

First analysis of world polarized DIS+SIDIS data with small- x helicity evolution

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Motivation

Proton spin puzzle:

Determining the angular momentum distribution inside of the proton

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Jaffe-Manohar Spin Sum Rule:

$$\begin{aligned}\text{proton spin} &= \frac{1}{2} \\ &= \mathbf{S}_q + \mathbf{L}_q + \mathbf{S}_G + \mathbf{L}_G\end{aligned}$$

Helicity Parton Distribution Functions (hPDFs)

Quark spin contribution:

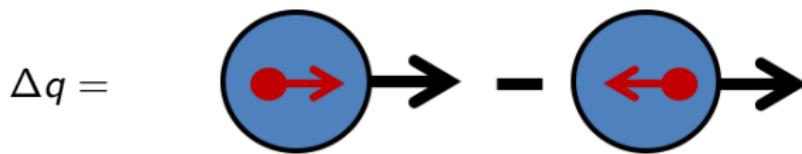
$$S_q(Q^2) = \frac{1}{2} \int_0^1 dx \sum_q (\Delta q(x, Q^2) + \Delta \bar{q}(x, Q^2))$$

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Helicity PDFs:



- Q^2 resolution at which we probe the proton
- $x \propto \frac{1}{s}$, we need theory to find the dependence of

Outline

- Using first principles QCD, we are able to describe the small- x evolution of helicity PDFs

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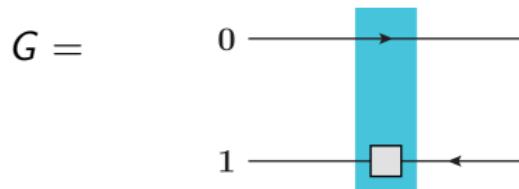
- Using first principles QCD, we are able to describe the small- x evolution of helicity PDFs
- This evolution requires that an initial condition be fit to data
- We use the JAM framework to determine the parameters of the initial condition
- Resulting in the successful description of polarized DIS and Semi-inclusive DIS data
- Allowing for the extraction of hPDFs and the computation of $S_q(x, Q^2)$

Calculating Helicity Distributions

Helicity distributions are computed from the polarized dipole amplitude

$$\Delta q^{+/-}(x, Q^2) = \frac{N_c}{2\pi^3} \int_0^{\ln \frac{Q^2}{x\Lambda^2}} d\eta \int_{\max\{0, \eta - \ln \frac{1}{x}\}}^{\eta} ds_{10} G_q^{S/NS}(s_{10}, \eta)$$

$$\Delta q^+ = \Delta q + \Delta \bar{q}, \quad \Delta q^- = \Delta q - \Delta \bar{q}$$



- Rapidity, $\eta = \ln \frac{zs}{\Lambda^2}$, z = momentum fraction of quark
- Log of transverse momentum, $s_{10} = \ln \frac{1}{x_{10}^2 \Lambda^2}$, x_{10} separation between quarks

Kovchegov Pitonyak Sievert (KPS) Evolution

The polarized dipole amplitude evolves through small- x helicity (KPS¹) evolution

In the large N_c limit, evolution closes:

$$G_q^S(s_{10}, \eta) = G_q^{S(0)}(s_{10}, \eta) + \frac{\alpha_s N_c}{2\pi} \int_{s_{10}}^{\eta} d\eta' \int_{s_{10}}^{\eta'} ds_{21} \left[\Gamma_q(s_{10}, s_{21}, \eta') + 3G_q^S(s_{21}, \eta') \right]$$

¹(Kovchegov, Pitonyak, Sievert: (2016), (2017), (2017), (2017), (2017); Kovchegov & Sievert: (2019); Kovchegov & Cougoulic :(2019))

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- $G_q^{S(0)}(s_{10}, \eta)$ is a flavour dependent initial condition that is fit to data.
- $G_q^{S(0)}(s_{10}, \eta) = a_q \eta + b_q s_{10} + c_q$

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Non-Singlet Evolution

$$G_q^{NS}(x_{10}^2, zs) = G_q^{NS(0)}(s_{10}, \eta) + \frac{\alpha_s N_c}{4\pi} \int_0^\eta d\eta' \int_{s_{10}-\eta+\eta'}^{\eta' ds_{21}} G_q^{NS}(s_{21}, \eta')$$

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Mid-talk recap

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To determine $G_q^{S(0)}$, we need G_q^{NS}

Constraining the initial condition

What enters observables are linear combinations of hPDFS

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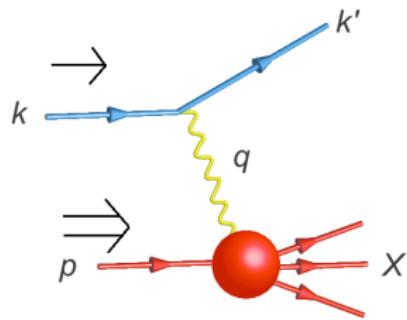
- D_q^h is the fragmentation function, taken from JAM fits
- 2 projectiles (proton neutron), 2 measured hadrons (pions, kaons) that have 2 different charges \rightarrow 8 new constraints

Fitting to data

Observables predicted by our formalism: Double spin asymmetries in DIS

$$A_{||} = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} \propto A_1 \propto g_1$$

- ↑ (↓) is Positive (negative) helicity electron
- ↑ (↓) is Positive (negative) helicity proton
- A_1 is a virtual photoproduction asymmetry



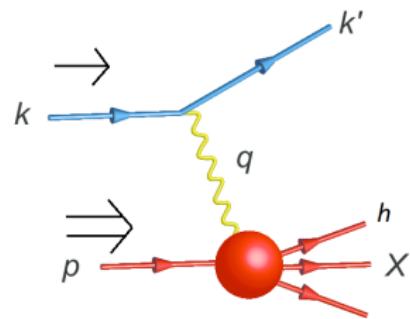
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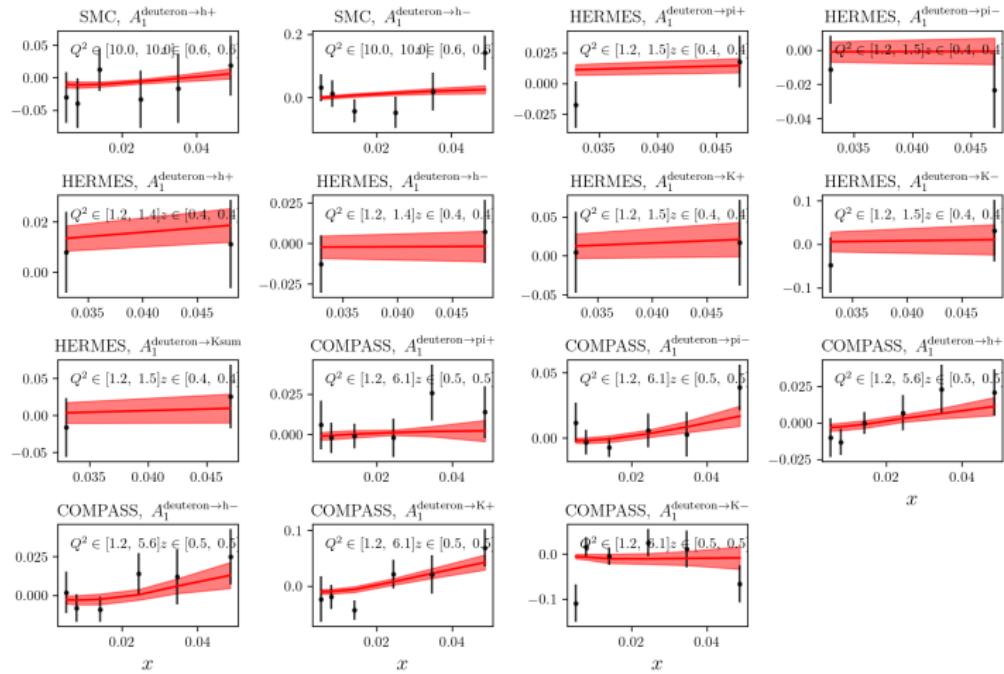
$$A_{||}(z) = \frac{\sigma^{\uparrow\downarrow} - \sigma^{\uparrow\uparrow}}{\sigma^{\uparrow\downarrow} + \sigma^{\uparrow\uparrow}} \propto g_1^h(z)$$

h is the tagged outgoing hadron

z is the momentum fraction of the virtual photon carried by the tagged hadron



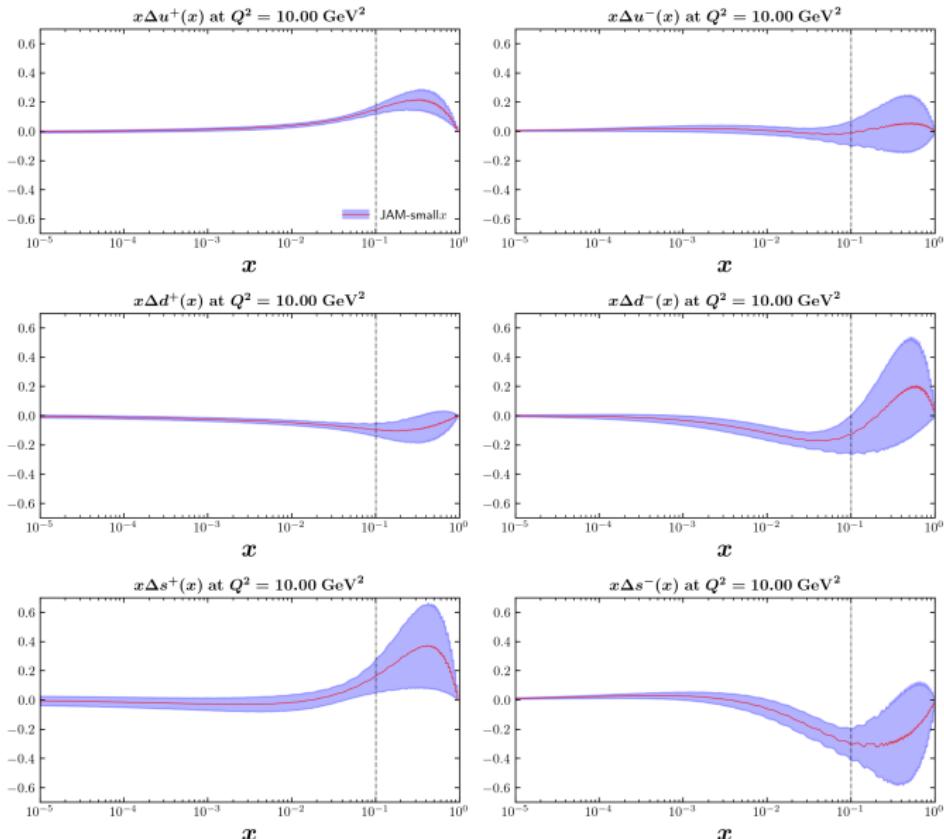
Fitting to SIDIS data



Fitting to data

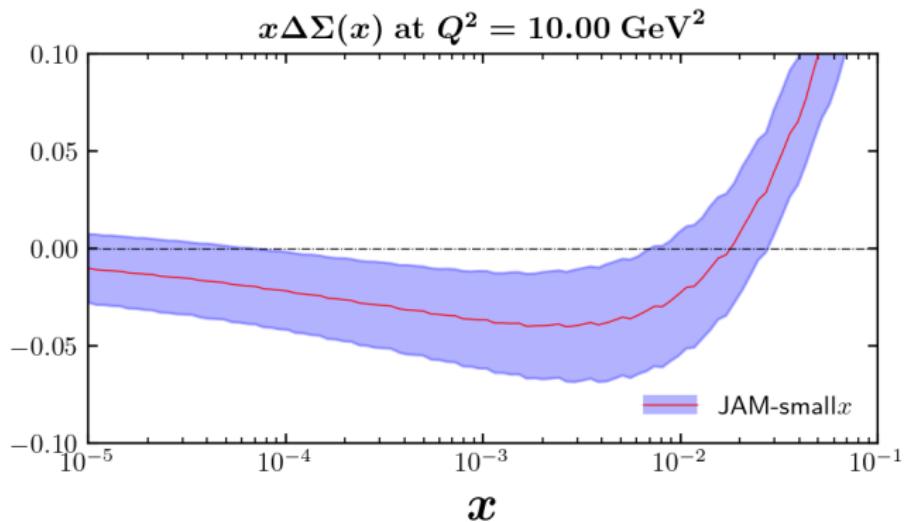
- First simultaneous fit of small- x theory to polarized DIS & SIDIS data
- Cut of $x < 0.1$
- Cut of $1.0 < Q^2 < 10.4$
- Cut of $0.2 < z < 1.0$
- Describing 234 data points
- With a $\chi^2/npts = 1.01$

(Preliminary) Helicity PDFs



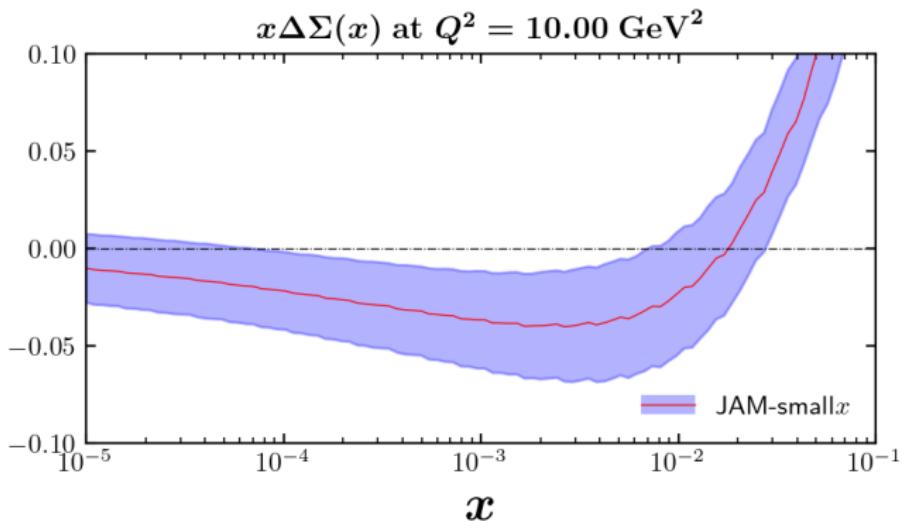
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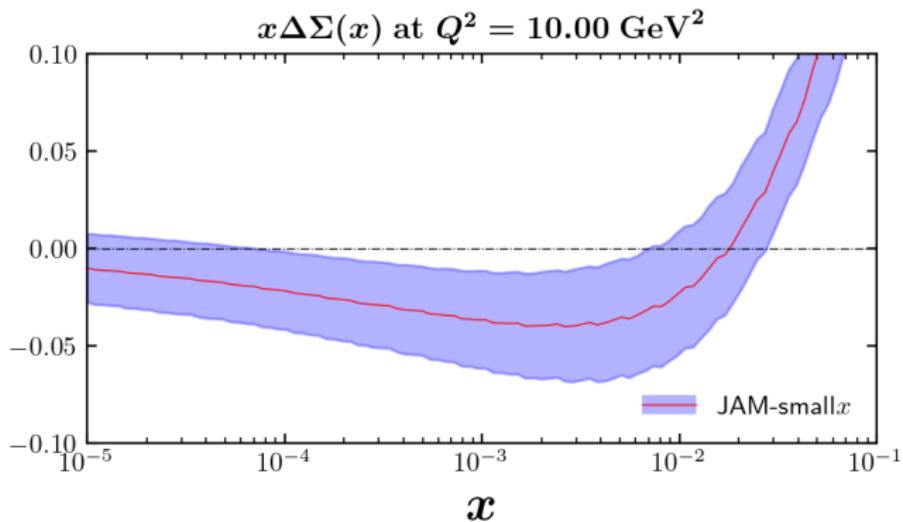
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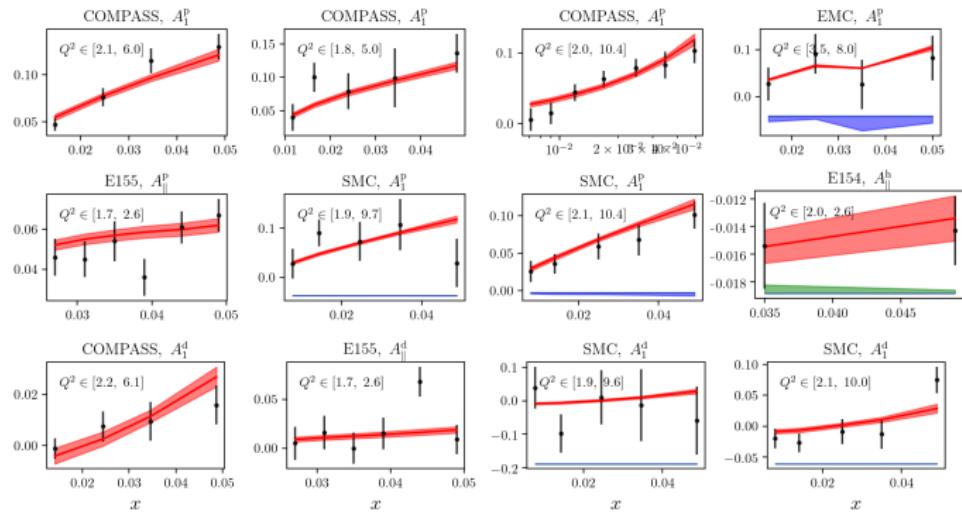
- (Preliminary) $\int_{10^{-5}}^{10^{-3}} dx \Delta\Sigma(x) = 0.1 \pm 0.1$
- Good control over the uncertainty!

Conclusions

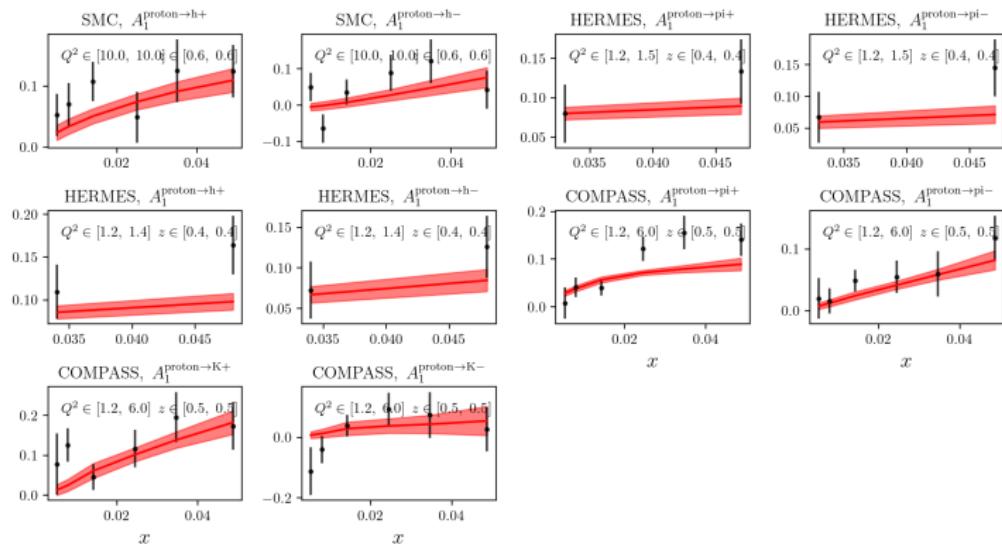
- We have a theory that describes the hPDFs in terms of the polarized dipole amplitude
- Performed the first small- x fit of world polarized DIS and SIDIS data
- Predicted Δq^\pm and $\Delta \Sigma$ down to $x = 10^{-5}$
- While maintaining control over the uncertainty
- In the future, incorporate higher order corrections to the theory and perform an EIC impact study

Thank you!

Backup - DIS data



Backup - more SIDIS data



Backup - more SIDIS data

