

# Measurement of the Effective Weak-mixing Angle $\sin^2 \theta_{eff}^l$ in $p\bar{p} \rightarrow Z/\gamma^* \rightarrow l^+l^-$

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➤ Overview

➤ 2017,  $8.6fb^{-1}$  RunIIb  
Muon Channel  
Precision:0.00064  
Best muon channel to date

➤ 2011,  $1.1fb^{-1}$  RunIIa  
+ $3.9fb^{-1}$  RunIIb  
Electron Channel  
Precision:0.0010

➤ D0 combination  
Precision:0.00040  
Best single experiment to date  
Best light-quark measurement



➤ 2008,  $1.1fb^{-1}$  RunIIa  
Electron Channel  
Precision:0.0019  
First hadron measurement

➤ 2015,  $1.1fb^{-1}$  RunIIa  
+ $8.6fb^{-1}$  RunIIb  
Electron Channel  
Precision:0.00047  
Best single channel to date  
First time close to LEP/SLD

## ➤ All D0 RunII weak-mixing angle measurements

### ➤ Strategy

- Measured from raw  $A_{FB}$
- Statistical dominated
- PDF uncertainty
- Systematic uncertainty: Lepton energy calibration

### ➤ Measured from raw $A_{FB}(M_{ll})$

- Not from unfolded  $A_{FB}(M_{ll})$
- Same sensitivity
- Extra systematic uncertainty from the response matrix

➤  $1.1fb^{-1}$  electron channel measurement (2008)

➤ First hadron measurement

- Tevatron RunIIa, 35K events
- Measured by observing  $A_{FB}(M_{ll})$
- PDF:CTEQ6L
- Simple higher-order correction(ZGRAD2)

$$\begin{aligned}\sin^2 \theta_{eff}^l &= 0.2326 \pm 0.0019 \\ &= 0.2326 \pm 0.0018(stat.) \pm 0.0003(syst.) \pm 0.0005(PDF)\end{aligned}$$

	$1.1fb^{-1}$ results	Theoretical expectation for $10fb^{-1}$ *
$\sigma_{stat}$	0.0018	0.0005
$\sigma_{syst}$	0.0003	0.00007
$\sigma_{PDF}$	0.0005	0.00007
$\sigma_{Total}$	0.0019	~0.0005

\*arXiv:hep-ex/0011009

➤  $5fb^{-1}$  electron channel measurement (2011)

➤ Mid-term estimation

- Tevatron RunIIa+part of RunIIb, 160K events
- Measured by observing  $A_{FB}(M_{ll})$
- PDF:CTEQ6L

$$\begin{aligned}\sin^2 \theta_{eff}^l &= 0.2309 \pm 0.0010 \\ &= 0.2309 \pm 0.0008(stat.) \pm 0.00029(syst.) \pm 0.00048(PDF)\end{aligned}$$

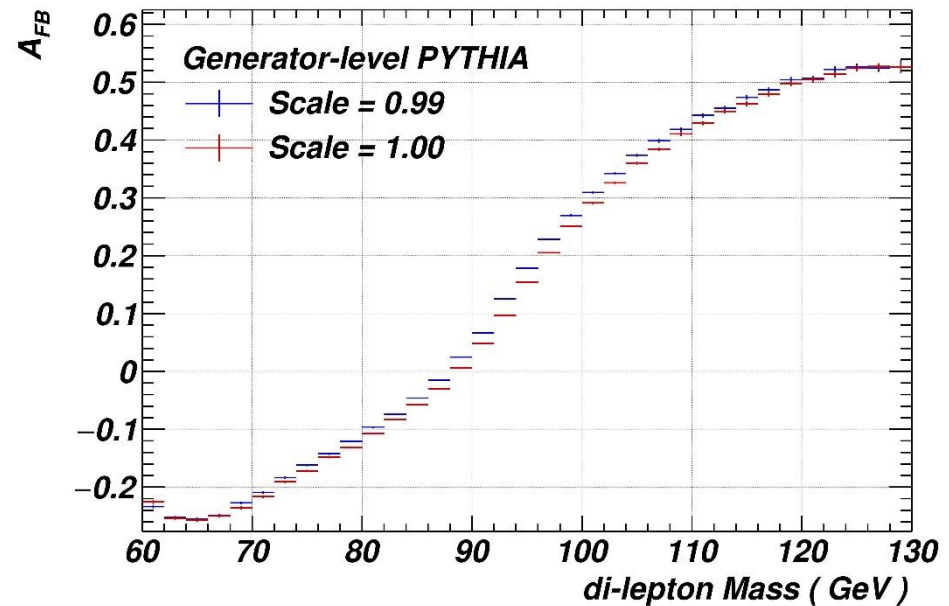
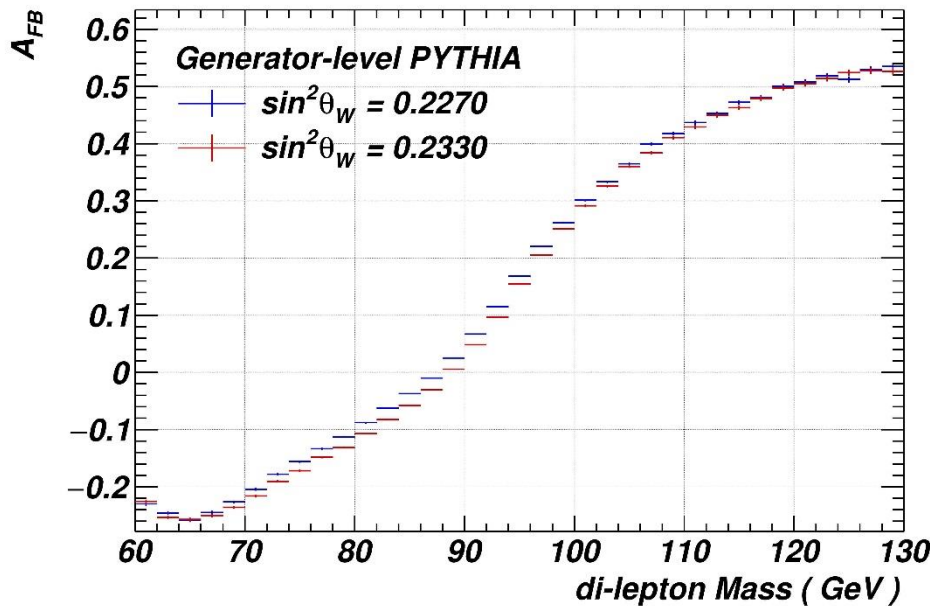
	$5fb^{-1}$ results	Theoretical expectation for $10fb^{-1}$	Expectation for $10fb^{-1}$ using $5fb^{-1}$ results
$\sigma_{stat}$	0.0008	0.0005	$> 0.0006$
$\sigma_{syst}$	<b>0.00029</b>	<b>0.00007</b>	<b>0.0003</b>
$\sigma_{PDF}$	0.00048	0.00007	$\sim 0.00048$
$\sigma_{Total}$	0.00048	$\sim 0.0005$	$\sim 0.00085$

## ➤ Systematic uncertainty

### ➤ Lepton calibration

- Affects  $A_{FB}(M_{ll})$  same with  $\sin^2 \theta_W$  does
- Very sensitive

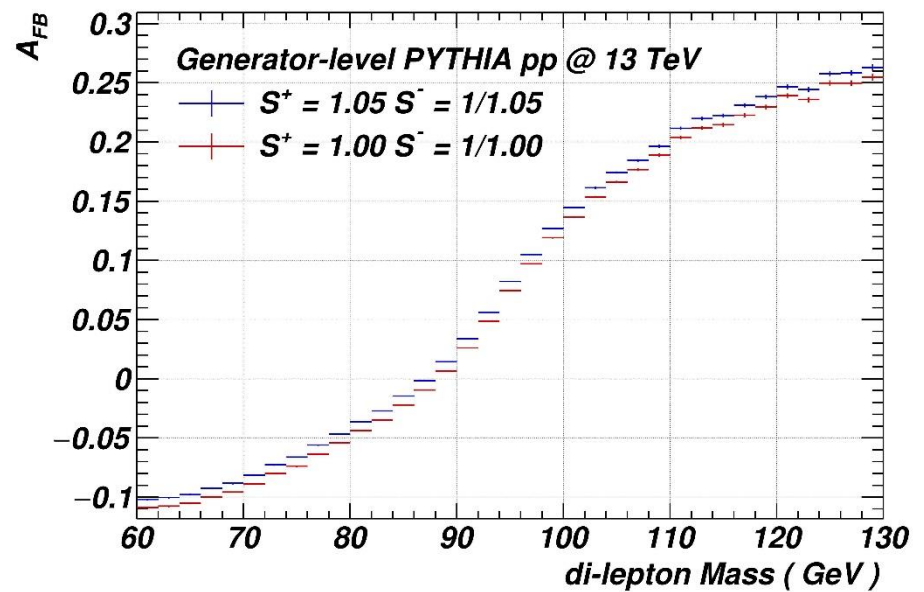
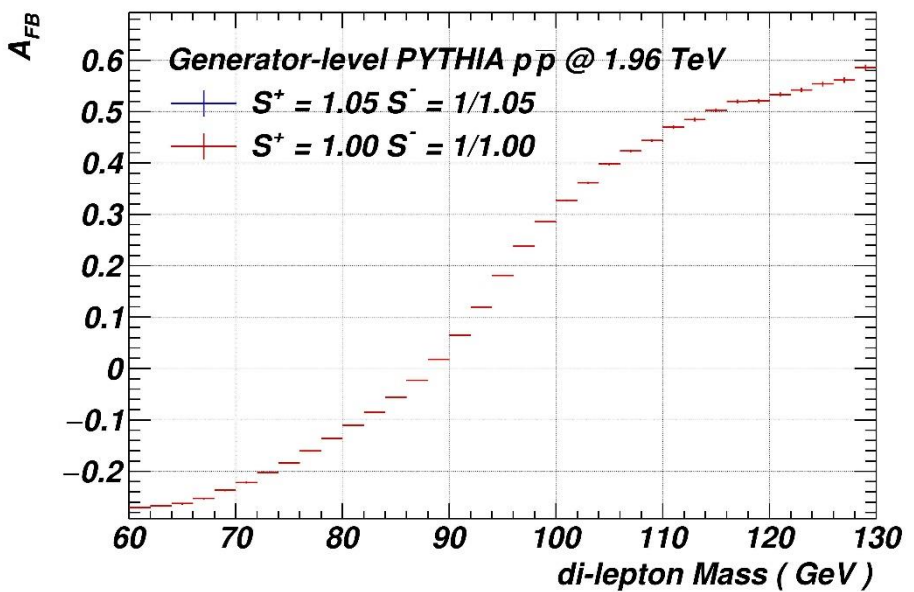
$$\frac{\delta M}{M} / \sigma_{\sin^2 \theta_W} \sim 0.01\% / 0.00003$$



➤ Lepton calibration

$$\frac{\delta M}{M} / \sigma_{\sin^2 \theta_W} \sim 0.01\% / 0.00003$$

- A mass calibration
  - Only mass scale affects  $A_{FB}(M_{ll})$  at Tevatron
  - At LHC, lepton energy scale directly affects  $A_{FB}(M_{ll})$
- In LHC,  $E_l$  becomes more important
  - Quark direction, according to Z boson boost( $p_Z$ )
  - May change the direction/the sign of  $p_Z$



➤  $9.7fb^{-1}$  electron channel measurement (2015)

- First high precision measurement
- Best electron channel measurement to date
  - Tevatron RunII, ~560K events
  - Measured by observing  $A_{FB}(M_{ll})$
  - PDF: NNPDF2.3/3.0

$$\begin{aligned}\sin^2 \theta_{eff}^l &= 0.23137 \pm 0.00047 \\ &= 0.23137 \pm 0.00043(stat.) \pm 0.00009(syst.) \pm 0.00017(PDF)\end{aligned}$$

	$9.7fb^{-1}$ results	Theoretical expectation for $10fb^{-1}$	Expectation for $10fb^{-1}$ using $5fb^{-1}$ results
$\sigma_{stat}$	0.00043	0.0005	> 0.0006
$\sigma_{syst}$	0.00009	0.00007	0.0003
$\sigma_{PDF}$	0.00017	0.00007	~0.0002
$\sigma_{Total}$	0.00047	~0.0005	~0.00085



➤  $8.6fb^{-1}$  muon channel measurement (2017)

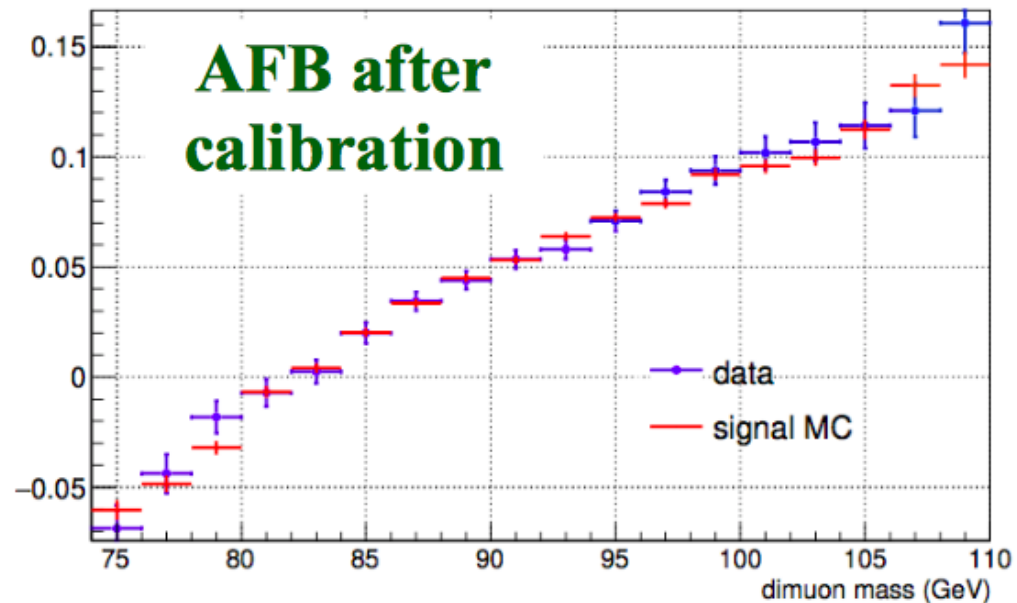
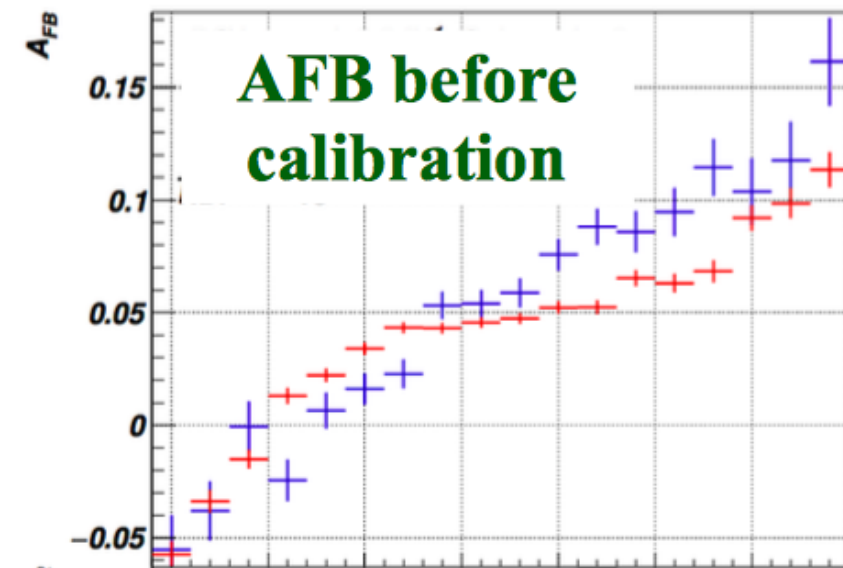
➤ Best muon channel measurement to date

- Tevatron RunIIb, ~480K events
- Measured by observing  $A_{FB}(M_{ll})$
- PDF: NNPDF3.0

$$\begin{aligned}\sin^2 \theta_{eff}^l &= 0.23016 \pm 0.00064 \\ &= 0.23016 \pm 0.00059(stat.) \pm 0.00006(syst.) \pm 0.00024(PDF)\end{aligned}$$

➤ Originally not in the plan

- Charge-dependent muon momentum scale



➤ DZero combination (2017)

$$\begin{aligned}\sin^2 \theta_{eff}^l &= 0.23095 \pm 0.00040 \\ &= 0.23095 \pm 0.00035(stat.) \pm 0.00007(syst.) \pm 0.00019(PDF)\end{aligned}$$

➤ Higher order correction

➤ Straight forward high order corrections

- ZFITTER-based form factor calculation
- ResBos vs. PYTHIA comparison

	$\Delta \sin^2 \theta_{eff}^l$
Different effective coupling for u and d quarks	+0.00008
Mass-scale dependence and complex calculation	+0.00014
Total	+0.00022

$$\Delta \sin^2 \theta_W = +0.00022 \pm 0.00004(\text{Dominated by } m_t)$$

## ➤ Summary

$$\begin{aligned}\sin^2 \theta_{eff}^l &= 0.23095 \pm 0.00040 \\ &= 0.23095 \pm 0.00035(stat.) \pm 0.00007(syst.) \pm 0.00019(PDF)\end{aligned}$$

- Best single experiment to date
- Best light-quark measurement
  
- High precision calibration
  - Both statistical uncertainty and systematic uncertainty
  - Only need mass scale at Tevatron
  
- Some systematic uncertainty will become more important in LHC
  
- Higher order correction
  - Straight forward higher order corrections
  - Uncertainty dominated by  $m_t$