Future LowNu Projects
LowNu: low energy (solar) neutrino

Summary (selective and biased) of the LowNu2002 Workshop at MPIK Heidelberg

Stefan Schönert, MPIK Heidelberg
Neutrino 2002
25.5.02
XMASS: Status

- 3kg detector (finished)
- 100kg detector (under construction)
- 10t scale detector

Low background setup
Vertex, energy reconstruction
Demonstration of self-shielding
Purification
e/ gamma separation
Attenuation length (special setup)
Neutron BG study

Achievement of super low bg in FV!

Fundamental study of LXe
PMT improvement (QE, radioactivity)

⇒ poster session
100kg detector LXe vessel

Transported into the mine on May 13, 2002

MgF₂ window
pp neutrino flux measurement (90% C.L.) by:
- 10 ton detector
- ve scattering experiment
- 5 years data
- Statistical error + SSM flux error (1%)

Accuracy of mixing angle:
$$\sin^2 2\theta = 0.77 \pm 0.03 \text{ (stat.+SSM)}$$
CLEAN – liquid neon scintillation detector

Possible schemes:

<table>
<thead>
<tr>
<th>buffer</th>
<th>active target</th>
</tr>
</thead>
<tbody>
<tr>
<td>liquid Ne</td>
<td>liquid Ne</td>
</tr>
<tr>
<td>solid Ne (ρ=1.4)</td>
<td>solid Ne</td>
</tr>
<tr>
<td>Ne</td>
<td>He</td>
</tr>
<tr>
<td>He</td>
<td>He</td>
</tr>
</tbody>
</table>

- Detection reaction: ES ($\nu + e^- \rightarrow \nu + e^-$)
- ~140 t (10 t fid.) detector (neon/neon)
- 1-2 m self-shield (ρ=1.20 g/cm$^3$)
- 15,000 (or more) scintillation photons/MeV
- active buffer
- Light detection with PMTs: wavelength shifter in front of PMT’s

Plan: submission of R&D proposal in autumn (McKinsey et al. Princeton/Boston/...)

HERON – liquid helium scintillation and phonon/roton detector

• **Target:** Superfluid He (~20t)
• **Detection reaction:** ES ($\nu + e^- \rightarrow \nu + e^-$)
• **Signal:** UV scintillation (80 nm; 15,000/MeV), delayed rotons/phonons (1 meV; $10^8$/MeV)
• **Detection of photons, phonons/rotons** with sapphire/silicon wafer calorimeters,
• ~2400 SQUID read-out channels

**Virtue:** Superfl. $^4$He (50mK) `self-cleaning` (gravity>$kT$) $\Rightarrow$ free of internal bgd

**Challenge:** He **limited self-shielding**
$\Rightarrow$ radio purity of cryostat
$\Rightarrow$ background discrimination: point-like events ($\nu$) vs. mult. compton scattering
$\Rightarrow$ position reconstruction by coded aperture

(Lanou et al.)
TPC's – ES with full kinematic information for pp- and Be-7 $\nu$

Goal:
measurement of $e^-$ recoil angle and energy
$\Rightarrow$ $\nu$-energy

Challenge:
angular resolution at low energies
$\Rightarrow$ low multiple scattering $\Rightarrow$ He, C
$\Rightarrow$ minimal self-shielding
TPC – He/methane for Homestake

Hellaz follow-up:
• ~4000m³, 10bar, 7t He
• Methane instead of isobutane \( \Rightarrow (^{14}\text{C}) \),
• He-methane gaseous at 112K \( \Rightarrow \) cold trap Rn

<table>
<thead>
<tr>
<th>Exposure</th>
<th>7 &amp; 70 t yr</th>
</tr>
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<tbody>
<tr>
<td>Energy res. (( \sigma ))</td>
<td>5% @ 100 keV</td>
</tr>
<tr>
<td>Angular res.</td>
<td>15° @ 100 keV</td>
</tr>
<tr>
<td>Uranium</td>
<td>0.5 ( \mu )g (surface) ( (0.7 \times 10^{-16} \text{ if mixed}) )</td>
</tr>
<tr>
<td>( ^{14}\text{C}/^{12}\text{C} )</td>
<td>( 10^{-19} )</td>
</tr>
</tbody>
</table>

Proposal submitted,
Plan for 9m³ prototype R&D
(G. Bonvicini, et al.)
TPC – MUNU: a prototype for solar ν detection

- Low background TPC (1m³) for ν-magnetic moment
- CF₄ @ 3 bar (3.7 g/l @ 1bar)
- Angular resolution: 23° @ 300-600 keV
- Sensitivity <10⁻¹⁰ Bohr magnetons
- Prototype for solar ν-TPC

Range 14cm
E=190 keV
p=1bar

Simulation: 10y 200m³ CF₄-TPC
@ 1bar (≈7t-year) (Broggini et al.)
CC – LowNu detection

pp - $\nu$

inv-$\beta$ (CC):
LENS
MOON
SIREN

$^7$Be - $\nu$

inv-$\beta$ (CC):
LENS
MOON
SIREN
LITHIUM
Candidate nuclei for real time CC solar neutrino detection

<table>
<thead>
<tr>
<th>Isotop</th>
<th>T$_{1/2}$</th>
<th>Häufig.</th>
<th>Tochter</th>
<th>Q [keV]</th>
<th>E$_γ$ [keV]</th>
<th>T$_{1/2}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>$^{115}$In (9/2$^+$)</td>
<td>5$ \cdot 10^{14}$ a</td>
<td>95,7%</td>
<td>$^{115}$Sn (7/2$^+$)</td>
<td>128</td>
<td>116</td>
<td>3,26 µs</td>
</tr>
<tr>
<td>$^{176}$Yb (0$^+$)</td>
<td>stabil</td>
<td>12,7%</td>
<td>$^{176}$Lu (1$^+$)</td>
<td>301</td>
<td>72</td>
<td>50 ns</td>
</tr>
<tr>
<td>$^{160}$Gd (0$^+$)</td>
<td>stabil</td>
<td>21,9%</td>
<td>$^{160}$Tb (1$^+$)</td>
<td>244</td>
<td>75</td>
<td>6 ns</td>
</tr>
<tr>
<td>$^{82}$Se (0$^+$)</td>
<td>1$ \cdot 10^{20}$ a</td>
<td>9,4%</td>
<td>$^{82}$Br (1$^+$)</td>
<td>339–771 diverse</td>
<td>173</td>
<td>29</td>
</tr>
<tr>
<td>$^{100}$Mo (0$^+$)</td>
<td>stabil</td>
<td>9,6%</td>
<td>$^{100}$Tc (1$^+$)</td>
<td>168</td>
<td>3202 (β)</td>
<td>15,8 s</td>
</tr>
<tr>
<td>$^{71}$Ga (3/2$^-$)</td>
<td>stabil</td>
<td>39,9%</td>
<td>$^{71}$Ge (1/2$^-$)</td>
<td>229</td>
<td>–</td>
<td>–</td>
</tr>
<tr>
<td>$^{71}$Ge (5/2$^-$)</td>
<td></td>
<td></td>
<td>$^{71}$Ge (5/2$^-$)</td>
<td>404</td>
<td>175</td>
<td>79 ns</td>
</tr>
<tr>
<td>$^{137}$Ba (3/2$^+$)</td>
<td>stabil</td>
<td>11,2%</td>
<td>$^{137}$La (5/2$^+$)</td>
<td>611</td>
<td>10,6</td>
<td>89 ns</td>
</tr>
<tr>
<td>$^{123}$Sb (7/2$^+$)</td>
<td>stabil</td>
<td>42,7%</td>
<td>$^{123}$Te (7/2$^+$)</td>
<td>541</td>
<td>330</td>
<td>31 ns</td>
</tr>
<tr>
<td>$^{159}$Tb (3/2$^+$)</td>
<td>stabil</td>
<td>100%</td>
<td>$^{159}$Dy (5/2$^+$)</td>
<td>543</td>
<td>177</td>
<td>9,3 ns</td>
</tr>
</tbody>
</table>

Further isotopes proposed (K. Zuber)
LowNu 2002
3rd International Workshop on Low Energy Solar Neutrinos
May 22-24, 2002
MPI für Kernphysik
Heidelberg

- Why low energy?
- $\nu$-e scattering
- Experimental techniques/$\nu$-sources
- Charged current experiments
- Reactor oscillation exp.
- What next?
MOON (Mo Observatory Of Neutrinos)
for Low energy solar ν.

MOON collaboration (Osaka-Tokushima-USC-UW)

- CC realtime spectroscopy.
- Large responses with low $Q_β$.
- Ground state contributes to $pp$-ν and $^7$Be-ν. B(GT) by EC and ($^3$He, t) reaction.
- Two $β$ correlation, $β$ from solar-ν and successive $β$ for tagging, to reduce BG.
- Used for $ββ$ and supernova ν.
MOON Detector
Supermodule of Mo-Scintillator

- Realistic Purity of $10^{-3}$ Bq/ton (0.1 ppt) U-Th. Position read 3mm
- Options
  1. Plastic fibers Mo-foils Ensemble,
     2.5m-2.5m-1m with 0.8 ton $^{100}$Mo. Multi-Anode PM.
  2. Liquid scintillator with WLS Read out.
Charged-Current sub-MeV Real-Time: 
**LENS: Low Energy Neutrino Spectroscopy**

**Method**
- charged current (CC) transition (inverse $\beta$-decay) to excited level ($\nu_e$ – only!)
- low-energy threshold: pp-, Be-7, pep,...
- $\nu_e$ – tag to discriminate against background
- $\nu_e$-target (=Yb, In) loaded into liquid scintillator

\[
E_e = E_{\nu_e} - E_{\text{thr}}
\]

$\nu_e + (A,Z) \Rightarrow e^- + (A,Z+1)^*$

delay

$(A,Z+1) + \gamma$
In-LENS

\[ ^{115}\text{In} \ (95.7\%) \]
\[ 4.4 \times 10^{14} \text{ a} \]
\[ \beta \ 486 \text{ keV} \]
\[ ^{115}\text{Sn} \]

Q-value: 128 keV

Indium Neutrino Tag--Signal topology

MACROcell

MICROcell (event vertex)

Events per 20 keV

Challenge:

Bgd from \(^{115}\text{In} \ \beta\)-decay 486 keV & Bremsstrahlung

\[ \Rightarrow \ 7\text{Be} \  \text{ok!} \]

\[ \Rightarrow \ pp\text{-}\nu \ \text{???} \]

(MC: \(\varepsilon_\nu \sim 11\% \) i.e. 0.1 ev/day 4t In)
Light Yield of In-loaded scintillators

LY vs [In] for our best In(iVal)3 • 0.25 M TBPO in PC

Absorption length ~4m achieved!
Spectrum obtained irradiating a 10 ml sample with CS source

Calibration curve obtained irradiating the cell with g sources. [In] = 90 g/l
LENS LOW BACKGROUND FACILITY @ Gran Sasso

Outside LLBF: 22h counting.
Spectra normalized at 525 h counting

LLBF closed and flushed
525 h counting time

Reduction factor: $10^5 - 10^6$ on lines
Experimental program for LLBF

- test prototype cells and scintillators
- Bck study from radioactive sources (single rates, correlated signals ...)
- Event reconstruction
- ...........

First test run with 20 cm $\Phi \times 170$ cm I quartz cell 70 cm acrylic buffer 8” Hamamatsu PM each side

measure total counting rate with well known LS

⇒ poster session
HLMA Project - proposal for a new reactor oscillation exp. if KamLAND sees spectral suppression but no oscillation ripples

LMA favoured by global analysis

Rates, SK(Sp, Zenith), SNO(CC/NC/DN)

@3σ: $2.5 \times 10^{-5} < \Delta m^2 < 3.7 \times 10^{-4} \text{ eV}^2$

$0.24 < \tan^2(\theta) < 0.89$

LMA favoured

All Inclusive

Best Fit:

$\Delta m^2 = 8 \times 10^{-5} \text{ eV}^2$

$\tan^2(\theta) = 0.35$

But

HLMA region

$(\Delta m^2 = 2 \times 10^{-4} \text{ eV}^2)$

allowed @3σ

Now disfavored directly by the latest SNO results since

the top part of LMA gives Ee solutions with Pee $\leq 1/2$, and SNO gives Pee $<1/2$
HLMA Focus: Solar mixing parameters

- 2 neutrino mixing
- $10^{31}$ protons
- No energy resolution
- 250 keV bins
- $\Delta m^2 < 10^4$ eV$^2$ only rate suppr.
- Optimised for HLMA region
- High sensitivity to $\Delta m^2$

$\sin^2 2\theta = 0.6$

$\sin^2 2\theta = 0.8$

$\sin^2 2\theta = 1.0$

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Poster session
(S.S., T. Lasserre, L. Oberauer)
„Schedule“

June 2001  SNO CC data: SK&SNO: 3.3 $\sigma$, large mixing
Dec. 2001  SK 1500 day: LMA
Aprile 2002 SNO NC data: 5$\sigma$, LMA strongly fav.

??? 2002  KamLAND: reactor: LMA or NOT LMA

2003  BOREXINO(KL) Be-7: LOW / VAC

$\geq$ 2005  next generation „LowNu-experiment“ operational
...other issues at LowNu2002

Ingredients for success – experimental art to (re)move atoms:

• metal removal/loading in LS
• noble gas impurities (Rn/Kr/Ar)
• artificial neutrino sources (workhorse for CC experiments)

Solar flux variability and implication (Sturrocks/Caldwell)
D.C: Ga (Cl) show 13.6 (12.8)/y frequency, hint for RSFP?
SK?
Summary & outlook

• Ongoing strong experimental R&D in Europe and Japan
• Both for ES and CC several projects proposed
• XMASS (ES) & LENS (CC) most advanced
• None of the projects has proven feasibility yet
• Co-operation across projects important
Physics impact of future LowNu experiments
N.B.: mixing parameter range (LMA, LOW, VAC) most likely known after KamLAND and Borexino!

(Bahcall, Giunti, Strumia, ....)

- **Test / refine neutrino oscillation solutions**
  - Same behavior at high energies
  - Different behavior at low energies
  - pp-flux: “precision beam” (1% uncert.)
  - 7Be: monoenergetic line (10% uncert.)
  - $\theta_{\text{sol}}$, $\nu_{\text{sterile}}$, CPT test, EM prop., ....

- **Test solar fusion theory**
  - SSM: 99.99% of solar neutrinos < 5 MeV
  - Low energy fluxes predicted more precisely

- **Redundancy / Discoveries**
Solar-$\nu$: ES vs. CC real time projects

$pp-\nu$

- ES (CC+NC)
  - XMASS
  - CLEAN
  - HERON
  - TPC
  - MUNU
  - GENIUS

- CC
  - LENS
  - MOON
  - SIREN

$^7\text{Be}-\nu$

- ES (CC+NC)
  - BOREXINO
  - KamLAND
  - TPC
  - MUNU
  - LITHIUM

- CC
  - LENS
  - MOON
  - SIREN

⇒ On R&D level, ES and CC detection of $pp$- and $^7\text{Be}$-$\nu$ redundantly covered
Neutral Current Probe

$\nu_e$ - capture (cc) vs. $\nu$-e$^-$ Scattering (cc+nc)

Example Be-7 $\nu^e$s

Normalized event rate ($R/R_{SSM}$) for cc-reaction (LENS),
Equiv. to $\phi(V_e)/\Sigma\phi_i(V)$
Projects: pp-$\nu$-ES experiments
Noble gas detectors

Comparison among noble gas detectors
(Ar & Kr not suitable: $^{39}$Ar, $^{42}$Ar, $^{85}$Kr radio active isotopes)

<table>
<thead>
<tr>
<th></th>
<th>Helium</th>
<th>Neon</th>
<th>Xenon</th>
</tr>
</thead>
<tbody>
<tr>
<td>Boiling temperature</td>
<td>4.2°K</td>
<td>27°K</td>
<td>165°K</td>
</tr>
<tr>
<td>Atomic number (Z)</td>
<td>2</td>
<td>10</td>
<td>54</td>
</tr>
<tr>
<td>Density (g/cm$^3$)</td>
<td>0.125</td>
<td>1.20</td>
<td>3.06</td>
</tr>
<tr>
<td>Radiation length (cm)</td>
<td>756</td>
<td>24</td>
<td>2.7</td>
</tr>
<tr>
<td>Scintillation w.l. (nm)</td>
<td>73</td>
<td>80</td>
<td>175</td>
</tr>
<tr>
<td>Number of photons / MeV</td>
<td>22,000</td>
<td>15,000</td>
<td>42,000</td>
</tr>
</tbody>
</table>

ES event rate (pp-$\nu$) : $\sim 2/\text{t/d} \Rightarrow \sim 10\text{t (fid.) target mass}$
XMASS – liquid xenon scintillation detector
Location: Kamioka

• Detection reaction: ES ($\nu + e^{-} \rightarrow \nu + e^{-}$)
• 23 t (10 t fid.) detector
• 30 cm self-shield ($\rho = 3.06 \text{ g/cm}^3$)
• 1350 3’’ PMTs
• 42,000 scintillation photons/MeV
• No inactive buffer (23 t volume active)

Background requirements: (<1BG/day)

$^{136}\text{Xe } 2\nu - \beta\beta$: $t_{1/2, \text{theory}} = 8 \times 10^{-21} \text{ y}$
  ⇒ 1000 events/d
  ⇒ isotope separation factor 10-100

Trace contaminations:
- $^{85}\text{Kr } (t_{1/2} = 10.7 \text{ y})$: $< 4 \times 10^{-15} \text{ gKr/gXe}$
- $^{42}\text{Ar } (t_{1/2} = 33 \text{ y})$: $< 4 \times 10^{-11} \text{ gAr/gXe}$
- U/Th:
  - In-situ spallation: 2/day ?? (assuming 10 mb)

Muon induced:

External Background:
  Similar to BOREXINO design
  Self-shielding ⇒ fiducial volume

(Y. Suzuki et al.)
XMASS: expected $\nu$-signal and $2\nu$-$\beta\beta$ background of $^{136}$Xe

Isotope separation $\sim 1/100$ needed