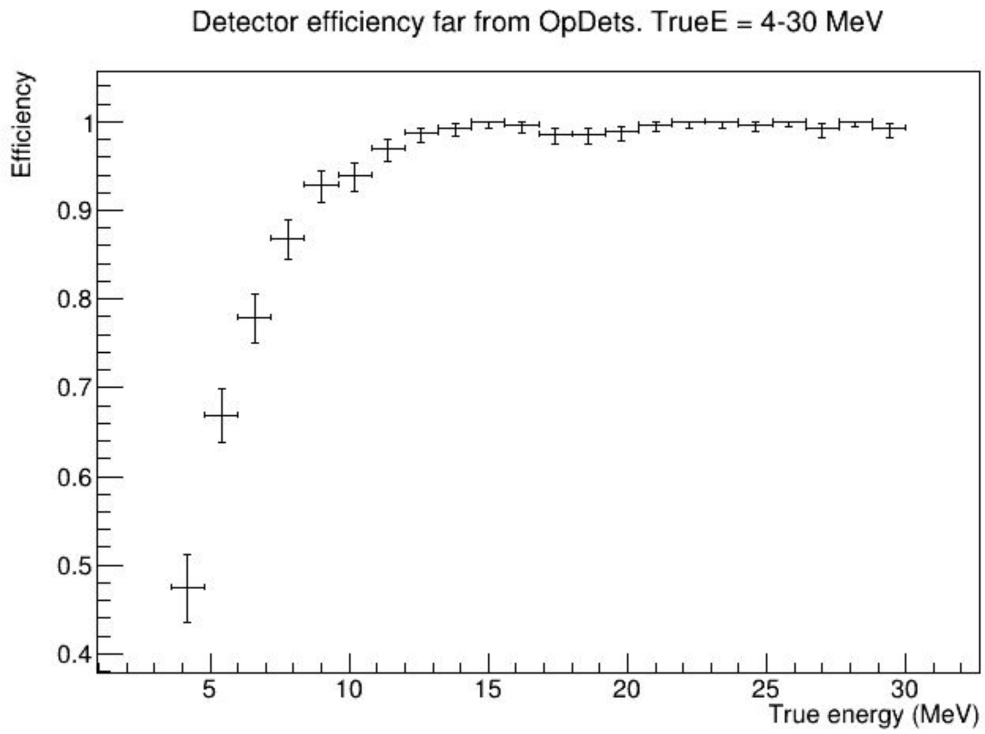

- <u>Objective:</u> explore clustering to maximise number of photons from the neutrino signal
- Explore discrimination capability as a function of spatial position

# Conclusions

- Clustering algorithm shows good performance for a signal only simulation, with a spatial resolution of ~1.2m when considering the largest flash
- Optimization of waveforms and peak finding parameters to increase detection efficiency is under study
- Background induces some significant alteration in the clustering process due to the high amount of extra PEs generated
- Obtain a set of parameters for signal identification and background discrimination

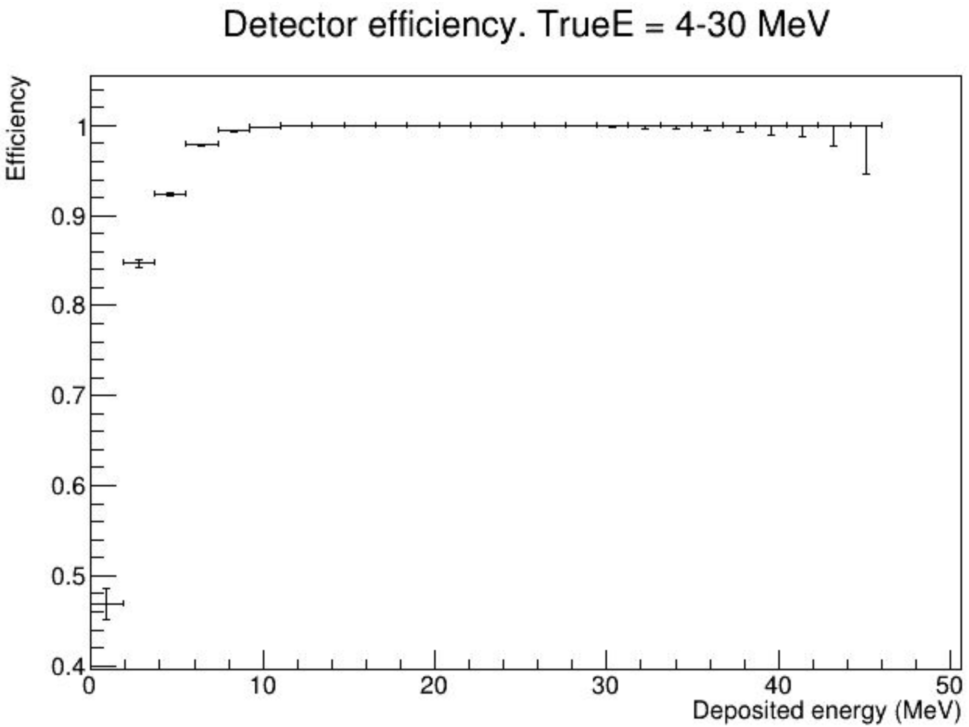
# Backup slides

# Detector efficiency, X and Y cuts

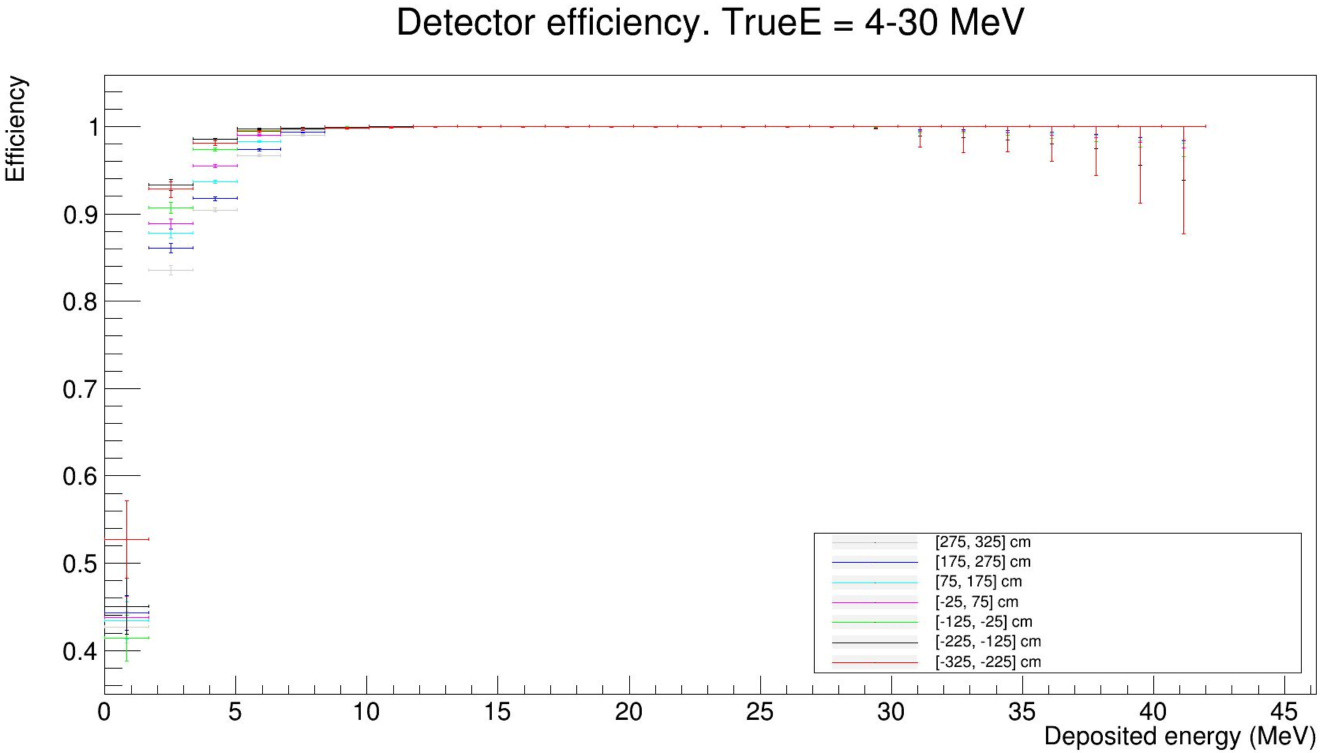



<u>Spatial cuts:</u>
225 cm < x < 325 cm
-100 cm < y < 100 cm

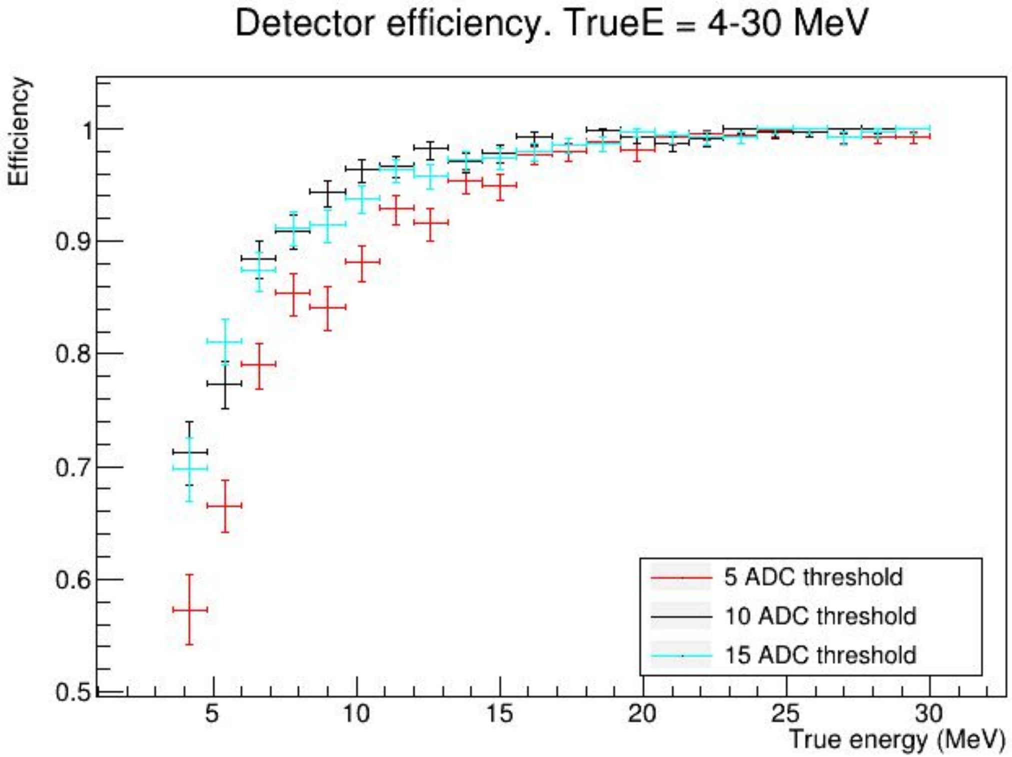
# Detector efficiency, deposited energy



# Detector efficiency, deposited energy



# PE waveform threshold variation




<LY> ~ 23 PE/MeV