RECODE program
for reactor neutrino CEvNS detection
and Physics beyond SM

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中国物理学会高能物理分会
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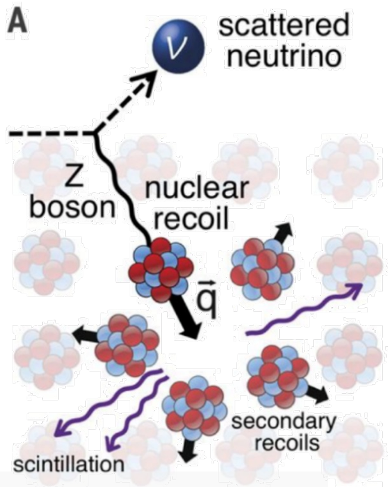
CEvNS

- Coherent Elastic Neutrino-Nucleus Scattering
  - Basic interaction between Neutrino and matter in SM
    - 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

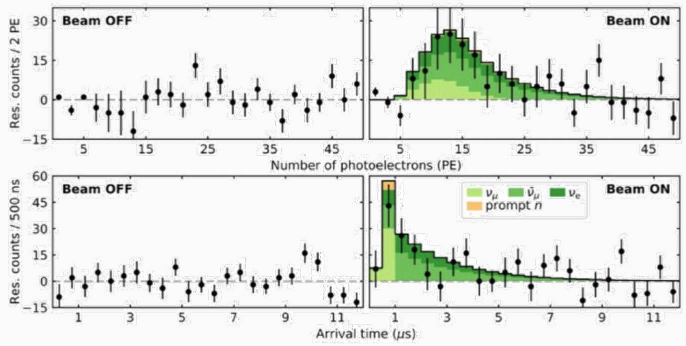
Daniel Z. Freedman†
National Accelerator Laboratory, Batavia, Illinois 60510
and Institute for Theoretical Physics, State University of New York, Stony Brook, New York 11790

(Received 15 October 1973; revised manuscript received 19 November 1973)

If there is a weak neutral current, then the elastic scattering process $\nu + A \to \nu + A$ should have a sharp coherent forward peak just as $e + A \to e + A$ 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} cm^2 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 $\nu + A \to \nu + A^*$ 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)

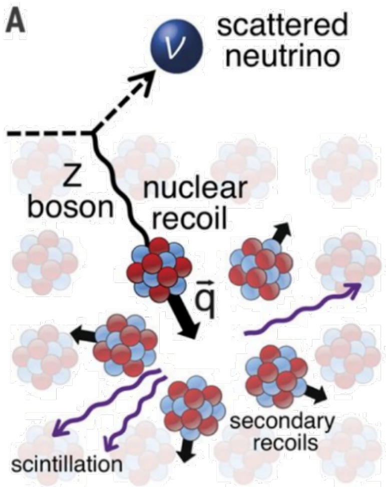
Experimental Evidence (2017)



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 $E_\nu \lesssim 50$ MeV $q \cdot R \ll 1$



CEvNS

Interaction with nuclei/electrons minimally disruptive

Interaction with nucleons disruptive

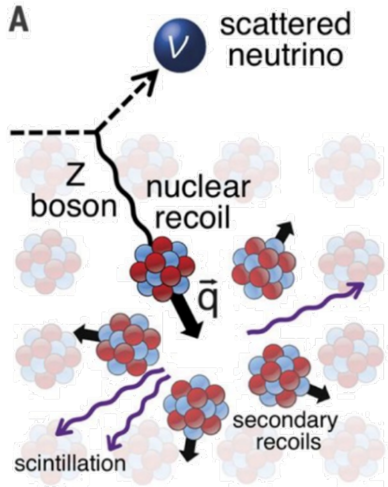
Deep Inelastic Scattering

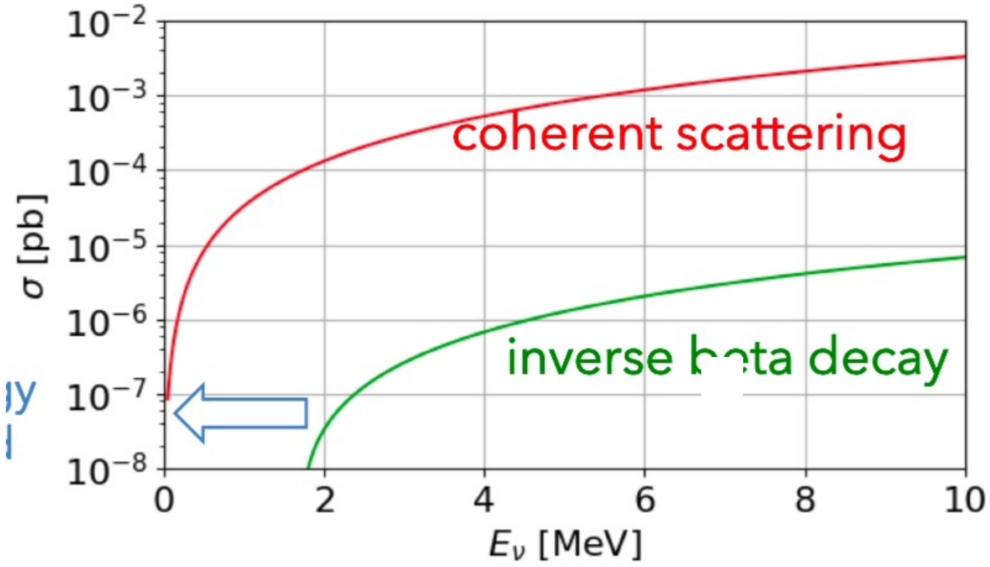
keV MeV GeV TeV




CEvNS

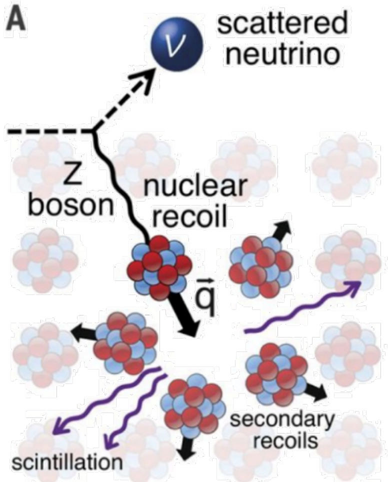
- Coherent Elastic Neutrino-Nucleus Scattering
  - Basic interaction between Neutrino and matter in SM
  - The nucleus scatters Neutrino as a whole
- Dominant for $E_\nu \lesssim 50$ MeV
- Elastic - No threshold





CEvNS

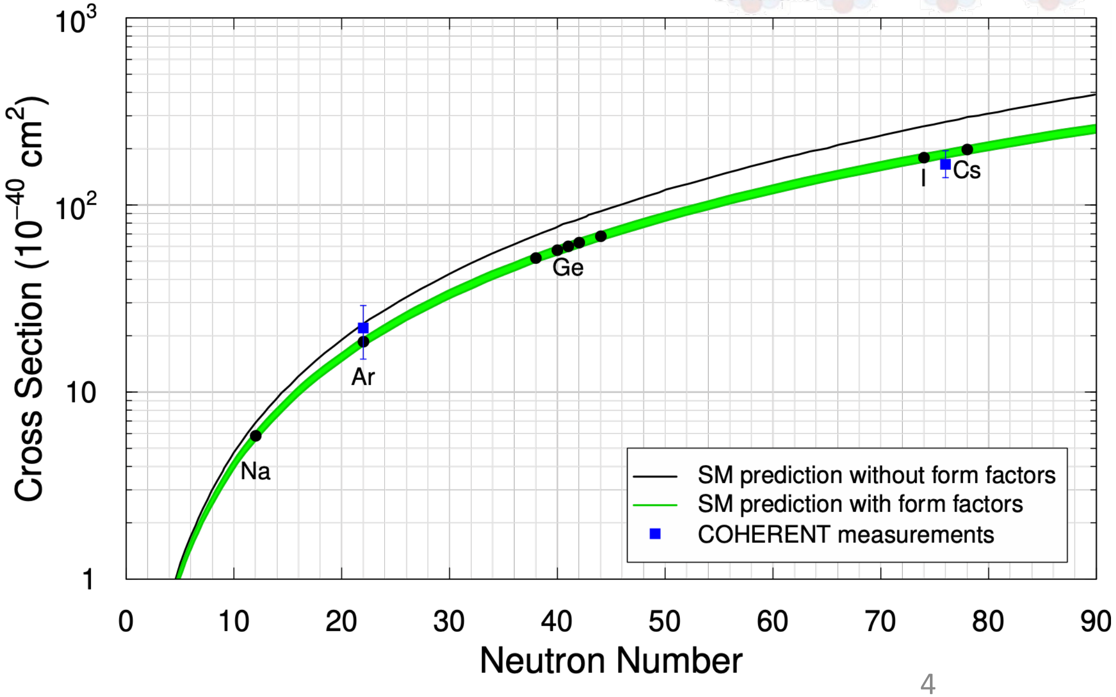
- Coherent Elastic Neutrino-Nucleus Scattering
  - Basic interaction between Neutrino and matter in SM
  - The nucleus scatters Neutrino as a whole
- Dominant for $E_\nu \lesssim 50$ MeV
- Coherent - Large Cross Section



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

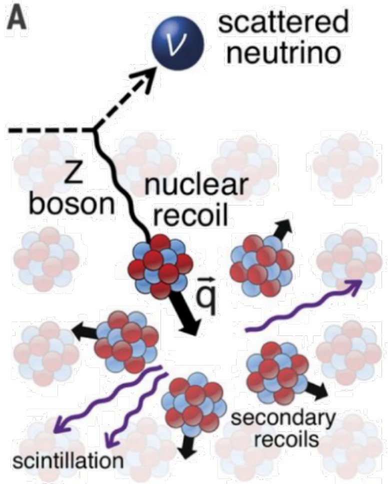
$q \cdot R \ll 1$

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

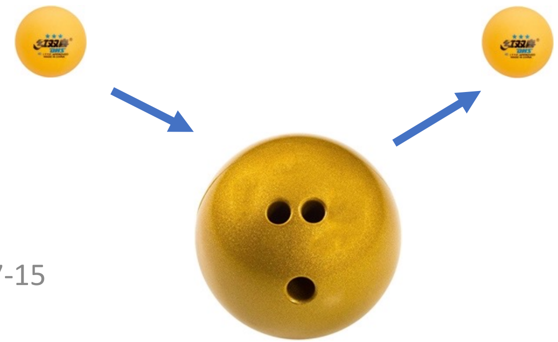


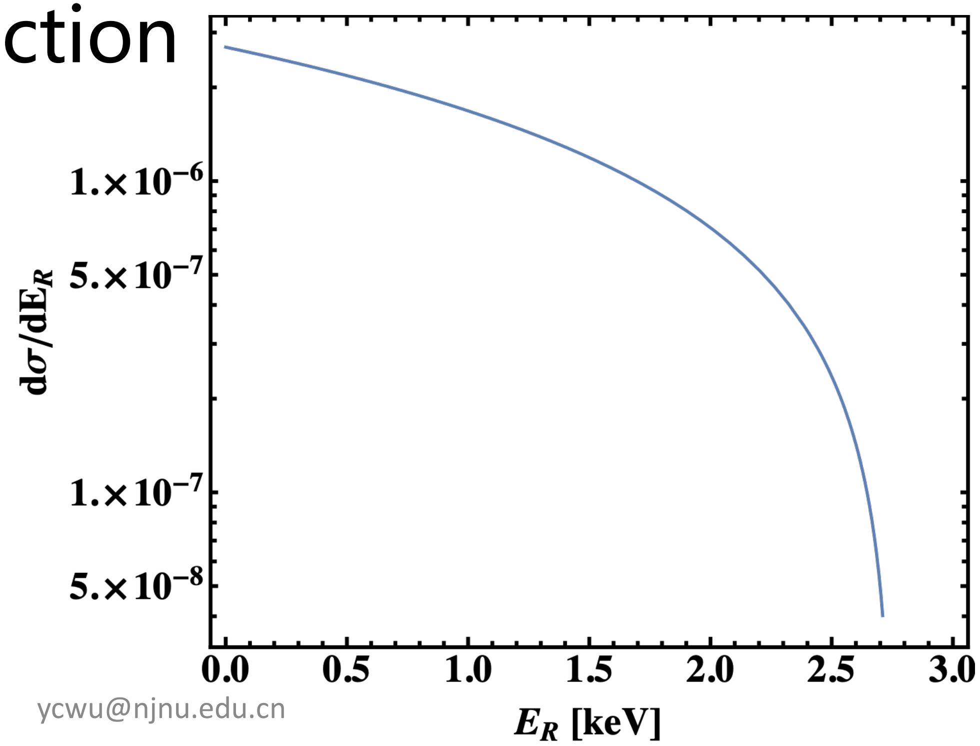
CEvNS

- 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
- Recoil Energy is Small



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

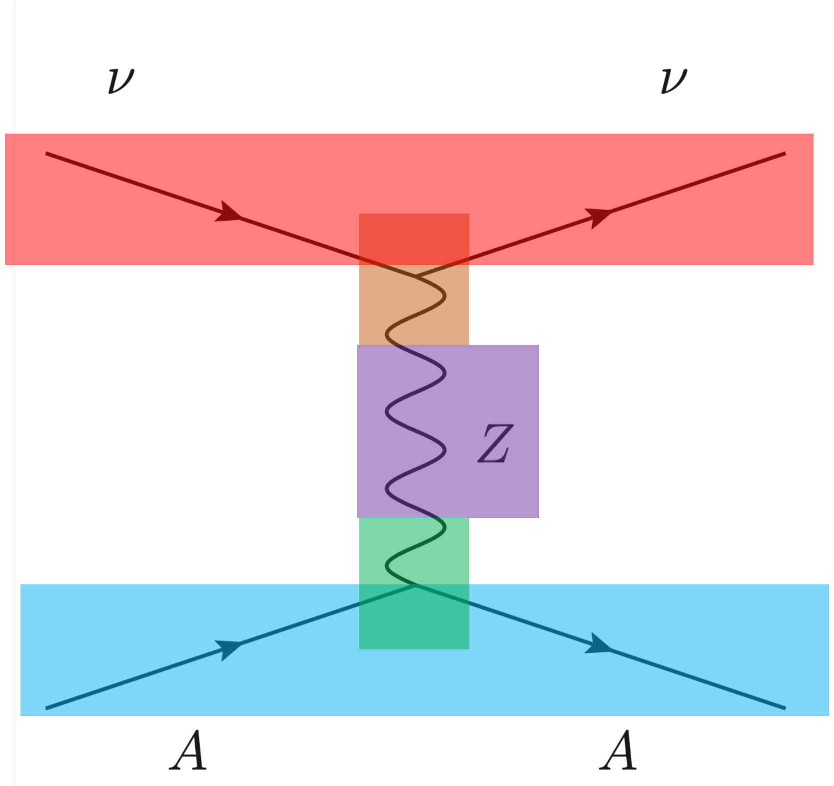




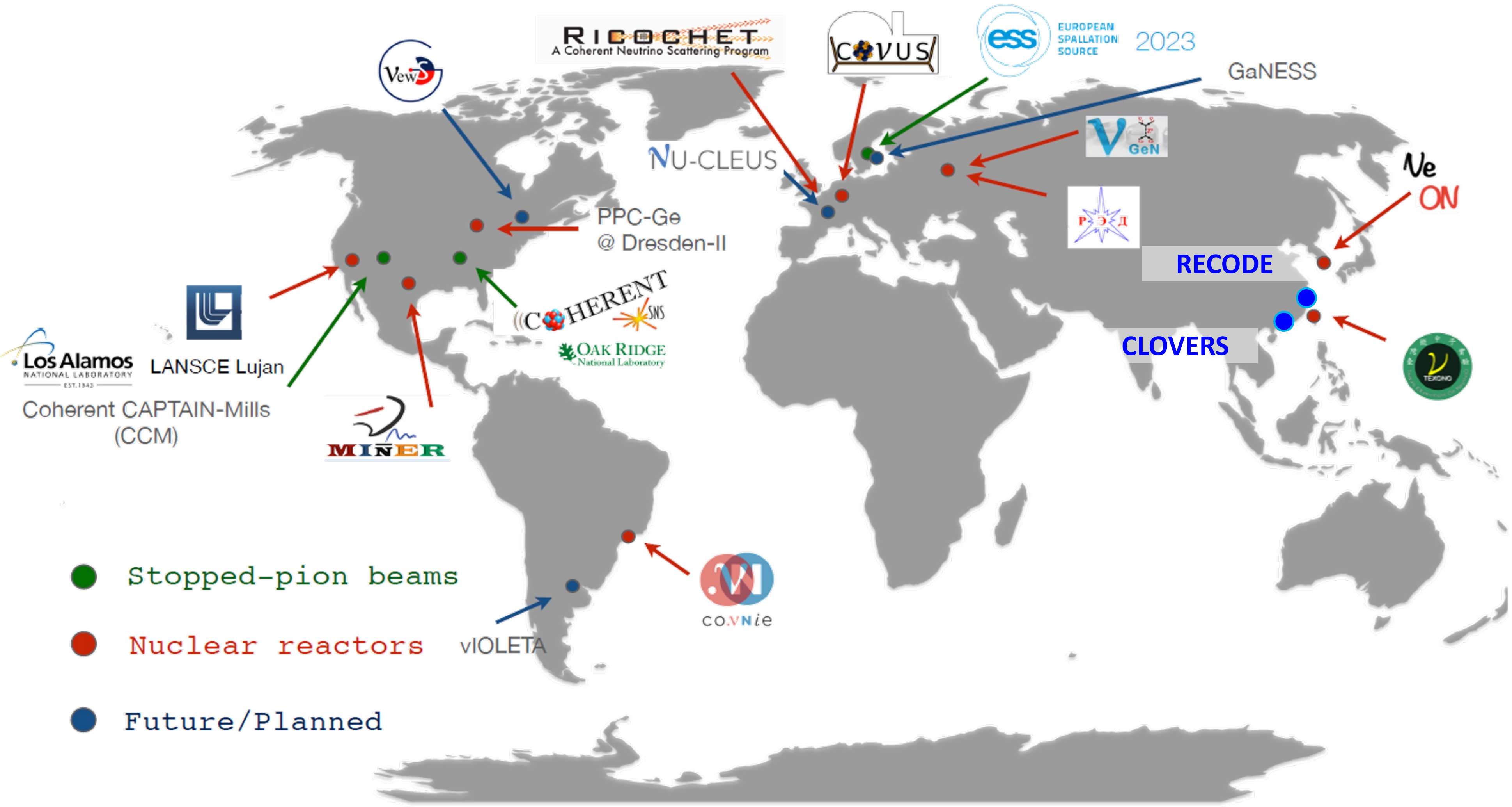
CEvNS: Physics Motivation

- 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

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



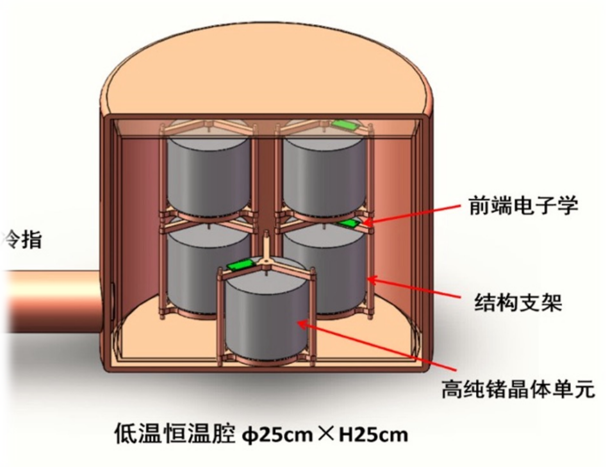
CEvNS: Experiments



RECODE Program

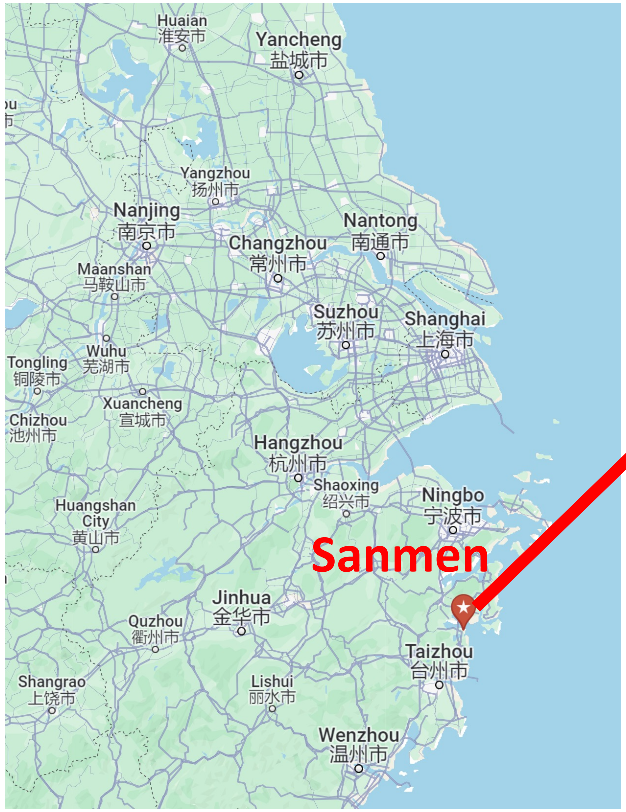
- RECODE
  - REactor neutrino COherent scattering Detection Experiment
  - Low threshold Ge detectors
  - Reactor neutrinos

- Project Goals:
  - Two Ge arrays (10kg in total)
    - Energy threshold ~ 1 keVnr (~160eVee)
    - ~ 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

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

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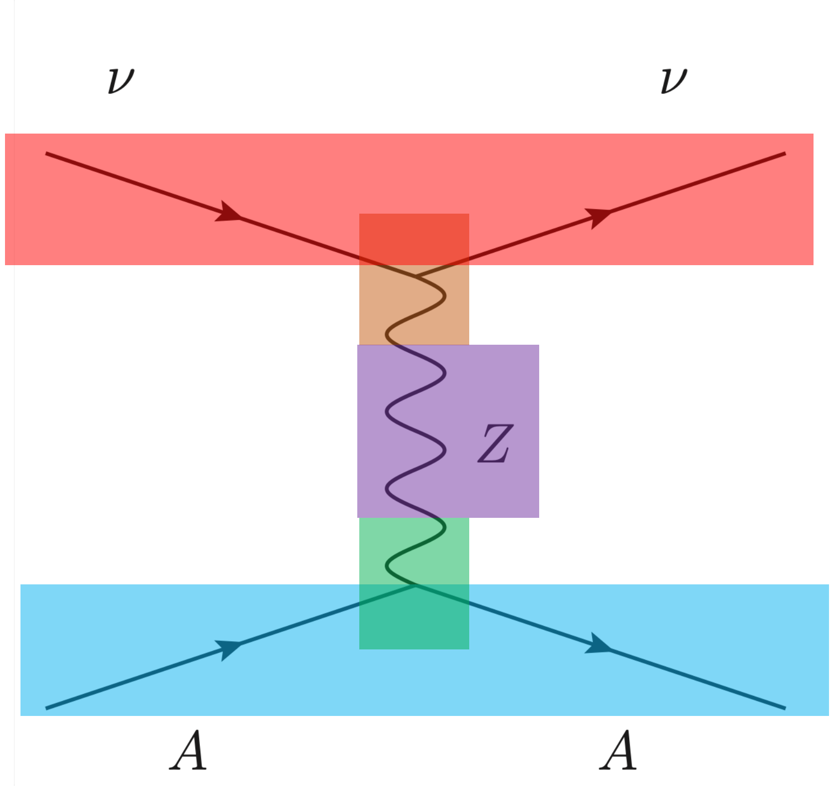
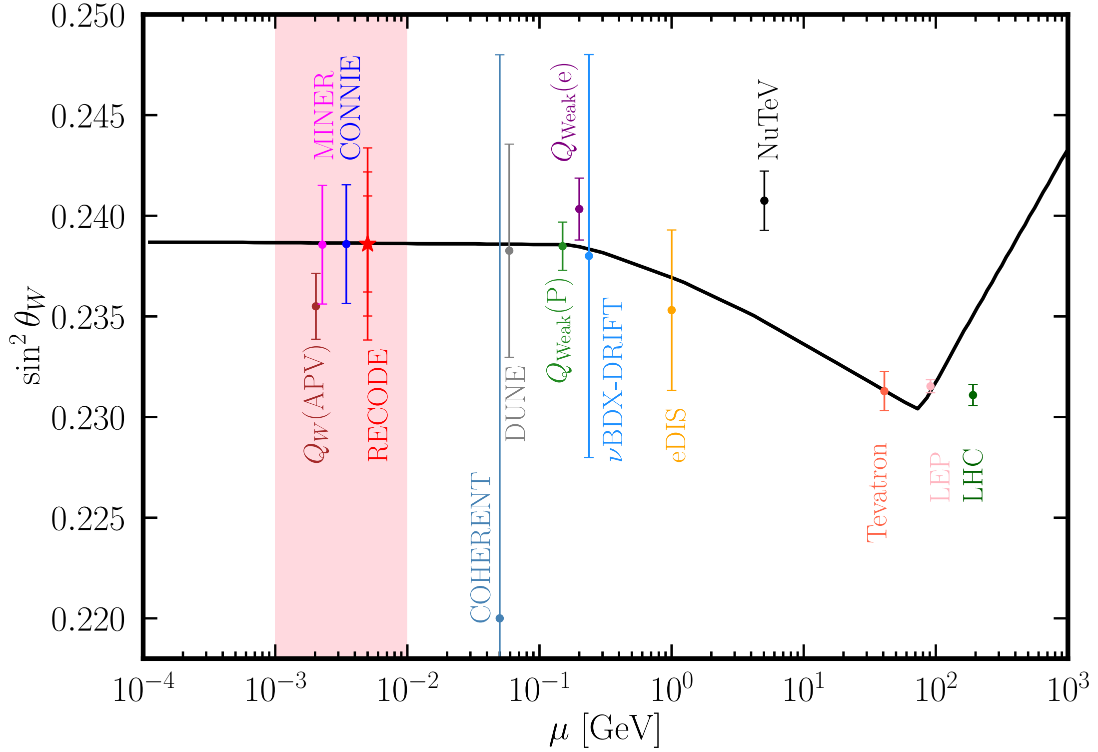


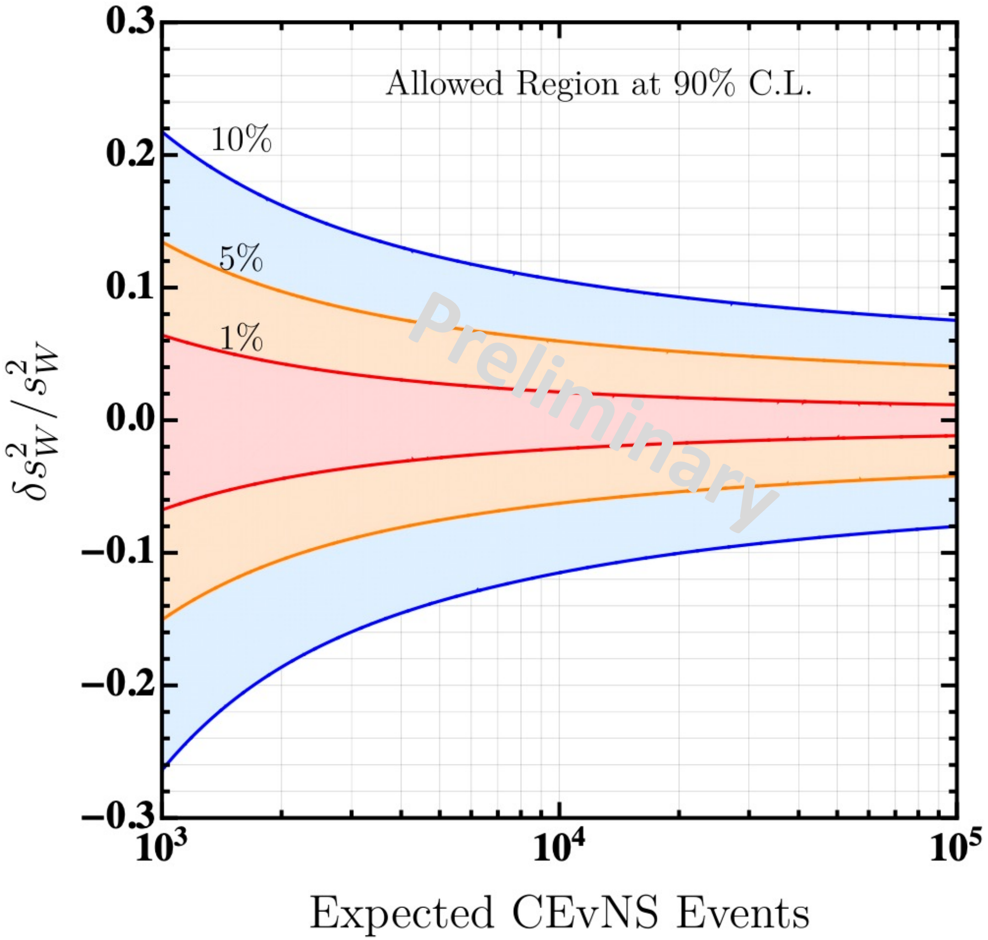
RECODE: Prospects

- Weak Mixing Angle

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

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



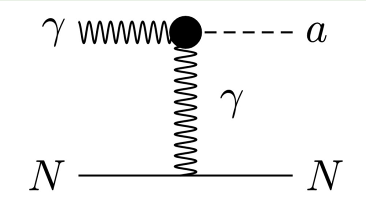
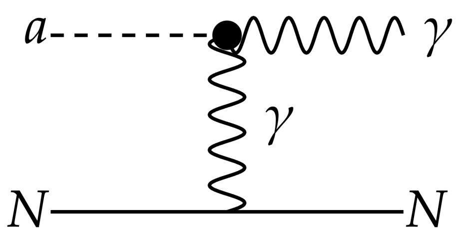
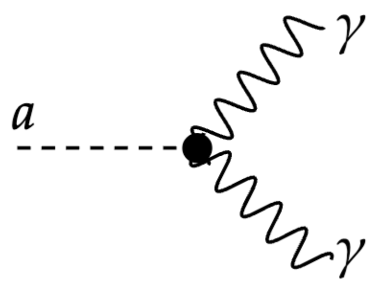
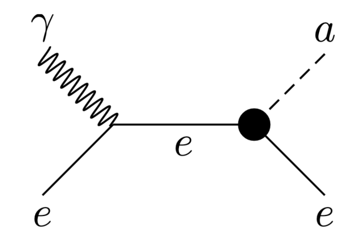
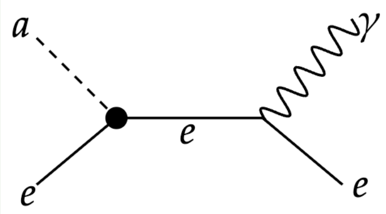
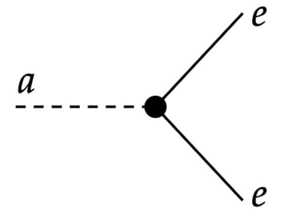
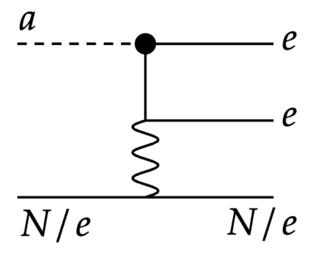
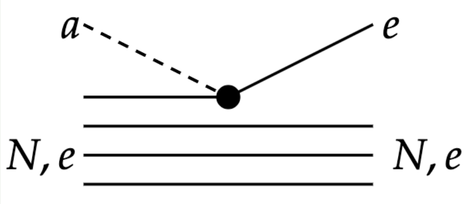


RECODE: Prospects

- ALP From Reactor
  - Photon Flux

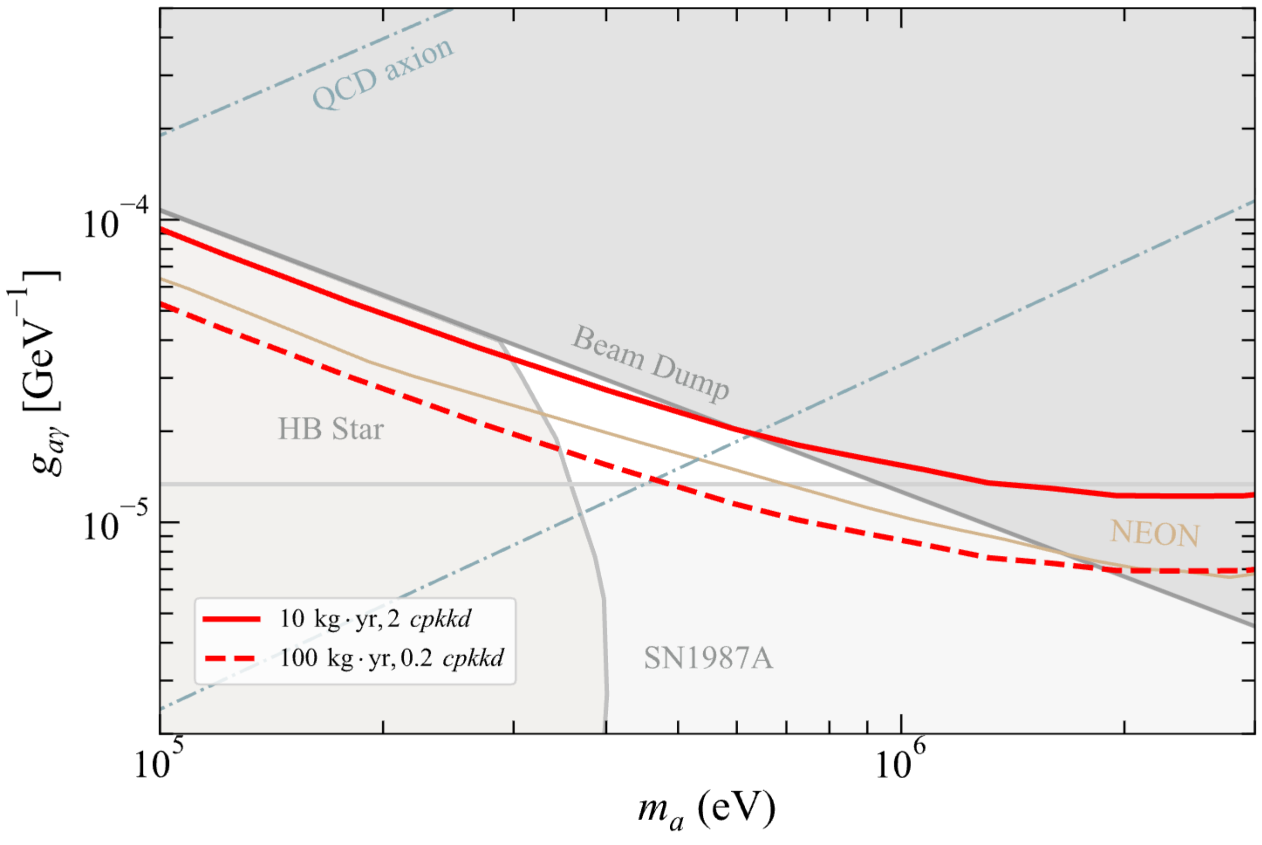
$$\frac{d\Phi}{dE_\gamma} = \frac{5.8\times10^{17}}{\mathrm{MeV}\cdot\mathrm{sec}}\left(\frac{P}{\mathrm{MW}}\right)e^{-1.1E_\gamma/\mathrm{MeV}}$$

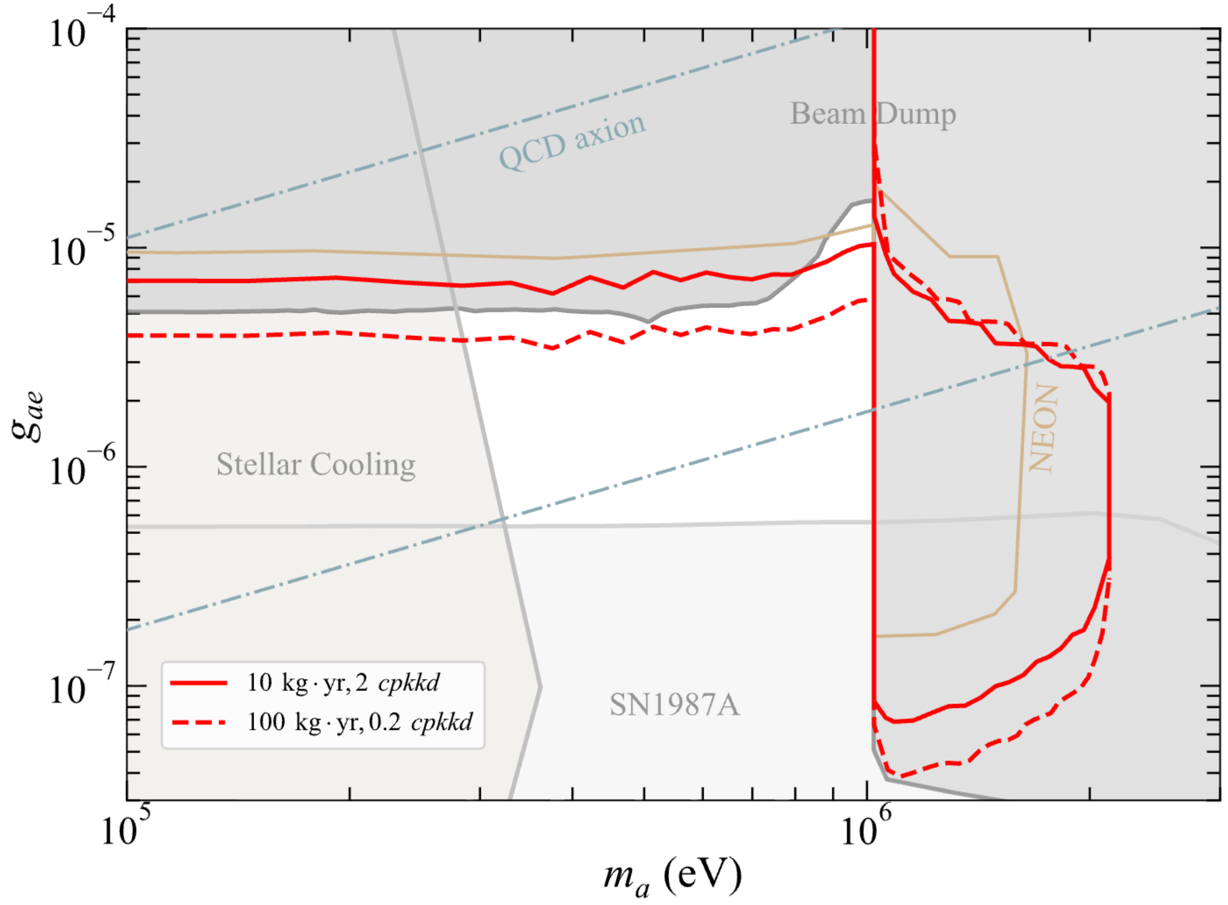
$$\mathcal{L} \supset -\frac{1}{4}g_{a\gamma}aF_{\mu\nu}\tilde{F}^{\mu\nu} - ig_{ae}a\bar{e}\gamma_5 e$$

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

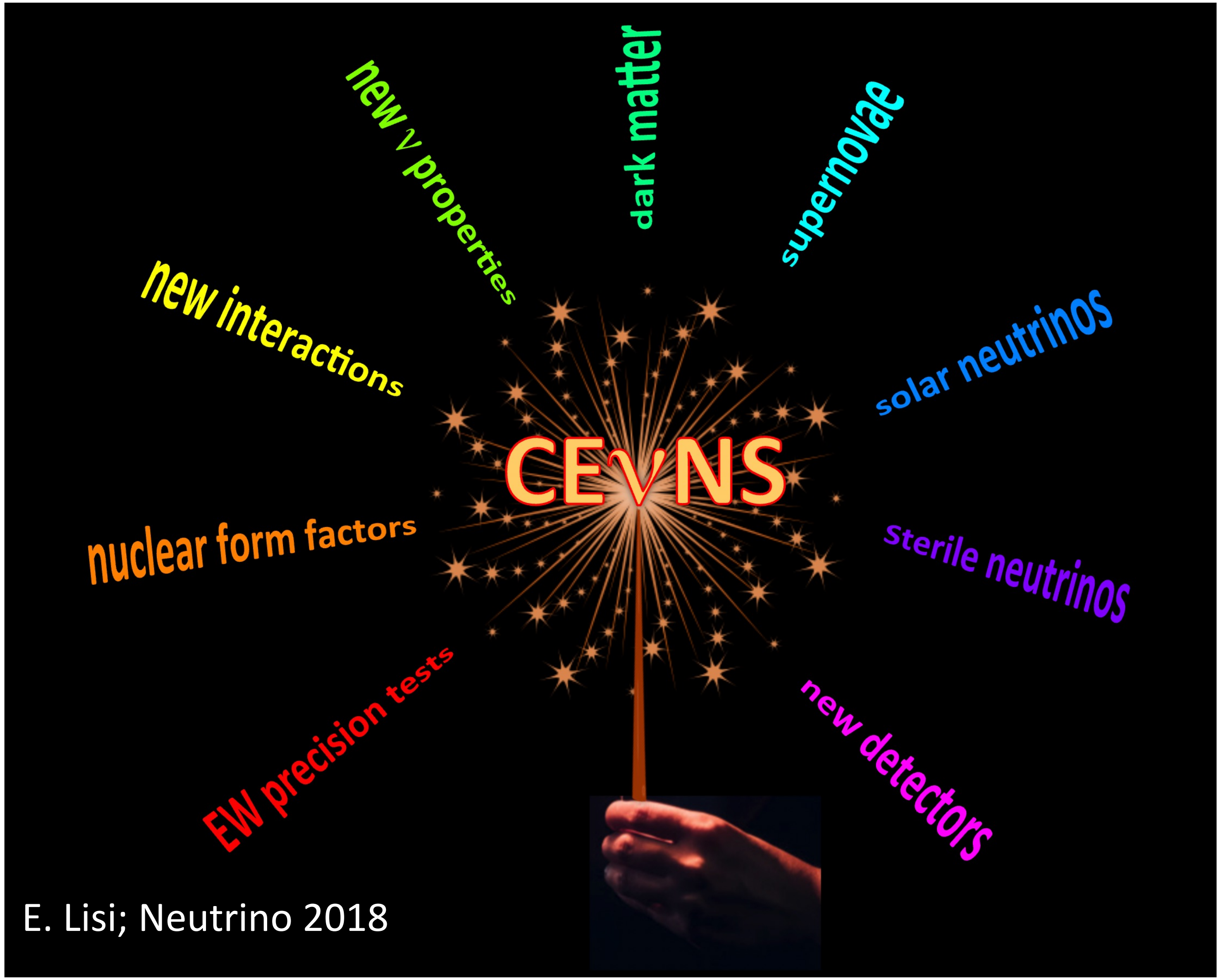
RECODE Prospects

- ALP From Reactor





Summary


new ν properties
dark matter
supernovae
new interactions
solar neutrinos
CEνNS
nuclear form factors
sterile neutrinos
EW precision tests
new detectors
E. Lisi; Neutrino 2018

CEvNS: Experiments