Dark Matter Searches with Germanium Detectors with sub-keV Sensitivities

- Overview (Collaboration ; Program ; Laboratory )
- Calibration & Energy definitions
- Event selection and efficiencies
- Dark Matter analysis
- Status & plans

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35th International Conference on High Energy Physics @ Paris, France. July 2010
TEXONO + CDEX Collaboration

- **TEXONO**: Kuo-Sheng (KS) Reactor Laboratory
  - Taiwan (AS, INER, KSNPS, NTHU)
  - + Turkey (METU)
  - + India (BHU)

- **CDEX**: China Jin-Ping Underground Laboratory (CJPL)
  - China (THU, SUC, IHEP, CIAE, NKU, EDHC)

- **Present Goals**: Develop $O(100 \text{ eV threshold} \oplus 1 \text{ kg mass} \oplus 1 \text{ cpkkd detector})$ for neutrino physics and dark matter searches
Sensitivity Plot for \textit{WIMP} direct search

\[ \chi N \rightarrow \chi N \]

- $A^2$ dependence (spin-independent)

Low (<10 GeV) WIMP Mass / Sub-keV Recoil Energy :

- Not favored by the most-explored specific models on galactic-bound SUSY-neutralinos as CDM; \textit{still} allowed by generic SUSY

- Various gravitational effects favor lower recoil energy \Rightarrow \textit{Solar-system bound} WIMPs; \textit{Dark Disk} etc.

- Other candidates favoring low recoils exist \Rightarrow \textit{non-pointlike SUSY Q-balls}, MSSM with MeV mass; SM+scalar; axion-like models; Mirror dark matter; Asymmetric dark matter; WIMPless.

- Less explored experimentally
Sub-keV Ge Prototypes built and being studied: (5-900) g

Physics for

- \( \nu N \) coherent scattering
- Low-mass WIMP searches
- Improve sensitivities on \( \mu_\nu \)
- Implications on reactor operation monitoring
- Open new detection channel & detector technology windows for surprises
Kuo-Sheng Reactor Neutrino Laboratory:

- 28 m from core#1 @ 2.9 GW
- Shallow site: ~30 m.w.e. overburden
- ~10 m below ground level
Analysis: Event Selection  CRV, ACV Cut

- compact all-solid design: ULEGe (4 X 5 g ; 500g) surrounded by active NaI/CsI anti-Compton detectors, plus passive shielding & cosmic veto

- Candidate events: survive Anti-Compton (ACV) and Cosmic-Ray (CRV) vetos
  --- Efficiency evaluated by Random trigger events.
Evaluation of Trigger Efficiency

- Max. amplitude of physics events → good margins above threshold
- Efficiency Evaluation: from (mean, RMS) of Max. amplitude distribution
- Evaluation from pulser generator also perform the same behavior
PSD Selection to **Suppress Electronic Noise**
– Correlate different gains & shaping times

- Sampling of Specific Range for 6 μs shaping time i.e. look for pulse fluctuations at specific and known times
- Energy as defined by integration

Integration of 12μs shaping time (keV)

4 x 5 g

Partial integration of 6μs shaping time

**Noise**

**Signal**
Clean physics event samples selected by ACV tag at a known interval of Ge-AC timing

\[ f = \frac{(\epsilon_{\text{PSD}} \times P + f_N \times N)}{P + N} \]

Threshold ~ 320 eV

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Before PSD
After PSD

Counts per Bin

ACV tag Events at 200-400eV

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Trigger:
- Pulser
- Background
- PSD

Coincidence

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PSD survival efficiency

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Discrimination on the Surface and Bulk events ($> 2 \text{ keV}$)

- **γ-rich background (CRV+ACT)**
- **n-rich background (CRT+ACV)**

Signal candidates (CRV+ACV)

Raw pulse

Smoothed
Quenching Factor [Ionization Yield $\Rightarrow$ Recoil Energy]

$\text{TRIM}$ (better fits to available data over extended energy)
WIMP searches

- Background Understanding & Subtraction
  - generic $\gamma$-like source
  - residues of cosmic–induced
  - surface events at low energy

- Threshold reduction by software

4 x 5 g ULEGGe

500gPCGe

Projected: CJPL at 1 cpkkd & 100-eV threshold
Pseudoscalar Candidates (axionlike)

Formula: Pospelov et al. PRD 78, 115012 (2008)

\[ R \approx \frac{1.2 \times 10^{19}}{A} g_{aee}^2 \left( \frac{m_a}{\text{keV}} \right) \left( \frac{\sigma_{\text{photo}}}{\text{bn}} \right) \text{ kg}^{-1}\text{day}^{-1} \]
China Jin-Ping Underground Lab (CJPL): WIMP searches

- 2500 m+ rock overburden
- Drive-in access in the Tunnel
Status & plans in CJPL

- 6X6X40 m Lab built (c/o THU): completed excavation
- Phase-I (2010.9-2011.3)
  - 20g ULE-HPGe detector @ CDUL
  - Shielding system construction
  - HPGe detector for radioactive measurement
  - Radon monitor system

First Step of construction: 6*6*40 m Lab.

Hall A Layout
Status and Plans

- Competitive limits at *WIMP-mass* < 10 GeV already obtained with Sub-keV Ge prototype at a shallow site, for both spin-independent and spin-dependent couplings.

- Further optimizations of experimental procedures, shielding configurations, and pulse shape analysis software, plus studies of systematic effects.

- Studies on background understanding, discrimination of surface and bulk events at *sub-keV* range.

- *Sub-keV* Ge quenching factor measurement & Ions Channeling effect at CIAE neutron facility in 2010.

- *Plan*: move to CJPL (>2 km rock) soon.

- *Goals*: open new detection channel and detector window for neutrino and dark matter physics.