

[Neutrino &] Dark Matter Physics with sub-keV Germanium Detectors

- Overview (Collaboration; Program)
- China Jinping Underground Laboratory (CJPL)
- Highlights on Light WIMPs
- sub-keV Ge Detectors for Low-Mass WIMP Searches
- Prospects & Outlook



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Academia Sinica / 中央研究院

December 2012

@

CJPL 

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

3rd International Workshop on

Dark Matter, Dark Energy and Matter-Antimatter Asymmetry

暗物質、暗能量及物質-反物質不對稱

TEXONO-CDEX Collaboration

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

TEXONO

Taiwan EXperiment On Neutrino

[since 1997] :

A Zero-Background Experiment !!

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

- Taiwan (AS, NTHU, INER, KSNPS)
- Turkey (METU)
- India (BHU)



CDEX

China Dark Matter EXperiment

[birth 2009] :

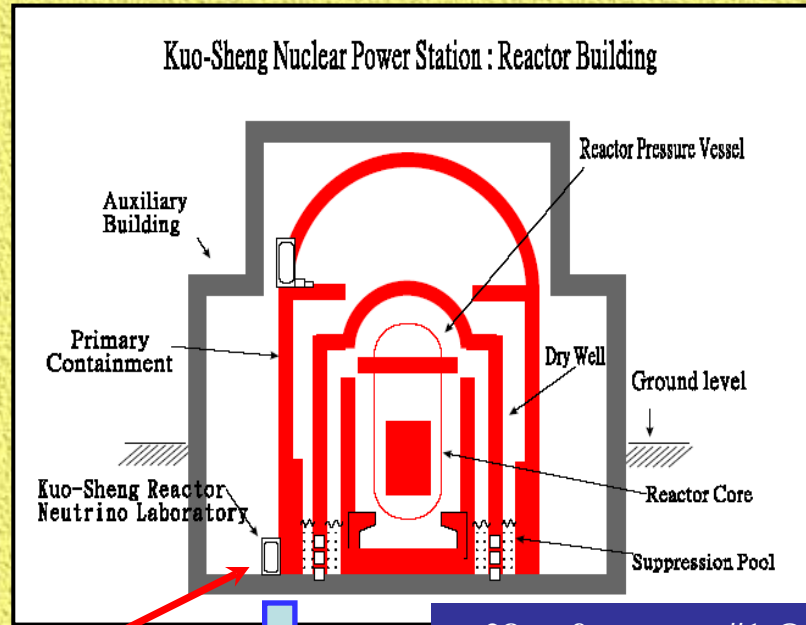


⊙ Dark Matter Searches at **China Jin- Ping Underground Laboratory (CJPL)**

- China (THU, CIAE, NKU, SCU, YLJHD)

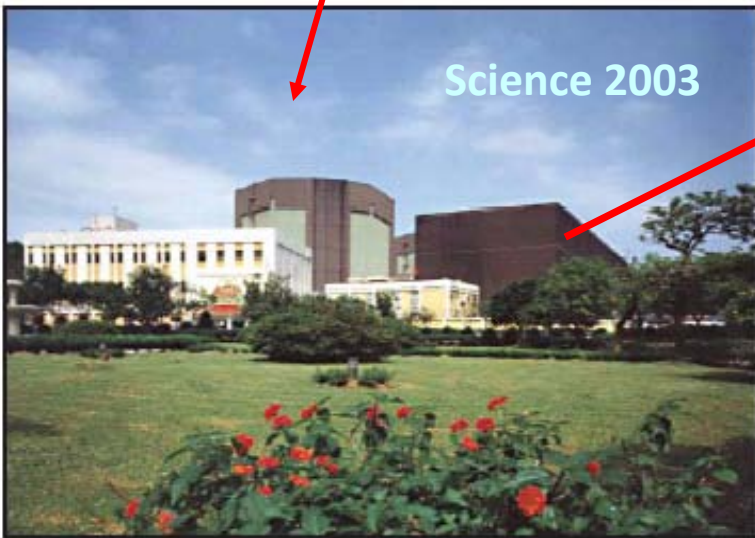


Kuo Sheng Reactor Neutrino Laboratory (KSNL)



28 m from core#1 @ 2.9 GW

Science 2003



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

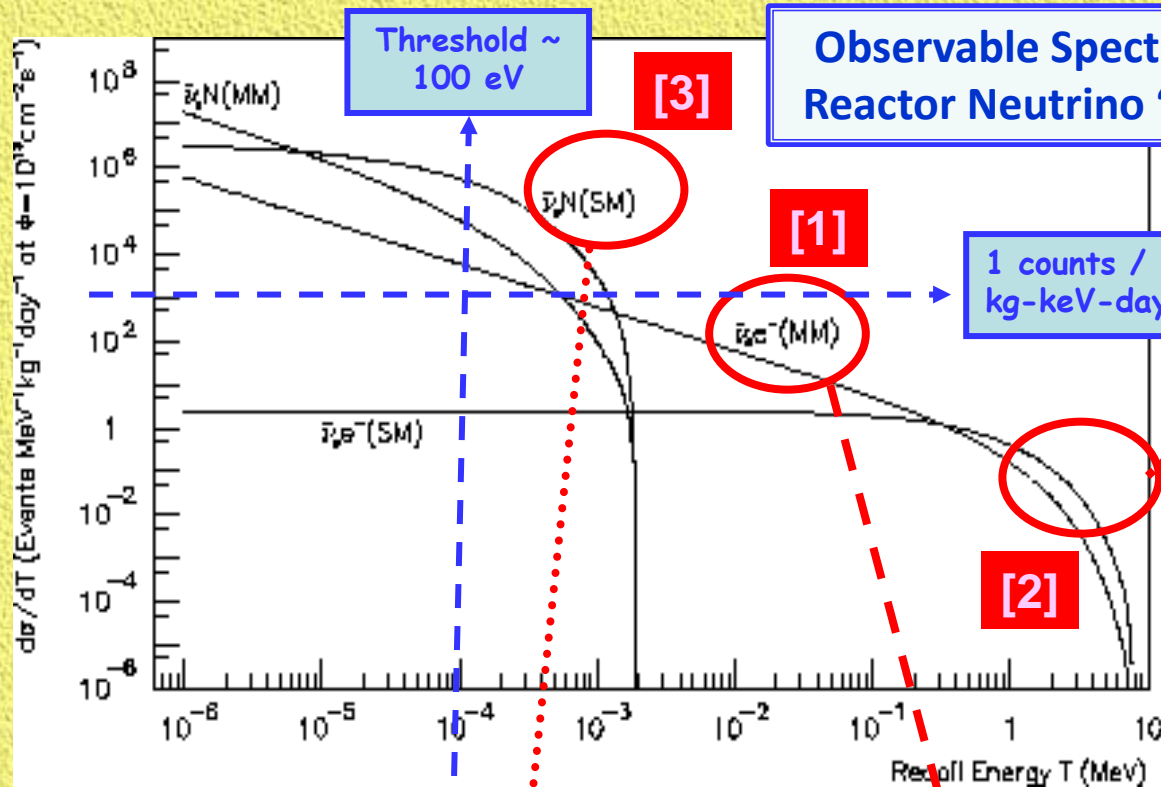


Neutrino Properties & Interactions at Reactor

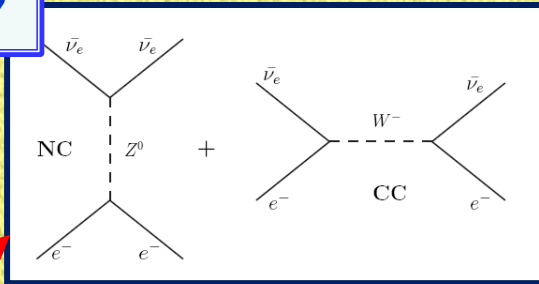
quality

Detector requirements

mass



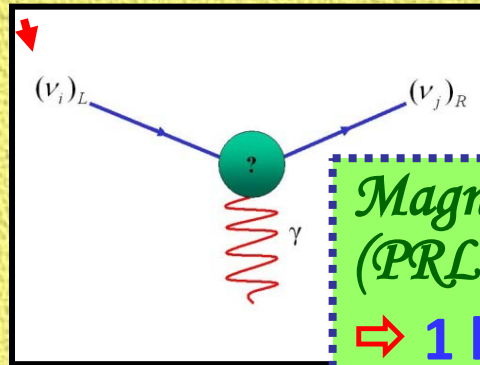
Observable Spectra with Reactor Neutrino "Beam"



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

νN Coherent Scattering

⇒ Dark Matter Searches (PRD-RC09)
⇒ sub-keV O(kg) ULEGe / PCGe



Magnetic Moments
(PRL03, PRD05, PRD07)
⇒ 1 kg HPGe

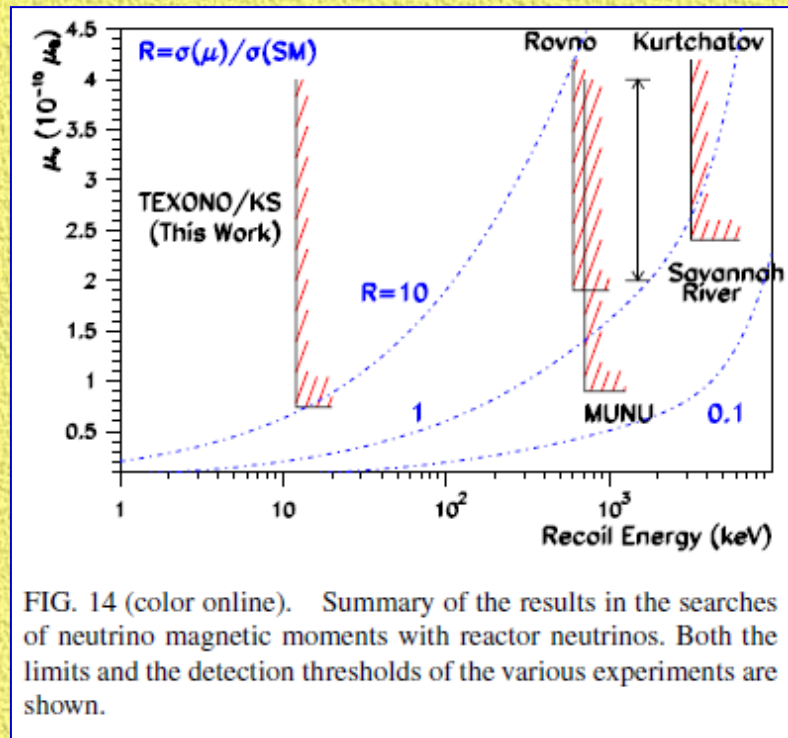
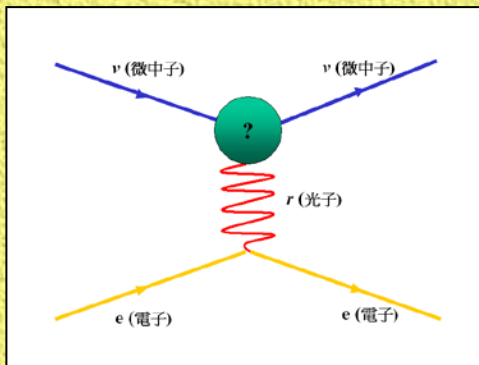
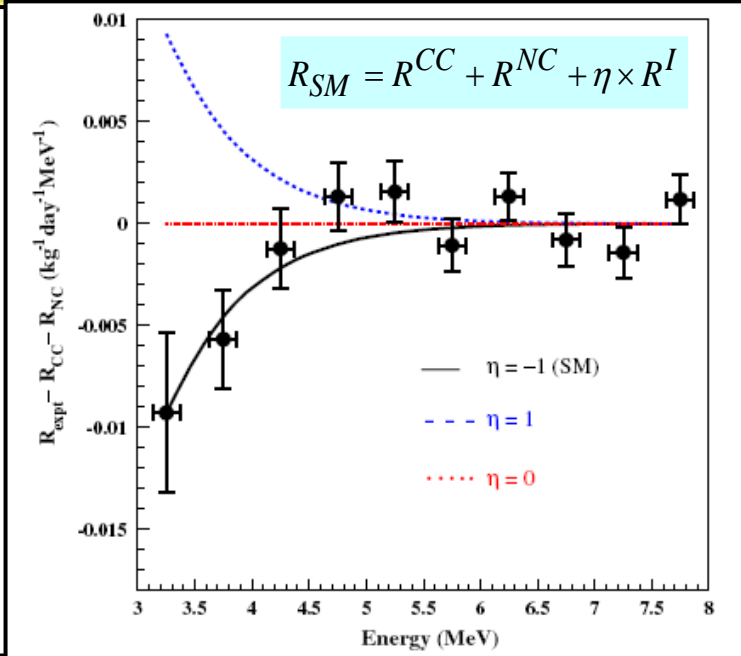
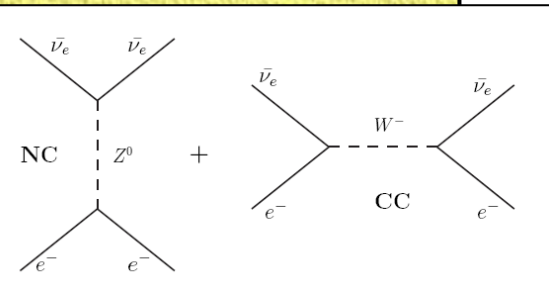
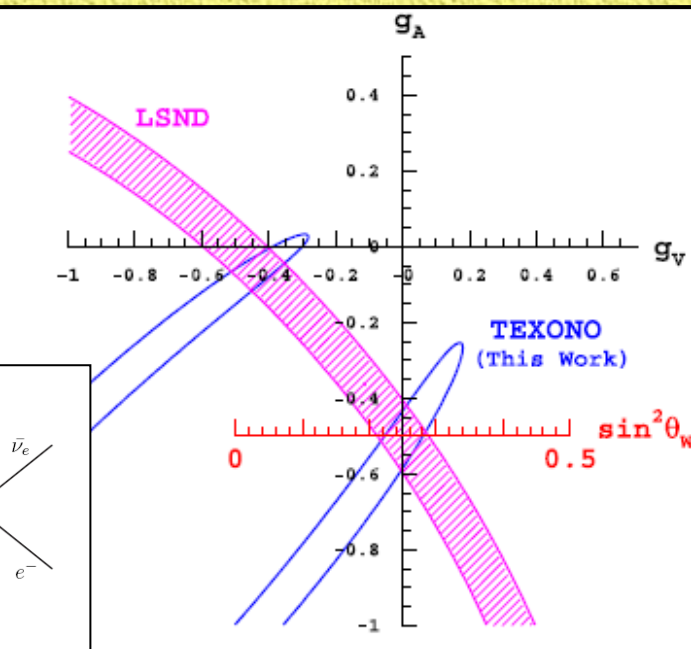


FIG. 14 (color online). Summary of the results in the searches of neutrino magnetic moments with reactor neutrinos. Both the limits and the detection thresholds of the various experiments are shown.



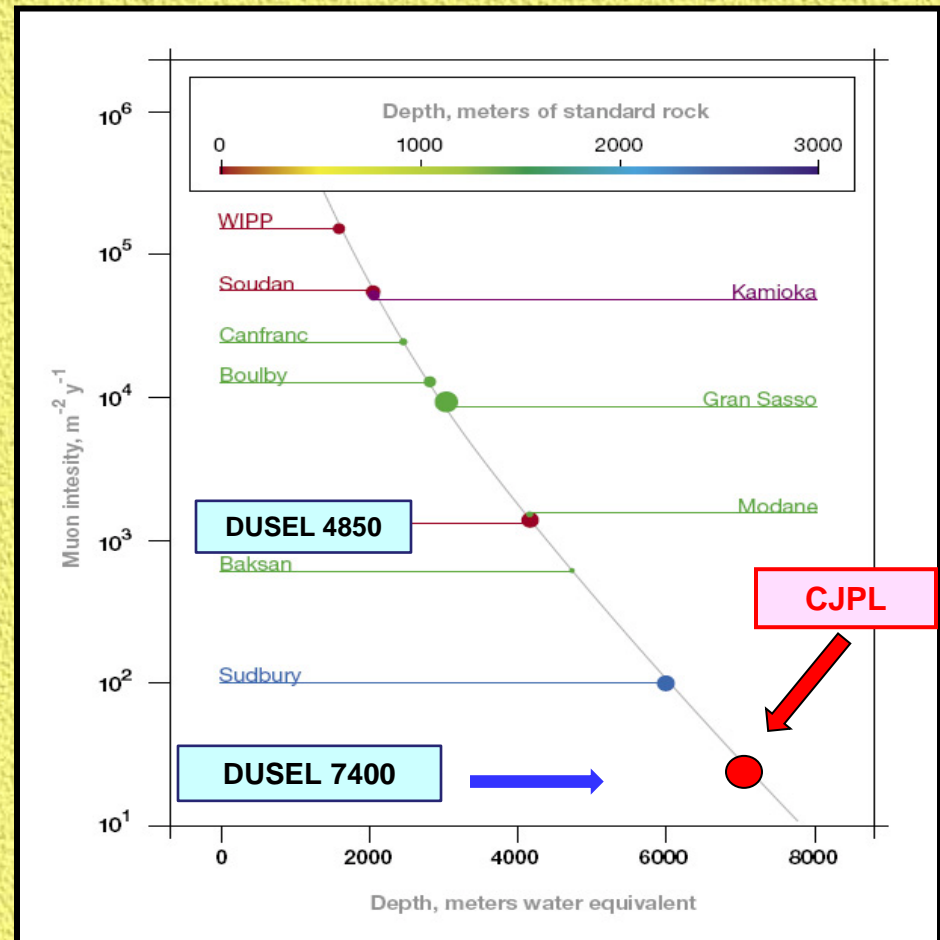
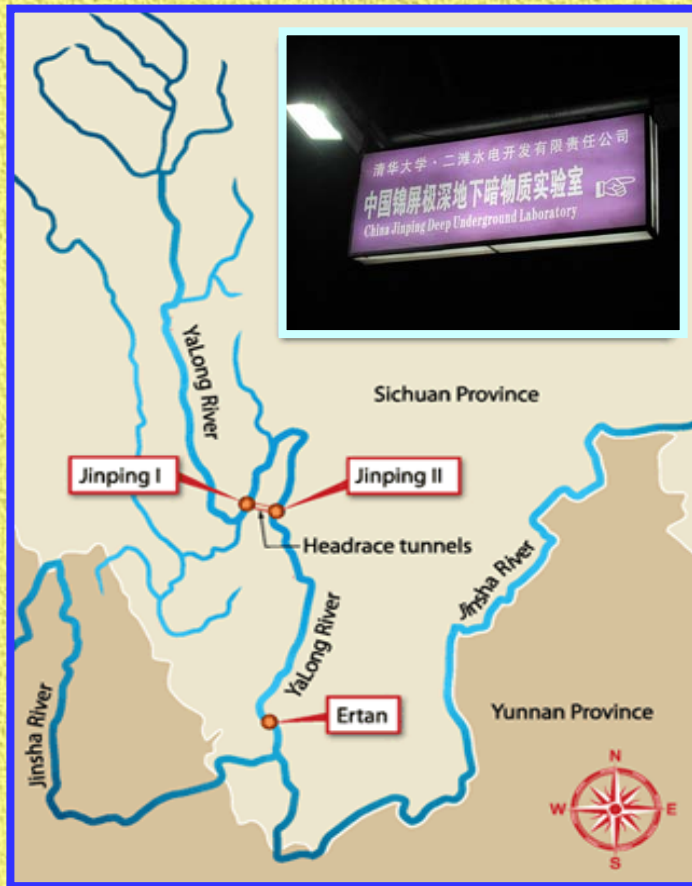
Current Research Theme:

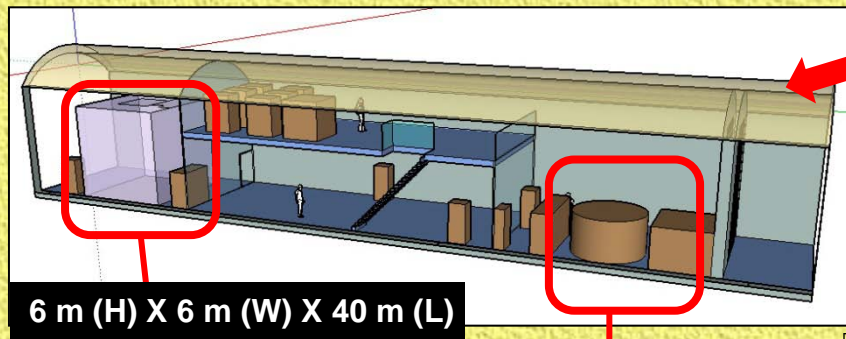
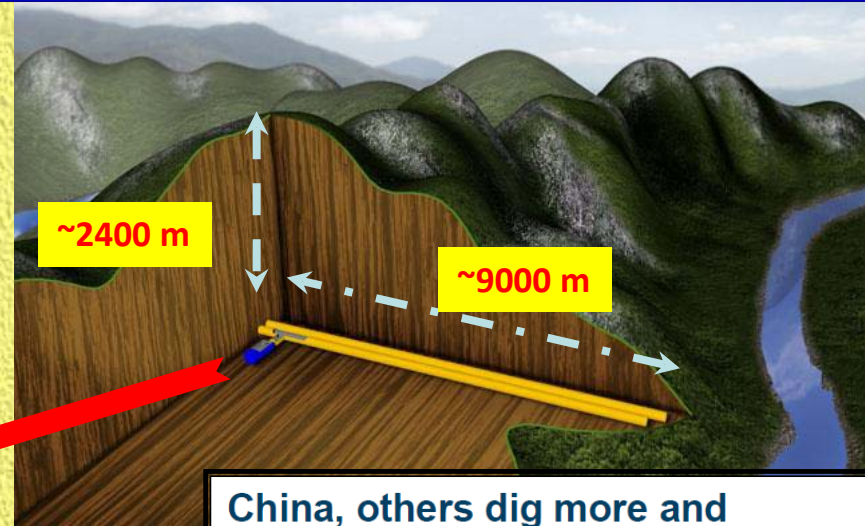
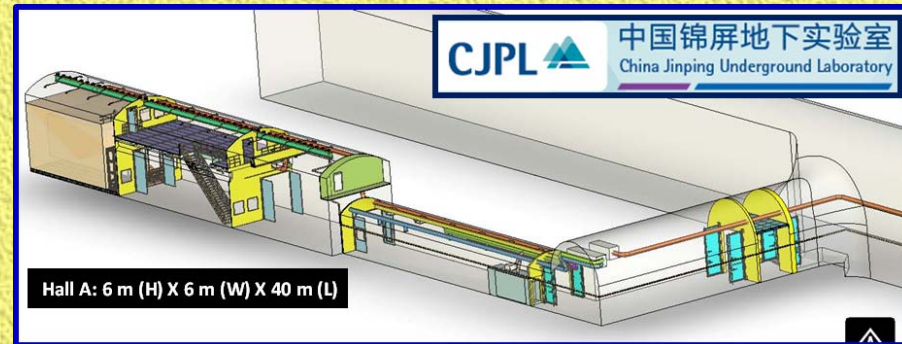
"sub-keV" Ge Detectors

🔦 **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

- ◎ 2400+ m rock overburden, drive-in road tunnel access
- ◎ 6X6X40 m cavern constructed [managed by THU & EHDC]
- ◎ CDEX-TEXONO Dark Matter Program Started





CDEX-TEXONO

PandaX

China, others dig more and deeper underground labs

From tiny to gargantuan, experiments are in the works to exploit the shielding from cosmic rays that being deep underground offers.

Physics Today September 2010

PARTICLE PHYSICS:
Chinese Scientists Hope to Make Deepest, Darkest Dreams Come True

Dennis Normile

Science 5 June 2009:
Vol. 324, no. 5932, pp. 1246 - 1247
DOI: 10.1126/science.324_1246

二滩水电开发有限责任公司 清华大学
战略合作协议签字仪式

2009年5月



THU-EHDC MoU 2009/5/8

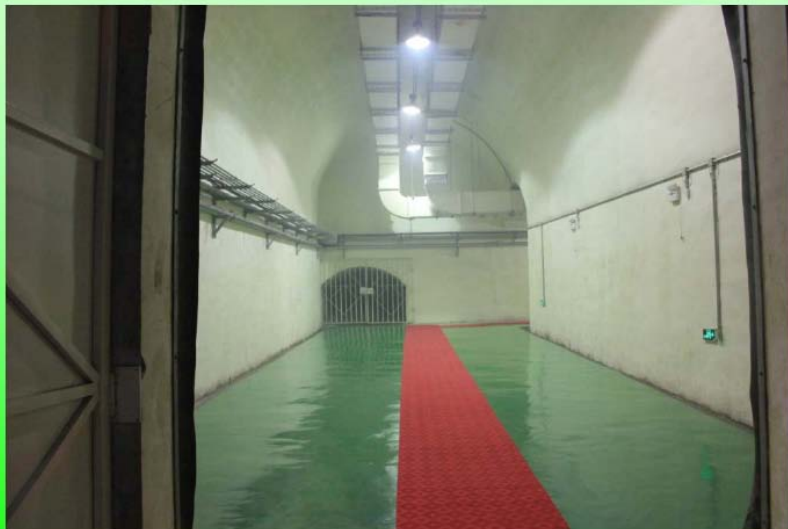


CJPL Excavation
2009/7 — 2010/4

2010/01/27

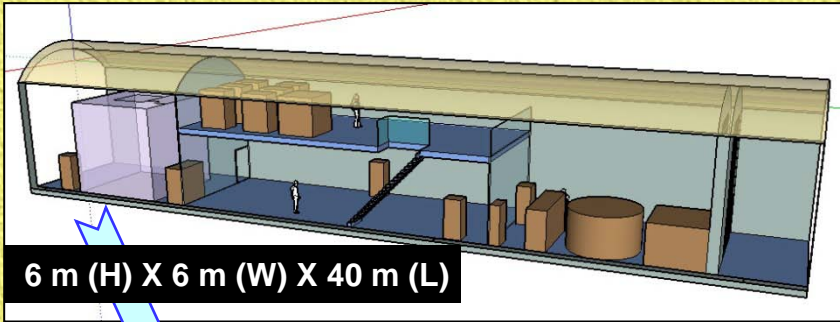
2010/04/24

Civil Engineering Completed 2010/6/12

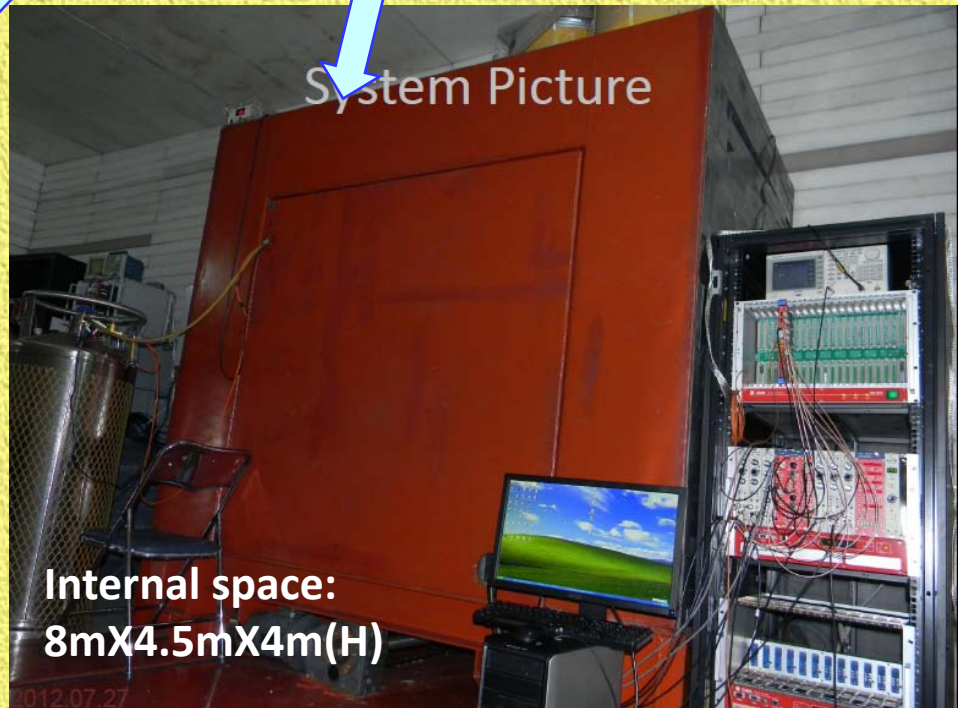


Inauguration Ceremony 2010/12/11

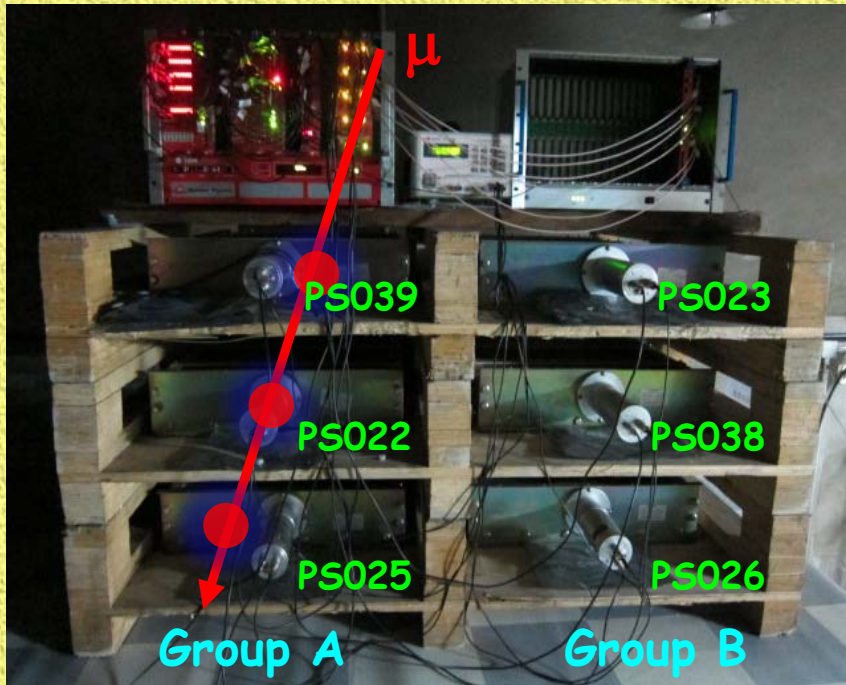
**CJPL Hall A:
Commissioning 2010/9/27
Ventilation Completed 2012/1**



1 m thick
PE House



Cosmic Ray Telescope



First Triple Coincidence Event

Date: 2010/12/02

Time: 04:49:19

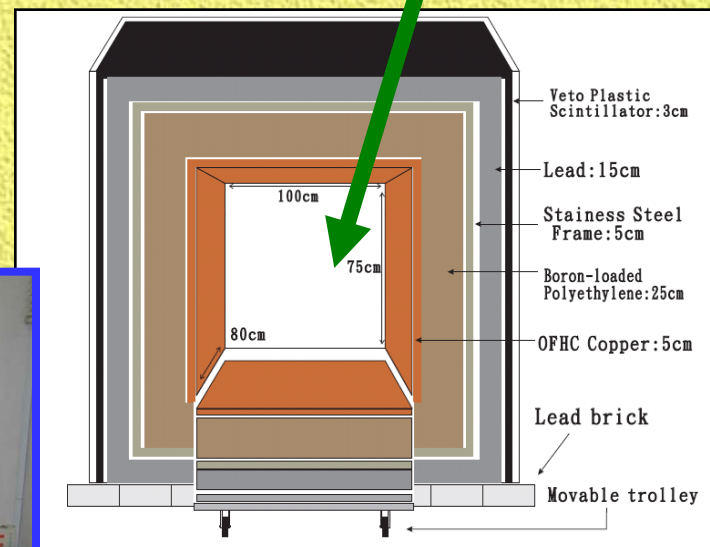
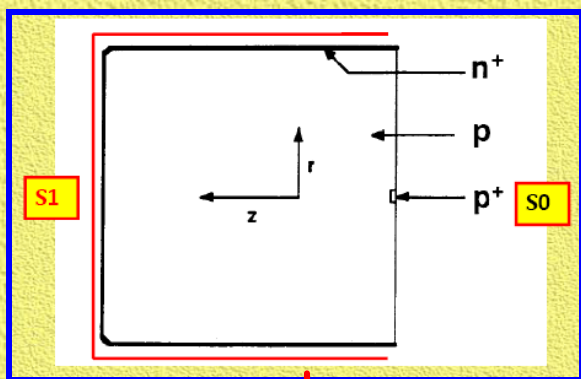
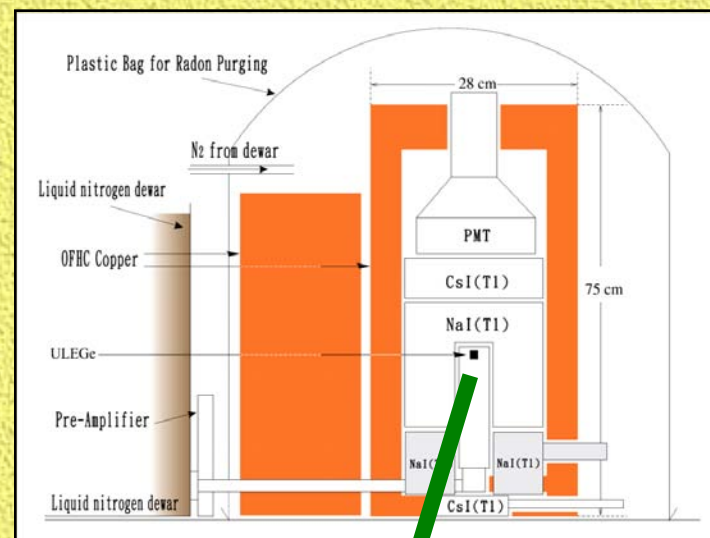
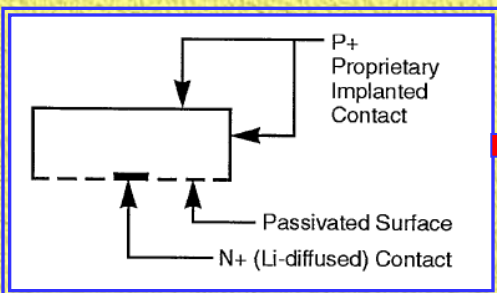
First Data Taking :

↳ ~ 6 events / [month - 1 m²]
(c.f. ~100 Hz / m² at sea-level)

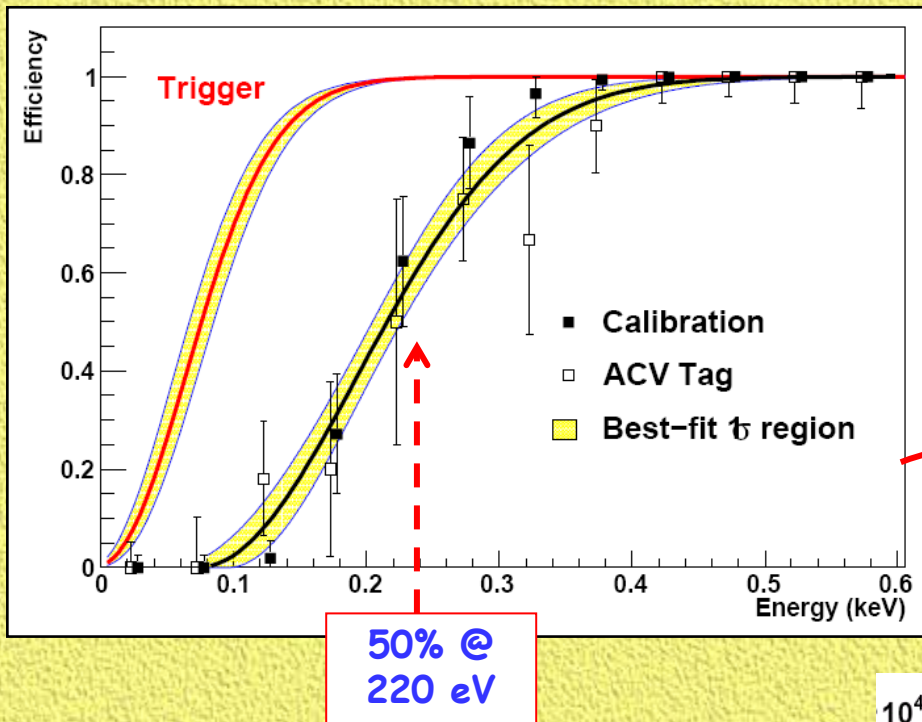
↳ Consistent with expectations

+ Measurements of ambient radioactivity (γ 's, neutrons, radon) underway

TEXONO-CDEX : ULEGe & PCGe @ KSNL & CJPL



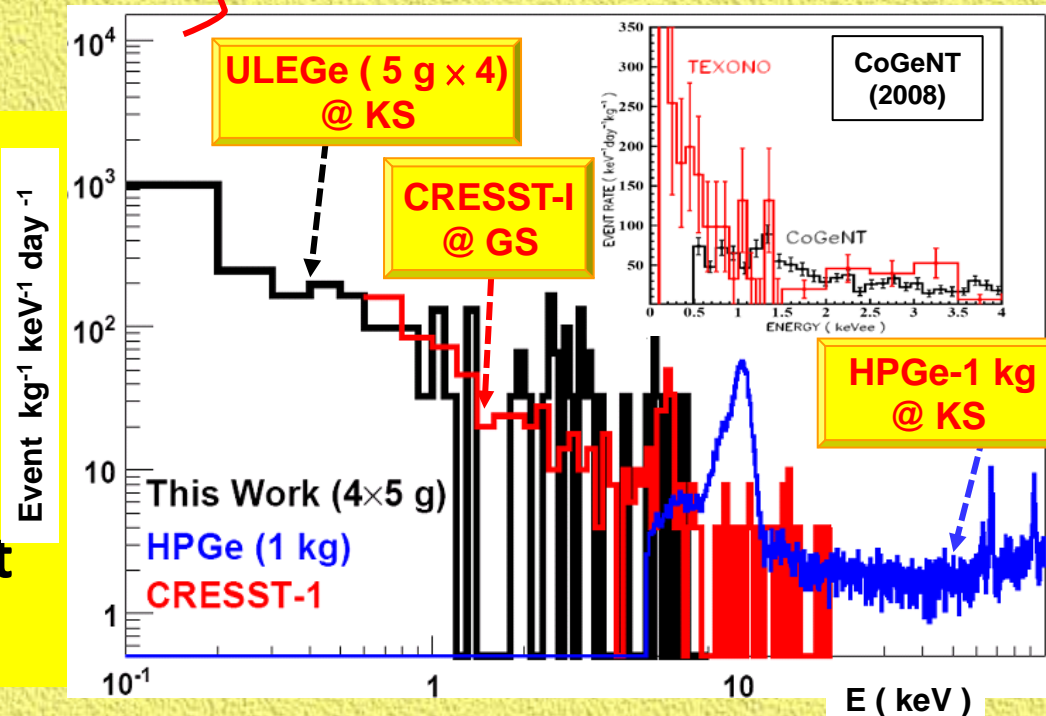
TEXONO-CDEX @ KSNL : Threshold & Efficiencies & Background for 20g ULEGe (2007)



Dark Matter
Searches
Analysis

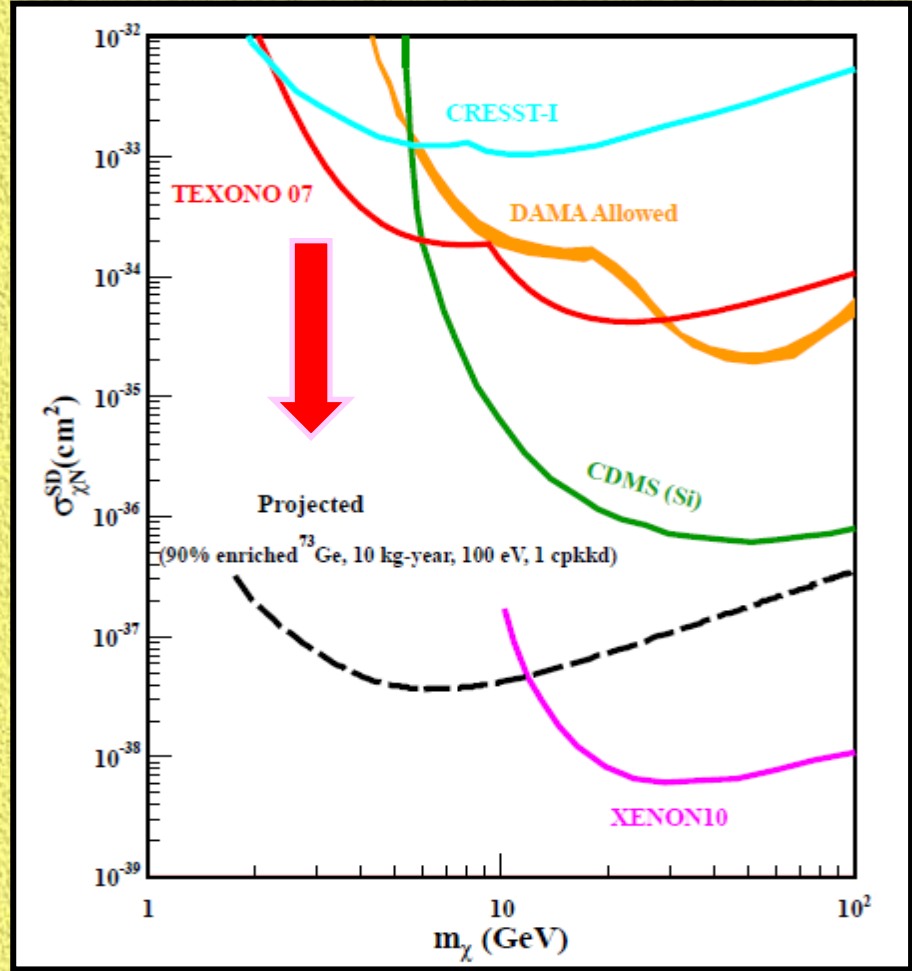
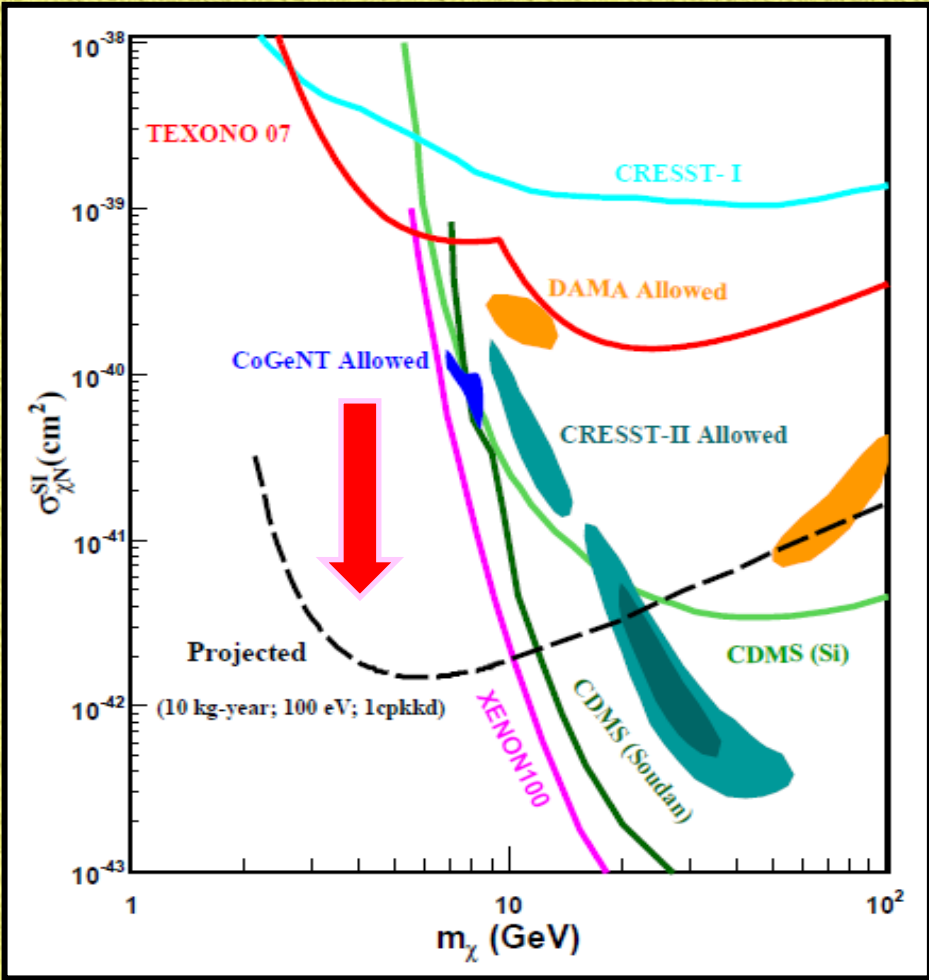
sub-keV Background :

- * Not fully explained with conventional background modeling
- * Intense work on hardware, software and data taking at new underground site





Limits (PRDRC09) & Projected Sensitivities on Low Mass WIMPs

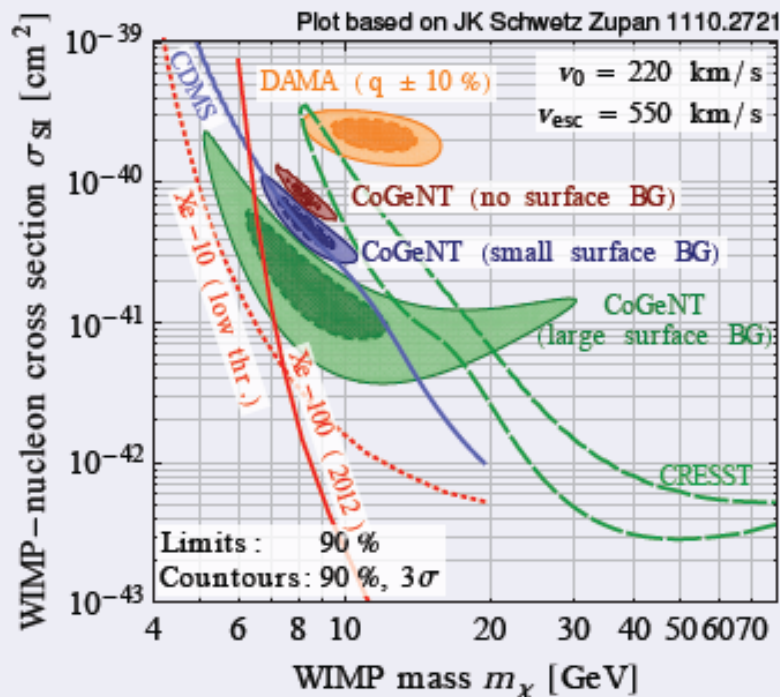


Much has happened world-wide since

Hints for light dark matter

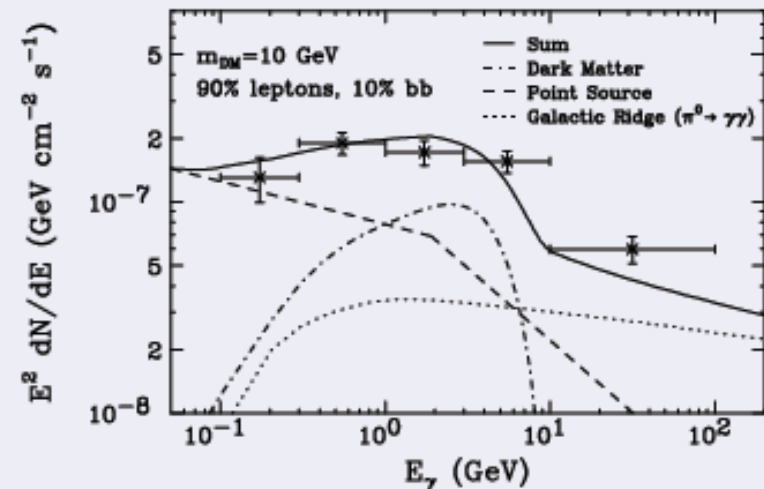
J. Kopp @ IDM12

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

Physics Case -- Recall discovery of neutrino oscillations :

- 🔗 small Vs large mixing angles
- 🔗 atmospheric neutrinos being irreducible background to proton decay.

🏆 **Moral:** Study new parameter space carefully wherever experimentally possible

“Some” Low-Mass Dark Matter Models:

- 🔗 Generic SUSY Framework ; Light SUSY [*PRD 72, 083521(2005)..*]
- 🔗 Composite DM ; Q-Balls [*PRL 89, 101302(2002)..*]
- 🔗 WIMPless DM [*PLB 670, 37 (2008)..*]
- 🔗 Mirror DM [*PRD 80, 091701(2009)..*]
- 🔗 Asymmetric DM [*PRD 79, 115016(2009)..*]
- 🔗 Singlet Fermion DM [*JHEP 0905, 036(2009)..*]
- 🔗 MeV DM [*PRD 77, 087302(2008)..*]
- 🔗 Leptophilic DM [*PRD 80, 083502 (2009)..*]
- 🔗 Axion-Like Particles
- 🔗 **OR ...** Alternative Astrophysics DM ρ - ν modeling may favor lower recoil energy (e.g. solar system bound) [*PRL 81, 5726(1998)..*]
- 🔗 Many other theory work

CoGeNT @ US 2007: Demonstrate use of "Point-Contact Ge Detector" 2010 (PRL11: limits & allowed region) / 2011 (PRL11: 2.8σ annual modulation) / 2012 (Long Paper)

⇒ intense theoretical interest and speculations on low-mass WIMPS

Sub-keV Excess not explained by conventional background modeling

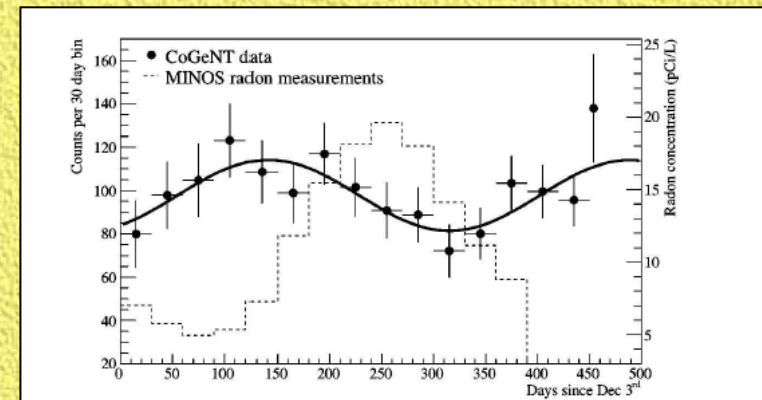
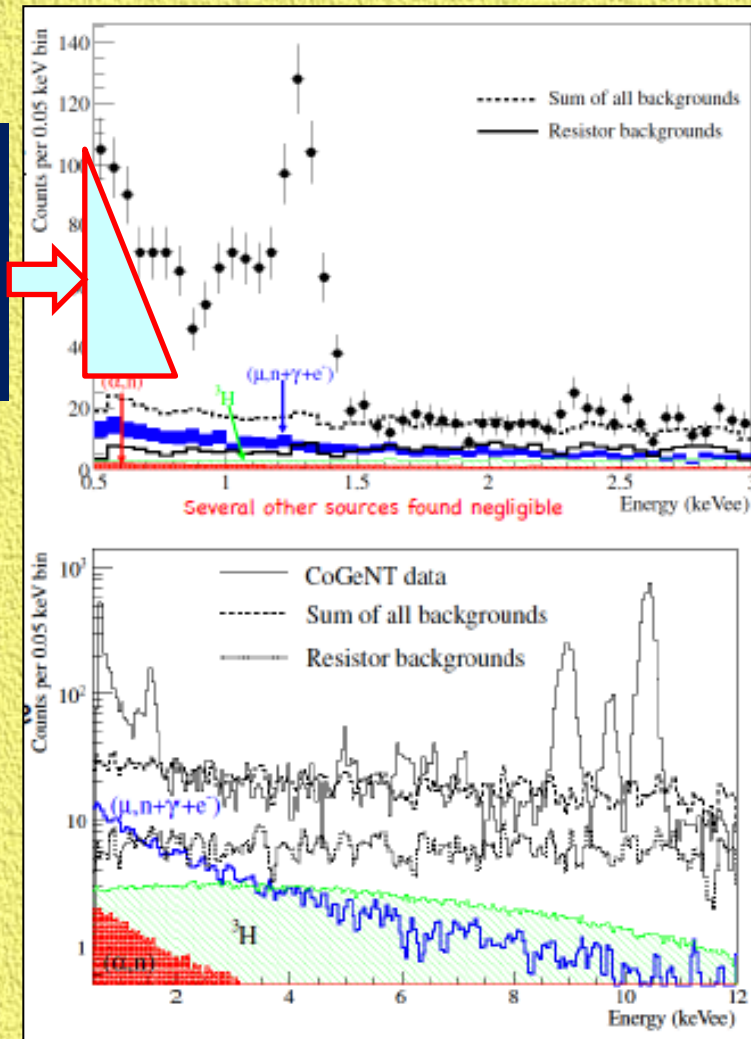
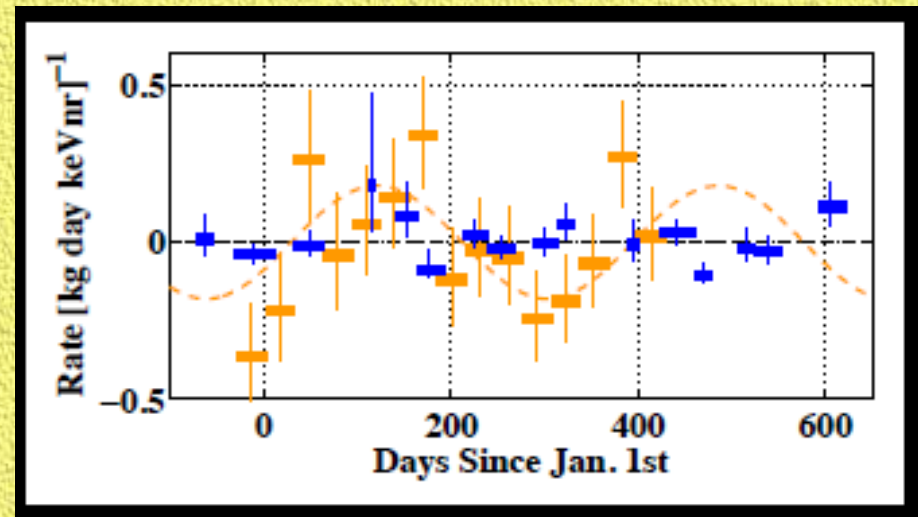
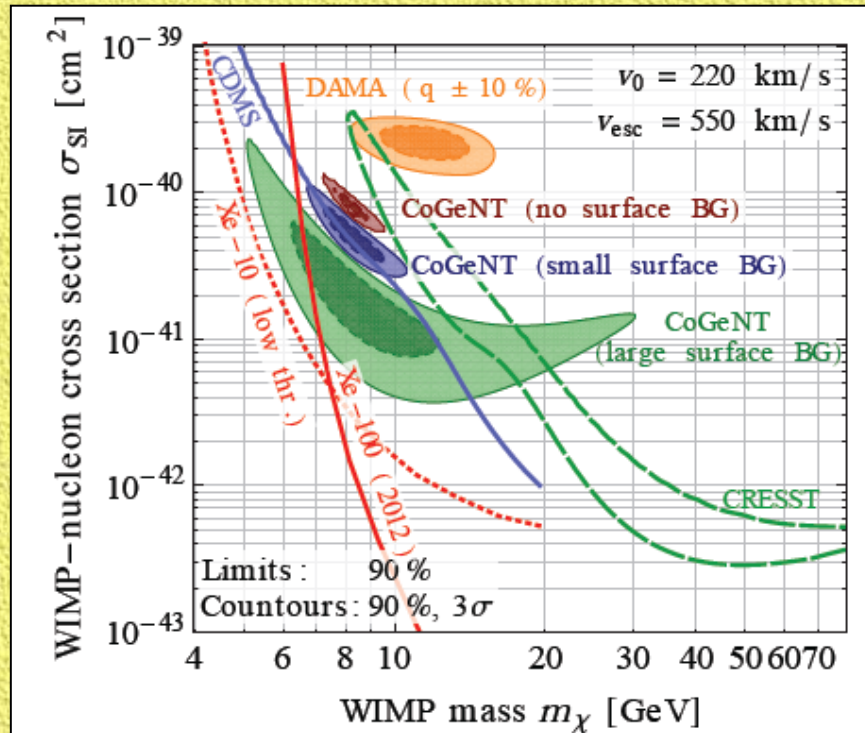


FIG. 26. Counts per 30 day bins from the 0.5 - 3.0 keVee CoGeNT energy window (black dots) compared to the MINOS radon data at SUL (dashed), averaged over the period 2007-2011, exhibiting a peak on August 28th [38, 39]. The solid curve represents a sinusoidal fit to CoGeNT data.

- ⌘ **CDMS & XENON10/100 (+ SIMPLE, Edelweiss ...)** extended design range, performed Low-Energy Analysis and probed/excluded CoGeNT Allowed Region
- ⌘ **CoGeNT's response/critique** : uncertainties in energy scale calibrations, ionization and scintillation yields, backgrounds, noise fluctuations *at/below threshold*
- ⌘ **Controversial** : Different Detector Technologies & Background Sensitivities ; Low Energy / Insufficient statistics ; Steep Dependence between Physics & Experimental Parameters

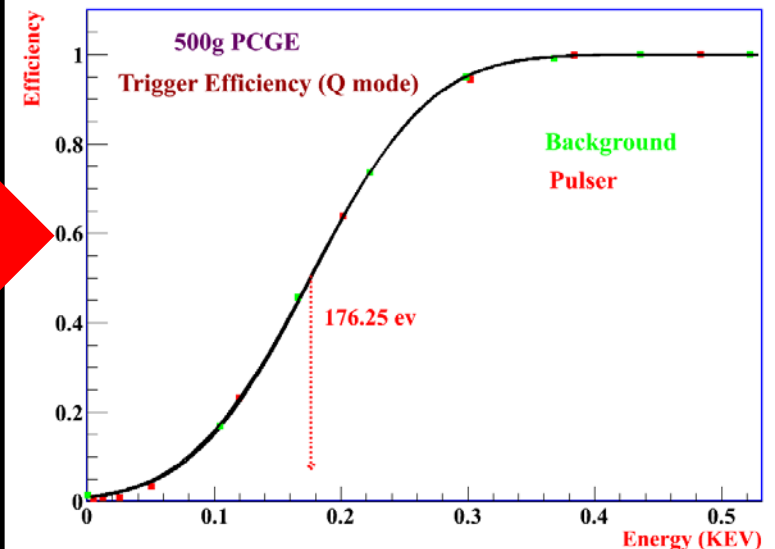
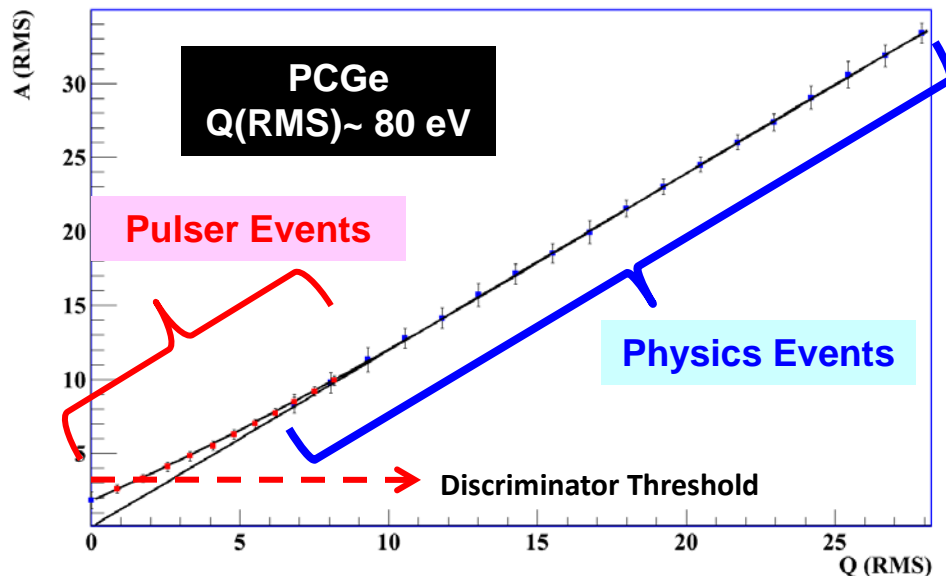


**Tension : CDMS Vs CoGeNT
annual modulation data**

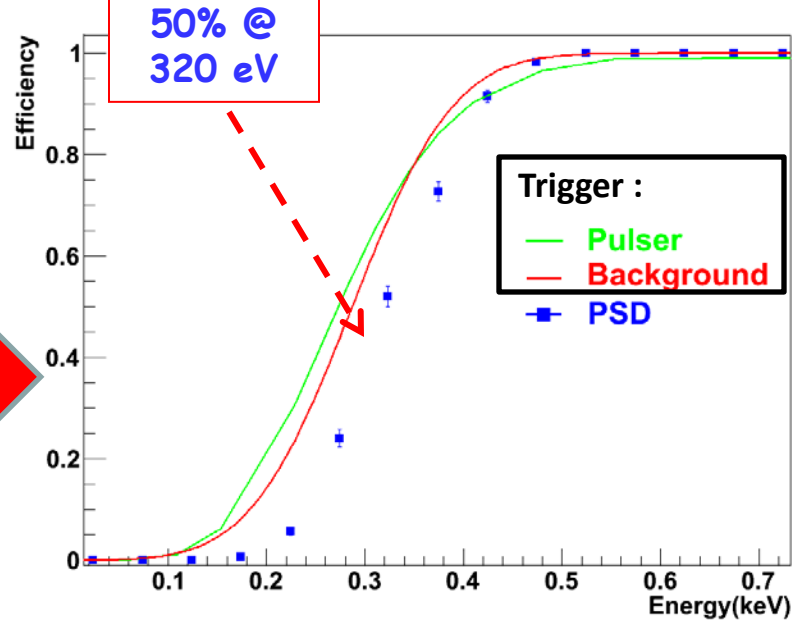
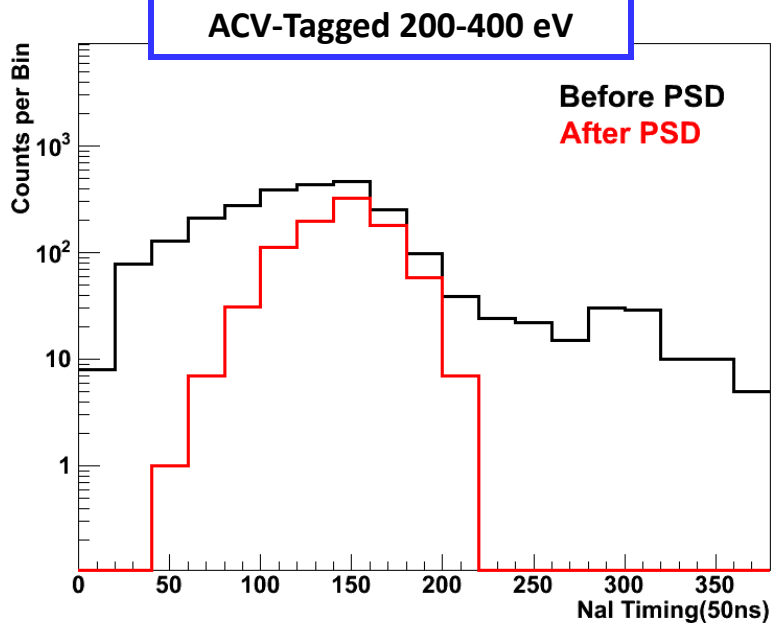
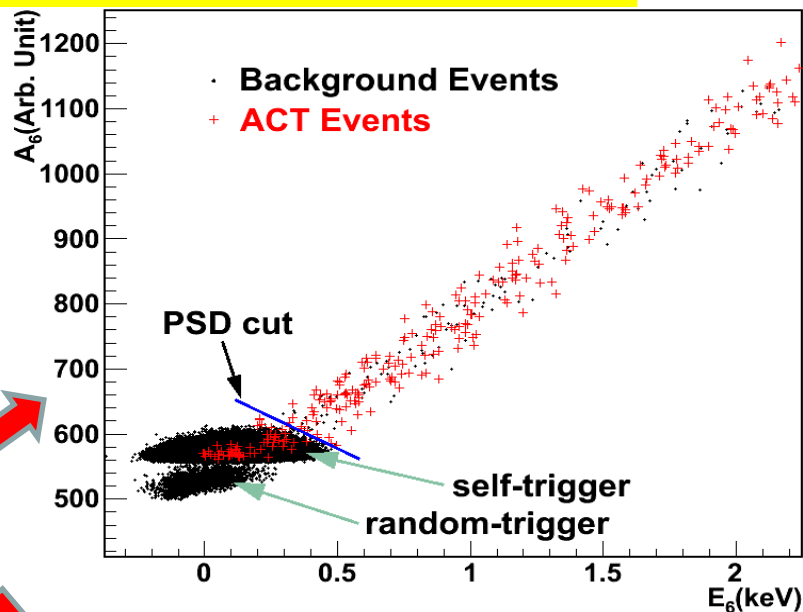
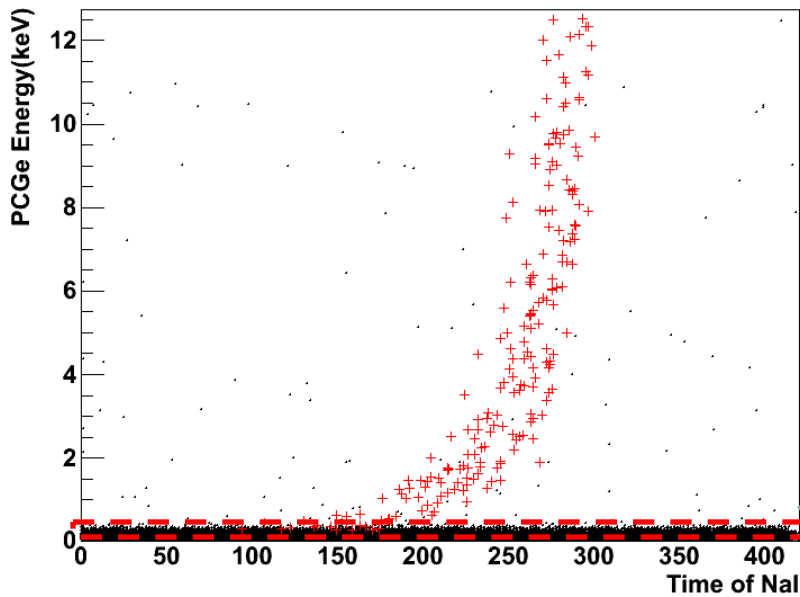
Sub-keV Ge Detector Techniques : R&D Items

- ❌ 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

Trigger Efficiency via Pulser Calibration

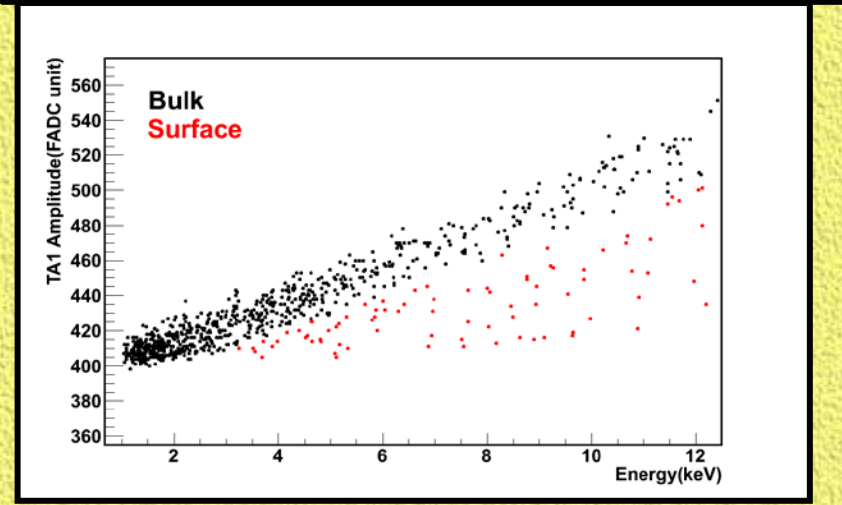
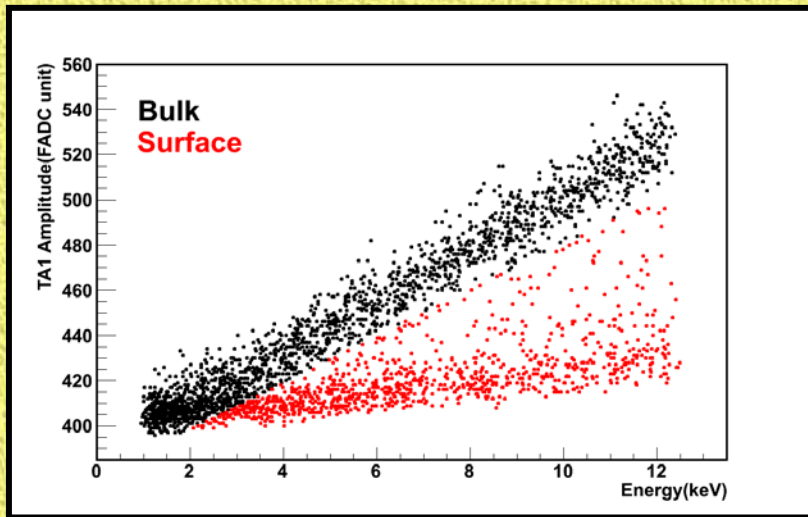
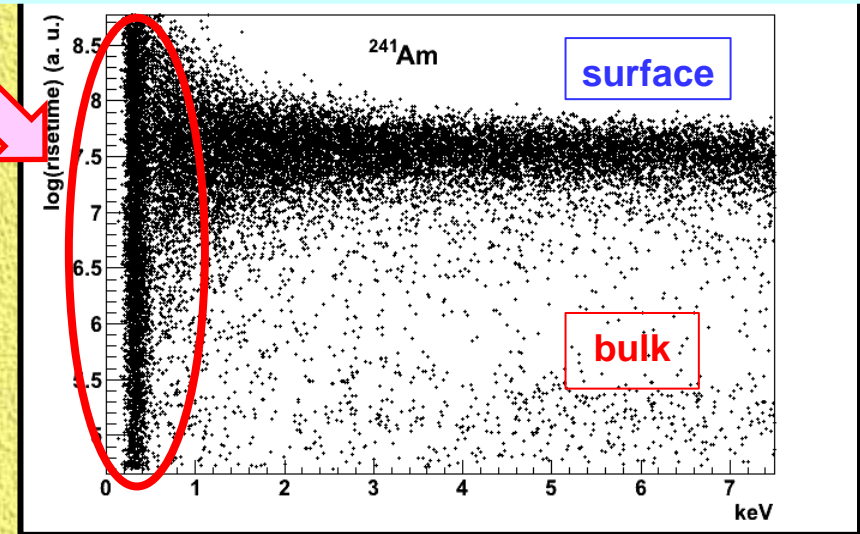
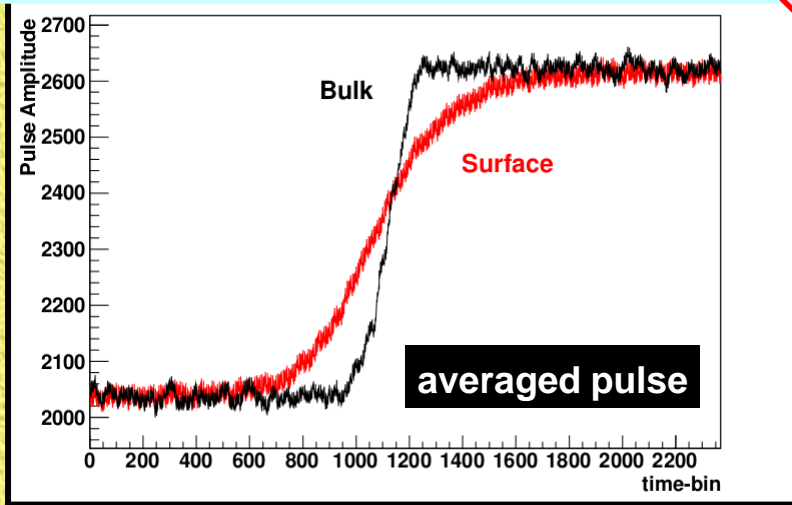


Threshold & Phys-Vs-Noise Selection Efficiency



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
- Intense efforts to devise schemes to measure efficiencies/leakages ...



γ -rich background: cosmic veto & anti-Compton trigger

n-rich background: cosmic trigger & anti-Compton veto

TEXONO-CDEX @ CJPL

- 📅 **2012+:** Repeat PRD-09 measurement with 20-g ULEGe & 1-kg PCGe
- 📅 **2012-15:** 10-kg range PCGe array , with Liquid Argon Anti-Compton ; Acquisition of Ge and LAr detector technology
- 📅 **2015 & Beyond:** Towards 1-ton scale experiment ; include Double Beta Decay to Physics program ; CJPL Extensions (10+ space)
- 📅 **2010+:** characterize background at CJPL ; set up low background material screening facilities

New Ideas Welcomed !!

Data Taking @ CJPL :

Engineering Run
2011 ;

Ventilation
Completed \Rightarrow
Physics Run June
2012

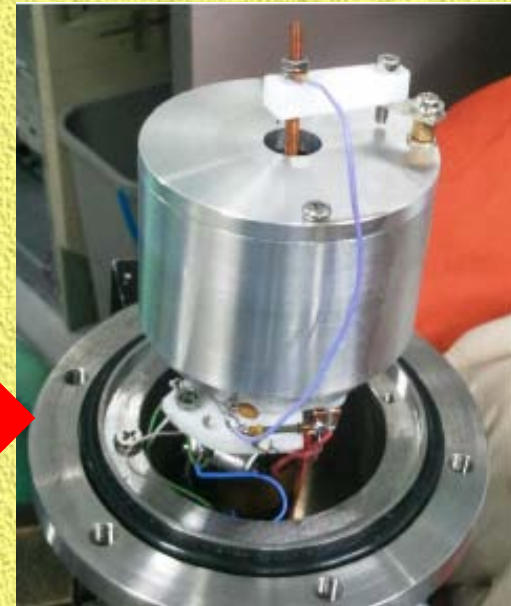
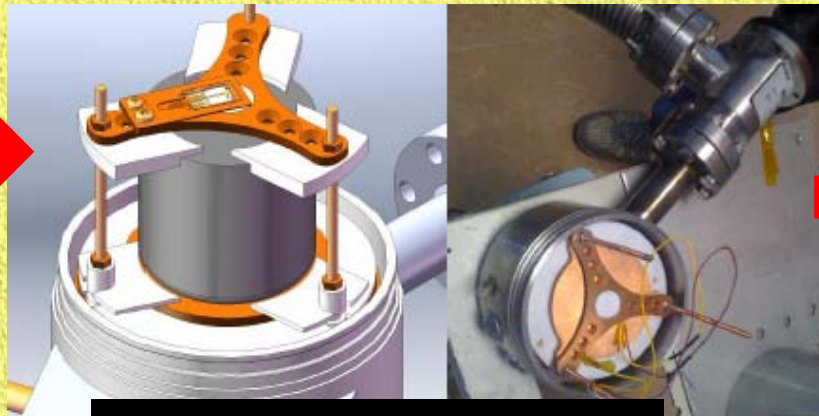


Ge Processing & Assembly Facility @ THU

- Clean room

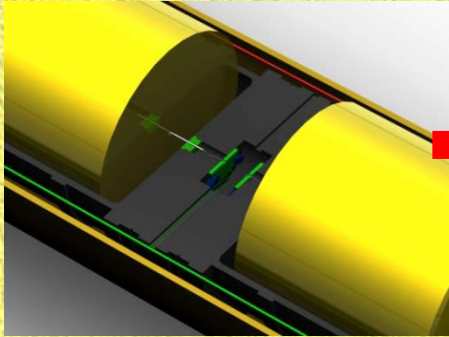


- Processing of raw Ge crystal
- Application-specific optimized assembly
- R&D on JFETs & Preamps
- Possible Future Commercial Marketing (THU)

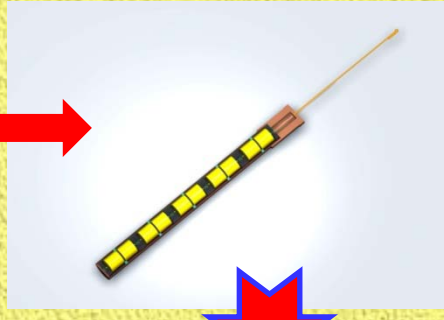


Design of CDEX-10 : with LAr Anti-Compton

Ge + JFET

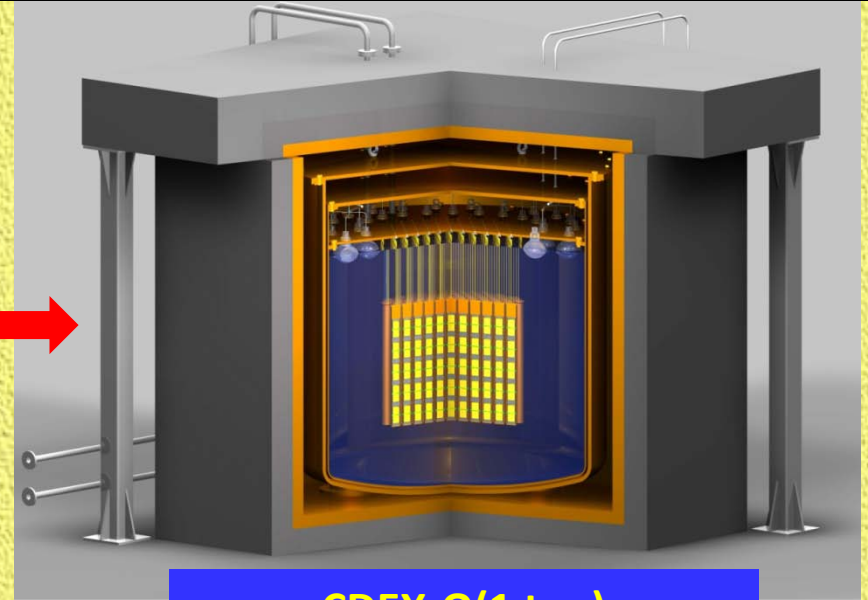
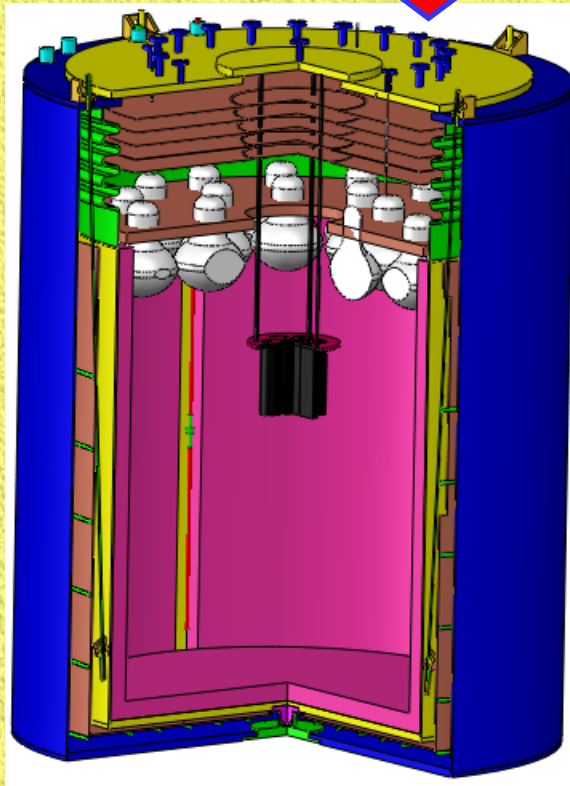
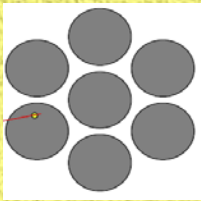


Ge Array in String



- PCGe in Arrays & Strings
- LiqAr as both cryogenics & active anti-Compton
- ~30-40 cm 4π shielding range
- Prototype 2nd half of 2012
- Baseline Design for Future O(1 ton) Experiment

CDEX-10
(2013+)



CDEX-O(1 ton)
Artist's Conception

Status and Plans and Prospects



- **CJPL**: deepest operating underground laboratory in the world
- **CDEX-TEXONO Dark Matter Program @ CJPL** focuses on sub-keV Ge detectors and low-mass WIMP region.
- **Focuses at KSNL**: sub-keV Ge to support dark matter program **AND** towards ν -N coherent scattering
- Intense efforts on **Ge & LAr Detector R&D + Background Understanding @ sub-keV**.
- **Goals** : open new *detection channel* and *detector window* for neutrino and dark matter physics ; available platform for *innovations & surprises*