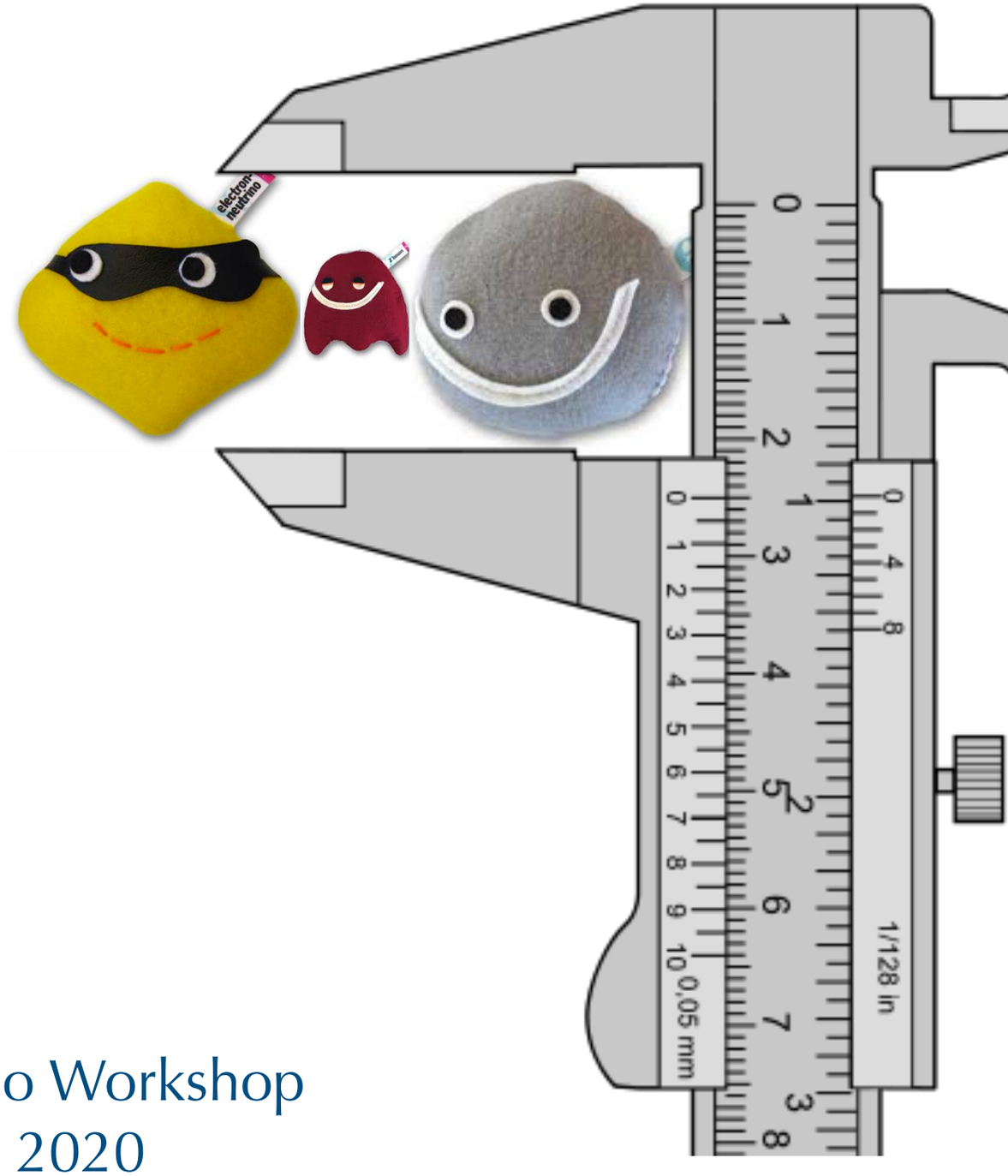
Electroweak precision measurements in low energy neutrino experiments

Yuber F. Perez-Gonzalez

LOI : SNOWMASS21-NF5_NF0-EF0_EF4-170



Solar and Geoneutrino Workshop
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Fermilab

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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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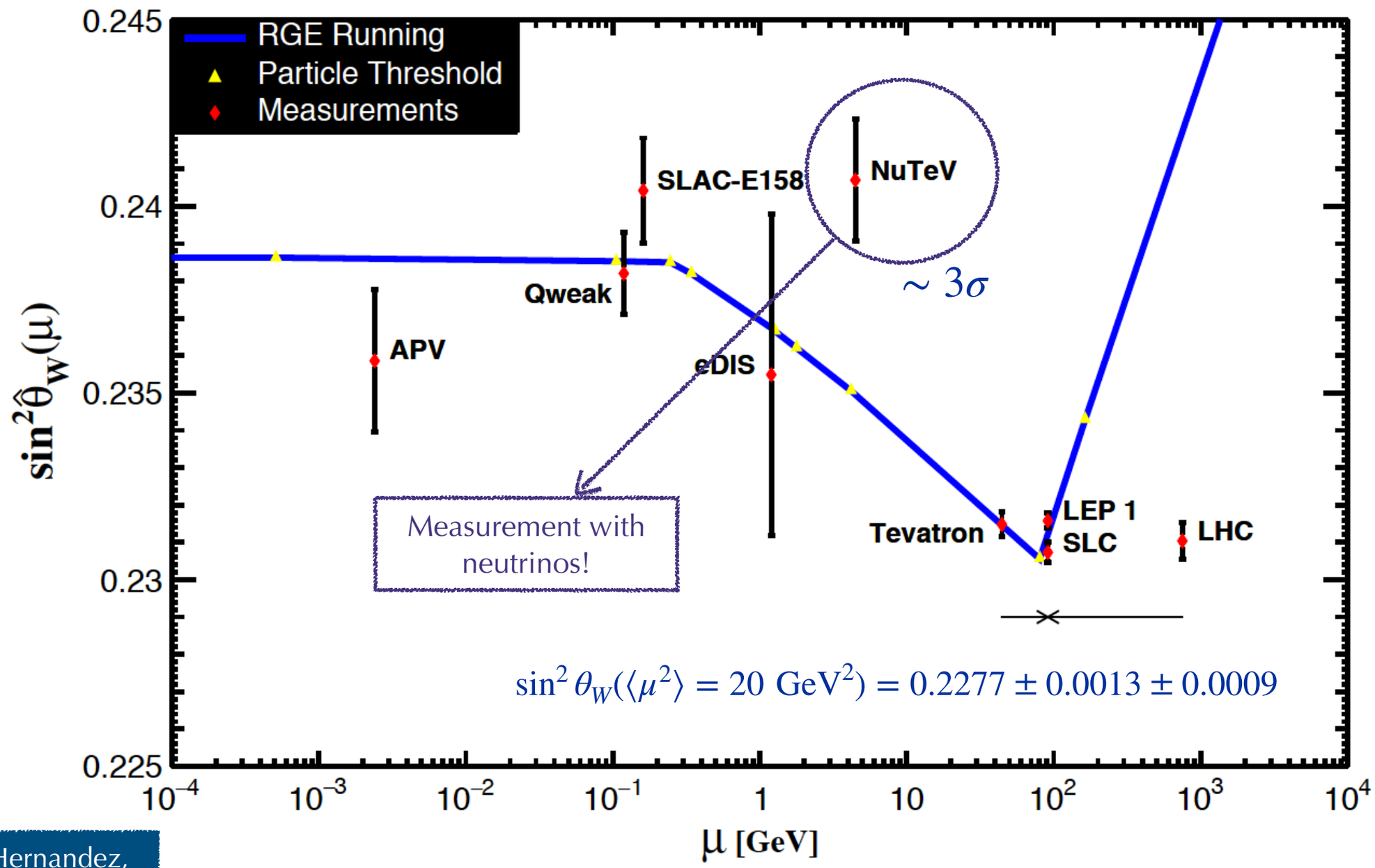
Weak mixing angle

Fermion Couplings

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

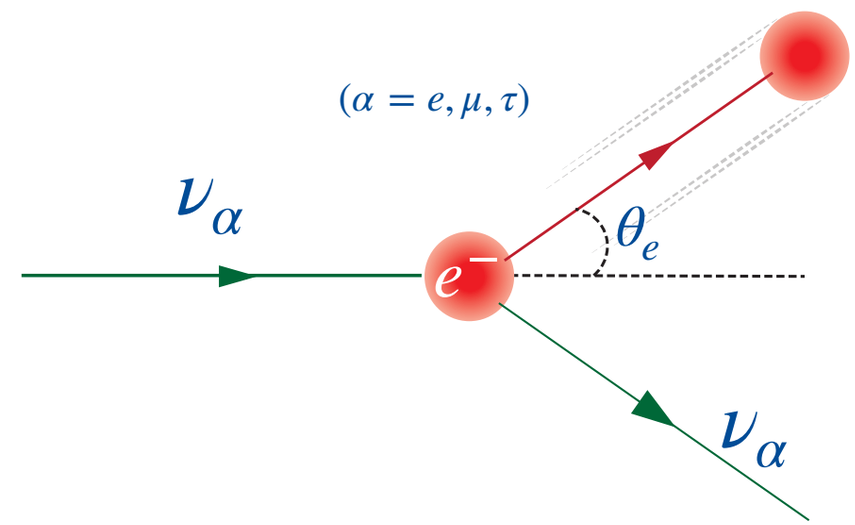
$\overline{\text{MS}}$: $$\sin^2\theta_W(\mu) \equiv \frac{g'(\mu)^2}{g(\mu)^2 + g'(\mu)^2}$$



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

Coherent Elastic Neutrino Nucleus Scattering

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

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

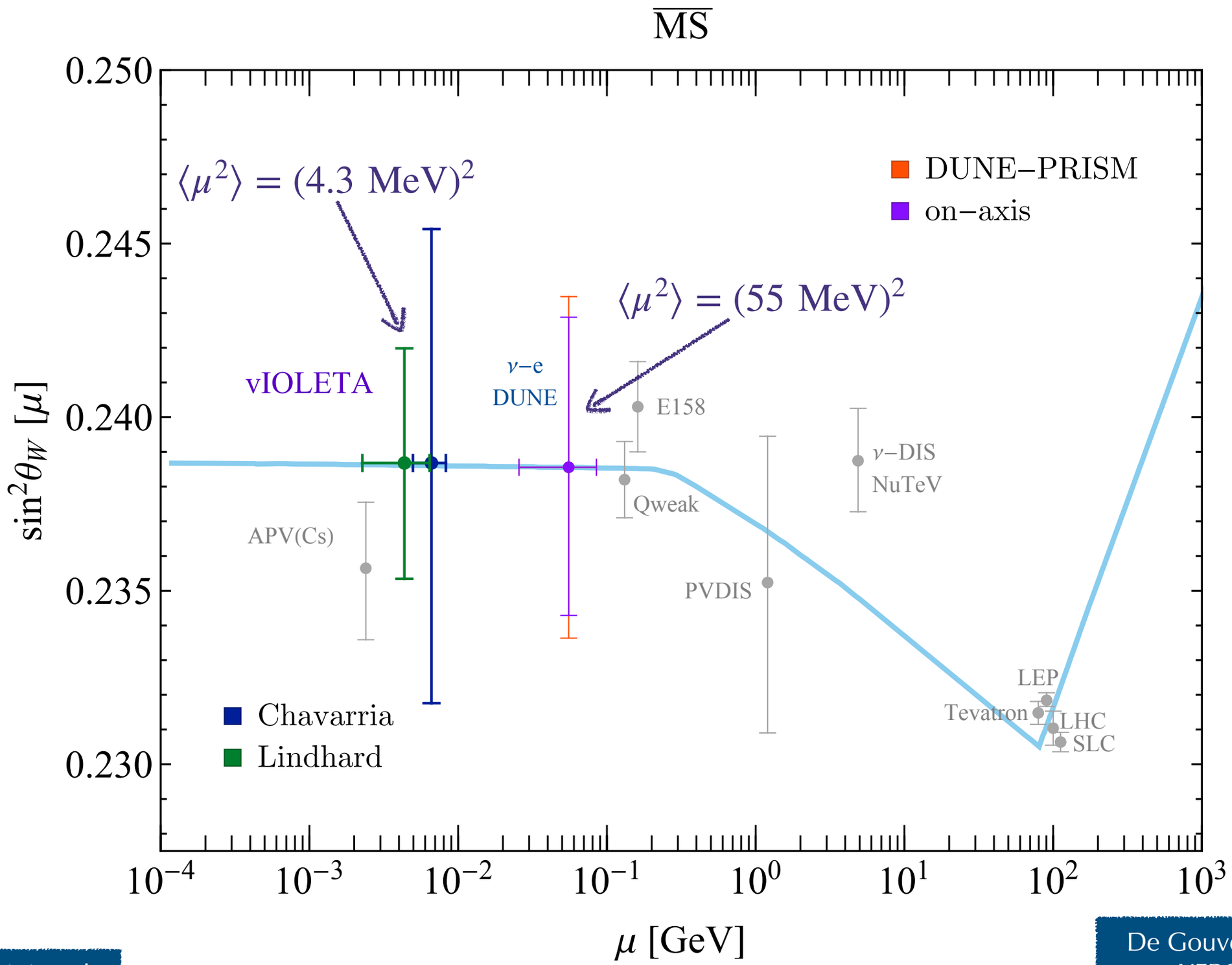
Neutrons

Protons

Low momentum transfer

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

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



Fernandez-Morini et al
2009.10741

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

Solar neutrinos

Borexino:

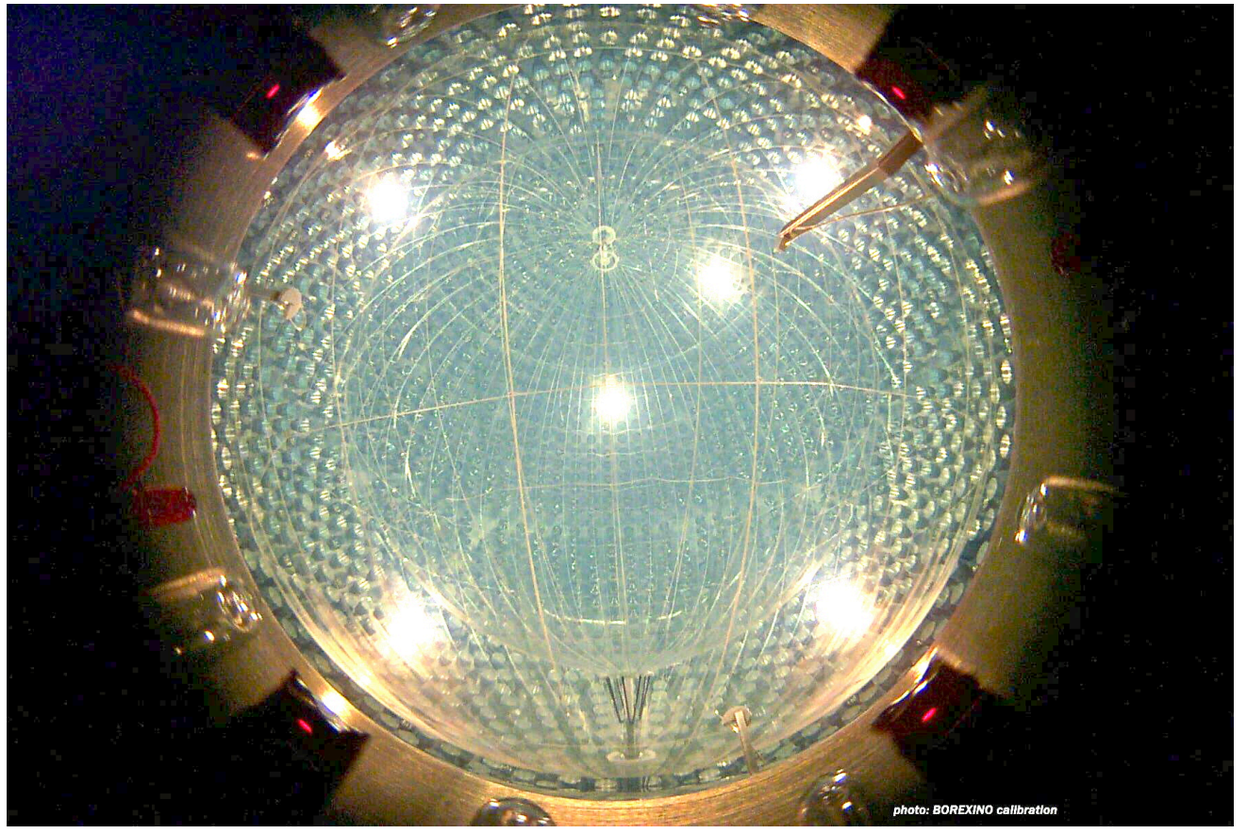
$$\sin^2\theta_W = 0.229 \pm 0.026\,(\text{stat+syst})$$

$\sim 11\,\%$

HZ-SSM

Measurement of nu-e elastic scattering

Known backgrounds
Measurement of several components



Borexino collaboration
JHEP3(2020)8

Solar neutrinos

SK, SNO?

$\mathcal{O}$(100k events)

Neutrino 2020

DUNE?

$>\mathcal{O}$(100k events)

Capozzi etal
PRL123(2019)131803

Degeneracies with oscillation parameters

JUNO

Dependence on solar model

Not known yet

DM detectors

Able to measure both nu-e and CEvNS interactions

Large volumes, known backgrounds

Combination of solar data?

Work on progress

Next generation

DARWIN-like

Exp.	$\sin^2\theta_W$
Measured	
G2	4.6% (4.5%)
Future-Xe	1.7% (1.7%)
Future-Ar	1.5% (1.4%)

Cerdeño etal
JHEP 05 (2016) 118

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!