Combined fitting of the weak mxing angle and the proton structure parameters using the forward-backward charge asymmetry

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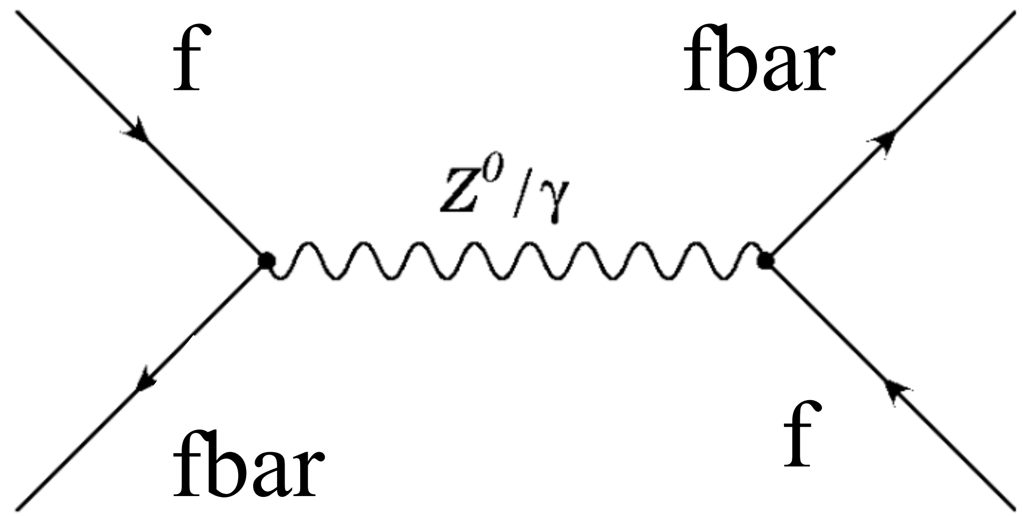
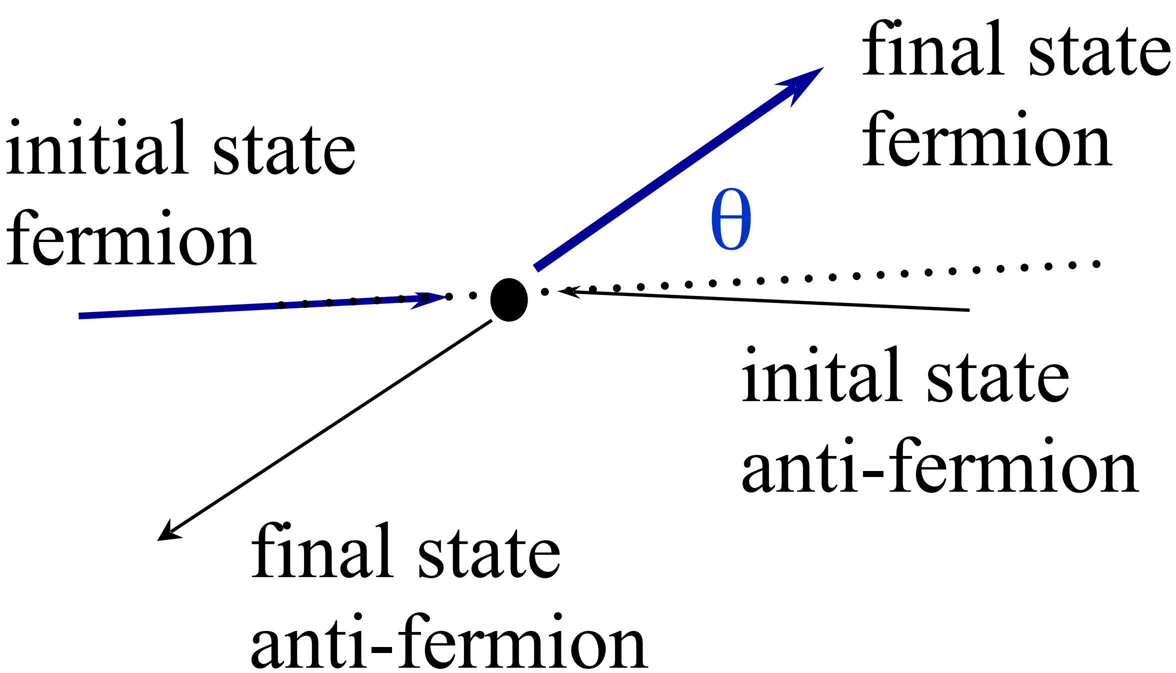
AFB from Drell-Yan process



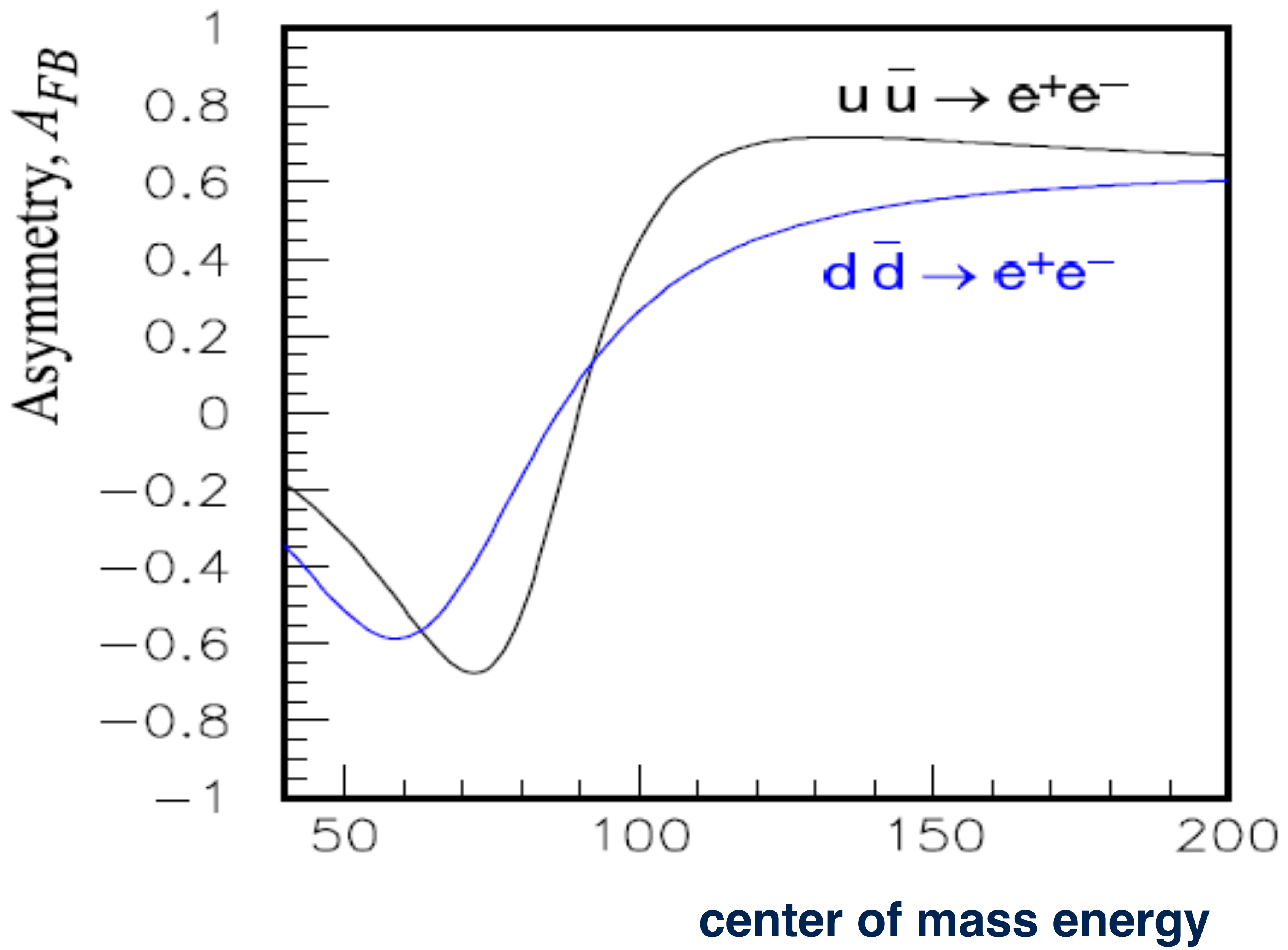


cosθ>0, forward

cosθ<0, backward

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

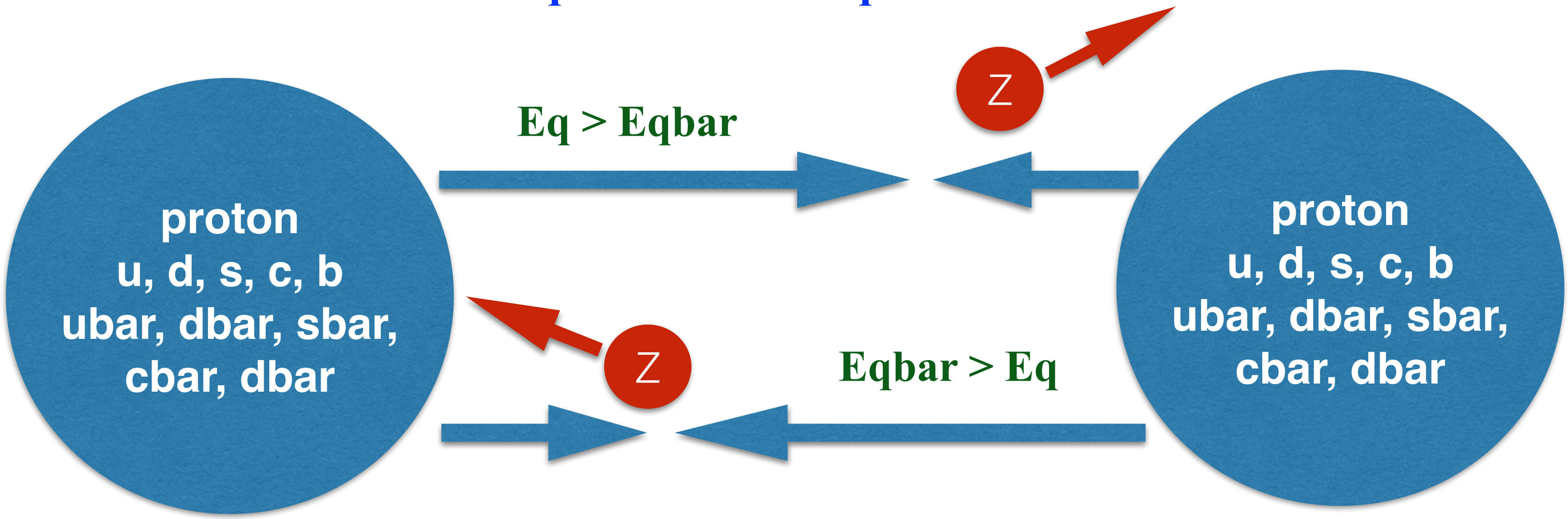
AFB from Drell-Yan process



AFB at hadron colliders

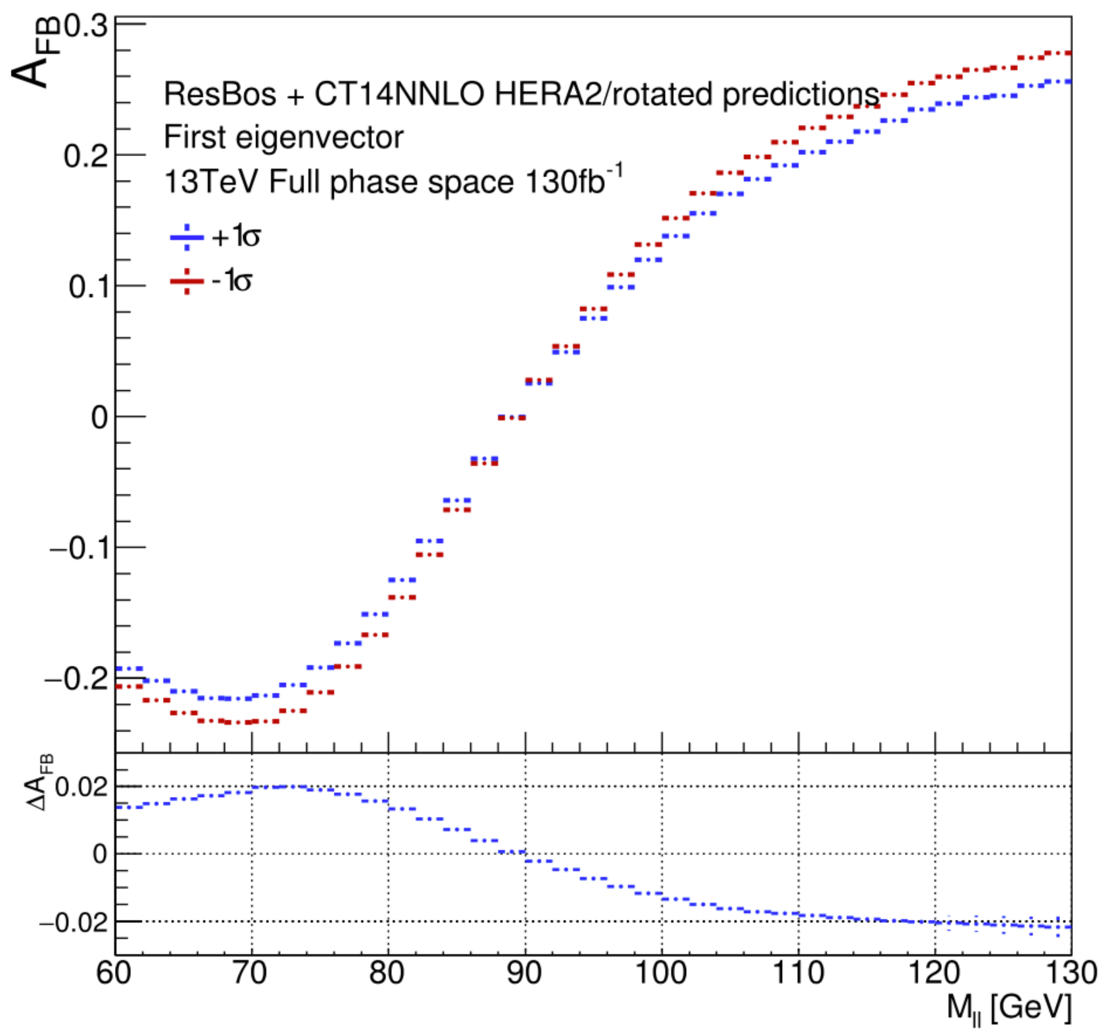
Dilution effect

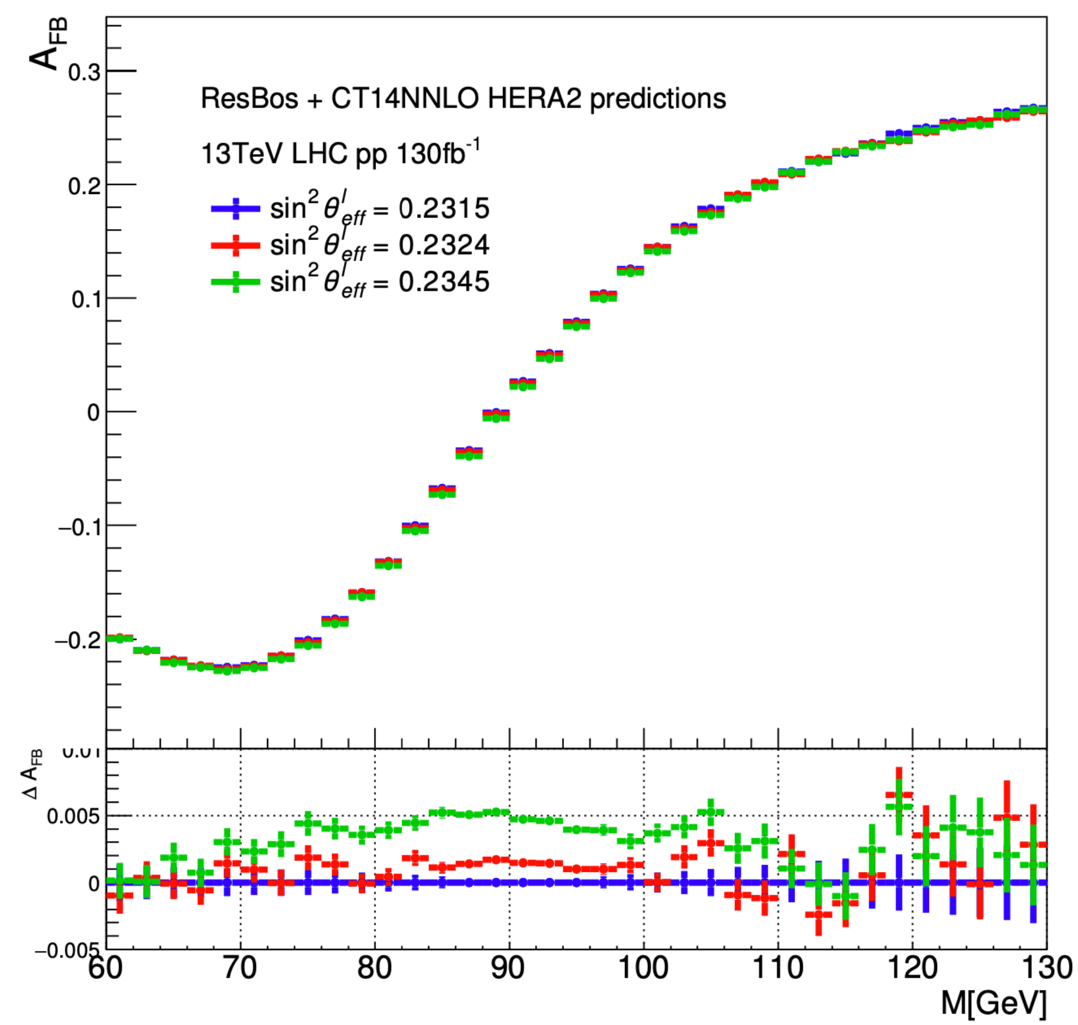
- Symmetrical initial state of proton-proton
- Asymmetry redefined according to the Z boson boost
- Relative difference between quarks and antiquarks



$$A_{FB} \rightarrow A^{h}_{FB}$$

AFB governed by EW and dilution effect

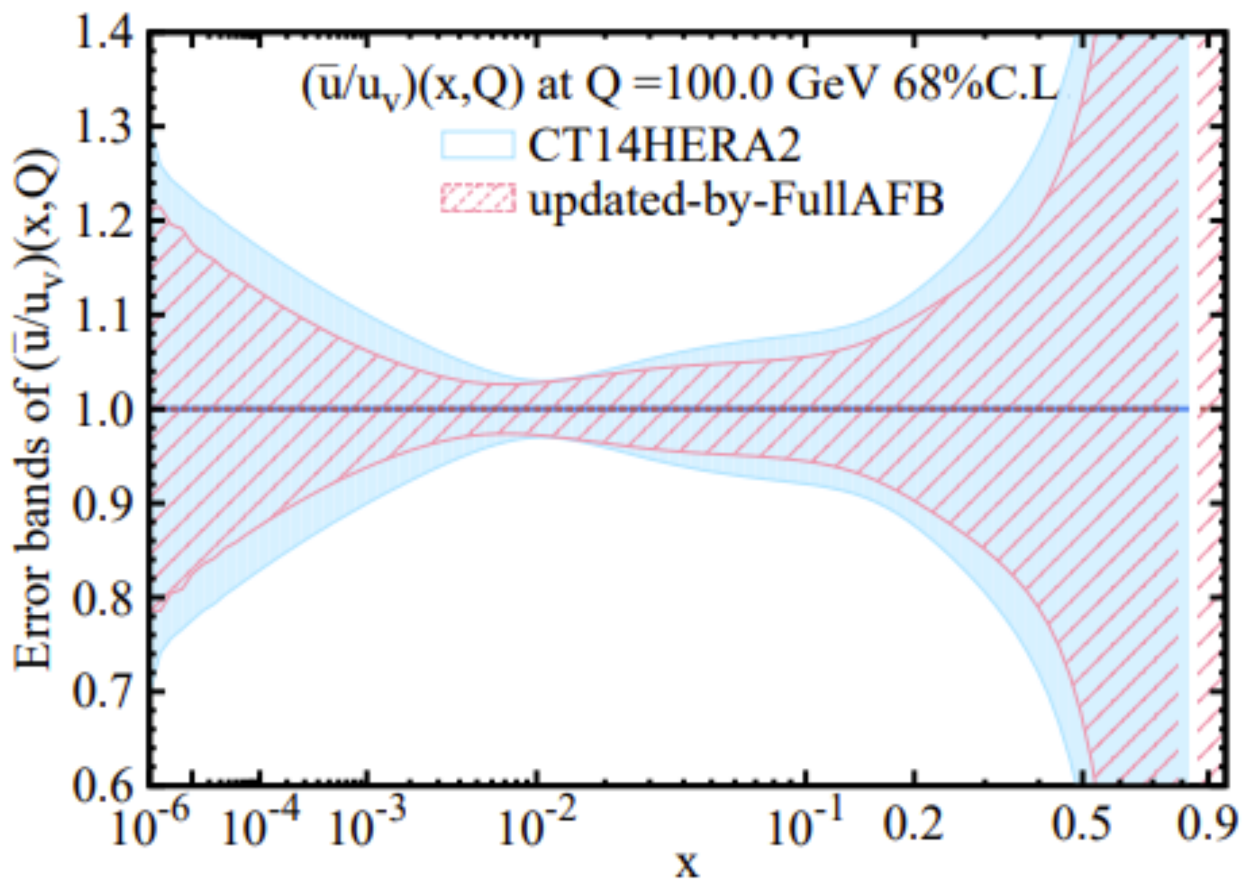


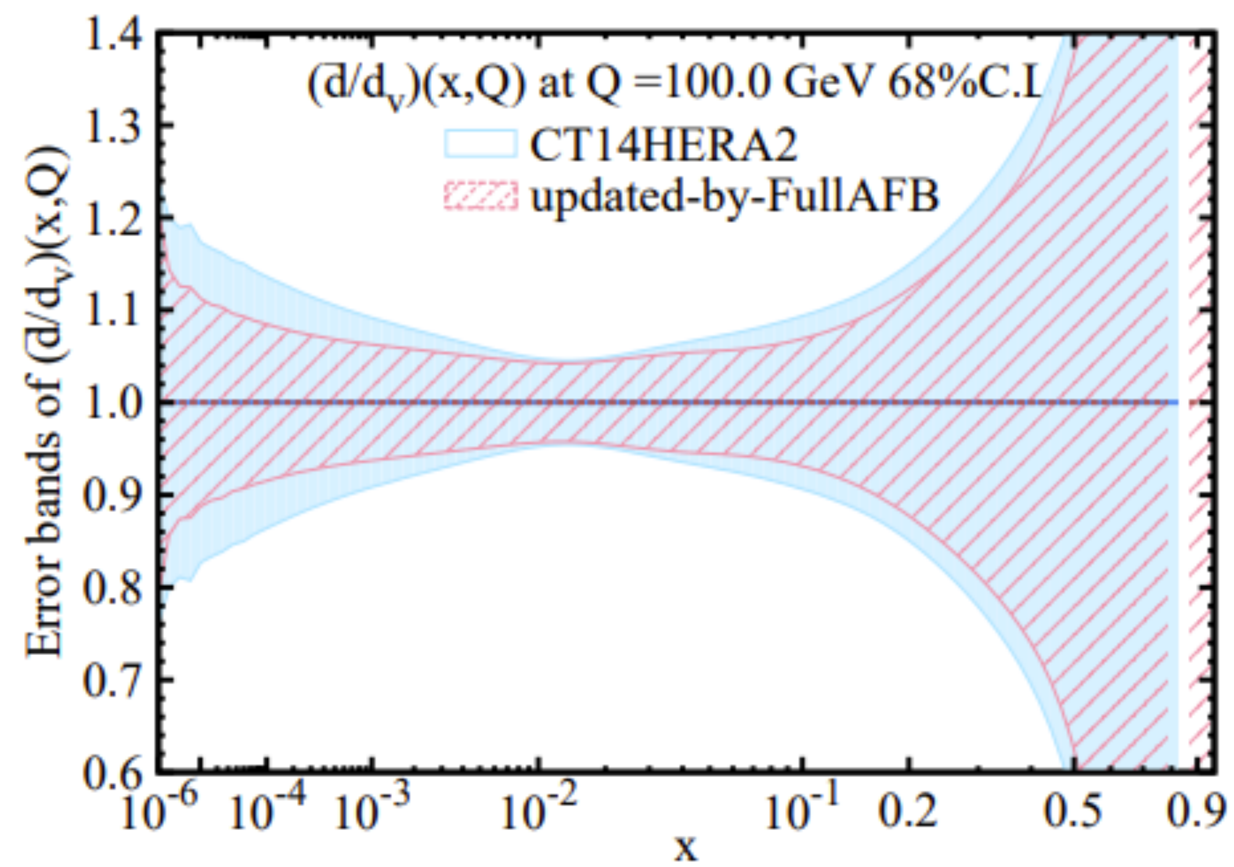


AFB governed by PDF, estimated by CT14

AFB governed by weak mixing angle

AFB used in PDF global fitting





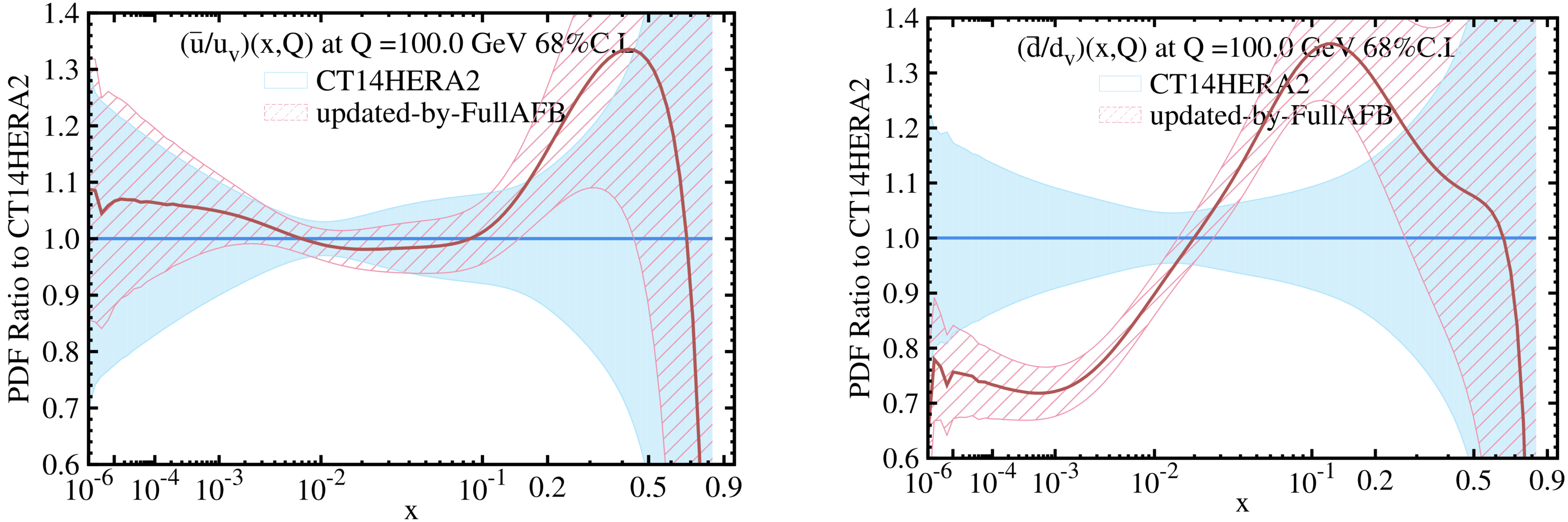
Using AFB in the PDF global fitting, corresponding to 130 fb^{-1} data collected by ATLAS or CMS (LHC Run 2)

AFB generated using ResBos+CT14HERA2

Correlations between EW and proton structure

Correlations

- Observation on proton structure highly correlated with determination on $\sin^2\theta_W$
- Proton structure: need PDF-independent measurement of $\sin^2\theta_W$ as input (LEP, SLC, or Tevatron)
- Measurement of $\sin^2\theta_W$: limited by the current modeling of proton structure



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)

Determination on $\sin^2\theta_W$ and proton structure

PDF global fitting strategy: not a good strategy

- Not supporting a combined fitting on $\sin^2\theta_W$ and proton structure
- Massive work to provide a unified EW calculation in extensive experimental results to treat stw and a floating parameter
- PDF global fitting is a combination of all data under various SM assumptions. Determinations on proton structure and stw are not single-data independent measurement

Factorization on AFB

Collins-soper frame

- Center of mass frame
- z-axis defined as bisector of the angle formed by the direction of one incoming hadron beam (HA) and the negative direction of the other incoming hadron beam (HB)

Collins-soper frame 1:

HA: according to "quark direction"
HB: according to "antiquark direction"

$$\cos\theta_q$$

Collins-soper frame 2:

HA: according to Z boson boost
HB: negative direction to HA

$$\cos\theta_h$$

if Eq > Eqbar: $\cos\theta_h = \cos\theta_q$

if Eqbar > Eq: $\cos\theta_h = -\cos\theta_q$

Factorization on AFB

Differential cross section of DY process in cosθq:

$$\frac{d\sigma}{d\cos\theta_q dY dM dQ_T} = \sum_f \alpha_f(Y,M,Q_T) \times \{(1+\cos^2\theta_q) + A_0^f(Y,M,Q_T)(1-3\cos^2\theta_q) + A_4^f(Y,M,Q_T)\cos\theta_q\},$$

Differential cross section of DY process in cosθh:

$$\frac{d\sigma}{d\cos\theta_h dY dM dQ_T} = \sum_f \alpha_f(Y,M,Q_T) \times \{(1+\cos^2\theta_h) + A_0^f(Y,M,Q_T)(1-3\cos^2\theta_h) + [1-2D_f(Y,M,Q_T)]A_4^f(Y,M,Q_T)\cos\theta_h\},$$

$$D_f(Y,M,Q_T)$$

probability of cosθh = -cosθq in a specific ffbar subprocess, i.e.
the probability of anti-quarks carries higher energy than quarks

Factorization on AFB

$$A^h_{FB}(Y,M,Q_T) = \frac{\sum_f [1-2D_f(Y,M,Q_T)]\alpha_f(Y,M,Q_T)A^f_{FB}(Y,M,Q_T)}{\sum_f \alpha_f(Y,M,Q_T)}$$

$$\begin{aligned} &A^h_{FB}(Y,M,Q_T) = \\ &[\Delta_u(Y,M,Q_T) + P^u_0(Y,Q_T)] \cdot A^u_{FB}(Y,M,Q_T;\sin^2\theta^\ell_{\rm eff}) \\ &+[\Delta_d(Y,M,Q_T) + P^d_0(Y,Q_T)] \cdot A^d_{FB}(Y,M,Q_T;\sin^2\theta^\ell_{\rm eff}) \end{aligned}$$

AFB^f is independent with proton structure. Fully calculated in EW theory !!

$$\begin{aligned} P^u_0(Y,Q_T) &= \int \frac{1-2D_u(Y,M,Q_T)\alpha_u(Y,M,Q_T)}{\sum_f \alpha_f(Y,M,Q_T)} dM \Big/ \int dM \\ P^d_0(Y,Q_T) &= \int \frac{1-2D_d(Y,M,Q_T)\alpha_d(Y,M,Q_T)}{\sum_f \alpha_f(Y,M,Q_T)} dM \Big/ \int dM \\ \Delta_u(Y,M,Q_T) &= \frac{1-2D_u(Y,M,Q_T)\alpha_u(Y,M,Q_T)}{\sum_f \alpha_f(Y,M,Q_T)} \\ &\quad -P^u_0(Y,Q_T) \\ \Delta_d(Y,M,Q_T) &= \frac{1-2D_d(Y,M,Q_T)\alpha_d(Y,M,Q_T)}{\sum_f \alpha_f(Y,M,Q_T)} \\ &\quad -P^d_0(Y,Q_T) \end{aligned} \quad (5)$$

Parton parameters

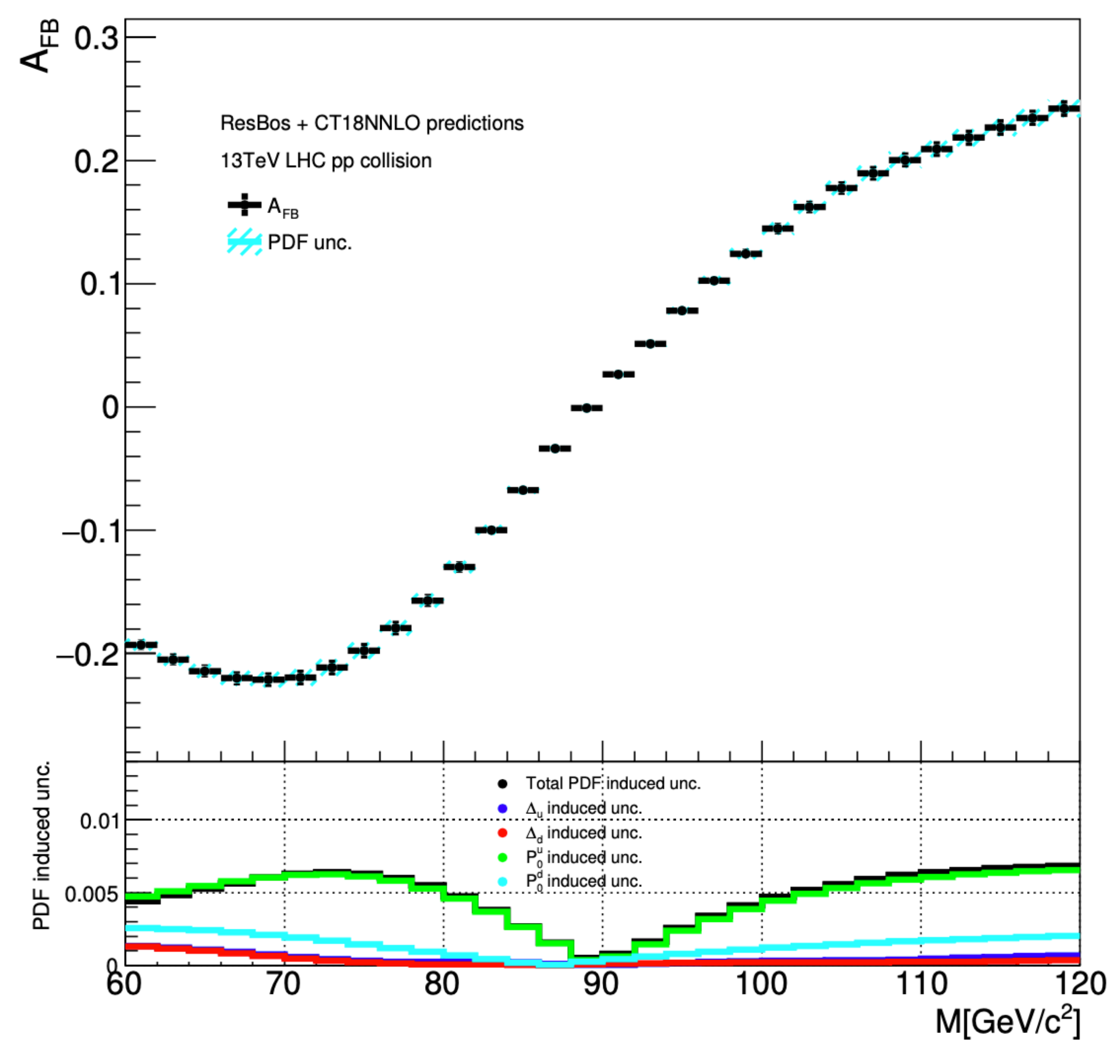
$$A^h_{FB}(Y,M,Q_T) =$$
$$[\Delta_u(Y,M,Q_T) + P_0^u(Y,Q_T)] \cdot A^u_{FB}(Y,M,Q_T;\sin^2\theta^\ell_{\text{eff}})$$
$$+[\Delta_d(Y,M,Q_T) + P_0^d(Y,Q_T)] \cdot A^d_{FB}(Y,M,Q_T;\sin^2\theta^\ell_{\text{eff}})$$

P0 parameters

- **Combined information on dilution effect and relative cross section, averaged in a given mass range (or x). Dominating part. P0 parameters and weak mixing angle will be the parameters in a combined fitting using AFB**

Δ parameters

- **Mass dependence (or x dependence). It is difficult to be determined using AFB due to lack of sensitivity.**
- **However it introduces small uncertainties, because AFB is observed in a very small mass region with respect to the O(10) TeV level collision energy**



Parton parameters

P0u vs P0d

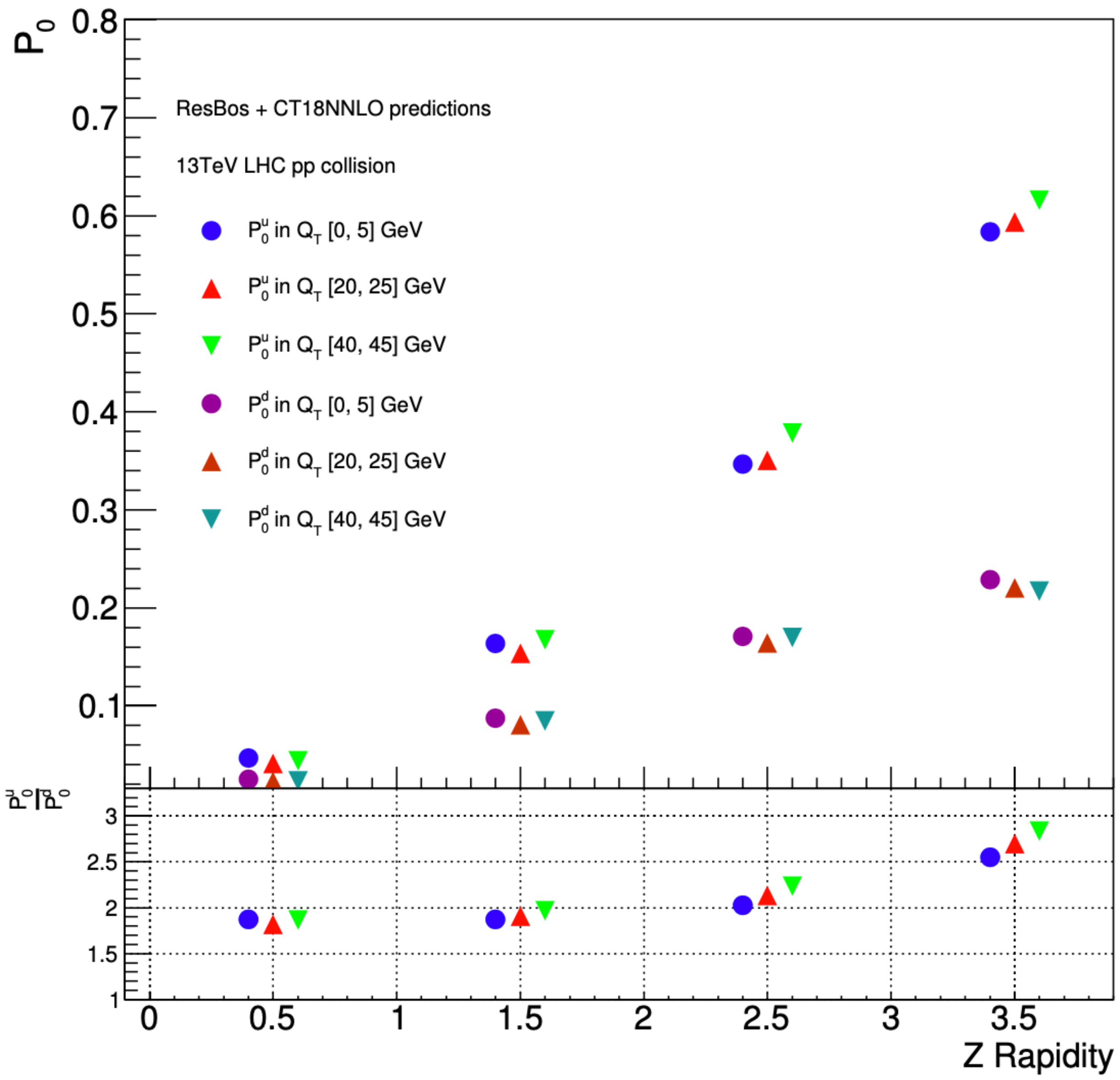
- P0u generally larger than P0d, due to a smaller dilution effect in uubar subprocess

As a function of ZY

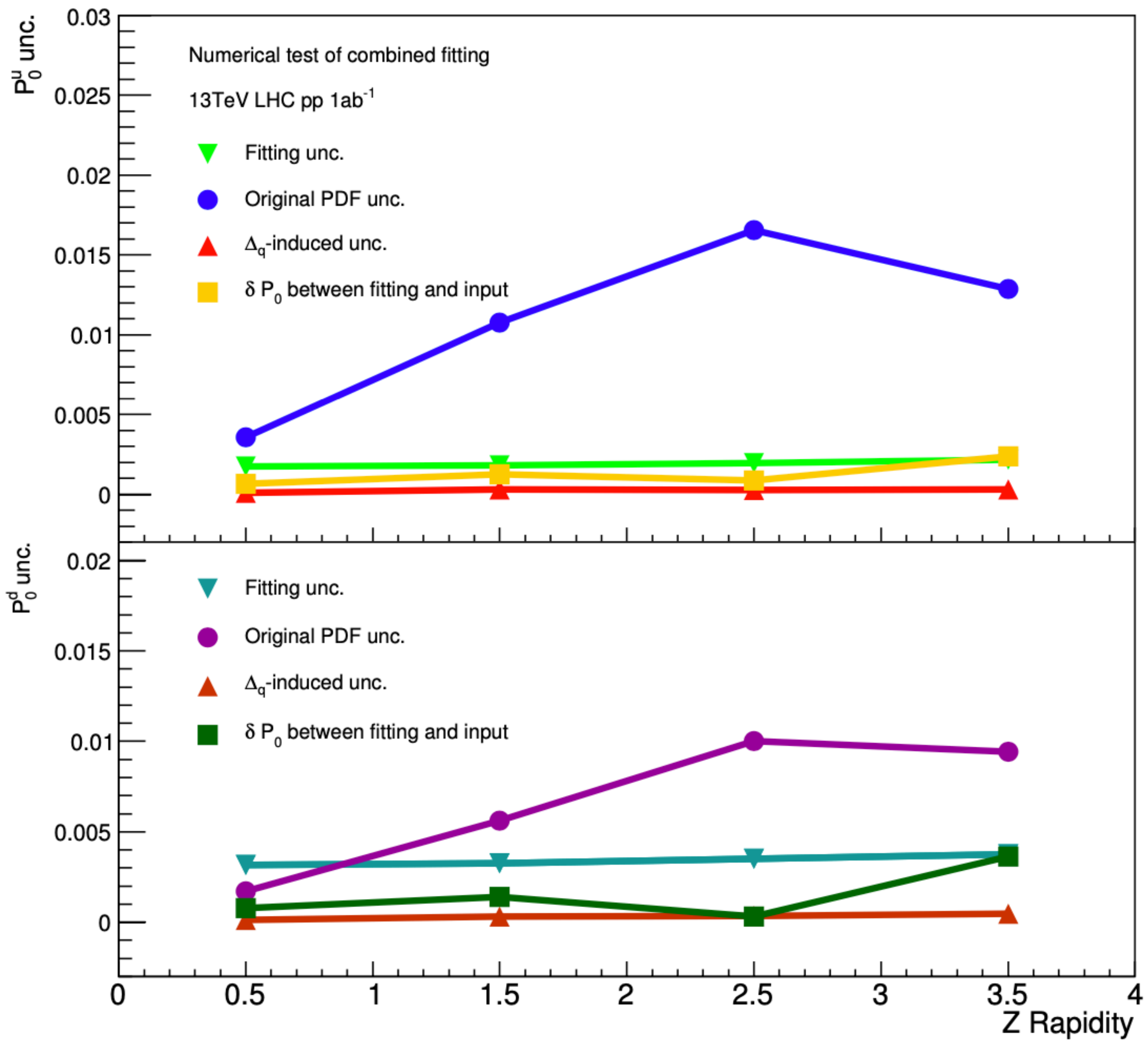
- Smaller ZY == larger dilution effect, P0 → 0
- Larger ZY == smaller dilution effect, P0 → relative cross section

Ratio of P0u / P0d

- s, c and b contributions cancel out
- Pure-observation on the difference between u and d quarks



A combined fitting procedure and closure



A proton structure observation using 1000 fb-1 data at the LHC

CT18 induced uncertainty on $\sin^2\theta_W$	0.00038
Combined fitting uncertainty on $\sin^2\theta_W$	0.00005
Δ-induced uncertainty on $\sin^2\theta_W$	0.00008
Input value of $\sin^2\theta_W$ in the pseudo-daeta	0.23150
Fitted value of $\sin^2\theta_W$	0.23156

Summary

Background review

- AFB@LHC are sensitive to both EW and proton structure
- However strongly correlated, both of them are limited

Factoriztion on AFB

- We report a method which factorize the observed AFB into EW calculations and well-defined proton structure parameters
- The protons structure parameters can be experimentally observed, universally derived in theory calculation. Its definition is model independent
- Relative difference between q and qbar; Relative difference between u and d

For future measurement

- Independent measurement using single AFB observation
- Correlation between EW and proton structure well considered
- Precision significantly improved for determination on both weak mixin angle and proton structure

Backup

An example of pre-work

Phys. Rev. Lett. 126, 041801
Emanuele Bagnaschi and Alessandro Vicini

$$\chi_k^2 = \sum_{i\in \text{bins}} \frac{[(\mathcal{T}_{0,k})_i - (\mathcal{D}^{\text{exp}})_i - \sum_{r\in\mathcal{R}} \alpha_r (\mathcal{S}_{r,k})_i]^2}{\sigma_i^2} + \sum_{r\in\mathcal{R}} \alpha_r^2,$$

- (T0, k)i: theory prediction of an observable
- (Dexp)i: data measurement
- αr: nuisance parameters
- (Sr, k)i: (Tr, k)i - (T0, k)i representing PDF uncertainties

Nuisance parameter fitting:

- Only for EW parameter determintion. Nuisance parameters can’t be used as observation on proton structure
- Model-dependent
- Assumption: the data used for measurement is well-consistent with current theory predictions both on EW and PDFs