Impact study of Kaon SIDIS at EIC on polarized strange quark distribution function

NNPDF Reweighting, Nucl.Phys.B849: https://arxiv.org/abs/1012.0836v4 [hep-ph]
NNPDF Collab.,Physics Letters B 728C: https://arxiv.org/abs/1310.0461 [hep-ph]
E. Aschenaur et.al, Phys. Rev. D. : https://arxiv.org/abs/1206.6014 [hep-ph]
E. Aschenaur et. al.Phys. Rev. D 99: https://arxiv.org/abs/1902.10663 [hep-ph]

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Advisors: Dr. Abhay Deshpande
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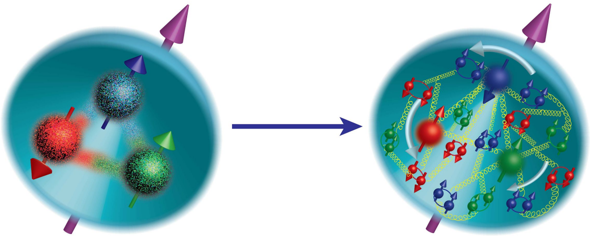
Proton spin problem



- We assume that the total spin should include contributions from the sea quarks and gluons. The fundamental proton spin sum rule is as follows.

$$\frac{1}{2} = S_q + L_q + S_g + L_g \ .$$

Here, we have

$$S_q(Q^2) = \frac{1}{2}\int_0^1 \Delta\Sigma(x,Q^2)dx \equiv \frac{1}{2}\int_0^1 \left(\Delta u + \Delta\bar{u} + \Delta d + \Delta\bar{d} + \Delta s + \Delta\bar{s}\right)(x,Q^2)dx$$

$$S_g(Q^2) = \int_0^1 \Delta g(x,Q^2)dx \ ,$$

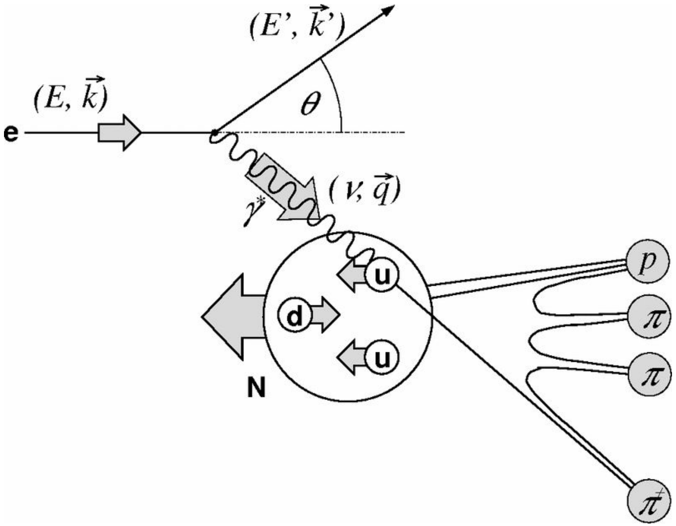
$$\Delta f(x,Q^2) \equiv f^+(x,Q^2) \ - \ f^-(x,Q^2) \ ,$$

Semi-inclusive Deep Inelastic Scattering

- Semi-inclusive DIS (SIDIS) involves measuring one or more (in the case of correlation measurements) final-state particles in addition to the detection of the scattered lepton.

- A measured hadron is typically characterised by its transverse momentum, pT, with respect to the virtual photon (not the incident beams) and its energy fraction, *z*

$$z = \frac{P_h \cdot p}{q \cdot p}$$



Kaon Asymmetry

- We define Hadron(Kaon) semi-inclusive asymmetry as follows

$$A_1^h(x, Q^2) = \frac{\sigma_{1/2}^h - \sigma_{3/2}^h}{\sigma_{1/2}^h + \sigma_{3/2}^h} \qquad A_1^h(x, Q^2) = \frac{\Sigma_q e_q^2 \Delta q(x, Q^2) D_q^h(Q^2)}{\Sigma_q e_q^2 q(x, Q^2) D_q^h(Q^2)}$$

- We can calculate the lepton-nucleon asymmetry of Kaons using the event generator (DJANGOH for this case)

$$A_{||}^h(x, Q^2) = \frac{R_L N_{\rightarrow\leftarrow}^h - N_{\rightarrow\rightarrow}^h}{R_L N_{\rightarrow\leftarrow}^h + N_{\rightarrow\rightarrow}^h} \qquad \delta A_{||}^h(x, Q^2) = \frac{1}{\sqrt{R_L N_{\rightarrow\leftarrow}^h + N_{\rightarrow\rightarrow}^h}}$$

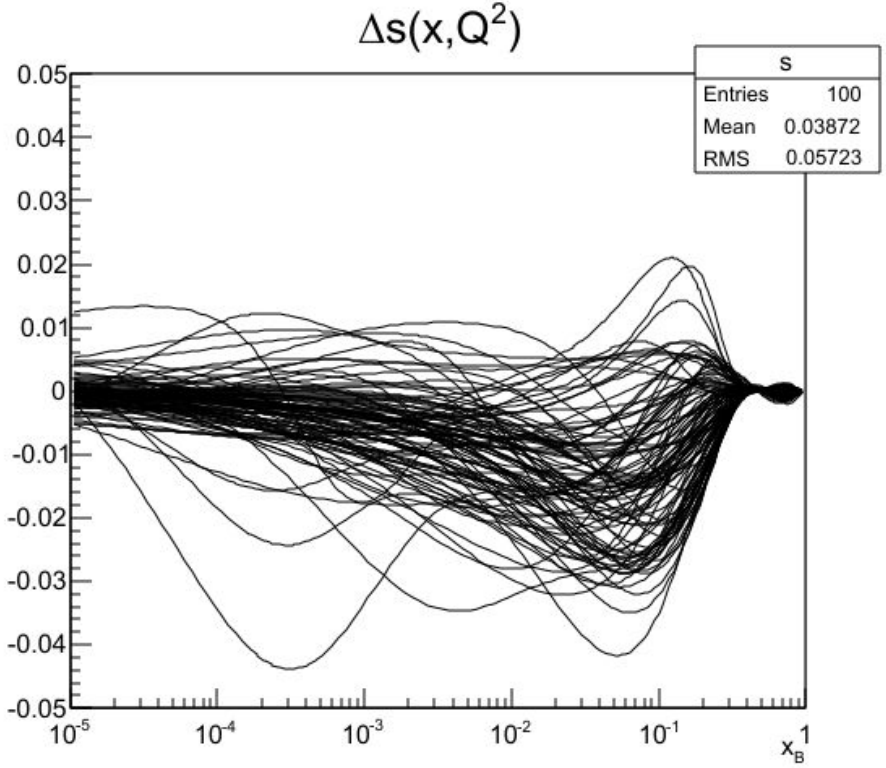
$$R_L = \frac{L_{\rightarrow\rightarrow}}{L_{\rightarrow\leftarrow}}$$

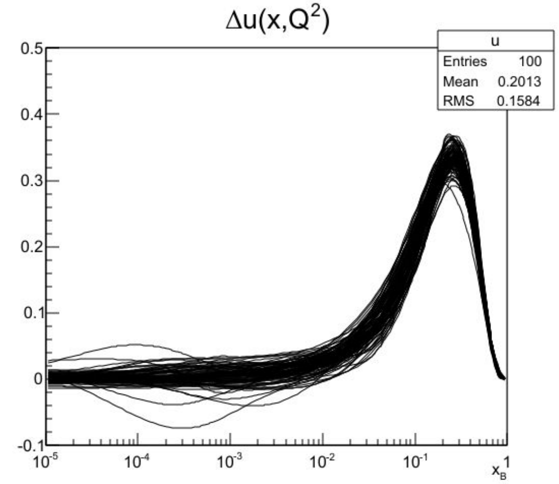
NNPDF*

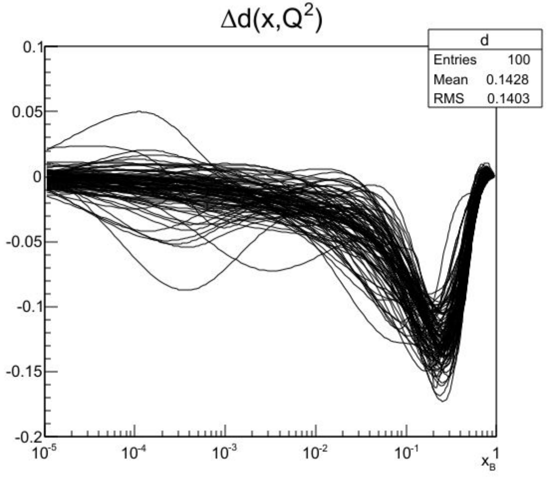
Perform global fits to data acquired at:

- Fixed target & colliders :
  - e-p, mu-p, p-p
  - (Neutrino) Deep Inelastic Scattering
  - Drell-Yan Process
- The experimental data are converted into an ensemble of 100 artificial Monte Carlo (MC) replicas.
- For this study, we used NNPDFpol1.1 gridfiles that comes with flavor separation.

*Ref: http://nnpdf.mi.infn.it/

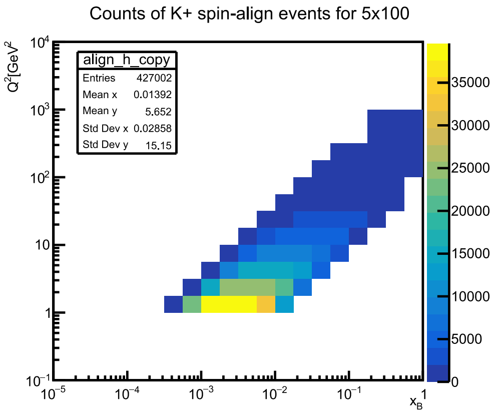

$\Delta s(x,Q^2)$
s
Entries 100
Mean 0.03872
RMS 0.05723
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x_B

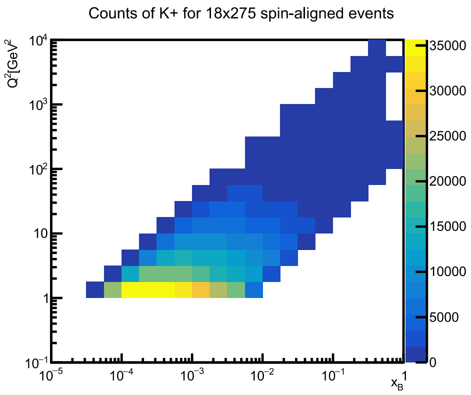

$\Delta u(x,Q^2)$
u
Entries 100
Mean 0.2013
RMS 0.1584
0.5
0.4
0.3
0.2
0.1
0
-0.1
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x_B


$\Delta d(x,Q^2)$
d
Entries 100
Mean 0.1428
RMS 0.1403
0.1
0.05
0
-0.05
-0.1
-0.15
-0.2
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
x_B

Simulation of SIDIS events in DJANGOH

- We modified DJANGOH to use polarized pdfs from NNPDFpol1.1 grid files (100 replicas) as input for generating polarized e-p scattering events and smear the events using EIC smear package.
- 5 GeV x 100 GeV and 18 GeV x 275 GeV
- $10^{-4} < x < 10^{-2} \cong 13 \text{ pb}^{-1}$ $10^{-2} < x < 1 \cong 12 \text{pb}^{-1}$





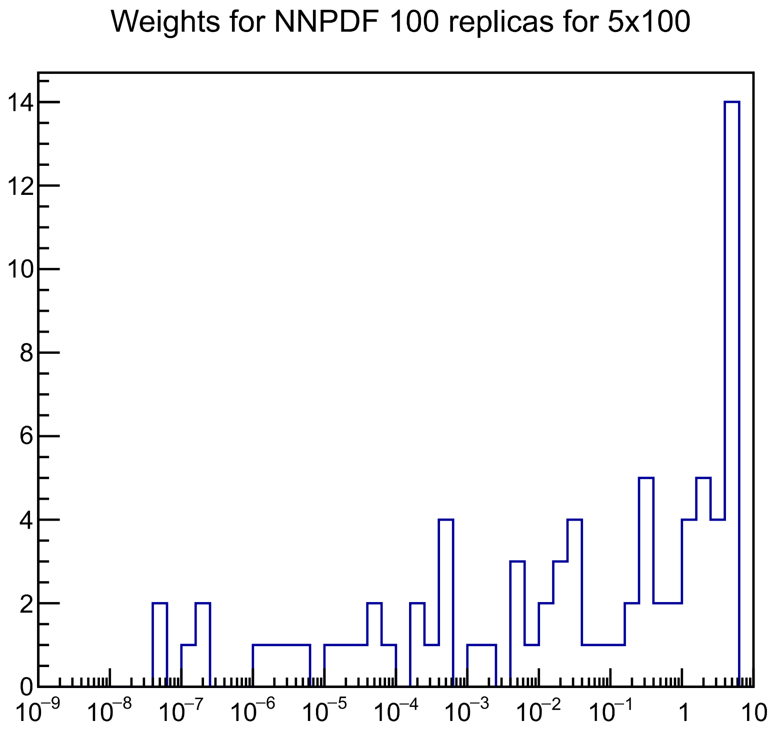
Reweighting NNPDF*

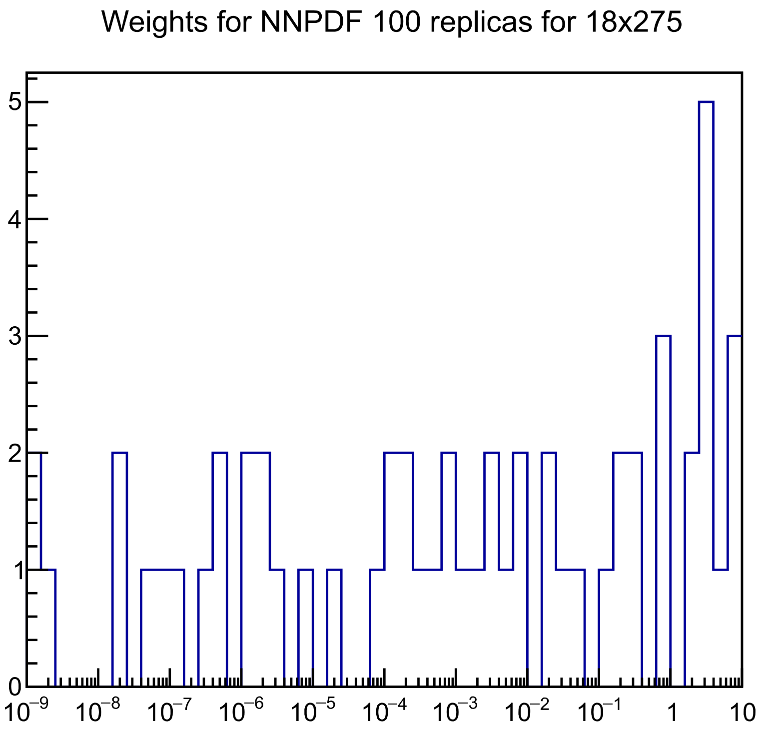
- With our new simulated data, instead of using NNPDF neural network based fitting method, we can reweight the old fit according to weights w_k, which assess the probability that each PDF replica f_k agrees with the new data and obtain a new fit.

$$\chi^2(y, f) = \sum_{i,j=1}^{n} (y_i - y_i[f])\sigma_{ij}^{-1}(y_j - y_j[f]).$$

$$w_k = \frac{(\chi_k^2)^{\frac{1}{2}(n-1)} e^{-\frac{1}{2}\chi_k^2}}{\frac{1}{N}\sum_{k=1}^{N}(\chi_k^2)^{\frac{1}{2}(n-1)} e^{-\frac{1}{2}\chi_k^2}}.$$

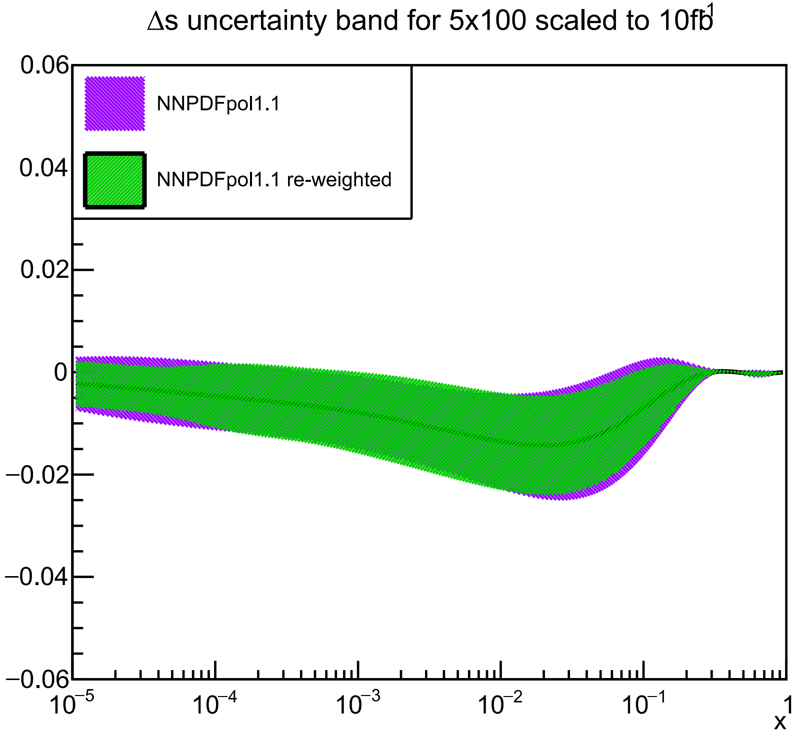
*Ref: https://arxiv.org/abs/1012.0836v4 [hep-ph]

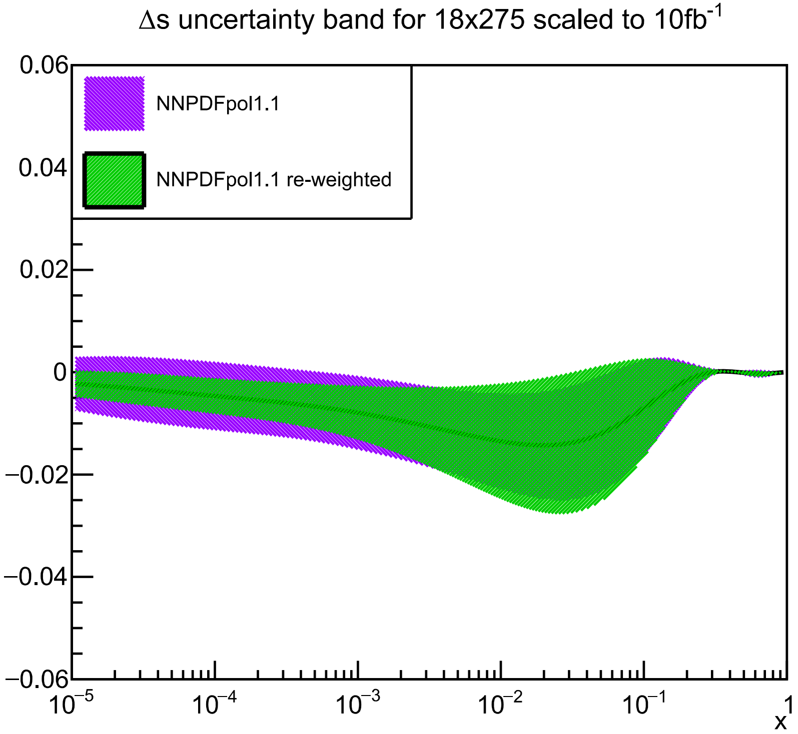




Generator Level

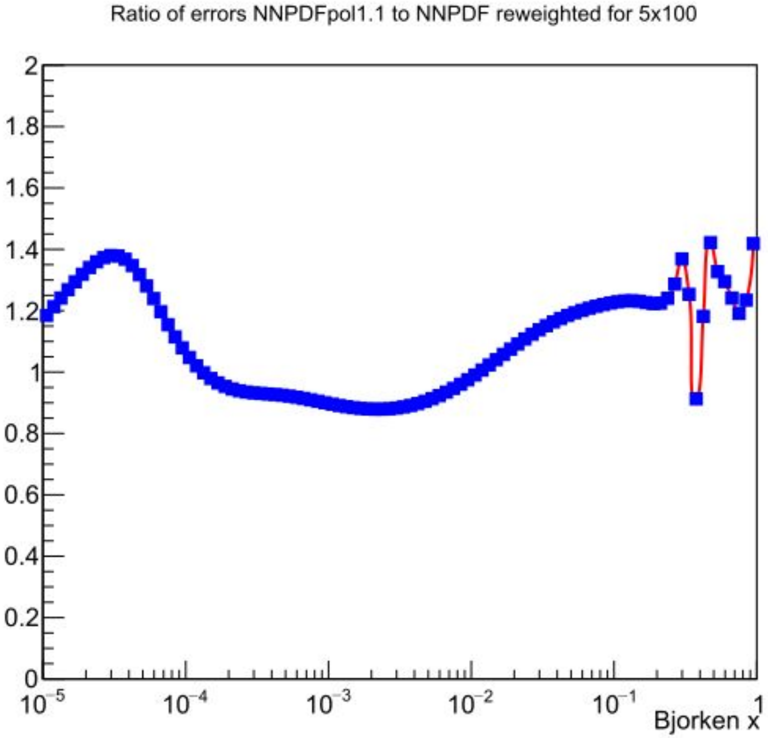
$Q^2 = 10\ GeV^2$

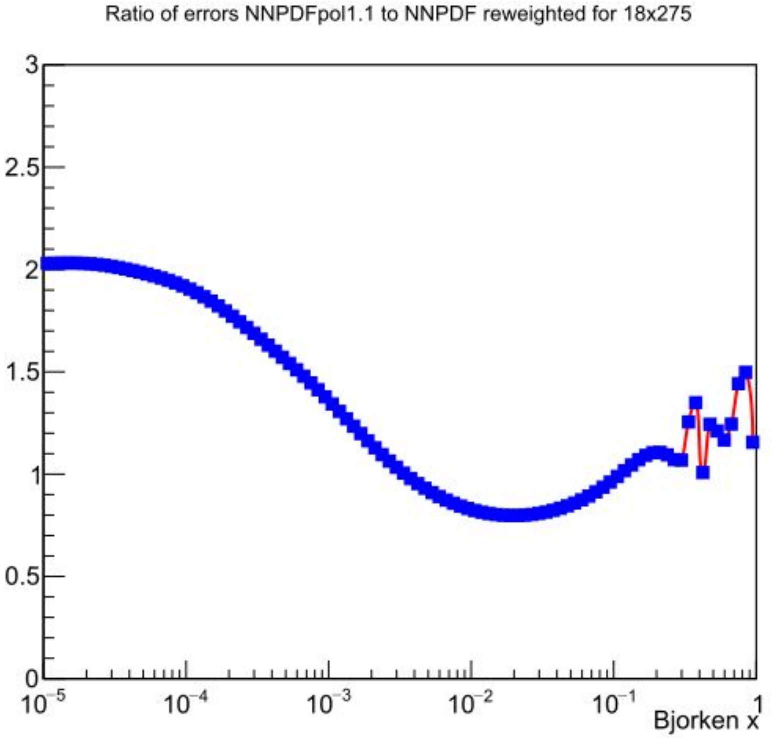




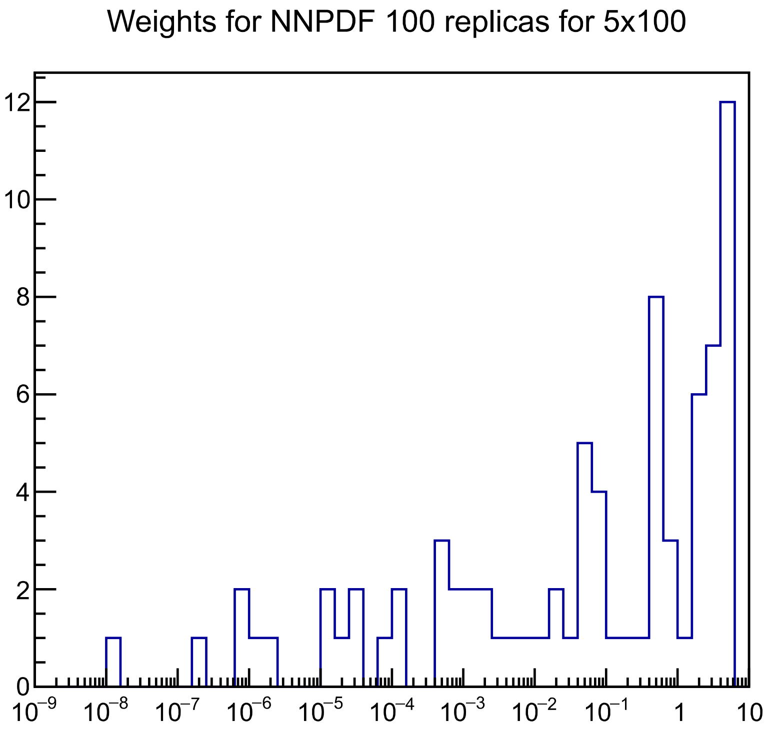
Generator Level

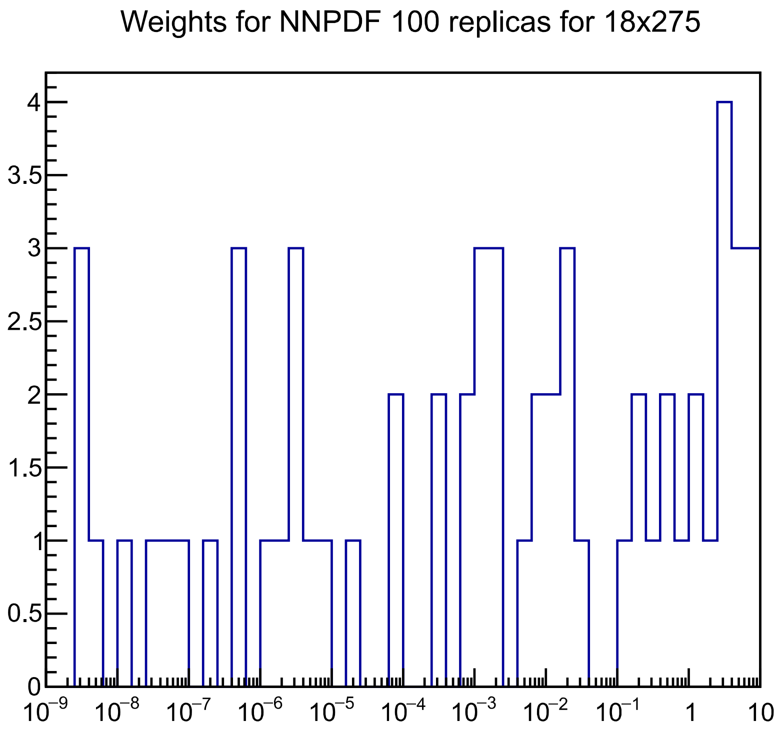
Ratio of errors





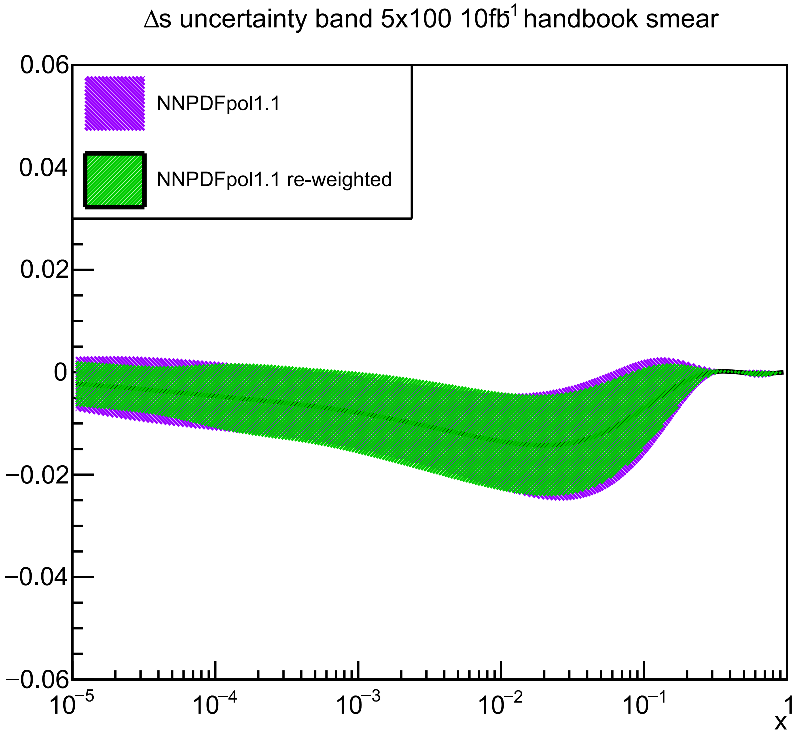
Generator Level

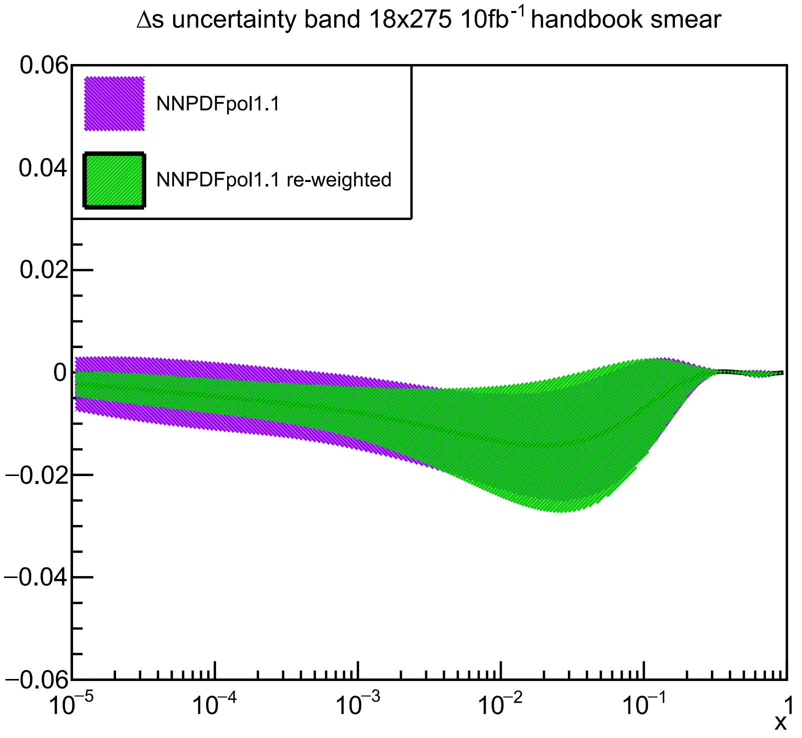

Weights for NNPDF 100 replicas for 5x100
0
2
4
6
8
10
12
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10


Weights for NNPDF 100 replicas for 18x275
0
0.5
1
1.5
2
2.5
3
3.5
4
10^{-9} 10^{-8} 10^{-7} 10^{-6} 10^{-5} 10^{-4} 10^{-3} 10^{-2} 10^{-1} 1 10

EIC Smear

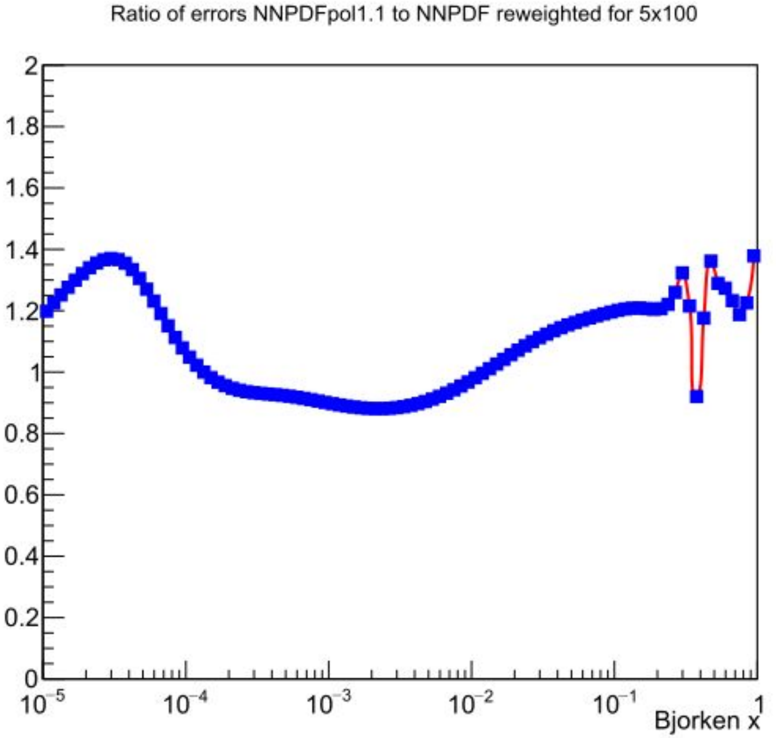
Q^2 = 10 GeV^2

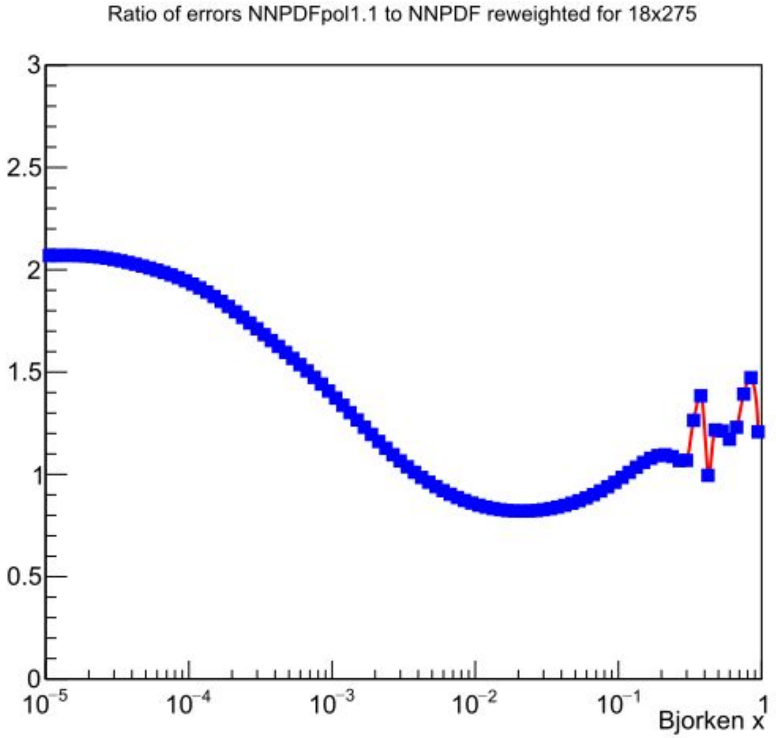




EIC Smear

Ratio of errors





EIC Smear

Summary and discussion

- We produced polarized SIDIS Kaon data and performed reweighting based on NNPDFpol1.1 gridfiles.
- Uncertainty for strange quark polarization will be significantly reduced by the Electron-ion collider(EIC).

$$S_{strange}(Q^2) = \int_0^1 (\Delta s + \Delta \bar{s})(x, Q^2) dx$$

- One can use the reweighting method shown here to compare different models of polarized parton distributions with the projected EIC uncertainties.

Thank you. Questions?

References

- A. Accardi et al., “Electron Ion Collider: The Next QCD Frontier: Understanding the glue that binds us all”. Eur. Phys. J. A, 52(9):268, 2016.
- Richard D. Ball et al. “Reweighting nnpdfs: The w lepton asymmetry”. Nuclear Physics B, 849(1):112 – 143, 2011.
- Aschenauer, Elke C. and Stratmann, Marco and Sassot, Rodolfo. “Helicity parton distributions at a future electron-ion collider: A quantitative appraisal”. Phys. Rev. D,86:054020, Sep 2012.
- Elke C. Aschenauer, Ignacio Borsa, Rodolfo Sassot, and Charlotte Van Hulse. Semi-inclusive deep-inelastic scattering, parton distributions, and fragmentation functions at a future electron-ion collider.Phys. Rev. D, 99:094004, May 2019.
- Richard D. Ball, Stefano Forte, Alberto Guffanti, Emanuele R. Nocera, Giovanni Ridolfi, Juan Rojo, “Polarized parton distributions at an electron–ion collider”, Physics Letters B, Volume 728, 2014, Pages 524-531

Backup

Kaon Asymmetry

- The asymmetry measured in the experiment is related to the lepton-nucleon asymmetry as follows

$$A^h_{meas} = f p_L p_N A^h_{||}$$

- The physically relevant photoabsorption asymmetry can be obtained when we divide by the Depolarization factor.

$$A^h_1 = \frac{A^h_{||}}{D}$$

Depolarization Factor (D)

- The asymmetry that you extract from your measurement after taking care of the detector efficiencies is the lepton-nucleon asymmetry.
- To extract the quark polarizations, the quantity that is important is the photoabsorption asymmetry on the nucleon level.

$$A_{||}^{h}(x, Q^2) = D A_1^h(x, Q^2)$$

Effective number of replicas

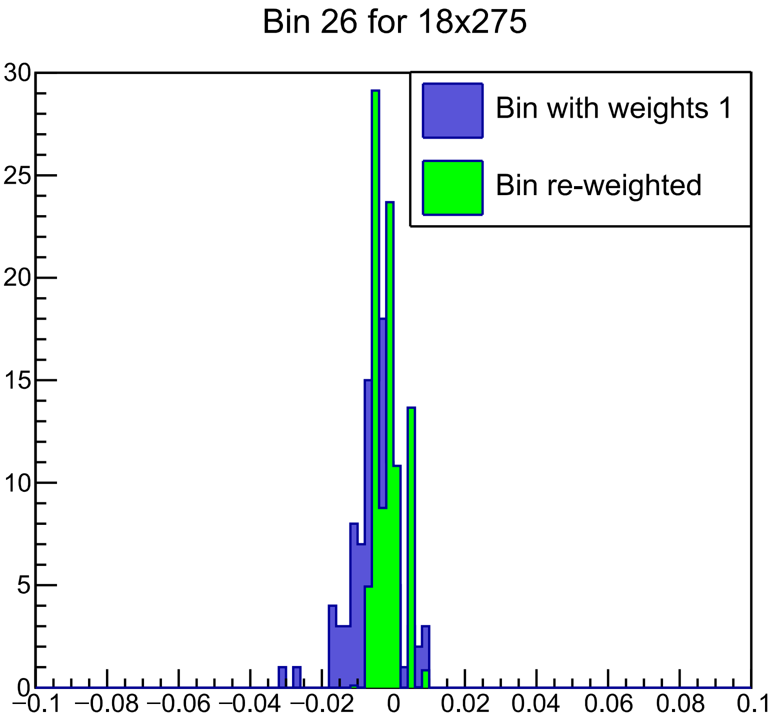
- The ensemble is chosen in such a way that it is the most efficient representation of the underlying $P_{old}(f)$ for a given number of replicas N.
- After we perform re-weighting, this won't be true for a given N.
- This loss of efficiency can be quantified by calculating the effective number of replicas

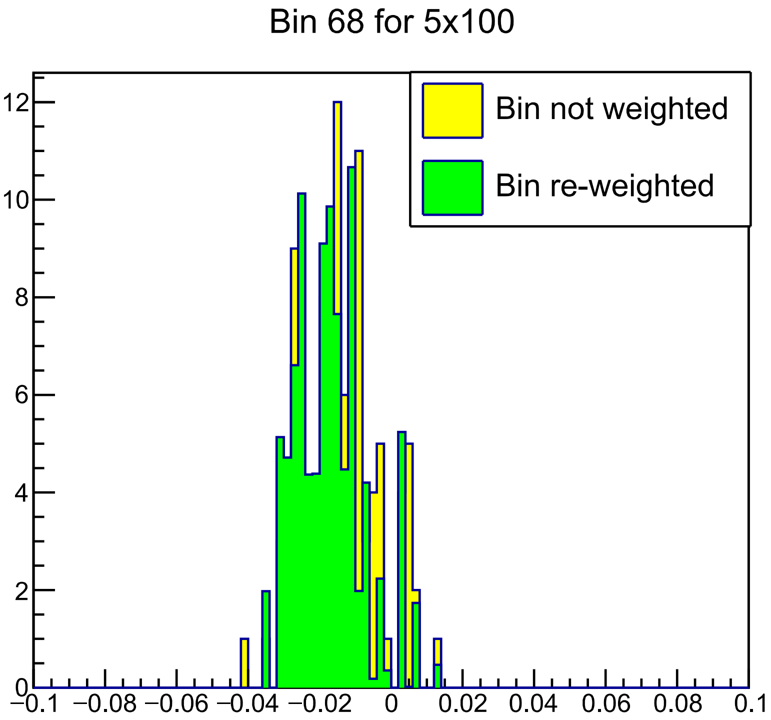
$$N_{eff} = exp\left\{\frac{1}{N}\sum_{k=1}^{N} w_k ln(N/w_k)\right\}$$

- Effective no. of replicas for 5x100 : 28.9633(≈28) smear: 31.6237(≈31)
  Effective no. of replicas for 18x275: 14.3808(≈14) smear: 15.2342 (≈15)

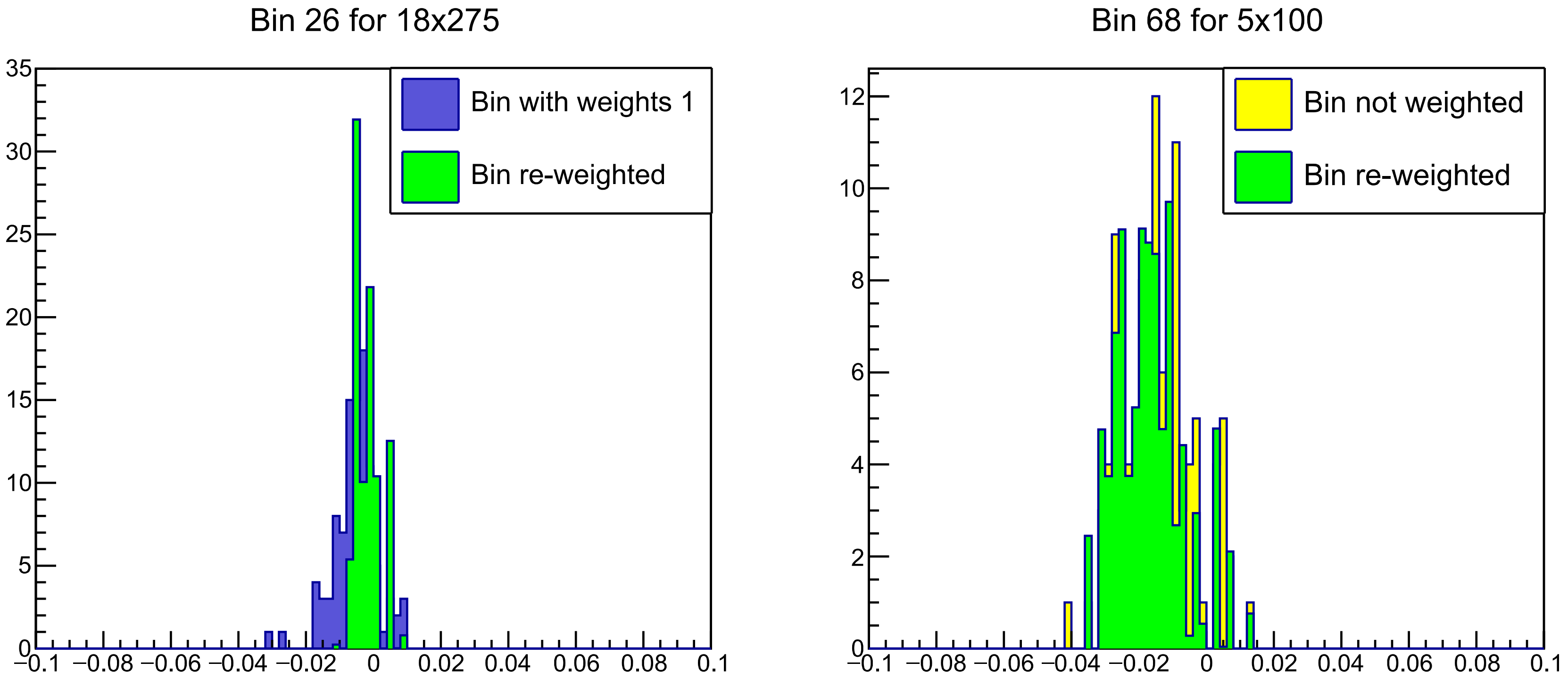
Reweighting strange quark

- We use the new weights obtained from re-weighting the cross-section asymmetry $A_1^{K+(-)}$ for the polarized strange quark distribution function replicas.
- For each x-bin, we create one histogram with weights 1, and another histogram using the new weights.
- The entry for the histograms will be the value of the polarized strange quark distribution function replicas from NNPDF pol1.1 version corresponding to each x-bin.





Generator Level


Bin 26 for 18x275
Bin with weights 1
Bin re-weighted
35
30
25
20
15
10
5
0
−0.1 −0.08 −0.06 −0.04 −0.02 0 0.02 0.04 0.06 0.08 0.1
Bin 68 for 5x100
Bin not weighted
Bin re-weighted
12
10
8
6
4
2
0
−0.1 −0.08 −0.06 −0.04 −0.02 0 0.02 0.04 0.06 0.08 0.1

EIC Smear

Lower and upper values of x

- 5 GeV × 100 GeV reweighting: Combined asymmetry data for K+ and K-

-Low-x value = 0.000562341

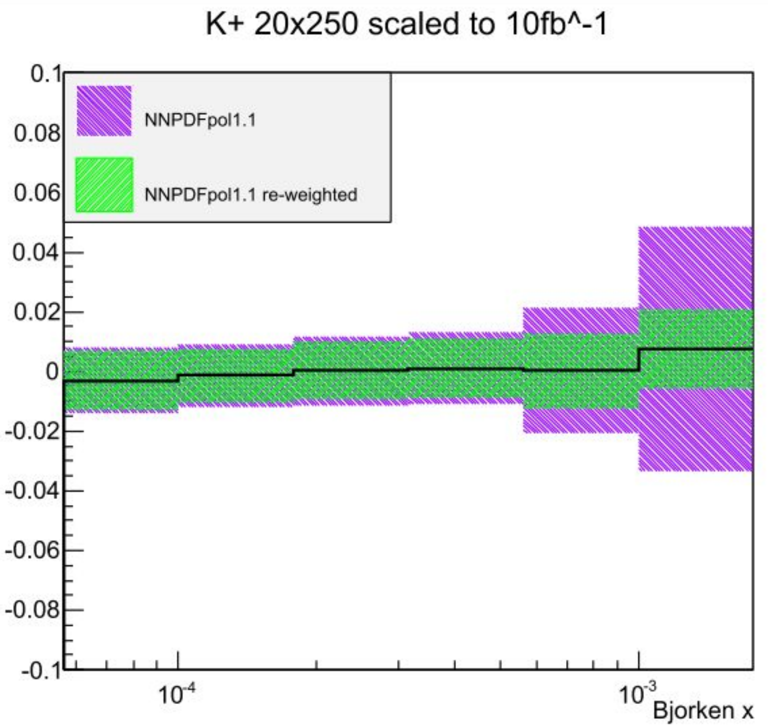
-Upper-x value = 0.0316228

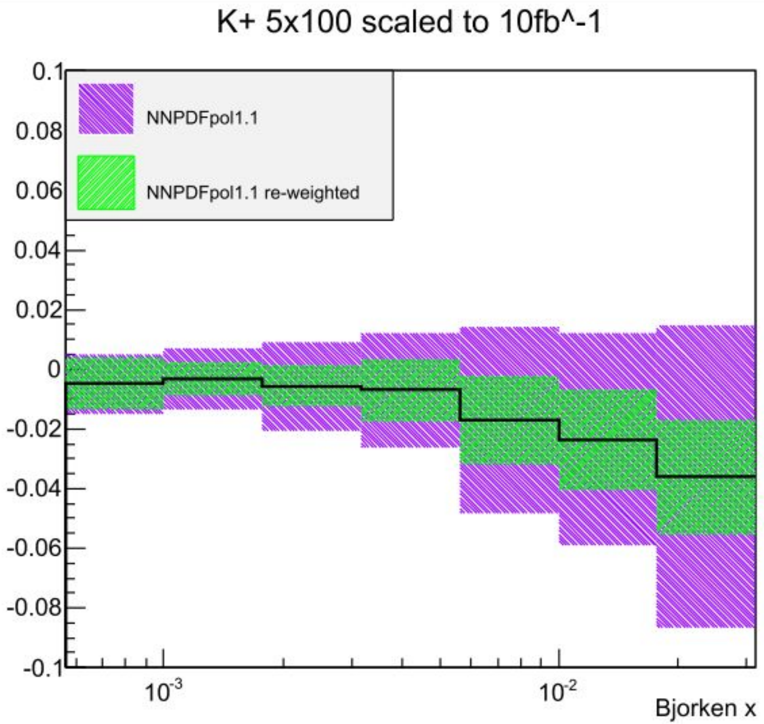
- 20 GeV × 250 GeV reweighting: Combined asymmetry data for K+ and K-

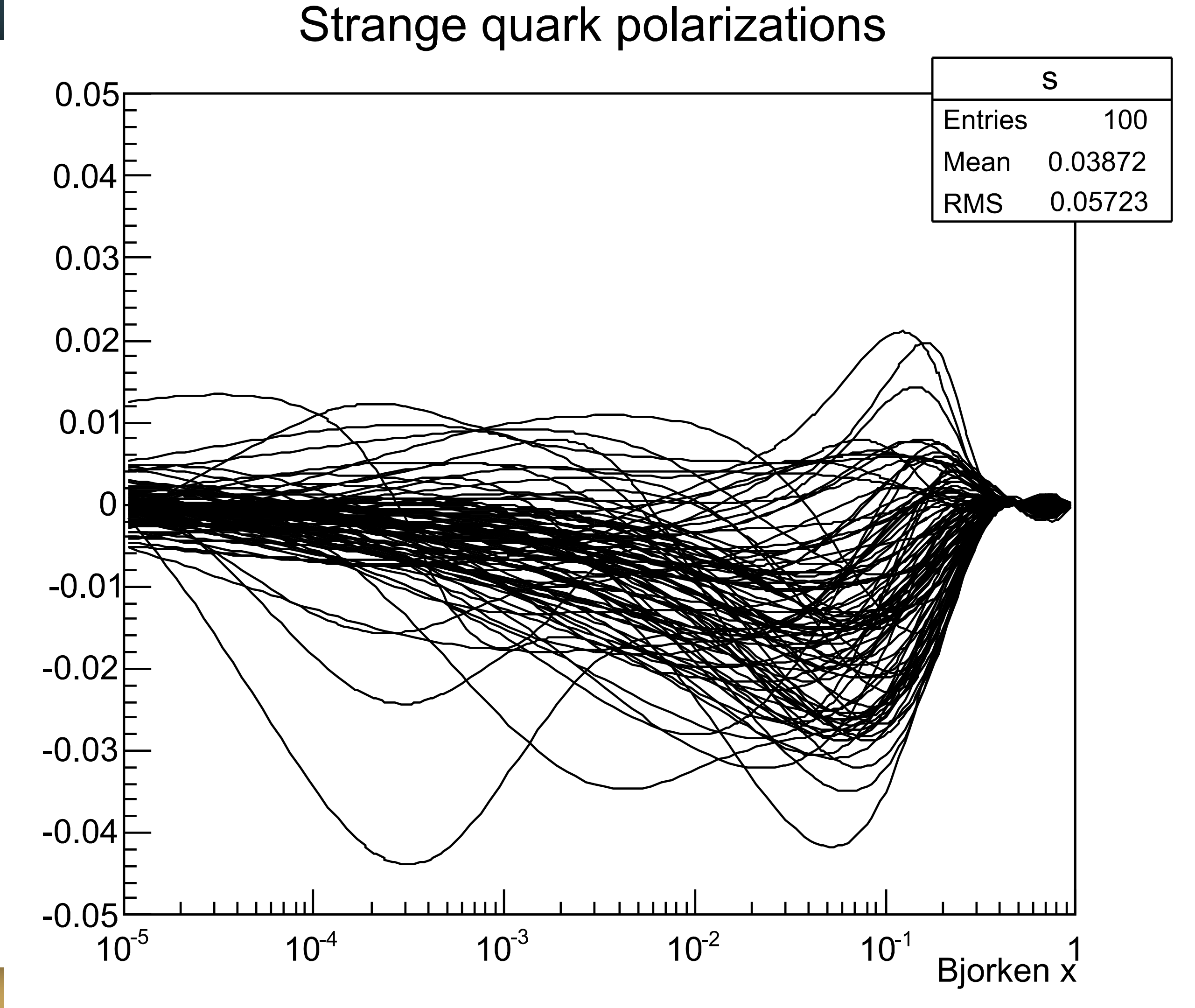
-Low-x value = 5.62341 x 10 − 5

-Upper-x value = 0.00177828

Reweighting Asymmetry






Strange quark polarizations
s
Entries 100
Mean 0.03872
RMS 0.05723
0.05
0.04
0.03
0.02
0.01
0
-0.01
-0.02
-0.03
-0.04
-0.05
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
1
Bjorken x

Proton spin problem

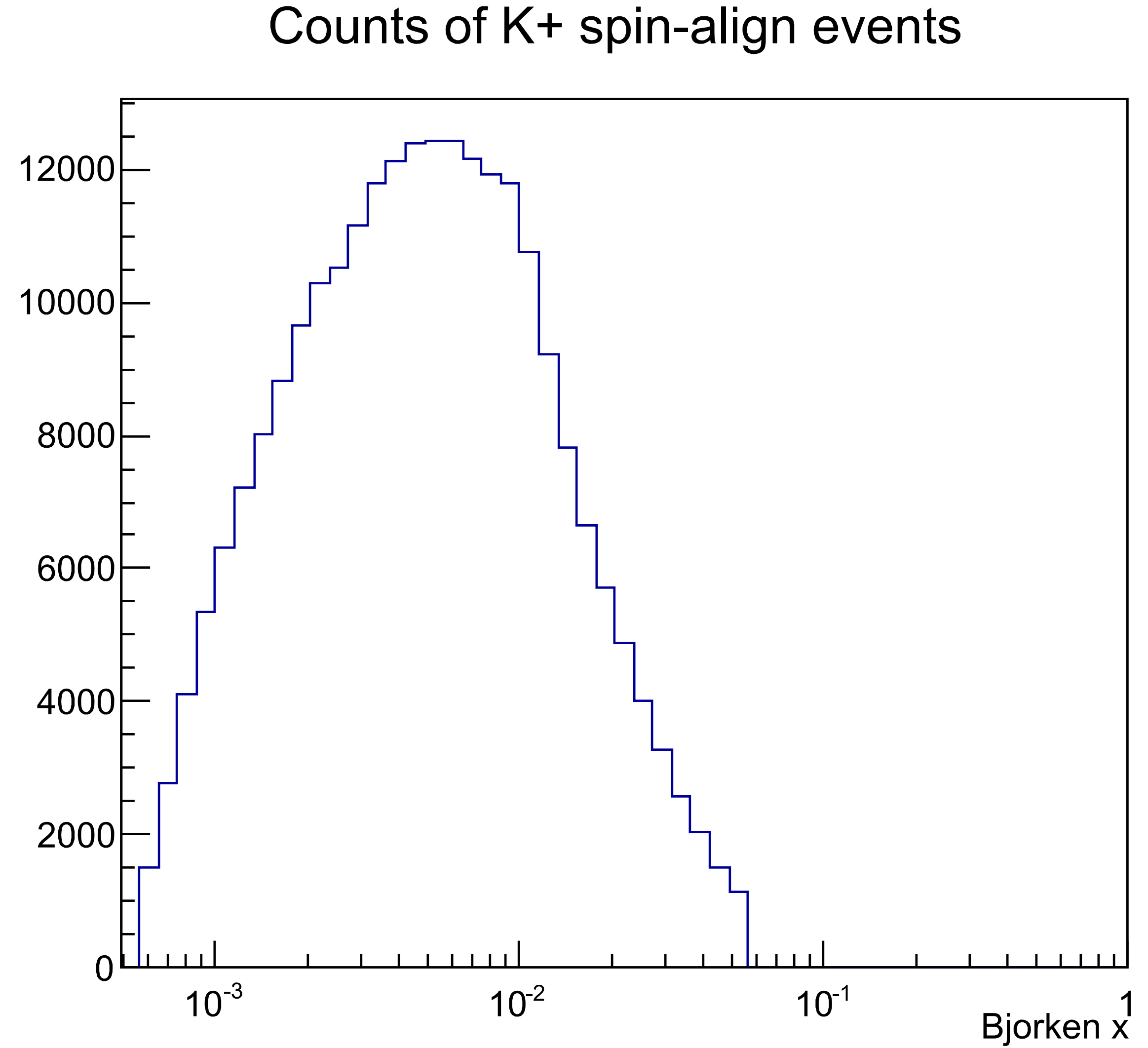
- Deep inelastic processes, when carried out with longitudinally polarized nucleons, probe the helicity distribution functions of the nucleon.

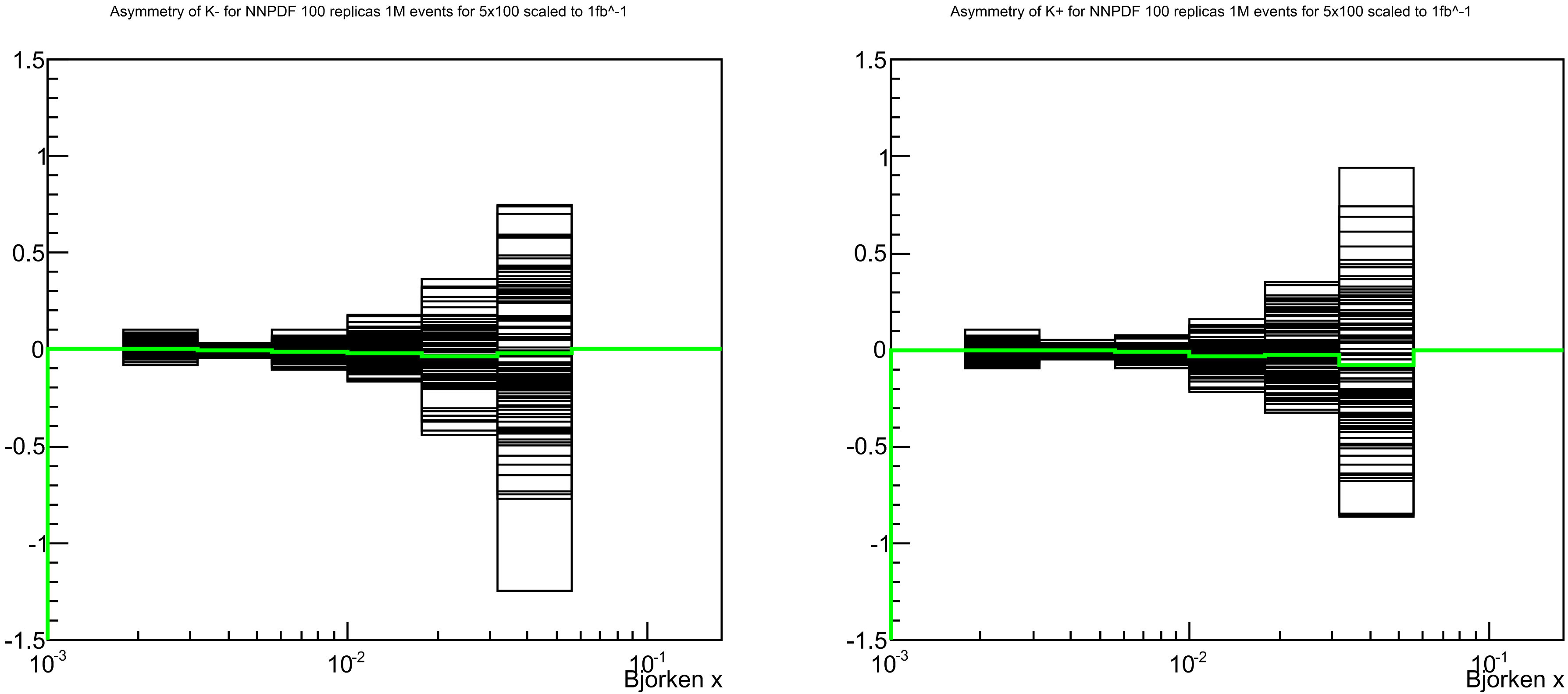
- The polarized parton distribution functions for each flavor f = u,d,s,g etc. is defined by

$$\Delta f(x, Q^2) \equiv f^{+}(x, Q^2) - f^{-}(x, Q^2) ,$$

Q^2 dependence

- The Q^2 - dependences of polarized quark distribution functions and the gluon helicity distribution function, like the unpolarized functions, are related by the QCD radiative processes that are calculable using th DGLAP evolution equation.


Counts of K+ spin-align events
12000
10000
8000
6000
4000
2000
0
10^{-3}
10^{-2}
10^{-1}
1
Bjorken x



Asymmetry of K- for NNPDF 100 replicas 1M events for 5x100 scaled to 1fb^-1
1.5
1
0.5
0
-0.5
-1
-1.5
10^{-3}
10^{-2}
10^{-1}
Bjorken x
Asymmetry of K+ for NNPDF 100 replicas 1M events for 5x100 scaled to 1fb^-1
1.5
1
0.5
0
-0.5
-1
-1.5
10^{-3}
10^{-2}
10^{-1}
Bjorken x