



*Global extraction of the
parton-to-pion fragmentations
at NLO accuracy in QCD*

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—*Motivation*—

- FFs are required in a pQCD calculation to consistently absorb collinear parton-parton singularities.
- The only way to extract them is from fitting experimental data.
- FFs fits assume factorization and universality.

The fitters

Name	Ref.	Species	Error	z_{\min}	Q^2 (GeV ²)
AKK	[4]	$\pi^\pm, K^\pm, K_s^0, p, p, \Lambda, \Lambda$	no	0.1	$2 - 4 \cdot 10^4$
AKK08	[5]	$\pi^\pm, K^\pm, K_s^0, p, p, \Lambda, \Lambda$	yes	0.05	$2 - 4 \cdot 10^4$
BKK	[6]	$\pi^+ + \pi^-, \pi^0, K^+ + K^-, K^0 + K^0, h^+ + h^-$	no	0.05	$2 - 200$
BFG	[7]	γ	no	10^{-3}	$2 - 1.2 \cdot 10^4$
BFGW	[8]	h^\pm	yes ¹	10^{-3}	$2 - 1.2 \cdot 10^4$
CGRW	[9]	π^0	no	10^{-3}	$2 - 1.2 \cdot 10^4$
DSS	[10,11]	$\pi^\pm, K^\pm, p, p, h^\pm$	yes ²	0.05-0.1	$1 - 10^5$
DSV	[12]	polarized and unpolarized Λ	no	0.05	$1 - 10^4$
GRV	[13]	γ	no	0.05	≥ 1
HKNS	[14]	$\pi^\pm, \pi^0, K^\pm, K^0 + K^0, n, p + p$	yes	0.01 - 1	$1 - 10^8$
KKP	[15]	$\pi^+ + \pi^-, \pi^0, K^+ + K^-, K^0 + K^0, p + p, n + n, h^+ + h^-$	no	0.1	$1 - 10^4$
Kretzer	[16]	$\pi^\pm, K^\pm, h^+ + h^-$	no	0.01	$0.8 - 10^6$

- AKK08: e+e- and pp data / Isospin symmetry for pions.
- HKNS: e+e- data only / Hessian method for uncertainties.

Properties of FFs

- The evolution of FFs is described with the DGLAP type scale evolution:

$$\frac{dD_i^h(z, \mu^2)}{d \ln \mu^2} = \int_z^1 \frac{dy}{y} P_{ji}^T(z, \alpha_s) D_j^h\left(\frac{z}{y}, \mu^2\right)$$

$$P_{ji}^T(z, \alpha_s) = \frac{\alpha_s}{4\pi} P_{ji}^{(0)T} + \left(\frac{\alpha_s}{4\pi}\right)^2 P_{ji}^{(1)T} + \left(\frac{\alpha_s}{4\pi}\right)^3 P_{ji}^{(2)T} + \dots$$

- Energy-momentum sum rule:

$$\sum_h \int_0^1 z D_i^h(z, \mu) = 1$$

- A parton fragments into something preserving its momentum with 100% probability.
- Mass effects neglected.

FFs in data: e^+e^- SIA

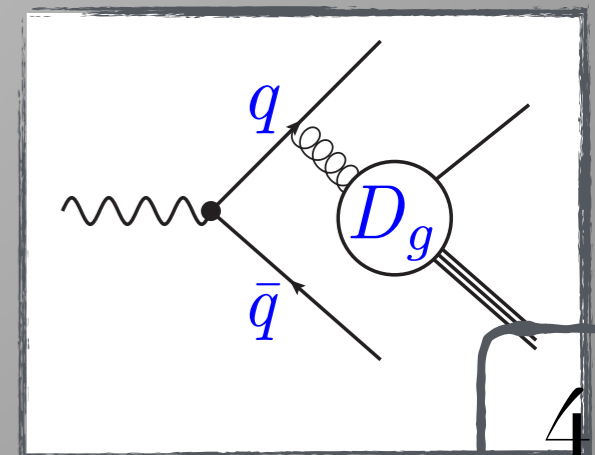
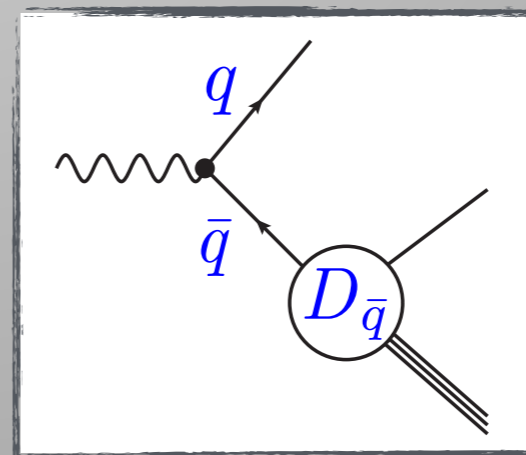
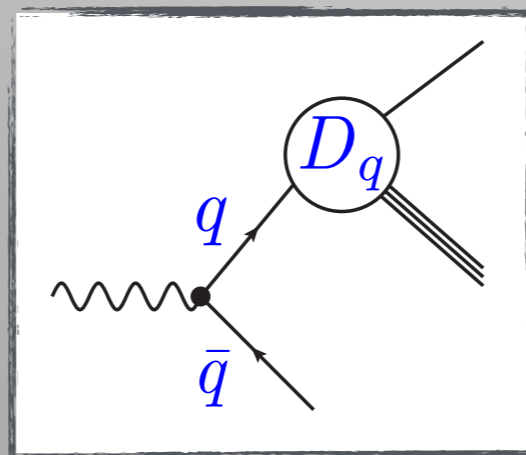
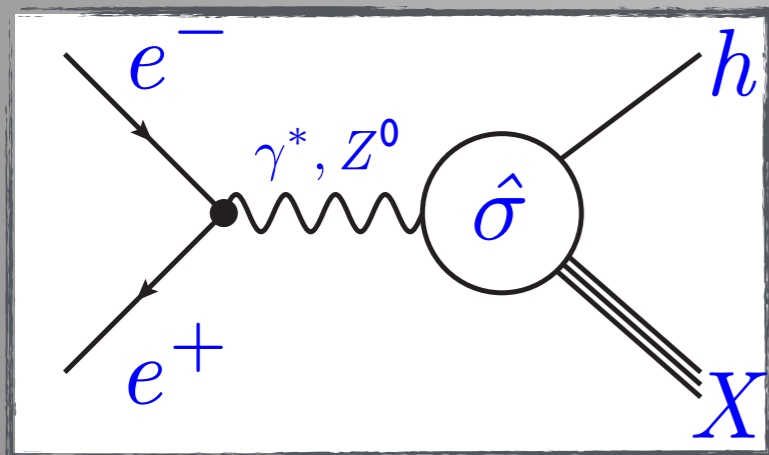
- The distribution is given terms of the structure functions,

$$\frac{1}{\sigma_{tot}} \frac{d\sigma^h}{dz} = \frac{\sigma^0}{\sum_q \hat{e}_q^2} [2F_1^h(z, Q^2) + F_L^h(z, Q^2)]$$

@NLO

$$2F_1^h(z, Q^2) = \sum_q \hat{e}_q^2 \left\{ [D_q^h + D_{\bar{q}}^h](z, Q^2) + \frac{\alpha_s(Q^2)}{2\pi} [C_q^1 \otimes [D_q^h + D_{\bar{q}}^h] + C_g^1 \otimes D_g^h](z, Q^2) \right\}$$

- Not possible to separate charge and flavour only with SIA.
- Only have information of the singlet.



FFs in data: SIDIS

- Distributions for SIDIS are given by,

$$\frac{d\sigma^h}{dx dy dz^h} = \frac{2\pi\alpha_s(Q^2)}{Q^2} \left[\frac{1 + (1-y)^2}{y} 2F_1^h + \frac{2(1-y)}{y} F_L^h \right] (x, z_h, Q^2)$$

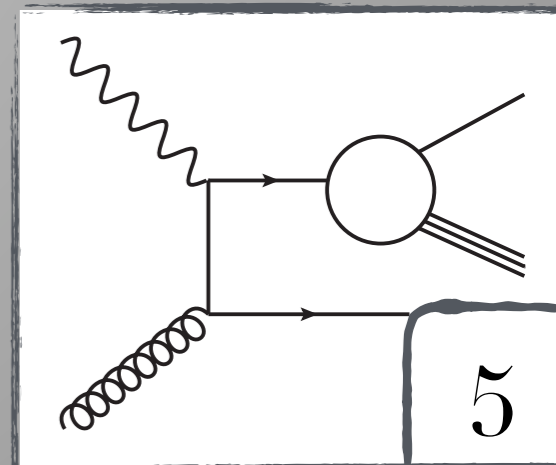
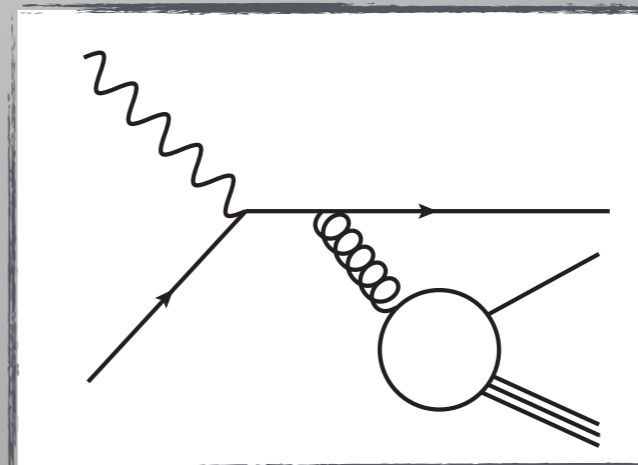
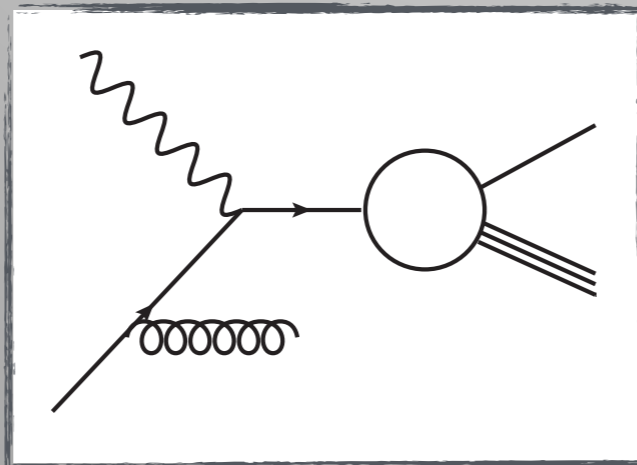
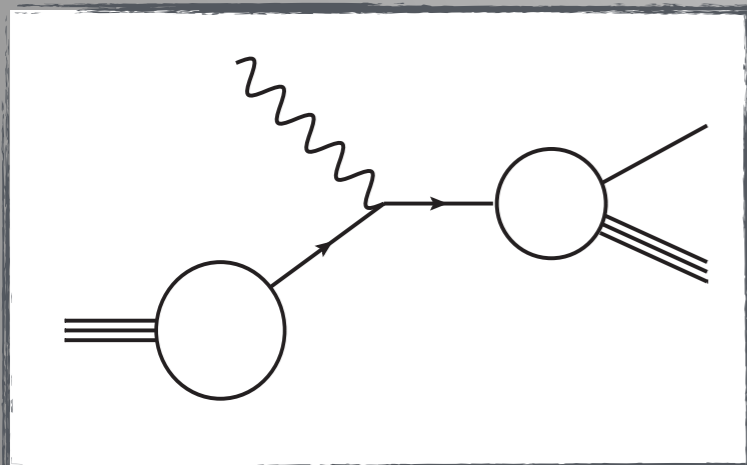
@LO:

$$2F_1^h(x, z_h, Q^2) = \sum_{q, \bar{q}} \hat{e}_q^2 \cdot q(x, Q^2) D_q^h(z_h, Q^2)$$

@NLO, all coefficients are known:

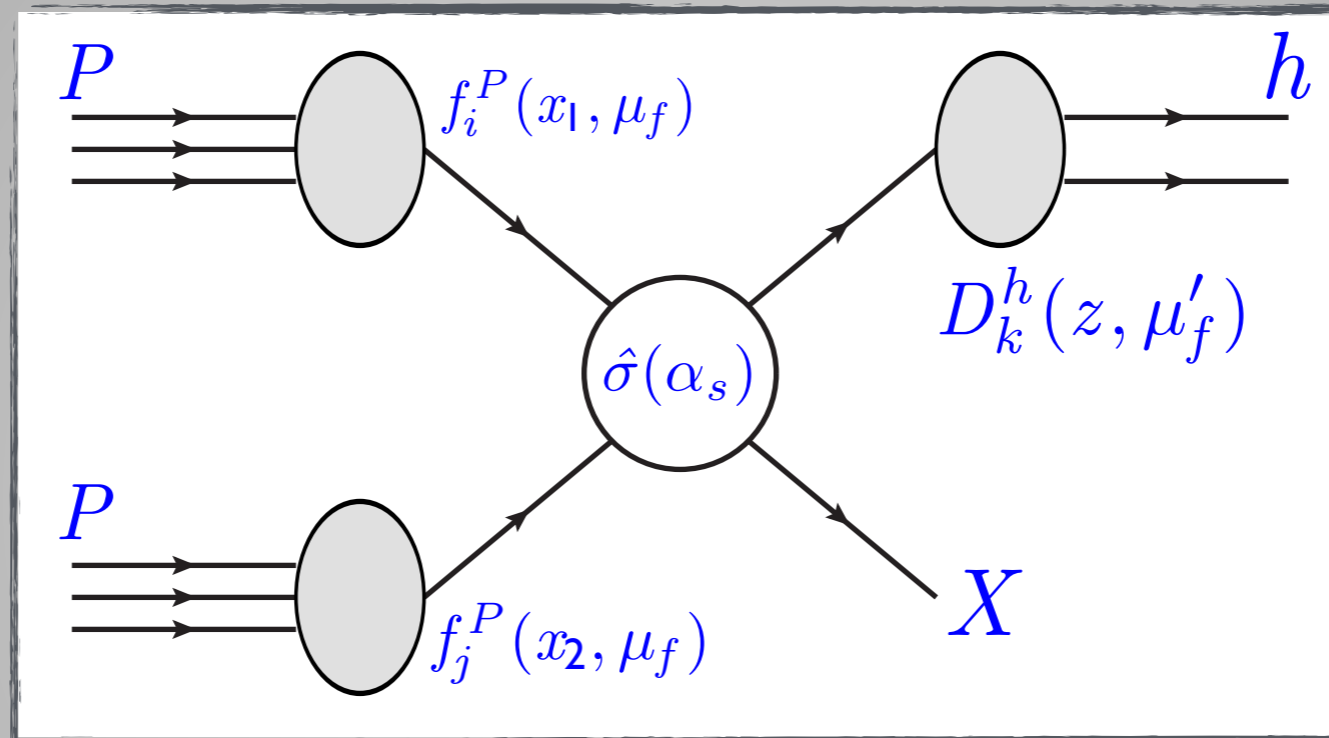
Altarelli et al. '79, Furmanski, Petronzio '82, de Florian, Stratmann, Vogelsang '98

- Charge and flavour separation is achieved by including SIDIS.
- However, gluon FF is not well constrained by SIA and SIDIS data.



FFs in data: Hadron collisions

- The general picture is:



- Therefore, transverse momentum distribution is given by:

$$\frac{d\sigma(pp \rightarrow hX)}{dp_T d\eta} = \sum_{i,j,k} \int dx_1 dx_2 dz \left[f_i^P(x_1, \mu_f) f_j^P(x_2, \mu_f) D_k^h(z, \mu'_f) \frac{d\hat{\sigma}(ij \rightarrow kX')}{dp_T d\eta} \right]$$

- It also allows charge and flavour separation.
- It contains large contributions from gluons.

DSS vs the new fit

- Number of parameters: 23 parameters > 28 parameters.
- HERMES data are replaced and added deuteron target data sets.
- Different treatment for the normalization of the experiments.
- PDFs: MSTW2008.
- Relaxing some of the FFs assumptions.
- Full correlation matrices are not available for some data sets, so errors are added in quadrature (stat & syst).

$$\begin{aligned} D_{d+\bar{d}}^{\pi^+} &= N_{d+\bar{d}} D_{u+\bar{u}}^{\pi^+} & D_{\bar{u}}^{\pi^+} &= D_d^{\pi^+} \\ D_s^{\pi^+} &= D_{\bar{s}}^{\pi^+} = N_s z^{\alpha_s} D_{\bar{u}}^{\pi^+} & \gamma_{c,b} &\neq 0 \end{aligned}$$

DSS vs the new fit

- pT cut in 5 GeV for pp data.
- We have used a penalisation to the χ^2 when the fit goes far from the optimum value,

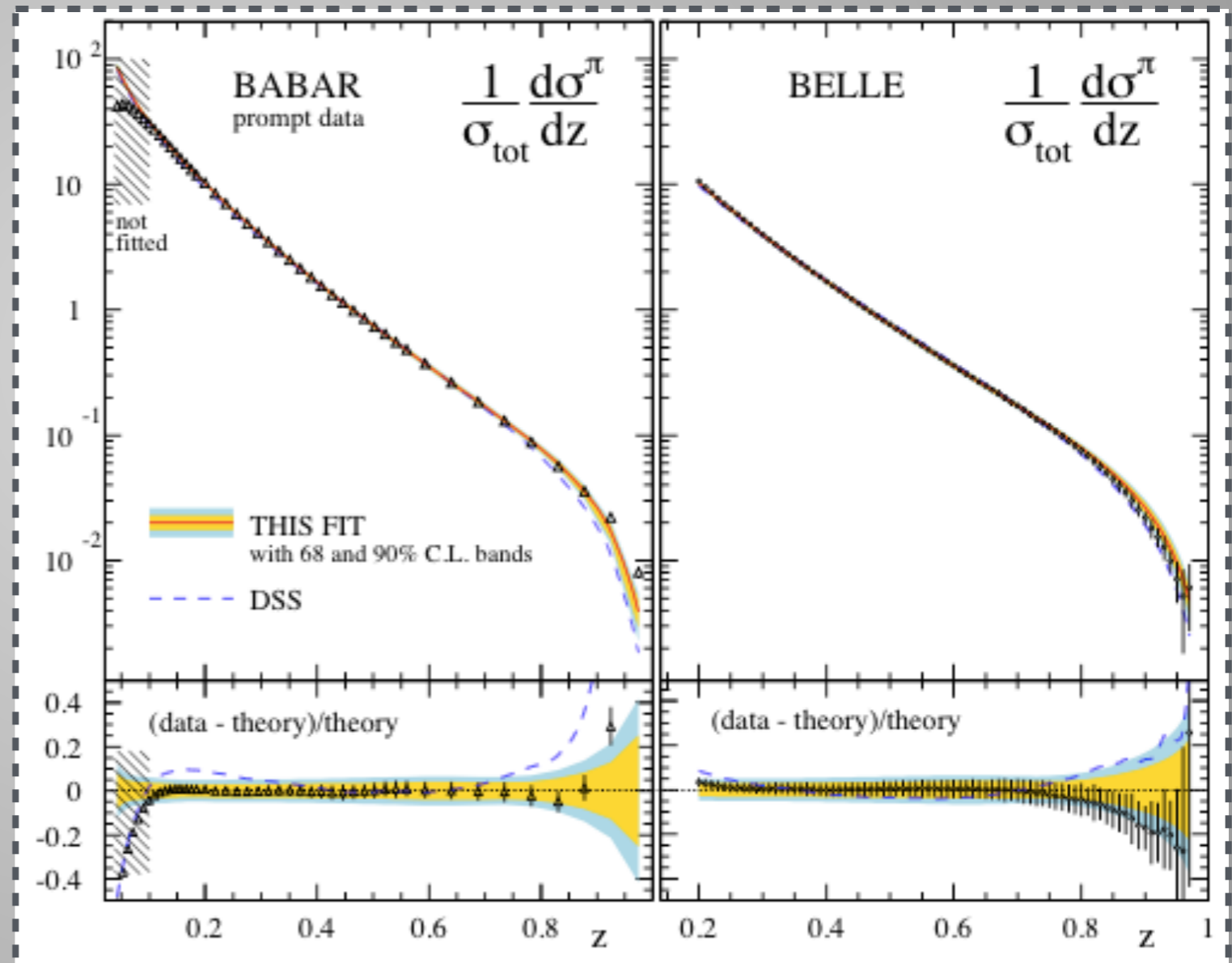
$$\chi^2 = \sum_{i=1}^N \left[\left(\frac{1 - \mathcal{N}_i}{\delta \mathcal{N}_i} \right)^2 + \sum_{j=1}^{N_i} \left(\frac{\mathcal{N}_i T_j - E_j}{\delta E_j} \right)^2 \right]$$

- Normalization of each experiment can be computed analytically,

$$\mathcal{N}_i = \frac{\sum_{j=1}^{N_i} \frac{\delta \mathcal{N}_i^2}{\delta E_j^2} T_j E_j + 1}{\sum_{j=1}^{N_i} \frac{\delta \mathcal{N}_i^2}{\delta E_j^2} T_j^2 + 1}$$

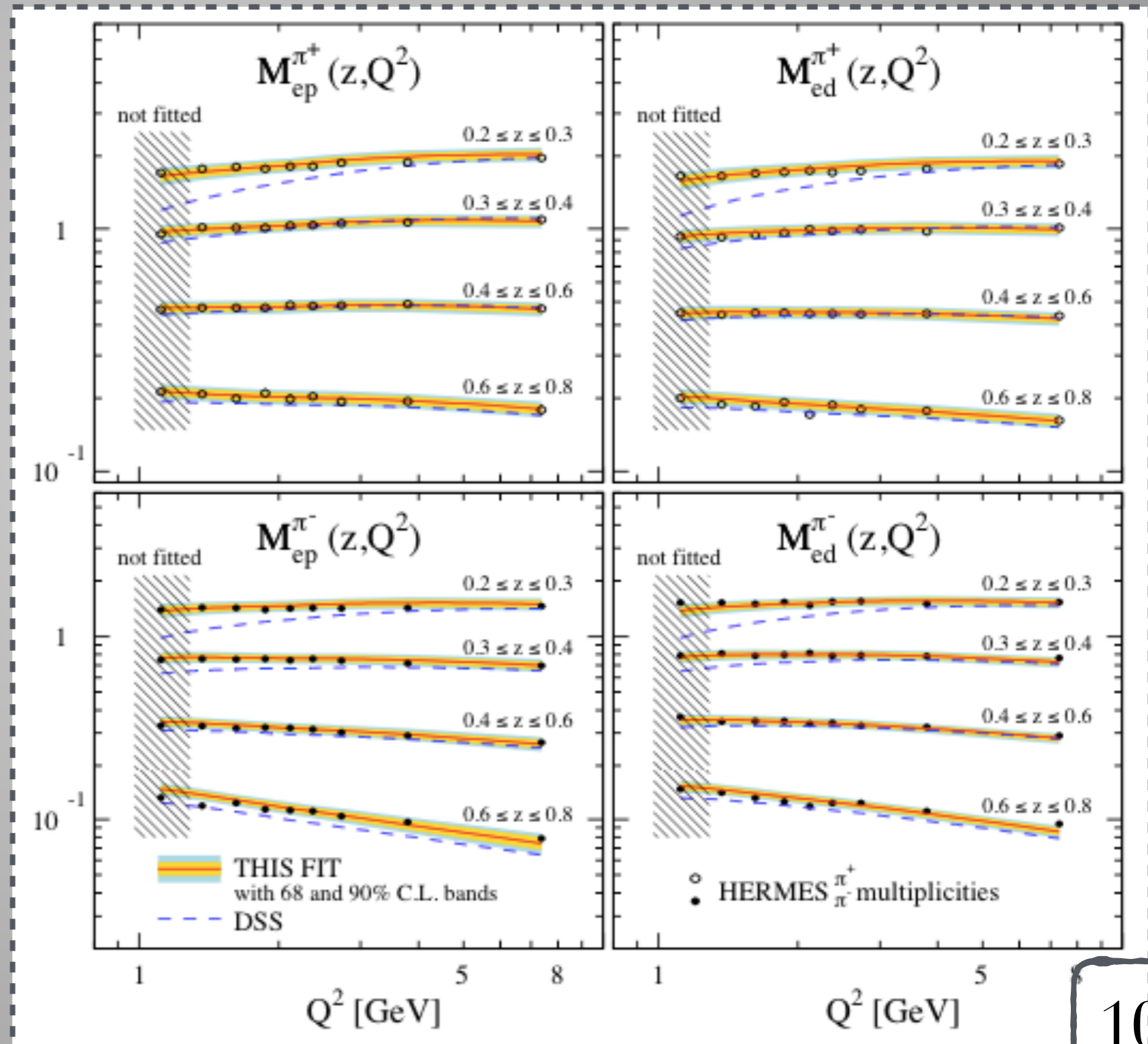
BELLE & BaBar

- BELLE and BaBar results can be fitted extremely well within the 68 and 90 % C.L.
- There is a drop on the large z regime for BELLE but it is consistent with the uncertainties.
- Large logarithmic corrections are expected at large values of z .



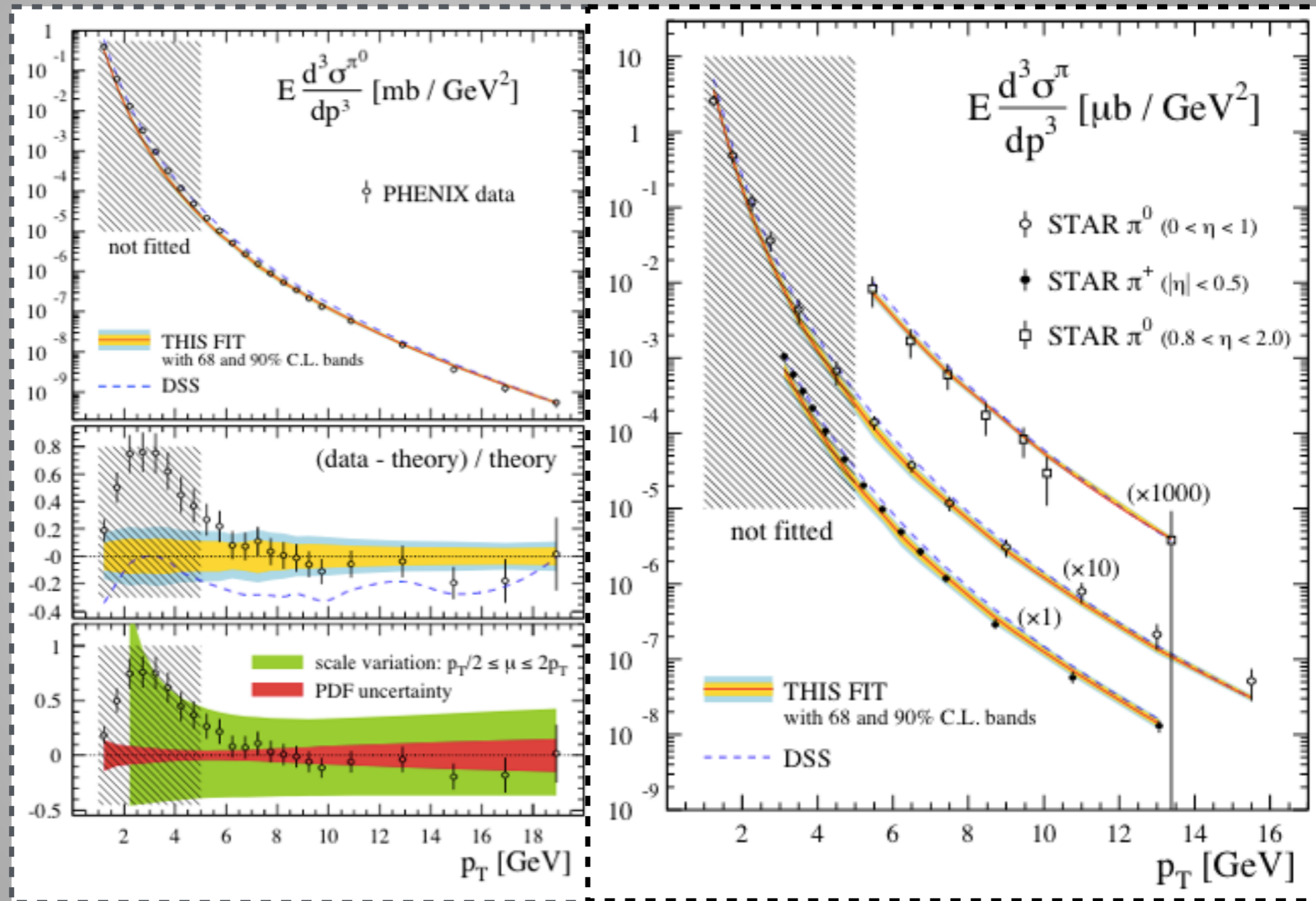
HERMES

- DSS cannot fit the new HERMES data for the smallest bin of z .
- In this new analysis, HERMES data have no problems to be fitted within the 68 and 90% C.L. for all bins of z .



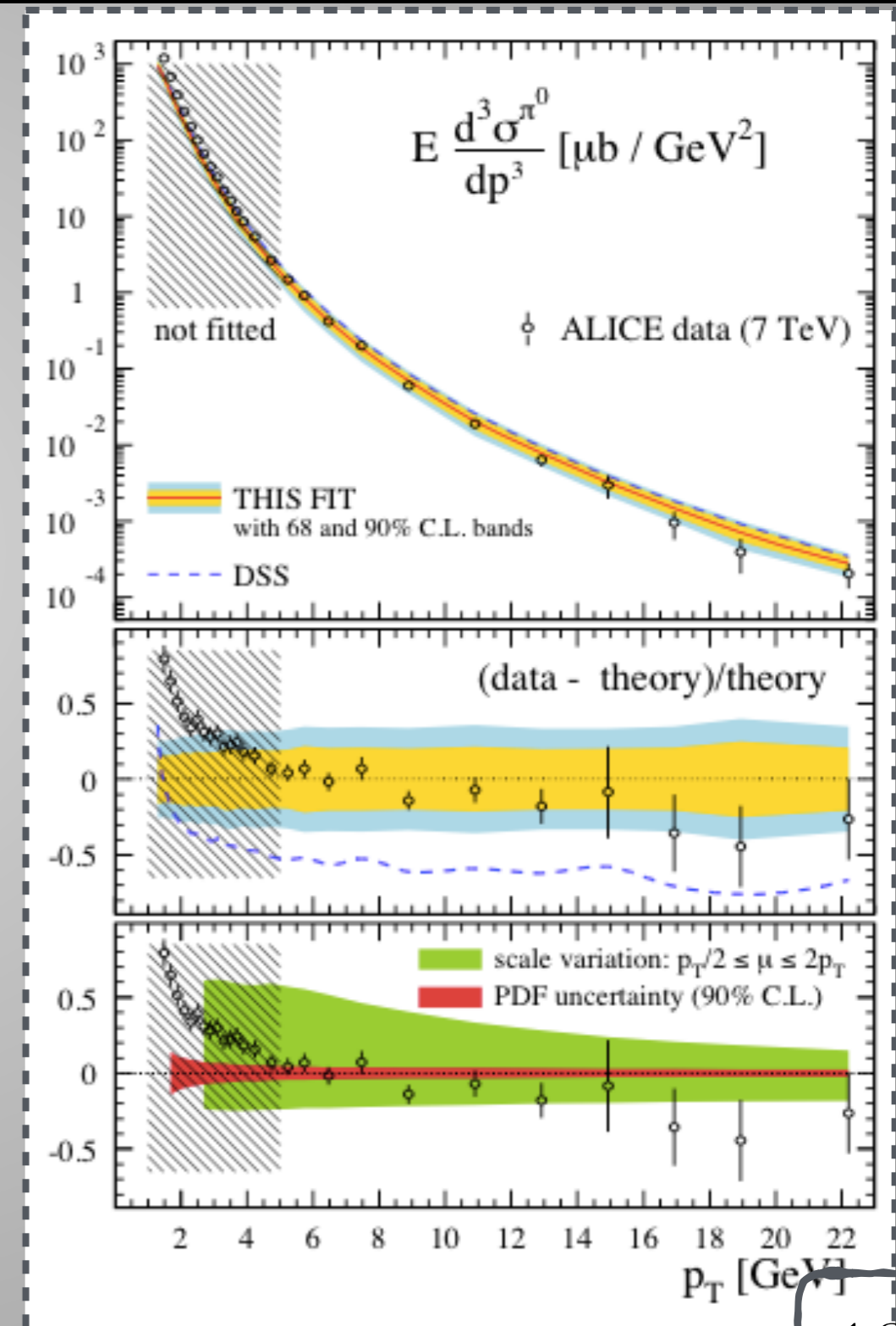
PHENIX & STAR

PDF uncertainties where computed with 90%CL MSTW and they are less significant than the scale ambiguities.



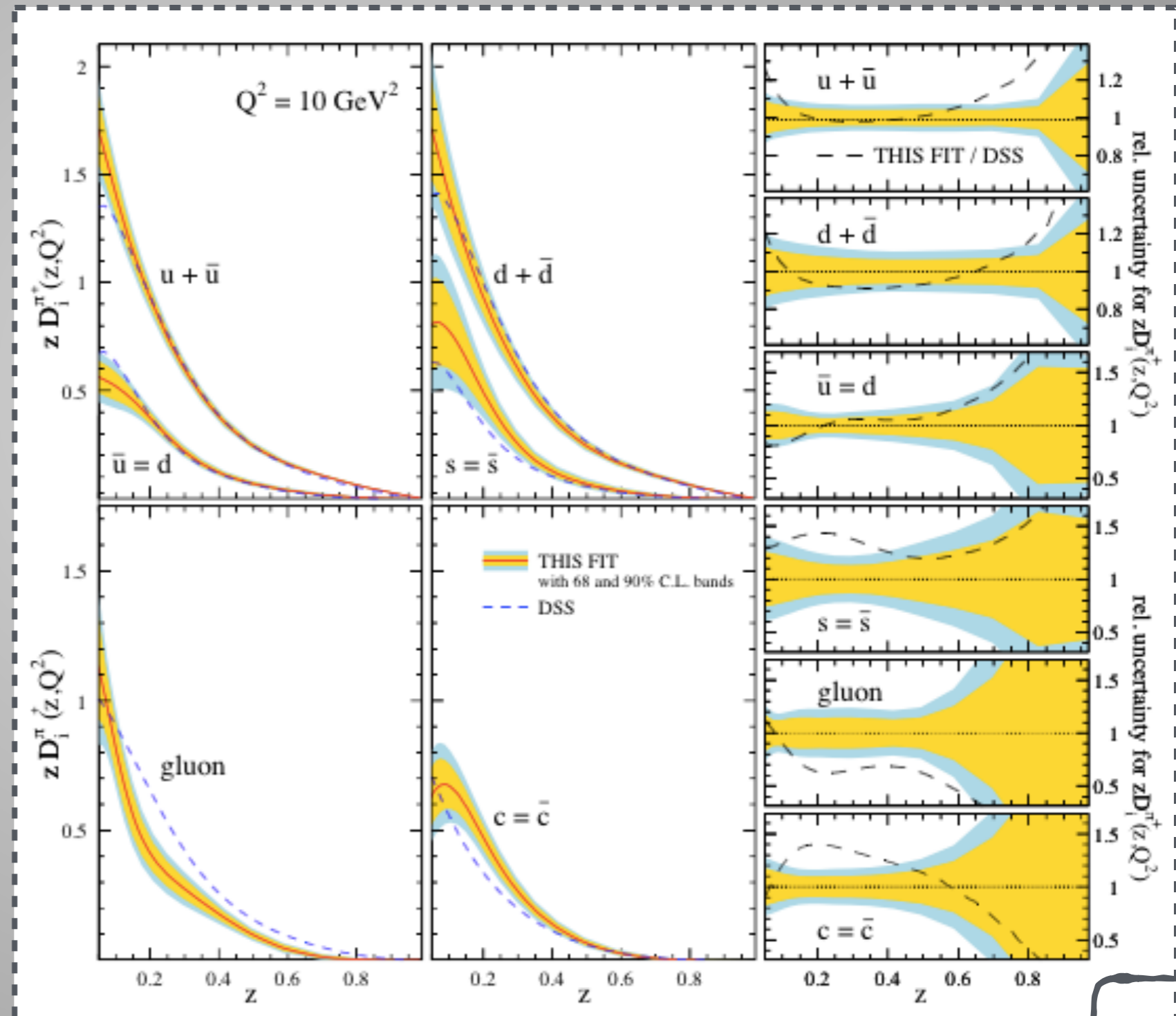
ALICE

- In the range of small p_T , RHIC and LHC data showed a tension during the fitting.
- By introducing the cut on the p_T , we achieved a reasonable agreement between both data sets.
- Nevertheless, we lost some data sets such as ALICE 900GeV which only stands with one point.
- Contribution of uncertainties due to PDF are again not relevant enough; the main contribution is coming from the scale variation.



parton-to-pion FFs

- Deviations from DSS is found on the gluon and charm FF.
- c -FF has a more flexible parametrisation (5 instead of 3 parameters).
- g -FF uncertainties is about 20% at 90%CL up to $z > 0.5$ and they increase towards larger values ($Q = 10 \text{ GeV}$).



How good is the fit ?

	DSS	NOW
Global	843/392(2.15)	1154.6/973(1.19)
LEP-SLAC	500.1/260(1.92)	412.6/260(1.58)
BELLE & BABAR	—	90.4/123(0.73)
HERMES	188.2/64(2.94)	175/128(1.36)
COMPASS	—	403.2/398(1.01)
RHIC	160.8/68(2.36)	45.7/53(0.86)
LHC	—	27.7/11(2.51)

— *Conclusions* —

- The analysis implemented strongly supports factorization and universality for the parton-to-pion FFs.
- The numerical results shown that the breaking of the charge asymmetry parameter is very close to one.
- Tension between RHIC & LHC data have been avoided when a lower cut is introduced in the proton-proton collisions.
- The new data do not favor any symmetry violation.
- Uncertainties have been estimated using the standard iterative Hessian method.
- An analytic procedure to determine the optimum normalization shift is implemented in the the new analysis.

THANKS...
