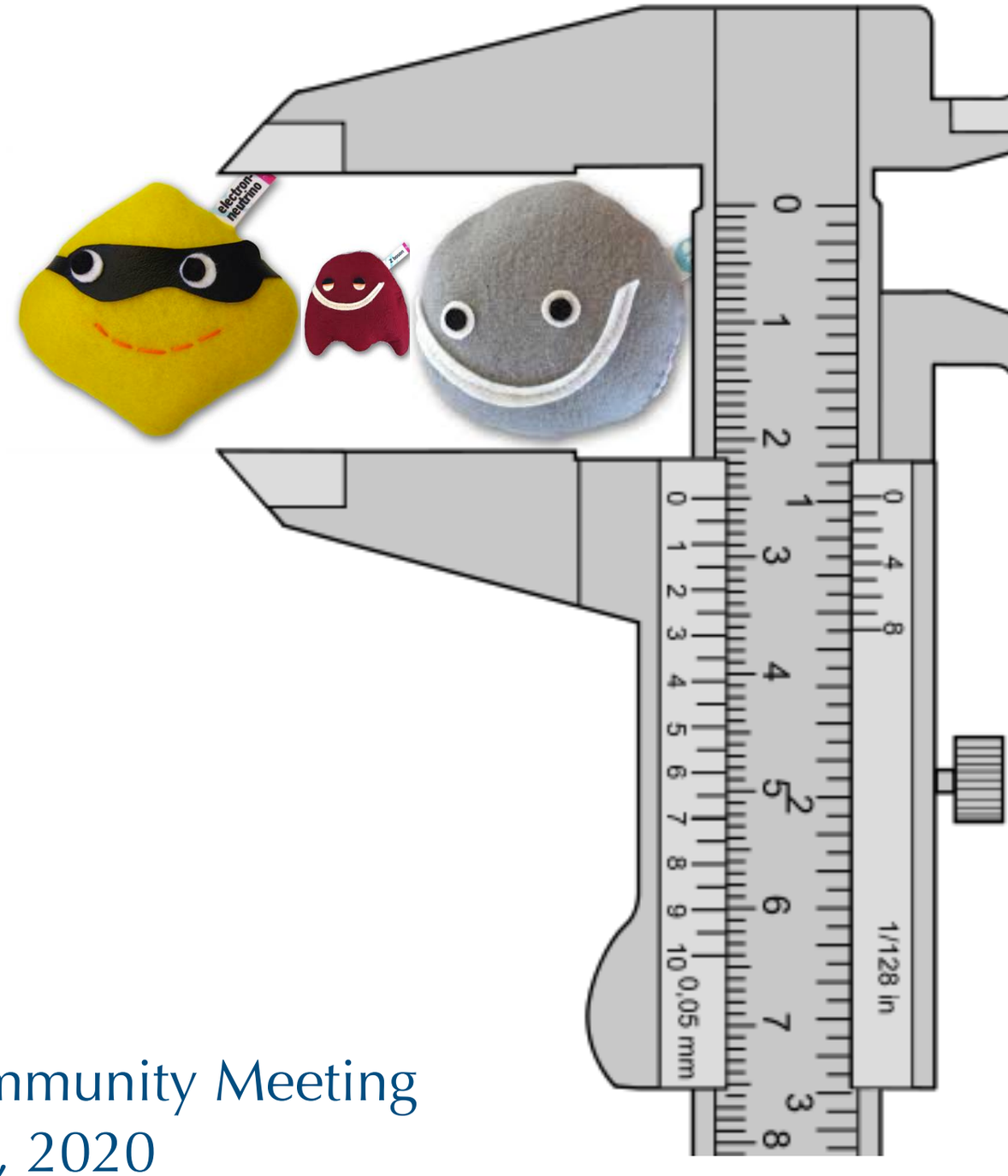
Electroweak precision measurements in low energy neutrino experiments

Yuber F. Perez-Gonzalez



LOI : SNOWMASS21-NF5_NF0-EF0_EF4-170

EF04 Topical Group Community Meeting
October 23rd, 2020

Fermilab

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Northwestern

Snowmass2021 - Letter of Interest

Electroweak precision measurements in low energy neutrino experiments.

NF Topical Groups: (check all that apply ☐/■)

☐ (NF1) Neutrino oscillations
☐ (NF2) Sterile neutrinos
☐ (NF3) Beyond the Standard Model
■ (NF4) Neutrinos from natural sources
■ (NF5) Neutrino properties
☐ (NF6) Neutrino cross sections
☐ (NF7) Applications
■ (NF9) Artificial neutrino sources
☐ (NF10) Neutrino detectors
■ (EF04) EW Physics: EW Precision Physics and constraining new physics

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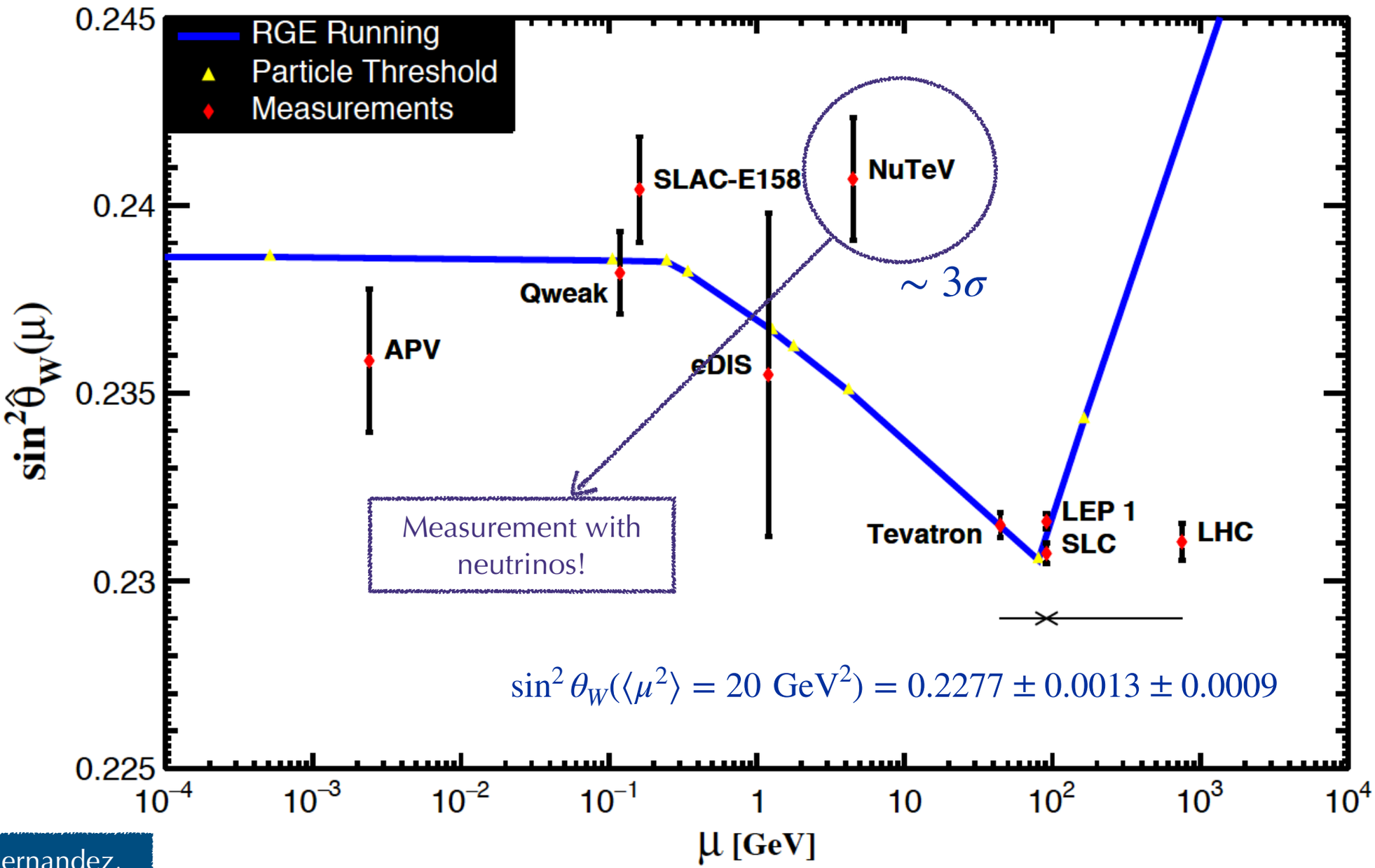
Weak mixing angle

Fermion Couplings

$$g_V^f = t_3^f - 2q_f \sin^2\theta_W$$
$$g_A^f = t_3^f$$

$\overline{\text{MS}}$: $$\sin^2\theta_W(\mu) \equiv \frac{g'(\mu)^2}{g(\mu)^2 + g'(\mu)^2}$$

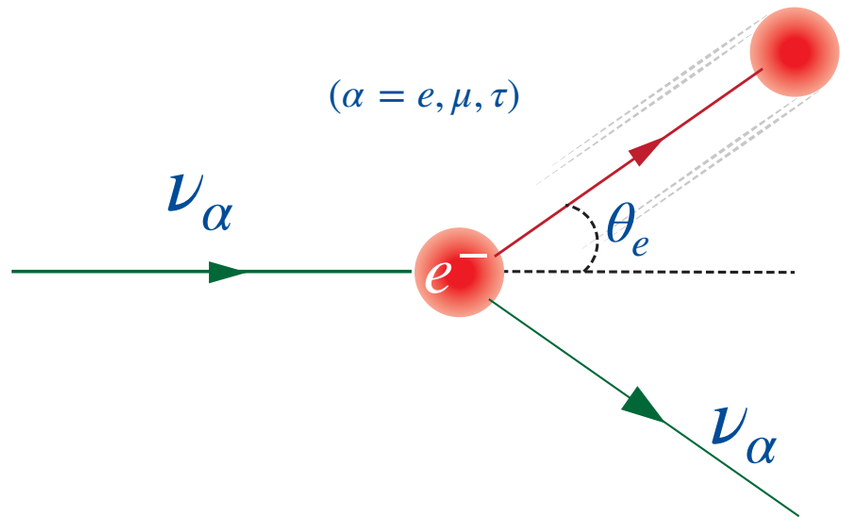


$$\sin^2\theta_W(\langle\mu^2\rangle = 20\ \text{GeV}^2) = 0.2277 \pm 0.0013 \pm 0.0009$$

Erler, Ferro-Hernandez, JHEP 1803, 196

Neutrino-electron Elastic Scattering

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



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

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

$g_2 = g_V - g_A$

CC contribution

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

$g_2 \leftrightarrow g_1$

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

Coherent Elastic Neutrino Nucleus Scattering

$$\frac{d\sigma^\nu}{dE_R} \simeq [Q_V^{\rm SM}]^2 \mathcal{F}^2(E_R) \frac{G_F^2 m_N}{4\pi}\left(1 - \frac{m_N E_R}{2E_\nu^2}\right)$$

$$Q_V^{\rm SM} = N - (1 - 4\sin^2\theta_W)Z$$

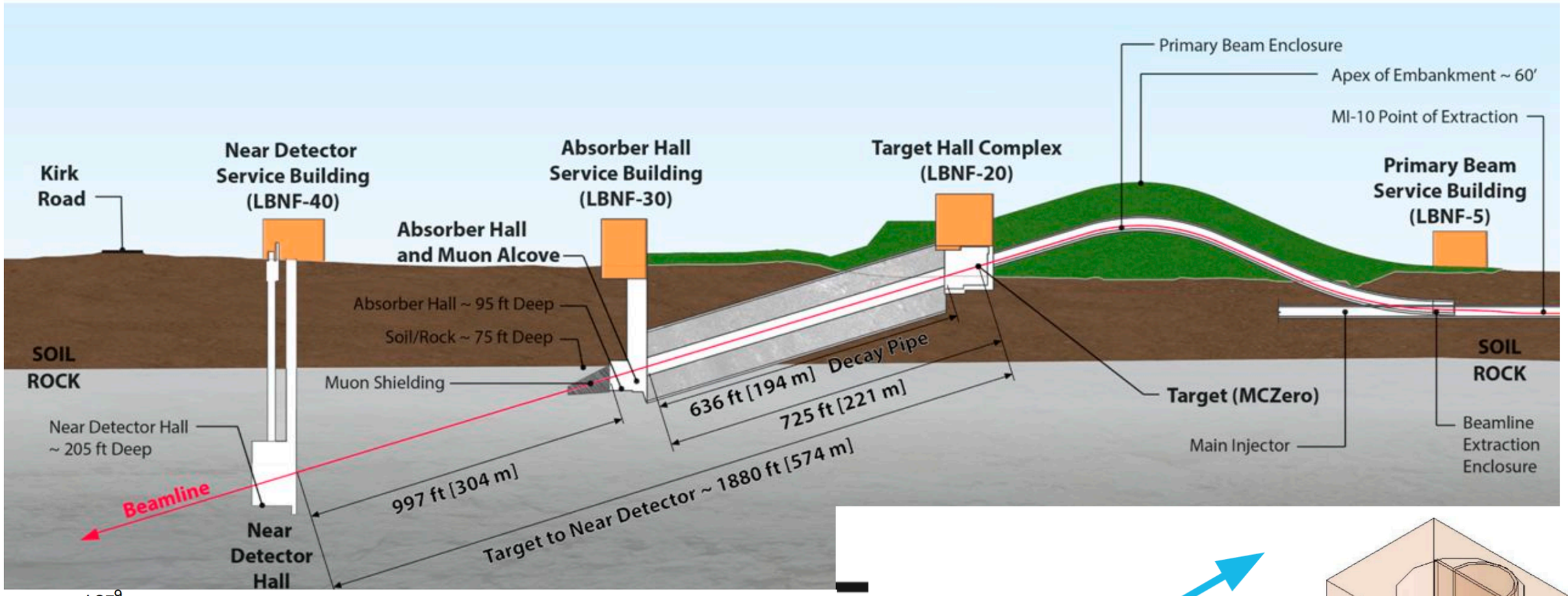
Neutrons

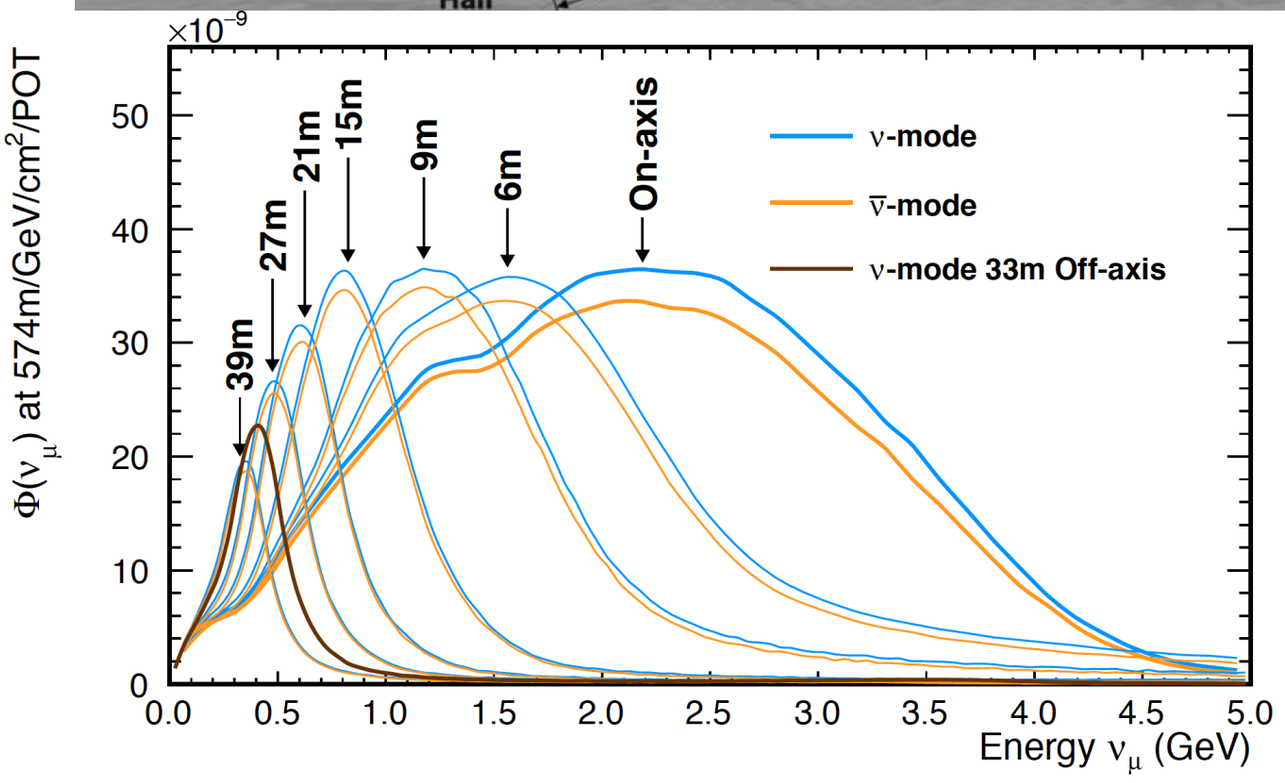
Protons

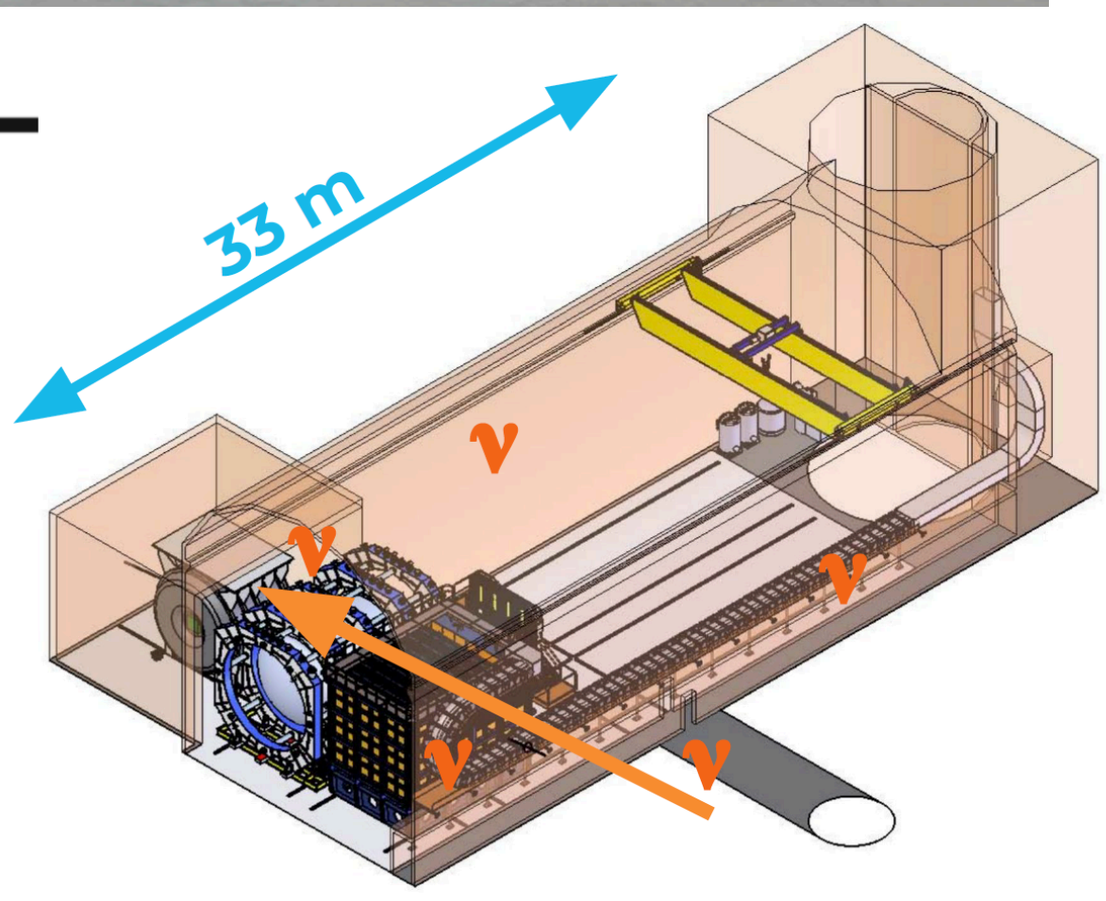
Low momentum transfer

$$\sqrt{-q^2} = \sqrt{2E_R m_N} \simeq 2.4\ \text{keV}\left(\frac{E_R}{100\ \text{eV}}\frac{m_N}{28 m_p}\right)^{1/2}$$

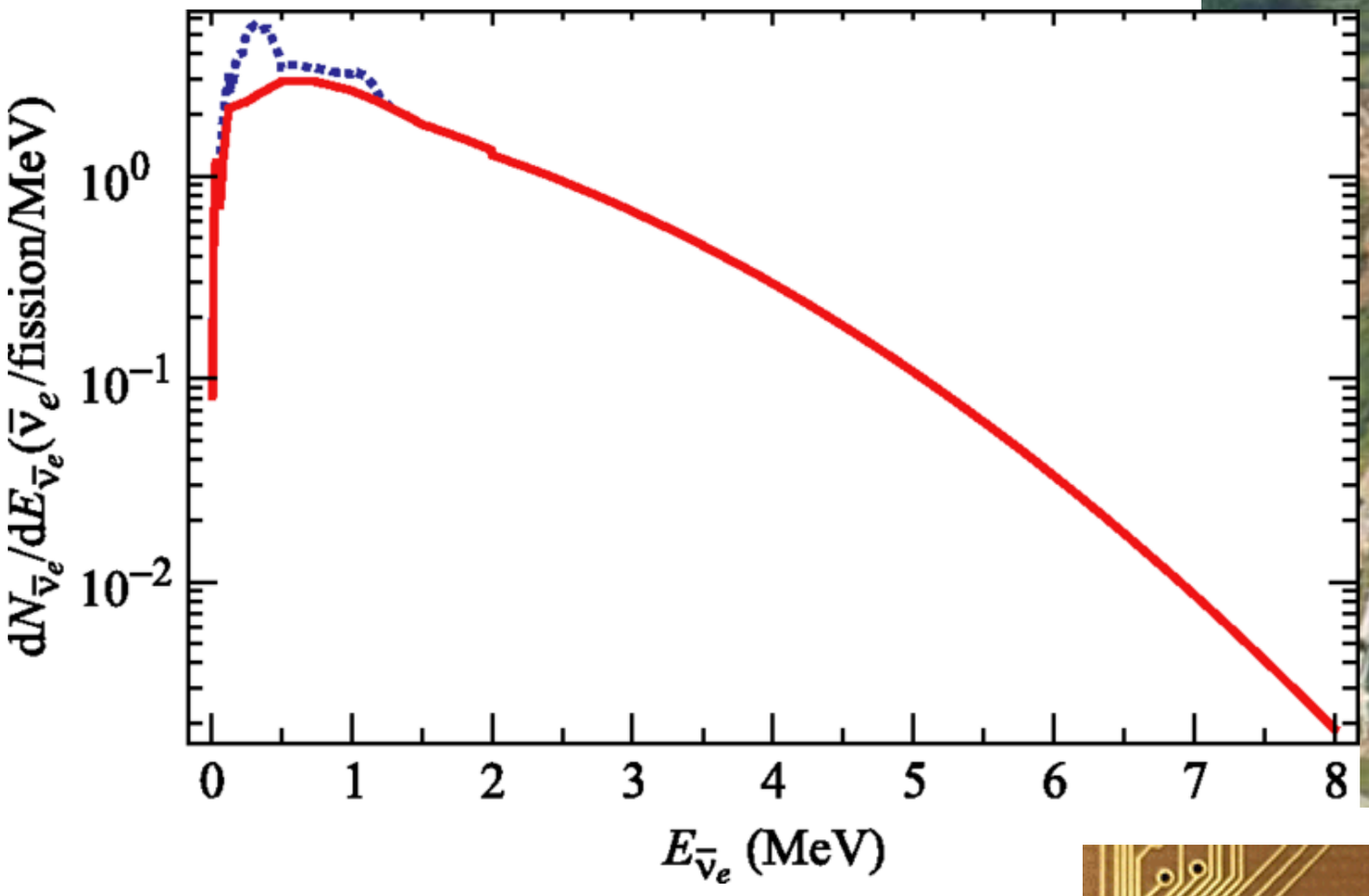
DUNE ND


Primary Beam Enclosure
Apex of Embankment ~ 60'
MI-10 Point of Extraction
Kirk Road
Near Detector Service Building (LBNF-40)
Absorber Hall Service Building (LBNF-30)
Target Hall Complex (LBNF-20)
Primary Beam Service Building (LBNF-5)
Absorber Hall and Muon Alcove
Absorber Hall ~ 95 ft Deep
Soil/Rock ~ 75 ft Deep
SOIL
ROCK
Muon Shielding
636 ft [194 m] Decay Pipe
725 ft [221 m]
Target (MCZero)
SOIL
ROCK
Near Detector Hall ~ 205 ft Deep
Main Injector
Beamline Extraction Enclosure
Beamline
997 ft [304 m]
Target to Near Detector ~ 1880 ft [574 m]
Near Detector Hall

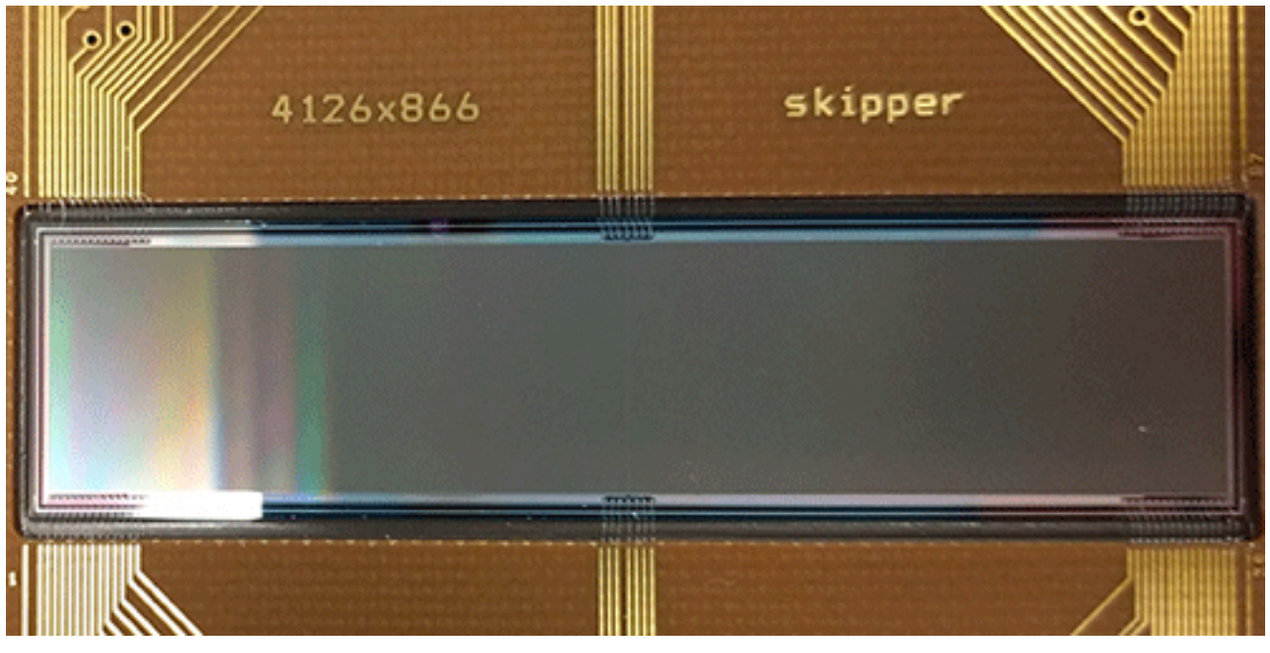

×10⁻⁹
Φ(ν_μ) at 574m/GeV/cm²/POT
39m
27m
21m
15m
9m
6m
On-axis
ν-mode
ν̄-mode
ν-mode 33m Off-axis
Energy ν_μ (GeV)


33 m
ν
ν
ν
ν
ν

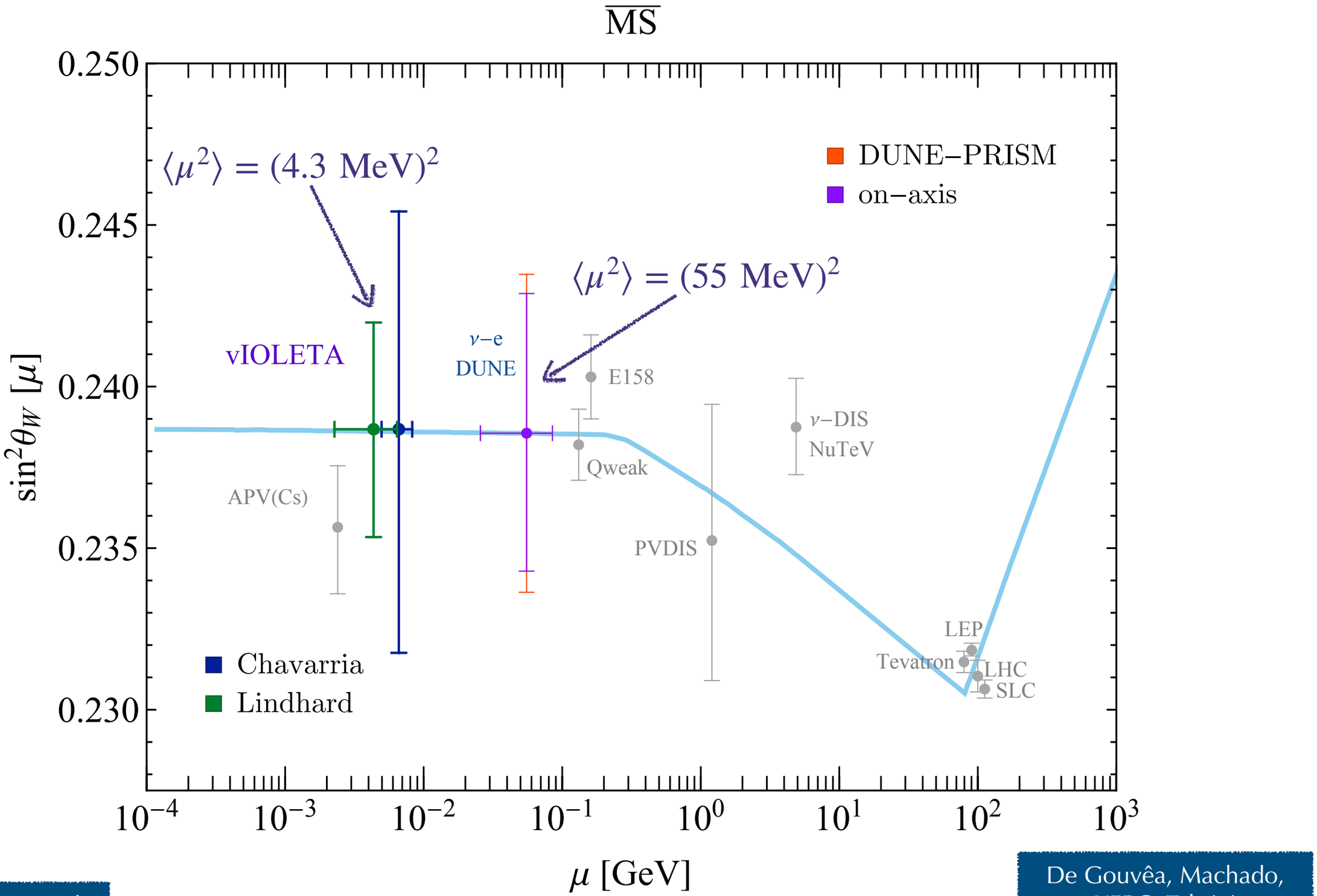
Reactor antineutrinos



GOAL: Measure CEvNS using reactor neutrinos



Measuring $\sin^2\theta_W$ with neutrino scatterings



Fernandez-Morini et al
2009.10741

De Gouvêa, Machado, YFPG, Tabrizi
PRL125(2020) 5, 051803

Conclusions

- Neutrino experiments will allow for precise measurements of the mixing angle at different momentum transfers.
- DUNE will be able to reach ~2% precision using neutrino-electron scattering
- Reactor experiments measuring CEvNS will reach ~3% precision, in a different region of $\langle \mu \rangle$
- Precision is dominated by systematic uncertainties
- Other possible ways to measure $\theta_{\mathrm{W}} \longrightarrow$ Solar neutrinos?

Thanks!