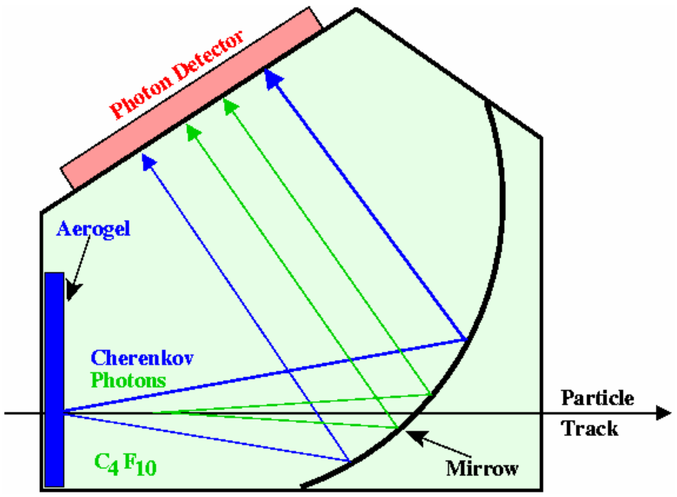
Strange Sea Contribution to the Nucleon Spin



Fatiha Benmokhtar

Carnegie Mellon University, USA

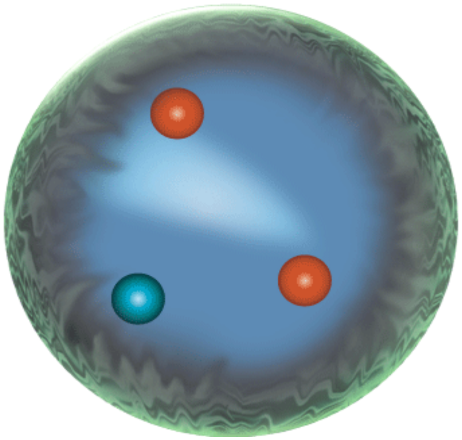
with

A. El Alaoui, (LPC Grenoble, France), H. Avakian (Jlab,USA),
K. Hafidi (ANL, USA)

Strange Sea Contribution to the Nucleon Spin

Outline

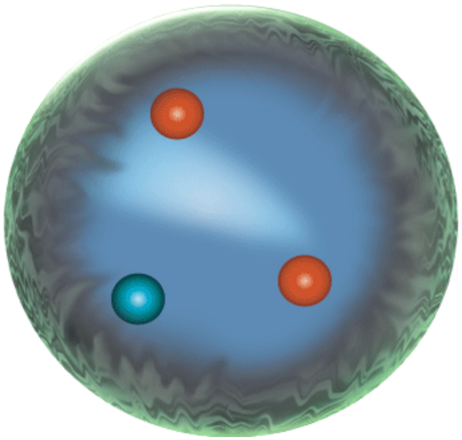
- Strange quark contributions to the nucleon properties (in general).
- Strange quark contribution to the nucleon spin.
- World data on ΔS
- Semi Inclusive DIS: - Five flavor tagging
  - Isosclar Method
- DeltaS with CLAS12?



Nucleon constituents

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

valence « sea= virtual pairs »



- The sea contains all flavors, but
  - the u and d sea can't be distinguished from the valence
  - the heavier quarks (c,b,t) are too heavy to contribute much
  - Strange quark is the natural candidate to study the sea.

With how much do virtual pairs contribute
to the structure of the nucleon ?
Mass? Momentum? Charge & Magnetisation
and Spin?

Strange Quark Contribution to the Nucleon Properties

(in brief)

- Mass: Hyp -> π-N -> $$= \langle \quad | \bar{\ } | \quad \rangle \quad 130\, MeV$$ → 0 to 30 % with big theoretical uncertainties…

- Longitudinal Momentum: -Study the spectral functions q(x), -From unpol DI ν_μ-Nucleon scattering (NuTeV)

  . For x <0.1 $$\int_0^1 x\,(s(x) + \bar{s}(x))\,dx \sim 4\%$$ → Difficult to connect with ordinary observable

- Electromagnetic Form Factors: Parity violation experiments: G0, HAPPEX, PVA4.

$$G^{s}_{E,M} = \left(1 - 4\sin^2\theta_W\right) G^{\gamma,p}_{E,M} - G^{\gamma,n}_{E,M} - G^{Z,p}_{E,M}$$

→Underway ☺

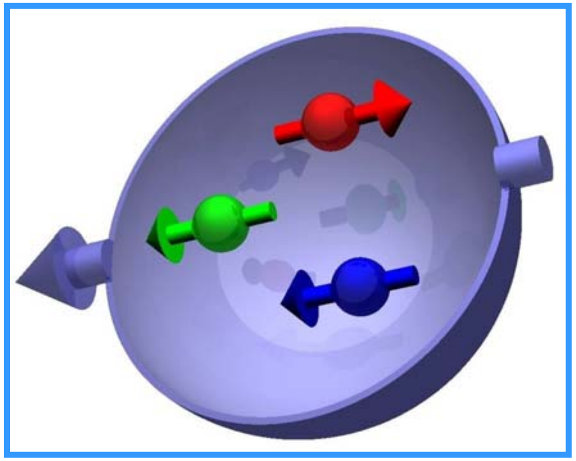
- What about the contribution to the Nucleon Spin?

$$\left\langle \boldsymbol{N} \,|\, \bar{\boldsymbol{s}}\gamma^{\mu}\gamma^{5}\boldsymbol{s} \,|\, \boldsymbol{N} \right\rangle = \boldsymbol{???}$$

Strangeness Contribution to the Nucleon Spin

$$S = \frac{1}{2}\Sigma, \quad \Sigma = \qquad + $$

$$= \frac{4}{3} \qquad d = \frac{1}{3}$$



BUT

In 1989 EMC measured

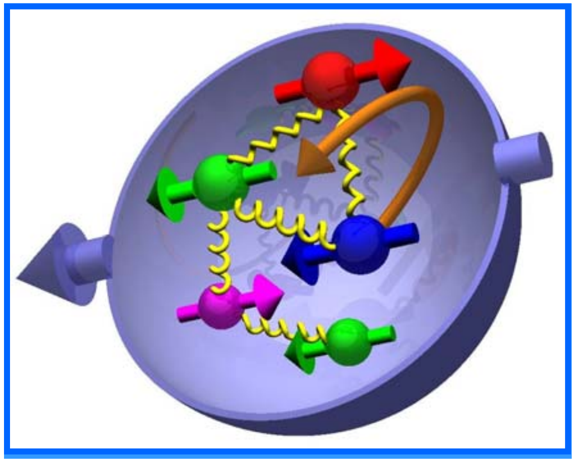
Σ = 0.120 $\pm$ 0.094 $\mp$ 0.138 -> ~20 % of the nucleon spin!!!

→ **Spin Crisis!**

Strangeness Contribution to the Nucleon Spin

$$S = \frac{}{} = \frac{}{}\sum_{q} \quad + \quad + \quad +$$

$$= \quad + \quad \bar{} + \quad + \quad \bar{} + \quad + \quad \bar{}$$



-> Gluon spin ΔG

-> Sea quark spin Δq

-> Orbital Angular Momentum L_G and L_q

Lattice Calculations predict: $\Delta s = -0.1$

World Data on ΔS

- Polarized deep-inelastic inclusive scattering (SMC)

$$\Delta u + \Delta d + \Delta s = 0.20 \pm 0.10$$
$$\Delta s = -0.1 \pm 0.1$$

- ν-p elastic scattering (E734 BNL)

$$\Delta s = -0.15 \pm 0.09$$

- Polarized Semi-Inclusive DIS (HERMES)

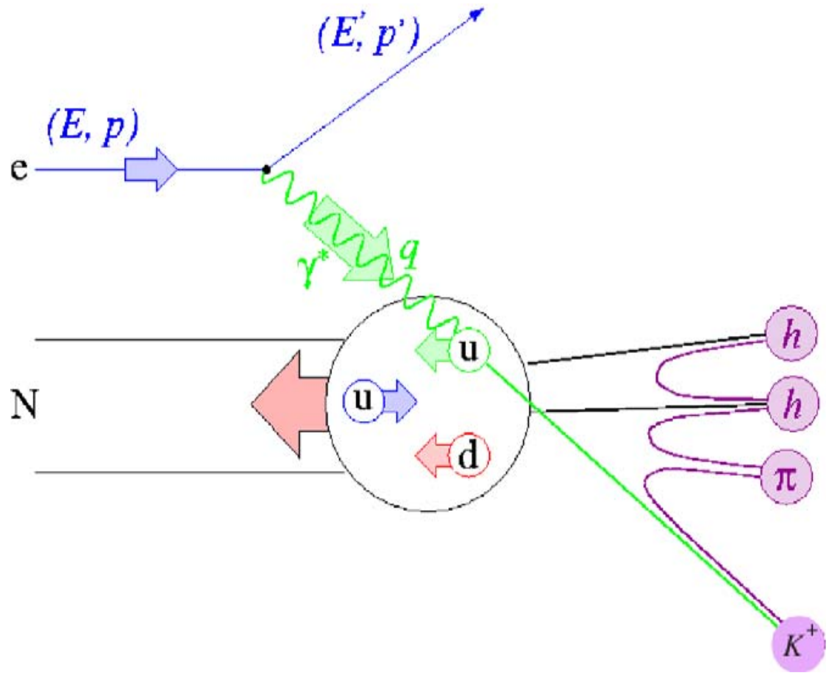
  *** 5 flavor tagging→ published**
  *** Isoscalar method-> preliminary**

$$\Delta s \sim$$

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

$$\langle N \mid \bar{s}\gamma^{\mu}\gamma^{5}s \mid N \rangle = ???$$

Semi Inclusive DIS



$$\sigma(e\,p \rightarrow e\,hX)$$

Sidis Selection:

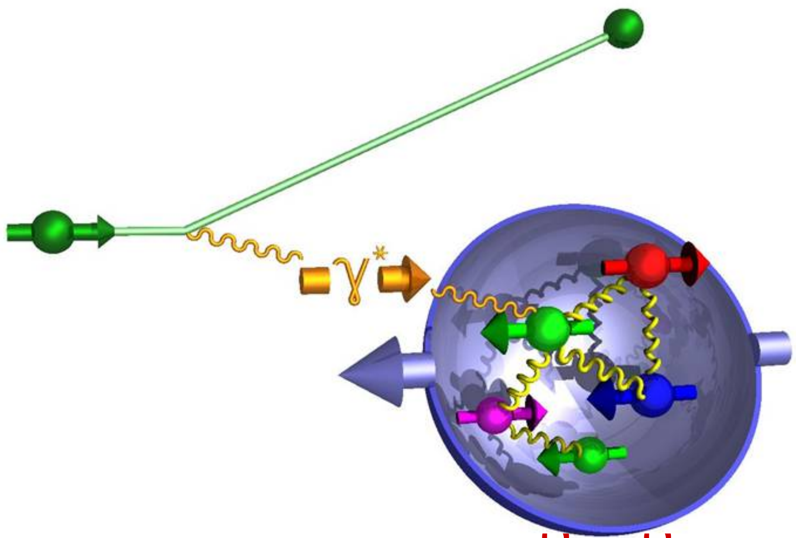
- $\nu = E - E'$
- $x = Q^2/(2M\nu)$
- $y = \nu/E$
- $W^2 = M^2 - 2M\nu - Q^2$
- $Q^2 = 4EE'\sin^2(\theta/2)$

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

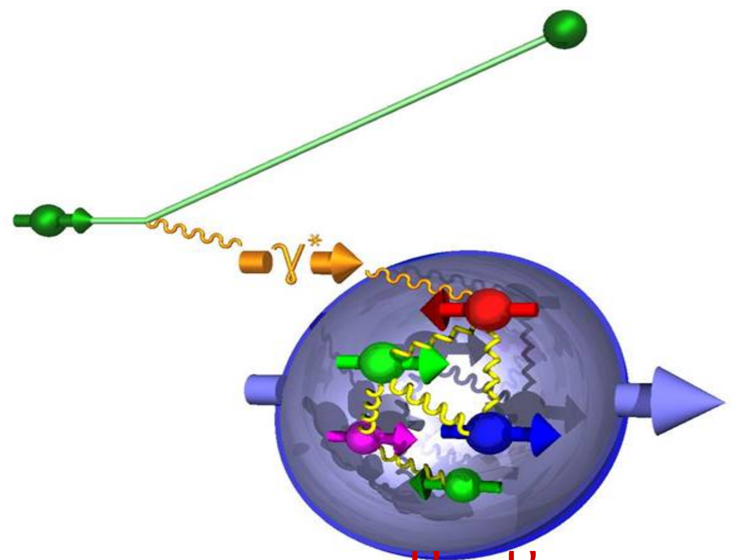
Hadron Selection:

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

Spin Asymmetries



$\sigma_{1/2} \sim q^{+}(x) \quad \vec{S}_{\gamma} + \vec{S}_{N} = 1/2$



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

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

Spin Independent Structure Function *F_1*

$$\sigma_{1/2} + \sigma_{3/2} \propto F_1(x) = \frac{1}{2}\sum_f e^2\left(q^{+}(x) + q^{-}(x)\right)$$

Spin Dependent Structure Function *g_1*

$$\sigma_{1/2} - \sigma_{3/2} \propto g_1(x) = \frac{1}{2}\sum_f e^2\underbrace{\left(q^{+}(x) - q^{-}(x)\right)}_{\Delta q}$$

Measurement of Δq in Semi-Inclusive DIS

$$A_1^{e(h)}(x,Q^2) = \frac{\sigma_{1/2}^{e(h)} - \sigma_{3/2}^{e(h)}}{\sigma_{1/2}^{e(h)} + \sigma_{3/2}^{e(h)}} = \frac{1}{(1+\eta\gamma)D} \frac{1}{< P_B P_T >} \frac{(N^{e(h)}/L)^{\overleftarrow{\Leftarrow}} - (N^{e(h)}/L)^{\overrightarrow{\Rightarrow}}}{(N^{e(h)}/L)^{\overleftarrow{\Leftarrow}} + (N^{e(h)}/L)^{\overrightarrow{\Rightarrow}}}$$

$$\sim \sum_q \underbrace{\frac{e_q^2 q(x) \int dz D_q^h(z)}{\sum_{q'} e_{q'}^2 q'(x) \int dz D_{q'}^h(z)}}_{P_q^h(x,z)} \frac{\Delta q(x)}{q(x)}$$

- 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

$$\vec{A}_1 = P \cdot \vec{Q}$$

ΔS from SIDIS

$$\vec{A}_1 = P \cdot \vec{Q}$$

1- Five flavor decomposition (Δq)

2-Isoscalar extraction of ΔS

Five flavor decomposition (Δq with SIDIS)

$$\vec{A}_1 = \begin{pmatrix} A_{1,p} \\ A_{1,p}^{\pi^+} \\ A_{1,p}^{\pi^-} \\ A_{1,d} \\ \cdot \\ \cdot \\ \cdot \\ A_{1,d}^{K^-} \end{pmatrix} \qquad P_q^h(x) = \frac{e_q^2 q(x) \int dz D_q^h(z)}{\sum_{q'} e_{q'}^2 q'(x) \int dz D_{q'}^h(z)} \qquad \vec{Q} = \begin{pmatrix} \Delta u / u \\ \Delta d / d \\ \Delta \bar{u} / \bar{u} \\ \Delta \bar{d} / \bar{d} \\ \Delta s / s \end{pmatrix}$$

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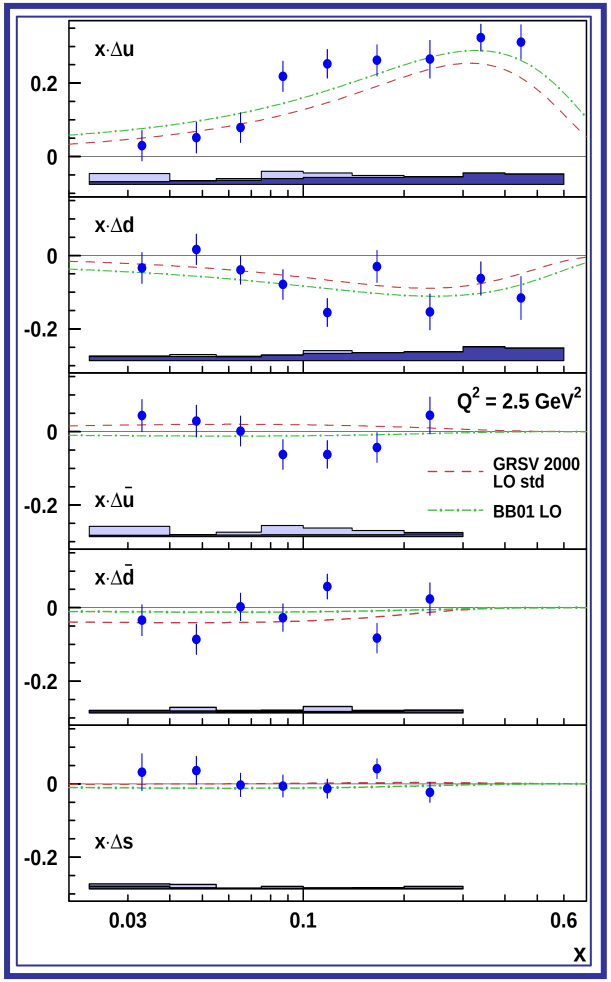


***-HERMES:* Purities calculated from MC simulation of the entire scattering process.**

$$\Delta u = 0.601 \pm 0.039 \pm 0.049 \qquad \Delta \bar{u} = -0.002 \pm 0.036 \pm 0.029$$

$$\Delta d = -0.226 \pm 0.039 \pm 0.050 \qquad \Delta \bar{d} = -0.054 \pm 0.033 \pm 0.011$$

$$\Delta s = 0.028 \pm 0.033 \pm 0.009$$

Isoscalar extraction of ΔS

$$K^{+} = u\bar{s} \qquad K^{-} = \bar{u}s$$

- Need a longitudinally polarized deuterium target
  - strange quark in proton and neutron identical
  - fragmentation simplifies

- Assumptions:
  - isospin symmetry between proton and neutron
  - charge-conjugation invariance in fragmentation

- Extraction from data of:
  - inclusive $A_{1d}(x,Q^2)$ and kaon $A_{1d}^{K}(x,Q^2)$ double spin asymmetries
  - kaon multiplicities

Isoscalar extraction of ΔS:

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

- Measure inclusive asymmetry $A_{1,d}$ and kaon asymmetries $A_{1(K^+ + K^-)}$
- Extract isoscalar combinations of ΔQ(x) and ΔS(x)

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

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

- Inclusive purities from PDFs (CTEQ6, MRST, GRV…)

$$P_Q(x) = \frac{5Q(x)}{5Q(x) + 2S(x)}, \quad P_S(x) = \frac{2S(x)}{5Q(x) + 2S(x)}$$

- Kaon purities can be computed from the kaon multiplicities and the pdfs: How? →

Kaon Multiplicities

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

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

- Using charge symmetry $D_q^{K^+ + K^-}(z) = D_{\bar{q}}^{K^+ + K^-}(z)$

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

Fit parameters

Measure

Multiplicities

HERMES Preliminary results (isoscalar)

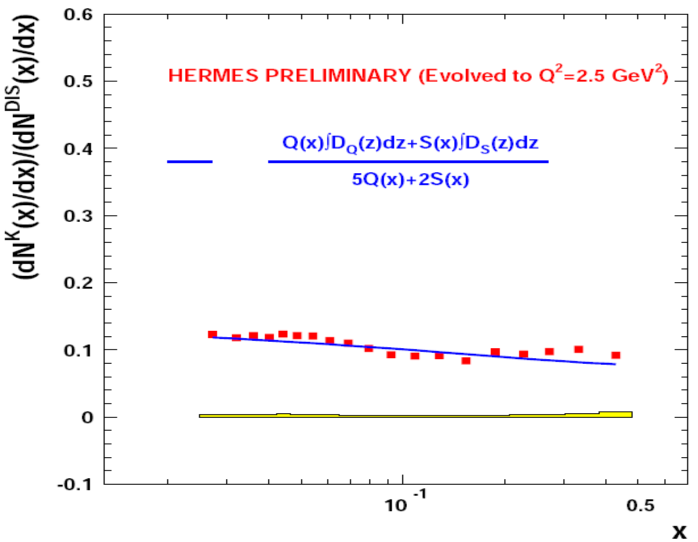


Fig. 1. Multiplicity in 4π of charged kaons in semi-inclusive DIS on a deuterium target as a function of Bjorken x. The statistical error bars are not visible, and the bands at the bottom represent the systematic uncertainties.

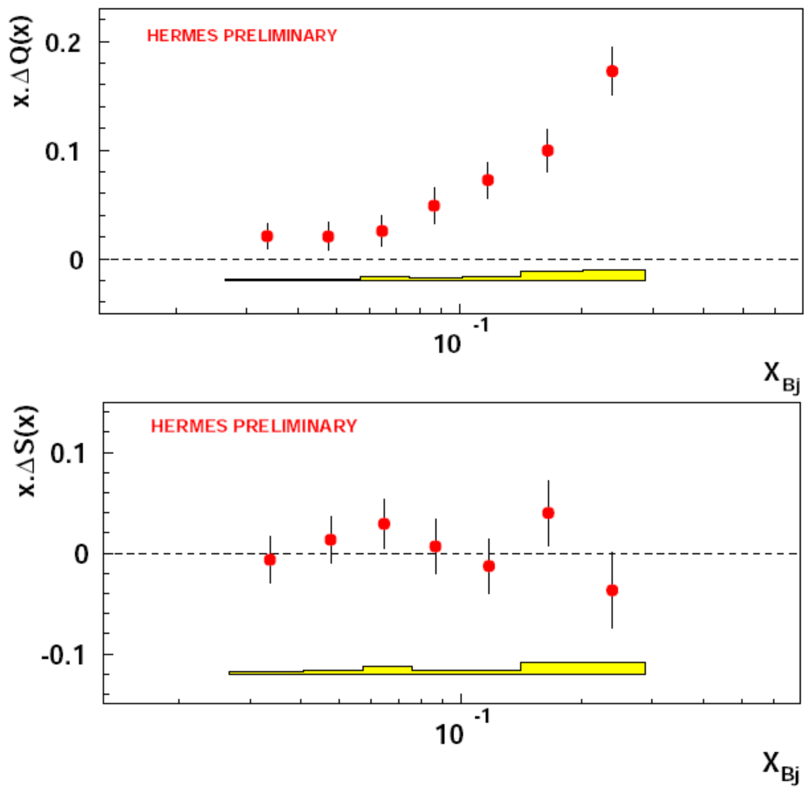
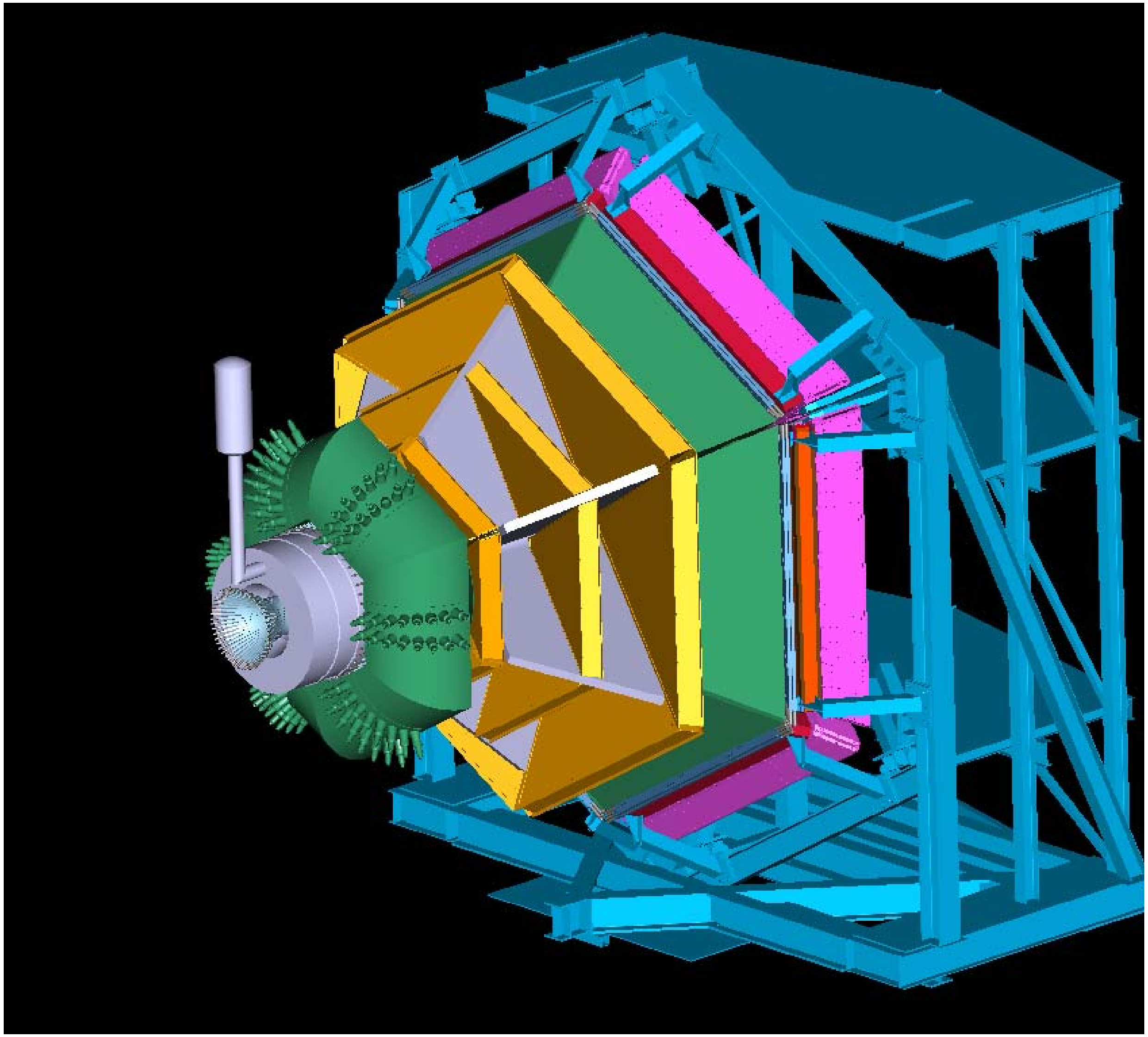


Fig. 2. Strange and non-strange quark helicity distributions at $\langle Q^2 \rangle = 2.5\,\mathrm{GeV}^2$ as a function of Bjorken x. The error bars are statistical, and the bands at the bottom represent the systematic uncertainties.

H. E.Jackson proceedings in EPJ 2006

What can we do with CLAS12?

CLAS12 @ 11GeV



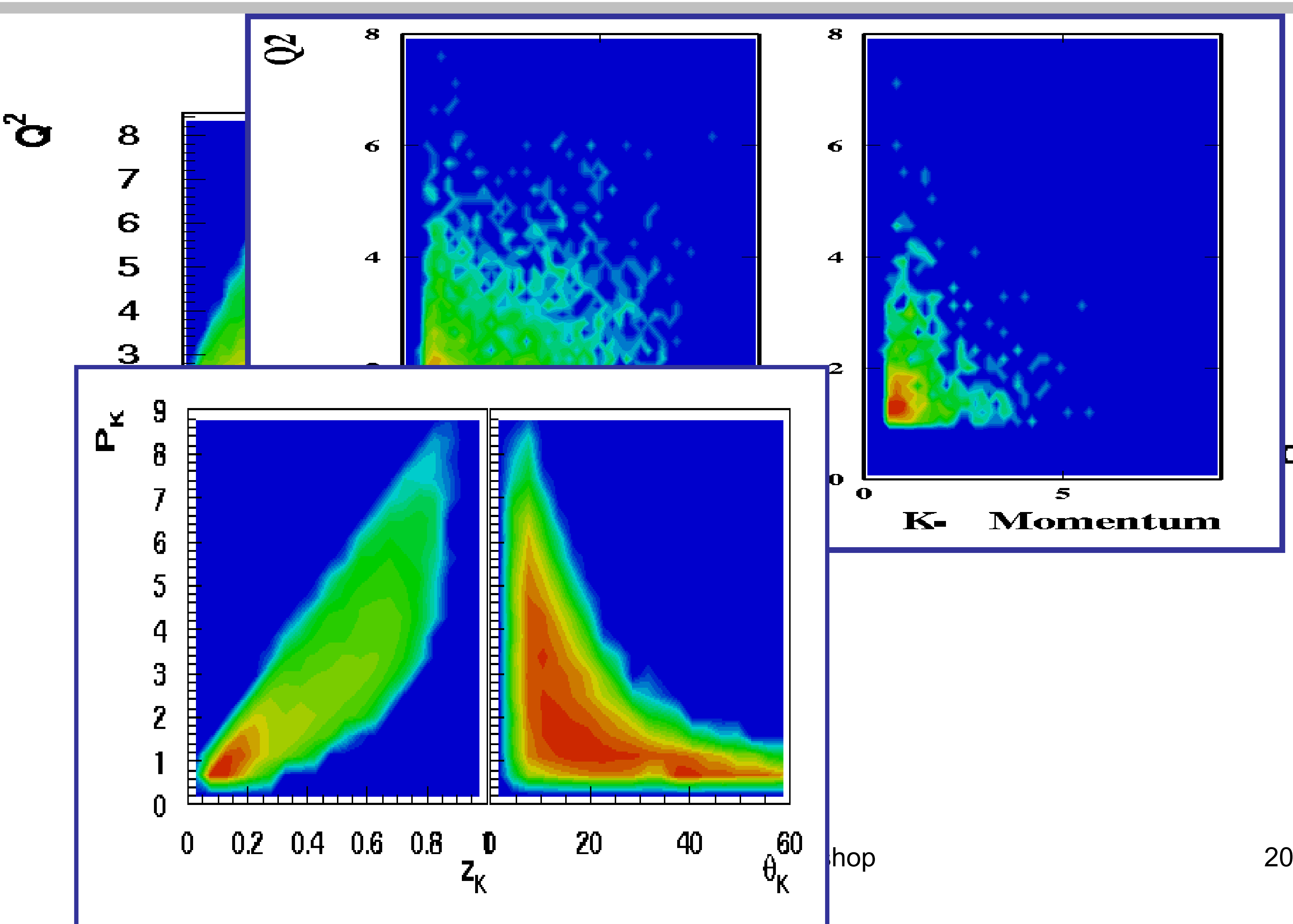
Wide detector and physics acceptance
(current/target fragmentation)
High beam polarization 85%
High target polarization 85%
NH_3,ND_3 targets

Track resolutions:

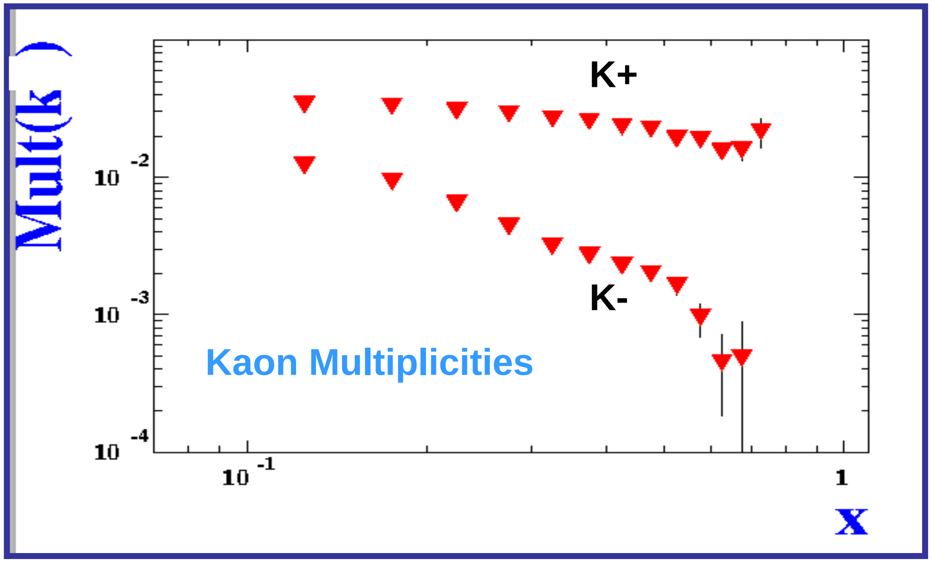
δp (GeV/c)		**$0.003p + 0.001p^2$**
δθ (mr)	<	**1**
δφ (mr)	<	**3**

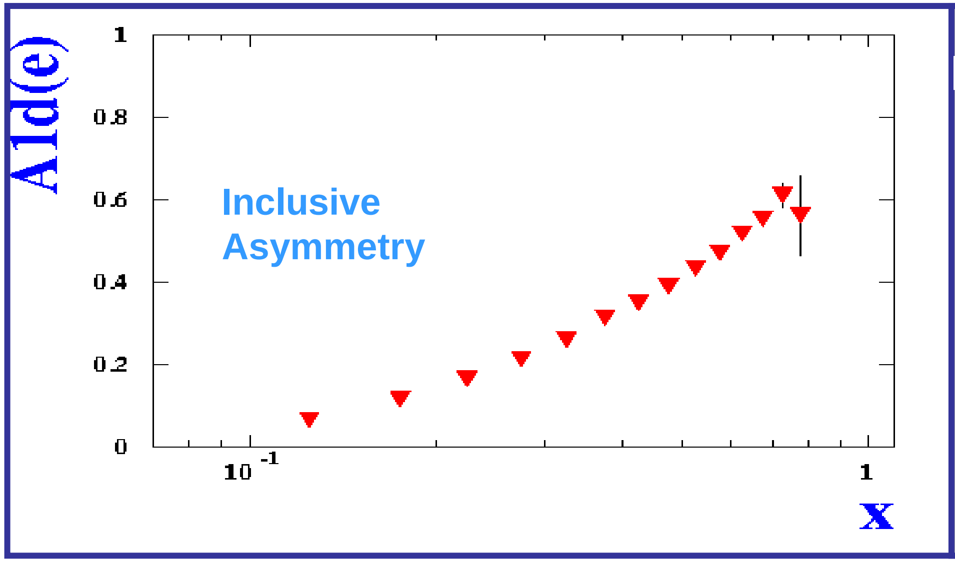
Lumi > $10^{35}cm^{-1}s^{-1}$

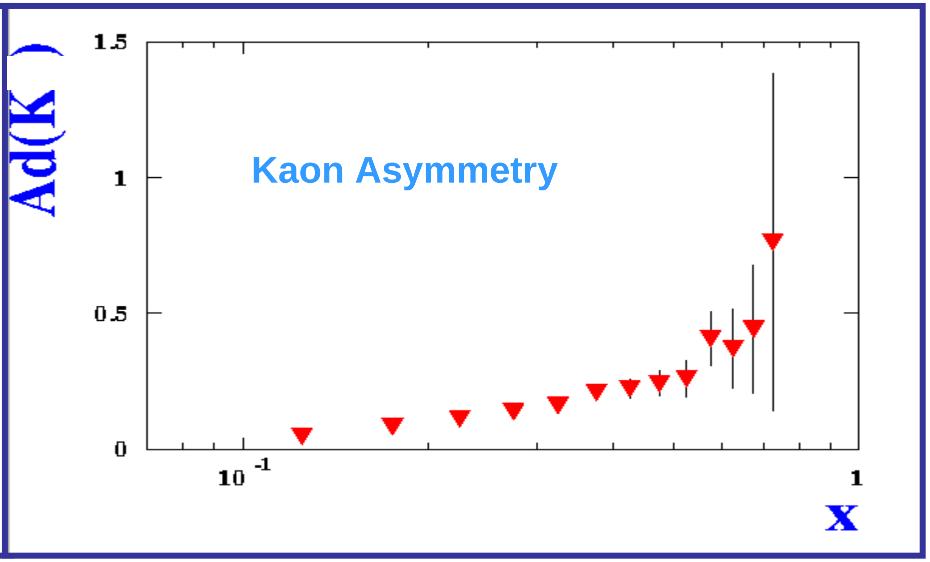
CLAS12 Kaon Distributions



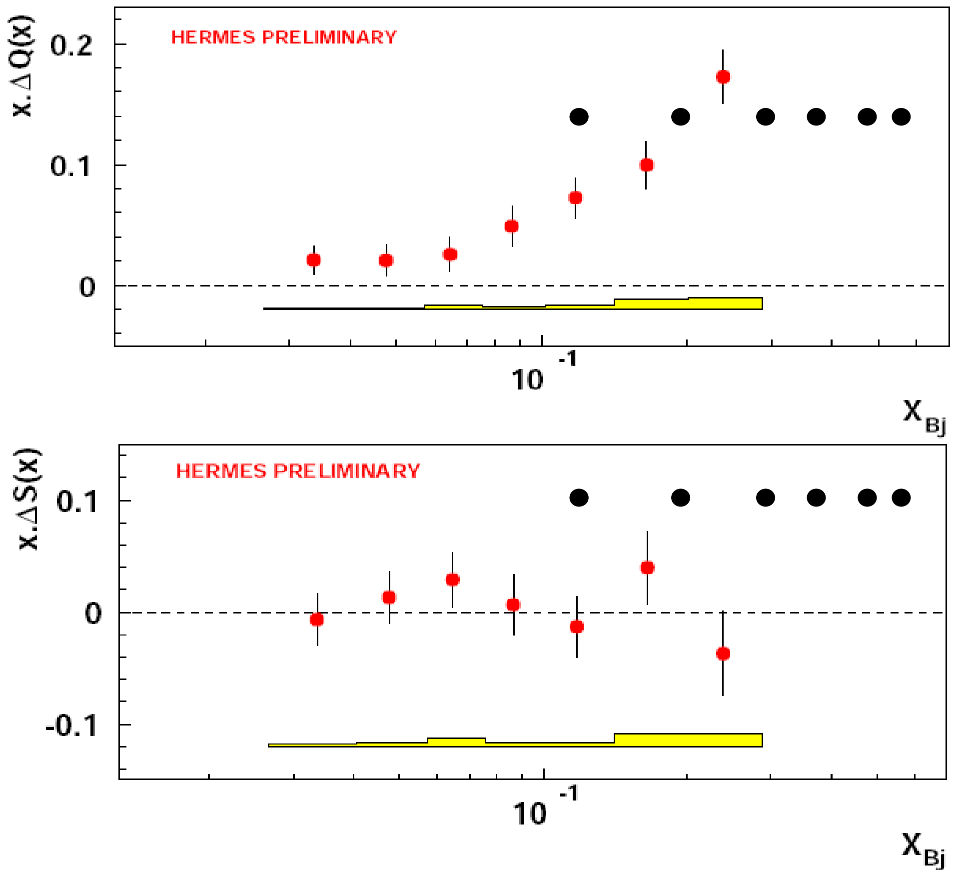
CLAS12 kaon SIDIS Simulations







CLAS12 points



- Overlap with Hermes
- What can one do with the data at x>0.1?

-Does it worth it to go ahead with a proposal? ☺

Support slides….

Beam time???

clasdisde.p1.e11.000.emn0.75tmn.12.xs57.78nb.dis92.dat

Data analyzed with 200 runs pol+, 200 runs pol-
& 450 runs unpol…> for what?

57.78nb per .dat ,
Number of events: 57780 per dat.
We have 400.dat polarized file in this simulation. --> 23.112.000 total events.

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

Neutrino-p technique

.ν-p elastic scattering (E734 BNL)

.Cross section contains a form factor G_1^s

.

.

$$G_1^s(Q^2 -> 0) = \Delta s$$

$$\Delta s = -0.15 \pm 0.09$$

Parity Violation and DeltaS

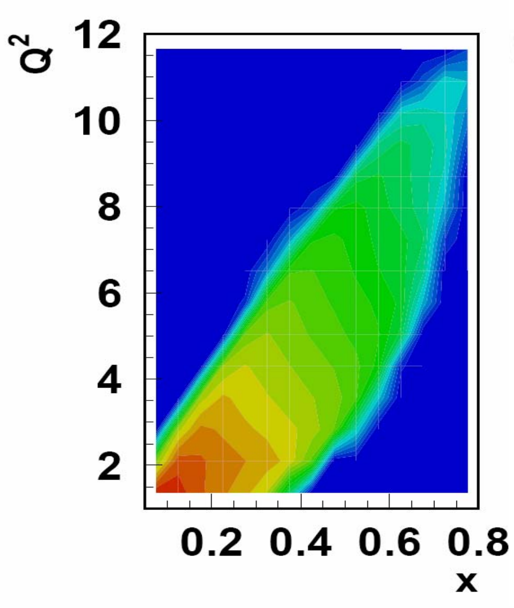
- Neutral weak probes have sensitivity to Ds

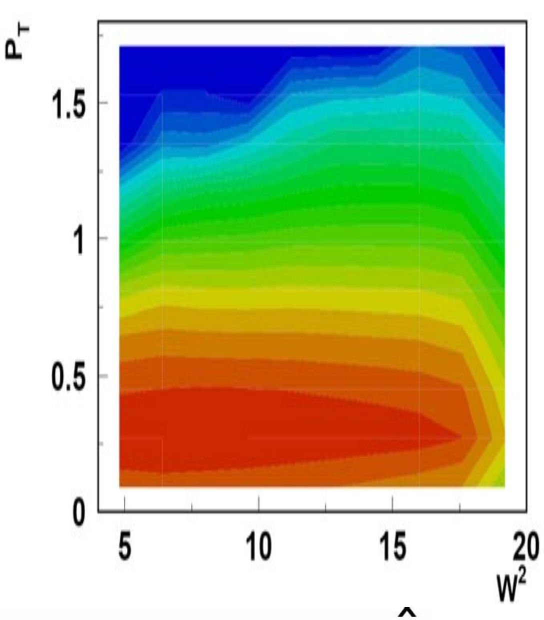
Ds contributes to parity violation electron scattering, however its sensitivity is suppressed due to the smallness of electron weak charge (at least at forward angles)

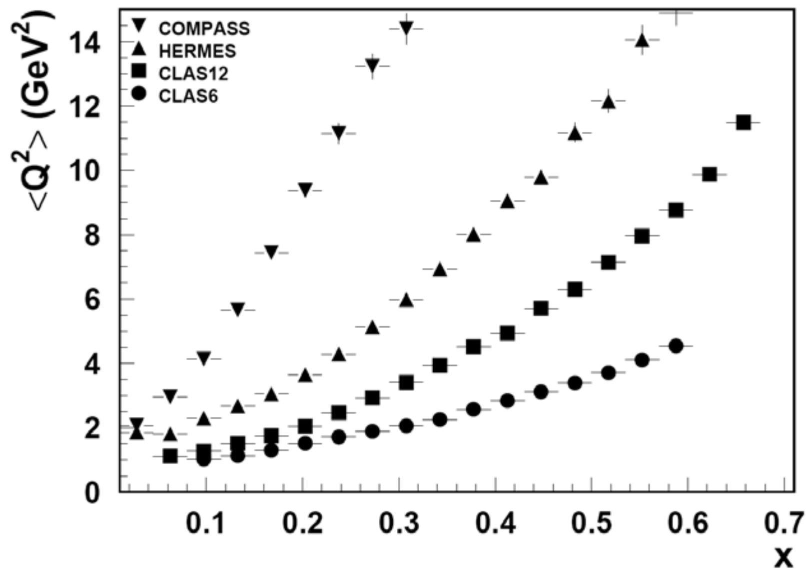
. The contribution of Ds is not suppressed in elastic neutrino-nucleon scattering. It can be determined by fitting the cross section with nucleon EM form factors inputs. → small and negative! Strange axial form factor behaves as

GAe at Q2->0

CLAS12: Kinematical coverage







SIDIS kinematics

$Q^2>1GeV^2$
$W^2>4\ GeV^2(10)$
$y<0.85$
$M_X>2GeV$

$x=0.3 \rightarrow Q^2=\sim 2\ GeV^2$ (CLAS),
$\sim 5\ GeV^2$ (HERMES)
$\sim 15\ GeV^2$ (COMPASS)

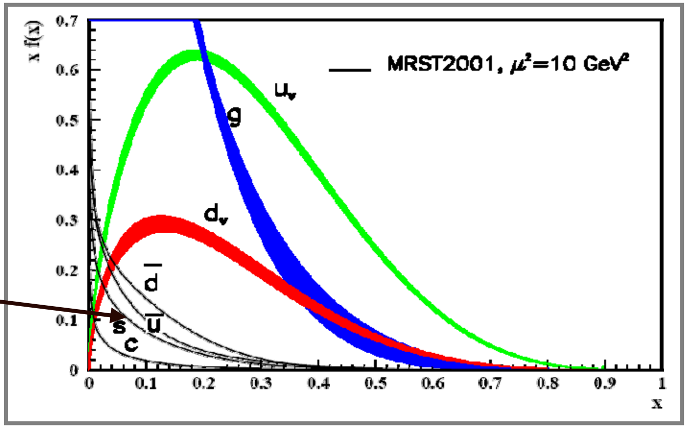
Large Q^2 accessible with CLAS12 are important for separation of HT contributions…need to change this.

- **DIS kinematics, $Q^2>1\ GeV^2$, $W^2>4\ GeV^2$, $y<0.85$**
- **$0.4>z>0.7$, $M_X^2>2\ GeV^2$**

Strangeness Contribution to the Nucleon Longitudinal Momentum

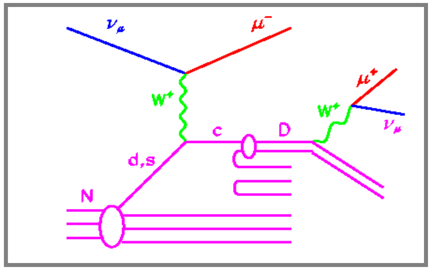
-Study the spectral functions q(x), $= \frac{}{\nu}$

-From unpolarized deep inelastic ν_μ-Nucleon scattering Experiments (NuTeV)



Momentum "fraction"

2 muon from charm quark production:



$$\nu_\mu + s \rightarrow c + X + \mu^-$$
$$c \rightarrow \mu^+ + \nu_\mu$$

. For x <0.1 $\int_0^1 x\,(s(x) + \bar{s}(x))\,dx \;\sim\; 4\%$ → Difficult to connect with ordinary observable

Strangeness Contribution to the Nucleon Mass

Mass of the Nucleon: $M_N = \langle N | H_{QCD} | N \rangle$

Quark mass term $H_{QCD} = \sum_i m_i \overline{q}_i q_i$

Chiral limit: $M_N = M_0 \neq 0$ -> gluon and $q\overline{q}$ condensate.

Turn on the quark masses: $M_N = M_0 + \hat{\sigma} + \sigma_s + heavy\ quark\ term$

$\hat{\sigma}$ and σ_s : scaler FF. = *f(Q²)*

$\hat{\sigma} = \hat{m} \langle N | \overline{u}u + \overline{d}d | N \rangle, \sigma_s = m_s \langle N | \overline{s}s | N \rangle$ $\hat{m} = \frac{1}{2}(m_u + m_d)$

-First constraint:

Hyperon mass splitting due the SU(3) flavor symmetry breaking effect.

$$\frac{1}{3}(1-\frac{m_s}{m})(1-y)\hat{\sigma} = M_\Lambda - M_\Xi$$

$$y = \frac{2\langle N|\bar{s}s|N\rangle}{\langle N|\bar{u}u+\bar{d}d|N\rangle}$$

strange content of the nucleon

- canonical ratio: $\mathrm{m_s/m} \approx 26$
- assume y =0
- Higher order chiral corrections

$$\hat{\sigma} = 35\ \mathrm{MeV}$$

-Second constraint:

$\pi - N$ sigma term

$$\Sigma_{\pi N} = F_\pi^2 \overline{D}^+(s = M_N^2, t = 2m_\pi^2)$$

Which is related to the isospin even $\pi - N$ scattering amplitude .

s= invariant mass of the $\pi - N$ system

t= four-momentum transfer

Lowest order PQCD low energy theorem states:

$$\Sigma_{\pi N} \approx \hat{\sigma}(t = 2m_\pi^2)$$

$(t=0)$ Extrapolation

$$\hat{\sigma} = 45\ MeV$$

Strangeness Contribution to the Nucleon Mass

Hyp -> $\hat{\sigma} = 35\ MeV$

π-N -> $\hat{\sigma} = 45\ MeV$

$y = 2\%$

$= \langle \quad | \bar{} \quad | \quad \rangle \quad 130 MeV$

Sea quark contribute to a sizable amount to the nucleon mass!

However: uncertainty quiet large due to many theoretical or experimental factors.

. Other lattice calculation lead to: $\sigma \sim 53\ MeV$ and $y = 0.36$

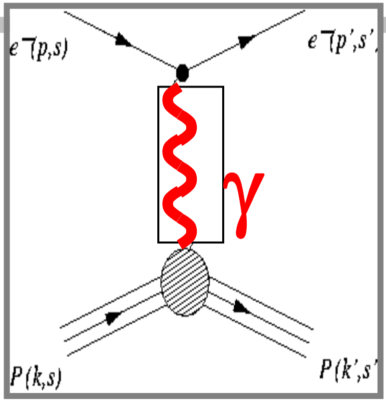
. Experimental input suggests sigma ~90+-8 MeV

. Analysis based on dispersion sum rules: sigma ~ 70+-9 MeV.

Etc..

Conclusion Mass : 0 to 30 % with big uncertainties...

Strange Electromagnetic Form Factors



Define vector (EM) form factors:

$$\langle N | J^{\mu}_{EM} | N \rangle \Rightarrow G^{\gamma}_{E,M}$$

Distribution of nucleon's charge and magnetization.

$$G^{\gamma}_{E,M} = \frac{2}{3} G^{u}_{E,M} - \frac{1}{3} G^{d}_{E,M} - \frac{1}{3} G^{s}_{E,M}$$

$$J^{\mu}_{EM} = \sum e_q \bar{q} \gamma^{\mu} q$$

- . Charge symmetry

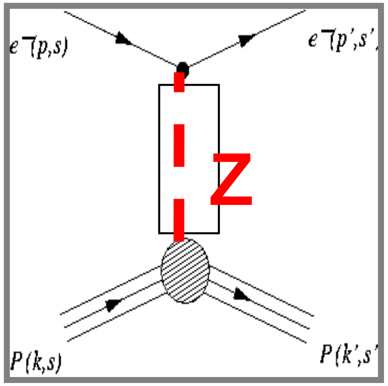
$$G^{u,p} = G^{d,n}; G^{d,p} = G^{u,n}; G^{s,p} = G^{s,n}$$

$$G^{\gamma,p}_{E,M} = \frac{2}{3} G^{u}_{E,M} - \frac{1}{3} G^{d}_{E,M} - \frac{1}{3} G^{s}_{E,M}$$

$$G^{\gamma,n}_{E,M} = \frac{2}{3} G^{d}_{E,M} - \frac{1}{3} G^{u}_{E,M} - \frac{1}{3} G^{s}_{E,M}$$

Need one more constraint …

Neutralweak Form Factors — Additional Constraint



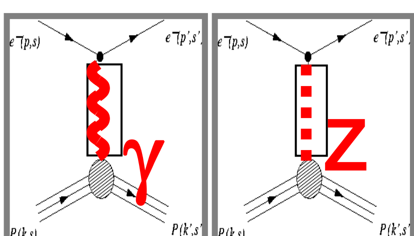
$$\langle N | J^{\mu,V}_{NC} | N \rangle \Rightarrow G^{Z}_{E,M}$$

Flavor decomposition of proton neutral weak form factor:

$$G^{Z,p}_{E,M} = \left(1 - \frac{8}{3}\sin^2\theta_W\right) G^{u}_{E,M} + \left(-1 + \frac{4}{3}\sin^2\theta_W\right) G^{d}_{E,M} + \left(-1 + \frac{4}{3}\sin^2\theta_W\right) G^{s}_{E,M}$$

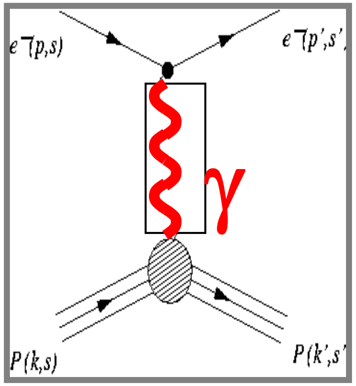
Quark weak charges in the unified electroweak theory in SM

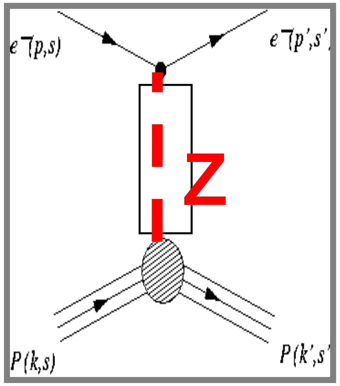
$\sin^2\theta_W = 0.2312 \pm 0.00015$



$$G^{s}_{E,M} = \left(1 - 4\sin^2\theta_W\right) G^{\gamma,p}_{E,M} - G^{\gamma,n}_{E,M} - G^{Z,p}_{E,M}$$

Parity Violation Asymmetry





Interference: $\sigma \sim |M^{EM}|^2 + |M^{NC}|^2 + 2Re(M^{EM*})M^{NC}$, $\frac{M_\gamma}{M_Z} \approx 10^5$

- Scatter polarized electrons off unpolarized target
- Tiny ($\sim 10^{-6}$) cross section asymmetry isolates weak interaction

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} \sim \frac{|M^{NC}_{PV}|}{|M^{EM}|} \sim \frac{Q^2}{(M_Z)^2}$$

$$A_{PV} = \left[\frac{-G_F Q^2}{4\pi\pi\sqrt{2}}\right] \frac{A_E + A_M + A_A}{\sigma_p}$$

Electric Magnetic Axial