Dark Matter Search with Germanium Detector at O (100 eV) threshold

- **Overview (Collaboration ; Program ; Laboratory)**
- **ULE-HPGe: Physics & Requirements**
- **Event selection and efficiencies**
- **Dark Matter analysis and Results** *[PRD 79(R), 2009]*
- **Status & plans**

Lin, Shin-Ted / 林欣德 On Behalf of TEXONO Collaboration

5th Patras Workshop on Axions, WIMPs and WISPs July 13-17 2009 @ Durham (UK)

TEXONO Collaboration

- *Collaboration :* **Taiwan (AS, INER, KSNPS, NTU) ; China (IHEP, CIAE, THU, NKU, NJU) ; Turkey (METU) ; India (BHU)**

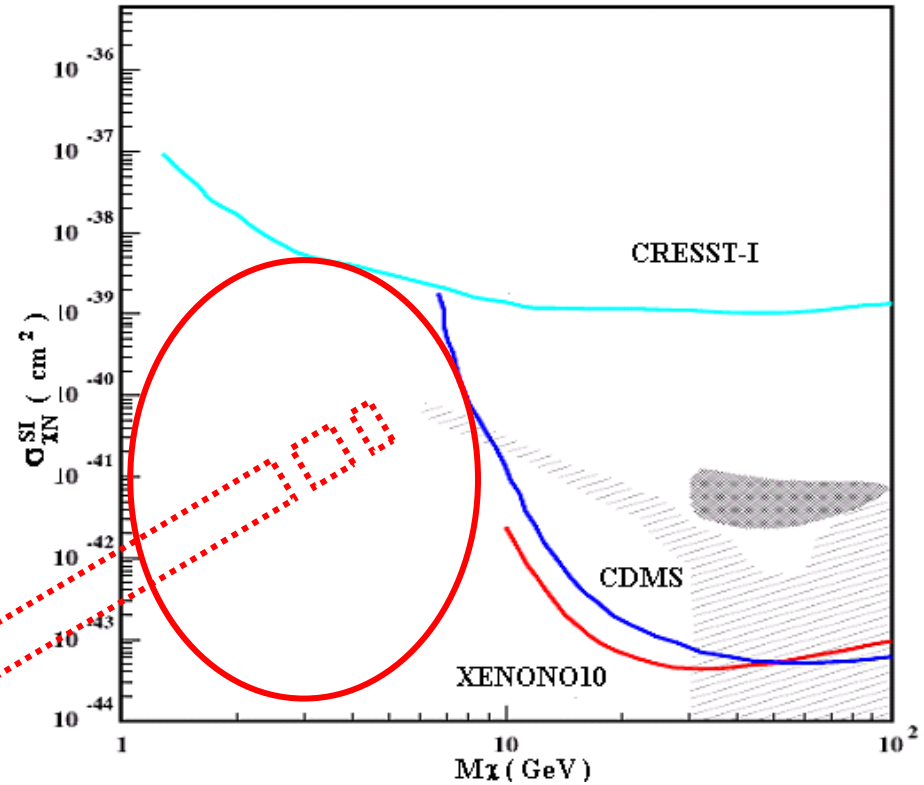
  + *partnership* KIMS (Korea)

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

Spin-independent Sensitivity Plot for *WIMP* direct search

$\chi N \rightarrow \chi N$

- A^2 dependence (spin-independent)

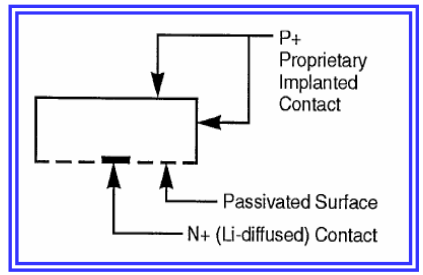


Low (<10 GeV) WIMP Mass / Sub-keV Recoil Energy :

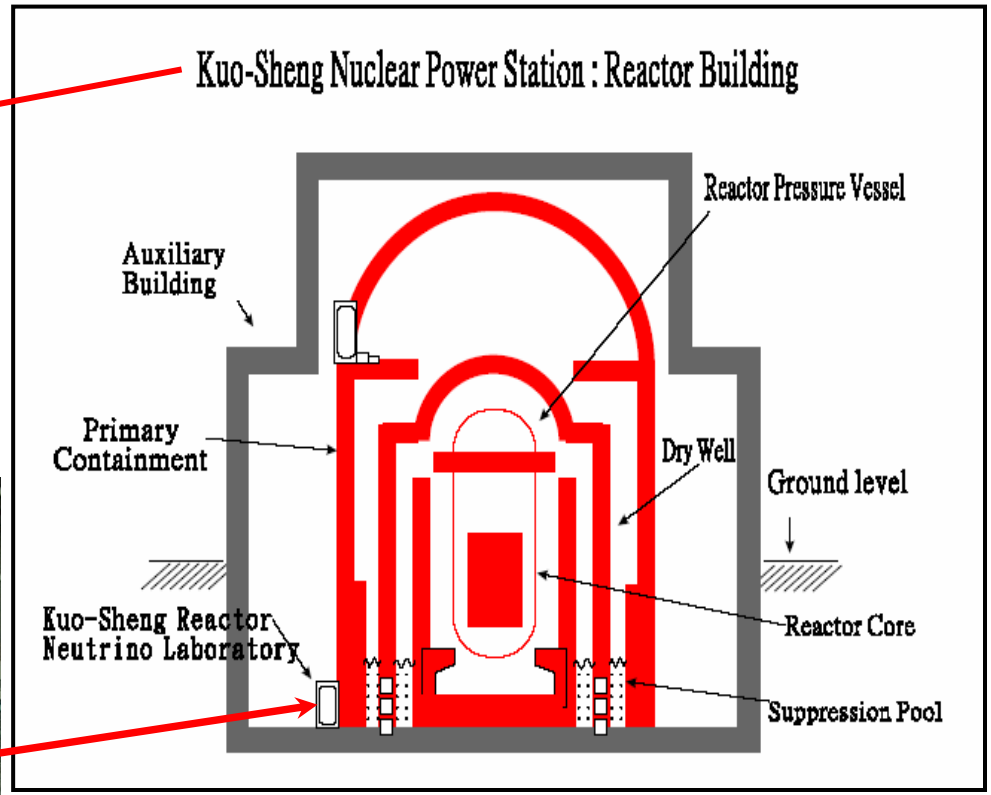
- Not favored by the most-explored specific models on galactic-bound SUSY-neutralinos as CDM ; *still* allowed by generic SUSY
- Various gravitational effects favor lower recoil energy ⇨ *Solar-system bound* WIMPs ; *Dark Disk* etc.
- Other candidates favoring low recoils exist ⇨ non-pointlike SUSY *Q-balls* , 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**
  - **Improve sensitivities on μ_ν**
  - **Low-mass WIMP searches ← *this talk***
  - **Implications on reactor operation monitoring**
  - **Open new detection channel & detector technology windows for surprises**



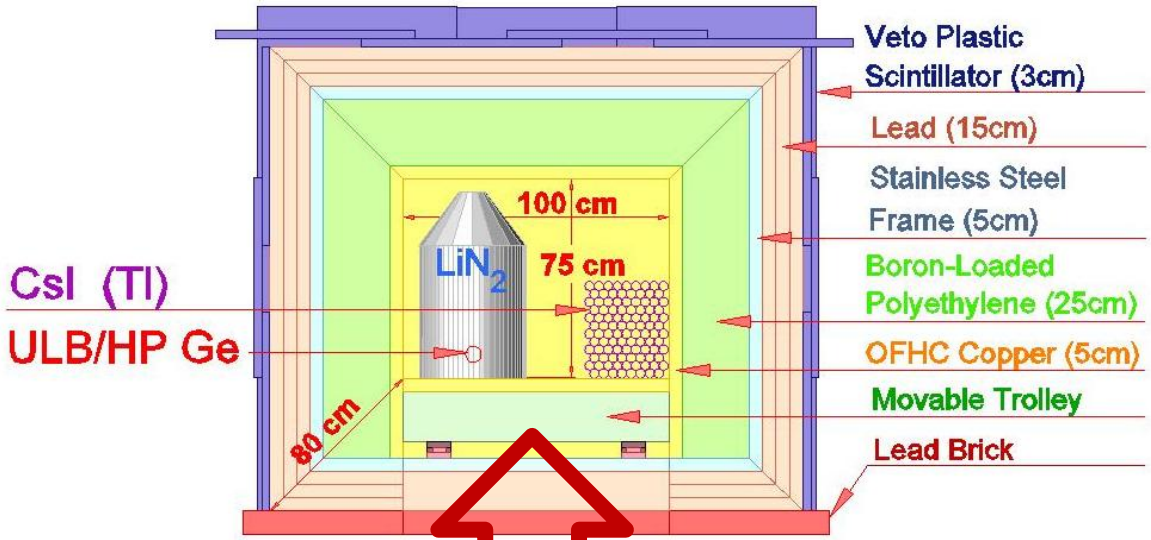
Kuo -Sheng Reactor Neutrino Laboratory：

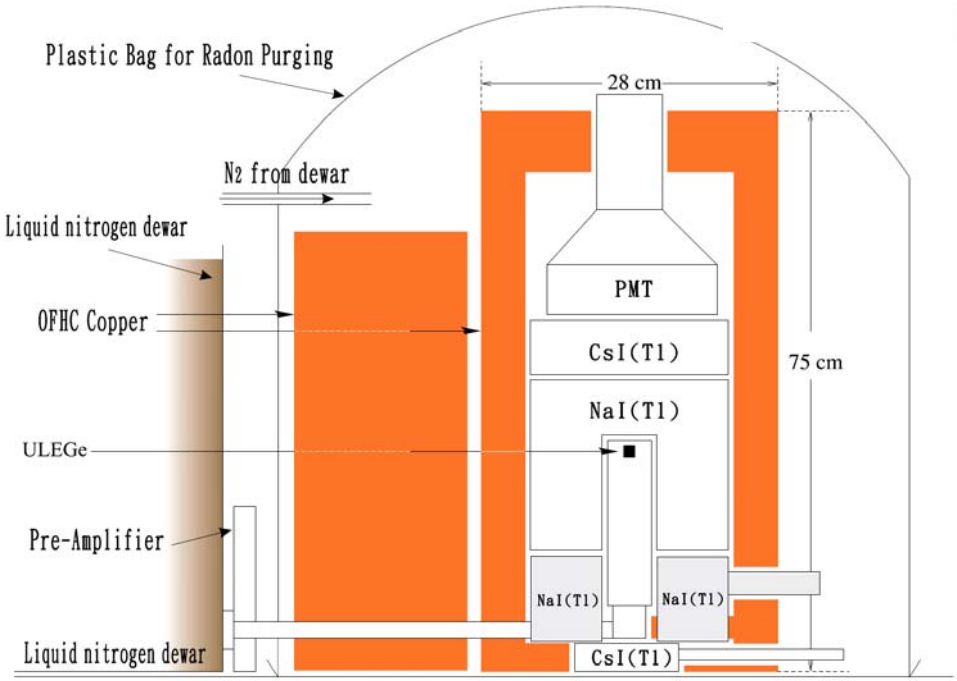


28 m from core#1 @ 2.9 GW
Shallow site : ~30 *m..w..e.* overburden
~10 m below ground level

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

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

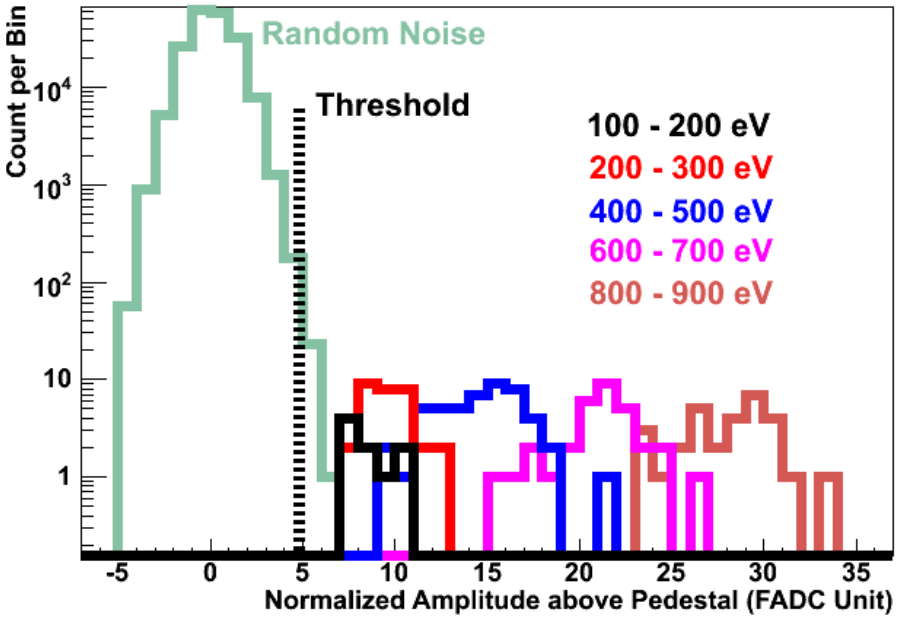


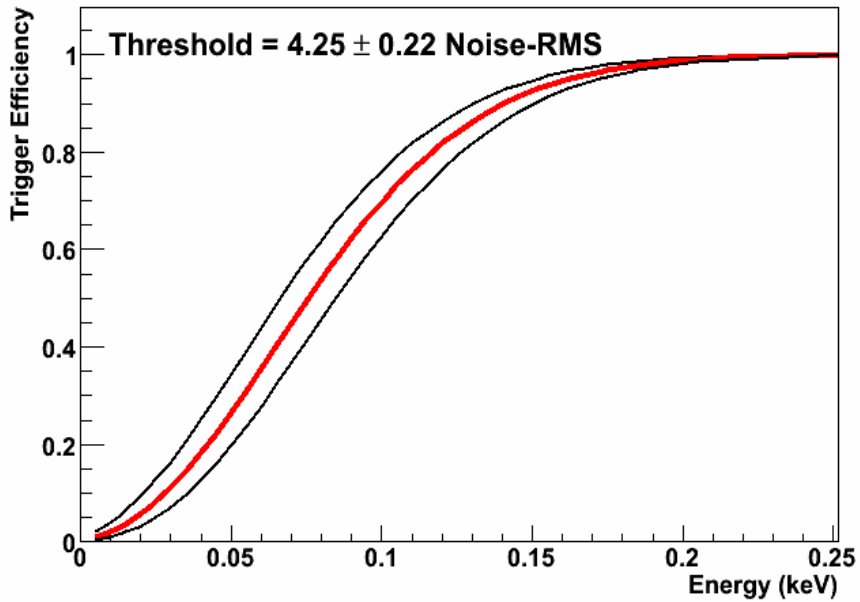


- **Candidate events : survive Anti-Compton (*ACV*) and Cosmic-Ray (*CRV*) vetos**

--- Efficiency evaluated by Random trigger events.

Evaluation of Trigger Efficiency



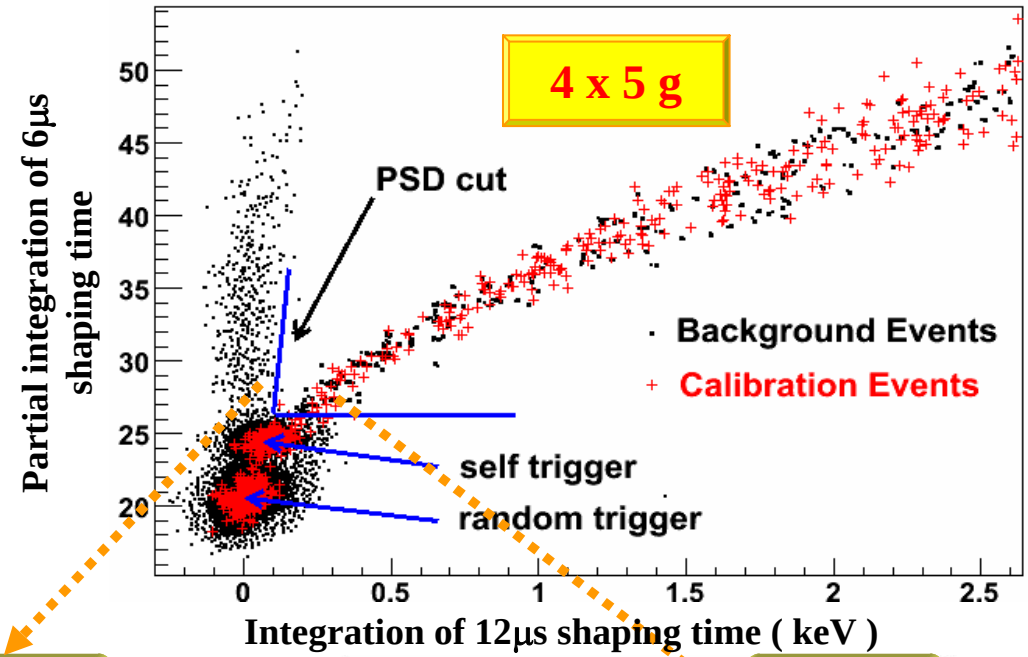


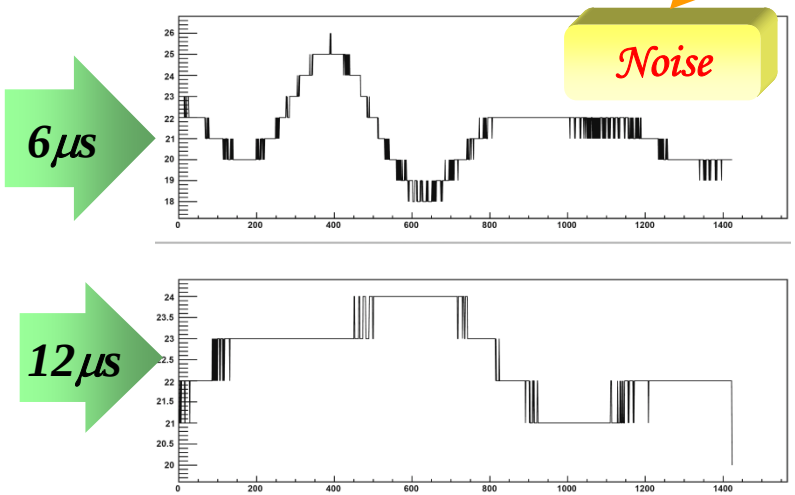
- DAQ threshold at ~ 4.3σ above mean of noise fluctuations → *no DAQ dead time concern*
- Max. amplitude of physics events → good margins above threshold
- Efficiency Evaluation : from (*mean* , *RMS*) of Max. amplitude distribution of physics events ⊕ test-pulser reference events

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

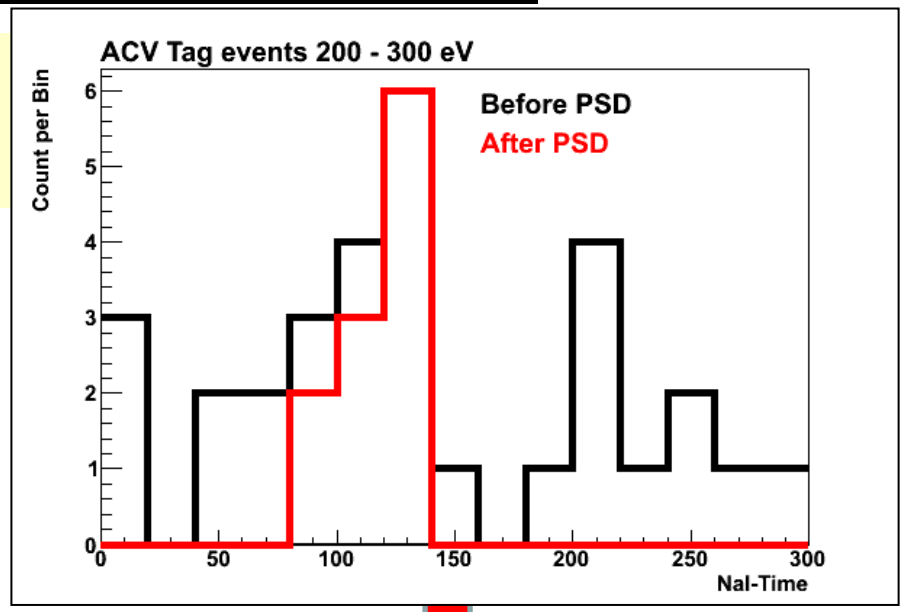
$$f = \frac{(\epsilon_{\mathrm{PSD}} * P + f_N * N)}{P + N}$$

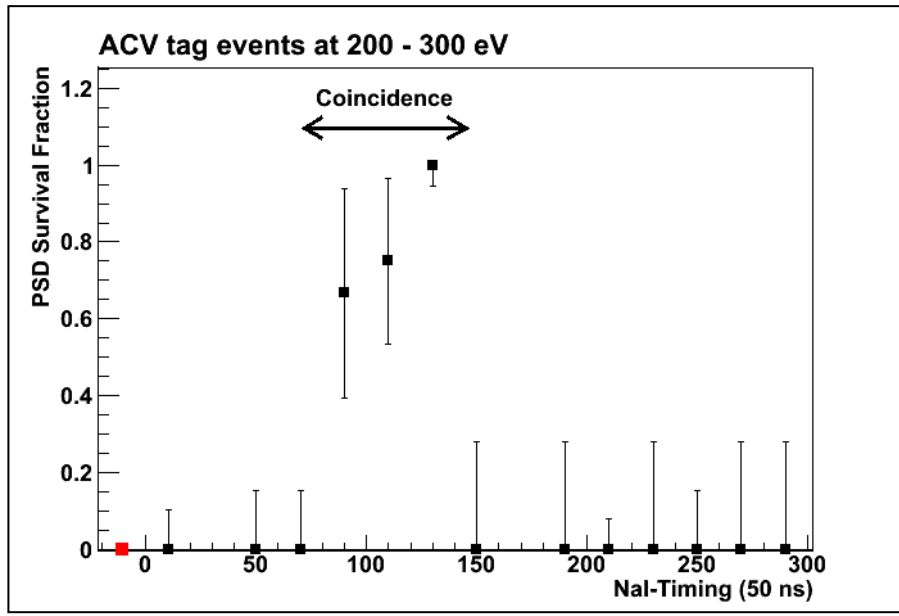
Measured: $f_N \sim 10^{-4}$

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

⇨ **Conservative choice :**

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



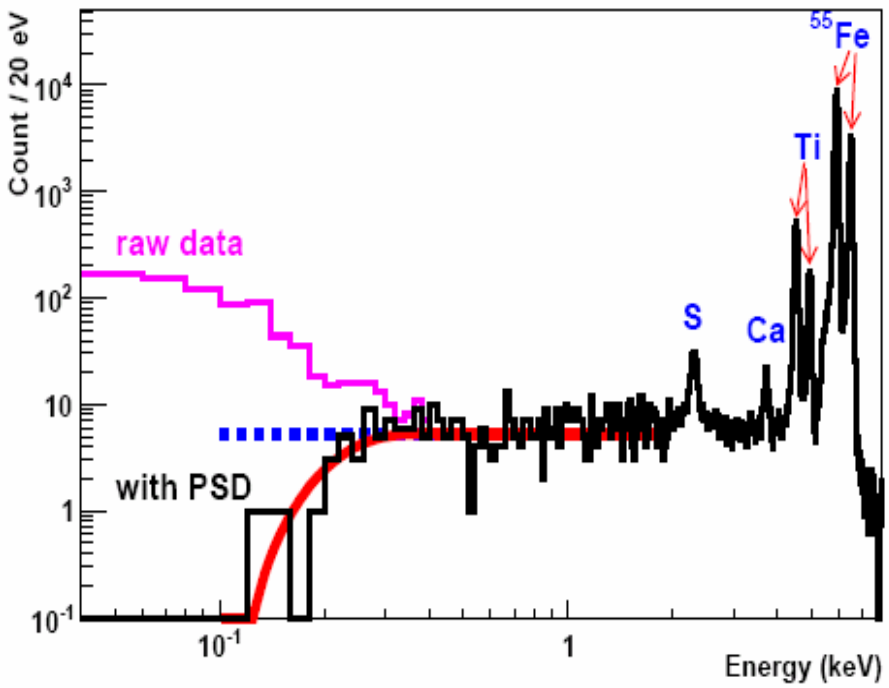


PSD Selection Efficiency

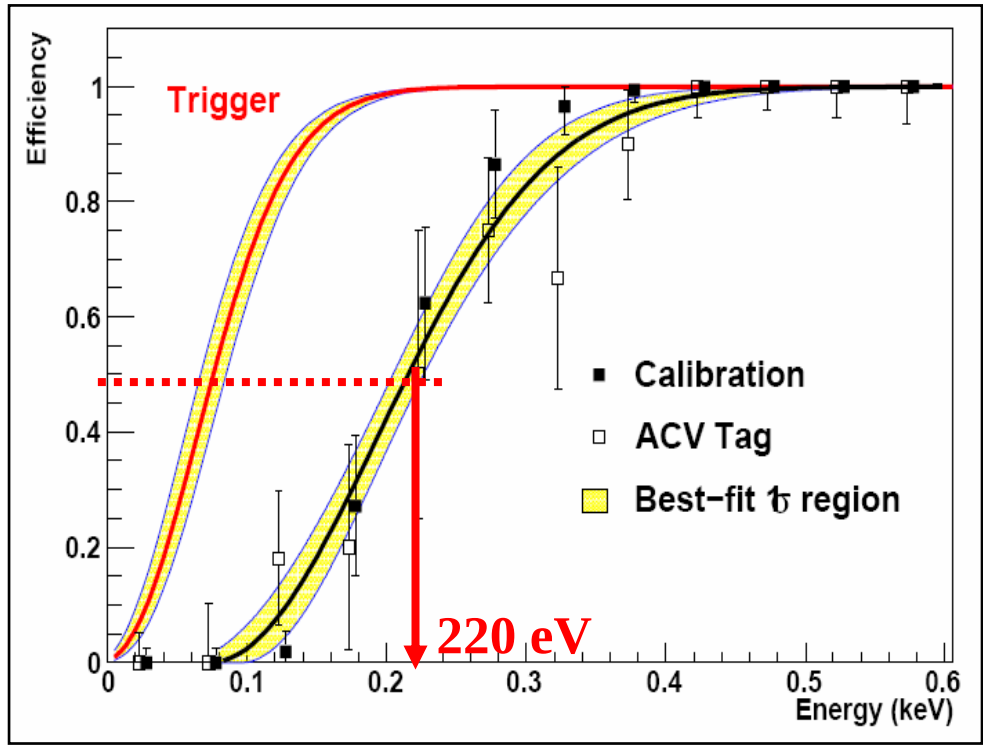
Supported & statistics reinforced by ^{55}Fe calibration spectra

⇨ deviations from flat at low energy.

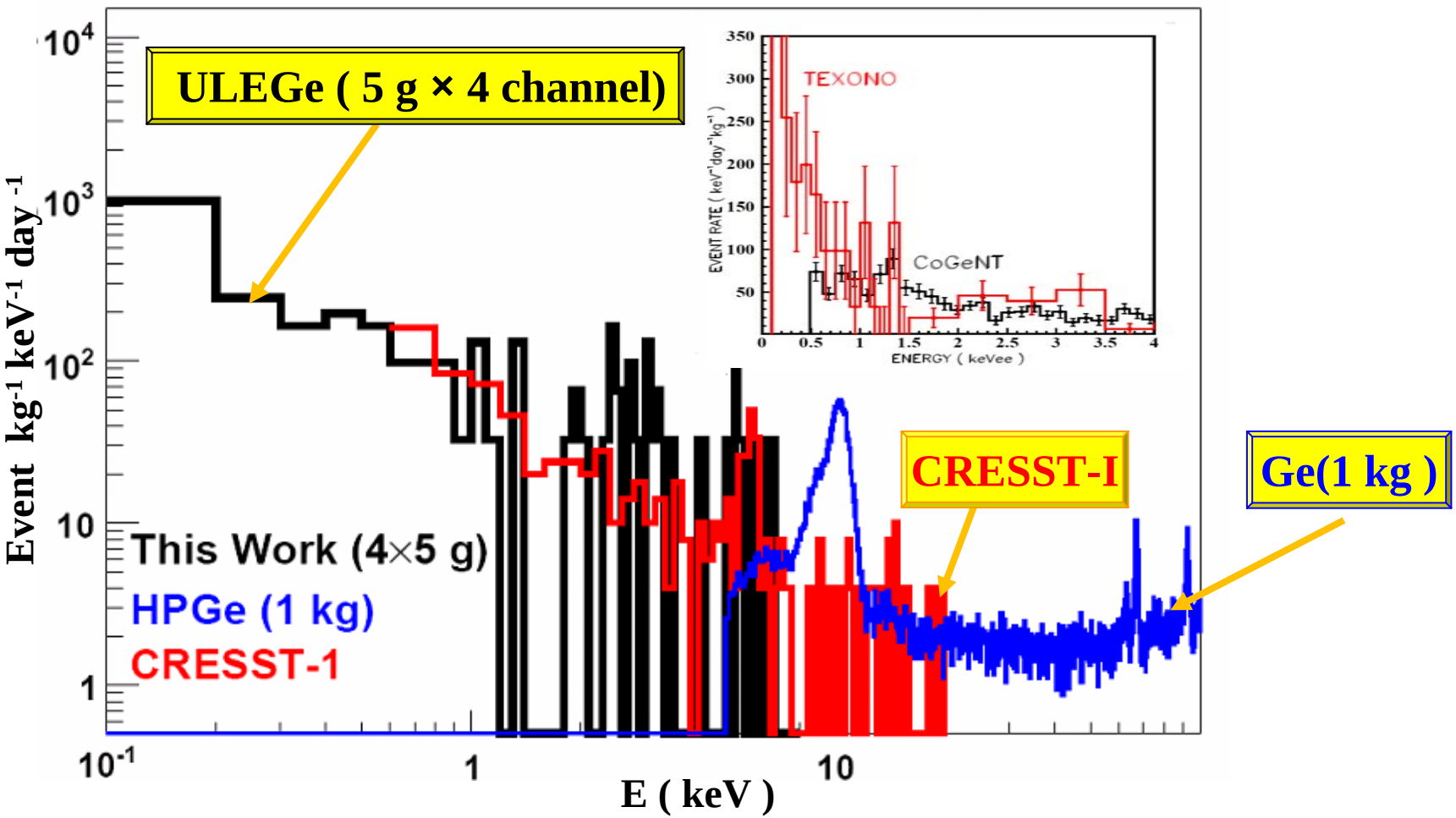
^{55}Fe sources for calibration & PSD efficiency



ε=50% @ 220 eV

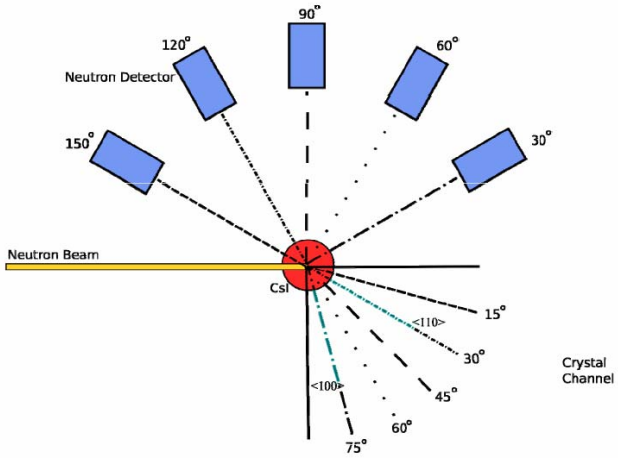


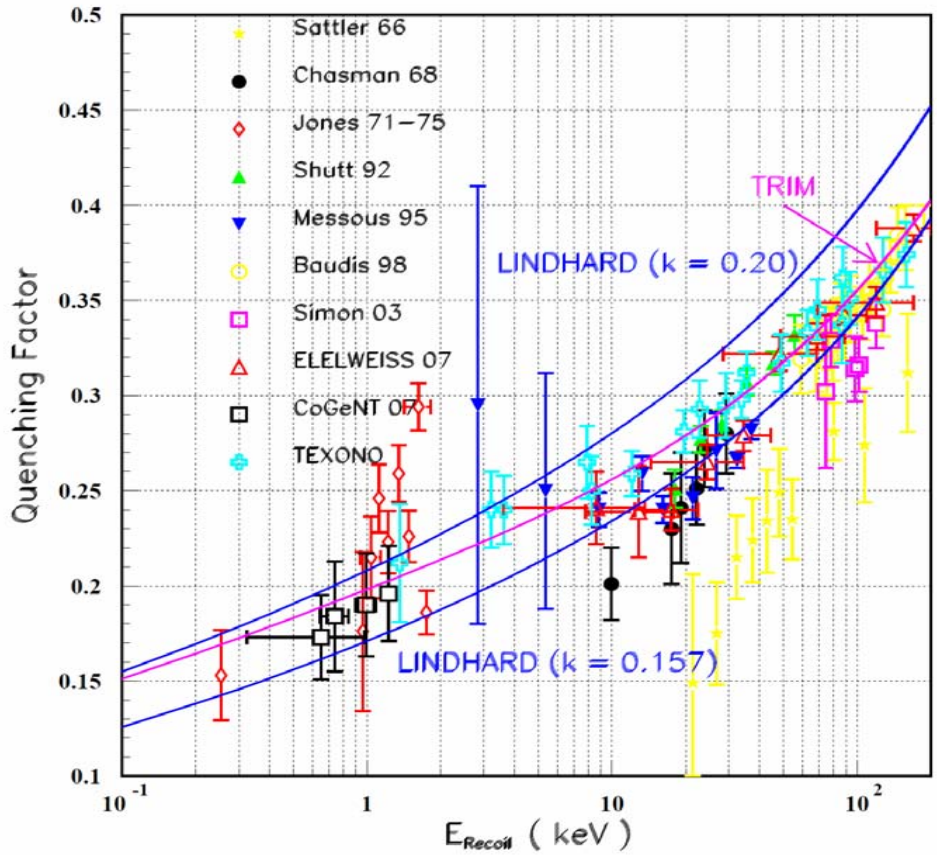
Sub-keV Background Measurements & Comparisons



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

Quenching Factor [Ionization Yield ⇨ Recoil Energy]





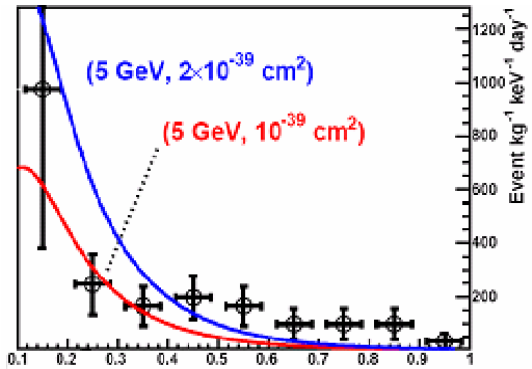
- **TRIM (better fits to available data)**
- **improved measurement planned at CIAE**

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

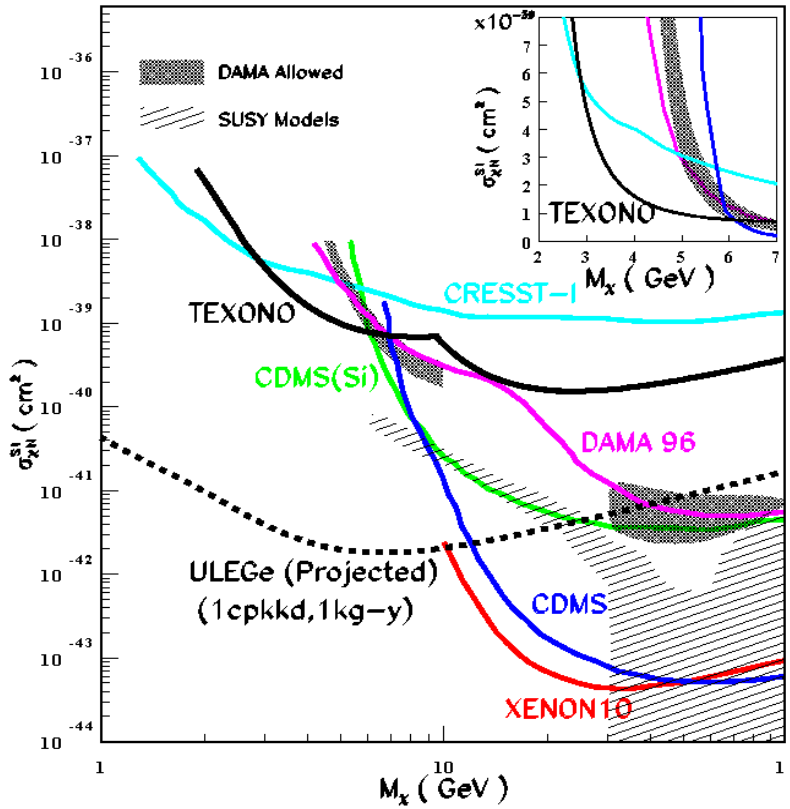
Results on WIMP Spin-Independent Cross Section

Limits & Sensitivities [PRD09]

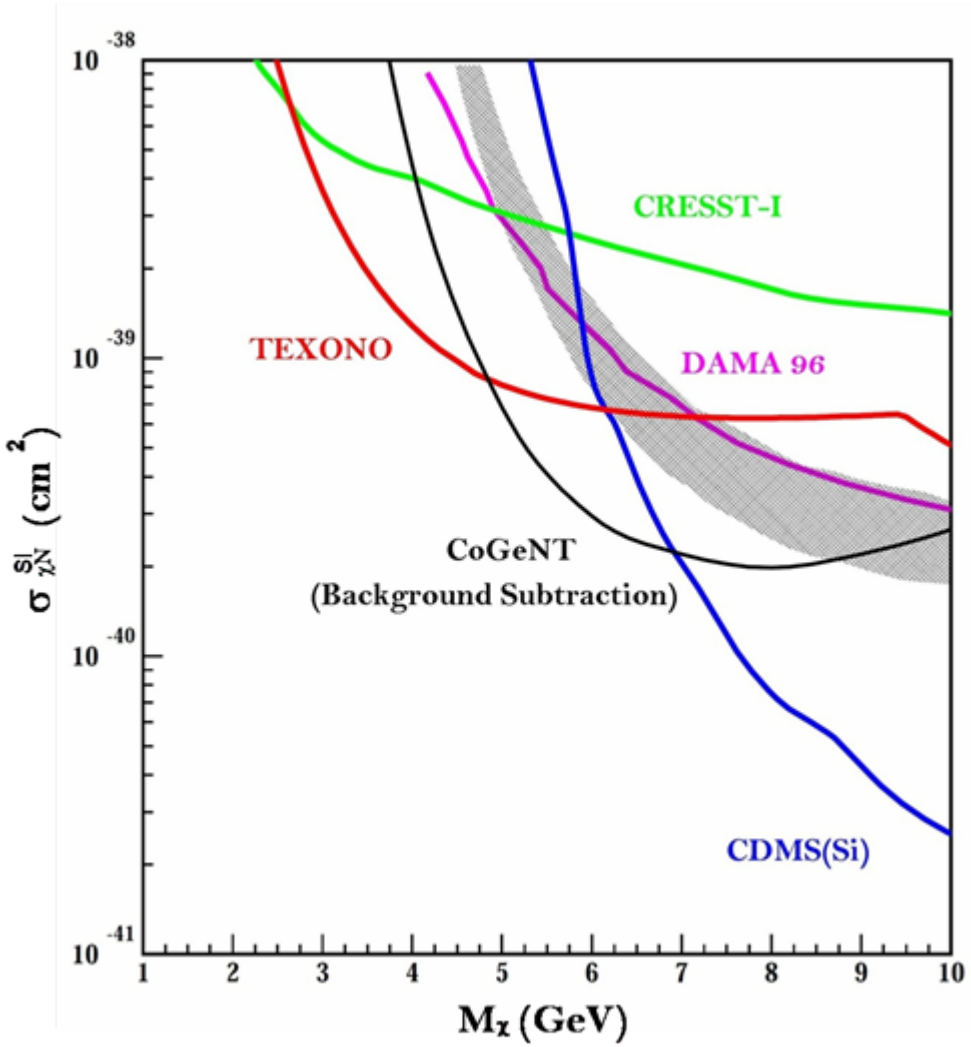
- **Standard conservative analysis ⇨ WIMP rates cannot be larger than total events measured** ***[NO BACKGROUND SUBTRACTION]***
- **Optimal Interval method** (*S. Yellin PRD 66 032005 (2002)*)

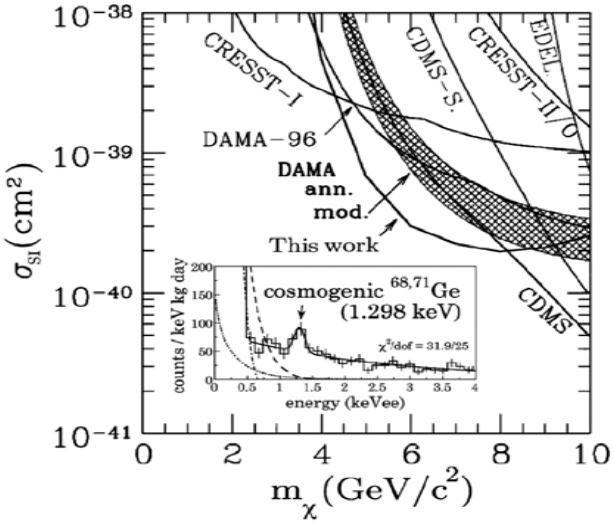


The sensitivity-defining bins		
Energy (eV)	198-241	1390-1870
Raw Counts	105212	75
Background after CRV-ACV-PSD	0	0
Net Efficiencies of signals	0.66	~1
Quenching Factor	0.202	0.245
Spin-independent Cross Section(cm^2) Limit at 90%C.L.	0.81x10^{-39} at 5 GeV	2.0x10^{-40} at 50 GeV
Spin-dependent Cross Section(cm^2) Limit at 90%C.L.	2.4x10^{-34} at 5 GeV	5.9x10^{-35} at 50 GeV



Expanded and Updates … … .



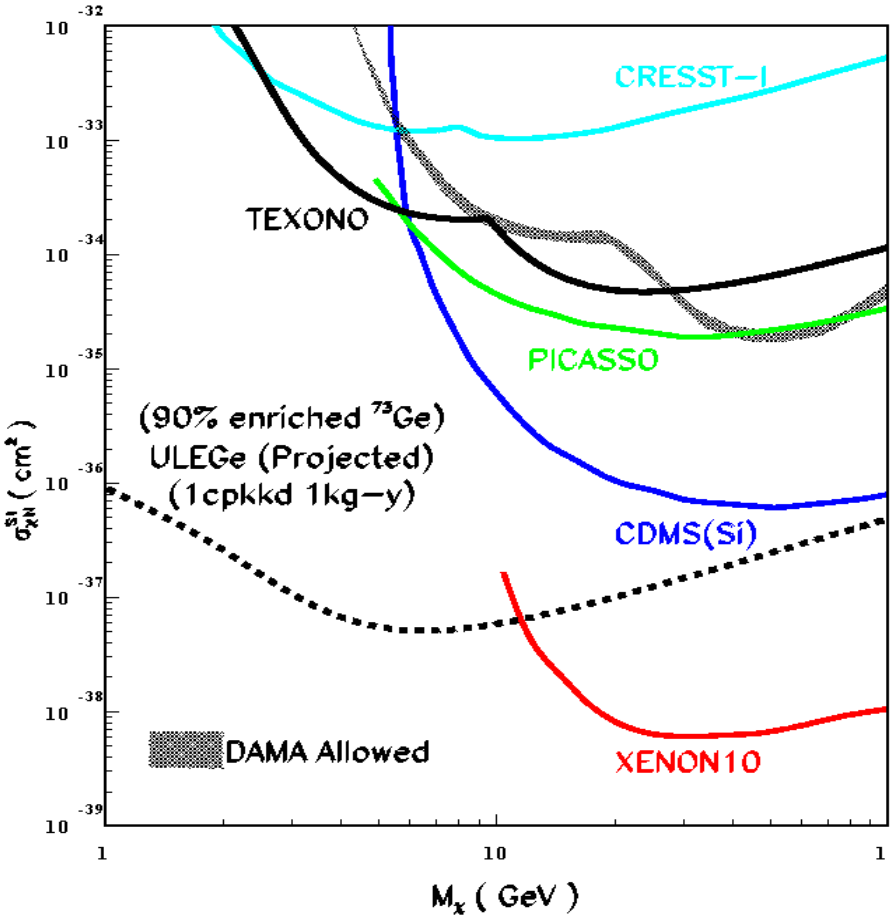


C..E. Aalseth et. al PRL 101,251301(2008)

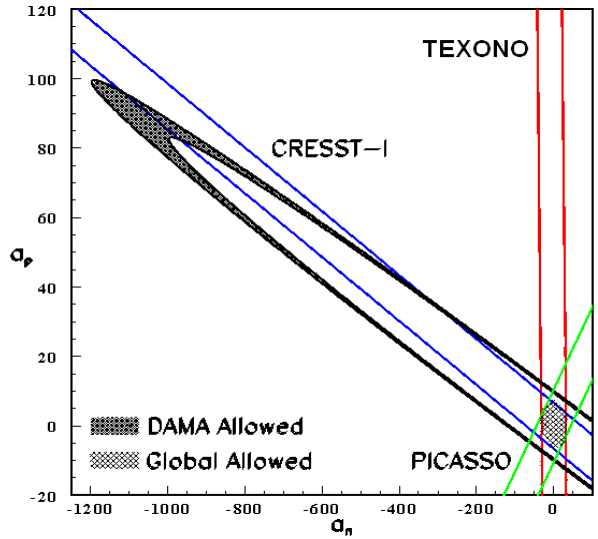
Results on WIMP Spin-dependent Cross Section

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)***

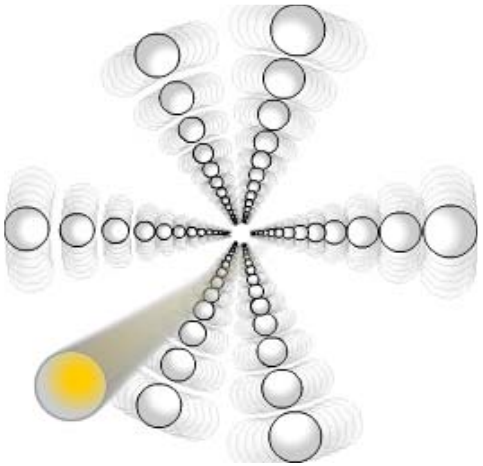


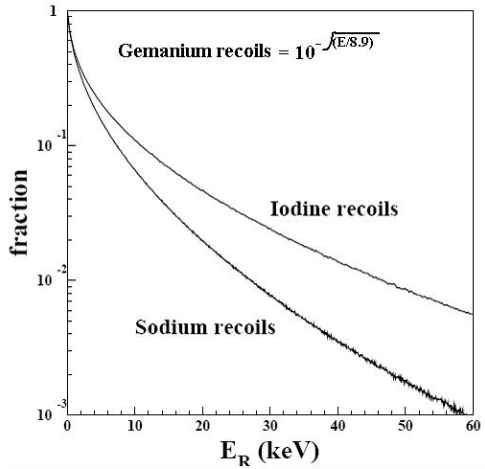
$M\chi$ = 5 GeV



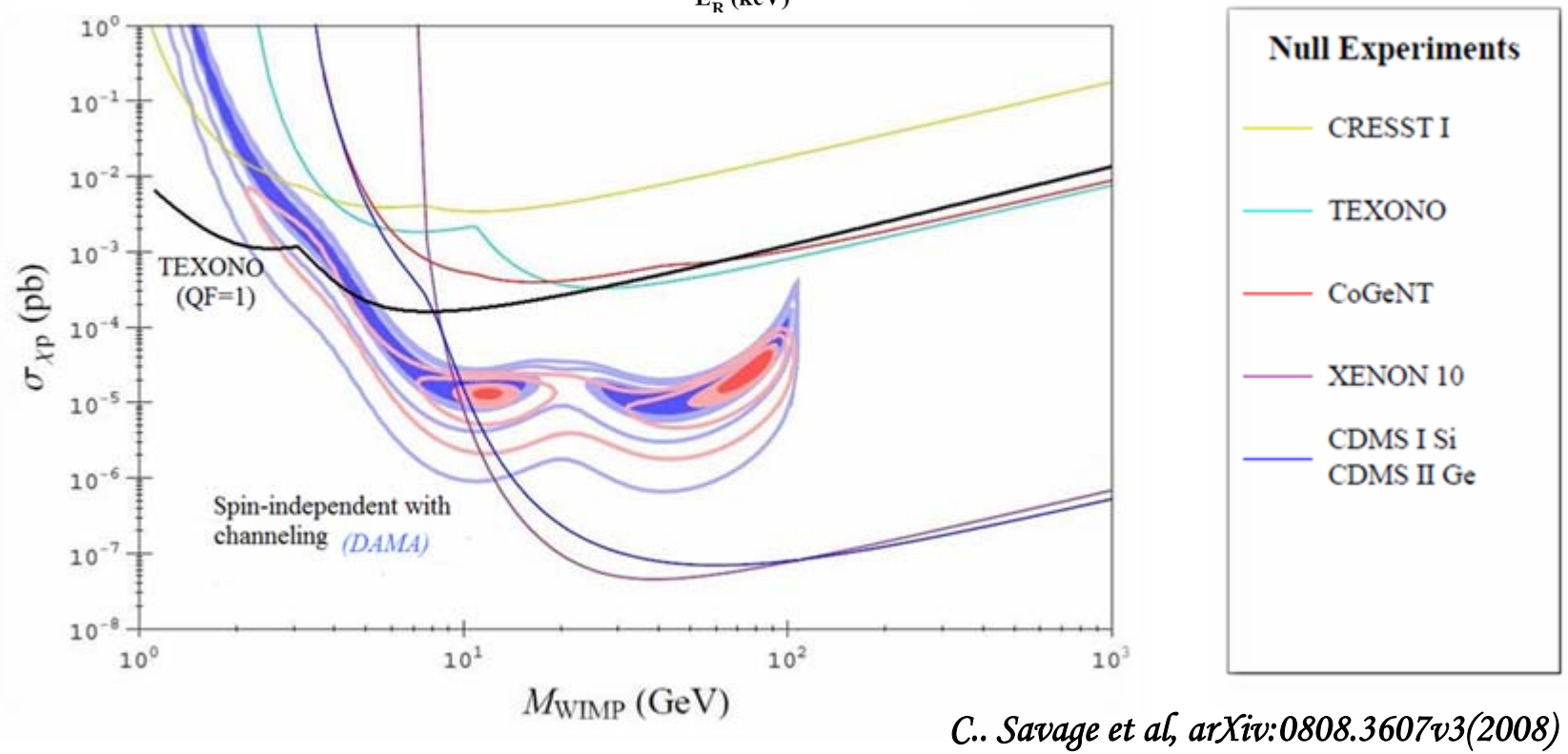
Allowed regions of WIMP-nucleon couplings (proton and neutron) with a WIMP mass of 5 GeV , at 90% C.L.

Recoiled Ion Channeling Effect ? (Q.F. → 1)



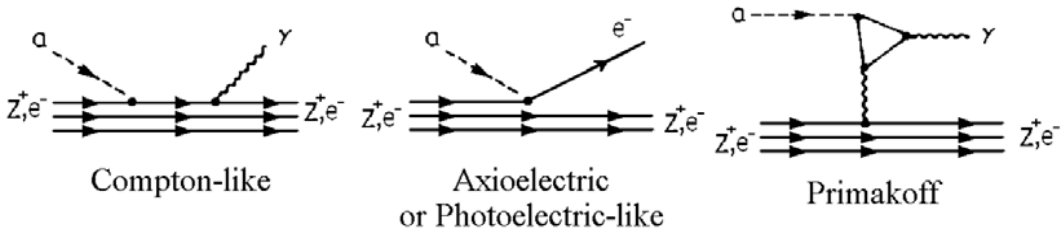


Q.F. value influences **: making and breaking of quasi-molecular bonds of channeled ions with ions in the channel walls, impurity of crystals, etc.** → *QF Measurement*



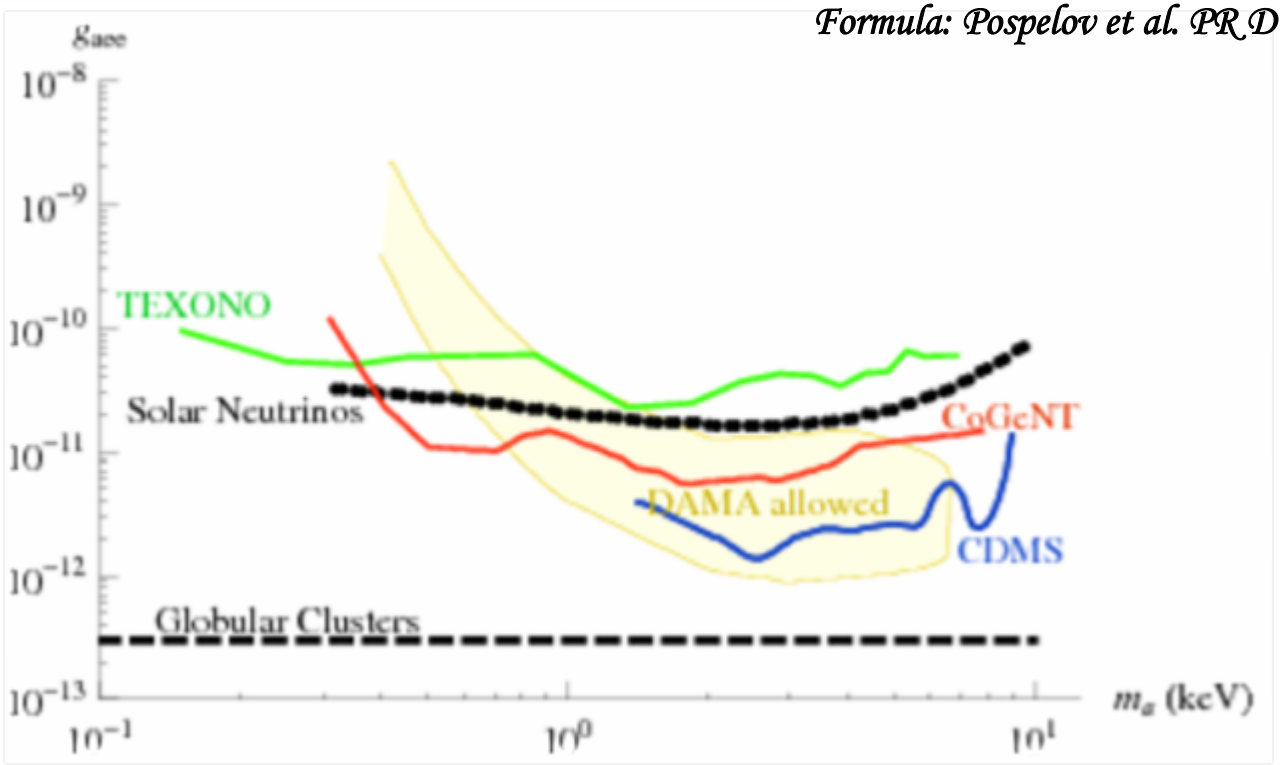
C.. Savage et al, arXiv:0808.3607v3(2008)

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. PRD 78, 115012 (2008)



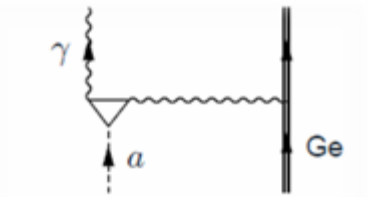
C..E. Aalseth et al. PRL 101, 251301(2008) ; Z. Ahmed et al. arXiv:0902.4693

Reactor axion search *[PRD 07]*

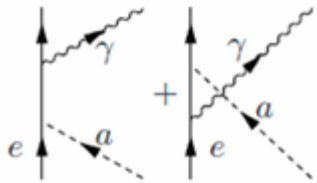
➢ Axion productions

	Energy (keV)	Mode	ϕ_γ (10^{10} cm^{-1}s^{-1})	
np→dγ	2230	Isovector M1	22.1	} dominant!
^{7}Li*	478	M1	24.7	
^{91}Y*	555	M4	2.10	
^{97}Nb*	743	M4	4.81	
^{135}Xe*	526	M4	0.85	
^{137}Ba*	662	M4	0.37	

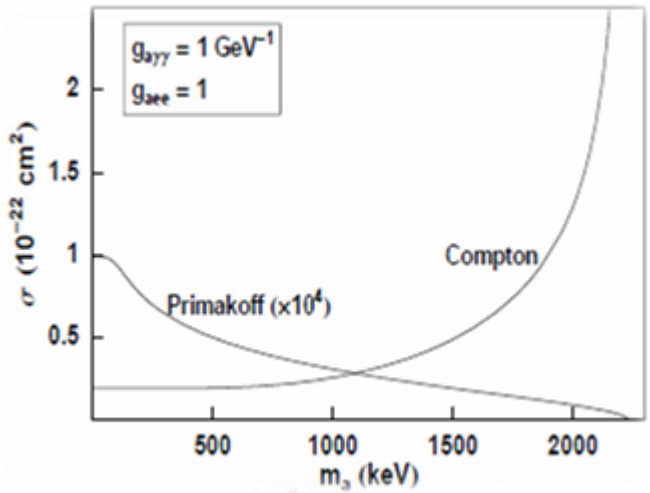
➢ Axion interactions



Primakoff conversion ($g_{a\gamma\gamma}$)



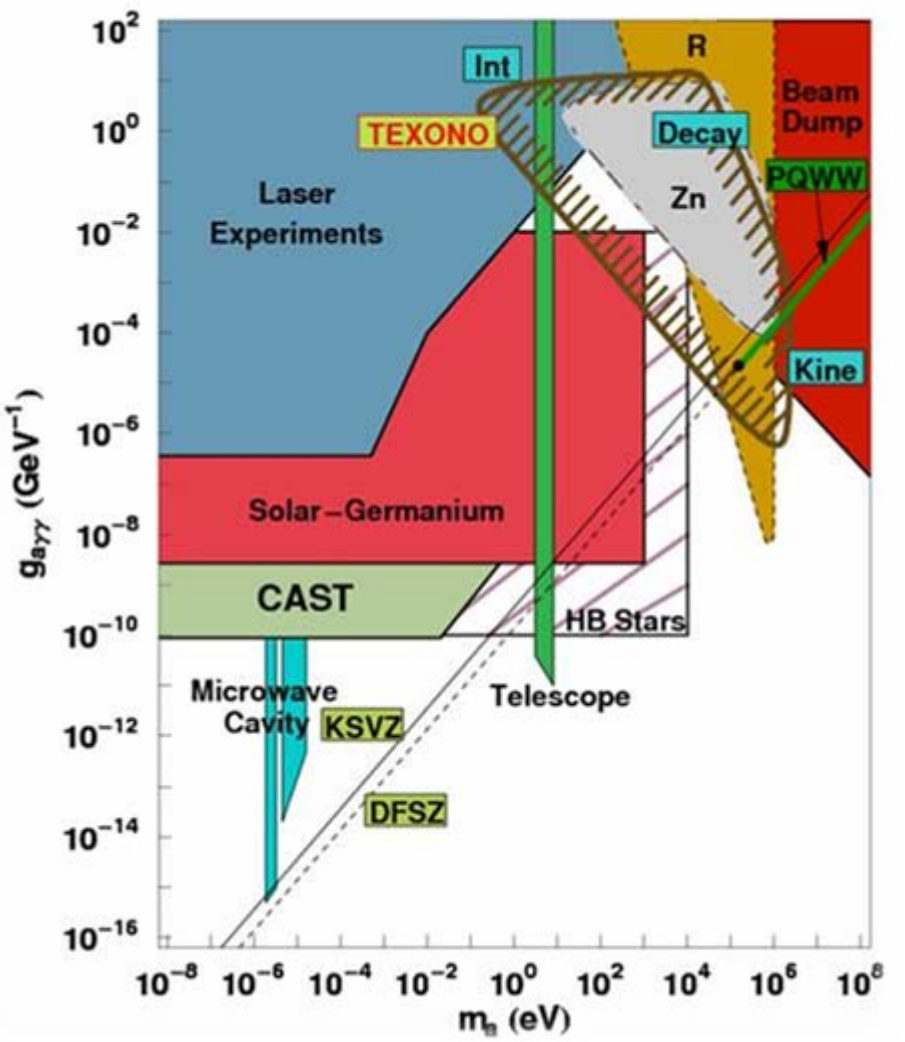
Compton conversion (g_{aee})

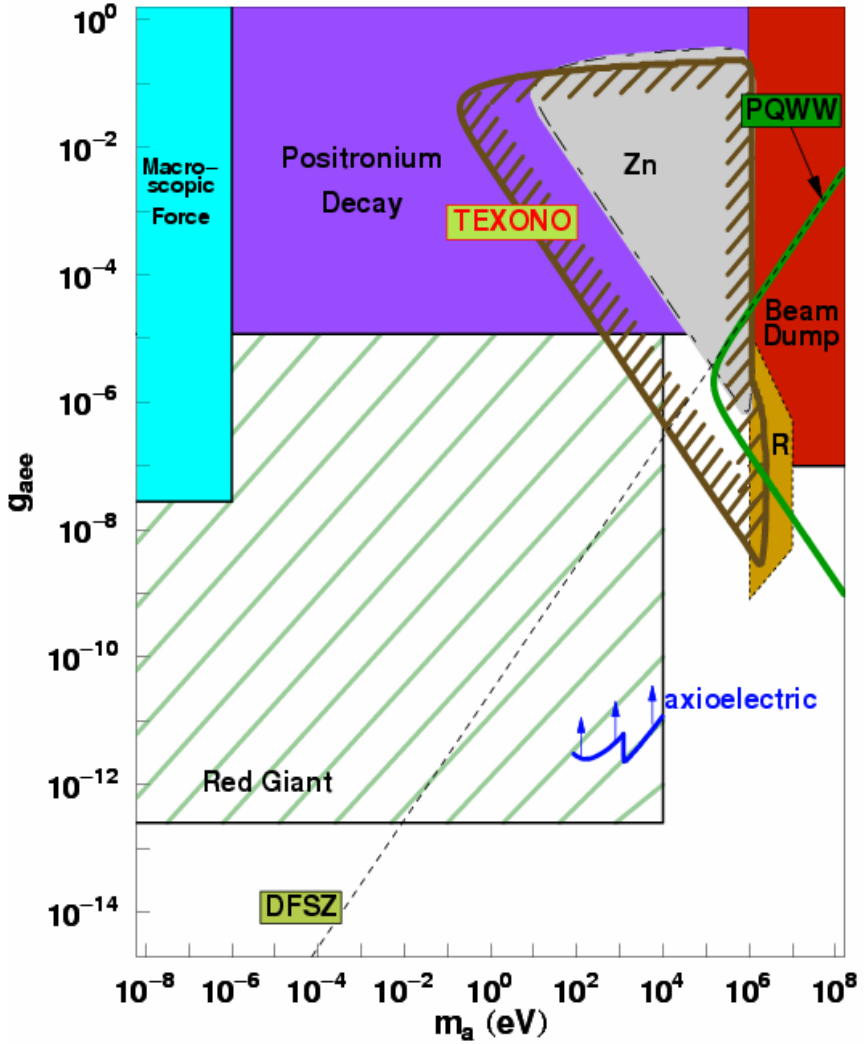


$$\sigma_{Pri} = g^2_{a\gamma\gamma} \cdot f(m_a, \epsilon_a)$$ **sensitive to low mass**

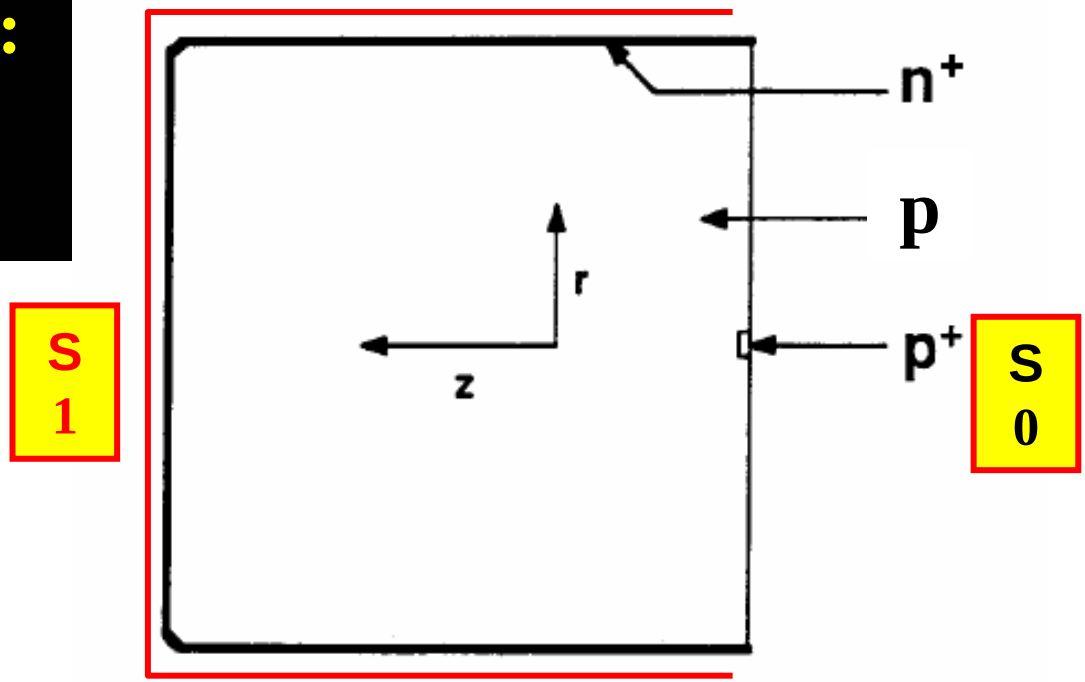
$$\sigma_{Com} = g^2_{aee} \cdot f(m_a, \epsilon_a)$$ **sensitive to high mass**

Results on axion *[PRD 07]*



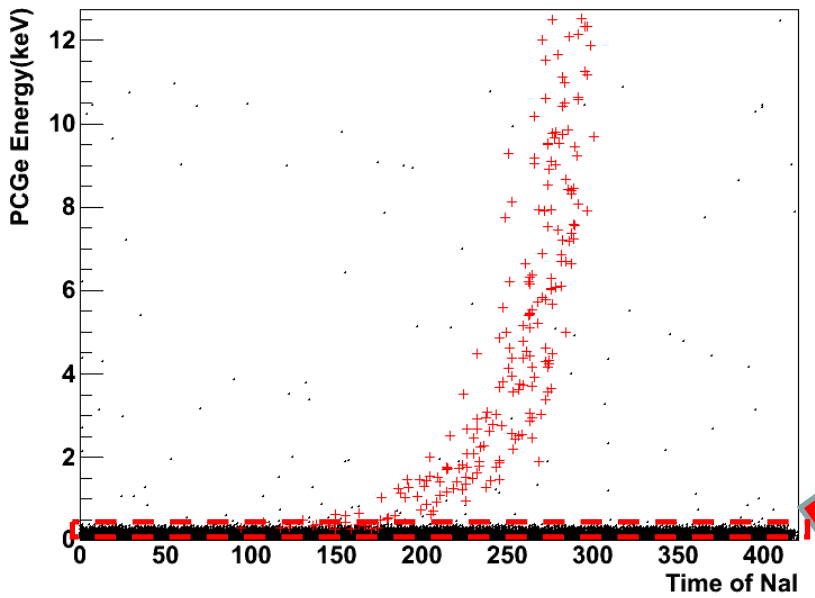


Detector Scale-up Plans: Point Contact Ge Detector

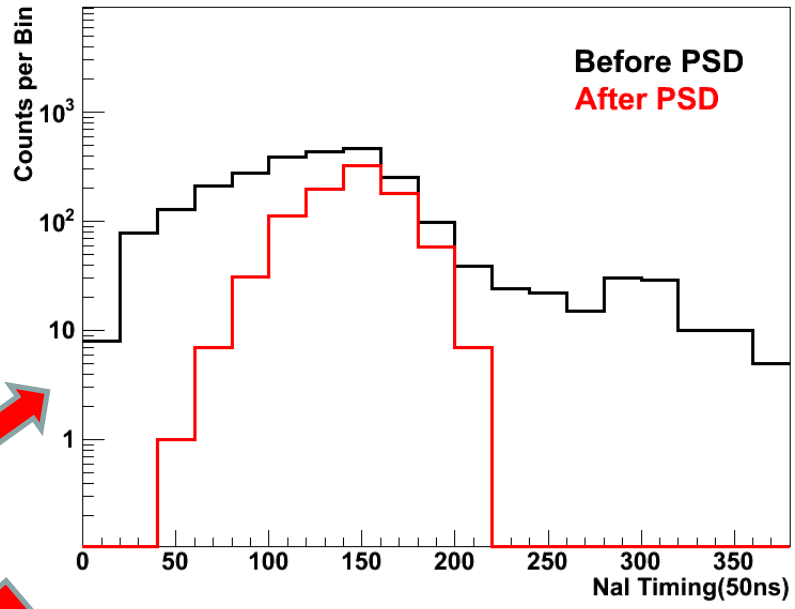


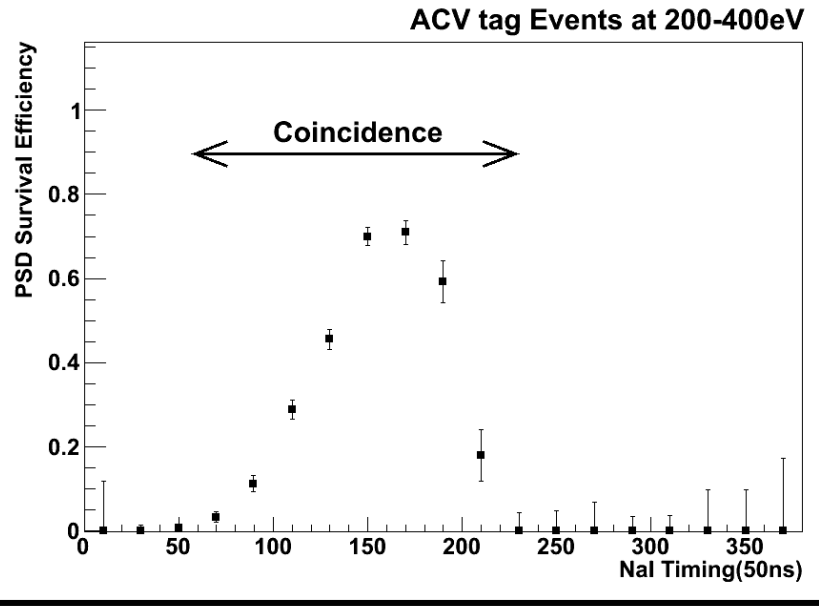
- Large Mass & Low Threshold -- Proposed *[Luke 80's]* ; successful demonstration *[CoGeNT 2007]*
- Position-sensitive from drift-profile pulse shape
- Add: Dual-electrode readout and ULB specification
- 500-g built ; KS data taking Nov 2008
- 900-g detector under construction

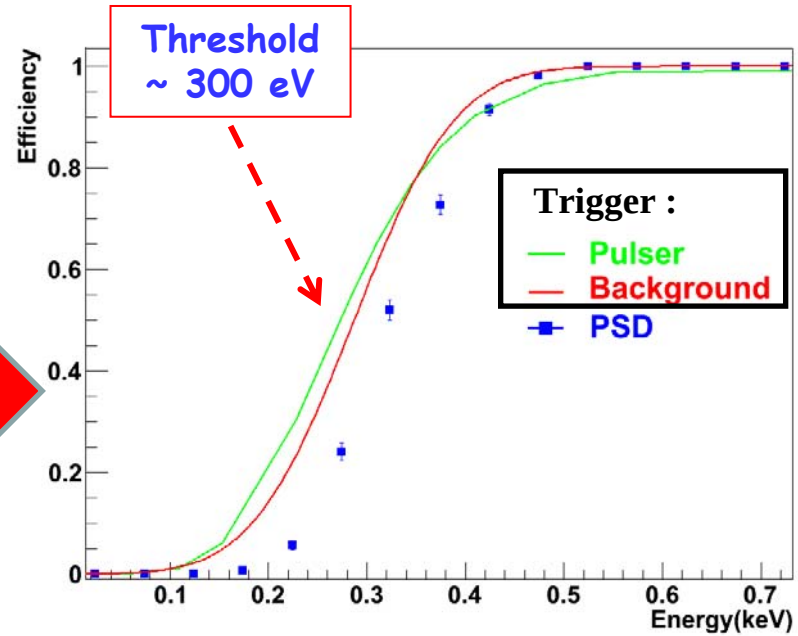
PCGe 500 g ⇨ Threshold *(Preliminary)*



ACV-Tagged 200-400 eV





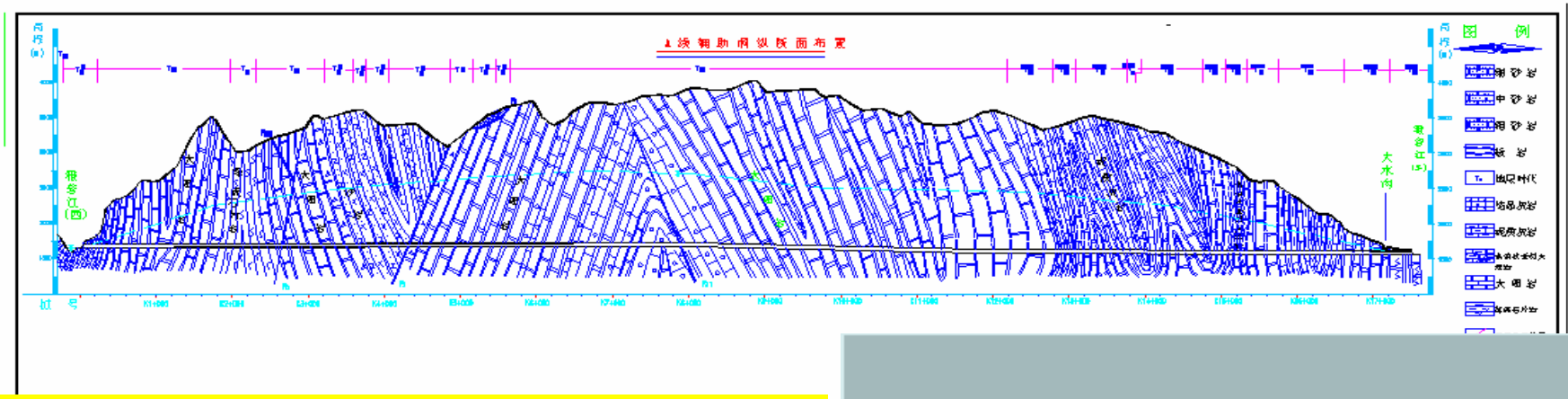


New opportunities (From By-Product Physics to Dedicated Experiment) :

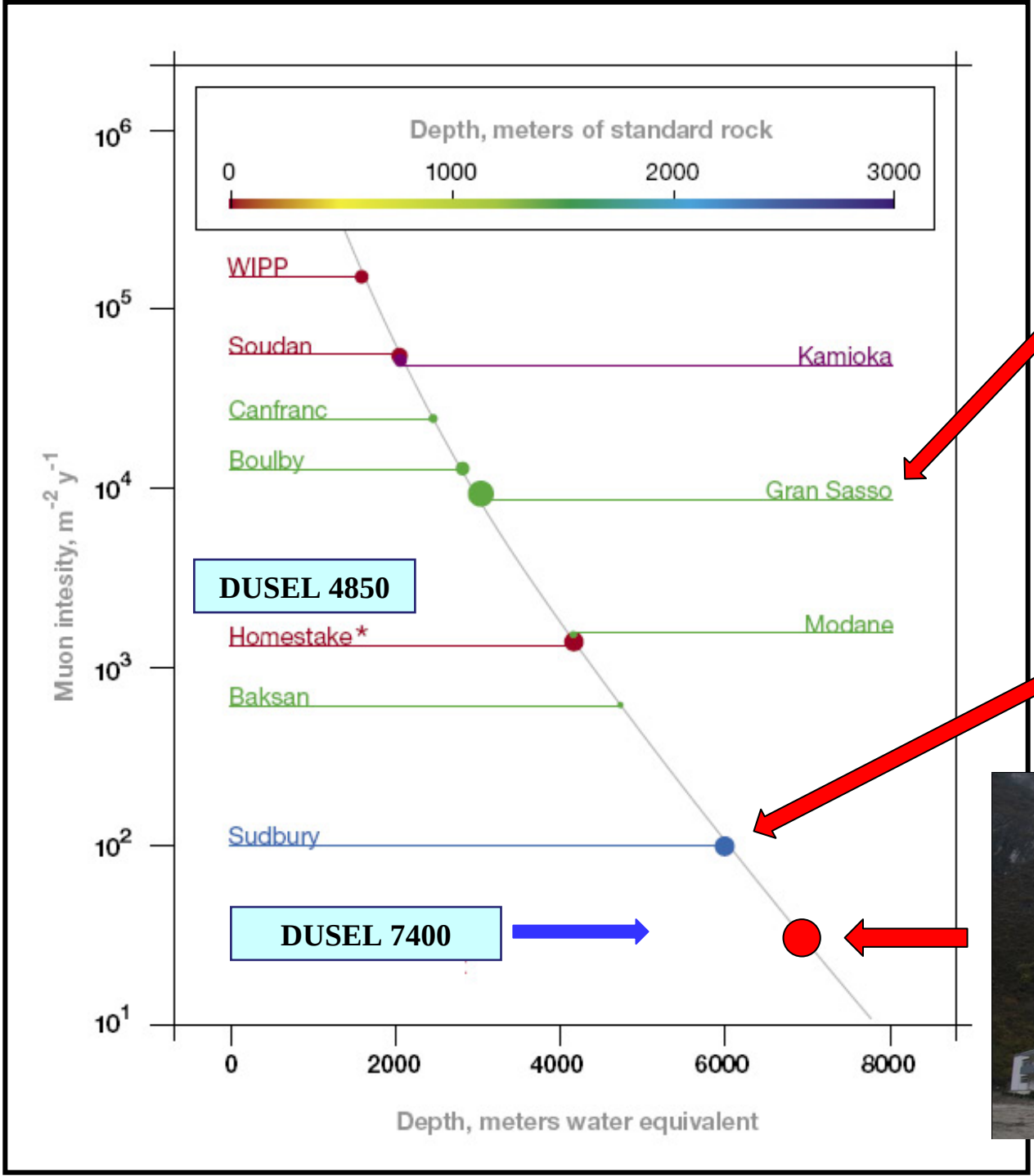
◎ Excellent Candidate Site for Underground Lab. at SiChuan –JinPing (四川 錦屏) , China

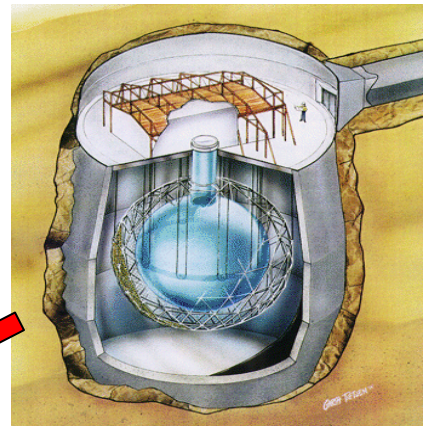
- Excavation of 1st cavern begins 2009
- Operating ULEGe (4X5g) in 2010

锦屏山隧道
Mt. Jin-Ping Tunnel



- ♥ **Tallest Peak 4193 m**
- ♥ **Max. Rock Overburden: 2375 m**
- ♥ **Road Tunnel Distance: 17.5 km**
- ♥ **Fraction of tunnel with >1500 Rock Overburden: >70%**


Depth, meters of standard rock
0
1000
2000
3000
WIPP
Soudan
Kamioka
Canfranc
Boulby
Gran Sasso
DUSEL 4850
Modane
Homestake*
Baksan
Sudbury
DUSEL 7400
Muon intesity, m-2 y-1
10^6
10^5
10^4
10^3
10^2
10^1
0
2000
4000
6000
8000
Depth, meters water equivalent




四川錦屏

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 2009**
- ***Plan* : move in Sichuan underground Lab. (>2 km rock) soon**
- ***Goals* : open new detection channel and detector window for neutrino and dark matter physics**