Update on HERON

Detection of PP and ⁷Be Solar Neutrino Elastic Scattering in Superfluid Helium


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With collaboration on wafer calorimetry by:

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General Properties

- Total Helium mass 20 (28) tonnes at 50mK.
- No internal backgnd (superfluid self-cleaning).
- Scintillation/rotons or Scintillation/e-bubbles (complement & redundancy).
- Scintillation: 35% of $E_e$ into 16 eV UV ( $\Delta_{\text{Rayl.}} > 200$ meter; self-transparent).
- Detection: wafer calorimeters above liquid.
- Event location: coded aperture array; few cm.
- Fiducial volume variable:
  1.25 evts/(day-tonne) SSM $E_{\text{recoil}} > 50$ keV.
- No radon diffusion at low temperature.
- Helium immune to muon spallation/capture.
- External backgrounds from Gammas:
  Deep site & Shielding Material
  Event signature (coded aperture) Fiducial cuts.
Unique opportunities:

- Precise measure of $\theta_{12}$:
  - ~ Independent of $\Delta m^2$ (LMA-I or II).
  - No matter effects.
  - High statistics.
  - SSM 1%

- Completion of solar campaign:
  - PP spectrum.
  - Total PP flux.
  - Very light steriles? w/ CC
  - Consistency w/ H.E. picture?
  - Stellar energy generation (PP +$^7$Be)
  - Solar luminosity by neutrinos.

- Other: CPT and Mag. mom. limit ($1 \times 10^{-11}$)

Require precise detector performance.
Can it be done sufficiently well (<3%)?
‘GENERIC’ HERON BUILDABLE, PRECISE EXPERIMENT?

- INITIATED ENGINEERING STUDIES FOR PROTOTYPE & FULL SCALE.
- ITERATIVE PROCESS:

VERSION (i) HERON

ENGINEERING ISSUES MECH./CRYOGENIC

SIMULATED PHYSICS PERFORMANCE

- U.S. mechanical code.
- Support of moderator.
  - Heat budget.
  - Cryogenic safety.
  - Fridge integration.
  - External shield.

- Full PP and $^7$Be spectrum.
- Container & external backgrounds.
  - Position & energy resolution.
  - Systematics of signal flux measurement.
  - Systematics of background rejection.

First: incorporate into need for external shield (‘Generic’ → Mod 1)
Some differences of Mod 1 → Mod 2

• Use “off-axis” coded aperture.
  - shallower & wider.
• Replace frozen N₂
  - High purity graphite.
  - 1ˢᵗ NAA study completed (ppt)
  - Pre-purify hydrocarbon?
• Shift mass: inner → outer cryostat.

Provides Improvements:

• Eliminates ~100KÌ ‘heavy’ cryogen (N₂).
• Eliminates plastic bag.
• Reduces some external shield.
• Allows larger fid. & non-fid. vol. (28T)
• Better background rejection.
EXPECTED PERFORMANCE Mod. 2 ON PP EVENTS

- Coded aperture re-construction with single 16 eV photon sensitive wafers.
- 5000 events, full PP spectrum, full volume (fid. & non-fid.)

<table>
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<tr>
<th>Resolutions (sigma) for $E_\text{e} &gt; 50$ keV</th>
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<tr>
<td>In fid. vol.</td>
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<td>X</td>
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<td>Y</td>
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<td>Z</td>
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Note: 2 cm error in all dim. $\Rightarrow$ 1% error in fid. vol.

Event cuts for flux and spectrum:
- Thresh. $E_\text{e} = 45$ keV and Fid. vol. = 68 m$^3$;
- Point-like source (Likelihoods) “DDL” $>0.3$

Expect: 1062 events. Find: 1075 events.
Difference: 1.2% (“wild” fits on low # hits)

Five year statistics expected w/ LMA: 10,000
EXPECTED PERFORMANCE Mod. 2 on BACKGROUND

- Gammas into superfluid from external sources (cosmogenics, primordials).
- GEANT simulation of full scale detector.
- Apply same cuts as previous slide.

Role & Effect of Moderator (graphite; 1.75g/cc):
- ~ 95% all interactions in He Comptons.
- Creates hi multiplicity (non-point-like) events in He.
- Shortens mean-free-path for all.
- Multiples mainly removed by DDL cut.
- Singles mainly removed by fid. vol. cut.

Cuts (scint. only):
- \(E_e > 45\) keV; DDL>-0.3; Fid. vol.
- Moderator + cuts: \(2.5 \times 10^{-5}\)
- Include e-bubble/phonons: \(~1.2 \times 10^{-5}\)
- Presently, signal/bckgnd: 6.5/1
- Use non-fid. vol. as monitor. Subtract?
Complementary channels’ status:

- **Phonon/rotons** (shorter delay/lower pulse size)
- **Electron drift ("e-bubbles")** (longer delay/larger pulse size)

How to decide?: wafer performance and electronic complexity

**Phonon/roton:** old story; published data PRL

![Roton image pattern](image1)

[Graph showing Roton arrivals and Photon trigger]

![3D plot of Roton image pattern](image2)
The idea:

• In superfluid He: isolated e → bubble → a = 2g, unimpeded.
• Wide expt’l & theory literature on phenomenon.
• In principle, with modest fields & cryo conditions can control its path & extract the un-recombined scattered electron(s).
• Detect with same wafers for positions and multiplicity.

Last year at LowNu-III (Heidelberg):
- Described our experiment set-up to measure effect.
- Too ambitious first try. All or nothing.
- Several effects not isolated
- Need more diagnostics.

Presently:
- Back to basics.
- New design with more controls.
- Use our more sensitive wafers.
- Simpler.
- Assembling now.
WAFER SENSITIVITY (single 16 eV photons and e-bubble/phonons)

Progress on metallic magnetic sensors for use on wafers:
- MMS’s were developed at Brown and Heidelberg for astrophysics.
- New results from Heidelberg collaborators.

Last year at LowNu-III (9.6 eV)

New world record 3.4 eV for energy dispersive resolution.

(Aplications for a CNO expt. with $^7$Li)
Progress on scaling up to heat capacity of full scale wafers:

At LowNu-III:
- Expt. to measure physics quantities for scale-up
- Energy transfer processes (electron-phonon, athermal/thermal, Kapitiza)
- Relative heat capacities
- Thermal links time constants

Results allow simulation of full scale wafer performance:

- Sapphire wafer 10x10x0.04 cm
- Metallic magnetic sensor (Er:Au) @ 50 gauss
- Single 16 eV photon:
  - factor 15 (20 mK)
  - above thermal & SQUID noise
  - factor 4 (30 mK)
- Sensitivity good; decay time needs work.
**SUMMARY REMARKS**

- PP solar surest way to measure $\Delta_{12}$ precisely.
- PP & $^7$Be excellent discovery potential for additional new $\Delta$ & solar physics.

**HERON**

**Established:**
- Photon & phonon physics in superfluid He.
- Coded aperture potential for flux & energy spectra.
- Superfluid freedom from any homogeneous background.
- Coded aperture potential to reject external-entering background.

**Preliminary results & still in progress:**
- 16 eV on full scale wafers.
- Engineering design iteration (large prototype & full scale).
- Moderator (purity & mechanical properties).
- Improvement in coded aperture background rejection.
- Testing of electron drift vs. phonon/roton channel.

Other possible applications of the techniques developed:
- Galactic supernovae by coherent NC (low rate but large pulses).
- Spallation source precision measure of coherent NC on nuclei. (but not in full scale HERON)
- High resolution calorimetry for radiochemical experiments. (e.g., solar CNO in $^7$Li.)
- Dark matter with some directional sensitivity (phonons) and active electron rejection.