# Studies of Coherent Neutrino Nucleus Elastic Scattering with the TEXONO Program

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**On behalf of TEXONO Collaboration**

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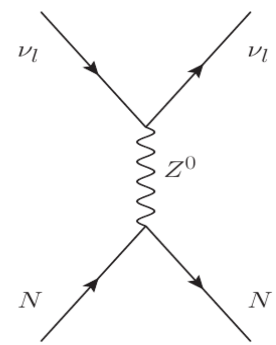
A neutrino interacts with a nucleus of neutron number "N" via exchange of Z - Boson.

$\nu + N \longrightarrow \nu + N$

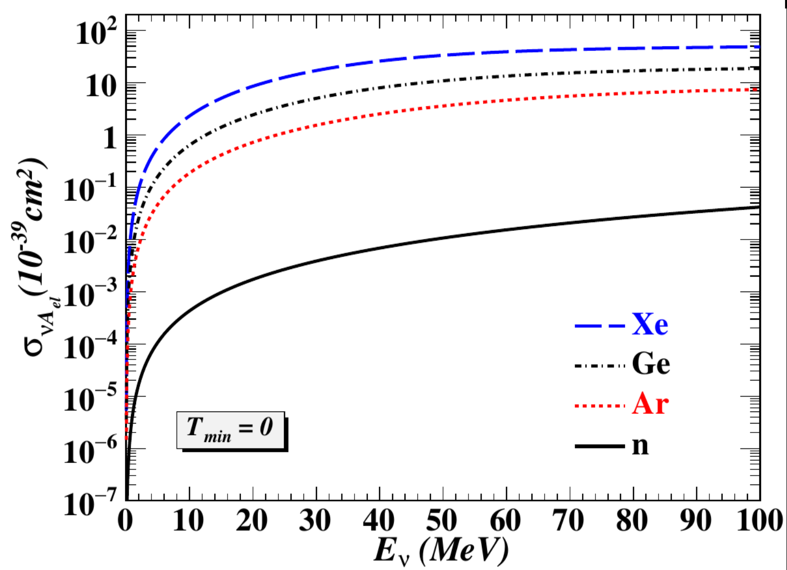



## Cross-Section of $\nu A_{el}$ :

$$\frac{d\sigma_{\nu A_{el}}}{dq^2}(q^2, E_\nu) = \frac{1}{2}\left[\frac{G_F^2}{4\pi}\right]\left[1 - \frac{q^2}{4E_\nu^2}\right][\varepsilon Z - N]^2 F(q^2)$$

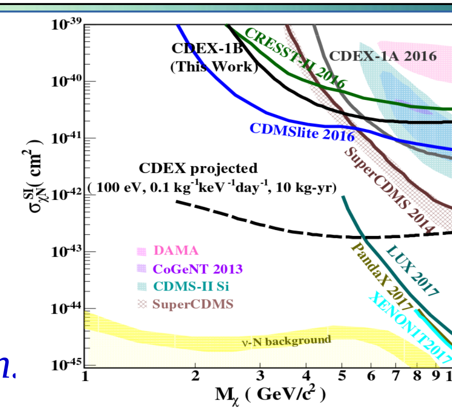
Where $G_F$ is fermi constant, $E_\nu$ is incident neutrino energy, Z(N) is Atomic(Neutron) number of nuclei and q is three momentum transfer.

$\varepsilon = 1 - 4\mathrm{Sin}^2\Theta_W = 0.045$, gives $\mathbf{N^2}$ dependence



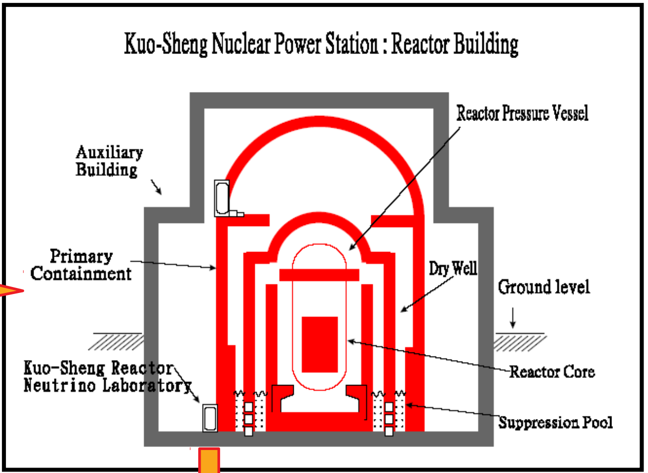

## Importance:

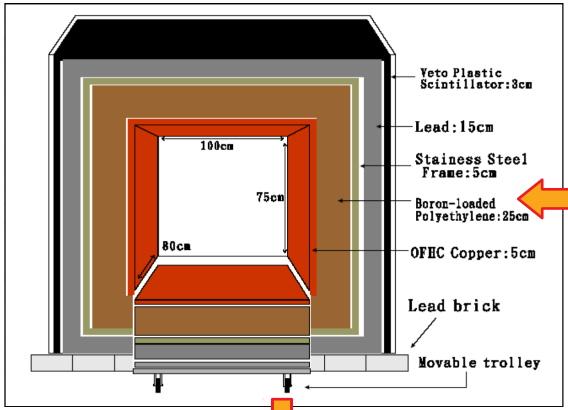
- *Important role in Supernova Explosions.*
- *Test of fundamental SM-electroweak interaction.*
- *In study of Beyond Standard Model Physics.*
- *Probe transition of Quantum Mechanical Coherency in electro-weak process.*
- *Potential use in Reactor monitoring* as a portable device.
- *$\nu A_{el}$ Scattering is important to study the irreducible background for Dark Matter Search.*



# TEXONO Collaboration

- **TEXONO (Taiwan EXperiment On NeutrinO)** Experiment is located at Kuo-Sheng Nuclear Power Plant -II on northern shore of Taiwan.
- **Theme:** Low Energy Neutrino Physics and Dark Matter Searches.
- Collaboration with Turkey, China and India.
- The reactor power of 2.9 GW gives $6.35\times10^{12}$ $cm^{-2}$ $s^{-1}$ electron anti-neutrinos at a distance of 28 m.
- Collaboration with CDEX Underground Dark-Matter Experinemt, China.





## p- PCGe

*[500g – 1 kg]*

$p^+$

$n^+$(~1mm Li diffused)


## n- PCGe

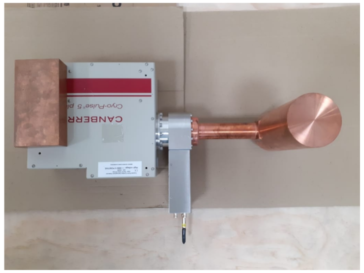
*[500 g]*

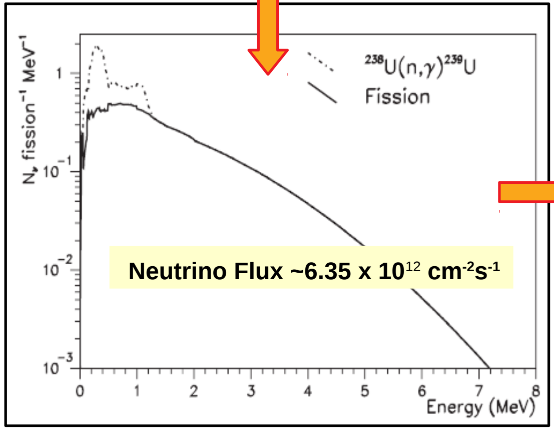
$n^+$

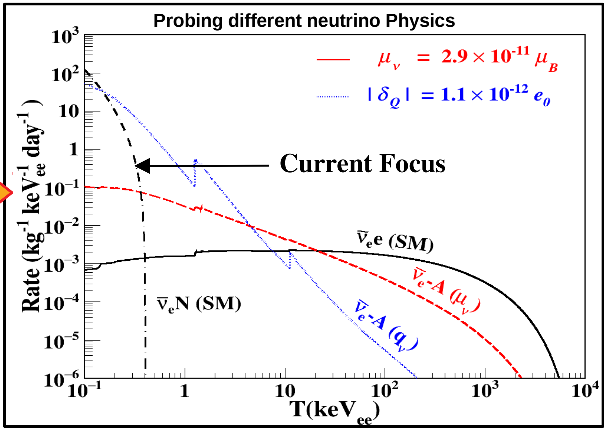
$p^+$(~0.5 μm Boron implanted)


**Electro-cooled Germanium Detector**

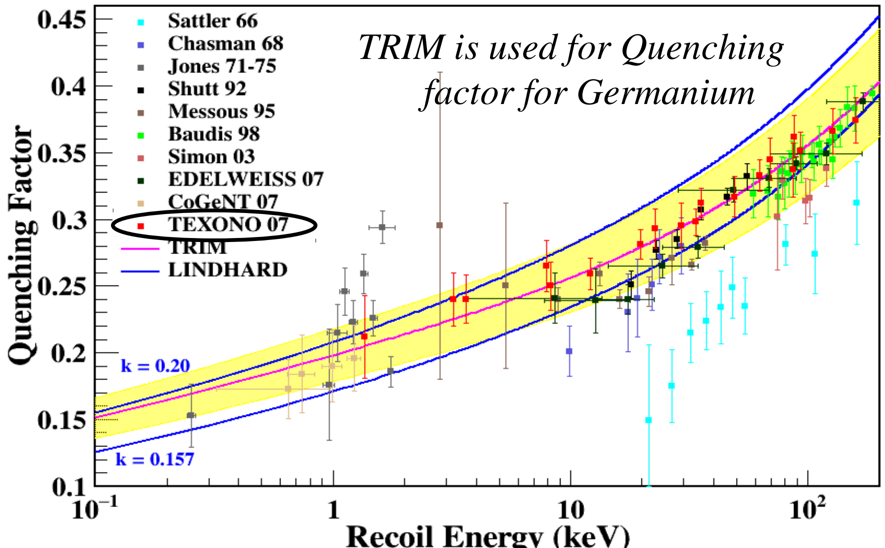
*# Thrd ~ 200 eV*

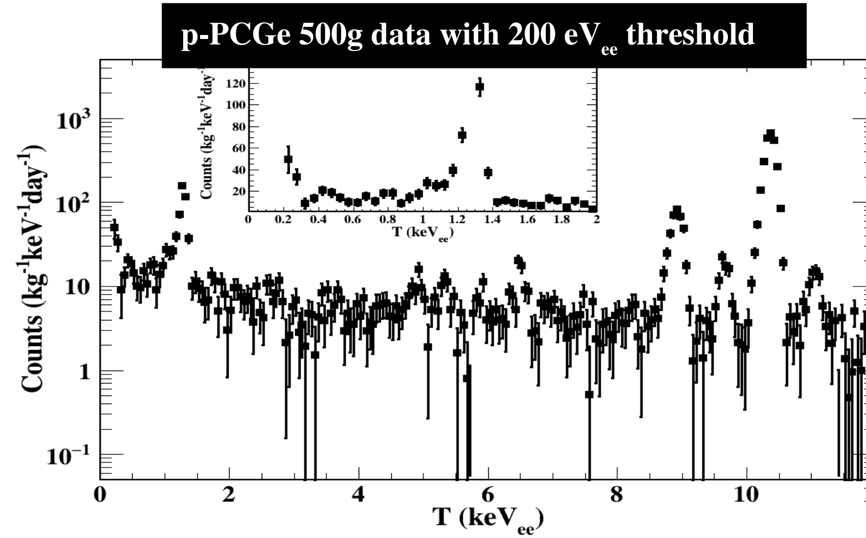


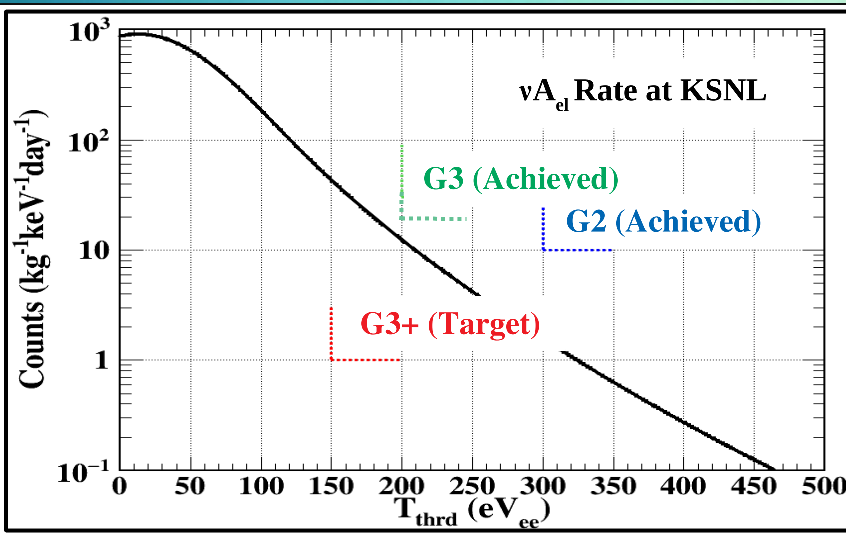


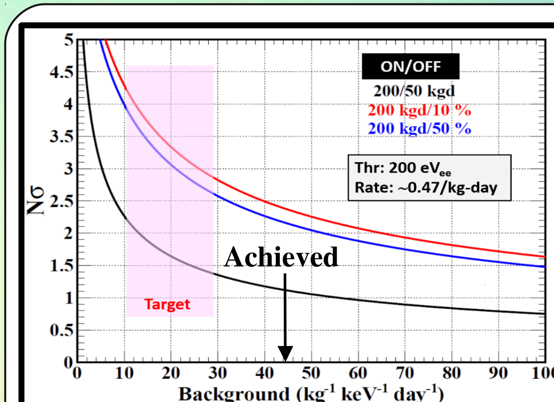
# $\nu A_{el}$ at KSNL with Reactor Neutrino..



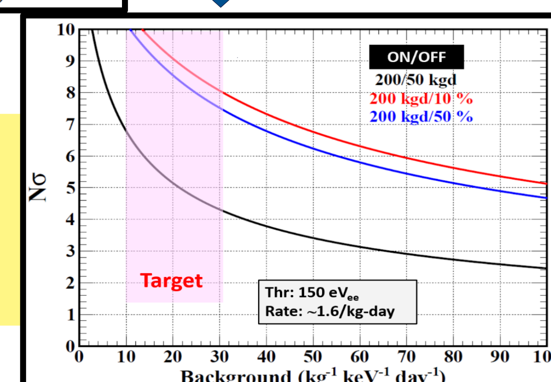




| Threshold | 300 eV | 200 eV | 150 eV | 100 eV |
|---|---|---|---|---|
| Differential (Cpkkd) | 0.8 | 8.3 | 27.3 | 109.5 |
| Integral (Cpkd) | 0.04 | 0.47 | 1.6 | 6.4 |




- Sensitivity of experiment w.r.t. different Reactor ON/OFF scenario is shown.
- G3 (500g, 200 eV) Data taken ON/OFF ~ >200/30 kg-days.
- Background in sub-keV region is <50 counts (kg$^{-1}$keV$^{-1}$day$^{-1}$)




- Current DAQ: G3+ (1450g).
- Power-plant Decommissioning: 2022-23.
- Different R&D are ongoing for achieving low energy threshold and less background.

# Coherency in $\nu A_{el}$ Scattering

*The differential cross-section of $\nu A_{el}$ in terms of many-body physics of the target nuclei can be written as:*

$$\left[\frac{d\sigma}{dq^2}(q^2, E_\nu)\right]_{\nu \mathrm{A}_{el}} = \frac{1}{2}\left[\frac{G_F^2}{4\pi}\right]\cdot\left[1 - \frac{q^2}{4{E_\nu}^2}\right]\cdot\Gamma(q^2)$$

The term $\boldsymbol{\Gamma(q^2)}$ have different description based on particular physics:

**A. Nuclear Physics:** $\Gamma_{NP}(q^2) = [\varepsilon Z F_Z(q^2) - N F_N(q^2)]^2$.

**B. Quantum Mechanical Coherency:** $\Gamma_{QM}(q^2) = [\varepsilon Z - N]^2 \alpha(q^2) + (\varepsilon^2 Z + N)[1 - \alpha(q^2)]$.

**C. Data-driven Description:** $\Gamma_{DATA}(q^2) = [\varepsilon Z - N]^2 \xi(q^2)$.

The formulation of degree of coherency α is described in ***Phys. Rev. D 93, 113006 (2016)*** gives the loss in coherency as $\boldsymbol{\alpha(q^2) \equiv \cos\varphi \in [0, 1]}$.

The term $\xi(q^2)$ is the cross-section suppression relative to the complete coherency condition.

$$\xi(q^2) \equiv \frac{(d\sigma/dq^2)_{\nu A_{el}}(\alpha)}{(d\sigma/dq^2)_{\nu A_{el}}(\alpha = 1)}$$

$$\xi(q^2) = \alpha(q^2) + [1 - \alpha(q^2)]\left[\frac{(\varepsilon^2 Z + N)}{(\varepsilon Z - N)^2}\right]$$

Quantum Mechanics Relation

⬅ $\xi(q^2)$ ➡

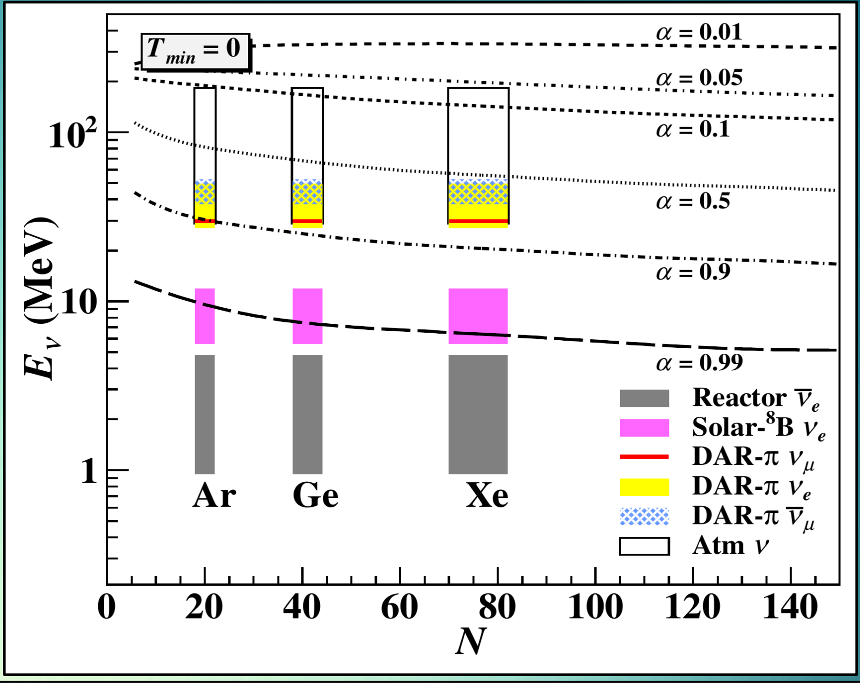
$$\xi(q^2) = \frac{\left[\varepsilon Z F_Z(q^2) - N F_N(q^2)\right]^2}{(\varepsilon Z - N)^2}$$

Nuclear Physics Relation

V. Sharma et al., arXiv:2010.06810v1 (2020); S. Kerman et al., PRD 93, 113006 (2016)

# Limits on Coherency at Measured cross-section

Expected coherency for three target nuclei [Ar,Ge,Xe] from different neutrino sources.



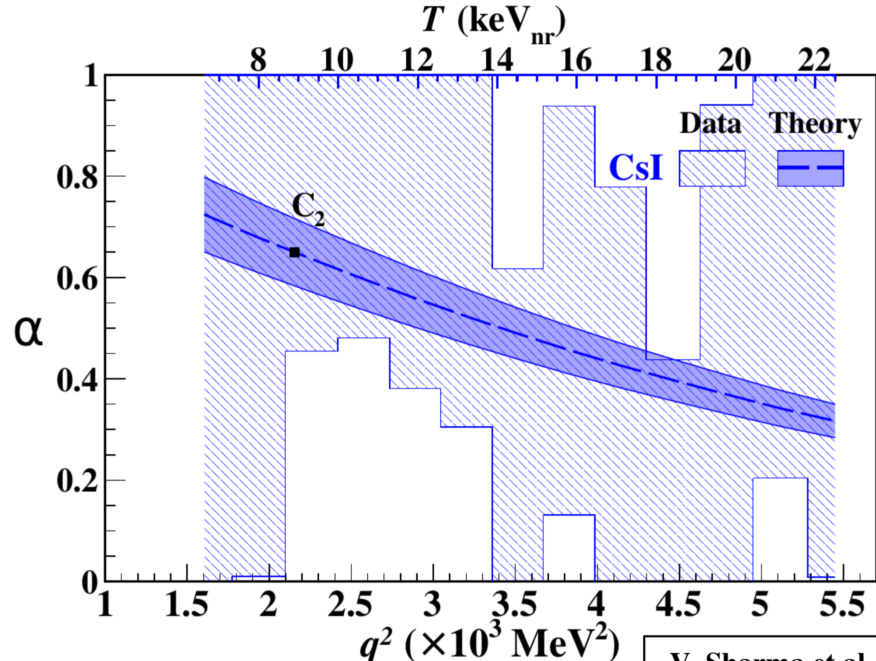

**Measurements from Data:**

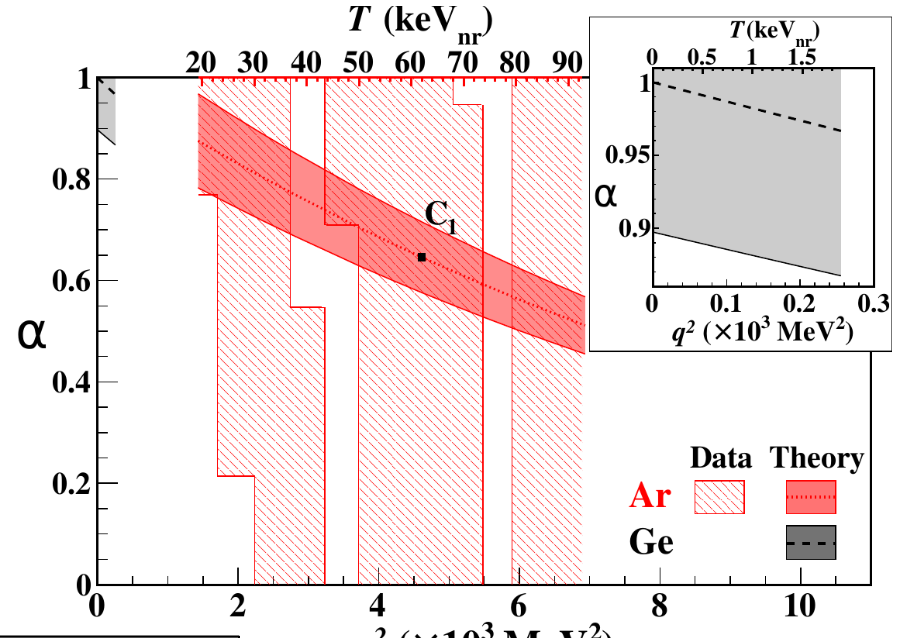
1. **CsI** (*J. I. Collar et al., PRD 100, 033003, 2019*)
2. **Ar** (*D. Akimov et al., arXiv:2003.106302, 2020*)

**Exclusion limit on p-value for CsI:**

**Complete Coherency @ $q^2 = 3.5\text{x}10^3$ MeV$^2$ $p$=0.023**

**Complete Decoherency @ $q^2 = 2.6\text{x}10^3$ MeV$^2$ $p$=0.013**




V. Sharma et al., arXiv:2010.06810v1 (2020)

# *Summary*

- Study of $\nu\mathbf{A}_{el}$ interaction has importance in the study of QM Coherency effects in Electroweak process, Astrophysical Processes, Irreducible background in Dark Matter searches, Neutron Density Distribution and BSM Physics.
- In TEXONO Experiment, we are currently studying $\nu\mathbf{A}_{el}$ with electro-cooled Germanium detectors at 200 $eV_{ee}$ threshold and intense R&D is ongoing to get the lower threshold with less ambient background.
- We formulate the Coherence effects in $\nu\mathbf{A}_{el}$ in the terms of Quantum Mechanics, Nuclear Physics, and Cross-Section Reduction and calculated $\alpha$ for measured CsI and Ar data from DAR-$\nu$ Source.

*Thank You*