Tevatron: EW measurement with single bosons (M_W, $\sin^2\theta_W^{eff}$, $\sin^2\theta_W^{on-shell}$)

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For the CDF and D0 Collaboration

Z decay (forward backward asymmetry → $\sin^2\theta_W^{eff}$)

DØ e^+e^- (9.7 fb^{-1}): Phys. Rev. Lett. 115, 041801(2015): $\sin^2\theta_W^{eff}$

CDF $\mu^+\mu^-$ (9.2 fb^{-1}) Phys. Rev. D89, 072005(2014): $\sin^2\theta_W^{eff}$ & $\sin^2\theta_W^{on-shell}$, $M_W^{indirect}$

CDF e^+e^- (9.4 fb^{-1}) →**LHCP New: $\sin^2\theta_W^{eff}$ & $\sin^2\theta_W^{on-shell}$, $M_W^{indirect}$**

arXiv:1507.02470 → **LHCP new method: PDF Constraints from Drell-Yan A_{FB}**

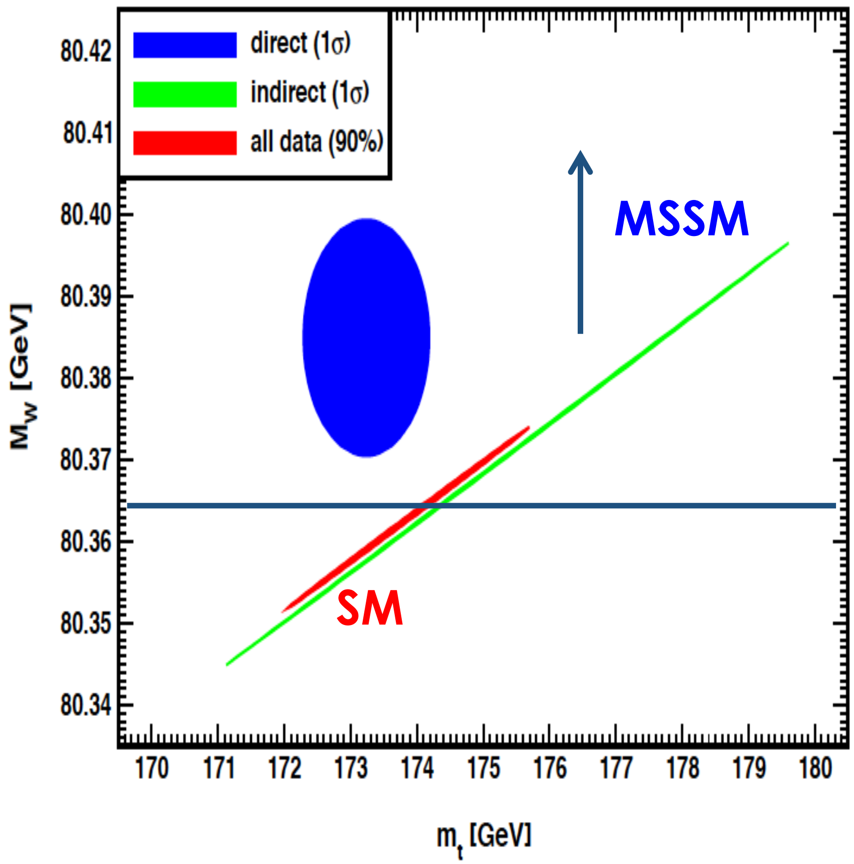
Plenary session 1 LHCP Saint Petersburg, Russia

Wed. Sept 2, 2015 9:30-10:00 AM

UNIVERSITY of ROCHESTER

http://pdg.lbl.gov/2014/reviews/rpp2014-rev-standard-model.pdf

K.A. Olive et al. (PDG), Chin. Phys. C38, 090001 (2014) (http://pdg.lbl.gov)



Some tension ~1.5σ between direct Measurements of Mw and SM

- M_W=80.385±0.015 GeV (D0+CDF combined)

With a known Higgs mass, the SM is over-constrained. A better measurement of M_W provides a more stringent constraints on SM than a better measurement of M_{top}

M_W can also be determined indirectly via the relation

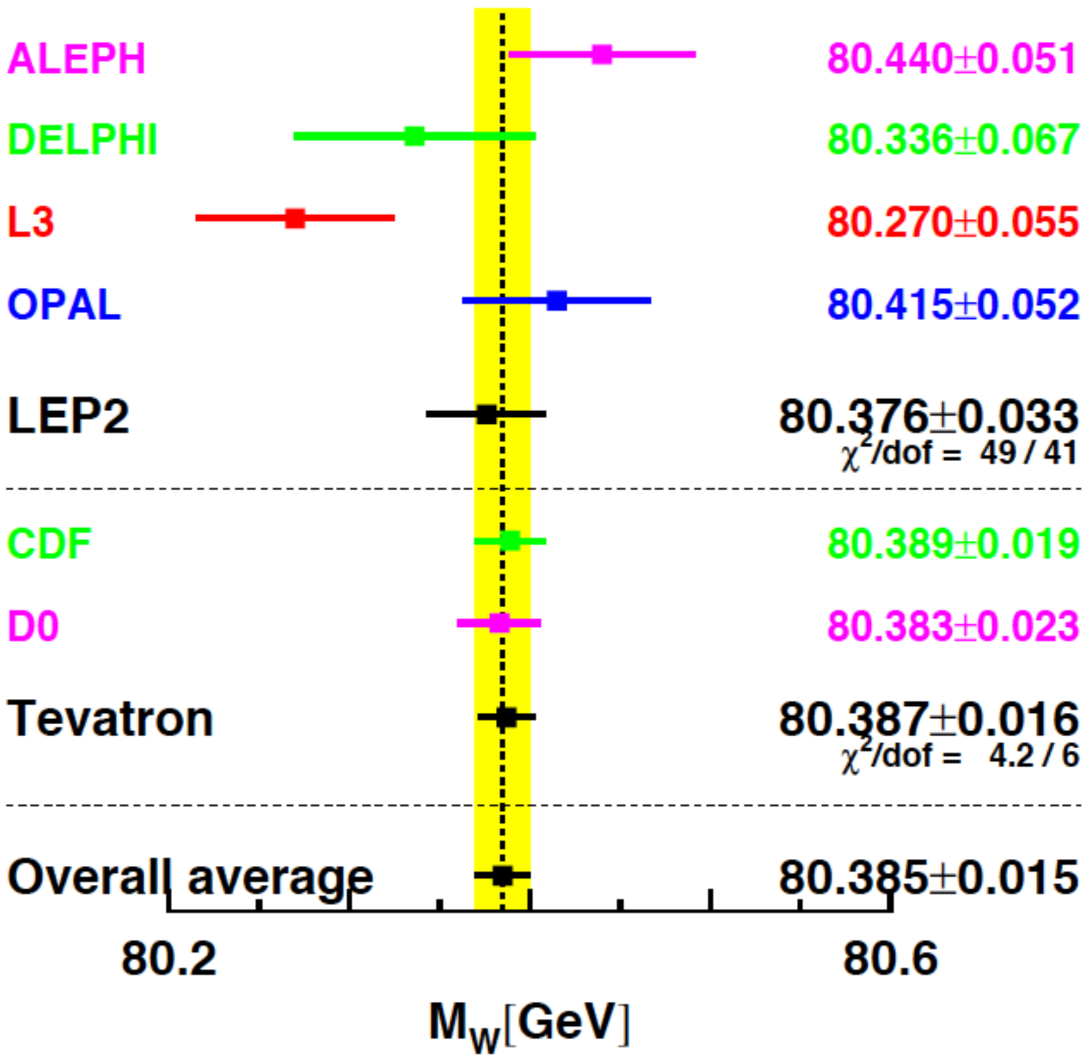
$$\sin^2\theta_W^{on\text{-}shell} = 1 - M_W^2 / M_Z^2$$

Both $\sin^2\theta_W^{on\text{-}shell}$ and $\sin^2\theta_W^{eff}$ can be extracted from Drell-Yan forward-backward asymmetry (Afb) if we include EW radiative corrections

If the SM is correct, than both direct and indirect measurements of M_W should agree. Deviations may imply The possibility of new physics

Direct measurment of W mass LEP & Tevatron 3

http://pdg.lbl.gov/2014/reviews/rpp2014-rev-w-mass.pdf



The most recent Tevatron experiments (CDF and Dzero) have errors of ~20 MeV

Measuring W mass at the Tevatron

Direct W mass analysis at the Tevatron

CDF 2.2 fb^{-1} Tevatron (9.7 fb^{-1} is ongoing)

Phys. Rev. Lett. 108, 151803 (2012)

Source CDF 2.2 fb-1	Uncertainty (MeV)
Lepton energy scale and resolution	→ 7
Recoil energy scale and resolution	6
Lepton removal	2
Backgrounds	3
$p_T(W)$ model	5
Parton distributions	→ 10
QED radiation	4
W-boson statistics	→ 12
Total	→ 19

- M_W=80.385±0.015 GeV (LEP/Tevatron combined)
- Each experiment has has an error of about ±20 MeV, ~10 MeV from statistics and ~10 MeV form systematics.

The statistical error of 12 MeV will be *reduced* in the 9.7 fb^{-1} ongoing analysis.

The PDF and energy scale errors are the largest systematic errors

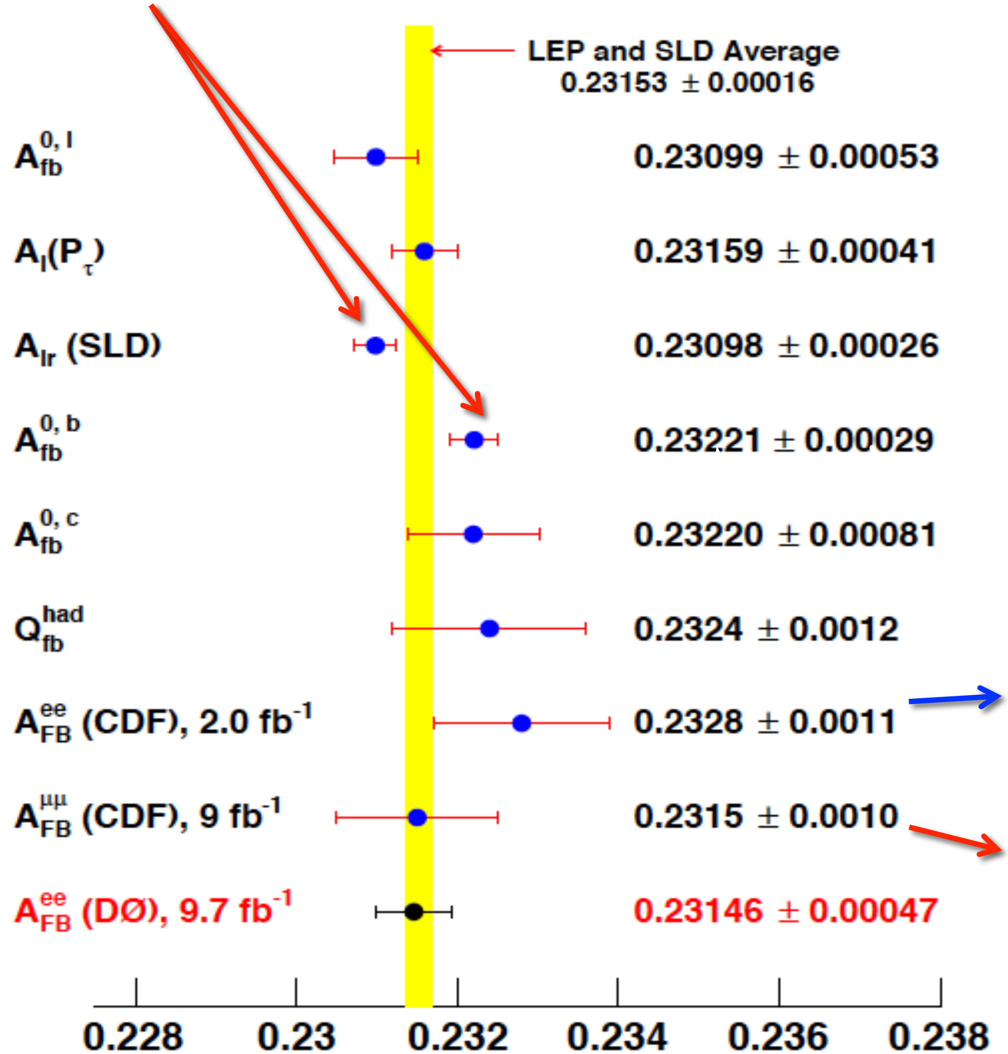
I will discuss how we can improve both in CDF

Published Mw and $\sin^2\theta_W$ Measurements

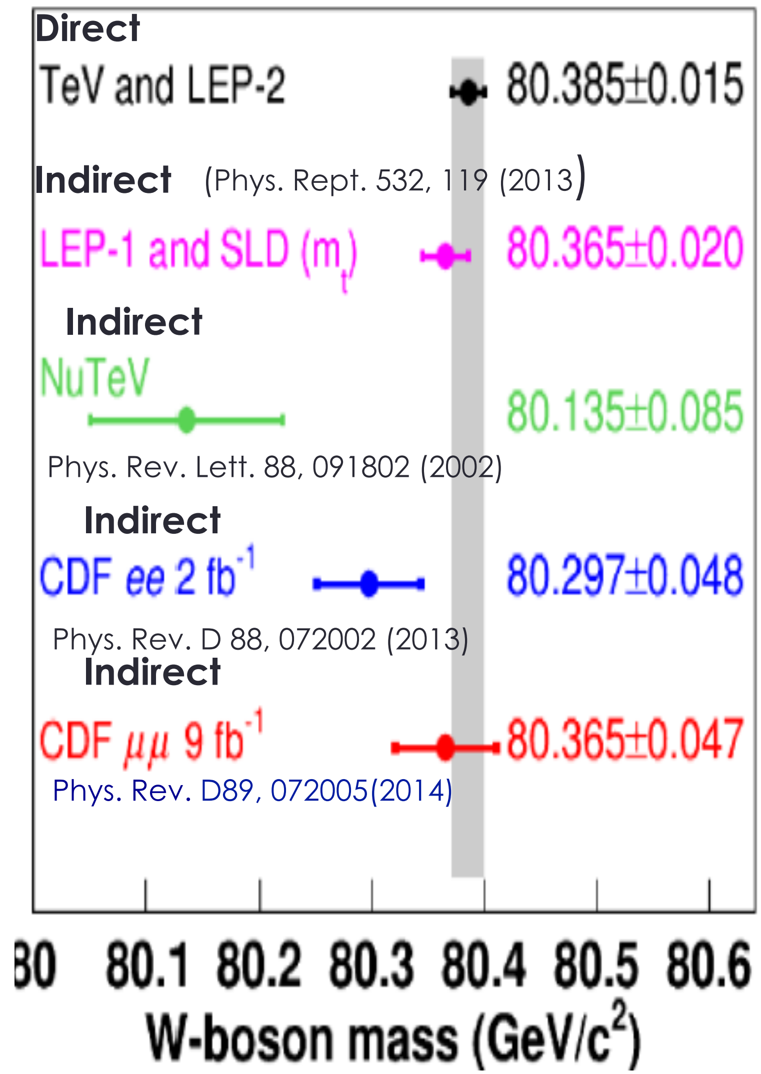
Effective mixing angle $\sin^2\theta_W^{eff}$.

$\sin^2\theta_{eff}$ LEP SLD difference 0.00122 3.2 σ

Error of +- 0.00040 in $\sin^2\theta_W$ is equiv. to +-20 MeV error in Mw.



Measurements of Mw



This conference: New results CDF ee 9.4 fb^{-1}

Measuring $\sin^2\theta_W$ at the Tevatron

- Measure the weak mixing angle from the forward-backward asymmetry of the polar angle distribution in Z/γ^* lepton pairs
- Dilepton frame (Collins-Soper): θ* polar angle of the ℓ^- with the incoming quark

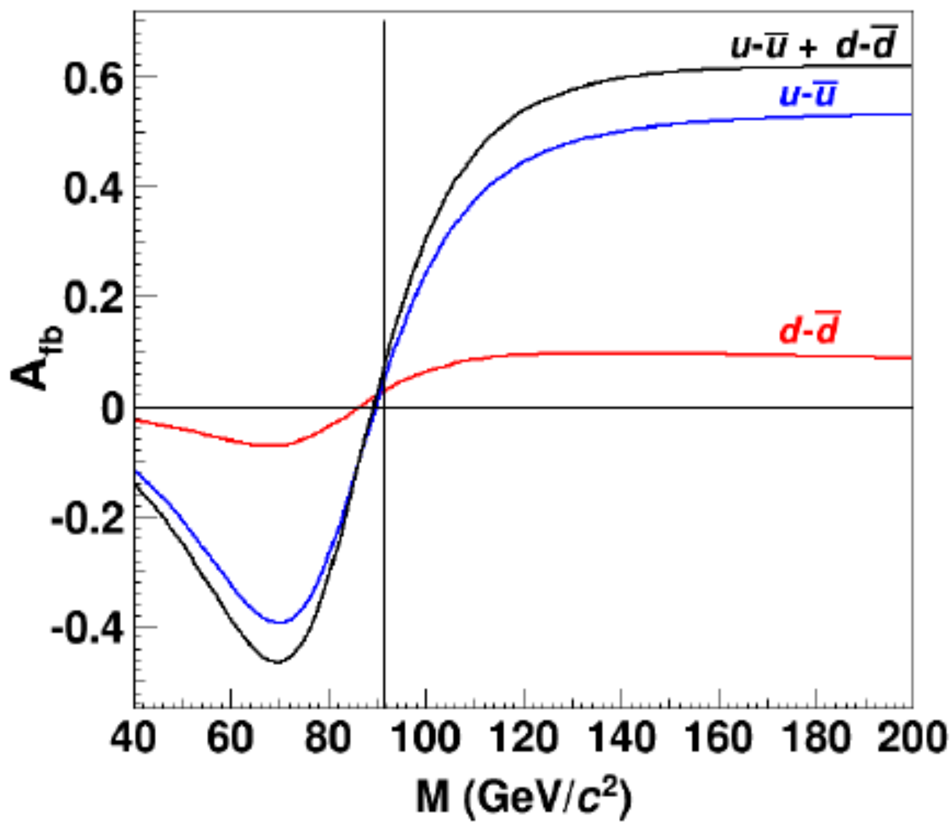
$$\frac{d\sigma}{dcos\theta^*} \propto 1 + cos^2\theta^* + A_4 cos\theta^*$$

$$A_{FB} \equiv \frac{\sigma^+ - \sigma-}{\sigma^+ + \sigma^-} = \frac{3}{8}A_4$$

$$A_{FB}^{d-type} \approx \frac{(dd)_F - (dd)_B}{(dd)_F + (dd)_B + (uu)_F + (uu)_B}$$

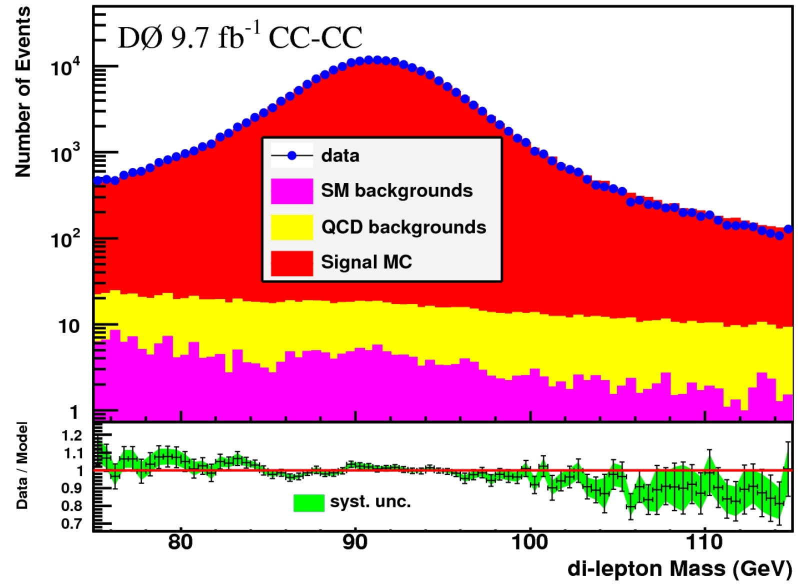
$$A_{FB}^{u-type} \approx \frac{(uu)_F - (uu)_B}{(dd)_F + (dd)_B + (uu)_F + (uu)_B}$$

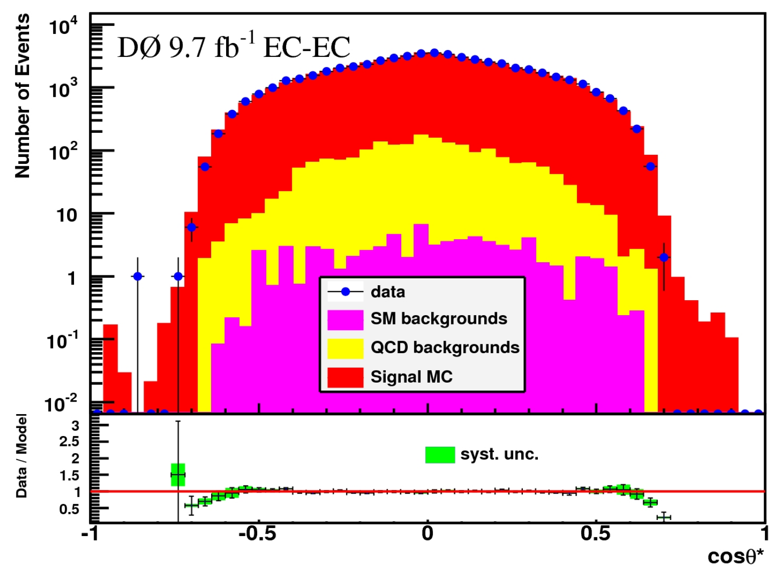
- A_4 term is parity violating from interference of vector and axial currents
- Measure A_{FB} in bins of $M_{\ell\ell}$
- Produce MC templates for A_{FB}, $M_{\ell\ell}$, $\sin^2\theta_W$
- Extract $\sin^2\theta_W$ by a χ^2 comparison between data and MC

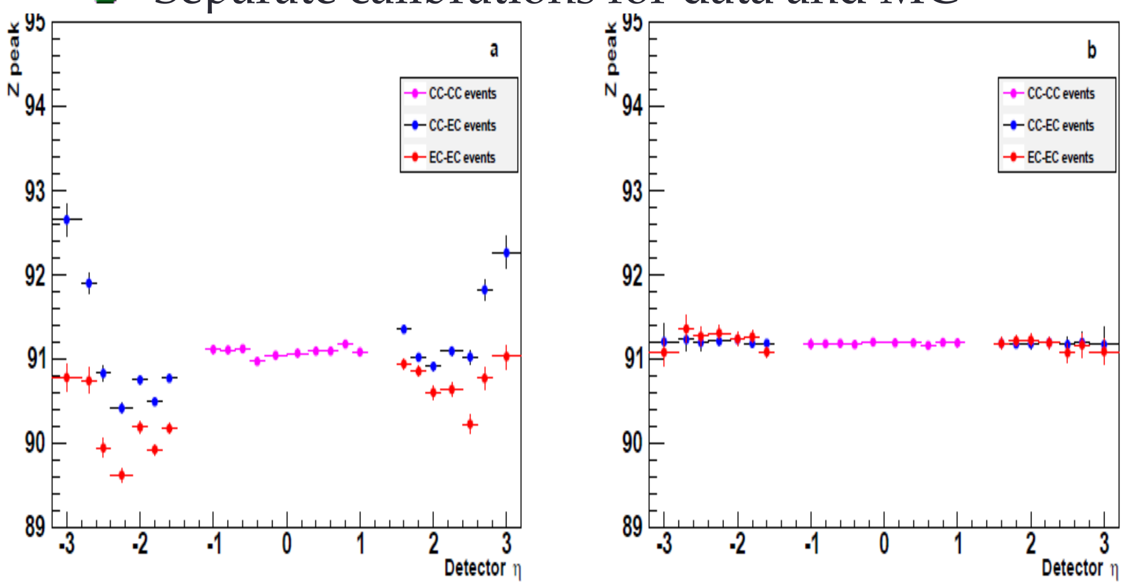


DØ e^+e^- 9.7 fb^{-1} $\sin^2\theta_W^{eff}$ analysis - I

- Require two electrons with p_T>25 GeV
  - Tight track match requirement
  - CC (|η|<1.1) and EC (1.5<|η|<3.2)
- Use 75<M_{ee}<115 GeV → 560k events
- New method for energy calibration (similar to CDF and CMS)
  - Apply scale factor as a function of L_{inst} first and then η
  - M_{ee} peak scaled to LEP value in each bin
  - Separate calibrations for data and MC





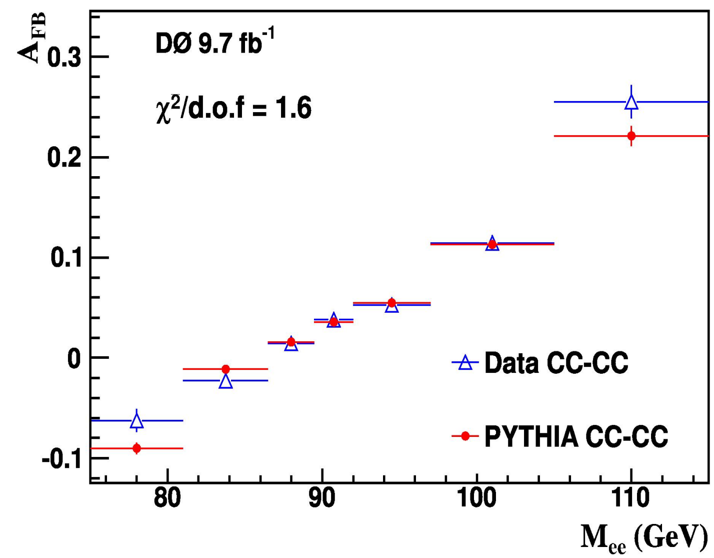


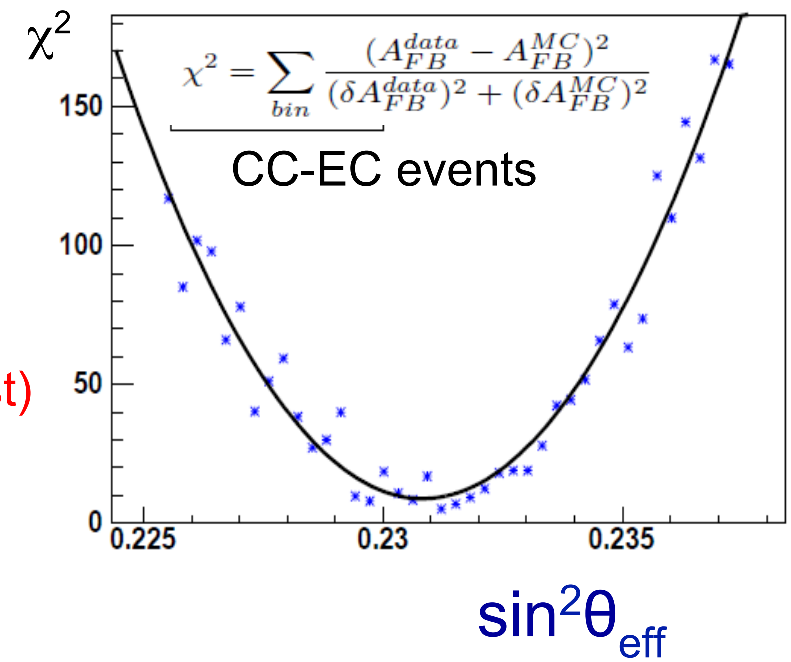
D0: Phys. Rev. Lett. 115, 041801 (2015)

DØ e^+e^- 9.7 fb^{-1} $\sin^2\theta_W^{eff}$ analysis - II

- Corrections are applied to MC to account for:
  - Smearing of electron energy
  - Efficiency corrections in $p_T(e)$, $\eta(e)$
  - L_{inst} and z_{PV} reweighting to match data
  - Higher order effects: NNLO Z p_T and y to match RESBOS
- Produce 2D templates of M_{ee} and $\cos\theta^*$ by reweighing default MC ($\sin^2\theta_{eff}$=0.232) as a function of $\sin^2\theta_{eff}$
- Extract $\sin^2\theta_{eff}$ by fitting raw A_{FB} to templates with different $\sin^2\theta_{eff}$ values
- No unfolding: MC is carefully corrected to describe the data

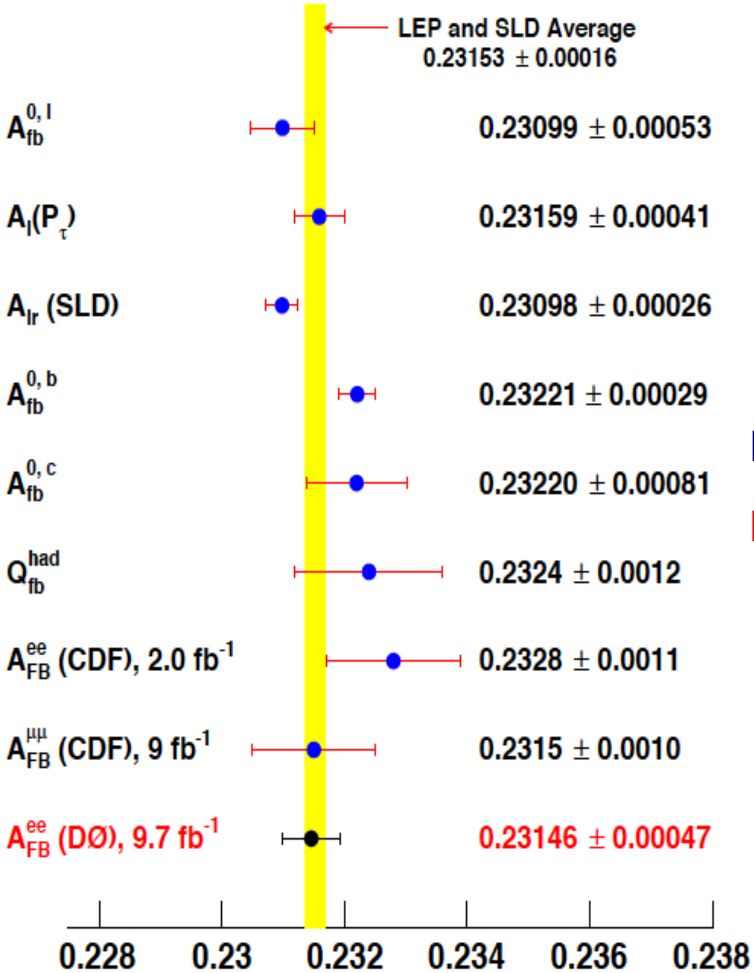
$\sin^2\theta_{efff}$ = 0.23138 ± 0.00043(stat) ± 0.00008(syst) ± 0.00017(NNPDF2.3 PDFs)
(no EW radiative corrections)





- D0: Phys. Rev. Lett. 115, 041801 (2015)

DØ e^+e^- 9.7 fb^{-1} $\sin^2\theta_W^{eff}$ analysis - III



- D0: Phys. Rev. Lett. 115, 041801 (2015)

An approximate way to correct for the flavor dependence of $\sin^2\theta_{\rm eff}$ from EW radiative corrections is used by the D0 collaboration. This is done by making the following corrections (proposed by Baur and collaborators [8]):

$$\sin^2\theta_{\rm eff}^{\rm u-quark} = sin^2\theta_{\rm eff}^{\rm lept} - 0.0001$$

$$\sin^2\theta_{\rm eff}^{\rm d-quark} = sin^2\theta_{\rm eff}^{\rm lept} - 0.0002$$

Change is +0.00008

Final results:

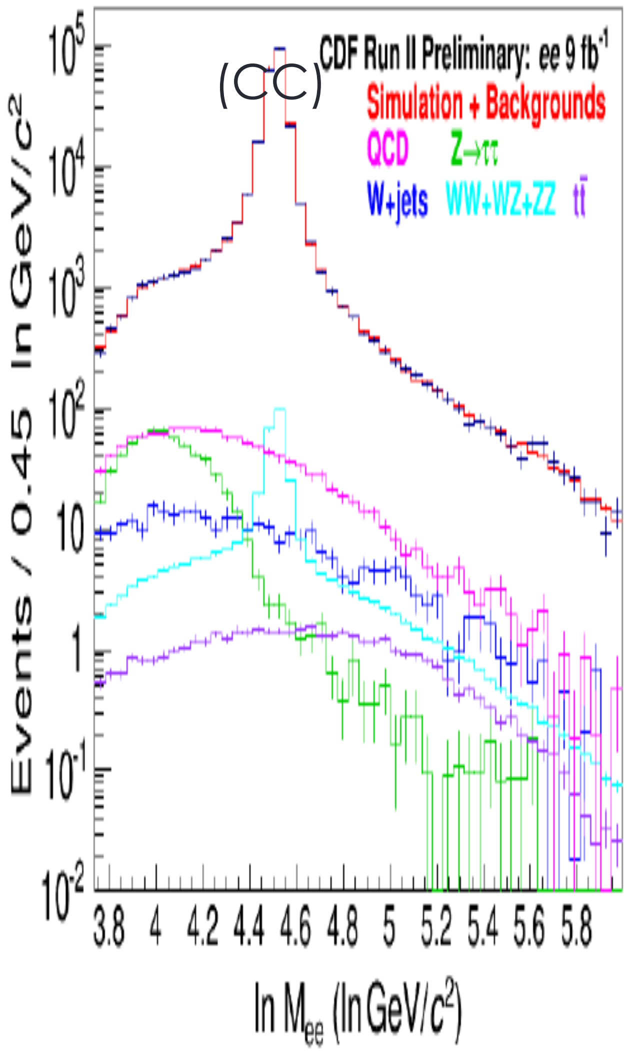
DØ ee $\sin^2\theta_{efff}^{leptonic}$ (Mz)=

= 0.23146 ± 0.00043(stat)
± 0.00008(syst)
±0.00017(PDFs -NNPDF2.3) NNLO

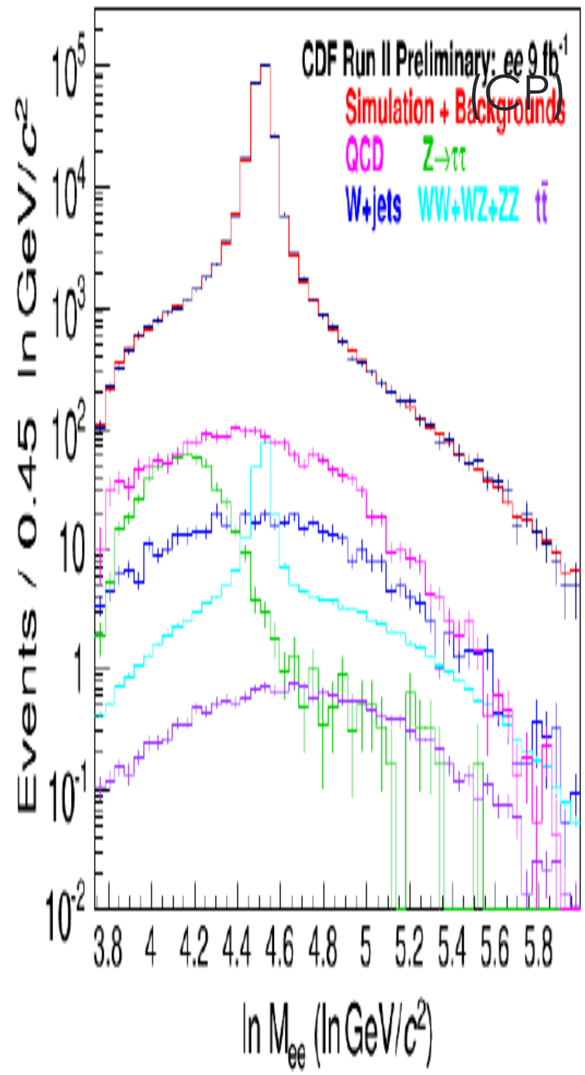
Or = 0.23146 ± 0.00047 (total)

CDF 9.4 fb^{-1} e^+e^- $\mu^+\mu$

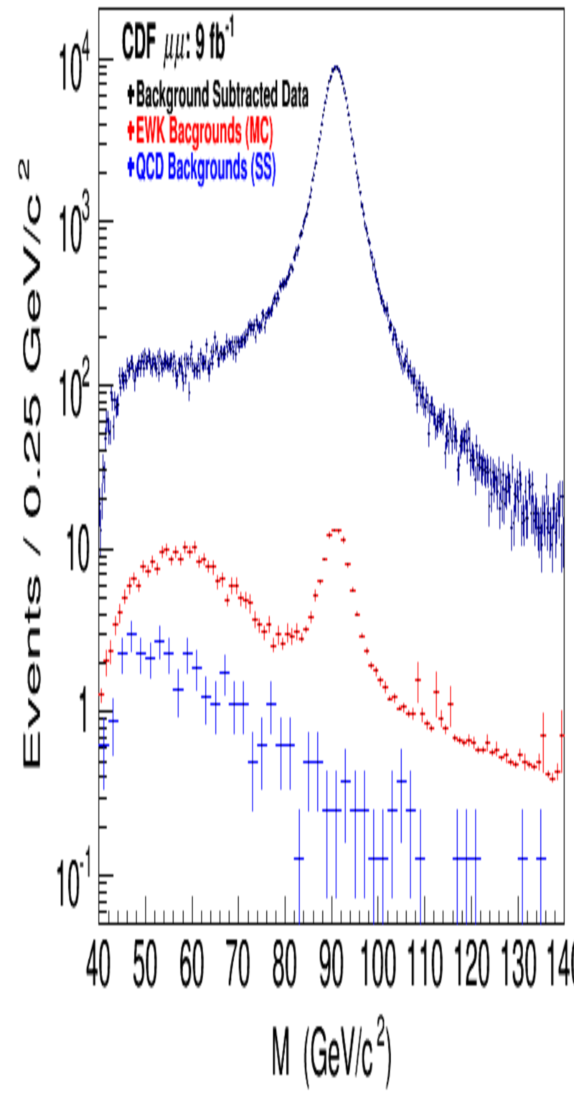
CDF e^+e^- Central-Central (CC)
227K events **background ~1.1%**



CDF e^+e^- Central-Plug (CP)
258K events **bkgd ~ 1.2 %**

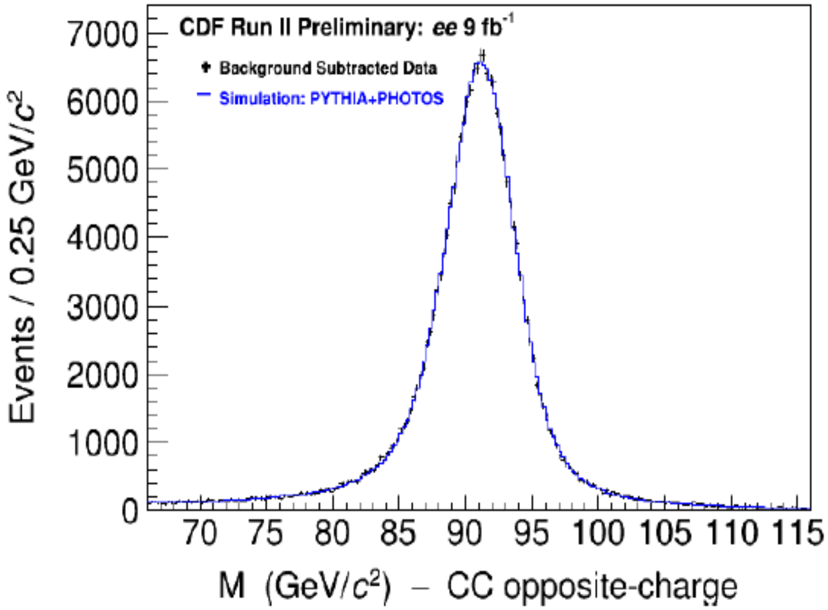


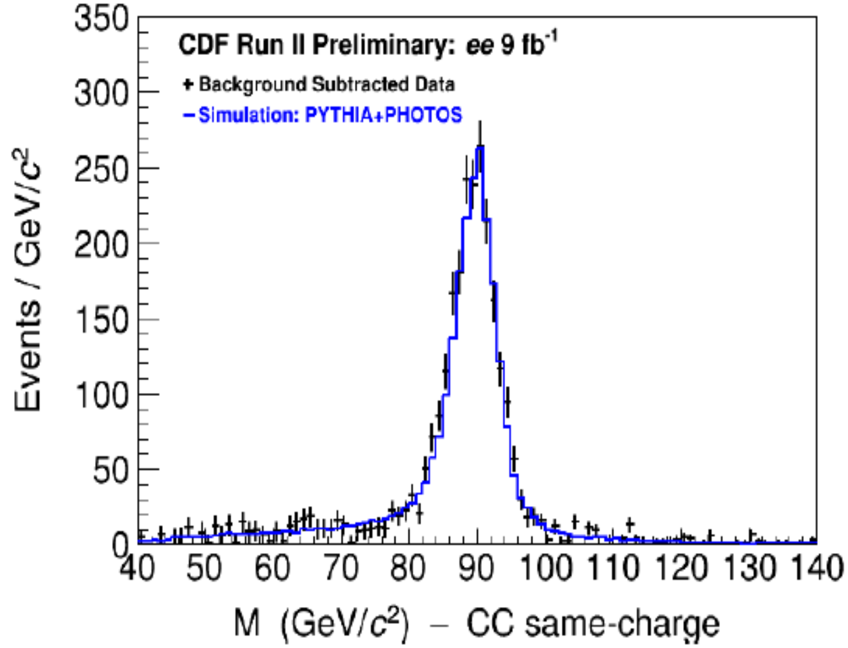
CDF $\mu^+\mu^-$ (CC)
227K events **bkgd** ***<1%***

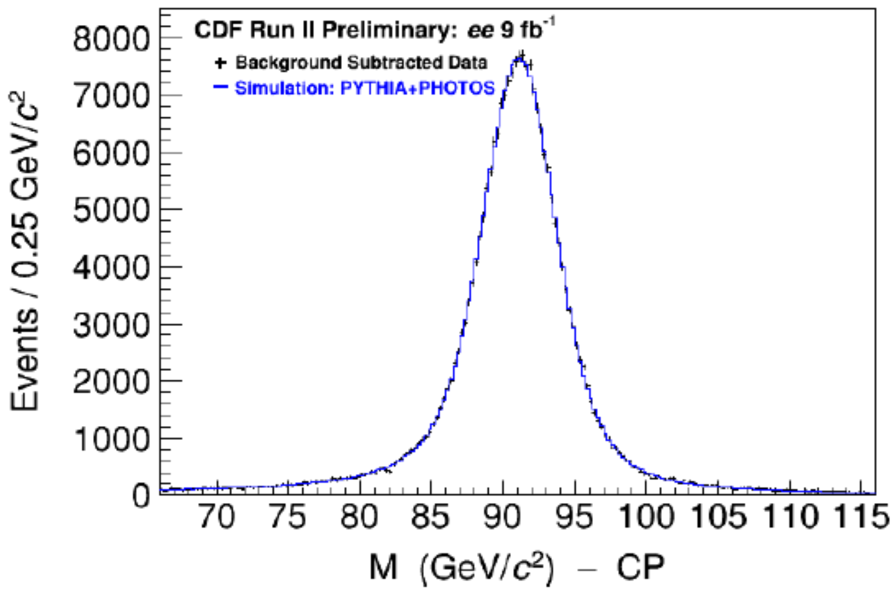


CDF $\mu^+\mu^-$: :Phys. Rev. D89, 072005 (2014)

CDF 9.4 fb^{-1} e^+e^-







Charge MisID small and well modeled by MC

CC: require opposite sign.
Charge misID is not relevant.
CP: sign is measure only for Central electron

Distributions are well modeled by MC

CDF $\mu^+\mu^-$ & e^+e^- 9.7 fb^{-1} $\sin^2\theta_W$ analyses

Indirect measurement of W mass:

1st innovation: $\sin^2\theta_W$ is constant while $\sin^2\theta_{eff}^{lept}$ (M_{ee} ,flavor) is not. Implement Full ZFITTER EW radiative corrections, Enhanced Born Approximation (EBA), include full complex form factors implemented in private versions of RESBOS, POWHEG, and LO. Ref Phys. Rev. D 88, 072002 (2013) Appendix A'.

2nd innovation: Precise lepton momentum/energy scale for muons and electrons using a new method- (will also reduce scale error for M_W measurement) Ref: A. Bodek et al. Euro. Phys. J. C72, 2194 (2012)

3rd innovation: Event weighting method for A_{FB} analyses (systematic errors in acceptance and efficiencies cancel)-
Ref. A. Bodek. Euro. Phys. J. C67, 321 (2010)

4th innovation: Use Drell-Yan forward-backward asymmetry to constrain parton distribution functions - (will also reduce PDF errors for M_W measurement) Ref A. Bodek et al arXiv:1507.02470v2 (2015)

1. Implement ZFITTER EBA EW radiative corrections

$\sin^2\theta_W$ (on-shell) is a constant while $\sin^2\theta_{eff}^{lept}$ (M_{ee}, flavor) is not.

Full ZFITTER EW radiative corrections, Enhanced Born Approximation (EBA), include full complex form factors implemented private versions of RESBOS, POWHEG, and LO) Phys. Rev. D 88, 072002 (2013) Appendix A'

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

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

They are modified by ZFITTER 6.43 form factors (which are complex)

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

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

$$\mathrm{SM}(\sin^2\theta_W) \overset{\mathrm{EWK}}{\longmapsto} \sin^2\theta_{\mathrm{eff}}(s) \overset{\mathrm{QCD}}{\longleftrightarrow} A_4(s),$$

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

- 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

Accounts for $\sin^2\theta_{eff}$ dependence on quark flavor and dilepton mass → get $\sin^2\theta_{eff}^{leptonic}(Mz)$ using Afb over a range of dilepton mass

2. Precise Energy/Momentum Scale corrections

New technique used for both $\mu^+\mu^-$ and e^+e^- for both data and hit level MC. (Ref A. Bodek et al. Euro. Phys. J. C72, 2194 (2012))

Step 1 : Remove the correlations between the scale for the two leptons by getting an initial calibration using Z events and requiring that the **mean <1/ P_T>** of each lepton in bins of η, Φ and charge be correct.

Step2: The Z mass (and J/psi and Upsilon) used as a calibration. The Z mass as a function of η,Φ, (and charge for $\mu^+\mu^-$) of each lepton be correct

- **Reference for muons:** Expected Z mass (post FSR) smeared by resolution (with acceptance cuts).
- **Reference for electrons:** Expected Z mass (post FSR, and FSR photons are clustered), smeared by resolution (with acceptance cuts).

3. Use event weighting Method

Event weighting method for A_{FB} analyses
Ref. A. Bodek, Euro. Phys. J. C67, 321(2010)

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

Angular event weighting is equivalent to extraction of $A_4(M)$ in bins of $\cos\theta$, and averaging the results.

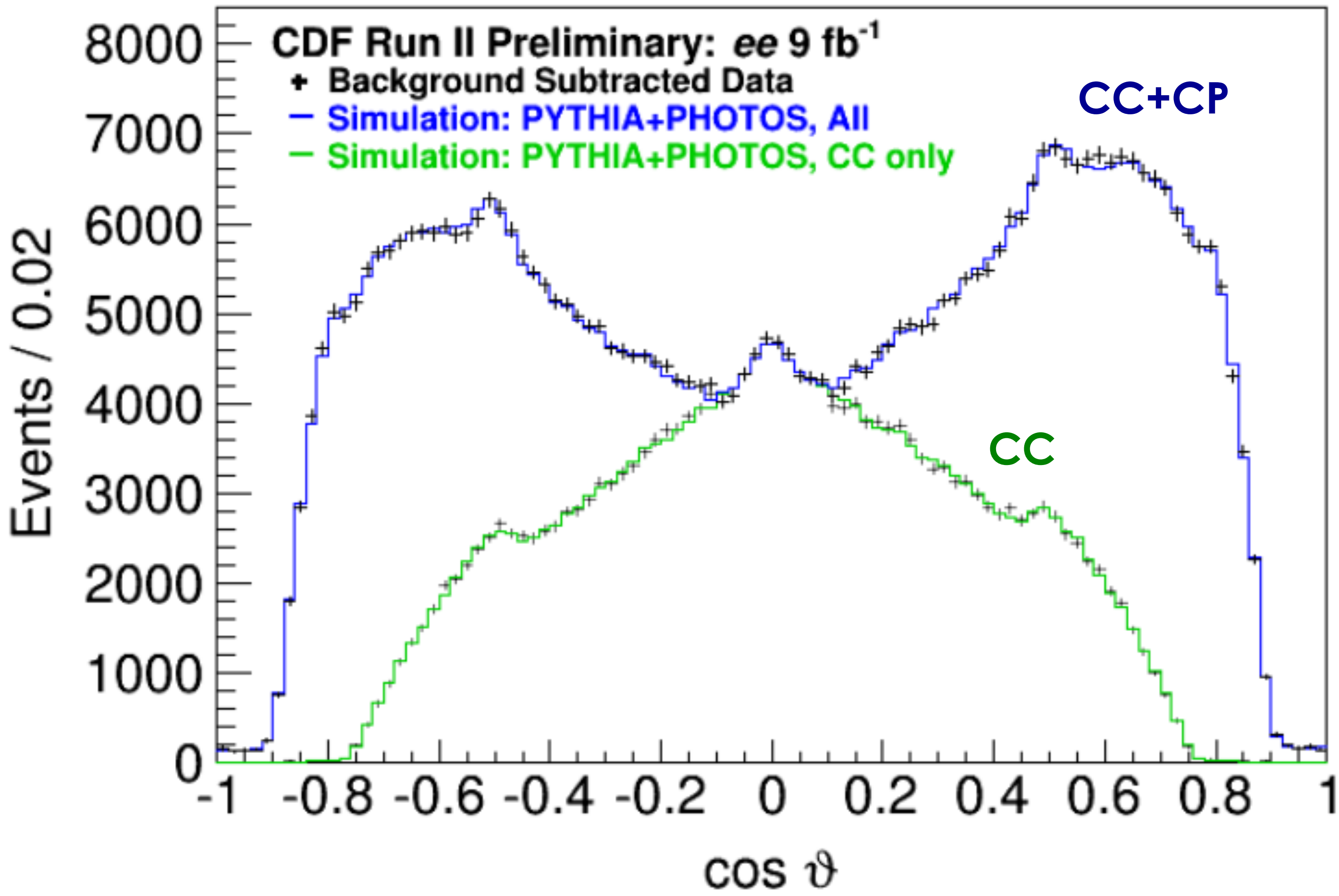
Events at large $\cos\theta$ provide better determination of A4, so they are weighted more than events at small $\cos\theta$.

For each $\cos\theta$ acceptance and efficiencies cancel to first order and the statistical errors are 20% smaller. Then extract $A_{fb} = (3/8)A_4$

Event weighting does not correct for resolution smearing and final state radiation, which are included later in the unfolding.

The 4th innovation: Using Drell-Yan forward-backward asymmetry to constrain parton distribution functions is discussed at the end of the talk.
(Ref A. Bodek et al arXiv:1507.02470v2 (2015))

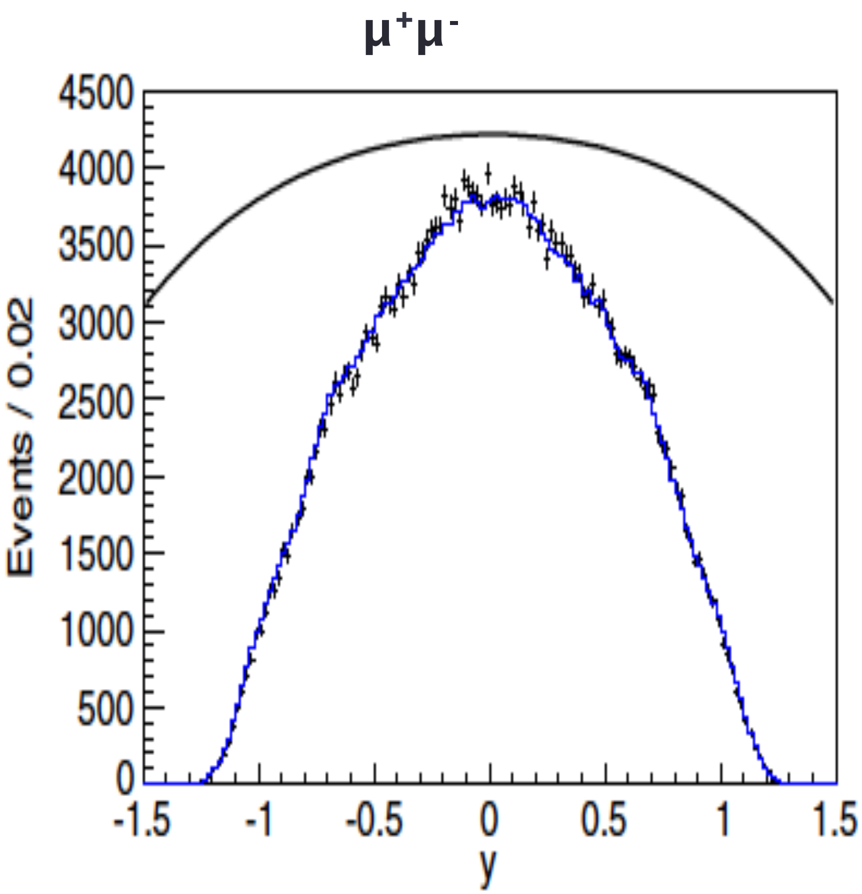
Why use event weighting Method

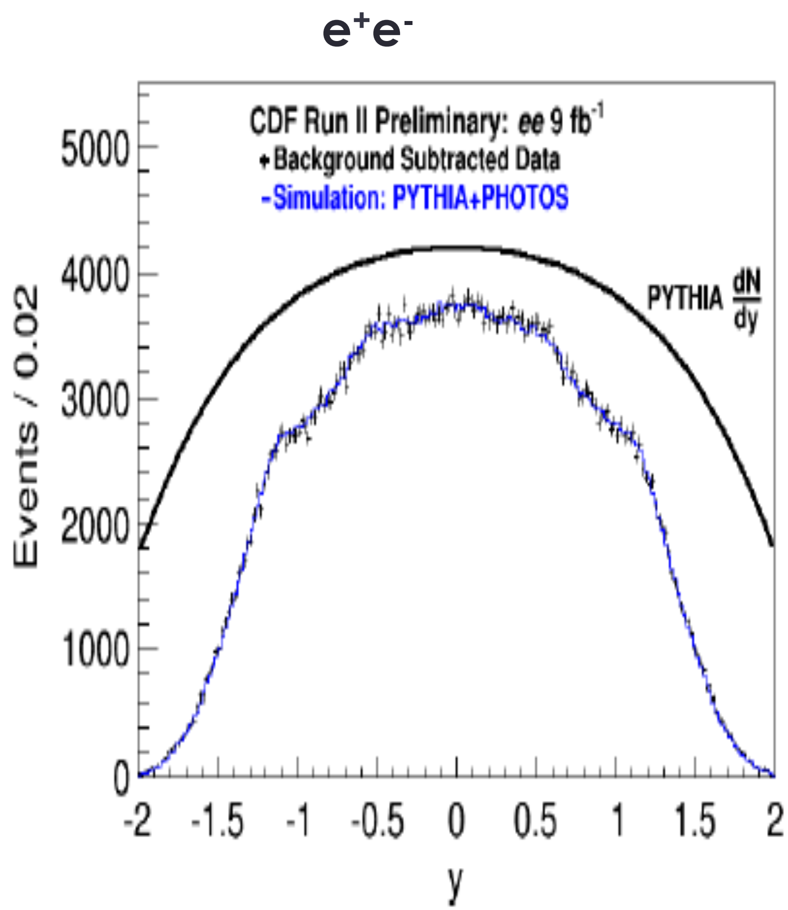


The error in *Afb* is reduced if we have more acceptance at large cosθ,
Standard Afb method requires precise knowledge of acceptance and efficiencies.

Measure A_4 → A_{FB}

CDF: $\mu^+\mu^-$ & e^+e^- Acceptance in Rapidity [17]





$\mu^+\mu^-$: require $|y| < 1$

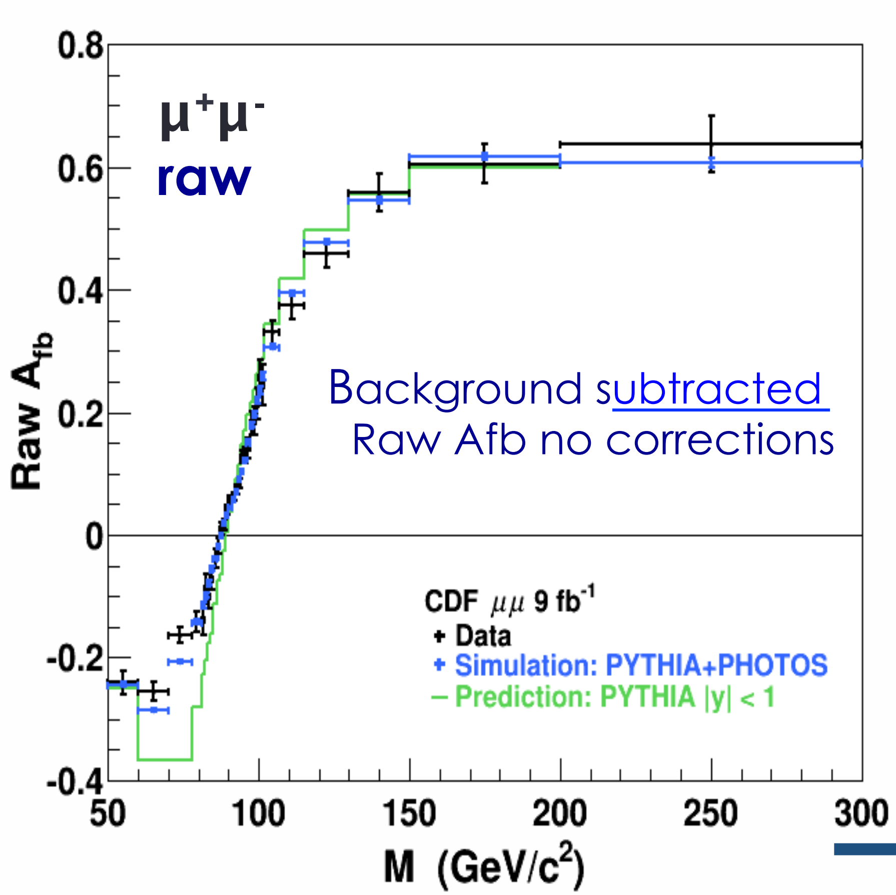
e^+e^- : require $|y| < 1.7$

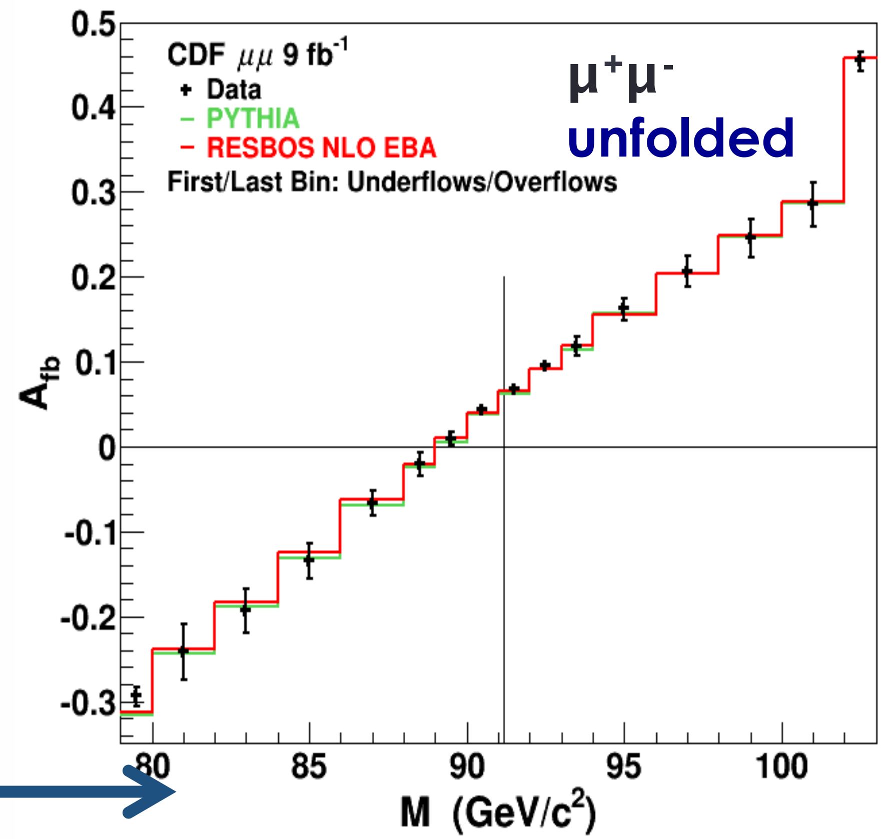
Note: Afb has a weak dependence on rapidity.
Angular event weighting does not correct for the rapidity dependence (it could be done by adding rapidity weighting, but here we correct for it using a MC correction)

CDF $\mu^+\mu^-$: unfolding for Resolution and FSR

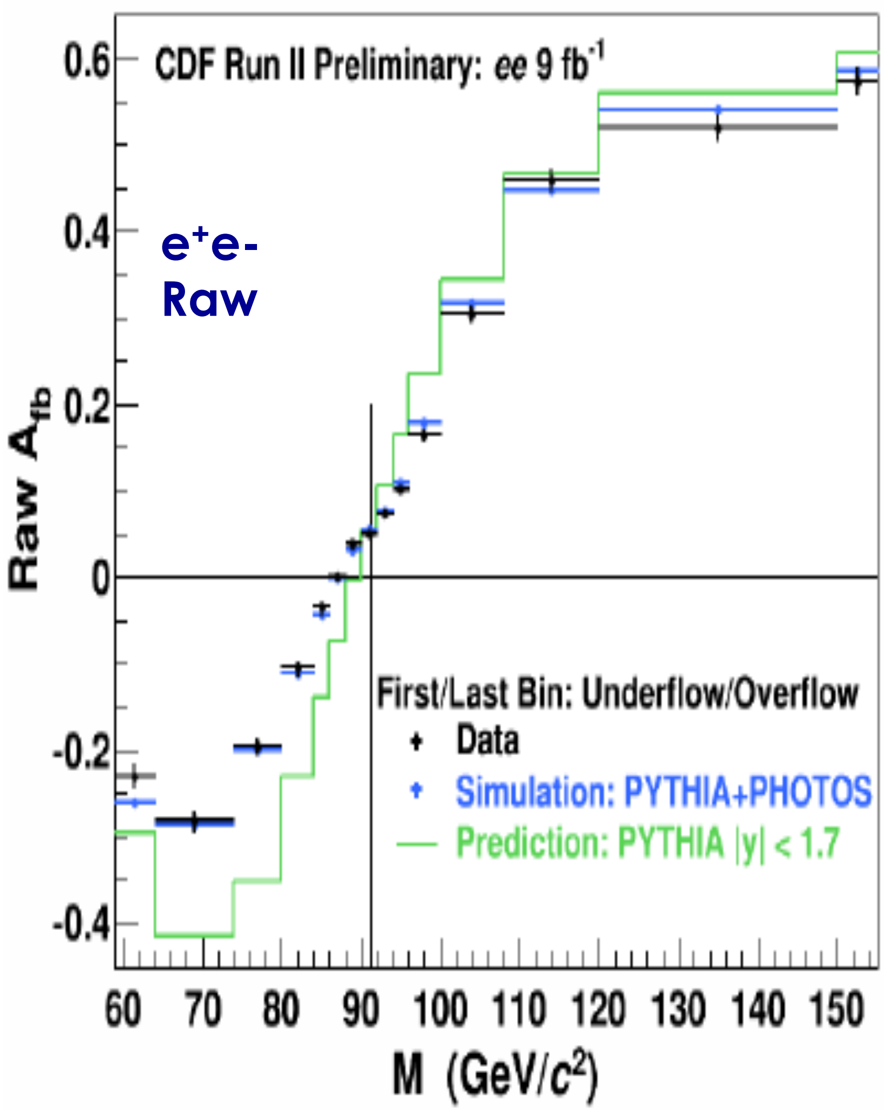
- Angular event weighting provides first order acceptance correction
- Use unfolding to correct for resolution and QED FSR:
  - Two 16x16 unfolding matrices (16 mass bins, +, - regions)
- Bin-by-bin second order bias correction (e.g. mean beam vertex not in center of detector)
  - Additive factor (True-Estimated) to unfolded A_{FB} in M bins

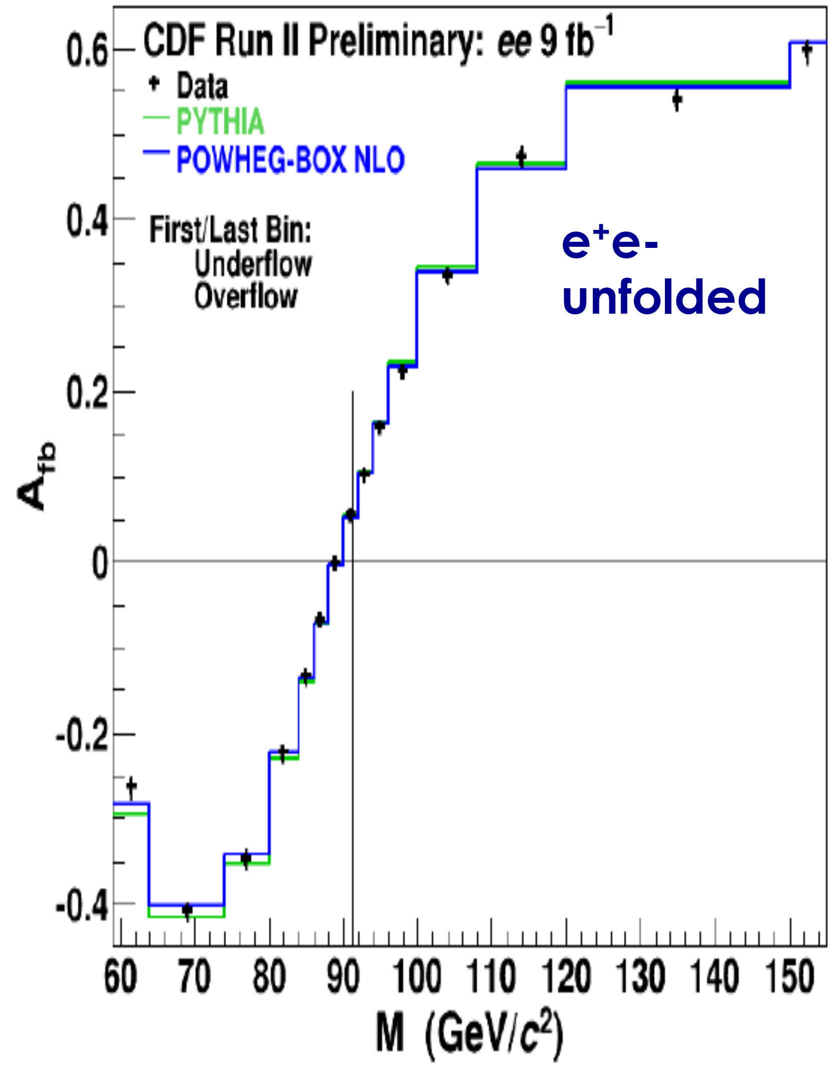
CDF:Phys. Rev. D89, 072005 (2014)





CDF e^+e^-: unfolding for Resolution and FSR





e^+e^-: Afb Background subtracted
Raw no corrections

→

e^+e^- Afb: Afb unfolded
fully corrected

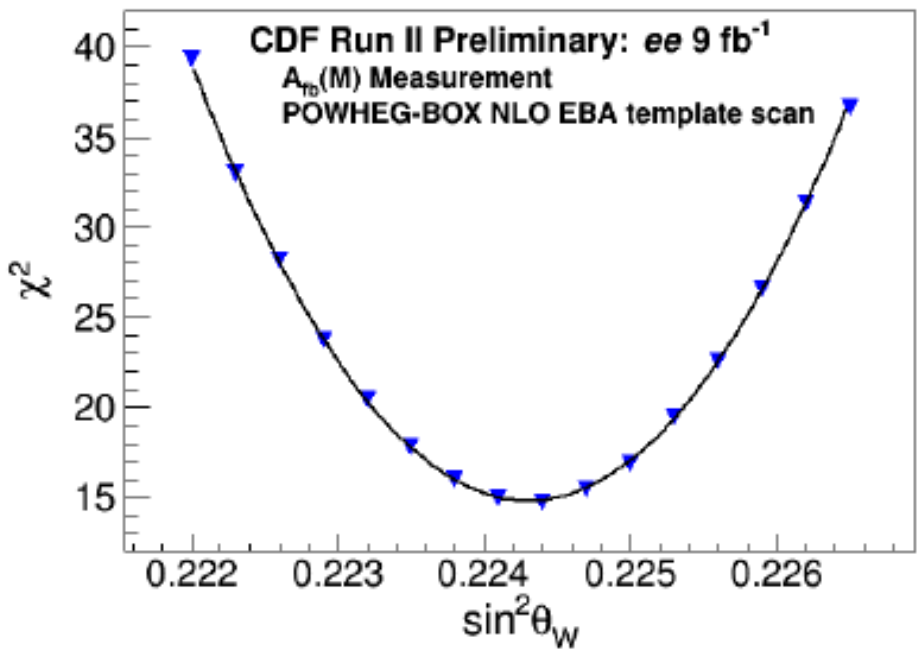
CDF e^+e: $\sin^2\theta_W$ extraction using templates

Comparisons of A_{fb} Measurement to Calculations

- Comparison χ^2: $\Sigma_M \Delta A_{fb}(M)^{\sim} \bullet E \bullet \Delta A_{fb}(M)$
  - Measurement: Fully corrected $A_{fb}(M)$
  - Calculated templates: $A_{fb}(M, \sin^2\theta_w)$ for 16 values of $\sin^2\theta_w$
  - E: Measurement error matrix

Example $\sin^2\theta_w$ template scan using data

- Afb template: Powheg-Box NLO + default PDF of NNPDF 3.0 (261000)
- Fit of scan points to a parabola: $\chi^2_{min} + (\sin^2\theta_w - \sin^2\theta_{w\,min})^2/\sigma_{min}^2$



This analysis is repeated with
1. POWEG ,2. RESBPOS
3. Tree-Level LO

For the POWHEG analysis, the extraction is repeated 100 times for all 100 NNPDF3.0 replicas to get PDF error.

CDF e^+e $\sin^2\theta_W$: template scans

- Fit uncertainties are statistical only,

Template (Measurements)	$\sin^2\vartheta_{eff}^{lept}$	$\sin^2\vartheta_W$	χ^2_{min}
Powheg-Box NLO	0.23249±0.00048	0.22429±0.00046	16.6
ResBos NLO, CTEQ66	0.23249±0.00048	0.22429±0.00046	22.4
Tree LO	0.23252±0.00048	0.22432±0.00046	23.4
Pythia, CTEQ5L	0.23207±0.00045	—	25.

Difference between NLO and LO (0.00003) is taken as QCD error

measurements ( ) are total uncertainties

(CDF ee 9 fb^{-1})	0.23249 ± 0.00052	0.22429 ± 0.00050	16.6 (15)
(CDF μμ 9 fb^{-1})	0.23150 ± 0.00100	0.22330 ± 0.00090	21.1 (16)
(D0 ee 9 fb^{-1})	0.23146 ± 0.00047		
(LEP1+SLD $A_{FB}^{0,b}$)	0.23221±0.00029		
(SLD A_l)	0.23098±0.00026		

CDF e^+e: $\sin^2\theta_W$ systematic errors

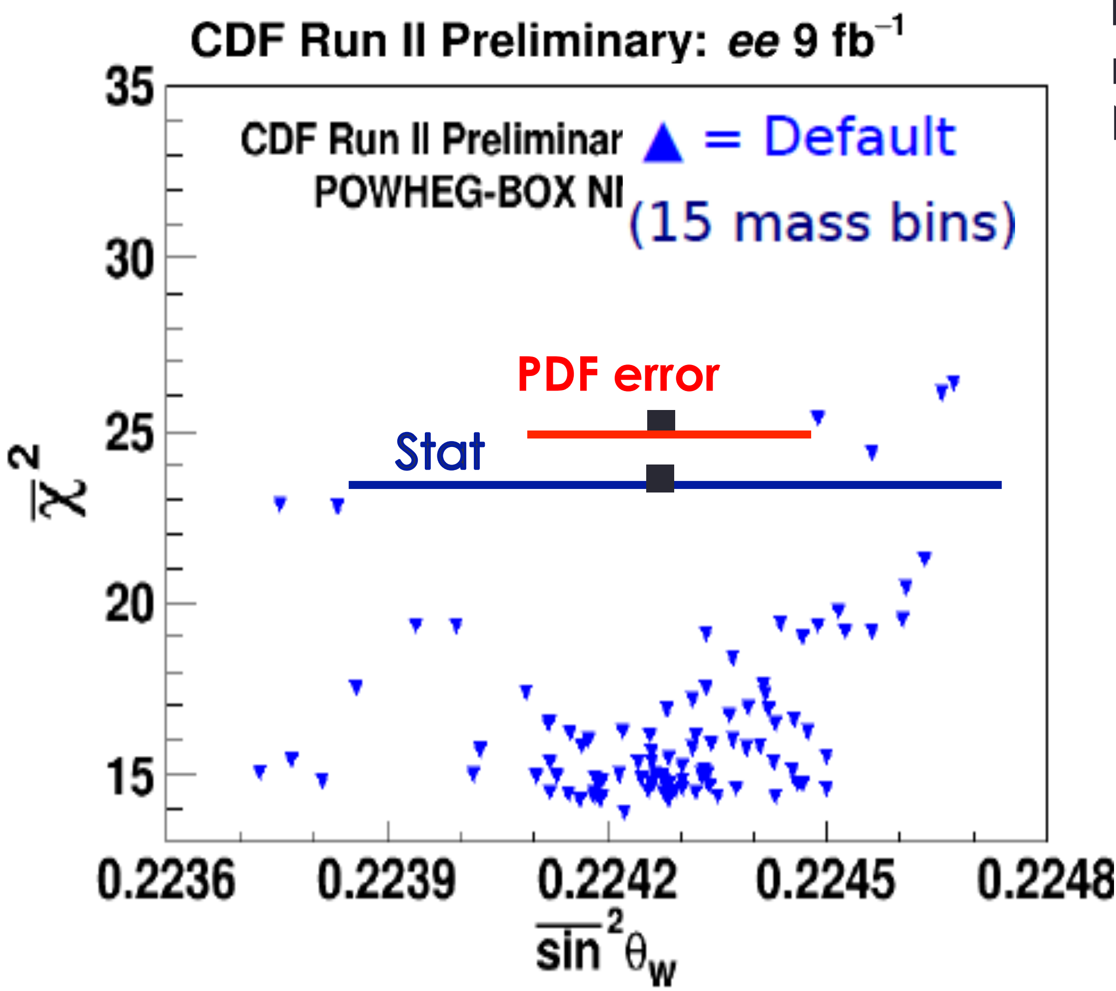
The statistical error of 0.00048 dominates. The experimental systematic error is much smaller 0.00005.
The PDF error is 0.00020

Source	$\sin^2\theta_{eff}^{lept}$	$\sin^2\theta_W$
Data: Measurement	±0.00048 (stat)	±0.00046 (stat)
Data: Energy scale	±0.00003 (syst)	±0.00003 (syst)
Data: Backgrounds	±0.00002 (syst)	±0.00002 (syst)
Pred: QCD scales	±0.00001 (syst)	±0.00001 (syst)
Pred: QCD PDFs	±0.00020 (syst)	±0.00020 (syst)
Pred: QCD EBA	±0.00003 (syst)	±0.00003 (syst)

CDF e^+e: $\sin^2\theta_W$ PDF errors

- NNPDF 3.0 ensemble measurement of $\sin^2\theta_w$
  - → Powheg-Box NLO and Tree (LO) Afb templates calculated with NNPDF
  - → Example:
    Each entry is the $\sin^2\theta_w$ fit value for an ensemble PDF

100 NNPDF 3.0 (NNLO) replicas



15 Mass bins. This plot indicates that the CDF measurement is consistent with NNPDF3.0 PDFs

100 replicas
NNPDF 3.0 (NNLO)
In the replica method
RMS is the PDF error
RMS= +- 0.00020

And the mean is the best value.
Mean = 0.22429

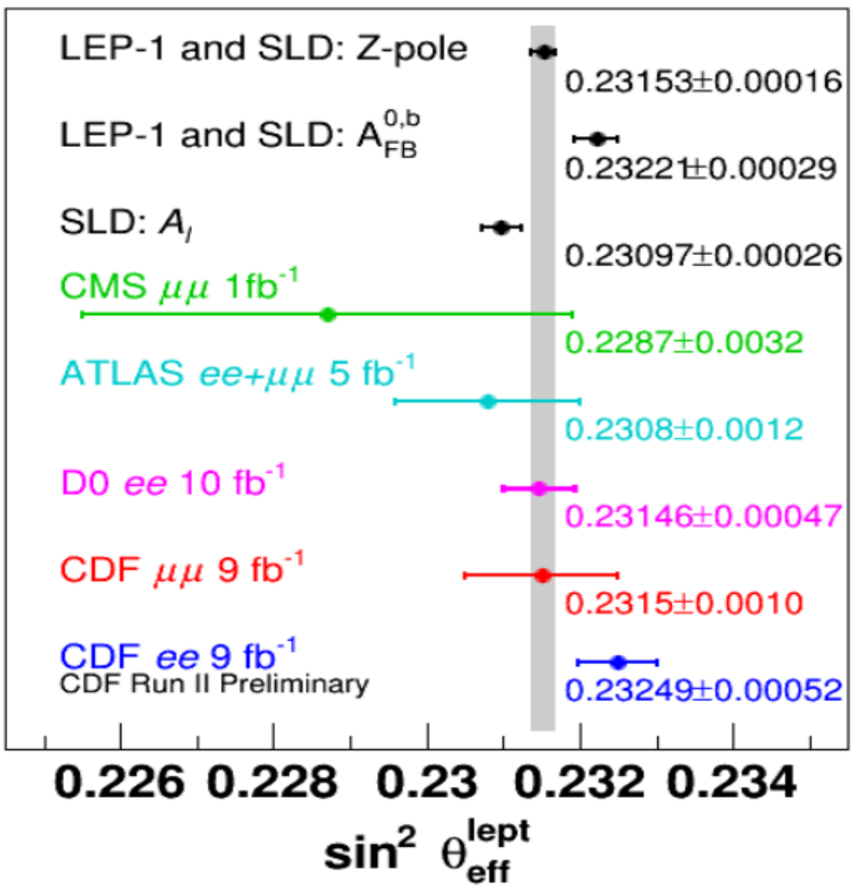
$\sin^2\theta_w$=0.22429

σ_{min}=0.00046

PDFs =0.00020

Tevatron ee & μμ 9 fb^{-1}: $\sin^2\theta_{eff}(M_z)$

CDF μμ $\sin^2\theta_{efff}$ =0.23150 ± 0.00100 (total)
CDF ee $\sin^2\theta_{eff\ f}$ =0.23249 ± 0.00048(stat) ± 0.00005(syst) ±0.00020 (NNPDF3.0 PDFs NNLO)
= 0.23249 ± 0.00052 (total)
DØ ee $\sin^2\theta_{efff}$ = 0.23146 ± 0.00043(stat) ± 0.00008(syst) ±0.00017 (NNPDF2.3 PDFs NLO)
= 0.23146 ± 0.00047 (total)
ATLAS (e+μ) 4.5 fb^{-1} 0.23080 ±0.00050(stat) ± 0.00060(syst) **± 0.00090(pdf))**



Note: NNPDF 3.0 PDFs (NNLO) include LHC data and supersede NNPDF2.3

The CDF PDF errors will be reduced from 0.00020 to 0.00015 (as described end of this talk slides)

CDF ee & μμ 9 fb^{-1} Indirect M_W measurement

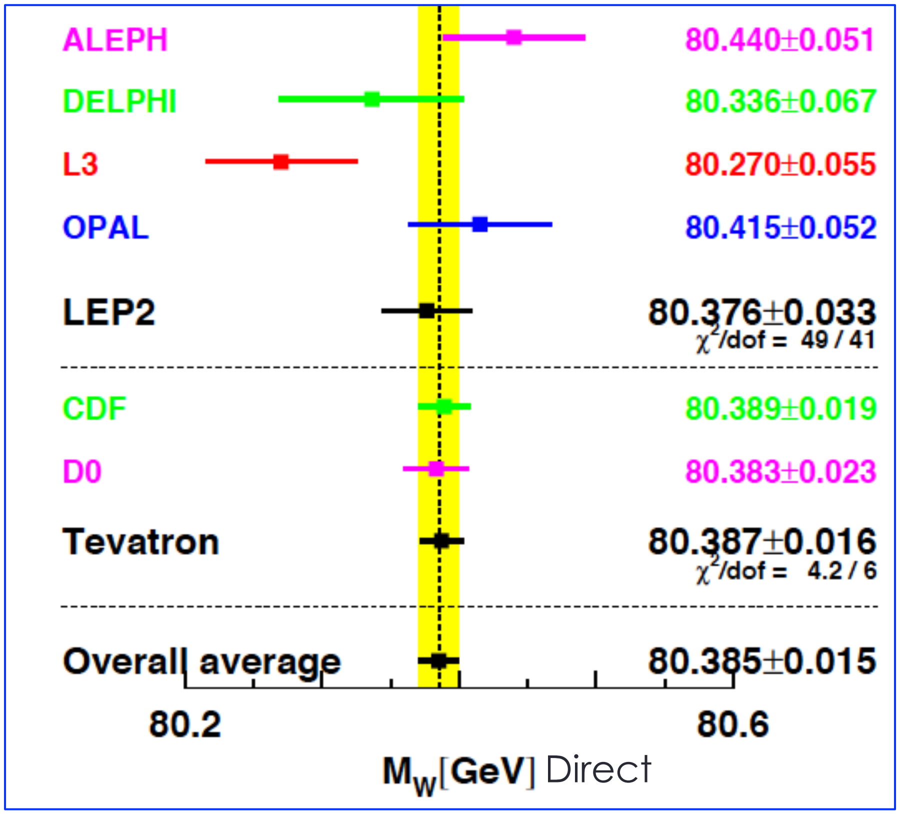
CDF Run II Legacy 9.4 fb^{-1}: ZFITTER on-shell scheme indirect measurements

$\sin^2\theta_W$ = 0.22429 ± 0.00046 (stat) ± 0.00020 (syst)

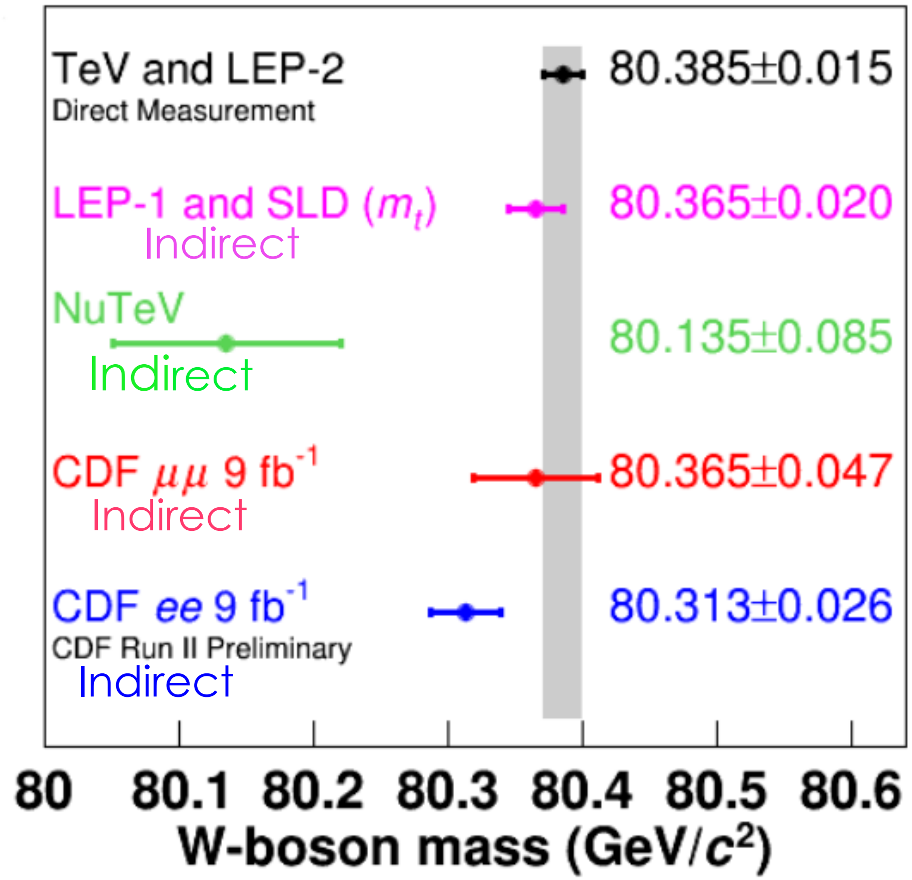
M_W(indirect) = 80.313 ± 0.024(stat) ± 0.010(syst) GeV/c^2

- $\Delta\sin^2\theta_W$=0.00030 yields to ΔM_W=15 MeV

Indirect Mw error is similar to the error in the direct Mw measurement

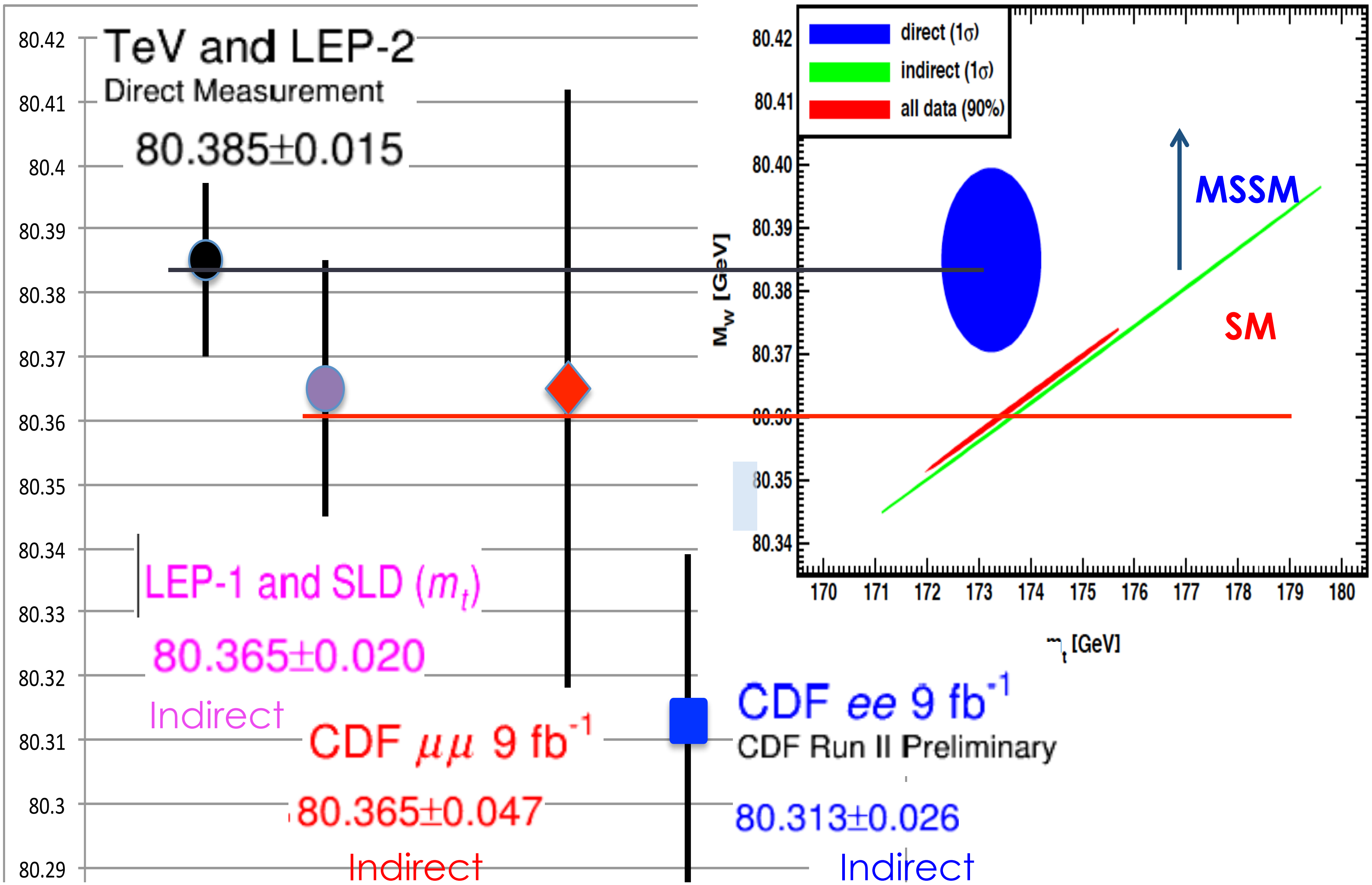


http://pdg.lbl.gov/2014/reviews/rpp2014-rev-w-mass.pdf



CDF ee & μμ 9 fb^{-1} Indirect M_W measurement

http://pdg.lbl.gov/2014/reviews/rpp2014-rev-standard-model.pdf
K.A. Olive et al. (PDG), Chin. Phys. C38, 090001 (2014) (http://pdg.lbl.gov)



Next step in error reduction

Next step in Dzero

D0 Afb ee : Was published→ $\sin^2\theta_{efff}$ = 0.23146 ± 0.00047 (total)

Next – D0 Afb analysis in the $\mu^+\mu^-$ channel

Next step in CDF (~Sept 2015):

Step 1: Combine electrons and muons

	$\sin^2\theta_{eff}^{lept}$	
CDF Afb $\mu^+\mu^-$ 9 fb-1	0.23150 +- 0.00100	→Mw = 80.365 ± 0.047 GeV
CDF Afb e+e 9 fb-1	0.23252 +- 0.00052	→Mw = 80.313 ± 0.026 GeV
My expectation: combined error	~ 0.00045	~0.023 GeV

CDF Indirect measurement and direct measurement of Mw have similar errors

Reducing PDF errors

Step 2 : **Use combined e+e $\mu^+\mu$ Afb data to constrain PDF replicas**

Ref : A. Bodek. J. Han, A. Khukhunaishvili, W. Sakumoto:" Using Drell-Yan forward-backward asymmetry to constrain parton distribution functions" arXiv:1507.02470.

→ Expect reduction in NNPDF 3.0 PDF error in $\sin^2\theta_{efff}$ fo go from +- 0.00020 to ~ 0.00015 (end of September 2015)

These constrained PDF can be used to reduce PDF errors in the direct measurement of Mw.

Step 3 : **Combine $\sin^2\theta_{efff\ fr}$ from e+e and $\mu^+\mu$ at CDF with $\sin^2\theta_{efff}$ from e+e $\mu^+\mu$ at D0.**
Error in $\sin^2\theta_{efff}$ will be similar to LEP SLD.

Replica PDFs

- New measurements can be incorporated into the ensemble without refits
  - Ensemble PDFs are reweighted

$$w_k = \frac{\exp(-\chi^2_k/2)}{\sum_{l=1}^{N} \exp(-\chi^2_l/2)}$$

χ^2_k: between new measurement and prediction with ensemble PDF k

This is clear for new data (e.g. new W asymmetry data)

However, How can we get both $\sin^2\theta_{eff}^{lept}$ AND constrain PDFs from the same Afb data ?

18. G. Watt and R. S. Thorne (MRST), JHEP 08:052 (2012) (arXiv:1205.4024)
19. https://mstwpdf.hepforge.org/random/
20. Walter T. Giele, and Stephane Keller, Phys.Rev. D58 (1998) 094023 (arXiv:hep-ph/9803393).
21. Nobuo Sato, J. F. Owens, Harrison Prosper, Phys. Rev. D 89, 114020 (2014) (arXiv:1310.1089)
22. Hannu Paukkunen, Pia Zurita, "PDF reweighting in the Hessian matrix approach", http://arxiv.org/abs/1402.6623
23. Richard D. Ball, Valerio Bertone, Francesco Cerutti, Luigi Del Debbio, Stefano Forte, Alberto Guffanti, Jose I. Latorre, Juan Rojo, Maria Ubiali, Nucl.Phys.B849, 112 (2011) arXiv:1012.0836.

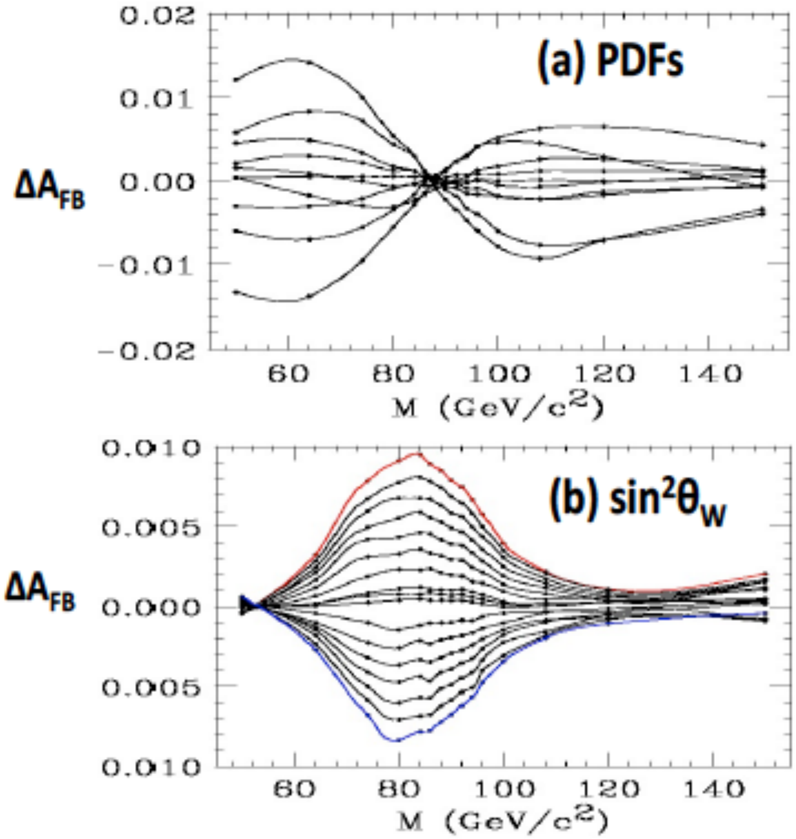
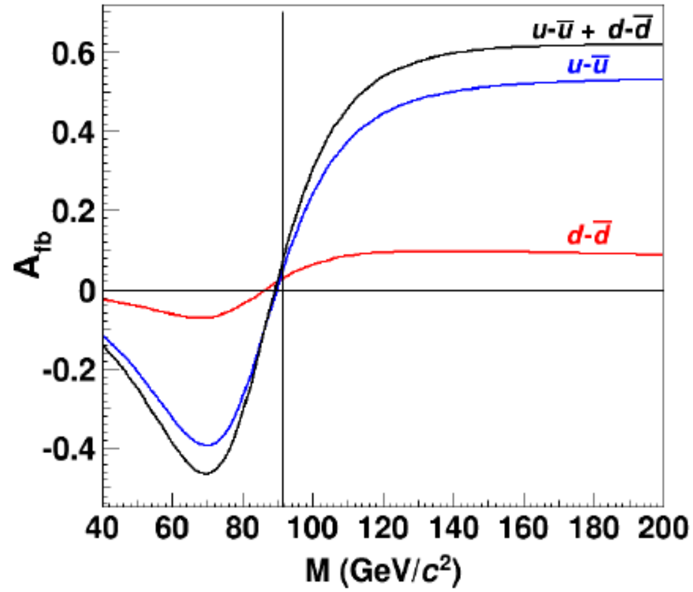


Fig. 3. Tevatron: (a) The difference between $A_{FB}(M)$ for 10 NNPDF3.0 (NNLO) replicas and $A_{FB}(M)$ calculated for the default NNPDF3.0 (NNLO) (261000). Much of the difference originates form the different dilution factors for each of the NNPDF replicas. Here $\sin^2\theta_W$ is fixed at a value of 0.2244. (b) The difference between $A_{FB}(M)$ for different values of $\sin^2\theta_W$ ranging from 0.2220 (shown at the top in red) to 0.2265 (shown on the bottom in blue), and $A_{FB}(M)$ for $\sin^2\theta_W$=0.2244. Here $A_{FB}(M)$ is calculated with the default NNPDF3.0 (NNLO).

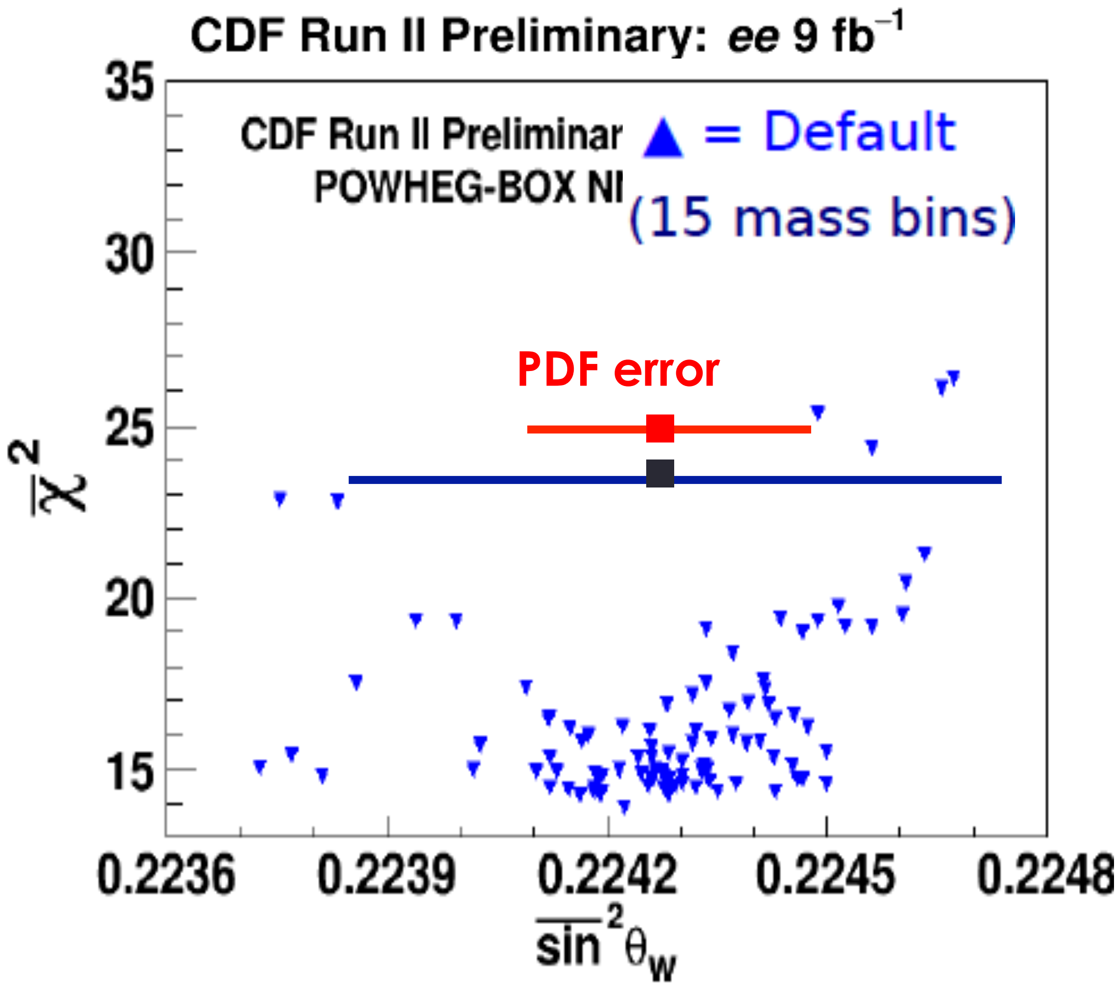


For details see:
A. Bodek. J. Han A. Khukhunaishvili, W. Sakumoto:" Using Drell-Yan forward-backward asymmetry to constrain parton distribution functions"
arXiv:1507.02470

Constraining PDFs & reducing PDF errors

χ^2_{min} versus $\sin^2\theta_W$ for each ensemble PDF:

100 NNPDF 3.0 (NNLO) replicas



CDF e+e Afb Data is compatible with NNPDF3.0 PDFs

In addition "Ensemble PDF can be constrained by reweighting"

$$w_k = \frac{\exp(-\chi^2_k/2)}{\sum_{l=1}^{N} \exp(-\chi^2_l/2)}$$

Technique can be used with any PDF set.

LHC A_{FB} data can also be used to constrain PDFs

See: A. Bodek arXiv:1507.02470

LHC CMS like Pseudo-Experiment LHC 15 fb^{-1} 8 TeV 6.7M $\mu^+\mu^-$ reconstructed events	input POWEG Default NNPDF3.0 (NLO) (261000)
$\sin^2\theta_{eff}$ input	0.23120
statistical error	±0.00050
$\Delta\sin^2\theta_{eff}$ CT10 PDF error	± 0.00080
Analysis replicas NNPDF set Templates	100 NNPDF3.0 (NLO) POWHEG
Average method extracted $\sin^2\theta_{eff}$ PDF error RMS	$N_{eff}=100$ 0.23121 ±0.00051
χ^2_{AFB} weighting extracted $\sin^2\theta_W$ Weighted PDF error RMS	$N_{eff}=46$ 0.23119 ±0.00029
$\chi^2_{AFB}+\chi^2_{W\,sym}$ weighting extracted $\sin^2\theta_W$ Weighted PDF error RMS	$N_{eff}=21$ 0.23122 ±0.00026

ATLAS (e+μ) 4.5 fb^{-1}
0.23080 ±0.00050(stat)
± 0.00060(syst)
± 0.00090(pdf)→need to reduce

With the existing 8 TeV μμ Afb sample from one LHC experiment the PDF errors on $\sin^2\theta_{efff}$ can be reduced From the current CT10 PDF error of **+- 0.00090 to to +-0.00026.**

The constrained PDFs can also be used to reduce PDF errors on the direct measurement of M_W at the LHC

The PDF errors can be **further reduced** with larger statistical samples at 13 TeV.

Conclusions

An Error of +- 0.00040 in $\sin^2\theta w$ is equiv. to +-20 MeV error in Mw.

Currently the Tevatron direct (L= 2.2 fb^{-1}) and indirect (L=9.4 fb^{-1}) measurements of Mw have similar errors. (~ 20 MeV per experiment)

Tevatron Run II Legacy measurements of $\sin^2\theta w$ and Mw (indirect) are in very good agreement with SM predictions from M_H and M_T. (no hint of super-symmetry)

$A_{FB}(M)$ data can also be used to put additional constraints on PDFs. These constraints will help reduce PDF errors in the ongoing Tevatron Run II Legacy (L=9.4 fb^{-1}) direct measurement of Mw.

Moving on to the LHC: With these new techniques, as the statistical errors in Afb become smaller, there is a corresponding reduction in both the statistical errors and PDF errors in the measurements of of $\sin^2\theta w$ and Mw (indirect).
Therefore, with 13 and 14 TeV LHC data, the errors in the indirect measurement of Mw can be lower than the errors in any of the direct measurements.