

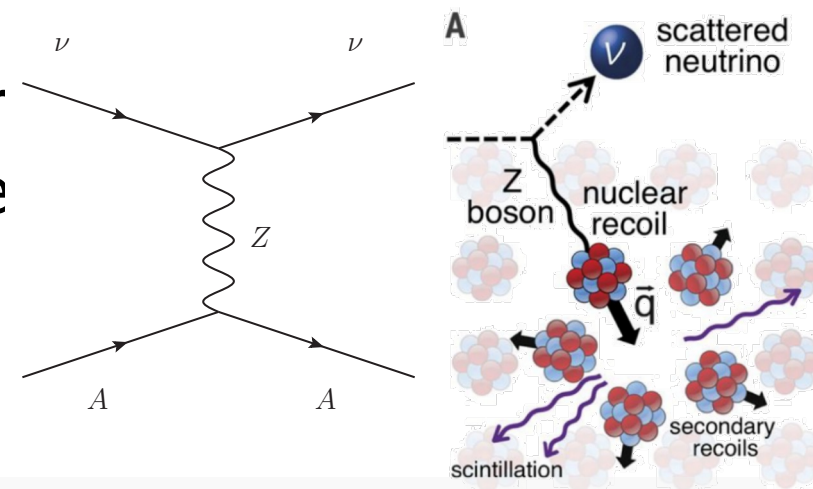
RECODE program for reactor neutrino **CEvNS** detection and Physics beyond SM

Yongcheng Wu/吴永成
Nanjing Normal University

第六届粒子物理前沿研讨会
Jul. 16 – Jul. 21, 2025

CEvNS

- Coherent Elastic Neutrino-Nucleus Scatter
 - Basic interaction between Neutrino and matter
 - Weak Neutral Current
 - The nucleus scatters Neutrino **as a whole**



Theoretical prediction (1974)



PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

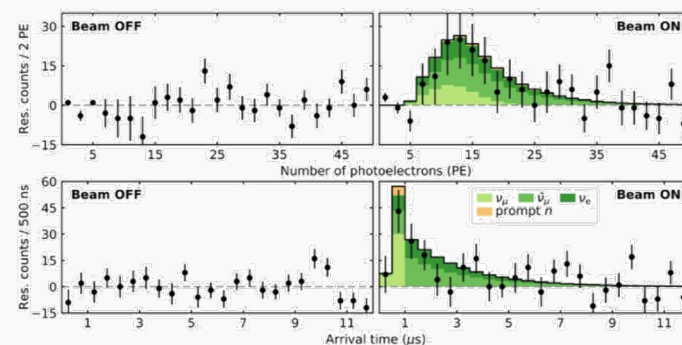
Coherent effects of a weak neutral current

Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790
(Received 15 October 1973; revised manuscript received 19 November 1973)

If there is a weak neutral current, then the elastic scattering process $\nu + A \rightarrow \nu + A$ should have a sharp coherent forward peak just as $e + A \rightarrow e + A$ does. Experiments to observe this peak can give important information on the isospin structure of the neutral current. The experiments are very difficult, although the estimated cross sections (about 10^{-38} cm² on carbon) are favorable. The coherent cross sections (in contrast to incoherent) are almost energy-independent. Therefore, energies as low as 100 MeV may be suitable. Quasi-coherent nuclear excitation processes $\nu + A \rightarrow \nu + A^*$ provide possible tests of the conservation of the weak neutral current. Because of strong coherent effects at very low energies, the nuclear elastic scattering process may be important in inhibiting cooling by neutrino emission in stellar collapse and neutron stars.

D. Freedman, PRD 9 1389 (1974)

Experimental Evidence (2017)

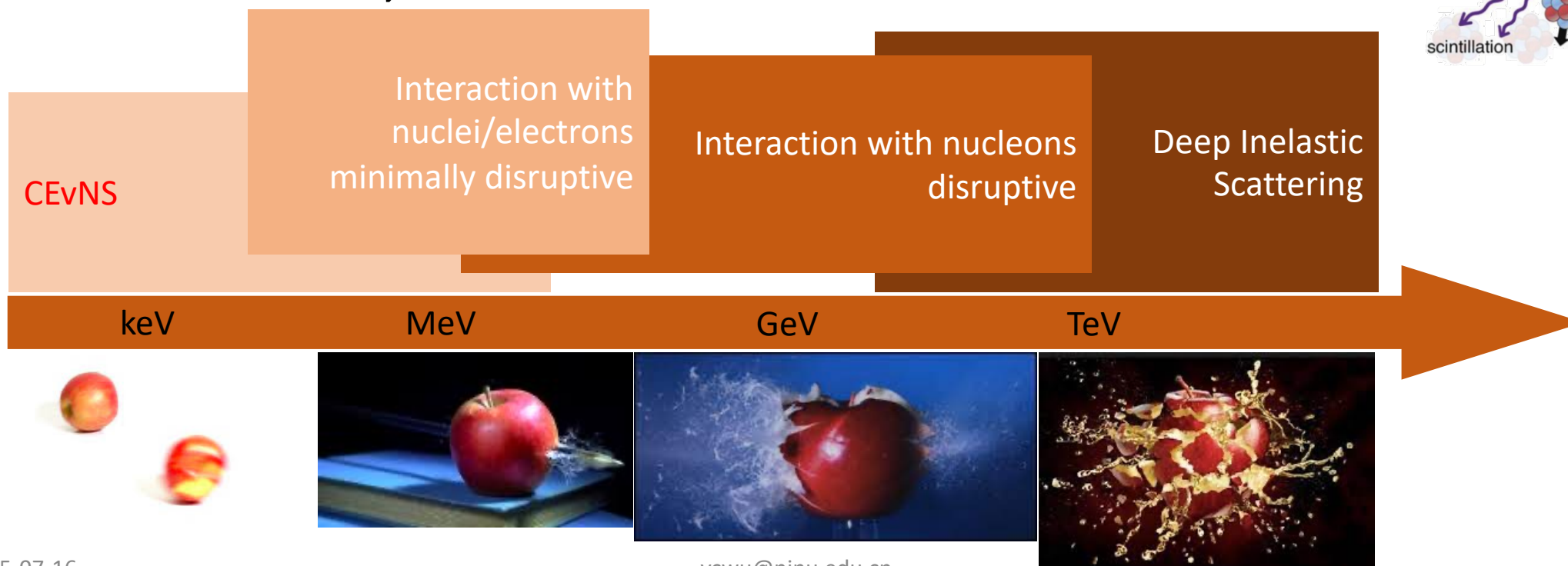
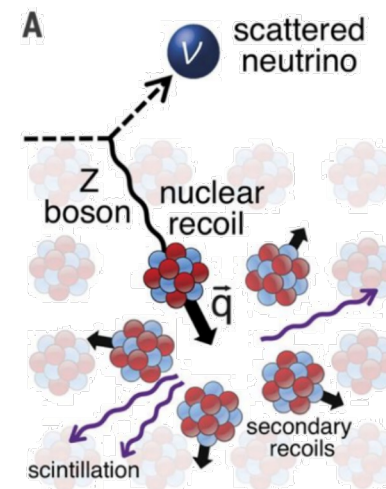


D. Akimov et al, Science 357 (2017)



CEvNS

- Coherent Elastic Neutrino-Nucleus Scattering
 - Basic interaction between Neutrino and matter in SM
 - The nucleus scatters Neutrino **as a whole**
- Dominant for $E_\nu \lesssim 50 \text{ MeV}$ $q \cdot R \ll 1$



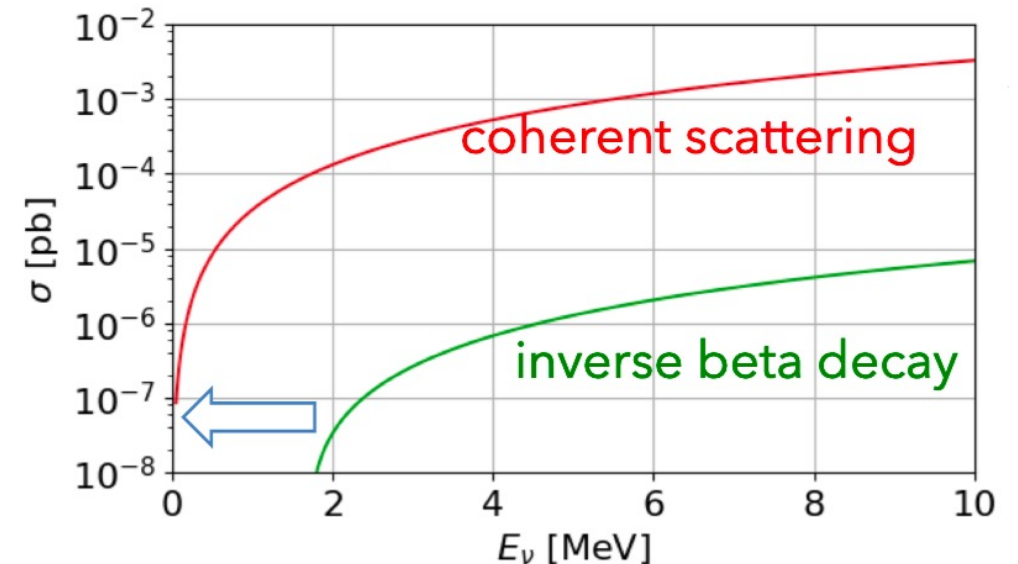
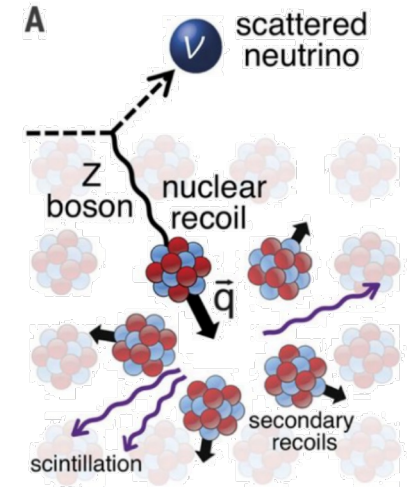
CEvNS

- Coherent Elastic Neutrino-Nucleus Scattering
 - Basic interaction between Neutrino and matter in SM
 - The nucleus scatters Neutrino **as a whole**
- Dominant for $E_\nu \lesssim 50$ MeV
- Coherent - Large Cross Section

$$\frac{d\sigma}{dE_R} = \frac{G_F^2 M}{8\pi} Q_W^2 |F(q)|^2 \left(2 - \frac{2E_R}{E_\nu} + \left(\frac{E_R}{E_\nu} \right)^2 - \frac{ME_R}{E_\nu^2} \right)$$

$$q \cdot R \ll 1$$

$$\left. \begin{aligned} Q_W &= N - (1 - 4 \sin^2 \theta_W)Z \\ \sin^2 \theta_W &\approx 0.23 \end{aligned} \right\} \sigma \propto N^2$$



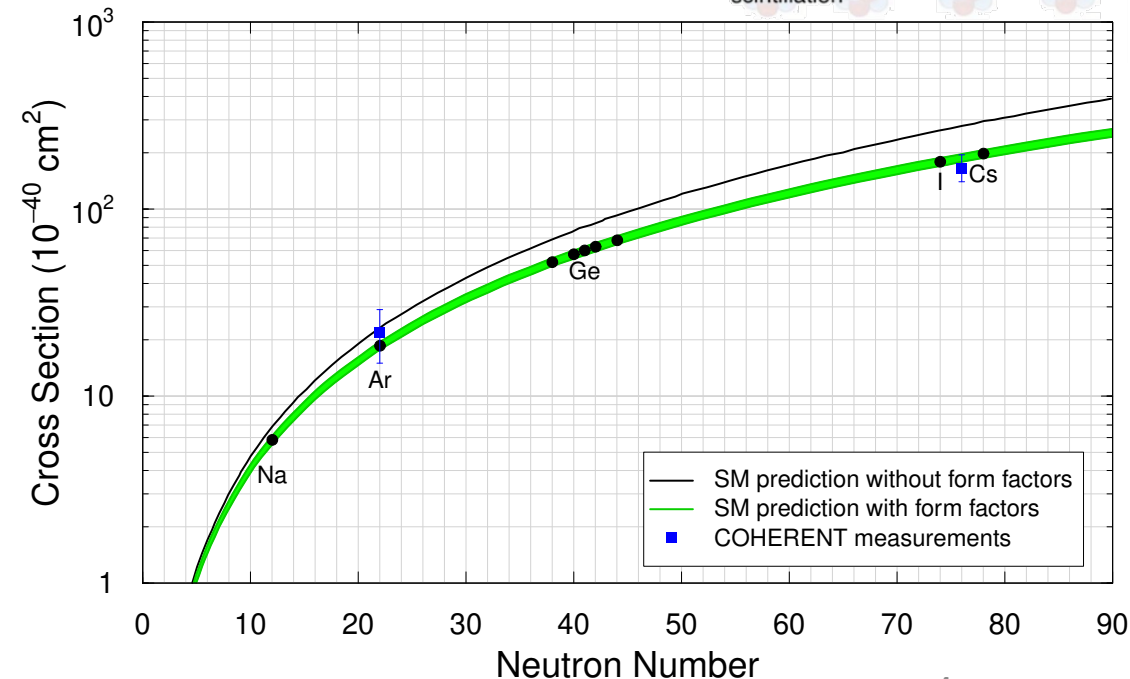
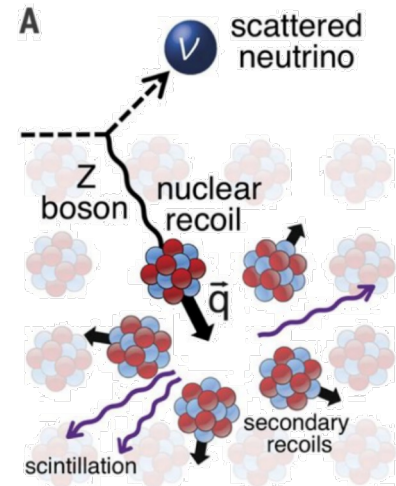
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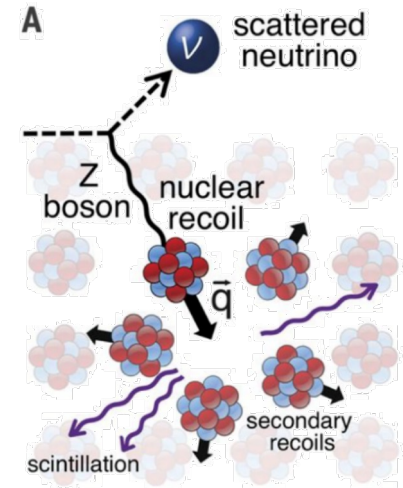
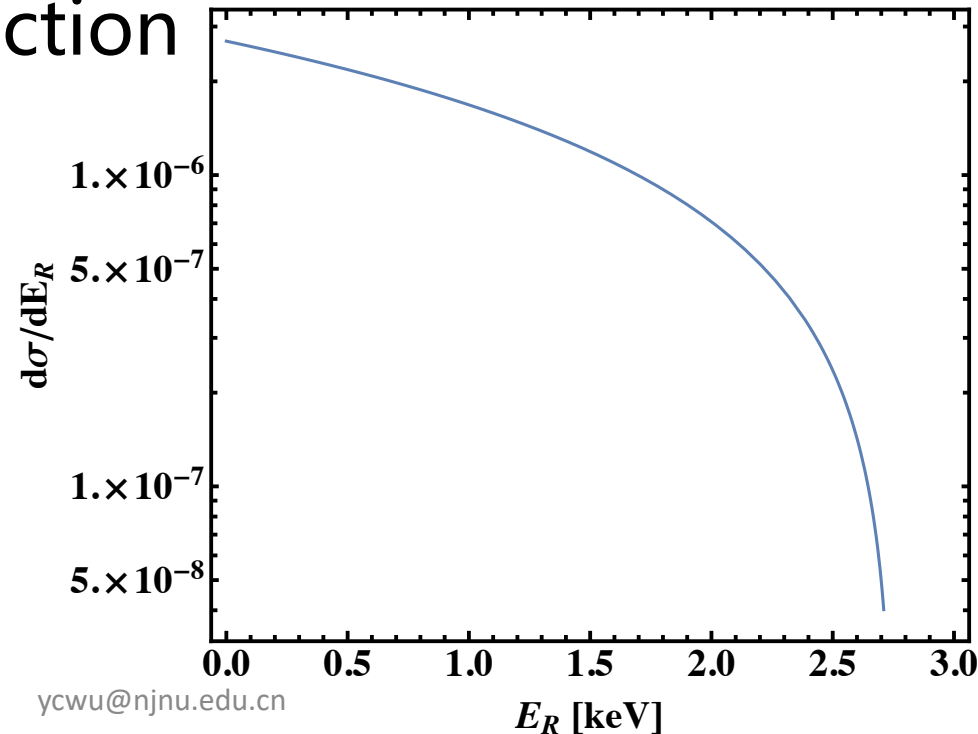
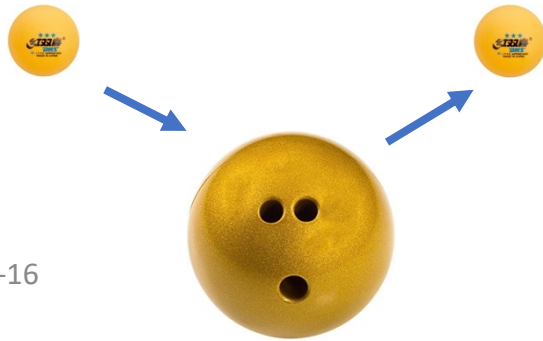
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CEvNS

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 - Basic interaction between Neutrino and matter in SM
 - The nucleus scatters Neutrino **as a whole**
- Dominant for $E_\nu \lesssim 50$ MeV
- Coherent - Large Cross Section
- Recoil Energy is Small

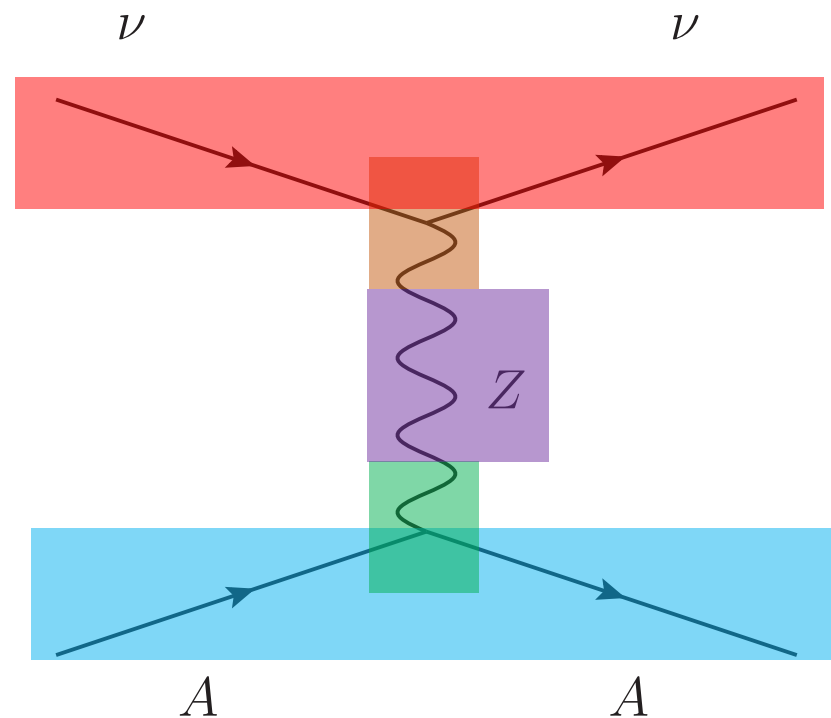
$$E_R \sim \frac{E_\nu^2}{M} = \frac{(E_\nu/\text{MeV})^2}{A} \text{ keV}$$



CEvNS: Physics Motivation

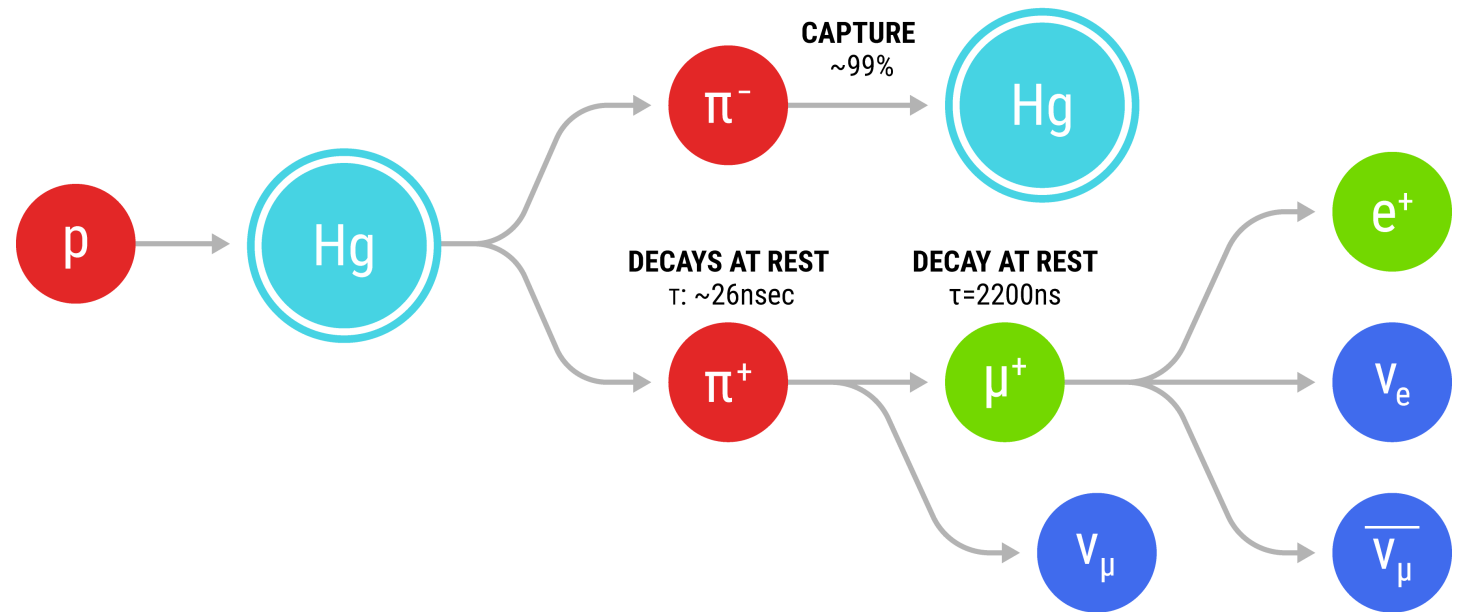
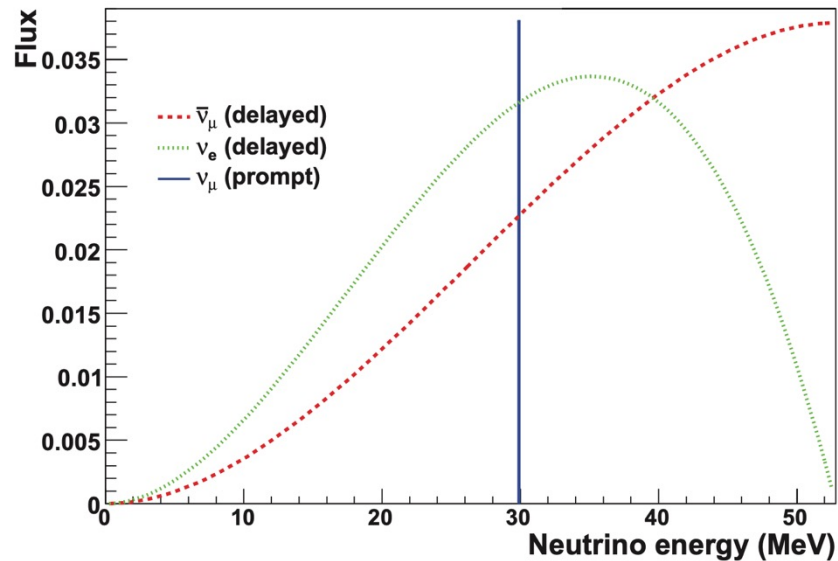
- For “Old” Physics
 - Testing Standard Model
 - Nuclear Form Factor
 - Neutron Distribution Radius
- For “New” Physics
 - Neutrino Interaction/Properties
 - Light Mediator/DM
 - Different in-coming particles:
 - ALP, Sterile Neutrino
- As Background for DM Detection
- Practical Tool
 - Monitoring

$$\frac{d\sigma}{dE_R} = \frac{G_F^2 M}{8\pi} Q_W^2 |F(q)|^2 \left(2 - \frac{2E_R}{E_\nu} + \left(\frac{E_R}{E_\nu} \right)^2 - \frac{ME_R}{E_\nu^2} \right)$$



CEvNS: Neutrino Sources

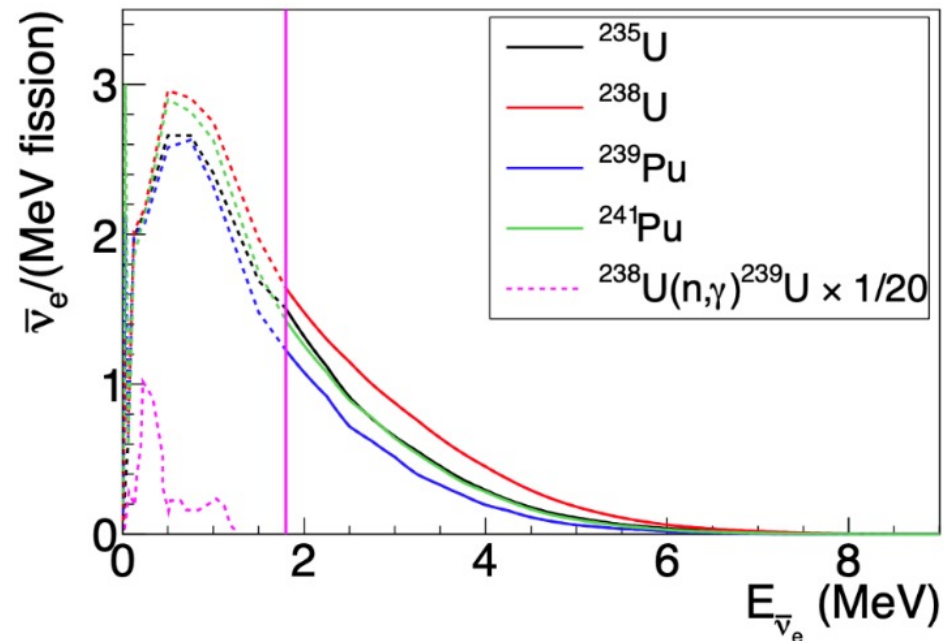
- Stopped-Pion Decay: π -DAR
 - Several 10s MeV
 - Pulsed beam
 - Good for Background rejection
 - $\sim 4.3 \times 10^7 \text{ cm}^{-2} \text{ s}^{-1}$ at 20m
 - $\nu_\mu, \bar{\nu}_\mu, \nu_e$



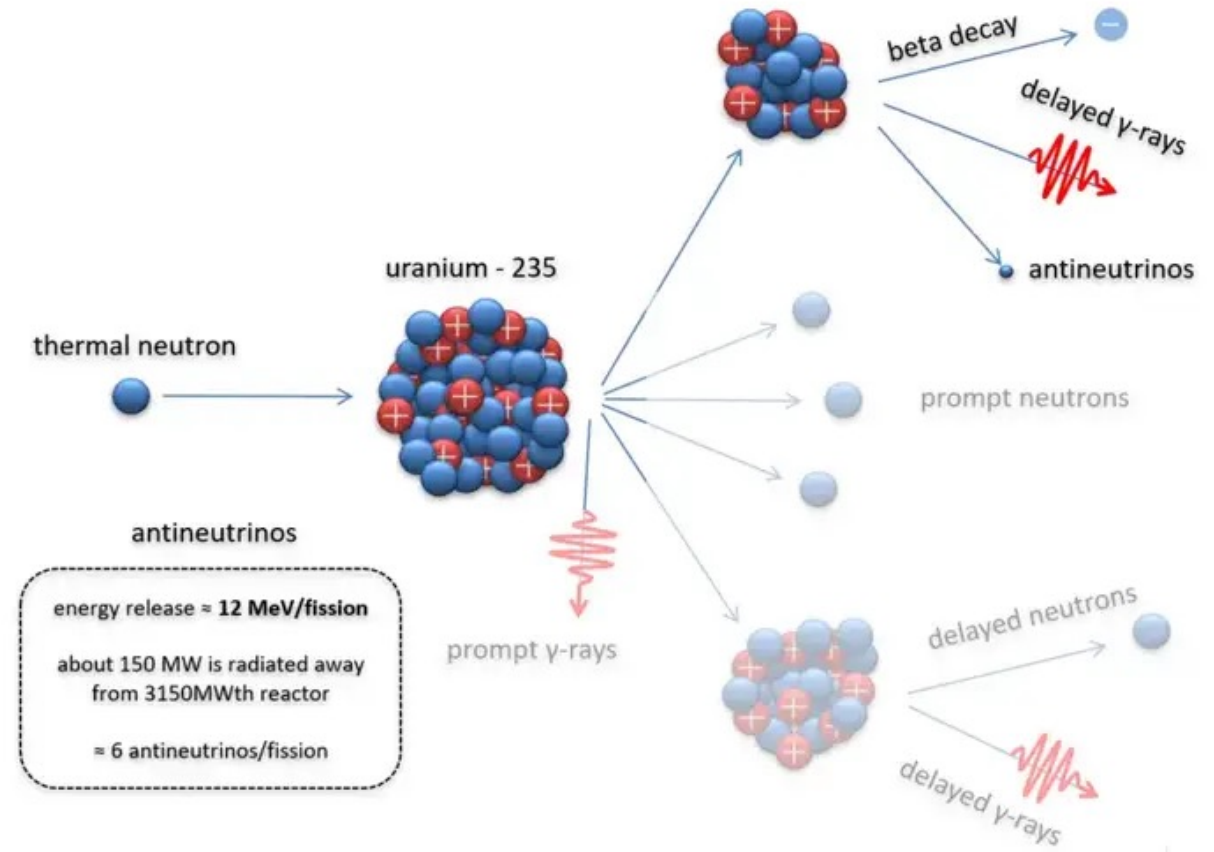
CEvNS: Neutrino Sources

- Reactor Neutrinos

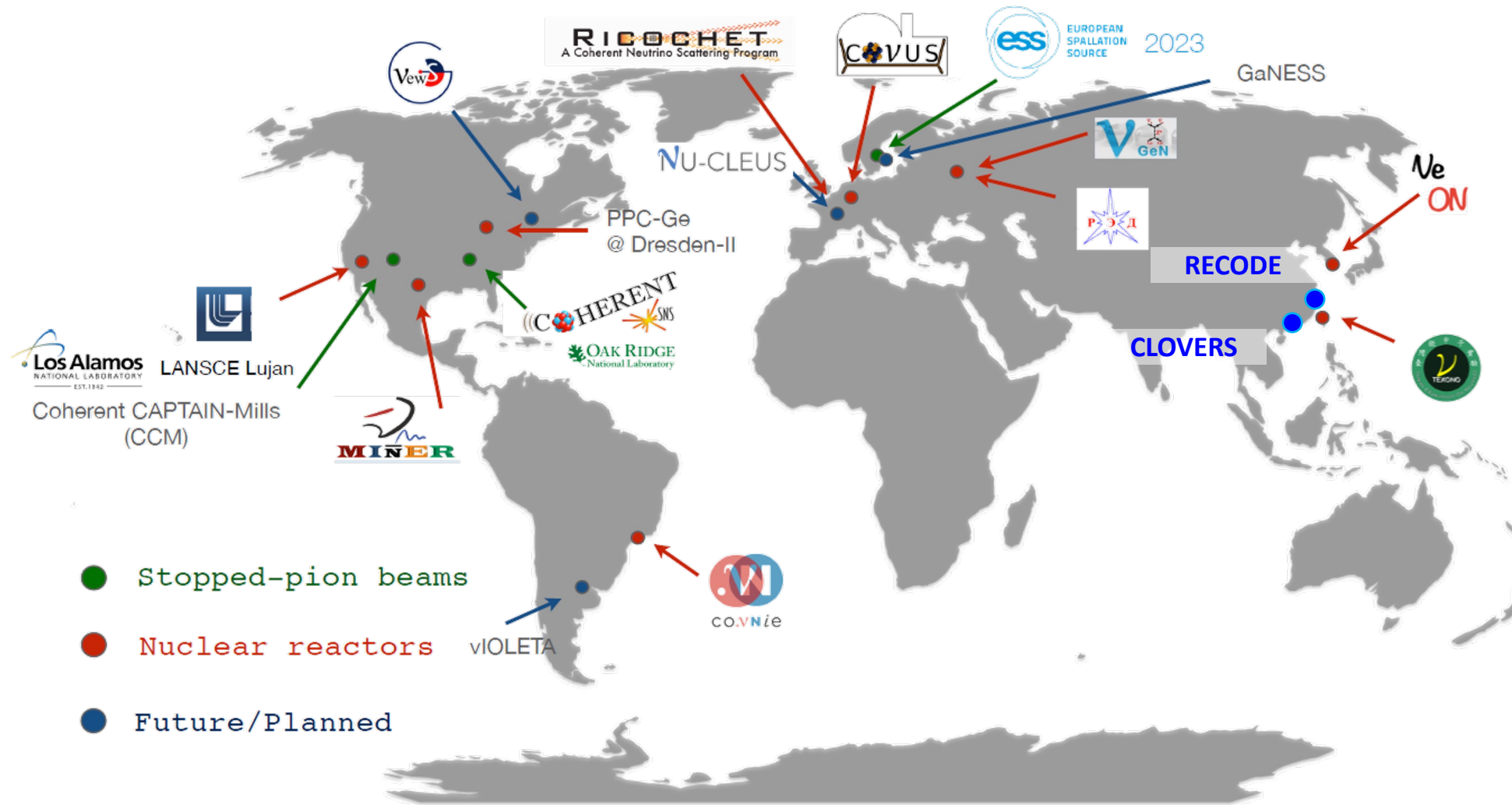
- High flux
 - $10^{12} - 10^{13} \text{ cm}^{-2} \text{ s}^{-1}$ at 15m
- Low energy, up to 8/10 MeV
 - Low threshold for detector
- Mainly $\bar{\nu}_e$



reactor antineutrinos

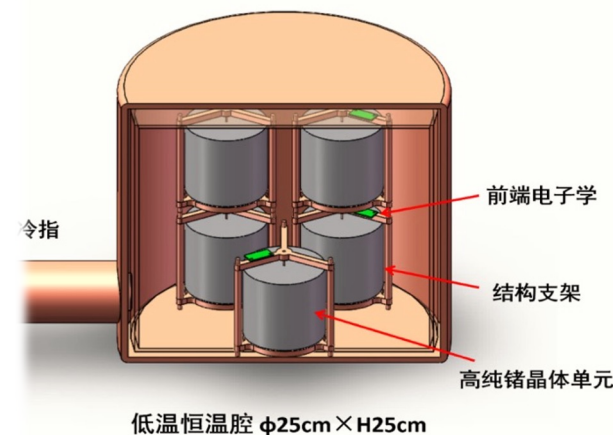


CEvNS: Experiments



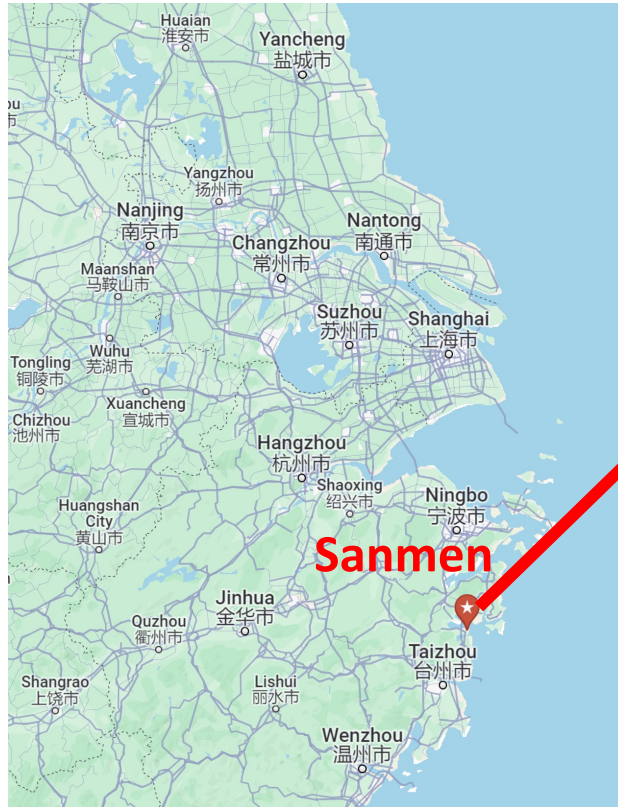
RECODE Program

- RECODE
 - REactor neutrino COherent scattering DEtection Experiment
 - Low threshold Ge detectors
 - Reactor neutrinos
- Project Goals:
 - Two Ge arrays (10kg in total)
 - Energy threshold ~ 1 keVnr (~ 160 eVee)
 - ~ 500 CEvNS events/kg/year
 - Background level < 2 counts/kg/keV/day



RECODE Location

- Sanmen Nuclear Power Plant (AP1000)
 - @Taizhou, Zhejiang
 - Thermal power: 3.4 GW

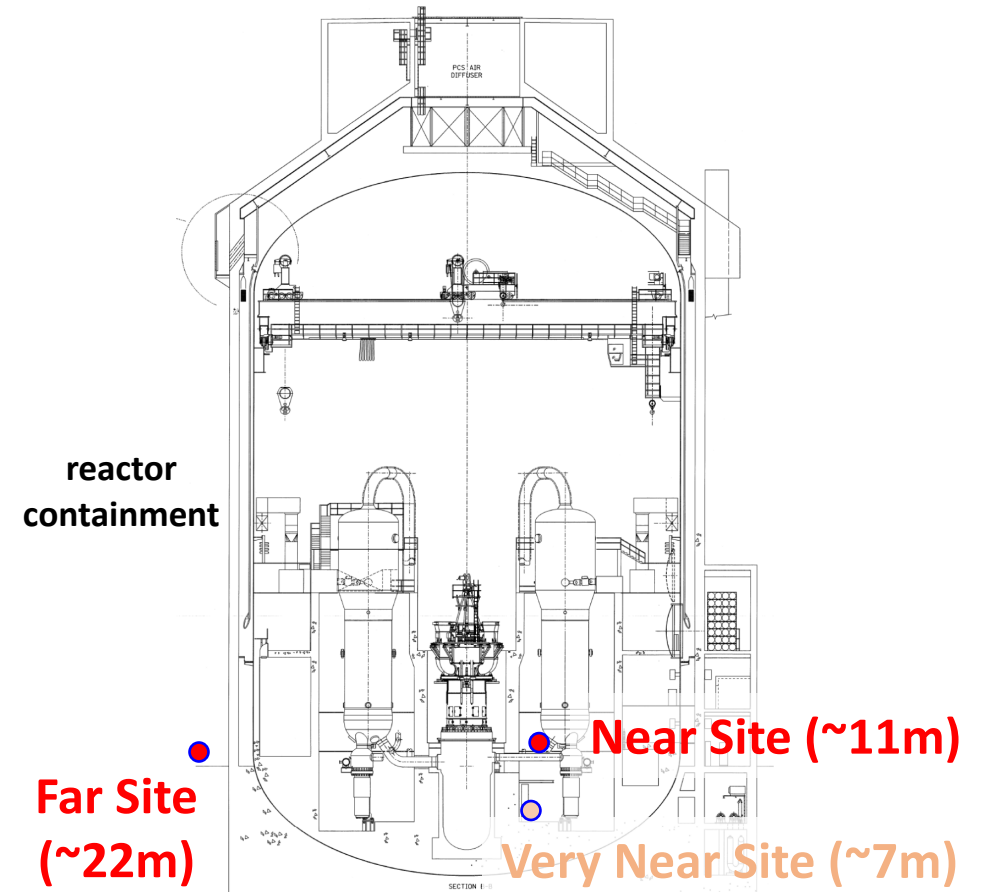


RECODE Detector Location

- First phase:
 - Far site (~22m) + Near Site (~11m)
- Future Option
 - Very Near Site (~7m)

Distance	Power	Neutrino Flux	Photon Flux
FS ~ 22m	3.4GWth	$1.4 \cdot 10^{13} \text{ v/cm}^2/\text{s}$	$9.4 \cdot 10^{12} / \text{cm}^2/\text{s}$
NS ~ 11m	3.4GWth	$5.6 \cdot 10^{13} \text{ v/cm}^2/\text{s}$	$3.8 \cdot 10^{13} / \text{cm}^2/\text{s}$
VNS ~ 7m	3.4GWth	$1.4 \cdot 10^{14} \text{ v/cm}^2/\text{s}$	$9.3 \cdot 10^{13} / \text{cm}^2/\text{s}$

- Movable Far site (~20 to 30 m)
- Joint analysis:
 - Far + Near (very near)
 - On + Off (18:1) - Background Analysis
 - Reduce systematical uncertainties



RECODE

- Comparison with other Exps.

Experiment	Target	Mass	Threshold	Reactor	Distance to reactor core	Thermal power	Neutrino Flux	Location
CONNIE	Si CCDs	50 g	~ 40 eVee	Angra 2 reactor	30 m	3.8 GWth	$7.8 \cdot 10^{12}$ v/cm ² /s	Brazil
MINER	Ge/Si	4 kg	~ 100 eVnr	TRIGA reactor	2~10m	1 MWth	$\sim 10^{12}$ v/cm ² /s	USA
RICOCHET	Ge & Zinc	32 g (Ge)	55 eVee	ILL reactor	8 m	58 MWth	$1.6 \cdot 10^{12}$ v/cm ² /s	France
CONUS	HPGe	3.74 kg	~ 210 eVee	Brokdorf (KBR)	17 m	3.9 GWth	$2.3 \cdot 10^{13}$ v/cm ² /s	Germany
COUNS+	HPGe	3.74 kg	~150 eVee	Leibstadt (KKL)	20.7m	3.6 GWth	$1.5 \cdot 10^{13}$ v/cm ² /s	Switzerland
Nu-Gen	HPGe	1.6 kg	350 eVee	Kalinin NPP	11.1-12.5 m	3.1 GWth	$3.4 - 4.4 \cdot 10^{13}$ v/cm ² /s	Russia
TEXONO	HPGe	1 kg	~200 eVee	Kuo-Sheng NPP	28m	2.9 GWth	$6.4 \cdot 10^{12}$ v/cm ² /s	Taiwan, China
RECODE	HPGe	1-5kg	~160 eVee	Sanmen NPP	NS ~ 11m	3.4GWth	$5.6 \cdot 10^{13}$ v/cm ² /s	China
	HPGe	10kg	~160 eVee		FS ~ 22m	3.4GWth	$1.4 \cdot 10^{13}$ v/cm ² /s	China
RELICS	LXe	50kg	~1 keVnr	Sanmen NPP	22m	3.4GWth	$1.4 \cdot 10^{13}$ v/cm ² /s	China

RECODE Detectors

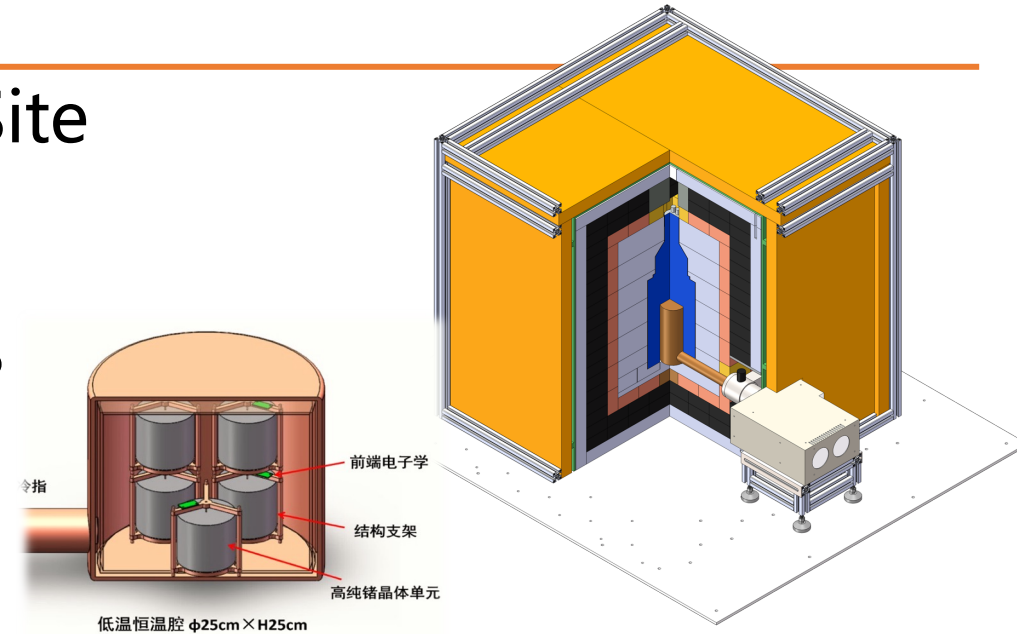
- 5kg EC PCGe for Near Site/Very Near Site
- 5kg LN PCGe for Far Site

■ **Shielding size: 1m(W)*1m(L)*1.1m(H)**

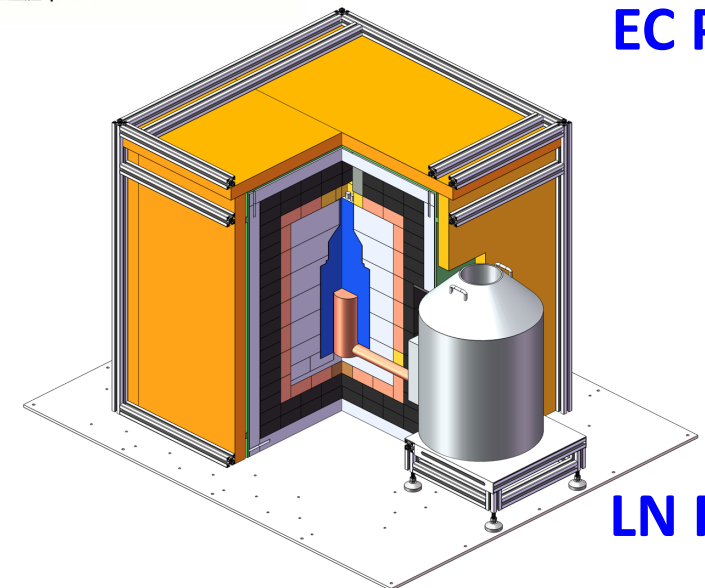
- Anti coincidence efficiency for **cosmic ray**: > 99%
- **Gamma** flux: reduce by 5 orders of magnitude
- **Neutron** flux: reduce by 3 orders of magnitude

■ **From outer to inner:**

- ✓ Plastic scintillator muon veto (3 cm), **CRV/CRT events**
- ✓ Aluminum Structure (4 cm)
- ✓ Acrylic box (0.8 cm), **N₂ purging to suppress radon bkg**
- ✓ Polyethylene (5 cm)
- ✓ Lead (10 cm)
- ✓ Copper (5 cm)
- ✓ Polyethylene (~15 cm)
- ✓ NaI anti-Compton Detector (5 cm), **ACV/ACT events**



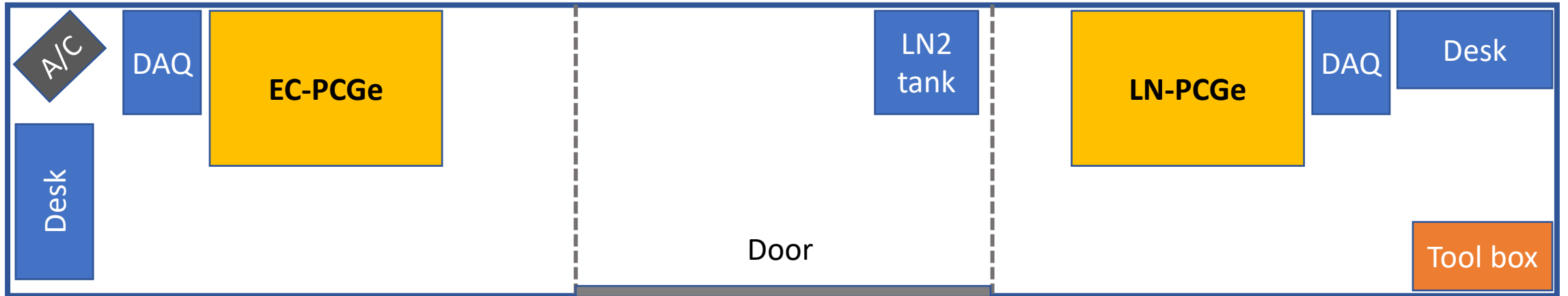
EC PCGe



LN PCGe

RECODE Detectors

- Ground Testing Container - Outside the containment of Sanmen NPP



2025-07-16

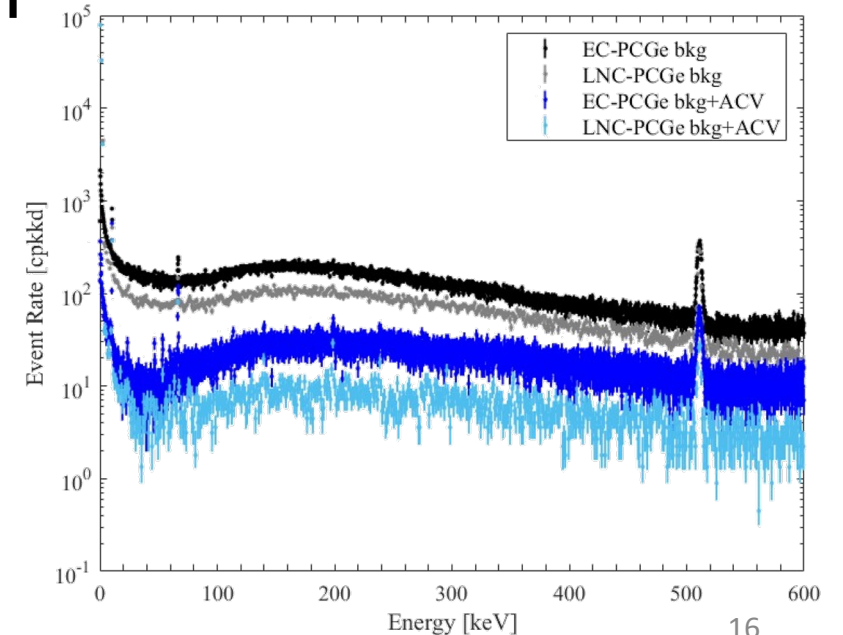
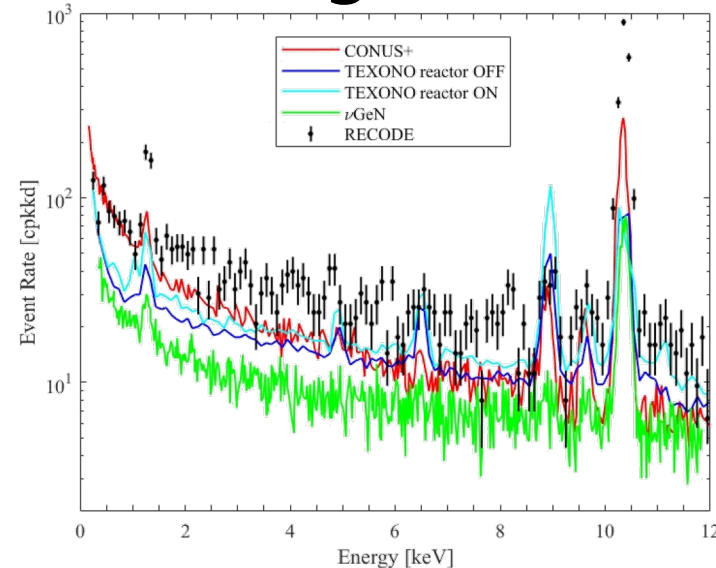
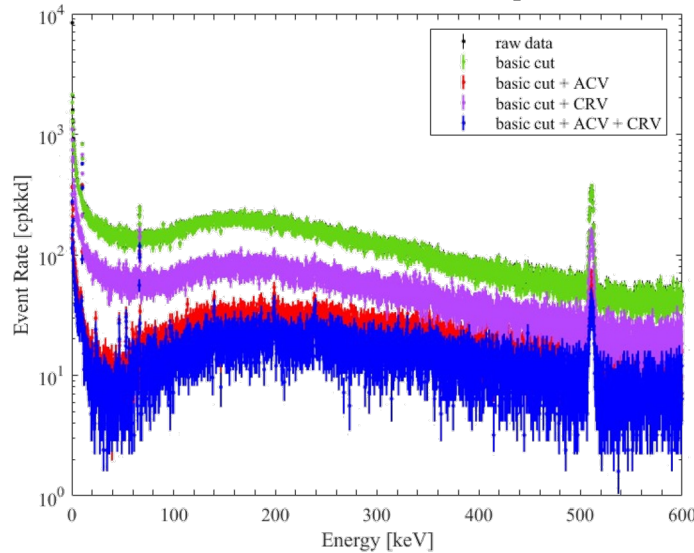
ycwu@nju.edu.cn



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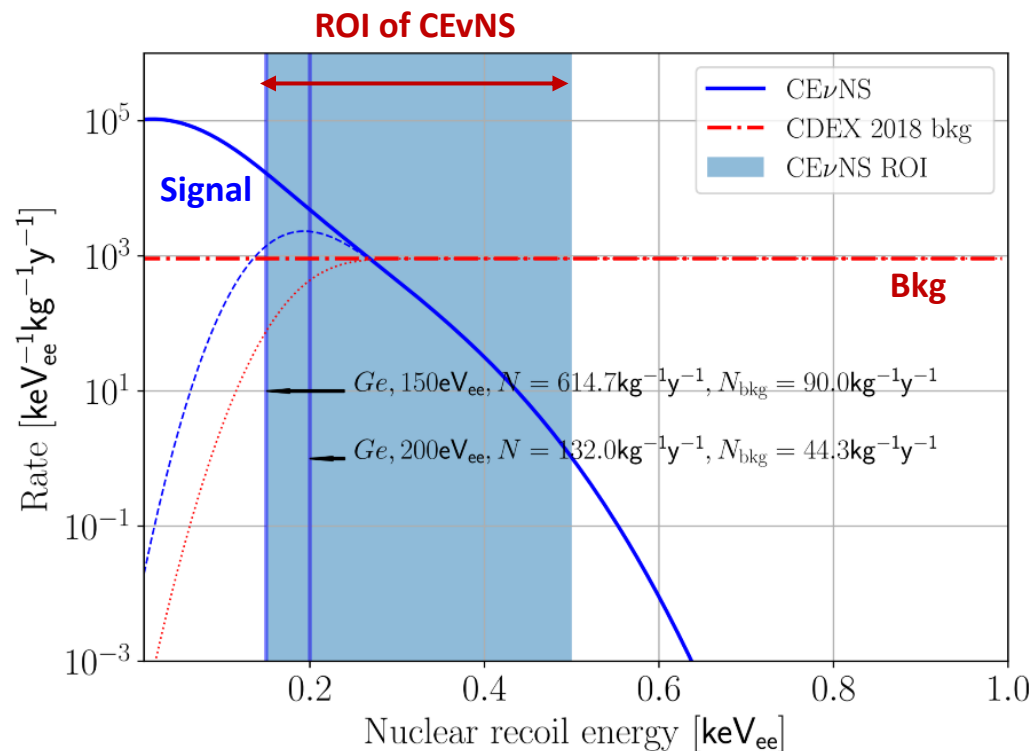
RECODE Ground test

- Test the shielding performance
 - Met the expectations w/o additional concrete coverage
 - Cosmic ray induced background will be further reduced when the detectors are placed at experimental sites
 - Additional reactor neutron background needs to be considered
 - Equivalent water depth coverage thickness is being evaluated
- Formal Operation starting this October



RECODE: Uncertainties

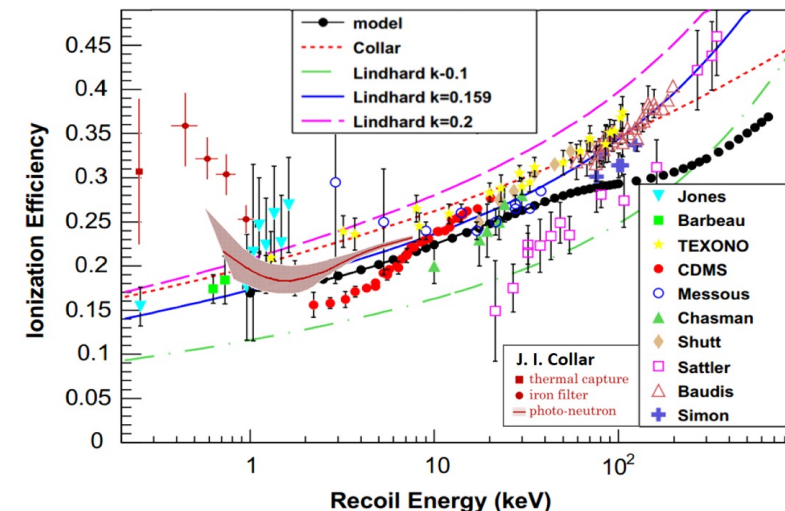
- Statistical:
 - Signal/Noise > 5:1
 - ~ 500 CEvNS events/kg/year
 - 1.5% statistical



2025-07-16 Expected CEvNS spectrum in Ge

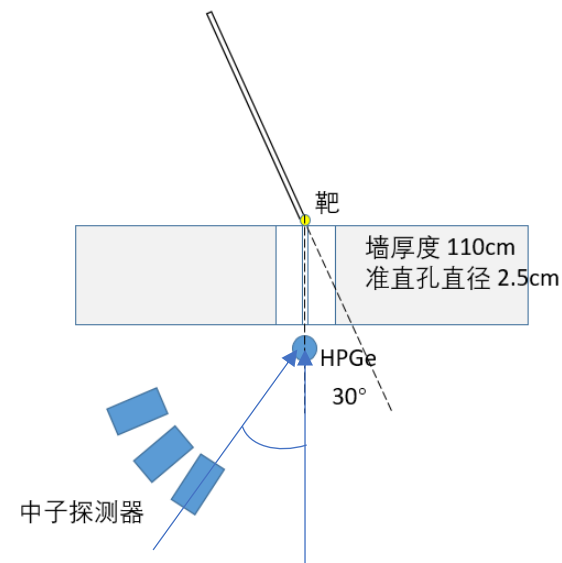
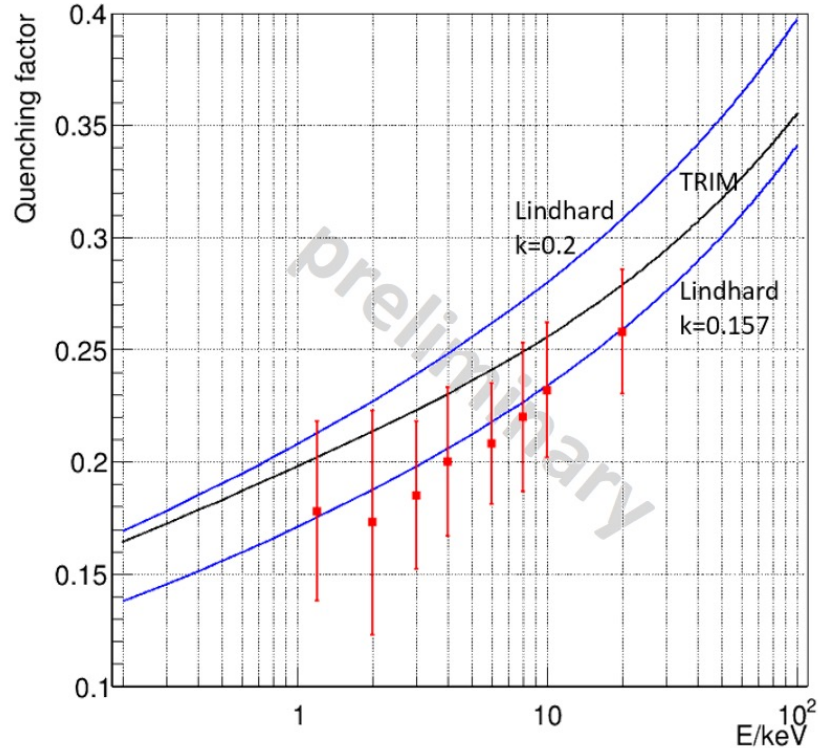
ycwu@nju.edu.cn

- Systematics:
 - Quenching factor: 10%-20%
 - Reactor neutrino intensity: 3%
 - Reduced through joint measurement
- Background modeling:
 - Ground Testing
 - ON/OFF measurement



RECODE: Quenching factor measurement

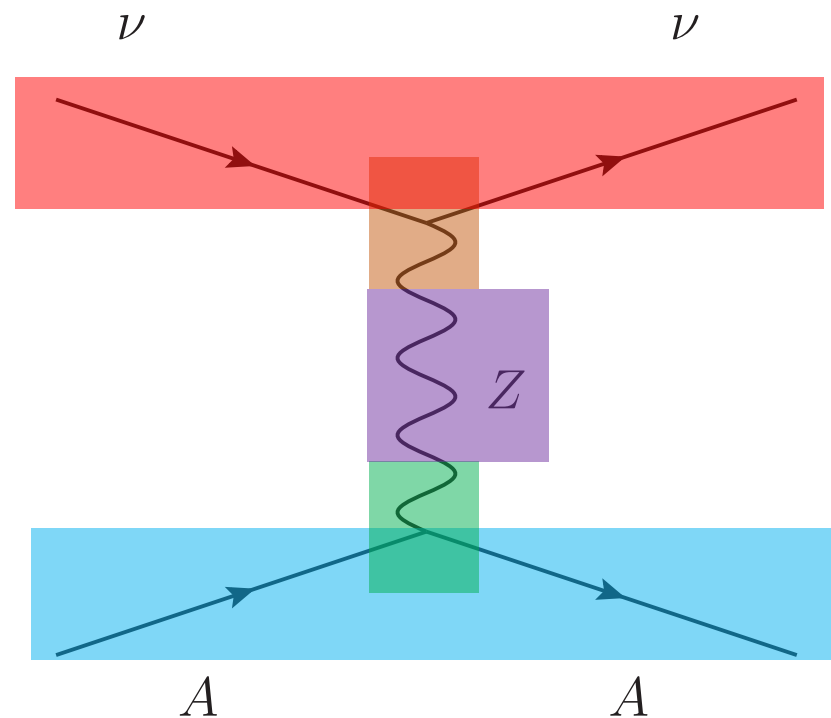
- Measurement of Ge QF @ 1-10 keV
 - 10g ultra-low threshold high-purity germanium detector



CEvNS: Physics Motivation

- For “Old” Physics
 - Testing Standard Model
 - Nuclear Form Factor
 - Neutron Distribution Radius
- For “New” Physics
 - Neutrino Interaction/Properties
 - Light Mediator/DM
 - Different in-coming particles:
 - ALP, Sterile Neutrino
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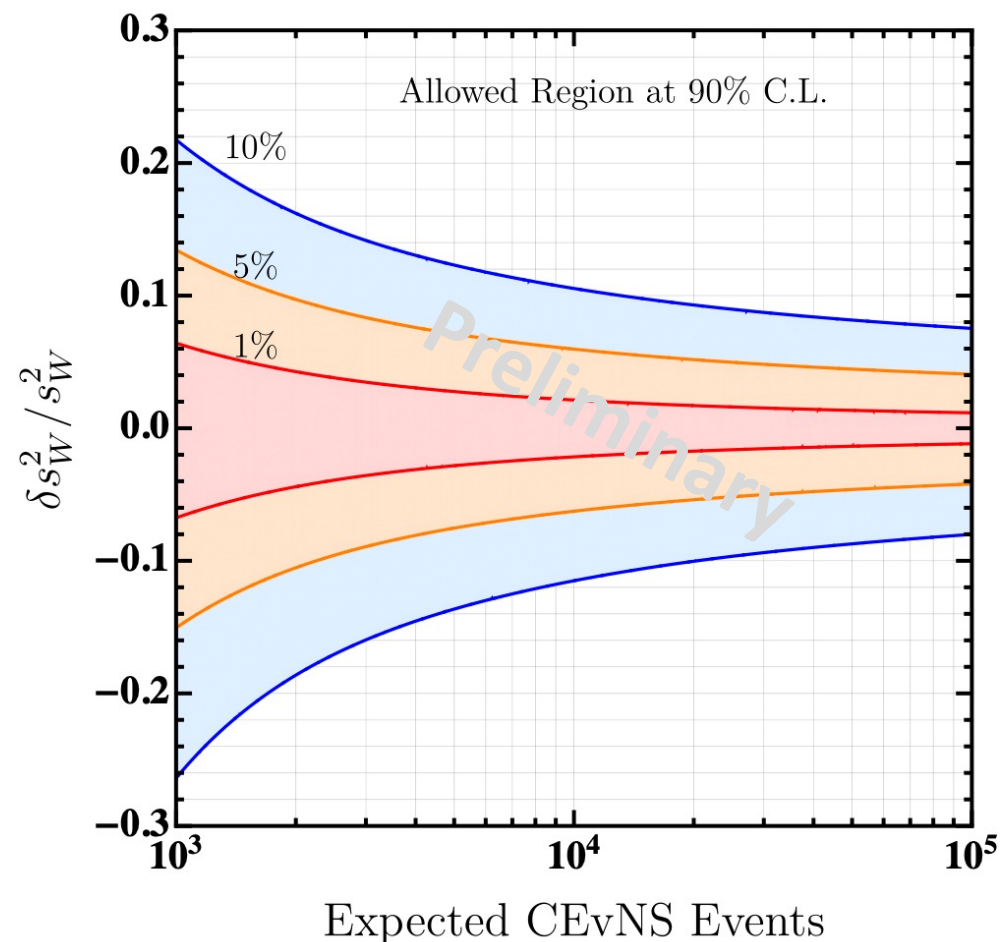
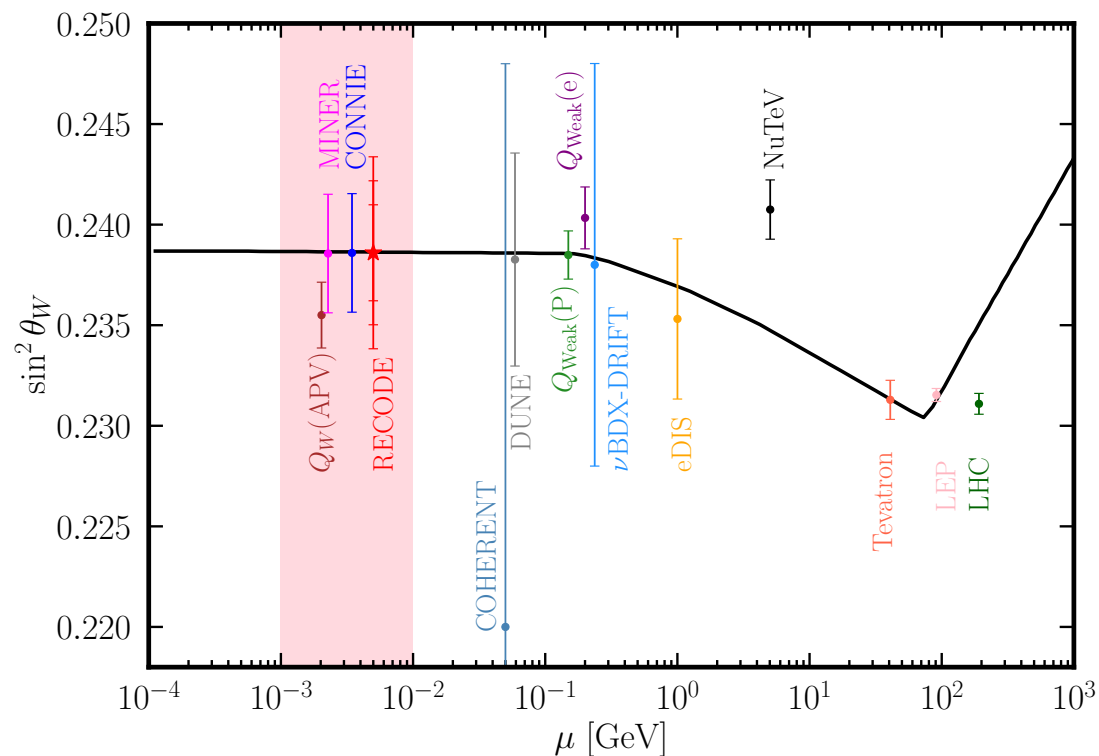


RECODE: Prospects

- Weak Mixing Angle

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$$Q_W = N - (1 - 4 \sin^2 \theta_W) Z$$



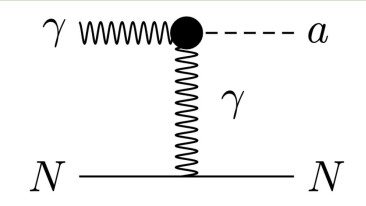
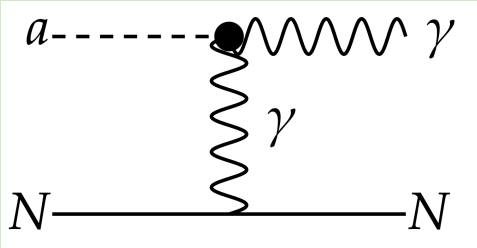
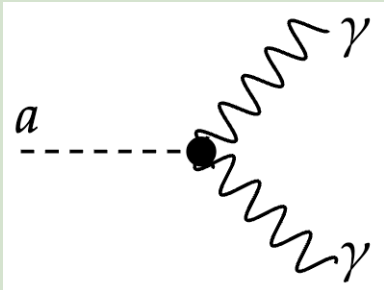
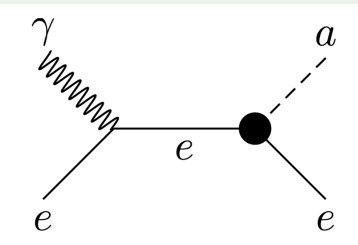
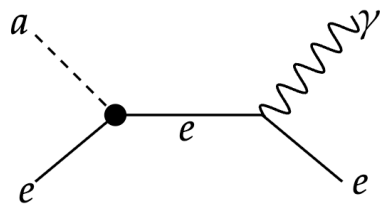
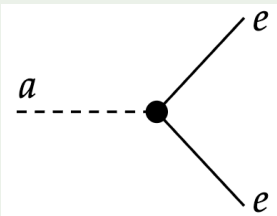
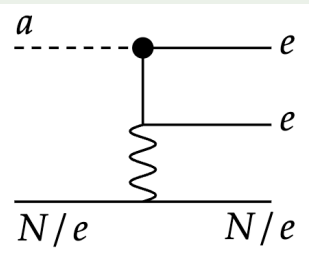
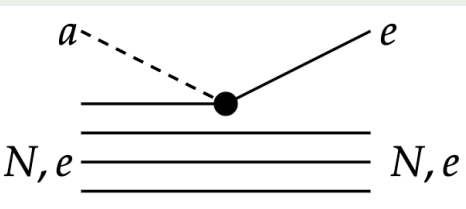
RECODE: Prospects

- ALP From Reactor

- Photon Flux

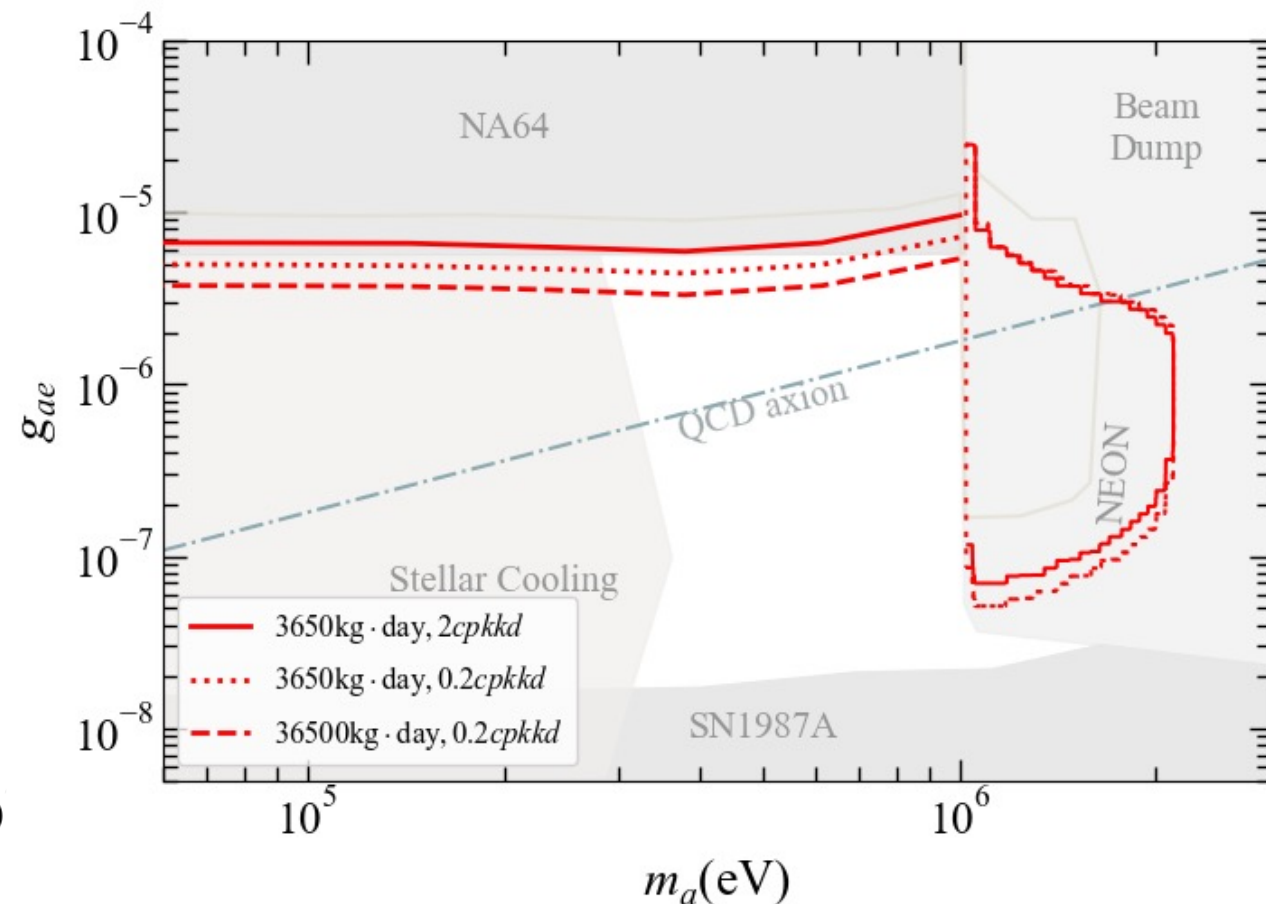
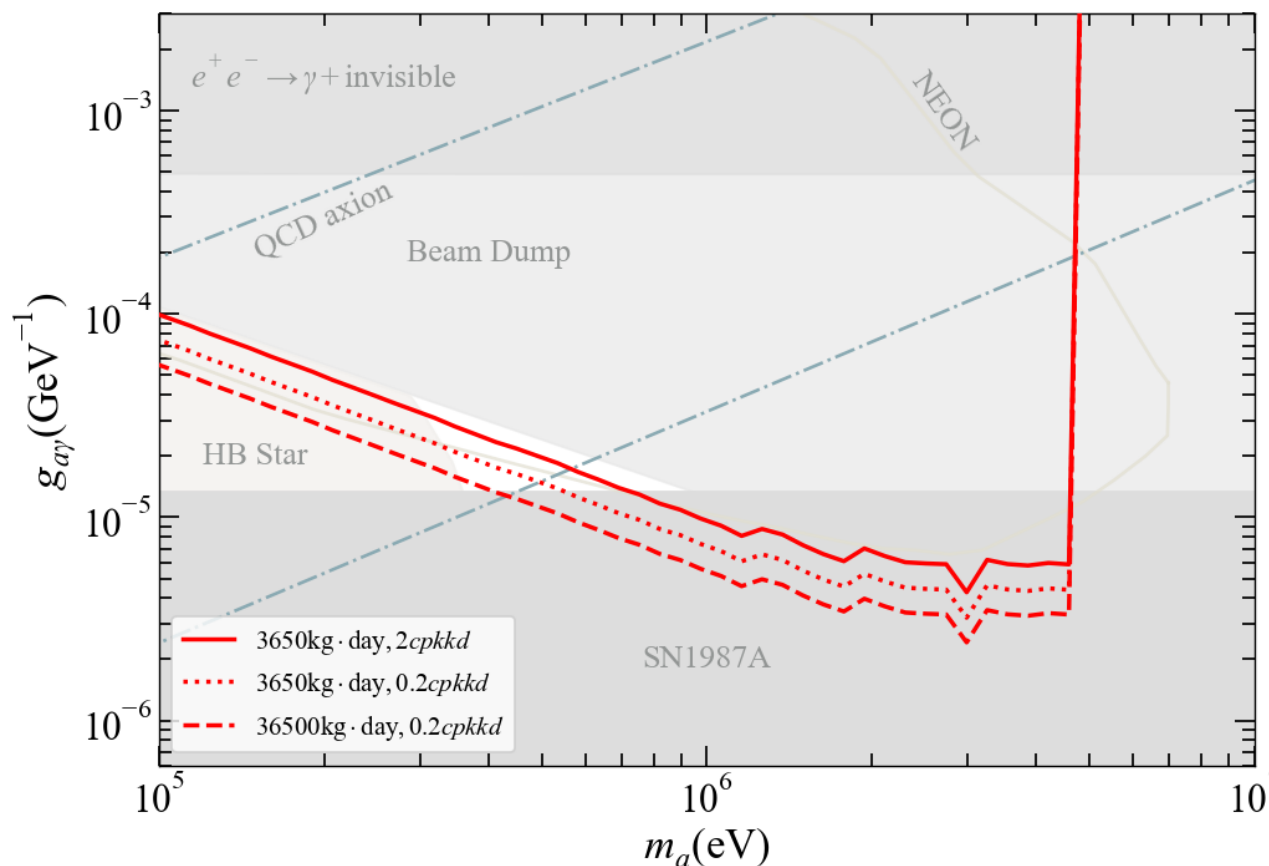
$$\mathcal{L} \supset -\frac{1}{4} g_{a\gamma} a F_{\mu\nu} \tilde{F}^{\mu\nu} - i g_{ae} a \bar{e} \gamma_5 e$$

$$\frac{d\Phi}{dE_\gamma} = \frac{5.8 \times 10^{17}}{\text{MeV} \cdot \text{sec}} \left(\frac{P}{\text{MW}} \right) e^{-1.1 E_\gamma / \text{MeV}}$$

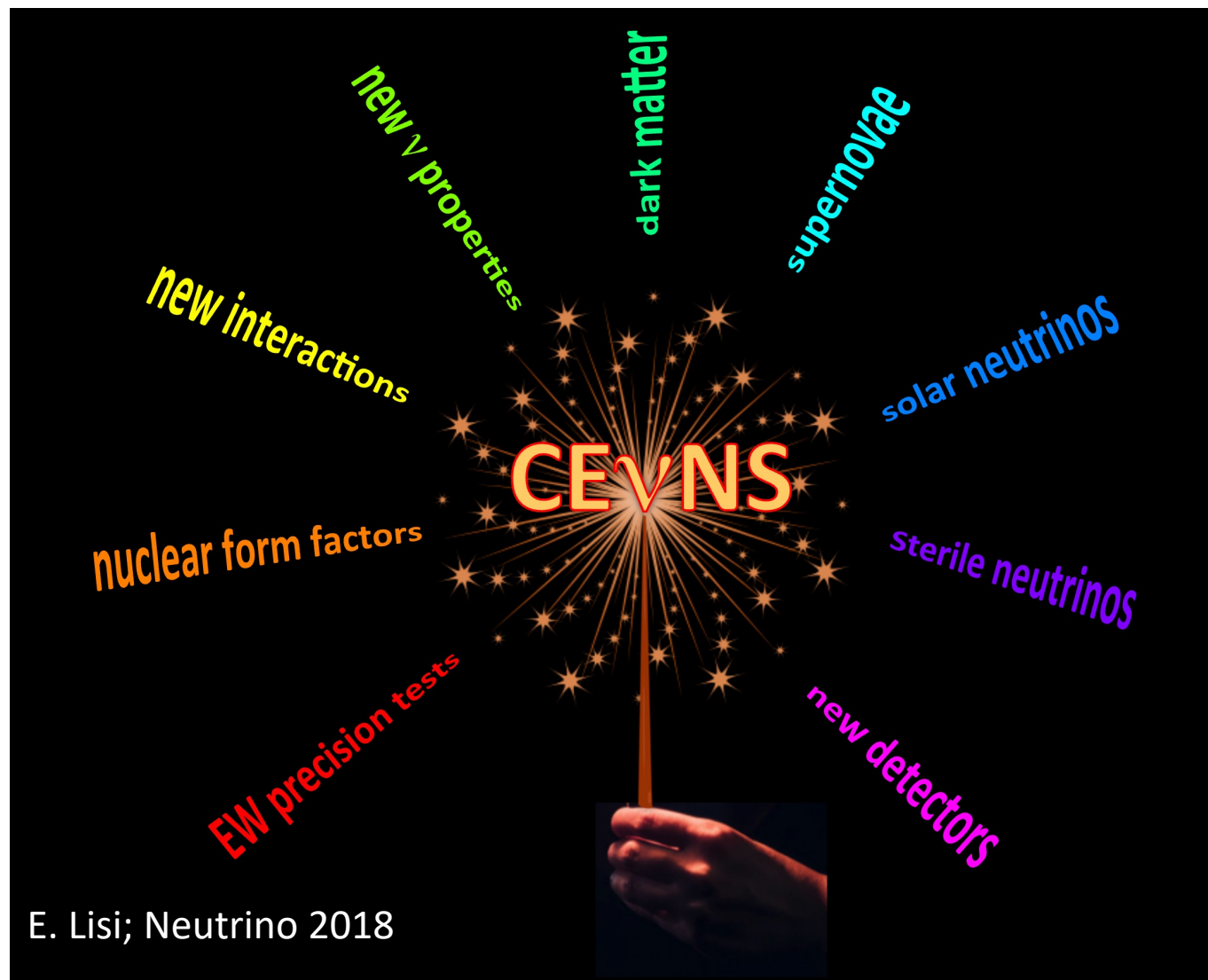
Couplings	Production	Detection
$g_{a\gamma}$		 
g_{ae}		   

RECODE Prospects

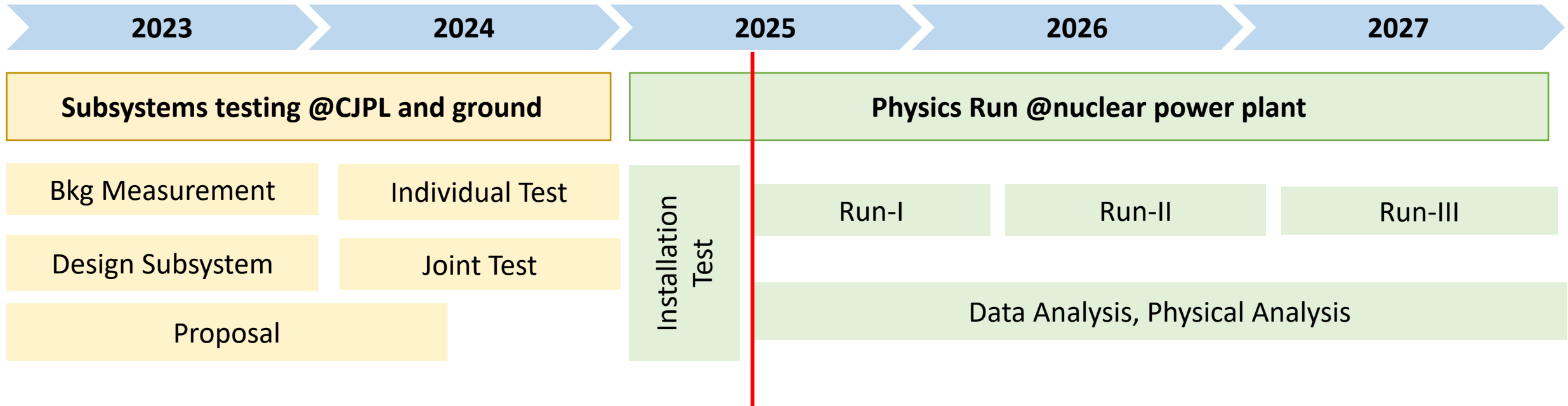
- ALP From Reactor



Summary



RECODE Roadmap & Schedule



Formal Data Taking starts this October – Stay tuned!