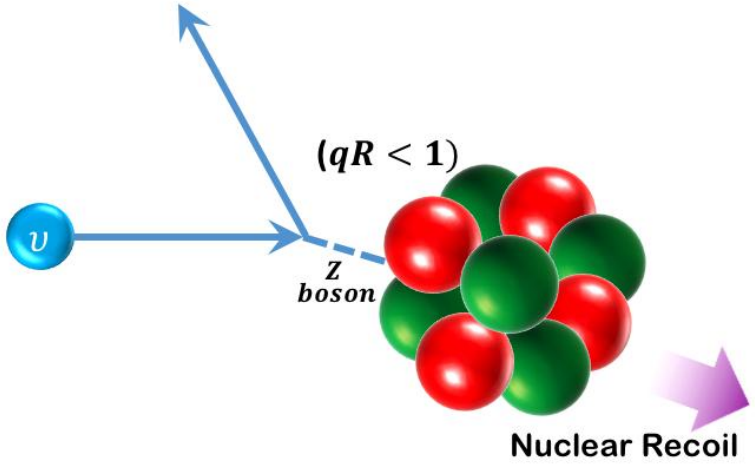
CICENNS: 300-kg CsI(Na) Detector for Coherent Elastic Neutrino-Nucleus Scattering(CEvNS)

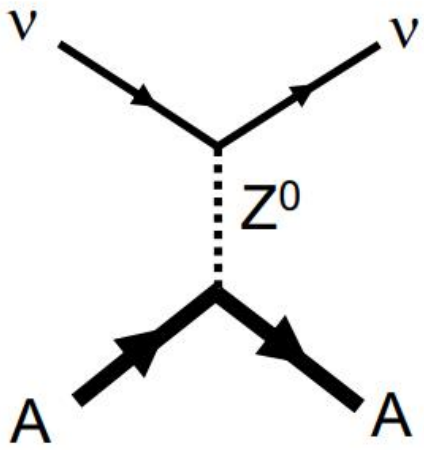
麦景宇（中山大学）

on behalf of the CICENNS Collaboration

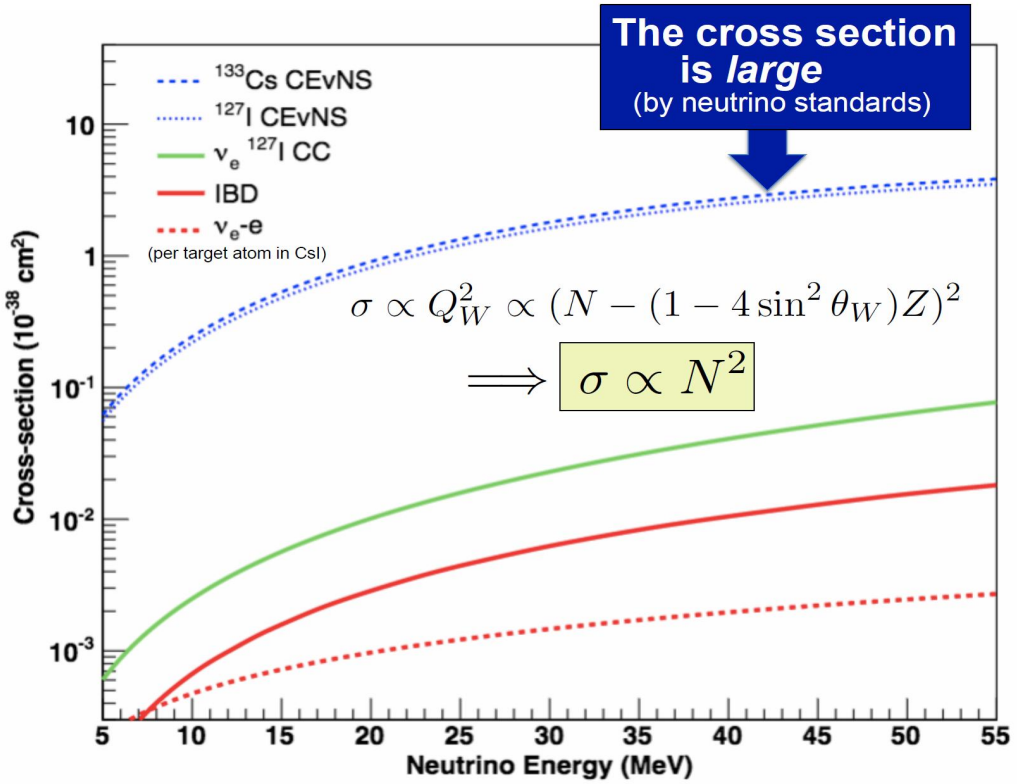
August 15, 2024

Coherent Elastic Neutrino-Nucleus Scattering (CEνNS)





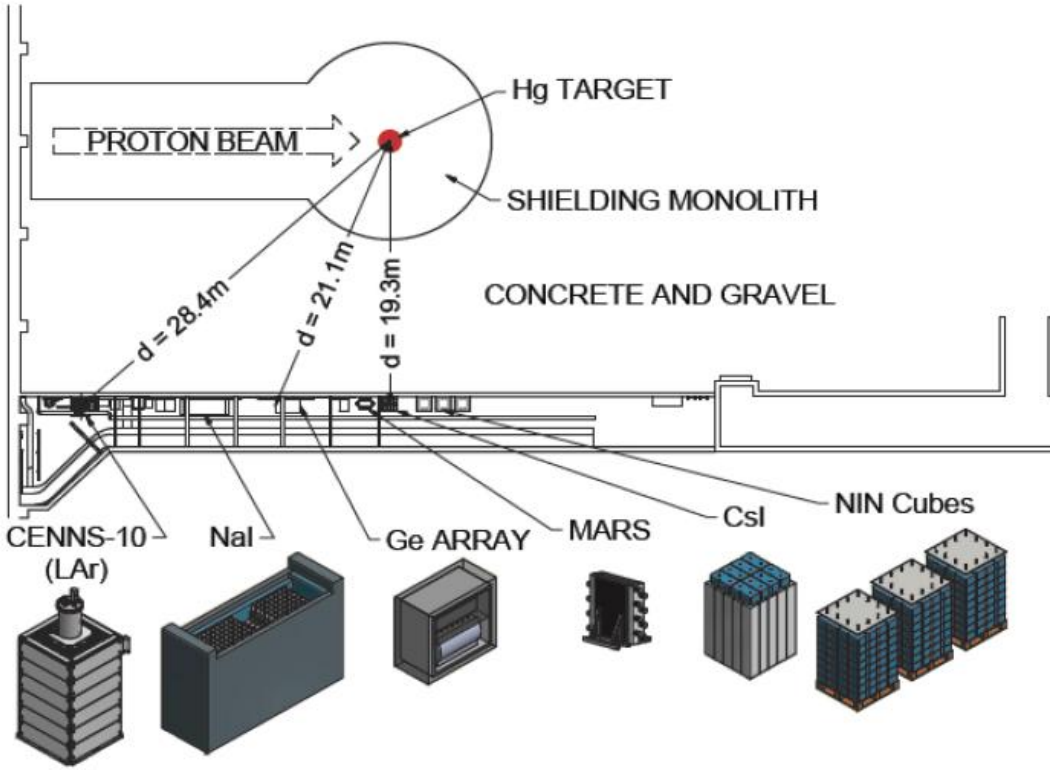
$$\left(\frac{d\sigma}{dT}\right)_{\text{coh}} = \frac{G_F^2 M}{4\pi} Q_W^2 F^2(Q) \left[1 - \frac{MT}{2E_\nu^2}\right]$$



- qR < 1
- Z-exchange between neutrino and nucleus
- Nucleus recoils as a whole
- Coherent up to $E_\nu \sim 50$ MeV

First experimental observation by COHERENT

SCIENCE 357, no. 6356, 1123-1126 (2017)



- 14.6 kg CsI(Na) detector
- 308.1 day live-time (beam-on)
- 134 ± 22 events observed
- 6.7 σ observation

Goals of CICENNS experiment

“Research contents”

Development of 300kg CsI(Na) detector
For Coherent Elastic Neutrino Nucleus Scattering (CEvNS)

- Obtain sufficient CEvNS event rate with substantial target mass
- Establish a new field of studying unexplored physics using CEvNS

Detection of neutrinos from pion/muon decays at rest
(at China Spallation Neutron Source)

“Scientific goals”

(1) *Precise measurements* (world-most accurate)
- CEvNS cross section → weak couplings at low momentum transfer (±3%)
- Mean radius of neutron distribution inside nucleus (±2%)
- Understanding of dark-matter background and detection of solar neutrinos

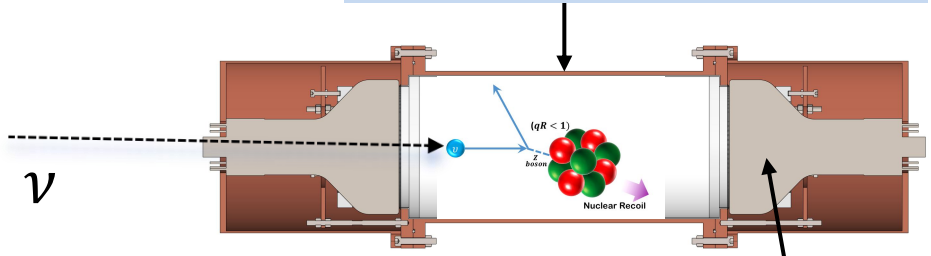
(2) *New physics searches*
- Non-standard (new) neutrino interactions (world-best search)
- New particle searches: dark photons or sub-GeV dark matter
- A new region of neutrino magnetic moment
- Efficient search for sterile neutrino oscillation by neutral current

[* CICENNS: **C**s**I** detector for **C**oherent **E**lastic **N**eutrino **N**ucleus **S**cattering]

Schematic view of CsI(Na) Crystal Detector

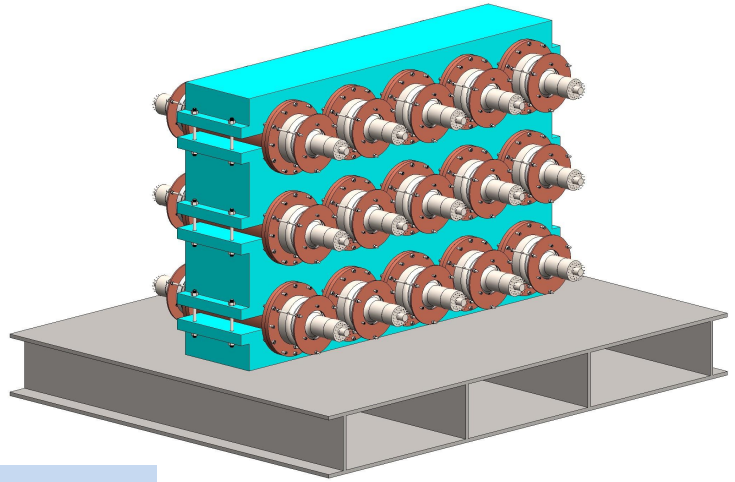
[* Building a good detector essential for this research]

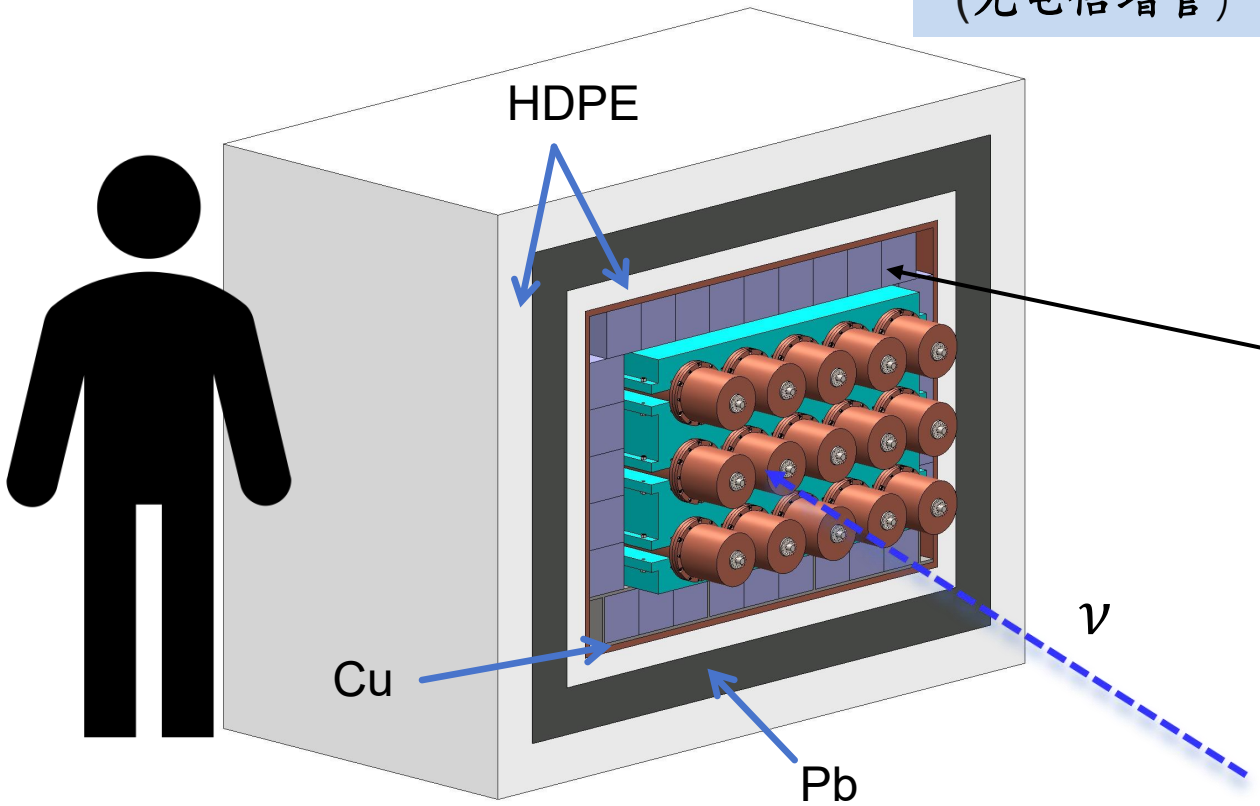
CsI(Na) crystal (闪烁晶体)



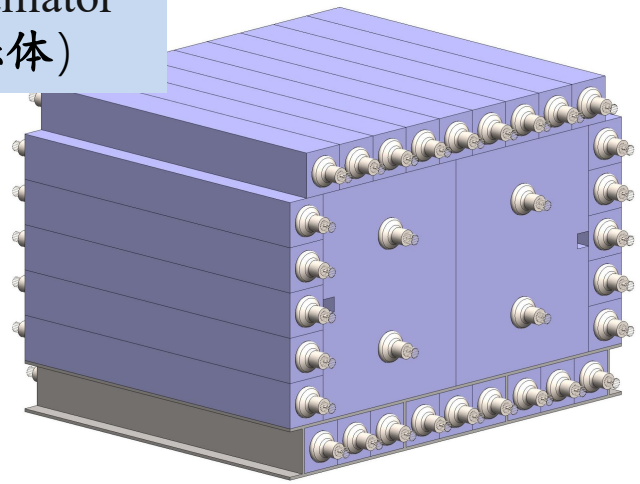
- 20 kg CsI x 15
- 14 cm (ϕ) x 28.7 cm each

5-inch PMT
(光电倍增管)

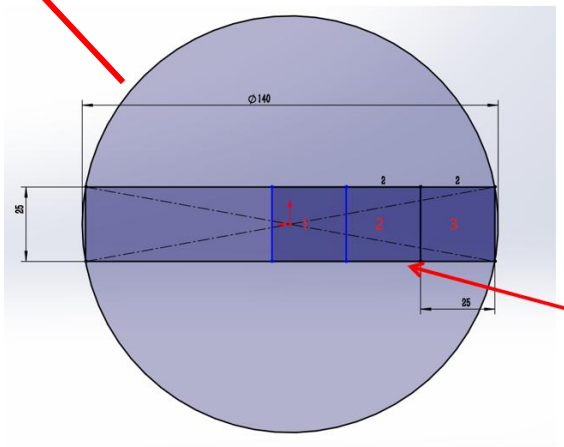


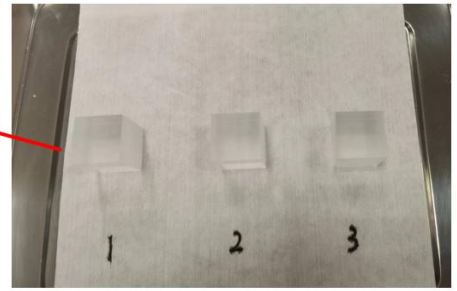


Plastic scintillator
(塑料闪烁体)



CsI(Na) crystal

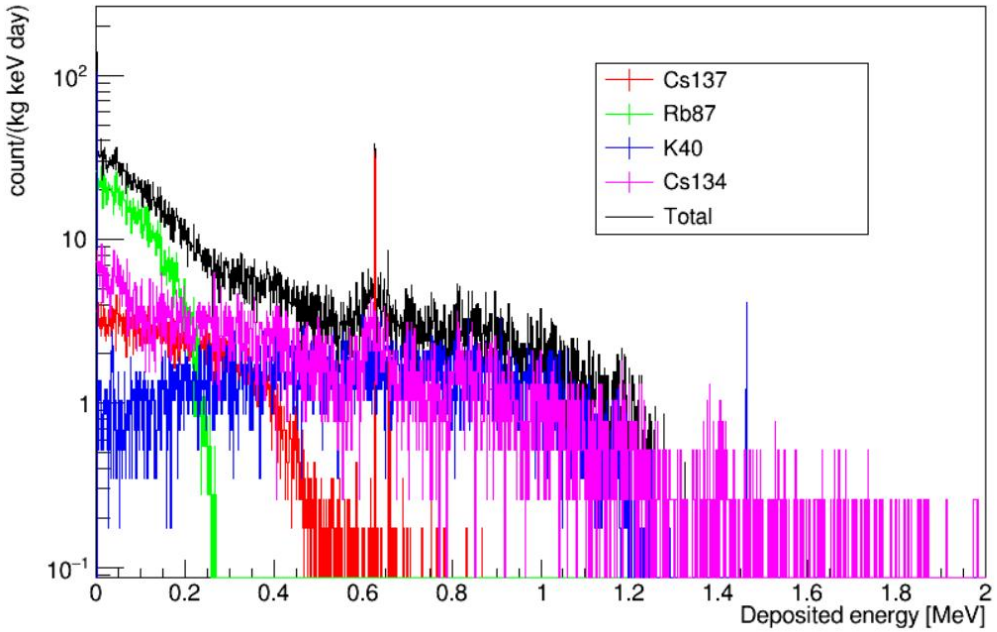




- The first full-size CsI(Na) crystal sample of has been produced by SICCAS
- Radioisotopes measurement
- optical measurement

Internal Radioactivity of Crystal

Isotopes	^{238}U (ppt)	^{232}Th (ppt)	^{87}Rb (ppb)	^{137}Cs (mBq/kg)	^{134}Cs (mBq/kg)
CICENNS	50±10	47±10	~2	??	??
KIMS	0.75±0.23	0.38±0.07	1.3±0.4	6.3±0.7	14.1±1.1
COHERENT	<1000	<1000	~20	28±3	26±2

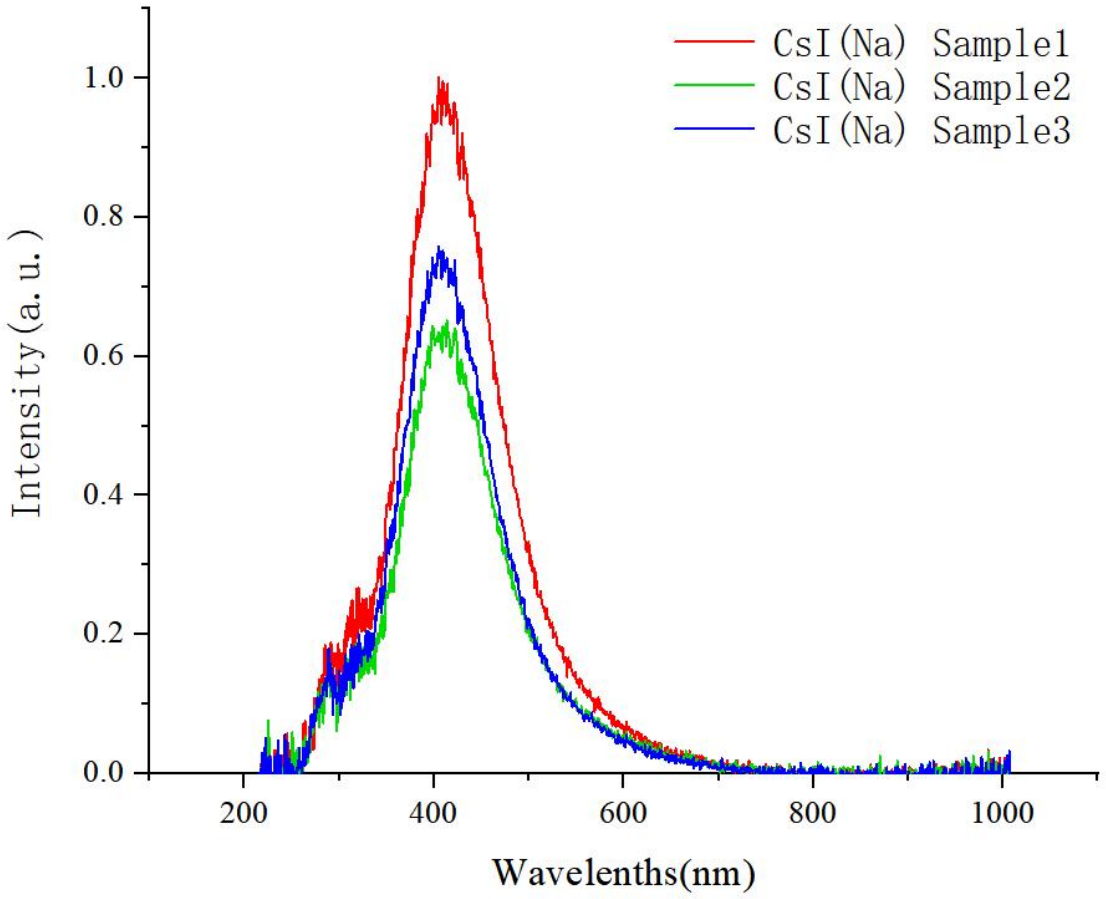


Background spectra obtained using GEANT4 simulation for a 20kg CsI(Na) with: ^{137}Cs ~10mBq/Kg, ^{134}Cs ~30mBq/Kg, ^{40}K ~20mBq/Kg, ^{87}Rb~10ppb.

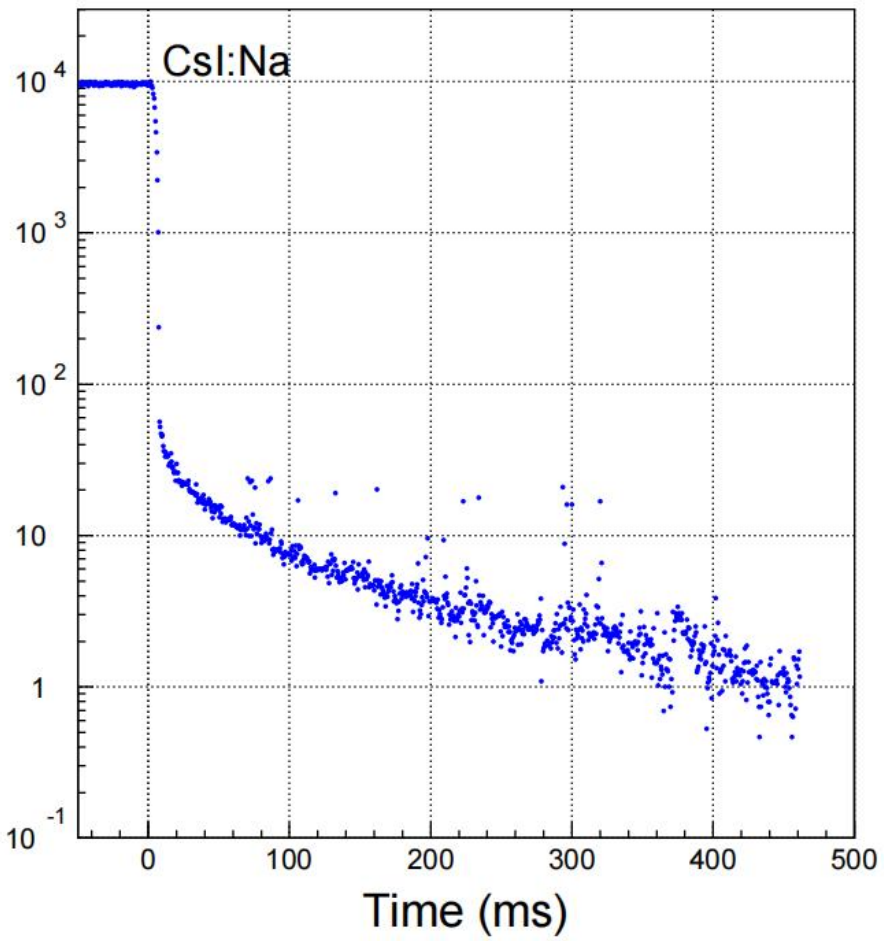
- The top part of the CsI(Na) crystal sample is the part of the entire crystal with a higher radioactive concentration
- Previous measurements of the same type of CsI(Na) sample

(6.7cm (ϕ) ×1.6 cm (L)):^{137}Cs<5.9 mBq/kg , ^{134}Cs~23 mBq/kg

Optical properties of CsI(Na) crystals

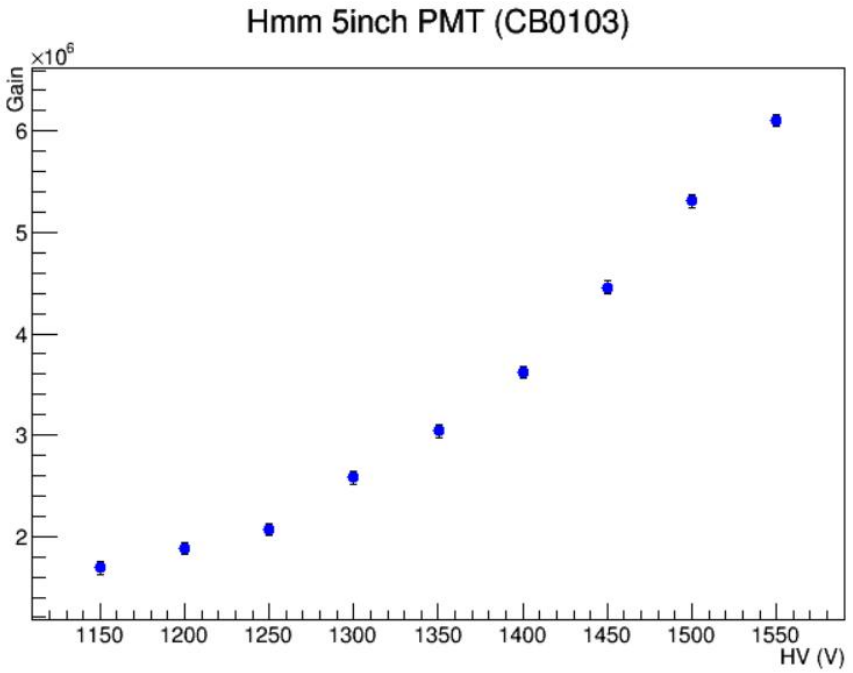


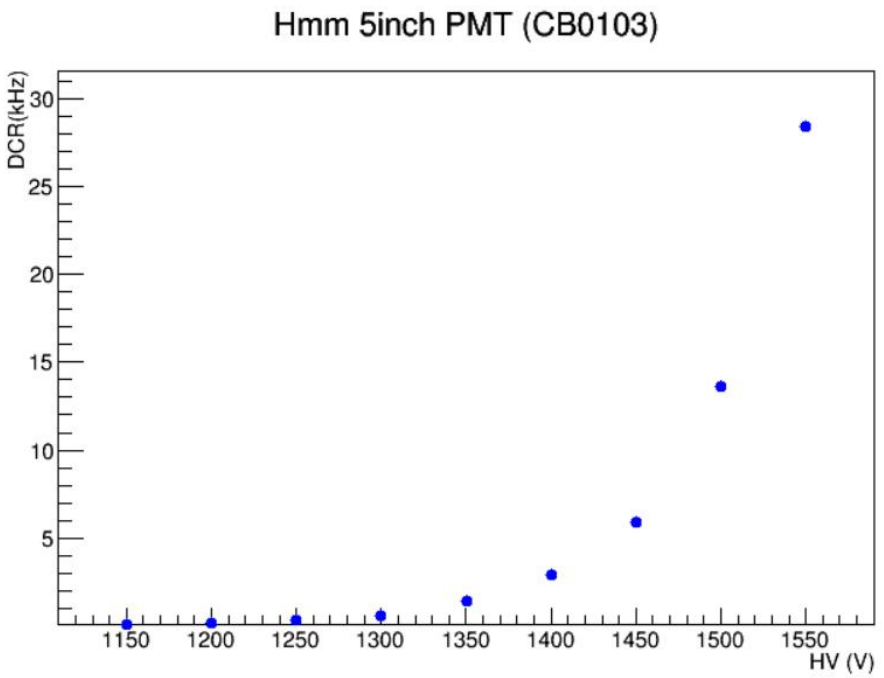
- Emission spectrum of CsI(Na) crystal
- The peak emission spectrum of crystal doped sodium is 405nm, which is consistent with PMT detection(290~650nm)



- Crystal doped sodium afterglow：~0.5%@6ms

Performance of 5-inch PMT





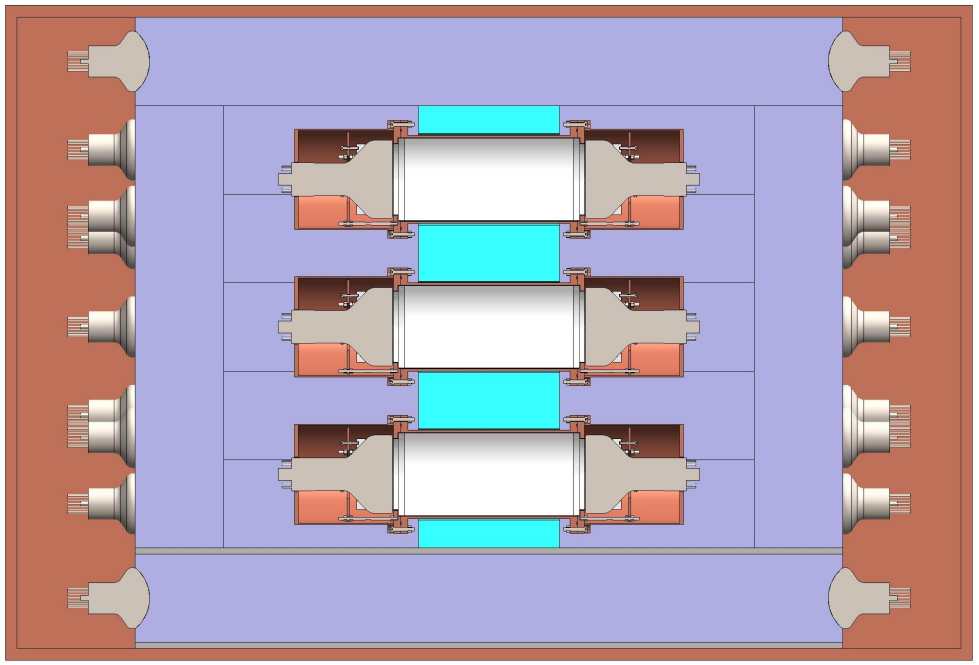
R877-100 PMTs (super-bialkali)

- QE：37% @420nm

Gain and DCR of PMT at different operating voltages.

- Gain: 3.6×10^6 @1400V
- DCR：2.9KHz @1400V

Plastic Scintillator Veto



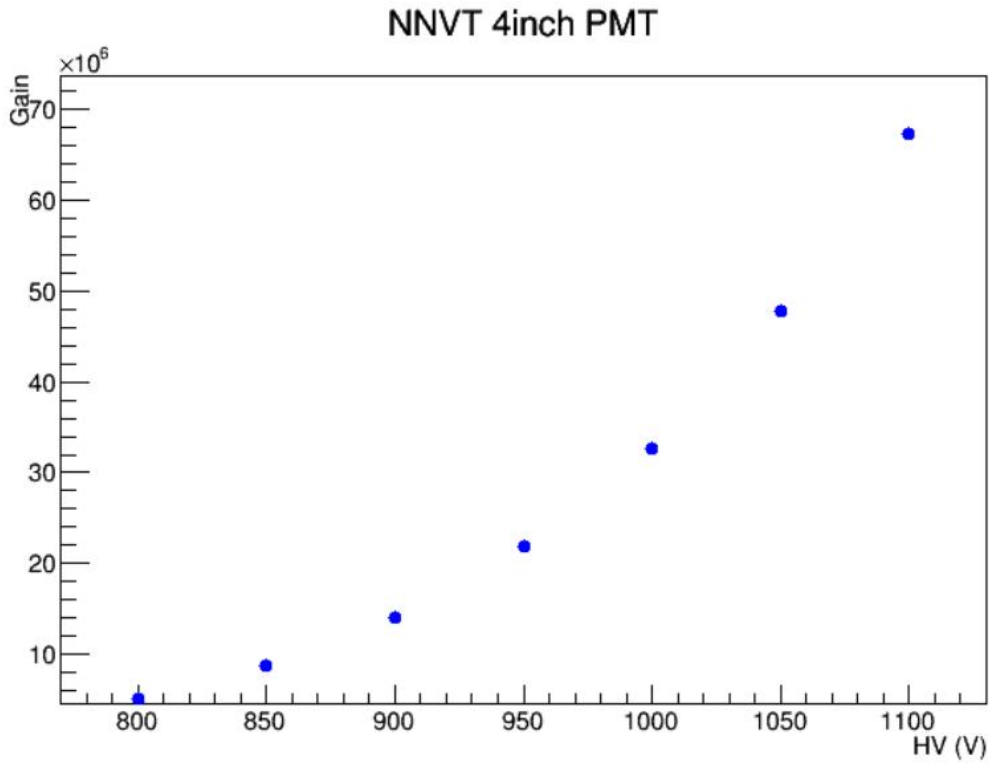
PSV detector

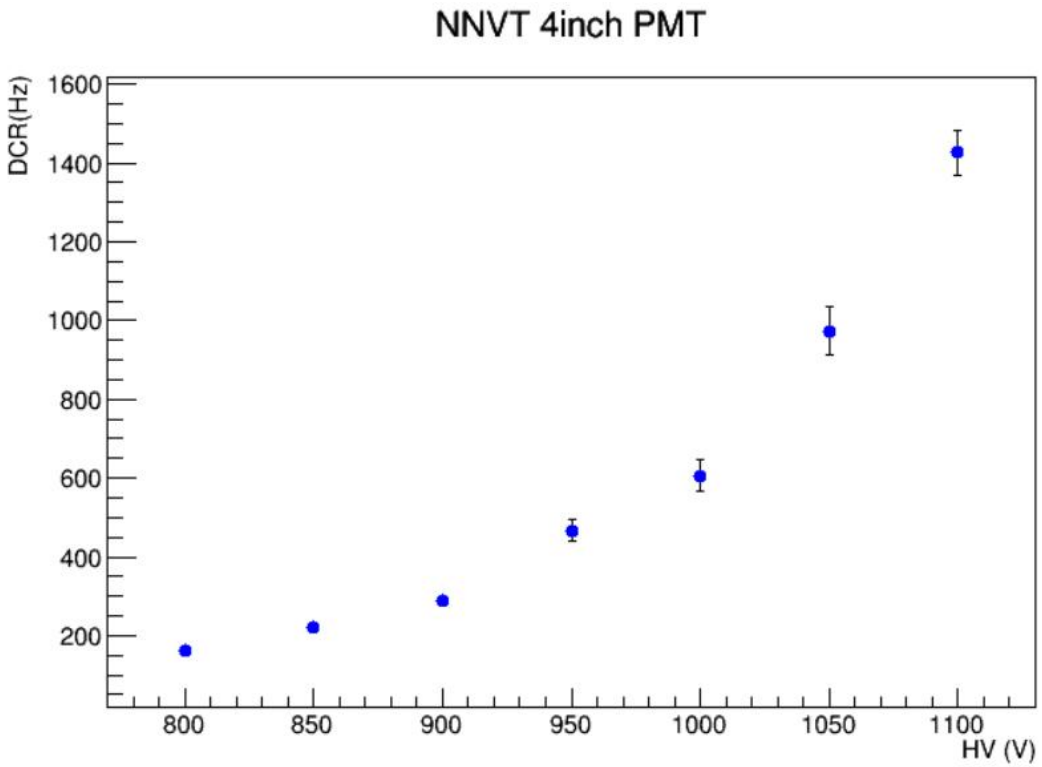
- Plastic Scintillator × 32
- 150 mm × 150mm × 1200 mm (L) each
- Two 4-inch N2041 PMTs

- Coupling of camber PMT to plastic scintillator with light collection efficiency of 14.5% (by GEANT4)

- Purpose:Identify and veto beam fast neutrons,cosmis muons,and gamma rays

Performance of 4-inch PMT

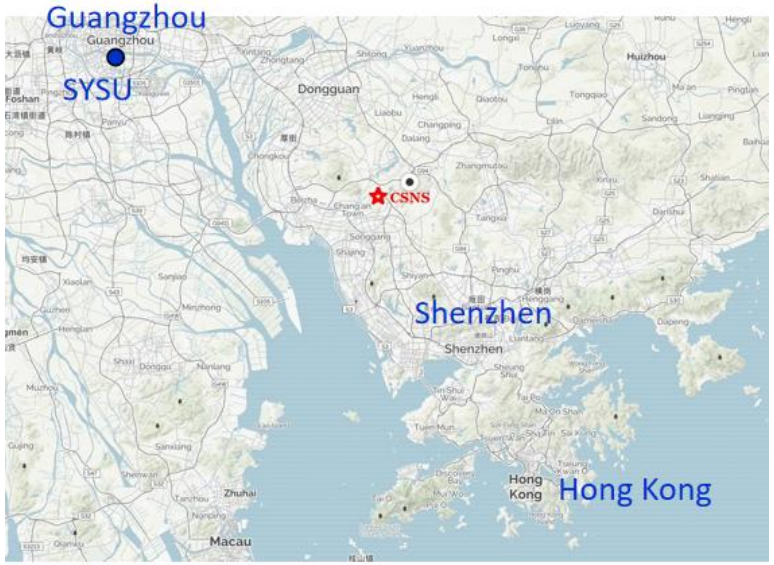




Gain and DCR of PMT at different operating voltages.

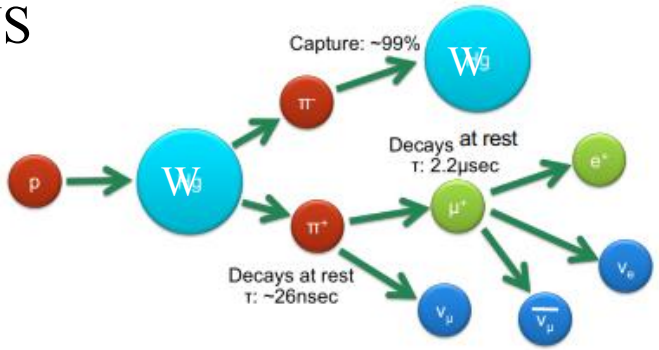
- Gain: 1.4×10^7 @900V
- DCR: 290Hz @900V

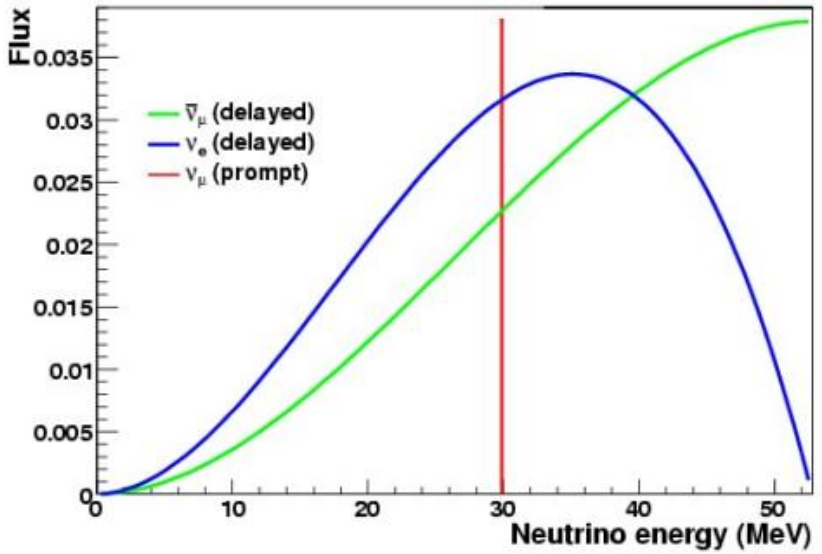
China Spallation Neutron Source (CSNS)



- The CICENNS experiment is initially planned to be conducted in the CSNS

CSNS 中国散裂中子源 China Spallation Neutron Source



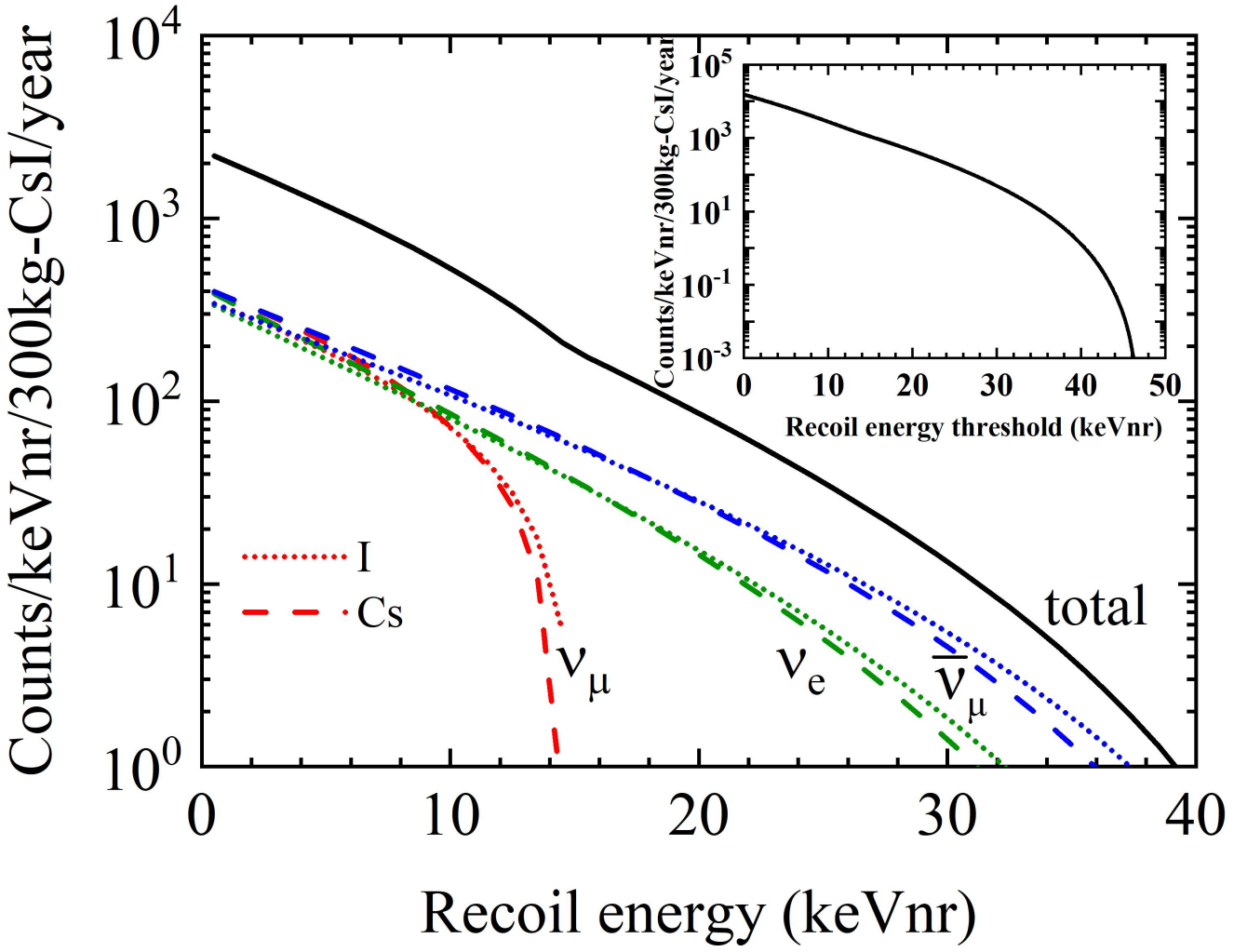


- 1.6 GeV proton beam
- 140 kW (→ 500 kW)
- 25 Hz repetition rate

Neutrino flux at 10.5 m: $6.71\times10^{6}/cm^{2}/s/flavor$ (~40% of COHERENT)

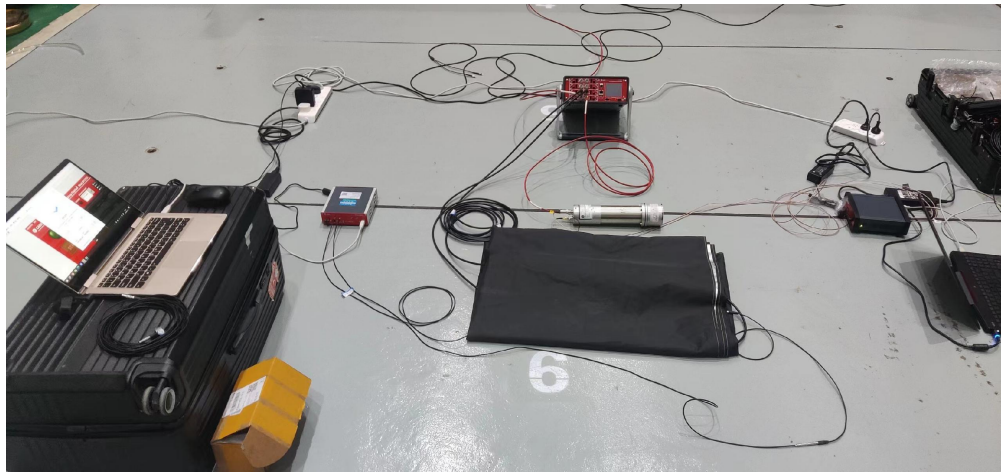
Expected CEvNS Signal of CICENNS at CSNS

- The maximum nuclear recoil energy is roughly 35 keVnr.
- 14.6 kg CsI(Na) crystal for ~300 CEvNS events (PRL 129, 081801, 2022)
- The expected CEvNS production rate per 300 kg for a year is about 4950 events at the energy threshold of 5 keVnr and 6450 events at 3 keVnr. (~20 times of COHERENT)

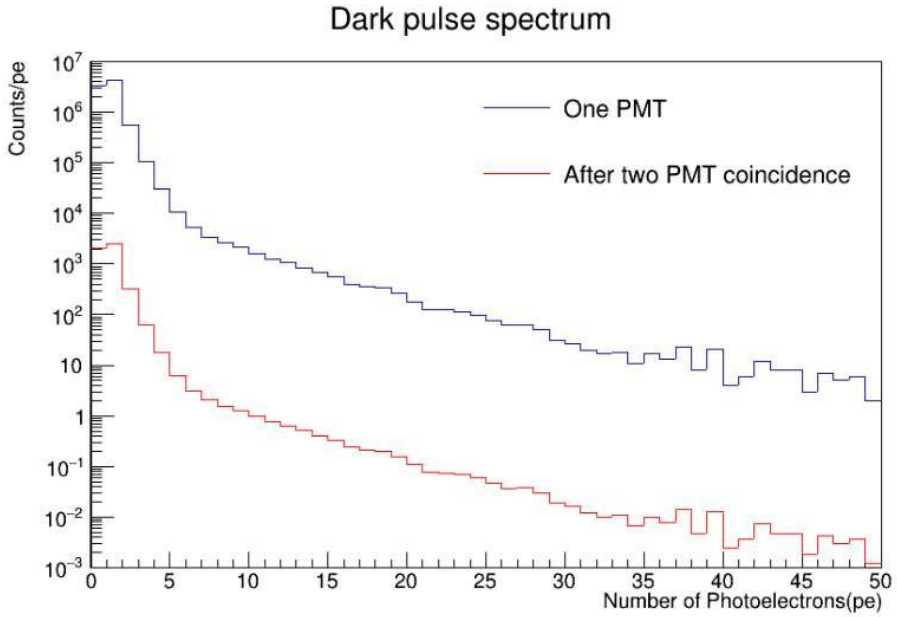


Background

- Beam related fast neutron
- The most significant background;
- On-site measurement on-going, joint effort from SYSU and UCAS;
- Identification and veto with PSV



- PMT dark-current noise
- By attaching two PMTs at both ends of a crystal, reduce PMT dark-current noise events by 3 orders of magnitude.



- Radioactivity in detector materials
- Low internal radioactivity in CsI(Na) crystal by purification; ^{87}Rb, ^{137}Cs, ...
- Background from PMTs and surrounding materials.

- Environmental radioactivity
- Most of gamma rays from the environmental radioactivity are expected to be attenuated by lead and other shielding.
- Cosmic muon induced neutrons and gammas

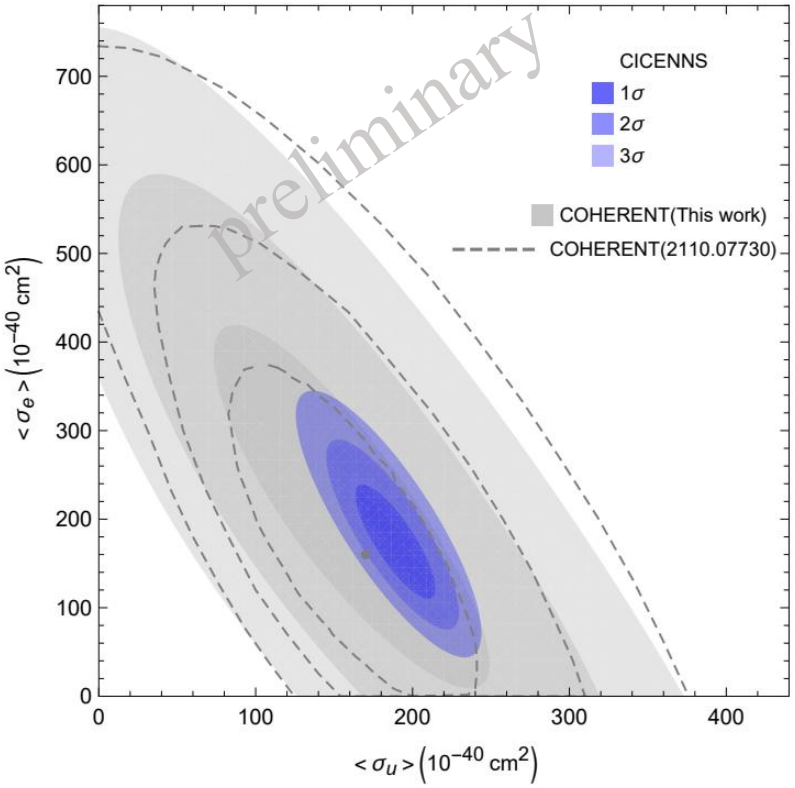
- Full Geant4-based MC on-going

Sensitivity: flavored CEvNS cross section and weak couplings

The CEvNS rate is a clean SM prediction

$$\frac{d\sigma}{dT} = \frac{G_F^2 M}{2\pi}\frac{Q_W^2}{4}F^2(Q)\left(2 - \frac{MT}{E_\nu^2}\right)$$

small nuclear uncertainties (±4.8%)



Uncertainty of CEvNS cross section:

- COHERENT: +18/-15%

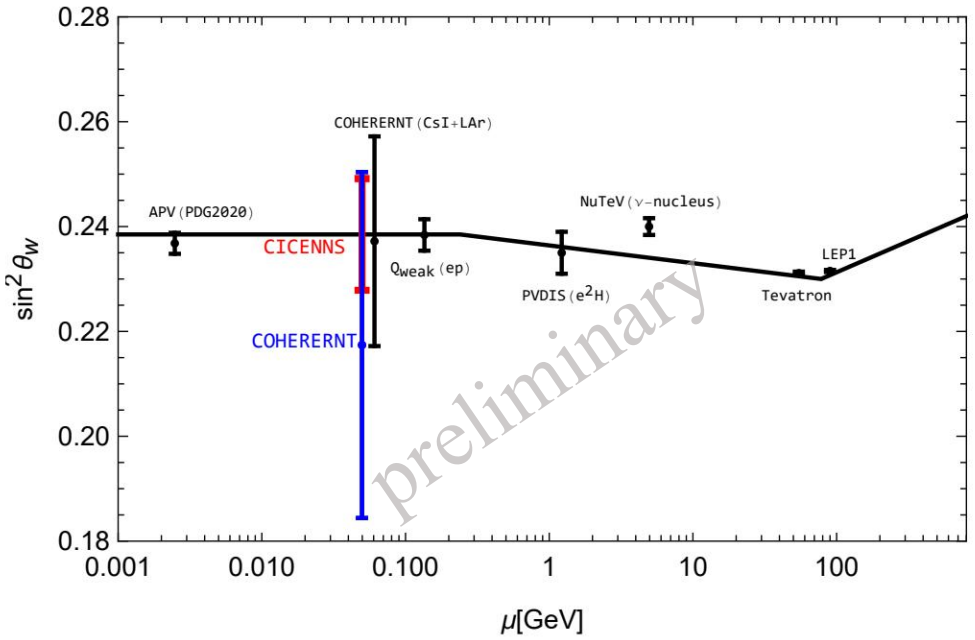
→ CICENNS: 6.5%

At momentum transfer Q=50 MeV/c

- COHERENT: $\sin^2\theta_W = 0.220^{+0.028}_{-0.026}$ (±10%)

→ CICENNS: ~1%

* SM prediction: 0.23857(5)



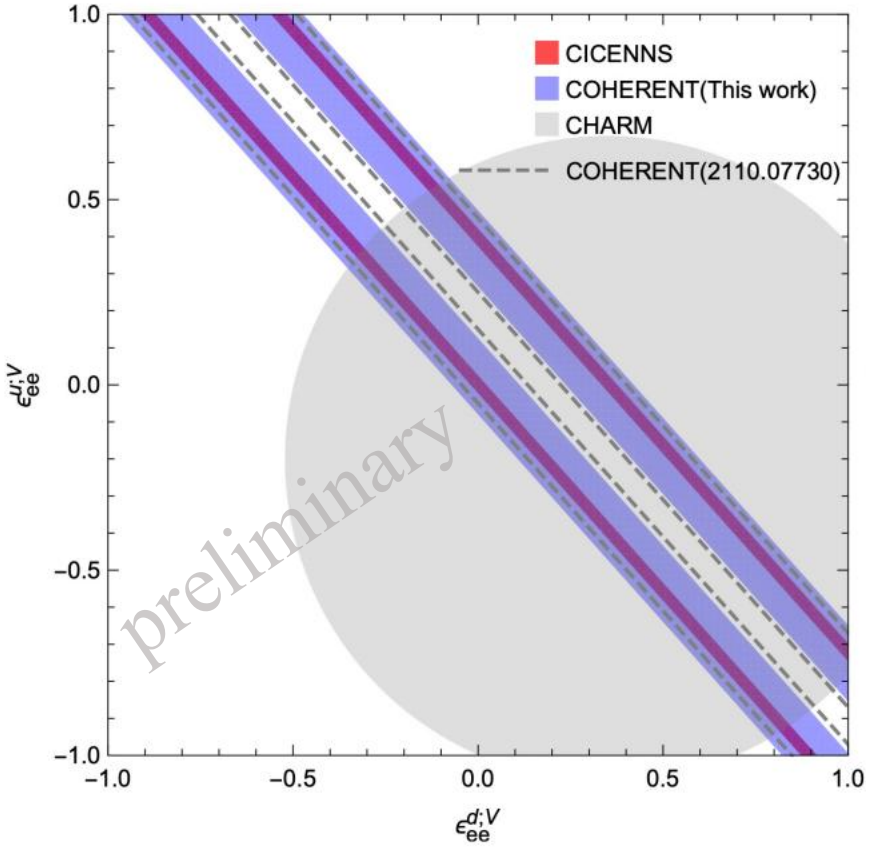
Sensitivity: Non-standard neutrino interaction

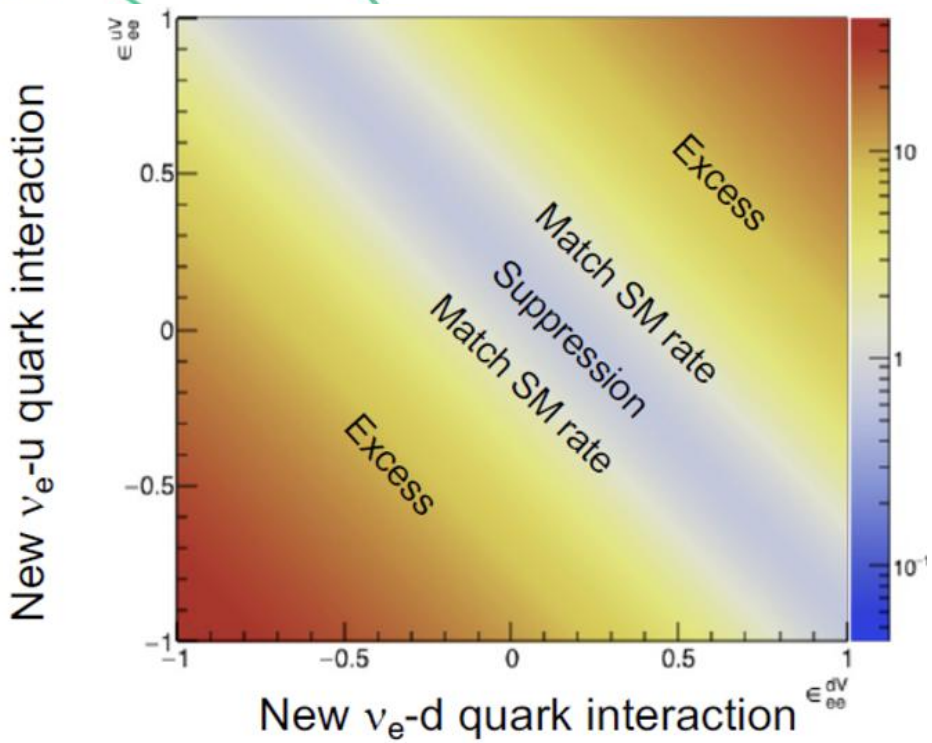
Look for a CEvNS **excess** or **deficit** wrt SM expectation

$$\mathcal{L}_{\nu H}^{NSI} = -\frac{G_F}{\sqrt{2}} \sum_{\substack{q=u,d \\ \alpha,\beta=e,\mu,\tau}} [\bar{\nu}_\alpha \gamma^\mu (1-\gamma^5)\nu_\beta] \times (\varepsilon_{\alpha\beta}^{qL}[\bar{q}\gamma_\mu(1-\gamma^5)q] + \varepsilon_{\alpha\beta}^{qR}[\bar{q}\gamma_\mu(1+\gamma^5)q])$$

Ratio wrt SM

CsI





Summary

- A 300-kg CsI(Na) crystal detector for CEνNS measurement at CSNS has been proposed, and is being built now.
- Through the above efforts, the threshold value of the recoil energy of the detector will be reduced(2 keV_{nr}).
- We wish to finalize the detector design and a TDR, and complete the detector construction in 2025.

Thanks!