New results on the parton-to-pion FFs

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Outline

- Motivation
- Theory & Uncertainties
- Results on parton-to-pion FFs
- 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 asume factorization and universality

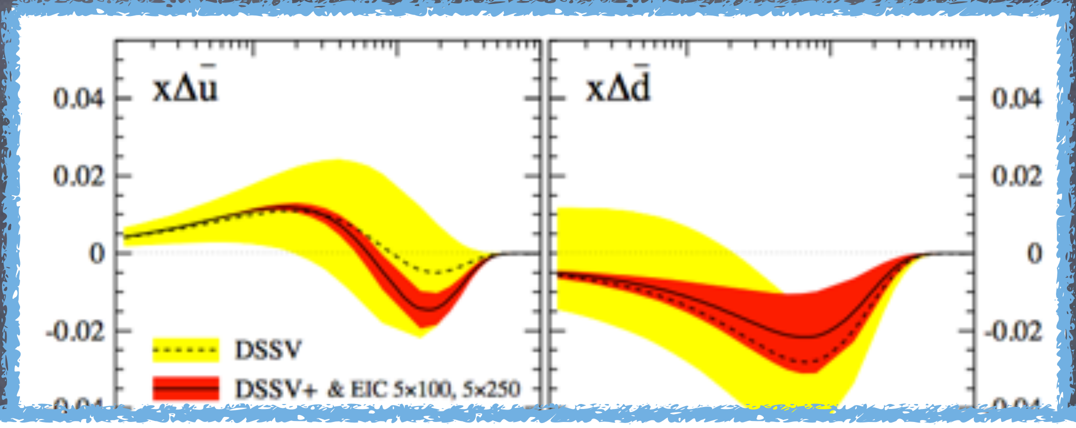
DSS results

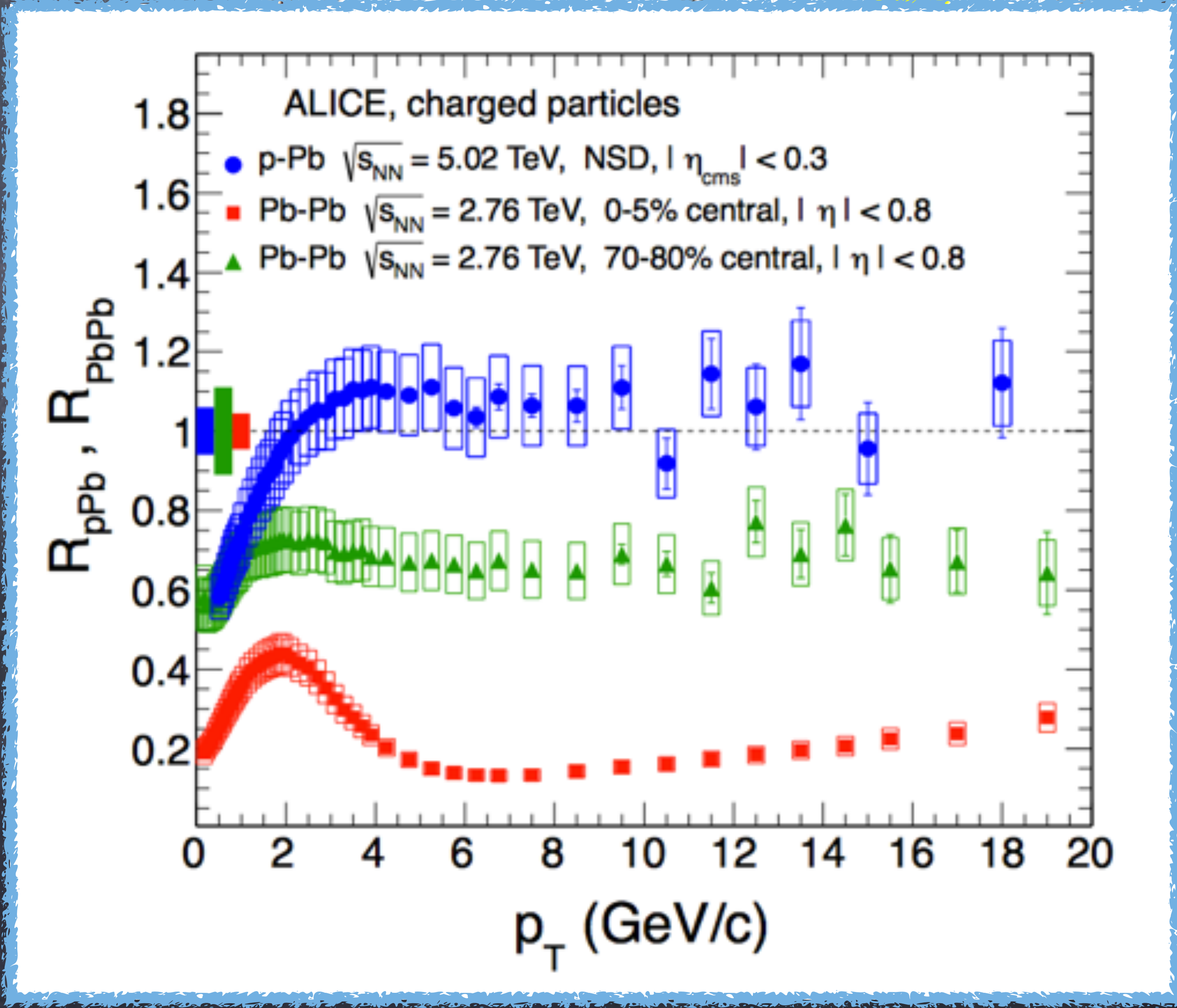
- DSS fit arrived to a data-driven separation of individual parton-to-pion FFs
- They found an unexpected large charge symmetry violation between the u- and d-quarks FFs (~10%)
- FFs of gluons was constrained for the first time with the BNL-RHIC data
- Uncertainties were estimated using the Lagrange multiplier technique

What are they good for ?

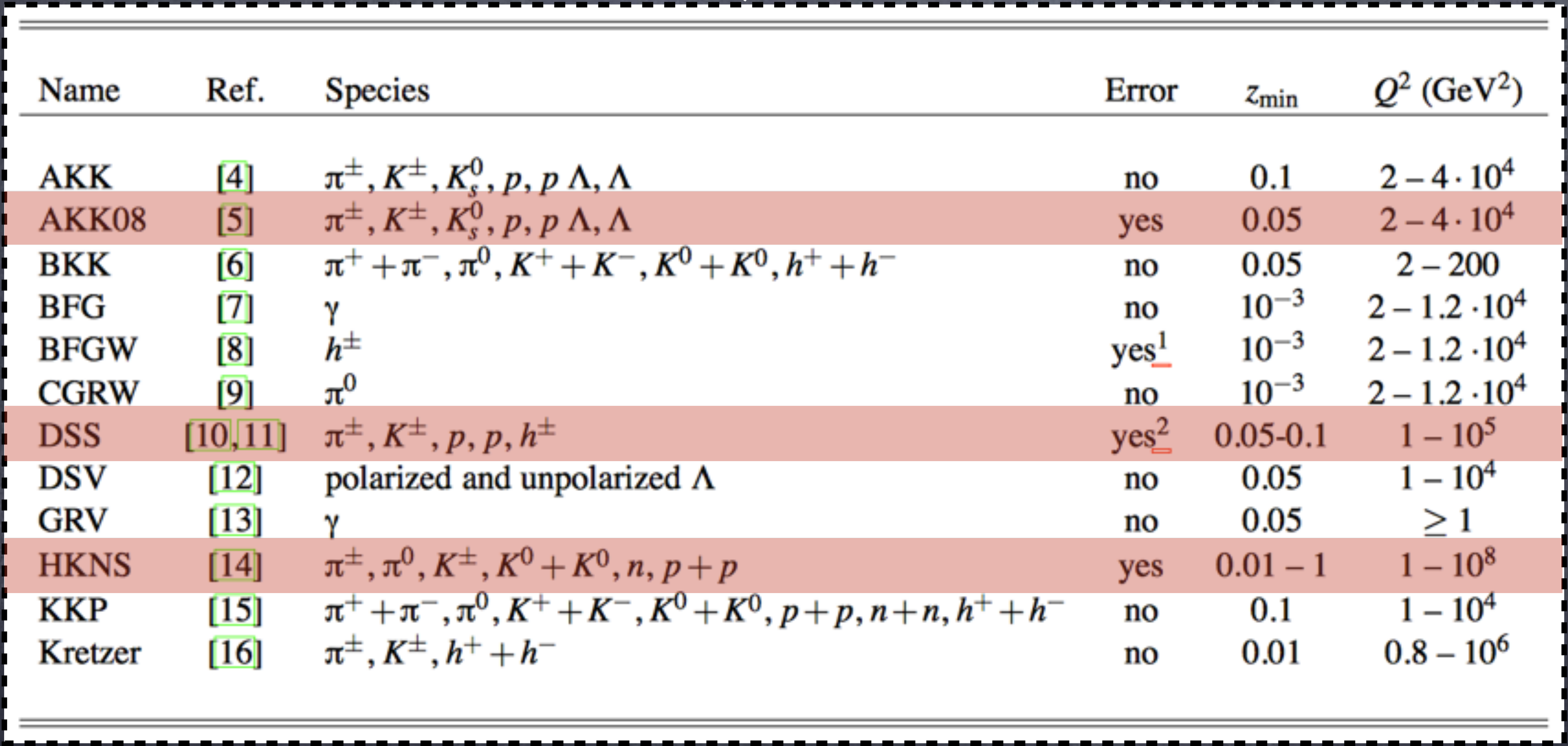
- Important input for extracting helicities PDFs and transverse momentum dependent PDFs
- Probe for the eRHIC era

- They help to quantify and understand possible modifications of hadron production yields in the presence of nuclear medium, as studied in heavy ion collisions both at RHIC and the 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	$2-4\cdot 10^4$
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
HKNS: e+e- data only

Impose isospin symmetry for pions
Hessian method for uncertainties

AKK08 contains large-z resummations and mass corrections

Theory & Uncertainties

- 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

e+e- SIA

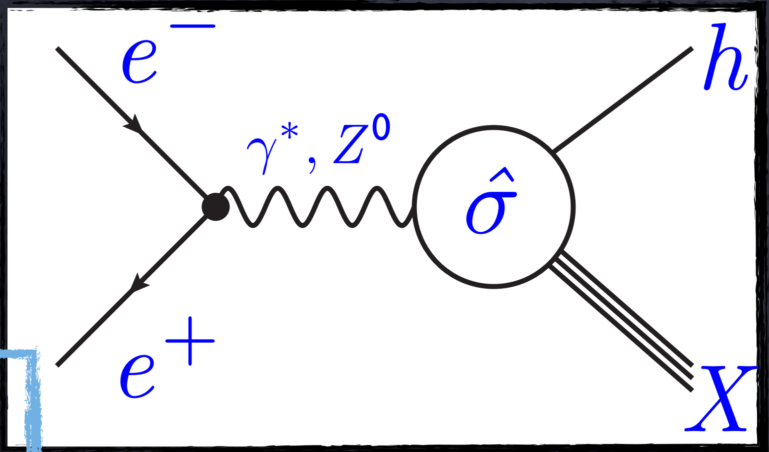
- The distribution is given in terms of the structure functions,

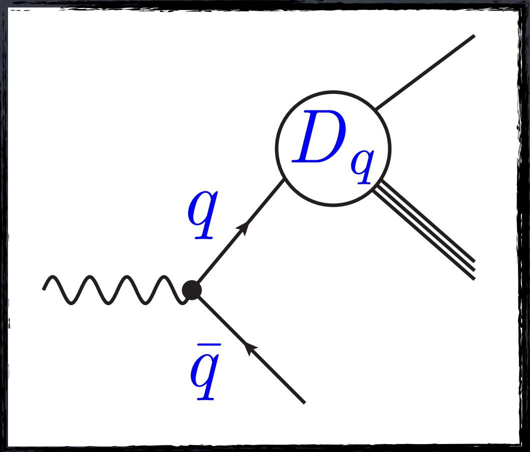
$$\frac{1}{\sigma_{tot}}\frac{d\sigma^h}{dz} = \frac{\sigma^0}{\sum_q \hat{e}_q^2}\left[2F_1^h(z,Q^2) + F_L^h(z,Q^2)\right]$$

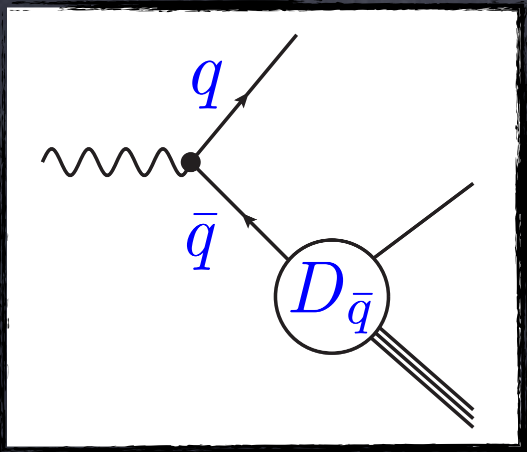
@NLO

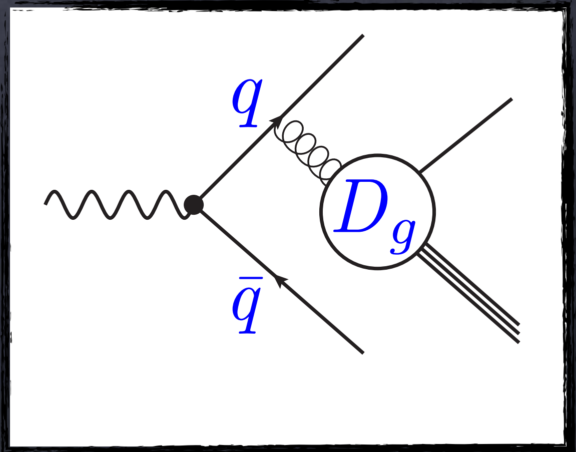
$$2F_1^h(z,Q^2) = \sum_q \hat{e}_q^2 \left\{ \left[D_q^h + D_{\bar{q}}^h\right](z,Q^2) + \frac{\alpha_s(Q^2)}{2\pi}\left[C_q^1 \otimes \left[D_q^h + D_{\bar{q}}^h\right] + C_g^1 \otimes D_g^h\right](z,Q^2) \right\}$$

- Not posible to separate charge & flavour only with SIA
- Only have information of the singlet









SIDIS

- Distributions for SIDIS are given by

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

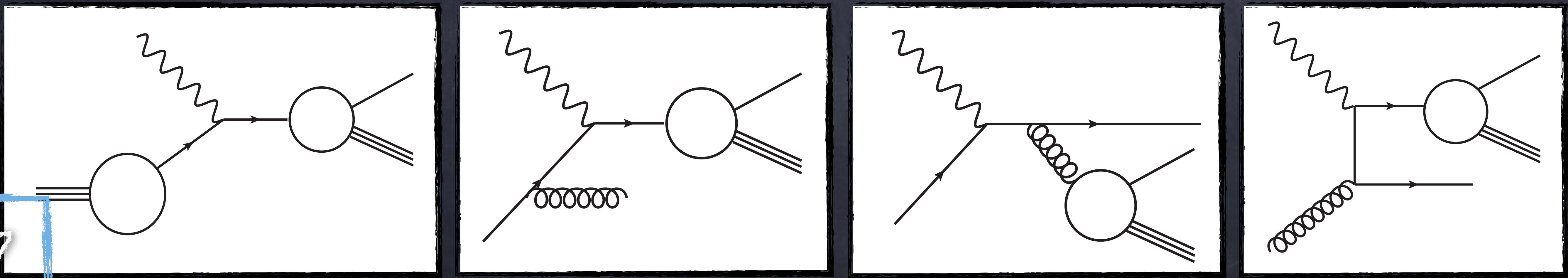
@LO

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

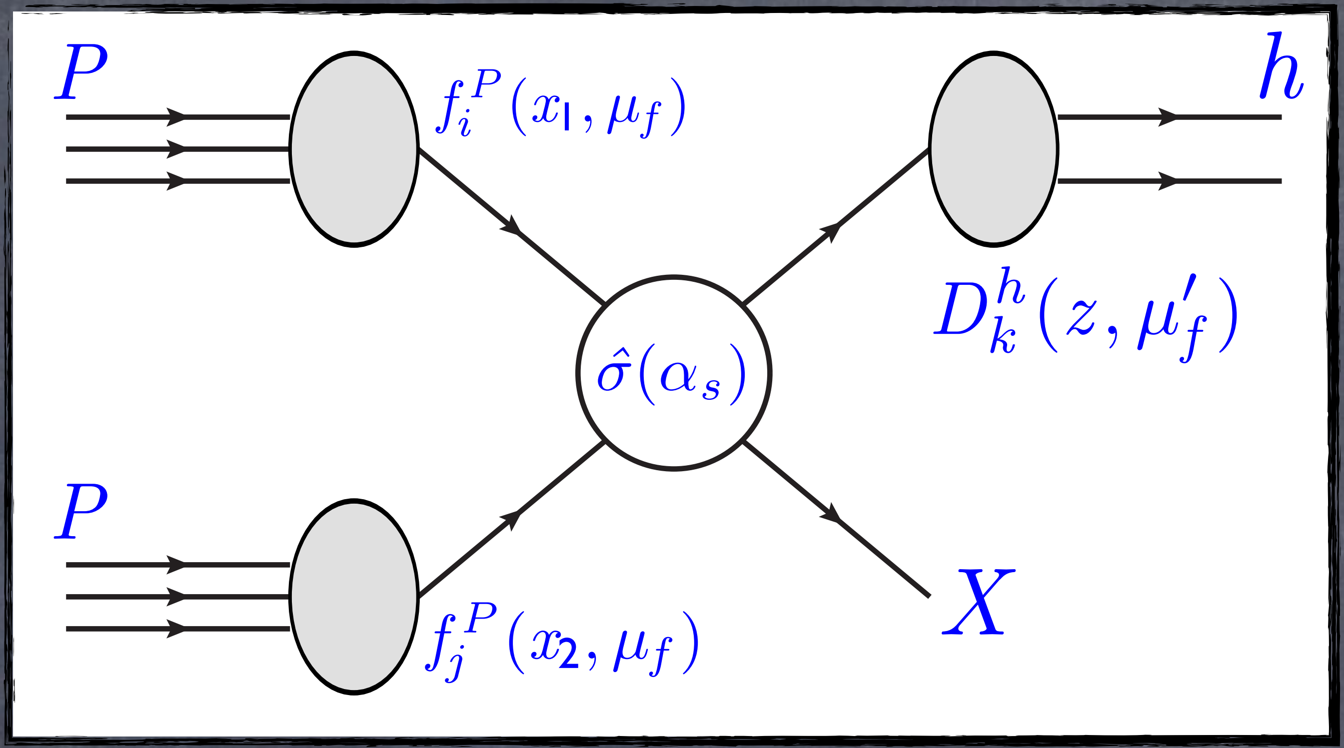
@NLO, all coefficients are lengthy but know

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

- Charge & flavour separatios is first achieved when SIDIS is included
- Gluon FF is not well constrained by SIDIS data



Hadron-Hadron collisions

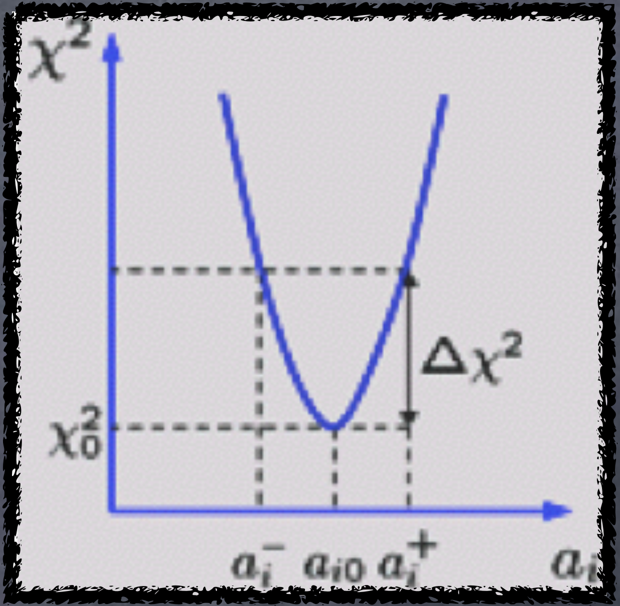


Transverse momentum distribution is

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

- It also allows charge/flavor separation.
- It contains large contributions from gluons.

Uncertainties



- Goal: provide Hessian sets to propagate FFs uncertainties

  Hessian method

- Idea: explore the vicinity of the best fit in quadratic approximation

  Issues:

- Caveat: Quadratic approximation is not perfect

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

Comparison between DSS and this analysis

- 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)

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

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

Comparison between DSS and this analysis

- 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

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

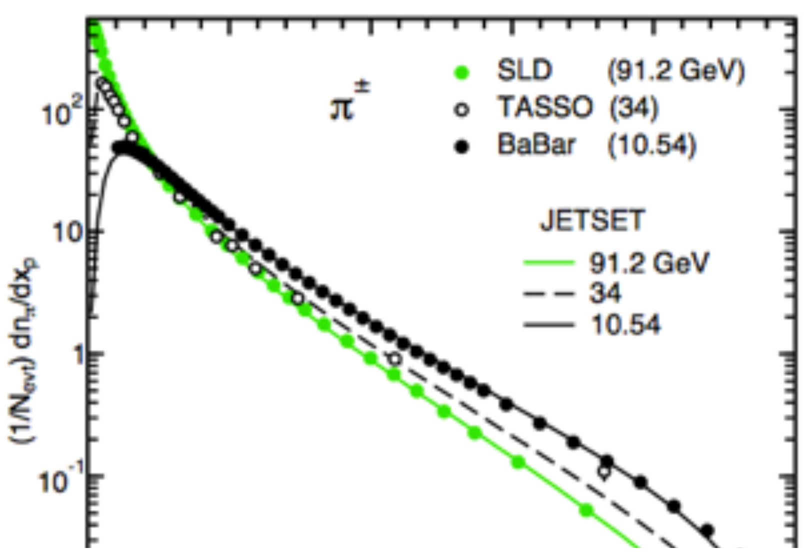
- Normalization of each experiment can be computed analytically

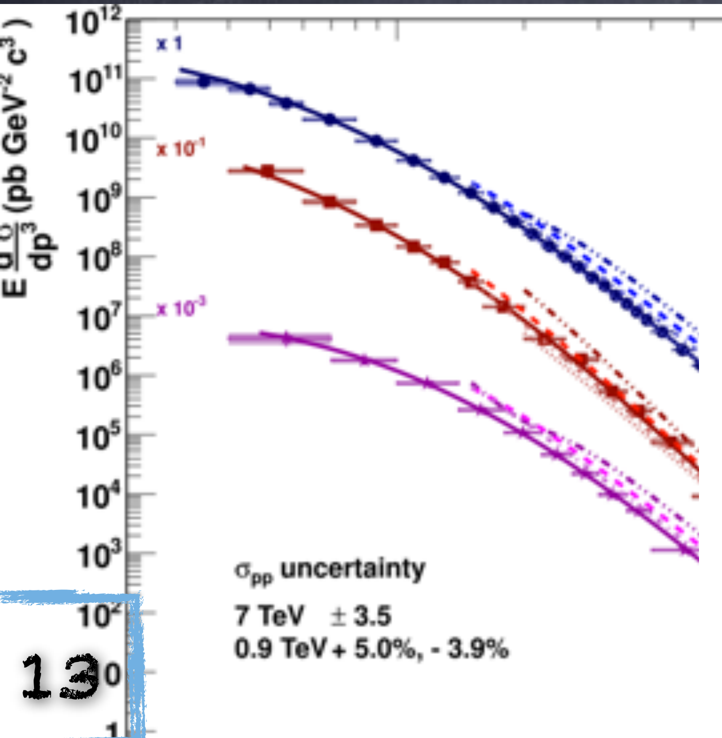
$$\mathcal{N}_i = \frac{\sum_{j=1}^{N_i} \frac{\delta \mathcal{N}_i^2}{\delta E_j^2} T_j E_j + 1}{\sum_{j=1}^{N_i} \frac{\delta \mathcal{N}_i^2}{\delta E_j^2} T_j^2 + 1}$$

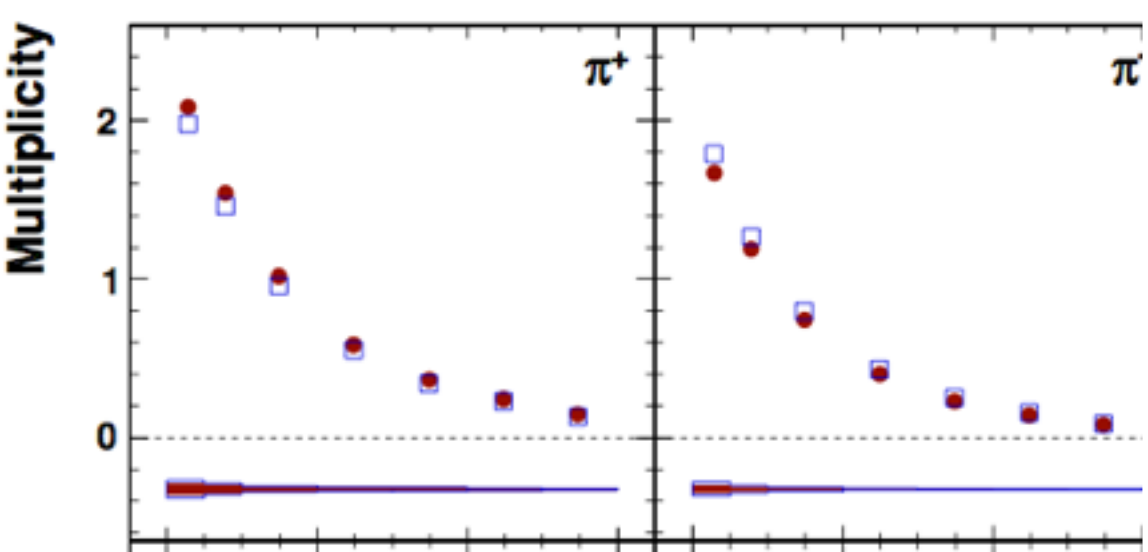
RESULTS

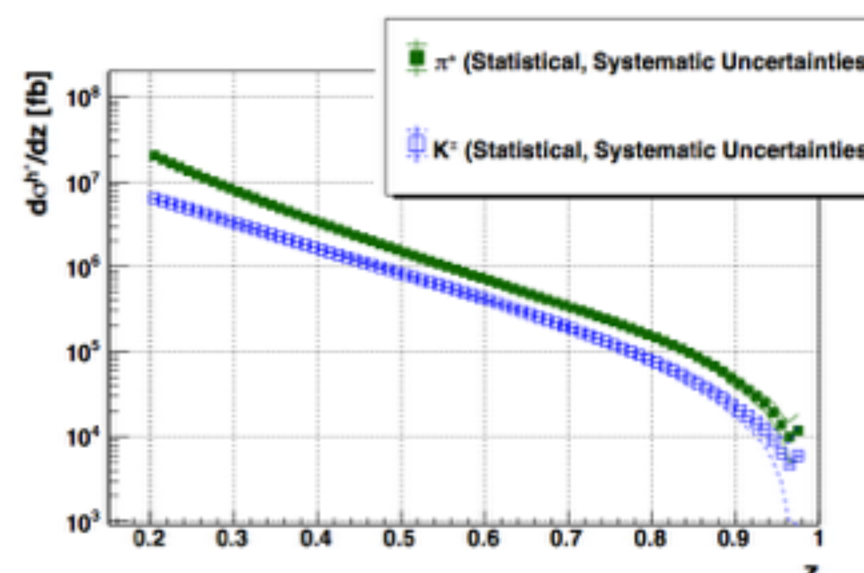
Many data sets have been published/shown since DSS analysis (2007)

- 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)







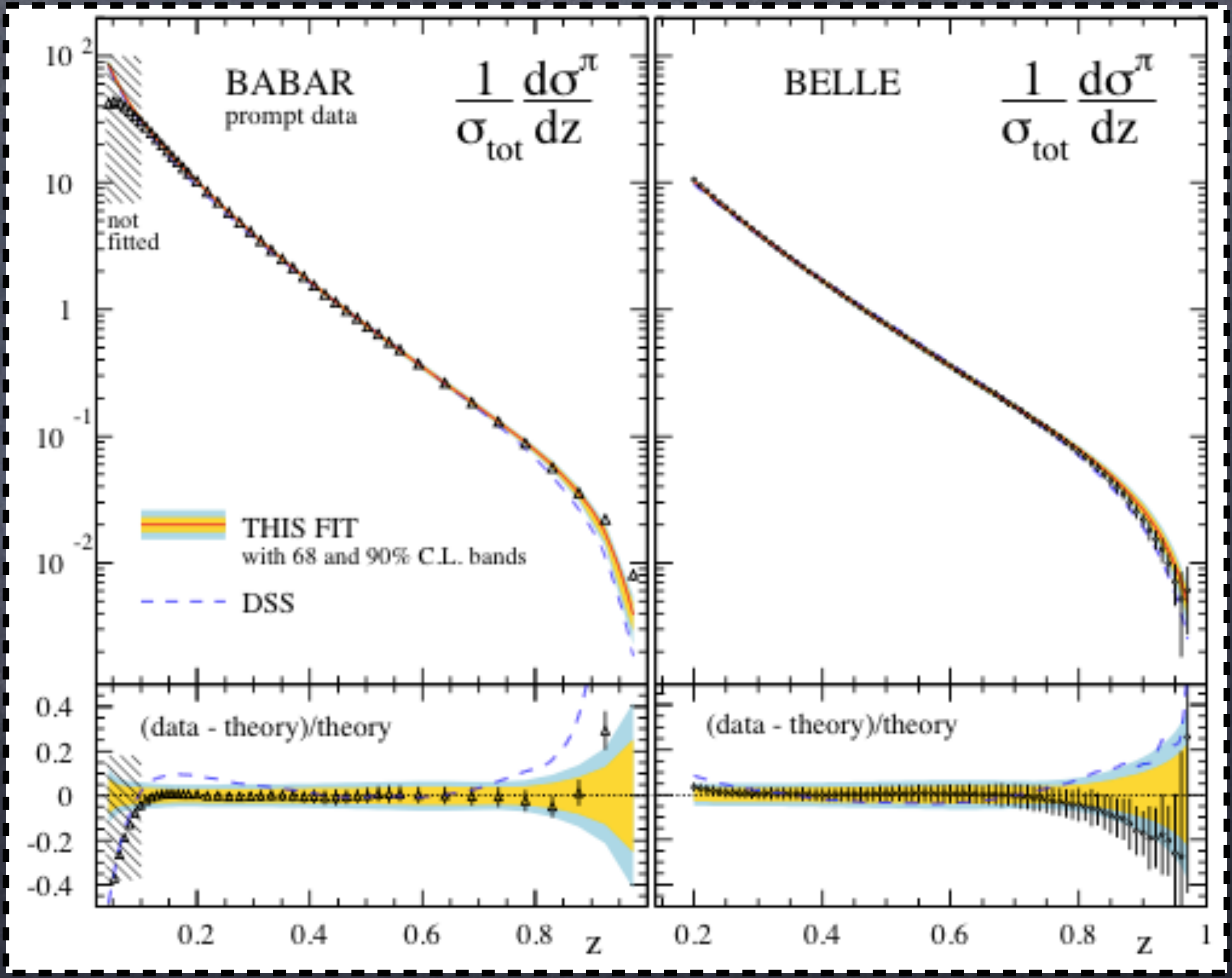


e+e- data: BELLE and BaBar

- 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 cms (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

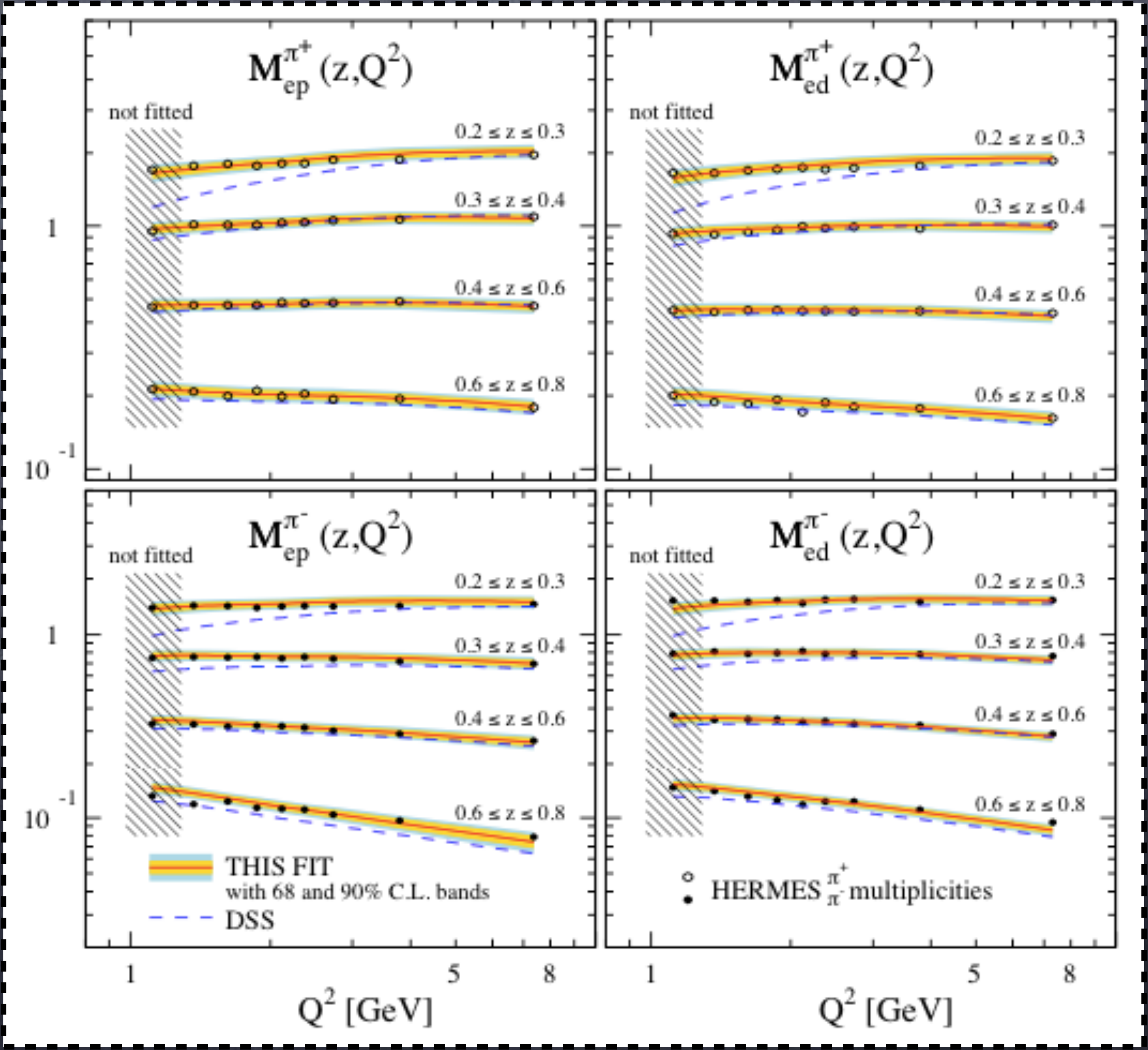


SIDIS data: HERMES and COMPASS

- 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

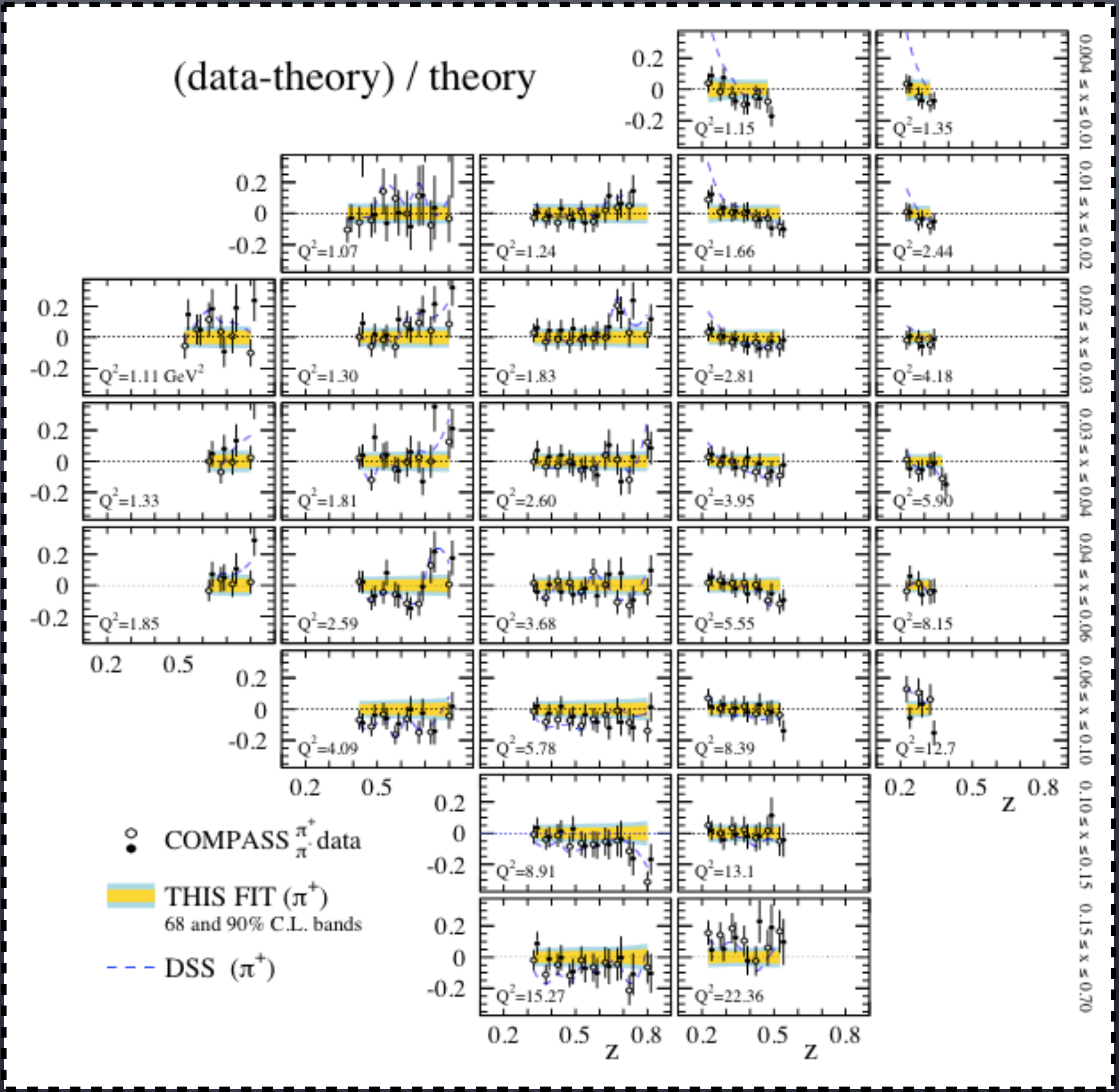
HERMES

- 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

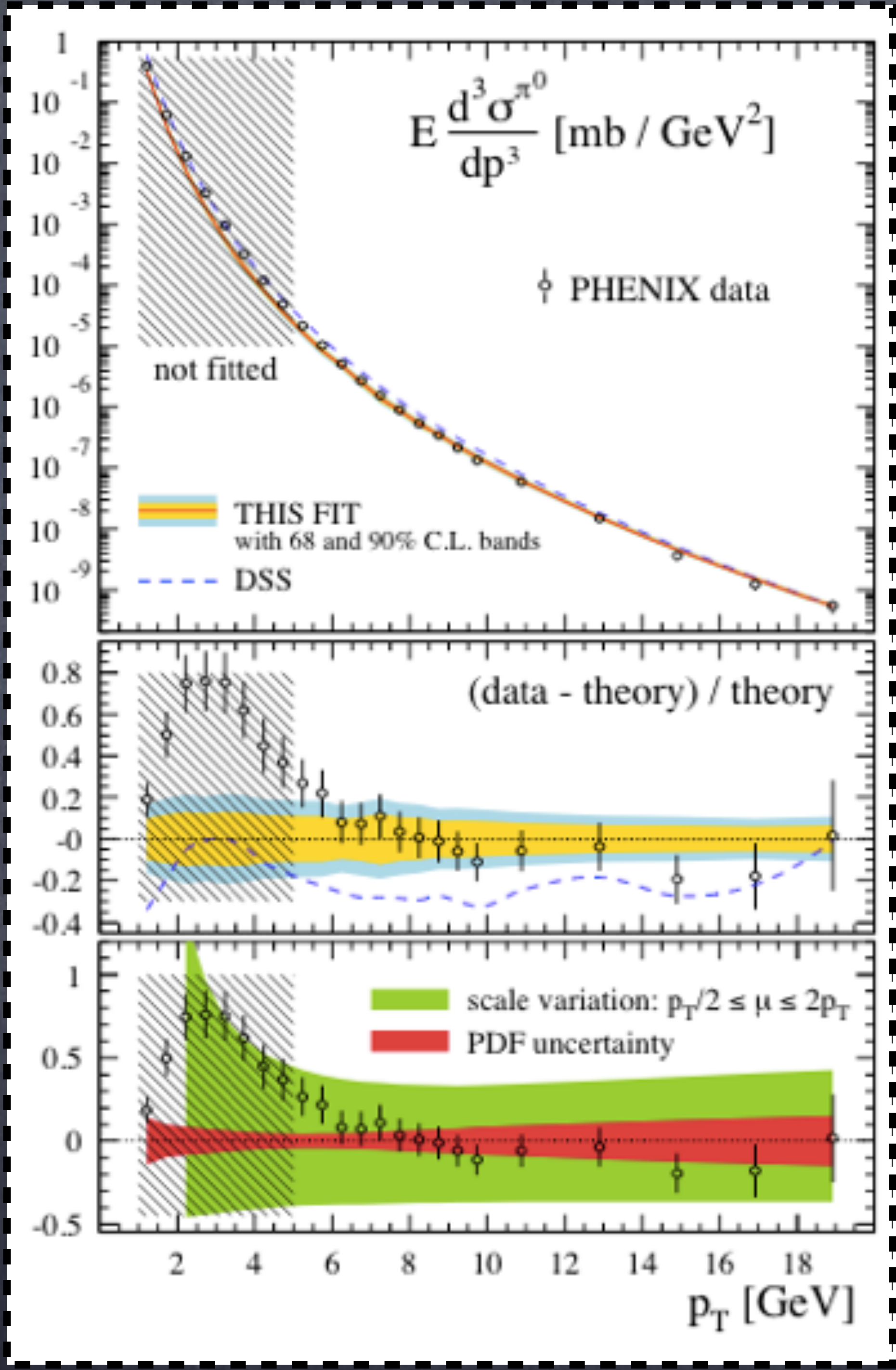


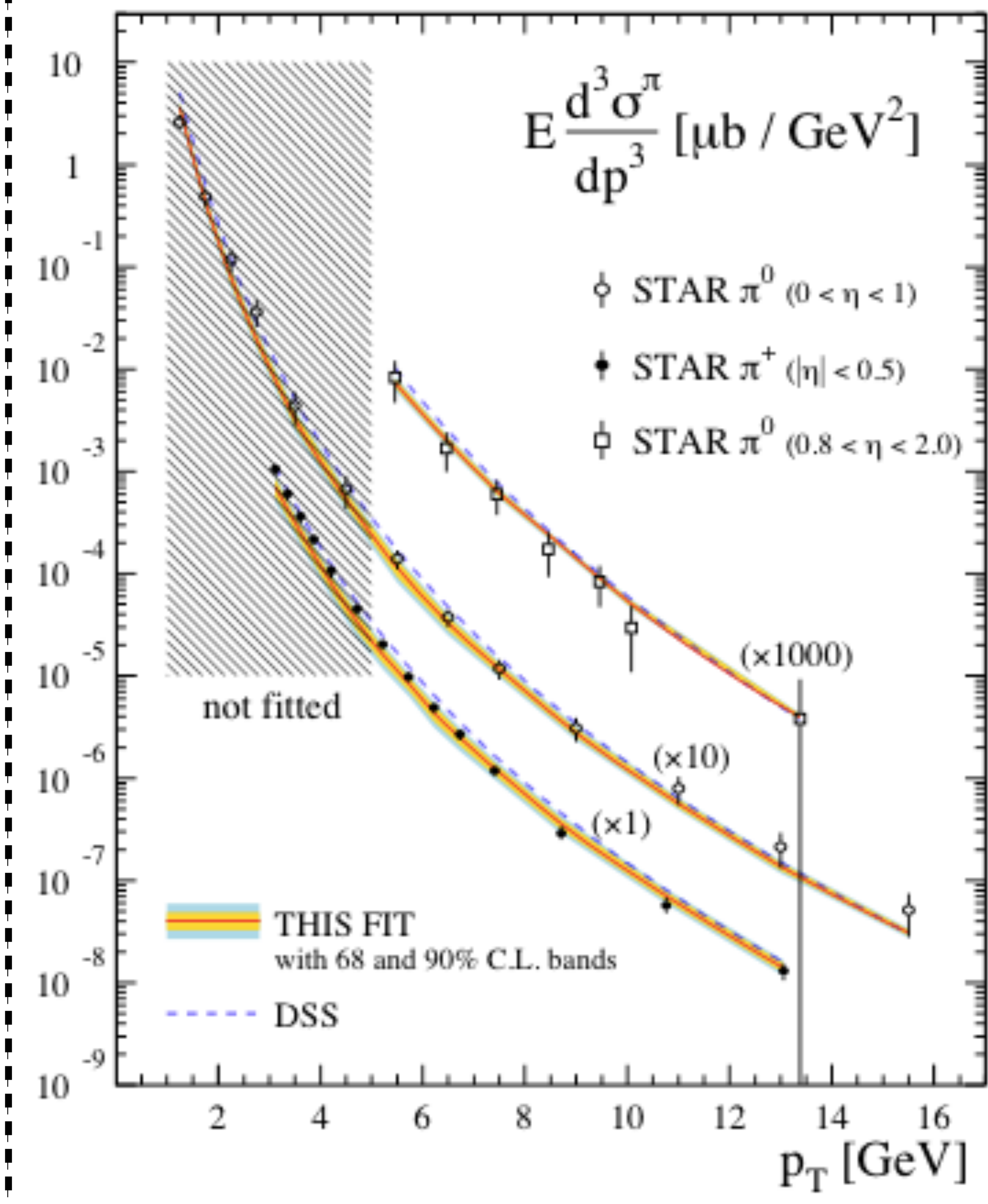
pp data: PHENIX and STAR

- 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

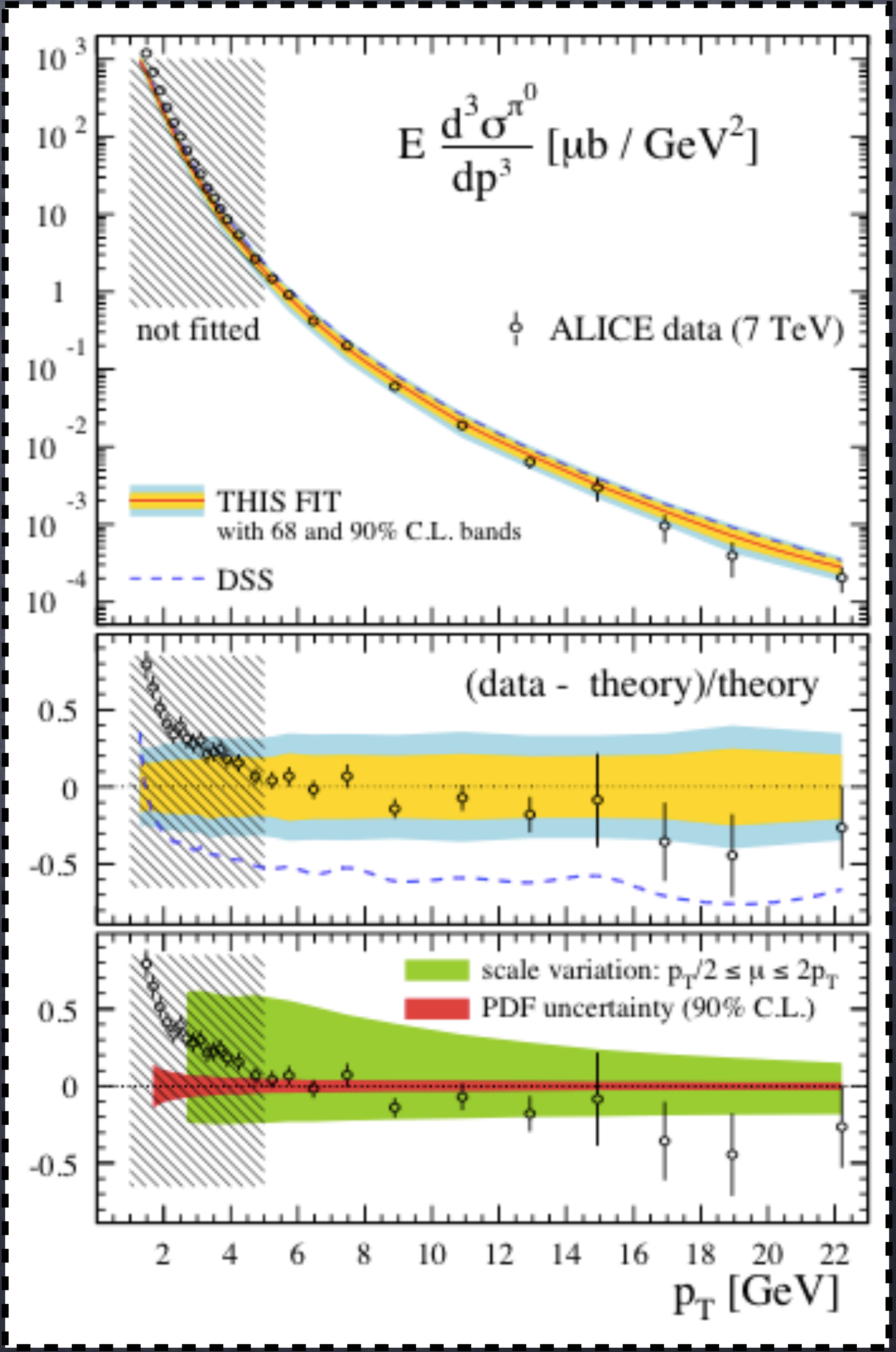
PDF uncertainties where computed with 90%CL MSTW and they are less significant than the scale ambiguities





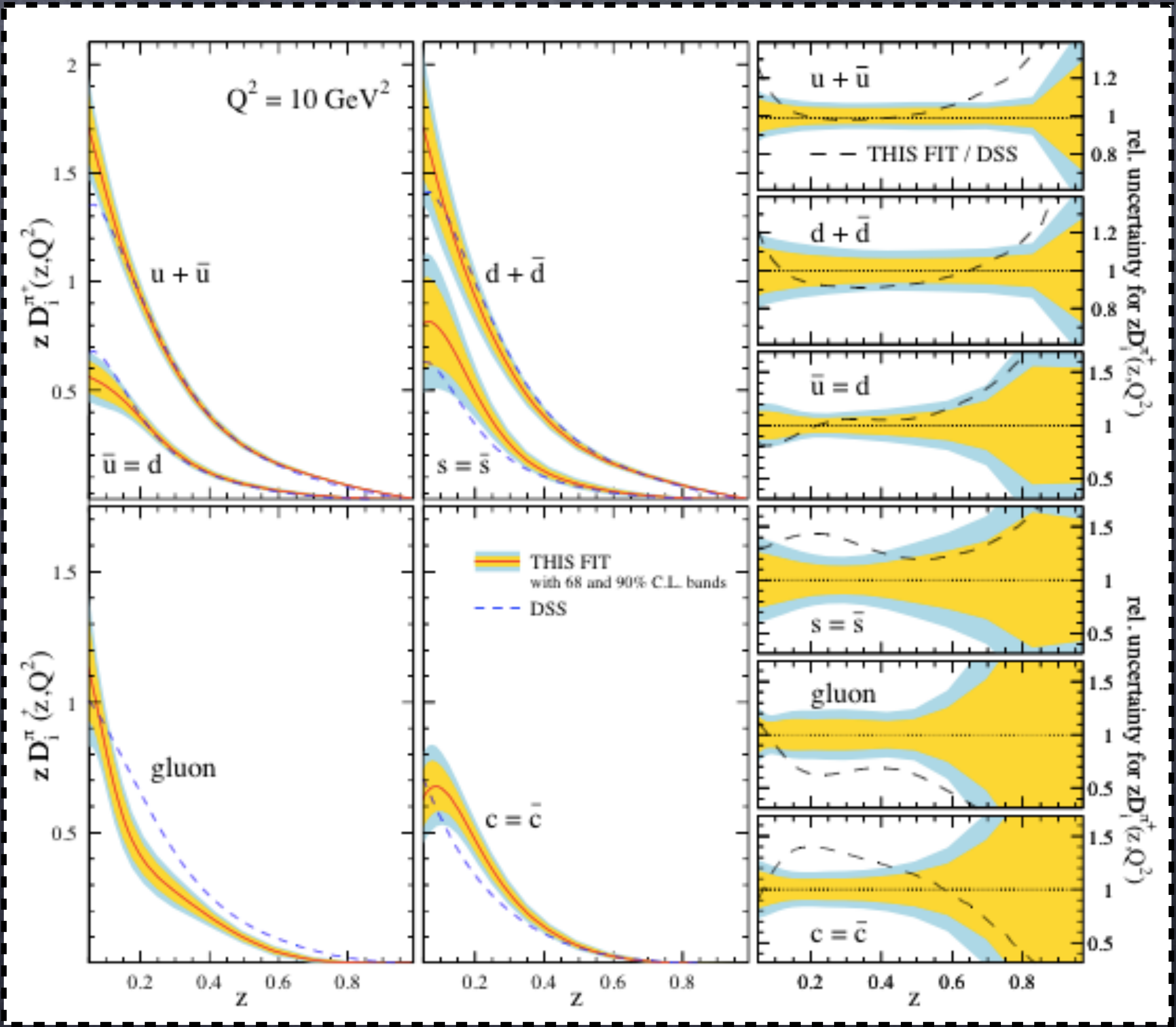
ALICE

- 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



FFs

- Deviations from DSS is found on the g- & c-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^2 = 10 GeV^2)



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^2 = 10 GeV^2)
- ALICE data contribute with a large chi^2 due to the normalisation shift

How good is the fit?

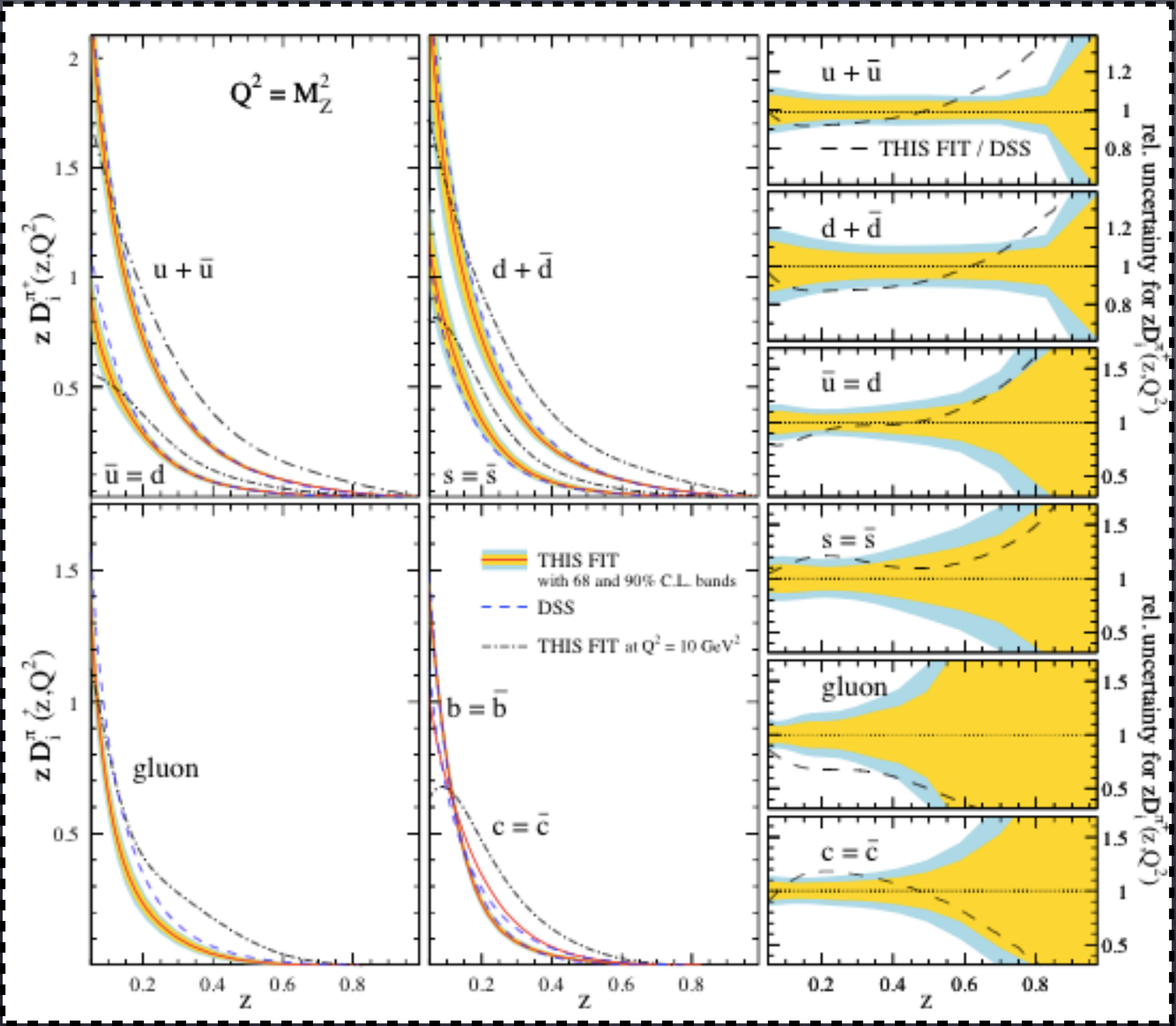
	DSS	NOW
Global	843/392(2.15)	1154.6/973(1.19)
LEP-SLAC	500.1/260(1.92)	412.6/260(1.58)
BELLE & BABAR	–	90.4/123(0.73)
HERMES	188.2/64(2.94)	175/128(1.36)
COMPASS	–	403.2/398(1.01)
RHIC	160.8/68(2.36)	45.7/53(0.86)
LHC	–	27.7/11(2.51)

Conclusions

- The analysis implemented strongly supports 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...

FFs


$Q^2 = M_Z^2$
$z\,D_i^{\pi^+}(z,Q^2)$
$u+\bar{u}$
$\bar{u}=d$
$d+\bar{d}$
$s=\bar{s}$
gluon
$b=\bar{b}$
$c=\bar{c}$
THIS FIT with 68 and 90% C.L. bands
DSS
THIS FIT at $Q^2 = 10$ GeV^2
THIS FIT / DSS
rel. uncertainty for $zD_i^{\pi^+}(z,Q^2)$
z
0.2
0.4
0.6
0.8
0.5
1
1.5
2
0.8
1.2