

Background for proton decay search

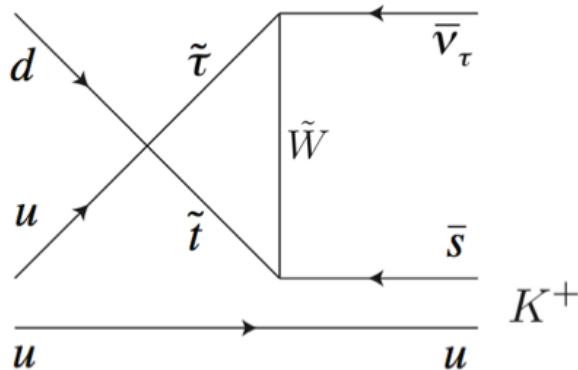
Vitaly A. Kudryavtsev

Brief history

- Cosmogenics group for LBNE (VK was one of co-conveners):
 - Formed in 2012.
 - Initial studies (even before formal structure): background for a proton decay at 800 ft level: $p \rightarrow K^+ \bar{\nu}$
 - Moved to the simulations for a surface detector 2012-2014.
 - Some work on background for proton decay at 4850 ft: $p \rightarrow K^+ \bar{\nu}$
 - Accurate muon model (see next talk and previous LBNE notes).
 - Preliminary results for a simplified geometry (box).
- Cosmogenics background for LBNO (not a formal WG/WP):
 - Estimates for the Expression of Interest to CERN (2012).
 - Simulations of background for proton decay: $p \rightarrow K^+ \bar{\nu}$
 - Simplified muon model ('flat' surface).
 - Simplified (cylindrical) geometry.
 - Results published in [Klinger et al. PLB, 746 \(2015\) 44](#).
- No event reconstruction.

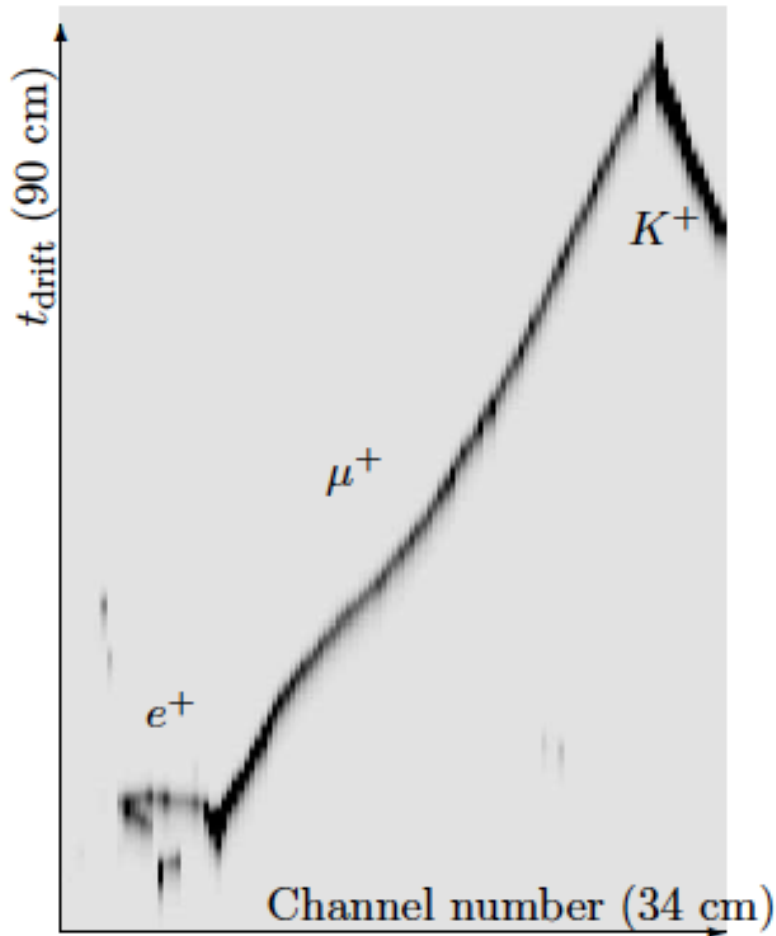
Proton decay

- Baryon number violation → physics beyond the standard model → testing GUT models.
- Best current limits on most decay modes (for instance $p \rightarrow e^+ \pi^0$) are from Super-K. LAr detectors can see most modes and have a better event reconstruction capability but the sensitivity is not as good as for Super-K/Hyper-K because of smaller exposure.
- The strength of LAr: $p \rightarrow K^+ \bar{\nu}$

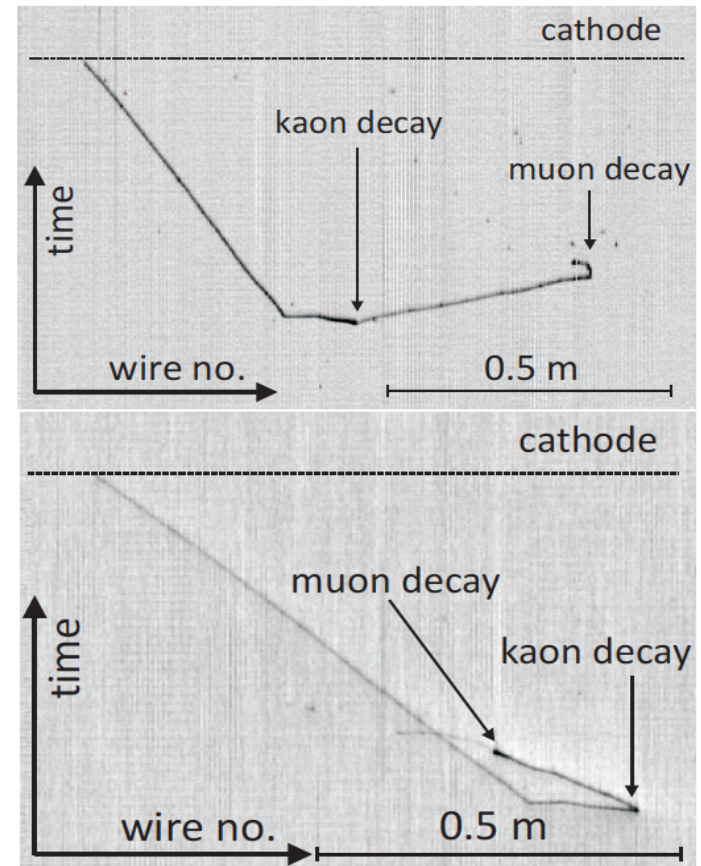


- SUSY motivated.
- Low threshold in LAr (no Cherenkov threshold).
- Good event reconstruction.
- Background can be under control.

Background for proton decay

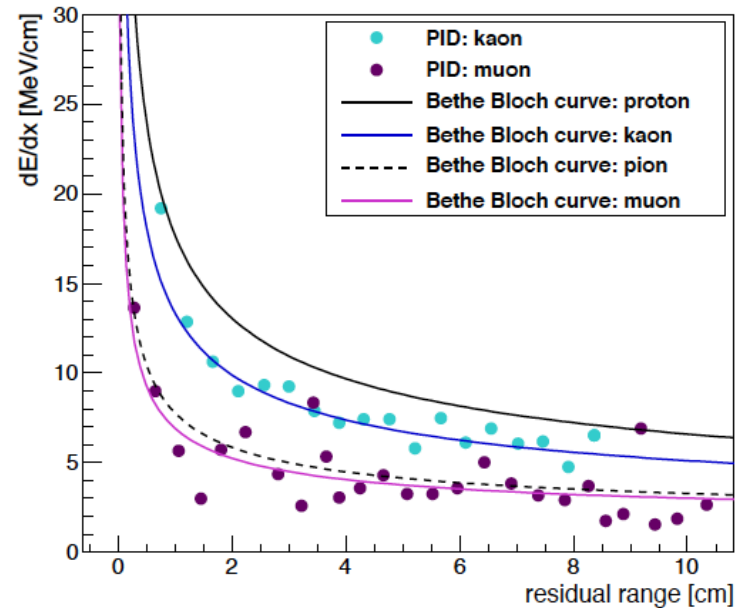
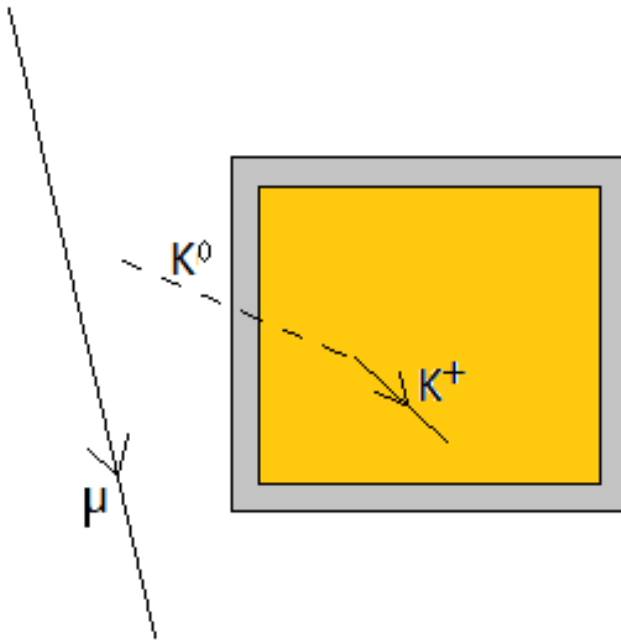


- Event simulation from Bueno et al. JHEP04 (2007) 041.



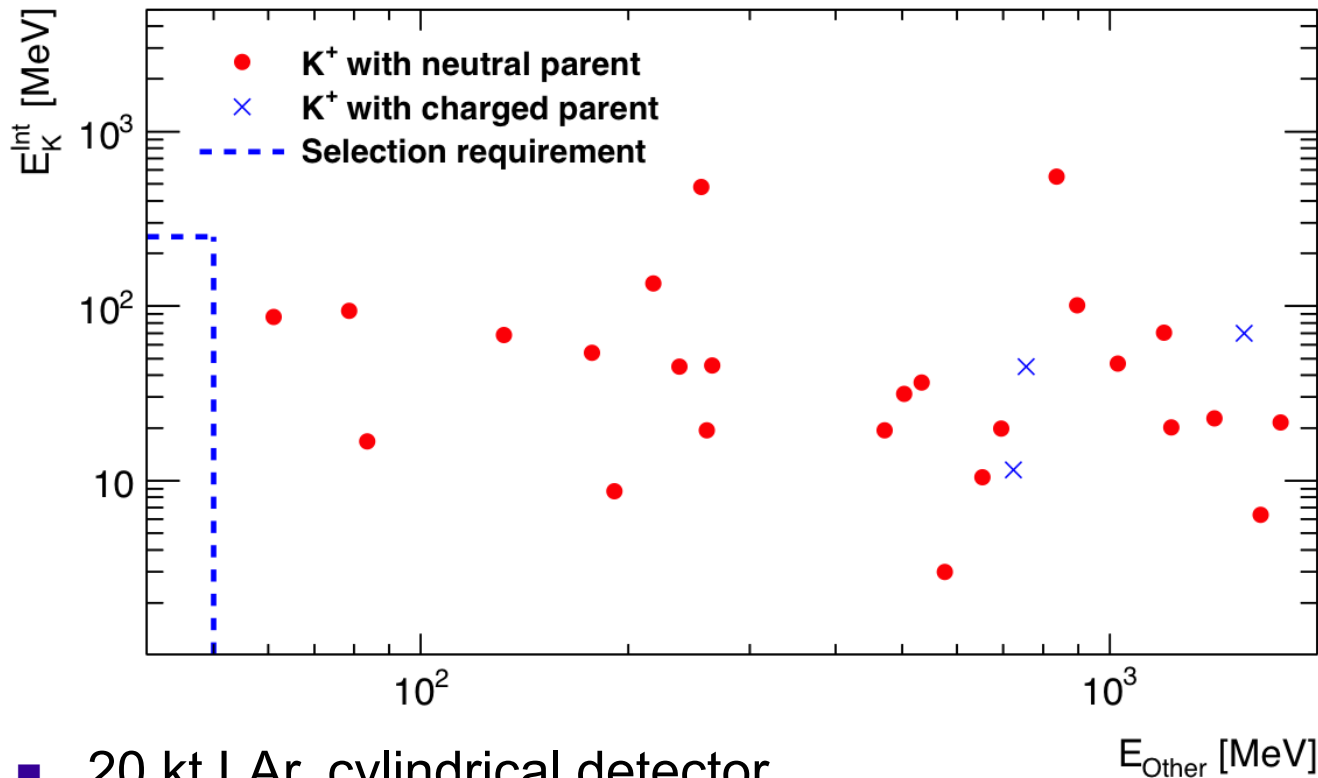
- ICARUS T600 event from Antonello et al. Adv. High Energy Phys. (2013) 260820.

Background for proton decay



- Kaon momentum 340 MeV ($E_{kin}=106$ MeV) smeared by Fermi motion and intranuclear scattering.
- Kaon ID and energy from dE/dx and range (see [Antonello et al. Adv. High Energy Phys. \(2013\) 260820](#)).
- Assume perfect kaon reconstruction.
- Cut on the energy deposition.

Cosmogenic background (LBNO type)



Klinger, Kudryavtsev,
Richardson and
Spooner, Physics
Letters B, 746 (2015)
44.

- 20 kt LAr, cylindrical detector.
- No muons (track length of a muon < 20 cm).
- No events close to the 'walls' (< 10 cm).
- Total energy deposition < 1 GeV.
- Small energy deposition from other particles.

Results for a cylindrical detector

Table 1

The number of expected events after 100 years of exposure, as a function of sequential selection criteria and the K^\pm production mechanism. Events are accepted into the table if the total energy deposition in the event is less than 2 GeV. Numbers presented in brackets indicate the subtotal number of K^- events, N refers to nucleons in the interaction.

| K^\pm parent | Exactly one K^\pm | No muon | No activity near wall | $(\mu^\pm \text{ or } K^\pm) \rightarrow e^\pm + X$ | $E_K^{\text{int}} < 250 \text{ MeV}$ | $E_K^{\text{int}} + E_K^{\text{Dec}} < 1 \text{ GeV}$ | $E_{\text{Other}} < 50 \text{ MeV}$ |
|-------------------------|---------------------|----------|-----------------------|---|--------------------------------------|---|-------------------------------------|
| $\mu^\pm + N$ | 255 (43) | 59 (10) | 0 | – | – | – | – |
| $\pi^\pm + N$ | 134 (20) | 79 (14) | 3 (0) | 3 | 3 | 3 | 0 |
| $(p/\bar{p}) + N$ | 13 (2) | 7 (1) | 0 | – | – | – | – |
| $\gamma + N$ | 8 | 6 | 0 | – | – | – | – |
| Σ^- | 1 | 1 | 0 | – | – | – | – |
| K_L^0 | 118 (28) | 63 (15) | 31 (2) | 31 (0) | 24 | 24 | 0 |
| $(\bar{n}/\bar{p}) + N$ | 11 (1) | 9 (1) | 0 | – | – | – | – |
| K_S^0 | 12 (2) | 10 (1) | 0 | – | – | – | – |
| Total | 552 (96) | 234 (42) | 34 (2) | 34 (0) | 27 | 27 | 0 |

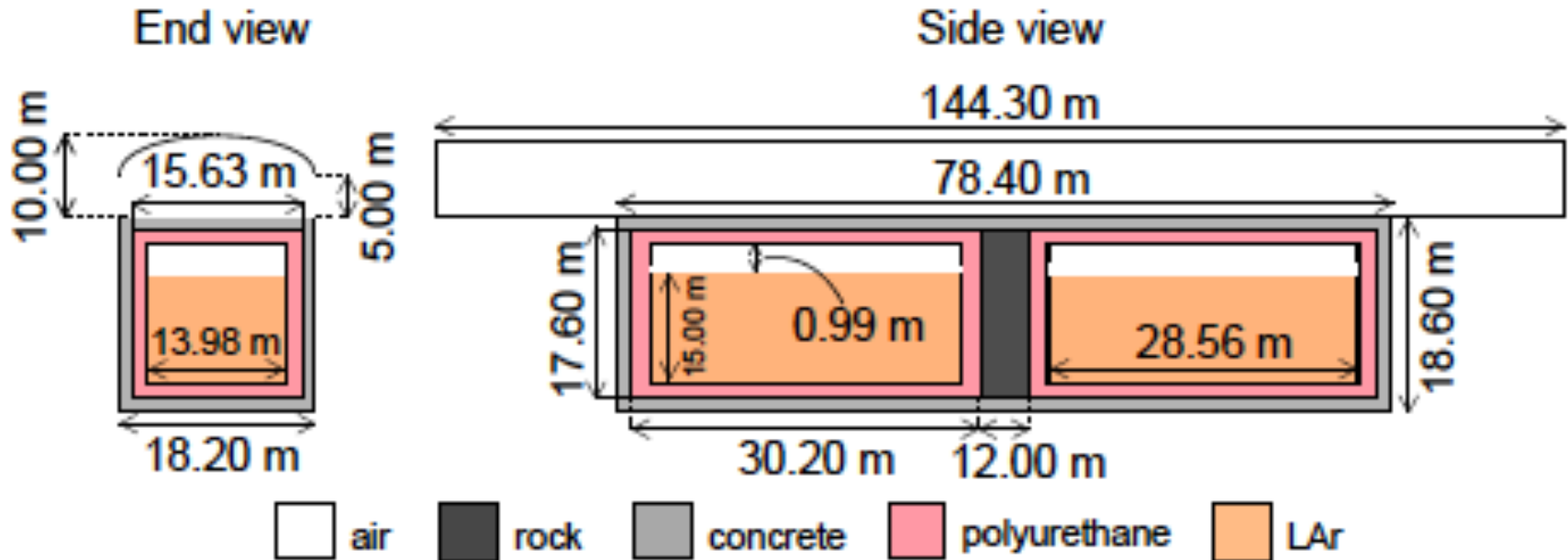
100 years of running, 40 kt active mass.

No events survived the cuts.

Efficiency loss < 2%.

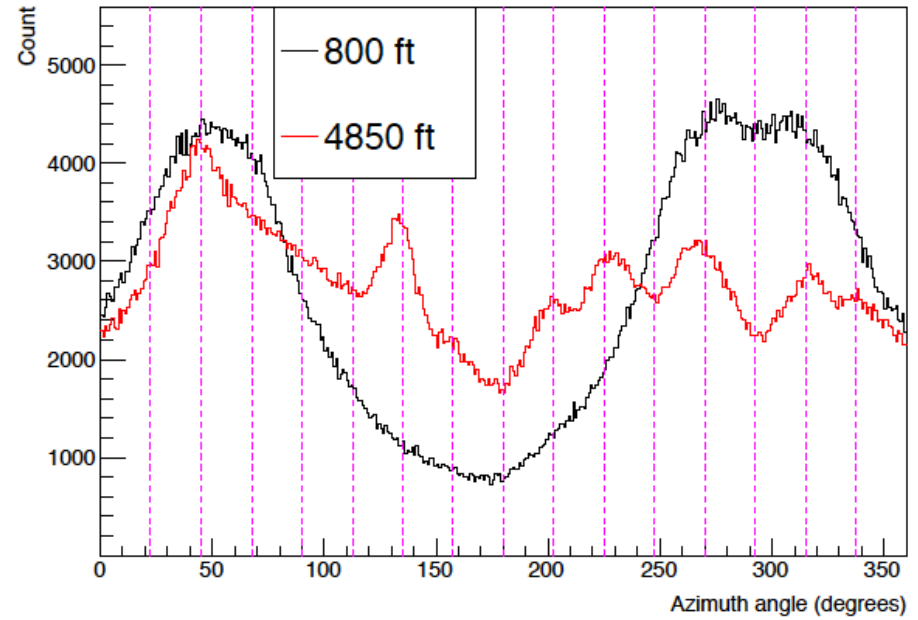
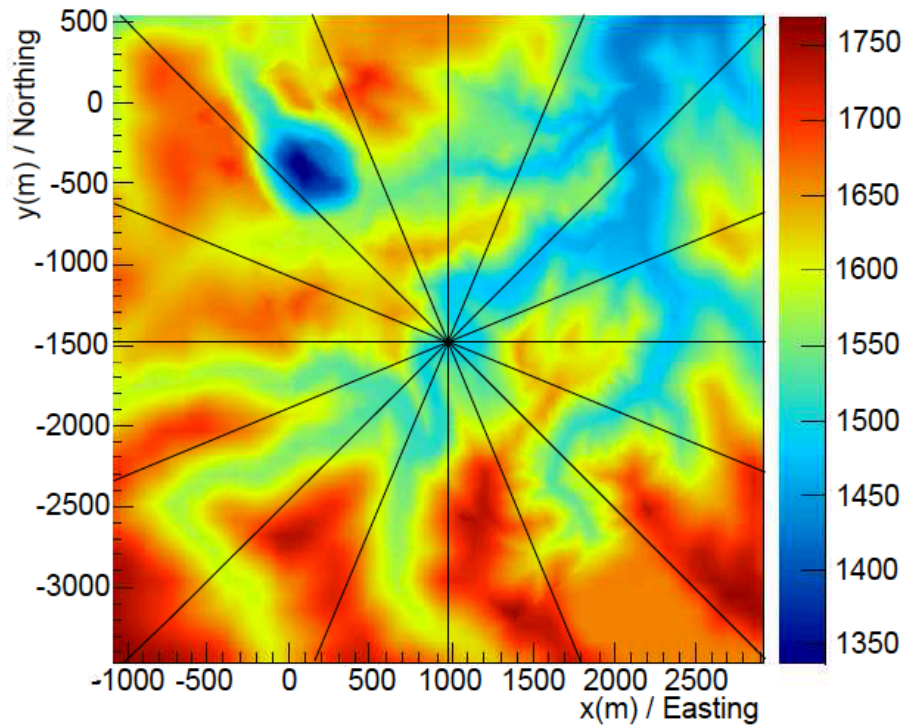
Upper limit: <0.0012 background events / kt / year.

Background in LBNE

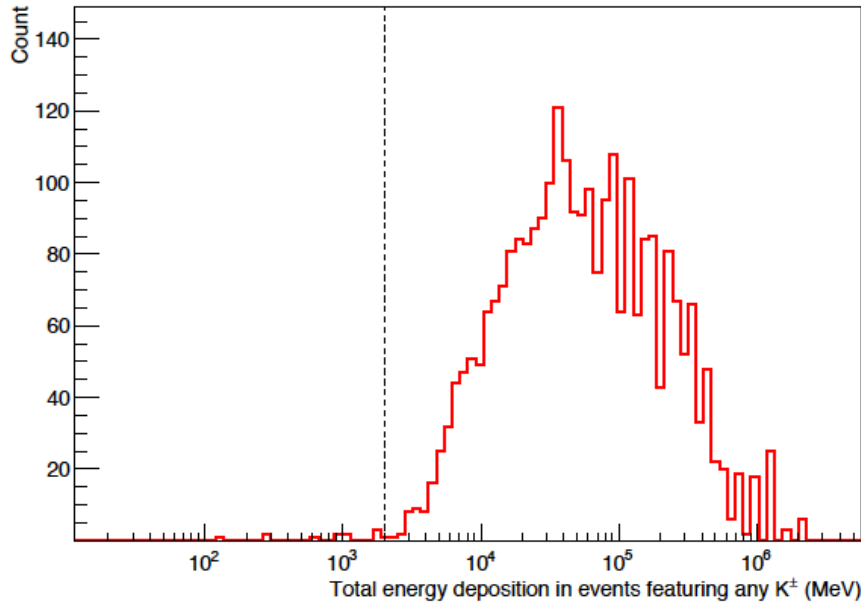


- Richardson (PhD thesis, draft) and Kudryavtsev (with help from many others in LBNE: Chao Zhang, Jeff de Jong, Eric Church, Karl Warburton...). All results are preliminary.
- A simplified geometry: 2 modules, 5 kt each.
- Accurate surface profile and muon model for SURF (close to Ross shaft).

Muon model

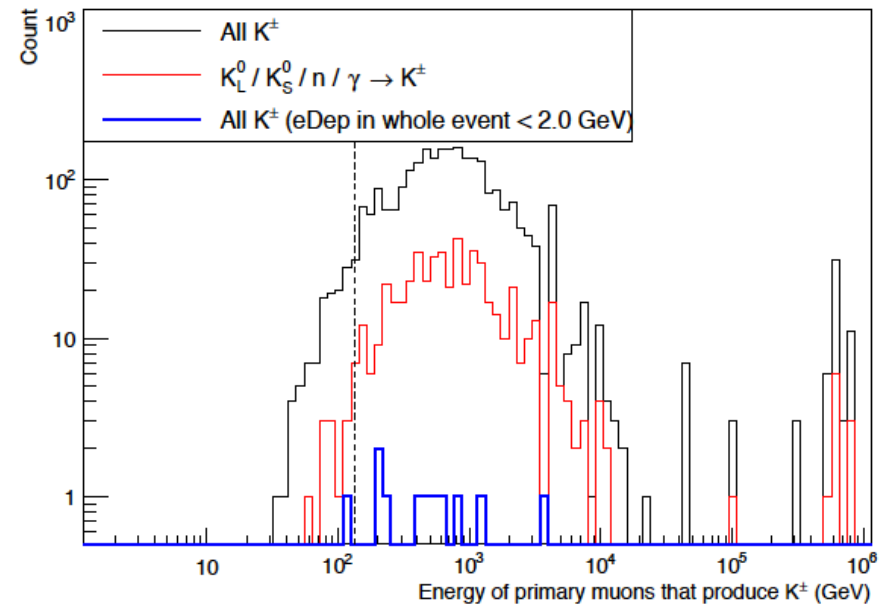


Energy spectra of events

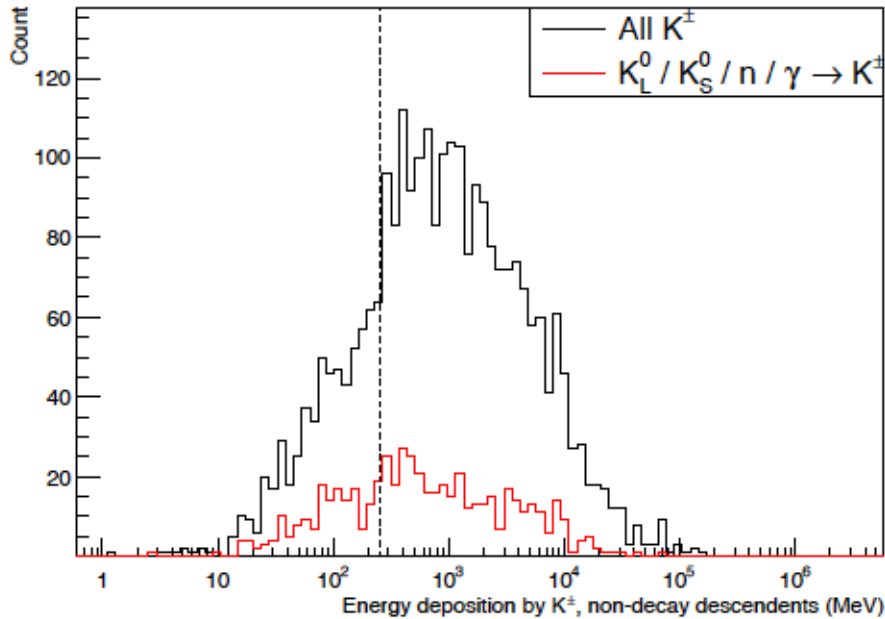


Spectra of total energy depositions in events with charged kaons (small statistics of 1.34 years for most plots)

Energy spectra of muons producing kaons in the detector.

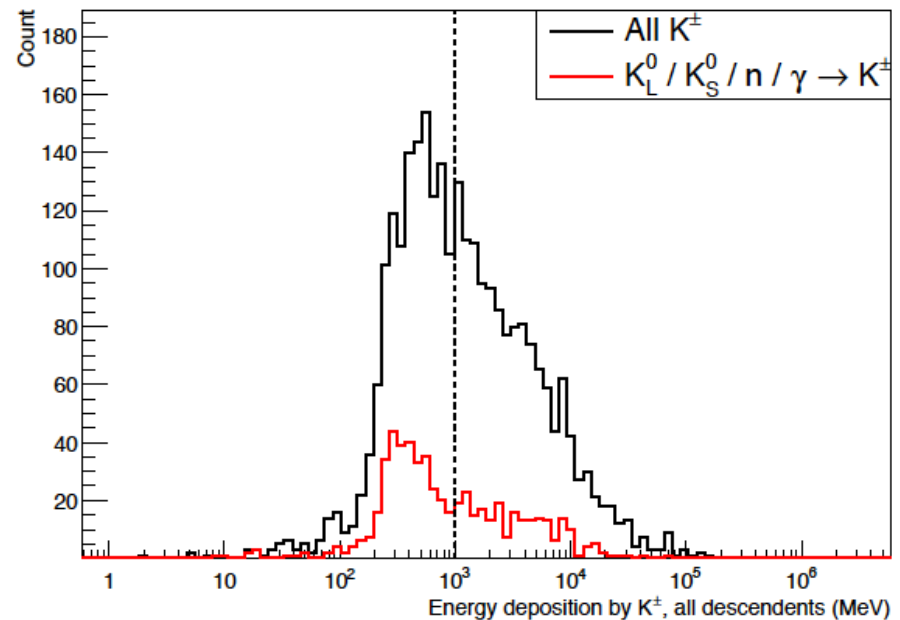


Cuts on energy deposition from kaons

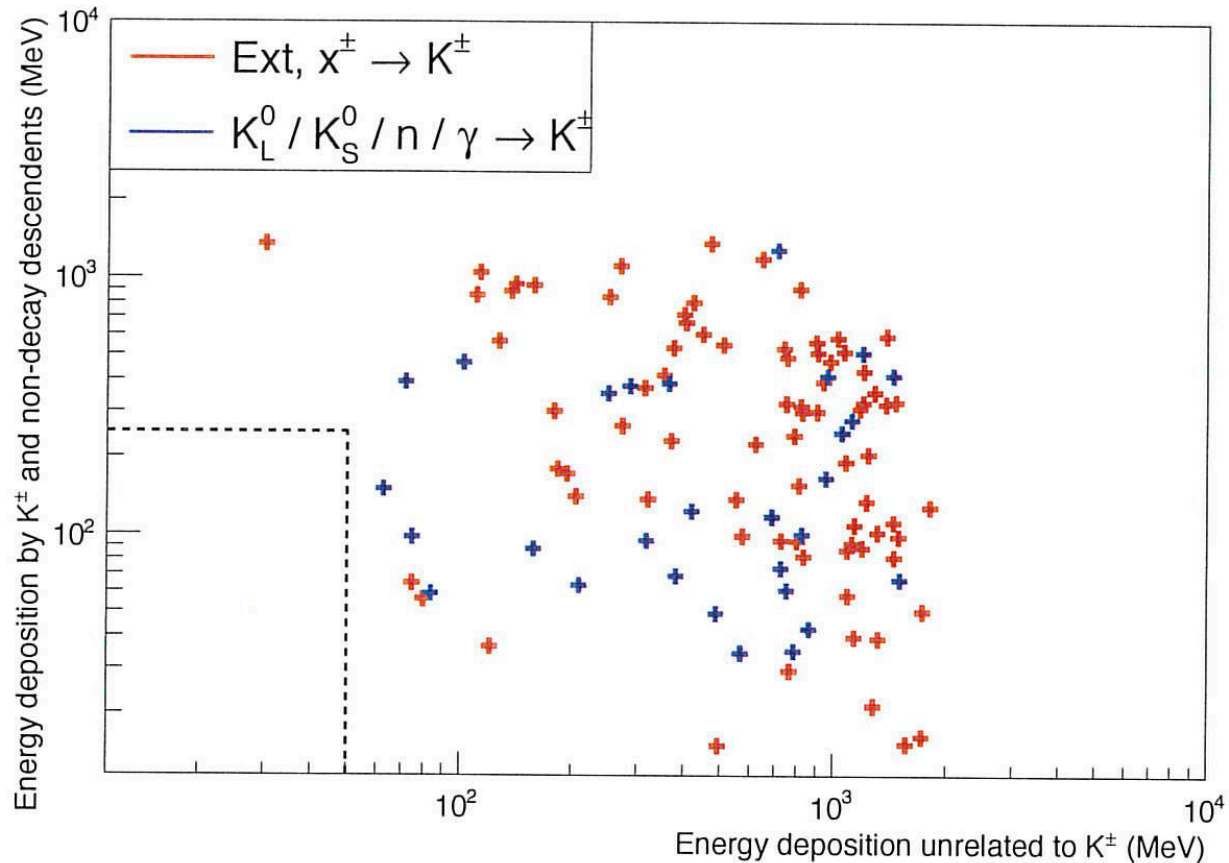


Energy deposition from charged kaons and their secondaries (excluding decay products).

Energy deposition from charged kaons and their secondaries (including decay products).



Results for 5+5 kt LBNE



67 years of statistics.

No events passed the cuts.

Upper limit of <0.036 events/year in 10 kt or $0.0036/\text{kt}/\text{year}$.

Background from atmospheric neutrinos

- Main background: NC interactions resulting in a K^+ and no other charged particles, such as: $\nu p \rightarrow \nu K^+ \Lambda^0 (\Sigma^0)$. Cut on associated strange baryon.
- There are also CC processes with a K^0 production followed by the charge exchange reaction and a K^+ as a result. Cuts on a lepton.
- Misidentification of a pion. Cuts on dE/dx and range.
- Table taken from [A. Blake. LBNE-doc-8836](#). 34.8 Mt×years.

| Selection | Events | Events/Mt-yr |
|---|------------|--------------|
| All interactions | 10,000,000 | 287,944 |
| K^+ emitted by interaction | 73,799 | 2,125 |
| K^+ in final state ('kIsStableFinalState') | 64,560 | 1,859 |
| One K^+ in final state | 63,576 | 1,831 |
| No other charged particles | 1,865 | 54 |
| No photons or neutral pions | 1,205 | 35 |
| $p_K < 800$ MeV [see next slide] | 701 | 20 |
| Reject neutral hyperons (Λ^0, Σ^0) | 1 | <1 |
| Reject neutral kaons (K^0) | 0 | 0 |

Conclusions and plans

- Initial work for LBNE and LBNO.
- No background events after cuts and optimistic limits on backgrounds.
- OK for CDR / CD1.
- CD1 refresh panel commented on the needs for background calculations (although the existing results may not have got through).
- No detector response and event reconstruction.
- Need to include accurate detector response and event reconstruction -> LArSoft.
- Atmospheric neutrino background: which WG?
- Other proton decay channels. Neutron-antineutron oscillations.
- Other topics:
 - Activation for SNB (which WG?)
 - ...