Measurements of Neutrino-Electron Scattering Cross-Section with CsI(Tl) Scintillating Crystal Detector at the Kuo-Sheng Reactor Neutrino Laboratory

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On behalf of TEXONO Collaboration

The Eight Particle Physics Phenomenology Workshop (PPP8)

NCKU, Tainan, 20-23 MAY 2009

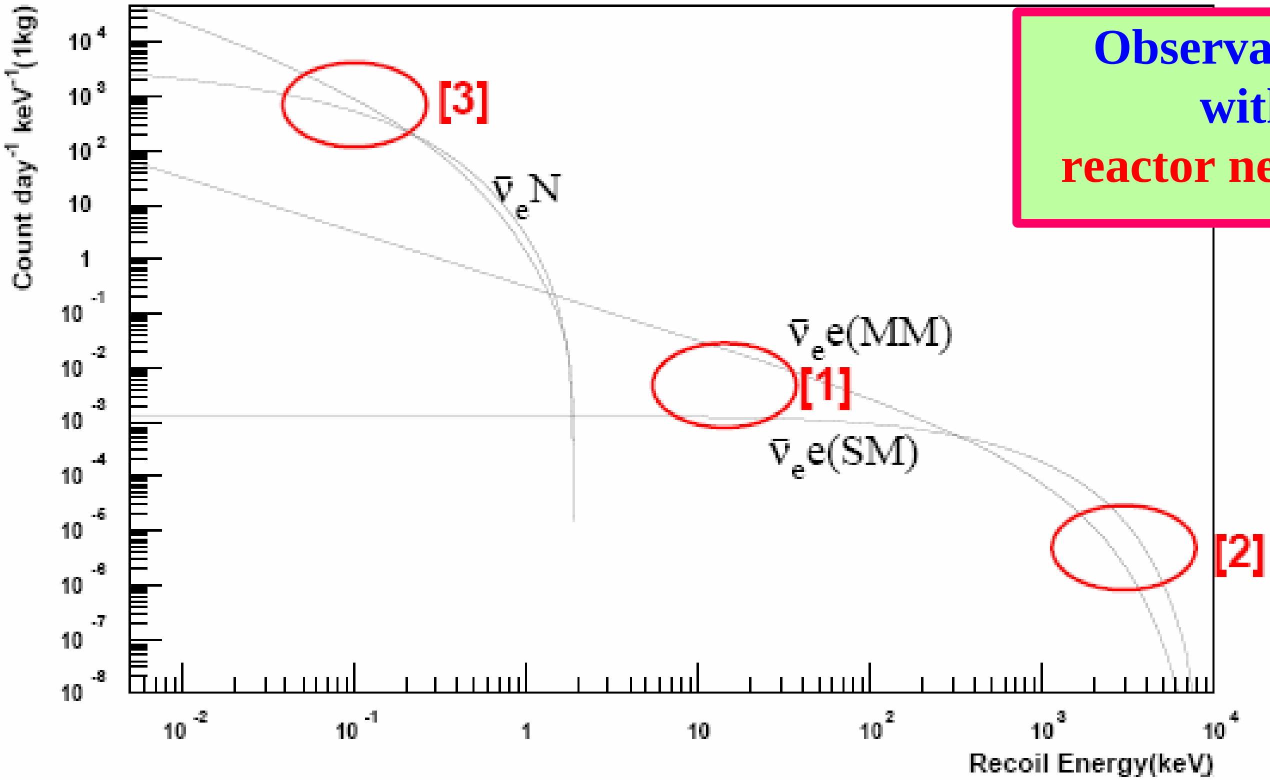
OUTLINE

- TEXONO Physics Program
- $\bar{\nu}_e - e^-$ Scattering – Motivation
- TEXONO Experiment – CsI(Tl) Array
- Event Selection & Data Analysis Outline
- Background Understanding & Suppression
- Preliminary Results
- Plans & Summary

Institute of Physics
Academia Sinica

TEXONO Physics Program

- TEXONO Collaboration : Taiwan(**AS, INER, KSNPS, NTU**), China(**IHEP, CIAE, THU, NJU**), Turkey(**METU**), India(**BHU**)
- Program : Low Energy Neutrino & Astroparticle Physics



Observable Spectrum with typical reactor neutrino "beam"

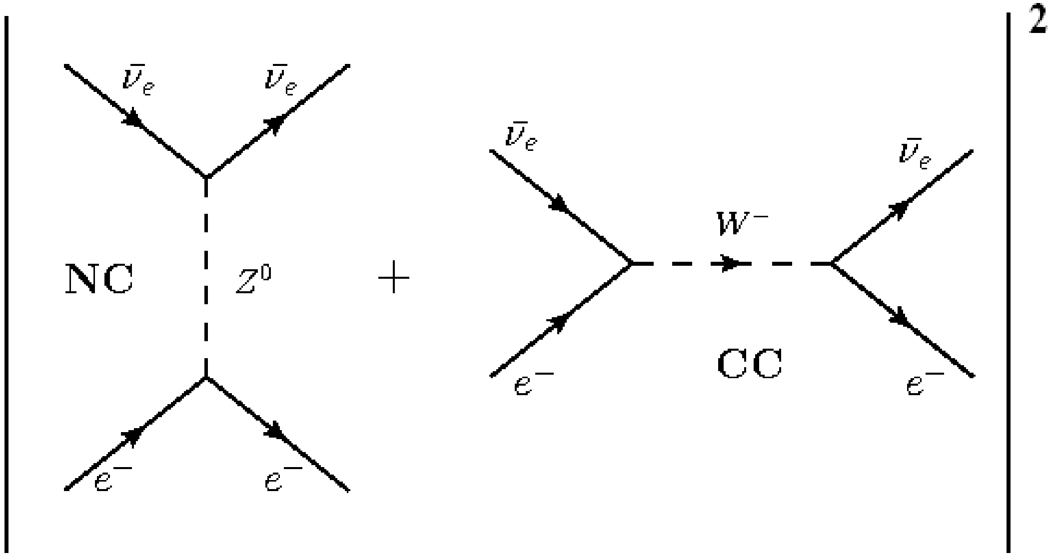
[1] Magnetic Moment Search at **~10 keV → PRL 2003, PRD 2007**

[2] $\sin^2\theta_W$ measurement at **~ MeV** range **→ This Talk – Preliminary Results**

[3] $\bar{\nu}_e N$ Coherent Scattering & WIMP Search at **sub keV** range

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

$\bar{\nu}_e + e^- \longrightarrow \bar{\nu}_e + e^-$



$$\frac{d\sigma_{SM}}{dT}(\bar{\nu}_e e) = \frac{G_F^2 m_e}{2\pi}\left[(g_V - g_A)^2 + (g_V + g_A + 2)^2\left(1 - \frac{T}{E_\nu}\right)^2 - (g_V - g_A)(g_V + g_A + 2)\frac{m_e T}{E_\nu^2}\right]$$

$$g_V = 2\sin^2\theta_W - \frac{1}{2} \qquad g_A = -\frac{1}{2}$$

$$R_{SM}(\bar{\nu}_e e) \rightarrow (0.77 : 0.92 : 0.69)$$
$$R_{SM}(\nu_e e) \rightarrow (1.83 : 0.17 : 0.99)$$

$$(R_{CC} : R_{NC} : R_{Int})$$

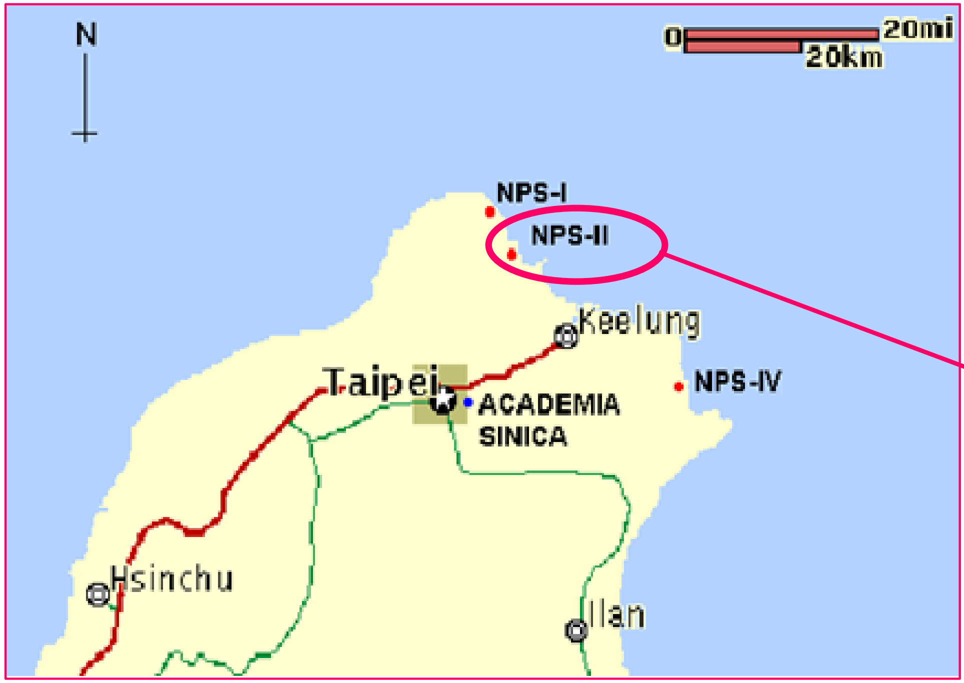
$$\delta[\sin^2\theta_W] \sim \begin{cases} 0.14 \cdot & \delta[\xi(\bar{\nu}_e e)] \\ 0.32 \cdot & \delta[\xi(\nu_e e)] \end{cases} \qquad \xi = \frac{R_{expt}(\nu)}{R_{SM}(\nu)}$$

- A basic SM process with **CC, NC & Interference**
- Not well-studied in reactor energy range **~ MeV**

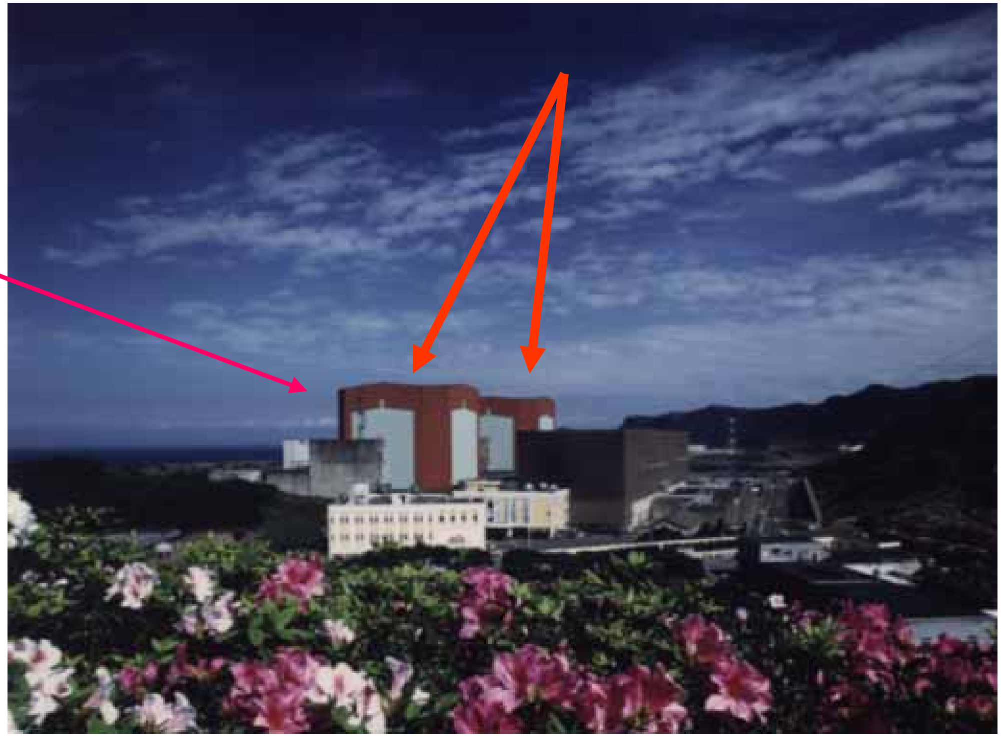
Experimental Approach -- CsI(Tl) Crystal Scintillator Array:

- proton free target (suppress $\bar{\nu}_e$-p background)
- scale to ϑ (tons) design possible
- good energy resolution, **alpha & gamma PSD**
- allows measure **energy, position, multiplicity**
- more information for **background understanding & suppression**
- focus at **>3 MeV** recoil energy range → less ambient **background** & **reactor $\bar{\nu}_e$** spectra well known.

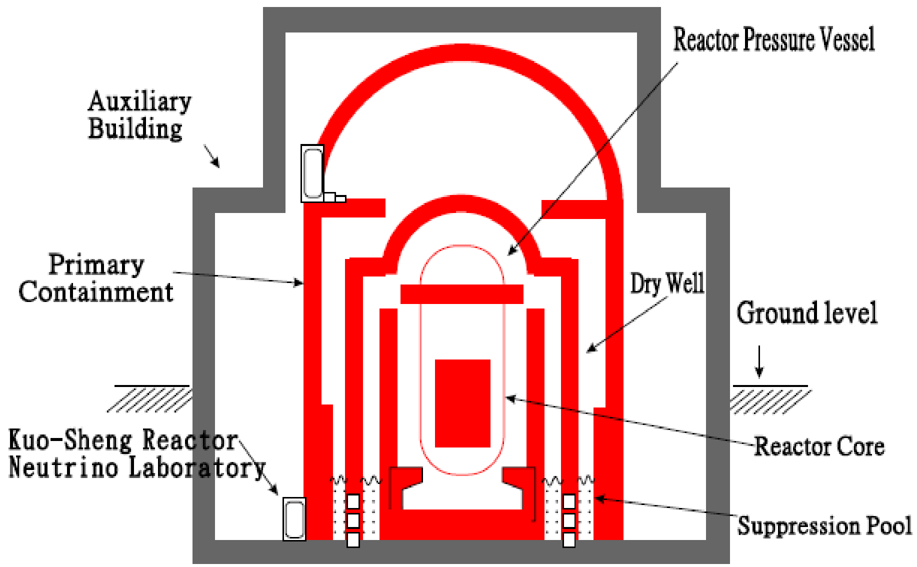
Kou-Sheng Reactor Power Plant



KS NPS -II : 2 cores × 2.9 GW



Kuo-Sheng Nuclear Power Station : Reactor Building

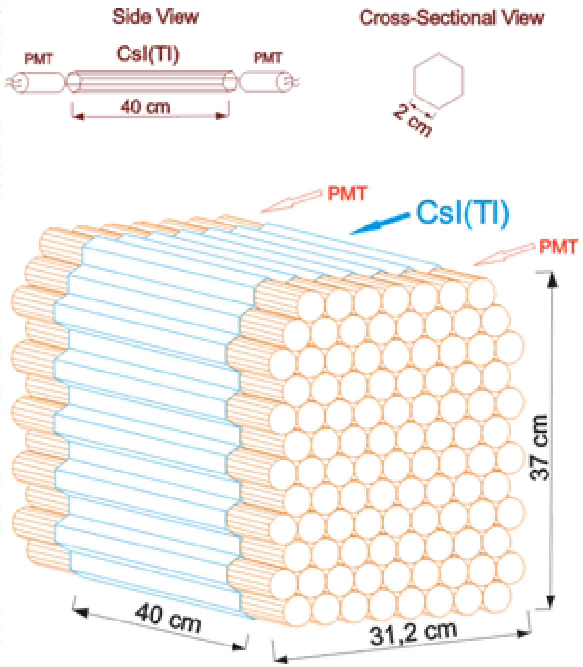


Total flux about 6.4×10^{12} $cm^{-2}s^{-1}$

KS ν Lab: 28m from core #1

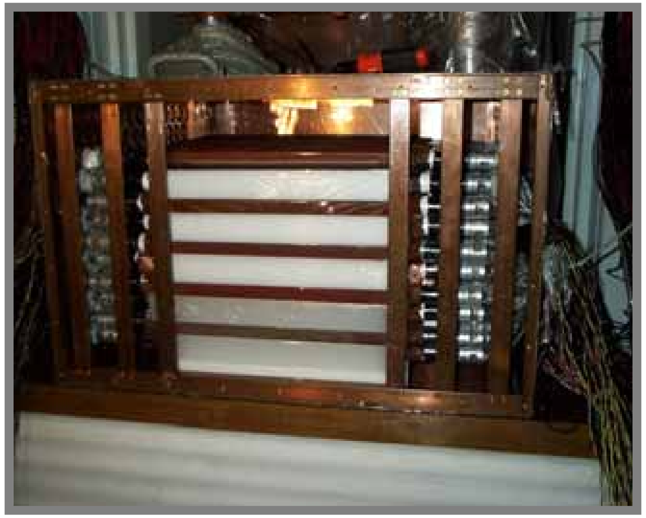
30 mwe overburden

Kuo-Sheng Reactor Neutrino Laboratory

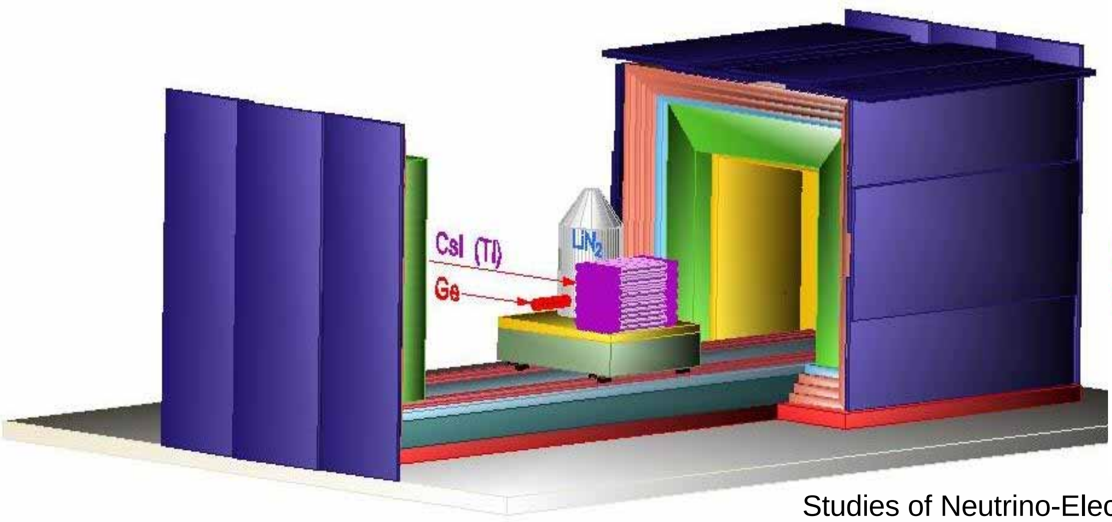


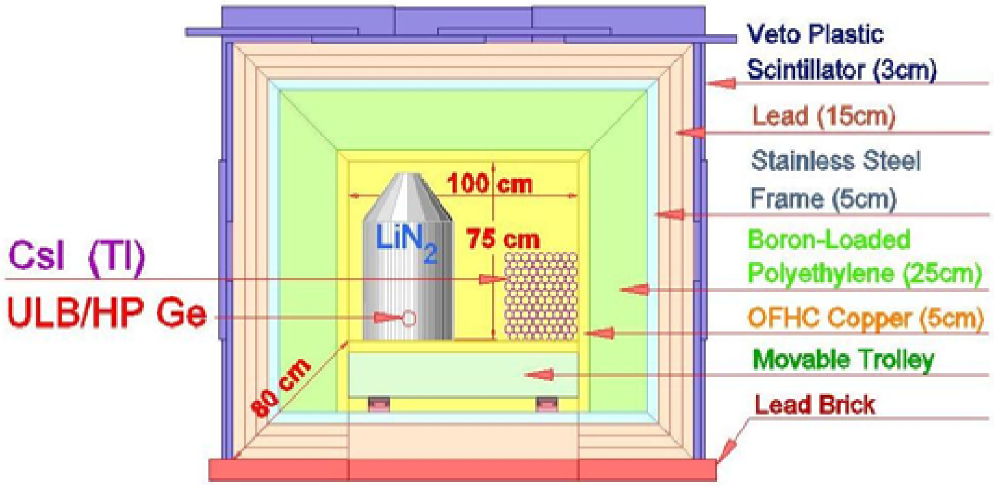
CsI(Tl) Detector

9x12 Array 200 kg

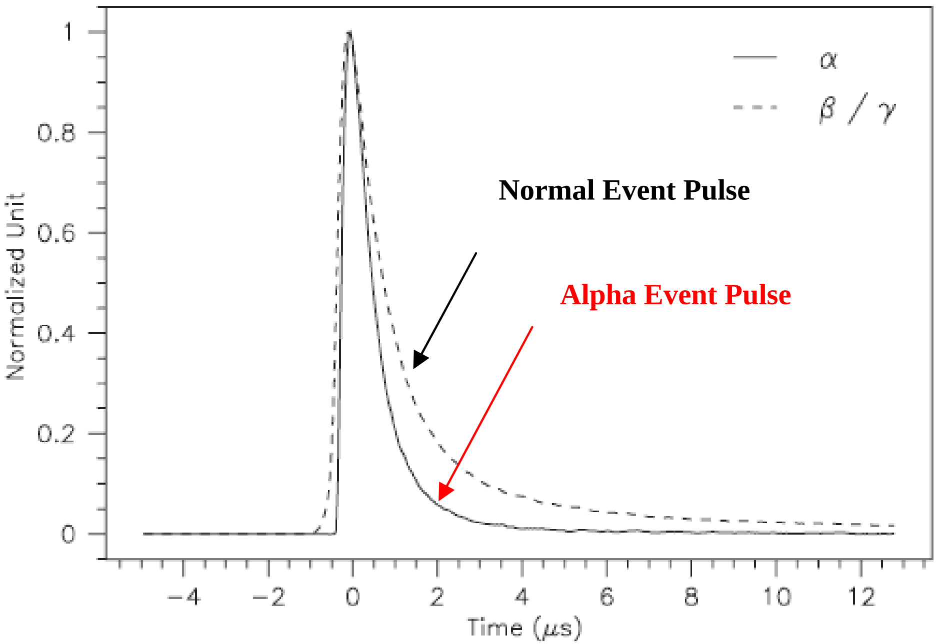


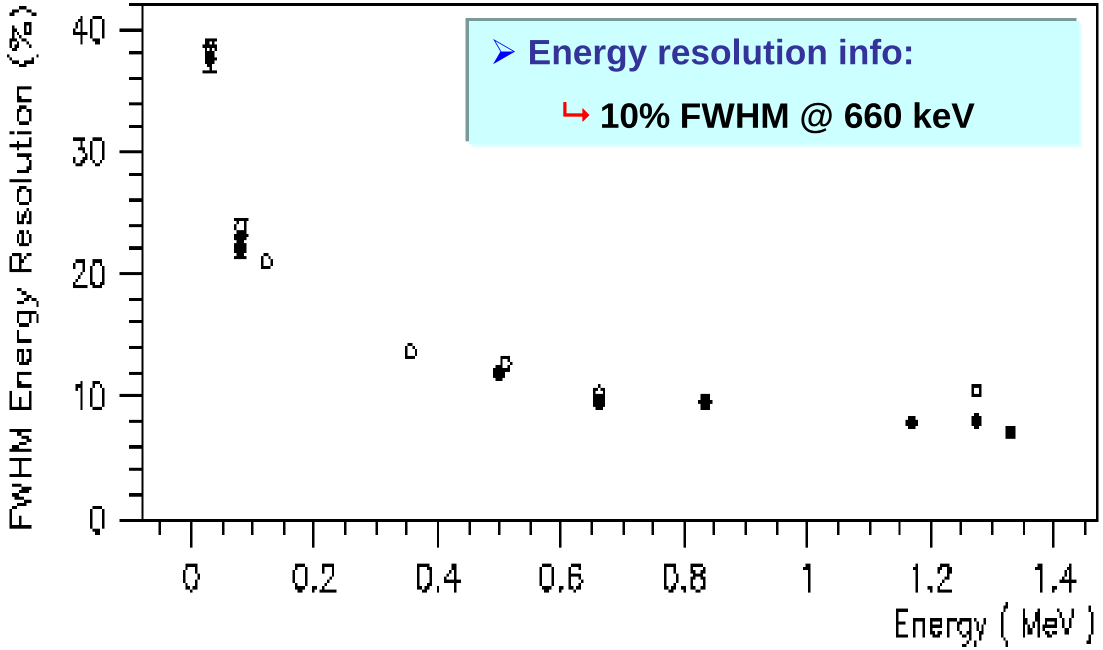
Inner Target Volume & Shielding



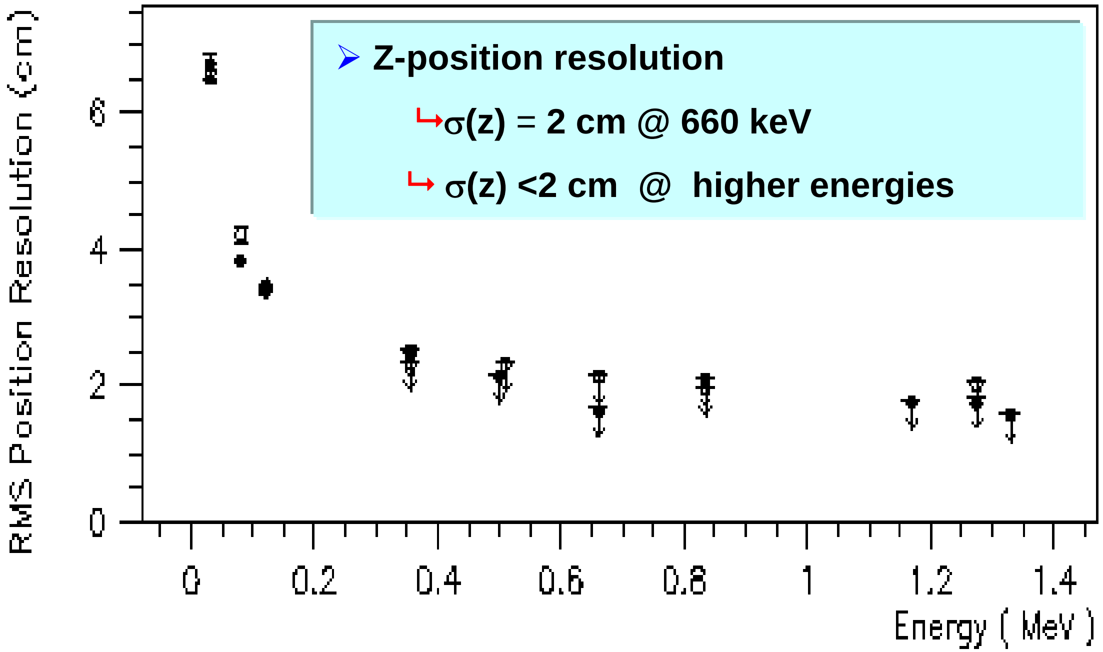


CsI(Tl) Array : Basic Performance



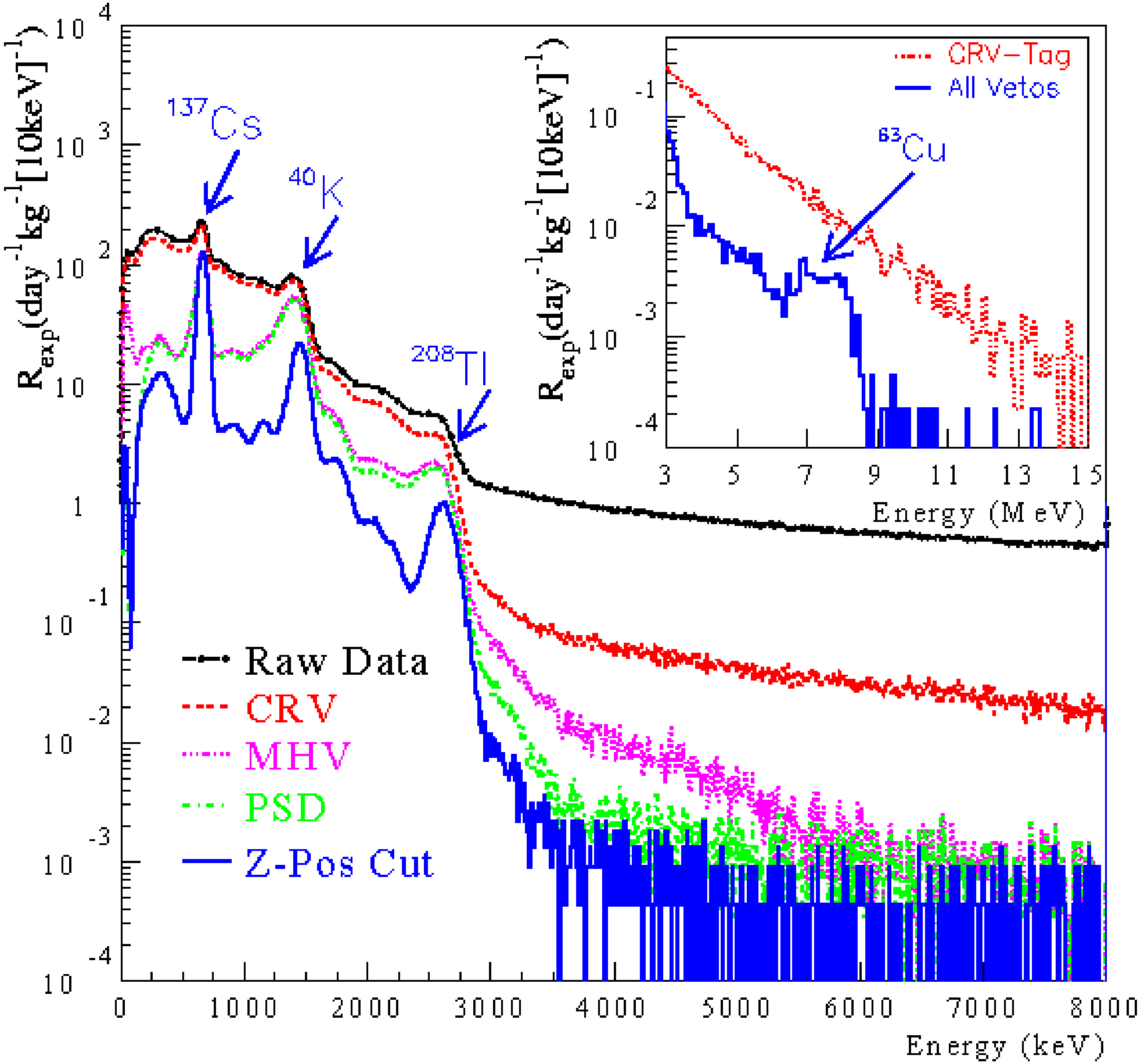


- **Energy:** Total Light Collection
  $E \sim \sqrt{Q_L \times Q_R}$
- **Z-Position:** The variation of Ratio
  $Z \sim (Q_L - Q_R)/(Q_L + Q_R)$
- DAQ Threshold : 500 keV
- Analysis Threshold : 3 MeV
- Data Volume:
  ~ 30000 kg-day ON
  ~ 7500 kg-day OFF



Event Selection

Reactor OFF

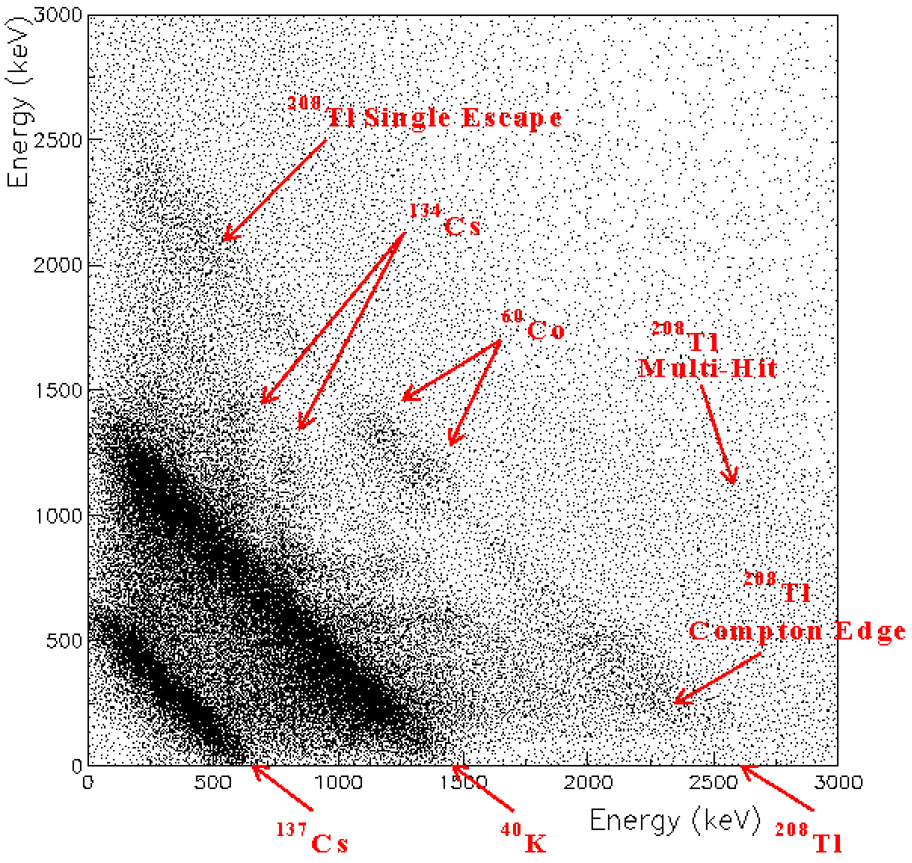


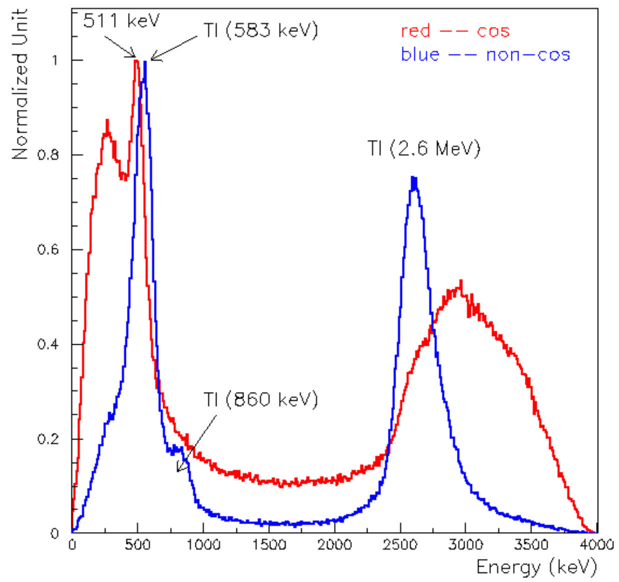
CUTS (3 - 8 MeV)	Efficiencies DAQ Live Time Eff. 88.78%
CRV	92.7 %
MHV	99.9 %
PSD	~100 %
Z-pos	80%
Total	77.1 %

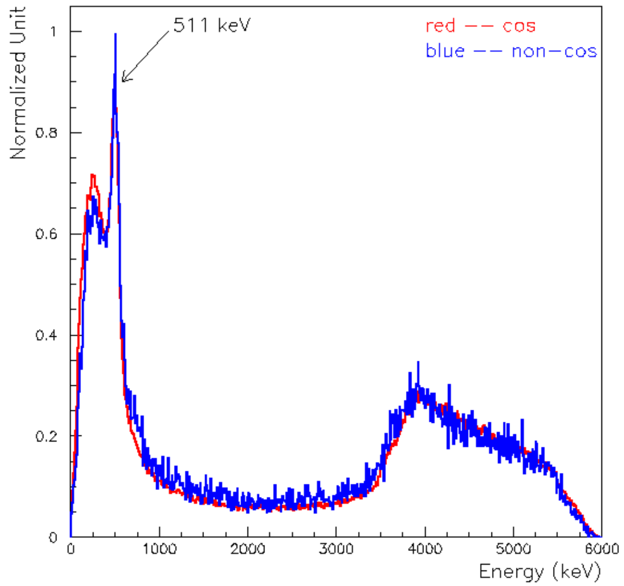
$$\frac{S}{B} \cong \frac{1}{15} \text{ at } 3 \text{ MeV}$$

Background Understanding: Due to ^{208}Tl and Cosmic Inefficiency

2 HIT SPECTRUM







Background Prediction via PAIR PRODUCTION

Residual Background Understanding & Suppression

Idea -- Use Multiple Crystal Hit (**MH**) spectra to **predict** Single Crystal Hit (**SH**) Background to the neutrino events

- Two Background Sources : **Cosmic Rays** and **^{208}Tl**

Cosmic Ray (3-8 MeV)

$$\left(\frac{MH_{non\ \cos}}{MH_{tot}}\right)_{ON,OFF} = 1-\varepsilon = \left(\frac{SH[\nu BKG(\cos)]}{SH_{tot}}\right)_{ON,OFF}$$

^{208}Tl (3-3.5 MeV)

$$\frac{SH[\nu BKG(2614+583)]}{MH[2614;583(data)]} = \frac{SH[2614+583(MC)]}{MH[2614;583(MC)]}$$

combined **BKG(SH)** from **three measurements:**

- Direct **Reactor OFF(SH)** spectra
- Predicted **BKG(SH)** from **OFF(MH)**
- Predicted **BKG(SH)** from **ON(MH)**

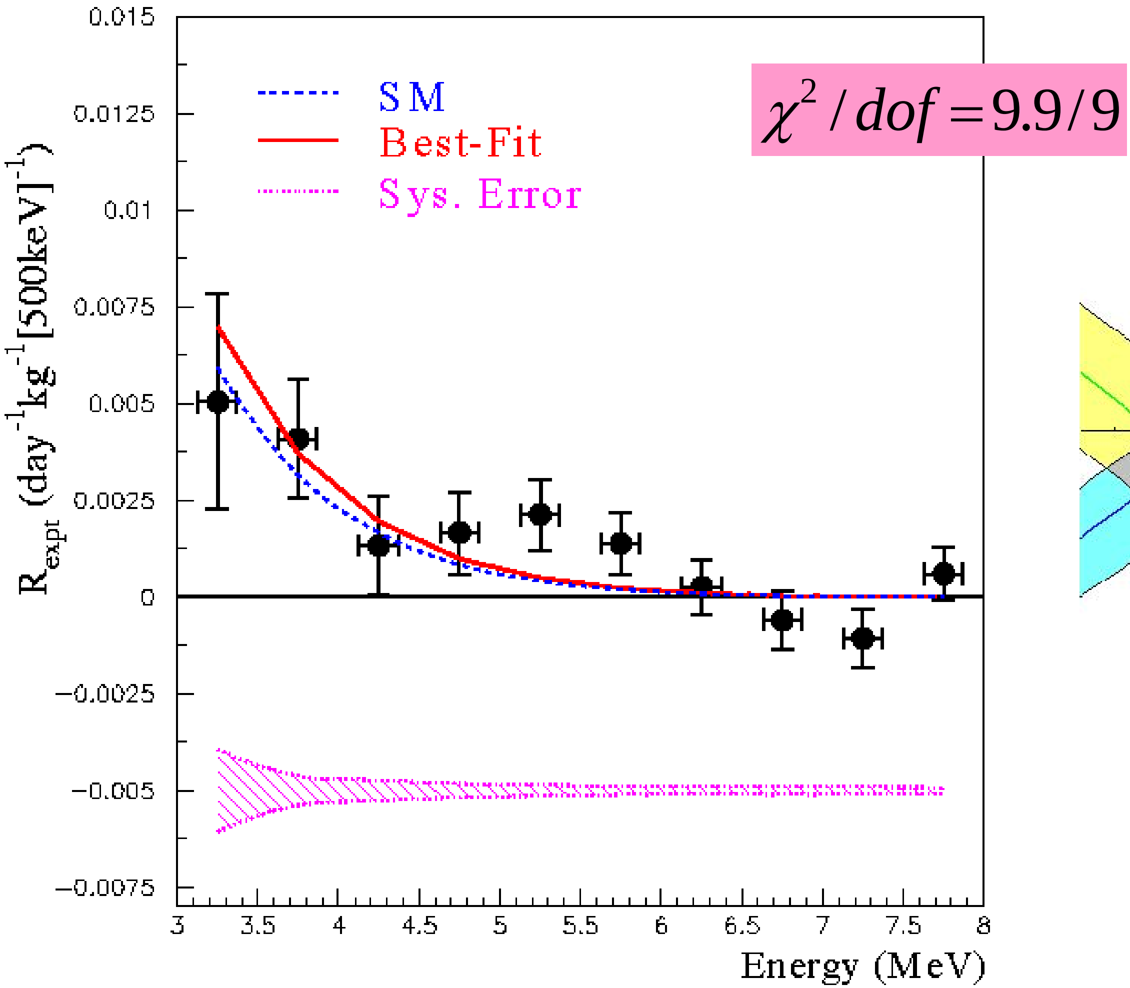
ν = ON(SH) – BKG(SH)

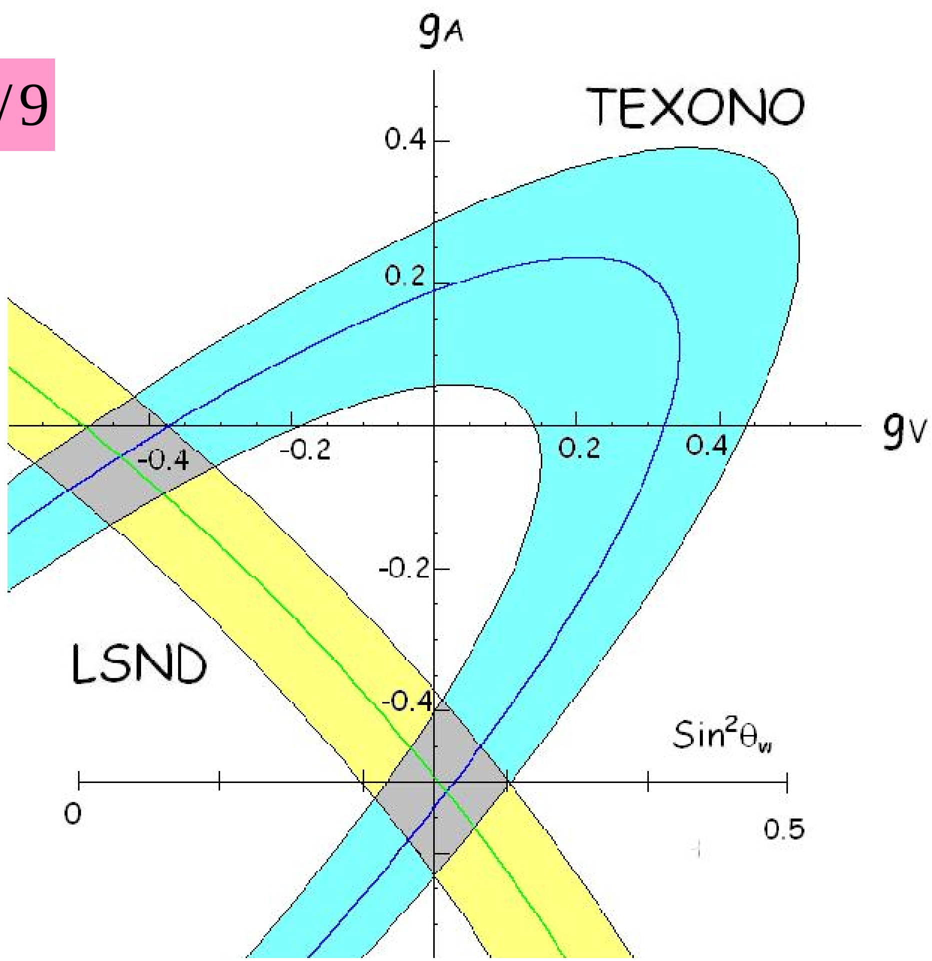
ε_{CRV} ~ 93 %	**BKG(SH) Sources**	
Energy (MeV)	**cosmic**	**Tl-208/Cu**
3.0 – 3.5	~ 65%	~ 35% Tl (γ,γ)
3.5 – 6.5	~ 100%	—
6.5 – 8.0	~ 55%	~ 45% Cu (n,γ)

Cross Section & Weinberg Angle

Cross-Section: $R = [1.18 \pm 0.29\,(stat) \pm 0.08(sys)] \times R_{SM}$

Weinberg Angle: $\sin^2\theta_W = 0.264 \pm 0.040\,(stat) \pm 0.010\,(sys)$



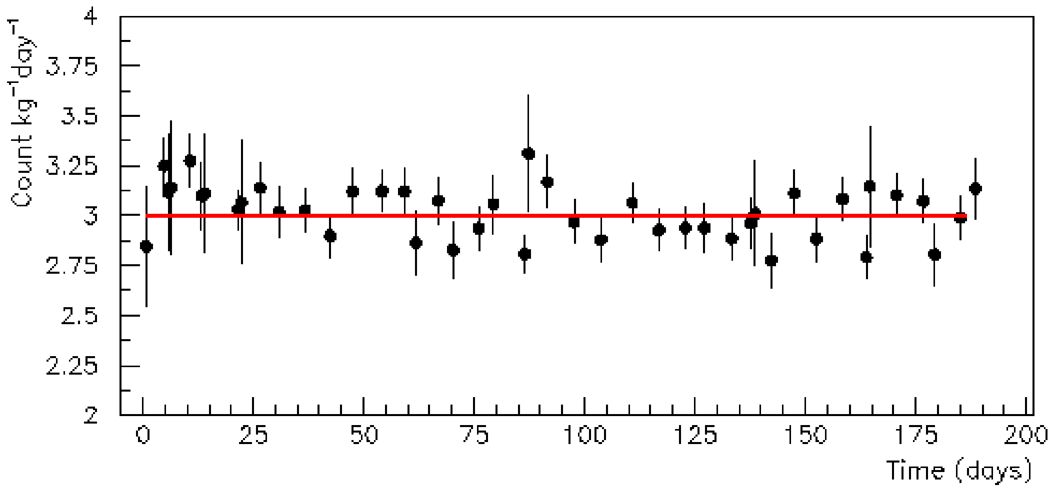


Summary Table with Other Experiments

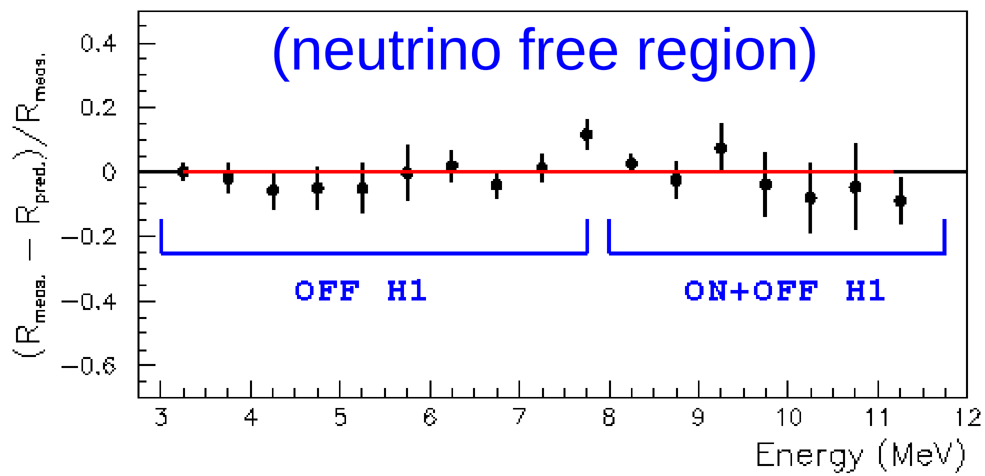
	Experiment	Energy (MeV)	Events	Cross-Section	$\sin^2\theta_W$
$\nu_e - e^-$	**LAMPF** [Liquid Scin.]	7 - 60	236	[10.0 ± 1.5 ± 0.9] x $E_{\nu e} 10^{-45} cm^2$	0.249 ± 0.063
$\nu_e - e^-$	**LSND** [Liquid Scin.]	10 - 50	191	[10.1 ± 1.1 ± 1.0] x $E_{\nu e} 10^{-45} cm^2$	0.248 ± 0.051
$\bar{\nu}_e - e^-$	**Savannah-River** [Plastic Scin.]	1.5 - 3.0 3.0 – 4.5	381 71	[0.86 ± 0.25] x σ_{V-A} [1.70 ± 0.44] x σ_{V-A}	0.29 ± 0.05
$\bar{\nu}_e - e^-$	**Savannah-River** **Re-analysed** (PRD1989, Engel&Vogel)	1.5 – 3.0 3.0 – 4.5	N/A	[1.35 ± 0.4] x σ_{SM} [2.0 ± 0.5] x σ_{SM}	N/A
$\bar{\nu}_e - e^-$	**Krasnoyarsk** (Fluorocarbon)	3.15 – 5.18	N/A	[4.5 ± 2.4] x 10^{-46} cm^2/fission	0.22 ± 0.75
$\bar{\nu}_e - e^-$	**Rovno** [Si(Li)]	0.6 – 2.0	41	[1.26 ± 0.62] x 10^{-44} cm^2/fission	N/A
$\bar{\nu}_e - e^-$	**MUNU** [CF_4(gas)]	0.7 – 2.0	68	1.07 ± 0.34 events day^{-1}	N/A
$\bar{\nu}_e - e^-$	**TEXONO** [CsI(Tl) Scin.]	3 - 8	~ 450	[1.18 ± 0.29 ± 0.08] x R_{SM}	0.264 ± 0.042

Study of Systematic Uncertainties Approach – Use non-ν events for demonstration

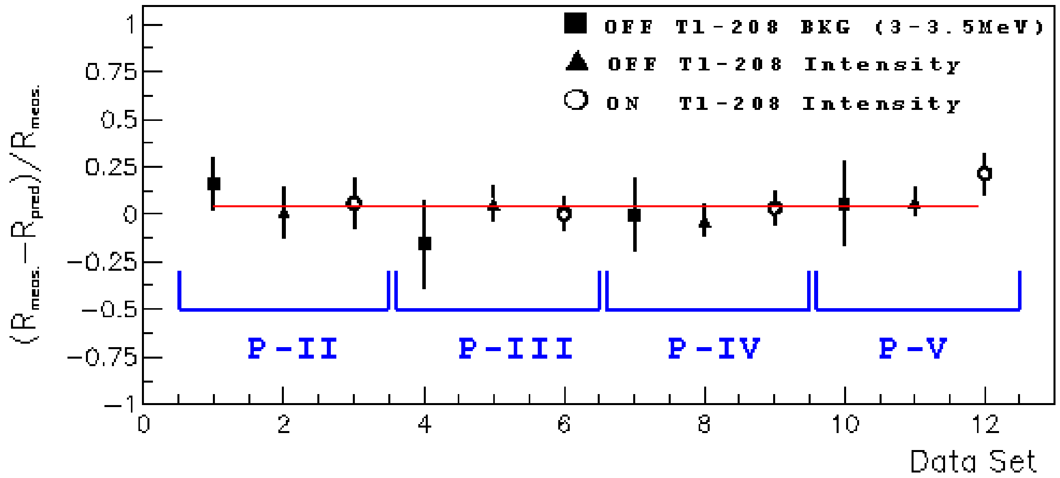
^{208}Tl Peak Events



BKG – Pred.



^{208}Tl (SH) Prediction



ON-OFF Stability < ~0.5%

- Random trigger events for **DAQ** & **Selection Cuts**
- **Stability** of **Tl-208 (2614 keV)** peak events

Cosmic Induced BKG(SH) Prediction < ~1.2%

- Successfully **Predict Cosmic BKG** at
  NEUTRINO FREE REGION

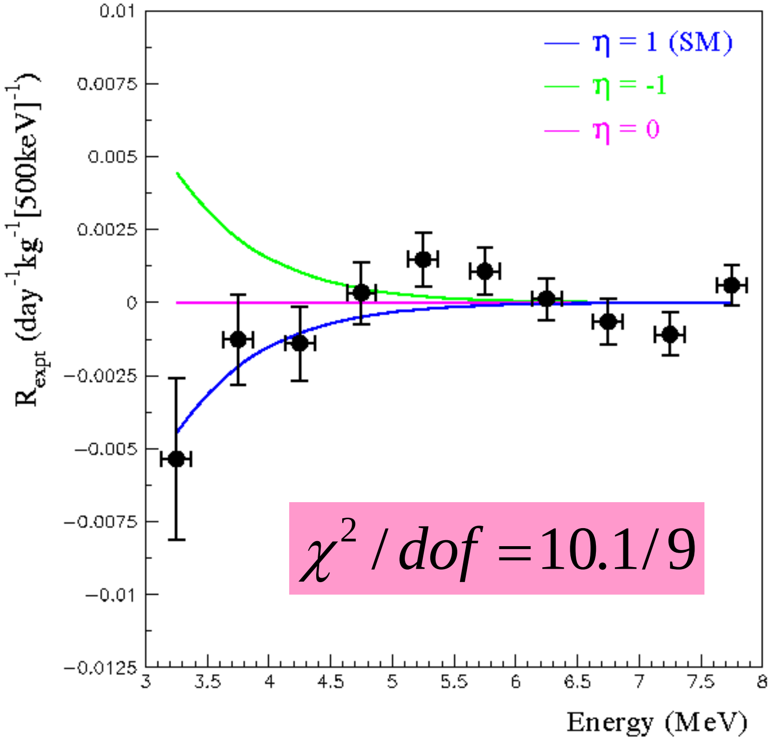
Tl-208 Induced BKG(SH) Prediction <~3%

- Successfully **Predict Tl-208 Induced BKG(SH) >3MeV** at Reactor **OFF** periods
- Successfully **Predict Tl-208** peak intensity for both Reactor **ON/OFF** with the same tools **(MC)**

Interference Term

Interference Term $R_{SM} = R^{CC} + R^{NC} + \eta \times R^{I}$

Case	R ($\times R_{SM}$) in 3-8 MeV
Destructive($\eta = 1$) (SM)	1
Constructive($\eta = -1$)	2.46
No Interference($\eta = 0$)	1.73
Measurement	1.18 ± 0.31



Interference Term

$\eta = 0.80 \pm 0.42(stat) \pm 0.11(sys)$

Neutrino Magnetic Moment and Charge Radius

Neutrino Magnetic Moment

$$R(ON-BKG) = R(SM) + \kappa^2 \times R(MM\,[\mu_\nu = 10^{-10}\mu_B])$$

κ^2 = 0.9 ± 2.51(stat) ± 0.71(sys) → $\mu_{\bar{\nu}} < 2.4 \times 10^{-10} \times \mu_B$

$\chi^2 / dof = 10.1/9$

at 90 % C. L.

Neutrino Charge Radius

$$\sin^2\theta_W \to \sin^2\theta_W + (\sqrt{2}\pi\alpha / 3G_F)\langle r^2_{\bar{\nu}_e}\rangle$$

$$\langle r^2_{\bar{\nu}_e}\rangle = [1.23 \pm 1.71(stat) \pm 0.36(sys)] \times 10^{-32}\ cm^2$$

$\chi^2 / dof = 9.8/9$

Summary and Status

- 200 kg CsI(Tl) Scintillating Crystal Array
  - Analysis Threshold at 3 MeV
- Preliminary Results:
  - $\sigma(\bar{\nu}_e - e^-)$ with $\sim 25\%$ accuracy
  - Weinberg Angle with $\sim 15\%$ accuracy
  - verify SM negative interference
  - μ_ν sensitivity $\sim 10^{-10}$
  - neutrino charge radius sensitivity $\sim 10^{-32}$