Precise Measurement of $\frac{pi^+}{pi^-}$ Ratios in SIDIS

Charge Symmetry Violation in valence quark distribution extraction

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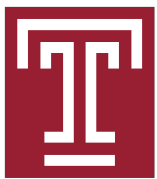


Motivation

Charge symmetry Violation

Charge symmetry (CS) is one special kind of isospin symmetry.

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

$$\delta u(x) = u^p(x) - d^n(x).$$

Londergan, Pang and Thomas PRD54(1996)3154

$$R^D_{meas}(x,z) = \frac{4N^{D\pi^-}(x,z) - N^{D\pi^+}(x,z)}{N^{D\pi^+}(x,z) - N^{D\pi^-}(x,z)} = \frac{4R_Y(x,z) - 1}{1 - R_Y(x,z)} \tag{1}$$

where $N^{D\pi^\pm}(x,z)$ is the yield of $\pi^\pm$ electroproduction on a deuterium target and the CSV of quark distributions can be extracted

Factorization

$$N^{Nh} = \sum_i e_i^2 q_i^N(x) D_i^h(z)$$

Impulse Approximation

$$N^{D\pi^\pm}(x,z) = N^{p\pi^\pm}(x,z) + N^{n\pi^\pm}(x,z)$$

Formalism

Londergan, Pang and Thomas PRD54(1996)3154

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

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

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

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

$$CSV(x) = (\delta d - \delta u)$$

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

$$B(x,z) = \frac{5}{2} + R^D_{sea\_S}(x,z) + R^D_{sea\_NS}(x), known$$

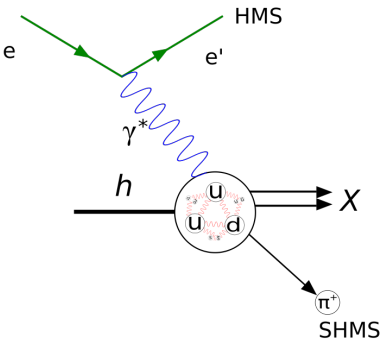
Extract simultaneously D(z) and CSV(x) from each (Q^2,x) setting

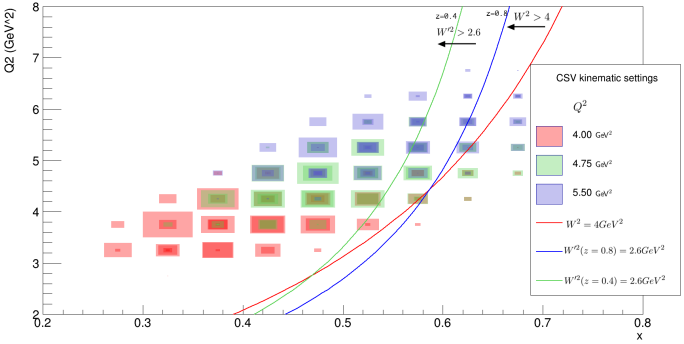
Factorization test from H_2 runs

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

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

Experiment Overview



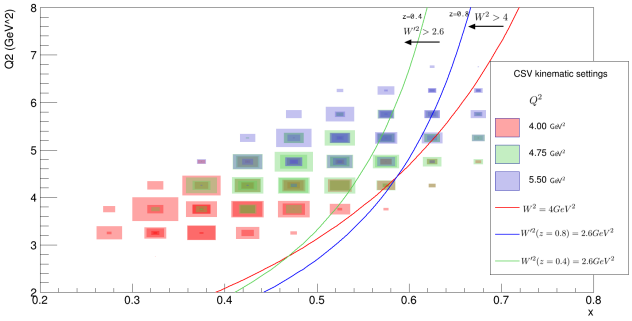


Semi-Inclusive Deep Inelastic Scattering (SIDIS)in Hall C
Electron: HMS,pion: SHMS
Fall 2018 and Spring 2019

- 10.6 GeV beam, LD_2(10 cm), LH_2(10 cm), Al-dummy
- HMS angle 13°-21°, 4.4-6.4 GeV, electrons
- SHMS angle 11°-21°, 1.7-4.5 GeV, $\pi+/\pi-$

Data Analysis

Kinematic Cut



4 z measurements (0.4,0.5,0.6,0.7) for each x, Q^2 setting.

$$Q^2 = 4.0GeV^2, x = 0.35, 0.4, 0.45, 0.5$$

$$Q^2 = 4.75GeV^2, x = 0.45, 0.5, 0.55, 0.6$$

$$Q^2 = 5.5GeV^2, x = 0.5, 0.55, 0.6, 0.65$$

DIS cut: Invariant mass squared $W^2 = (P + k - k')^2 = M^2 + \frac{1-x}{x}Q^2$

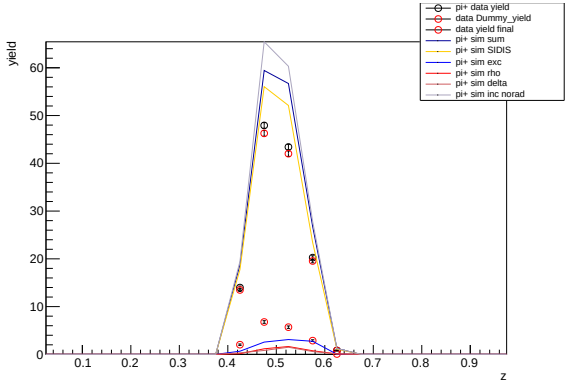
SIDIS cut: Mass of the unobserved final state squared

$$W'^2 = (P + k - k' - P_h)^2 = M^2 + Q^2\frac{1-x}{x} + M_h^2 - 2 \cdot (z + 1)\frac{Q^2}{2 \cdot Mx}$$

DIS: $W^2\ GeV^2$ and SIDIS: $W'^2 > 2.8\ GeV^2$

Data Analysis

$\langle x \rangle = 0.5, \langle Q^2 \rangle = 5GeV^2, \langle z \rangle = 0.5$



Data yield

$$Y^D_{corr} = \frac{N_{\text{pions}}}{Q\,\varepsilon_{\text{t}}\,\varepsilon_{\text{LT}}\,\varepsilon_{\text{PID}}}$$

Radiative correction: $\text{RC} = \frac{Y_{SIMC,noradia}}{Y_{SIMS,radia}}$

Backgrounds from SIMC:

Y_{exc}: Exclusive radiative backgrounds $D(e,e'\pi^{\pm})n(p)\gamma$

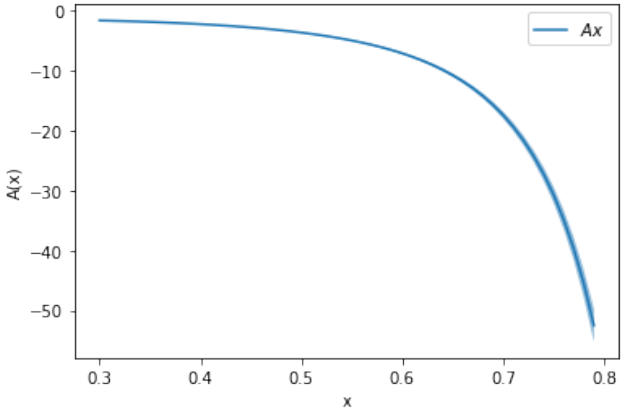
Y_{delta}: Delta radiative backgrounds $D(e,e'p)\pi$

Y_{ρ}: Diffractive ρ $D(e,e'\rho \rightarrow \pi^+\pi^-)$

$$Y_D(x,z) = \text{RC}(Y^D_{\text{corr}} - 0.245Y_{\text{Dummy}} - Y_{\text{exc}} - Y_{\text{delta}})$$

Model dependence

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

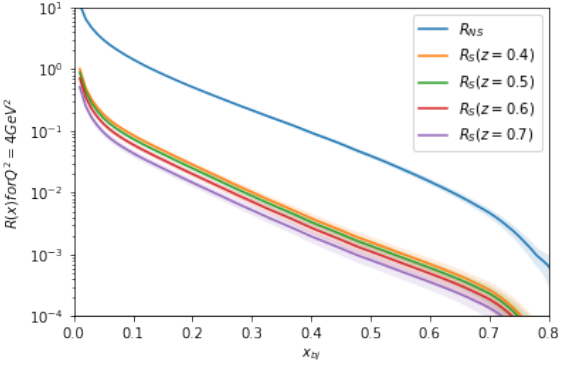


$$A(x) = \frac{-4}{3(u_v + d_v)}$$

A(x) is calculated from Parton Distribution Function. Plot is calculated from JAM20 PDF.

Model dependence

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



cteq6 PDF and JAM20 FF

$$B(x,z) = \frac{5}{2} + R^D_{sea\_S}(x,z) + R^D_{sea\_NS}(x)$$

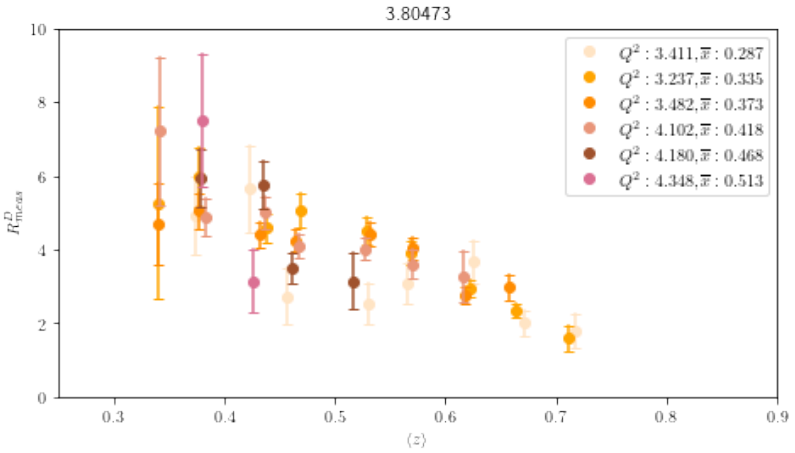
$$R^D_{sea_{NS}} = \frac{5(\overline{u}^p(x) + \overline{d}^p(x)}{[u^p_v(x) + d^p_v(x)]}$$

$$R^D_{sea_S} = \frac{\Delta_s(z)[s(x) + \overline{s}(x)]/(1 + \Delta(z))}{[u^p_v(x) + d^p_v(x)]}$$

$$\Delta_s(z) = \frac{D^-_s(z) + D^+_s(z)}{D^+_u(z)}$$

R^D_{meas} from data

$$D(z)\ R(x,z) + A(x)CSV(x) = B(x,z), R(x,z) = \frac{5}{2} + R^D_{meas}(x,z)$$



$R^D_{meas}(x,z)$ for $\langle Q^2 \rangle = 4GeV^2$ projected on z axis.
All variables are bin center corrected.
For each of (Q^2,x,z), weighted average are taken for the overlap of the different group of runs

Fragmentation ratio and CSV extraction

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

$$\Delta(z) \equiv \frac{D_u^{\pi^-}(z)}{D_u^{\pi^+}(z)} = z^\alpha (1-z)^\beta$$

$$CSVx \equiv \delta d - \delta u = x^a (1-x)^b (x-c)$$

constrain: $\int_0^1 CSV(x)dx = 0$

$$c = \frac{\int_0^1 x^{(a+1)}(1-x)^b}{\int_0^1 x^a (1-x)^b} = \frac{B(a+2,b+1)}{B(a+1,b+1)}, B(x,y) = \frac{\Gamma(x)\Gamma(y)}{\Gamma(x+y)}$$

$$R_{fit}^D(x,z) = \frac{B(x,z) - A(x)CSV(x)}{D(z)} - \frac{5}{2}$$

Diffractive ρ background subtraction

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

Assumption:

- 1,The ρ decay into pions are charge symmetric: $N^{\rho}_{\pi^-} = N^{\rho}_{\pi^+}$
- 2.The ρ subtraction for π^+ runs and π^- runs are same

$$Y^{D\pi^-}_{corr} = Y^{D\pi^-} + \gamma Y^{\rho}_{\pi^-}$$

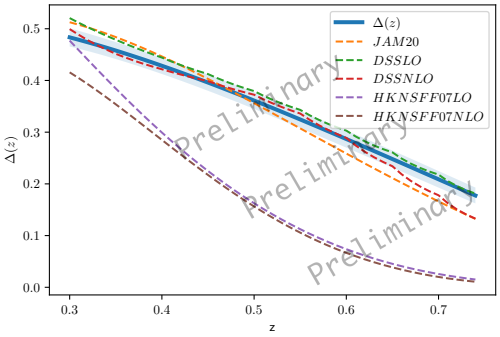
,

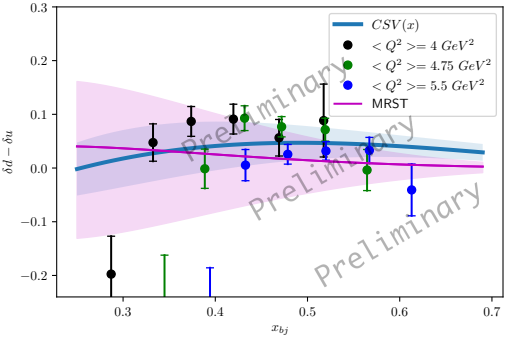
$$Y^{D\pi^+}_{corr} = Y^{D\pi^+} + \gamma Y^{\rho}_{\pi^-}$$

$$\delta R^D_{\rho} = \delta R^D_{\rho}(\gamma, Y^{\rho}_{\pi^-}, Y^{D\pi^+}, Y^{D\pi^-})$$

For standard ρ subtraction, γ is -1

Results after standard ρ background subtraction





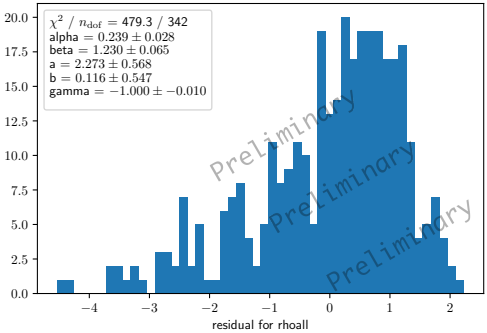
$$\Delta(z) \equiv D_u^{\pi^-}(z)/D_u^{\pi^+}(z) = z^\alpha(1-z)^\beta \qquad CSVx \equiv \delta d - \delta u = x^a(1-x)^b(x-c)$$

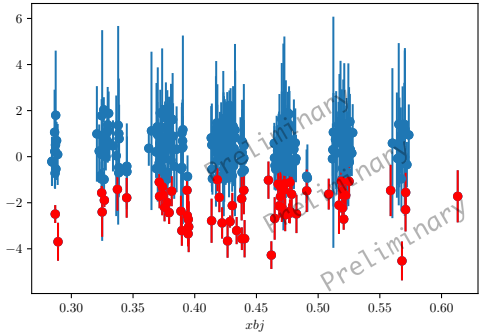
$$D(z)\ R(x,z) + A(x)CSV(x) = B(x,z)$$

From the fitting result $\Delta(z)$, CSV can be calculated for each kinematic point. Weighted average are taken for overlap

Results

Residual for standard ρ background subtraction



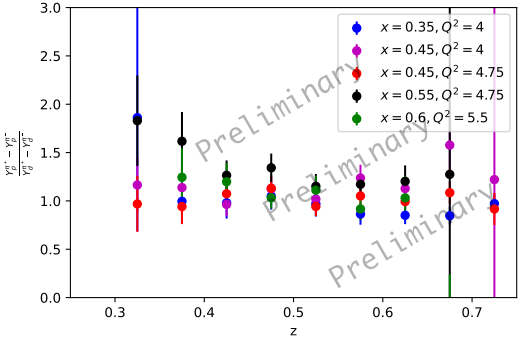


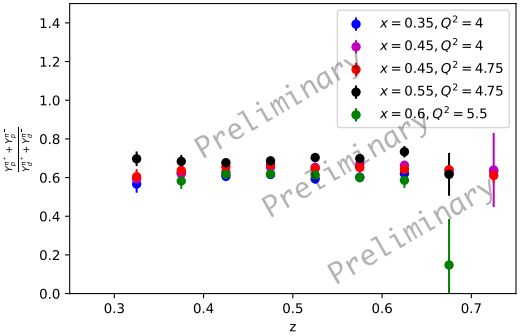
H_2 runs results

H_2 runs are taken for some kinematic to test the assumption of factorization.

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

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





Future work

- Improve and update ρ background subtraction
- Systematic Uncertainty
- Finalize the analysis cuts and data set, cross check with Hem's ratio
- Fit with more data from PtSIDIS experiment

Acknowledgement

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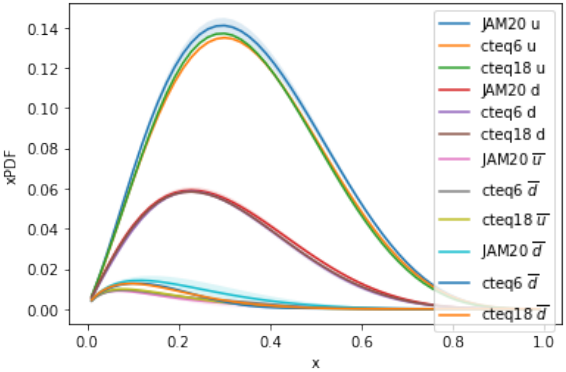
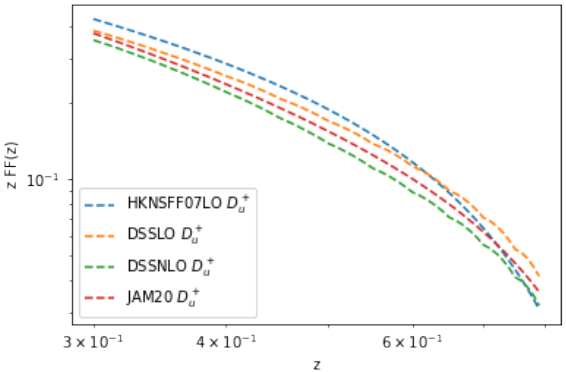
Thank you!

Backups

Model dependence

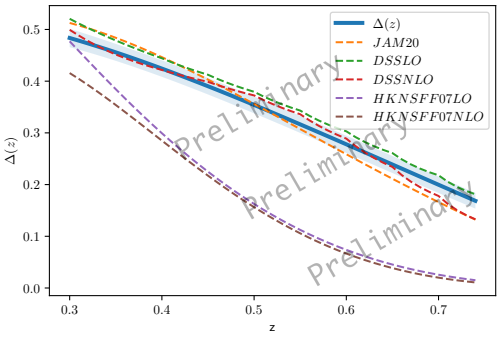


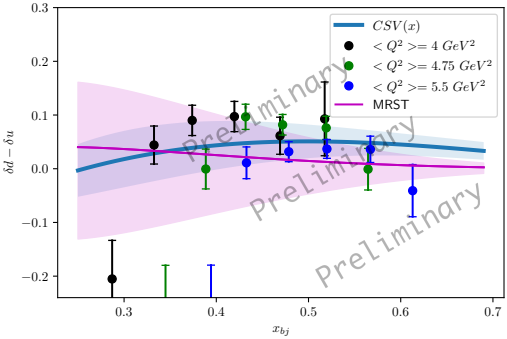
Parton Distribution Functions



Fragmentation Functions

Results after different diffractive ρ subtraction





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$$\delta R_\rho^D = \delta R_\rho^D(\gamma, N^{neg\text{-}\rho}, N^{\pi^+}, N^{\pi^-})$$

γ ranges 20%. Doesn't change too much