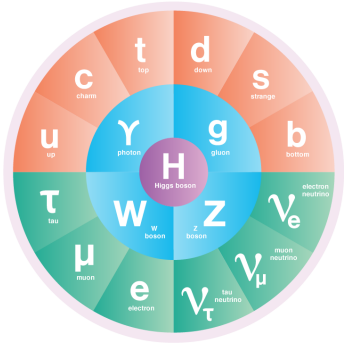
Polarized PDFs from phenomenology

Nobuo Sato
Jefferson Lab

EINN19, Cyprus

The big picture

hadrons as emergent phenomena of QCD



quarks and gluons

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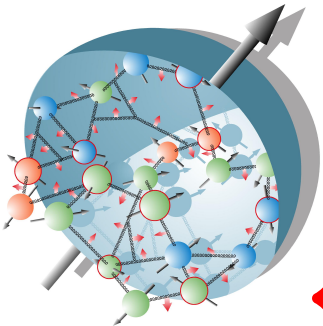
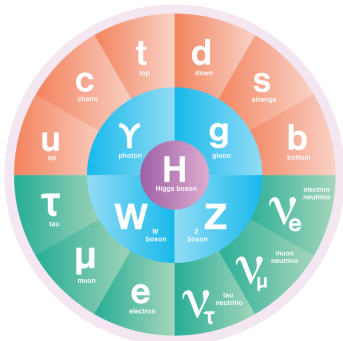


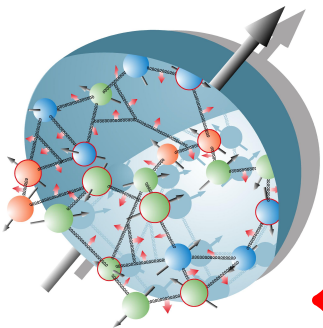


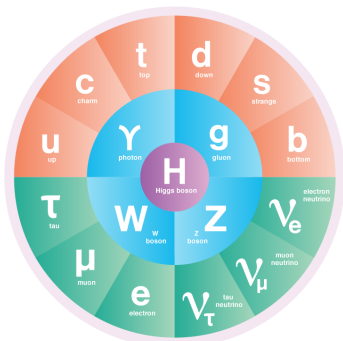
nucleon structure

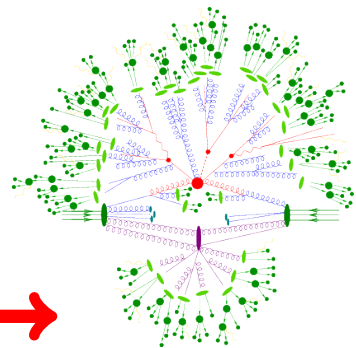
quarks and gluons

The big picture

hadrons as emergent phenomena of QCD







nucleon structure

quarks and gluons

hadronization

The challenge

The challenge

- Quark and gluon d.o.f. **cannot be measured** directly

The challenge

- Quark and gluon d.o.f. **cannot be measured** directly

- Experimental measurements **can be interpreted** in terms of quark and gluon d.o.f.

The methodology

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- Identify relevant quantum correlation functions (QCFs) $\rightarrow$ **PDFs, $\triangle$PDF, FF,...**

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- Identify relevant quantum correlation functions (QCFs) $\rightarrow$ **PDFs, $\triangle$PDF, FF,...**
- Identify and measure observables sensitive to QCFs $\rightarrow$ **factorization**
- Bayesian inference $\rightarrow$ **global analysis**

The community effort

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- Adding/updating experimental/lattice observables

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- Improve soft/hard separation $\rightarrow$ HO corrections

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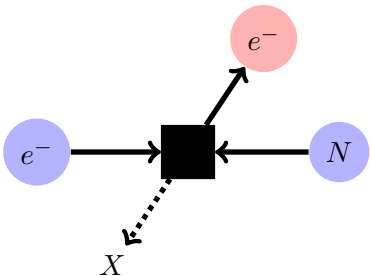
- Adding/updating experimental/lattice observables
- Improve soft/hard separation $\rightarrow$ HO corrections
- Simultaneous extraction of QCFs
- Improving the Bayesian regression

Pheno overview

Valence polarization

Valence polarization



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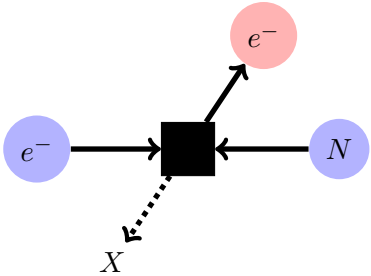

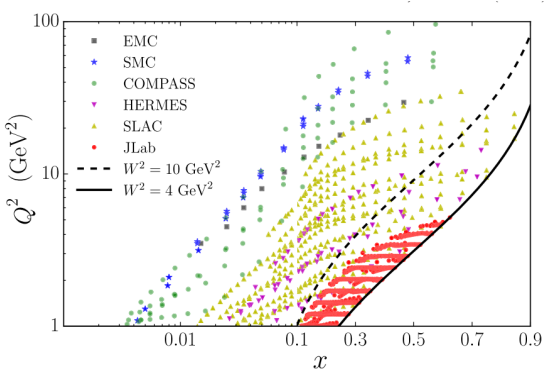

Iterative Monte Carlo analysis of spin-dependent parton distributions

Nobuo Sato, W. Melnitchouk, S. E. Kuhn, J. J. Ethier, and A. Accardi (Jefferson Lab Angular Momentum Collaboration)
Phys. Rev. D **93**, 074005 – Published 5 April 2016

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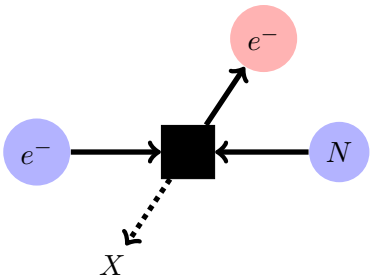

$$g_1 = g_1^{\tau 2} + g_1^{\tau 3} + g_1^{\tau 4}$$

$$g_2 = g_1^{\tau 2} + g_2^{\tau 3}$$

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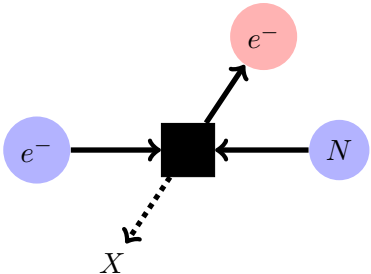
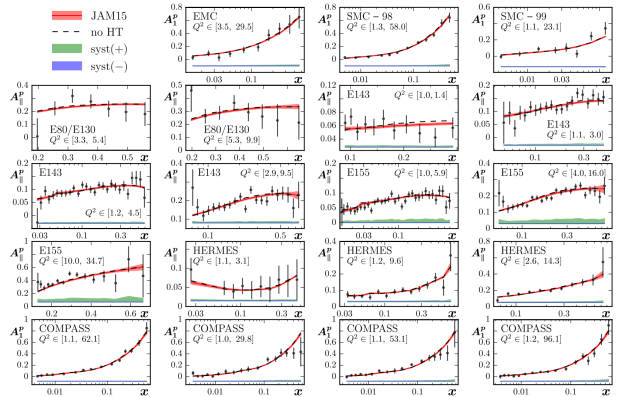


$A_{\parallel}$



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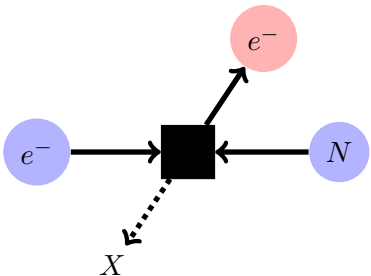
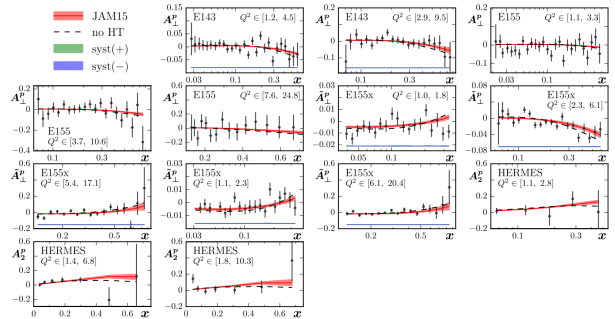


$A_\perp$



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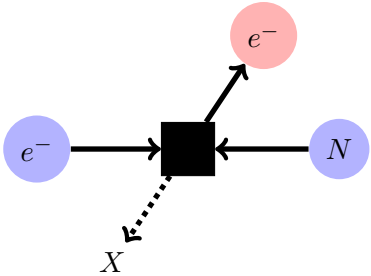

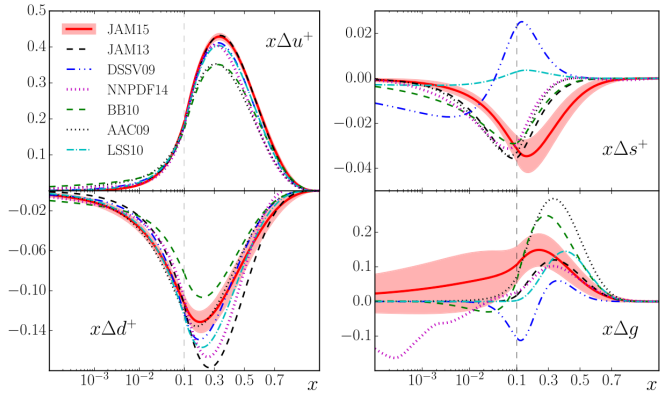

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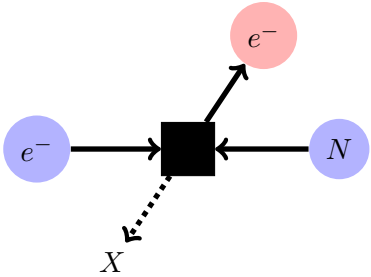
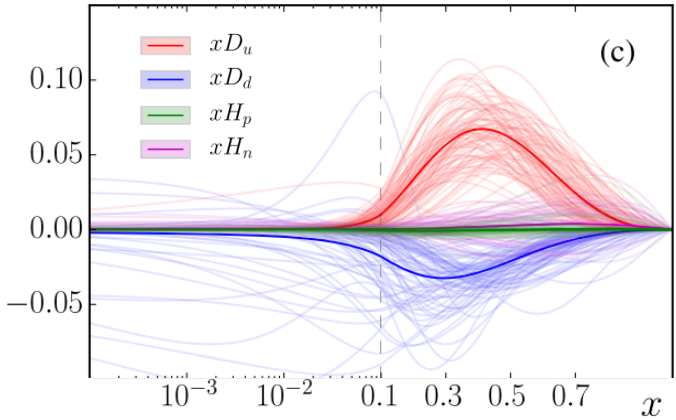
Higher twists





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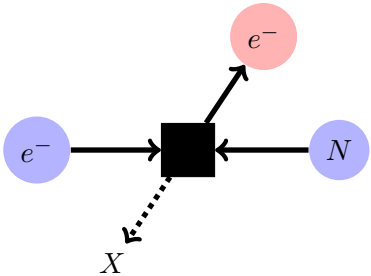
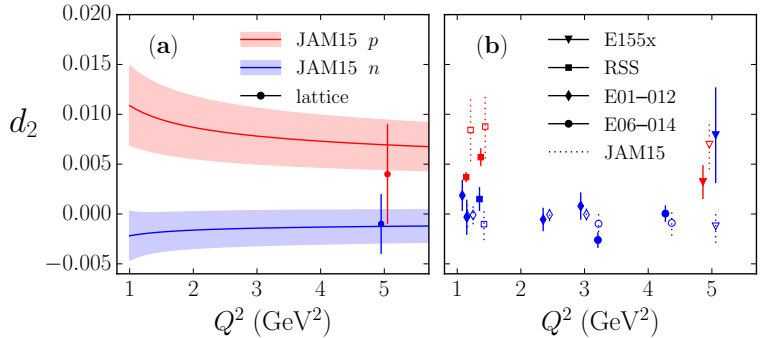


"Color polarizability"



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Strange polarization “puzzle”

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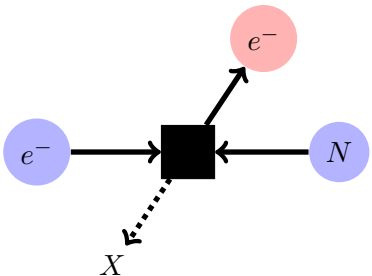

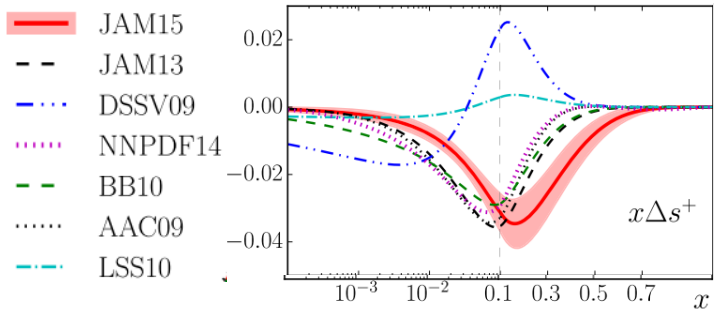

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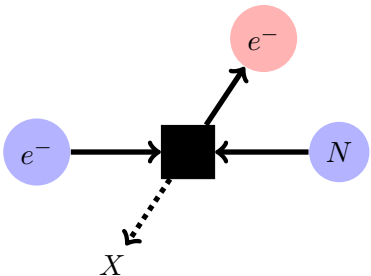
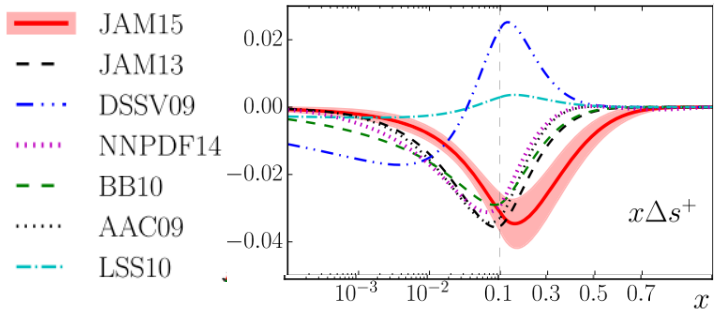
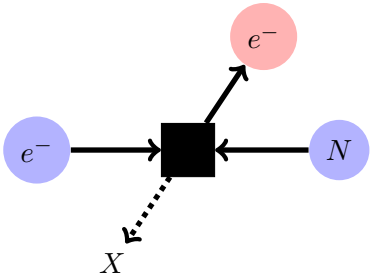
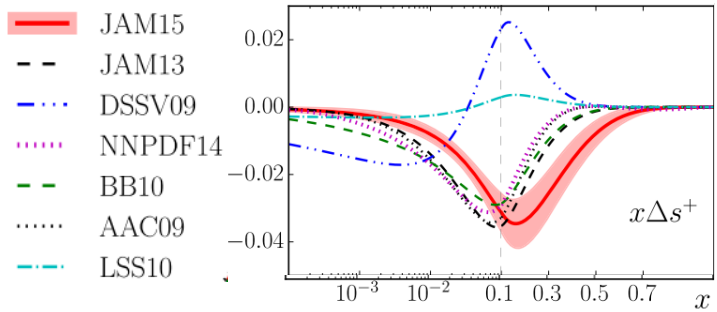




- $\Delta\text{DIS} + g_8 \rightarrow$ negative Δs^+

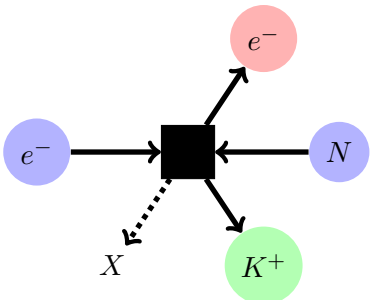
Strange polarization "puzzle"





- ΔDIS $+ g_8 \rightarrow$ negative Δs^+
- ΔDIS $+ \Delta$SIDIS $+ g_8 \rightarrow \Delta s^+$ with sign change

Strange polarization “puzzle”



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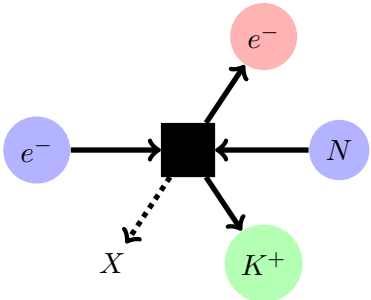

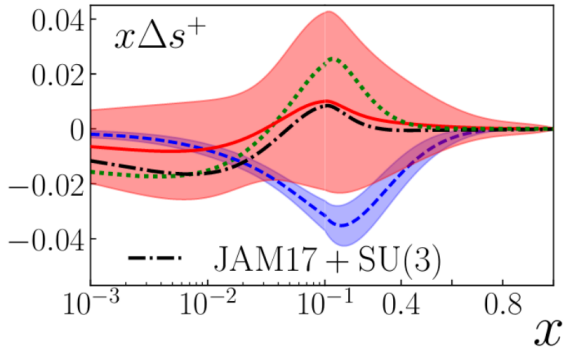

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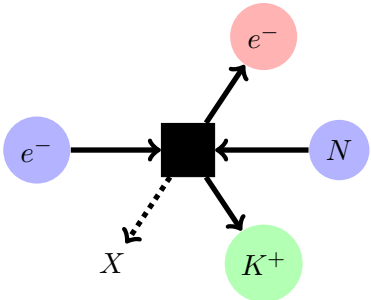

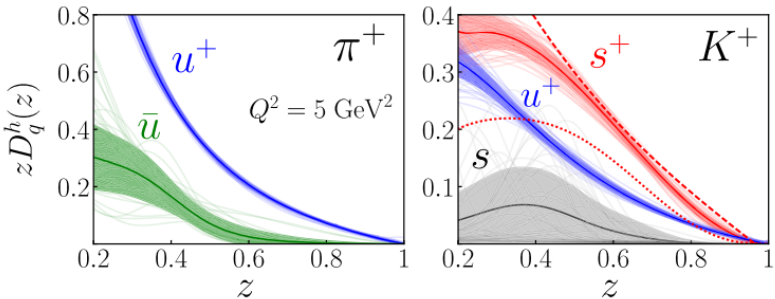

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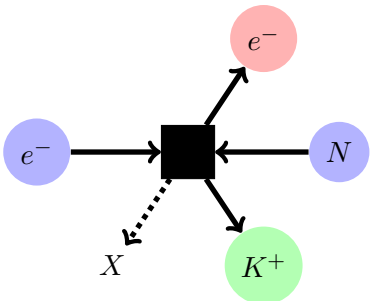

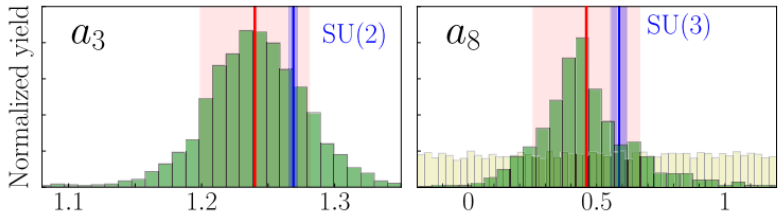

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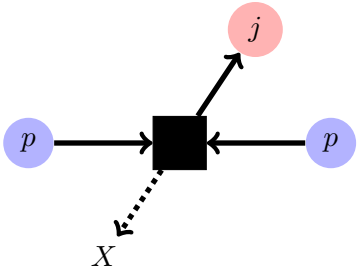
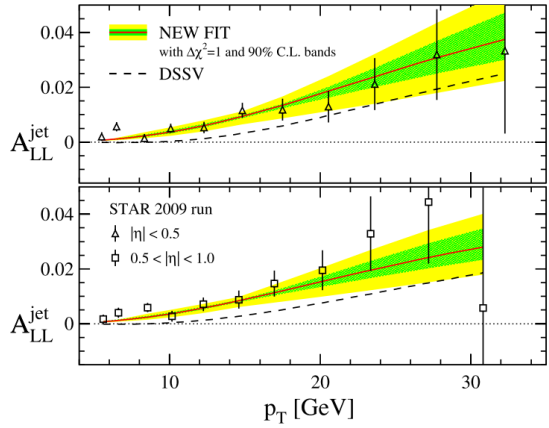
Gluon polarization





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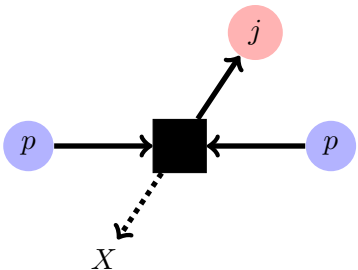

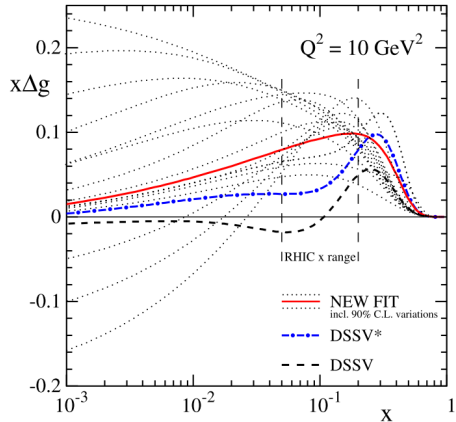

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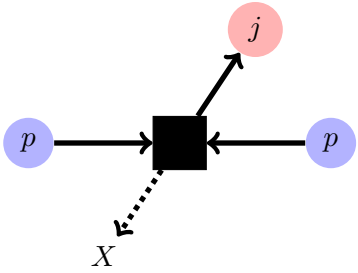

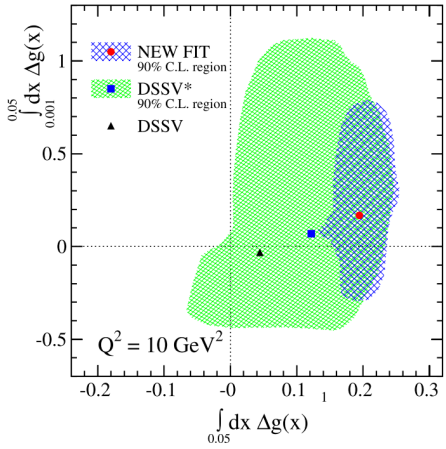

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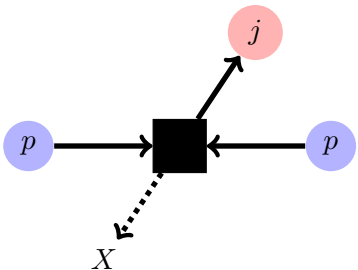

$$\int_{0.001}^{1} dx \Delta g(x) = 0.013 + 0.702 - 0.314$$

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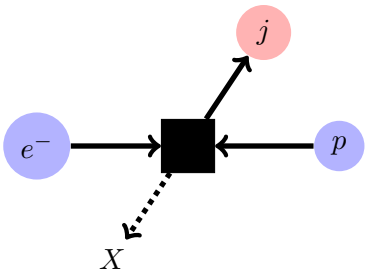

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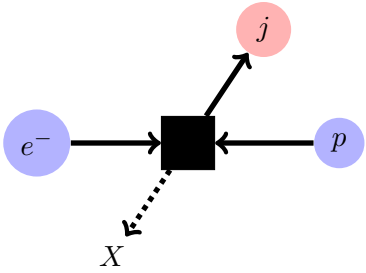

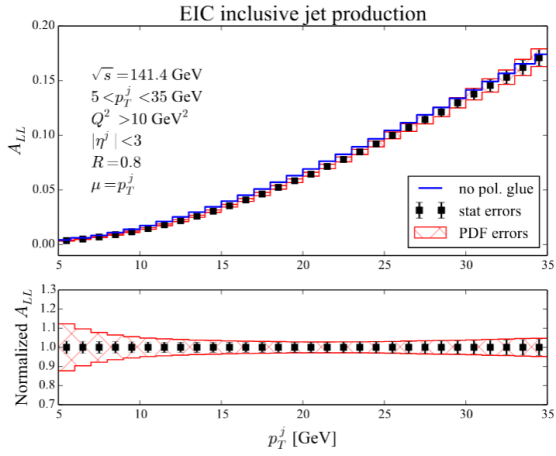

Inclusive jet production as a probe of polarized parton distribution functions at a future EIC

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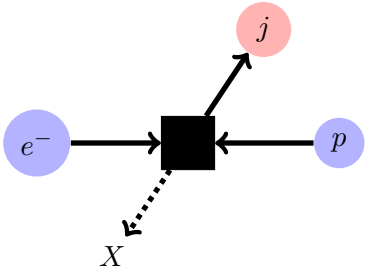
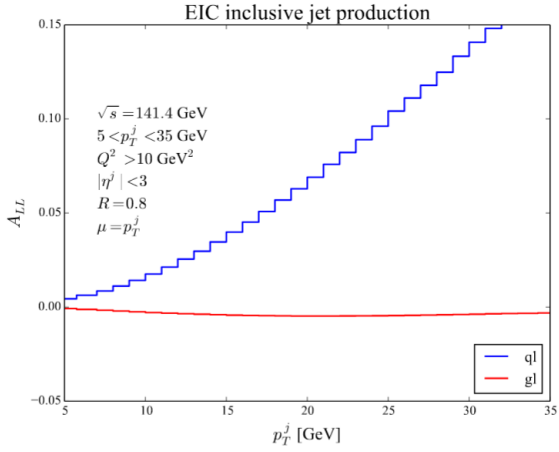
Phys. Rev. D **98**, 054031 – Published 27 September 2018

Gluon polarization





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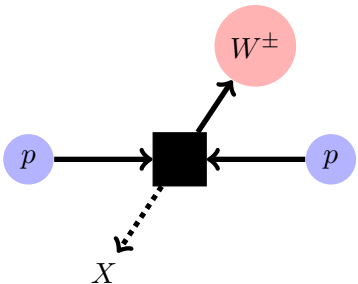
Light sea polarization



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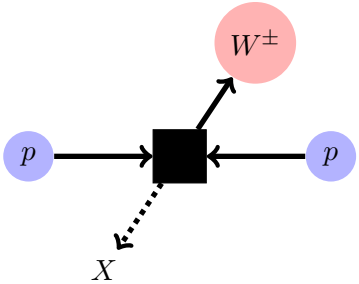

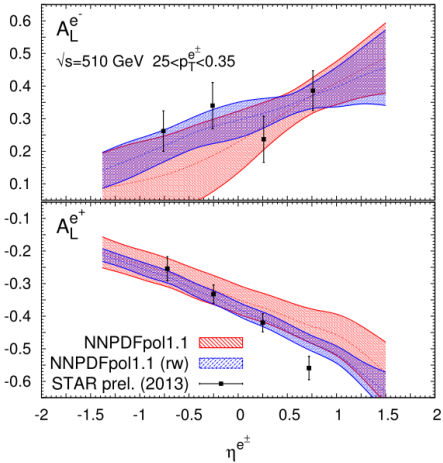

Impact of Recent RHIC Data on Helicity-Dependent Parton Distribution Functions

Emanuele R. Nocera (Oxford U., Theor. Phys.)

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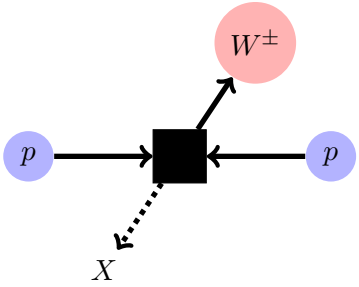

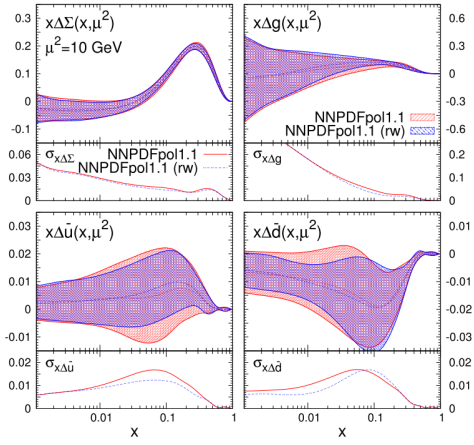

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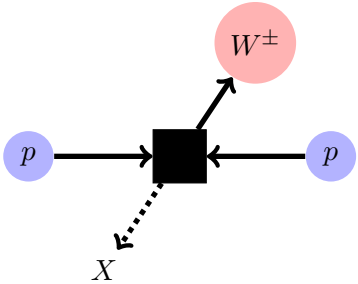

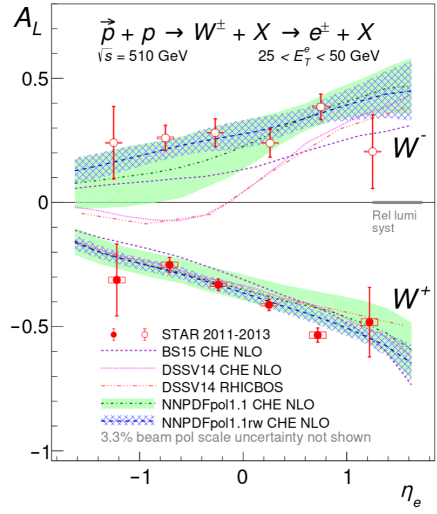

Measurement of the longitudinal spin asymmetries for weak boson production in proton-proton collisions at $\sqrt{s} = 510$ GeV

J. Adam *et al.* (STAR Collaboration)
Phys. Rev. D **99**, 051102(R) – Published 14 March 2019

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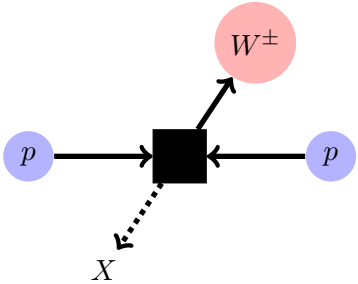

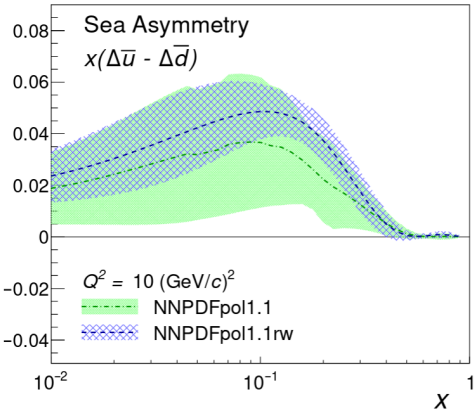

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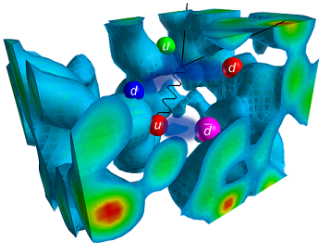

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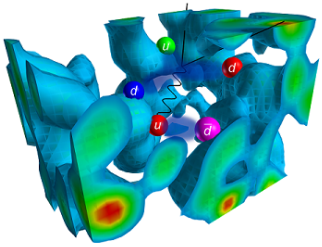

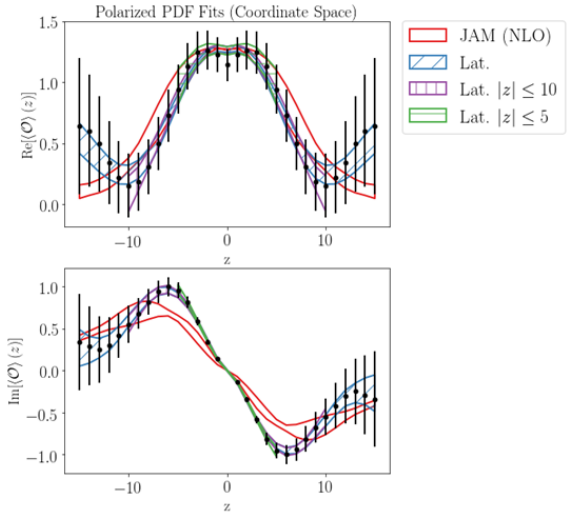

Bringewatt, Constantinou Melnitchouk, Qiu, NS, Steffens

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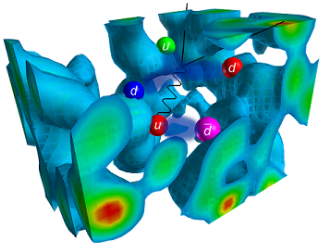

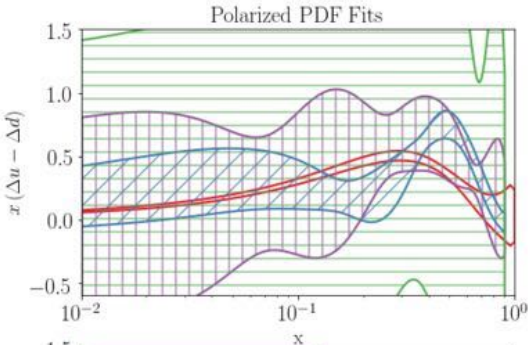

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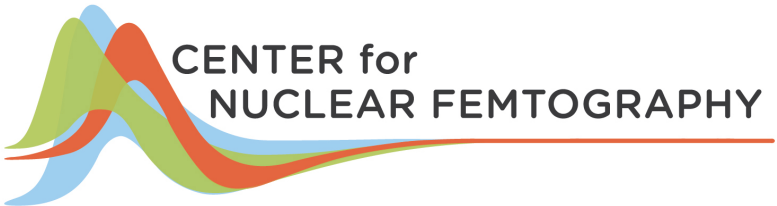

Next generation of QCD global analysis tools

Current paradigm

- Global analysis uses Bayesian regression
- It is done via posterior sampling

$$\rho(\boldsymbol{a}|\mathrm{data}) = \mathcal{L}(\boldsymbol{a}, \mathrm{data})\pi(\boldsymbol{a})$$

- $\boldsymbol{a}$ are the "shape" parameters for QCF

Why do we use posterior sampling?

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- We know how to go from $\boldsymbol{a}$ to cross sections e.g.

$$\frac{d\sigma}{dxdQ^2} = \sum_q \int_x^1 \frac{d\xi}{\xi} H(\xi) f_q \left(\frac{x}{\xi}, \mu; \boldsymbol{a} \right)$$

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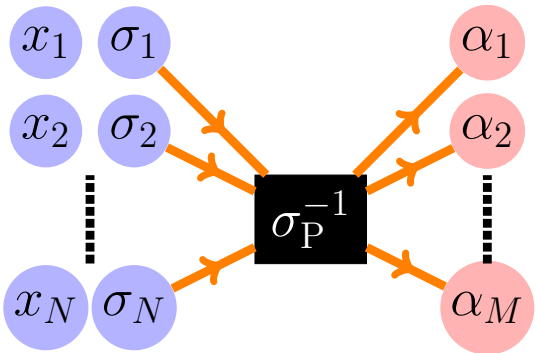
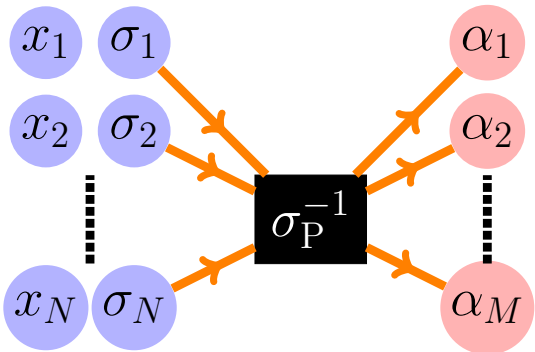
- We **DON'T** have the inverse function to go from cross sections to $\boldsymbol{a}$

The inverse mapper



$$R^N \to R^M$$

The inverse mapper



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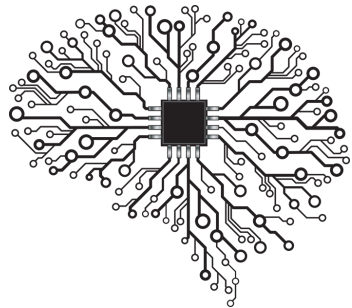


Can we use Machine Learning?

Partnership with computer scientists

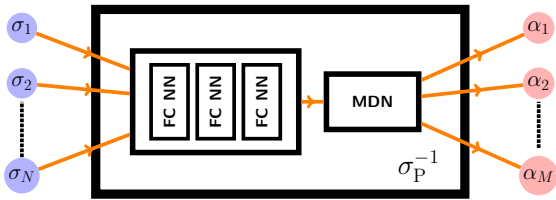
- M. Almaeen (ODU)
- Y. Awadh Alanazi (ODU)
- M. Houck (Davidson College)
- M. P. Kuchera (Davidson College)
- Y. Li (ODU)
- W. Melnitchouk (JLab)
- R. Ramanujan (Davidson College)
- NS (JLab)
- E. Tsitinidi (Davidson College)

ODU

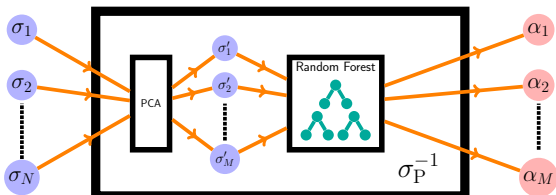
DAVIDSON

Jefferson Lab

ML prototypes

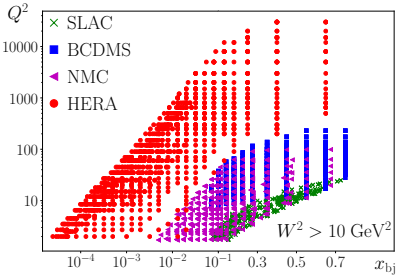


- Tested and validated in toy DIS–like examples



- How about real QCD analysis?

Application to unpolarized DIS



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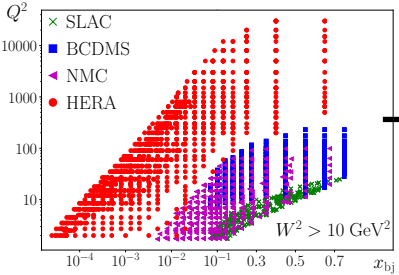

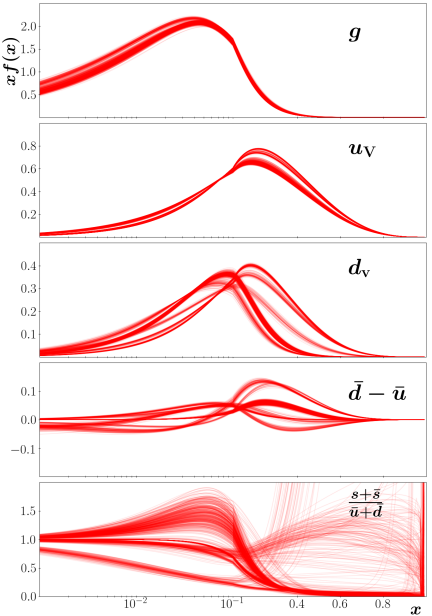

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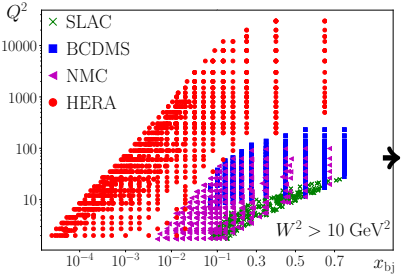

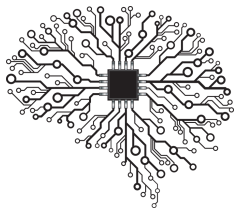

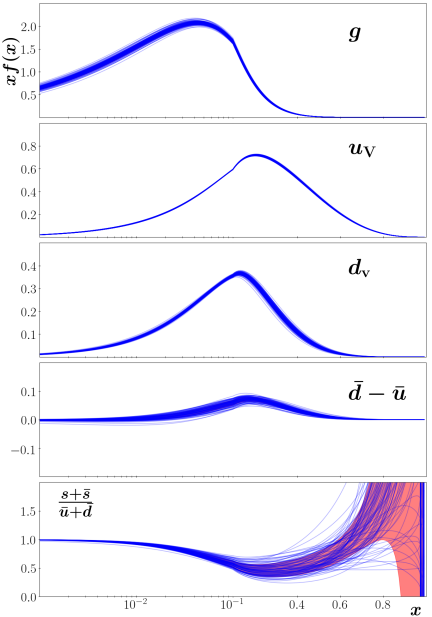

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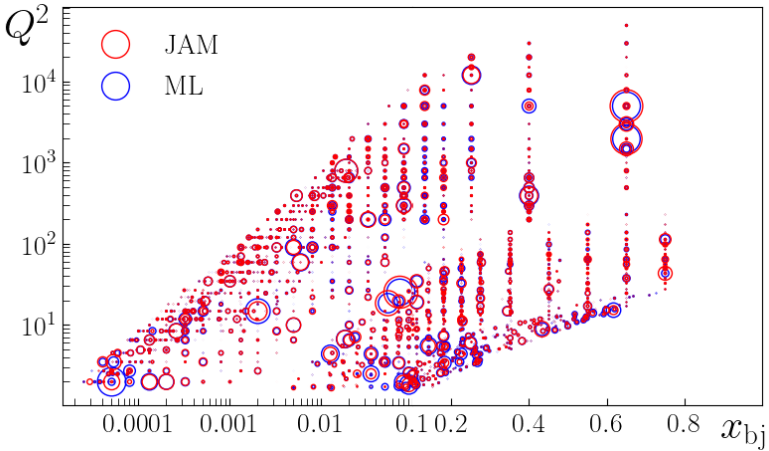

- Proton DIS kinematics
- Blobs $\propto \chi^2$
- $\frac{\chi^2_{\mathrm{JAM}}}{N_{\mathrm{pts}}} = 1.25$
- $\frac{\chi^2_{\mathrm{ML}}}{N_{\mathrm{pts}}} = 1.36$

Summary and outook

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- Still long way to get $\triangle$PDFs as precise as PDFs

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- New tools for global analysis using machine learning