LHCphenOnet

Global QCD fits

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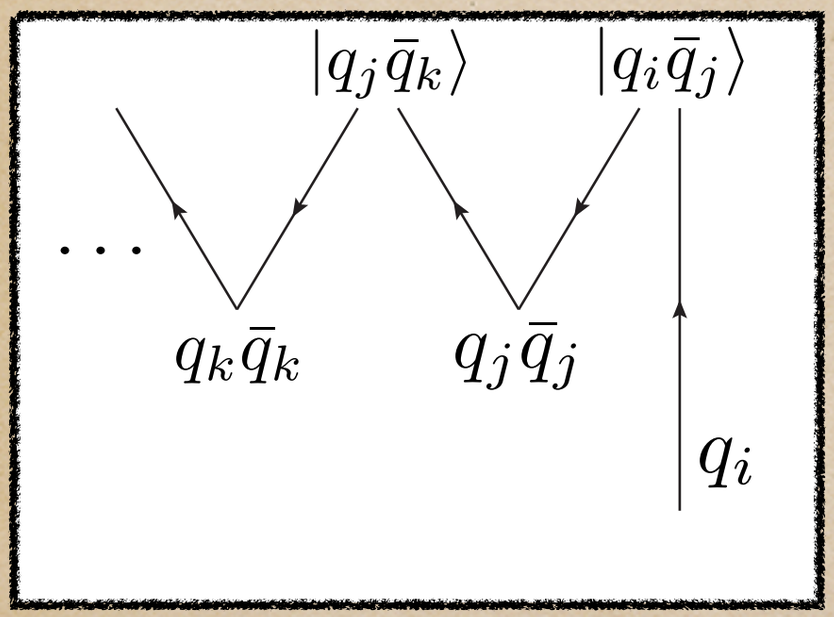
Outline

- Introduction to FFs
- FFs on the market
- Treatment of uncertaintes
- Towards a new set of FFs
- Conclusions

Introduction to FFs

Hadronization long ago...

At the beginning it was the "cascade fragmentation" model

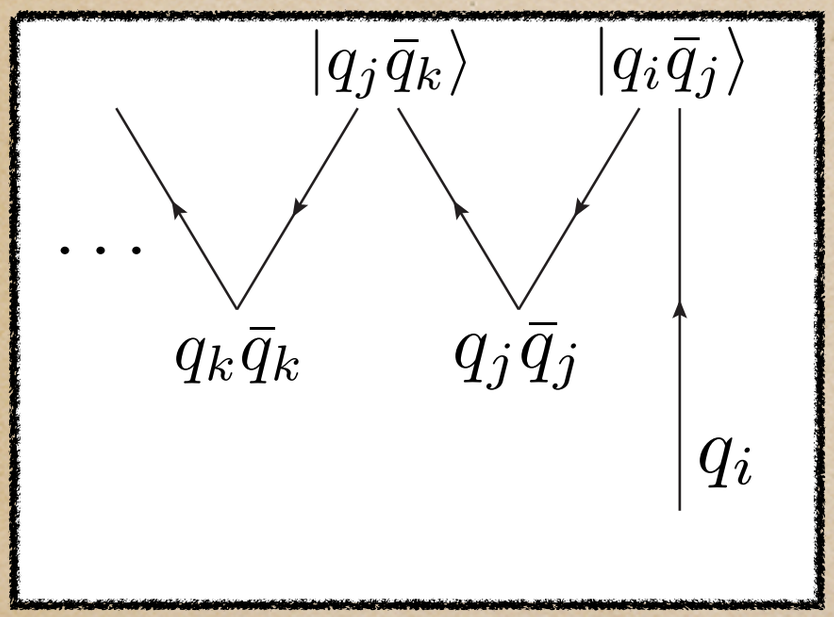


rank = 1 : "valence", e.g. $u \to \pi^+$

rank > 2 : "sea", e.g. $u \to \pi^-$

Hadronization long ago...

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rank = 1 : "valence", e.g. $u \to \pi^+$

rank > 2 : "sea", e.g. $u \to \pi^-$

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 $\left(\mathcal{D}_q^h(z,\mu)\right)$

- FFs are relevant any time a hadron is produced in High Energy Collisions.
- Non-perturbative objects to be extracted from data (like PDFs). They are scale dependent predicted by QCD.
- Describe the collinear transition of a massless parton “q” into a massless hadron “h” carrying fractional momentum “z”.
- The fragmentation is independent of other colored particles.
- Needed to consistently absorb final-state collinear singularities.
- Precise FFs are needed to extract PDFs more precisely.

Properties of FFs

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

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

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

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- 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- Single Inclusive Annihilation

The distribution is given in terms of the structure functions,

$$\frac{1}{\sigma_{tot}}\frac{d\sigma^h}{dz} = \frac{\sigma^0}{\sum_q \hat{e}_q^2}\left[2F_1^H(z,Q^2) + F_L^H(z,Q^2)\right] \quad \sigma_{tot} = \sum_q \frac{4\pi\alpha_s^2}{s}\hat{e}_q^2\left(1+\frac{\alpha_s}{\pi}\cdots\right)$$

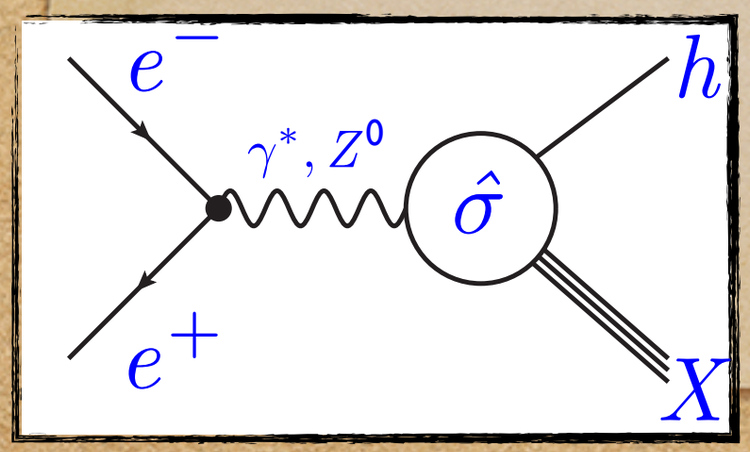
@NLO

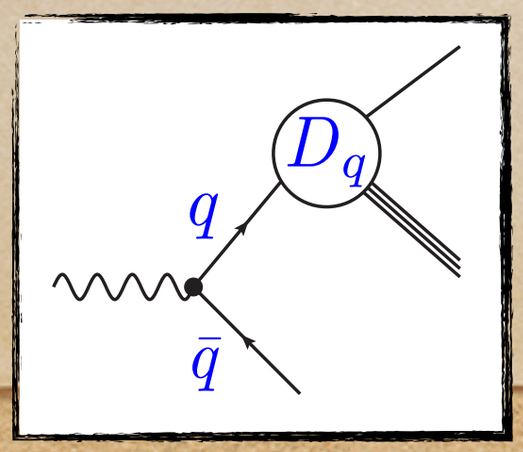
$$2F_1^H(z,Q^2) = \sum_q \hat{e}_q^2\left\{[D_q^H(z,Q^2) + D_{\bar{q}}^H(z,Q^2)] + \frac{\alpha_s(Q^2)}{2\pi}[C_q^1 \otimes [D_q^H + D_{\bar{q}}^H] + C_g^1 \otimes D_g^H](z,Q^2)\right\}$$

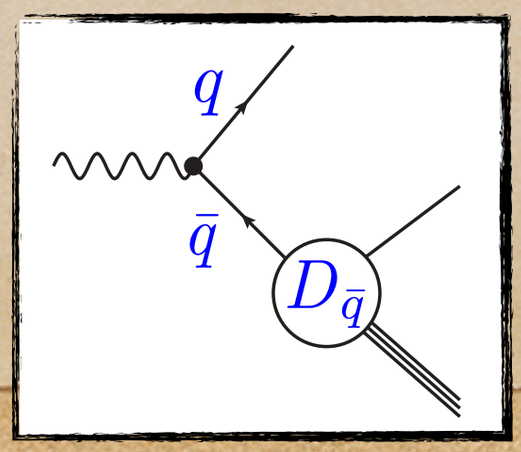
FFs depend on energy fraction and energy scale: DGLAP evolution

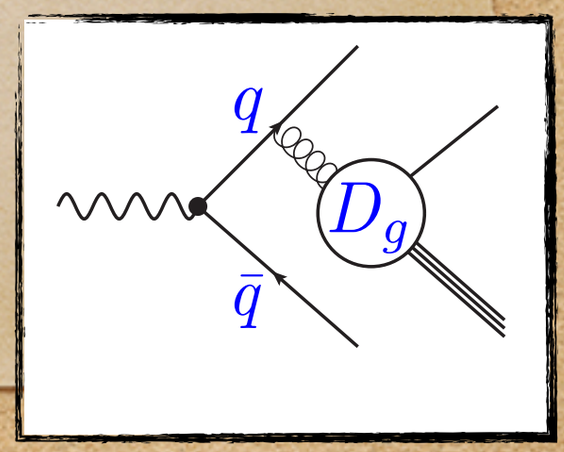
$$\frac{d}{d\ln Q^2}\mathbf{D}^H = \left[\hat{P}\otimes\mathbf{D}^H\right](z,Q^2)$$

Not possible to separate $\mathcal{D}_q^h(z,\mu)$ and $\mathcal{D}_{\bar{q}}^h(z,\mu)$









SIDIS

Distributions for SIDIS are given by

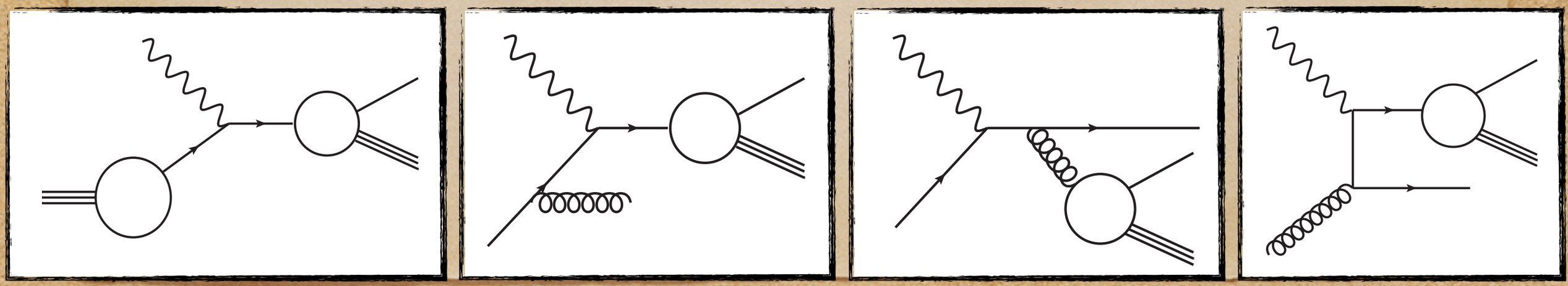
$$\frac{d\sigma^H}{dxdydz^H} = \frac{2\pi\alpha_s}{Q^2}\left[\frac{1+(1-y)^2}{y} 2F_1^H(x, z_H, Q^2) + \frac{2(1-y)}{y} F_L^H(x, z_H, Q^2)\right]$$

@LO $$2F_1^H(x, z_H, Q^2) = \sum_{q,\bar{q}} \hat{e}_q^2 \cdot q(x, Q^2) D_q^H(z_H, Q^2)$$

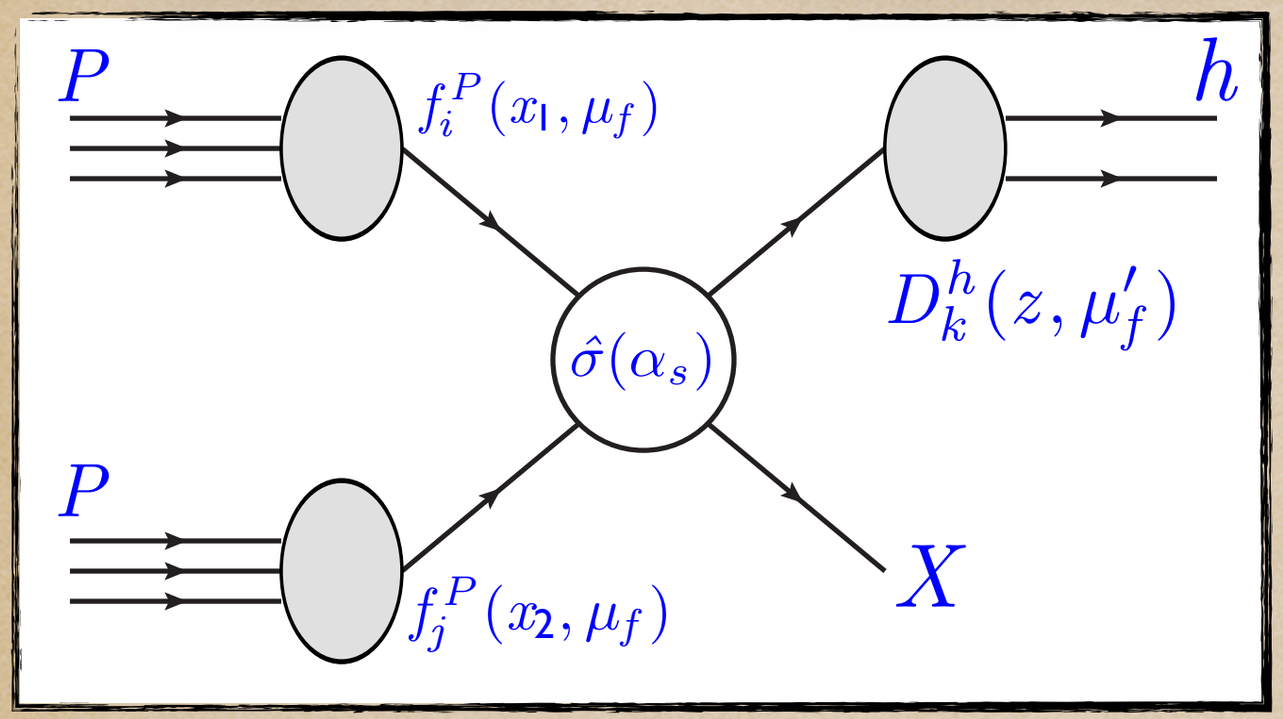
effective charge

Allows charge/flavor separation.

@NLO *Altarelli et al.'79;*
Furmanski, Petronzio'82;
de Florian, Stratmann, Vogelsang'98



Hadron-Hadron Collisions



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

Transverse momentum distribution is

$$\frac{d\sigma(pp \to hX)}{dp_T d\eta} = \sum_{i,j,k} \int_0^1 dx_1 f_i^P(x_1,\mu_f) \int_0^1 f_j^P(x_2,\mu_f) \int_0^1 dz D_k^h(z,\mu'_f) \frac{d\hat{\sigma}(ij \to kX')}{dp_T d\eta}$$

It also allows charge/flavor separation.

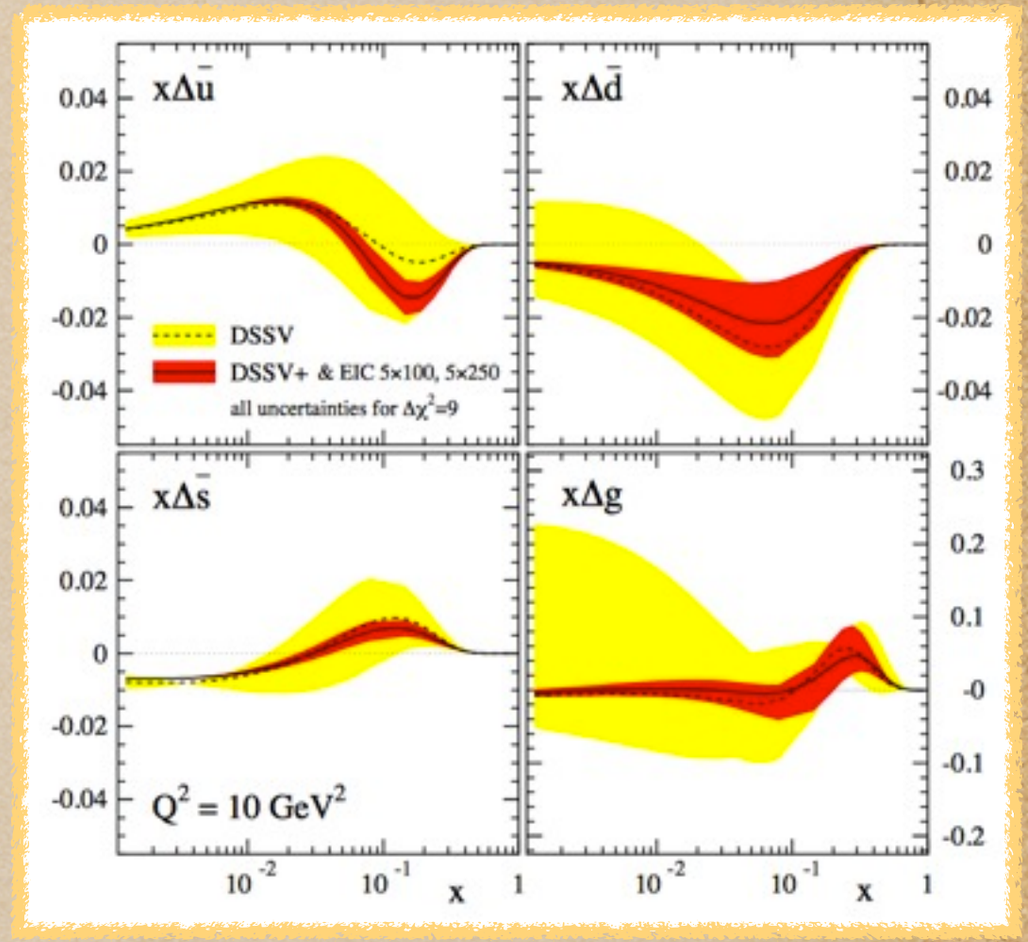
It contains large contributions from gluons.

What are they good for ?

Important input for extracting helicities

PDFs

Probe for the eRHIC era

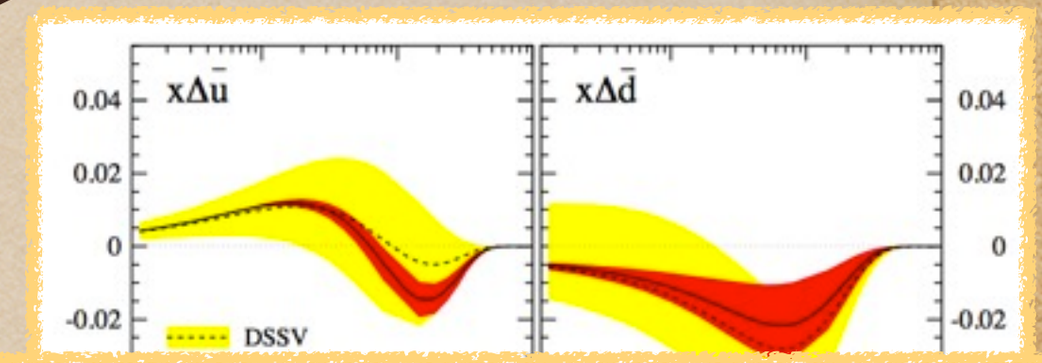


What are they good for ?

Important input for extracting helicities

PDFs

Probe for the eRHIC era



pp baseline for heavy-ion program at LHC and RHIC

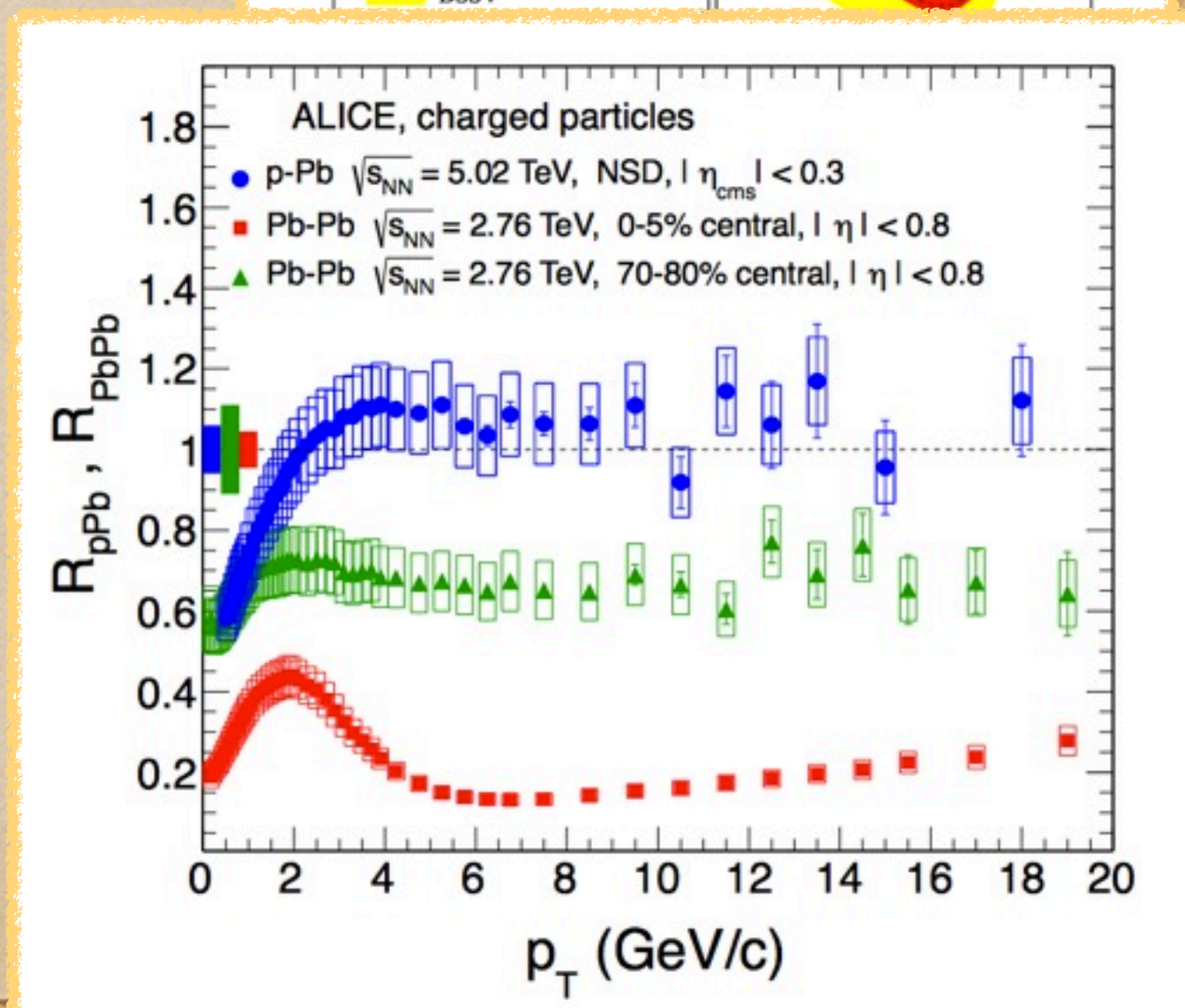
first results from pPb test run in

objectives:

nuclear PDFs

importance of saturation effects

medium modification of hadronization



FFs on the market

The fitters...

Name	Ref.	Species	Error	z_{min}	Q^2 (GeV^2)
AKK	[4]	$\pi^{\pm}, K^{\pm}, K^0_s, p, p\,\Lambda, \Lambda$	no	0.1	$2-4\cdot10^4$
AKK08	[5]	$\pi^{\pm}, K^{\pm}, K^0_s, p, p\,\Lambda, \Lambda$	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 pions

Hessian method for uncertainties

AKK08 contains large-z resummations and mass corrections

DSS

Provides LO and NLO FFs for charged pions and kaons

Global analysis of all available e+e-, ep, and pp data for 1-hadron production

Flexible functional form

$$D_i^h(z, 1\ \mathrm{GeV}) = N_i z^{\alpha_i}(1-z)^{\beta_i}\left[1+\gamma_i(1-z)^{\delta_i}\right]$$

Avoid assumptions on parameter space as much as possible

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

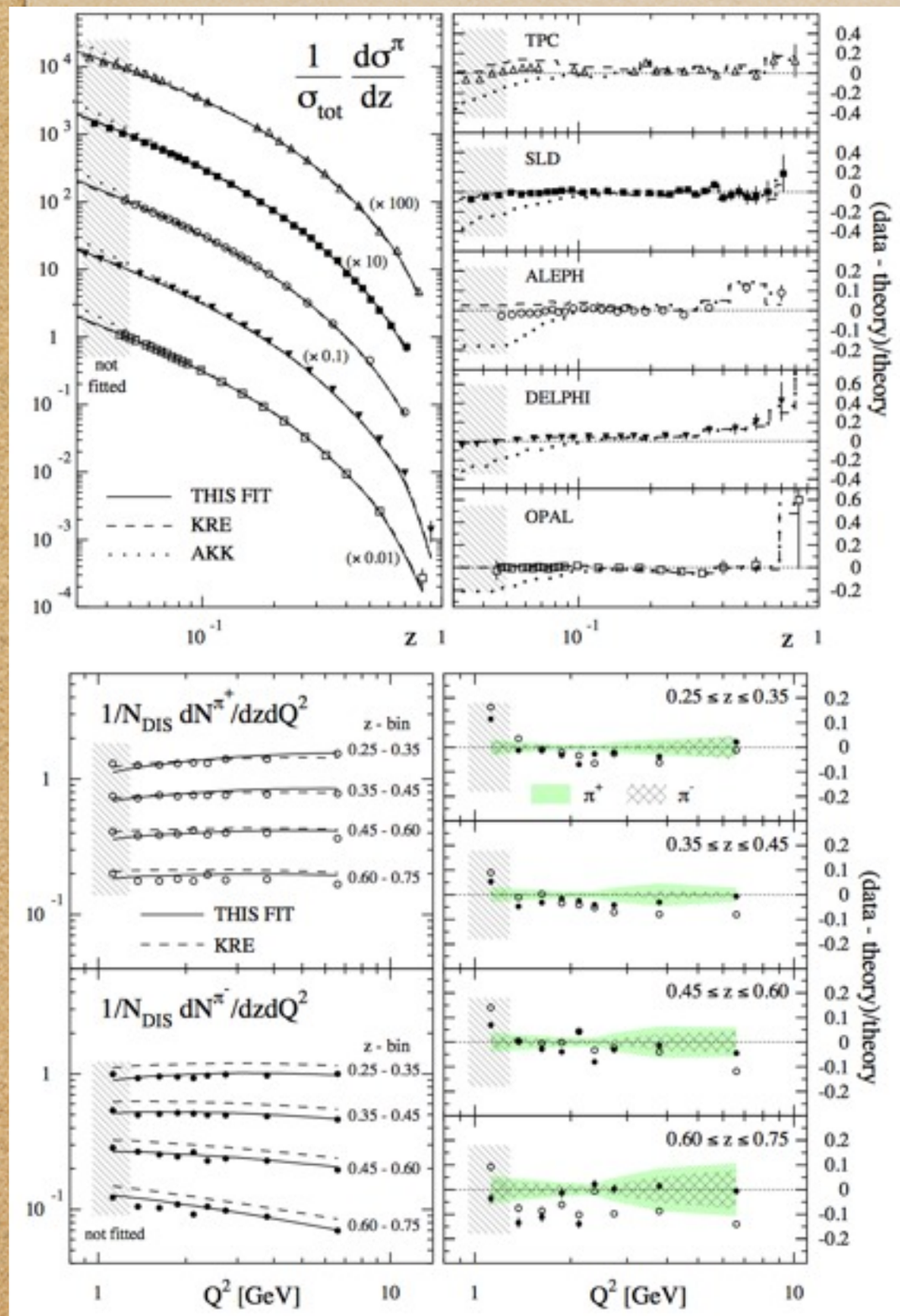
$$D_{\bar{u}}^{K^+} = D_s^{K^+} = D_d^{K^+} = D_{\bar{d}}^{K^+}$$

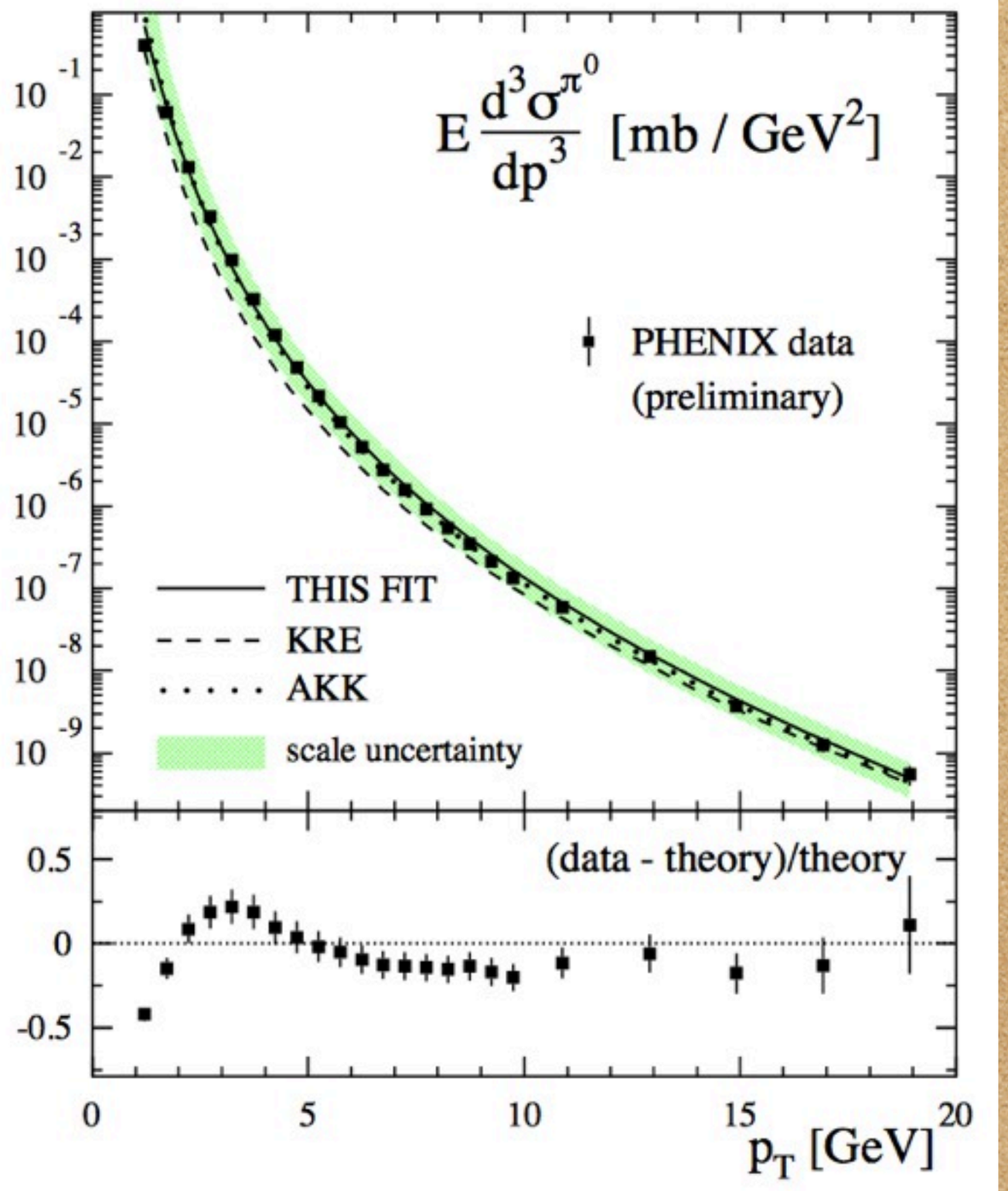
Allow for: Relative normalizations

Theory uncertainties

cuts on data: z>0.05 for pions and z>0.1 for kaons

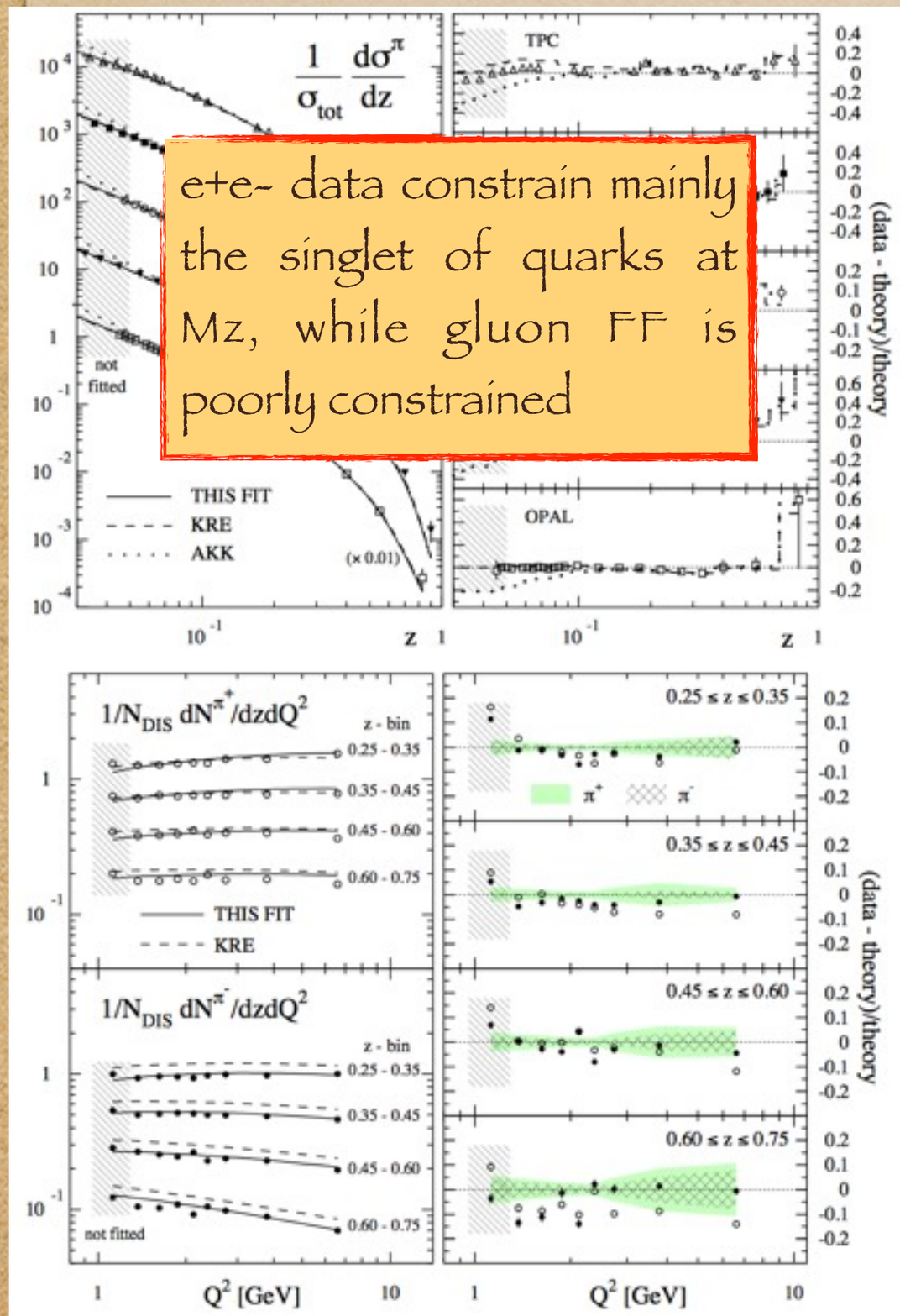
Remarks on DSS

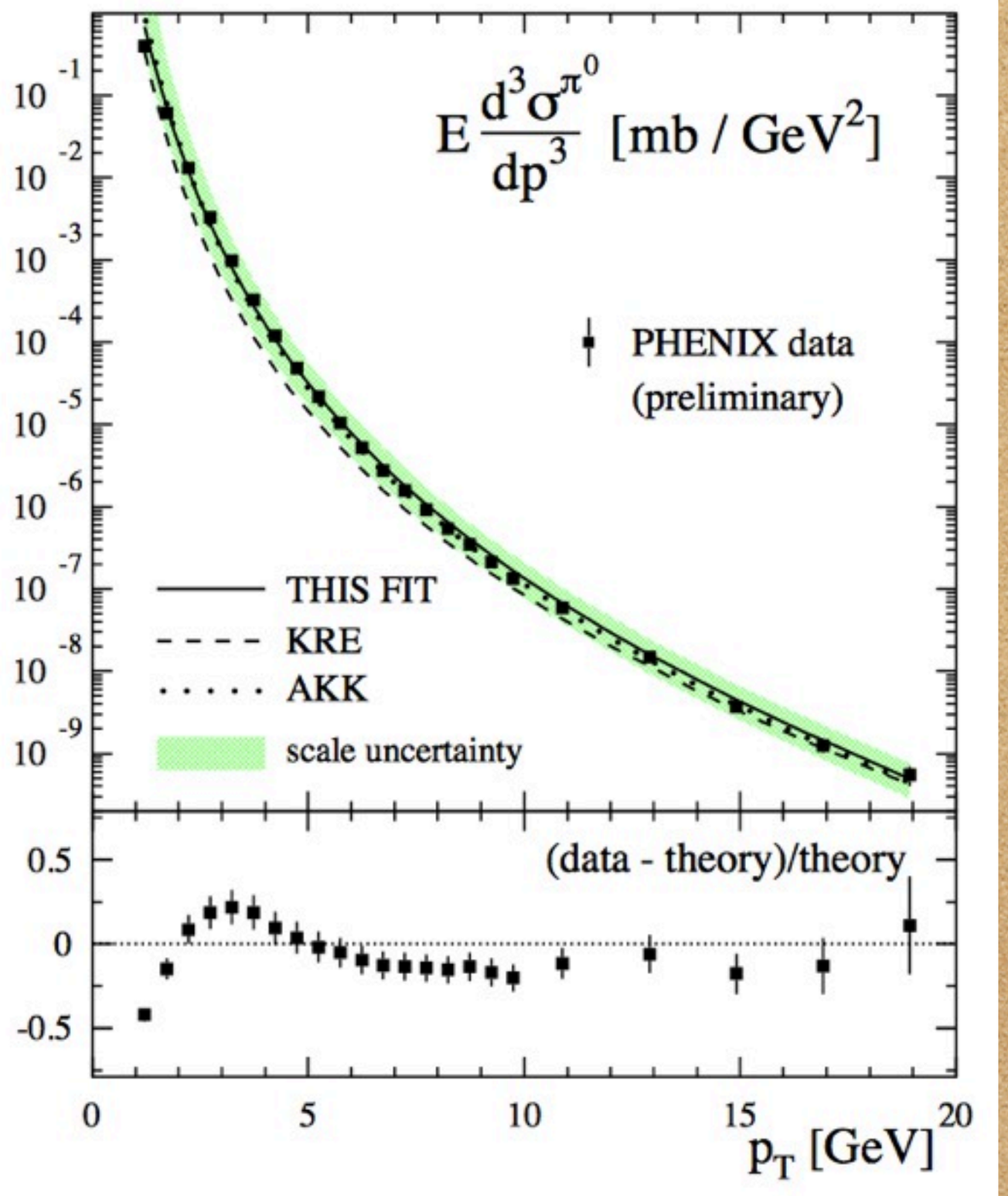




Remarks on DSS

e+e- data constrain mainly the singlet of quarks at Mz, while gluon FF is poorly constrained



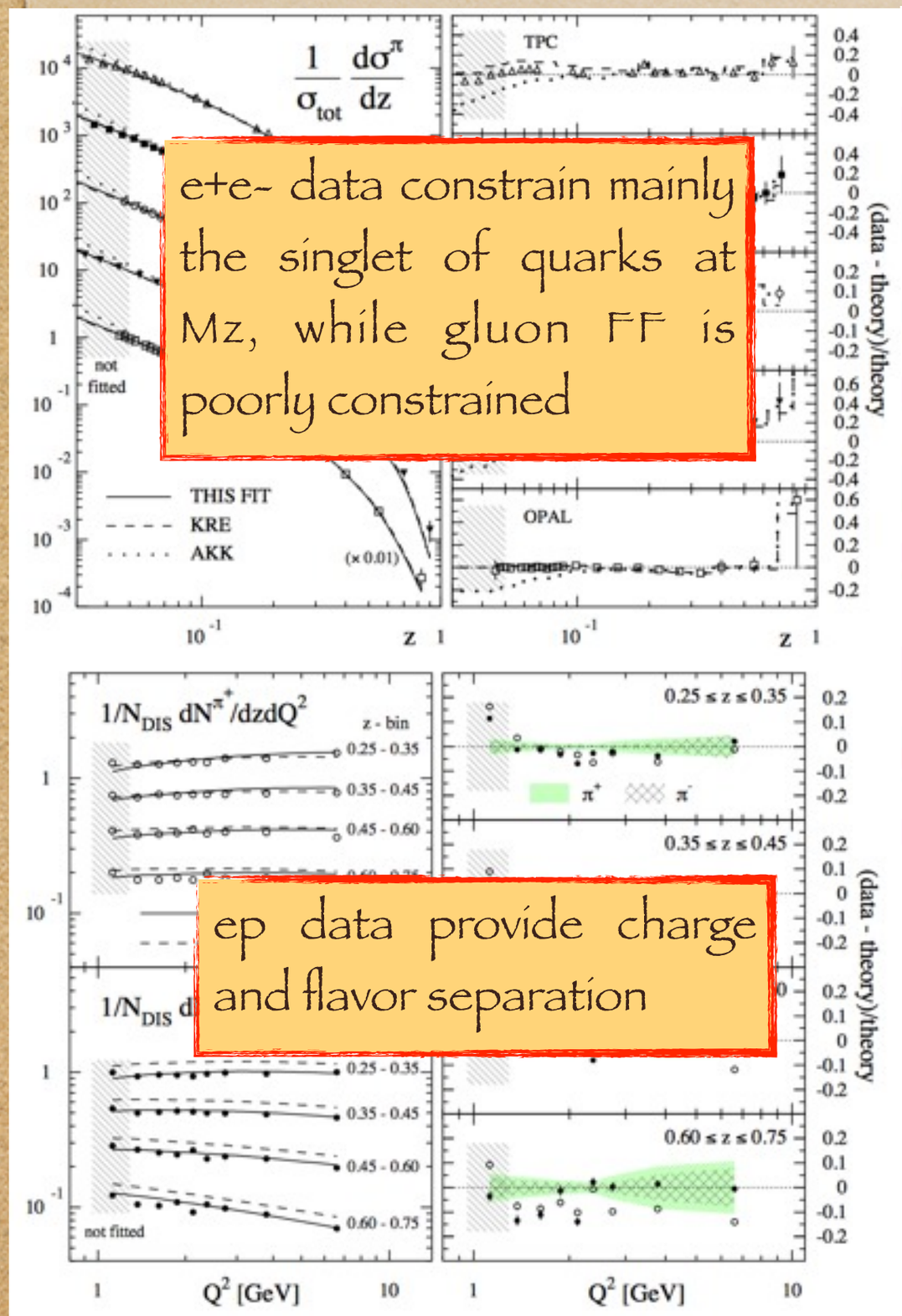


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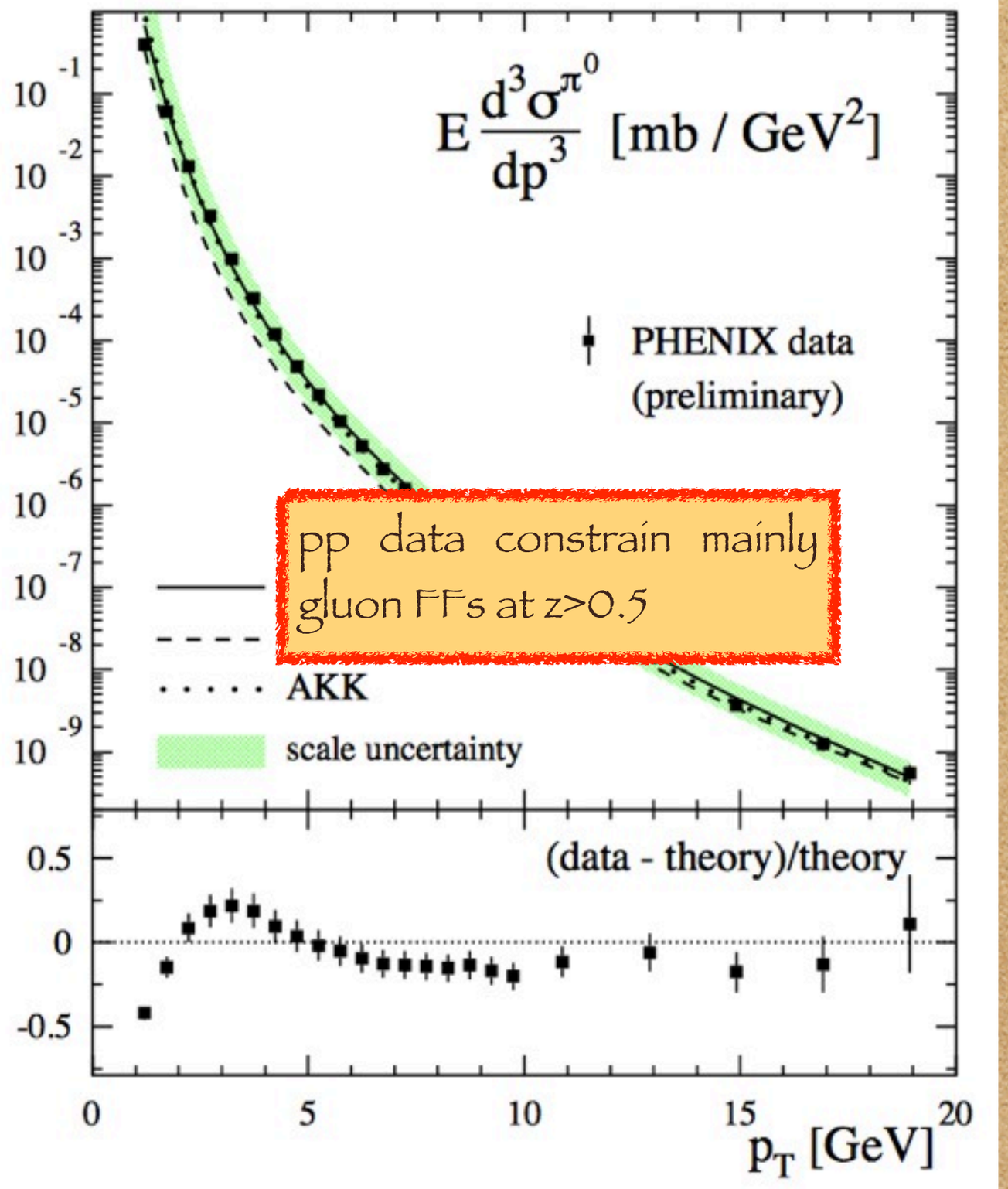
ep data provide charge and flavor separation

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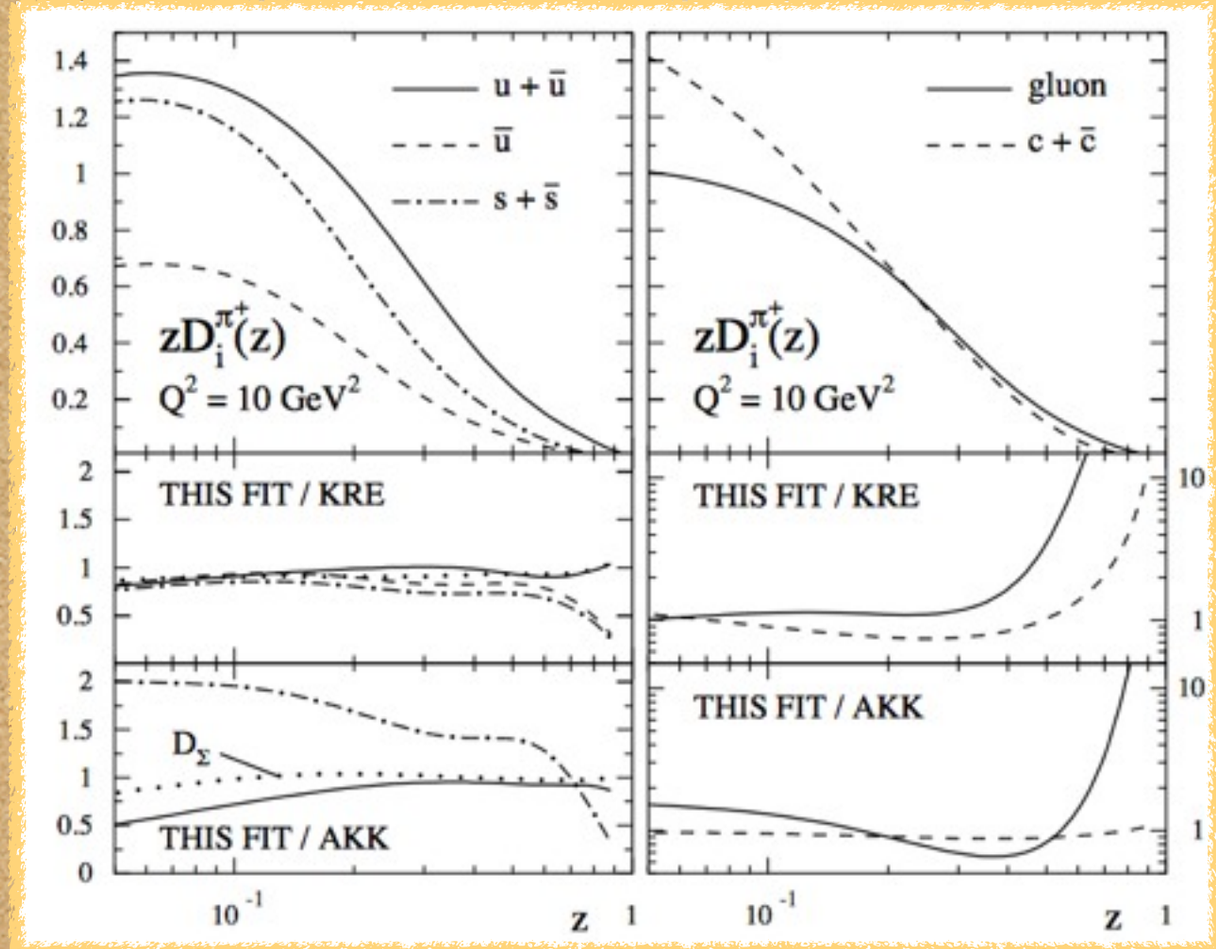


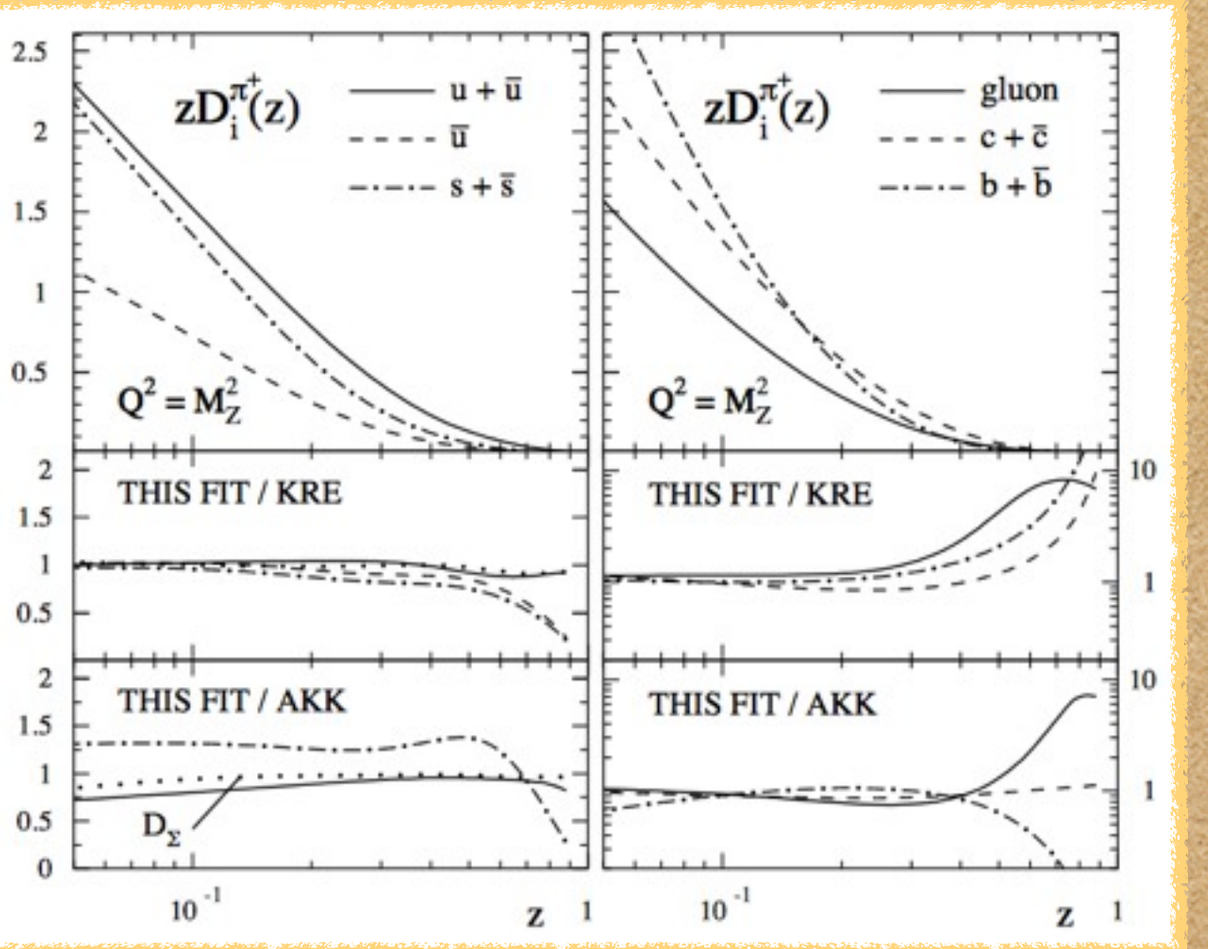
pp data constrain mainly gluon FFs at z>0.5

FFs in DSS analysis

Singlet FF is very similar in different fits

pp data could be explained by different gluon FFs





Treatment of Uncertainties

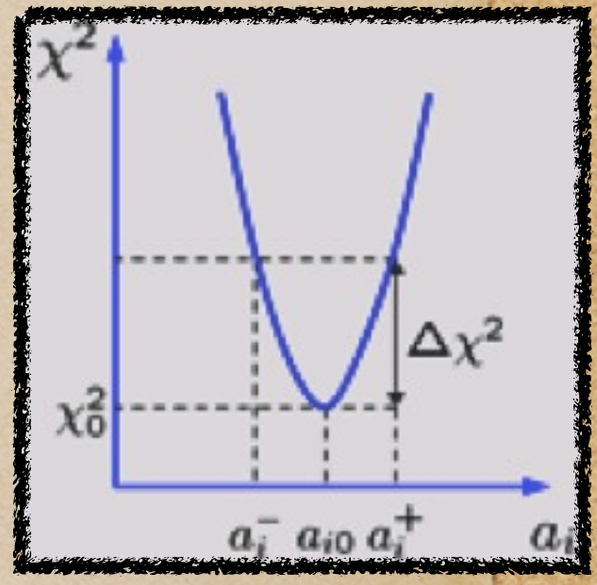
Uncertainties

Goal: provide Hessian sets to propagate FFs uncertainties

Hessian method

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

Issues: It is often unstable
needs validation with Lagrange multiplier method



Caveat: Quadratic approximation is not perfect

$$D_i^h(z, 1\ \mathrm{GeV}) = N_i z^{\alpha_i}(1-z)^{\beta_i}\left[1+\gamma_i(1-z)^{\delta_i}\right]$$

N_i parameter are rather well determined

α_i and β_i parameters

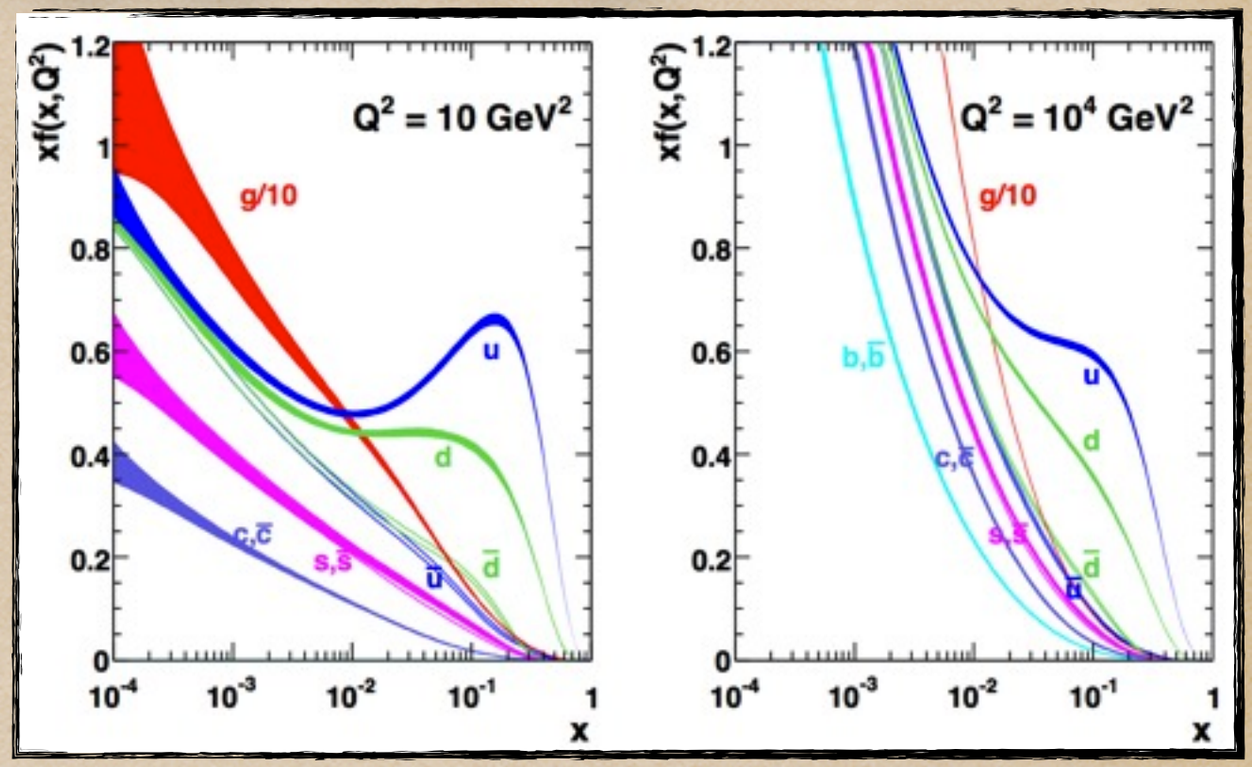
N and N'

γ_i and δ_i parameters are the least well constrained

Towards a new set of FFs

PDFs & FFs

Global analyses have improved the understanding of PDFs, such like that MSTW2008 collaboration



What about FFs ??

Processes like SIA, SIDIS and Hadron-Hadron collisions can help to understand them by doing a similar analysis. We can use a similar parametrization as the used for MSTW,

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

Global Analyses

- Constrain FFs with almost all available data.
- Check of pQCD framework
- Precise determination of the distributions

Data are taken from the experiments,

- SIA : TPC, TASSO, SLD, ALEPH, DELPHI, OPHAL, BELLE and BaBar
- SIDIS: HERMES, COMPASS
- Hadron-Hadron Collisions: PHENIX, STAR, BRAHMS, UA1 and ALICE

Global analysis method

Parametrization

$$\mathcal{D}_i^H(z, Q_0^2) = N_i z^{\alpha_i}(1-z)^{\beta_i}[1+\gamma_i(1-z)^{\delta_i}]$$

at scale

$$Q_0^2 = 1\ \text{GeV}^2 \qquad u, d, s, g$$

$$Q_0^2 = m_Q^2 \qquad c, b$$

Normalization for different experiments

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

$$D^{\pi^+}_{d+\bar{d}} = N D^{\pi^+}_{u+\bar{u}} \qquad D^{\pi^+}_{s} = N' D^{\pi^+}_{\bar{u}}$$

Allow flexible distributions for unfavored fragmentations,

$$\mathcal{D}^{\pi^+}_{\bar{u}} = N_{ud}(1-z)^{\epsilon_{ud}} \mathcal{D}^{\pi^+}_{d}$$

Model Ansatz for FFs with initial set of parameters

$$\mathcal{D}_i^H(z, Q_0^2) = N_i z^{\alpha_i}(1-z)^{\beta_i}[1+\gamma_i(1-z)^{\delta_i}]$$

28 parameters to fit

Evolve FFs to relevant scale using DGLAP

Integration using the Mellin Technique

$\otimes \rightarrow \cdot$

Calculate the observable and the χ^2

Minimum χ^2??

no

yes

adjust parameters

all data points

New grids using NLO MSTW2008 PDFs

Standard χ^2 minimization (MINUIT)

$$\chi^2 = \sum_{i=1}^{N} \frac{(T_i - E_i)^2}{\delta E_i}$$

Comparison between DSS and this analysis

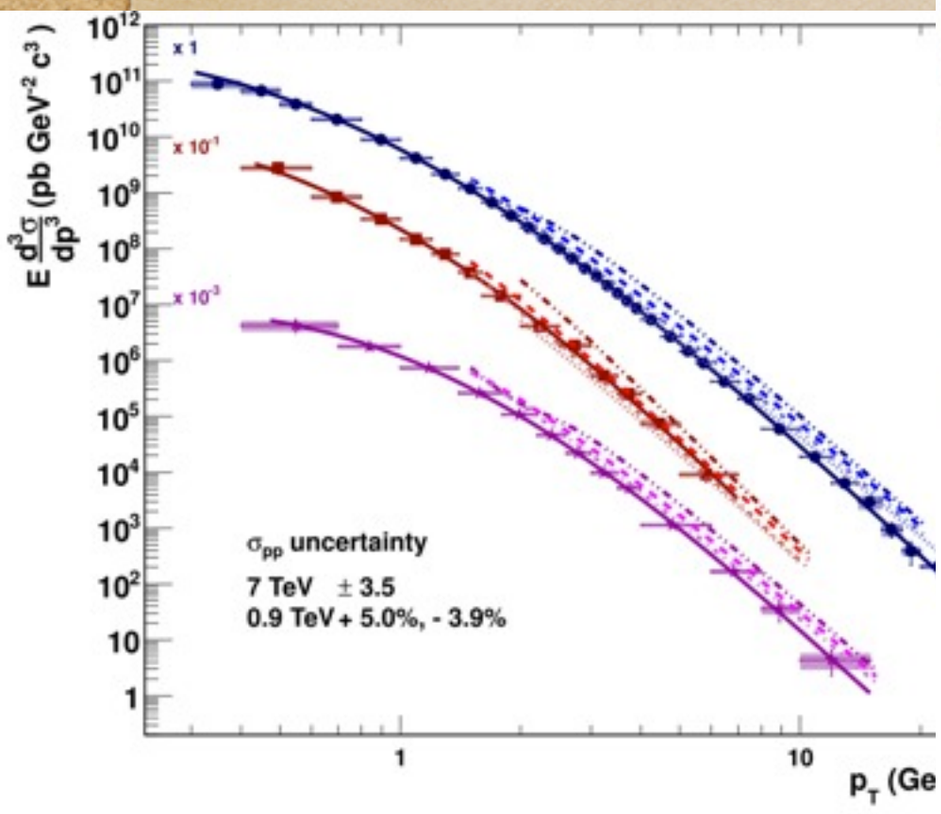
- Number of parameters: 23 parameters > 28 parameters
- HERMES data are replaced
- Apart from having new data sets, HERMES have replaced the data of proton and they include data from deuteron target
- Different treatment of normalization (analytical approach)
- PDFs: MSTW2008
- Relaxing some of the FFs assumptions

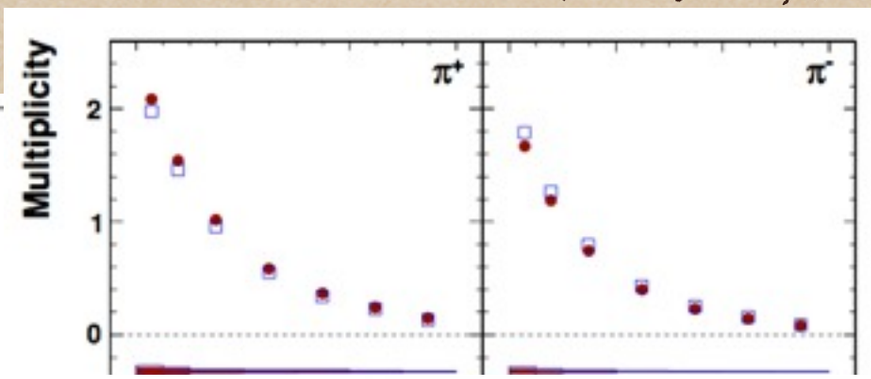
$$D^{\pi^+}_{d+\bar{d}} = N D^{\pi^+}_{u+\bar{u}} \qquad D^{\pi^+}_{\bar{u}} = D^{\pi^+}_{d} \qquad D^{\pi^+}_{s} = N' D^{\pi^+}_{\bar{u}}$$

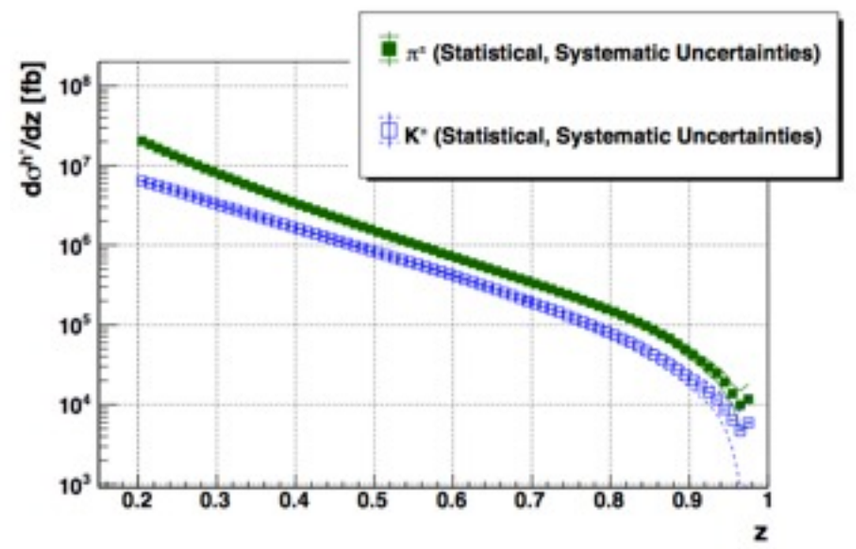
$$D^{\pi^+}_{s} \neq D^{\pi^+}_{\bar{s}}$$

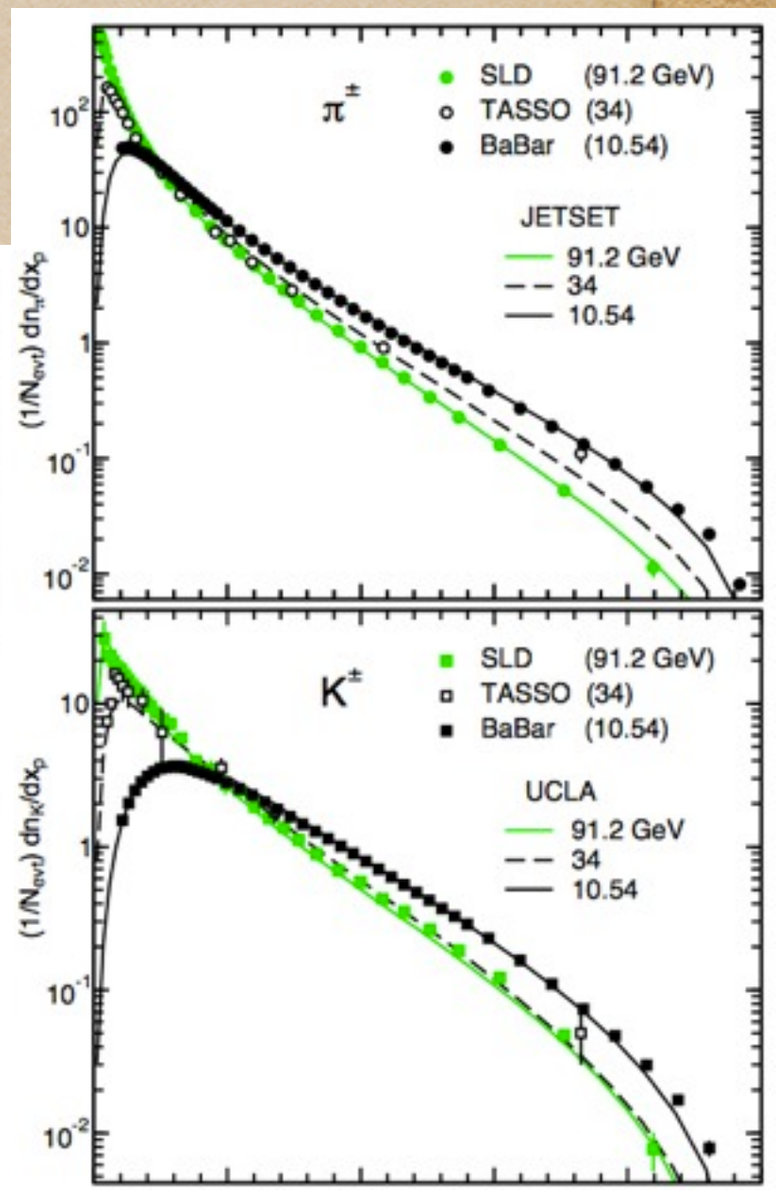
Many data sets have been published/shown since DSS analysis (2007)

- 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

- e+e- data are extremely important for the new fit because:

- They cover an unexplored high region of z

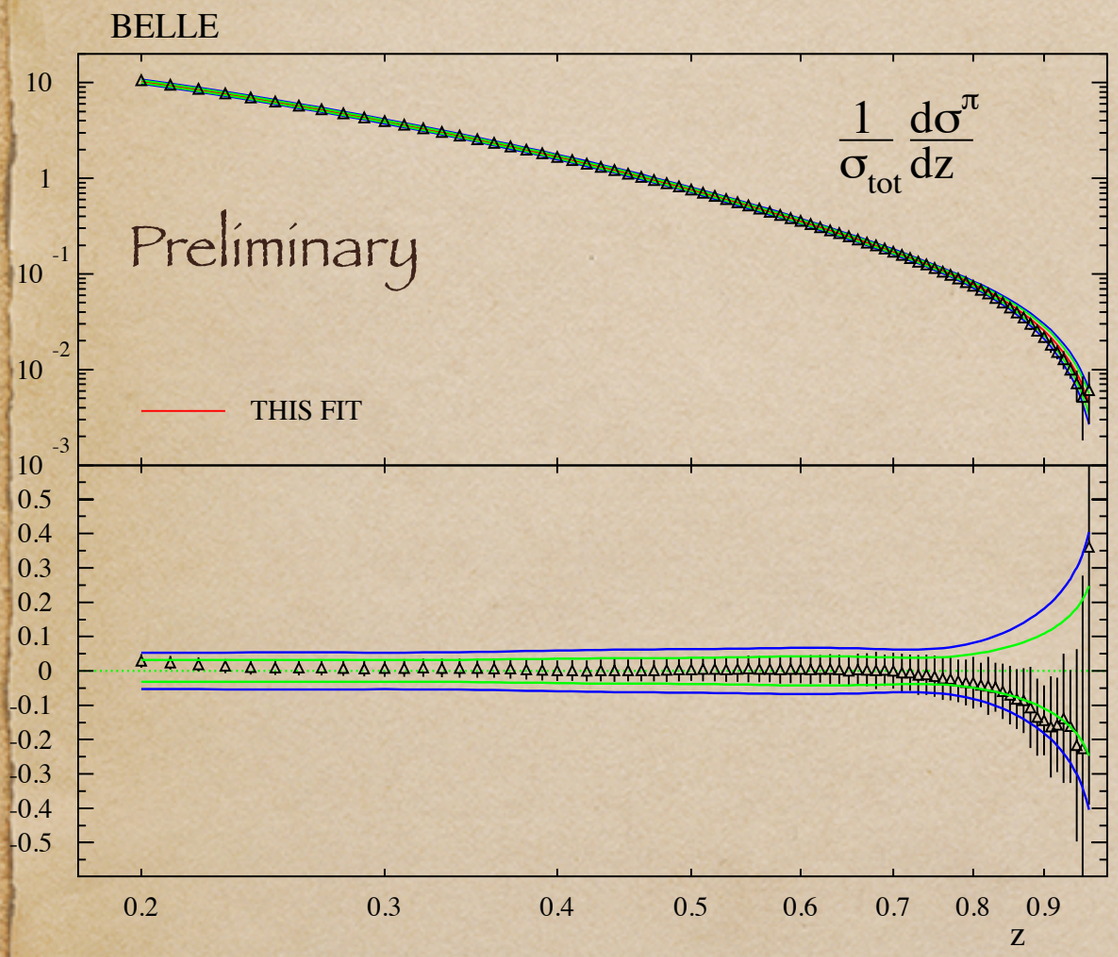
- BELLE has binning steps of 0.01 !!

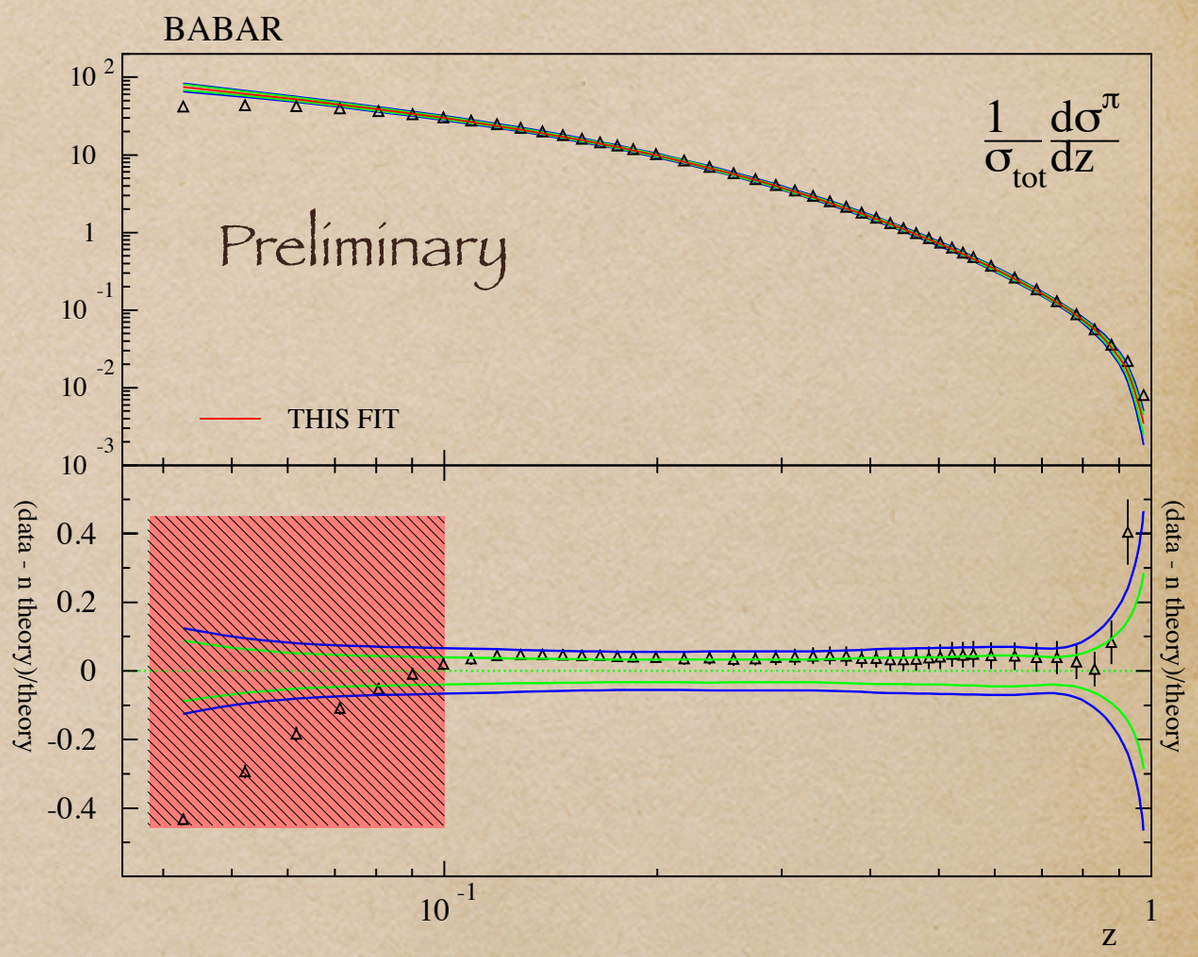
- Experimental measurements are determined with extreme accuracy

- Data normalization for BELLE has changed from preliminary > arXiv > PRL

- BELLE provides $d\sigma/dz$ not $(1/\sigma_{tot})d\sigma/dz$

BELLE & BaBar





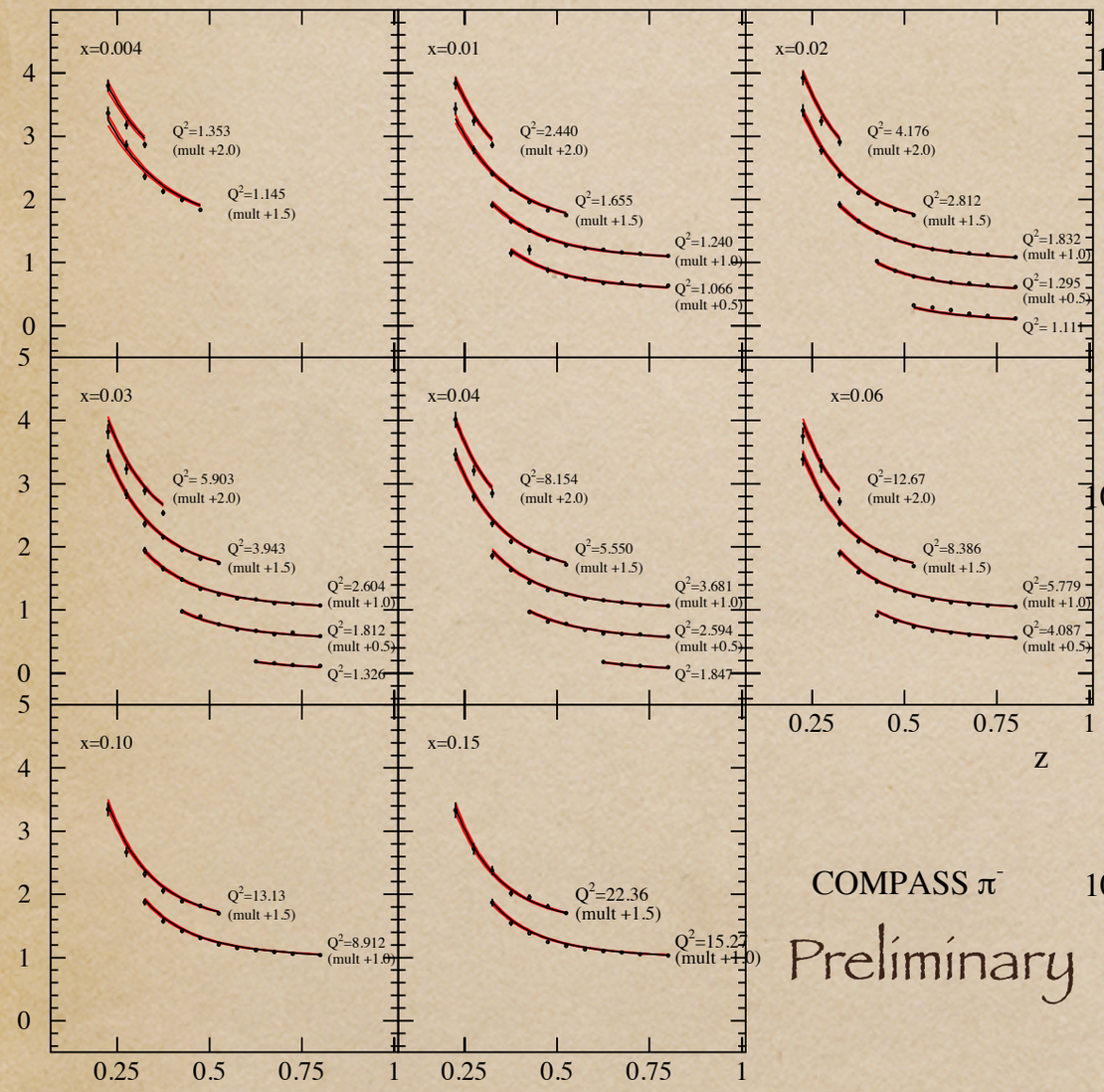
- BELLE and BaBar results can be fitted extremely well within the 68 and 90 % C.L.
- There is a drop on the large z regime for BELLE but it is consistent with the uncertainties

SIDIS data:
HERMES and COMPASS

- HERMES published their data sets (1212.5407), where they have modified the data for proton target and furthermore, they present the multiplicities for deuteron target

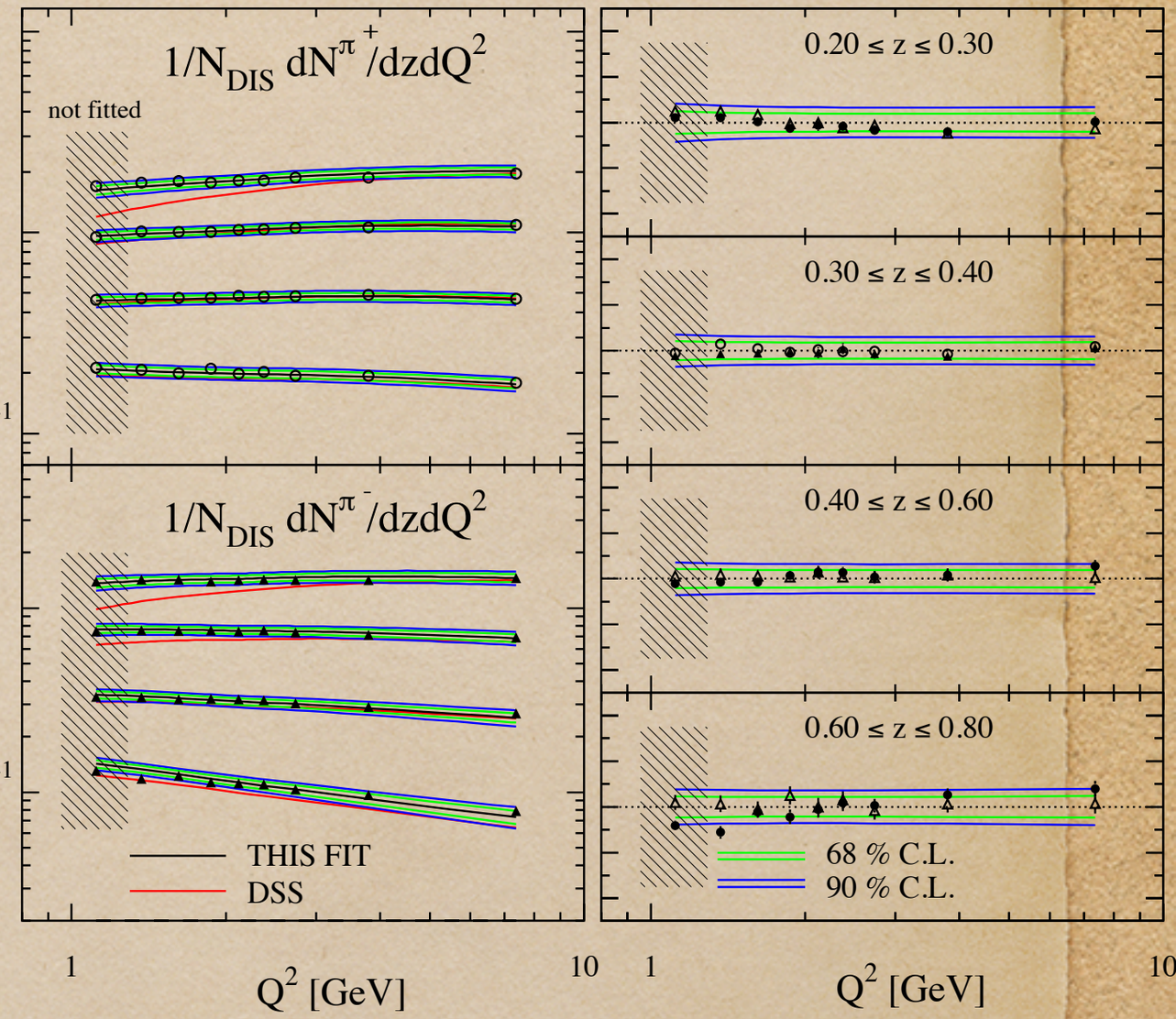
- COMPASS data is still preliminary (but they have shown pions multiplicities at DIS2013, arXiv:1307.3407) and we still not have the data for kaon multiplicities

COMPASS & HERMES



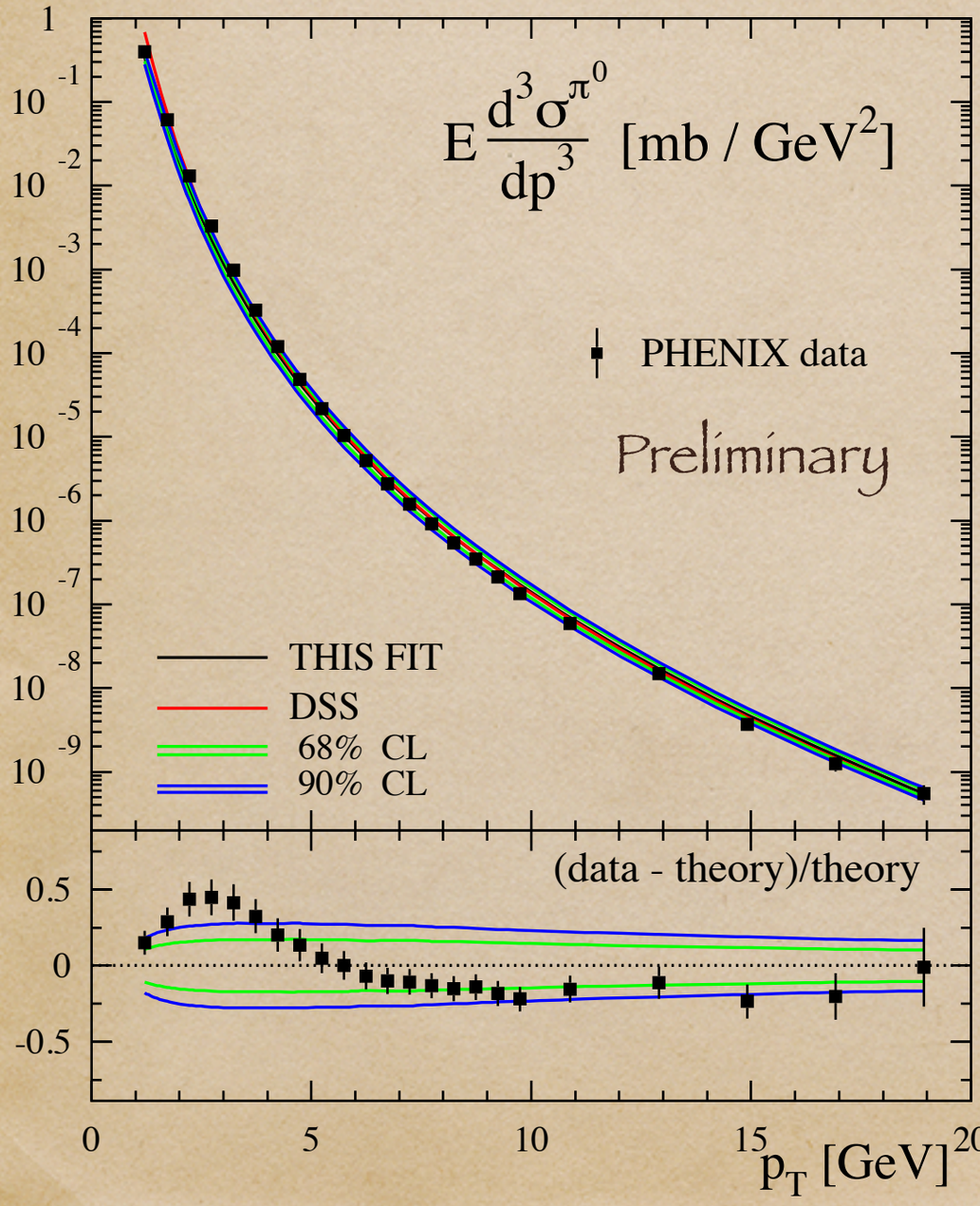
COMPASS π^-

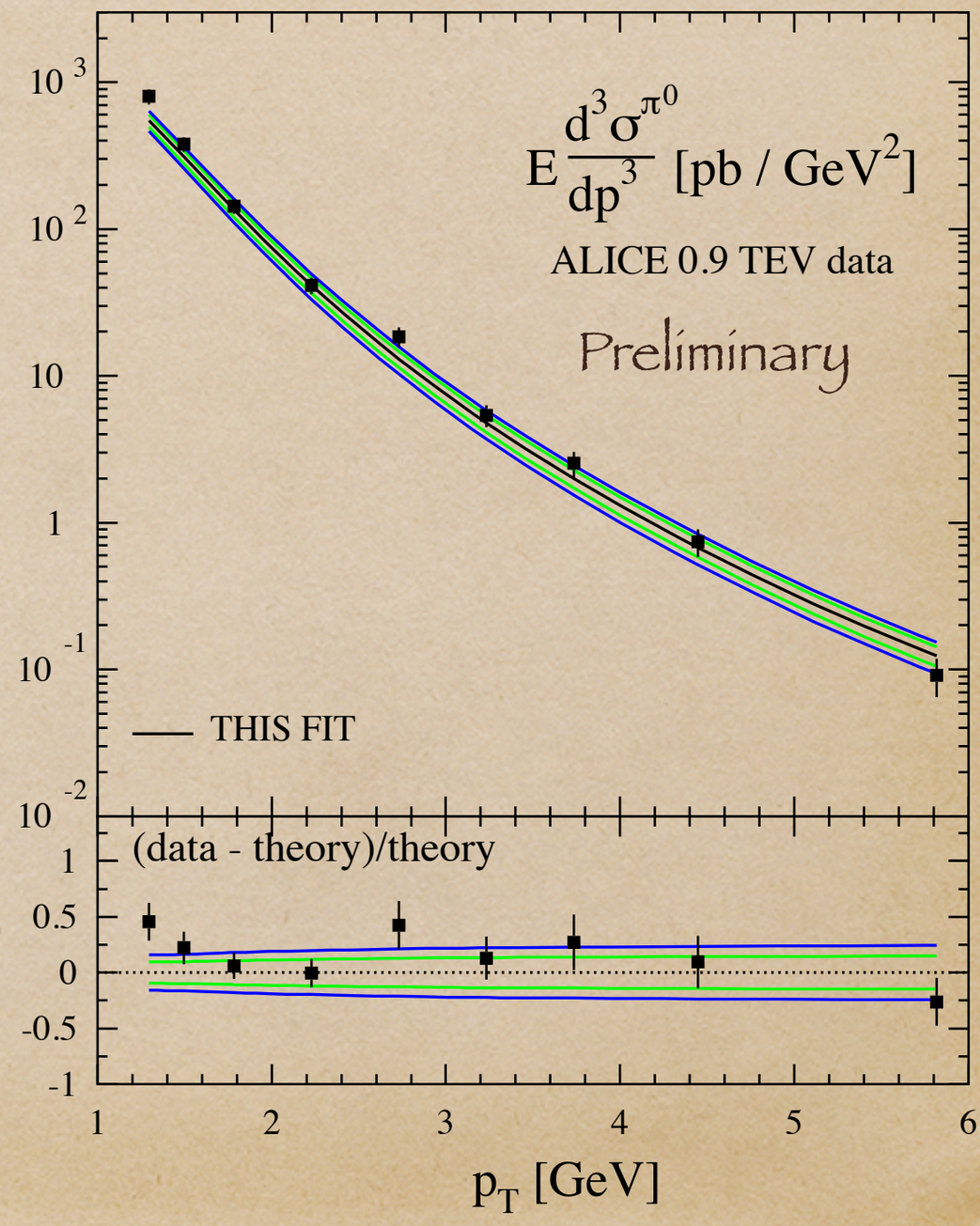
Preliminary



- COMPASS and HERMES data have no problems to be fitted in the 68 and 90% C.L. for all bins of z

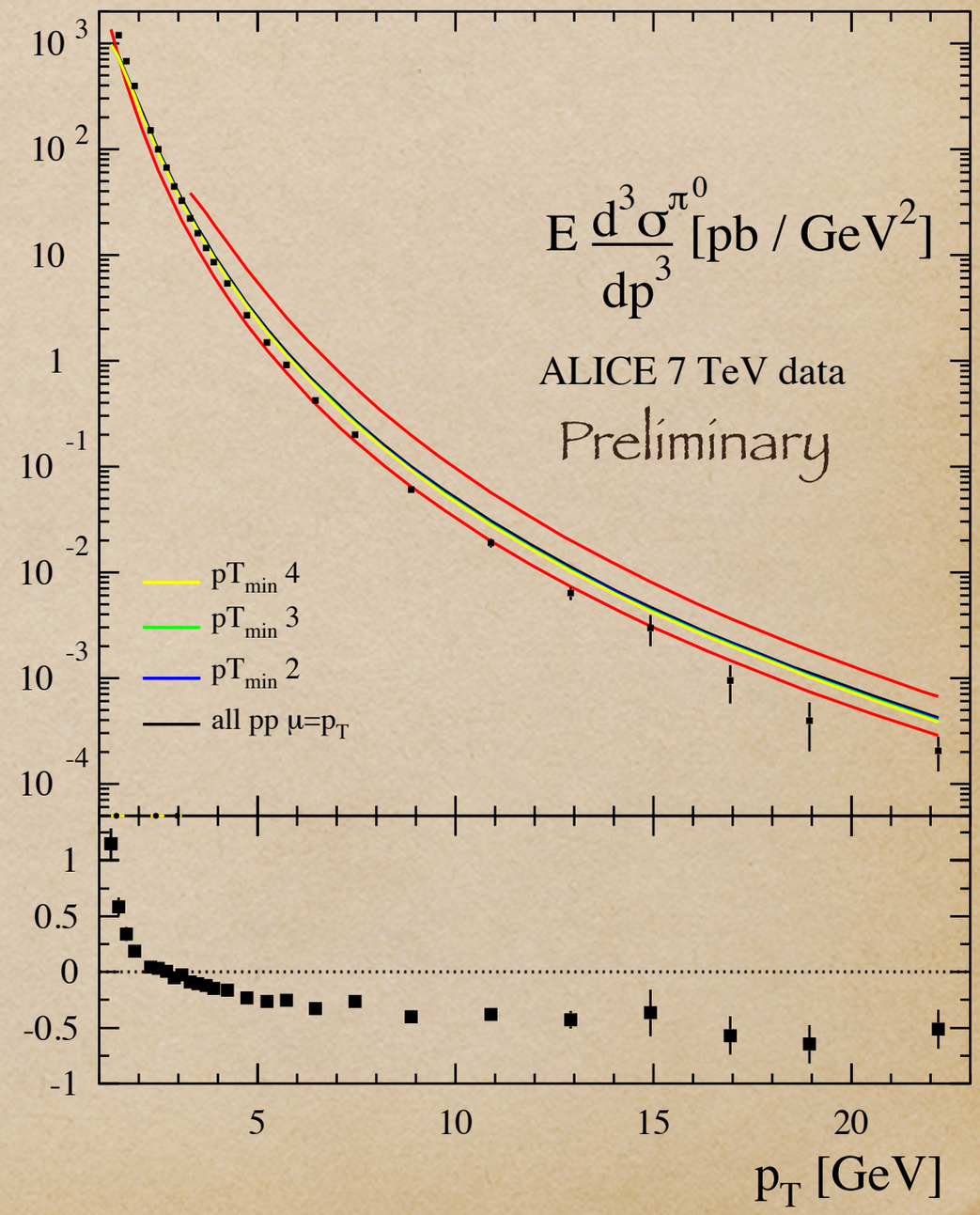
pp data:
PHENIX and ALICE



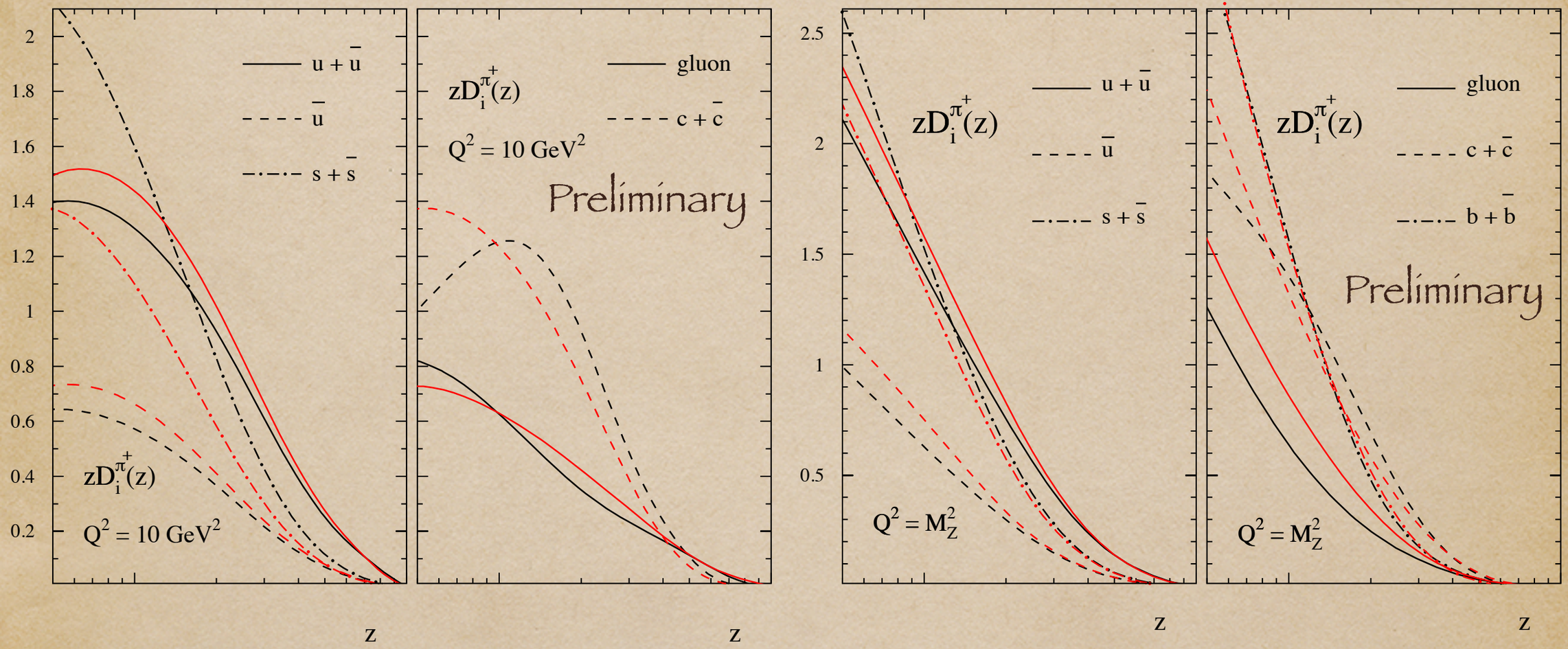


Remarks on pp data

- Not too complicated to fit the new RHIC data
- This fit works very well with almost all data except for 7 TeV ALICE
- It is hard to have a good agreement with respect to the other pion data ??
- Scale variation helps but it is still off.
- It is sensitive to lower pT cut



FFs

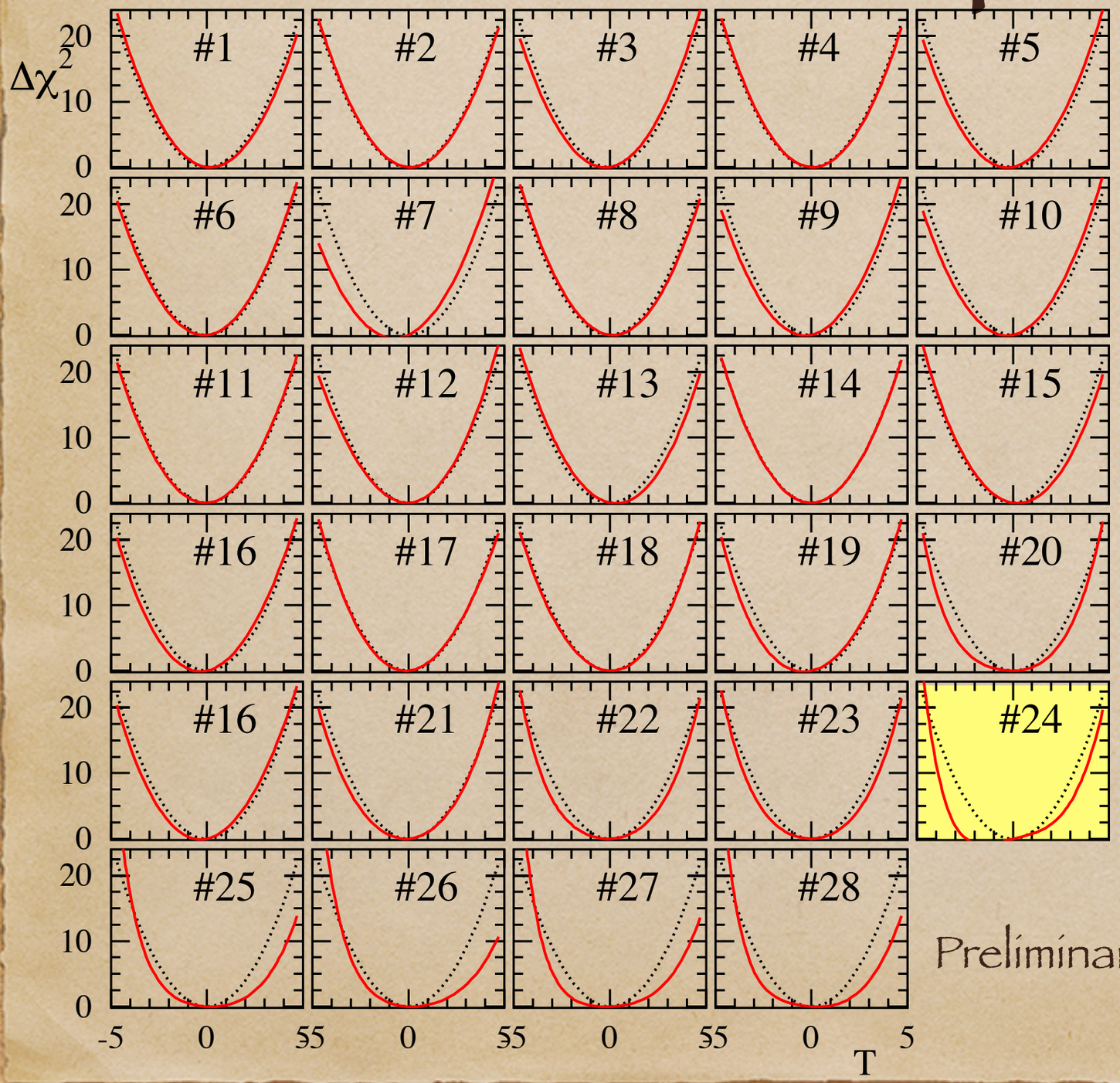


This preliminary fit is different from DSS since:

Charm and Bottom fragmentation functions have been given more freedom

FFs of strange quarks has been also relaxed

Profile of the parameters



Profiles are almost parabolic for all the 28 parameters !!!

It means that they are well determined from the fit

But, we still have something to check

Preliminary

After all, the numbers are...

flavor i	N_i	α_i	β_i	γ_i	δ_i
$u+\overline{u}$	0.345	-0.015	1.20	11.06	4.23
$d+\overline{d}$	0.380	-0.015	1.20	11.06	4.23
$\overline{u}=d$	0.115	0.520	3.27	16.26	8.46
$s+\overline{s}$	0.190	0.520	3.27	16.26	8.46
$c+\overline{c}$	0.271	-0.905	3.23	0.00	0.00
$b+\overline{b}$	0.501	-1.305	5.67	0.00	0.00
g	0.279	0.899	1.57	20.00	4.91

flavor i	N_i	α_i	β_i	γ_i	δ_i
$u+\bar{u}$	0.413	-0.263	0.941	11.99	4.48
$d+\bar{d}$	0.421	-0.263	0.941	11.99	4.48
$\bar{u}=d$	0.140	0.036	1.533	13.95	4.96
$s+\bar{s}$	0.409	0.036	1.533	13.95	4.96
$c+\bar{c}$	0.305	1.087	5.838	15.00	8.48
$b+\bar{b}$	0.409	-0.526	4.113	15.00	10.11
g	0.151	0.406	1.631	20.00	11.88

2007

t	data type	rel. norm. in fit	data points fitted	χ^2
TPC [15]	incl.	0.94	17	18.5
	"*uds* tag"	0.94	9	1.9
	"*c* tag"	0.94	9	5.7
	"*b* tag"	0.94	9	7.4
TASSO [17]	incl. (34 GeV)	0.94	11	30.1
	incl. (44 GeV)	0.94	7	20.5
SLD [16]	incl.	1.008	28	14.0
	"*uds* tag"	1.008	17	11.6
	"*c* tag"	1.008	17	11.1
	"*b* tag"	1.008	17	33.2
ALEPH [11]	incl.	0.97	22	38.3
DELPHI [12]	incl.	1.0	17	42.3
	"*uds* tag"	1.0	17	26.4
	"*b* tag"	1.0	17	42.8
OPAL [13, 14]	incl.	1.0	21	9.2
	"*u* tag"	1.10	5	11.8
	"*d* tag"	1.10	5	9.0
	"*s* tag"	1.10	5	49.8
	"*c* tag"	1.10	5	38.3
	"*b* tag"	1.10	5	73.0
HERMES [18]	π^+	1.03	32	67.4
	π^-	1.03	32	120.8
PHENIX [19]	π^0	1.09	23	76.4
STAR [22]	π^0, $\langle\eta\rangle = 3.3$	1.05	4	3.4
	π^0, $\langle\eta\rangle = 3.7$	1.05	5	9.8
BRAHMS [21]	π^+, $\langle\eta\rangle = 2.95$	1.0	18	28.2
	π^-, $\langle\eta\rangle = 2.95$	1.0	18	43.0
TOTAL:			392	843.7

2013

Experiment	Data type	Data points fitted	χ^2
TPC	Inclusive	17	32.6
	"*uds* tag"	9	2.2
	"*c* tag"	9	7.1
	"*b* tag"	9	8.9
TASSO	Inclusive (34 GeV)	11	28.4
	Inclusive (44 GeV)	7	21.9
SLD	Inclusive	28	15.0
	"*uds* tag"	17	18.2
	"*c* tag"	17	21.9
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ALEPH	Inclusive	22	18.1
DELPHI	Inclusive	17	23.9
	"*uds* tag"	17	24.0
	"*b* tag"	17	12.5
OPAL	Inclusive	21	17.9
	"*u* tag"	5	19.9
	"*d* tag"	5	17.9
	"*s* tag"	5	32.1
	"*c* tag"	5	24.9
	"*b* tag"	5	14.1
BELLE	π^0	78	36.6
BABAR	π^0	39	103.5
HERMES	$\pi^\pm$, proton target	32	57.9
	$\pi^\pm$, deuteron target	32	65.7
COMPASS	π^+	199	176.3
	π^-	199	246.9
PHENIX	π^0	23	1.32
STAR	π^0, $\langle\eta\rangle = 3.3$	4	0.05
	π^0, $\langle\eta\rangle = 3.7$	5	0.18
	π^0, 2009 data	13	1.26
	π^0, 2012 data	14	1.20
	$\pi^\pm$	16	6.26
BRAHMS	π^+, $\langle\eta\rangle = 2.95$	18	7.3
	π^-, $\langle\eta\rangle = 2.95$	18	5.5
ALICE	π^0, $\sqrt{s} = 900$ GeV	9	2.80
	π^0, $\sqrt{s} = 7$ TeV	27	61.66
TOTAL:		986	1,144.3

2007

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	"*uds* tag"	17	24.0
	"*b* tag"	17	12.5
OPAL	Inclusive	21	17.9
	"*u* tag"	5	19.9
	"*d* tag"	5	17.9
	"*s* tag"	5	32.1
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ALEPH [11]			22	38.3
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	π^-, $\langle\eta\rangle = 2.95$	1.0	18	43.0
TOTAL:			392	843.7

$\chi^2 \sim 2.07$

2013

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	"*b* tag"	17	8.4
ALEPH	Inclusive	22	18.1
DELPHI	Inclusive	17	23.9
			24.0
			12.5
OPA			17.9
			19.9
			17.9
	"*s* tag"	5	32.1
	"*c* tag"	5	24.9
	"*b* tag"	5	14.1
BELLE	π^0	78	36.6
BABAR	π^0	39	103.5
HERMES	$\pi^\pm$, proton target	32	57.9
	$\pi^\pm$, deuteron target	32	65.7
COMPASS	π^+	199	176.3
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PHENIX	π^0	23	1.32
STAR	π^0, $\langle\eta\rangle = 3.3$	4	0.05
	π^0, $\langle\eta\rangle = 3.7$	5	0.18
	π^0, 2009 data	13	1.26
	π^0, 2012 data	14	1.20
	$\pi^\pm$	16	6.26
BRAHMS	π^+, $\langle\eta\rangle = 2.95$	18	7.3
	π^-, $\langle\eta\rangle = 2.95$	18	5.5
ALICE	π^0, $\sqrt{s} = 900$ GeV	9	2.80
	π^0, $\sqrt{s} = 7$ TeV	27	61.66
TOTAL:		986	1,144.3

$\chi^2 \sim 1.2$

2007

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TPC [15]	incl.	0.94	17	18.5
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TOTAL:			392	843.7

$\chi^2 \sim 2.07$

2013

Experiment	Data type	Data points fitted	χ^2
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	"*uds* tag"	9	2.2
	"*c* tag"	9	7.1
	"*b* tag"	9	8.9
TASSO	Inclusive (34 GeV)	11	28.4
	Inclusive (44 GeV)	7	6.[illegible]
SLD	Inclusive	28	
	"*uds* tag"	17	
	"*c* tag"		
	"*b* tag"		
ALEPH	Inclusive		
DELPHI	Inclusive		
OPAL			2.5
			17.9
			19.9
			17.9
		5	32.1
		5	24.9
		5	14.1
		78	36.6
	π^0	39	103.5
	proton target	32	57.9
	, deuteron target	32	65.7
	π^+	199	176.3
	π^-	199	246.9
PHENIX	π^0	23	1.32
STAR	π^0, $\langle\eta\rangle = 3.3$	4	0.05
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	π^0, 2009 data	13	1.26
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ALICE	π^0, $\sqrt{s} = 900$ GeV	9	2.80
	π^0, $\sqrt{s} = 7$ TeV	27	61.66
TOTAL:		986	1,144.3

χ^2

Preliminary

Conclusions

- Global QCD fit of pion fragmentation functions are well understood
- Many data sets help to extract more accurate FFs
- e+e-: BELLE and BaBar add more data at scales other than LEP
- SIDIS: Both COMPASS and HERMES pion multiplicities are very well fitted
- pp: new RHIC and LHC results are considered in the new fit although it could be a normalization issue with ALICE results
- The Hessian method have been used to extract also the uncertainties on the FFs and the data is consistent at 68 and 90% C.L.
- More data help to extract precisely pion FFs with uncertainties
- Kaon FFs will be released once COMPASS results become available...

Thanks...