New Detectors for keV to GeV Neutrino Physics, Particle Physics and Astrophysics

BNL Particle Physics Seminar
Oct 5, 2005

R. S. Raghavan
Virginia Tech

Neutrino Physics Program at VT

- Borexino at Gran Sasso (in construction in Italy)

- LENS--Advanced R&D—approaching Test Detector
- HSD—hyper scintillation detector --study group
- Low Background Underground Test Laboratory--
  under construction in the Kimballton Mine

VT Nu **Group:**

Zheng Chang
Christian Grieb
Steve Hardy
Matt Joyce
Mark Pitt
Derek Rountree
RSR
Bruce Vogelaar

New Tenure Track Faculty position approved- Search Process initiated

LENS: 125 ton Indium Liq. Scintillation Detector

Solar neutrinos:

>10 keV signals from >~100 keV solar nu (pp,Be, CNO, pep)

→Neutrino Luminosity of the Sun

→Nu Physics, Particle Physics, Astrophysics

Kimballton Lab?

HSD: ~50 kT Liq. Scintillation Detector

Geo Neutrinos

Supernova Relic Neutrinos

Proton Decay

Long Baseline Neutrino Physics

Homestake DUSEL?

→***MeV to GeV signals***

→Geophysics, Nu Physics, Particle Physics, Cosmology

→*Large Scale Liquid Scint. Detectors—Technology Mature –Imaginative Applications Possible*

NEUTRINO Physics-
Non-zero Nu mass settled

What Next ?

- **Nail down new mass-mixing matrix**
- **Use massive neutrino as tool for probing new particle interactions, symmetries**
- **Probe sun deeply**

The new solar neutrino chapter:

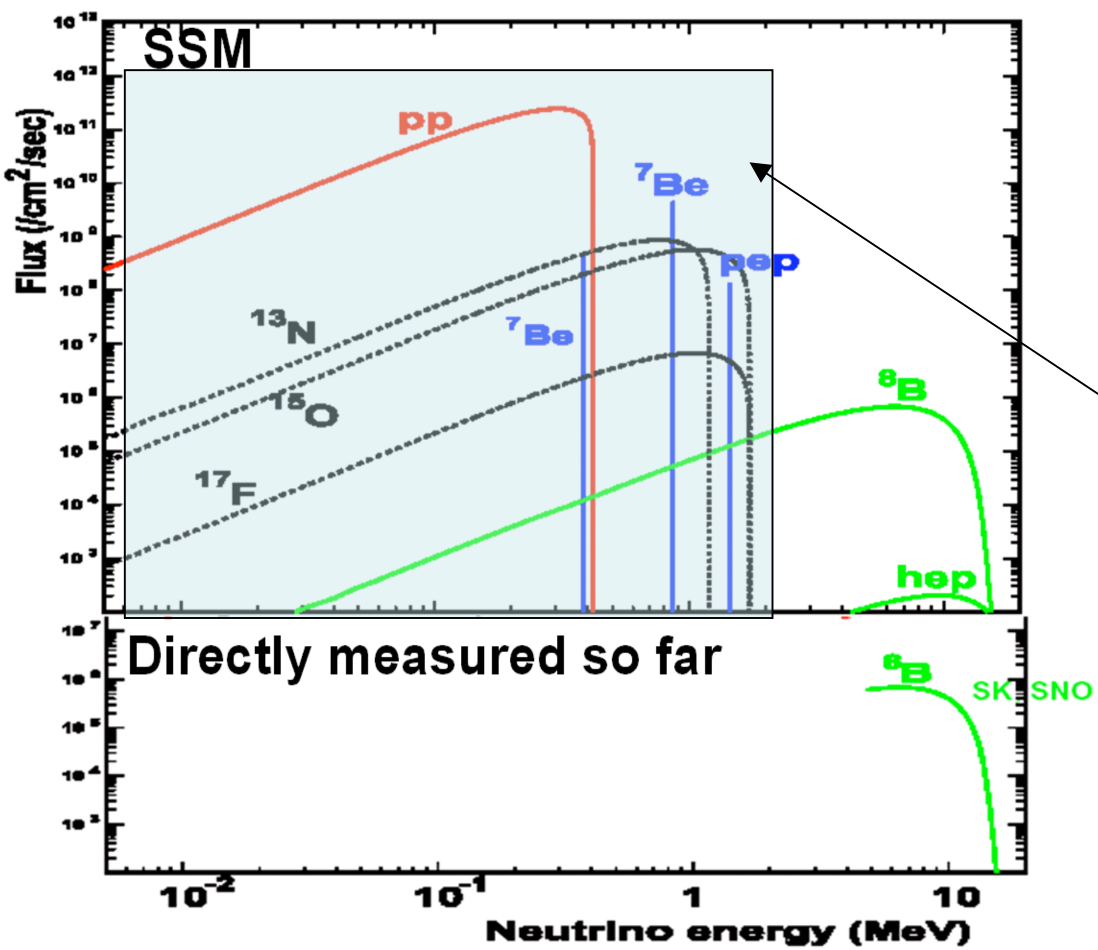
---high precision data, unprecedented questions;
unique answers

SOLAR NEUTRINOS

Sun as ideal neutrino factory

- ***Highest Flux***
- ***Flavor specific –electron flavor only***
- ***Longest baseline***
- ***Largest Mass***
- ***Low E spectrum-Several specific sources***
- ***Low Energies—Unique tools, largest flavor effects***
- ***Neutrino flux at source STANDARDIZED (via photon luminosity)***
- **→ Best Machine –Available FREE-- for**
- **New Physics of Neutrinos**
- **Sun ideal Laboratory for study of Non-std Neutrino phenomenology.**

How well has this Factory been utilized?



- **Spectral Data ONLY for 10^{-4} part**
- **Current data only for Enu > 5 MeV**
- **Discovery Potential Highest at LOW energies**
- **NO SPECTRAL DATA AT LOW ENEREGIES**

basic pp neutrinos?

“holy grail” of solar nus

FULL POWER OF MACHINE

NOT USED AT ALL !

→→ Need New Technology

→LENS (Low Energy Neutrino Spectrometer)

based on the Indium Target

LENS (Indium): SCIENCE GOAL

Precision Measurement of the
Neutrino Luminosity of the Sun

LENS-Sol

To achieve Goal → Measure low energy nu spectrum (pp, Be, CNO)

→ ± ~3% pp flux

→ Exptl Tool: Tagged CC Nu Capture in ^{115}In

→ $\nu_e + {}^{115}In \rightarrow e^- + \text{(delay) } 2\gamma + {}^{115}Sn$

e^-: solar signal; 2γ: tag

LENS-Cal

→ Measure *precise* B(GT) of ^{115}In CC reaction using MCi neutrino source at BAKSAN (tagged ν-capture to *specific* level of ^{115}Sn unlike radiochem case)

Note: B(GT) = 0.17 measured via (p,n) reactions

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LENS-Sol / LENS-Cal Collaboration
(Russia-US: 2004---)

Russia:

INR (Mosow): I. R. Barabanov, L. Bezrukov, V. Gurentsov, E. Yanovich
INR (Troitsk): I. V. Gavrin et al;
II. A.V. Kopylov, I. V. Orekhov, V. V. Petukhov, A. E. Solomatin
ITEP (Moscow): B. P. Kochurov, V. N. Konev, V. Kornoukhov,

U. S.

BNL: A. Garnov, R. L. Hahn, C. Musikas, M. Yeh
U. North Carolina: A. Champagne
ORNL: J. Blackmon, C. Rascoe, A. Galindo-Urribari
Princeton U. : J. Benziger
Virginia Tech: Z. Chang, C. Grieb, M. Pitt, R. S. Raghavan*, R. B. Vogelaar

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NEW COLLABORATORS (US & INTERNATIONAL) CORDIALLY WELCOME !

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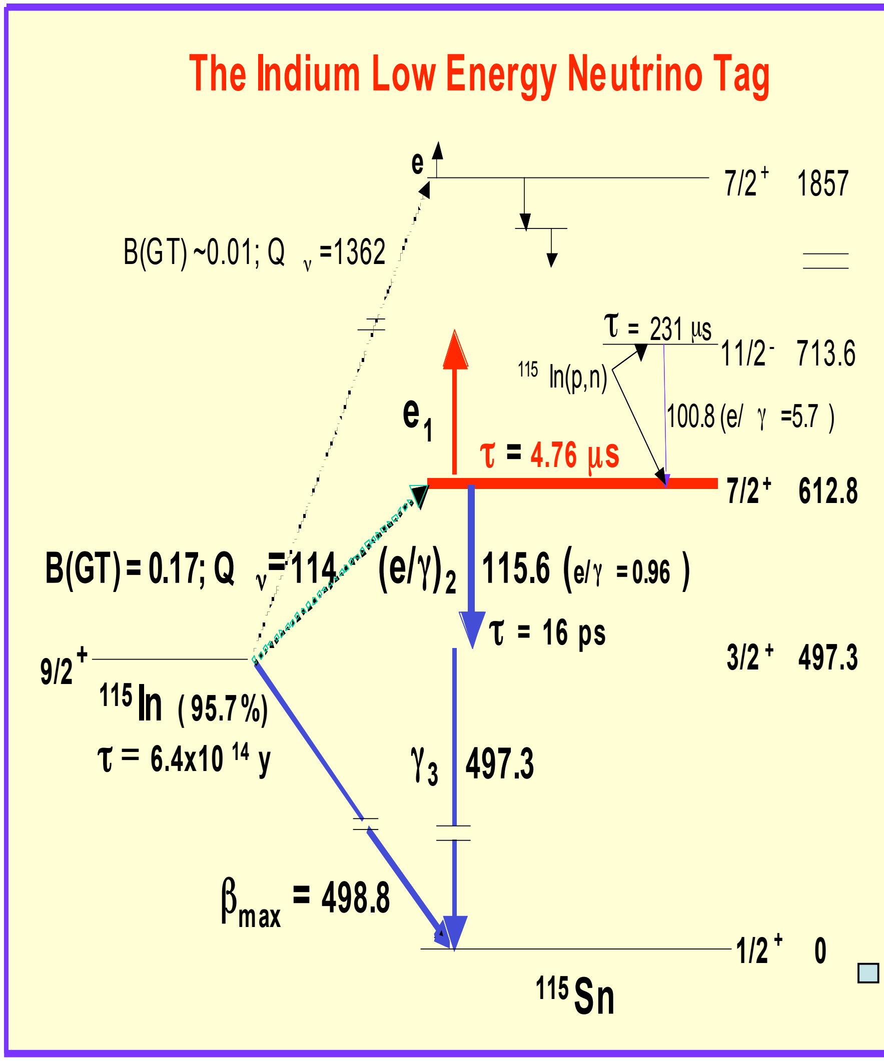
LENS-Sol-In ---Foundations



CC Nu Capture in ^{115}In to excited isomeric level in ^{115}Sn

3 Unique Features:

Tag: Delayed emission of 2 γ's

Threshold: 114 keV → pp Nu

^{115}In abundance: ~96%

Basic Bgd Challenge:

- **Indium Nu target is radioactive !** **(τ =6x10^{14} y)**
- **^{115}In β-Spect. overlaps pp signal**

- **Basic bgd discriminator: Tag Energy:**
  E(Nu tag) = E(βmax) +116 keV

Be, CNO & LENS-Cal signals not affected by Indium bgd

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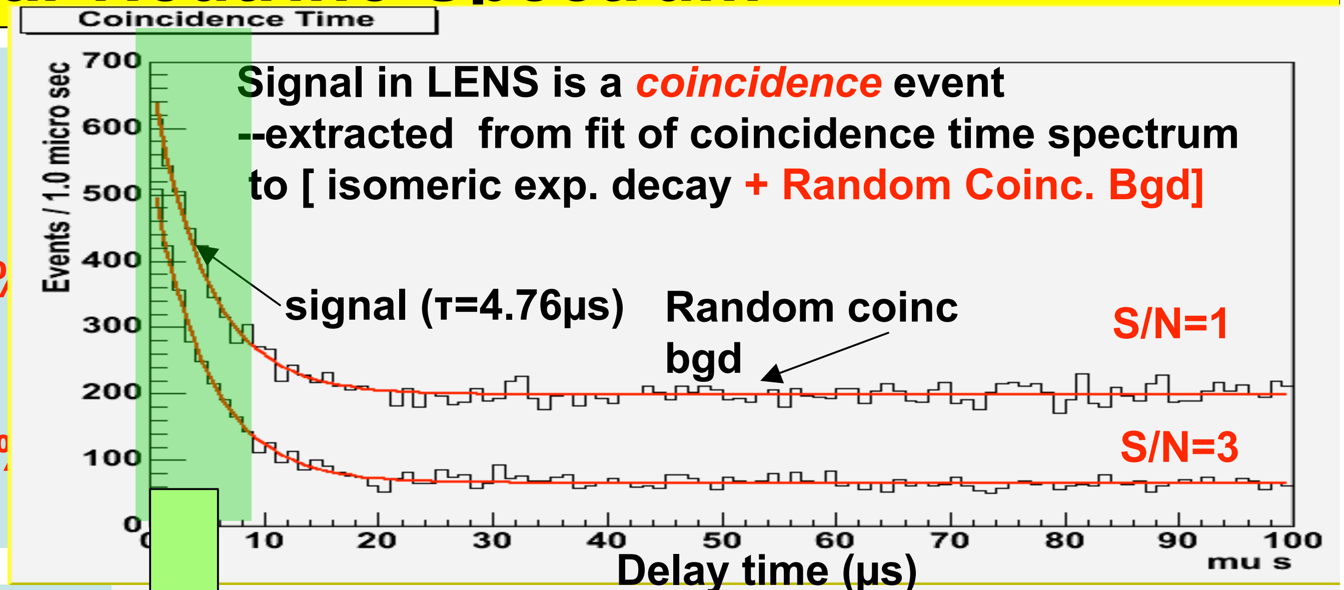
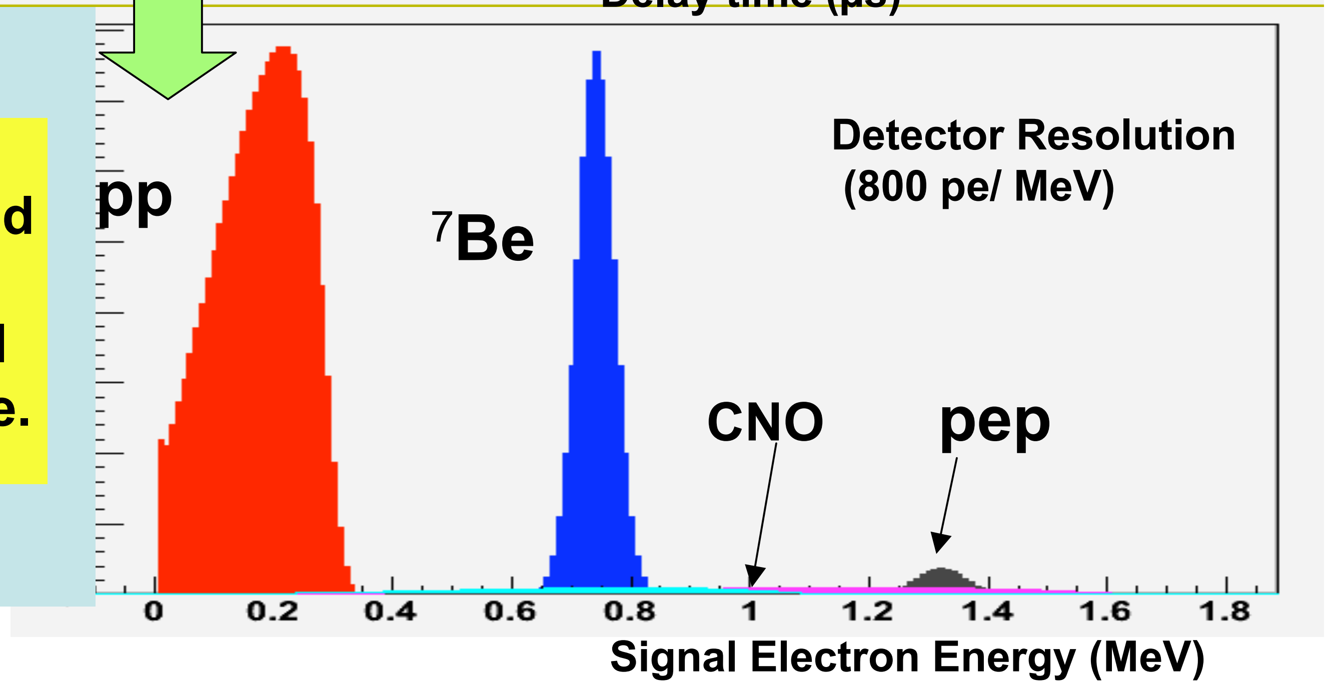
Expected Result:
Low Energy Solar Neutrino Spectrum

LENS-Sol Signal =
[SSM(low CNO)+LMA] x Detection Efficiency:
pp 64%; Be 85%; pep 90

→Rate: pp 40 /y /t In
→2000 pp ev. / 5y→ ±2.5
→Design Goal: S/N ≥ 3



With currently achieved energy resolution, access to pp Spectral *Shape* for the first time.



Tools for New Science from LENS low energy nu spectrum

1. ***Energy dependence of Flavor survival***
   → Physics Proof of MSW-LMA
   →New Particle/Neutrino Phys Scenarios
2. ***Appearance Effects*** **→ New physics**

3. ***Absolute Fluxes*** **→Neutrino Luminosity**
   Ultimate test of neutrino physics—
   Is the Neutrino luminosity derived with the best known nu physics CORRECT?

The LAST & ONLY Global test—with *photon luminosity* which provides absolute calibration of the sun’s energy mechanism.

NEW SCIENCE—Discovery Potential of LENS

Massive Nu's Open Door for probing a series of fundamental Questions

APS Nu Study 2004→ Lo Energy Solar Nu Spectrum : one of 3 Priorities

In First Two years:Focus on energy & time dependence of P_{ee}

Unique answers to many basic questions without Source Calibration

- ***Test of MSW LMA Physics --no proof yet !***

  no B8 d/n effect, spectral shape?)

  → **P_{ee} (pp) = P_{ee} (vac) ≈ (1- 0.5$\sin^2 2\theta_{12}$)? Precision value of θ_{12}**

- ***Non-standard Fundamental Interactions?***

  → **P_{ee} (Be) / P_{ee} (pp) < ≅1 ? P_{ee} (pep)/P_{ee} (pp) < ≈ 1 ?**

- ***Mass Varying Neutrinos? (ditto)***
- ***CPT Invariance of Neutrinos ?***

  → **If not LMA for ν's (contra $\bar{\nu}$), what else? What effect?**
  Oscillations in pp spectrum? (RSR JCAP 2003**)**

- ***RSFP/ Nu magnetic moments***

  → **Time Variation of pp and Be? (No Var. of ^{8}B nus, no data on Lo Nu)**

  (Chauhan et al JHEP 2005

Lo Nu

Only way to answer these questions !

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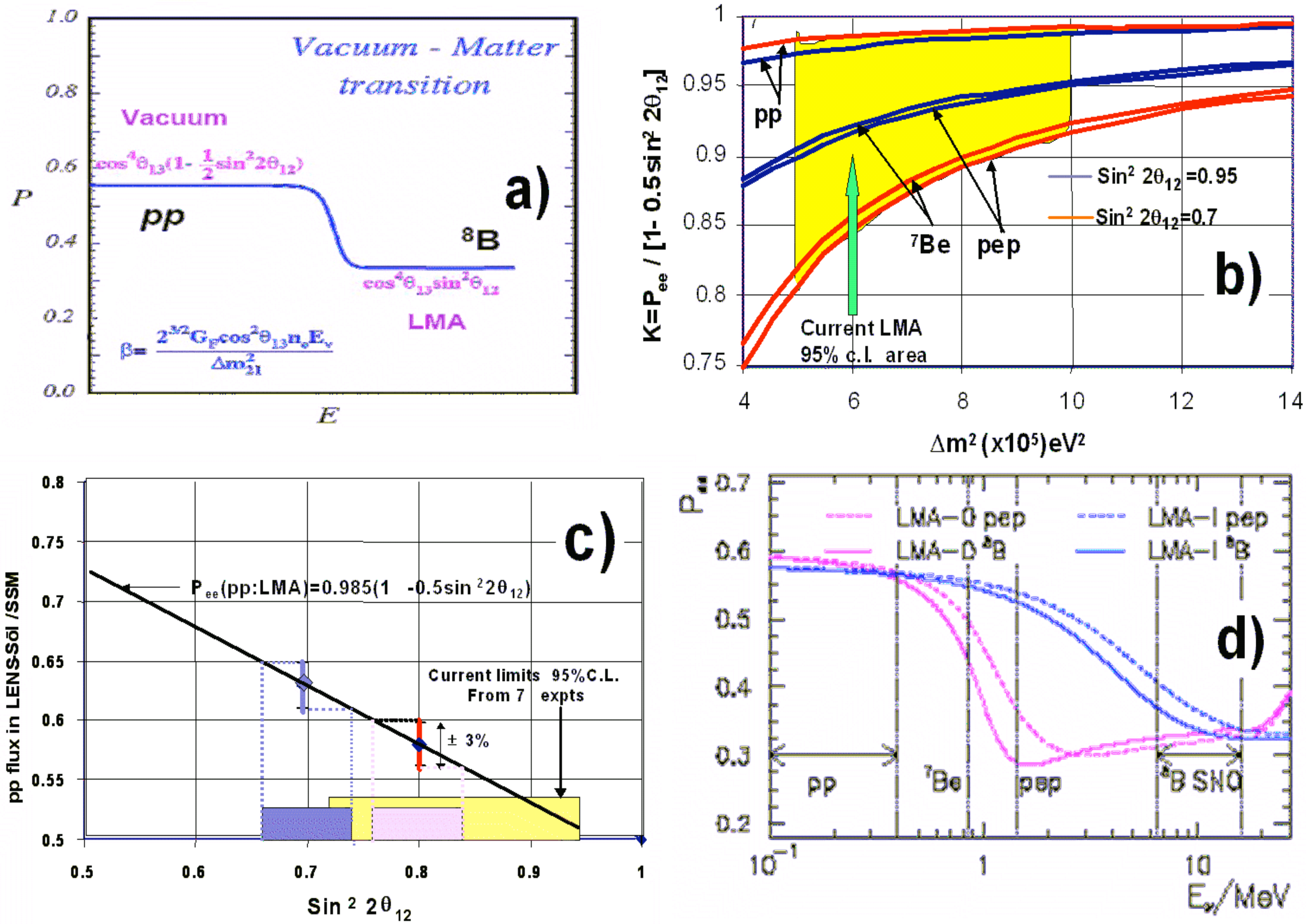
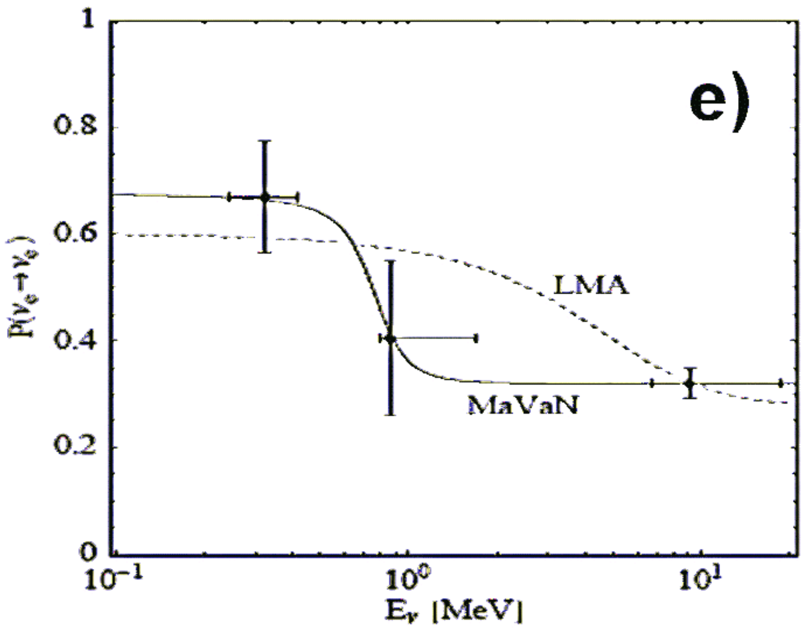
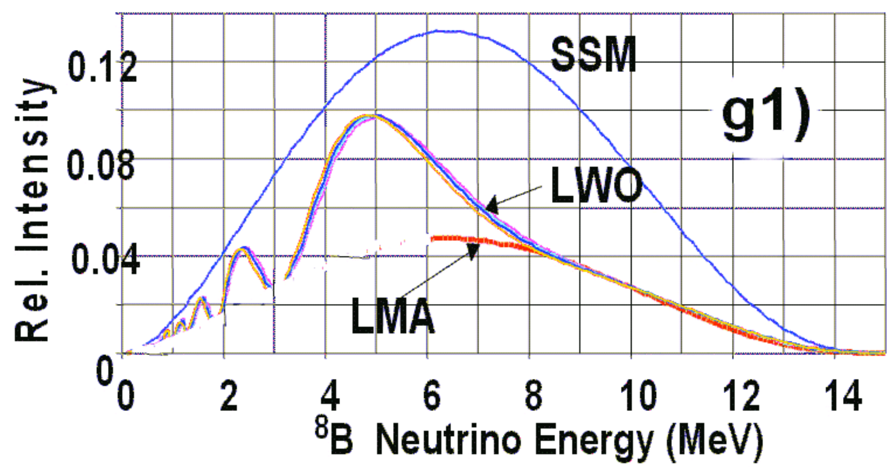
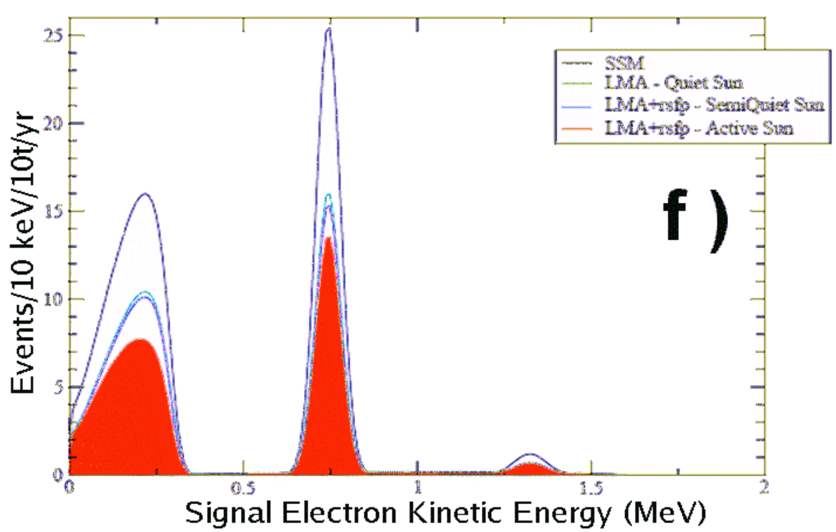
New Science from Relative Fluxes

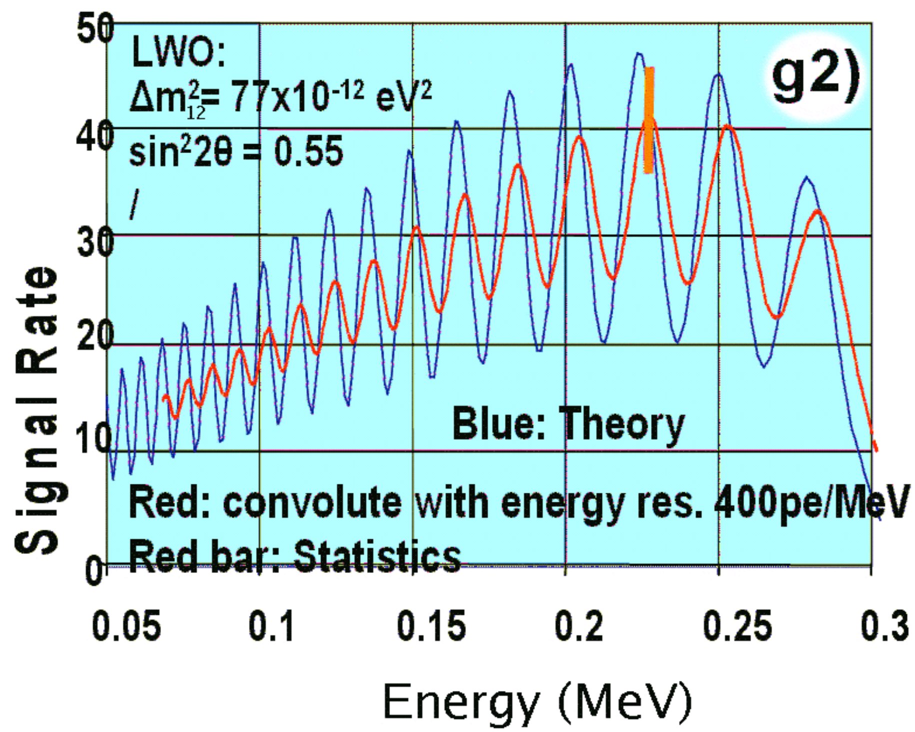


New Science from “Appearance” Effects









In Five Years (**with source Calib**):

→ **Absolute pp, Be, pep nu fluxes at earth**

→ ***Measured* Neutrino Luminosity (~4%)**

Neutrino- Sun Dichotomy in solar nu data

Use Photon output of sun to standardize neutrino output

Photon Luminosity ←→ Neutrino Luminosity

"External" Test of our best knowledge of the Neutrino & the Sun

***Exptl. Status (after 6 expts/40 y) --No useful constraint* !**

L(v inferred) / L(hv) = $1.4^{+0.2}_{-0.3}{}^{+0.7}_{-0.6}$

Precise L(v) at earth→Nu parameters→Precise L(v) in Sun→ L(hv)?

→Neutrino Physics:

→ ***Final*** **Precision Values of θ_{12} ,θ_{13} , sterile nu?**

→Astrophysics:

L(v) > L(hv) Is the Sun getting Hotter?

L(v) < L(hv) Sub-dominant non-nuclear source of energy of Sun?

Answers for Big Questions with Small L(v)≠L(hv)

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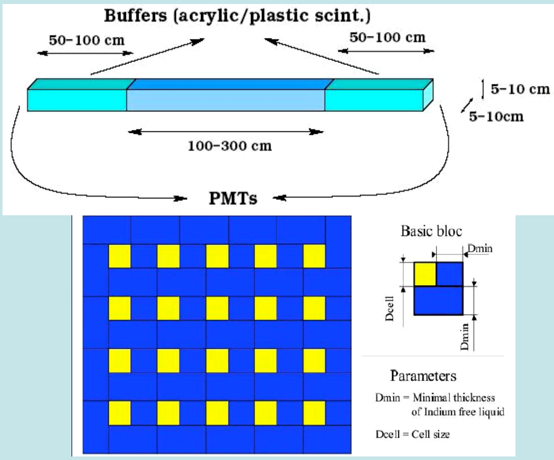
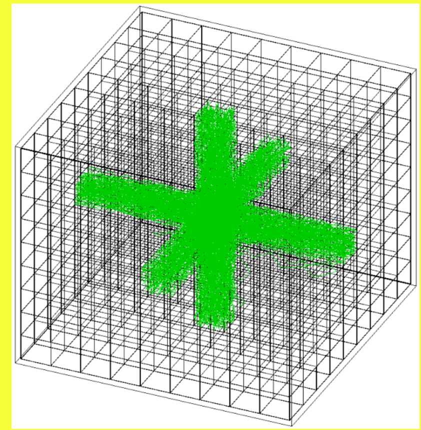
In-LENS: Studied world wide since 1976 !

- Dramatic Progress in 2005-

Status Fall 2003 → *Status Summer 2005*



- In Liq Scint
- New Design
- Bgd Structure
- New Analysis Strategy



Longit. modules + hybrid (InLS + LS)

InLS: 5% In; L(1/e)=1.5m;
230 pe//MeV In:
Total mass LS: 6000 ton
In: 30 ton for 1900 pp's /5 y
PMTs: ~200,000
Detection Efficiency: ~20%
S/N~1 (single decay BS only
~1/ 25 (All In decay modes)

(MPIK Talk at DPG 03/2004)

Cubic Lattice Non-hybrid (InLS only)

- **InLS: 8% In; L(1/e)>10m;**
  900 pe/MeV
- **Mass InLS : 125 to 190 ton**
- **In:10-15 ton for 1970 pp's /5y**
- **PMTs: 13300 (3")-- 6,500 (5")**
- **Detection Efficiency: 64-45%**
- **S/N ~3 (ALL In decay modes)**

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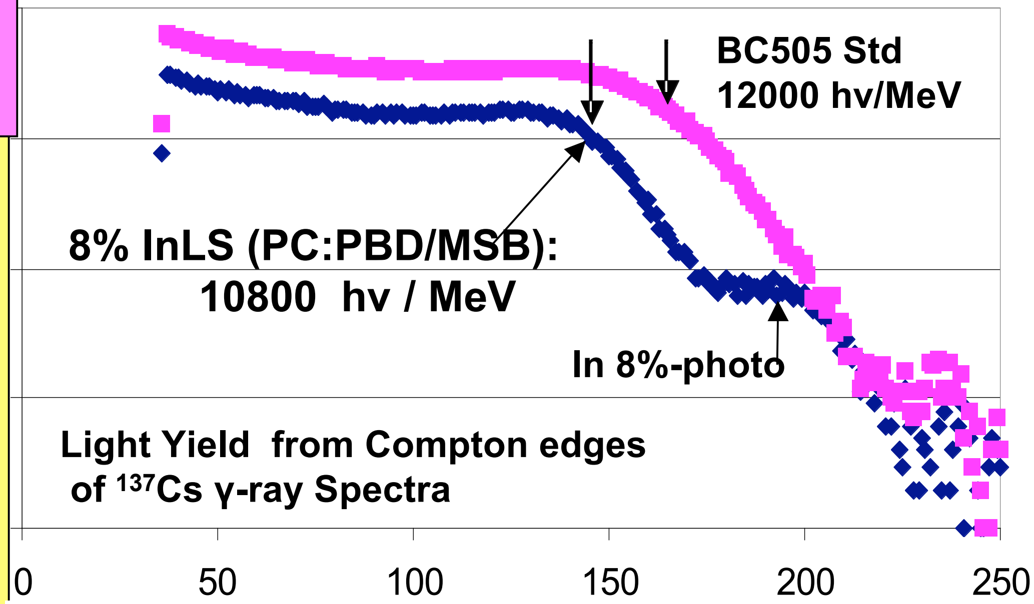
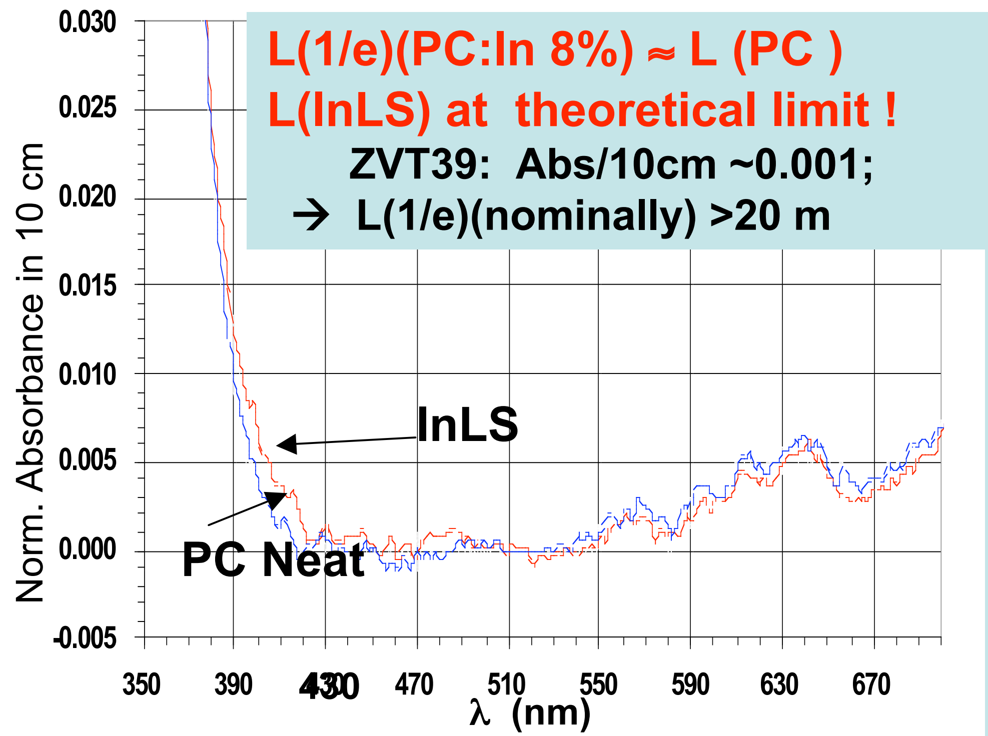
InLS Status (Aug '05 (VT(BL)-BNL) Summary

1. Indium conc. ~8 wt%
   (higher may be viable)
2. Scintillation signal efficiency
   (working value): 9000 hv/MeV
3. Transparency at 430 nm:
   L(1/e) (working value): 10 m
4. Chemical and Optical
   Stabililty: ~ 2 years
5. InLS Chemistry-- Robust

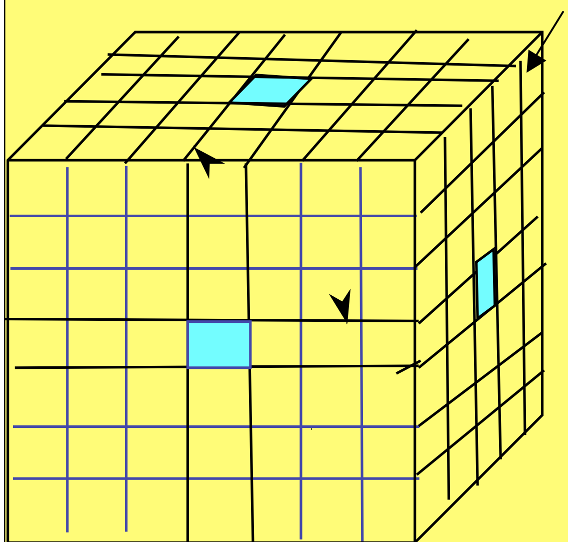


- Milestones unprecedented in metal LS technology
- LS technique relevant to many other applications

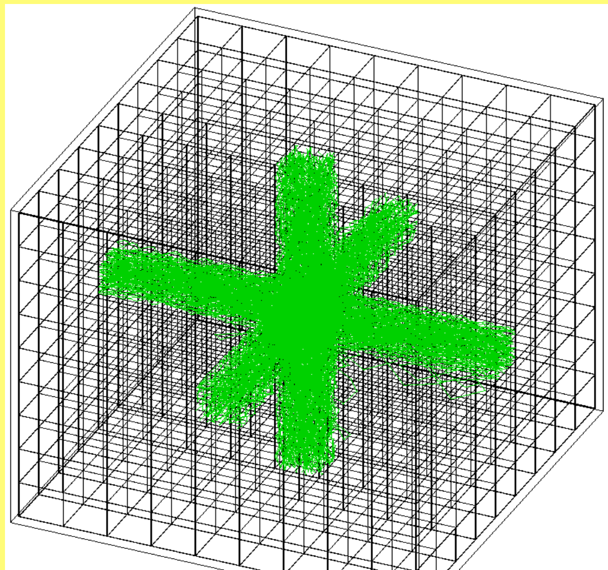
- Basic Bell Labs Patent
Filed: 2001; awarded: 2004



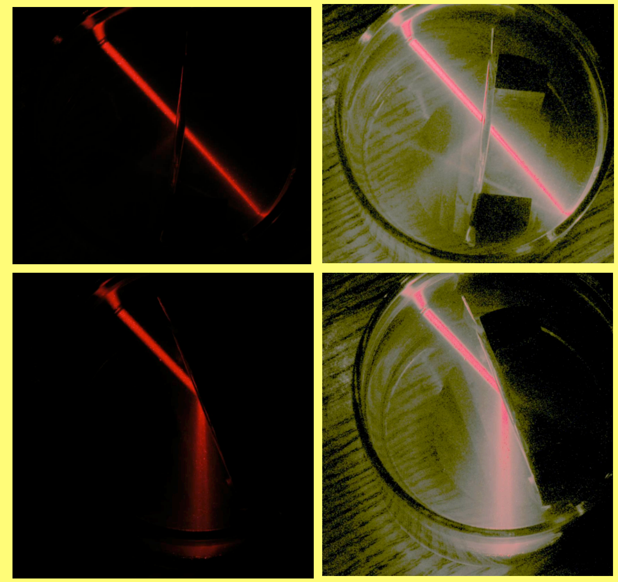
NEW DETECTOR CONCEPT—SCINTILLATION LATTICE CHAMBER



Concept/test model



Optical segmentation by double foils with airgap



Test of double foil mirror in liq. @~2bar

- **3D** Digital Localizability of Hit within one cube

→ ~75mm precision vs. 600 mm (±2σ) by TOF in longitudinal modules

→ x8 less vertex vol → x8 less random coinc. → **Big effect on bgd**

→ Hit localizability independent of event energy

- HE particle (e.g. μ) tracks, γ- shower structure directly seen

→ **SCINTILLATION CHAMBER**

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Effect of *non-smooth* foil assembly on hit definition

12.5 cm cells in 4x4x4m cube; 100 keV event; /9000 hv/MeV; Signal=6x20 pe

Perfect optical surfaces : 20 pe

Rough optical surfaces = 20% chance of non- ideal optics at every reflection

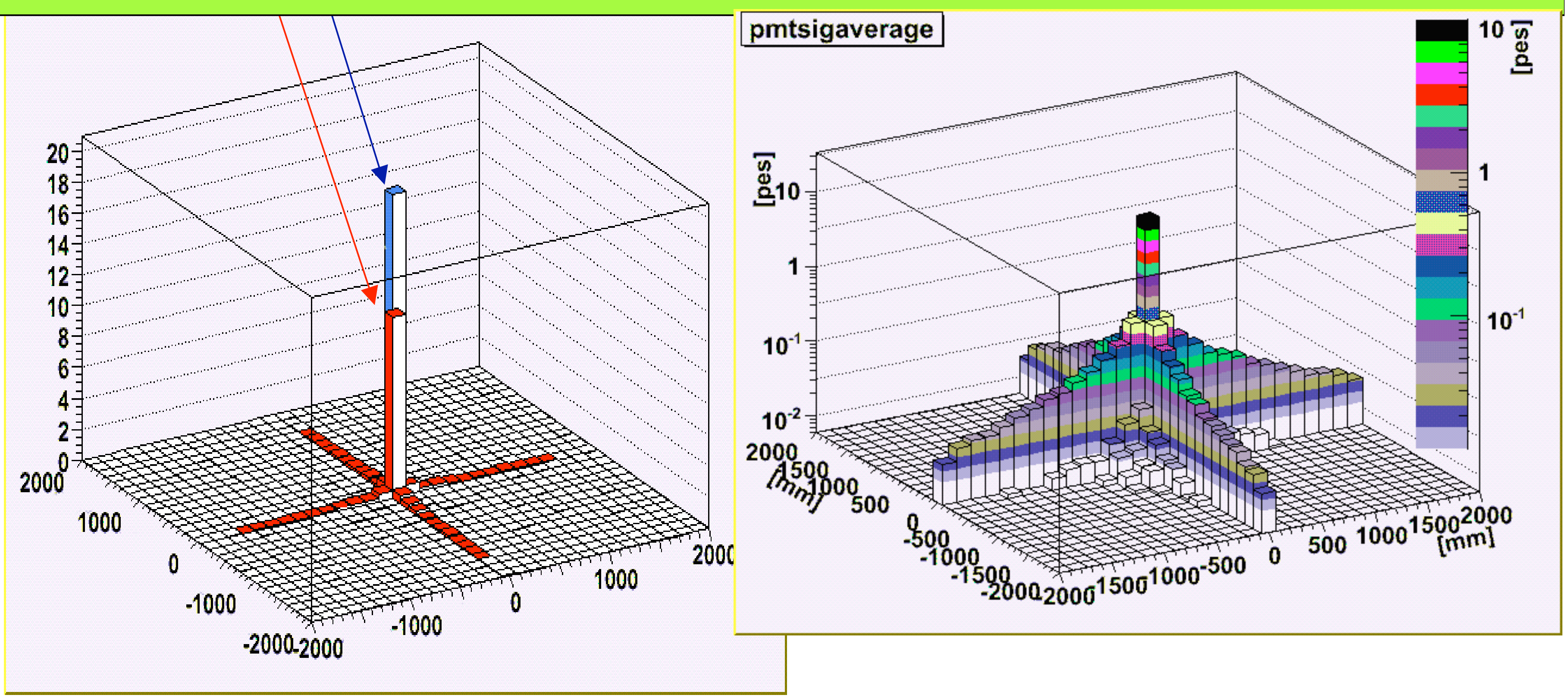
12 pe in vertex + ~8 pe in "halo"

Conclude:

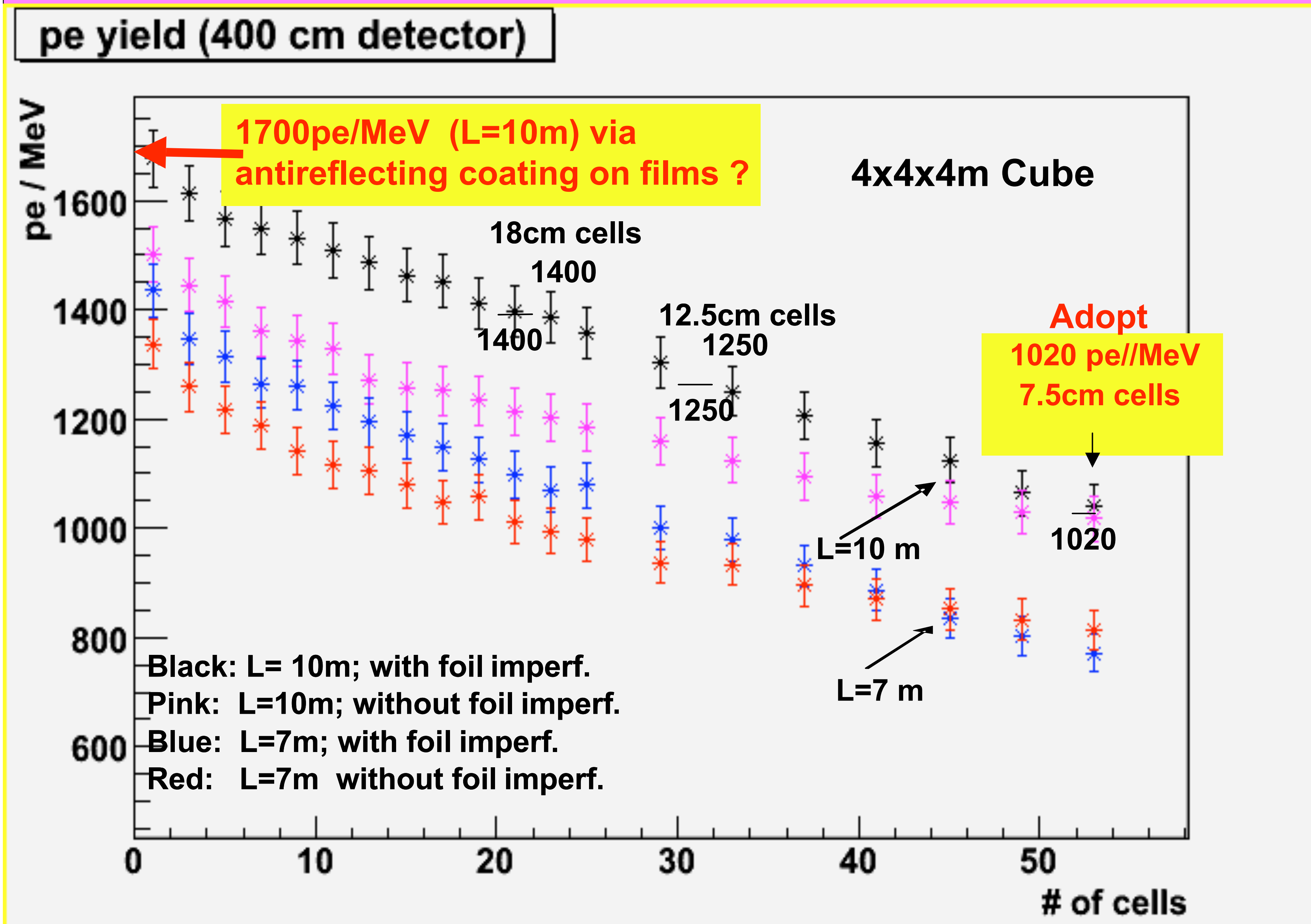
Effect of non-smooth segmentation foils:

No light loss. (All photons in hit *and* halo counted)

Hit localization accuracy virtually unaffected



Light loss by Multiple Fresnel Reflection at intervening air gaps

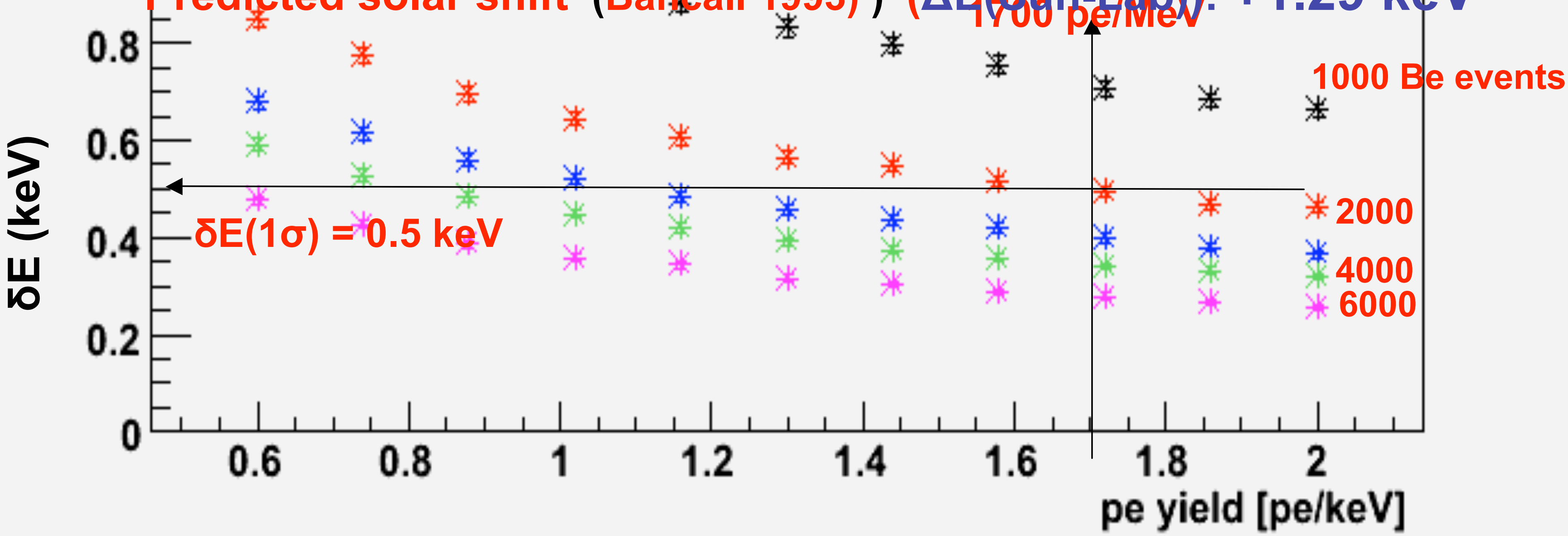


Hi pe/MeV in LENS? → New Window into the Sun's Interior
Direct Measurement of Central Temperature of Sun

Central Temp. in Sun shifts energy of Be line by ΔE (Sun-Lab)
Can one detect ΔE in the observed energy of Be line in LENS?

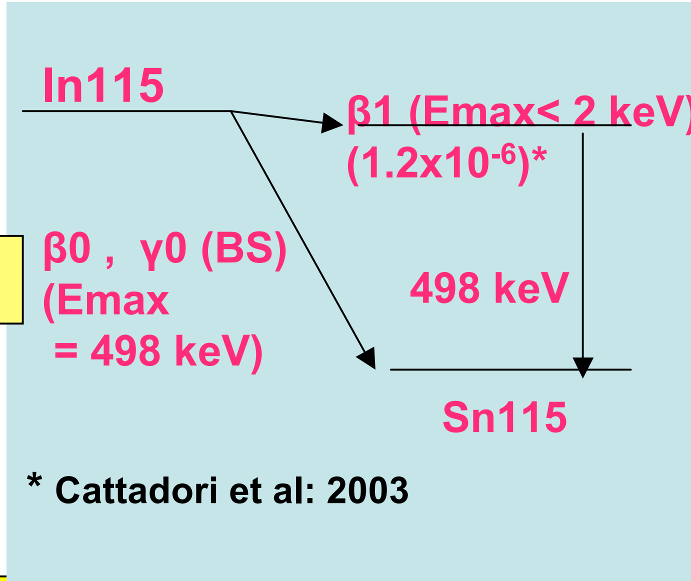
Expected precision of centroid energy of ^{7}Be Line in LENS
***(Statistics Only, 2000 events, 1700 pe/MeV)*: δE(1σ) ± 0.5 keV**

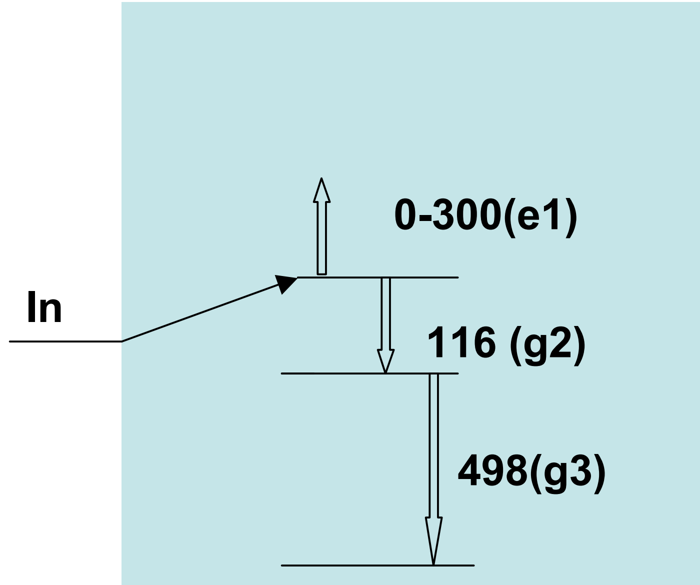
Predicted solar shift (Bahcall 1993)) (ΔE(Sun-Lab)): +1.29 keV



Complexity of Indium radioactivity background

BGD





SIGNAL

Basic tag candidate: Shower with Nhit ≥ 3

BGD tag: shower near vertex --chance coincident with In β in vertex

Multiple In decays simulate tag candidate in many ways

One In decay: → A1 = β + BS γ (E_{tot} = 498 keV) (x1)

→ A2 = 498 γ (x1)

Two In decays : → B = β + BS or 498γ in any combination from each decay ($x10^{-8}$)

Three In decays : → C = 3 β-decays All combinations ($x10^{-16}$)

\ **Four In decays :** → D = 4 β-decays All combinations ($x10^{-24}$)

Only A1 (single decay – BS) considered up to 2004 !

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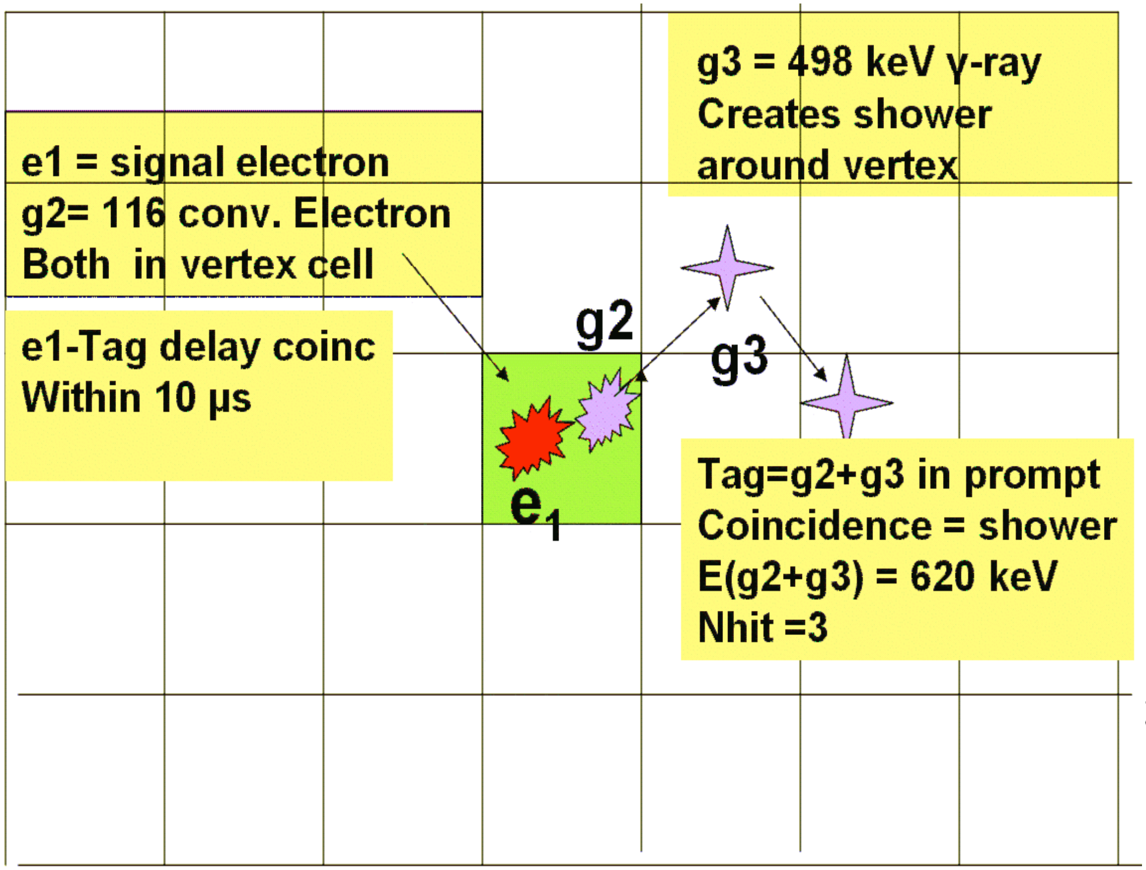
Nu tag template



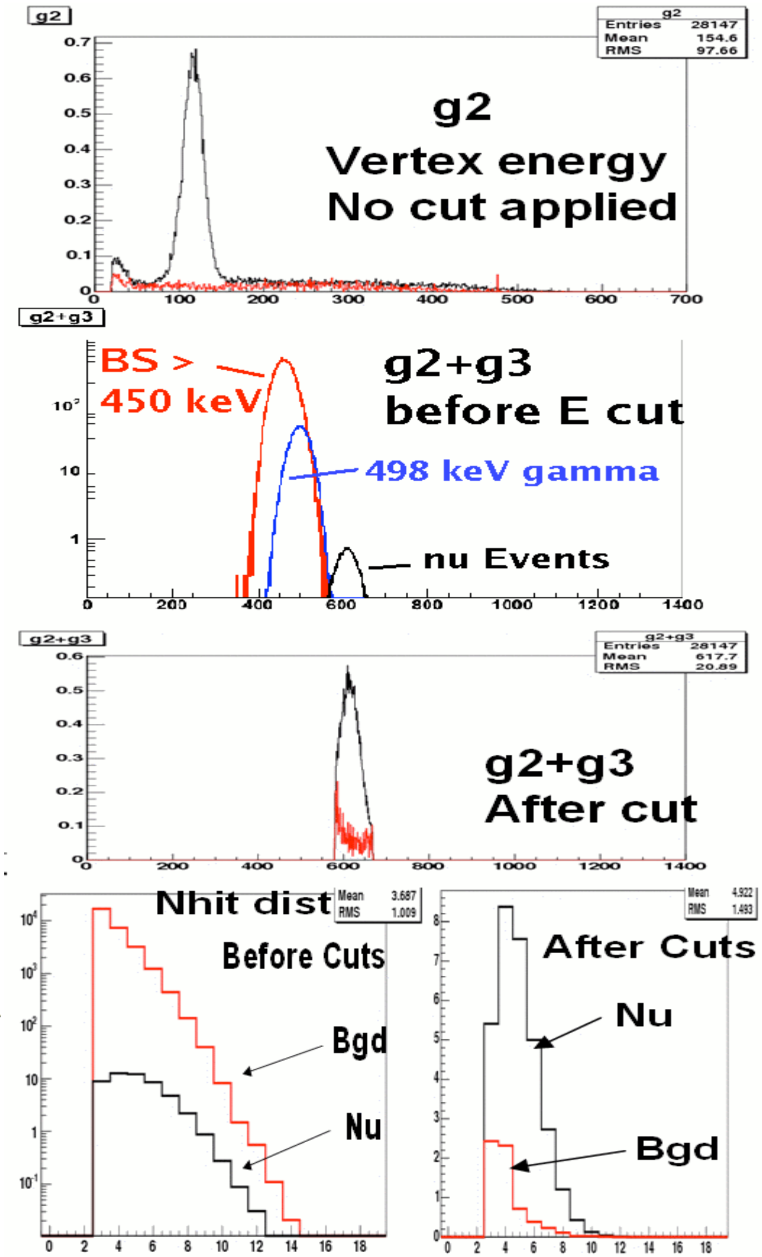


Figure 17 Typical results of analysis cuts on background (red) and signal (black) events in LENS . (Note the log scales in panels 2 and 4.)

Indium bgd Simulations and Analysis

Data: Main Simulation of Indium Events

- ~4x10^6 In decays in one cell centered in ~3m^3 vol (2-3 days PC time)
- Analysis trials with choice of pe/MeV and cut parameters (5' /trial)

Analysis-- Basics

- Primary selection --tag candidate shower events with Nhit ≥ 3
- Every hit in the bgd shower is a possible tag vertex
  in random coincidence (10μs) with a previous β in that cell

ANALYSIS STRATEGY (NEW)

- Classify all eligible events (Nhit ≥ 3) according to Nhit
- Optimize cut conditions *individually for each Nhit class*

→Leads to significanly higher overall detection efficiency than with old method of same cuts for all Nhit

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Role of Experimental Tools in Bgd Suppression
Basic task: Analysis of tag candidate

RAW (singles)	Signal /t In/y 62.5	Bgd tot /t In/y 79 x10^11	Bgd A1 - BSγ /t In/y	Bgd A2 -498γ /t In/y	Bgd B- β1+BSγ2 /t In/y
Valid tag (Energy, branching, shower coinc, hits > 3 pe) in Space/Time delay coinc with prompt event in vertex →	50	"Free" ↓ $2.76x10^5$	$8.3x10^4$	$2.8x10^3$	$1.9x10^5$
+ ≥3 Hits in Tag shower	46	$2.96x10^4$	$2.6x10^4$	$2.5x10^3$	$1.4x10^3$
+Tag Energy = 620 keV	44	306	0.57	4.5	293
+Tag topology	40	13 ± 0.6	0.57	4.0	8.35

→Tag analysis must suppress bgd by ~$2x10^4$--**NOT 10^{11}**

→ ~$4x10^6$ ntuples sufficient for bgd event survivals with ~5% precision

Final Result: Overall Bgd suppresion >10^{11}
At the cost of signal loss by factor~1.6

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Typical LENS-Sol: DESIGN FIGURES OF MERIT

Preliminary!---Work in Progress

InLS: 8% In; L(1/e) =1000cm; Y (InLS) = 9000 hv/MeV; Hits > 3pe

Cell Size mmx mmx mm	Det Eff %	Nu Rate /T In/y	Bgd Rate /T In/y	S/N	Mass for 2000pp/5y (ppflux3%) T (In)	T (InLS) PMT's
75 10^3pe/ MeV 4x4x4	64	40	13	3	10	125 13300 (3")
125 950pe/ MeV 5x5x5	41.8	26	9	2.9	15.3	190 6500 (5")
180 1000 p/MeV 6x6x6	33.1	20.7	22	1	19.3	240 3300 (8")

For first time:

- **Bgd problem Solved**
- **Smallest In detector achieved**

Summary

Major breakthroughs

- **In LS Technology**
- **Detector Design**
- **Background Analysis**

→ **Basic feasibility of In-LENS-Sol secure**

→ **extraordinary suppression of In background**
(all other bgd sources not critical)
→ **Scintillation Chamber– InLS only**
→ **High det. efficiency → low detector Tonnage**
→ **Good S/N**

IN SIGHT: Simple Small LENS (~10 t In /125 t InLS)

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Next Steps—Final test: MINILENS (2007)

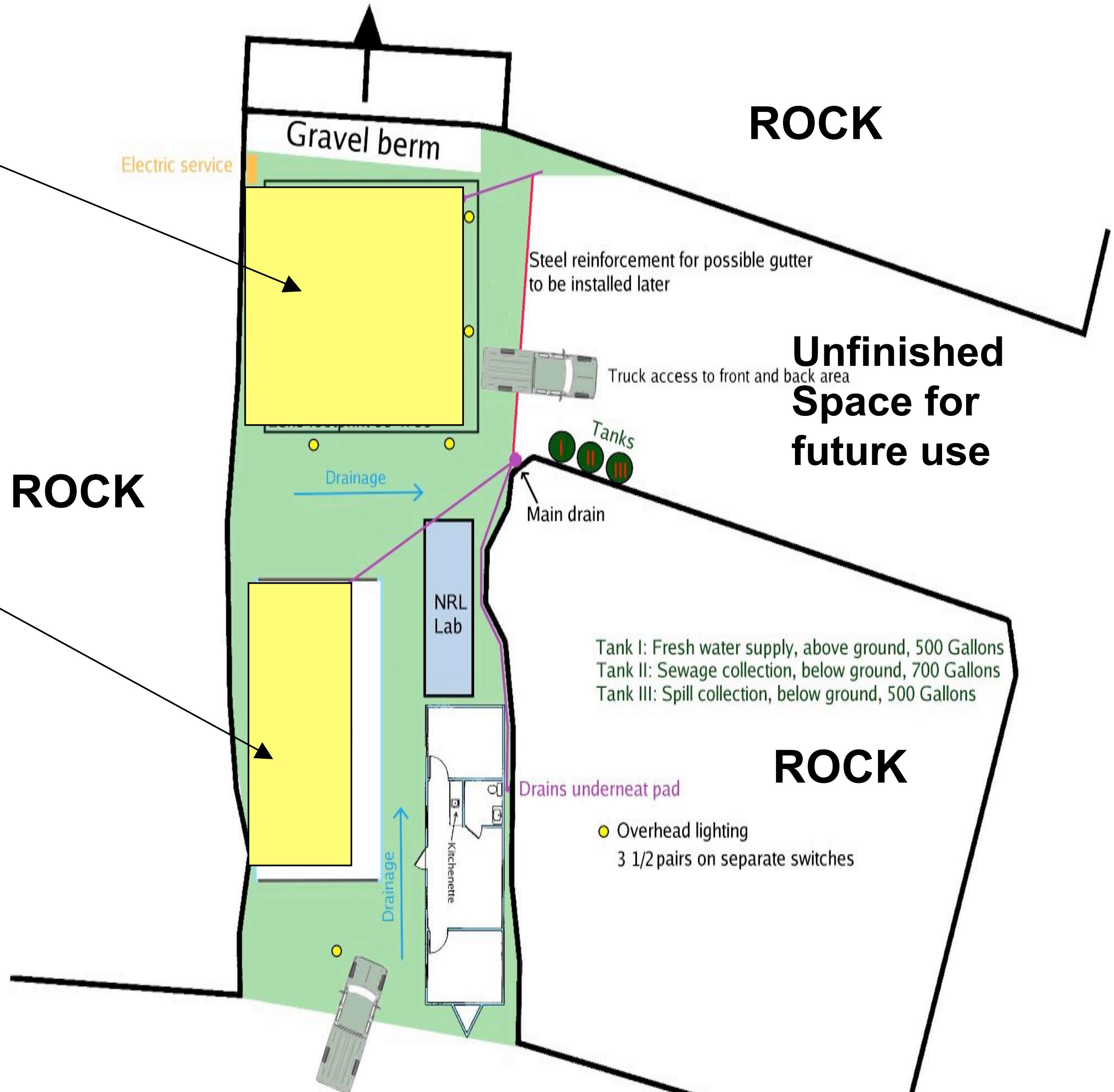
- **Chemical Technology of large scale InLS production**
- **Detector construction technology for Scintillation Chamber**

VT-NRL Low Bgd Laboratory @ Kimballton Limestone Mine VA

30 min by car from Virginia Tech

Space (10x10x10m) Adequate for full scale LENS-Sol

Assembly area



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HSD—Hyper- Scintillation Detector
50-100 KT LIQUID SCINTILLATION DEVICE?

Next generation device beyond CTF, Borexino, Kamland, LENS… The technology now has a large worldwide group of experts with experience/expertise in constructing and operating massive LS detectors (upto 1 kT so far), for *precision* low energy (>100 keV) astro-particle physics

Essential questions for a large scale project like this:

- **What science can be achieved that may be unique?**
- **Can one achieve multidisciplinary functionality?**
- **Are the possible science questions of first rank impact?**
- **Can it be competitive with other large scale detector technologies in science payoff, cost. technical readiness …?**

Working Group (Theory and Experiment):

- **F.Feilitzsch, L. Oberauer (TU Munich0**
- **R. Svoboda (LSU)**
- **Y. Kamyshkov, P. Spanier (U. Tennessee)**
- **J. Learned, S. Pakvasa (U. Hawaii)**
- **K. Scholberg (Duke U.)**
- **M. Pitt, B.Vogelaar, T. Takeuchi, M. Koike, C. Grieb, Lay Nam Chang, R. S. R (VT)**

Bring together earlier work:

- **Munich Group -LENA (aimed at a European site)**
- **R. Svoboda et al**
- **Y. Kamishkov et al**
- **RSR**

LS Technology (Targets in LS: ^{12}C, p)

Pluses: +Signal x50 that of Cerenkov

+Low Energy (>100 keV) Spectroscopy

(in CTF (5T, 20% PMT coverage) ^{14}C spectrum >30 keV)

+Heavy Particle Detection well below C-threshold

+Tagging of rare events by time-space correlated cascades

+Ultrapurity-ultralow bgds even < 5 MeV (radio "Wall")

+Technology of massive LS well established

Minus: -Isotropic signal—no directionality

Unique Tool for Neutrino Physics--Antineutrinos

==Nuebar tagging by delayed neutron capture by protons

Very low fluxes (~1/cm^2/s @5 MeV) conceivable with care and effor

- Good depth to avoid β-n cosmogenics (e.g. ^9Li—prefer no heavy element for n-capture)
- Efficient muon veto of n, std 5m water shield to cut n, PMT, rock γ
- Ultrapurity to cut internal γ < 5 MeV
- Locate far from high power reactors

Main Topics in Focus

Particle Physics

- **Proton Decay**
- **Moderately long baseline Neutrino Physics**

Geophysical Structure and Evolution of Earth

- **Global measurement of the antineutrinos from U, Th in the interior of the earth**
- **Fission Reactor at the center of the earth ?**

Supernova Astrophysics and Cosmology

- **Precursor and Live Supernovae**
- **Relic Supernova Spectrum**

Test of present geophysical Models by

First ever measurement of *global* geophysical parameters

- **radiogenic energy output,**
- **chemical analysis such as U/ Th ratio**
-
- **geophysical distribution**

- **discovery of new geophysics**
  - **--e.g.core fission reactor**

Terrestrial Radiogenic Energy Sources *Location*

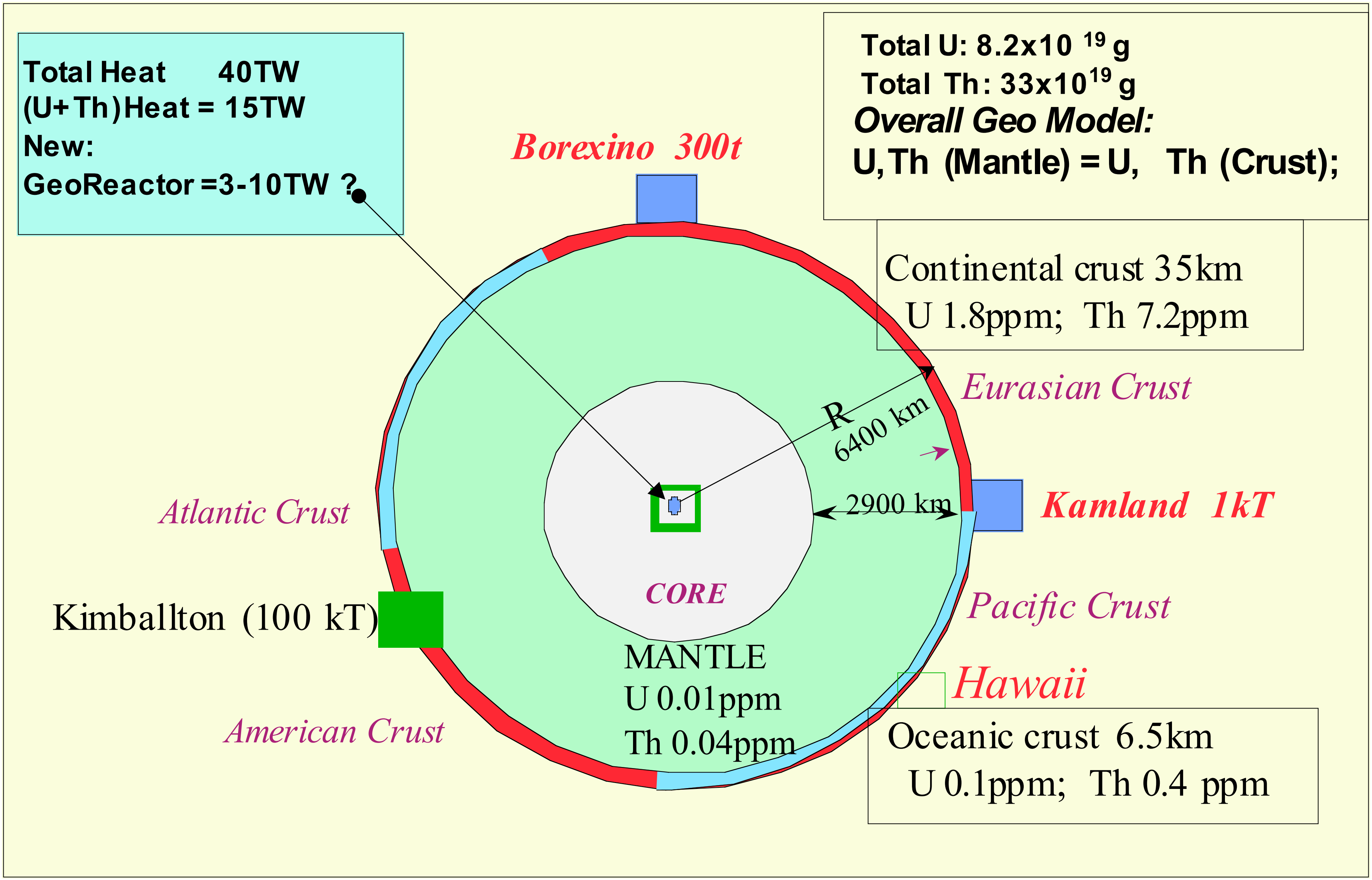
1) Radioactivity of U and Th (and others) — Mostly Crustal Layer
2) Fission Reactor ?? — In ner Core
3) Man-made Power Reactors — Surface

ALL ABOVE SOURCES EMIT ANTINEUTRINOS

- ANTINEUTRINO SPECTROSCOPY CAN PROBE THE EARTH
- Just as neutrino spectroscopy has probed the Sun
- TECHNOLGY MATURE AND AVAILABLE
- PARASITIC MEASUREMENT IN DETECTORS FOR OTHER PHYSICS
- TIMELY TO CONSIDER FOR NUSL

Long Literature: Problem: G. Elders (1966) G. Marx (1969)
Detection methods; Krauss et al Na ture 310 191 1984 (and ref therein)...many others
Spectroscopy & Specific Model Tests: Raghavan et al PRL 80 635 1998
Rotschild et al Geophys. Res. Lett 25 1083 1998

Internal Energy Sources in the Earth and their Distribution



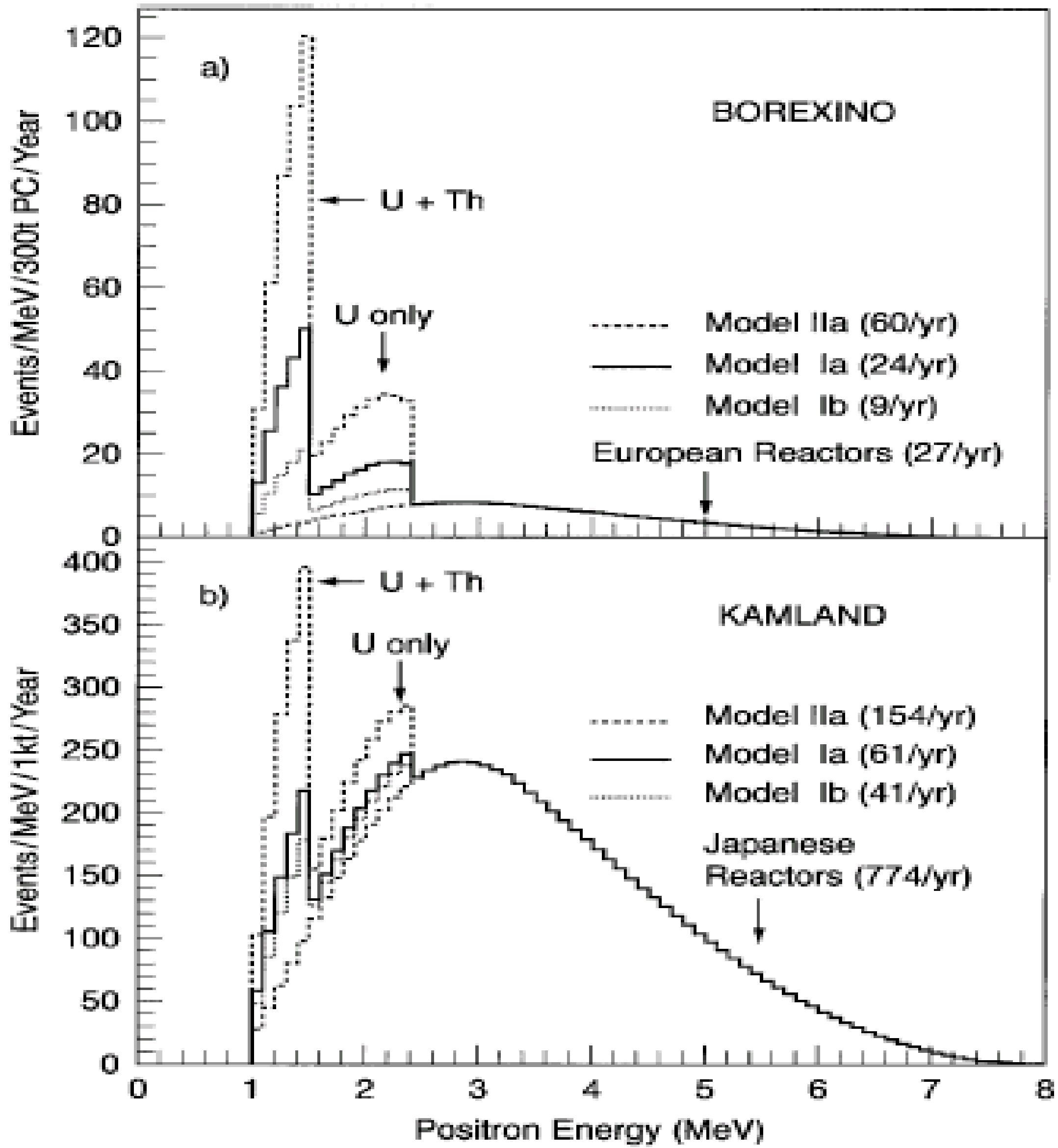


FIG. 2. $\bar{\nu}_e$ (positron) signal spectra from the Earth and from nuclear reactors at Borexino (a) and at Kamland (b). The signal rates point to several years of measurement for data of statistical significance to different aspects of geophysical interpretation.

Reactor bg/Kt/yr

Kamioka: 775
Homestake: 55
WIPP: 61
San Jacinto: 700
Kimballton: ~100

(RSR et al PRL 80 (635) 1998)

Aug 2005—New Glimpse of U/Th Bump in Kamland!

Birth of Neutrino Geophysics
Situation like 1964
In solar Neutrinos

Fission Reactor at Center of the Earth

Herndon, PNAS 93 646 (1996)
Hollenbach and Herndon PNAS 98 11085 2001

Proposed as Source of Energy of the Earth's Magnetic field

Caution: Highly Controversial—not accepted by Geochemists

BASIC MODEL:
NiSi INNER CORE OF THE EARTH

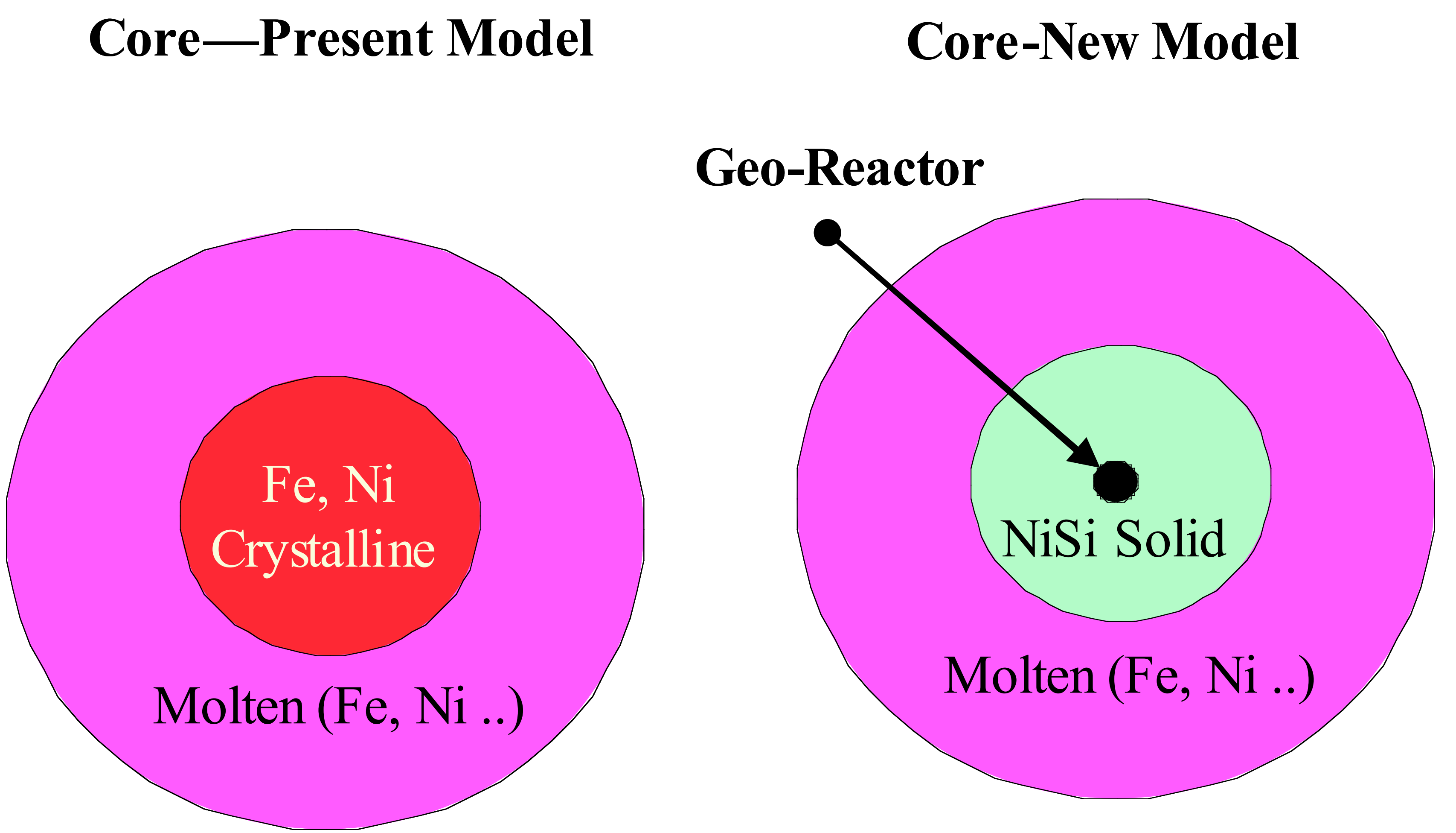
•CHEMISTRY of NiSi FORMATION RESULTS IN HIGHLY CONCENTRATED CONDENSATE OF U/Th AT CENTER

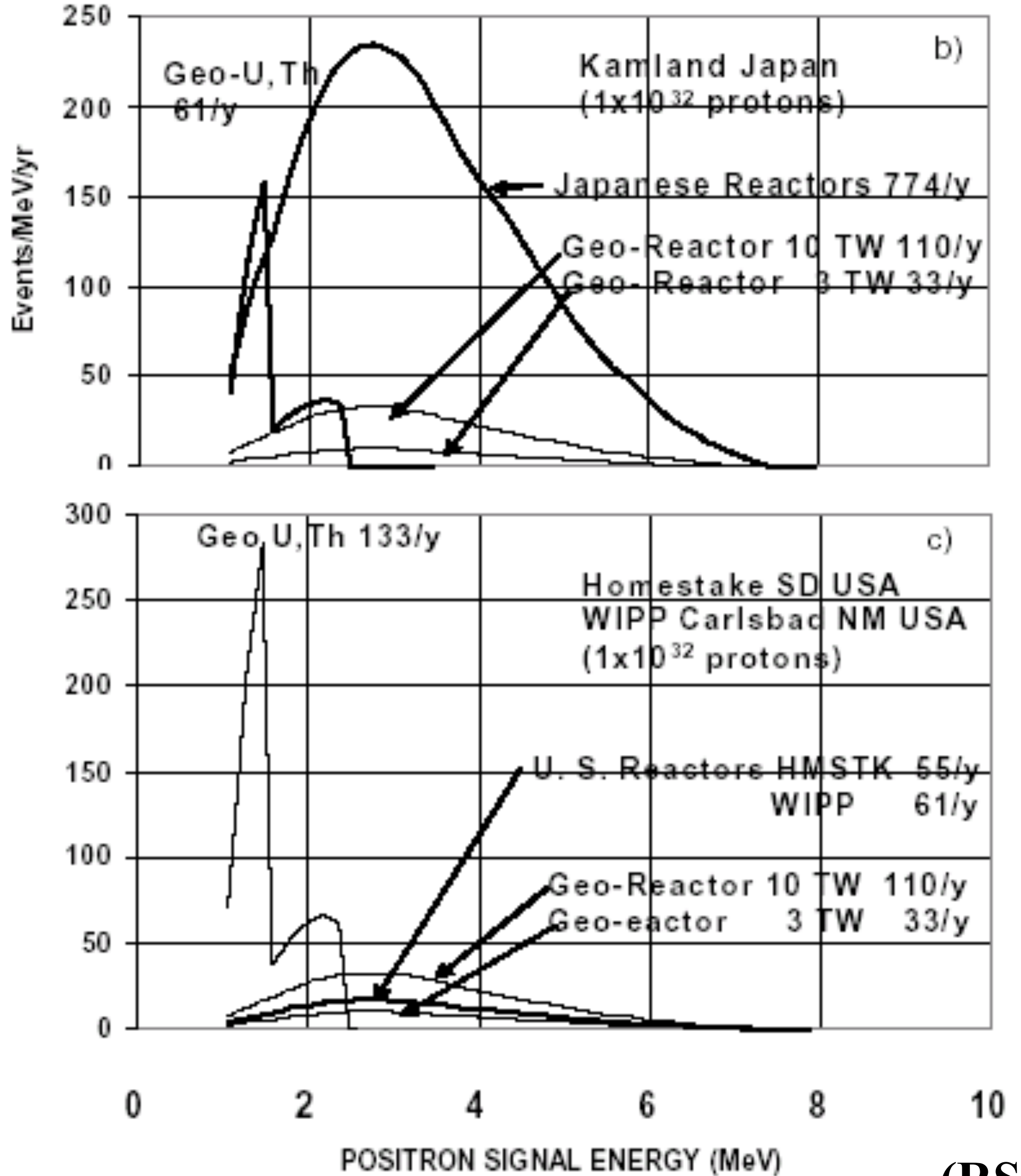
•**High 235/238 Isotopic Ratio 5 gY AGO**
Starts Natural Fission Chain Reaction

•FAST NEUTRON BREEDER REACTIONS Sustain fission to the present day

•3-10 TW energy output at present

•***ONLY WAY TO DIRECTLY TEST MODEL—***
•***DETECT FISSION ANTINEUTRINO SPECTRUM***


Core—Present Model
Core-New Model
Geo-Reactor
Fe, Ni
Crystalline
Molten (Fe, Ni ..)
NiSi Solid
Molten (Fe, Ni ..)

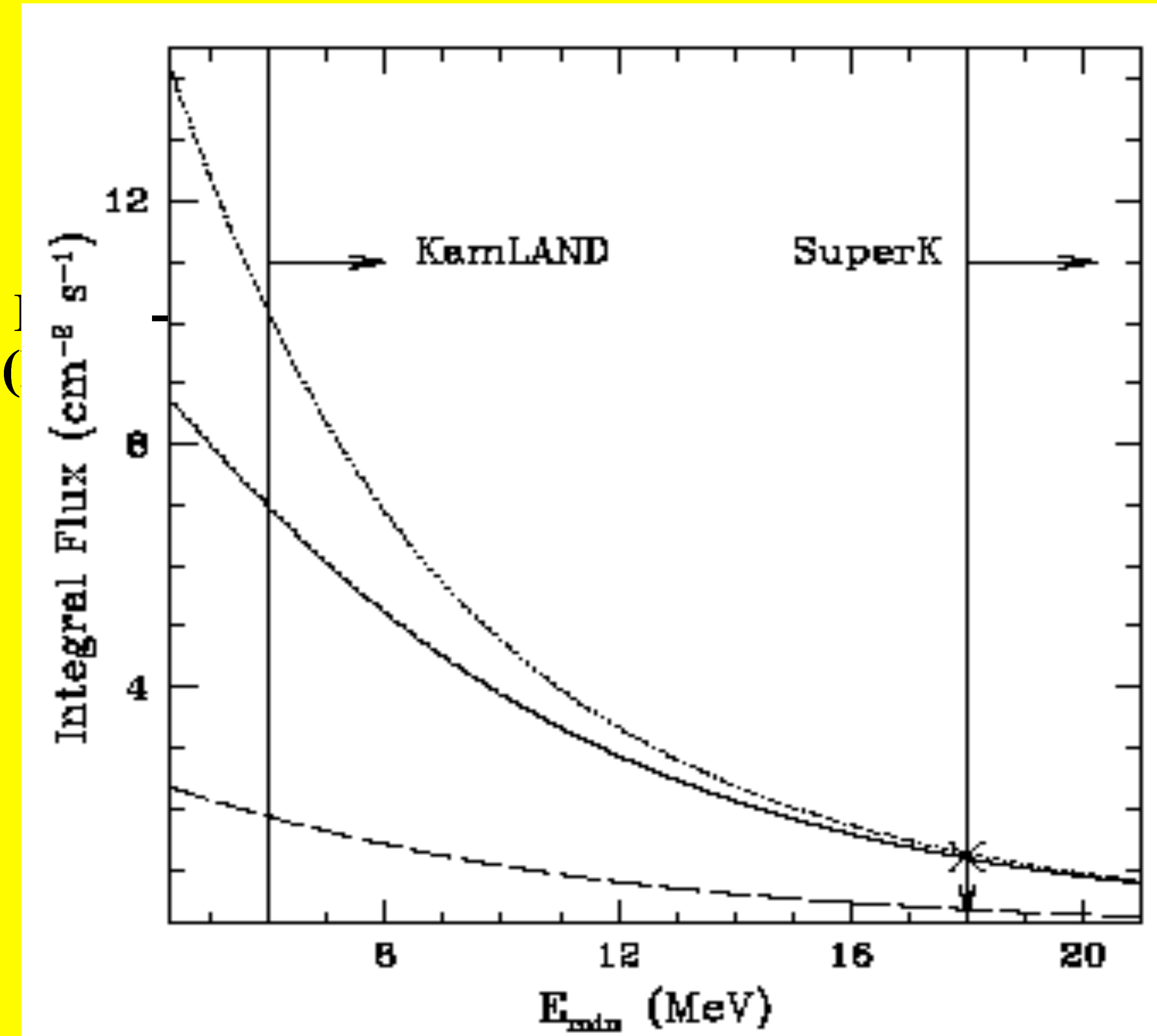


(RSR hep-ex/0208038a0

Super Nova Relic (Anti) Neutrino Sensitivity
(Strigari et al)

Low Energy Sensitivity
is KEY for:

•High Rates
•Access to HIGH red
  Shift part



PROTON DECAY SEARCH

Why look beyond Cerenkov?

- **Insensitive to particles below Cerenkov threshold**
- Poor energy resolution
- Hi water solubility of most things –ultrapurity hard
- Low light levels require many PMT's

Typical Cerenkov thresholds

- ***Electron T=0.262 MeV***
- ***Gamma E=0.421 MeV (Compton)***
- ***Muon T=54 MeV***
- ***Pion T=72 MeV***
- ***Kaon T=253 MeV***
- ***Proton T=481 MeV***
- ***Neutron T~1 GeV (elastic scatter)***

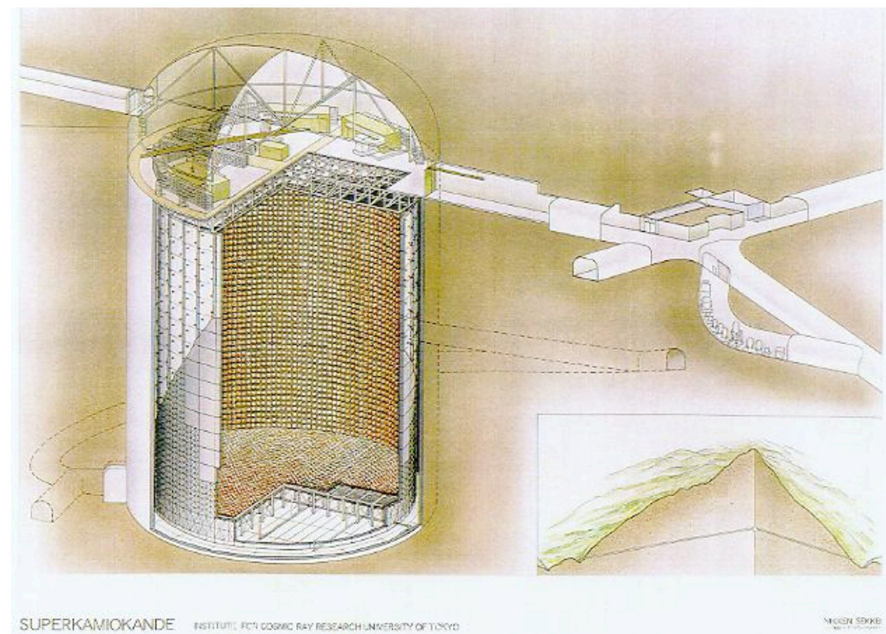
Limitations from Cerenkov Threshold

- **No K+ from 2-body nucleon decay can be seen directly**
- **many nuclear de-excitation modes not visible directly**
- "stealth" muons from atmospheric neutrinos serious background for proton decay, relic SN search

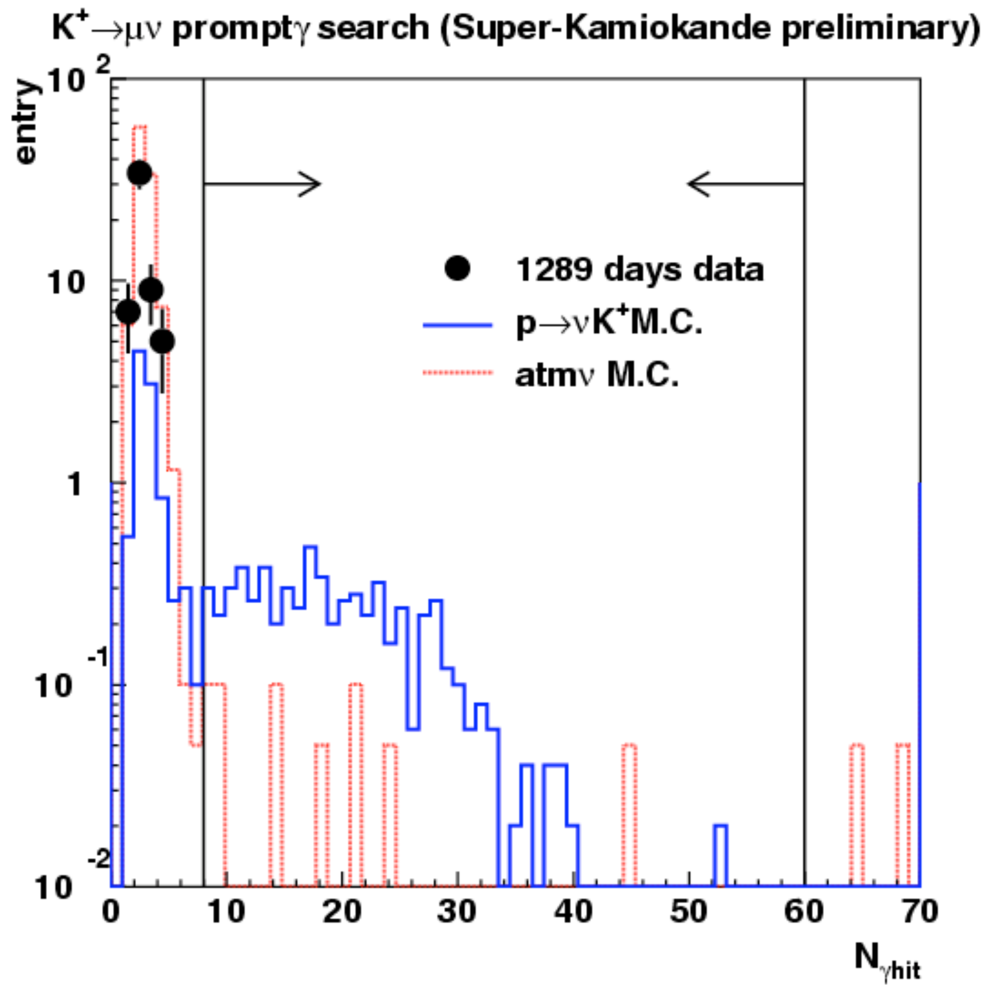
$P \Rightarrow \nu K^+$

The Cerenkov experience

- SUSY and other models in which decay strength depends on quark mass
- K^+ **below C-threshold**
- $K^+ \Rightarrow \mu^+ \nu_\mu$ 63.5%
- $K^+ \Rightarrow \pi^+ \pi^0$ 21.2% $\beta_\pi = 0.86$
- $\pi^+ \Rightarrow \mu^+ \nu_\mu$ **muon below C-threshold**



- **Super-K sees about 170 background single ring muons with 33% eff.**
- **This would become 22 events with the KamLAND energy resolution**
- **SK improves this by looking for gamma from ^{15}N de-excitation**
- **$P_{3/2}$ proton hole gives a single 6.3 MeV γ with BR = 41%**
- **Difficulties in detecting this gamma drop the efficiency from 33% to 8.7%**
- **Background drops from 170 to 0.3 events**
- **Requires excellent PMT coverage**
- **2-3 event positive signal would not be very convincing**



K± are visible in scintillator

Gold-plated triple tag

τ(K+) = 12.8 ns T(K) =105 MeV

K± ♉ _+ _ (63.5%)

T(_+ = 152 MeV):

K± ♉ π+ πo (21.2%);

T(π+) = 108 MeV

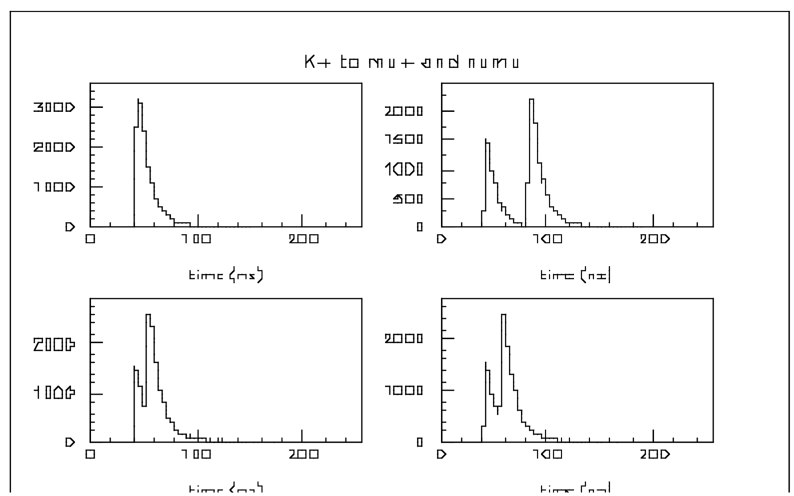
EM shower= 135 MeV

μ+ ♉ e+νν (τ= 2.2 μs)

π+ ♉ μ+ν (T=4 MeV)

μ+ ♉ e+νν (τ = 2.2μs)

- KamLAND MC for 340 MeV/c K+
- K+ gives over 10,000 p.e.'s
- μ+ gives over 15,000 p.e.'s
- K+/μ+ separation is possible
- Light curves for first 6 events from KL MC ⇨



Major Motivation for Scintillation for p   -decay

Efficiency for prominent modes increases by   x8-10 in Scint vs C

Instead of 1 Megaton water   Cerenkov Detector use 100 kiloton Scintillation detector (e.g. HSD)

HSD enables search for Mode-free Nucleon Decay

- Disappearance of n in ^{12}C leads to 20 MeV excitation of ^{11}C followed by delayed coincidences at few MeV energy
- This pioneering technique opens the door to a very different way of looking for nucleon decay –best facilitated in LS technique
- Kamyshkov and Kolbe (2002)

Moderately long base line neutrino physics?

Kimballton-DUSEL—

Many Hall C type Caverns now at 2000 mwe

DUSEL Plan Large Campus suitable for HSD

Initial ideas being developed:

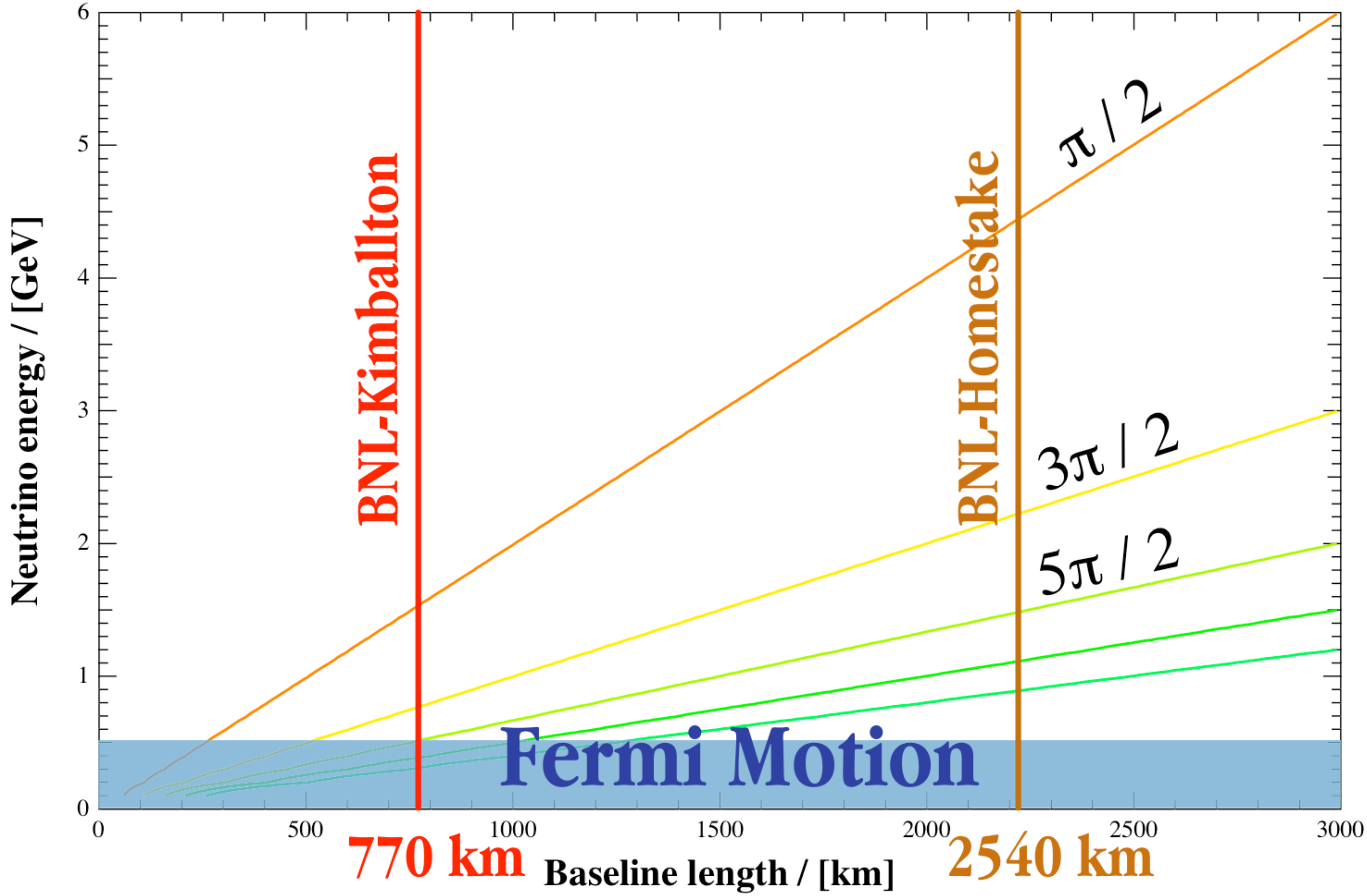
Fix Kimballton as detector site

---plan calls for large detector in campus at 4500 feet

---baseline 770 km from BNL

---Examine antineutrinos $\nu_\mu \rightarrow \nu_\varepsilon$ to utilize strong antineutrino tagging

VT Muon Telescope Tent



Neutrino energy / [GeV]
Baseline length / [km]
0
1
2
3
4
5
6
0
500
1000
1500
2000
2500
3000
BNL-Kimballton
BNL-Homestake
π / 2
3π / 2
5π / 2
Fermi Motion
770 km
2540 km

Initial focus:
Short Base line→ Lower energy 0.5-1.5 GeV anti numu

Minus: lower cross section
second maximum probably seen only
with free protons (fermi motion)
Plus: Higher flux at start (x4 than at 6 GeV)
and at target (shorter baseline)
than for numu at higher energies considered in VLBL planF
---- First maximum well observable for
C and p targets

Initial conclusions for long baseline research

- **Appearance Oscillation can be seen in tagged mode with low background**
- **More work needed to see if 2nd max can be seen sufficiently well to go beyond osc. to see**
  - **solar interference**
  - **CP violation**
  - **Heirarchy effects.**
  - **Energy close to Fermi motion limit— can one use C and p or only p?**

Simulations group being formed for detailed work

Stay tuned!

Conclusions:

- HSD will be a Major Science Opportunity
- Top notch multi-disciplinary science justifying cost (~300M?)

1. Geophysics
2. SN physics and cosmology
3. Proton/nucleon decay
4. Moderately long base line neutrino physics

- #1 not possible in any other detector—Uniqueness--Discovery
  #2 best served by low energy sensitivity--
  higher event yields and access to
  high red shift cosmology—
  best chance for definitive landmark result
  #3 better opportunities in HSD than Cerenkov
  and at least as good handles as in LAr
- #4 Preliminary considerations positive
  Much more work needed for firm conclusions

Conclusions

•New types of Detectors emerging
for low *and* high energy particle physics

•Massive Liquid Scintillation Detectors
ideal for a large number of outstanding
problems

•Vigorous R&D needed to solve
Challenging frontiers ahead in
several “alpha Science” Problems

ADDITIONAL SLIDES

CPT violation !
ν ≠ $\bar{\nu}$

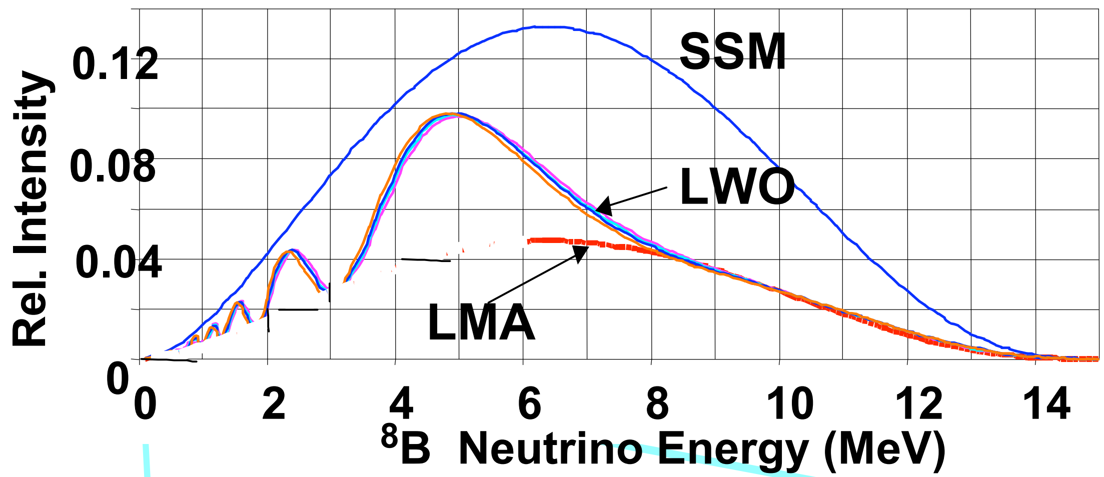
If not LMA for ν, What else?

Best fit model, solar *neutrino* data only— LWO, long wavelength *vacuum* oscillations (upper panel)

Detect LWO via fast oscillations in pp spectrum (lower panel)

(RSR JCAP 2003)

R.S.Raghavan/VT/Aug05



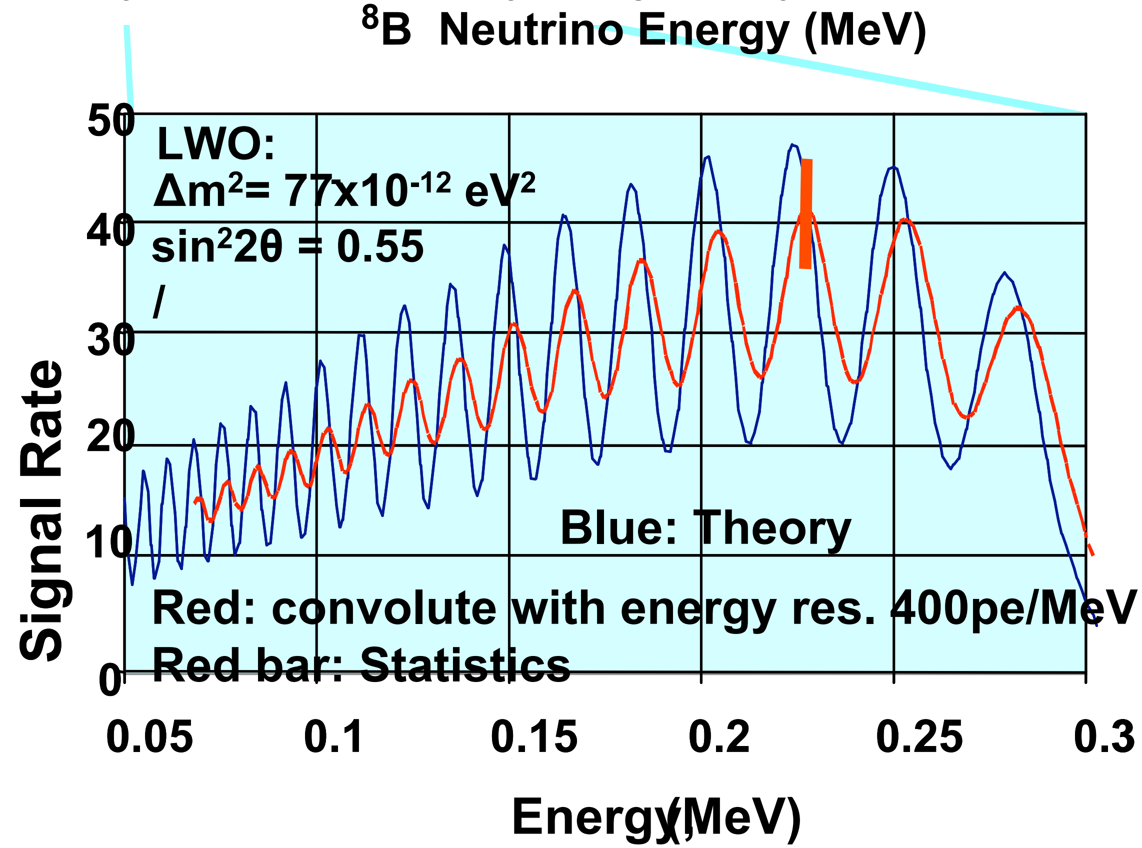
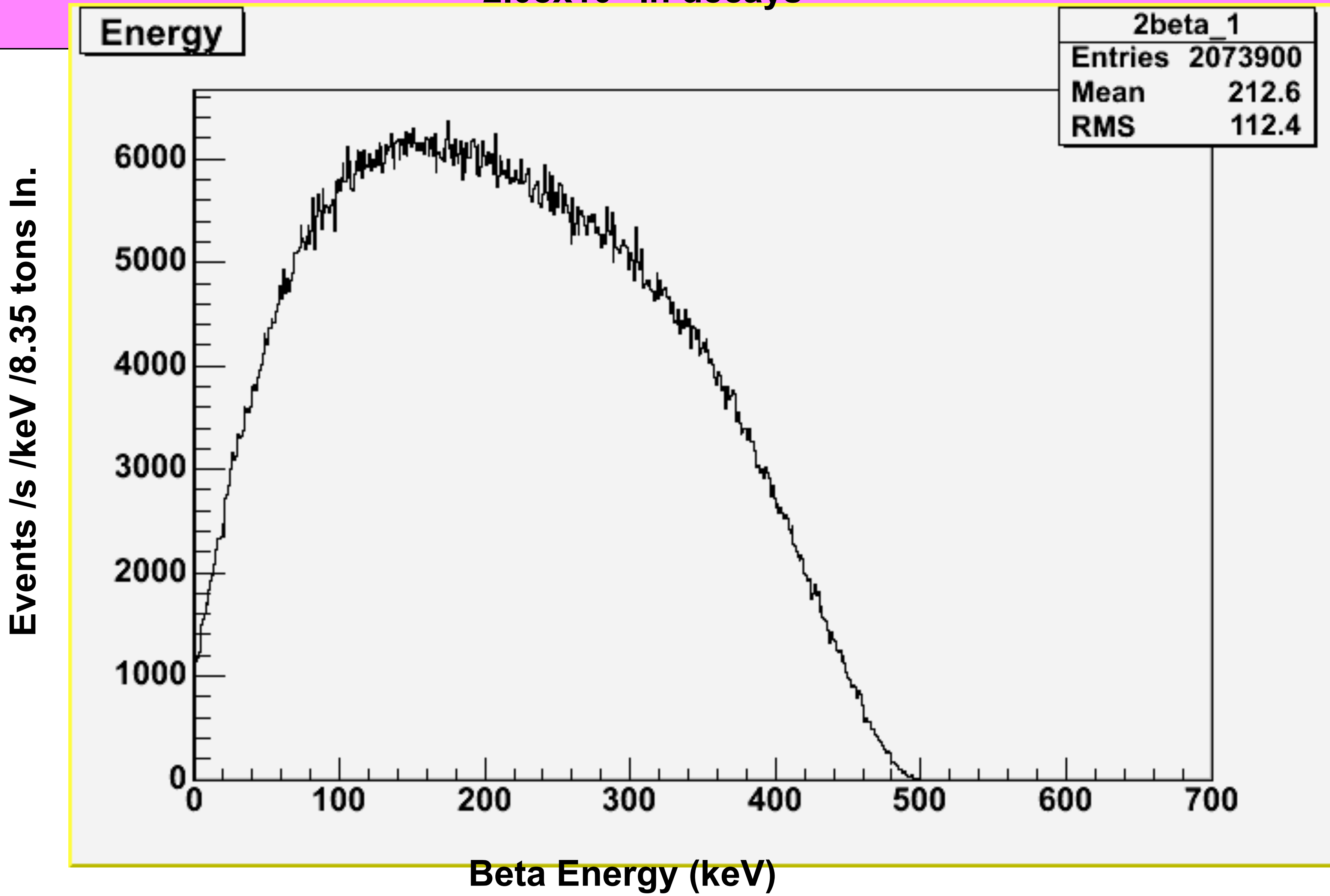


Table 1. Error Budget for pp nu flux measurement with 2000 events/5y at S/N=3

Item	Percent Uncertainty
Signal/Bgd Statistics ΔS/S%	2.5
Coinc. Detection Efficiency Δε/ε %	0.7
No. of Target Nuclei ΔN/N%	0.3
Cross Section (Q value) ΔI/I%	0.3
Cross Section (B(GT)) ΔM/M%	1.8
Total Flux Uncertainty Δφ/φ%	**3.2**

Indium-115 Beta Spectrum (Pfeiffer et al *PR 1979*)
~2.08x10^6 In decays



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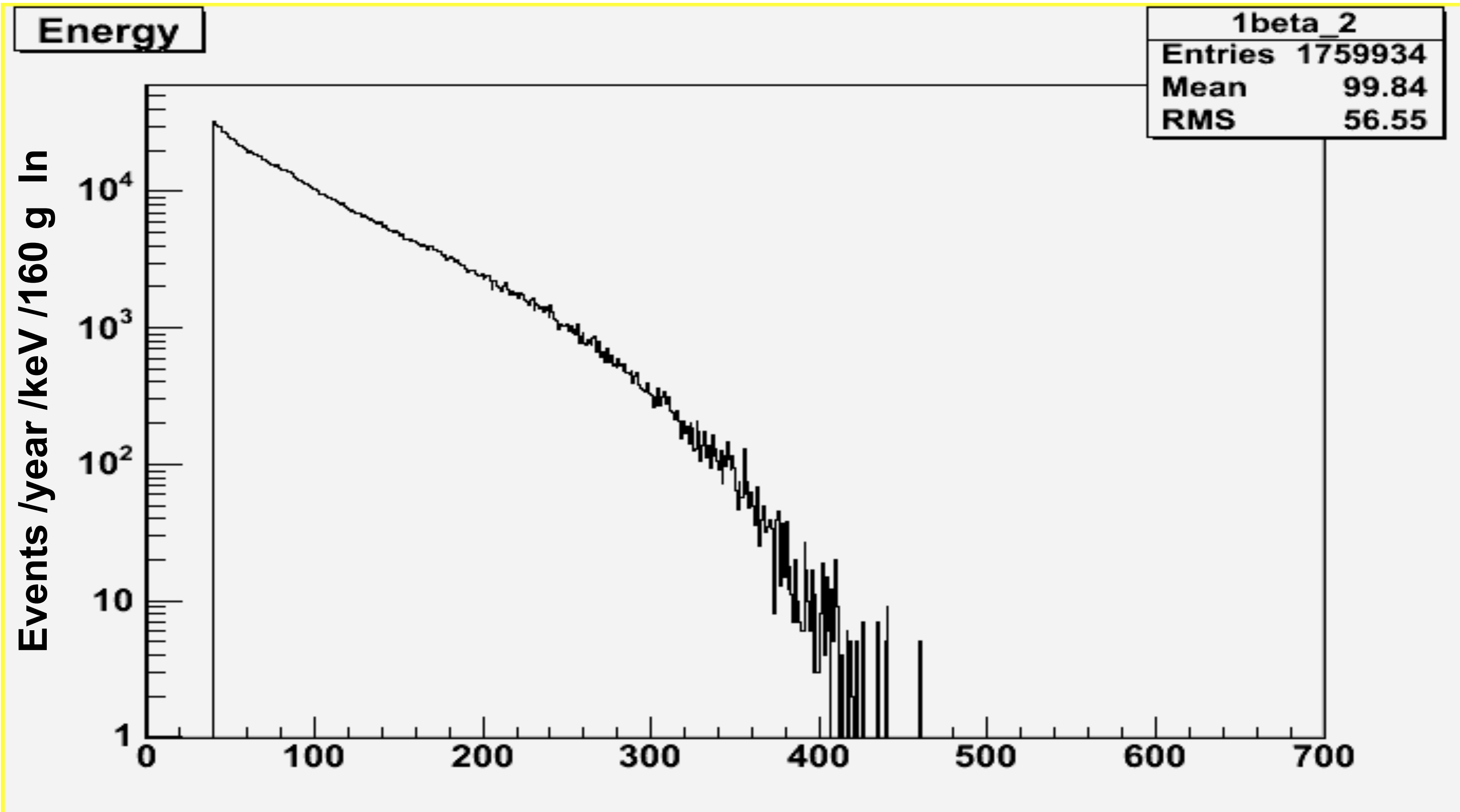
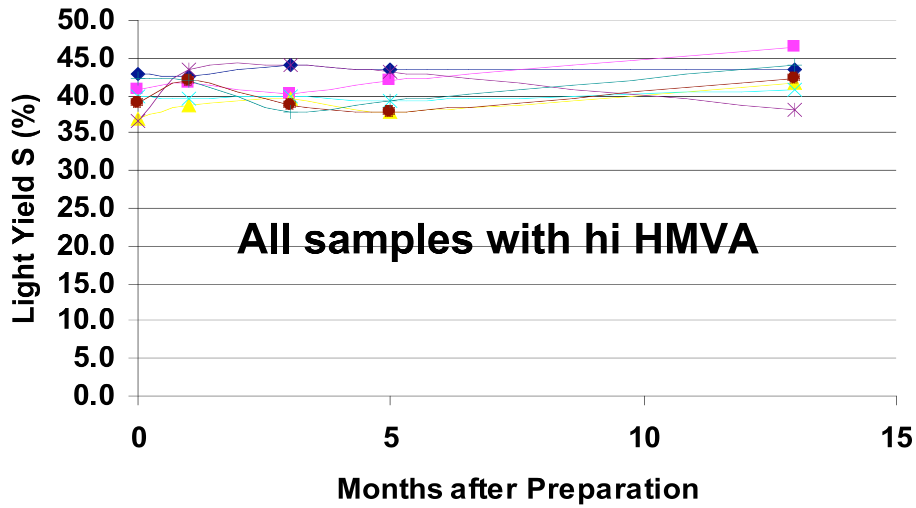
Bremmstrahlung Spectrum of 100,000 In decays with energy > 450 keV (1/111)+ at least one photon >40 keV (1/116)
Corresponding total In decays = 10^5 x111x116 = 1.29×10^9
(GEANT IV-- ; Pfeiffer In-beta spectrum)

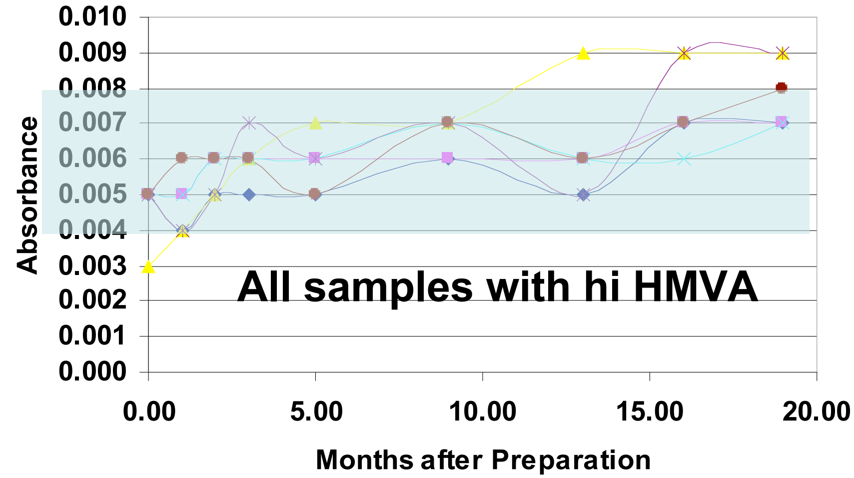


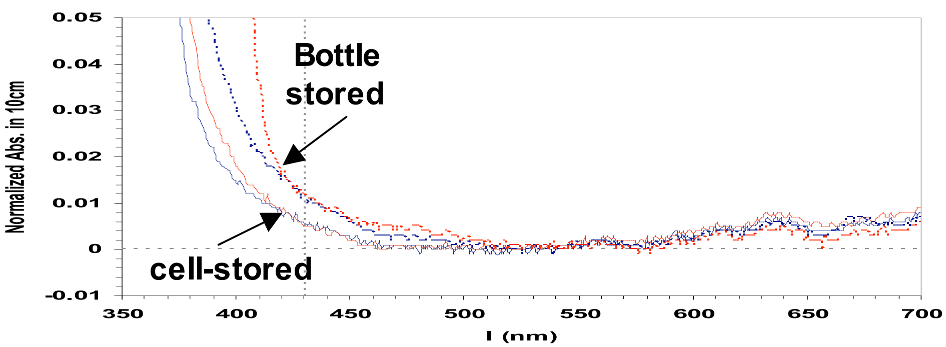
BS Photon Energy (keV)

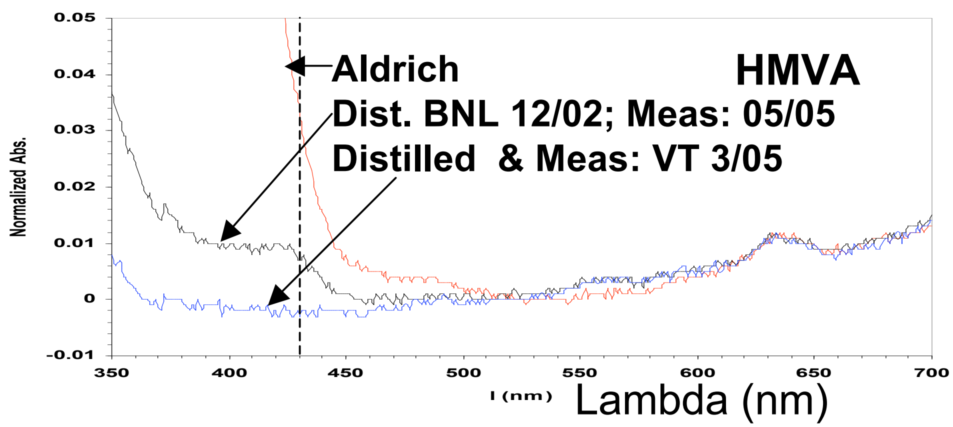
R.S.Raghavan/VT/Aug05

LONG TERM (Yrs) STABILITY--CHEM, OPT, SCINTILLATION









Long term Stability in typical samples (BNL & Bell Labs)

- All samples above were made at *low pH-Hi HMVA* and stored without special precautions on air exposure
- Light yield very stable
- L(1/e) degrades somewhat (see band)
- Traced to HMVA degradation from air exposure (left)
- Present lnLS contains no HMVA
→higher stability over several years

R.S.Raghavan/VT/Aug05

Example of Detailed results: 75x75x75mm Cells; (2x[4x4x4m Cube]
L(1/e) = 10m; Y = 9 hv/keV; pe/keV = 1.0; Hits ≥ 3 pe

Bgd Type	A1	C	D	A2	B
Events before Cuts	500000	20000	1000	200000	$3x10^{6}$
Rate before Cuts	$6.17.10^{8}$	14.6	$2.24.10^{-3}$	$6.17.10^{8}$	$9.49.10^{4}$
Overall Rej. Eff.	$9.3(38).10^{-10}$	$6.5(18).10^{-4}$	$0(1).10^{-3}$	$6.53(20).10^{-9}$	$8.80(54).10^{-6}$
Rate After Cuts	$5.7(23).10^{-1}$	$9.5(26).10^{-3}$	$0(2).10^{-6}$	4.03(12)	8.3(5)
Events After Cuts	6	13	0	1088	264

Neutrino detection efficiency: 64%
Neutrino Event rate: 40 solar pp per ton In per year
Indium Background rate: 13.0 (6) per ton In per year
S/B-ratio: 3.08

R.S.Raghavan/VT/Aug05