Nucleon sea polarizations from p+p collision at RHIC

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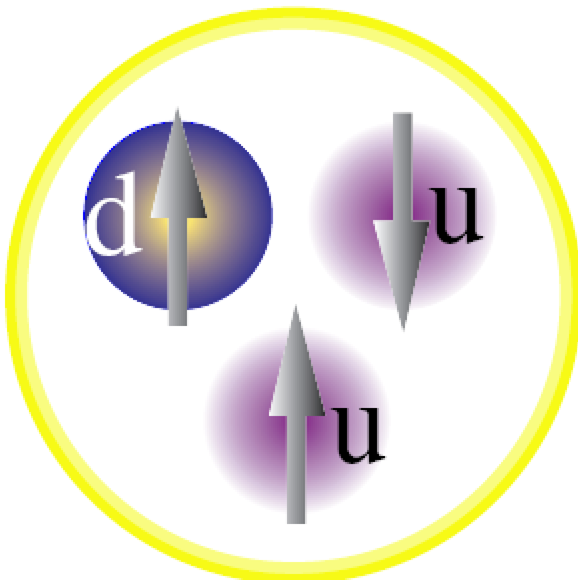
The structure of the nucleon

Constituent Quarks

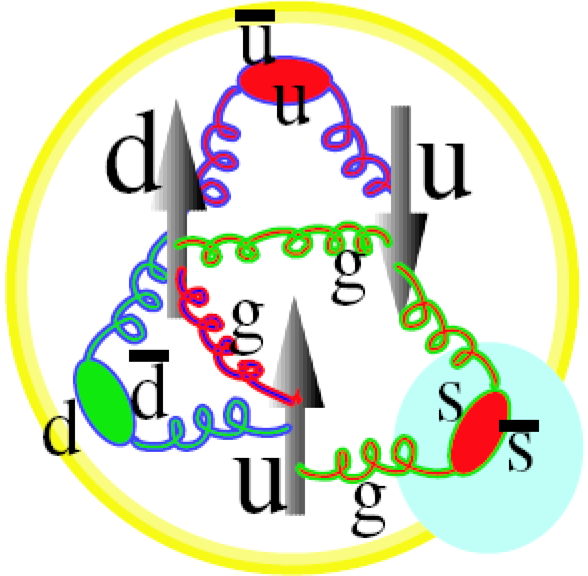


($Q^2 = 0$ GeV^2)

baryon octet

masses,magn. momenta

Parton Distributions



($Q^2 > 1$ GeV^2)

structure functions

momentum, spin

Surprises & Anomalies

about the Quark Structure of Nucleon: Sea

- **Spin Structure:** $\Sigma = \Delta u + \Delta d + \Delta s \approx 0.3$

  spin "crisis" or "puzzle": where is the proton's missing spin

- **Flavor Asymmetry** $\bar{u} \neq \bar{d}$

- **Strange Content** $\Delta s \neq 0 \quad s(x) \neq \bar{s}(x)$?

  Brodsky & Ma, PLB381(96)317

- **Isospin Symmetry Breaking**

  or Charge Symmetry Violation $\bar{u}_p \neq \bar{d}_n \quad \bar{d}_p \neq \bar{u}_n$?

  Ma, PLB 274 (92) 111
  Boros, Londergan, Thomas, PRL81(98)4075

The Proton "Spin Crisis"

$$\Sigma = \Delta u + \Delta d + \Delta s \approx 0.3$$

In contradiction with the na ïve quark model expectation:

Naive Quark Model:

$$\Delta u = \frac{4}{3}; \qquad \Delta d = -\frac{1}{3}; \qquad \Delta s = 0$$

$$\Sigma = \Delta u + \Delta d + \Delta s = 1$$

The Ellis-Jaffe sum rule & Its violation

$$A_1^p = \int_0^1 dx g_1^p(x) = \frac{1}{2}\left[\frac{4}{9}\Delta u + \frac{1}{9}\Delta d + \frac{1}{9}\Delta s\right]$$

- **Neutron beta decay and isospin symmetry**

$$\Delta u - \Delta d = \frac{G_A}{G_V} = 1.261$$

- **Strangeness changing hyperon decay and SU(3) symmetry**

$$\Delta u + \Delta d - 2\Delta s = 0.675$$

- **The assumption of zero strange spin constribution** $\Delta s = 0$

The Ellis-Jaffe sum $A_1^p = \int_0^1 dx g_1^p(x) = 0.198$

However, what EMC measured $A_1^p = \int_0^1 dx g_1^p(x) = 0.126$

The first stage of experiments

- **Non-zero strange spin constribution**

$$\Delta u = 0.750$$

$$\Delta d = -0.511$$

$$\Delta s = -0.218$$

$$\Sigma = \Delta u + \Delta d + \Delta s \approx 0.020$$

A large strange spin contribution?

A previous global fit:

SU(3) symmetry+measured g_1^p g_1^n

$$\Delta u = 0.83 \pm 0.03$$

$$\Delta d = -0.43 \pm 0.03$$

$$\Delta s = -0.10 \pm 0.03$$

$$\Sigma = \Delta u + \Delta d + \Delta s \approx 0.3$$

The second stage of experiments.

The third stage of experiments:
g_1^p g_1^n +semi-inclusive DIS process

$$\Delta u = 0.599 \pm 0.022 \pm 0.065$$

$$\Delta d = -0.280 \pm 0.026 \pm 0.057$$

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

$$\Sigma = \Delta u + \Delta d + \Delta s \approx 0.347 \pm 0.024 \pm 0.040$$

HERMES Collaboration, PRL92 (2004) 012005.

The strange contribution

to the proton spin

$$\Delta s \approx -0.2 \rightarrow -0.1 \rightarrow 0.03$$

$$\Delta s \neq 0, \quad \text{how large?}$$

The Strange-Antistrange Asymmetry

The strange quark and antiquark distributions are

symmetric at leading-orders of perturbative QCD

$$s(x) = \bar{s}(x)$$

However, it has been argued that there is strange-antistrange distribution asymmetry in pQCD evolution at three-loops from non-vanishing up and down quark valence densities.

S.Catani et al. PRL93(2004)152003

Strange-Antistrange Asymmetry

from Non-Perturbative Sources

- **Meson Cloud Model** $s(x) < \bar{s}(x)$ at large x

  A.I. Signal and A.W. Thomas, PLB191(87)205

- **Chiral Field** $s(x) > \bar{s}(x)$ at large x

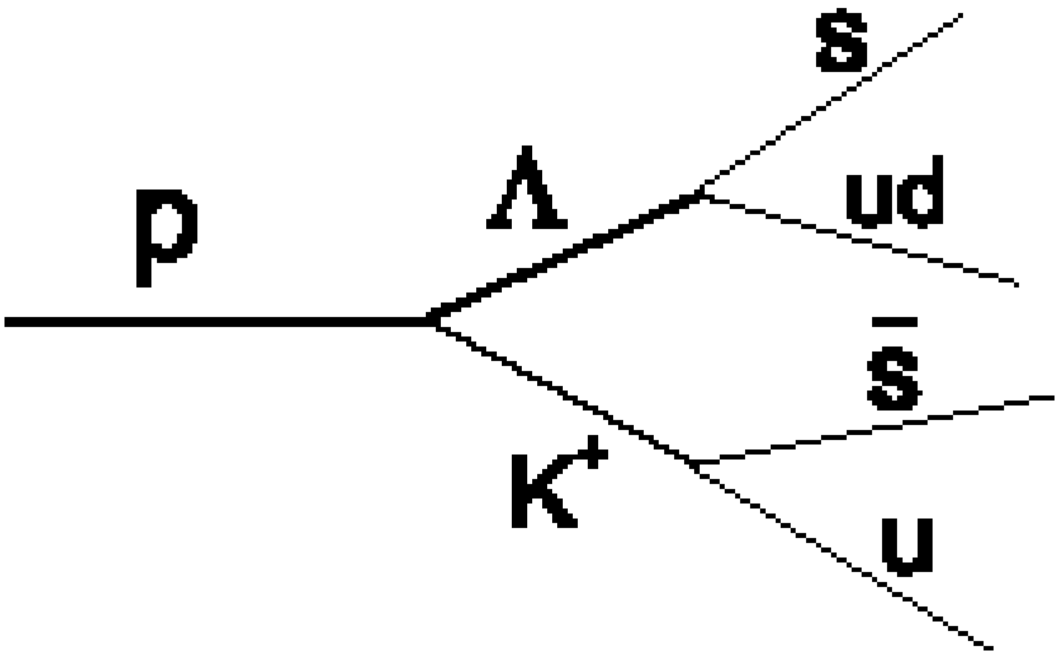
  M. Burkardt and J. Warr, PRD45(92)958

- **Baryon-Meson Fluctuation** $s(x) > \bar{s}(x)$ at large x

  S.J. Brodsky and B.-Q. Ma, PLB381(96)317

S.J. Brodsky and B.-Q. Ma, PLB381(96)317

Mechanism for s-sbar asymmetry



$s(x) \neq \bar{s}(x)$

Phenomenological supports for s-sbar asymmetry

The nucleon strangeness asymmetry can explain a number of experimental observations:

- **The NuTeV anomaly.**

Y.Ding, B.-Q.Ma, PLB590 (2004) 216
Y.Ding, R.-G.Xu, B.-Q.Ma, PLB607 (2005) 101

- **With heavy quark recombination to give a sizable influence on the measurement of the nucleon strangeness asymmetry in CCFR and NuTeV dimuon measurements.**

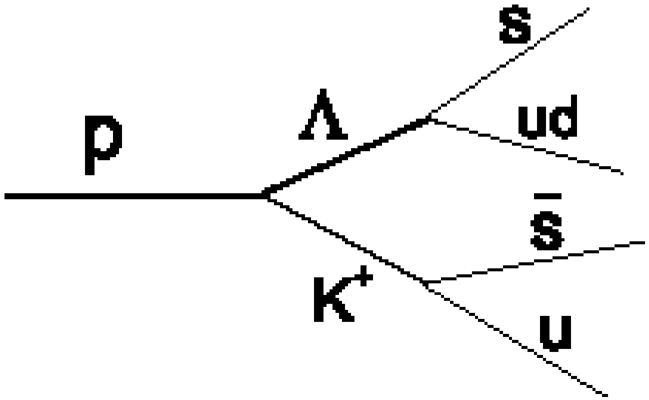
P.Gao, B.-Q.Ma, PRD77(2008)054002, EPJC58(2008)37.

- **The difference between Lambda and anti-Lambda spin transfers.**

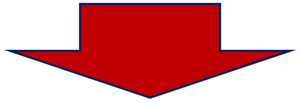
X.Du, B.-Q. Ma, PRD95 (2017) 014029

S.J. Brodsky and B.-Q. Ma, PLB381(96)317

Prediction of s-sbar spin asymmetry



$s(x) \neq \bar{s}(x)$



$$\Delta s \neq \Delta \bar{s}$$

$$\Delta s \approx -0.05 \text{ to } -0.01 \text{ and } \Delta \bar{s} \approx 0$$

Xiaonan Liu and B.-Q. Ma, arXiv:1905.02360, EPJC (2019) in press

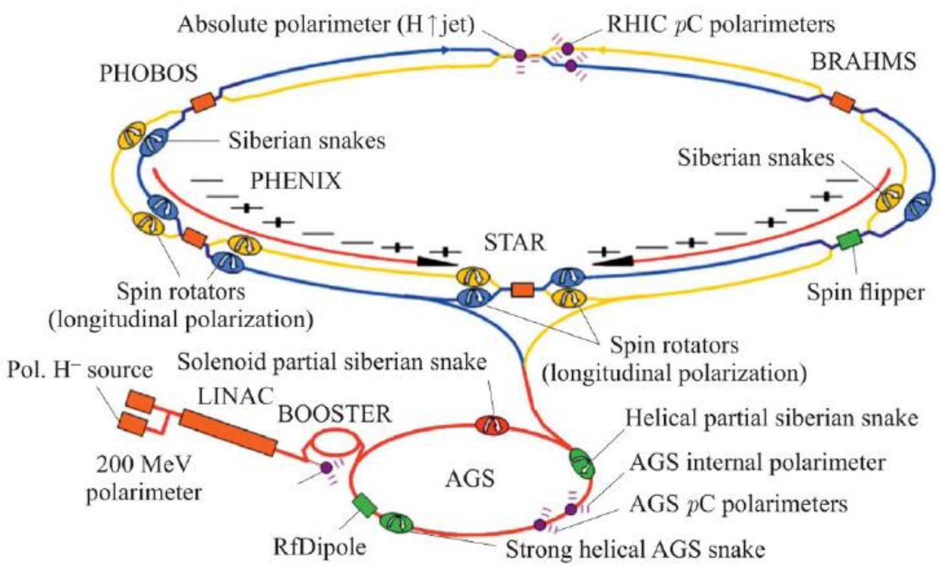
Nucleon strangeness polarization from $\Lambda/\bar{\Lambda}$ hyperon production in polarized proton-proton collision at RHIC

STAR results to indicate $\Delta s \neq \Delta \bar{s}$

$$\Delta s \approx -0.025 \pm 0.019$$

$$\Delta \bar{s} \approx -0.001 \pm 0.012$$

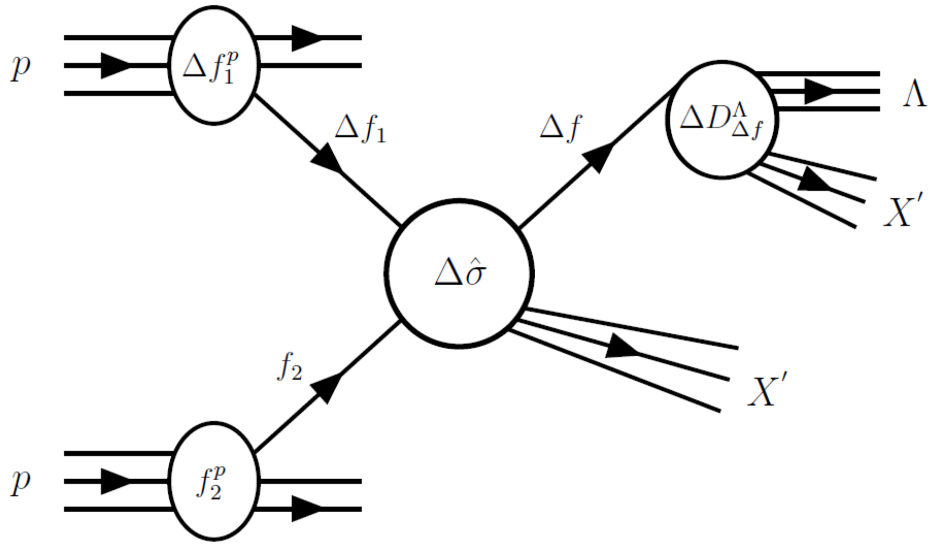
STAR at RHIC



Polarized $p + p$ collider at BNL

The STAR experiment at Relativistic Heavy Ion Collider (RHIC) is carrying out a spin physics program in high-energy polarized proton-proton collisions at $\sqrt{s} = 200\,\mathrm{GeV}$ and $\sqrt{s} = 500\,\mathrm{GeV}$.

$\vec{p}p \to \vec{\Lambda}X$



Providing information about

- the inclusive production of hadrons
- the strange and antistrange quark polarizations of the proton.

Formalism

$$A^{\Lambda/\bar{\Lambda}} = E_{\mathrm{c}} \frac{\Delta d\sigma}{d^3 p_{\mathrm{c}}} \Big/ E_{\mathrm{c}} \frac{d\sigma}{d^3 p_{\mathrm{c}}}$$

$$E_{\mathrm{c}} \frac{\Delta d\sigma}{d^3 p_{\mathrm{c}}} (\mathrm{AB} \to \mathrm{C} + \mathrm{X})$$
$$= \sum_{abcd} \int_{\bar{x}_a}^{1} dx_a \int_{\bar{x}_b}^{1} dx_b \Delta f_a^{\mathrm{A}}(x_a, Q^2) f_b^{\mathrm{B}}(x_b, Q^2)$$
$$\Delta D_c^{\mathrm{C}}(z_c, Q^2) \frac{1}{\pi z_c} \frac{\Delta d\hat{\sigma}}{d\hat{t}} (ab \to cd),$$

Parametrization of Λ fragmentation functions

$$
\begin{aligned}
D_d^\Lambda(x,Q^2) &= D_u^\Lambda(x,Q^2) \\
&= \left(\frac{D_u^\Lambda(x)}{D_{u+\bar{u}}^\Lambda(x)}\right)^{\rm th} D_{u+\bar{u}}^\Lambda(x,Q^2)^{\rm AKK} \\
D_{\bar{d}}^\Lambda(x,Q^2) &= D_{\bar{u}}^\Lambda(x,Q^2) \\
&= \left(\frac{D_{\bar{u}}^\Lambda(x)}{D_{u+\bar{u}}^\Lambda(x)}\right)^{\rm th} D_{u+\bar{u}}^\Lambda(x,Q^2)^{\rm AKK} \\
\Delta D_d^\Lambda(x,Q^2) &= \Delta D_u^\Lambda(x,Q^2) \\
&= \left(\frac{\Delta D_u^\Lambda(x)}{D_{u+\bar{u}}^\Lambda(x)}\right)^{\rm th} D_{u+\bar{u}}^\Lambda(x,Q^2)^{\rm AKK} \\
D_s^\Lambda(x,Q^2) &= \left(\frac{D_s^\Lambda(x)}{D_{s+\bar{s}}^\Lambda(x)}\right)^{\rm th} D_{s+\bar{s}}^\Lambda(x,Q^2)^{\rm AKK}, \\
D_{\bar{s}}^\Lambda(x,Q^2) &= \left(\frac{D_{\bar{s}}^\Lambda(x)}{D_{s+\bar{s}}^\Lambda(x)}\right)^{\rm th} D_{s+\bar{s}}^\Lambda(x,Q^2)^{\rm AKK}, \\
\Delta D_s^\Lambda(x,Q^2) &= \left(\frac{\Delta D_s^\Lambda(x)}{D_{s+\bar{s}}^\Lambda(x)}\right)^{\rm th} D_{s+\bar{s}}^\Lambda(x,Q^2)^{\rm AKK}.
\end{aligned}
$$

X.Du, B.-Q. Ma, PRD95 (2017) 014029

Gluon to Λ fragmentation functions

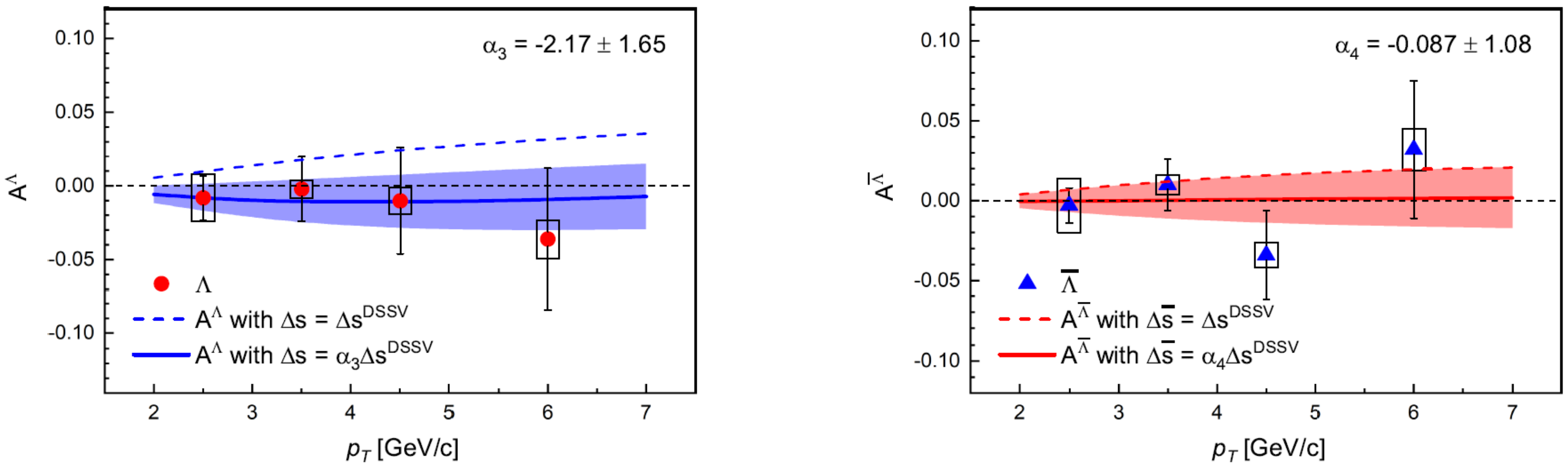
$$\Delta D_g^\Lambda(z,Q^2) = D_g^\Lambda(z,Q^2)\left(\frac{\Delta g^\Lambda(z,Q^2)}{g^\Lambda(z,Q^2)}\right)$$

assuming that the gluon polarization evolves in the same way between the octet baryons, i.e.,

$$\frac{\Delta g^\Lambda(z,Q^2)}{g^\Lambda(z,Q^2)} = \frac{\Delta g^p(z,Q^2)}{g^p(z,Q^2)},$$

Xiaonan Liu, B.-Q. Ma, arXiv:1905.02360, EPJC(2019)in press

Fitting to STAR DATA



Xiaonan Liu, B.-Q. Ma, arXiv:1905.02360, EPJC(2019)in press

Xiaonan Liu, B.-Q. Ma, EPJC(2019)in press

Results from fitting STAR data

Table: Fitting results of α_i and calculated results of Δs and $\Delta \bar{s}$.

	value	Δs	$\Delta \bar{s}$	$\chi^2_{\rm min}$
α_1	-1.20±1.31	-0.014±0.015		0.37
α_2	-0.24±0.49		-0.003±0.005	2.48
α_3	-2.17±1.65	-0.025±0.019		0.42
α_4	-0.087±1.08		-0.001±0.012	2.24

Two options: with/without gluon polarization

Xiaonan Liu, B.-Q. Ma, EPJC(2019)in press

Comparison with Predictions & Results

The central values of the fitting results are basically compatible with

- the light-cone meson-baryon fluctuation model[24] prediction $\Delta s(x) \approx -0.05$ to -0.01 and $\Delta \bar{s}(x) \approx 0$.
- the recent lattice QCD determination[25], $\Delta s^{+} = -0.02(1)$ at $Q^2 \approx 7\mathrm{GeV}^2$.
- the results from Jefferson Lab Angular Momentum (JAM) Collaboration[26] $\Delta s^{+}(Q_0^2) = -0.03(10)$.

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[24] S. J. Brodsky and B.-Q. Ma, Phys. Lett. B 381, 317 (1996).
[25] G. S. Bali et al. [QCDSF Collaboration], Phys. Rev. Lett. 108, 222001 (2012)
[26] J.J.Ethier, N.Sato and W.Melnitchouk, Phys. Rev. Lett. 119, 132001 (2017)

Feasibility of Strange Polarization Determination

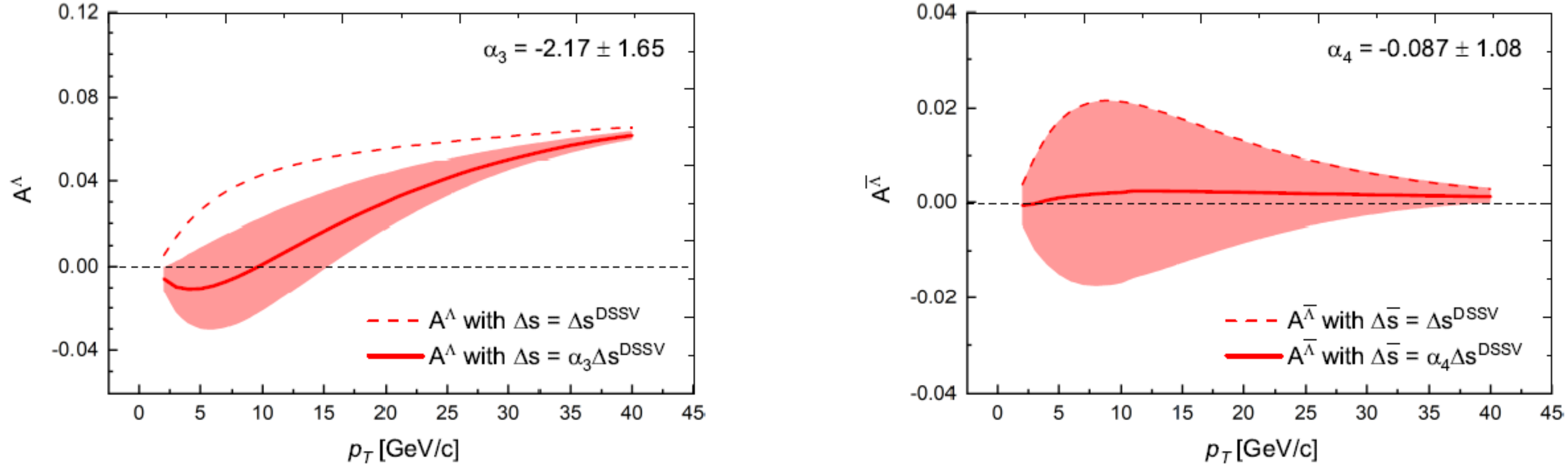

Figure: Comparison of the symmetric and asymmetric input of polarized strange

Further improvement in precision can determine the strange-antistrange polarization asymmetry of the nucleon sea

Xiaonan Liu, B.-Q. Ma, EPJC(2019)in press

F.Tian, C.Gong, B.-Q. Ma, NPA961 (2017) 154

Extraction of ubar and dbar polarizations

- **The earlier unpolarized experiments confirmed the flavor asymmetry of light-flavor sea quarks:**

$$\bar{u}(x) \neq \bar{d}(x)$$

- **It is natural to speculate:**

$$\Delta\bar{u}(x) \neq \Delta\bar{d}(x)$$

- **We show that the ubar helicity is positive and dbar helicity is negative from RHIC W asymmetry data:**

$$\Delta\bar{u} > 0, \qquad \Delta\bar{d} < 0$$

M.Liu, B.-Q. Ma, PRD98 (2018) 036024

Light-flavor sea quark-antiquark asymmetry

- **The flavor asymmetry of light-flavor sea quarks can be produced from an intuitive statistical model:**

$$\Delta\bar{u} > 0, \qquad \Delta\bar{d} < 0$$

- **There is also an asymmetry between antiquarks and quarks of the sea:**

$$\Delta q_s(x) \neq \Delta\bar{q}_s(x)$$

- **The valence part of spin structure can be well descried by a light-cone quark-diquark model with the Melosh-Wigner rotation effect due to quark transversal motions.**

B.-Q. Ma, PLB 375 (1996) 320

Conclusions

- **The spin transfer process of $\vec{p}p \to \vec{\Lambda}X$ is feasible to study strange-antistrange polarizations of the nucleon.**
- **The fitting to STAR data suggests:** $\Delta s \neq \Delta \bar{s}$

$$\Delta s \approx -0.025 \pm 0.019$$

$$\Delta \bar{s} \approx -0.001 \pm 0.012$$

- **The results are compatible with the light-cone baryon-meson fluctuation model prediction.**


谢谢！