Measurement of the forward-backward charge asymmetry (AFB) at hadron colliders in the future

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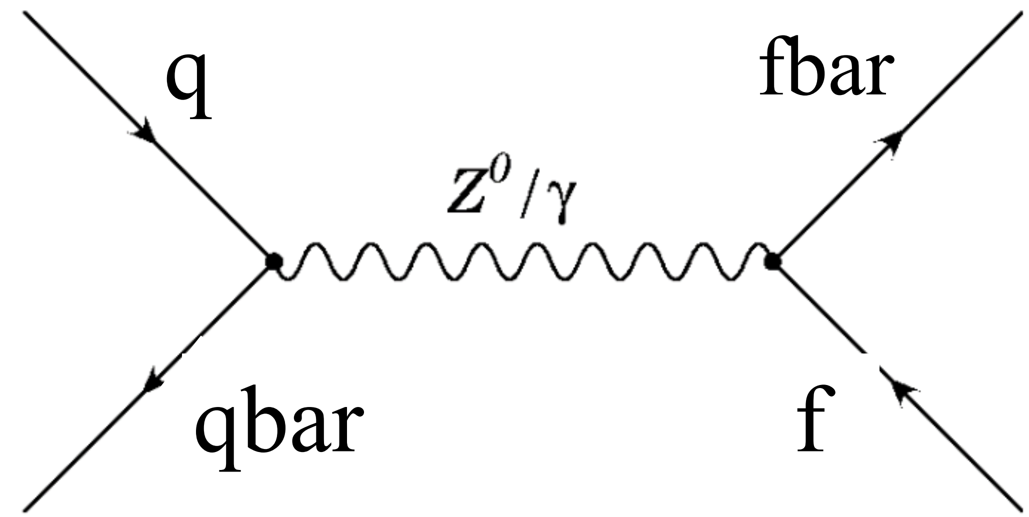
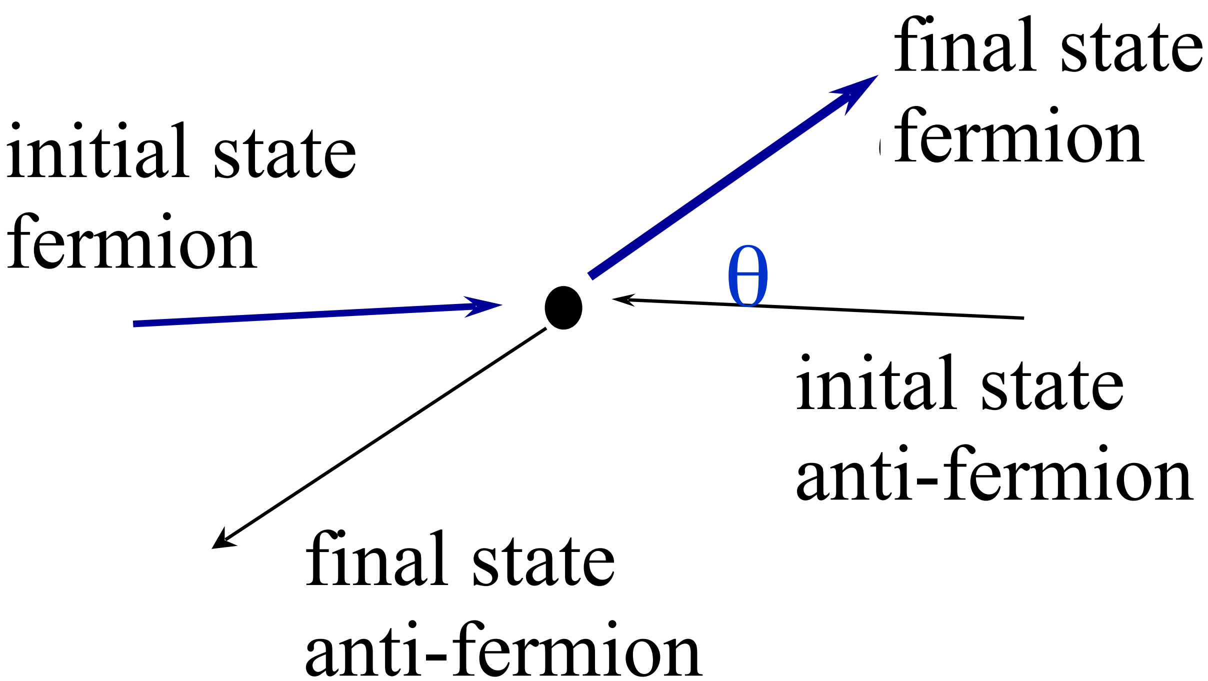
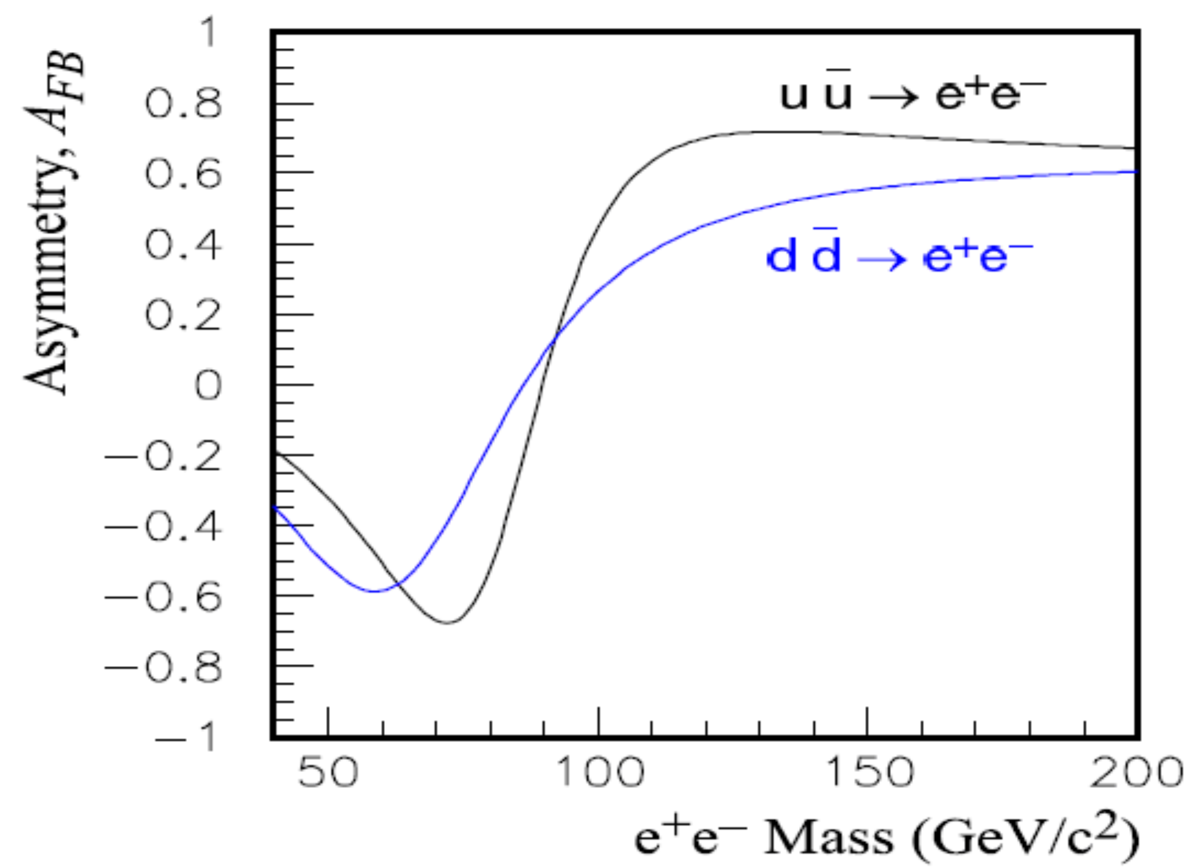
Forward-Backward Asymmetry at hadron colliders

Asymmetry at Z pole

- **Forward-Backward Asymmetry (A_{FB})**
- **A function of invariant mass**







cosθ>0, forward

cosθ<0, backward

$$A_{FB} = \frac{\sigma_F - \sigma_B}{\sigma_F + \sigma_B} = A_{FB}(\sin^2\theta^f_{\mathrm{eff}})$$

AFB: determination on $\sin^2\theta_W$

2008, D0 1 fb^{-1}
electron channel
precision: 0.0019
first hadron collider measurement

2011, D0 5.1 fb^{-1}
electron channel
precision: 0.0010

2013, CDF 2.1 fb^{-1}
electron channel
precision: 0.0011

2014, CDF 9.2 fb^{-1}
muon channel
precision: 0.0010
CDF muon final result

2015 ATLAS 7 TeV
precision: 0.0012

2015, D0 9.7 fb^{-1}
electron channel
precision: 0.00047
D0 electron final result
Best single channel to date
First time close to LEP/SLD

2016 LHCb 7+8 TeV
precision: 0.00105

2016, CDF 9.4 fb^{-1}
electron channel
precision: 0.00053
CDF electron final result

CDF Combine precision: 0.00046

2017 CMS 8 TeV
precision: 0.00052

2017, D0 8.6 fb^{-1}
muon channel
precision: 0.00064
D0 muon final result

D0 Combine precision: 0.00040
Best single experiment to date
Best light-quark measurement

2018, Tevatron combined
precision: 0.00033

AFB: determination on $\sin^2\theta_W$

Uncertainty from LEP/SLC/Tevatron	0.00029 0.00026 0.00033
Uncertainty from LHC (full Run II)	Stat. <0.00020 PDF. >0.00020 Exp. Syst. ~0.00010
Uncertainty from LHC (>1000 fb^{-1})	Stat. <0.00010 PDF. >0.00020 (??) Exp. Syst. ~0.00010 (??)
Theoretical uncertainty from 2-loop correation	0.00005

AFB: determination on $\sin^2\theta_W$

Measurement at the LHC

- light-quark (ud) initial state / lepton final state
- Statistical uncertainty very small
- PDF uncertainty dominated (even if in the future it could be reduced)

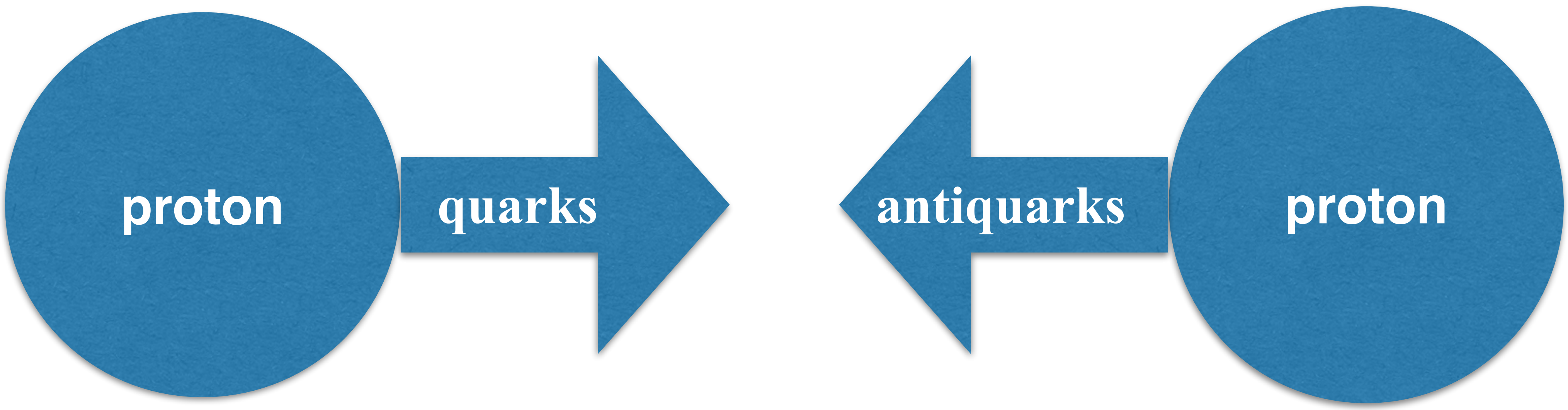
High precision measurement from single experiment more important than LHC combination

- Combination does not provide higher precision
- Various assumptions needed

AFB: dilution and proton structure

Forward-backward definition at the LHC

- Assume q = Z boost direction (valence quark E > sea quark E, statistically)
- Dulition: valence quark E < sea quark E



Unique proton struction information

- Relative difference between quark and antiquark at Q=100 GeV, x=0.01~0.001
- Not directly covered by other experimental results

AFB: dilution and proton structure

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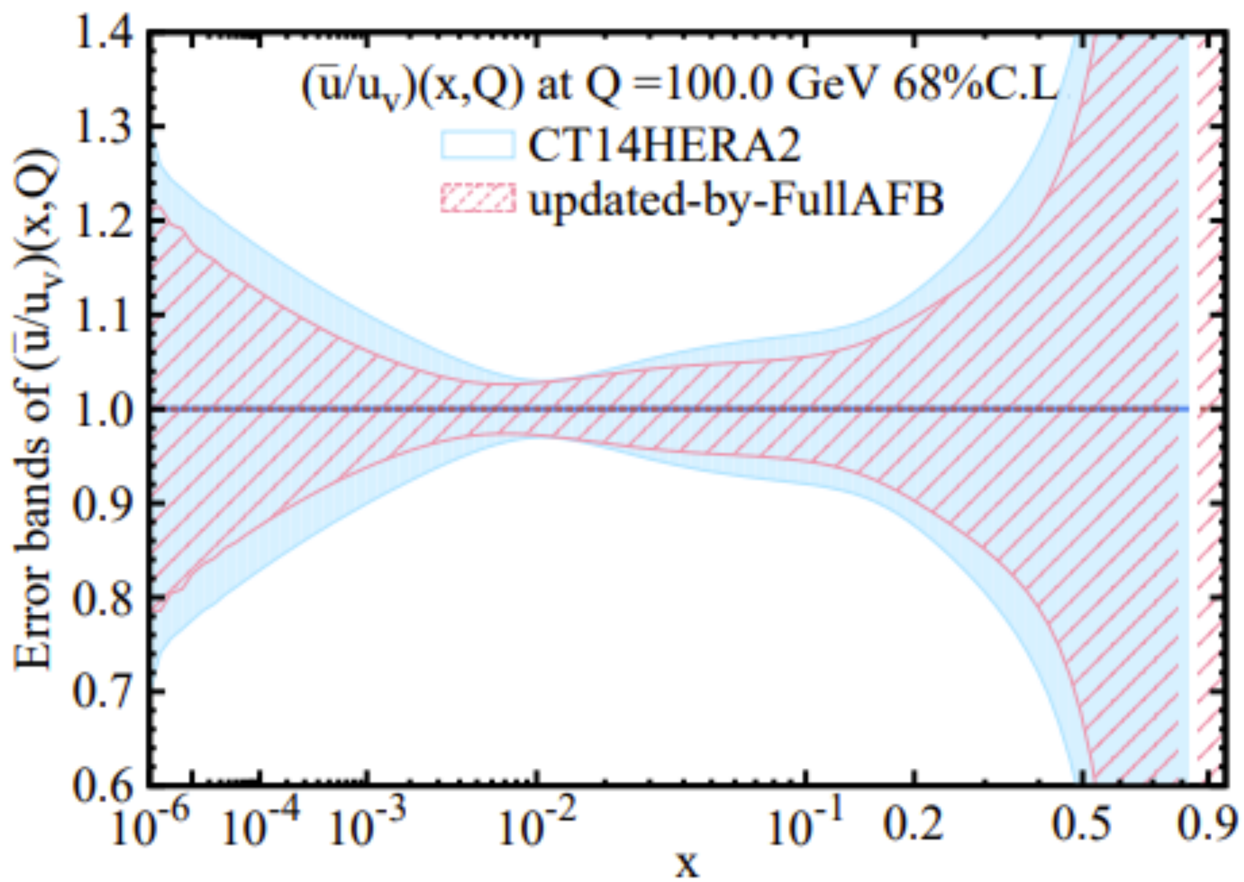
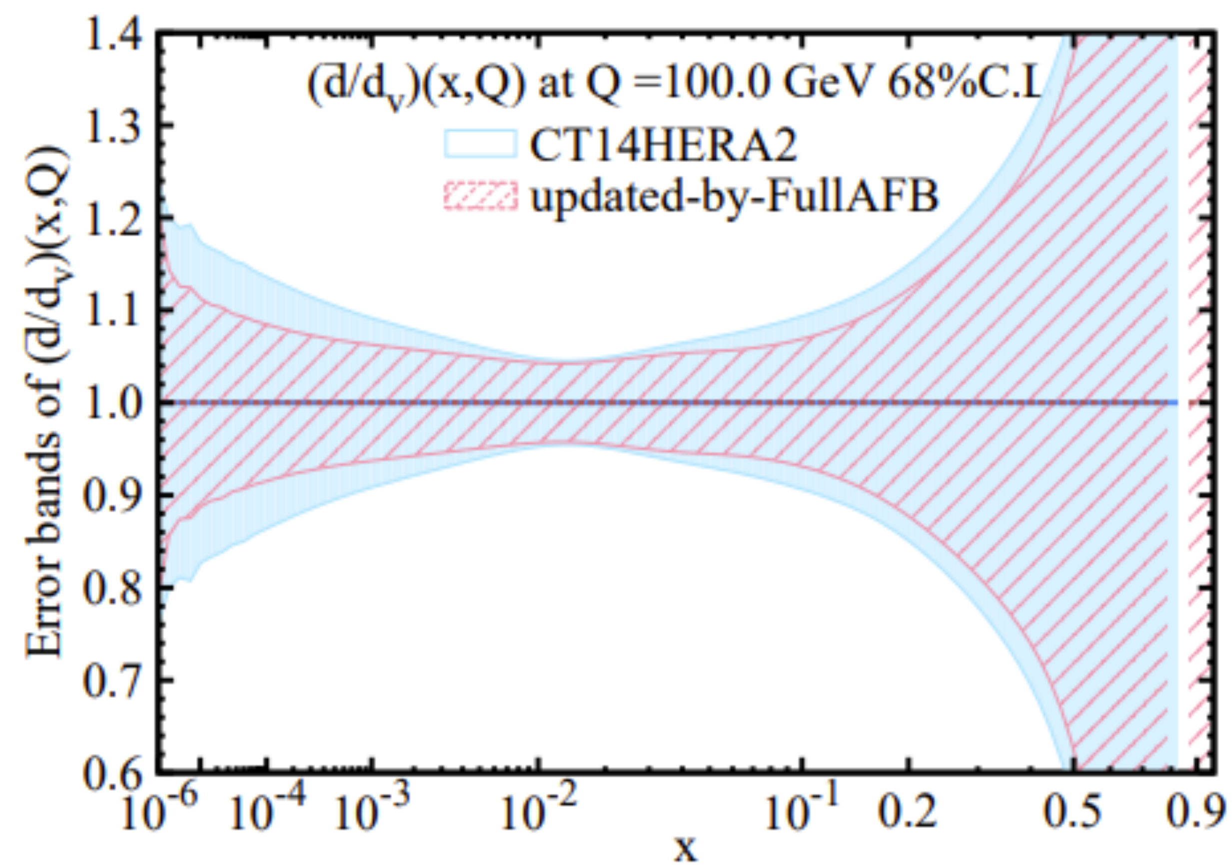




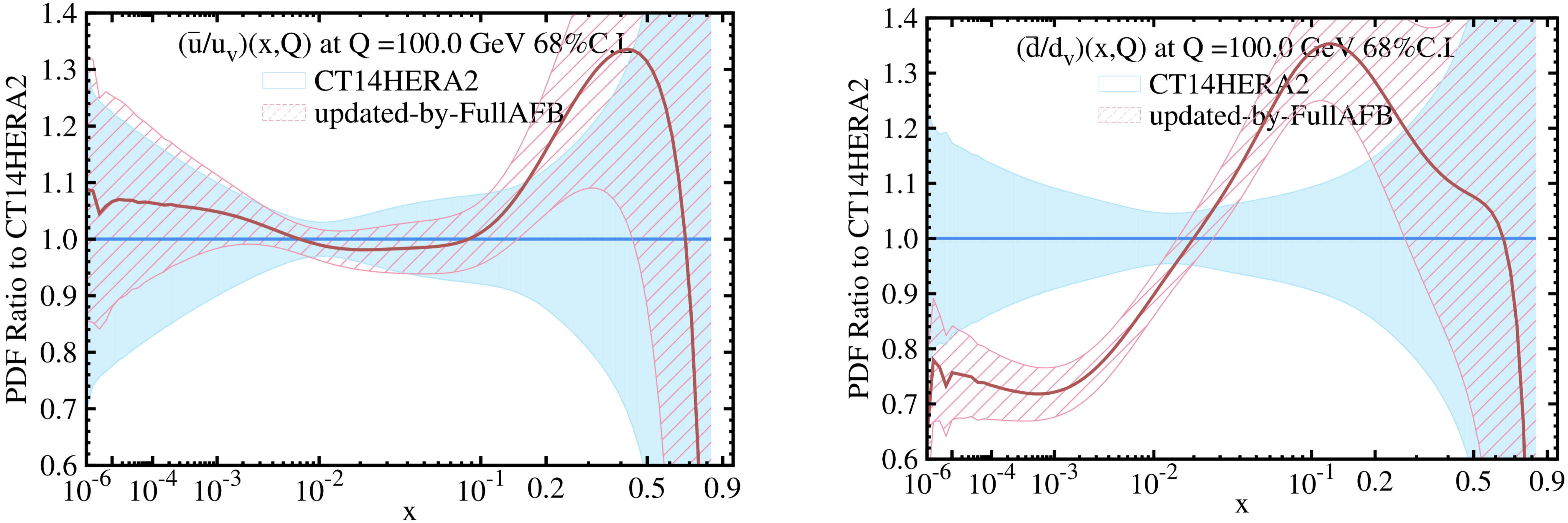
Using AFB in the PDF global fitting, corresponding to 130 fb^{-1} data collected by ATLAS or CMS (LHC Run 2)

AFB generated using ResBos+CT14HERA2

AFB: correlations between proton structure and $\sin^2\theta_W$

Correlations

- **Observation on proton structure highly correlated with determination on $\sin^2\theta_W$**
- **Difficult to be considered in the PDF global fitting theory**



Using AFB in the PDF global fitting. The input AFB is generated with its $\sin^2\theta_W$ value different from the PDF global fitting theory (0.2315 vs 0.2324)

Reducing the correlation (1) sideband

Sideband region AFB

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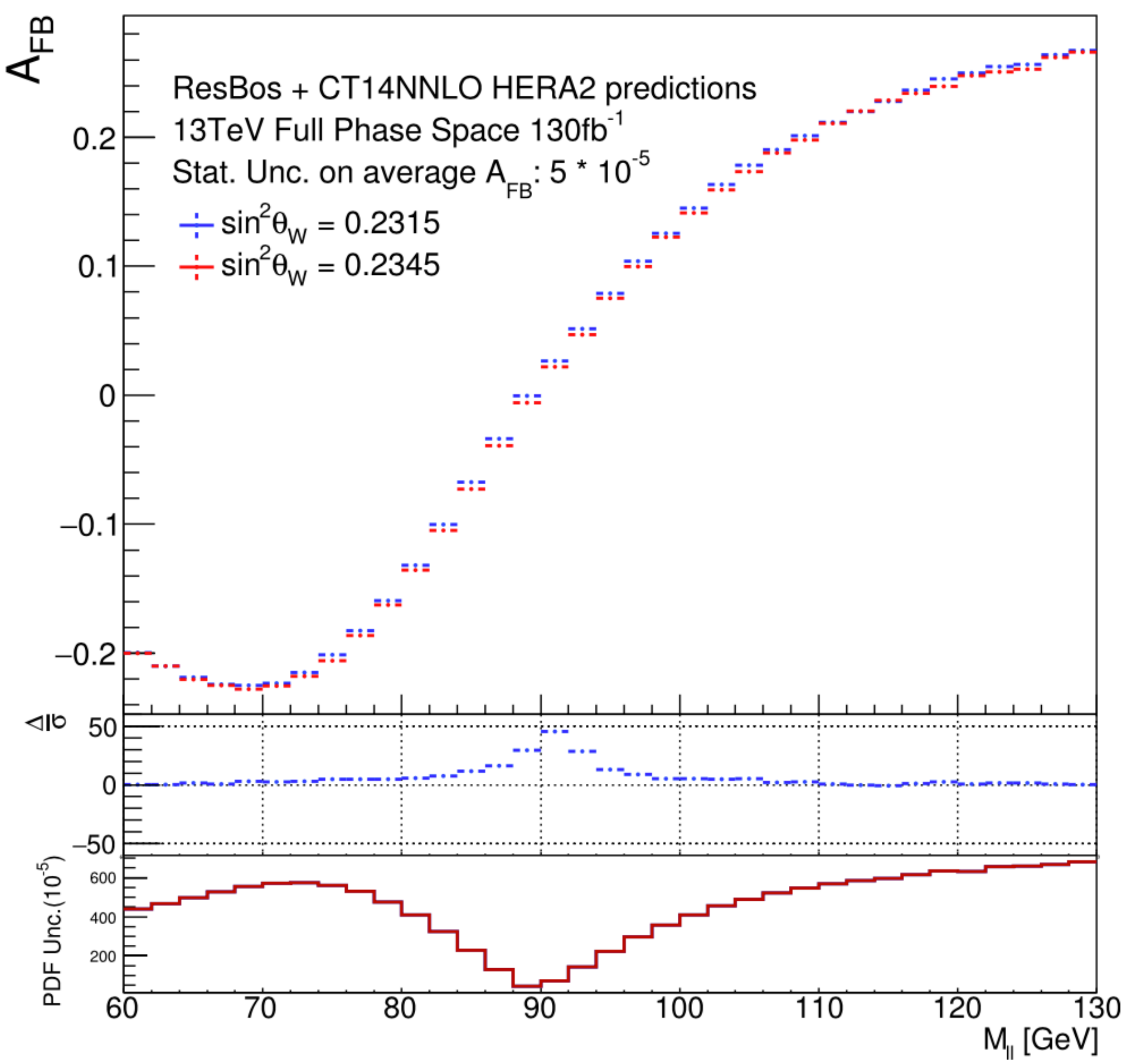
- AFB-to-$\sin^2\theta_W$ sensitivity dominated by Z pole region
- AFB-to-dilution sensitivity dominated by sideband region
- Using sideband AFB in PDF global fitting would reduce the correlation

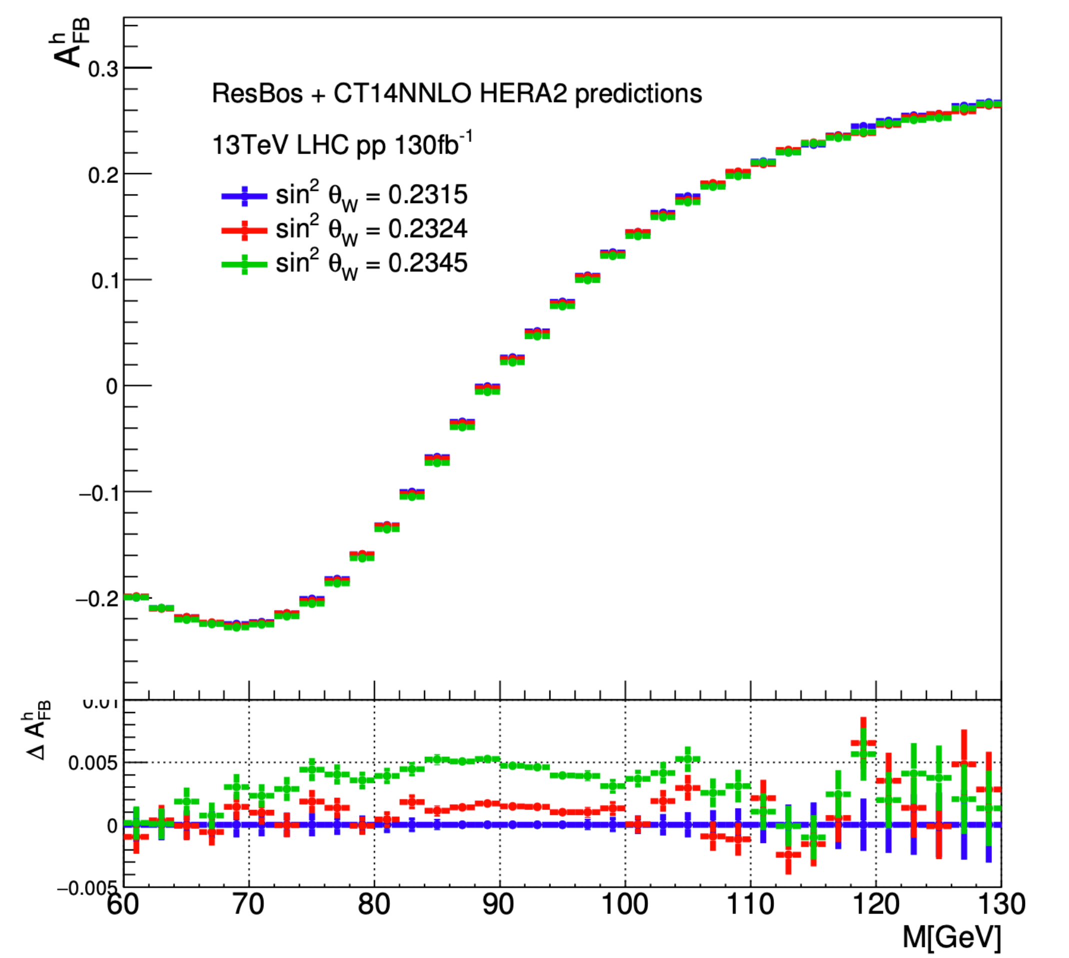


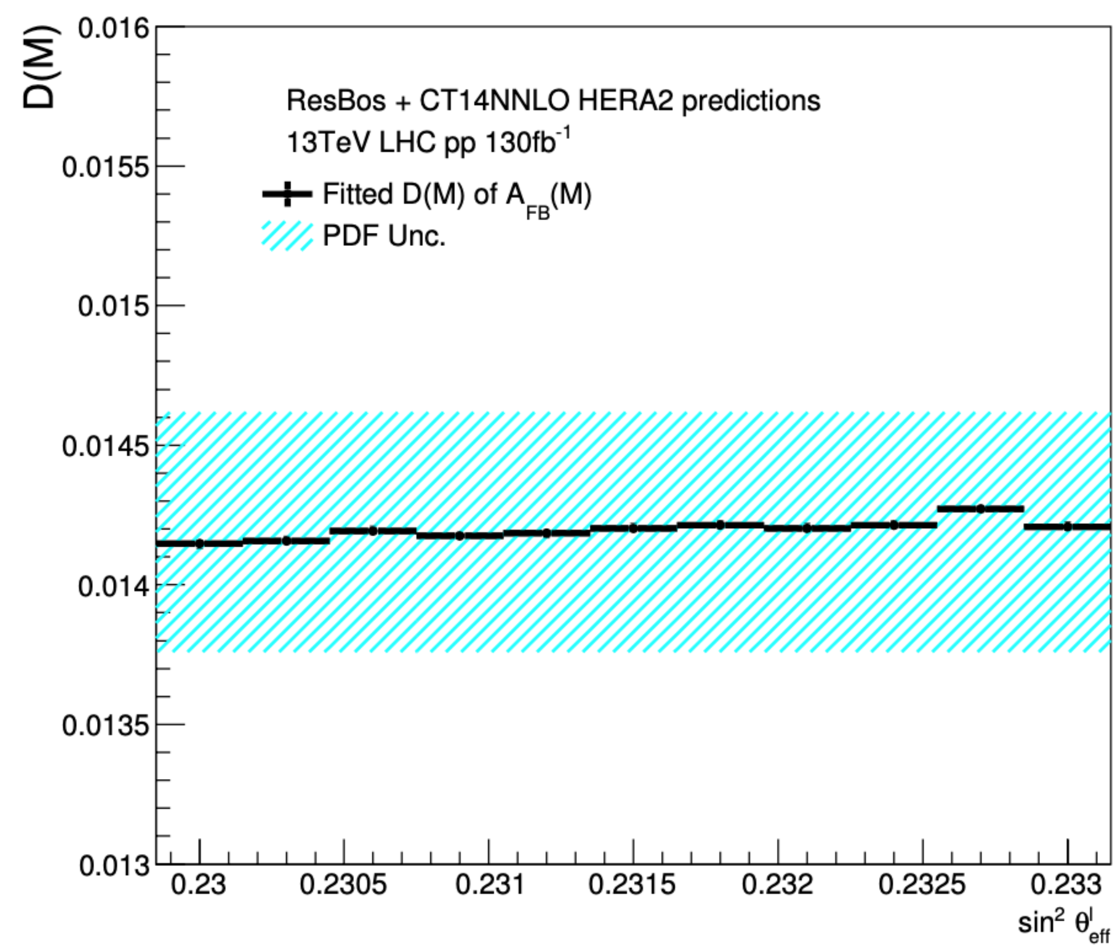
Reducing the correlation (2) gradient

Shape information of AFB vs M

arXiv: 2108.06550

- sin²θ$_W$ governs AFB vs M in the way as a global shift
- dilution govers AFB vs M in the way as a shape rotation
- using only the "shape" information of AFB would reduce the correlation

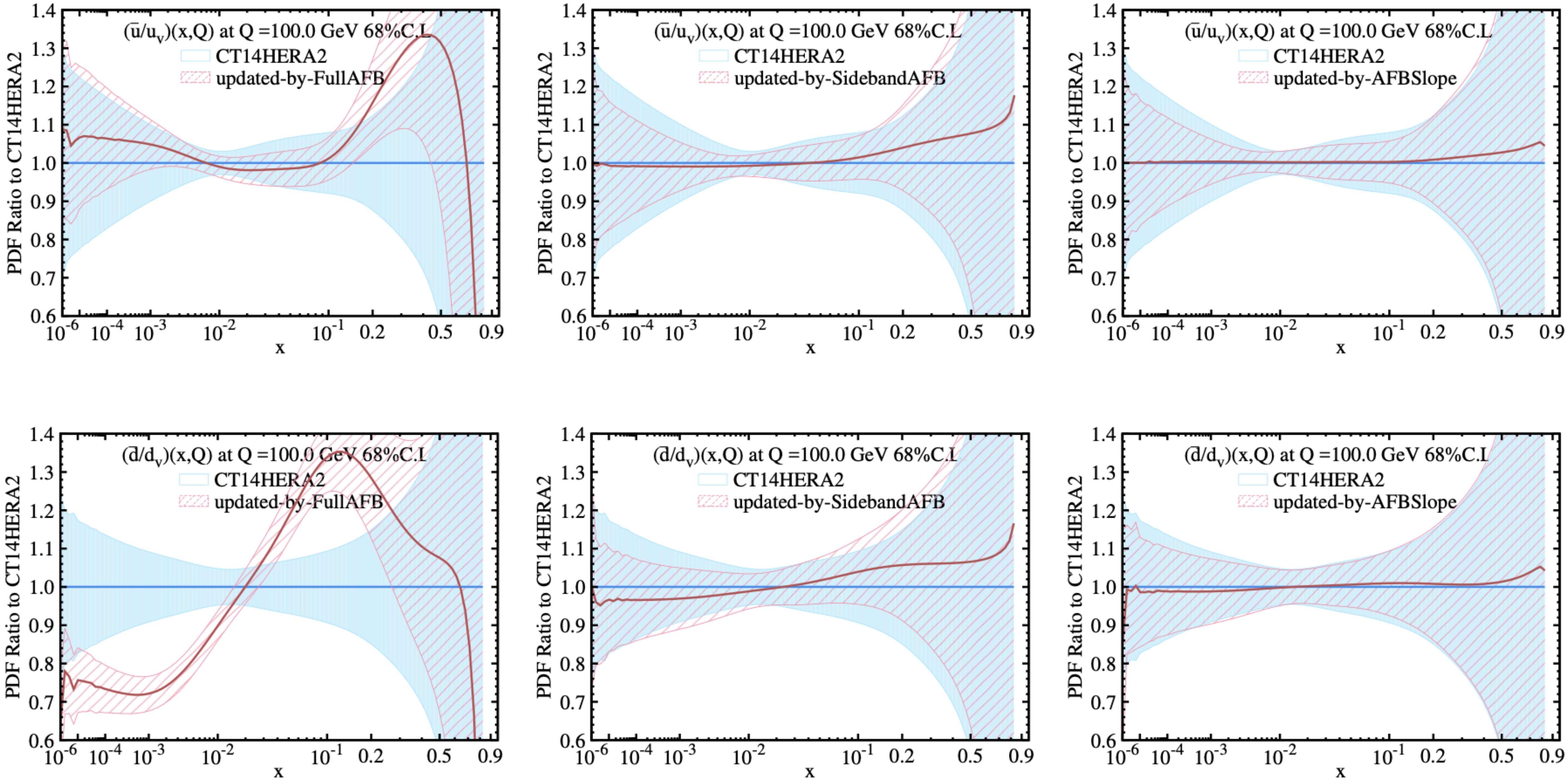




The slope of AFB vs M at Z pole (if treated as a linear type), as a function of sin²θ$_W$

Reducing the correlation

Chinese Physics C 45, 053001 (2021)
and arXiv: 2108.06550



Full-AFB updating **Sideband AFB updating** **AFB slope updating**

Measurement of the effective weak mixing anlge at CEPC

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Precision determination on $\sin^2\theta_W$

Fundamental parameters in electroweak sector

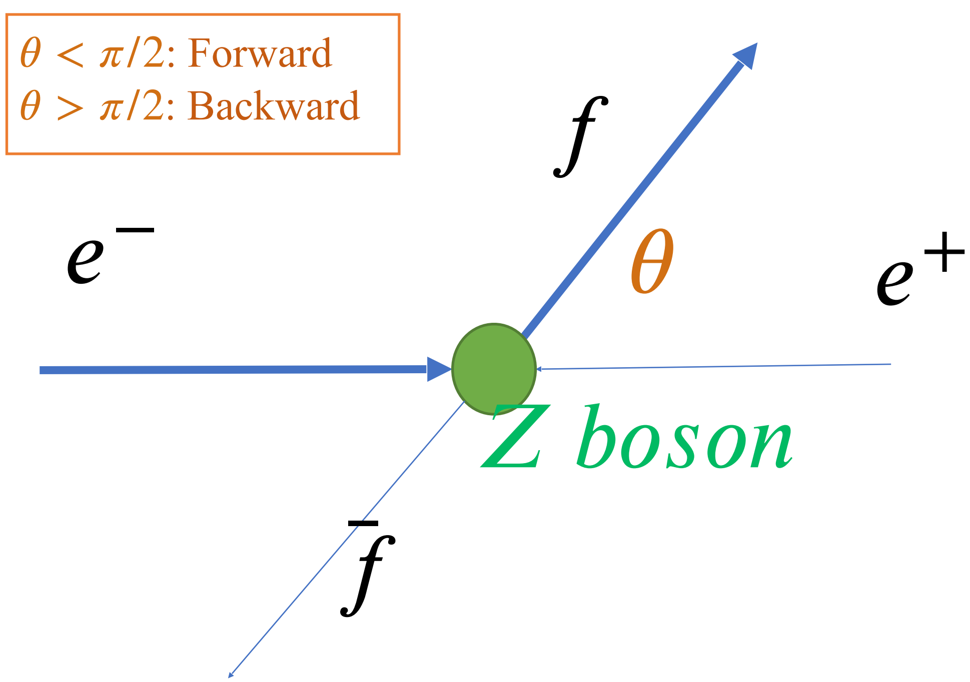
- **α, G_μ, M_Z, M_W, $\sin^2\theta_W$**

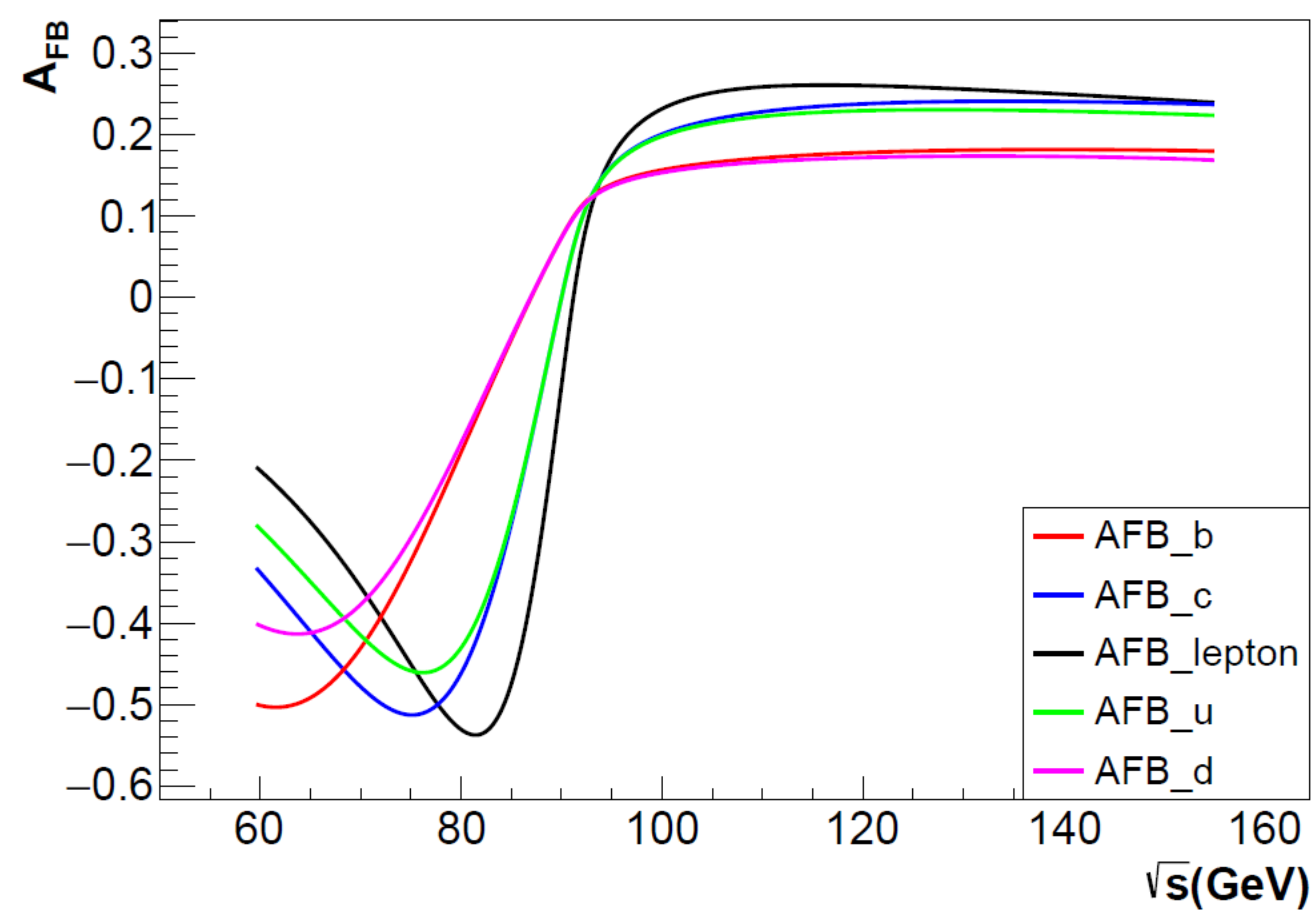
	Precision
Fine structure constant	$\sim 10^{-8}$
Fermi-constant	$\sim 10^{-5}$
MZ	$\sim 10^{-5}$
MW	close to 10^{-4}
$\sin^2\theta_W$	10^{-3}

Measurement at CEPC

High luminosity at the CEPC

- **600 billion Z events in a 2 years plan**
- **Low systematics**





Measurement at CEPC

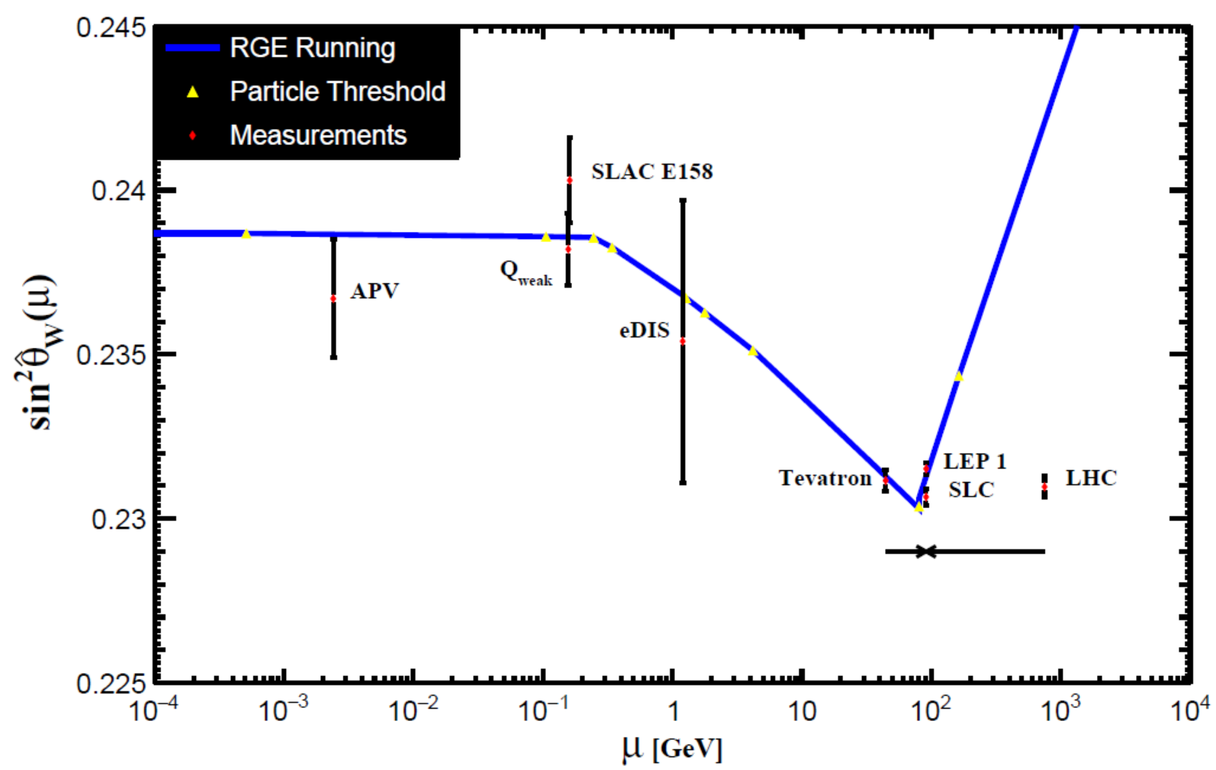
High precision determination

- Best preicions on $\sin^2\theta_W \sim 0.00001$

Independent measurements from lepton, light quarks and heavy quarks

- ee, μμ, ττ, u/d light quark and b, c heavy quark final states

$\sin^2\theta_W$ determination as a function of energy



Low systematics

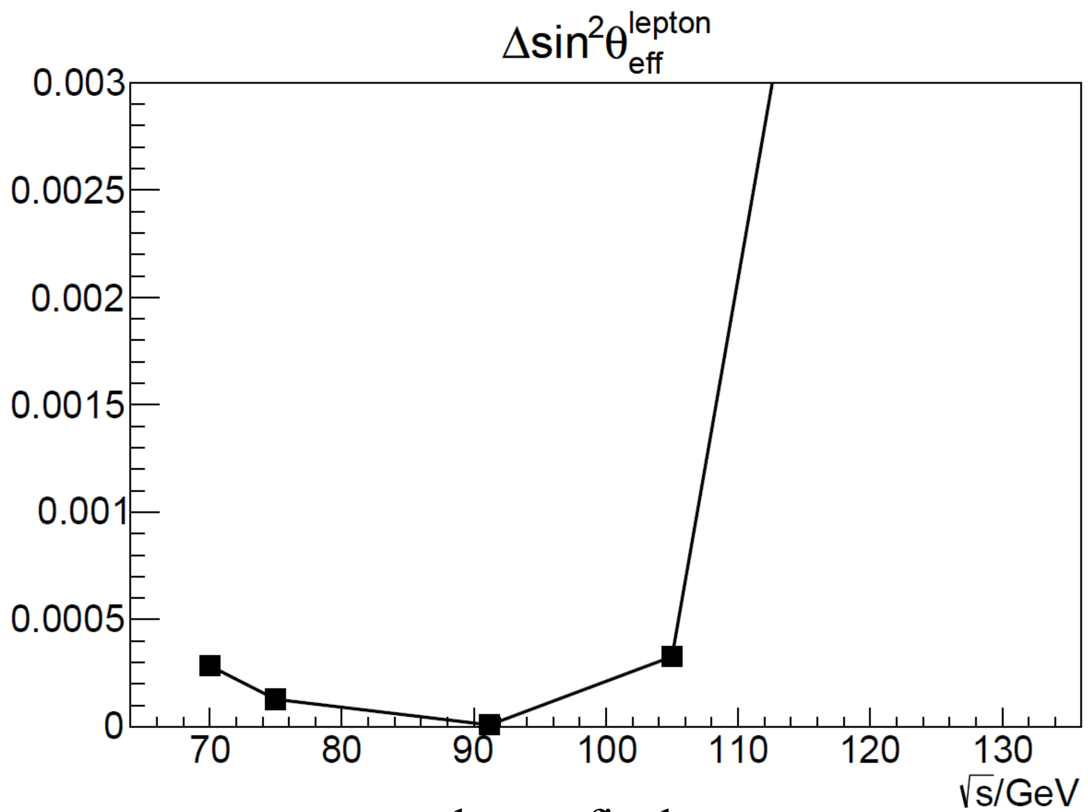
$$\frac{dA_{FB}^{obs}}{d\sin^2\theta_W} = \frac{1}{1-2f} \cdot \sqrt{\frac{1}{\epsilon_{\text{tagging}}}} \cdot \frac{dA_{FB}}{d\sin^2\theta_W}$$

	Leptons	Quarks
tagging power = ε x (1-2f)^2	~ 100%	~0.138 (b quarks) ~0.283 (c quarks)

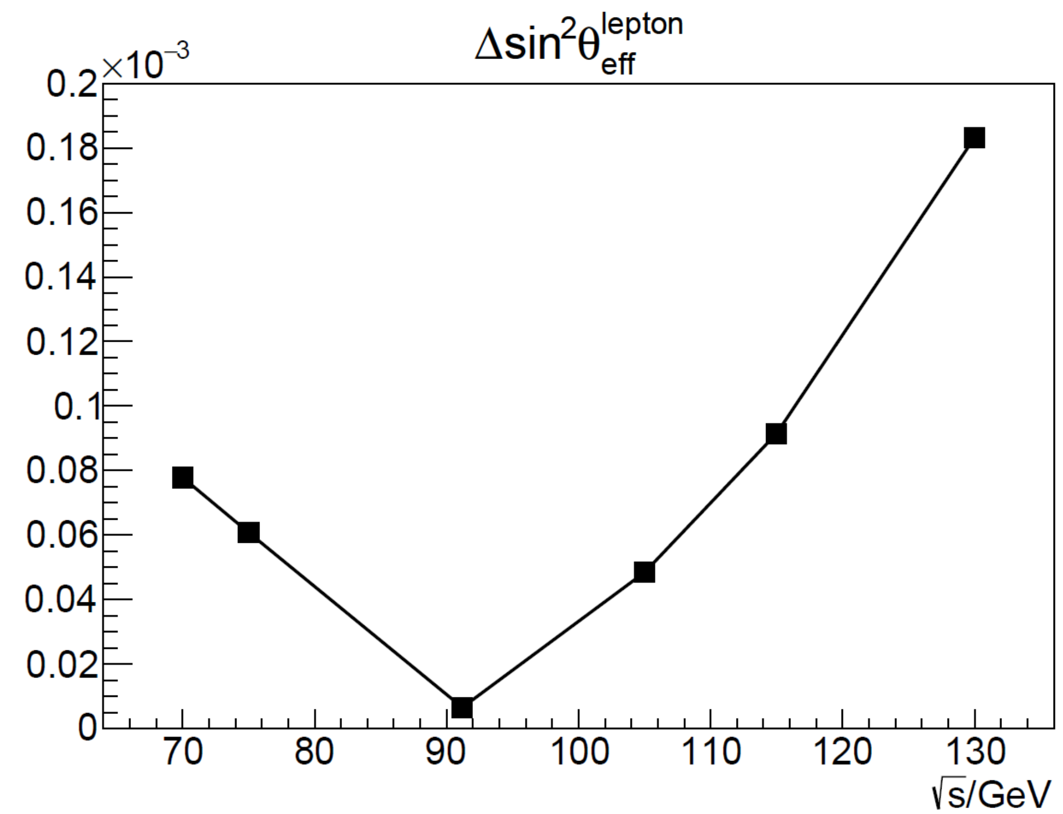
- **efficiency does not extrapolate as systematics, for it cancelled out in the AFB definition**
- **charge-misID probability can be precisely determinted from data**
- **invariant mass is precisely controlled by the beam energy**

Results

Statistics of each measurement point correspond to 1 month data taken



lepton final state
$(ee + \mu\mu + \tau\tau)$



b quark final state

Collision	70 GeV	75 GeV	91.19 GeV	105 GeV	115 GeV	130 GeV
Uncertainty from lepton final state	0.00028	0.00013	0.00001	0.00033	0.00385	0.00766
Uncertainty from b quark final state	0.00008	0.00006	<0.00001	0.00005	0.00009	0.00018

Summary

High precision measurement at CEPC

- **According to 1 month data taken**

Best precision at Z pole	Precision in lepton/quark comparison at Z pole	Precision in energy running
0.00001	0.00001	~0.00010