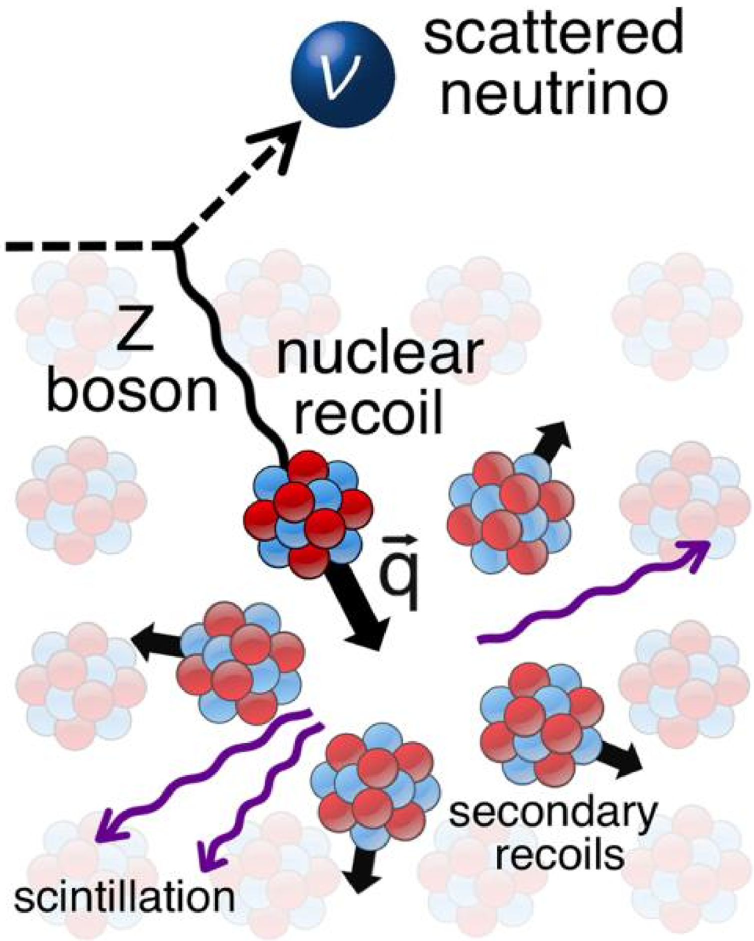

Coherent elastic neutrino-nucleus scattering – the newly observed type of neutrino interaction.

D. Akimov
NRC «Kurchatov Institute» - ITEP
&
NRNU MEPhI

The 3rd international conference on particle physics and astrophysics (ICPPA-2017)
Moscow, 02 - 05 October 2017

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Summary

On August 3 2017 the COHERENT collaboration reported on the 1st observation of CEνNS at SNS

Electronic version:

Science

10.1126/science.aao0990 (2017)

Science REPORTS

Cite as: D. Akimov *et al.*, *Science* 10.1126/science.aao0990 (2017).

Observation of coherent elastic neutrino-nucleus scattering

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#The collaboration consists of all listed authors. There are no additional collaborators.

The coherent elastic scattering of neutrinos off nuclei has eluded detection for four decades, even though its predicted cross-section is the largest by far of all low-energy neutrino couplings. This mode of interaction provides new opportunities to study neutrino properties, and leads to a miniaturization of detector size, with potential technological applications. We observe this process at a 6.7-sigma confidence level, using a low-background, 14.6-kg CsI[Na] scintillator exposed to the neutrino emissions from the Spallation Neutron Source (SNS) at Oak Ridge National Laboratory. Characteristic signatures in energy and time, predicted by the Standard Model for this process, are observed in high signal-to-background conditions. Improved constraints on non-standard neutrino interactions with quarks are derived from this initial dataset.

The characteristic most often associated with neutrinos is a very small probability of interaction with other forms of matter, allowing them to traverse astronomical objects while undergoing no energy loss. As a result, large targets (tons to tens of kilotons) are used for their detection. The discovery of a weak neutral current in neutrino interactions (*1*) implied that neutrinos were capable of coupling to quarks through the exchange of neutral Z bosons. Soon thereafter it was suggested that this mechanism should also lead to coherent interactions between neutrinos and all nucleons present in an atomic nucleus (*2*). This possibility would exist only as long as the momentum exchanged remained significantly smaller than the inverse of the nuclear size (Fig. 1A), effectively restricting the process to neutrino

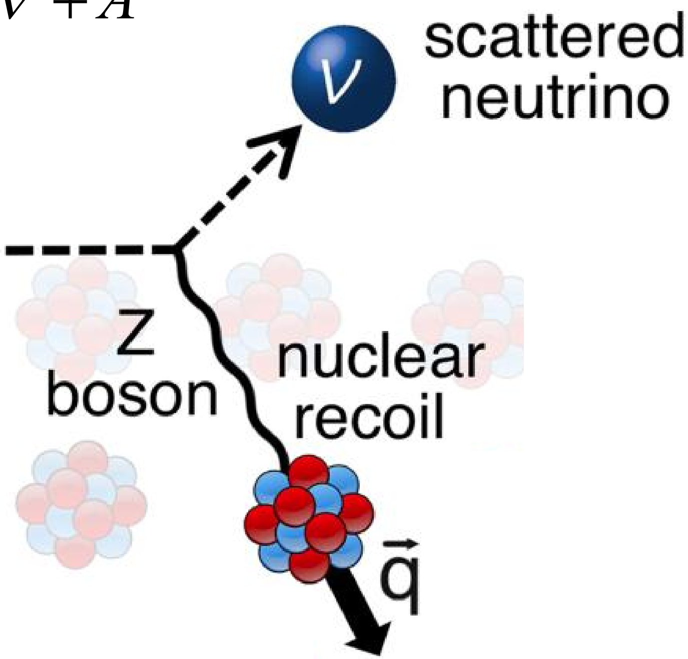
Printed version:

Science

Vol. 357,15 Sep. 2017, p. 1123

Coherent elastic neutrino-nucleus scattering (CEνNS):

$$\nu + A \rightarrow \nu' + A'$$



In 1973, a neutral current has been observed in a neutrino interaction:
Observation of neutrino-like interactions without muon or electron in the Gargamelle neutrino experiment. *Phys. Lett. B* 46, 138–140 (1973).

Soon after that

In 1974, the idea of coherency:
D.Z. Freedman, Coherent effects of a weak neutral current, Phys. Rev. D 9 (1974) 1389.

$E_\nu \leq 50$ MeV

The process has not been observed experimentally until this year because of the very low energy transfer (keV- and sub keV energy deposition)

Cross section

$$\frac{d\sigma}{dT_A} = \frac{G_F^2}{4\pi} m_A [Z(1-4\sin^2\theta_W) - N]^2 \left[1 - \frac{m_A T_A}{2E_\nu^2}\right] \cdot F(q^2)^2$$

m_A – mass of nucleus with atomic number A,
T_A – nuclear recoil kinetic energy,
E_ν – neutrino energy,
Z – number of protons,
N – number of neutrons,
$F(q^2)$ – nuclear formfactor,

θ_w – Weinberg angle, $\sin^2\theta_w \approx 0.22$; $(1 - 4\sin^2\theta_w) = o(1) \rightarrow$ $\boldsymbol{\sigma \sim N^2}$

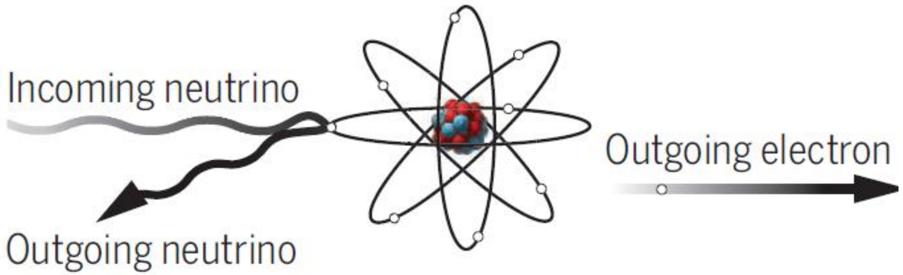
$$\sigma \approx 0.4\ 10^{-44}\ N^2\ E_\nu^2\ \text{см}^2$$

averaged over energy spectrum of reactor antineutrinos (0 – 10 MeV):
for Xe nucleus: $\langle\sigma\rangle \approx 7\cdot10^{-41}$ cm^2
for inverse beta decay on proton: $\tilde{\nu} + p \rightarrow e^+ + n$ $\langle\sigma\rangle \approx 1\cdot10^{-43}$ cm^2

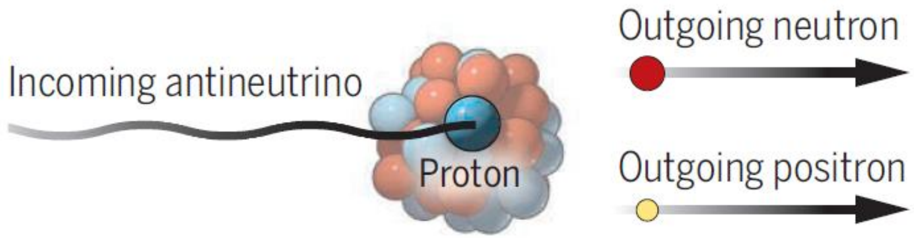
CEνNS is a DOMINANT channel of neutrino-substance interaction at low energies

3 common types of low-energy neutrino interaction with atomic substance

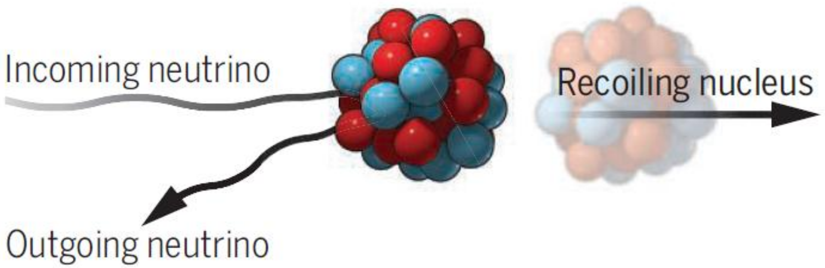
1 Neutrino-electron elastic scattering



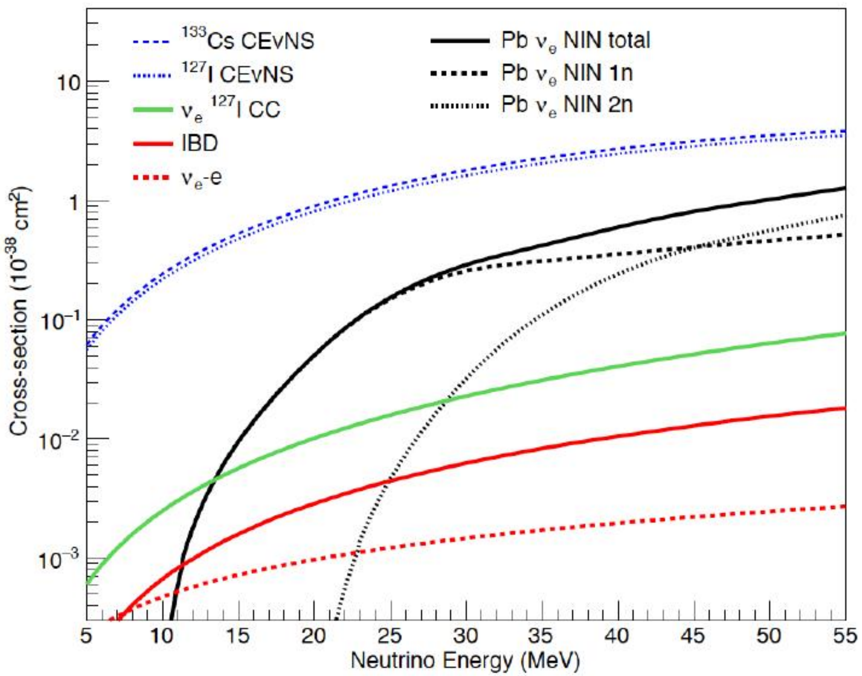
2 Inverse beta decay



3 Coherent elastic neutrino-nucleus scattering (CEνNS)

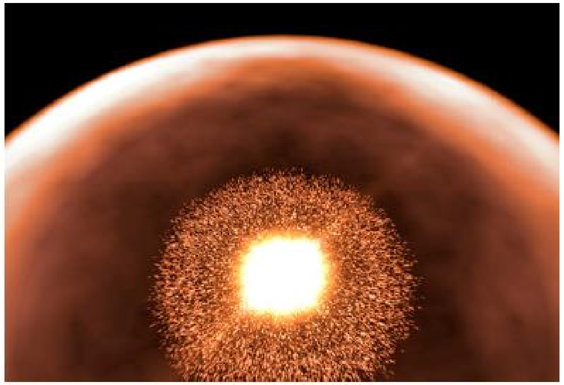


Images from J.M. Link
Science **Vol 357,** p. 1098



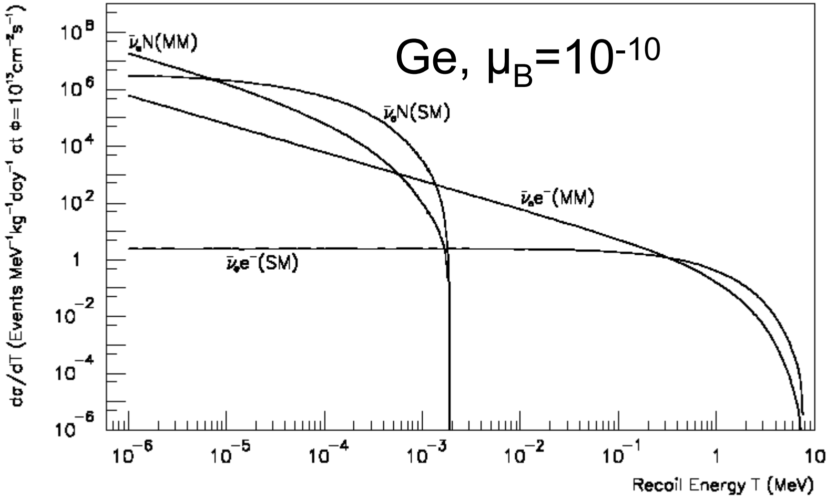
Motivation of experiments

Coherent scattering significantly affects supernova dynamics

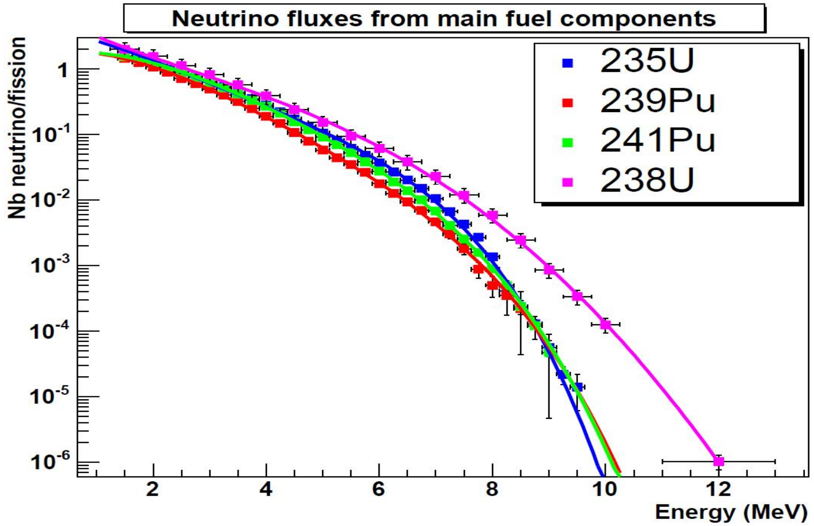


99% of gravitational binding energy goes to ν!

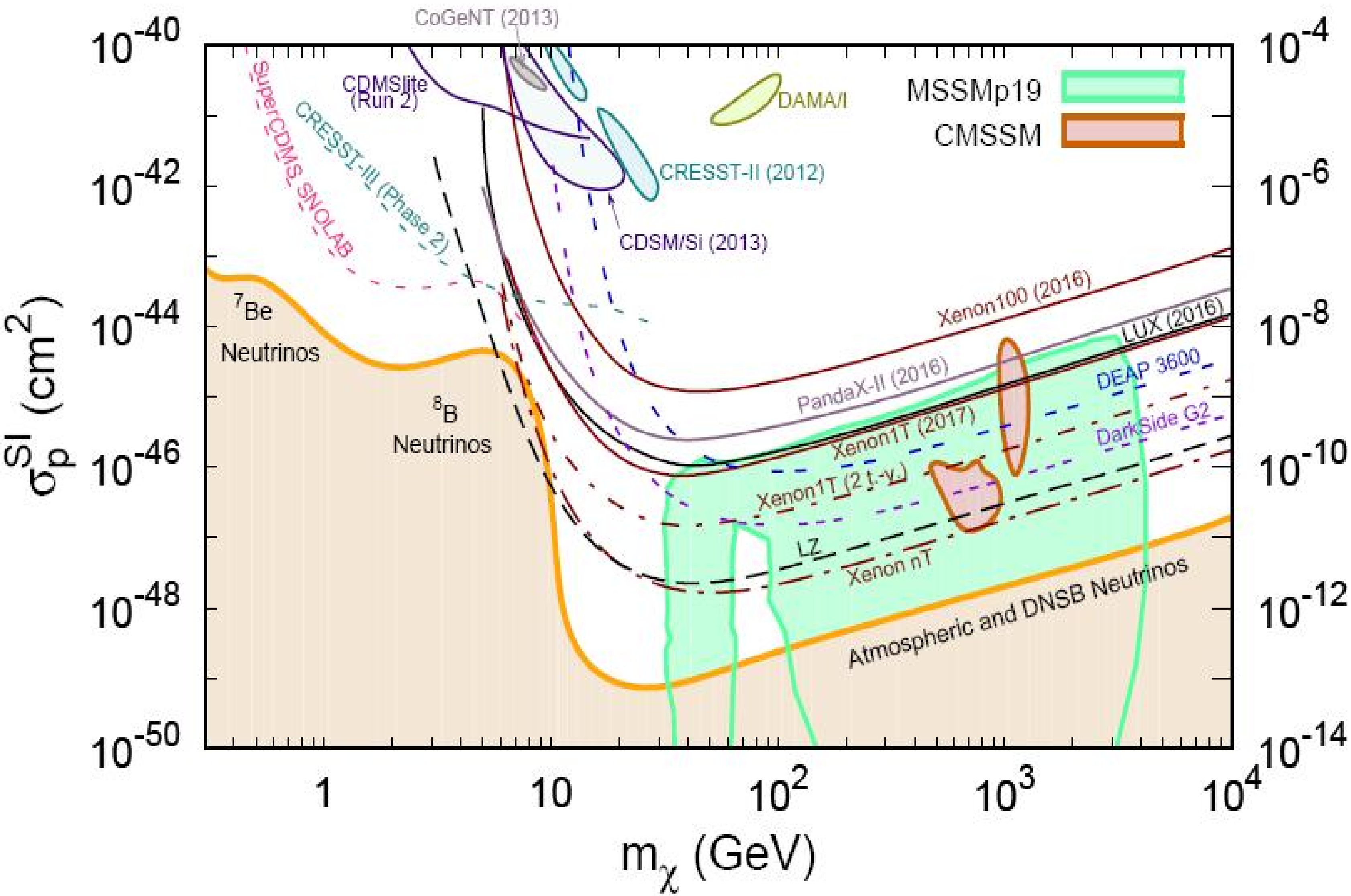
“Non-standard” physics



Monitoring of nuclear reactors



CEνNS is irreducible background floor for DM experiments



The 1st experimental proposal on CEνNS detection

PHYSICAL REVIEW D VOLUME 30, NUMBER 11 1 DECEMBER 1984

Principles and applications of a neutral-current detector for neutrino physics and astronomy

A. Drukier and L. Stodolsky
Max-Planck-Institut für Physik und Astrophysik, Werner-Heisenberg-Institut für Physik, Munich, Federal Republic of Germany
(Received 21 November 1983)

We study detection of MeV-range neutrinos through elastic scattering on nuclei and identification of the recoil energy. The very large value of the neutral-current cross section due to coherence indicates a detector would be relatively light and suggests the possibility of a true "neutrino observatory." The recoil energy which must be detected is very small (10–10^3 eV), however. We examine a realization in terms of the superconducting-grain idea, which appears, in principle, to be feasible through extension and extrapolation of currently known techniques. Such a detector could permit determination of the neutrino energy spectrum and should be insensitive to neutrino oscillations since it detects all neutrino types. Various applications and tests are discussed, including spallation sources, reactors, supernovas, and solar and terrestrial neutrinos. A preliminary estimate of the most difficult backgrounds is attempted.

The idea of a detector

- in a superconducting colloidal system, there are small (micron-size) metastable superconducting granules;
- the detector is placed in a magnetic field, and the temperature of the detector is tuned so that even with very little energy deposition by a nuclear recoil some of the granules lose their superconductivity;
- this leads to the measurable change of magnetic field that gives information about the deposited energy in the detector.

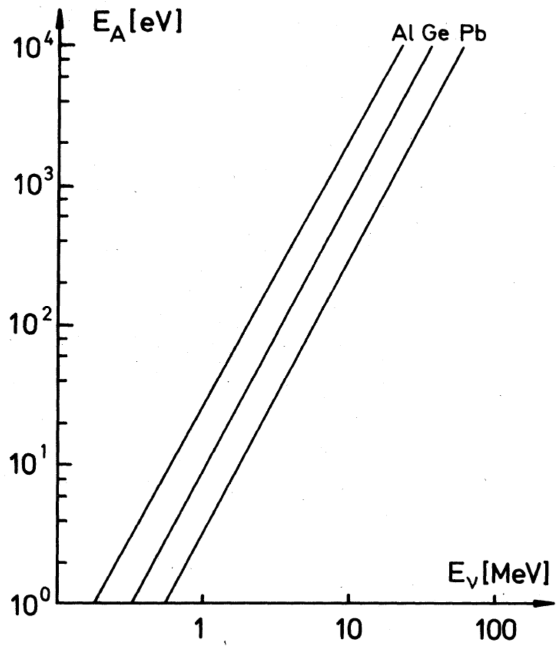


FIG. 2. Average recoil energy for various nuclei as a function of neutrino energy.

1^{st} experimental proposal on WIMP detection

PHYSICAL REVIEW D VOLUME 31, NUMBER 12 15 JUNE 1985

Detectability of certain dark-matter candidates

Mark W. Goodman and Edward Witten
Joseph Henry Laboratories, Princeton University, Princeton, New Jersey 08544
(Received 7 January 1985)

We consider the possibility that the neutral-current neutrino detector recently proposed by Drukier and Stodolsky could be used to detect some possible candidates for the dark matter in galactic halos. This may be feasible if the galactic halos are made of particles with coherent weak interactions and masses $1-10^6$ GeV; particles with spin-dependent interactions of typical weak strength and masses $1-10^2$ GeV; or strongly interacting particles of masses $1-10^{13}$ GeV.

The idea was not realised too.

However, it stimulated the new experimental direction of low-threshold low-background detectors to search for DM.

Experiments & projects

Ge detectors: CoGeNT *(USA),* **TEXONO** *(Taiwan),*

νGen, CONUS, *…*

Reactor: *CONNIE (Brazil), MINER, RICOCHET*

Liq. noble gases: LAr Livermore, LXe ITEP&INR,

LXe ZEPLIN-III, RED-100

π decay at rest: **ISIS:** **LXe ZEPLIN-III**

Fermilab BNB: **CENNS**

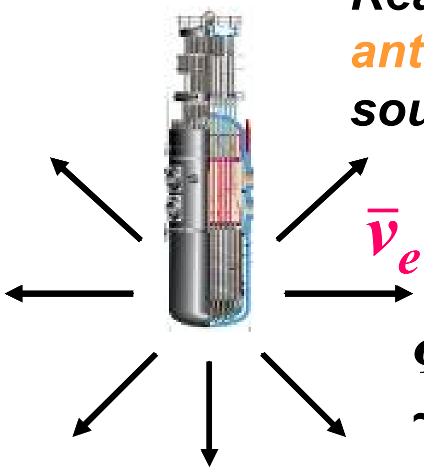
SNS: **LAr - CLEAR,**

COHERENT (LXe, LAr-CENNS-10,

Ge,CsI(Na), NaI)

ν sources: reactor or π decay at rest source?

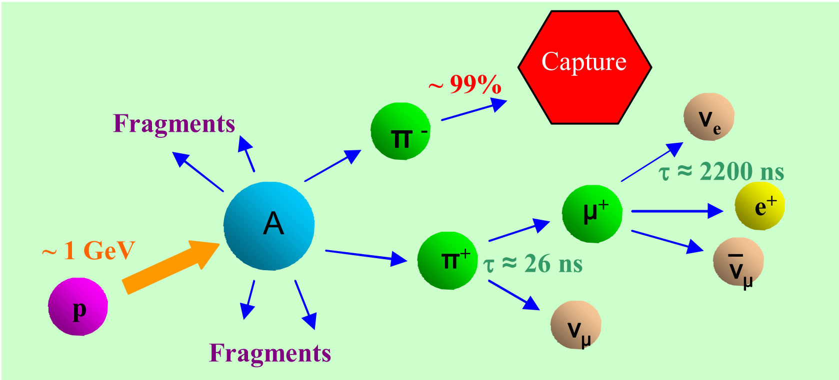
Reactor – antineutrino source



$\bar{\nu}_e$ ~ $6\cdot10^{20}$ s^{-1}

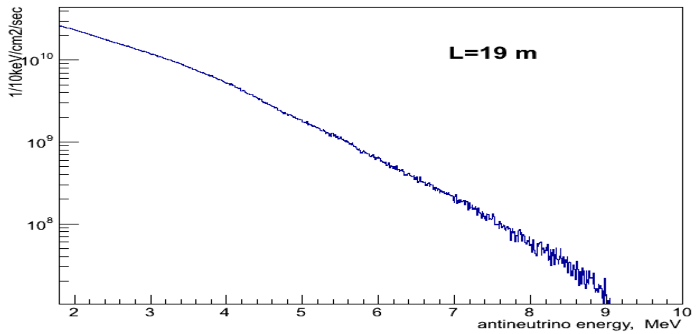
Φ_ν @19m ~ $1.3\cdot10^{13}$ cm^{-2}s^{-1}

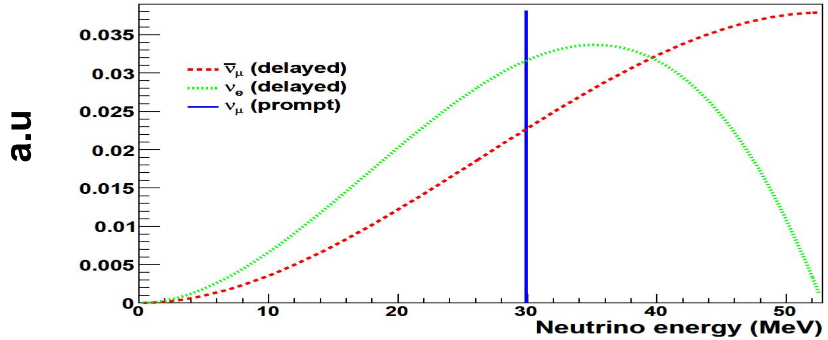
πDAR - $\bar{\nu}_\mu, \nu_\mu, \nu_e$ source



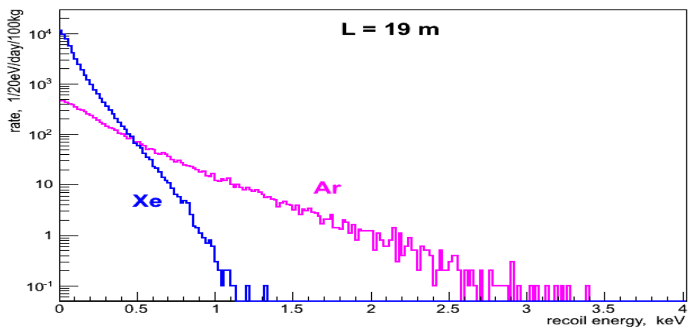
Φ_ν is by a factor of $>10^6$ lower, but σ is by $> 10^2$ higher

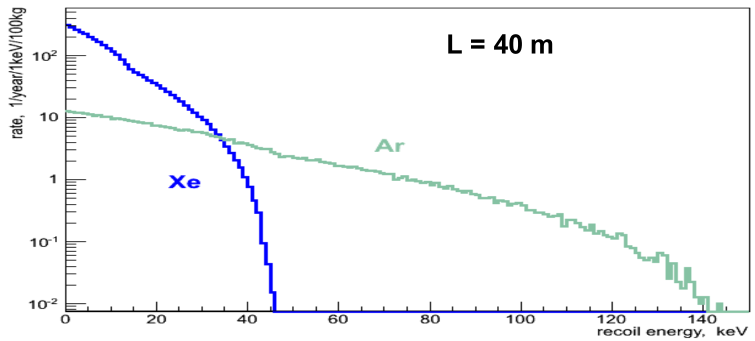
ν energy spectra





Xe and Ar n.r. spectra

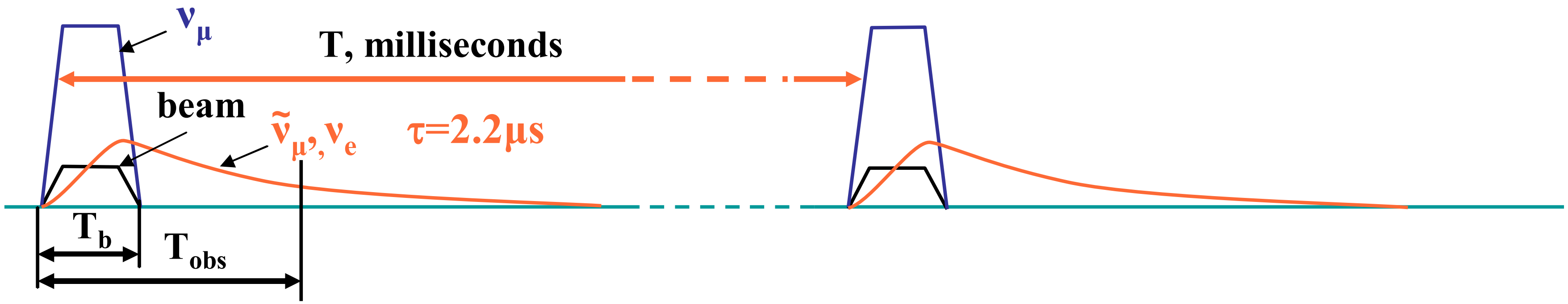


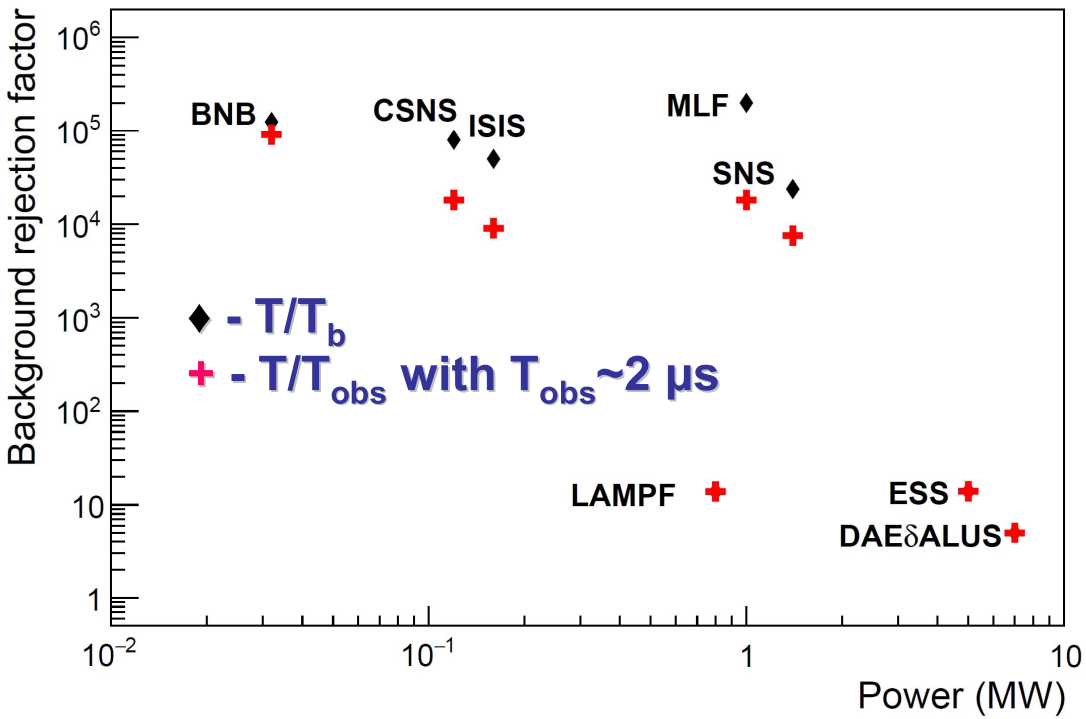


Reactor or π decay at rest source?

Pulsed beam of an accelerator is an essential factor of background reduction!

Duty factor = $T_{obs}/T \sim 10^{-1} \div 10^{-5}$

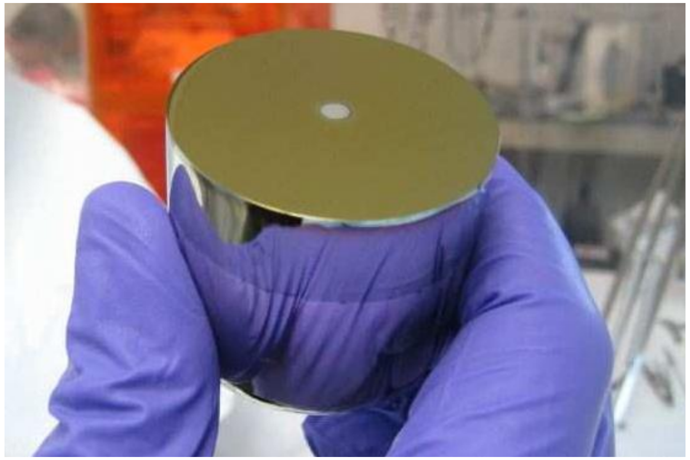




LAMPF	US (LANL)
ISIS	UK (RAL)
BNB	US (FNAL)
SNS	US (ORNL)
MLF	Japan (J-PARC)
CSNS	China (planned)
ESS	Sweden (planned)
DAE_ALUS	US (planned)

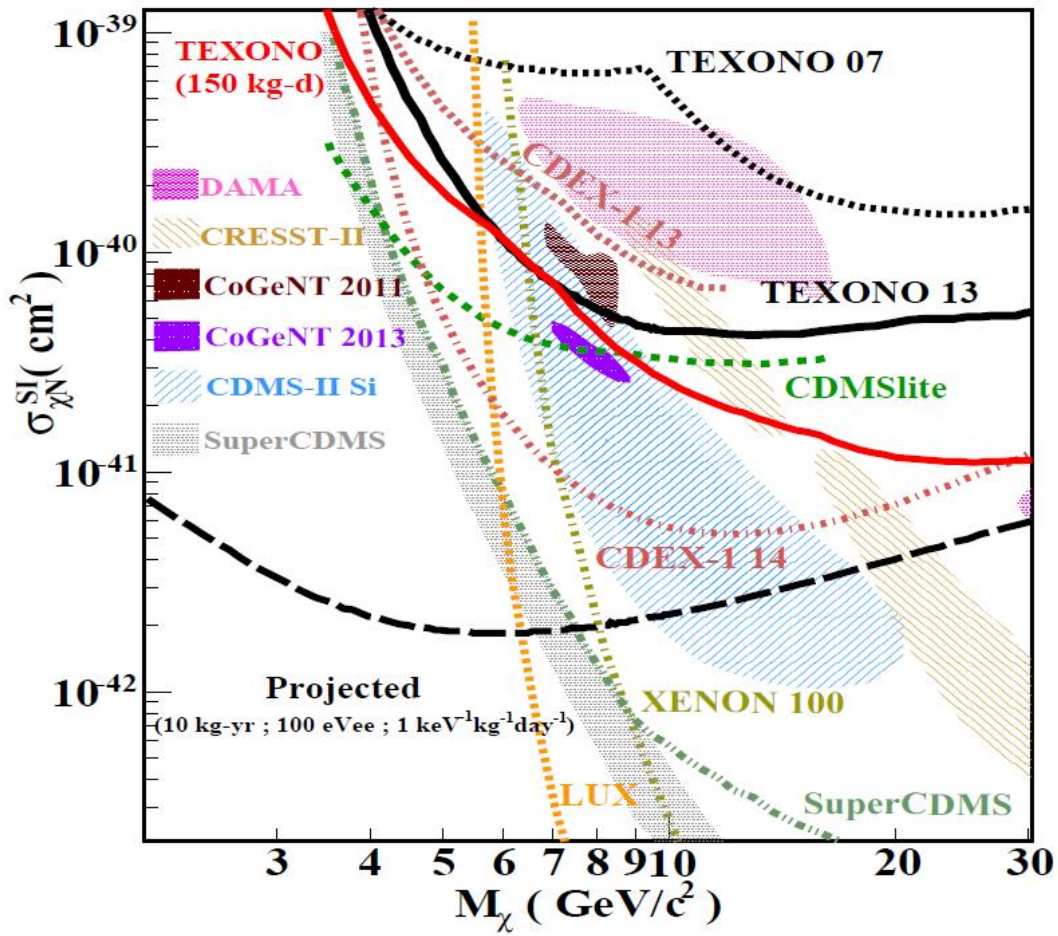
Ge detectors: CoGeNT *(USA)*, TEXONO *(Taiwan)*

point contact (PPC) Ge detector:

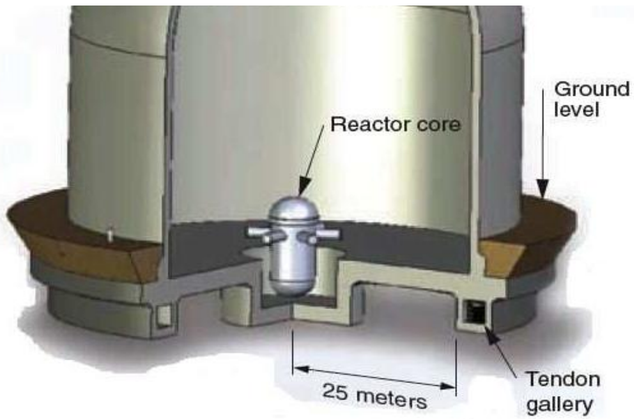


Can operate with a very low threshold (below 1 keV)!

Both detectors were used in DM search experiments:

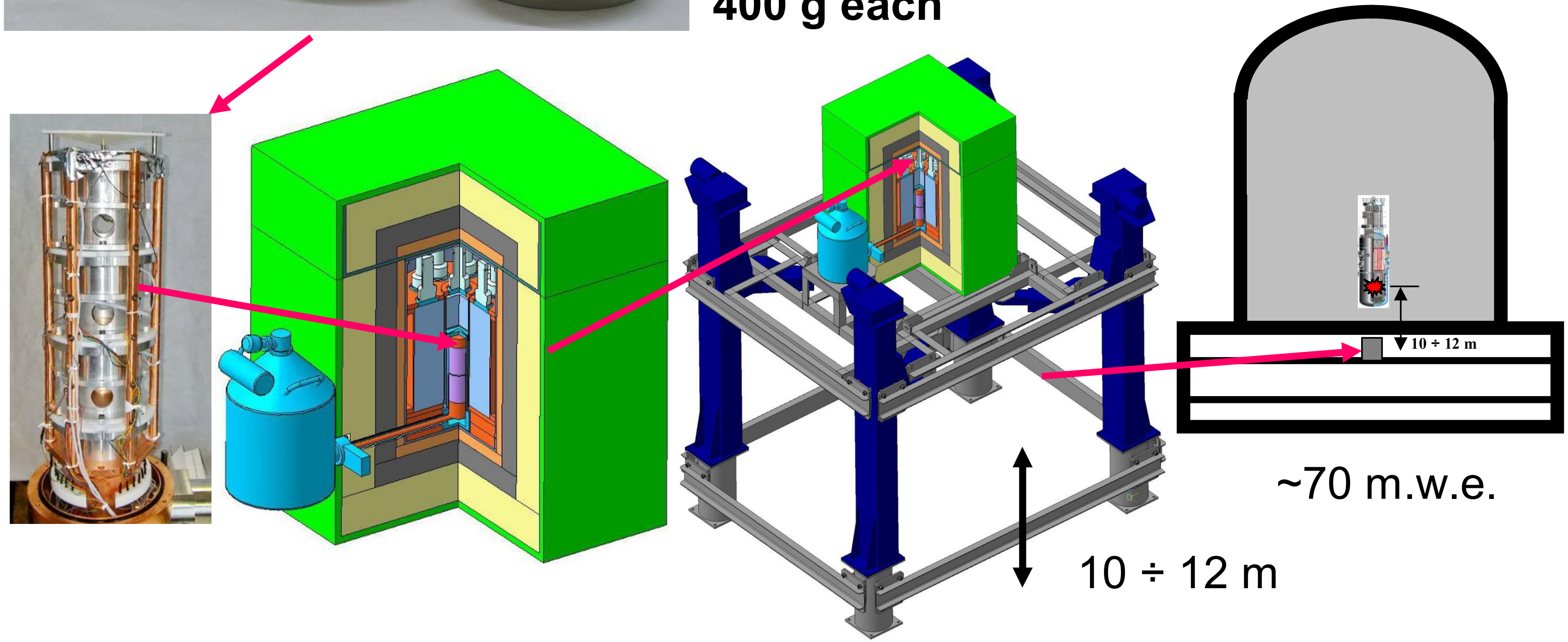


CoGeNT - San Onofre Nuclear Power Reactor, USA



point contact Ge detectors

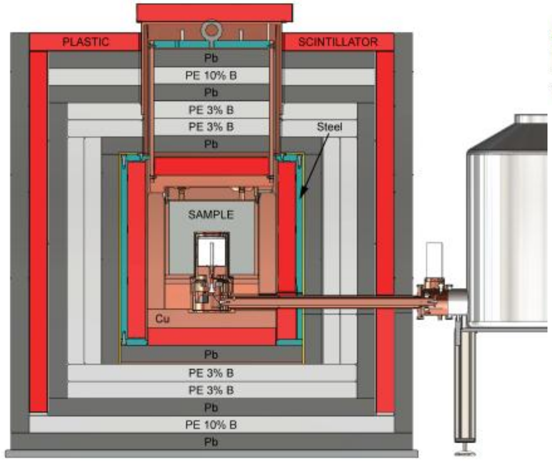
400 g each

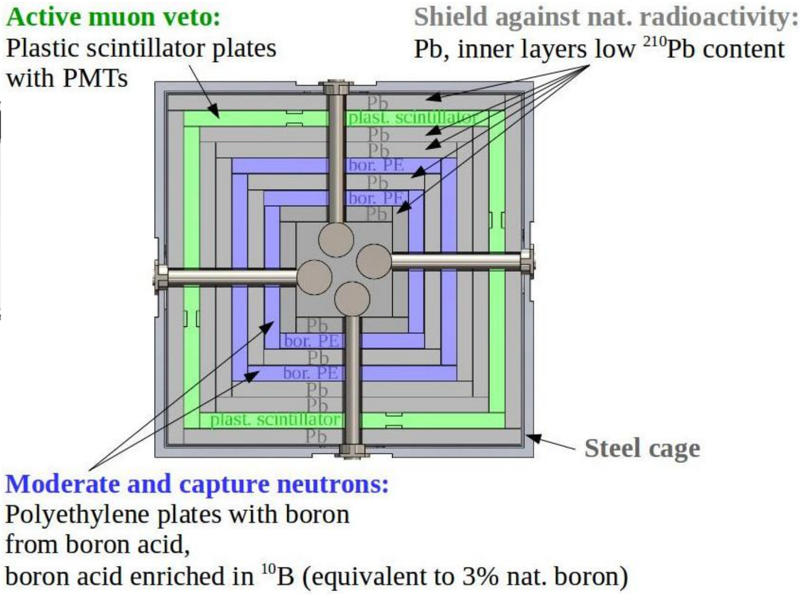


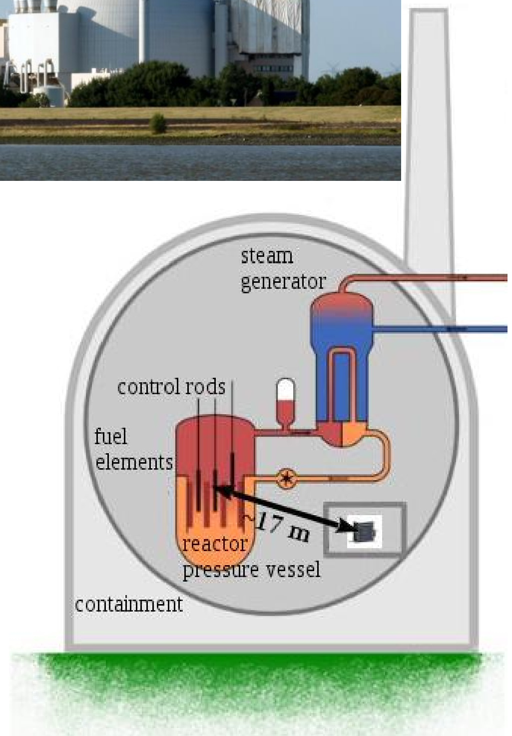
Background index < 1 event/kg/day in <1 keV range
Energy threshold ~ 350 eV.

CONUS

Max Plank Institute







Background index < 1 event/kg/day (45-50 keV)

Signal/bckg:

E_{Ion}^{Th}[keV_{ee}]	Qf=0.15	**Qf=best fit**	Qf=0.2
0.30	0.4	**1.8**	4.0
0.24	3.2	**8.6**	16
0.18	22	**35**	59

Noble gas detectors

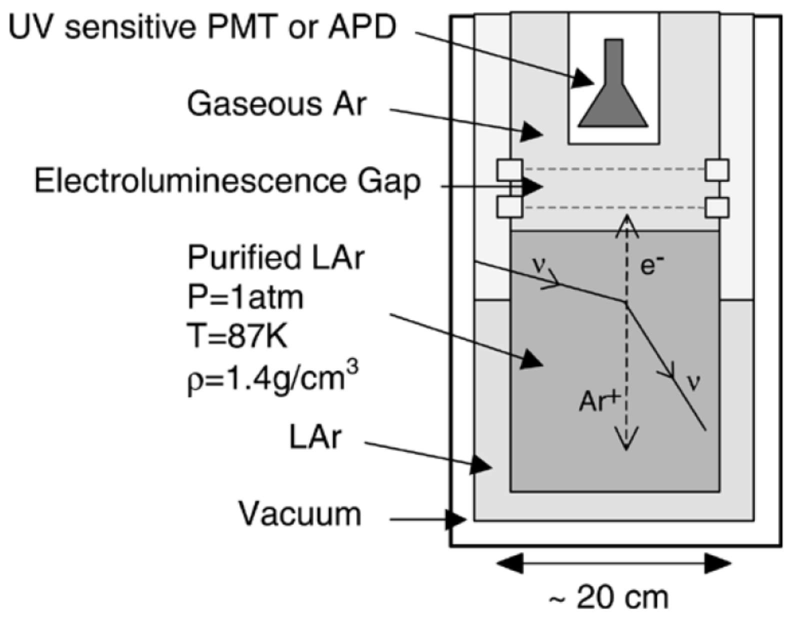
1^{st} proposal (in 2004); LAr detector

IEEE TRANSACTIONS ON NUCLEAR SCIENCE, VOL. 51, NO. 5, OCTOBER 2004 2151

Two-Phase Emission Detector for Measuring Coherent Neutrino-Nucleus Scattering

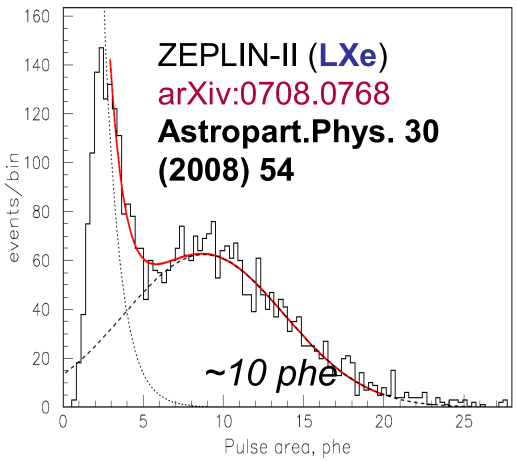
Chris Hagmann and Adam Bernstein

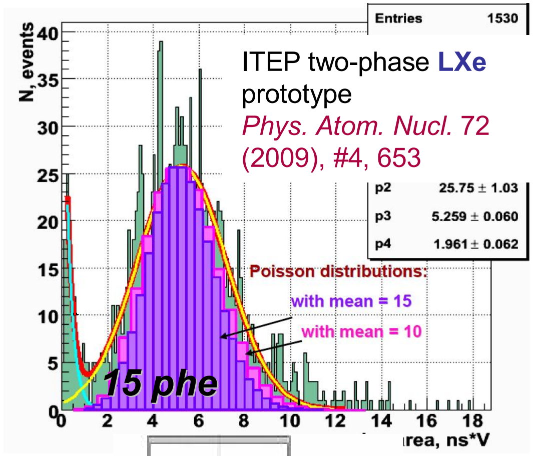
***Abstract*—Coherent scattering is a flavor-blind, high-rate, as yet undetected neutrino interaction predicted by the Standard Model. We propose to use a compact (kg-scale), two-phase (liquid–gas) argon ionization detector to measure coherent neutrino scattering off nuclei. In our approach, neutrino-induced nuclear recoils in the liquid produce a weak ionization signal, which is transported into a gas under the influence of an electric field, amplified via electroluminescence, and detected by phototubes or avalanche diodes. This paper describes the features of the detector, and estimates signal and background rates for a reactor neutrino source. Relatively compact detectors of this type, capable of detecting coherent scattering, offer a new approach to flavor-blind detection of man-made and astronomical neutrinos, and may allow development of compact neutrino detectors capable of nonintrusive real-time monitoring of fissile material in reactors.**

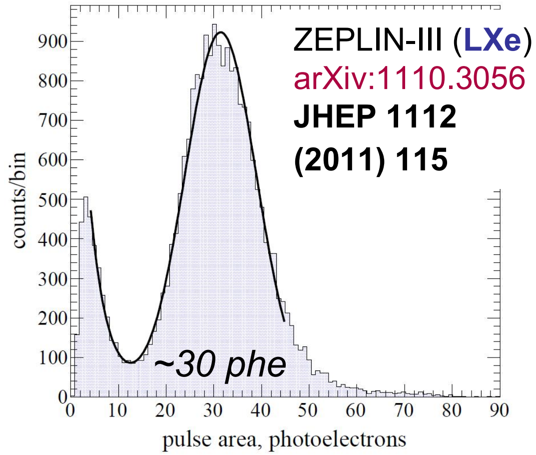


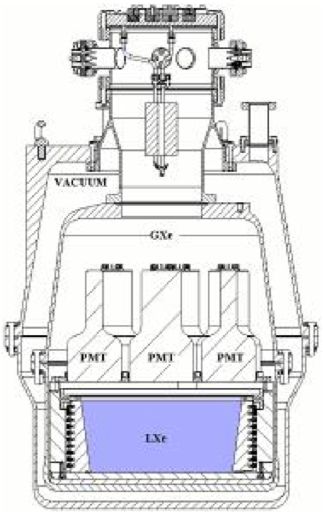
Projects with LXe

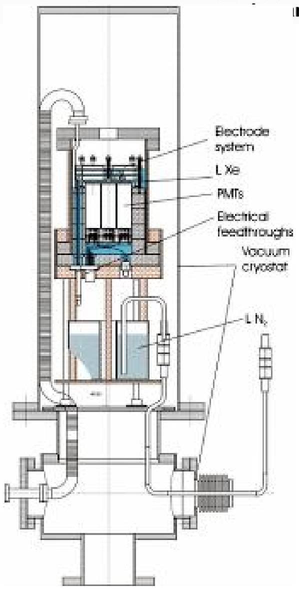
were followed after demonstration of the possibility of detection of single ionization electrons (**SE**)

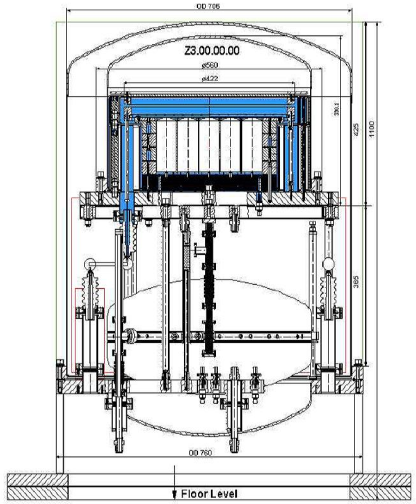










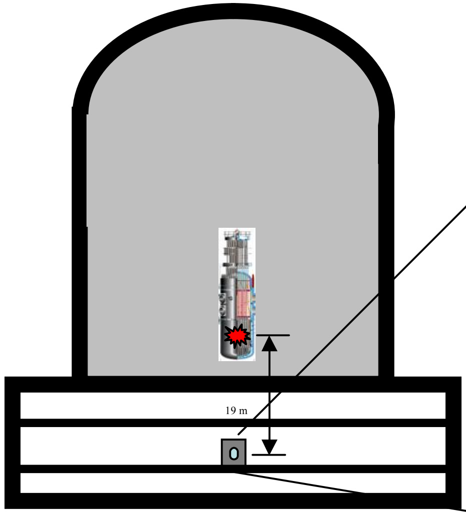


Проекты по регистраци и CEvNS:

ИТЭФ&ИЯФ LXe:
JINST 4 (2009) P06010 [arXiv:0903.4821]

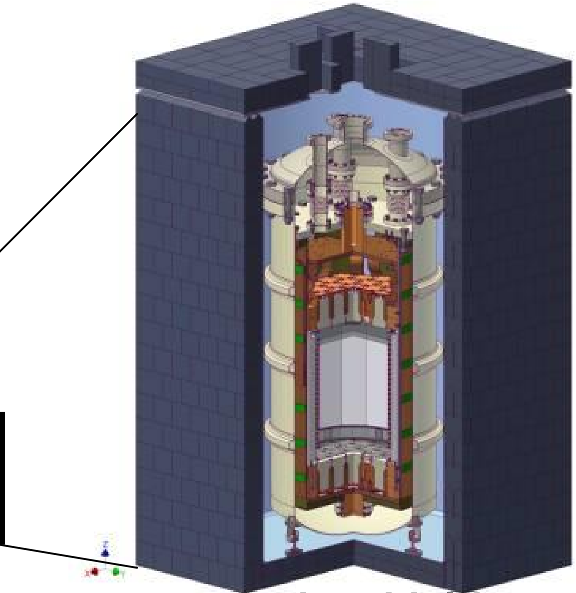
ZEPLIN-III Collaboration LXe:
JHEP 1112 (2011) 115 [arXiv:1110.3056].

RED-100 detector; Kalinin NPP

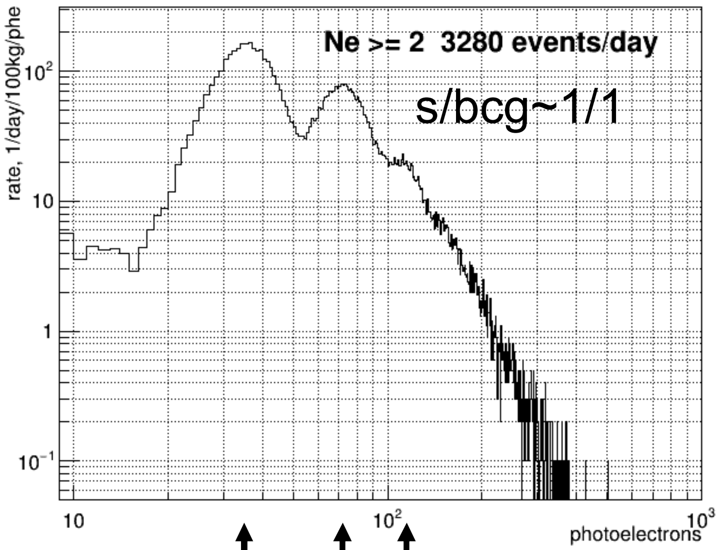


19 м from core

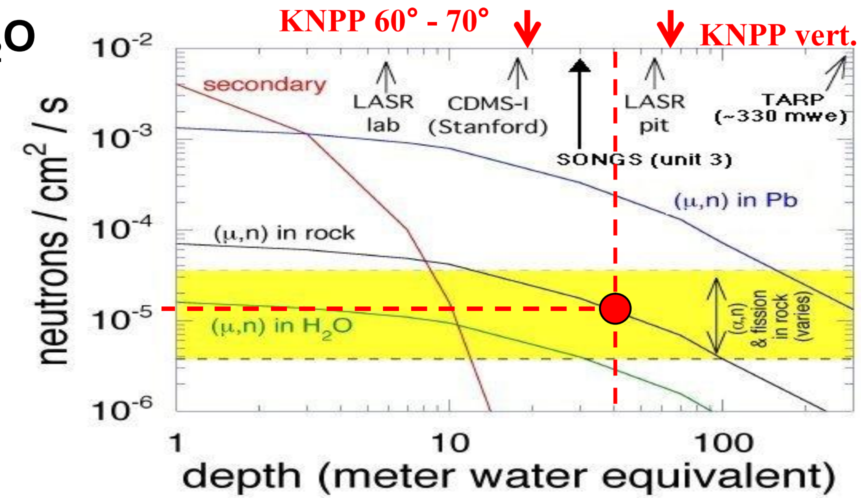
Φ_ν @19m ~ $1.3 \cdot 10^{13}$ $cm^{-2}s^{-1}$



γ and n shield:
10 ÷ 15 cm Pb +
~15 cm H_2O



Neutron flux



The building and the reactor is a good shield from cosmic rays

The RED-100: the laboratory tests are under way in MEPhI

RED-100 is a two-phase noble gas emission detector.

Contains ~200 kg of LXe, ~100 kg in FV (Fiducial Volume).

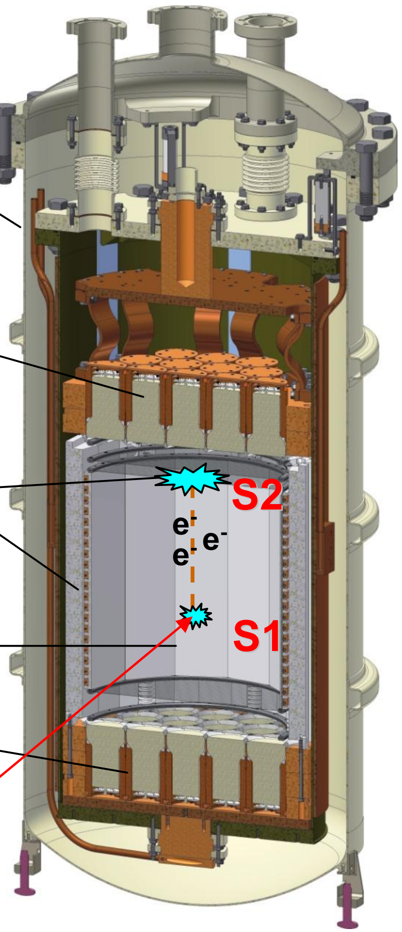
The sensitive volume ~ 45 cm in diam., ~ 45 cm in height, is defined by the top and bottom optically transparent mesh electrodes and field-shaping rings.

Titanium cryostat

Top PMT array

19 PMTs Hamamatsu R11410-20

Electrodes & field shaping rings

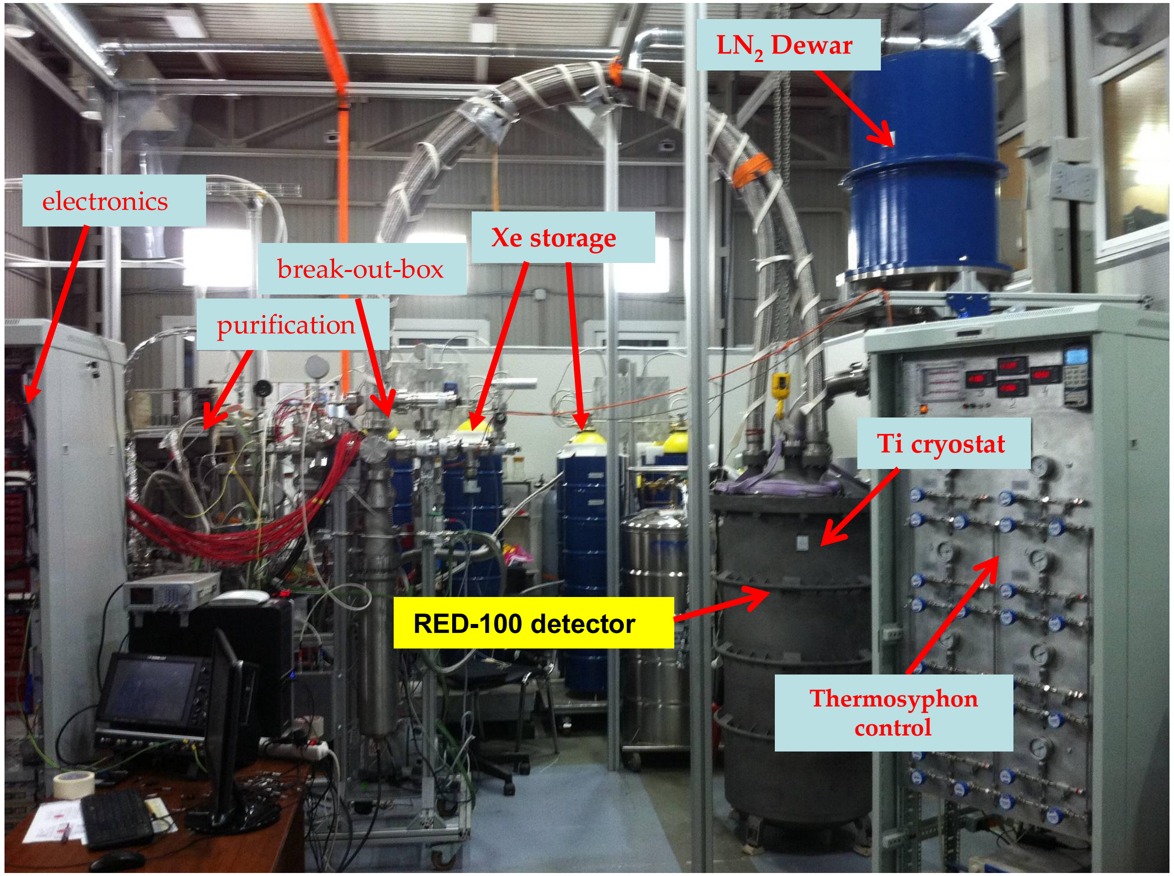


Sensitive volume LXe

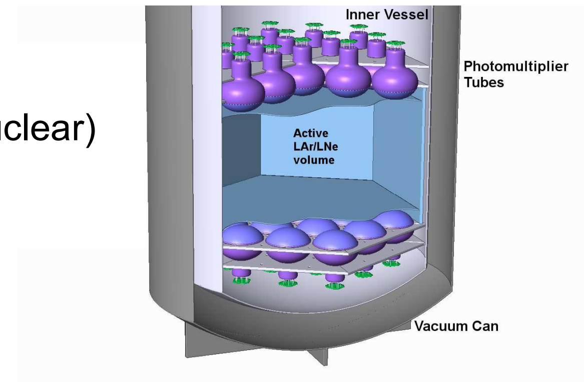
Bottom PMT array

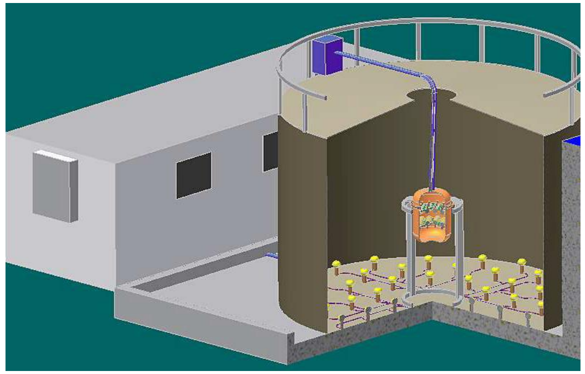
19 PMTs Hamamatsu R11410-20

$\tilde{\nu}_e$



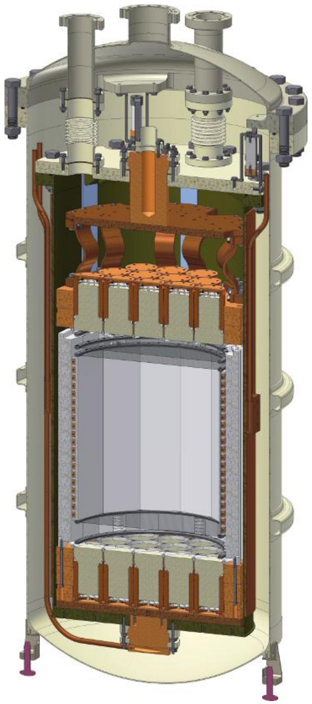
CEνNS at SNS Oak Ridge National Lab., USA



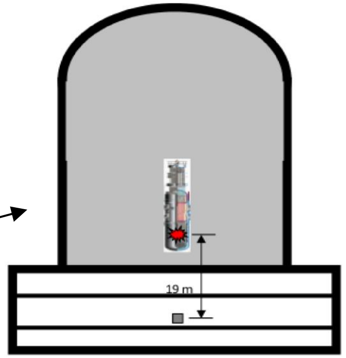


CLEAR (2009)
Coherent Low Energy A (Nuclear) Recoils
arXiv:0910.1989

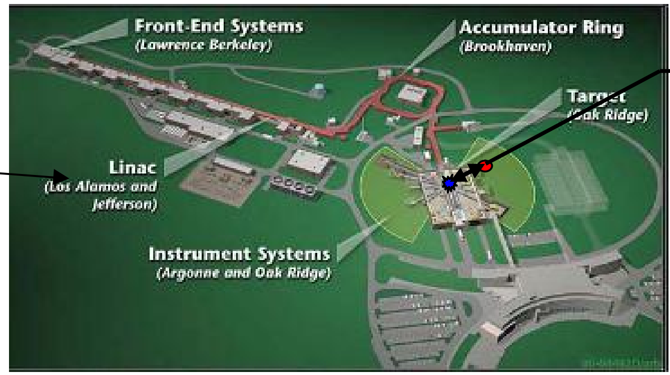
Р Э Д



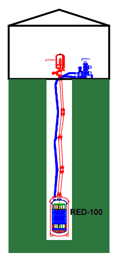
LOI: JINST 8 (2013) P10023
e-Print: arXiv:1212.1938



Kalinin Nuclear Power Plant, Udomlya, RF



~ 40 m from the target; ~ 10 m underground



Spallation neutron source (SNS, Oak Ridge National Lab., USA)

COHERENT collaboration

21 institutions and universities:

18 – USA

2 – RF

1 - Korea

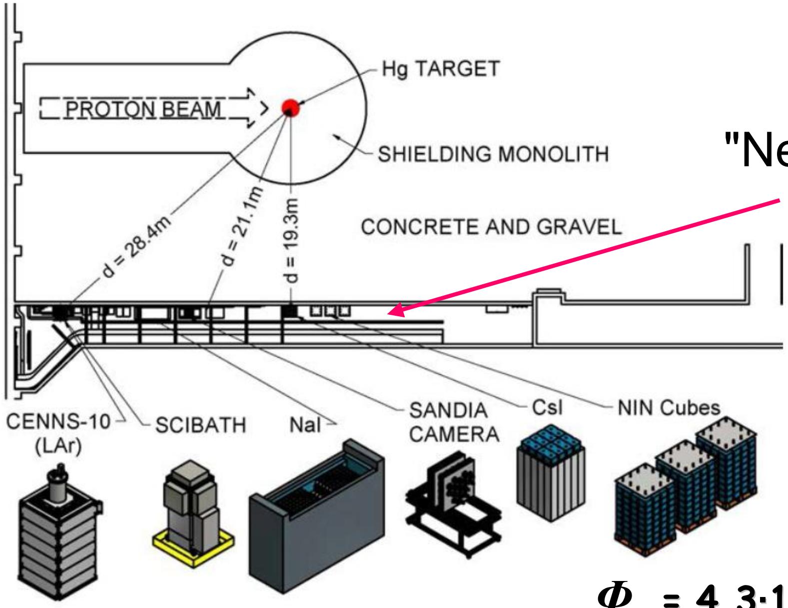
The goal is the discovery of CEνNS using three different detection techniques at SNS:

Initial detector set:

LXe – RED-100

Ge – Majorana detectors

CsI(Na) crystals (CsI and Xe targets has close neutron numbers)



"Neutrino alley"

Basement 8 m.w.e.

Cosmic n-bckg suppression

20 m of concrete and gravel

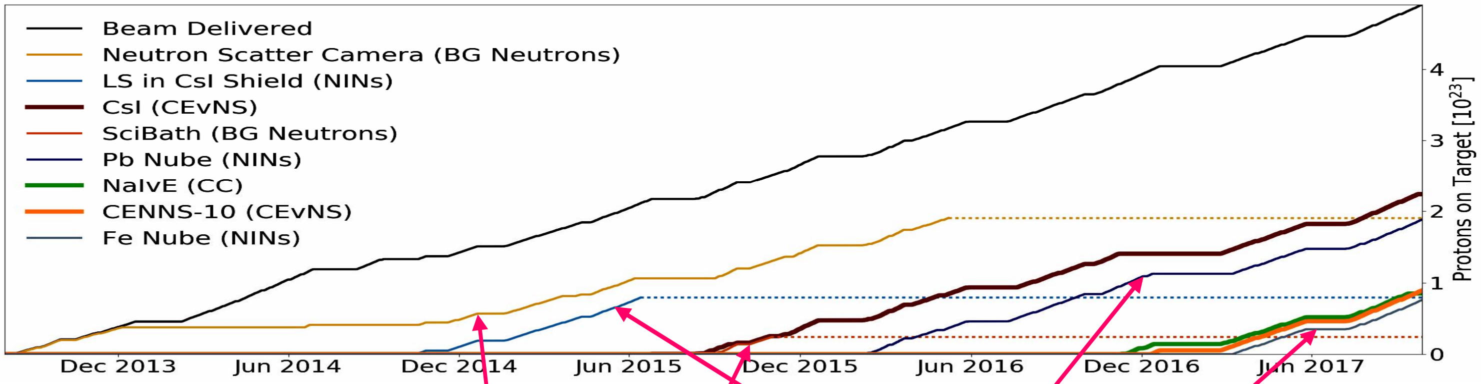
Dramatic suppression of neutrons from target

$\Phi_\nu = 4.3 \cdot 10^7\ cm^{-2}s^{-1}$ at 20m

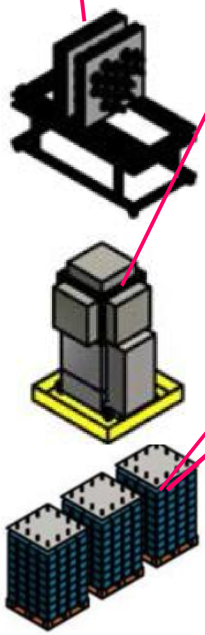
A. Kumpan talk, Oct. 3, morning session CENNS-10
A. Konovalov talk, Oct. 3, evening session CsI(NaI)

Details of CEνNS observation with CsI(NaI)

"Neutrino alley" life status



n-background measurements:

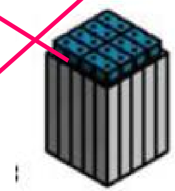


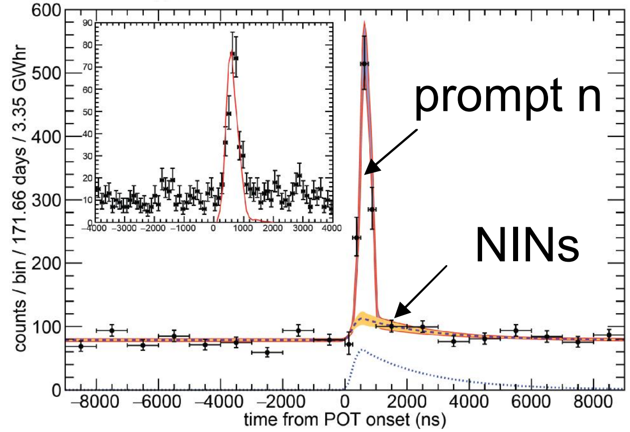
Neutron Scatter Camera
2 arrays of Lscint

SciBath
Lscint + fiber readout

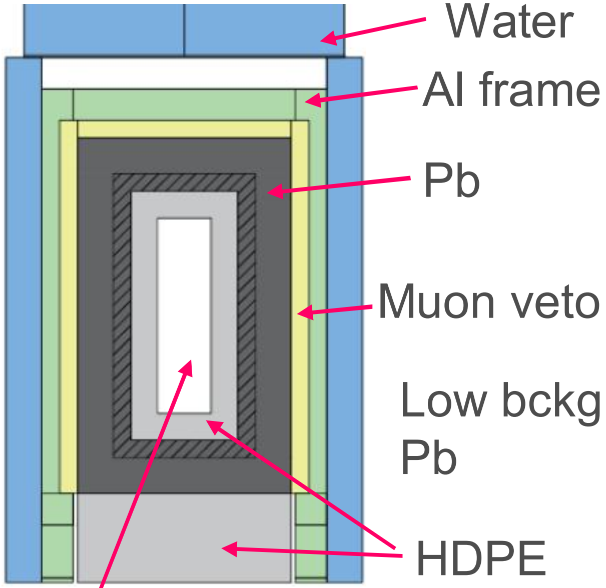
Nubes - NIN cubes
NIN (neutrino induced n)
Lscint inside the moderator

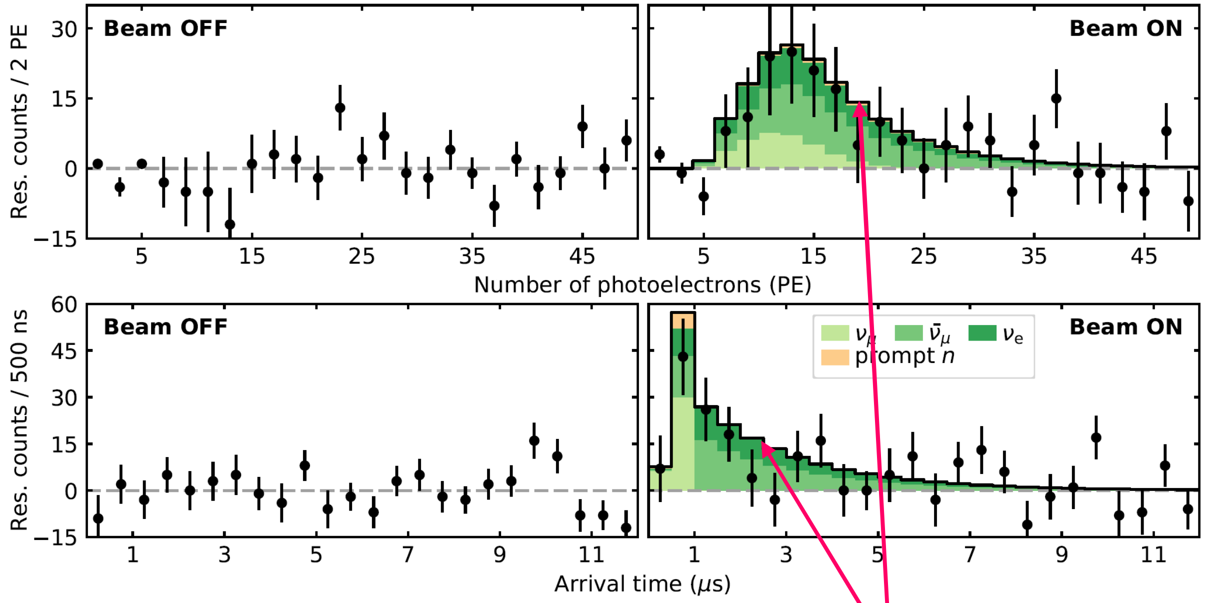
With Liquid Sc. inside CsI shield





Neutrino signal in CsI[Na] detector

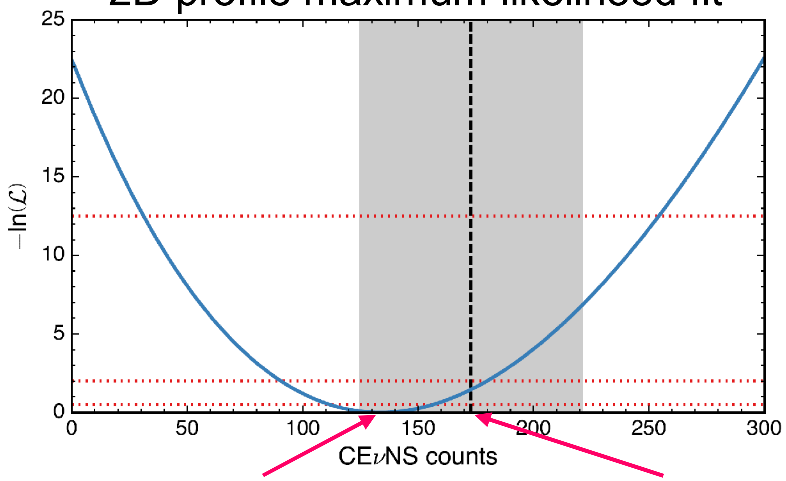




Predicted: prompt n, ν_μ

delayed $\overline{\nu}_\mu, \nu_e$ (τ = 2.2μs)

2D profile maximum likelihood fit



6.7σ

More details in A. Konovalov talk

Obtained 134+/-22

Predicted 173+/-48

CONLUSION

1. ***The CEνNS process has been observed first time at SNS at a confidence level of 6.7σ with the use of CsI[Na] detector***
2. ***Experiments with detectors of other types (Ge, LAr) are about to obtain the results***