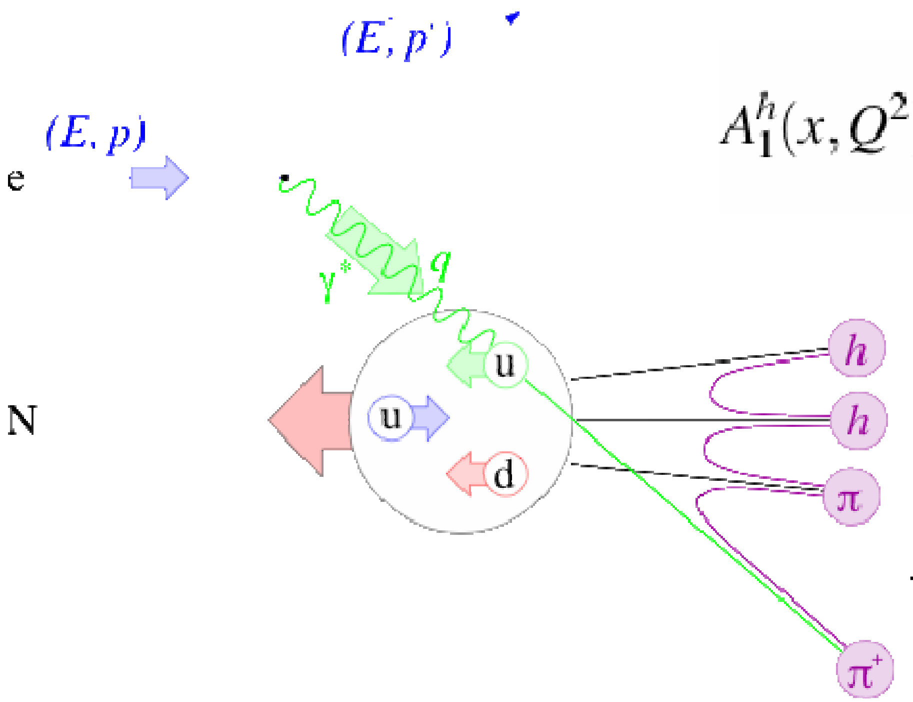
Flavour decomposition and fragmentation

- An attempt to summarise the results, concepts and prospects in the “traditional”, i.e. integrated polarised quark distributions and fragmentation functions (current and target region)
- Talks by E. Christova, S. Albino,P .Reimer, L. Zhu, L. Trentadue, A. Kotzinian, W. Melnitchouk, M. Osipenko
- Mistakes and omissions entirely my fault…

Quark Polarization from Semi-Inclusive DIS (SIDIS)

In SIDIS, a hadron h is detected in coincidence with the scattered lepton:



Flavor Tagging: Flavor content of observed hadron *h* is related to flavor of struck quark *q* via the fragmentation functions *D*(*z*)

$$A_1^h(x,Q^2) = \frac{\int_{z_{min}}^1 dz \sum_q e_q^2 \, \Delta q(x,Q^2) \cdot D_q^h(z,Q^2)}{\int_{z_{min}}^1 dz \sum_q e_q^2 \, q(x,Q^2) \cdot D_q^h(z,Q^2)}$$

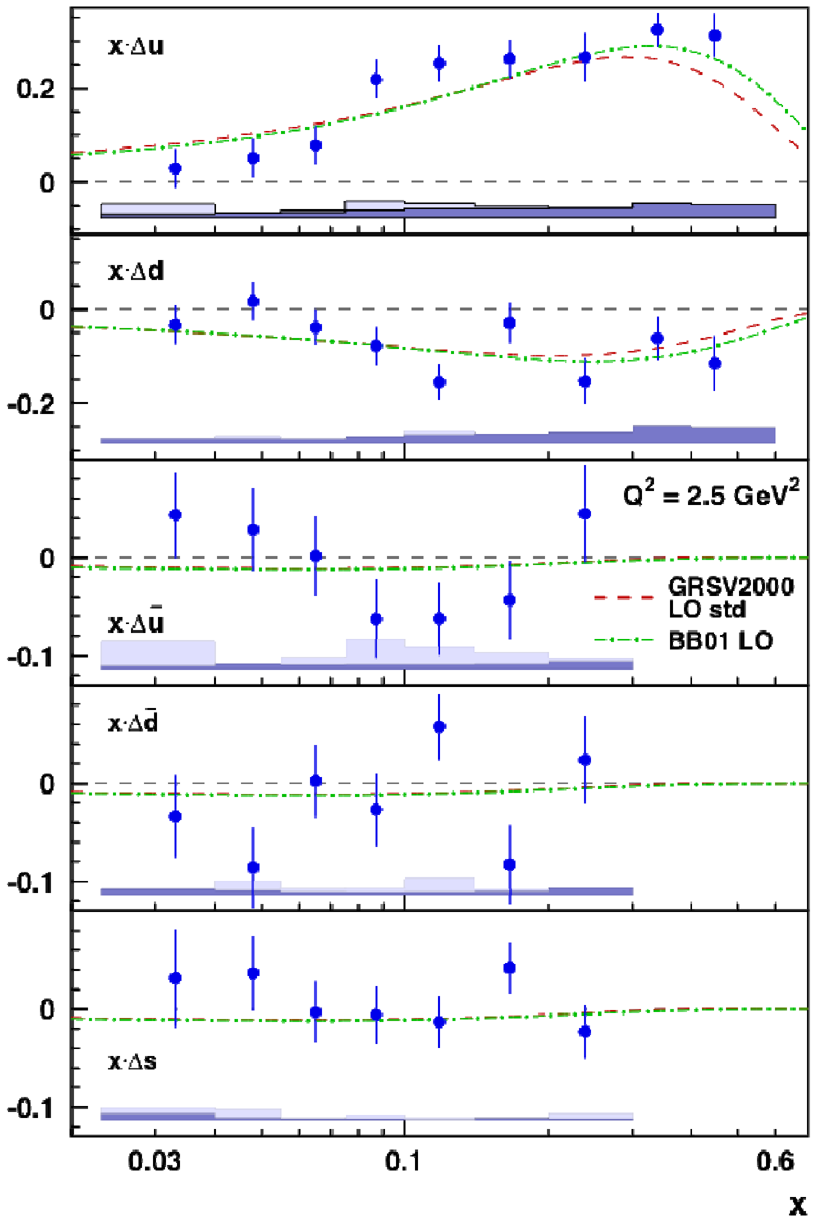
scaling variable $z \equiv E_h/\nu$

Favored / disfavored fragmentation functions:

$$D_{\text{fav}}(z) \equiv D^{u\to\pi^+}(z) = D^{d\to\pi^-}(z) = \ldots$$

$$D_{\text{dis}}(z) \equiv D^{d\to\pi^+}(z) = D^{u\to\pi^-}(z) = \ldots$$

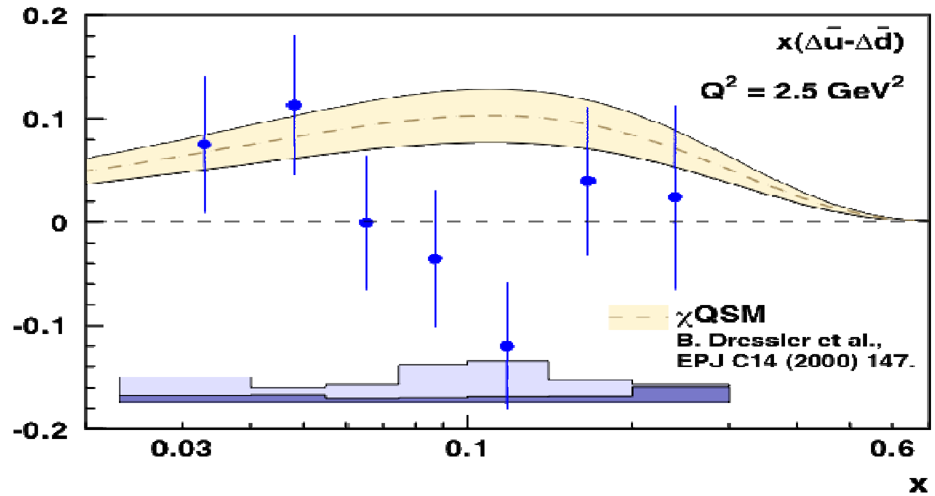
Final Δq Measurement from HERMES



using all polarized data taken from 1996 - 2000

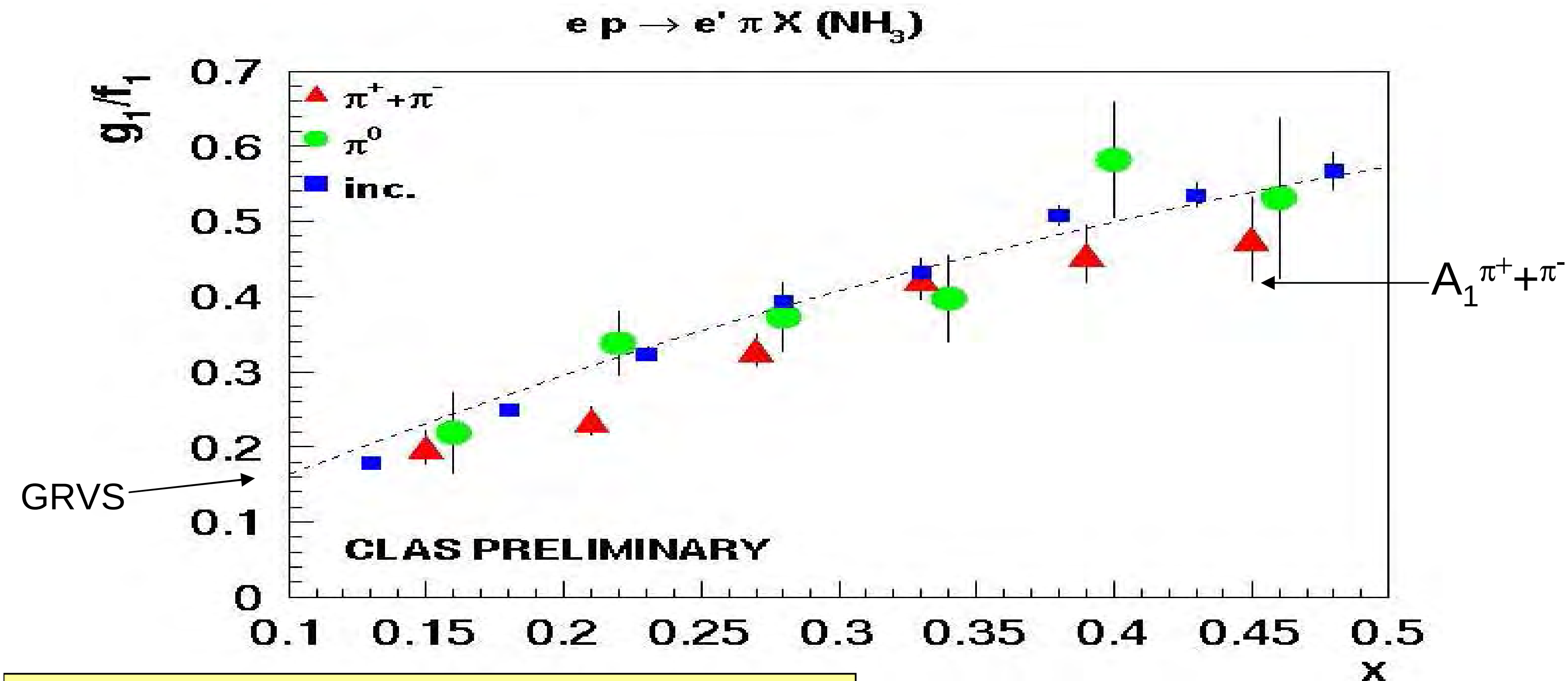
First 5-flavor fit to Δq(x)

No evidence of anti-quark polarization, or flavor-asymmetry, Δs≈0



Sensitive to factorization

Additional information from π^0 ?



1) SIDIS π^0 production not contaminated by diffractive ρ
2) HT effects and exclusive π^0 suppressed
3) Simple PID by π^0-mass (no Kaon contamination)

Complementary information on PDFs

➢ **A_1** inclusive and **A_1** from $\pi^+ + \pi^-$ and π^0 are consistent for $0.4<z<0.7$

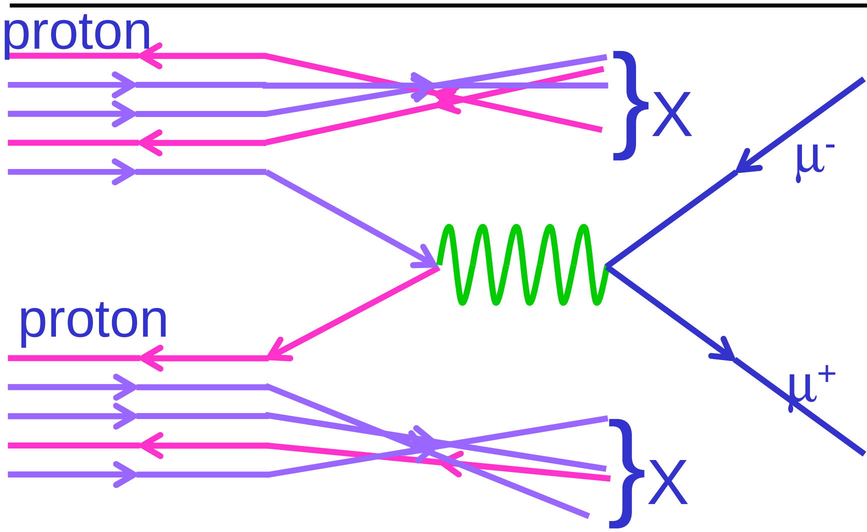
➢ Indication that **A_1^p** of $\pi^+ + \pi$ is lower than inclusive at large z

“Alternative (model independent)” approach

- Measure the difference in π^+ (K^+) and π^- (K^-) asymmetries

  ….. and combine with Bjorken Sum Rule
- Direct determination of Δu_V, Δd_V and Δu-Δd in leading order and NLO
- possible problems: statistical precision (denominator: difference in unpolarised h^+ and h^- cross sections
- to be explored at Jlab in the near future

Probing quark structure with Drell-Yan scattering (Fixed Target)

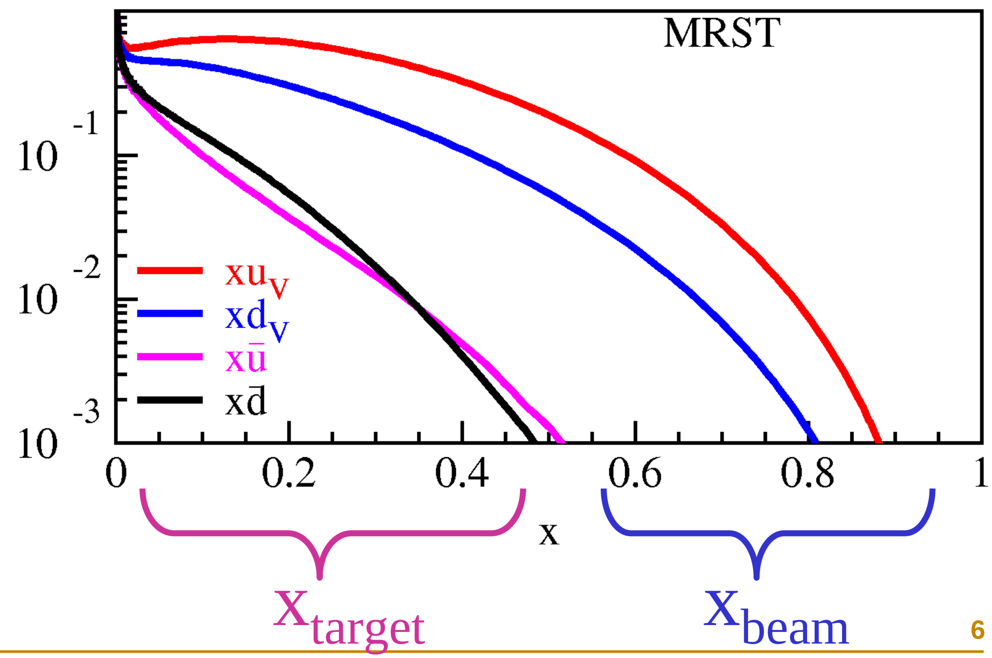


Leading Order

$$\frac{d^2\sigma}{dx_1 dx_2} = \frac{4\pi\alpha^2}{9x_1x_2}\frac{1}{s}\times \sum_i e_i^2 \left[q_{ti}(x_t)\bar{q}_{bi}(x_b) + \bar{q}_{ti}(x_t)q_{bi}(x_b)\right]$$

- Detector acceptance chooses range in x_{target} and x_{beam}.
- $x_F = x_{beam} - x_{target} > 0$
- high-x Valence *Beam* quarks.
- Low/interm.-x sea *Target* quarks.

$$x_F \approx 2p_L/\sqrt{s} = x_1 - x_2$$
$$M^2_{\mu^+\mu^-} = s x_1 x_2$$



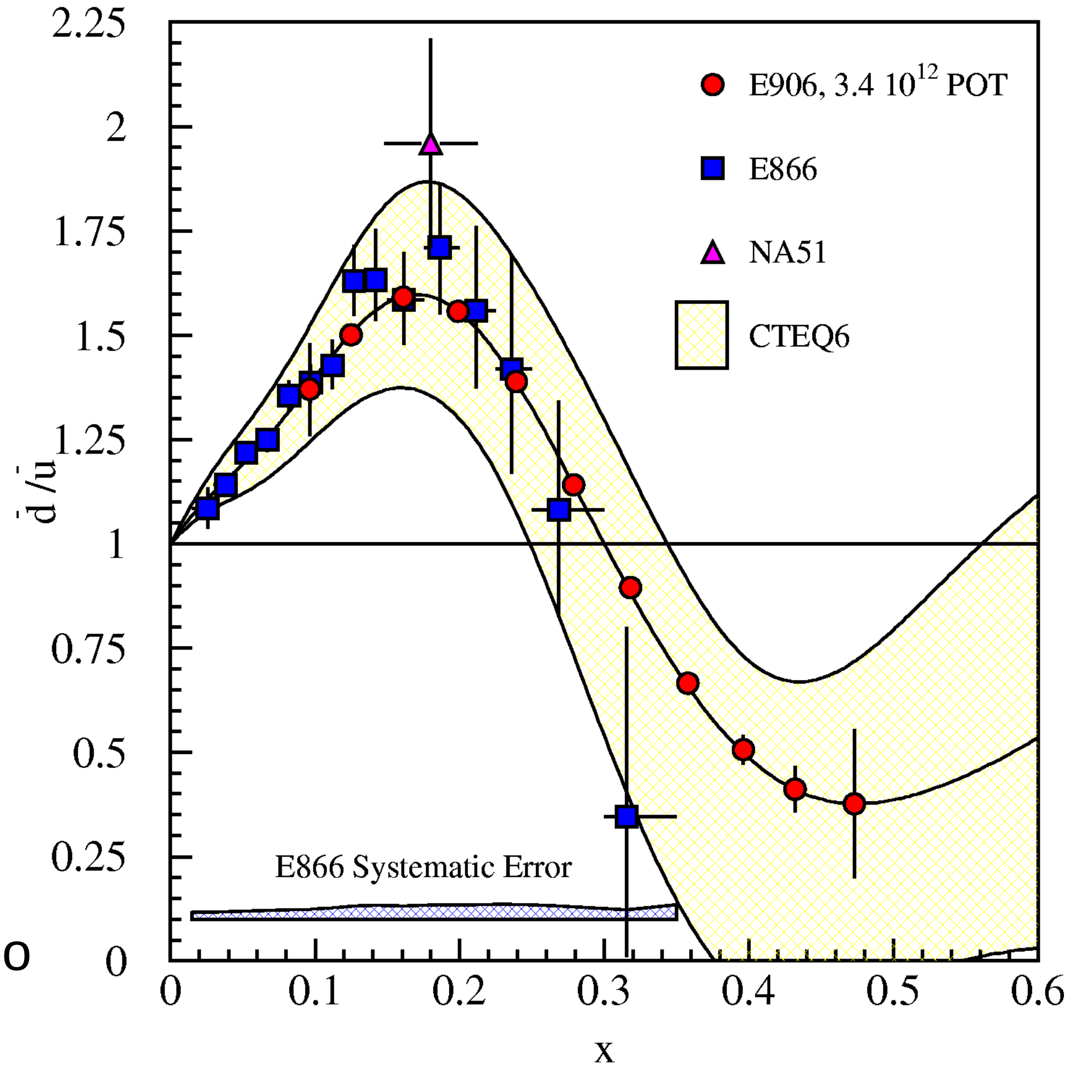
What is the structure of the nucleon: What is d-bar / u-bar in the proton?

Parton Distributions

- PDF fits are completely dominated by E866 data
- Uncertainties of PDF fits are dictated by E866 uncertainties.
- E906 will significantly extend these measurements and improve on uncertainty.
- Impact on sensitivity of Collider/LHC tests of the Standard Model (understanding of background).

Origins of the Proton Sea

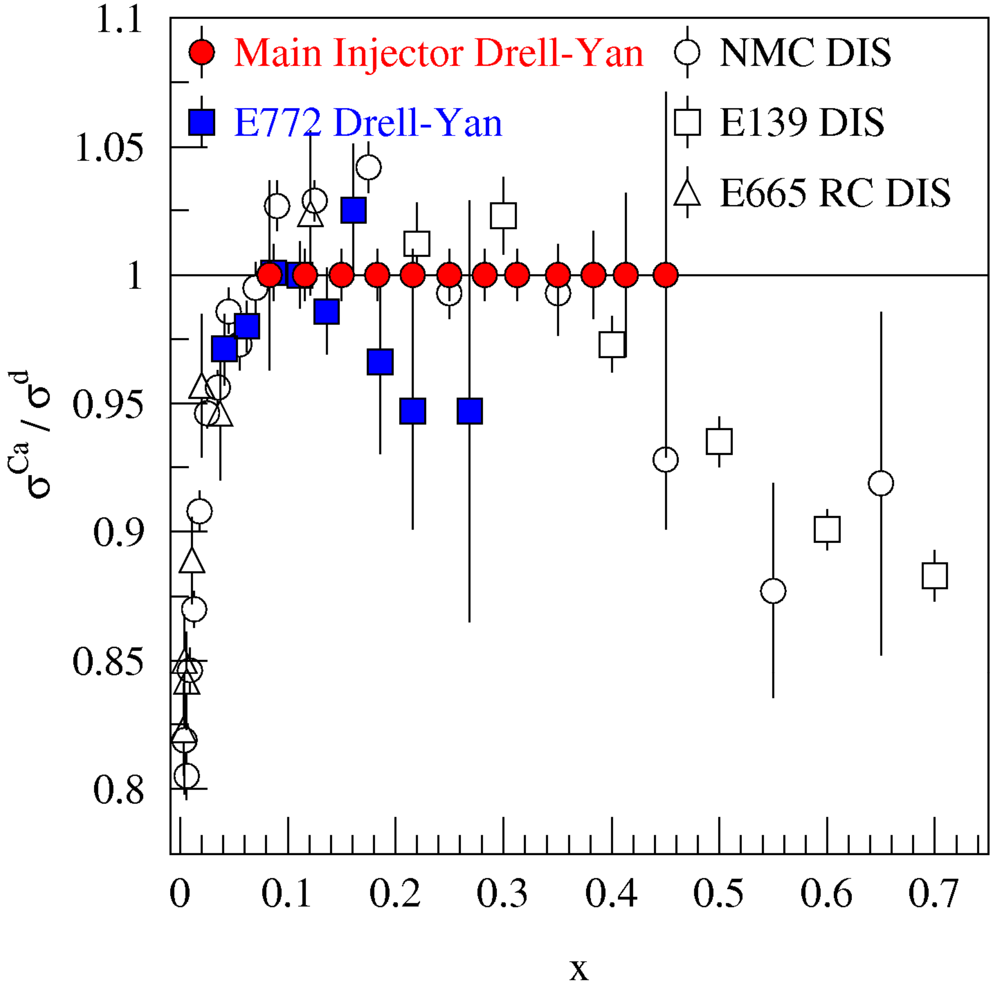
- Models explain d-bar ¸ u-bar. No theory expects the results seen for x ¸ 0.3.



What is the structure of nucleonic matter: How do sea quark distrib. differ in a nucleus?

Comparison with Deep Inelastic Scattering

- Antishadowing not seen in Drell-Yan—Valence only effect?—better statistical precision needed—E906.
- Intermediate-*x* *sea* PDF's set by ν-DIS on iron—unknown nuclear effects.
- What can the sea parton distributions tell us about nuclear binding?



New fit to fragmentation data

- Update of KKP analysis
- Do not use charged data
- AKK also fitted OPAL data on

individual light quark flavour tagging probabilities,

$\longrightarrow$ light quark flavour FFs

determined phenomenologically for first time

Improved determination of $s, d \to K^{\pm}$ transition.

- Find only slight shift towards PHENIX data
- Big difference between AKK and KKP

for K^0_S $(= K^{\pm})$ production:

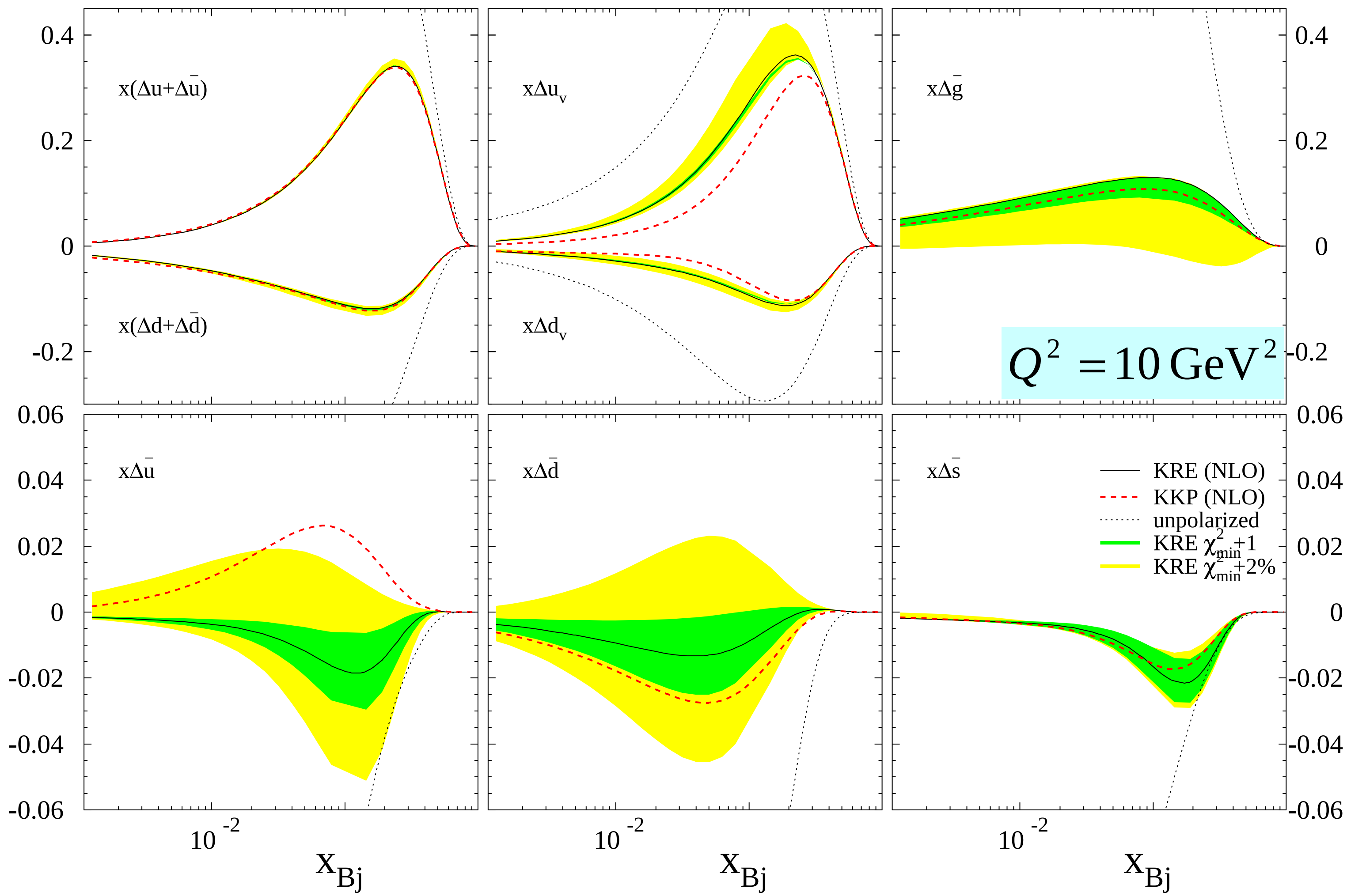
Find shift towards STAR data

but away from UA1 data

- AKK's $\alpha_s(M_Z)$ consistent with KKP's and PDG

The impact of FFs on PDFs

Florian, Navarro and Sassotrom, hep-ph/0504155



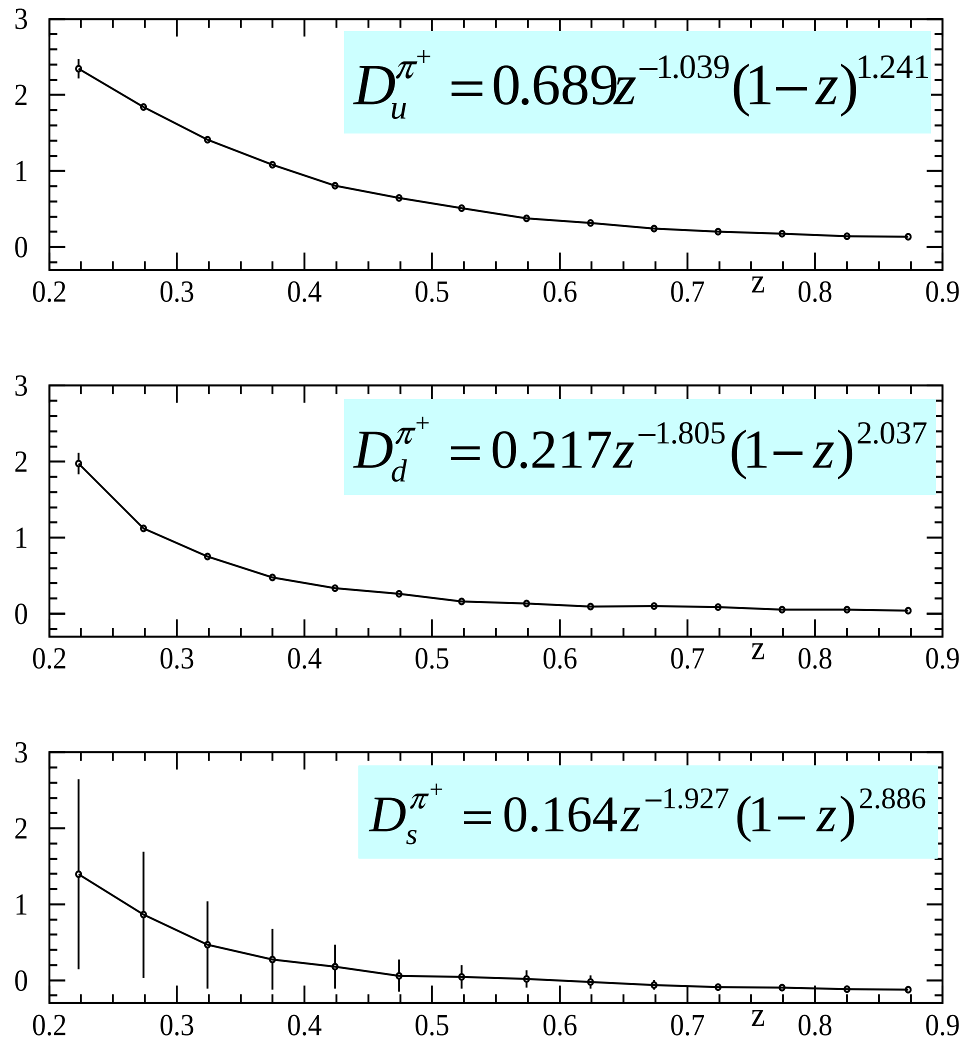
The Δd and especially Δq_s are significantly affected by FFs

Also see Kretzer, Leader & Christova, EPC22,269(2001)

FFs from HERMES SIDIS

Kretzer, Leader & Christova, EPC22,269(2001)

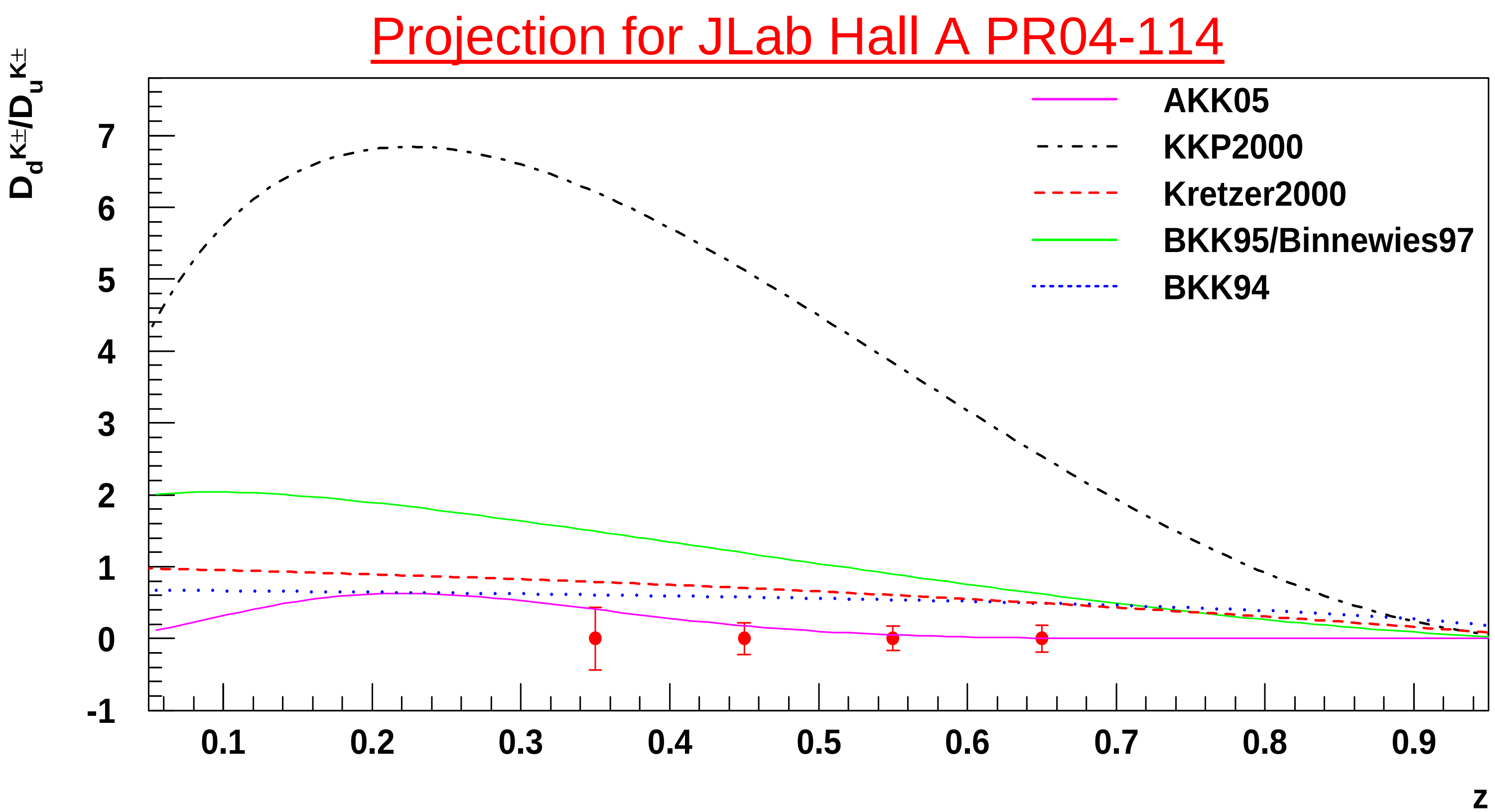
- The fragmentation functions from HERMES SIDIS together with $D_{u+d+s}^{\pi^+}$ from e$^+$e$^-$ data.
  at $< Q^2 >= 2.5\,(\mathrm{GeV/c})^2$



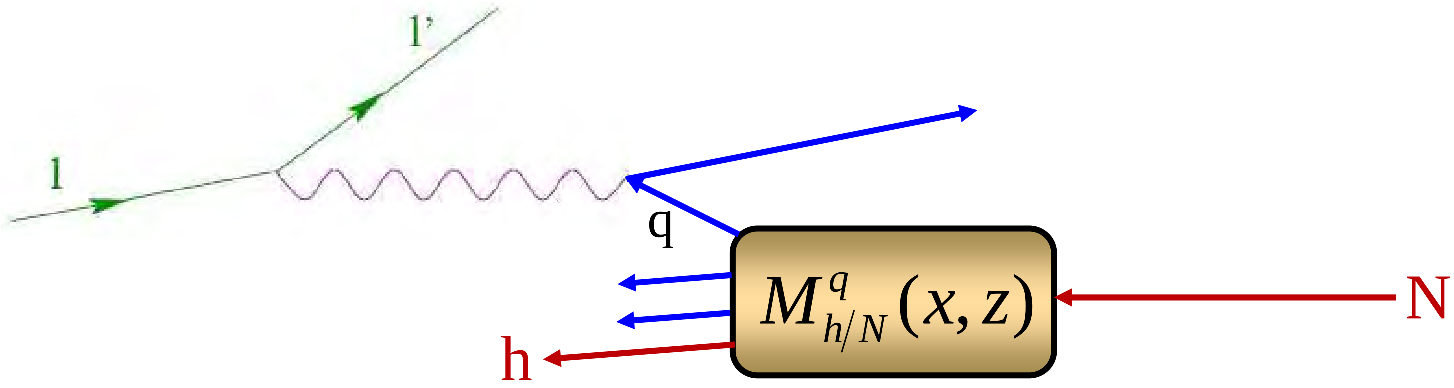
Kaon Fragmentation Function Ratio

- If ignoring strange quark contribution,

$$\frac{D_d^{K^++K^-}}{D_u^{K^++K^-}} \equiv \frac{2D_{\bar{d}}^{K^+}}{D_u^{K^+}+D_{\bar{u}}^{K^+}} = 4\cdot\frac{(Y_n^{K^+}+Y_n^{K^-})-\frac{d+\bar{d}}{u+\bar{u}}(Y_p^{K^+}+Y_p^{K^-})}{(Y_p^{K^+}+Y_p^{K^-})-\frac{d+\bar{d}}{u+\bar{u}}(Y_n^{K^+}+Y_n^{K^-})}$$



TFR & Fracture Functions



$$d\sigma^{lN \to lhX} = \sum_q d\sigma^{lq \to lq} \otimes \left(f_q(x) \otimes D_q^h(z) + M^q_{h/N}(x,z) \right)$$

1994: Trentadue & Veneziano; Graudenz; … Fracture functions: probability of finding a parton ***q*** with momentum fraction ***x*** and a hadron ***h*** with the CMS energy fraction $\mathbf{E_h/E_N}$

More correlations for TMD dependent FracFuncs $M^q_{h/N}(x, \mathbf{k_T}, \mathbf{s}_q; z, \mathbf{p}_\mathbf{T}^h; \mathbf{S}_N)$

$$\mathbf{S_L} \cdot (\mathbf{p}_\mathbf{T}^h \times \mathbf{k_T}); \quad \mathrm{s_L} \cdot (\mathbf{p}_\mathbf{T}^h \times \mathbf{k_T})$$

$$(\mathbf{S_T} \times \mathbf{p}_\mathbf{T}^h) \cdot (\mathbf{s_T} \times \mathbf{k_T}) \ldots$$

Fracture functions

- DGLAP evolution equation with standard splitting functions

$$Q^2 \frac{\partial}{\partial Q^2} M_q^h(x,z,t,Q^2) = \sum_i \frac{\alpha_S(Q^2)}{2\pi} \int_{x/(1-z)}^{1} \frac{du}{u} P_q^i(u) M_i^h(\frac{x}{u}, z, t, Q^2)$$

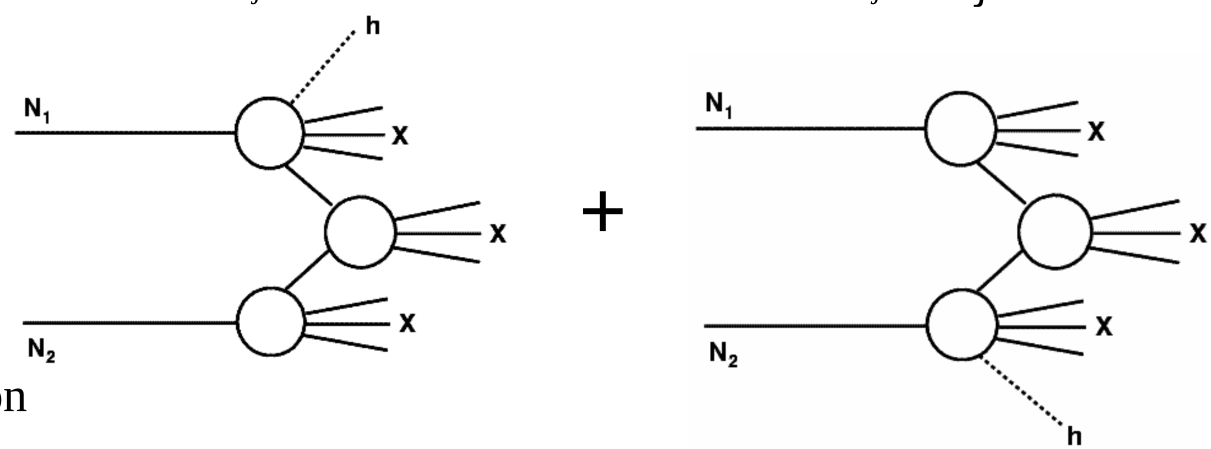
- Momentum sum rule

$$\sum_h \int_0^{t_{\max}} dt \int_0^1 dz z M_q^h(x,z,t,Q^2) = (1-x) F_2^q(x,Q^2)$$

- Process independent definition

$$\sigma_{tr} = \sum_{ij} \int_0^{1-z} \frac{dx_i}{x_i} \int_0^{1-z} \frac{dx_j}{x_j} \left\{ M_i^{h(N_1)}(x_i,z,t,Q^2) F_2^{j(N_2)}(x_j,Q^2) + M_i^{h(N_2)}(x_i,z,t,Q^2) F_2^{j(N_1)}(x_j,Q^2) \right\} \sigma_{hard}^{ij}(i+j \to h)$$

Hadron-hadron collisions $N_1+N_2 \rightarrow hX$

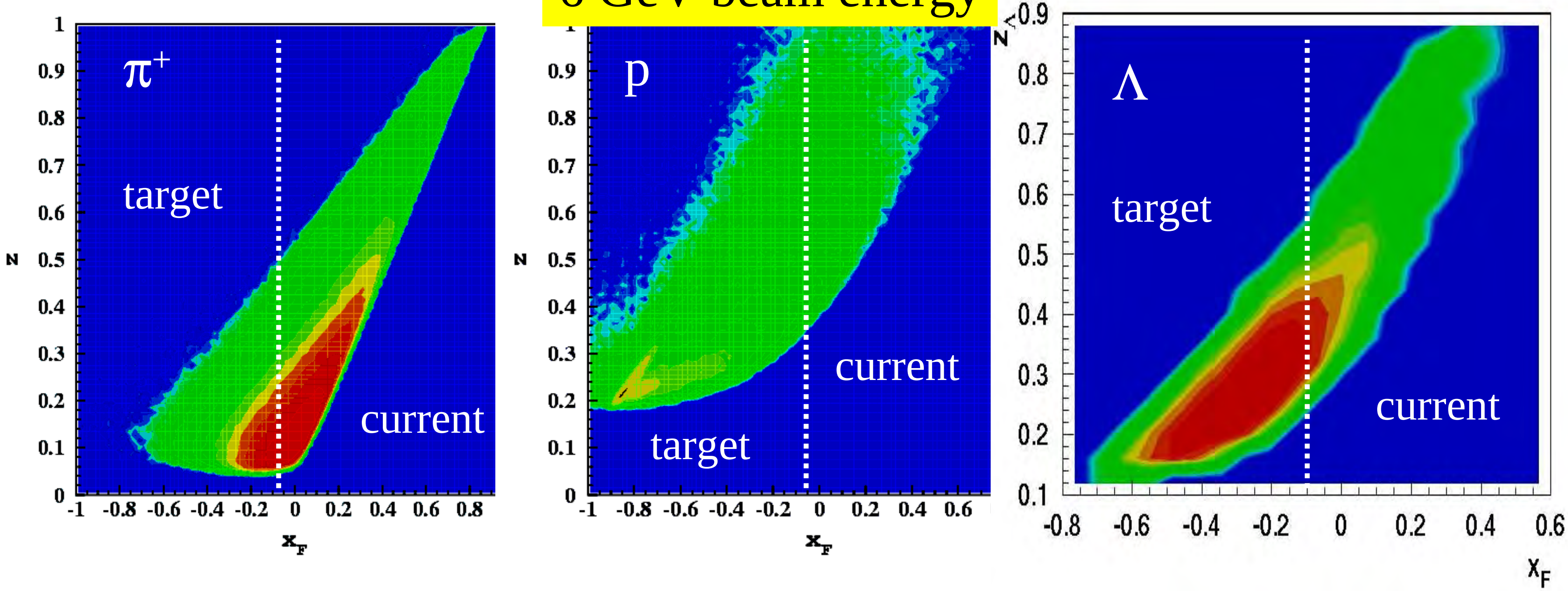


In assumption of the factorization

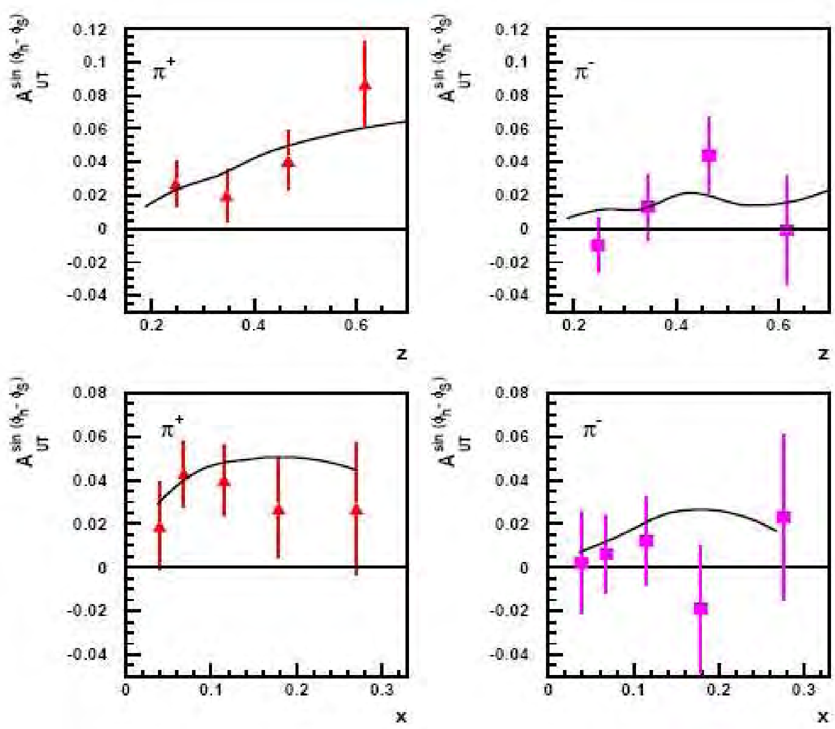
Longitudinal Momentum

- CEBAF beam energy in combination with CLAS acceptance allow to explore <u>current</u> fragmentation for *light mesons* and <u>target</u> fragmentation for *baryons*.
- In DIS Feynman $x_F = \frac{2p_{\parallel}^{h(CM)}}{W}$ permits to disentangle two regions, however, at small invariant masses W separation is ambiguous.

6 GeV beam energy

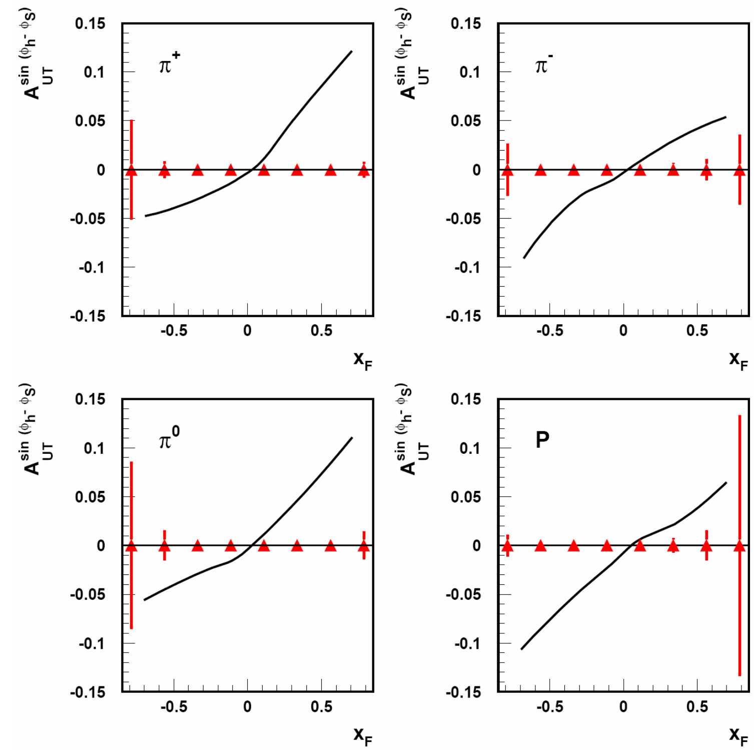


Results: Sivers



HERMES data on $A_{UT}^{\sin(\phi_\pi - \phi_S)}$

z and x_{Bj}-dependences



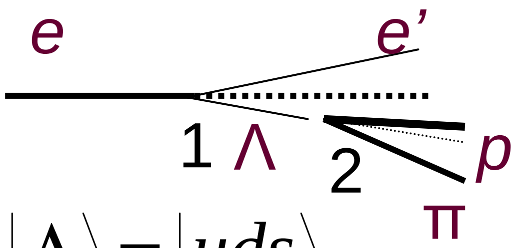
Predictions for JLab 12 GeV

x_F-dependence

Red triangles with error bars – projected statistical accuracy for 1000h data taking (H.Avagyan).

Λ Polarization

(H. Avakian)

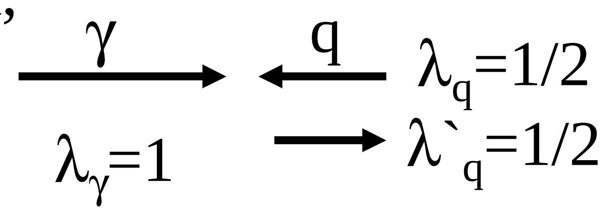


$$|\Lambda\rangle = |uds\rangle$$

Λ – unique tool for polarization study due to it’s self-analyzing parity violating weak decay.

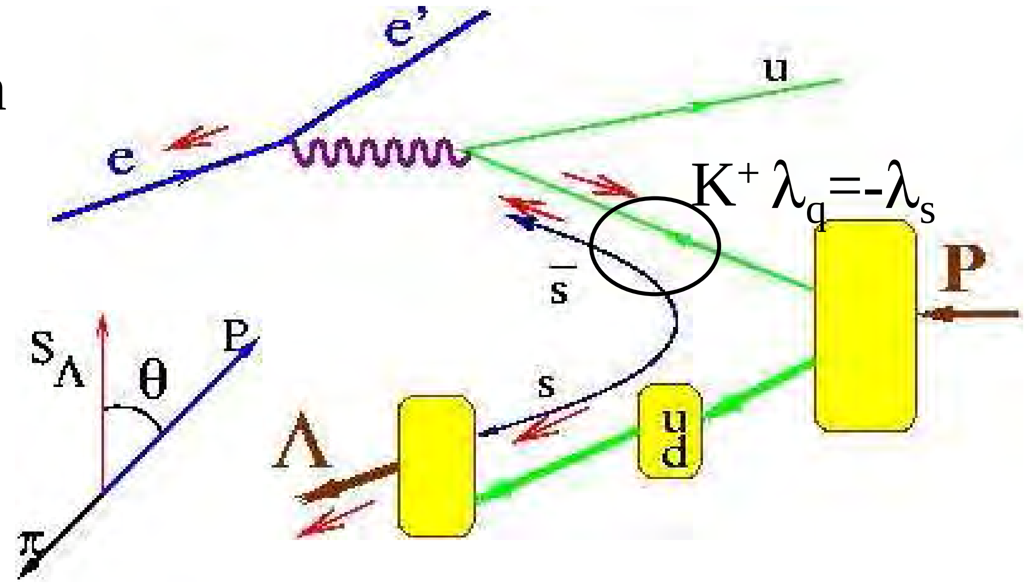
$$\frac{d\sigma}{d\theta^{CM}_{\pi p}} = \sigma_0\left(1+\beta P_\Lambda \cos\theta^{CM}_{\pi p}\right) \qquad \beta = 0.642 \pm 0.013$$

- (ud)-diquark is a spin and isospin singlet => s-quark carries entire spin of Λ,



- Λ polarization in TFR provides information on contribution of strange sea to proton spin.

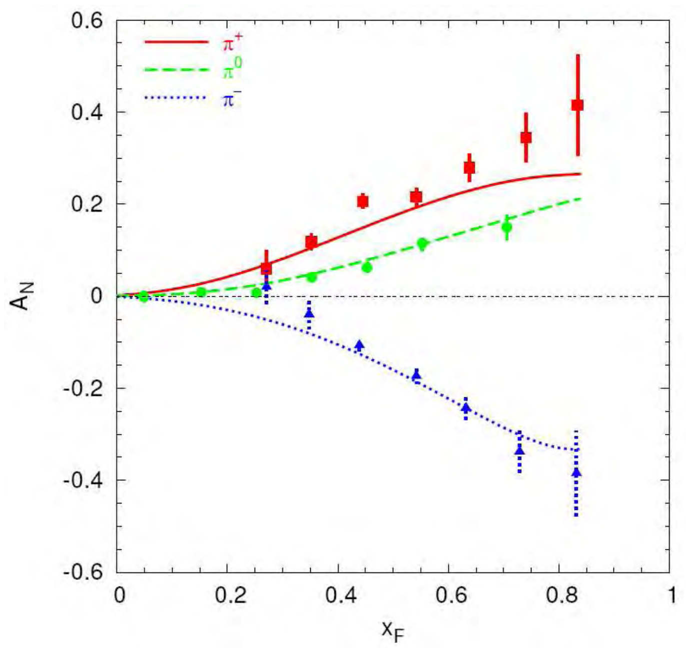
W.Melnitchouk and A.W.Thomas ‘96
J.Ellis, D.Kharzeev, A. Kotzinian ‘96



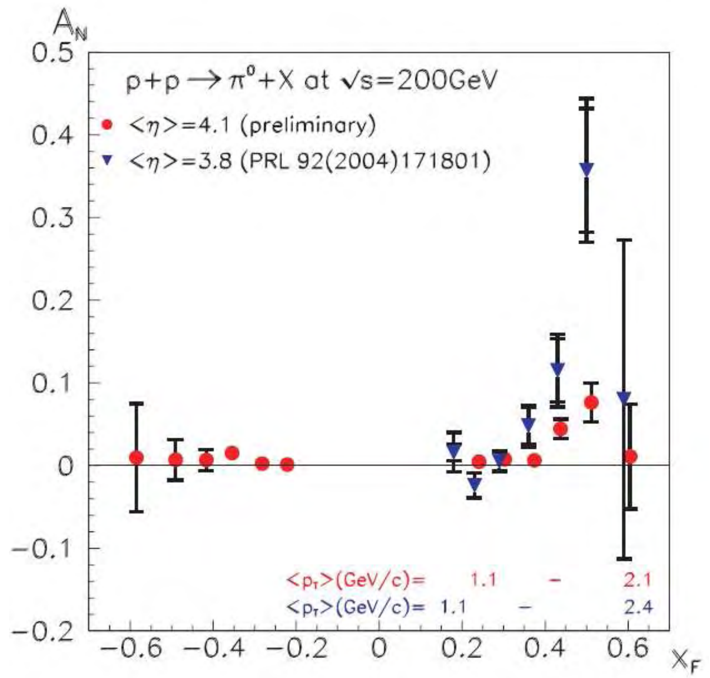
Polarized beam gives unique possibility to perform an “acceptance independent” measurement of Λ polarization in electroproduction.

SSA in PP-interactions

E704. Curves: by Anselmino *et al*,



STAR (hep-ex/0505024)



$x_F<0$ in PP corresponds to $x_F>0$ in SIDIS (backward with respect to polarized proton flight direction in CMS)

Target fragmentation as a tool to separate different models for the nucleon sea asymmetry

- various models can explain E866 data
- difference in polarised sea distribution promising tool to separate between model
- investigating correlation of □Λ^{++} and p spin could support the pion cloud model
- similarly: correlation between Λ and p spin could indicate presence of kaon cloud