Charge Symmetry Violation in valence quark distribution extraction

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

Shuo Jia
shuojia@temple.edu

Temple University & Argonne National Lab

June 15, 2022

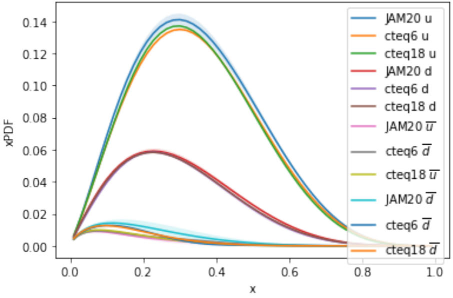
Motivation

Charge symmetry Violation

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

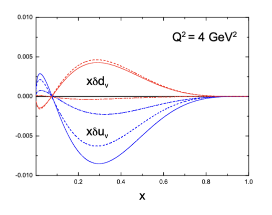
$$\delta d(x) = d^p(x) - u^n(x),$$

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



Lattice limits

CSV limits from lattice calculation:



arXiv:1512.04139v1

Experimental Limits

$CSV(x)$ contains $\delta d - \delta u$, where

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

Theoretical limits

Model by Sather:

$$\delta d(x) \sim 2 - 3\%, \delta u(x) \sim 1\%$$

E. Sather, Phys. Lett. B274, 433 (1992)

Model by Rodionov, Thomas and Londergan
$\delta d(x)$ could reach up to 10% at high x

E. N. Rodionov, A. W. Thomas and J. T. Londergan, Mod. Phys. Lett. A 9, 1799 (1994)

Phenomenological limits

CSV parameterization

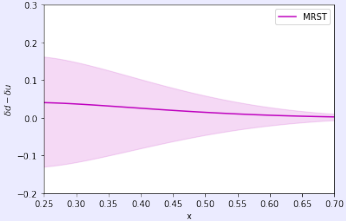
$\delta u_v = \delta d_v = k(1-x)^4 x^{0.5}(x - 0.0909)$

The form has to satisfy the normalization condition

$\int dx \delta uv(x) = \int dx \delta dv(x) = 0$

k was varied in the global fit: 90% CL

Eur. Phys. J.35(2004)325



Formalism

Semi-inclusive Deep Inelastic Scattering

Charge symmetry Violation

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

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

Londergan, Pang and Thomas PRD54(1996)3154

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

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

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 No. 1

Londergan, Pang and Thomas PRD54(1996)3154

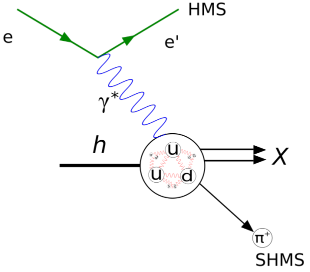
$$D(z)\ R(x,z) + A(x)CSV(x) = B(x,z)$$

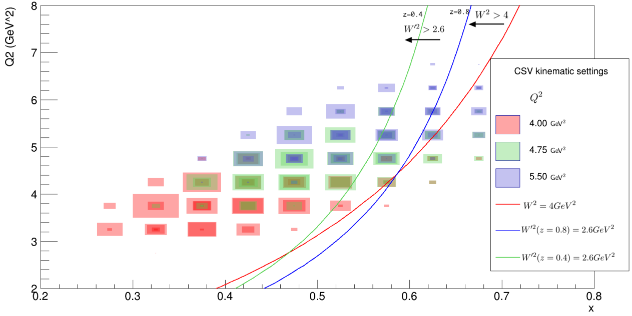
$R(x,z) = \frac{5}{2} + R^D_{meas}, A(x) = \frac{-4}{3(u_v+d_v)}, known B(x,z) = \frac{5}{2} + R^D_{sea\_S}(x,z) + R^D_{sea\_NS}(x), known$

$$D(z) = \frac{1-\Delta(z)}{1+\Delta(z)}, \Delta(z) = D_u^{\pi^-}(z)/D_u^{\pi^+}(z), CSV(x) = (\delta d - \delta u)$$

1. Calculate CSV(x) for each (Q^2,x) setting from different Fragmentation Functions
2. Extract simultaneously D(z) and CSV(x) from each (Q^2, x) setting

Experiment Overview





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

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

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

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

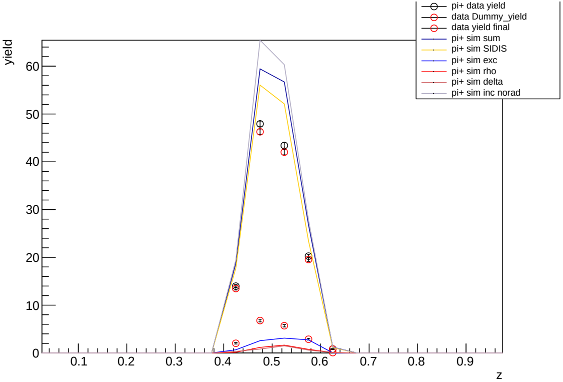
Electron: HMS,pion: SHMS
Fall 2018 and Spring 2019

- 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, $\pi+/\pi-$

$W^2 > 4GeV^2$ and $W'^2 > 2.8GeV^2$ for SIDIS region

Data Analysis

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



Data yield

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

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

Backgrounds from SIMC:

Y_{exc}: Exclusive radiative backgrounds

$D(e, e'\pi^{\pm})n(p)\gamma$

Y_{delta}: Delta radiative backgrounds

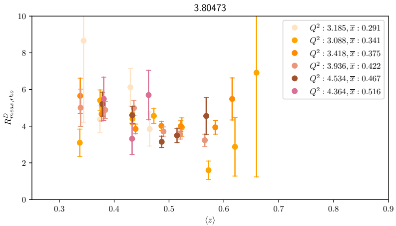
$D(e, e'p)\pi$

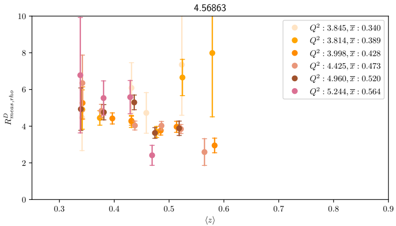
Y_{ρ}: Diffractive ρ $D(e, e'\rho \to \pi^+\pi^-)$

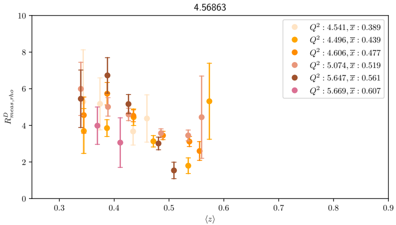
$$Y_D(x, z) = \mathrm{RC}(Y^D_{\rm corr} - 0.245 Y_{\rm Dummy} - Y_{\rm exc} - Y_{\rm delta})$$

R^D_{meas} from data

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





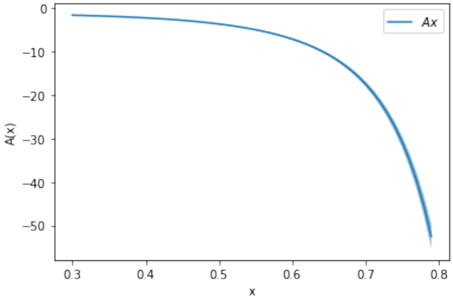


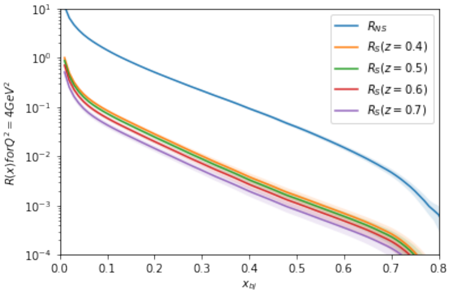
$R^D_{meas}(x,z)$ for $\langle Q^2 \rangle = 4GeV^2$ projected on z axis.
All variables are bin center corrected.
For each of (Q^2,x,z), weighted average are taken for the overlap of the different group of runs

Formalism No.1

Model Dependence

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





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

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

Calculate CSV from formula No.1

Different Fragmentation Functions

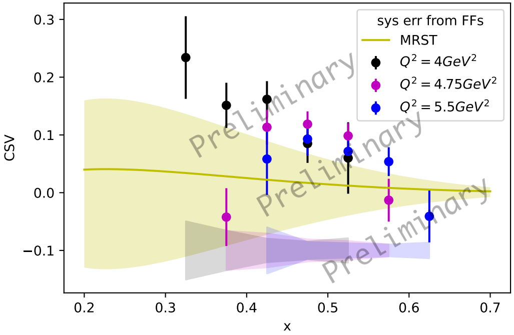
$$D(z)\ R(x,z) + A(x)CSV(x) = B(x,z)$$

$$CSV(x) = \frac{B(x,z) - D(z)\ R(x,z)}{A(x)}$$

$$D(z) = \frac{1-\Delta(z)}{1+\Delta(z)}, \Delta(z) = D_u^{\pi^-}(z)/D_u^{\pi^+}(z)$$

Fragmentation Functions:

- JAM20SIDIS
- fDSS LO
- fDSS NLO



Extract simultaneously from formula No.1

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

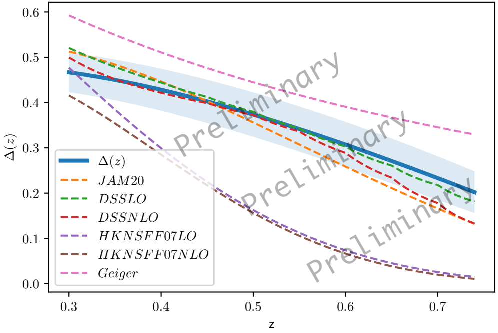
$$c = \frac{\int_0^1 x^{(a+1)}(1-x)^b}{\int_0^1 x^a(1-x)^b} = \frac{B(a+2,b+1)}{B(a+1,b+1)}, B(x,y) = \frac{\Gamma(x)\Gamma(y)}{\Gamma(x+y)}$$

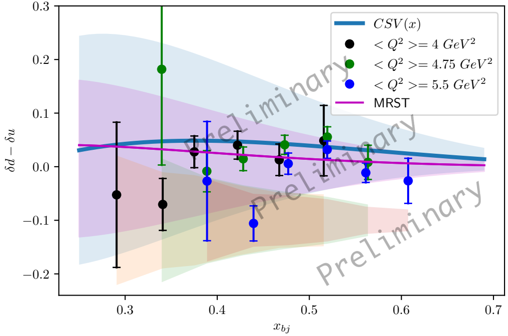
$$R^D_{fit}(x,z) = \frac{B(x,z) - A(x)CSV(x)}{D(z)} - \frac{5}{2}$$

Diffractive $\rho : Y_{corr}^{D\pi^-} = Y^{D\pi^-} + \gamma Y_{\pi^-}^{\rho}$

Extract simultaneously from formula No.1

Results after standard ρ background subtraction





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

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

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

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

New Formalism

Proposal equation

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

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

This equation used simple expansion.

New equation

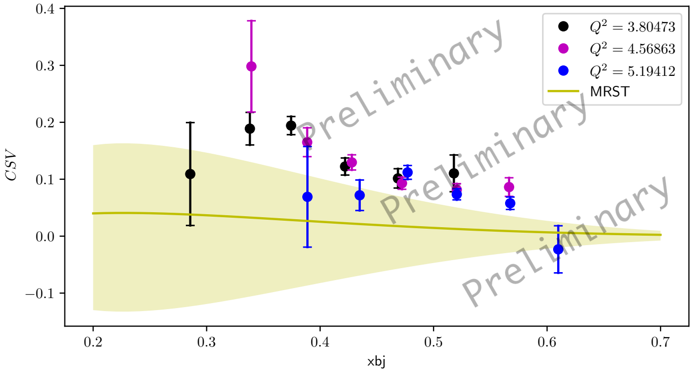
Assume $T = \frac{\overline{u}+\overline{d}}{u+d}$, $S = \frac{2(s+\overline{s})}{u+d}$ and $D_s^+ = D_s^- = D_u^-$, $\delta d = -a\delta u$,CSV $= \delta d - \delta u$

$$Y = \frac{(4+T+S)\Delta(z) + (4T+1) + (4a\Delta(z) - 1)\delta u}{(4T+1+S)\Delta(z) + (4+T) + (4a - \Delta(z))\delta u}$$

1. Calculate δu from existing FFs using the Yield ratio.
2. Fit the Yield ratio to extract simultaneously $\Delta(z)$ and δu

Calculate CSV from the new Formula

$$Y = \frac{(4+T+S)\Delta(z) + (4T+1) + (4a\Delta(z)-1)\delta u}{(4T+1+S)\Delta(z) + (4+T) + (4a-\Delta(z))\delta u}$$



Using JAM20PDF and JAM20FF

Extract simultaneously from new formula

$$Y = \frac{(4+T+S)\Delta(z) + (4T+1) + (4a\Delta(z)-1)\delta u}{(4T+1+S)\Delta(z) + (4+T) + (4a-\Delta(z))\delta u}$$

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

$$\delta u(x) = kx^a(1-x)^b(x-c)$$

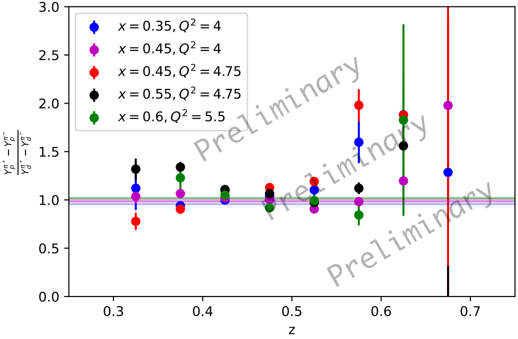
In progress...
H_2 runs are added to constrain fragmentation functions

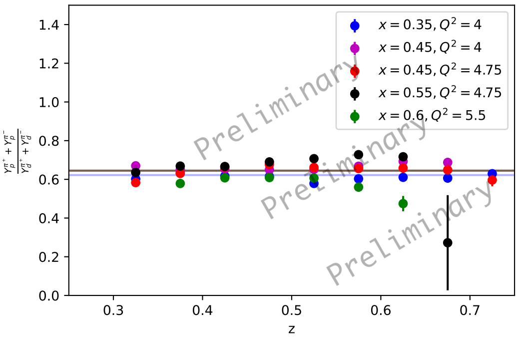
$$Y_{H_2} = \frac{(4u+\overline{d})\Delta(z) + (4\overline{u}+d) + (s+\overline{s})\Delta(z)}{(4u+\overline{d}) + (4\overline{u}+d)\Delta(z) + (s+\overline{s})\Delta(z)}$$

H_2 runs results

Factorization test from H_2 runs

$$\frac{\sigma_p^{\pi^+} - \sigma_p^{\pi^-}}{\sigma_d^{\pi^+} - \sigma_d^{\pi^-}} = \frac{4u + 4\overline{u} + d + \overline{d}}{5(u + \overline{u} + d + \overline{d})} \qquad \frac{\sigma_p^{\pi^+} + \sigma_p^{\pi^-}}{\sigma_d^{\pi^+} + \sigma_d^{\pi^-}} = \frac{4u_v - d_v}{3(u_v + d_v)}$$

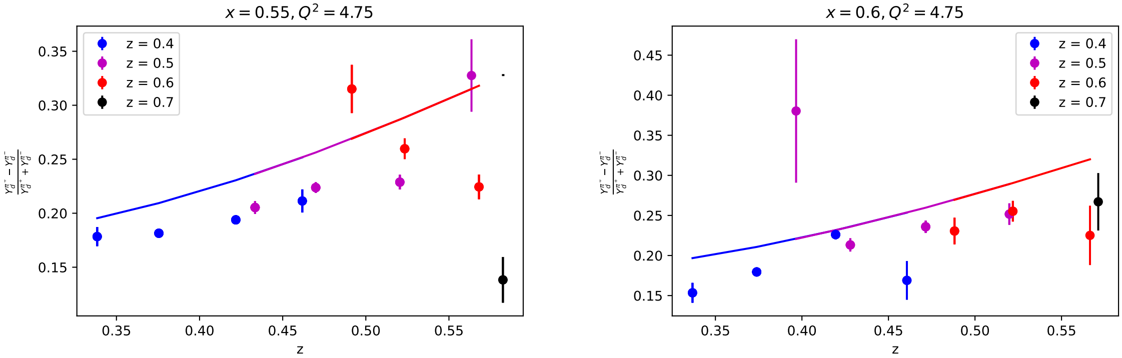




(predictions are from JAM20 PDFs)

Some other quantity by our D_2 runs

$$\frac{N_D^{\pi^+} - N_D^{\pi^-}}{N_D^{\pi^+} + N_D^{\pi^-}} = \frac{3(u_v + d_v)(D_u^+ - D_u^-)}{5(u + d + \overline{u} + \overline{d})(D_u^+ + D_u^-)}$$



(predictions are from JAM20 PDFs and FFs)

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

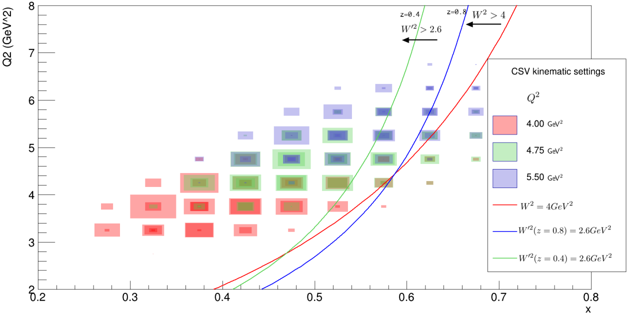
Acknowledgement

I would like to acknowledge my advisor Dr. Zein-Eddine Meziani. And thanks to Dr. Dipangkar Dutta, Dr. Dave Gaskell, Dr. Peter Bosted and Dr. Whitney Armstrong for their help. Also I thank my collaborator Hem Bhatt.
This work is supported in part by the U.S. Department of Energy, Office of Science, Office of Nuclear Physics, under Contract No DE-FG02-94ER4084 and US DOE contract DE-AC02-06CH11357.
Thank you!

Backups

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

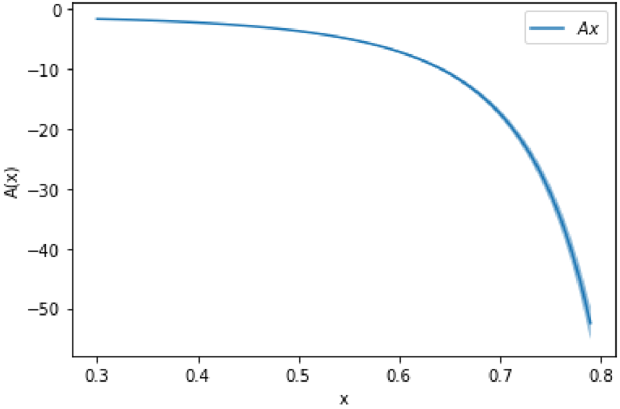
SIDIS cut: Mass of the unobserved final state squared

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

DIS: $W^2 > 4GeV^2$ and SIDIS: $W'^2 > 2.8\ GeV^2$

Model dependence for Formular No.1

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

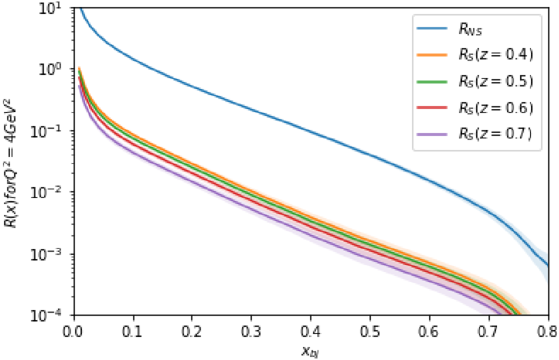


$$A(x) = \frac{-4}{3(u_v + d_v)}$$

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

Model dependence for Formular No.1

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



cteq6 PDF and JAM20 FF

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

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

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

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

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