Studies of Partonic Distributions using Kaon SIDIS

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Outline

- ❑ Flavor decomposition Program using Semi-Inclusive hadron production from polarized and unpolarized hydrogen and deuterium targets using CLAS12 detector enhanced with a RICH counter

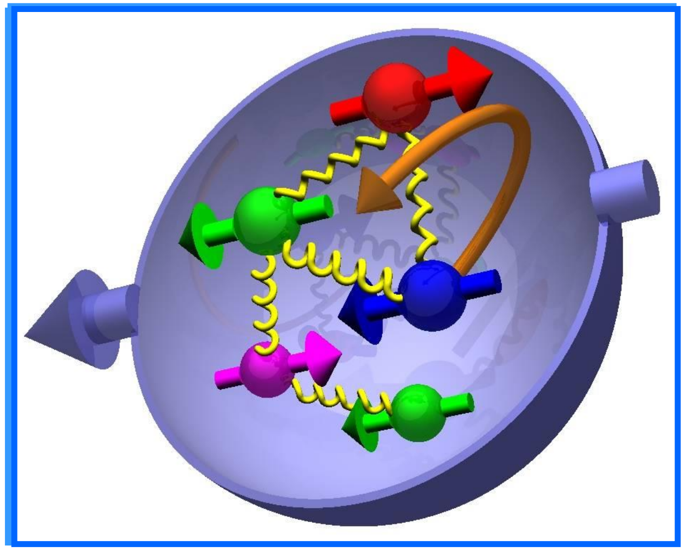
- ❑ The Hybrid Ring Imaging Cerenkov Counter (RICH)

- ❑ Expected Precisions and outlook

Flavor Contributions to the Nucleon Spin

$$P = uud + u\bar{u} + d\bar{d} + s\bar{s} + g + \ldots..$$

valence « sea= virtual pairs »



$$S = \frac{1}{2} = \frac{1}{2}\sum_q \Delta q + L_q + \Delta G + L_G$$

$$\Delta q = \Delta u, \Delta\bar{u}, \Delta d, \Delta\bar{d}, \Delta s, \Delta\bar{s}$$

-Our interest is on getting all the flavors! With a special interest of the strangeness.

E12-09-007 CLAS12 – Jefferson Lab-CLAS12

(H. Avakian, F. Benmokhtar, A. EL Alaoui, K. Hafidi & M. Mirazita)

Goal: **Measurements of pions and kaons multiplicities and longitudinal double spin asymmetries using SIDIS off hydrogen and deuterium targets.**

Extract all the flavors!

- → **Control of the fragmentation functions used in the extraction of the individual quark and antiquark contribution to the nuclear spin.**
- → **shape of the strange pdfs.**

- → **improvement of the statistical precision in the extraction of individual quark contributions to the nucleon spin**

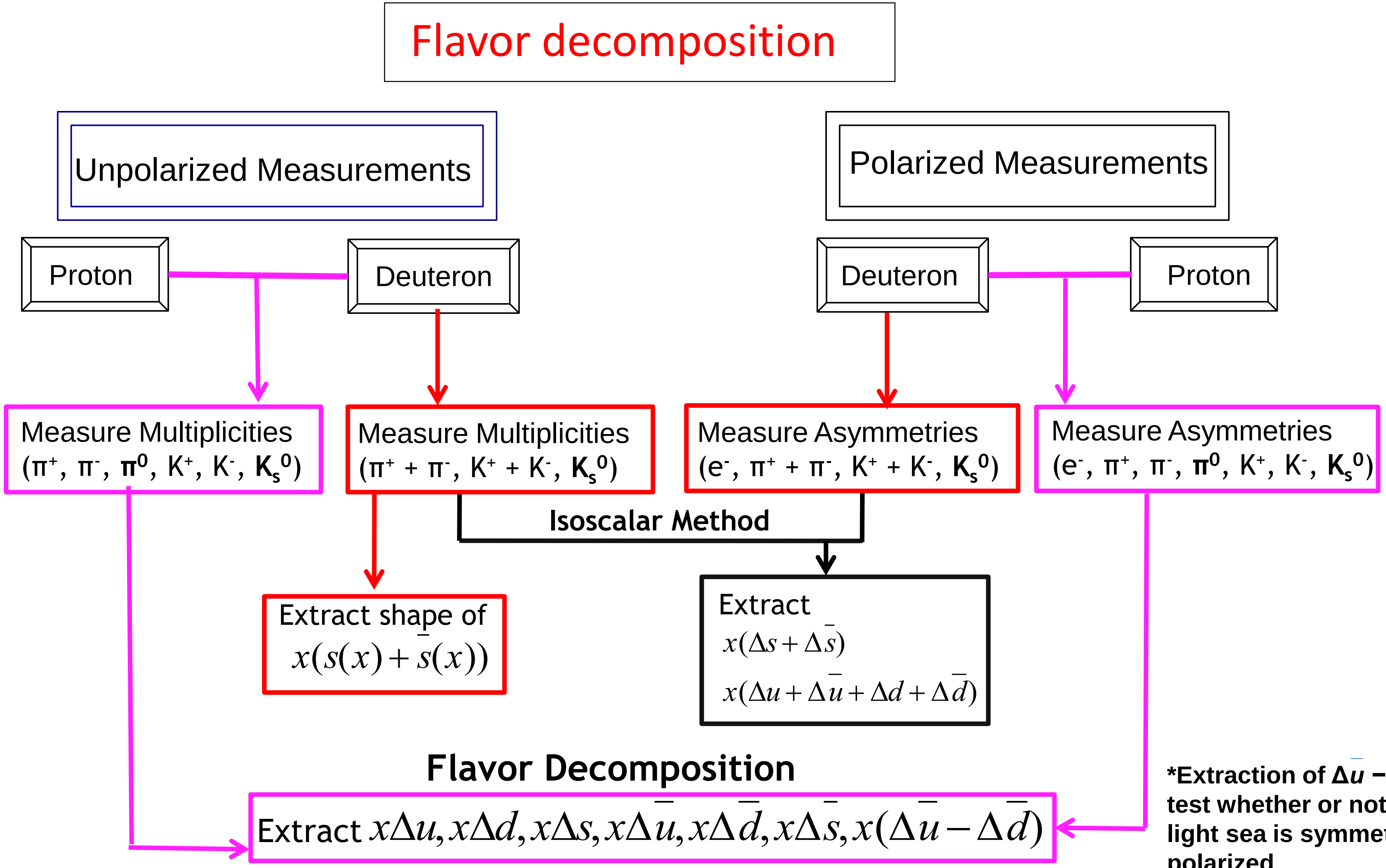
- → **110 days approved PAC days**

Abstract

The proposed measurements are two-fold. First, we propose to measure the multiplicities for several hadron species ($\pi^+, \pi^-, \pi^0, K^+, K^-, K^0_s$) using both hydrogen and deuterium targets. The goal of these measurements is the control of the fragmentation functions used in the extraction of the individual quark and antiquark contributions to the nucleon spin. In addition to the measurement of the shape (x dependence) of the strange parton distribution function for several z and Q^2 bins with three independent measurements ($\pi^+ + \pi^-$, $K^+ + K^-$ and K^0_s). This part of the proposal can run simultaneously with the approved 12 GeV proposal to measure the magnetic form factor of the neutron in CLAS12. The second fold is the polarized measurements. The aim is to use two different methods to access the quark polarization. The first is the so called isoscalar method where only polarized deuterium is used to extract the non strange and strange polarized parton distribution functions. The second method is also a flavor decomposition method using the information on both hydrogen and deuterium targets to extract individual contributions of the quarks to the nucleon spin. This part of the proposal can run simultaneously with the already approved single and double spin asymmetry program in Hall B. Both polarized and unpolarized measurements will cover a x range from $0.05 < x < 0.7$. An important part of the proposed measurements requires a good charged kaon identification for the whole momentum range. Therefore, to enhance the existing good particle identification, one needs to seriously consider a RICH detector for CLAS12.

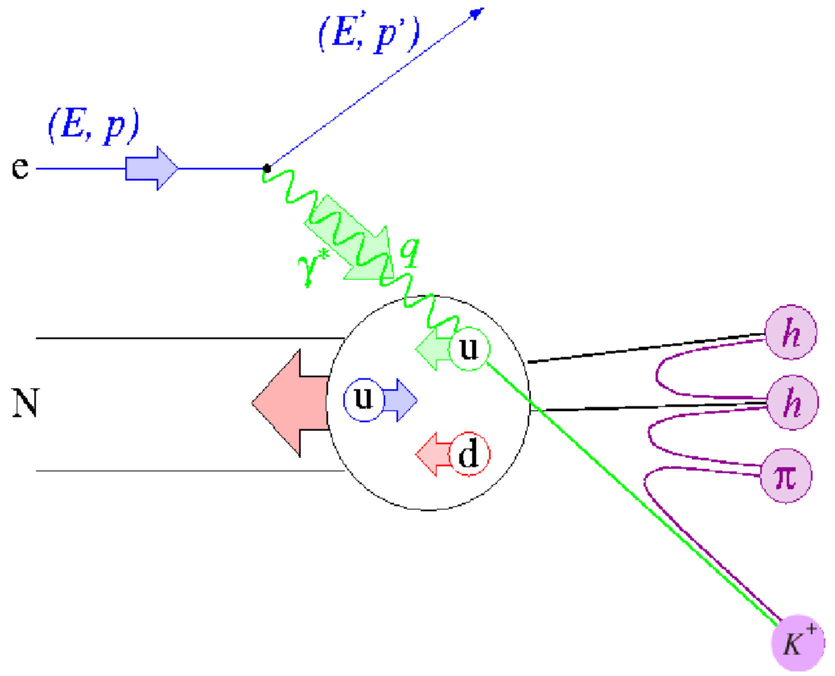
E12-09-007 CLAS12 – Jefferson Lab

(H. Avakian, F. Benmokhtar, A. EL Alaoui, K. Hafidi & M. Mirazita)

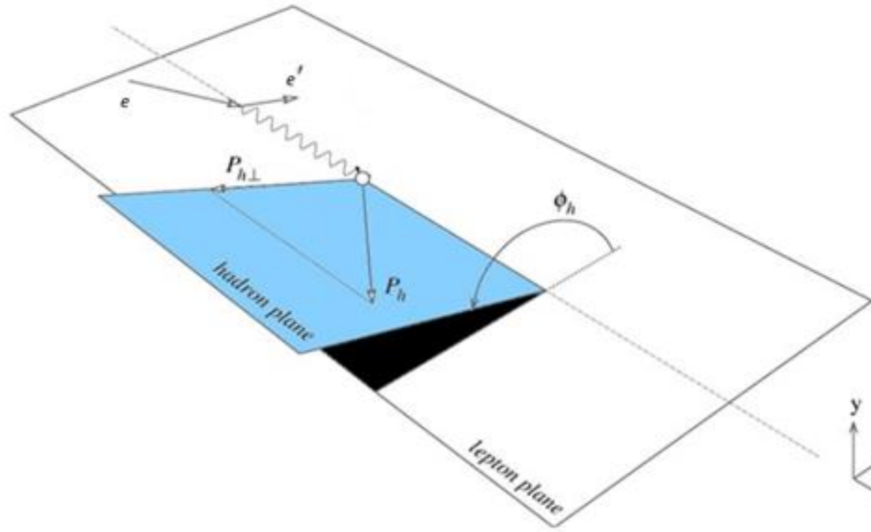


***Extraction of $\Delta\bar{u} - \Delta\bar{d}$ to test whether or not the light sea is symmetrically polarized**

Semi Inclusive DIS



$$\sigma\,(e\,p \rightarrow e\,h\,X)$$



SIDIS Selection:

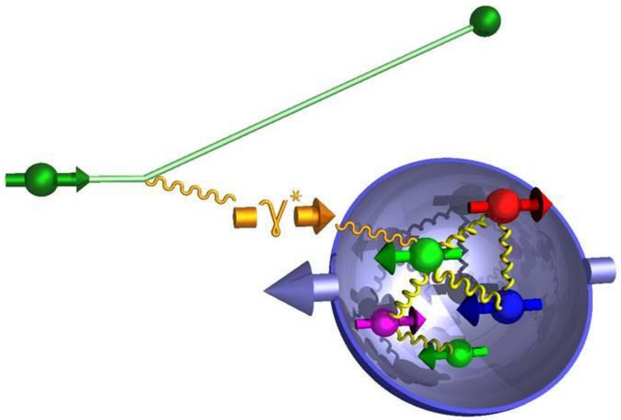
- $\nu = E-E'$
- $x = Q^2/(2M\nu)$
- $y = \nu/E$
- $W^2 = M^2 - 2M\nu - Q^2$
- $Q^2 = 4EE'\sin^2(\theta/2)$

$$\frac{d^2\sigma}{d\Omega dE'} = \frac{\alpha^2}{MQ^4}\frac{E}{E'} L_{\mu\nu} W^{\mu\nu}$$

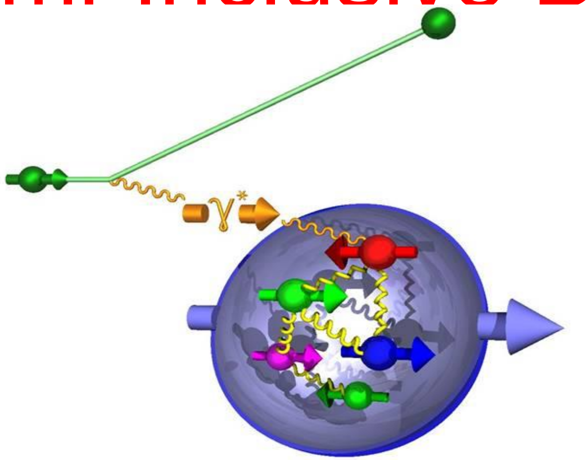
Hadron Selection:

- $z = E_h / \nu$
- $x_F = 2\,|p_{||}| / W$

Measurement of Δq in Semi-Inclusive DIS



$\sigma_{1/2} \sim q^{+}(x) \quad \vec{S_\gamma} + \vec{S_N} = 1/2$



$\sigma_{3/2} \sim q^{-}(x) \quad \vec{S_\gamma} + \vec{S_N} = 3/2$

$$q_f(x) = q_f^{\rightrightarrows}(x) + q_f^{\rightleftarrows}(x)$$

$$\Delta q_f(x) = q_f^{\rightrightarrows}(x) - q_f^{\rightleftarrows}(x)$$

- **Select PDFs : *$q^{-}(x)$* or *$q^{+}(x)$* by changing the orientation of target nucleon spin or helicity of incident lepton beam**

$$A_1^{e(h)}(x,Q^2) = \frac{\sigma_{1/2}^{e(h)} - \sigma_{3/2}^{e(h)}}{\sigma_{1/2}^{e(h)} + \sigma_{3/2}^{e(h)}} \sim \sum_q \underbrace{\frac{e_q^2 q(x) \int dz D_q^h(z)}{\sum_{q'} e_{q'}^2 q'(x) \int dz D_{q'}^h(z)}}_{P_q^h(x,z)} \frac{\Delta q(x)}{q(x)}$$

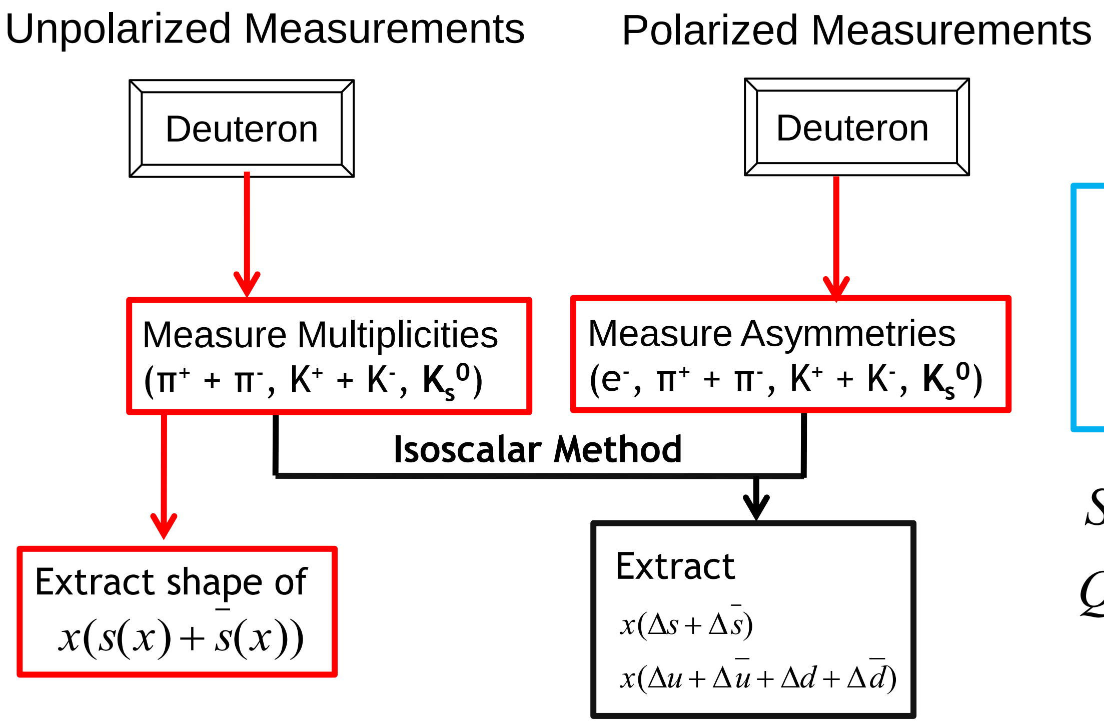
Leading order
Double spin asymmetry

- ***P_q^h* Purity is a conditional probability that a hadron of type *h* observed in the final state is originated from** a struck quark of flavor *q* in case of unpolarized beam/target.

- ***D_q^h*** **is a measure of the probability that a quark of flavor *q* will fragment into a hadron of type h = fragmentation function**

$$\vec{A}(x,Q^2) = (A_{1p}, A_{1p}^{\pi^+}, A_{1p}^{\pi^-}, A_{1p}^{\pi^0}, A_{1p}^{K^+}, A_{1p}^{K^-}, A_{1p}^{K_s^0}, A_{1d}, A_{1d}^{\pi^+}, A_{1d}^{\pi^-}, A_{1d}^{\pi^0}, A_{1d}^{K^+}, A_{1d}^{K^-}, A_{1d}^{K_s^0})$$

Isoscalar Measurements



For a deuteron target: Assuming isospin symmetry & charge conjugation invariance:

$$\begin{pmatrix} A_d(x,Q^2) \\ A_d^H(x,Q^2) \end{pmatrix} = C_R \begin{pmatrix} P_{NS}(x,Q^2) & P_S(x,Q^2) \\ P_{NS}^H(x,Q^2) & P_S^H(x,Q^2) \end{pmatrix} \begin{pmatrix} \Delta Q(x,Q^2)/Q(x,Q^2) \\ \Delta S(x,Q^2)/S(x,Q^2) \end{pmatrix}$$

$H = K^+ + K^-$
$H = K_s^0$
$H = \pi^+ + \pi^-$

$$S = s + \bar{s} \qquad \Delta S(x) \equiv \Delta s(x) + \Delta \bar{s}(x)$$

$$Q = u + \bar{u} + d + \bar{d} \qquad \Delta Q(x) \equiv \Delta u(x) + \Delta \bar{u}(x) + \Delta d(x) + \Delta \bar{d}(x)$$

- Extract isoscalar combinations of ΔQ(x) and ΔS(x)
- Inclusive purities from PDFs **(CTEQ-n, MRST, GRV**…)
- Example: for Kaons, purities can be computed from the Kaon multiplicities and the pdfs.

Example: Kaon Purities

$$\begin{pmatrix} A_d(x) \\ A_d^K(x) \end{pmatrix} = \begin{pmatrix} P_Q(x) & P_S(x) \\ P_Q^K(x) & P_S^K(x) \end{pmatrix} \begin{pmatrix} \Delta Q(x)/Q(x) \\ \Delta S(x)/S(x) \end{pmatrix}$$

$$P_Q^K(x) = \frac{Q(x)\mathcal{D}^K_{\text{non strange}}}{Q(x)\mathcal{D}^K_{\text{non strange}} + 2S(x)\mathcal{D}^K_{\text{strange}}}$$

$$P_S^K(x) = \frac{S(x)\mathcal{D}^K_{\text{strange}}}{Q(x)\mathcal{D}^K_{\text{non strange}} + 2S(x)\mathcal{D}^K_{\text{strange}}}$$

- Using charge symmetry

$$\frac{dN^K(x)/dx}{dN^{DIS}(x)/dx} = \frac{Q(x)\mathcal{D}^K_{\text{non strange}} + 2S(x)\mathcal{D}^K_{\text{strange}}}{5Q(x) + 2S(x)}$$

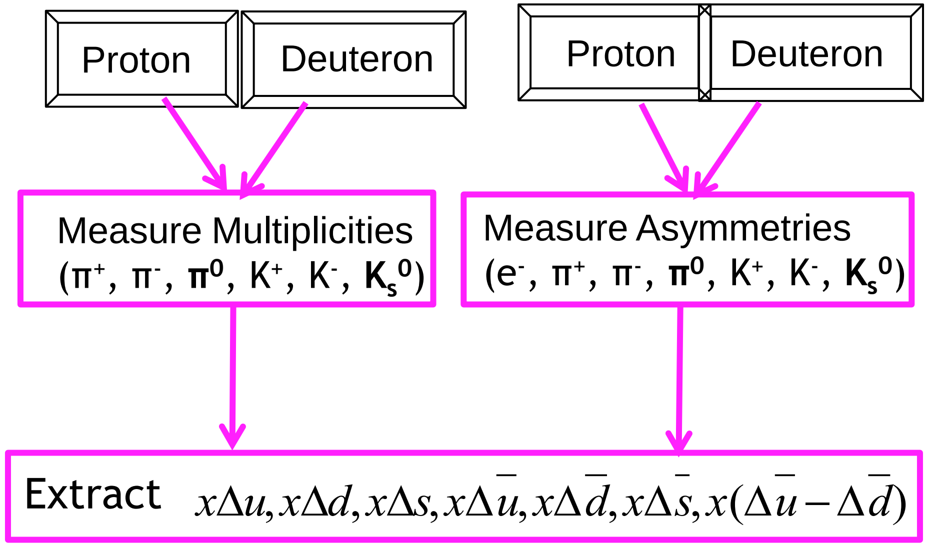
Measure

Multiplicities

FF=Fit parameters

Flavor Decomposition

Unpolarized Measurements Polarized Measurements



$$\vec{\mathcal{A}}(x,Q^2) = \mathcal{P}(x,Q^2)\cdot\vec{\mathcal{Q}}(x,Q^2)$$

$$\vec{\mathcal{Q}}(x,Q^2) = \left(\frac{\Delta u}{u}, \frac{\Delta d}{d}, \frac{\Delta s}{s}, \frac{\Delta\bar{u}}{\bar{u}}, \frac{\Delta\bar{d}}{\bar{d}}, \frac{\Delta\bar{s}}{\bar{s}}\right)$$

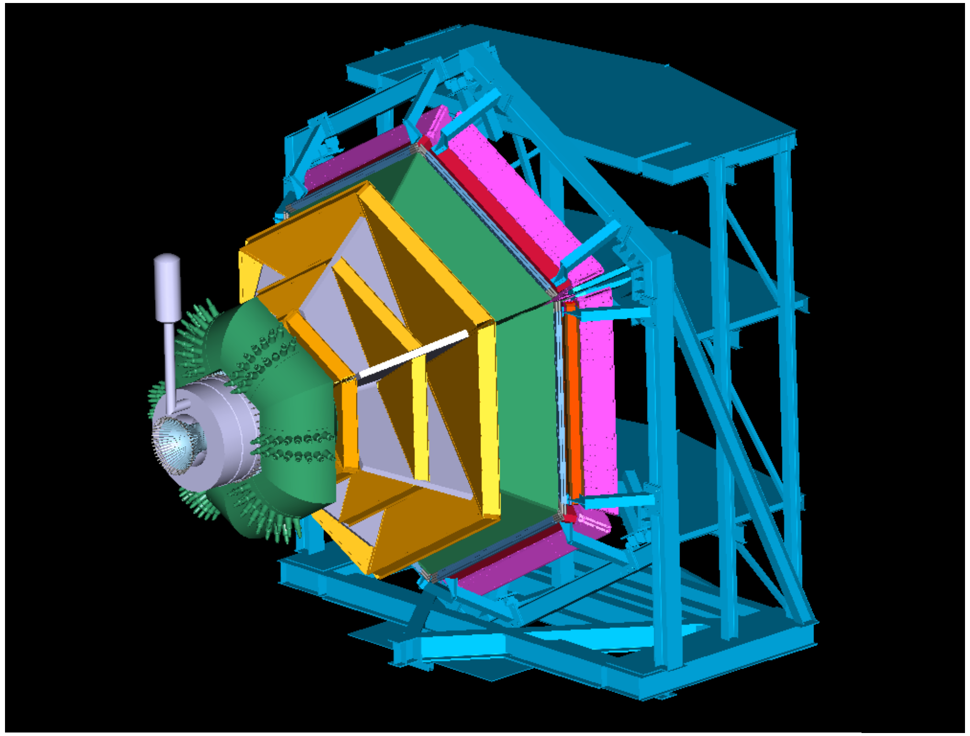
$$\vec{\mathcal{A}}(x,Q^2) = (A_{1p}, A_{1p}^{\pi^+}, A_{1p}^{\pi^-}, A_{1p}^{K^+}, A_{1p}^{K^-}, A_{1p}^{K_s^0}, A_{1d}, A_{1d}^{\pi^+}, A_{1d}^{\pi^-}, A_{1d}^{K^+}, A_{1d}^{K^-}, A_{1d}^{K_s^0})$$

- Purities depend on the unpolarized PDFs and the fragmentation functions.

- For the FFs, one can constrain them using measured pion and kaon multiplicities in the same kinematical range from unpolarized proton and deuteron data,

- System can be solved by χ_2 minimization accounting for the correlations between the various asymmetries.

Jefferson Lab CLAS12 @ 11GeV

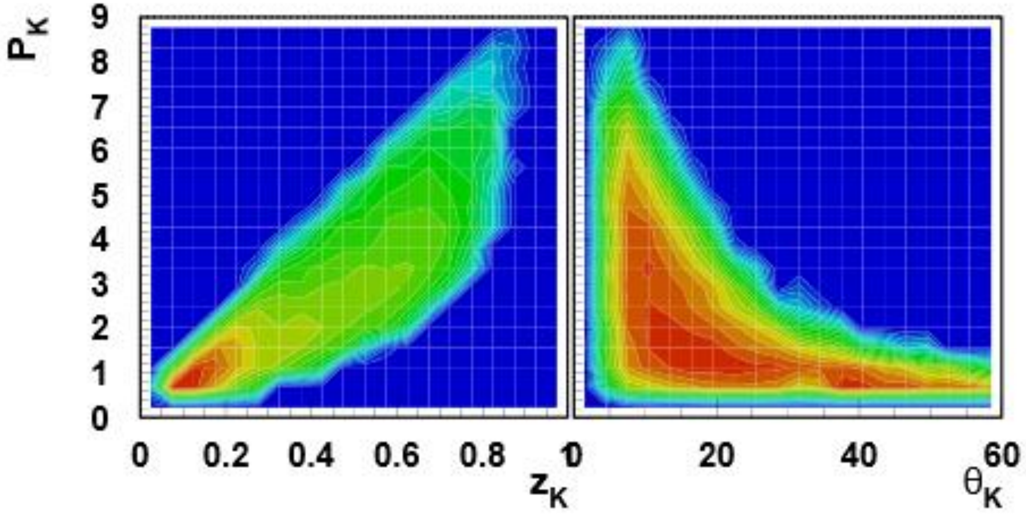


Wide detector and physics acceptance **(current/target fragmentation)**
High beam polarization 85%
High target polarization 85%
Hydrogen and Deuterium targets.

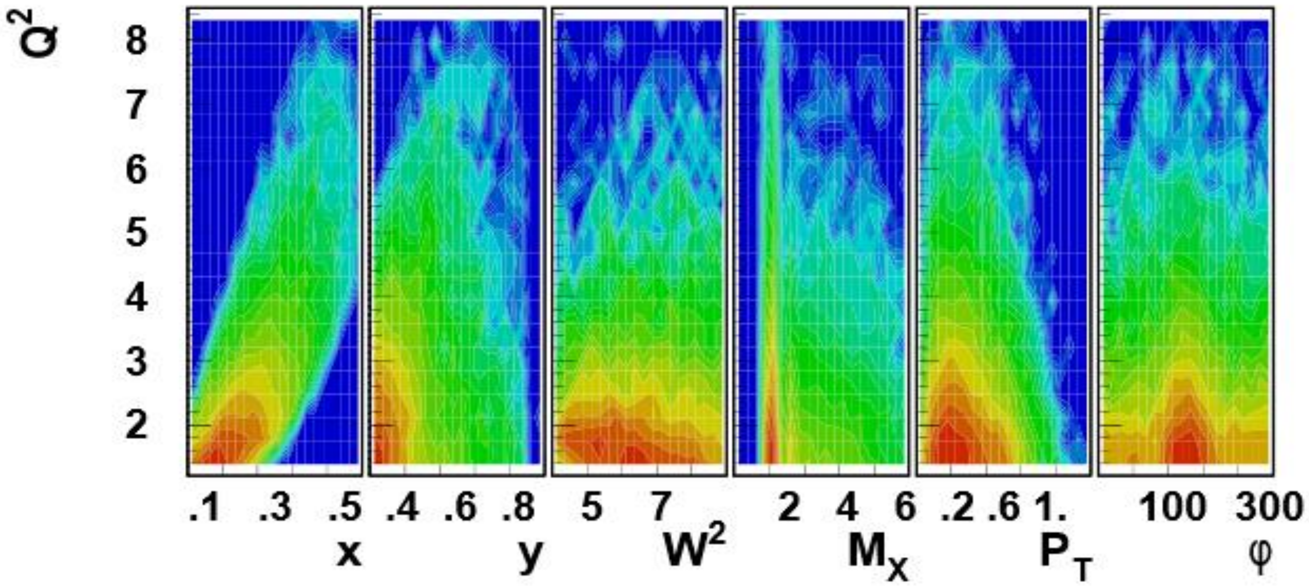
Track resolutions:

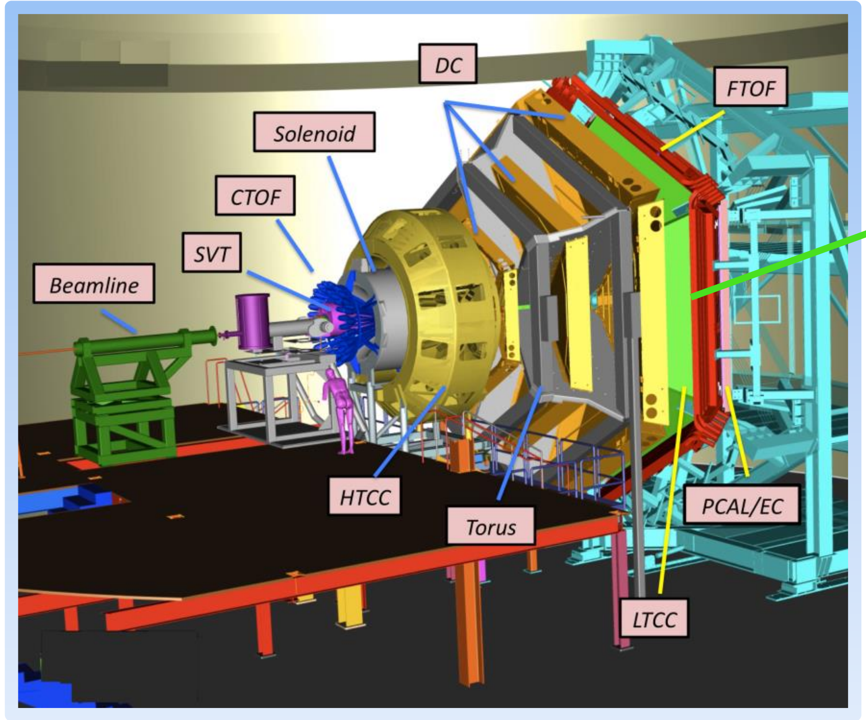
δp (GeV/c)		**$0.003p + 0.001p^2$**
δθ (mr)	**<**	**1**
δϕ (mr)	**<**	**3**

Lumi > $10^{35}cm^{-1}s^{-1}$

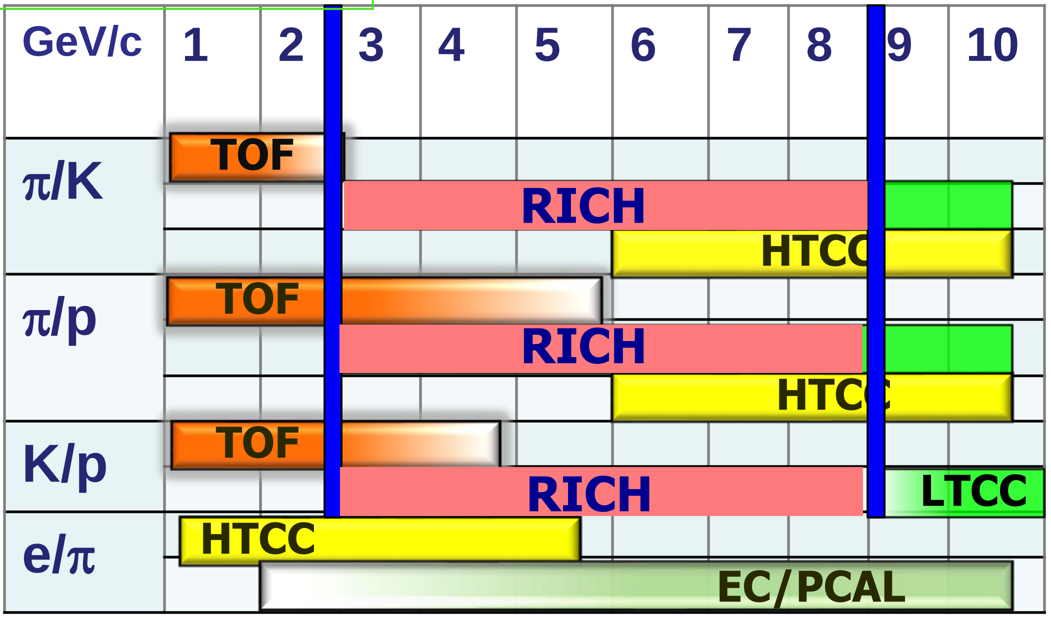


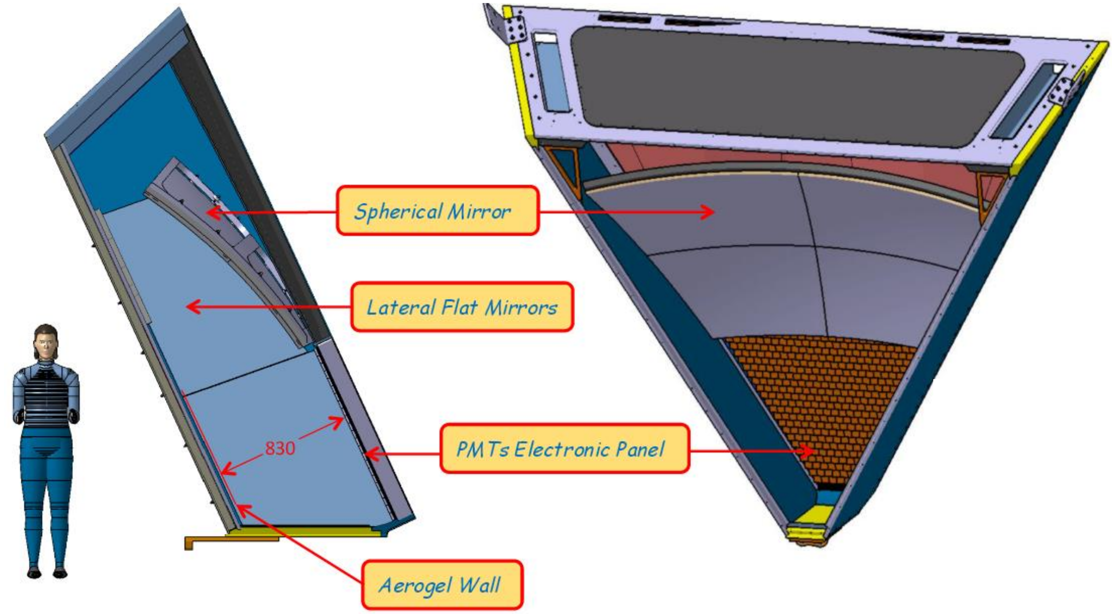
:htar, Kaoı





Replace two LTTC with a Ring Imaging CHerenkov

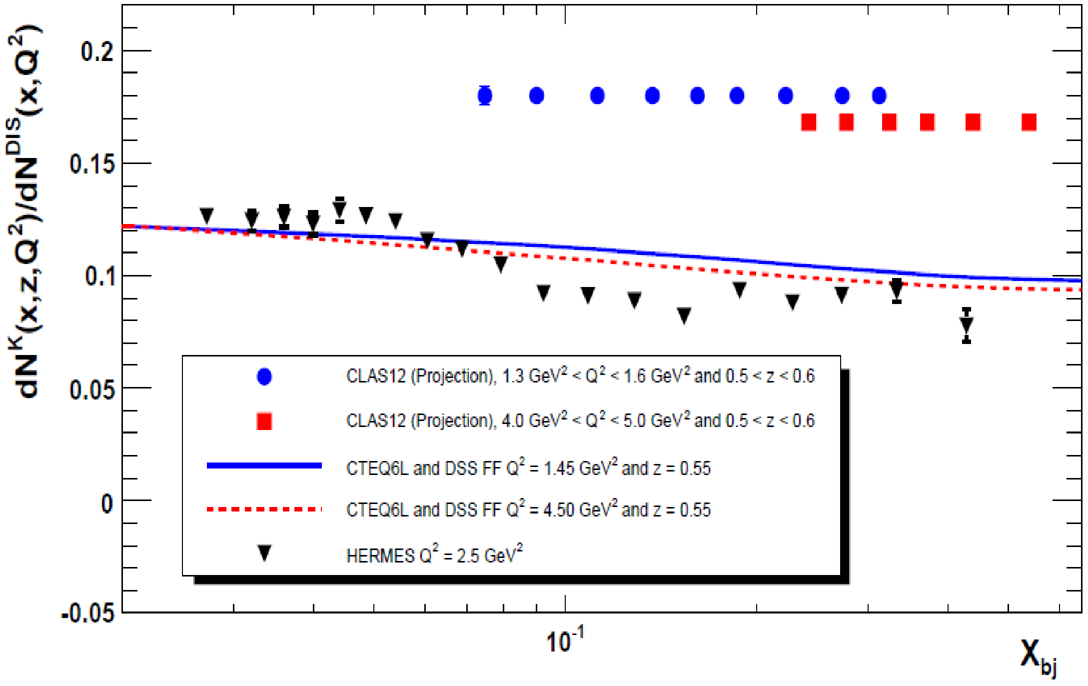


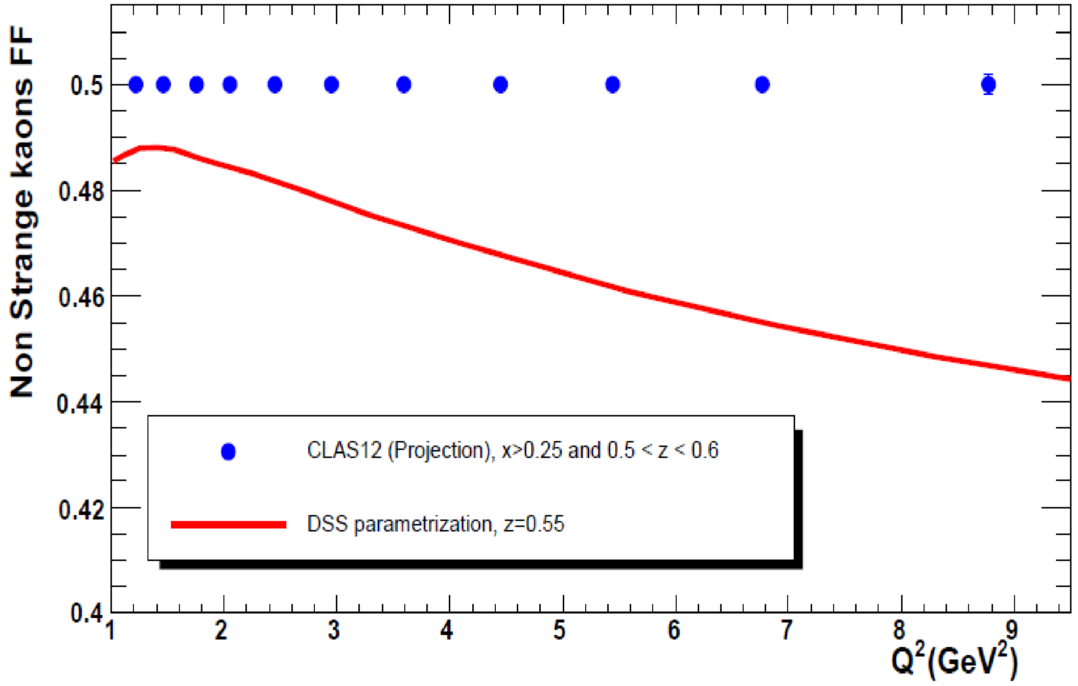


2 RICH

INSTITUTIONS
INFN (Italy) Bari, Ferrara, Genova, L.Frascati, Roma/ISS
Jefferson Lab (Newport News, USA)
Argonne National Lab (Argonne, USA)
Duquesne University (Pittsburgh, USA)
Glasgow University (Glasgow, UK)
J. Gutenberg Universitat Mainz (Mainz, Germany)
Kyungpook National University, (Daegu, Korea)
University of Connecticut (Storrs, USA)
UTFSM (Valparaiso, Chile)
The George Washington University (DC, USA)

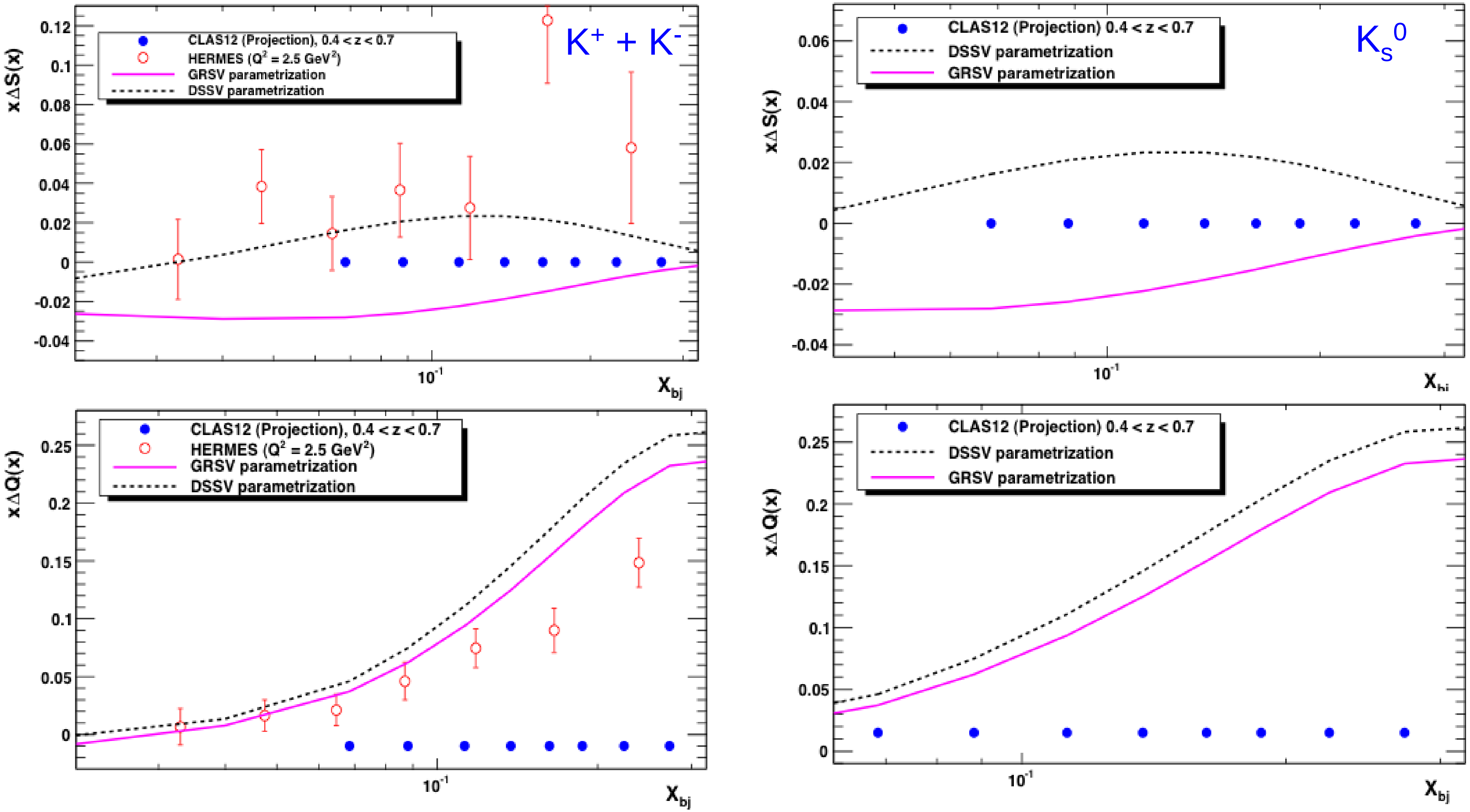
Expected Precisions
Kaon Multiplicities and Frag. Func.





Projections – Isoscalar Method

Sources	Uncertainty on Asym.
Beam & target pol.	2%
Depol. and R	4%
Dilution factor	3%
Rad. corrections	3%
Trans. Spin effect	3%

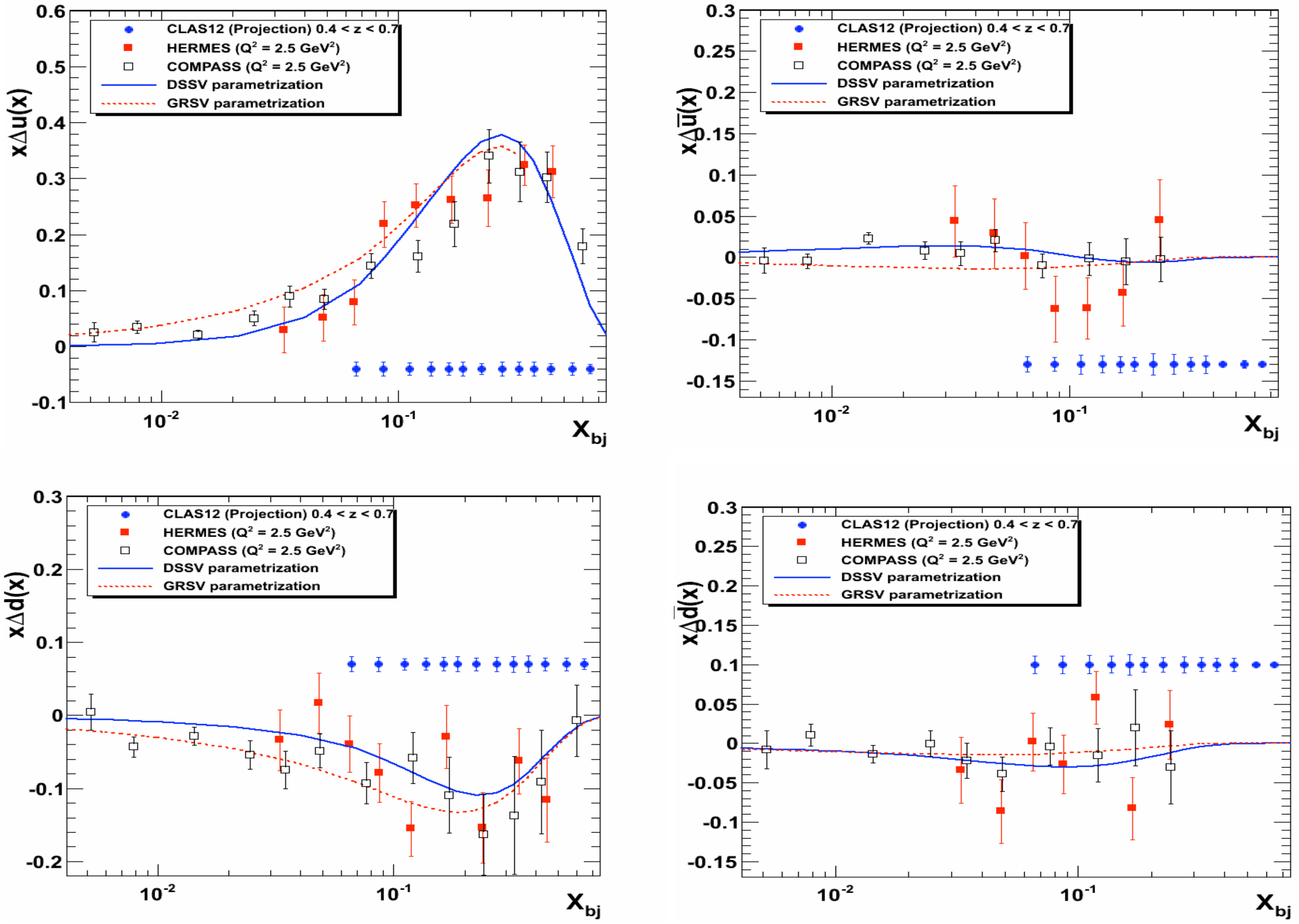


Corrections:

- Charge symmetric background
- Radiative and detector smearing effects
- Acceptance correction
- Diffractive vector meson contributions
- Background subtraction (π^0, K^0)
- PID inefficiencies

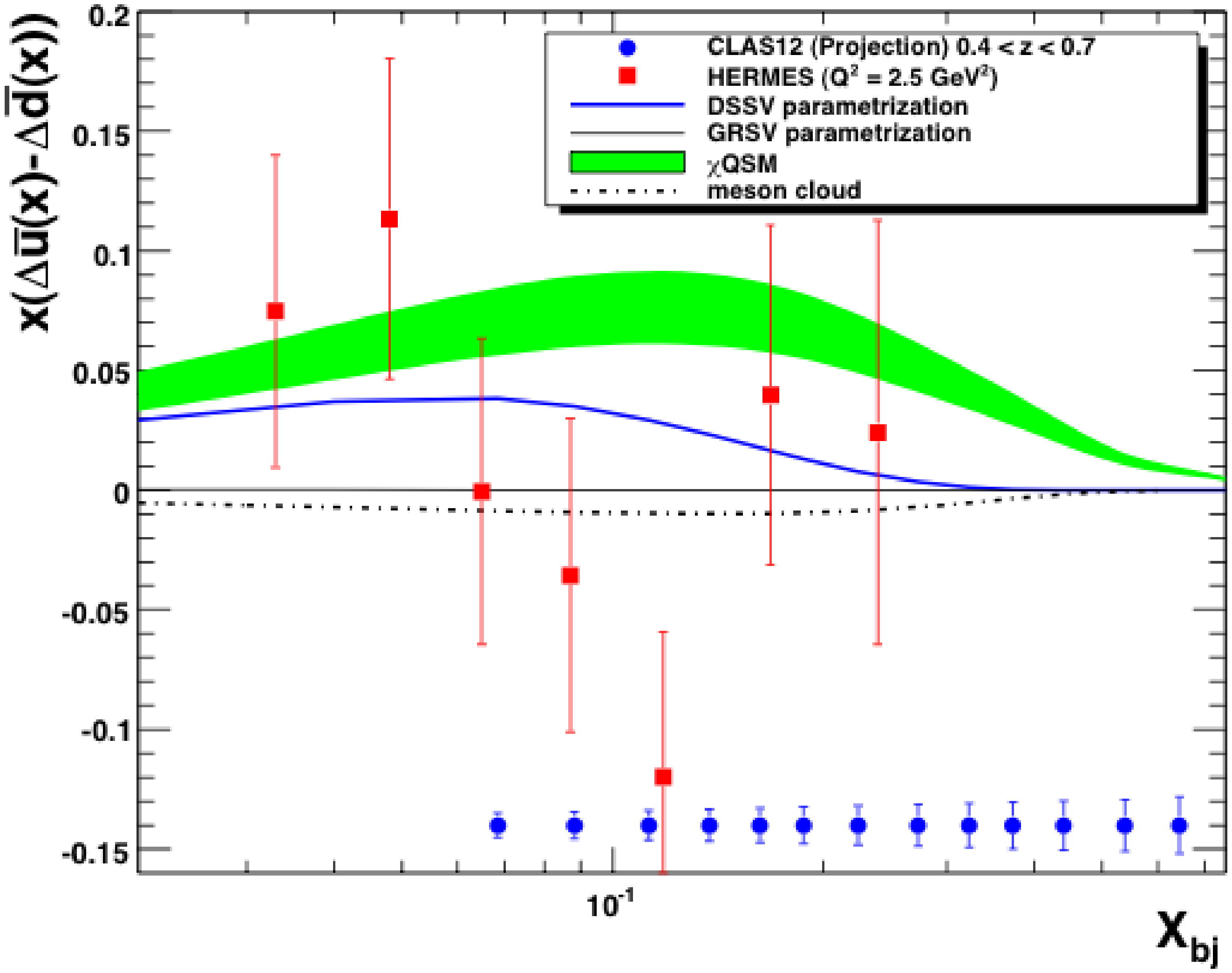
Projections – Flavor decomposition (1) - 10% systematics on asymmetries

Sources	Uncertainty on Asym.
Beam & target pol.	2%
Depol. and R	4%
Dilution factor	3%
Rad. corrections	3%
Trans. Spin effect	3%



Projections – (2) - 10% systematics on asymmetries

✧Test whether or not the light sea is symmetrically polarized



Corrections:

- Charge symmetric background
- Radiative and detector smearing effects
- Acceptance correction
- Diffractive vector meson contributions
- Background subtraction (π^0, K^0)
- PID inefficiencies

World Data on ΔS

- Polarized deep-inelastic inclusive scattering(SMC) $\Delta u + \Delta d + \Delta s = 0.2 \pm 0.1$

  $\Delta s = -0.1 \pm 0.1$

- ν-p elastic scattering (E734 BNL) $\Delta s = -0.15 \pm 0.0$[illegible]

- Polarized Semi-Inclusive DIS (HERMES)
  - *** 5 flavor tagging→** $\Delta s \sim 0$ and positive
  - *** Isoscalar method-> published (2008) then reviewed and published (2014), slightly positive**

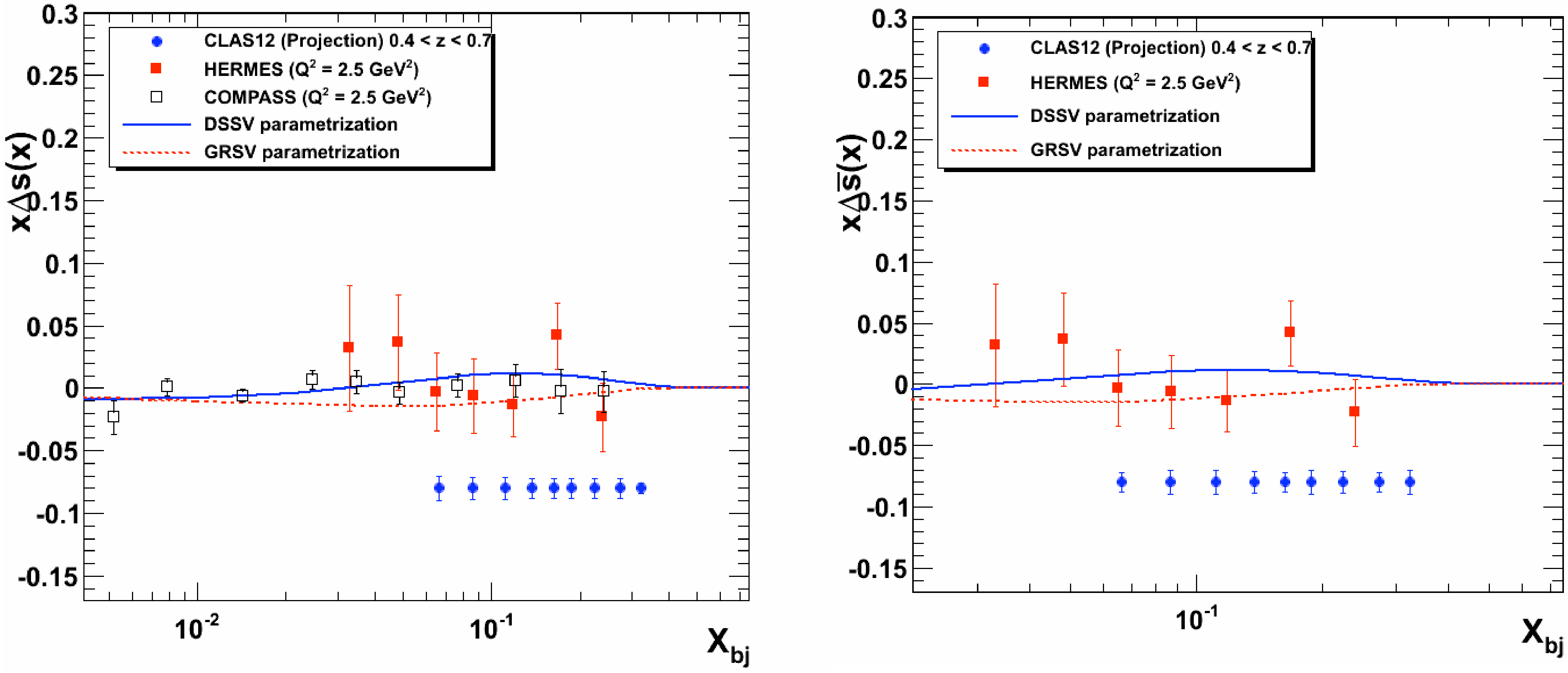
- COMPASS: sidis μ-NH3 (2010) → compatible with zero.

- ATLAS results (2012) suggest that at small *x* the strangeness contribution can be substantially larger than assumed. Phys. Rev. Lett. 109, 012001 – Published 5 July 2012

So far, the results vary widely and the uncertainties are big

“Strange quark polarization puzzle”

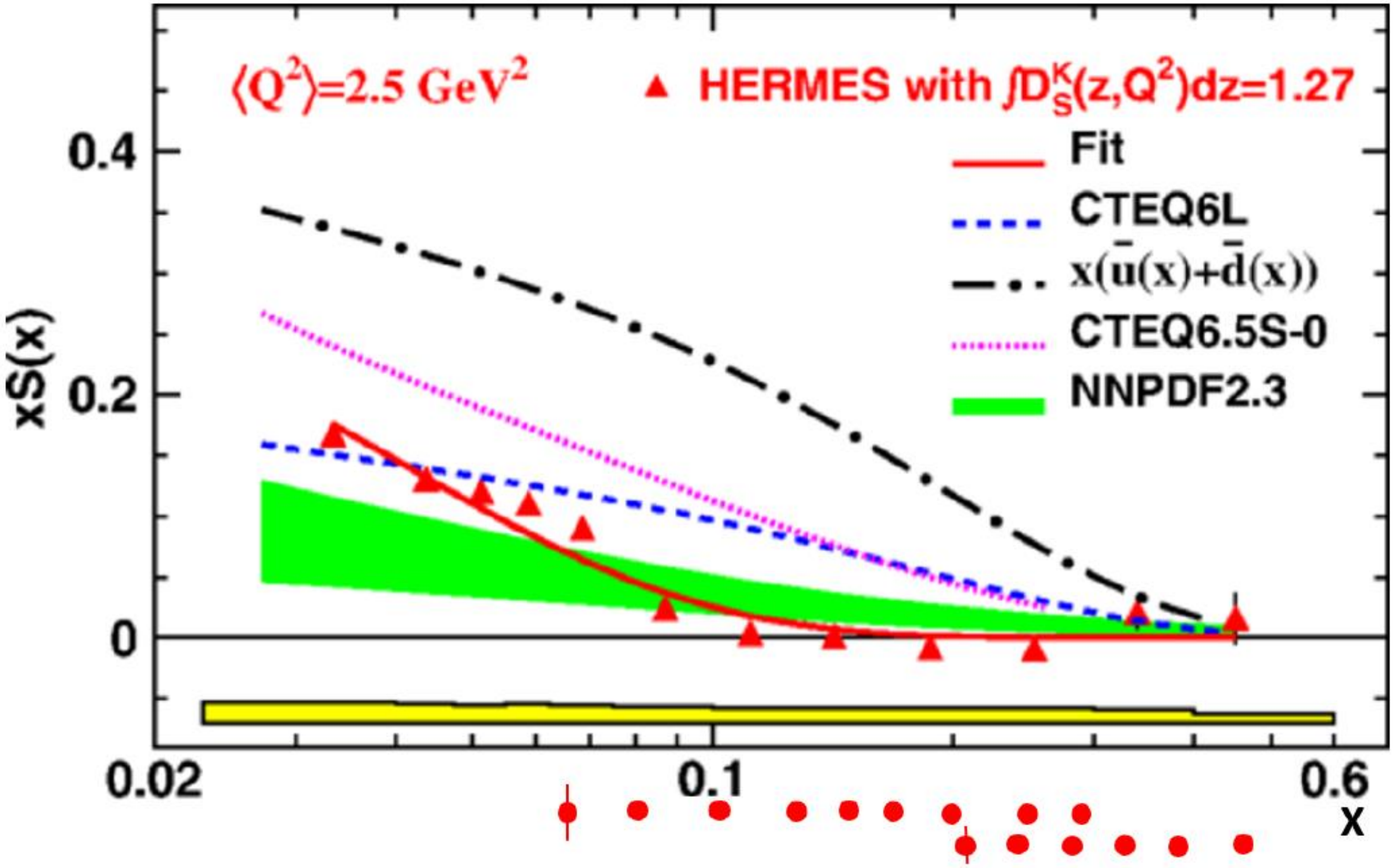
Projections – Flavor decomposition (2) - 10% systematics on asymmetries



Corrections:

- Charge symmetric background
- Acceptance correction
- Background subtraction (π^0, K^0)
- Radiative and detector smearing effects
- Diffractive vector meson contributions
- PID inefficiencies

Expected Precisions x S(x)



Conclusion and Outlook

- ✧ **The combination of high luminosity and the large acceptance of CLAS12 will allow a dramatic improvement of the statistical precision in the extraction of individual quark contributions to the nucleon spin**

- ✧ The systematics related to our knowledge of fragmentation functions can further be reduced with high precision multiplicity measurements.

- ✧ Test whether or not the light sea is symmetrically polarized.

- ✧ Improve NLO global analysis of Helicity Parton densities and their uncertainties.

Thanks!

Backup Slides

2.2 Formalism for unpolarized deuteron target: Multiplicities and Strange PDFs

At the leading order of QCD and for unpolarized Semi Inclusive Deep Inelastic Scattering (SIDIS), the cross section for hadron production at a given x, Q^2 and z, normalized to the corresponding inclusive cross section takes the factorized form

$$\frac{d\sigma^h(x,Q^2,z)/dxdQ^2dz}{d\sigma^{DIS}(x,Q^2)/dxdQ^2} = \frac{dN^h(x,Q^2,z)}{dN^{DIS}(x,Q^2)} = \frac{\sum_q e_q^2 q(x,Q^2) D_q^h(z,Q^2)}{\sum_q e_q^2 q(x,Q^2)}$$

where q is the parton distribution function for a quark of flavor q, e_q its charge. D_q^h is the fragmentation function, a measure of the probability that a quark of flavor q fragments into a hadron of type h. At our kinematics, only light quarks and anti-quarks flavors, $q = (u, \bar{u}, d, \bar{d}, s, \bar{s})$, are considered. z is the fraction of the photon energy carried by a hadron h. For deuterium; an isoscalar target, the fragmentation functions become isospin independent. By assuming isospin symmetry, the strange PDF to be same for both nucleons and charge conjugation invariance in the fragmentation functions, the multiplicity for a final product (H) simplifies to:

$$\frac{dN^H(x,Q^2)}{dN^{DIS}(x,Q^2)} = \frac{Q(x,Q^2)\int D_{NS}^H(z,Q^2)dz + S(x,Q^2)\int D_S^H(z,Q^2)dz}{5Q(x,Q^2) + 2S(x,Q^2)}$$

where $H = K^+ + K^-$, $\pi^+ + \pi^-$ or K_s^0. The sum of non strange and strange parton distribution functions are $Q = u + \bar{u} + d + \bar{d}$ and $S = s + \bar{s}$, respectively. Furthermore, $D_{NS}^H = 4D_u^H + D_d^H$ and $D_S^H = 2D_s^H$ are the non strange and strange fragmentation functions, respectively. The term $2S(x,Q^2)$ is at the most $1\%(0.05 \leq x \leq 0.075)$ of the $5Q(x,Q^2)$ term, therefore one can safely drop it off. We then realize that once we are in the region where the sum of the strange parton distribution functions $S(x)$ vanishes, the multiplicity becomes independent of x

$$\frac{dN^H(x,Q^2)}{dN^{DIS}(x,Q^2)} = \frac{\int D_{NS}^H(z,Q^2)dz}{5}$$

Once in that region, one can extract for each z bin, the Q^2 dependence of the NS fragmentation function from the measured multiplicities. By taking the non strange PDFs from most up to date parameterizations available at the time of the data analysis and plugging them back to the multiplicity equation, one can extract the x dependence of strange contribution $S(x,Q^2)\int D_S^H(z,Q^2)dz$ for specific (z,Q^2) bins. This method is very reliable in getting the shape of the sum of the strange PDFs. However its absolute value $S(x,Q^2)$ relies on the quality of the used parameterization for the fragmentation functions.