Low Energy Neutrino and Dark Matter Physics with Sub-keV Germanium Detector

- Overview (Collaboration ; Program ; Laboratory)
- ULE-HPGe : Physics & Requirements
- Event selection and efficiencies
- Dark Matter analysis and Results
- Status & plans

Lin, Shin-Ted / 林欣德

On Behalf of TEXONO Collaboration, Academia Sinica

5th BEYOND 2010 @ Cape Town, South Africa Feb. 2010

TEXONO Collaboration

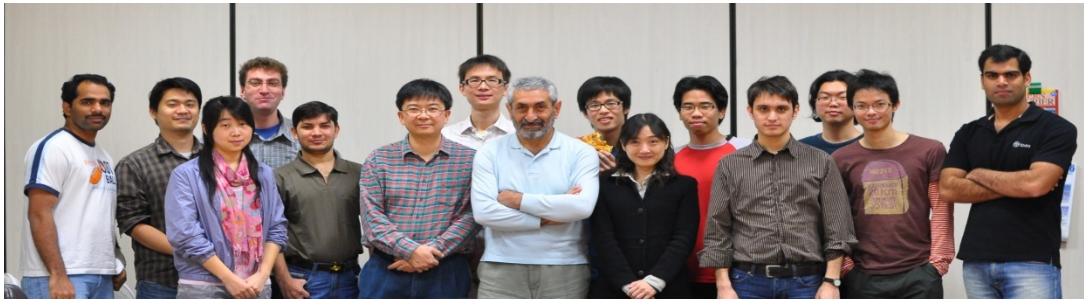
- *Collaboration* :

  Taiwan (AS, INER, KSNPS, NTHU)

  + China (IHEP, CIAE, THU, NKU, NJU,SUC)

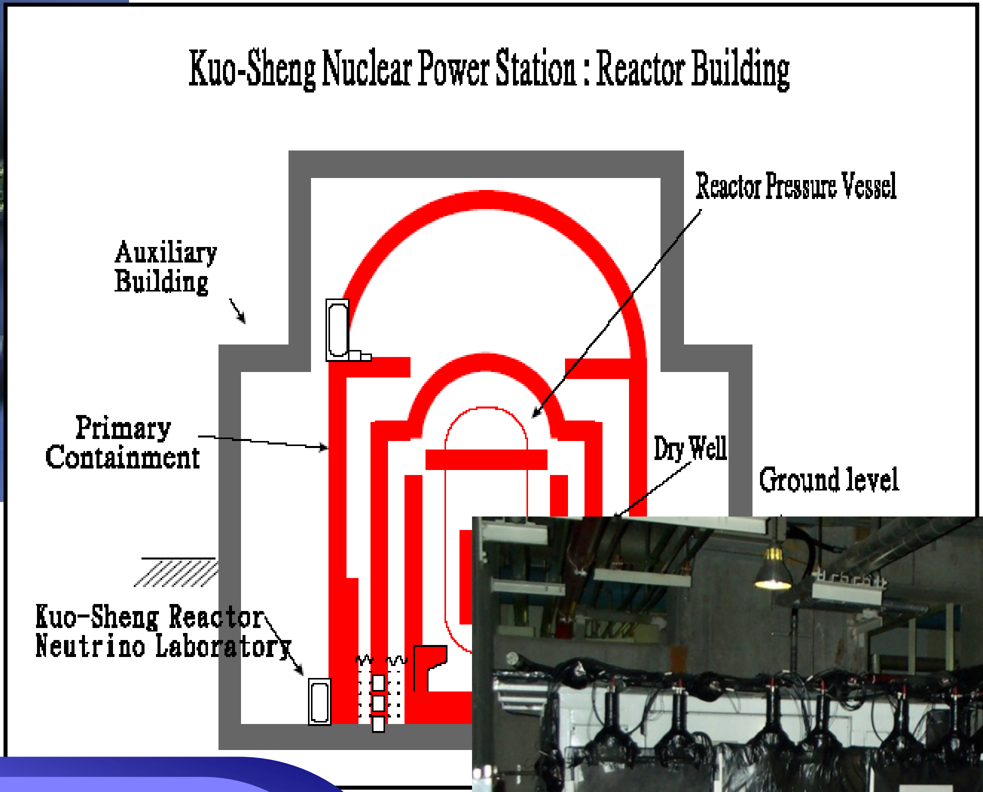
  + Turkey (METU)

  + India (BHU)



- *Facilities* : Kuo-Sheng Reactor Lab (Taiwan) ; CIAE Neutron Beam (China) ;China Jin-Ping Underground Laboratory (CJPL in China)
- *Program* : Low Energy Neutrino & Dark Matter Physics
- *Present Goals* : Develop *O[100 eV threhold⊕1 kg mass⊕1 cpkkd detector]* for neutrino physics and dark matter searches

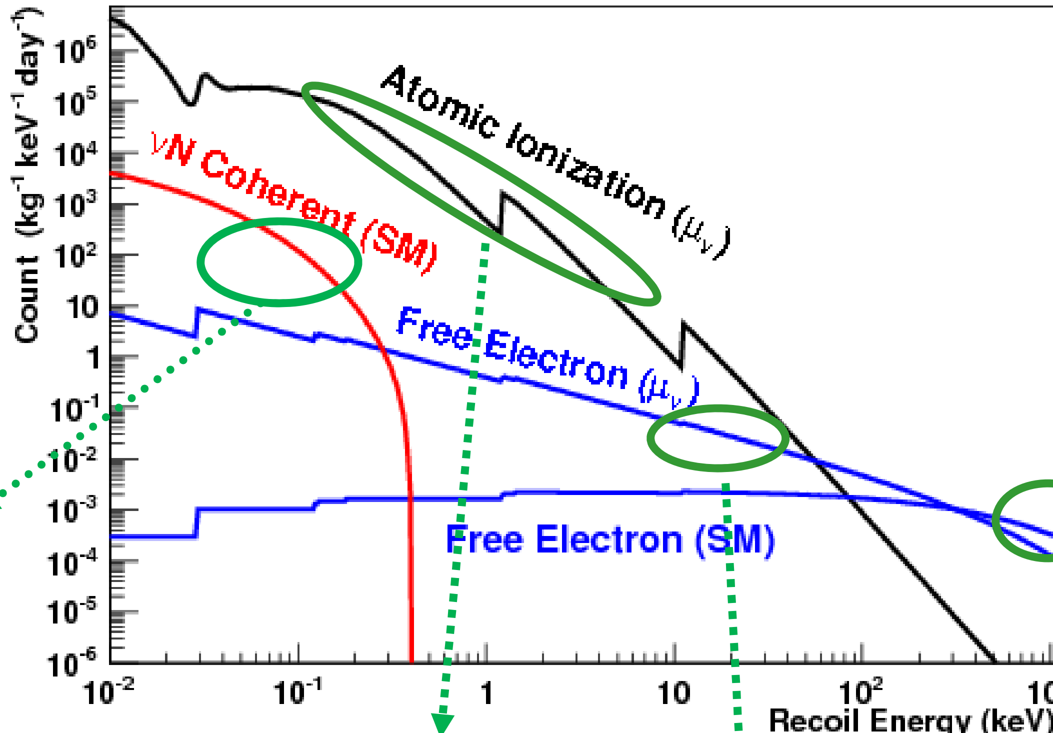
Kuo -Sheng Reactor Neutrino Laboratory：

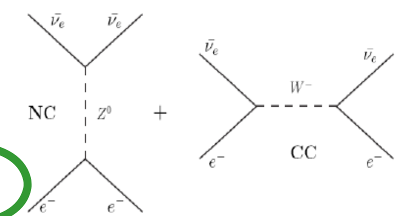


28 m from core#1 @ 2.9 GW
Shallow site : ~30 *m..w..e.* overburden
~10 m below ground level

Neutrino properties &Interaction at reactor

quality ← **Detector requirements** → **mass**



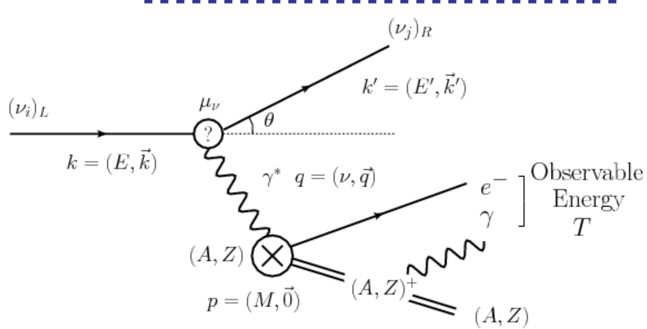


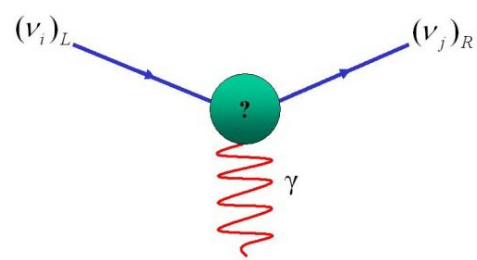
νN Coherent Scattering & Dark Matter Searches
PRD 79(R) 2009

Atomic Ionization μ_ν
arXiv: 1001.2074

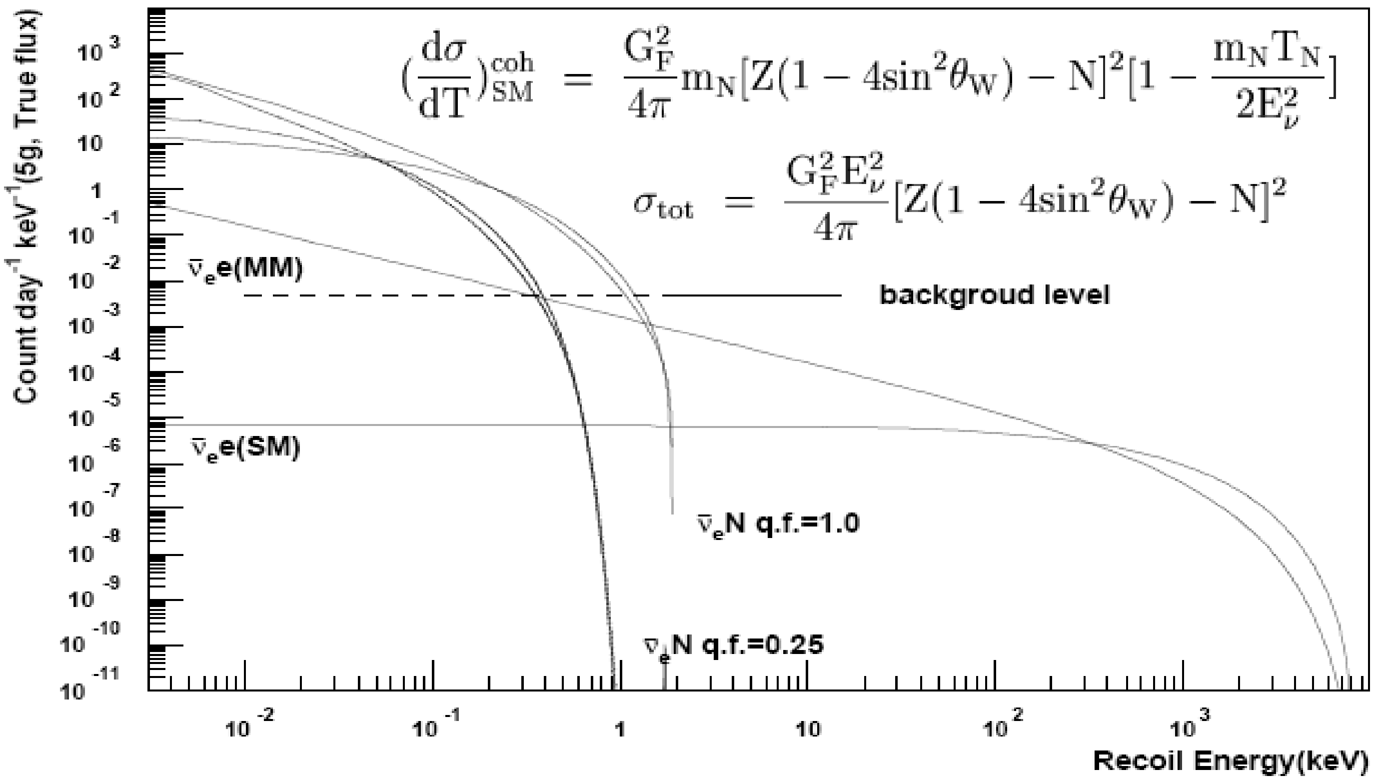
Magnetic Moments (μ_ν)
PRL 90 2003 ; PRD 75 2007

Standard Model
νe scattering
arXiv: 0911.1597





Neutrino-Nucleus Coherent Scattering

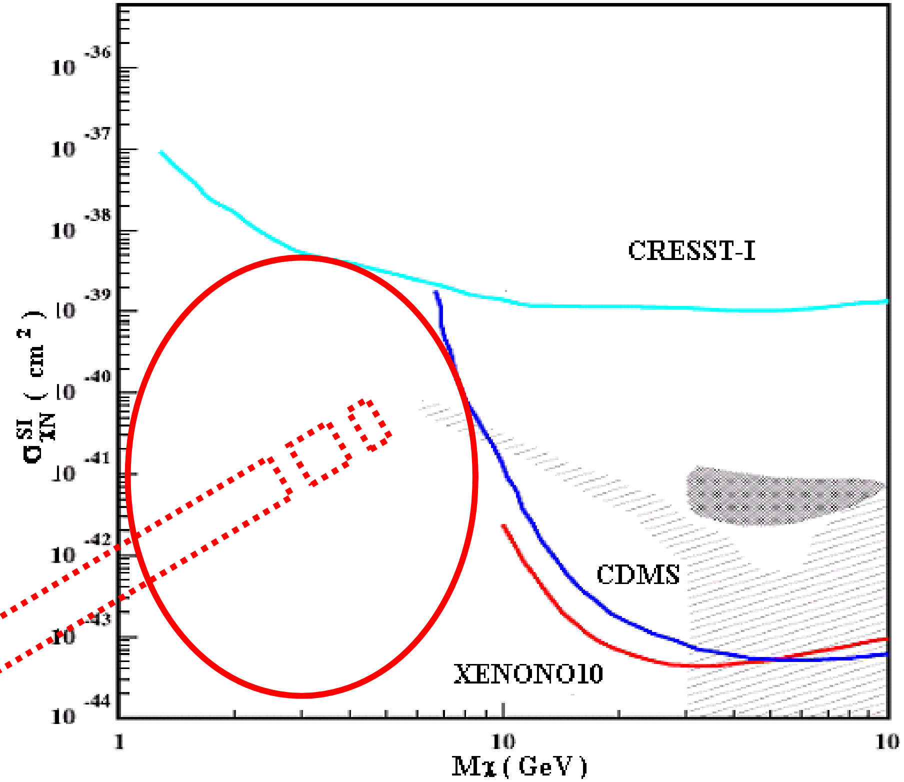


- A fundamental neutrino interaction never been experimentally-observed
- $\sigma \propto \sim N^2$ applicable at E_ν<50 MeV (Take Q.F. =0.25 ; $\mathcal{S}/\mathcal{N}$>1 at 250 eV of threshold; At threshold 100 eV-> 11 cpkkd)
- a sensitive test to Standard Model
- an important interaction/energy loss channel in astrophysics media
- a promising new detection channel for neutrinos, relative compact detectors possible (implications to reactor monitoring)

Sensitivity Plot for *WIMP* direct search

$$\chi N \rightarrow \chi N$$

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

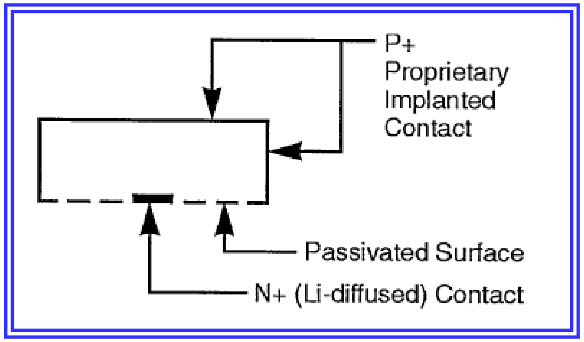


Low (<10 GeV) WIMP Mass / Sub-keV Recoil Energy :

- **Not favored by the most-explored specific models on galactic-bound SUSY-neutralinos as CDM ; *still* allowed by generic SUSY**
- **Various gravitational effects favor lower recoil energy ⇨ *Solar-system bound* WIMPs ; *Dark Disk* etc.**
- **Other candidates favoring low recoils exist ⇨ non-pointlike SUSY *Q-balls* , MSSM's *LLN* ; SM+scalar ; axion-like models etc.**
- **Less explored experimentally**

"Ultra-Low-Energy" HPGe Detectors

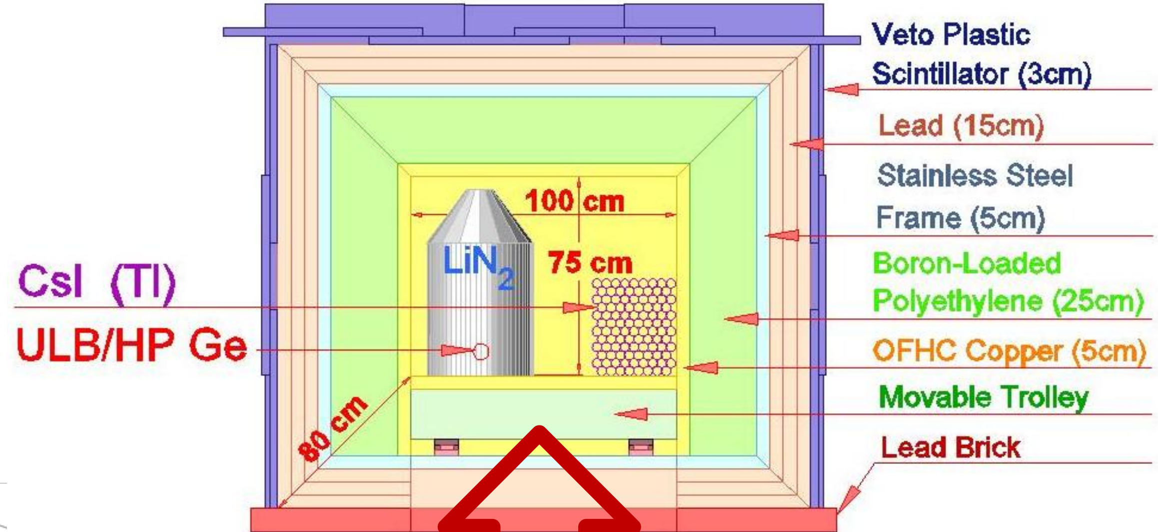
- ULEGe – developed for soft X-rays detection ; robust operation & easy in handling
- ULEGe Prototypes built and being studied : (5-500) *g* → This analysis : 4×5 *g*

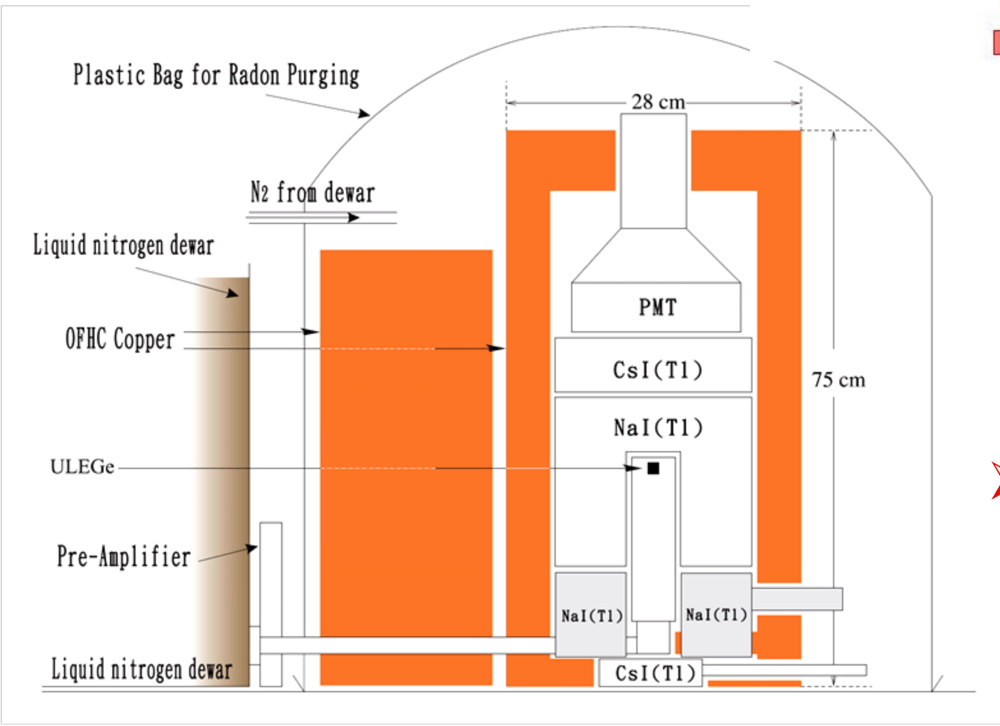


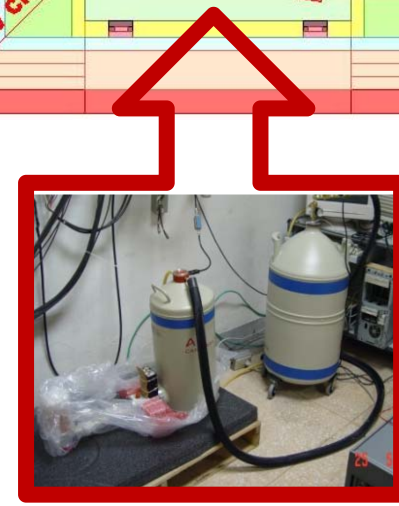
- Physics for
  - νN coherent scattering
  - Low-mass WIMP searches
  - Improve sensitivities on μ_ν
  - Implications on reactor operation monitoring
  - Open new detection channel & detector technology windows for surprises

Analysis : Event Selection *CRV* 、 *ACV* Cut

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



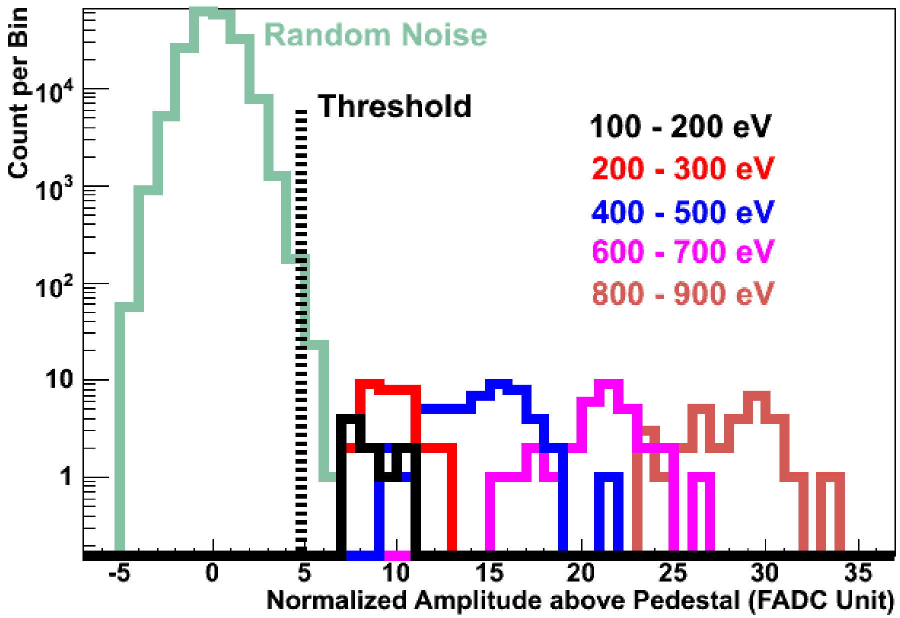


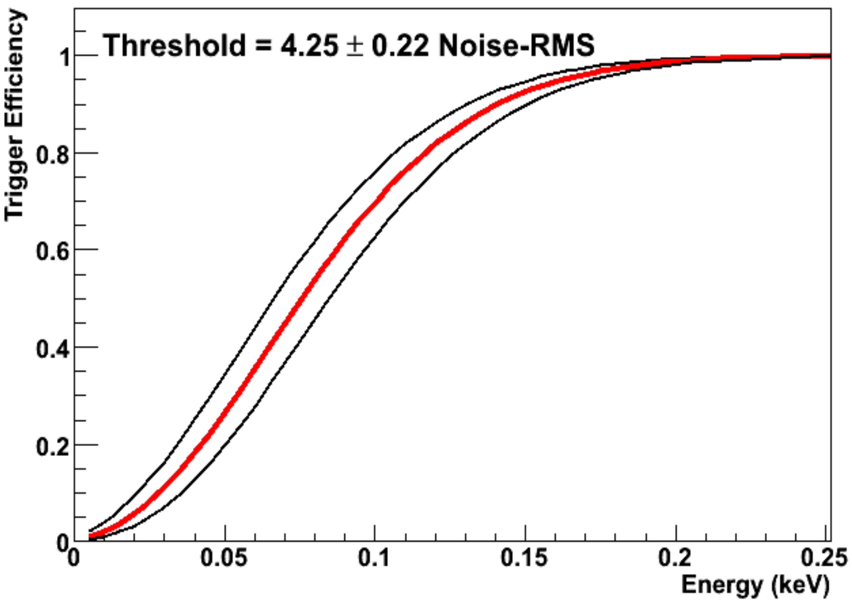


- Candidate events : survive Anti-Compton (*ACV*) and Cosmic-Ray (*CRV*) vetos

--- Efficiency evaluated by Random trigger events.

Evaluation of Trigger Efficiency



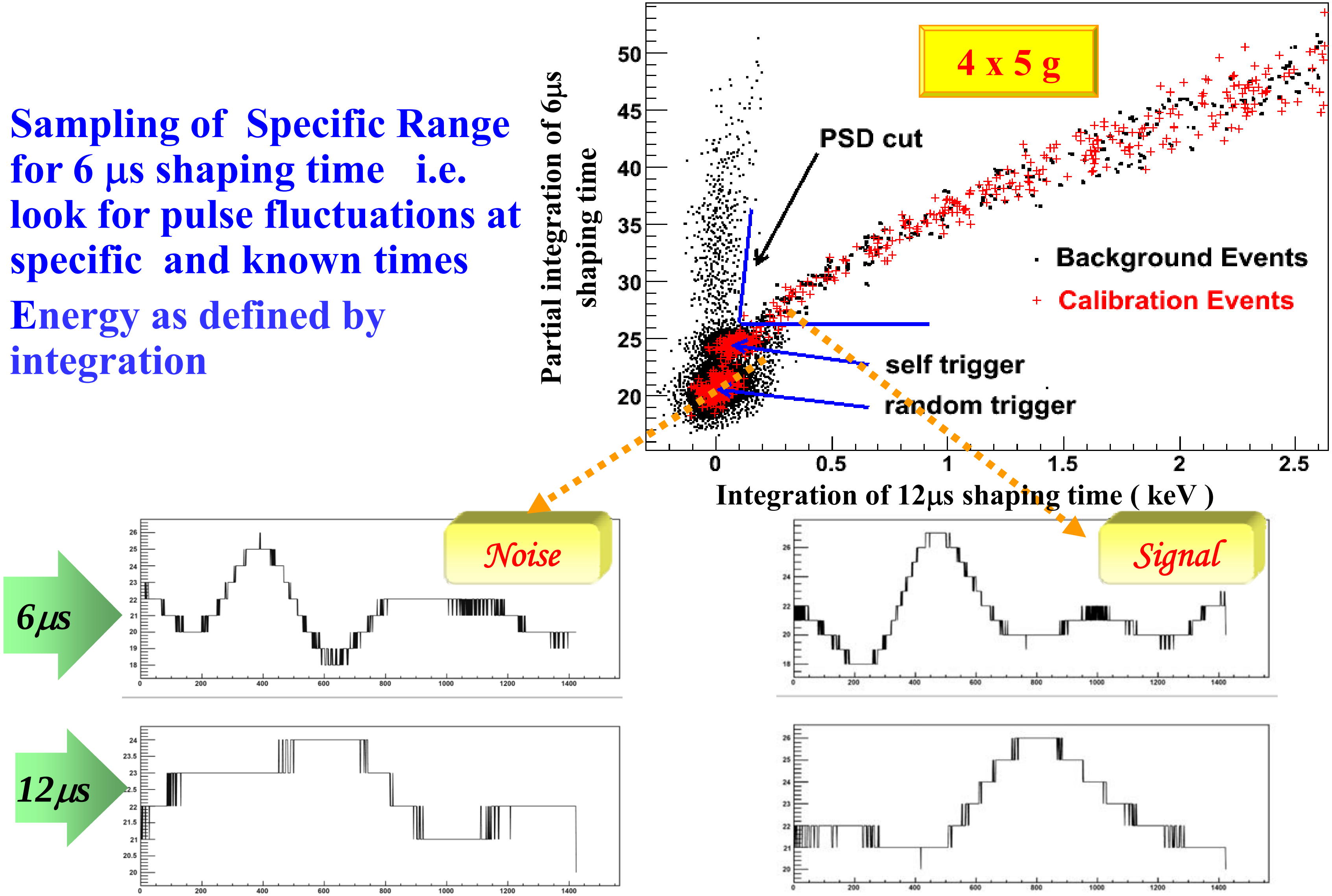


- **DAQ threshold at ~4.3σ above mean of noise fluctuations →** ***no DAQ dead time concern***
- **Max. amplitude of physics events → good margins above threshold**
- **Efficiency Evaluation : from (*mean* , *RMS*) of Max. amplitude distribution**
- **Evaluation from pulser generator also perform the 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



PSD Selection Efficiency

♥ **Clean physics event samples selected by ACV-tag**

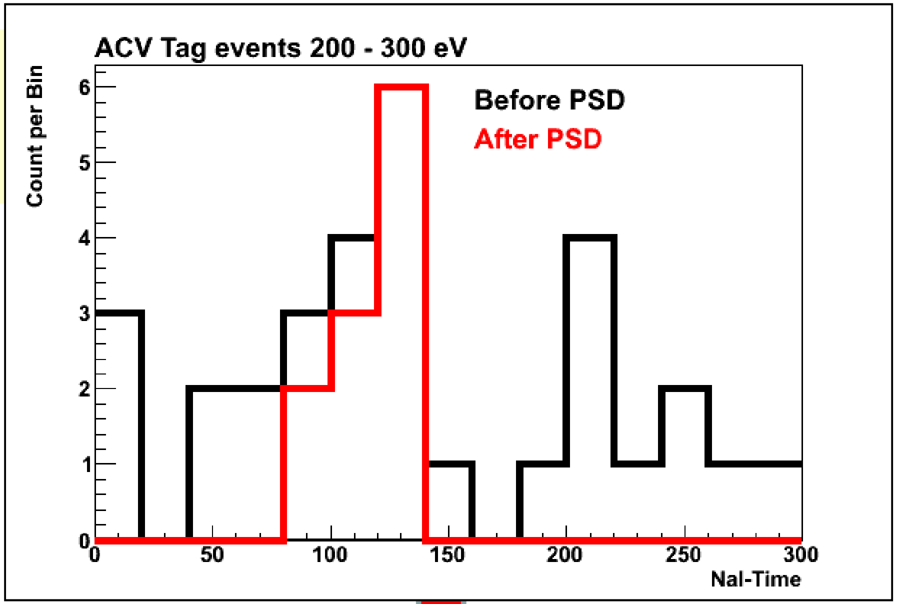
$$f = \frac{(\epsilon_{\rm PSD} * P + f_N * N)}{P + N}$$

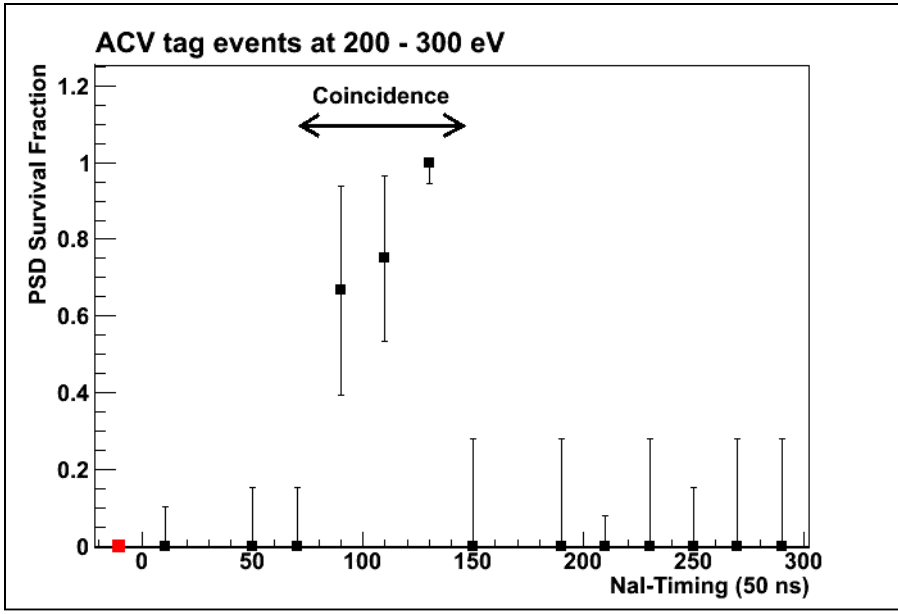
Measured: $f_N \sim 10^{-4}$

In General $\epsilon_{\rm PSD} \geq f$

⇨ **Conservative choice :**

ε_{PSD} **== survival probability after cut at correct timing**



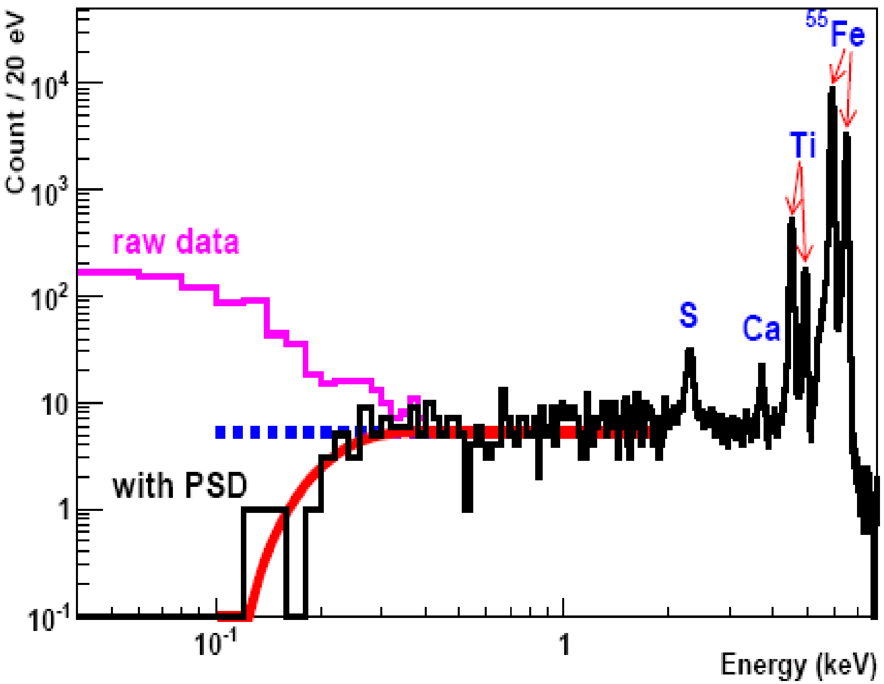


PSD Selection Efficiency

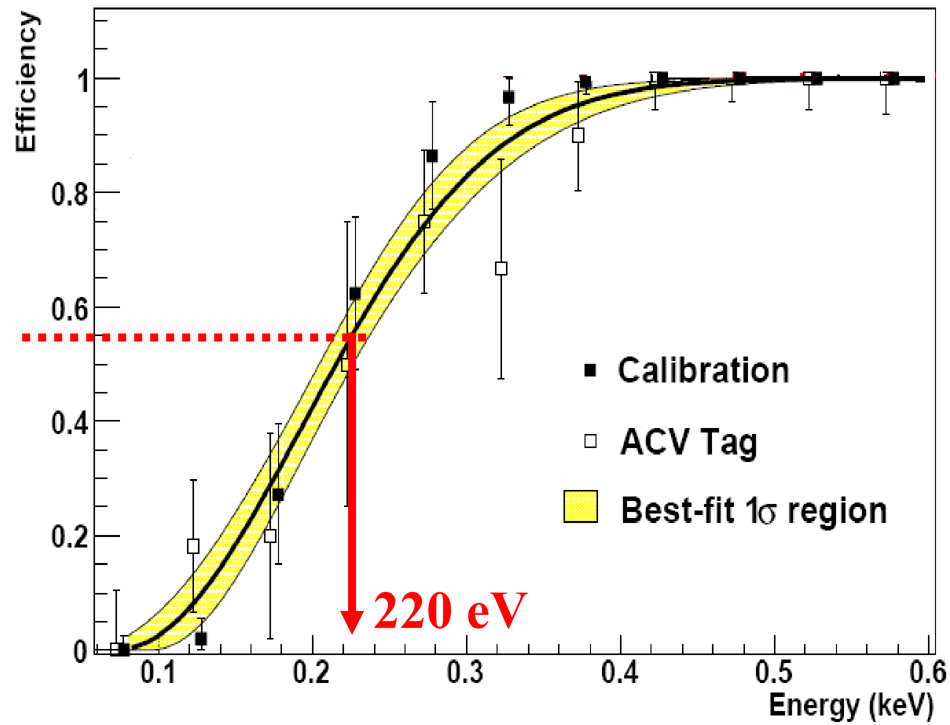
Supported & statistics reinforced by ^{55}Fe calibration spectra

⇨ deviations from flat at low energy.

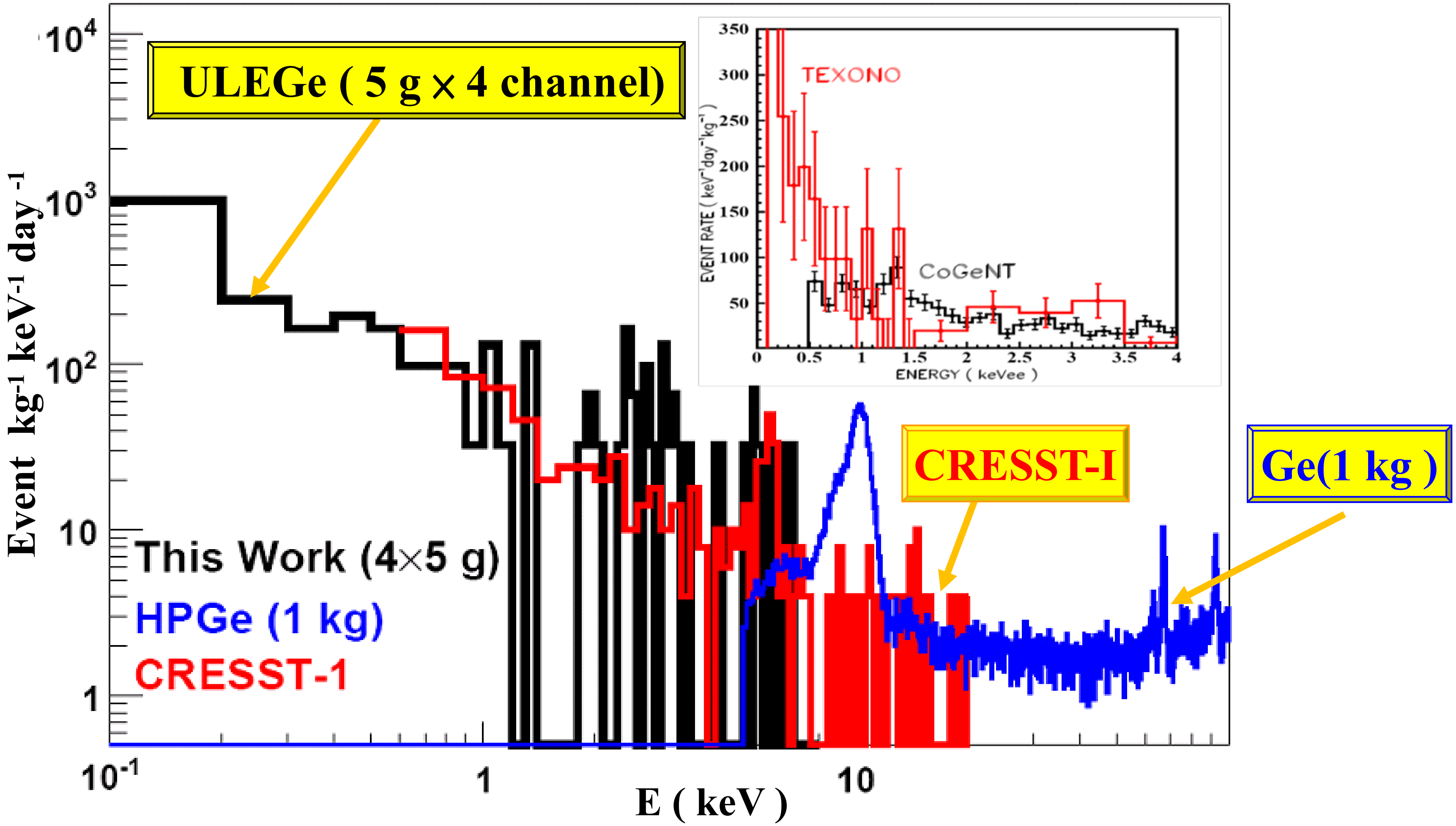
^{55}Fe sources for calibration & PSD efficiency



ε=50% @ 220 eV

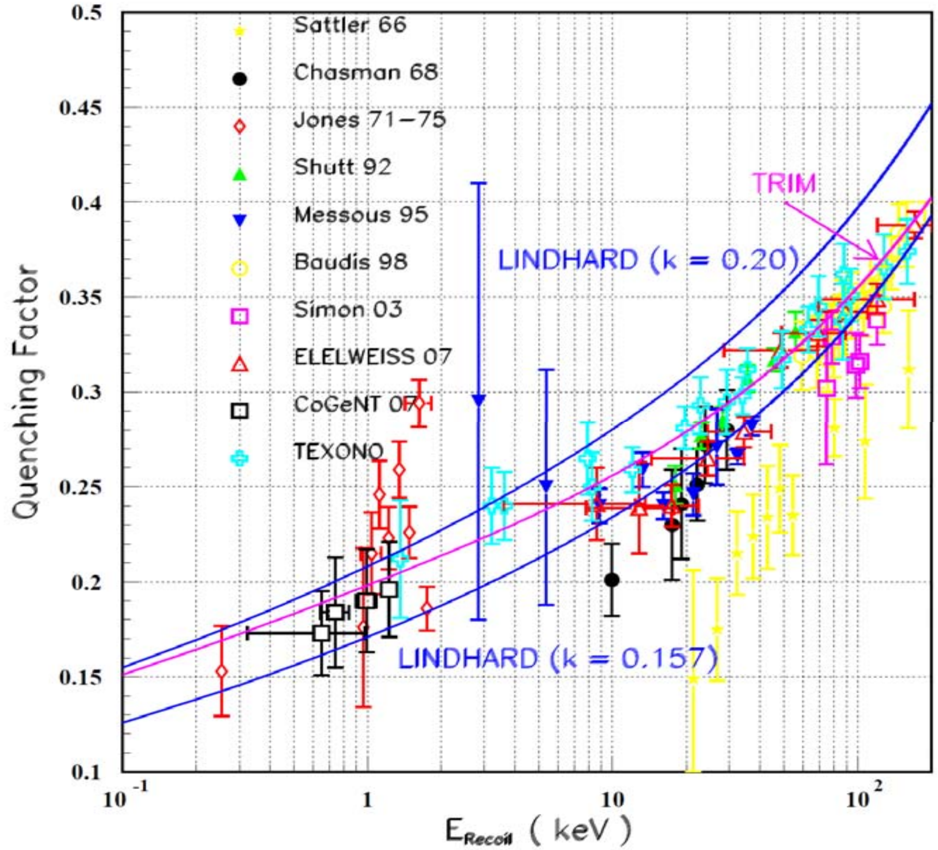


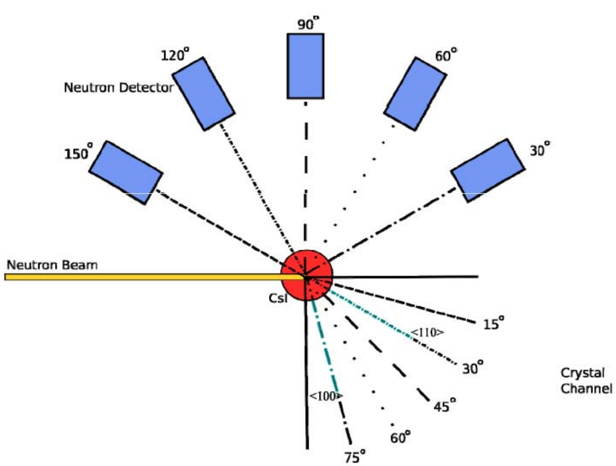
Sub-keV Background Measurements & Comparisons



- Bkg ~ O(1) cpd/kg/keV >10 keV, ~ to underground expts.
- Background comparison to CRESST-1 & CoGeNT results
- Intensive studies on background understanding

Quenching Factor [Ionization Yield ⇨ Recoil Energy]





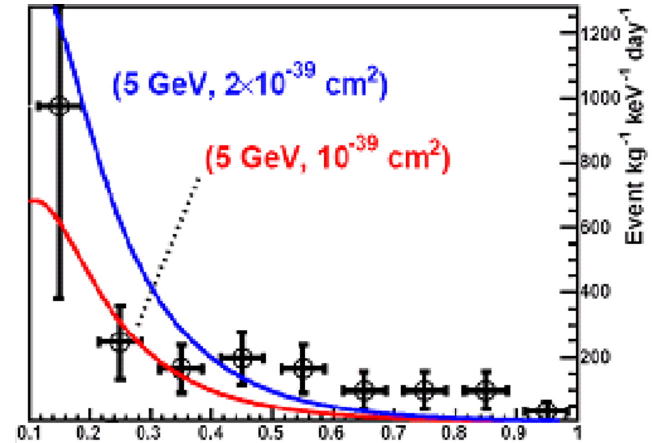
- **TRIM (better fits to available data)**
- **improved measurement planned at CIAE**

(Get to sub-keV ; Improve on present sensitivities ; Channeling effect)

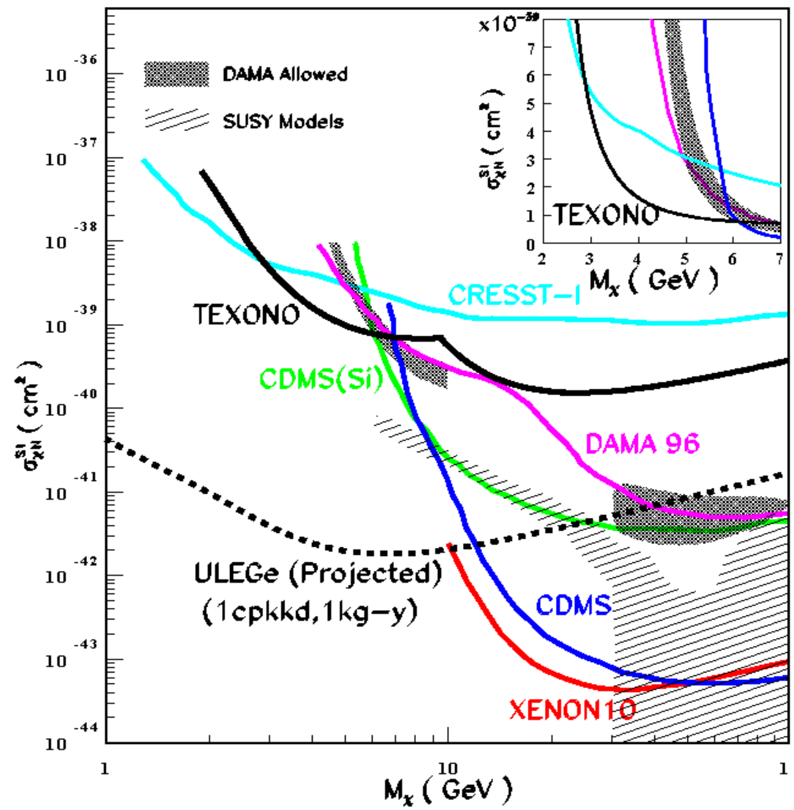
WIMP Spin-Independent Cross Section

Standard conservative analysis :WIMP rates cannot be higher than total events measured – Optimal Interval method

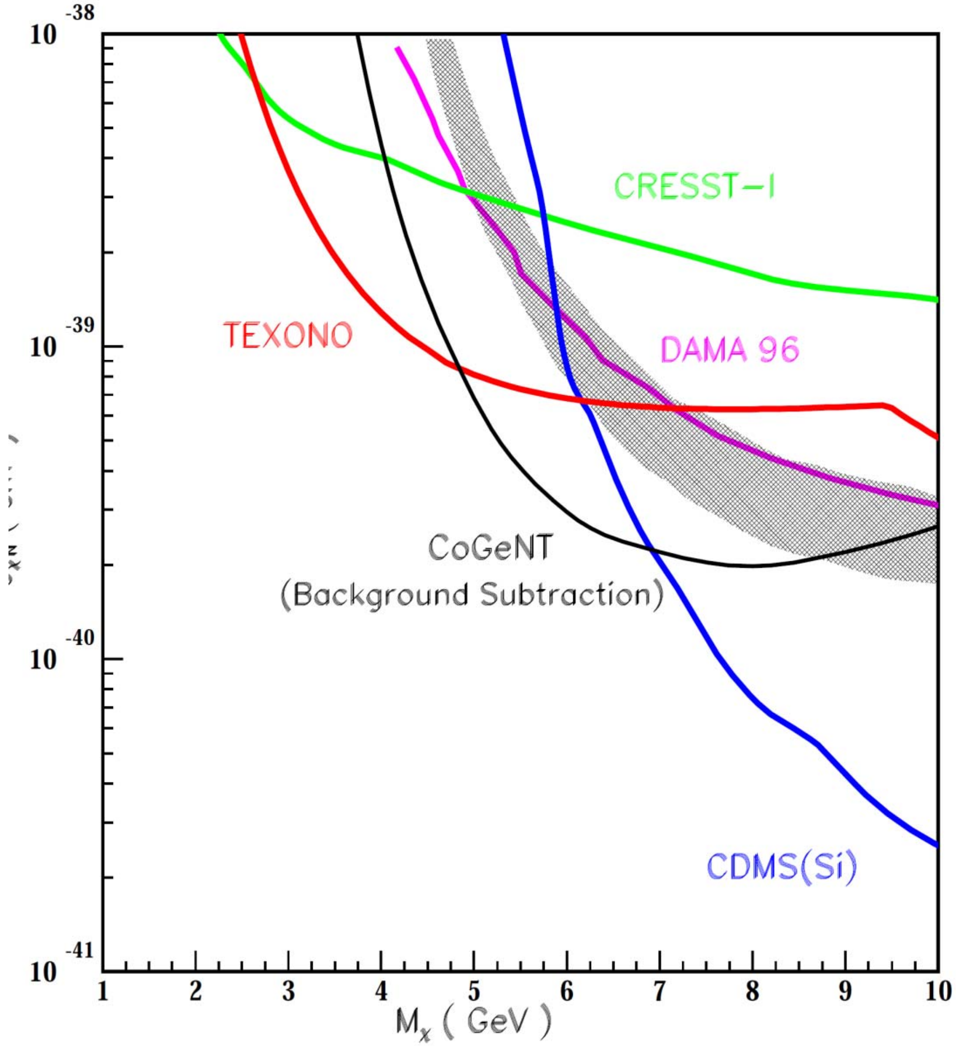
(*S. Yellin PRD 66 032005 (2002)*)

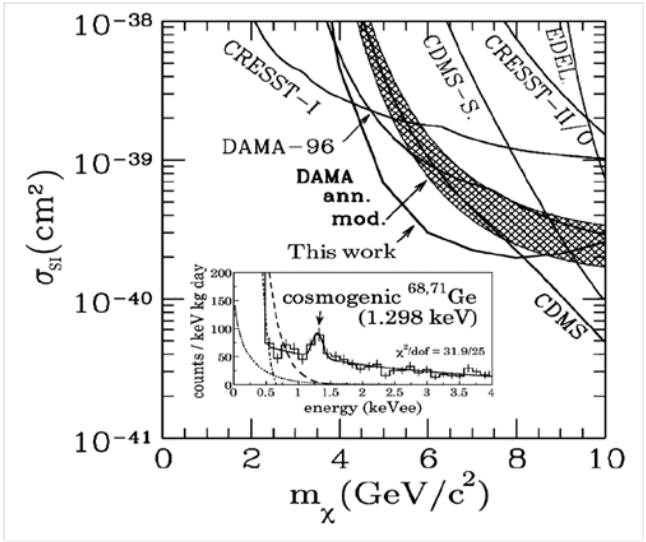


The sensitivity-defining bins		
Energy (eV)	198-241	1390-1870
Raw Counts	105212	75
Background after CRV-ACV-PSD	0	0
Net Efficiencies of signals	0.66	~1
Quenching Factor	0.202	0.245
Spin-independent Cross Section(cm^2) Limit at 90%C.L.	0.81×10^{-39} at 5 GeV	2.0×10^{-40} at 50 GeV
Spin-dependent Cross Section(cm^2) Limit at 90%C.L.	2.4×10^{-34} at 5 GeV	5.9×10^{-35} at 50 GeV



Expanded and Updates … … .

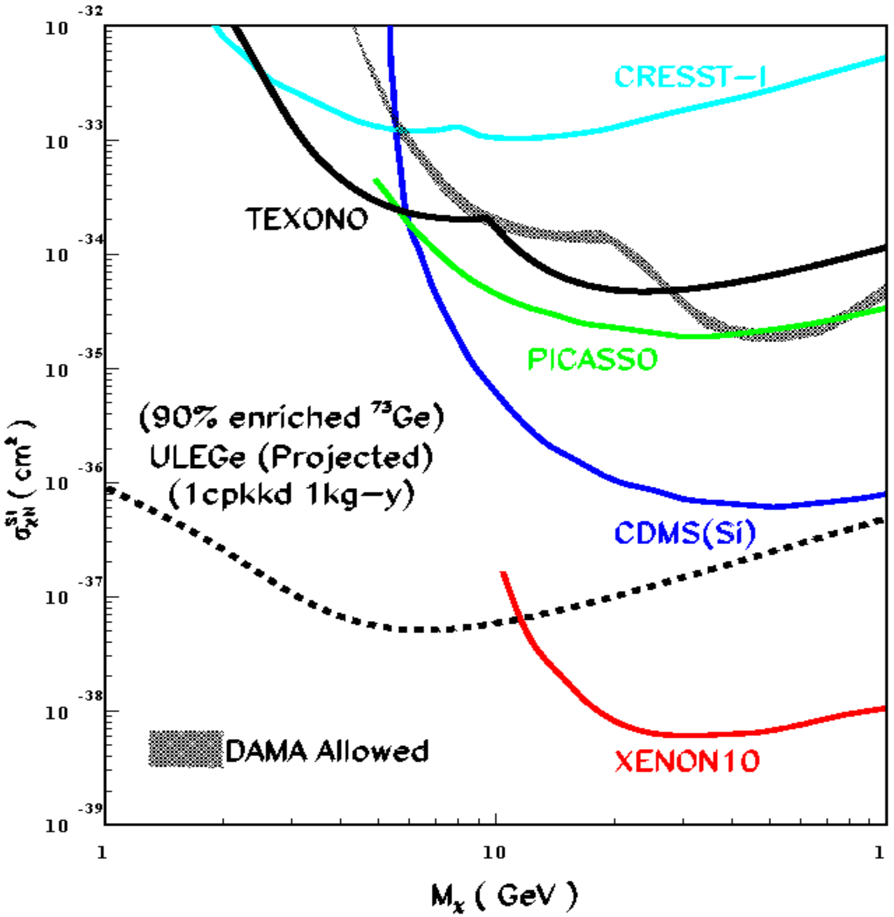




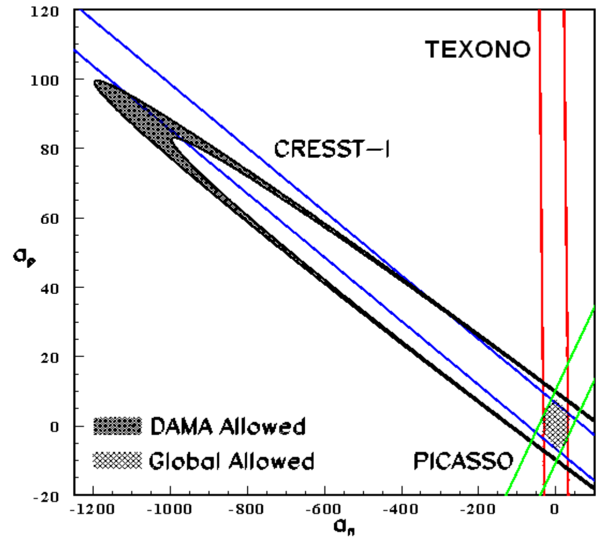
C..E. Aalseth et. al PRL 101,251301(2008)

Results on WIMP Spin-dependent Cross Section
Limits & Sensitivities [PRD 09]

Spin Dependent cross-sections:
Formalism - *T.R. Tovey et al, PLB 488 (2000)*
with Ge matrix elements - *V.I Dimitrov et al, PRD 51 R291 (1995)*

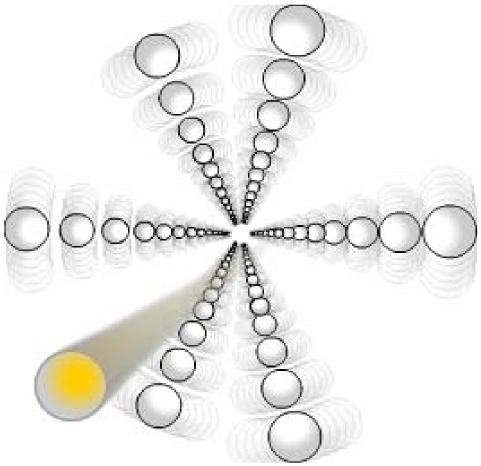


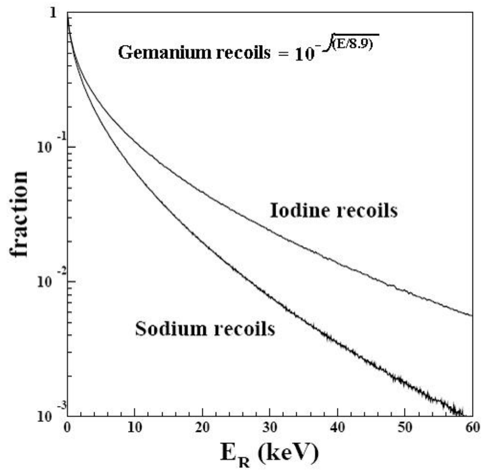
Mχ = 5 GeV



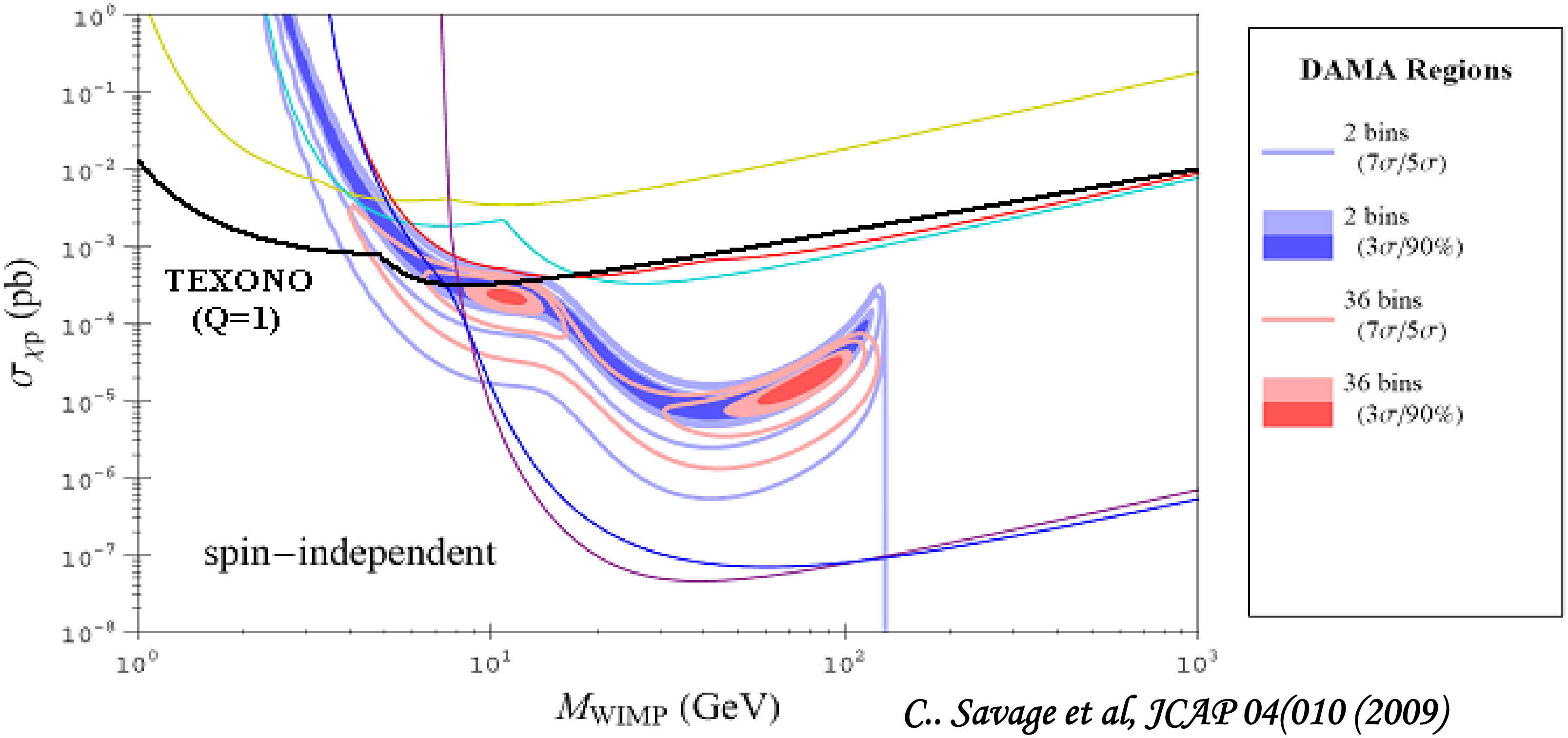
Allowed regions of WIMP-nucleon couplings (proton and neutron) with a WIMP mass of 5 GeV , at 90% C.L.

Ion Channeling Effect in Ge crystals (Q.F. ?→ 1)



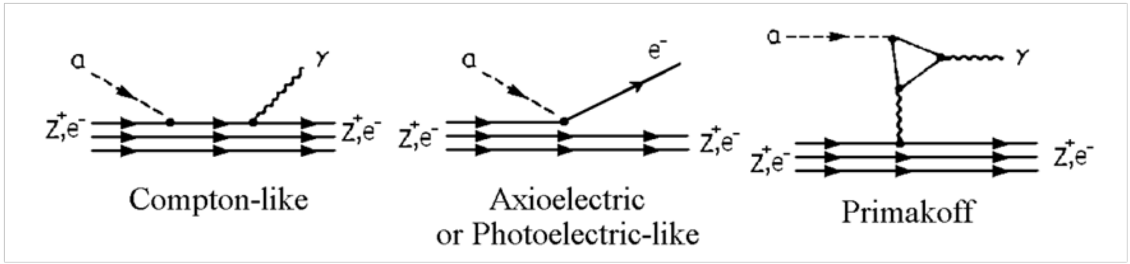


Q.F. value influences **: making and breaking of quasi-molecular bonds of channeled ions with ions in the channel walls, impurity of crystals, etc.** → *QF Measurement*



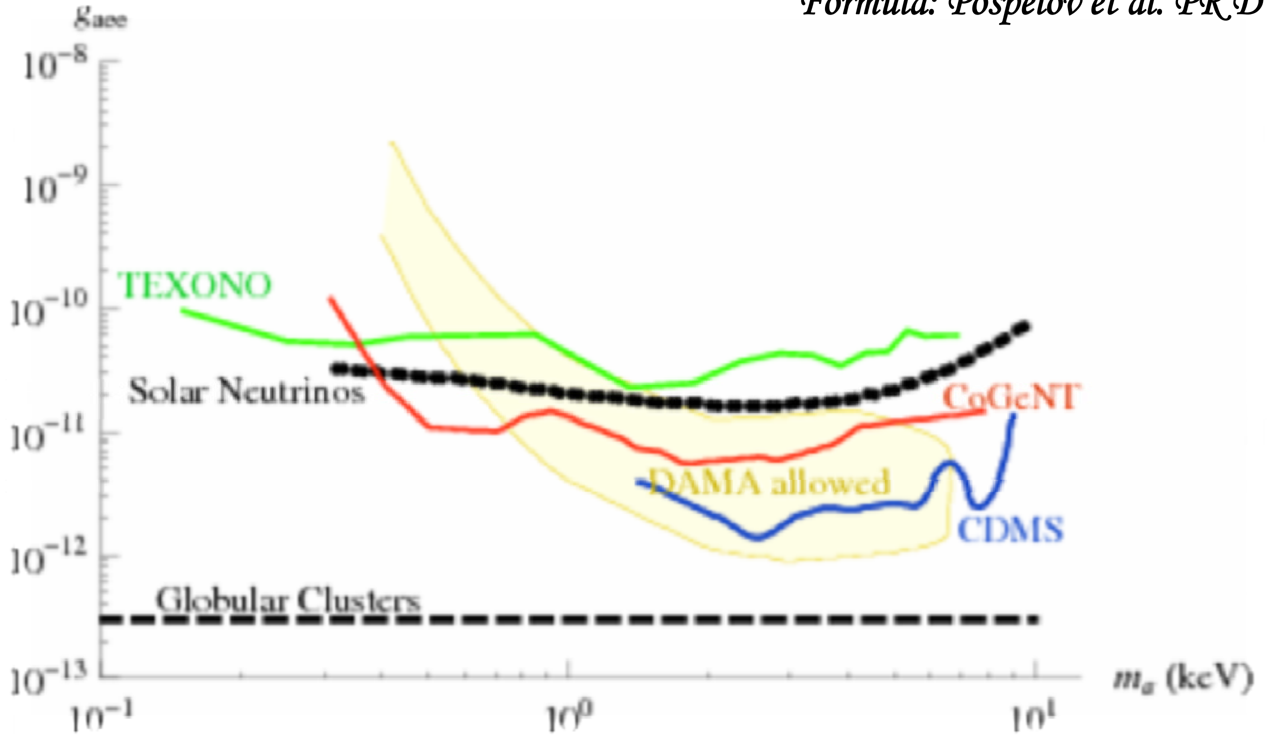
C.. Savage et al, JCAP 04(010 (2009)

Pseudoscalar Candidates (*axionlike*)



$$R \simeq \frac{1.2 \times 10^{19}}{A} g_{aee}^2 \left(\frac{m_a}{\mathrm{keV}}\right) \left(\frac{\sigma_{photo}}{\mathrm{bn}}\right) \ \mathrm{kg}^{-1}\mathrm{day}^{-1}$$

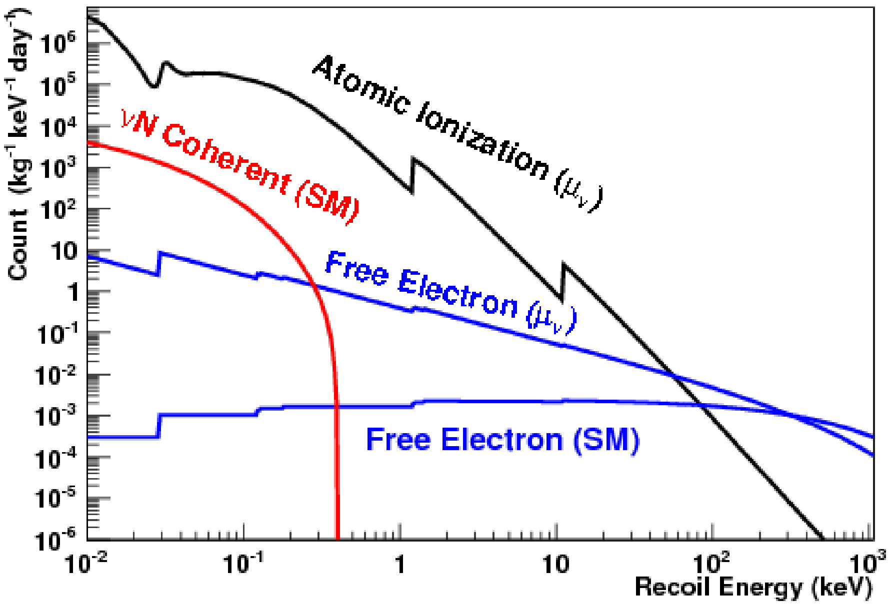
Formula: Pospelov et al. PR D 78, 115012 (2008)

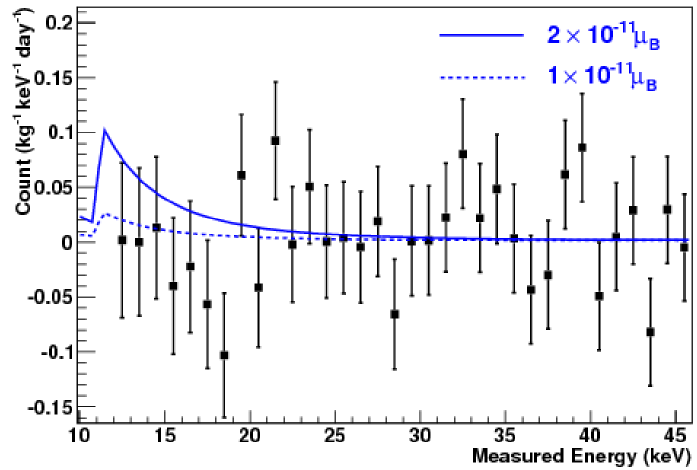


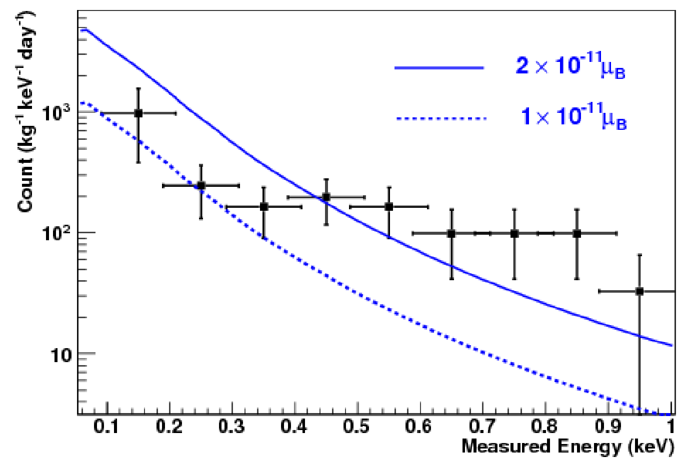
C..E. Aalseth et al. PRL 101, 251301(2008) ; Z. Ahmed et al. PRL103, 41802(2009)

Neutrino Magnetic Moment through Atomic Ionization channel

$$\left(\frac{d\sigma}{dT}\right)^{AI} \simeq \mu_\nu^2 \, \frac{\alpha_{em}}{\pi} \, \left(\frac{E_\nu}{m_e}\right)^2 \frac{1}{T} \, \sigma_{\gamma A}(E_\gamma = T)$$





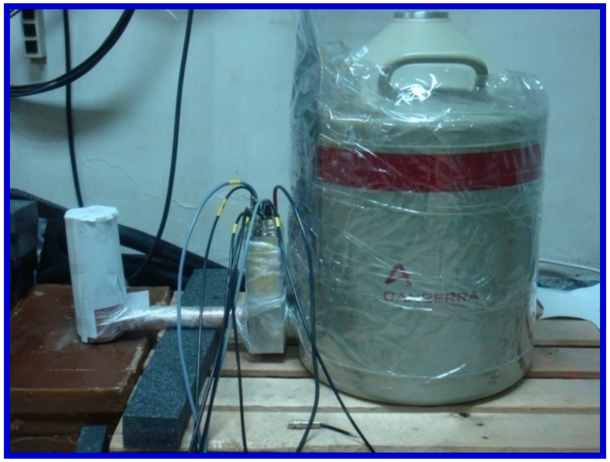


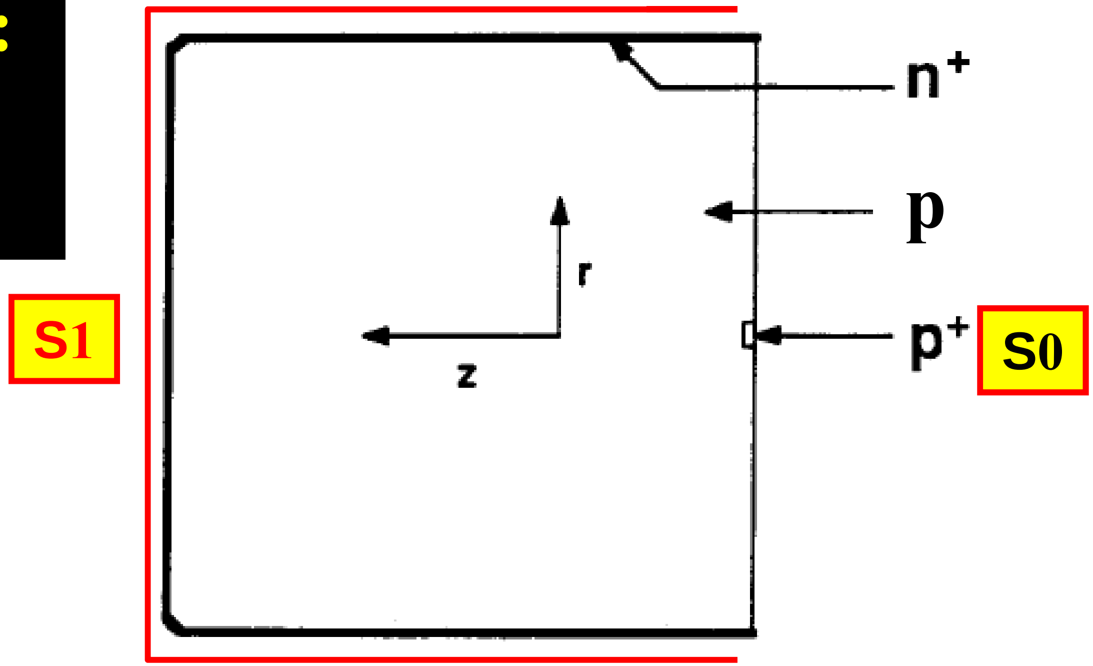
- **The limit analyzed with the same method of *WIMP* search**

  $\mu_\nu(\nu_e)$ < 1.3 X 10^{-11} μ_B (90% CL) *@arXiv:1001. 2074*

- **Based on *100 eV* threshold & *1 cpkkd* background can probe down to ~ 10^{-13} μ_B**

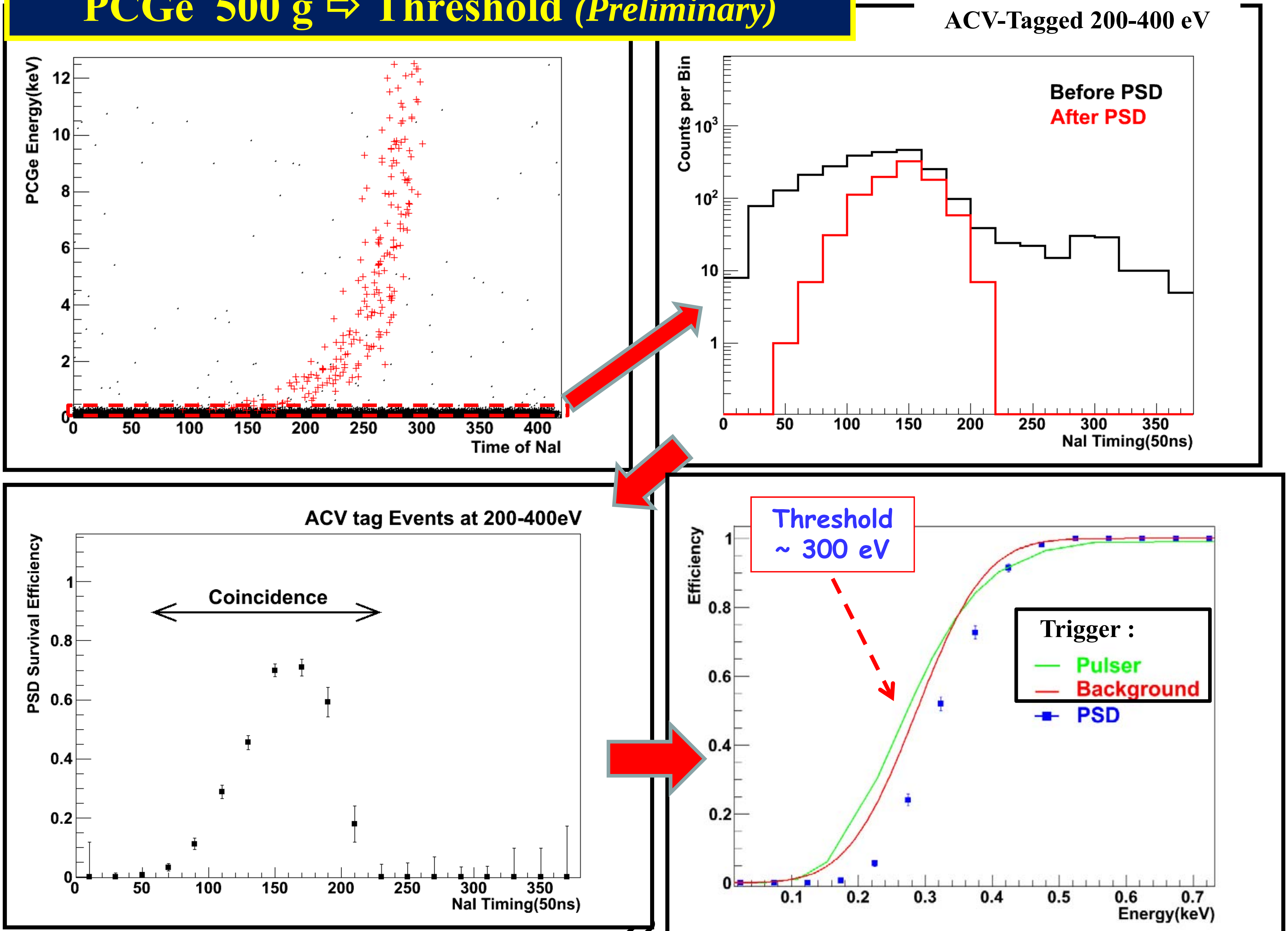
Detector Scale-up Plans: Point Contact Ge Detector





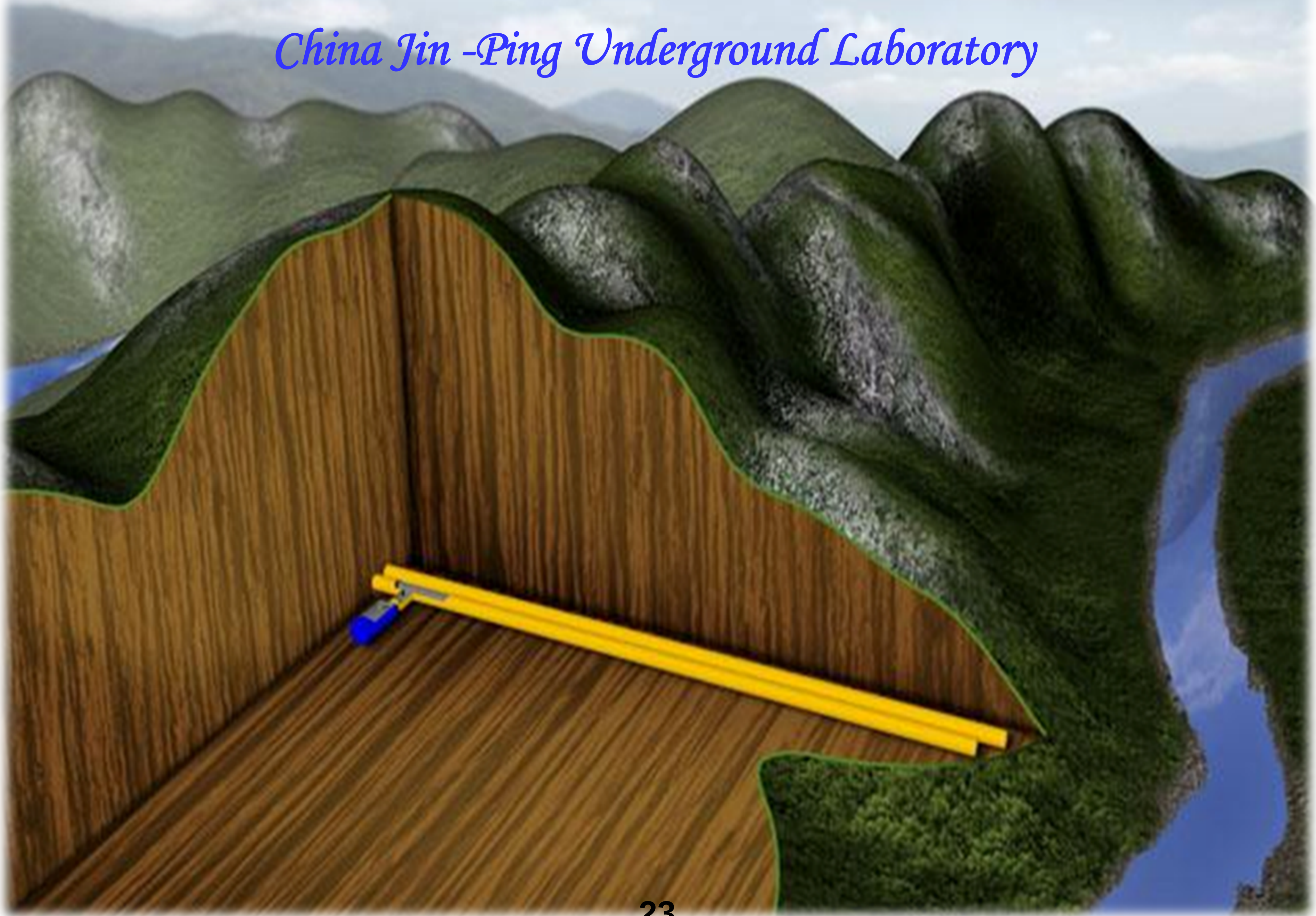
- Large Mass & Low Threshold -- Proposed *[Luke 80's]* ; successful demonstration *[CoGeNT 2007]*
- Position-sensitive from drift-profile pulse shape
- Add: Dual-electrode readout and ULB specification
- 500-g built ; KS data taking Nov. 2008
- 900-g detector 2010

PCGe 500 g ⇨ Threshold *(Preliminary)*



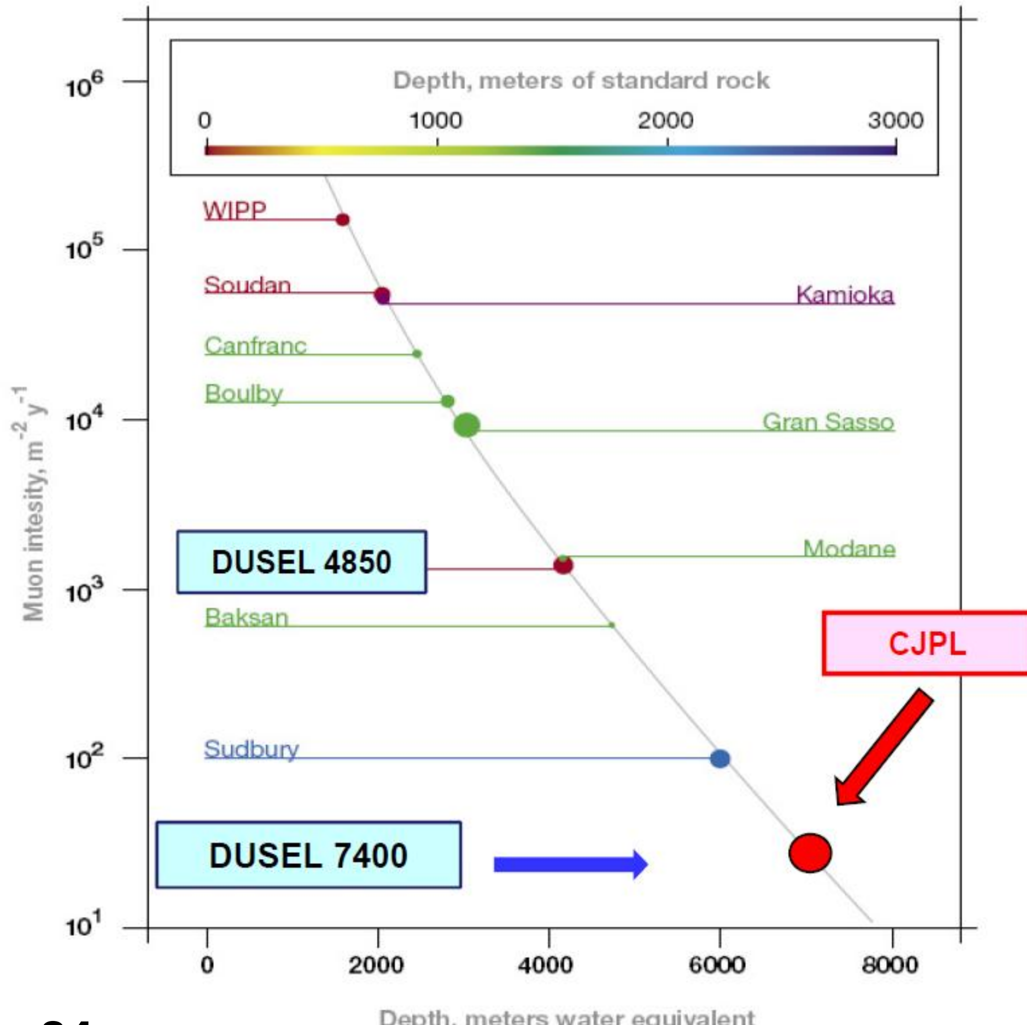
From By-Product Physics to Dedicated Experiment :

China Jin -Ping Underground Laboratory

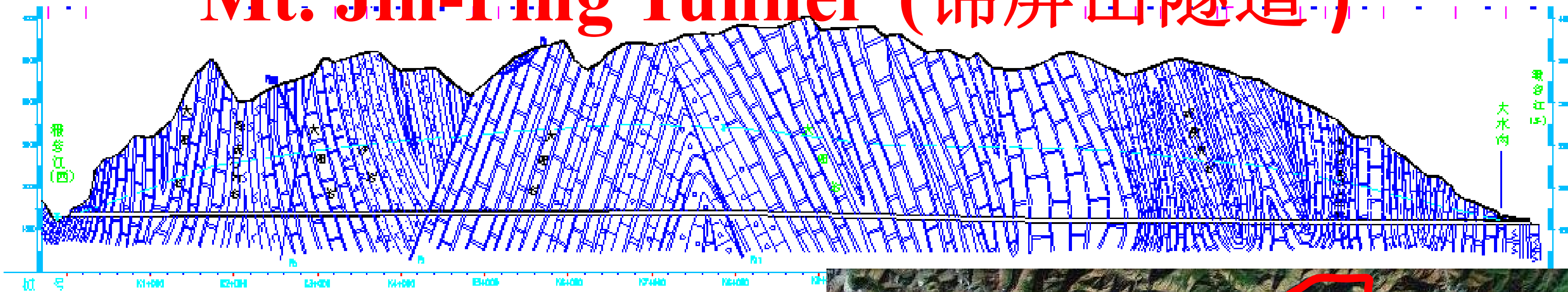


WIMP search : *China Jin-Ping Underground Lab*

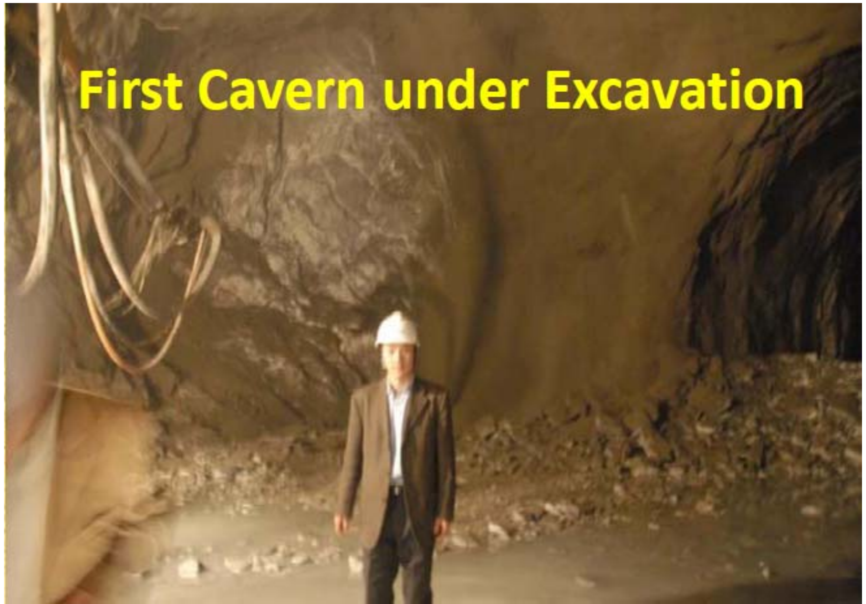
- 2500 +m rock overburden
- 6X6X40 m cavern under construction (c/o THU)
- 20 g ULEGe 2010 ; 500 g PCGe 2011

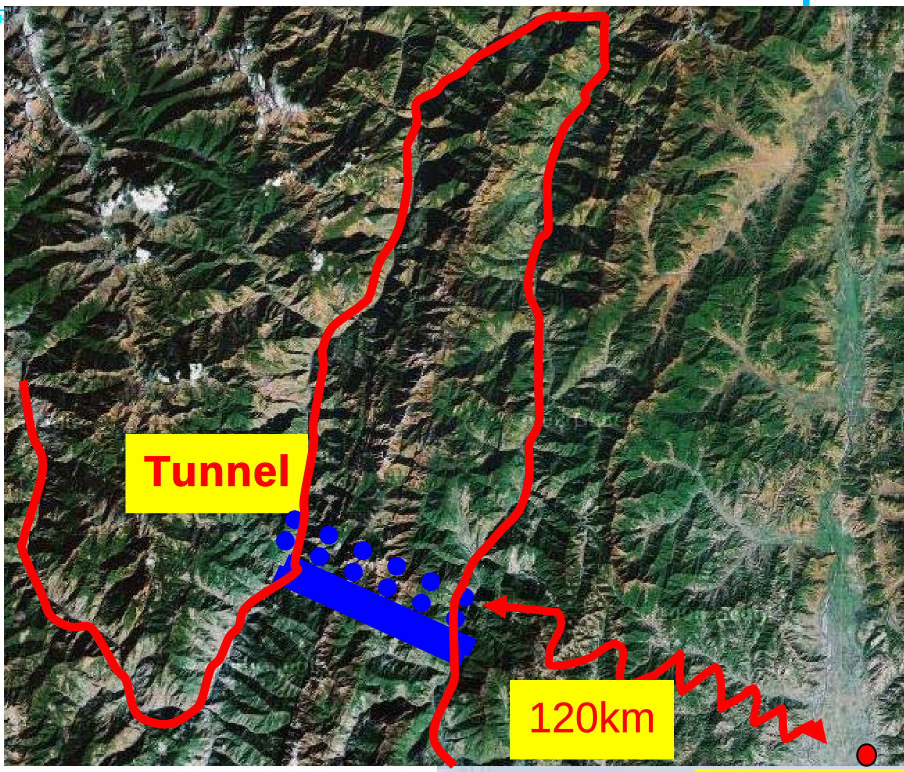


Mt. Jin-Ping Tunnel (锦屏山隧道)



- Max. Rock Overburden: 2375 m
- Road Tunnel Distance: 17.5 km
- 1 hour drive from Xi-Chang where 30 min flight from Cheng-Du





Status and Plans

- **Competitive limits at *WIMP-mass < 10 GeV* already obtained with ULEGe 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 at *sub-keV* range.**
- **Installed the 500-g Point-Contact HPGe at *KS Lab* in *Nov.* 2008**
- ***Sub-keV* Ge quenching factor measurement & Ions Channeling effect at *CIAE* neutron facility in 2010**
- ***Plan* : move in Sichuan underground Lab. (>2 km rock) soon**
- ***Goals* : open new detection channel and detector window for neutrino and dark matter physics**