Fragmentation Function studied with e+-e- data and its impact on the nucleon spin structure analysis

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Contents

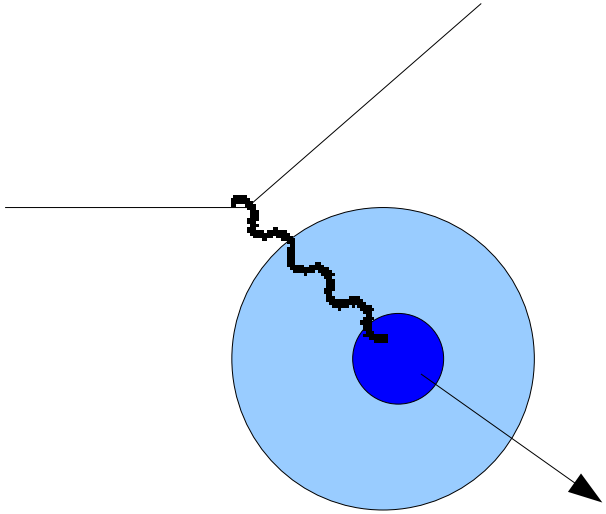
- Fragmentation and parton distribution function
- Resent fragmentation function analysis
- Impact on the proton spin structure analysis
  - Strange quark component and kaon fragmentation
- Quark transversity and Collins fragmentation function
- Fragmentation function analysis in Belle
- Summary

Parton distribution and Fragmentation functions

q(x)

Probability of finding a parton with momentum fraction x of a parent proton q

Deep inelastic scattering (DIS)

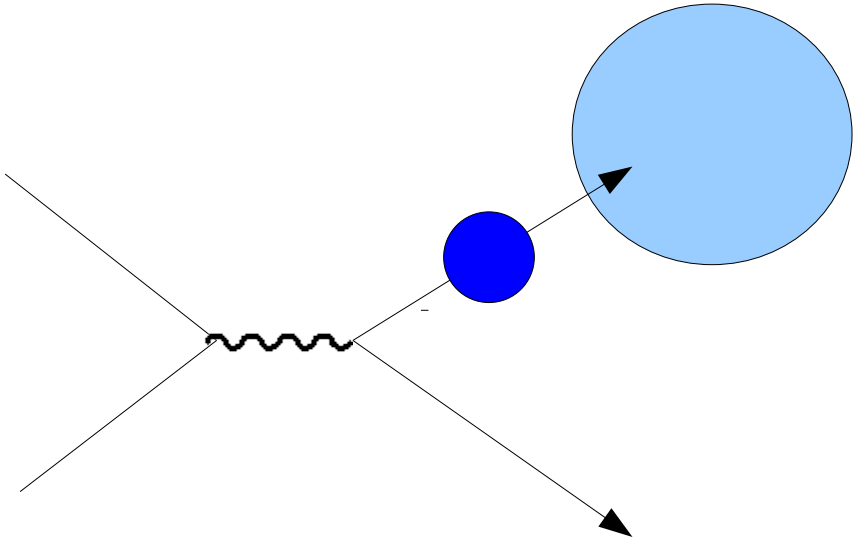


$$\sum_q \int_0^1 dx\, x \cdot q(x) = 1$$

$D_q^h(z)$

Probability of fragmenting to a hadron h with energy fraction z of a parent parton q

Single inclusive anihiration (SIA)



$$\sum_h \int_0^1 dz\, z\, D_q^h(z) = 1$$

Semi-inclusive DIS

$$\vec{l} + \vec{N} \to l' + h + X$$

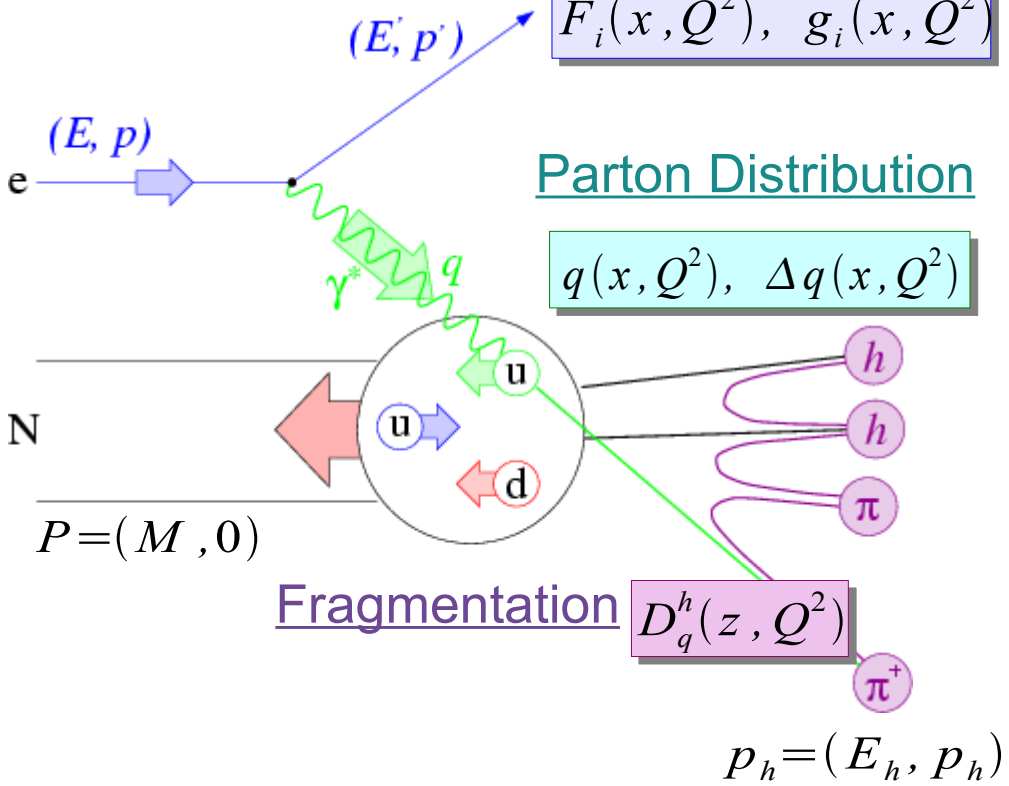
$$\frac{d^3\sigma^h}{dx\,dz\,dQ^2} \propto \sum_i e_q^2 q(x,Q^2) D_q^h(z,Q^2)$$

$$\frac{d^3\Delta\sigma^h}{dx\,dz\,dQ^2} \propto \sum_i e_q^2 \Delta q(x,Q^2) D_q^h(z,Q^2)$$

$$z = \frac{P\cdot p_h}{P\cdot q} = \frac{E_h}{\nu}$$

Structure Function

$F_i(x,Q^2),\ \ g_i(x,Q^2)$



Parton Distribution

$q(x,Q^2),\ \ \Delta q(x,Q^2)$

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

$p_h=(E_h, p_h)$

FF and PDF are equally important to analyze high energy process with hadron production

Flavor Tagging:

Hadron carries information on quark flavor through fragmentation function

Fragmentation function parametrization

Parametrize functional form:

$$D(z) \propto N_i z^{\alpha} (1-z)^{\beta} \left[1 + \gamma (1-z)^{\delta} \right]$$

N: 2nd moment of D(z)

Constraint: no sensitivity on quark and anti-quark separation
weak quark flavor sensitivity (especially for light quarsk: u, d, s)
Favored – dis-favored fragmentation

$$D^{disfav} = (1-z) \cdot D^{fav}$$

Fit the available data from the experiments:
Determine the parameters (and possibly their uncertainty)

- S. **Kretzer**	Phys. Rev. D 62, 054001 (2000)
- B.A. **K**niehl, G. **K**ramer and B. **P**ötter	Nucl. Phys. B582, 514 (2000)
- M. **H**irai, S. **K**umano, T.-H. **N**agai, K. **S**udoh.	Phys. Rev. D75, 094009 (2007)
- **D**. de Florian, R. **S**assot, M. **S**tratmann	Phys. Rev. D75, 114010 (2007)
	Phys. Rev. Lett. 76, 074033 (2007)

Including Hadron multiplicity in SIDIS and hadron cross-section in p-p
(allow to loose some constraint)

Available data for FF analysis

DSS, Phys. Rev. D75, 114010 (2007),

pion

Experiment	Data type	Relative normalization in fit	Data points fitted	χ^2
TPC [15]	Inclusive	0.94	17	18.5
29GeV	"uds tag"	0.94	9	1.9
	"c tag"	0.94	9	5.7
	"b tag"	0.94	9	7.4
TASSO [38]	Inclusive (34 GeV)	0.94	11	30.1
	Inclusive (44 GeV)	0.94	7	20.5
SLD [16]	Inclusive	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]	Inclusive	0.97	22	38.3
DELPHI [12]	Inclusive	1.0	17	42.3
	"uds tag"	1.0	17	26.4
	"b tag"	1.0	17	42.8
OPAL [13,14]	Inclusive	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 [17]	π^+	1.03	32	67.4
	π^-	1.03	32	120.8
PHENIX [18]	π^0	1.09	23	76.4
STAR [22]	$\pi^0, \langle\eta\rangle = 3.3$	1.05	4	3.4
	$\pi^0, \langle\eta\rangle = 3.7$	1.05	5	9.8
BRAHMS [21]	$\pi^+, \langle\eta\rangle = 2.95$	1.0	18	28.2
	$\pi^-, \langle\eta\rangle = 2.95$	1.0	18	43.0
Total			392	843.7

Phys. Rev. Lett. 76, 074033 (2007)

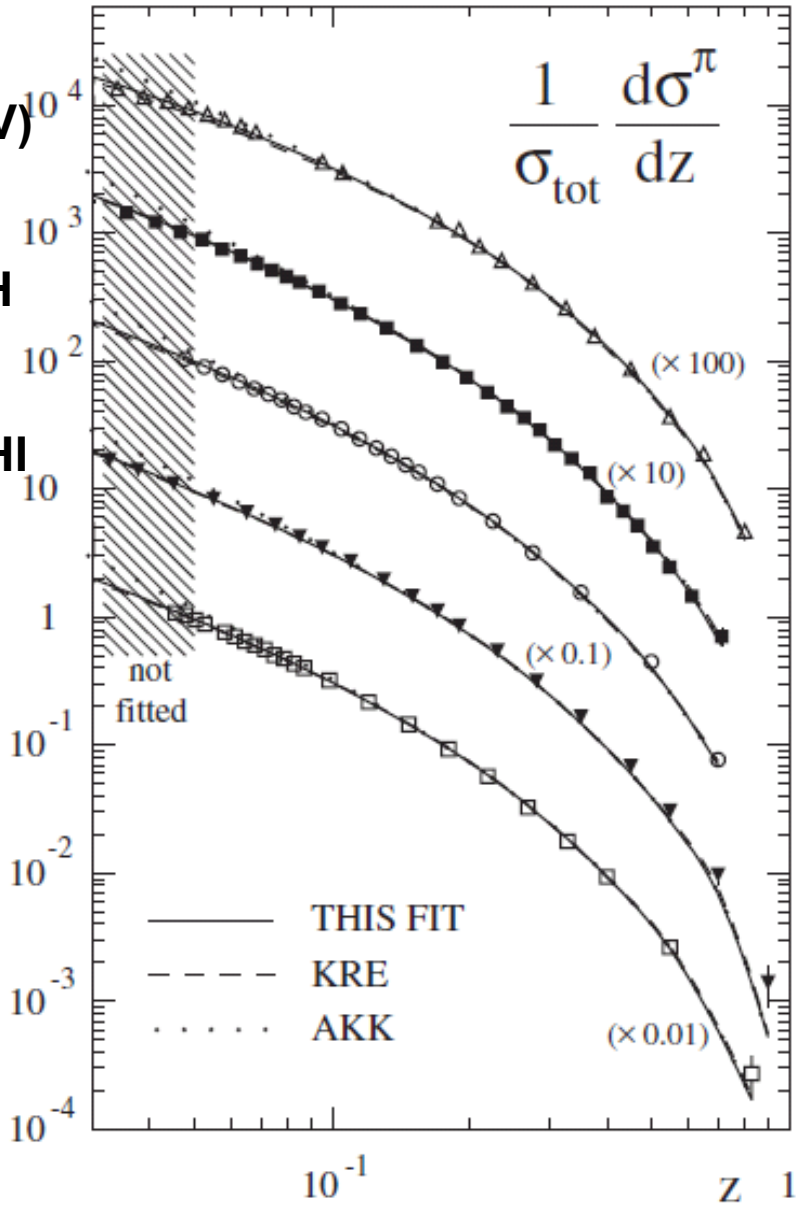
kaon

Experiment	Data type	Relative normalization in fit	Data points fitted	χ^2
TPC [15]	Inclusive	0.94	12	9.5
29GeV SLD [16]	Inclusive	0.983	18	14.4
	"uds tag"	0.983	10	14.4
	"c tag"	0.983	10	17.2
	"b tag"	0.983	10	15.2
ALEPH [11]	Inclusive	0.97	13	12.3
DELPHI [12]	Inclusive	1.0	12	1.0
	"uds tag"	1.0	12	2.3
	"b tag"	1.0	12	4.3
OPAL [14]	"u tag"	1.10	5	6.5
	"d tag"	1.10	5	9.9
	"s tag"	1.10	5	36.8
	"c tag"	1.10	5	44.9
	"b tag"	1.10	5	18.6
HERMES [17]	K^+	1.03	24	15.0
	K^-	1.03	24	79.3
STAR [20]	K^0_S	0.95	14	40.0
BRAHMS [21]	$K^+, \langle\eta\rangle = 2.95$	1.0	18	28.8
	$K^-, \langle\eta\rangle = 2.95$	1.0	18	21.5
Total			232	394.1

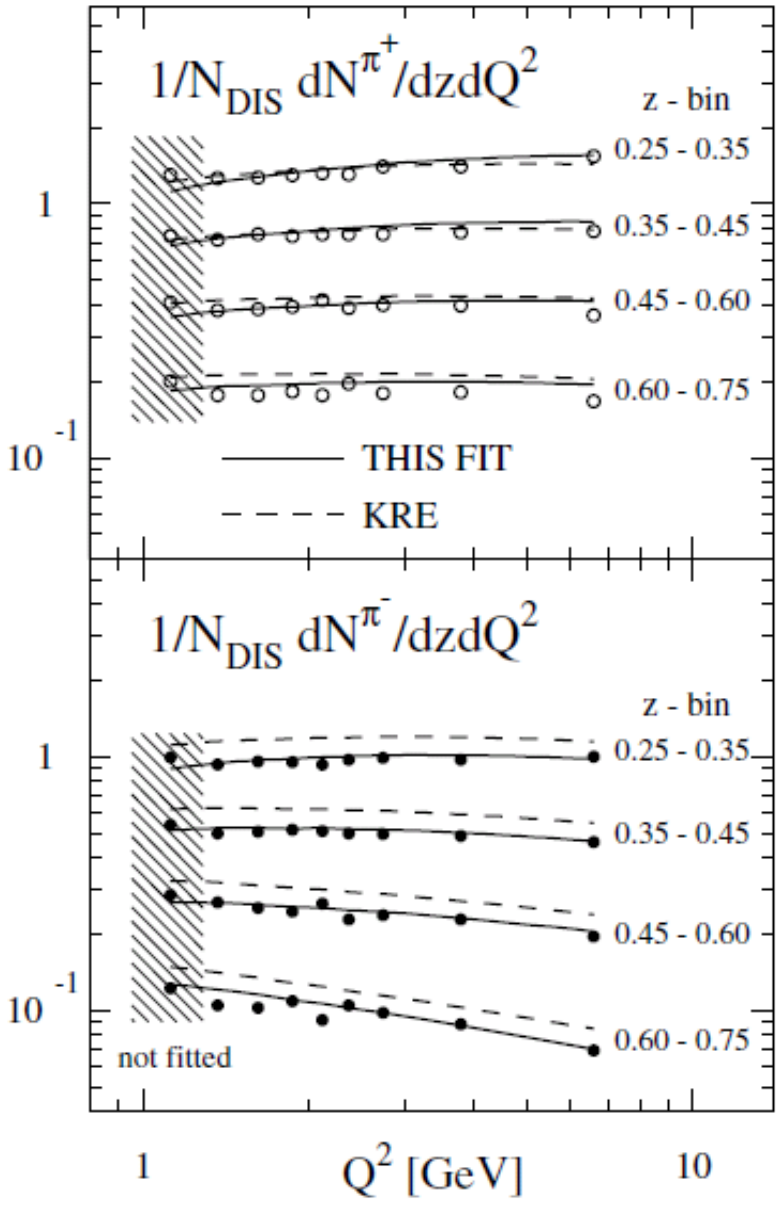
Pion Fragmentation Analysis

DSS, Phys. Rev. D75, 114010 (2007)

TPC (29GeV)
SLD (Mz)
ALEPH (Mz)
DELPHI (Mz)
OPAL (Mz)



HERMES



HERMES

+ charged and neutral pions in pp

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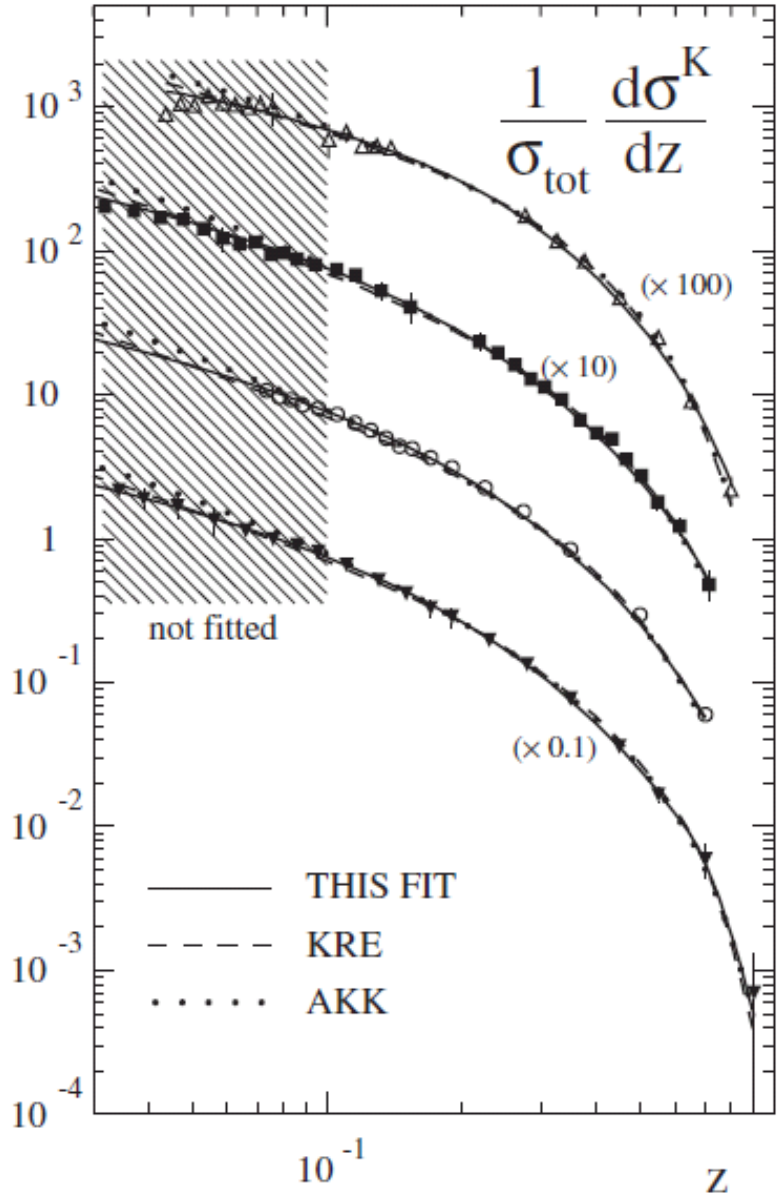
Data used for kaon fragmentation

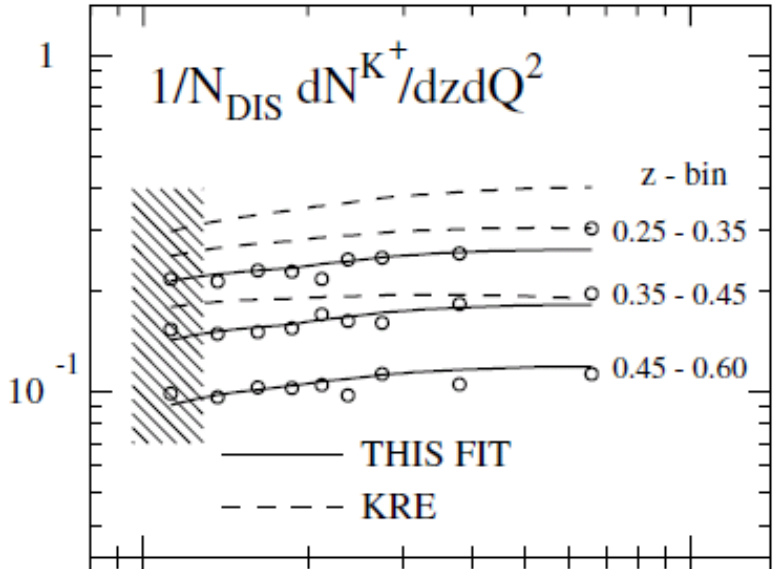
DSS, Phys. Rev. D75, 114010 (2007)

TPC (29GeV)
SLD (Mz)
ALEPH (Mz)

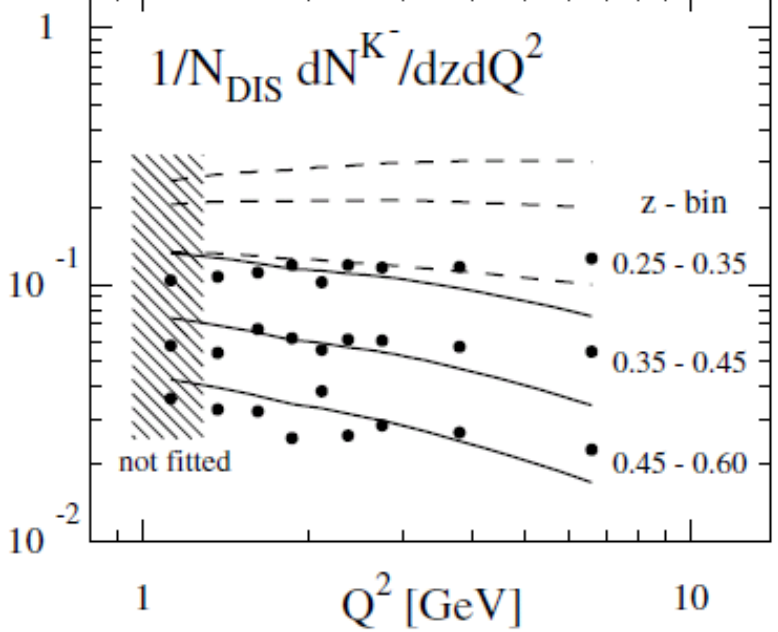
DELPHI (Mz)



HERMES



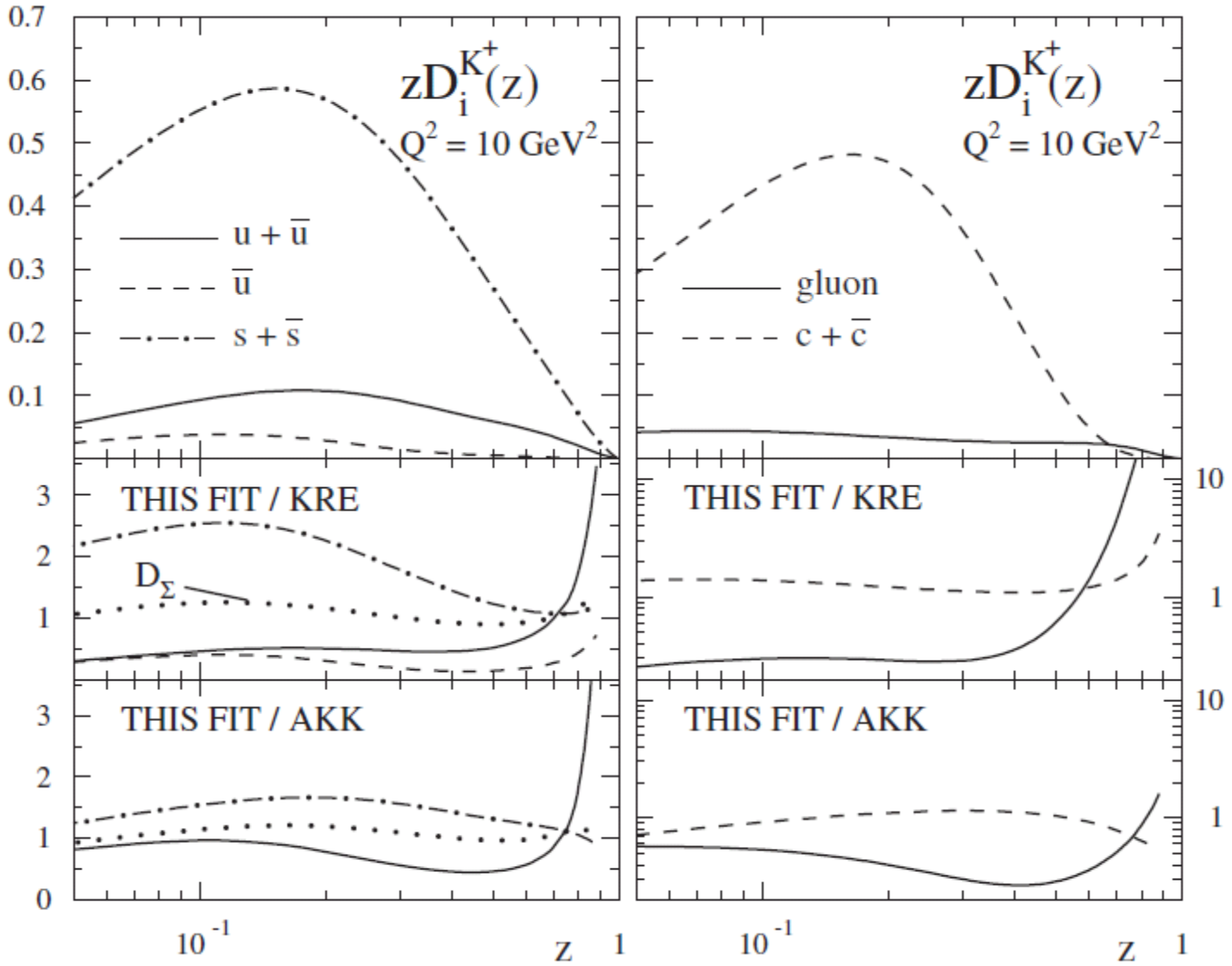
HERMES



+ charged kaon produciton in pp scattering

Extracted kaon fragmentation function

DSS, Phys. Rev. D75, 114010 (2007)



DSS: e+e-, SIDIS, pp

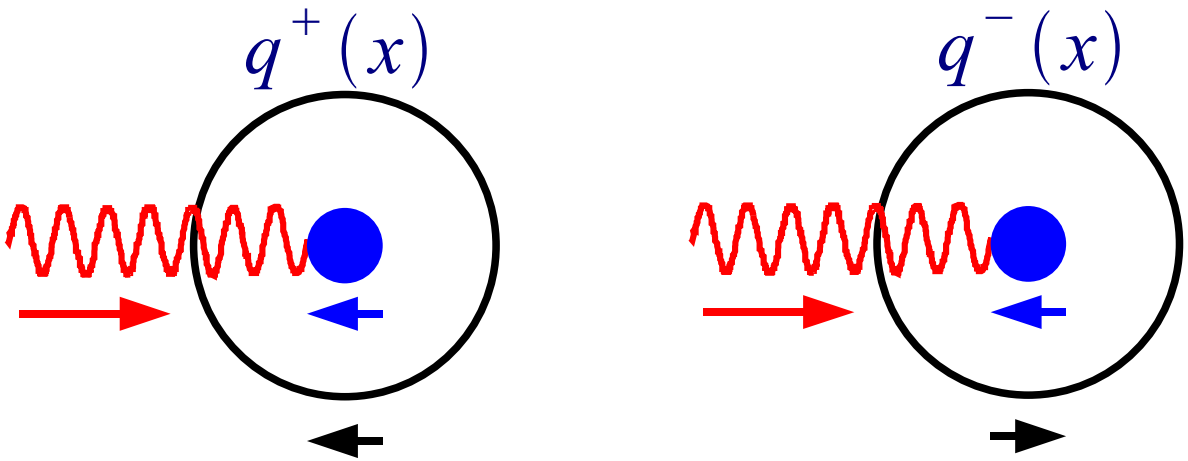
Kretzer: e+e-

AKK: e+e-

Impact on the nucleon spin analysis

- strange quark spin component Δs

Helicity distribution function Δq



$$F_1(x)=\frac{1}{2}\sum_q e_q^2 q(x) \qquad q(x)=q^+(x)+q^-(x)$$

$$g_1(x)=\frac{1}{2}\sum_q e_q^2 \Delta q(x) \qquad \Delta q(x)=q^+(x)-q^-(x)$$

Spin sum rule: $$\sum_q \int_0^1 \Delta q(x)=\frac{1}{2}$$

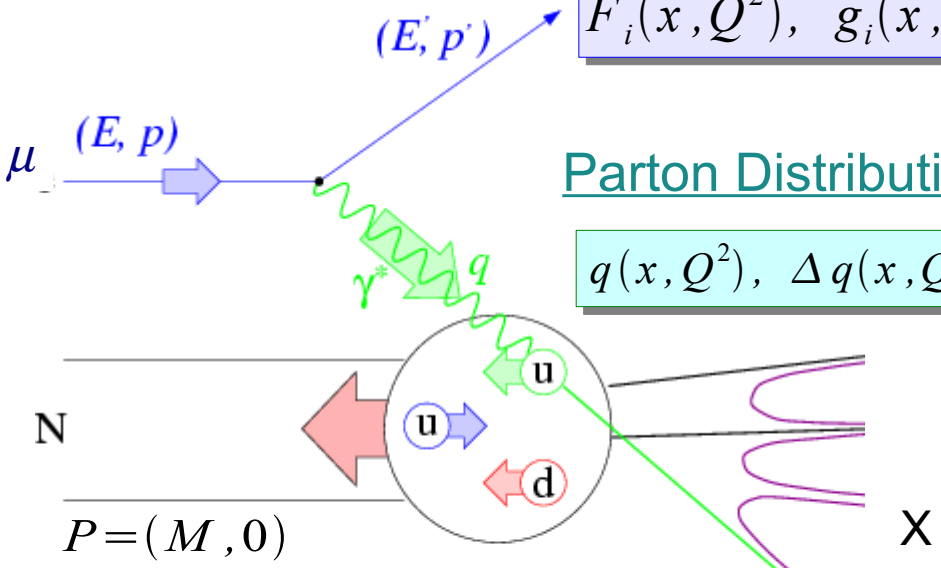
Proton spin problem

Polarized DIS:

$$\vec{\mu} + \vec{N} \rightarrow \mu' + X$$

Structure Function

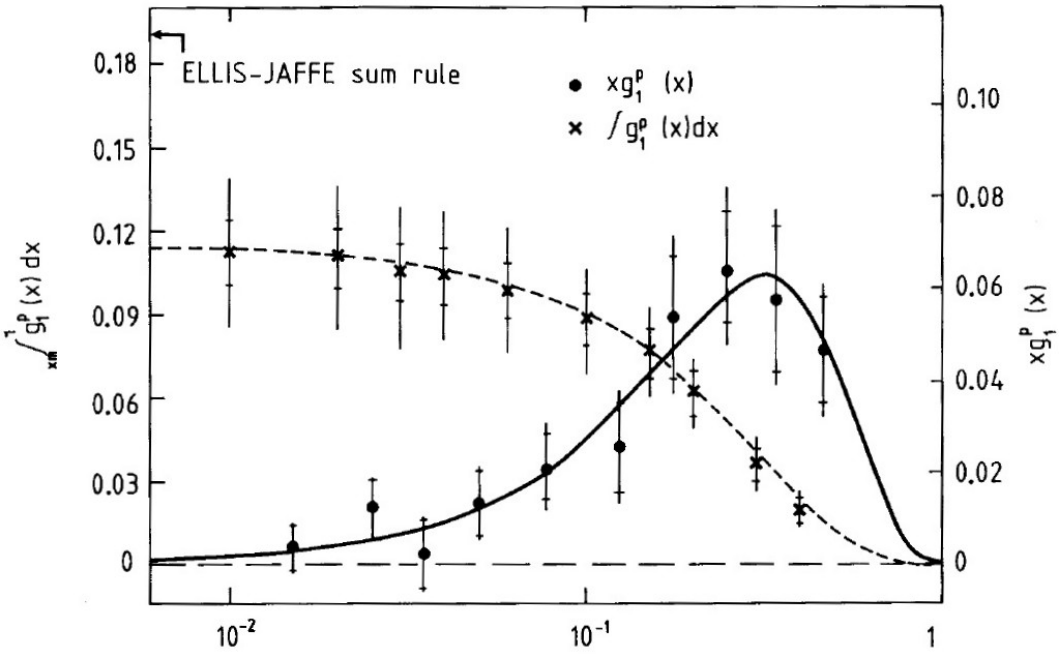
$$F_i(x, Q^2), \quad g_i(x, Q^2)$$



Parton Distribution

$$q(x, Q^2), \quad \Delta q(x, Q^2)$$

Nucl. Phys. B328 (1989) 1, Phys. Lett. B206 (1988) 364



$$\int_0^1 dx\, g_1^p(x) = \frac{1}{9} a_0 + \frac{1}{12} a_3 + \frac{1}{36} a_8$$

$$= 0.126 \pm 0.01 \pm 0.015$$

SU(3) flavor symmetry

$$a_3 = 1.26, \; a_8 = 0.58$$

$$\sum_q \Delta q \sim 0.1 \qquad \Delta s \sim -0.19 \qquad \Delta G > 0$$

Updated results on g_1 and Δs

Phys. Rev. D 75 (2007) 012007

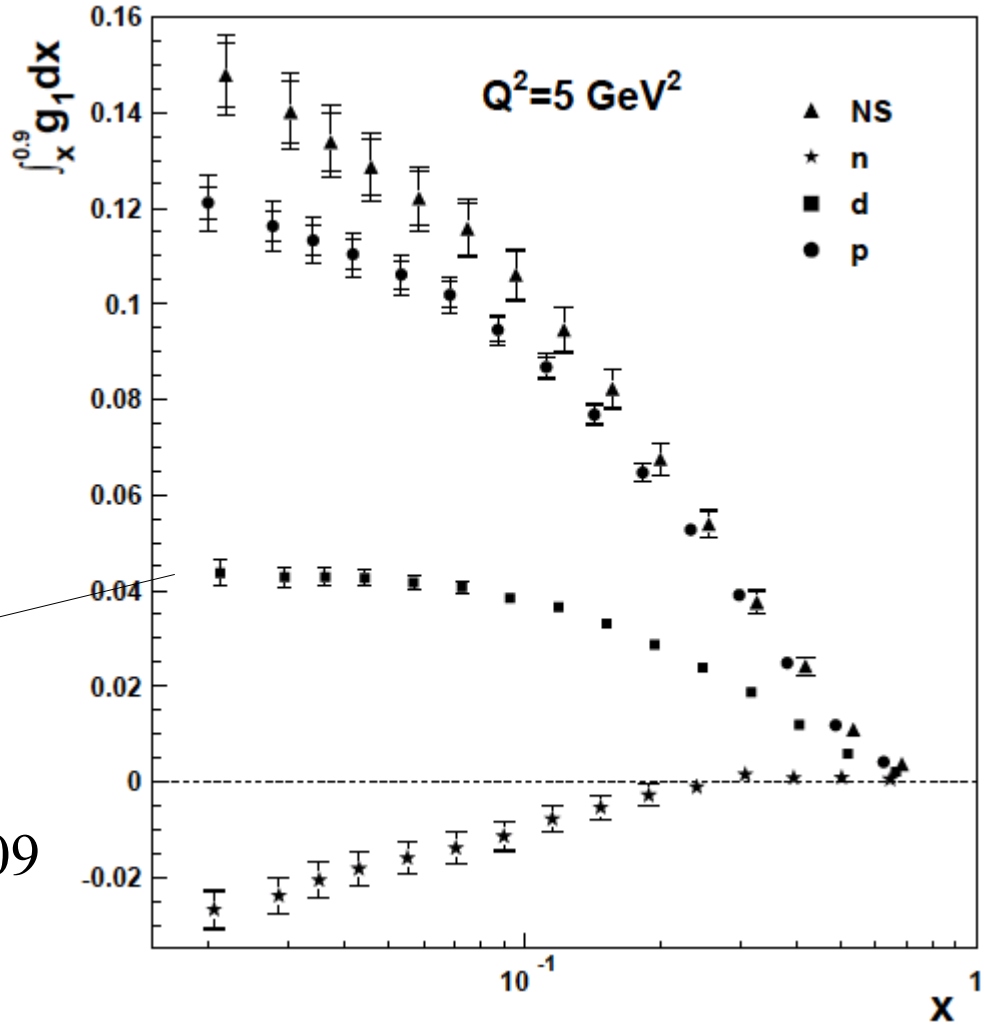
Procedure and assumption:

- Q^2 evolution to 5GeV² with NLO pQCD
- High x contribution = 0
- Saturation in the lower *x* region
- SU(3) flavor symmetry:

$$\int_{0.021}^{0.9} g_1^d(x, 5\,\mathrm{GeV}^2)dx =$$

$$0.0436 \pm 0.0012 \pm 0.018 \pm 0.0008 \pm 0.0026$$

$$\Delta s(5\,\mathrm{GeV}^2) = -0.085 \pm 0.013 \pm 0.008 \pm 0.009$$



Phys. Lett. B 647 (2007) 8:

Assuming SU(3) flavor symmetry

$$\Delta s(\infty) = -0.08 \pm 0.01 \pm 0.02$$

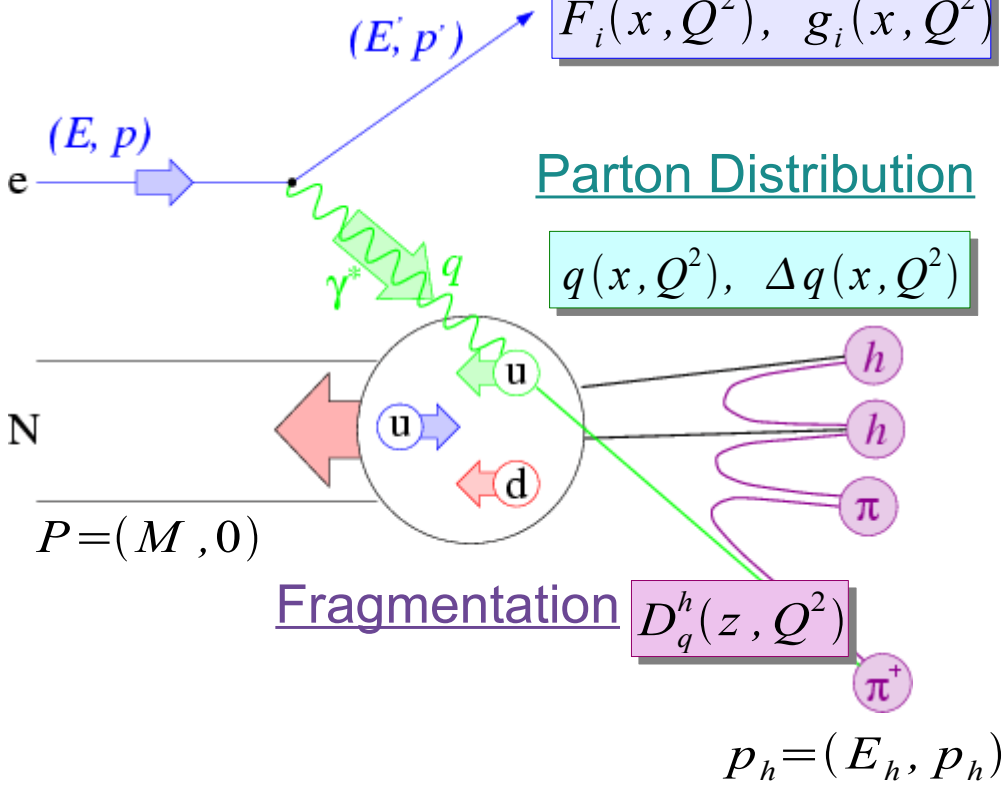
No Fragmentation function involved.

Semi-inclusive DIS

$$\vec{l} + \vec{N} \rightarrow l' + h + X$$

Structure Function

$F_i(x, Q^2),\ \ g_i(x, Q^2)$



Parton Distribution

$q(x, Q^2),\ \ \Delta q(x, Q^2)$

$$\frac{d^3\sigma^h}{dx\,dz\,dQ^2} \propto \sum_i e_q^2 q(x, Q^2) D_q^h(z, Q^2)$$

$$\frac{d^3\Delta\sigma^h}{dx\,dz\,dQ^2} \propto \sum_i e_q^2 \Delta q(x, Q^2) D_q^h(z, Q^2)$$

$$z = \frac{P\cdot p_h}{P\cdot q} = \frac{E_h}{\nu}$$

FF and PDF are equally important to analyze high energy process with hadron production

Flavor Tagging:

Hadron carries information on quark flavor through fragmentation function

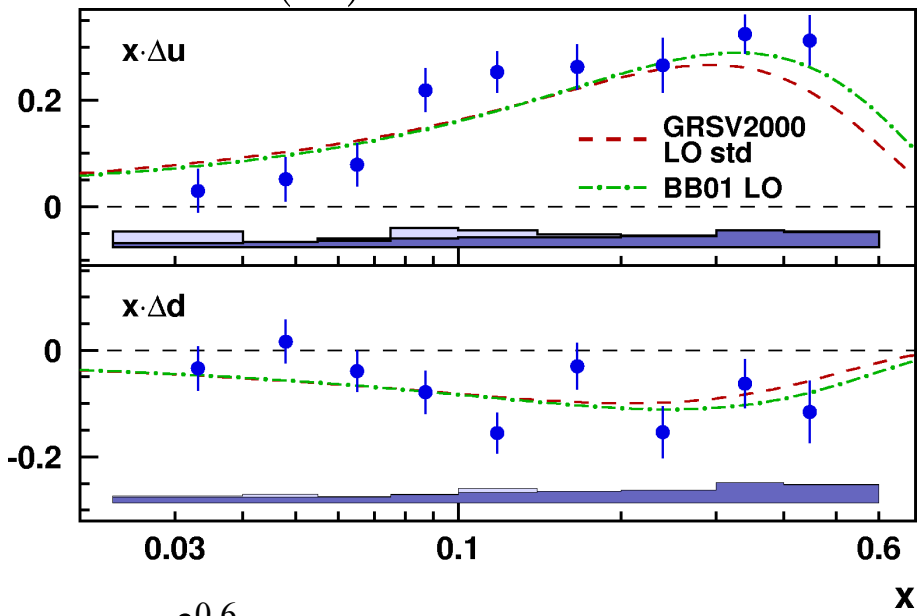
Helicity distribution with SIDIS data

$\vec{e}+\vec{N}\rightarrow e'+h+X$ **- LO extraction -**

hermes

Phys. Rev D 71 (2005) 012003

$\Delta\bar{s}(x)=0$ assumed



$$\Delta q=\int_{0.023}^{0.6} dx\,\Delta q(x) \qquad Q^2=2.5\,GeV^2$$

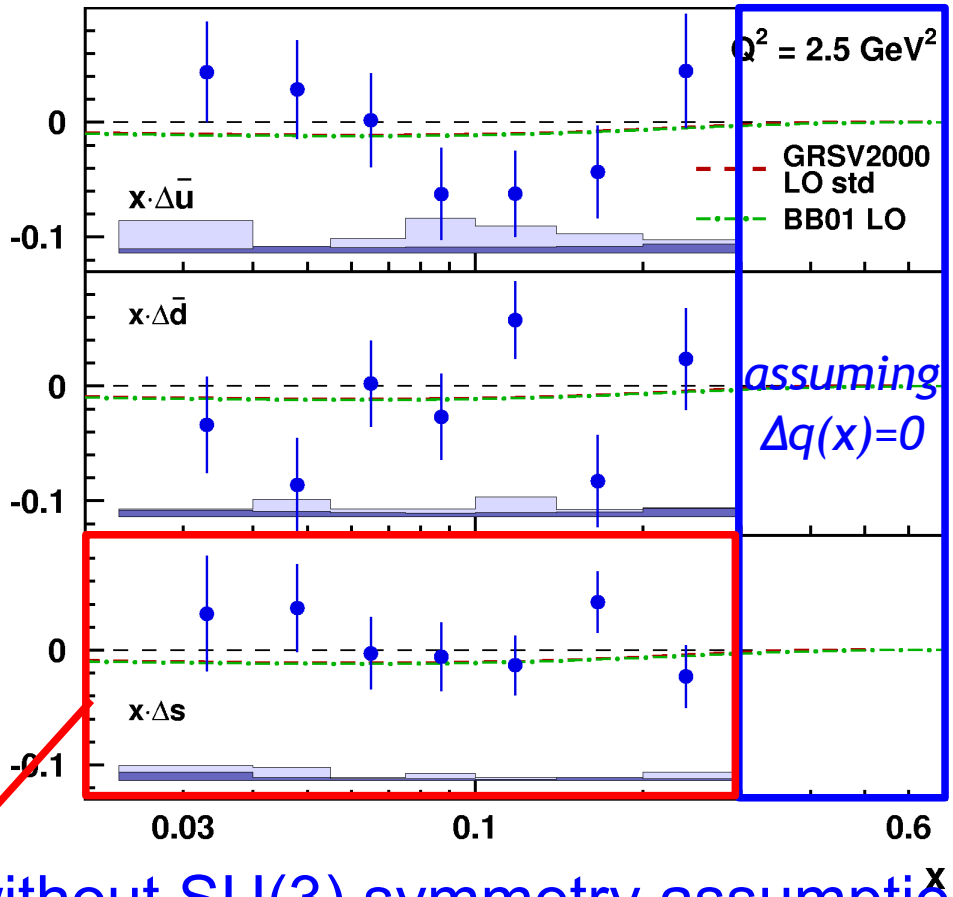
$\Delta u=0.601\pm0.039\pm0.049$

$\Delta d=-.226\pm0.039\pm0.050$

$\Delta\bar{u}=-.002\pm0.036\pm0.023$

$\Delta\bar{d}=-.054\pm0.033\pm0.011$

$\Delta s=0.028\pm0.033\pm0.009$



- without SU(3) symmetry assumption
- only partial moments are available
- "LO" extraction
- String model based MC for FF
  (<Q²> ~ 2.5GeV²)

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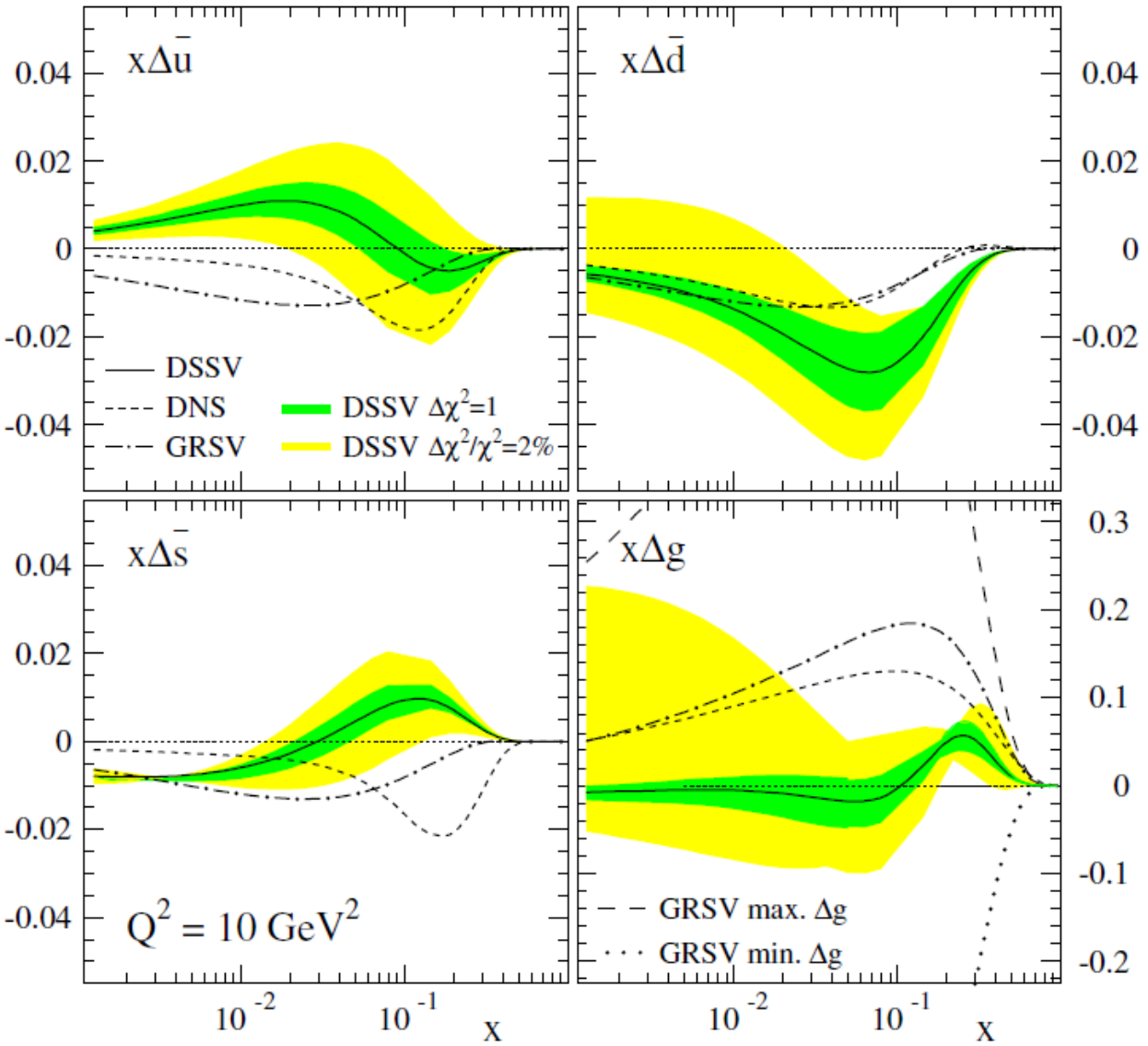
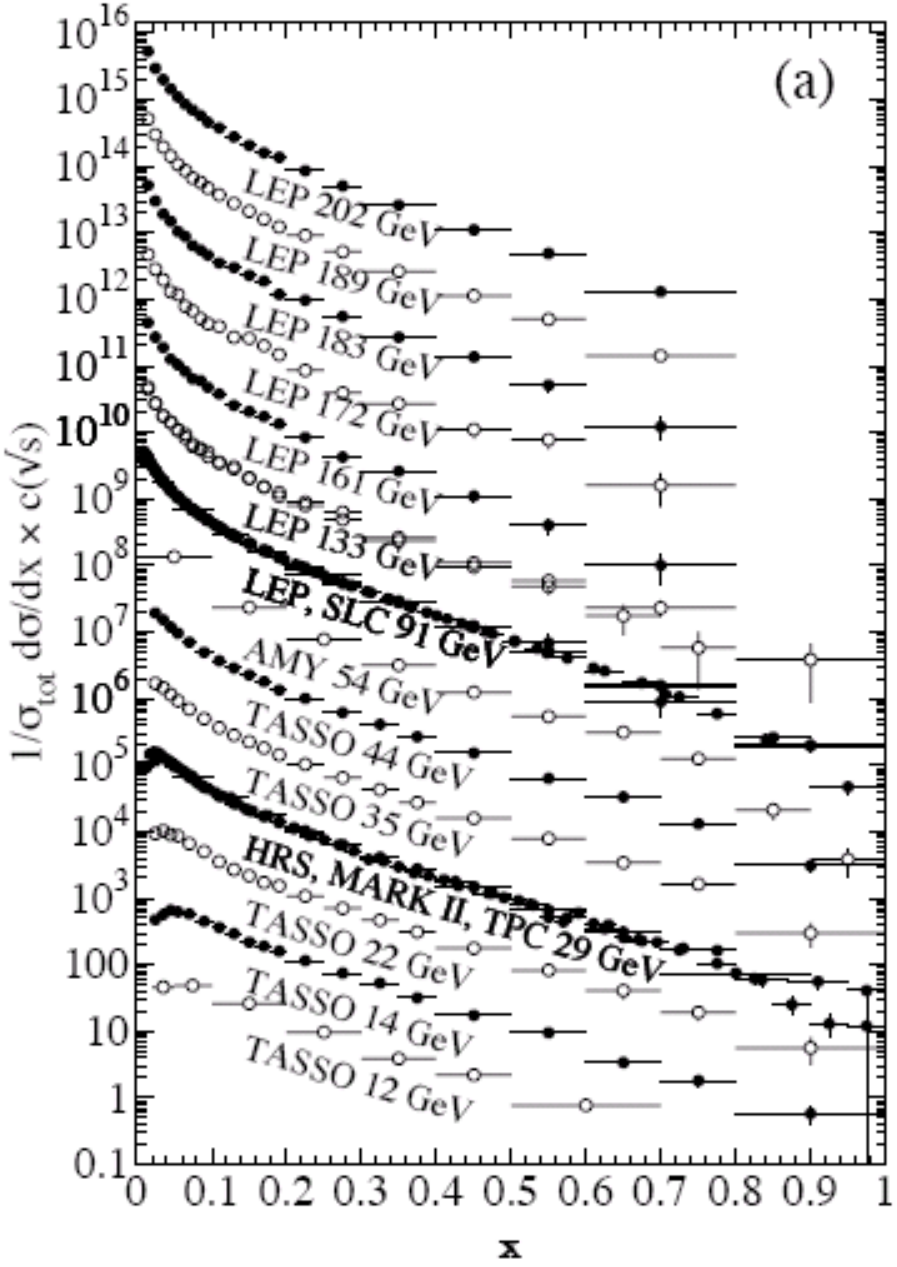
Helicity distribution from QCD fit

D. de Florian, R. Sassot, M. Stratmann, and W. Vogelsang,
Phys. Rev. Lett. 101, 072001 (2008)



	Data	FF
DSSV	DIS, SIDIS	DSS
	pp	
DNS	DIS	
	SIDIS	Kretzer
GRSV	DIS	-------

Belle and Fragmentation function



- Fragmentation function at Belle (**on going**)
- sqrt(s) ~ 10.52 GeV
  - Cover the lowest scale
  - Gluon FF from scale violation
  - Similar scale to pol. DIS
- Light quarks: u, d, s
- pion, kaon

Fragmentation function analysis in Belle

- Collins Fragmentation Function
  - Belle collaboration, Phys. Rev. D78 (2008) 032011
  - Transverse momentum dependence: kT
  - Vector meson
- Di-hadron fragmentation function
- Unpolarized Fragmentation function
  - Charged pion, charged kaon, proton
    - sqrt(s) = 10.8 GeV: cover lower Q2 (for gluon), similar Q2 with SIDIS and p-p
  - Other mesons: pi0, eta, f0, phi, Ks, ...
  - Barions: Lambda, ...

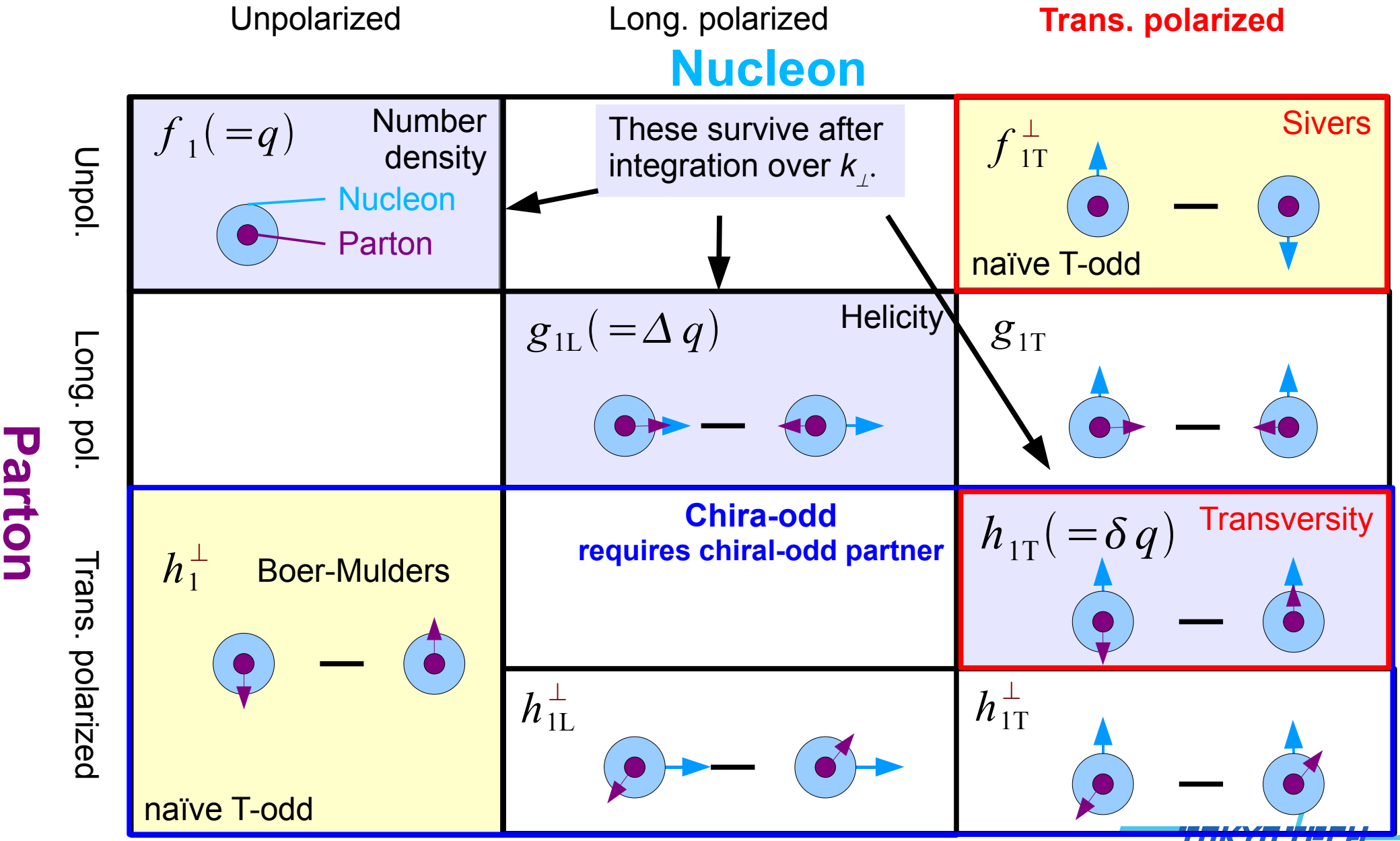
- published
- on-going
- plan/idea

Contents

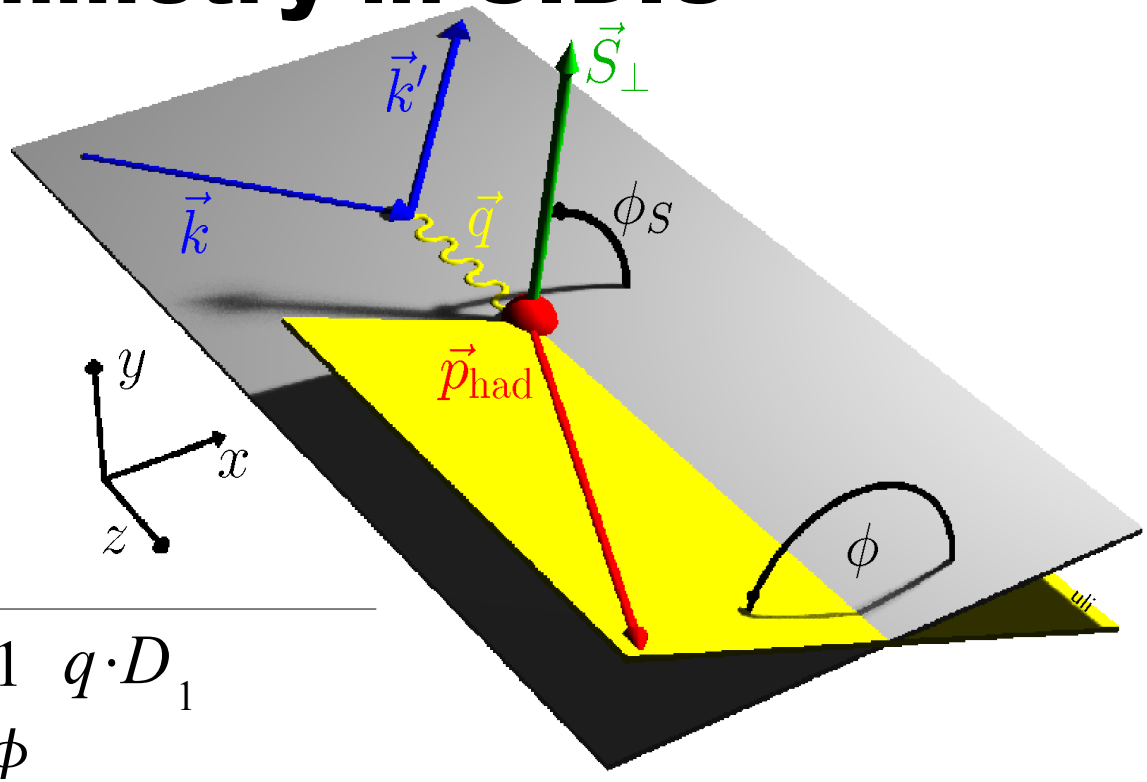
- Fragmentation Function has been analyzed with e+e- data, SIDIS, and pp data together
- Fragmentation function is important for analysis of high energy scattering with hadron production
  - With DSS kaon FF, $\Delta s > 0$ was obtained in the middle x
  - Neutral pion FF is also important for ΔG. (especially gluon part)
- Fragmentation function analysis at Belle
  - Collins fragmentation (published)
  - Normal fragmentation function analysis (on-going)
    - sqrt(s) = 10.52 GeV, pion, kaon

Quark Transversity and Collins Fragmentation

Transverse momentum dependent parton distribution function

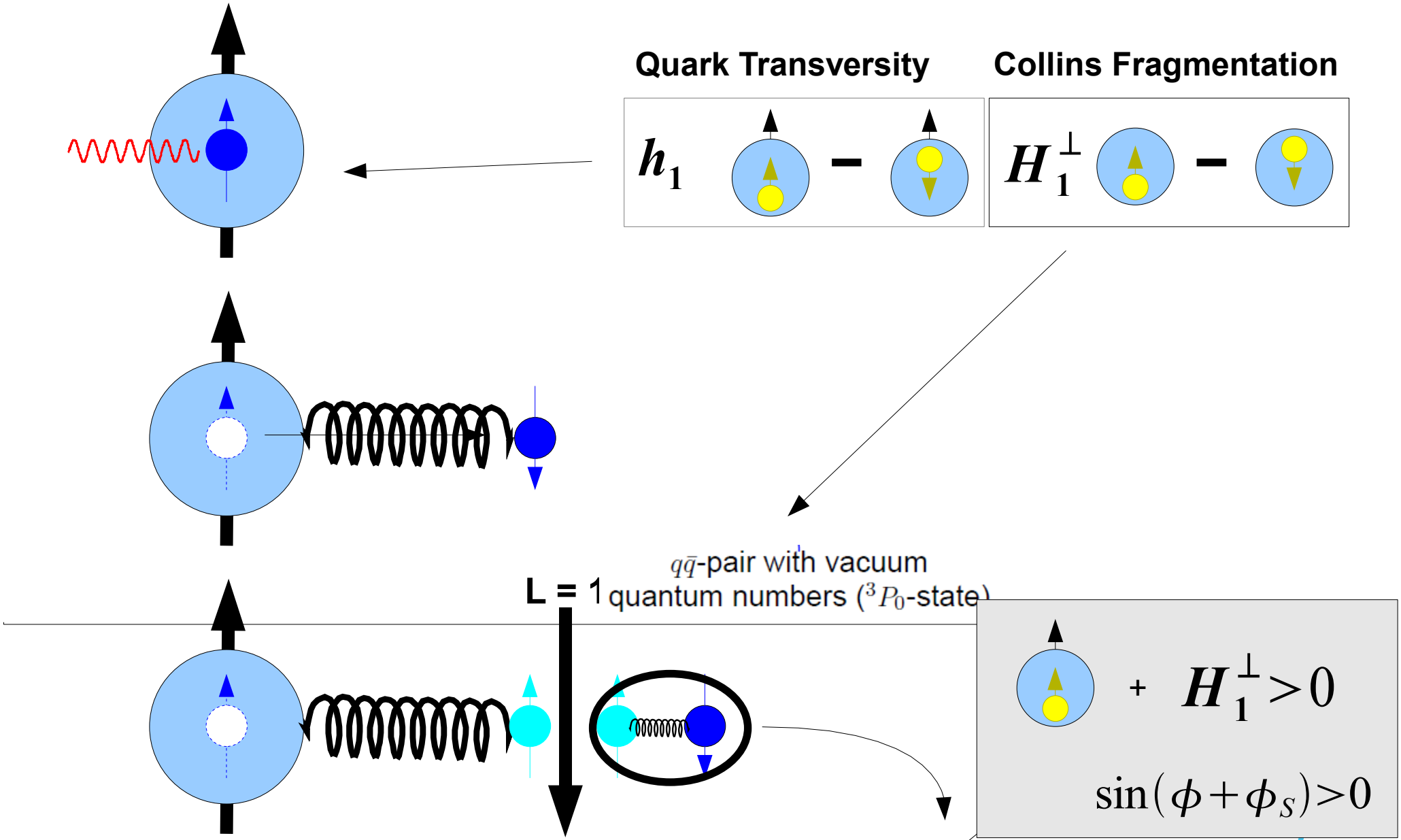


Collins asymmetry in SIDIS



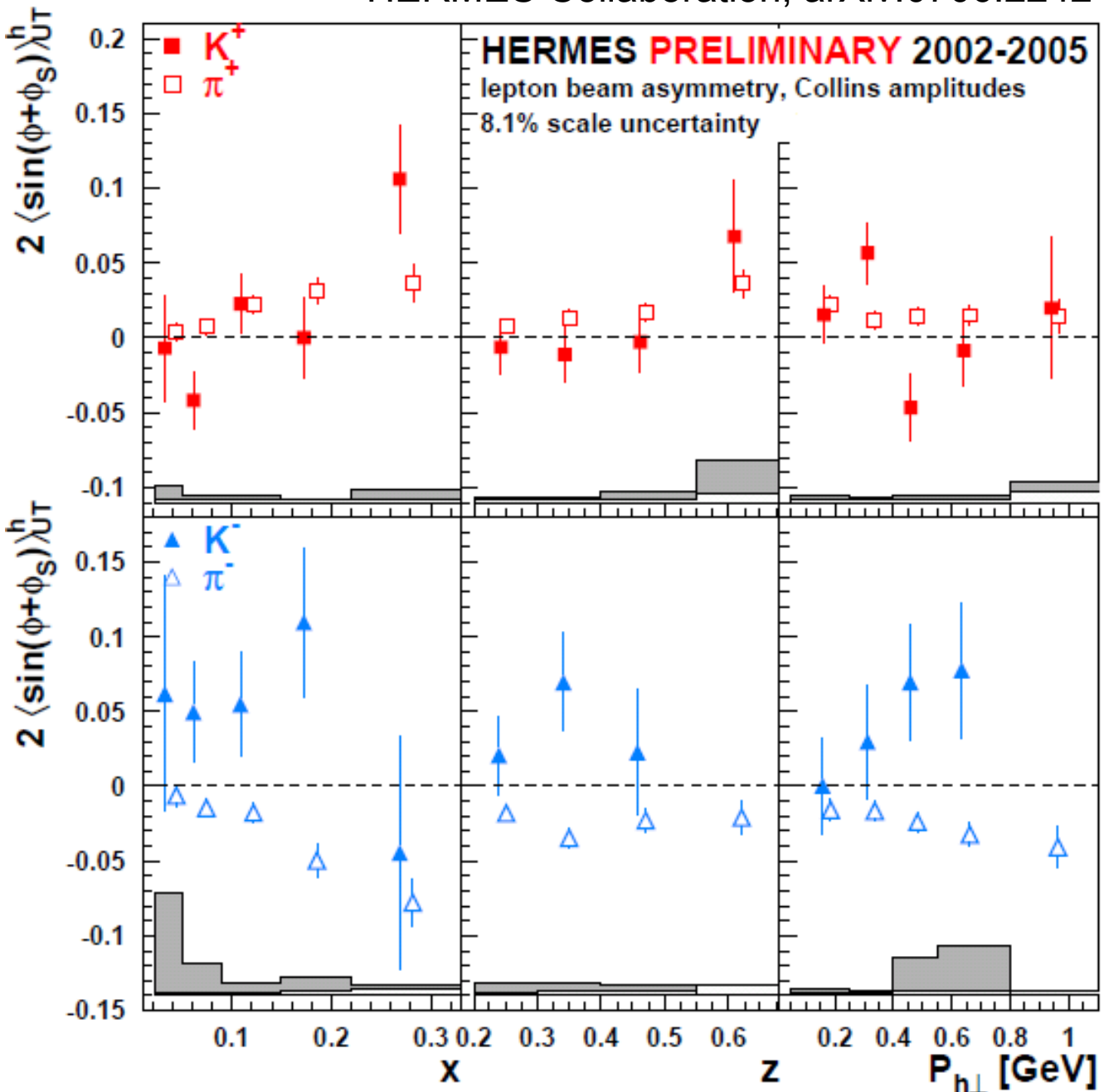
Unpol Target	$d\sigma_{UU}$	1	$q\cdot D_1$
		$\cos 2\phi$	
Long. Pol. Target	$d\sigma_{UL}$	$\sin 2\phi$	
S_L			
Trans. Pol. Target	$d\sigma_{UT}$		
S_T		$\sin(\phi-\phi_S)$	$f_{1T}^{\perp}\cdot D_1$ Siverse
		$\sin(\phi+\phi_S)$	$h_1\cdot H_{1T}^{\perp}$ Collins
		$\sin(3\phi-\phi_S)$	

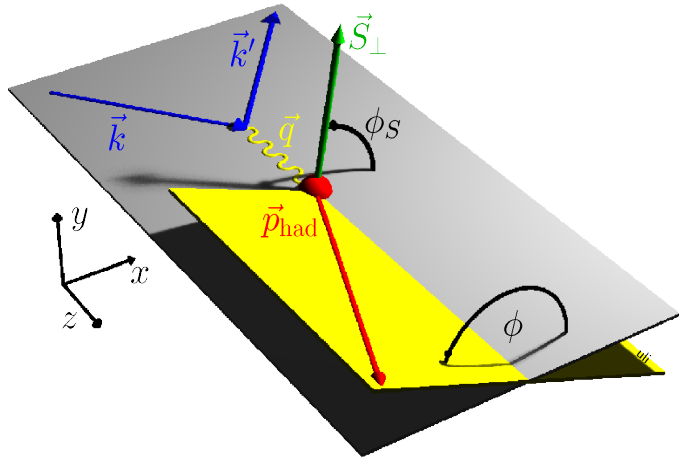
Collins mechanism



Collins Asymmetry at HERMES

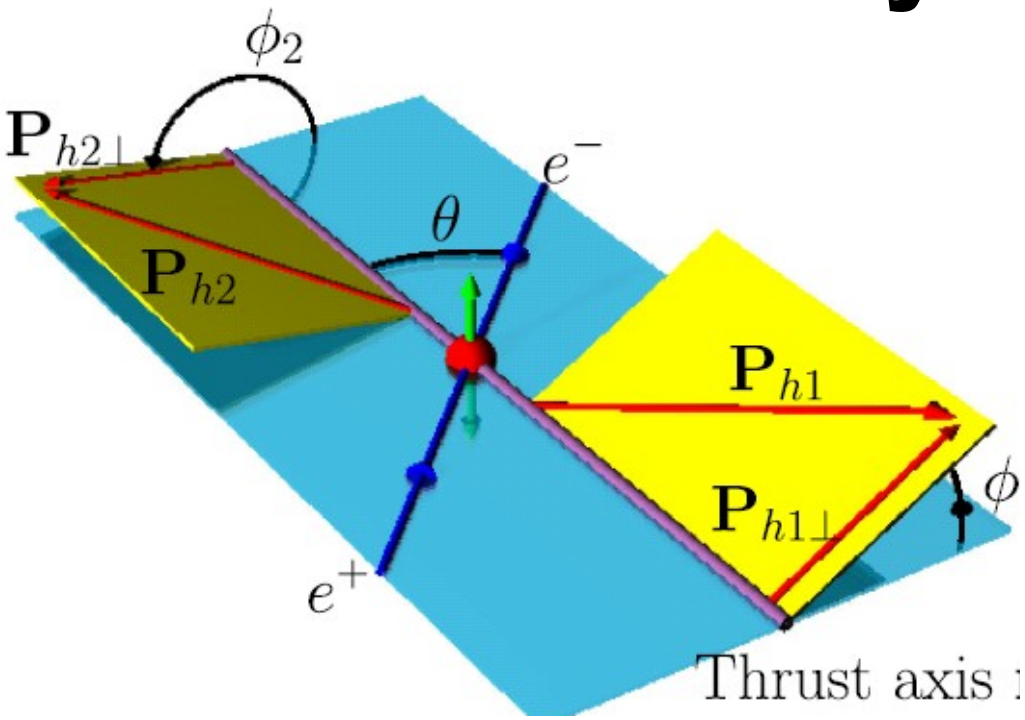
HERMES Collaboration, arXiv:0706.2242

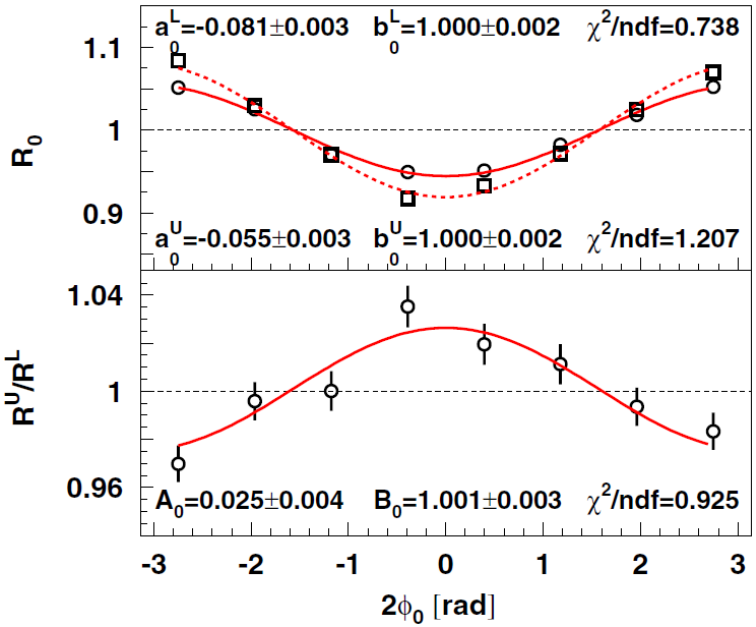




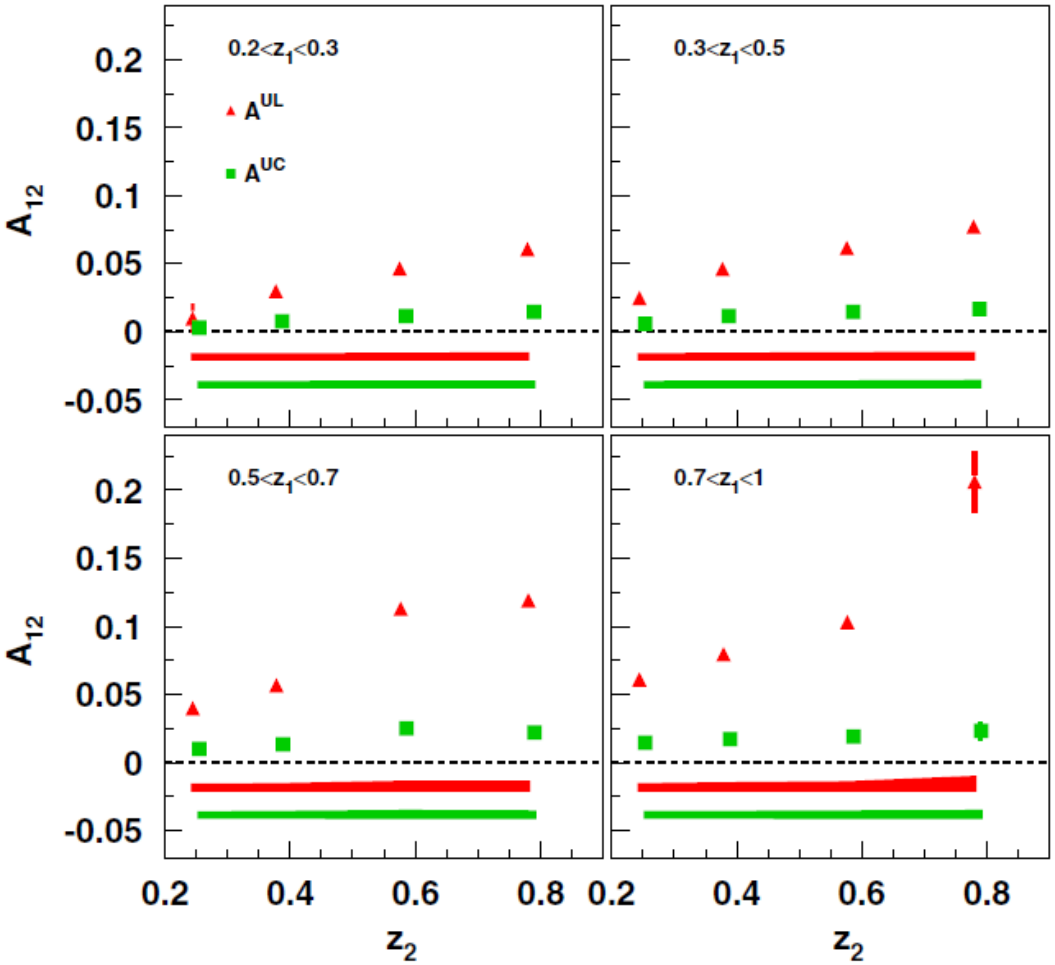
Collins asymmetry at Belle

Belle collaboration, Phys. Rev. D78 (2008) 032011





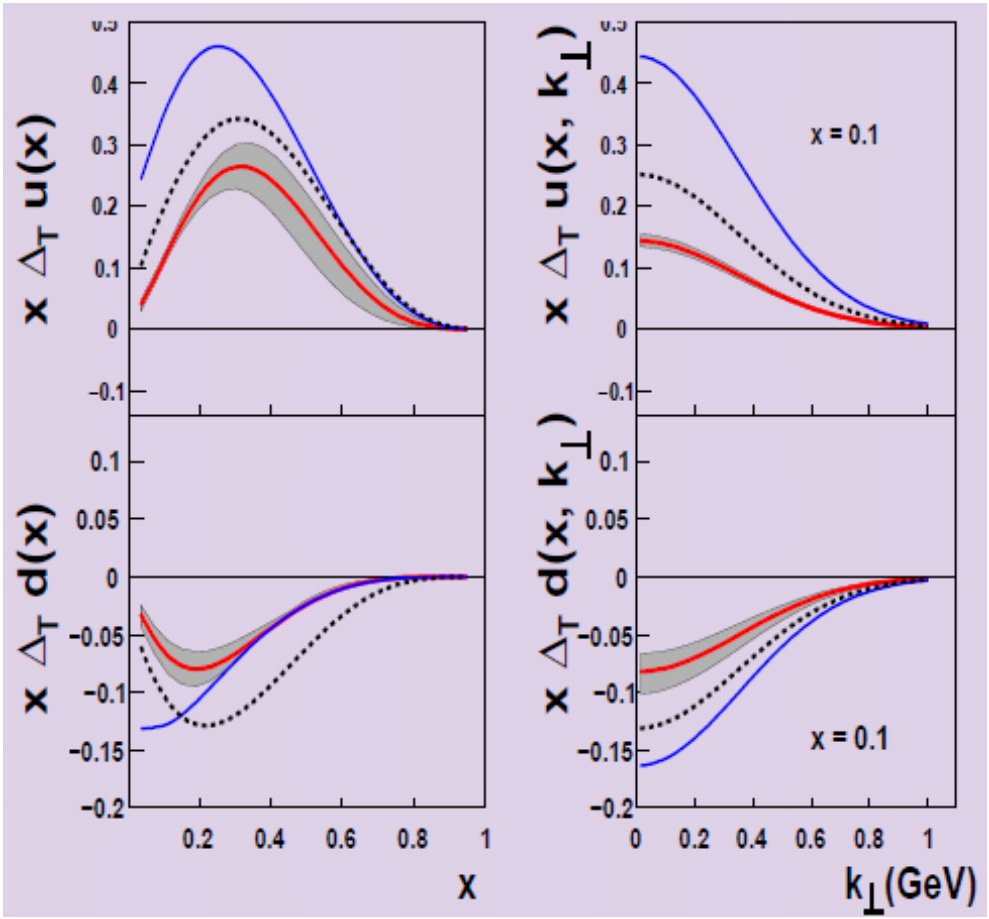
$$R_\alpha^i / R_\alpha^j = A_\alpha^{ij} \cos(\beta_\alpha) + B_\alpha^{ij}$$



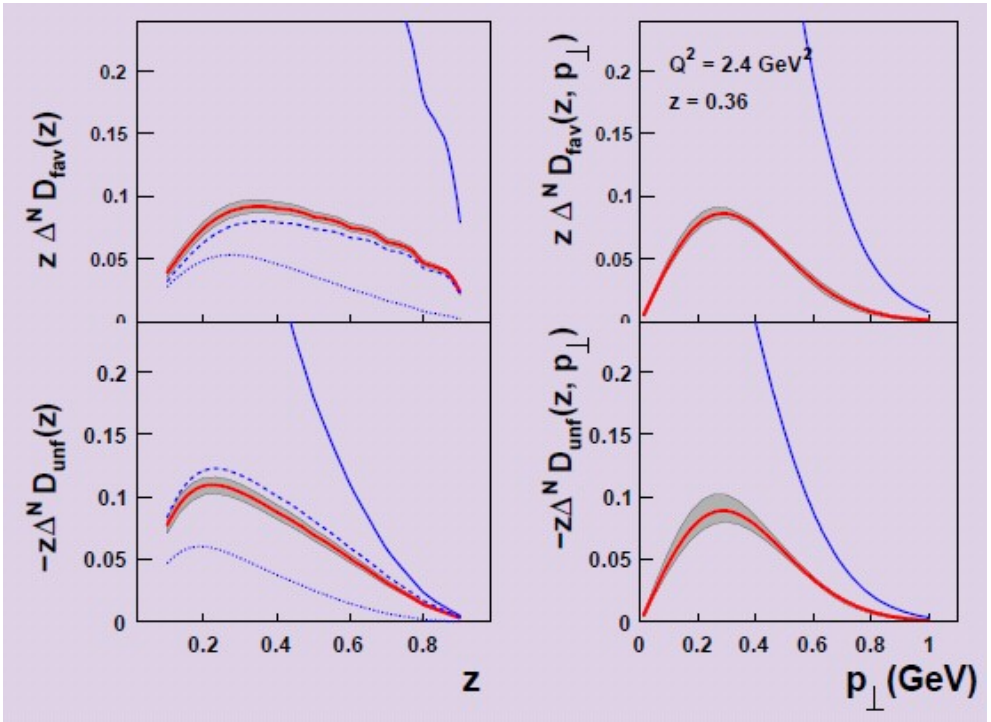
Extracted transversity and Collins FF

Alexei Prokudin @ SPIN2008

Quark tarnsversity



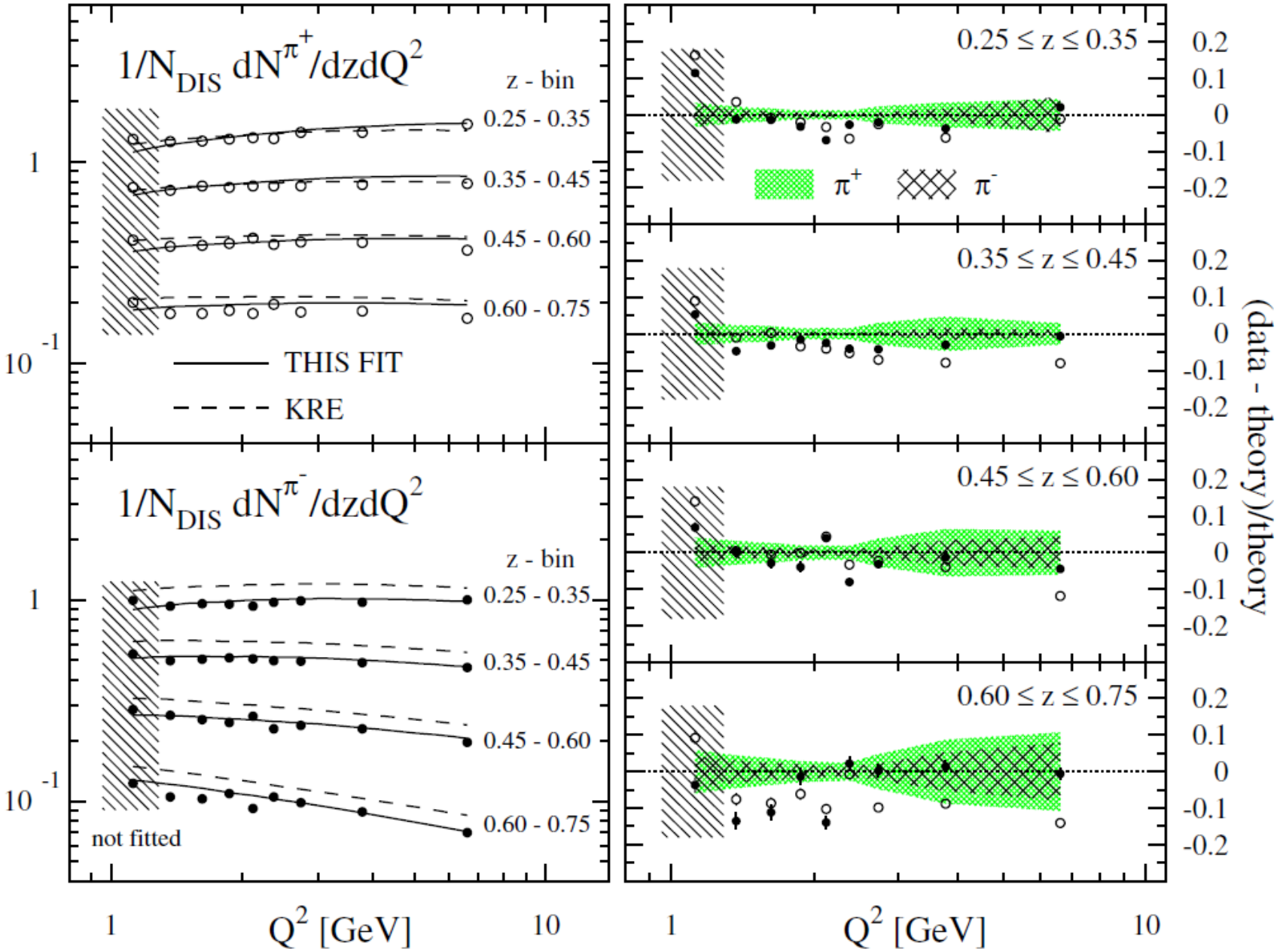
Collins fragmentation function



END

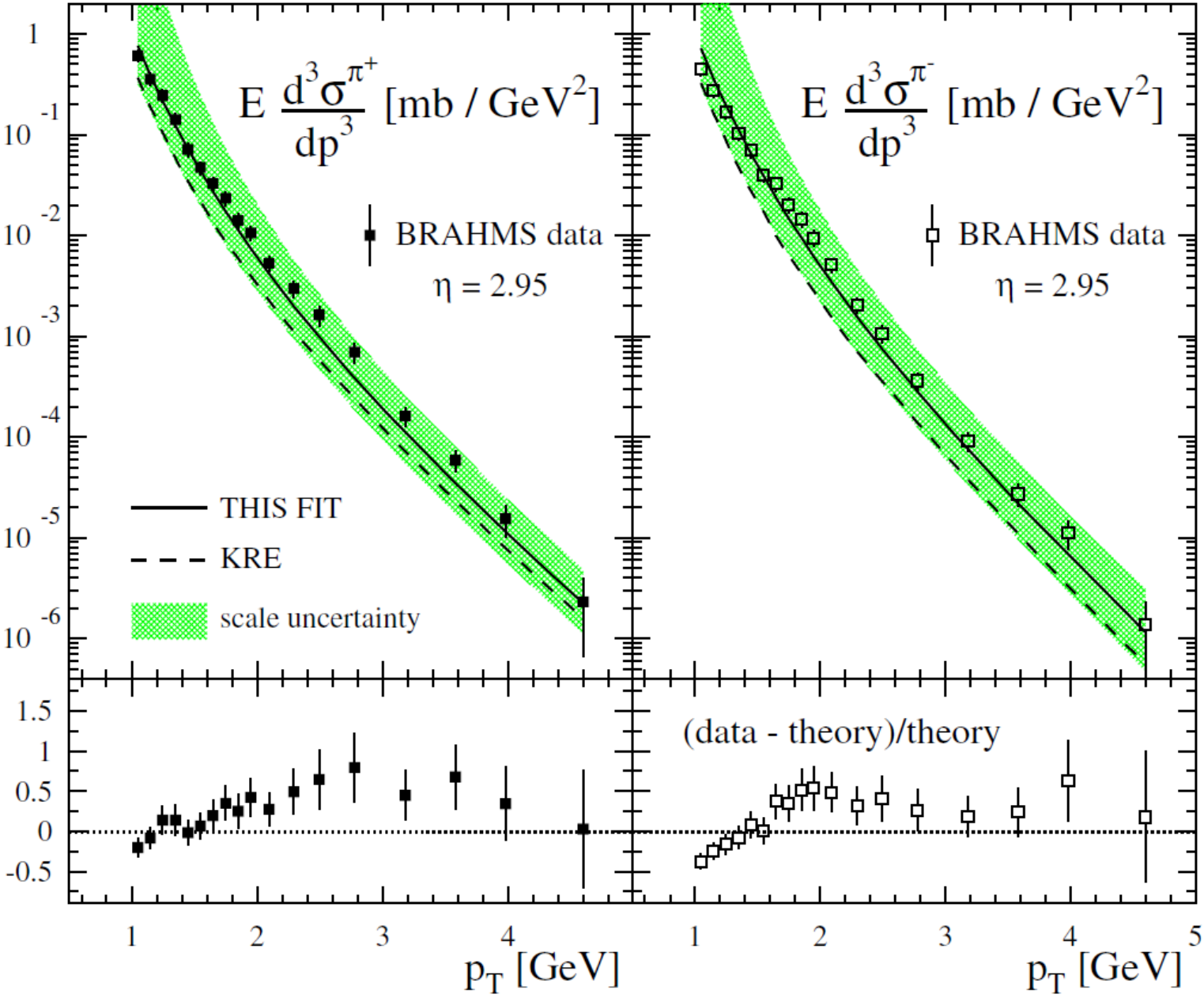
HERMES Multiplicity: pion

DSS, Phys. Rev. D75, 114010 (2007)



Charged pion production in p-p

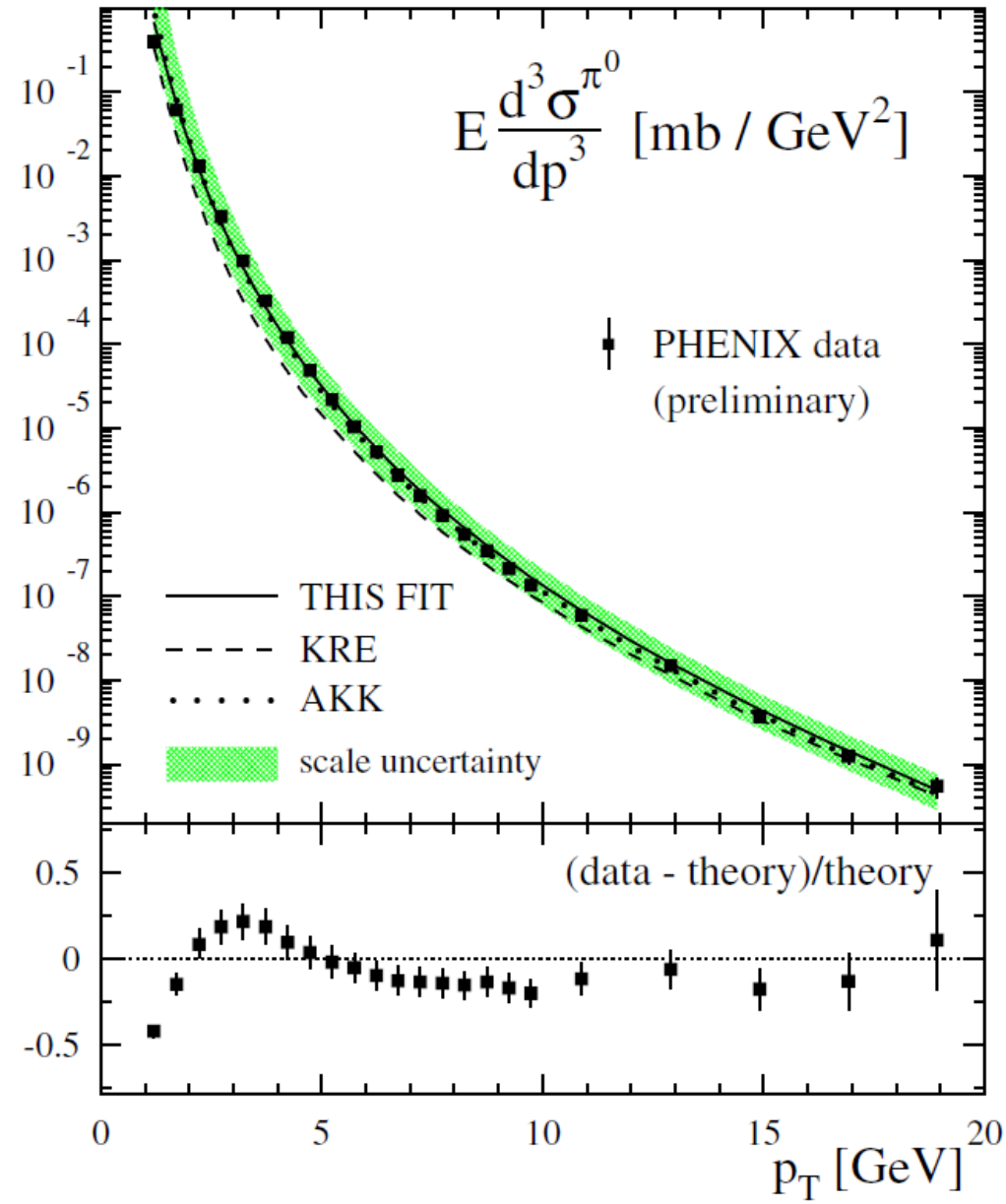
DSS, Phys. Rev. D75, 114010 (2007)

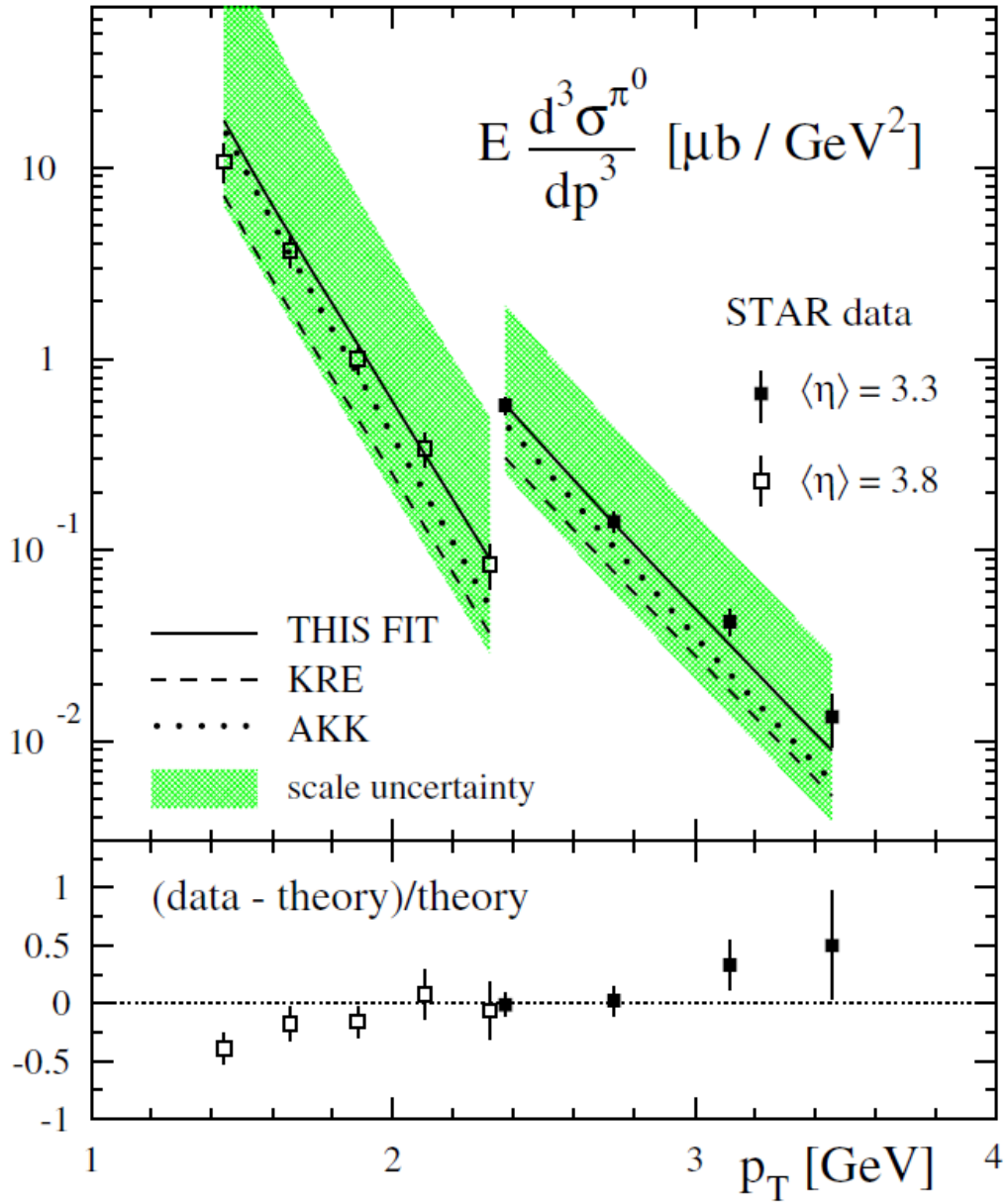


Neutral pion production in p-p

DSS, Phys. Rev. D75, 114010 (2007)

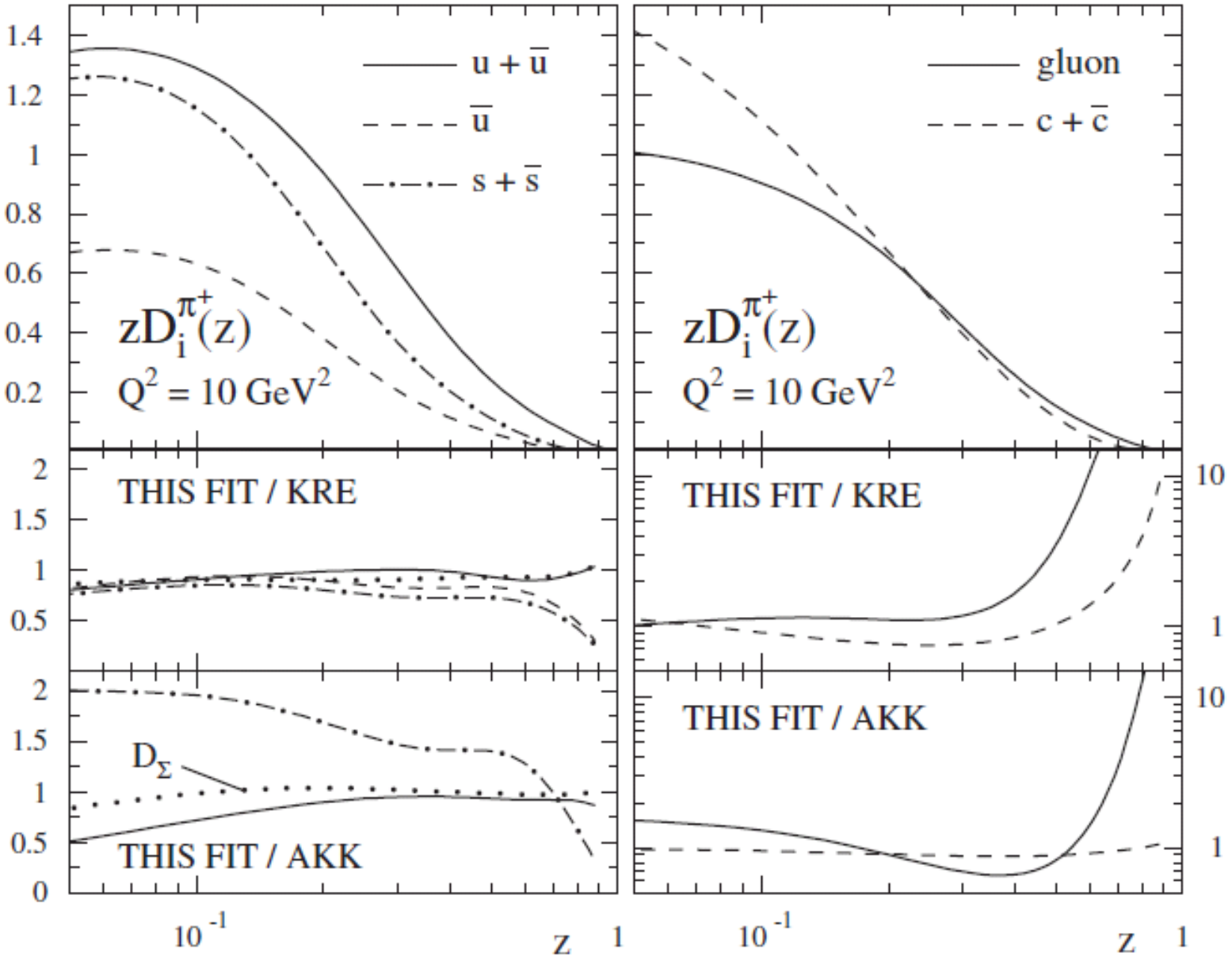
neutral pions by assuming $D_i^{\pi^0} = [D_i^{\pi^+} + D_i^{\pi^-}]/2$.





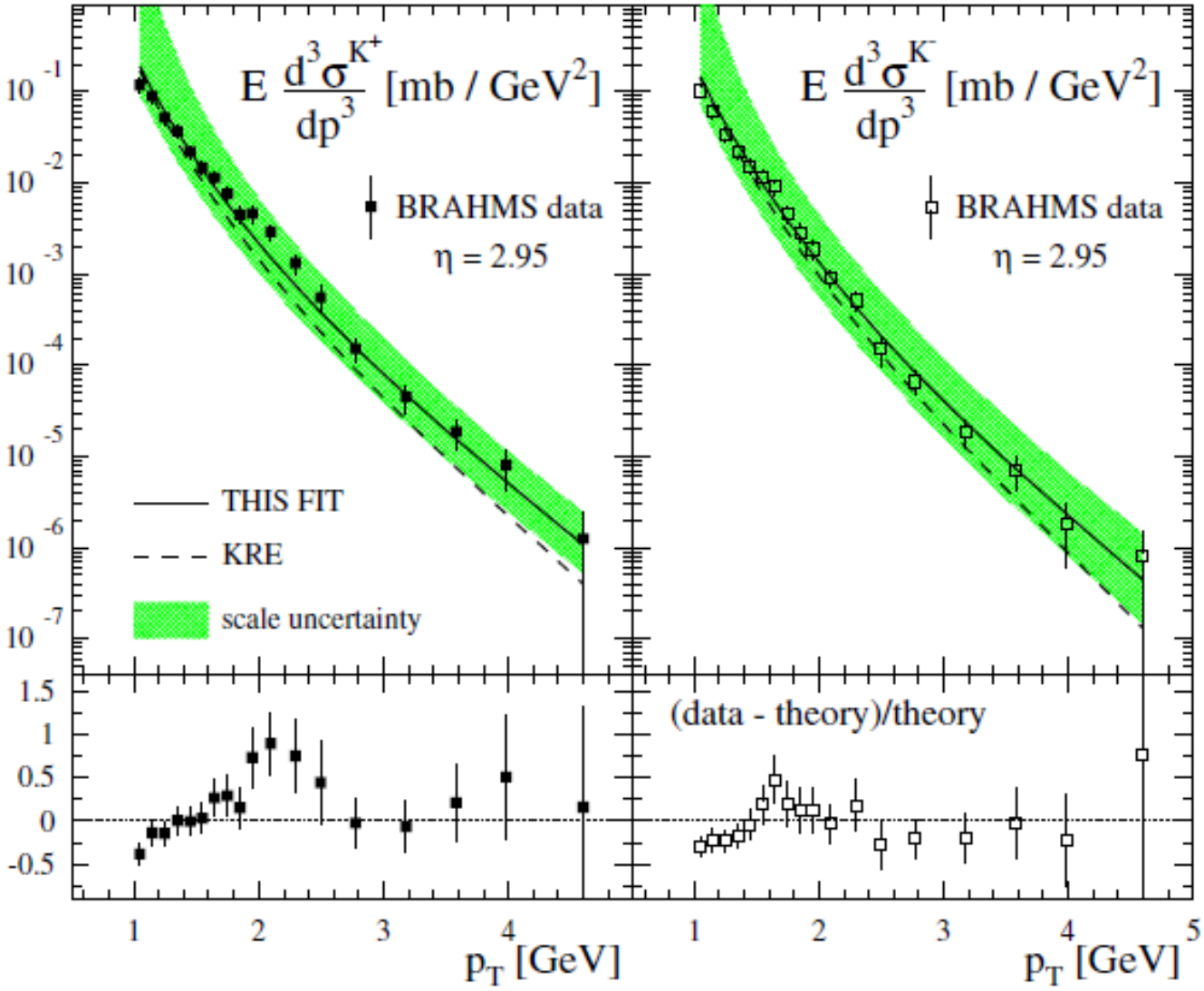
Extracted pion fragmentation function

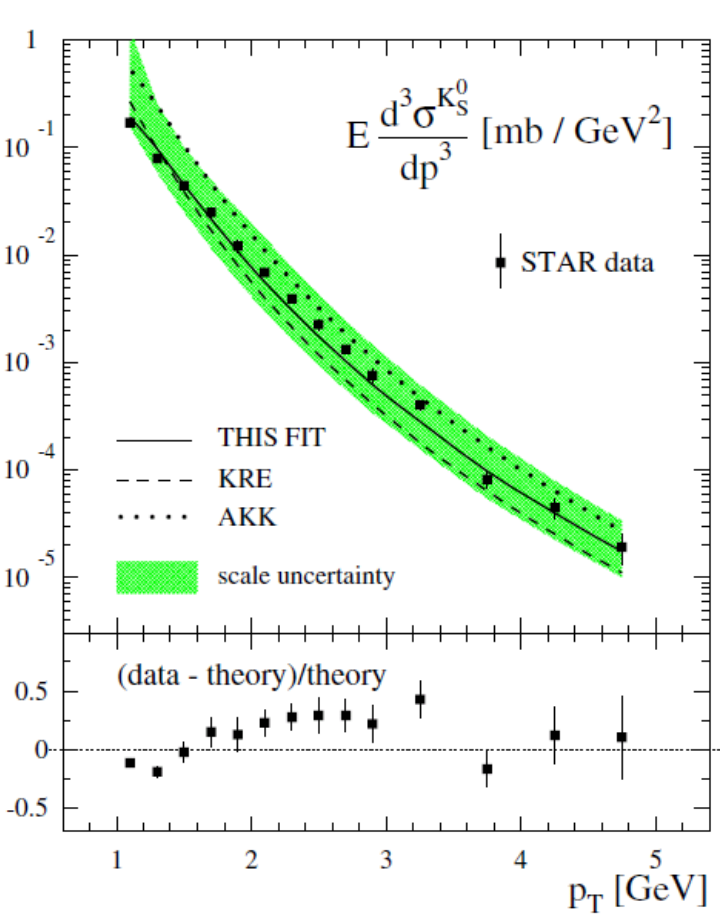
DSS, Phys. Rev. D75, 114010 (2007)



Kaon production in pp scattering

DSS, Phys. Rev. D75, 114010 (2007)

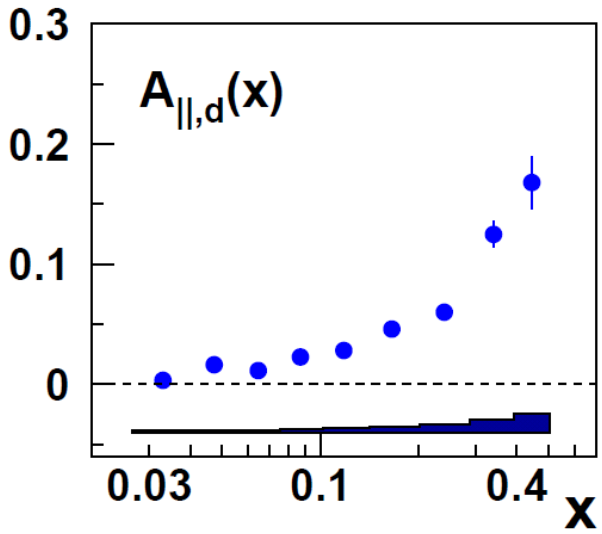




Helicity distribution function

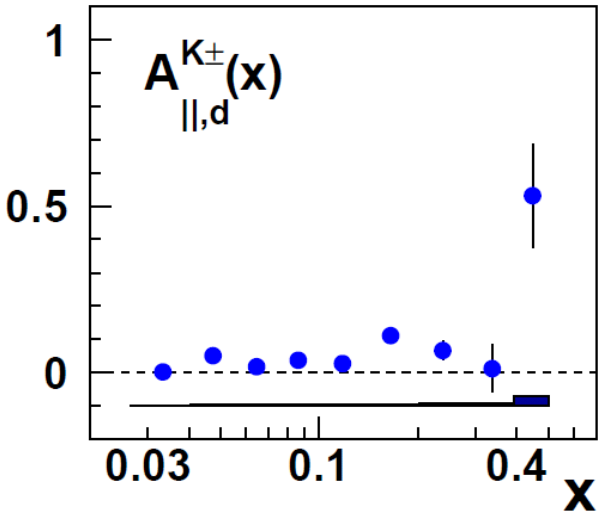
LO extraction

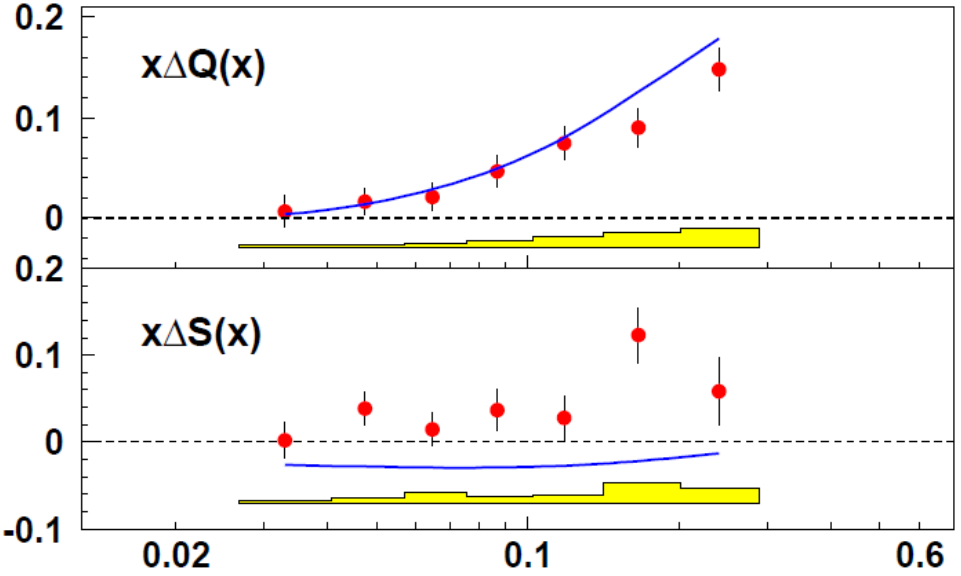
HERMES Collaboration, Phys. Lett. B666 (2008) 446-450



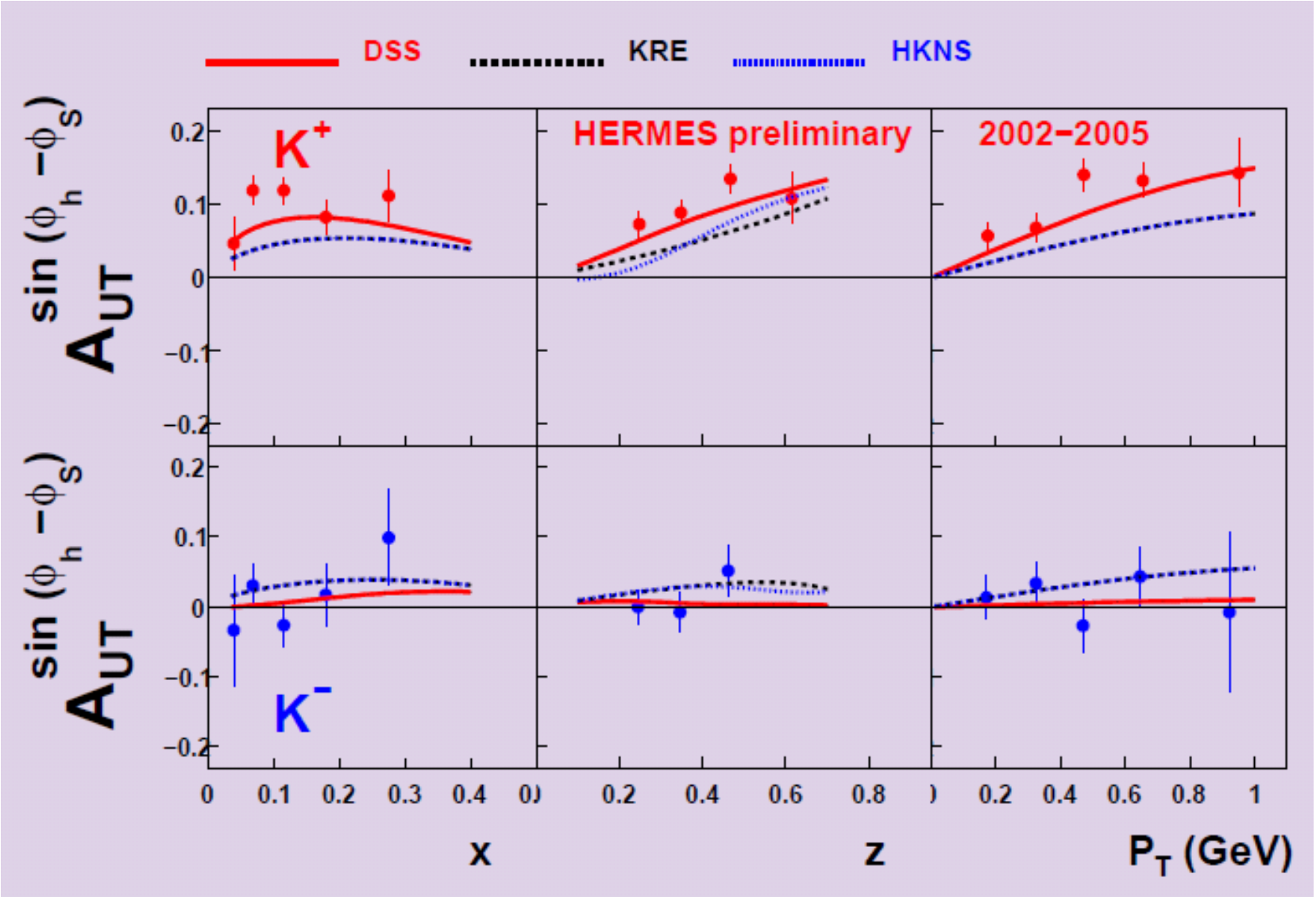
$$A_{\parallel,d}(x)\frac{\mathrm{d}^2N^{DIS}(x)}{\mathrm{d}x\,\mathrm{d}Q^2} = \mathcal{K}_{LL}(x,Q^2)\left[5\Delta Q(x)+2\Delta S(x)\right]$$

$$A^{K^\pm}_{\parallel,d}(x)\frac{\mathrm{d}^2N^{K}(x)}{\mathrm{d}x\,\mathrm{d}Q^2} = \mathcal{K}_{LL}(x,Q^2)\times \left[\Delta Q(x)\int \mathcal{D}^K_Q(z)dz + \Delta S(x)\int \mathcal{D}^K_S(z)dz\right]$$





FF choice in Siverse function analysis



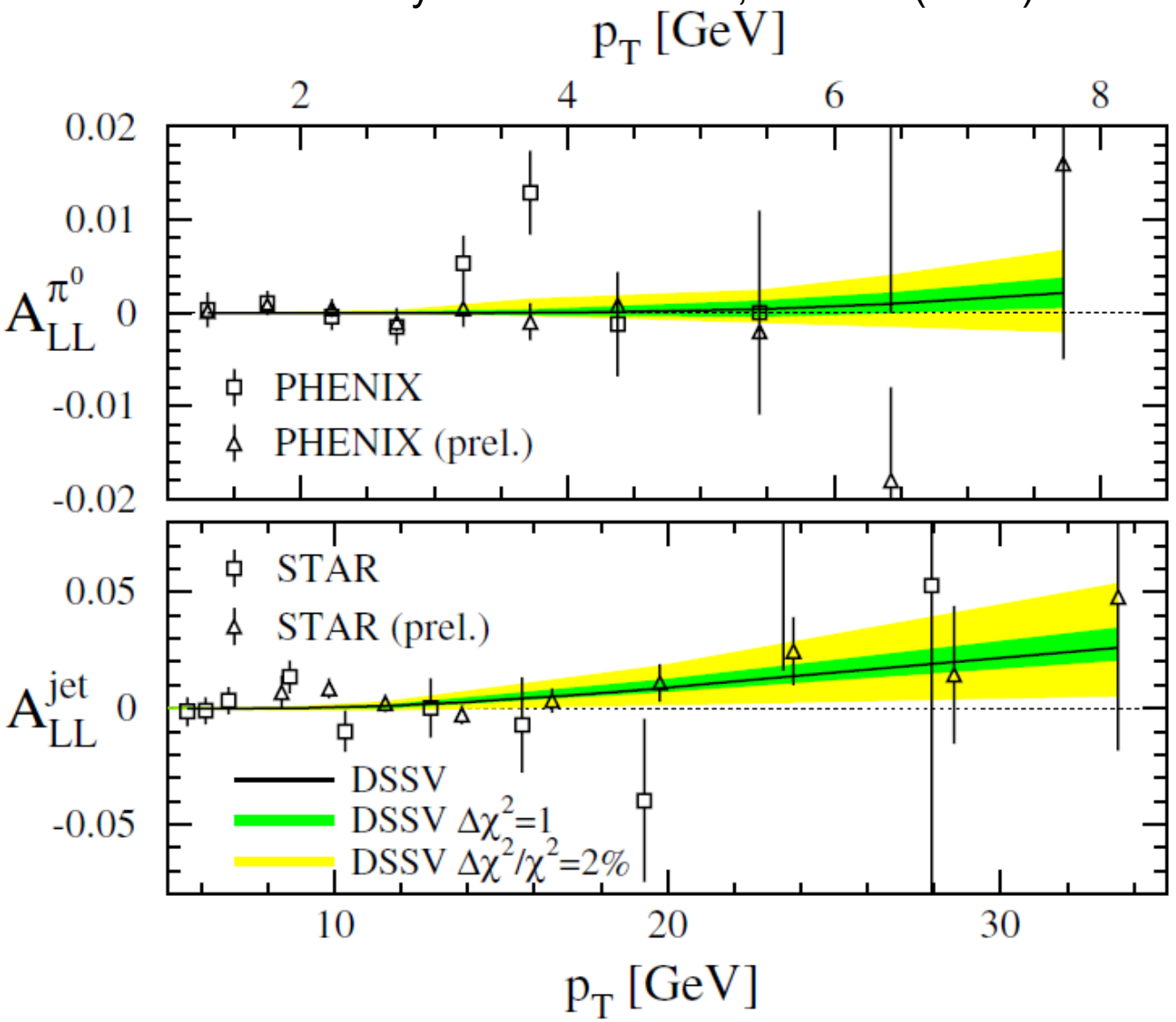
Data used in helicity distribution

D. de Florian, R. **S**assot, M. **S**tratmann, and W. **V**ogelsang,
Phys. Rev. Lett. 101, 072001 (2008)

Experiment	Data fitted	χ^2
DIS: EMC, SMC, COMPASS, E142, E143, E154, E155, HALL-A, CLAS, HERMES	234	186
SIDIS $\pi^{\pm}$, $K^{\pm}$, $h^{\pm}$: SMC, HERMES, COMPASS	189	166.5
p-p 200 GeV, π^0: PHENIX (in part prel.)	20	21.3
p-p 62 GeV, π^0: PHENIX (prel.)	5	3.1
p-p 200 GeV, jet: STAR (in part prel.)	19	15.7
TOTAL:	467	392.6

Double spin asymmetry in p-p

D. de Florian, R. Sassot, M. Stratmann, and W. Vogelsang,
Phys. Rev. Lett. 101, 072001 (2008)

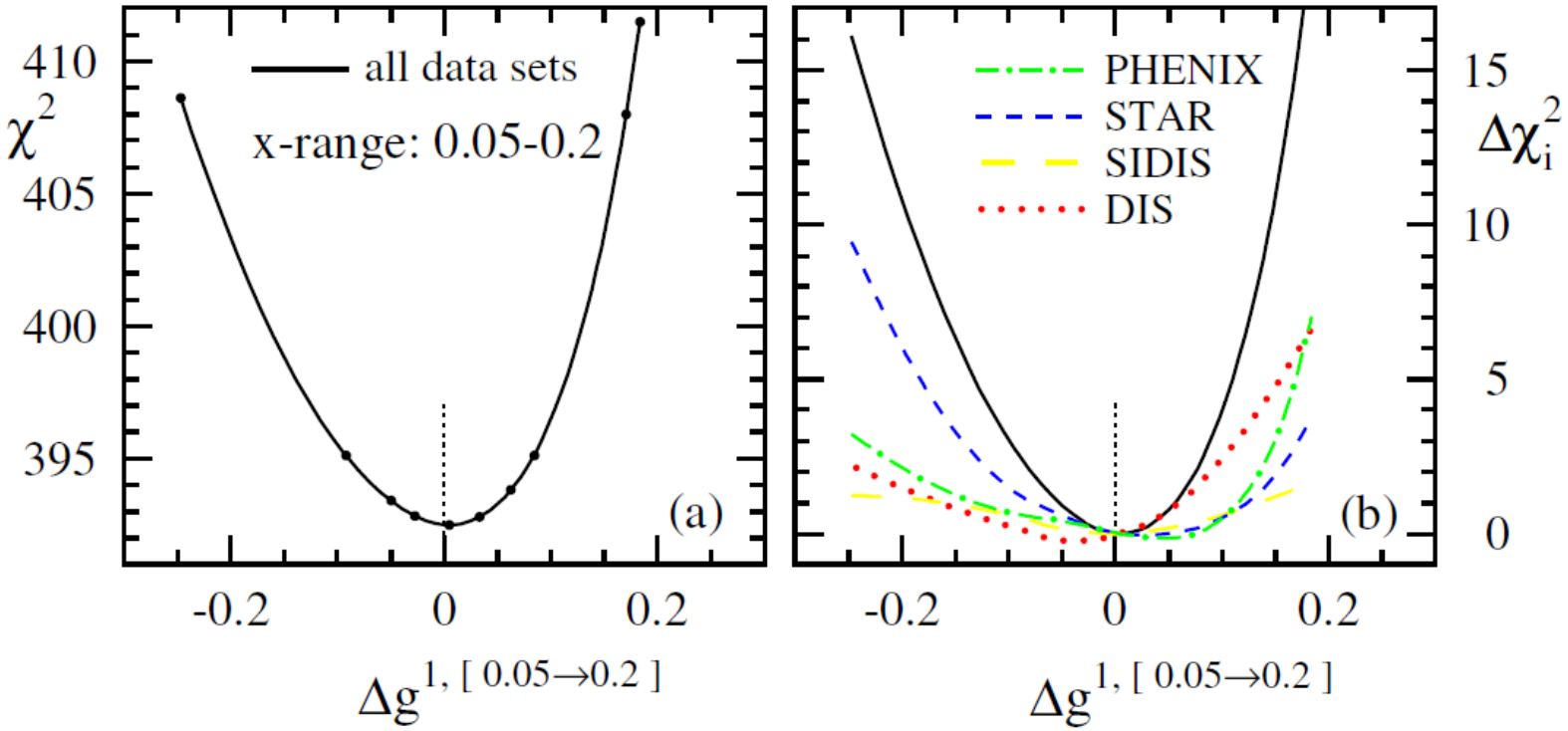


neutral pions by assuming $D_i^{\pi^0} = [D_i^{\pi^+} + D_i^{\pi^-}]/2$.

Gluon polarization in polarized proton-proton scattering

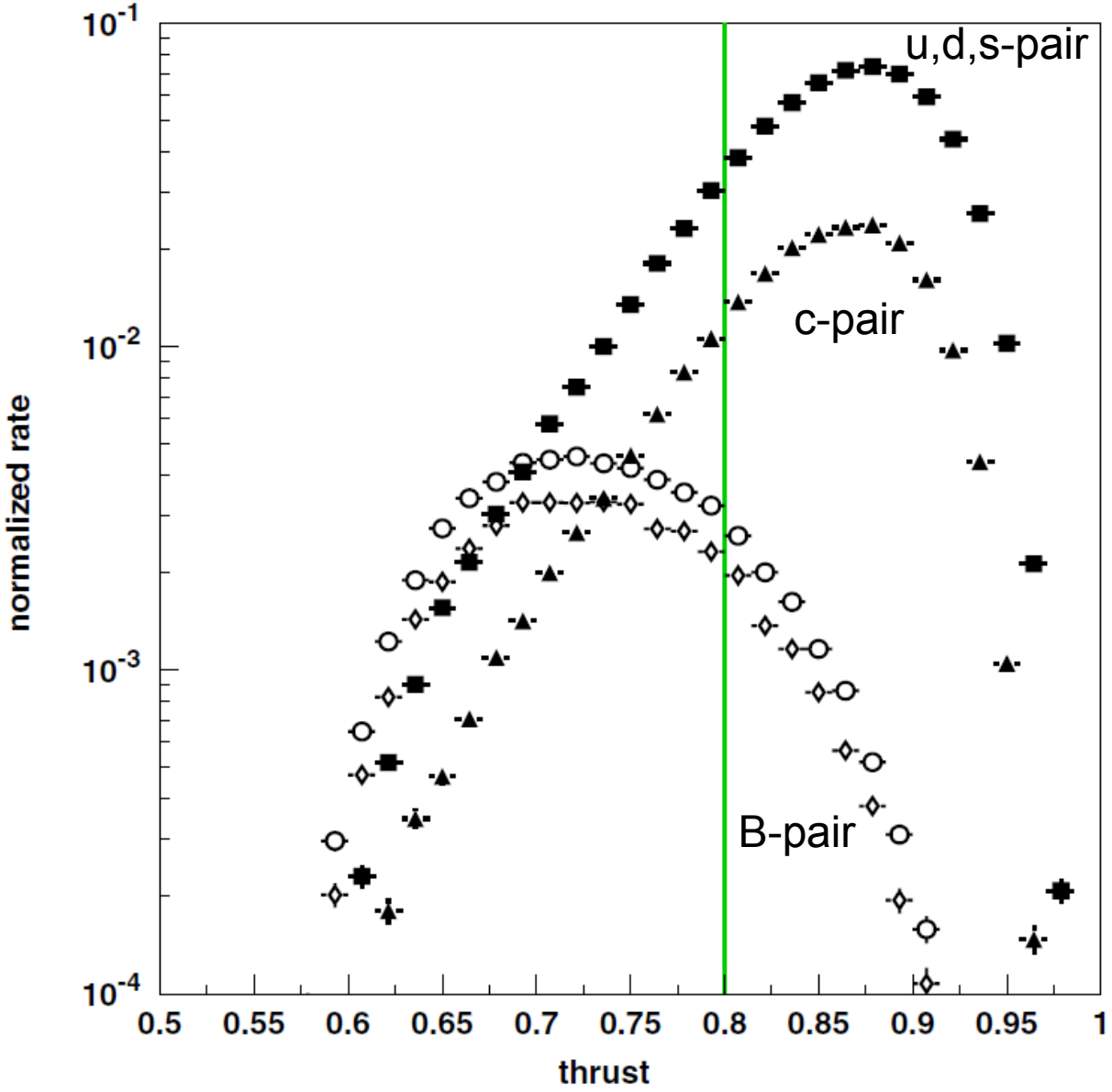
DSSV results....

$$E_H \frac{d^3\sigma}{dp_H^3} = \sum_{a,b,c} f_a \otimes f_b \otimes d\hat{\sigma}_{ab}^c \otimes D_c^H,$$



Quark flavor sensitivity

Belle collaboration, Phys. Rev. D78 (2008) 032011



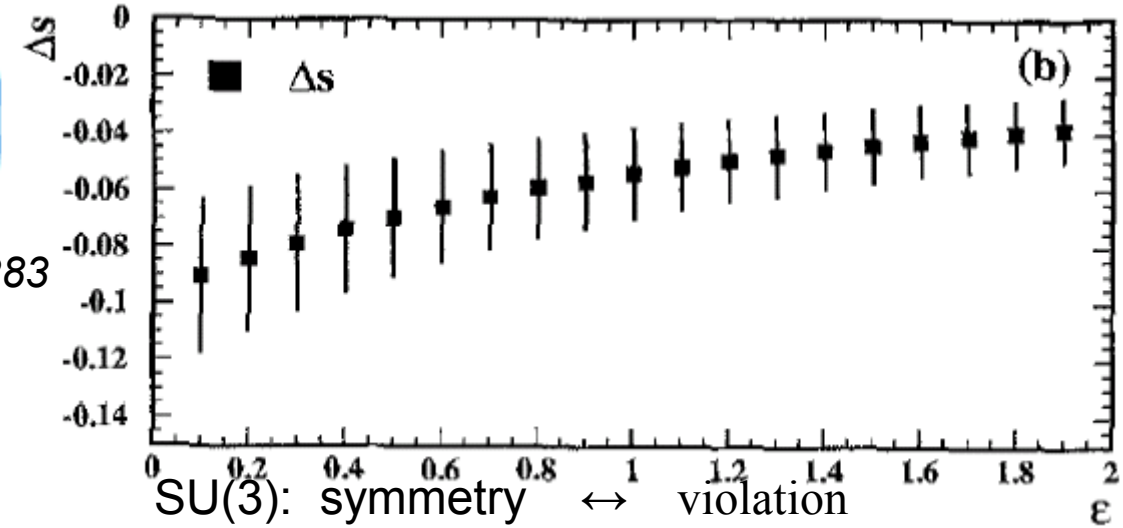
SU(3) violation and impact on Δs

J. Lichtenstadt and H. J. Lipkin, Phys. Lett. B353 (1995) 119

$$\Delta s = 3\Gamma_1^p - \frac{3}{2}D\left(F/D + \frac{1}{9}\right)$$

E. Leader et. al., Phys. Lett. B488 (2000) 283

a_8	$-(\Delta s + \Delta\bar{s})$
0.40	0.02 ± 0.01
3F − D	0.06 ± 0.01
0.86	0.15 ± 0.02



SU(3): symmetry ↔ violation

χQM calculation:

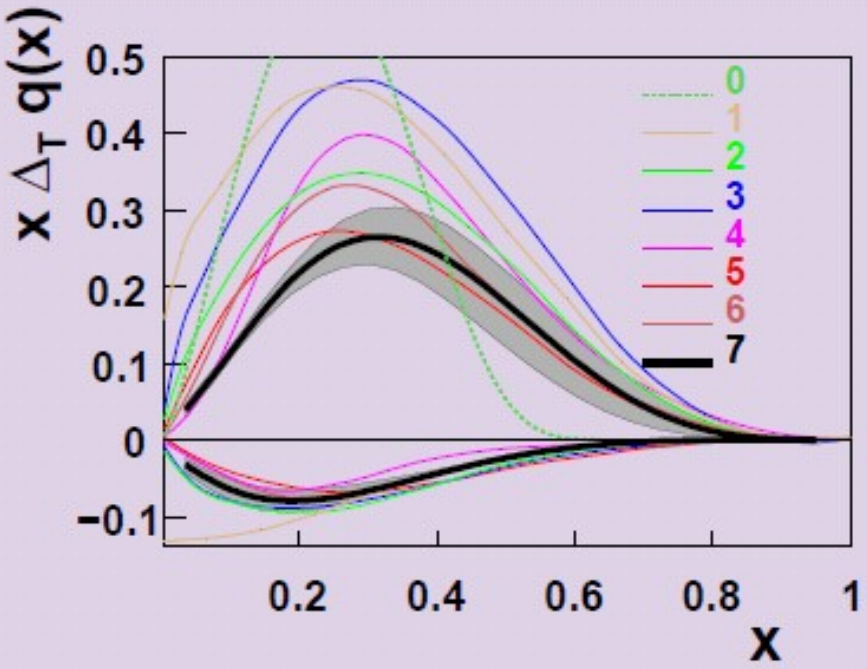
(*X. Song et. al, Phys. Rev. D55 (1997) 2624-2629*)

SU(3) symmetry: Δs = -0.1

SU(3) breaking: Δs = -0.05

Extracted Transversity and models

New extraction is close to most models.



0. Barone, Calarco, Drago PLB 390 287 (97)
1. Soffer et al. PRD 65 (02)
2. Korotkov et al. EPJC 18 (01)
3. Schweitzer et al. PRD 64 (01)
4. Wakamatsu, PLB B653 (07)
5. Pasquini et al., PRD 72 (05)
6. Cloet, Bentz and Thomas PLB 659 (08)
7. This analysis.

Alexei Prokudin @ SPIN2008