Electro-weak Precision Tests with nuSTORM

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Electro-weak Theory

- The Standard Model (SM) provides a remarkably accurate description of a wide range of phenomena in nuclear and particle physics

- The SM unifies the weak and electromagnetic forces into one gauge group, $SU(2)_L \times U(1)_Y$

- Weak sector ➔ precision at 0.1% level are reached
  Electromagnetic sector ➔ precision at 1 part per billion

- The SM is incomplete due to ➔

  - the discovery of neutrino mass
  - the existence of dark matter
  - the recent advent of dark energy

Precision Test

- Precision low energy observables have been and continue to be an invaluable tool to learn about the scale of new physics and to shed light into flavor sector

J. Erler and M.J. Ramsey-Musolf, Prog. Part. Nucl. Phys. 54, 351 (2005)

- These tests are complimentary to the more canonical measurements done at colliders like LHC looking for new physics at higher energy scales

- These tests are highly sensitive to the presence of oblique corrections affecting vacuum polarization of the photon, Z and W bosons through new particles in quantum loops and vertex corrections

M.E. Peskin and T. Takeuchi, Phys. Rev. Lett. 65, 964 (1990)
G. Altarelli and R. Barbieri, Phys. Lett. B 253, 161 (1991)
G. Degrassi, A. Sirlin and W.J. Marciano, Phys. Rev. D 39, 287 (1989)

Weinberg Angle / Weak Mixing Angle

- The Weinberg angle is defined by the ratio of the $SU(2)_L$ gauge coupling g and the $U(1)_Y$ gauge coupling g′

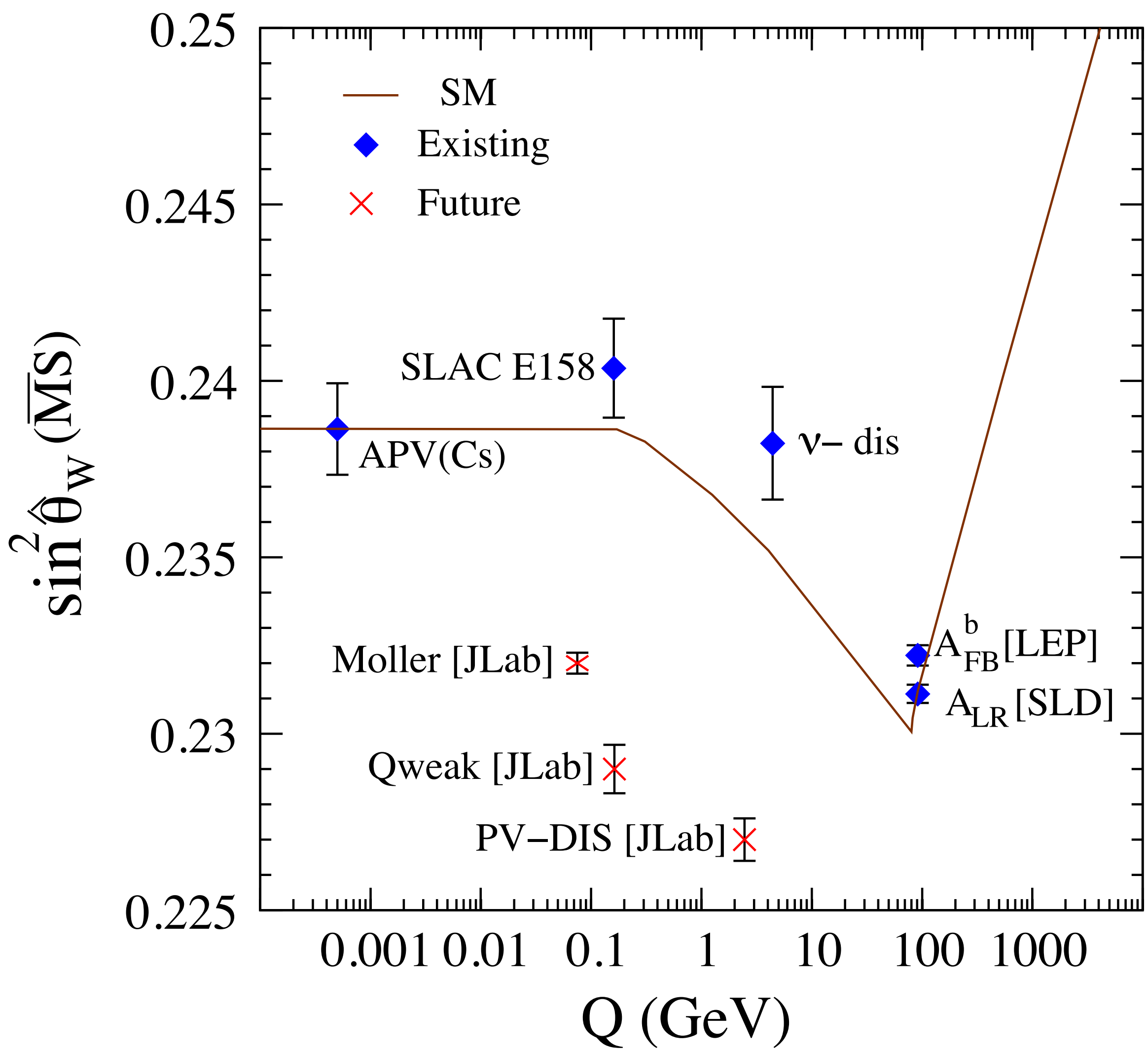
$$\sin^2\theta_W = \frac{g'^2}{g^2+g'^2}$$

➔ a key parameter in the electro-weak theory

- Its value depends on the energy scale. Renormalization group running of the Weinberg angle is an inevitable consequence of the electro-weak theory

- Experimental demonstration of the running of the Weinberg angle has been considered to be an *experimentum crucis* for the SM

Running of $\sin^2\hat{\theta}_W$ ($\overline{MS}$)



World data for the Weinberg angle as a function of Q

Solid curve shows the running in the MS-bar renormalization scheme

S.K. Agarwalla and P. Huber, JHEP 1108 (2011) 059

Discrepancies

- Leptonic (0.23113 ± 0.00021) and hadronic (0.23222 ± 0.00027) measurements of $\sin^2\theta_W$ at Z-pole differ by 3.2 standard deviations

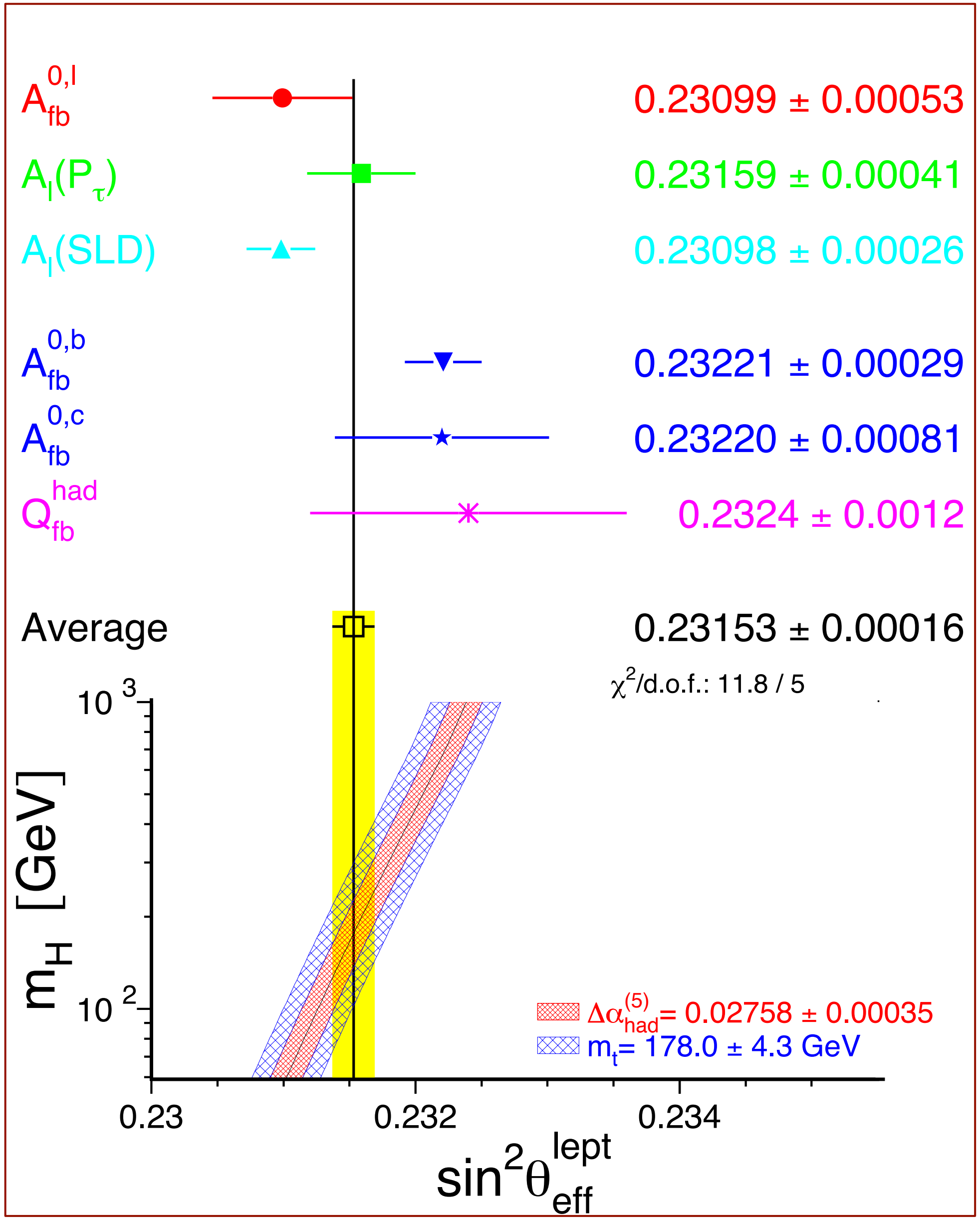
The ALEPH, DELPHI, L3, OPAL, SLD Collaborations, Phys. Rept. 427, 257 (2006)

- NuTeV collaboration reported a 3σ discrepancy with the SM value of $\sin^2\theta_W$

G.P. Zeller etal., [NuTeV Collaboration], Phys. Rev. Lett. 88, 091802 (2002) [Erratum-ibid. 90, 239902 (2003)]

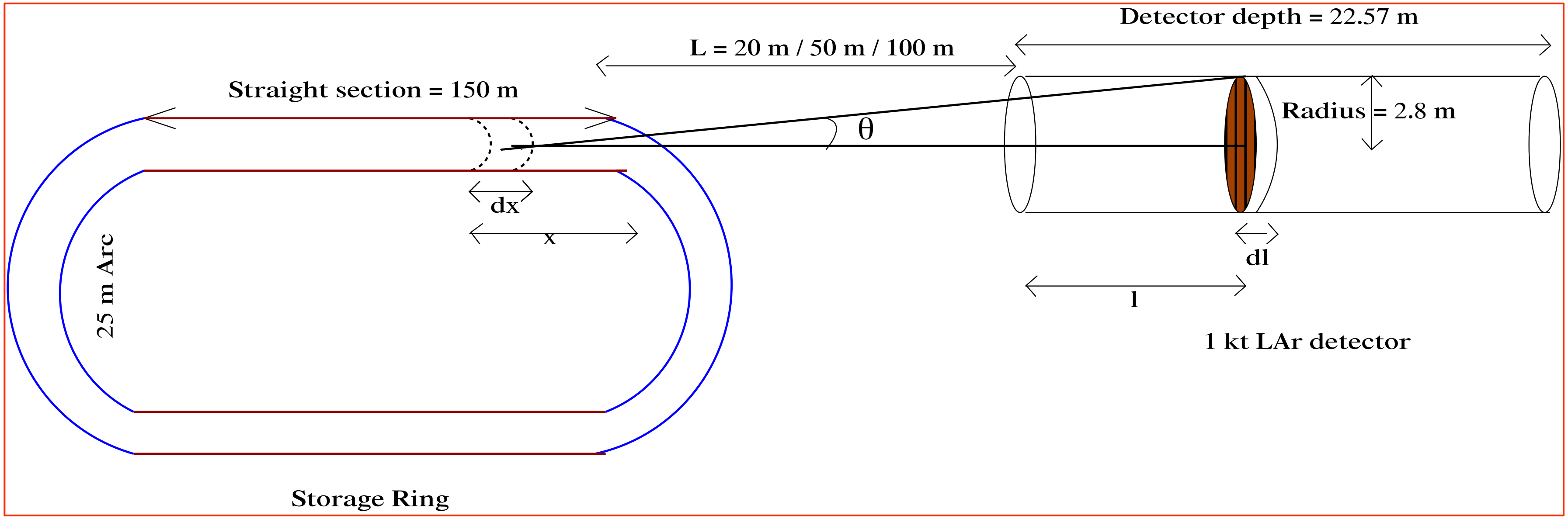
- These discrepancies could be a sign for new physics or may be for not understood experimental effects

$\sin^2\theta_W$ .vs. Higgs mass



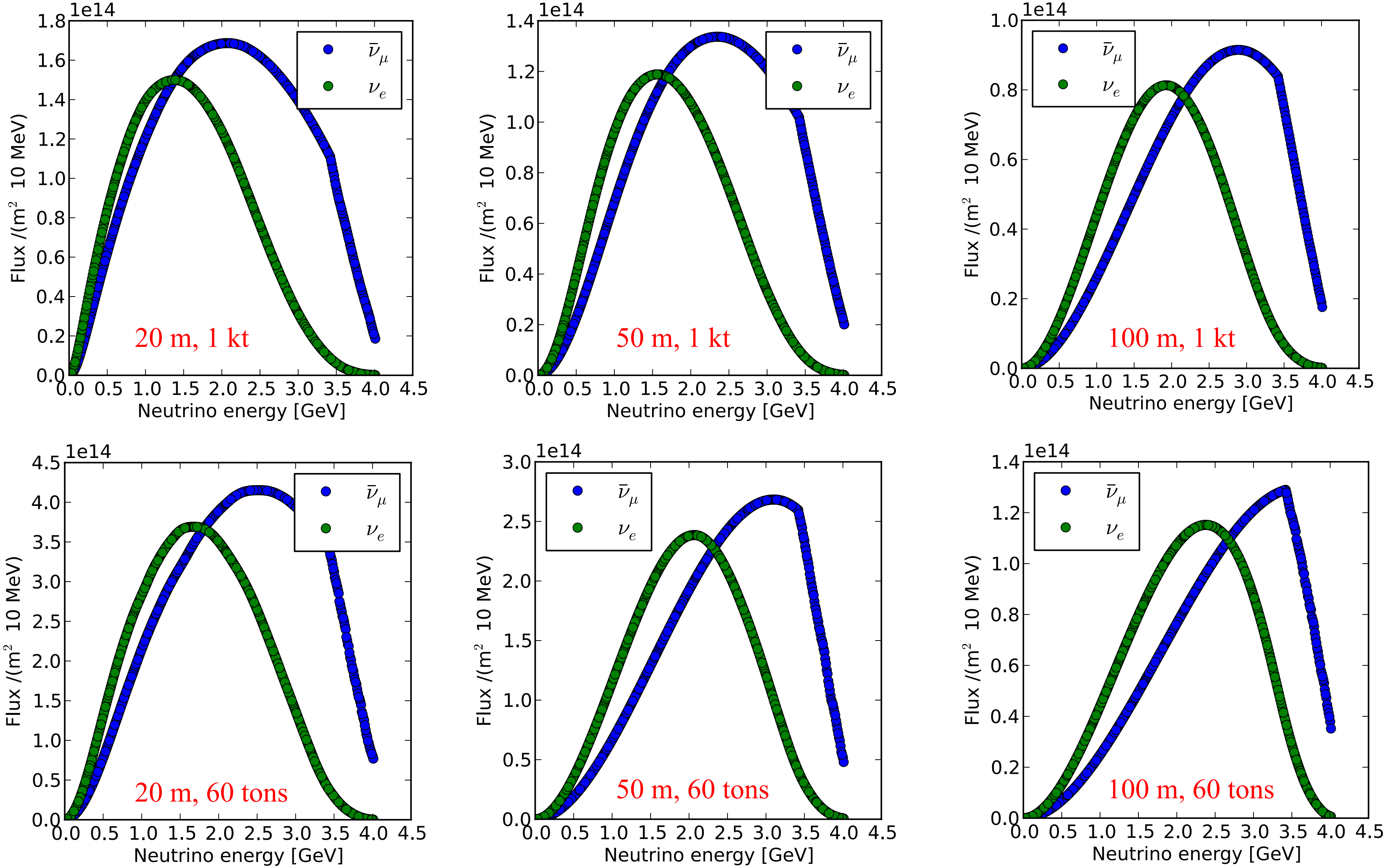
- SM prediction for $\sin^2\theta_W$ as a function of Higgs mass
- Precise information on $\sin^2\theta_W$ is very helpful to constrain the Higgs mass

nuSTORM Near Detector Setup



- $E_\mu = 3.8$ GeV with 1.8×10^{18} effective μ^+ decays in 5 years
- Length of the Straight Section = 150 m
- Distance between the front end of the storage ring and detector = 20 m / 50 m / 100 m
- 1 kt LArTPC (Radius = 2.8 m & Length = 22.57 m) with 100% efficiency
- Energy resolution, $\sigma(E)$ in GeV = 5% × $\sqrt{E}$ in GeV
- 50 MeV bin-size in reconstructed recoil kinetic energy

Geometry Integrated Flux



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ν-e scattering

Simple, purely leptonic, weak interactions, plays an essential role to prove the validity and perform precision tests of the SM

$$\frac{d\sigma}{dT} = \frac{2G_F^2 m_e}{\pi E_\nu^2}\left[\alpha^2 E_\nu^2 + \beta^2 (E_\nu - T)^2 - \alpha\beta m_e T\right]$$

E_ν = Incoming neutrino energy, T = Electron recoil kinetic energy

$$0 \leq T \leq T^{\max} = \frac{E_\nu}{1+m_e/2E_\nu}$$

θ = Angle between incident neutrino direction and recoil electron

$$\cos\theta = (1+m_e/E_\nu)/\sqrt{1+2m_e/T}$$

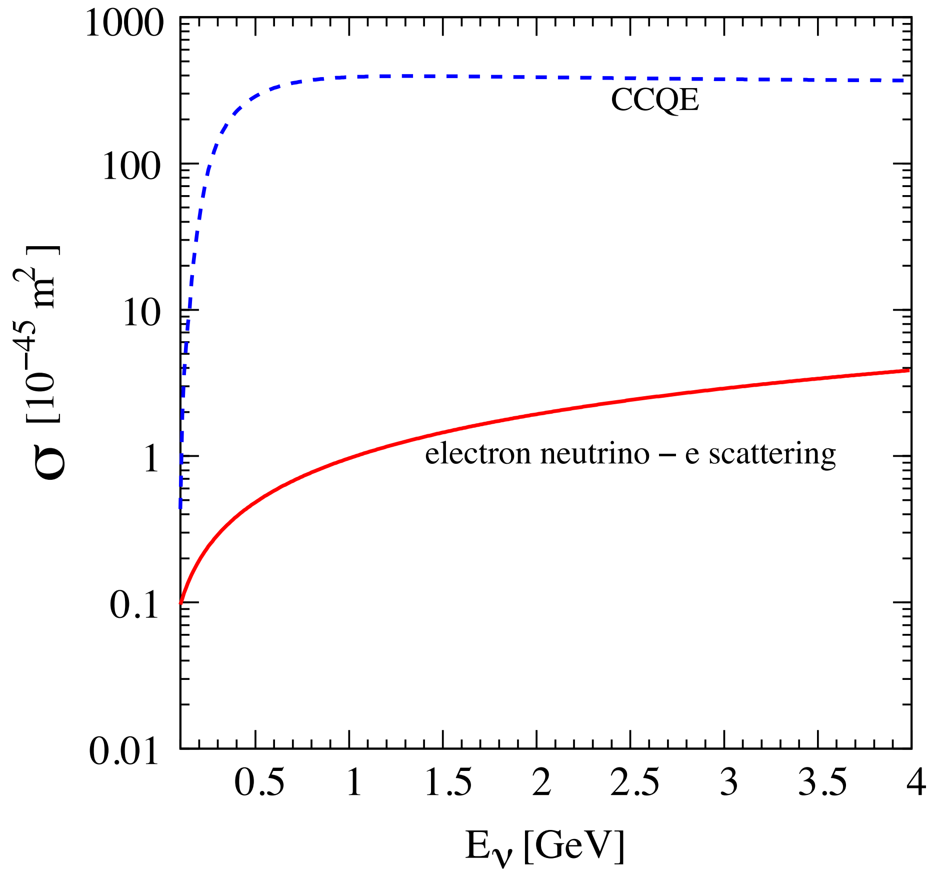
The values of α and β in the SM for different processes

	$\nu_e e \to \nu_e e$	$\nu_\mu e \to \nu_\mu e$	$\bar{\nu}_\mu e \to \bar{\nu}_\mu e$
α	$\frac{1}{2} + \sin^2\theta_W$	$-\frac{1}{2} + \sin^2\theta_W$	$\sin^2\theta_W$
β	$\sin^2\theta_W$	$\sin^2\theta_W$	$-\frac{1}{2} + \sin^2\theta_W$

The signal is a forward electron track with no hadronic activity

The transverse momentum of the outgoing electron is very small, $p_t \sim \sqrt{m_e E_\nu}$

CCQE .vs. ν-e scattering



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Main source of background in studying the ν-e scattering process is quasi-elastic ν_eN scattering

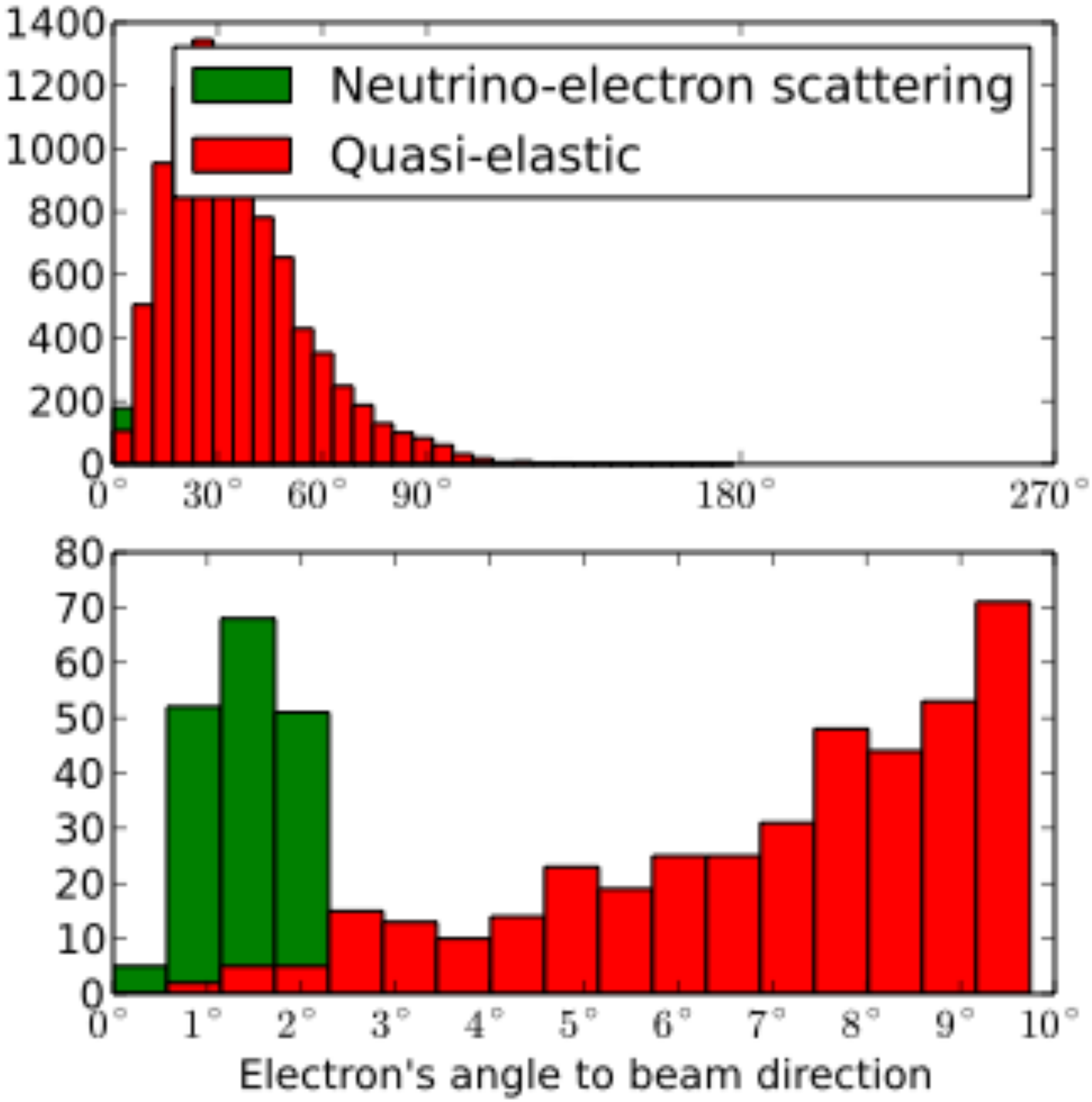
But, the transverse momentum of the outgoing electron is very large for CCQE process compared to ν-e scattering

CCQE : $p_t \sim \sqrt{m_N E_\nu}$

ν-e scattering : $p_t \sim \sqrt{m_e E_\nu}$

We can use the p_t and E_e cut to reject most of the CCQE backgrounds provided that the detector has very good angular and energy resolution!

CCQE Background Study



Looking for electron neutrino

Deep-inelastic backgrounds rejected looking at the hadronic activity

$$\nu_e n \rightarrow e^- p$$

Further cuts like:

$E_p > 50$ MeV and $\theta_p > 20$ degrees

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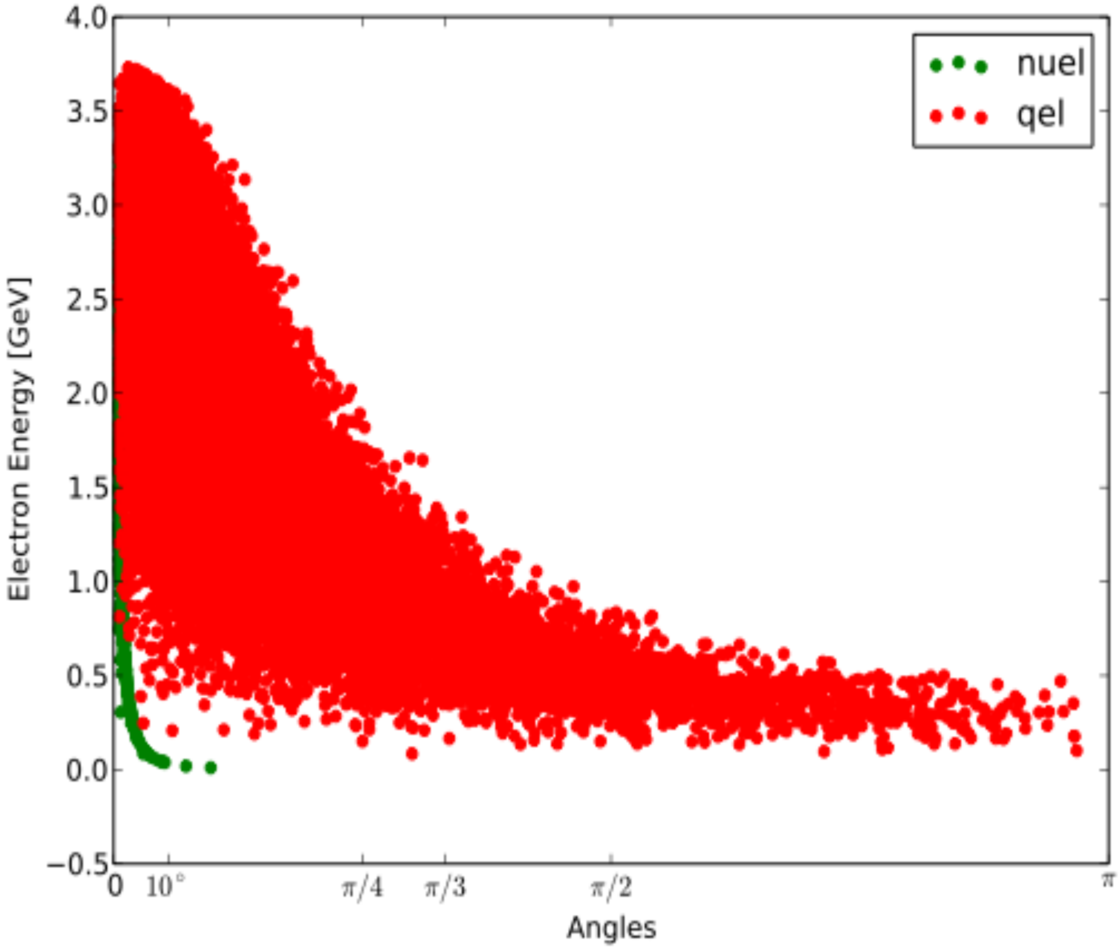
Queries on LArTPC



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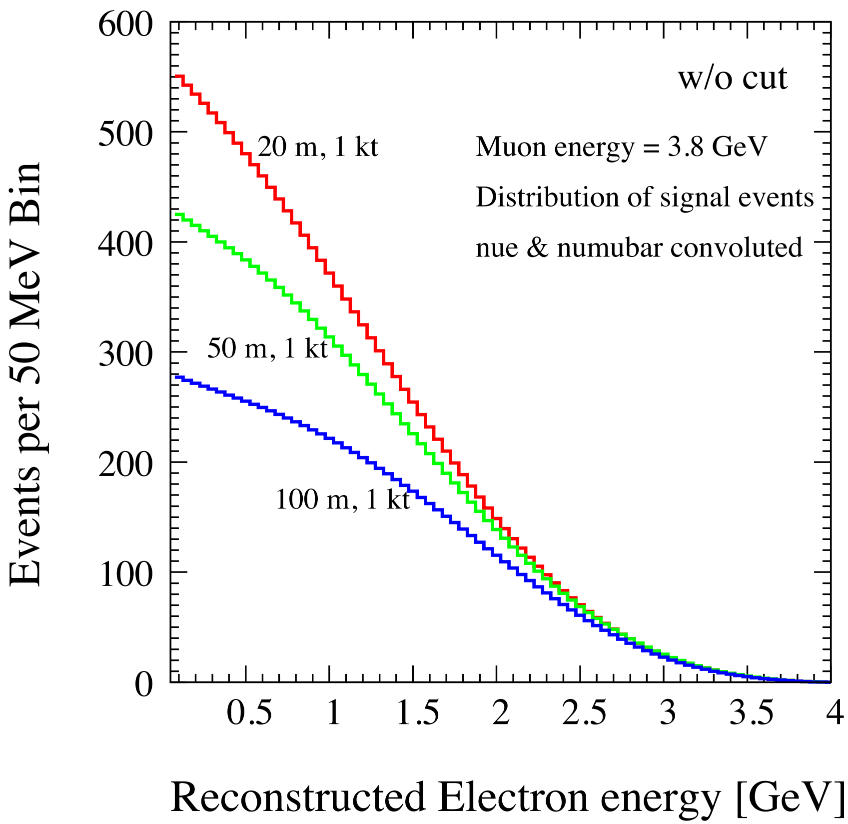
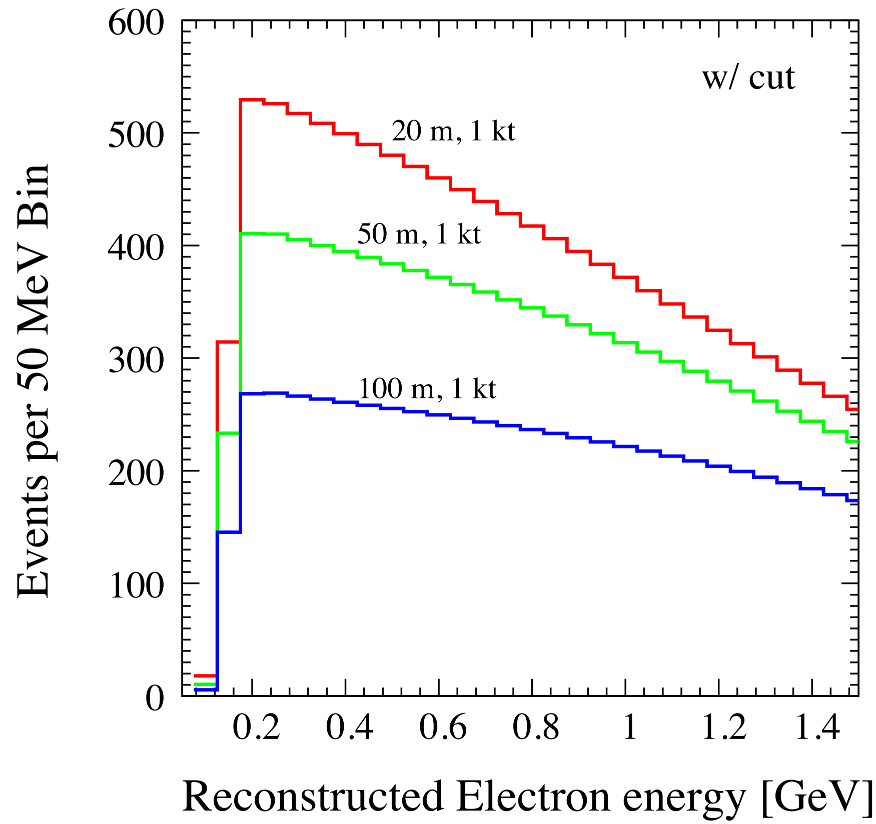
- What type of electron energy resolution can we expect?
- What type of angular resolution can we expect for LAr?
- HIRESMNU has 0.2 degrees for 2 GeV electrons
- Intrinsic angular resolution limited to 1 degree from accelerator

Signal with and without cut





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To reject CCQE background, we consider an energy window of 0.05 GeV to 1.5 GeV in reconstructed recoil electron kinetic energy and an angular cut of $\cos\theta > 0.9961946$

Event Rates and Precision

Condition	100 m, 1 kt	50 m, 1 kt	20 m, 1 kt
w/o cut	9513	13103	15489
w/ cut	6501	9387	11416

Total neutrino electron scattering event rates in 1 kt detector

We consider an energy window of 0.05 GeV to 1.5 GeV in reconstructed recoil electron kinetic energy and an angular cut of $\cos\theta > 0.9961946$

Systematic error	100 m, 1 kt	50 m, 1 kt	20 m, 1 kt
0.1%	1.9%	1.5%	1.4%
1%	2.4%	2.1%	2%

Relative error on weak mixing angle at 1σ

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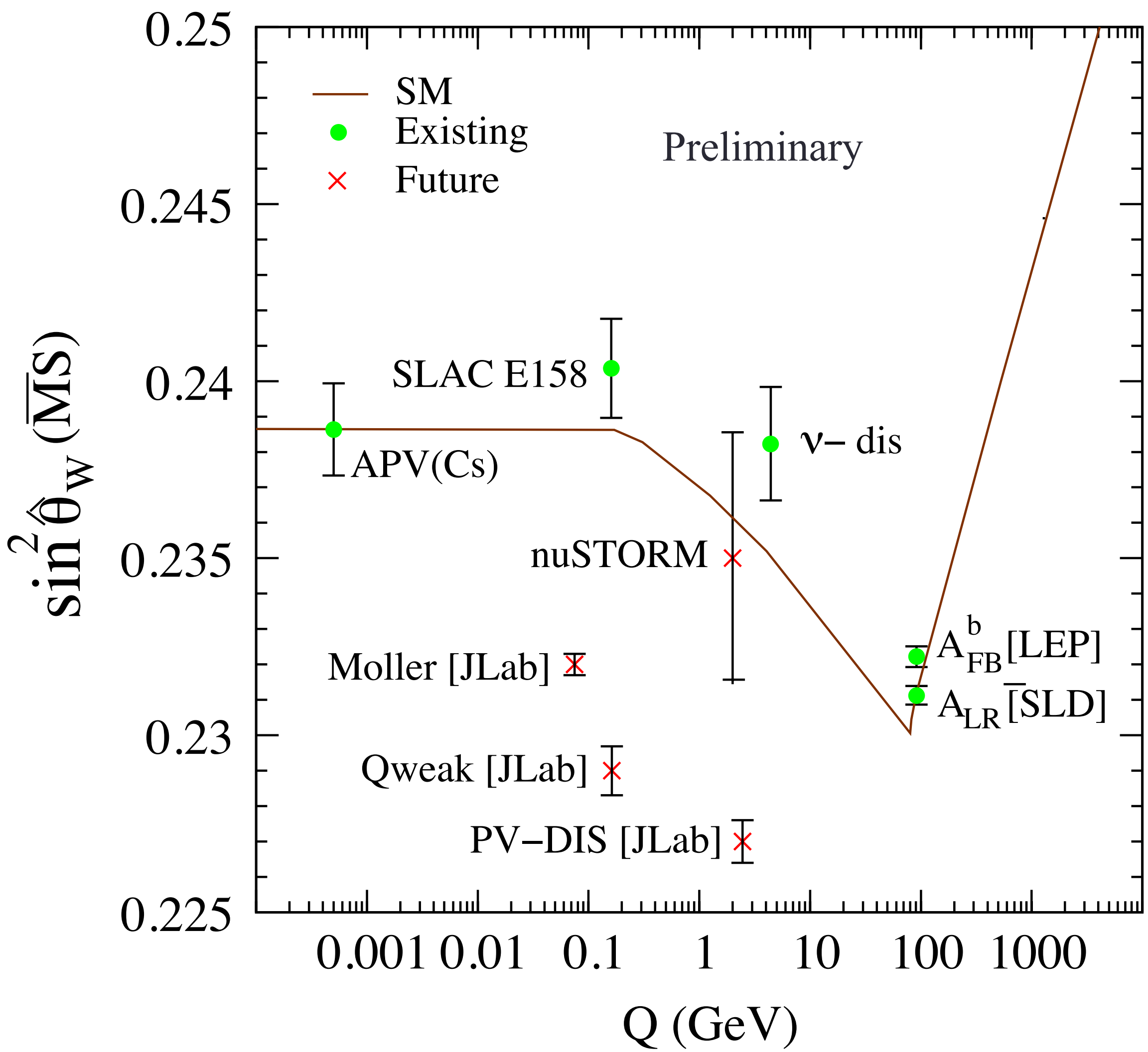

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nuSTORM will provide a ≈ 1.5% measurement of weak mixing angle at Q ≈ 2 GeV

More studies on electro-weak measurements will come soon!

Thank you!