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IAEA International Atomic Energy Agency

2047-4

Workshop Towards the Neutrino Technologies

13 - 17 July 2009

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

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

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July 13-17, 2009 Trieste, Italy

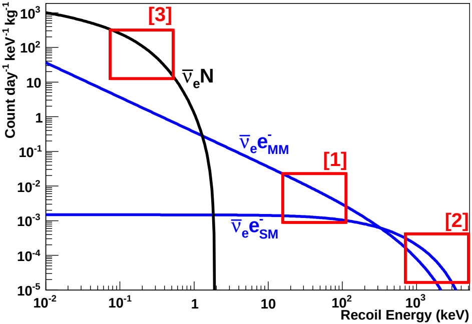
NUTECH-09

OUTLINE

- TEXONO Overview
  - Neutrino Magnetic Moment Search
  - $\sin^2\theta_W$, g_A/g_V Measurement on $\bar{\nu}_e e^-$ Scattering
- νN coherent scattering
  - Basic : cross-section, spectrum.
  - Non Standard Interaction & Unparticle.
- Detector R & D.
- 4×5 g Detector
  - Data, threshold, Efficiencies.
  - Quenching factor.
  - Dark Matter Search.
- 500 g PCGe detector.
  - Data, threshold, Efficiencies.
- Plans
  - Channeling effect, Quenching factor Measurement.
  - Jin-Ping Underground Lab.
- Summary

TEXONO collaboration & Physics Programs

- Taiwan(AS, INER, KSNPS)
- China(IHEP, CIAE, THU, NKU, SCU, LNU)
- Turkey(METU), India(BHU)



[1] Magnetic Moment search at ~ 10 keV range → [PRD 75 2007].

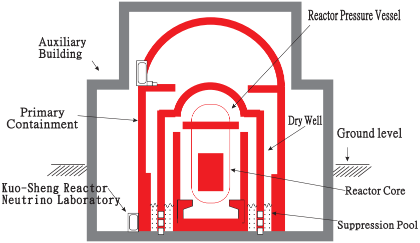
[2] $sin^2\theta_W$ measurement at ~ MeV range → Results will be published.

[3] WIMP Search at sub keV range → [PRD 79 2009].

[3] $\bar{\nu}_e N$ Coherent Scattering → Goal.

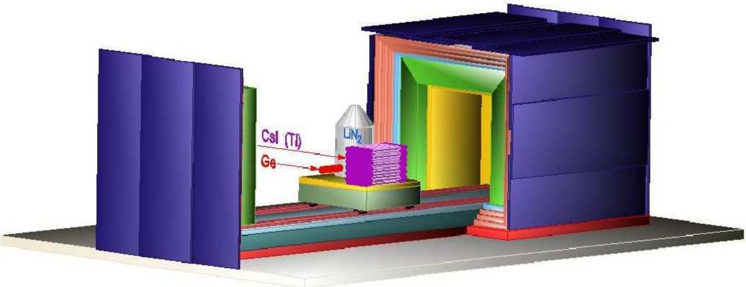
Kuo-Sheng Reactor Plant

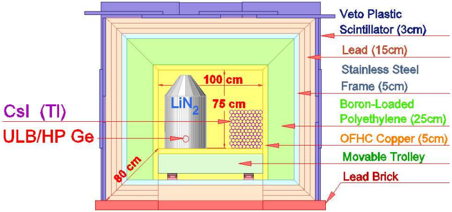
Kuo-Sheng Nuclear Power Station : Reactor Building



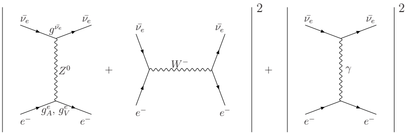
- $\phi_\nu = 6.4\times10^{12}\mathrm{cm}^{-2}\mathrm{s}^{-1}$
- Lab : 28 m from core,
- 30 mwe concrete.

Kuo-Sheng Neutrino Lab





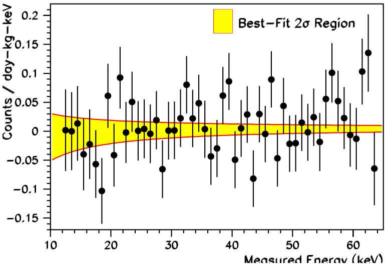
Neutrino Magnetic Moment

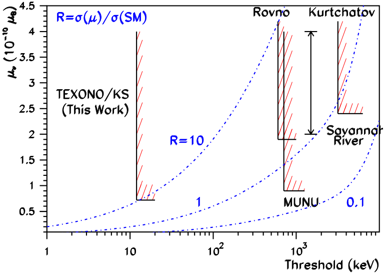


- $\left(\frac{d\sigma}{dT}\right)_{SM} \propto \mathrm{const.}$
- $\left(\frac{d\sigma}{dT}\right)_{MM} = \frac{\pi\alpha^2\mu_\nu^2}{m_e^2}\left(\frac{1}{T} - \frac{1}{E_\nu}\right)$
- $(d\sigma/dT)_{MM} >> (d\sigma/dT)_{SM}$ at $T << E_\nu$

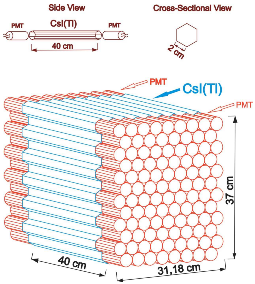
- 1 kg HPGe detector at reactor 571/128 days ON/OFF data.
- Background level ~ 1 cpd
- $\mu_\nu < 7.4 \times 10^{-11} \mu_B$ 90% C. L.

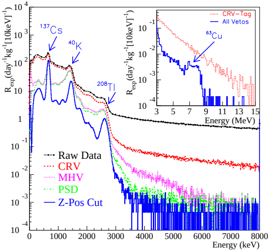
ref : [PRD 75 2007]

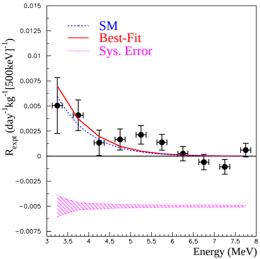




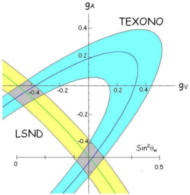
$\bar{\nu}_e e^-$ Scattering at MeV







- Data Volume : ~ 30000 kg-day ON, ~ 7500 kg-day OFF
- DAQ Threshold : 500 keV : Analysis Threshold : 3 MeV



- $\sigma_{measured}/\sigma_{\bar{\nu}_e e^-}$ = 1.18 $\pm$ 0.29(stat) $\pm$ 0.08(sys)
- $\sin^2\theta_W$ = 0.264 $\pm$ 0.04(stat) $\pm$ 0.01(sys)

νN Coherent Scattering

- Probe $\bar{\nu}_e N$ Coherent Scattering below $\sim$ 500 eV.
- $\nu + N \rightarrow \nu + N$
  - $(\frac{d\sigma}{dt})_{SM} = \frac{{G_F}^2 m_N}{4\pi}[Z(1-4\sin^2\theta_W) - N]^2[1 - \frac{M_N T_N}{2E_\nu^2}]$

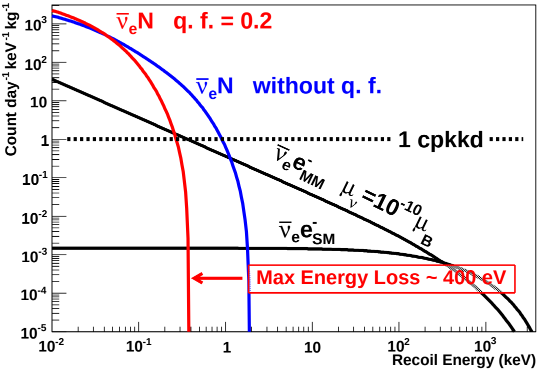
    $\rightarrow N^2$ enhancement
  - Low recoil energy : $\sim$ 1.9 keV for $E_\nu = 8$ MeV, Ge

    $\rightarrow \sim$ 500 eV after Quenching Factor.

- A fundamental neutrino interaction never been expermentally observed.
- An important interaction/energy loss channel in astrophysics media.
- new detection channel for neutrinos $\rightarrow$ reactor monitoring.

  $\rightarrow$ compact and portable(?).
- WIMP search in sub-keV range and improve magnetic moment limit on same detector.

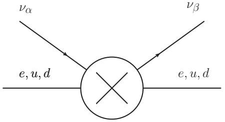
νN Coherent Scattering



- Take Q. F. $=$ 0.2, extrapolate 1 cpkkd to eV level
  $\Rightarrow$ signal/noise $>$ 1 at 300 eV
- At threshold = 100 eV $\Rightarrow$ 3.1 count day^{-1} kg^{-1}
  At threshold = 200 eV $\Rightarrow$ 0.23 count day^{-1} kg^{-1}
  At threshold = 300 eV $\Rightarrow$ 0.0084 count day^{-1} kg^{-1}

Non Standard Interaction & Unparticle

- Non Standard Interaction:
  - Parametrize by $\epsilon^{fP}_{\alpha\beta}$,
    - f = e, u or d.
      α, β = ν-flavors.
      P = L, R.
  - νN Coherent Scattering sensitive to quark part of ϵ.



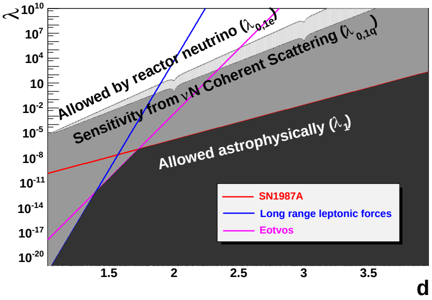
$$\epsilon^{fP}_{\alpha\beta} 2\sqrt{2} G_F (\bar{\nu}_\alpha \gamma_\mu L \nu_\beta)(\bar{f} \gamma^\mu P f)$$

$\epsilon^{qV}_{\mu e} < 7.7 \times 10^{-4}$ from limit of $\mu^- Ti \to e^- Ti$ conversion

	Present Limits	ν Factory	^{76}Ge $T_{th}=400eV$ (^{76}Ge $T_{th}=100eV$)
ϵ^{dV}_{ee}	$-0.5 < \epsilon^{dV}_{ee} < 1.2$	$\lvert\epsilon^{dV}_{ee}\rvert < 0.002$	$\lvert\epsilon^{dV}_{ee}\rvert < 0.003$ ($\lvert\epsilon^{dV}_{ee}\rvert < 0.001$)
$\epsilon^{dV}_{\tau e}$	$\lvert\epsilon^{dV}_{\tau e}\rvert < 0.78$	$\lvert\epsilon^{dV}_{\tau e}\rvert < 0.06$	$\lvert\epsilon^{dV}_{\tau e}\rvert < 0.032$ ($\lvert\epsilon^{dV}_{\tau e}\rvert < 0.020$)
ϵ^{uV}_{ee}	$-1.0 < \epsilon^{uV}_{ee} < 0.61$	$\lvert\epsilon^{uV}_{ee}\rvert < 0.002$	$\lvert\epsilon^{uV}_{ee}\rvert < 0.003$ ($\lvert\epsilon^{uV}_{ee}\rvert < 0.001$)
$\epsilon^{uV}_{\tau e}$	$\lvert\epsilon^{uV}_{\tau e}\rvert < 0.78$	$\lvert\epsilon^{uV}_{\tau e}\rvert < 0.06$	$\lvert\epsilon^{uV}_{\tau e}\rvert < 0.036$ ($\lvert\epsilon^{uV}_{\tau e}\rvert < 0.023$)

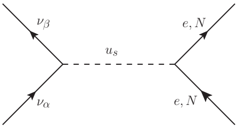
[J. Barranco, et. al., hep-ph/0508299]

Non Standard Interaction & Unparticle



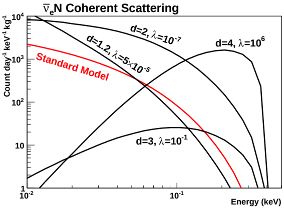
[J. Barranco, et. al., hep-ph/0901.2099]

- Parametrize by d: dimension, $\lambda^{\alpha\beta}_{if}$: coupling.
  $\rightarrow$ α, β: neutrino flavors,
  $\rightarrow$ $f = e, u, d$
- Bounds on λ_{ie} by νe^- experiments.
- νN Coherent Scattering set limits on $\lambda_{iu,d}$.



$$\lambda_{0f}\frac{1}{\Lambda^{d-1}}\bar{f}fO_U + \lambda^{\alpha\beta}_{0\nu}\frac{1}{\Lambda^{d-1}}\bar{\nu}_\alpha\nu_\beta O_U,$$

$$\lambda_{1f}\frac{1}{\Lambda^{d-1}}\bar{f}\gamma_\mu fO^\mu_U + \lambda^{\alpha\beta}_{1\nu}\frac{1}{\Lambda^{d-1}}\bar{\nu}_\alpha\gamma_\mu\nu_\beta O^\mu_U$$



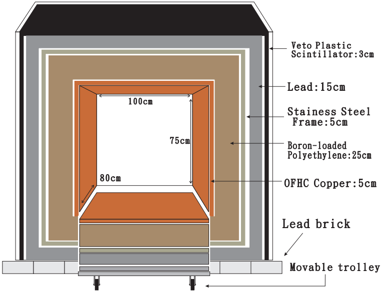
Ge Detector

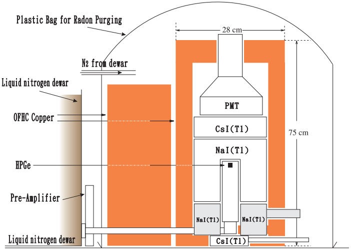
- ULE-HPGe $\longrightarrow$ developed for soft X-rays detection
  $\longrightarrow$ easy & inexpensive & robust operation
- threshold $\sim$100 eV achievable.
- $\bar{\nu}_e$N coherent scattering, CDM search, μ_ν search.
- possible reactor monitoring and other new detection channel.
- Prototype detectors:
  - 5 g(at KS & Y2L), 4$\times$5 g(at KS & Y2L),
    10 g(at AS & CIAE), 180 g segmented(at AS).
- 500 g single element PCGe at KS.

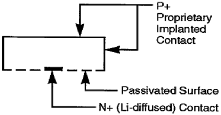
5 g Detector

4$\times$5 g Detector

4×5 g Ge Detector

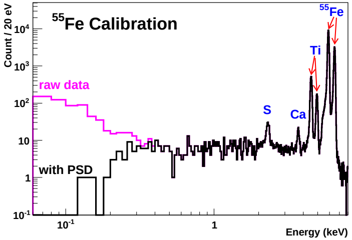


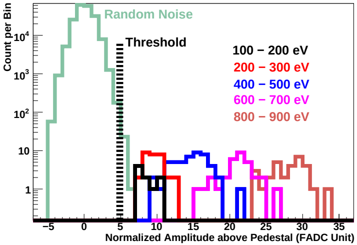




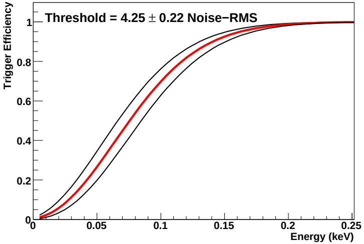
- Event Selection :
  - Anti-Compton, cosmic veto, PSD.
- Random trigger events :
  - Deadtime.
  - Anti-Compton & cosmic veto cut efficiencies.

4×5 g Detector : Threshold & Trigger Efficiency

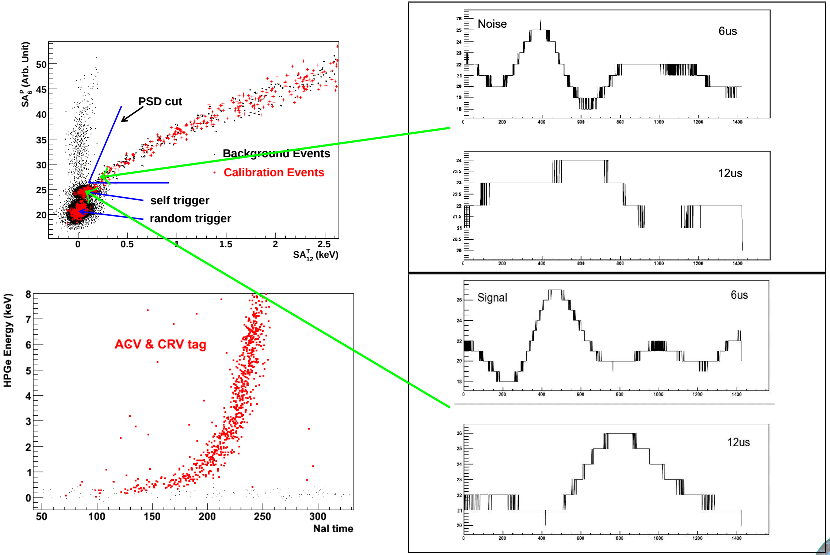




- Fraction of pulser-amplitude > threshold.
- Noise edge ~ 300 eV.
- Trigger threshold ~ 100 eV.



4×5 g Detector : PSD Efficiency

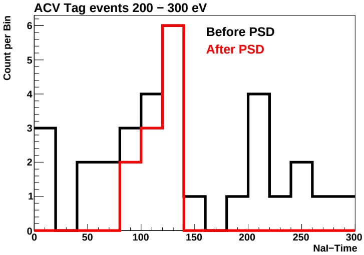


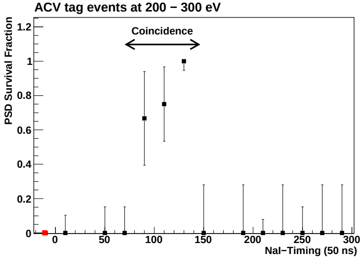
- Correlate between $12\mu s$ & $6\mu s$ pulse.
- Anti-Compton Tag events to evaluate PSD efficiency.

4×5 g Detector : PSD Efficiency

$$f = \frac{(\epsilon_{PSD} \times P + f_N \times N)}{p + N}$$

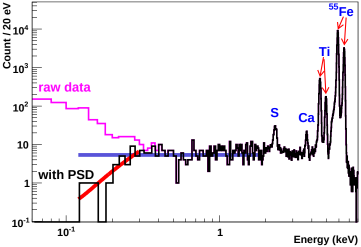
- ϵ_{PSD}: real PSD efficiency.
- P: Physical events count,
  N: Noise count.
- f_N fraction of noise survived, measured: $f_N \sim 10^{-4}$.
- f: Estimate PSD efficiency by this method.
- $\epsilon_{PSD} > f$, conservative choice.

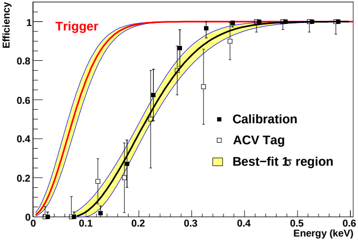




- Anti-Compton Tag events to evaluate PSD efficiency.

4×5 g Detector : PSD Efficiency

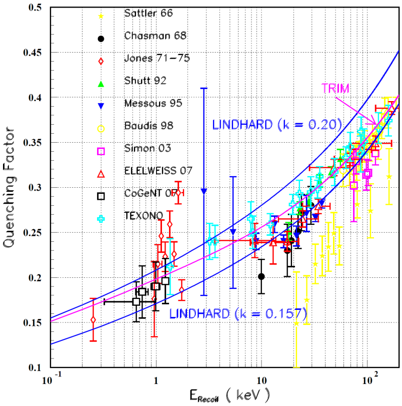




- ACV tag method & spectrum-edge fitting method consistent.
- Trigger(50% eff.) ~ 100 eV.
- PSD(50% eff.) ~ 220 eV.

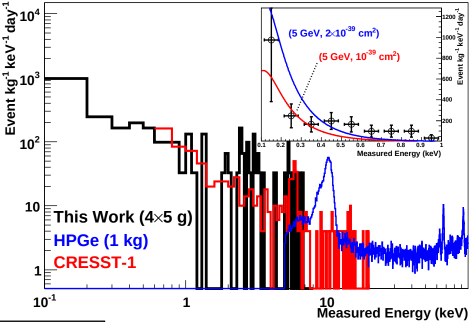
Quenching Factor

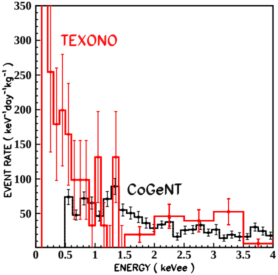
CIAE neutron beam facility



- Adopt TRIM approach.
- Quenching Factor ~ 0.2 at keV.

Background

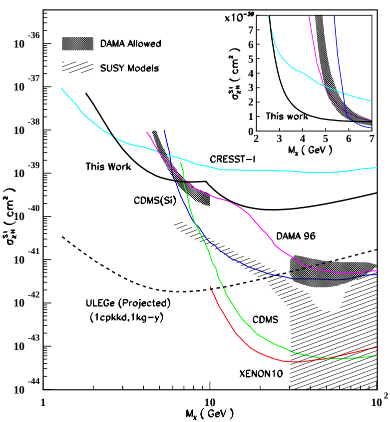


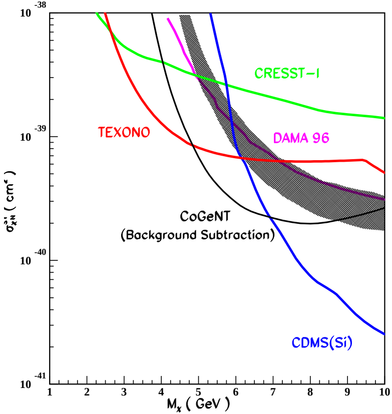


- Background compare to CRESST-1 & CoGeNT.
- Study on Background understanding under way.

Dark Matter Search

WIMP Spin-Independent Cross Section

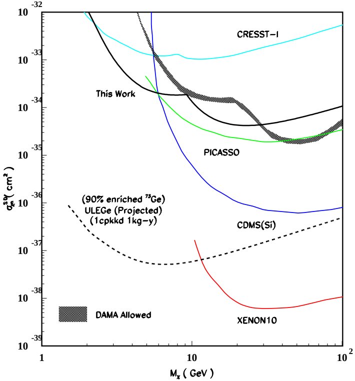




- Standard conservative analysis
  $\rightarrow$ WIMP rate $<$ total events rate (No background subtraction)
- Adopt standard astrophysics parameters.
- Optimal Interval Method [Yellin, PRD 2002]

Dark Matter Search

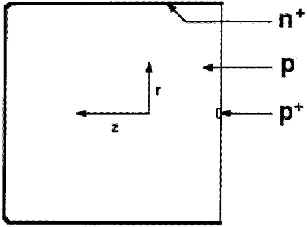
WIMP Spin-Dependent Cross Section



- Formalisms [Tovey, et. al., PLB 2000]
- Ge Matrix elements [Dimitrov, et. al., PRD 1995]

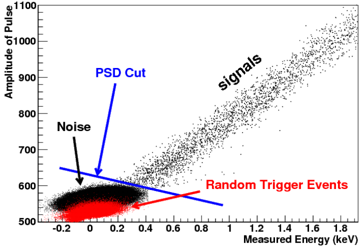
Published : S. T. Lin, et. al., PRD 79, 061101(R) 2009

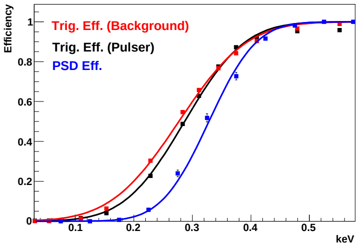
Point Contact Ge Detector



- Proposed by Luke (80's),
  successful demonstration by CoGeNT (2007).
- Position sensitive from drift-profile pulse shape.
- Dual-electrode readout for PSD.
- Utra-Low-Background specification.
- 500 g, Data taking in Nuclear Power Plant since November 2008.
- 900 g under construction.

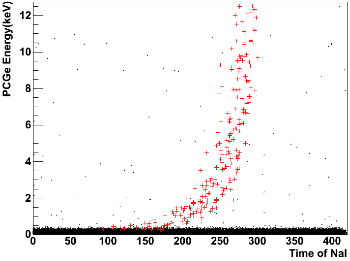
Trigger & PSD Effeciency



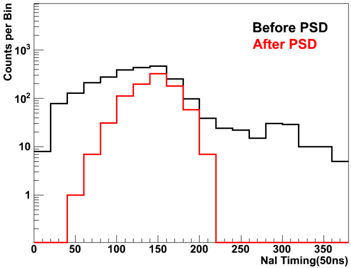


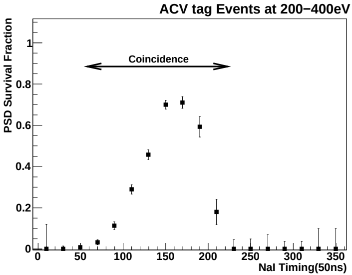
- Trigger Eff. from background data.
- Trigger Eff. from pulser.
- Trigger threshold (Eff. = 50%) ~ 280 eV
- PSD threshold (Eff. = 50%) ~ 320 eV

PSD Effeciency

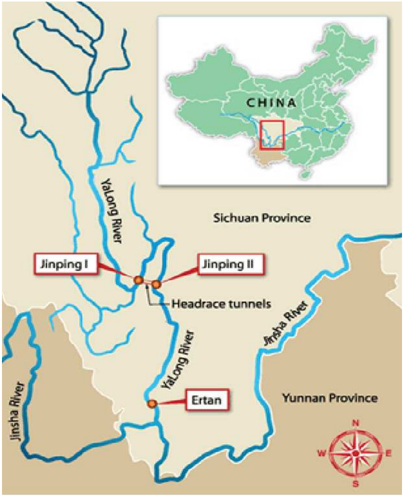


- Anti-Compton Tag events.



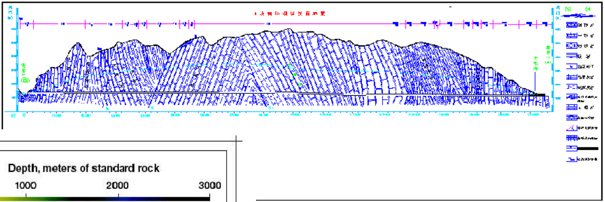


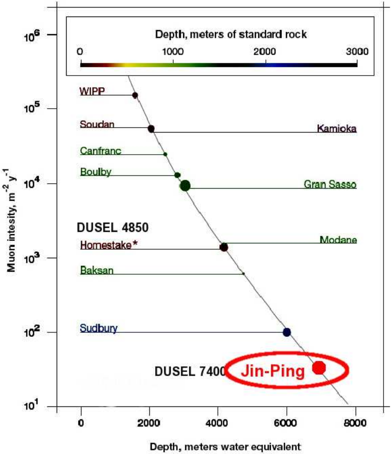
Jin-Ping Underground Lab



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

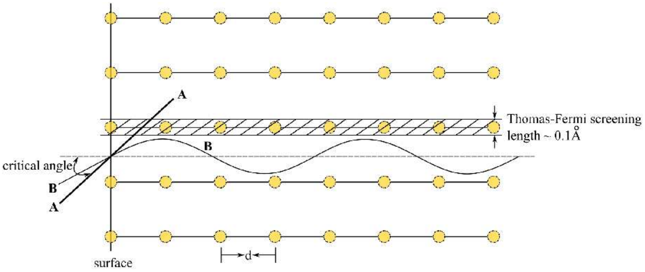
Jin-Ping Underground Lab

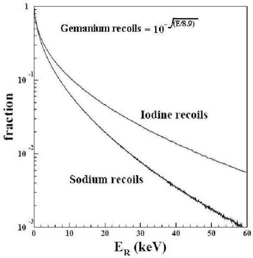




- Suppress cosmic-induced neutron background.
- Background understanding & Dark Matter Search.
- Move in 20 g Ge detector at 2010. 500 g PCGe at 2011.

Channeling Effect





- Proved on injected ions, but never on recoiled ion.
- Plan (This year) :
  - Quenching Factor Measurement at CIAE with 10 g Ge detector.
  - Channeling Effect Measurement with CsI.

Summary

- Point Contact Ge detector :
  - 500 g PC-Ge detector had been installed.
  - Preliminary result : Threshold $\sim$ 300 eV.
- Physics :
  - Magnetic Moment to $10^{-11}\mu_B$ level.
  - νN coherent scattering, threshold $<$ 500 eV.
  - WIMP search at low mass region.
- Plans :
  - Quenching Factor mesurement of Ge.
  - Channeling Effect measurement of CsI.
  - Further PSD analysis and background suppression.
  - Further background understanding & WIMP search $\rightarrow$ move in Sichuan underground Lab. (>2 km rock).

Thanks for invitation.