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NUFAC ØØ
Monterey
5/25/00

Electroweak Precision Studies @ NUFAC

- Intro
- Current Status
- What NUFAC could contribute
- Conclusion

Introduction

- High intensity ν beams
  $\Rightarrow$ possibility of precision EW studies at $\lesssim$ current precision

- The easy part (this talk):
  IT WOULD BE GREAT!
  - Resolve puzzles in present data
  - Improve constraint on m_H
  - Probe/constrain new physics beyond discovery of Higgs sector

- The hard part - next talks – McFarland, Yu
  Overcome formidable exptl/systematic problems to realize statistical potential.

ALSO probe new tree-level physics
(complement SLAC-E158, polarized $ee \to ee$)

E.g., $x_W^{SM} - x_W^{APV-Cs} \sim 2\sigma$

$3 - N_\nu^{(Z)} \sim 2\sigma$ } Related by crossing to $(e\nu_e)_{NC}$

Probe for

unmixed Z'

leptoquarks

$\frac{1}{\Lambda^2}\,\bar{q}q\bar{\nu}\nu$, $\frac{1}{\Lambda^2}\,\bar{\ell}\ell\bar{\nu}\nu$

Interesting, not focus of this talk

FOCUS: precision measurement of $\sin^2\theta_W$, to probe Higgs sector & other new physics.

(New physics in precision measurements & tree-level probes could be related.)

$\nu e \to \nu e$

↓

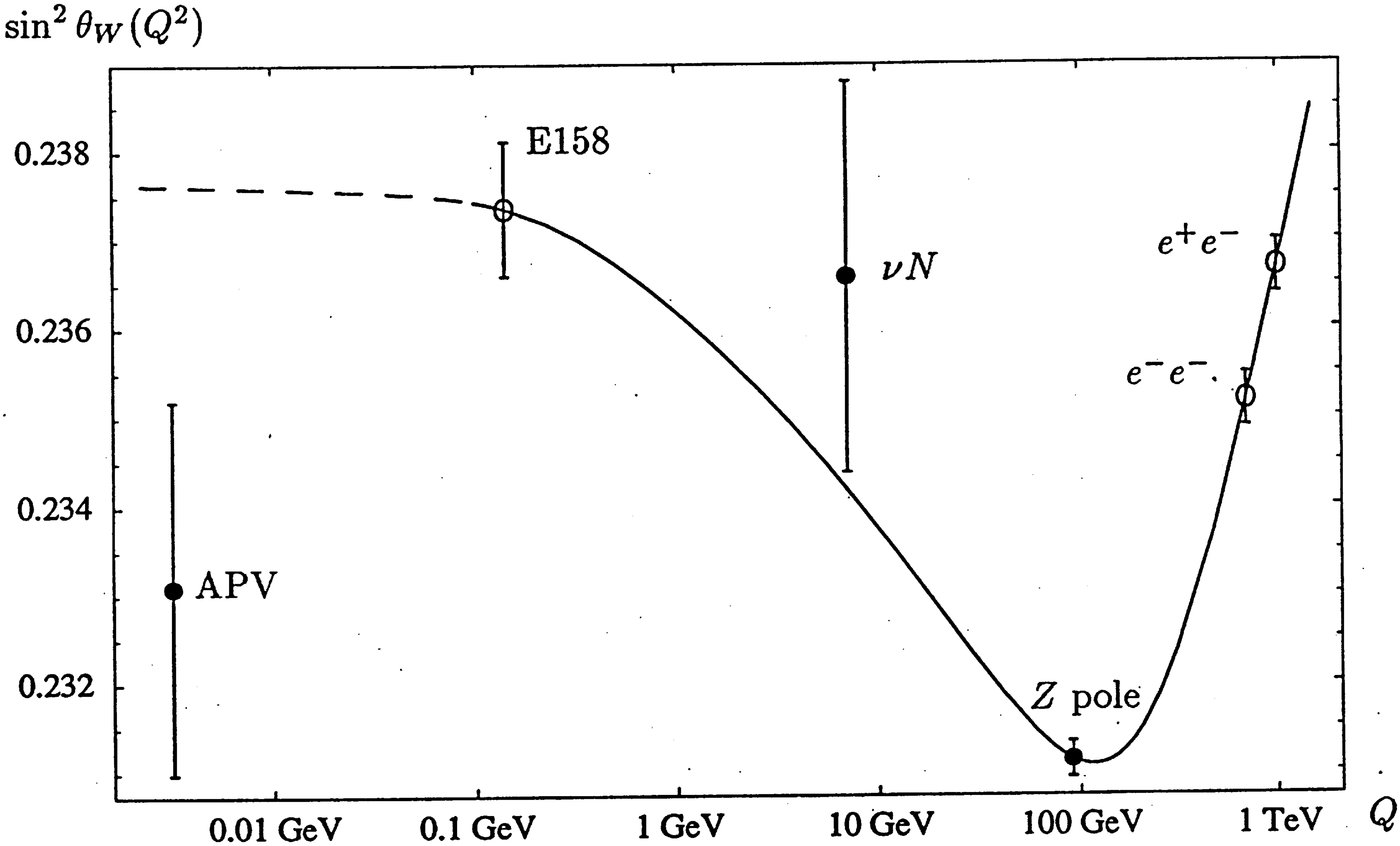


Fig. 3. Predicted running of $\sin^2\theta_W(Q^2)$ and evidence from existing experiments (dark circles) along with expectations from potential future Møller and e^+e^- asymmetry measurements at $\sqrt{s} =$ 1 TeV.

Czarnecki & Marciano
hep-ph/0003049

Current Status

After 10 years of beautiful precision EW studies at LEP, SLAC, FNAL

- No clear sign of new physics
- BUT agreement with SM is MARGINAL at the stated precision

- EWWG global SM fit: $\chi^2 = 23/15$ $CL = 0.08$

  ($x_W^{\ell,eff}$) $A_{LR}, A_{FB}^{\ell}, A_e, A_\tau$ + $A_{FB}^{b}, A_{FB}^{c}, Q_{FB}$

  $\chi^2 = 12.4/6$ $CL = 0.05$

  Most precise: A_{LR} vs A_{FB}^{b} 3σ $CL = 0.003$

  Leptonic: $A_{LR}, A_{FB}^{\ell}, A_e, A_\tau$ $\chi^2 = 3.4/3$

- A_b $A_b^{SLC} = A_{FBLR}^{b}$ $\oplus$ $A_b^{LEP} = \frac{4}{3} A_{FB}^{b}/A_\ell$

  $\Longrightarrow A_b^{SM} - A_b = 2.6\sigma$ $CL = 0.01$

  (& $A_c^{SM} - A_c = 2.1\sigma$ $CL = 0.04$)

A_b not sensitive to m_H, but impacts SM fit of m_H via

$$A_{FB}^b = \frac{3}{4} A_b A_\ell$$

Cannot extract x_W^ℓ from A_{FB}^b

IF new physics affects A_b } GEN$_3$ plausible venue for new physics

OR

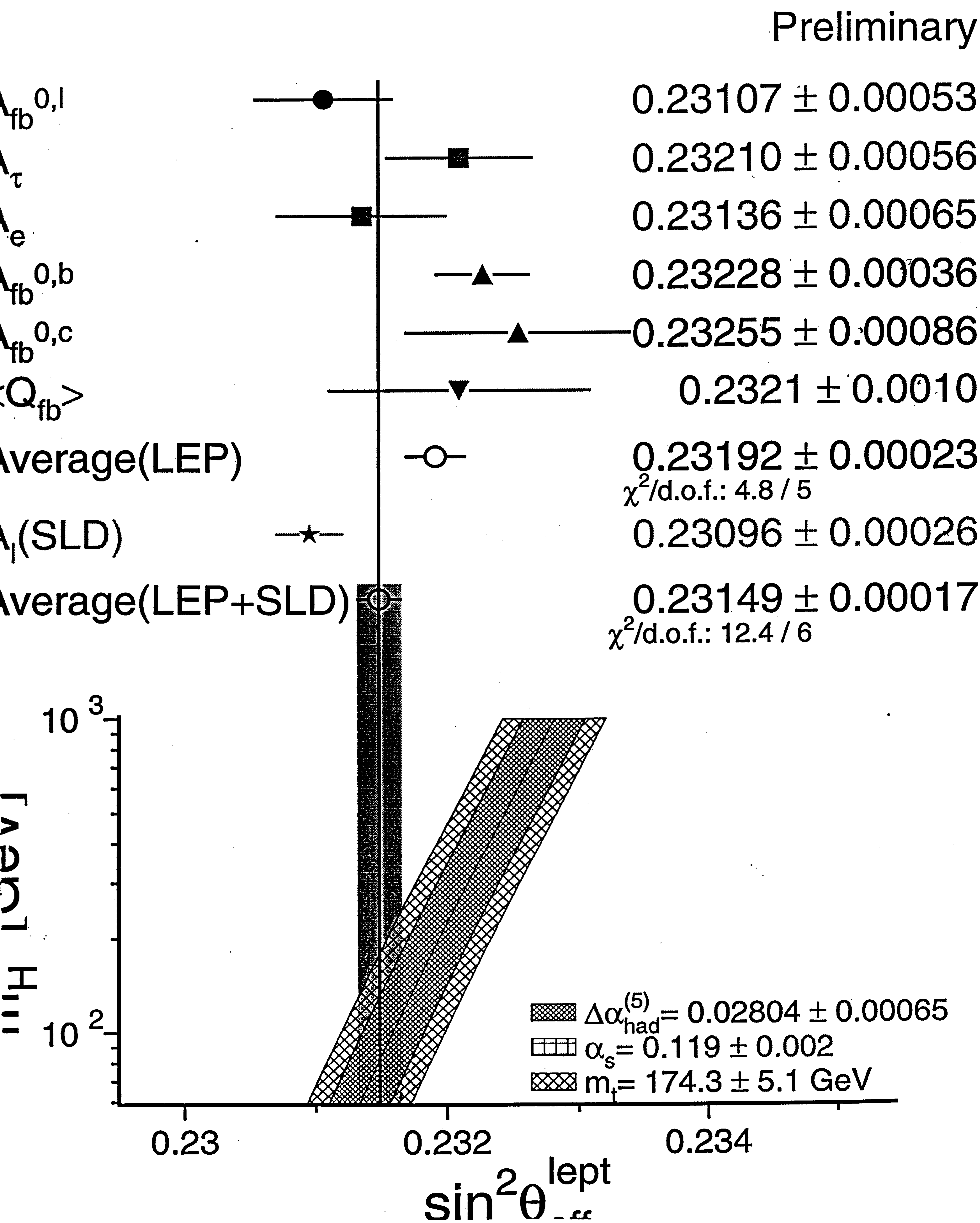
IF A_{FB}^b afflicted by sys. errors } Difficult measurement $\frac{\delta A_b}{A_b} \gg \frac{\delta R_b}{R_b}$ → looks 'fishy'

⇒ consider 2 fits to m_H

$$x_W^\ell = \begin{cases} 0.23149\ (17) & \text{All} \\ 0.23117\ (20) & \text{Leptons} \end{cases}$$

+ $m_W = 80.419\ (38)$ LEP II + CDF/DØ

$m_t = 173.8\ (5.1)$ CDF/DØ



Preliminary
0.23107 ± 0.00053
0.23210 ± 0.00056
0.23136 ± 0.00065
0.23228 ± 0.00036
0.23255 ± 0.00086
0.2321 ± 0.0010
Average(LEP)
0.23192 ± 0.00023
χ²/d.o.f.: 4.8 / 5
(SLD)
0.23096 ± 0.00026
Average(LEP+SLD)
0.23149 ± 0.00017
χ²/d.o.f.: 12.4 / 6
10³
10²
Δα(5)had= 0.02804 ± 0.00065
αs= 0.119 ± 0.002
mt= 174.3 ± 5.1 GeV
0.23
0.232
0.234
sin²θ lept

$m_H(x_W^l) \oplus m_H(m_W)$ (DeGrassi et al)

$\alpha(m_Z)$: $\Delta\alpha_5 = 0.02778\ (25)$ Eidelmann - Jegerlehner '98

	All Asym	Lepton Asym.
m_H	$90 \cdot 1.54^{0\pm1}$	$54 \cdot 1.58^{0\pm1}$
95% upper	< 182	< 114

LEP II: $m_H > 108$ 95%

Lepton fit: $m_H < 108$ 93%

$\Rightarrow$ SM does not live easily with A_{FB}^b or without it.

IF fit conflicted with search limits

$\Rightarrow$ new physics affecting x_W^l

$\Rightarrow$ EW data no longer constrains m_H (until new physics is known).

$\Rightarrow$ All bets are off on scale of EWSB.

What could NUFAC contribute?

Statistical level of NC measurements could exceed current precision for x_W^ℓ, but sys. uncertainties are formidable.

νN

NUTEV D.I.S. $\frac{(\nu_\mu N - \bar{\nu}_\mu N)^{NC}}{(\nu_\mu N - \bar{\nu}_\mu N)^{CC}} = \frac{1}{2} - \sin^2\theta_W^{\text{On-Shell}}$

$$x_W^{OS} = 0.2253 \pm 0.0019 \pm 0.0010$$

$$\Rightarrow \quad m_W = 80.26 \pm 0.11$$

$$\left(\Delta x_W^{OS}\right)_{NUTEV} \cong 10 \cdot \left(\Delta x_W^{\ell,eff}\right)_{LEP/SLC}$$

(x_W^{OS} 2 times more sensitive to $\ln m_H$ — less dependent on $\alpha(m_Z)$)

νN @ NUFAC

- $10^4 - 10^6$ more ν's than NUTEV, but some measurements need low density target to identify $(\bar{\nu}_e N)^{CC}$
- Combination of $\nu_\mu + \bar{\nu}_e$ probe EW variables differently than NUTEV, e.g., $\delta\rho \oplus x_W^{\ell,\,eff}$ (not a problem)
- At NUTEV

$$\Delta x_W^{OS} \Big|_{Theory} = 7 \times 10^{-4}$$

How much can this be reduced?

Expt'l issues in Yu's talk.

νe

$\nu e \to \nu e$ probes $x_W^{\ell,\mathrm{eff}}$, like Z asyms.

Charm II $\quad \dfrac{(\nu_\mu e)^{NC}}{(\bar{\nu}_\mu e)^{CC}} = \dfrac{16 x_W^2 - 12 x_W + 3}{16 x_W^2 - 4 x_W + 3}$

$$\frac{d}{dx_W}\left(\text{"} \right) \cong -8 \quad \left\{ \text{Same as } A_{LR} \right.$$

5400 $\nu + \bar{\nu}$ $\quad x_W^\ell = 0.2324 \pm 0.0058 \pm 0.0059$

$$(\Delta x_W)_{\mathrm{Chm\ II}} \sim 40\,(\Delta x_W)_{\mathrm{LEP/SLC}}$$

NUFAC

- Statistical precision could exceed $(\Delta x_W)_{\mathrm{LEP/SLC}}$ $\Longrightarrow$ possible major impact
- Like E158, probes $x_W^\ell(Q)$ at $Q \sim 100$ MeV

(FIG)

BUT

- $\bar{\nu}_\mu + \nu_e$ lacks clean flux calibration (νN ?)

- $\nu_\mu + \bar{\nu}_e$ calibrated by

$$\nu_\mu e \to \mu \nu_e \quad + \quad \bar{\nu}_e e \to \bar{\nu}_\mu \mu$$

but insensitive to x_W at high y

(NB - want big E_e, small p_{Te} to enhance signal over νN bkgd.)

$$\frac{d\sigma}{dy}(\nu_\mu + \bar{\nu}_e)^{NC} \propto g_L^2 + g_R^2 + (1-y)^2\left(g_R^2 + (1+g_L)^2\right)$$

$$\frac{d}{dx_W}\left(g_L^2 + g_R^2\right) = -1 + 4x_W$$

Suppression persists with actual $\nu_\mu, \bar{\nu}_e$ beam profiles (FIG)

(No similar problem for $\bar{\nu}_\mu + \nu_e$)

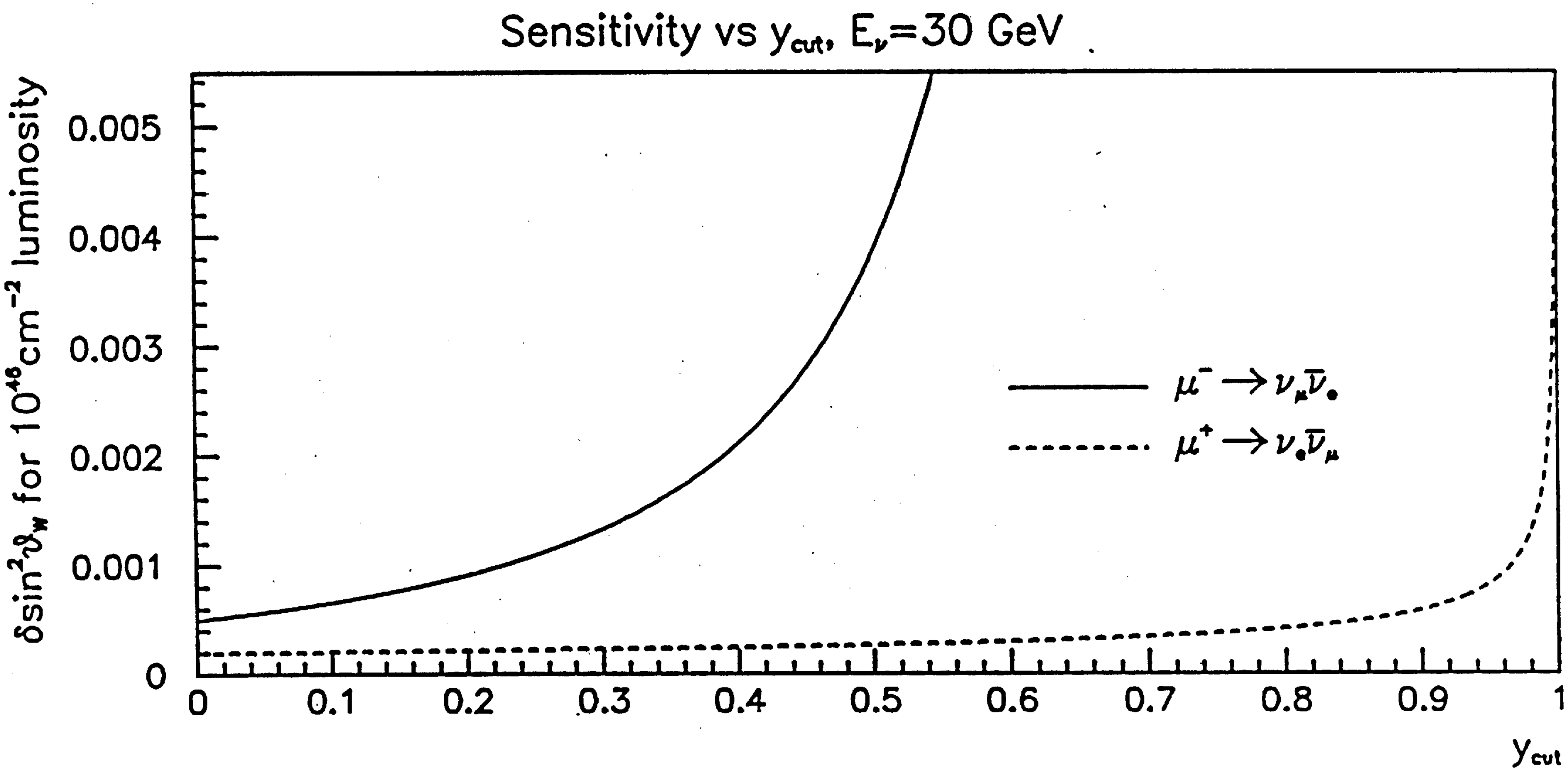


Figure 59: Statistical uncertainty in $\sin^2\theta_W$ for a luminosity of 10^{46} cm^{-2} as a function of $y_{\rm cut}$ for a 30 GeV neutrino beam. Note that the μ^- produced beam is much less sensitive to $\sin^2\theta_W$ due to nearly exact cancellation in the $\sin^2\theta_W$ dependence of the two neutrino species in the beam.

$(\text{BUT})^2$

$\mu^-_R \rightarrow \nu_\mu$ boosted

$\mu^-_R \rightarrow \bar{\nu}_e$ anti-boosted

- Suppress $\sigma^{TOT}_{\bar{\nu}_e e}$

- Suppress $\sigma_{\bar{\nu}_e e}$ for $E_e > E_{MIN}$

(Please refer all difficult questions to McFarland)

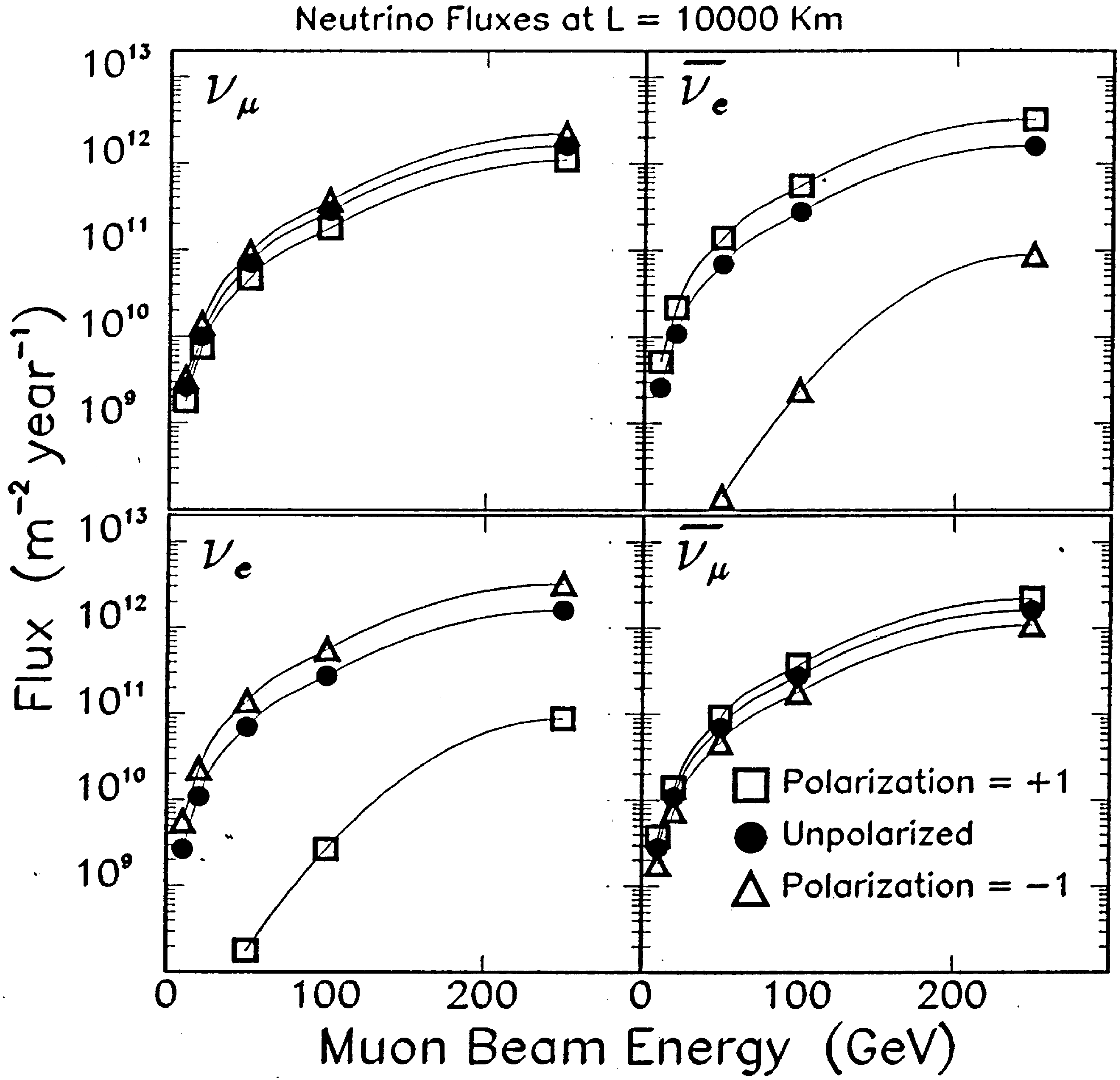


Figure 1: Calculated ν and $\overline{\nu}$ fluxes in the absence of oscillations at a far sit located 10000 km from a neutrino factory in which 2×10^{20} muons have decaye in the beam–forming straight section. The fluxes are shown as a function of the energy of the stored muons for negative muons (top two plots) and positiv muons (bottom two plots), and for three muon polarizations as indicated. Th calculated fluxes are averaged over a circular area of radius 1 km at the far sit Calculation from Ref. 2.

S. Geer PRD 57:6989 '98

Physics at a ν Factory
FERMILAB-FN-692

Potential Impact

Two scenarios

I. $(\Delta x_W^l)_{NUFAC} \sim 2 \cdot 10^{-4}$

$\oplus$

Current data

II. $(\Delta x_W^l)_{NUFAC} \sim 1 \cdot 10^{-4}$

$\oplus$

Projected Run 2 data

$m_H\ (x_W^\ell)$

Uncertainties

Source	$\Delta x_W^\ell\ (10^{-5})$	
LEP/SLC	17	All
	20	Leptons
$\Delta m_t = 5.1$	17	
$\longrightarrow 2.5$	8	
$\Delta \alpha^{-1}(m_Z) = 0.090$	23	EJ 95
$\Delta \alpha^{-1}(m_Z) = 0.035$	9	EJ 98

EJ 95 : Pert Th'y for $\sqrt{s} > 12$ GeV

EJ 98 " " " $\sqrt{s} > 2.5$ GeV

Use EJ 98 but uncertainty might be bigger

— BEPC, DAFNE, VEPP-2M could help ...

I. $(\Delta x_W)_{NUFAC} \sim 2 \cdot 10^{-4}$

	Lepton Asyms	All
LEP/SLC		
Δx_W^ℓ (10^{-5})	0.23117 (20)	0.23149 (17)
m_H	$58 \cdot 1.69^{0 \pm 1}$	$106 \cdot 1.63^{0 \pm 1}$
⊕ NUFAC		
Δx_W^ℓ	14	13
m_H	$58 \times 1.56^{0 \pm 1}$	$106 \times 1.56^{0 \pm 1}$

$\Rightarrow$ little impact on nominal precision, but may illuminate conflict in existing data between leptonic & hadronic asyms.

$\lesssim 0.2313$ $\gtrsim 0.2314$

↙ ↘

Confirm discrepancy

↓

New physics OR sys error in A_{FB}^{b}

↓

Omit A_{FB}^{b} from $m_H(x_W)$

Suggests discrepancy statistical

↓

m_H (x_W^{ℓ}) from all asyms.

<u>NB</u> $m_H(x_W)$ still interesting even after m_H is directly measured $\Rightarrow$ probes additional new physics

II $(\Delta x_W^\ell)_{NUFAC} \sim 1\cdot 10^{-4}$

Assume $\Delta m_t = 2.5$ GeV, $\Delta m_W = 25$ MeV

	Lepton Asyms	All
NUFAC		
m_H	$58 \cdot 1.34^{0\pm1}$	$106 \cdot 1.34^{0\pm1}$
95% CL	< 94	< 174

⊕ LEP/SLC

m_H ~ No Change

⊕ m_W (Run 2)

m_H ~ No Change

($\Delta m_W \sim 20$ MeV ⇒ same $\Delta(\ln m_H)$ as from $\Delta x_W^\ell \sim 2\cdot 10^{-4}$)

⇒ factor 2 gain in $m_H(x_W^\ell)$ + crisper resolution of existing discrepancies.

Conclusion

- $\sin^2\theta_W$ is a fundamental parameter
  - probes Higgs scale + other new phys.

Presently $\Delta x_W >$ nominal error

- $(\Delta x_W)^{NUFAC} \sim 2 \cdot 10^{-4}$ would help resolve present discrepancies
- Also interesting at lower precision:
  - running of $x_W(Q)$
  - new tree-level physics
- $(\Delta x_W)^{NUFAC} \sim 1 \cdot 10^{-4}$ could be the archival measurement, rivaled only by a Giga-Z factory

$\Rightarrow$ clearly worthwhile to try to master the exp't'l and systematic difficulties.