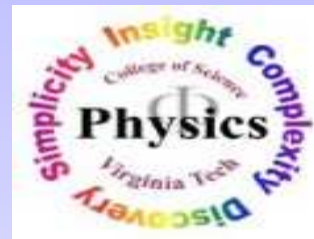


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Ultra precise leptonic measurement of Weinberg angle

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work done in collaboration with

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arXiv:1005.1254, appeared yesterday...

Electro-weak theory

- The Standard Model 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 \Rightarrow precisions at 0.1% level are reached
Electromagnetic sector \Rightarrow precision 1 part per billion
- The SM is incomplete \Rightarrow the discovery of neutrino mass, the existence of dark matter and 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

M. J. Ramsey-Musolf and S. Su, *Phys. Rept.* 456, 1 (2008)

- 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 suppressed vertex corrections

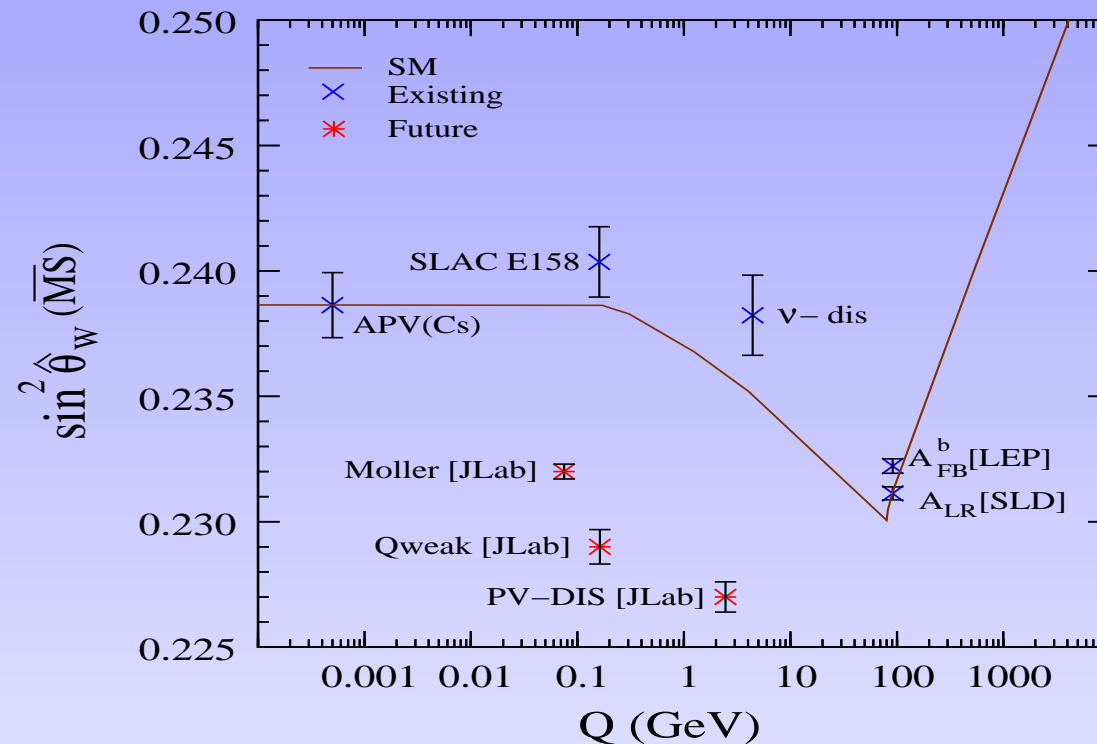
M. E. Peskin and T. Takeuchi, *Phys. Rev. Lett.* 65, 964 (1990)

Weinberg angle

- The Weinberg angle is defined by $\cos \theta_W = M_W/M_Z$, 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 $\sin^2 \hat{\theta}_W$ ($\overline{\text{MS}}$)

The Weinberg angle is defined by $\cos \theta_W = M_W/M_Z$



J. Erler and M. J. Ramsey-Musolf, Phys. Rev. D 72, 073003 (2005)

World data for the Weinberg angle as a function of Q . Solid curve shows the running of $\sin^2 \hat{\theta}_W$ in the $\overline{\text{MS}}$ renormalization scheme

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)

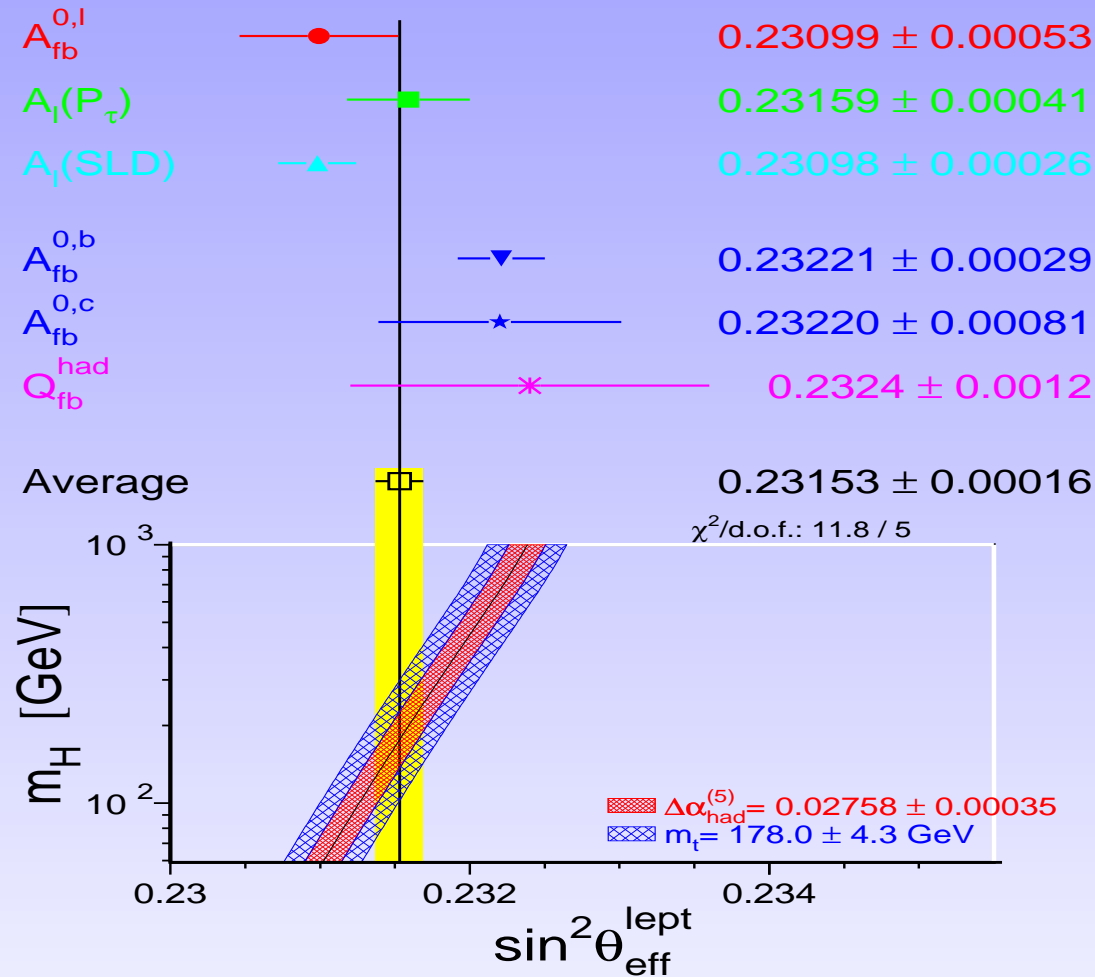
- NuTeV collaboration reported a 3σ discrepancy with the SM value of $\sin^2 \theta_W$

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

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

$\sin^2 \theta_W$.vs. m_H

SM prediction for $\sin^2 \theta_W$ as a function of m_H



Information on $\sin^2 \theta_W \Rightarrow$ helpful to constrain the Higgs mass

Neutrino Flux

- Cyclotron accelerators bombarding 2 GeV protons at 2.5 mA during a 100 μs pulse every 500 μs , delivering 9.4×10^{22} protons per year to a beam dump
- Stopped pions produced in a proton beam dump decay at rest i.e. $\pi^+ \rightarrow \mu^+ + \nu_\mu$ followed by $\mu^+ \rightarrow e^+ + \nu_e + \bar{\nu}_\mu$
- This facility can provide an equal, high-intensity, isotropic, decay at rest ν_μ , ν_e and $\bar{\nu}_\mu$ beam
- We can have 4×10^{22} /flavor/year of ν_μ , ν_e , and $\bar{\nu}_\mu$ from each cyclotron. We consider two cyclotrons in our case

J. M. Conrad *et al.*, *Phys. Rev. Lett.* **104**, 141802 (2010)

R. Lazauskas and C. Volpe, arXiv:1004.0310 [hep-ph]

ν -e scattering

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

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

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

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

	$\nu_e e \rightarrow \nu_e e$	$\nu_\mu e \rightarrow \nu_\mu e$	$\bar{\nu}_\mu e \rightarrow \bar{\nu}_\mu e$
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 values of α & β in the SM for different processes involved in our case

DUSEL Detector

- 300 kt water Cerenkov detector consisting of two volumes of right cylinder of 150 kt each, separated by 60 m

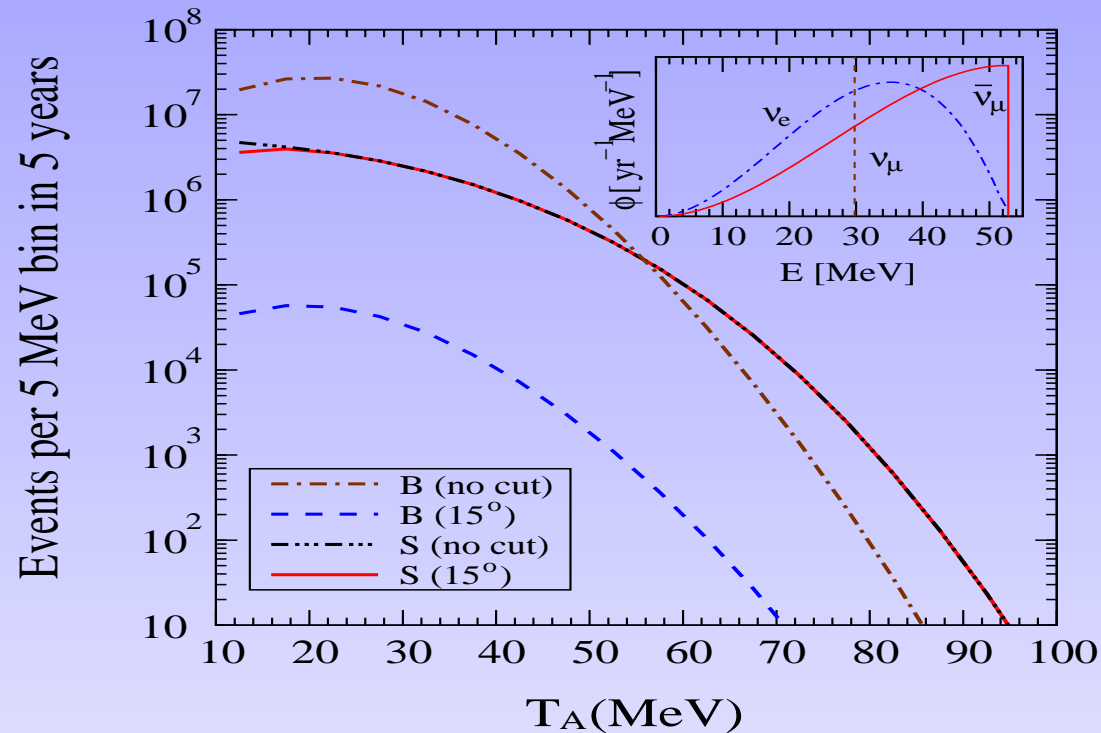
<http://www.lbl.gov/nsd/homestake/>

S. Raby *et al.*, arXiv:0810.4551 [hep-ph]

- Neutrino source is in the middle between the two detector modules so that both the detector volumes will receive the same amount of neutrino flux
- Average distance of the each detector module from the source is 54 m
- Incoming ν_e , ν_μ and $\bar{\nu}_\mu$ will scatter with the electrons inside the detector and we will measure the kinetic energy and the direction of the recoil electron.

Events

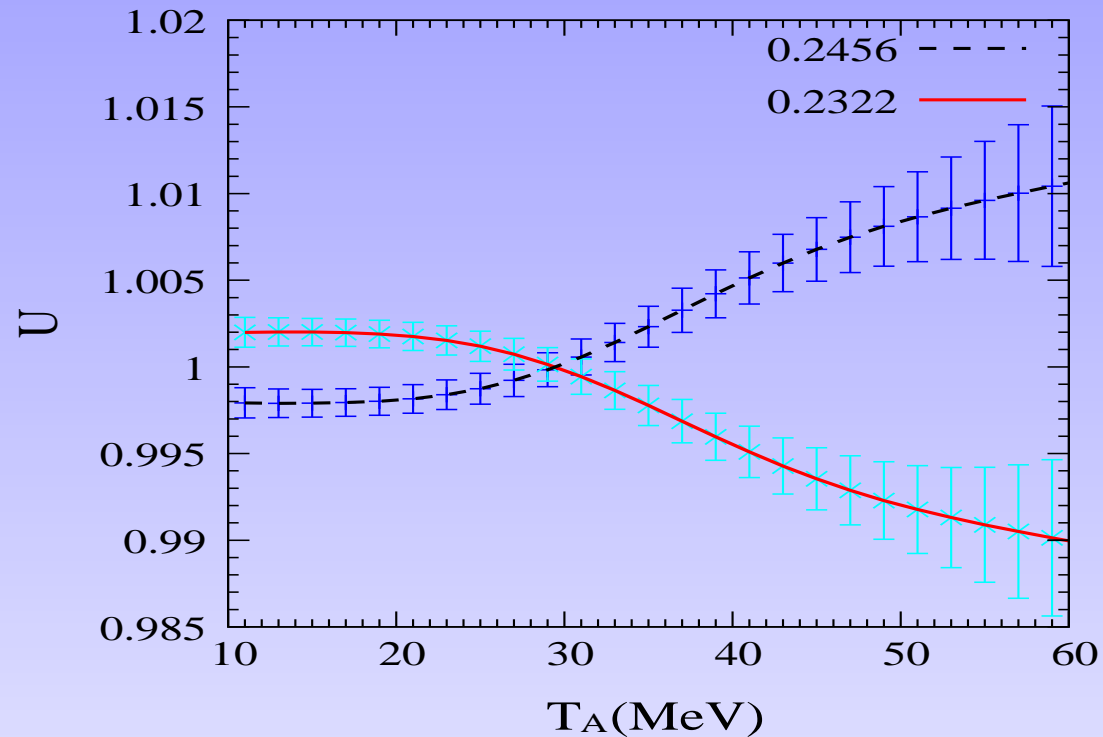
We have 20 million signal events



The neutrino-electron scattering events in 5 years with 2 cyclotrons as a function of T_A . The expected background events from CC ν_e -Oxygen reaction are also shown

Shape Effect

Measuring $\sin^2 \theta_W$ using its shape dependence



$$U = \frac{N_i(\sin^2 \theta_W)}{\hat{N}_i(\sin^2 \hat{\theta}_W)} \frac{\sum_{i=1}^n \hat{N}_i(\sin^2 \hat{\theta}_W)}{\sum_{i=1}^n N_i(\sin^2 \theta_W)}$$

$\sin^2 \hat{\theta}_W = 0.23863$, corresponds to the value measured at the Z-pole evolved down to $Q = 0.03$ GeV in \overline{MS} scheme

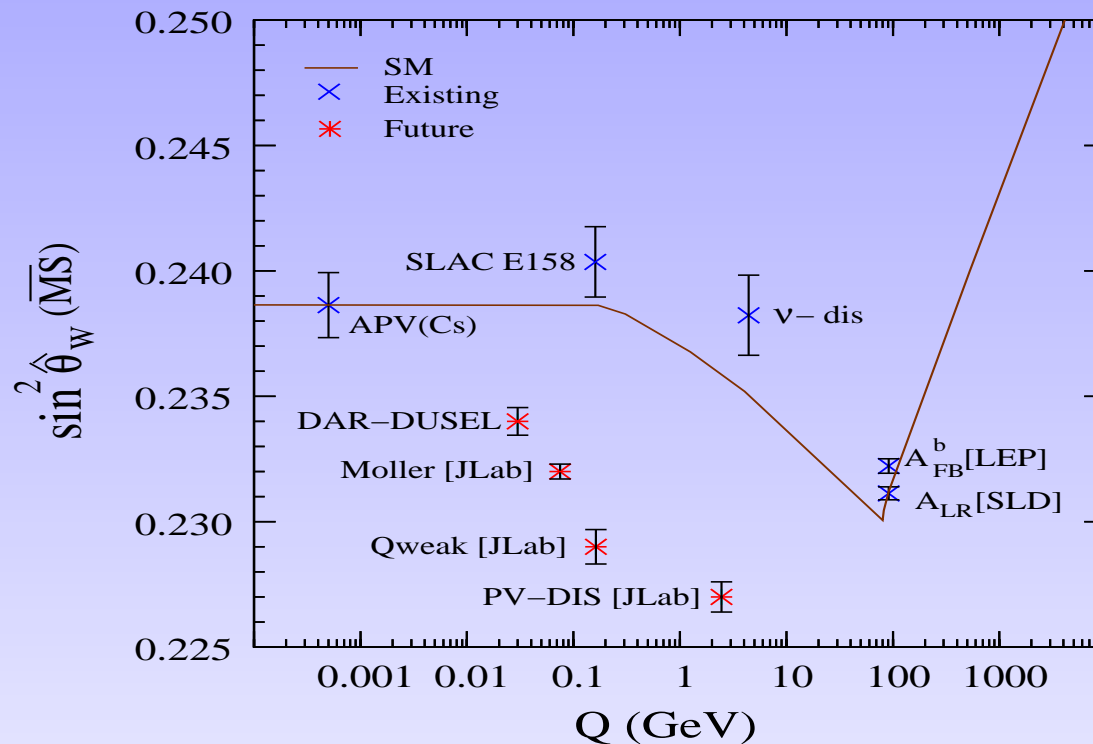
Results

θ	S	B	S/B	rel. error on $\sin^2 \theta_W$
no cut	21.2×10^6	122×10^6	0.17	0.57%
30°	21.2×10^6	1.4×10^6	15	0.25%
15°	19.8×10^6	0.26×10^6	78	0.24%

Expected number of signal and background events with and without angular cut have been given in second and third column respectively. The relative, 1σ , error in measuring $\sin^2 \theta_W$ is quoted in the last column

DAR-DUSEL

Our proposed experiment will provide a $\simeq 0.24\%$ measurement of $\sin^2 \theta_W$



This configuration can be a natural part of the proposed physics program for DUSEL