

Neutrino & Dark Matter Physics with sub-keV Germanium Detectors

- Overview (Collaboration; Program)
- Facilities : KSNL & CJPL
- Detector & Physics: Highlights
- Dark Matter Results [*1303.0925 ; PRL13*]

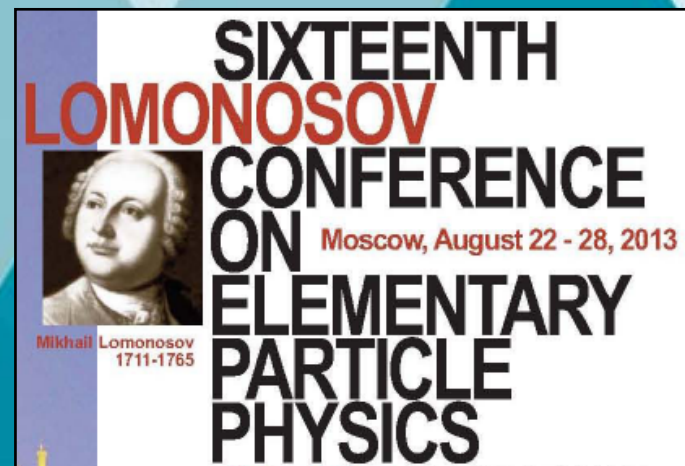
Henry T. Wong / 王子敬

Academia Sinica / 中央研究院

@



中国锦屏地下实验室
China Jinping Underground Laboratory



TEXONO Collaboration

TEXONO

Taiwan EXperiment On Neutrino [since 1997] :

⊙ Neutrino Physics at **Kuo-Sheng Reactor Neutrino Laboratory (KSNL)**

- **Taiwan** (AS, NTHU, INER, KSNPS)
- **China** (THU, CIAE, NKU, SCU)
- **Turkey** (METU)
- **India** (BHU)



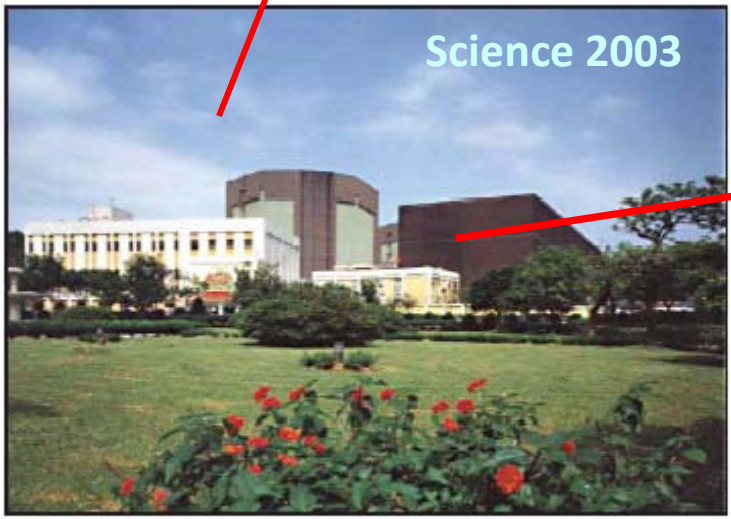
⊕ Partner in CDEX -1 Program [PI: THU]

⊙ O(1-kg) single-element Ge class Dark Matter Searches @

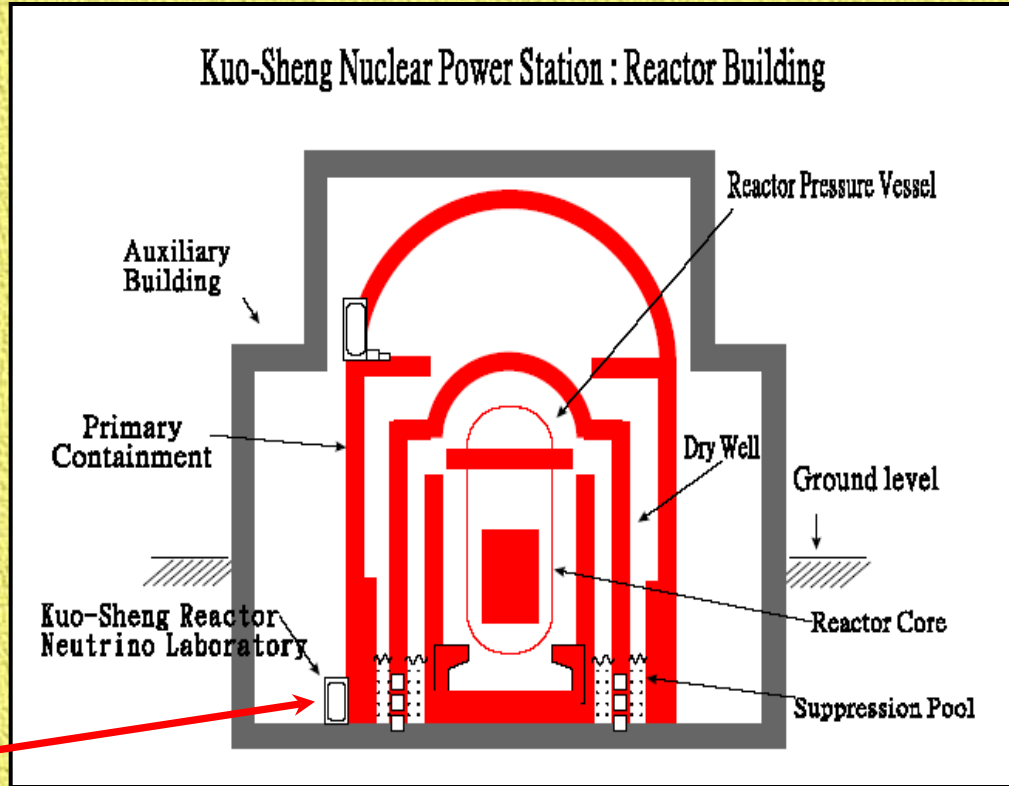


🏆 *Research Program:* Low Energy Neutrino and Dark Matter Physics

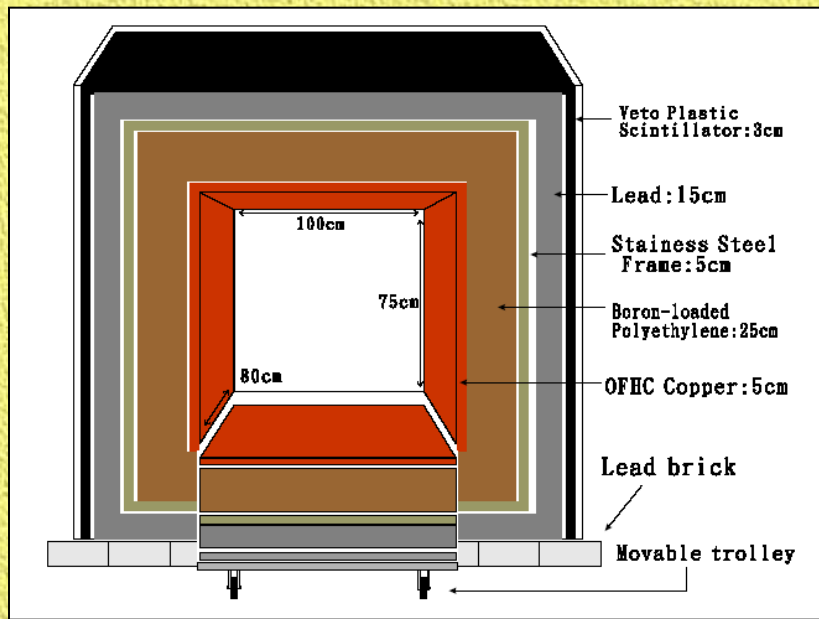
Kuo Sheng Reactor Neutrino Laboratory [KSNL]



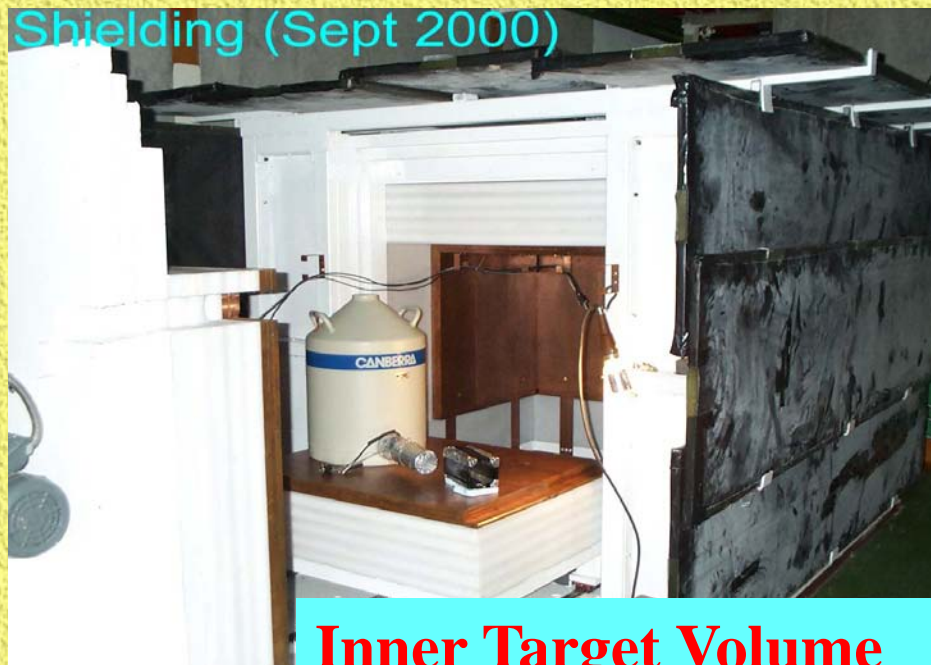
Powerful collaboration. Scientists from Taiwan and mainland China are studying neutrino emissions from this nuclear power plant outside Taipei.



- 28 m from core#1 @ 2.9 GW
- Shallow site : ~30 mwe overburden
- ~10 m below ground level



Front View (*cosmic vetos, shieldings, control room*)



Inner Target Volume

Configuration: Modest yet Unique

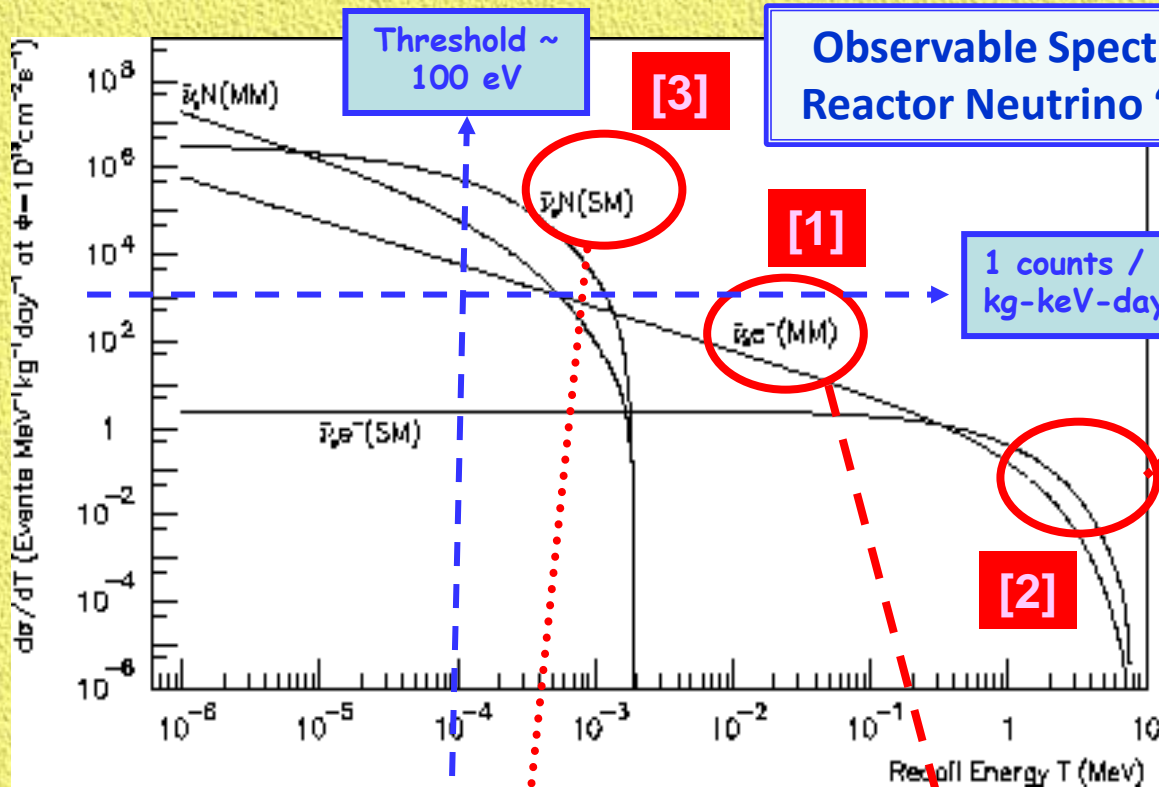
Flexible Design: Allows different detectors conf. for different physics

Neutrino Properties & Interactions at Reactor

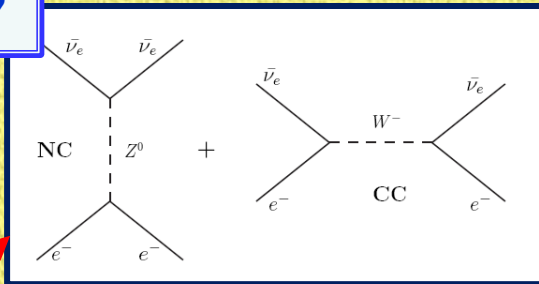
quality

Detector requirements

mass



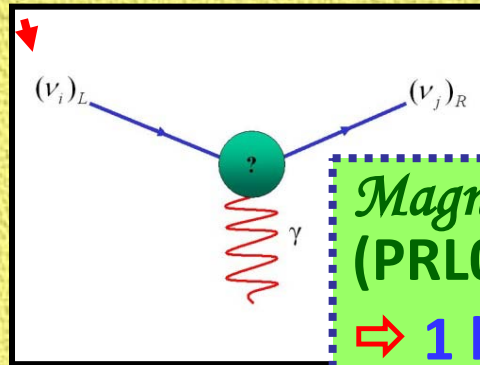
Observable Spectra with Reactor Neutrino "Beam"



SM & NSI/BSM νe Scattering
 (2 \otimes PRD10, PRD12)
 \Rightarrow 200 kg CsI(Tl)

νN Coherent Scattering

\Rightarrow Dark Matter Searches (PRD-RC09, PRL13)
 \Rightarrow sub-keV O(kg) ULEGe / PCGe



Magnetic Moments
 (PRL03, PRD05, PRD07)
 \Rightarrow 1 kg HPGe



Reactor Neutrino @ KSNL : Summary

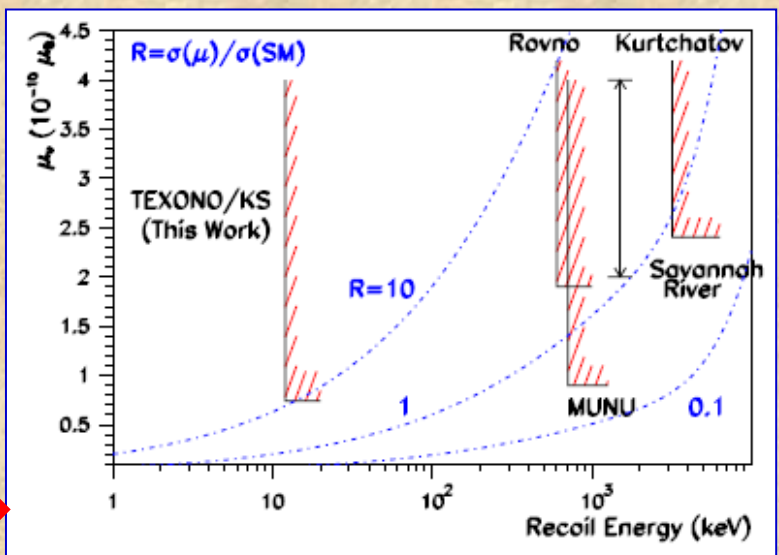
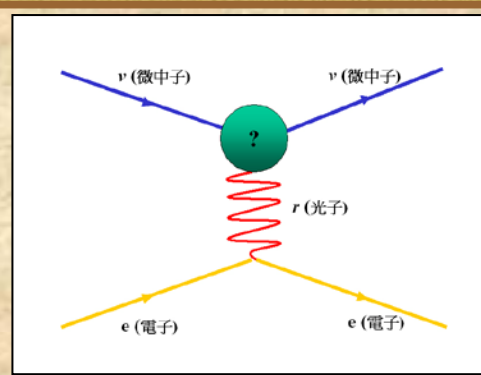
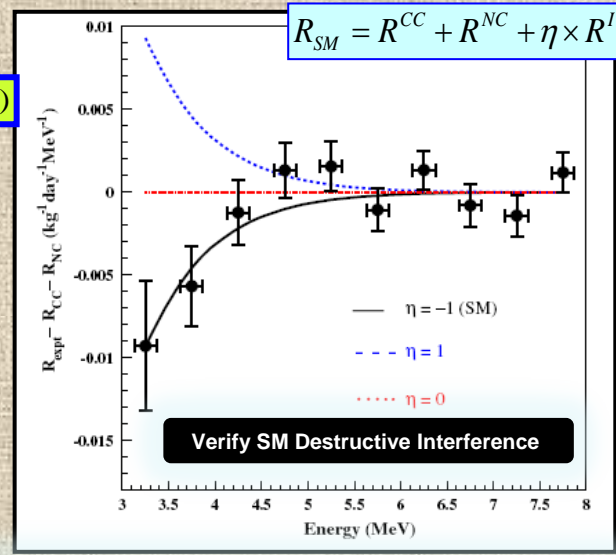
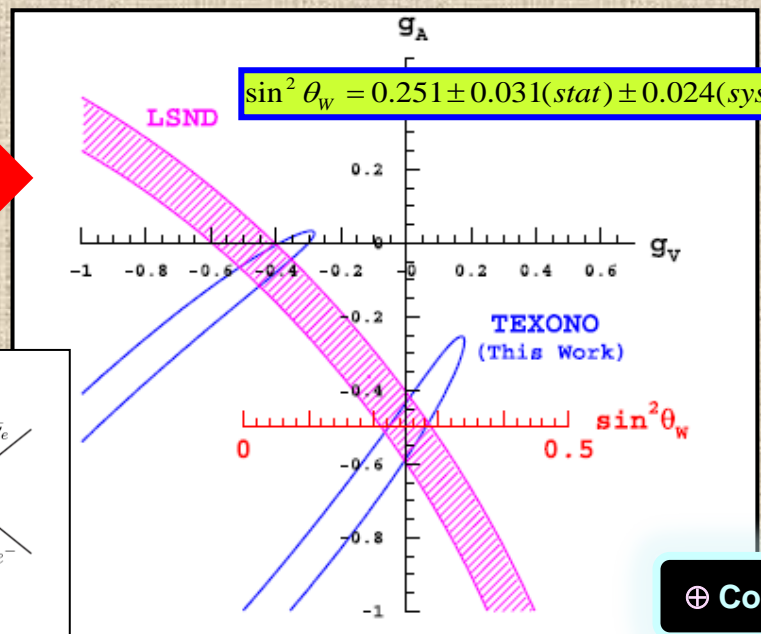
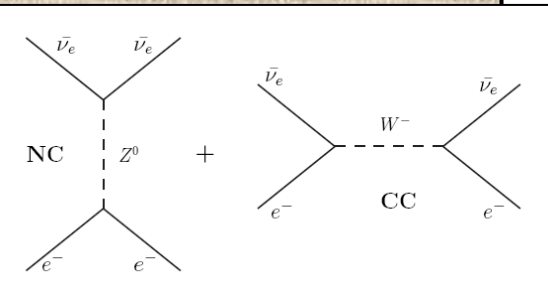


FIG. 14 (color online). Summary of the results in the searches of neutrino magnetic moments with reactor neutrinos. Both the limits and the detection thresholds of the various experiments are shown.



⊕ Constraints on Various Beyond SM Effects

Current Research Theme:

"sub-keV" Ge Detectors

🔦 **Physics Goals for $O[100 \text{ eV threshold} \oplus 1 \text{ kg mass} \oplus 1 \text{ cpkkd}]$ detector :**

- ⊙ νN coherent scattering
- ⊙ Low-mass WIMP searches
- ⊙ Improve sensitivities on neutrino magnetic moments
- ⊙ Implications on reactor operation monitoring
- ⊙ Open new detector window & detection channel available for surprises

Baseline Hardware Design

p- PCGe
[500g – 1 kg]

p^+

n^+ (~1mm Li diffused)

900 g

4x5g ULEGe

P+ Proprietary Implanted Contact

Passivated Surface

N+ (Li-diffused) Contact

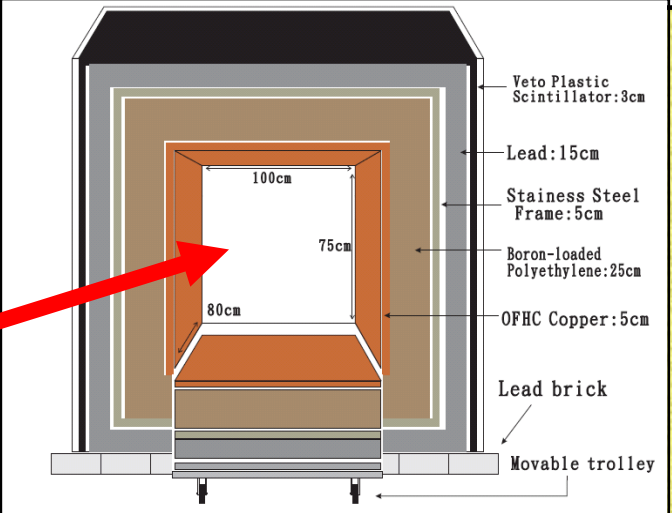
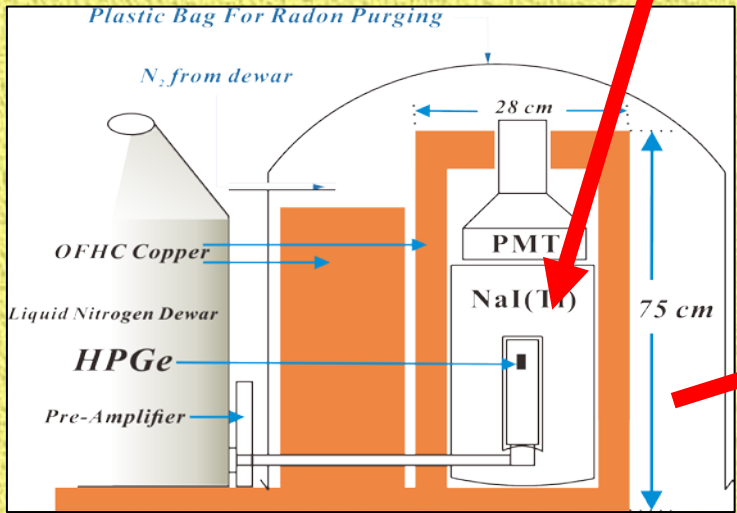


n- PCGe
[500 g]

n^+

p^+ (~0.5 μm Boron implanted)

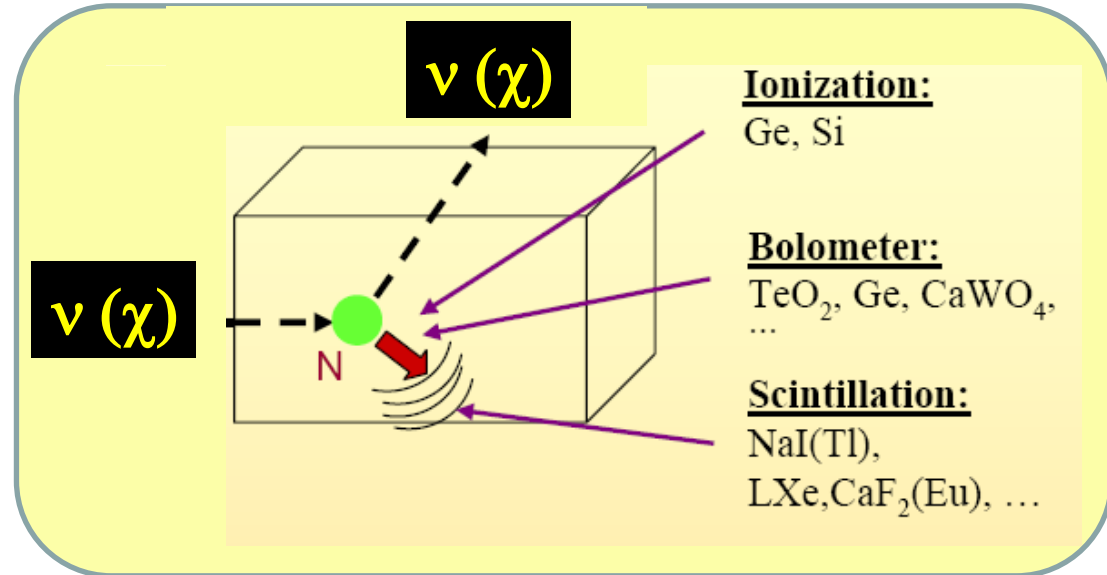
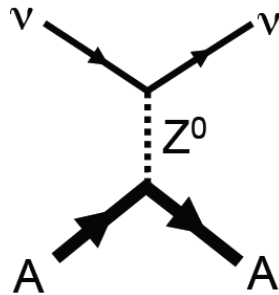
500 g



Neutrino-Nucleus Coherent Scattering :

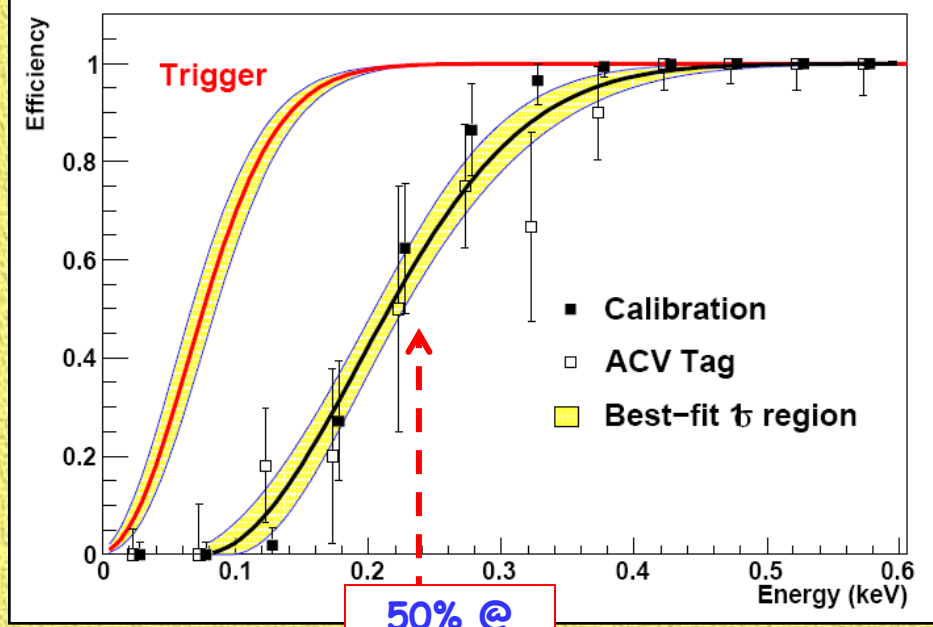
Standard Model allowed and predicted processes :

$$\nu + A \rightarrow \nu + A$$

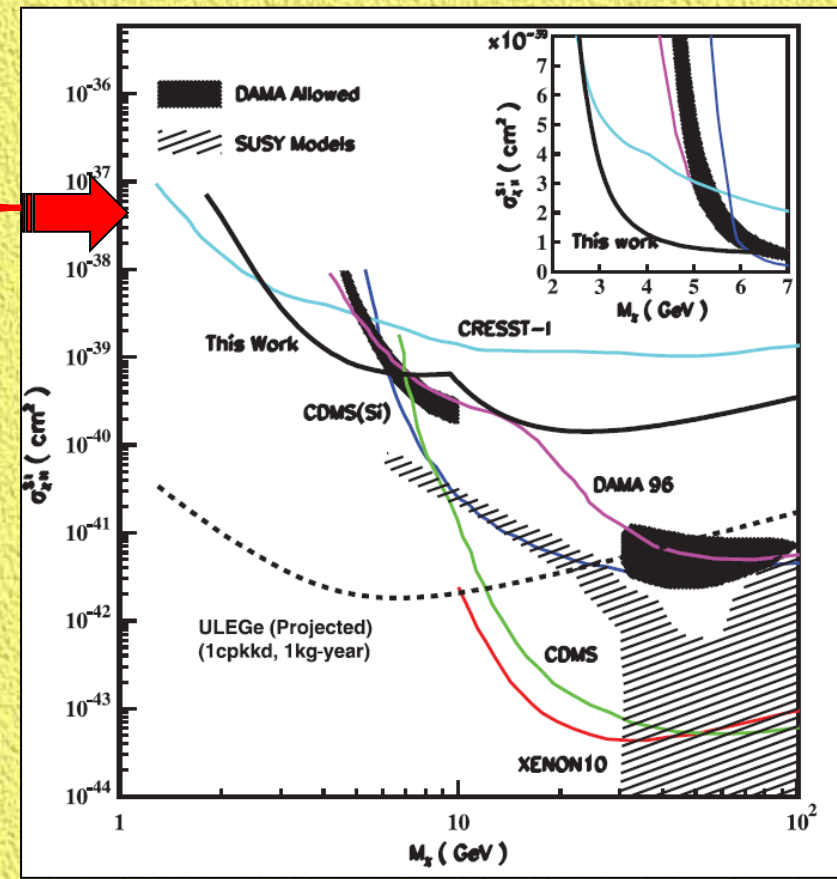
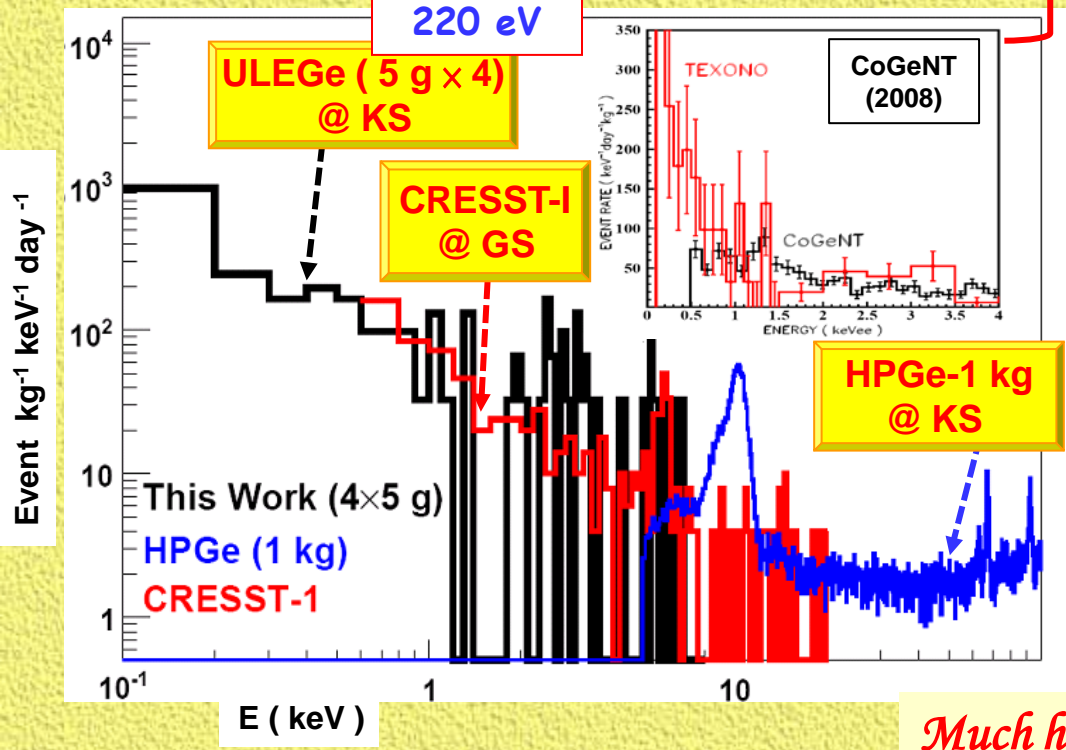


- Neutral current process (same for all ν -flavor)
- $\sigma \propto N^2$ @ $E_\nu < 50$ MeV
⇒ “Coherent” [probe “sees” the whole nucleus]
- sensitive probe for **BSM** ; interest in reactor monitoring
- important process in **stellar collapse & supernova explosion**
- analogous interaction used in **dark matter detection**
- **Ge at KSNL @ QF~0.2 : cut-off ~ 300 eV ;**
Rate ~10 kg⁻¹ day⁻¹ @ threshold~100 eV

TEXONO @ KSNL : Threshold & Efficiencies & Background for 20g ULEGe (2007)



50% @
220 eV

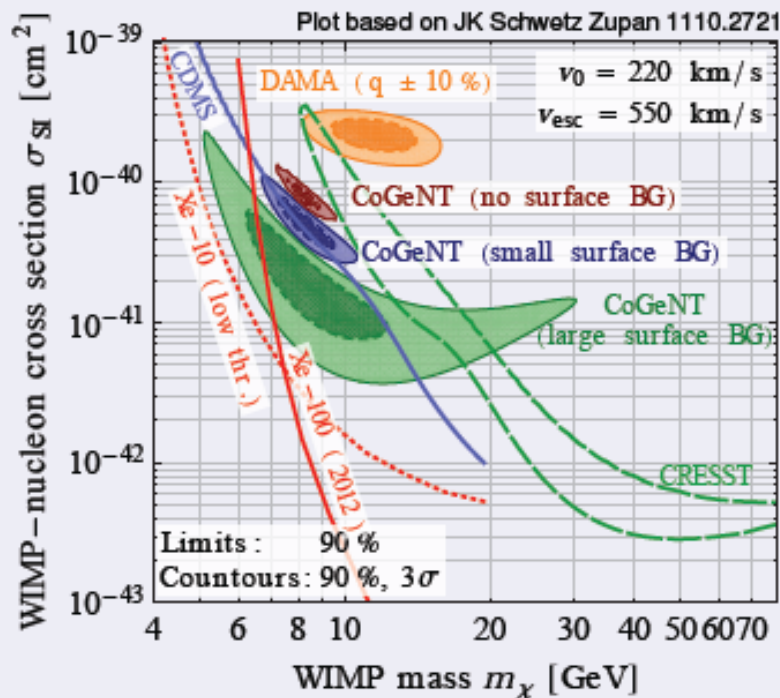


Much has happened world-wide since

Hints for light dark matter

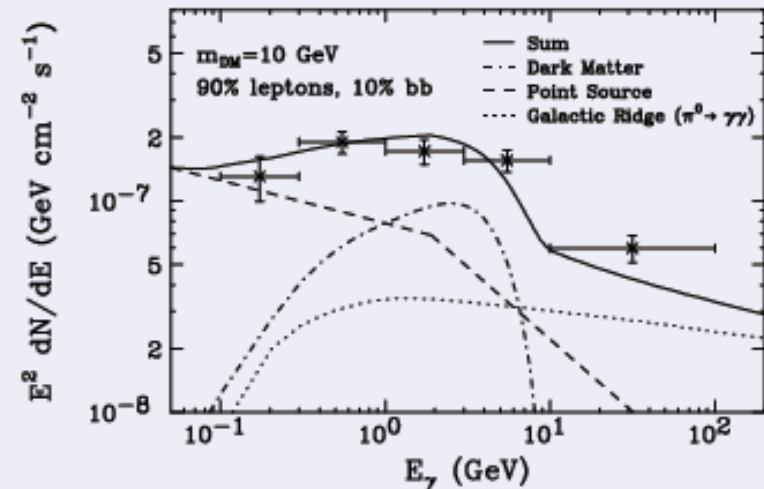
J. Kopp @ IDM12

On the Earth ...



- Several intriguing direct detection signals
- But **severe tension** with null results

... and in the skies



- An tentative γ ray excess from the Galactic Center

Hooper Goodenough 0912.2998, 1010.2752, [1201.1303](#)

► Morphology \neq point source






- Radio filaments

Linden Hooper Yusef-Zadeh 1106.5493

- Isotropic radio background

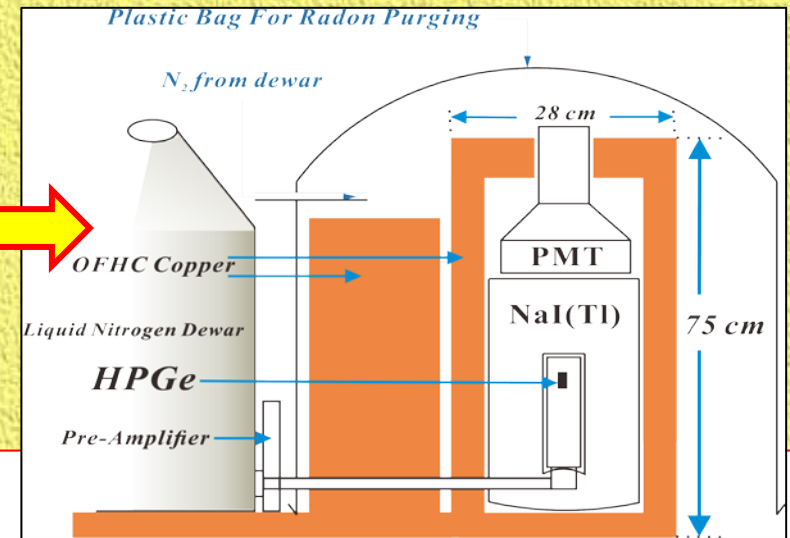
Hooper Belikov Jeltema Linden Profumo Slatyer 1203.3547

Sub-keV Ge Detector Techniques : R&D Items

-  **Quenching Factors -- nuclear recoils' Ionization Yields**
-  **Energy Definition & Calibration**
-  **Trigger Efficiencies near threshold**
-  **Physics Vs Noise Pulse-Shape Selection -- algorithms & efficiencies**
-  **Bulk Vs Surface Events Selection – algorithms & efficiencies**

Configurations:

- * 39.5 kg-days of data @ KSNL
- * Baseline design with NaI(Tl) AC & active CR vetos
- * PPCGe , 840 g fiducial mass
- * Analysis above electronic noise edge of 500-eV

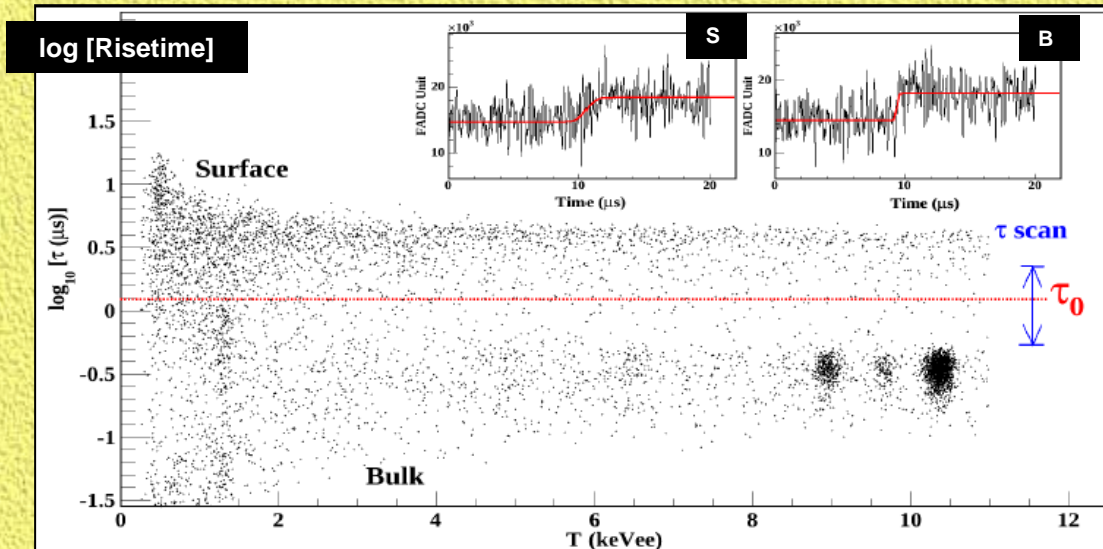
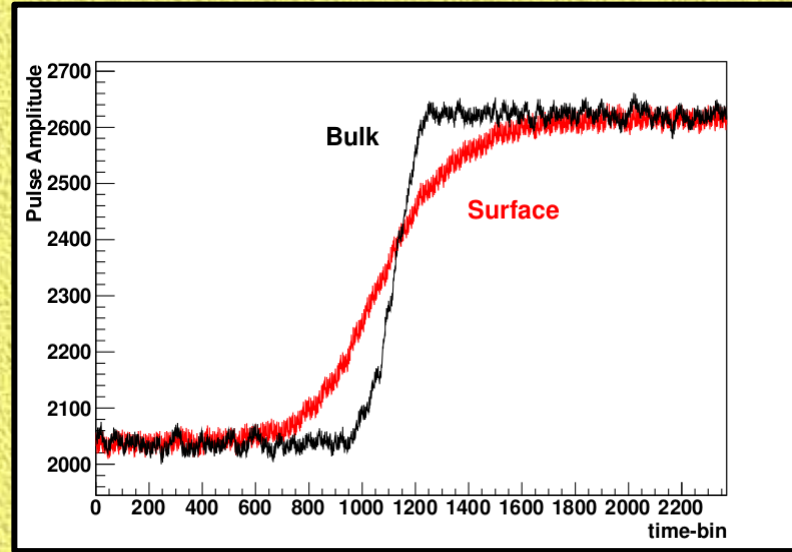


Selection Criteria:

- ✂ Physics Vs Electronics Noise (PN) – pulse shape
- ✂ Anti-Compton vetos (ACV) – NaI(Tl)
- ✂ Cosmic-Ray vetos (CRV) – plastic scintillators
- ✂ Bulk Vs Surface Cut (BS) – pulse shape

PSD for Surface Vs Bulk Events @ PCGe

- n+ "inactive layer" is not totally dead; signals finite but slower rise time
- ACV+CRT events (neutron rich) samples do not show surface band
- Understand/Measure Efficiencies and Suppression Factors

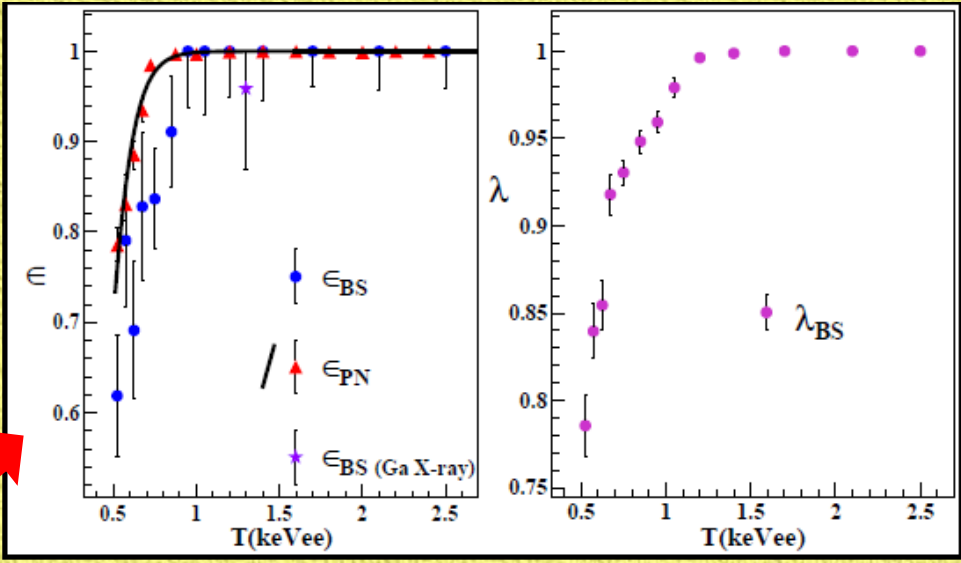
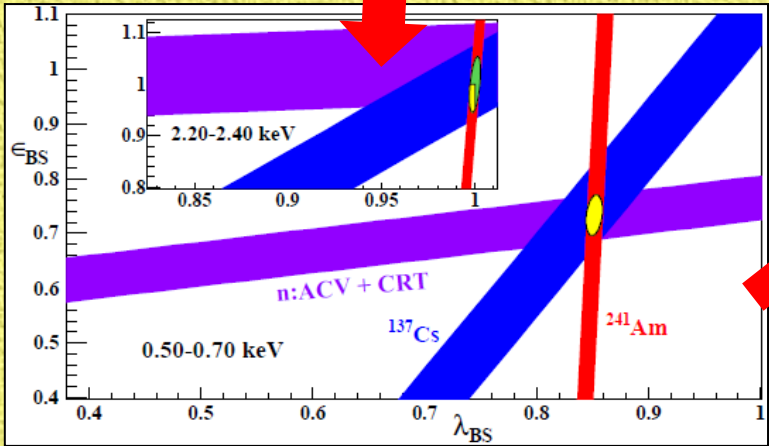
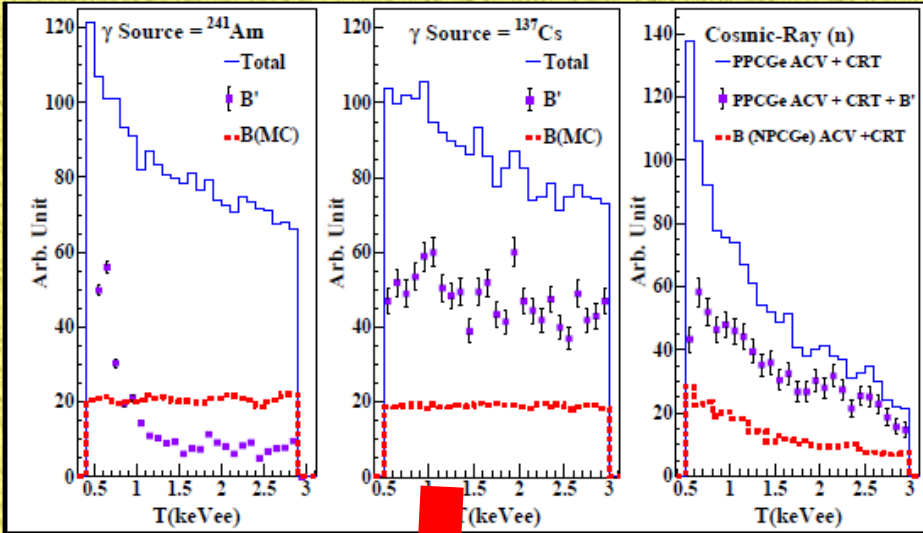


Valid scheme should produce physics rates insensitive to location

Three complementary [different depth distributions] calibration data:

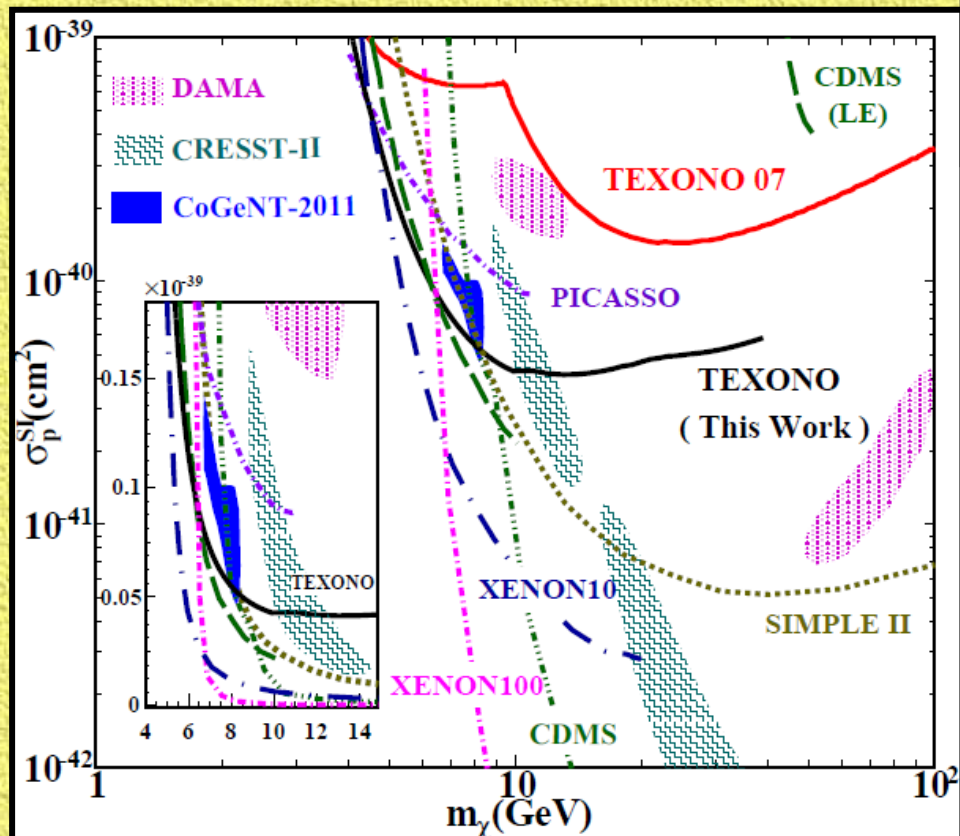
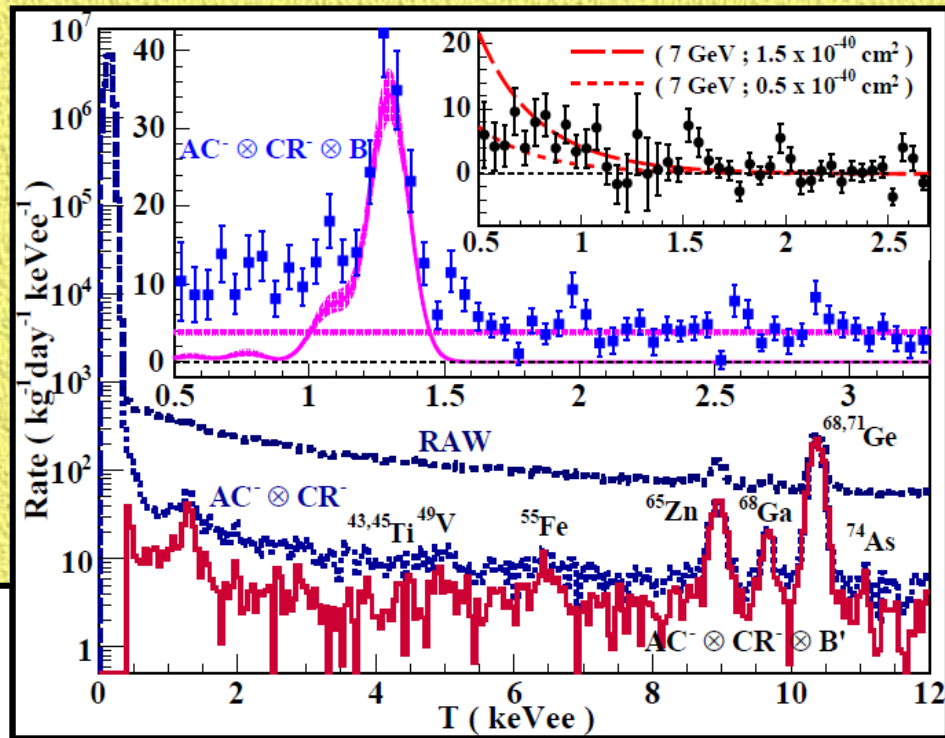
- ✓ Very Surface-rich **low-energy γ** (^{241}Am , 60 keV) ; B=simulation
- ✓ Surface-rich **high-energy γ** (^{137}Cs , 660 keV) ; B=simulation
- ✓ Bulk-rich cosmic-induced **high energy neutrons** by ACV+CRT tagging ; B=same tag from NPCGe

“Calibration” \equiv measure energy-dependent signal-retaining (ϵ_{BS}) & background-suppressing (λ_{BS}) efficiencies



“Candidate Events” = $AC \otimes CR \otimes B$

- $ACV+CRV+B'$ + $(\varepsilon_{BS}, \lambda_{BS})$ correction
- insensitive to exact BS-cut location
- Subtract flat γ background & L-X-ray
- \boxminus not-yet-accounted-for sub-keV events



TEXONO 1303.0925:

- 🏆 New limits probed and excluded some of the low-mass WIMP allowed regions implied by other experiments.
- 🏆 Provide probable explanations to CoGeNT-2011's excess

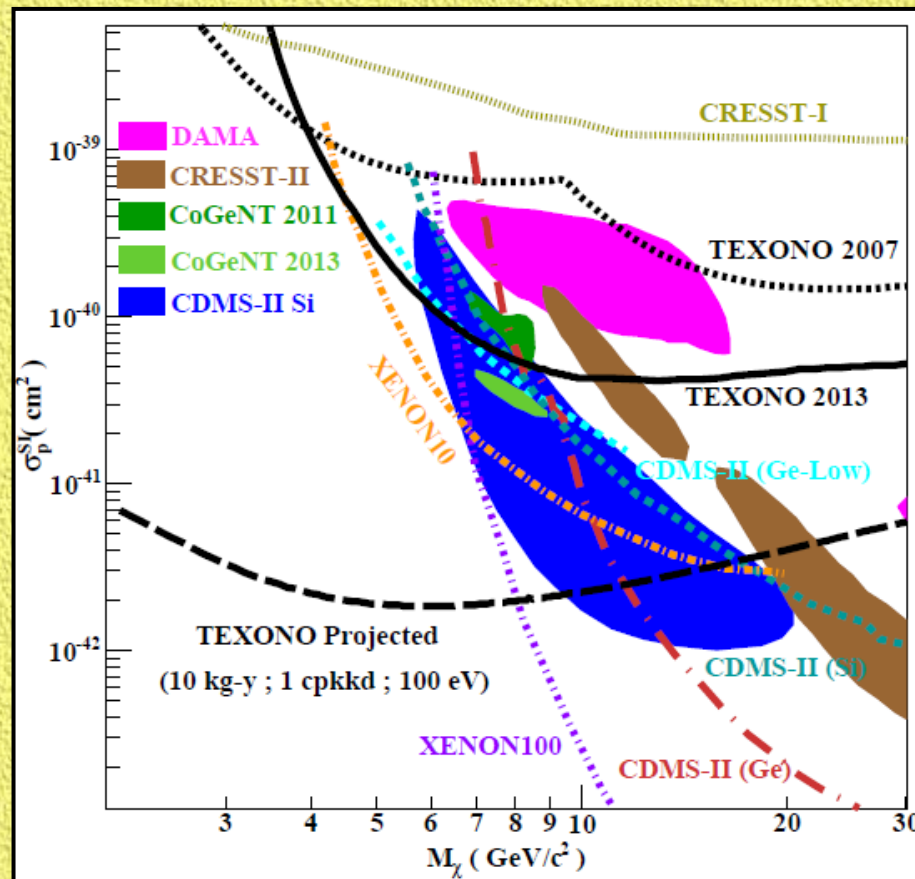
New Development

☑ **CoGeNT – April 2013** [1208.5737v3 ; PRD13]

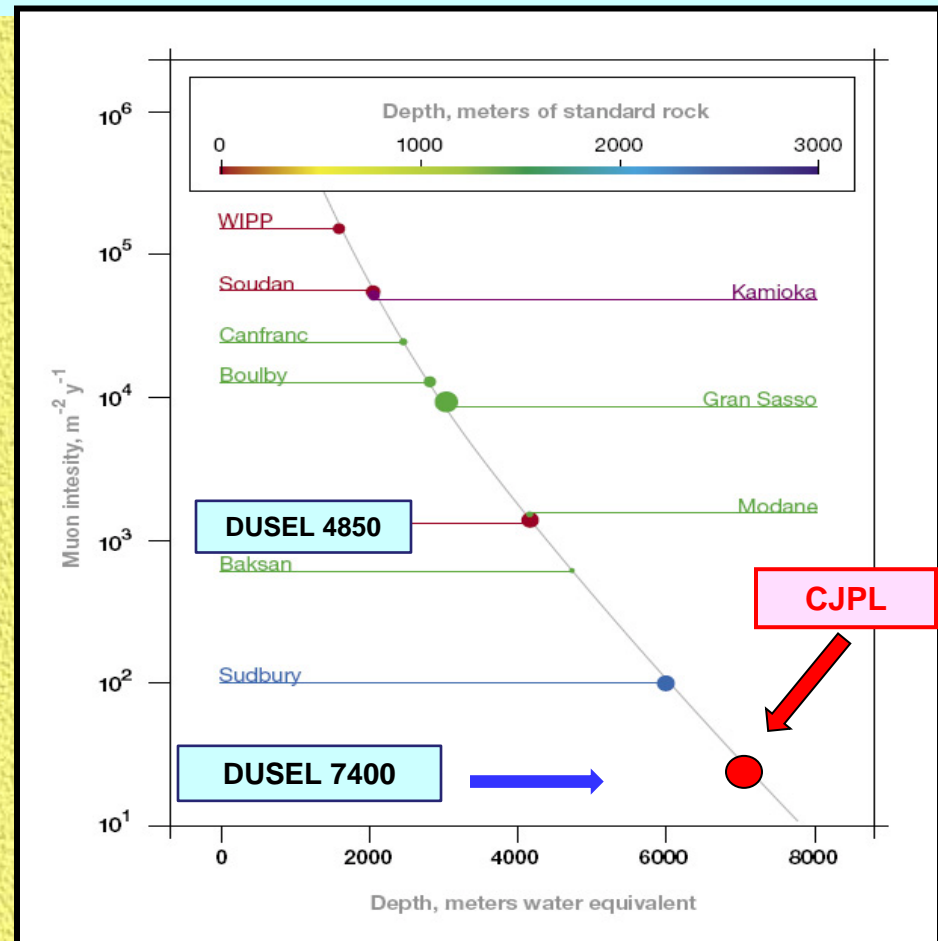
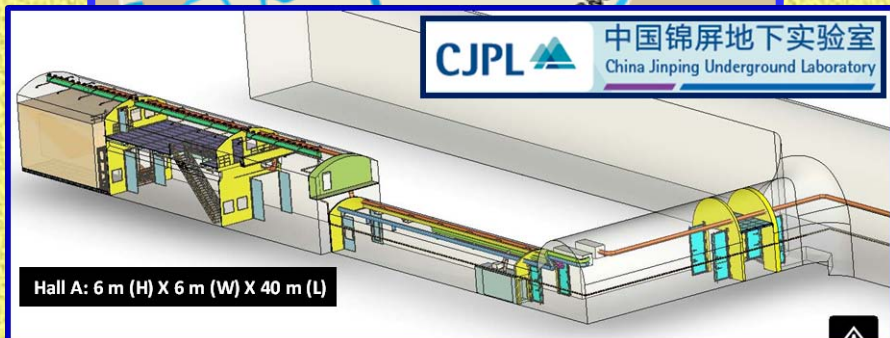
↪ Revised Allowed region (wrt PRL-2011) with surface background subtraction due to $\lambda_{BS} < 1$

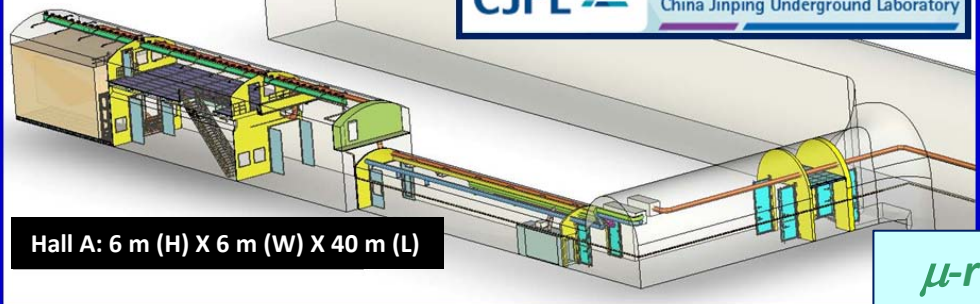
☑ **CDMS-II (Si)** [1304.4279] :

↪ 3 events observed out of 0.7 expected background !!



- ◎ 2400+ m rock overburden, drive-in road tunnel access
- ◎ 6X6X40 m cavern constructed [managed by THU & EHDC]
- ◎ **CDEX-1** Dark Matter Program Started ; **Panda-X** Experiment under preparation

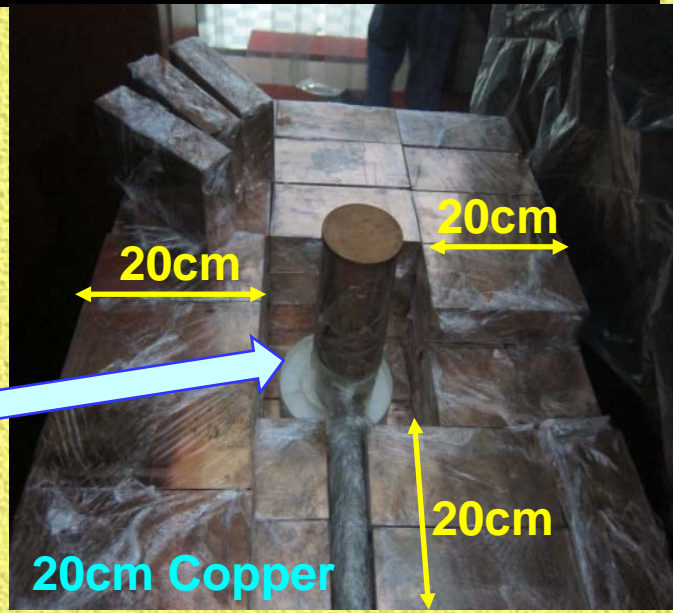
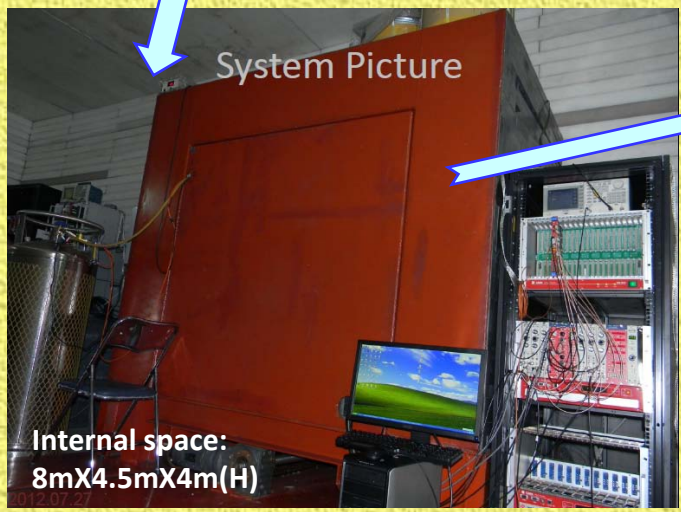




μ -rate ~ 6 per m² per month

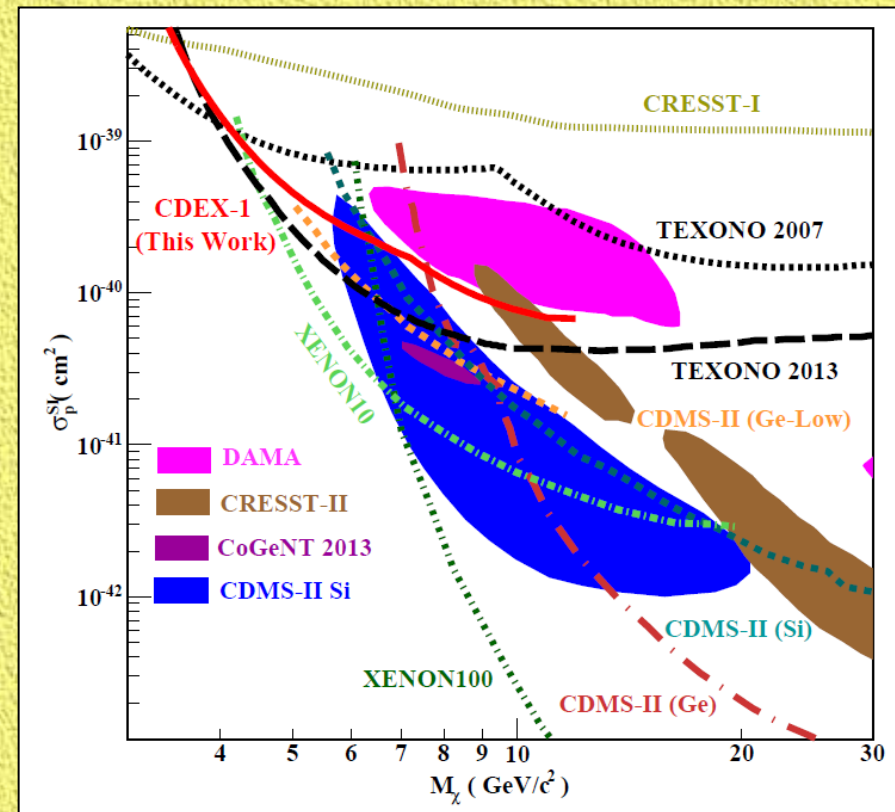
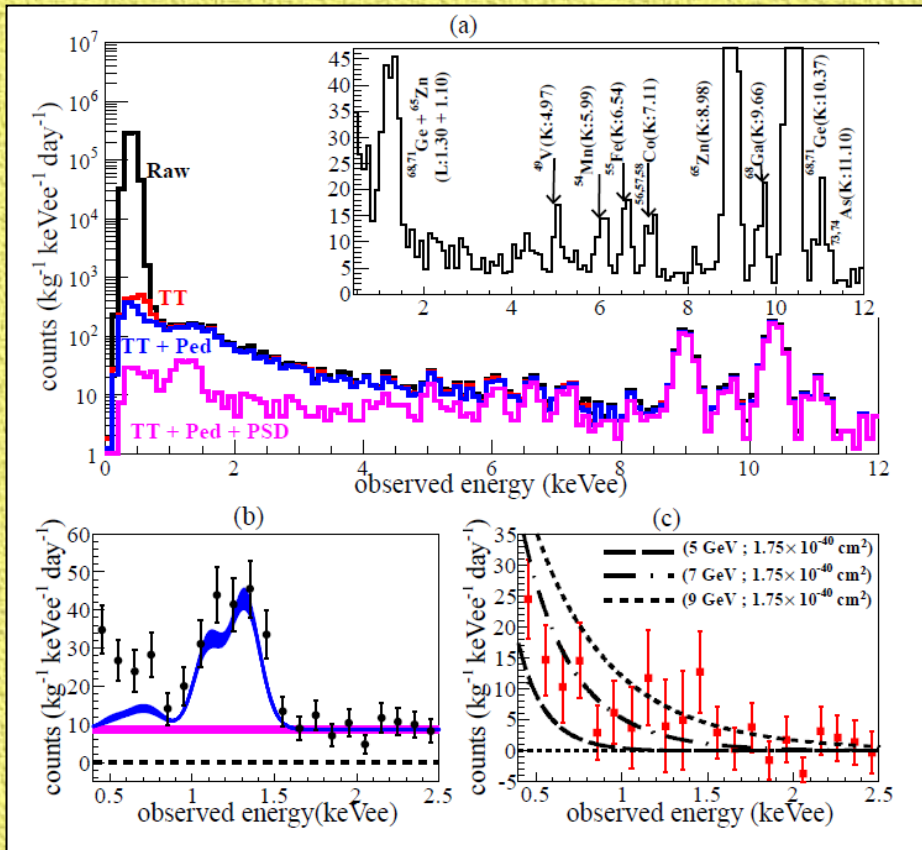
CDEX-1 Data Taking @ CJPL :

- 🚩 Adopt KSNL Baseline Design
- 🚩 Engineering Run 2011
- 🚩 Physics Run June 2012



First “No-Cut” Results of CDEX-1 @ CJPL [arXiv: 1306.4135]

- ✓ **TEXONO “Baseline Design”**
- ✓ **14.6 kg-days data ; fiducial mass 994 g PPCGe**
- ✓ **ONLY timing & pulse shape selection**
- ✓ **PRIOR TO anti-Compton veto & Bulk-Surface Selection**



Summary & Prospects



- Competitive and relevant results on low-mass WIMPs with sub-keV Ge detector, *even at* a surface location
- Same design at underground laboratory (CDEX-1 @ CJPL) can only be better
- more matured now to return to original goal
 - ◎ νN coherent scattering