Deciphering the parton-to-kaon FF using global QCD fits

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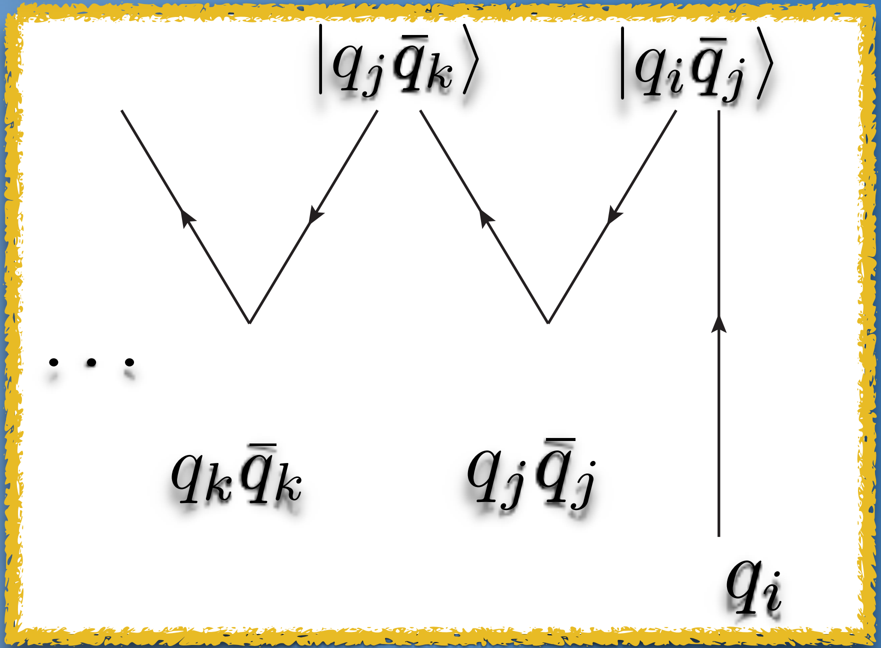
Outline

- Hadronization &
  Fragmentation Functions
- Theory & Uncertainties
- Results on parton-to-kaon FFs
- Conclusions

Hadronization

Basics: At the beginning it was the "cascade fragmentation" model

Rank 2 1



rank = 1 : "valence",

e.g.

$s \rightarrow K^+$

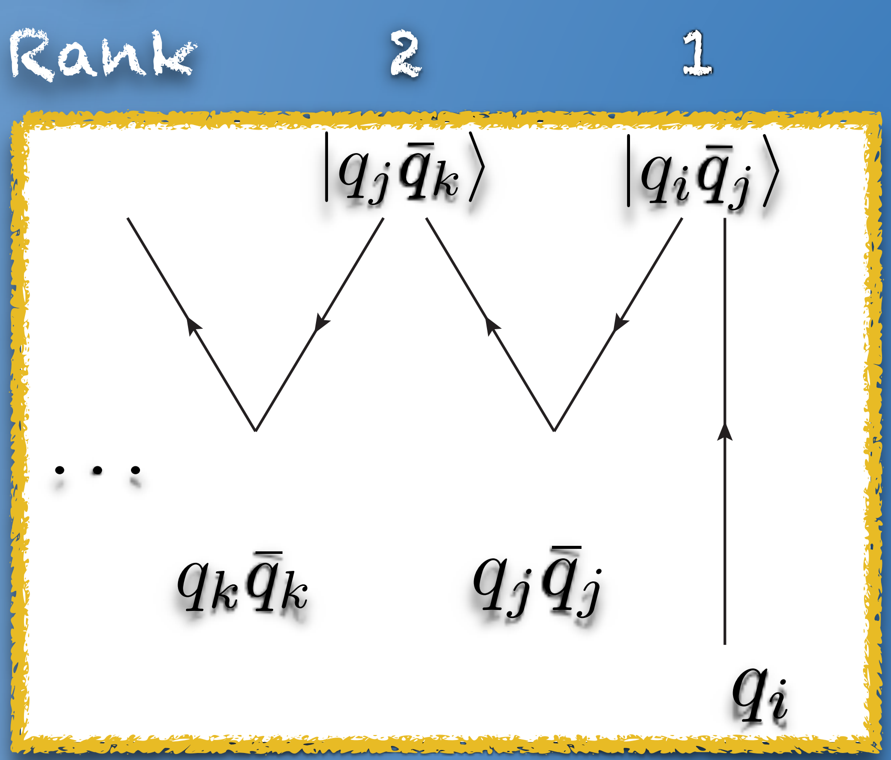
rank > 2 : "sea",

e.g.

$s \rightarrow K^-$

Hadronization

Basics: At the beginning it was the "cascade fragmentation" model



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

$s \to K^+$

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

$s \to K^-$

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

FFs ($D_q^h(z,Q^2)$)

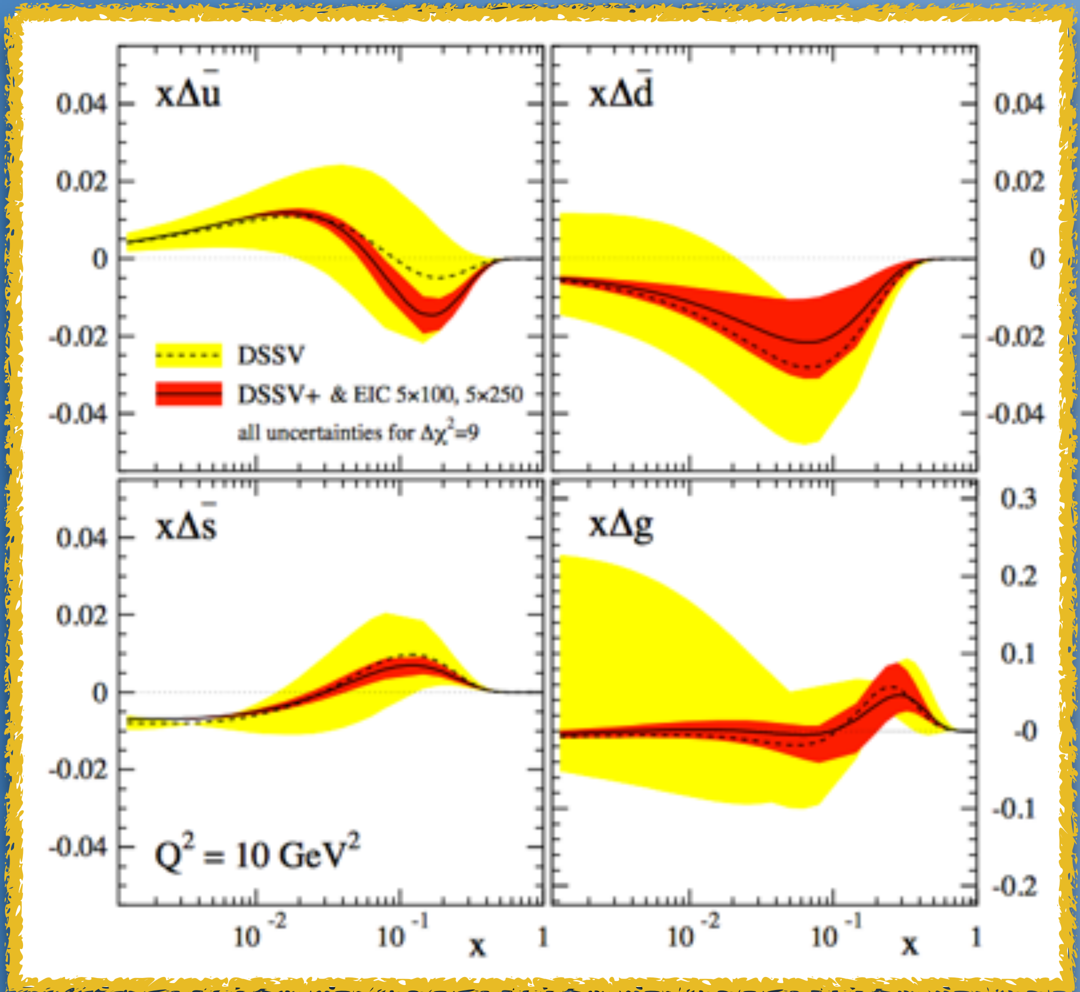
- Collinear transition of a massless parton "q" into a massless hadron "h" carrying fractional momentum "z"
- Relevant any time a hadron is produced
- They are scale dependent predicted by QCD
- Independent of other coloured particles

Motivation

- Parton-to-hadron FF parametrize how quarks and gluons confine themselves into hadrons measured and identified in experiment.
- 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

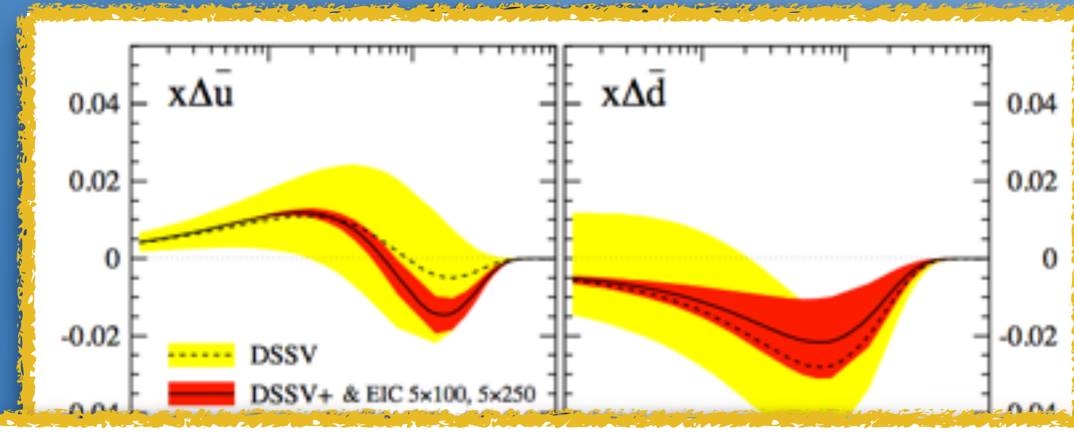
What are they good for ?

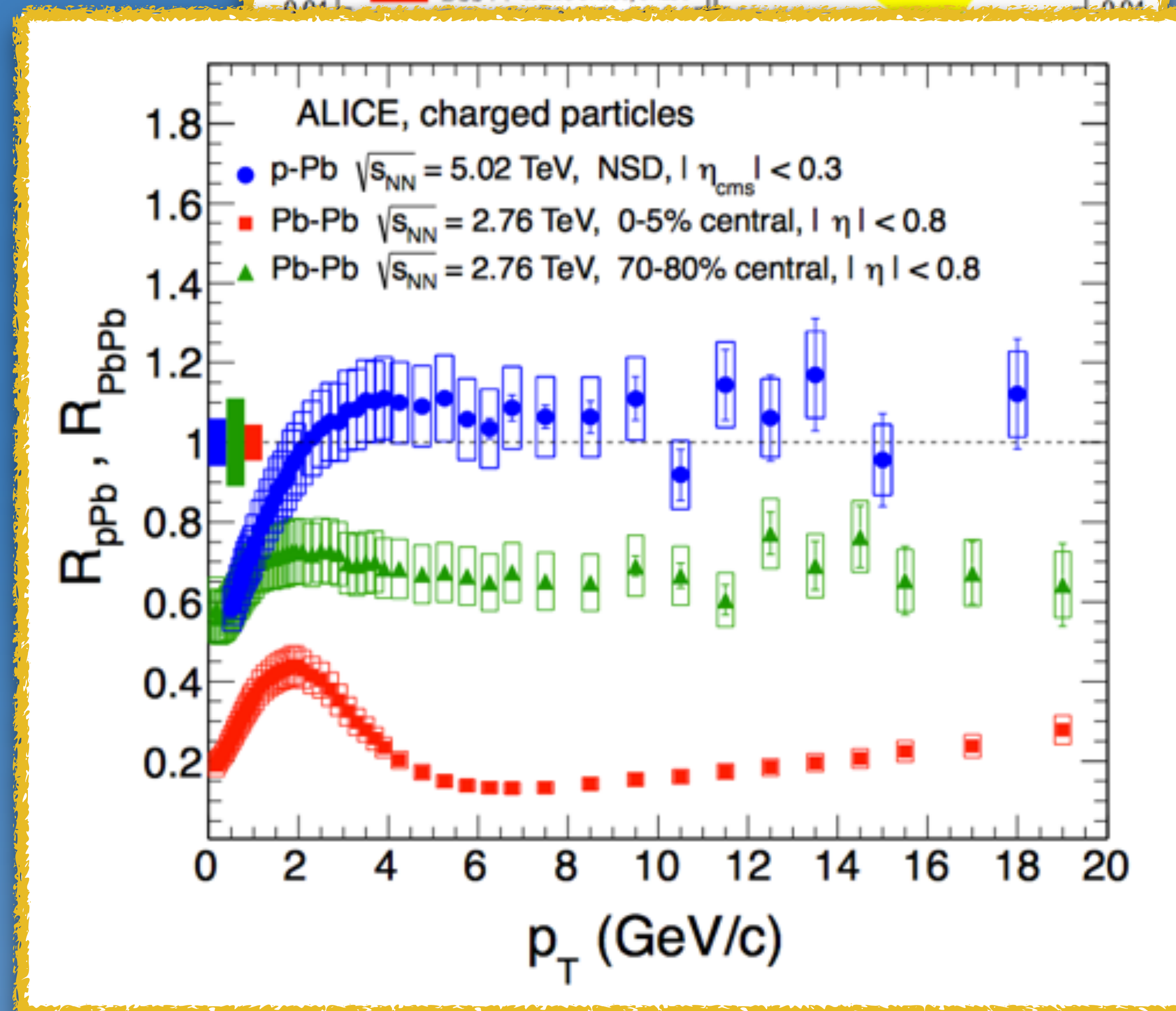
- Key ingredient to probe the strangeness content of the nucleon
- Input for extracting helicities PDFs and transverse momentum dependent PDFs



What are they good for ?

- Key ingredient to probe the strangeness content of the nucleon
- Input for extracting helicities PDFs and transverse momentum dependent PDFs
- Probe for the eRHIC era
- Analysis of media modifications of hadron production (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
HKNS: e+e- data only

Impose isospin symmetry for kaons
Hessian method for uncertainties

AKK08 contains large-z resummations and mass corrections

DSS remarks

- DSS is still the only available global QCD analysis at NLO of kaon FFs
- DSS fit arrived to a data-driven separation of individual parton-to-kaon FFs
- Lagrange multiplier technique was used for the treatment of uncertainties
- FFs of gluons was constrained for the first time with the BNL-RHIC data

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

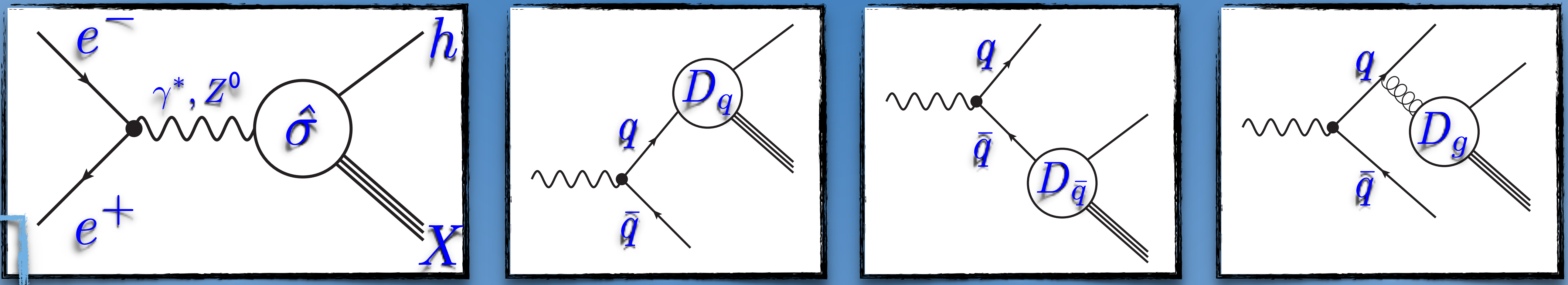
- The distribution is given in terms of the structure functions,

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

@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

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

@LO

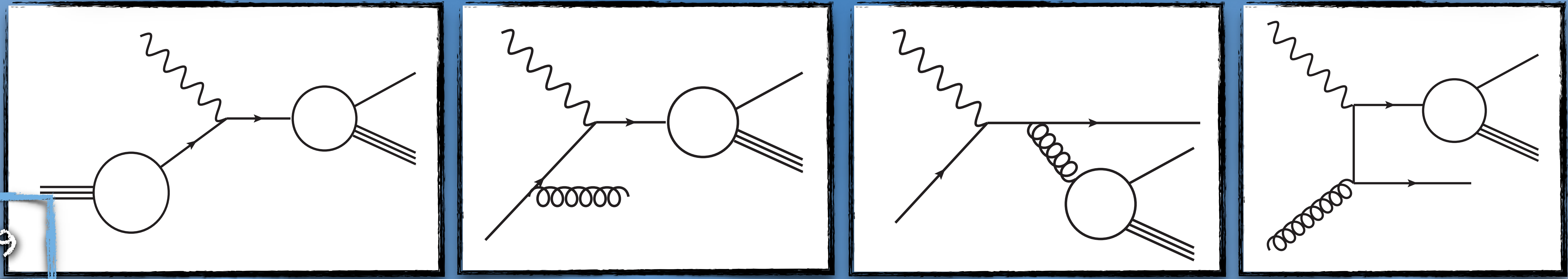
$$2F_1^h(x, z_h, Q^2) = \sum_{q,\bar{q}} \hat{e}_q^2 \cdot q(x, Q^2) D_q^h(z_h, Q^2)$$

@NLO, all coefficients are lengthy but known

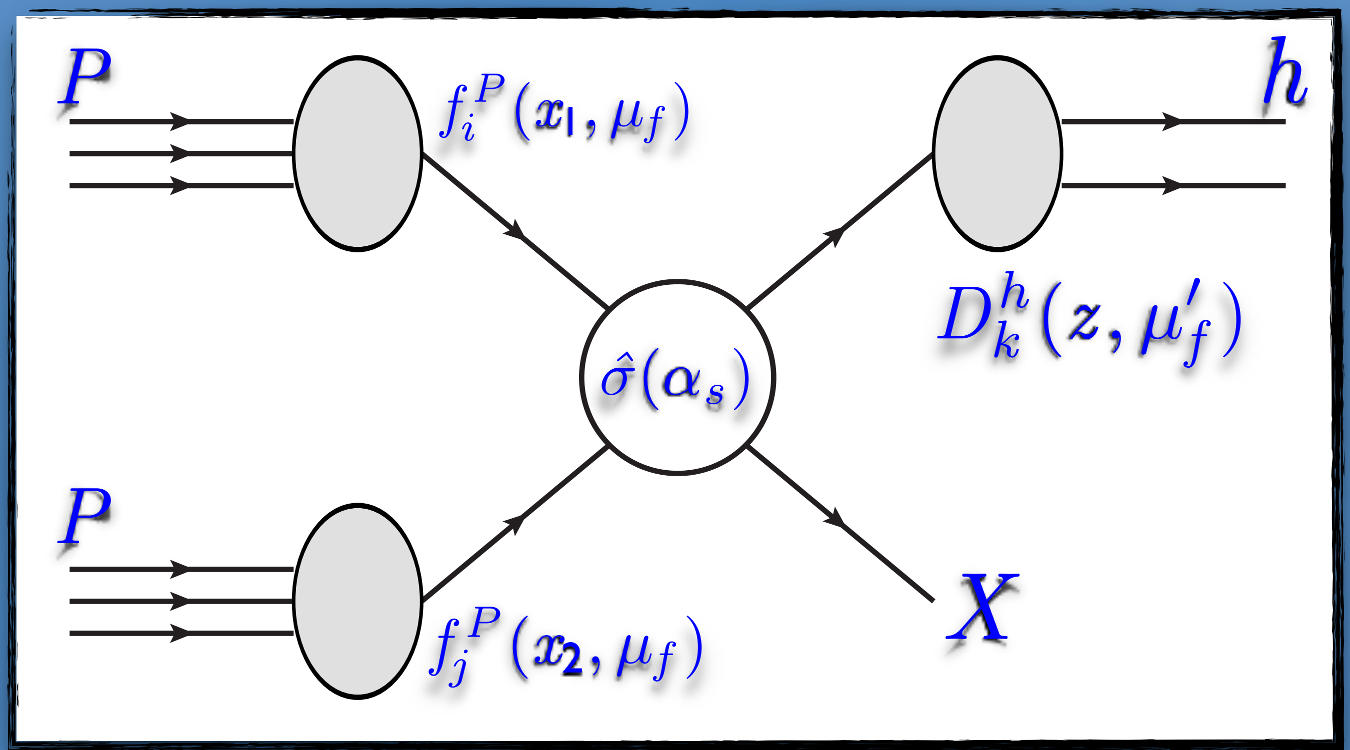
Altarelli et al. '79, Furmanski, Petronzio '82, de Florian, Stratmann, Vogelsang '98

★ Charge & flavour separation is first achieved when SIDIS is included

★ Gluon FF is not well constrained by SIDIS data



Hadron-Hadron collisions



Transverse momentum distribution is

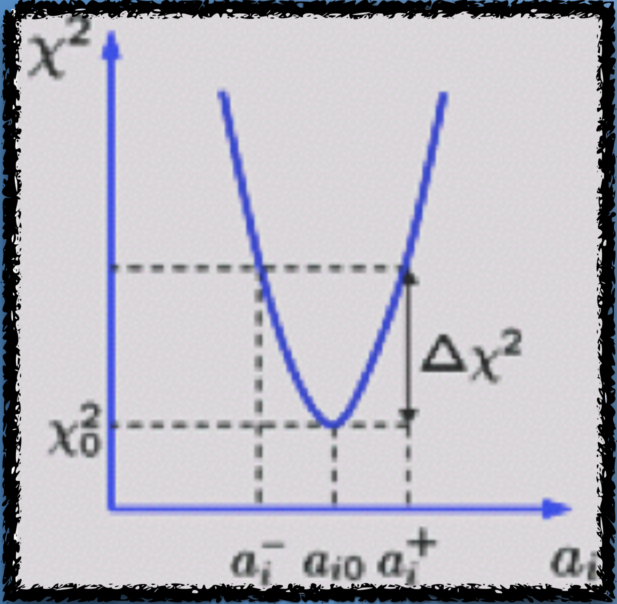
$$\frac{d\sigma(pp\to hX)}{dp_T d\eta} = \sum_{i,j,k}\int dx_1 dx_2 dz \left[f_i^P(x_1,\mu_f) f_j^P(x_2,\mu_f) D_k^h(z,\mu'_f) \frac{d\hat\sigma(ij\to kX')}{dp_T d\eta}\right]$$

- ★ 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: 24 parameters to 20 parameters
- HERMES data are replaced and added deuteron target data sets
- Different treatment for the normalization of the experiments
- PDFs: MMHT 2014
- Relaxing some of the FFs assumptions
- Full correlation matrices are not available for some data sets, so errors are added in quadrature (stat & syst)

$$D_{\bar{u}}^{K^+} = D_{d}^{K^+} = D_{\bar{d}}^{K^+} = D_{s}^{K^+}$$

$$\alpha_{c+\bar{c}} = \alpha_{b+\bar{b}} \qquad \beta_g \simeq \beta_{\bar{u}} \qquad \gamma_{s+\bar{s}} \simeq \gamma_{\bar{u}}$$

$$\gamma_{c+\bar{c}} = \gamma_{b+\bar{b}} \simeq 0 \qquad \delta_{s+\bar{s}} \simeq \delta_{\bar{u}}$$

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

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

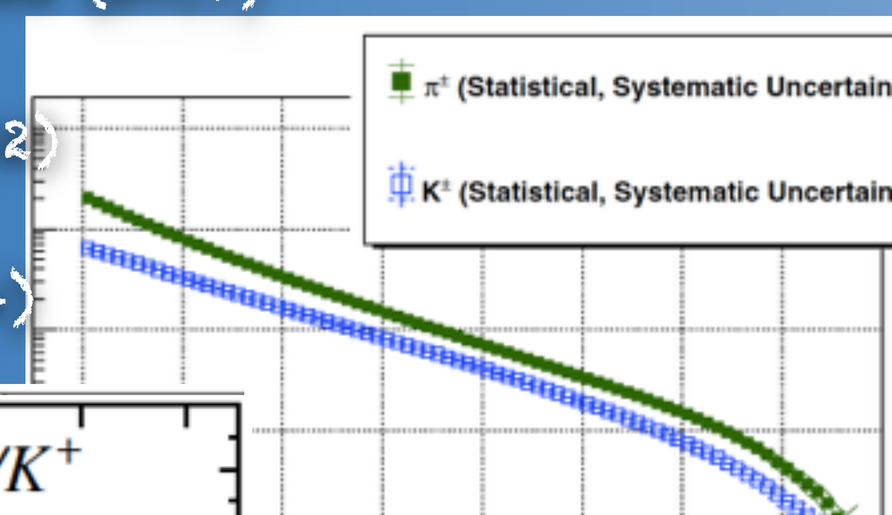
- Normalization of each experiment can be computed analytically

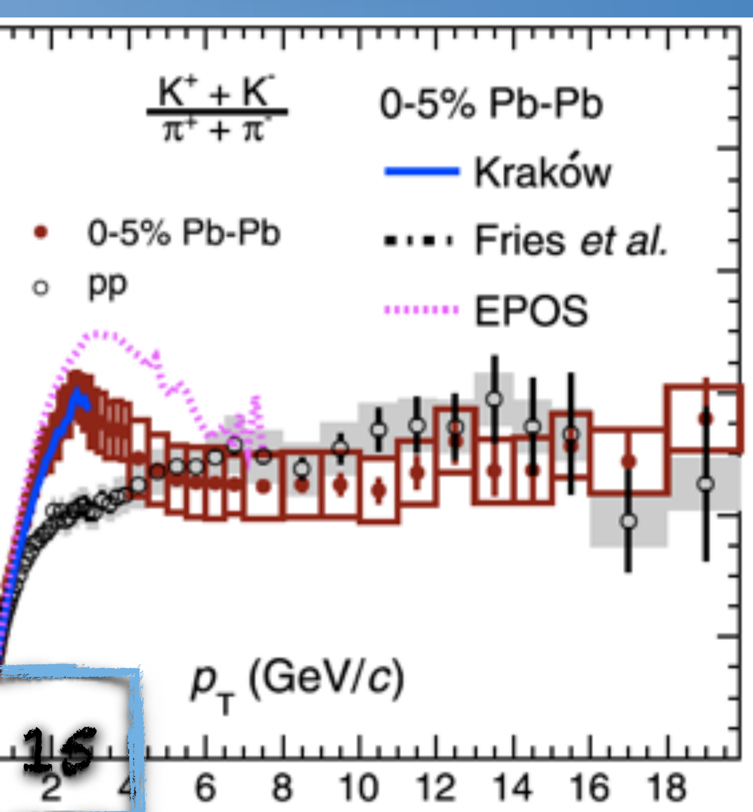
$$\mathcal{N}_i = \frac{\sum_{j=1}^{N_i} \frac{\delta \mathcal{N}_i^2}{\delta E_j^2} T_j E_j + 1}{\sum_{j=1}^{N_i} \frac{\delta \mathcal{N}_i^2}{\delta E_j^2} T_j^2 + 1}$$

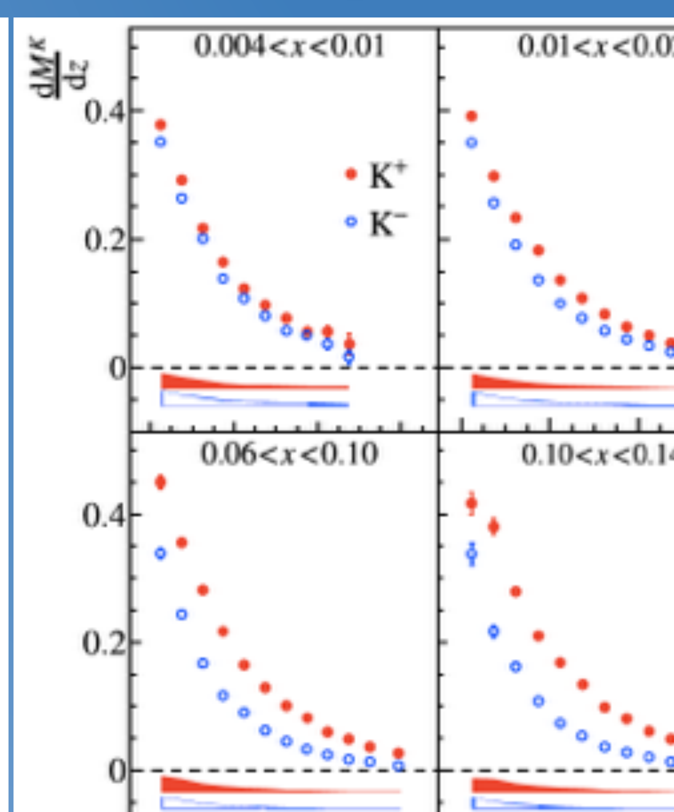
RESULTS

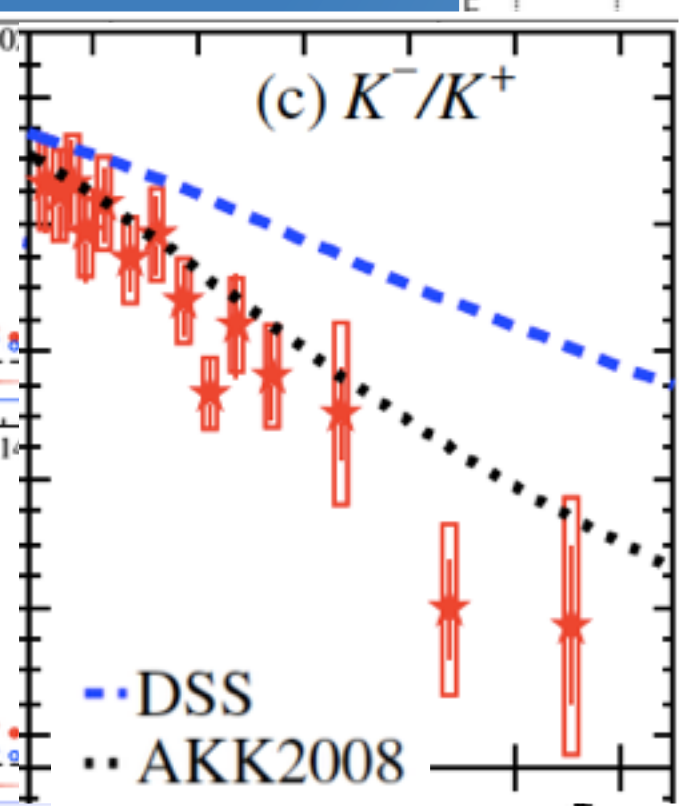
Many data sets have been published since DSS analysis (2007)

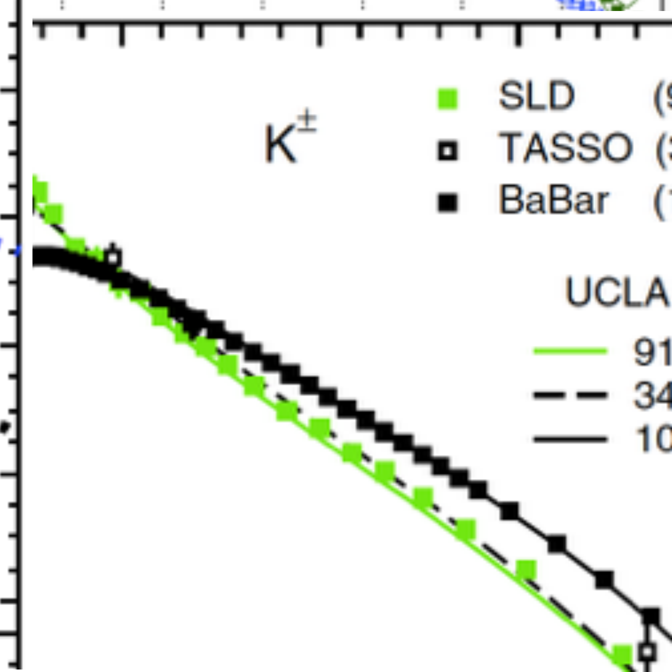
- e+e- data from BELLE (Phys. Rev. Lett. 111, 062002 (2013)) and BaBar (Phys. Rev. D 88, 032011 (2013))
- Final SIDIS multiplicities from HERMES: Phys. Rev. D 87, 074029 (2013)
- SIDIS multiplicities from COMPASS: Phys. Lett. B 767, 133 (2017)
- New data from STAR: Phys. Rev. Lett. 108, 072302 (2012
- Data from the ALICE-LHC: Phys. Lett. B 736, 196 (2014









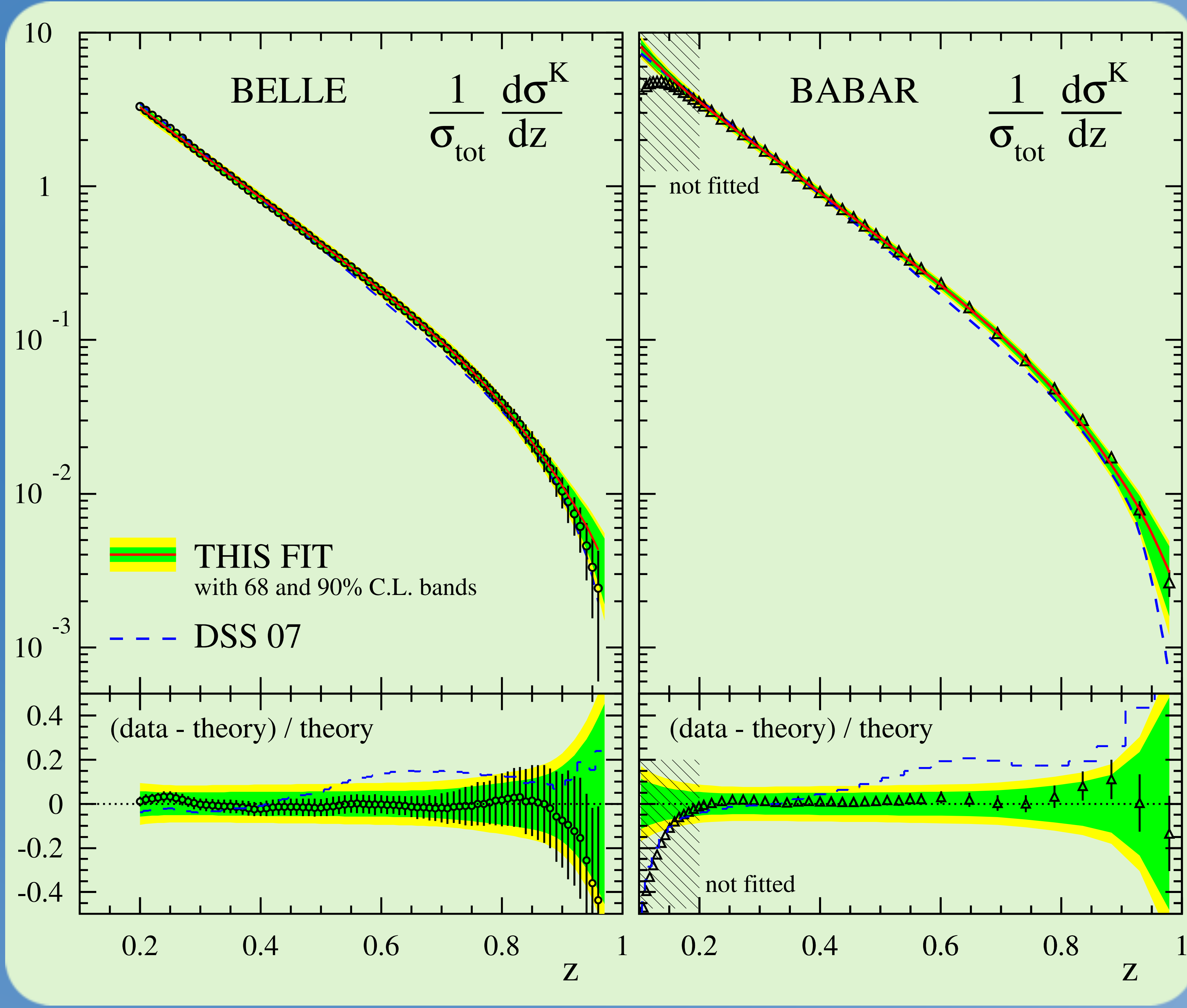


e+e- data: BELLE and BaBar

- 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

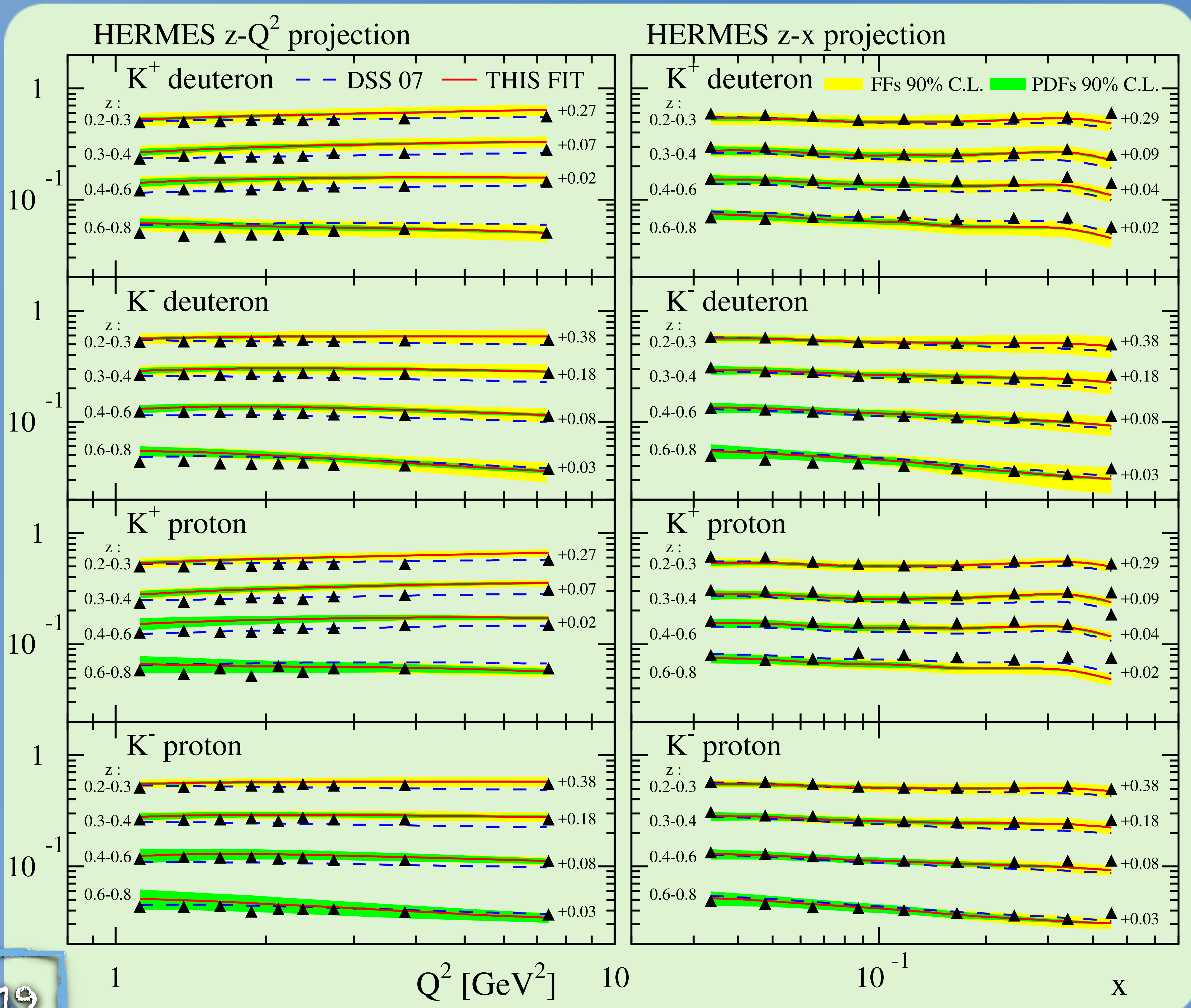
- BELLE and BaBar results can be fitted extremely well within the 68 and 90 % C.L.
- Usual cut for z<0.1 in all SIA data
- Large logarithmic corrections are expected at large values of z



SIDIS data: HERMES and COMPASS

- HERMES published their data sets and they included the data for a deuteron target.
- COMPASS data is extremely important for the charge and flavour separation and also because they released around 600 data points to fit.
- SIDIS produce positively and negatively charge kaons in a different rate when the target is changed.

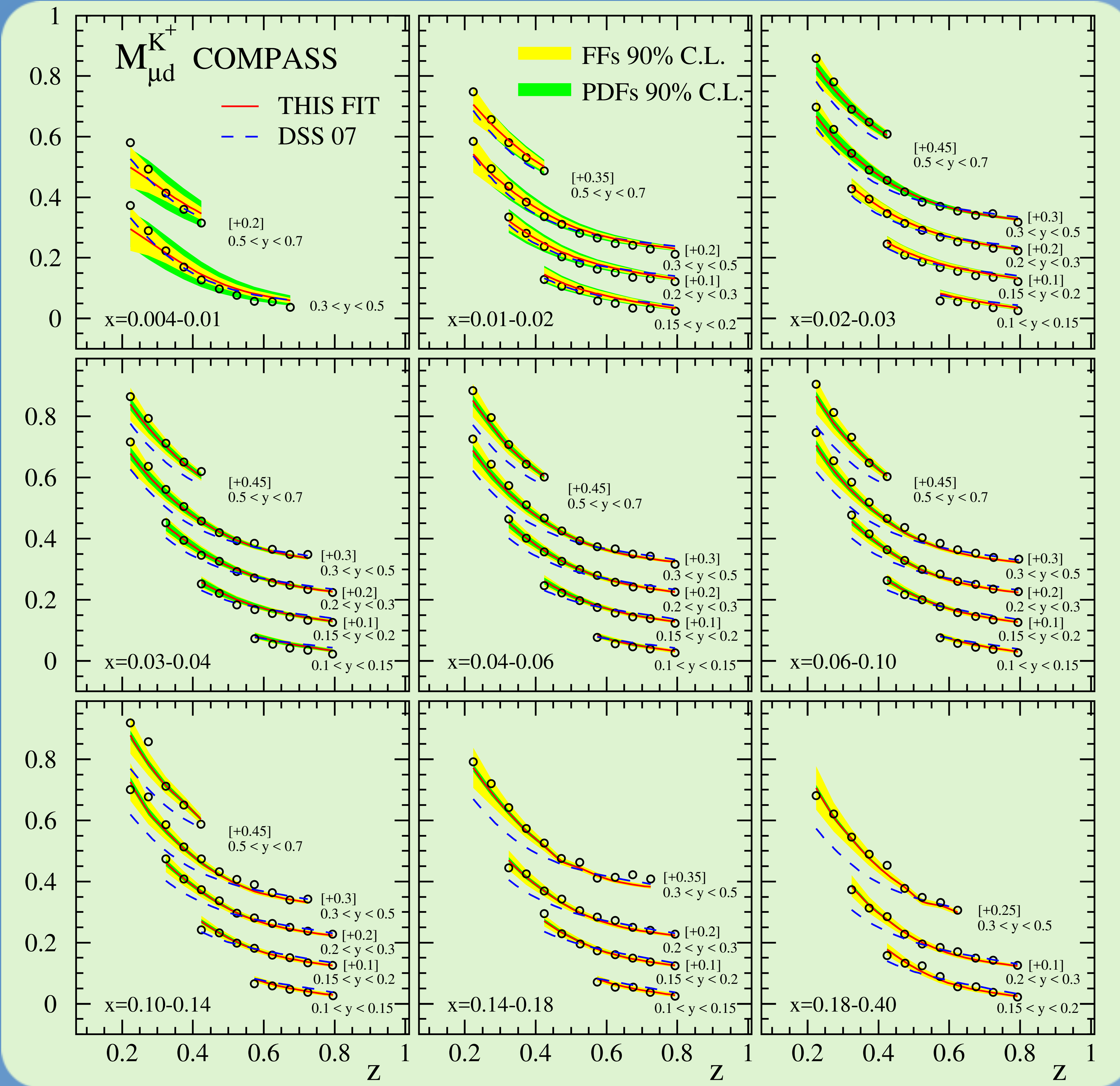
HERMES



- The most powerful constraint for flavour separated FFs
- In this new analysis, two projections are well fitted

COMPASS

- DSS has some tensions with COMPASS data sets
- COMPASS is now well fitted
- It is been shown also in the chi^2 ~ 0.9

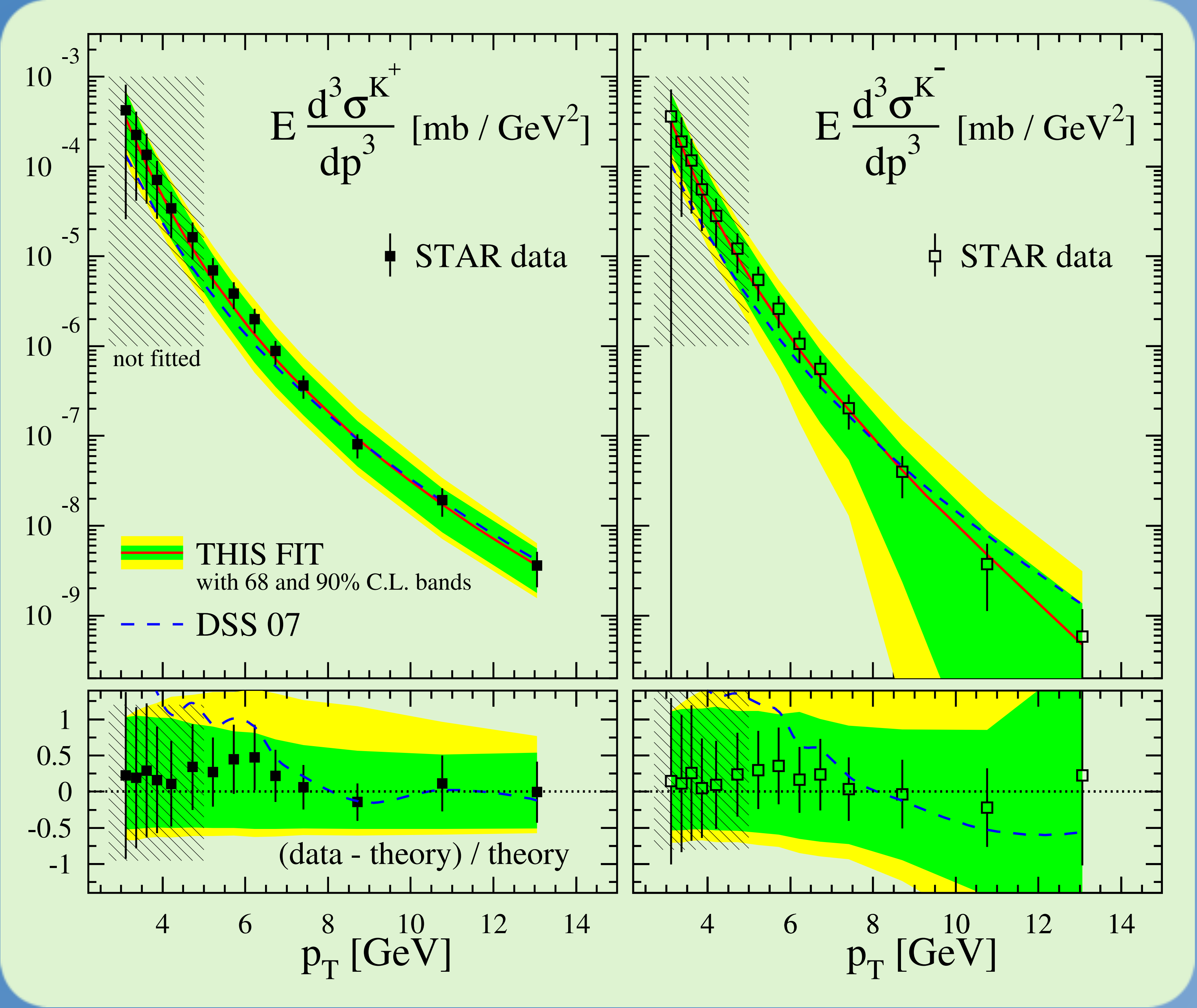


pp data: STAR

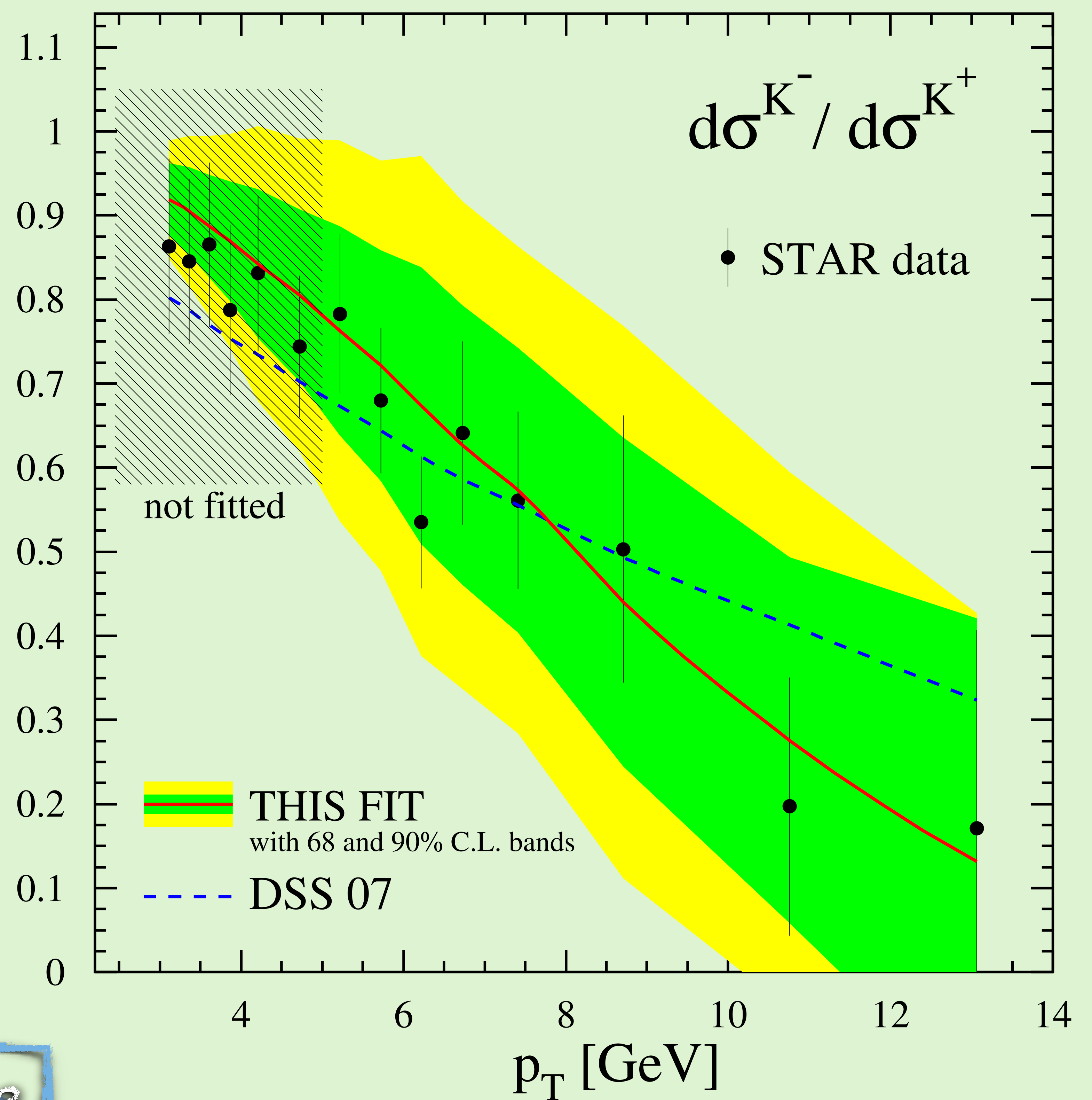
- Tension between RHIC and LHC data is largely resolved when a pT cut in 5 GeV for pp data is taken
- Brahms data is now eliminated due to the pT cut
- STAR data are for a sqrt(s)=200 GeV
- Ratio between positively charged over negatively charged kaon xsecs due to theoretical scale and PDF ambiguities partially cancel

STAR

- PDF uncertainties where computed with 90%CL MMHT and they are less significant than the scale ambiguities
- STAR data is well fitted within the 68 and 90 % C.L.



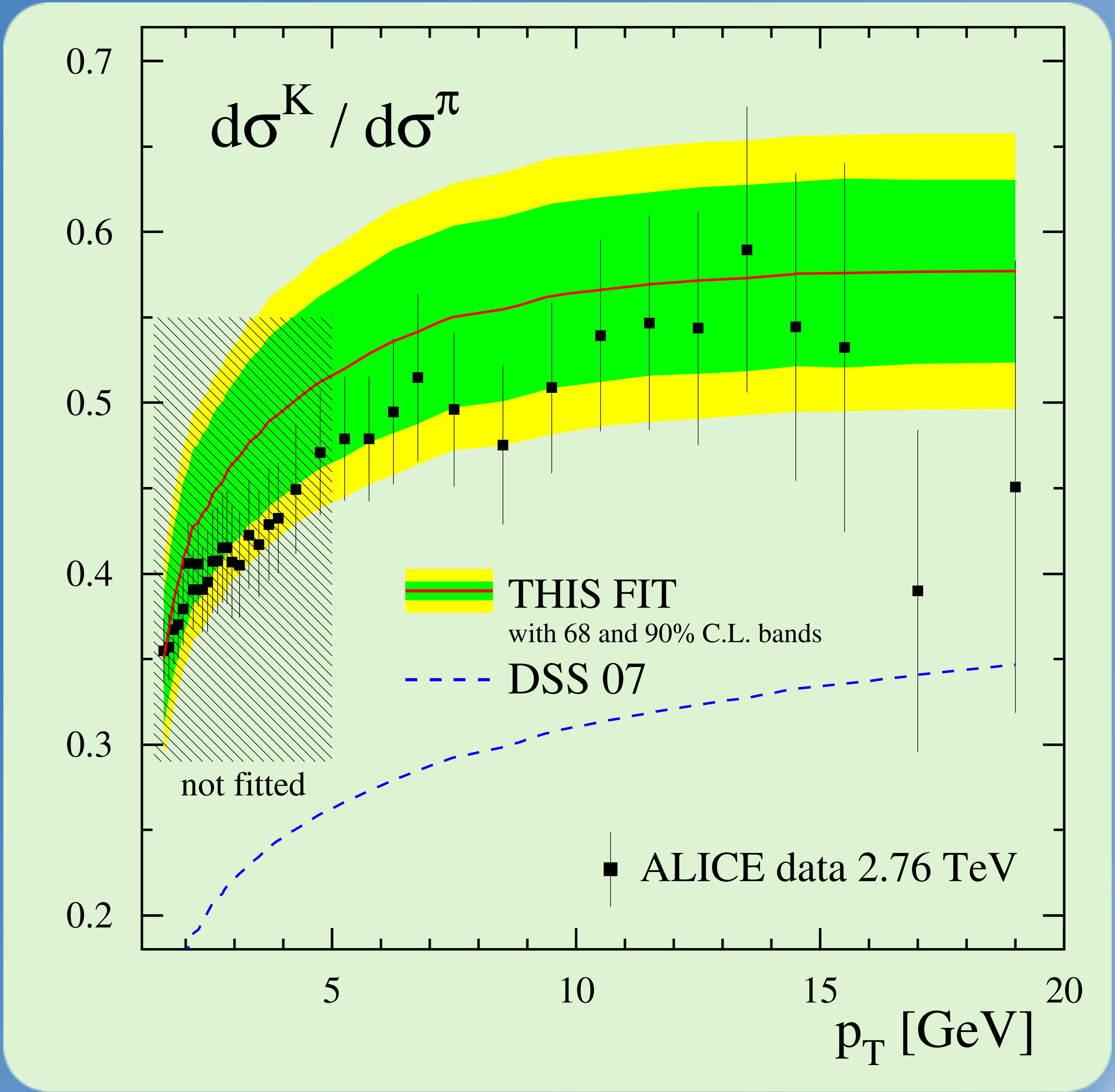
STAR



- To avoid double counting, we discard the K- xsec in the chi^2
- Quality of the fit is very good even when extrapolated to pt<5GeV
- Less tension with the LHC data compared to the pions

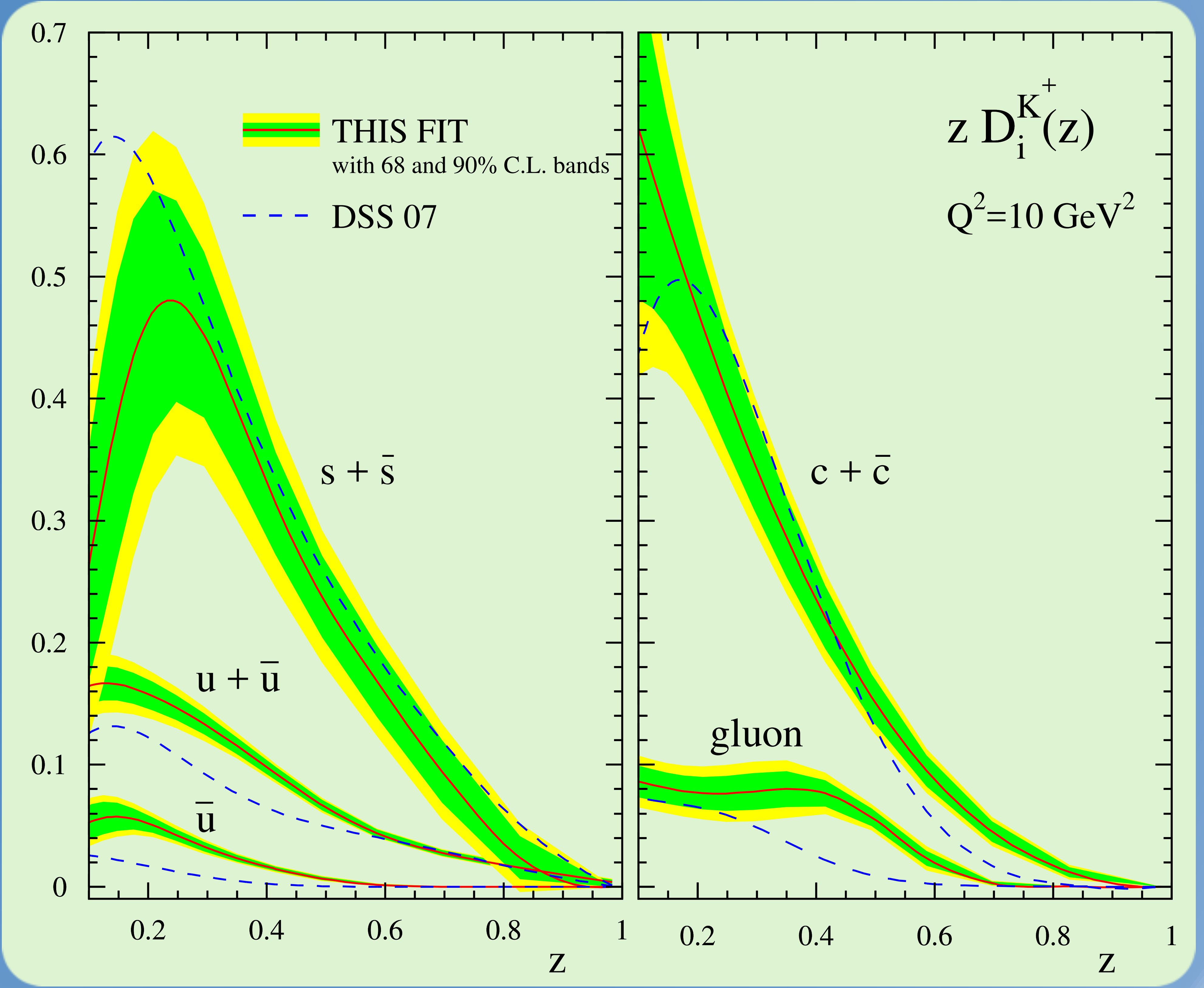
ALICE

- Ratio over the parton-to-pion is implemented in order to reduce theoretical uncertainties
- DSS 14 parton-to-pion FF was used for normalisation
- Contribution of uncertainties due to PDF are again not relevant enough; the main contribution is coming from the scale variation



parton-to-kaon FFs

The new kaon FF is more sensitive to: Belle and BaBar data sets, the z-x projection of the multiplicities of HERMES and COMPASS and by the data from STAR



How good is the fit?

	DSS	NOW
Global	391.9/232(1.67)	1271.7/1194(1.06)
LEP-SLAC	207.3/134(1.54)	256.1/134(1.91)
BELLE & BABAR	–	46.2/123(0.37)
HERMES	94.3/48(1.96)	389.3/288(1.35)
COMPASS	–	550.9/618(0.89)
RHIC	90.3/50(1.81)	7.6/16(0.47)
LHC	–	21.6/15(1.44)

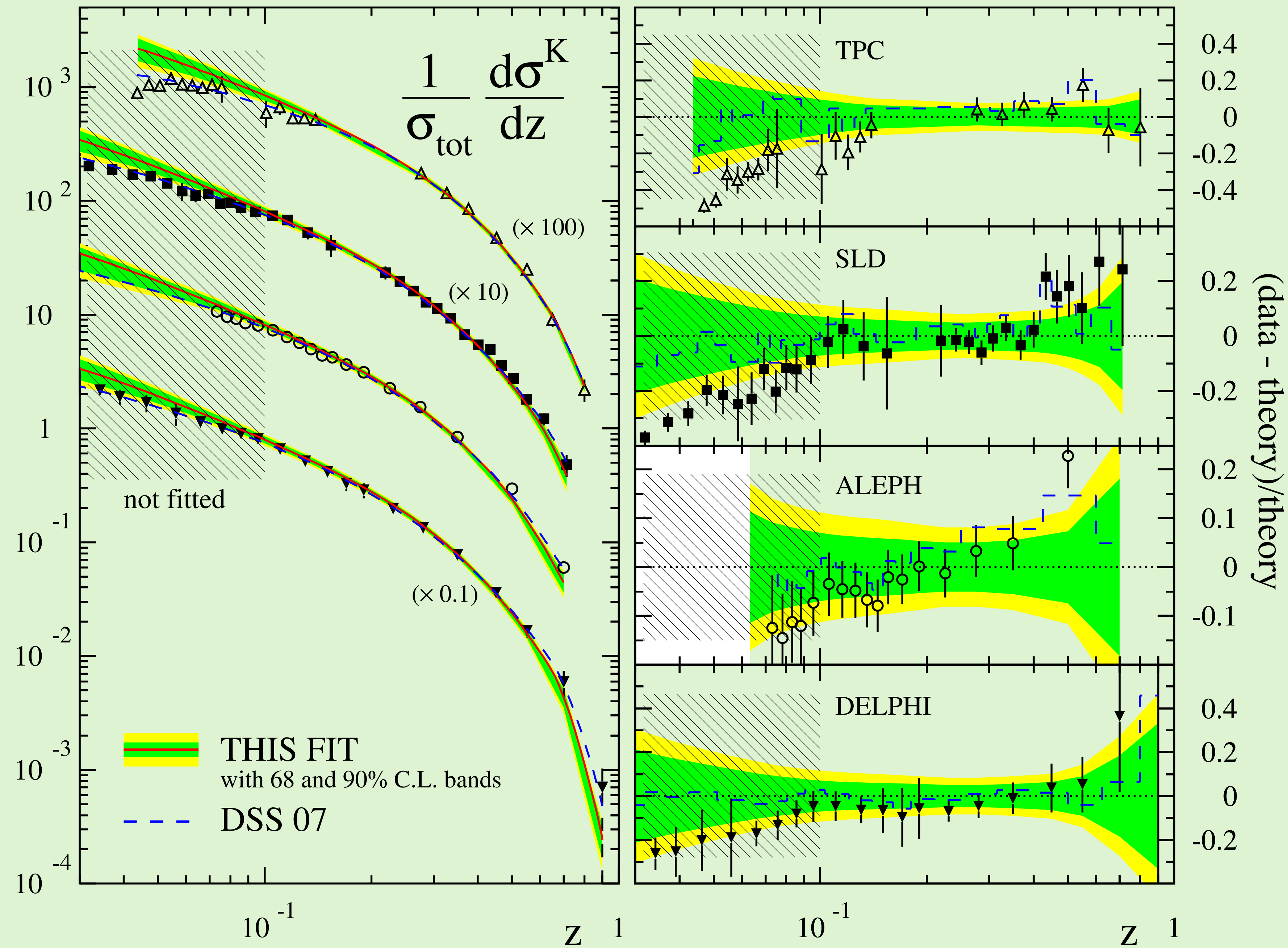
Conclusions

- The analysis implemented strongly supports factorization and universality for the parton-to-kaon FFs
- 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

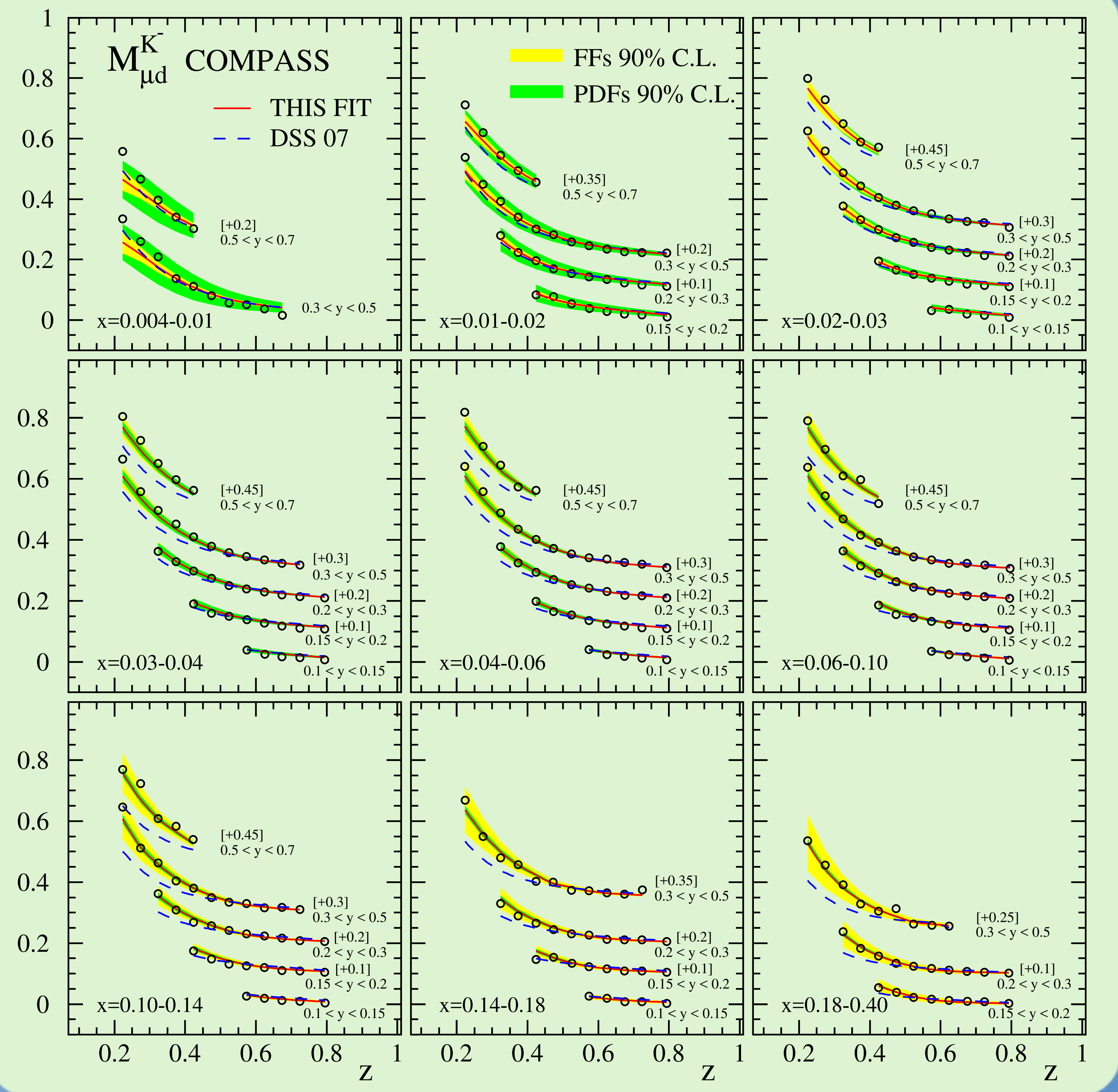
GRACIAS ...

BACKUP

LEP



$\frac{1}{\sigma_{tot}} \frac{d\sigma^K}{dz}$
(× 100)
(× 10)
(× 0.1)
not fitted
THIS FIT
with 68 and 90% C.L. bands
DSS 07
TPC
SLD
ALEPH
DELPHI
(data - theory)/theory
z



$M^{K^-}_{\mu d}$ COMPASS
THIS FIT
DSS 07
FFs 90% C.L.
PDFs 90% C.L.
x=0.004-0.01
x=0.01-0.02
x=0.02-0.03
x=0.03-0.04
x=0.04-0.06
x=0.06-0.10
x=0.10-0.14
x=0.14-0.18
x=0.18-0.40
z

COMPASS

Parton-to-kaon FF @ Q=Mz