Measurement of $\overline{\nu}_e$-e^- Scattering Cross-Section and Beyond the Standard Model Search at the Kuo-Sheng Nuclear Power Reactor

- Non-Standard Interaction of Neutrino (NSI)
- Unparticle Physics
- Non-Commutative Physics

2011 ANKARA YEF GÜNLERİ

27-30 ARALIK 2011

Selçuk Bilmiş

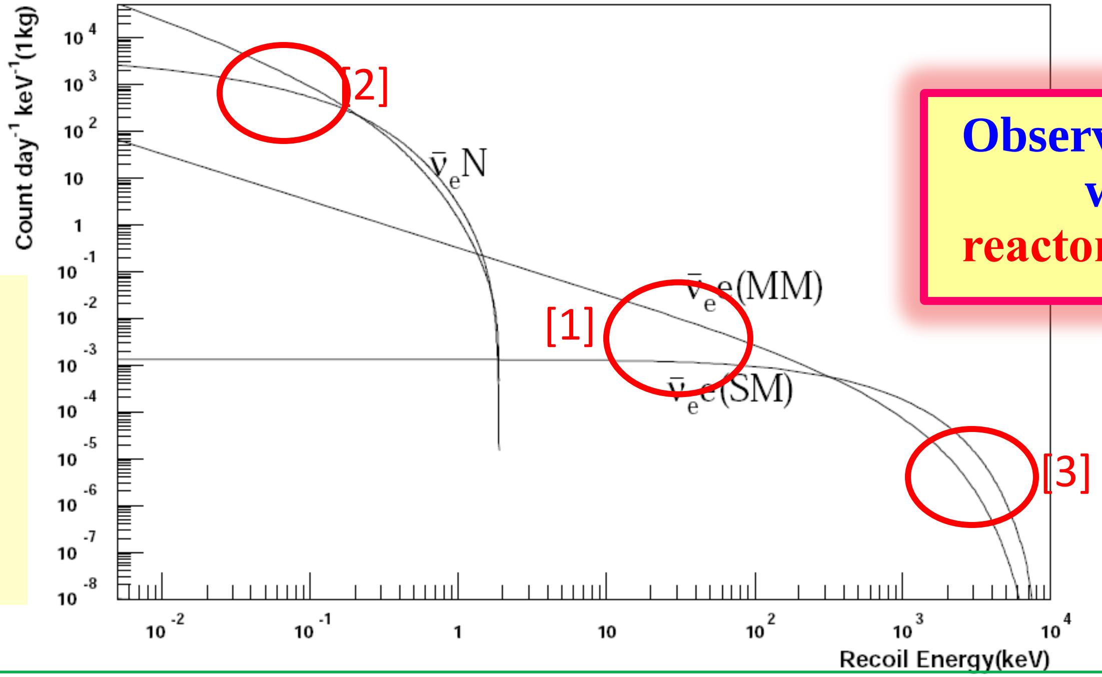
OUTLINE

- Overview (Collaboration; Program; Laboratory)
- Physics Motivations & Detector Requirements
- Cross Section & *EW* Parameters – World Status
- Probing New Physics – NSI & UP & NC with $\bar{\nu}_e - e^-$
- Analysis & Results [PRD 81, PRD 82 2010]

TEXONO Physics Program

TEXONO Collaboration: **Taiwan** (AS,INER,KSNPS,NTU);
China (IHEP,CIAE,THU,NKU,SCU,LNU); **Turkey** (METU, KTU); **India** (BHU)
Program: **Low Energy Neutrino & Astroparticle Physics**

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



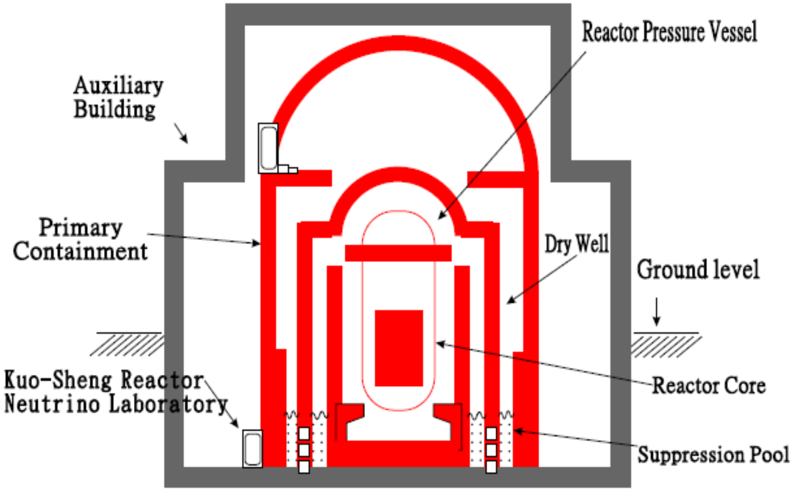
Observable Spectrum
with typical
reactor neutrino "beam"

Taiwan
EXperiment
On
NeutrinO

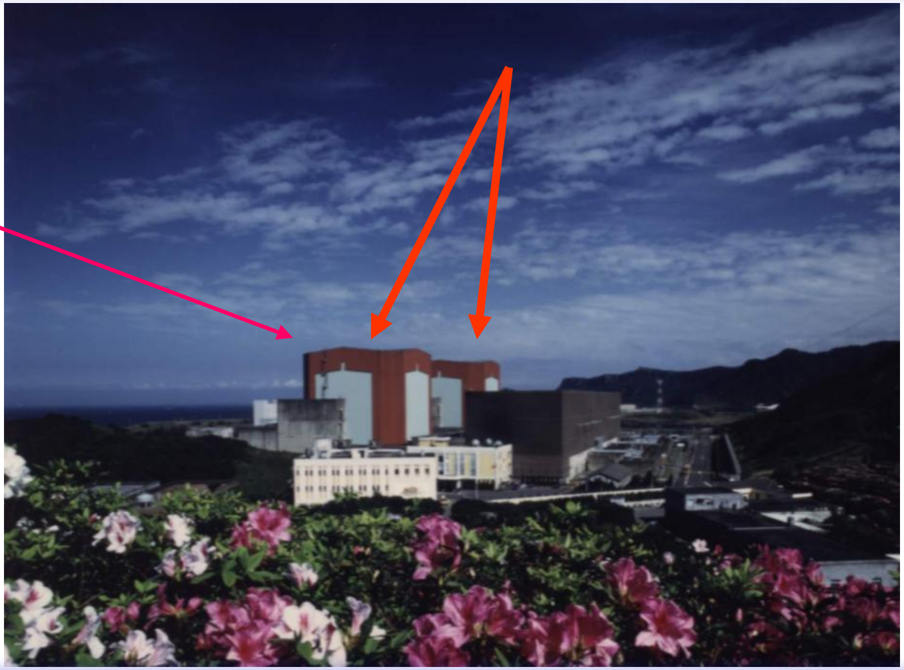
[1] **Magnetic Moment** Search at **~10 keV** → **PRL 2003, PRD 2007**
[2] **$\bar{\nu}_e$ N Coherent Scattering & WIMP** Search at **sub keV** range → **PRD 2009**
[3] **Cross-Section and EW Parameters** measurement at **MeV** range → **PRD 2010**
[1,2,3] **NSI & Unparticle** → **PRD 2010** ***Non-Commutative Physics***

Kou-Sheng Reactor Power Plant

Kuo-Sheng Nuclear Power Station : Reactor Building



KS NPS -II : 2 cores × 2.9 GW



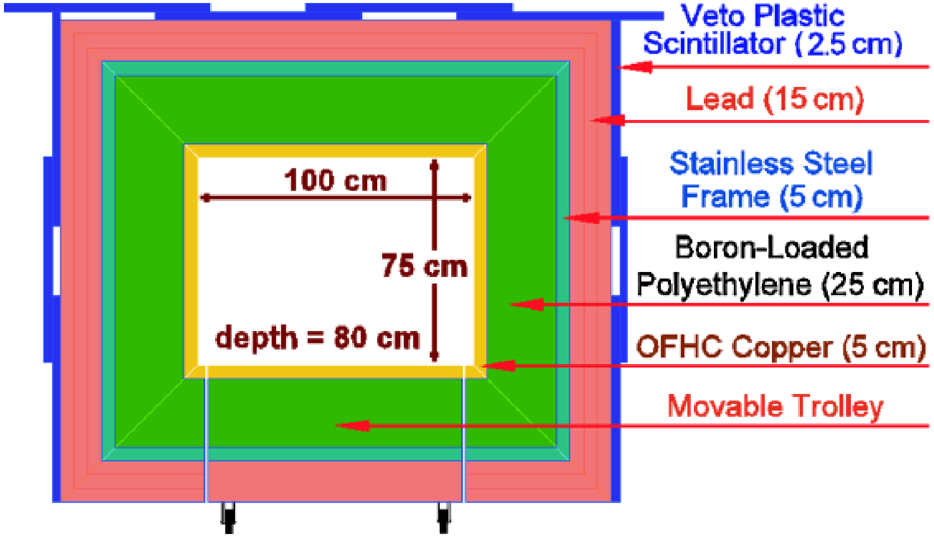
Total flux about 6.4×10^{12} $cm^{-2}s^{-1}$

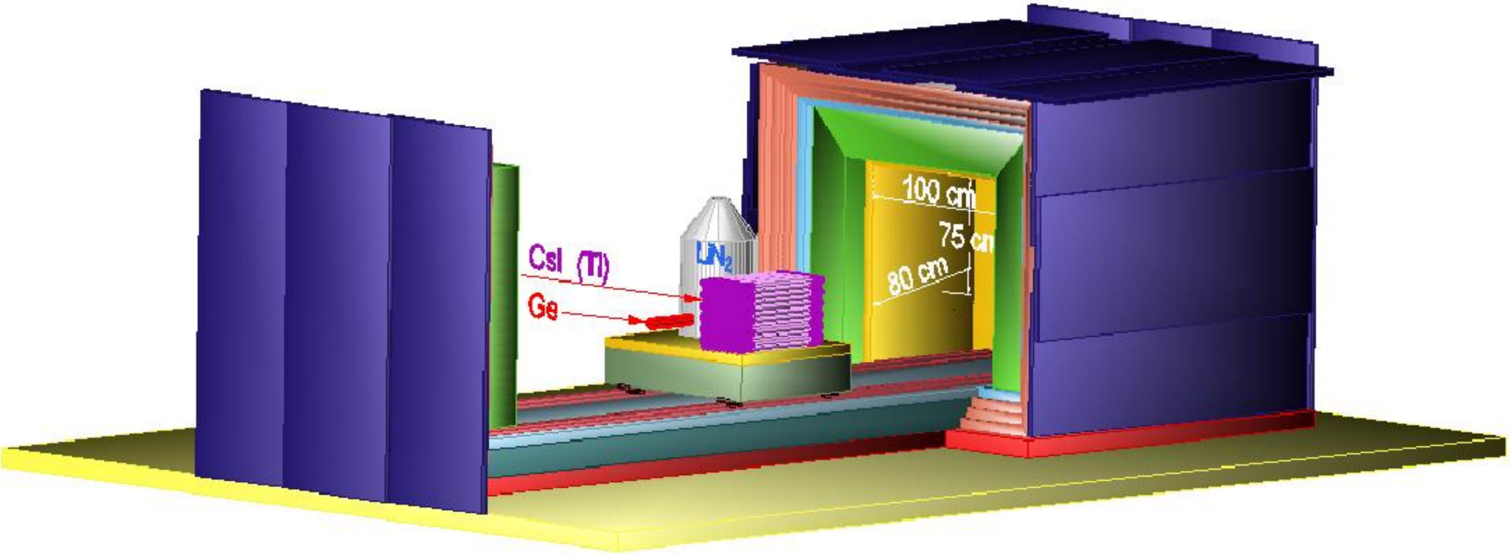
KS ν Lab: 28m from core #1

- ➢ 10 m below the surface
- ➢ Reactor Cycle : ~50 days OFF every 18 months

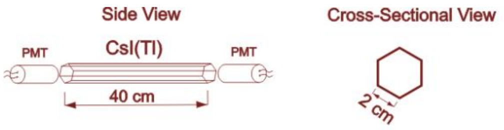
Neutrino Laboratory

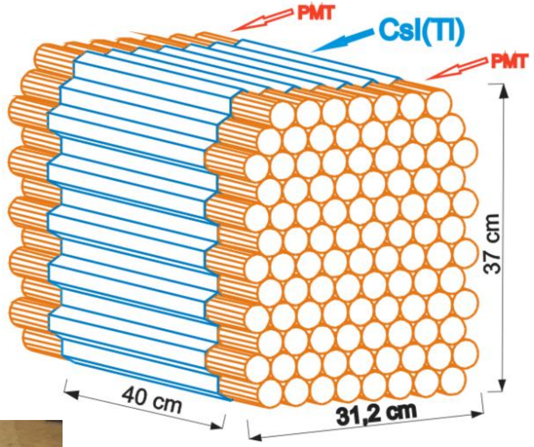
Inner Target Volume & Shielding





TEXONO DATA SETS





DS1-CsI(Tl) :

- Data with **29 882 / 7369 kg day** of reactor ***ON/OFF***
- Total mass of ***187 kg***
- Analysis range is ***3-8 MeV***
- **$\sin^2\theta_w = 0.251 \pm 0.031$ (stat) ± 0.024 (sys)**

DS2-HPGe :

- Data ***with 570.7 / 127.8 kg day*** of reactor ***ON/OFF***
- Target mass is ***1.06 kg***
- Threshold of ***10 keV*** is achieved.
- Analysis range is ***10 – 50 keV.***
- **$\mu_\nu < 7.4 \times 10^{-11}\ \mu_B$**

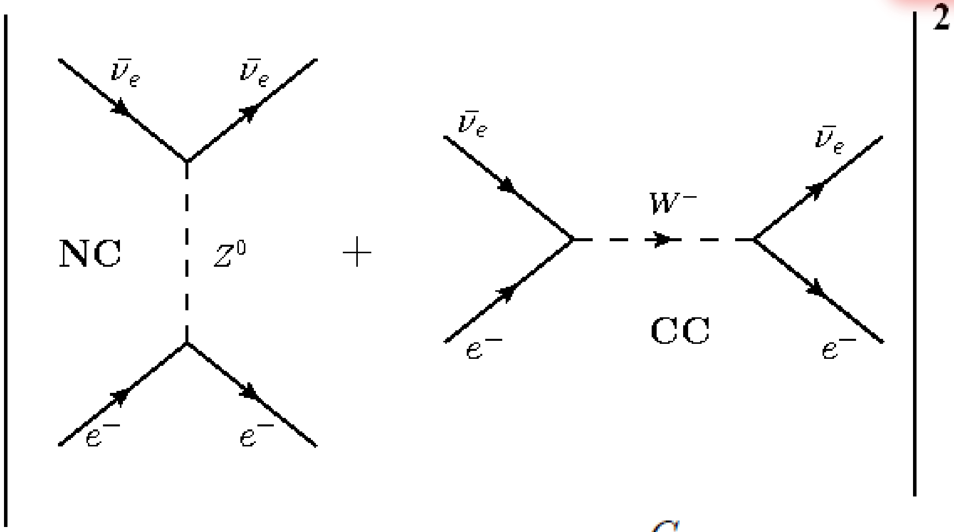
DS3-ULEGe.

- Data with ***0.338 kg days*** of reactor ***ON***
- Total mass of ***20 g (4 x5 g)***
- Threshold of ***220 ± 10 eV*** is achieved.
- WIMP mass ***< 10 GeV*** is searched.

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

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

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



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

$$\boxed{\begin{array}{lcl} R_{SM}(\bar{\nu}_e e) & \rightarrow & (0.77 : 0.92 : -0.69) \\ R_{SM}(\nu_e e) & \rightarrow & (1.83 : 0.17 : -0.99) \end{array}}$$

$$\boxed{\delta[\sin^2\theta_W] \sim \left\{ \begin{array}{l} 0.14 \cdot \ \delta[\xi(\bar{\nu}_e e)] \\ 0.32 \cdot \ \delta[\xi(\nu_e e)] \end{array} \right.}$$

$$\xi = \frac{R_{expt}(\nu)}{R_{SM}(\nu)}$$

$$\mathcal{L}^{NC} = -\frac{G_F}{\sqrt{2}} [\bar{\nu}_e \gamma^\alpha (1 - \gamma_5) \nu_e] [\bar{e} \gamma_\alpha (g_V - g_A \gamma_5) e]$$

$$\mathcal{L}^{CC} = -\frac{G_F}{\sqrt{2}} [\bar{e} \gamma^\alpha (1 - \gamma_5) \nu_e] [\bar{\nu}_e \gamma_\alpha (1 - \gamma_5) e]$$

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

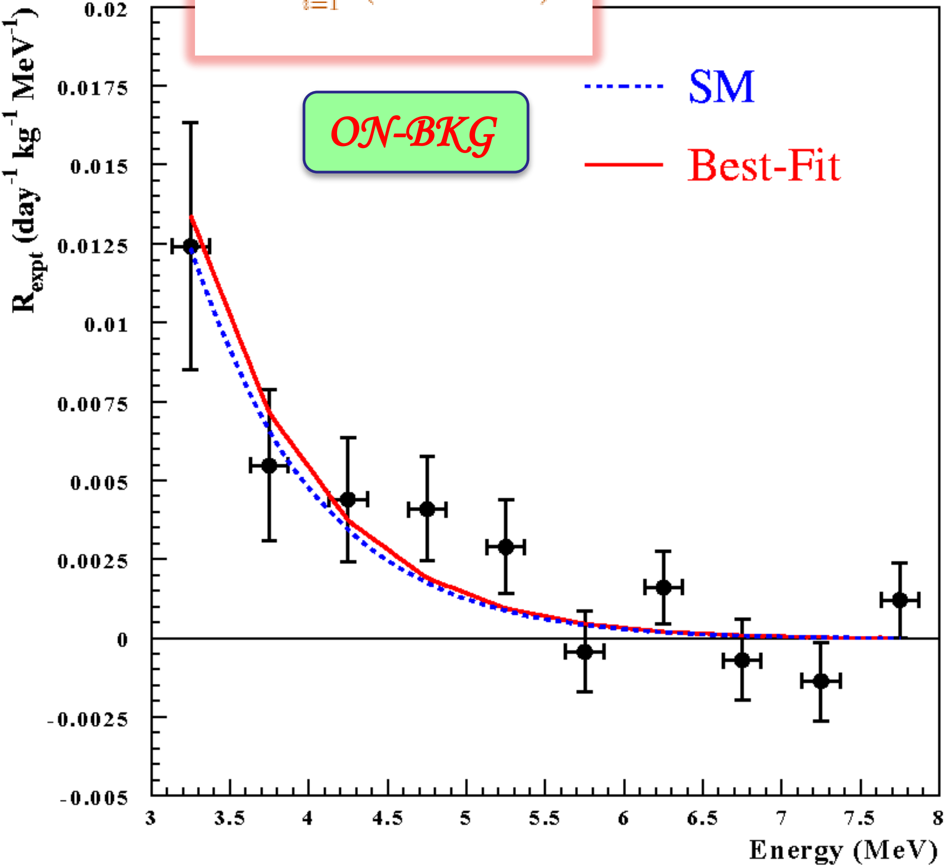
$$g_A = -\frac{1}{2}$$

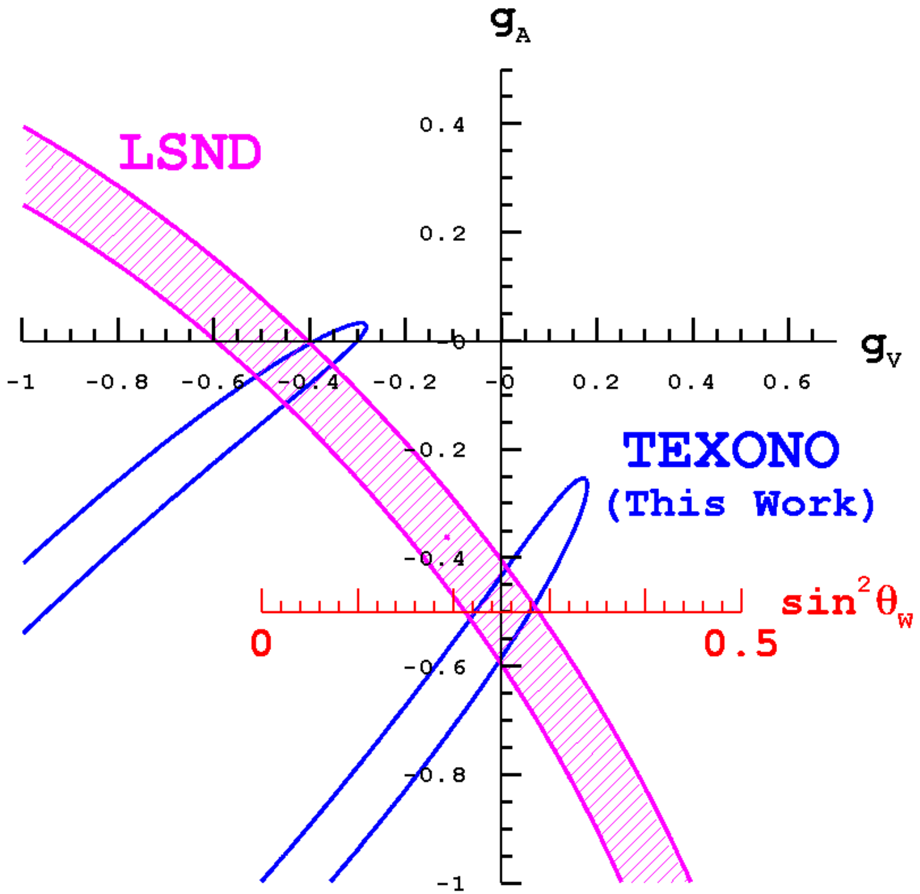
$$g_V = 2\sin^2\theta_W - \frac{1}{2}$$

Cross Section & Weak Mixing Angle

Phys. Rev. D 81, 072001 (2010)

$$\chi^2 = \sum_{i=1}^{10} \left(\frac{R_i - \zeta R_i^{SM}}{\sigma_i} \right)^2$$





$$R = [1.08 \pm 0.21(stat) \pm 0.16(sys)] \times R_{SM}$$

$$\sin^2\theta_W = 0.251 \pm 0.031(stat) \pm 0.024(sys)$$

Better sensitivity is achieved in the measurement of weak mixing angle

World Status: Summary Table

	Experiment	Energy (MeV)	Events	Cross-Section	$\sin^2\theta_W$
$\nu_e - e^-$	**LAMPF** [Liquid Scin.]	7 - 60	236	$[10.0 \pm 1.5 \pm 0.9]$ $\times E_{\nu e} 10^{-45} cm^2$	0.249 ± 0.063
	LSND [Liquid Scin.]	10 - 50	191	$[10.1 \pm 1.1 \pm 1.0]$ $\times E_{\nu e} 10^{-45} cm^2$	0.248 ± 0.051
$\bar{\nu}_e - e^-$	**Savannah-River** [Plastic Scin.]	1.5 - 3.0 3.0 – 4.5	381 71	$[0.86 \pm 0.25] \times \sigma_{V-A}$ $[1.70 \pm 0.44] \times \sigma_{V-A}$	0.29 ± 0.05
	Savannah-River **Re-analysed** (PRD1989, Engel&Vogel)	1.5 – 3.0 3.0 – 4.5	N/A	$[1.35 \pm 0.4] \times \sigma_{SM}$ $[2.0 \pm 0.5] \times \sigma_{SM}$	N/A
	Krasnoyarsk (Fluorocarbon)	3.15 – 5.18	N/A	$[4.5 \pm 2.4]$ $\times 10^{-46}$ cm^2/fission	0.22 ± 0.75
	Rovno [Si(Li)]	0.6 – 2.0	41	$[1.26 \pm 0.62]$ $\times 10^{-44}$ cm^2/fission	N/A
	MUNU [CF_4(gas)]	0.7 – 2.0	68	1.07 ± 0.34 events day^{-1}	N/A
	TEXONO [CsI(Tl) Scin.]	3 - 8	~ 410	$[1.08 \pm 0.21 \pm 0.16]$ $\times R_{SM}$	0.251 ± 0.039

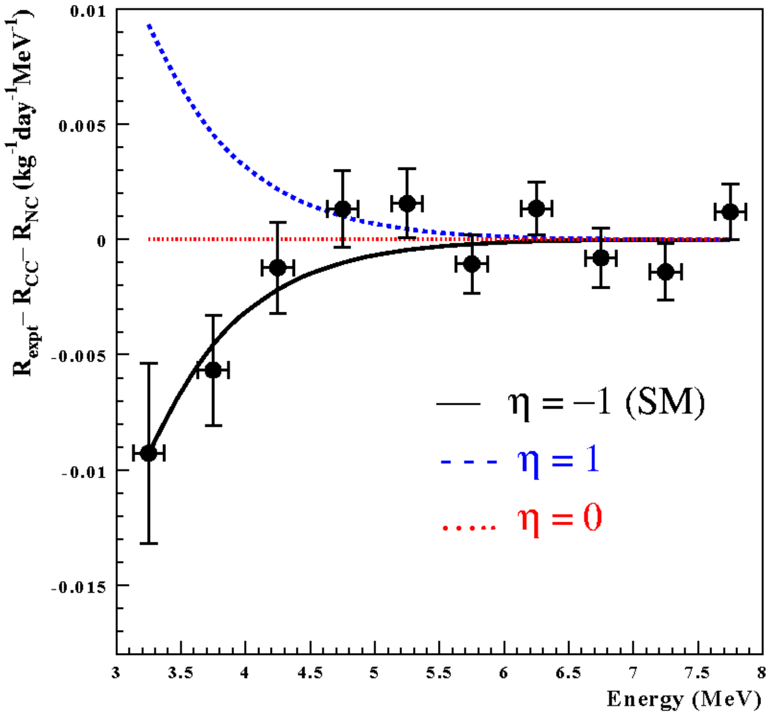
Interference, Neutrino Magnetic Moment and Charge Radius

Interference Term

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

Interference Term

η= − 0.92 ± 0.30(stat) ± 0.24(sys)



Neutrino Magnetic Moment

$$R(ON-BKG) = R(SM) + \mu_\nu^2 \times R(MM)$$

$$\left(\frac{d\sigma}{dT}\right)_{\mu_\nu} = \frac{\pi\alpha_{em}^2\mu_\nu{}^2}{m_e^2}\left[\frac{1-T/E_\nu}{T}\right]$$

$\mu_\nu^2 = [0.42 \pm 1.79(stat) \pm 1.49(sys)].\mu_B^2$

$$\mu_{\bar{\nu}} < 2.2\times10^{-10}\times\mu_B$$

Ge , 12 keV threshold

$$\mu_{\bar{\nu}} < 0.74\times10^{-10}\times\mu_B$$

at 90% C. L.

Neutrino Charge Radius

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

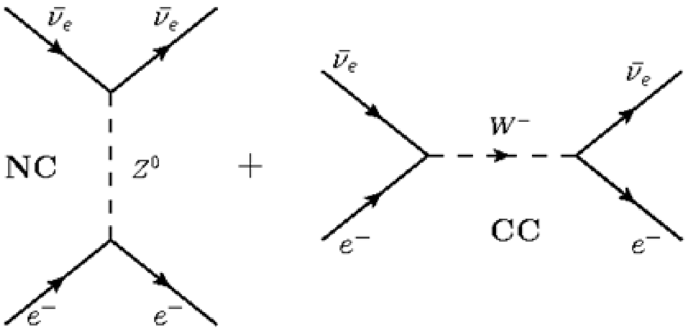
$$-2.1\times10^{-32} < \left\langle r^2_{\bar{\nu}_e}\right\rangle < 3.3\times10^{-32}\ cm^2$$

Non Standard Interactions (NSI)

Predicted by beyond the Standard model Physics, especially neutrino mass theories predict neutral current non-standard interactions:

- *From The Exchange of Heavy Gauge Boson Z` (de Gouvea & Jenkins (2006))*
- *Seesaw – type models (Schecter & Valle (1980))*
- *In SUSY Models with Broken R-parity (Hirsch & Valle (2004))*
- *In unified SUSY Models as a renormalization effect (Hall, Kostelecky & Raby (1986)*
- *In models where neutrino masses are calculable from radiative corrections due to the presence of extra Higgs boson. (Zee (1980), Babu (1988))*
- *etc…*

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



$$\pounds^{NC} = -\frac{G_F}{\sqrt{2}}\left[\bar{\nu}_e\gamma^\alpha(1-\gamma_5)\,\nu_e\right]\left[\bar{e}\gamma_\alpha(g_V-g_A\gamma_5)\,e\right]$$

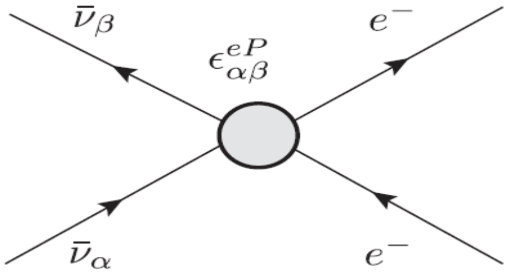
$$\pounds^{CC} = -\frac{G_F}{\sqrt{2}}\left[\bar{e}\gamma^\alpha(1-\gamma_5)\,\nu_e\right]\left[\bar{\nu}_e\gamma_\alpha(1-\gamma_5)\,e\right]$$

Differential cross section for the $\overline{\nu_e}\, e \rightarrow \overline{\nu_e}\, e$

$$\frac{d\sigma}{dT} = \frac{2G_F^2 M_e}{\pi}\left[g_R^2 + g_L^2\left(1-\frac{T}{E_\nu}\right)^2 - g_L g_R\frac{m_e T}{E_\nu^2}\right]$$

$$g_L = \frac{1}{2} + \sin^2\theta_W$$
$$g_R = \sin^2\theta_W$$

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



Model independent way of introducing NSI is via the effective four fermion Lagrangian;

$$\mathcal{L}^{NSI}_{eff} = -\sum_{\alpha\beta fP}\varepsilon^{fP}_{\alpha\beta}\,2\sqrt{2}G_F(\bar{\nu}_\alpha\gamma_\rho L\nu_\beta)(\bar{f}\gamma^\rho P f)$$

$\alpha,\beta = e,\mu,\tau;\quad f = e\,;\ P = L,R;\quad L = (1-\gamma_5)/2;\quad R = (1+\gamma_5)/2$

Differential cross section for the $\overline{\nu_e}\, e \rightarrow \overline{\nu}_\alpha\, e$

$$\frac{d\sigma(E_\nu,T)}{dT} = \frac{2G_F^2 M_e}{\pi}\Big[\big(\tilde{g}_R^2 + \sum_{\alpha\neq e}|\epsilon^{eR}_{\alpha e}|^2\big) + \big(\tilde{g}_L^2 + \sum_{\alpha\neq e}|\epsilon^{eL}_{\alpha e}|^2\big)\left(1-\frac{T}{E_\nu}\right)^2 - \big(\tilde{g}_L\tilde{g}_R + \sum_{\alpha\neq e}|\epsilon^{eL}_{\alpha e}||\epsilon^{eR}_{\alpha e}|\big)m_e\frac{T}{E_\nu^2}\Big]$$

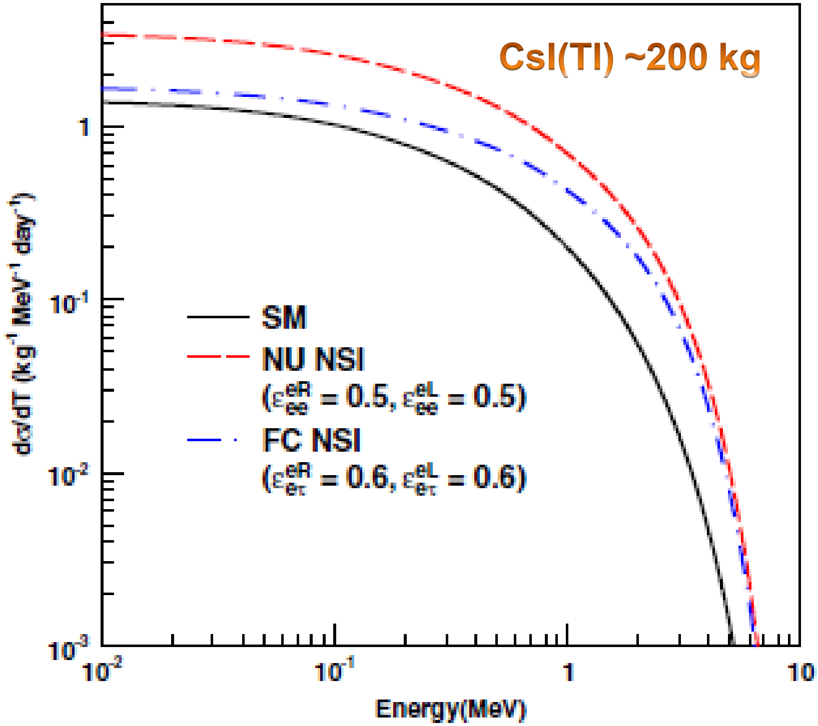
$$\tilde{g}_L = g_L + \epsilon^{eL}_{ee} \qquad \tilde{g}_R = g_R + \epsilon^{eR}_{ee}$$

(NU) NSI: ϵ^{eLR}_{ee}

(FC) NSI: $\epsilon^{eLR}_{e\mu}$ $\epsilon^{eLR}_{e\tau}$

NSI of Neutrino

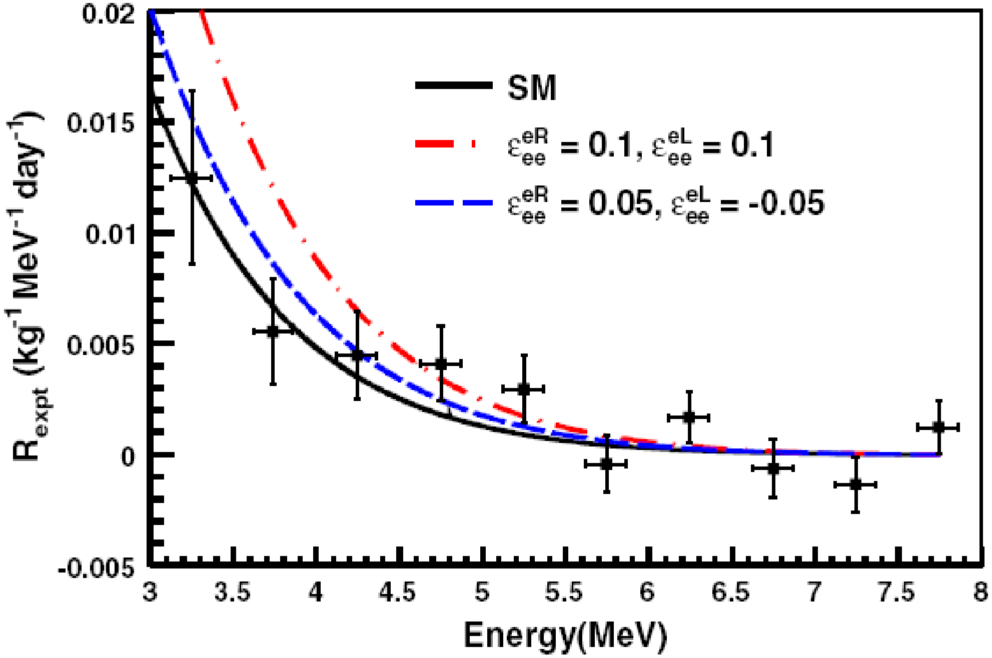
The measurable recoil spectra with typical neutrino "flux" at typical values of NSI parameters for both ***NU and FC NSI***



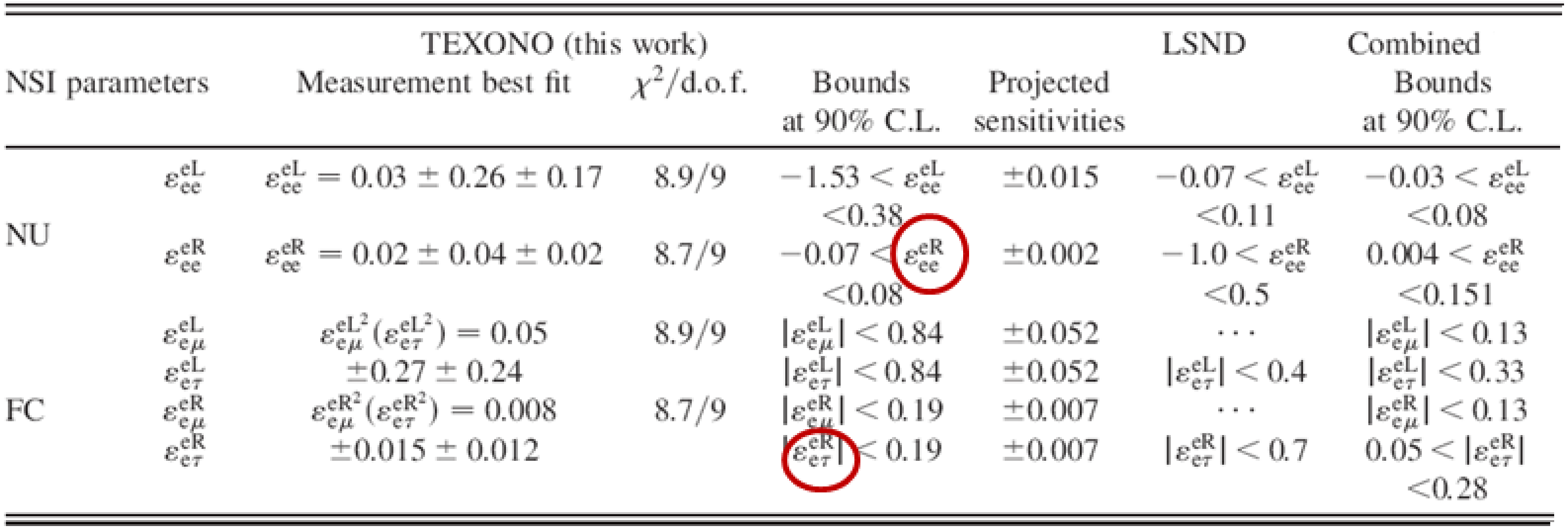
— The NSI parameters are constrained by the accuracy of the SM cross-section measurements

$$R_{\mathcal{NP}+\mathcal{SM}} = t\,\rho_e \int_T \int_{E_\nu} \left(\frac{d\sigma}{dT}\right)_{\mathcal{NP}+\mathcal{SM}} \frac{d\phi_{(\bar{\nu}_e)}}{dE_\nu}\, dE_\nu\, dT$$

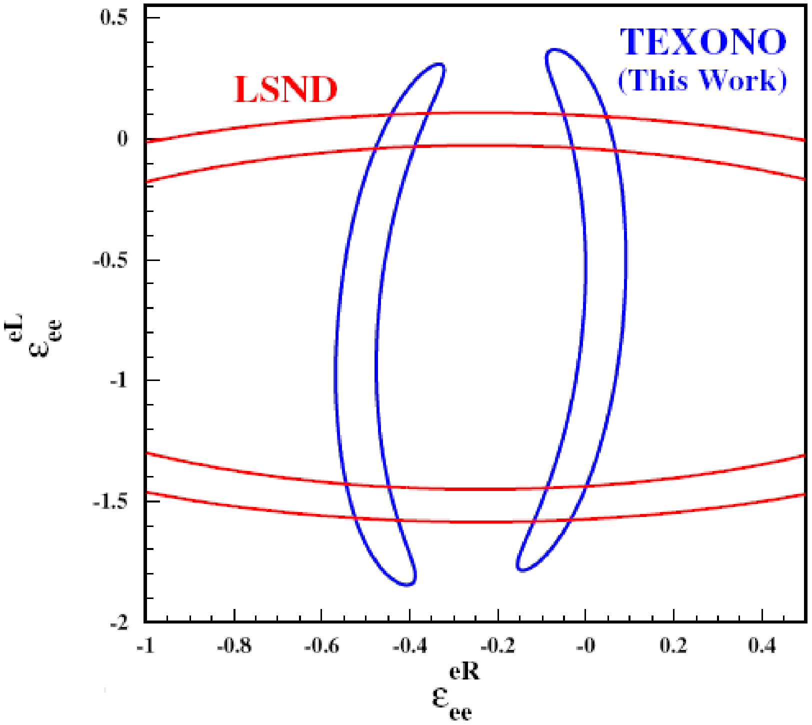
$$\chi^2 = \sum_{i=1} \left[\frac{R_{\rm expt}(i) - [R_{\rm SM}(i) + R_X(i)]}{\Delta_{\rm stat}(i)} \right]^2 ,$$



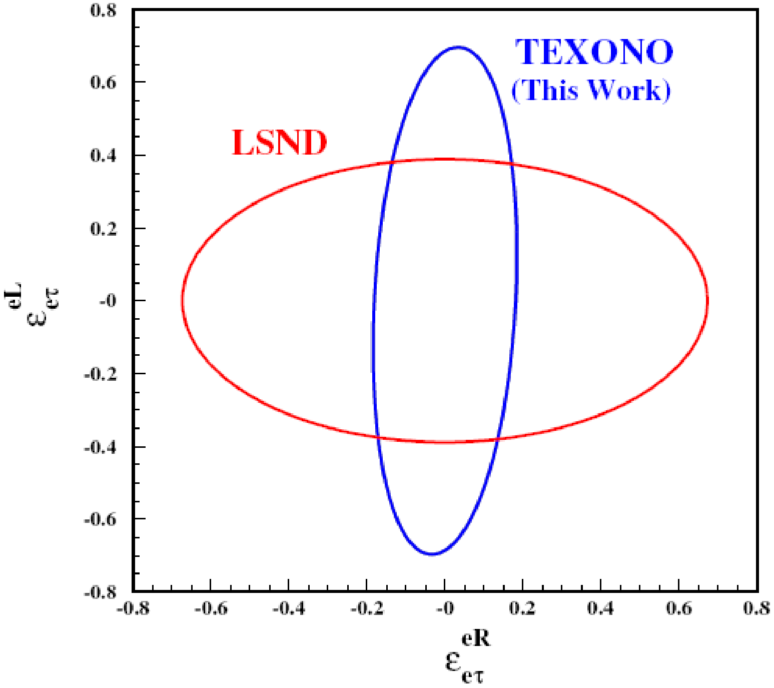
Comparison of Bounds of NSI Parameters



NSI parameters		TEXONO (this work)				LSND	Combined
		Measurement best fit	χ^2/d.o.f.	Bounds at 90% C.L.	Projected sensitivities		Bounds at 90% C.L.
NU	ε_{ee}^{eL}	$\varepsilon_{ee}^{eL} = 0.03 \pm 0.26 \pm 0.17$	8.9/9	$-1.53 < \varepsilon_{ee}^{eL} < 0.38$	± 0.015	$-0.07 < \varepsilon_{ee}^{eL} < 0.11$	$-0.03 < \varepsilon_{ee}^{eL} < 0.08$
	ε_{ee}^{eR}	$\varepsilon_{ee}^{eR} = 0.02 \pm 0.04 \pm 0.02$	8.7/9	$-0.07 < \varepsilon_{ee}^{eR} < 0.08$	± 0.002	$-1.0 < \varepsilon_{ee}^{eR} < 0.5$	$0.004 < \varepsilon_{ee}^{eR} < 0.151$
FC	$\varepsilon_{e\mu}^{eL}$	$\varepsilon_{e\mu}^{eL^2} (\varepsilon_{e\tau}^{eL^2}) = 0.05 \pm 0.27 \pm 0.24$	8.9/9	$\|\varepsilon_{e\mu}^{eL}\| < 0.84$	± 0.052	$\cdots$	$\|\varepsilon_{e\mu}^{eL}\| < 0.13$
	$\varepsilon_{e\tau}^{eL}$			$\|\varepsilon_{e\tau}^{eL}\| < 0.84$	± 0.052	$\|\varepsilon_{e\tau}^{eL}\| < 0.4$	$\|\varepsilon_{e\tau}^{eL}\| < 0.33$
	$\varepsilon_{e\mu}^{eR}$	$\varepsilon_{e\mu}^{eR^2} (\varepsilon_{e\tau}^{eR^2}) = 0.008 \pm 0.015 \pm 0.012$	8.7/9	$\|\varepsilon_{e\mu}^{eR}\| < 0.19$	± 0.007	$\cdots$	$\|\varepsilon_{e\mu}^{eR}\| < 0.13$
	$\varepsilon_{e\tau}^{eR}$			$\|\varepsilon_{e\tau}^{eR}\| < 0.19$	± 0.007	$\|\varepsilon_{e\tau}^{eR}\| < 0.7$	$0.05 < \|\varepsilon_{e\tau}^{eR}\| < 0.28$



% C. L.



Non-Commutative Physics (NC)

- *Idea dates back to 1940s when it was used to get rid of the divergences in QFT by Snyder, Heisenberg & Pauli.*
- *After the renormalization concept was introduced, the idea was ignored until the idea become popular again, with the String Throry (NCQFT is low energy limit of certain String Theories (Seiberg & Witten, 1999)*

$$[\,\hat{x}_\mu,\ \hat{x}_\nu\,] = i\,\theta_{\mu\nu}$$

$$\Delta x_\mu\,\Delta x_\nu \geq \frac{1}{2}\,|\theta_{\mu\nu}|$$

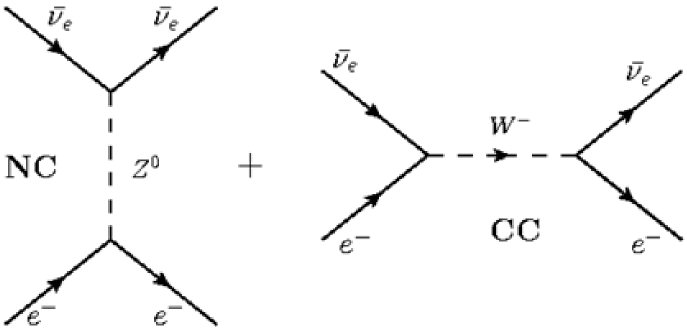
$$\Lambda_{NC} = (1/\sqrt{|\theta_{\mu\nu}|})$$

- *Space-time NC is an extension of QM.*
- *Not explored, nor ruled out.*
- *Λ_{NC} is the scale where NC effects become important*
- *There is no theoretical bound on Λ_{NC}*
- *Most likely scale for Λ_{NC};*
- *m_{Pl} ~ 10^{19} GeV*
- *m_{λ} ~ TeV (possibility of large extra dimensions where gravity becomes strong at TeV order)*

NCQED is constructed via the definition of ***Weyl-Moyal * Product***

$$(f*g)(x) = f(x)e^{\frac{i}{2}\overleftarrow{\partial^\mu}\theta_{\mu\nu}\overrightarrow{\partial^\nu}}g(x) = f(x)g(x) + \frac{i}{2}\theta_{\mu\nu}\frac{\partial f(x)}{\partial x_\mu}\frac{\partial g(x)}{\partial x_\nu} + \mathcal{O}(\theta^2)$$

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



$$\pounds^{NC} = -\frac{G_F}{\sqrt{2}}\left[\bar{\nu}_e\gamma^\alpha\left(1-\gamma_5\right)\nu_e\right]\left[\bar{e}\gamma_\alpha\left(g_V-g_A\gamma_5\right)e\right]$$

$$\pounds^{CC} = -\frac{G_F}{\sqrt{2}}\left[\bar{e}\gamma^\alpha\left(1-\gamma_5\right)\nu_e\right]\left[\bar{\nu}_e\gamma_\alpha\left(1-\gamma_5\right)e\right]$$

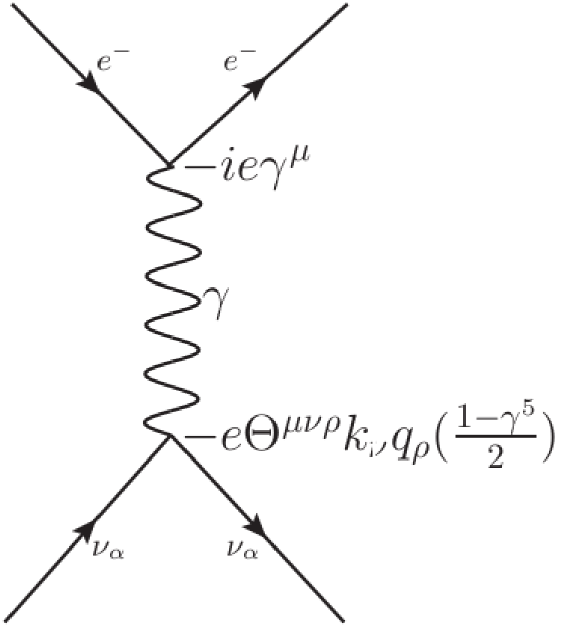
Differential cross section for the $\overline{\nu_e}\, e \rightarrow \overline{\nu_e}\, e$

$$\frac{d\sigma}{dT} = \frac{2G_F^2 M_e}{\pi}\left[g_R^2 + g_L^2\left(1-\frac{T}{E_\nu}\right)^2 - g_L g_R \frac{m_e T}{E_\nu^2}\right]$$

$$g_L = \frac{1}{2} + \sin^2\theta_W$$

$$g_R = \sin^2\theta_W$$

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



$$\theta^{\mu\nu\rho} = \theta^{\mu\nu}\gamma^\rho + \theta^{\nu\rho}\gamma^\mu + \theta^{\rho\mu}\gamma^\nu$$

$$\left[\frac{d\sigma(\nu e)}{dT}(E_\nu)\right]_{NC} = \pi\alpha^2\Theta^2E_\nu^2\left[\frac{1}{T} - \frac{2}{E_\nu} + \frac{3T-2m_e}{2E_\nu^2} - \frac{T^2-2m_eT}{2E_\nu^3} - \frac{m_eT^2}{4E_\nu^4}\left(1-\frac{m_e}{T}\right)\right].$$

Present Bounds on NC Parameter

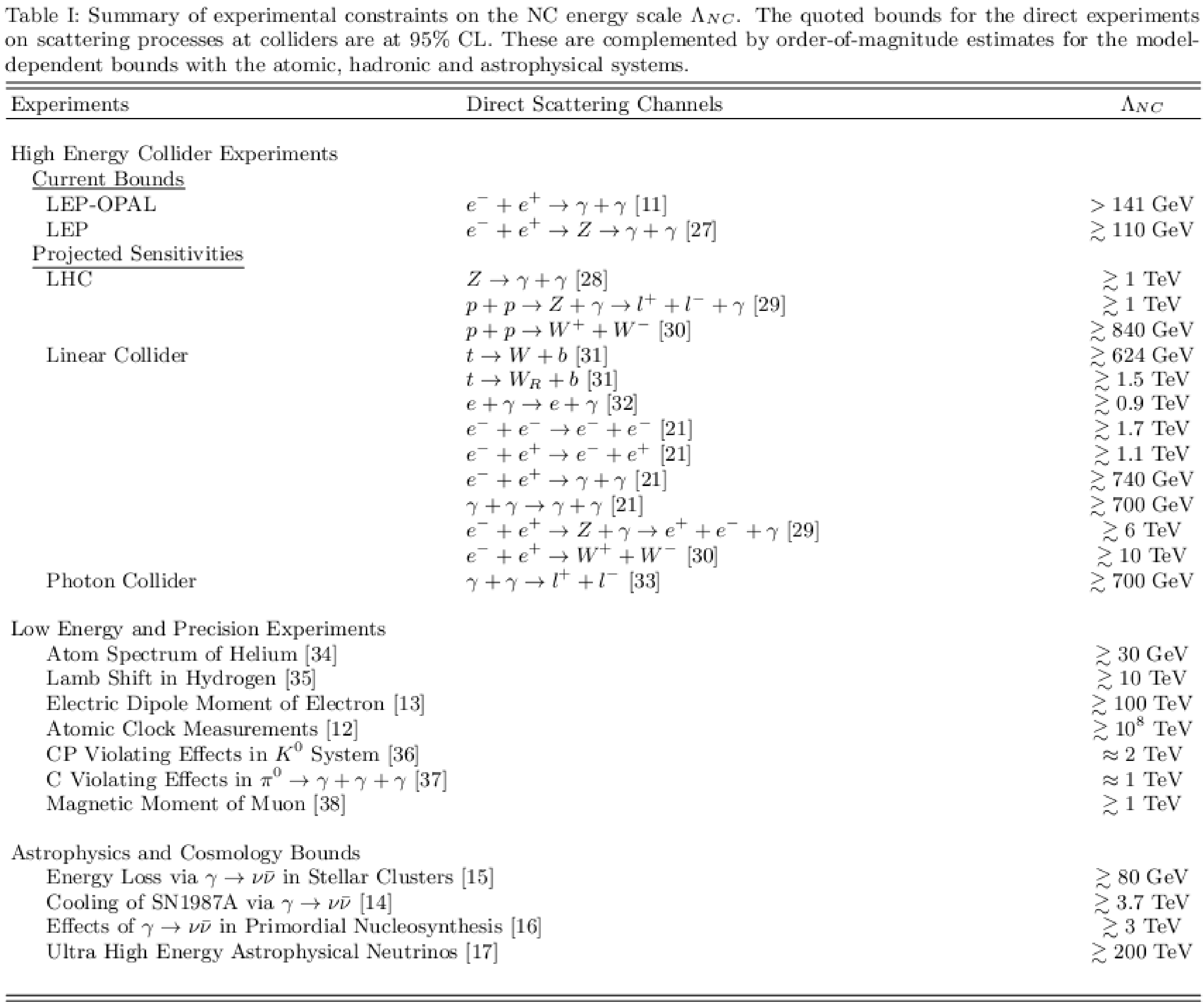
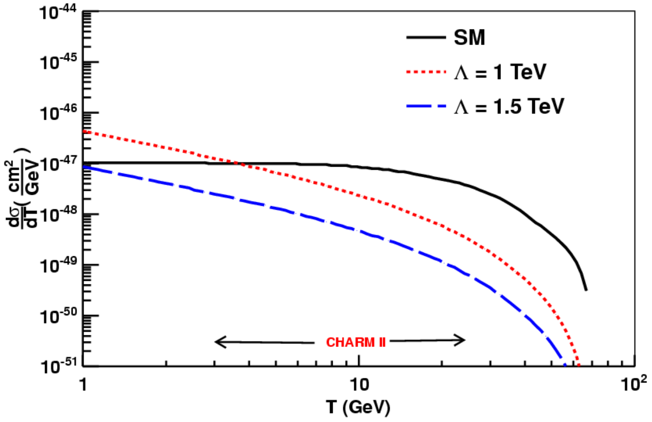
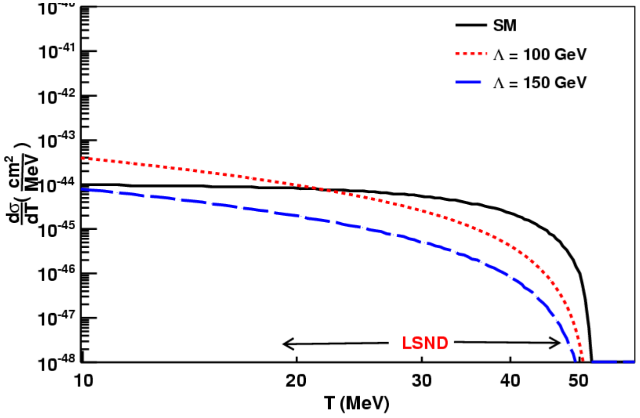


Table I: Summary of experimental constraints on the NC energy scale Λ_{NC}. The quoted bounds for the direct experiments on scattering processes at colliders are at 95% CL. These are complemented by order-of-magnitude estimates for the model-dependent bounds with the atomic, hadronic and astrophysical systems.

Experiments	Direct Scattering Channels	Λ_{NC}
High Energy Collider Experiments		
Current Bounds		
LEP-OPAL	$e^- + e^+ \to \gamma + \gamma$ [11]	> 141 GeV
LEP	$e^- + e^+ \to Z \to \gamma + \gamma$ [27]	$\gtrsim 110$ GeV
Projected Sensitivities		
LHC	$Z \to \gamma + \gamma$ [28]	$\gtrsim 1$ TeV
	$p + p \to Z + \gamma \to l^+ + l^- + \gamma$ [29]	$\gtrsim 1$ TeV
	$p + p \to W^+ + W^-$ [30]	$\gtrsim 840$ GeV
Linear Collider	$t \to W + b$ [31]	$\gtrsim 624$ GeV
	$t \to W_R + b$ [31]	$\gtrsim 1.5$ TeV
	$e + \gamma \to e + \gamma$ [32]	$\gtrsim 0.9$ TeV
	$e^- + e^- \to e^- + e^-$ [21]	$\gtrsim 1.7$ TeV
	$e^- + e^+ \to e^- + e^+$ [21]	$\gtrsim 1.1$ TeV
	$e^- + e^+ \to \gamma + \gamma$ [21]	$\gtrsim 740$ GeV
	$\gamma + \gamma \to \gamma + \gamma$ [21]	$\gtrsim 700$ GeV
	$e^- + e^+ \to Z + \gamma \to e^+ + e^- + \gamma$ [29]	$\gtrsim 6$ TeV
	$e^- + e^+ \to W^+ + W^-$ [30]	$\gtrsim 10$ TeV
Photon Collider	$\gamma + \gamma \to l^+ + l^-$ [33]	$\gtrsim 700$ GeV
Low Energy and Precision Experiments		
Atom Spectrum of Helium [34]		$\gtrsim 30$ GeV
Lamb Shift in Hydrogen [35]		$\gtrsim 10$ TeV
Electric Dipole Moment of Electron [13]		$\gtrsim 100$ TeV
Atomic Clock Measurements [12]		$\gtrsim 10^8$ TeV
CP Violating Effects in K^0 System [36]		≈ 2 TeV
C Violating Effects in $\pi^0 \to \gamma + \gamma + \gamma$ [37]		≈ 1 TeV
Magnetic Moment of Muon [38]		$\gtrsim 1$ TeV
Astrophysics and Cosmology Bounds		
Energy Loss via $\gamma \to \nu\bar{\nu}$ in Stellar Clusters [15]		$\gtrsim 80$ GeV
Cooling of SN1987A via $\gamma \to \nu\bar{\nu}$ [14]		$\gtrsim 3.7$ TeV
Effects of $\gamma \to \nu\bar{\nu}$ in Primordial Nucleosynthesis [16]		$\gtrsim 3$ TeV
Ultra High Energy Astrophysical Neutrinos [17]		$\gtrsim 200$ TeV

Bounds on Λ_{NC} from Neutrino Experiments





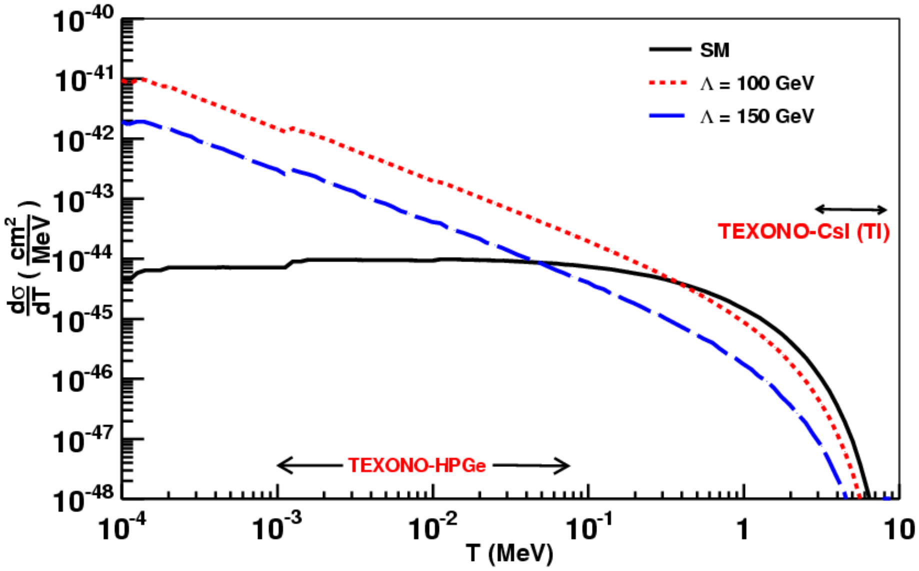


Table II: The key parameters of the TEXONO, LSND and CHARM-II measurements on $\nu - e$ scattering, and the derived bounds on NC physics. The best-fit values in Θ^2 and the 95% CL lower limits on Λ_{NC} are shown.

Experiment	ν	$< E_\nu >$	T	Measured $\sin^2\theta_W$	Best-Fit on Θ^2	Λ_{NC} (95% CL)
TEXONO-HPGe [23]	$\bar{\nu}_e$	1–2 MeV	12–60 keV	–	$(9.27 \pm 6.65) \times 10^{-22}$	$>$ 145 GeV
TEXONO-CsI(Tl) [5]	$\bar{\nu}_e$	1–2 MeV	3–8 MeV	0.251 ± 0.039	$(0.81 \pm 5.74) \times 10^{-21}$	$>$ 95 GeV
LSND [24]	ν_e	36 MeV	18–50 MeV	0.248 ± 0.051	$(0.38 \pm 2.06) \times 10^{-21}$	$\gtrsim$ 123 GeV
CHARM-II [25]	ν_μ	23.7 GeV	3-24 GeV	0.2324 ± 0.0083	$(0.20 \pm 1.03) \times 10^{-26}$	$\gtrsim$ 2.6 TeV
	$\bar{\nu}_\mu$	19.1 GeV	3-24 GeV	0.2324 ± 0.0083	$(-0.92 \pm 4.77) \times 10^{-27}$	$\gtrsim$ 3.3 TeV

Summary

- **Detector:** CsI(Tl) Scintillating Crystal Array (~ 200 kg)
  - Threshold: 3 MeV
  - $\sigma(\bar{\nu}_e - e^-)$ with ~ 25% accuracy
  - Weak Mixing Angle with ~ 15% accuracy
  - μ_ν sensitivity ~ 10^{-10} μ_B
  - Verify SM negative interference
  - neutrino charge radius ~ 10^{-32} cm^2

- **HPGe (1 kg)**
  - Threshold is ***10 keV***
  - **$\mu_\nu < 7.4 \times 10^{-11}$ μ_B**
  - ***ν_e N measurement is aimed***

- **4 x 5 gr Ge**
  - WIMP is searched.

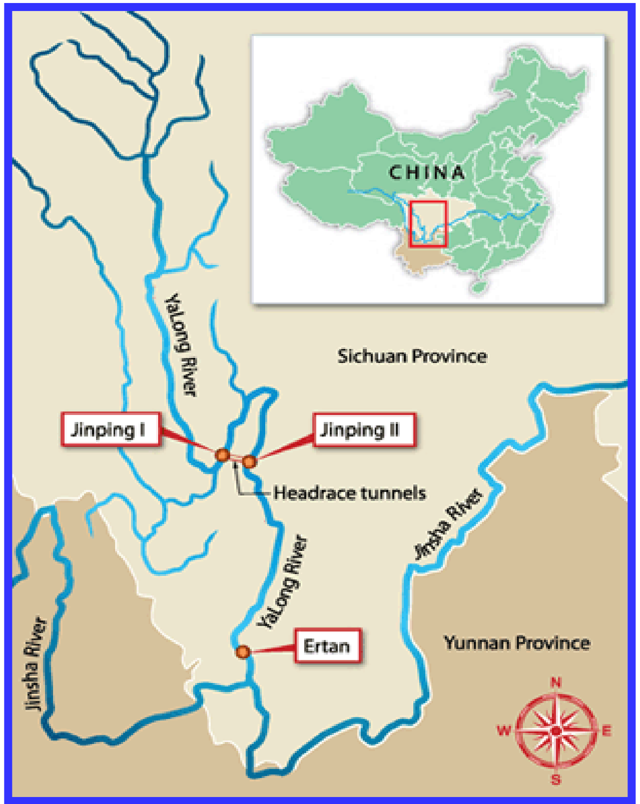
- **Probing new Physics :** NSI , UP & NC
  - Searching for the excess number of events apart from SM prediction makes it possible to put constraints on BSM physics
  - Current bounds are improved over those from the previous experiments

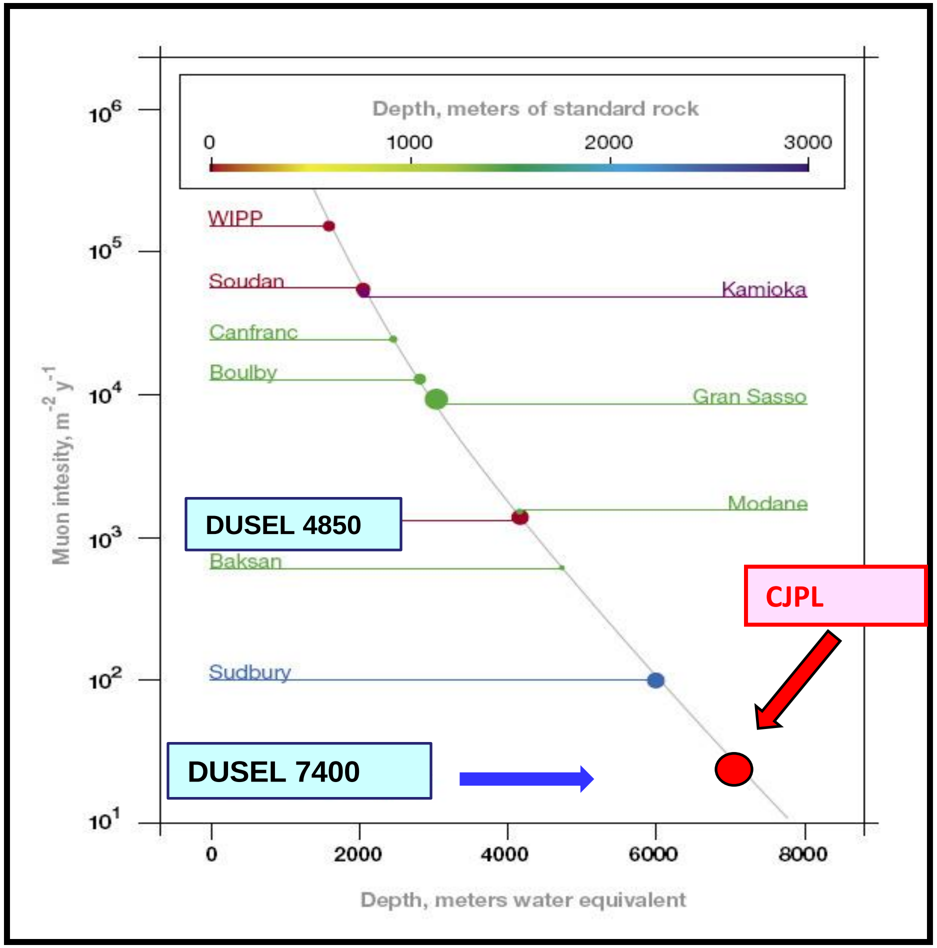
China Jin-Ping Underground Laboratory (CJPL) 中國四川錦屏

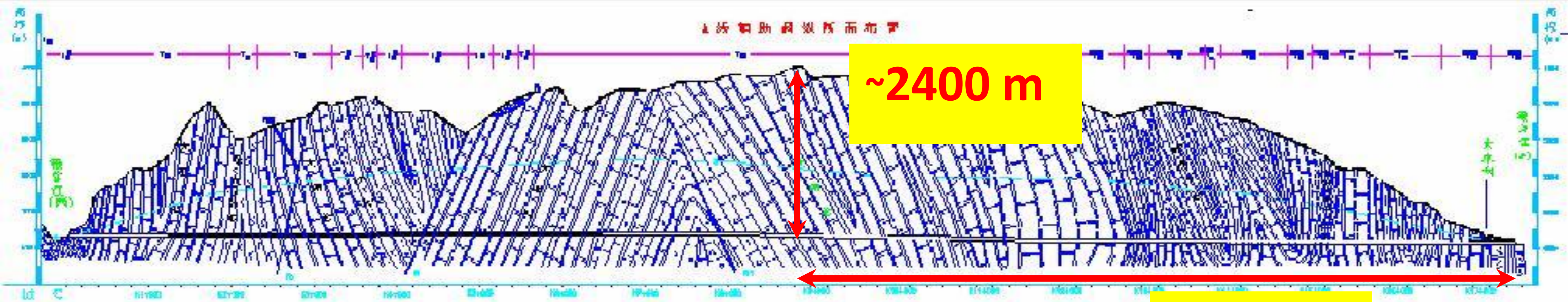
- ◎ **2500+ m rock overburden, drive-in road tunnel access**
- ◎ **6×6×40 m cavern has built**
- ◎ **DM-Search: 20 g ULEGe 2010 ; 1 kg PCGe 2011**

CJPL 中国锦屏地下实验室

China Jinping Underground Laboratory

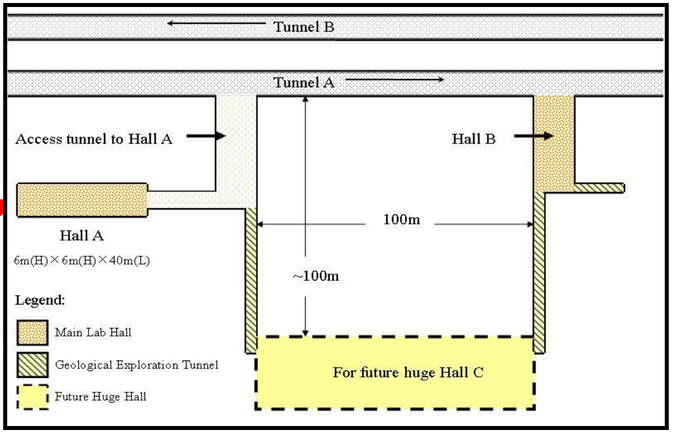


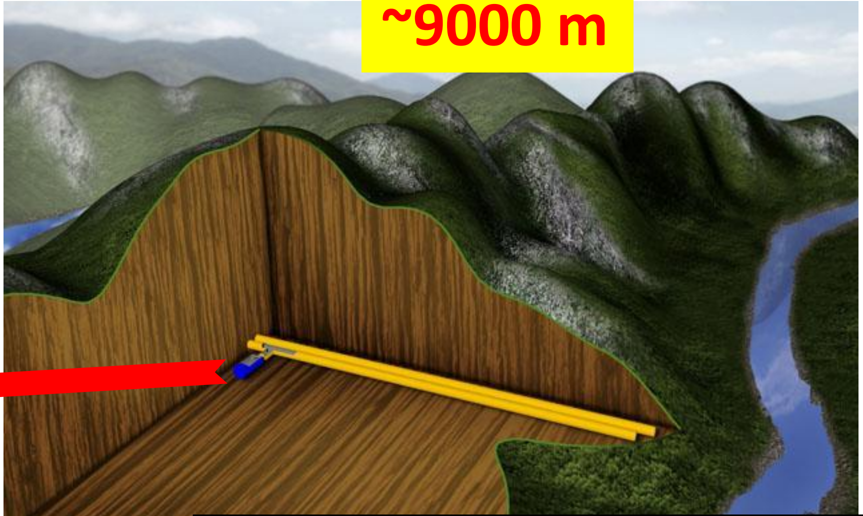


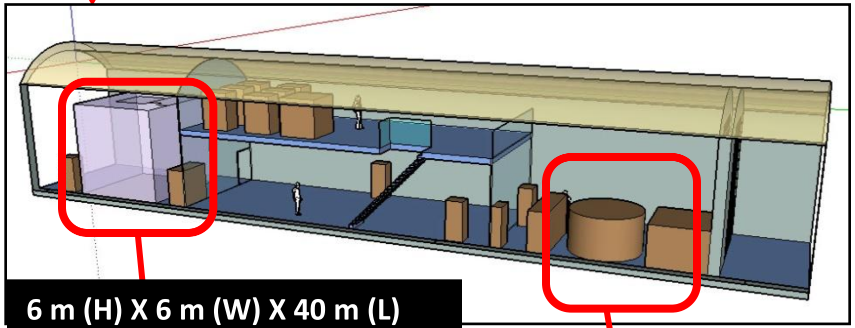


~2400 m

~9000 m







6 m (H) X 6 m (W) X 40 m (L)

CDEX-TEXONO

PandaX

China, others dig more and deeper underground labs

From tiny to gargantuan, experiments are in the works to exploit the shielding from cosmic rays that being deep underground offers.

Physics Today September 2010

PARTICLE PHYSICS:

Chinese Scientists Hope to Make Deepest, Darkest Dreams Come True

Dennis Normile

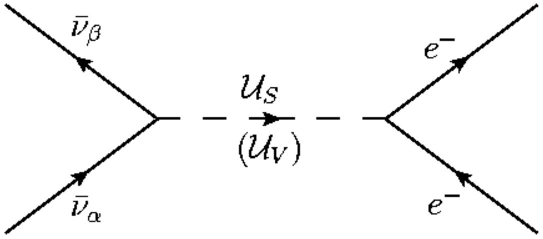
Science 5 June 2009:
Vol. 324. no. 5932, pp. 1246 - 1247
DOI: 10.1126/science.324_1246

TEŞEKKÜRLER

Backup Slides

Unparticle Physics

- ❖ The notion of unparticles is introduced by Howard Georgi . A scale invariant sector which decouples at a suffciently large energy scale exists. *[Phys. Rev. Lett. 98, 221601 (2007)]*
- ❖ The signatures of Unparticles can also be observed by reactor neutrinos by searching the effects of virtual unparticle exchange between fermionic currents.
- ❖ This interaction can be either exchange of **Scalar Unparticles** or **Vector Unparticles**.



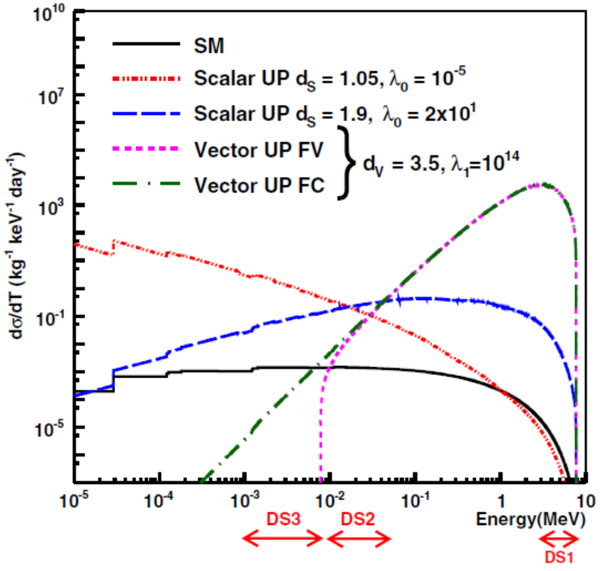
1. Exchange of Scalar Unparticles

$$\frac{d\sigma_{\mathcal{U}_S}}{dT} = \frac{[g_{0e}^{\alpha\beta}(d)]^2}{\Lambda^{(4d-4)}} \frac{2^{(2d-6)}}{\pi E_\nu^2} (m_e T)^{(2d-3)} (T + 2m_e)$$

2. Exchange of Vector Unparticles

$$\frac{d\sigma_{\mathcal{U}_V}}{dT} = \frac{1}{\pi} \frac{[g_{1e}^{\alpha\beta}(d)]^2}{\Lambda^{(4d-4)}} 2^{(2d-5)} (m_e)^{(2d-3)} (T)^{(2d-4)} \left[1 + \left(1 - \frac{T}{E_\nu}\right)^2 - \frac{m_e T}{E_\nu^2}\right]$$

$$\frac{d\sigma_{\mathcal{U}_V - SM}}{dT} = \frac{\sqrt{2} G_F}{\pi} \frac{g_{1e}(d)}{\Lambda^{(2d-2)}} (2m_e T)^{(d-2)} m_e \left\{ g_L + g_R \left(1 - \frac{T}{E_\nu}\right)^2 - \frac{(g_L + g_R)}{2} \frac{m_e T}{E_\nu^2} \right\}$$

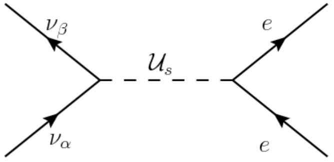


i= 0(1) : Unparticle scalar/vector field
λ_0 (λ_1) : Scalar(Vector) unparticle couplings
f : e, u, d
α, β: denotes neutrino flavours
d: Unparticle mass dimension
Λ : Unparticle energy scale

$$\lambda_0 \ (\lambda_1) = \sqrt{\lambda_{0\nu}^{e\beta} \lambda_{0e}} \ \left(\sqrt{\lambda_{1\nu}^{e\beta} \lambda_{1e}}\right)$$

$$g_{if}^{\alpha\beta}(d) = \frac{\lambda_{i\nu}^{\alpha\beta} \lambda_{if}}{2 \sin(d\pi)} A_d \qquad A_d = \frac{16\pi^{5/2}}{(2\pi)^{2d}} \frac{\Gamma(d + 1/2)}{\Gamma(d-1)\Gamma(2d)} .$$

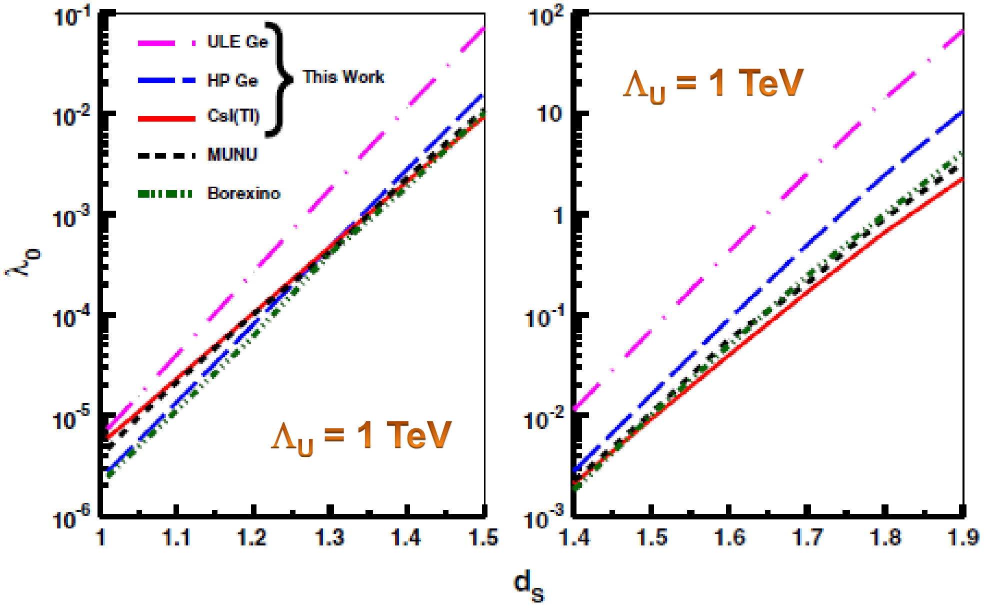
Scalar Unparticle

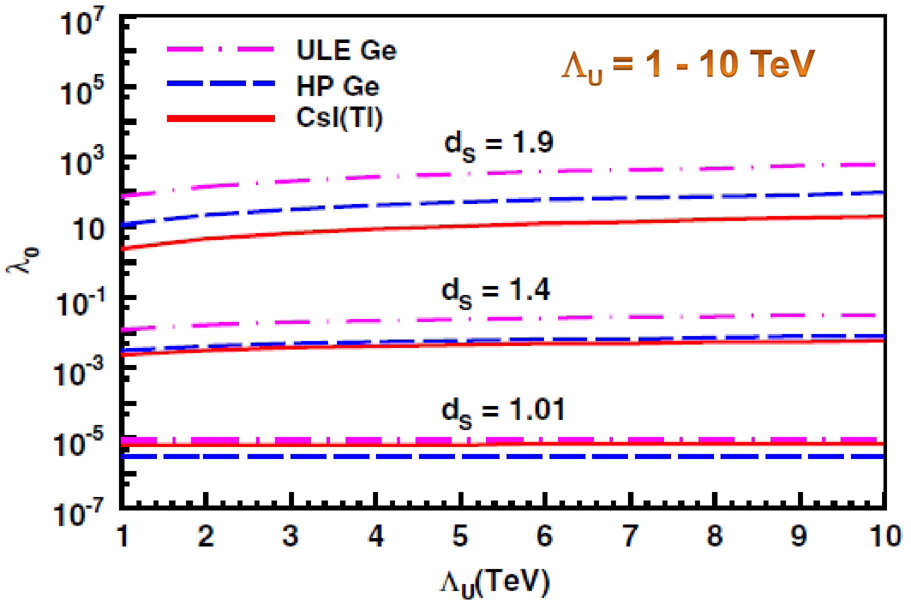


1 < d < 2

$$\frac{d\sigma_{\mathcal{U}_S}}{dT} = \frac{[g_{0e}^{\alpha\beta}(d)]^2}{\Lambda^{(4d-4)}}\,\frac{2^{(2d-6)}}{\pi E_\nu^2}(m_eT)^{(2d-3)}(T+2m_e)$$

For the Scalar Unparticle Case for $d < 1.3$ number of event rate increases for lower thresholds, therefore ***HPGe and ULEGe*** *data expected to give more sensitive results. However, for $d > 1.3$* ***CsI (Tl)*** *data is more sensitive to scalar unparticle.*





Since the cross sections vary as λ_0^4 the potential of placing more strict constants due to experimental sensitivities is only modest.

Vector Unparticle

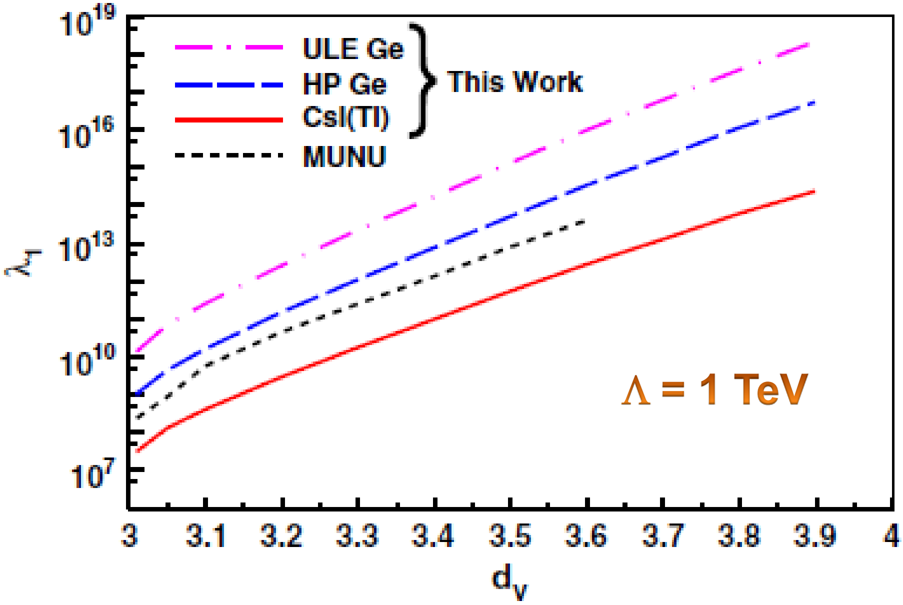
$$\frac{d\sigma_{\mathcal{U}_V}}{dT} = \frac{1}{\pi}\frac{[g_{1e}^{\alpha\beta}(d)]^2}{\Lambda^{(4d-4)}}2^{(2d-5)}(m_e)^{(2d-3)}(T)^{(2d-4)}\left[1+\left(1-\frac{T}{E_\nu}\right)^2-\frac{m_eT}{E_\nu^2}\right]$$

$$\frac{d\sigma_{\mathcal{U}_V-SM}}{dT} = \frac{\sqrt{2}G_F}{\pi}\frac{g_{1e}(d)}{\Lambda^{(2d-2)}}(2m_eT)^{(d-2)}m_e\left\{g_L+g_R\left(1-\frac{T}{E_\nu}\right)^2-\frac{(g_L+g_R)}{2}\frac{m_eT}{E_\nu^2}\right\}$$

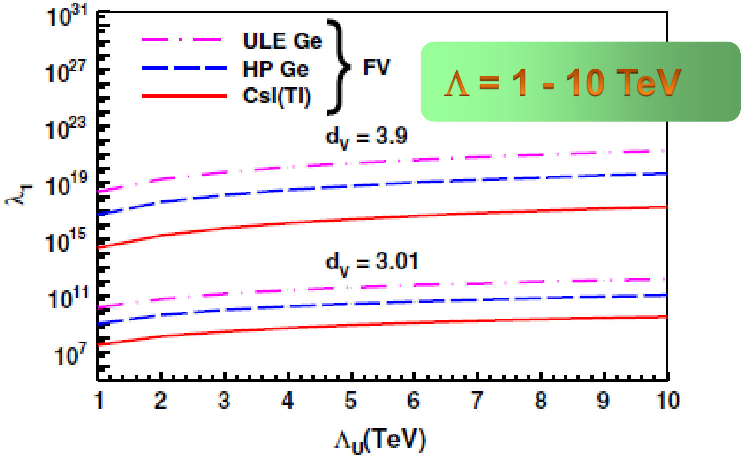
$d > 3$

B. Grinstein, K. A. Intriligator, and I. Z. Rothstein, Phys. Lett. B 662, 367 (2008)

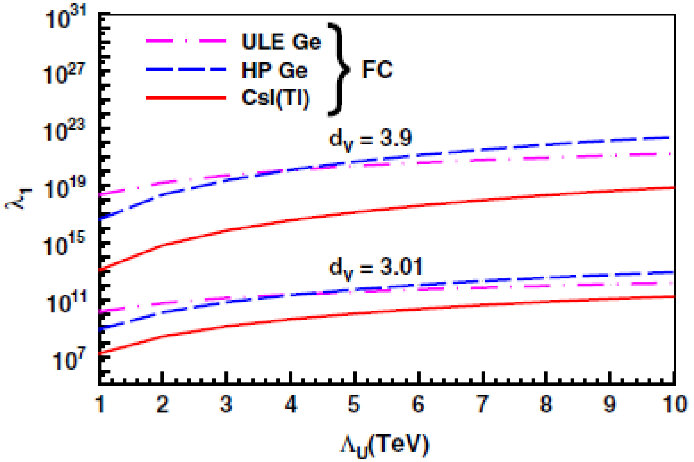
— *both FC and FV scenario are considered and analysed*



Λ = 1 TeV

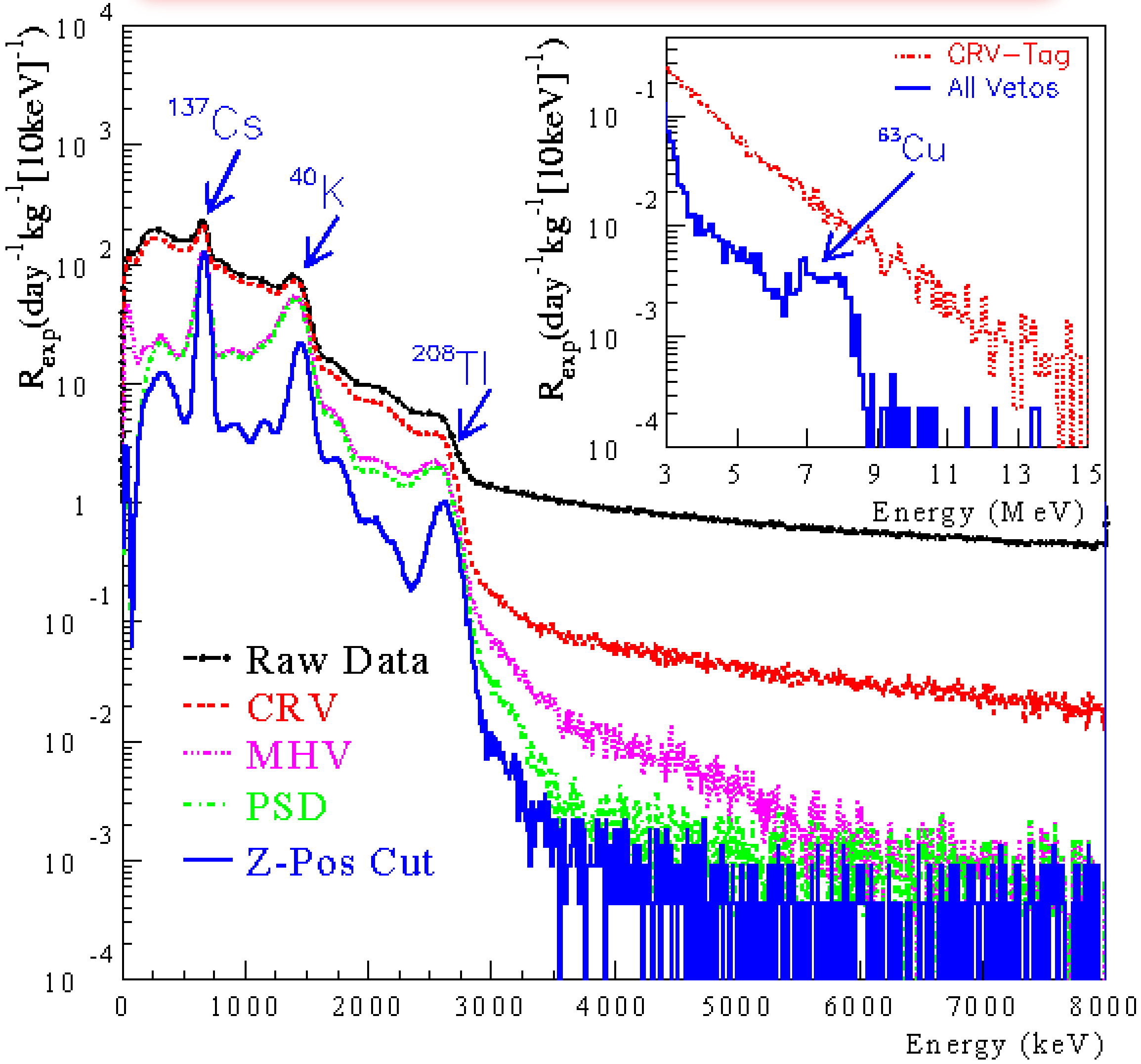


Λ = 1 - 10 TeV



Data Analysis: Event Selection

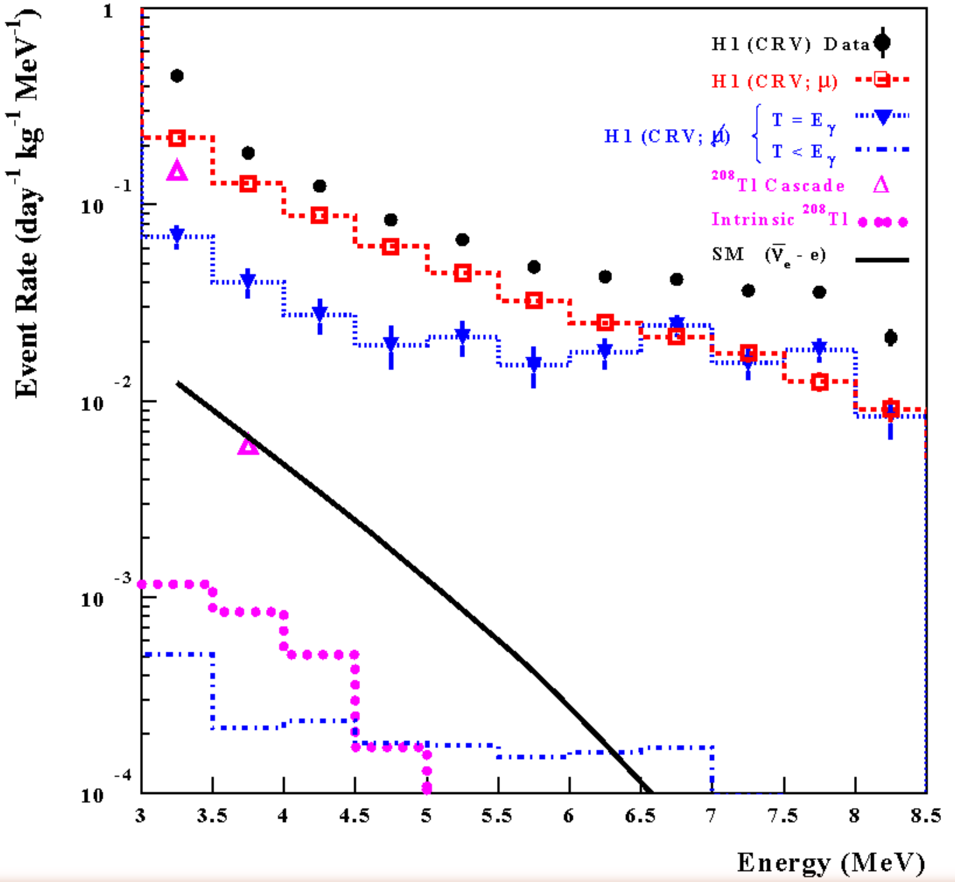
Reactor OFF



CUTS **(3 - 8 MeV)**	**Efficiencies** DAQ Live Time Eff. **~ 90%**
CRV	**92.7 %**
MHV	**99.9 %**
PSD	**~100 %**
Z-pos	**80%**
Total	**77.1 %**

$$\frac{S}{B} \cong \frac{1}{30} \text{ at } 3\,\mathrm{MeV}$$

Background Understanding & Suppression

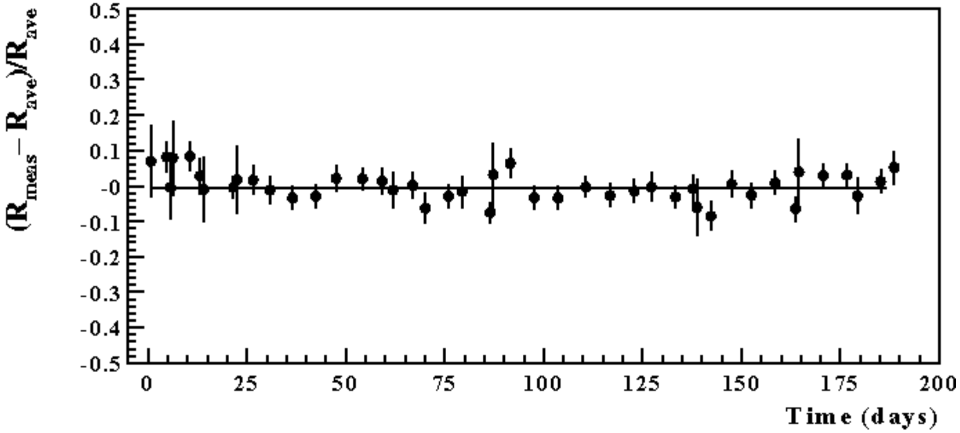


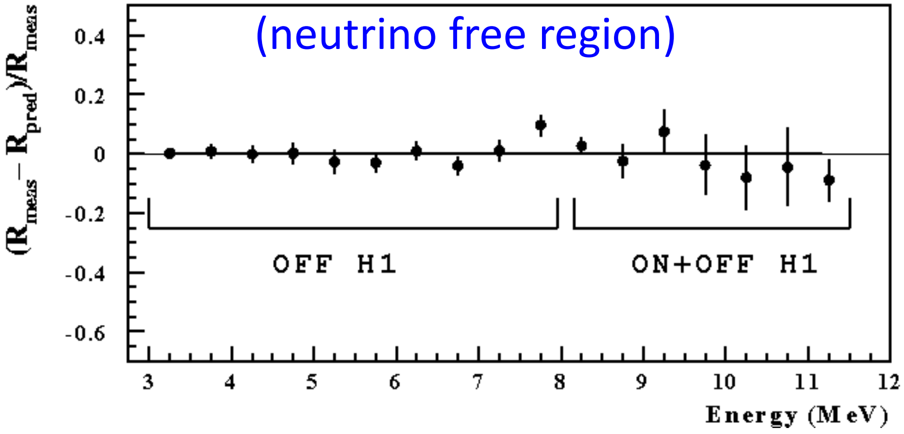
Combined ***BKG(SH)*** **from** ***three measurements*****:**

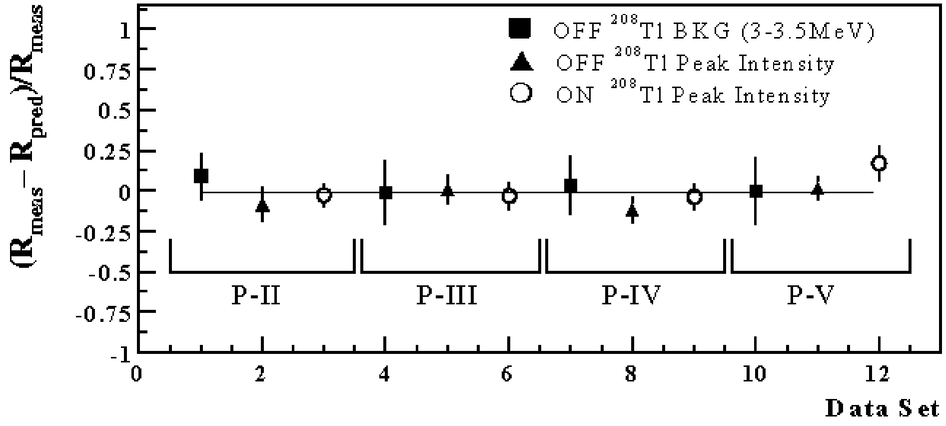
● Direct **Reactor OFF(SH)** spectra ⊕ Predicted **BKG(SH)** from **OFF(MH)**
⊕ Predicted **BKG(SH)** from **ON(MH)**

ν = ON(SH) – BKG(SH)

Systematic Uncertainties
Approach – Use non-ν events for demonstration


^{208}Tl Peak Events Stability


BKG – Pred.
(neutrino free region)


^{208}Tl (SH) Prediction

ON-OFF Stability < ~0.5%

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

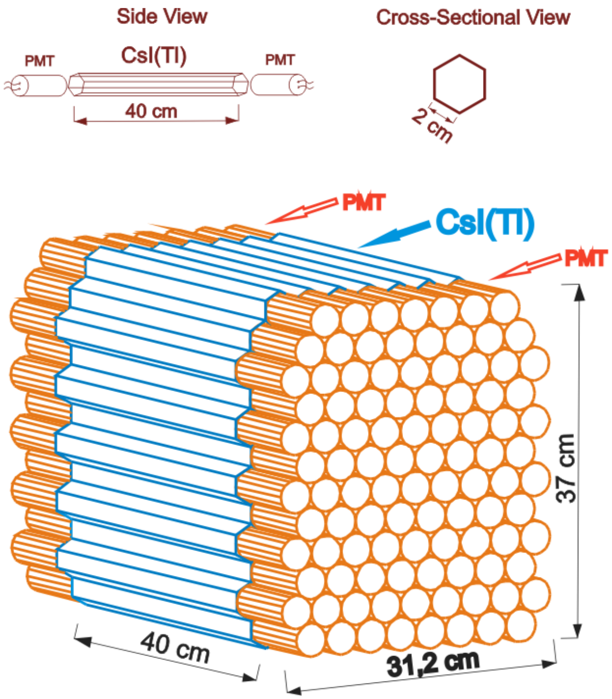
Cosmic Induced BKG(SH) Prediction < ~1 %

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

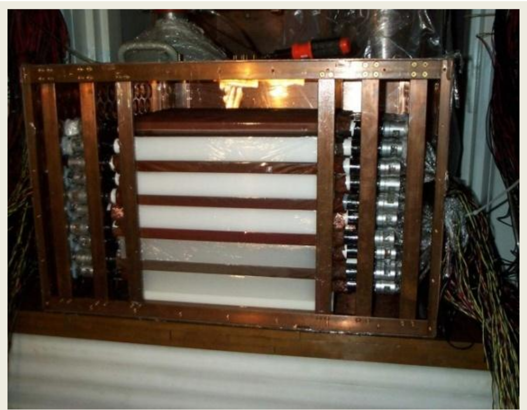
Tl-208 Induced BKG(SH) Prediction <~3%

- 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)**

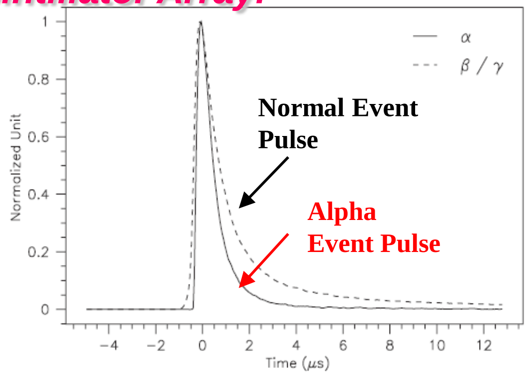
CsI Scintillating Crystal Array



CsI(Tl) Detector
9x12 Array 200 kg



Experimental Approach; CsI(Tl) Crystal Scintillator Array:



- proton free target

(suppress ν_e-p background)

- scale to ϑ (tons) design possible
- good energy resolution, **alpha & gamma Pulse Shape Discrimination (PSD)**
- allows measure **energy, position, multiplicity**
- more information for
  - **background understanding** & **suppression**

- ☐ **DAQ Threshold: 500 keV**
- ☐ **Analysis Threshold: 3 MeV**

(less ambient **background** & **reactor** ν_e spectra well known)

- ☐ Data Volume: **~ 29883 kg-day / 7369 kg-day Reactor ON/OFF**

- **Energy : Total Light Collection**
  - **σ (E) ~ 6% @ E>660 keV**
- **Z-position : The variation of Ratio**
  - **σ (Z) ~ 1.3 cm @ E>660 keV**

$$E \approx \sqrt{Q_L \times Q_R}$$

$$Z \approx (Q_L - Q_R)/(Q_L + Q_R)$$