Basic Technologies for MiniLENS and LENS

by

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(for the LENS Collaboration)
Low Energy Neutrino Spectroscopy
LENS

- 3-D Scintillation Lattice
- Metal Loaded Scintillator Technology
LENS Detection Method

- CC $\nu_e$ capture on $^{115}$In (95.7%)
- Prompt e- gives neutrino energy (-Q)
- Delayed cascade ($\tau = 4.76 \mu s$) gives triple coincidence against background

The Indium Low Energy Neutrino Tag

$$\nu_e + ^{115}In \rightarrow e^- + \gamma + (\gamma/e^-) + ^{115}Sn$$

- Solar signal
- Delayed tag ($\tau = 4.76 \mu s$)
10 tons of $^{115}$In
2.5 MHz $^{115}$In Beta decay

In order to suppress the background ~1L resolution is needed.

Typical time of flight measurements give resolution to ~ 100L

How can 1L resolution be achieved in a 130,000 L liquid detector?

→ Convert isotropic emission into channeled light – *throughout the whole* detector

Can it be done?
Scintillation Lattice Technology

$\theta_{\text{critical}} = 45^\circ$ for cubic lattice

$\Rightarrow n \sim 1.07$

Teflon FEP \hspace{1cm} n \sim 1.34
Water \hspace{1cm} n \sim 1.33
Perfluorohexane \hspace{1cm} n \sim 1.27
Air \hspace{1cm} n \sim 1.0

PMT’s Needed for cubic lattice LENS of size $N^3 = 6 \times N^2$

The index of liquid scintillator is 1.52 for these calculations
## Signal vs Background in LENS

### RAW rate

<table>
<thead>
<tr>
<th>Condition</th>
<th>Signal (pp) $y^{-1} t \ln(t)^{-1}$</th>
<th>Background (In) $y^{-1} (t \ln(t))^{-1}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Tag in Space/Time delayed coincidence with prompt event in vertex</td>
<td>62.5</td>
<td>$79 \times 10^{11}$</td>
</tr>
<tr>
<td>B. $\geq 3$ Hits in tag shower</td>
<td>50</td>
<td></td>
</tr>
<tr>
<td>C. Tag Energy = 614 keV</td>
<td>46</td>
<td>$2.96 \times 10^{4}$</td>
</tr>
<tr>
<td>D. Tag topology</td>
<td>40</td>
<td>$13 \pm 0.6$</td>
</tr>
</tbody>
</table>

Background suppression $> 10^{12}$

Results of GEANT4 Monte Carlo simulation (cell size = 7.5cm, S/N=3)
Lattice Structure

\[ n = 1.3 \]

Solid Teflon segmentation

\[ n = 1.0 \]

Double-layer (air-gap) lattice
Photon time to PMT
- Can you build it?
- With liquids?
- Film and structure?
  - Various single films (Fluorinated)
  - Double films with various fluids
- Test small scale.
  - Ethylene Glycol
  - Teflon FEP with Acrylic film for support
FEP Lattice in Ethylene Glycol
Questions and R&D for the Progression of the LENS Lattice Technology

- Single foils – vs – sealed double layers
- Multi-layers?
- Antireflective coatings
- Chemical compatibility
- Optical attenuation
- Structural integrity
- Cost?
Scintillator Goals for LENS

- >8%wt $^{115}$In
- >8m attenuation length
- >35% Light yield of unloaded PC
- Low health and environmental hazard
- Cost
Chemical Purification of components

- Evaporation distillation of 2-Methylvaleric Acid (HMVA)
- For all aqueous components – removing organic chromophores in aqueous parts by chelating with Tri-n-butylphosphine oxide (TBPO) in Toluene
- Optical purification of solvents (LAB, Hexane, PC…) – Activated $\text{Al}_2\text{O}_3$ dry column absorption
Metal Loaded Liquid Scintillator (LAB) Synthesis

1. Neutralization

- HMVA (>98%) + NH₄OH → NH₄MVA + NH₄OH

2. Online purification and solution preparation

- TBPO-toluene
  - NH₄MVA-II
  - InCl₃-II

- TBPO-toluene
  - NH₄MVA-I
  - InCl₃-I

3. Solvent extraction and vacuum evaporation

- Liquid-liquid extraction System in Hexane

- In(MVA)₃ and LAB in Hexane

- Aq. Waste

- InLAB

- Org. Waste

Vacuum Evaporation

stir
## Metal Loaded Liquid Scintillator Technology

<table>
<thead>
<tr>
<th>Metal loaded LS status</th>
<th>InPC</th>
<th>InLAB</th>
</tr>
</thead>
<tbody>
<tr>
<td>1. Indium concentration</td>
<td>8%</td>
<td>8%</td>
</tr>
<tr>
<td>2. Scintillation signal efficiency</td>
<td>~8000 h(v/\text{MeV})</td>
<td>~6000 h(v/\text{MeV})</td>
</tr>
<tr>
<td>3. Transparency at 430 nm:</td>
<td></td>
<td></td>
</tr>
<tr>
<td>L(1/e) (working value):</td>
<td>10m</td>
<td>8m</td>
</tr>
<tr>
<td>4. Light yield (Y%pc) (working value):</td>
<td>55%</td>
<td>36%</td>
</tr>
<tr>
<td>5. Chemical and Optical Stability:</td>
<td>Stable &gt; 1 yr</td>
<td>L(1/e) degrades to ~2m after 30d. Oxidation of free HMVA?</td>
</tr>
<tr>
<td>6. InLS Chemistry</td>
<td>Robust</td>
<td>Robust</td>
</tr>
</tbody>
</table>

### Why InLAB when PC is good?

1. Availability in large quantity / Lower cost
2. Safer – Low toxicity
3. Higher flash point 140C vs 25C – better suited for underground applications
4. Better compatibility with plastics
5. Good optical properties
Increasing Light Yield

- Increase extraction pH
  - $\text{InMVA}_3 \rightarrow \text{InMVA}_2 \text{OH}$
- $\text{C}_6\text{H}_{11}\text{O}_2^-$ replaced with $\text{OH}^-$
- Higher fraction of aromatic
Increasing Long-term Attenuation Length

- Decrease oxidation of free HMVA
- Eliminate oxygen contamination
  - Improve quality control during production
  - Improve storage facilities
Work in Progress

- Building a closed Indium LS synthesis system flushed with inert gas
- Scaling up to a MiniLENS size production phase – 20L batch production – total volume of 125L
- Accelerated aging tests of InLS
- Accelerated aging tests of materials in InLS
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