Experimental searches for neutron-antineutron oscillations in nuclei

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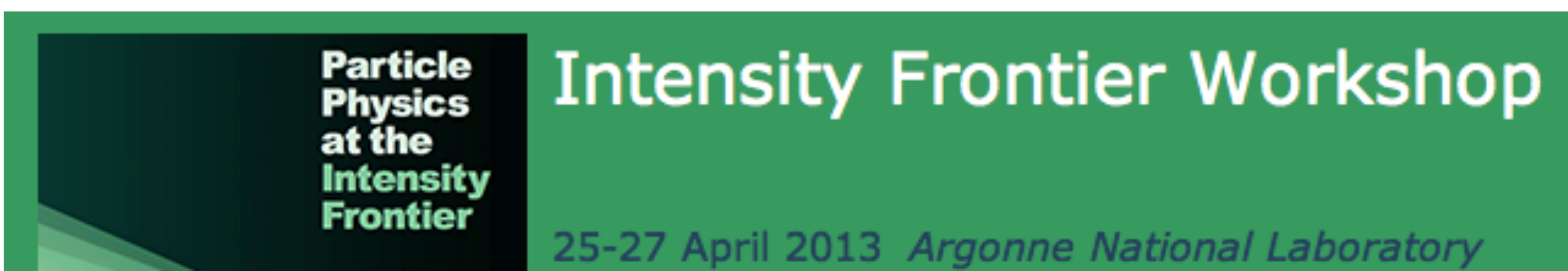
April 26, 2013

Brief report for completeness – More slides, mostly the same, shown at 2012 Project X Workshop

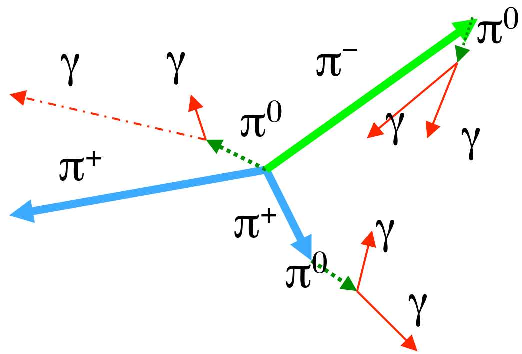


Motivation

- Analogous to well-observed $K^0 \longleftrightarrow K^0$-bar mixing
- Source of B-violation (BAU connection)
- Probes scales from multi-TeV to GUT
- Variety of interesting models
- Competitive with free neutron experiments

  after correction of nuclear potential suppression $\tau_{free} = \sqrt{\frac{T_{nuc}}{R}}$
- Long history of this search by proton decay expts.

Signature



$\bar{n}+p$		$\bar{n}+n$	
$\pi^+\pi^0$	1%	$\pi^+\pi^-$	2%
$\pi^+2\pi^0$	8%	$2\pi^0$	1.5%
$\pi^+3\pi^0$	10%	$\pi^+\pi^-\pi^0$	6.5%
$2\pi^+\pi^-\pi^0$	22%	$\pi^+\pi^-2\pi^0$	11%
$2\pi^+\pi^-2\pi^0$	36%	$\pi^+\pi^-3\pi^0$	28%
$2\pi^+\pi^-2\omega$	16%	$2\pi^+2\pi^-$	7%
$3\pi^+2\pi^-\pi^0$	7%	$2\pi^+2\pi^-\pi^0$	24%
		$\pi^+\pi^-\omega$	10%
		$2\pi^+2\pi^-2\pi^0$	10%

- Created antineutron annihilates with nearby nucleon
- About 2x nucleon mass is released as pions
- Final states may be predicted from annihilation data
- Pion propagation in nucleus must be modeled
- Atmospheric neutrino background rejection:

  no CC muons or electrons

  no energetic recoil protons or neutrons

Summary of Results

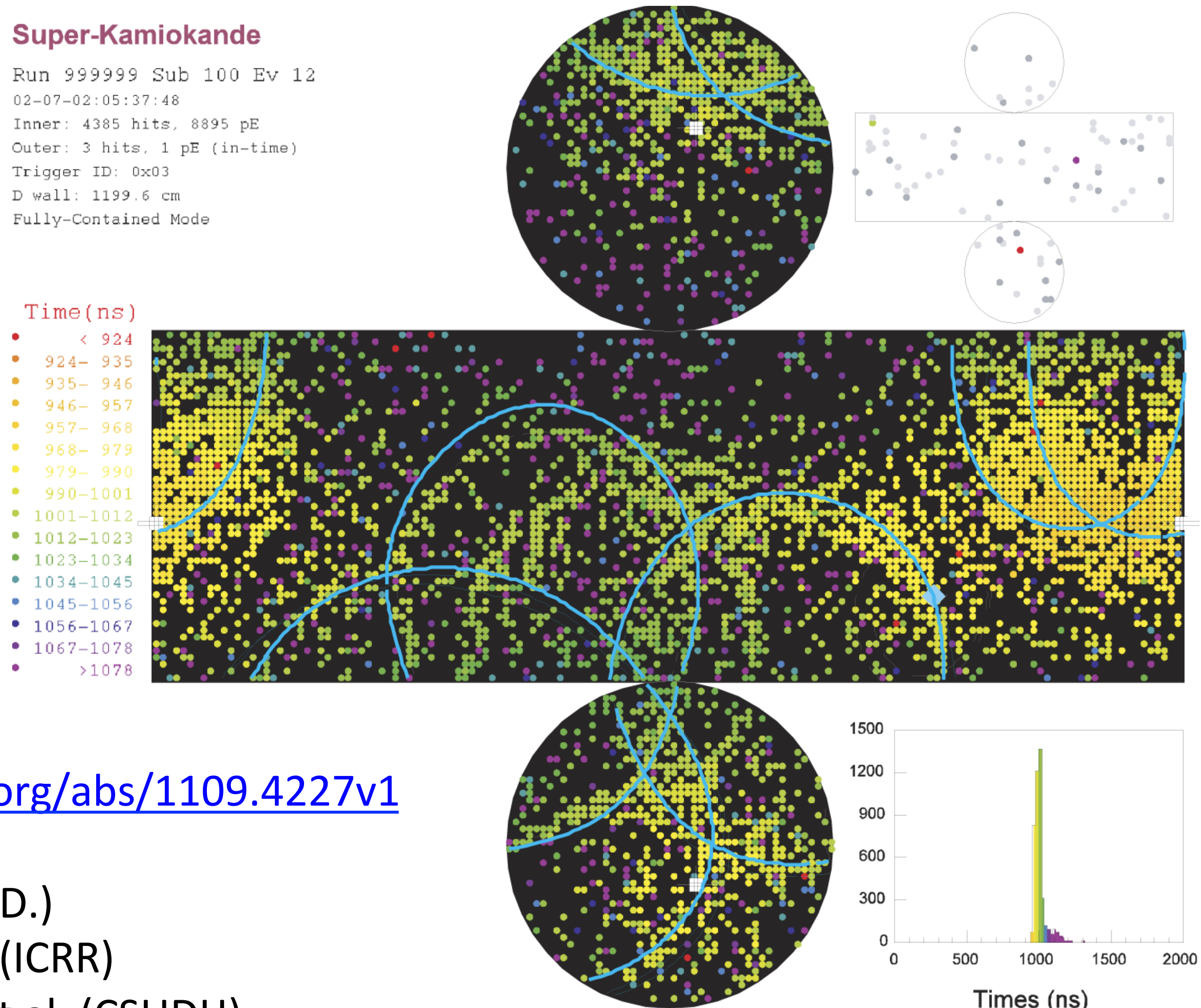
Cf. $\tau > 0.86 \times 10^8$ s [ILL/Grenoble]

Experiment	nucleus	N(10^{32}) [n years]	Effic.	Bkgd.	Cand.	R (10^{23}) [s^{-1}]	$T_{nucl.}$(10^{32}) [yr]
IMB	^{16}O	3.2	50%	-	3	1.0	0.24 $t > 0.9 \times 10^8$ s
Kamiokande	^{16}O	3.0	33%	0.9	0	1.0	0.43 $t > 1.2 \times 10^8$ s
Frejus	^{56}Fe	5.0	30%	2.5	0	1.4	0.65 $t > 1.2 \times 10^8$ s
Soudan 2	^{56}Fe	21.9	18%	4.5	5	1.4	0.72 $t > 1.3 \times 10^8$ s
Super-K	^{16}O	245.5	12%	24.1	24	1.0	1.89 $t > 2.4 \times 10^8$ s
SNO	$^{2}H/^{16}O$	2.7	52%	9.7	4	0.85	1.52 $t > 2.4 \times 10^8$ s

Notes: just reusing published adopted values for R
Most (all?) limits based on volume, not peripheral, suppression

Super-Kamiokande Result

The Search for $n - \bar{n}$ Oscillation in Super-Kamiokande I

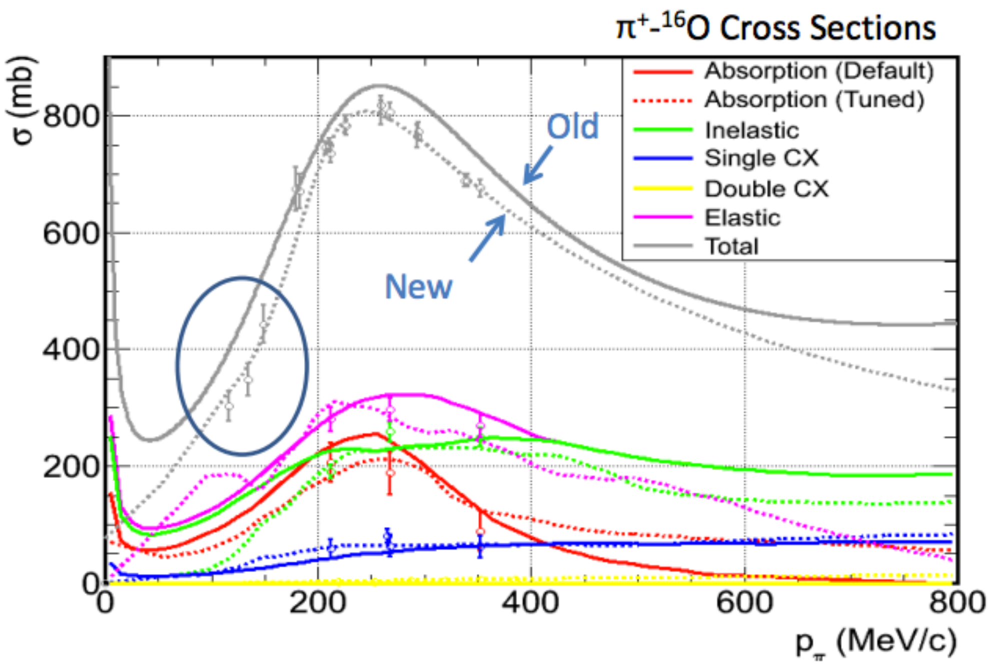


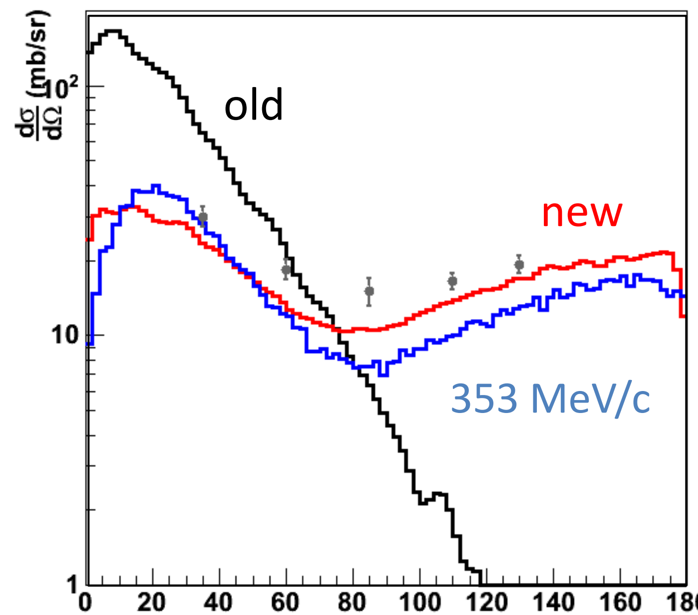
http://arxiv.org/abs/1109.4227v1

J.S. Jang (Ph.D.)
Jun Kameda (ICRR)
K. Ganezer et al. (CSUDH)

Must model intranuclear reactions

- Elastic scattering
- Absorption
- Charge exchange



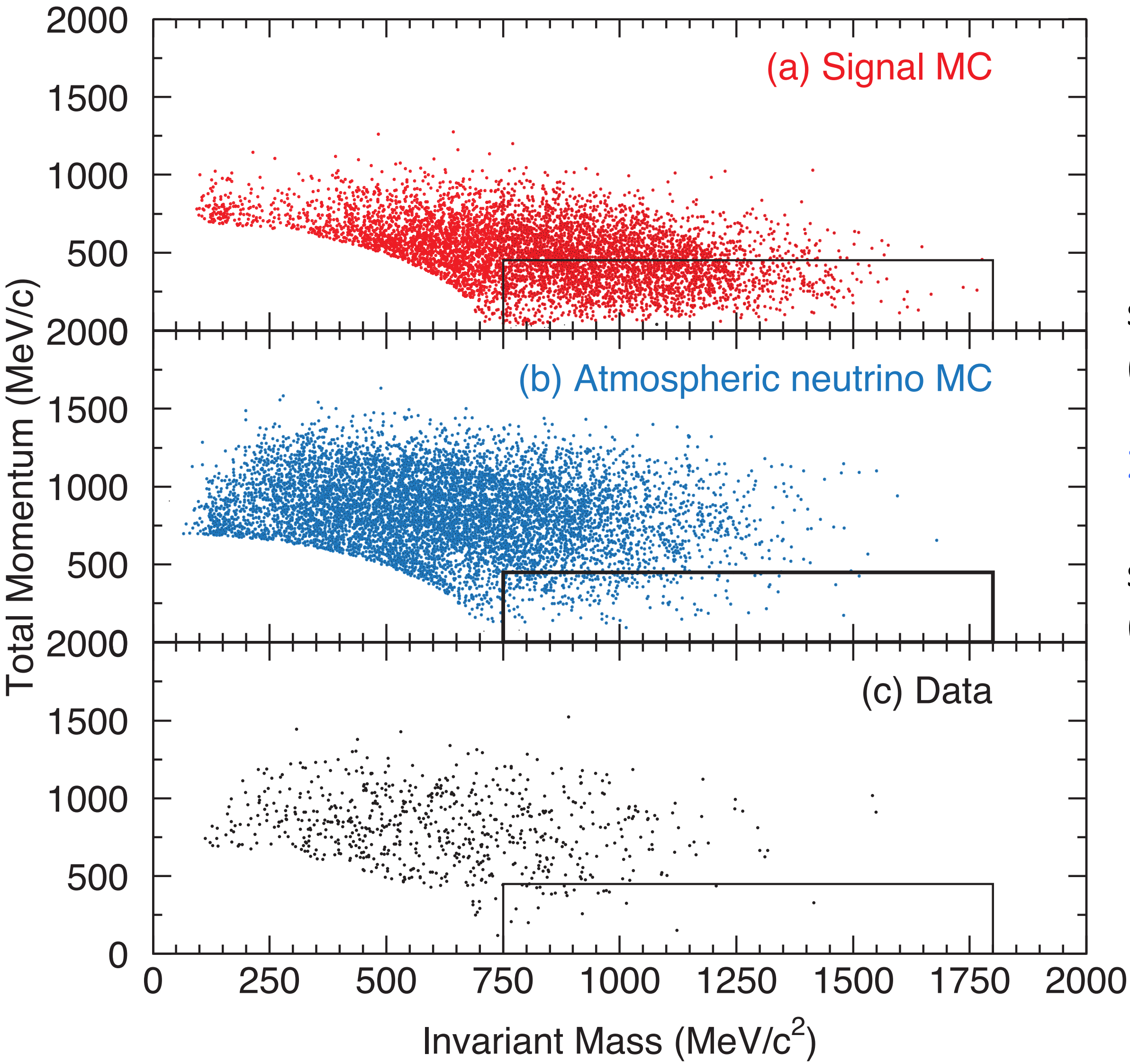


Lab angle

Pion interactions modeled for Intranuclear propagation

(“Old” was used– SK is improving the pion model “neut”)

Super-Kamiokande Result



Selection Criteria:
$N_{ring} \geq 2$
E_{vis} between 700-1300 MeV

12 % detection efficiency
sys. uncertainty 23%
(mostly intranuclear scattering)

24.1 background events
ν osc. effects are included
sys. uncertainty 24%
(mostly flux, cross sections)

24 candidates

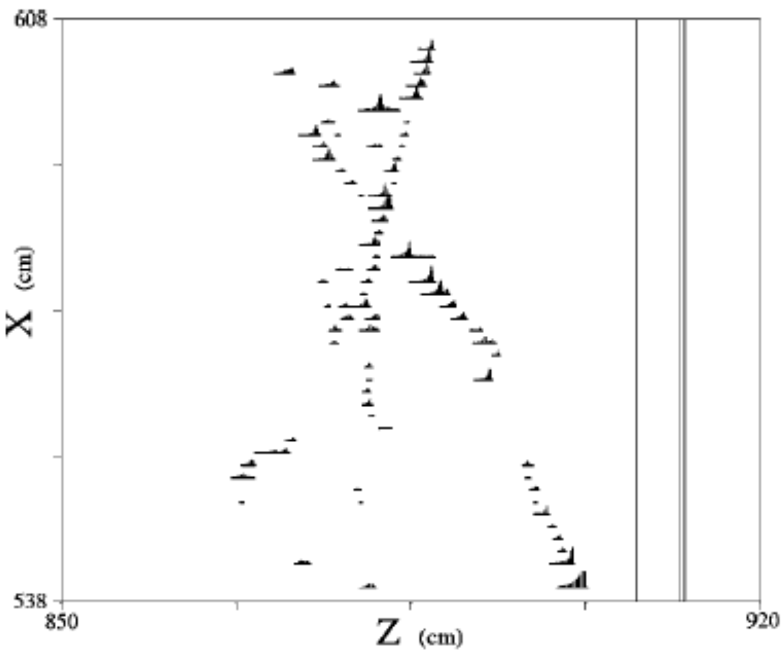
$$T_{bound} > 1.89 \times 10^{32} \text{ years}$$

$$\tau_{free} = \sqrt{\frac{T_{bound}}{1 \times 10^{23}\ \text{s}^{-1}}} = 2.4 \times 10^{8}\ \text{s}$$

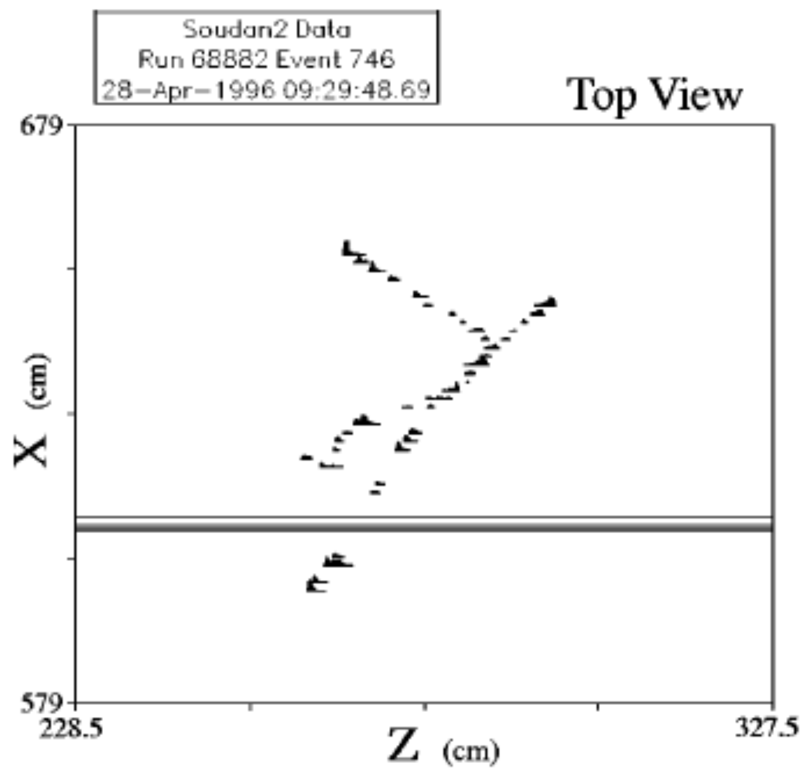
Iron Calorimeters

Review to get a feel for how a LAr TPC analysis might proceed

Soudan 2:
- hand scan
- require n-charged ≥ 4
- eliminate protons, muons
- kinematic cuts



simulation



candidate

Liquid Argon TPC

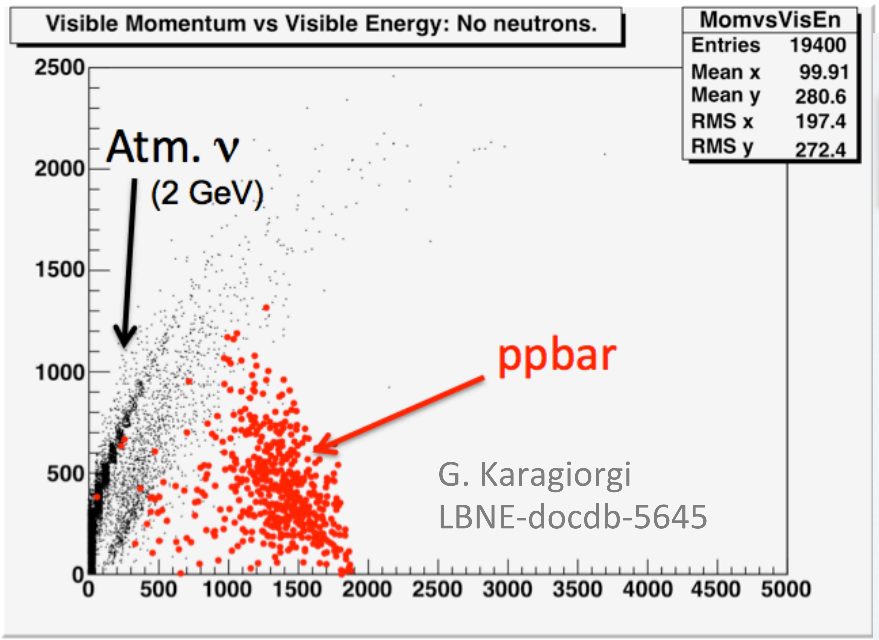
Compared to Iron Calorimeters:

- can do better than requiring n_{ch} >= 4

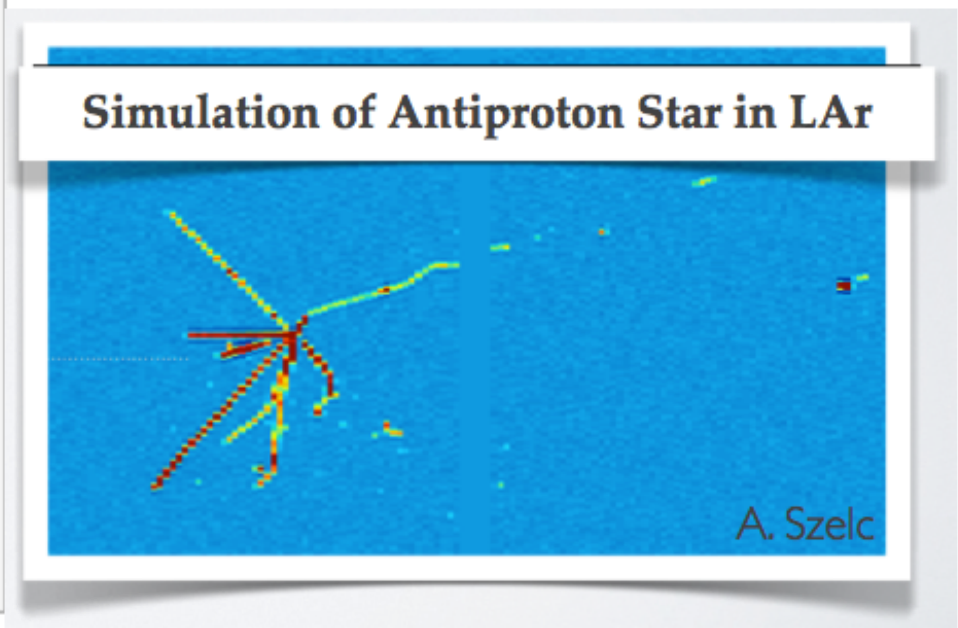
Compared to WC

- can exclude background with recoil proton, charged current lepton

Potentially big gains in efficiency and BG rejection!



Good discrimination at least at truth level.



Sample of such events is an objective of LArIAT (LAr In A Testbeam @ FNAL)

Remarks

- Proton decay detectors have a long history of studying nnbar. Usual desirable qualities apply:
  large mass, high efficiency, low background

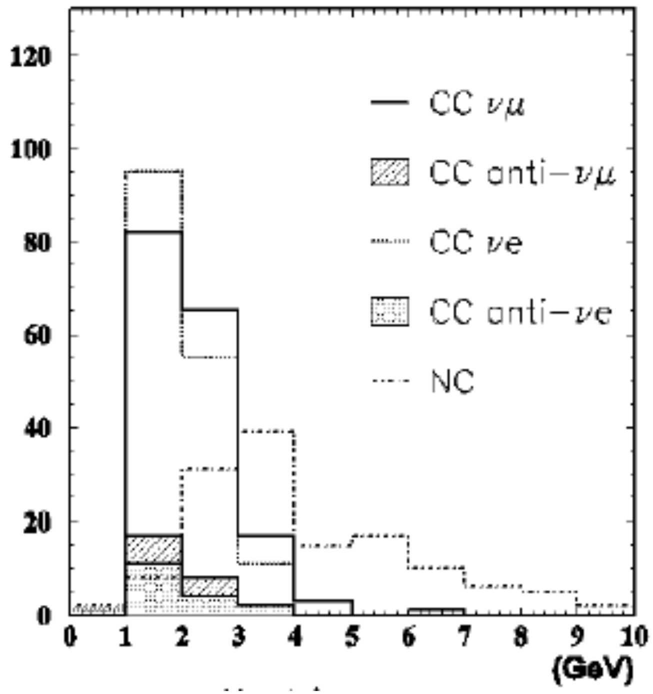
- Analyses have been fairly crude so far.
  High background rate in water cherenkov is daunting.

- LAr TPC, even one as small as LBNE10 kton could do very well. Need signal efficiency and background rate. Under study.

- Nuclear interactions in LAr should be treated with care.

BACKUP

Atmospheric Neutrino Background



Neutrino Energy

DIS : 58%
1-meson resonance : 37%
CC/NC ES : 5%

Interaction Type:

CC 1π : 27.2% (6.5 evt)

NC 1π : 4.1% (1.0 evt)

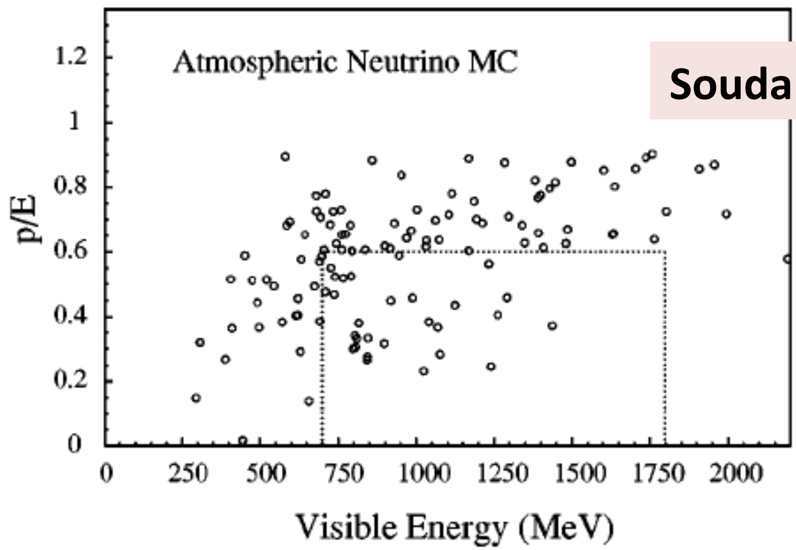
CC mπ : 32.5% (7.8 evt)

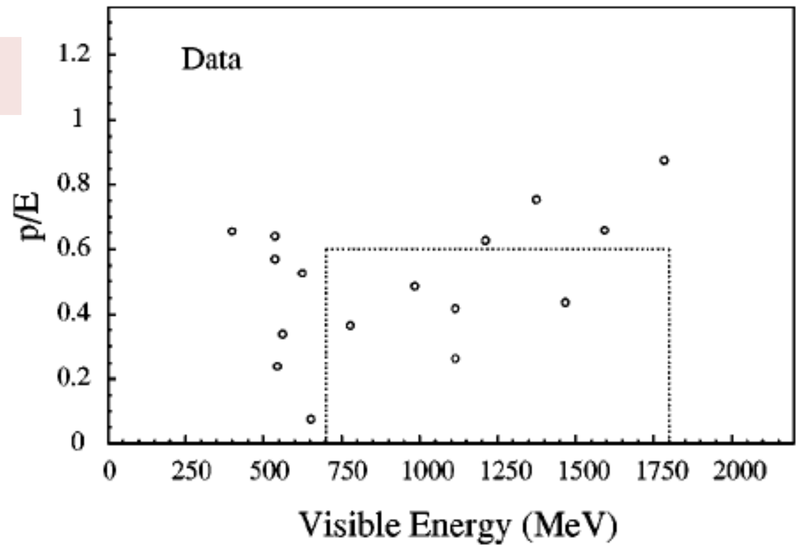
NC mπ : 25.4% (6.1 evt)

Most CC atm. nu BG comes from nu (not nubar) due to higher momentum transfer

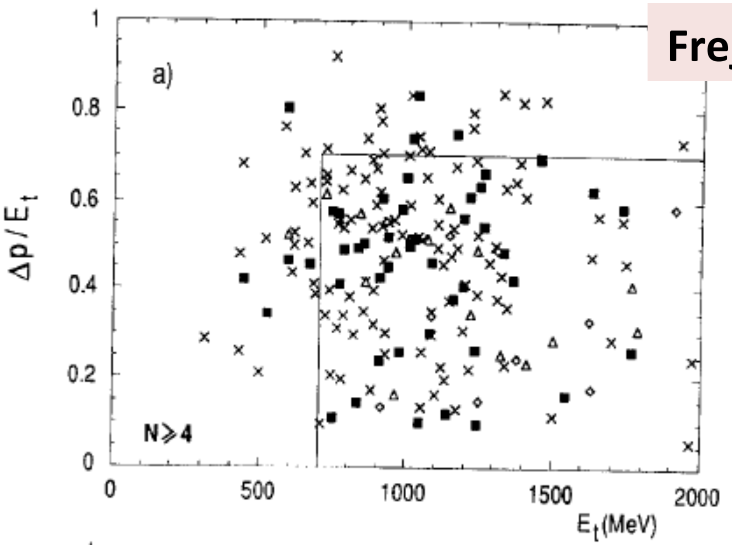
Iron Calorimeters

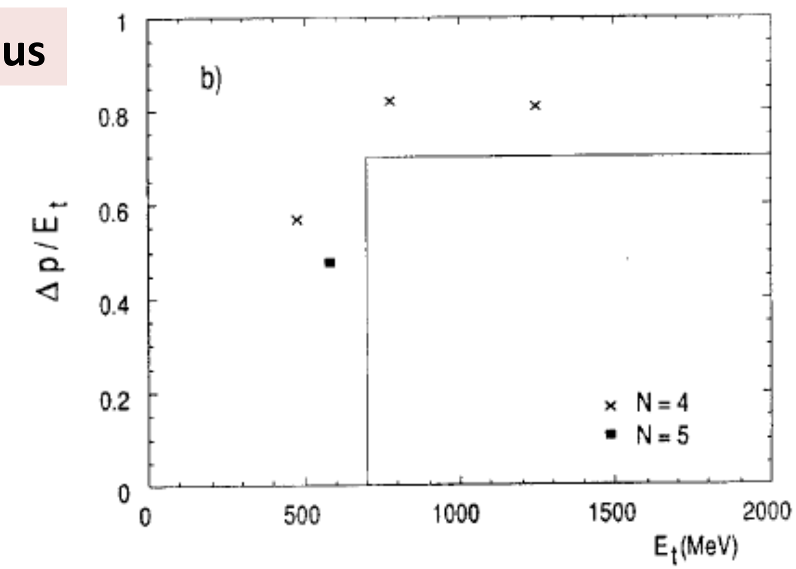
Soudan 2





Frejus





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Super-K	^{16}O	245.5	12%	24.1	24	1.0	1.89 $t > 2.4 \times 10^8$ s
LBNE (10 kt x 5 yr)	^{40}Ar	165.5	30%	5	5	1.0	10 $t > 6 \times 10^8$ s
LBNE (10 kt x 5 yr)	^{40}Ar	165.5	20%	1	1	1.0	10 $t > 6 \times 10^8$ s
LBNE (10 kt x 5 yr)	^{40}Ar	165.5	50%	0.5	0.5	1.0	30 $t > 10^9$ s

Purely speculative numbers for LAr, targets not results.