LENS -- A Novel Technology to Measure the Low Energy Solar Neutrino Spectrum (pp, $^7$Be, and CNO)

Presented by S. Derek Rountree – Project Manager For the LENS Collaboration

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Solar Neutrino Spectrum

- Solar neutrino spectral measurements limited to $^8$B at $E > 2.8$ MeV and $^7$Be.
- Next step is precise spectroscopic measurements of the low energy neutrino fluxes from the sun - pp, pep, and CNO neutrinos.
- Such measurements will continue to address important questions in solar physics and neutrino physics using this unique source - high matter density, long baseline, pure $v_e$ flavor at source, with low neutrino energies.
LENS Science Objectives

Solar physics:
1. Solar luminosity inferred from neutrino flux - compare to luminosity determined from photon flux
2. CNO flux - metallicity of the sun’s core & stellar opacity; transport of CNO elements- “NEW SOLAR NEUTRINO PROBLEM”

Neutrino physics:
1. Test of MSW-LMA neutrino oscillations - energy dependence of $P_{ee}$
2. Place constraints on Standard Model extensions - non-standard interactions, mass-varying neutrinos, magnetic moments
3. Improve current precision of $\theta_{12}$
4. Is there any evidence for sterile neutrinos at low energies? (LENS-Sterile)

Non-standard interactions

Image credit: NASA/Transition Region & Coronal Explorer
The LENS Experiment

Technique: Tagged charged current neutrino capture on $^{115}$In loaded (~8%) in liquid scintillator

$$\nu_e + ^{115}\text{In} \rightarrow e^- + \gamma + \left( \frac{\gamma}{e^-} \right) + ^{115}\text{Sn}$$

- $^{115}$In abundance ~ 96%
- Low threshold = 115 keV (access to 95.5% of pp $\nu$)
- Directly measures neutrino energy $E_\nu = E_e + Q$ (115 keV)
- Principle challenge: background from $^{115}$In beta decay ($\tau_{1/2} = 6.4 \times 10^{14}$ years) ($E_{\text{endpoint}} \approx 499$ keV) (but this only affects p-p neutrinos, not $^7\text{Be}$, pep, CNO neutrinos)

- $\rightarrow 10$ tons In $\rightarrow 8 \times 10^{13}$ decays/year (2.5 MHz)
- compare to 400 $\nu_{\text{pp}}$ events/year

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1 (R.S. Raghavan, Phys. Rev. Lett. 37, 259 (1976).)

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LENS Indium Loaded Scintillator

Indium Loaded LAB Synthesis

1. Neutralization

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

2. Online purification

TBPO-toluene NH₄MVA → TBPO-toluene NH₄MVA

TBPO-toluene InCl₃ → TBPO-toluene InCl₃

3. Solvent extraction and vacuum evaporation

Liquid-liquid extraction system → In(MVA)₃ and LAB in Hexane → Aq. Waste

Vacuum Evaporation

InLAB: In% = 8 S% 34-38 l_{1/2} > 8 m

Org. Waste
LENS Scintillation Lattice - Concept

→ Optically segment (in 3D) a volume of scintillator
→ Use total internal reflection to channel the isotropically emitted scintillation light down axes of segmentation

Ideal for cubic lattice: $\theta_{\text{critical}} = 45^\circ \rightarrow n = 1.07 \rightarrow$ no light leakage (for $n=1.52$ scintillator)

\[ \begin{align*}
\theta_{\text{critical}} < 45^\circ, & \quad n < 1.07 \rightarrow \text{no light leakage} \\
\theta_{\text{critical}} > 54.7^\circ, & \quad n > 1.24 \rightarrow \text{no light trapped}
\end{align*} \]

Indices of some prospect materials:  
- Teflon FEP \quad n \sim 1.34  
- Water \quad n \sim 1.33  
- Perfluorhexane \quad n \sim 1.25  
- Air \quad n \sim 1.0
**LENS Scintillation Lattice - Implementation**

**Film and structure?**
- Various single films (Fluorinated)
- Double films with various fluids

**Two methods**
- Teflon Acrylic (TA) combs
- Fiber supported Lattice

**Solution:** Fiber supported Teflon FEP Lattice (µLENS)

n = 1.34  \( \theta_{\text{critical}} = 62^\circ \)

about 50% of light channeled with good timing properties
LENS Scintillation Lattice - Fiber Supported Lattice

* T. WRIGHT, session JA. Astrophysics, LENS Prototyping -- Construction and Deployment of MicroLENS
LENS Scintillation Lattice - Teflon Acrylic Combs

μLENS Scintillation Lattice Filled with LAB
µLENS - A Test bed for LENS Optics Technologies

- Test as built Scintillation Lattice (SL) optics
- Prepare Kimballton Underground Research Facility (KURF)* for the miniLENS prototype
  - Dark containment construction and testing
  - Electronics development
  - Fluid handling construction and tests
  - Spill control systems for total volume
- Benchmark Monte Carlo for miniLENS
- Study KURF background rates for miniLENS

bullet points:

- R.B. VOGELAAR, NA. Opportunities at National Labs and User Facilities in the SESAPS Area, Kimballton Underground Research Facility
  22-Oct-2011 09:30

Virginia Tech
Invent the Future

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μLENS Status

Detector
- μLENS in place at KURF

Electronics & DAQ
- 36 Channels ready to instrument with TDC’s and QDC’s for initial tests
- Software development for CAEN V1721 ADC. Multiplexed instrumentation using the V1721 soon

Scintillator
- μLENS LAB on site at KURF with fluid handling system near
- 2 to 10L InLAB (8% by wt.) batch production demonstration for miniLENS feasibility test. (this InLAB may be incorporated into the μLENS program)

Infrastructure at KURF (VT)
- KURF (Kimballton Underground Research Facility near VT - 1400 mwe depth)
- Dark Containment
- DAQ housing and power
- Liquid handling spill control systems
μLENS to MiniLENS - A Test bed for LENS Technologies

To test LENS technologies, we are constructing a ~ 0.5 m³ prototype instrument (~ 0.5% of volume of full LENS detector)
~ 30 kg Indium in center active region → 2.5 kHz In beta decay rate

- Topology of events in miniLENS contained and identical to full LENS - allows the discriminating power of the geometry to be fully tested
- Measurements will be carefully bench-marked to Monte Carlo to establish the spectroscopy of the full instrument
- Will demonstrate all key aspects and establish scale-up route to full LENS
- Mini-LENS will be instrumented with 150 PMTs ~20% photocathode coverage. Multiple coverage patterns can be investigated.
Thanks

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    Brookhaven National Lab (M. Yeh– PI)
    Louisiana State University (J. Blackmon– PI)

And especially to the students & postdocs

Thank You