the deep underground prototype
for undersea and ice ν detectors…

Capone
Spiering
Waxman

Proton Decay and Atmospheric Neutrino Oscillations:

Results from Super - K and Outlook for Future "Megaton" Detectors

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broad brush, round-number overview...

physics motivation

- proton decay theories severely constrained
- precision ν oscillation measurements
  - mass difference Δm^2 for $\nu_\mu \rightarrow \nu_\tau$
  - mixing angle θ_{23}
  - search for CP violation
  - sign of Δm^2 ...using matter interference
- synergism with superbeams, ν factories

current status of Super - K

- proton decay
- atmospheric neutrino oscillations

our goals?

- near, medium, long-term
- K2K/Minos, hot ν beams and factories

comparison of future detector technologies

- water Cherenkov
- liquid argon
- (balanced scintillator & Cherenkov oil?)

where are we? where going?

Proton Decay Search, now

Current State...size is everything

Super-K: 3.5 yr % 22 kT { 80 kT-yr

IMB still best for most of ~40 modes

SK PDK limits $e^{+}\pi^{o}$ 5 % 10^{33}, background 0.2

νK^{+} 1.6 % 10^{33}, background 2.2

with wide-open cuts for SK

...could soon be µ 5 x more restrictive

K2K: probably no background to 10 yr % 0.5 MT

IMB (1981-90) & SK: 10 yr realistic lifetime

Near Term Program: Super-K (2003 to ~2007 with 1/2 pms)

increase exposure ~2-fold

statistically improve limits

develop improved cuts and reconstruction for Hyper-K

find 1 or 2 proton decay candidates

invaluable guide to designing next detector

determine mode to focus on

define size of detector

set technology

study atmospheric ν background to proton decay

compare with events in near detector of K2K

2003 - 5: K2K long baseline study of ν oscillations

Super - Kamiokande, longer term

Medium Term Goal

Super-K (between 2007 and ~2012)

proton decay search with original pm density

μ 2007 JHF 1 superbeam for neutrino properties

Long Term Goal: New Megaton Detector

want significant increase of sensitivity x 10-20

sensitivity = mass x detection efficiency

need knowledge of neutrino interactions

minimize atmospheric background for linear gain

mode focus? K^+ detection could drive technology

Long Term Detector Technology?

1) 0.5 - 2 MT water Cherenkov

UNO / Hyper-K

for JHF 2, μ 2012 4MW superbeam

Titanic - sunken, water/pm-filled tanker

Suzuki

2) liquid argon LANNDD

3) detector with balanced scintillator / Cherenkov oil

Svoboda

what are the options?

New Detector Technology: water

water Cherenkov - low cost/MT

- underground
  - Super-K 50 kT total, 22 kT fiducial →
    - Hyper-K / UNO...2-3 x 100kT
  - no scale-up of Super-K...just repeat
    - array of 10-20 ~ Super-K tanks
  - does cavern size set ultimate limit?
- undersea
  - embedded, fine grain in Antares, Nestor
    - piggy back on infrastructure
    - 10 GeV threshold veto sufficient?
    - deployment inside existing array feasible?
  - submerged vessel, *e.g.* Titanic
    - no excavation: avoid dominant time and cost
    - no bioluminescence, sea currents movement
    - raise to surface for maintenance
    - >100m must use pressure-tolerant enclosures
- under-ice
  - Amanda
    - 50 GeV threshold? diffuse light? spacing?

what are the options, continued?

New Detector Technology: Scintillator

liquid scintillator...2 options as water substitute for $p\nu \rightarrow K^+$

1) high light yield, *e.g.* Kamland ***or***,
2) doping balanced: *e.g.* LSND / Miniboone 2003
    a) isotropic scintillator for calorimetry
        and timing signature of K^+
    b) but dilute, Cherenkov not overwhelmed
        for ring imaging and directionality

νK^+ detection efficiency 10% $\rightarrow$ 40%
but potential problem: μ/e discrimination degraded?

tech information to come from Miniboone
    e. g. electron π^o discrimination

what if SUSY discovered?
what if Super-K gets 1 or 2 candidates for νK^+ ?
    should we fill S-K with dilute scintillator?

MegaTon project: $1B/MT oil...show stopper?

what are the options, continued?

New Detector Technology: Liquid Argon

liquid argon time projection chamber - Icarus

everything charged visible...3 x 3 x 0.6 mm pixels

1/2 of 600T studied at surface...moving to
1.5 m drift, achieving 1.8 ms lifetime
(*vs.* 30 ms needed for scaling up)

+ 2 x 1200T = 3 kT proposed for 2005 in Gran Sasso
safety under consideration

technical evaluation awaited see muon decay pix
reconstruction of stopping muons and decay:
vertices of end of muon and beginning of e
dE/dx vs. range for stopping muons
cross-check with multiple scattering
electron energy distribution...Curie Plot

LANNDD 70 kT

~6 x better efficiency than water for K^+
(but not for $e^+ \pi^o$)
⇒ 420 kT effective (8 x Super-K total)

moderate cost: $200 M for the liquid

proposal sites: Frejus & WIPP, New Mexico

New Detector TechnologySummary

Reach	4x better than Super-K		10^{35} years		
Technology	**Strong Scintillation**	**Scintillator balanced w/ Cherenkov**	**Liquid Argon**	**Water Cherenkov underground**	**Water Cherenkov in sea**
Current detector	Kamland 1KT	LSND	Icarus 0.3kT	Super-K 50KT	-----
Proposal detector	---	Miniboone	LANNDD 70kT	Hyper-K and UNO	Titanic
Scale Factor	500	5000	~200	(x7 IMB δSK) 10 - 20	∞
νK^+ Detection Efficiency	0.5	0.5	1.0	0.15	0.15
Cost	High	High	Medium	Excavation: Time & $	?
Pros	calorimetry on all charged particles	Directionality	Superb detail; 6x better for νK^+	Mature technology, going since 1981	get > 2MT reach atm ν $e^+ \pi^o$ limit?
Cons	Single Goal ...νK^+ no direction	Single Goal ...νK^+ μ/ e id	Safety cost to be proven	Limited by cavern size Magnetic Field?	Unknown technology, pm pressure

summary...

physics motivation strong for PDK search

theories severely constrained

synergism with superbeams, ν factories

next goals

detailed understanding of neutrino bkgnd

vigorous r & d for detector options

...decision only after questions answered

if $e^+ \pi^o$ 1 candidate, oil in Super-K?

then big water detector?

if SUSY, look for K^+

economy determines detector

K2K precision studies of ν oscillations

Next generation detectors

water Cherenkov to largest size limited by ultimate atmospheric ν background

far detector for superbeams

liquid argon, if scalable a factor of 200,

highest resolution study of all PDK modes

possible Frejus detector for ν oscillations