Measurement of A_{FB} and extraction of $\sin^2\theta_W$ using $p\bar{p}\rightarrow Z/\gamma^*\rightarrow e^+e^-$ events at DØ

Junjie Zhu

State University of New York @ Stony Brook

For the DØ Collaboration

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Introduction

◆ Vector and axial-vector coupling of fermions to the Z bosons:

$$g_V = I_f^3 - 2Q_f \sin^2\theta_W \qquad g_A = I_f^3$$

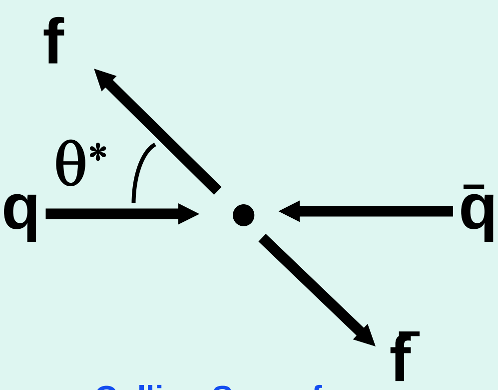
Fermion			I^3_f	Q_f	g_V	g_A
u	c	t	1/2	2/3	$(1/2 - 4/3 \times \sin^2\theta_W) \sim 0.191$	1/2
d	s	b	-1/2	-1/3	$(-1/2 + 2/3 \times \sin^2\theta_W) \sim -0.345$	-1/2
ν_e	ν_μ	ν_τ	1/2	0	1/2	1/2
e	μ	τ	-1/2	-1	$(-1/2 + 2 \times \sin^2\theta_W) \sim -0.036$	-1/2

◆ θ^*-dependent cross sections:

$d\sigma/d\cos\theta^* = A\times(1+\cos^2\theta^*) + B\times\cos\theta^*$

A and B depend on I^3_f, Q_f and $\sin^2\theta_W$

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = \frac{\sigma(\cos\theta^* > 0) - \sigma(\cos\theta^* < 0)}{\sigma(\cos\theta^* > 0) + \sigma(\cos\theta^* < 0)} = \frac{3B}{8A}$$



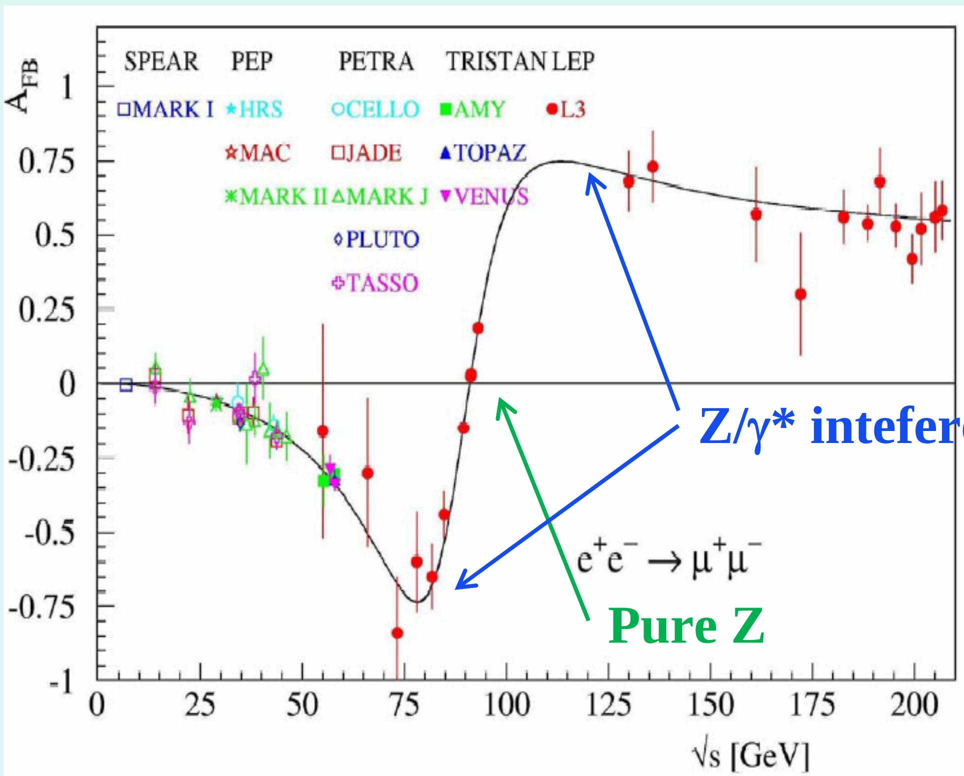
Collins-Soper frame

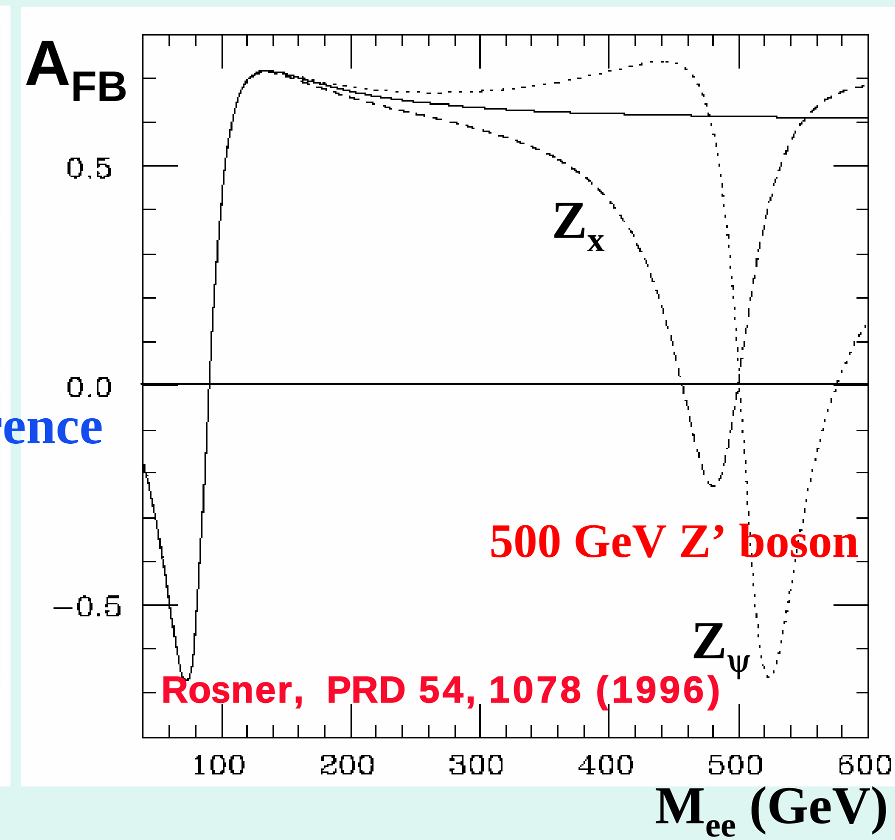
◆ Directly probing the Z-quark and Z-lepton couplings

A_{FB} at e^+e^- collider and hadron collider

- Precise measurement around Z pole
- Hard to reach very high energies (> 200 GeV)

- New resonance (Z', LED etc) can interfere with Z and γ (M. Carena *et al.*, PRD 70 093009 (2004))

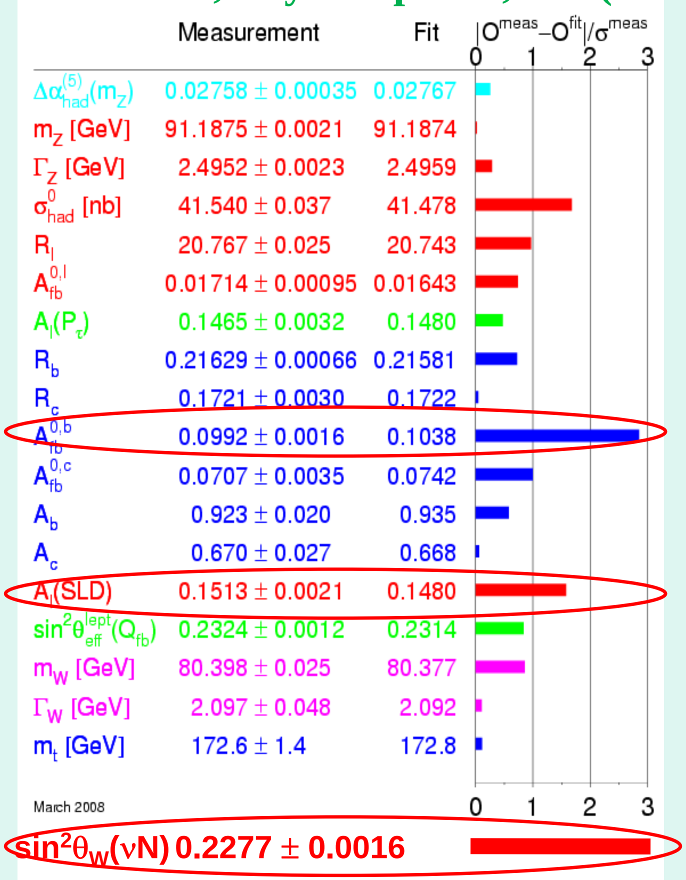




Weak mixing angle $\sin^2\theta_W$

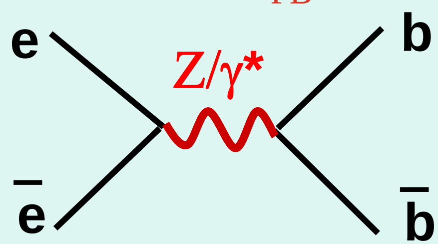
- A_{FB} is sensitive to $\sin^2\theta_W$ ($\sin^2\theta^{eff}_W$ includes higher order corrections)
- LEP A^b_{FB} and SLD A_{LR}: off by 3σ in opposite direction
- NuTeV $\sin^2\theta_W$ result: 3σ away from the global EW fit

LEP EWWG, Phys. Rep. 427, 257 (2006)

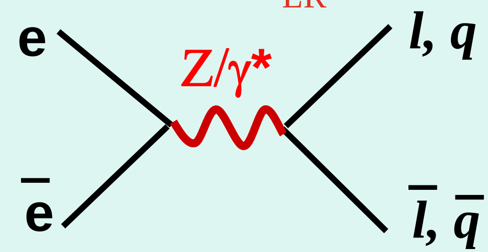


G.P. Zeller *et al.*, PRL 88, 091802 (2002)

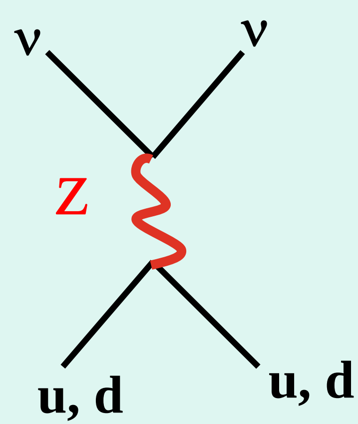
LEP A^b_{FB}



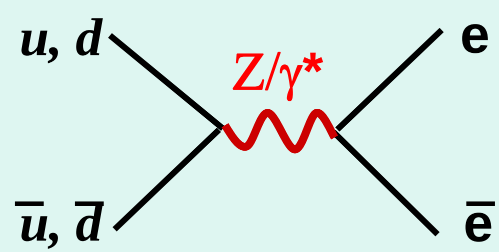
SLD A_{LR}



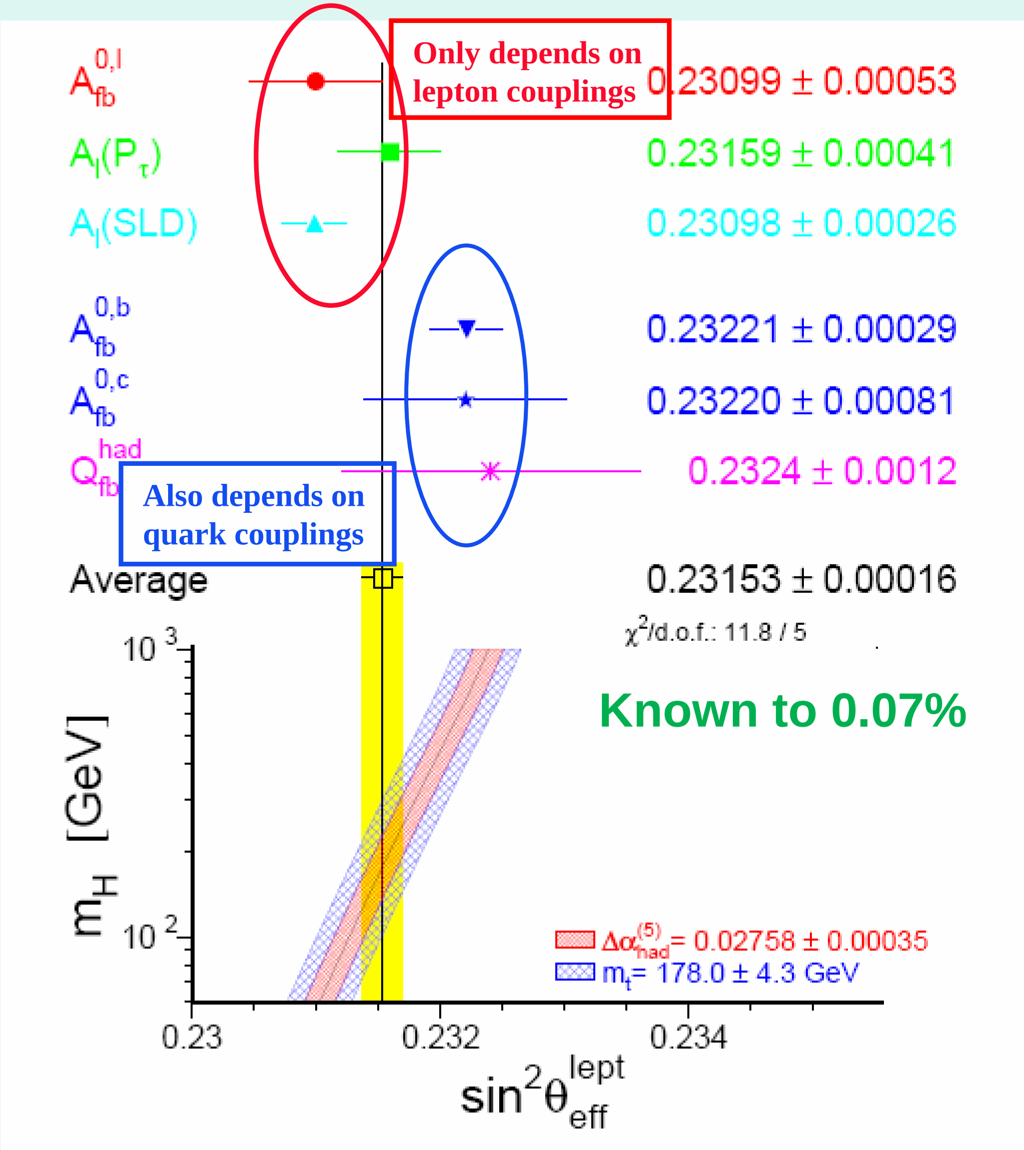
NuTeV

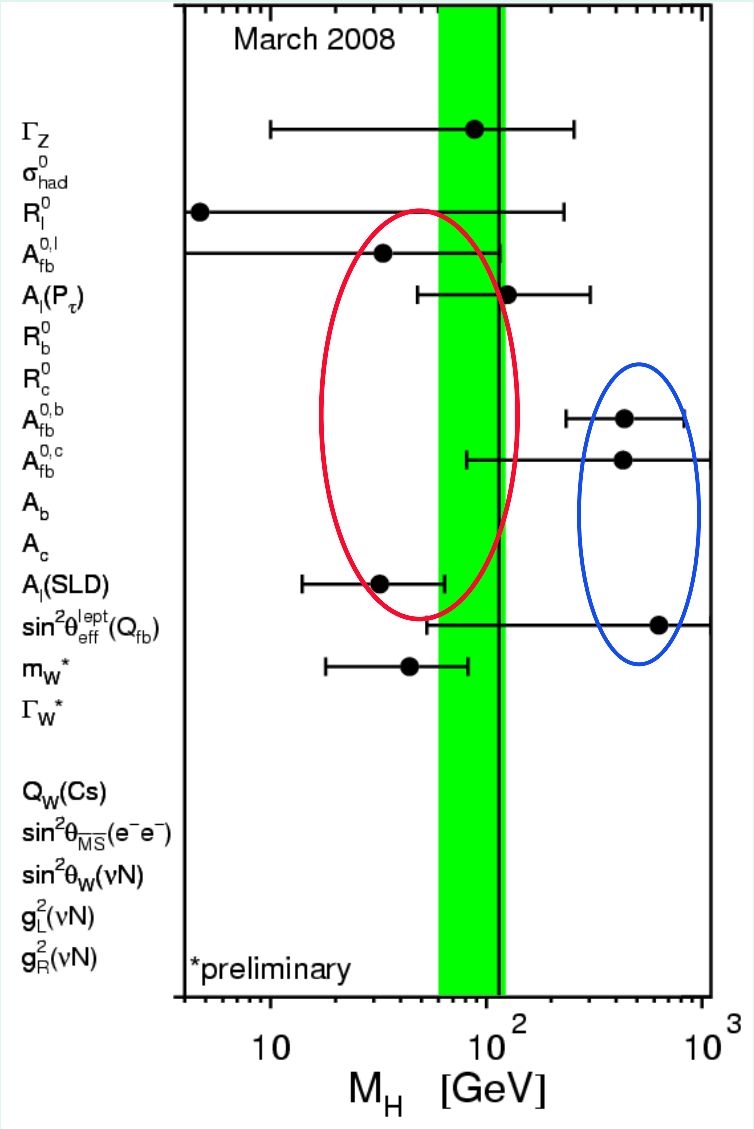


This measurement

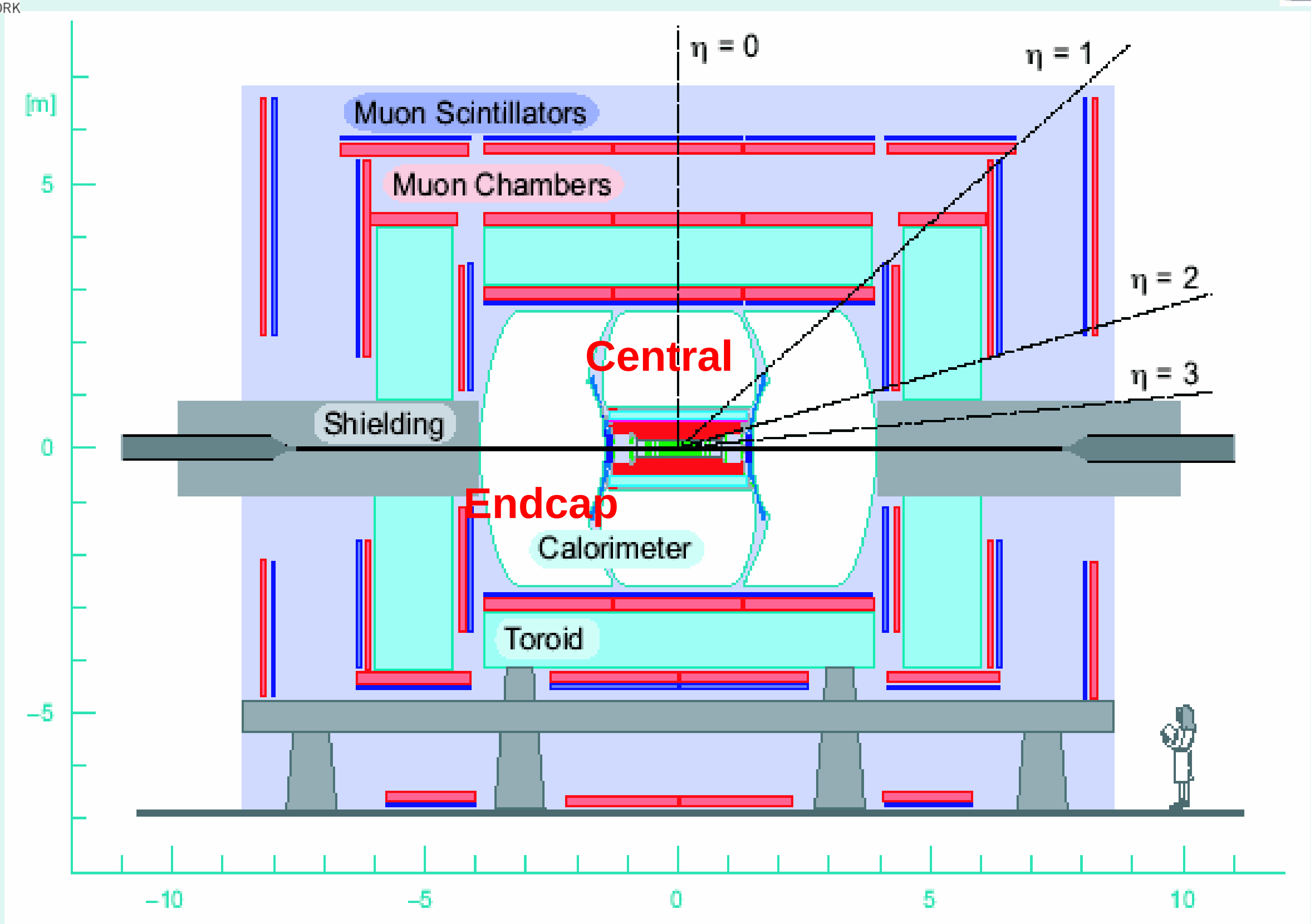


Weak mixing angle $\sin^2\theta_W$ (cont.)





DØ detector



- Silicon Microstrip Tracker and Central Fiber Tracker (Tracks |η| < 3.2)
- Central and endcap calorimeters (Electrons |η| < 4.2)

Event selection

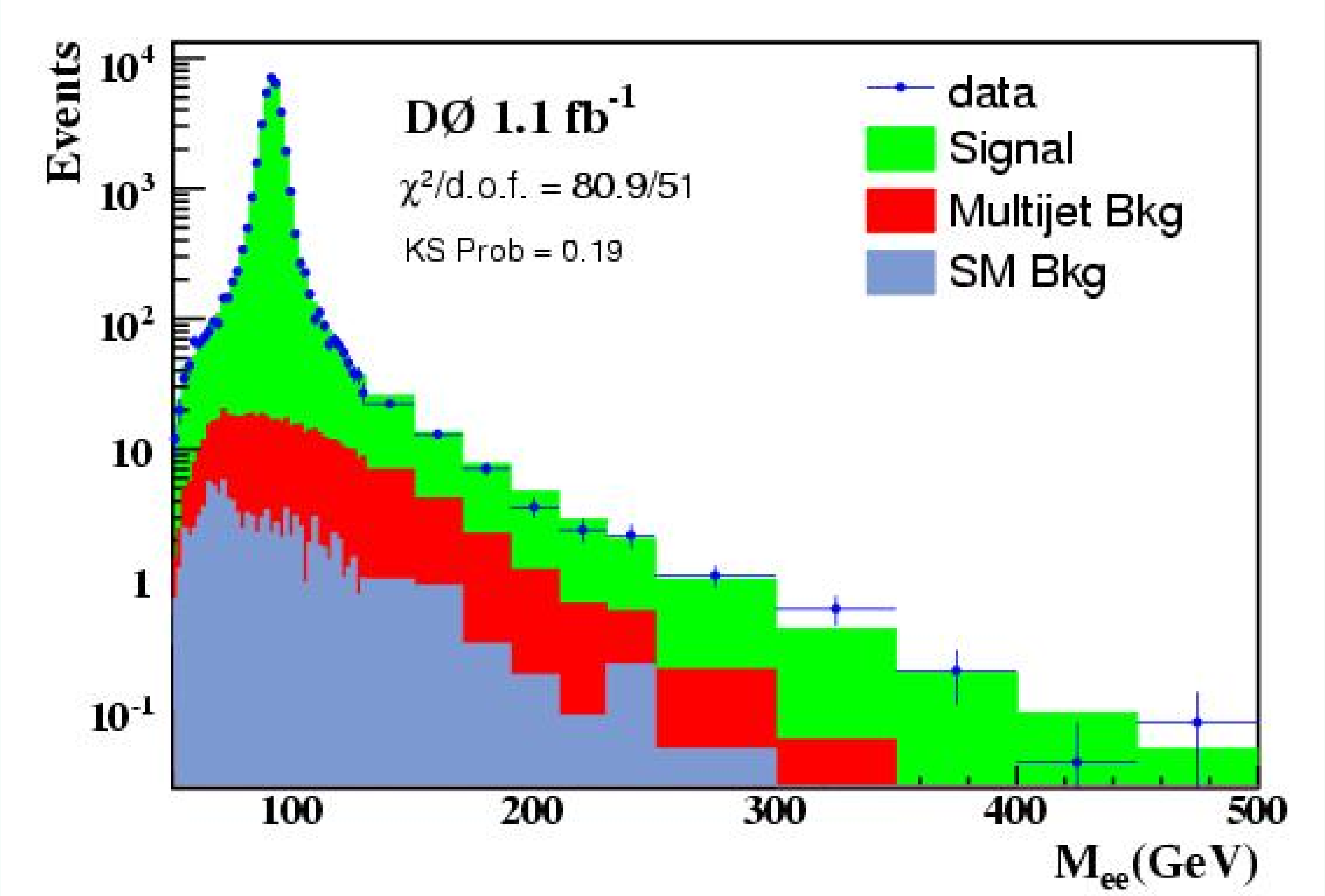
- Run II data: 1065 ± 65 pb^{-1} ($Z/\gamma^* \rightarrow ee$)
- Two electrons satisfy:
  - pT > 25 GeV
  - Isolated with large EM fraction
  - Shower shape consistent with that of an electron
- $50 < M_{ee} < 500$ GeV
- Look at CC and CE events
- 35,626 events after selection
- 558 events with $130 < M_{ee} < 500$ GeV
- A_{FB} measured in 14 mass bins

Mass range (GeV)	CC		CE	
	Forward	Backward	Forward	Backward
50 – 60	69	78	15	16
60 – 70	104	158	51	91
70 – 75	96	117	64	93
75 – 81	191	235	172	293
81 – 86.5	749	763	843	970
86.5 – 89.5	1388	1357	1860	1694
89.5 – 92	2013	1918	2543	2214
92 – 97	2914	2764	3132	2582
97 – 105	686	549	867	470
105 – 115	153	97	243	88
115 – 130	101	39	167	61
130 – 180	91	33	202	69
180 – 250	31	13	53	16
250 – 500	14	15	17	4

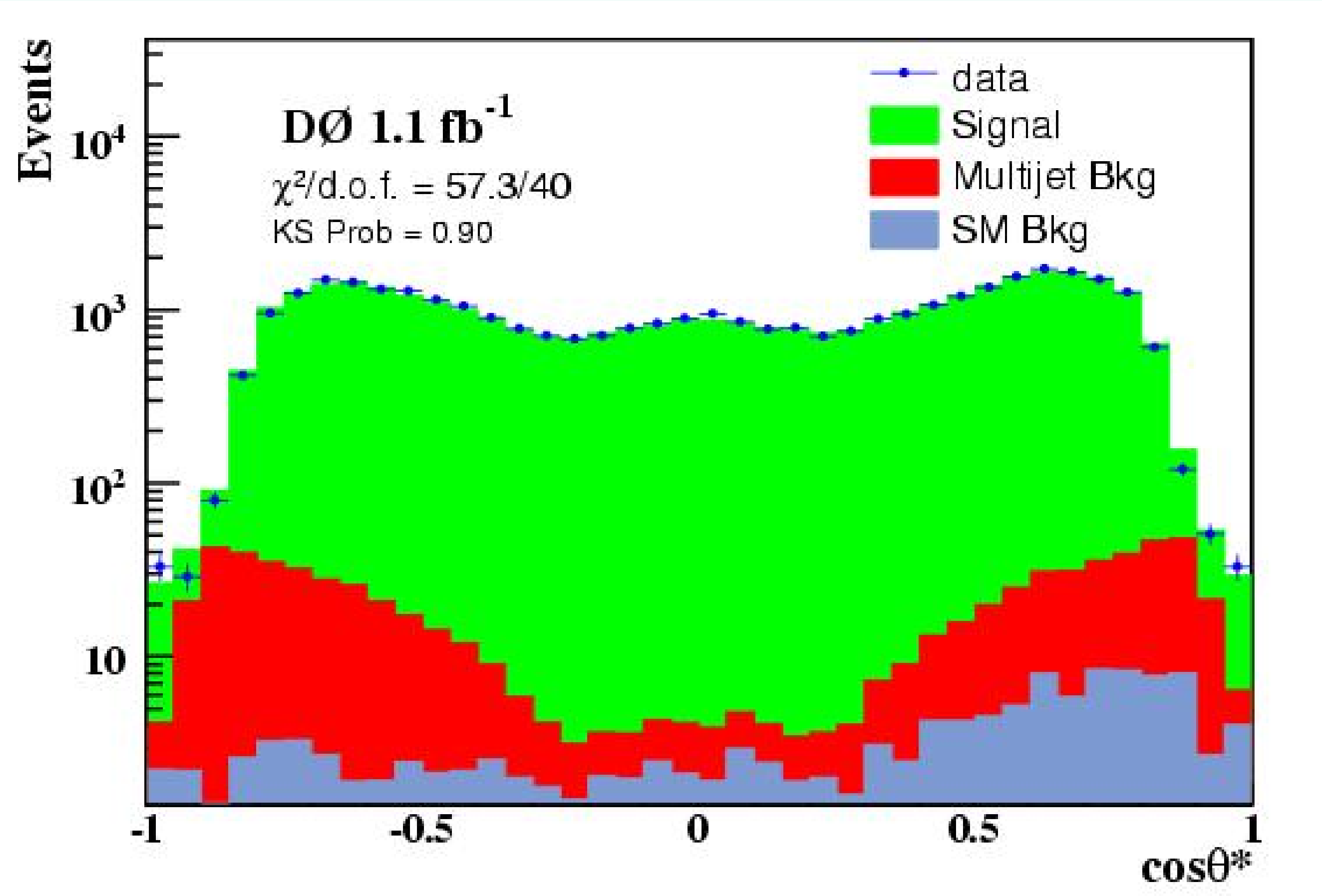
Signal and Backgrounds

- Signal events:
  - PYTHIA events with 15 < M < 1000 GeV
  - Passed through the GEANT simulation of DØ detector
  - Efficiencies, energy scale and resolution tuned to agree with data
- Backgrounds:
  - Electroweak backgrounds measured using GEANT MC simulation:
    - $Z/\gamma^* \rightarrow \tau\tau$, W+X, WW, WZ, $t\bar{t}$
    - Negligible for most mass bins
  - QCD multijet backgrounds measured using real data:
    - Invert electron shower shape requirements
    - 0.9% for the whole mass bins

M_{ee} distribution



cosθ* distribution



$\sin^2\theta^{eff}_W$ Result

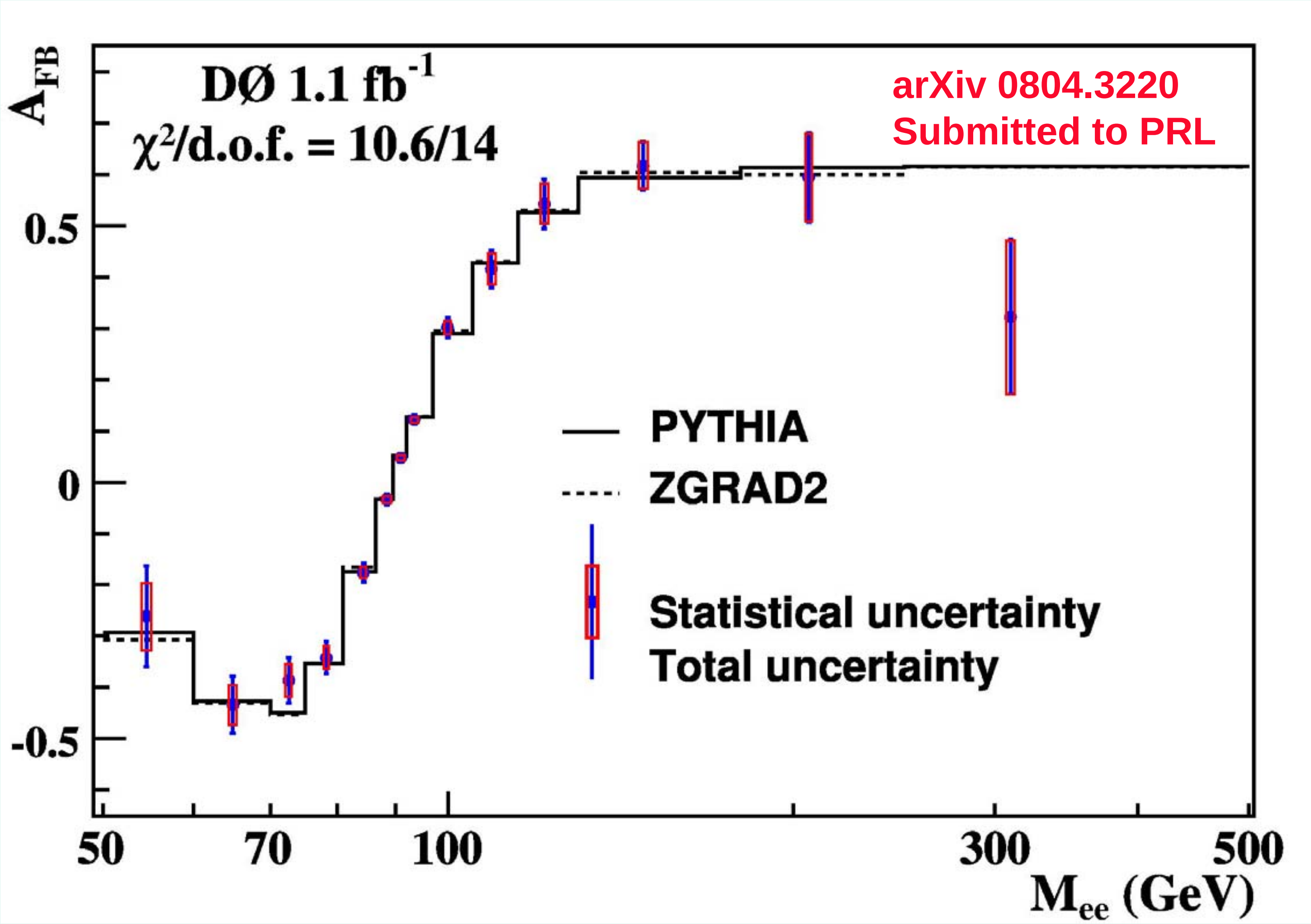
- Extraction of $\sin^2\theta^{eff}_W$ using PYTHIA:
  - Obtained from backgrounds-subtracted A_{FB} distribution
  - Compared with A_{FB} templates according to different values of $\sin^2\theta^{eff}_W$ generated with PYTHIA and GEANT-based MC simulation
- Higher-order QCD and EW corrections estimated using ZGRAD2 program (U. Baur *et al.*, PRD 57, 199 (1998); PRD 65, 033007 (2002))
  - ***$\sin^2\theta^{eff}_W = 0.2327 \pm 0.0018$ (Stat.) ± 0.0006 (syst.)***
  - Systematic uncertainties dominated by PDFs (0.0005) and EM energy scale/resolution (0.0003)

- Our result agrees with the global EW fit
- Uncertainty comparable with the uncertainties from LEP inclusive hadron charge asymmetry (Q^{had}_{FB}) (0.0012) and NuTeV measurement (0.0016)

A_{FB} Unfolding

- Raw A_{FB} → Unfolded A_{FB} (compare with theoretical predictions easily)
  - Detector resolution
  - Acceptance and selection efficiencies
  - Charge mis-identification
- Procedure tested by comparing the true and unfolded spectrum generated using pseudo-experiments
- Systematic uncertainty on the unfolded A_{FB}
  - Corrections used for unfolding
  - Electron energy scale and resolution
  - Backgrounds
  - PDFs

Unfolded A_{FB}



STONY BROOK
STATE UNIVERSITY OF NEW YORK

Unfolded A_{FB}

$\langle M_{ee}\rangle$ (GeV)	Predicted A_{FB} PYTHIA	Predicted A_{FB} ZGRAD2	Unfolded A_{FB}
54.5	−0.293	−0.307	$-0.262 \pm 0.066 \pm 0.072$
64.9	−0.426	−0.431	$-0.434 \pm 0.039 \pm 0.040$
72.6	−0.449	−0.452	$-0.386 \pm 0.032 \pm 0.031$
78.3	−0.354	−0.354	$-0.342 \pm 0.022 \pm 0.022$
84.4	−0.174	−0.166	$-0.176 \pm 0.012 \pm 0.014$
88.4	−0.033	−0.031	$-0.034 \pm 0.007 \pm 0.008$
90.9	0.051	0.052	$0.048 \pm 0.006 \pm 0.005$
93.4	0.127	0.129	$0.122 \pm 0.006 \pm 0.007$
99.9	0.289	0.296	$0.301 \pm 0.013 \pm 0.015$
109.1	0.427	0.429	$0.416 \pm 0.030 \pm 0.022$
121.3	0.526	0.530	$0.543 \pm 0.039 \pm 0.028$
147.9	0.593	0.603	$0.617 \pm 0.046 \pm 0.013$
206.4	0.613	0.600	$0.594 \pm 0.085 \pm 0.016$
310.5	0.616	0.615	$0.320 \pm 0.150 \pm 0.018$

- Stat and syst uncertainties are comparable near Z-pole
- Stat uncertainty dominates at high mass

Conclusions

- Measure A_{FB} and extraction of $\sin^2\theta^{eff}_W$ using 1.1 fb^{-1} DØ RunII data
- A_{FB} measurement:
  - Unfolded A_{FB} agrees with SM predictions
  - About ten times more data used than previous results
- $\sin^2\theta^{eff}_W$ extraction:
  - ***$\sin^2\theta^{eff}_W = 0.2327 \pm 0.0018$ (stat.) ± 0.0006 (syst.)***
  - Result agrees with the global EW fit
  - Only electron channel used, the precision is comparable with the uncertainty of LEP Q^{had}_{FB} and that of NuTeV measurement
  - With ~ $8fb^{-1}$ data, using e + μ channels with CDF, expected uncertainty will be comparable with WA uncertainty
- Will benefit from the improvements in current MC generators incorporating higher order QCD and EW corrections

BACKUP

Fermion			g_V	g_A	A_f	$\partial A_f / \partial \sin^2 \theta_W$
u	c	t	0.191	0.5	0.66	-3.5
d	s	b	-0.345	-0.5	0.94	-0.6
ν_e	ν_μ	ν_τ	0.5	0.5	1.00	0
e	μ	τ	-0.036	-0.5	0.16	-7.9

- Left- and right-handed couplings: $g_V = g_L + g_R$, $g_A = g_L - g_R$
- Fermion asymmetry parameter: $A_f = 2g_V g_A/(g^2_V + g^2_A)$
- At e^+e^- collider:
  - Forward-backward asymmetry: $A^f_{FB} = (\sigma^f_F - \sigma^f_B)/(\sigma^f_F + \sigma^f_B) = 0.75 A_e A_f$
  - Left-right F/B asymmetry (direct measurement of final-state coupling)

    $$A^{LR}_{FB} = [(\sigma^L_F - \sigma^R_F) - (\sigma^L_B - \sigma^R_B))]/[(\sigma^L_{F+}\sigma^R_F) + (\sigma^L_{F+}\sigma^R_F)] = 0.75 P_e A_f$$
  - Left-right asymmetry: $A_{LR} = (\sigma_L - \sigma_R)/(\sigma_{L+}\sigma_R) = P_e A_e$

Measurement Techniques used at SLD and LEP

- Measurement of A_{LR}, A^{FB}_{LR}, A^{l}_{FB} at SLD:
  - Excludes electron mode to avoid the added complexity of correcting for t-channel interference
  - Determination of the beam polarization
- Measurement of A^{l}_{FB} at LEP
- Measurement of P^{τ} (τ polarization)
- Measurement of A^{b}_{FB}, A^{c}_{FB}
  - Use lepton tag: P and P_T of leptons can be used to assign a probability that the lepton is a *b* or a *c* quark
  - Sign of the lepton tags the quark charge
- Measurement of Q^{had}_{FB}:
  - Use momentum-weighted jet charge to tag the quark charge
  - Relies on MC to determine the relative abundance of the different quark species

$\sin^2\theta^{eff}_W$ depends on scale

- Moller scattering
- ν-nucleon scattering
- Atomic parity violation in Cesium