What Can LBNE Do?

R.Svoboda, DURA 3 September 2010

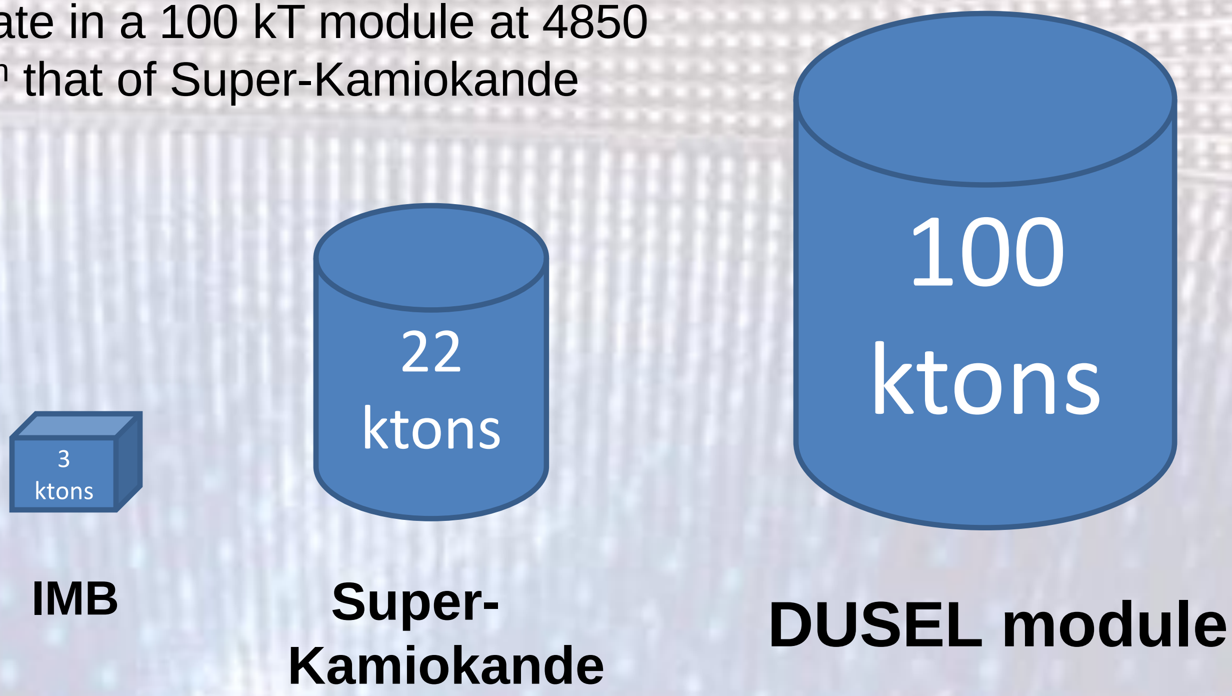
A New Physics

- *Explain* the seeming symmetry of the mixing matrices.
- *Explain* the smallness of the neutrino mass scale relative to u,d quarks and electrons. Note: plausibility of seesaw mechanism does not make it true. If it is true, why is RH neutrino mass scale *not* the GUT scale?
- *Understand* the role of neutrinos in the Big Bang. Neutrino mass and interactions are closely linked to the origins of our universe and its evolution to the current epoch.

A Large Water Cherenkov Detector Option for DUSEL

Note: the DUSEL detector would
be realized in 1-3 modules

The muon rate in a 100 kT module at 4850
will be 1/30th that of Super-Kamiokande



3 ktons

IMB

22 ktons

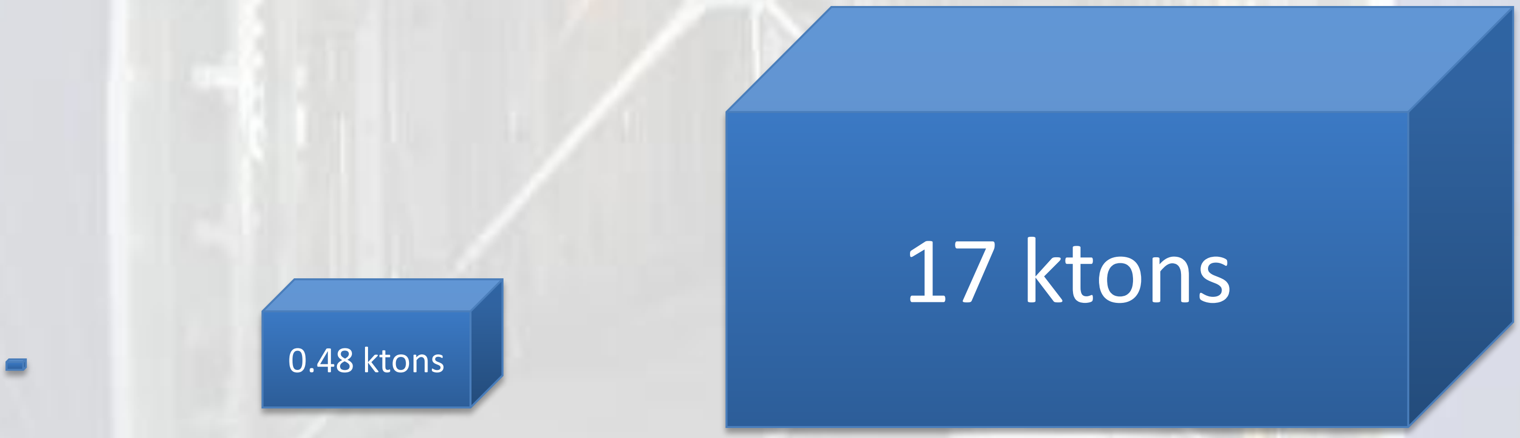
Super-Kamiokande

100 ktons

DUSEL module

A Large Liquid Argon Detector for DUSEL

Note: The DUSEL detector would be realized in 1-3 modules.



0.48 ktons

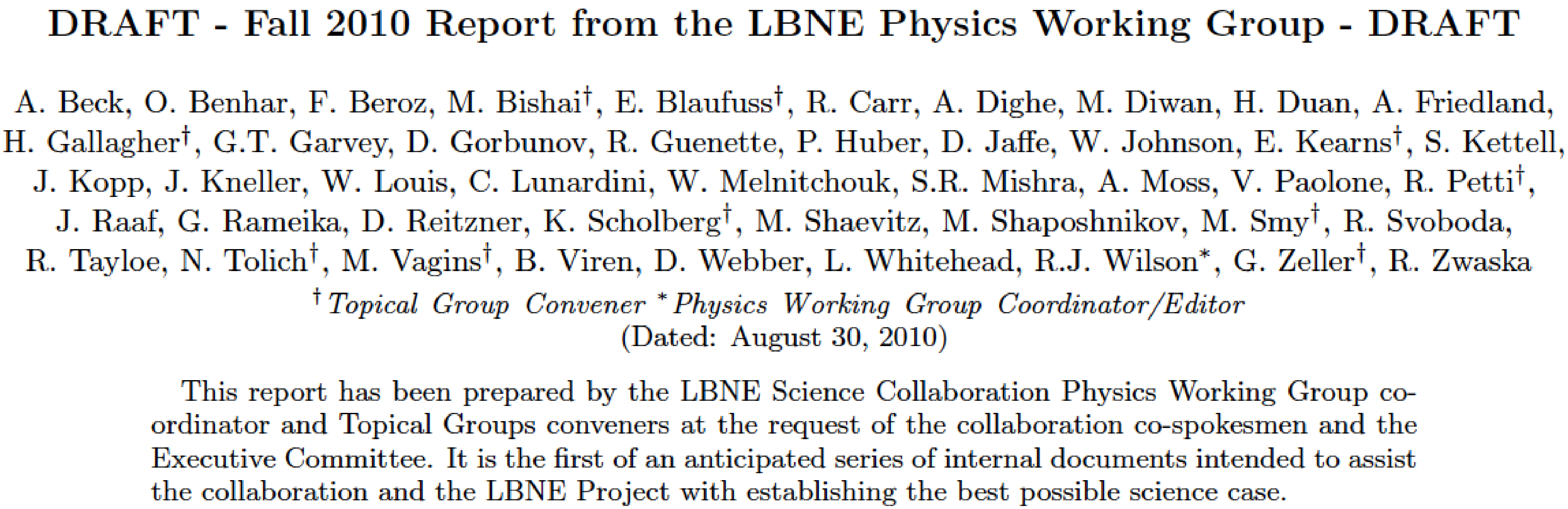
17 ktons

ArgoNEUT

ICARUS

DUSEL module

Give a group of physicists the world's largest detectors, in the world's largest underground lab, with the most intense neutrino beam ever made – what could they do?



DRAFT - Fall 2010 Report from the LBNE Physics Working Group - DRAFT

A. Beck, O. Benhar, F. Beroz, M. Bishai[†], E. Blaufuss[†], R. Carr, A. Dighe, M. Diwan, H. Duan, A. Friedland, H. Gallagher[†], G.T. Garvey, D. Gorbunov, R. Guenette, P. Huber, D. Jaffe, W. Johnson, E. Kearns[†], S. Kettell, J. Kopp, J. Kneller, W. Louis, C. Lunardini, W. Melnitchouk, S.R. Mishra, A. Moss, V. Paolone, R. Petti[†], J. Raaf, G. Rameika, D. Reitzner, K. Scholberg[†], M. Shaevitz, M. Shaposhnikov, M. Smy[†], R. Svoboda, R. Tayloe, N. Tolich[†], M. Vagins[†], B. Viren, D. Webber, L. Whitehead, R.J. Wilson[*], G. Zeller[†], R. Zwaska

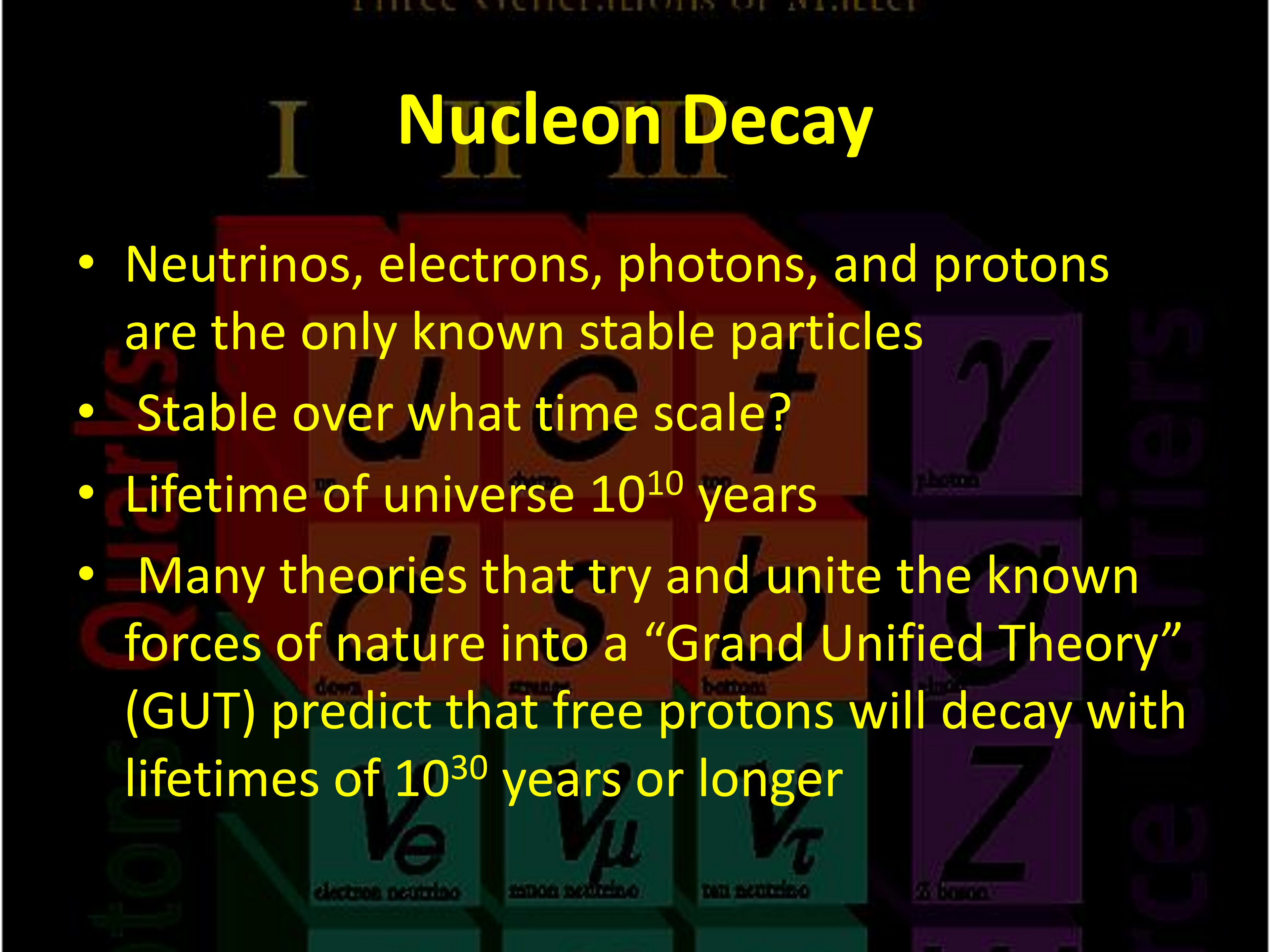
[†] *Topical Group Convener* [*] *Physics Working Group Coordinator/Editor*

(Dated: August 30, 2010)

This report has been prepared by the LBNE Science Collaboration Physics Working Group coordinator and Topical Groups conveners at the request of the collaboration co-spokesmen and the Executive Committee. It is the first of an anticipated series of internal documents intended to assist the collaboration and the LBNE Project with establishing the best possible science case.

Answer: They can tell you in only 106 pages.

Nucleon Decay

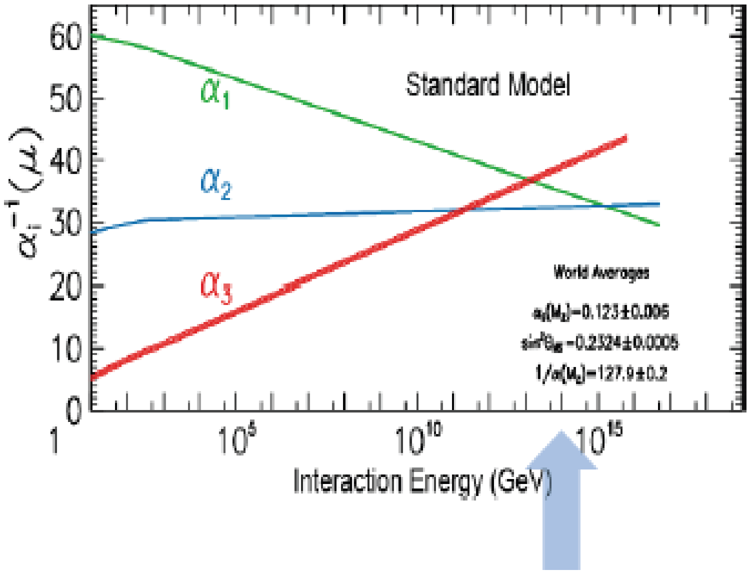


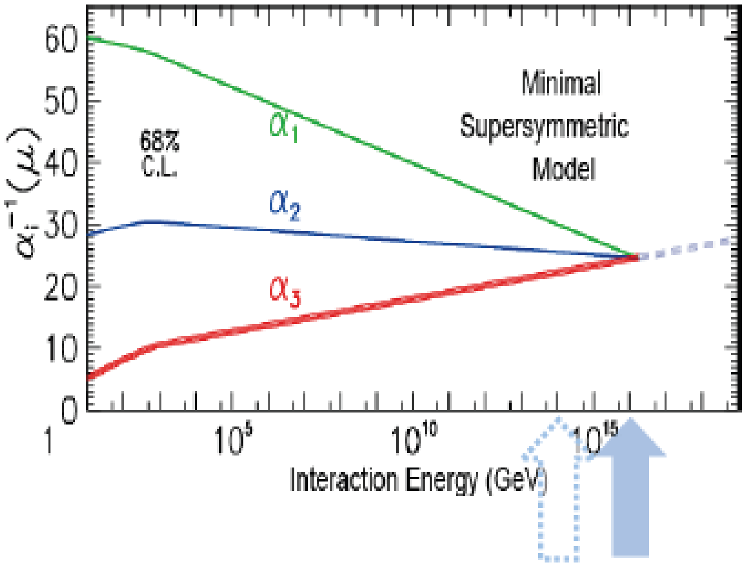
- Neutrinos, electrons, photons, and protons are the only known stable particles
- Stable over what time scale?
- Lifetime of universe 10^{10} years
- Many theories that try and unite the known forces of nature into a “Grand Unified Theory” (GUT) predict that free protons will decay with lifetimes of 10^{30} years or longer

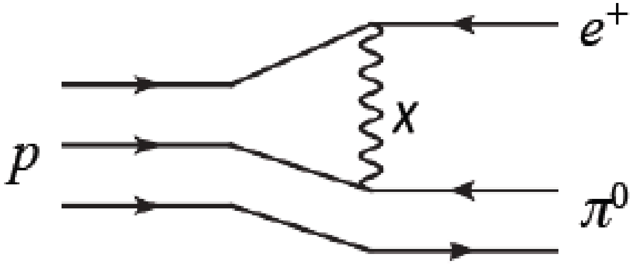
Model	Ref.	Modes	τ_N (years)
Minimal $SU(5)$	Georgi, Glashow [2]	$p \to e^+\pi^0$	$10^{30} - 10^{31}$
Minimal SUSY $SU(5)$	Dimopoulos, Georgi [11], Sakai [12] Lifetime Calculations: Hisano, Murayama, Yanagida [13]	$p \to \bar{\nu}K^+$ $n \to \bar{\nu}K^0$	$10^{28} - 10^{32}$
SUGRA $SU(5)$	Nath, Arnowitt [14, 15]	$p \to \bar{\nu}K^+$	$10^{32} - 10^{34}$
SUSY $SO(10)$ with anomalous flavor $U(1)$	Shafi, Tavartkiladze [16]	$p \to \bar{\nu}K^+$ $n \to \bar{\nu}K^0$ $p \to \mu^+K^0$	$10^{32} - 10^{35}$
SUSY $SO(10)$ MSSM (std. $d=5$)	Lucas, Raby [17], Pati [18]	$p \to \bar{\nu}K^+$	$10^{33} - 10^{34}$
		$n \to \bar{\nu}K^0$	$10^{32} - 10^{33}$
SUSY $SO(10)$ ESSM (std. $d=5$)	Pati [18]	$p \to \bar{\nu}K^+$	$10^{33} - 10^{34}$ $\lesssim 10^{35}$
SUSY $SO(10)/G(224)$ MSSM or ESSM (new $d=5$)	Babu, Pati, Wilczek [19, 20, 21], Pati [18]	$p \to \bar{\nu}K^+$	$\lesssim 2 \cdot 10^{34}$
		$p \to \mu^+K^0$	$B \sim (1-50)\%$
SUSY $SU(5)$ or $SO(10)$ MSSM ($d=6$)	Pati [18]	$p \to e^+\pi^0$	$\sim 10^{34.9\pm1}$
Flipped $SU(5)$ in CMSSM	Ellis, Nanopoulos and Wlaker[22]	$p \to e/\mu^+\pi^0$	$10^{35} - 10^{36}$
Split $SU(5)$ SUSY	Arkani-Hamed, *et. al.* [23]	$p \to e^+\pi^0$	$10^{35} - 10^{37}$
$SU(5)$ in 5 dimensions	Hebecker, March-Russell[24]	$p \to \mu^+K^0$ $p \to e^+\pi^0$	$10^{34} - 10^{35}$
$SU(5)$ in 5 dimensions option II	Alciati *et.al.*[25]	$p \to \bar{\nu}K^+$	$10^{36} - 10^{39}$
GUT-like models from Type IIA string with D6-branes	Klebanov, Witten[26]	$p \to e^+\pi^0$	$\sim 10^{36}$

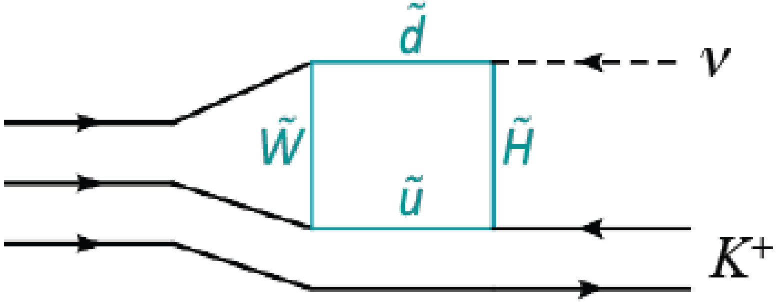
TABLE I: Summary of the expected nucleon lifetime in different theoretical models.

Unification of Running Coupling Constants









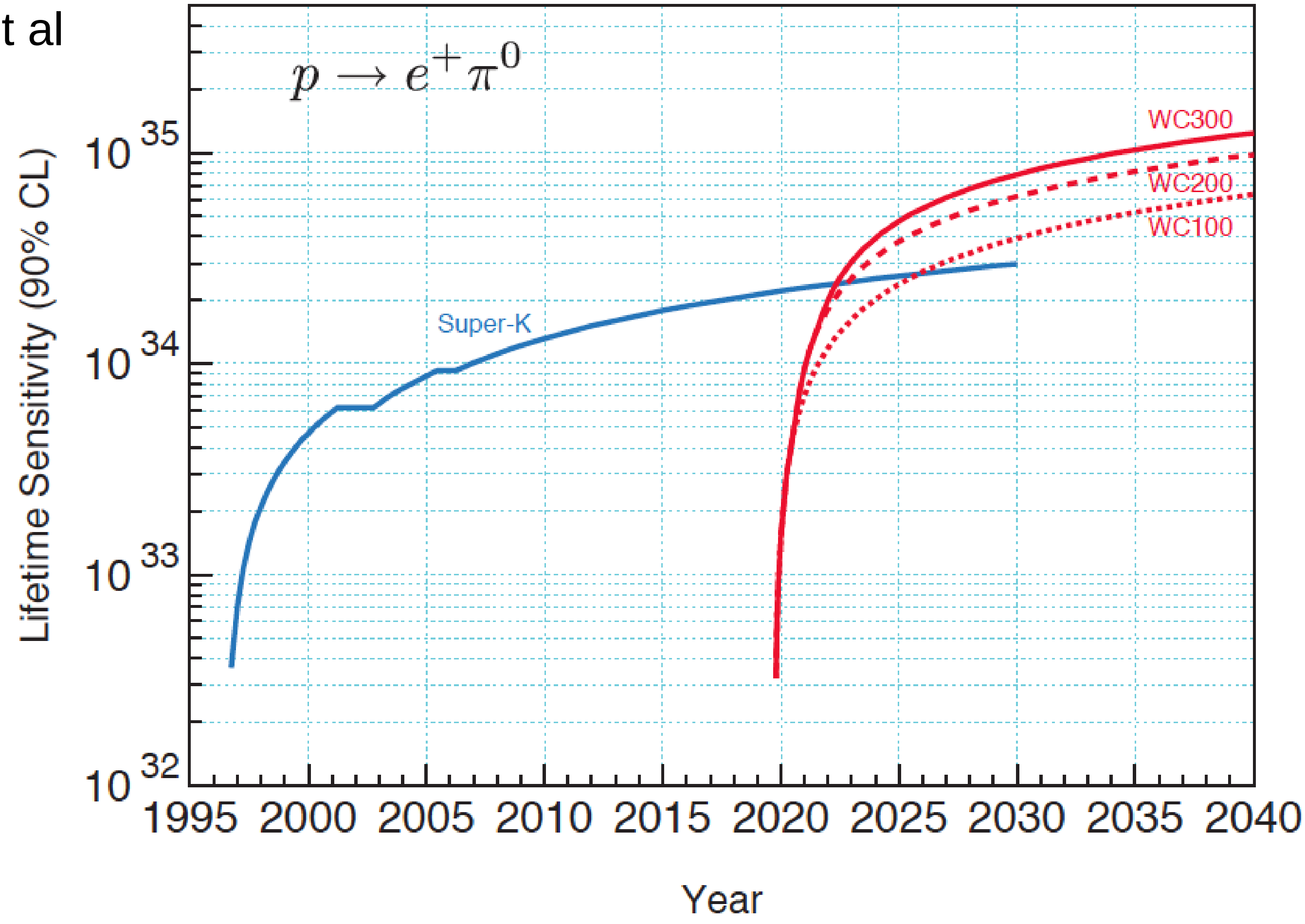
$\tau/B = 4.5 \times 10^{29\pm1.7}\text{years} \quad \mathrm{SU(5)}$

$\tau/B > 8.4 \times 10^{33}\text{years} \quad \mathrm{SK\ I+II}$

$\tau/B = 10^{29-35}\text{years} \quad \mathrm{SUSY}$

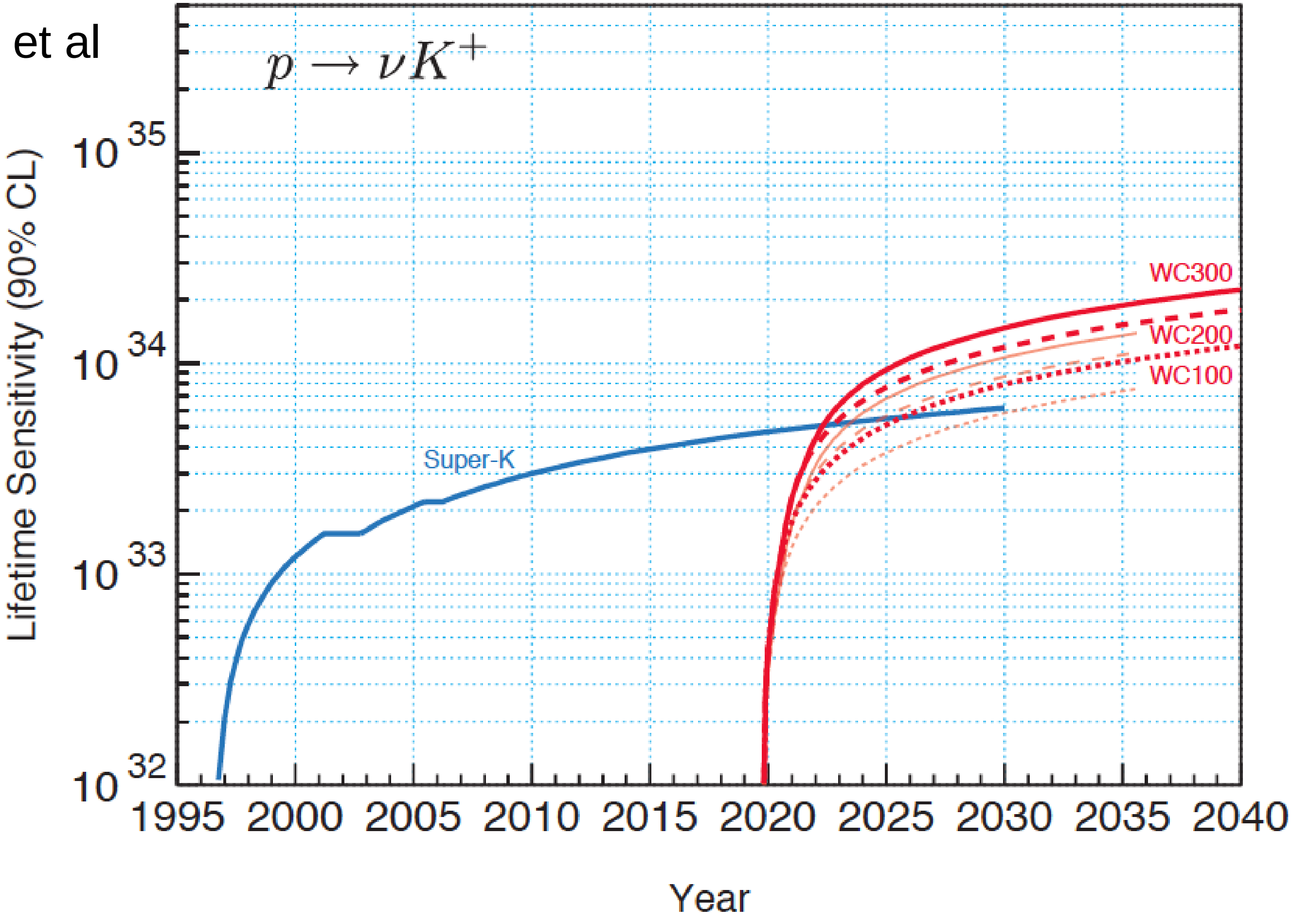
$\tau/B > 2.3 \times 10^{32}\text{years} \quad \mathrm{SK\ I}$

E.Kearns, et al



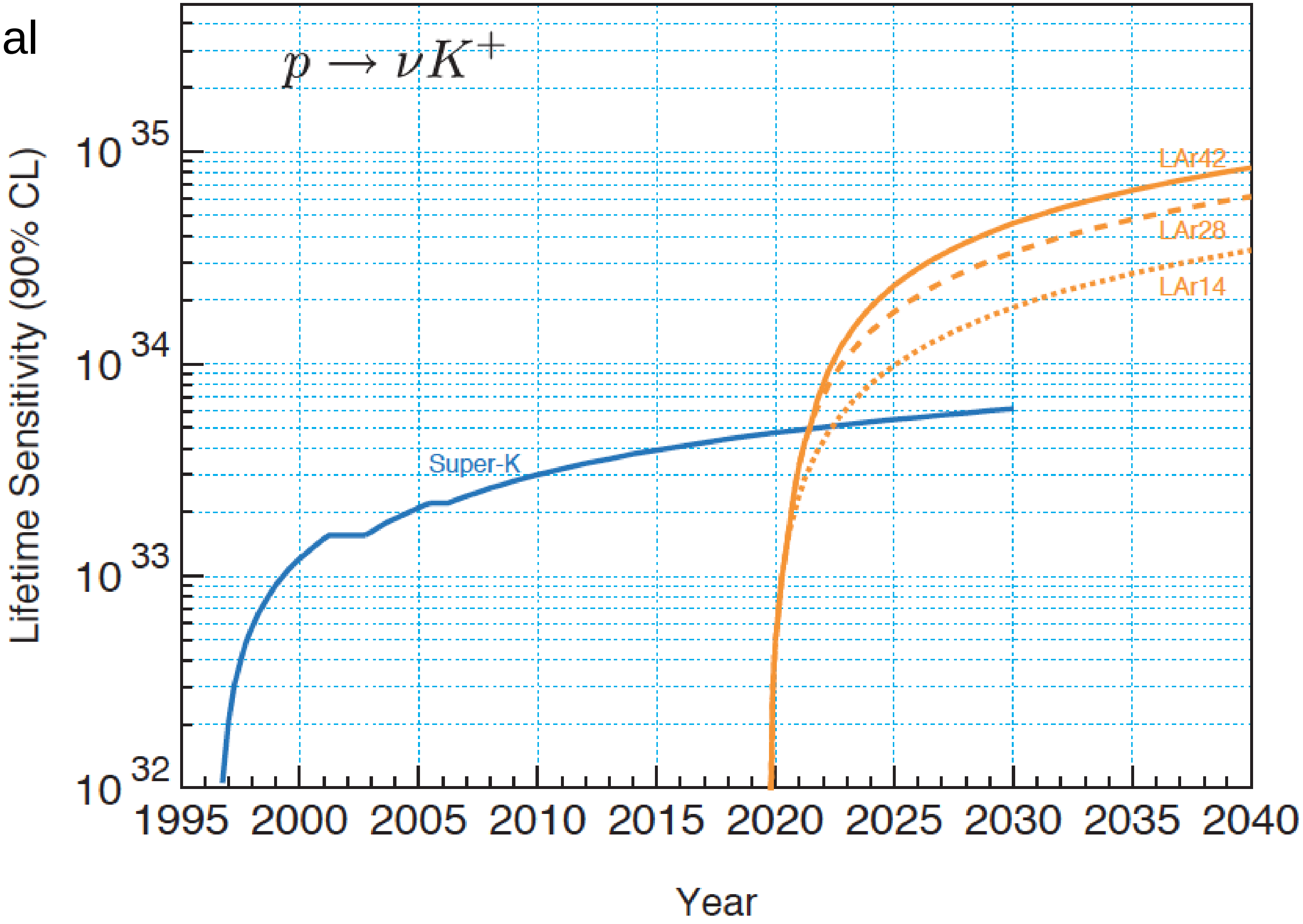
After 20 years, if no improvements are made to SK analysis LBNE would have 14 background events in 300 ktons. Can we do better? E.g. gadolinium tagging or More precise background measurements? Note: SK currently has no candidates In this mode.

E.Kearns, et al



For this mode, if we just used SK analysis – we would have ~40 events background After 20 years? Note: SK currently has no candidates in this mode. Can we do better with gadolinium tagging and improved photomultipliers and electronics?

E.Kearns, et al



While a liquid argon detector is too small to make significant improvement in the $e^+\pi^0$ mode, there is the possibility to have a factor of ten improvement in νK^+ if the detector is large enough.

There are issues with backgrounds at shallow depths. Studies by Bueno, et al (arXiv:hep-ph/0701101) indicate that a muon veto could solve these issues.

The Issues

- pions can scatter in the nucleus via charge exchange, ruining momentum balance. Thus detector efficiency is ultimately determined mostly by the free proton ratio and nuclear size.
- Conservation of strangeness does us a favor for postive kaons.

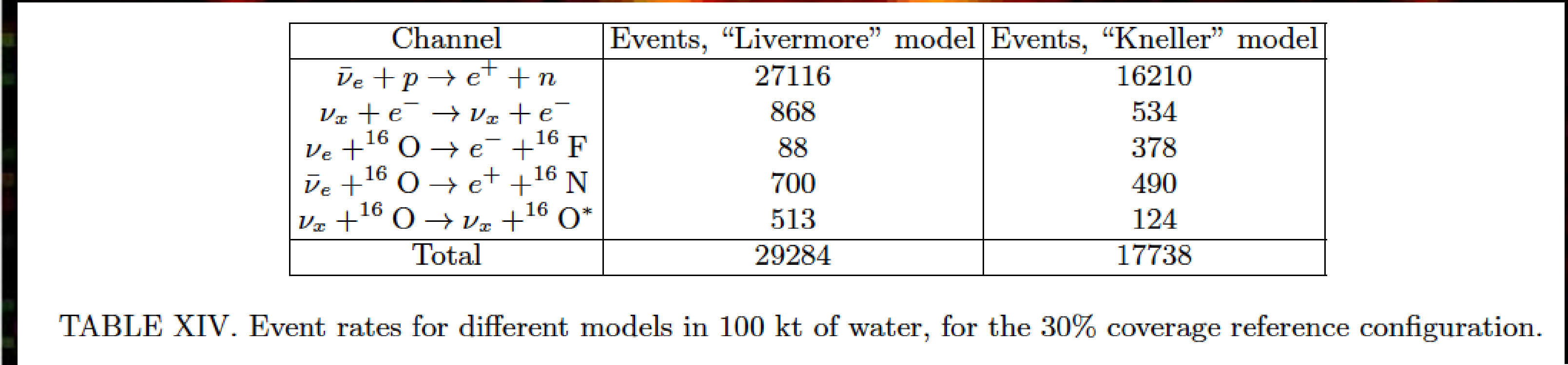
Reaction	Q-value
K^- + n -> π^0 + Σ^-	101 MeV
K- + p -> π^0 + Σ^0	104 MeV
K^- + n -> π^- + Λ	178 MeV
K- + p -> π^0 + Λ	181 MeV
K^+ + n -> K^0 + p	-2.6 MeV
K^+ + p -> K^0 + Δ^{++}	-298 MeV

K^+ inelastic scattering in nucleus
Is limited to K^+n mode, with small
phase space/. Not true for K^-

Production of K^+ by atmospheric neutrinos is small and reasonably well-understood. K^0, n, and Λ production by CR muons is the big issue. These can enter the detector, then make real K^+ - chipping away at the useable fiducial volume. What is the production, and what is the trade-off Between muon veto, depth, and fiducial volume?

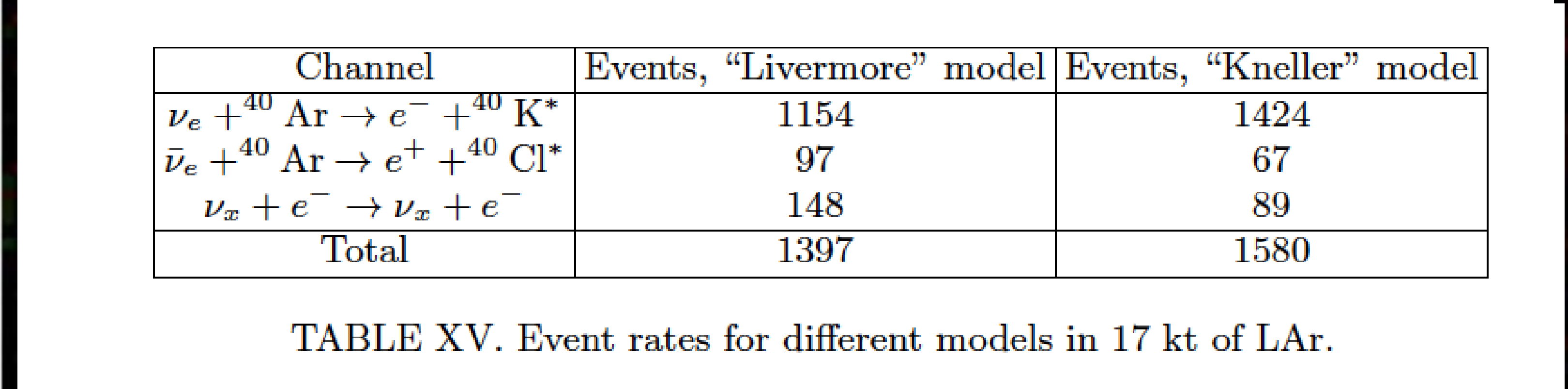
Supernova Burst

- Huge signal for a galactic supernova. Potential to select between generic SN models
- Spectral evolution is sensitive to mass hierarchy and mixing – work ongoing to investigate this.



Channel	Events, "Livermore" model	Events, "Kneller" model
$\bar{\nu}_e + p \rightarrow e^+ + n$	27116	16210
$\nu_x + e^- \rightarrow \nu_x + e^-$	868	534
$\nu_e + ^{16}\mathrm{O} \rightarrow e^- + ^{16}\mathrm{F}$	88	378
$\bar{\nu}_e + ^{16}\mathrm{O} \rightarrow e^+ + ^{16}\mathrm{N}$	700	490
$\nu_x + ^{16}\mathrm{O} \rightarrow \nu_x + ^{16}\mathrm{O}^*$	513	124
Total	29284	17738

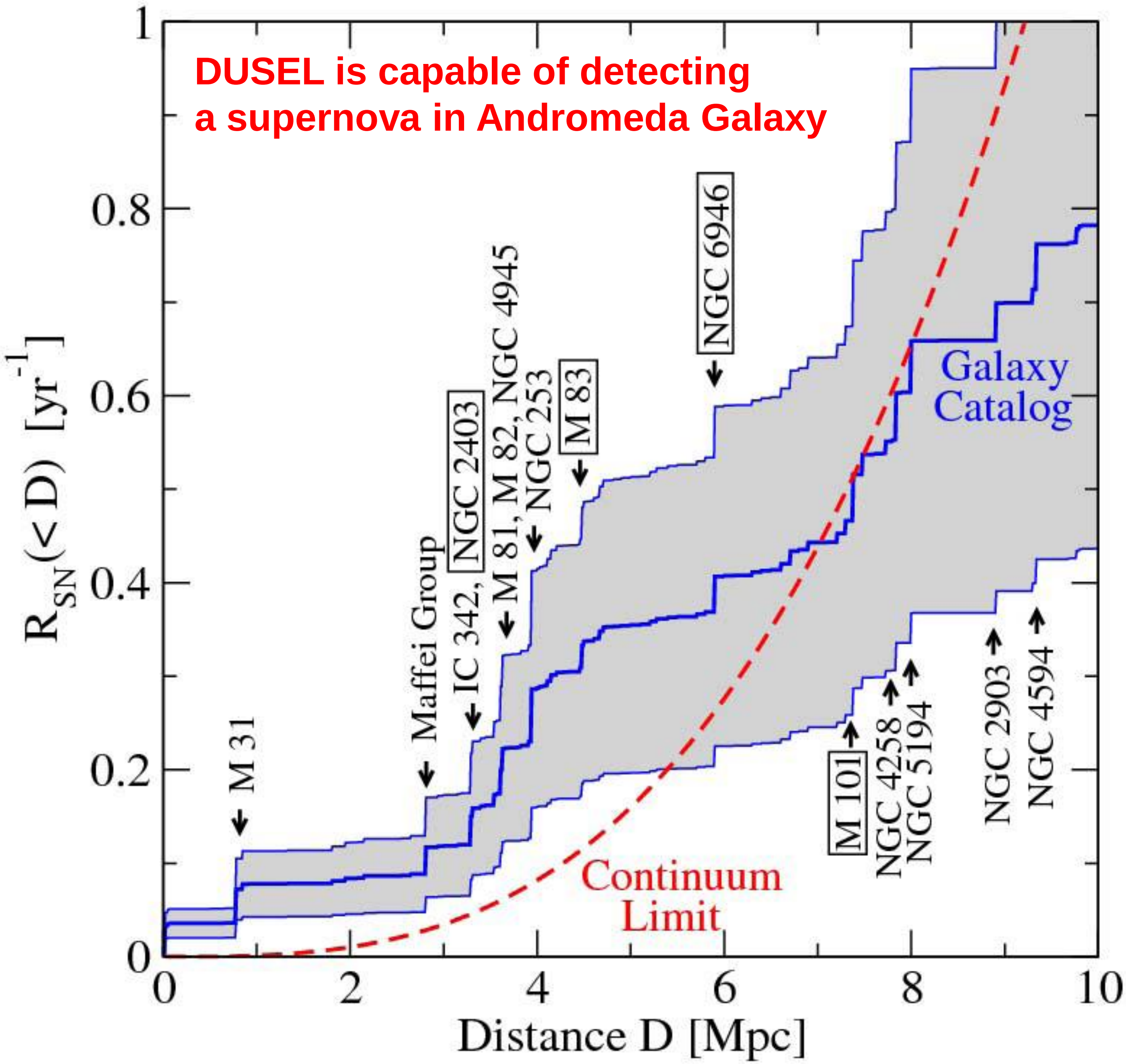
TABLE XIV. Event rates for different models in 100 kt of water, for the 30% coverage reference configuration.



Channel	Events, "Livermore" model	Events, "Kneller" model
$\nu_e + ^{40}\mathrm{Ar} \rightarrow e^- + ^{40}\mathrm{K}^*$	1154	1424
$\bar{\nu}_e + ^{40}\mathrm{Ar} \rightarrow e^+ + ^{40}\mathrm{Cl}^*$	97	67
$\nu_x + e^- \rightarrow \nu_x + e^-$	148	89
Total	1397	1580

TABLE XV. Event rates for different models in 17 kt of LAr.

S. Ando, J. F. Beacom and H.Yuksel,
astro-ph/0503321



DUSEL is capable of detecting a supernova in Andromeda Galaxy

A SN in M31 would ~3-5 events/100 kton

It would be easily detectable in a large water detector of Size ~300 ktons

Background is large bursts of spallation products following a muon-induced shower

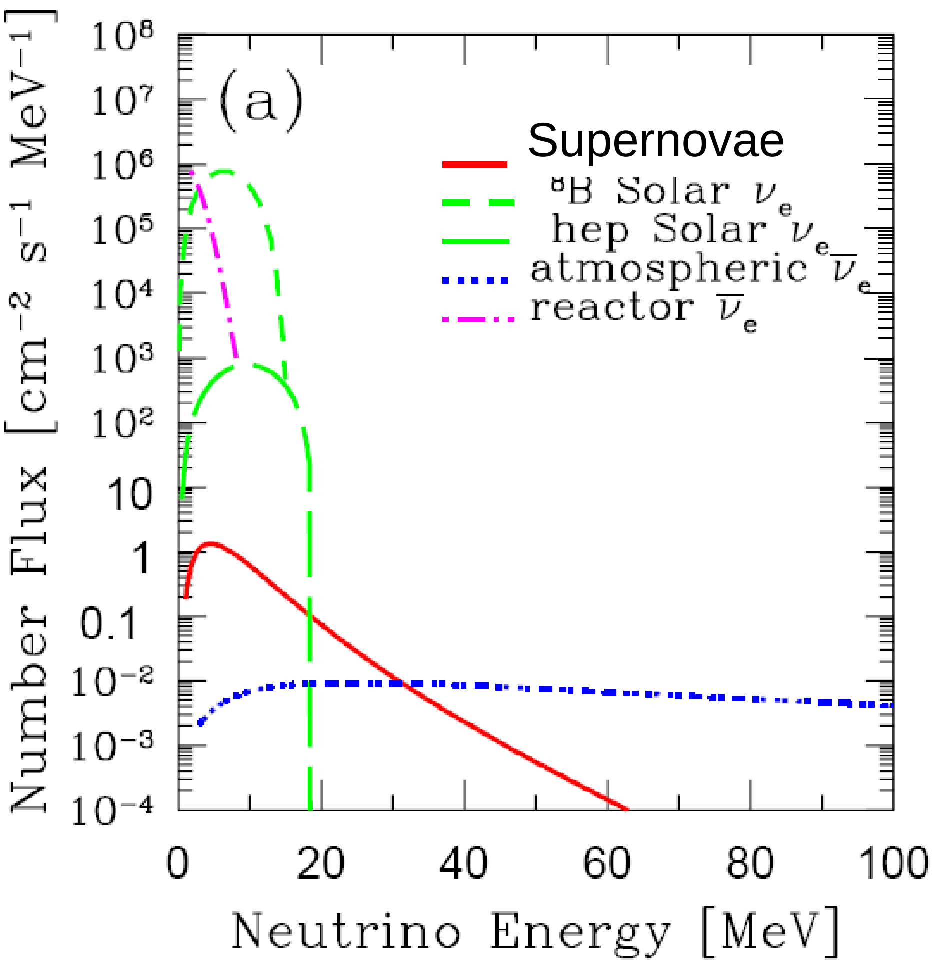
deeper is better

The feeble signal of all SNe

- Sum up supernovae over the whole

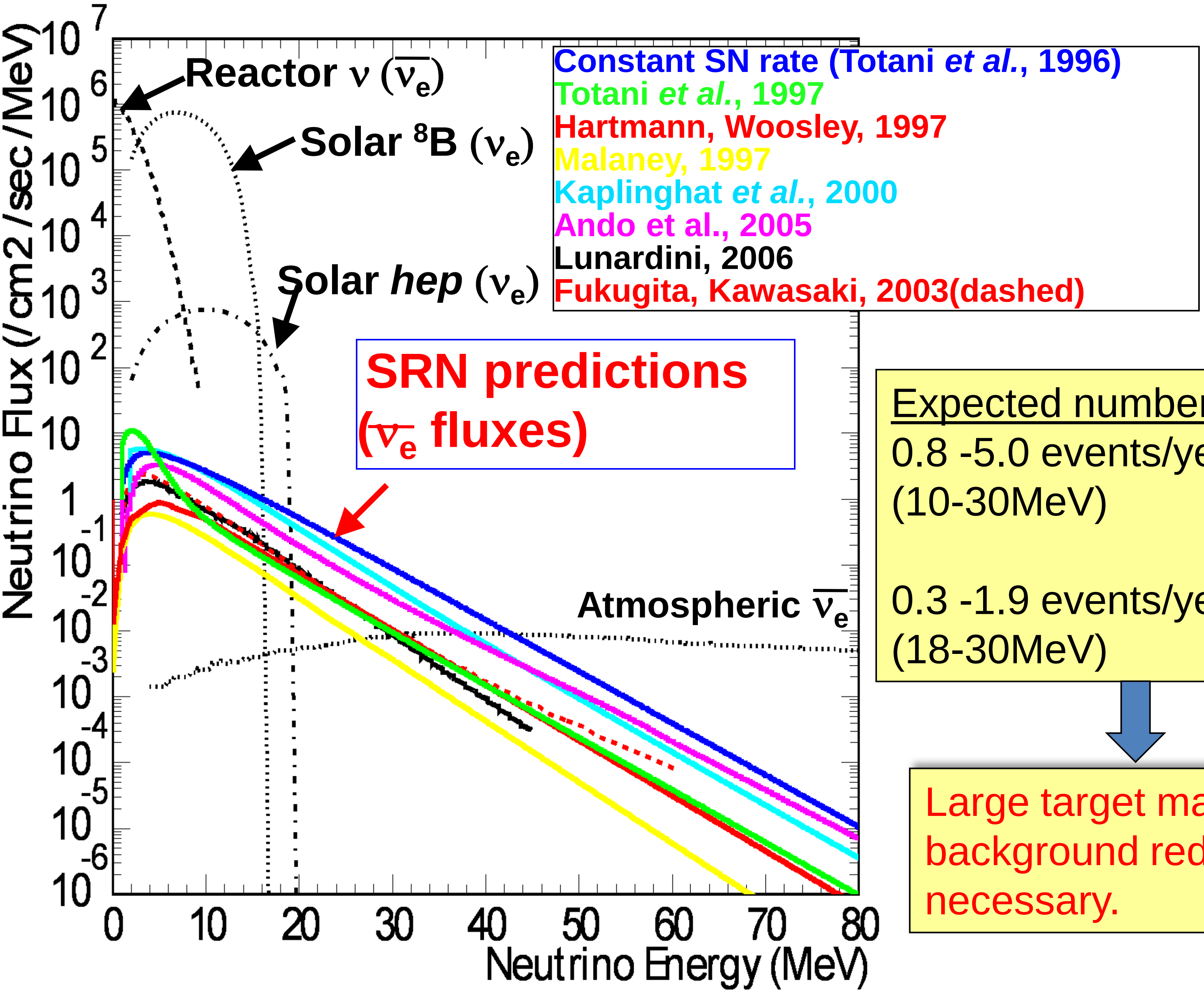
$$\sum_{\star} \Phi_{\nu}^{\star}$$

- This is detectable
- We can verify our expectations for stellar formation rate at large redshifts



S. Ando and K. Sato, New J.Phys.6:170,2004.

Supernova Relic Neutrinos



SRN predictions ($\overline{\nu}_e$ fluxes)

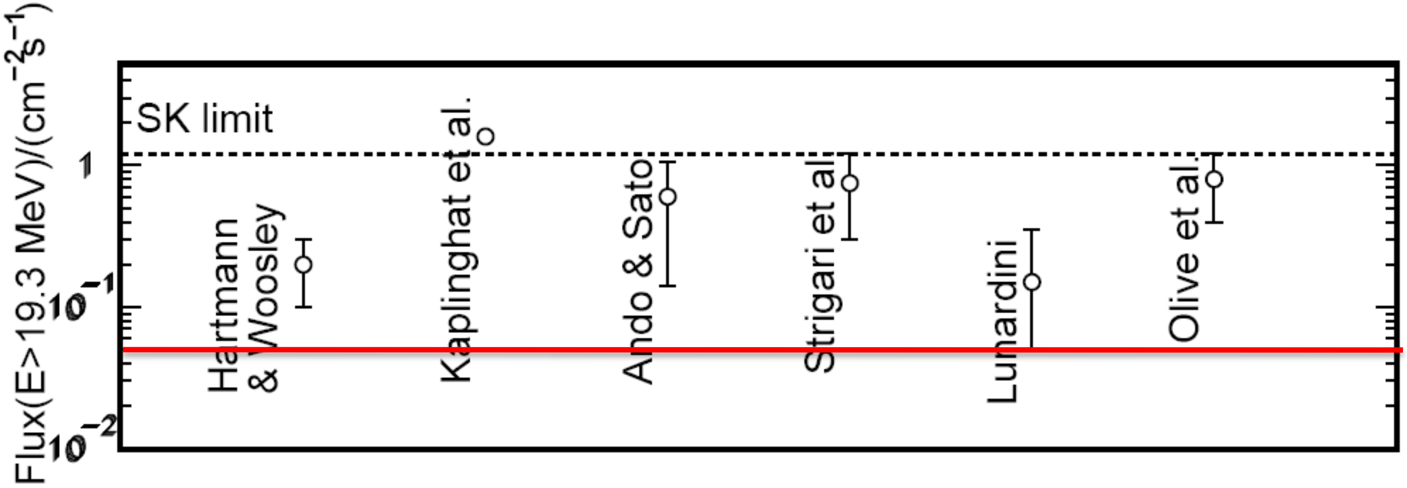
<u>Expected number SRN events</u>

0.8 -5.0 events/year/22.5kton (10-30MeV)

0.3 -1.9 events/year/22.5kton (18-30MeV)

Large target mass and high background reduction are necessary.

Diffuse SN flux: Added depth at DUSEL and large detector mass would makes detection possible



DUSEL
300 kT
Gd loaded
at 4850’
depth

(for a complete description, see arXiv 0907.4183)

DUSEL muon rate an order of magnitude smaller than Kamioka, so expect 15.5 MeV threshold instead of 19.3 MeV.

This enhances signal by 40% in addition to just detector mass scaling.

Gadolinium loading *plus* extra depth would increase sensitivity by ~factor of two. Thus improvement of factor of more than twenty is possible.

Technical Issues

- How expensive will this option be? What is the minimum phototube coverage to ensure a successful measurement?
- How well do we know the background reduction? Do we need to measure this?
- Preservation Of Gadolinium Option (POGO) is currently part of the plan.

Many Other Active Physics Working Groups

- Atmospheric neutrinos
- High energy neutrinos (astrophysics, dark matter, etc.)
- Solar neutrinos
- Short baseline neutrino physics (cross sections, new phenomenon)
- Low energy neutrino physics

We want a broad program. Neutrinos have a history of confounding our expectations (especially at Homestake!)

Looking Ahead: How will LBNE will decide what they want to build? Why is it so hard?

- What is the Science? (done!)
- What are the Issues?
- What is the Process?
- Meet in Geneva

Lake Geneva, Wisconsin

- The LBNE Executive Committee will meet next week for a two day Retreat
- We will deal with these last two issues
- We will look at narrowing down the possible options
- We will present our recommendation at the LBNE collaboration meeting on September 13

H.Sobel
W.Louis
M.Marshak
R.McKeown
E.Blucher
E.Kearns
R.Kadel
K.Scholberg
J.Klein
B.Fleming
G.Rameika
G.Sullivan
Ex-officio Members
R.Svoboda
M.Diwan
M.Goodman
J.Strait
Gina Rameika
V.Papadimitriou
C.Mauger
J.Stewart
B.Baller

Thanks!

Disassembly of the Davis solar neutrino experiment to make room for LUX, October 2009

backup

Gadolinium Doping

- Sensitivity to neutron capture via 8 MeV gamma cascade (e.g. M.Vagins, NNN08)
- Inexpensive, low risk. Could be implemented after construction completed, no schedule risk.
- Technical challenges:

  - material compatibility. Chose materials that do not contaminate the water.

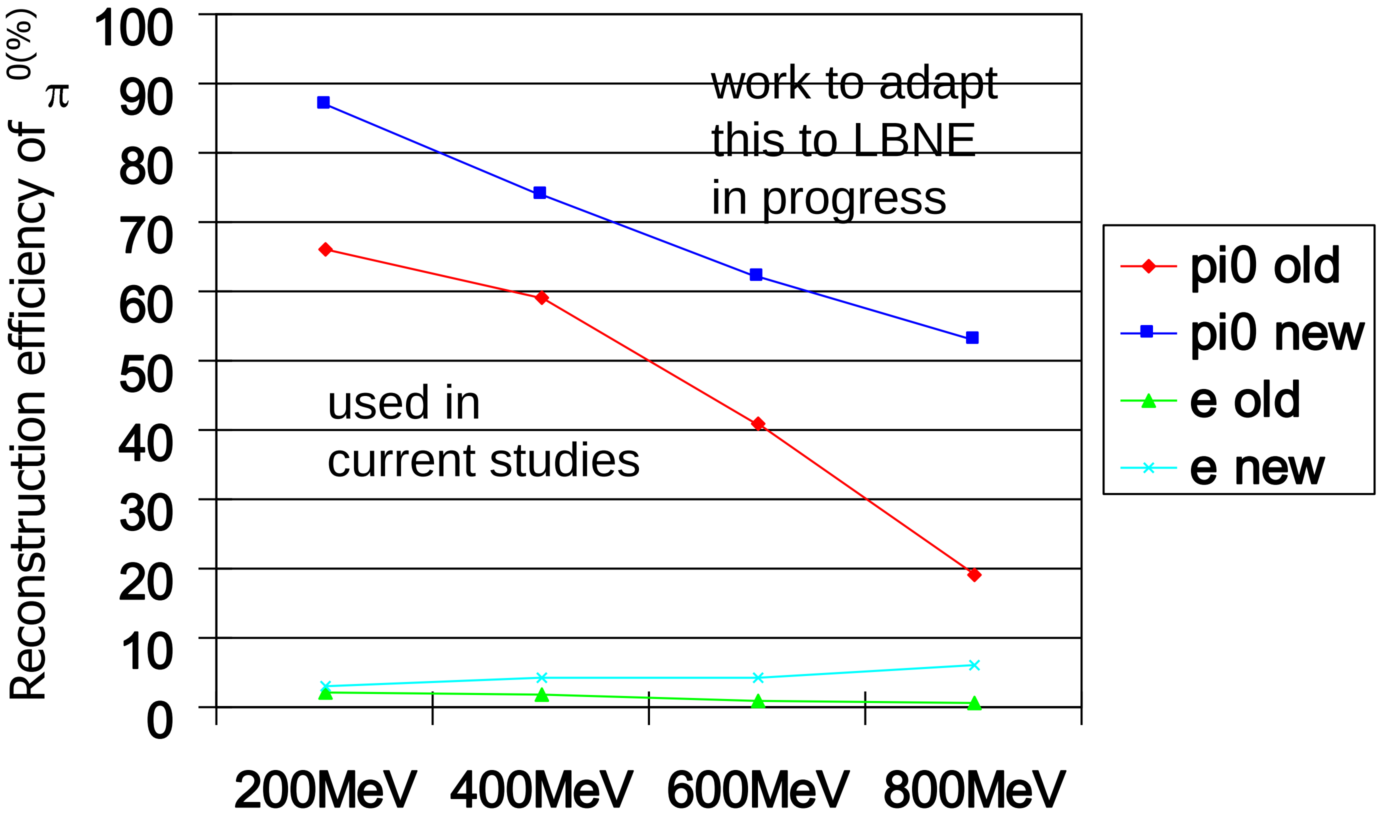
  - water treatment . Remove impurities but leave gadolinium in solution.

Liquid Argon versus Water Cherenkov

- Two major backgrounds for CPV/mass hierarchy measurement: intrinsic ν_e in beam and misidentification of NC π^o.
- A liquid argon detector should be much better with π^o identification. Downside: technology not as well-developed, cost and schedule risks not well known.
- A water Cherenkov detector can be made much larger for more signal. Downside: poorer resolution on π^o background.

Improved π^0/e separation in SK

- 2-R e-like tag (old ring-finder)
- π^0 fitter (improved ring-finder)

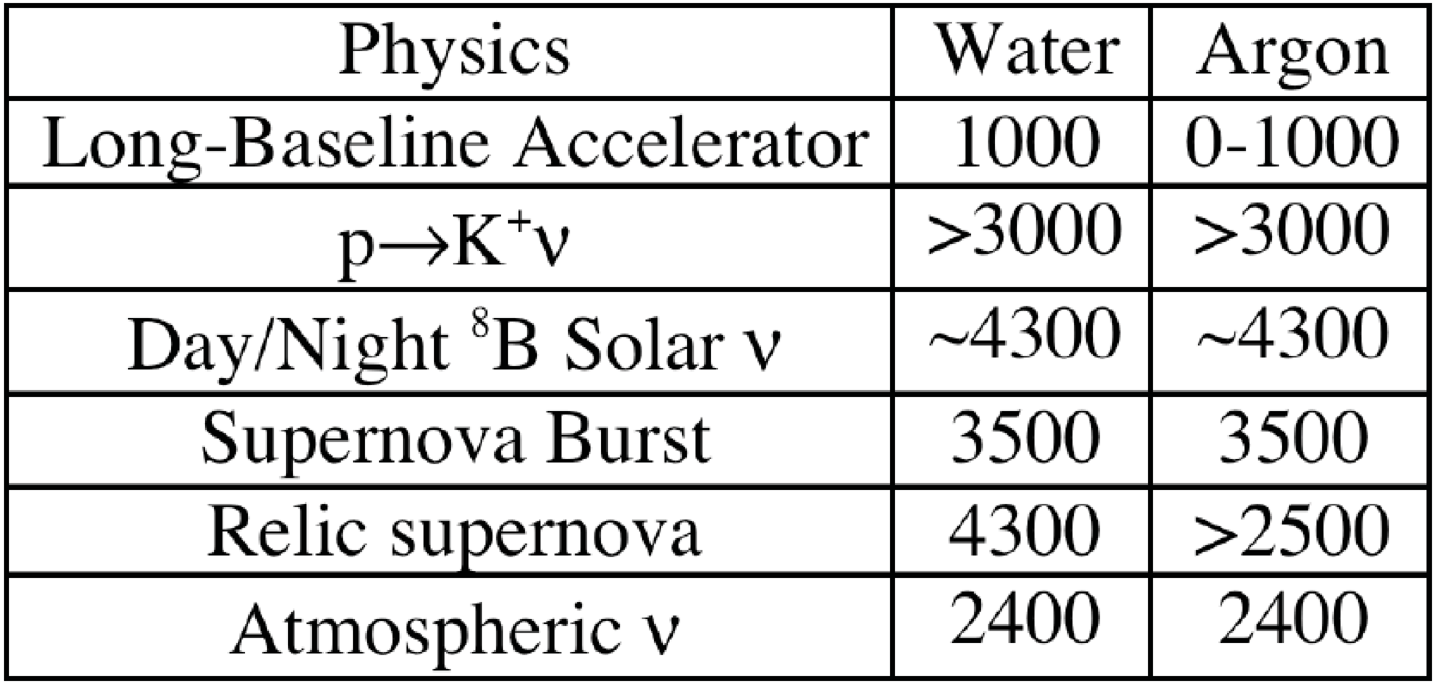


work to adapt this to LBNE in progress

used in current studies

From M.Smy

LBNE Science Collaboration : Depth Document



Physics	Water	Argon
Long-Baseline Accelerator	1000	0-1000
$p \rightarrow K^+ \nu$	>3000	>3000
Day/Night ^{8}B Solar ν	~4300	~4300
Supernova Burst	3500	3500
Relic supernova	4300	>2500
Atmospheric ν	2400	2400

Required depth in meters of water equivalent (MWE) for Water Cherenkov and liquid argon detectors

arXiv:0907.4183