Indirect measurement of $\sin^2\theta_W$ (M_W) using $\mu^+\mu^-$ pairs in the Z boson Region at CDF

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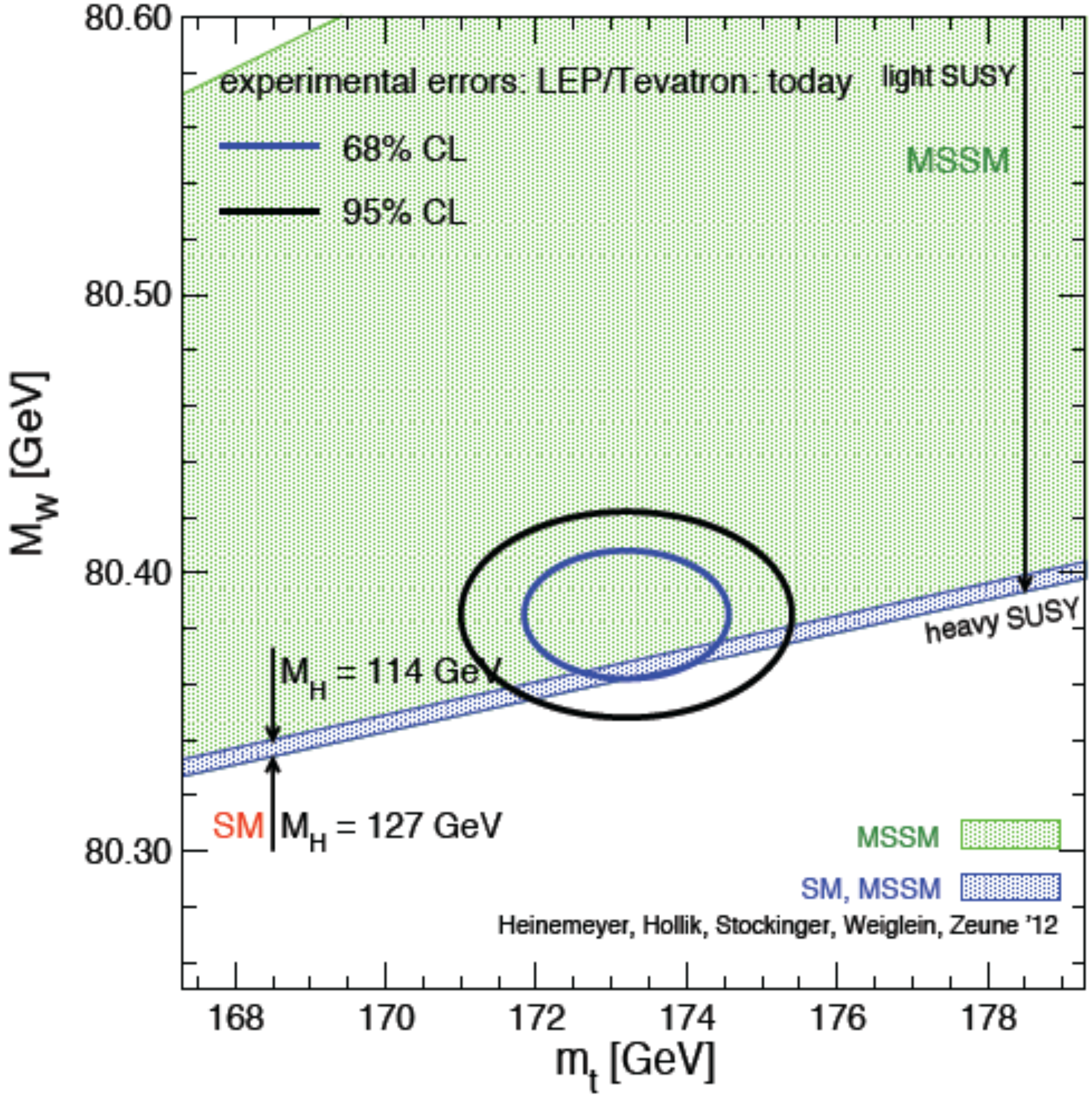
WIN 2013, Sept 16-21, 2013, Natal, Brazil (abstract 53)
Friday Sept. 20, 2013 10:30-11:00 am (group 3)

Tension Between direct measurments of M_w, M_H and M_t In SM



Is there an alternate method to measure M_w?

In SM:

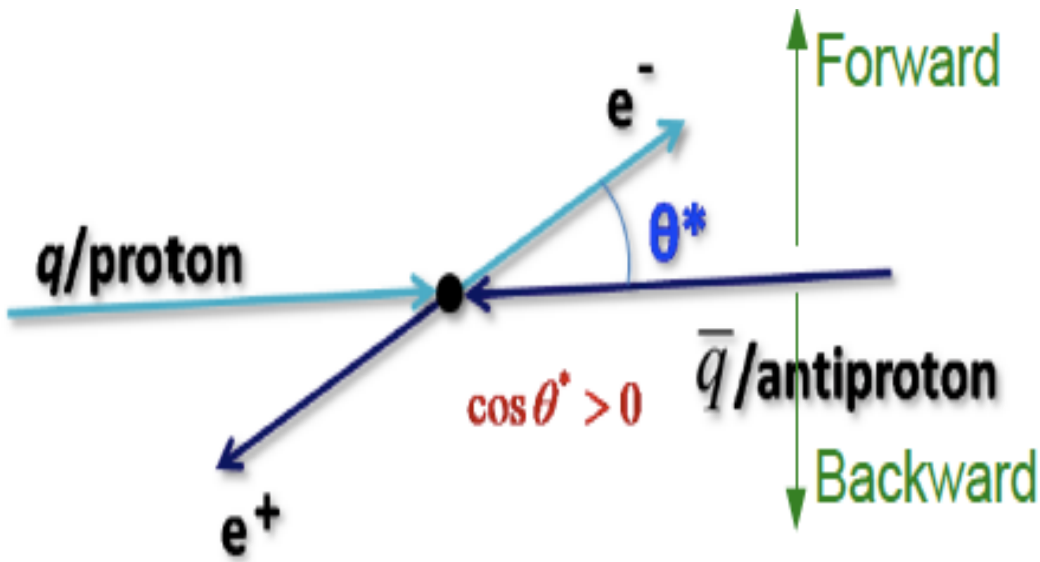
$\sin^2\theta_w = 1 - M_w^2 / M_z^2$

Therefore, a measurement of $\sin^2\theta_w$ **is equivalent to an indirect measurement of M_w.**

In hadron colliders:

A_{FB} for e^+e^- or $\mu^+\mu^-$ pairs in the Z boson Region is sensitive to $\sin^2\theta_{eff}$

Born level polar angle distribution: $1 + \cos^2\vartheta + A_4\cos\vartheta$



Define
Forward-Backward asymmetry:

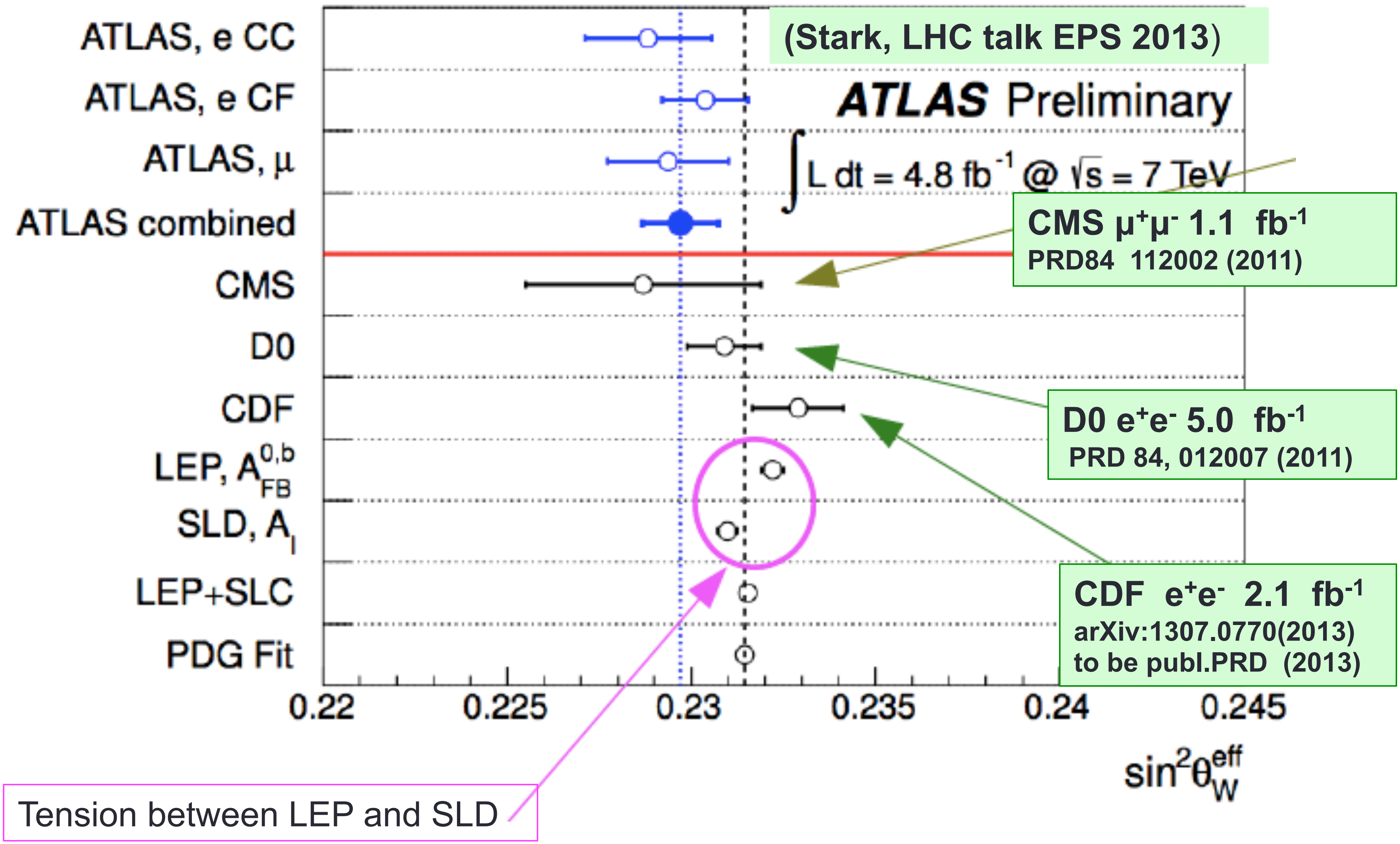
$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B}$$

$A_{FB} = (3/8)\, A_4$

$\sin^2\theta_{eff}^{lept} \simeq 1.037 \cdot \sin^2\theta_W$ [ZFITTER $\kappa_e(\sin^2\theta_W, M_Z)$ form factor]

$\sin^2\theta_w = 1 - M_w^2 / M_z^2$

Tension between measurements of effective EW $\sin^2\theta_{eff}$



New measurements of $\sin^2\theta_{eff}$ are valuable

Goal: An indirect measurement of M_W at CDF:
(with precision equivalent to the direct measurement at CDF ~ 20 MeV)

Current errors in the direct measurement of the W mass at the Tevatron (MeV)

ΔM_W [MeV]	CDF	D0	combined
$\mathcal{L}[\mathrm{fb}^{-1}]$	2.2	4.3(+1.1)	7.6
PDF	10	11	10
QED rad.	4	7	4
$p_T(W)$ model	5	2	2
other systematics	10	18	9
W statistics	12	13	9
Total	19	26(23)	16

Expected final errors in direct measurement of W mass at the Tevatron (MeV)

final CDF	final D0	combine
10	10	20
5	5	5
4	3	3
2	2	2
4	11	4
6	8	5
10	15	9

Today's talk: CDF - Three new innovations in the measurement of A_{FB} –> $\sin^2\theta_W$ ->M_W
-we get an error of *43 MeV* in the indirect measurement of of M_W with 9 fb^{-1} $\mu^+\mu^-$ data sample.
The application of the same techniques for 9 fb^{-1} the e^+e^- channel will yield an error of *22 MeV* (combined e^+e^- & $\mu^+\mu^-$ will yield an error of 20 MeV) results expected in Spring 2014).

1. Z fitter EW radiative corrections (Spring 2013
2. Precise momentum scale corrections
3. Event weighting technique

$\Delta \sin^2\theta^l_{\rm eff}$ [10^{-5}] final state	D0 e^+e^-	CDF e^+e^-	CDF $\mu^+\mu^-$	final CDF e^+e^-	final CDF combined
$\mathcal{L}$[fb^{-1}]	5.0	2.1	9.0	9.0	9.0 $\mu\mu$ + 9 e^+e^-
PDF	48	12	8	8	8
higher order corr.	8	13	10	10	10
other systematics	38	5	11	5	5
statistical	80	90	80	40	36
total $\Delta \sin^2\theta_w$		**105**	**82**	**42**	**38**
total $\Delta \sin^2\theta^l_{\rm eff}$	**101**	**110**	**86**	**44**	**40**
Indirect W_{mass} error of		55 MeV	43 MeV	22 MeV	20 MeV

This talk

Expected Spring 2014

Drell-Yan asymmetry is measured in the Collins-Soper frame.
The Collins-Soper frame is the CM frame of the dilepton pair.

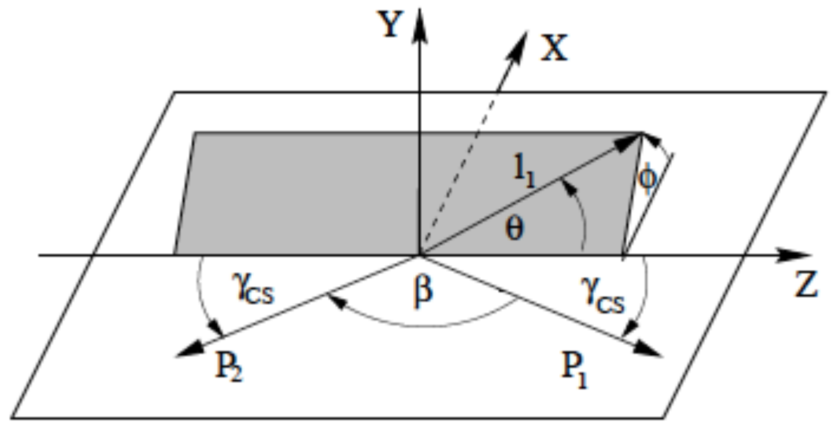


Fig. 1: The Collins-Soper frame: the z-axis cuts the angle between $\mathbf{P}_1$ and $-\mathbf{P}_2$ into halves (the half angle is called the Collins-Soper angle γ_{CS}) while the x-axis is perpendicular to $\mathbf{P}_1$ and $\mathbf{P}_2$. The direction of one lepton momentum $\mathbf{l}_1$ can then be given by the angles θ and ϕ

The dilepton pair can have P_T in the laboratory frame. The P_T could originate from gluon emission by the quark in the proton, or the antiquark in the antiproton. Therefore, the q and qbar are not collinear in the CM of the dilepton pair.

For dileptons with a P_T, The change in the ***cosθ*** *distribution in the Collins-Soper frame is well understood and is taken into account (adds a term $A_0(P_T)$ to the angular distribution).*

Cosθ in the Collins-Soper (CM frame of the dilepton pair)

The Collins-Soper frame angle, $\cos\vartheta$ [7], is reconstructed using these laboratory-frame quantities: the lepton energies (E), the lepton momenta along the beam line (P_z), the dilepton mass (M), and the dilepton transverse momentum (P_{T}). The angle of the negatively-charged lepton is

$$\cos\vartheta = \frac{l_+^- l_-^+ - l_-^- l_+^+}{M\sqrt{M^2 + P_{\mathrm{T}}^2}} \ ,$$

where $l_\pm = (E \pm P_z)$ and the $+$ $(-)$ superscript specifies that $l_\pm$ is for the positively- (negatively-)charged lepton. A similar expression is used for φ.

PDF errors

In proton-antiproton (Tevatron) collisions we know that the direction of the quark is usually in the proton direction and the direction of the anti-quark is primarily in the direction of the anti-proton.

There is a small dilution of the asymmetry from the small fraction of events which originate from the interactions of the antiquark sea in the proton with the quark sea in the antiproton. This dilution is determined from PDFs. Since this contribution is small, the interpretation of asymmetry measurements at the Tevatron are not very sensitive to PDFS.

In proton-proton collisions (LHC), the direction of the quark is taken to be the direction of the rapidity of the Z boson (since quarks carry more momentum than antiquarks). However, there is significant dilution from events in which the antiquark carries more momentum than the quark in the interaction. Because of this large dilution, the PDF dependent corrections at the LHC are much larger than at the Tevatron.

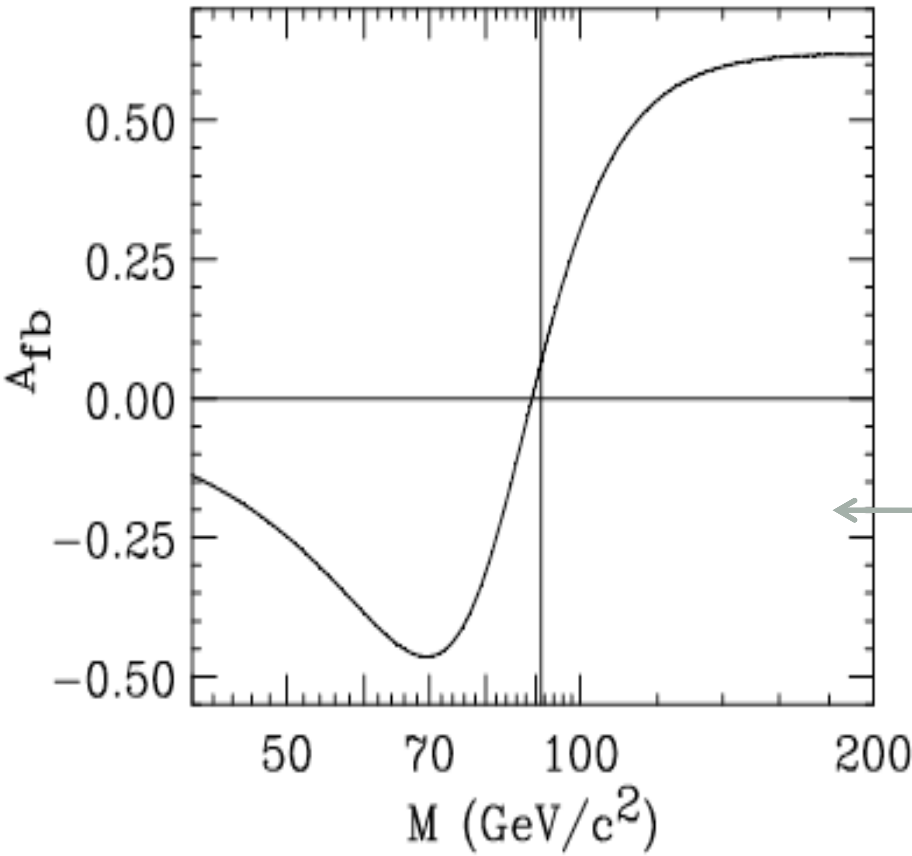


FIG. 2. The typical behavior of A_{fb} as a function of the lepton-pair mass. The vertical line is at $M = M_Z$.

$$
\begin{aligned}
\frac{dN}{d\Omega} \propto\ & (1+\cos^2\vartheta) + \\
& A_0\,\frac{1}{2}\,(1-3\cos^2\vartheta) + \\
& A_1\ \sin 2\vartheta\cos\varphi + \\
& A_2\,\frac{1}{2}\ \sin^2\vartheta\cos 2\varphi + \\
& A_3\ \sin\vartheta\cos\varphi + \\
& A_4\ \cos\vartheta + \\
& A_5\ \sin^2\vartheta\sin 2\varphi + \\
& A_6\ \sin 2\vartheta\sin\varphi + \\
& A_7\ \sin\vartheta\sin\varphi\ .
\end{aligned}
$$

Terms in boxes are zero when integrating over φ . Which yields

$(1+\cos^2\theta) + A_4 \cos\theta$
$+ A_0(M,P_T)\ (1- 3\cos^2\theta)/2$

$A_0(M,P_T=0)=0$

Note that Afb is not Zero at the Z pole. Most of the sensitivity to **$\sin^2\theta_{eff}$** is at the Z pole.

CDF Analysis

- Drell-Yan lepton angular distributions are used to infer $\sin^2\theta_W$
  - Lepton (e,μ^-) angular distributions (ϑ,φ) measured in γ^*/Z CM frame: separates boson production and decay kinematics
  - Born level polar angle distribution: $1 + \cos^2\vartheta + A_4\cos\vartheta$ $\quad A_{FB} = (3/8)\,A_4$
  - $\cos\vartheta$ forward-backward asymmetry: sensitive to $\sin^2\theta_W$
- Vector with axial-vector interference: contributes to A_4 coefficient
  - A_4 term due to Z-boson self-interference $\propto (1-4|Q^e|\sin^2\theta_W)(1-4|Q^q|\sin^2\theta_W)$
  - Fermion (f) couplings to Υ^*/Z bosons: $(g_V + g_A\gamma^5)\gamma^\mu$

    $q\bar{q} \to \Upsilon^* \to e^+e^-$: $g_V^{\,f} = Q^f$ $\quad g_A^{\,f} = 0$ $\quad$ (Q: fermion charge)

    $q\bar{q} \to Z \to e^+e^-$: $g_V^{\,f} = T_3^{\,f}(1-4|Q^f|\sin^2\theta_W)$ $\quad g_A^{\,f} = T_3^{\,f}$ $\quad$ (T_3: weak isospin)

    $\sin^2\theta_W = 1 - M_W^2/M_Z^2$ $\quad$ ($\sin^2\theta_W$ equiv. to M_W)
- Weak radiative corrections complicate this simple Born interpretation
  - Implementation: ZFITTER 6.43 enhanced Born approximation (EBA)
  - T_3 and $\sin^2\theta_W$ → effective T_3 and $\sin^2\theta_W$: 1-4% multiplicative form factors
  - On-mass shell scheme: $\sin^2\theta_W \equiv 1 - M_W^2/M_Z^2$ to all orders

What is measured is: $\sin^2\theta_{eff}^{lept} \simeq 1.037 \cdot \sin^2\theta_W$ [ZFITTER $\kappa_e(\sin^2\theta_W, M_Z)$ form factor] (approx)

In the analysis we measure **$\sin^2\theta_{eff}$**. We also use the full **complex EW radiative corrections** to **extract** **$\sin^2\theta_W$**, to obtain an indirect measurement of the W mass.

1^{st} innovation:

ZFITTER EW radiative corrections Enhanced Born Approximation (EBA)

Implemented by Univ. of Rochester (W. Sakumoto, A. Bodek, J.-Y. Han), CDF 2.1 **fb^{-1}** ee analysis, arXiv:1307.0770 (2013) Appendix A'

$g_V^f \gamma_\mu + g_A^f \gamma_\mu \gamma_5$. The Born-level couplings are

$$g_V^f = T_3^f - 2Q_f \sin^2\theta_W$$
$$g_A^f = T_3^f,$$

$$\mathrm{SM}(\sin^2\theta_W) \xmapsto{\mathrm{EWK}} \sin^2\theta_{\mathrm{eff}}(s) \xleftrightarrow{\mathrm{QCD}} A_4(s),$$

$A_{FB} = (3/8)\, A_4$

They are modified by ZFITTER form factors (which are complex)

$$g_V^f \to \sqrt{\rho_{eq}}\,(T_3^f - 2Q_f\kappa_f \sin^2\theta_W), \text{ and}$$
$$g_A^f \to \sqrt{\rho_{eq}}\,T_3^f,$$

These EW modification (Enhanced Born Approx - EBA)) are incorporated into various QCD calculation of A_{FB} (e.g. POWHEG, RESBOS) with CT10 NLO PDFs.

The value of **$\sin^2\theta_{eff}$** extracted with RESBOS EBA radiative corrections is ~0.00031 larger than the value extracted using Pythia 6.4 with no radiative corrections. This is 1/3 of the statistical error of this measurement which is 0.0009.

2nd innovation: Precise muon momentum scale corrections
A. Bodek et al. Euro. Phys. J. C72, 2194 (2012)

New technique now used in CDF, CMS (and is also being implemented in LHCb).

- In all experiments, there are η, Φ and charge dependent errors on the muon momentum because of residual misalignments in the detector.

- Muon scale corrections are essential for precise measurements of asymmerties, Higgs mass, and high mass Drell Yan pairs.

The Z mass is well known, and can be used as a calibration. However, the measured mass depends on the scale correction for two muons.

Need a simple technique to removes the correlations between the scales for the two muons.

Precise muon momentum scale corrections - A. Bodek et al. Euro. Phys. J. C72, 2194 (2012)

The method:

- Find the $<1/P_T>$ muons from Z events in bins of η, Φ and charge. Compare to the expected for a perfectly aligned detector with the same resolution. These yield the scale corrections for positive and negative muons in bins of η, and Φ .
- Compare the corrections for positive and negative muons to obtain additive corrections to <1/PT> *from residual misalignment* and multiplicative corrections (B field scale). The corrections *from residual misalignment* dominate.
- Now compare the mean Z mass in bins of η, Φ and charge to the mass expected from a perfectly aligned detector. These are used to fine tune the corrections.

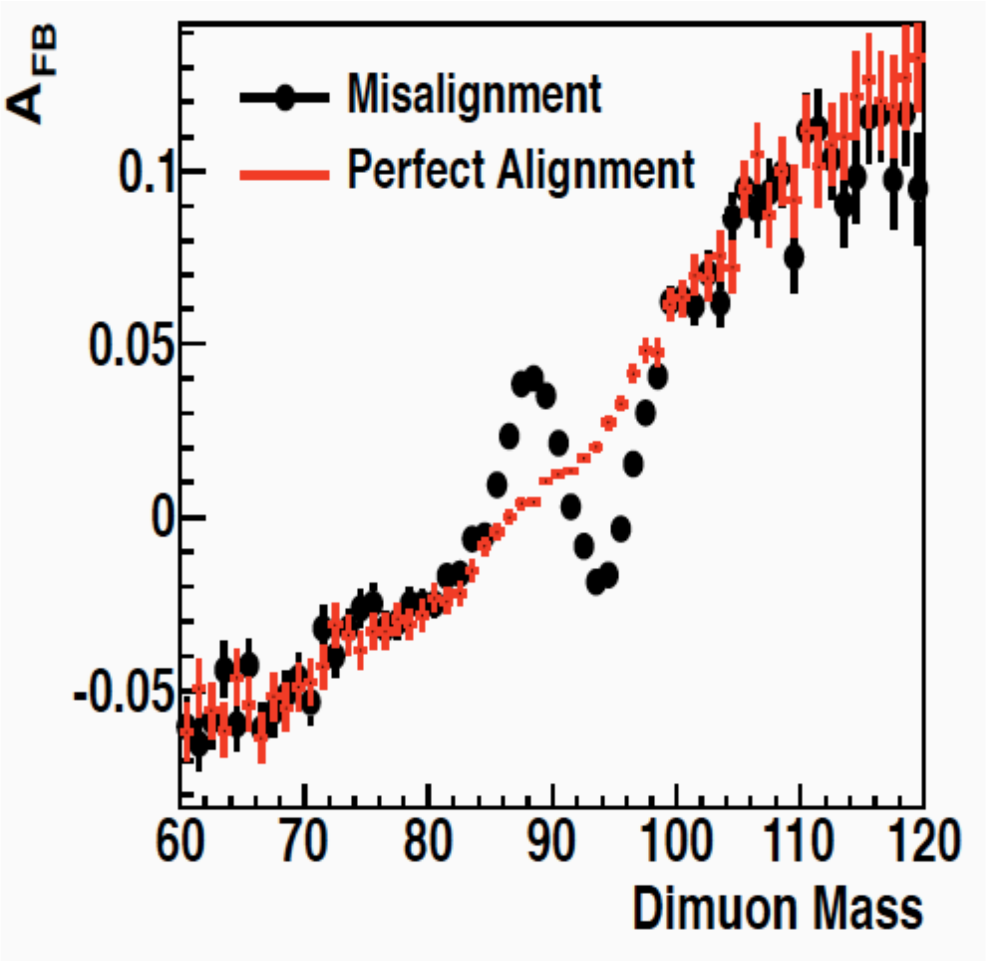
Checks of the method

- Check for charge bias by looking at the Φ distribution in the Collins-Soper frame which is very sensitive to a bias between positive and negative muons
- Check the corrections against other candles such as upsilon and J/psi at low mass.
- Extract the corrections using the technique for a MC simulation which incorporates the best estimate of the misalignments, and find how well the corrections work for very high mass.

How important are the momentum scale corrections for residual misalignments at the Tevatron and LHC>

From: A. Bodek et al. Euro. Phys. J. C72, 2194 (2012)

An example of a simulated Afb measurement in an LHC CMS-like detector with typical residual misalignments as compared to a perfectly aligned detector.



(CDF 9 fb^{-1}: 277K $\mu^+\mu^-$ events)

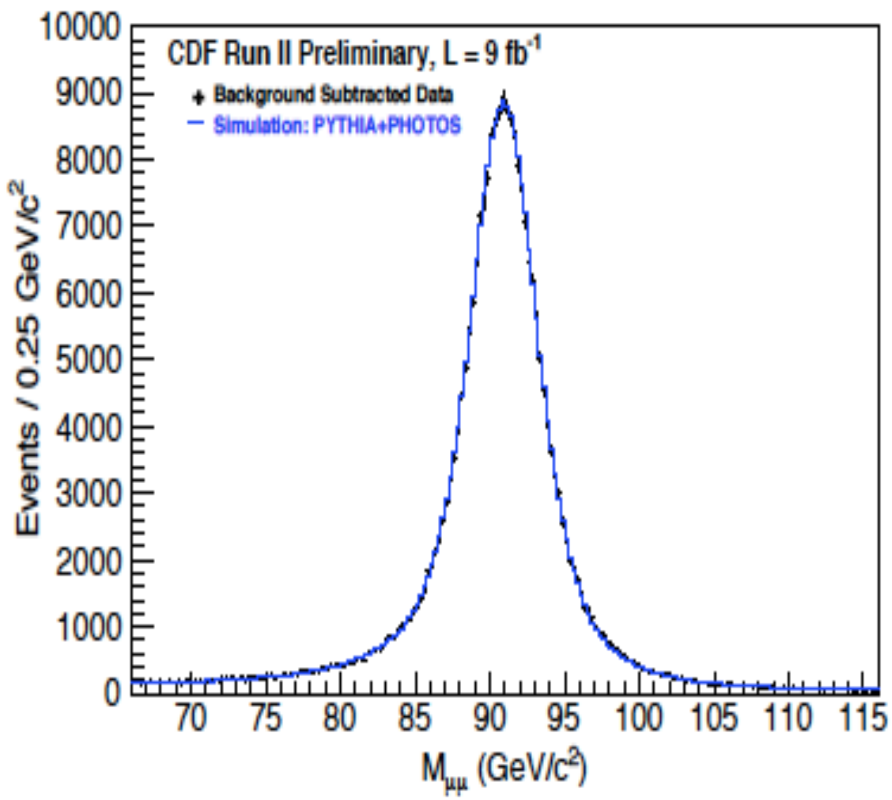


FIG. 3. Calibrated muon-pair mass distributions. The crosses are the background-subtracted data, and the solid histogram is the simulation.

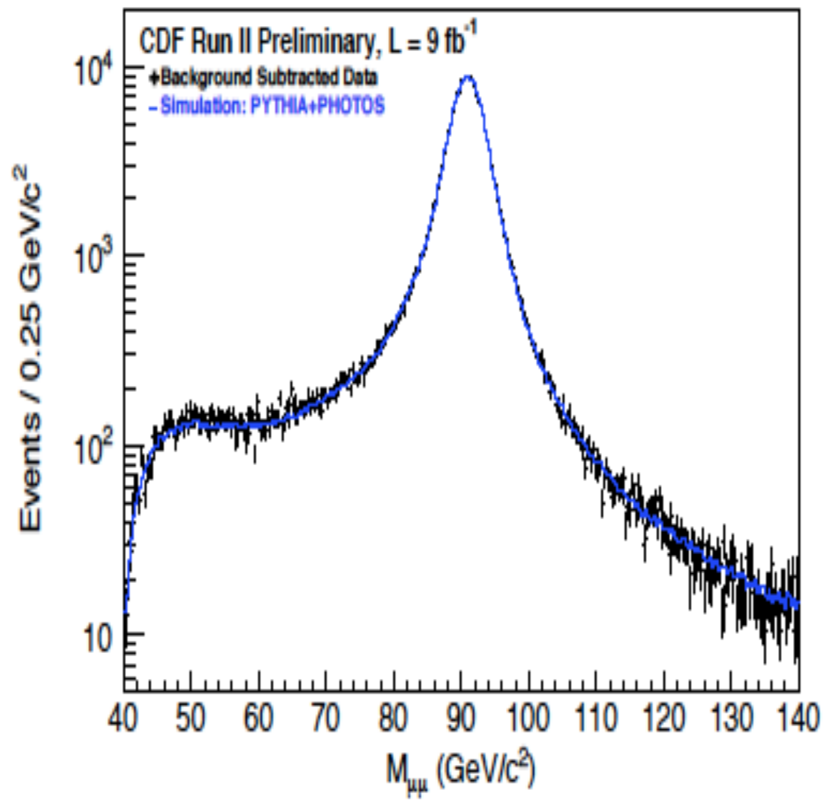


FIG. 4. Calibrated muon-pair mass distributions. The crosses are the background-subtracted data, and the solid histogram is the simulation.

(CDF 9 fb^{-1}: 277K $\mu^+\mu^-$ events)

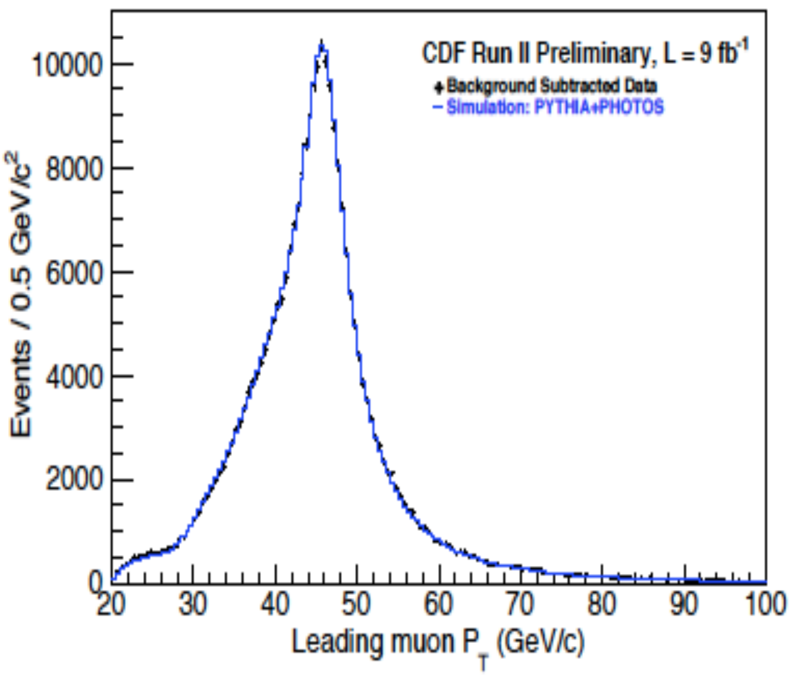


FIG. 5. Calibrated P_T distribution for the muon with the largest P_T. The crosses are the background-subtracted data, and the solid histogram is the simulation.

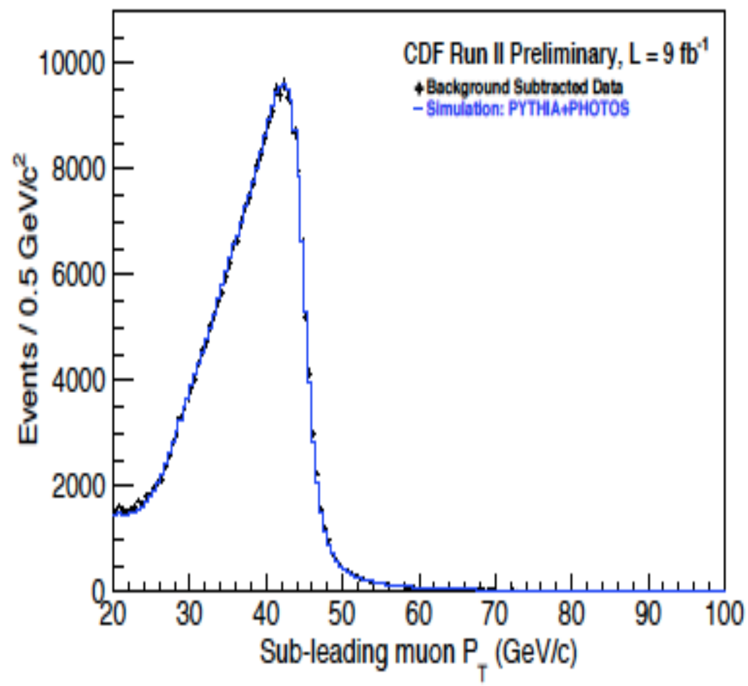


FIG. 6. Calibrated P_T distribution for the muon with the smallest P_T. The crosses are the background-subtracted data, and the solid histogram is the simulation.

(CDF 9 fb^{-1}: 277K $\mu^+\mu^-$ events)

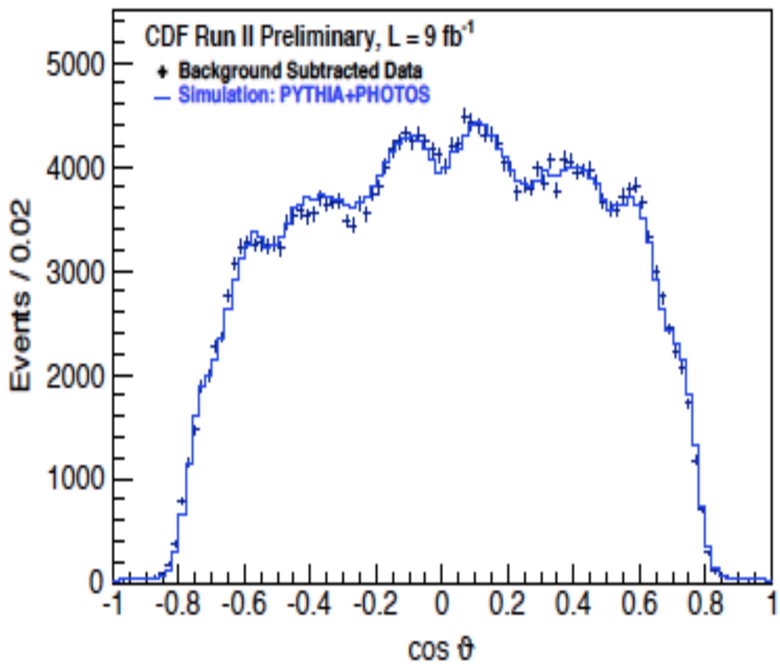


FIG. 7. The adjusted $\cos\vartheta$ distribution. The crosses are the background-subtracted data, and the solid histogram is the simulation.

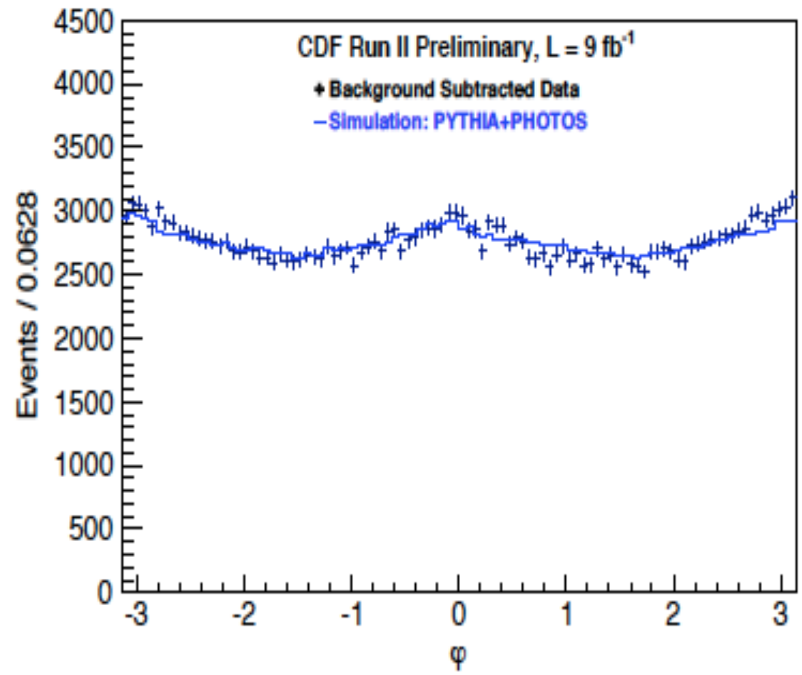


FIG. 8. The observed φ distribution. The crosses are the background-subtracted data, and the solid histogram is the simulation.

3rd innovation: Event weighting method for AFB analyses

A. Bodek, Eur. Phys. J. C **67**, 321 (2010).

In this technique, all cosθ acceptance and efficiencies cancel to first order and the statistical errors are 20% smaller.

$$\frac{d\sigma}{d(\cos\theta)} = A[1+\cos^2\theta + h(\theta)] + B\cos\theta$$

$$h(\theta) = \frac{1}{2}A_0(M_{\ell\ell}, P_T)(1-3\cos^2\theta)$$

A_0 (M, P_T) is a small QCD correction originating from the P_T of the lepton pair resulting from gluon emission. A_0=0 for P_T=0. It has been measured at CDF and is in agreement with QCD calculations. It is described by the following form with k=1.65

$$A_0 = \frac{kP_T^2}{kP_T^2 + M^2}$$

We now investigate how much can be gained by looking at the asymmetry in bins of $|c_j| = |\cos\theta_j|$. We start with the case of $\bar{q}q$ collisions and divide the sample into ten bins in $|\cos\theta_j|$. The asymmetry as a function of $|c_j|$ bin is:

$$A_{fb-j}(c_j) = \frac{\sigma_f(|c_j|) - \sigma_b(|c_j|)}{\sigma_f(|c_j)| + \sigma_b|(c_j|)} \qquad (22)$$

$$A_{fb-j}(c_j) = \frac{N_{f,j} - N_{b,j}}{N_{f,j} - N_{b,j}}$$

$$= \frac{B|c_j|}{A(1+c_j^2 + h(M_{\ell\ell}, \theta, P_T)}$$

$$= A_{fb-j}^{total}\left[\frac{8|c_j|}{3(1+c_j^2+h(\theta)}\right]$$

For each bin in **cosθ** the acceptance and efficiencies cancel.

Event Weighting Technique - continued

A. Bodek, Eur. Phys. J. C **67**, 321 (2010).

$$A_{fb-j}(c_j) = A^{total}_{fb-j}\left[\frac{8|c_j|}{3(1+c_j^2+h(\theta)}\right]$$

At $|c_j| = |\cos\theta_j| = 0$, the measured asymmetry $A_{fb-j}(0)$=0. At $|c_j| = |\cos\theta_j| = 0.45$, the measured asymmetry $A_{fb-j}(0.45)$ = A^{total}_{FB}. At $|c_j| = |\cos\theta_j| = 1$, the asymmetry $A_{fb}(1) = (4/3)A^{total}_{fb}$. The measured asymmetry in each $|c_j| = \cos\theta_j$ bin can be related to the total (integrated over all $\cos\theta$) asymmetry. Therefore each $|\cos\theta_j|$ bin provides an independent measurement A^{total}_{fb-j} of the total asymmetry.

$$A^{total}_{fb-j} = \frac{3}{8}\cdot\frac{N_{f,j}-N_{b,j}}{N_{f,j}+N_{b,j}}\cdot\frac{1}{M_j}$$

$$M_j = \frac{|c_j|}{(1+c_j^2+h(M_{\ell\ell},\theta,P_T))}$$

However, one does not need to bin the data in cosθ . Using proper event weights, one can combine the events from all values of cos θ. The events at cosθ = 0 where the asymmetry is 0 have a weight of zero, and events at cosθ = 1 have a maximum weight.

With event weighting, all cosθ acceptance and efficiencies cancel to first order and the statistical errors are 20% smaller. 2nd order corrections are applied using a MC.

The asymmetry measurement in the muon channel could not be done with any other technique.

This is because of the multiple number of muon detectors at various values of eta (10 topologies) which have a very complicated and very hard to model acceptance

TABLE I. The number of events after background subtraction for the various muon-pair topologies.

Muon 1	Muon 2	Events
CMUP	CMUP	43 900.0
CMUP	CMX	69 704.0
CMUP	CMU	18 651.7
CMUP	CMIO	50 121.8
CMUP	BMU	15 773.9
CMX	CMX	26 316.5
CMX	CMU	14 359.7
CMX	CMIO	30 752.1
CMX	BMU	6 822.8
CMUP+CMX	CMP	447.7

After background subtraction : 276,623 events in CDF run II (**9 fb^{-1} $\mu^+\mu^-$**)

Comparison of the cosθ distribution for all 10 topologies in the 9 fb^{-1} $\mu^+\mu^-$ sample to the cosθ distribution for the two topologies (CC and CP) for the 2.1 fb^{-1} e^+e^- sample..

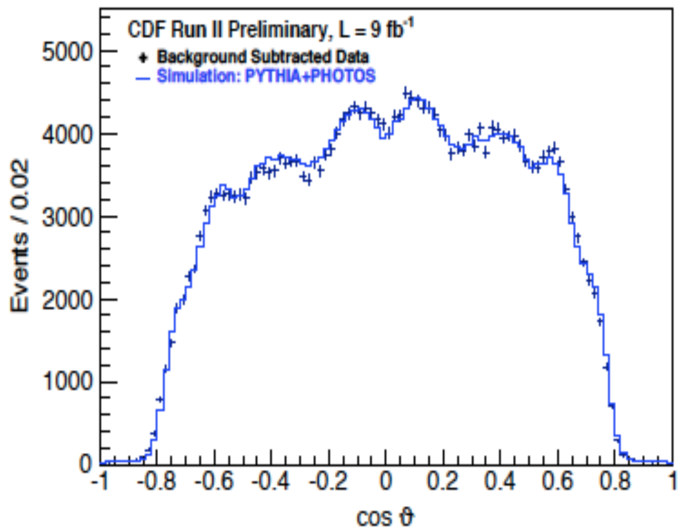


FIG. 7. The adjusted $\cos\vartheta$ distribution. The crosses are the background-subtracted data, and the solid histogram is the simulation.

Number of events for all 10 topologies as a function of cosθ for the 9 fb^{-1} $\mu^+\mu^-$ sample (277K $\mu^+\mu^-$ events)

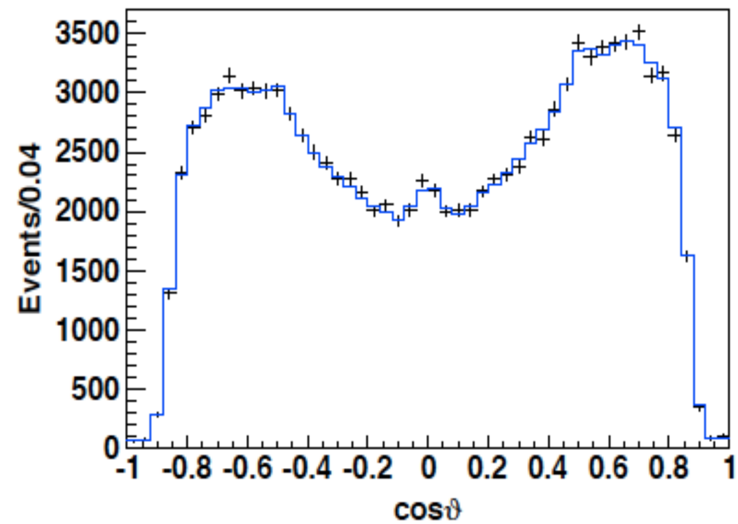


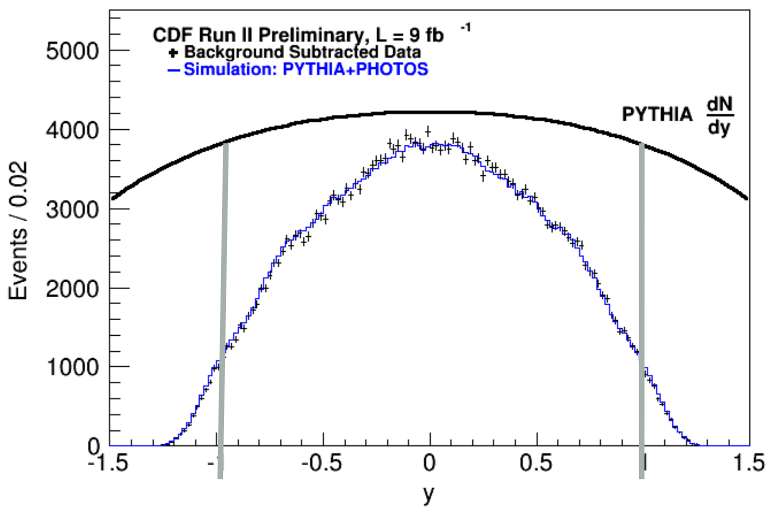
FIG. 7. The observed $\cos\vartheta$ distribution for the combined CC and CP topologies. The crosses are the background-subtracted data, and the solid histogram is the simulation.

Number of events for the two topologies (CC and CP) a function of cosθ for the 2.1 fb^{-1} e^+e^- sample (123K e^+e^- events)

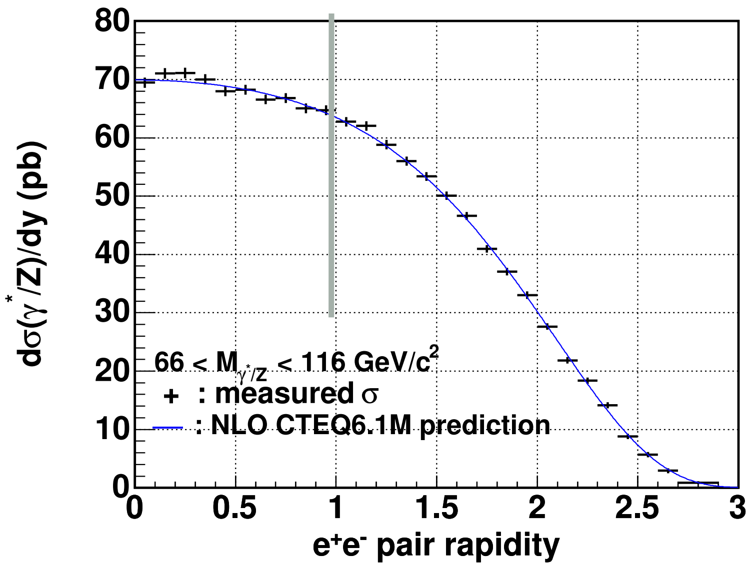
Because of the larger acceptance in cosθ for e^+e^- events, future errors in $\sin^2\theta_W$ for the 9 fb^{-1} e^+e^- are expected to be half of the errors of the current 9 fb^{-1} $\mu^+\mu$ sample

2nd order corrections to event weighting

Acceptance in rapidity needs to be accounted for. In the $\mu^+\mu^-$ analysis we measure the asymmetry for |y|<1 and compare to theory with |y|<1



Number of events as a function of rapidty for all $\mu^+\mu^-$ topologies **for the 9 fb^{-1} $\mu^+\mu^-$ sample.**



Acceptance corrected rapidity distribution for the three e^+e^- topologies (CC, CP and PP) **for the 2.1 fb^{-1} e^+e^- sample**

Because of the dilution from the small fraction of antiquarks in the proton and the small fraction of quarks in antiproton, Afb has a weak dependence on y. The bias from the variation of the acceptance with y for y<1 is included in a 2nd order correction.

backgrounds

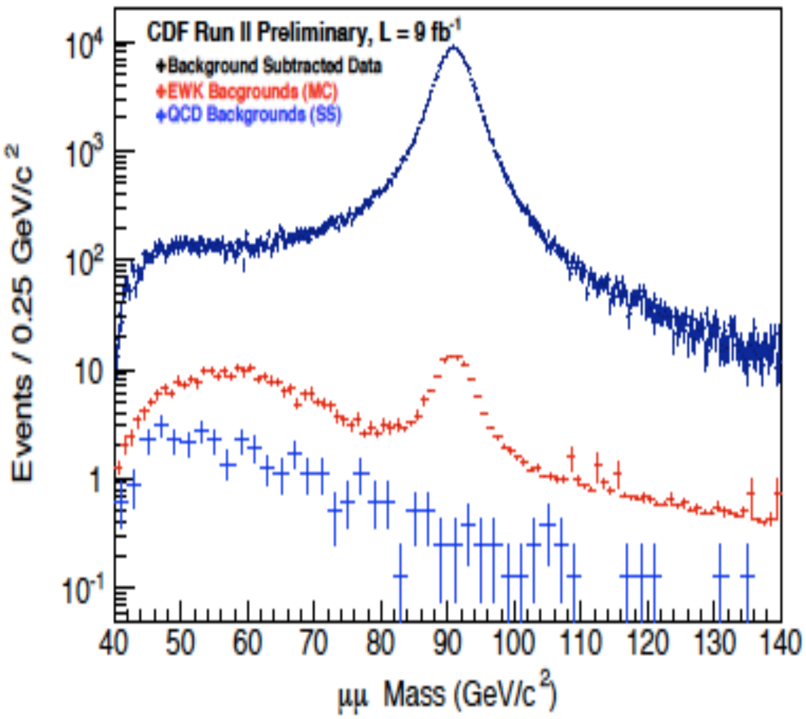
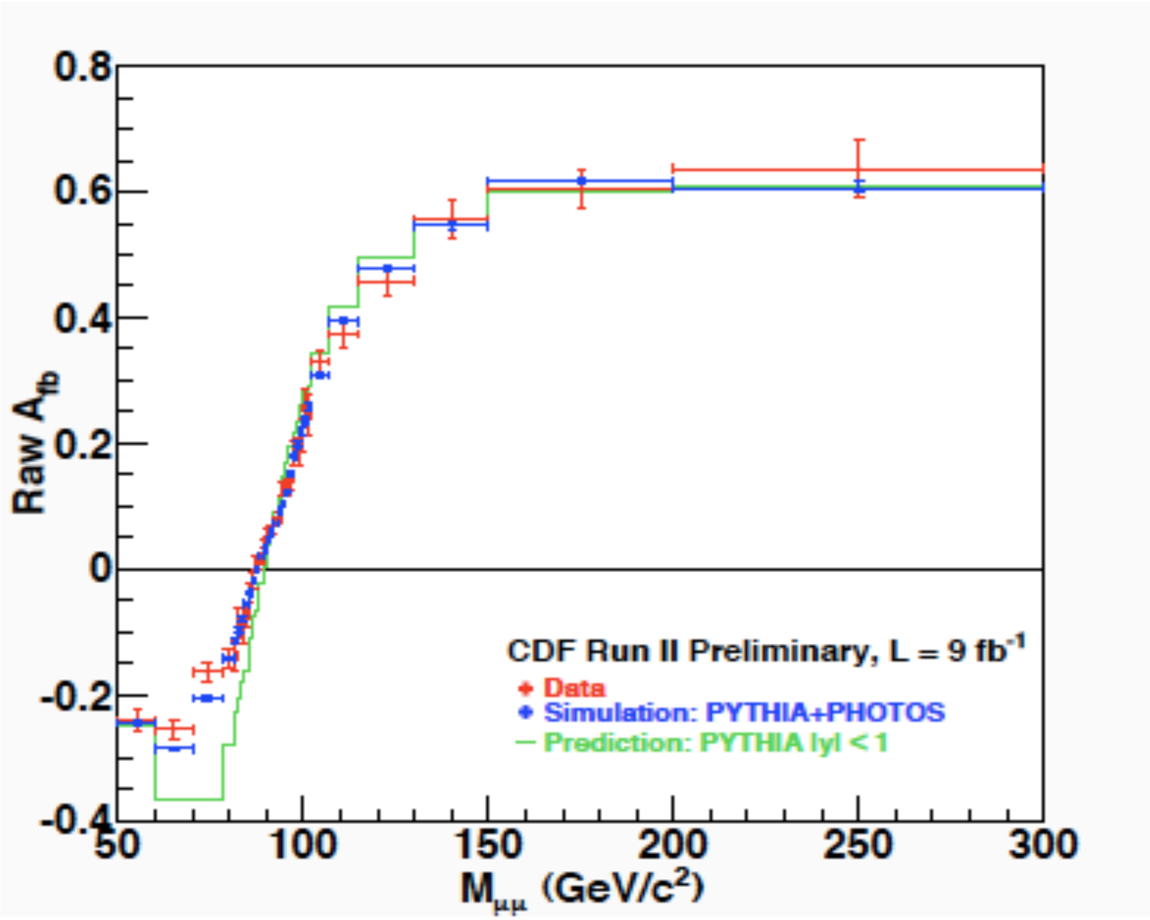


FIG. 1. Muon-pair mass distributions. The upper set of crosses are the background subtracted data, the middle set of crosses are the EWK backgrounds, and the lower set of crosses are the SS charge (QCD) events.

Small Backgrounds from electroweak processes (0.5%, shown in red) are well understood. These include WW, WZ, ZZ, t-tbar, W+jets and Z to τ+τ-.

QCD background (in blue) is extremely small, 0.1% estimated from then number of same sign muons.



QED FSR and detector resolution change the mass distribution and are corrected for using matrix unfolding.

FIG. 9. The raw A_{fb} measurement in bins of the muon-pair mass. The red crosses are for the data, and the blue crosses are for the simulated data. Only statistical uncertainties are shown. For the simulated data, the uncertainties represent the full precision of the simulation. The green histogram is the prediction from PYTHIA for $|y| < 1$ (before QED FSR).

Afb results 9 fb^{-1} $\mu^+\mu^-$

2nd order correction to event weighting
From MC simulation,

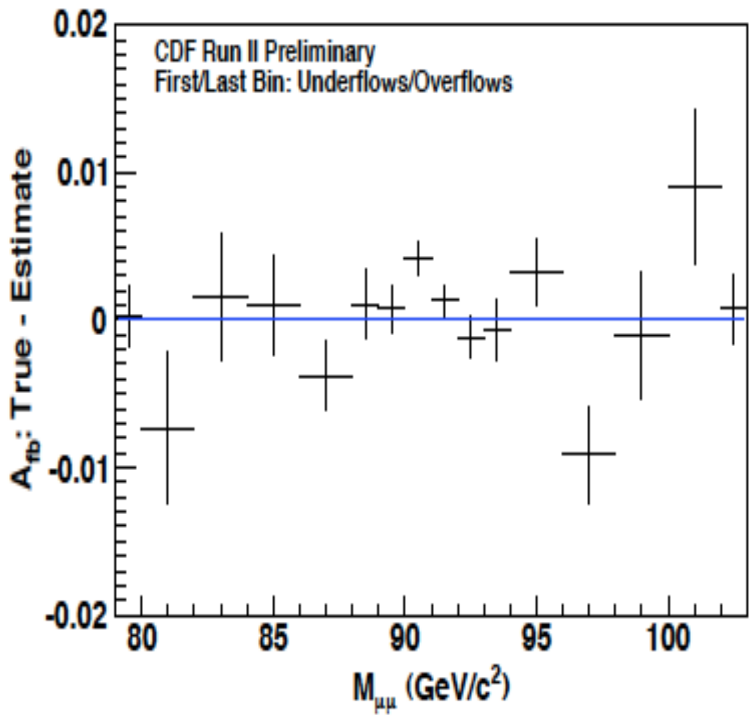
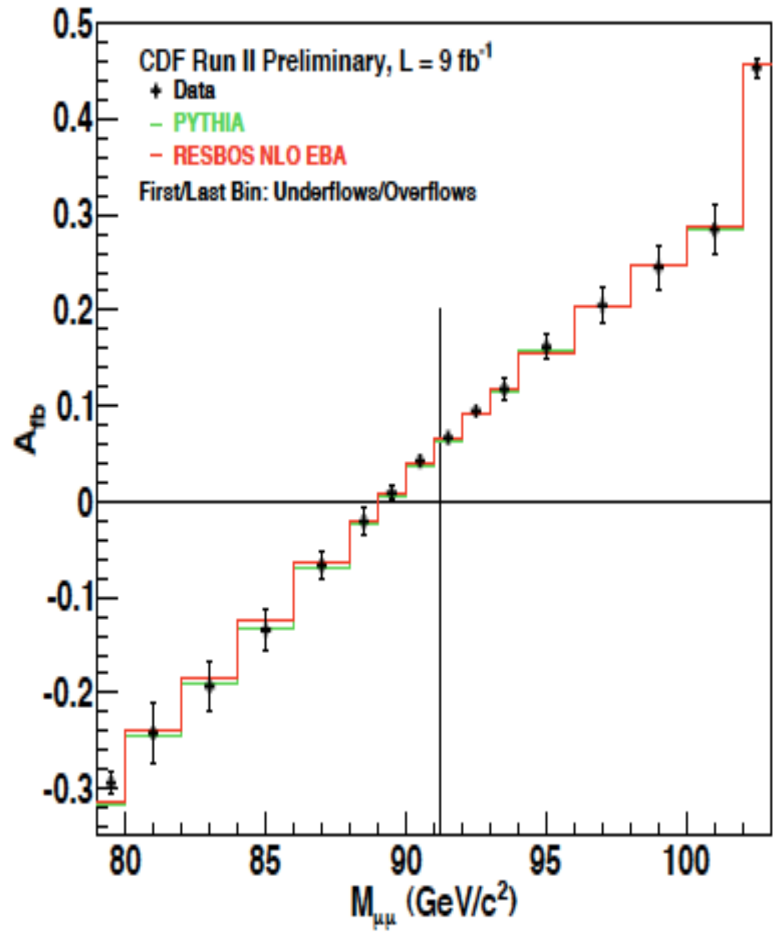


FIG. 11. The event-weighting bias for each of the muon-pair mass bins. The bias is estimated with the simulation, and the uncertainties represent the full precision of the simulation.

Matrix unfolding for resolution and QED FSR

Fully corrected and unfolded Afb



How do we determine the 2nd order (bias) correction?

- **Start with CDF Pythia 6.2 with a certain input Afb,. Extract the input Afb for |y|<1 to match the muon acceptance region.**
- **Do a complete detector simulation.**
- **Reconstruct the MC data and perform the complete analysis (using event weighting, and resolution and FSR unfolding).**
- **The difference between the "measured" Afb for the MC simulated data and the input Afb (for |y|<1) is the bias correction.**
- **The bias correction corrects for "all" 2nd order effects, such as the fact that the acceptance (for |y|<1) is not uniform, and any other 2nd order effects.**

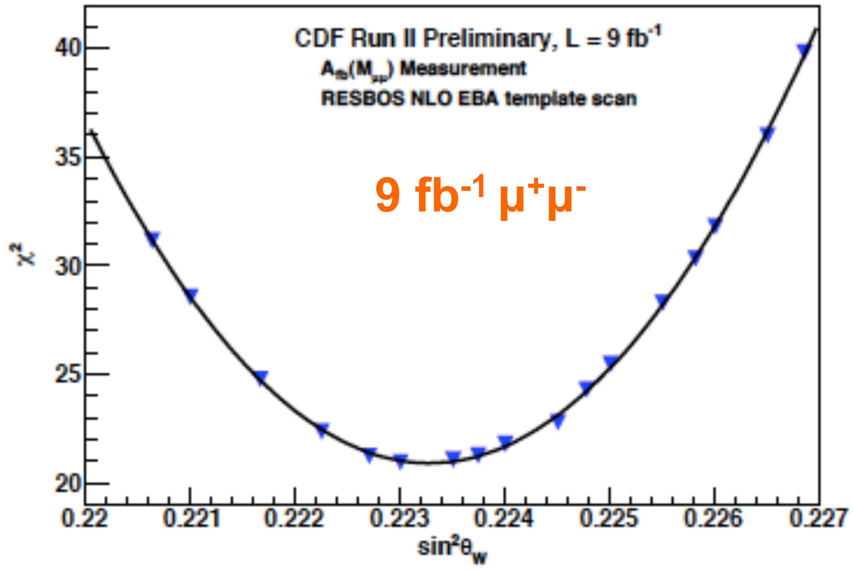


FIG. 13. Comparison of the $A_{\rm fb}$ measurement with the RESBOS NLO templates. The triangles are the scan points, and the solid curve is the fit of those points to a generic χ^2 functional form. EBA (enhanced Born approx) templates

Template (Measurement)	$\sin^2\theta^{\rm lept}_{\rm eff}$	$\sin^2\theta_W$	$\bar{\chi}^2$
RESBOS NLO	0.2315 ± 0.0009	0.2233 ± 0.0008	20.9
POWHEG-BOX NLO	0.2314 ± 0.0009	0.2232 ± 0.0008	21.1
Tree LO	0.2316 ± 0.0008	0.2234 ± 0.0008	24.3

TABLE III. Summary of the systematic uncertainties on the extraction of the weak mixing parameters $\sin^2\theta^{\rm lept}_{\rm eff}$ and $\sin^2\theta_W$.

Source		$\sin^2\theta^{\rm lept}_{\rm eff}$	$\sin^2\theta_W$
Momentum scale	exp	± 0.00005	± 0.00005
Backgrounds		± 0.00010	± 0.00010
QCD scales	theory	± 0.00002	± 0.00002
CT10 PDFs		± 0.00009	± 0.00009
EBA		± 0.00010	± 0.00010
Total syst		± 0.00017	± 0.00018

ResBos $\sin^2\theta^{\rm lept}_{\rm eff} = 0.2315 \pm 0.0009 \pm 0.0002$ ← measured

$\sin^2\theta_W = 0.2233 \pm 0.0008 \pm 0.0002$ ← inferred

$M_W = 80.365 \pm 0.043 \pm 0.010$ GeV

Statistical errors still dominate. Expect factor of 2 reduction of errors the with 9 **fb**$^{-1}$ e+e- sample

EBA radiative corrections increased the extracted values of $Sin^2\theta_w$

Resbos NLO template – by 0.00031
POWHEG-BOX NLO template - by 0.00021
Pythia LO template - by 0.00047

1. **Muon Momentum Calobration of Data and Simulation is critical for Afb.**
A. Bodek et al. Eur. Phys. J. C72, 2194 (2012)
   - Consistent Z-peak mass independent of muon (η,φ) trajectory
   - Very good $M_{\mu\mu}$ distribution agreement between simulation and data

2. **Event weighting technique is critical, detector acceptance cancels.**
A. Bodek, Eur. Phys. J. C67, 321 (2010)

3. **Enhanced Born Approximation (EBA) EW radiative corrections**:
Increases the extracted $\sin^2\theta_{eff}$ by ~0.0003 CDF arXiv:1307.0770 (2013) appendix A

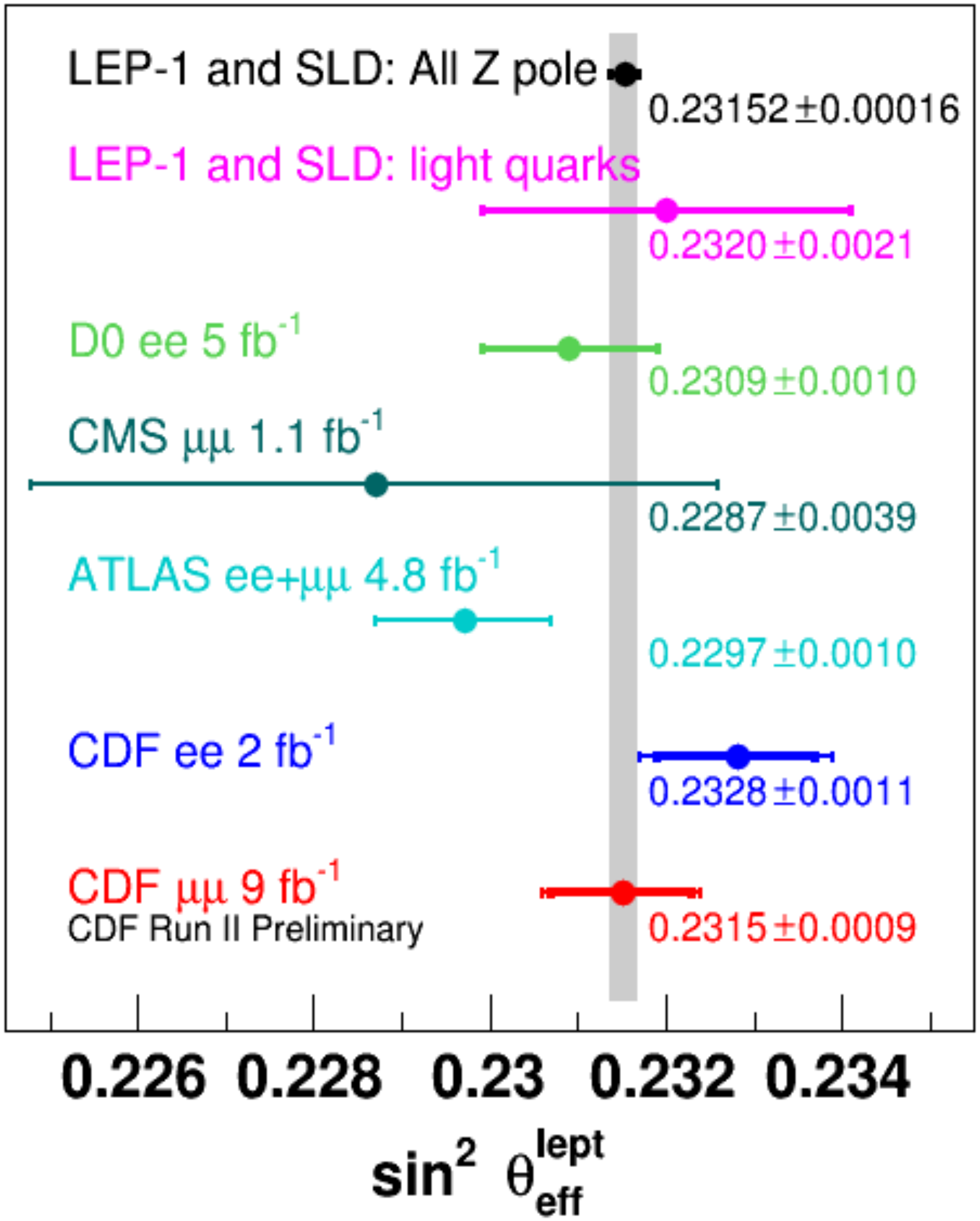
- Results from EBA Afb template scans (fits)
   - ResBos NLO $\sin^2\theta_{eff}^{lept}$=0.2315±0.0009 CT66
   - Powheg NLO $\sin^2\theta_{eff}^{lept}$=0.2314±0.0009 CT10
   - Tree LO $\sin^2\theta_{eff}^{lept}$=0.2316±0.0008 CT10

   errors are dominated by the statistical errors. Expect a factor of 2 reduction in Spring 2014 when we add *9* **fb**$^{-1}$ *in the ee channel*

   - Total $\sin^2\theta_W$ systematics: ±0.00017 [$\Delta\sin^2\theta_{eff}^{lept}$=±0.00018]
- 9 fb^{-1} muon Afb: ResBos $\sin^2\theta_{eff}^{lept}$ = 0.2315 ± 0.0009 ± 0.0002 ← measured
  $\sin^2\theta_W$ = 0.2233 ± 0.0008 ± 0.0002 ← inferred
  M_W = 80.365 ± 0.043 ± 0.010 GeV ↲

Analysis of 9 **fb**$^{-1}$ *ee channel (~500K events) is in progress (factor of 2 reduction in errors- Spring 14)*

Comparison to other experiments



Involves average of LEP1 and SLD (which are somewhat inconsistent)

Directly comparable to q-qbar -> ee, $\mu^+\mu$

Phys. Rev. D84, 012007 (2011)

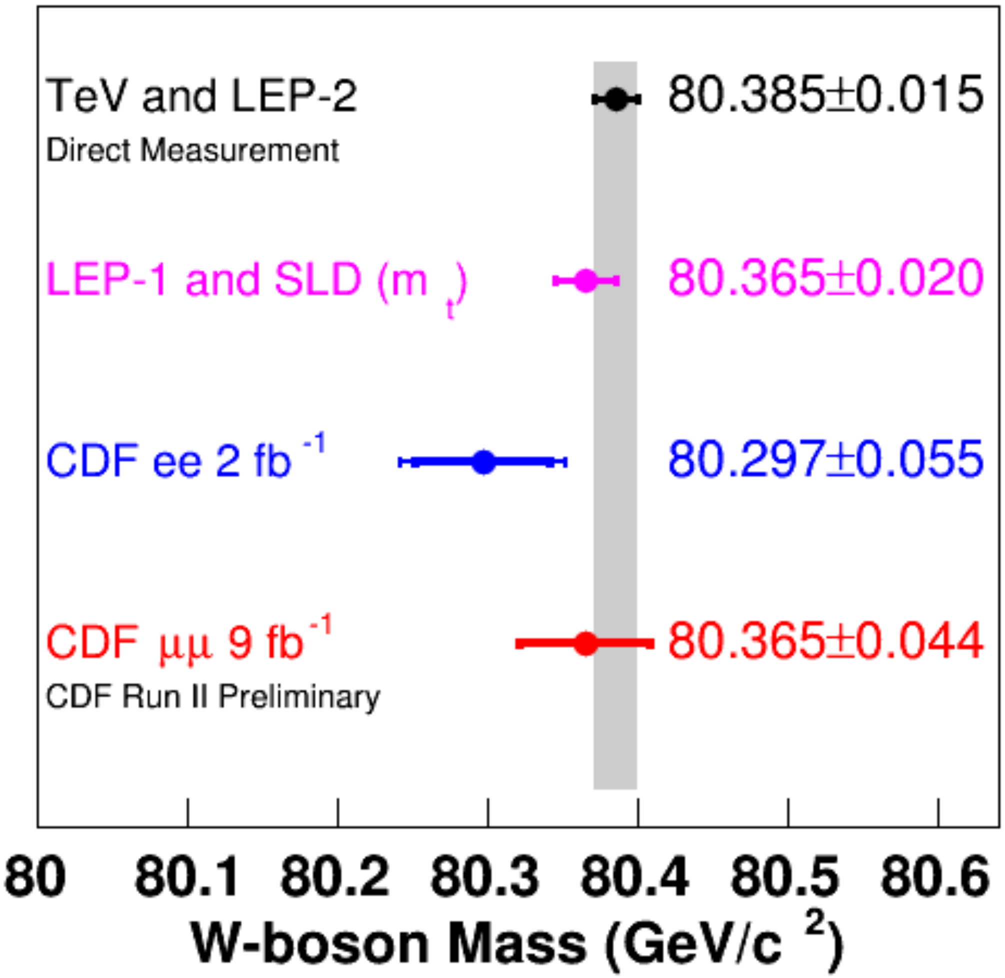
Phys. Rev. D84, 112002 (2011)

EPS 2013

arXiv:1307.0770 (2013)-> PRD 2013
partial (CDF 2 fb^{-1}) e^+e^- Run II data)

WIN 2013 ->PRD 2013
(all CDF 9 fb^{-1} $\mu^+\mu^-$ Run II data)

CDF 9 fb^{-1} $\mu^+\mu$: Comparison to direct measurement of Mw



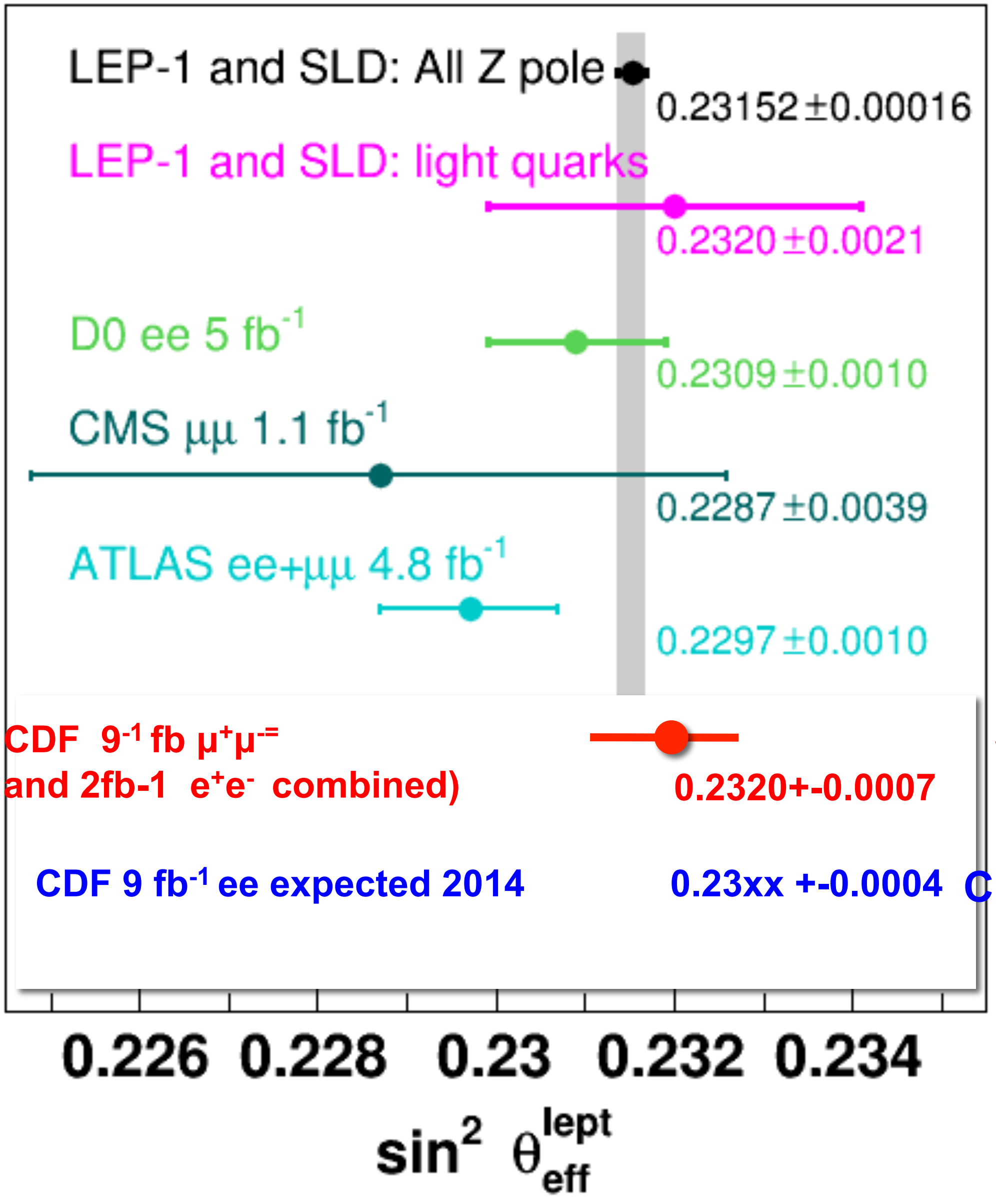
All direct: (CDF, D0, LEP2)
World average

(LEP 1 indirect + top mass)

arXiv:1307.0770 (2013)-> PRD 2013
partial (CDF 2 fb^{-1}) e^+e^- Run II data)

WIN 2013 ->PRD 2013
(all CDF 9 fb^{-1} $\mu^+\mu^-$ Run II data)

Expected in Spring 14



Involves average of LEP1 and SLD (which are somewhat inconsistent)

Directly comparable to q-qbar -> ee, $\mu^+\mu$

Phys. Rev. D84, 012007 (2011)

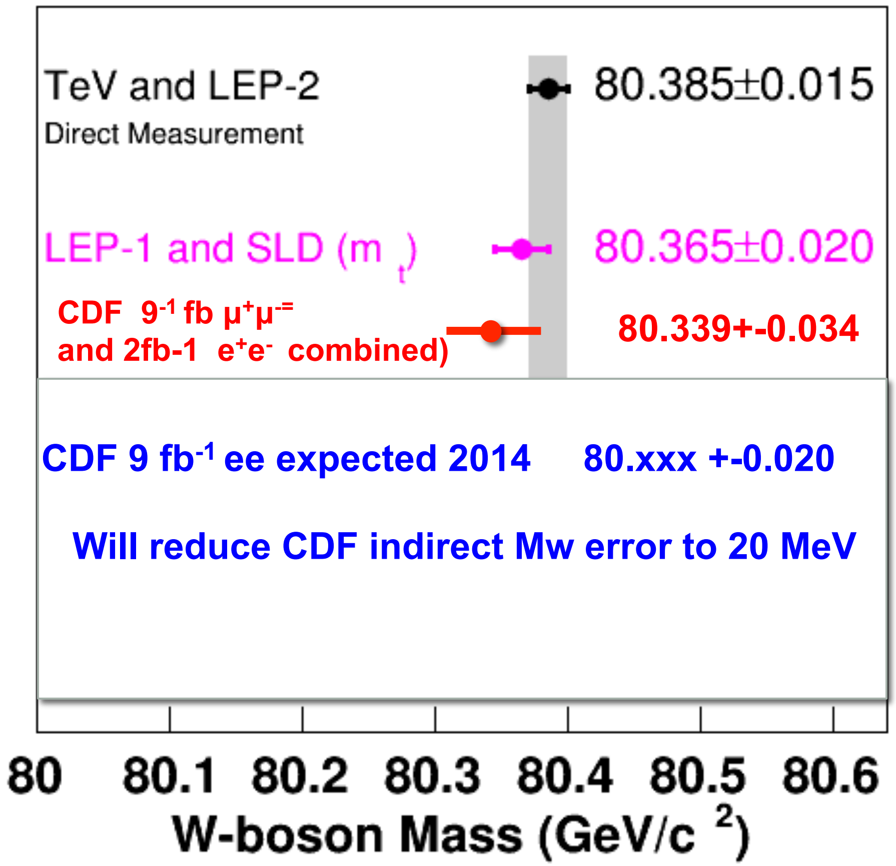
Phys. Rev. D84, 112002 (2011)

EPS 2013

WIN 2013 --my CDF $9fb^{-1}$ $\mu^+\mu^-$ and $2fb^{-1}$ e^+e^- average

CDF Expected in Spring 14

Expected errors in Spring 2014



WIN 2013 --my CDF
$9fb^{-1}$ $\mu^+\mu^{-=}$ and $2fb^{-1}$ e^+e^- average

CDF Expected in Spring 14