New Limits on the *Coherent Neutrino-Nucleus Elastic Scattering Cross Section* at the Kuo-Sheng Reactor-Neutrino Laboratory

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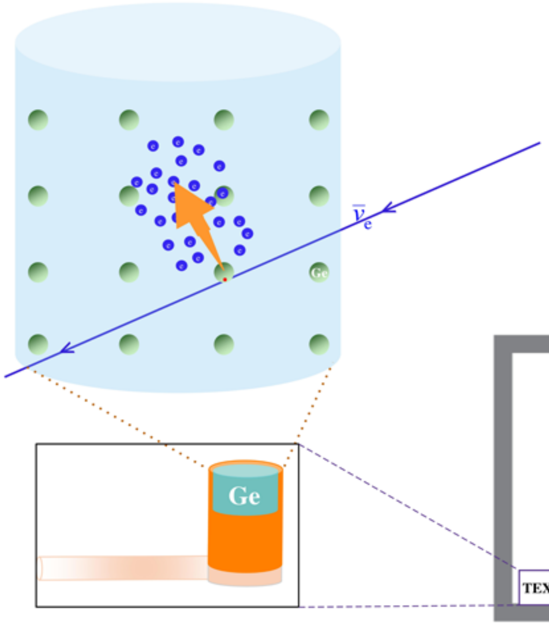
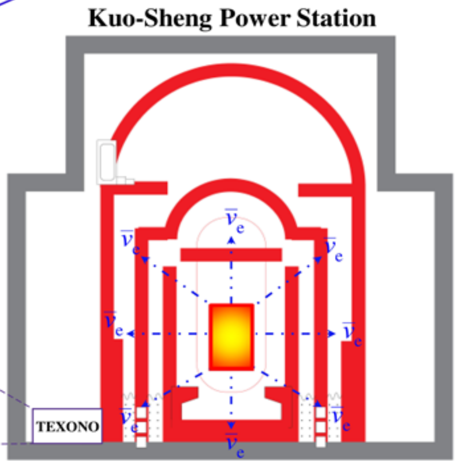
[On behalf of the TEXONO Collaboration]

Based on: *Phys. Rev. Lett. 134, 121802 (2025)*





Introduction to CνA$_{el}$

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

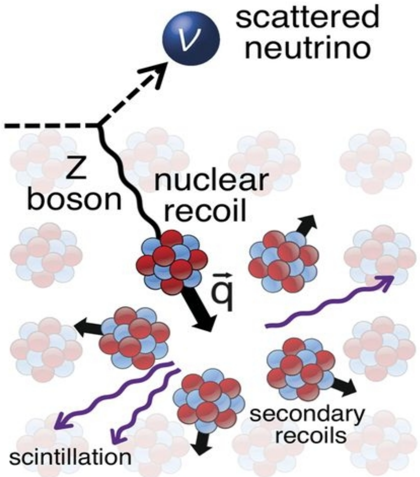
Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, ...
(Received 15 October 1973; revised manuscript received 19 November 1973)

1st Proposal [Theory]

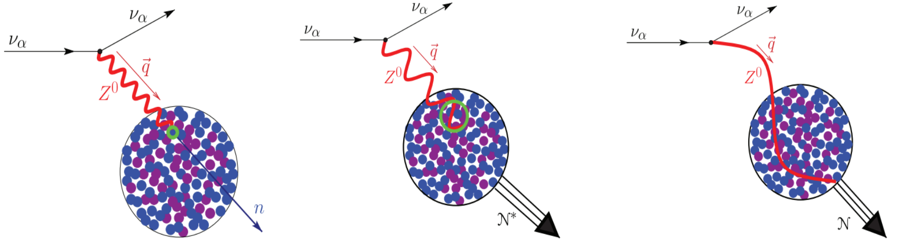
- **Proposed right after the discovery of Neutral Current – D. Z. Freedman [1974]**
- **Signature → Nuclear Recoil < $\mathcal{O}(1)$(keV)**
- **ν + N(A,Z) → ν + N(A,Z)**
- **Coherent:** ***Outgoing nucleon wave-functions are in phase*** **[$E_\nu < \mathcal{O}(10)$MeV]**
- **Elastic:** ***Target remains in the same energy state***

$$\frac{d\sigma_{C\nu A_{el}}}{dT} = \frac{G_F^2}{\pi} m_A \mathcal{Q}_W^2 \left(1 - \frac{m_A T_A}{2E_\nu^2}\right) \mathcal{F}^2(T_A)$$

$$\mathcal{Q}_W = g_V^p Z + g_V^n N = \left(\frac{1}{2} - 2\sin^2\theta_W\right) Z - \frac{1}{2} N$$

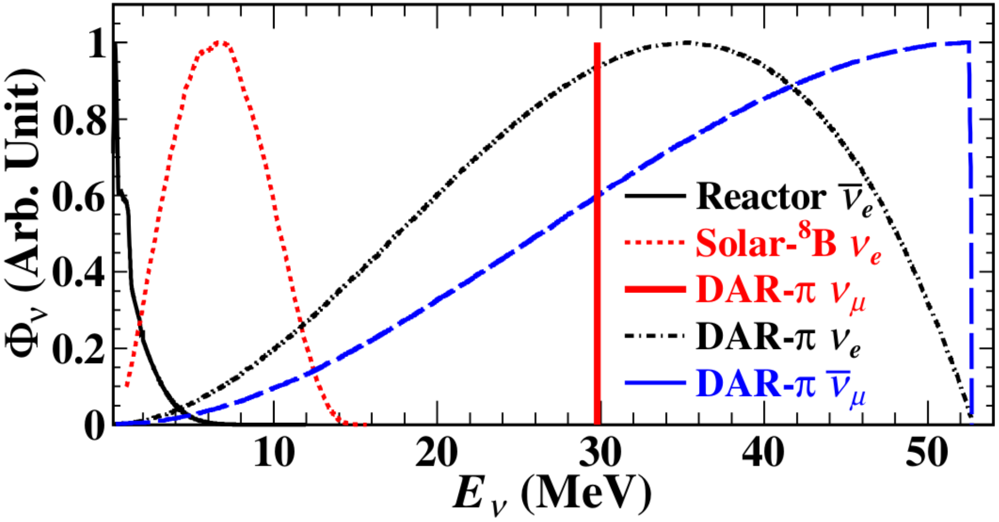


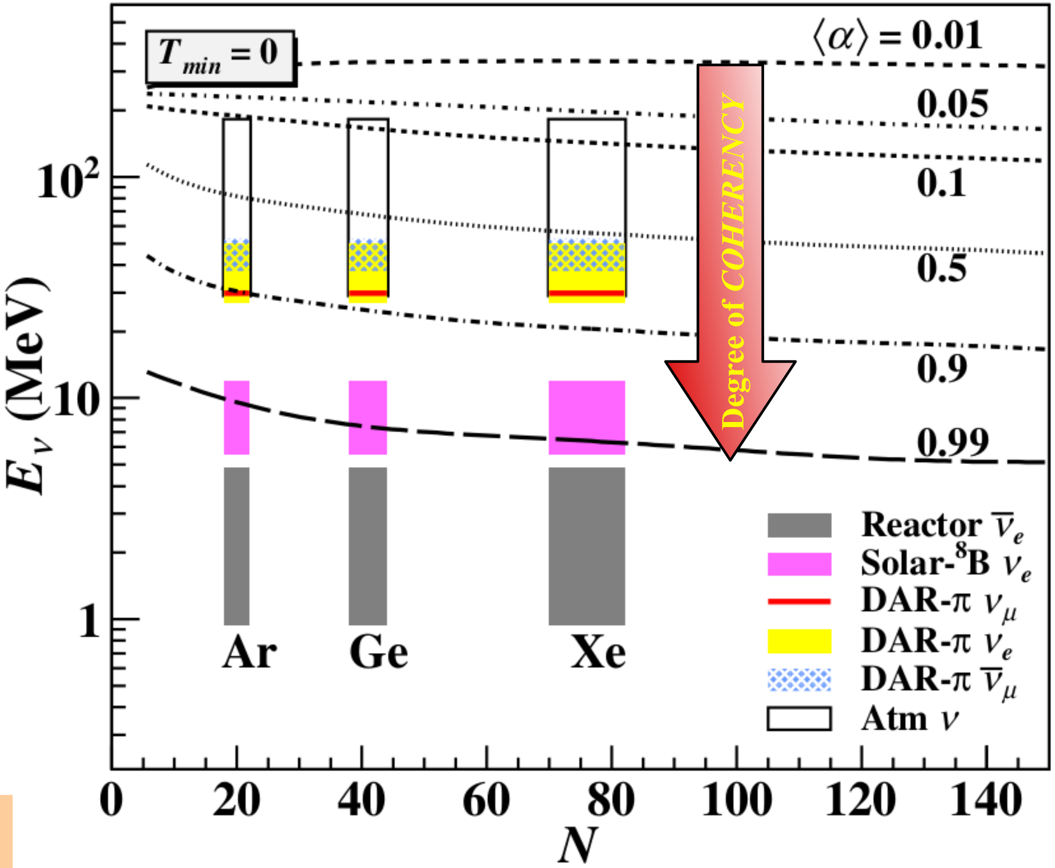
- ***Blind to flavor***
- Precision test ***Nuclear & Particle Physics***
- ***Neutrino floor*** for DARK MATTER
- ***Extensions of SM, & NSI's test***



Inelastic incoherent $\lambda_{Z^0} \ll 2R$ | Elastic incoherent $\lambda_{Z^0} \lesssim 2R$ | Elastic coherent (CEνNS) $\lambda_{Z^0} \gtrsim 2R$

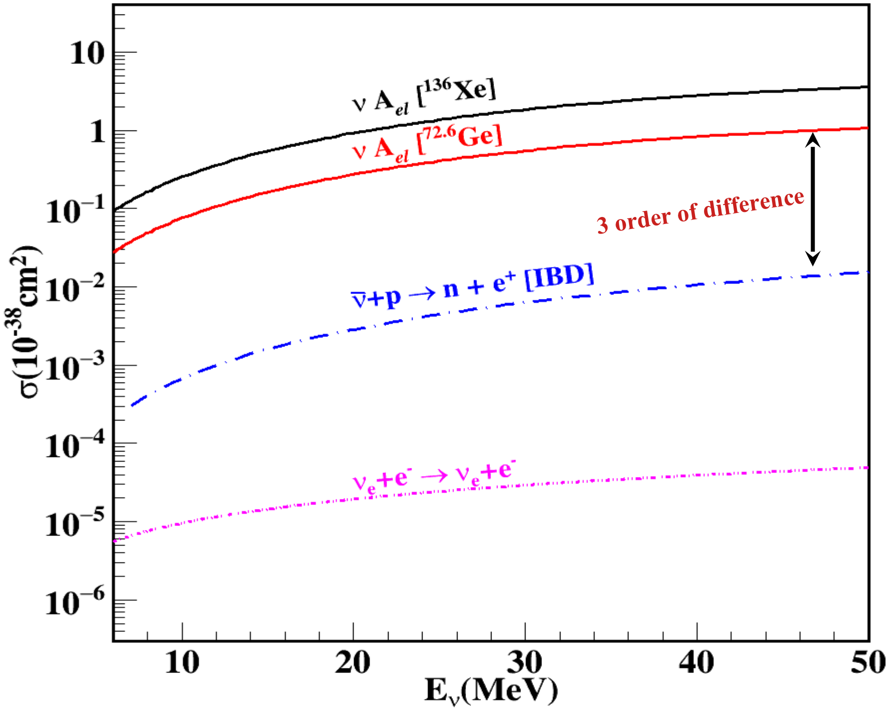
Reactor and Ge for CνA$_{el}$ study

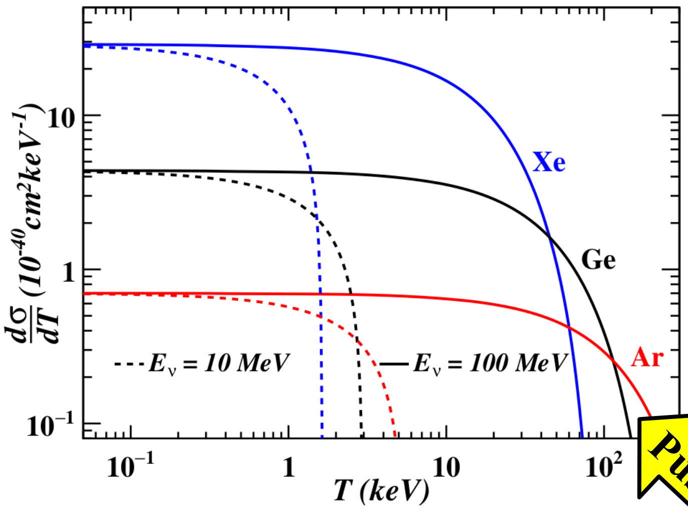


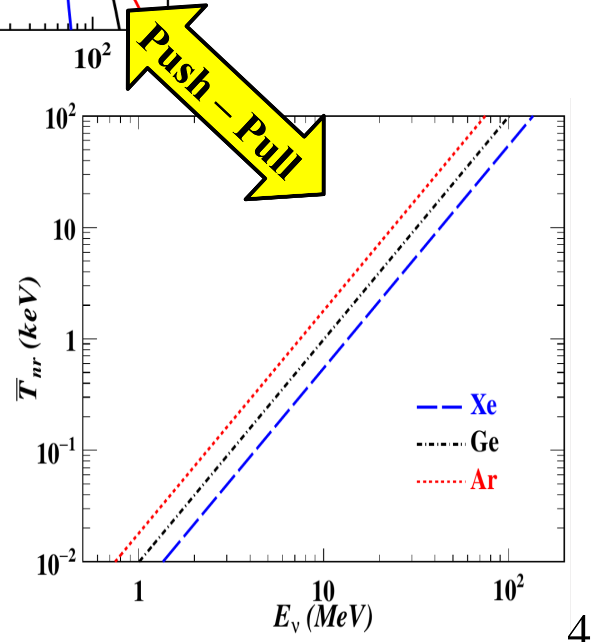


- ☑ Sources:: Solar, Accelerator, Reactor, ….
- ☑ Reactor:: Intense Pure anti-ν_e flux ~10^{12} cm^{-2}s^{-1}
- ☑ >95% Coherent process (anti-ν_e<10 MeV)
- ☑ Ge is *OPTIMAL* target

Reactor and Ge for CνA$_{el}$ study

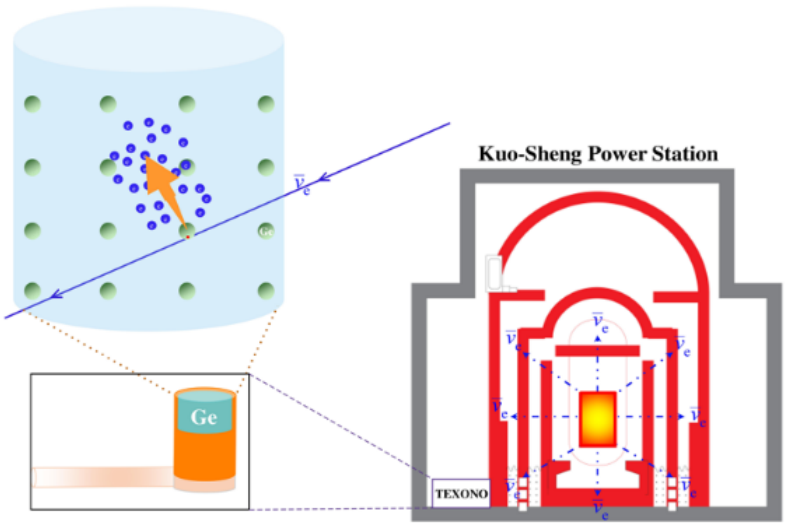






- **Largest cross section @ *low energy neutrino* → *Smaller Target***
- ***Scaled with N^2 (Neutron)***
- **Differential cross section *independent* @ low energy**

Quenching Factor for CνA$_{el}$ study



☑ The *recoil spectrum* → Convoluted *with QUENCHING FACTOR*

☑ Lindhard *k = 0.157 (Ge)*

- ☑ No *Binding effect*
- ☑ *Ionized electrons do not* produce *recoil atoms of appreciable energy*

☑ *Migdal effect*

Quenching factor

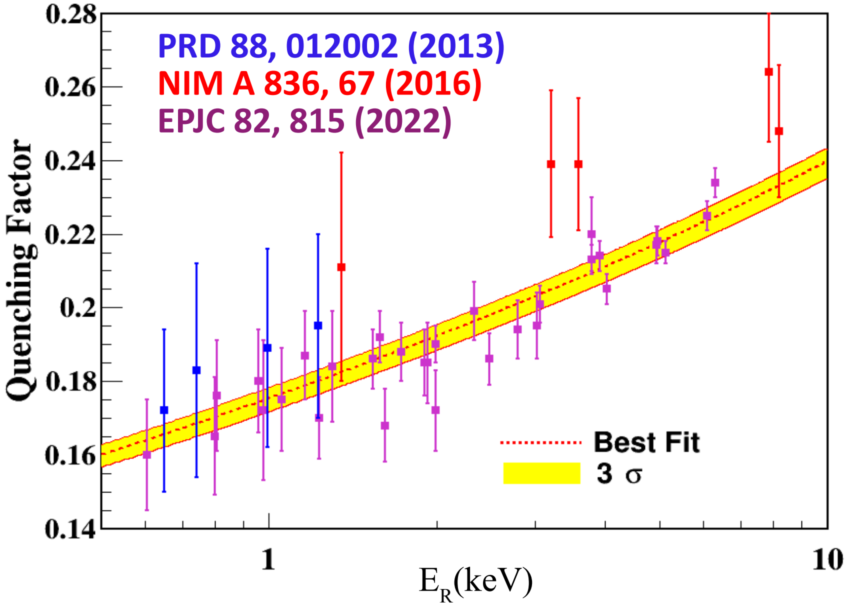
$$\frac{dR}{dE_I} = \frac{dR}{dE_R}\left(\frac{1}{Q} - \frac{E_I}{Q^2}\frac{dQ}{dE_I}\right)$$

"q" can be (+/-) in Sign

- ☑ (+) Sharp cutoff to *energy transfer*
- ☑ (-) Enhancement to *energy transfer*
- ☑ (0) For the Current Work

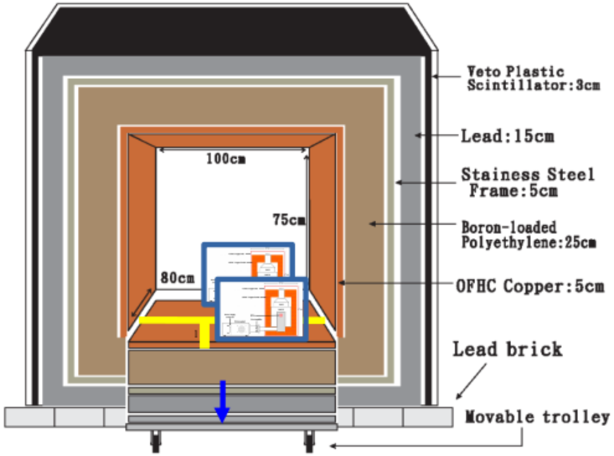
Standard Lindhard QF definition

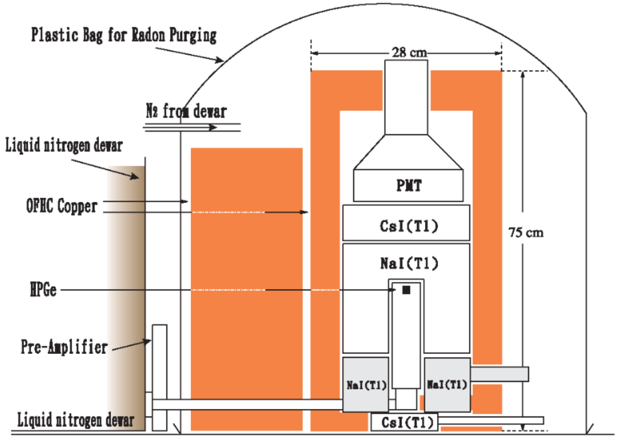
$$Q(E_R) = \frac{kg(\epsilon)}{1+kg(\epsilon)} \quad \Longrightarrow \quad Q(E_R) = \frac{kg(\epsilon)}{1+kg(\epsilon)} - \frac{q}{\epsilon}$$

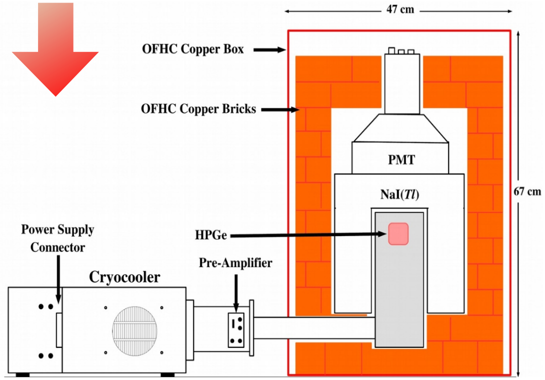


TEXONO [Taiwan EXperiment On NeutrinO]

- ☑ Location: Kuo-Sheng Nuclear Power Plant -II on northern shore of Taiwan
- ☑ Theme: Low Energy Neutrino Physics and Dark Matter Searches
- ☑ Collaboration: India, China [CDEX] & Turkey
- ☑ Flux: Reactor Power of 2.9 GW gives 6.35×10^{12} $cm^{-2}s^{-1}$ @ distance of 28 m
- ☑ Shielding: 30 m.w.e. overburden



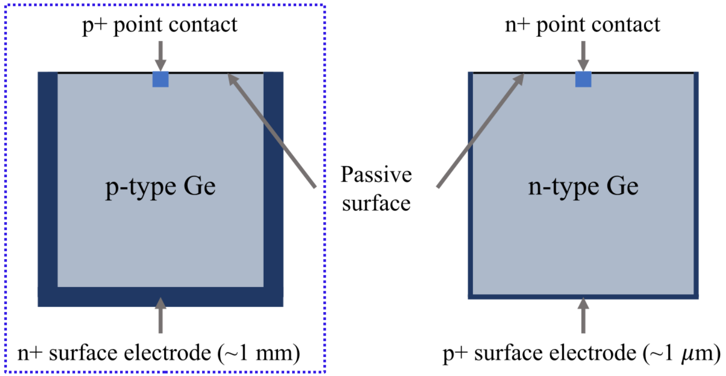


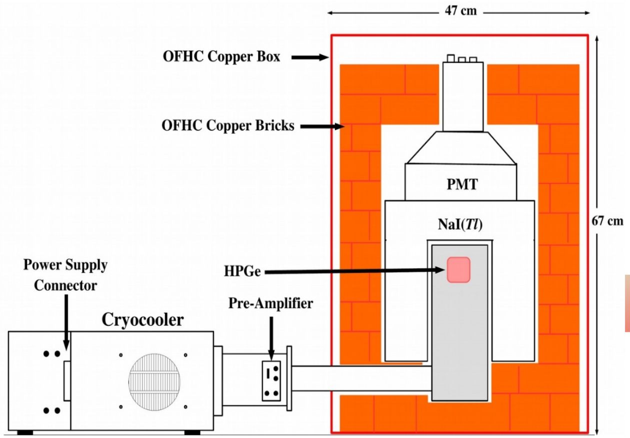


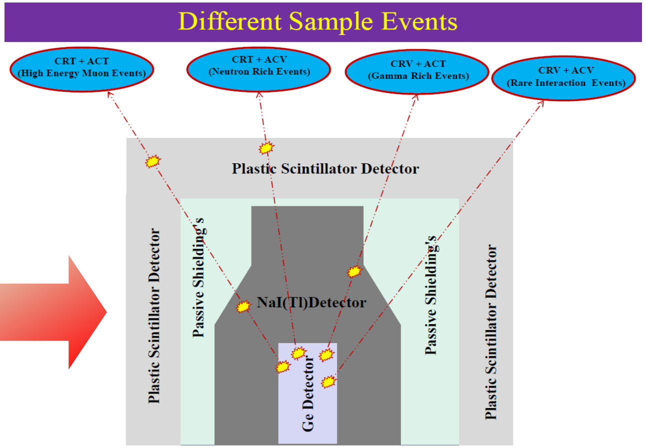
Eelectrocool Upgrade

- ☑ Extra Space
- ☑ *Two detector configuration in working*
- ☑ *Custom Cold-tip temp & Real-time monitoring*
- ☑ *No LN_2 required & Less human exposure*
- ☑ *Less micro-phonic noise*

Shielding & Bkg @ TEXONO



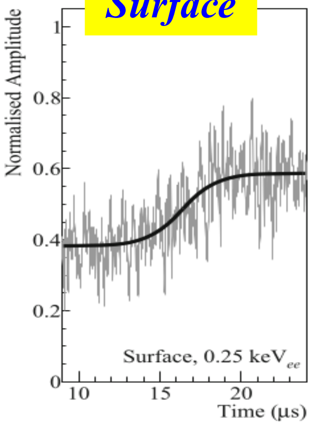




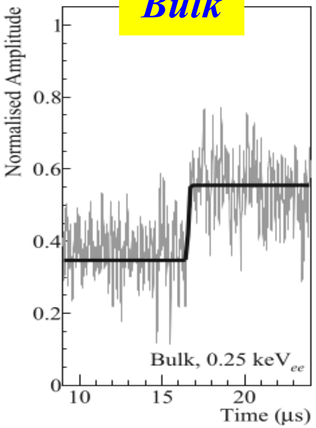
- ☑ *p*PCGe → ***Surface layer*** **Thickness** → *𝒪 (1mm)*
- ☑ *n*PCGe → ***Surface layer*** **Thickness** → *𝒪 (~1μm)*

CR $^{\pm}$ ⊗ AC $^{\pm}$ ⊗ B/S → Eight Categories
CR $^{-}$ ⊗ AC $^{-}$ ⊗ B → PHYS candidate (ν/χ) events, uncorrelated
→ Anti-correlated Events from Active shielding

Surface

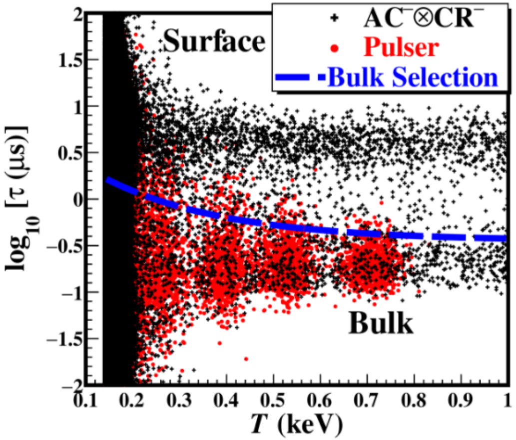


Bulk



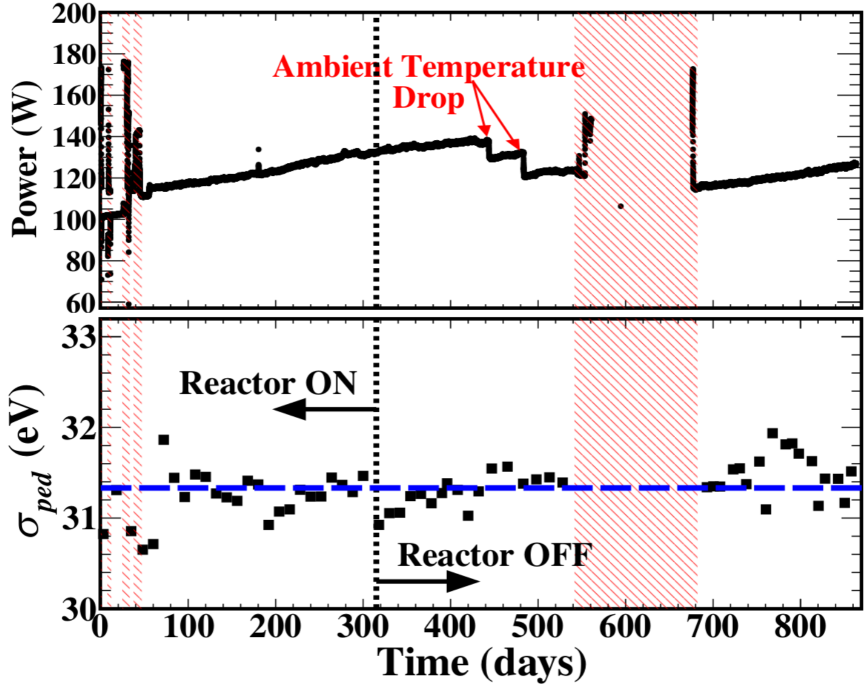
Rise-Time (τ)

$$\frac{1}{2}A_0 \times \tanh\left(\frac{t-t_0}{\tau}\right) + P_0$$



- ❒ BS Selection
  Optimized Pulsar
- ❒ Reference as Bulk
- ❒ ***Efficiency >80%***

Generations of HPGe Detector @ TEXONO & Stability



LN_2

Electro-Cooling

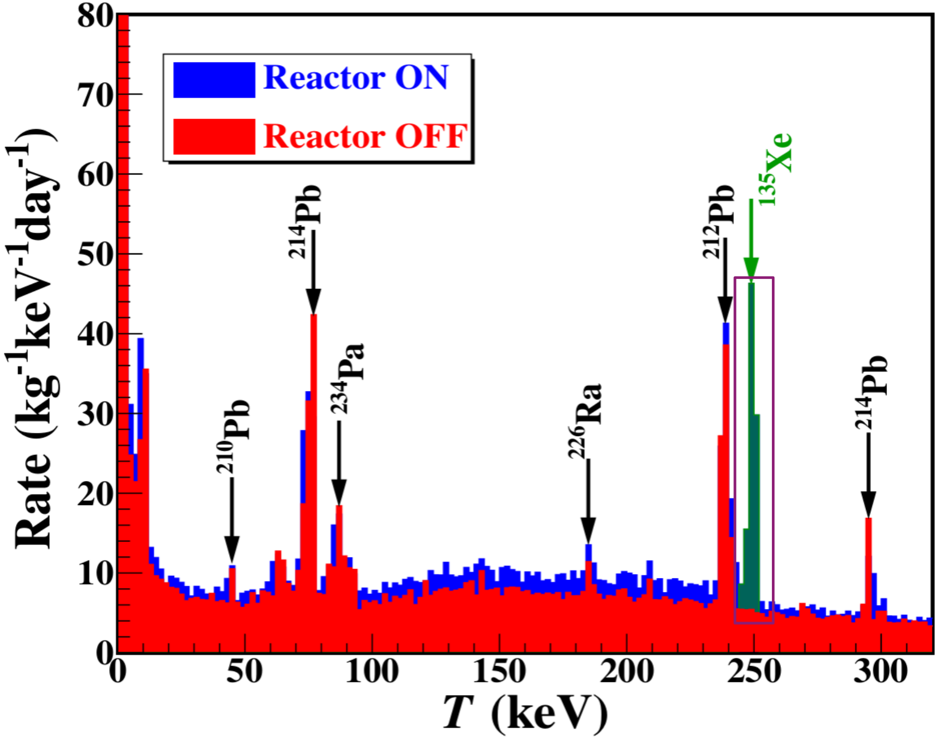
Generation	Mass (g)	Pulsar FWHM (eV)	Threshold
G1	500	130	500
G2	900	100	300
G3	500	70	200
	900	70	~230
$G3^+$	1383	70	200
G4	900	<50	<140

***Secured Key Parameters*:**

- ❐ **200 eV Threshold**
- ❐ ***Pulsar FWHM 70 eV***
- ❐ **Controlled Background**
- ❐ **Stable: >3.5 years**

- ➔ **Pedestal fluctuation < 0.5 eV @ <3.5 eV**
- ➔ **Power consumption**
  - **Ambient temperature**
  - **Outgasing**

$C\nu A_{el}$ @ KSNL



PHYSICAL REVIEW D **75**, 012001 (2007)

TABLE IV. Summary of γ-lines intensity measured in Period-III.

Energy (keV)	Isotopes	Source/ Decay Series	$\tau_{1/2}$	Intensity (kg^{-1}day^{-1})
66.7	^{73m}Ge	cosmic	0.5 s	15.4 ± 0.4
92.6	^{234}Th	^{238}U	24.1 d	11.9 ± 0.5
143.8	^{235}U	^{235}U	7.0×10^8 y	5.1 ± 0.8
185.7	^{235}U	^{235}U	7.0×10^8 y	17.2 ± 0.4[a]
186.2	^{226}Ra	^{238}U	1600 y	
238.6	^{212}Pb	^{232}Th	10.6 h	18.8 ± 0.5
249.8		unidentified		11.6 ± 0.5
295.2	^{214}Pb	^{238}U	26.8 m	6.3 ± 0.3
338.3	^{228}Ac	^{232}Th	6.2 h	3.7 ± 0.5
351.9	^{214}Pb	^{238}U	26.8 m	17.1 ± 0.4
463.0	^{228}Ac	^{232}Th	6.2 h	1.6 ± 0.3
583.2	^{208}Tl	^{232}Th	3.1 m	14.4 ± 0.3

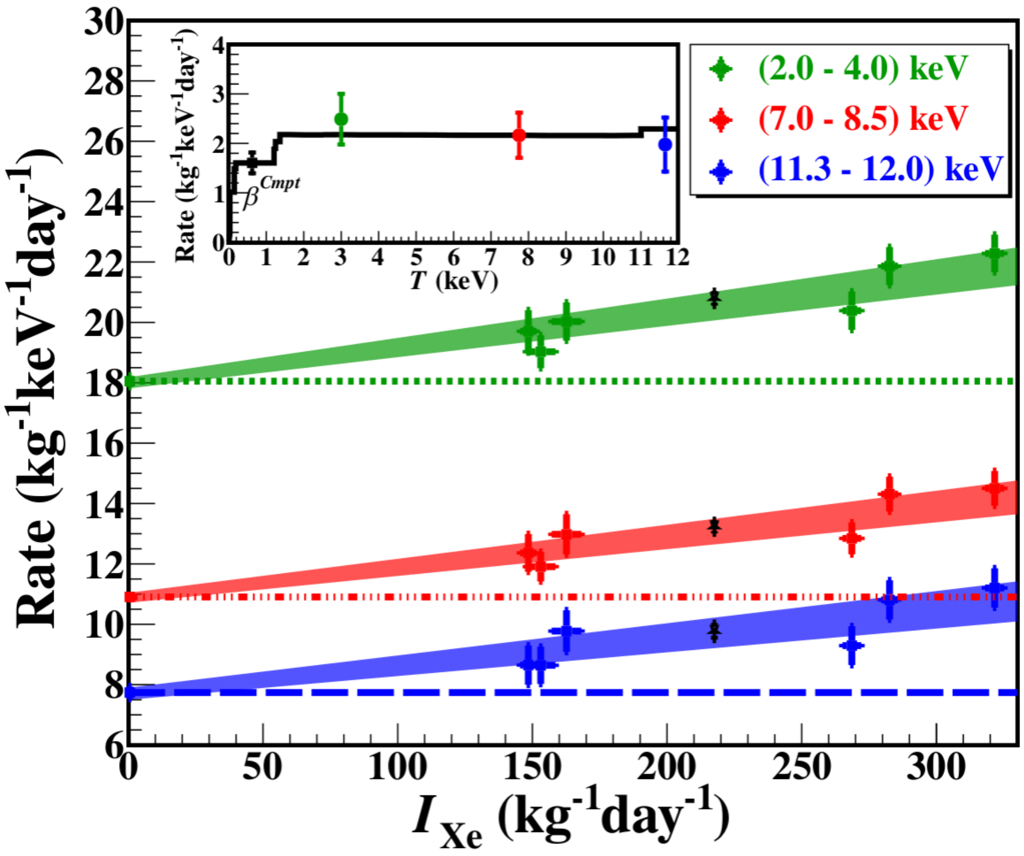
To Achieve Better Sensitivity:

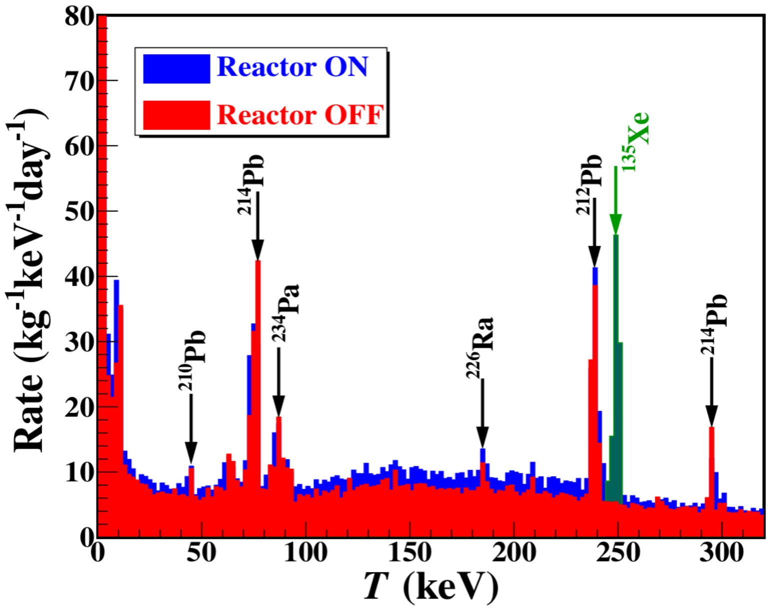
- Reactor OFF data collection
- R&D to achieve Low Energy Threshold & Less Background

- **Background**
  - **In sub-keV region: ~ 50 counts (kg^{-1} keV^{-1} day^{-1})**
  - **^{135}Xe @ REACTOR ON**

†$AC^{-} \otimes CR^{-} \otimes B_r$ → Anti-Compton veto ⊗ Cosmic Ray veto ⊗ Bulk Events Corrected

TEXONO: ^{135}Xe Subtraction [250-keV γ]



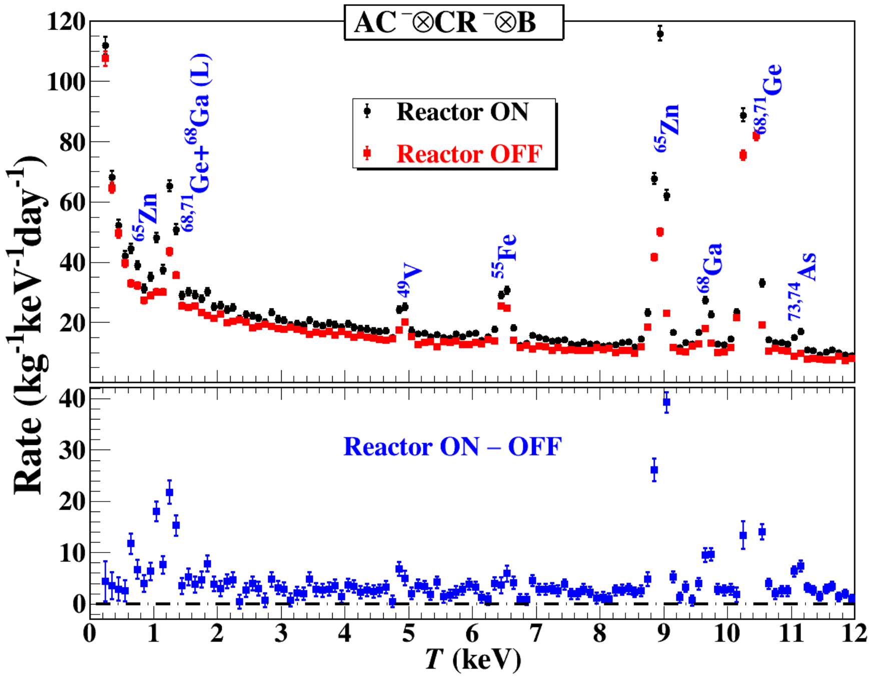


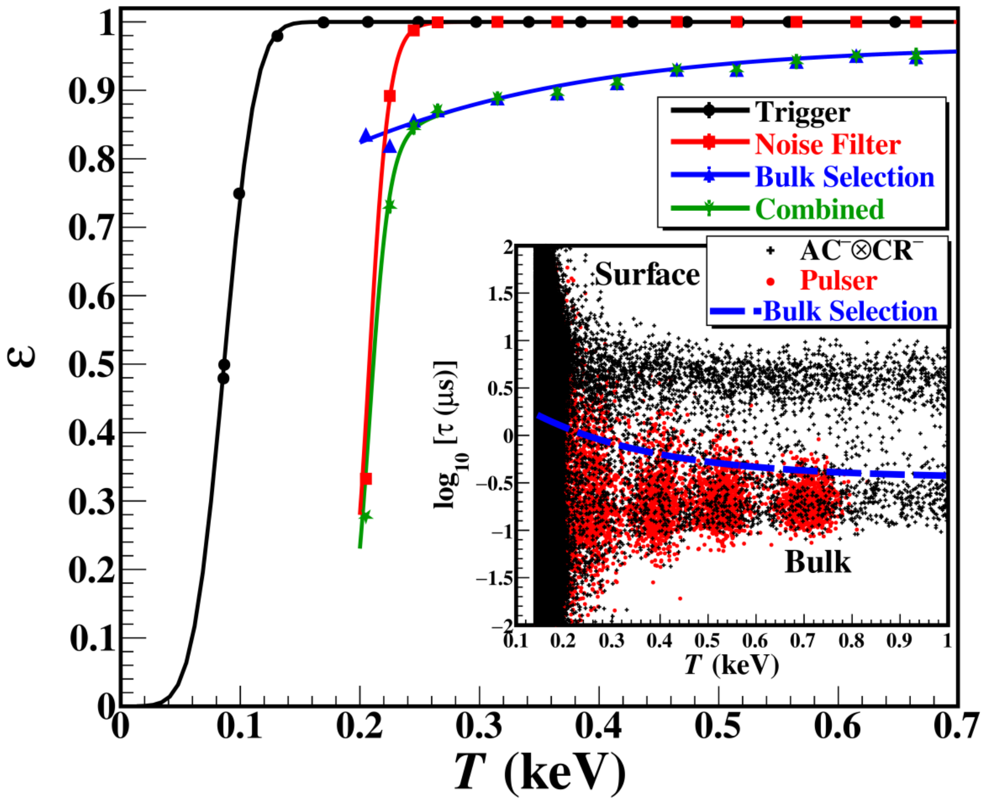
- A Decay Product of ^{235}U
  - $^{135}Xe \rightarrow {}^{135}Cs^* + \text{anti-}\nu_e + e^-$
  - $^{135}Cs^* \rightarrow {}^{135}Cs + \gamma$ *(249.8 keV)*
  - NIM A 705, 117 (2013)
- Very Good Neutron Absorber
  - Poison For Reactor
- Half-life = 9.14 h
- On-average: Contributes ~1.61 ± 0.21 $kg^{-1}.keV^{-1}.day^{-1}$ [Sub-keV Energy Region]

J. Phys. G: Nucl. Part. Phys. 47 045202

†$AC^- \otimes CR^- \otimes B_r \rightarrow$ Anti-Compton veto ⊗ Cosmic Ray veto ⊗ Bulk Events Corrected

CvA_{el} @ KSNL

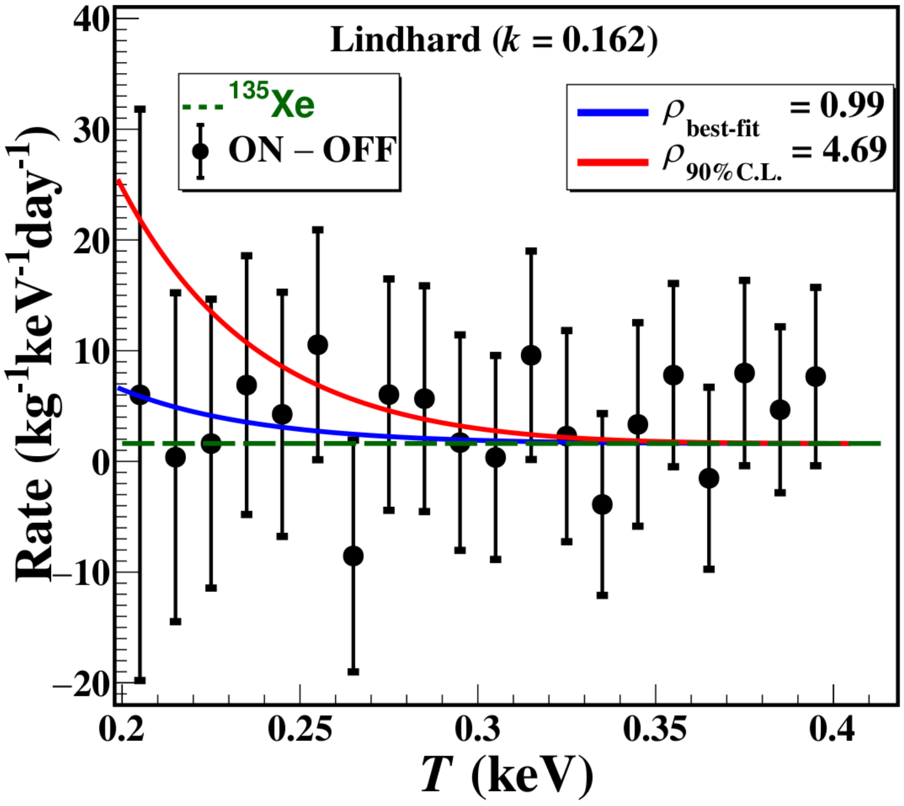




- The *cosmogenic x-ray* lines are identified
- Reactor ON-OFF → *Finite ^{135}Xe Compton excess*
- Cosmogenic peaks are observed → *Isotopes with half-lives comparable to exposure*

†AC⁻⊗CR⁻⊗B$_r$ → Anti-Compton veto ⊗ Cosmic Ray veto ⊗ Bulk Events Corrected

Limits @ TEXONO



- ρ estimate the excess over SM prediction
- β_{Cmpt} ^{135}Xe excess calibrated @ Sub-keV

Classical Statistic

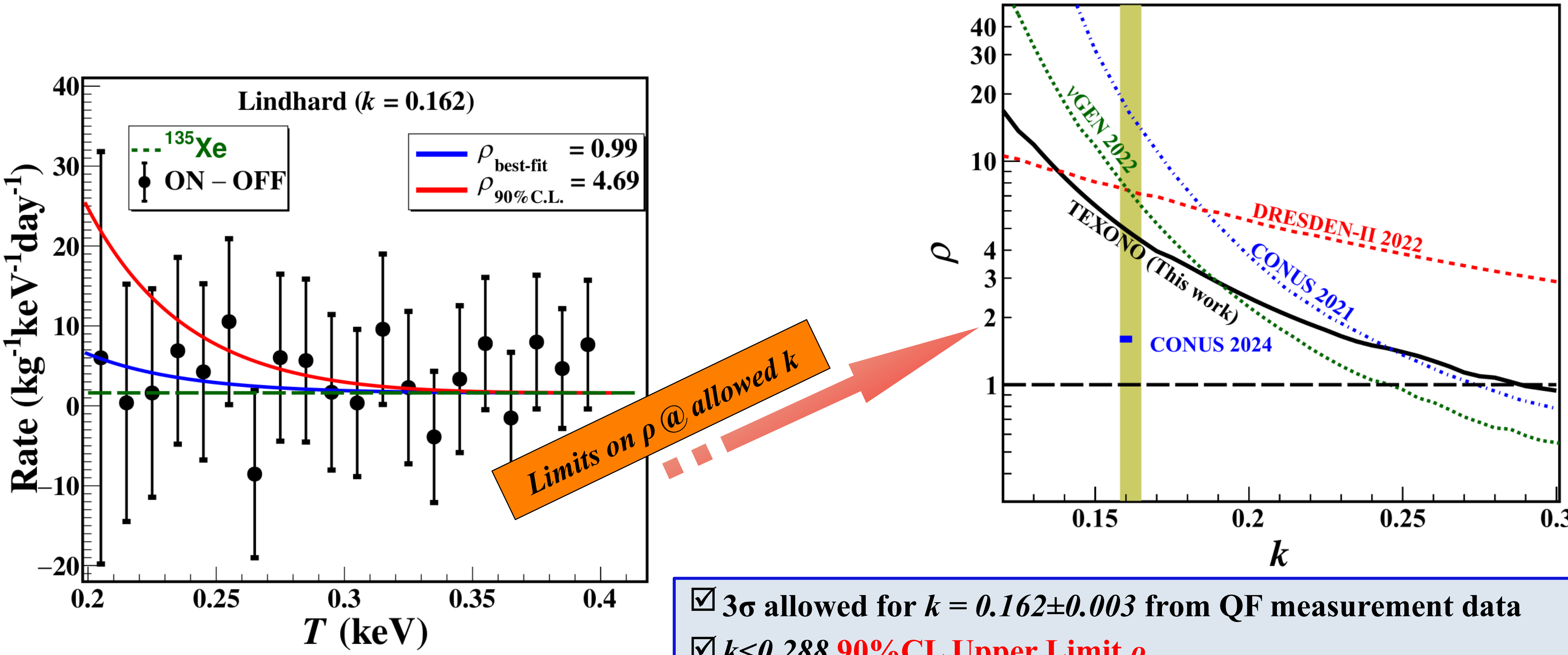
$$\chi^2(\rho,\beta;k) = \sum_i \left[\frac{N_i - \rho\nu_i^{\text{SM}}(k) - \beta}{\Delta_i}\right]^2 + \left[\frac{\beta - \beta^{\text{Cmpt}}}{\Delta^{\text{Cmpt}}}\right]^2$$

- < 280 eV contribute 90% of νA_{el} *signal*
- Spectral uncertainty 4.26 cpkkd < 280 eV

- *β = 1.62 ± 0.22* cpkkd
- *β < Spectral Uncertainty* @ RoI
- *Rising Uncertainty → COMBINED Efficiency < 250 eV*

*cpkkd → counts.kg^{-1}. keV^{-1}.day^{-1}

Limits @ TEXONO



☑ 3σ allowed for *k = 0.162±0.003* from QF measurement data

☑ *k<0.288* 90%CL Upper Limit ρ_{SM}

☑ TEXONO [with 200 eV threshold]

- @90%CL Upper Limit – ρ < 4.7 @ SM [Lindhard *k*=0.162]

Result & Conclusion

☑ **Large data volume collected [ON[OFF] > 500[800] kg.days]**

☑ **Achieved [with 200 eV threshold]**

- **ρ = *0.99 ± 2.23 (Stat.) ± 0.05 (Sys.)* @ SM [Lindhard *k*=0.162]**
- **90%CL → ρ < 4.7 @ SM [Lindhard *k*=0.162]**
- **Reactor ON[OFF] → *242[357]* kg-days**

☑ **Have *not observed any excess* above *SM prediction***

☑ **Set the benchmark for *precision testing of SM & Beyond***

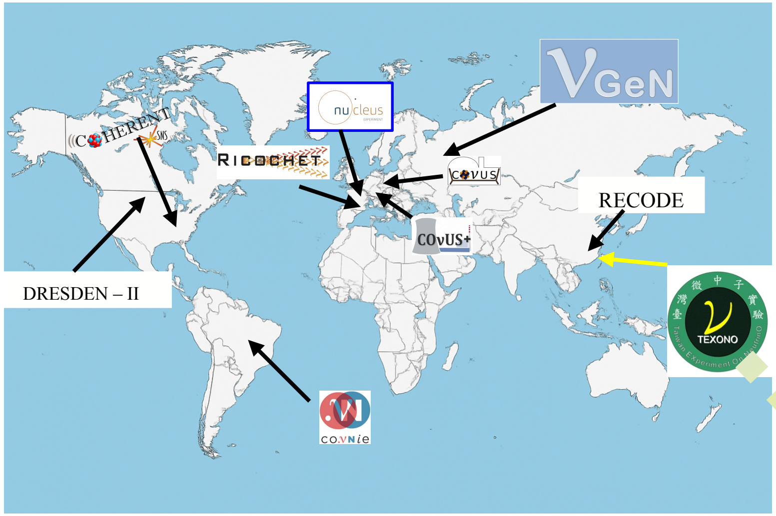
RECODE
[Sanmen Reactor @ Zhejiang]

Future goals

- ***KS Reactor decommissioned 2023* → Permission of data taking till end of 2028**
- ***R&D continues to achieve* → *Lower* (~150 eV_{ee}) threshold Cross-Correlation, Optimized Pulsar, etc.**
- **New [G4] Detector → Characterization and Commissioning for Dark Matter studies**
- ***New Reactor site* → RECODE [Sanmen Reactor @ Zhejiang]**

[RECODE program]
See the Talk of "Yufeng Wang"
ID: 408 (Wednesday, August 27, 17:20)

World's Effort & TEXONO



Thank You !

谢谢

TEXONO