Low Energy Reactor Neutrino Physics with Germanium Detectors + ...

- Physics & Experiments & Requirements
- Crisis / Challenges / Opportunities
- Wish (Wishful Thinking) List from Users
- TEXONO@KSNL New Results *[arXiv: 1303.0925]*

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Original - Photocopie of PLC 0393
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Offener Brief an die Gruppe der Radioaktiven bei der Gauvereins-Tagung zu Tübingen.

Abschrift

Physikalisches Institut
der Eidg. Technischen Hochschule
Zürich

Zürich, 4. Dez. 1930
Gloriastrasse

Liebe Radioaktive Damen und Herren,

Wie der Ueberbringer dieser Zeilen, den ich huldvollst anzuhören bitte, Ihnen des näheren auseinandersetzen wird, bin ich angesichts der "falschen" Statistik der N- und Li-6 Kerne, sowie des kontinuierlichen beta-Spektrums auf einen verzweifelten Ausweg verfallen um den "Wechselsatz" (1) der Statistik und den Energiesatz zu retten. Nämlich die Möglichkeit, es könnten elektrisch neutrale Teilchen, die ich Neutronen nennen will, in den Kernen existieren, welche den Spin 1/2 haben und das Ausschliessungsprinzip befolgen und sich von Lichtquanten ausserdem noch dadurch unterscheiden, dass sie nicht mit Lichtgeschwindigkeit laufen. Die Masse der Neutronen müsste von derselben Grössenordnung wie die Elektronenmasse sein und jedenfalls nicht grösser als 0,01 Protonenmasse.- Das kontinuierliche beta- Spektrum wäre dann verständlich unter der Annahme, dass beim beta-Zerfall mit dem Elektron jeweils noch ein Neutron emittiert wird, derart, dass die Summe der Energien von Neutron und Elektron konstant ist.

Nun handelt es sich weiter darum, welche Kräfte auf die Neutronen wirken. Das wahrscheinlichste Modell für das Neutron scheint mir aus wellenmechanischen Gründen (näheres weiss der Ueberbringer dieser Zeilen) dieses zu sein, dass das ruhende Neutron ein magnetischer Dipol von einem gewissen Moment μ ist. Die Experimente verlangen wohl, dass die ionisierende Wirkung eines solchen Neutrons nicht grösser sein kann, als die eines gamma-Strahls und darf dann μ wohl nicht grösser sein als $e \cdot (10^{-13}$ cm).

Ich traue mich vorläufig aber nicht, etwas über diese Idee zu publizieren und wende mich erst vertrauensvoll an Euch, liebe Radioaktive, mit der Frage, wie es um den experimentellen Nachweis eines solchen Neutrons stände, wenn dieses ein ebensolches oder etwa 10mal grösseres Durchdringungsvermögen besitzen würde, wie ein gamma-Strahl.

Ich gebe zu, dass mein Ausweg vielleicht von vornherein wenig wahrscheinlich erscheinen wird, weil man die Neutronen, wenn sie existieren, wohl schon längst gesehen hätte. Aber nur wer wagt, gewinnt und der Ernst der Situation beim kontinuierliche beta-Spektrum wird durch einen Ausspruch meines verehrten Vorgängers im Amte, Herrn Debye, beleuchtet, der mir kürzlich in Brüssel gesagt hat: "O, daran soll man am besten gar nicht denken, sowie an die neuen Steuern." Darum soll man jeden Weg zur Rettung ernstlich diskutieren.- Also, liebe Radioaktive, prüfet, und richtet.- Leider kann ich nicht persönlich in Tübingen erscheinen, da ich infolge eines in der Nacht vom 6. zum 7 Dez. in Zürich stattfindenden Balles hier unabkömmlich bin.- Mit vielen Grüssen an Euch, sowie an Herrn Back, Euer untertänigster Diener

gez. W. Pauli

Tuebingen:

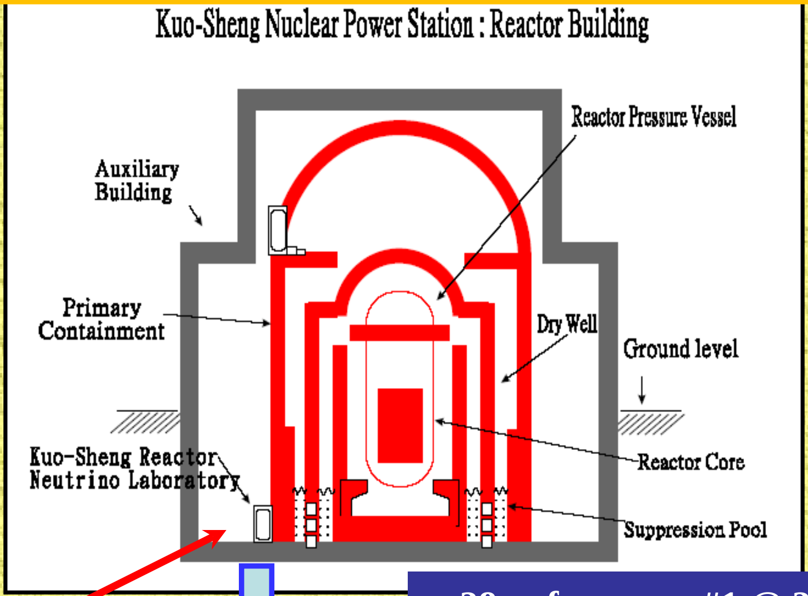
- stage of the most famous absence from a meeting in History of Physics
- Appears in 1st page of every neutrino physics text book
  ⇨Introduction of the idea of neutrinos to science by Pauli, 1930.

Kuo Sheng Reactor Neutrino Laboratory (KSNL)
TEXONO Collaboration (since 1997) *[Taiwan, China, India, Turkey]*


Science
AAAS
16 MAY 2003 VOL 300 SCIENCE
Taiwan-China Collaboration

A Bridge Over Troubled Waters

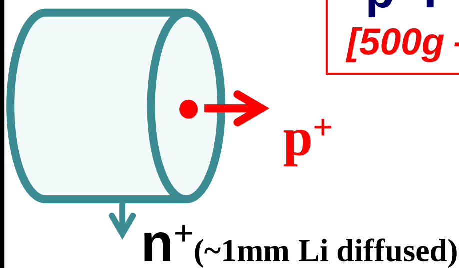
Researchers from Taiwan and the mainland have hit scientific pay dirt with the first—and so far the only—collaboration between two institutions across the Taiwan Strait



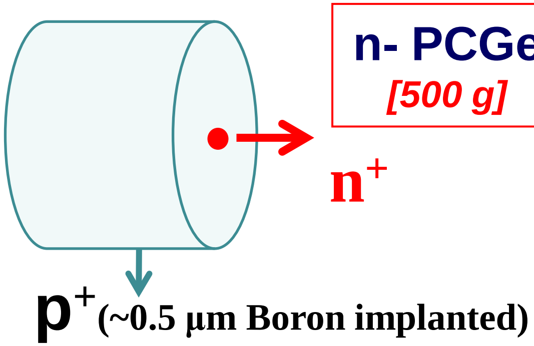
28 m from core#1 @ 2.9 GW
~30 mwe overburden

Baseline Hardware Design

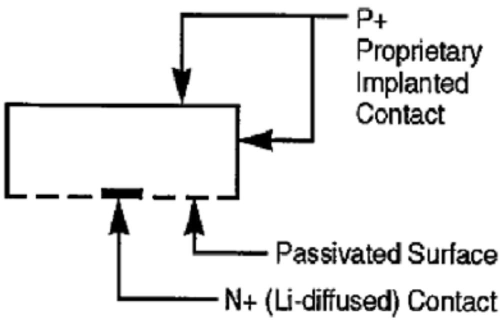
p- PCGe
[500g – 1 kg]

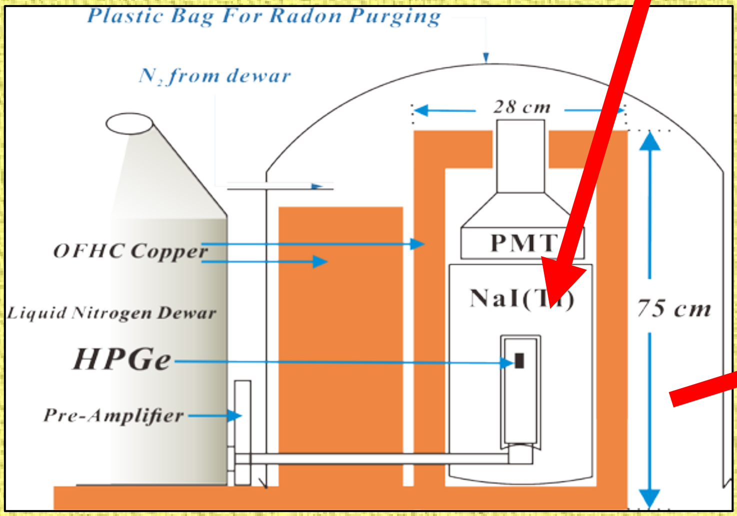


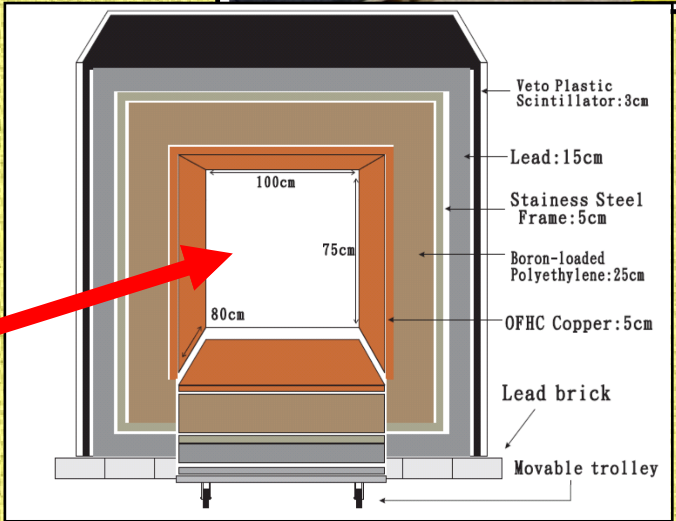
n- PCGe
[500 g]



4x5g ULEGe







Current Research Theme:

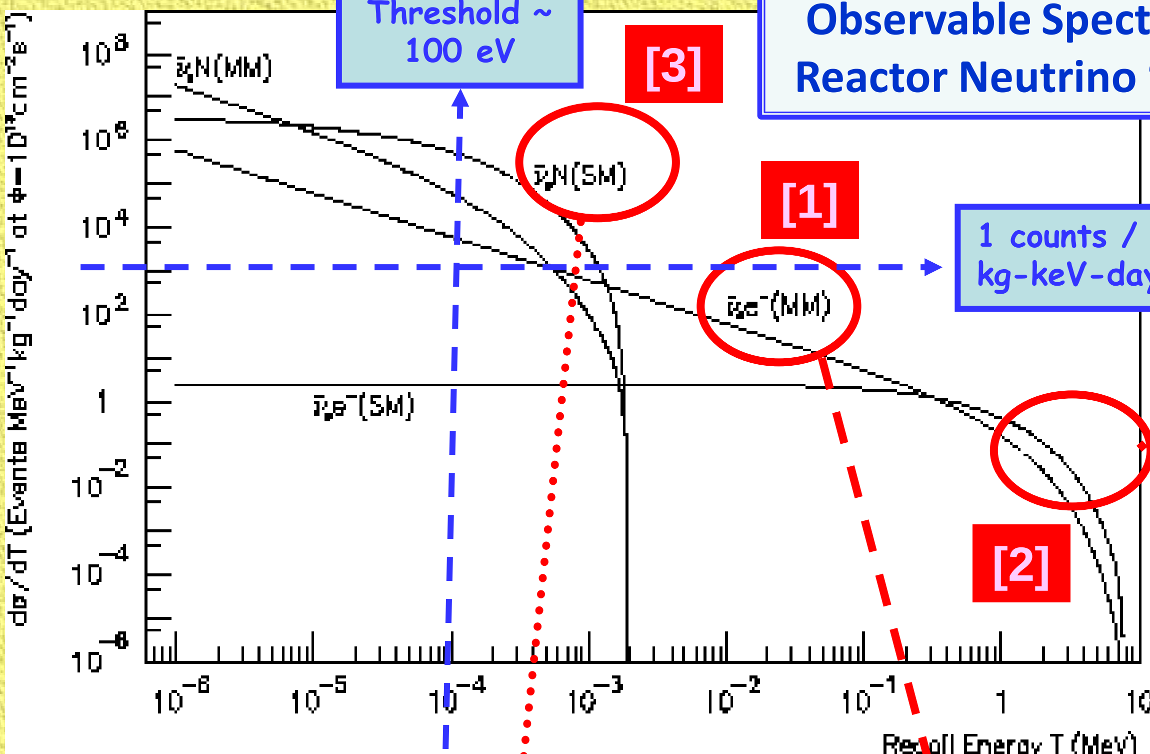
"sub-keV" Ge Detectors

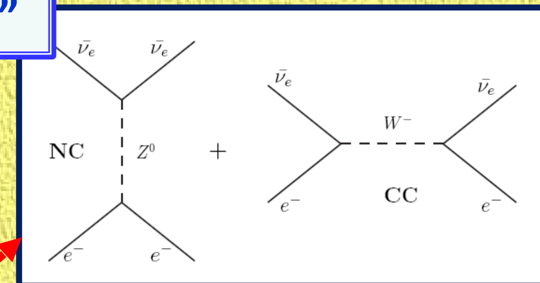
- **Physics Goals for *O[100 eV threhold⊕1 kg mass⊕1 cpkkd] detector* :**
  - **νN coherent scattering , potential applications to reactor monitoring**
  - **Low-mass WIMP searches**
  - **neutrino magnetic moments**
  - ***Open & Explore* new detector window & detection channel & physics parameter space**

Neutrino Properties & Interactions at Reactor

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

Observable Spectra with Reactor Neutrino "Beam"



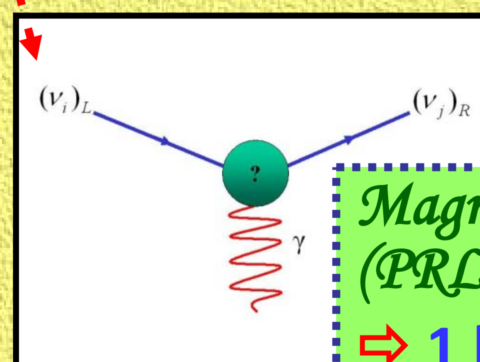


SM & NSI/BSM νe Scattering (2⊗ PRD10,PRD12)

⇨ **200 kg CsI(Tl)**

νN Coherent Scattering

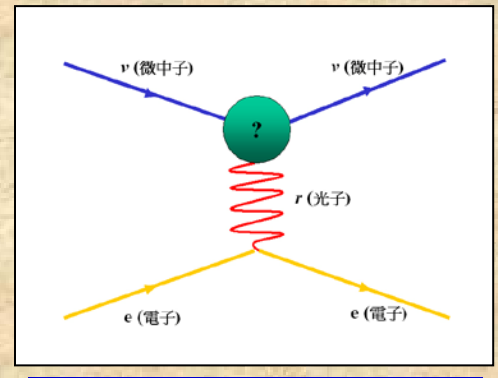
- sub-keV O(kg) Ge
- Dark Matter Searches (PRDRC-09)
- DM@CJPL
- *.. more twists & turns (the "Beyonds")!?*



Magnetic Moments (PRL03,PRD05,PRD07)

⇨ **1 kg HPGe**

Reactor Neutrino @ KSNL : Summary



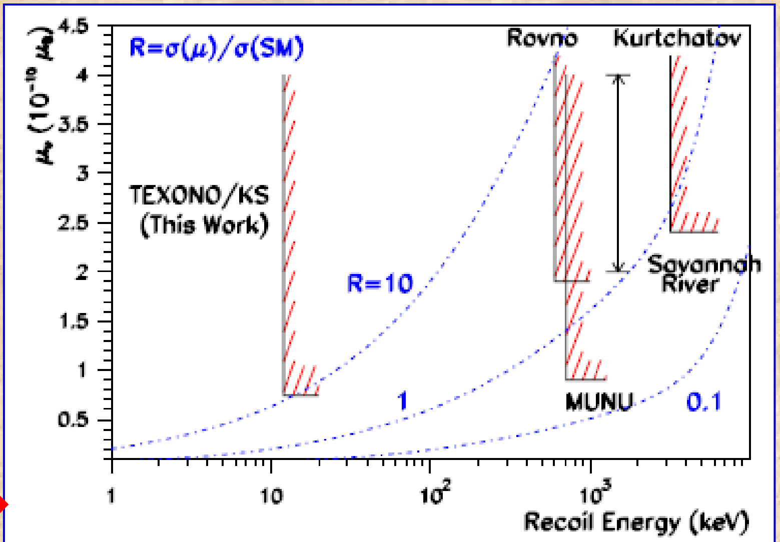
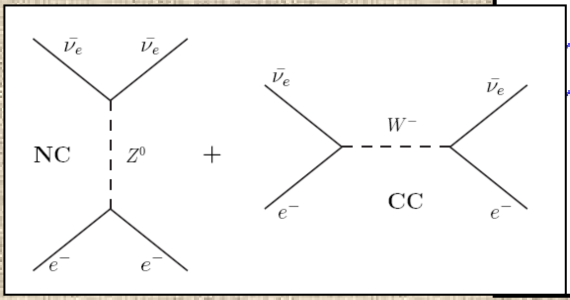
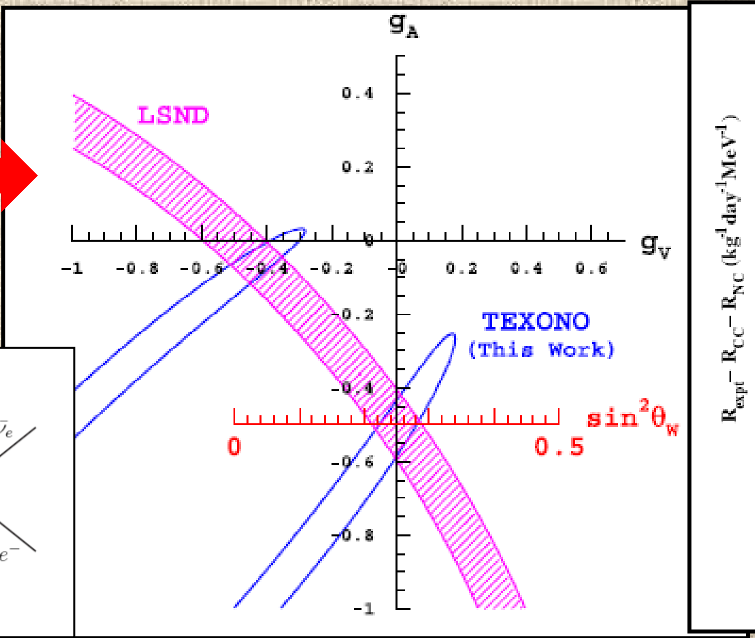
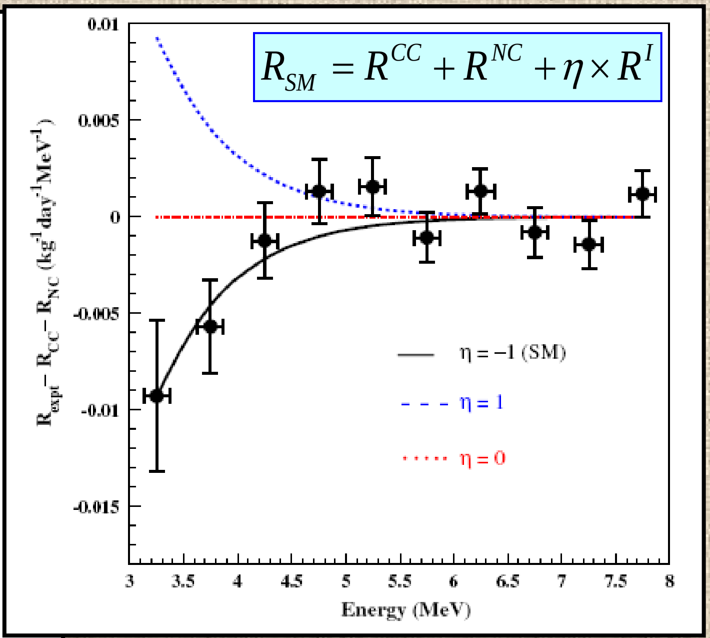


FIG. 14 (color online). Summary of the results in the searches of neutrino magnetic moments with reactor neutrinos. Both the limits and the detection thresholds of the various experiments are shown.



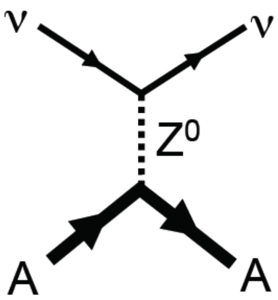


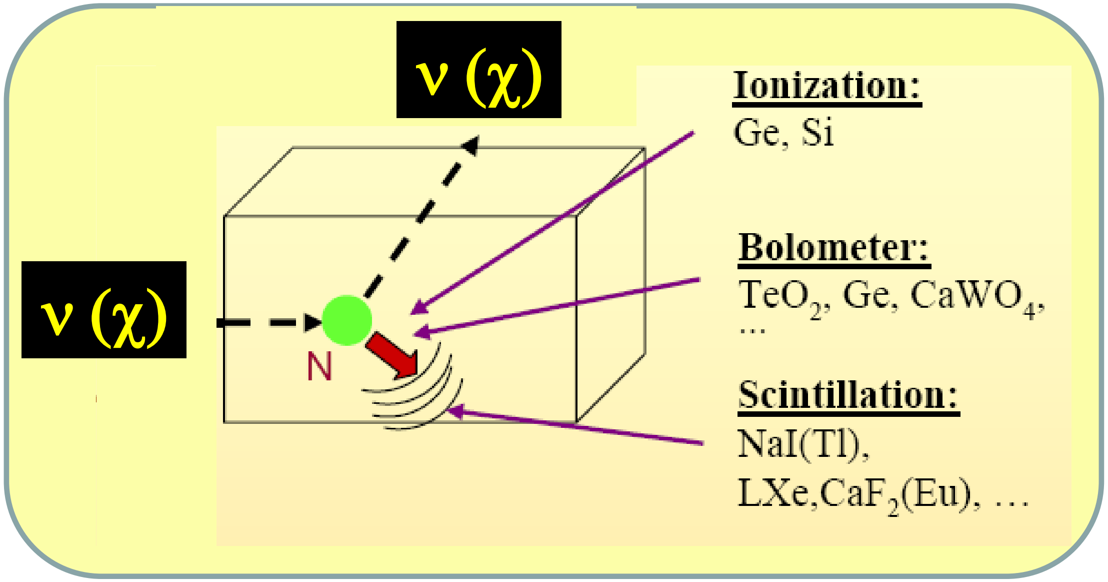


Neutrino-Nucleus Coherent Scattering :

Standard Model allowed and predicted processes :

$$\nu + A \rightarrow \nu + A$$



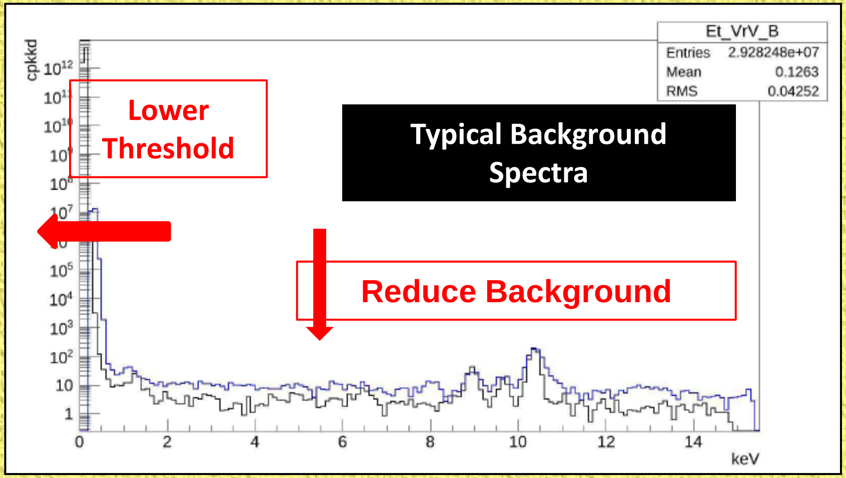


- Neutral current process (same for all ν-flavor)
- $\sigma \propto N^2$ @ $E_\nu < 50$ MeV

  $\Rightarrow$ ***"Coherent"*** *[probe "sees" the whole nucleus]*
- sensitive probe for BSM ; interest in reactor monitoring
- important process in stellar collapse & supernova explosion
- analogous interaction used in dark matter detection
- Ge at KSNL @ QF~0.2 : cut-off ~ 300 eV ;

  Rate ~10 kg^{-1} day^{-1} @ threshold~100 eV

Wishes & Challenges



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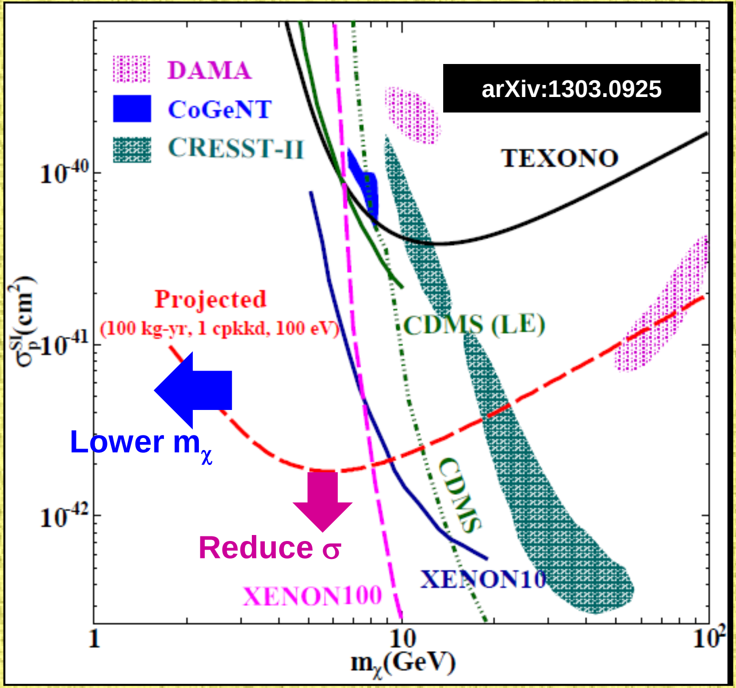


Reduce Bkg

- > keV : O(1 cpkkd) achieved
- Sub-keV Bkg goal : O(10 cpkkd)→O(1 cpkkd)
- How? Understand background and detector response ; radiopure materials
- *Novel Ideas ?? Nuclear Vs Electron recoil differentiation ??*

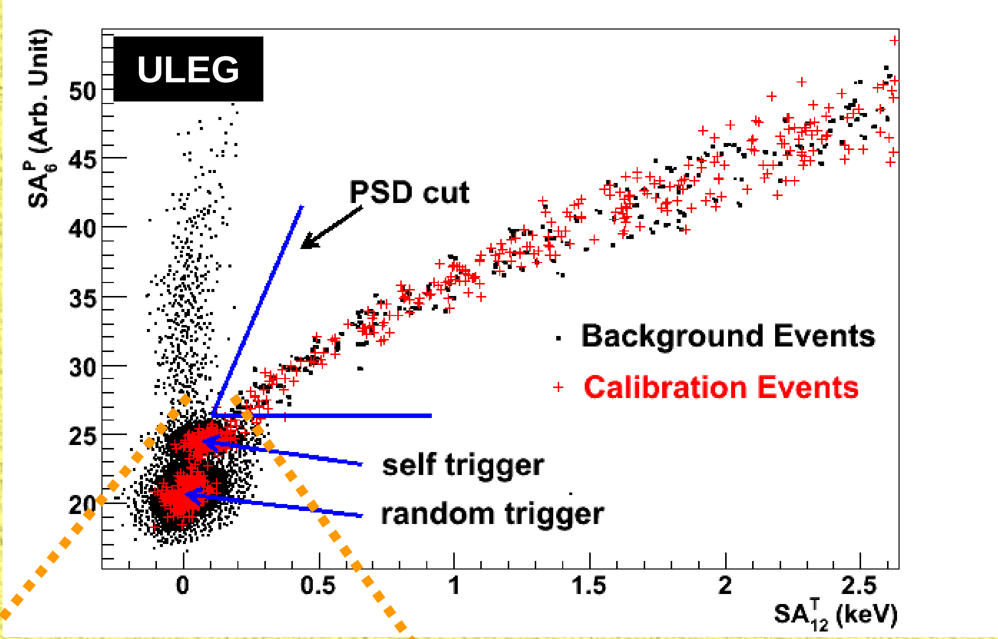
Lower Threshold

- 20 g target : 200-eV physics threshold achieved
- Kg-target Threshold goal : ~500 eV → 100 eV
- How? Sub noise-edge analysis ; electronics JFET R&D
- *Novel Ideas ?? Signal Amplification ??*

PSD Selection to Suppress Electronic Noise

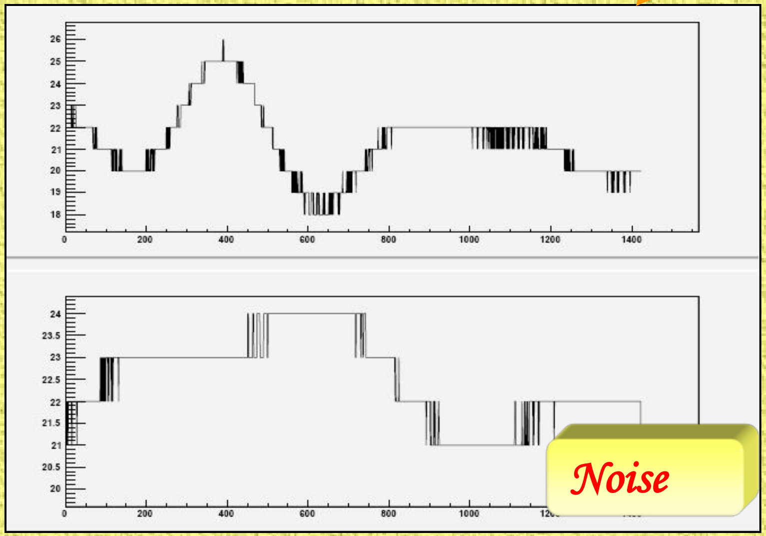
E.g. 1 ⇨ correlations in two readout of different gains & shaping times

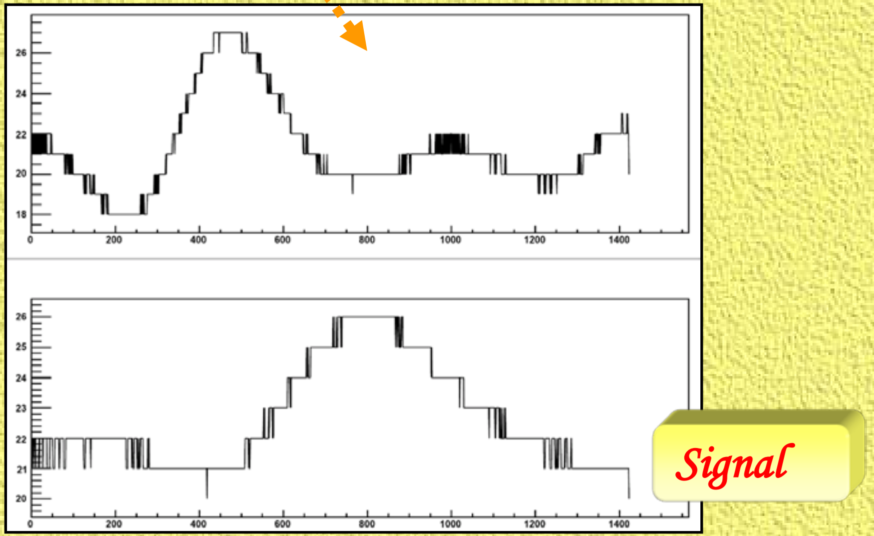
◎ **look for specific +ve pulse fluctuations at specific & known timing**



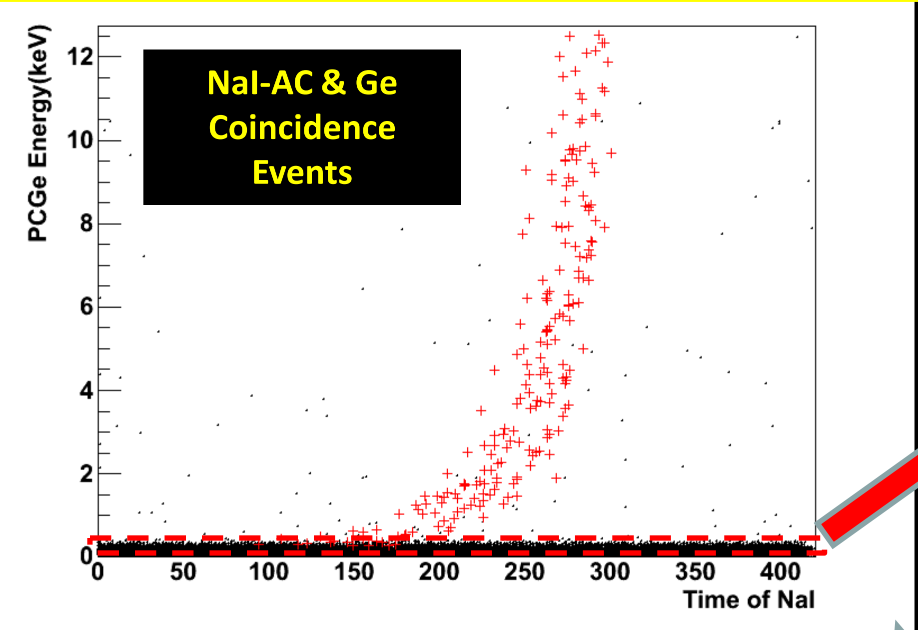
6μs

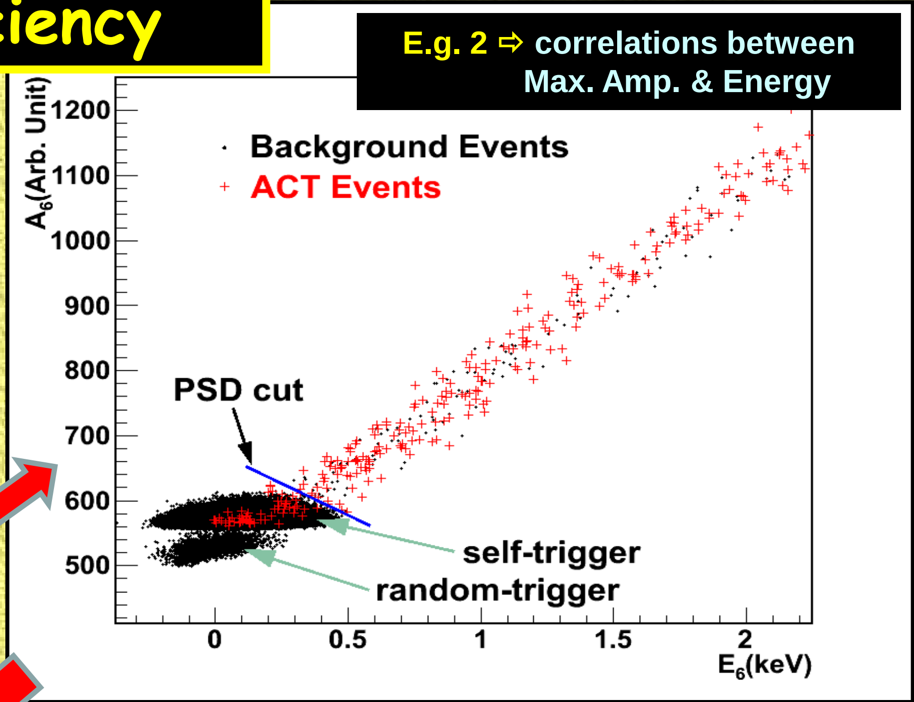
12μs

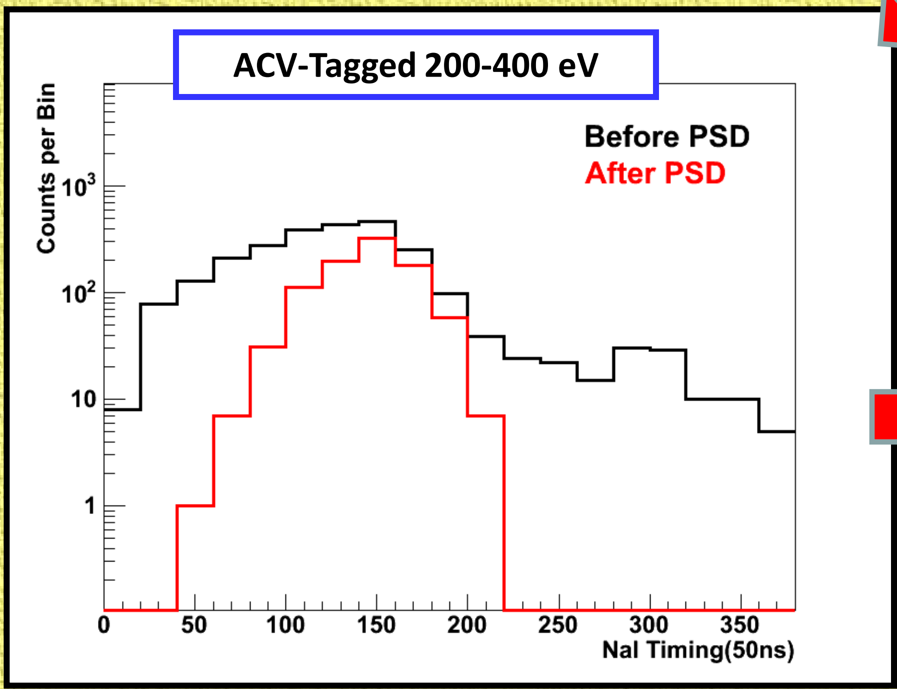


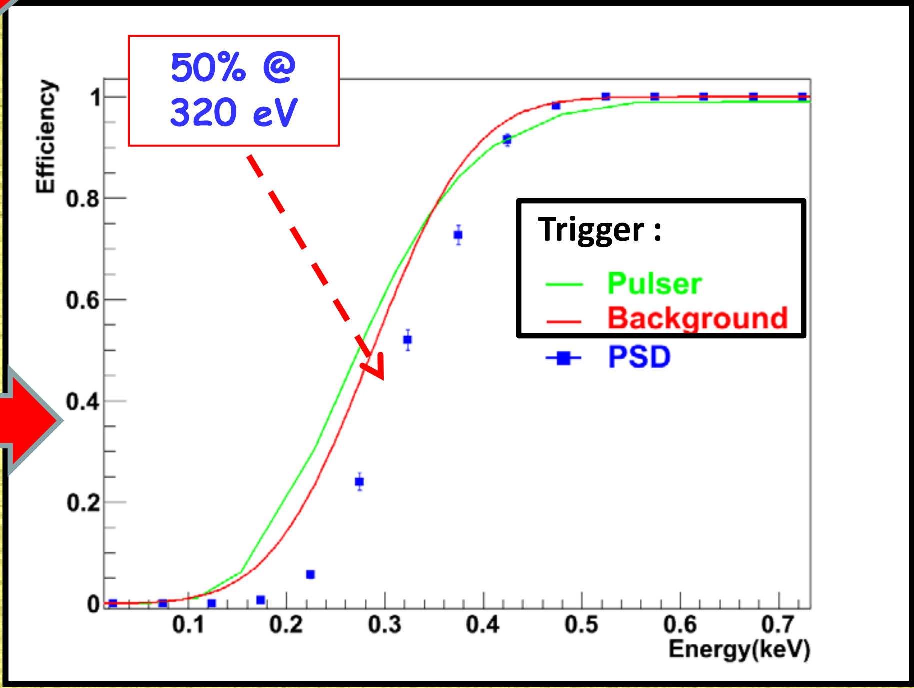


Phys-Vs-Noise Selection Efficiency









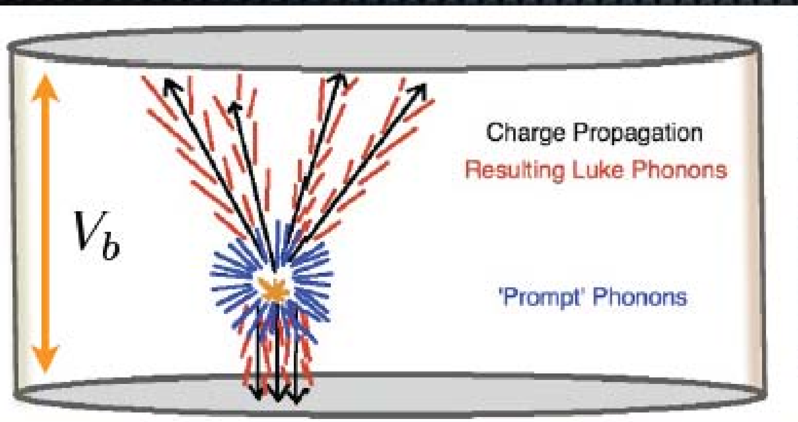
Exciting (Worrying) Development :
CDMS Experiment exploiting "phonon amplification at high drift voltage"

Luke, P.N.[a], Beeman, J.[a], Goulding, F.S.[a], Labov, S.E.[b], Silver, E.H.[b]
Calorimetric ionization detector
(1990) *Nuclear Inst. and Methods in Physics Research, A*, 289 (3), pp. 406-409. Cited 7 times.

[a] Lawrence Berkeley Laboratory, 1 Cyclotron Road, Berkeley, CA 94720, United States
[b] Lawrence Livermore Laboratory, Livermore, CA, United States

Abstract
A new mode of operation for ionization detectors is described. The amount of ionization produced in a detector is determined by measuring the amount of heat generated during the carrier collection process. Very high detection sensitivities, including single carrier detection, may be achieved at cryogenic temperatures. Results from an experimental device operated at T = 0.3 K are presented. © 1990.

Luke Phonons:



Apart from initial 'Prompt' phonons, Charge transport produces radiative "Luke" Phonons.

- **Luke**-Neganov Gain

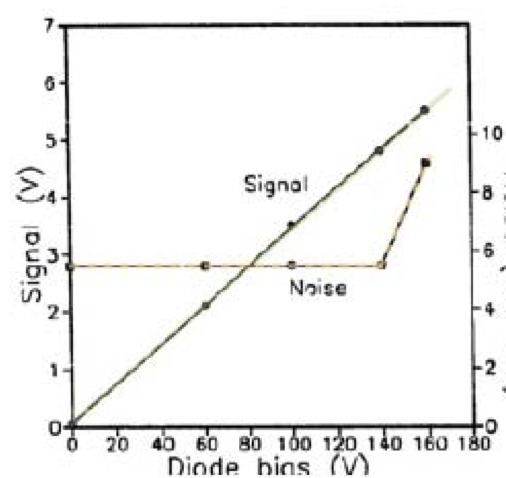
$$E_{tot} = E_r + E_{luke}$$
$$= E_r + n_{eh} e V_b$$
$$= E_r \left(1 + \frac{eV_b}{\epsilon_{eh}}\right)$$

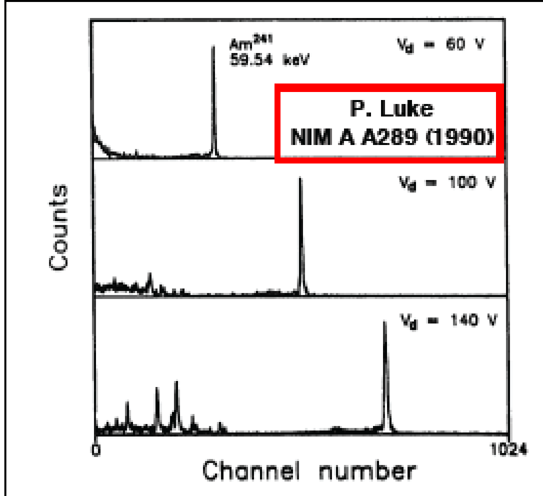
Luke's† experimental observations

Energy of phonons ~ V_{bias}

Noise is roughly constant up to some break down potential

†Calorimetric Ionization detector, Luke et al Nuclear Instruments and Methods in Physics Research A 289 (1990). Neganov-Torfimov reported similar results.





Public Conference Statements by CDMS

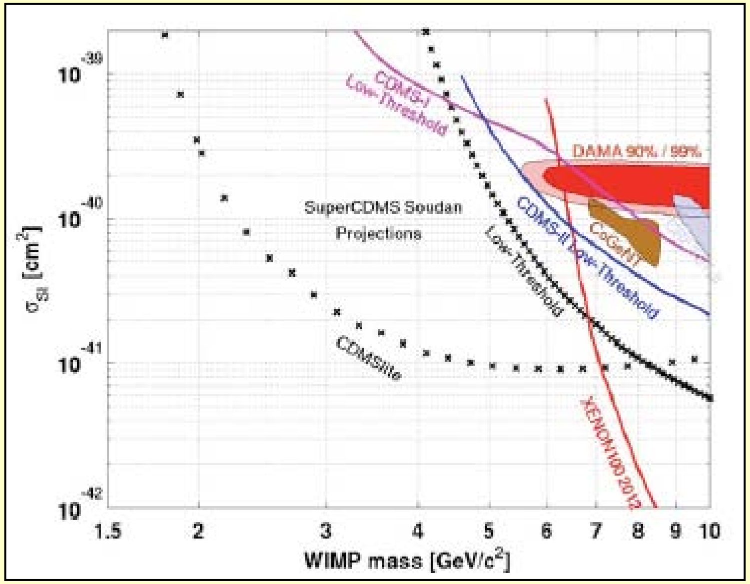
Noise is very well behaved

We could reach a threshold of 0.085 keVee !

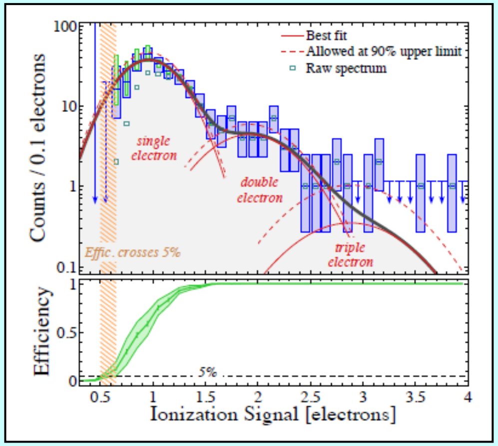
- Single Excitation Sensitivity Should Be Possible

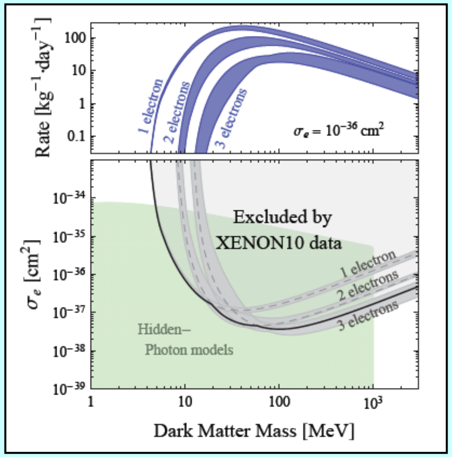
- The performance of the new iZIP detectors deployed in SuperCDMS Soudan has already proven to be excellent. We expect initial science results in 2013 for light mass WIMPs.

- Exciting possibilities for much lower phonon thresholds and substantial improvements in charge thresholds with HEMTs.



ALSO ***[arXiv:1206.2644, PRL12]*** **:**
LiqXe techniques may have achieved single-electron sensitivities or O(10 eV) threshold.

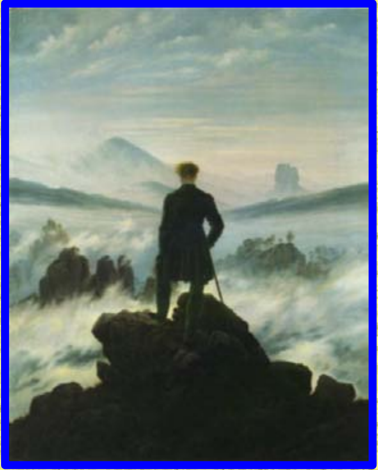




Wish (Wishful Thinking) from Physicist Users:

Climb Every Mountain ……..

- Innovations to do nuclear/electron differentiation, even down to 10-keVee ??
- Innovations to do electron-hole amplifications ??



Germanium Detector with Internal Amplification for Investigation of Rare Processes

arXiv:hep-ex/0002063v1 25 Feb 2000

A.S Starostin, A.G.Beda

SSC RF ITEP, Moscow 117259, Russia

Abstract

Device of new type is suggested - germanium detector with internal amplification. Such detector having effective threshold about 10 eV opens up fresh opportunity for investigation of dark matter, measurement of neutrino magnet moment, of neutrino coherent scattering at nuclei and for study of solar neutrino problem. Construction of germanium detector with internal amplification and perspectives of its use are described.

TEXONO@KSNL New Results *[arXiv:1303.0925]*

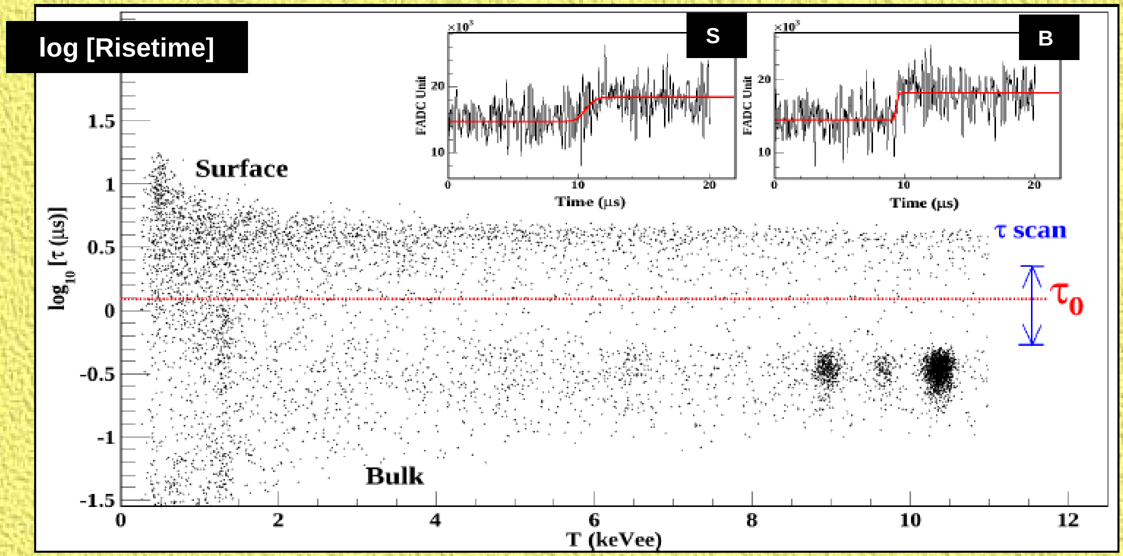
Configurations:

- 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

Basic (Previously Used) Selection Criteria:

- **Physics Vs Electronics Noise (PN) :**
  - pedestal tails, microphonics, preamp-reset induced ……
  - Via pulse shape analysis & timing
  - WIMP-eff ~ survival of doubly-tagged ACT+CRT events
- **Anti-Compton vetos (ACV) :** NaI(Tl) anti-coincidence
  - WIMP-eff ~ survival of random trigger (RT) events
- **Cosmic-Ray vetos (CRV) :**
  - WIMP-eff ~ survival of RT
  - CR-rejection eff : survival of reference samples with NaI(Tl)>20 MeV

Bulk Vs Surface (BS) Events Selection & Efficiencies



Valid scheme should produce physics rates insensitive to location

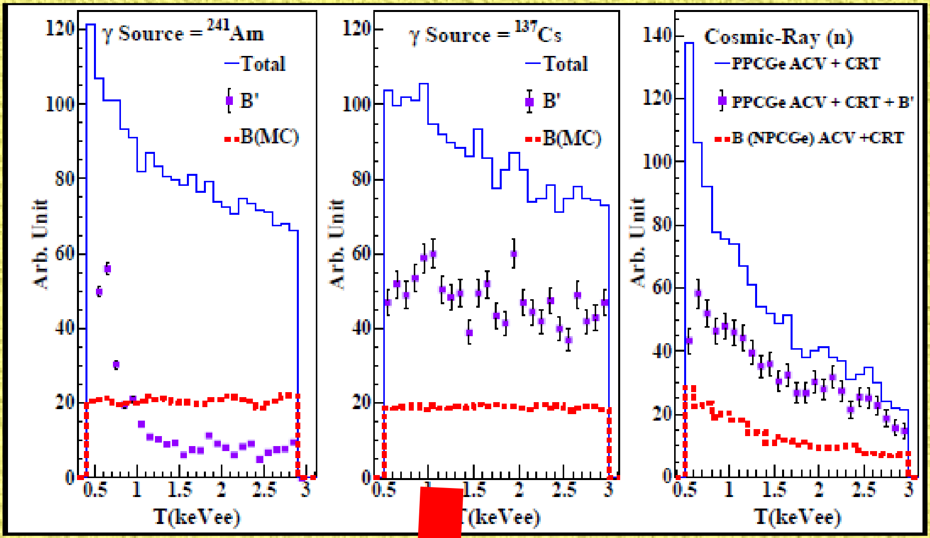
"Calibration" ≡ measure energy-dependent signal-retaining (ε_{BS}) & background-suppressing (λ_{BS}) efficiencies, such that [B,S=real ; B'S'=measured]

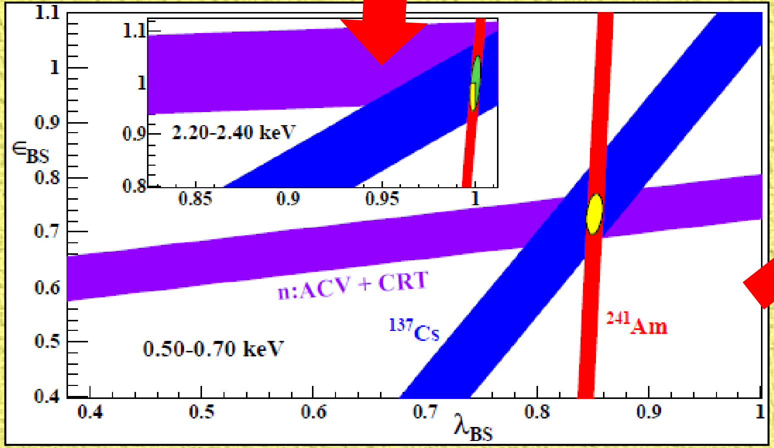
$$\boxed{\begin{aligned} B' &= \epsilon_{\rm BS} \cdot B + (1-\lambda_{\rm BS}) \cdot S \\ S' &= (1-\epsilon_{\rm BS}) \cdot B + \lambda_{\rm BS} \cdot S \end{aligned}}$$

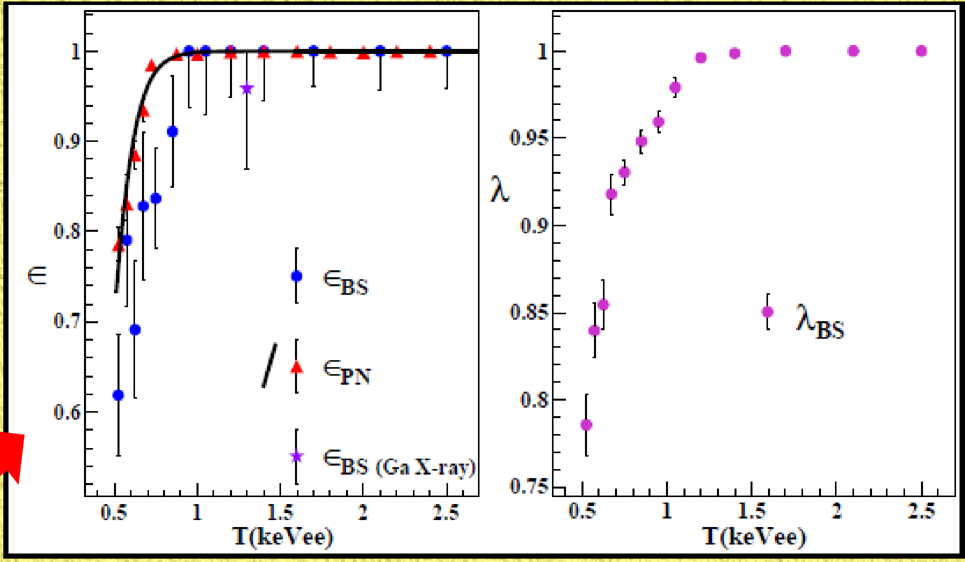
Approach: Identify *at least* two calibration data where (B,S) are known & (B',S') measured ⊕ solve coupled equation for (ε_{BS}, λ_{BS}) ⇨ correct physics (B'S') to get (B,S)

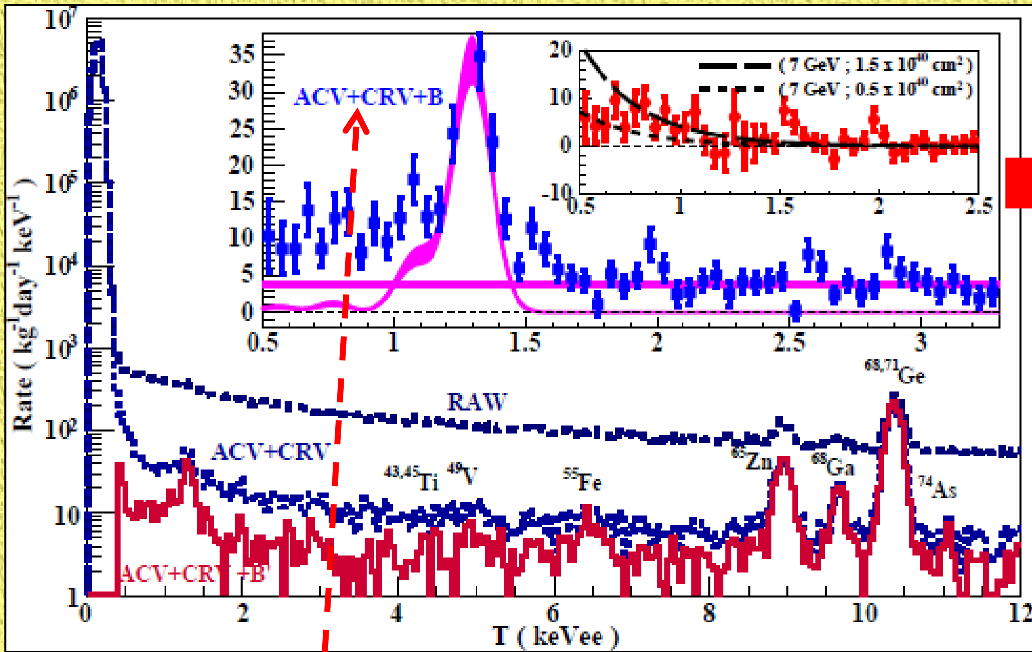
Three complementary *[different depth distributions]* **calibration data:**

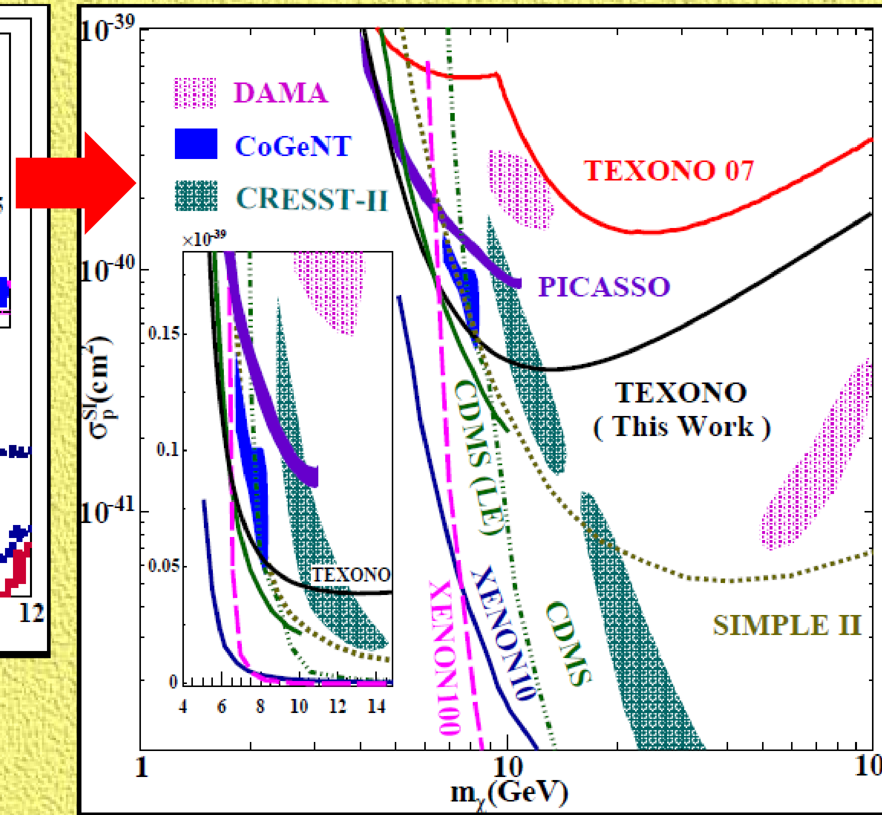
- ☑ Very Surface-rich **low-energy γ** (^{241}Am, 60 keV) ; B=simulation
- ☑ Surface-rich **high-energy γ** (^{137}Cs, 660 keV) ; B=simulation
- ☑ Bulk-rich cosmic-induced **high energy neutrons** by ACV+CRT tagging ; B=same tag from NPCGe











"Candidate Events" = ACV+CRV+B

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

Prospects & Outlook

- Interesting windows on neutrino and dark matter experiments are opened up with detectors having sub-keV sensitivities.
- Ge as ionization detectors has been and is a leading technology ; competitive results achieved.
- Formidable (potentially *game-changing*) challenges arising from bolometric *Ge* and liquid xenon techniques.
- In addition to incremental improvements, the users would *love (need)* to have quantum leaps through innovative techniques to maintain competitive edges

  [🛠 …. for brainstorming in this meeting]