Nucleon Decay at LBNE

pre-Snowmass IF meeting at Argonne

Eric Church, Yale, 25-27-Apr-2013

LBNE is…

- A new neutrino beam at Fermilab
  - 700 kW proton beam, 2.3 MW capable
- A near neutrino detector
- An optimal 1300 km baseline: Fermilab-SURF
- A 34 kt Liquid Argon TPC with 4850’ overburden

- An optimized cost/time effective path to the science

- This conceptual design…
  - Completed a successful CD-1 Director’s Review (March 2012)
  - Updated cost estimate (July 2012):
    ~$1.5B (incl. contingency + escalation)

LBNE update, continued

December 2012: CD-1 approval for $867M first phase DOE funding

- We have completed an extensive cost/schedule for 10 kt LAr far detector (LBNE10) on the surface but the design is **not** fixed
- ***CD-1 approval explicitly allows for scope change enabled by new partners***

First phase goal: *greater than 10 kt* far detector *underground* and a *full capability near detector*

In the past 3 months there has been considerable progress towards international partnerships (encouraged by European Strategy statement

Underground!

- A nucleon decay search is vital for the physics case for the flagship US program.
- Hence, LBNE is as motivated by nucleon decay studies as it is in filling out the PMNS matrix and finding the Mass Hierarchy
- As B-mode Cosmic Microwave Background polarization would be evidence of Inflation at the Planck scale of 10^19 GeV, so is nucleon decay a window into Grand Unification Theories (GUTs) on scales of 10^16 GeV.

ideas of the GUT modelers in this room!

OSU-HEP-13-02
MAN/HEP/2012/017
UMD-PP-013-003

Post–Sphaleron Baryogenesis and an Upper Limit on the Neutron–Antineutron Oscillation Time

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[hep-ph] 27 Mar 2013

Such modes imply nnbar oscillations ...

OSU-HEP-12-08

$B - L$ Violating Proton Decay Modes and New Baryogenesis Scenario in $SO(10)$

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24 Jul 2012

breaking scenario with O(1000 TeV) color sextet particles would allow d=7 B-L modes. B-L means low temperature baryogenesis is possible

Type II Seesaw Dominance in Non-supersymmetric and Split Susy $SO(10)$ and Proton Life Time

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(Dated: October 31, 2011)

28 Oct 2011

Type II seesaw, no SUSY, is/was possible. Some TeV scale particles needed, in any case.

MIFPA-13-0
UMD-PP-013-00
February, 201

Proton decay and $\mu \to e + \gamma$ Connection in a Renormalizable SO(10) GUT for Neutrinos

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[hep-ph] 11 Feb 2013

Abstract

Type I or II seesaw is potentially distinguishable

GUT phenomenology

require/get	discovered/ accommodated	needed	bonus
coupling unification	m_ν	**nucleon decay**	nnbar oscillations
(depending on type I/II seesaw) Cabibo angle, $m_b=m_\tau$, ... at M_G	large θ_{13}	normal hierarchy O(1-1000 TeV) particles	B,L (δ_{CP}) asymmetry O(1-1000 TeV) particles!

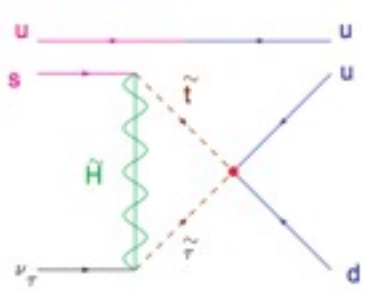
example pdk Modes

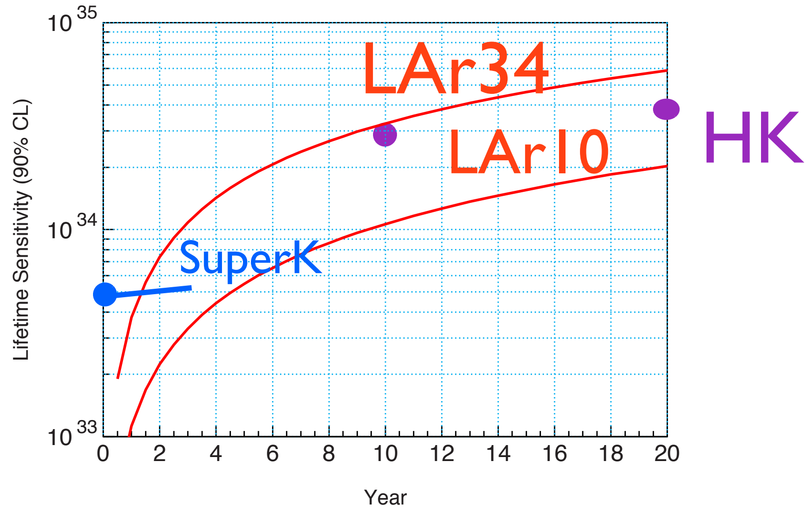
	Mode	SK Eff (%)	SK Bkgd (1/MT-yr)	LAr Eff (%)	LAr Bkgd (1/MT-yr)
B-L	$p \rightarrow e^+\pi^0$	45	2	45	1
	$p \rightarrow K^+\overline{\nu}$	6	7	97	1
	$p \rightarrow \mu^+K^0$	10	5-10	47	<2
B+L	$p \rightarrow \mu^-\pi^+K^+$	?	?	97	1
	$p \rightarrow e^-K^+$	10	3	96	<2

unofficial SK! Bueno, et al.

golden mode:

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





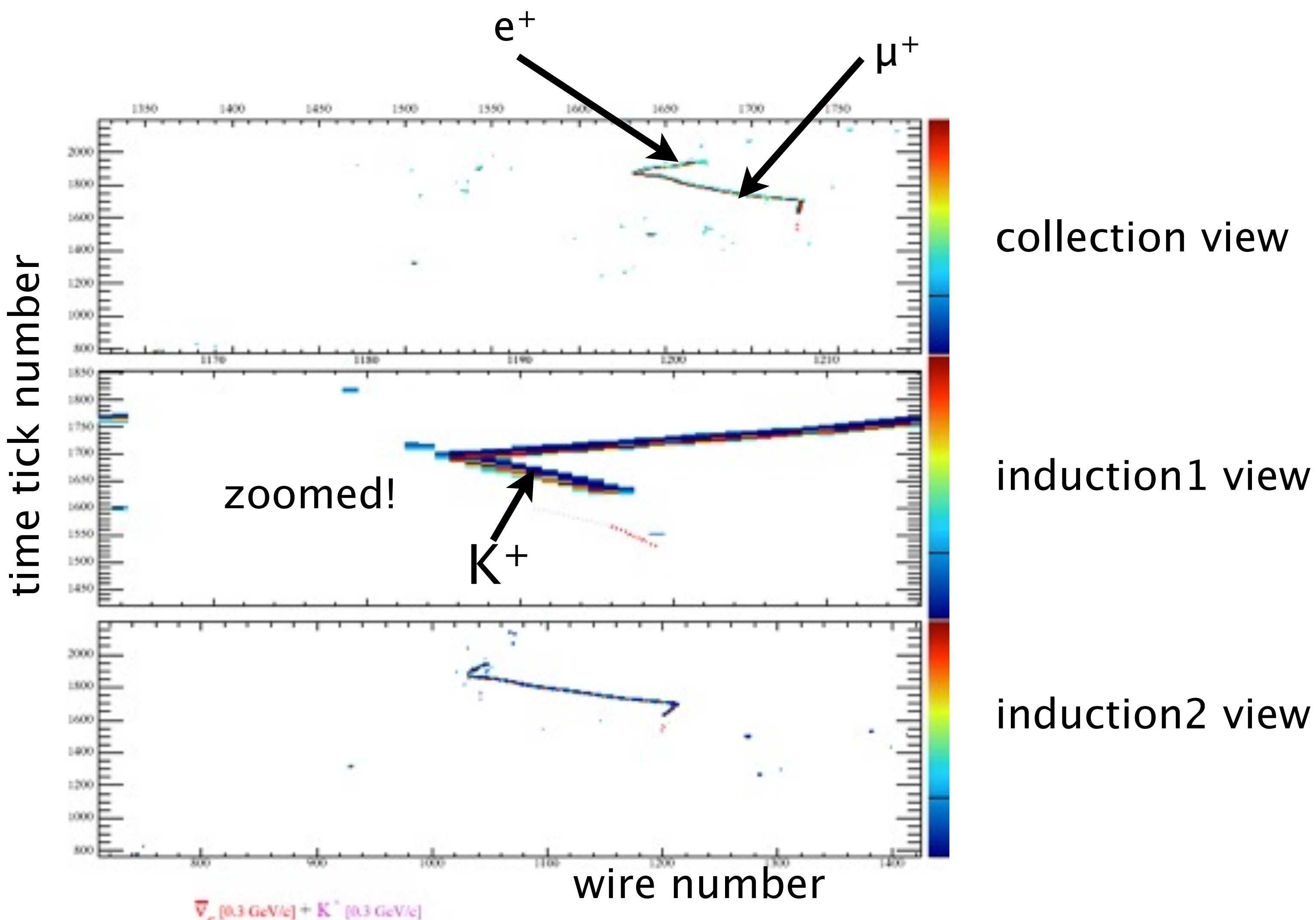
Ed Kearns

Assuming <0.1
K+ bgd/100kt-yr,
we get ~6x(1.5x) still-
running SK(HK)
sensitivity.

$$\frac{\tau}{B} = \frac{N_0 \, \Delta t \, \epsilon}{n_{obs} - n_{bg}}, \qquad \frac{\sum_{n=0}^{n_0} P(n, b+S)}{\sum_{n=0}^{n_0} P(n, b)} = \alpha$$

S

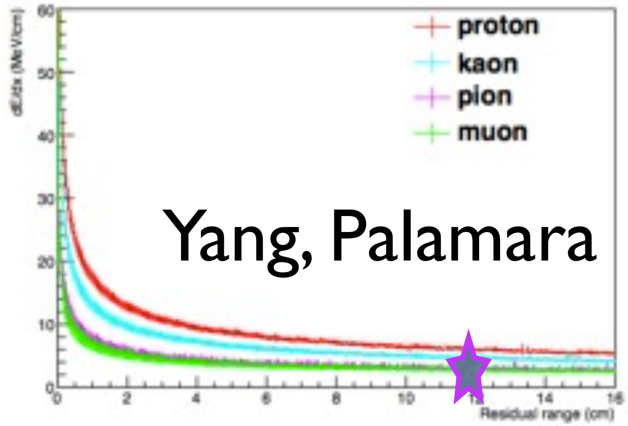
$$p \to K^+ \overline{\nu}$$



MicroBooNE Event Display

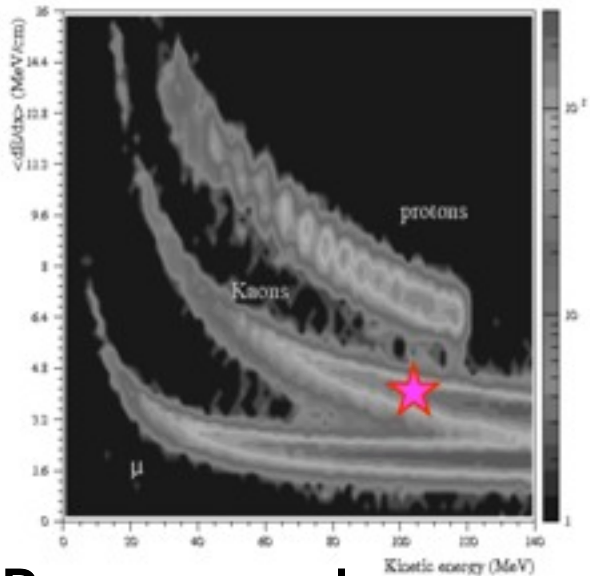
K+ from pdk

Kaons: particle ID well-separated at this momentum, even with Fermi smearing.



Yang, Palamara

ArgoNeuT MC truth



Bueno, et al.

truth?

•Bill Willis impressed the following upon me. (In fact, this is his slide, almost unedited.)

Bill made important contributions and provided insightful leadership to novel detector techniques and liquid argon calorimetry and LAr TPCs, particularly. There is a symposium in his honor at BNL today.

... due to isospin - in all a considerable increase in rate, about 12 times the pi-zero rate in Hyper K. (2-3x Bill Marciano's claim.)

-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 on following page (the channels with negative pions are expected to have double the rate)

Bill Marciano and Bill Willis suggest inclusive searches

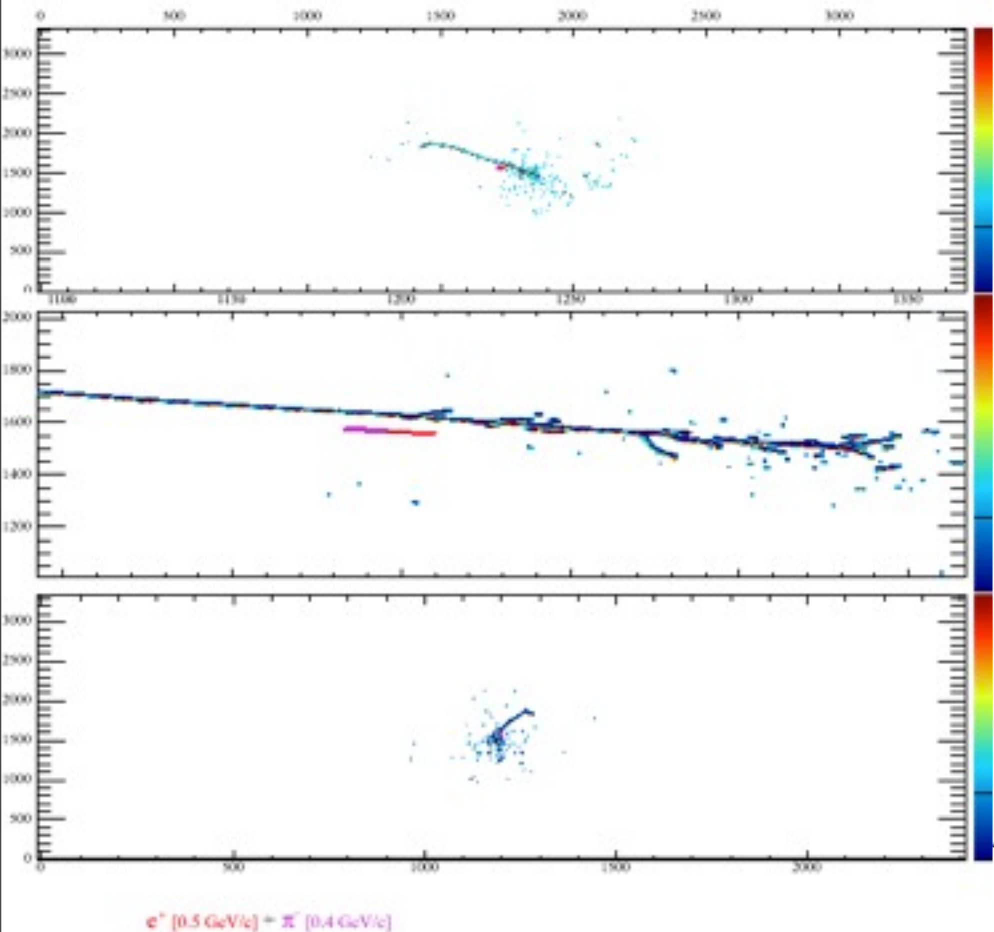
e.g., B-L conserving modes

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

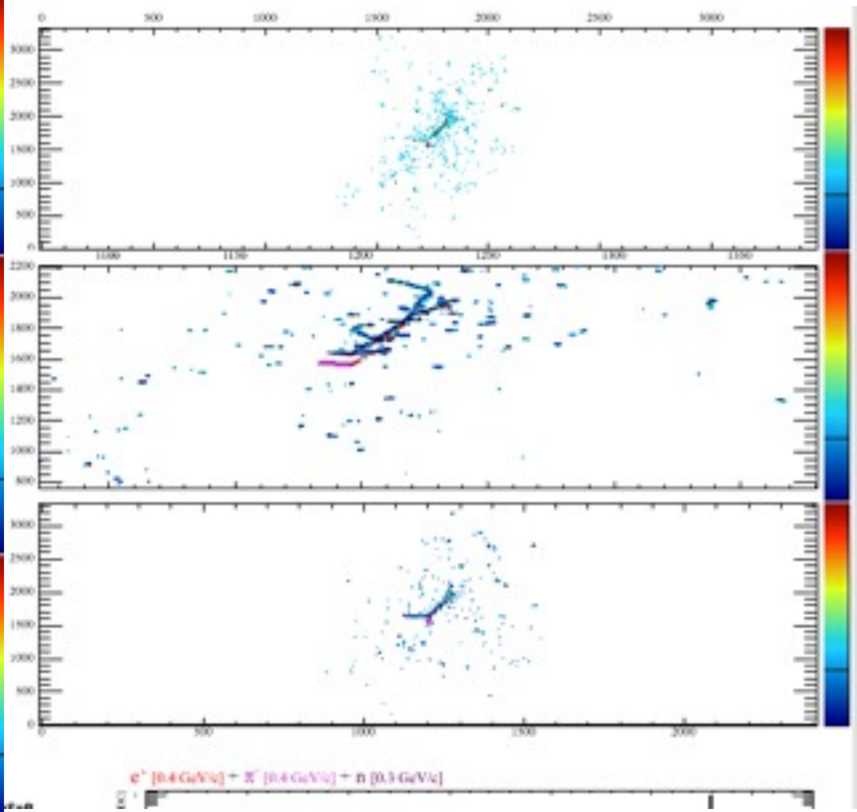
(and swap μ in for e everywhere too.)

$$n \to e^+ \pi^-$$

Easy

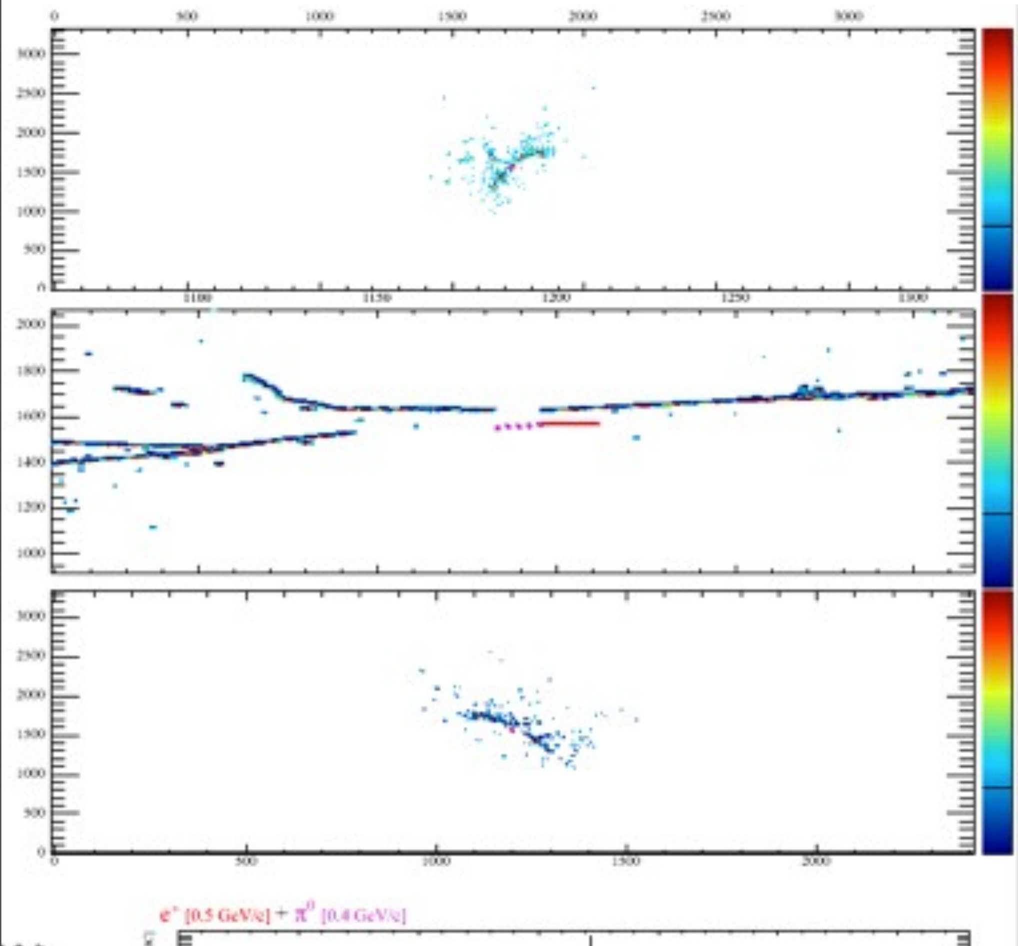


Hard

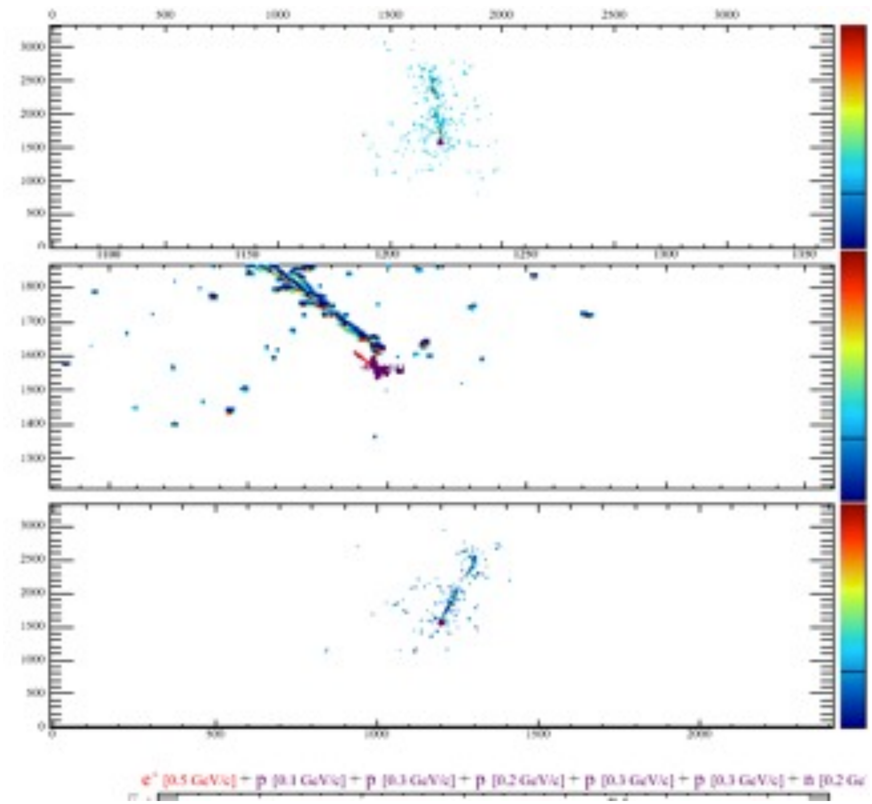


$$p \to e^+ \pi^0$$

Easy



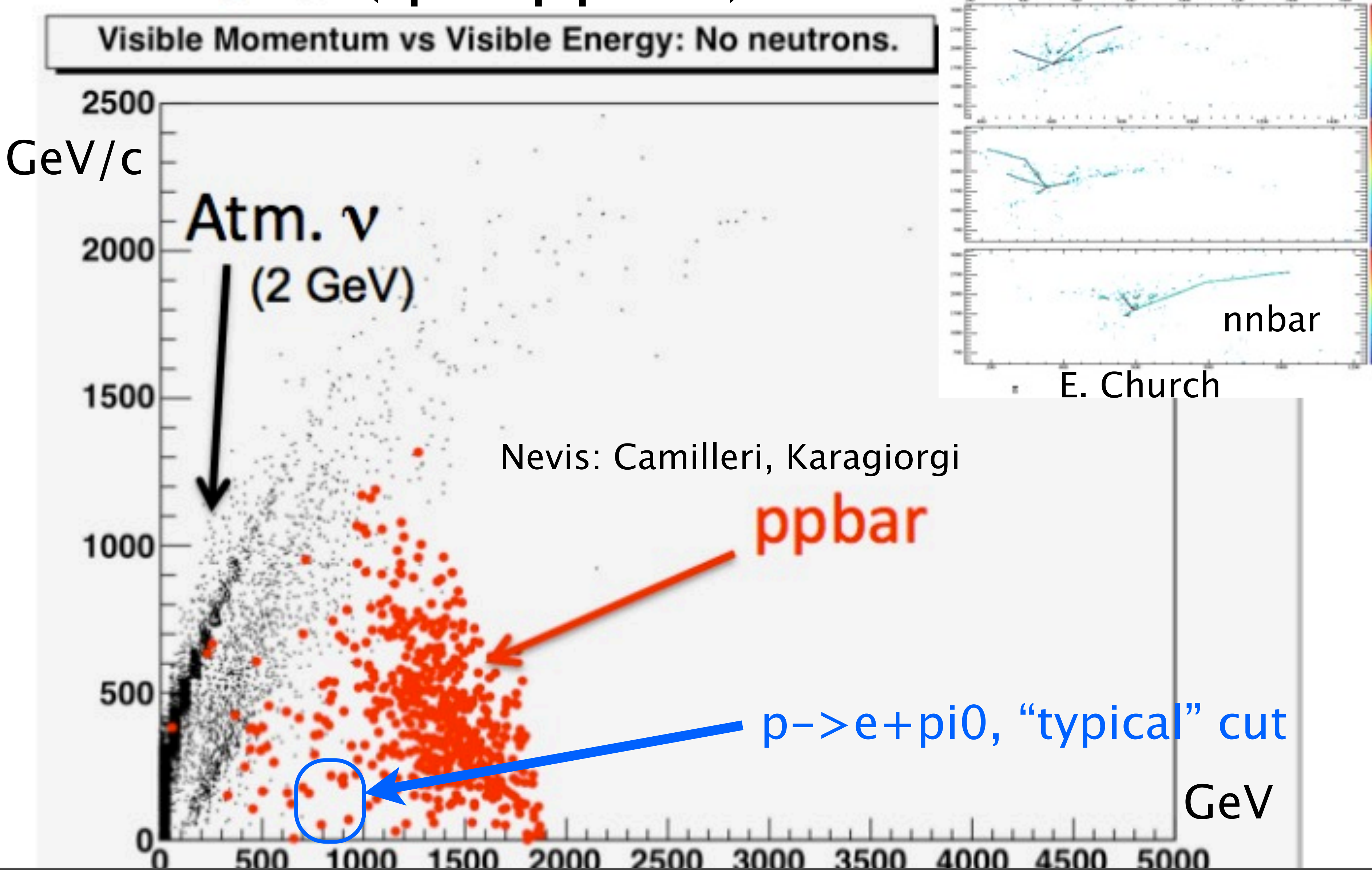
Hard

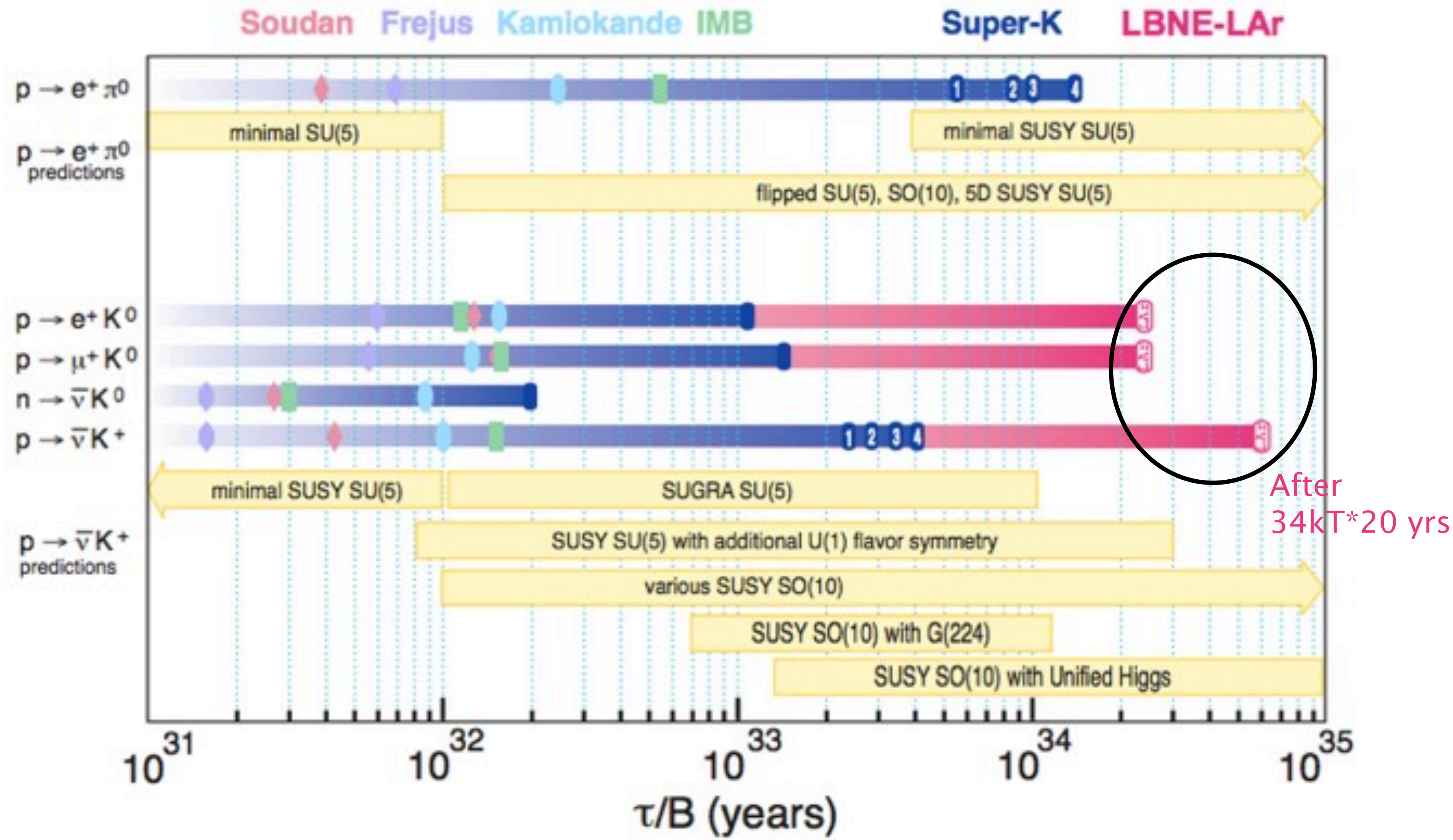


At 4850’

- Atmospheric generator works in LArSoft (the Argon simulation and reconstruction software package).
  - Expect atmospheric neutrino interactions to dominate
  - We have generated muons at 4850’. K0 and cosmic muon-Ar spallation products need to be understood too.
- Then we need to walk through the modes
- We have a Ndk generator (GENIE) now for most interesting modes.
  - Not clear that FSI for Kaons in GENIE make sense.
  - No n->K0,ν

momentum-energy balance in nnbar (qua ppbar) annihilation





The theory space is vast and the sense of satisfactorily vanquishing any one class of models is elusive, but of course our job is to do the experiment(s).

Ndk summary, per Bill M.

- 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.

Bkup

800 feet (not longer considered), K^0_L bkgd

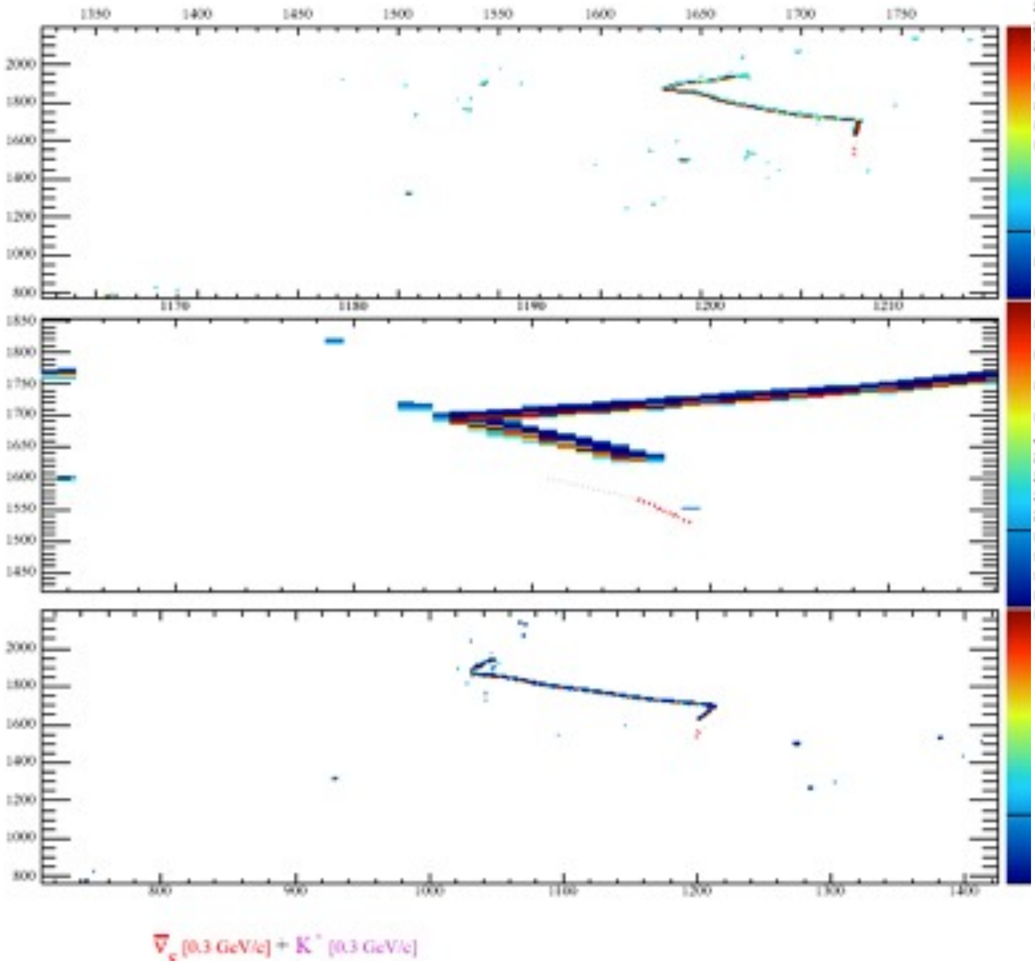
study/Authors	Muon Simulation Package	Exposure	Bgd/100 kt-yr
Bueno, et al	Geant4 and FLUKA	10+ years	<0.1
LBNE.Sheffield	MUSIC/Geant4	X	<0.1
LBNE.JdJ+EC	Geant4	200 kt-years	<<0.1

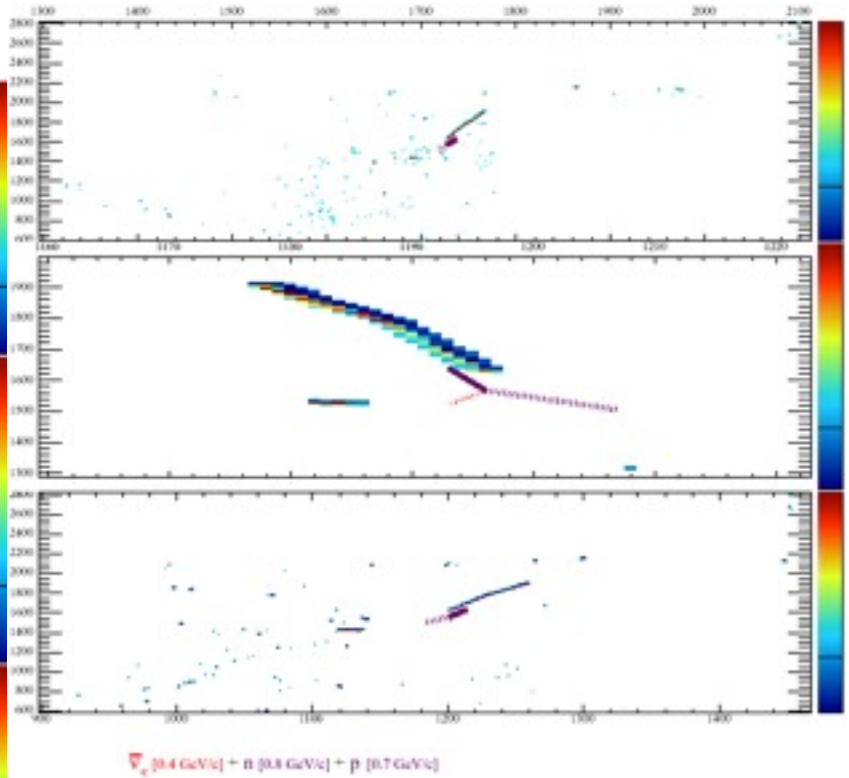
Slide 8 again

p->K$^+$ nubar

less nice event.
K+ lost in FSI,
GENIE says.

Nice “prototypical” event.





Does GENIE FSI make sense?

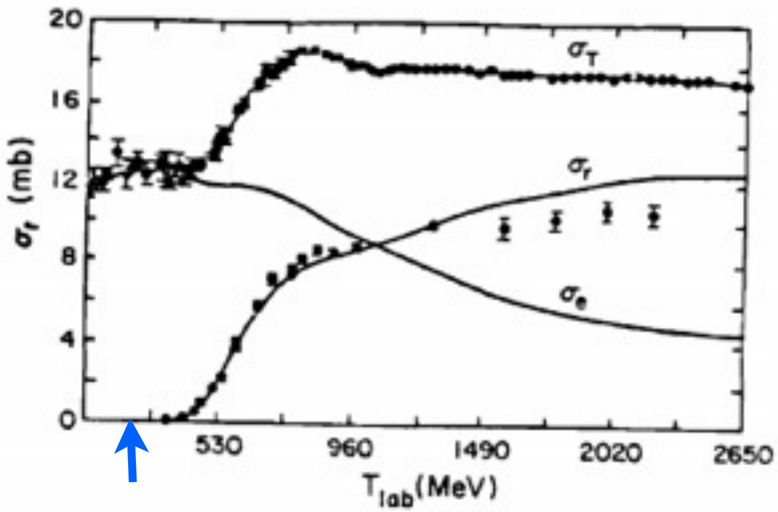


FIG. 4.4. Total (σ_T), inelastic (σ_r), and elastic (σ_e) K^+p cross sections. [From Arndt and Roper (85).]

charge exchange

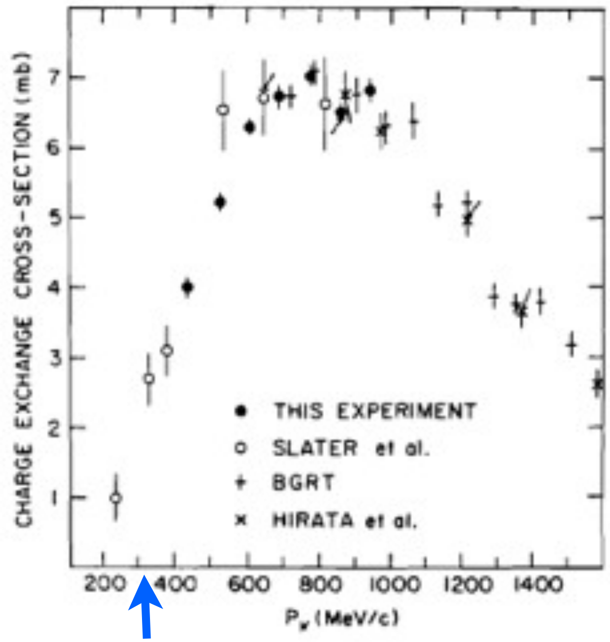


FIG. 4.7. Cross section for $K^+n \rightarrow K^0p$ charge exchange. [From Darnerell, et al. (85).]

arrow at $T(p)_{K+}$ = 106 MeV 337 (MeV/c)

1 mb => 1.5 Argon radius interaction length