Charge Symmetry Violation in Quark Distributions

CS violating distributions:

$$\delta u(x,Q^2) = u^p(x,Q^2) - d^n(x,Q^2)$$
$$\delta d(x,Q^2) = d^p(x,Q^2) - u^n(x,Q^2)$$

Charge Symmetry

$$\delta u(x,Q^2) = \delta u_V(x,Q^2) + \delta\bar{u}(x,Q^2) \xrightarrow{CS} 0$$
$$\delta d(x,Q^2) = \delta d_V(x,Q^2) + \delta\bar{d}(x,Q^2) \xrightarrow{CS} 0$$

CS in parton distributions almost universally assumed for the past 40 years!

Sometimes it is assumed without mention.

CS at low energies

CS respected down to $\sim 1\%$ after EM corrections

CS in quark distributions

CSV expected to be $\sim (m_d - m_u)/\langle M\rangle$
with $\langle M\rangle$ = 0.5 - 1 GeV $\rightarrow$ CSV effect of 1%

- CSV measurements important step in studying the inner structure of the nucleon
- Validity of CS is necessary condition for many relations between structure functions
- Flavor symmetry violation extraction $\bar{u}(x) \neq \bar{d}(x)$ relies on the implicit assumption of CS (sea quarks)
- Important to know CSV for parton distribution extractions/models: PDFs, TMDs, GPDs, GTMDs, etc.
- CSV is a viable explanation for the anomalous $\sin^2\theta_W$ extracted by NuTeV

Experiment limits and calculations

From F_2^ν and F_2^γ on iso-scalar targets (NMC, CCFR, FNAL) $0.1 \leq x \leq 0.4 \rightarrow$ 9% upper limit for CSV!

Bag Model calculations $\sim$ 1 - 10 %

Sather (PLB274 1992), Rodionov *et.al.* (Mod PLA9 1994)

PDF fit with CSV ($\delta u_v = -\delta d_v = \kappa f_v$) gives large uncertainty: $-0.65 < \kappa < 0.8$

MRST (EPJ35 2004)

Lattice improved result: κ_u=0.26(8), κ_d=0.19(4)

Londergan and Thomas PRD83 (2011), Wang *et.al.* PLB753 (2016)

Formalism

Londergan, Pang, and Thomas PRD54 (1996) 3154

$$R^D_{\text{Meas}}(x,z) = \frac{4N^{D\pi^-}(x,z) - N^{D\pi^+}(x,z)}{N^{D\pi^+}(x,z) - N^{D\pi^-}(x,z)}$$

Factorization

$$N^{Nh}(x,z) = \sum_q e_q^2 q^N(x) D_q^h(z)$$

Impulse Approximation

$$N^{Dh}(x,z) = N^{ph}(x,z) + N^{nh}(x,z)$$

$$D(z)\, R(x,z) + A(x)\mathbf{C(x)} = B(x,z)$$

$$D(z) = \frac{1-\Delta(z)}{1+\Delta(z)}$$

$$\Delta(x) = D_u^{\pi^-}/D_u^{\pi^+}$$

$$R(x,z) = \frac{5}{2} + R^D_{\text{Meas}}$$

$$A(x) = \frac{-4}{3(u_v(x)+d_v(x))}$$

$$\mathbf{C(x) = \delta d(x) - \delta u(x)}$$

$$B(x,z) = \frac{5}{2} + \frac{5\left[\bar{u}(x)+\bar{d}(x)\right]}{u_v(x)+d_v(x)} + \frac{\Delta_s(z)\left[s(x)+\bar{s}(x)\right]/\left[1+\Delta(x)\right]}{u_v(x)+d_v(x)}$$

$$\Delta_s(z) = \frac{D_s^{\pi^+}(z)+D_s^{\pi^-}(z)}{D_u^{\pi^+}(z)}$$

$A(x)$ and $B(x,z)$ are known.

Extract simultaneously D(z) and C(x) in each Q^2 bin!

Important Test of Factorization: z-independent ratios are only function of x

$$\frac{\sigma_p(\pi^+)+\sigma_p(\pi^-)}{\sigma_d(\pi^+)+\sigma_d(\pi^-)} = \frac{4u+4\bar{u}+d+\bar{d}}{5(u+\bar{u}+d+\bar{d})}$$

$$\frac{\sigma_p(\pi^+)-\sigma_p(\pi^-)}{\sigma_d(\pi^+)-\sigma_d(\pi^-)} = \frac{4u_v-d_v}{3(u_v+d_v)}$$

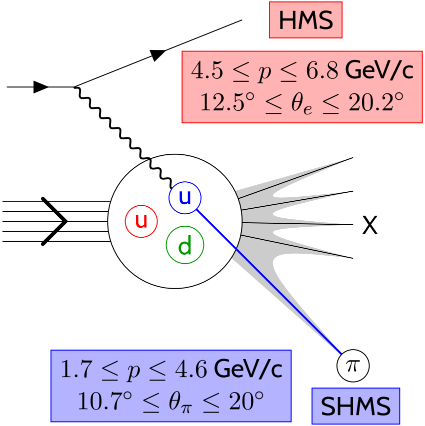
E12-09-002: Precise Measurement of SIDIS $\frac{\pi^-}{\pi^+}$ Ratio

Is there CSV in the valence quark distributions?

Setup

- 11 GeV e^- beam
- 10 cm LD_2 target
- I_{beam} = 50 (25) μA
- SHMS $\rightarrow \pi^-$ (π^+)
- HMS $\rightarrow e'$

Q^2 = 3.5 GeV^2 $\rightarrow$ x = 0.30, 0.35, 0.40, 0.45
Q^2 = 5.1 GeV^2 $\rightarrow$ x = 0.45, 0.50, 0.55, 0.60
Q^2 = 6.2 GeV^2 $\rightarrow$ x = 0.50, 0.55, 0.60, 0.65
Each x setting has 4 z measurements:
z = 0.4, 0.5, 0.6, 0.7



$$R_Y(x,z) = Y^{D\pi^-}(x,z)/Y^{D\pi}(x,z)$$

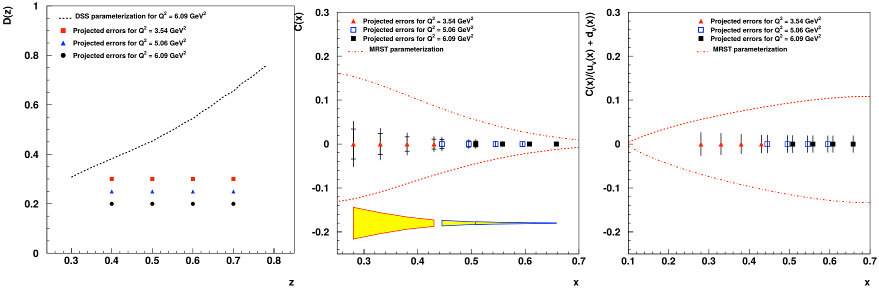
$$R^D_{\text{Meas}}(x,z) = \frac{4R_Y(x,z) - 1}{1 - R_Y(x,z)}$$

For each Q^2 we have 16 equations and 8 unknowns: $D(z_i)$ and $C(x_i)$

$$D(z)\,R(x,z) + A(x)C(x) = B(x,z)$$

Projected Experimental Results

- Will provide most basic SIDIS cross sections
- Provide Important information about factorization.
- A straightforward SIDIS experiment in Hall C: don't have to go to 5 degrees.



$$D(z)\, R(x,z) + A(x) C(x) = B(x,z)$$

E12-09-002 Collaboration

Spokespersons: D. Dutta, D. Gaskell, and K. Hafidi†

- D. Gaskell helped implement SIDIS in SIMC
- K. Hafidi has experience from CLAS and HERMES
- Argonne has a long history with Hall C and committed to the 12 GeV physics program.

J. Arrington, R. Dupré, D. Geesaman, K. Hafidi (spokesperson[1]), R. J. Holt, D. H. Potterveld,
P. E. Reimer, P. Solvignon
Argonne National Laboratory, Argonne, IL

W. Chen, H. Gao, X. Qian, Y. Qiang, Q. Ye
Duke University, Durham, NC

P. Markowitz
Florida International University, Miami, FL

C. .E. Keppel
Hampton University, Hampton, VA

G. Niculescu, I. Niculescu
James Madison University, Harrisonburg, VA

P. Bosted, R. Ent, H. Fenker, D. Gaskell (spokesperson), D. Mack, G. Smith
Jefferson Lab, Newport News, VA

J. Dunne, D. Dutta (spokesperson), E. Leggett, A. Narayan, L. Ndukum, Nuruzzaman, A. Subedi
Mississippi State University, Mississippi State, MS

A. Daniel
Ohio University, Athens, OH

E. Beise
University of Maryland, College Park, MD

G. Huber
University of Regina, Regina, SK, Canada

H. Baghdasaryan, D. Day, N. Kalantarians
University of Virginia, Charlottesville, VA

F. .R. Wesselman
Xavier University of Louisiana, New Orleans, LA

Manpower and Analysis Readiness

Grad Students

- Frank Cao - U. Conn. / Argonne
- Hem Bhatt - MSU

Postdocs

- Whitney Armstrong - Argonne
- Mohammad Hattawy - Argonne
- Dedicated 1/2 postdoc (MSU) who will work on commissioning SHMS and help run experiment

- Simulation tools are ready (`SIMC`)
- Tested in the 6 GeV Meson Duality SIDIS experiment