Global Analysis of Fragmentation Functions

Daniel de Florian

Dpto. de Física - FCEyN- UBA

Global Analysis of Polarized Parton Distributions in the RHIC Era

BNL - October 8

Departamento de Física Juan José Giambiagi

Facultad de Ciencias Exactas y Naturales Universidad de Buenos Aires

in collaboration with M. Stratmann and R. Sassot

Disclaimer

We (TH) can compute observables in pQCD with high precision

But about errors ..hmmmmmmm

$$1.1 \pm 0.1 \pm 0.2$$

$$1.1^{\pm 0.1 \pm 0.2}$$

$$1.1 \pm \sqrt{0.1^2 + 0.2^2}$$

Fragmentation functions

Represent the probability that a parton hadronizes in h

From TH point of view at the same level of pdfs

Relevant any time a hadron is produced in high energy collisions

e+e- : primary "source"

SIDIS : complement DIS to allow flavor separation

pp collisions: signal and "background" for a lot of physics

Heavy Ions
polarized pdfs

Global Fit (DSS) that includes all those processes

In the framework of this workshop:
Fragmentation functions play a very relevant role

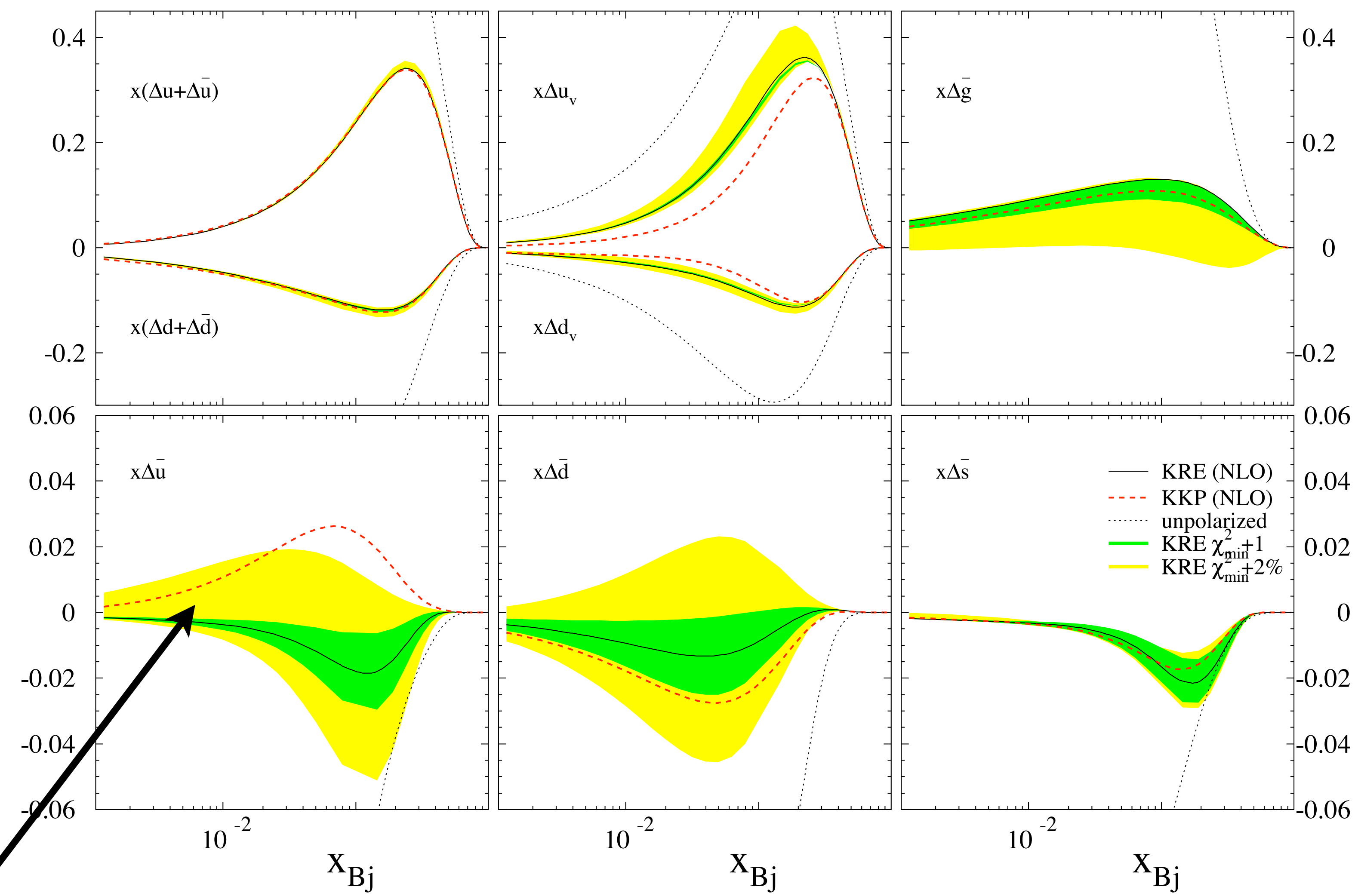
Single hadron production in polarized pp collisions great tool to unveil the gluon distribution : gluons enter at LO

Precise FF needed to perform pdf extraction

Otherwise: “error” in FF propagates to pdf

Trivial example: if gluon FF too small, the mistake in analysis of pp collisions will result in a gluon pdfs too large to compensate!

Actual example: analysis of polarized pdfs from SIDIS using different FF (see Rodolfo's talk)

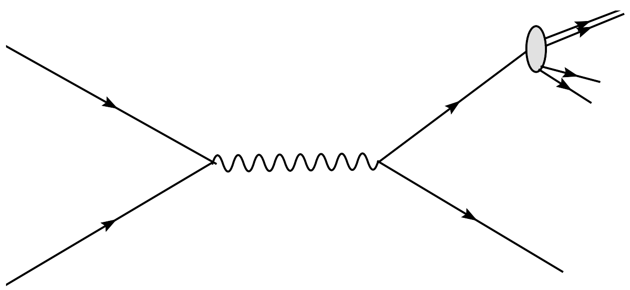


DdeF, G.Navarro, R.Sassot

Using Kretzer or KKP can lead to very different sea distributions

e+e- (SIA) single-inclusive annihilation

$$e^+e^- \to (\gamma,\, Z) \to H$$



Cross section depends on two structure functions

$$\frac{1}{\sigma_{tot}}\frac{d\sigma^H}{dz} = \frac{\sigma_0}{\sum_q \hat{e}_q^2}\left[2\,F_1^H(z,Q^2) + F_L^H(z,Q^2)\right]$$

$$\sigma_{tot} = \sum_q \hat{e}_q^2\,\sigma_0\left[1 + \frac{\alpha_s(Q^2)}{\pi}\right]$$

At NLO they can be written as

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

Fragmentation functions depend on both energy fraction (z) and energy scale : AP evolution

$$\frac{d}{d\ln Q^2}\vec{D}^H(z,Q^2) = \left[\hat{P}^{(T)} \otimes \vec{D}^H\right](z,Q^2)$$

Notice that SIA can only give information on the sum $D_q^H(z,Q^2) + D_{\bar{q}}^H(z,Q^2)$

e+e- (SIA) single-inclusive annihilation

Advantages

Very precise data from LEP/SLD

Heavy quark tagged data

Only fragmentation functions enter (clean process)

Disadvantages

SIA data dominated by precise LEP/SLD measurements at M_Z

weak scale dependence (bad resolution for g fragmentation)

mostly determine "singlet" distribution (high precision)

$$\Sigma = D_u + D_{\bar{u}} + D_d + D_{\bar{d}} + D_s + D_{\bar{s}} + D_c + D_{\bar{c}} + D_b + D_{\bar{b}}$$

not precise at large z (relevant for pp collisions)

Can not separate $D_q^h(z, Q^2)$ from $D_{\bar{q}}^h(z, Q^2)$

$$D_{q+\bar{q}}^{h^+}(z,Q^2) = D_{q+\bar{q}}^{h^-}(z,Q^2)$$

flavor/charge average

$$D_q^{h^++h^-}(z,Q^2) = D_{\bar{q}}^{h^++h^-}(z,Q^2)$$

Some ansatz needed if only SIA data used, like "linear suppression"

$$D_{\bar{q}}^{h^+}(z,Q^2) = (1-z)\,D_q^{h^+}(z,Q^2)$$

Recent NLO analyses

CGGRW(1994), BFGW(2000) — L.Bourhis et al., Eur.Phys.J C19 (2001) 89.

BKK(1995), KKP(2000), AKK(2005) — S. Albino et al., Nuc.Phys.B725 (2005) 206.

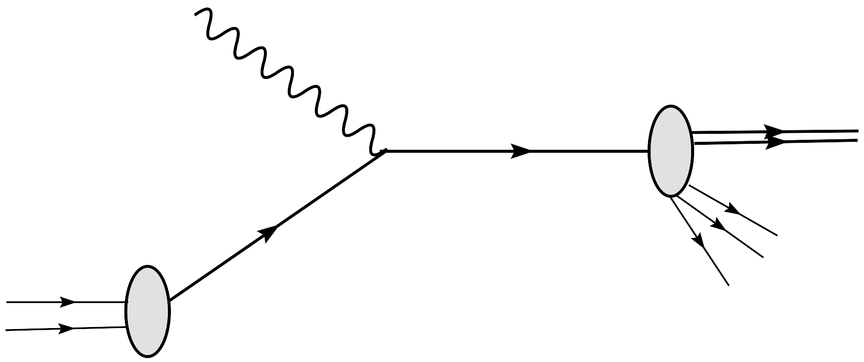
KRE(2000) — S. Kretzer, Phys. Rev.D62 (2000) 0540001.

HKNS(2007) — M. Hirai et al., Phys. Rev.D75 (2007) 094009.

use only SIA: no separation or ad-hoc assumption

And some "reasonable" ansatz about charge separation don't work well

SIDIS



Distributions in x and z

$$\frac{d\sigma^H}{dx\,dy\,dz_H} = \frac{2\,\pi\alpha^2}{Q^2}\left[\frac{(1+(1-y)^2)}{y}2\,F_1^H(x,z_H,Q^2)+\frac{2(1-y)}{y}F_L^H(x,z_H,Q^2)\right]$$

at LO

$$2F_1^H(x,z_H,Q^2) = \sum_{q,\overline{q}} e_q^2 \cdot\; q(x,Q^2)D_q^H(z_H,Q^2)$$

"effective charge"

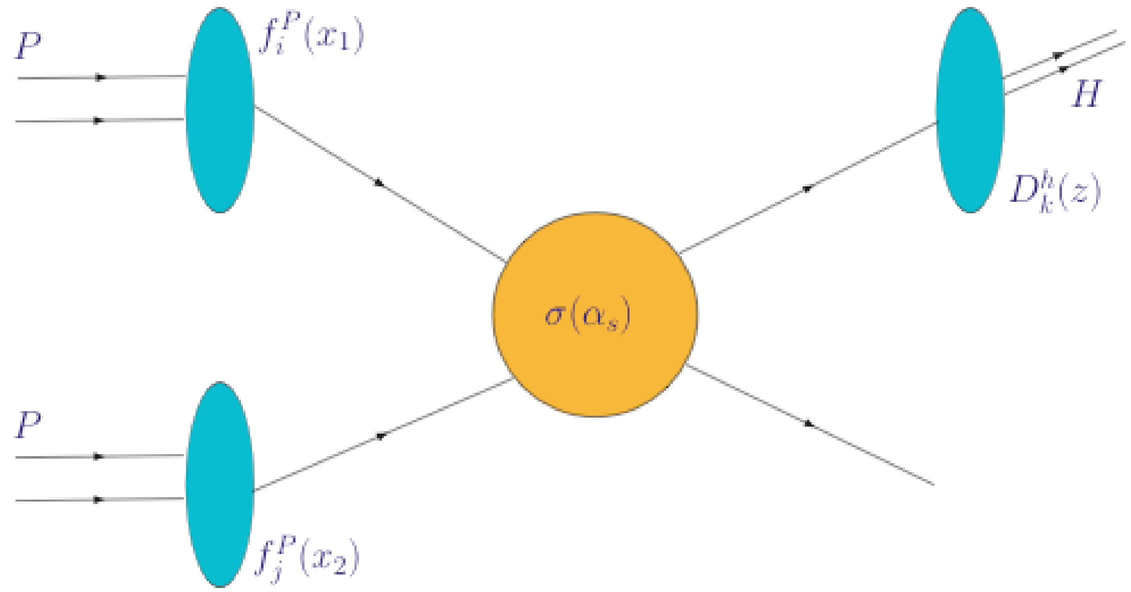
Advantages : allows flavor/charge separation
larger z
smaller Q^2, improves scale coverage in evolution : D_g
Hermes and Compass kinematics

Disadvantage : would introduce "dependence" on pdfs (but unpolarized pdfs very well constrained from DIS in the same kinematical range)
non-perturbative corrections at small Q^2?

Hadron-Hadron collisions

Transverse momentum distribution

hard scale



$$q\bar{q} \longrightarrow g$$
$$qq \longrightarrow q$$
$$qg \longrightarrow g$$
$$qg \longrightarrow q$$
$$gg \longrightarrow q$$
$$gg \longrightarrow g$$

$$d\sigma(pp \to h) = \sum_{i,j,k} \int_0^1 dx_1\, f_i^P(x_1, \mu_{FI}^2) \int_0^1 dx_2\, f_j^P(x_2, \mu_{FI}^2) \int_0^1 dz\, D_k^h(z, \mu_{FF}^2)\, d\hat{\sigma}(ij \to k)$$

Advantages : allows flavor/charge separation form hadron measurements
several subprocesses
much larger z
large contribution from D_g
analysis of data allows to have FF that work at RHIC and can be used in polarized/heavy ion collisions!

Disadvantage : Problems for fixed target experiments, use only colliders
Otherwise Threshold resummation needed (not in first approach)
larger TH uncertainty (scale dependence)

DdeF, W.Vogelsang

Global FIT

Advantages : Constrain FF with almost all available data
Check of pQCD framework
Precise determination of distributions and estimation of uncertainties

Disadvantage : more work required !
Feasible if Mellin technique used (Marco's talk)
Tension between different observables requires careful analysis

Complicated observables: without simple NLO interpretation
involving MC
"averaged" bins
large scale dependence
Weights

DSS global analysis

fragmentation functions for $\pi^+, \pi^-, \pi^0, K^+, K^-, K^0, \overline{K}^0, p, \overline{p}, n, \overline{n}, h^+, h^-$

residual

$h^+ = \pi^+ + K^+ + p + res^+$

LO and NLO global fits available

SIA data includes: TPC, TASSO, SLD, ALEPH, DELPHI, OPAL + "flavor" tag

SIDIS data from : HERMES, EMC

pp data from : PHENIX, STAR, BRAHMS, CDF, UA1, UA2

Checks with other data sets: STAR, p_T distributions at HERA (H1)

Estimation of uncertainties using Lagrange multipliers

Technical details

Flexible parametrization

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

at initial scale

$$\begin{aligned} Q_0^2 &= 1\,\mathrm{GeV}^2 \quad u,d,s,g \\ Q_0^2 &= m_Q^2 \quad c,b \end{aligned}$$

with

α_s and Λ_{QCD} from MRST

Normalizations for different experiments (if not included in syst.)

Try to avoid Isospin symmetry assumptions

Allowing for possible breaking of SU(3) of sea and SU(2) in favored distributions

$$D_{d+\bar{d}}^{\pi^+} = N D_{u+\bar{u}}^{\pi^+}$$

$$D_s^{\pi^+} = D_{\bar{s}}^{\pi^+} = N' D_{\bar{u}}^{\pi^+}$$

unless data can not discriminate for unfavored fragmentations

$$D_{\bar{u}}^{\pi^+} = D_d^{\pi^+}$$

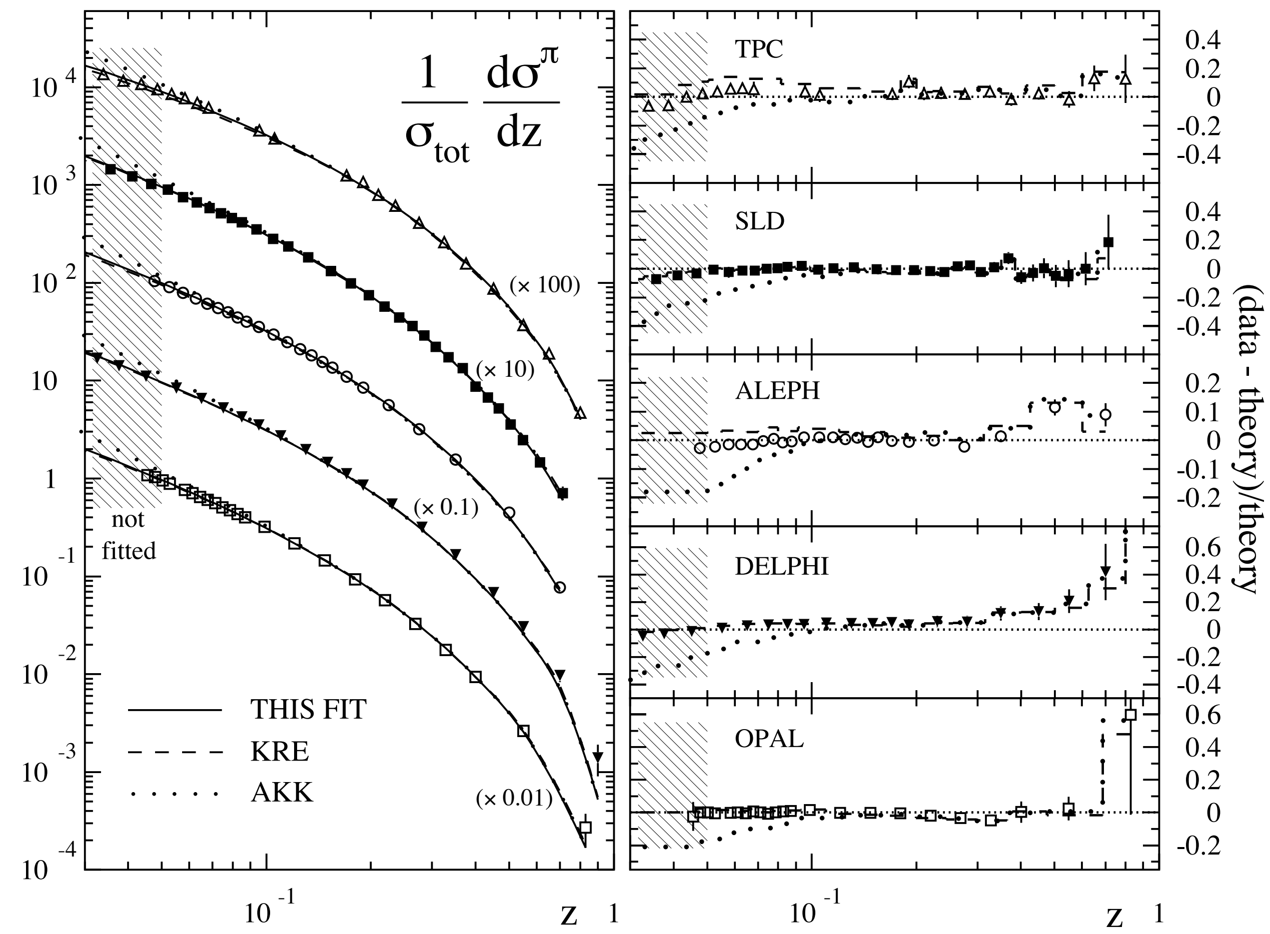
$$D_{\bar{u}}^{K^+} = D_s^{K^+} = D_d^{K^+} = D_{\bar{d}}^{K^+}$$

Some plots

z>0.05 (0.1 for Kaons/Protons)

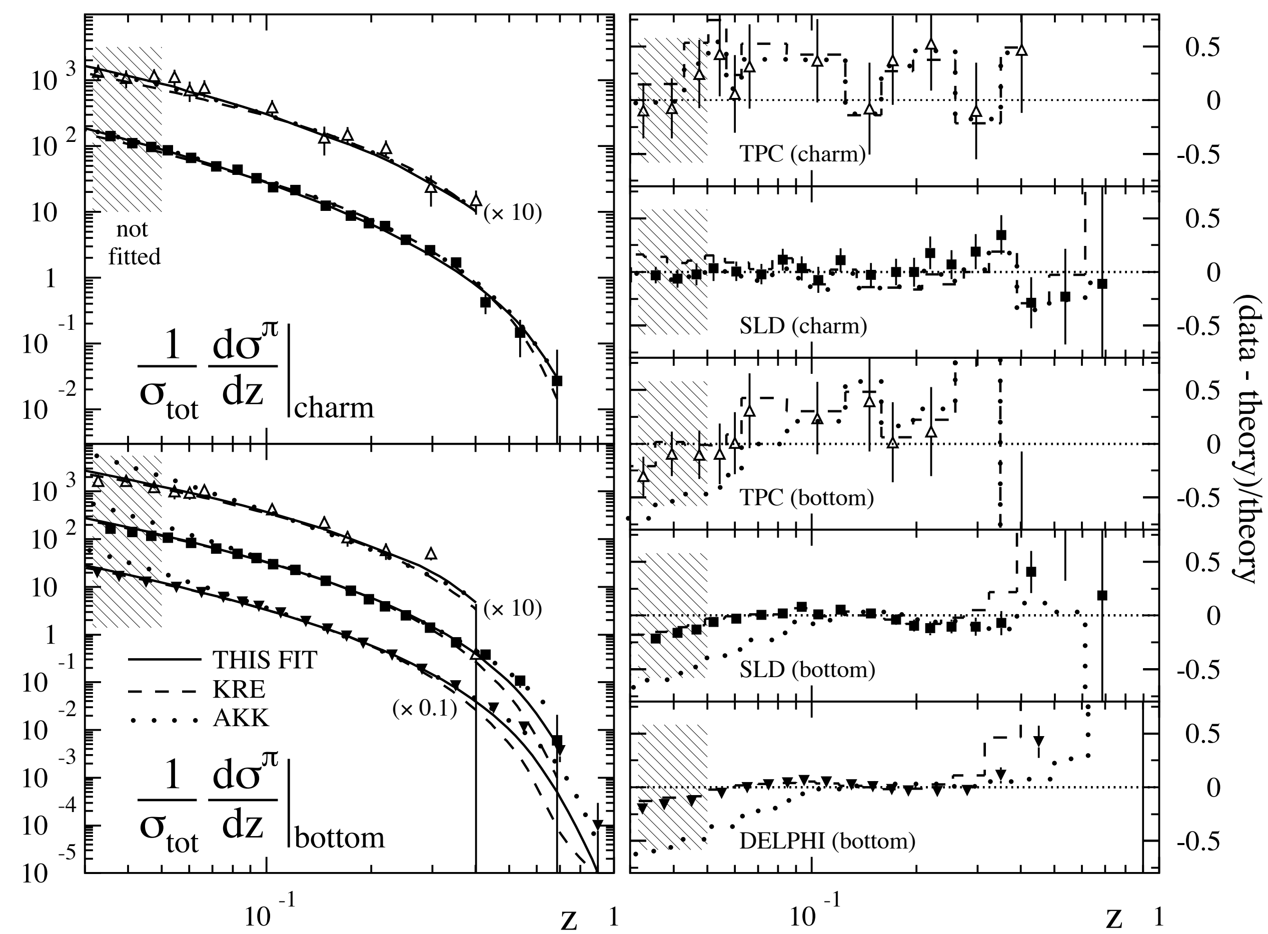
SIA: still works very well within the global fit

“inclusive”



Large errors at z>0.5

heavy quark tagged

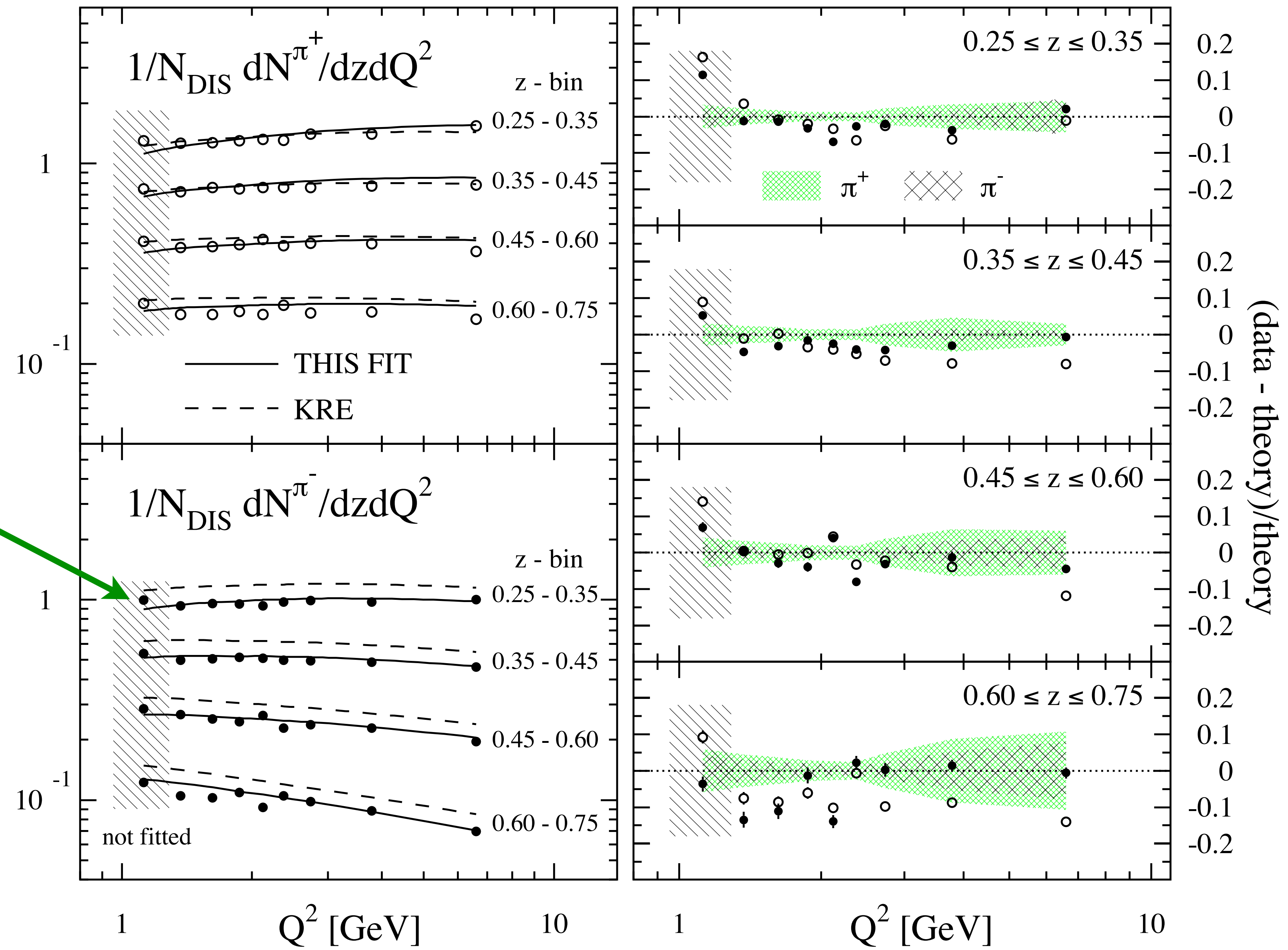


✓ extrapolation to smaller z

SIDIS

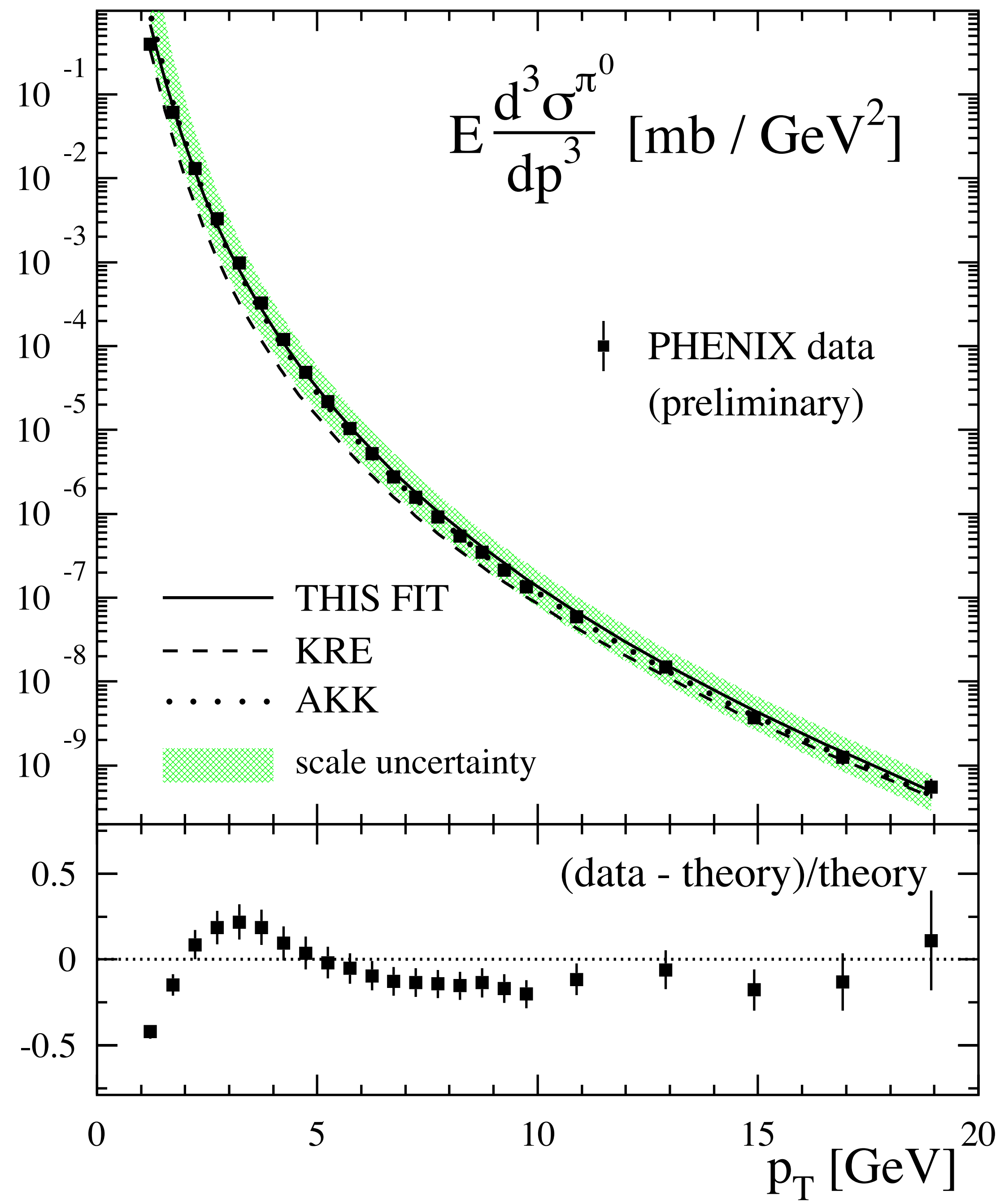
Hermes

ad-hoc charge separation from Kretzer fails



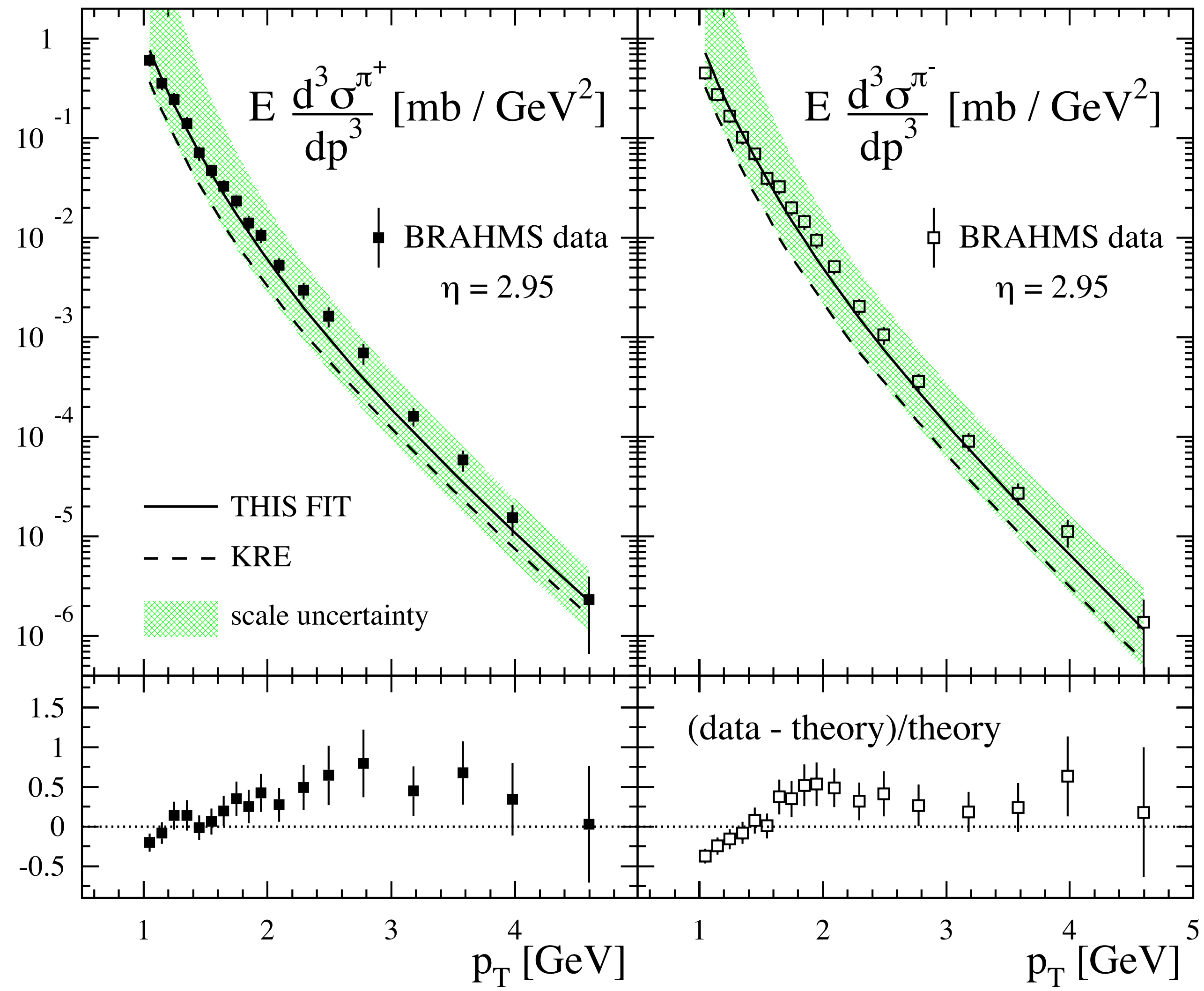
large z covered

pp data



Neutral pions at Phenix

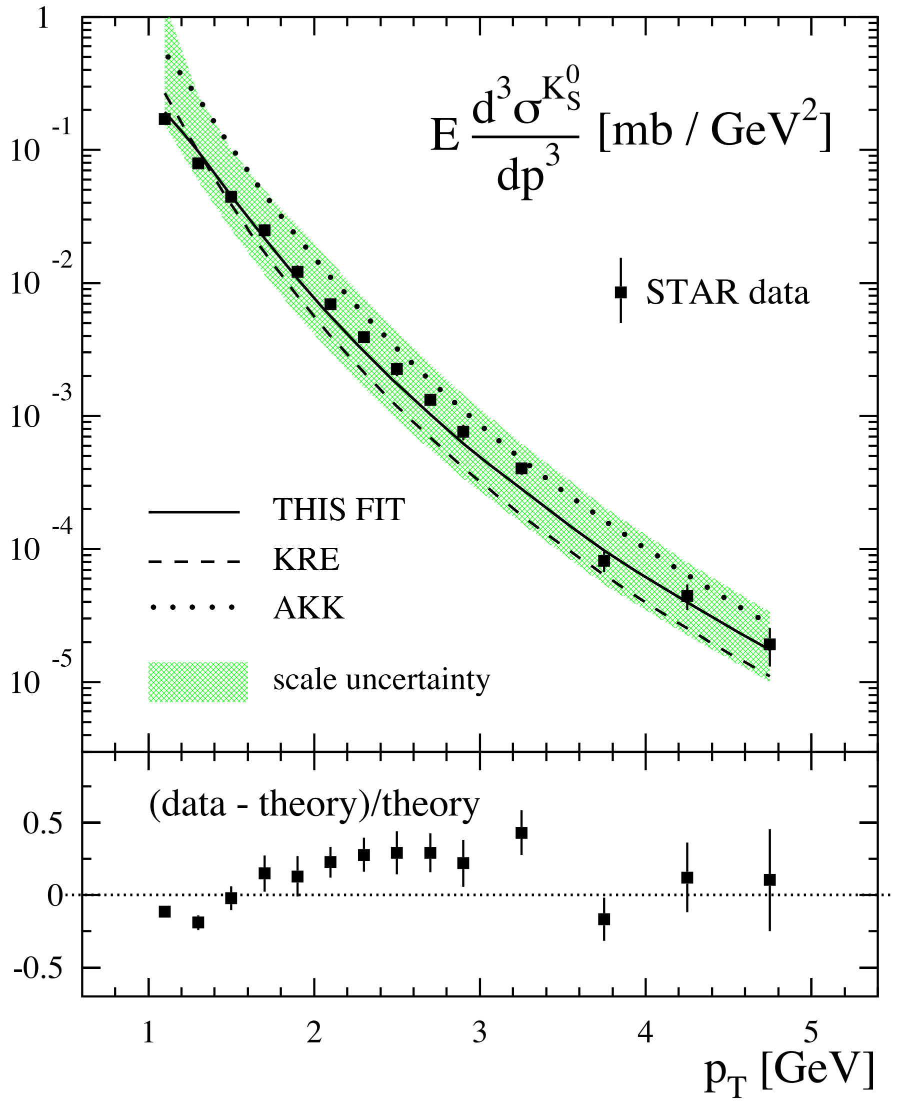
$\mu_F = \mu_R = p_T$



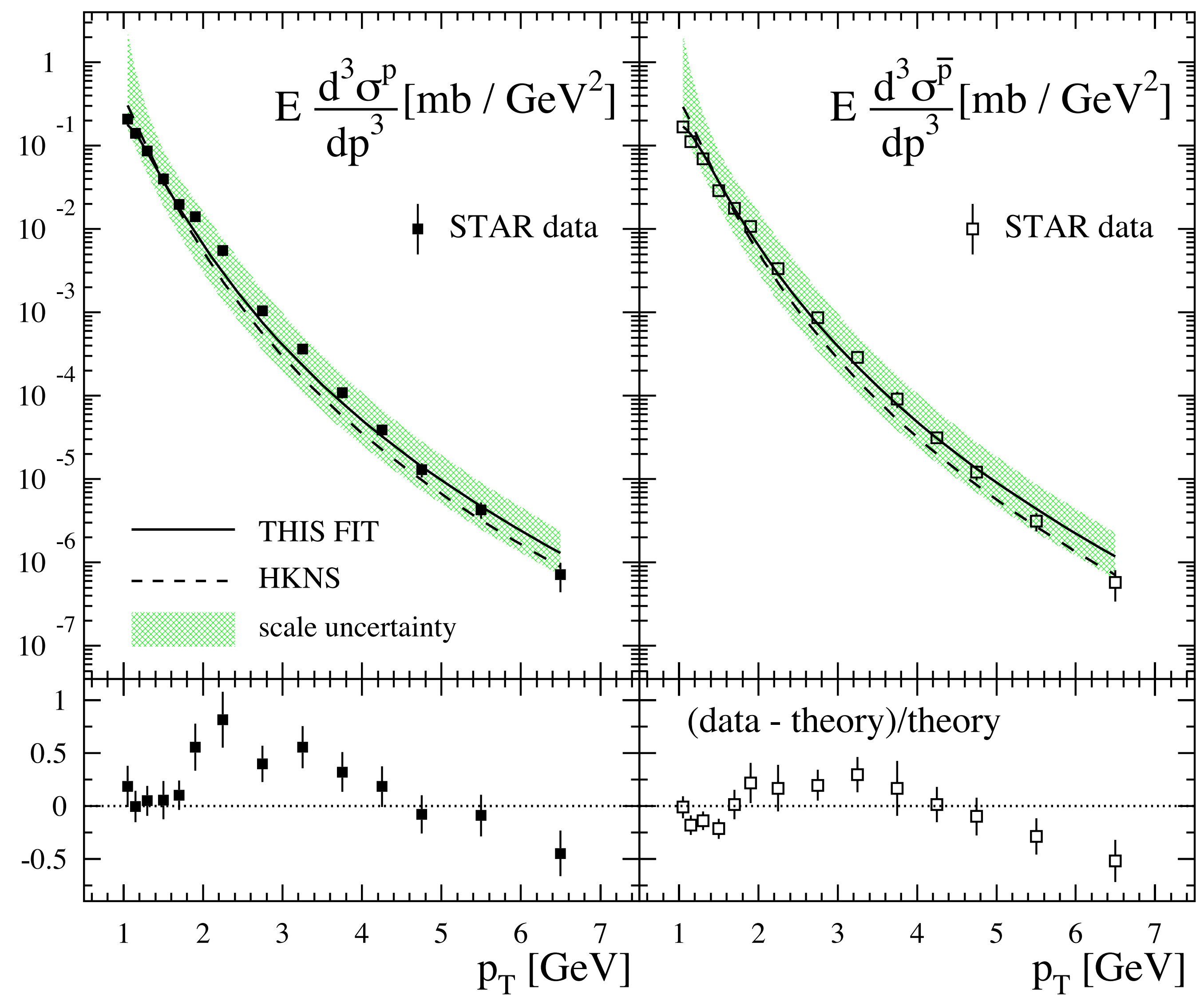
Charged pions (at large z)

pp data

Kaons



Protons



Good agreement with all RHIC data and visible differences with other sets

Typically $\chi^2/dof \sim 2$

Large χ^2 from a few isolated data points (small z in SIA, and some SIDIS and pp)

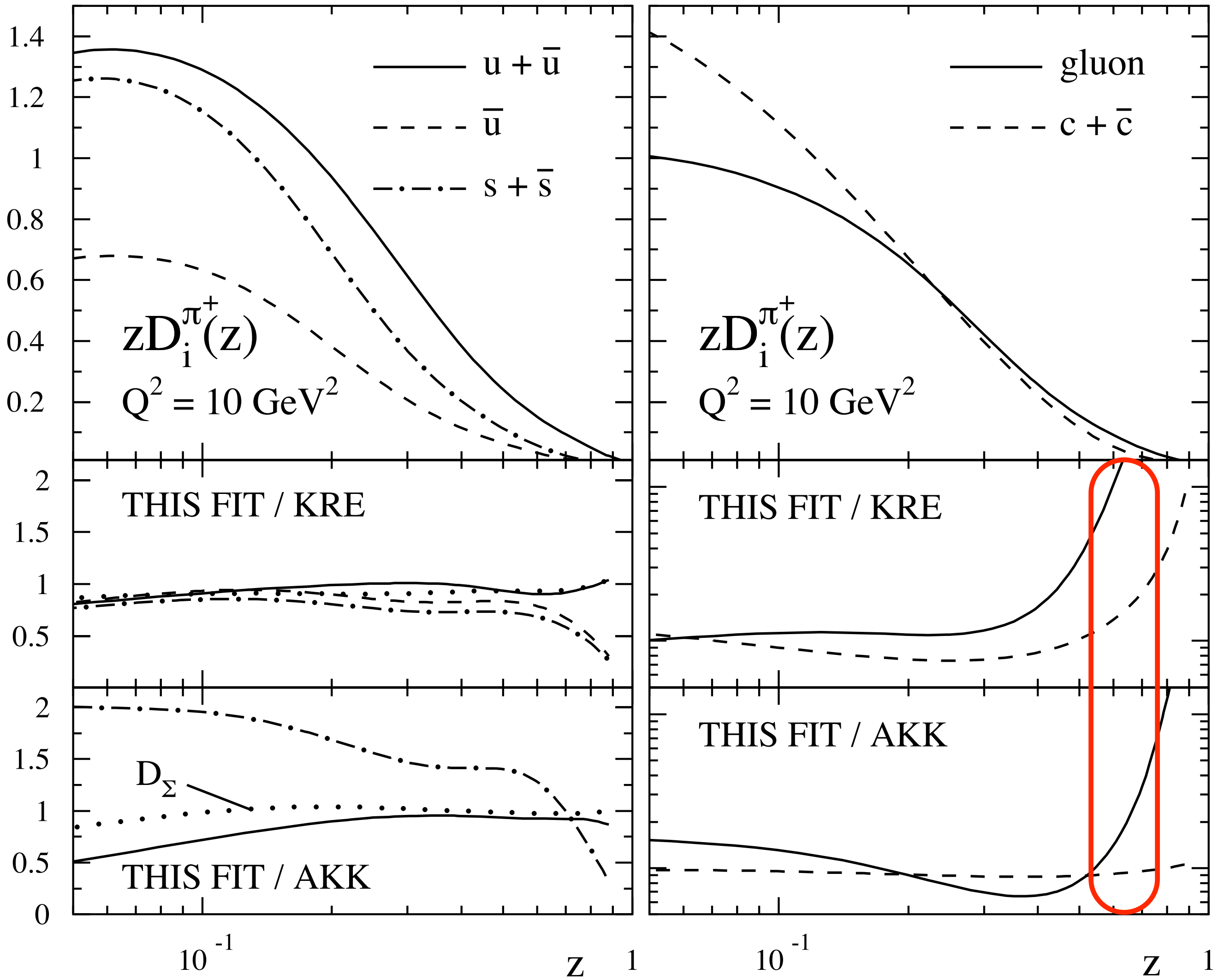
very precise SIA

Also tension between experiments (like Delphi at large z)

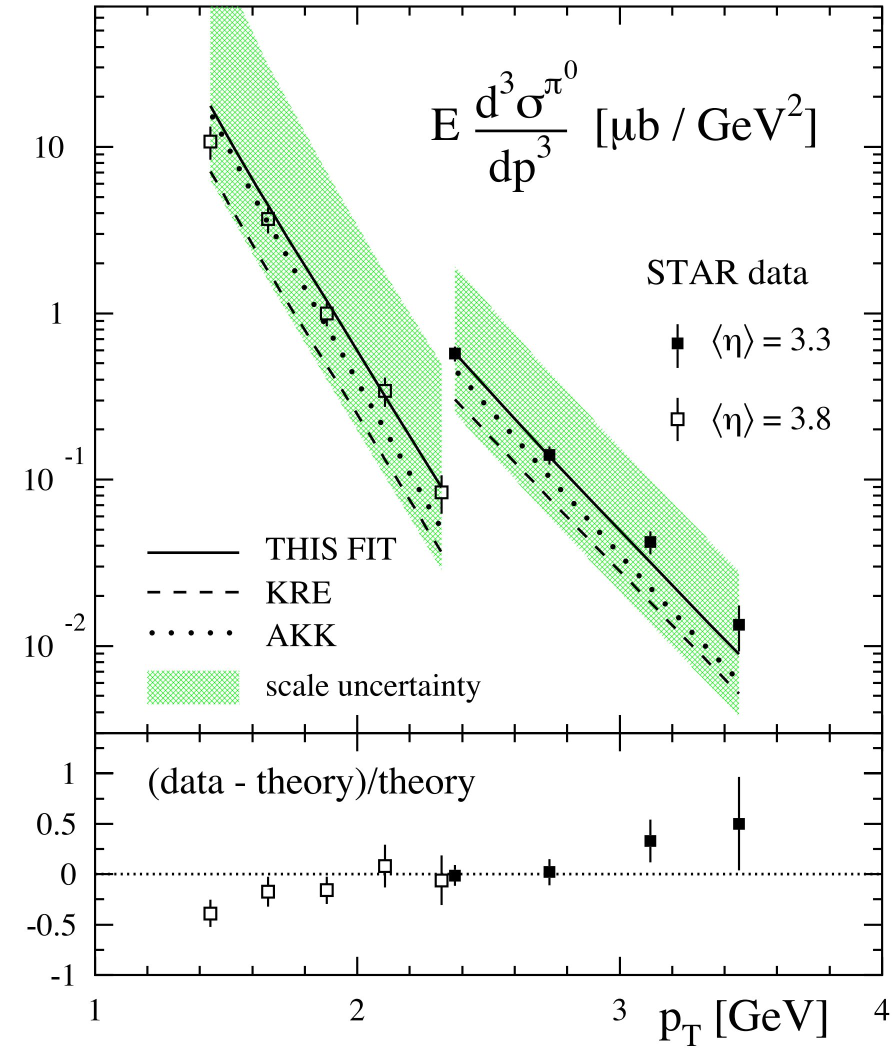
χ^2 grows (~25%) for LO fits : mostly from pp data
where NLO corrections are very large

Pions + kaons + protons almost saturate charged hadrons:
residual only sizable for HQ

Distributions (pions)



large rapidity at STAR



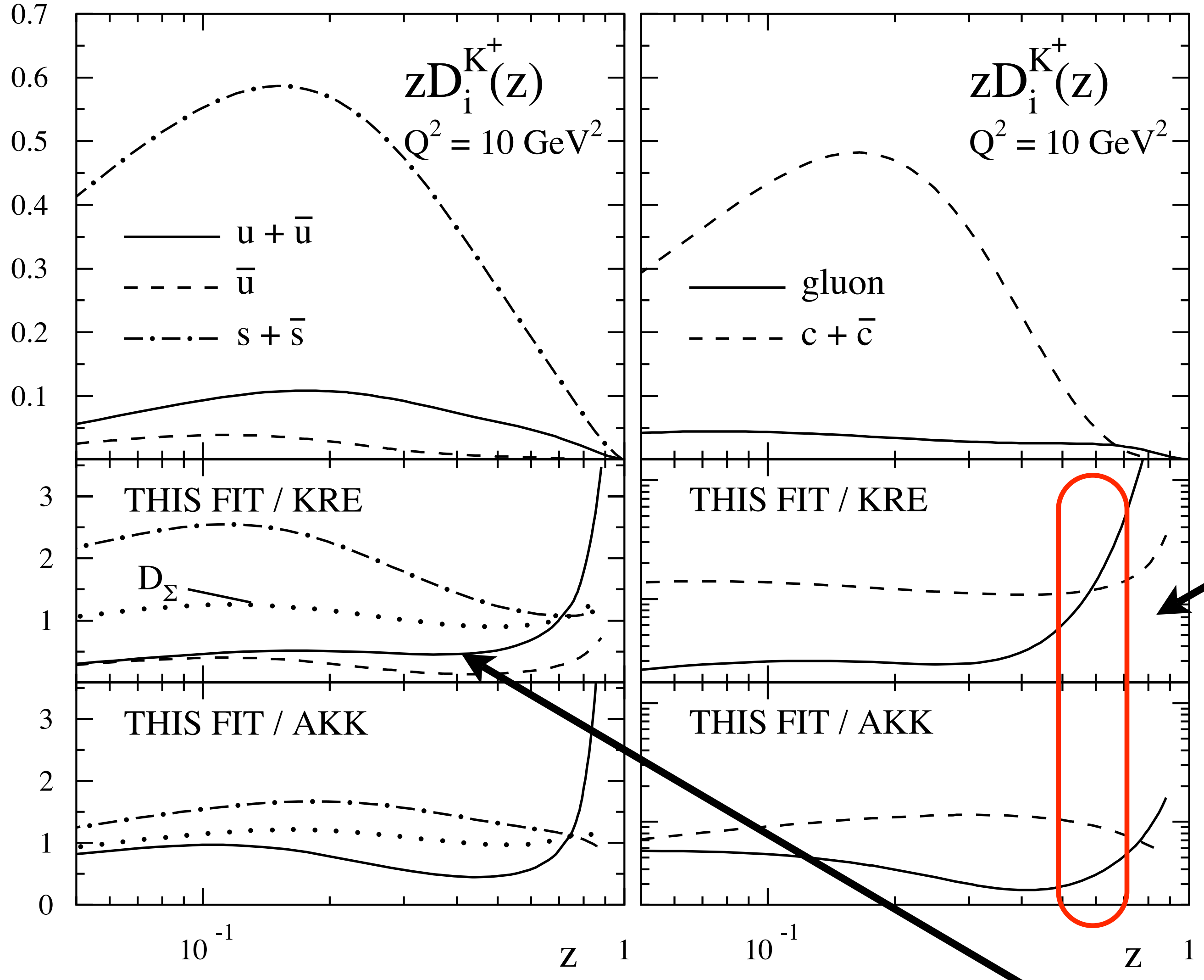
Large differences visible in the gluon at large z : explains pp

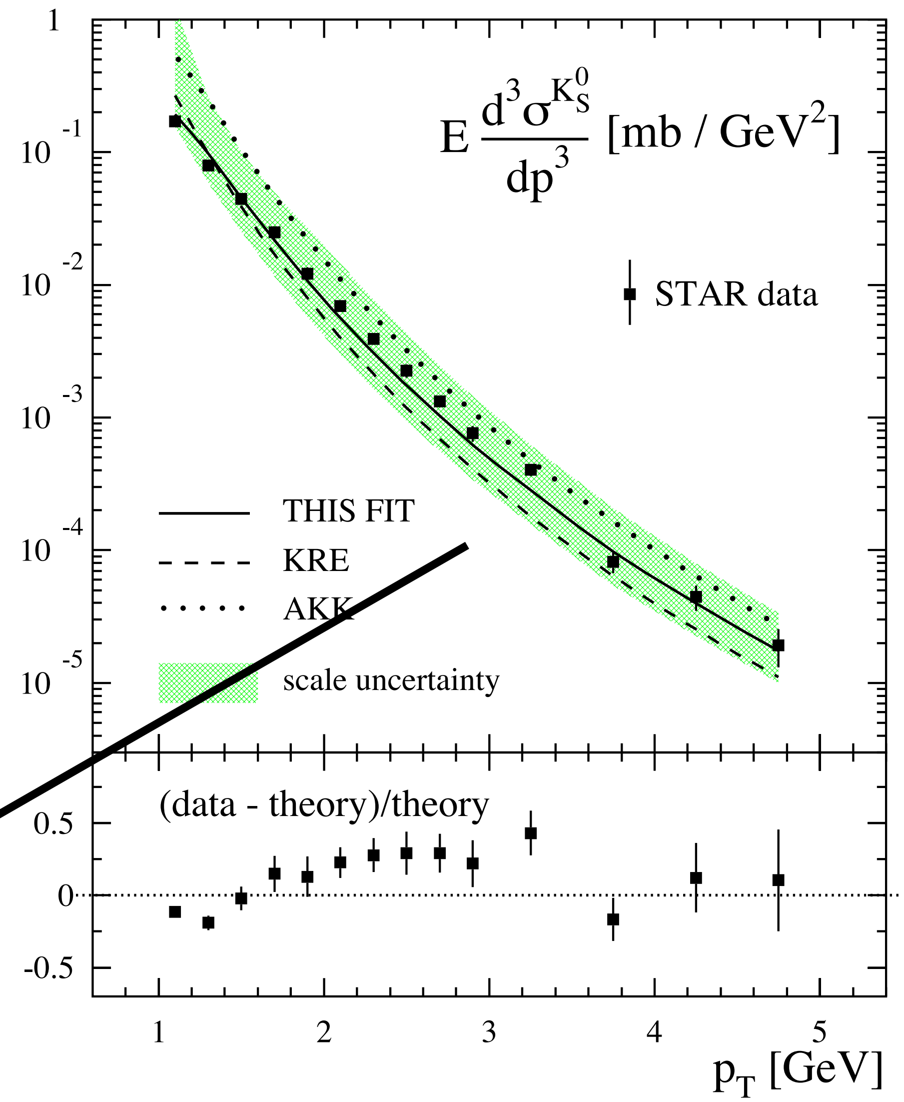
Large differences in unfavored distributions : explains SIDIS and pp

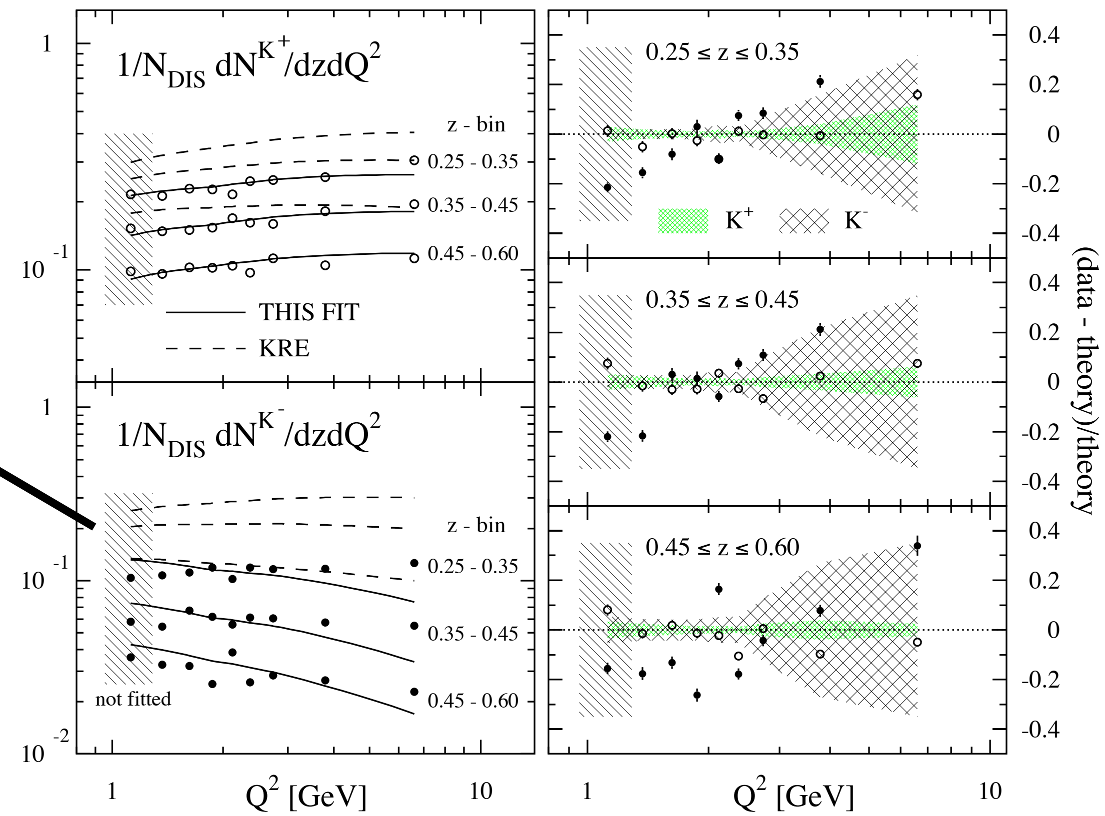
For pions u fragmentation smaller than AKK : required by SIDIS and compensated in SIA by larger s

Similar singlet

Distributions (Kaons)







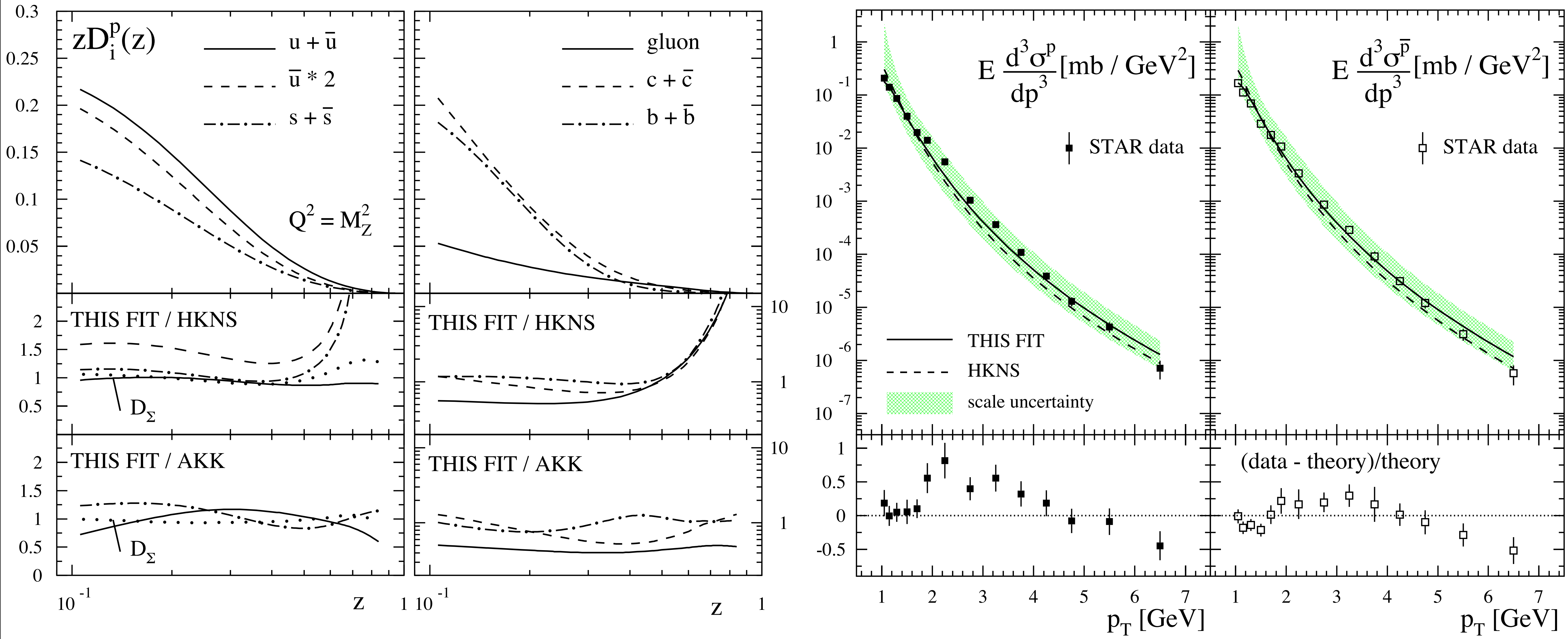
Smaller u required by SIDIS

VERY different gluon by pp

Similar singlet (larger dominant s)

Issues for K- (s and ū in proton at large x)

Distributions (protons)



Differences with HKNS also sizeable : gluons, unfavored and large z (pp)

Similar singlet, but large diff. between HKNS and AKK (using same data)

In general differences look much larger than for pdf fits :
comparison between GLOBAL fits

To “estimate” uncertainties using different sets (like MRST vs CTEQ),
more global fits needed

Uncertainties

Use Lagrange multipliers technique to estimate uncertainties (from exp. errors) on some observables

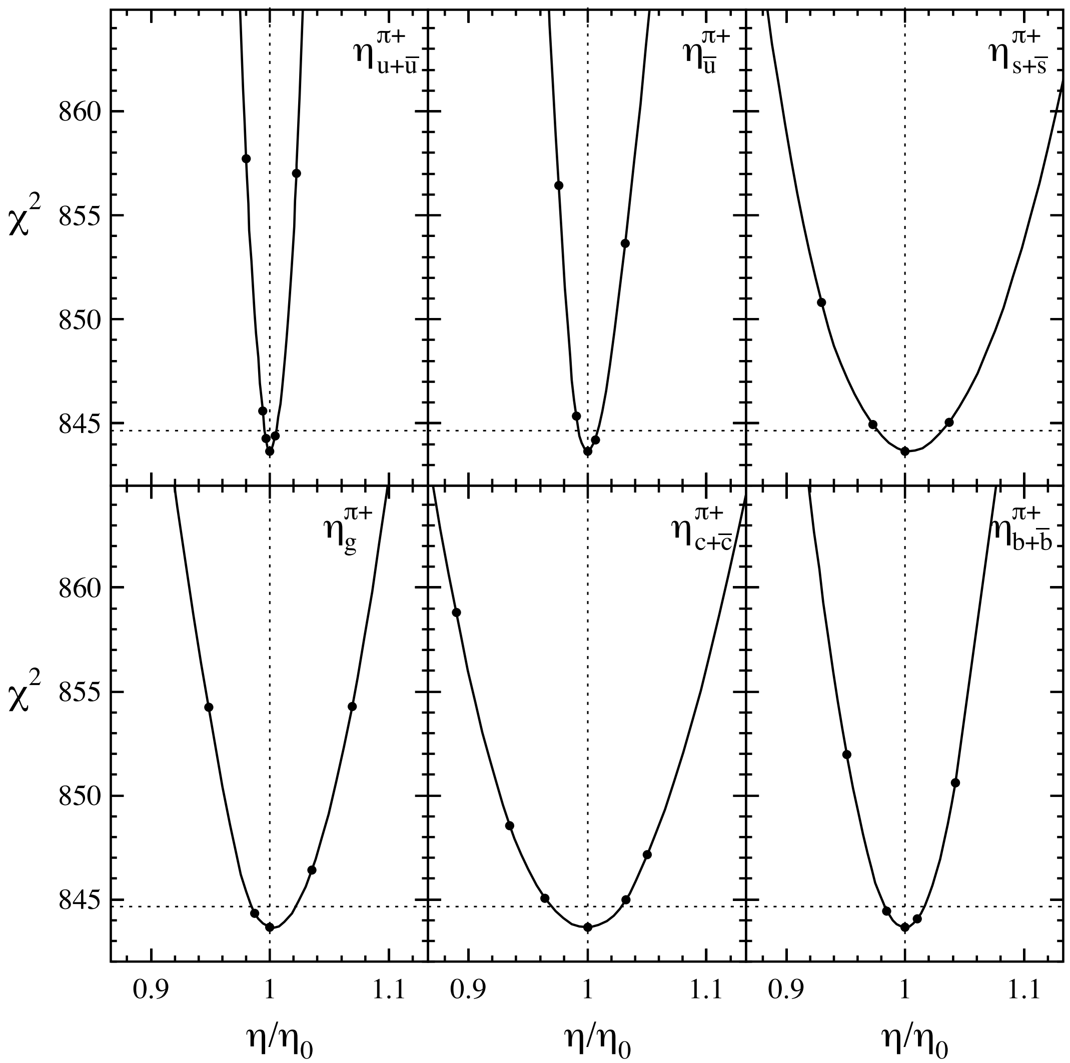
$$\Phi(\lambda_i, \{a_j\}) = \chi^2(\{a_j\}) + \sum_i \lambda_i \, \mathcal{O}_i(\{a_j\})$$

See how fit deteriorates when FFs forced to give different prediction for $\mathcal{O}_i$

$\Delta\chi^2_n$ should be parabolic if data set can determine the observable (otherwise monotonic o flat)

We study truncated moments: $\int_{0.2}^{1} z \, D_i^H(z, Q = 5\,\mathrm{GeV}) \, dz$

Uncertainties

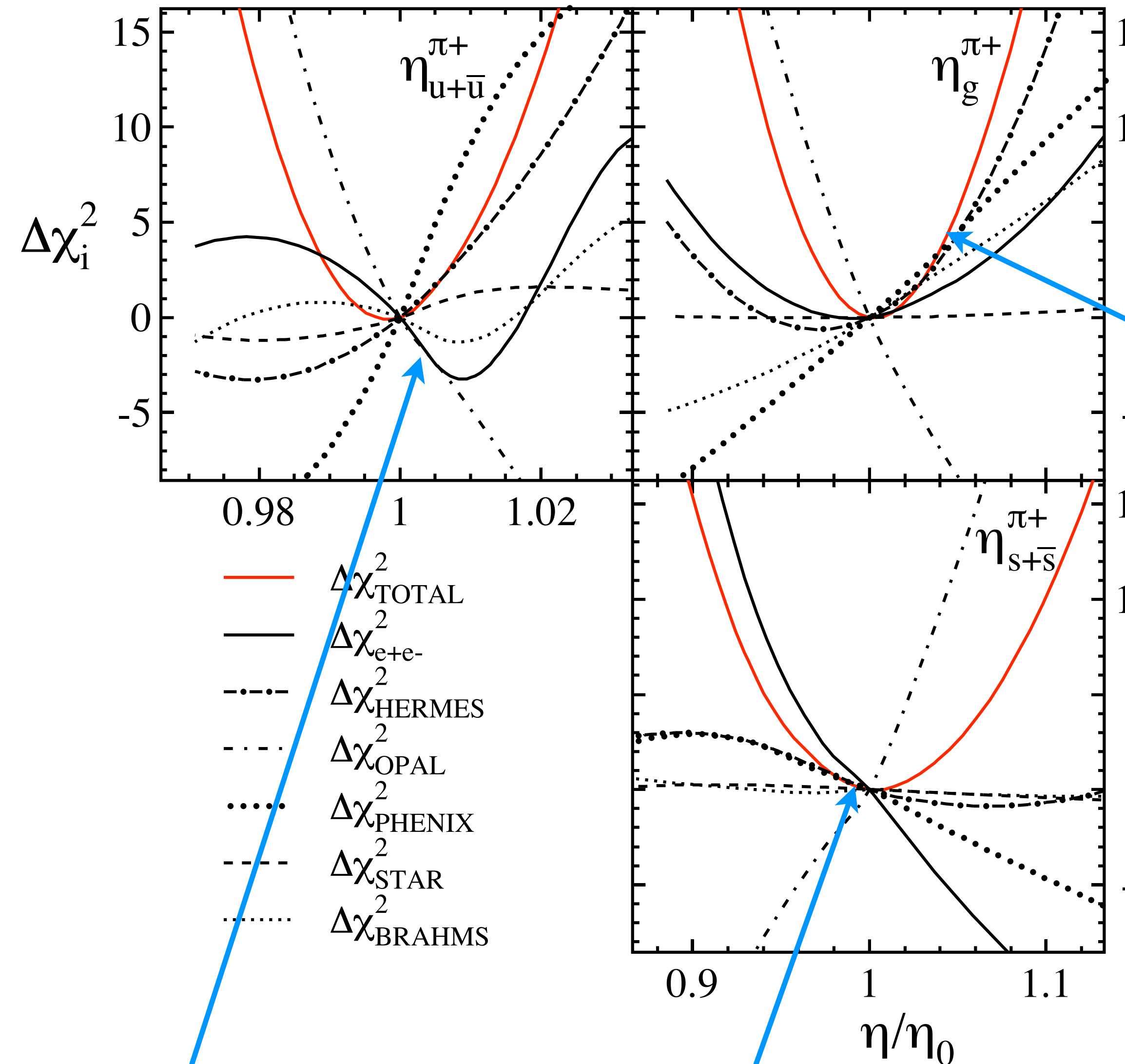


$$\Delta\chi^2 = 15(\sim 2\%)$$

u < 5%
s ~ 10 %

dominated by z~0.2

Individual profiles



Precision RHIC

Tension

Complementarity

Constrained parabola as a result of global fit

Conclusions

FFs are a fundamental tool to describe HEP observables within pQCD

NLO (and LO) fragmentation functions from a global fit: electron-positron, lepton-nucleon and hadron-hadron scattering

Charge and flavor separation from data (no ad-hoc assumptions)

For this workshop: ffs work in the kinematic range relevant for polarized pdfs extraction: RHIC, Hermes, Compass

First "global" fit fully developed using Mellin techniques : it can be done!