The CryoCube Detector Array for RICOCHET

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November 3, 2018
The Magnificent CEνNS Workshop
Unraveling New Physics with the Study of the CENNS Process

- New physics signatures would arise at the lowest energy $\rightarrow O(10)$ eV threshold
- Particle identification to reach background rejection: $> 10^3$
The CryoCube

Detector wish list:

1. Very low energy threshold: $O(10)$ eV
2. EM background rejection: $> 10^3$
3. Significant target mass: 1 kg
4. Target complementarity: Ge and Zn

CryoCube $\rightarrow$ A compact array of 27 cubic 32g detectors ($8 \times 8 \times 8\text{cm}^2$ with the infrared-tight copper casing)
Double Energy Measurement for Semiconductor Germanium Detectors

- Ionization / heat ratio depends on the particle type
- Achieve a 10 eV ionization resolution
- Great synergy with the EDELWEISS collaboration
Prompt / delayed heat signals depend on the particle type

New technology that may achieve meV threshold
IPNL Cryogenic Lab

- **Feedthrough (300 K)**
- Decoupled stage (50 K - 100 K)
  - MDM + Kapton PCB
- 1st stage (50 K)
- 2nd stage (4 K)
- Still (~1 K)
- Cold plate (~100 mK)
- **Thermal clamps**
- Mixing Chamber (~10 mK)
- **Detectors**
Vibration Mitigation

- Vibration mitigation mandatory especially for high impedance sensor
- First complete cold-head decoupling demonstrated
- Development of a suspended tower, huge gain in bolometer performance

→ Similar suspension strategy for the CryoCube holding solution
Towards the $O(10)$ eV threshold: Thermal Sensors

EDELWEISS expertise in

- NTD Germanium
- NbSi deposited on Germanium/Sapphire Thermal Chip

→ Compatible with Ge and Zn crystals, as similar heat capacities ($\Theta_D \sim 350 K$)
→ Physical properties can be tuned for optimization.
Towards the $O(10)$ eV threshold: Electro-Thermal Modelization

- Optimization of the cryogenic bolometers based on data driven electro-thermal modelization
- Non-linear differential electro-thermal equations are solved based on first order perturbation and linear algebra
- Use of a MCMC approach to tune the heat sensor parameters to reach best achievable energy resolution and thresholds (includes all sources of noise)

→ Paper in preparation
Early Demonstrator: RED20, heat channel only

Groundbreaking results:

- 18 eV energy resolution (RMS)
- 55 eV energy threshold
- with a 32g Ge Detector
We took data for six days (22nd to 27th of May 2018) with one day blinded (26th of May).

Continuous data stream mode with offline trigger and event processing based on optimal filtering.

Amazing detector stability despite its operation in an above ground lab!

Steady 18 eV (RMS) heat energy resolution and 55 eV energy threshold.

Data were blinded below 4 keV, WIMP search window (ROI) between 0 keV and 2 keV.
RED20 Dark Matter Surface Run: Recoil energy spectrum

→ Limit based on a Poisson optimal interval method

### Data and Background Model

- **Excluded WIMP model: 0.7 GeV/c^2, 9.8e-35 cm^2**
- **Excluded WIMP model: 2.0 GeV/c^2, 4.5e-37 cm^2**
- **Excluded WIMP model: 10.0 GeV/c^2, 1.1e-37 cm^2**

### Analysis Threshold

- **Analysis threshold (60 eV)**

#### Energy Distribution

- **Number of counts [evts/keV]**
  - $10^{-1}$ to $10^{5}$

#### Energy [keV]

- **Data**
- **Background model**
RED20 Dark Matter Surface Run: Contribution of CENNS process

Event rate [evts/kg/keV/day]

Energy [keV]

Strong source  
(Brokdorf)  
$2.4 \times 10^{13}$ nu/cm$^2$/s

Moderate source  
(DC @ 80 m)  
$1.2 \times 10^{12}$ nu/cm$^2$/s

Weak source  
(DC @ 400 m)  
$5 \times 10^{10}$ nu/cm$^2$/s

RED20: 55 eV energy threshold, moderate lead shield (10 cm thick, 70% coverage) and no discrimination
RED20 Dark Matter Surface Run Improving the sensitivity to CENNS

- Sensitivity improvement needed towards CENNS sensitivity at reactors
- Neutrino-WIMP equivalent independent of target material

![Graph showing WIMP-nucleon cross section vs WIMP mass]
High EM background discrimination (in Ge)

$O(10)$ eV ionization resolution $\leftrightarrow$ EM background rejection $> 10^3$

- HEMT have lower intrinsic noise than JFET
- Compatible with cryogenic temperatures and mounted near detectors for reduced stray capacitance
- Design of new electrode scheme based on electrostatic simulation is on-going
Science data taking in RICOCHET
Accurate Low-Energy Calibration

Quenching factor at low recoil energy

- Nuclear recoil energy calibration will be the largest source of systematics
- In-situ calibration technique based on a multiple detector coincidence
- Low-energy mono-energetic neutron sources such as:
  \( \rightarrow \) Y/Be (152 keV) and Sb/Be (23 keV)
Probing new physics

Science Goal
Reach unprecedented sensitivity to physics Beyond the Standard Model

- Accurate control of systematics
- 1 year of on-site science data taking
- Advanced data analysis techniques

2022 to 2024

New physics?
New electroweak mediator Z’, Anomalously large neutrino magnetic momentum, Non Standard Interaction, Sterile neutrino
Thanks you for your attention!

Acknowledgments:
Still looking for an optimal site with large signal and reasonable overburden in France and abroad (decision: end-2019)

<table>
<thead>
<tr>
<th>Experiment*</th>
<th>Detector**/threshold</th>
<th>Country</th>
<th>Power</th>
<th>Distance</th>
<th>nu fux</th>
<th>CryoCube rate</th>
<th>Overburden</th>
<th>Reference</th>
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<tbody>
<tr>
<td>v-GEN</td>
<td>HPGe/\sim 300 eV</td>
<td>RUSSIA</td>
<td>3 GW</td>
<td>10 m</td>
<td>5x10^{13}</td>
<td>600</td>
<td>\sim 50</td>
<td>VLVnT-2018</td>
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<td>CONUS</td>
<td>HPGe/\sim 300 eV</td>
<td>GERMANY</td>
<td>3.9 GW</td>
<td>17 m</td>
<td>2.4x10^{13}</td>
<td>290</td>
<td>10-45</td>
<td>Neutrino 2018</td>
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<td>CONNIE</td>
<td>CCD-Si/\sim 100 eV</td>
<td>BRAZIL</td>
<td>3.8 GW</td>
<td>30 m</td>
<td>7.8x10^{12}</td>
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<td>TEXONO</td>
<td>HPGe/\sim 300 eV</td>
<td>TAIWAN</td>
<td>2.9 GW</td>
<td>28 m</td>
<td>6.4x10^{12}</td>
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<td>MINER</td>
<td>Cryo (Ge&amp;Si)/\sim 100 eV</td>
<td>USA</td>
<td>1 MW</td>
<td>2 m</td>
<td>4x10^{11}</td>
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<td>USA</td>
<td>5.5 MW</td>
<td>4 m</td>
<td>4.5x10^{11}</td>
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<td>FRANCE</td>
<td>9.5 GW</td>
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<td>NuCleus Cryo / \sim 20 eV R&amp;D ongoing ERC funding</td>
<td>FRANCE</td>
<td>9.5 GW</td>
<td>80 m</td>
<td>1.2x10^{12}</td>
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</table>

*The COHERENT and RED-100 experiments are located at SNS emitting higher energy neutrinos (~30 MeV)

** CryoCube is the only envisioned technology combining \sim 50 eV/nr threshold and active background rejection capabilities
Nuclear Site Prospection

- The Ricochet collaboration is actively looking for its optimal nuclear reactor site with large signal and reasonable overburden in France and abroad (decision: end-2019)
- Depth studies performed at MITR (JINST 2018) and Double Chooz (J.Phys. G. 2017)
CEνNS: The process

Coeherent Elastic Neutrino-Nucleus Scattering (CENNS)

\[
\frac{d\sigma(E_\nu, E_r)}{dE_r} = \frac{G_f^2}{4\pi} Q^2 m_N \left(1 - \frac{m_N E_r}{2E_\nu^2}\right) F^2(E_r)
\]

- Largest neutrino cross section at low energies by few orders of magnitude
- From ton-scale experiments to kg-scale ones!
- No energy threshold
EM background discrimination (in Zn)

Thanks to collaborative effort between MIT, CNSM and IPNL, first 30g Zn detector tested

Clear detection of particles!

Clear evidence of two time constants (fast & slow)!

Evidence of vanishing quasiparticle-phonon coupling required for PSD?

Next steps:

- Characterize the crystal purity and heat capacity
- Design a dedicated pulse shape sensitive data processing software
Suspended tower to reach nanometer-scale vibration levels (RMS): CryoCube holding solution

Bolometers are now only limited by their intrinsic thermodynamic noise
The analysis threshold was set to 60 eV to avoid edges effect from trigger efficiency.

Analysis based on pulse simulation where fake events were inserted in the data streams.

Event selection based on: data quality and pulse shape discrimination.

Background model constructed from the 4.7 days of unblinded data.

Limit based on a Poisson optimal interval method.