Limits on Low-Mass WIMP Dark Matter with an Ultra-Low-Energy Germanium Detector at 220 eV Threshold

- **ULE-HPGe: Physics & Requirements**
- **Event selection and efficiencies**
- **Dark Matter searches**

  -- Based on S.T. Lin et al.(TEXONO) PR D 79, 061101(R) 2009
- **Status & plans**

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

8th Particle Physics Phenomenology Workshop (PPP8) May 20-23 2009 @ Tainan

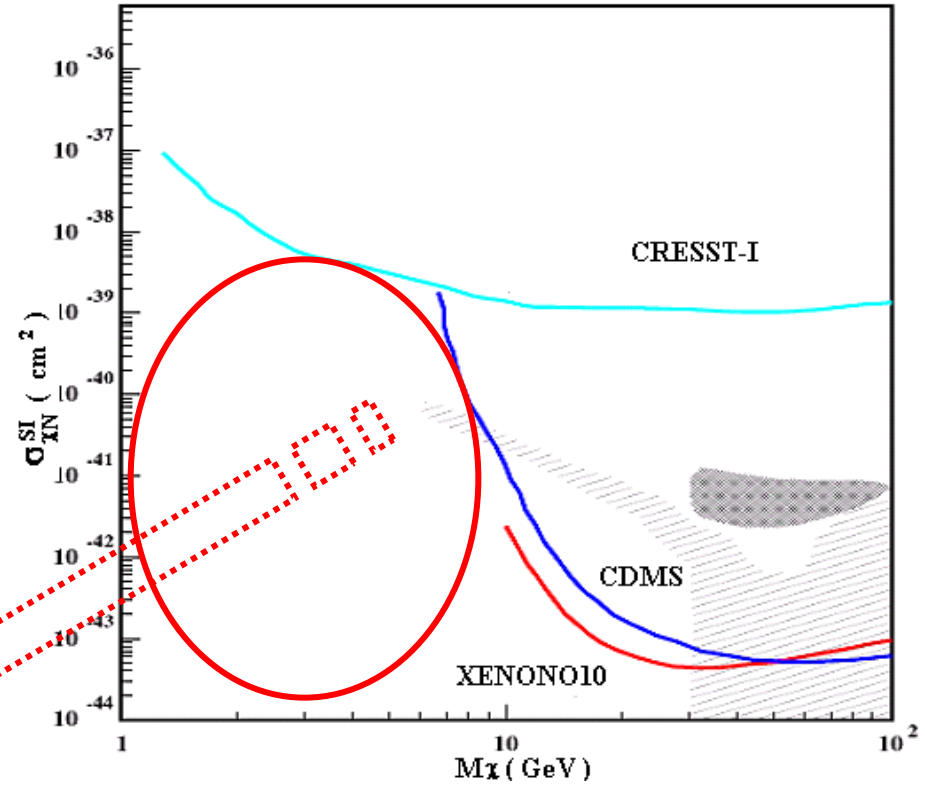
TEXONO Collaboration

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

Sensitivity Plot for *WIMP* direct search

$\chi N \rightarrow \chi N$

- A^2 dependence (spin-independent)



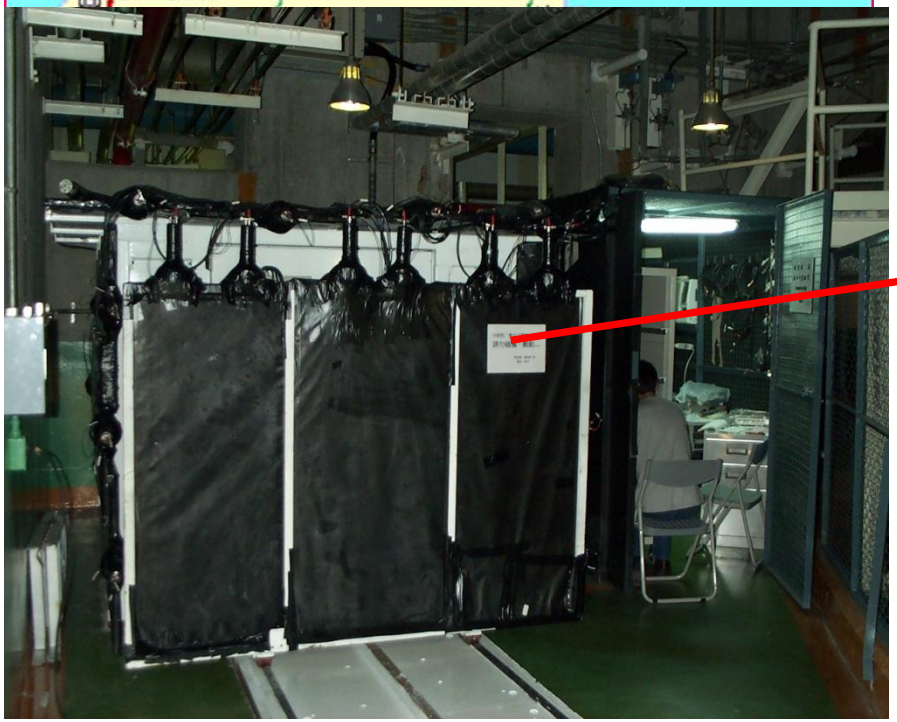
Low (<10 GeV) WIMP Mass / Sub-keV Recoil Energy :

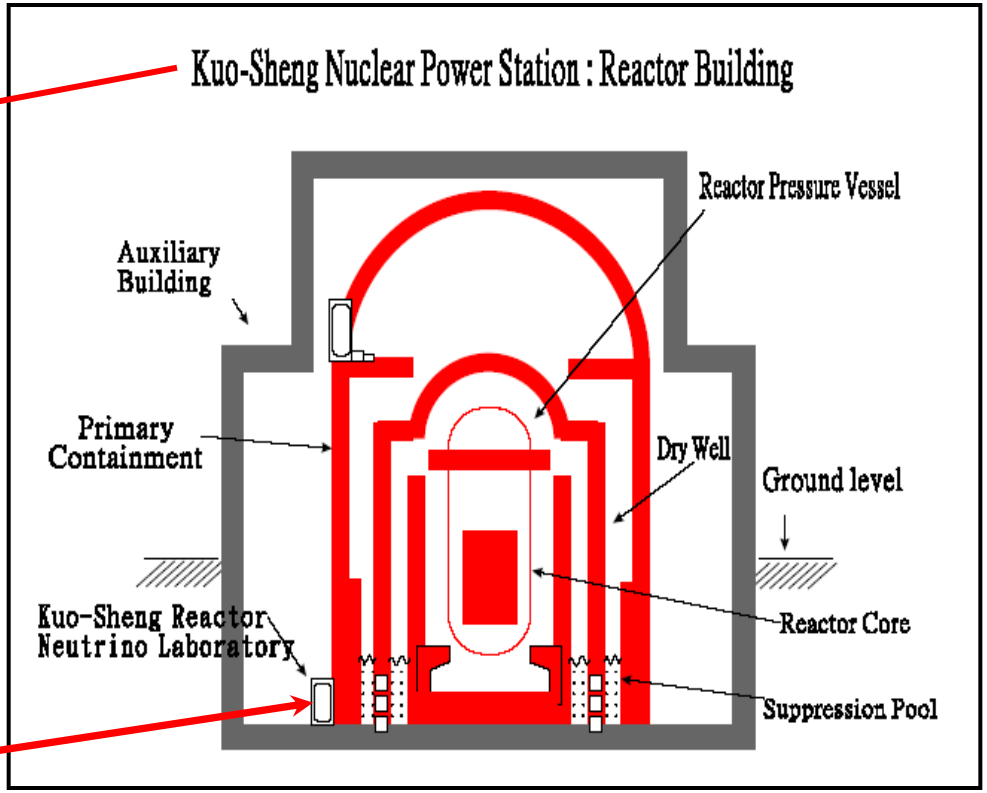
- Not favored by the most-explored specific models on galactic-bound SUSY-neutralinos as CDM ; *still* allowed by generic SUSY
- *Solar-system bound* WIMPs require lower recoil energy detection
- Other candidates favoring low recoils exist: e.g. non-pointlike SUSY Q-balls , MSSM's *LLN* ; scalar and pseudoscalar (axion-like particles).
- 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：

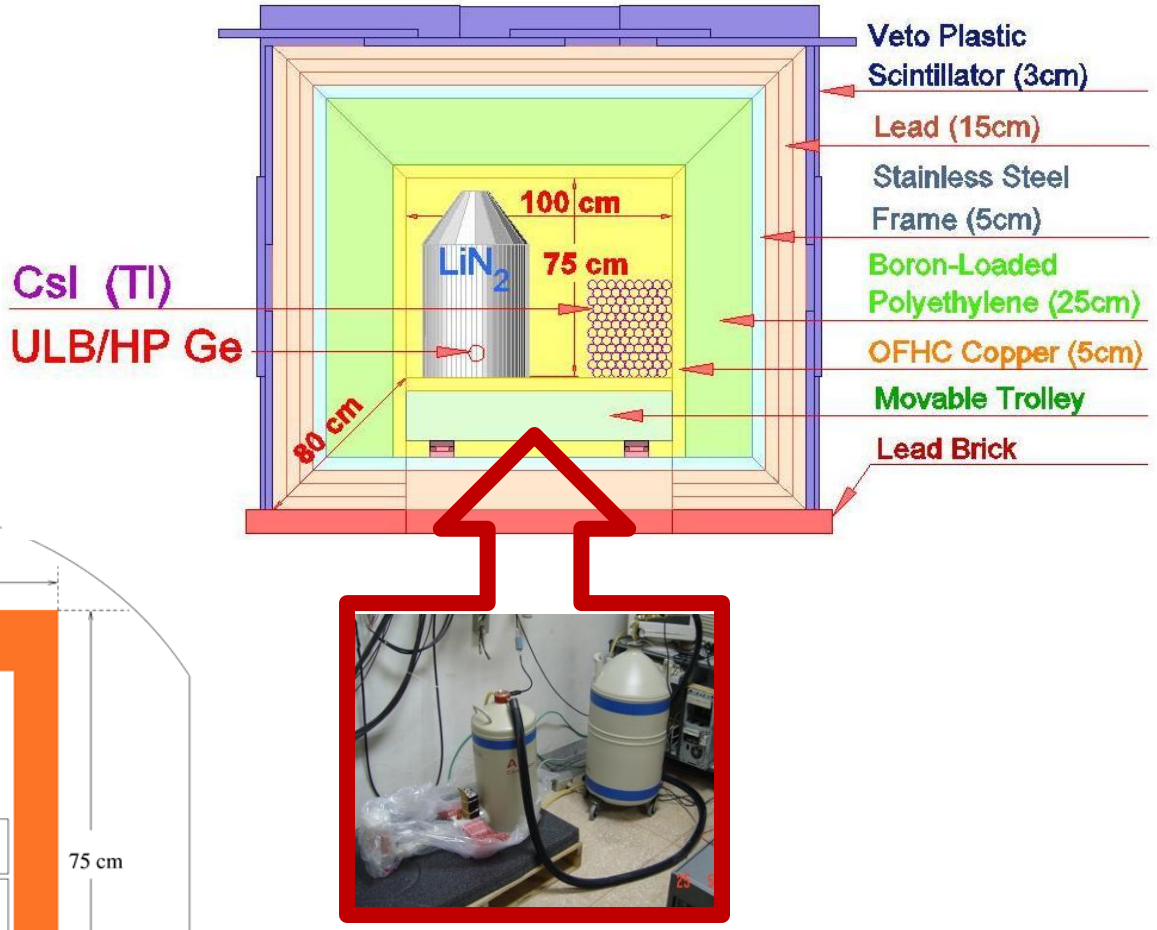


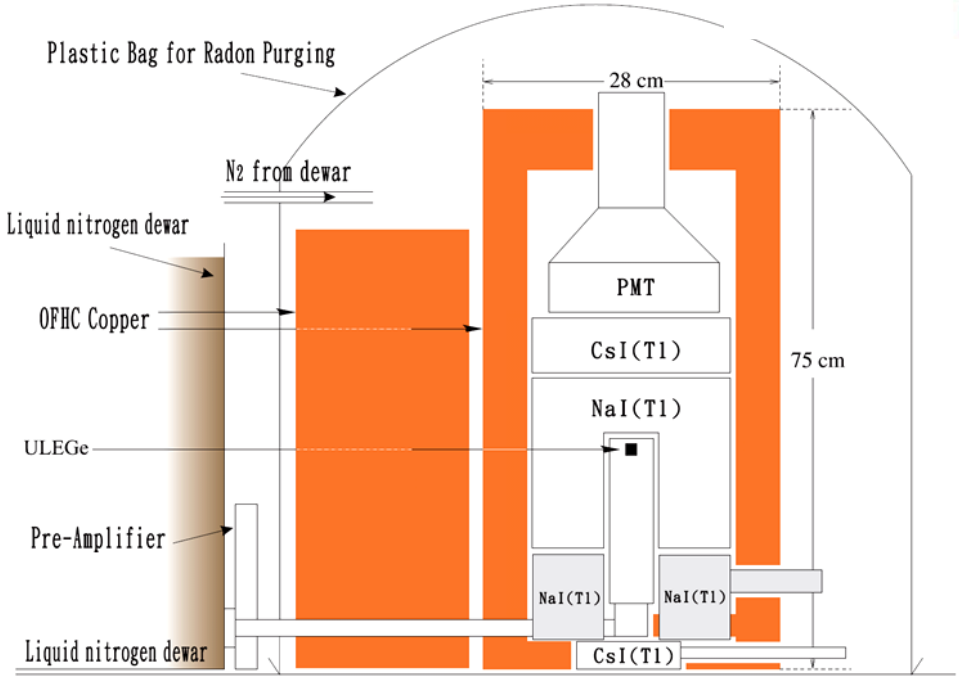


28 m from core#1 @ 2.9 GW
Shallow site : ~30 *m..w..e.* overburden
~10 m below ground level

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**

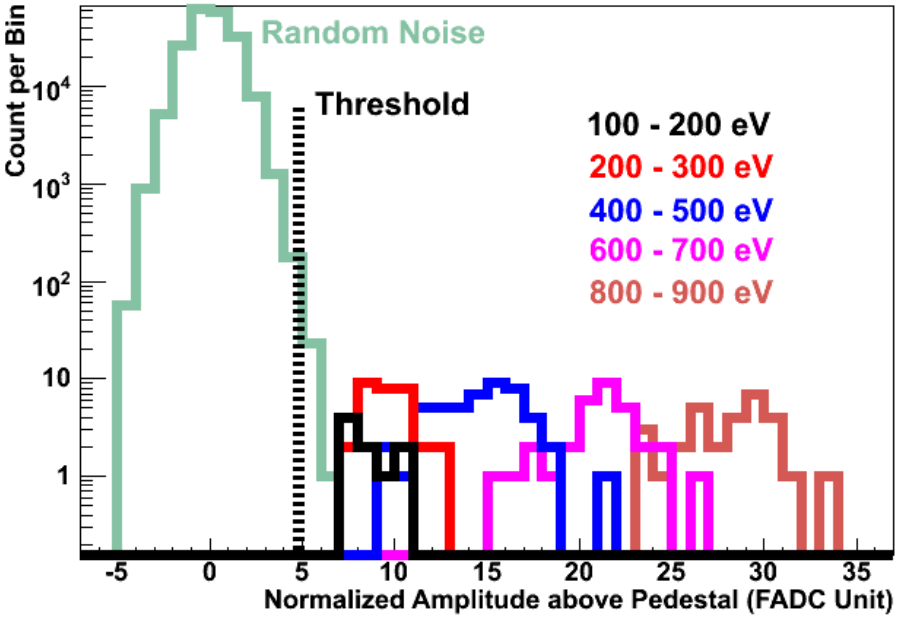


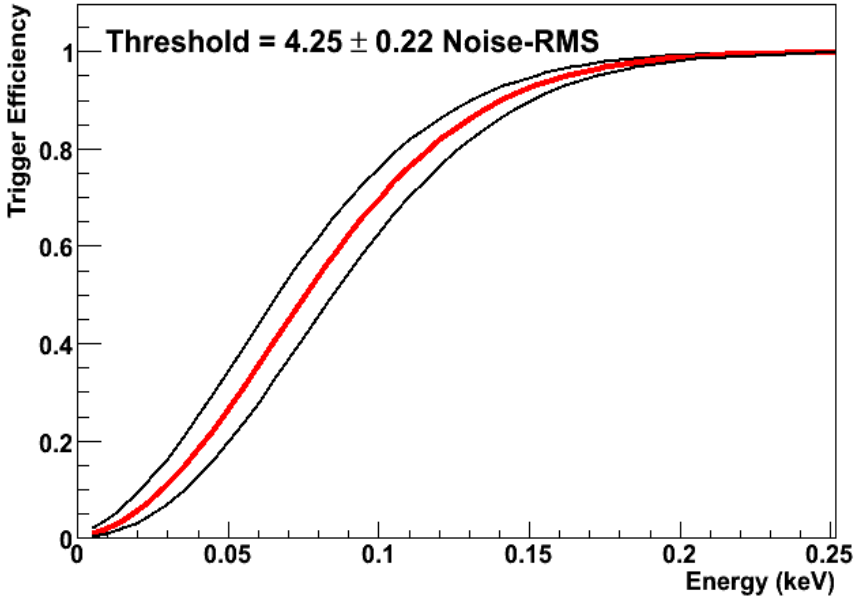


- **Candidate events : survive Anti-Compton (*ACV*) and Cosmic-Ray (*CRV*) vetos**

--- Efficiency evaluated by Random trigger events.

Evaluation of Trigger Efficiency



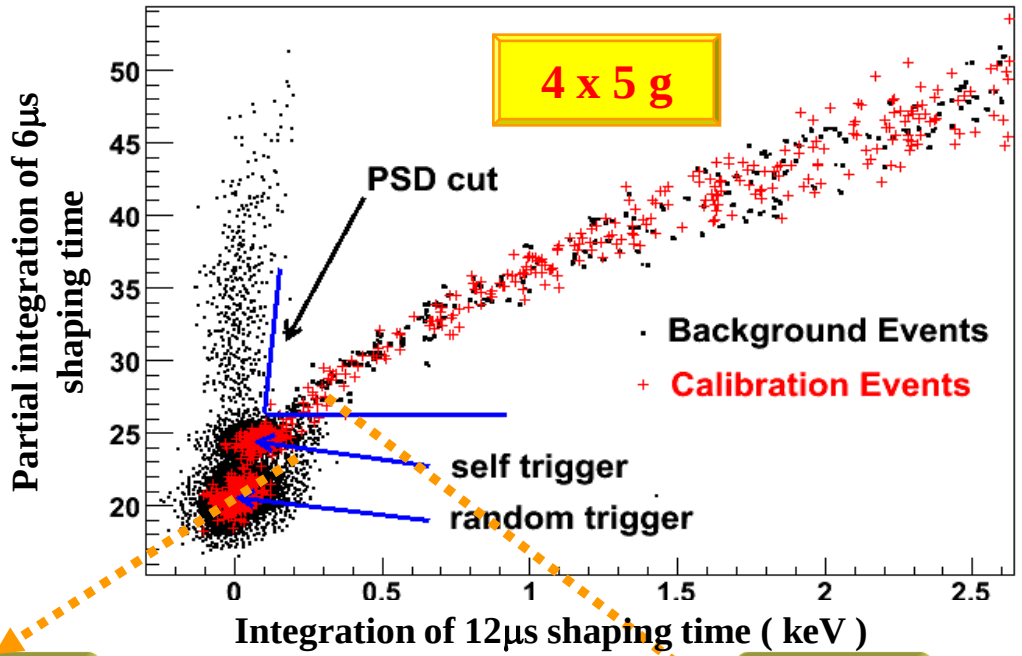


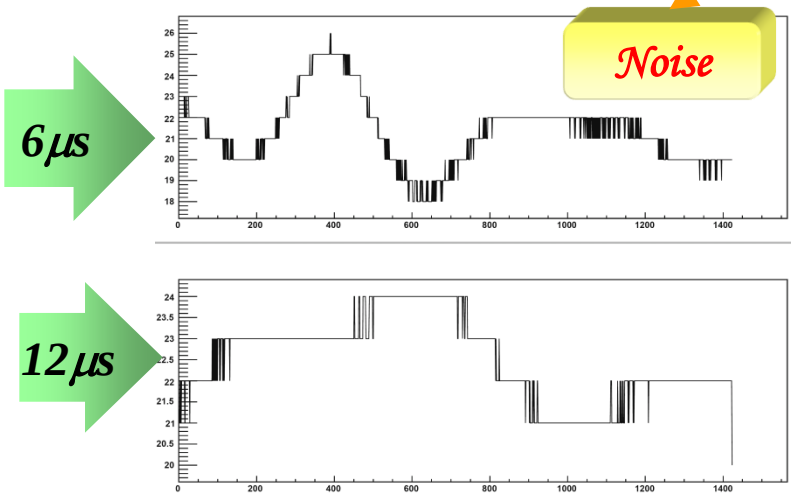
- DAQ threshold at ~ 4.3σ above mean of noise fluctuations → *no DAQ dead time concern*
- Max. amplitude of physics events → good margins above threshold
- Efficiency Evaluation : from (*mean* , *RMS*) of Max. amplitude distribution
- Evaluation from pulser generator also perform the same behavior

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





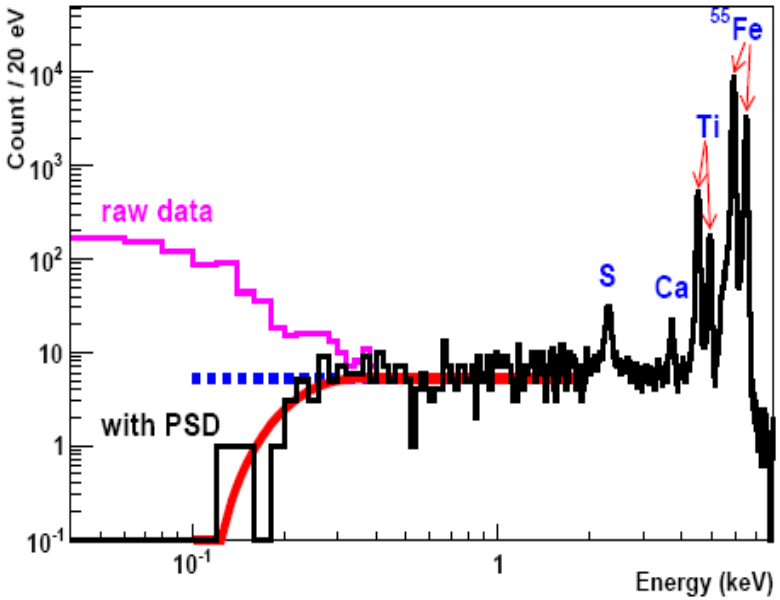
Analysis *PSD* Efficiency

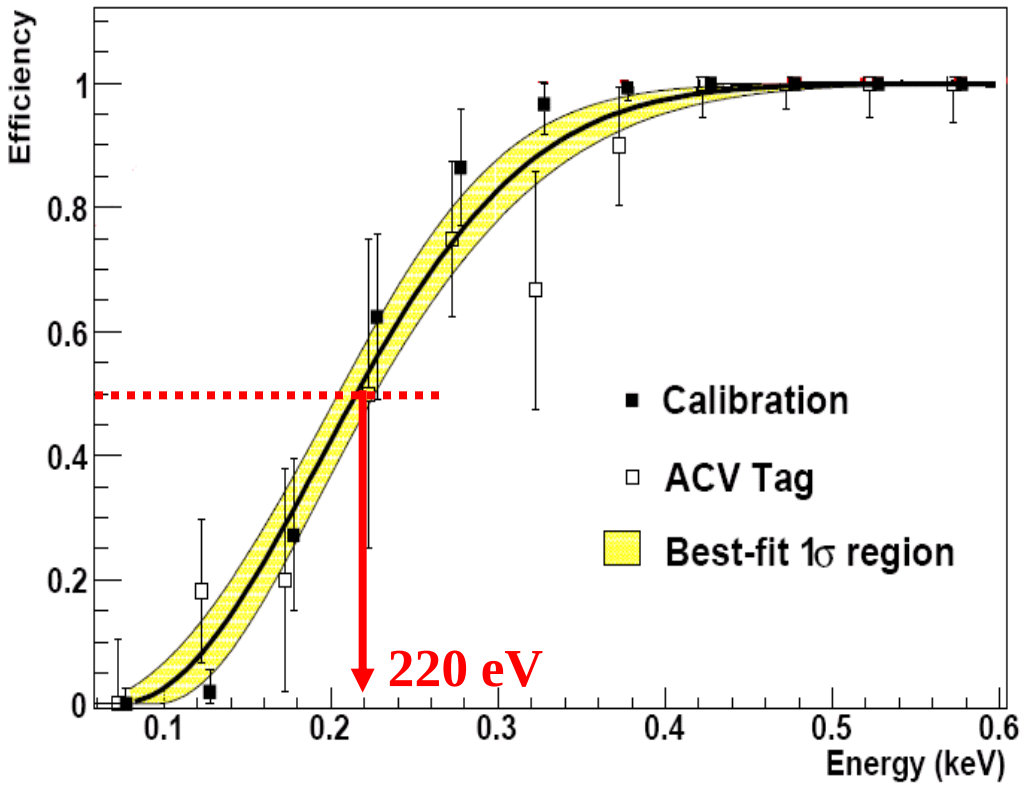
From two samples :

1) ^{55}Fe calibration events - *deviations from flat spectrum*

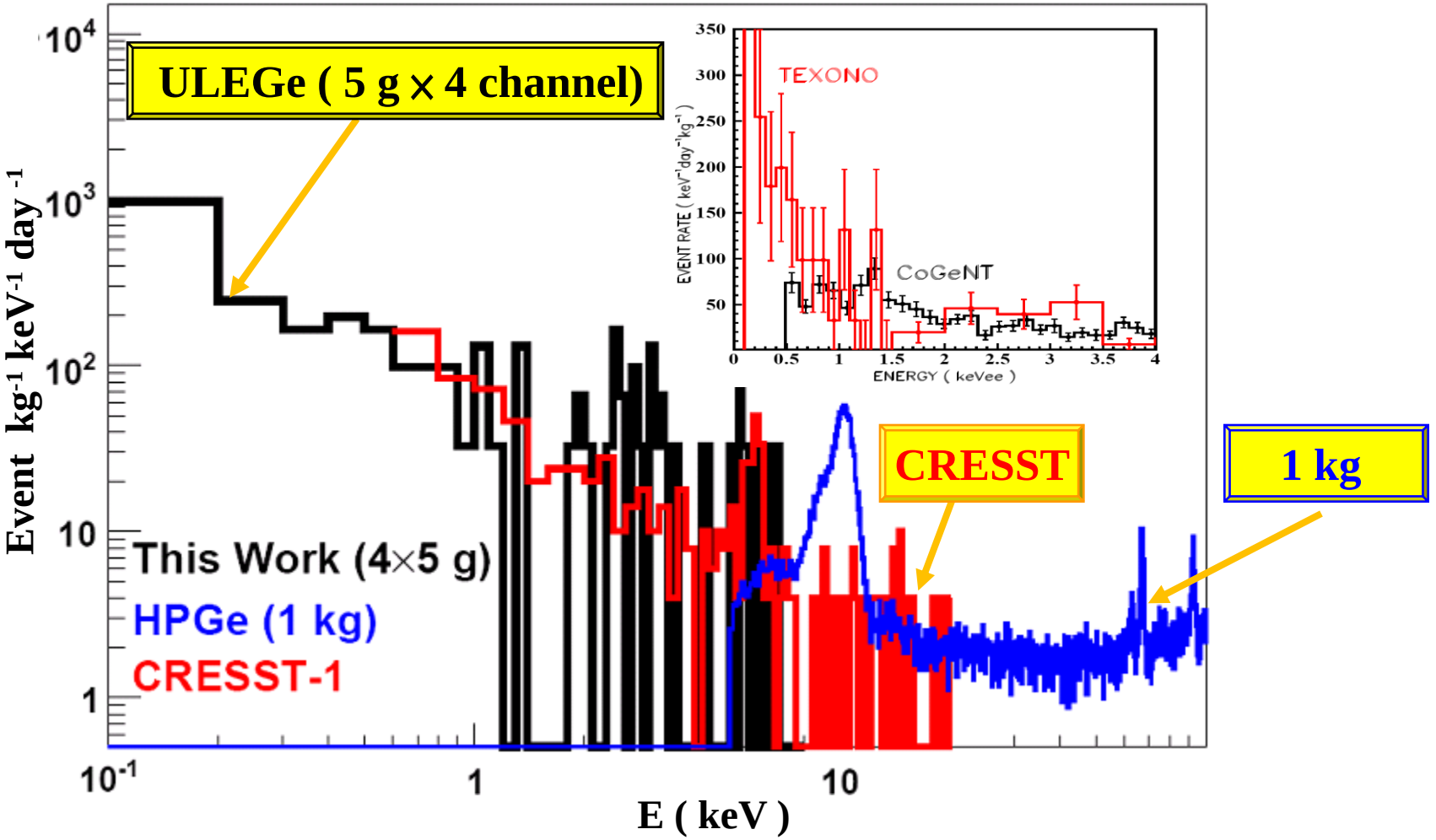
2) physics events with *CRV* and *ACV* tags – *survival probabilities*

^{55}Fe sources for calibration & PSD efficiency



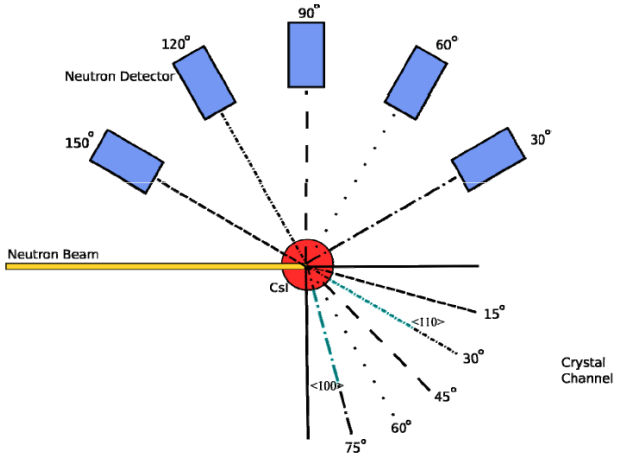


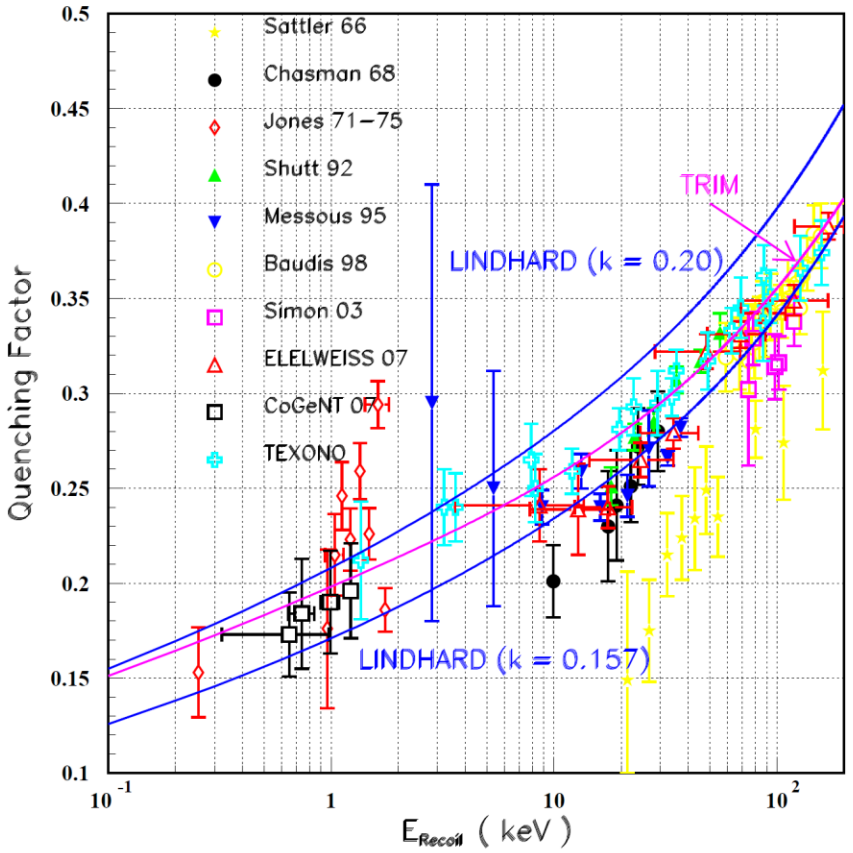
Sub-keV Background Measurements & Comparisons



- Background comparison to CRESST-1 & CoGeNT results
- Intensive studies on background understanding under way

Quenching Factor Measurement for Ge at CIAE





Goals for 2009 Run :

- Get to sub-keV
- Improve on present sensitivities
- Channeling effect

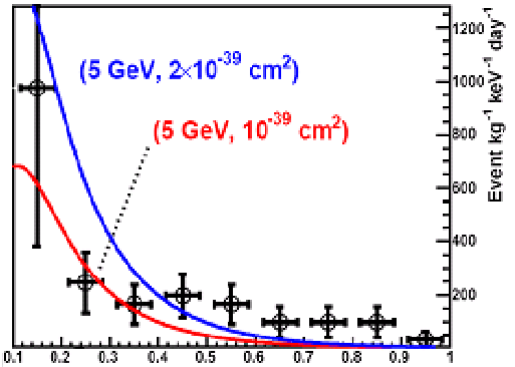
Results on WIMP Spin-Independent Cross Section

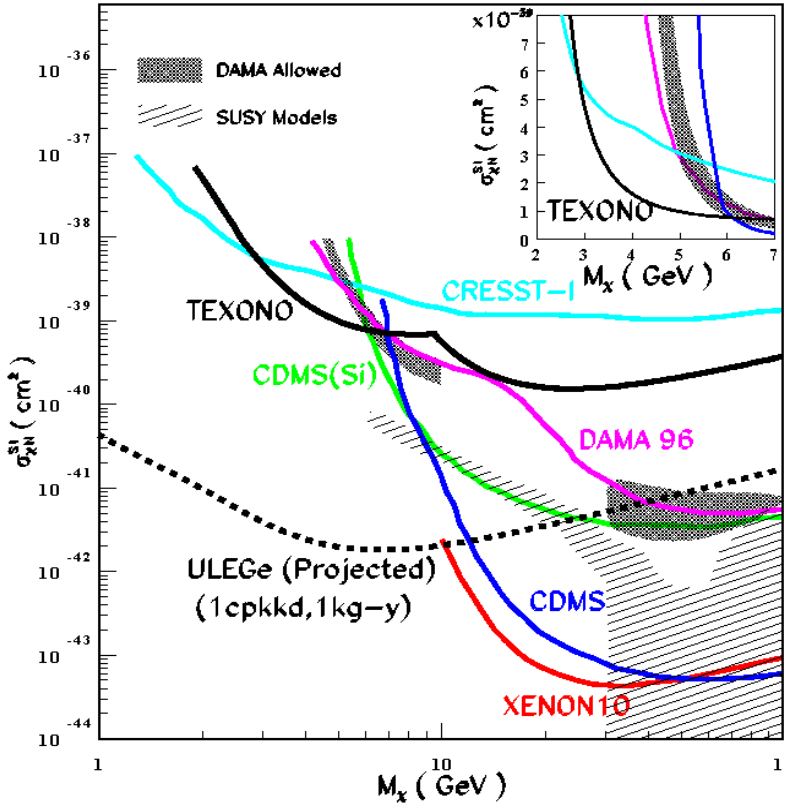
Limits & Sensitivities

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

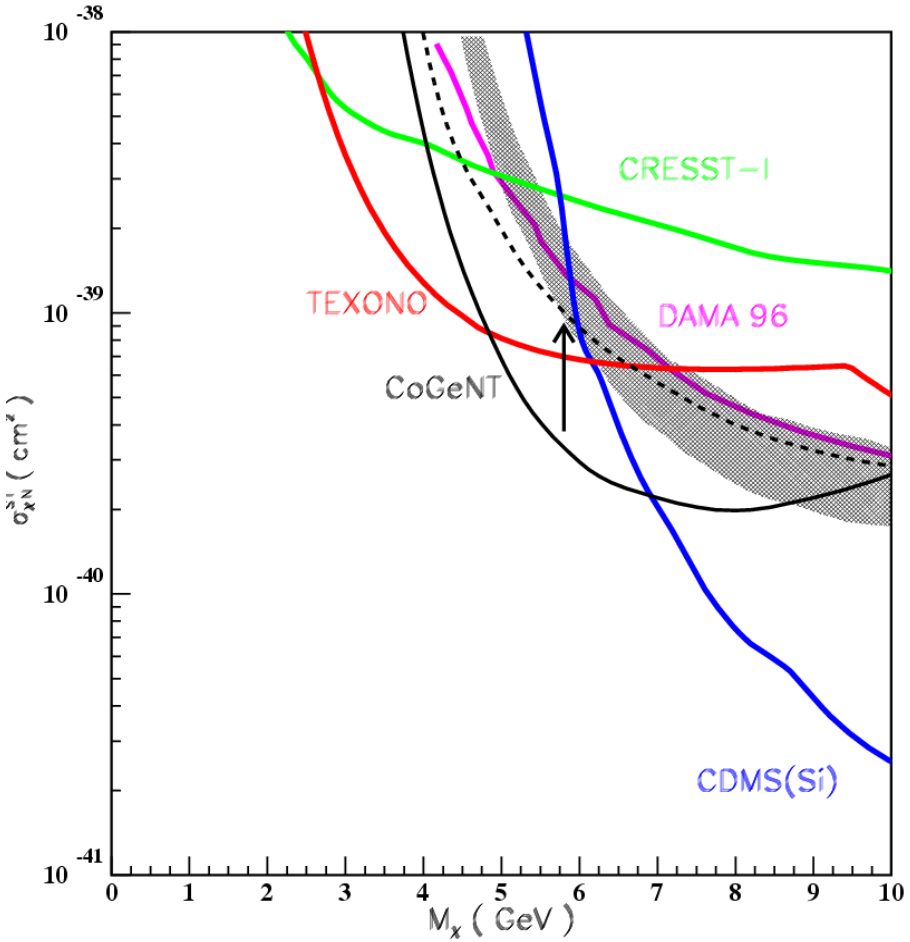
S. Yellin PRD 66 032005 (2002))

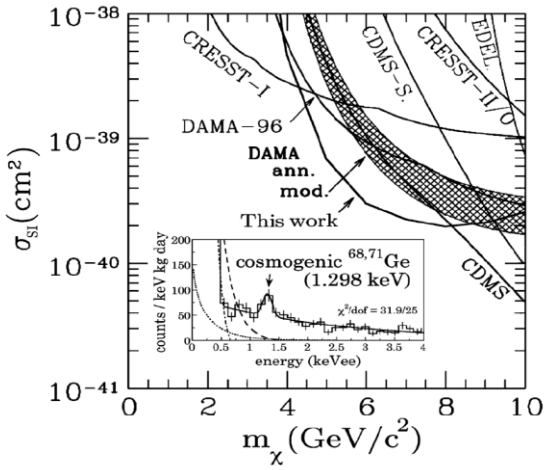
The sensitivity-defining bins		
Energy (eV)	198-241	1390-1870
Raw Counts	105212	75
Background after CRV-ACV-PSD	0	0
Net Efficiencies of signals	0.66	~1
Quenching Factor	0.202	0.245
Spin-independent Cross Section(cm^2) Limit at 90%C.L.	0.81×10^{-39} at 5 GeV	2.0×10^{-40} at 50 GeV
Spin-dependent Cross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

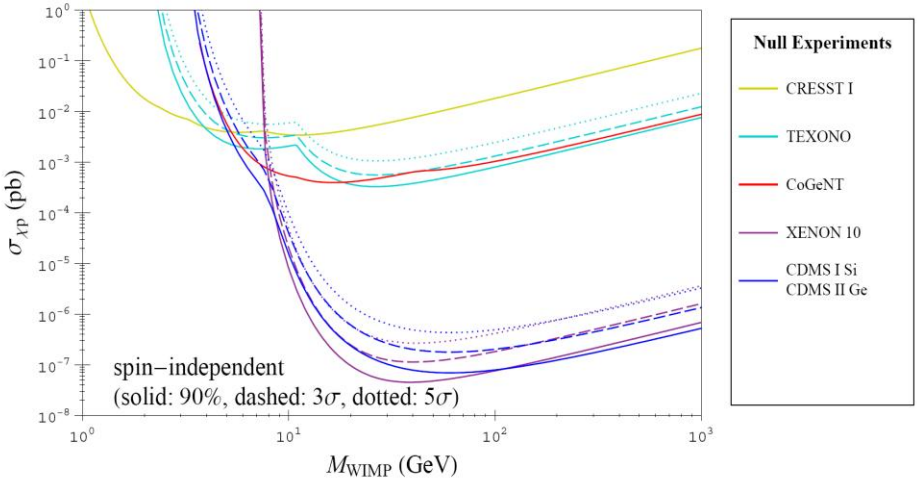




Spin-Independent Cross Section *on Low mass WIMP (<10 GeV)*







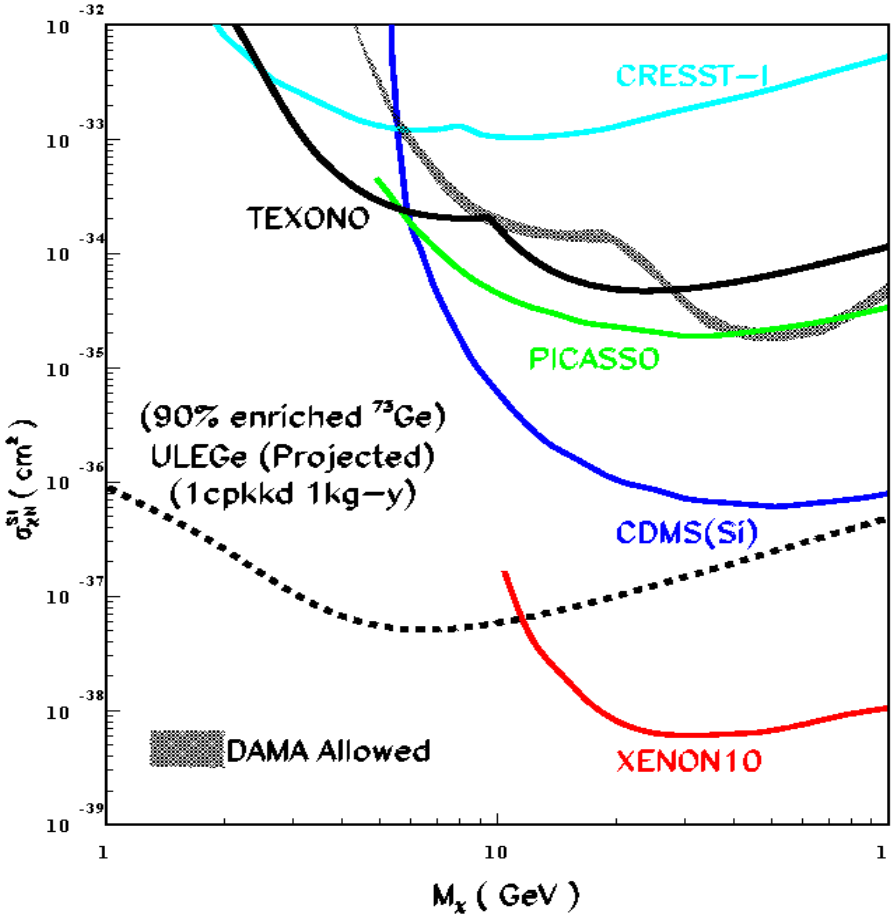
Top: C..E. Aalseth et. al PRL 101,251301(2008)

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

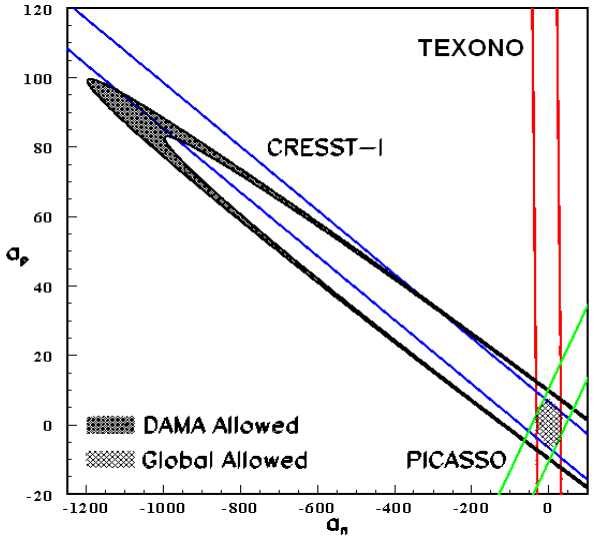
Results on WIMP Spin-dependent Cross Section

Limits & Sensitivities

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)***

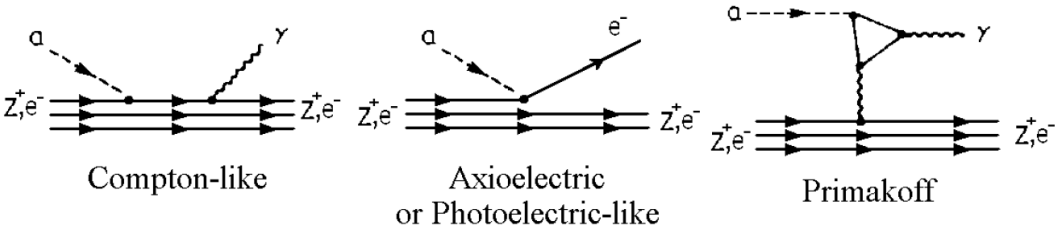


$M\chi = 5\ GeV$

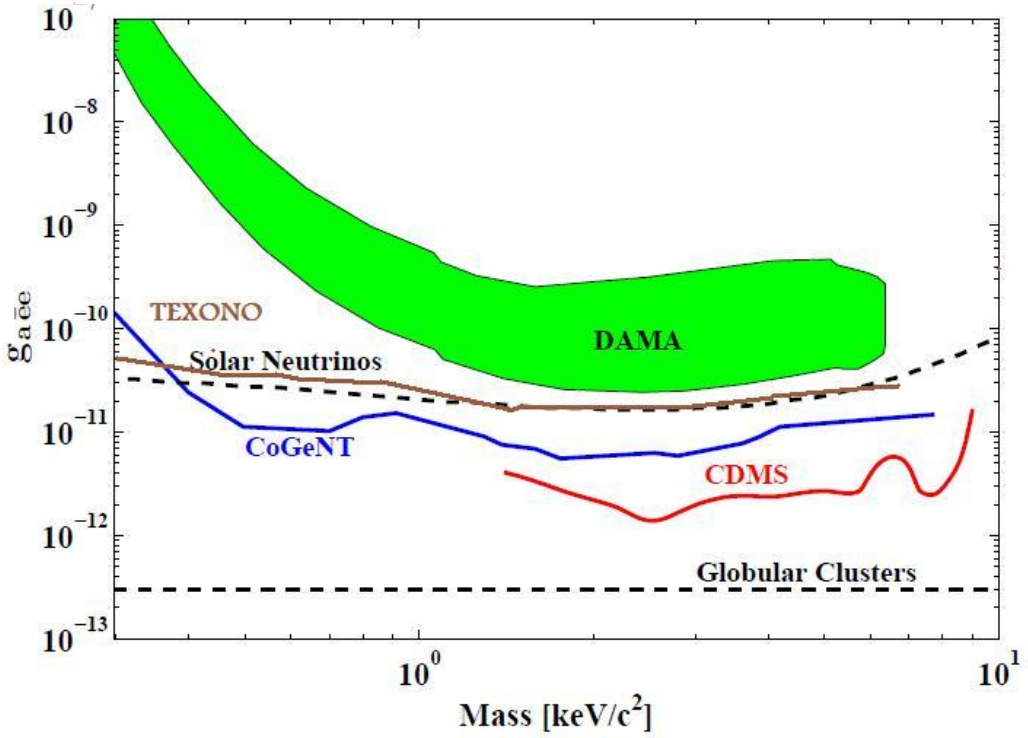


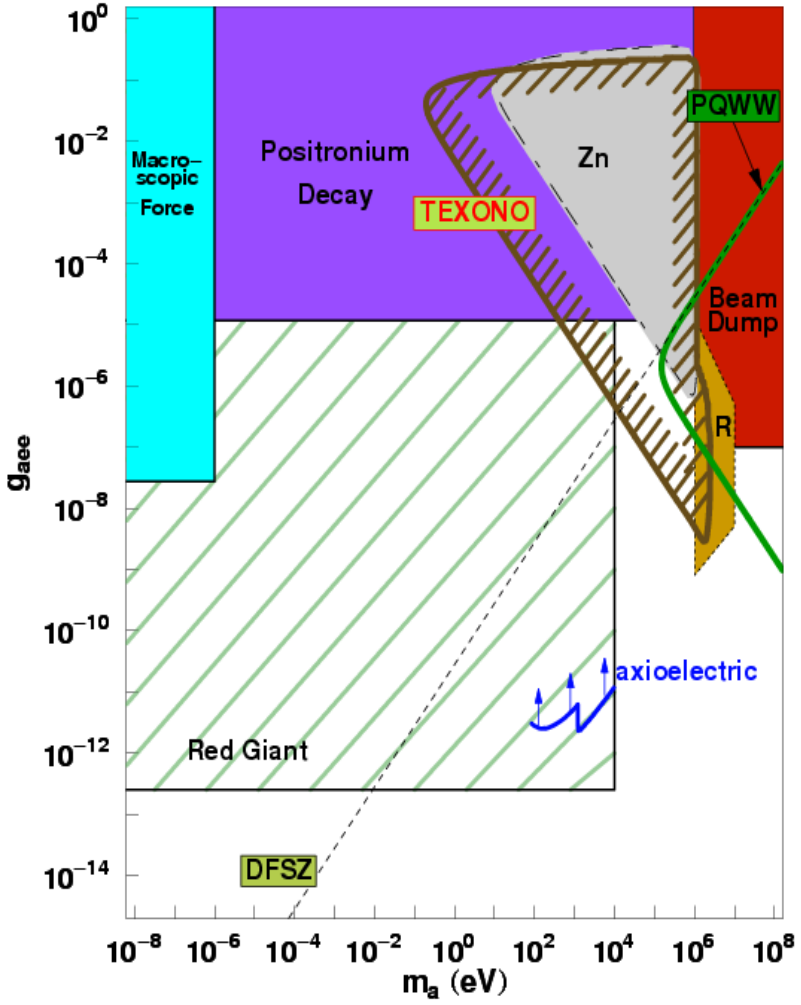
Allowed regions of WIMP-nucleon couplings (proton and neutron) with a WIMP mass of 5 GeV , at 90% C.L.

Pseudoscalar Candidates (*axionlike*)



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

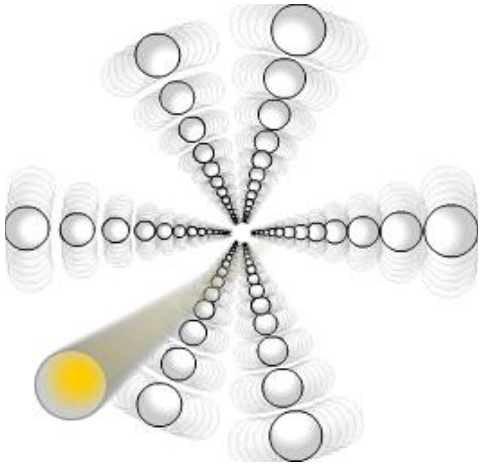


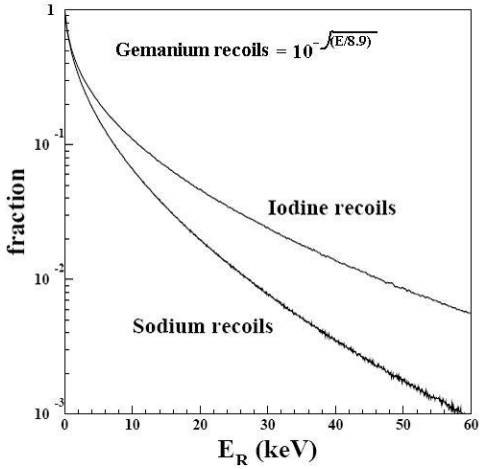


Formula: Pospelov et al. PR D 78, 115012 (2008)

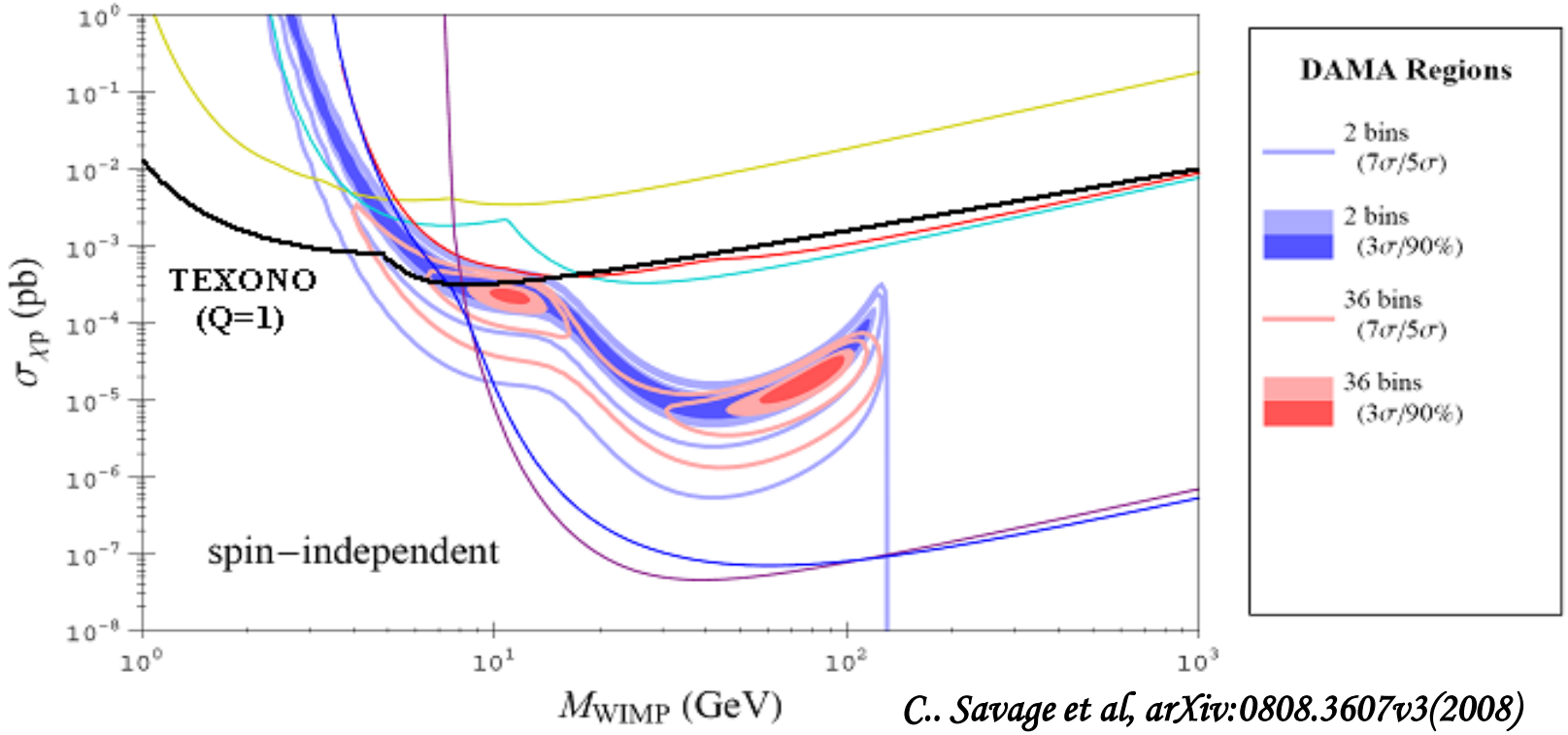
C..E. Aalseth et al. PRL 101, 251301(2008) ; Z. Ahmed et al. arXiv:0902.4693

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





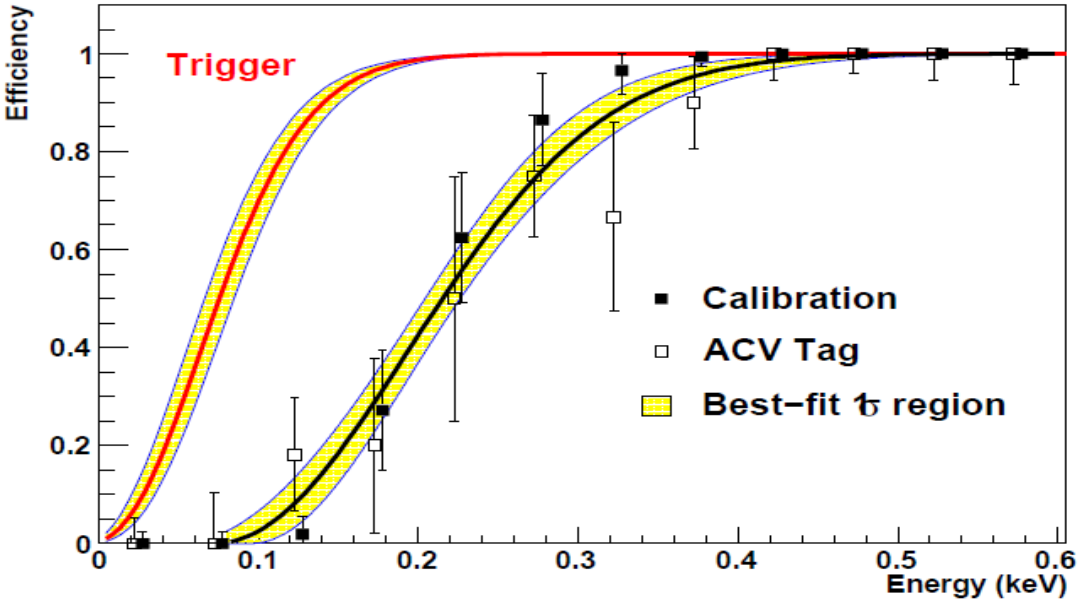
Q value influences **: making and breaking of quasi-molecular bonds of channeled ions with ions in the channel walls, impurity of crystals, etc.** → ***QF Measurement***



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

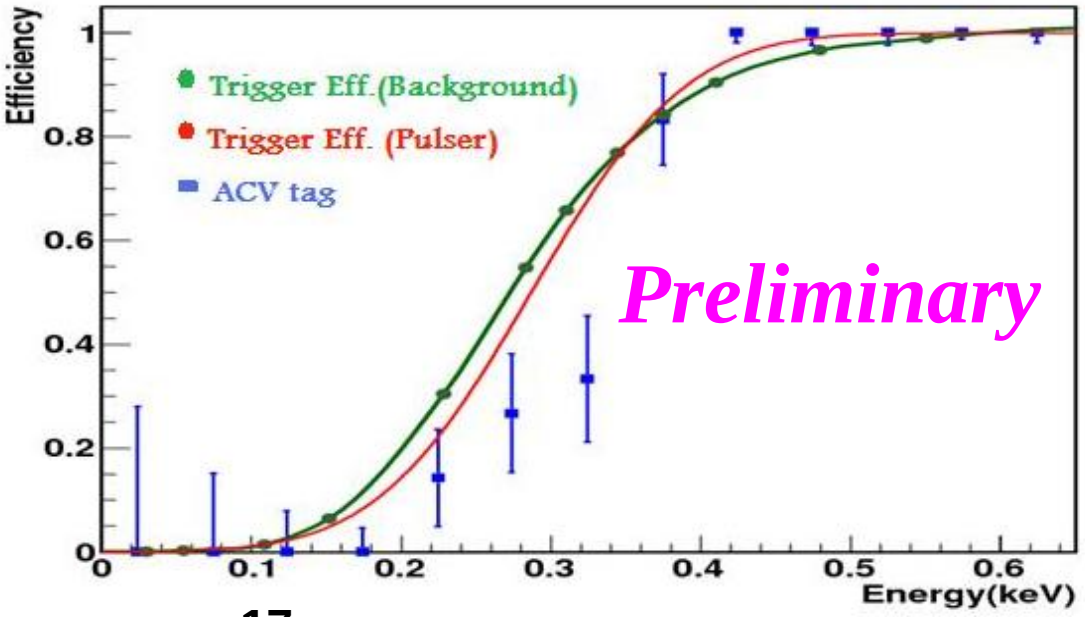
Performance of *Point-Contact* Germanium Detector(500g)

- **Efficiencies comparison with** *5g x4 channel (Top)* **and** *Point-Contact (Bottom)* **Germanium detectors**



- **Pulser Method**

  - It is consistence with the trigger efficiencies for Background and Pulser



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 *Dec.* 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**