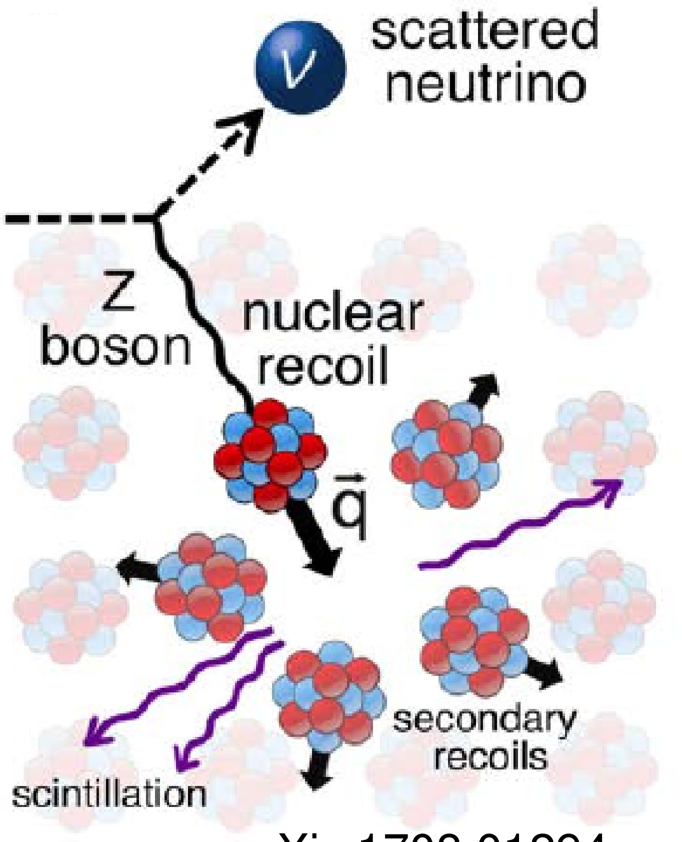
Non-Standard Neutrino Interactions in COHERENT

Gleb Sinev
for the COHERENT Collaboration
APS April Meeting
April 14, 2018

Outline

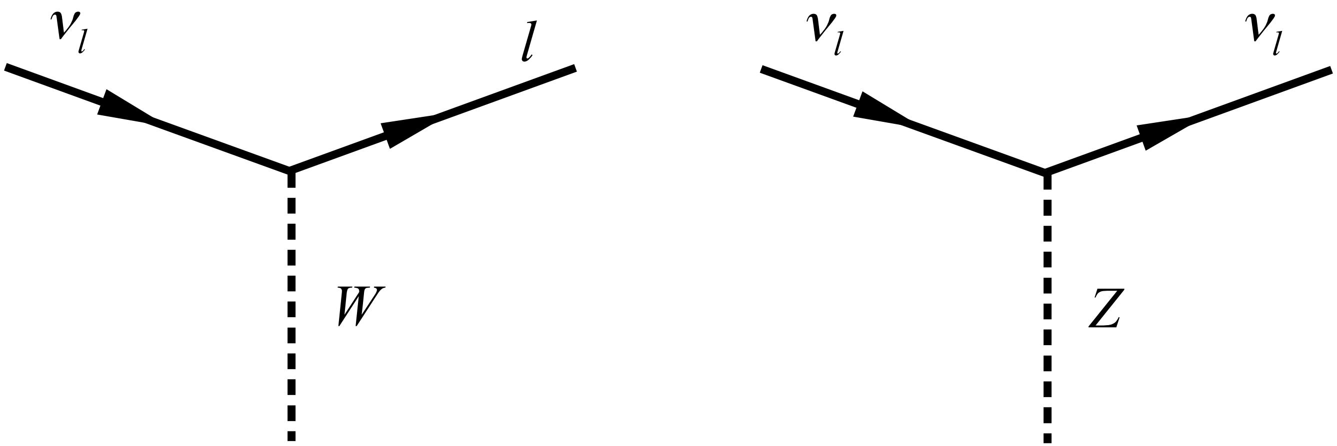
- NSI
- CEvNS
- COHERENT
- CsI NSI
- Conclusions



arXiv:1708.01294

Neutrino interactions

- SM weak interactions



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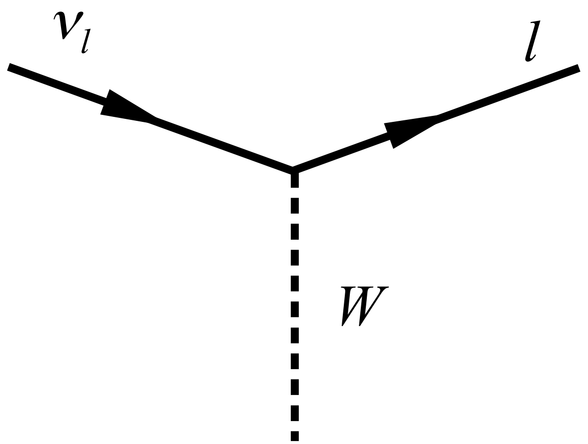
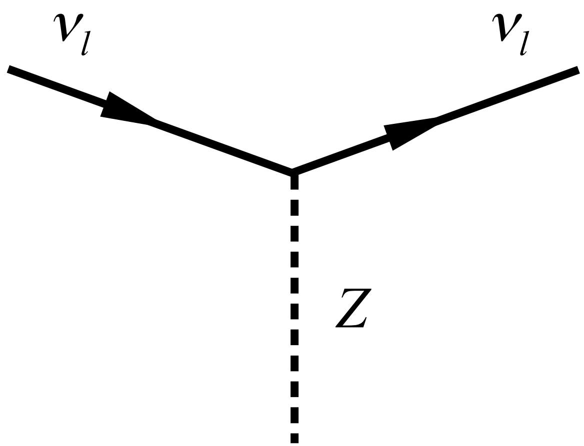
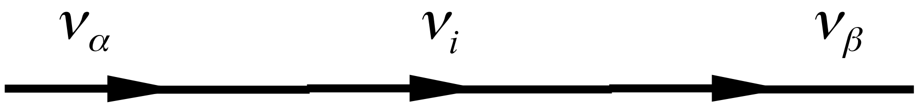




- Neutrino mixing

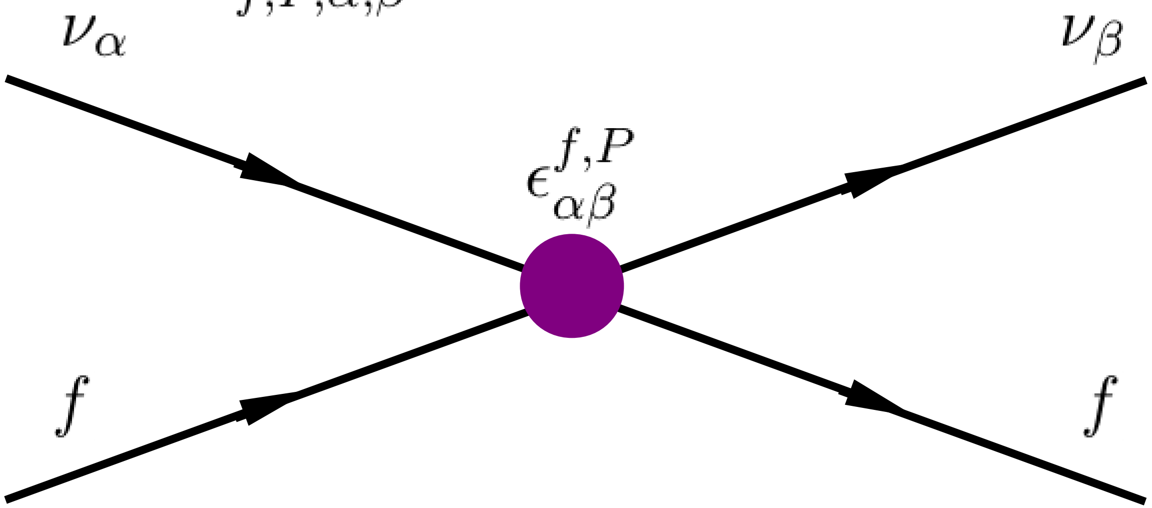


Other interactions?

- Parameterization of new interaction

arXiv:1701.04828

$$\mathcal{L}_{\rm NSI} = -2\sqrt{2}G_F \sum_{f,P,\alpha,\beta} \epsilon_{\alpha\beta}^{f,P} (\bar{\nu}_\alpha \gamma^\mu P_L \nu_\beta)(\bar{f}\gamma_\mu P f)$$



Non-standard interactions

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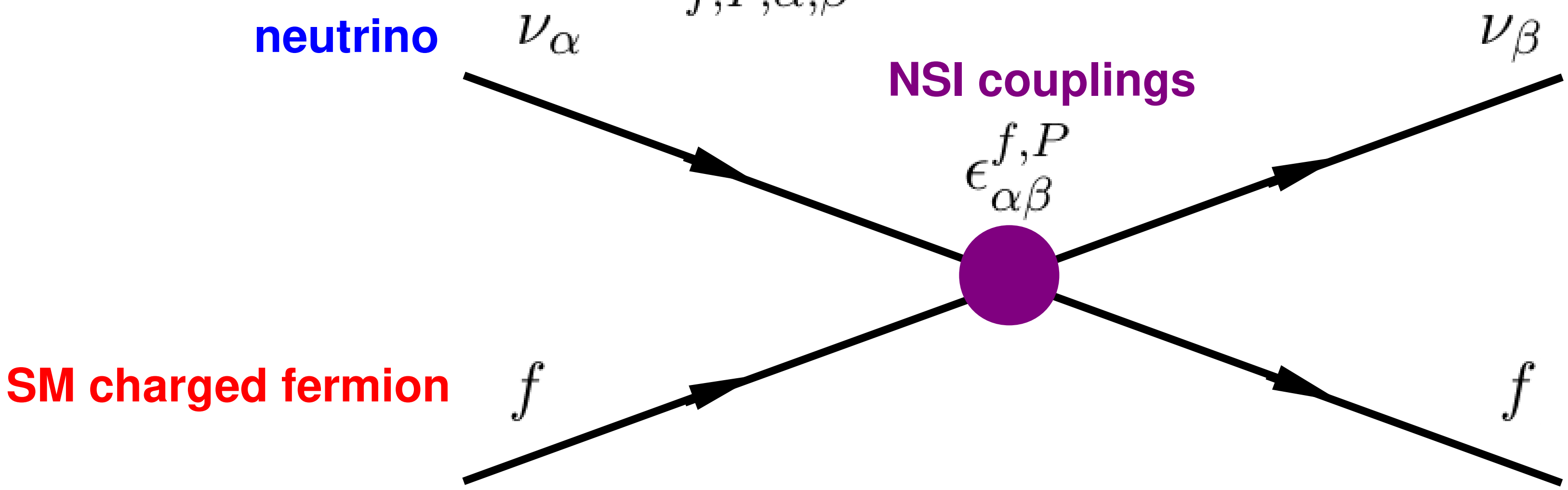

Current limits

- Some NSI couplings are well constrained

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$$\epsilon_{\mu\tau}^{d,V} \qquad [-0.01, 0.01]$$

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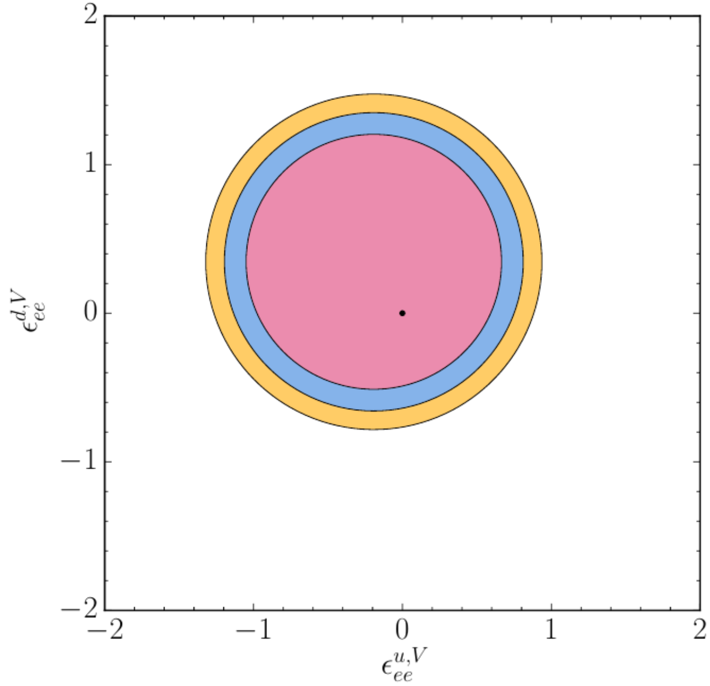
$$\epsilon_{\mu\tau}^{d,V} \qquad [-0.01, 0.01]$$

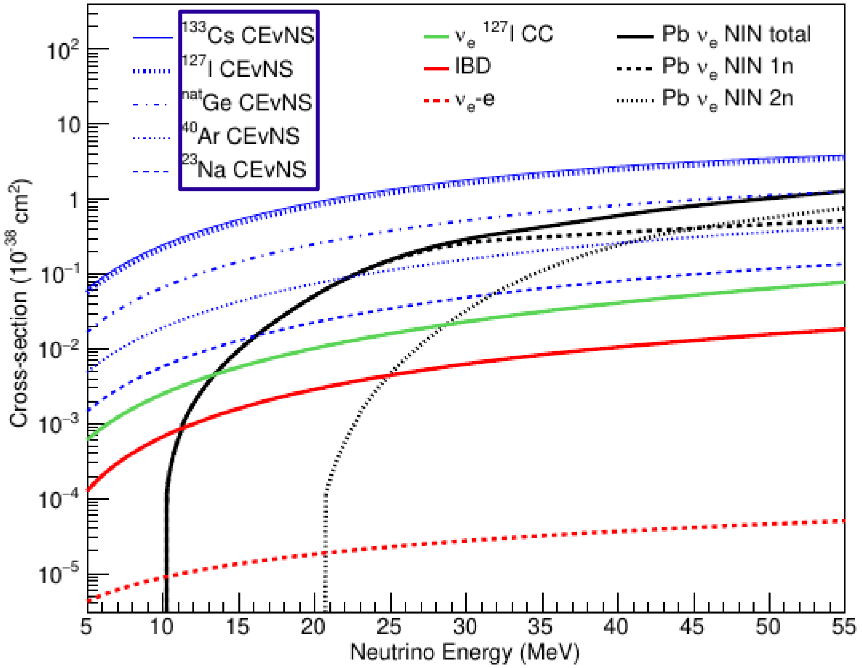
- While others aren't



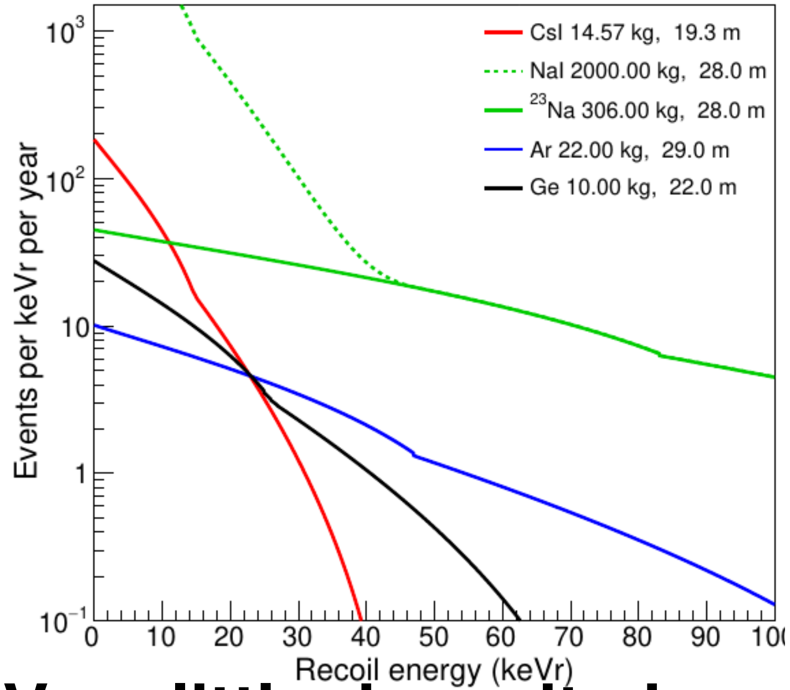
CEvNS

- Coherent Elastic Neutrino-Nucleus Scattering

arXiv:1803.09183



Very high cross section



Very little deposited energy

CEvNS (continued)

$$\frac{d\sigma}{dT}_{coh} = \frac{G_F^2 M}{2\pi}\left[(G_V+G_A)^2+(G_V-G_A)^2\left(1-\frac{T}{E_\nu}\right)^2-(G_V^2-G_A^2)\frac{MT}{E_\nu^2}\right]$$

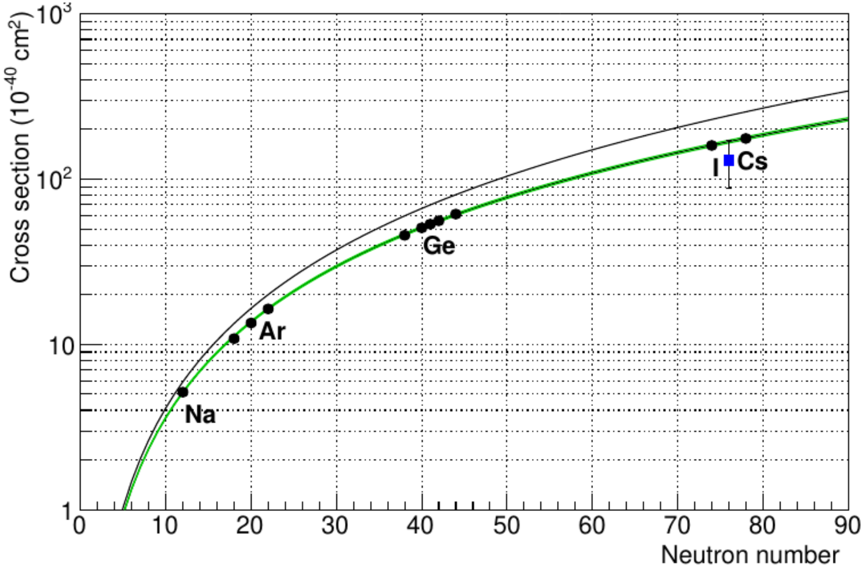
$$G_A = (g_A^p(Z_+ - Z_-) + g_A^n(N_+ - N_-))F_{\rm nucl}^A(Q^2) \approx 0$$

$$G_V = (g_V^p Z + g_V^n N)F_{\rm nucl}^V(Q^2)$$

$$\frac{T}{E_\nu} << 1 \quad g_V^p \cong \left(\frac{1}{2} - 2\sin^2\theta_W\right) \approx 0$$

$$\Rightarrow \sigma_{coh} \sim N^2$$

Well understood theoretically
Great for studying NSI!



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COHERENT

- 1-MW SNS

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COHERENT

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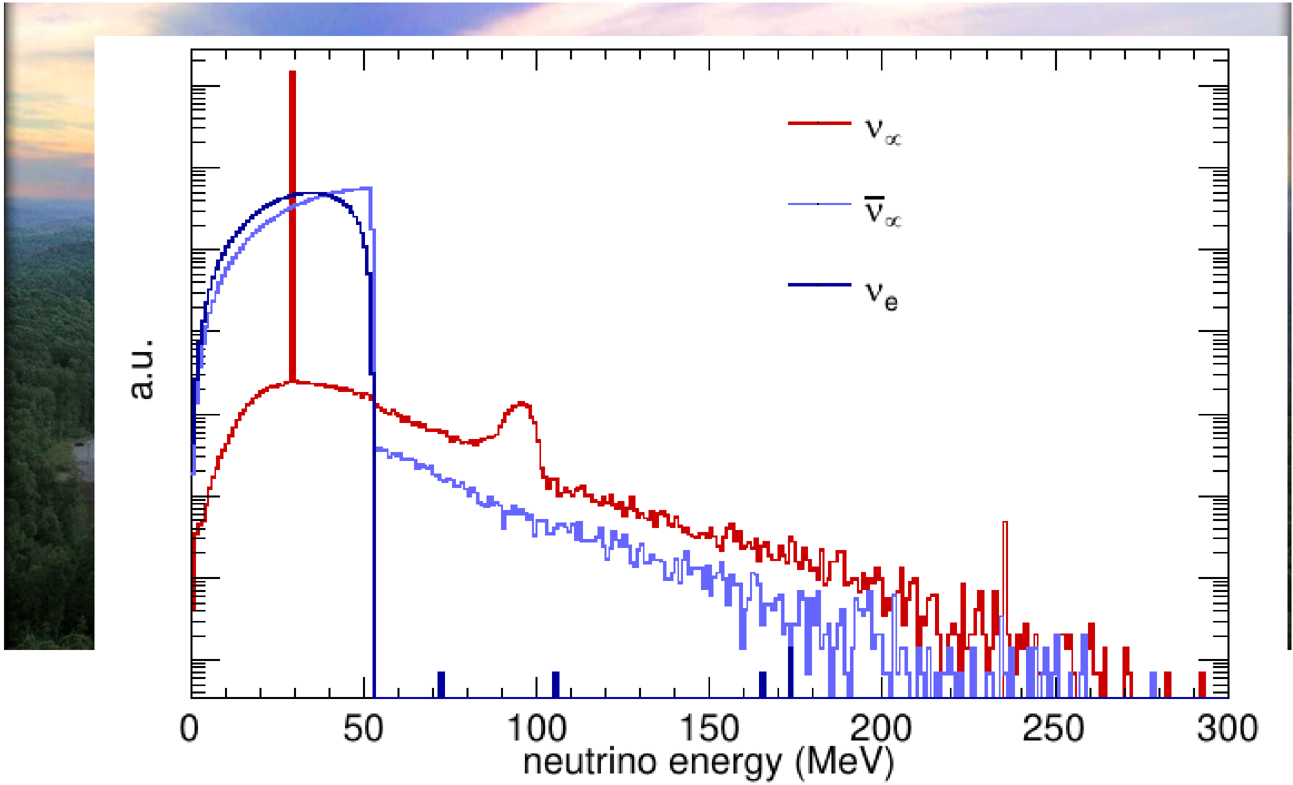
  - pion decay at rest



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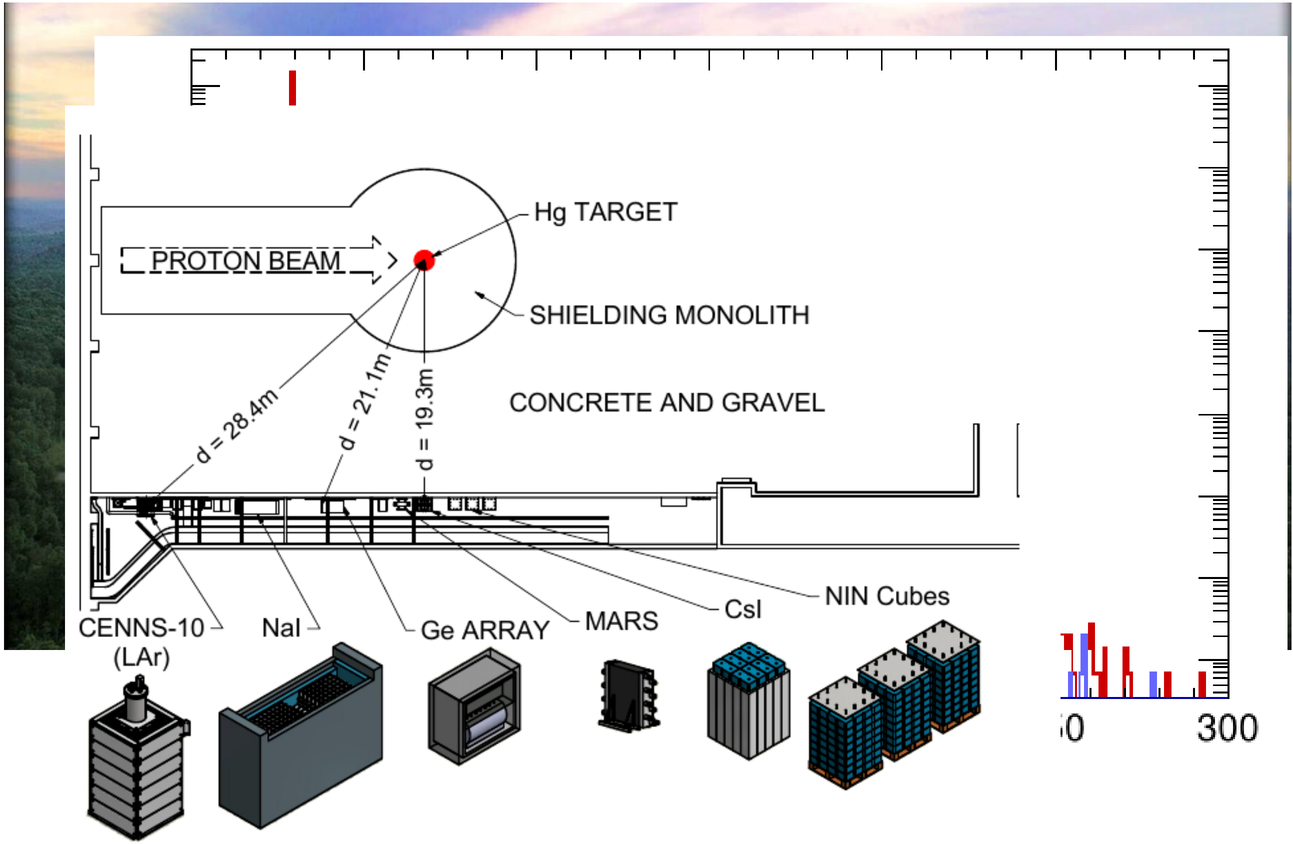
COHERENT

- 1-MW SNS
  - pion decay at rest
- Various detectors



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- 1-MW SNS
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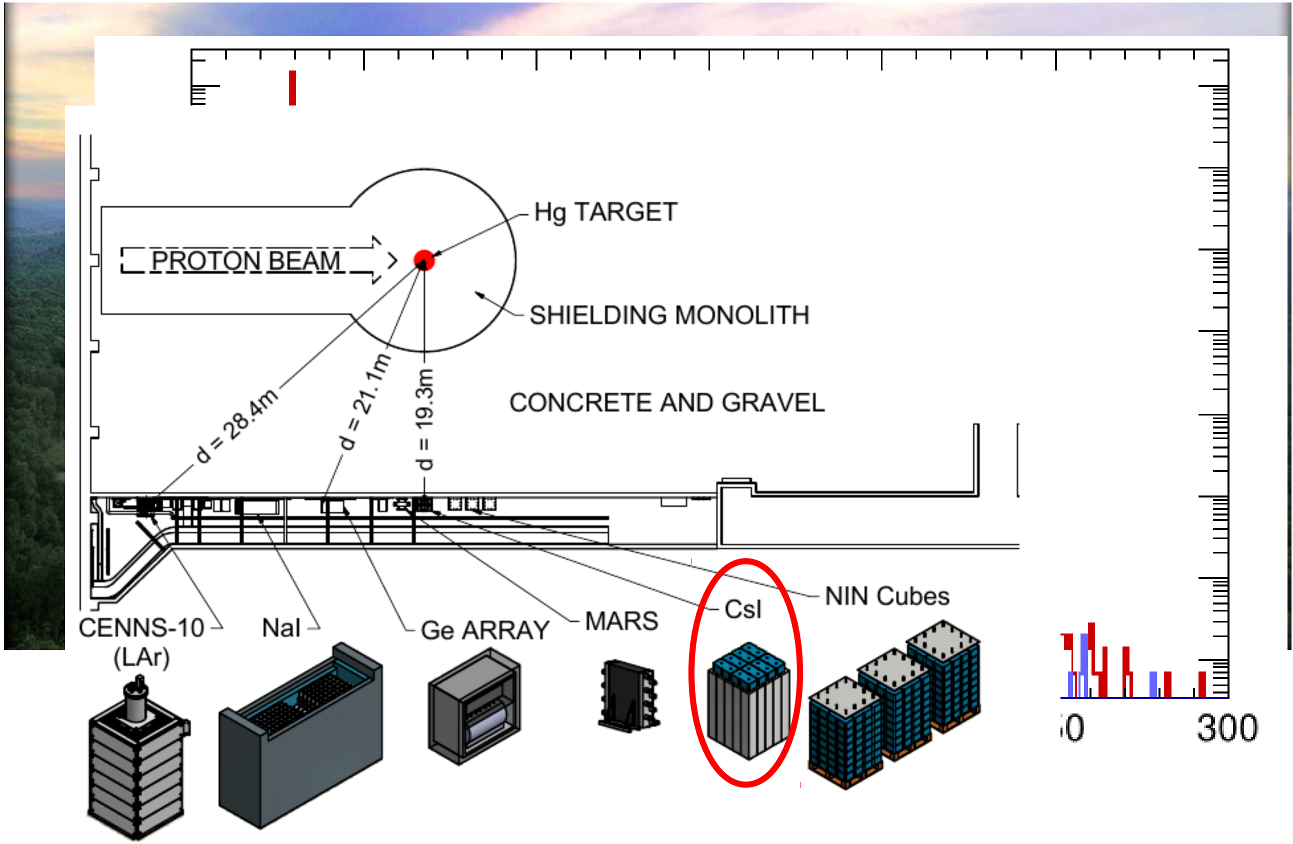
- Various detectors
  - CEvNS observed in 1



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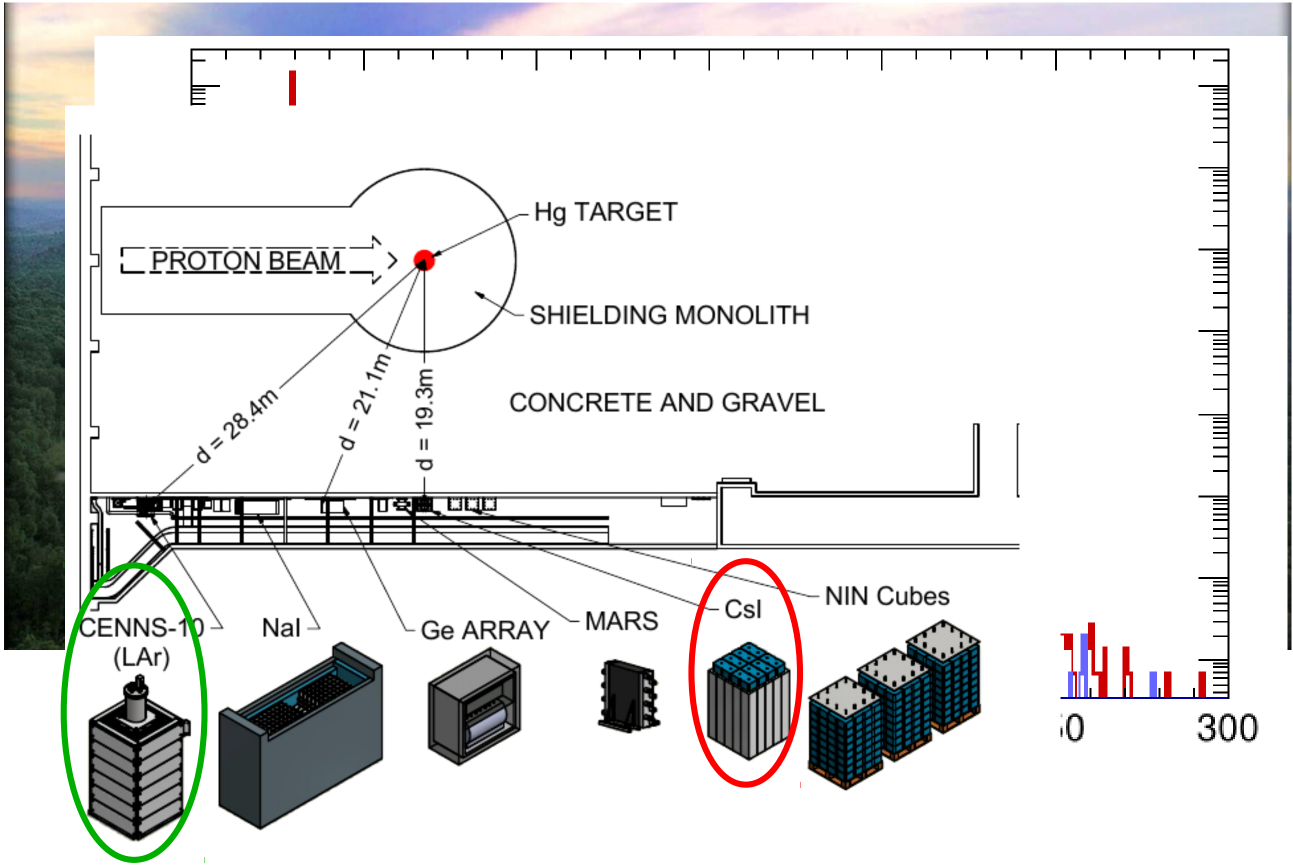
COHERENT

- 1-MW SNS
  - pion decay at rest
- Various detectors
  - CEvNS observed in 1
  - 1 more taking data



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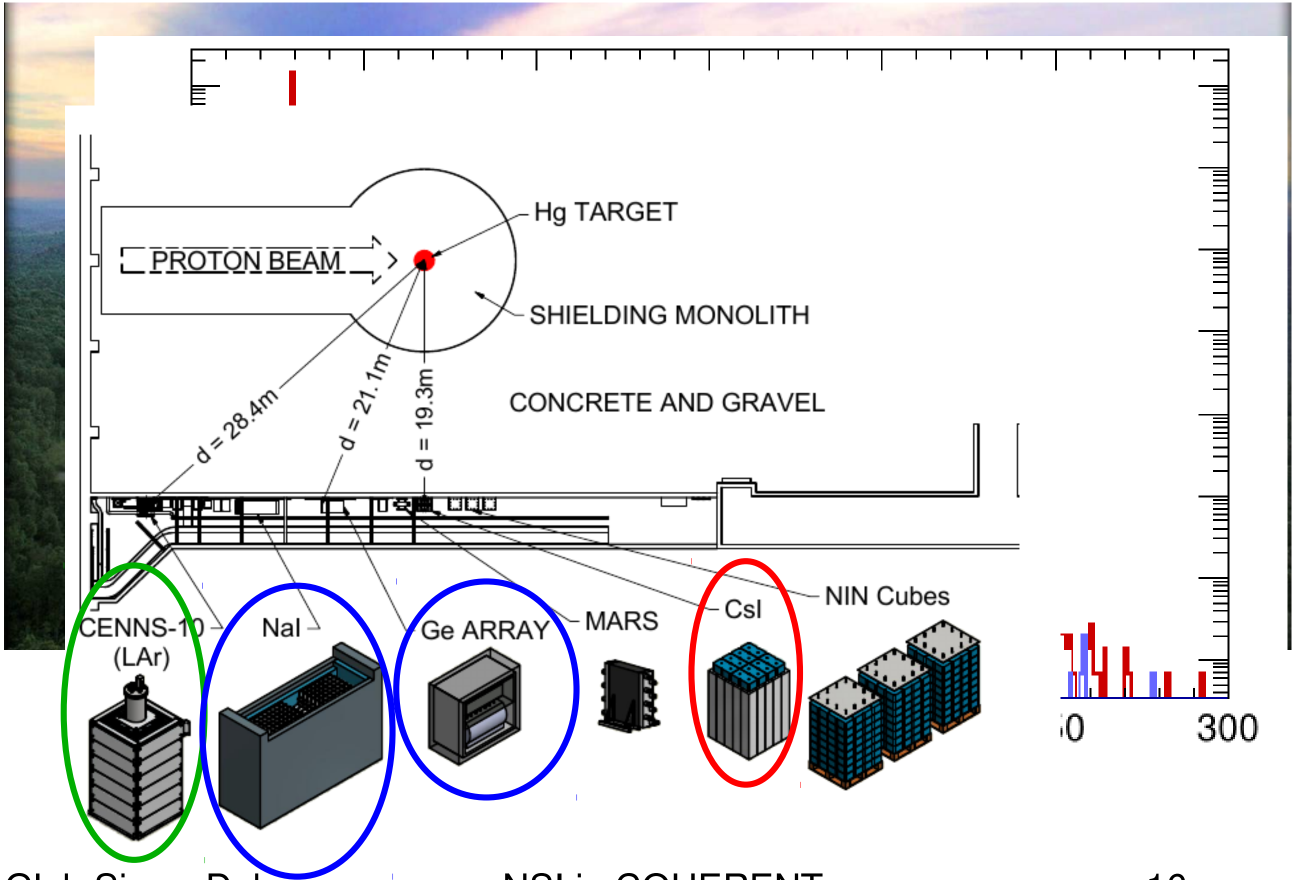
COHERENT

- 1-MW SNS
  - pion decay at rest
- Various detectors
  - CEvNS observed in 1
  - 1 more taking data
  - 2 to be deployed soon



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For more COHERENT information

- D08.00001: Search for CEvNS at the SNS with the COHERENT experiment
- D08.00002: Status of CEvNS Search with the CENNS-10 Liquid Argon Detector for COHERENT
- G08.00005: Toward a CEvNS Observation With Germanium
- G08.00008: Measurement of the neutrino-induced neutron cross section in lead at the Spallation Neutron Source

COHERENT CsI

- Considering two NSI couplings:

$$\varepsilon_{ee}^{uV} \quad \text{and} \quad \varepsilon_{ee}^{dV}$$

COHERENT CsI

- Considering two NSI couplings:

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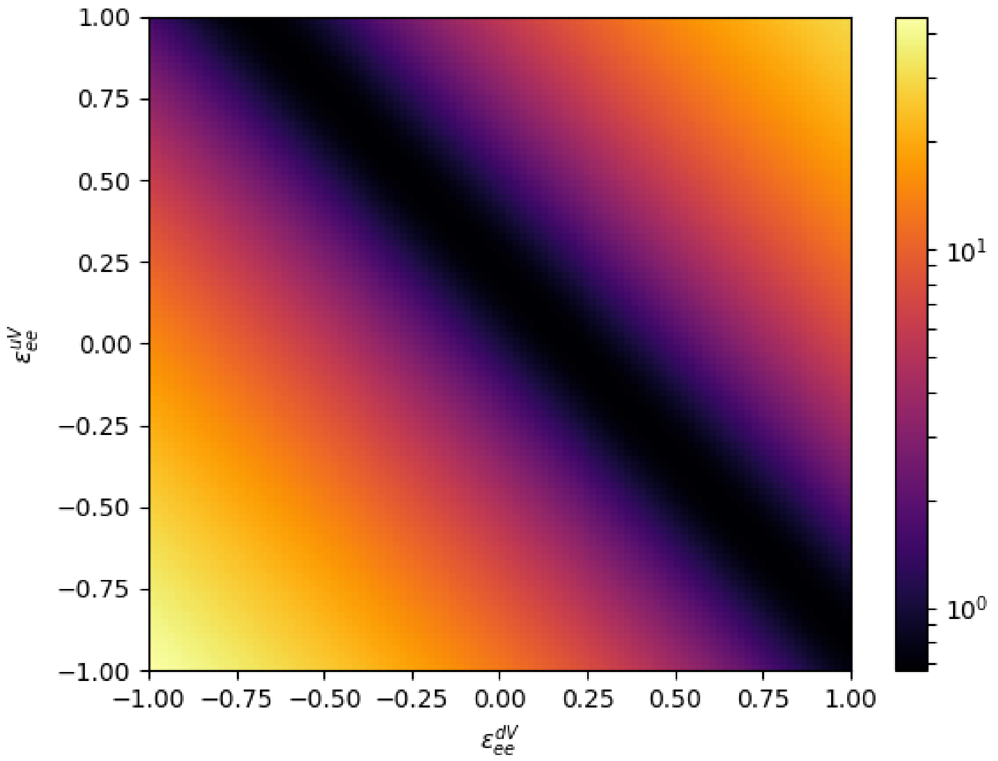
- Rate modification due to NSI



Pull method for χ^2

- Taking into account correlated systematics with

$$\chi^2_{\text{pull}} = \min_{\{\xi_k\}} \left[\sum_{n=1}^{N} \left(\frac{R_n^{\text{expt}} - R_n^{\text{theor}} - \sum_{k=1}^{K} \xi_k c_n^k}{u_n} \right)^2 + \sum_{k=1}^{K} \xi_k^2 \right]$$

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- Equivalent to covariance-matrix approach

$$\chi^2_{\mathrm{covar}} = \sum_{n,m=1}^{N} (R_n^{\mathrm{expt}} - R_n^{\mathrm{theor}})[\sigma^2_{nm}]^{-1}(R_m^{\mathrm{expt}} - R_m^{\mathrm{theor}})$$

COHERENT CsI NSI

$$\chi^2 = \frac{\left(N_{\text{meas}} - N_{NSI}(\varepsilon_{ee}^{uV}, \varepsilon_{ee}^{dV})[1+\alpha] - B_{\text{on}}[1+\beta]\right)^2}{\sigma_{\text{stat}}^2} + \left(\frac{\alpha}{\sigma_\alpha}\right)^2 + \left(\frac{\beta}{\sigma_\beta}\right)^2$$

- Assume 2 systematics:
  - Prediction uncertainty $\sigma_\alpha = 28\ \%$
  - Beam-on background uncertainty $\sigma_\beta = 25\ \%$ (small effect: $B_{on} = 6$)

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- Assume 2 systematics:
  - Prediction uncertainty σ_α = 28 %
  - Beam-on background uncertainty σ_β = 25 % (small effect: B_{on} = 6)
- Prediction N_{SM} = 173.6
- Measurement N_{meas} = 142 with σ_{stat} = 30.95

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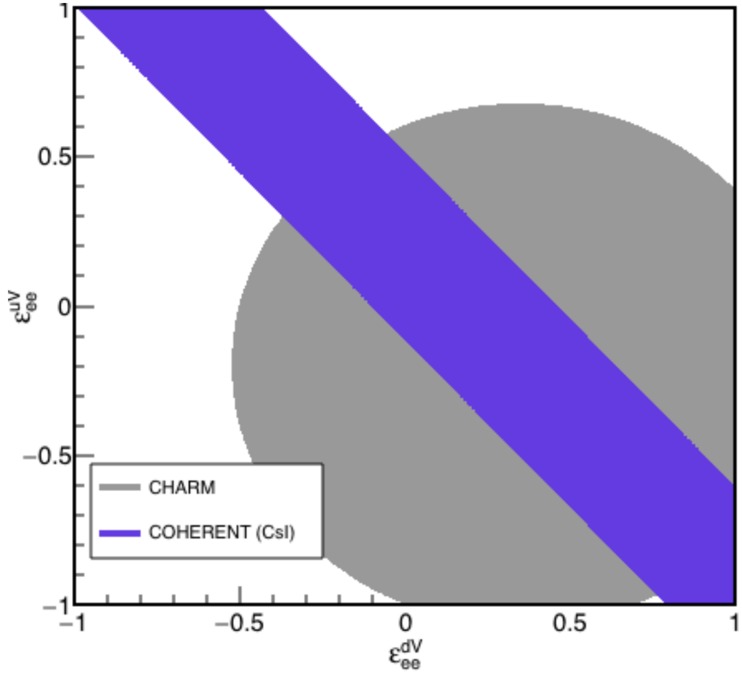

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COHERENT CsI NSI

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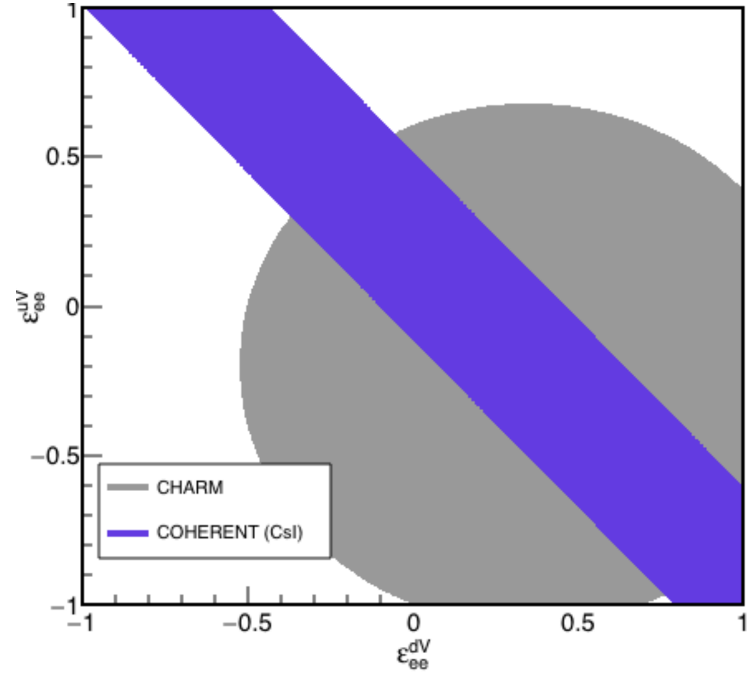
- Assume systematics
  - $\sigma_\alpha = 28\ \%$ and $\sigma_\beta = 25\ \%$ ($B_{on} = 6$)
- Prediction $N_{SM} = 173.6$
- Measurement $N_{meas} = 142$
  with $\sigma_{stat} = 30.95$
- **Significant fraction of parameter space ruled out!**



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Conclusions

- Parts of NSI parameter space remain largely unexplored
- COHERENT provides unique opportunity to study NSI
- One CsI CEvNS observation already significantly improves limits for NSI couplings

Backup Slides

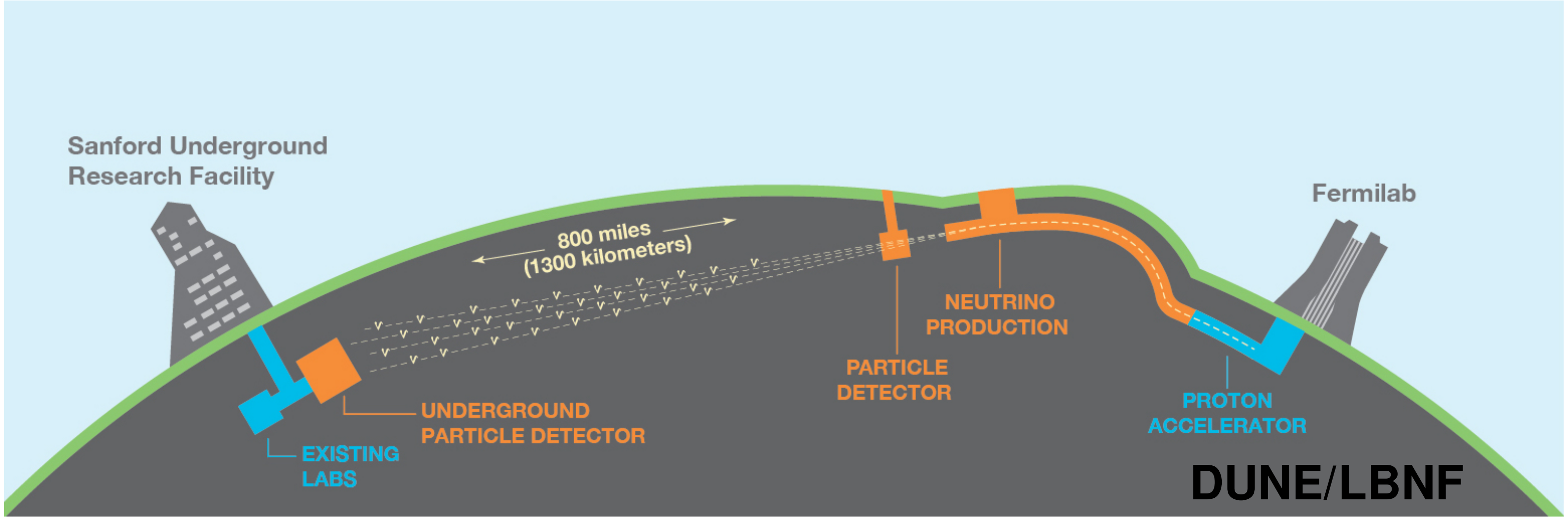
COHERENT Collaboration

THE UNIVERSITY OF CHICAGO
Duke UNIVERSITY
UF UNIVERSITY of FLORIDA
KAIST
Laurentian University Université Laurentienne
Los Alamos NATIONAL LABORATORY EST. 1943
Carnegie Mellon University
MEPhI
NORTH CAROLINA CENTRAL UNIVERSITY FOUNDED 1910
NC STATE UNIVERSITY
NM STATE UNIVERSITY
OAK RIDGE National Laboratory
Sandia National Laboratories
THE UNIVERSITY of TENNESSEE KNOXVILLE
TUNL
UNIVERSITY of WASHINGTON

CNEC Consortium for Nonproliferation Enabling Capabilities
KICP
NNSA National Nuclear Security Administration
NSF
U.S. DEPARTMENT OF ENERGY

Introduction

- Neutrino oscillation measurements
  - revolutionized neutrino physics
  - will obtain most unknown parameters in SM (δ^{CP}, mass ordering, θ_{23} octant)



Neutrino propagation

arXiv:1701.04828

$$H^\nu = H_{\rm vac} + H_{\rm mat} \equiv \frac{1}{2E} U_{\rm vac} \begin{pmatrix} 0 & & \\ & \Delta m^2_{21} & \\ & & \Delta m^2_{31} \end{pmatrix} U^\dagger_{\rm vac} + \sqrt{2} G_F N_e(x) \begin{pmatrix} 1+\epsilon_{ee} & \epsilon_{e\mu} & \epsilon_{e\tau} \\ \epsilon^*_{e\mu} & \epsilon_{\mu\mu} & \epsilon_{\mu\tau} \\ \epsilon^*_{e\tau} & \epsilon^*_{\mu\tau} & \epsilon_{\tau\tau} \end{pmatrix}$$

- CPT $\Rightarrow H^\nu \to -(H^\nu)^*$ does not change observation
- $\Rightarrow$ $$\Delta m^2_{31} \to -\Delta m^2_{31} + \Delta m^2_{21} = -\Delta m^2_{32}\,,$$ $$\sin\theta_{12} \to \cos\theta_{12}\,,$$ $$\delta \to \pi - \delta\,,$$ if $$(\epsilon_{ee} - \epsilon_{\mu\mu}) \to -(\epsilon_{ee} - \epsilon_{\mu\mu}) - 2\,,$$ $$(\epsilon_{\tau\tau} - \epsilon_{\mu\mu}) \to -(\epsilon_{\tau\tau} - \epsilon_{\mu\mu})\,,$$ $$\epsilon_{\alpha\beta} \to -\epsilon^*_{\alpha\beta} \quad (\alpha \neq \beta)\,,$$
- $\Rightarrow$ Degeneracy that is hard to resolve without knowing NSI couplings