Limits on spin-independent couplings of WIMP dark matter with a p-type point-contact germanium detector

- Overview (Program; Collaboration)
- Highlights : Facilities & Detector
- Analysis of Bulk/Surface & Results *[PRL 2013]*
- Outlook & Prospects

TEXONO Collaboration

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

TEXONO : *Taiwan EXperiment On NeutrinO* *[Since 1997]*

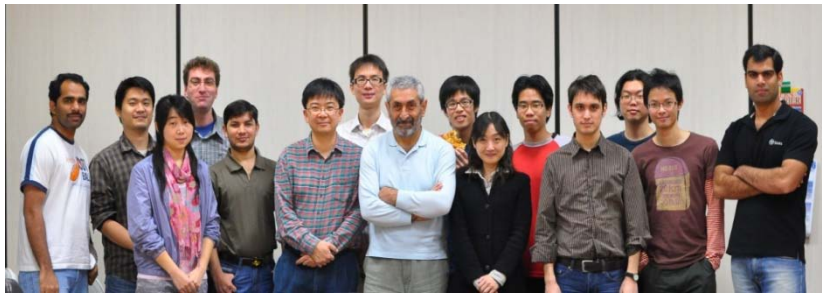
- *Neutrino Physics at Kuo Sheng Neutrino Laboratory (KSNL)*

Taiwan (AS, INER, KSNPS, NTHU)

+ China (THU,CIAE,NKU,SCU)

+ Turkey (DEU, METU)

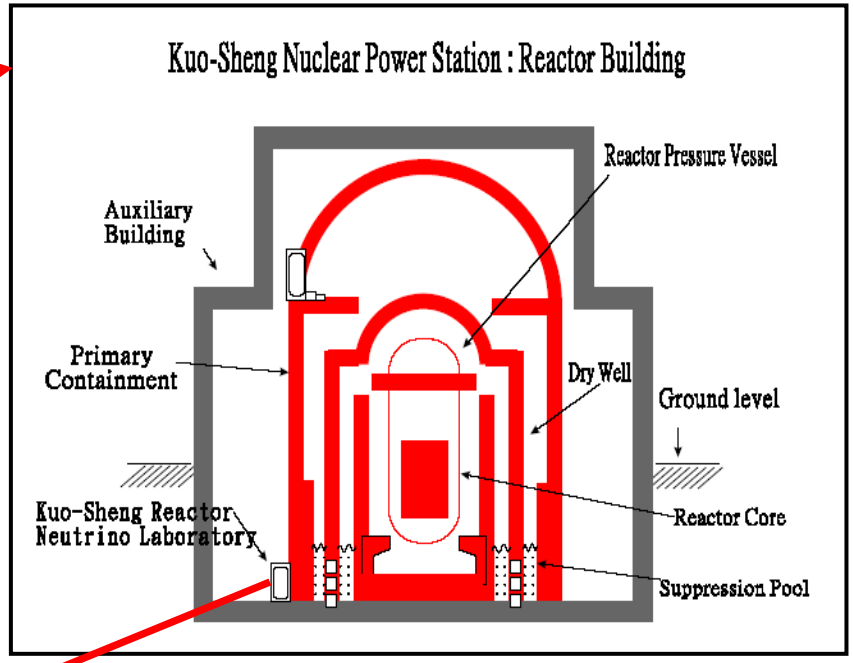
+ India (BHU)

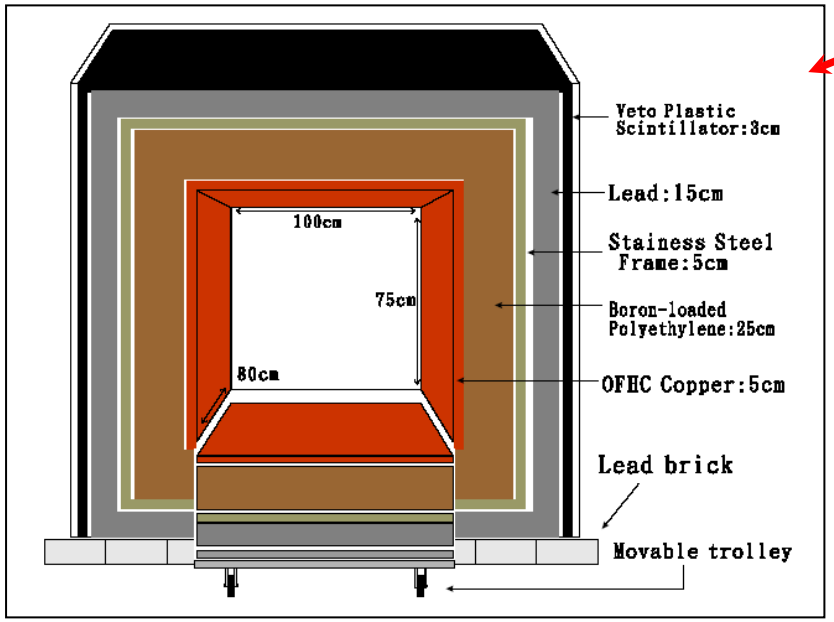


⊕Participate in CDEX-1 Program

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

Kuo Sheng Reactor Neutrino Laboratory





Physics Program:

- Neutrino Magnetic Moment PRL03, PRD05, PRD07
- neutrino-electron scattering (SM/BSM) PRD10x2, PRD12
- Dark Matter Search PRD-RC09, PRL13 (This talk)

Physics goals/Sub-keV Ge Detector Techniques

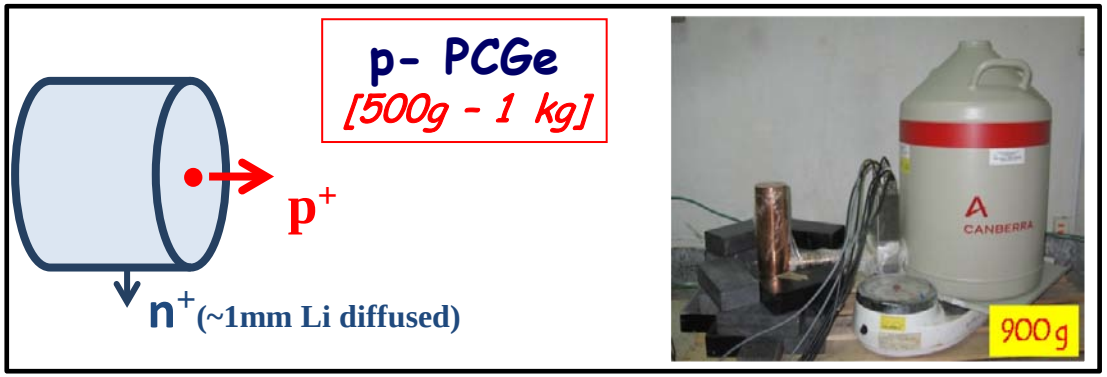
Physics Goals for *O[100 eV threhold ⊕ 1 kg mass ⊕ 1 cpkkd] detector* : Low mass WIMP searches & Neutrino Physics [νN(coh)]

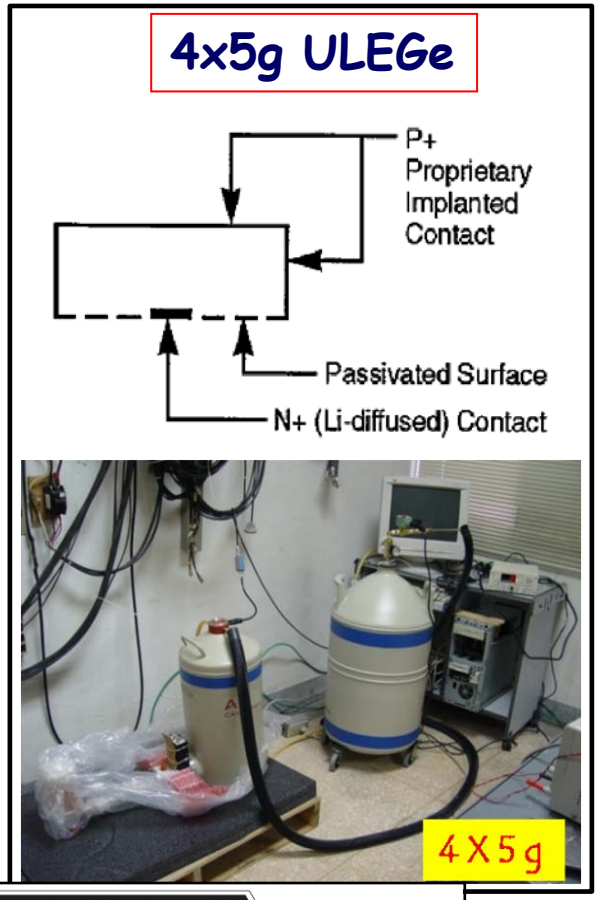
- ✓ Energy Definition & Calibration
- ✓ Trigger Efficiencies near threshold
- ✓ Physics Vs Noise Pulse-Shape Selection
- ✓ PSD & Timing – suppress electronics noise
- ✓ Quenching Factors --

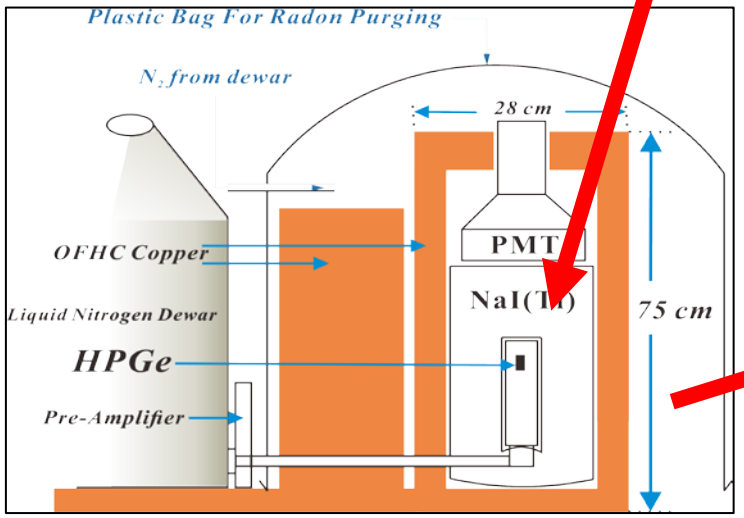
  nuclear recoils' Ionization Yields (adopted TRIM)
- ✓ Bulk Vs Surface Events Selection --

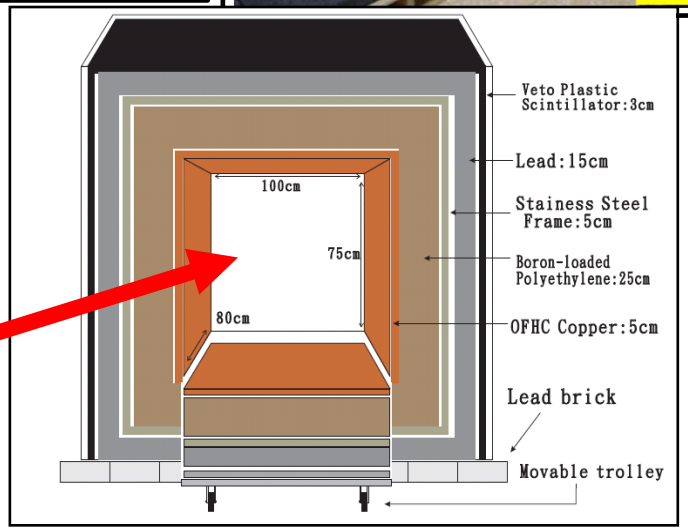
  algorithms & efficiencies
- ✓ Background understanding

Various Sub-keV Germanium Detectors

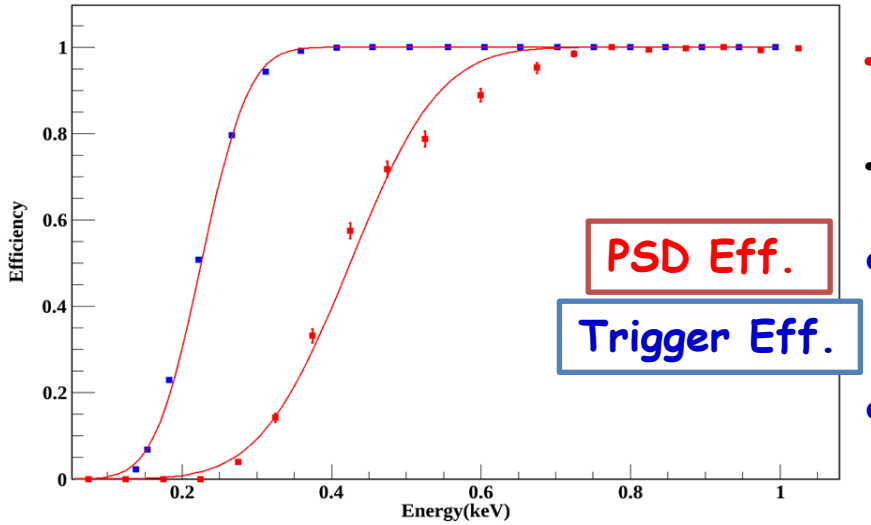








PPC germanium detector @ KSNL [PRL 2013]



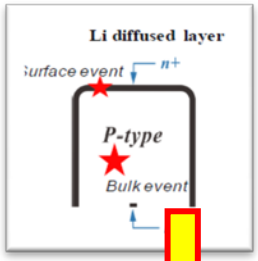
Trigger & PSD Efficiency

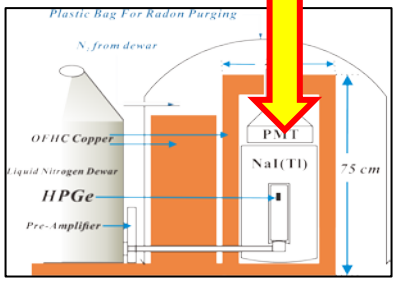
from background data & pulser.

- Trigger threshold (Eff. = 50%)
  ~ 200 eV
- PN threshold (Eff. = 50%)
  ~ 400 eV

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



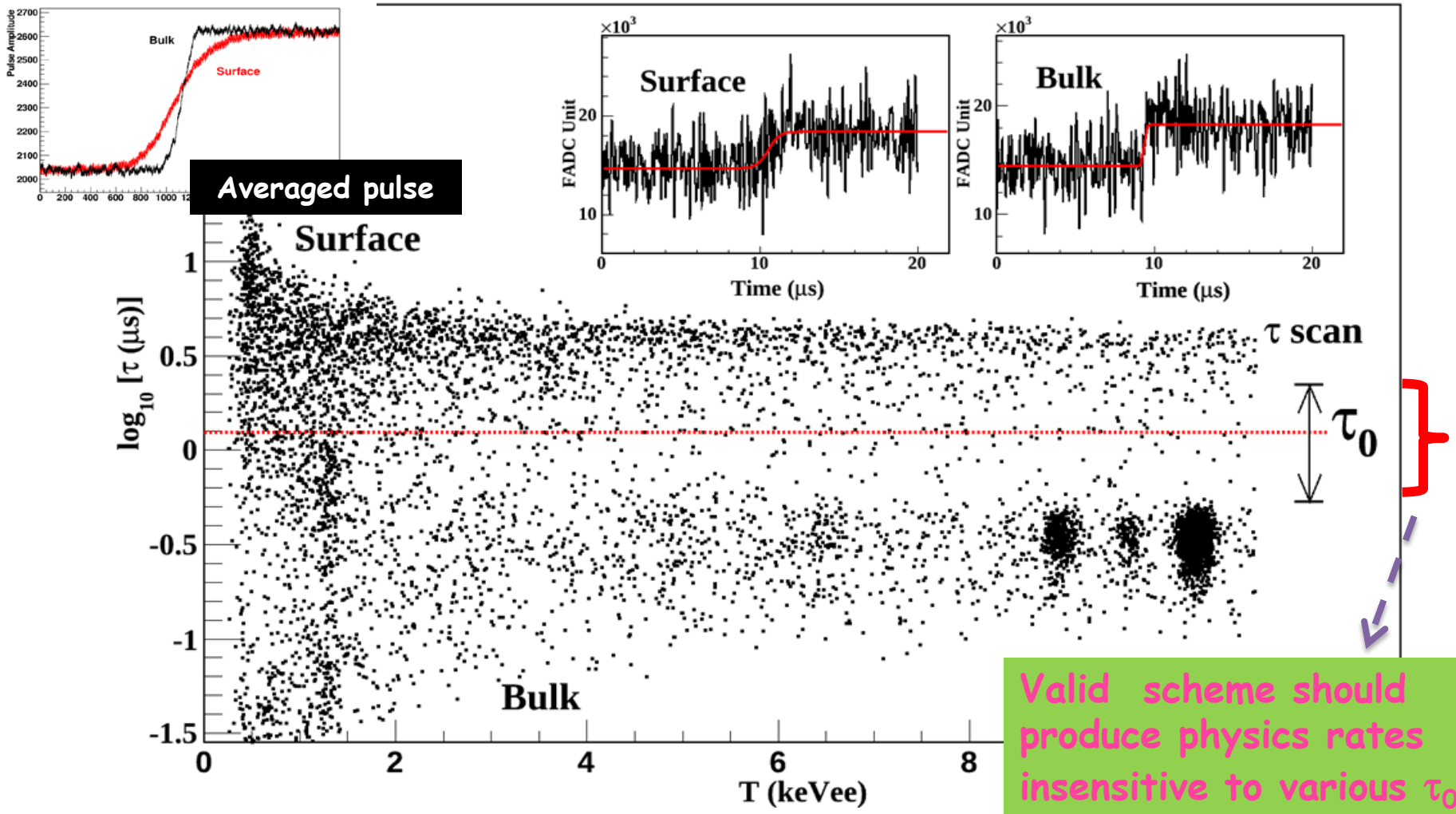


Selection Criteria:

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

PSD for Surface Vs Bulk Events @ PPCGe

- n+ "inactive layer" is not totally dead; signals finite but slower rise time
- Understand/Measure Efficiencies and Suppression Factors
- NPCGe (sub-micro inactive layer) does not show surface events



Valid scheme should produce physics rates insensitive to various τ_0

Abnormal Surface layer = 1.16 mm (^{133}Ba source) ref: NIMA 701 176 (2013)

Bulk Vs Surface (B/S) Events Selection & Efficiencies

$$B' = \epsilon_{\rm BS} \cdot B + (1 - \lambda_{\rm BS}) \cdot S$$
$$S' = (1 - \epsilon_{\rm BS}) \cdot B + \lambda_{\rm BS} \cdot S$$

algorithm

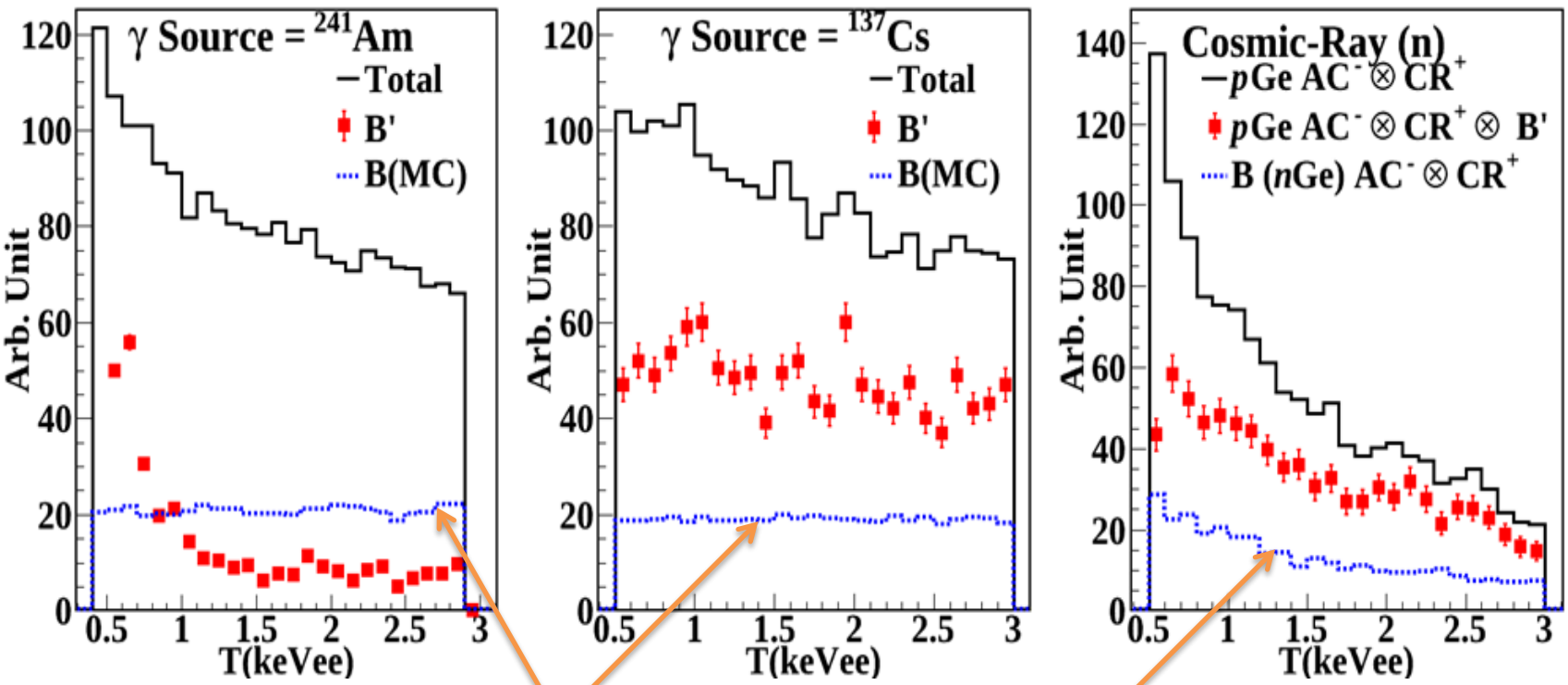
➢ **"Calibration" ≡ measure energy-dependent signal-retaining (ε_{BS}) & background-suppressing (λ_{BS}) efficiencies, such that [B,S=real ; B'S'=measured]**

Measured Bulk = Remaining real Bulk ⊕ Surface leakage

➢ **Approach: Identify *at least* two calibration data where (B,S) are known & (B',S') measured**

Solve coupled equation for (ε_{BS}, λ_{BS}) ⇨ correct physics (B'S') to get (B,S)

Bulk Vs Surface (B/S) : Calibration data



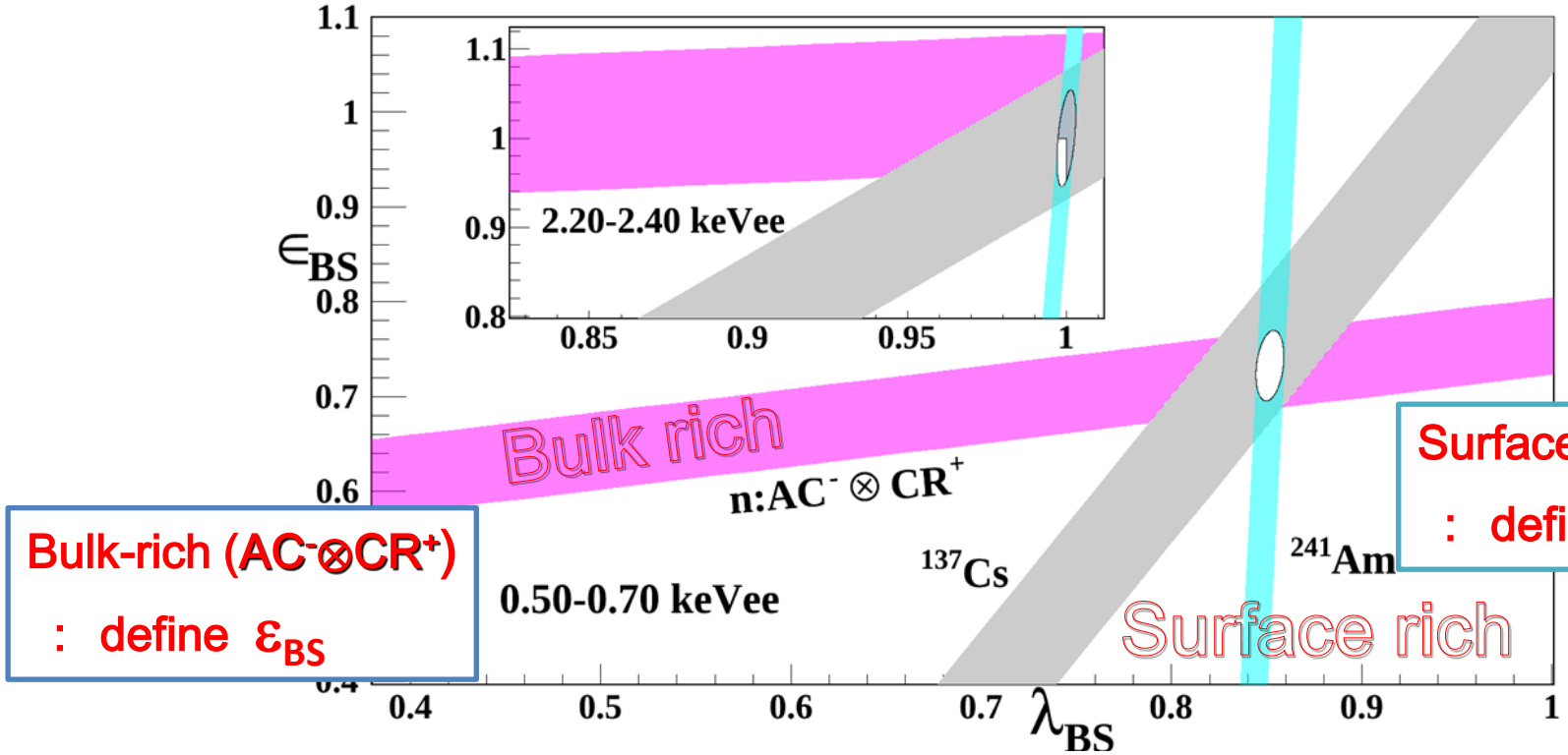
Flat "bulk" spectrum by MC

Bulk rich, ($AC^{-} \otimes CR^{+}$) from NPCGe

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 $AC^{-} \otimes CR^{+}$ tagging ; B=same tag from NPCGe

Solving coupled equation from calibration data

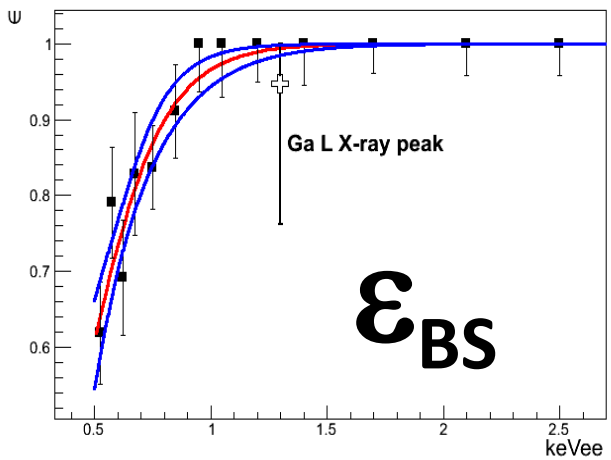


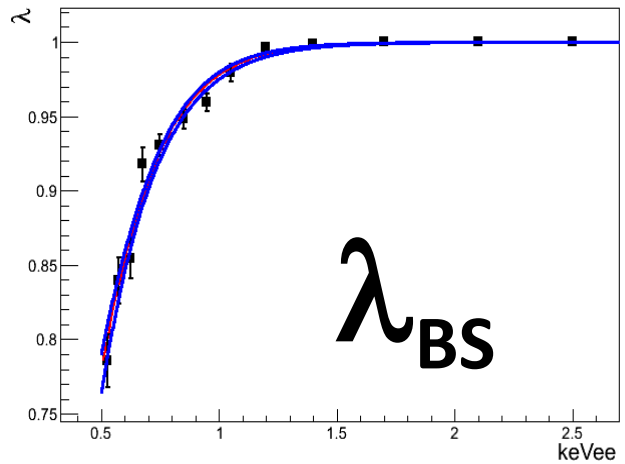
Bulk-rich ($AC^- \otimes CR^+$)

: define ε_{BS}

Surface-rich (^{241}Am)

: define λ_{BS}

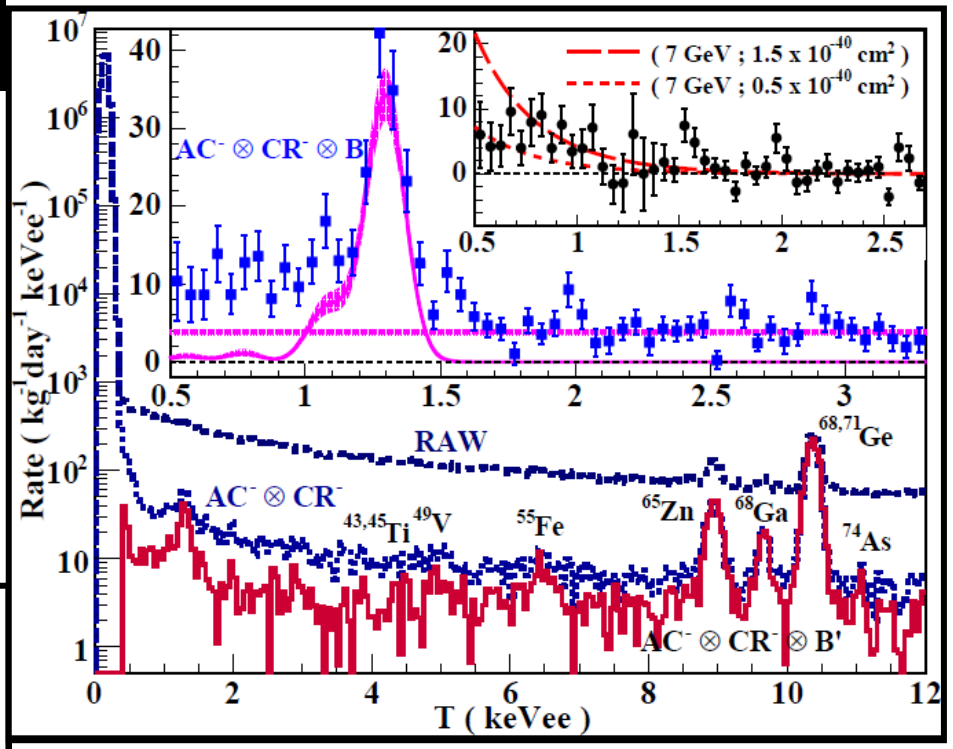


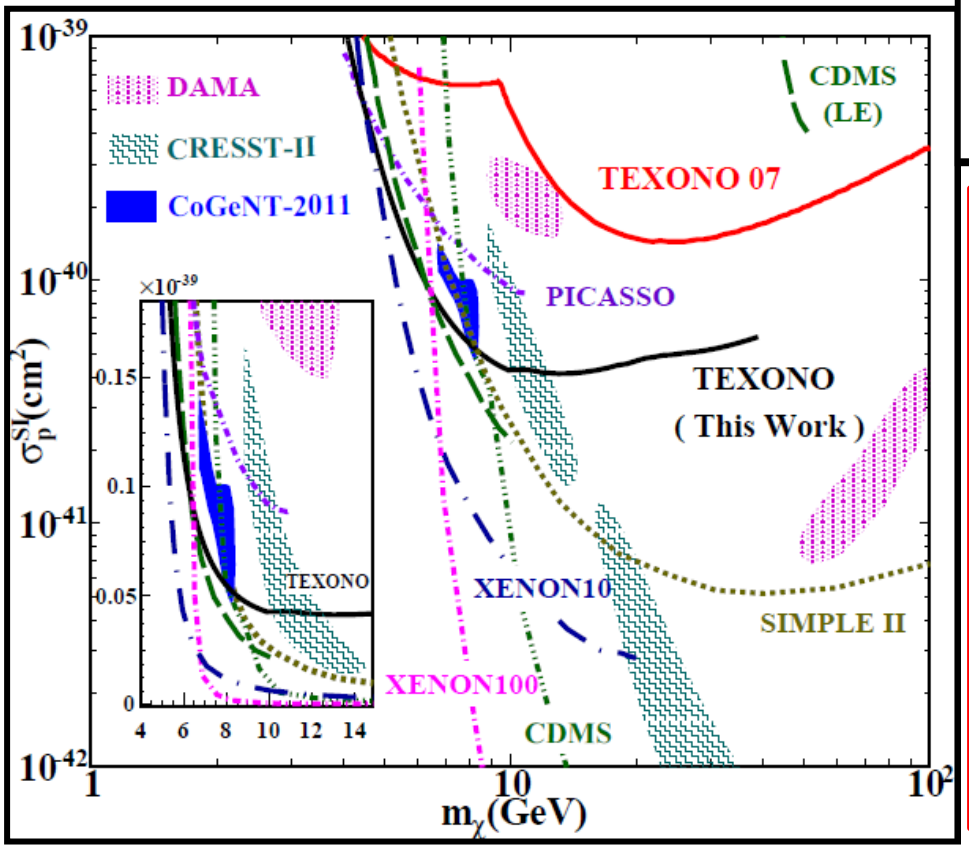


Recoil spectrum & exclusion plot

"Candidate Events"= AC⁻⊗CR⁻⊗B

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

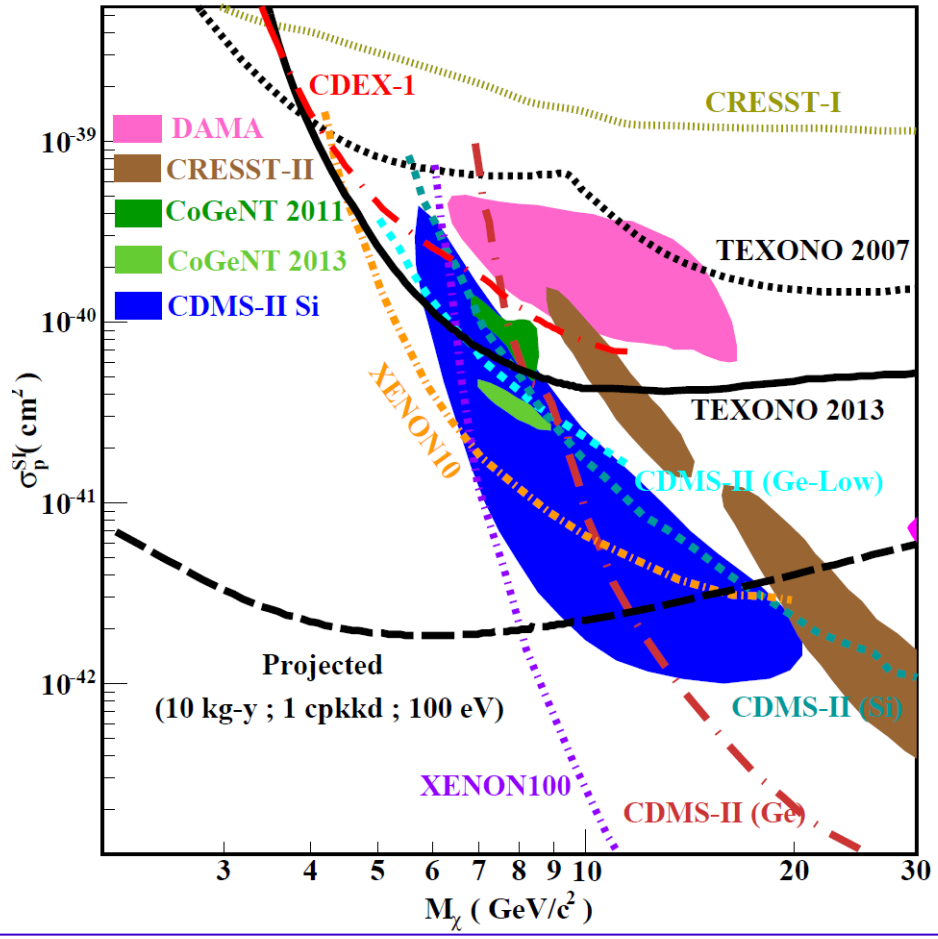




TEXONO *[1303.0925, PRL 110 261301 (2013)]*:

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

New developments on light WIMPs…



CoGeNT – 2013 [see talk by *Juan Collar, Sep. 9*]
MAJORANA [see talk by *Graham K. Giovanetti, Sep. 9*]
CDMS-II (Si) (low-thr.) [see talks by *Julien Billard, Sep. 9 ; Jeter Hall, Sep. 11*]
CDEX-1 [see talk by *CDEX's group, Sep. 12*]
EDELWEISS-II [see talk by *Klaus Eitel, Sep. 10*]

Outlook & Prospects

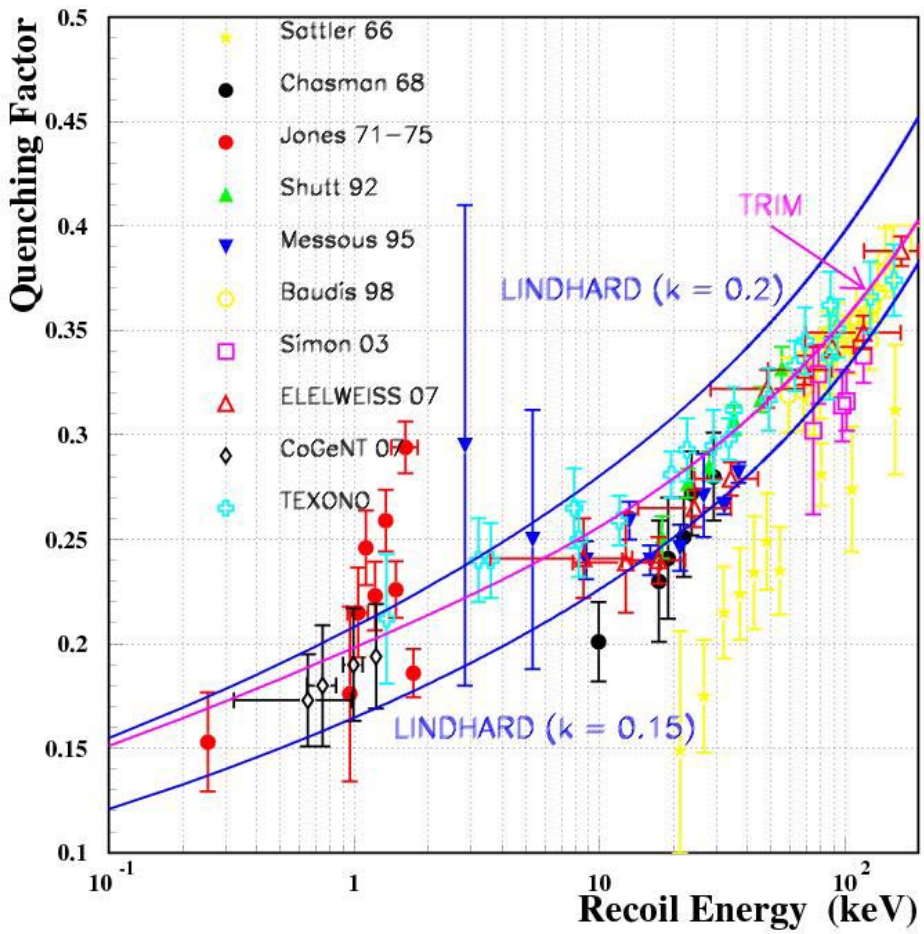
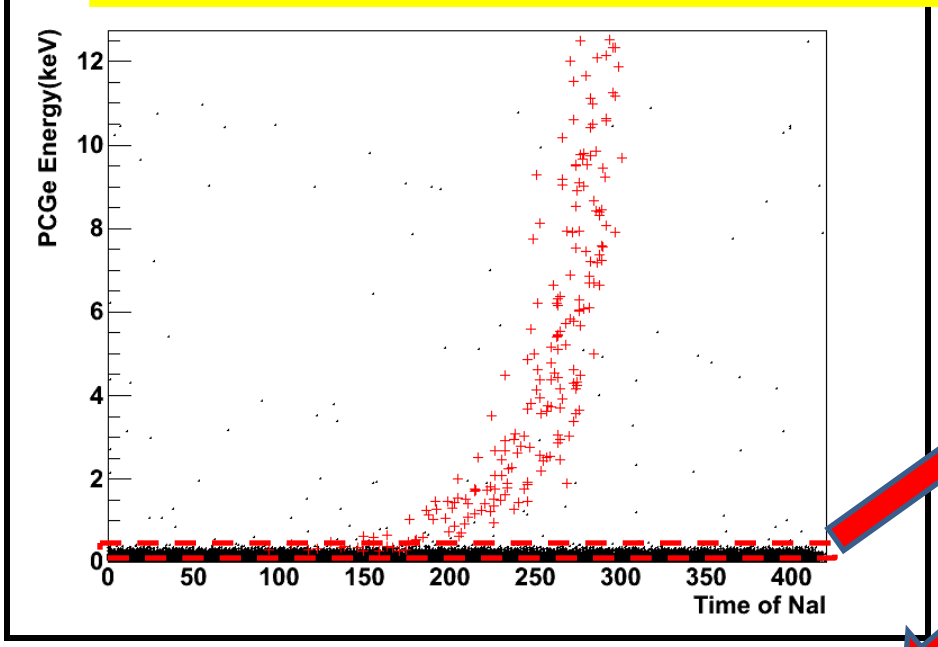
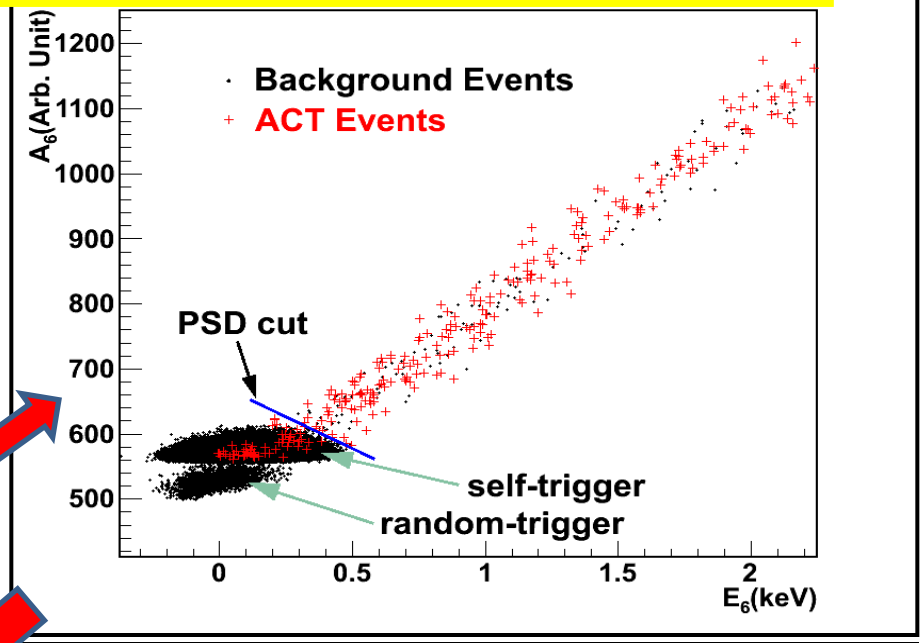
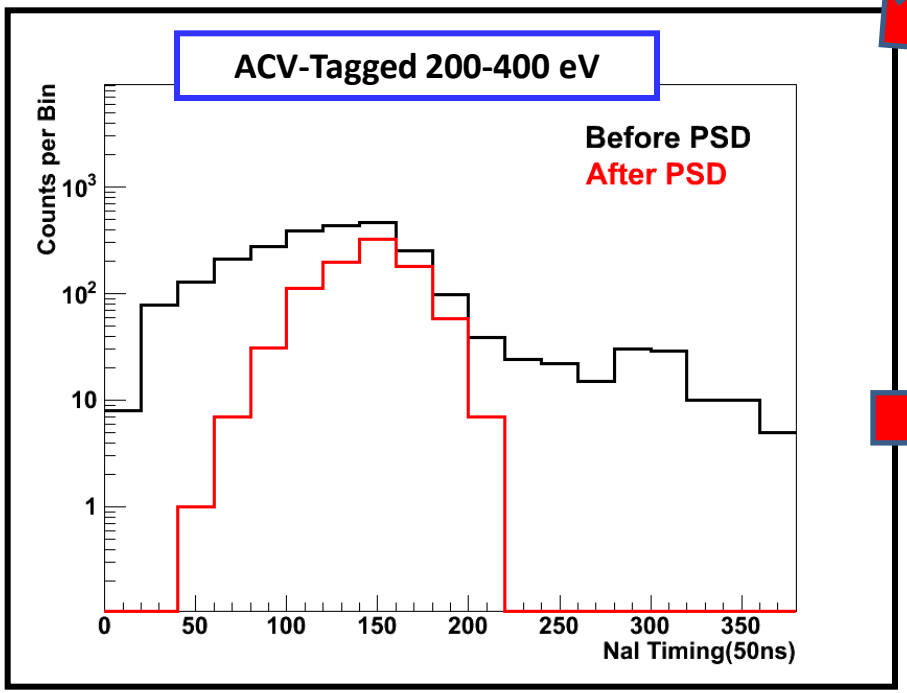
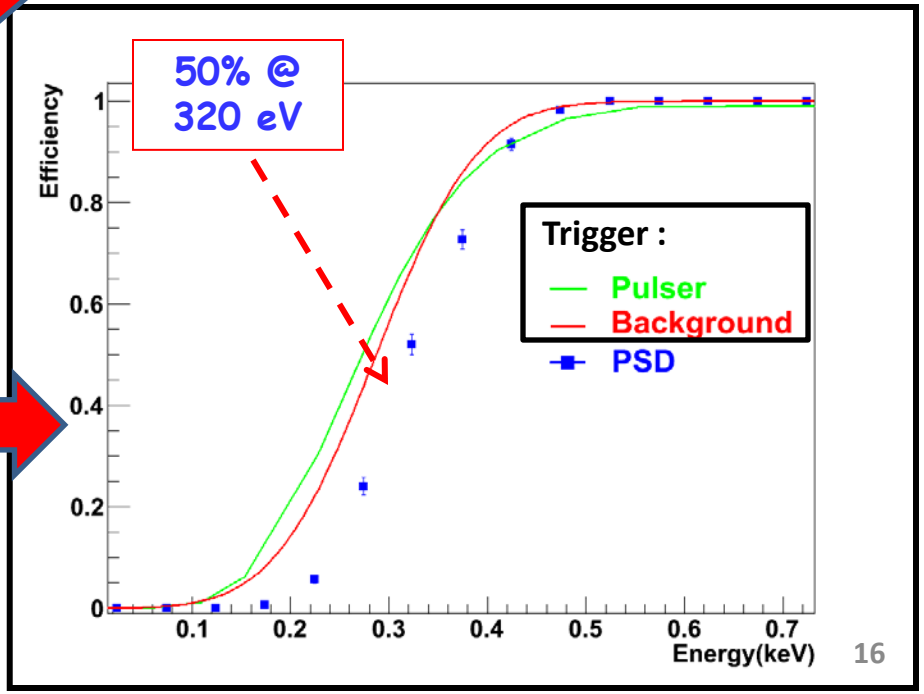
- Competitive and relevant results on low-mass WIMPs with sub-keV Ge detector, even at a surface location (KSNL)
- Same design at underground laboratory (CDEX-1 @ CJPL) can only be better
- Devised calibration schemes to characterize bulk-Vs-surface demonstrated that leakage of surface background to bulk signals is important
- There exists residual excess at sub-keV not-accounted-for by present analysis ; intense work on their understanding
- more matured now to return to original goal

  ⇨ 🏆νN coherent scattering @ KSNL

Backup slides

Quenching Factor [Ionization Yield → Energy] :

- TRIM Simulation Software (better fits to available data over extended energy)



Threshold & Phys-Vs-Noise Selection Efficiency