Fermilab

The Weak mixing angle in the DUNE
NEAR DETECTOR COMPLEX

Northwestern

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The Weak mixing angle

Running of the weak mixing angle → A crucial test of the consistency of the Standard Model

$\overline{\text{MS}}$ prescription: Define the weak mixing angle from gauge couplings in the $\overline{\text{MS}}$ scheme at the scale Q:

$$\sin^2\theta_W(Q) \equiv \frac{g'(Q)^2}{g(Q)^2 + g'(Q)^2}$$

Neutrino-electron scattering

The cross section depends on the flavor ($\alpha = e, \mu, \tau$) of the incoming neutrino,

$$\frac{d\sigma}{dE_R} \propto g_1^2 + g_2^2\left(1 - \frac{E_R}{E_\nu}\right)^2 - g_1 g_2 \frac{m_e E_R}{E_\nu}$$

For $\nu_\alpha e^- \to \nu_\alpha e^-$:

$$g_1 = g_V + g_A + 2\delta_{\alpha e}$$
$$g_2 = g_V - g_A$$

For $\overline{\nu_\alpha} e^- \to \overline{\nu_\alpha} e^-$:

$$g_2 \leftrightarrow g_1$$

Degeneracies:

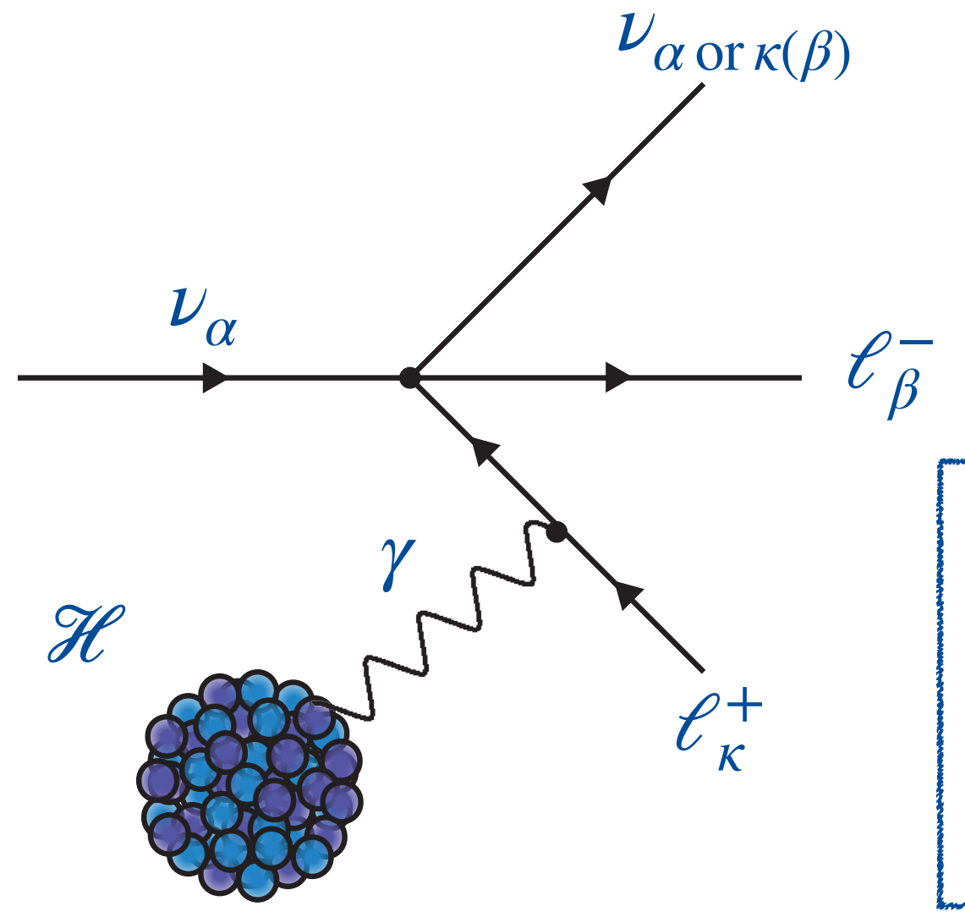
$$\nu_\mu e^- : (g_V, g_A) \to (g_A, g_V) \text{ and } (g_V, g_A) \to (-g_V, -g_A)$$
$$\nu_e e^- : (g_V, g_A) \to (g_A, g_V)$$

In the SM at tree level: $g_A = -\frac{1}{2}$, $g_V = -\frac{1}{2} + 2\sin^2\theta_W$

Neutrino trident scattering

Cross section depends on (g_V, g_A)

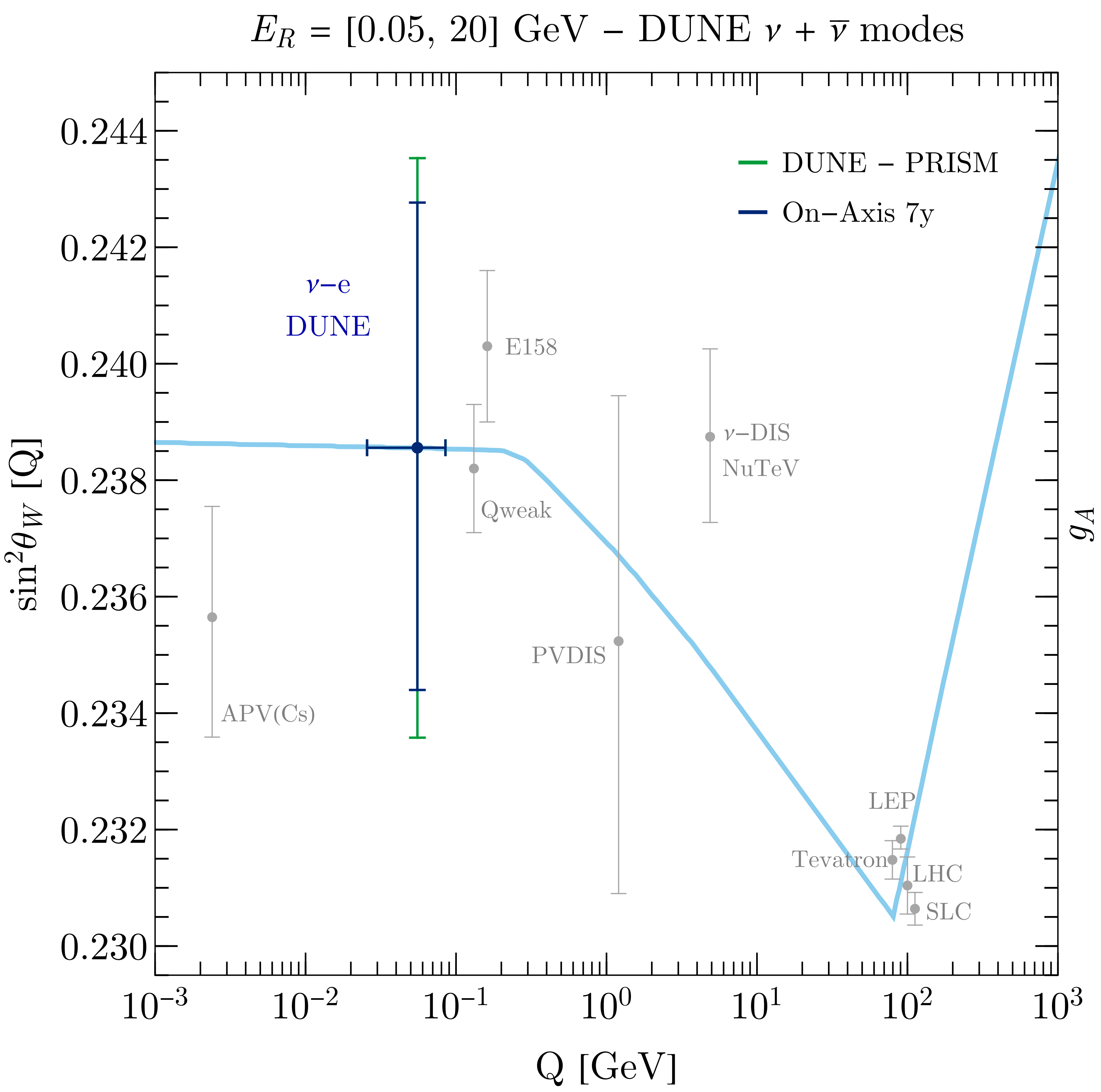
$$\sigma \sim (g_V\delta_{\beta\kappa} + \delta_{\alpha\beta})^2 + (g_A\delta_{\beta\kappa} + \delta_{\alpha\beta})^2$$

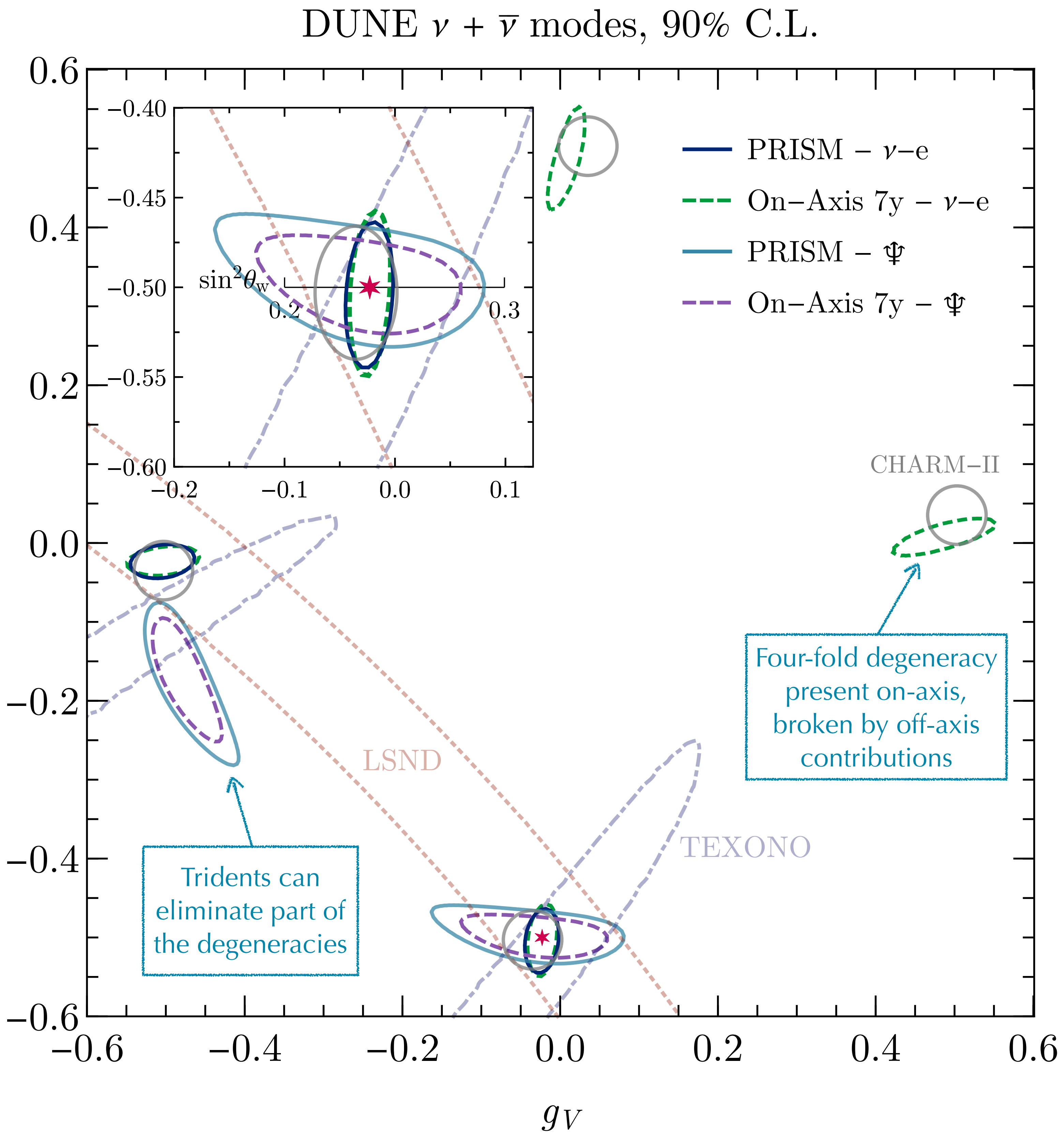


This rare process is accessible in DUNE

References:
[1] Golan *et.al.* PRC86(2012)015505
[2] Ballet *et.al.* JHEP01(2019)119

Rare neutrino scatterings will allow DUNE to measure the weak mixing angle with a precision of ~2%, and remove existing degeneracies in the (g_V, g_A) electron–Z boson couplings plane.





Four-fold degeneracy present on-axis, broken by off-axis contributions

Tridents can eliminate part of the degeneracies

For further details, see arXiv:1912.06658 [hep-ph]

Main assumptions

- ❖ 525 ton-year exposure
- ❖ A year of data taking distributed as:
  - ✦ 1/2 year in the on-axis position
  - ✦ 1/2 year equally divided in the off-axis positions
- ❖ Angular resolution of 1°.
- ❖ Energy resolution of $10\,\%/\sqrt{E_\nu/1\text{ GeV}}$.
- ❖ Energy threshold of $E_R > 50$ MeV
- ❖ NuWro [1] for background simulation.

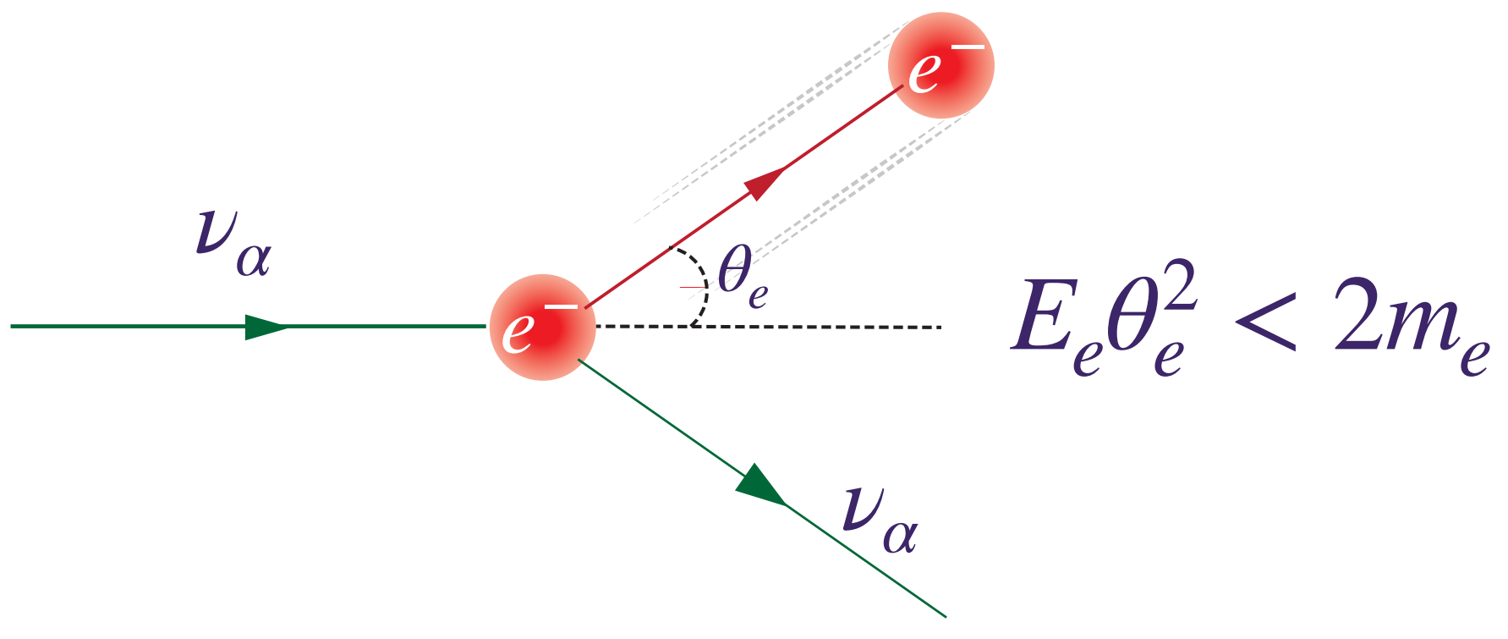
Results

- ❖ The high intensity DUNE flux will allow for a competitive measurement of the weak angle
- ❖ The ν_e flux component, modified as one goes off-axis, is crucial for the breaking of degeneracies.
- ❖ Tridents can contribute to break the final degeneracy.
- ❖ DUNE can test the electron–Z (gV, gA) couplings without the aid of external data.

Backgrounds

❖ *ν_α-electron scattering*

- ν_e CCQE, $\nu_e A \to e^- A'$, with no visible hadronic activity.
- Misidentified $\nu A \to \nu\pi^0 A'$ events with no or invisible hadronic activity.



We use $E_e\theta_e^2$ as kinematic variable to improve background rejection

❖ *Neutrino trident scattering*

- Misidentified γ's and $\pi^\pm$ mimicking $e^-$and $\mu^\pm$.

We use the cuts on $m^2_{\ell^+\ell^-}$ and angles to reduce backgrounds [2].

Systematics

- ❖ Hadron production
- ❖ Beam focusing
- ❖ Horn alignment
- ❖ POT counting

We consider a covariance matrix derived from detailed simulations of hadron production

Acknowledgements

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