The spin content of the nucleon sea from recent RHIC experimental data

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CUSTIPEN-Beijing Workshop on RIB Science 2nd China-US-RIB Meeting

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Based on :

F. Tian, C. Gong, B.-Q. Ma, Nucl.Phys. A968 (2017) 379-390

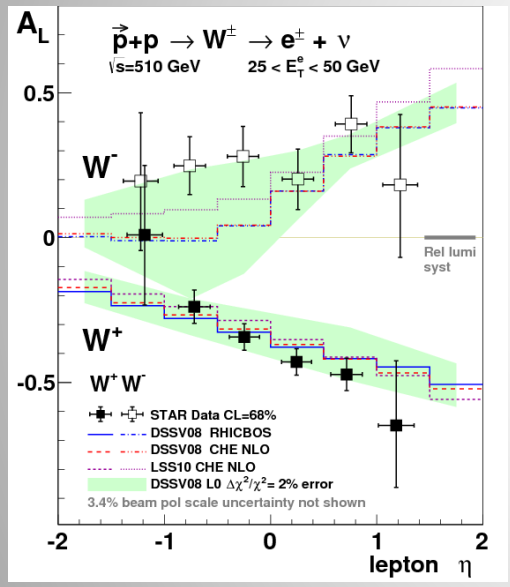
F. Tian, C. Gong, B.-Q. Ma, Nucl.Phys. A961 (2017) 154-168

Outline

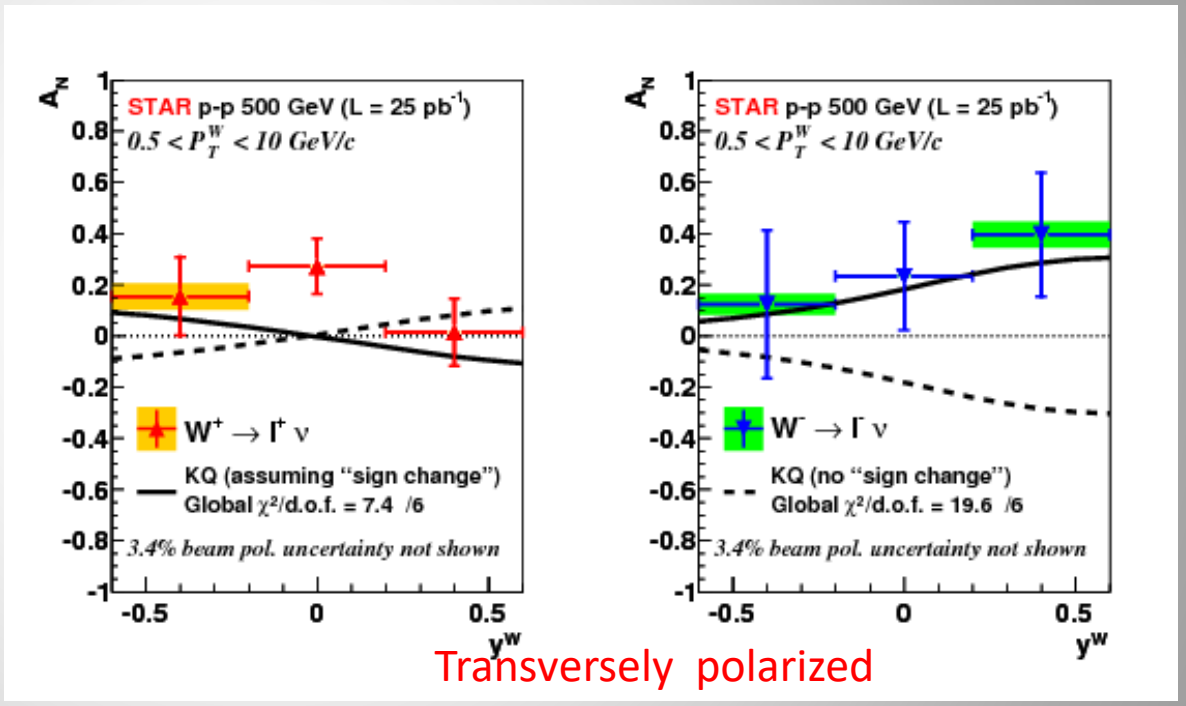
- motivation
- Effect of sea quarks on $A_L^{W^\pm}$
- Effect of sea quarks on $A_N^{W^\pm}$
- Summary

Motivation

- Proton spin structure
- Polarized proton-proton collision experiments (STAR, PHENIX)



Longitudinal polarized



Transversely polarized

STAR data: Phys.Rev.Lett. 113 (2014), 072301

DSSV08 RHICBOS: D. de Florian, R. Sassot, M. Stratmann, and W. Vogelsang Phys.Rev. D80 (2009) 034030
DSSV08 CHE NLO: E. Leader , A. V. Sidorov , D. B. Stamenov Phys.Rev. D82 (2010) 114018
LSS10 CHE NLO: D. de Florian and W. Vogelsang, Phys. Rev. D 81, 094020 (2010)
DSSV08 LO: P. M. Nadolsky and C. Yuan, Nucl. Phys. B666, 31(2003)

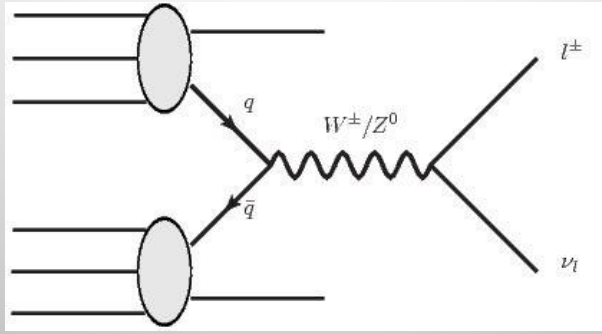
STAR, Phys.Rev.Lett. 116 (2016) ,132301

Effect of sea quarks on $A_L^{W^\pm}$

- At leading order,

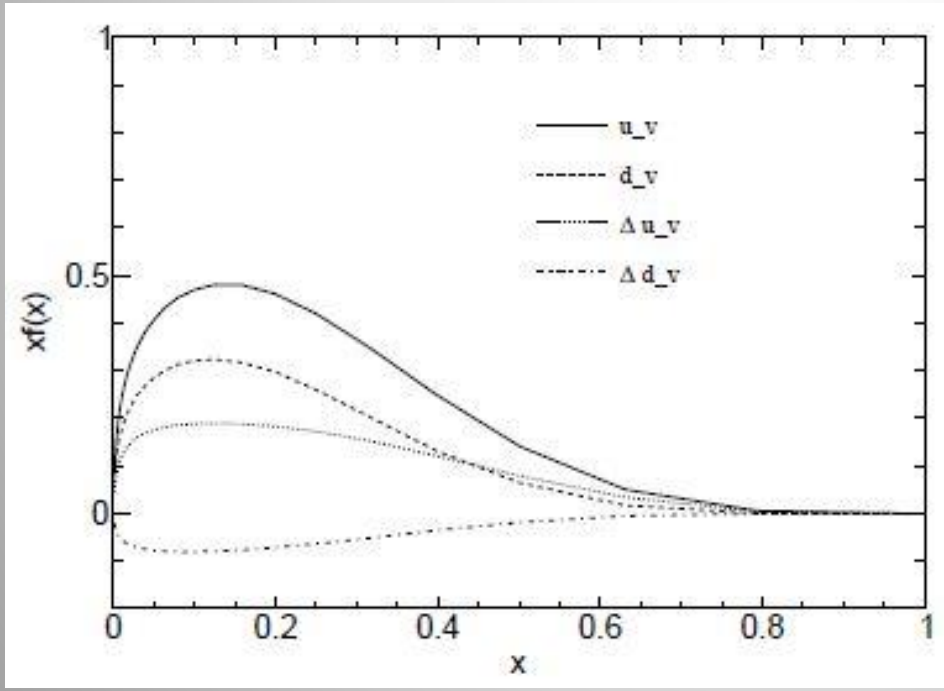
$$A_L^{W^+} = \frac{-\Delta u(x_1)\bar{d}(x_2)+\Delta\bar{d}(x_1)u(x_2)}{u(x_1)\bar{d}(x_2)+\bar{d}(x_1)u(x_2)}$$
$$A_L^{W^-} = \frac{-\Delta d(x_1)\bar{u}(x_2)+\Delta\bar{u}(x_1)d(x_2)}{d(x_1)\bar{u}(x_2)+\bar{u}(x_1)d(x_2)}$$

- Comparing with the experimental data of $A_L^{W^\pm}$, many extractions or parametrizations of quark helicity distributions from DIS and SIDIS data prefer a sizable positive $\Delta\bar{u}$ distributions and a negative $\Delta\bar{d}$ distributions.



Effect of sea quarks on $A_L^{W^\pm}$

- In our work, for the valence quark helicity distributions, we adopt the quark-spectator-diquark model (qD model).



B.-Q. Ma, Phys.Lett. B375 (1996) 320-326

Effect of sea quarks on $A_L^{W^\pm}$

- We extract the sea quark helicity distributions from the corresponding single spin asymmetries of $W^\pm$ bosons(RHIC) and $\Gamma_1^{p,n}$(COMPASS).
- Linear form: $\Delta\bar{q}(x) = N_{\bar{q}}\bar{q}(x), \quad q = u \text{ or } d$
- Nonlinear form: **F. Tian, C. Gong, B.-Q. Ma, Nucl.Phys. A961 (2017) 154-168**

$$\Delta\bar{q}(x) = n_{\bar{q}}\frac{\Gamma(a_{\bar{q}}+b_{\bar{q}}+2)}{\Gamma(a_{\bar{q}}+1)\Gamma(b_{\bar{q}}+1)}x^{a_{\bar{q}}}(1-x)^{b_{\bar{q}}}\bar{q}(x) \quad q = u \text{ or } d$$

Relation	Mode	β_D	Data	Parameter							
				$N_{\bar{u}}$	$N_{\bar{d}}$	$n_{\bar{u}}$	$n_{\bar{d}}$	$a_{\bar{u}}$	$a_{\bar{d}}$	$b_{\bar{u}}$	$b_{\bar{d}}$
Linear	1	330	$W^\pm$	0.242	-0.309	-	-	-	-	-	-
	2		$W^\pm + \Gamma_1^{p,n}$	0.001	-0.040	-	-	-	-	-	-
	3	600	$W^\pm$	0.254	-0.440	-	-	-	-	-	-
	4		$W^\pm + \Gamma_1^{p,n}$	0.009	-0.057	-	-	-	-	-	-
NLinear	5	330	$W^\pm$	-	-	0.150	-0.225	1.0	1.0	3.0	3.0
	6		$W^\pm + \Gamma_1^{p,n}$	-	-	0.010	-0.197	1.0	1.0	3.0	3.0
	7	600	$W^\pm$	-	-	0.159	-0.319	1.0	1.0	3.0	3.0
	8		$W^\pm + \Gamma_1^{p,n}$	-	-	0.100	-0.276	1.0	1.0	3.0	3.0

Effect of sea quarks on $A_L^{W^\pm}$

- From the table, we can see that the signs of $\Delta\bar{u}$ are positive and the signs of $\Delta\bar{d}$ are negative for all modes.

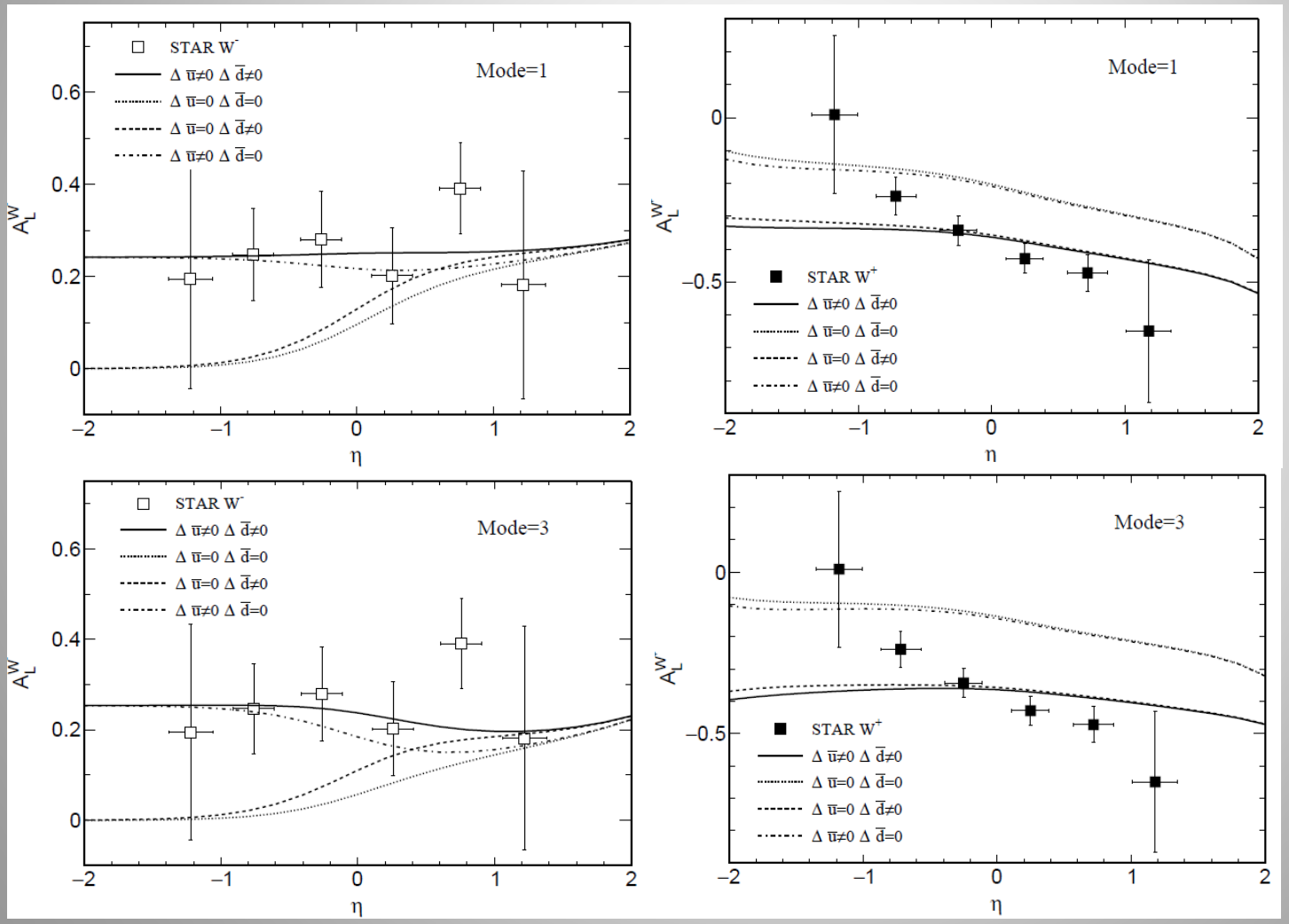
F. Tian, C. Gong, B.-Q. Ma, Nucl.Phys. A961 (2017) 154-168

Quantities from model calculations at $Q = \sqrt{10}$ GeV.

Relation	Mode	β_D	Data	Quantity						
				Γ_1^p	Γ_1^n	$\Delta\Sigma$	Δu^+	Δd^+	$\Delta\bar{u}$	$\Delta\bar{d}$
Linear	1	330	$w^\pm$	0.289	−0.210	0.282	1.64	−1.35	0.396	−0.508
	2		$w^\pm + \Gamma_1^{p,n}$	0.163	−0.057	0.380	0.851	−0.471	0.002	−0.066
	3	600	$w^\pm$	0.245	−0.285	−0.144	1.521	−1.666	0.415	−0.724
	4		$w^\pm + \Gamma_1^{p,n}$	0.137	−0.050	0.316	0.720	−0.404	0.015	−0.093
NLinear	5	330	$w^\pm$	0.186	−0.078	0.391	0.991	−0.599	0.071	−0.130
	6		$w^\pm + \Gamma_1^{p,n}$	0.159	−0.078	0.290	0.857	−0.567	0.005	−0.114
	7	600	$w^\pm$	0.154	−0.083	0.256	0.842	−0.585	0.075	−0.184
	8		$w^\pm + \Gamma_1^{p,n}$	0.145	−0.075	0.250	0.786	−0.536	0.048	−0.159
Parametrization	–		NNPDFpol1.1 [35]	–	–	0.25 ± 0.10	0.76 ± 0.04	-0.41 ± 0.04	0.04 ± 0.05	-0.09 ± 0.05
	–	–	DSSV08 [35]	–	–	$+0.366^{+0.042}_{-0.062}$ (+0.124)	$+0.793^{+0.028}_{-0.034}$ (+0.020)	$-0.416^{+0.035}_{-0.025}$ (−0.042)	$+0.028^{+0.059}_{-0.059}$ (+0.008)	$-0.089^{+0.090}_{-0.080}$ (−0.026)

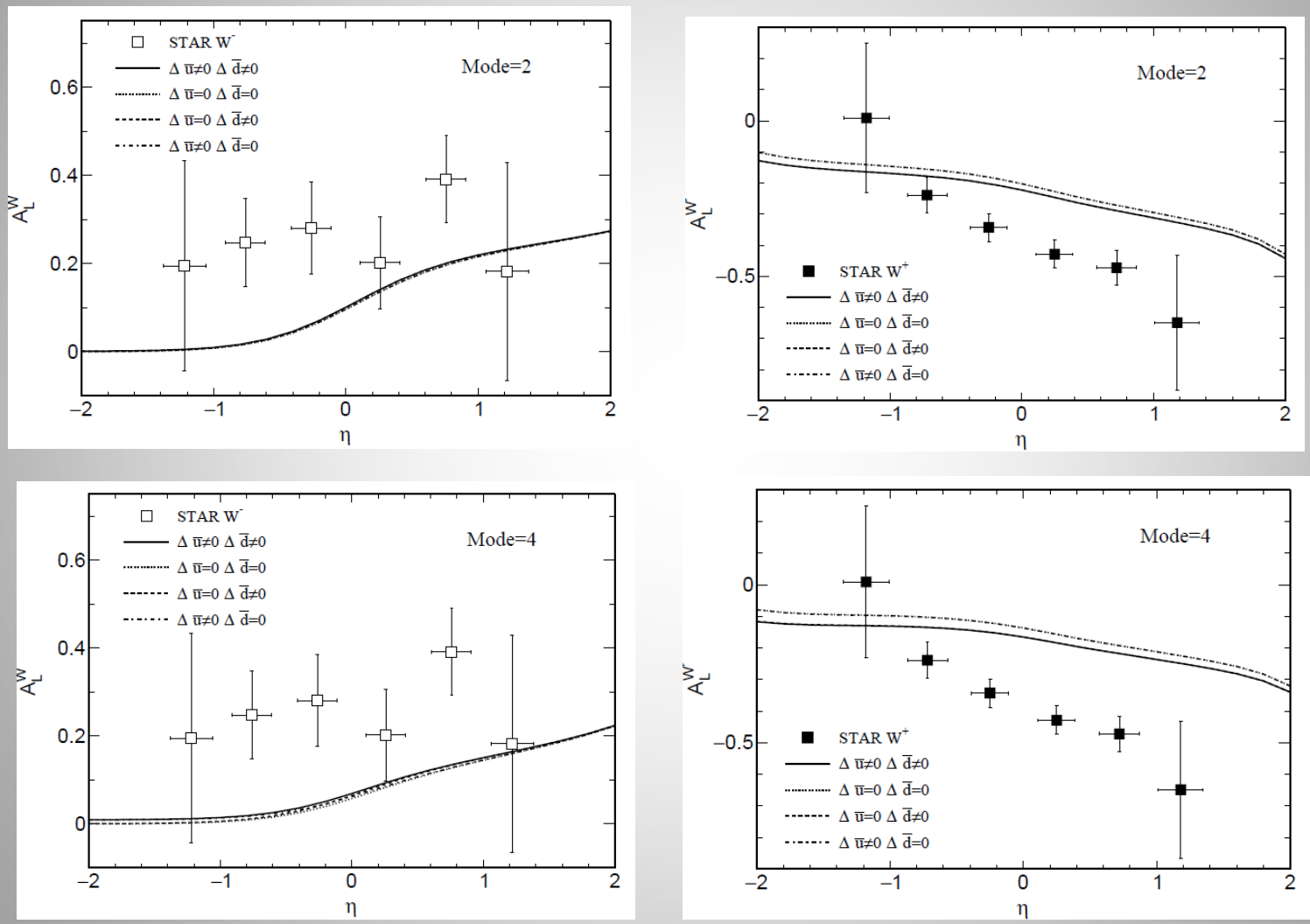
Effect of sea quarks on $A_L^{W^\pm}$

- For linear form (without the constraints of $\Gamma_1^{p,n}$),



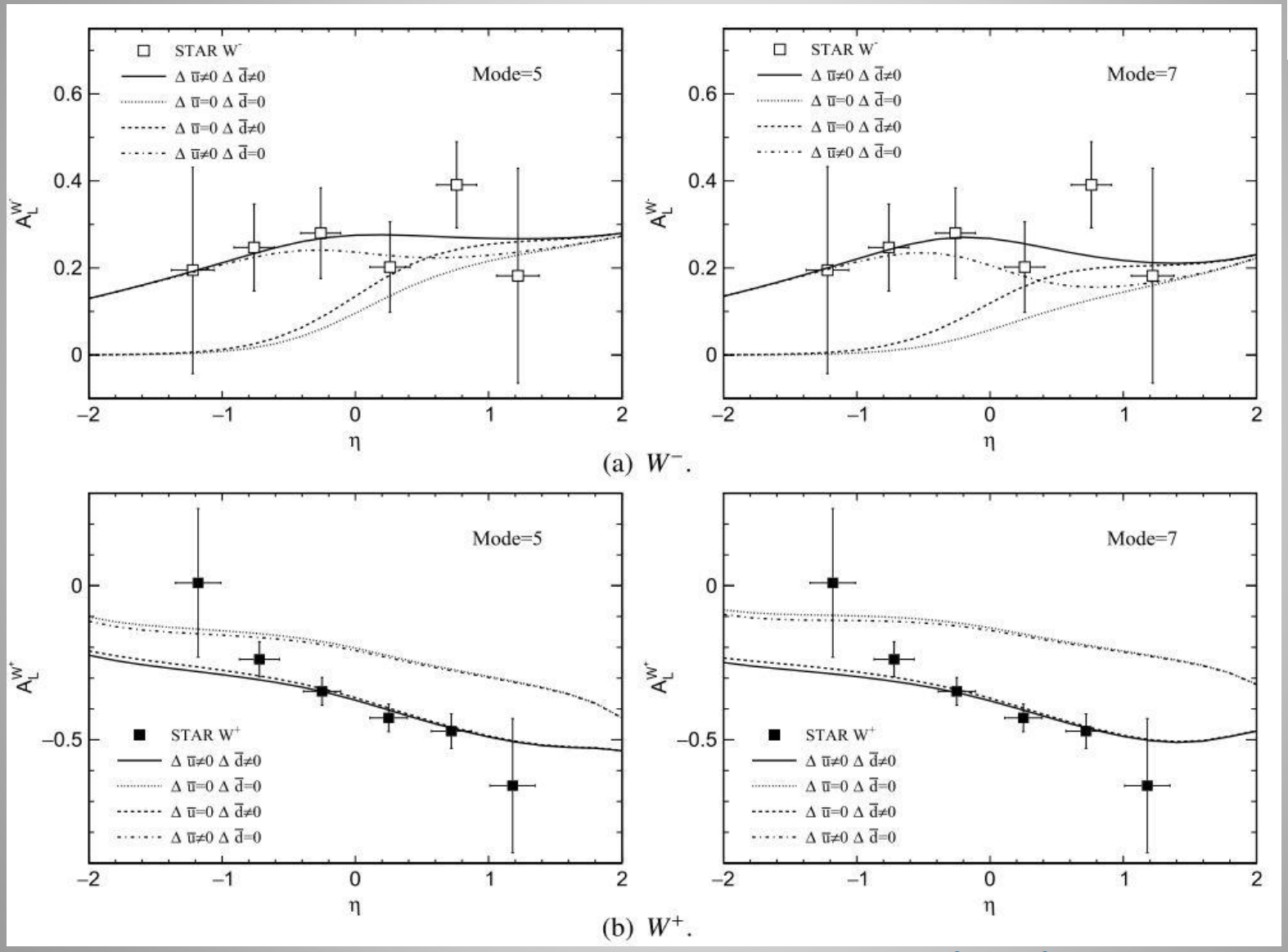
F. Tian, C. Gong, B.-Q. Ma, Nucl.Phys. A961 (2017) 154-168

The linear form (with the constraints of $\Gamma_1^{p,n}$),



F. Tian, C. Gong, B.-Q. Ma, Nucl.Phys. A961 (2017) 154-168

For nonlinear form (without the constraints of $\Gamma_1^{p,n}$),



F. Tian, C. Gong, B.-Q. Ma, Nucl.Phys. A961 (2017) 154-168

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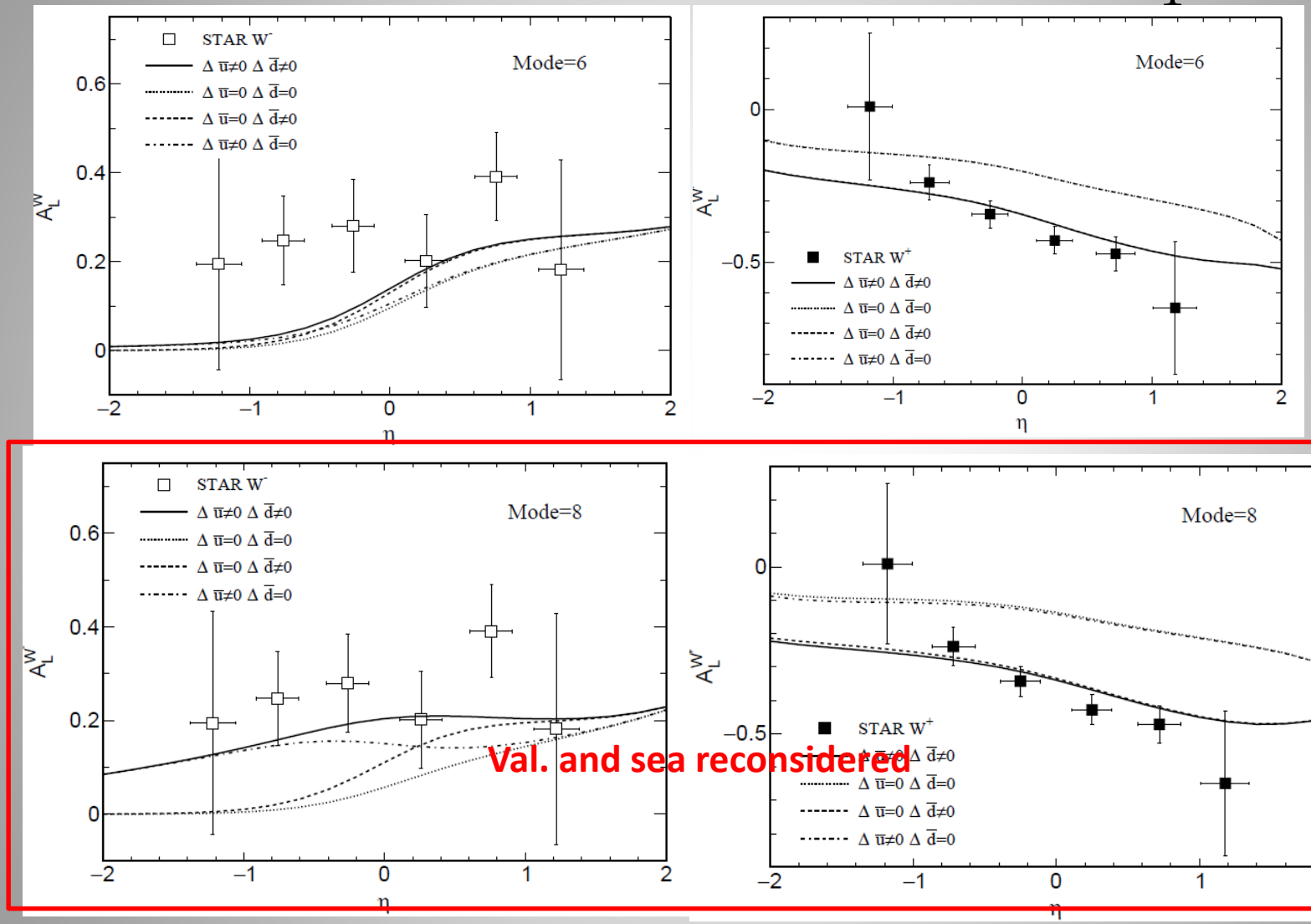

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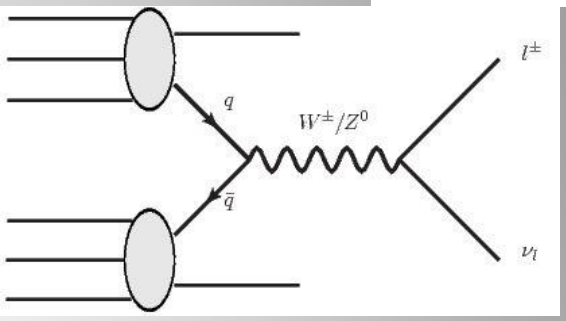
Effect of sea quarks on $A_L^{W^\pm}$

- From mode 1-8, we know that $A_L^{W^\pm}$ need large sizes of sea quark helicity distributions to match the experimental data at RHIC.
- By reconsidering the valence quark helicity distributions in the qD model, corresponding to mode 4 and mode 8, we can see that the results can give both reasonable results of $\Delta\Sigma$ and ${A_L}^{W^\pm}$.
- Comparing mode 4 and mode 8, we can see that the ${A_L}^{W^\pm}$ data have strong constraints on the explicit forms of sea quarks helicity distributions. The x-dependent relation can describe the data better.

F. Tian, C. Gong, B.-Q. Ma, Nucl.Phys. A961 (2017) 154-168

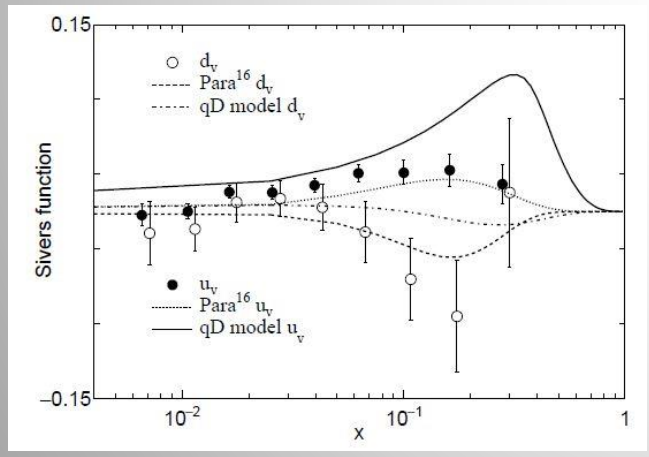
Effect of sea quarks on $A_N^{W^\pm}$

$$A_N = \frac{\sum_q |V_{q\bar{q}'}|^2 \left[\Delta^N f_{a/p\uparrow}(x_1)\cdot f^{\bar{q}'}(x_2) + 1 \leftrightarrow 2\right]}{\sum_q |V_{q\bar{q}'}|^2 \left[f_{a/p}(x_1)\cdot f^{\bar{q}'}(x_2) + 1 \leftrightarrow 2\right]}$$

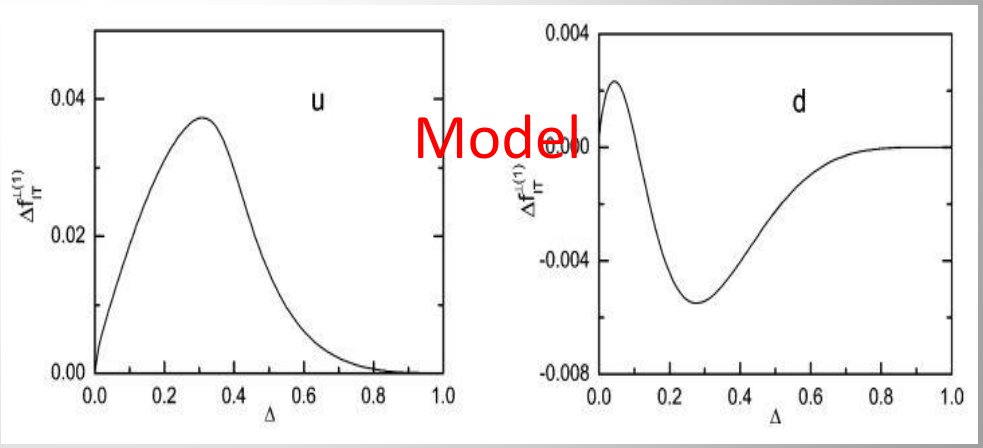


Valence quarks Sivers function:

Parameters



Model



Para^{16}: **M. Anselmino et al, J. High Energy phys. 1704 (2017), 046**

qD model: **Zhun lu, Bo-Qiang Ma, Nucl. Phys. A 741 (2004),200**

Effect of sea quarks on $A_N^{W^\pm}$

- Valence Sivers functions: adopt Para[16] and qD model.
- We extract the sea quark Sivers functions from the transversely single spin asymmetries of $W^\pm$ bosons ${A_N}^{W^\pm}$.

$$f_{q/p}(x,k_\perp) = f_q(x)\,\frac{1}{\pi\langle k_\perp^2\rangle}\,e^{-k_\perp^2/\langle k_\perp^2\rangle}\,,$$

$$\Delta^N f_{q/p^\uparrow}(x,k_\perp) = 2\mathcal{N}_q(x)\,h(k_\perp)\,f_{q/p}(x,k_\perp)\,,$$

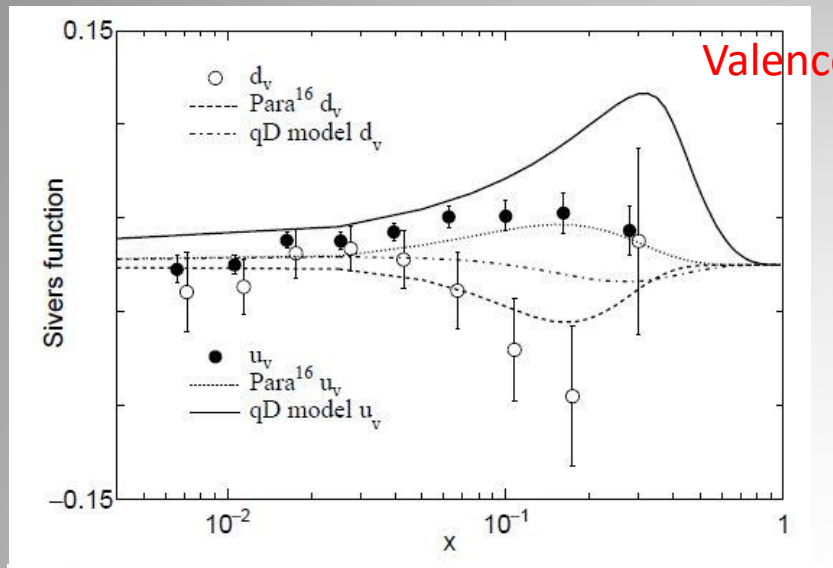
$$\mathcal{N}_q(x) = N_q\,x^{\alpha_q}(1-x)^{\beta_q}\,\frac{(\alpha_q+\beta_q)^{(\alpha_q+\beta_q)}}{\alpha_q^{\alpha_q}\,\beta_q^{\beta_q}}\,,$$

$$h(k_\perp) = \sqrt{2e}\,\frac{k_\perp}{M_1}\,e^{-k_\perp^2/M_1^2}\,,$$

Parameterization forms

$\Delta^N q_V$	Mode	$\langle k_\perp^2\rangle$	Data	Parameter						
				$N_{\bar u}$	$N_{\bar d}$	$\alpha_{\bar u}$	$\alpha_{\bar d}$	$\beta_{\bar u}$	$\beta_{\bar d}$	M_1
Para[16]	1	0.57	$W^\pm$	-1.0	-1.0	4.559	3.265	14.97	14.903	$\sqrt{0.8}$
qD model	2	0.57	$W^\pm$	-1.0	-1.0	3.338	3.293	11.370	14.185	1.241

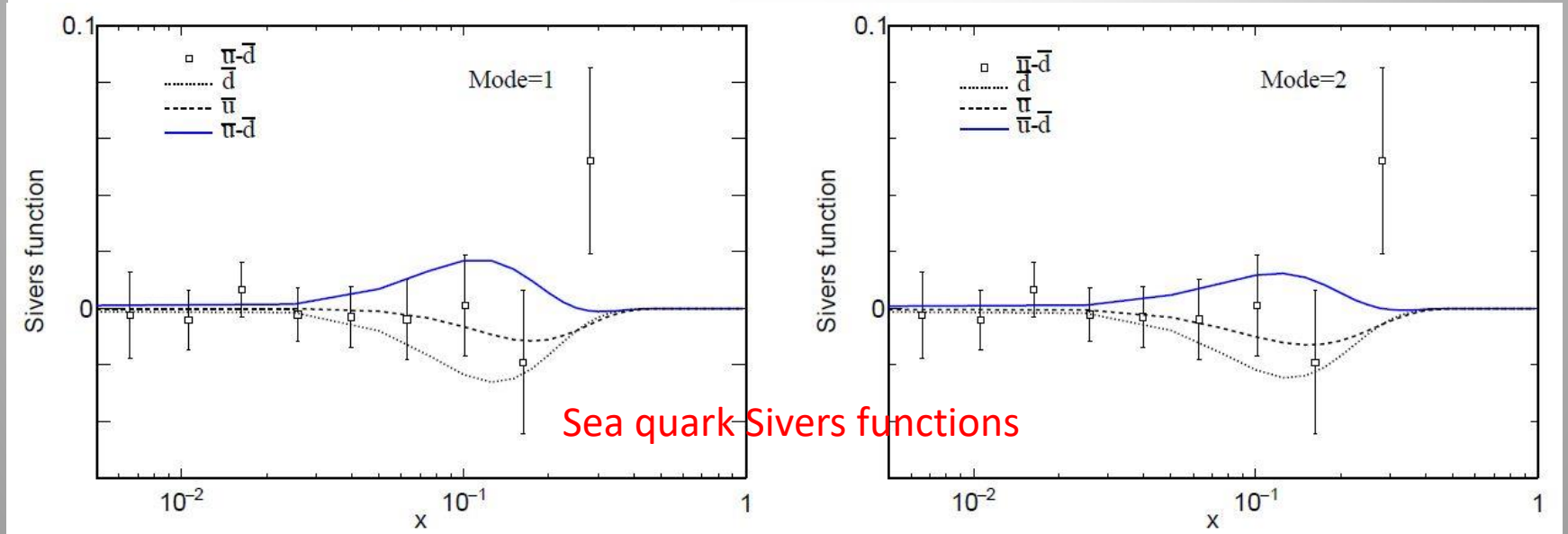
Valence quark Sivers functions



$$f_{1T}^{\perp u_v} > 0 \qquad f_{1T}^{\perp d_v} < 0$$

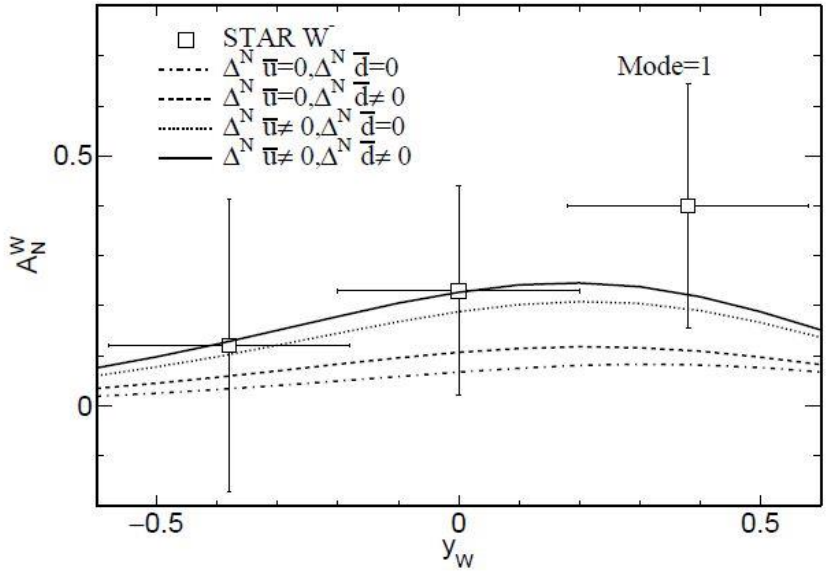
Points: extracted results from
A. Martin et al, Phys. Rev. D 95 (2017) 094024

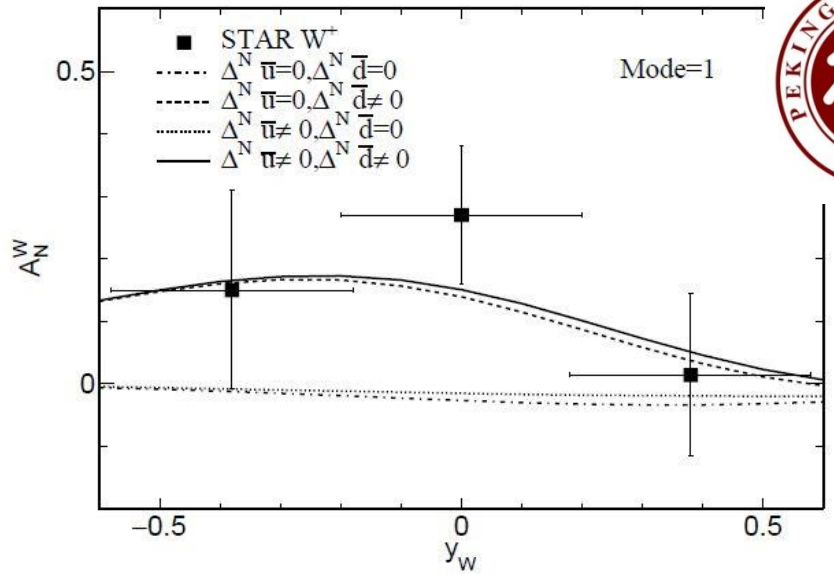
Sea quark Sivers functions



(a) $xf_{1T}^{\perp(1)}(x)$. (b) $xf_{1T}^{\perp(1)}(x)$.

F. Tian, C. Gong, B.-Q. Ma, Nucl. Phys. A968 (2017) 379-390





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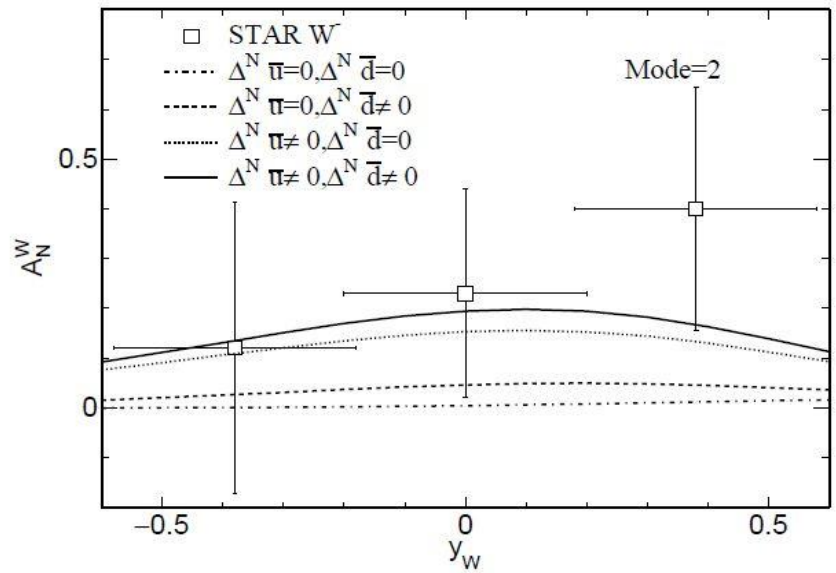
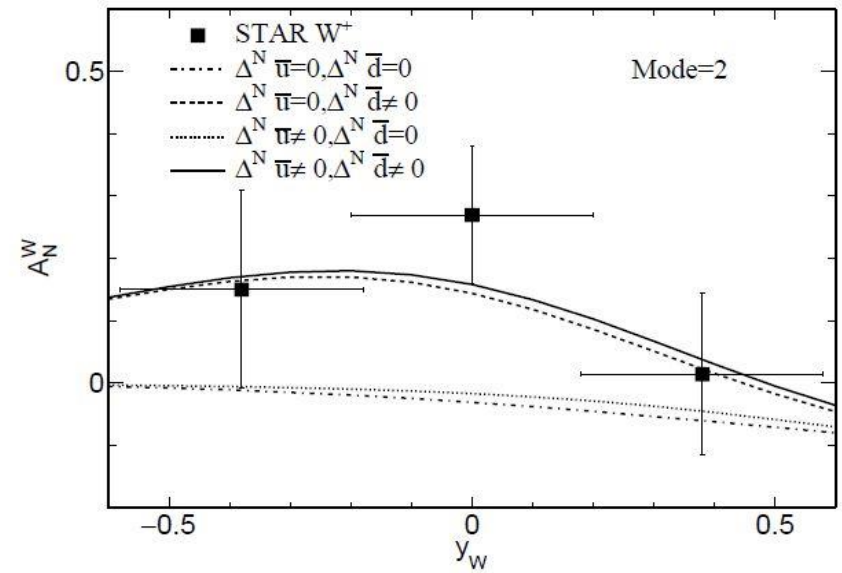
(a) $A^N_{W^-}$.

(b) $A^N_{W^+}$.





(a) $A^N_{W^-}$.

(b) $A^N_{W^+}$.

Effect of sea quarks on $A_N^{W^\pm}$

- The theoretical calculations of $A_N^{W^\pm}$ could match the experimental data with sizable sea quarks Sivers functions.
- The sea quarks Sivers function have the same sign,

$$\Delta^N \bar{u} < 0 \qquad \Delta^N \bar{d} < 0$$

while the sea quarks helicity distributions have different signs,

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

F. Tian, C. Gong, B.-Q. Ma, Nucl.Phys. A968 (2017) 379-390

Summary

- The longitudinal single-spin asymmetry of $W^{\pm}$ are sensitive to the helicity distributions of quarks, especially the sea quarks.
- Further studies of both sea and valence quarks helicity distributions of the nucleon are needed.
- The transversely single-spin asymmetry of $W^{\pm}$ prefer sizable Sivers functions of u and d sea quarks, with both of then have opposite signs to that of valence u Sivers functions.

Thanks!