DUNE DEEP UNDERGROUND NEUTRINO EXPERIMENT

The University Of Sheffield.

Cosmic rays and cosmogenics: Status and future plans

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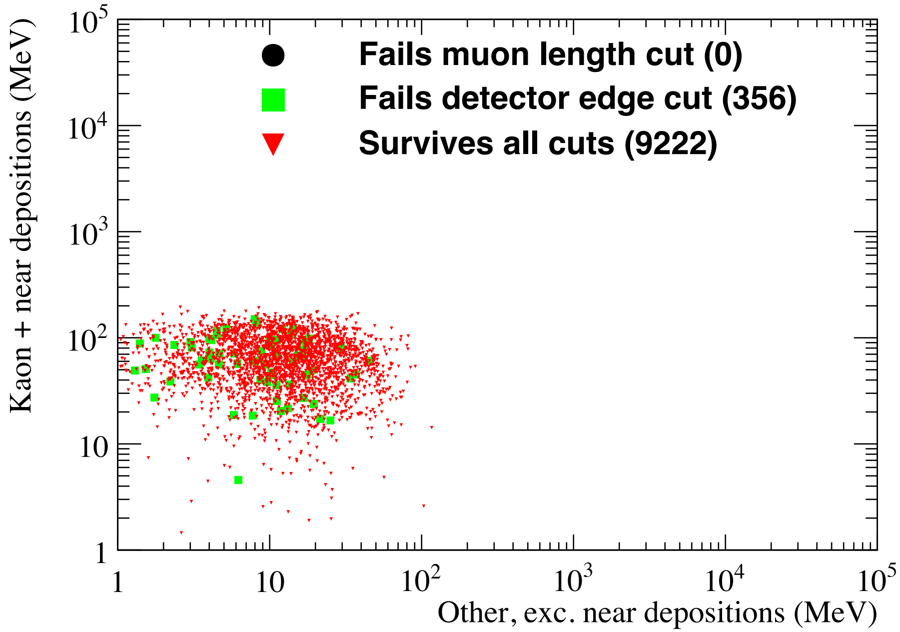
Muons sampling

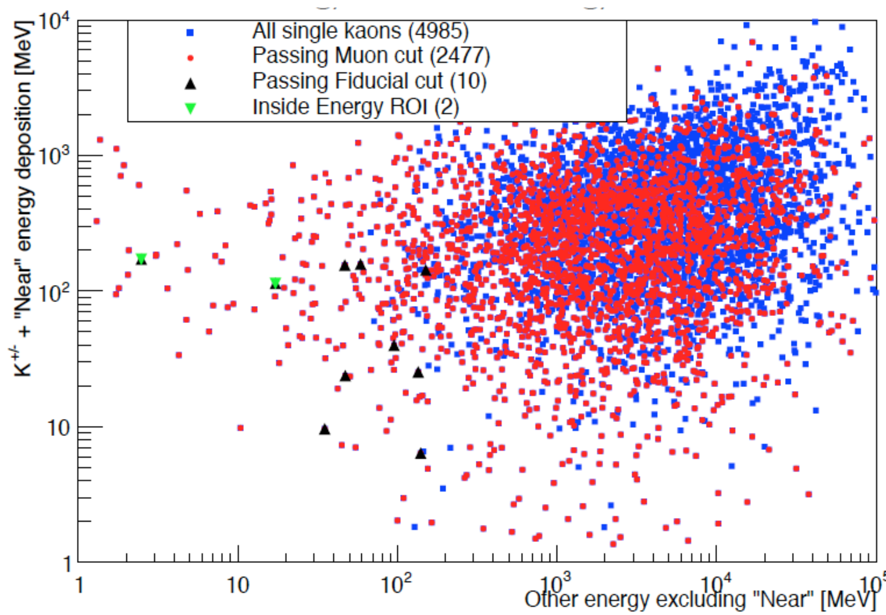
- MUSUN (MUon Simulations UNderground) muon generator.
- Original code was re-written and incorporated into LArSoft (Karl Warburton + others).
- Uses pre-transported muons with the whole surface profile included.
- Samples muons according to their angular distributions and energy spectra for each angle.
- Uncertainty in the total rate about 20%. Better normalisation requires measurements.
- Muons are sampled in rock a few metres above and around the cavern.
- At the moment only one module (~ 10 kt fiducial).

Status of muon background for NDK search

- About 2×10^9 muons were generated (Matt Robinson).
- Geometry: 1 module with about 10 kt fiducial mass.
- About 5×10^6 muons per year -> 400 years of live time (1 module).
- Pre-selection: no primary muon track more than 1 m long, total energy deposition more than 10 MeV, ~1.7% of all events.
- Initially only MC truth info for these muons.
- Analysis of MC truth for all 2×10^9 muon events was completed (for 2 nucleon decay modes: $p \to K^+\bar{\nu}$ and $n \to K^+e^-$).
- Currently two background events found for $p \to K^+\bar{\nu}$: $K^0{}_L$ enters the TPC and produces an isolated K^+ with the right momentum.
- Final state interactions change the picture: kaon energy is smaller, proton tracks and neutron hits can be present.
- Muon event sample can be used for other tasks to study backgrounds but not for any other task (like calibration).

Proton decay: $p \rightarrow K^{+}\overline{\nu}$





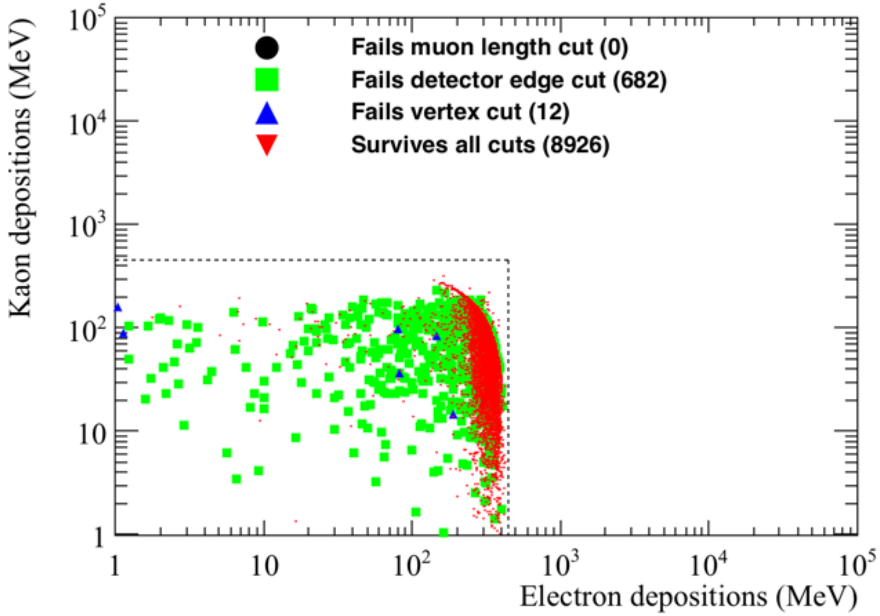
Cuts:

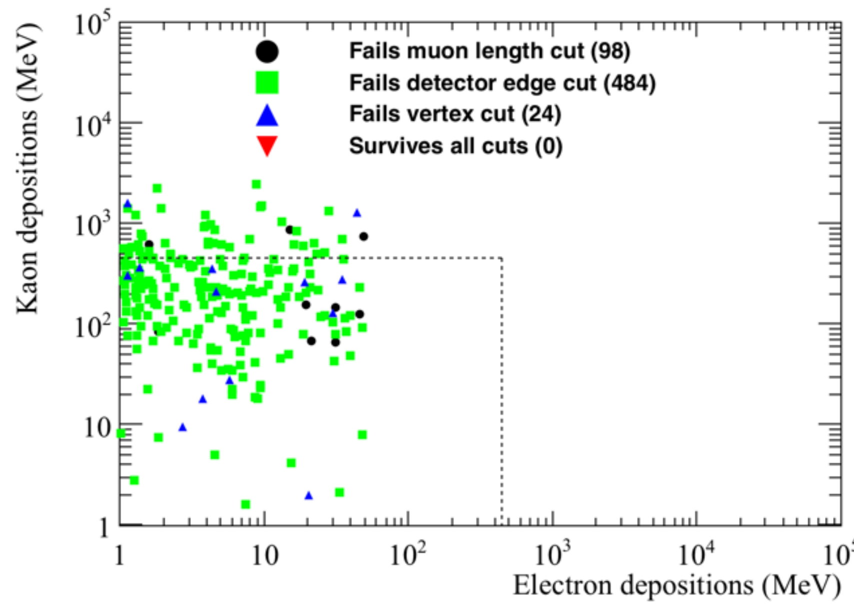
- No primary muon track longer than 20 cm.
- Single kaon.
- No hits within 2 cm from the walls.
- Kaon energy deposition <250 MeV.

Only MC truth.

Number of events passing the cut depends on the ROI: 2 events if 'Other' energy deposition is less than 30 MeV. Background rate 0.5 events / Mtonne / year (Matt Robinson).

Neutron decay: $n \to K^+ e^-$



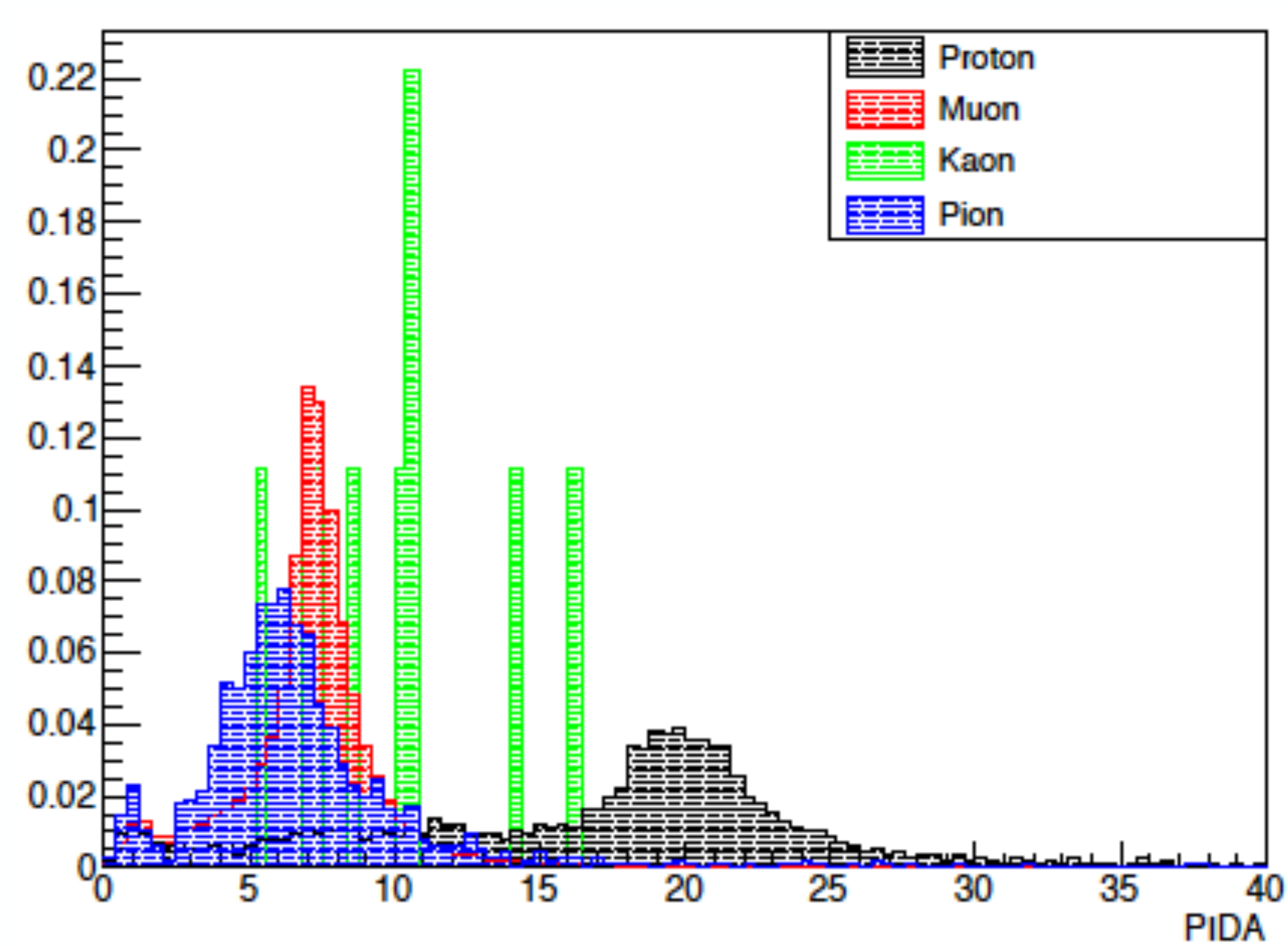


- Kaon energy versus electron energy from neutron decay events (left – defines the energy range of interest) and muon background (right).
- Additional constraint of requiring an electron track reduces the number of candidate background events.
- Generally, background events which do have an electron track, have too much energy deposited in the detector to be a signal event.
- A very promising decay mode to consider but so far MC truth only.
- No background events survived the cuts: rate < 0.6 / Mtonne / year (Karl Warburton).

Further processing

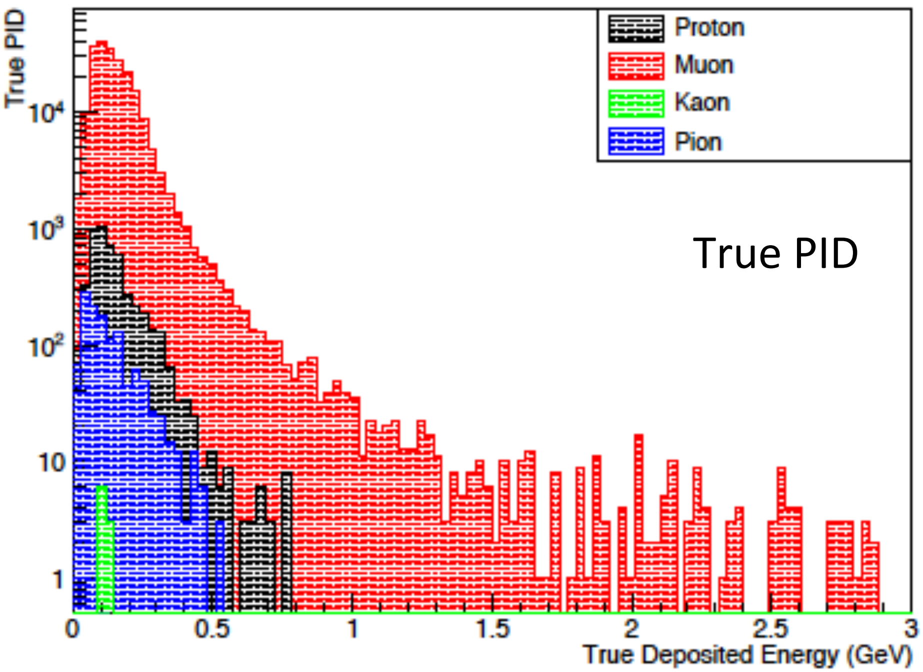
- Second filtering (the first one was: muon track < 1 m, energy deposition > 10 MeV):
  - Total energy deposition between 10 MeV and 3 GeV (to study nucleon decay candidates);
  - Energy deposition within 10 cm of the TPC edges < 5 MeV.
  - About 0.23% of events pass all cuts; 4.6×10^{6} out of 2×10^{9}.
  - Manageable but requires intensive CPU usage and storage.
- Work started on reconstruction (Matt Robinson, Mike Wallbank).

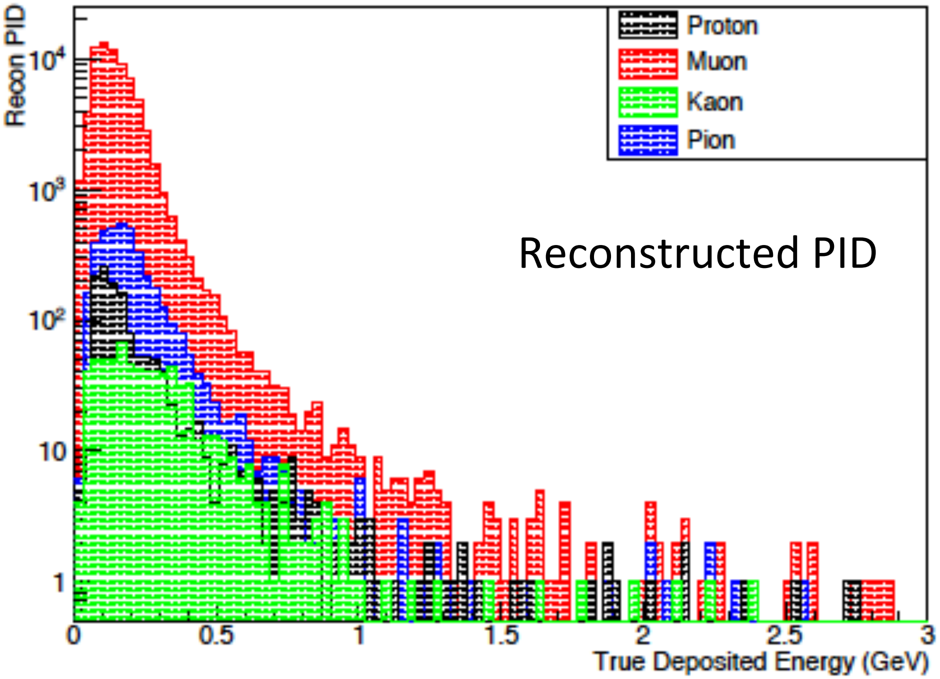
First results (very preliminary)



- Pandora reconstruction.
- Standard PIDA parameter for particle ID.
- Only 7 kaons.
- Large overlap between species.

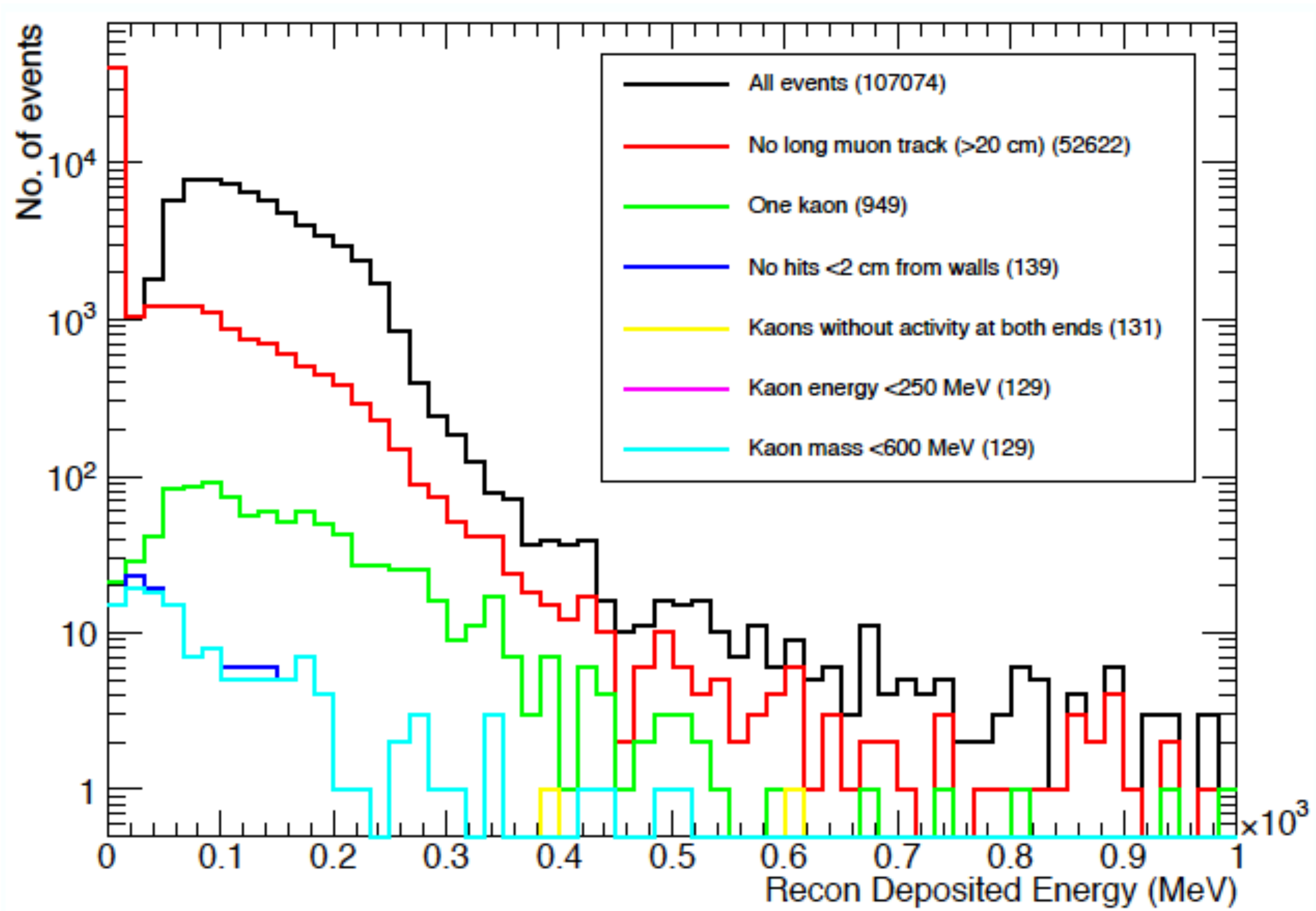
Energy spectra





- Lots of misidentified kaons, mainly from muons and protons.

Reconstructed energy spectra



Conclusions and Plans - I

- Promising results based on MC truth information:
  - Two (or more) events survive the cuts for a proton decay mode, event rate ~0.5 events/Mt/year.
  - No event survives the cuts for neutron decay mode, <0.6 events/Mt/year.
- Reconstruction of cosmic events is tough (can experts help?).
  - One of the main problems – particle ID, many muons and protons mimic kaons.
  - Final state interactions in a real proton/neutron decay event reduce the kaon energy making the reconstruction difficult.
  - Allowing low kaon energy in the ROI, an additional activity in the kaon production vertex (escaping protons) and an additional activity due to neutron interactions somewhere nearby (escaping neutrons), increases the number of background events.

Conclusions and Plans - II

- Key issue: particle ID.
- Need to work closely with the reconstruction people to make it working.
- Include kaon decay modes in particle ID.
- So far reconstruction was tuned to neutrino events; cosmic events also require attention as a potential background.
- Some physics with cosmic events is also possible, e.g. activation studies, cascades etc.
- Calibration with cosmic-ray muons.
- First years of the first one or two 10 kt module(s) may not see beam data, only cosmics.
- This work desperately needs attention; 30% FTE in Sheffield is not enough.
- Please, e-mail us if you can and want to contribute.