Neutrino-electron scattering Project X

Richard Imlay
University of Virginia

June 4,2012

Topics

- Neutrino magnetic moment
- Weak mixing angle $\sin^2(\theta_w)$ at low Q^2
- Neutrino Flux Calibration

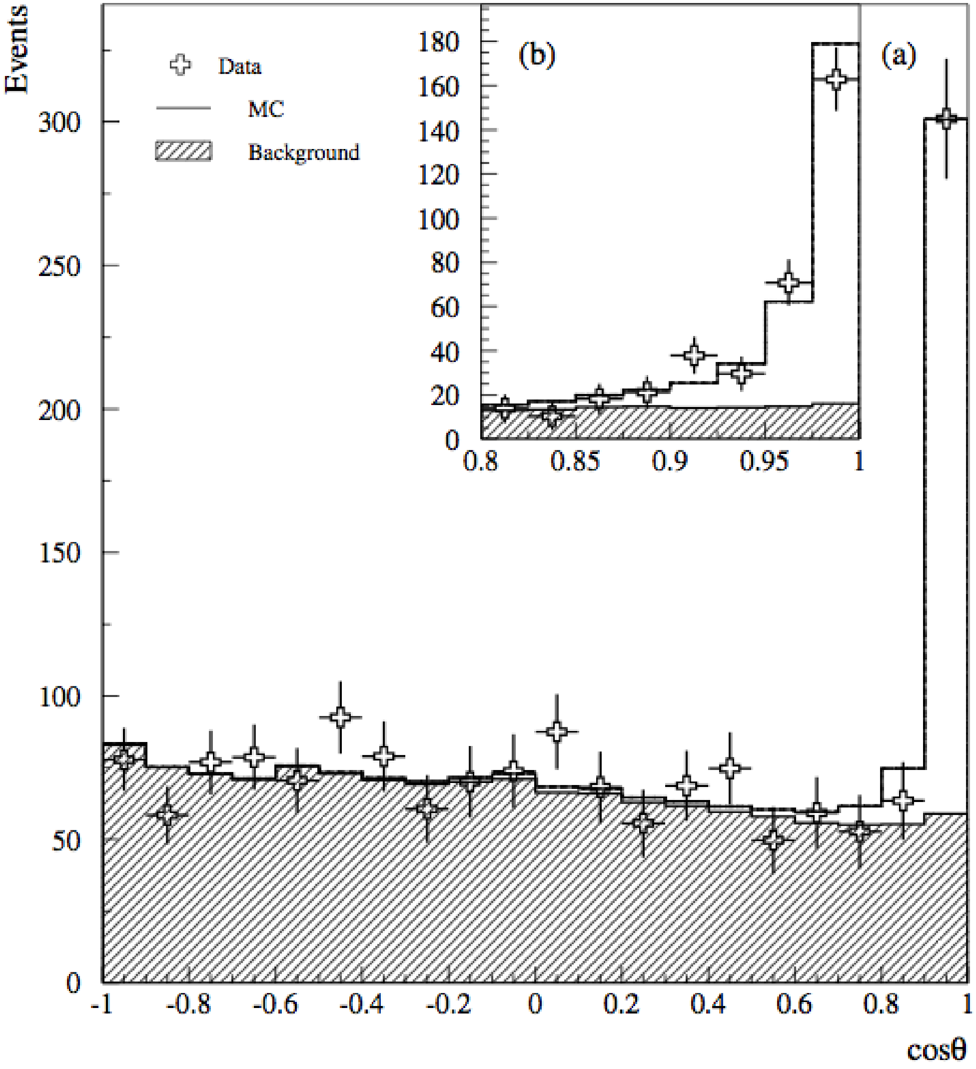
Neutrino Magnetic moment

- In minimally extended SM with Dirac Neutrinos expect less then 10^{-19} Bohr Magnetons.
- Majorana neutrino transition moments or right-handed weak currents could enhance to experimentally relevant ranges.

Neutrino Magnetic Moment

- Present limit for v_{μ} is $6.8*10^{-10}$ Bohr Magnetons. LSND PRD 63,112001
- Present limit for v_e is $0.5*10^{-10}$ Bohr Magnetons. Borexino PRL 101, 091302
- Neutrino mixing complicates interpretation of the limits. Could be Dirac or Majorana
- Because of mixing v_{μ} limit may not be very useful if it is much worse then v_e limit

LSND


Events
Data
MC
Background
(a)
(b)
0
50
100
150
200
250
300
-1
-0.8
-0.6
-0.4
-0.2
0
0.2
0.4
0.6
0.8
1
cosθ
0
20
40
60
80
100
120
140
160
180
0.8
0.85
0.9
0.95
1

ν_μ magnetic moment

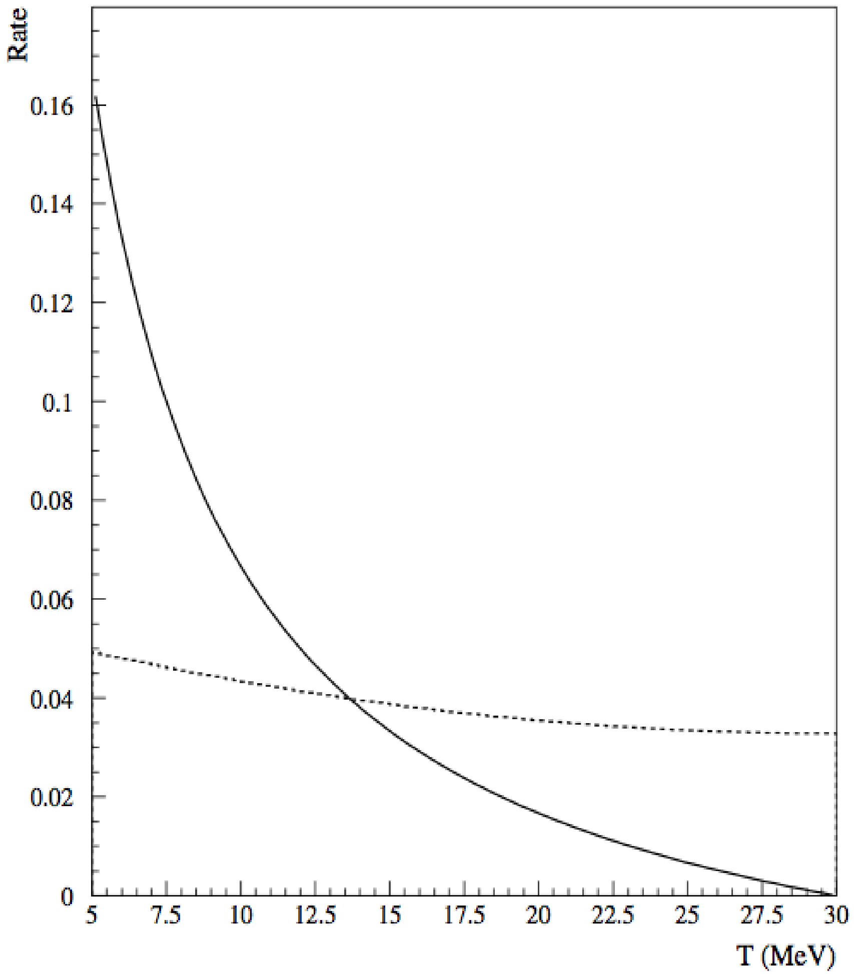
- At low electron energy, T_e, the magnetic moment cross section is given by $d\sigma^M/dT_e = f^2 * 2.5 * 10^{-25}\ \mathrm{cm}^2/T_e$ for $T_e << E_\nu$ where f = magnetic moment in electron Bohr magnetons
- Because of $1/T_e$ factor want to look at as low an electron energy as possible

Standard model cross section

- For v_μ $d\sigma^{SM}/dT_{e\,=}= 22*10^{-46}cm^2/MeV$ for $T_e<<E_v$

- In the SM the number of elastic scattering events at low T_e measures the total flux for a beam like the LBNE v_μ beam up to calculable corrections. This assumes no magnetic moment contribution.

Electron Energy



Neutrino Magnetic Moment

- Ratio of magnetic to SM cross section for $T_e << E_v$ is given by $d\sigma^M/dT_e \,/\, d\sigma^{SM}/dT_e = 1.1*10^{20}f^2/T_e$
- So event rates and ratio at low T_e depend on total neutrino flux. The shape is not important as long as $T_e << E_v$

Neutrino Magnetic Moment

- Experiments at high intensity proton sources might reach f = 10^{-10}.
- At T_e = 15 MeV and f = 10^{-10} have $d\sigma^M/dT_e$ / $d\sigma^{SM}/dT_e$ = 0.07
- MiniBooNE set limit < $10*10^{-10}$ Bohr Magnetons for $5*10^{20}$ POT. The number of electron scattering events in the final sample was low(~5 events) because ~500 m downstream of target.

Neutrino Magnetic Moment-miniBooNE

- Selected electrons T_e > 15 MeV.
- Cosmic ray background below 50 MeV was handled by rejecting past time muons.
- Below 15 MeV have large Boron 12 beta decay background in carbon target.
- Use angle cut and electron ID

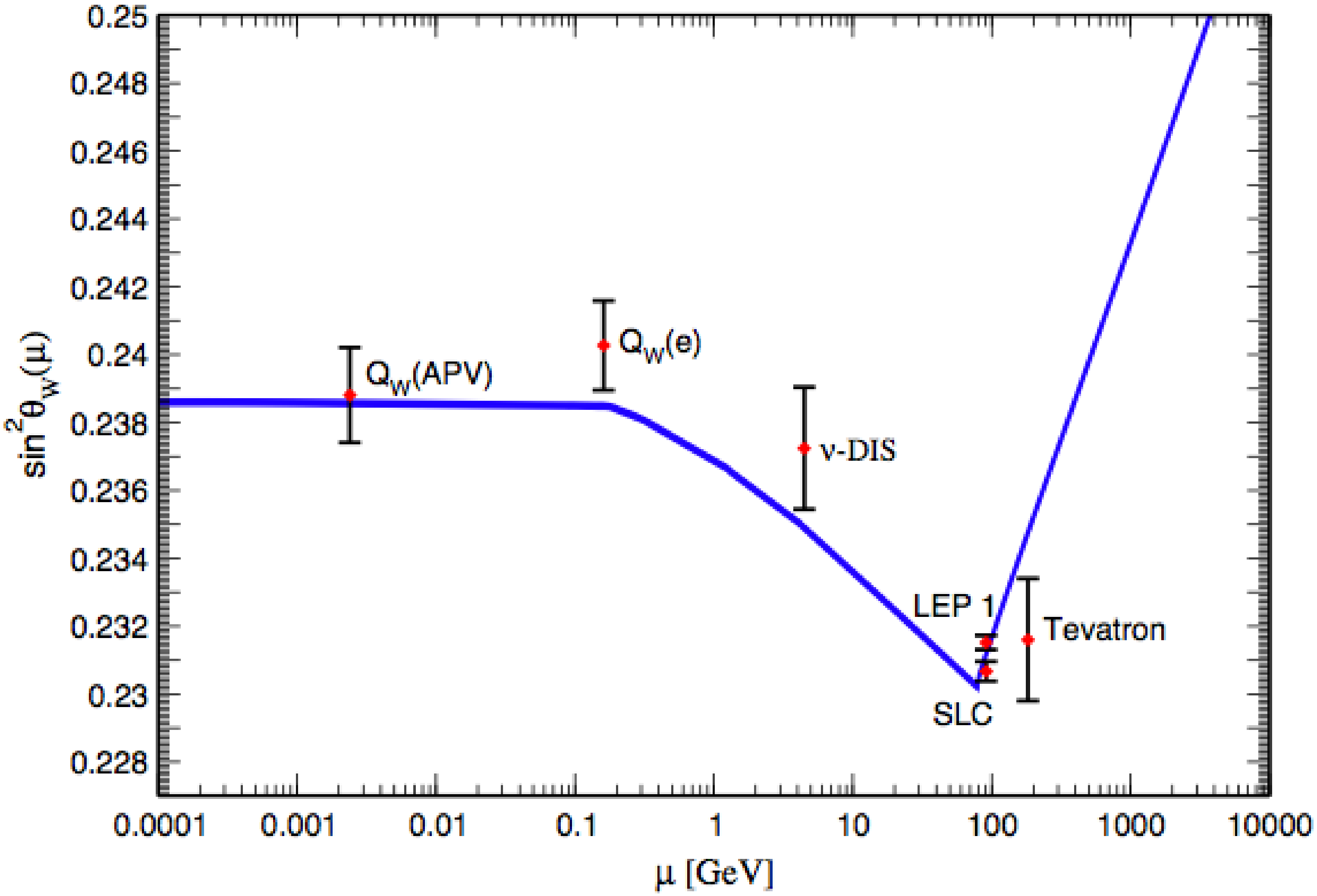
Magnetic Moment Future Experiments

- Need to do better then MiniBooNE.
- Cosmic ray background drops compared to signal with higher neutrino flux, better beam spill or location underground.
- Beam background is very detector specific. It may be limiting factor in sensitivity. Angular resolution very important.
- Could also reach f= 10^{-10} with stopped π^+ neutrino beam

Weak mixing angle at low Q^2

- Running with Q^2 of $\sin^2\theta_w$.
- Present low Q^2 limit ~0.5% from parity violation asymmetry experiment.
- LBNE near detector report- get similarly sensitivity at fairly low Q^2.

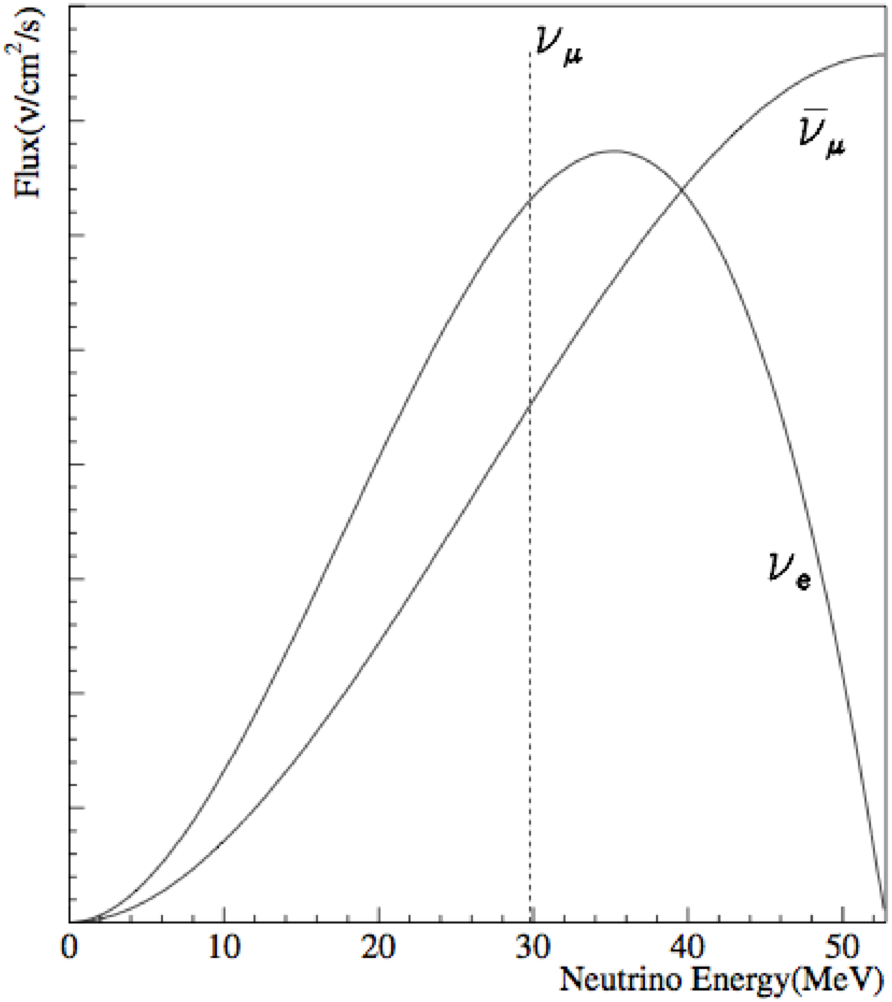
PDG 2010

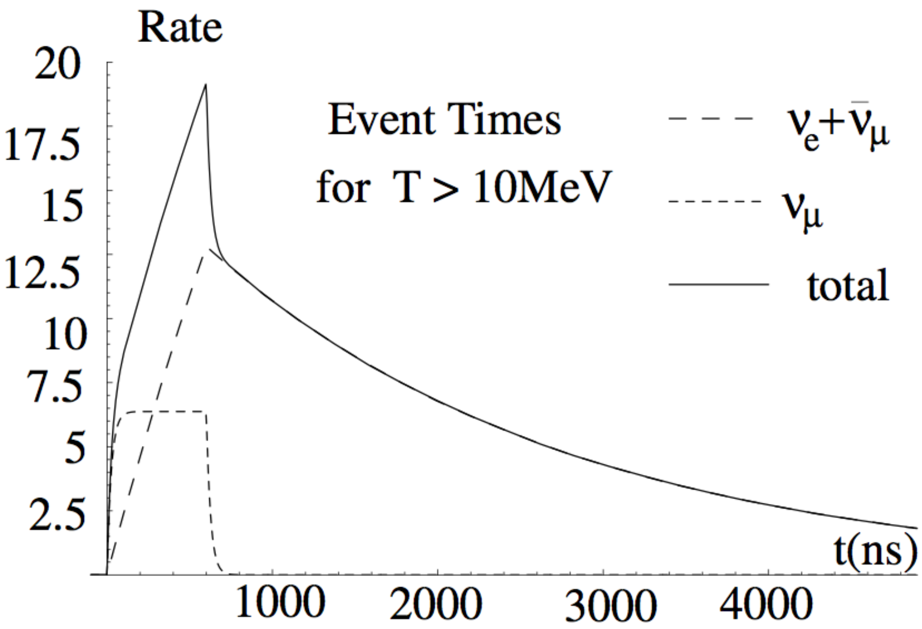

0.25
0.248
0.246
0.244
0.242
0.24
0.238
0.236
0.234
0.232
0.23
0.228
$\sin^2\theta_W(\mu)$
0.0001
0.001
0.01
0.1
1
10
100
1000
10000
μ [GeV]
Q_W(APV)
Q_W(e)
ν-DIS
LEP 1
SLC
Tevatron

Stopped Pion Source

- Could get another low Q^2 measurement with a stopped pion neutrino source.
- Use high Z, high density target to minimize π^- decay in flight background.
- Put detector ~90 degrees to minimize μ^- decay in flight background.

Stopped Pion Beam





Weak mixing angle at low Q^2

- Get mostly v_e and $v_\mu$bar from μ^+ decay with 2.2 μs lifetime and v_μ from π^+ decay with 26 ns lifetime.
- The ratio $R = \sigma(v_\mu e)/[\sigma(v_e e) + \sigma(v_\mu\text{bar-}e)] =(0.75-3\sin^2\theta_w+4\sin^4\theta_w)/(1+2\sin^2\theta_w +8\sin^4\theta_w)$

Weak mixing angle at low Q^2

- See J.Phys. G. Nucl. Part.Phys. 29(2003) 2647-2664 for design for SNS
- Measure R to 2-3% for 600 ns spill and $\sin^2\theta_w$ to 1 to 2% in oil or water detector.
- Might do factor of 2 better with 200 ns spill.

Weak mixing angle at low Q^2

- A stopped pion experiment is also of interest because:
- The elastic scattering of v_e on e is one of very few reactions that has a large destructive interference between CC and NC channels
- Can set limits on the electron-neutrino charge radius.

Flux Calibration

- For v_μ $d\sigma^{SM}/dT_e$= $12.8*10^{-46}cm^2/MeV[1+0.73(1-T_e/E_v)^2]$
- $Cos\theta =(1+m_e/E_v)/(1+2m_e/T_e)^{0.5}$
- For a given neutrino flux shape the shape of the electron energy spectrum is completely determined.

Flux Calibration

- In principle, a perfectly known electron spectrum determines the neutrino spectrum.
- But in practice this does not work in a simple way.
- Electrons of a given energy have comparably contributions from all neutrinos with $E_v > T_e$.

Flux Calibration

- This is particularly bad at the lower end of the spectrum where the difference between the number of events in adjacent T_e bins provides information on the neutrino flux in that region but with huge statistical errors.
- Extreme case: the lowest energy electrons measure the total flux as discussed before. Have approximately equal contributions from the full spectrum.

Flux Calibration

- Do much better on the upper part of the neutrino spectrum.
- For example may be able to measure the high energy tail of LBNE fairly well if have clean elastic scattering sample.

Flux Calibration

- Need to include radiation corrections.
- Need to include information on ν_e contribution and wrong sign contribution.
- The number of ν_e from muon decay are tightly constrained by the number of ν_μ from π^+ decay. Need to include ν_e from kaon decay.
- For anti-neutrino running have a large wrong sign contribution.

Wrong Sign Contribution

- Want a good determination of wrong sign flux.
- For reference- MiniBooNE determined WS flux to 13% of its value using two methods: $CC\pi^+$ and μ^- capture.
- An experiment like LBNE could determine the WS flux in the near detector much better in several different ways.
- This is a discussion for another time.

Flux Shape

- Here is some guess work on how one might better determine the flux shape using the electron energy shape.
- Start with the simulated neutrino flux in energy bins with flux shape error matrix. The simulated spectrum will have strong correlations between adjacent energy bins.

Flux shape

- Do a fit to the electron energy distribution varying the flux shape as allowed by the flux shape correlated error matrix.
- The T_e distribution will help determine the relative flux for E_v bins far apart.
- As discussed before the T_e distribution will help more with the higher part of the E_v spectrum then the lower part.

Conclusions

- Can improve limit on v_μ magnetic moment significantly. Unlikely to detect a signal and so this can’t be the main motivation for an experiment.
- Can measure $\sin^2\theta_W$ at low Q^2 with comparably sensitivity to present Parity violating asymmetry experiments.
- Can measure flux normalization to 1-2% and in conjunction with the simulated flux and its errors improve on the flux shape.