JAMboreé

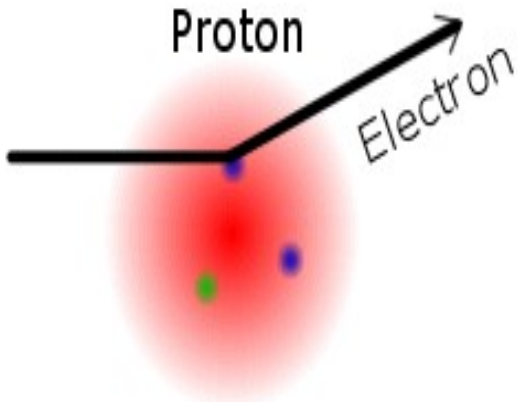
Theory Center Jamboree
Jefferson Lab, Dec 13, 2013

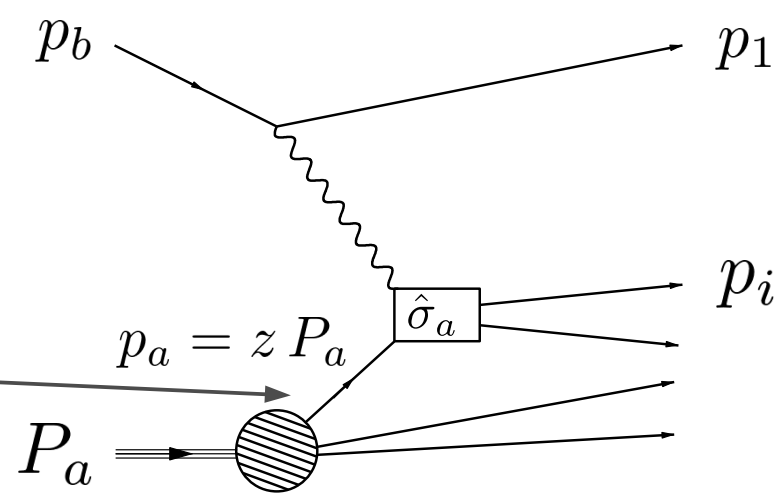
Pedro Jimenez-Delgado

Jefferson Lab

Introduction

Hadrons composed of *quarks* and *gluons* $\Rightarrow$ *scattering off* ***partons***





Parton distribution functions

$$d\sigma \propto \sum_f \int dz\, \hat{\sigma}_f\; f(z)$$

Plausible at high energies (from GeV): ***Perturbative QCD***

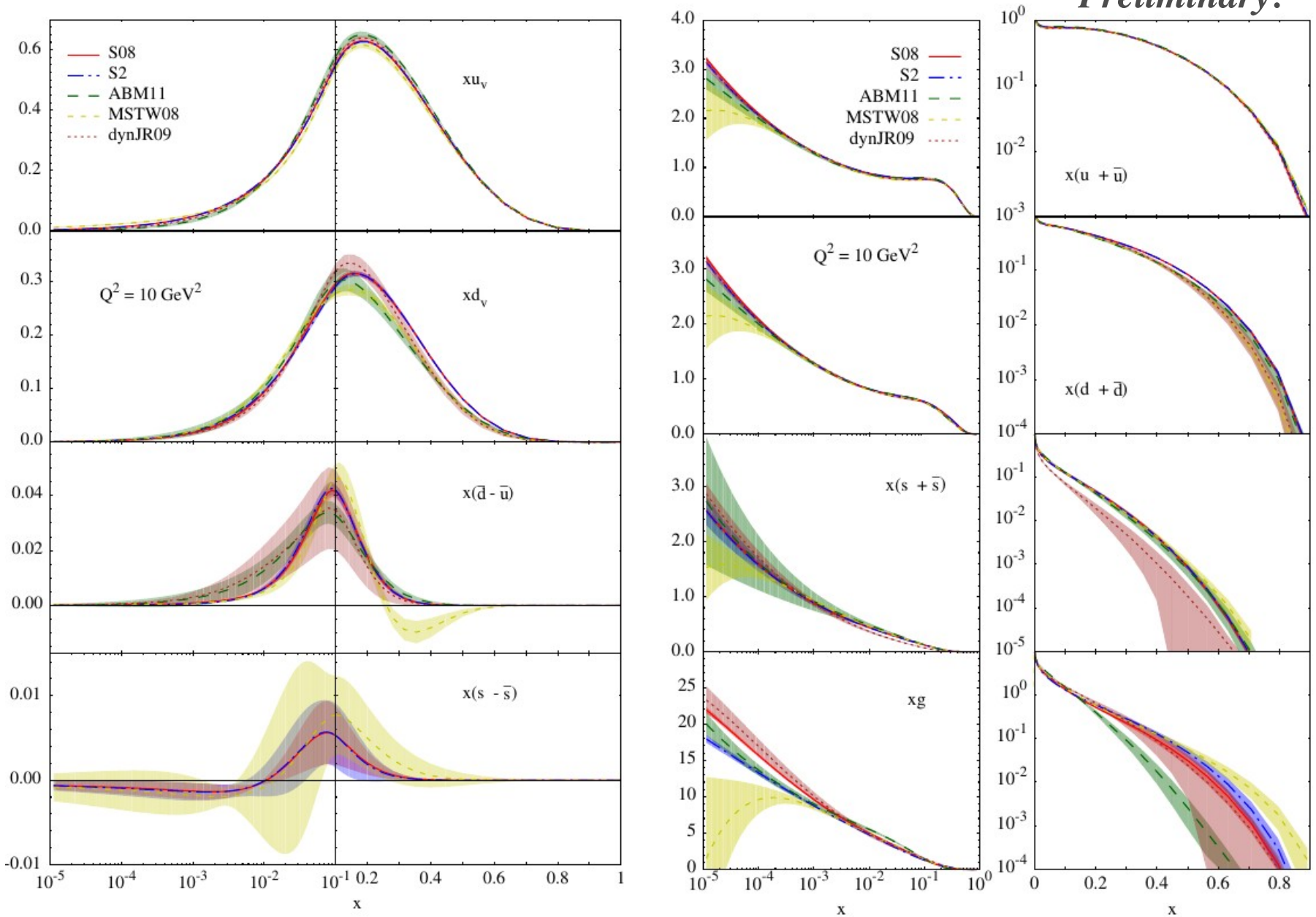
Ordinary PDFs depend on parton *longitudinal momentum* (fraction) and a *factorization* scale from QCD radiation: $f(x, Q^2)$

Determined through **global analysis** of many observables (DIS, *pp* colliders)

Unpolarized NNLO PDFs: JR

with E. Reya: analysis completed (article in preparation)

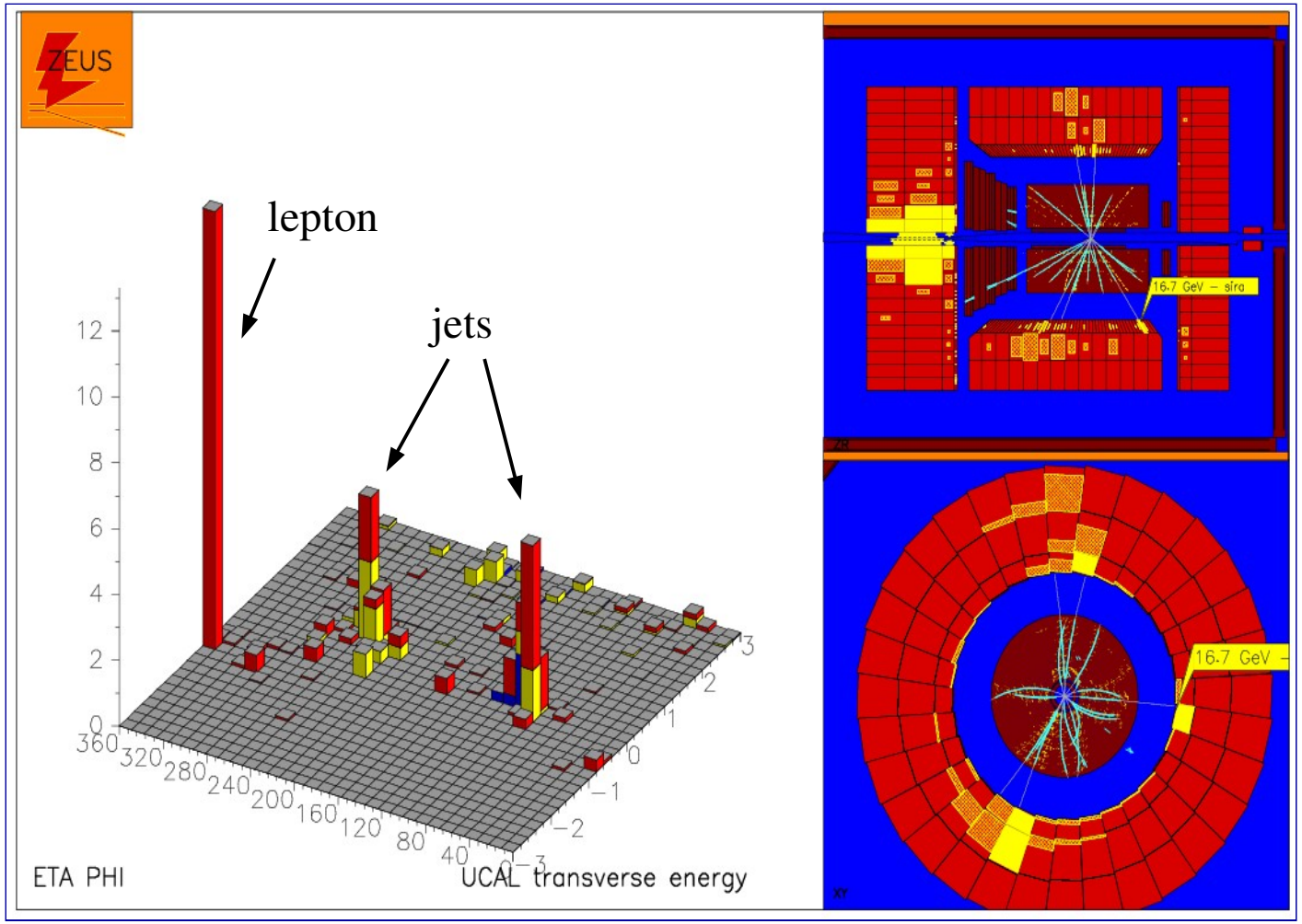
Preliminary!

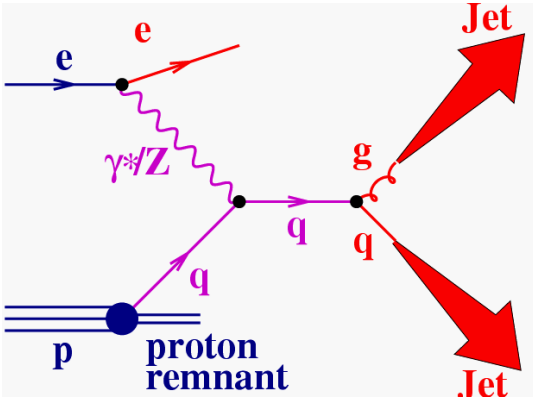


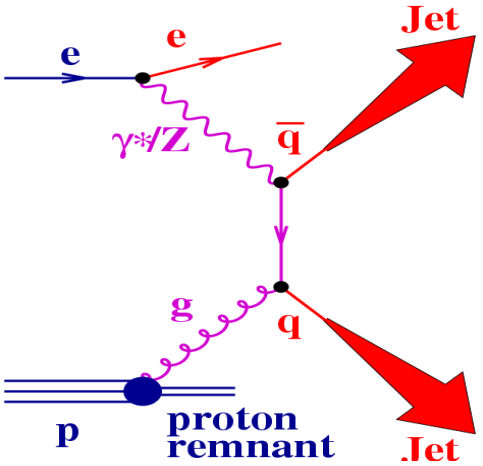
ANTJETS

with T. Gehrmann and G. Luisoni (not much progress since I moved to JLab)

Parton-level Monte Carlo for (2+1)-jet production in DIS up to NNLO of QCD







Polarized parton distributions

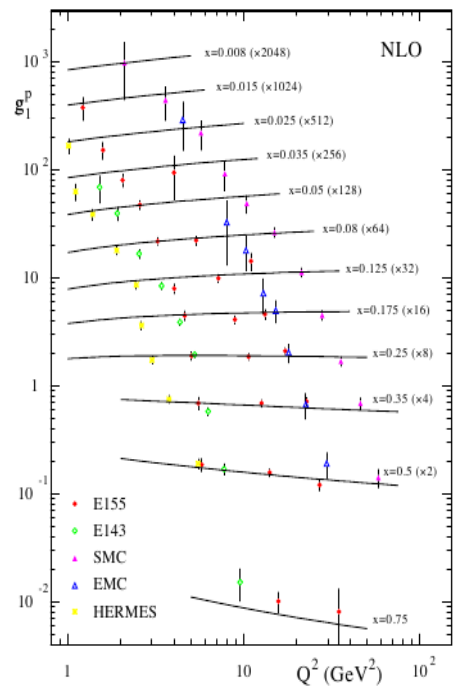
Spin-dependent PDFs: $\Delta f(x, Q^2) = f^+(x, Q^2) - f^-(x, Q^2)$

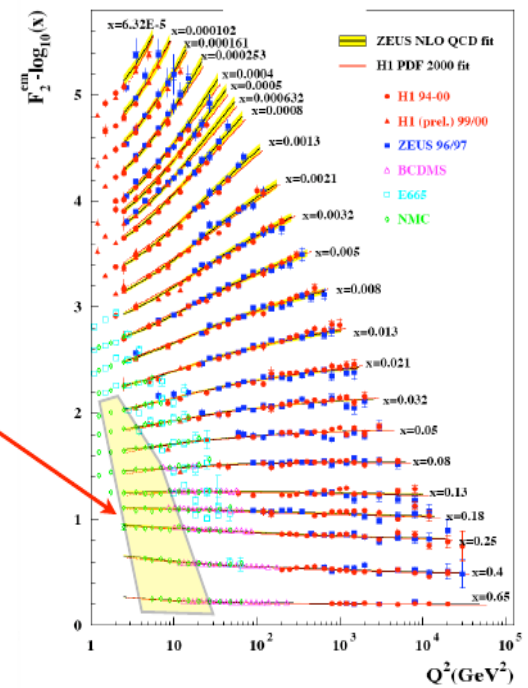
Key ingredients to understand **proton spin** (puzzle): $\frac{1}{2} = \frac{1}{2}\Delta\Sigma + \Delta g + L$

State-of-the-art is NLO

DIS structure functions $\Rightarrow \Delta\Sigma$

Reduced kinematic coverage:
need to work with *lower-energy* data





Main current groups:

DSSV: de Florian, Sassot, Stratmann, Vogelsang

LSS: Leader, Sidorov, Stavenov

BB: Blümlein, Bötcher

AAC: Asymmetry Analysis Collaboration

NNPDF: Neural Network Collaboration

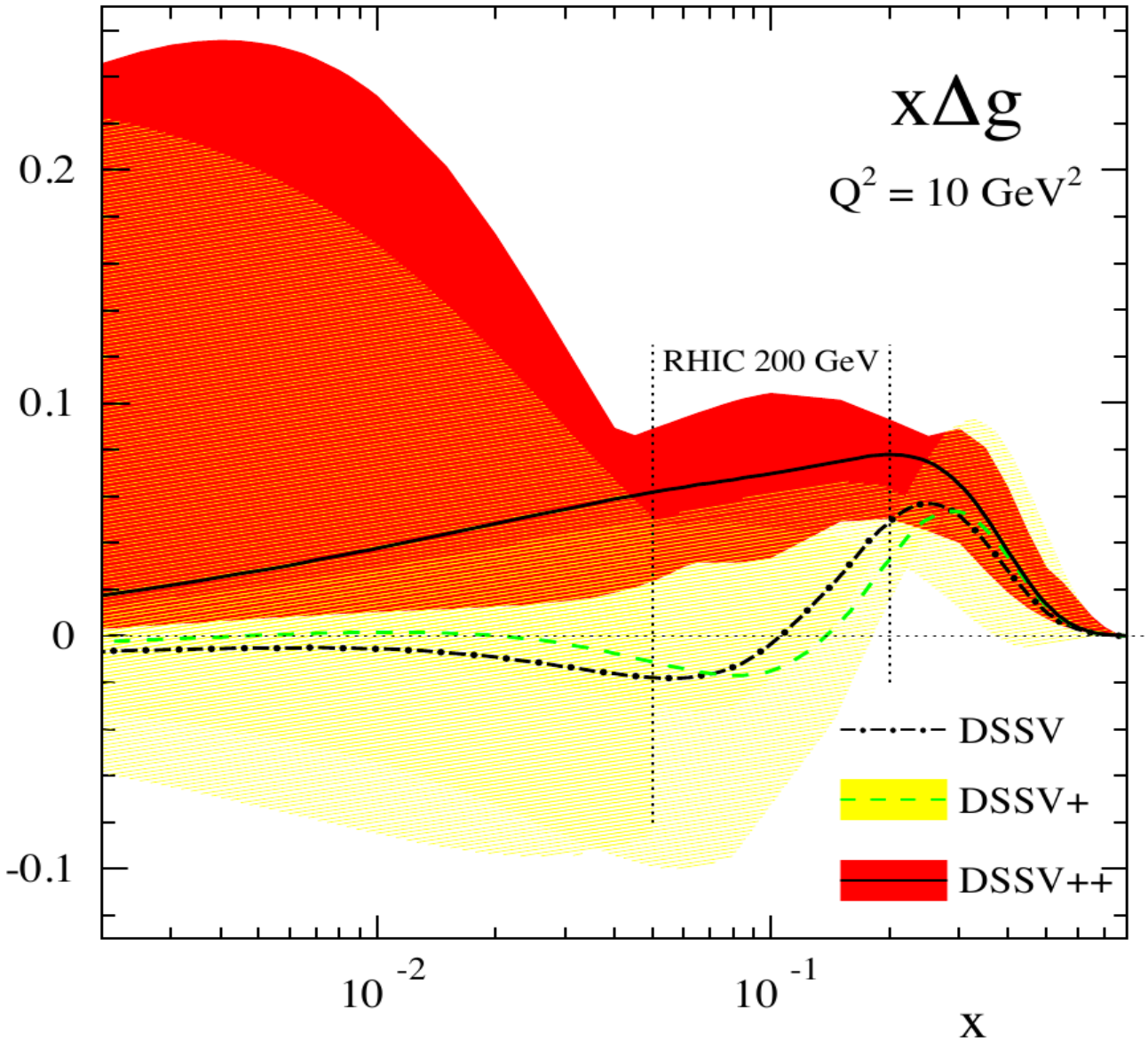
JAM: Jefferson Lab Angular Momentum Collaboration

In addition one can use:

SIDIS $\Rightarrow \Delta\bar{q}$

RHIC data $\Rightarrow \Delta g$

RHIC/DSSV polarized gluons



Strong support for the experimental program at RHIC

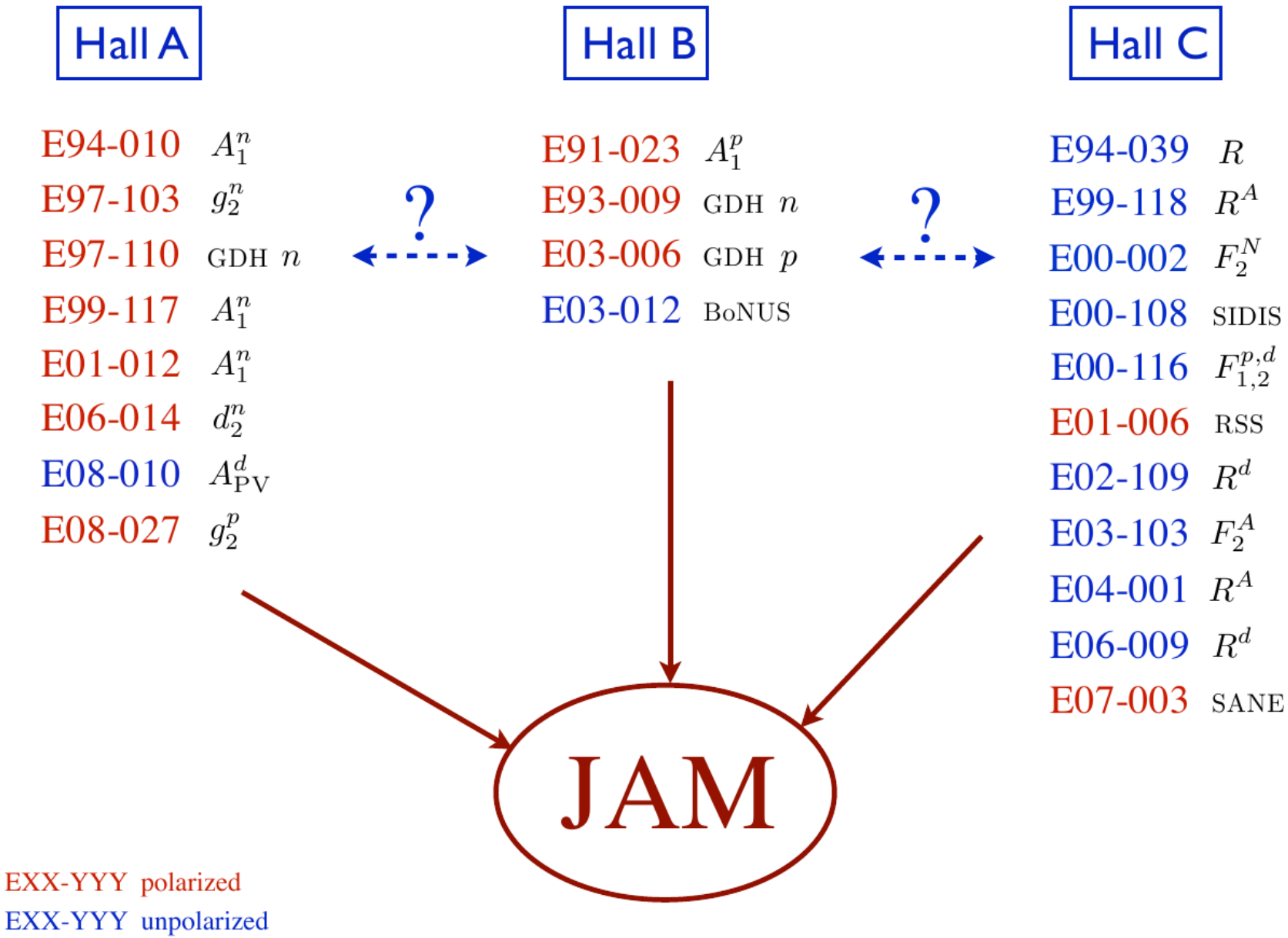
First experimental evidence of ***non-zero gluon polarization***:

$$\int_{0.05}^{0.2} \Delta g(x, Q^2 = 10\,\mathrm{GeV}^2)\,dx = 0.10^{+0.06}_{-0.07}$$

Focus in the small-*x* region

Only group with *complete* NLO description of *pp* data

JLab 6 GeV data



The JAM collaboration

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Jefferson Lab Angular Momentum Collaboration

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About JAM

- 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 structure 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 transition region at low and intermediate values of W and Q^2.
- The first results of the JAM global PDF analysis, based on the world's inclusive polarized asymmetry data, have recently appeared at arXiv:1310.3734 [hep-ph]
- The next phase of the JAM analysis involves the inclusion of **semi-inclusive deep-inelastic** and polarized **proton-proton** scattering data, which will constrain the polarized sea quark and gluon distributions, in addition to the valence.
- A longer term goal of JAM is to generalize the analysis to **transverse momentum dependent** parton distributions (TMDs).

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contact Wally Melnitchouk
updated December 6, 2013

Parallel effort to our unpolarized PDFs: CTEQ-JLab and JR

The JAM collaboration

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Collaboration

The JAM Collaboration consists of the following members:

Theory

- Pedro Jimenez-Delgado (*Jefferson Lab*)
- Alberto Accardi (*Hampton University and Jefferson Lab*)
- Wally Melnitchouk (*Jefferson Lab*)

Experiment

- Peter Bosted (*Jefferson Lab / College of William and Mary*)
- Jian-ping Chen (*Jefferson Lab*)
- Keith Griffioen (*College of William and Mary*)
- Sebastian Kuhn (*Old Dominion University*)
- Yelena Prok (*Old Dominion University*)
- Oscar Rondon (*University of Virginia*)
- Brad Sawatzky (*Jefferson Lab*)

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updated December 6, 2013

to start with, open to further contributions (e.g. for TMDs)

The JAM database

Interactive database with all data on polarized scattering (DIS for now)

Jefferson Lab
EXPLORING THE NATURE OF MATTER

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U.S. DEPARTMENT OF ENERGY

MENU:

- JAM main page
- DB Instructions

Experiments

- All data
- proton
- deuteron
- 3He

JAM database - Experiments

Experiment	Description
COMPASS	proton and deuteron A1, g1
EMC	proton A1, g1
HERMES	proton, deuteron, and 3He A_par, neutron A1
HERMES2012	proton A2 and g2
JLab Hall A (E01-012)	3He A_par, A1, g1
JLab Hall A (E97-103)	3He (and neutron) asymmetries, g1, g2
JLab Hall A (E99-117)	3He (and neutron) asymmetries, g1, g2
JLab Hall B (EG1b)	proton and deuteron A1
JLab Hall C (E01-006 "RSS")	proton and deuteron A_parallel and A_perp (resonance region)
SLAC E142	3He A1, A2, g1, g2
SLAC E143	proton and deuteron A_par, A_perp
SLAC E154	3He A_par, A_perp
SLAC E155	proton and deuteron A_parallel (longitudinal), A_perp (transverse), A1, A2, g1, g2
SLAC E155x	proton and deuteron A_perp (transverse), A2, g2
SLAC E80/E130	proton A_parallel
SMC	proton and deuteron A1, g1

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Data and theory comparison with other groups

First phase just finalized: improvements in the theoretical description of DIS

	DIS	SIDIS	RHIC	nuclear smearing	TMC	HT g_1	HT g_2
DSSV 09	✓	✓	✓				
AAC 09	✓		✓				
BB 10	✓				✓	✓	~
LSS 10	✓	✓			✓	✓	
NNPDF 13	✓				✓		
JAM 13	✓			✓	✓	✓	✓

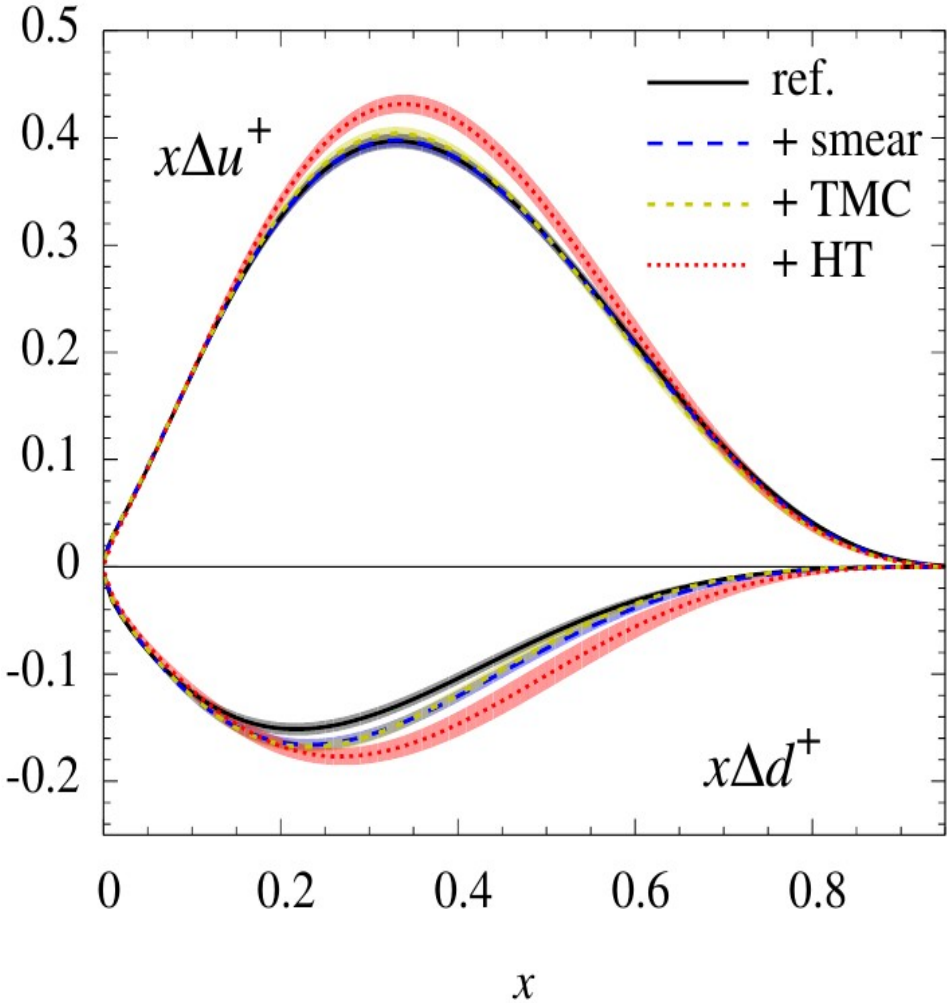
[arXiv:1310.3734, to appear in PRD]

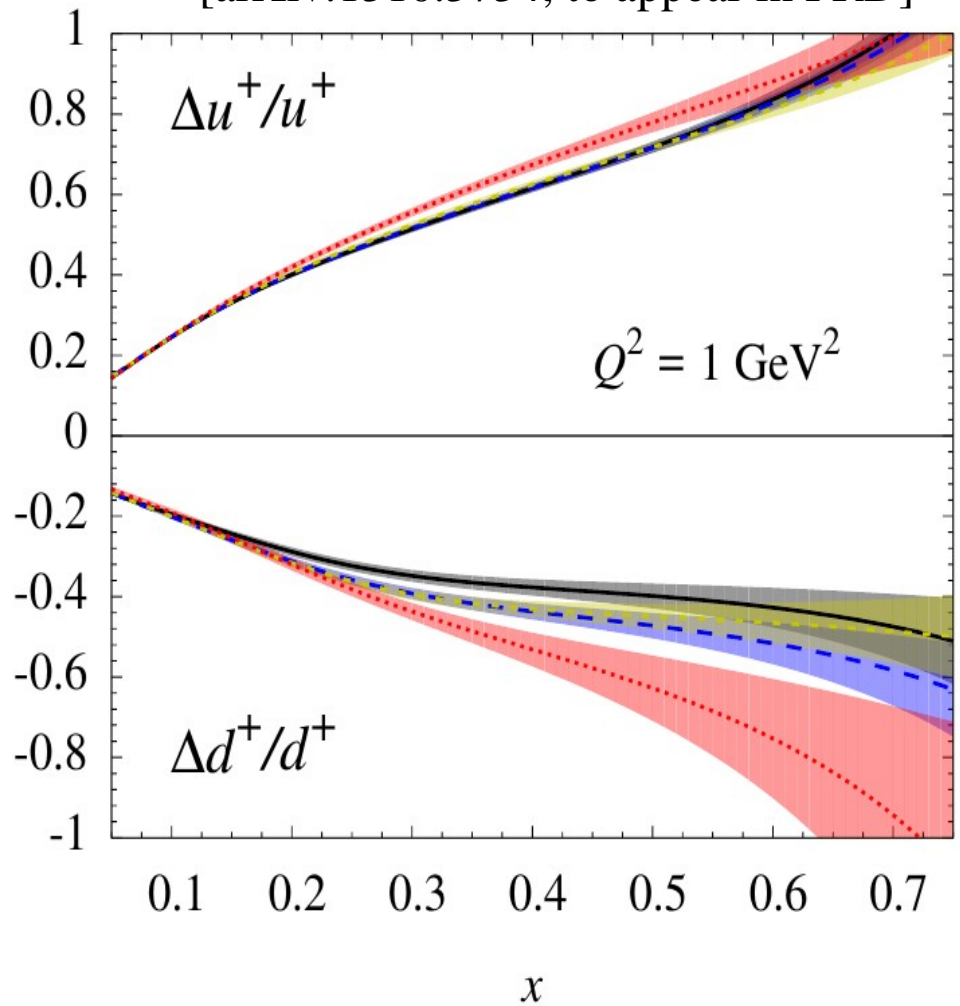
Next goals: analysis of SIDIS and *pp* data

Impact of hadronic and nuclear corrections

Global analysis of world data on polarized DIS

[arXiv:1310.3734, to appear in PRD]

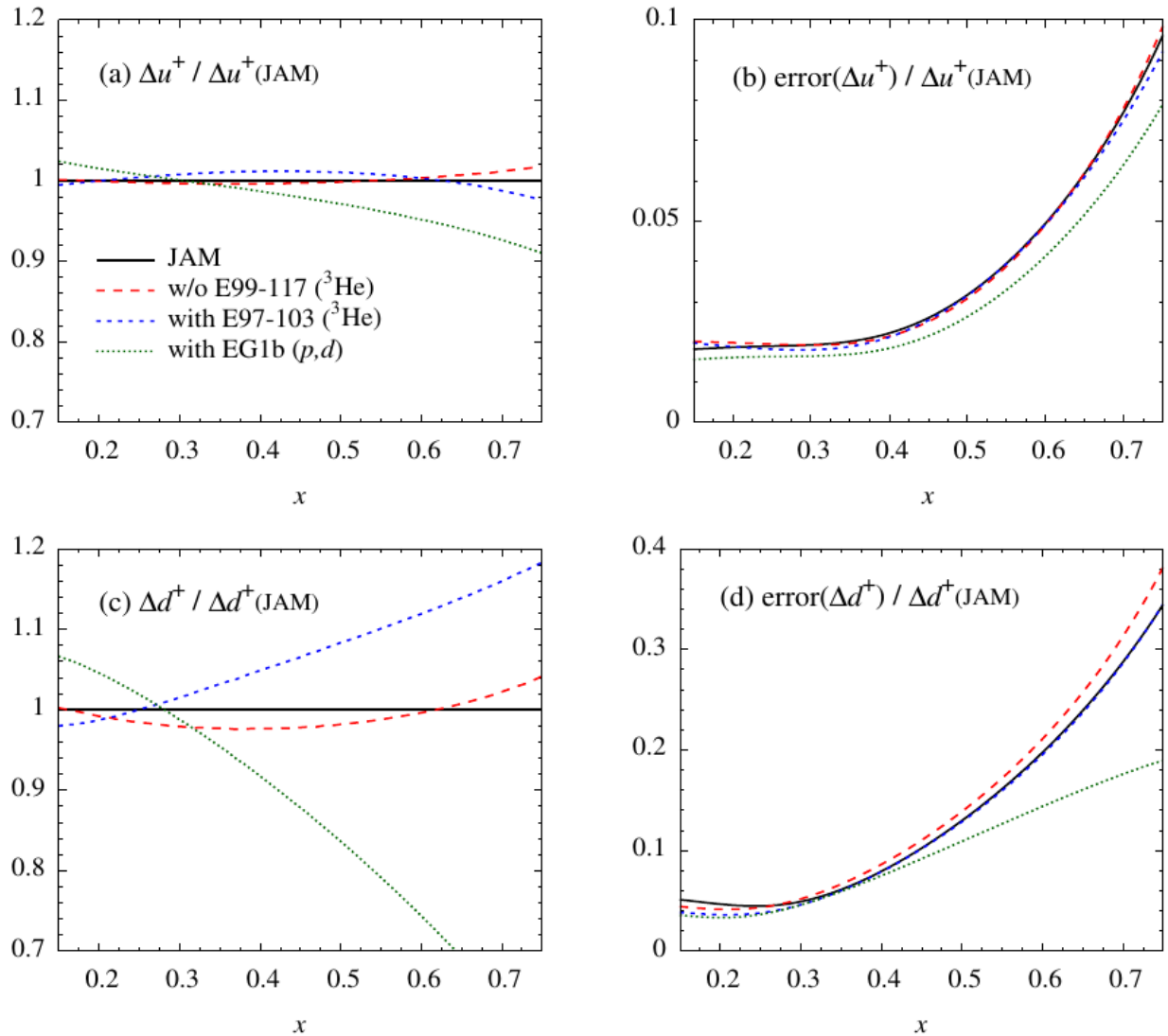




These corrections are ***manifestly important*** for PDF extractions

Impact of Jefferson Lab data

Dedicated analysis of JLab data



[arXiv:1310.3734, to appear in PRD]

Phenomenological support for the experimental program

Relevance for Jefferson Lab

[Oscar Rondon, *5th Workshop on hadron physics in China and opportunities in US*, Huangshan 2013]

Recent SSF Studies at JLab

Hall	Publication	Measurement	Experiment
CLAS	PL B672 (2009) 12	Moments of g1p and g1d for 0.05 < Q**2 < 3.0-GeV**2	eg1b
CLAS	PL B704 (2011) 397	Beam Spin Asymmetries in Semi-Inclusive pi0 production	eg1b
CLAS	PR C80 (2009) 035206	Beam Spin Asymmetries in DVCS with CLAS at 4.8-GeV	eg1-dvcs
CLAS	PRL 105 (2010) 262002	Single and Double Spin Asymmetries in Deep Inelastic Pion Electroproduction with a Longitudinally Polarized Target	eg1b
Hall A	arXiv:1304.4497	Moments of Neutron g2 SF at Intermediate Q**2	01-012
Hall A	PRL 107 (2011) 072003	Single Spin Asymmetries in Charged Pion Production from SIDIS on a Transversely Polarized 3He Target	06-010
Hall A	PRL 108 (2012) 052001	Beam-Target Double Spin Asymmetry A_LT in Charged Pion Production from DIS on a Transversely Polarized He-3 Target	06-010
Hall C	PRL 105 (2010) 101601	Probing Quark-Gluon Interactions with Transverse Polarized Scattering	01-006
Hall A	Very preliminary	Precision d2n: Color Polarizabilities	06-014
Hall C	Very preliminary	Spin Asymmetries of the Nucleon – SANE	07-003
Hall A	Very very preliminary	g2p and the Longitudinal-Transverse Spin Polarizability	08-027
JAM JLab Angular Momentum	APS April 2013	Global PDF fits	Phenomenology

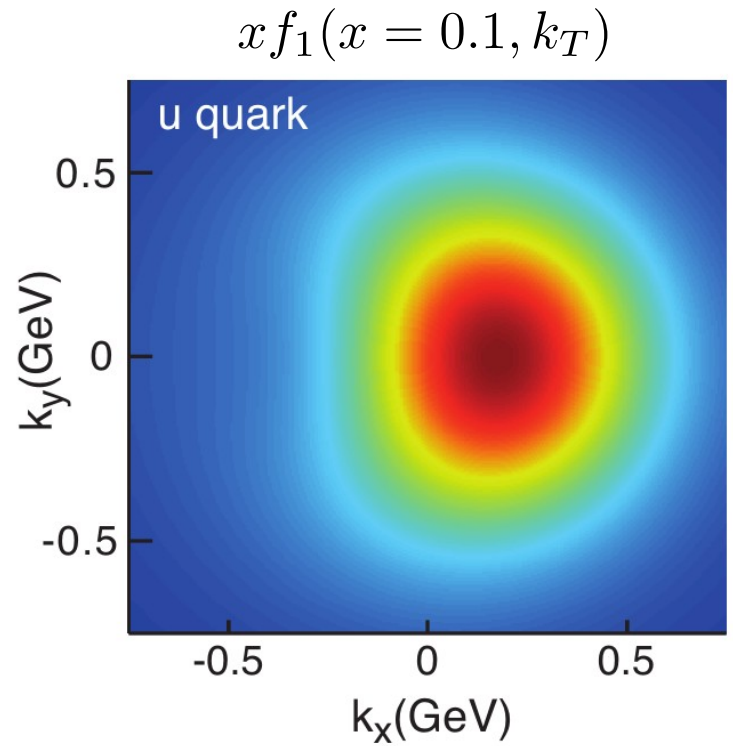
Phenomenological support for the experimental program

Phenomenological analyses of TMDs

Transverse momentum dependent PDFs

$$f(x, k_T)$$

3D structure of the nucleon



Much more data to come (JLab12, EIC)

Advances in a QCD framework (evolution) have become available

Formalism less developed than in the collinear case

Entering the field in collaboration with A. Prokudin and REU/SULI students:
first determination of *Pretzelosity*

Also in theory center: production mechanism of SIDIS (C. Weiss)
and gluon TMDs (A. Tarasov, I. Balitsky)

Current and (near) future plans

Analyses based on ***Chromopolis***: complete QCD framework (JR + JAM)

Determination of the sea quark polarization from SIDIS:

- Initial analysis in progress (with J. Ethier, PhD student W&M)
- TMCs, nuclear corrections on the way (for the first time)
- Fragmentation function dependence

Determination of gluon polarization from RHIC data

- First (LO + K-factor) inclusion of $pp \to \pi^0 X$ on the way (with Kumano, KEK)
- NLO corrections and jet production more complicated
  $\longrightarrow$ need *additional resources* (or collaborate with DSSV)

Extension to Transverse Momentum Dependent distributions

- First studies in progress (pretzelosity)
- Implementation/integration of TMD evolution

Looking forwards to JLab12 (and EIC)

Approved 12 GeV experiments

	Hall A	Hall B	Hall C	Hall D	other	Total
The Hadron spectra as probes of QCD		1		2		3
The transverse structure of the hadrons (Elastic and transition Form Factors)	4	3	2	1		10
The longitudinal structure of the hadrons (Unpolarized and polarized PDFs)	**2+1***	**2**	**7+2***			**14**
The 3D structure of the hadrons (GPDs + **TMDs**)	5 (1 + **4**)	10 (4 + **5**)	4 (1 + **1**)			19 (6+**10**)
Hadrons and cold nuclear matter	4	2	6*		1	13
Low-energy tests of the Standard Model and fundamental symmetries	2*			1	1	4
TOTAL	17	18	18	4	2	**59**

Will need support and dedicated phenomenological analyses

Summary and outlook

Several research activities in parallel: JR, ANTJETS, JAM, TMDs

Presently focused on JAM analyses and framework development

JAM collaboration has been established and first results produced:

Hadronic and nuclear corrections manifestly important

Close interaction with experimentalist and dedicated studies of JLab data:

providing support for the experimental program of Jefferson Lab

Extensions to TMDs natural, envisioned and developing

Continuity and stability of the project in the JLab12 (and EIC) era is crucial