Coherent Elastic Neutrino Nucleus scattering

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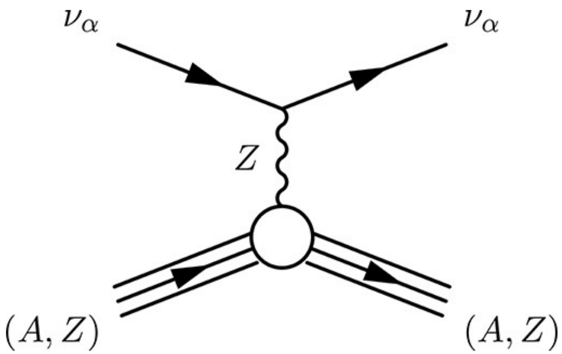
First flavor day at IJClab, 27 October 2021

What is CEvNS?



CEvNS stands for **Coherent Elastic Neutrino Nucleus Scattering**. It is a process in which the neutrino scatters off a nucleus as a whole via exchage a Z boson and the **nucleus recoils**.

PHYSICAL REVIEW D VOLUME 9, NUMBER 5 1 MARCH 1974

Coherent effects of a weak neutral current

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(Received 15 October 1973; revised manus

If there is a weak neutral current, then the elasti
have a sharp coherent forward peak just as $e + A \rightarrow$
peak can give important information on the isospin
experiments are very difficult, although the estima
carbon) are favorable. The coherent cross sections
energy-independent. Therefore, energies as low as
coherent nuclear excitation processes $\nu + A \rightarrow \nu + A^*$
the weak neutral current. Because of strong cohere
nuclear elastic scattering process may be importan
emission in stellar collapse and neutron stars.

Our suggestion may be an act of hubris, because the inevitable constraints of interaction rate, resolution, and background pose grave experimental difficulties for elastic neutrino-nucleus scattering. We will discuss these problems at the end of this note, but first we wish to present the theoretical ideas relevant to the experiments.

The first CEvNS detection

The first CEvNS nuclear recoil was observed **after more than 40 years** from Freedman's prediction.

First CEvNS detection in 2017 by COHERENT collaboration using 14.6 kg of CsI scintillating crystal

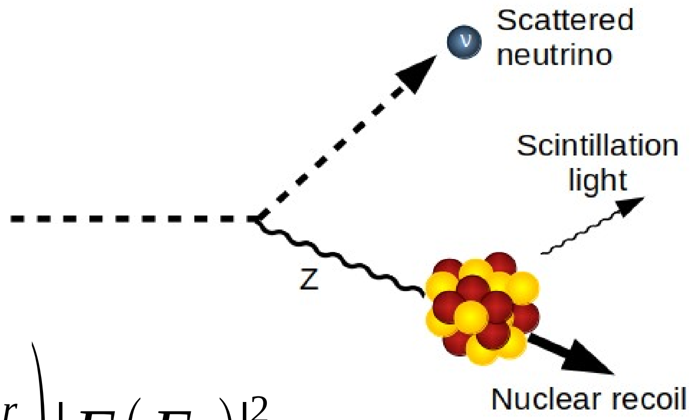
D. Akimov et al. Science 357.6356 (2017)

Second CEvNS detection in 2020 using Ar by COHERENT collaboration

D. Akimov et al., arxiv:2003.10630

CEvNS cross section

Assuming $q \cdot R = \sqrt{2 m_N E_R} \cdot R \ll 1$, namely the interaction is coherent (up to about E_ν ~ 50 MeV for medium size nuclei):

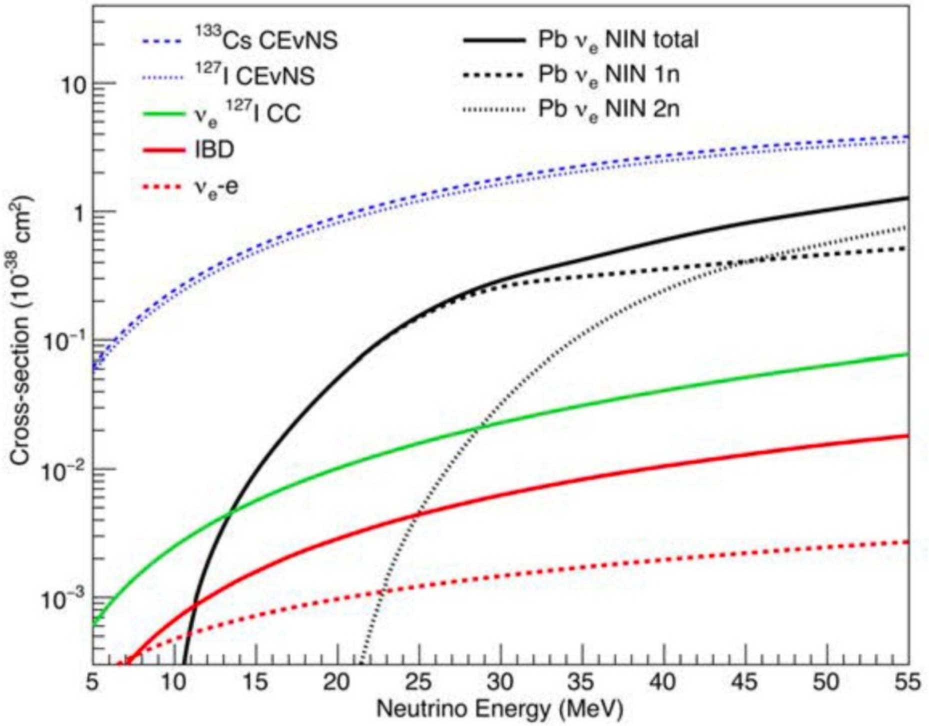


$$\frac{d\sigma^{CE\nu NS}(E_\nu, E_r)}{dE_r} \simeq \frac{G_F^2}{4\pi} Q_W^2 m_N \left(1 - \frac{m_N E_r}{2 E_\nu^2}\right) |F(E_r)|^2$$

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

Contribution of the nucleons in Q_W. However, since the Z is multiplied by the Weinberg angle, $4\sin^2\theta_W$ is small and $(1-4\sin^2\theta_W)$ close to zero. The main contribution is coming from neutrons. Moreover, $\sigma \propto N^2$.

CEvNS cross section



D.Akimov et al. Science 357.6356 (2017)

This σ is rather large compared to other cross sections in ν physics due to this coherent effect but the coherence condition, the unique process signature is a tiny nuclear recoil energy.

$$E_r^{max} \simeq \frac{2 E_\nu^2}{m_N + 2 E_\nu}$$

In keV range for E_ν~50keV.

Dark matter detector often used for CEvNS detection (sensitive to ~keV to 10's of keV recoils)

Neutrino sources

ν SOURCE WISHLIST:

High flux neutrino source in order to have as much statistics as possible;

Very **well understood flux** to know how many neutrinos are interacting in our detector;

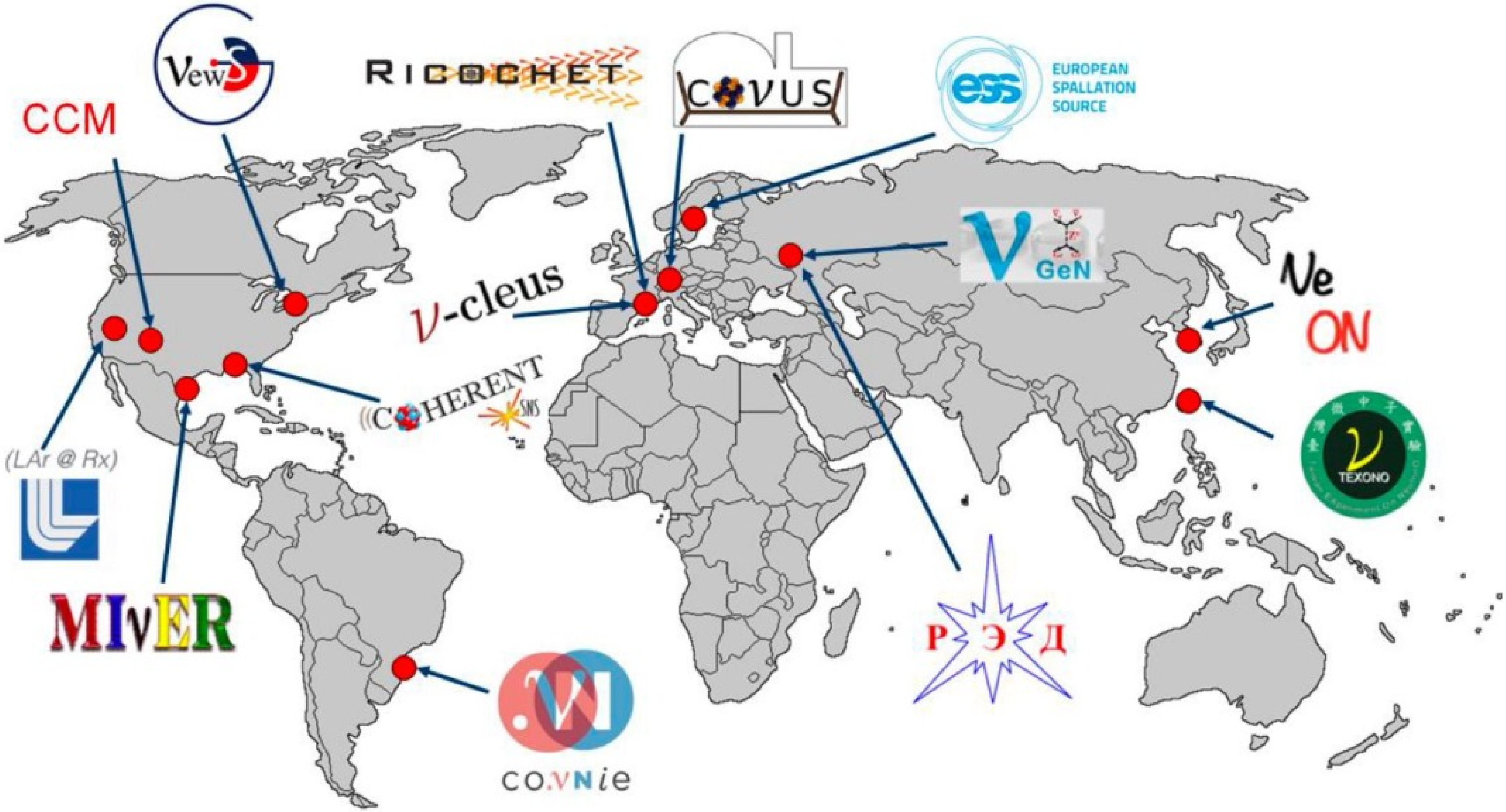
Pulsed source: operate at tiny time window whenever we expect a pulse to accumulate less background as possible;

Multiple flavor: CEvNS is flavor independent. If our experiment is able to distinguish ν flavor, we can study different properties.

Nuclear reactor source:
produced in beta decays of fission fragments;

Spallation neutron source:
neutrinos produced from pions/muons decay.

Ongoing and future experiments

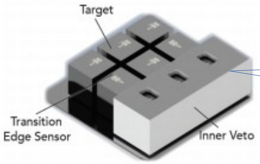


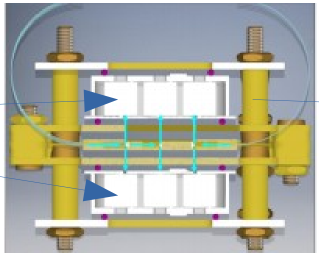
An example: NUCLEUS experiment

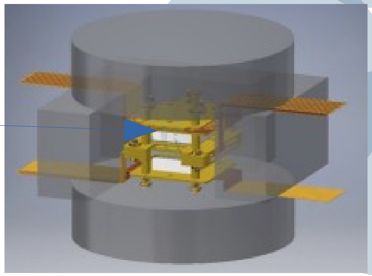
CEvNS detection using the following features:

- Anti-neutrinos from nuclear reactors
- Gram scale cryogenic calorimeter
- Ultra-low energy (E_r=20keV in 1g prototype)
- Multi-target: $CaWO_4$ and Al_2O_3 crystals

The NUCLEUS cryostat will hold a system of nested cryogenic detectors that will allow the reduction of the background counting rate thanks to the anti-coincidence technique + passive shildings.







What can we learn?

Nuclear Physics
- Neutron distribution radius in CsI
- Neutron distribution radius in Ar

Cadeddu et al, *arXiv*:2102.06153
Cadeddu et al., *PRL* 120, 072501 (2018)
Cadeddu et al., *PRD* 101, 033004 (2020)
Papoulias, *PRD* 102, 113004 (2020)
Khan and Rodejohann, *PRD* 100, 113003 (2019)
Coloma et al, *JHEP* 08:030 (2020)
Aristizabal Sierra et al., *JHEP* 6, 141 (2019)
Cadeddu et al., *PRD* 102, 015030 (2020)
Payne et al., *PRC* 100, 061304 (2019)
Miranda et al., *JHEP* 05 (2020) 130
Reed at al., *PRL* 126, 172503 (2021)
Horowitz et al., *PRL* 86, 5647 (2001)
Cadeddu et al., *arXiv*:2102.06153

New neutrino interactions:
- Light and heavy mediators

C. Giunti, *PRD* 101, 035039 (2020)
J. Barranco et al, *JHEP* 0512:021 (2005)
P. Coloma et al, *JHEP* 01 (2021) 114
Miranda et al, *JHEP* 05 (2020) 130
P. Coloma et al, *PRD* 96, 115007 (2017)
Denton at al., *arXiv*: 1804.03660
Denton and Gehrlein, *JHEP* 04 (2021) 266
J. Barranco et al, *JHEP* 0512:021 (2005)
Dutta et al., *JHEP* 2020, 106 (2020)

Electroweak precision
- Weinberg angle

Cadeddu et al, *arXiv*:2102.06153

Neutrino properties:
- Electromagnetic interactions
- Neutrino charge radius

C. Giunti, A. Studenikin, *Rev Mod Phys*, 87, 531 (2015)
Bernabeu et al, *PRD* 62 (2000) 113012, *NPB* 680 (2004) 450
Cadeddu et al, *PRD* 102, 015030 (2020)
Cadeddu et al, *PRD* 101, 033004 (2020)

But CEvNS detection can also be useful for…
...dark matter searches
...axions searches
...sterile neutrinos
...supernova neutrinos

Bohem et al., *arXiv*: 1809.06385 (2018)
Dutta et al., *PRL*124, 121802 (2020)
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Formaggio et al., *PRD* 85, 013009 (2012)
Blanco et al., *PRD* 101, 075051 (2020)
Miranda et al., *PRD* 102, 113014 (2020)
Horowitz et al., *PRD* 68, 023005
DarkSide-20k, *JCAP*03(2021)043

Conclusions

CEvNS observation is a new window on physics beyond the standard model

Application to different sectors of particle and nuclear physics

Growing interest in this process from the experimental and theoretical point of view

New results by several collaborations expected soon