

NuTeV and Precision Electroweak Measurements

Outline

1. 30 Anomalies (SM cracks?)

i) $\sin^2 \theta_W(M_Z)_{MS}$: $A_{LR}^{e^+e^-}$ vs $A_{FB}^{b\bar{b}}$

ii) π_W : $\pi_W(e^+e^-, p\bar{p})$ vs $R_{\nu} = \sigma(\nu_\mu N \rightarrow \nu_\mu X) / \sigma(\nu_\mu N \rightarrow \mu X)$

iii) a_μ^{exp} vs a_μ^{SM} ($e^+e^- \rightarrow \text{hadrons}$)

2. NuTeV Comments

* i) Radiative Corrections (Questions?) Large & Important

ii) Parton Distributions: $U \neq D, S \neq \bar{S}$ } see: Davidson, Forte,
Gambino, Riaz,
Strumia

iii) "New Physics"

3. Hadronic Vacuum Pol. $\tilde{\Pi}^{\mu\nu}$ ($e^+e^- \rightarrow \text{hadrons}$)

i) $\pi_W \rightarrow R_{LR} \rightarrow \pi_H$ vs a_μ

ii) "Hints" of Supersymmetry

4. Outlook (& Comments)

1. 3σ Anomalies

We now have many precision measurements → ±0.1%!
 SM loop effects observed! $m_t \approx 175 \text{ GeV}$ required!

→ $m_H \approx 90_{-35}^{+57} \text{ GeV}$ < 210 GeV (95% CL)

LEP II $m_H > 114 \text{ GeV}$

SUSY $m_H \lesssim 130 \text{ GeV}$

} Narrow Window

But, SM global fit is not so good!

i) $\sin^2 \theta_W(m_Z)_{\overline{MS}}$

$\sin^2 \theta_W(m_Z)_{\overline{MS}} = 0.23084(20)$ $A_{LR}, A_{FB}^{\ell\ell}$ (low) } 3.6σ
 $\sin^2 \theta_W(m_Z)_{\overline{MS}} = 0.23210(29)$ $A_{FB}^{b\bar{b}}$ (high)

Average is fine!

ii) W^\pm Mass

$m_W = 80.451(33) \text{ GeV}$ direct $e^+e^-, p\bar{p}$ (high)
 $m_W = 80.140(80) \text{ GeV}$ NuTeV $\sin^2 \theta_W = 1 - m_W^2/m_Z^2$ (low)

iii) $a_\mu^{\text{exp}} = 116592030(80) \times 10^{-11}$
 $a_\mu^{\text{SM}} = 116591691(70)(35)(4) \times 10^{-11}$



($e^+e^- \rightarrow$ hadrons data!)
 main uncertainty

$a_{\mu}^{exp} - a_{\mu}^{SM} = 339 \pm 112 \times 10^{-11}$ (30) Large Deviation

If $\gamma \rightarrow \nu_{\mu} \pi \pi^0$ is used near ρ (< 1.76eV) + isospin corr.
 m_{ρ} increases:

$a_{\mu}^{exp} - a_{\mu}^{SM} = 167 \pm 107 \times 10^{-11}$ (1.6 σ)

Note, different m_{ρ} change m_H by $\approx 18\%$! from precision $\sin^2 \theta_W(m_Z, \bar{m}_S, m_W, \dots)$
 $e^+e^- \rightarrow$ larger m_H
 $\gamma \rightarrow$ smaller $m_H \rightarrow$ SM Conflict!

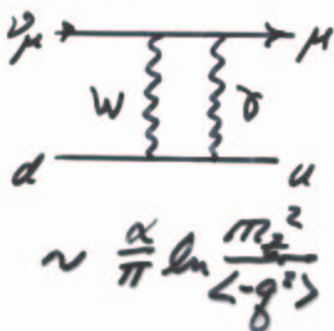
2. NuTeV Comments

$\sin^2 \theta_W \equiv 1 - m_W^2 / m_Z^2 = 0.2277 \pm 0.0013 \pm 0.0009$ (NuTeV) } 3.6 σ
 vs. 0.2216 ± 0.0006 direct $m_W + m_Z$

$R_{\nu} \equiv \frac{\sigma(\nu_{\mu} N \rightarrow \nu_{\mu} X)}{\sigma(\nu_{\mu} N \rightarrow \mu^- X)} \rightarrow \sin^2 \theta_W$ $R_{\nu} \rightarrow$ charm thresh.

i) Radiative Corrections (R. Sirlin + W.M. 1981) } History of SUL5

Large corrections to $\nu_{\mu} N \rightarrow \mu^- X$ ($\bar{\nu}_{\mu} N$)
Reduce value of $\sin^2 \theta_W$ extracted from R_{ν} ($\sim -5\%$)



$\delta \sin^2 \theta_W = \underline{-0.0090}$ large (clear) ~~modification~~

Other final state effects?
 Unlikely

Cuts: $E_{\text{hadron}} > 20 \text{ GeV}$ (Significant)

Effect of cut very different with rad. corr. (spectrum of μ^-)
 $\epsilon < y < 1$ $\epsilon \approx 0.1 - 0.2$ changes

(Was that difference included?)

Bardin Code used by NuTeV for R.C.

We found (in 1991) $\delta \sin^2 \theta_W \approx -0.004$ { About the size ($\frac{2}{3}$)
of deviation

Isospin Violation QED $\rightarrow U \neq D$ (Cancellation in R_2 , partial)

One finds $\delta \sin^2 \theta_W \approx -0.0010 \approx \left(\frac{\alpha}{\pi} \ln \frac{\langle -g^2 \rangle}{m_g^2} \right)$
very uncertain
QCD

NuTeV has total unc. from R.C. $\delta S^2 \approx \pm 0.0001$ too small

Main question: were all such effects included via Bardin?
(probably, but?)

ii) Parton Distributions $U \neq D, S \neq \bar{S}, \text{EMC} \dots$

No Smoking Gun see Davidson et al.

Appears "Best Bet" for deviation, But not obviously true


iii) "New Physics" Z' (very light), Mixing, ...

or Reduce $Z \nu \bar{\nu}$ coupling by -0.6% (good for $Z \rightarrow \nu \bar{\nu}$)

etc. eg Babu + Pati

3. Hadronic Vacuum Pol. $\gamma \text{ } \textcircled{\text{hadrons}} \text{ } \gamma$

$\text{Im } \Pi_{\gamma\gamma}(q^2) \sim \sigma(e^+e^- \rightarrow \text{hadrons})$

enters $a_\mu = \frac{g_\mu^{-2}}{2}$ 

Dominated by $\pi^+\pi^- (\rho, \dots)$

$a_\mu^{\text{Had. (vac. pol.)}} = 6847(60)(36) \times 10^{-11} \text{ } e^+e^- \rightarrow \text{hadrons}$
 $= 7019(47)(12)(38) \times 10^{-11} \text{ } \gamma \rightarrow \gamma + \text{hadrons}$ } *Not Consistent ~ 2.5%*



$\Delta \alpha_{\text{had}}^{(5)}(m_Z)$  $q^2=0 \rightarrow q^2=m_Z^2$

increase by 2.4×10^{-4} for γ data \approx 1% \rightarrow reduced π_H

$\Delta \Gamma(m_Z, m_H, \Delta \alpha) = 1 - \frac{\pi \alpha}{\sqrt{2} G_\mu m_W^2 (1 - m_W^2/m_Z^2)}$

$\Delta \hat{\Gamma}(m_Z, m_H, \Delta \alpha) = 1 - \frac{2\sqrt{2} \pi \alpha}{G_\mu m_Z^2 \sin^2 2\theta_W(m_Z) M_S}$ } *more sensitive to $\Delta \alpha$*

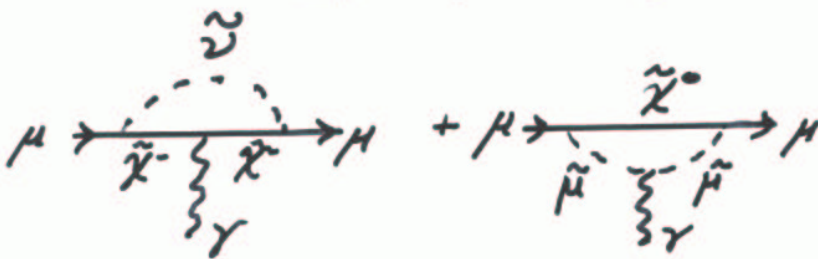
$m_W = 80.451(33) \text{ GeV} \rightarrow m_H \approx 38 \text{ GeV}$ } *For e^+e^- data*
 SLAC A1R $\rightarrow m_H \approx 50 \text{ GeV}$

Reduced by ~16% if γ data used

Reduced by ~32% if all a_μ deviation due to m_W unacceptable!

It seems that either a_μ^{exp} or $m_W, \sin^2 \theta_W(m_Z)_{MS}$ or both are showing signs of "New Physics" (or problems)

Supersymmetry



$$\Delta a_\mu(\text{susy}) \approx (\text{sgn } \mu) \times 130 \times 10^{-11} \left(\frac{100 \text{ GeV}}{m_{\text{susy}}} \right)^2 \tan \beta$$

$$\underline{m_{\text{susy}} \approx 64 \sqrt{\tan \beta} \text{ GeV}} \quad \tan \beta \gtrsim 3-4$$

Alternative susy loops in $\Delta a_\mu + \Delta \tilde{a}_\mu$ ($m_W, m_Z, \sin^2 \theta_W(m_Z)_{MS}$)

eg Altarelli, Caravaglios, Giudice, Gambiro, Ridolfi

light sneutrinos, charged sleptons, gauginos

SUSY may be around the corner

Happy Days for LHC, Linear e^+e^- Collider
Dark Matter ...

4. Outlook + Comments

Detailed accounting of NuTeV Rad. Corr should be given.
(effects of cuts) $R_D, R_{\bar{D}}$

e^+e^- - tau Discrepancy must be resolved!

$a_\mu^{exp} \rightarrow \pm 62 \times 10^{-11}$ Interpretation? (μ data analysis)

KLOE, babar $e^+e^- \rightarrow \underbrace{\pi^+\pi^-}_\rho \gamma$ Radiative Return
soon



Theory: Isospin Violation in e^+e^- vs γ
(Some unaccounted additional effect)?
Lattice Calculation?

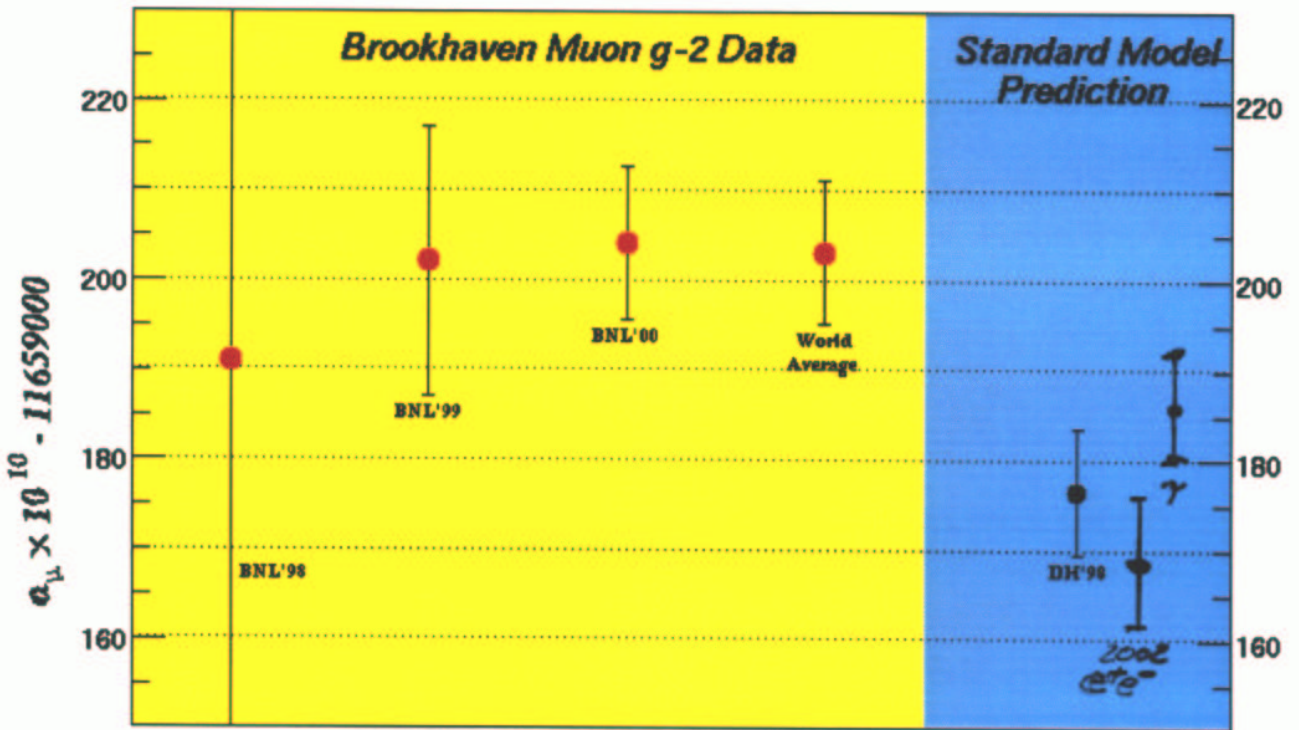
Otherwise Giga Z $R_{LR} \rightarrow \Delta \sin^2 \theta_W (m_Z)_{NS} = \pm 0.00002$

$$\rightarrow \frac{\Delta \pi_H}{\pi_H} \simeq \pm 5\%$$

will carry $\pm 20\%$ $e^+e^- \rightarrow \gamma$ uncertainty!
(cannot be utilized properly)

Time Will Tell

The End



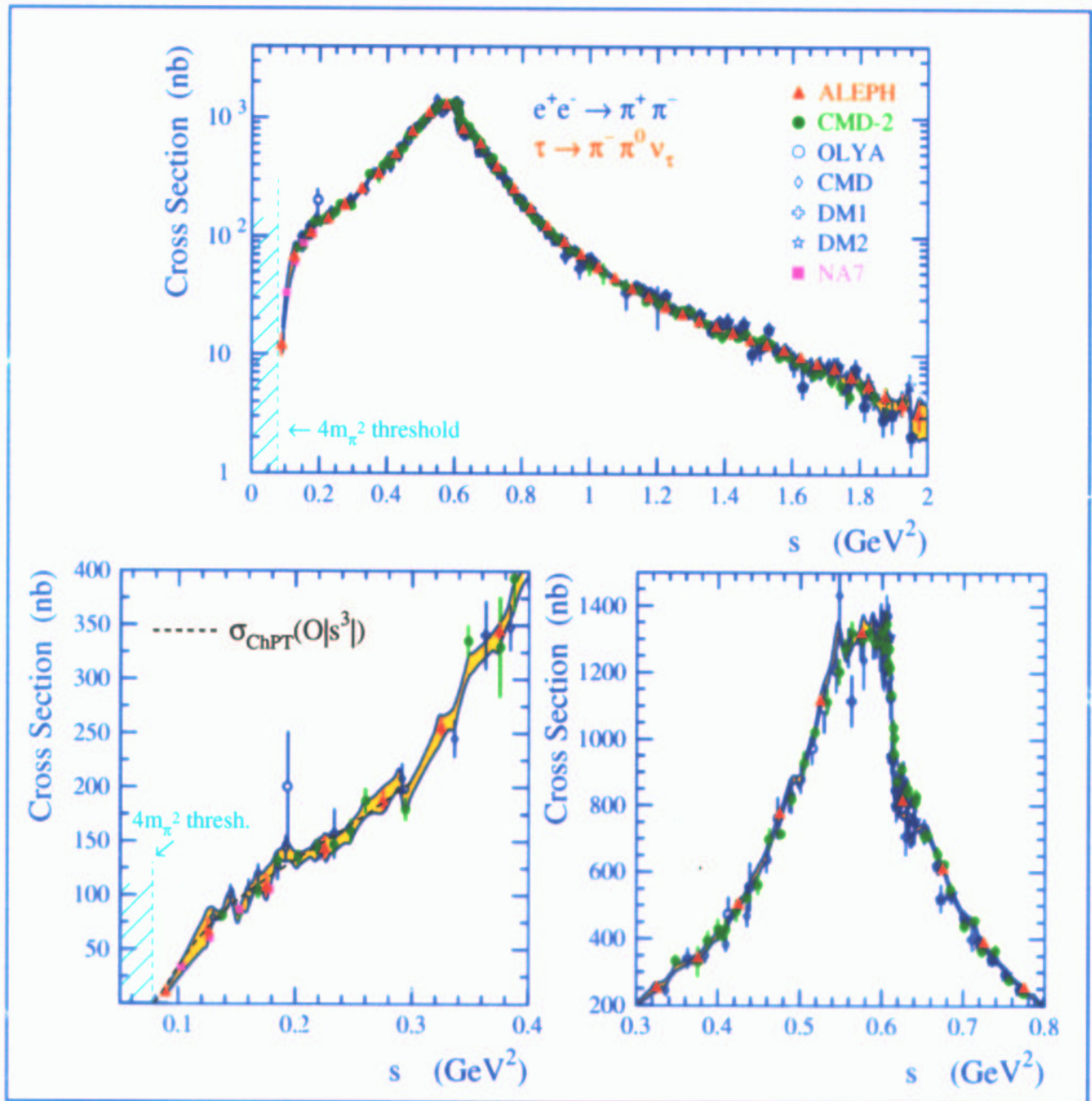
References: BNL'98 PRL 86 2227
 BNL'99 PR 62D 091101
 BNL'00 accepted for publication in PRL

DM'98 $a_\mu(\text{had};1)$ from PL 435B 427

From R. Höcker

Compare $\sigma(e^+e^- \rightarrow \pi^+\pi^-)$ for e^+e^- and τ data

Introduce ρ - ω interference from fit of form factor to e^+e^- data



Green dots: newest data from CMD-II

From A. Höcker

HADRONIC CONTRIBUTION TO $(g - 2)_\mu$

RENCONTRES DE MORIOND, March 2001

TESTING CVC (III)

Relate isovector e^+e^- cross section to τ vector spectral function:

