TEXONO's νA_{el} @ KSNL : Results & Status

- TEXONO-ν @ KSNL
- νA_{el} @ KSNL : Evolution
- νA_{el} with EC-PCGe @ KSNL : Latest Updates
- Moving On ….

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June 2024

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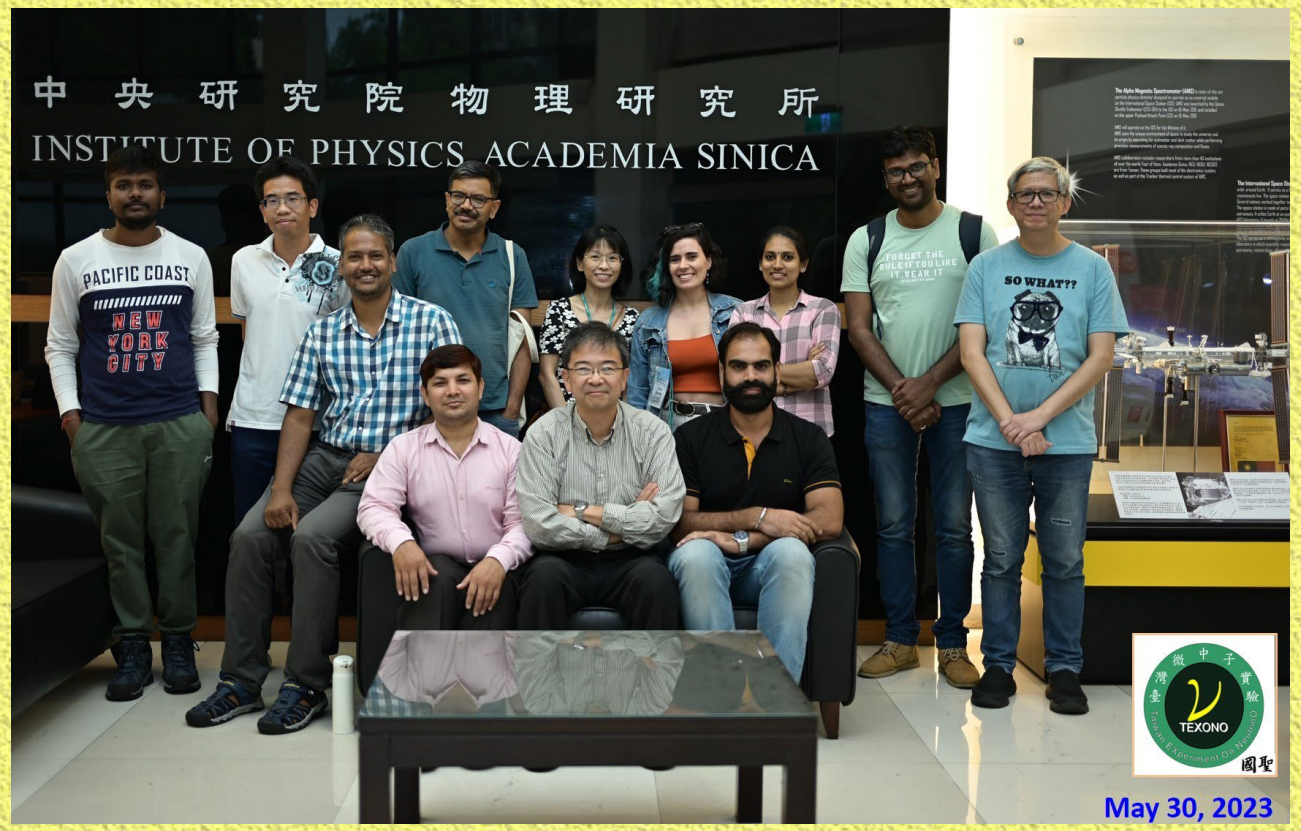
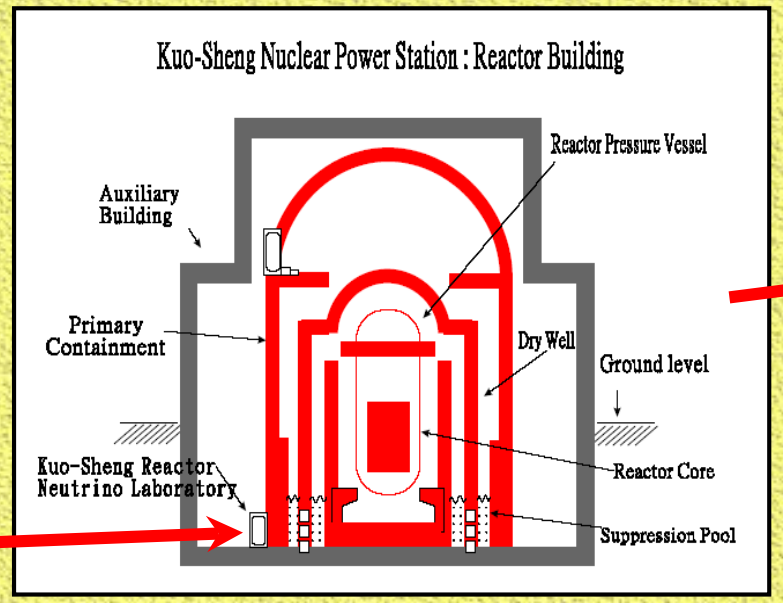


AS, KSNPS, NTU, NDHU,
IHEP, CIAE, THU, SCU,
BHU, CUSB, GLAU,
HNBGU, METU, DEU.....

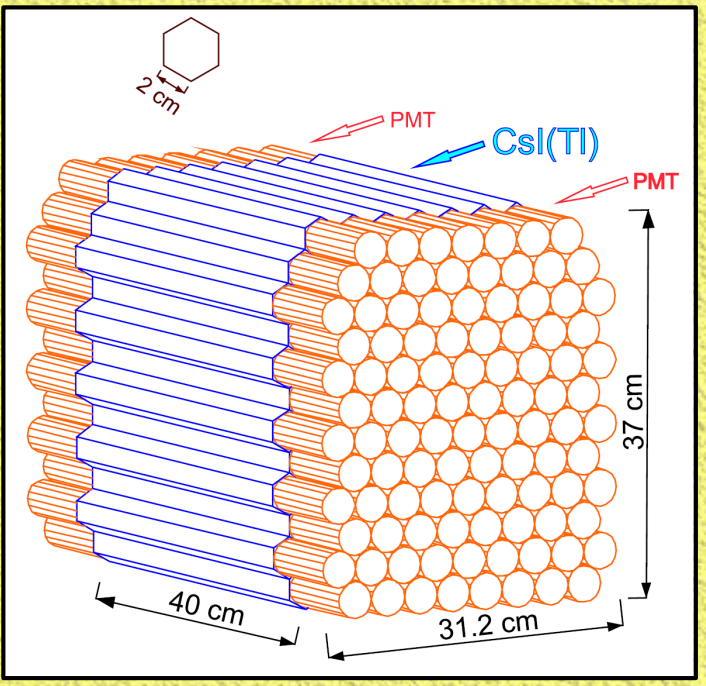
TEXONO Program *[since 1997]* :

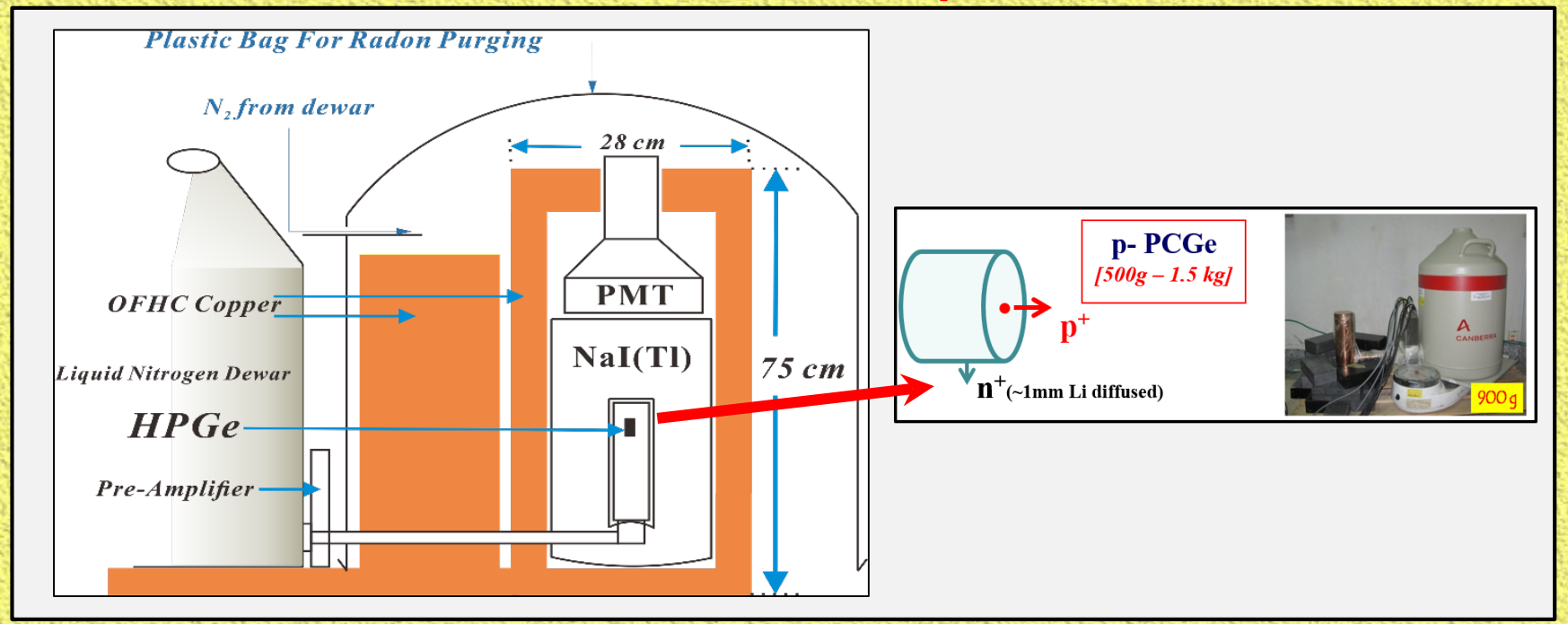
- Low Energy Neutrino (SM+EM) physics at Kuo-Sheng Neutrino Laboratory (KSNL), 28 m from 2.9 GW_{th} reactor core, $\phi_\nu \sim 6 \times 10^{12}$ cm^{-2} s^{-1}
- Founding partner of CDEX@CJPL Dark Matter Experiment *[since 2008]*
- Theory Program *[since 2010]*


TEXONO


Kuo-Sheng Nuclear Power Station : Reactor Building
Reactor Pressure Vessel
Auxiliary Building
Primary Containment
Dry Well
Ground level
Kuo-Sheng Reactor Neutrino Laboratory
Reactor Core
Suppression Pool


N
0
20mi
20km
NPS-I
NPS-II
Keelung
Taipei
ACADEMIA SINICA
NPS-IV
Hsinchu
Ilan

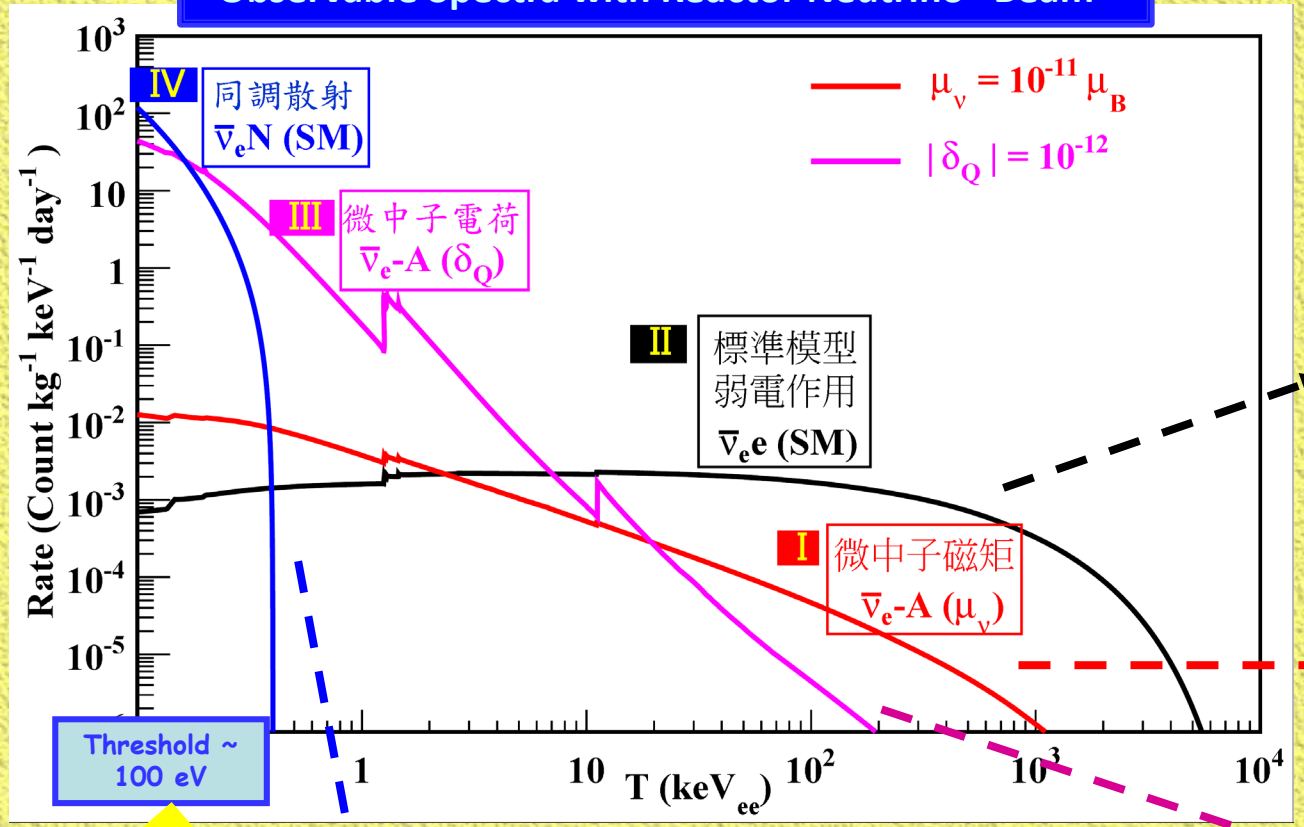

2 cm
PMT
CsI(Tl)
PMT
37 cm
40 cm
31.2 cm


Plastic Bag For Radon Purging
N2 from dewar
28 cm
OFHC Copper
PMT
NaI(Tl)
Liquid Nitrogen Dewar
75 cm
HPGe
Pre-Amplifier
p- PCGe
[500g – 1.5 kg]
p+
n+(~1mm Li diffused)
900g

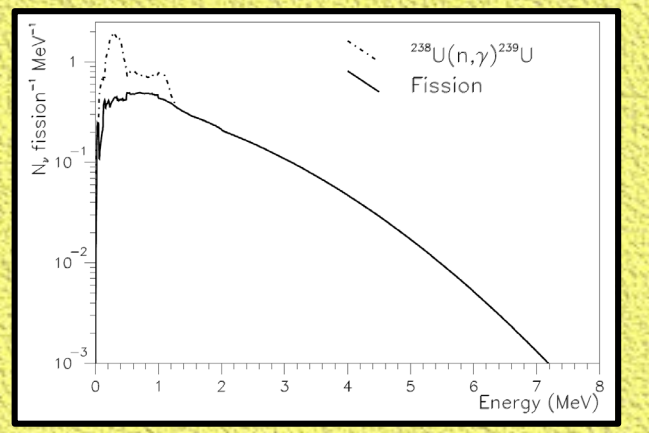
Neutrino Properties & Interactions at Reactor

quality ← Detector requirements → mass

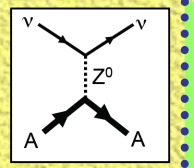
Observable Spectra with Reactor Neutrino "Beam"



Reactor Neutrino Spectrum



KSNL: $\phi_\nu \sim 6 \times 10^{12}$ cm^{-2} s^{-1}



νN Coherent Scatte… *ent Theme;PRD16,PRD21]*

- Pioneered sub-ke… LEGe / PCGe [MPLA08, NIMA16]
  - Light Da… earches @ KSNL *[PRD09,PRL13,AP14,PRD19]*
  - CDEX… um@CJPL *[PRD13……]*
  - Theo… am *[PLB14……]*

Convoluted Evolution ! → Next Page

sub-keV PCGe

ν-e Scattering SM
[PRD10] & *NSI/BSM*
[PRD10,PRD12,PRD15,PRD17]
⇨ 200 kg CsI(Tl)

Magnetic Moments
[PRL03,PRD05,PRD07]
⇨ 1 kg HPGe

Neutrino Milli-charge
[PRD14]
⇨ sub-keV O(kg) PCGe

(Our) Evolution *[with Twists]*

- *"CEvNS"* theoretically considered, Freedman 1974 ❤❤❤
- **TEXONO @ KSNL:**
  - ☑ Idea (Ge for reactor νA_{el}) first raised in TAUP2003 etc., following μ_ν results with threshold MeV→ 10 keV ,
  - ☑ requiring *"sub-keV"* sensitivities (Ge Detectors)
  - ☑ Spin-off to *"Light Dark Matter"* searches, first results (20 g ULEGe @ 220 eV) 2007
  - ☑ Inspire theory program on $(\nu/\chi/\alpha)$-Atom cross-sections
- CEvNS proposed with ν@π-DAR, Scholberg 2006 👍👍👍
  - ☑ Experimental ObservationS since 2017, and BEYOND.
- CoGeNT 👍👍👍 :
  - ☑ Demonstration of *"Point-Contact Ge"* 2007
  - ☑ large modular mass detectors → νA_{el} + LDM + $0\nu\beta\beta$
- **CDEX @ CJPL:**
  - ☑ Ge for νA_{el} : catalyzed *foundation of CJPL* in China & CDEX program
  - ☑ Dedicated LDM experiment with Ge, starts 2010
  - ☑ ~2015: explore future $0\nu\beta\beta$ with Ge
  - ☑ ~2023: return to NG Reactor νA_{el} at Sanmen.

QM Coherency as a Qualifier for νA_{el}

[PRD16 ; PRD21]

- ☑ **Coherent Vs Elastic are TWO distinct aspects of C+E-νNS !!**
- ☑ **QM Coherency (for a EW-process) is central**
- ☑ **Coherency is a *continuous* variable dependent on q^2 via E_ν & Target A(Z,N) in νA_{el}**
- ☑ **Define a *quantifiable* parameter beyond qualitative descriptions**
- ☑ **Parametrize: $\alpha(q^2) \equiv \cos\langle\phi\rangle \in [0,1]$,**
  where $\langle\phi\rangle(q^2)$ is the QM *phase mis-alignment angle* between two non-identical nucleons in A(Z,N)
- ☑ **Unified Description for all A(Z,N) ; consistent comparison possible.**

Coherency in Neutrino-Nucleus Elastic Scattering [PRD16,PRD21]

- Quantify transitions between QM Coherency & Decoherency
- Universal Characterization between different Sources & Target

νA_{el} with Reactor Neutrinos:

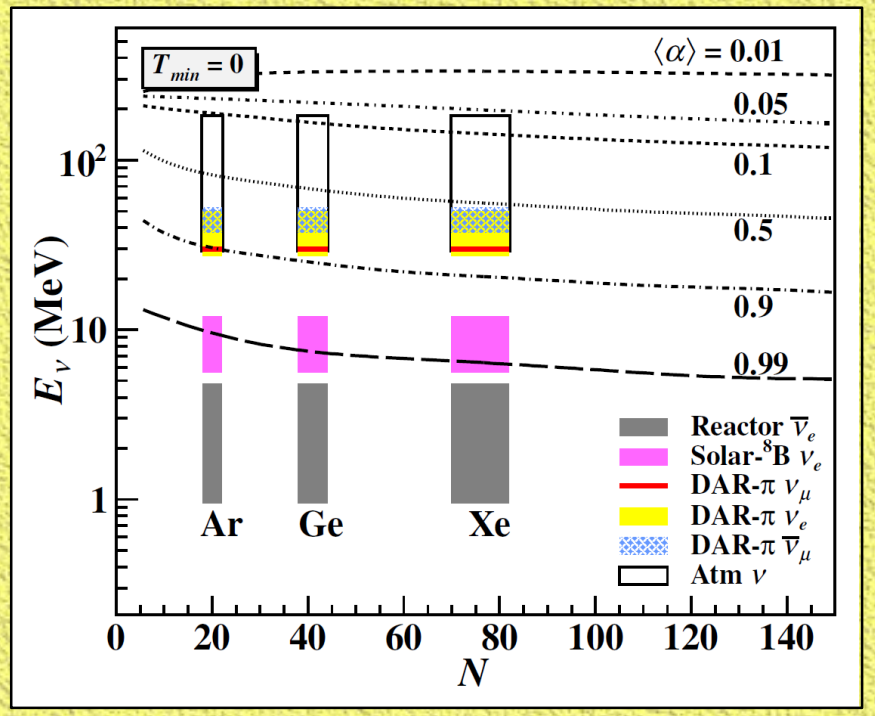
- ☑ Different kinematics regimes : $q^2 \rightarrow 0$; Form Factor $F(q^2)=1$
- ☑ Full QM Coherency *[DAR-νN @~0.6 - 0.7]*
- ☑ BSM/NSI Searches → no degeneracy with nuclear physics FF uncertainties

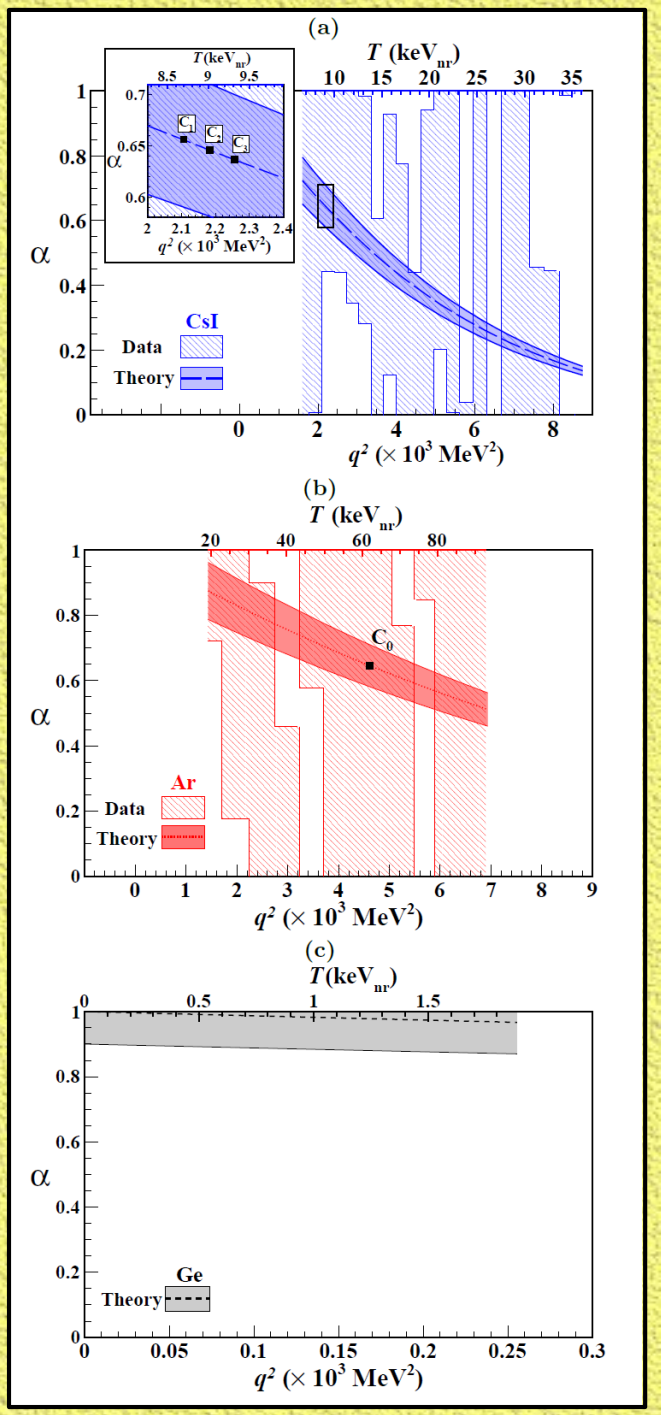
$$\alpha \equiv \cos\langle\phi\rangle \in [0,1]$$

<ϕ> : averaged decoherence angle

Seek Input / Inspirations:

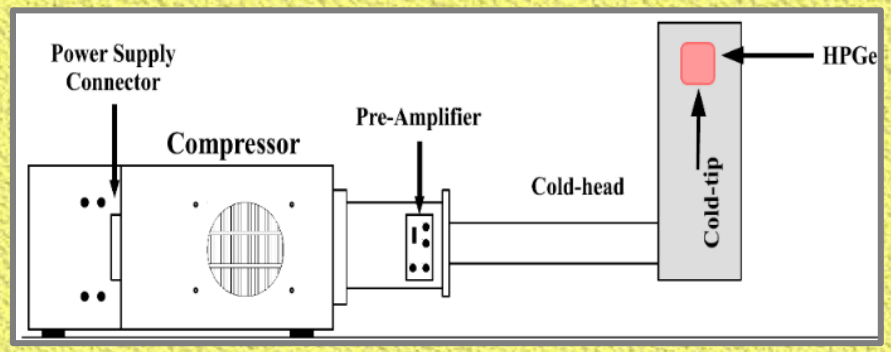
- ☑ Derive α from basics QM & Relate to nuclear physics

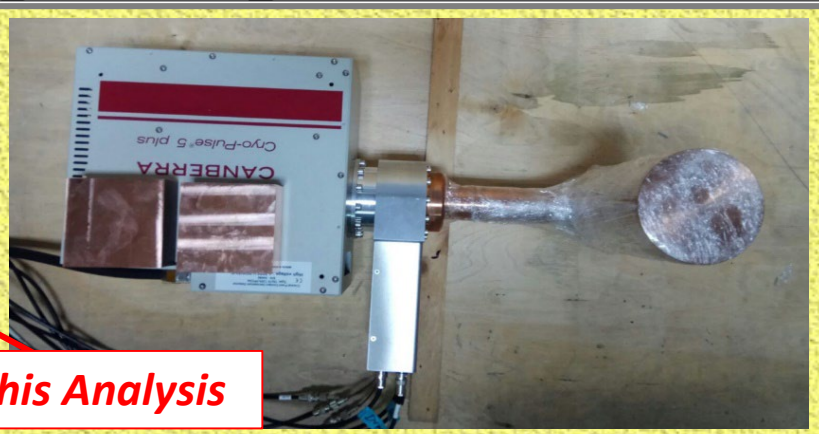




νA_{el} with Electro-cooled PCGe

	Generation	Mass (g)	Pulsar FWHM (eV_{ee})	Threshold (eV_{ee})
LN_2	G1	500	130	500
LN_2	G2	900	100	300
Electro-cool	G3	500	70	200
Electro-cool	G3	900	70	~230
Electro-cool	$G3^{+}$	1430	~60	~160
Electro-cool	$G3^{++}$	1430	70	200
Electro-cool	G4	900	~50	~150

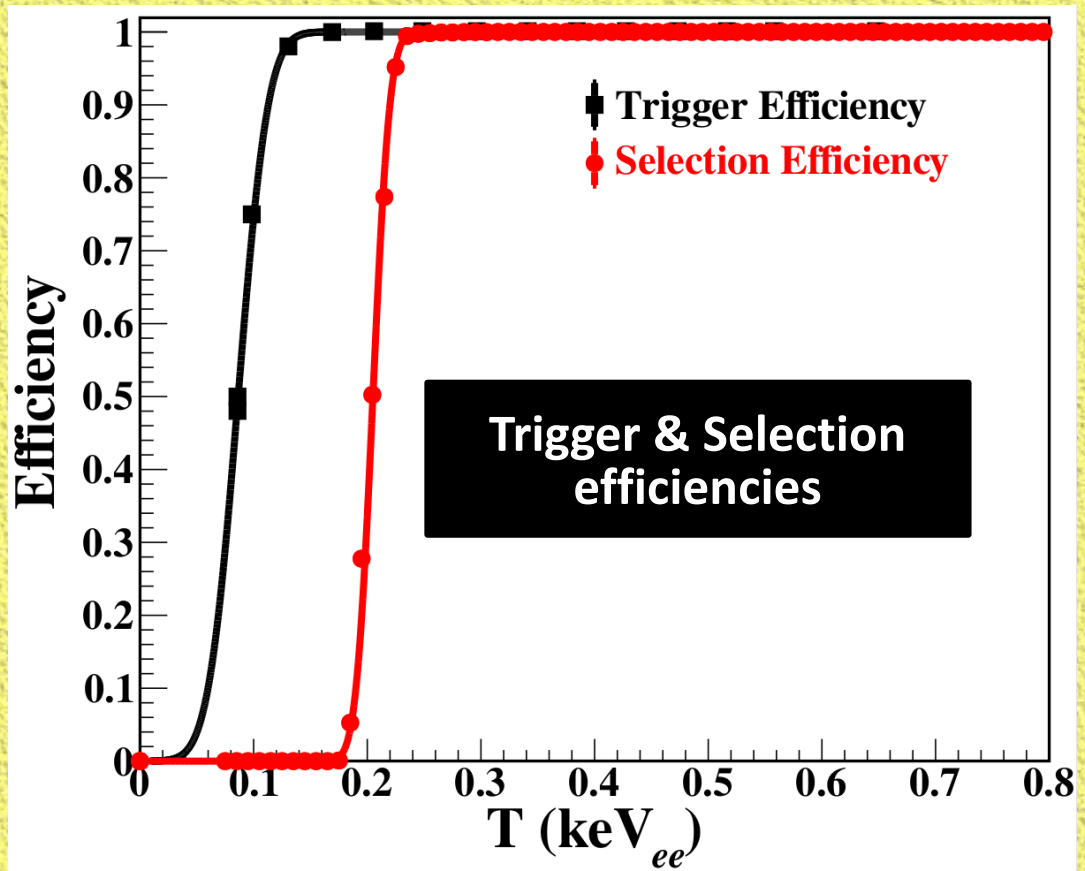




This Analysis

νA_{el} Data Analysis Strategies:

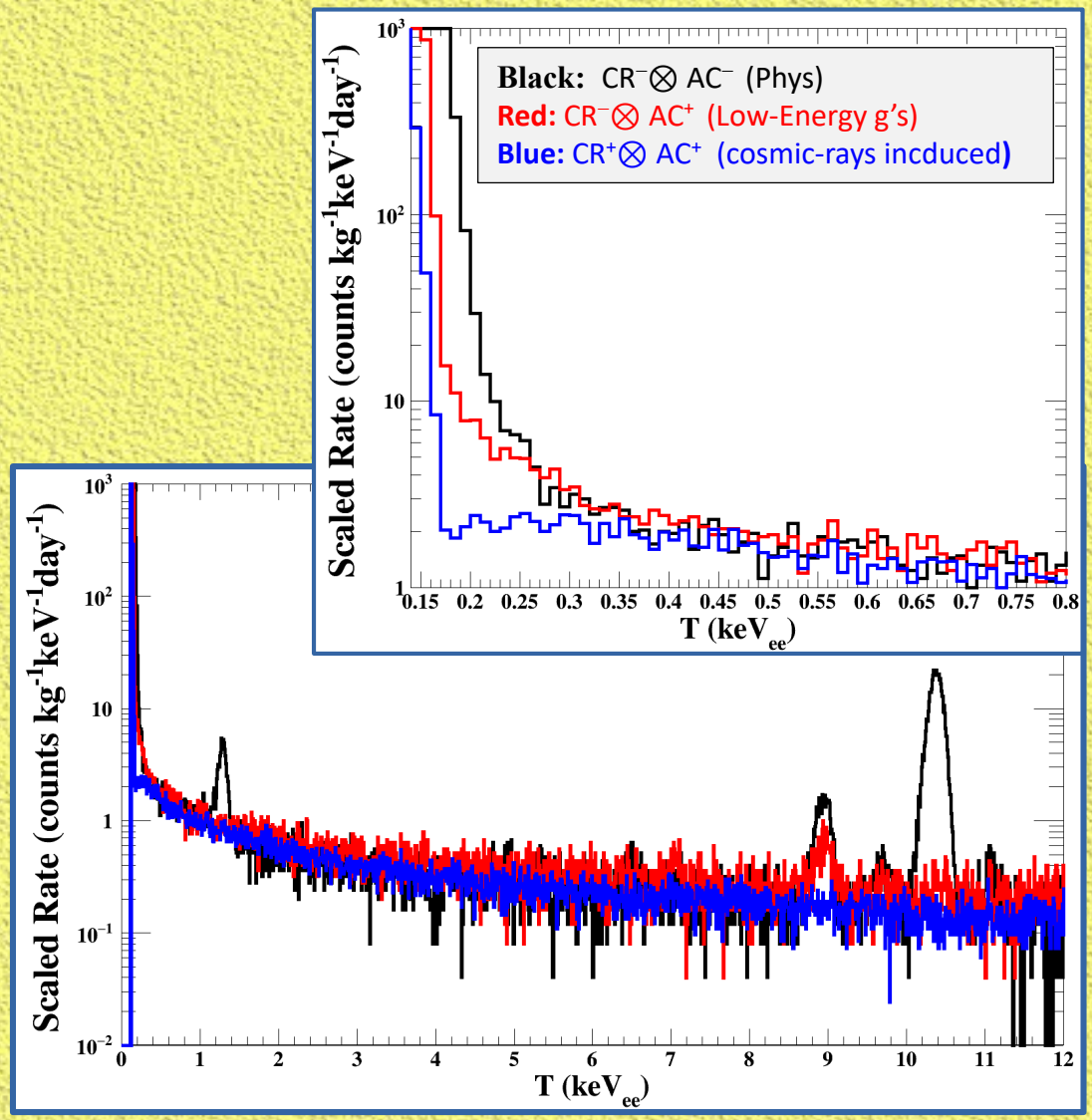
- Events identified in 8 categories
  - $CR^{\pm} \otimes AC^{\pm} \otimes B/S$ [Cosmic-Ray / Anti-Compton / Bulk or Surface]
  - $CR^{-} \otimes AC^{-} \otimes B$ are *PHYS* candidate (ν/χ) events, uncorrelated with other signals
  - others are *"background/benchmark"* samples, *in situ* with PHYS data
- Benchmark samples for optimizing analysis parameters & procedures, monitor stability & performance, measuring efficiencies, & reducing systematic uncertainties
- Optimized procedures & parameters applied to analysis of PHYS Samples



ε(Trig)~1 at T>120 eVee

⇒ Room to reduce threshold on ε(Selection) with improving new software

⇒ improve phys reach of same data

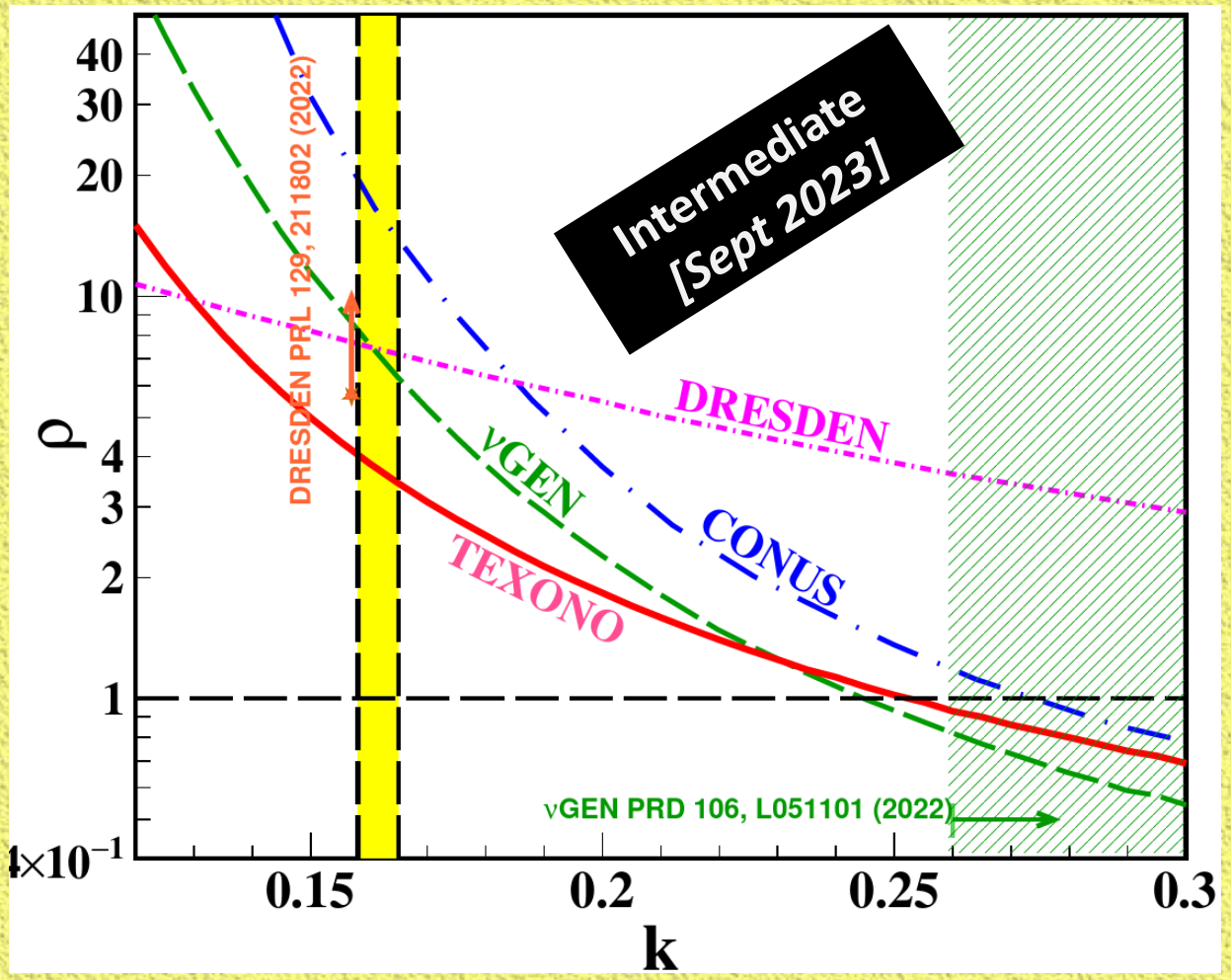


Coincidence in Benchmark Samples

⇒ Background Lower Threshold than Phys.

⇒ Improve in PSD B/S/Noise ID

"Preliminary"(Intermediate) Results Presented at TAUP-2023



- ☑ Reactor ON/OFF: 65/438 kg-days G3++
- ☑ ρ : ratio of measured to SM cross-sections
- ☑ 3σ allowed for *k* from QF measurement d
- ☑ TEXONO [with 200 eV threshold]
- 🛠 @90%CL Upper Limit :

  $\rho < 4.2$ @ Lindhard SM $k=0.157$

CONUS Latest Results *[arXiv2401]*

$\rho < 2$ at SM-k

[Similar experimental performance, but T with lower flux, less mass]

■ **June 2024:** *Despite being an original target & hard efforts by the team [towards completing 245/560 kg-days G3++ ON/OFF data], we are not ready to update these results.* **Apologies !**

Near-threshold Analysis Procedures Require:

- Produce Numerous Expected Features with in situ Benchmark samples

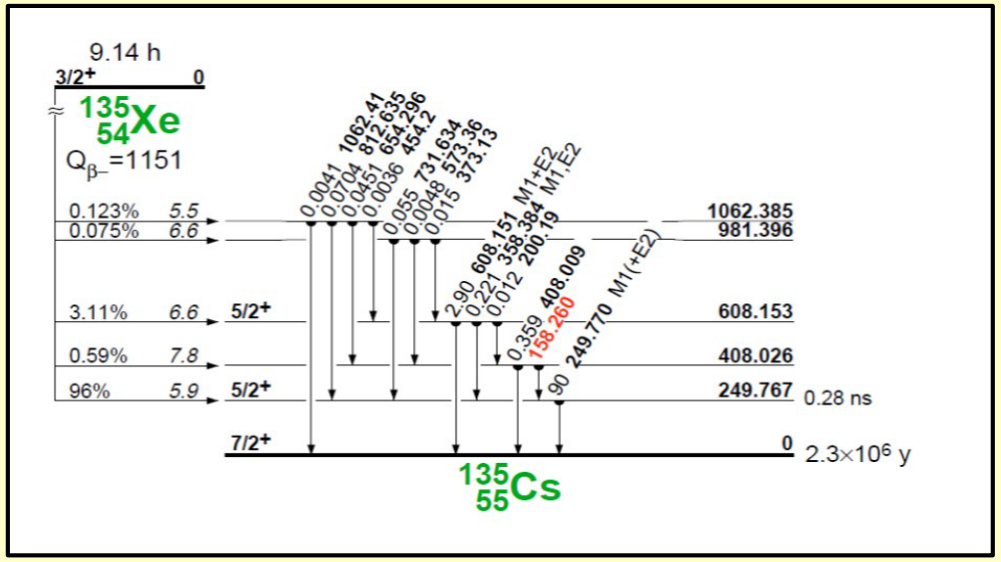
Challenges for *THIS* analysis:

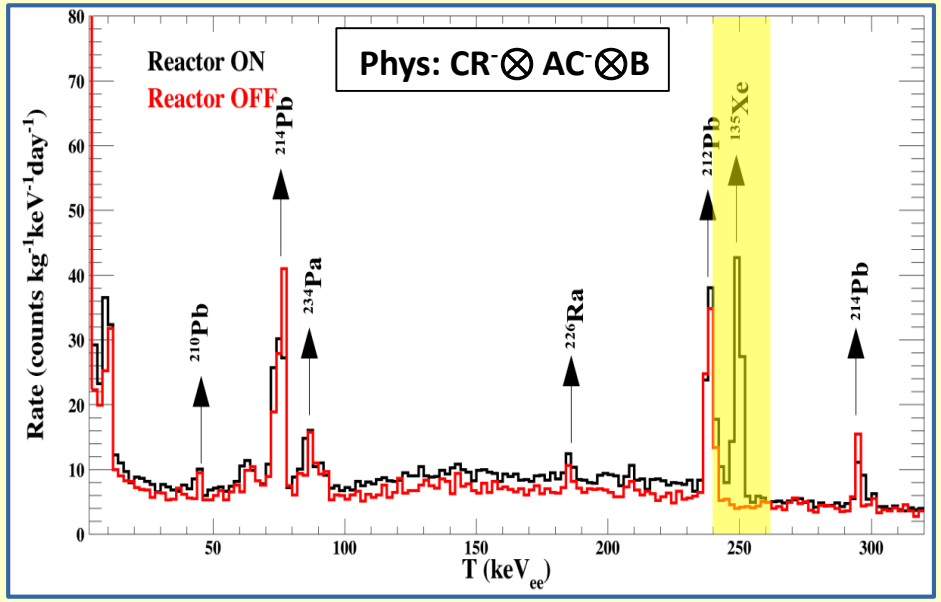
- Most data taken during the difficult times of COVID lockdown
- DAQ @ KSNL are unattended & hardware operating at sub-optimal conditions without repairs for long time
- Workable DAQ Live Time-to-Real Time Ratio ~ only 1/2 to 2/3
- Instabilities detection & correction with subsequent analysis requires big efforts

Status:

- Not all analysis of all benchmark data sets are producing expected features & uncertainties *YET* …..

Reactor ON-related ^{135}Xe Background -- 250-keV γ





- A Decay Product of ^{235}U- β

  $^{135}Xe \rightarrow {}^{135}Cs^{*} + \bar{\nu}_e + e^-$ *[Half-life = 9.14 h]*

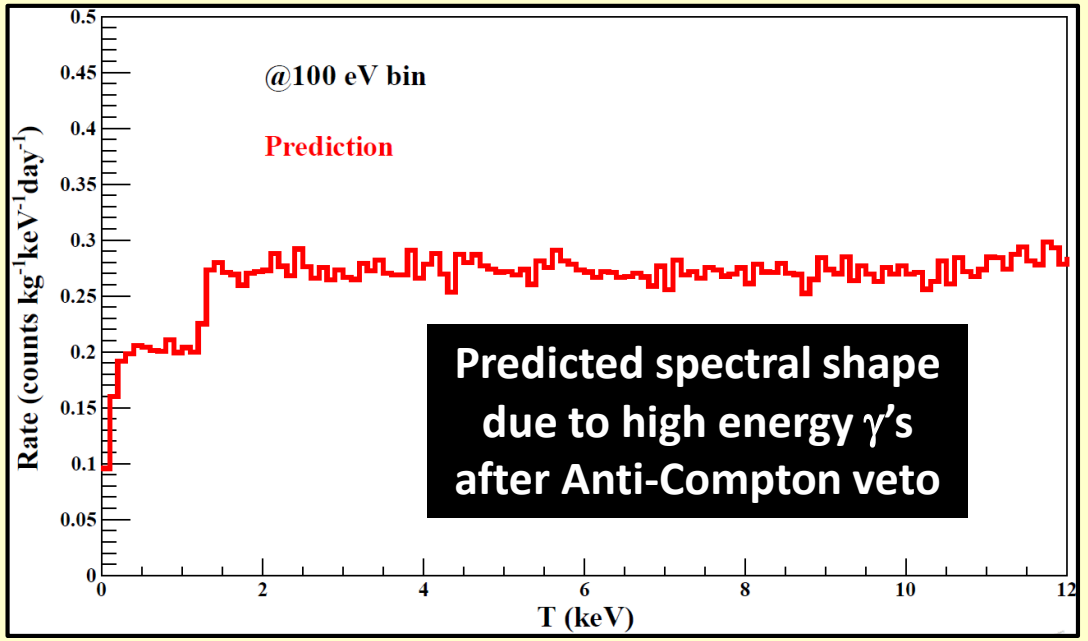
  $^{135}Cs^{*} \rightarrow {}^{135}Cs + \gamma$ (249.8 keV)

- Very Good Neutron Absorber **Poison For Reactor**
- Contributes **2.9 ± 0.8 counts.kg^{-1}.keV^{-1}.day^{-1}**

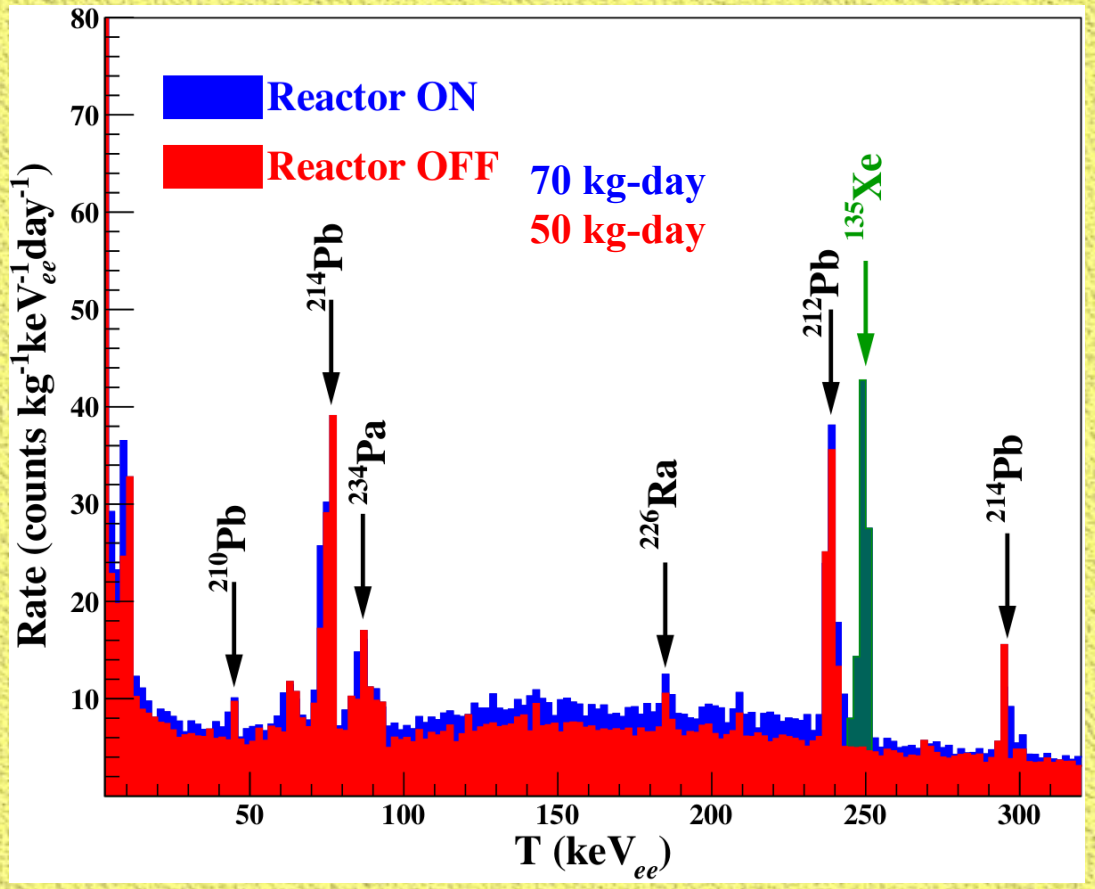
  @ sub-keV energy region
- Reactor ON PHYS background

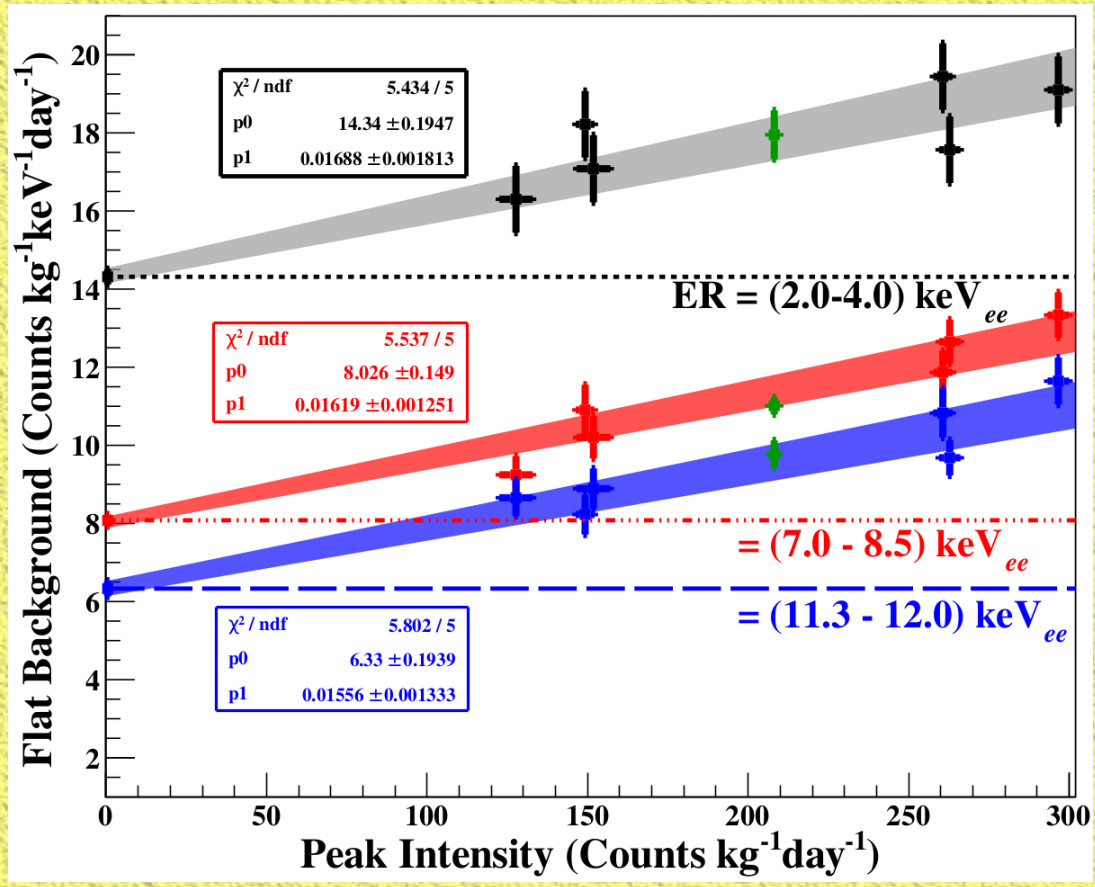
  ~90 counts.kg^{-1}.keV^{-1}.day^{-1}

  i.e. Minor and known background source.



^{135}Xe Background and Correction

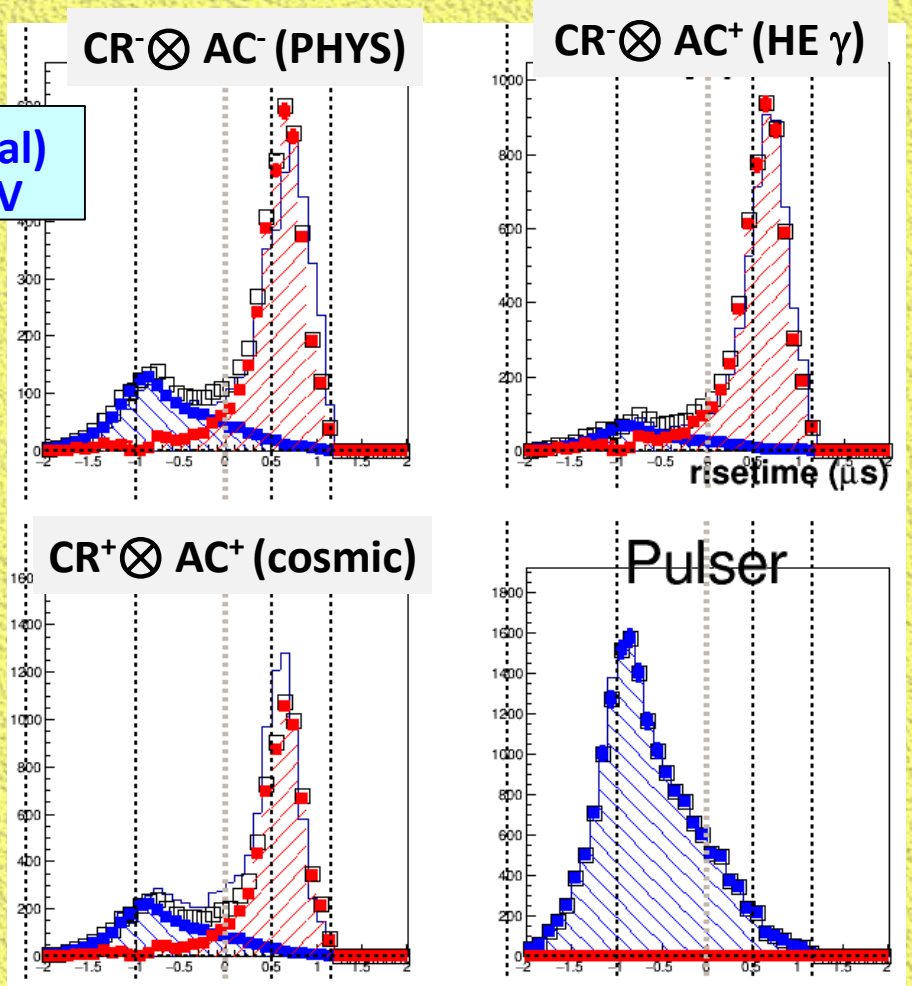


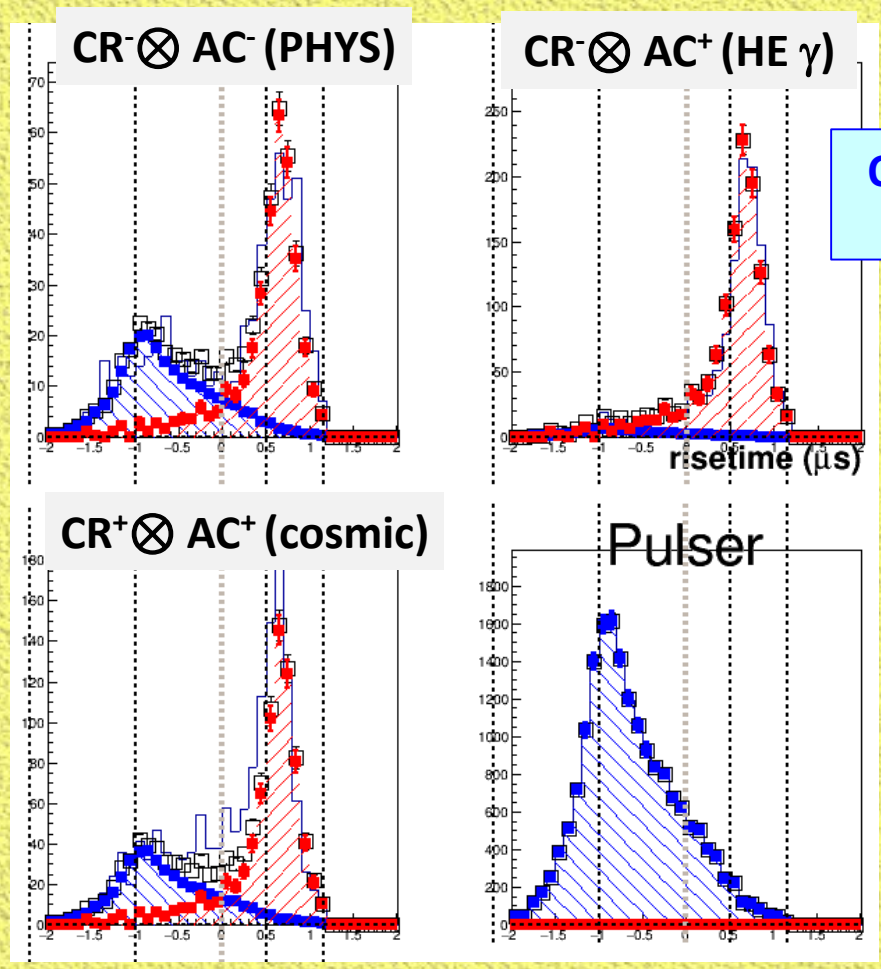


- ☑ Time Variation of Xe135 LE flat continuum background correlated with 250-keV peak
- ☑ Accurately measured LE background to subtract in ON—OFF residual spectra
- ☑ At 200-eV threshold, Xe-continuum ~3% of PHYS--Reactor ON counts

Validity Checks: Rise-time distributions

ON data (Total)
200—300 eV

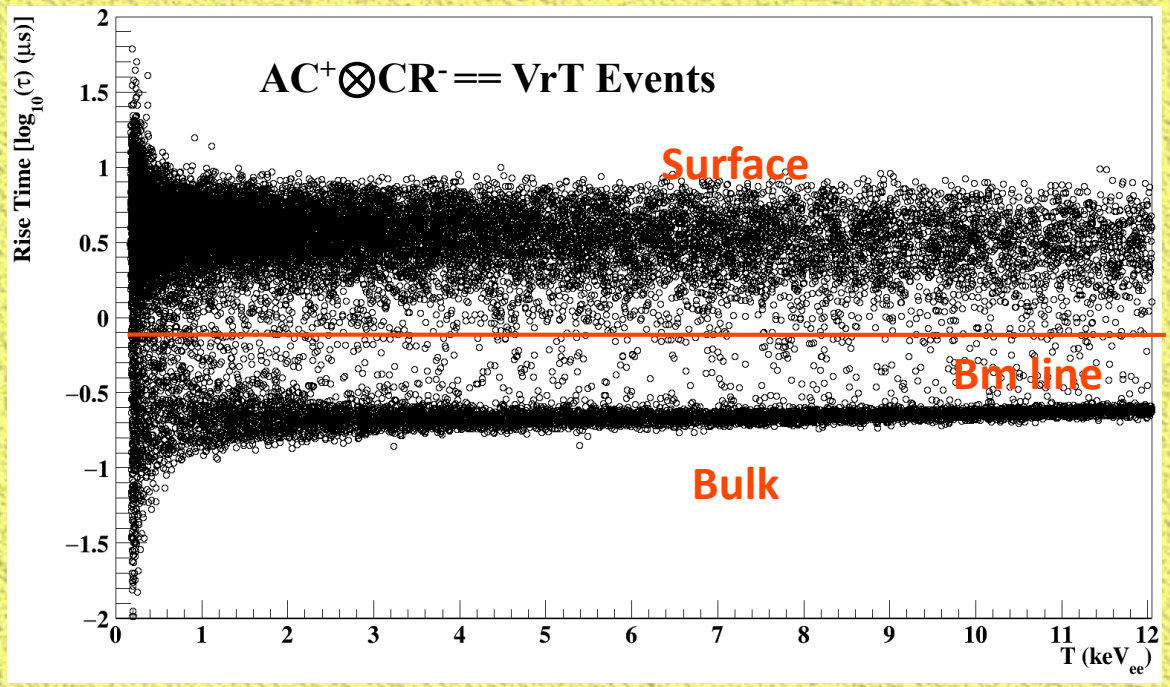


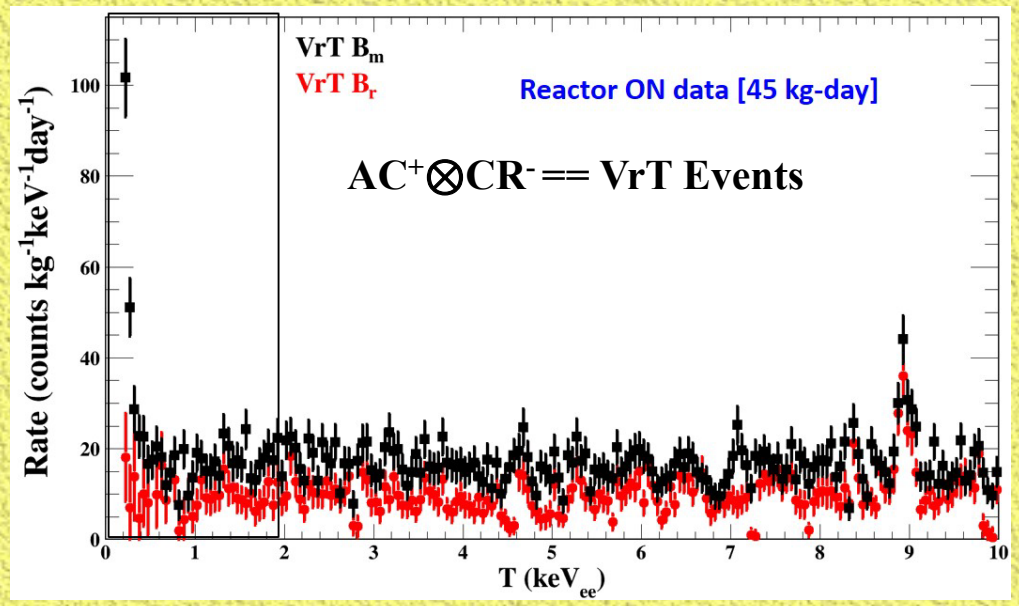


OFF data (Partial)
200-300 eV

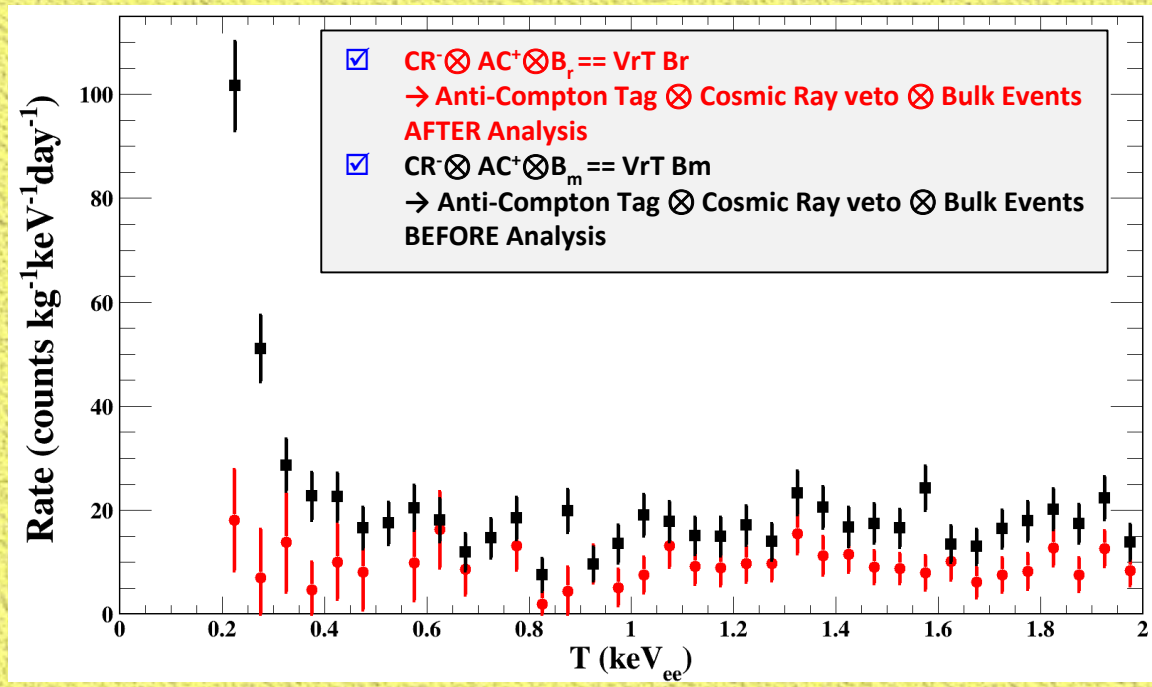
- Global Bulk-Surface (BS) Analysis with in situ data [NIM A 886, 13 (2018)]
- **Validity:** Benchmark data sets AND TEST Pulser events give consistent τ-distributions, per energy bin, as above.
- **Status:** Some data set have not yet passed this criteria

Check: Validity of Bulk/Surface Fits





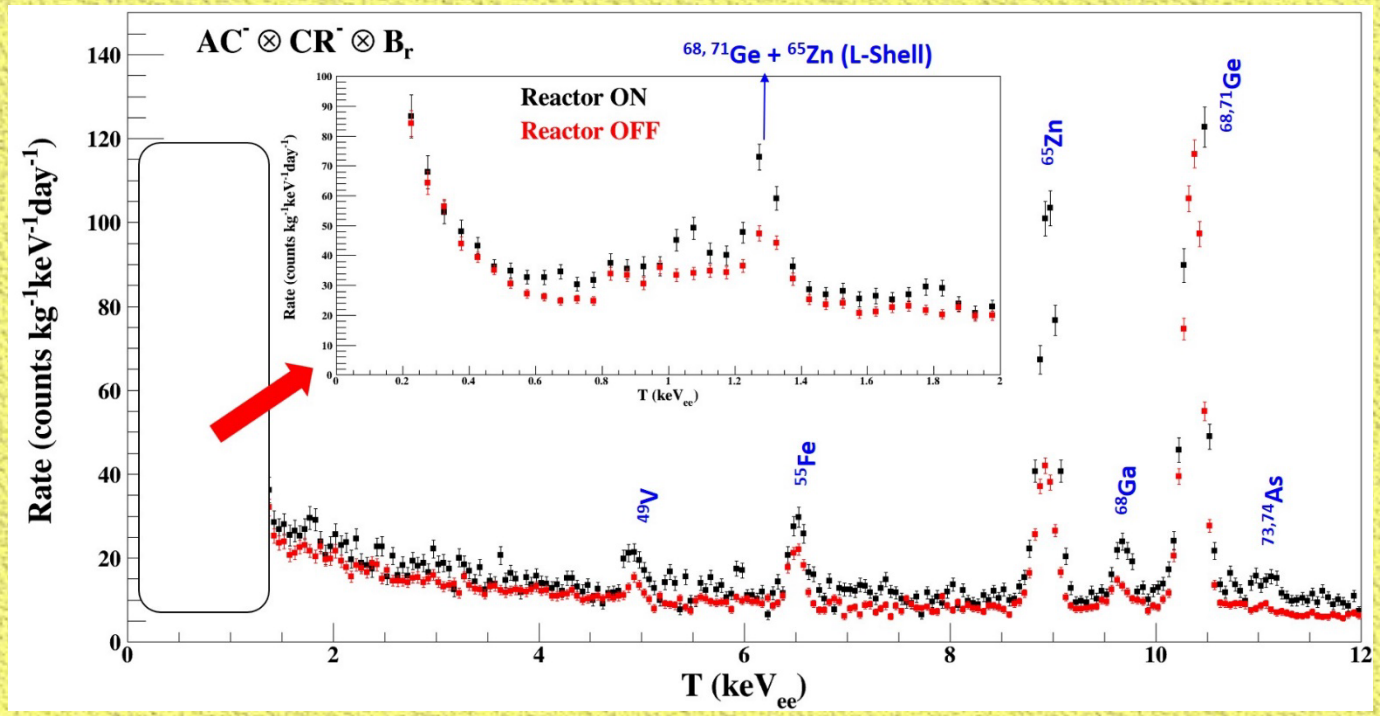
- ☑ CR⁻⊗ AC⁺⊗B_r → high energy γ-induced Compton scattering, non-cosmic
- ☑ Valid analysis: should produce flat spectra (from input rising spectra with surface contaminated events)
- ☑ Status : Some data set not yet passed this criteria

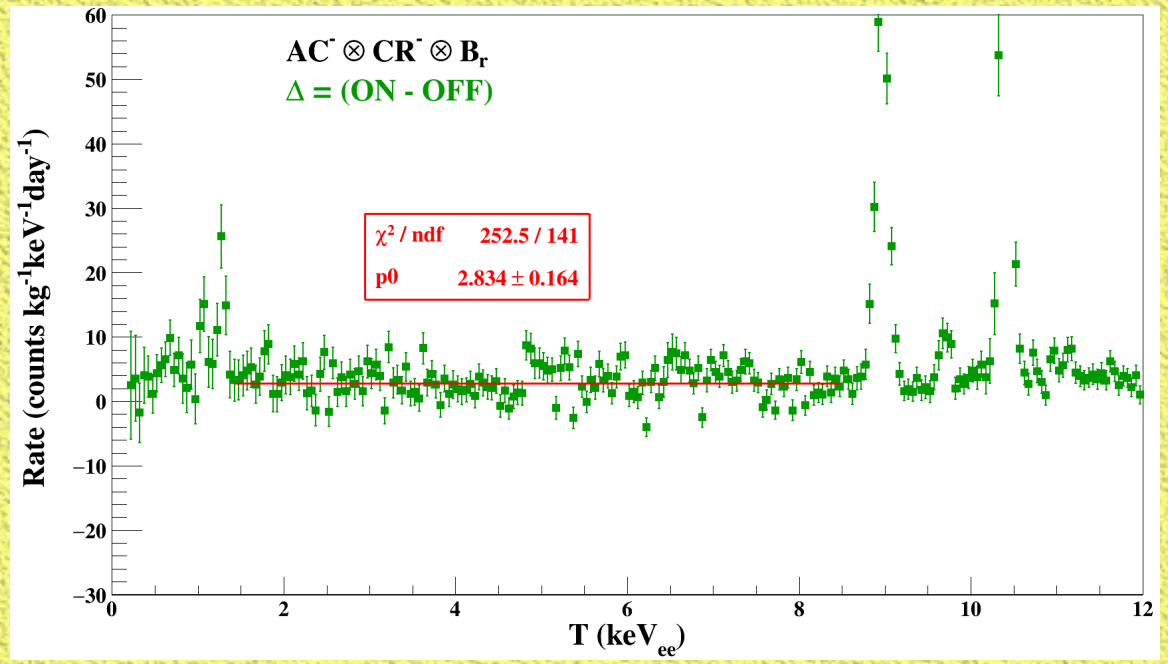


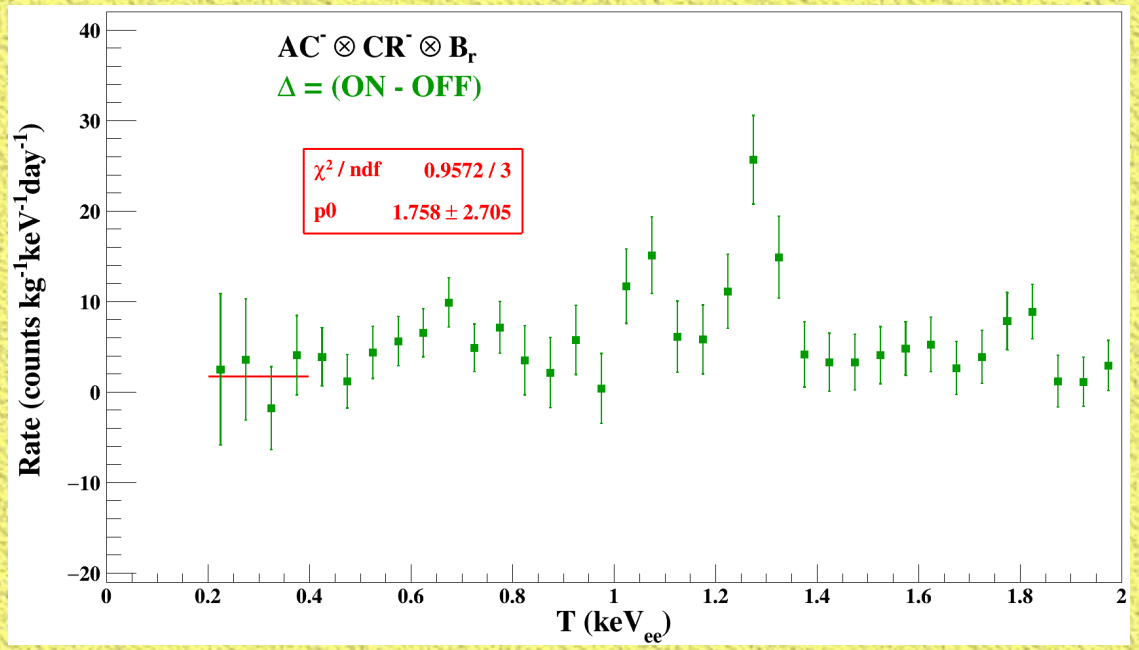
Current (Intermediate) Spectra on PHYS samples

[$CR^{-} \otimes AC^{-} \otimes B_r$]

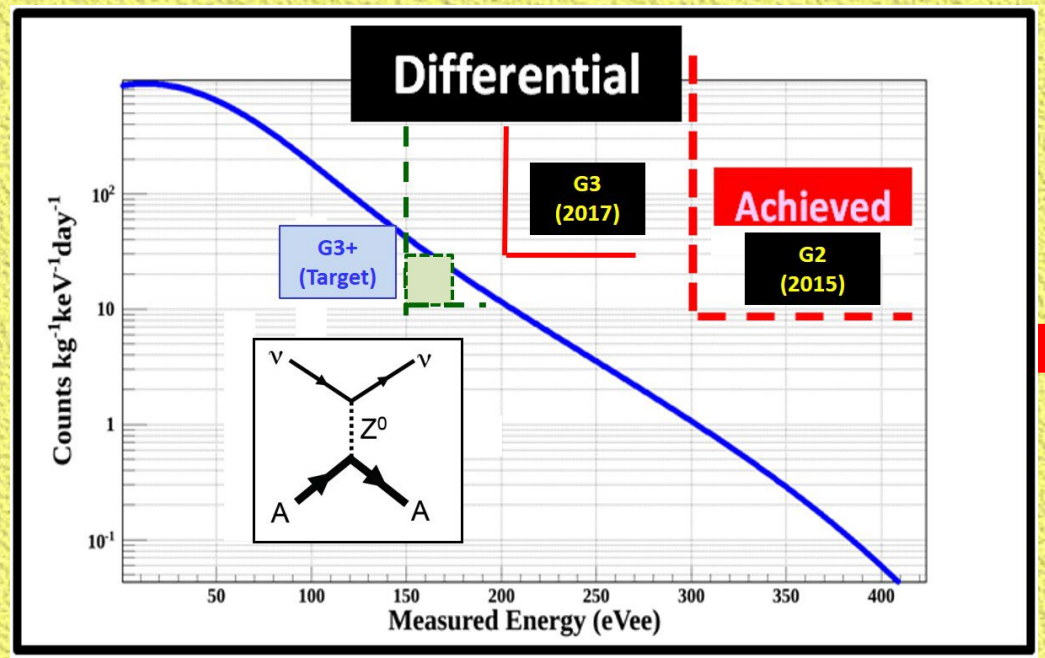
- [ON/OFF= 245/560 kg-days]
- Data Size & Details & Uncertainties may evolve after benchmark samples passing validity tests.

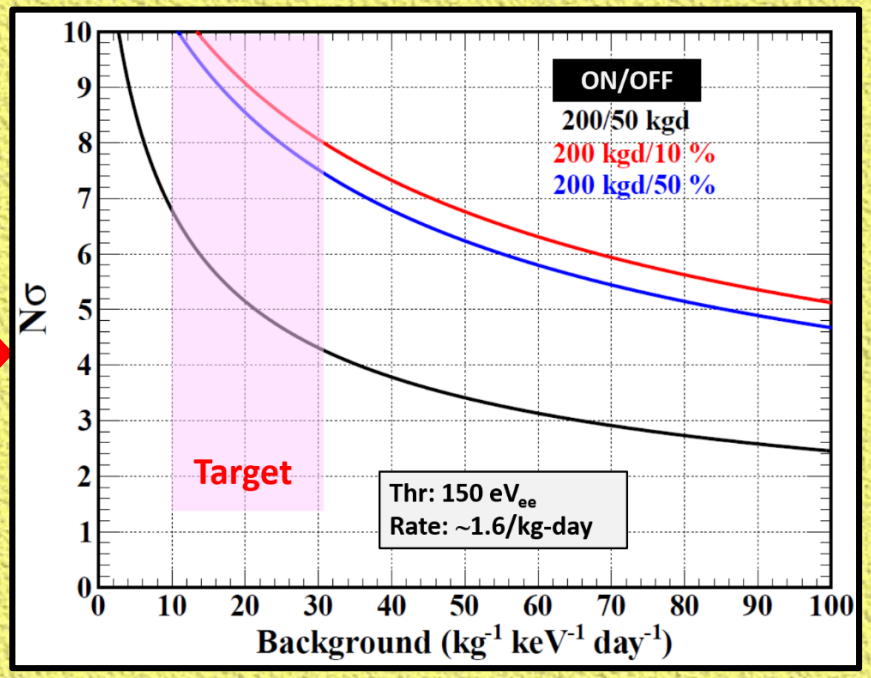






νA_{el} @ KSNL: Projected (Hypothetical) Sensitivities





Prospects:

- ☑ KSNL (2.9GW, 28m):
  - ➢ G3 (200-eV) Data ON/OFF ~ >500 / >800 kg–days
  - ➢ ν Decommissioned : 2023, Access till at least end of 2025
- ☑ R&D: G4 *(@150 eV noise edge demonstrated)* & PSD at threshold
- ☑ New site under preparation (under CDEX): *[L.T. Yang's talk]*
  Sanmen（三門）Reactor (3.4GW) @ Zhejiang（浙江）
  - ➢ possibility of site at ~11 m !

Prospects & Outlook

- Our Pursuit of C+E νNS has convoluted evolutions & spinoffs
- νA_{el} @ KSNL with TEXONO
  - ➡ Complete G3+ & G3++ analysis
  - ➡ expecting ON/OFF [>500/>800 kg-day]
- New Reactor Site at Sanmen with CDEX
  - ➡ Complementing to/Enhancing CDEX DM & $0\nu\beta\beta$ @ CJPL with Ge
- Theory: LE ν/χ/ALP cross-sections, BSM searches, QM coherency, Follow our nose ….