

JAM-small \times Helicity Phenomenology

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QCD Evolution 2021

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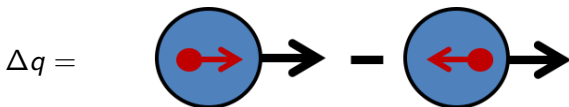
- Using first principles QCD, we are able to describe the small- x evolution of helicity PDFs
- This evolution requires that an initial condition be fit to data
- We use the JAM framework to determine the parameters of the initial condition
- Resulting in the successful description of existing proton and neutron g_1 structure functions
- as well as predictions for measurements to be made at the EIC

Proton Spin Puzzle and hPDFs

Jaffe-Manohar Spin Sum Rule:

$$\frac{1}{2} = \mathbf{S}_q + L_q + S_G + L_G$$

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

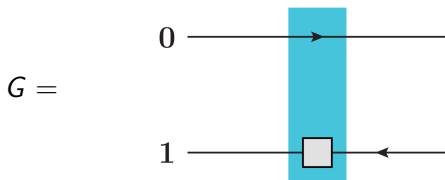


- Q^2 resolution at which we probe the proton
- $x \propto \frac{1}{s}$, we need theory to find the dependence of

Calculating Helicity Distributions

Helicity distributions are computed from the polarized dipole amplitude

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



- 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

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

In the large N_c limit, evolution closes:

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

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

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- $\Gamma_q(s_{10}, s_{21}, \eta')$ is an auxiliary function which obeys a separate integral equation that mixes with G .

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- $\Gamma_q(s_{10}, s_{21}, \eta')$ is an auxiliary function which obeys a separate integral equation that mixes with G .
- $G_q^{(0)}(s_{10}, \eta)$ is a flavour dependent initial condition that is fit to data.
- $G_q^{(0)}(s_{10}, \eta) = a_q \eta + b_q s_{10} + c_q$

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Constraining the initial condition

What enters observables are linear combinations of hPDFS

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- Three relevant hPDFs in DIS: Δu^+ , Δd^+ and Δs^+
- Three observables that contain these hPDFs in linearly independent combinations: g_1^P , g_1^N and $g_1^{\gamma Z}$.
- Only have data for g_1^P and g_1^N

$$g_1^P(x, Q^2) = \frac{1}{2} \sum_q Z_q^2 \Delta q^+(x, Q^2)$$

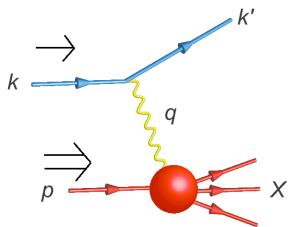
Observables predicted by our formalism: Double spin asymmetries in DIS

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

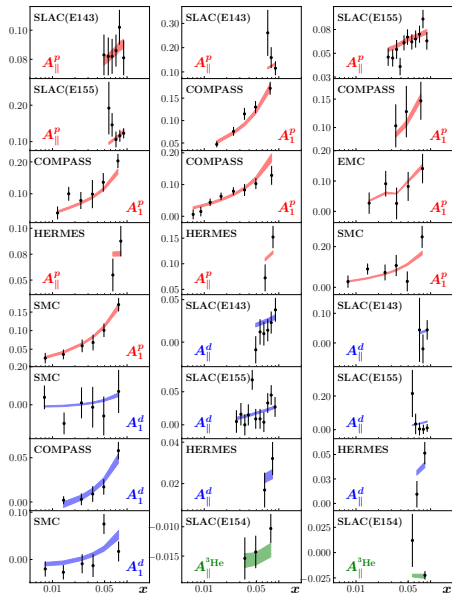
\uparrow (\downarrow) is Positive (negative) helicity electron

\uparrow (\downarrow) is Positive (negative) helicity proton

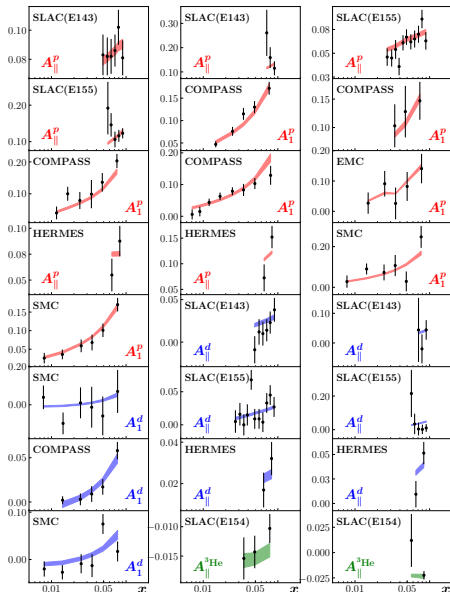
A_1 is a virtual photoproduction asymmetry



Fitting to data

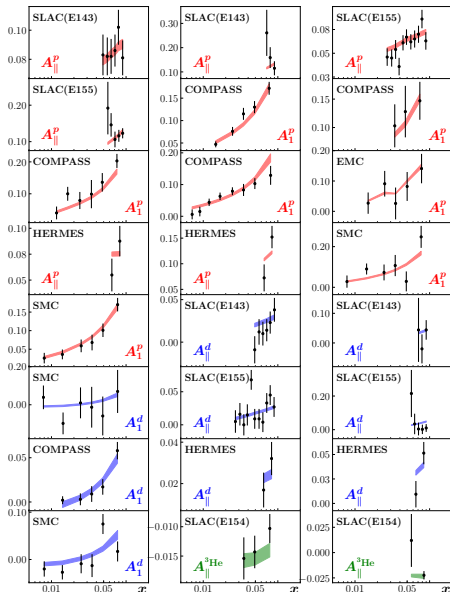


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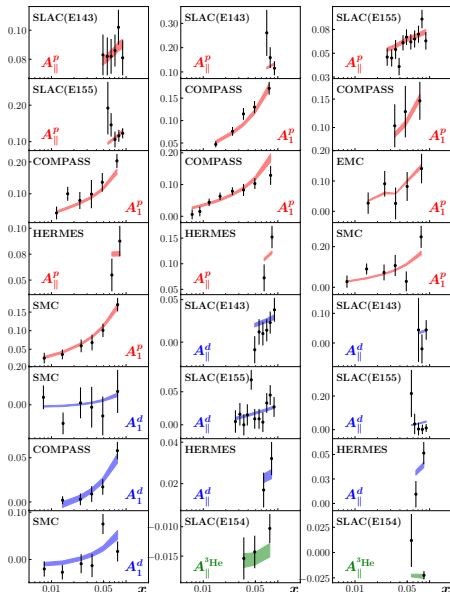
- First fit of small- x theory to polarized data
- With a cut of $x < 0.1$

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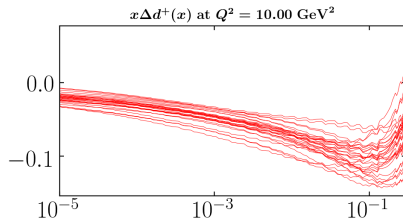
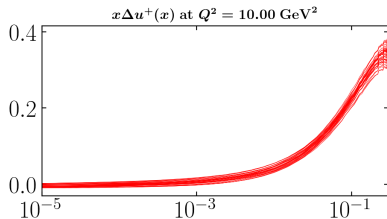
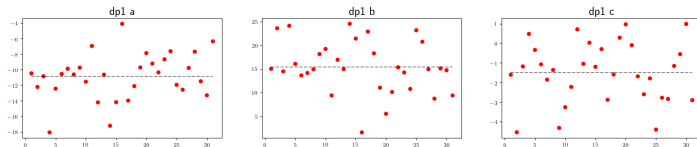
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- We re-sum $\alpha_s \ln^2 \frac{1}{x}$, which allows us to start at larger x than unpolarized DIS (which resums $\alpha_s \ln \frac{1}{x}$)

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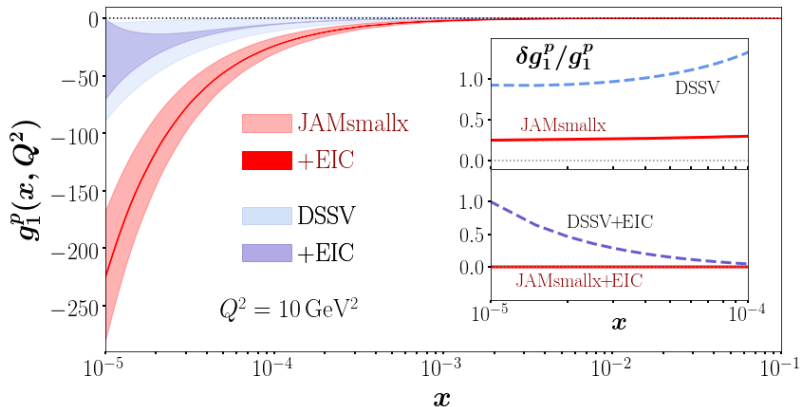


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- $\chi^2/npts = 1.01$

Monte-Carlo generation of parameters that tend towards minimum χ^2



Predictions for Electron Ion Collider

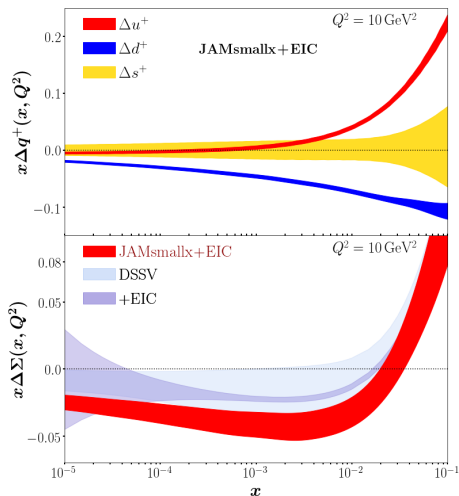


- Predict large negative g_1
- Significant improvement in error from EIC

Helicity PDFs

Preliminary extraction of hPDFs and $\Delta\Sigma = \sum_q \Delta q^+(x, Q^2)$

(EIC pseudo data generated assuming $\Delta s^+ = 0$, then fitted with $\Delta s^+ \neq 0$)



- 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 data
- Predicted g_1 down to $x = 10^{-5}$
- While maintaining control over the uncertainty
- Preliminary extraction of the small- x hPDFs and quark spin contribution

Thank you!