

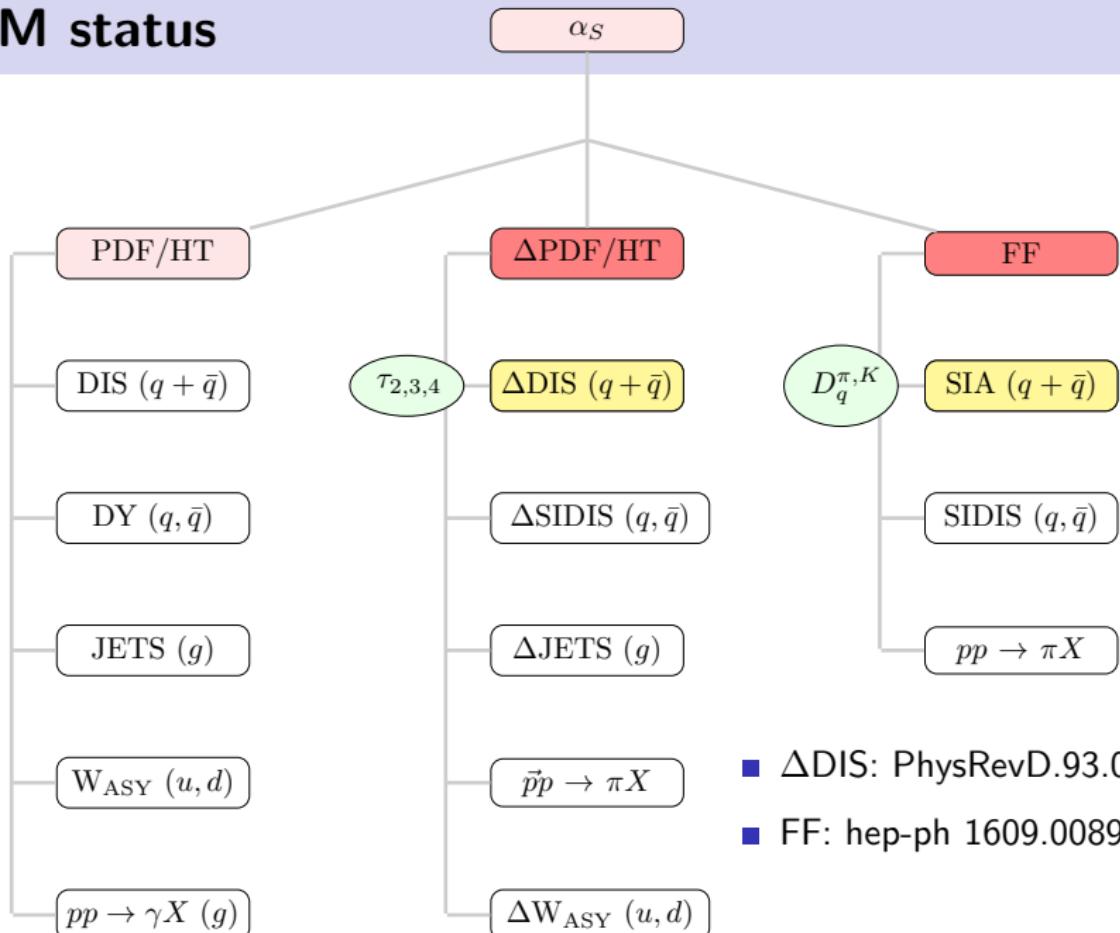
New global QCD analysis of spin dependent parton distribution functions and fragmentation functions

Nobuo Sato



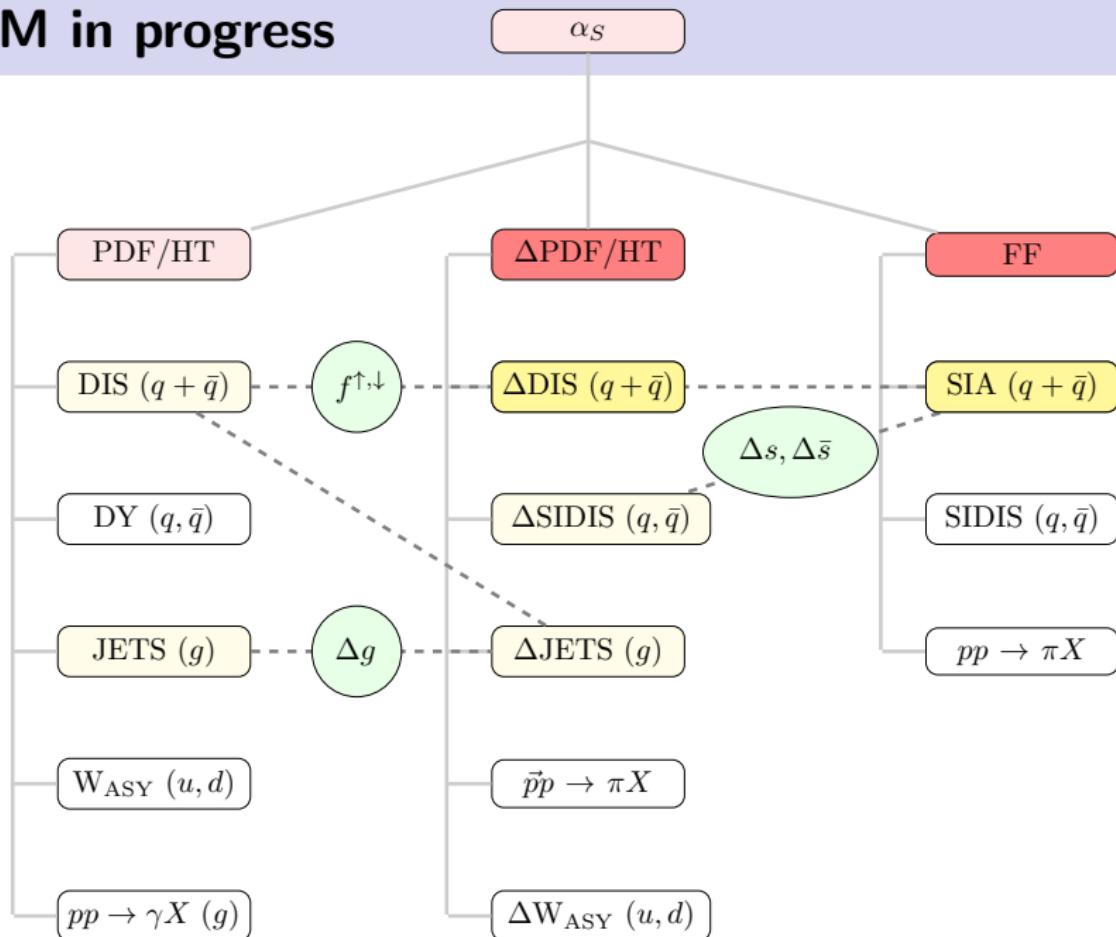
22nd International SPIN Symposium, 2016

JAM status



- ΔDIS: PhysRevD.93.074005
- FF: hep-ph 1609.00899

JAM in progress



Theory of fitting

The goal is to estimate:

$$\text{E}[\mathcal{O}] = \int d^n a \quad \mathcal{P}(a|data) \quad \mathcal{O}(a)$$

$$\text{V}[\mathcal{O}] = \int d^n a \quad \mathcal{P}(a|data) \quad [\mathcal{O}(a) - \text{E}[\mathcal{O}]]^2$$

- $\mathcal{O} = \Delta q, D_q^h, \dots$
- $\sqrt{V[\mathcal{O}]} = 1\sigma$
- $a \rightarrow$ PDF/FF parameters
- $\mathcal{P}(a|data) \propto \mathcal{L}(data|a)\pi(a)$
- $\mathcal{L}(data|a) \propto \exp\left(-\frac{1}{2}\chi^2(a)\right)$
- $\chi^2(a) = \sum_i \left(\frac{D_i - T_i(a)}{\delta D_i}\right)^2$
- $\pi(a) \rightarrow priors.$ i.e $\prod_i \theta(a_i - a_i^0)$

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- $\pi(a) \rightarrow$ priors. i.e $\prod_i \theta(a_i - a_i^0)$
- How to evaluate $E[\mathcal{O}], V[\mathcal{O}]?$

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Monte Carlo methods

Maximum Likelihood

- $\mathcal{P}(a|data) \rightarrow \{a_k\}$
- $E[\mathcal{O}] \approx \frac{1}{N} \sum_k \mathcal{O}(a_k)$
- $V[\mathcal{O}] \approx \frac{1}{N} \sum_k [\mathcal{O}(a_k) - E[\mathcal{O}]]^2$
- Maximize $\mathcal{P}(a|data) \rightarrow a_0$
- $E[\mathcal{O}] \approx \mathcal{O}(a_0)$
- $V[\mathcal{O}] \approx$ hessian, $\Delta\chi^2$ envelope, ...

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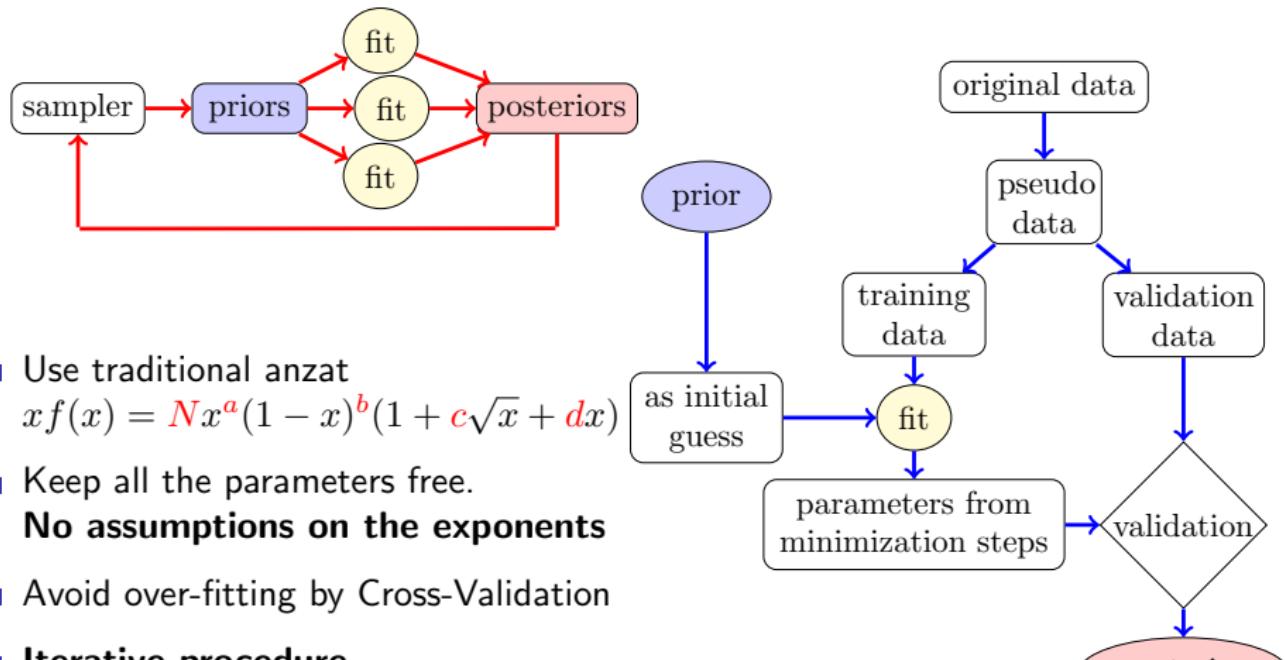
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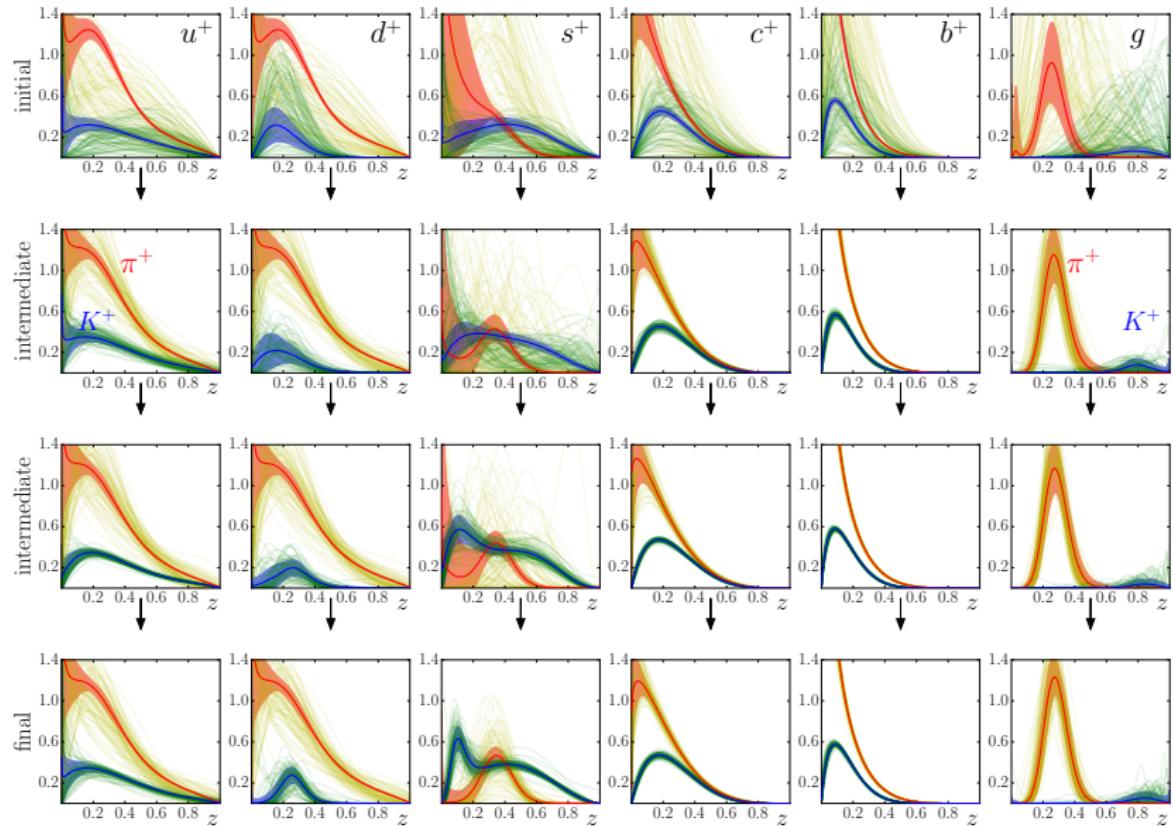
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- $V[\mathcal{O}] \approx \text{hessian}, \Delta\chi^2 \text{ envelope}, \dots$

Iterative Monte Carlo analysis (IMC)



- Use traditional anzat
 $xf(x) = Nx^a(1-x)^b(1+c\sqrt{x}+dx)$
- Keep all the parameters free.
No assumptions on the exponents
- Avoid over-fitting by Cross-Validation
- **Iterative procedure**
→ Adaptive MC integration (like in Vegas)
- Robust estimation of uncertainties

IMC in action (FF case)

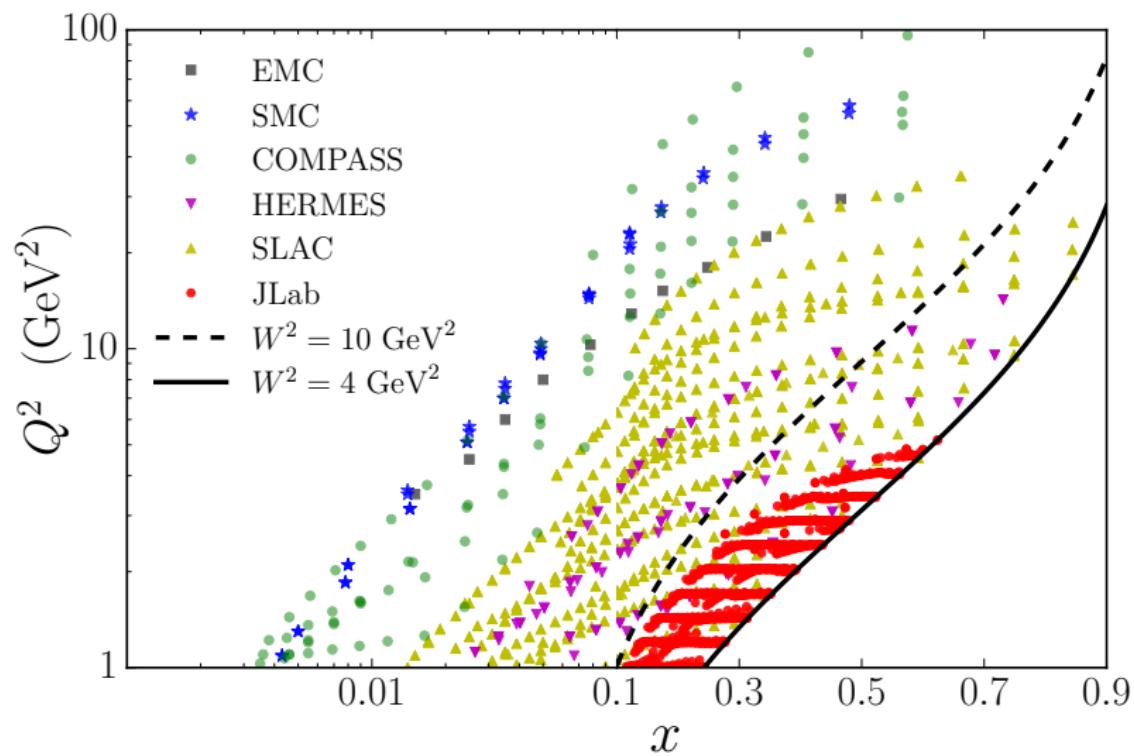


Spin PDFs from polarized DIS

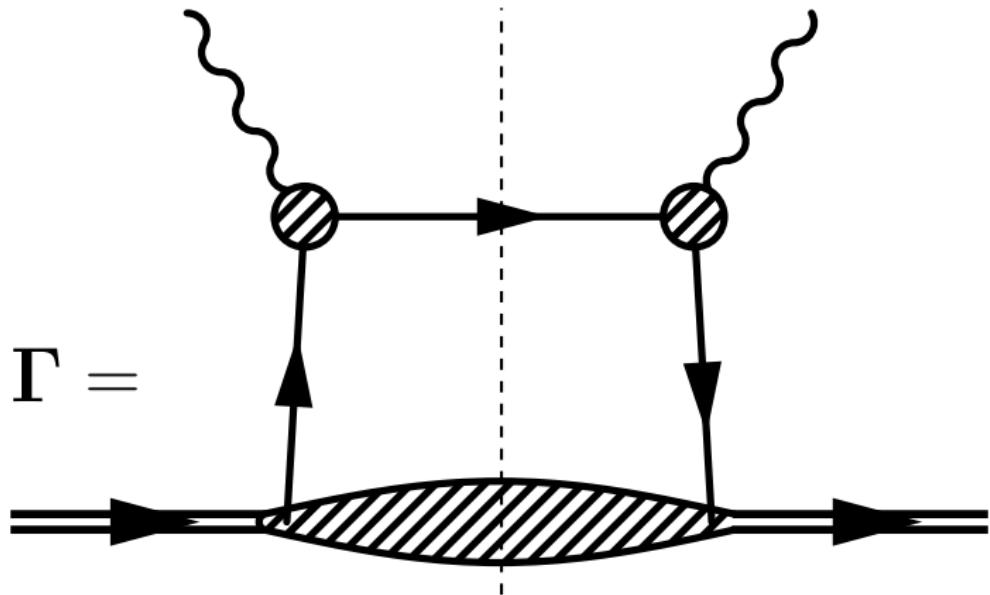
In Collaboration with:

- J. J. Ethier (College of William and Mary)
- W. Melnitchouk (Jefferson Lab)
- A. Accardi (Hampton U. and Jefferson Lab)
- S. E. Kuhn (Old Dominion U.)

Global polarized DIS data



Theory framework Collinear Factorization



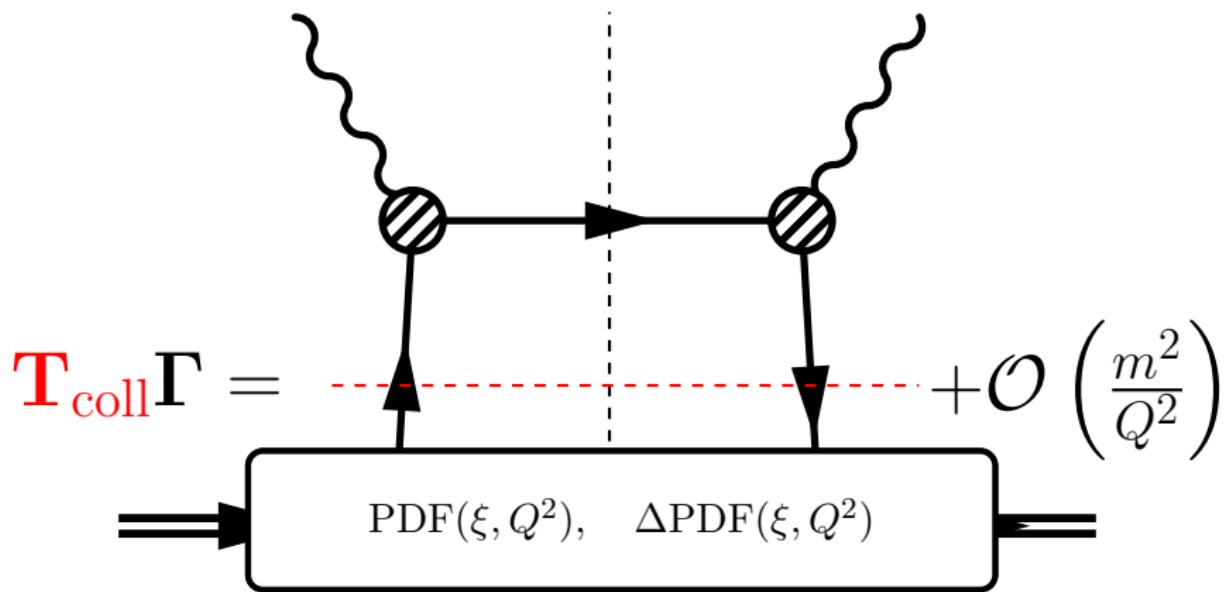
Theory framework Collinear Factorization

$$T_{\text{coll}} \Gamma = \text{---} + \mathcal{O}\left(\frac{m^2}{Q^2}\right)$$

A Feynman diagram illustrating collinear factorization. The diagram shows a process where a particle (represented by a horizontal line with arrows) enters from the left, splits into two paths, and then recombines. The regions where the momenta of the particles become collinear are shaded with diagonal lines. A dashed red line and a vertical dashed line divide the diagram into regions of different scales.

- m is a SMALL hadronic mass scale
- Q (mass of γ^*) is a LARGE scale

Theory framework Collinear Factorization



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Polarized DIS @ small $Q^2 \simeq 1$ and high- x_{bj}

- Collinear factorization:

$$\Gamma \approx \mathbf{T}_{\text{coll}} \Gamma + \mathcal{O} \left(\frac{m^2}{Q^2} \right)$$

- “Extensions”
 - Target mass corrections (TMC). [Georgi,Politzer]
 - Higher twist [Blümlein,Tkabladze]
 - Nuclear corrections for ${}^3\text{He}$ and deuteron targets
 - Threshold corrections from soft gluon radiation

Polarized DIS @ small $Q^2 \simeq 1$ and high- x_{bj}

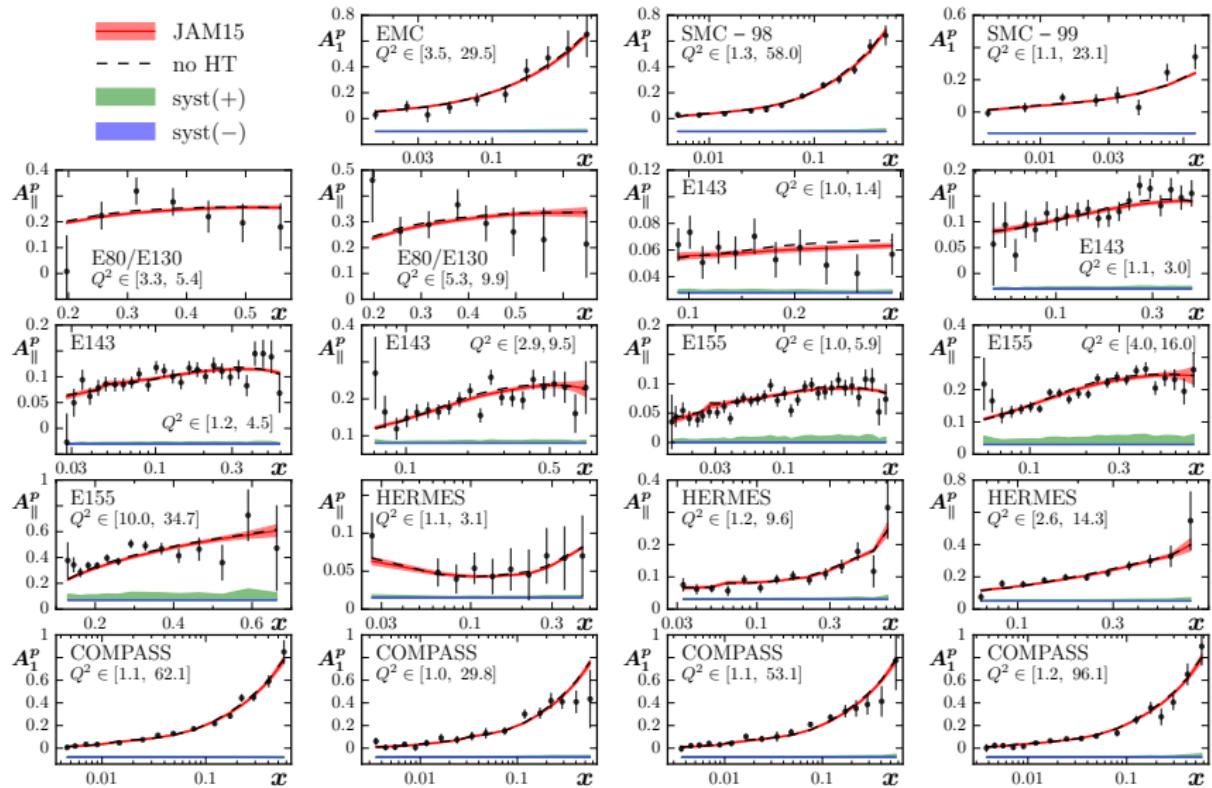
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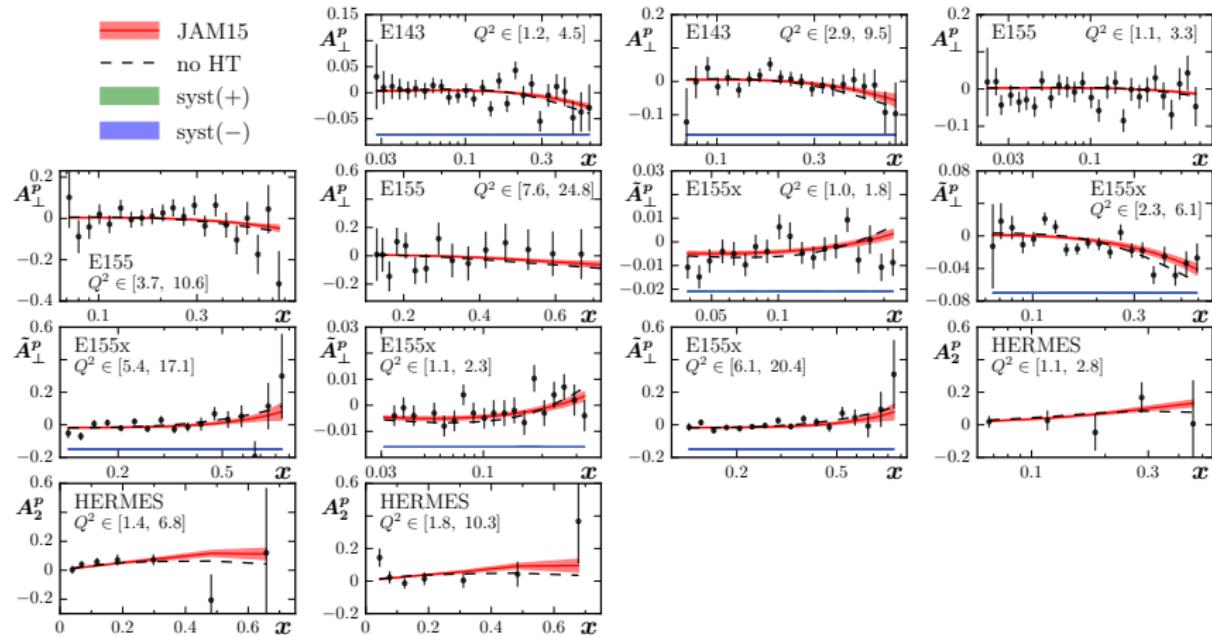
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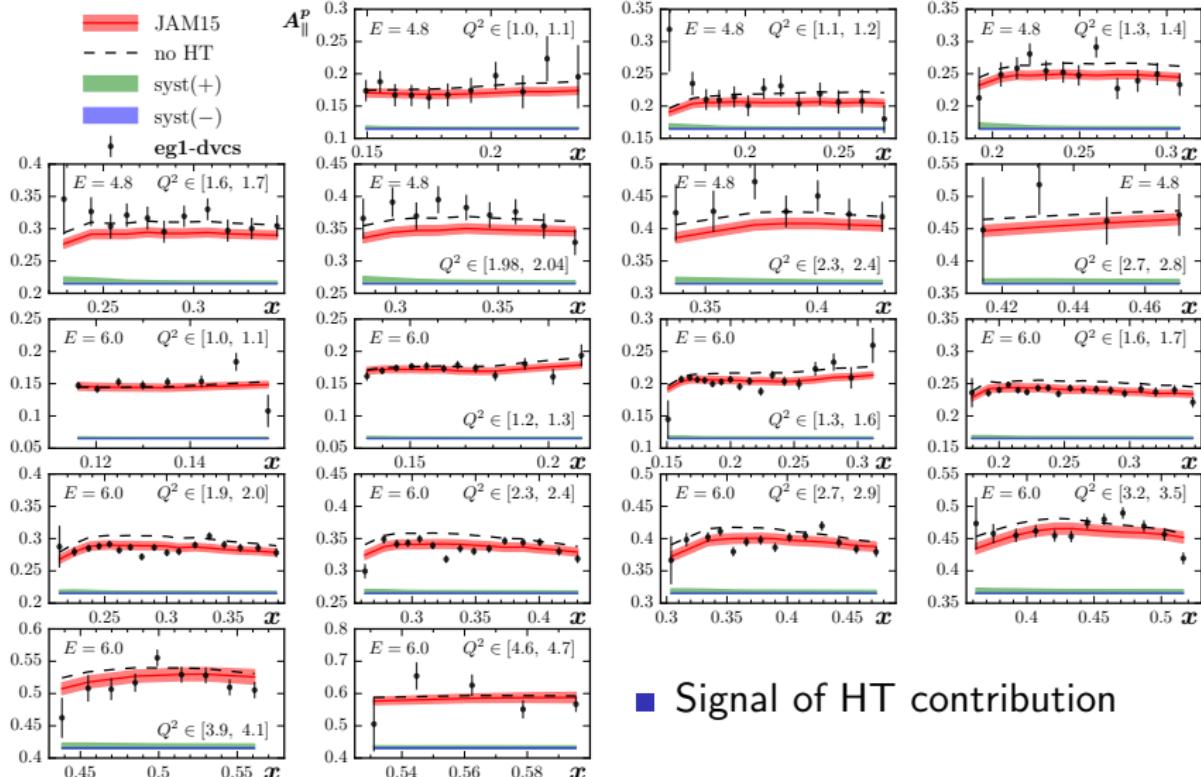
Data vs theory: proton



Data vs theory: proton

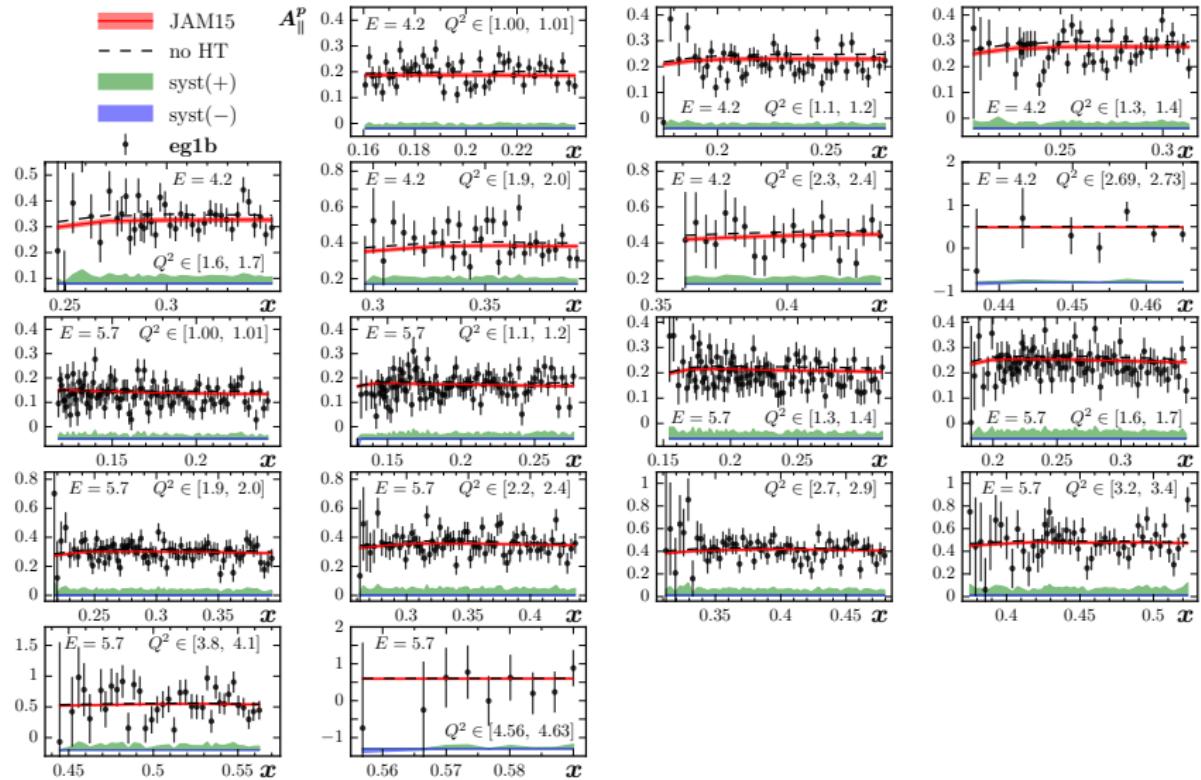


Data vs theory: proton JLab eg1-dvcs

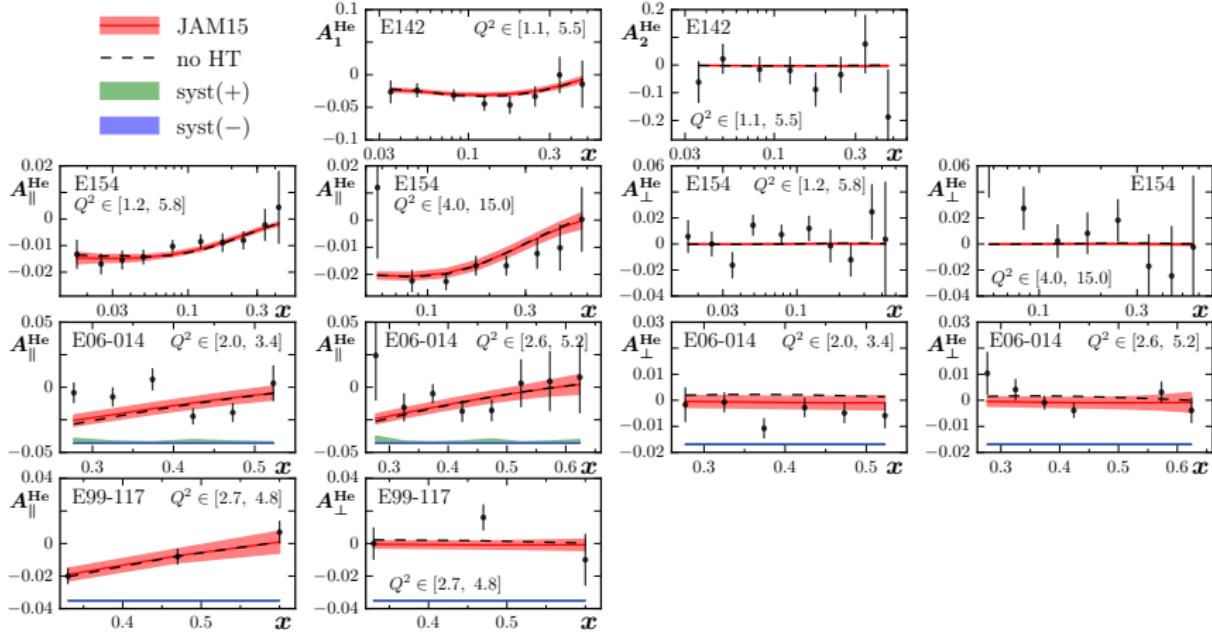


■ Signal of HT contribution

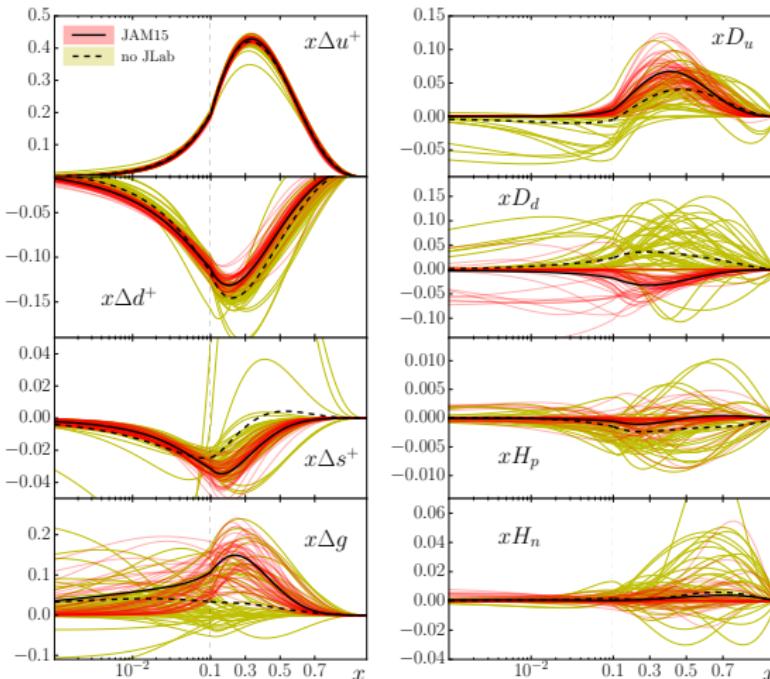
Data vs theory: proton JLab eg1b



Data vs theory: ^3He

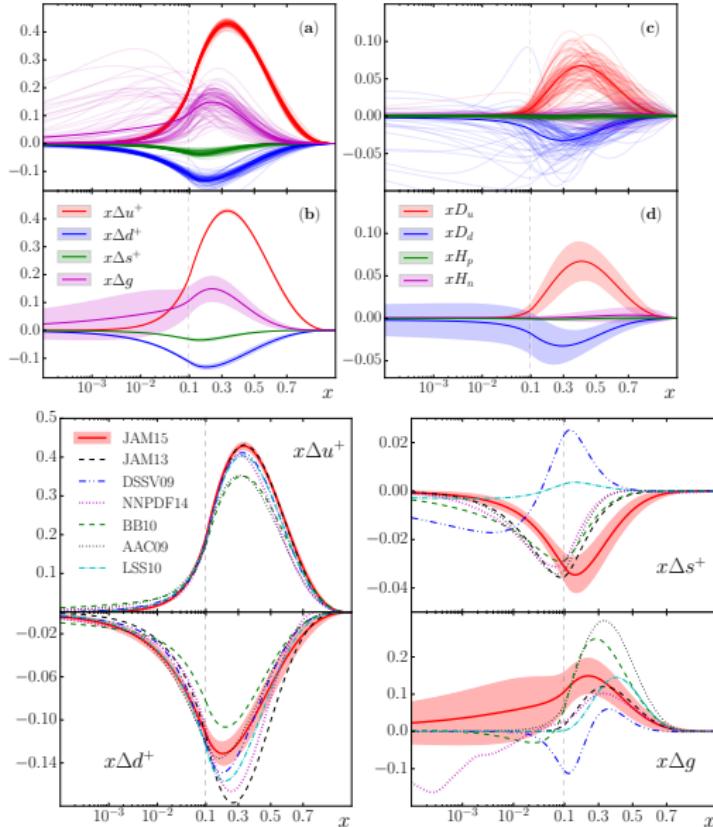


Impact of JLab data



- JLab data $\rightarrow 0.1 < x < 0.7$
- Constraints on small x from large $x \rightarrow$ weak baryon decay constraints
- Large uncertainties in Δs^+ , Δg removed by JLab data
- Non vanishing τ_3 quark distributions
- τ_4 distributions consistent with zero

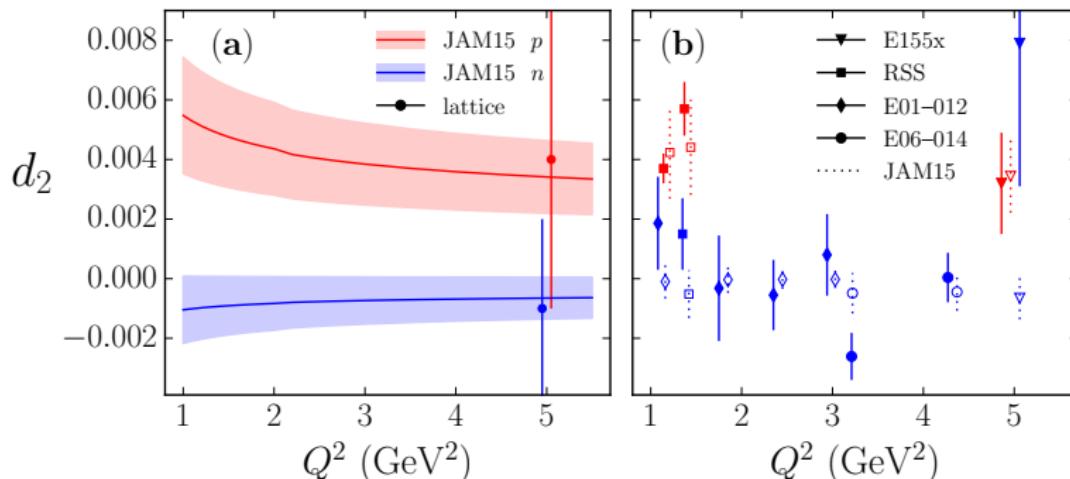
Results



moment	truncated	full
Δu^+	0.82 ± 0.01	0.83 ± 0.01
Δd^+	-0.42 ± 0.01	-0.44 ± 0.01
Δs^+	-0.10 ± 0.01	-0.10 ± 0.01
$\Delta \Sigma$	0.31 ± 0.03	0.28 ± 0.04
ΔG	0.5 ± 0.4	1 ± 15
d_2^p	0.005 ± 0.002	0.005 ± 0.002
d_2^n	-0.001 ± 0.001	-0.001 ± 0.001
h_p	-0.000 ± 0.001	0.000 ± 0.001
h_n	0.001 ± 0.002	0.001 ± 0.003

- $\chi^2/N_{npts} = 1.07$
- Sign of τ_3 distributions is the same as τ_2
- **Negative Δs^+**
- Δg compatible with the most recent DSSV fits
- moments of Δg not constrained.

Results: d_2 matrix element



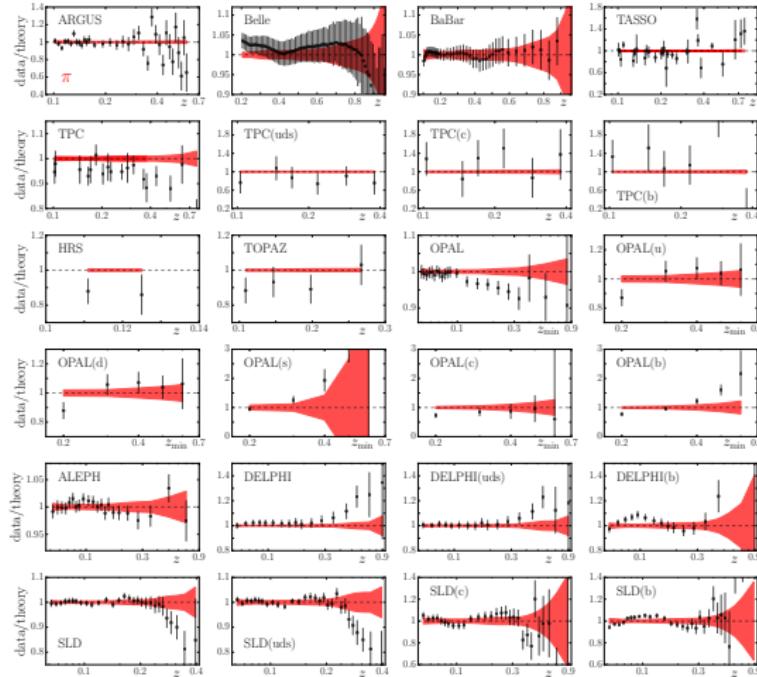
- $d_2(Q^2) \equiv \int_0^1 dx x^2 [2g_1^{\tau_3}(x, Q^2) + 3g_2^{\tau_3}(x, Q^2)]$
- d_2 is related to “color polarizability” or the “transverse color force” acting on quarks
- Existing measurements of d_2 are in the resonance region (contains TMC, τ_4 and beyond)
- Agreement with data indicates quark-hadron duality

Fragmentation Functions from SIA data

In Collaboration with:

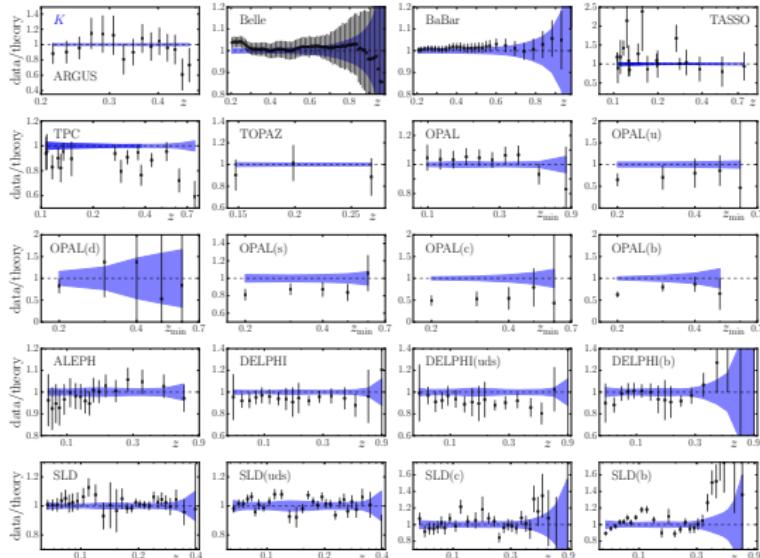
- J. J. Ethier (College of William and Mary)
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- A. Accardi (Hampton U. and Jefferson Lab)
- S.Kumano (KEK, J-PARC)
- M.Hirai (Nippon Institute of Technology)

π analysis ($\chi^2/N_{\text{npts}} = 1.31$)



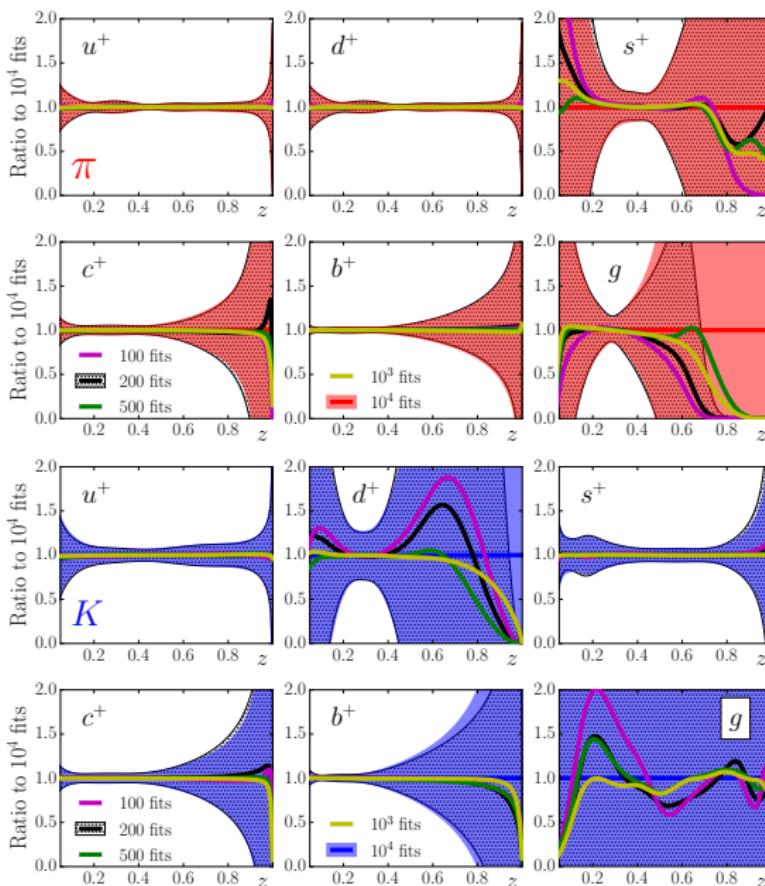
- $z_{\text{cut}} > 0.1$ for low energies
- $z_{\text{cut}} > 0.05$ for high energies
- We use BaBar prompt data set
- Belle data set needs 10% normalization
- Good agreement at low- z for inclusive data sets
- Data inconsistencies at large- z for $Q^2 = M_z^2$

K analysis ($\chi^2/N_{\text{npts}} = 1.01$)



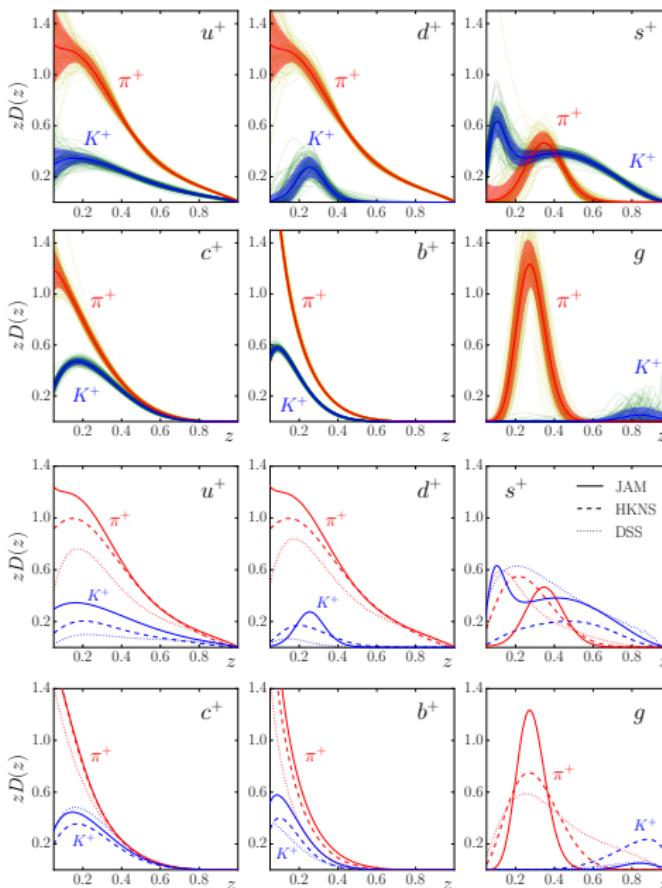
- $z_{\text{cut}} > 0.2$ for low energies to avoid hadron mass corrections
- $z_{\text{cut}} > 0.05$ for high energies
- Smaller χ^2 than π due to larger errors
- Consistent shapes across all z
- Inconsistencies mostly due to normalizations

Fragmentation functions



- Larger constraints on favored FFs than unfavored FFs
- More sensitivity on D_g^π than D_g^K
- D_g^K is unknown
- HQ tagged data provides similar constraints for π and K
- Convergence attained with ~ 200 posteriors

Fragmentation functions



- Similar behavior of unfavored $D_{s^+}^\pi$ and $D_{d^+}^K$
- In contrast the D_g^π and D_g^K behave differently
- The charm and bottom FFs become compatible at large- z
- Favored $D_{u^+}^\pi$ and $D_{s^+}^K$ have similar shape at large- z
- JAM $D_{s^+}^K$ is compatible with DSS. **Will it change the sign of Δs^+ ?**

Outlook

Polarized DIS data

- New JAM analysis to study impact of all JLab 6 GeV inclusive DIS data at low W and high x
- New extraction of LT & HT distributions
- Constraints on d_2

SIA data

- New study of SIA data including recent Belle and BaBar data
- New extraction of fragmentation functions
- The setup for combined pol DIS, SIA and pol SIDIS is ready!

JAMLIB

- JAM SPDFs and FFs are available at [github](#)
- Python, Fortran and LHAPDF interfaces provided

JAM for public

Jefferson Lab Angular Momentum Collaboration

LINKS

- Home
- JAMLIB
- References
- Database
- Talks
- Collaboration
- Links

About

The JAM (Jefferson Lab Angular Momentum) Collaboration is an enterprise involving theorists and experimentalists from the Jefferson Lab community to study the quark and gluon spin structures of the nucleon by performing global fits of spin-dependent parton distribution functions (PDFs).

Because of the unique capabilities of Jefferson Lab's CEBAF accelerator in measuring small cross sections at extreme kinematics, the JAM spin PDFs are particularly tailored for studies of the large Bjorken- x region, as well as the resonance-deep inelastic scattering transition region at low and intermediate values of W^2 and Q^2 .

Library

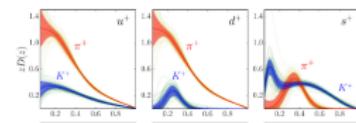
We provide a collection of codes/scripts (in fortran, python, mathematica), along with interpolation tables for the collinear parton distributions in the nucleon, as well as the collinear parton to hadron fragmentation functions. The library is available at [JAMLIB](#).

Theory Framework

Our analysis uses collinear factorization at NLO in perturbative QCD with an emphasis on the large- x region which includes a treatment of higher twist as well as target mass corrections. A treatment of nuclear corrections for deuteron and ${}^3\text{He}$ targets in DIS data sets is included.

Results

Pion and Kaon fragmentation from JAM16



JeffersonLab/JAMLIB

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JAMLIB — Edit

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The repository contains interpolation tables for the collinear parton distribution functions in the nucleon, and the collinear