Toward precision physics test with CEνNS cryogenic COHERENT CsI detectors

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MAYORANA School 2025

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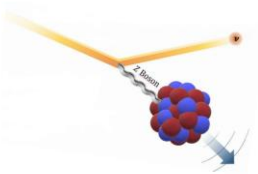
Coherent Elastic Neutrino Nucleus Scattering (CEvNS)

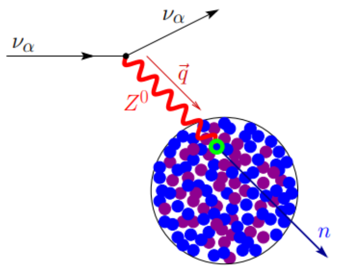


Predicted by Freedman in 1974
*Daniel Z. Freedman Phys. Rev. D **9**, 1389*

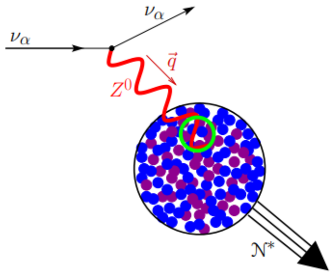
Weak mixing angle

Nuclear form factor

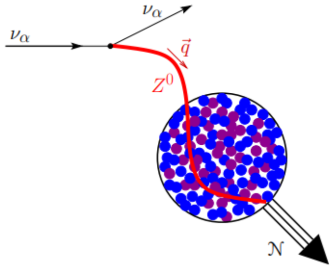
$$\frac{d\sigma}{dE_r} = \frac{G_F^2 m_N}{\pi}\left(1 - \frac{m_N E_r}{2E_\nu^2}\right)\underbrace{\left[g_V^p(\sin^2\vartheta_W) Z F_Z(q^2) + g_V^n N F_N(q^2)\right]^2}_{Q_W^2}$$



Inelastic incoherent
$\lambda_{Z^0} \ll 2R$



Elastic incoherent
$\lambda_{Z^0} \lesssim 2R$

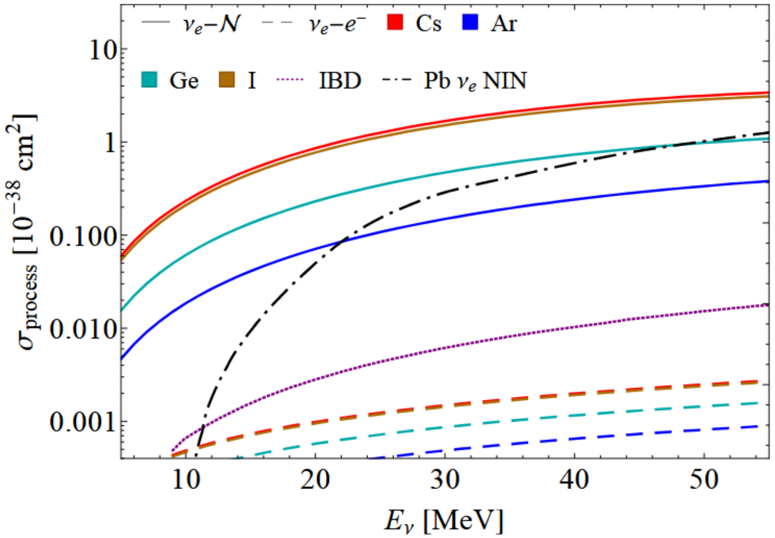


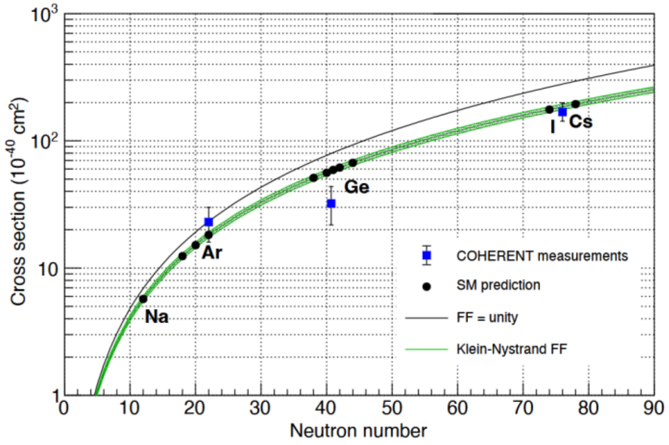
Elastic coherent (CEνNS)
$\lambda_{Z^0} \gtrsim 2R$

Neutrino-nucleon tree level couplings:

- $g_V^p = \frac{1}{2} - 2\sin^2(\vartheta_W) \cong 0.02274$
- $g_V^n = -\frac{1}{2} = -0.5$

$\propto N^2$

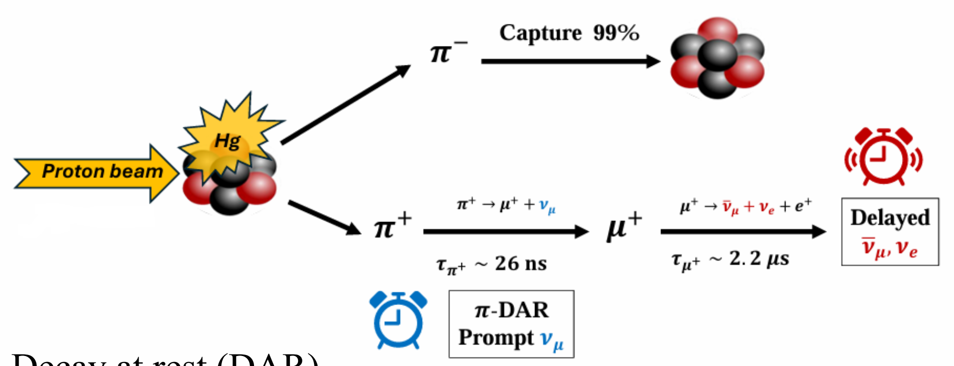




From EPL 143 (2023) 3, 34001

Neutrino Sources

1 Neutrinos from Spallation Neutron Source (SNS)



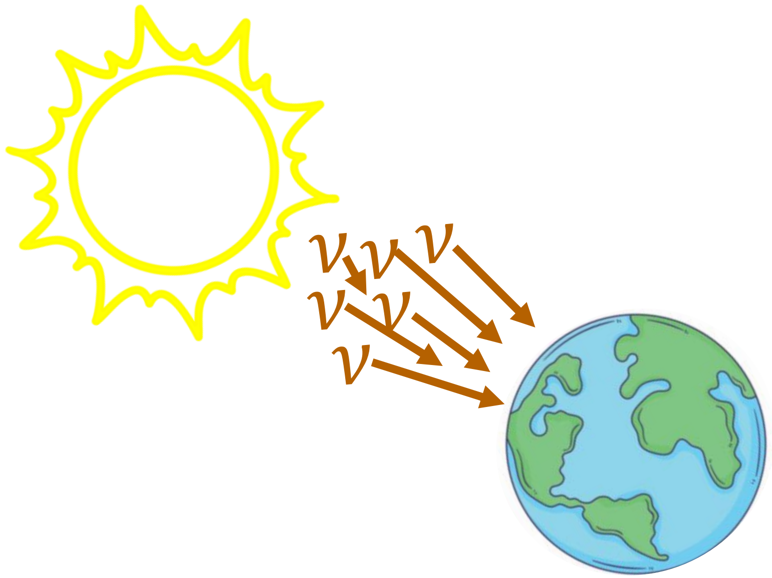
Decay at rest (DAR)

- Pulsed beam
- Time distribuition
- Muon and electron flavors
- $E_\nu \sim 30$ MeV (up to 50 MeV)

2 Reactor neutrinos

- High Flux
- Only $\bar{\nu}_e$
- $E_\nu \sim 1 - 10$ MeV

3 Solar neutrinos



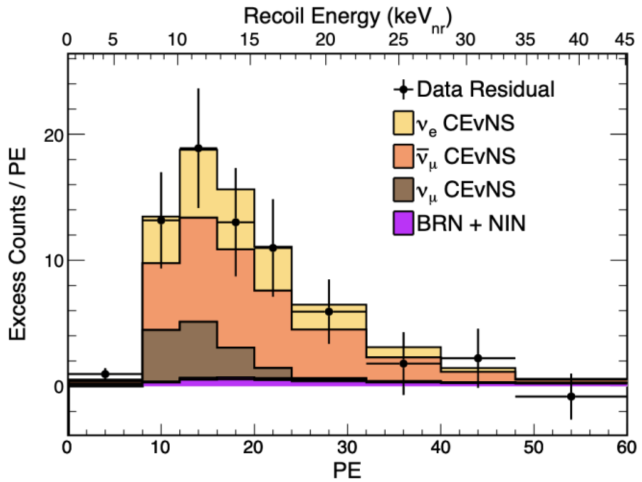
- All flavors
- $E_\nu \lesssim 10$ MeV

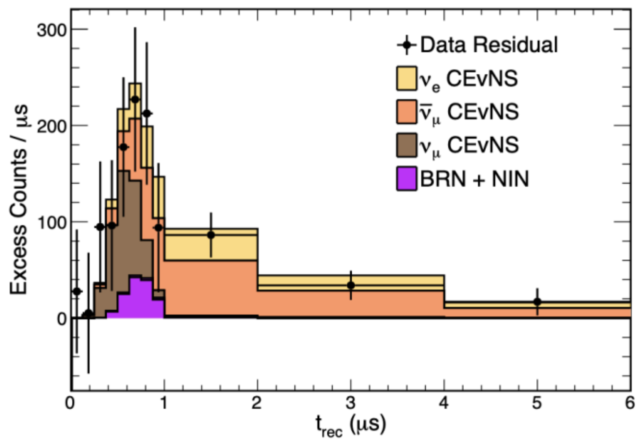
The COHERENT experimental program

COHERENT, PRL 129, 081801 (2022)

COHERENT experimental program

- **CsI crystal**:
  - 14.6 kg scintillating crystal
  - 19.3 m away from the SNS target
  - 11.6 σ evidence





Future detectors

Cryo-I

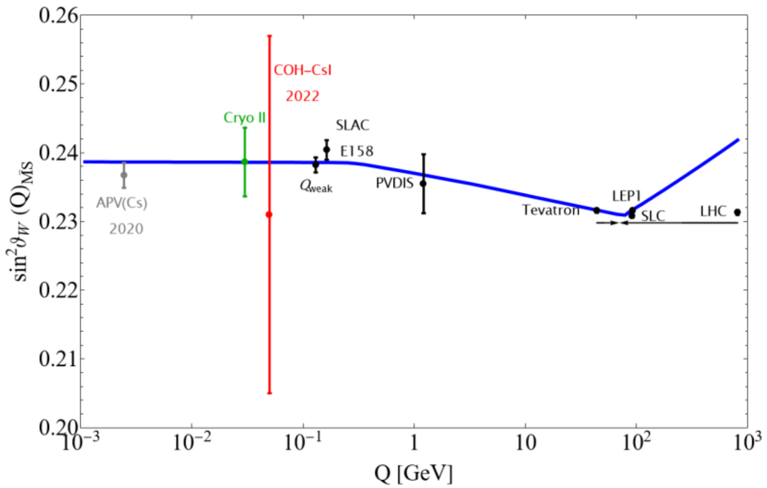
- 10 kg undoped cryogenic CsI detector
- ~19 m away from the SNS
- $E_{thr} \simeq 0.5\ keV_{nr}$ (compared to $7\ keV_{nr}$)
- Expected about **3000** events x 3 SNS yr
- SNS power up to 2 MW
- Systematic on flux about 3%
- Systematic on Quenching at low energies

Cryo-II

- 700 kg undoped cryogenic CsI detector
- ~19 m away from the SNS
- $E_{thr} \simeq 0.5\ keV_{nr}$ (compared to $7\ keV_{nr}$)
- Expected about **300 000** events x 3 SNS yr
- SNS power up to 2.8 MW
- Systematic on flux about 3%
- Systematic on Quenching at low energies

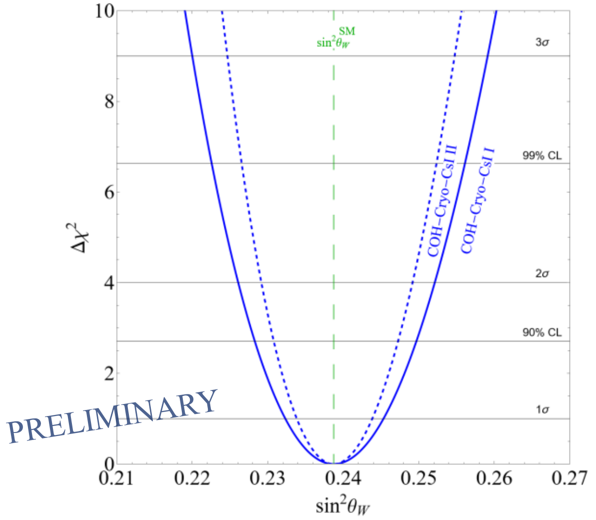
COHERENT, PhysRevD 109 (2024) 9, 092005

Weak mixing angle and neutron distribution

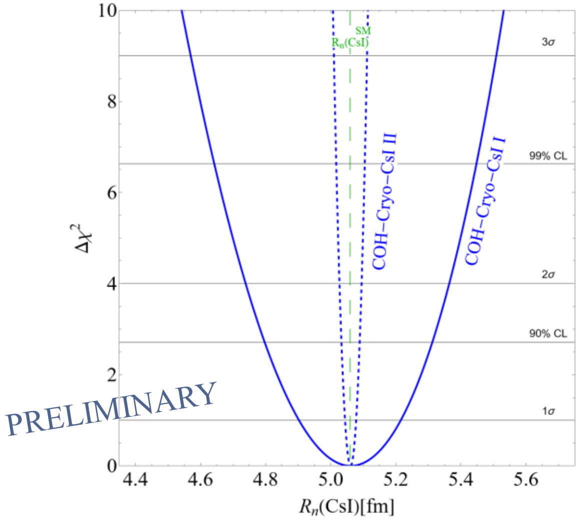


CEvNS allows one to test the SM through the **weak mixing angle**, and to access to the **weak nuclear distributions**:

- Weak mixing angle agrees with SM, best precision achieved about **10%**
- Tends to favor large nuclear radii, best precision achieved about **7%**



Reducing the systematics to achieve the precision on weak mixing angle



Improving statistics to achieve the precision on the neutron distribution radius

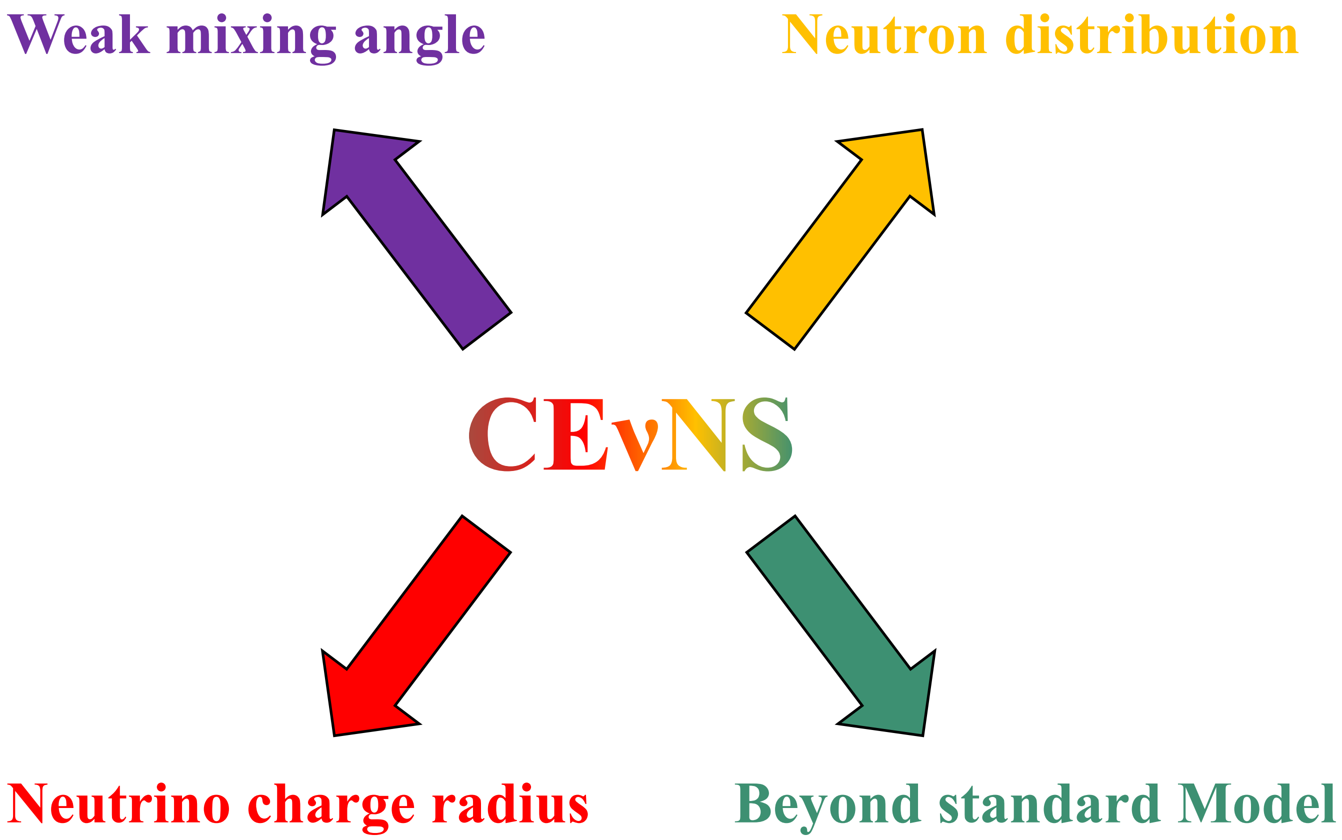
Cryo I: $\sigma_{sin^2\vartheta_W} \sim 3\%$
Cryo II: $\sigma_{sin^2\vartheta_W} \sim 2\%$

Cryo I: $\sigma_{R_n} \sim 3\%$
Cryo II: $\sigma_{R_n} \sim 0.4\%$

From observation to precision

We are entering in the "precision era" of the CEνNS thanks to:

- Several features of different neutrino sources
- Improvement of systematics and statistics in the new detectors



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