Nucleon decay: motivation, tools.

Eric Church, Yale, 13-July-2012

MicroBooNE R&D group meeting

First: I'd like to thank the MicroBooNE R&D organizers for the invitation ...

- Ndk is not per-se relevant for uBooNE
- We want to do Ndk in an underground large detector: LAr20+!

- But, Background understanding to this game-changing would-be discovery can be contributed by uBooNE: see Nevis doc-db entries.

- Software tools to do study Ndk are relevant to uBooNE

Motivation for nucleon decay

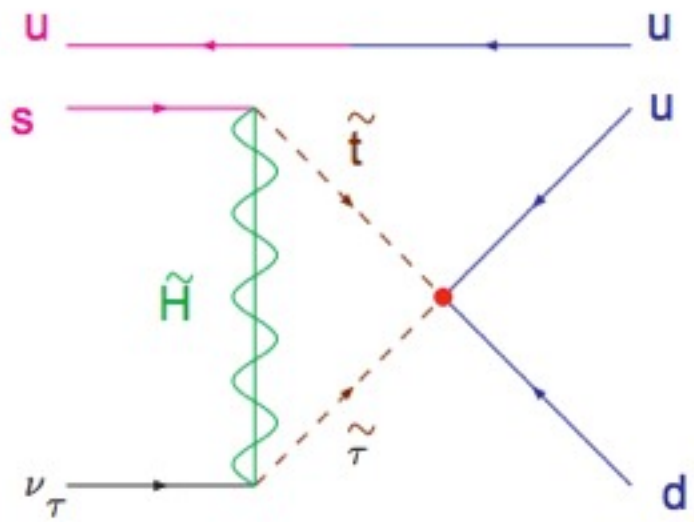
... (a nucleon decay search) is vital for the physics case for the flagship US program. The sensitivity largely involves leveraging the power of liquid argon detectors for maximum efficiency and minimum backgrounds, and understanding those backgrounds well. As B-mode Cosmic Microwave Background polarization would be evidence of Inflation at the Planck scale of 10^19 GeV [3], so is nucleon decay a window into Grand Unification Theories (GUTs) on scales of 10^16 GeV [4]. Hence, LBNE is as motivated by nucleon decay studies as it is in filling out the PMNS matrix....

Nucleon Decay

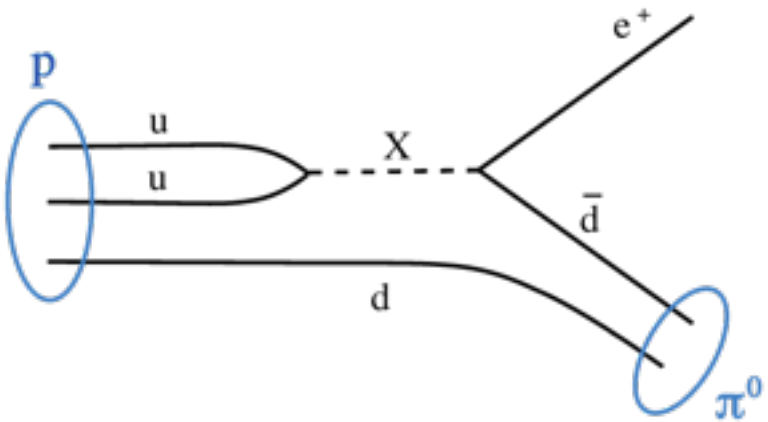
- Mohapatra, et al. (arXiv:1007.1633) ... can build SO(10) models that break to SU(2)_LxSU(2)_R that are not so contrived that contain right handed neutrinos naturally, predict m_tau=m_b at M_U, get the Cabibo angle right, get the three neutrino (!) mixing angles in the ballpark (th_13~0.05) and get all the quark and neutrino masses consistent with reality, ... run the couplings together, call for Seesaw and therefore leptogenesis ...
- It's incumbent to search for Ndk.

Famous modes

LAr's Golden mode



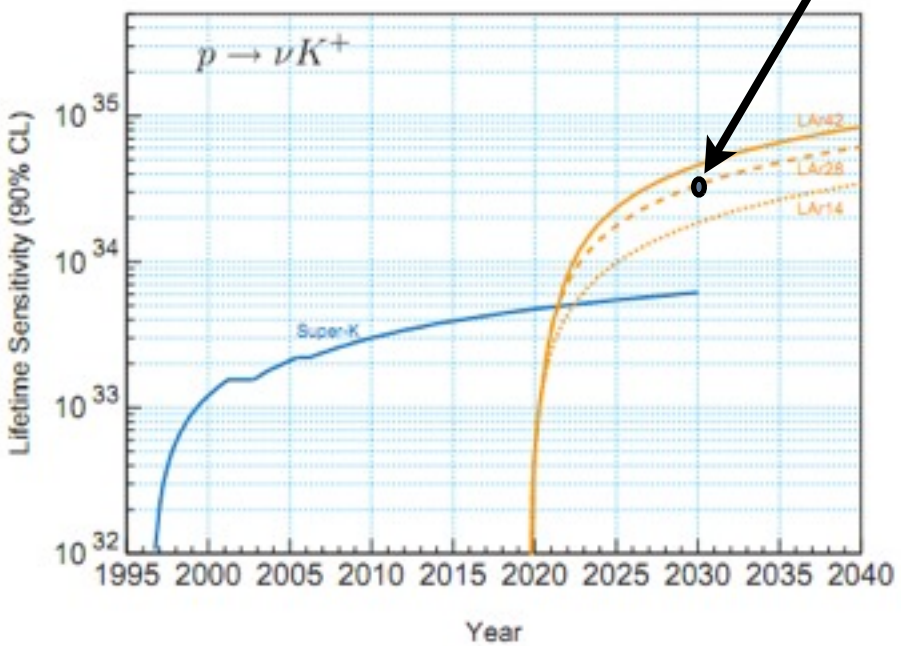
WCkv's bread and butter



golden mode:

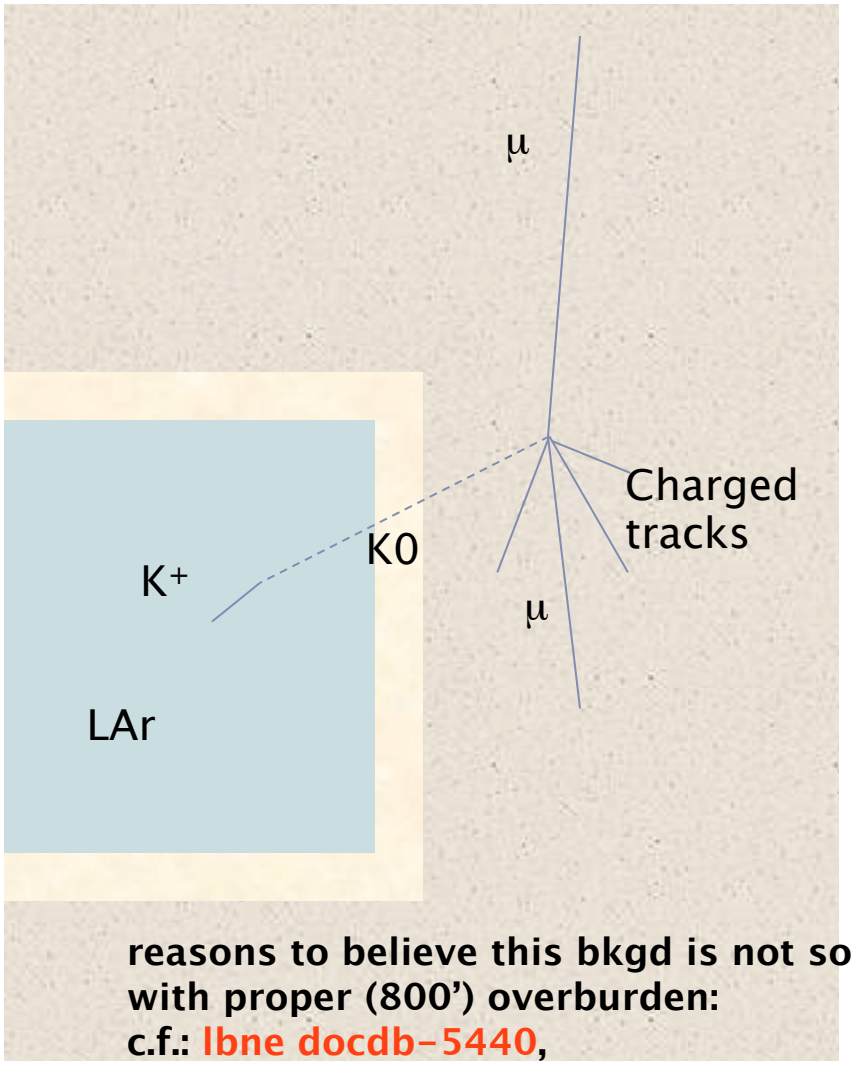
$$p \rightarrow K^+ \overline{\nu}$$

$$\frac{\tau}{B} = \frac{N_0 \, \Delta t \, \epsilon}{n_{obs} - n_{bg}},$$



Assuming <0.1 K+ bgd/100kt-yr, we get ~6x still-running SK sensitivity.

Cosmic Ray Spallation Background



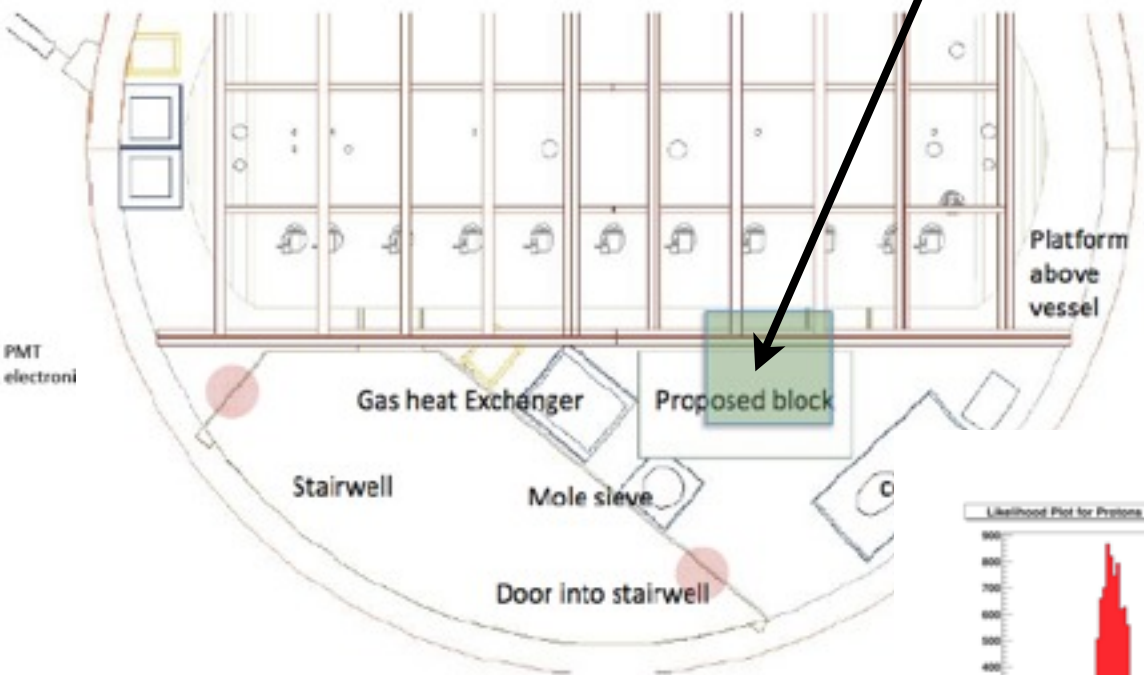
- Background probability
  - Muon rate
    - 0.16 Hz/m^2 at 800L
  - Spallation K0 production
  - K0 isolated from charged trks
  - K0 range in rock/LAr
  - K0 → K^+ charge exchange
    - Associated particles are all neutral or below threshold
  - K^+ range consistent with pdk

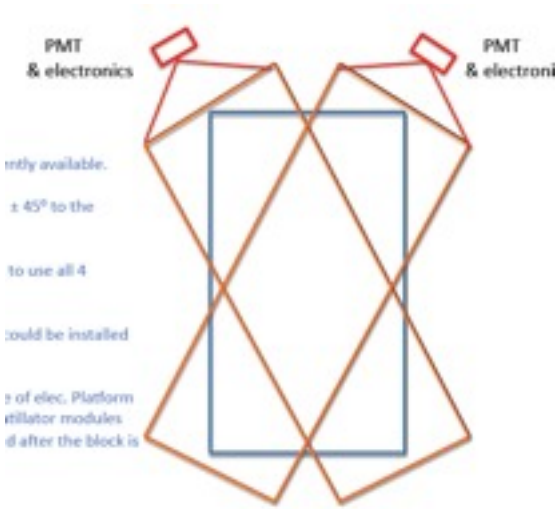
reasons to believe this bkgd is not so odious with proper (800') overburden:
c.f.: lbne docdb-5440,
(to be published with Sheffield group?)

Nevis effort for MicroBooNE

20 tons granite

Leslie's Talk!





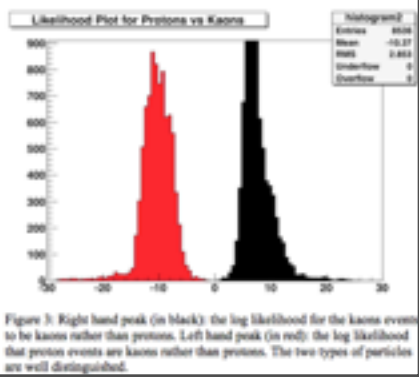
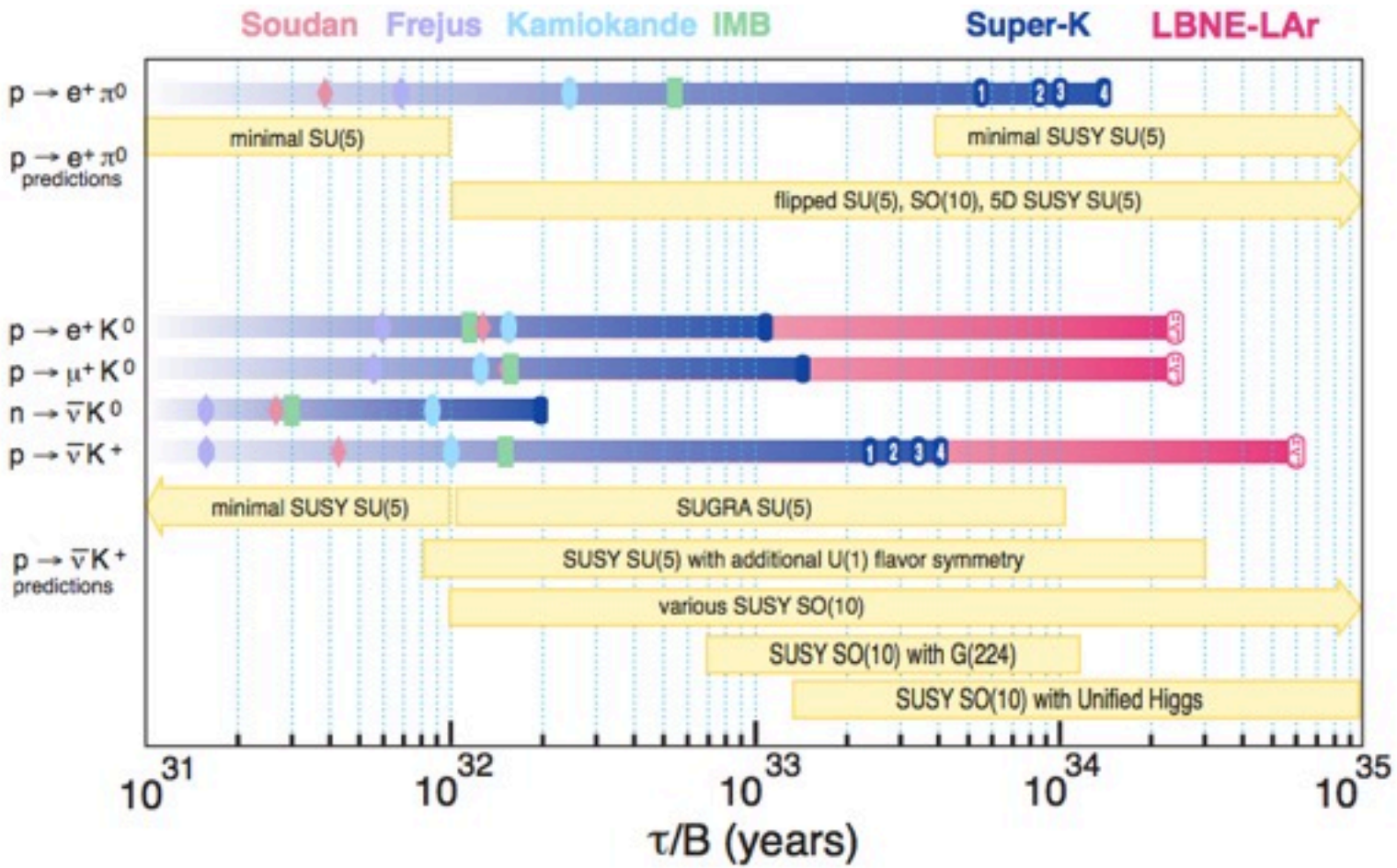


Figure 3: Right hand peak (in black): the log likelihood for the kaons events to be kaons rather than protons. Left hand peak (in red): the log likelihood that proton events are kaons rather than protons. The two types of particles are well distinguished.

Nucleon Decay



Bill Marciano and Bill Willis suggest inclusive searches

- Meaning, instead of $p \to e^+\pi^0$
- limited by inherent 45% absorption, which only gets worse for Argon, we can hope to see $n \to e^+\pi^-$ too and $p, n \to \bar{\nu}\pi^{+,0}$ and $p \to e^+\omega \to \pi\pi\pi$

(and swap mu in for e everywhere too.)

- **... due to isospin – in all a considerable increase in rate, about 12 times the pi-zero rate in Hyper K.**

-Keeping the expected number of background events for a given reaction << 1 is important, to allow discovery with just a few events.

-some reactions allow near zero background events, others (like K+ neutrino) allow an almost perfect fake.

-Capturing all modes is important: a good example is the set of decays detected in liquid argon from nucleon decay to lepton + pion, with two signs of lepton (those with negative sign disfavored by GUTS, but detected efficiently if they do occur) and three signs of pion, (the channels with negative pions are expected to have double the rate)

Summary of Nucleon Number Violation Processes Study:

- A very powerful tool: rejecting events with coincident tracks not allowed in real events from muon showers or cosmic ray neutrino events, NOT discovered by simulating real events, and since "soft" events are important, will not be reliably measured in simulation.
- The efficiency of their detection depends on the performance of the detector near threshold energy; tracks generated by neutrons are an example, needs MicroBoone results.
- The difference in net momentum between decays and hadronic or cosmic neutrino events is the most important tool, except for events with a neutrino, like $p->K^+$ neutrino

In Short

- Bill W thinks -- optimistically, we all agree -- a 34 ktonne fiducial LAr can compete with a 500 ktonne Water HK!

- We must try to demonstrate such a thing with inclusive studies in LAr.

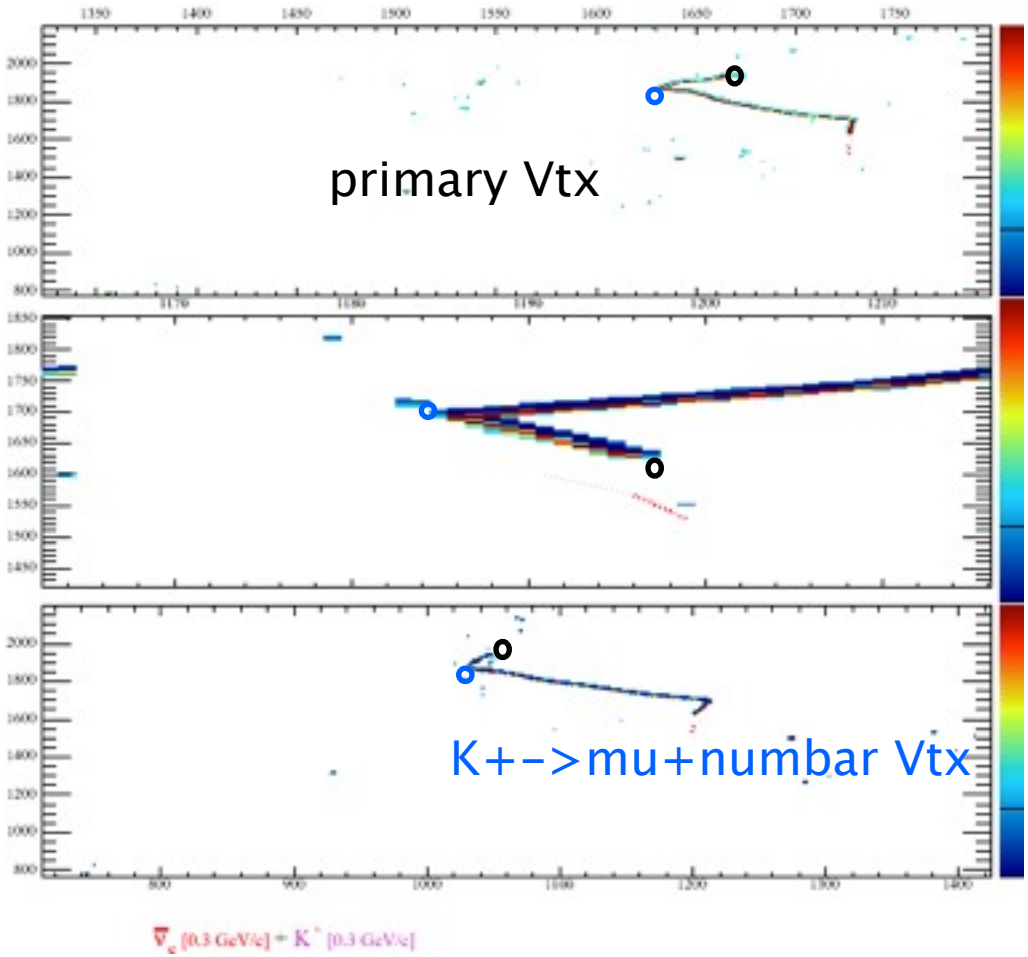
Nearterm work

- I can imagine work on a nucleon decay generator with some approximate effects of excited Cl, Ar states accounted for, and see how LAr40 responds.
- All modes in homegrown code. SuperK's and Icarus's code are proprietary.
- It's been suggested FLUKA is the preferable route here. Could bolt this onto front end of LArSoft, then propagate stable particles in Geant4 with appropriate low energy physics list.

Work done (finally!)

- Ran GENIE Ndk modes standalone
- Wrote the parser, ala NUANCEGen (yay, Saima!), significantly customized, to read up the GENIE txt file.
- Ran through LArSoft's LArG4+UbooNE DetSim modules.
- Sucked 'em up into EVD with evd_uboone.fcl

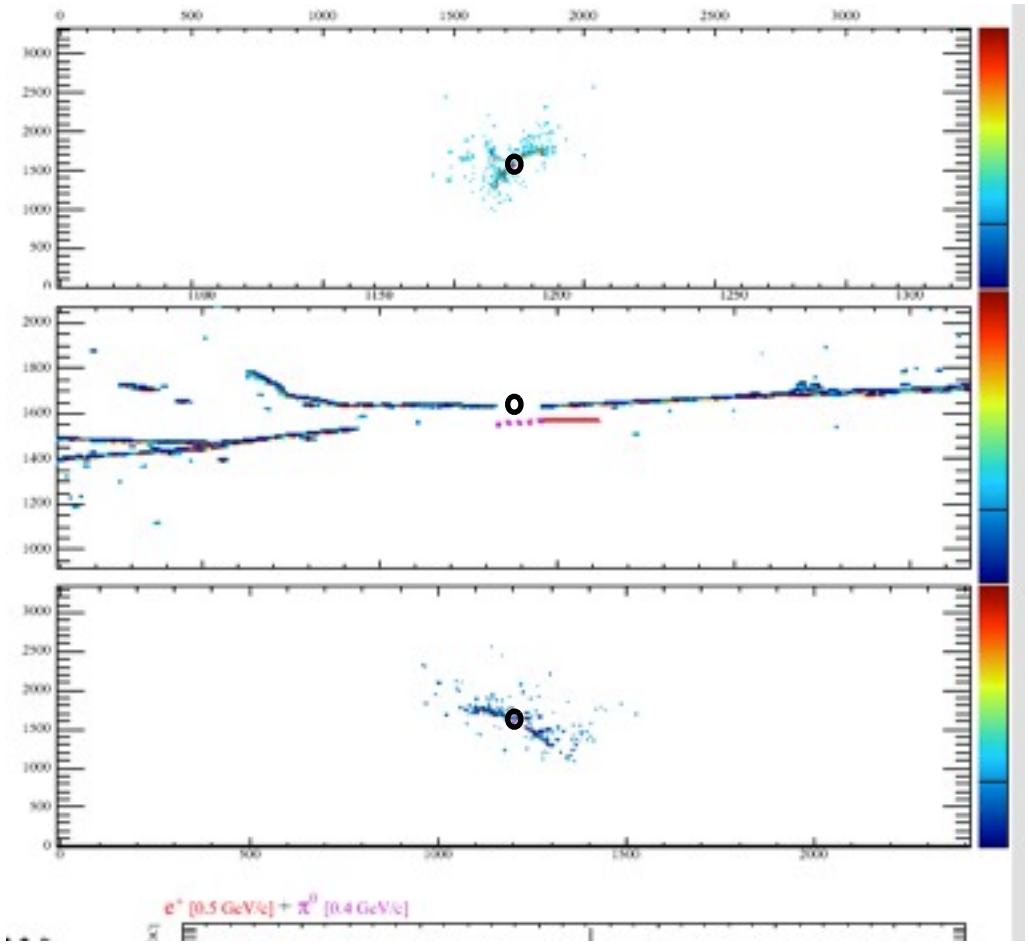
LAr Golden Mode



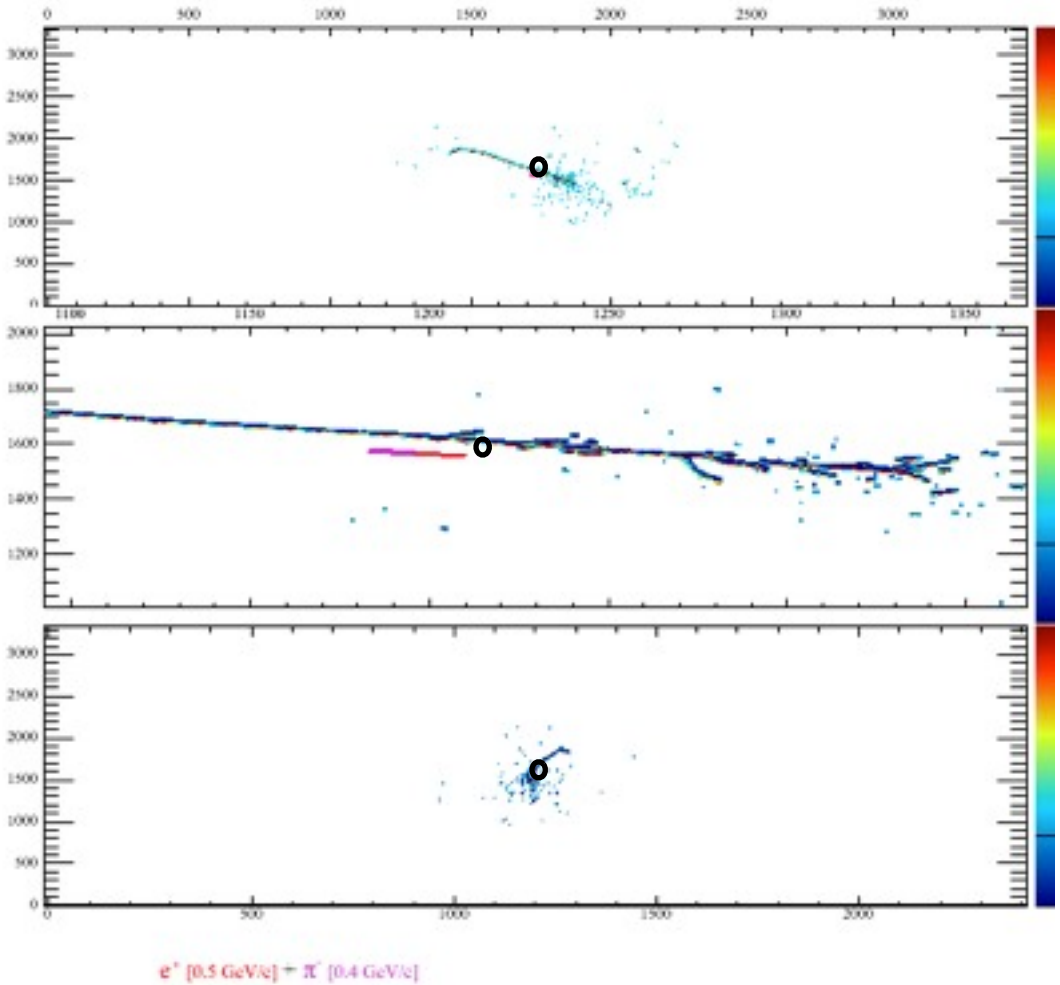
p->K+nubar

Middle panel
always zoomed here

p->e+pi0

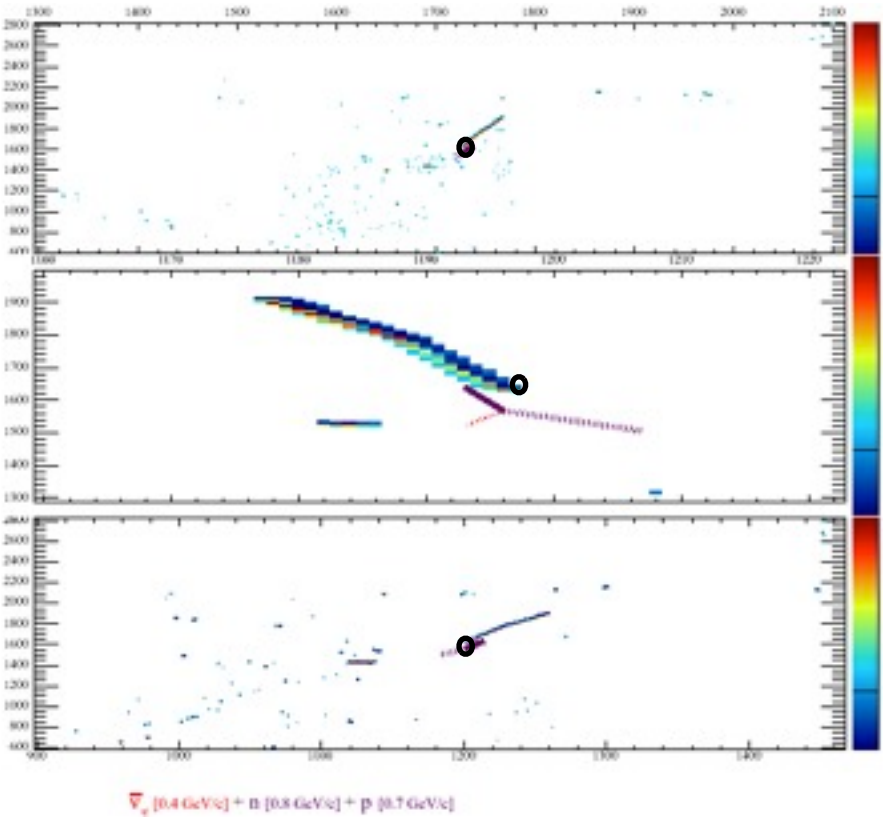


n->e+pi0 decay



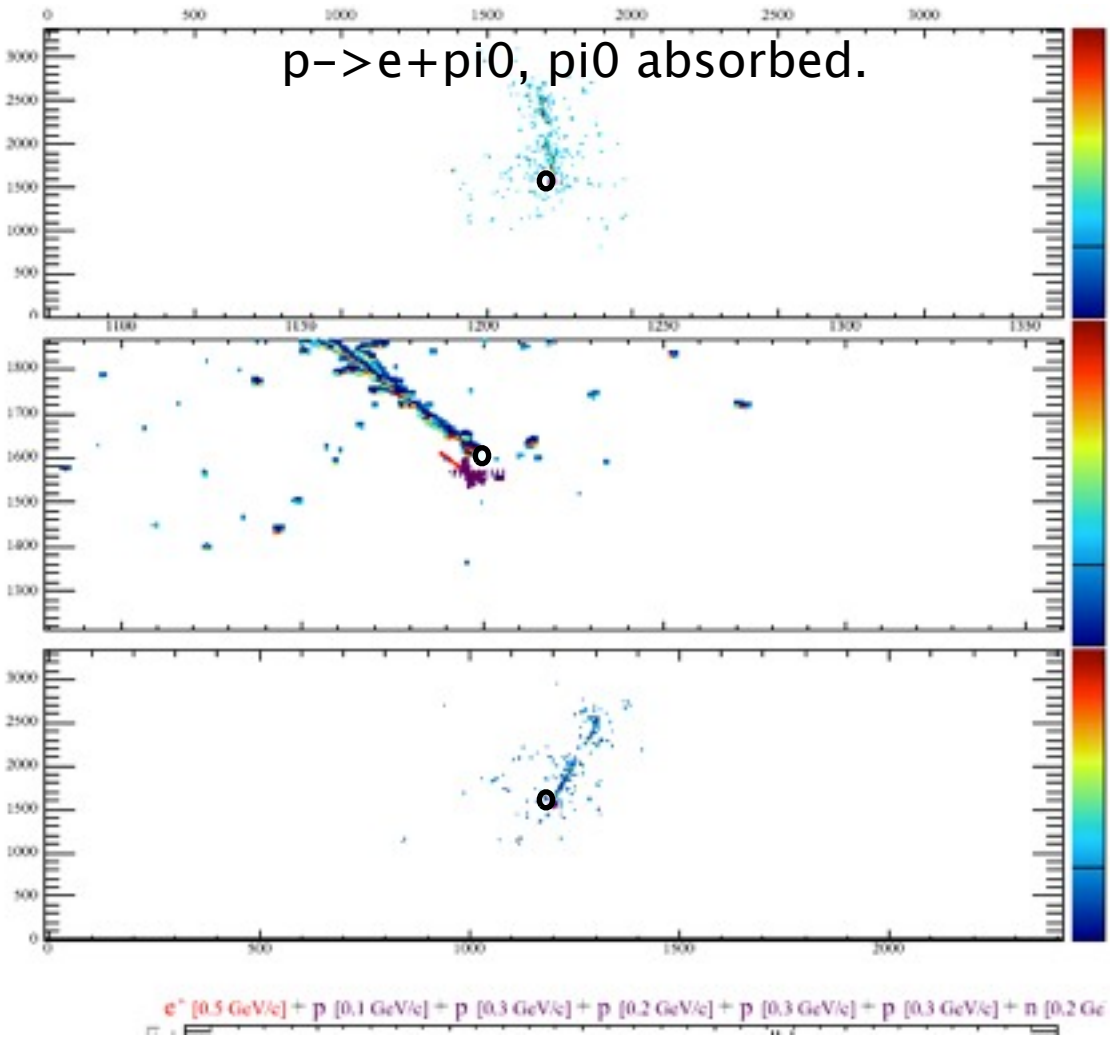
But, Ndk events are not always so spectacular.

"Golden" where the K+ disappears

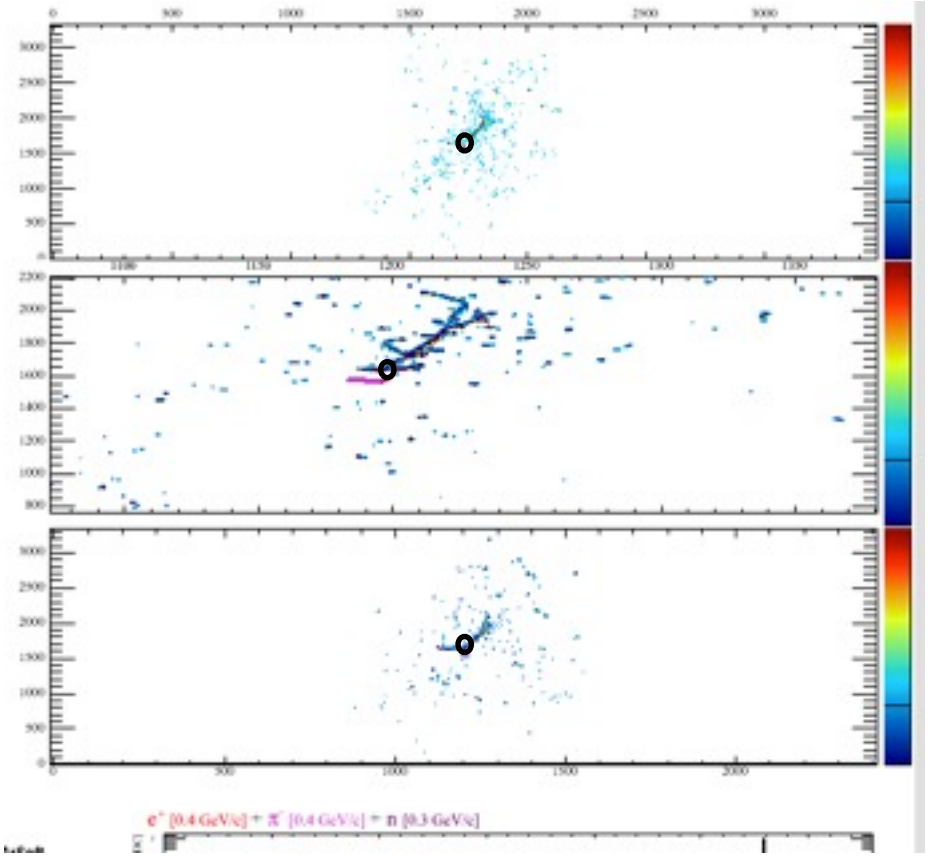


A quick decay and/ or
charge exchange to K0, then intra-nuclear interactions.

pi0 often absorbed, as is known



n->e+pi-



pi- absorbed, as always,
but now a neutron was kicked out by FSI. Event no longer "spherical."

Issues

- We are sensitive to the Argon nuclear physics here, due to the low (106 MeV central!) kinetic energy of outgoing K+.
- Not to mention the intranuclear effects.
- Are all those irritating p's really there?
- ArgoNeut data!
- GENIE can't be totally correct.
- More motivation to get NuWro up to generate these Ndk events. (It's close!)

Ndk summary

- Generically, partial lifetime for $p \to e^+\pi^0$ goes like ~ sqrt(1 TeV/ M_susy). 10^35+/-1 yr

- As LHC push on M_susy from below, we push down on lifetime from above.