Searching the parton-to-pion fragmentation functions at NLO accuracy in QCD

Roger J. Hernández-Pinto
FCFM, Universidad Autónoma de Sinaloa

In collaboration with D. de Florian, R. Sassot, M. Epele and M. Stratmann
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Outline

- Motivation
- Theory and Uncertainties
- Results
- Conclusions

—*Motivation*—

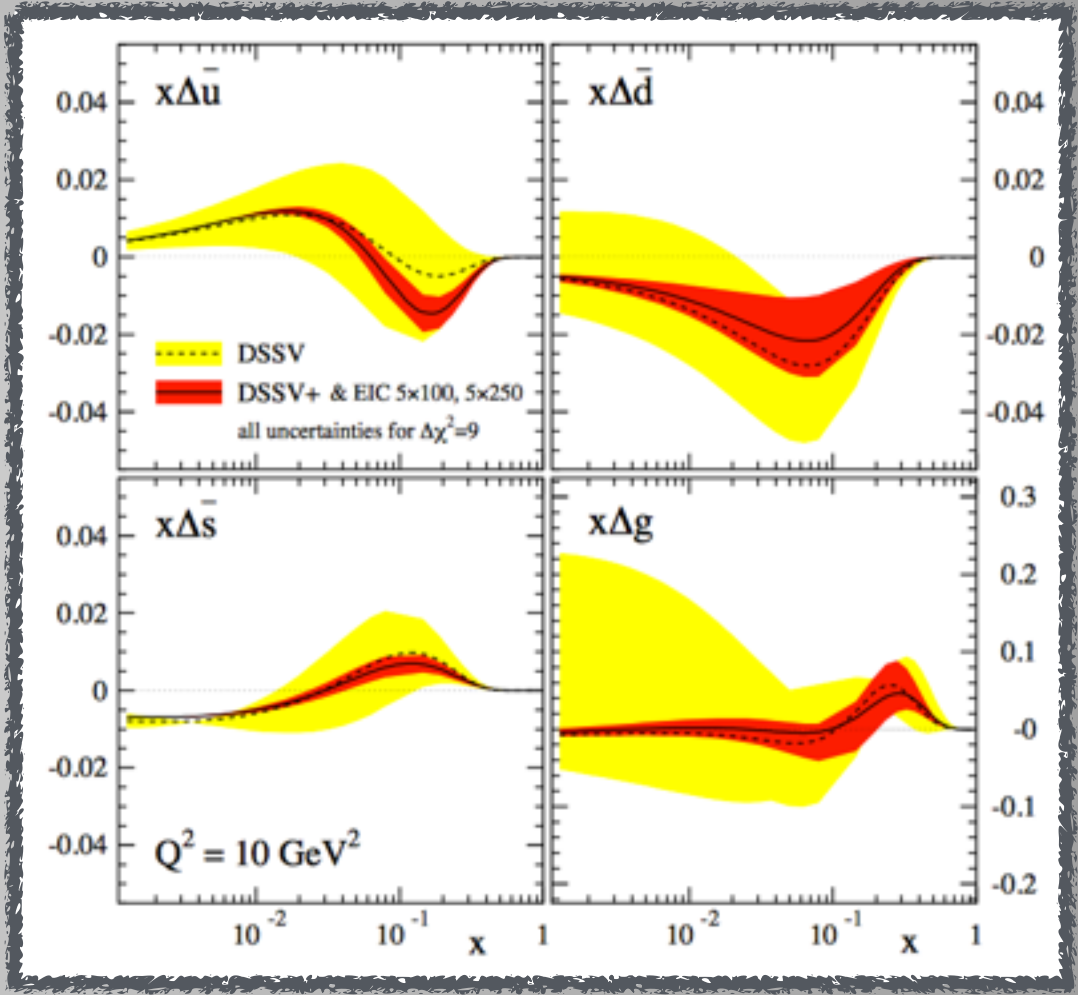
- FFs are required in a pQCD calculation to consistently absorb collinear parton-parton singularities.
- The only way to extract them is from fitting experimental data.
- FFs fits assume factorisation and universality.

DSS results

- DSS fit arrived to a data-driven separation of individual parton-to-pion fragmentations.
- Large charge symmetry violation between u- and d-quarks FFs (~10%).
- Gluon FFs was constrained for the first time with BNL-RHIC data.
- Lagrange multiplier technique was used for estimating uncertainties.

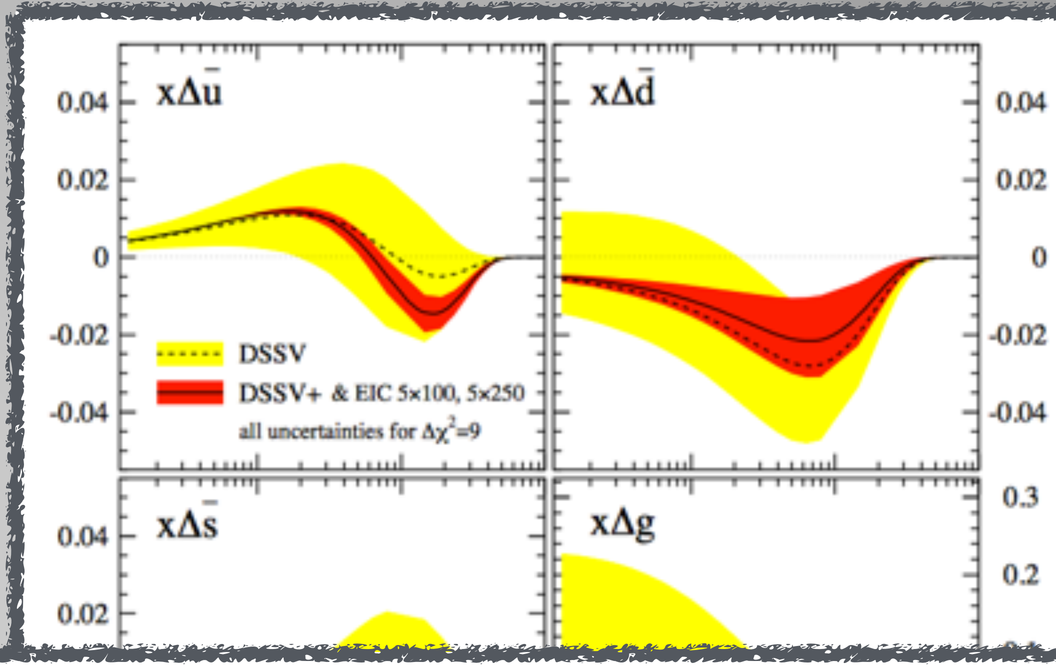
Why are they needed for?

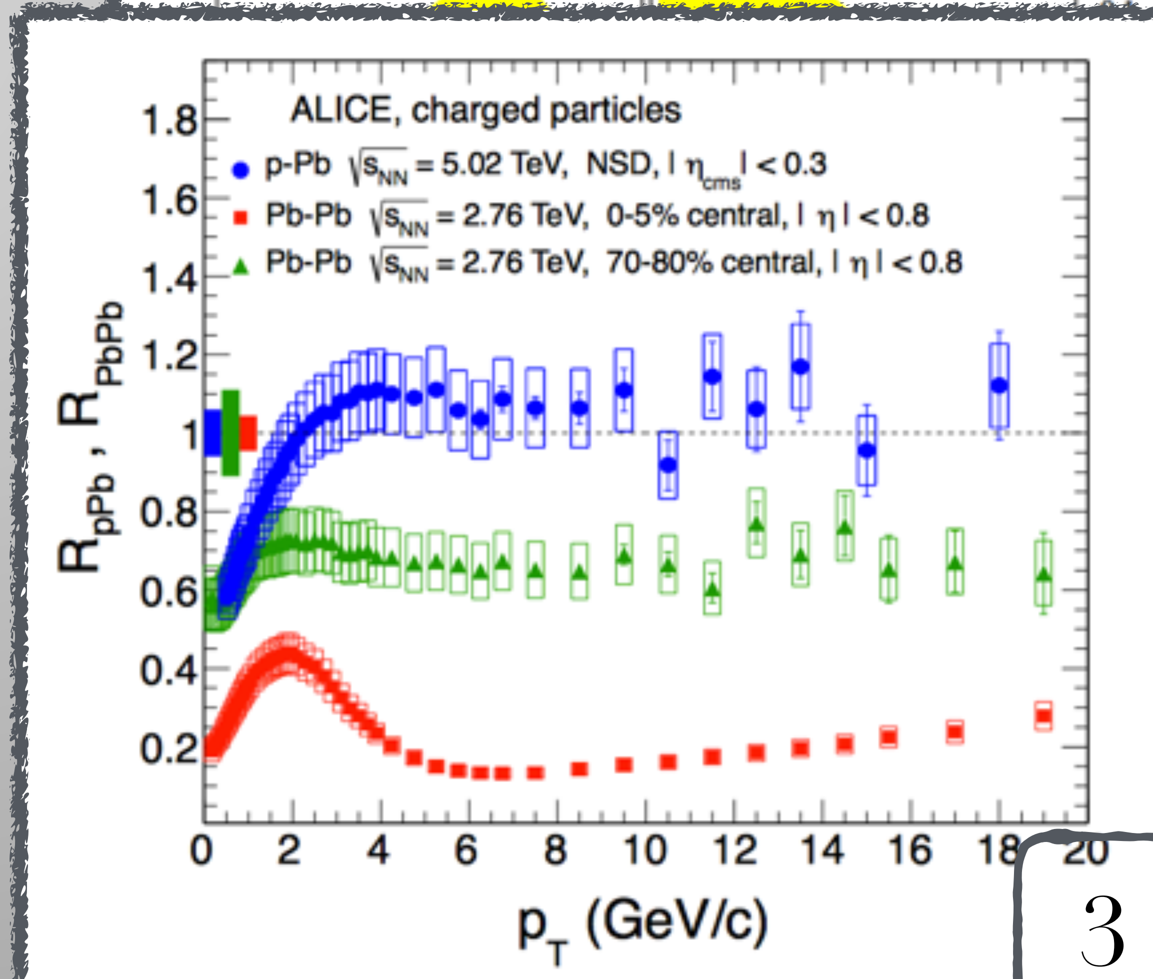
- Input for helicities PDFs and transverse momentum PDFs.



Why are they needed for?

- Input for helicities PDFs and transverse momentum PDFs.
- Necessary for a complete understanding of hadron production in presence of nuclear medium.
- Heavy Ion programs: RHIC and LHC.





The fitters

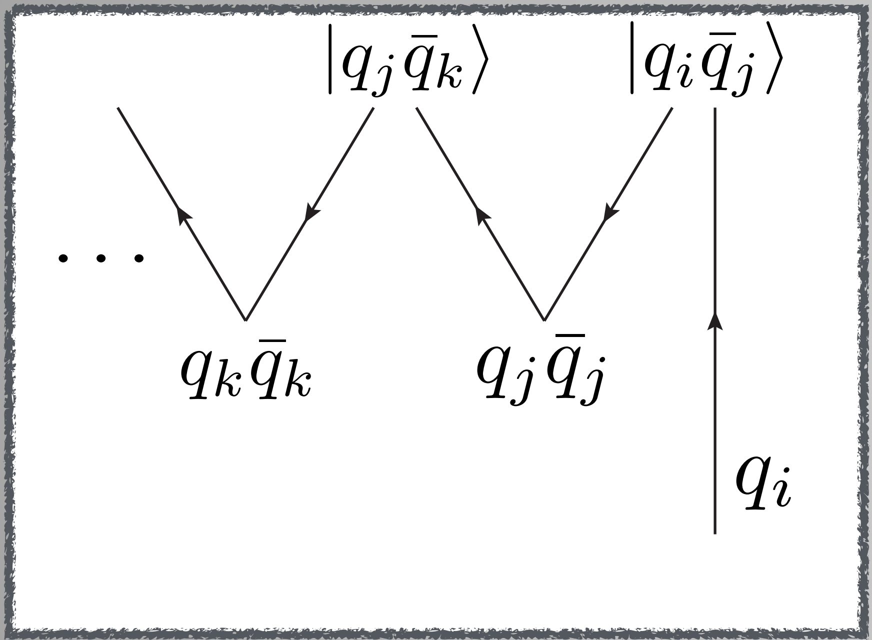
Name	Ref.	Species	Error	z_{min}	Q^2 (GeV^2)
AKK	[4]	$\pi^{\pm}, K^{\pm}, K_s^0, p, p\ \Lambda, \Lambda$	no	0.1	$2-4\cdot10^4$
AKK08	[5]	$\pi^{\pm}, K^{\pm}, K_s^0, p, p\ \Lambda, \Lambda$	yes	0.05	$2-4\cdot10^4$
BKK	[6]	$\pi^+ + \pi^-, \pi^0, K^+ + K^-, K^0 + K^0, h^+ + h^-$	no	0.05	$2-200$
BFG	[7]	γ	no	10^{-3}	$2-1.2\cdot10^4$
BFGW	[8]	$h^{\pm}$	yes[1]	10^{-3}	$2-1.2\cdot10^4$
CGRW	[9]	π^0	no	10^{-3}	$2-1.2\cdot10^4$
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.

— Theory & Uncertainties —

Basic idea of hadronization: Cascade fragmentation

Rank 2 1



rank = 1 : "valence", e.g.

$$u \to \pi^+$$

rank > 2 : "sea", e.g.

$$u \to \pi^-$$

- Theory framework: "independent fragmentation".
- QCD approach based on factorisation.
- e+e-: first data used for extracting FFs with LEP data (BKK '95 and KRE '00).

Properties of FFs

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

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

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

- 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

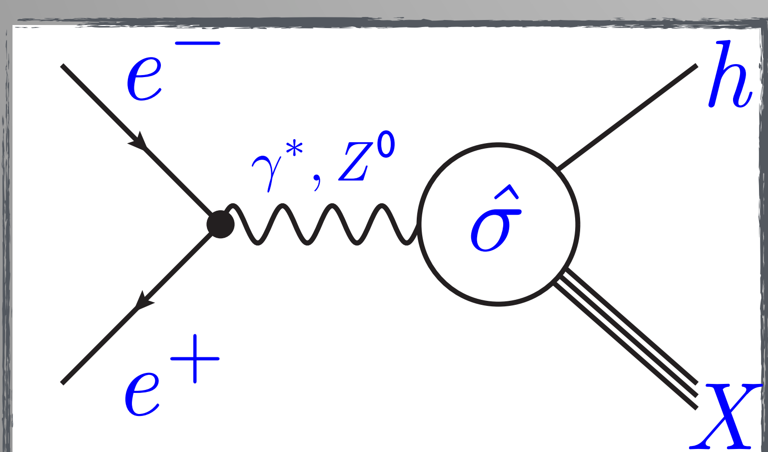
- The distribution is given terms of the structure functions,

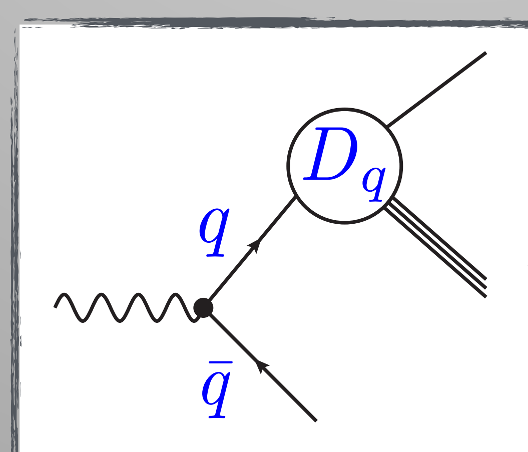
$$\frac{1}{\sigma_{tot}}\frac{d\sigma^h}{dz} = \frac{\sigma^0}{\sum_q \hat{e}_q^2}\left[2F_1^h(z,Q^2) + F_L^h(z,Q^2)\right]$$

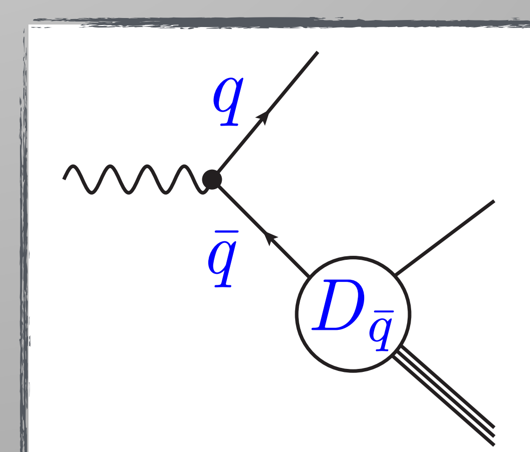
@NLO

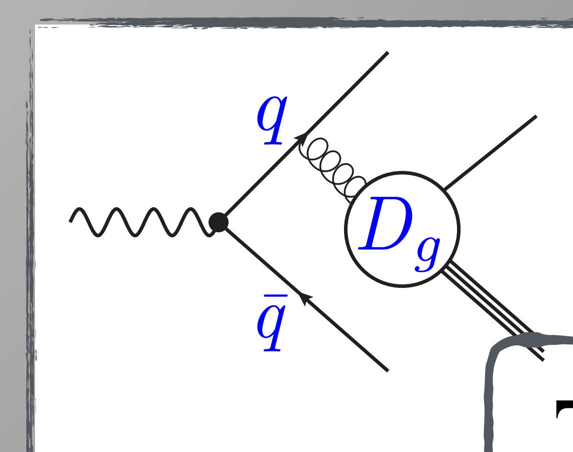
$$2F_1^h(z,Q^2) = \sum_q \hat{e}_q^2 \left\{ \left[D_q^h + D_{\bar{q}}^h\right](z,Q^2) + \frac{\alpha_s(Q^2)}{2\pi}\left[C_q^1 \otimes \left[D_q^h + D_{\bar{q}}^h\right] + C_g^1 \otimes D_g^h\right](z,Q^2)\right\}$$

- 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,

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

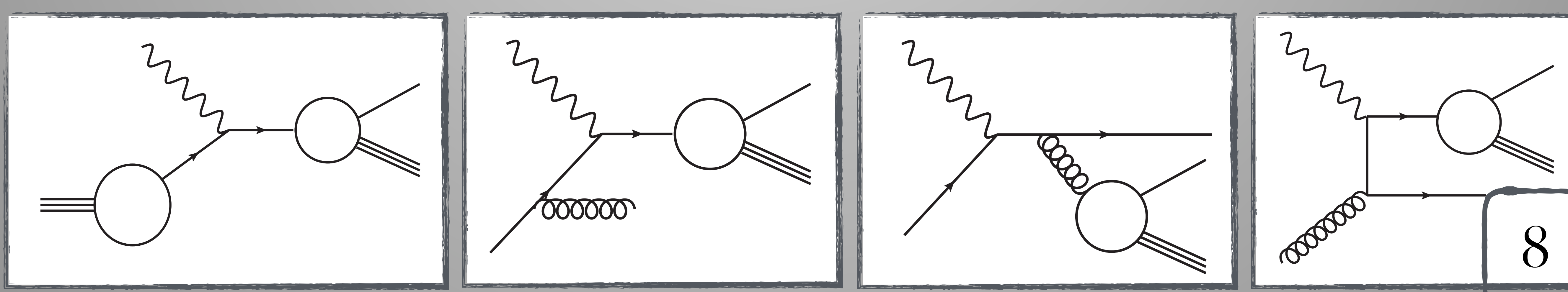
@LO:

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

@NLO, all coefficients are known:

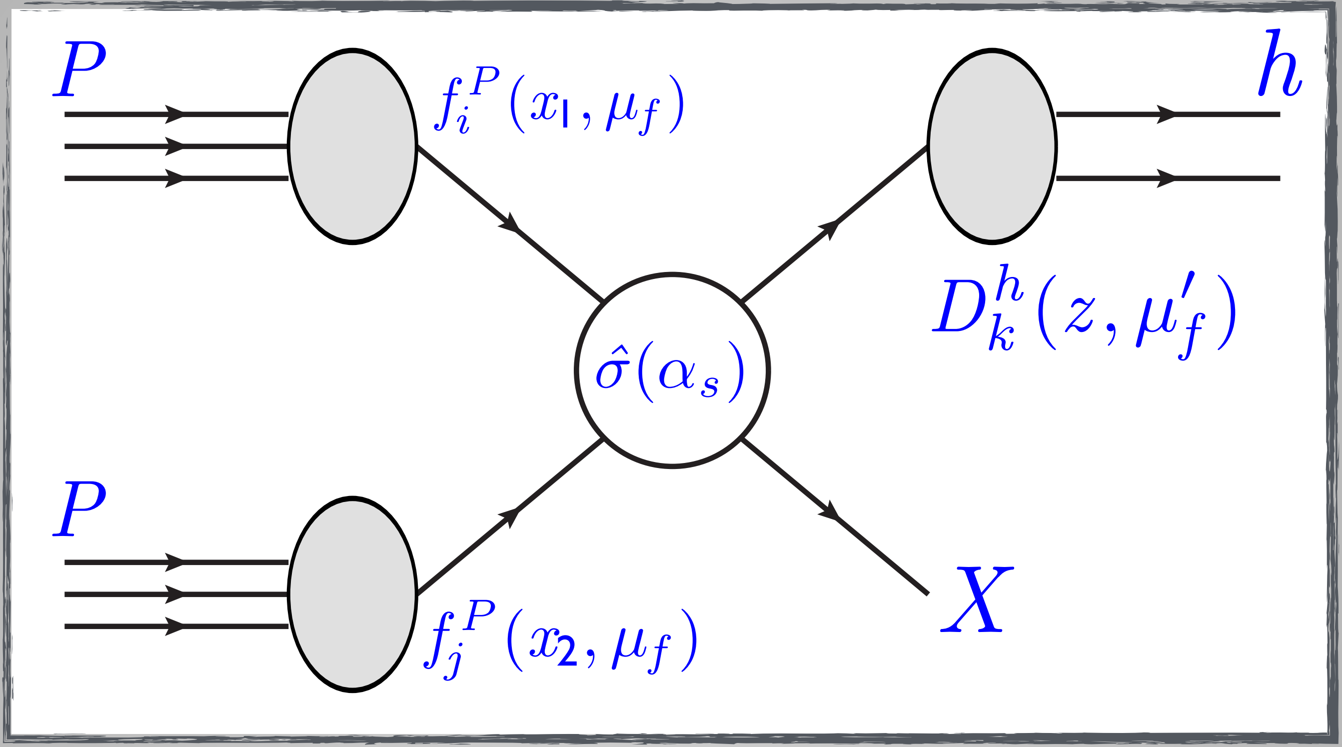
Altarelli et al. '79, Furmanski, Petronzio '82, de Florian, Stratmann, Vogelsang '98

- 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:

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

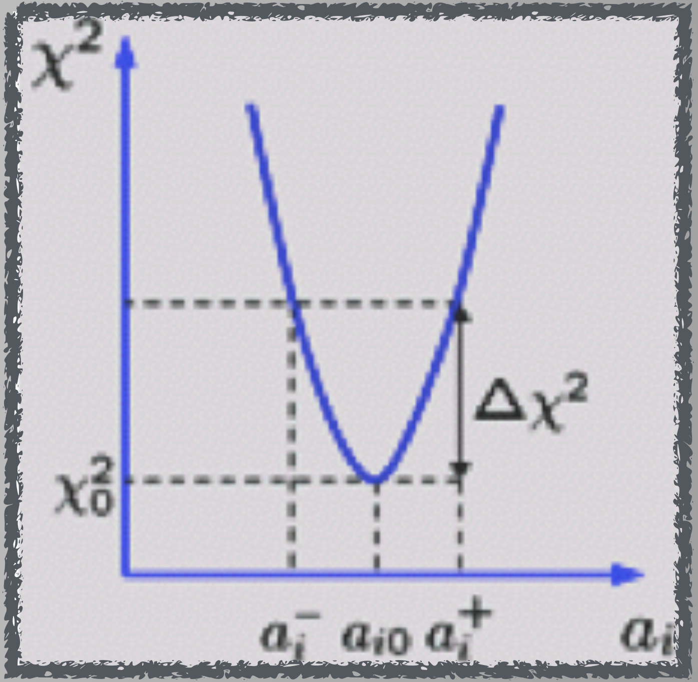
- It also allows charge and flavour separation.
- It contains large contributions from gluons.

Uncertanties

Goal: Provide Hessian sets to propagate FFs uncertainties.

HESSIAN METHOD

- Idea: Explore the vicinity of the best fit in quadratic approximation.
- Caveat: Quadratic approximation is not exactly what is used for the global fits, i.e. PDFs too.
- However, it is a good test of the convergence of the fitting procedure.



$$D_i^{\pi^+}(z,Q_0) = \frac{N_i z^{\alpha_i}(1-z)^{\beta_i}[1+\gamma_i(1-z)^{\delta_i}]}{B[2+\alpha_i,\beta_i+1]+\gamma_i B[2+\alpha_i,\beta_i+\delta_i+1]}$$

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 normalisation 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).

$$D^{\pi^+}_{d+\bar{d}} = N_{d+\bar{d}} D^{\pi^+}_{u+\bar{u}} \qquad D^{\pi^+}_{\bar{u}} = D^{\pi^+}_{d}$$

$$D^{\pi^+}_{s} = D^{\pi^+}_{\bar{s}} = N_s z^{\alpha_s} D^{\pi^+}_{\bar{u}} \qquad \gamma_{c,b} \neq 0$$

DSS vs the new fit

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

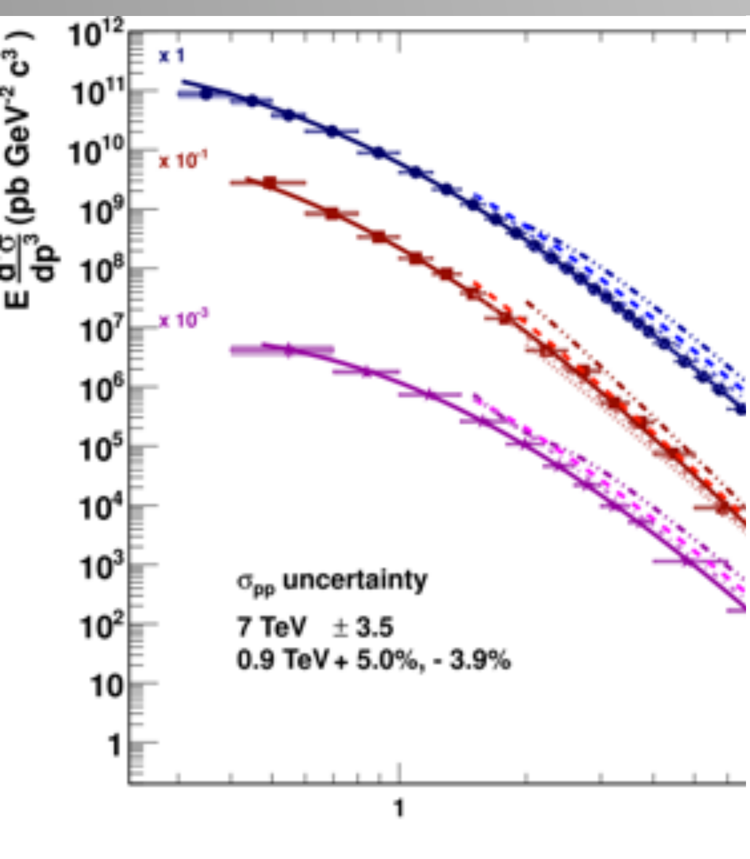
$$\chi^2 = \sum_{i=1}^{N} \left[\left(\frac{1 - \mathcal{N}_i}{\delta \mathcal{N}_i} \right)^2 + \sum_{j=1}^{N_i} \left(\frac{\mathcal{N}_i T_j - E_j}{\delta E_j} \right)^2 \right]$$

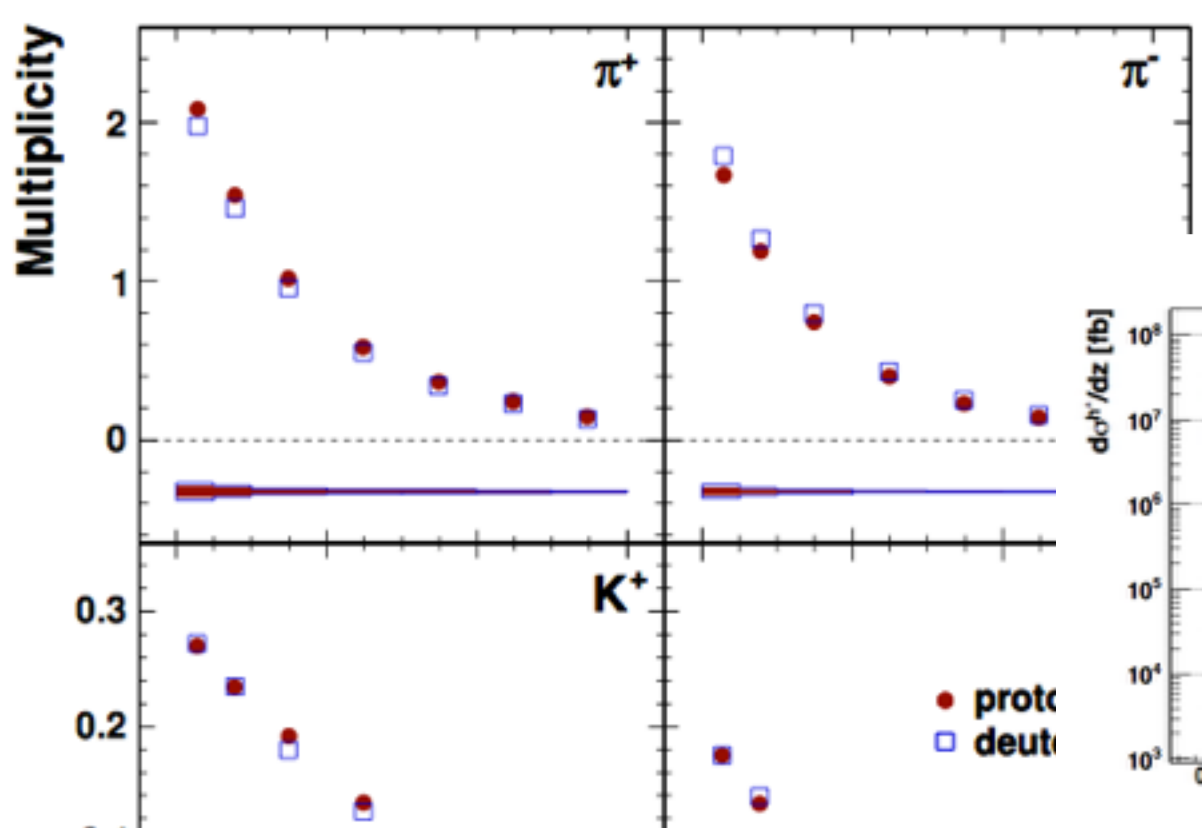
- Normalisation of each experiment can be computed analytically,

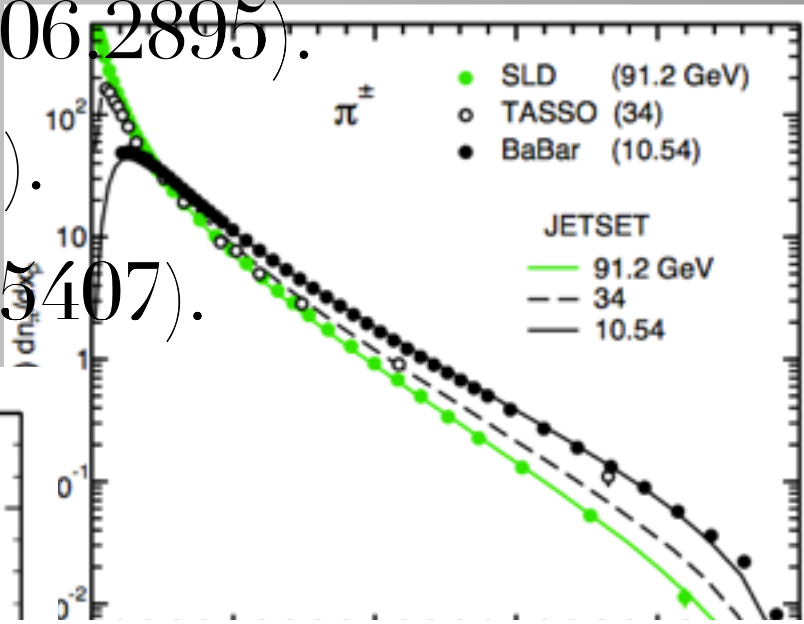
$$\mathcal{N}_i = \frac{\sum_{j=1}^{N_i} \frac{\delta \mathcal{N}_i^2}{\delta E_j^2} T_j E_j + 1}{\sum_{j=1}^{N_i} \frac{\delta \mathcal{N}_i^2}{\delta E_j^2} T_j^2 + 1}$$

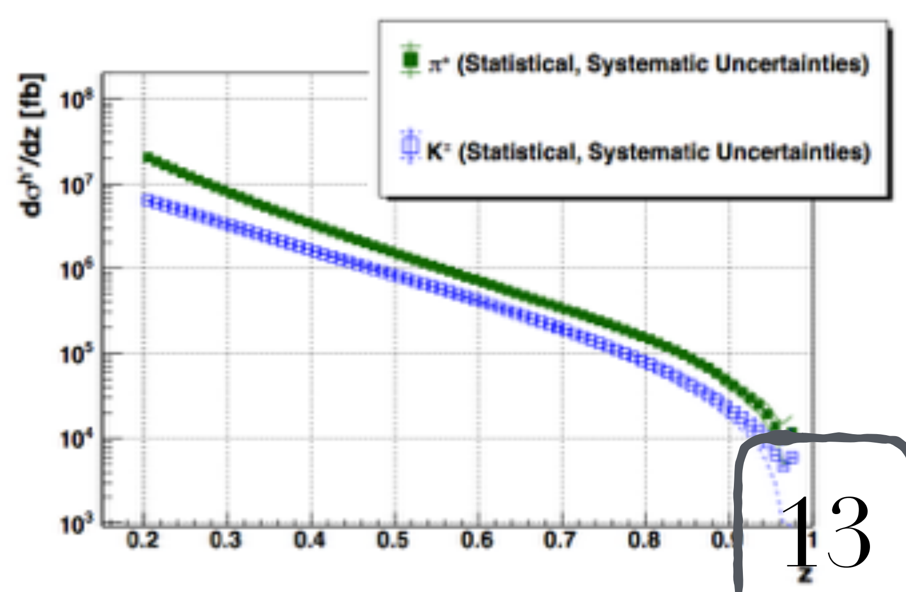
—*Results*—

- New data from PHENIX and STAR (Phys.Rev.C81(2010)064904; PRL 108(2012)072302;…).
- Data from the LHC (Phys.Lett.B717(2012)162;1307.1093;…).
- e+e- data from BELLE(1301.6183) and BaBar (1306.2895).
- SIDIS multiplicities from COMPASS (1307.3407).
- Final SIDIS multiplicities from HERMES (1212.5407).







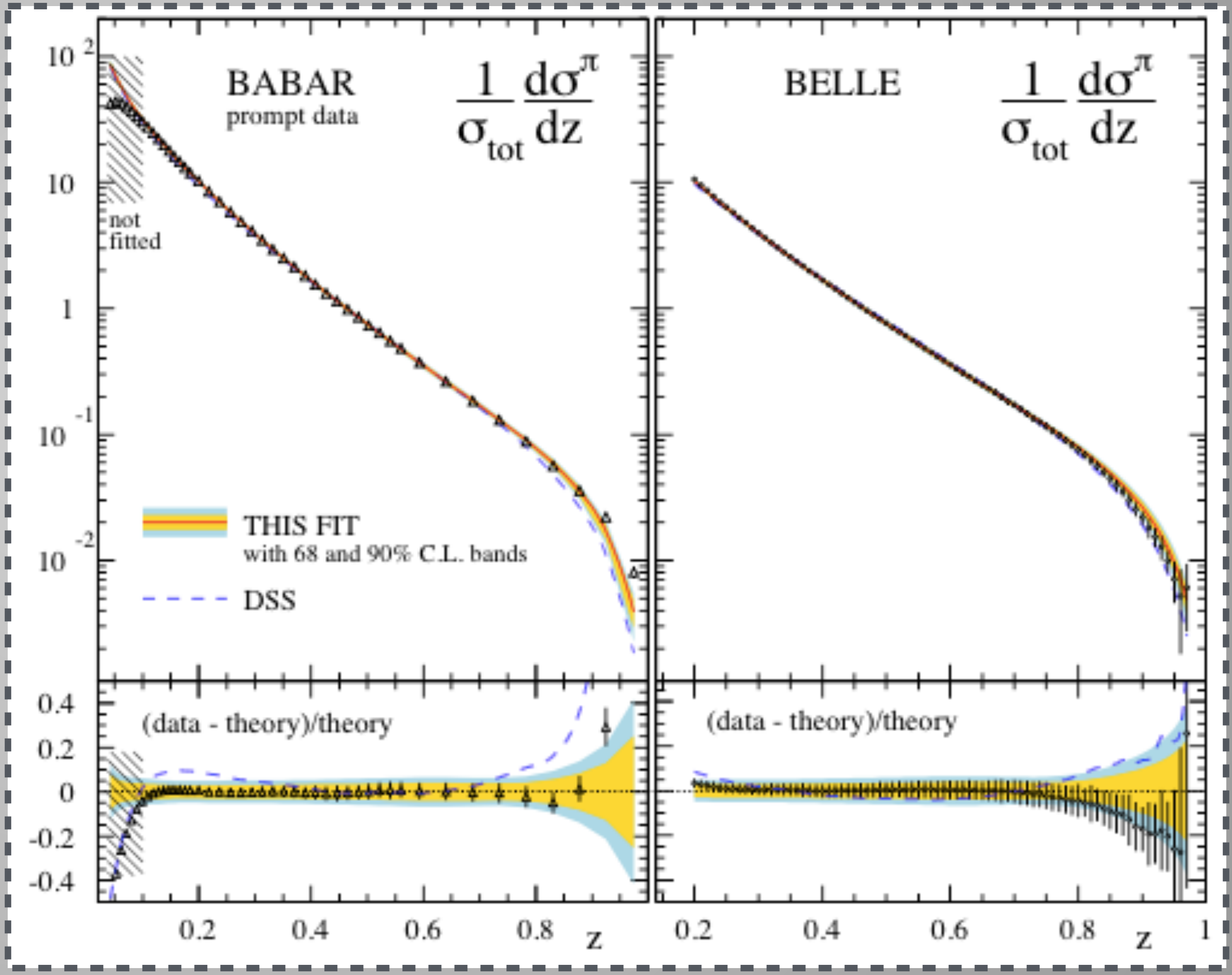


e+e- data: BELLE and BaBar

- They cover an unexplored high region of z.
- BELLE has the finest binning and reach values of $z > 0.8$
- Experimental measurements are determined with extreme accuracy.
- BELLE and BaBar helps to constraint the singlet of FFs but due to the c.m.s. (sqrt(s)=10.5 GeV) it will contribute mainly to the photon exchange channel.
- Partial flavour separation.

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.

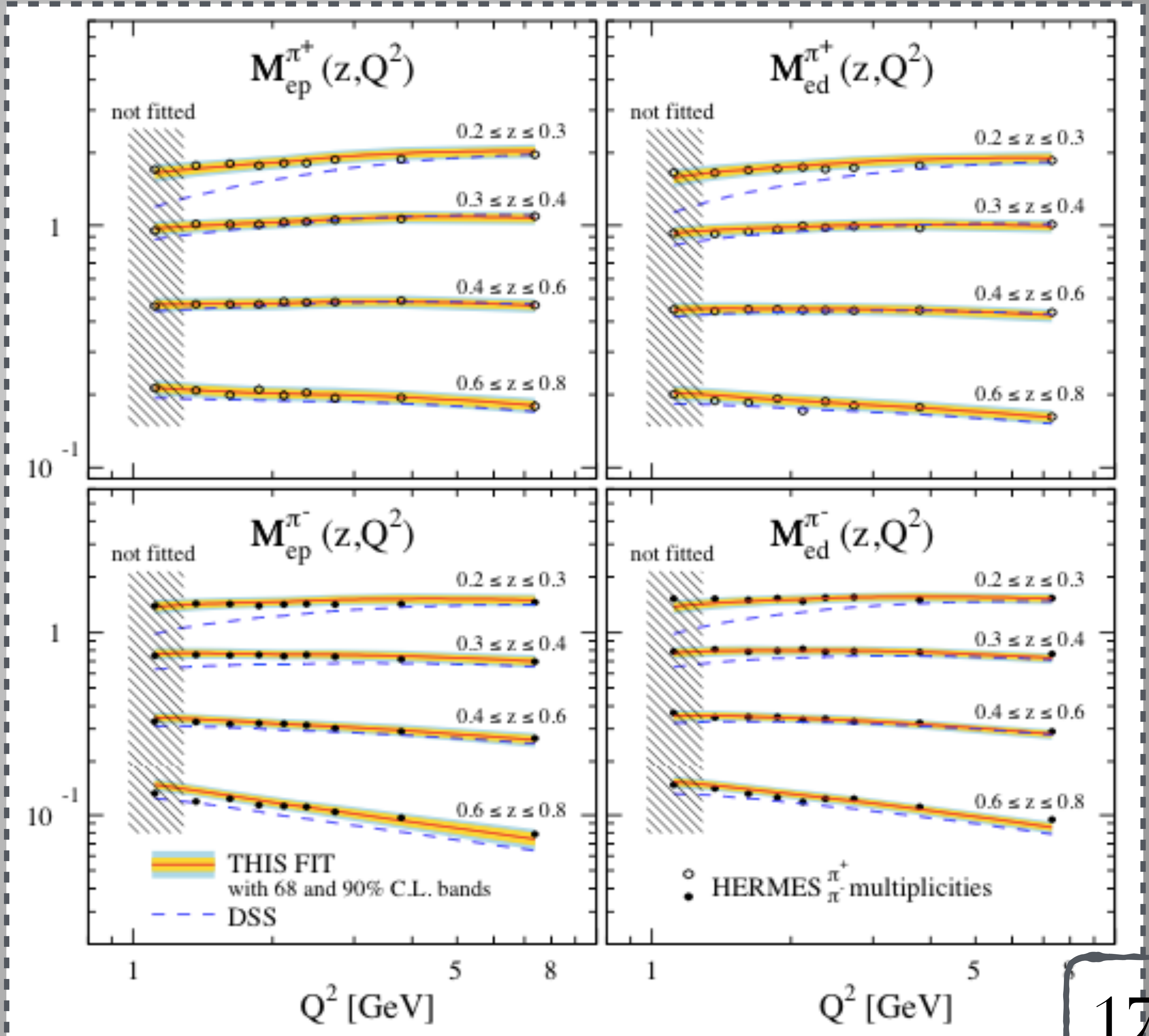


SIDIS data: HERMES and COMPASS

- HERMES published their data sets and they included the data for a deuteron target.
- COMPASS data is still preliminary (but they have shown pions multiplicities at DIS2013, arXiv:1307.3407) but it is extremely important to consider it for the charge and flavour separation.
- SIDIS produce positively and negatively charge pions in a different rate when the target is changed.

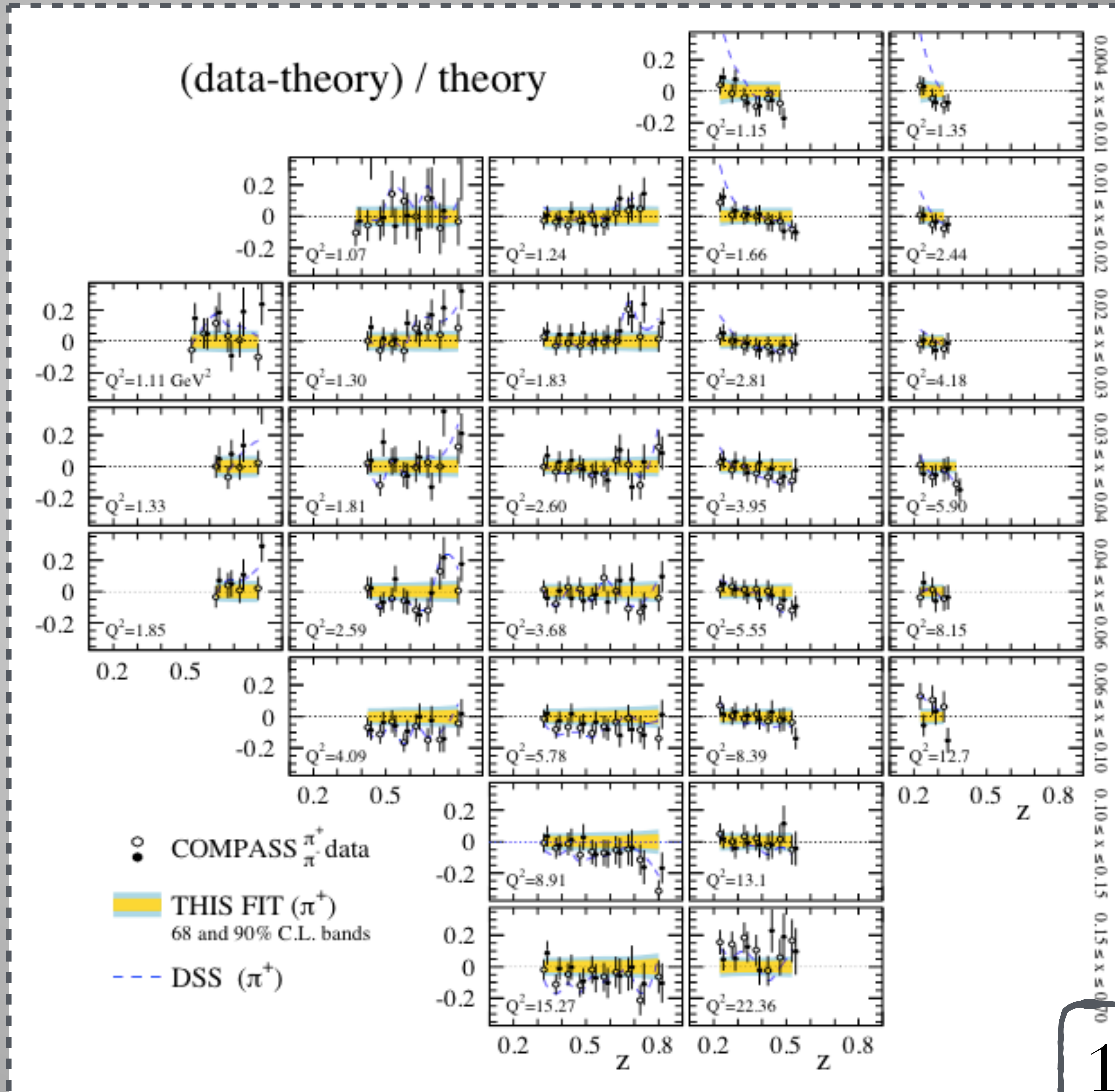
HERMES

- 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.



COMPASS

- DSS also has some tensions with COMPASS data sets.
- For all values of z, COMPASS is well fitted.
- It is been shown also in the chi^2 ~ 1.01.



pp data: PHENIX and STAR

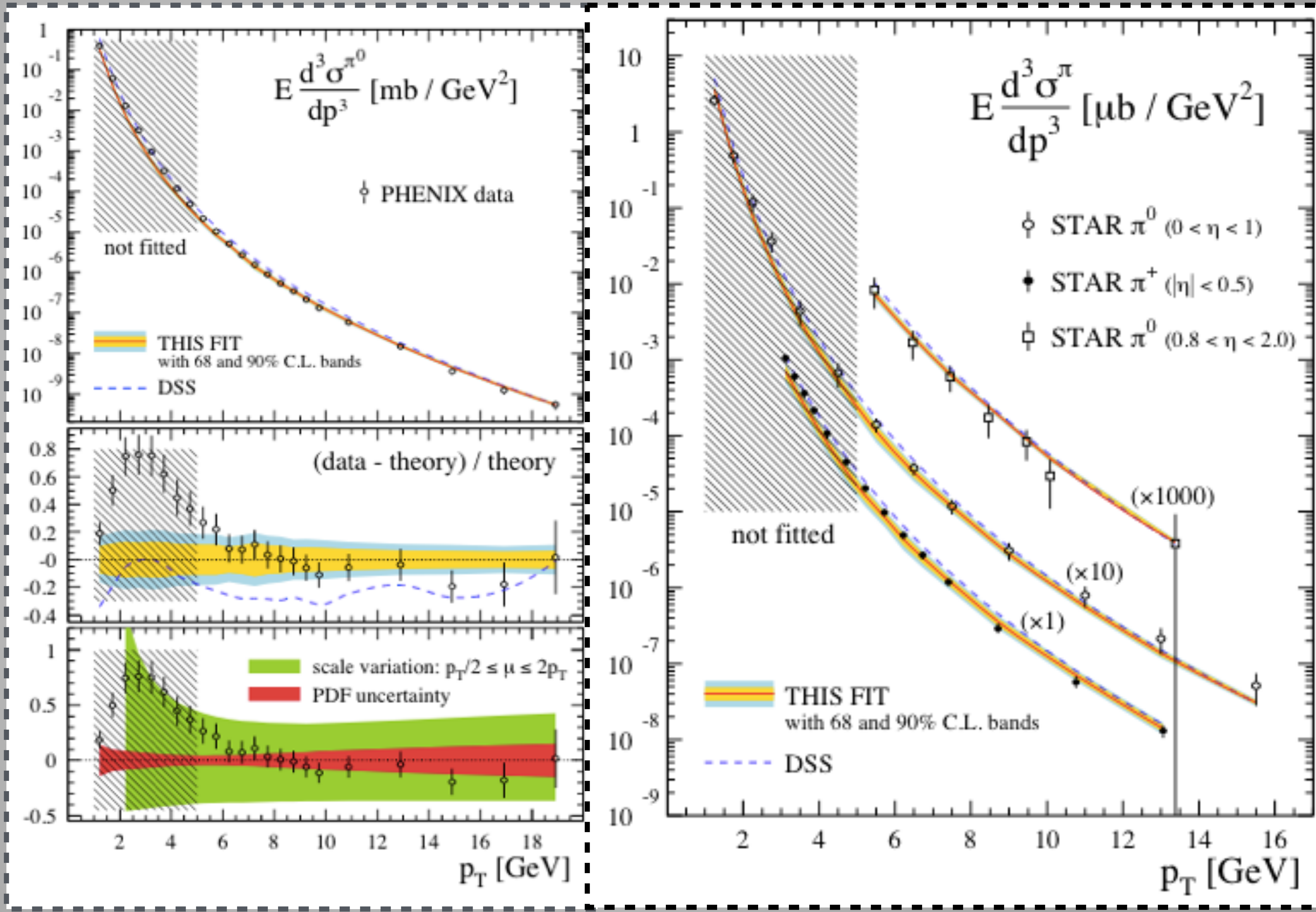
- DSS use mainly of the PHENIX data for neutral pion production at mid rapidity

- We added the data from the STAR collaboration for neutral and charged pions and also from the LHC

- Tension between RHIC and LHC data is largely resolved when a pT cut in 5 GeV for pp data is taken

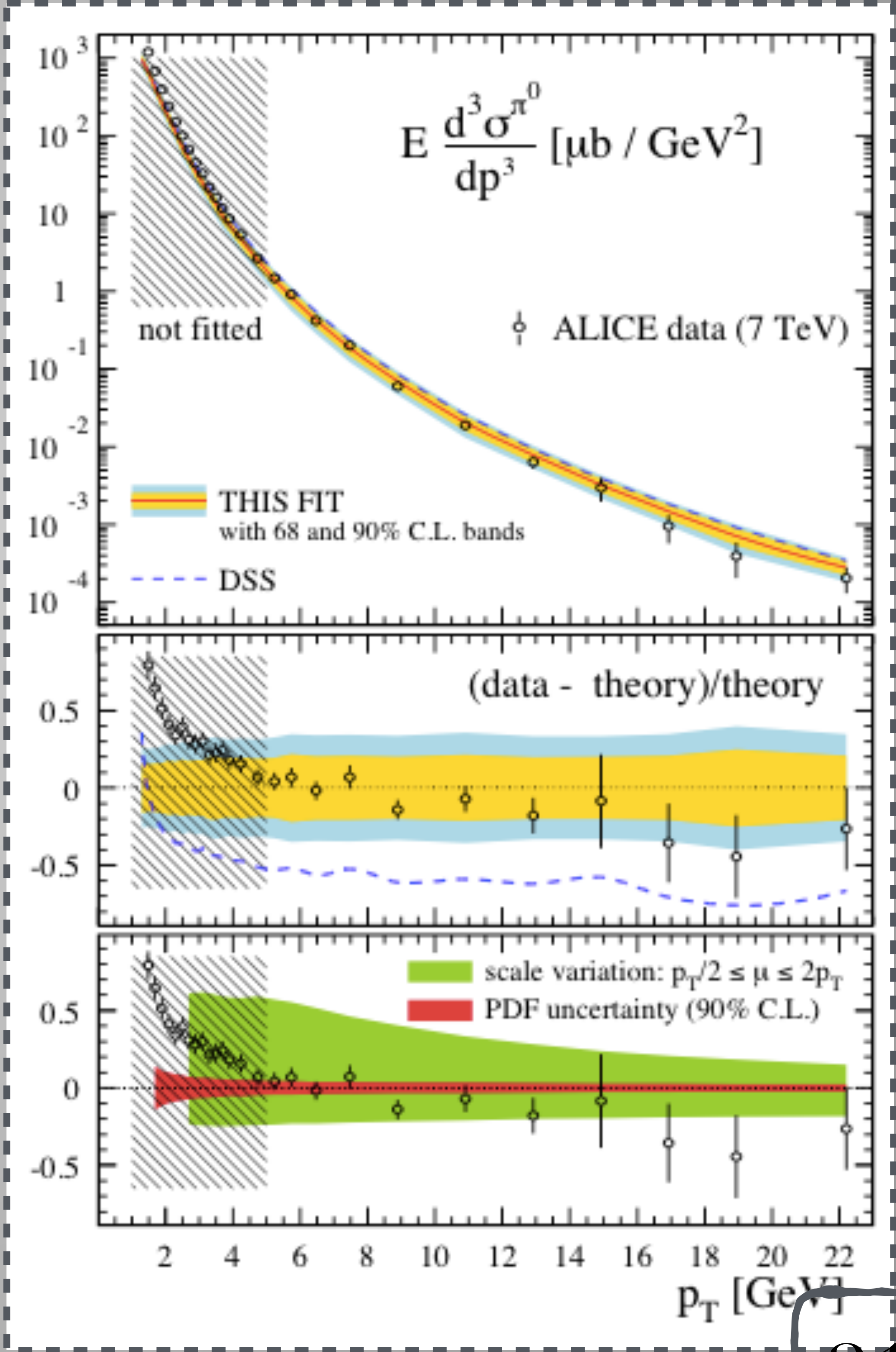
PHENIX & STAR

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



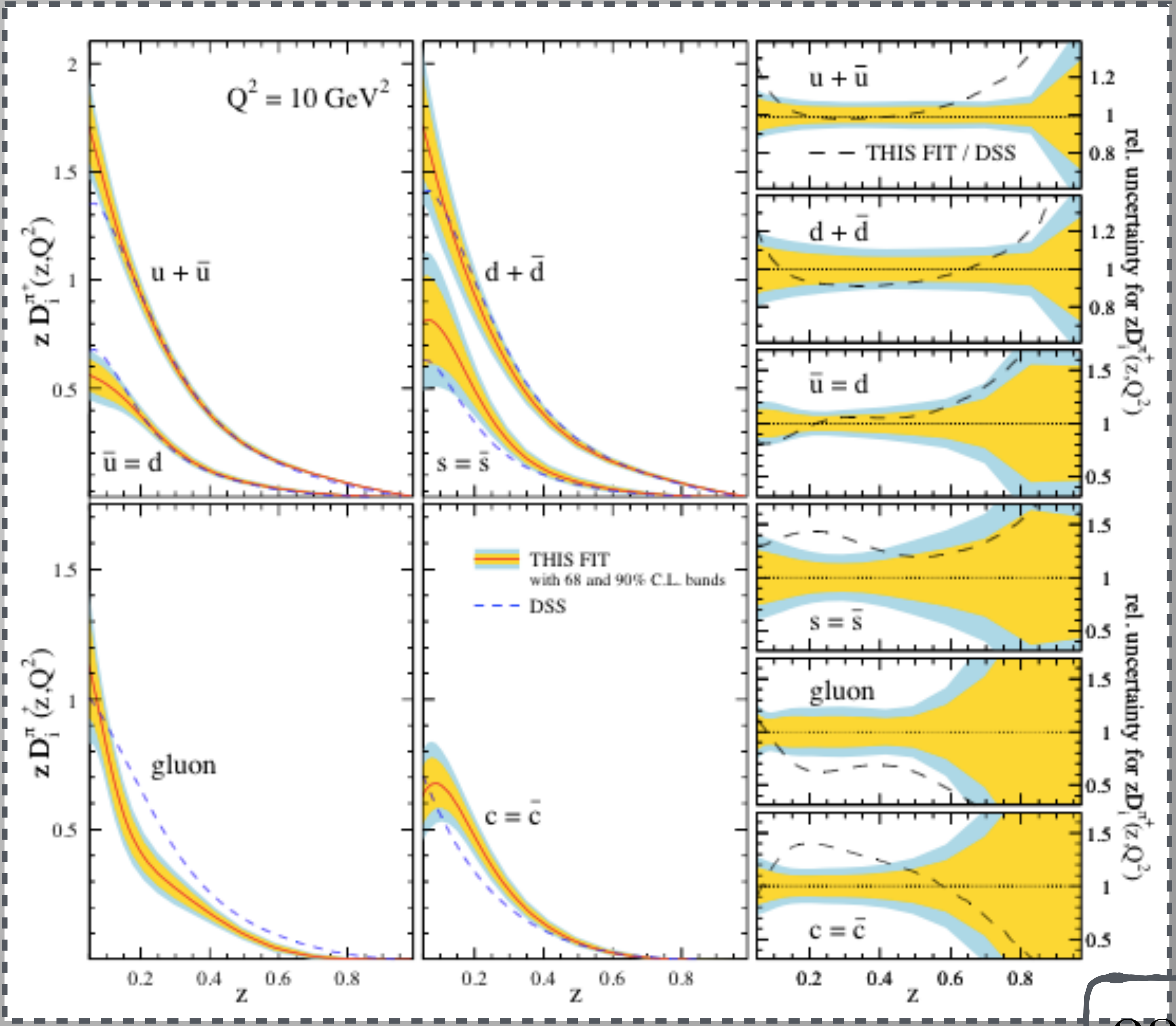
ALICE

- In the range of small pT, RHIC and LHC data showed a tension during the fitting.
- By introducing the cut on the pT, 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.

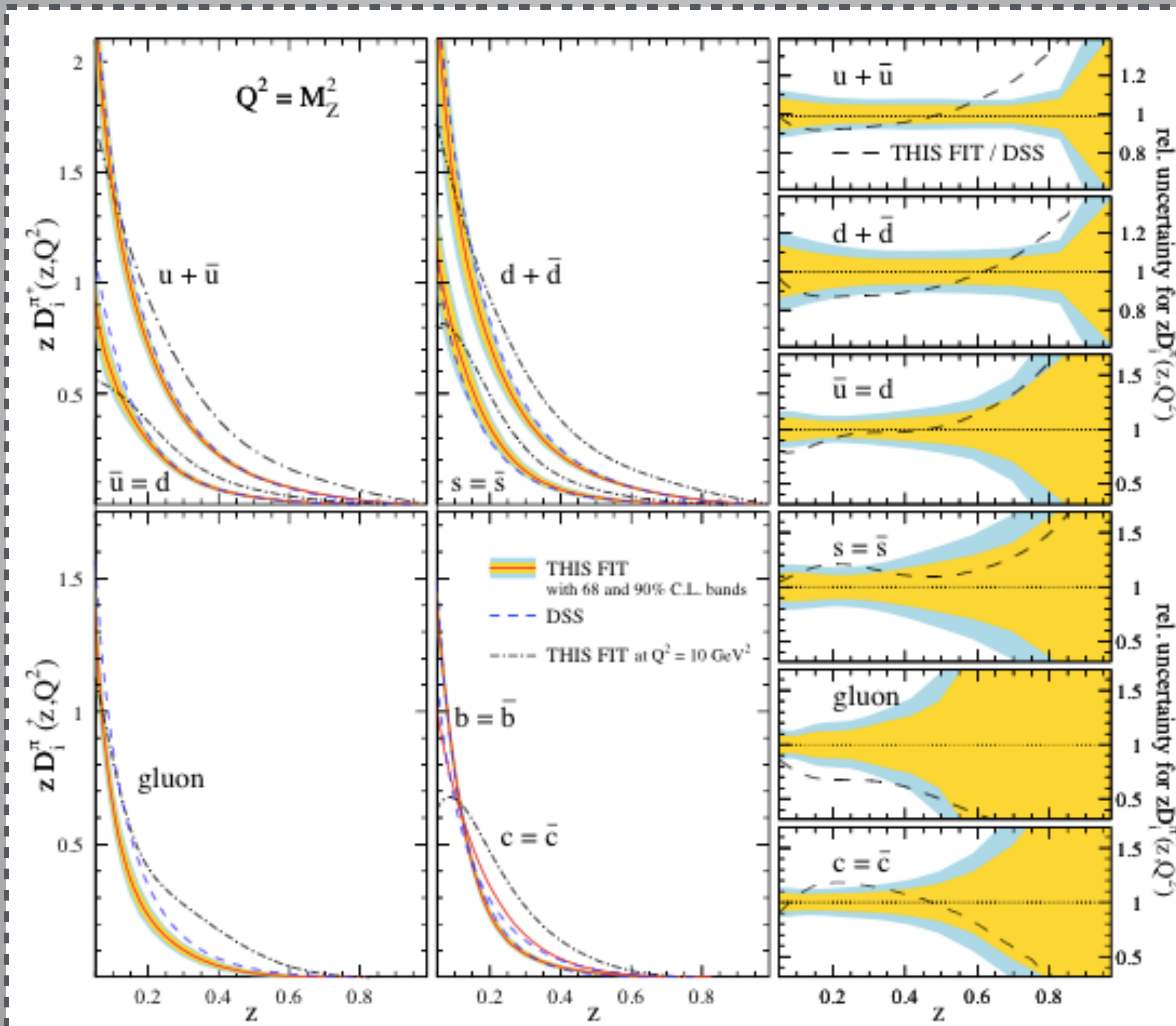


parton-to-pion FFs

- 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 GeV).



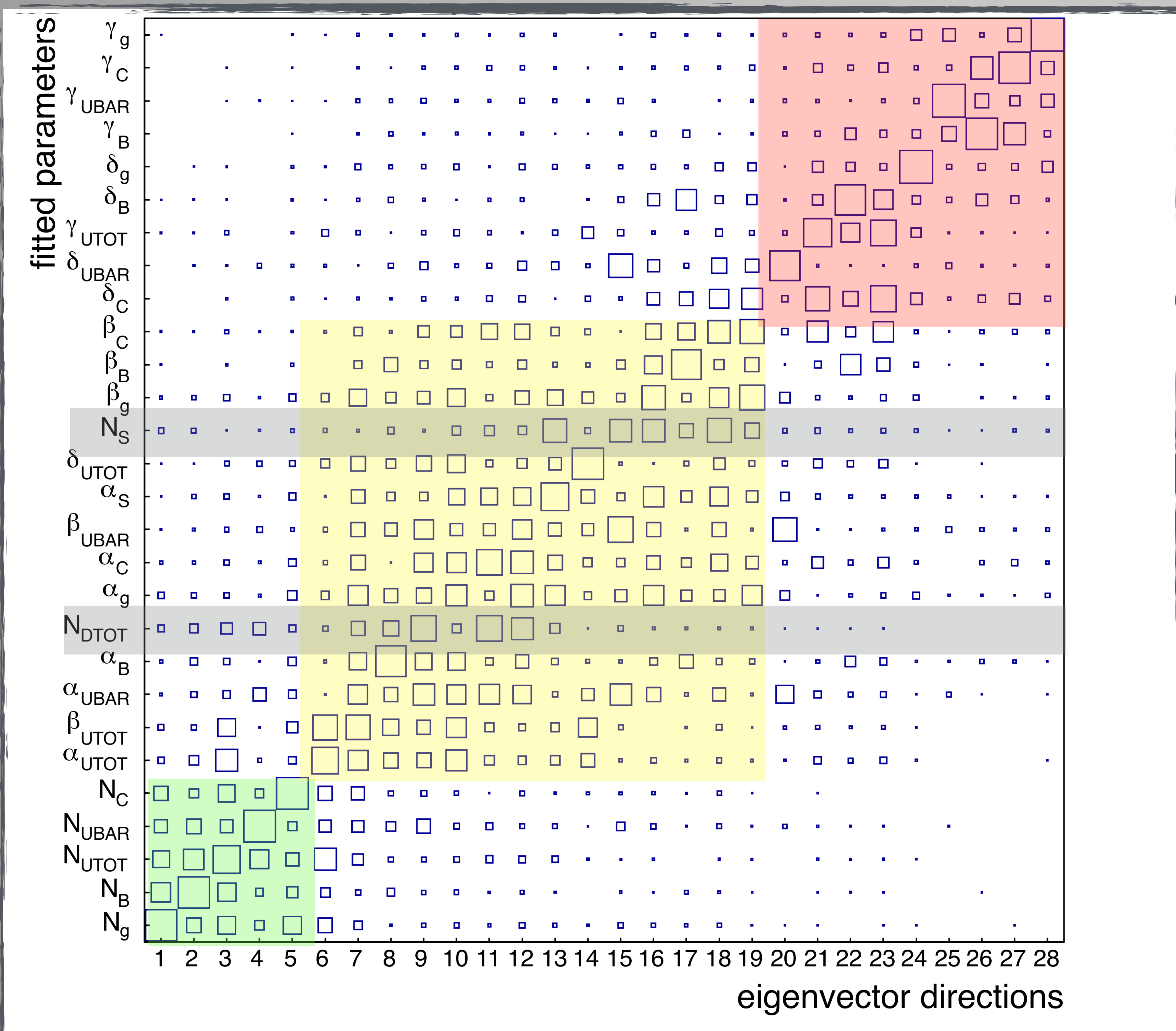
$FFs @ Q = Mz$

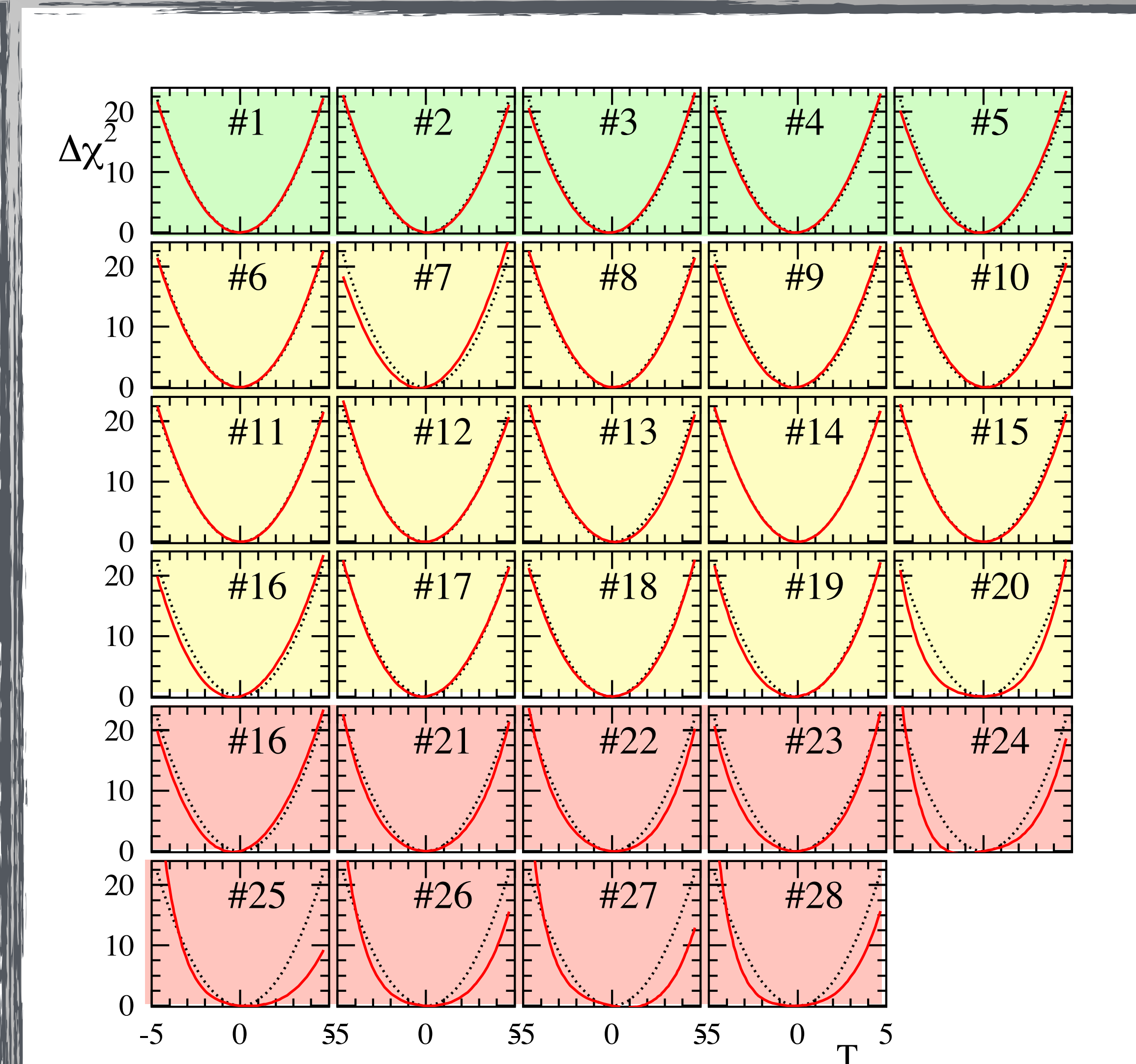


$Q^2 = M_Z^2$
u + ū
ū = d
d + d̄
s = s̄
gluon
b = b̄
c = c̄
THIS FIT
with 68 and 90% C.L. bands
DSS
THIS FIT at $Q^2 = 10$ GeV^2
THIS FIT / DSS
$z D_i^{\pi^+}(z,Q^2)$
rel. uncertainty for $zD_i^{\pi^+}(z,Q^2)$
z

Hessian method & convergence

$$D_i^{\pi^+}(z, Q_0^2) = N_i z^{\alpha_i} \left[(1-z)^{\beta_i} + \gamma_i (1-z)^{\delta_i}\right]$$





Comments on the FFs

- The numerical results shown that the breaking of the charge asymmetry parameter is very close to one.
- Bigger deviations from DSS is found on the gluon and charm FF.
- Charm FF has a more flexible parametrisation (5 instead of 3 parameters).
- Gluon FF uncertainties is about 20% at 90%CL up to $z > 0.5$ and they increase towards larger values ($Q = 10$ GeV).
- ALICE data contribute with a large chi^2 due to the normalisation shift.

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 factorisation 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 normalisation shift is implemented in the the new analysis.

Thanks...