Recent Results from HERMES

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Petersburg Nuclear Physics Institute

(for HERMES collaboration)

DSPIN-07 ***Dubna, September 3-7, 2007***

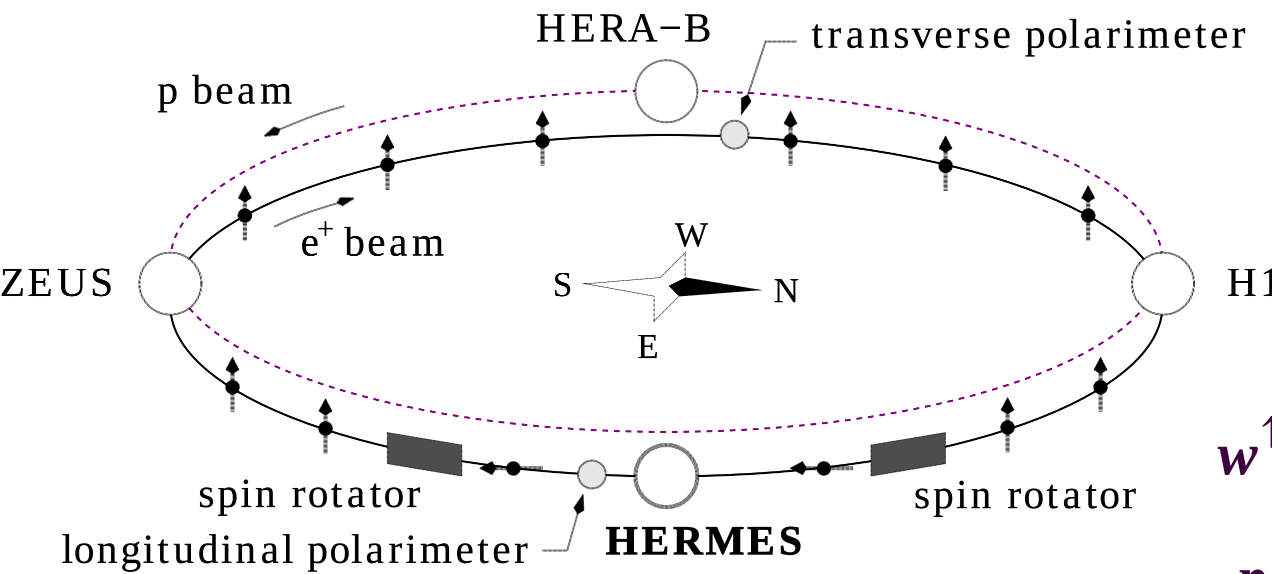
Included in SPIN 07 agenda:

- *A.Borissov "New results on rho and phi mesons"*
- *V.Korotkov "Transverse physics at HERMES"*
- *M.Varanda "Measurements of g1 and strange quark spin content in nucleon"*
- *D.Veretennikov "Λ polarization in photoproduction at HERMES"*
- *I.Vilardi "HERMES Recoil Detector"*

Outline

- HERMES spectrometer and accumulated data set
- Inclusive Deep Inelastic Scattering (DIS) and quark contribution to the nucleon spin $\Delta\Sigma$
- Semi-inclusive DIS and $\Delta u(x)$, $\Delta d(x)$ and $\Delta s(x)$ –quark helicity distributions in the nucleon
- High-PT hadron production and gluon contribution to the nucleon spin ΔG

HERA polarized positron beam



$E_e = 27.5\ GeV$

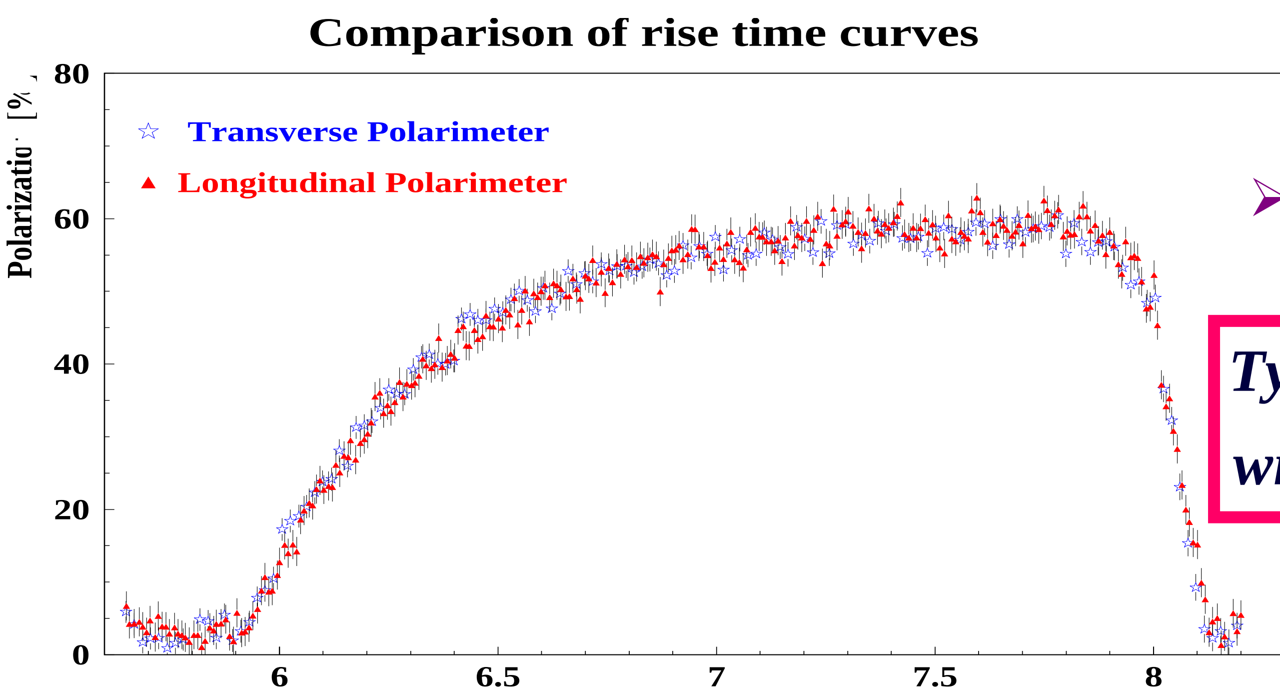
Sokolov-Ternov effect

$spin - flip\ for\ e^+$

$$w^{\uparrow} = \frac{1}{38.5\,\min} \quad w^{\downarrow} = \frac{1}{16.2h}$$

$pol\ rise\ time\ \tau \sim 30\,\min$

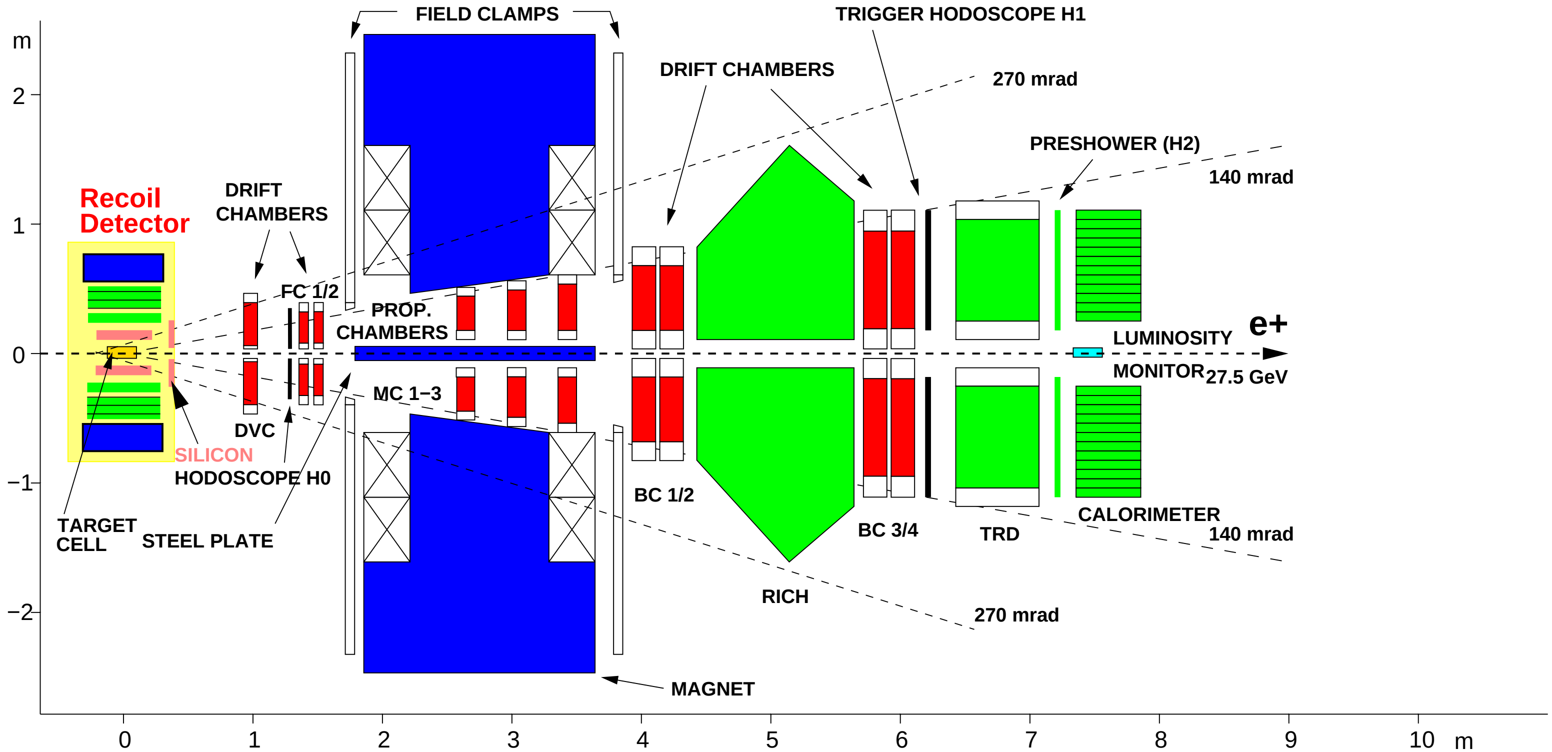
$\tau \sim 1/\gamma^5$! $\quad \gamma = 5.38 \cdot 10^4$



- **Beam polarization flips about monthly**

Typical $P_{beam} \simeq 40 - 50\%$
with fract. sys. err. <3.5%

HERMES SPECTROMETER



$$HERMES\ dipole\quad BL=1.3\ TM \qquad \frac{\Delta p}{p} \simeq 1\% \qquad \Delta\theta_x, \Delta\theta_y \simeq 1 mrad$$

$$-170 < \theta_x < +170\, mrad \qquad -140 < \theta_y < -40 mrad \qquad 140 > \theta_y > 40 mrad$$

$$40 < \theta < 220 mrad$$

Recoil Detector → *talk I.Vilardi*

Very good PID !!

HERMES PID ⟺ CALO+TRD+RICH+Pre

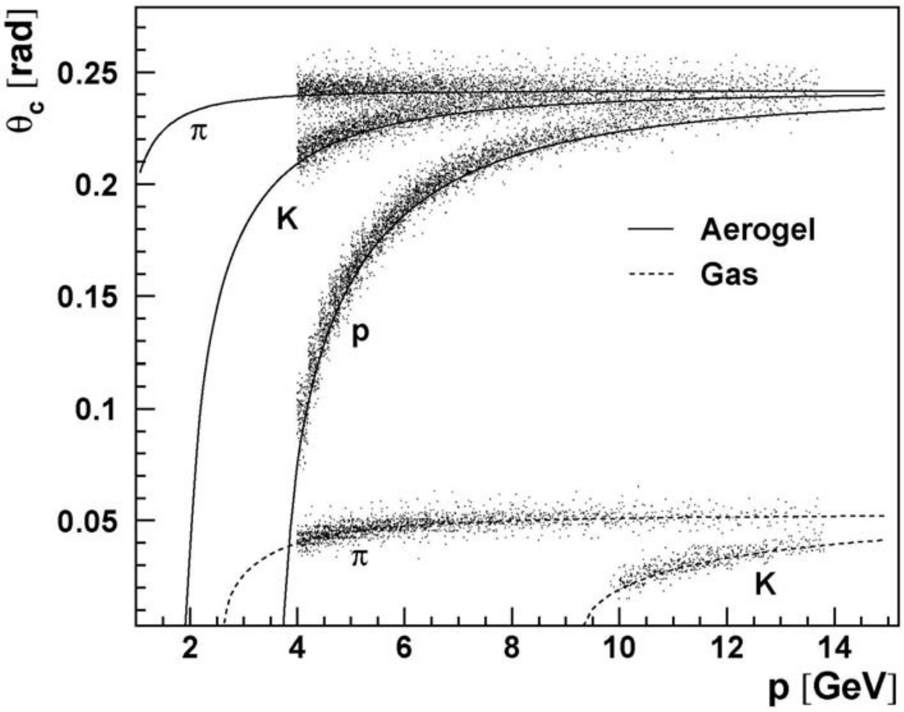
hadron/lepton separation

$$\varepsilon ff.(lepton) > 98\%$$

$$@ \frac{hadr.}{lept.} \; sup.f. \simeq 10^4$$

$$with \; hadron \; cont. < 0.5\%$$

pion/kaon/proton separation



Summary of HERMES data-taking with polarized targets

1994 HERMES test RUN

1995-2000 HERMES RUN I

Beam pol. =51%

Lumi H,D pol=259 pb-1

Lumi upol = 593 pb-1

(H,D, ^{3}He, ^{4}He, ^{14}N, ^{20}Ne and ^{84}Kr)

Longitudinal polarization

year	type	target polar. %
1995	^{3}He	46
1996	H	76
1997	H	85
1998	D	86
1999	D	83
2000	D	84.5

2001-2002 HERA lumi upgrade

2002-2007 HERMES RUN II

Beam pol. =36%
Lumi H pol=161 pb-1
Lumi unpol ~ 530 pb-1

Transverse polarization

years	type	polar.%
2002-2005	H	78

2006-2007 unpol (RD)

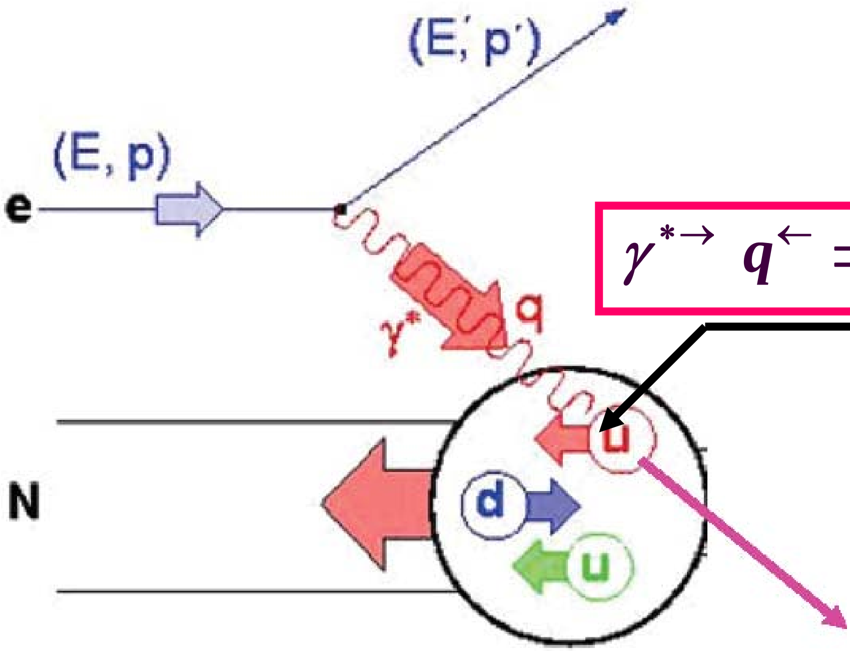
Phys. Rev. D 2007

Polarized DIS gives access to quark polarization

$$\vec{e} + \vec{p}, \vec{d} \Rightarrow e' + X \quad at\ Q^2 > 1 GeV$$

inclusive case

$$\frac{q(x,Q^2)\Uparrow\uparrow - q(x,Q^2)\Uparrow\downarrow}{q(x,Q^2)\Uparrow\uparrow + q(x,Q^2)\Uparrow\downarrow} = \frac{\Delta q(x,Q^2)}{q(x,Q^2)}$$



$$\gamma^{*\rightarrow}\ q^{\leftarrow} \Rightarrow q^{\rightarrow}$$

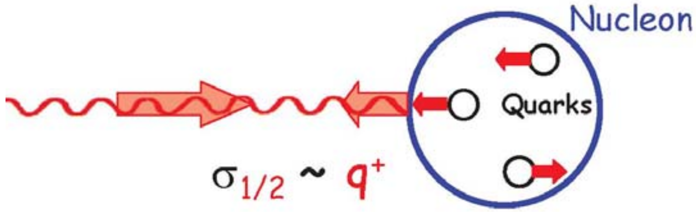
DIS kinematics in Lab frame

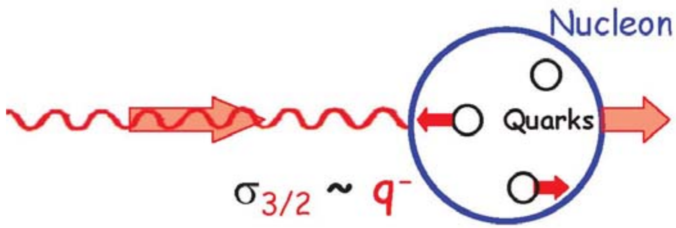
$$\nu = E - E' \quad \vec{q} = \vec{p}' - \vec{p}$$

$$Q^2 = -q^2$$

$$x = \frac{Q^2}{2M\nu}$$

For polarized nucleon





$$\sigma_{1/2} \sim q \Uparrow\uparrow \equiv q^{+} \qquad \sigma_{3/2} \sim q \Uparrow\downarrow \equiv q^{-}$$

small

$$(\gamma^{*}\,nucleon)\,asymmetry \quad A_1(x) = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1 - \frac{Q^2}{E_e \nu} g_2}{F_1} \approx \frac{g_1(x)}{F_1(x)}$$

$$g_1(x,Q^2) = \frac{1}{2}\sum_{q.\bar{q}} e_q^2 [q^{+}(x,Q^2) - q^{-}(x,Q^2)] = \frac{1}{2}\sum_{q.\bar{q}} e_q^2 \Delta q(x,Q^2)$$

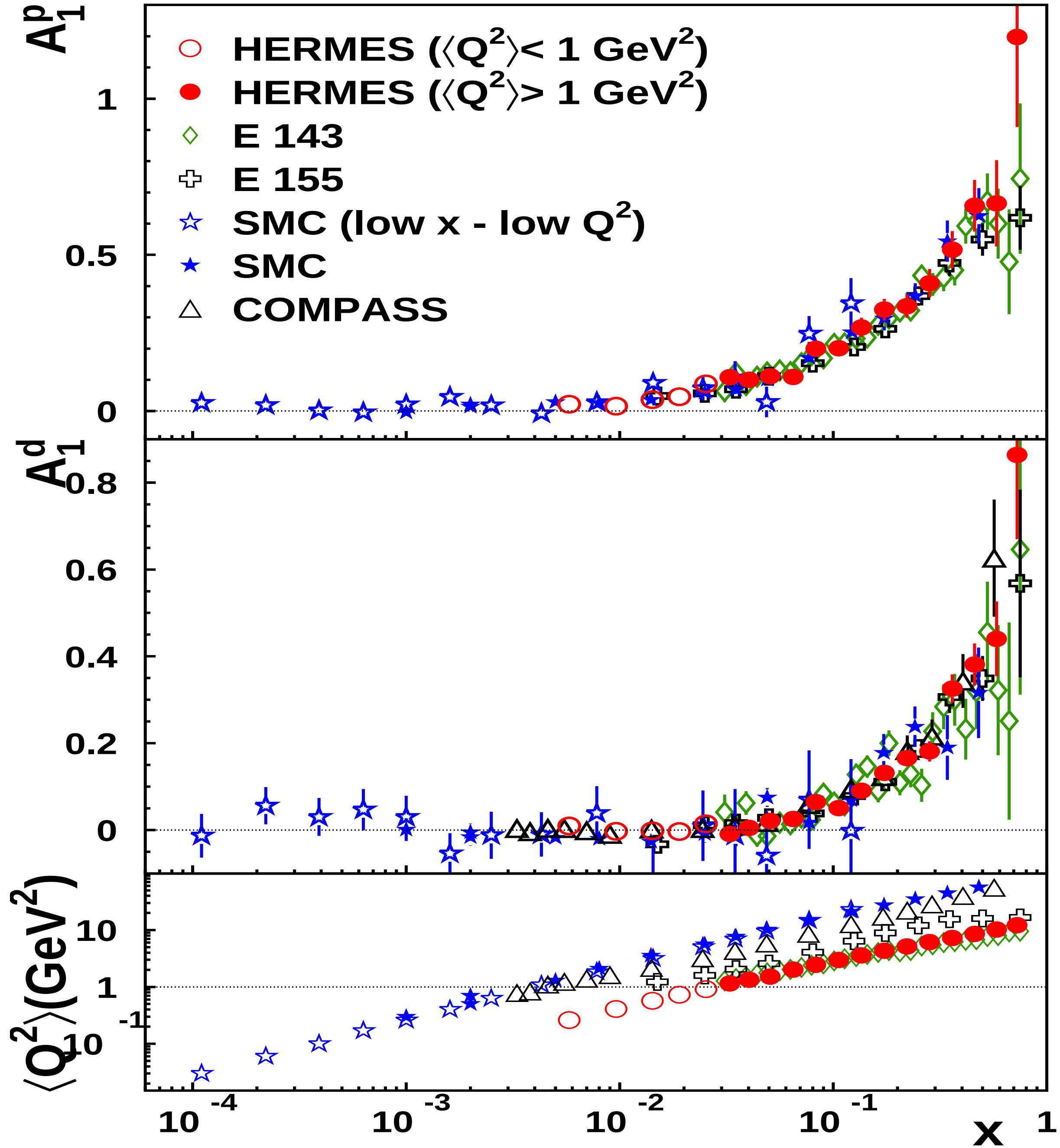
$$F_1(x,Q^2) = \frac{1}{2}\sum_{q.\bar{q}} e_q^2 [q^{+}(x,Q^2) + q^{-}(x,Q^2)] = \frac{1}{2}\sum_{q.\bar{q}} e_q^2 q(x,Q^2)$$

A1 HERMES

and world data

proton target

deuteron target



Integrals of spin-dependent structure functions

$$\Gamma_1^{p,n}(Q^2) = \int_0^1 dx g_1^{p,n}(x, Q^2) = \frac{1}{36}(4a_0 \pm 3a_3 + a_8)$$

$$a_0 = (\Delta u + \Delta \bar{u}) + (\Delta d + \Delta \bar{d}) + (\Delta s + \Delta \bar{s}) \equiv \Delta\Sigma$$

$$a_3 = (\Delta u + \Delta \bar{u}) - (\Delta d + \Delta \bar{d}) = \frac{1}{6}(\Gamma_p - \Gamma_n) \Leftarrow \text{from DIS}$$

$$a_8 = (\Delta u + \Delta \bar{u}) + (\Delta d + \Delta \bar{d}) - 2(\Delta s + \Delta \bar{s})$$

$a_0 = \Delta\Sigma$ ***cannot be extracted from DIS experiments only***

Due to SU(3) flavor symmetry additional equations come from hyperon ß-decay

$$a_3 = F + D = g_A / g_V = 1.269 \pm 0.003$$

$$a_8 = 3F - D = 0.586 \pm 0.031$$

Evaluation of ΔΣ

$$\Delta\Sigma = a_0 = (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) + (\Delta s + \Delta\bar{s})$$

neglecting $\frac{\alpha_S(Q^2)}{2\pi}$

$$= \frac{9}{2}(\Gamma_p + \Gamma_n) - a_8 = 9\Gamma_d/(1 - \frac{3}{2}\omega_d) - a_8$$

$$a_8 = 0.586 \pm 0.031$$

D-state correction

PRL 2005

ΔΣ evaluated at $\alpha_S = 0.29 \pm 0.01 \quad ...(\alpha_S{}^2)$

$Q_0^2 \sim 5 GeV^2 \quad \omega_d = 0.05 \pm 0.01 \quad 0.021 < x < 0.9 \quad a_8 = 3F - D = 0.586$

Integral $\int_x^{0.9} g_1^d(x)dx$ *starting from* $x = 006$ *well saturated,*

talk M.Varanda

i.e., $\int_{0.021}^{0.9} g_1^d(x)dx \simeq \int_0^1 g_1^d(x)dx \equiv \Gamma_d$

$$\Delta\Sigma = 0.330 \pm 0.025(\text{exp.}) \pm 0.011(\text{theo.}) \pm 0.028(\text{evol.})$$

Evaluation of $\mathbf{a}_3$, BJSR

$$\mathbf{a}_3 = (\Delta \mathbf{u} + \Delta \bar{\mathbf{u}}) - (\Delta \mathbf{d} + \Delta \bar{\mathbf{d}})$$

$$\mathbf{a}_3 \rightarrow \int_{0.021}^{0.9} g_1^p(\mathbf{x})\mathbf{dx} - \int_{0.021}^{0.9} g_1^n(\mathbf{x})\mathbf{dx} = 0.148 \pm 0.014$$

BJSR $$\frac{1}{6}\mathbf{a}_3 = \frac{1}{6} g_A / g_V = 0.182 \pm 0.002$$

too low for BJSR

BUT agrees with HERMES semi-inclusive DIS

$$\frac{1}{6}[(\Delta \mathbf{u} + \Delta \bar{\mathbf{u}}) - (\Delta \mathbf{d} + \Delta \bar{\mathbf{d}})]_{\mathbf{xmin}=0.023}^{\mathbf{xmax}=0.6} = 0.146 \pm 0.016$$

$\Rightarrow$ $\mathbf{x\,min} = 0.02$ ***is not enough for*** $\int_{0.02}$ .. ***saturation***

ΔS -content in nucleon

DIS (saturated)

from hyperon decay

$$(\Delta s + \Delta \bar{s}) = \frac{1}{3}(a_0 - a_8) \simeq 3\Gamma_1^d - \frac{5a_8}{12}$$

$$\Rightarrow -0.085 \pm 0.013(\text{theo.}) \pm 0.008(\text{exp})$$

Δu,Δd-content in nucleon

Assuming BJSR validity

$$(\Delta u + \Delta \bar{u}) = 0.842 \pm 0.004(\text{theo.}) \pm 0.008(\text{exp})$$

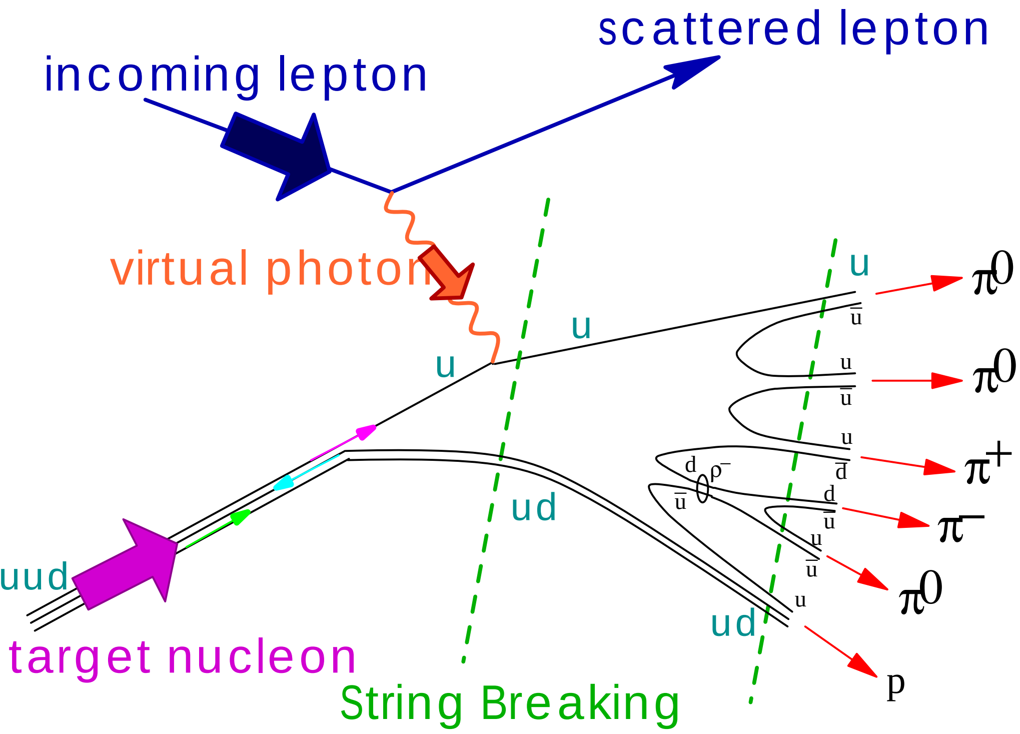
$$(\Delta d + \Delta \bar{d}) = -0.427 \pm 0.004(\text{theo.}) \pm 0.008(\text{exp})$$

Phys. Rev. D 2005

Quark helicity distributions from semi-inclusive DIS

$$\vec{e} + \vec{p}, \vec{d} \Rightarrow e' + h + X \quad at\ Q^2 > 1 GeV$$

semi-inclusive case



FF q to hadron

$$A_1^h(x,Q^2,z) = \frac{\sum_q e_q^2 \Delta q(x,Q^2) D_q^h(Q^2,z)}{\sum_{q'} e_{q'}^2 q(x,Q^2) D_{q'}^h(Q^2,z)}$$

$$= \sum_q P_q^h(x,Q^2,z) \cdot \frac{\Delta q(x,Q^2)}{q(x,Q^2)}$$

fractional q-contribution

new variable

$$z = \frac{E^h}{\nu}$$ *hadron fractional energy*

Measured asymmetries

proton target

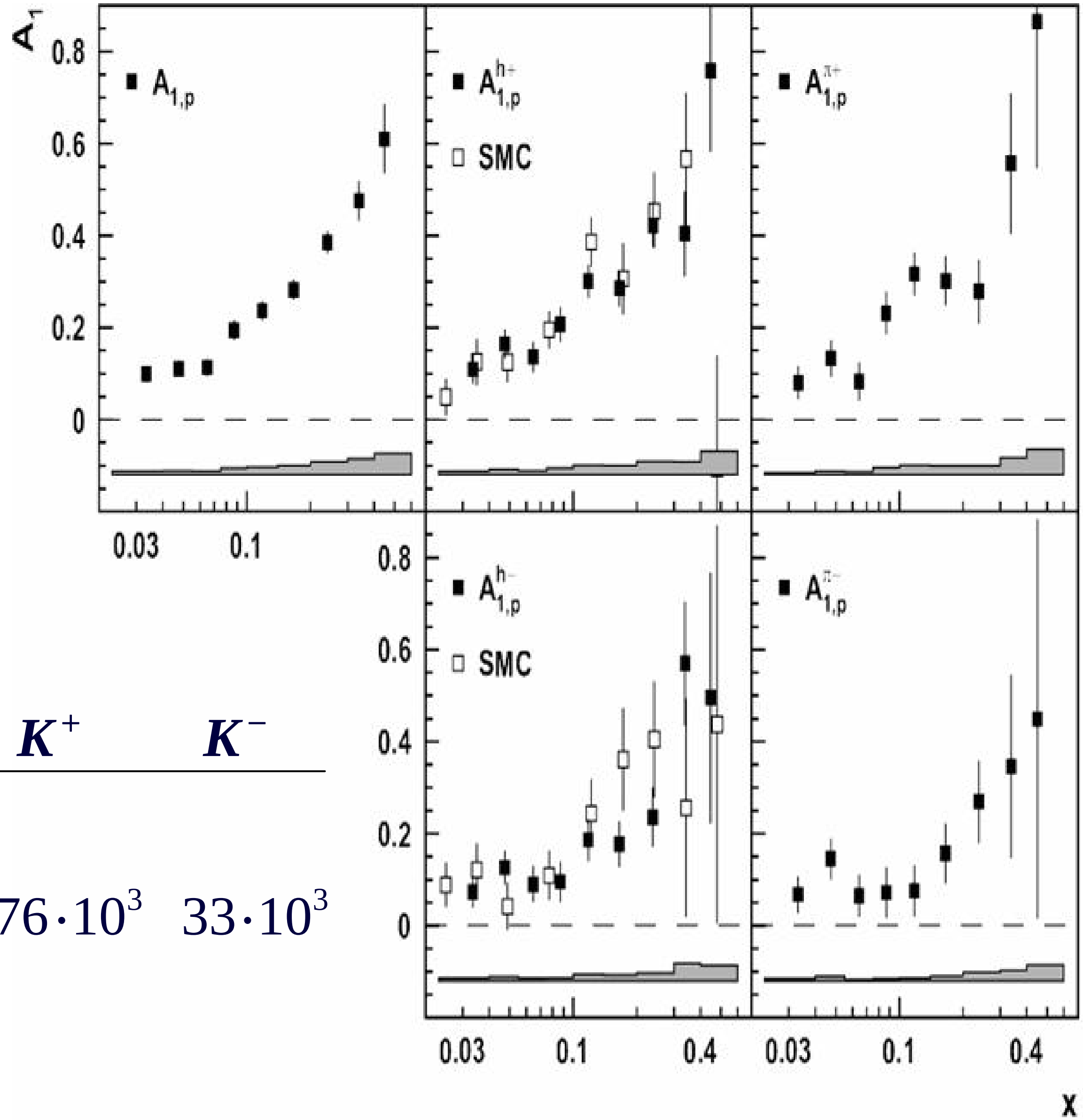
Kinematical conditions:

$$Q^2 > 1\,GeV^2, W^2 > 10\,GeV^2,$$

$$y = \frac{\nu}{E} < 0.85,\ 0.2 < z < 0.8$$

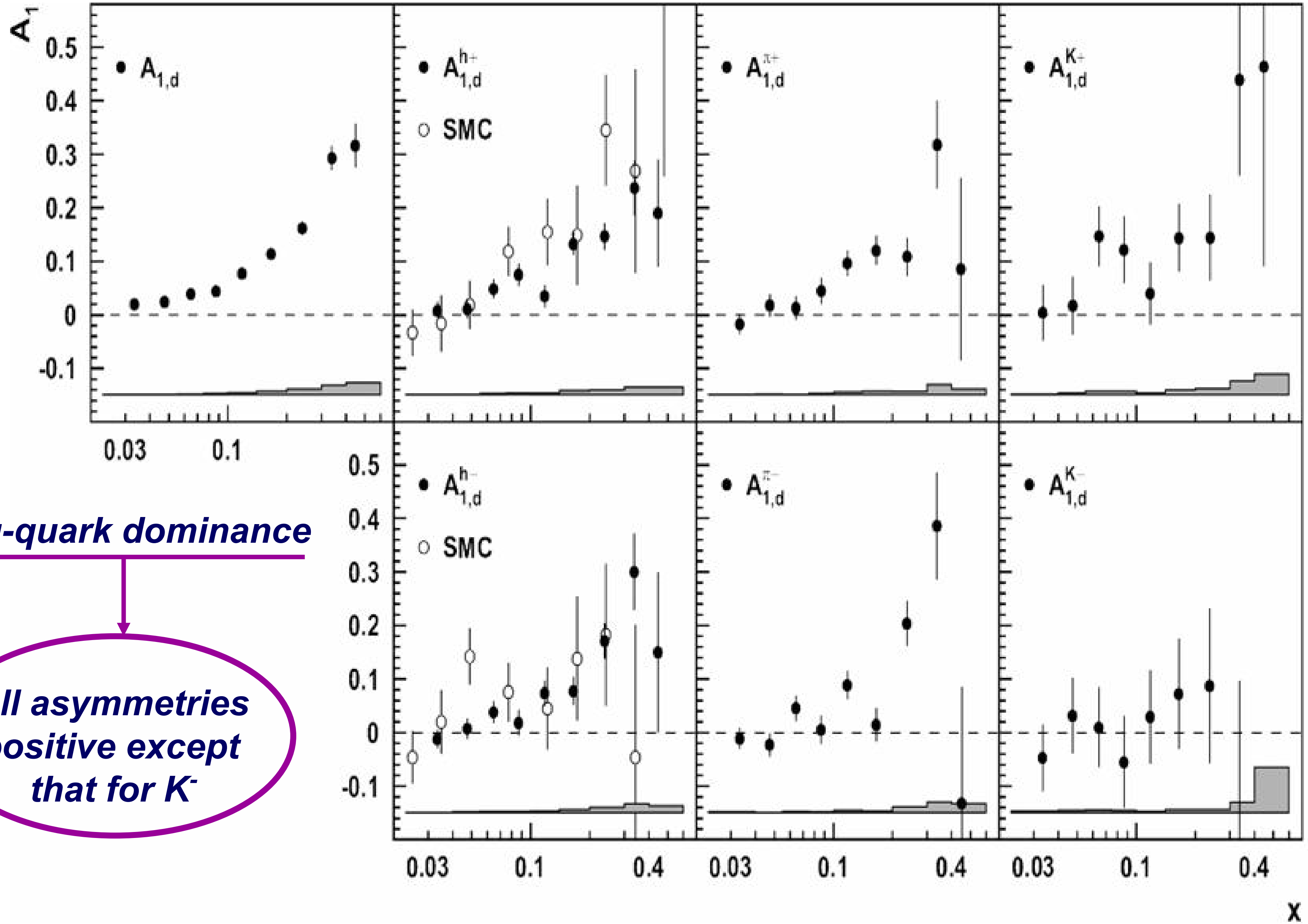
Data sample

	π^+	π^-	K^+	K^-
H	$117\cdot10^3$	$82\cdot10^3$		
D	$491\cdot10^3$	$385\cdot10^3$	$76\cdot10^3$	$33\cdot10^3$



Measured asymmetries

deuteron target



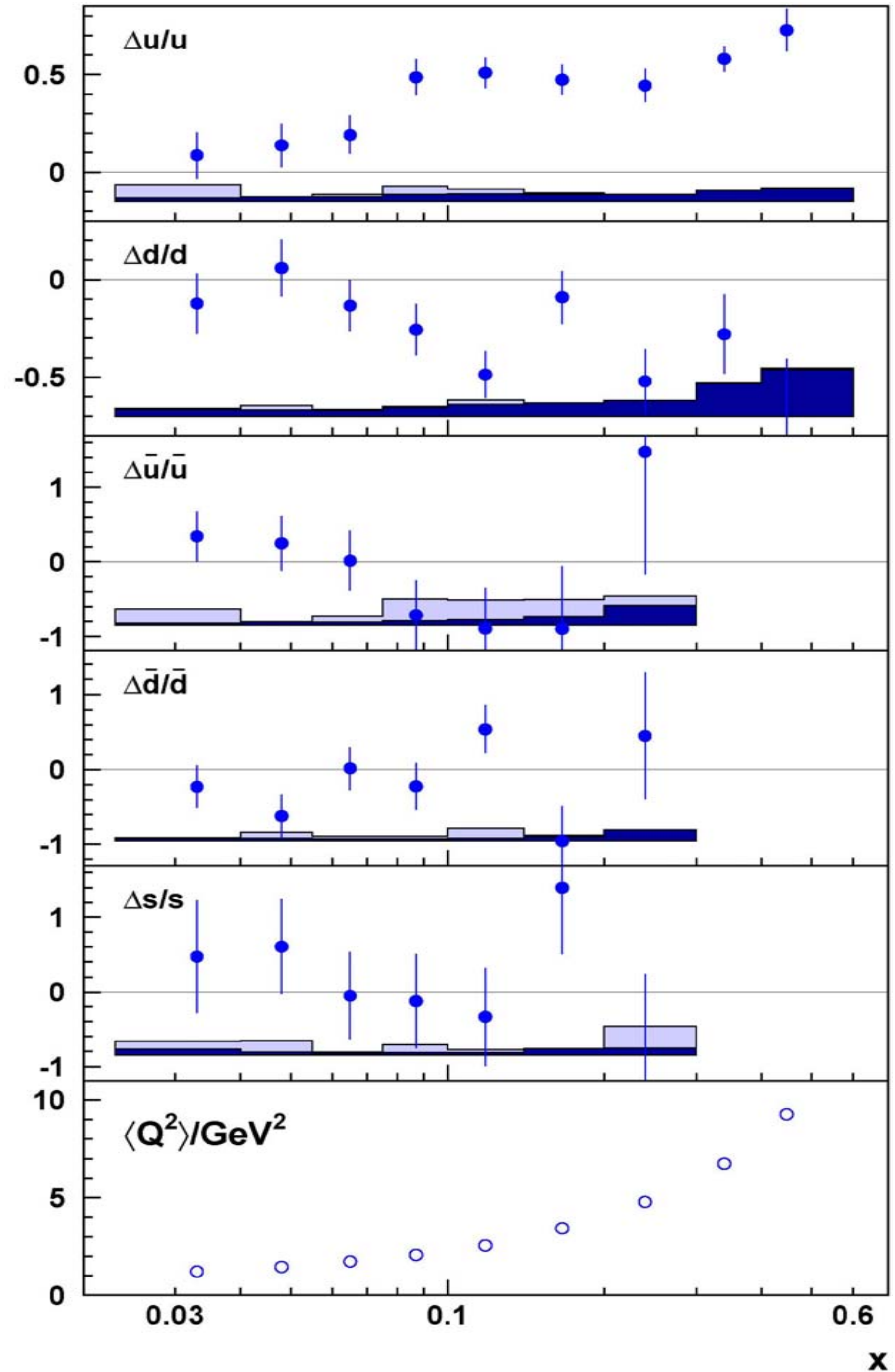
u-quark dominance

all asymmetries positive except that for K^-

quark polarizations

- Extracted using purity calculations in the frame of LUND fragmentation model.
- LUND MC tuned by fit to unpolarized pion / kaon multiplicity distributions
- Constrained by

$$\begin{cases} \Delta\bar{s} \equiv 0 \quad \textit{and} \\ \dfrac{\Delta s}{s} = \dfrac{\Delta\bar{u}}{\bar{u}} = \dfrac{\Delta\bar{d}}{\bar{d}} \equiv 0 \ \textit{at}\ x > 0.3 \end{cases}$$



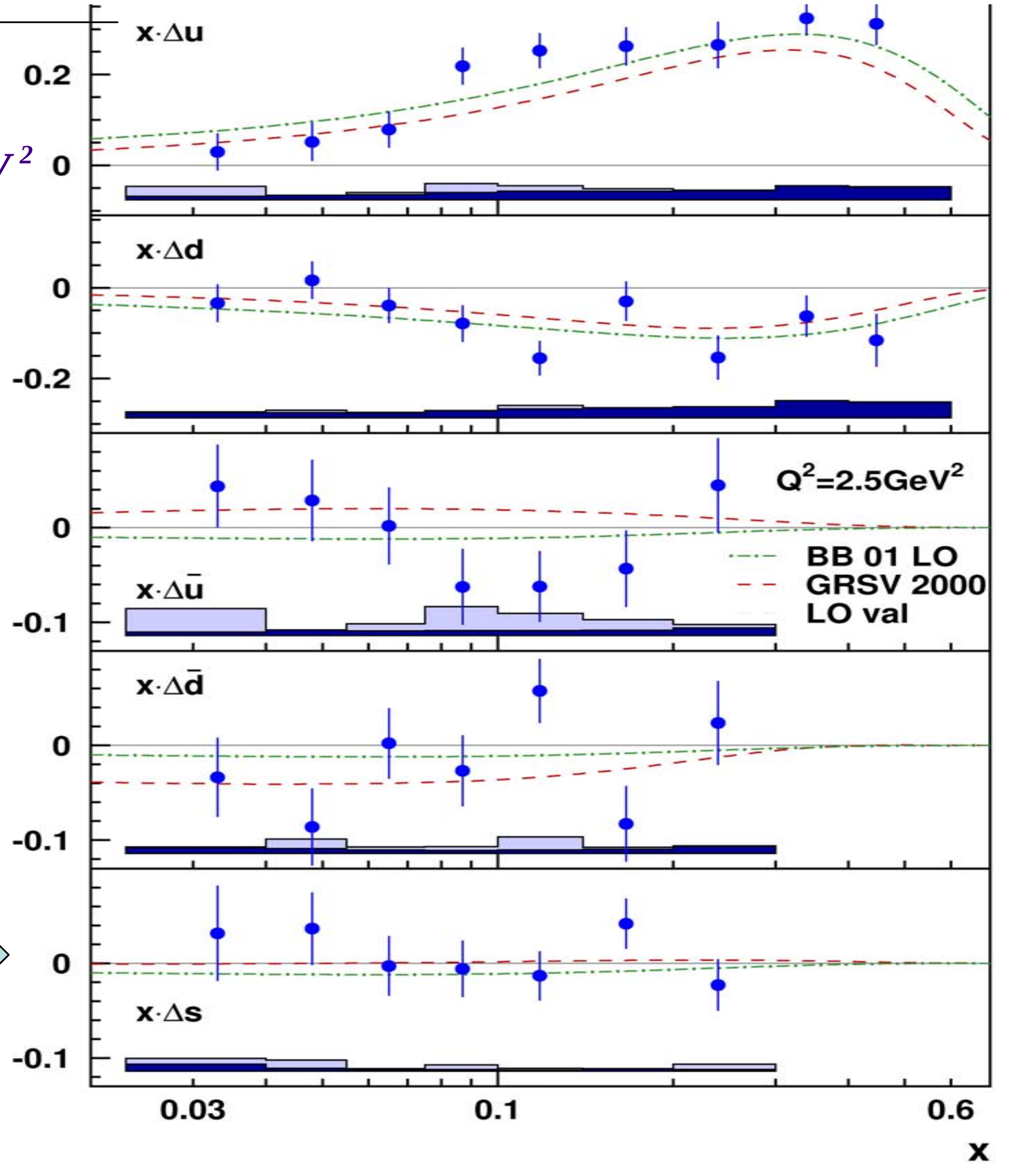
quark helicity distributions.

evaluated at $Q_0^2 = 2.5 GeV^2$

theory: QCD fit to inclusive DIS, SU(3), BJSR required.

Agreement looks fine

Δs compatible with zero



Integrals of Δq(x) in explored x-range

$\Rightarrow$ 0.023 < x < 0.6

$$\widehat{\Delta u} + \widehat{\Delta \bar{u}} = \int_{0.023}^{0.6} [\Delta u(x) + \Delta d(x)]dx$$

$$= 0.599 \pm 0.022 \pm 0.065 \Rightarrow 0.842$$

$$\widehat{\Delta d} + \widehat{\Delta \bar{d}} = -0.280 \pm 0.026 \pm 0.057 \Rightarrow -0.427$$

Large contribution from low x: $x < 0.023.$

Inclusive DIS with SU(3)

But $\widehat{\Delta\Sigma} = 0.347 \pm 0.024 \pm 0.066 \Rightarrow 0.330$

Not a surprise $\Rightarrow$ $\widehat{\Delta\Sigma} = \frac{3}{5}[12 \cdot \Gamma_1^d + (\Delta s + \Delta \bar{s})]$

well saturated

small

ΔG from HERMES hadron high PT data

ΔG is poorly known till now. In principle , it can be accessed by investigating NLO structure function g1:

E155, SMC →pQCD fit to NLO g1

/J.Blumlein,M.Hirai,D.de Florian,Leader et al/

Unfortunately , the results obtained are very uncertain:

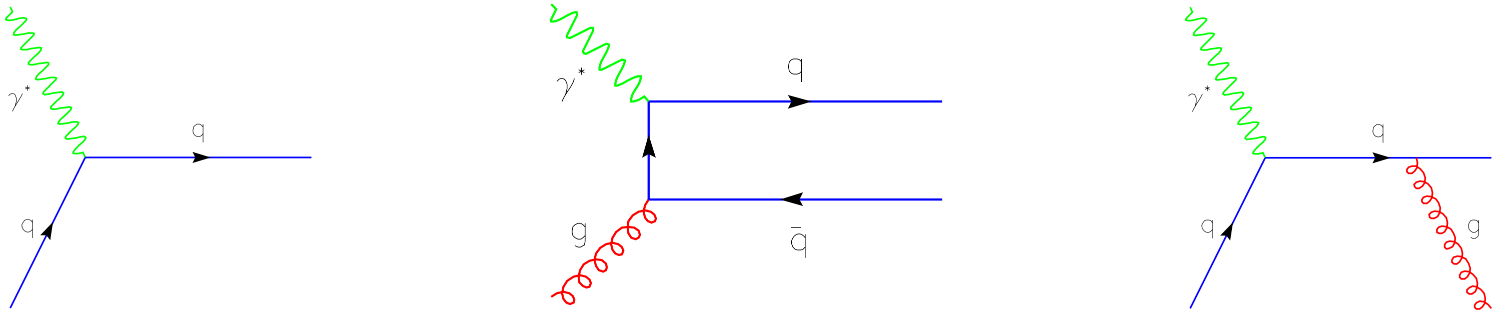
$$\Delta G(x,Q^2) = \int_0^1 \Delta g(x,Q^2)dx \approx (0.5\ to\ 1) \pm 1$$

Δg may be also accessed in polarized pp collisions,

e.g. A_{LL} in $\vec{p}\vec{p} \Rightarrow \pi^0 X$ is sensitive to $\frac{\Delta g}{g}$

→ PHENIIX&STAR new results are expected

In polarized charged lepton scattering (NLO), access to ΔG is possible via PGF mechanism



DIS leading	PGF	QCD Compton
$A_{LL} \sim \frac{\Delta q}{q}$	$A_{LL} \sim \frac{\Delta g}{g}$	$A_{LL} \sim \frac{\Delta q}{q}$

PGF dominates in the case of CHARM PRODUCTION

$$q = c\,,\ \bar{q} = \bar{c}$$

low bgr experiment, but usual problem is lack of statistics

Another option to enhance PGF mechanism is detection of hadrons with high PT.

$$A_{LL}^{meas}(p_T) = \sum_i R_i(p_T) a_{LL}^i(p_T) \qquad i - subprocess$$

$R_i(p_T)$ fraction of i – subprocess $\Leftarrow$ PYTHIA 6.2

$a_{LL}^i(p_T)$ asymmetry of i – subprocess

$$a_{LL}(p_T) = \alpha_{LL}(s,t) \bullet \frac{\Delta f_a^{\gamma}(x_a, Q^2)}{f_a^{\gamma}(x_a, Q^2)} \bullet \frac{\Delta f_b^{N}(x_b, Q^2)}{f_b^{N}(x_b, Q^2)}$$

qq,gq, etc. calculable

photon pol/unpol PDF

nuclon pol/unpol PDF

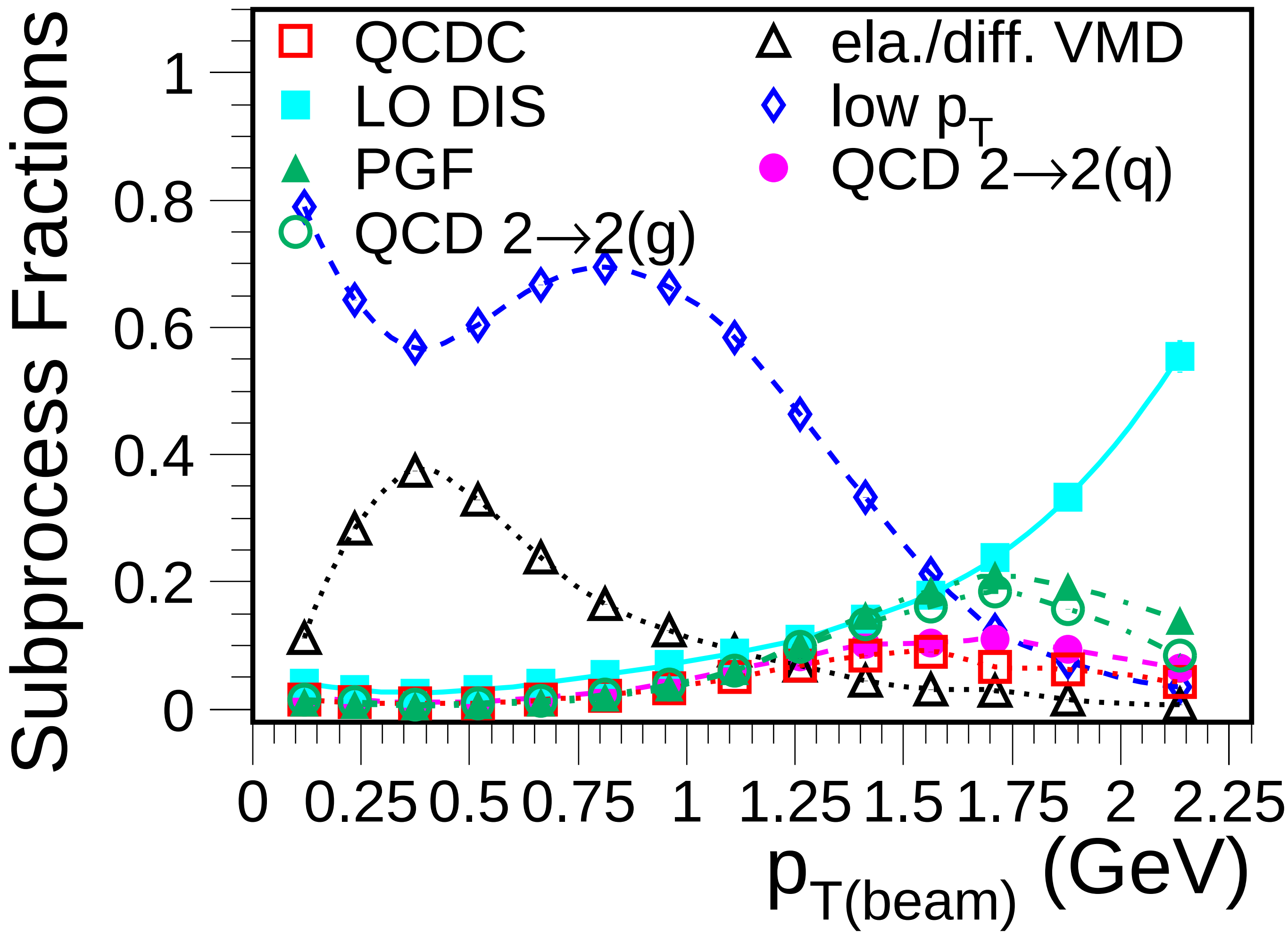
For PGF
$$\alpha_{LL}(s,t) = \frac{\Delta\sigma_{\gamma g \to q\bar{q}}}{\sigma_{\gamma g \to q\bar{q}}}(s,t)$$

$$\frac{\Delta f_b^{N}(x_b, Q^2)}{f_b^{N}(x_b, Q^2)} \Rightarrow \frac{\Delta g_b^{N}(x_b, Q^2)}{g_b^{N}(x_b, Q^2)}$$

Unknown gluon polarization can be found using measured asymmetry $A_{LL}^{meas}(p_T)$

Contributions from various subprocesses

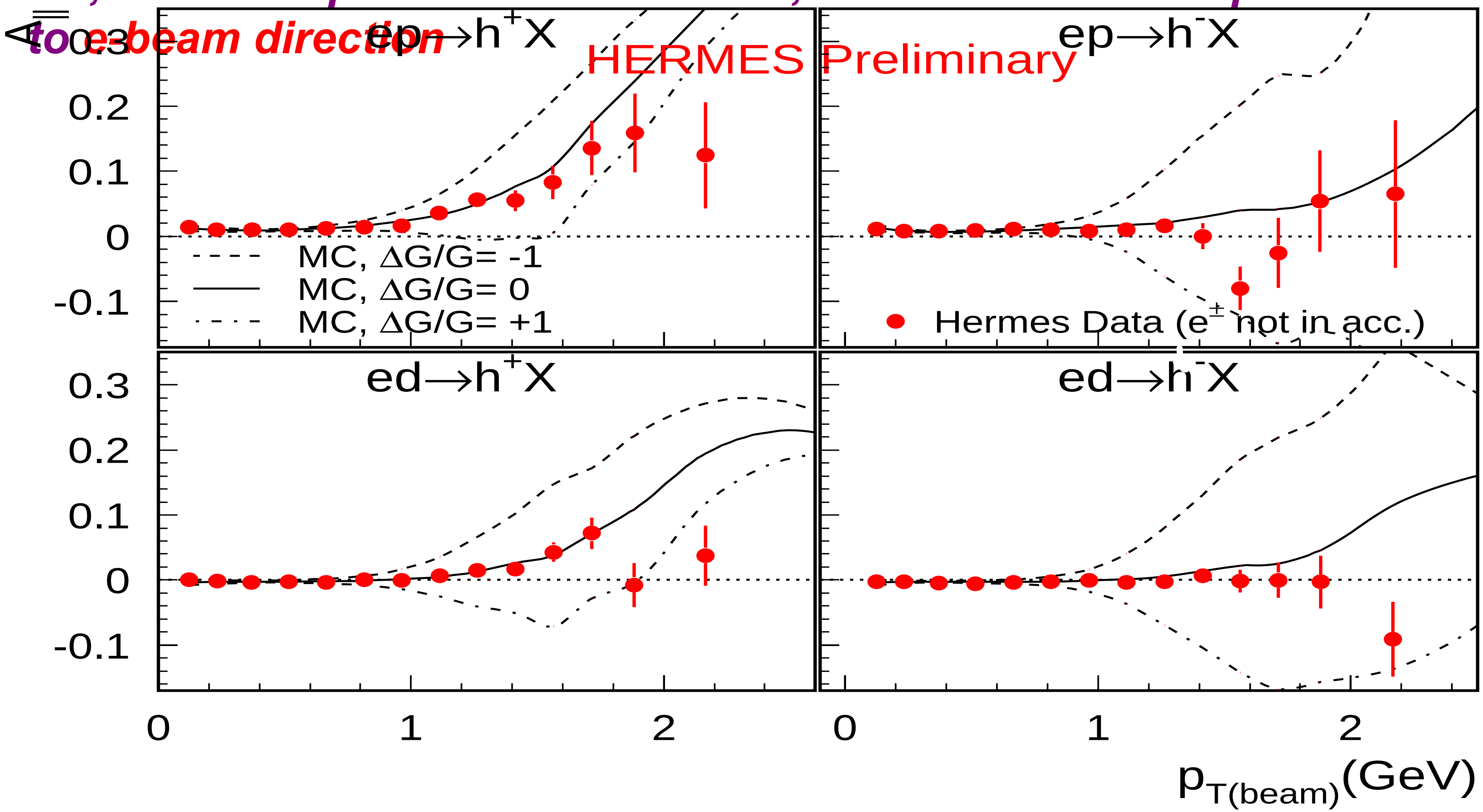
$R_i(p_T)$ fraction of $i-subprocess \Leftarrow$ *PYTHIA*



Measured high PT hadron asymmetries

$$\vec{e} + \vec{p}, \vec{d} \Rightarrow h^{\pm}(h^{\mp}) + (e) + X$$ ***asymmetry*** A_{LL} ***measured***

Most of data collected from d-target in "untaged (e)" variant, i.e., scattered positron not detected, PT is defined in respect to e-beam direction



Extraction of ΔG/G

$$A_{LL}^{signal} = A_{LL}^{meas} - A_{LL,BGR}^{MC} \qquad (R_{subpr}^{i}\ \text{weighted})$$

Method I, factorization

$$A_{LL}^{signal} = R^{PGF} \bullet \langle \alpha_{LL}(s,t) \frac{\Delta f_q^{\gamma}(x_q)}{f_q^{\gamma}(x_q)} \frac{\Delta g(x)}{g(x)} \rangle \approx \frac{\Delta g}{g} \bullet R^{PGF} \bullet \langle \alpha_{LL}(s,t) \frac{\Delta f_q^{\gamma}(x_q)}{f_q^{\gamma}(x_q)} \rangle$$

Method II, Δg(x)/ g(x) parameters fitted to data

$$\frac{\Delta g}{g}(x) = x(1+p_1(1-x)^2) \ \text{or} \ x(1+p_1(1-x)^2 + p_2(1-x)^3)$$

Results

Method I:

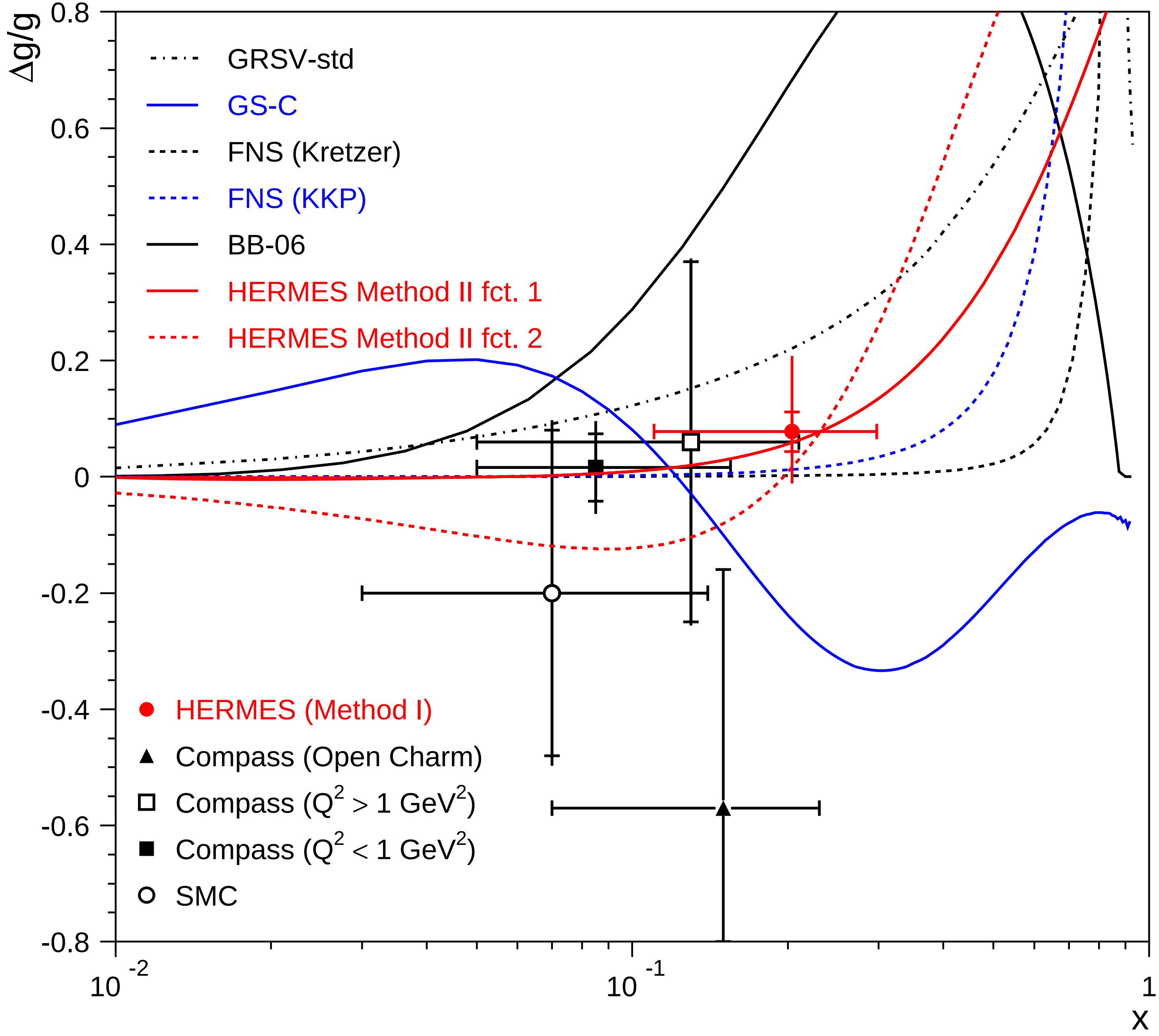
$$\frac{\Delta g}{g} = 0.078 \pm 0.034 \pm 0.011 \quad \text{at} \quad \langle x \rangle = 0.204$$

Method II:

$$\frac{\Delta g}{g} = 0.071 \pm 0.034 \pm 0.010 \quad \text{at} \quad \langle x \rangle = 0.222$$

uncertainty due to model-dependence $\approx \pm 0.11$

ΔG final result compilation



Summary

- Using well -saturated Γ_d and under SU(3) f.sym. assumption it is found

at $Q^2 = 5\,\mathrm{GeV}^2$

$$\Delta\Sigma = 0.330 \pm 0.025(\exp.) \pm 0.011(\text{theo.}) \pm 0.028(\text{evol.})$$

$$(\Delta s + \Delta\bar{s}) = -0.085 \pm 0.013(\text{theo.}) \pm 0.008(\exp)$$

- Quark polarizations and helicity distributions are extracted from SIDIS data for 5 quark flavors (of 6) for the first time. ΔS(x) is compatible with 0.

talk M.Varanda

- From analyis of high PT hadron production, ΔG/G is estimated to be $0.078 \pm 0.034 \pm 0.011$ with theor. uncertainty of ~0.1.

- other hermes topics…

Transverse spin effects at HERMES

Phys. Rev D 2007
Phys. Lett. B 2005
Phys.Rev. Lett. 2005

HERMES measured transverse spin effects in semi-inclusive $\pi^{\pm}, \pi^{0}, K^{+}, K^{-}$ production related to

- ✓ longitudinal beam polarization $\Rightarrow A_{LU}(\Phi)$
- ✓ longitudinal target polarization $\Rightarrow A_{UL}(\Phi)$
- ✓ transverse target polarization $\Rightarrow A_{UT}(\Phi, \Phi_S)$

access to

$\delta q(x) = q\uparrow(x) - q\downarrow(x)$

Collins FF, Sivers DF

Deep Virtual Compton Scattering DVCs, Hard exclusive meson production

GPD, access to quark orbital moments J_q

→ talk of V. Korotkov

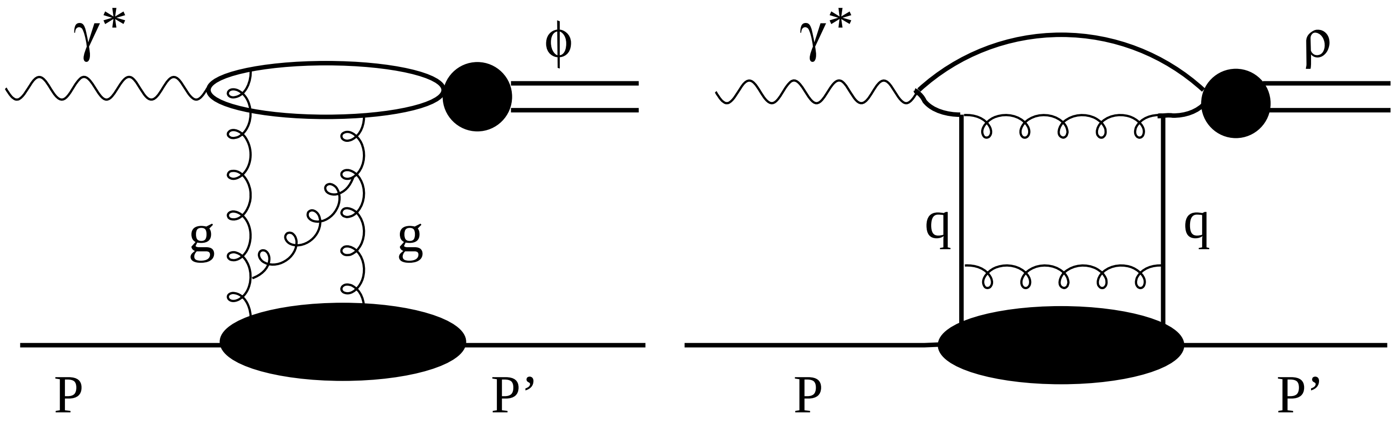
Vector Meson (VM) production at HERMES

Exclusive VM production provides access to GPDs:

both unpolarized $H, \tilde{H}$ ***and polarized*** $E, \tilde{E}$

First POLARIZED data for Φ-meson production

→ ***gluon exchange***



talk of A. Borisov

Phys Rev. D 2006

Polarized Λ physics at HERMES

Self-analyzing polarized Λ –decay gives a unique opportunity to measure (in addition to DSA and SSA) new polarization observables related to

polarization of the produced Λ hyperon

HERMES has measured:

✓ In semi-inclusive DIS spin-transfer from polarized beam beam

$D^{\Lambda}_{LL'}$ at $Q^2 > 0.8 GeV^2$

✓ In quasi-real photoproduction with Λ inclusively detected

- Transverse Λ polarization — P_n^{Λ} at $Q^2 \approx 0$
- Spin-trasfer from long. polarized target — K_{LL}^{Λ} at $Q^2 \approx 0$

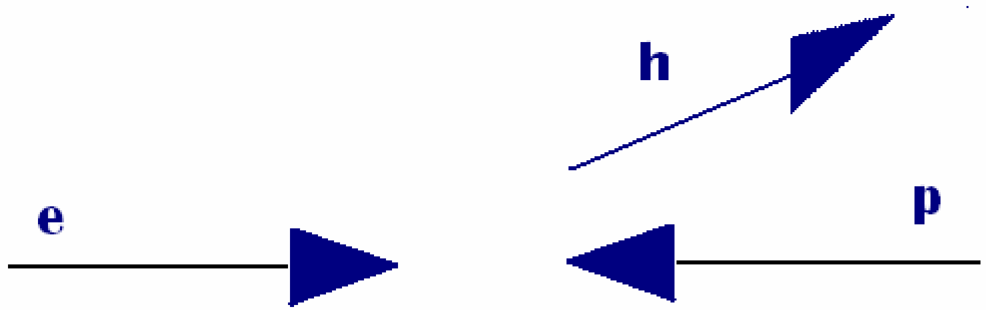
talk of D. Veretennikov

HERMES Recoil Detector

Design and performance, first results → *talk I.Vilardi*

THANK YOU VERY MUCH FOR ATTENTION

Backup Slides



The HERMES experiment from 1994 to 2007

hermes

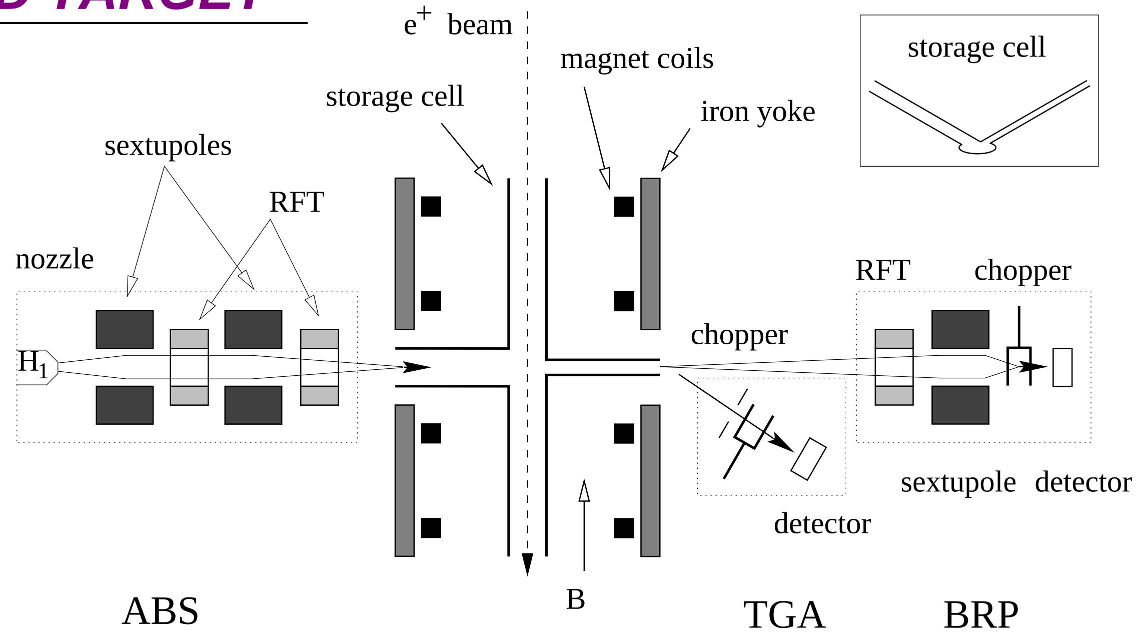
A second generation experiment designed to study the spin structure of the nucleon at HERA

Alberta	Freiburg	Munich	Bari
Argonne	Gent	N. Mex. St.	Beijing
Cal Tech	Illinois	NIKHEF	Hefei
Colorado	JINR, Dubna	Pennsylvania	Giessen
DESY, Ham.	Kentucky	Rome	Glasgow
DESY, Zeuthen	Liverpool	St. Petersburg	Michigan
Erlangen	Marburg	Tokyo	Protvino
Ferrara	MIT	TRIUMF	Regensburg
Florida Int.	Moscow	Wisconsin	Uni. Amsterdam
Frascati	MPI, Heidelberg	Yerevan	Warsaw

HERMES POLARIZED TARGET

NIM A540 2005

target
polarization
flips every
60s



Opt.Pump.	Atomic Beam Source (ABS)		
Longitudinally polarized			Transversely polarized
1995	1996-1997	1998-2000	2001-2006
He3	H	D	H
B= 350 mT			B=297 mT
	target cell		
125 µm ,25K	wall=75µm l=400mm s=29.8x9.8		s=21.0x8.9 T~70-100K
3.3×10^{14}	$\approx 2\times10^{14}$		$lim. \approx 10^{15}\, atom / cm^2$
$P_T = 40\% \pm 5\% (frac.)$	$85\% \pm 5\% (frac.)$		$78\% \pm 4\% (frac.)$

Evaluation of $\Delta\Sigma$

$$\Delta\Sigma = a_0 = (\Delta u + \Delta\bar{u}) + (\Delta d + \Delta\bar{d}) + (\Delta s + \Delta\bar{s})$$

neglecting $\frac{\alpha_s(Q^2)}{2\pi}$

$$= \frac{9}{2}(\Gamma_p + \Gamma_n) - a_8 = 9\Gamma_d / (1 - \frac{3}{2}\omega_d) - a_8$$

$$a_8 = 0.586 \pm 0.031$$

D-state correction

$\Delta\Sigma$ evaluated at $\alpha_s = 0.29 \pm 0.01 \quad ...(\alpha_s{}^2)$

$Q_0^2 \sim 5 GeV^2 \quad \omega_d = 0.05 \pm 0.01 \quad 0.021 < x < 0.9 \quad a_8 = 3F - D = 0.586$

Integral $\int_x^{0.9} g_1^d(x)dx$ *at* $x = 006 \to 0.02$ *well saturated,*

talk M.Varanda

i.e., $\int_{0.021}^{0.9} g_1^d(x)dx \simeq \int_0^1 g_1^d(x)dx \equiv \Gamma_d$

$$\Delta\Sigma = 0.330 \pm 0.025(\text{exp.}) \pm 0.011(\text{theo.}) \pm 0.028(\text{evol.})$$

EMC $\Delta\Sigma = 0.12 \pm 0.09 \pm 0.04$ *COMPASS* $\Delta\Sigma = 0.25 \pm 0.03$ *Theo* ≈ 0.6

Phys. Rev. D 2005

Quark helicity distributions from semi-inclusive DIS

$$\vec{e} + \vec{p}, \vec{d} \Rightarrow e' + h + X \quad at\ Q^2 > 1 GeV$$

semi-inclusive case

SIDIS kinematics

$$Q^2,\ x = \frac{Q^2}{2M_p\nu},\ \nu = E_e - E'_{e'}$$

$$z = \frac{E^h}{\nu}$$ hadron fractional energy

$$A_1^h(x,Q^2,z) = \frac{\sum_q e_q^2\,\Delta q(x,Q^2)\,D_q^h(Q^2,z)}{\sum_{q'} e_{q'}^2\,q(x,Q^2)\,D_{q'}^h(Q^2,z)} = \sum_q P_q^h(x,Q^2,z)\cdot\frac{\Delta q(x,Q^2)}{q(x,Q^2)}$$

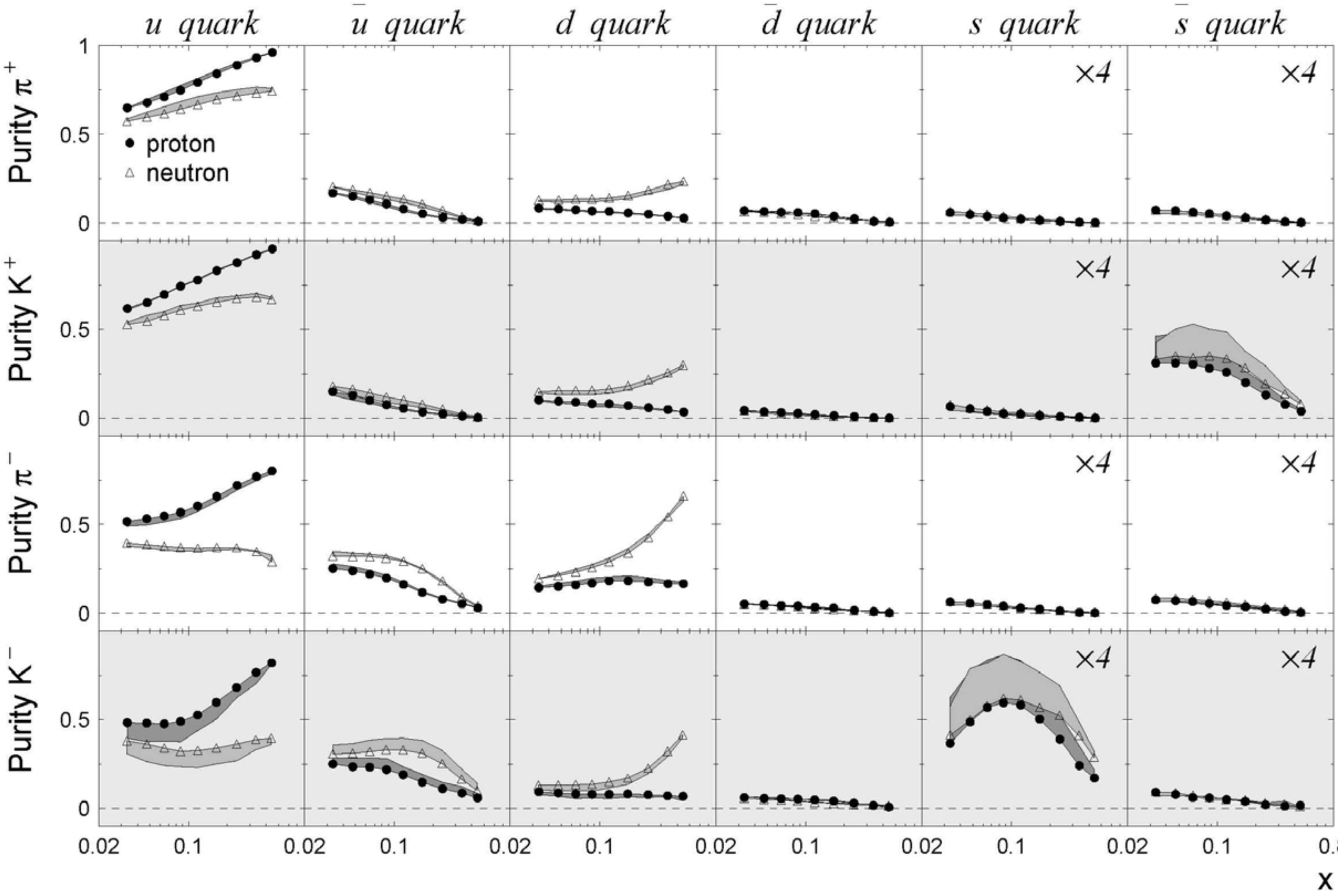
FF q to hadron

fractional q-contribution

$$\sum_q P_q^h(x,Q^2,z) = 1$$

Purity distributions

Lund MC tuned to experimental HERMES π^+, π^-, K^+, K^- multiplicities



Comparison with SMC

	HERMES	*SMC*
Δu_v	$0.603 \pm 0.071 \pm 0.040$	$0.614 \pm 0.082 \pm 0.068$
Δd_v	$-0.172 \pm 0.068 \pm 0.045$	$-0.334 \pm 0.112 \pm 0.089$
$\Delta \bar{u}$	$-0.002 \pm 0.036 \pm 0.023$	$0.015 \pm 0.034 \pm 0.024$

$Q_0^2 = 2.5\ GeV^2$ *integrated over HERMES x- range*

SMC constrained $\Rightarrow$ $\Delta\bar{u}(x) = \Delta\bar{d}(x) = \Delta s(x) = \Delta\bar{s}(x)$

SSA in semi-inclusive hadron production

Under study is $$\vec{e} + \vec{p}, \vec{d} \Rightarrow e' + H + X$$

Azimuthal asymmetry around virtual photon direction is measured related to:

- ✓ longitudinal beam polarization $\Rightarrow A_{LU}$
- ✓ longitudinal target polarization $\Rightarrow A_{UL}$
- ✓ transverse target polarization $\Rightarrow A_{UT}$

Motivations

Helicity DF

$$\Delta q(x)=\vec{q}(x)-\overleftarrow{q}(x)$$

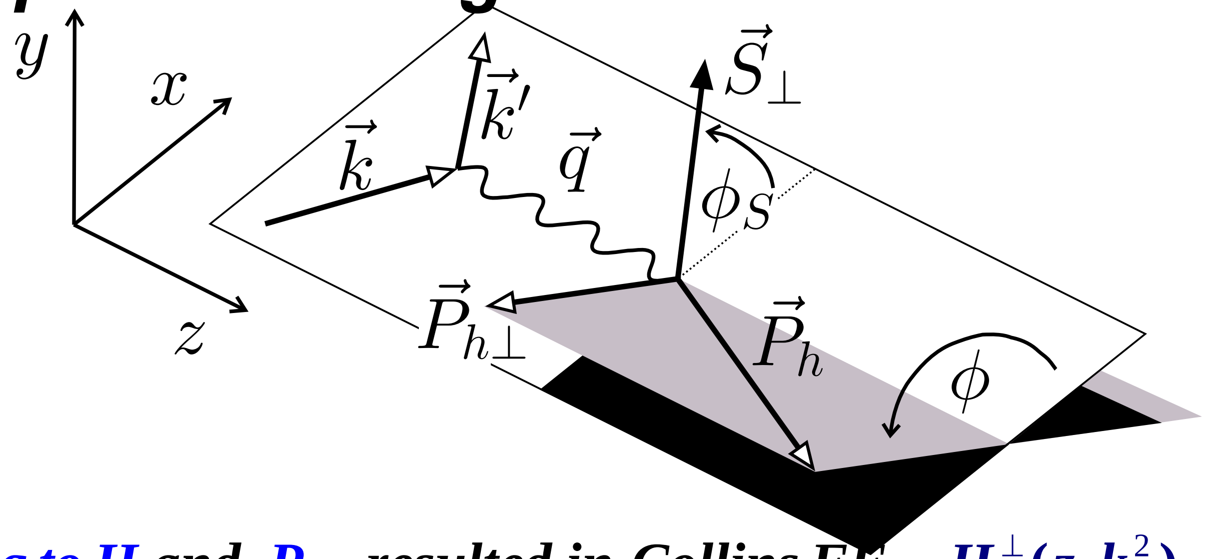
Transversity DF

$$\delta q(x)=q\uparrow(x)-q\downarrow(x)$$

Transversity DF is practically unknown till now.
SSA measured on transversely polarized target gives access to

$$\delta q$$

Transversely polarized target and Collins FF



Correlation between

spin of q ↑ fragmenting to H and $P_{H\perp}$ resulted in Collins FF $H_1^\perp(z, k_T^2)$

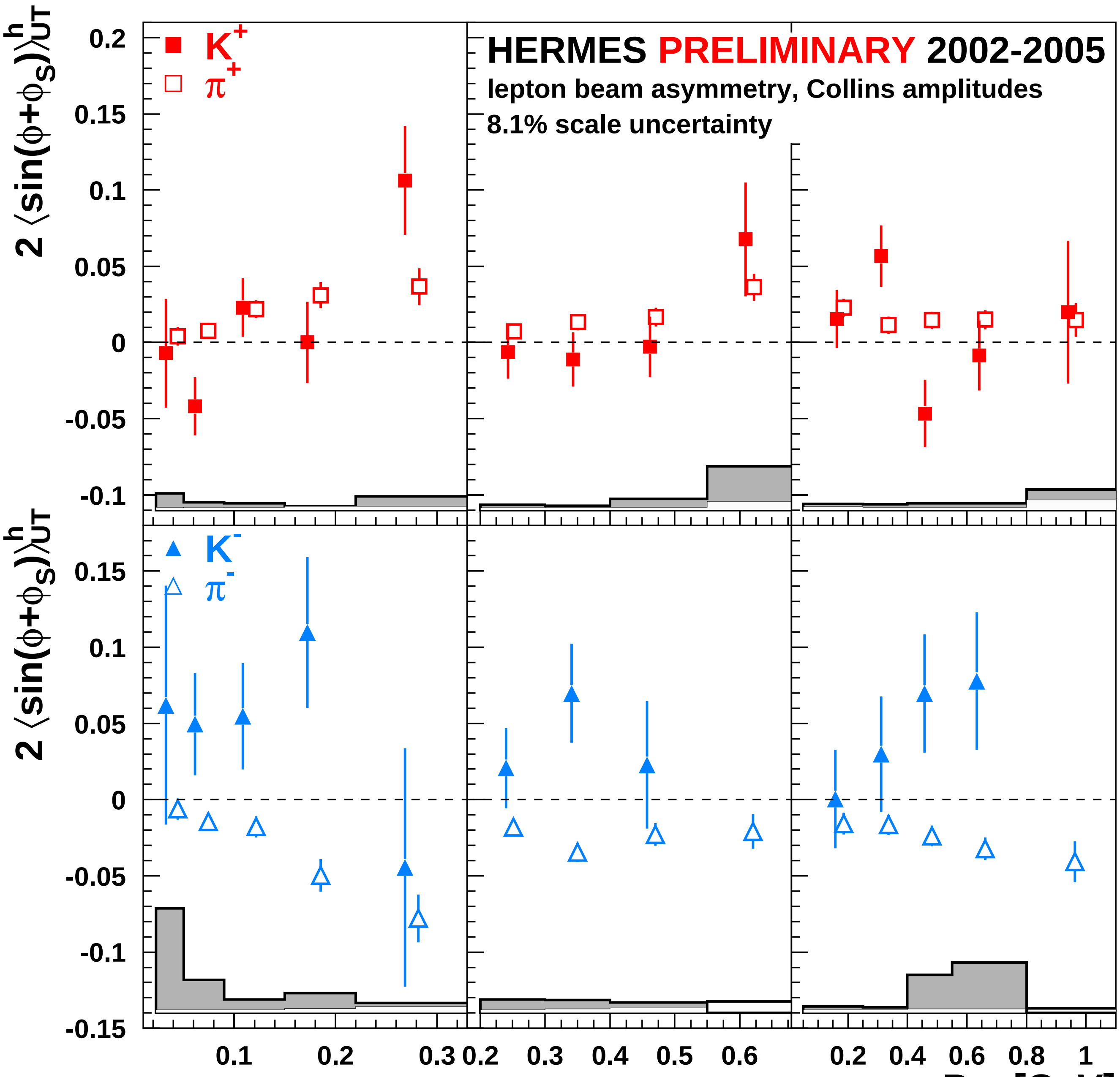
Access to transversity DF

$$A_{UT}^h \propto \sin(\phi + \phi_S) \sum_q e_q^2 h_{1T}^q(x, P_T^2) \otimes H_1^{\perp q}(z, k_T^2)$$

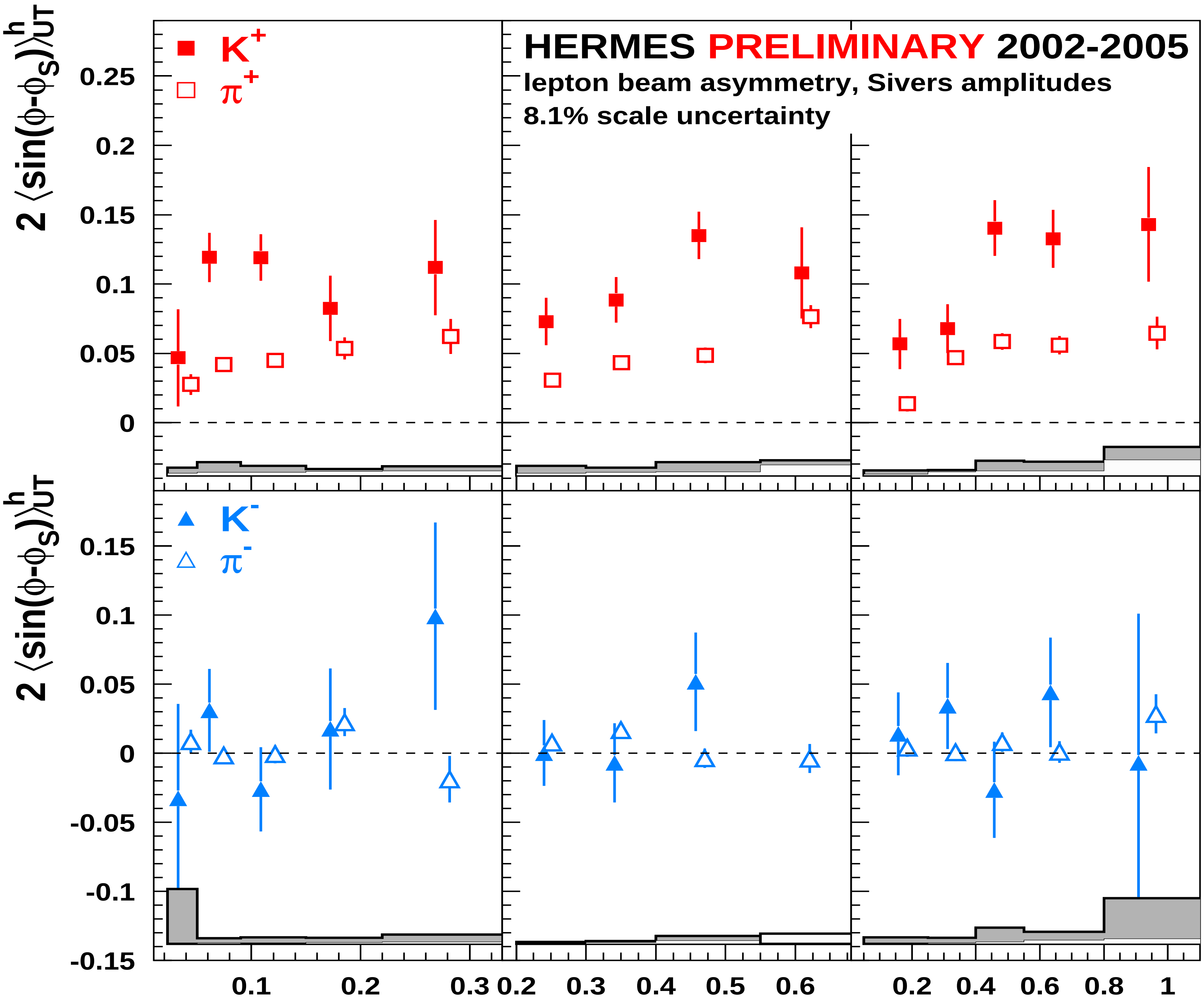
$$= \sin(\phi + \phi_S) \langle \sin(\phi + \phi_S) \rangle,$$

$$\langle \sin(\phi - \phi_S) \rangle \quad \textit{Sivers DF corr. quark spin with } P_T$$

Very recent results, Collins FF



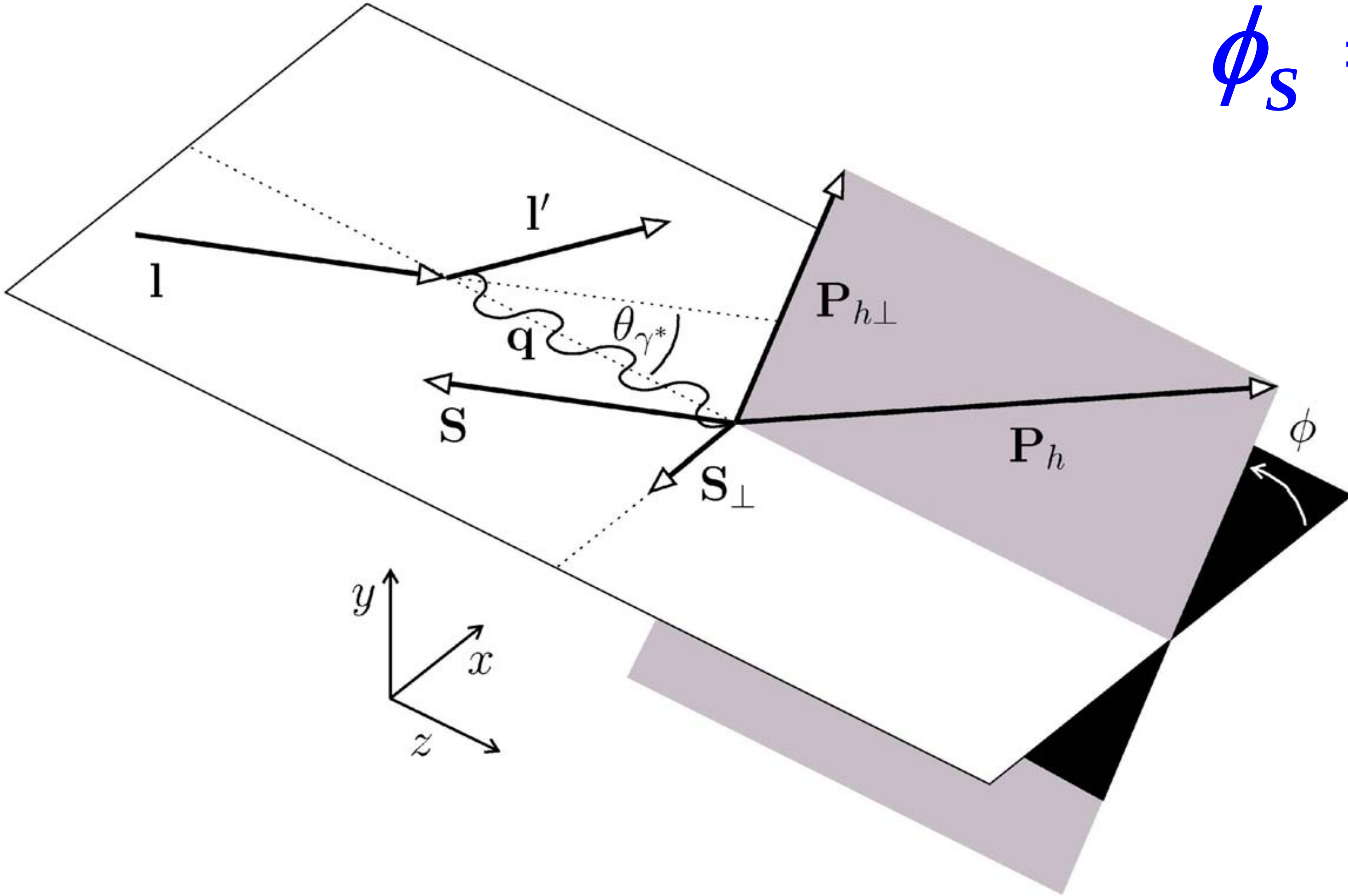
Very recent results, Sivers DF



Transverse effects related to longitudinally polarized beam and/or target

$$\mathbf{S}_{\perp} \neq 0$$

$$\phi_S = \pi$$



Measured asymmetries

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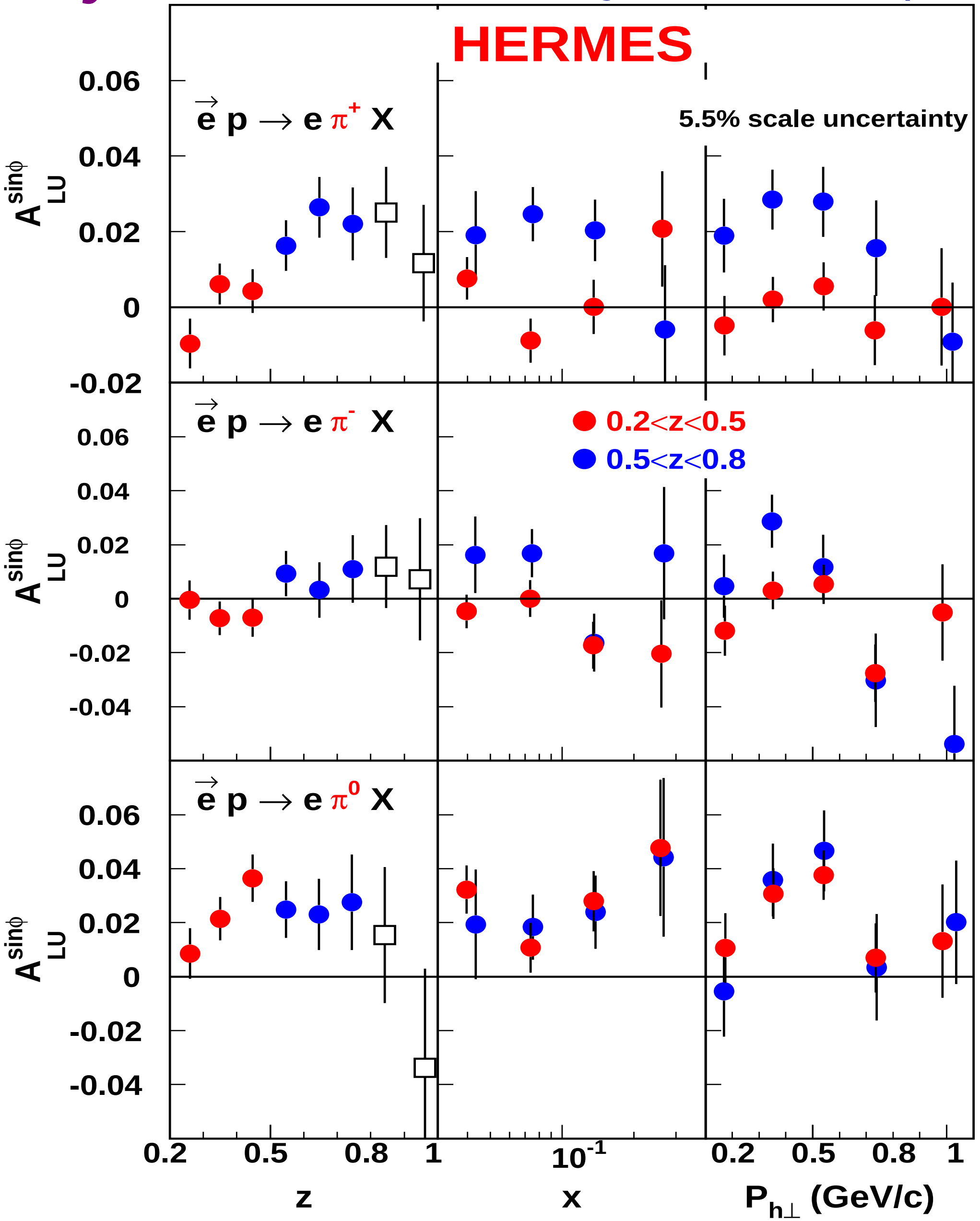
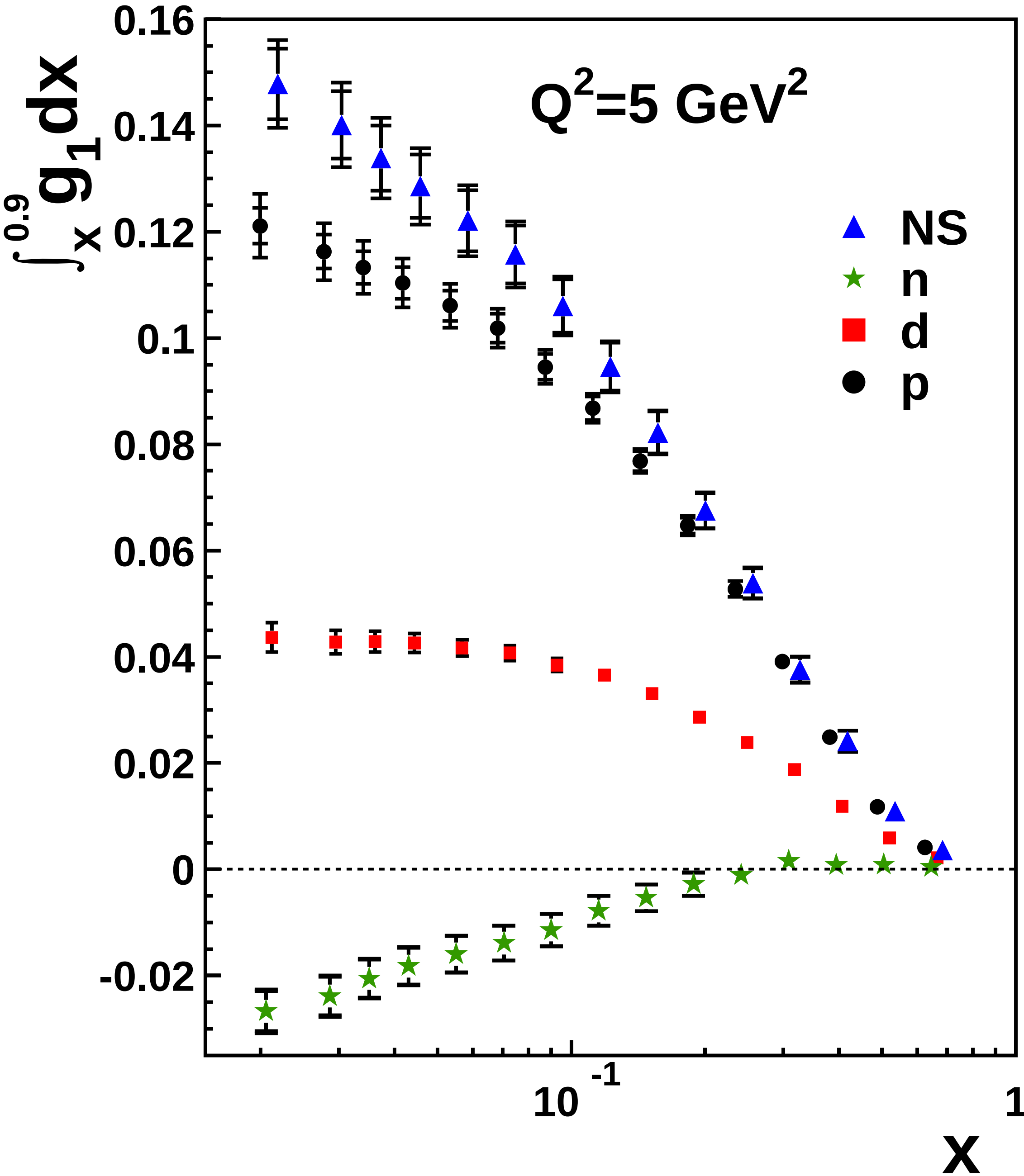
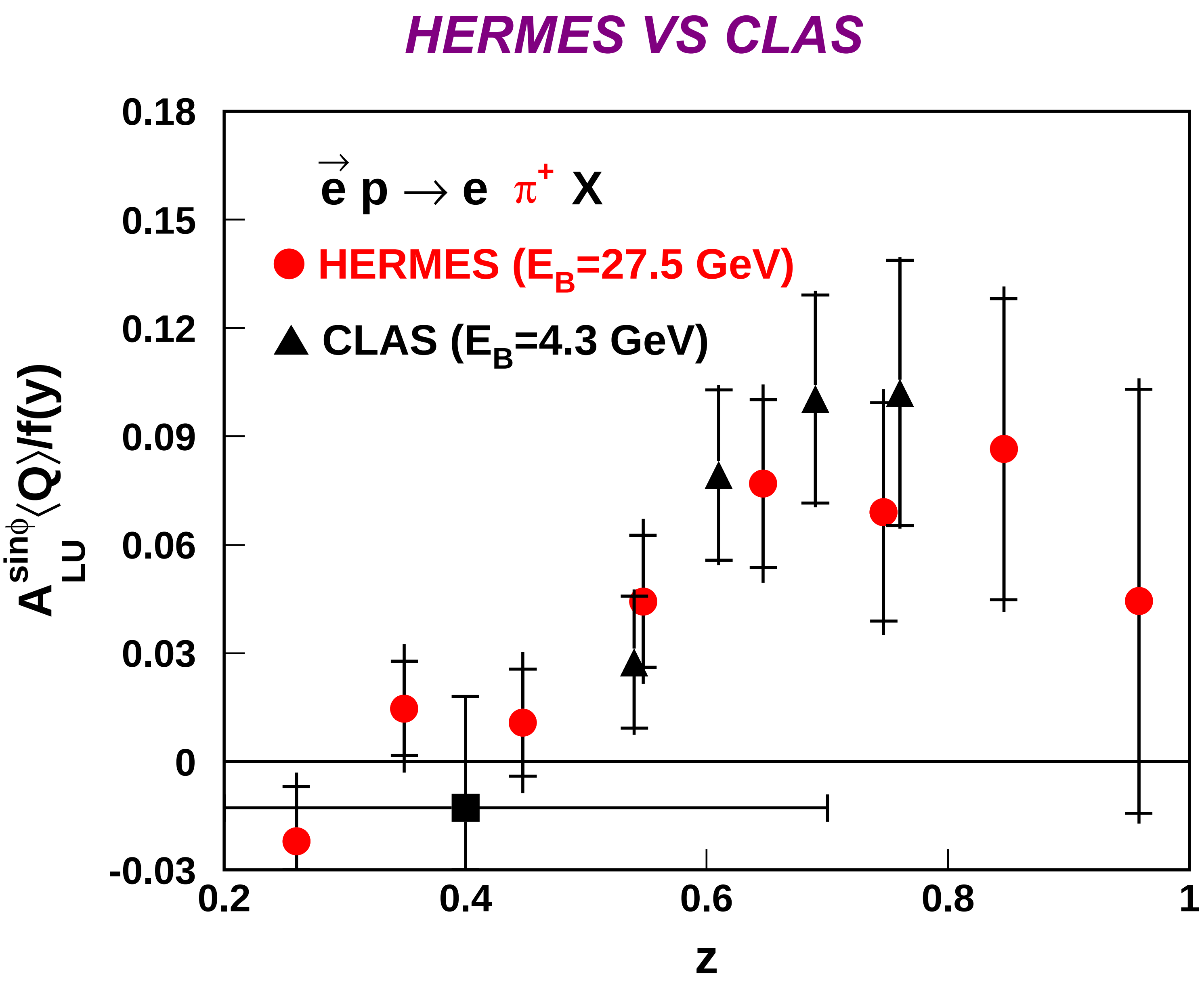


saturation of integrals

➢ ***Deutron Integral saturated at x<0.05***

➢ ***NS no saturation***

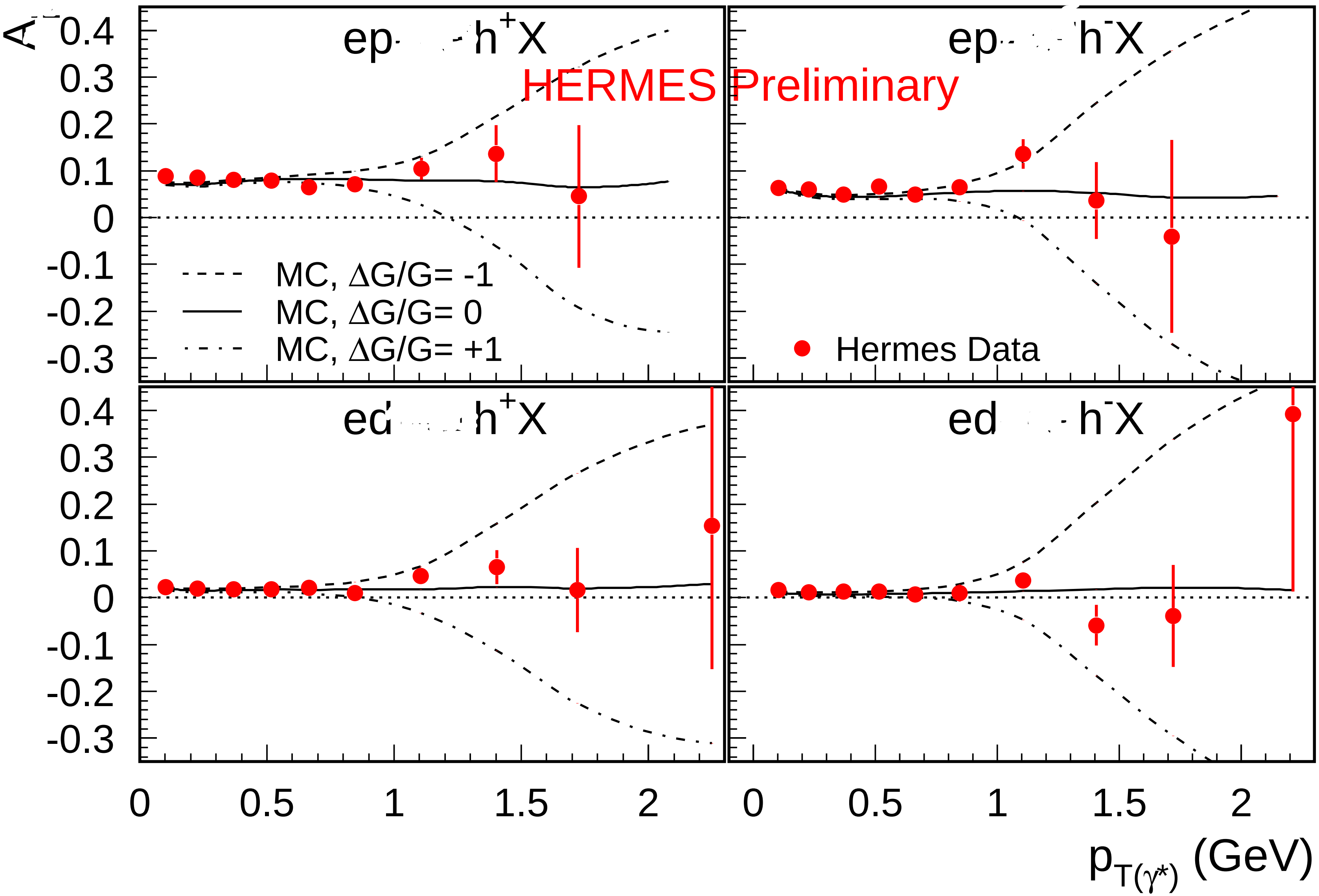




HERMES VS CLAS
$\vec{e}\, p \rightarrow e\, \pi^{+} X$
HERMES (E_B=27.5 GeV)
CLAS (E_B=4.3 GeV)
$A_{LU}^{\sin\phi}\langle Q\rangle/f(y)$
z
0.18
0.15
0.12
0.09
0.06
0.03
0
-0.03
0.2
0.4
0.6
0.8
1

HERMES high PT experiment,

semi-inclusive, PT in respect to virt. photon direction



Longitudinal spin-transfer to Λ- hyperon

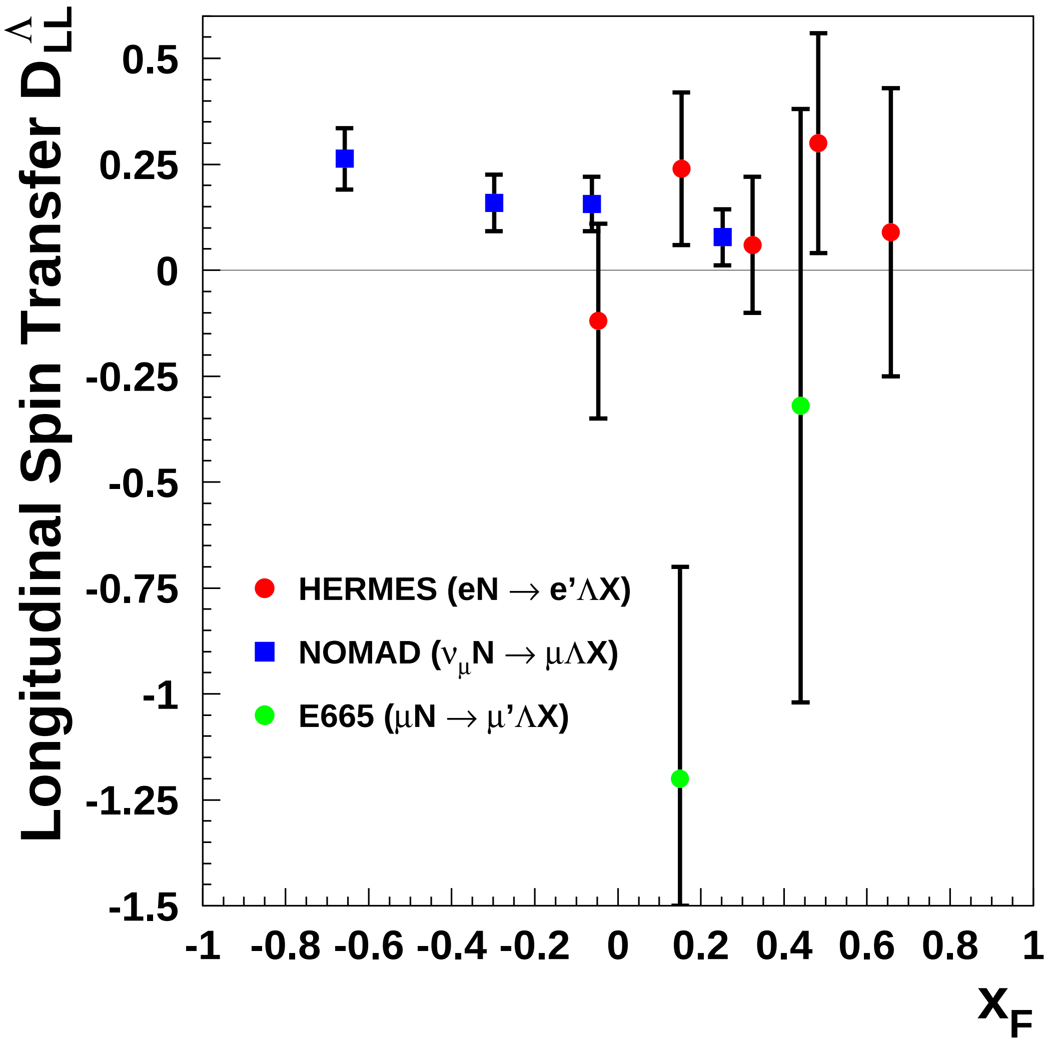
$$D^{\Lambda}_{LL'} = 0.11 \pm 0.10 \pm 0.03$$
$$Q^2 > 0{,}8\,GeV^2,\ x_F > 0,$$
$$\langle z \rangle = 0.45$$

Compatible with

Δu=0 nCQM

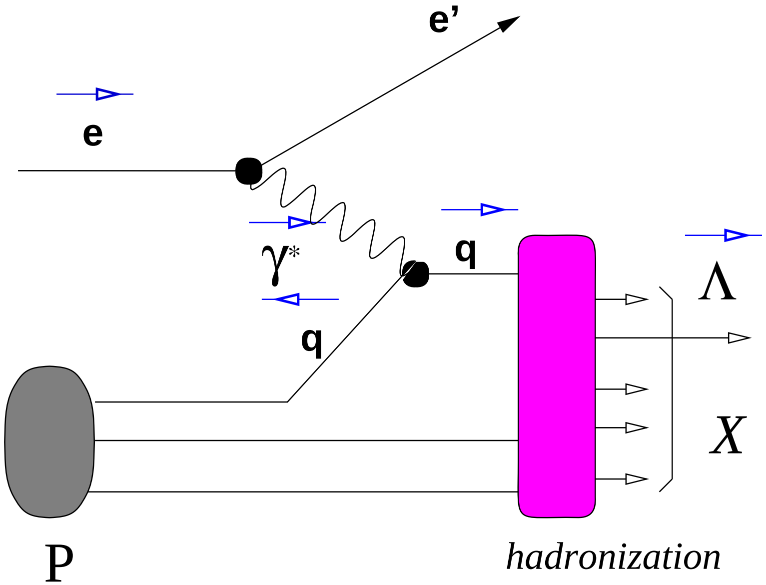
Δu=-0,09 SU(3)

Δu=-0.02 lattice-QCD



Longitudinal spin-transfer to Λ- hyperon

Phys Rev. D 2006

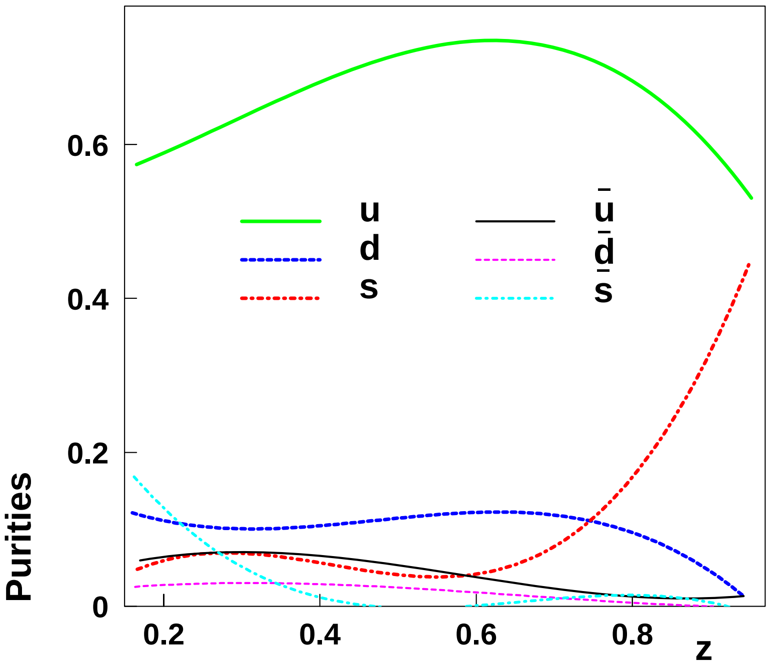


$$P_{L'}^{\Lambda} = P_b D(y) D_{LL'}^{\Lambda}$$

$$D_{LL'}^{\Lambda}(z) = \sum_q \tilde{P}_q(z) \cdot D_{LL'q}^{\Lambda}(z)$$

$$\tilde{P}_q(z) = \int \tilde{P}_q(x,z) dx$$

$$D_{LL'q}^{\Lambda}(z) = \frac{FF_q^{\Lambda\uparrow}(z) - FF_q^{\Lambda\downarrow}(z)}{FF_q^{\Lambda\uparrow}(z) + FF_q^{\Lambda\downarrow}(z)}$$



Partial spin - transfer

Due to strong u-dominance

$$D_{LL'}^{\Lambda} \approx \frac{\Delta u^{\Lambda}}{u^{\Lambda}}$$