Studies of Coherency Effects in Neutrino-Nucleus Elastic Scattering using PCGe Detectors

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On behalf of TEXONO Collaboration

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Outline

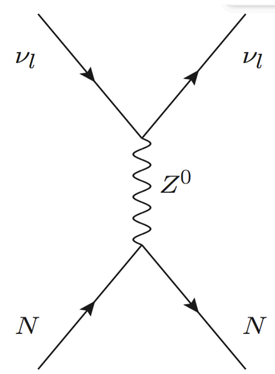
- *Introduction*
- *Status of νA_{el} @ KSNL*
- *Coherency in νA_{el} scattering*
- *Study of Quenching Factor*
- *Summary*

The Magnificent CEvNS workshop-2023, Munich, Germany

Introduction

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

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

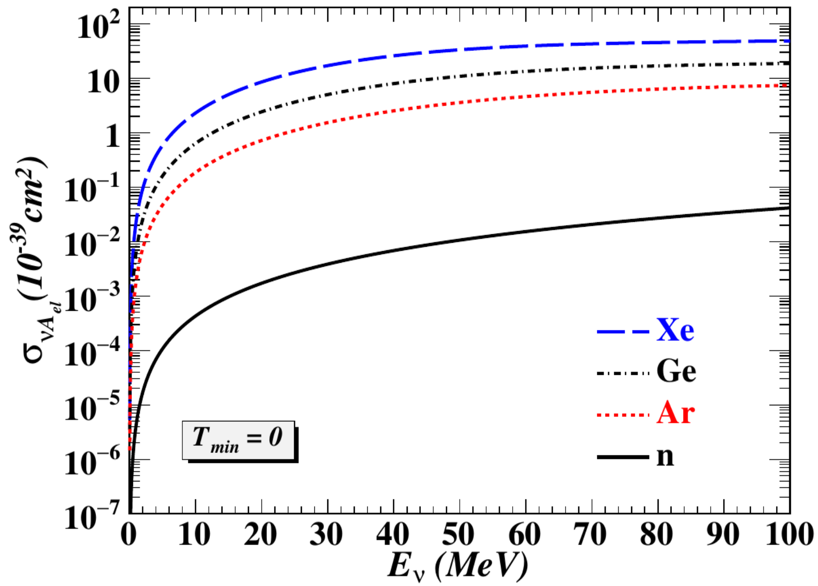


Cross-Section of νA_{el} :

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

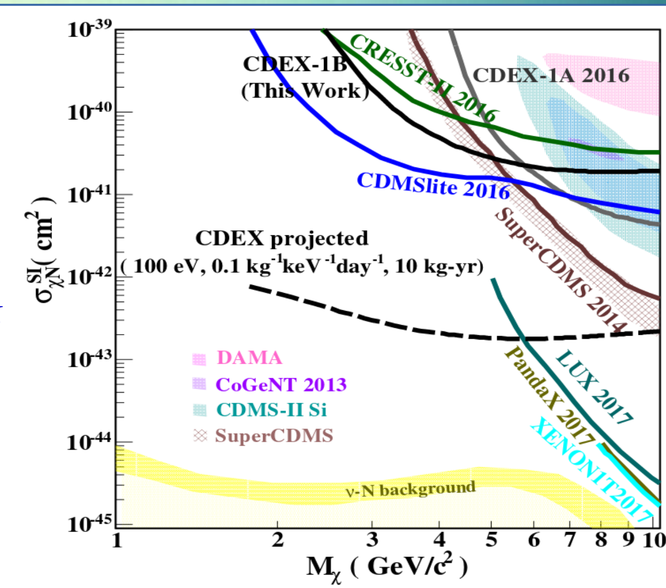
Where G_F is fermi constant, E_ν is incident neutrino energy, Z(N) is Atomic(Neutron) number of nuclei and q is three momentum transfer.

$\varepsilon = 1 - 4\mathrm{Sin}^2\Theta_W = 0.045$, 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.
- *νA_{el} Scattering is important to study the irreducible background for Dark Matter Search.*

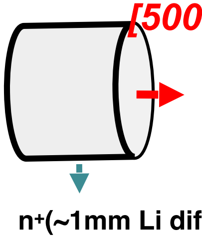


TEXONO Collaboration

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

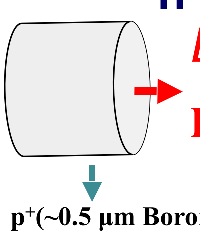
p- PCGe

[500g – 1.5 kg]

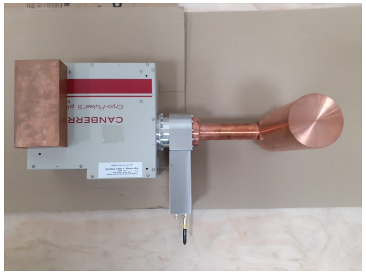


n- PCGe

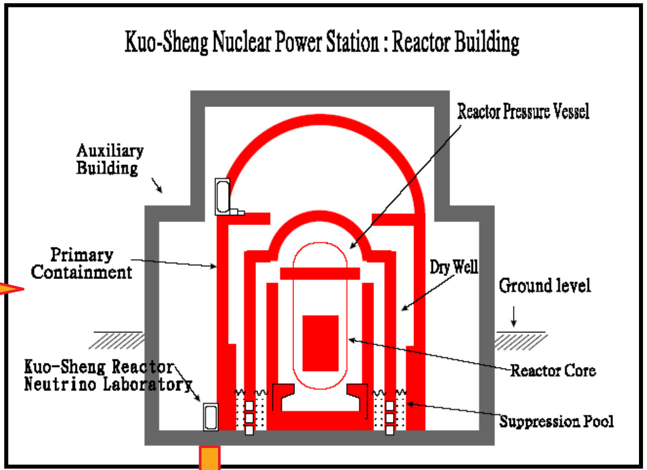
[500 g]

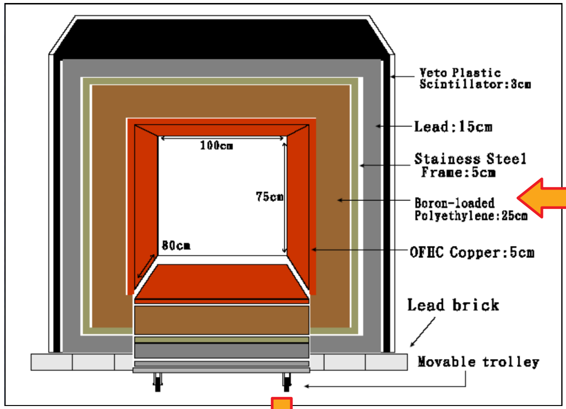


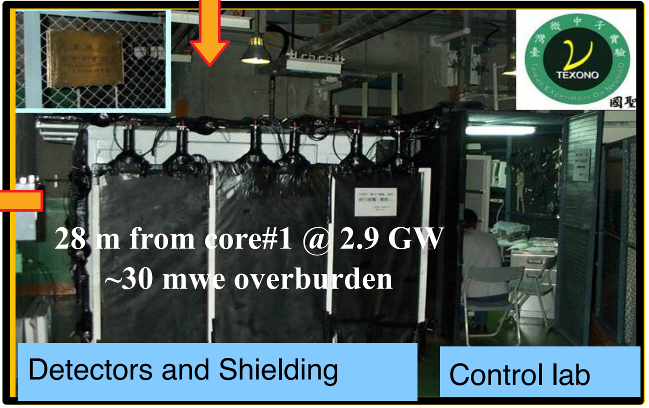
Electro-cooled Germanium Detector

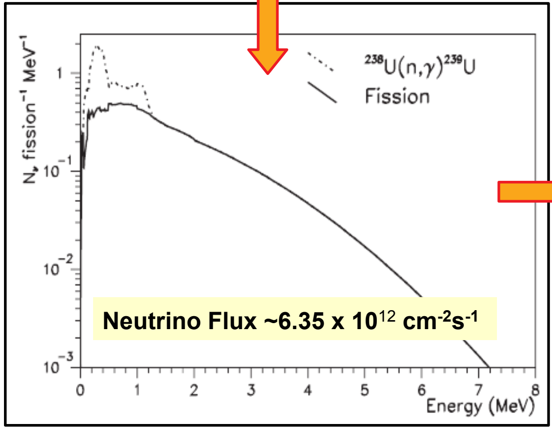


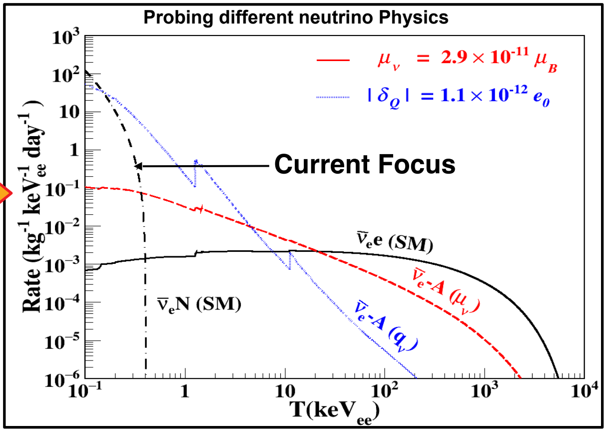
 # Thrd ~ 200 eV



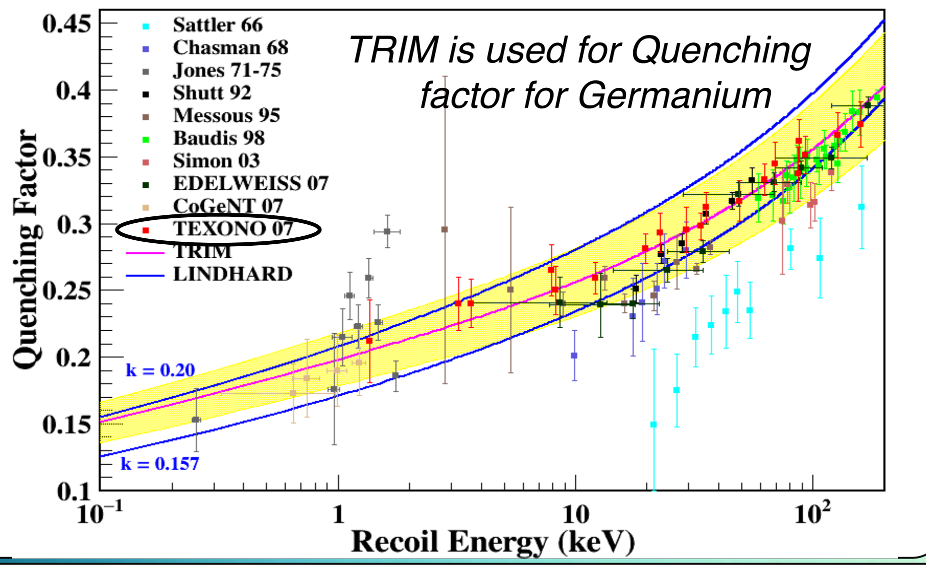


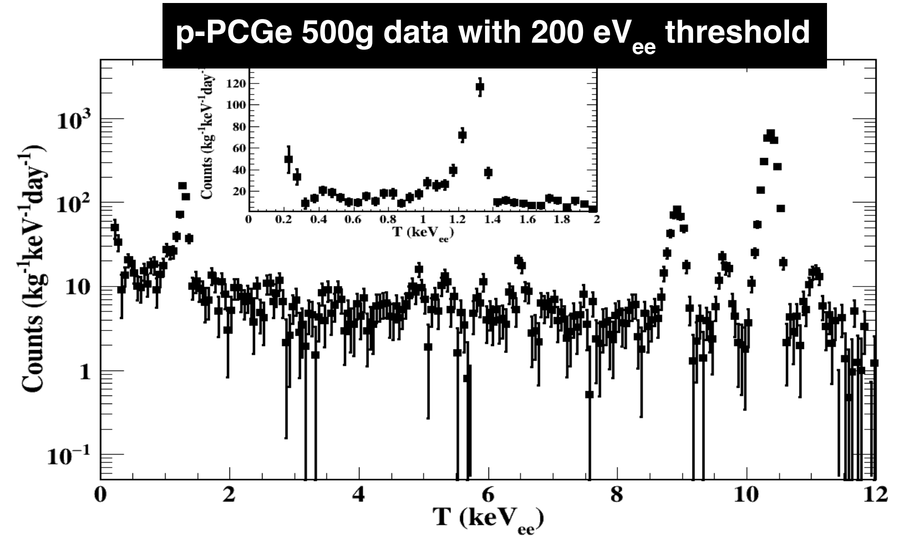


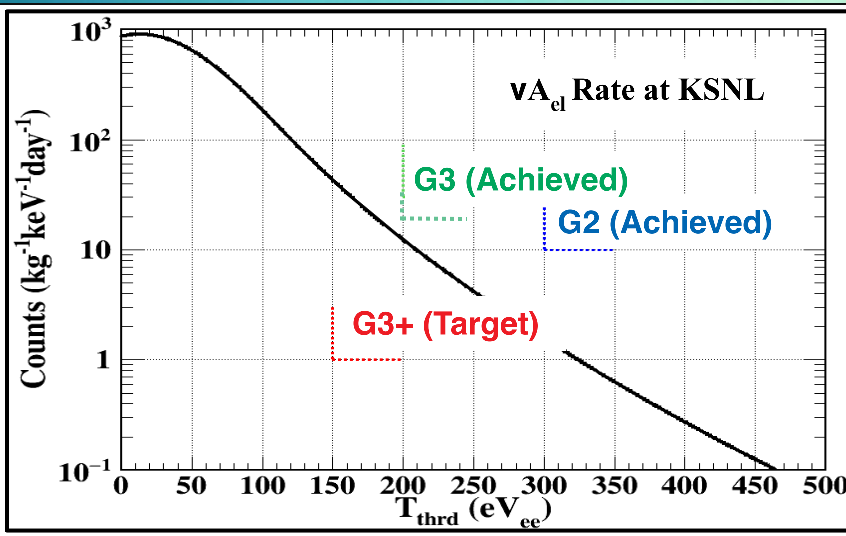




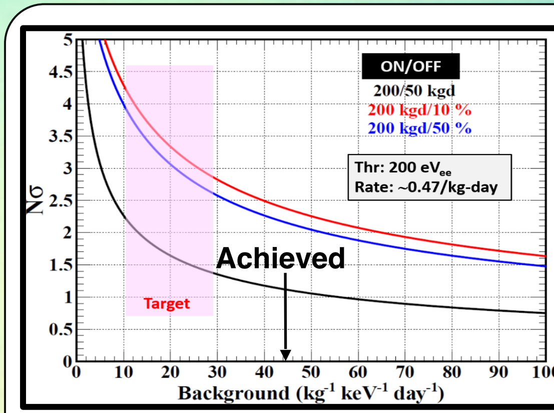
νA_{el} at KSNL with Reactor Neutrino..





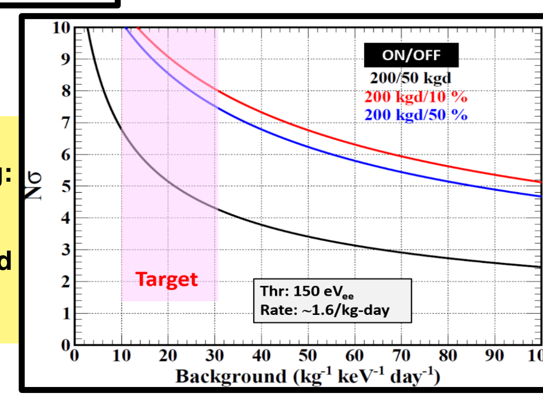


Threshold	300 eV	200 eV	150 eV	100 eV
Differential (Cpkkd)	0.8	8.3	27.3	109.5
Integral (Cpkd)	0.04	0.47	1.6	6.4



- Sensitivity of experiment w.r.t. different Reactor ON/OFF scenario is shown.
- G3 (500g, 200 eV) Data taken ON/OFF ~ >500/300 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.



Challenges and Strategies for νA_{el} at Reactors

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 optimisation and monitoring.
- Use of precision pulsar (adjustable rise-time) for high-statistics samples and for probing sub-noise-edge responses.

Coherency in νA_{el} Scattering

The differential cross-section of νA_{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 $\Gamma(q^2)$ 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 **$\alpha(q^2) \equiv \cos\phi \in [0, 1]$**.

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

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

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

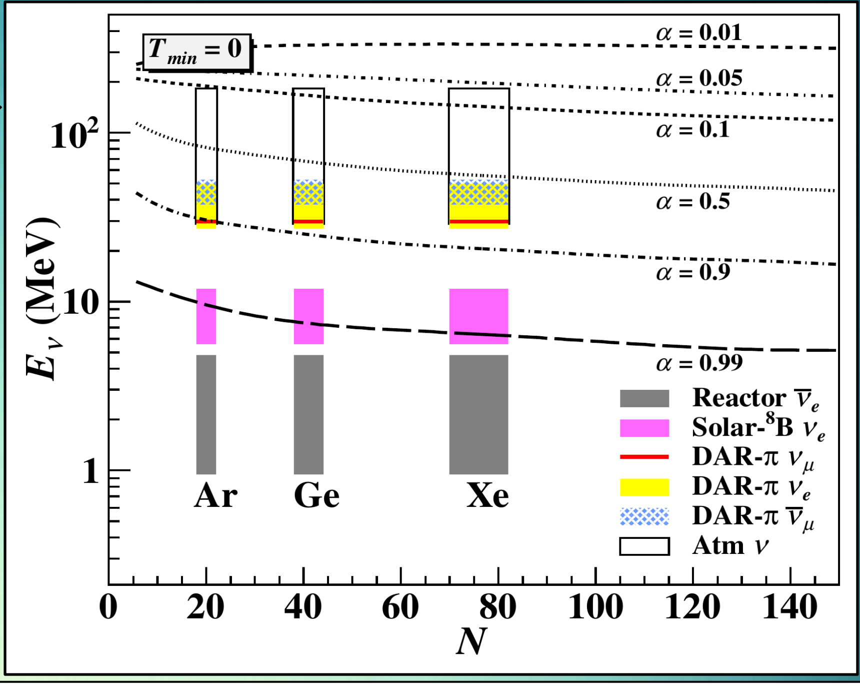
Quantum Mechanics Relation ⟵ $\xi(q^2)$ ⟶ **Nuclear Physics Relation**

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

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

Coherency Limits on COHERENT Measurement

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



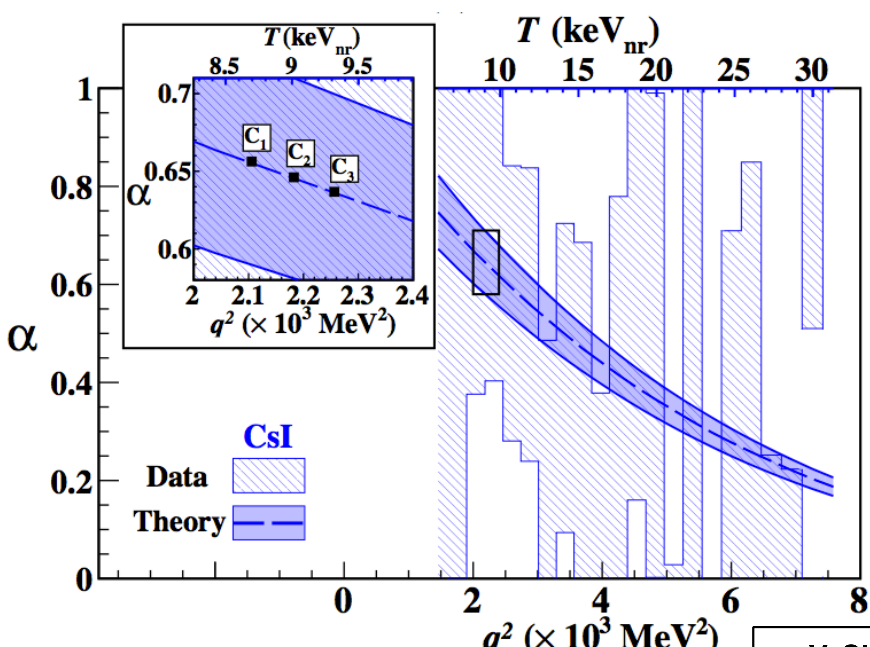
Measurements from Data:

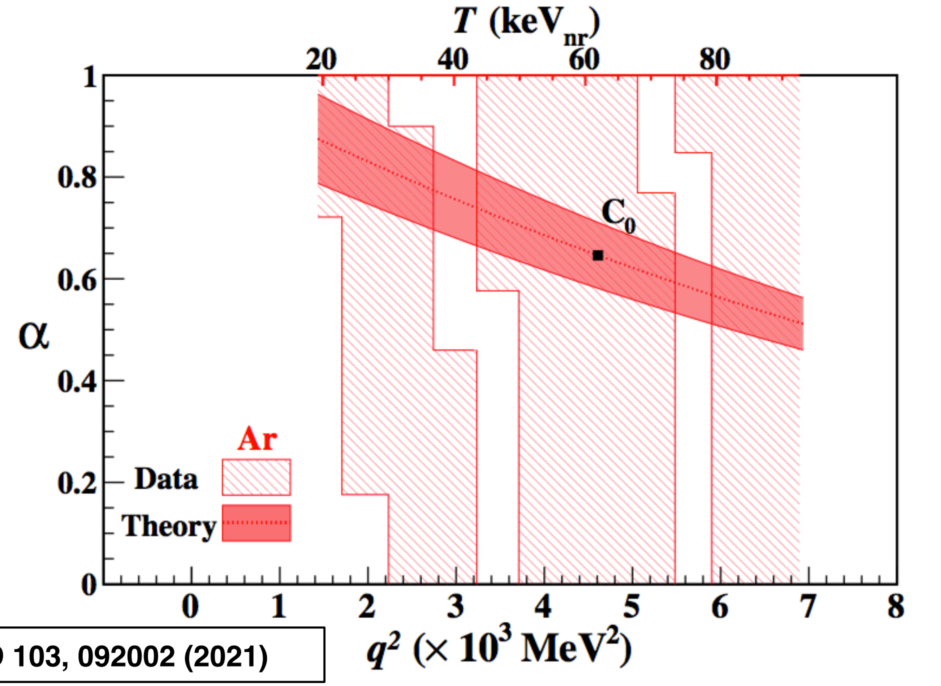
1. **CsI** (*J. I. Collar et al., PRD 100, 033003, 2019*)
2. **Ar** (*D. Akimov et al., PRL 126, 012002 (2021)*)

Exclusion limit on p-value for CsI:

Complete Coherency @ $q^2 = 3.1\text{x}10^3$ MeV^2 p=0.004

Complete Decoherency @ $q^2 = 2.3\text{x}10^3$ MeV^2 p=0.016





V. Sharma et al., PRD 103, 092002 (2021)

Constraints on Cross-section

Standard Lindhard Quenching factor → $\frac{kg(\varepsilon)}{1+kg(\varepsilon)}$

where g(ε) and ε are given by,

$$g(\varepsilon) = 3\varepsilon^{0.15} + 0.7\varepsilon^{0.6} + \varepsilon$$

$$\varepsilon \equiv E\frac{a}{2Z^2e^2}$$

Physical Review D 91, 083509 (2015)

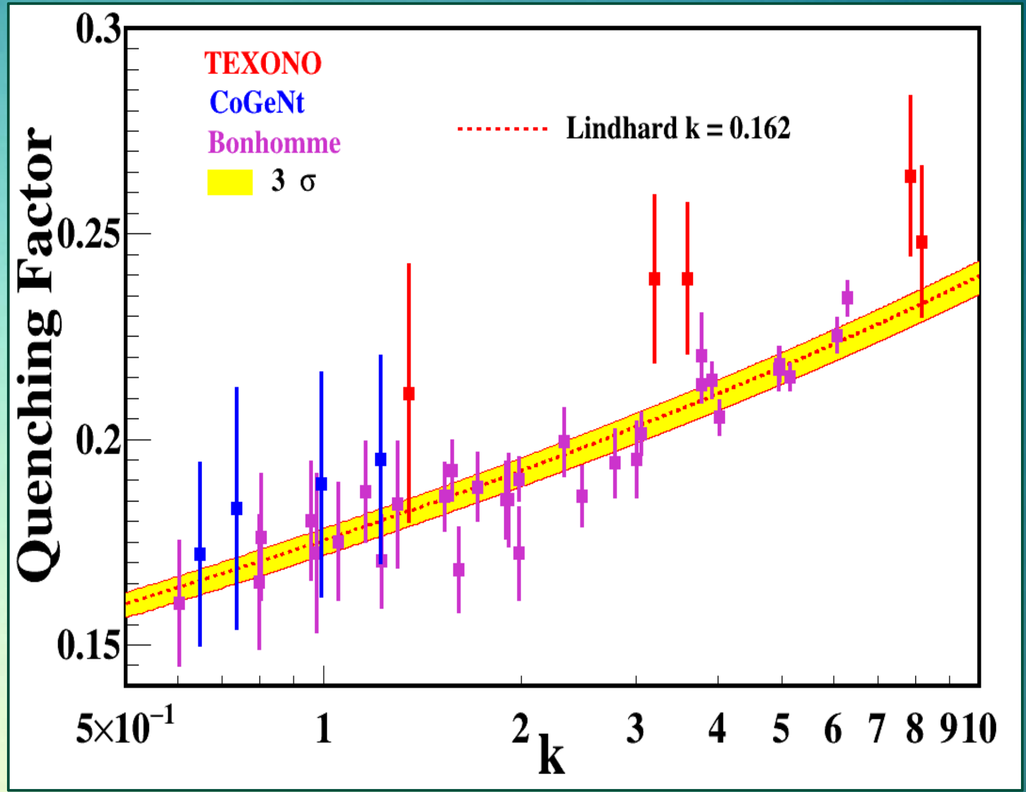
Physical Review D 106, 031702 (2022)

➢For ***quenching nuclear recoil decreased by ~O(10) in region of interest*** Suggesting the importance in νA_{el}

❒Experimental Data fit for Standard Lindhard Model

❒***Best fit is for k = 0.162***

❒***3σ*** allowed region ***[0.158,0.165]***

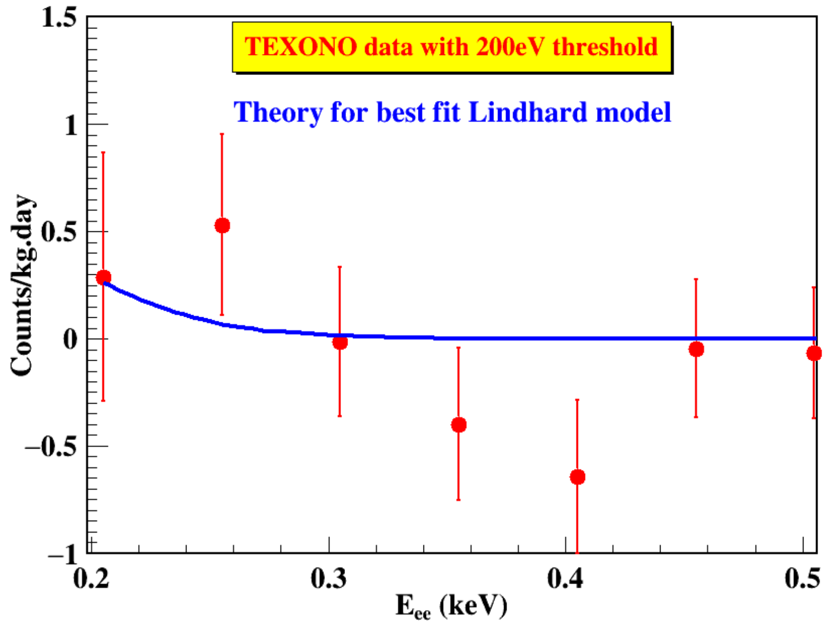


NIM A836 (2016) 67-82

C.E. Aalseth et al., PRL106, 131301 (2011)

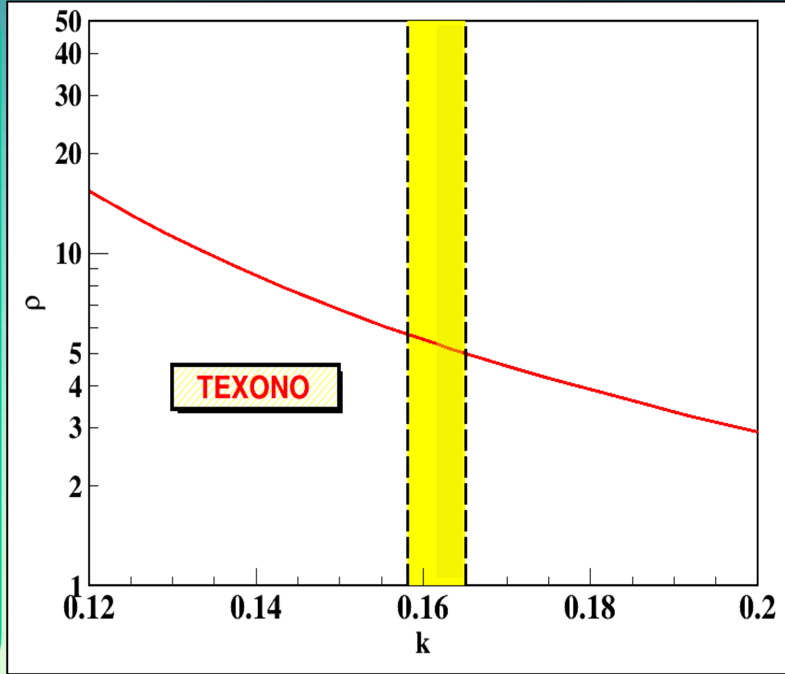
Eur. Phys. J. C (2022) 82:815

Preliminary Results in νA_{el}



TEXONO: The analysis threshold @ $200eV_{ee}$

Theory line is for the best fit k from QF measurement



Experiment	Flux ($\times 10^{12} cm^{-2}s^{-1}$)	Detector mass	Data Size ON(OFF) kg.day	Resolution FWHM (eV)
TEXONO	6.3	1(1.5kg) 1(.5kg)	203(33)	70

Data available

580 kg-day ON data

700 kg-day OFF data

Achieved analysis Threshold is 200 eV

Target: 150 eV

- ***ρ estimate the strength of signal times the standard model prediction***
- Shaded region → ***3σ allowed*** for ***k*** from Quenching factor measurement data
- ***TEXONO is more sensitive experiments with 90% CL upper limit*** in the most sensitive standard Lindhard "***k***"

Summary

TEXONO Experiment @ KSNL

- Large data volume collected, as low as 200 eV_{ee} noise-edge.
- Challenges in analysis, with strategies defined. Sub-noise edge PSD, R&D continues to achieve lower (~150 eV_{ee}) threshold.
- New detector characterisation and commissioning for Dark Matter studies.
- Reactor de-commissioned 2023; Permission of data taking till end of 2025; Looking for possibility of the new Reactor site.

Coherency and Quenching in 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 νA_{el}
- The detailed understanding of quenching factor has importance in the study of νA_{el} process.

Thank You