Probing the Neutrino-Nucleus Elastic Scattering with Point Contact Germanium detectors and its Quantum-Mechanical Coherency Effects

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Outline

- ***TEXONO Facilities for νA_{el}.***
- ***νA_{el} activities at KSNL.***
- ***Coherency in νA_{el} scattering.***
- ***Challenges and Strategies.***
- ***Summary.***

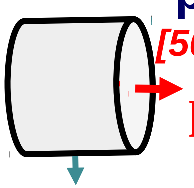
Magnificent CEνNS-2021

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 6.35×10^{12} cm^{-2} s^{-1} electron anti-neutrinos at a distance of 28 m.
- Collaboration with CDEX Underground Dark-Matter Experinemt, China.

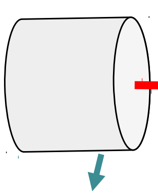
p- PCGe

[500g – 1 kg]



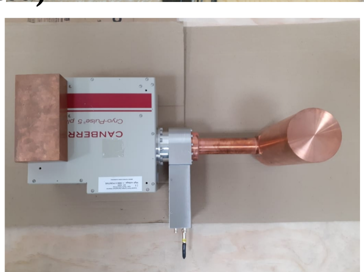
n- PCGe

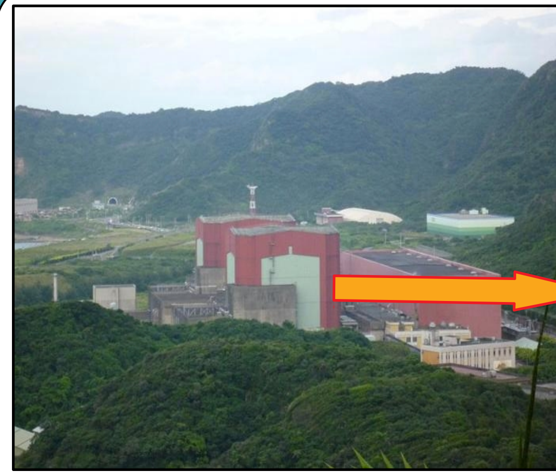
[500 g]

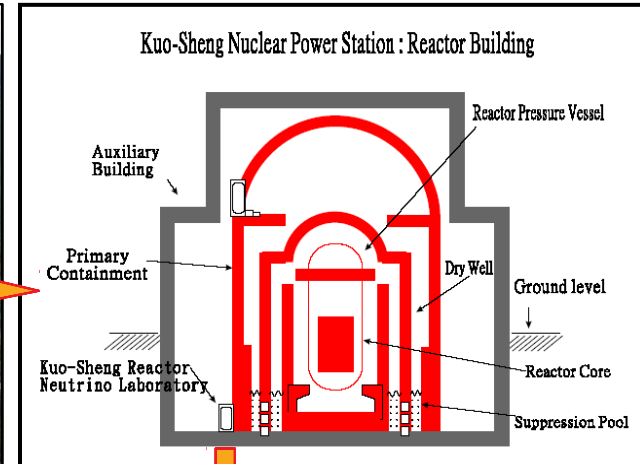


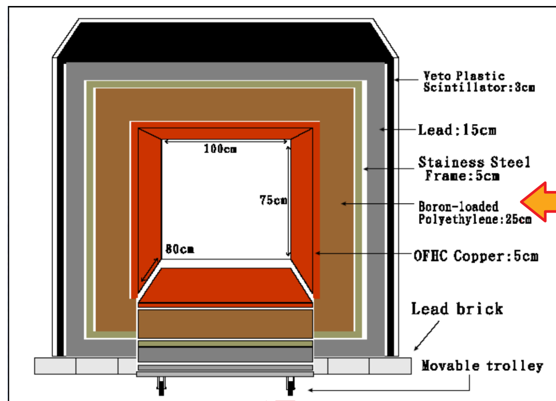
Electro-cooled Germanium Detector

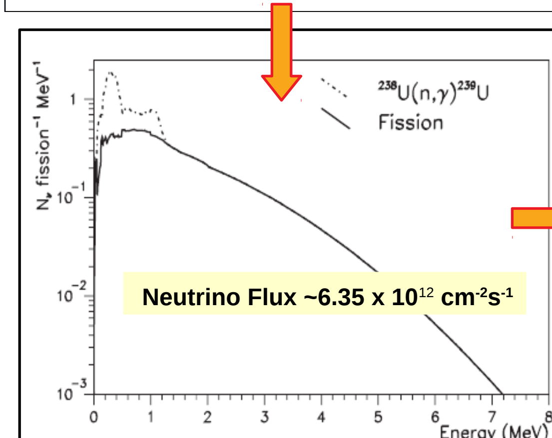
 # Thrd ~ 200 eV

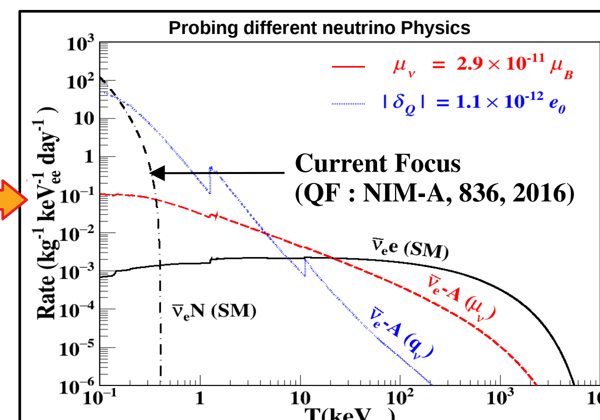








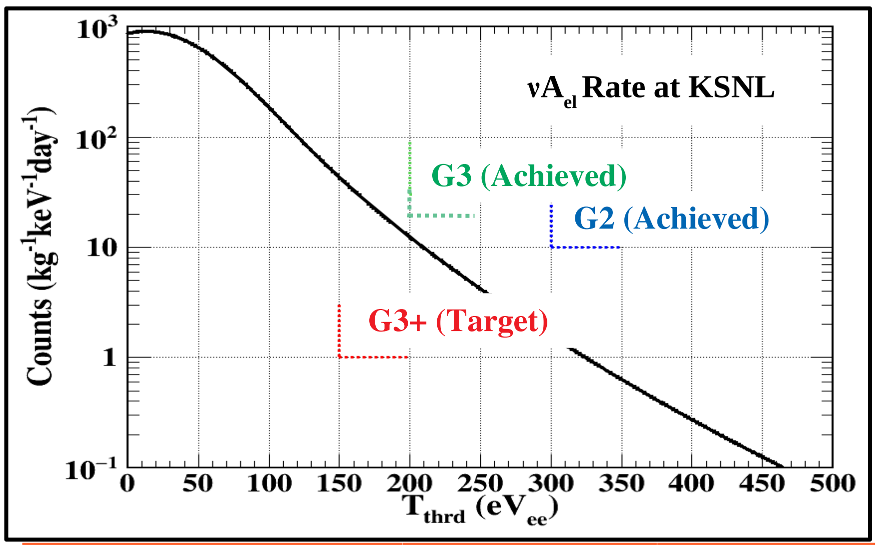




νA_{el} at KSNL with Reactor Neutrino..

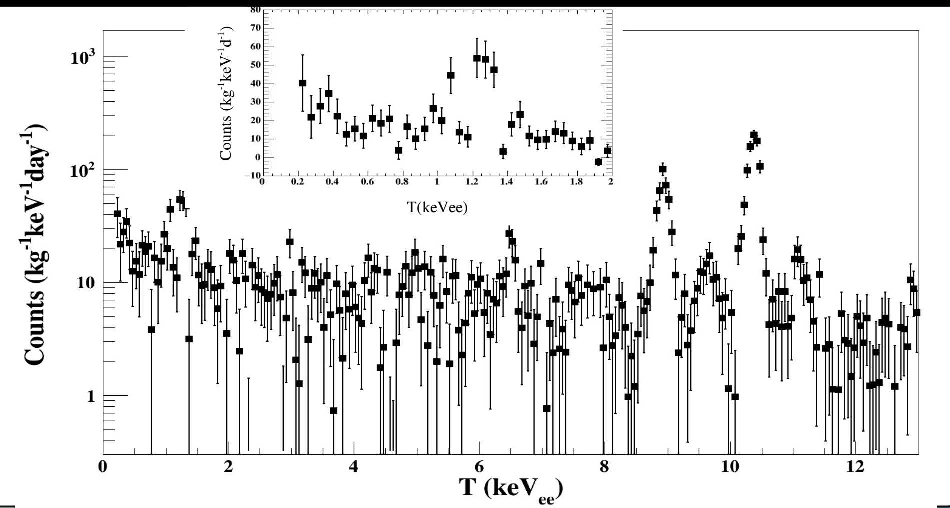
Hardware Performance

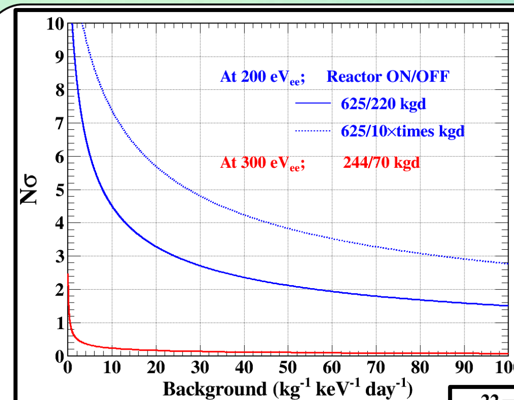
Detector	Pulsar FWHM (eV_{ee})	Noise Edge (eV_{ee})
p-PCGe 1500g (G3)	~70	200
p-PCGe 500 g (G3)	~70	200
p-PCGe 500g (G2)	~95	300
n-PCGe 500g (G2)	~117	300
p-PCGe 900 g (G2)	~100	300



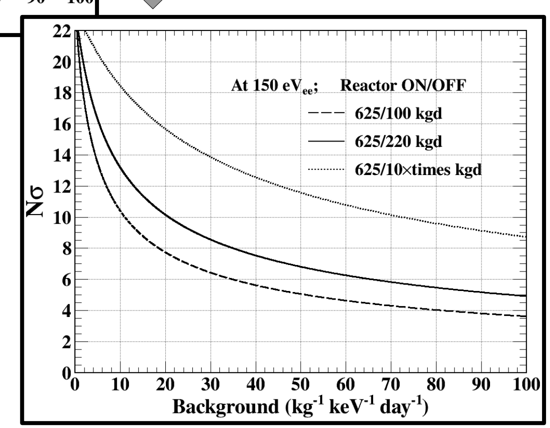
Data Size (Till Sept, 2021)	300 eV (G2)	200 eV (G3)
Reactor ON	244 kgd	625 kgd
Reactor OFF	70 kgd	220 kgd

Typical p-Ge 500g; 200 eV_{ee} Thrd; 15 kgd Data (Incomplete Analysis)





- Sensitivity of experiment w.r.t. different Reactor ON/OFF scenario is shown.
- G3 (500g, 200 eV) Data taken ON/OFF ~ >625/220 kg-days.
- Background in sub-keV region is <50 counts ($kg^{-1}keV^{-1}day^{-1}$)



- Current DAQ: G3+ (1450g).
- Power-plant Decommissioning: 2023.
- Data taking till end of 2025.
- Different R&D are ongoing for achieving low energy threshold and less background.

Coherency in νA_{el} Scattering

Differential cross-section of νA_{el} in terms of many-body physics of the target:

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

The degree of coherency α is a intuitive universal parametrization of the QM coherency (PRD-16). It is described by cosine of Averaged Phase Misalignment angle between nucleons (Φ) as $\alpha(q^2) \equiv \cos\Phi \in [0, 1]$.

The term $\Gamma(q^2)$ 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: $\Gamma_{QM}(q^2) = [\varepsilon Z - N]^2\alpha(q^2) + (\varepsilon^2 Z + N)[1-\alpha(q^2)]$.

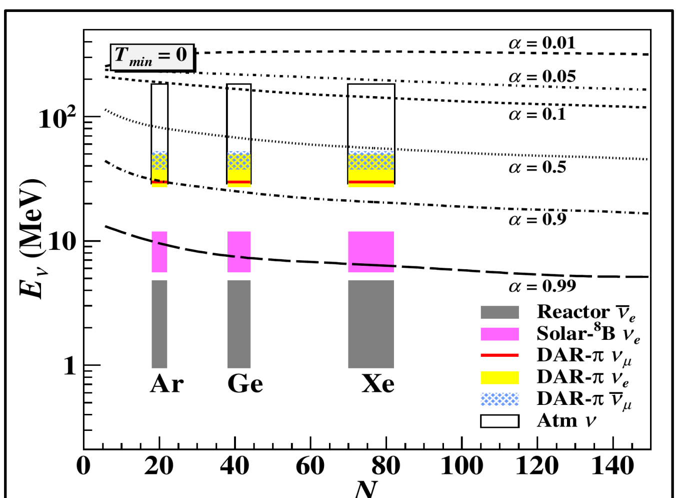
C. Data-driven Description: $\Gamma_{DATA}(q^2) = [\varepsilon Z - N]^2\xi(q^2)$.

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

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

Quantum Mechanics Relation — Nuclear Physics Relation

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



Measurements from Data:

1. **CsI** (*Science-17; PRD- 19; A. Konovalov: Magnificent-2020*)

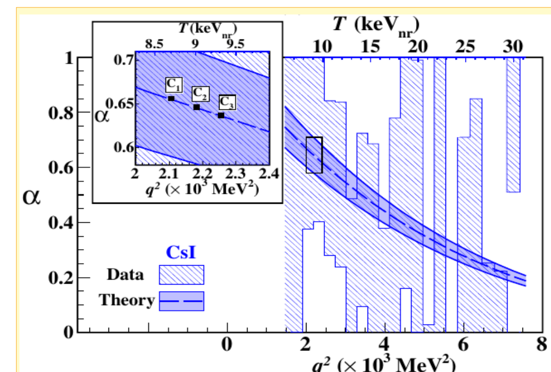
2. **Ar** (*PRL-21, and Supplementary Material*)

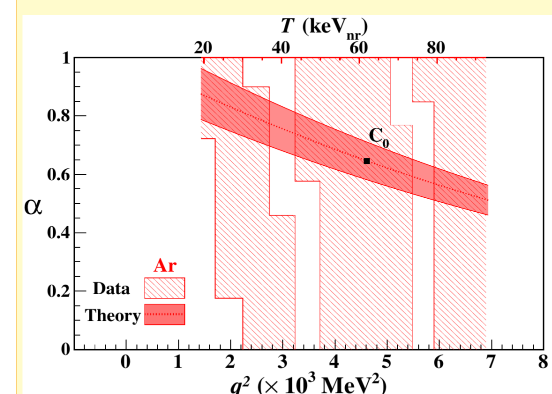
Most stringent constraints in the Region of Interest for CsI data:

Excluding Complete Coherency (α<1)
@ $q^2 = 3.1\times10^3$ MeV^2 p=0.004
=>Nuclear Many Body Effects

Excluding Complete Decoherency (α>0)
@ $q^2 = 2.3\times10^3$ MeV^2 p=0.016
=>QM Superpositions

In Electro-Weak process.





V. Sharma et al., PRD 103, 092002 (2021); S. Kerman, V. Sharma et al., PRD 93, 113006 (2016)

Challenges and Strategies

Challenges:

- Stabilities (hardware, ambient conditions, software parameters...) over long periods.
- Multi-detectors and experimental configurations.
- Effects of electronic noise near detector threshold.

Strategies :

- Use of in situ data from background channels (anti-Compton, cosmic-rays, surface events) for calibration and optimization and monitoring.
- Use of precision pulsar (adjustable rise-time) for high-statistics samples and for probing sub-noise-edge responses.

Summary

TEXONO Experiment @ KSNL

- Large data volume collected, as low as 200 eV_{ee} noise-edge.
- Challenges in analysis, with strategies defined.
- Detector hardware + sub-noise edge PSD R&D continues to achieve lower threshold.
- Reactor de-commissioned 2023; Permission of data taking till end of 2025.

QM Coherency in EW νA_{el} Process

- Universal parameter α corresponds to mis-alignment angle in QM superposition.
- Allowed ranges placed for COHERENT data => Verify QM & Nuclear effects in $\nu \mathbf{A}_{el}$

Thank You