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NuFact 2003

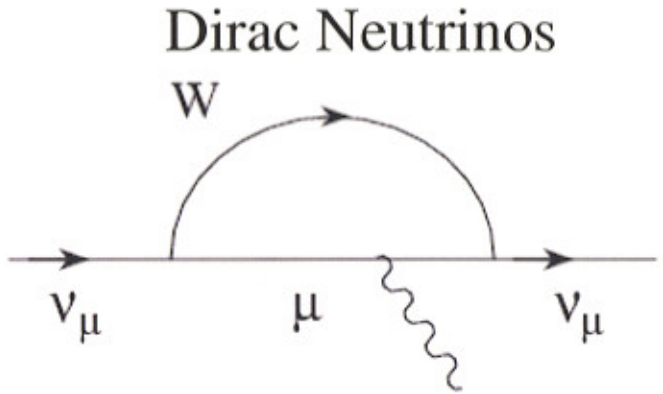
Neutrino Magnetic Moments: Measurements and predictions from the Standard Model and astrophysics

- Neutrino magnetic moments in beyond the Standard Model theories
- Predictions from Astrophysics
- Limits and upcoming measurements
- Next generation measurements

How does a neutrino magnetic moment (NMM) arise?

Minimally extended Standard Model:

Massive neutrinos can have a magnetic moment via one-loop radiative corrections



Neutrinos of mass m_ν:

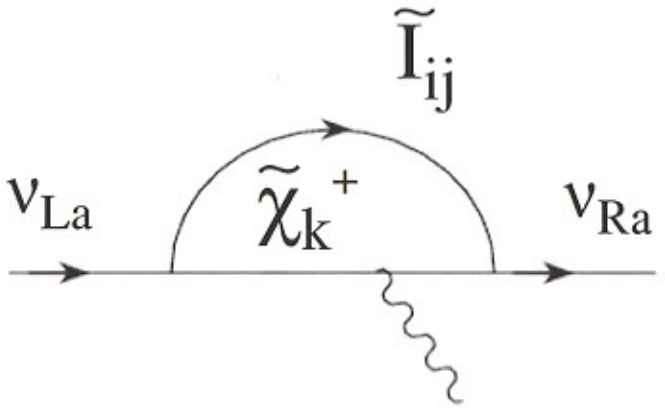
$$\mu_\nu = \frac{3eG_F}{8\sqrt{2}\,\pi^2}\, m_\nu \sim 3 \times 10^{-19}\, \mu_B \frac{m_\nu}{1eV}$$

SUSY models

$$\mu_{\nu_e} \cong 10^{-15} - 10^{-16}\mu_B$$

$$\mu_{\nu_\mu} \cong 10^{-12} - 10^{-13}\mu_B$$

$$\mu_{\nu_\tau} \cong 10^{-12}\mu_B$$



Large Extra Dimensions

$$\mu_\nu \cong 10^{-11}\mu_B$$

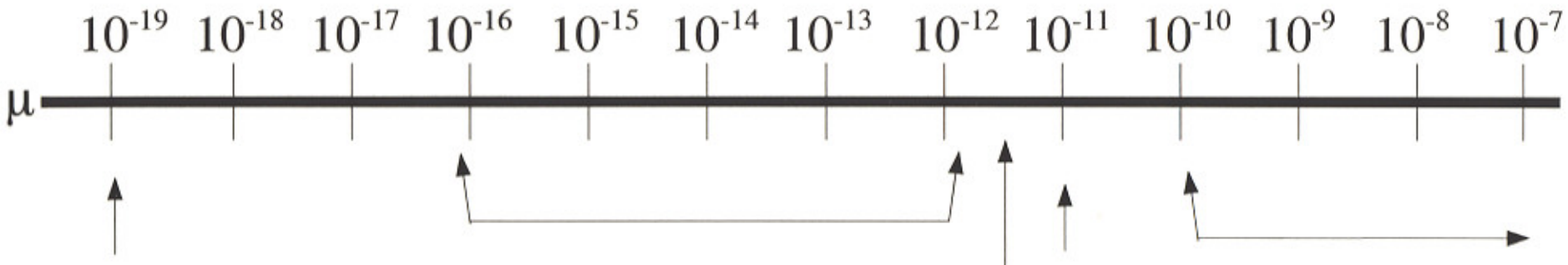
Neutrino magnetic moments $\rightarrow$ indicator of which beyond the Standard model physics

→ *Astrophysical limits*

- slow rate of plasmon decay in horizontal branching stars
  → $\mu_\nu < 10^{-11}\mu_B$
- neutrino energy loss rate from supernova 1987a
  → $\mu_\nu < 10^{-12}\mu_B$

⋆ model assumptions made in these cases

Neutrino magnetic moments → indicator of what astrophysics



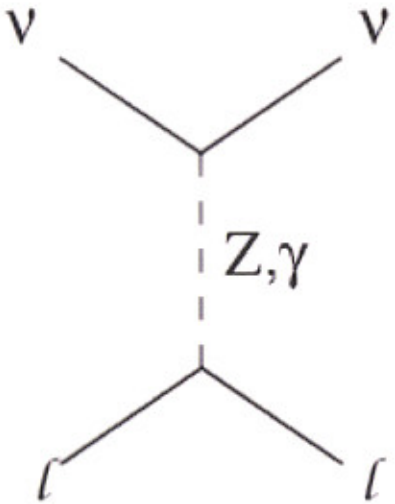
Minimally extended Standard Model

SUSY

Extra Dimensions

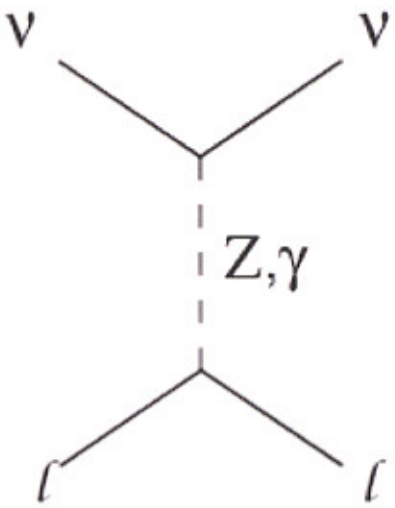
Astophysical Limits

Limits from Experiments



Experimental limits set by measuring νe elastic scattering

Can look for excess of νe elastic cross section.....



$$\sigma_{EM} = \frac{\pi\alpha^2\mu_\nu^2}{m_e^2}\left[\frac{E_e}{E_\nu} - \ln\frac{E_e}{E_\nu} - 1\right]$$

sensitivity depends on

$$\left(\frac{\Delta\sigma}{\sigma}\right)^2 = \left(\frac{\Delta N}{N}\right)^2 + \left(\frac{\Delta F}{F}\right)^2$$

increase in
overall cross section

$\sigma_{tot} = \sigma_{weak} + \sigma_{EM}$

flux error a big issue!

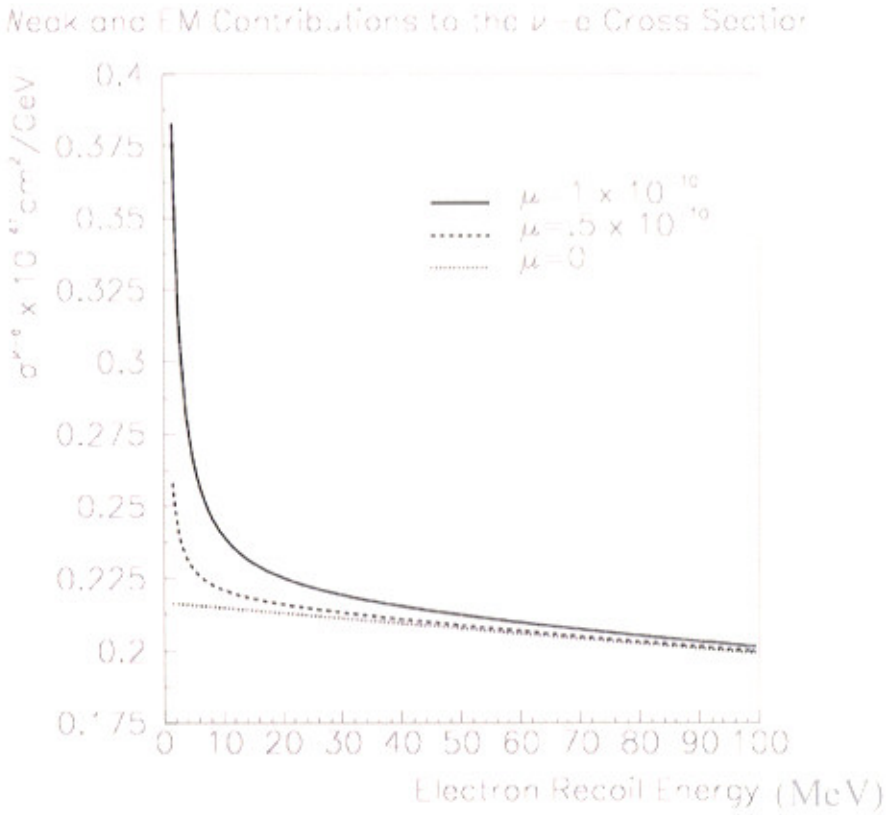
Avoid flux error by measuring differential cross section!

$$\frac{d\sigma^{weak}}{dT} = \frac{2m_e G_F^2}{\pi}\left[g_L^2 + g_R^2\left(1-\frac{T}{E_\nu}\right)^2 - \frac{m_e}{E_\nu} g_R g_L \frac{T}{E_\nu}\right]$$

$$\frac{d\sigma^{EM}}{dT} = \frac{\pi\alpha^2\mu_\nu^2}{m_e^2}\left(\frac{1}{T}-\frac{1}{E_\nu}\right)$$

where T=electron recoil energy

E_ν= Neutrino energy



shape change in the differential cross section

no flux error!

Limits set from previous experiments

→ Electron neutrino magnetic moment

$$\mu_{\nu_e} \leq 1.5\text{-}1.8 \times 10^{-10}\ \mu_B$$

- Super K data: shape fit to recoil electron spectrum
- reactor experiments: combined measurements

Future experiments plan to measure μ_{ν_e} to ~ 10^{-12}

tritium ν experiments well understood energy spectrum endpoint

→ Muon n magnetic moment

$$\mu_{\nu_\mu} \leq 6.8 \times 10^{-10}\ \mu_B$$

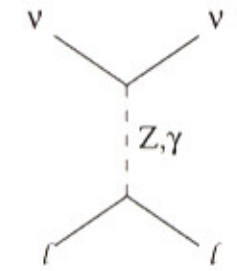
- LSND experiment: combine measurement for electron and muon neutrino magnetic moments using total $\nu_{e,\mu}$ - e elastic cross section

→ Tau neutrino magnetic moment

$$\mu_{\nu_\tau} \leq 5.4 \times 10\text{-}7\ \mu_B$$

Experimental challenges and signatures:

- measuring electron recoil
  the lower the better!
- high statistics
  νe elastic cross section is small



clean signature!

↓

νe elastic scatters are very forward

easy to separate from most backgrounds

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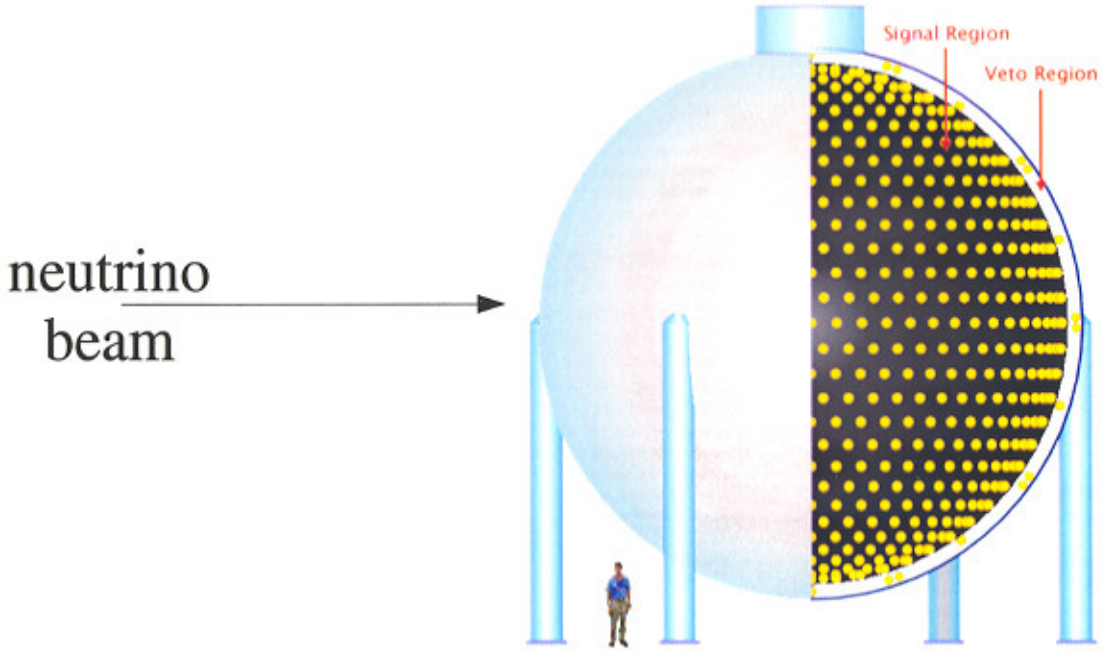
- beam timing cuts
- forward cone cut
- ^{12}B -- energy cut

MiniBooNE Detector



MiniBooNE's sensitivity depends on threshold for detection of recoil electrons and number of νe elastic scatters

for 100 νe elastic scatters with electron recoils from 10-1000 MeV

Determining Sensitivity

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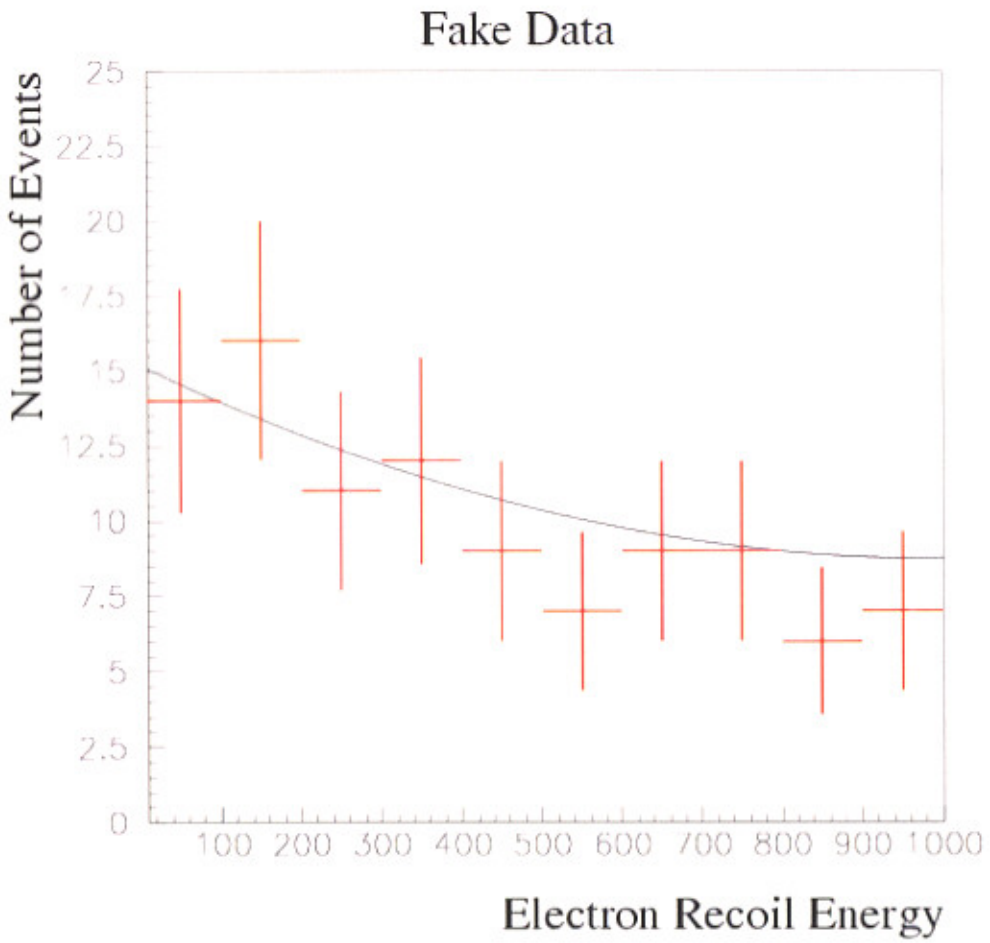
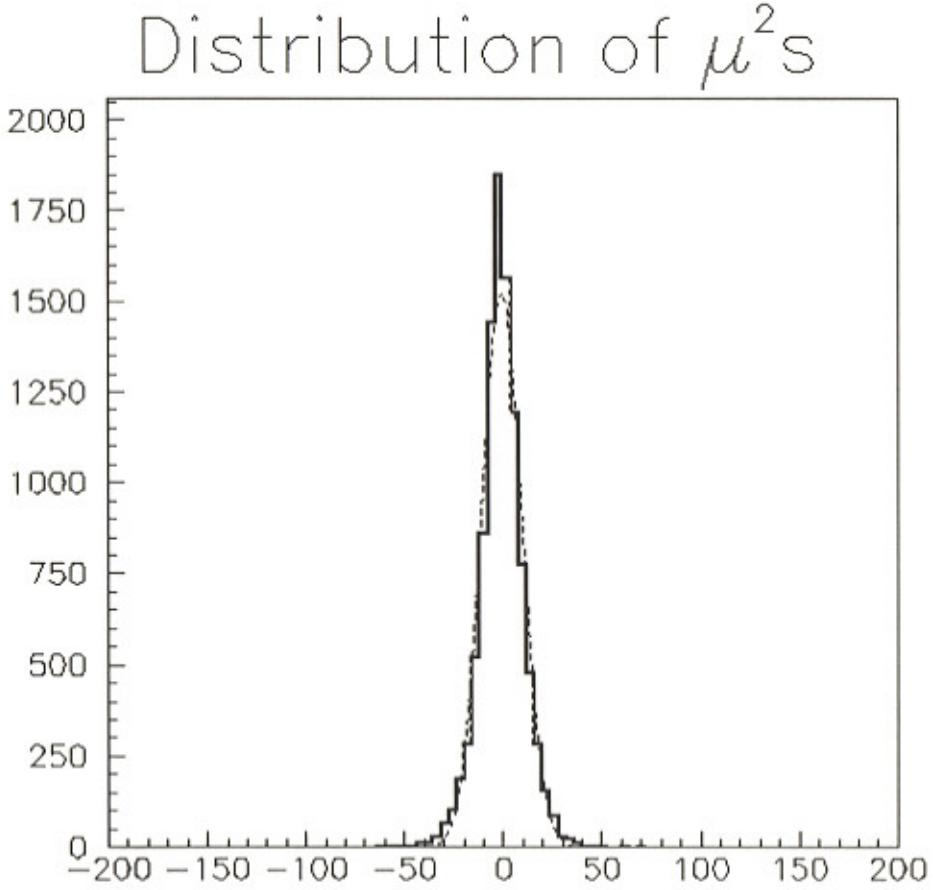
throw fake data against the weak cross section

fit to weak + EM
fit parameters:
magnetic moment, μ
Normalization -- flux

repeat many times!



MiniBooNE sensitivity for 5 x 10^{20} pot



fitted values of $\mu_{\nu\mu}$ for 10,000 fake data experiments

↓

sensitivity:

$\mu_{\nu\mu} = 3.2 \times 10^{-10} \mu_B$

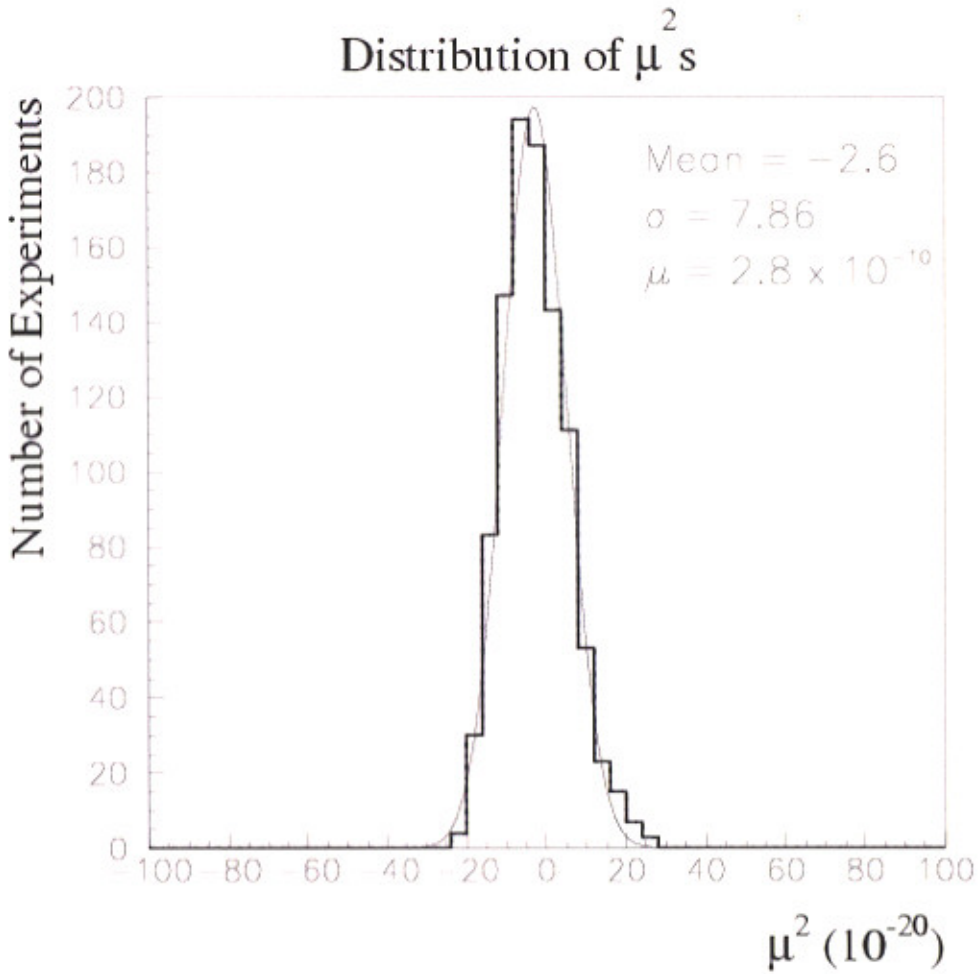
Can we improve on this?

- lower electron recoil
  - finely segmented detectors
  - liquid argon TPCs
    - → few GeV

- higher statistics
  - neutrino superbeams
  - neutrino factories

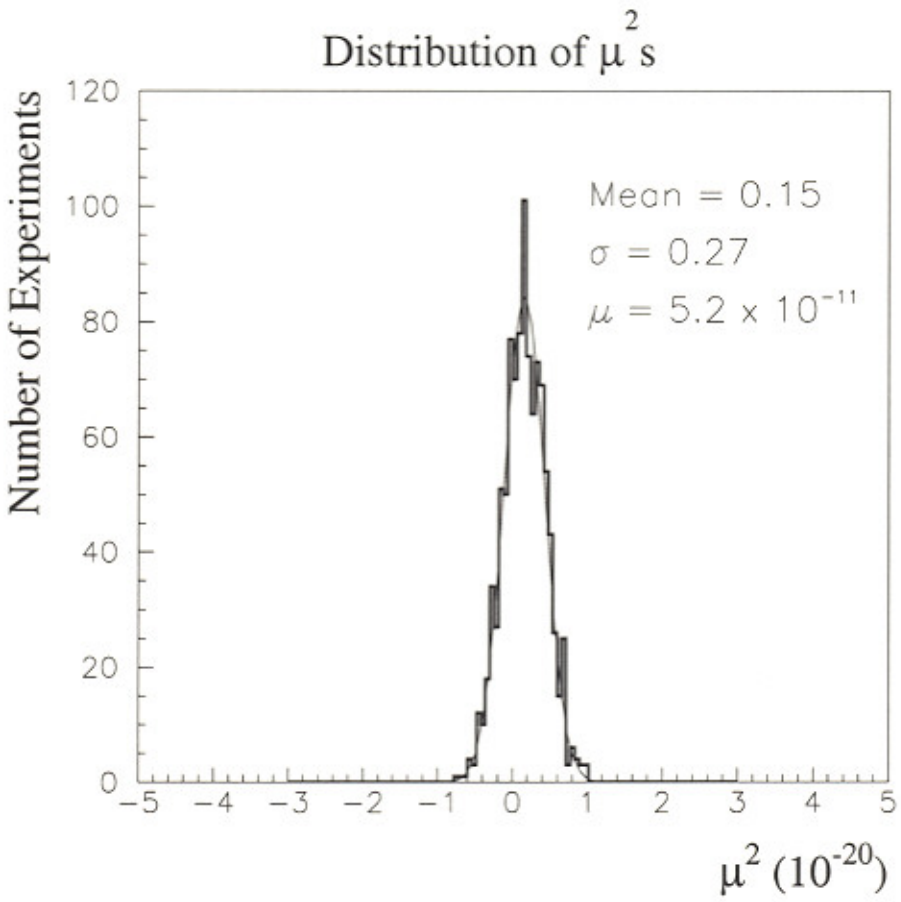
ν_μs *and* ν_es

MiniBooNE upgraded to reduce electron recoil to 1 MeV with 300 events



at a superbeam facility[1]

15000 $\nu - e$ events with $E_\nu = 1$ GeV
1 MeV $< T_e <$ 1000MeV

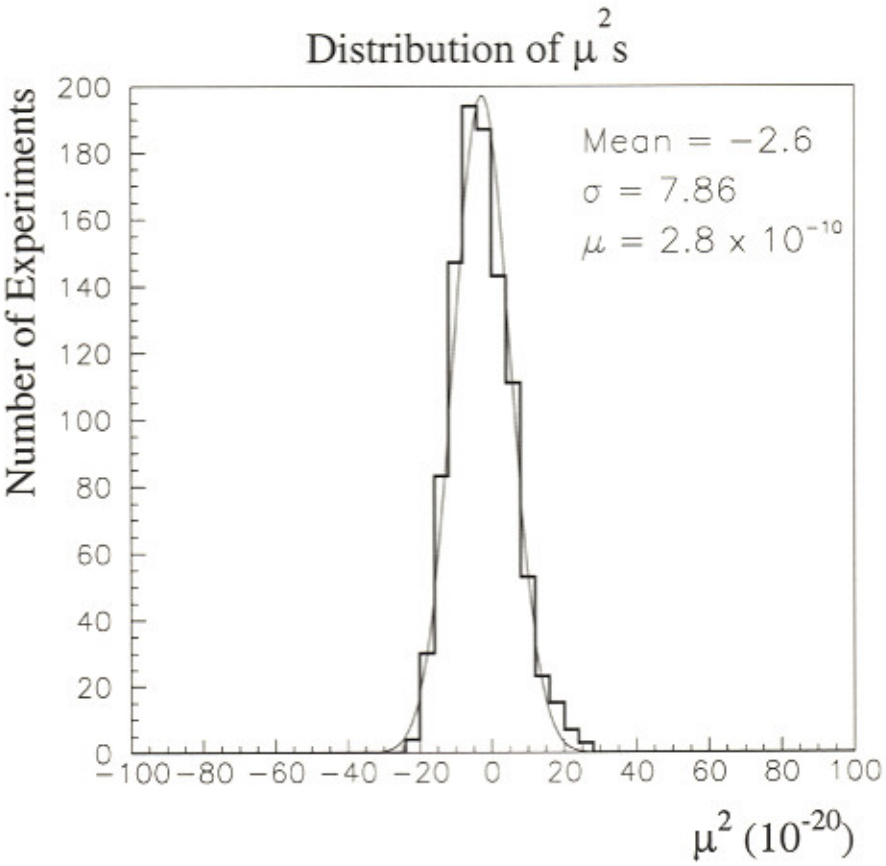


Sensitivity: $\mu_{\nu_\mu} < 5.2 \times 10^{-11} \mu_B$

[1] C. Ankenbrandt et. al., "Physics study group report on physics potential at FNAL with stronger proton sources," in preparation, http://projects.fnal.gov/protondriver/

Neutrino magnetic moment measurements at an upgrade to MiniBooNE

300 $\nu - e$ events with $E_\nu = 1$ GeV
1 MeV $< T_e <$ 1000MeV



Sensitivity: $\mu_{\nu_\mu} < 2.8 \times 10^{-10} \mu_B$

Conclusions

- Neutrino magnetic moments can point us toward
  - which beyond the SM physics
  - what astrophysics

- With neutrino superbeams and high precision detectors -- into interesting region!