Getting Ready for the EIC

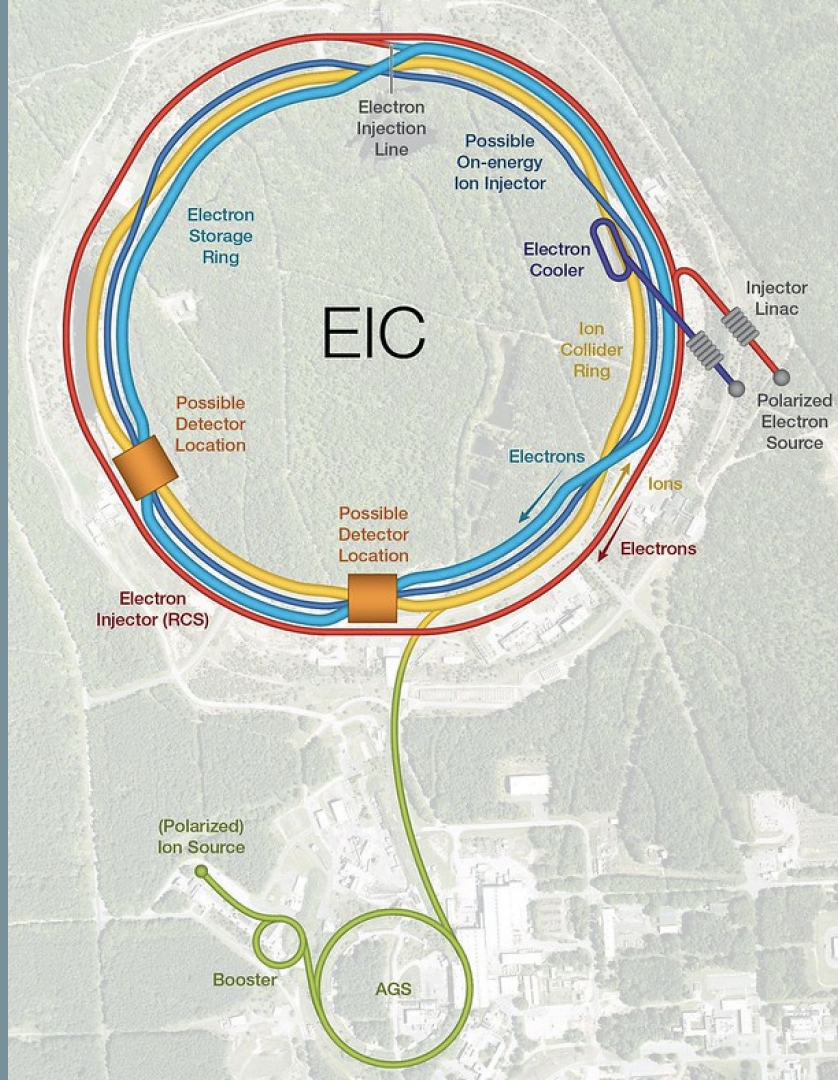
Nobuo Sato

Jefferson Lab

Aug. 5, 2022

Outline

1. Status
2. Pre-EIC physics
3. Challenges
4. Synergies with LQCD



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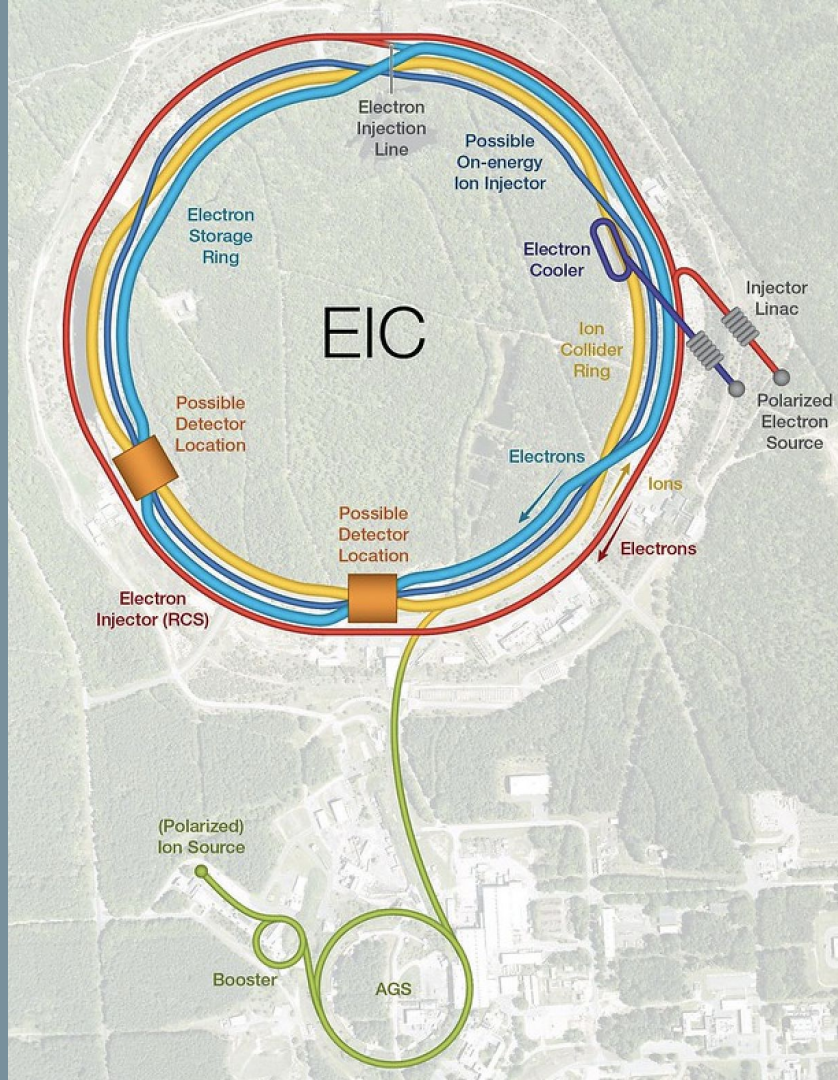


Department of Energy

U.S. Department of Energy Selects Brookhaven National Laboratory to Host Major New Nuclear Physics Facility

JANUARY 9, 2020

WASHINGTON, D.C. – Today, the **U.S. Department of Energy (DOE)** announced the selection of Brookhaven National Laboratory in Upton, NY, as the site for a planned major new nuclear physics research facility.

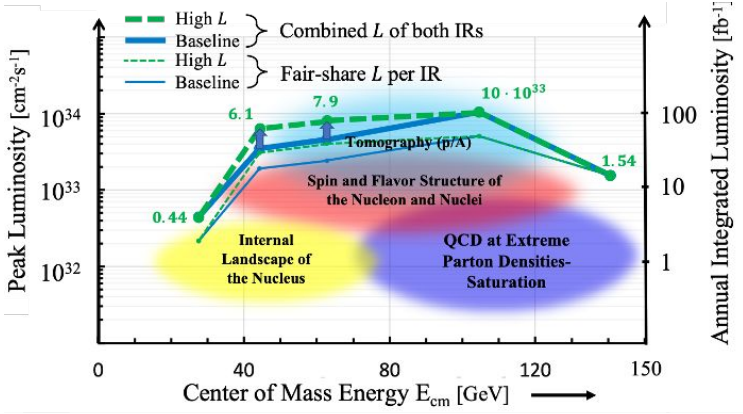
Secretary Brouillette approved Critical Decision-0, "Approve Mission Need," for the EIC on December 19, 2019.

Thomas Jefferson National Accelerator Facility in Newport News, VA will be a major partner in realizing the EIC, and several other DOE laboratories are expected to contribute to EIC construction and to the groundbreaking nuclear physics research program that will be accomplished there.

Yellow Report (2020-2021)

Key science questions:

- Origin of spin and mass
- Nuclear tomography
- Understanding the nuclear medium: hard probes, emergence of hadronic states, nuclear binding



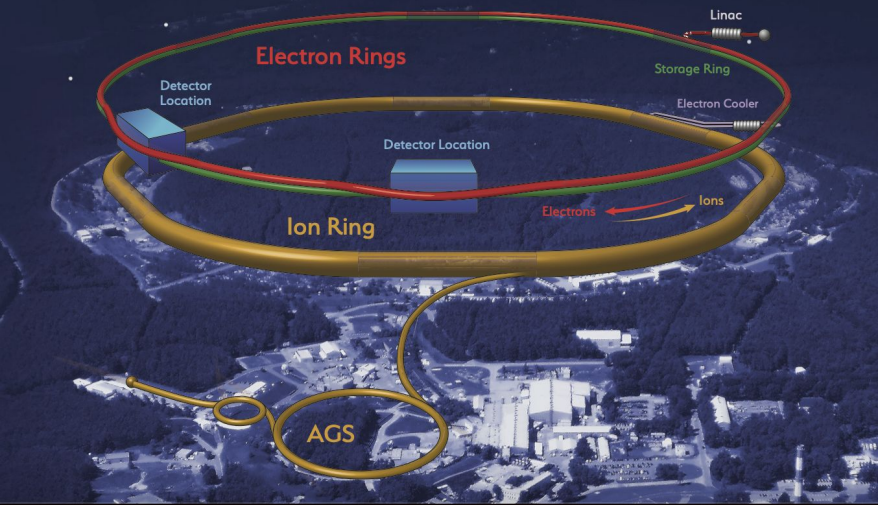
BROOKHAVEN NATIONAL LABORATORY Jefferson Lab

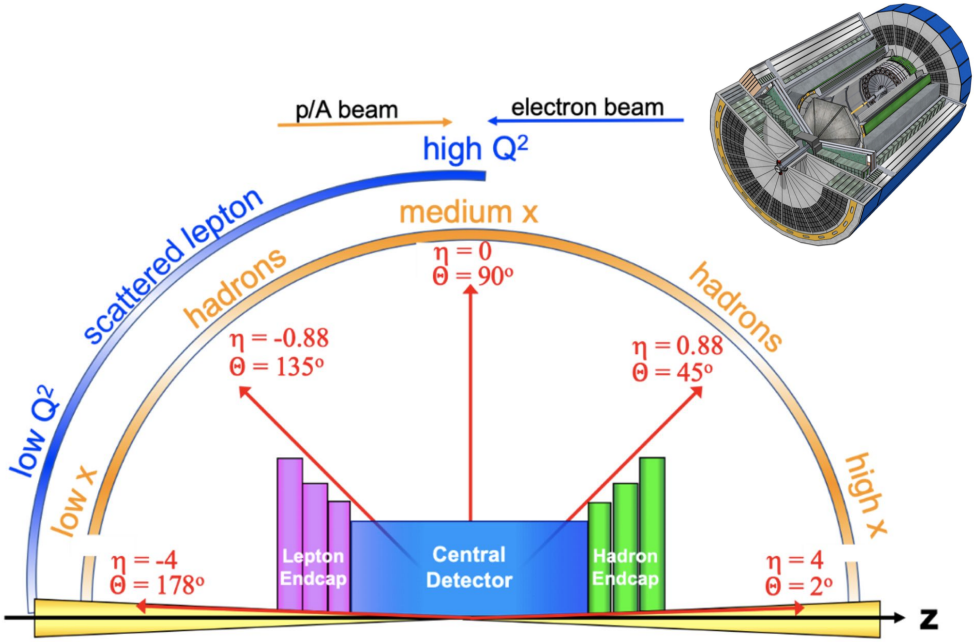
Electron-Ion Collider

at Brookhaven National Laboratory

Conceptual Design Report

2021





"While outside the present scope of the DOE-funded EIC project, there is considerable interest in the international scientific community for implementing a second detector whose capabilities would complement, in some way, those of the first. Appendix A describes a concept for a second IR design, optimized for maximum luminosity toward the lower end of the EIC range of collision energies"

Detector proposals

ATHENA (https://sites.temple.edu/eicatip6/)

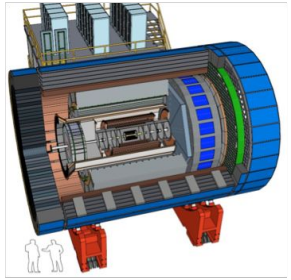
- Focus on becoming the “project detector”@IP6
- New 3 T magnet and the YR Reference Detector
- Leadership: S. Dalla Torre (INFN Trieste, B. Surrow (Temple)
- ~117 collaborating institutions from Armenia, Canada, China, Czech, France, Germany, Italy, India, Poland, Romania, UK

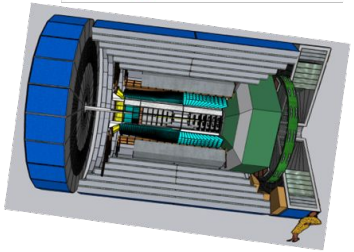
CORE (https://eic.jlab.org/core/)

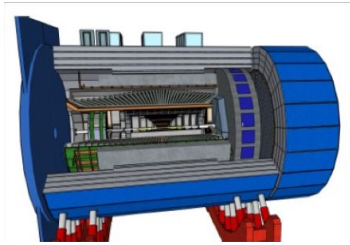
- An EIC Detector proposal based on a new 3 T compact magnet for the 2nd EIC detector @ IP8
- Contacts: Ch. Hyde (ODU) and P. Nadel-Turonski (SBU)
- Smaller-scale effort, ~20-30 active collaborators

ECCE (https://www.ecce-eic.org)

- Project detector @IP6 or the 2nd EIC detector @ IP8 using existing 1.5T “Babar” solenoid
- Leadership: O. Hen (MIT), T. Horn (CUA), J. Lajoie (Iowa State)
- ~98 collaborating institutions from Armenia, Canada, Chile, Croatia, China, Czech, France, Germany, Israel, Japan, Senegal, Korea, Russia, Slovenia, Taiwan, UK





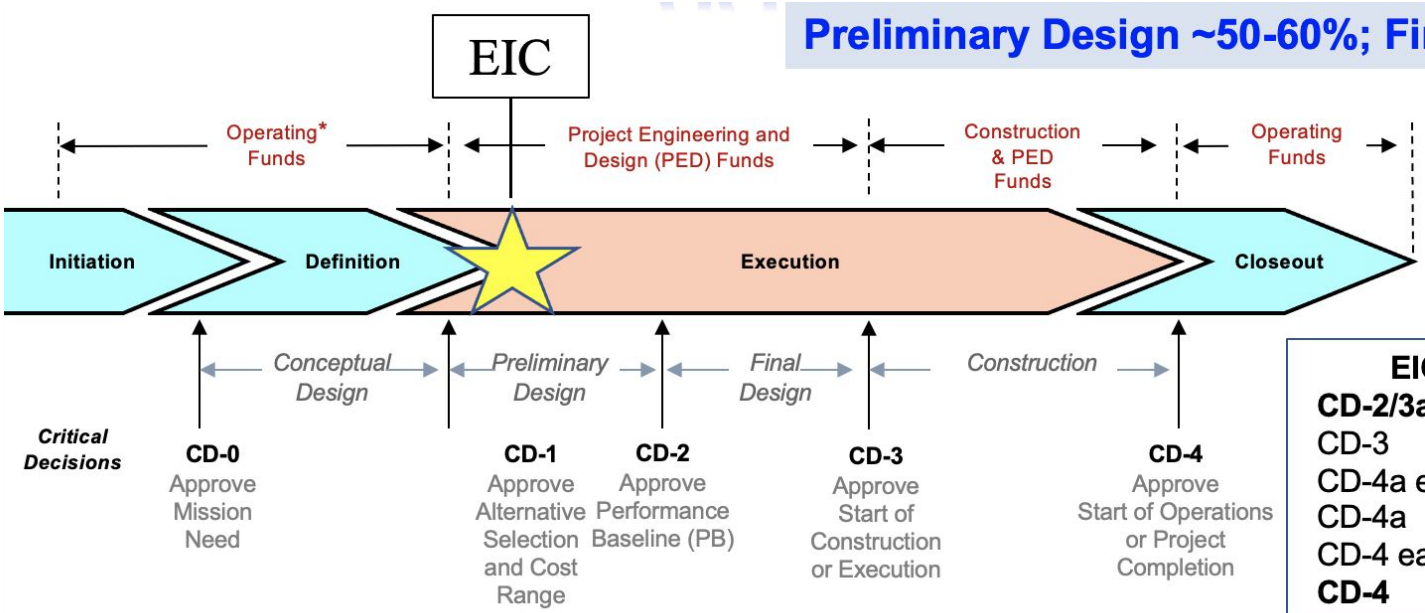


Proto-Collaborations are merged and working on ECCE baseline

See talk by E.C. Aschenauer @ CFNS (link)

Timeline

See talk by E.C. Aschenauer @ CFNS (link)



EIC Critical Decision Plan	
CD-2/3a	**January 2024**
CD-3	April 2025
CD-4a early finish	April 2031
CD-4a	April 2032
CD-4 early finish	April 2032
CD-4	**April 2034**

We have ~10 years to get ready

Outline

1. Status
2. Pre-EIC physics
   ->Global analysis
3. Challenges
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A holistic approach to global analysis

GPD

PDF

Hadron Structure

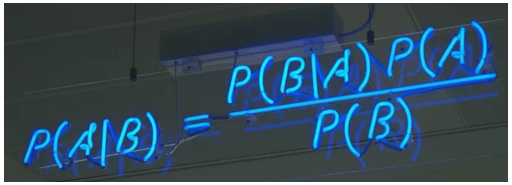
TMD PDF

FF

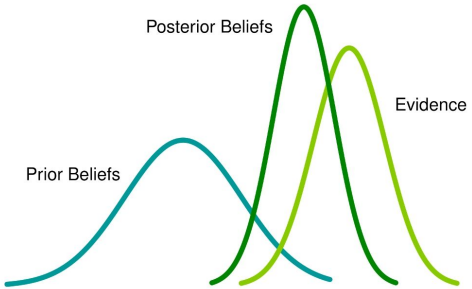
Hadronization

TMD FF

Factorization



Bayesian Inference



Lat.

Exp.

USQCD

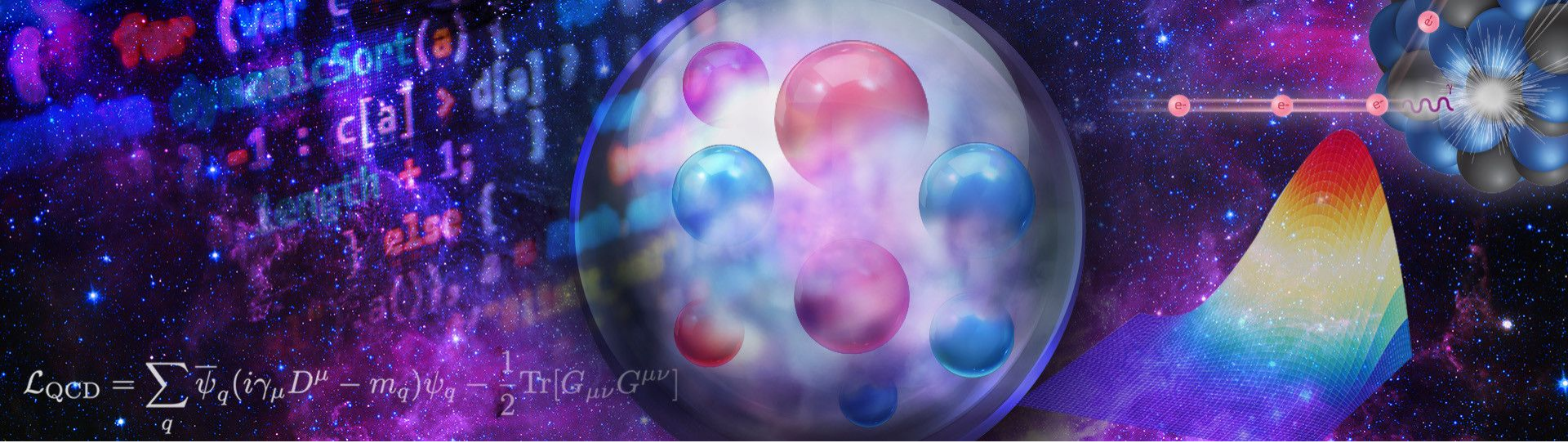
Extended Twisted Mass Collaboration

CERN

Jefferson Lab

KEK

BROOKHAVEN NATIONAL LABORATORY

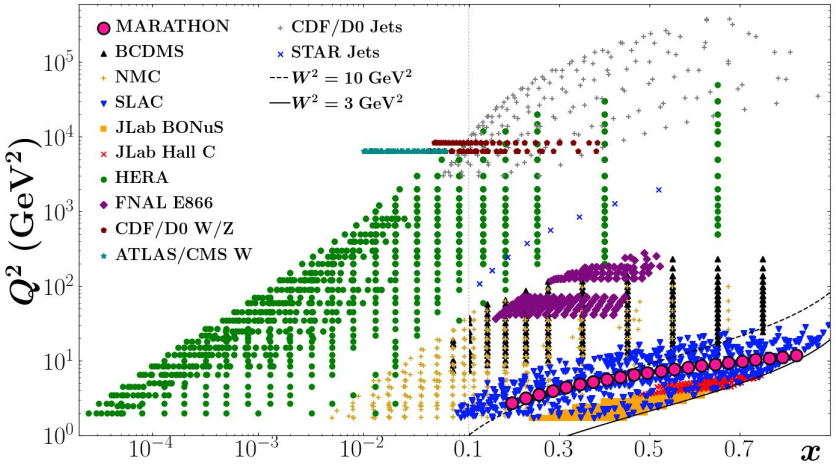


JEFFERSON LAB ANGULAR MOMENTUM COLLABORATION

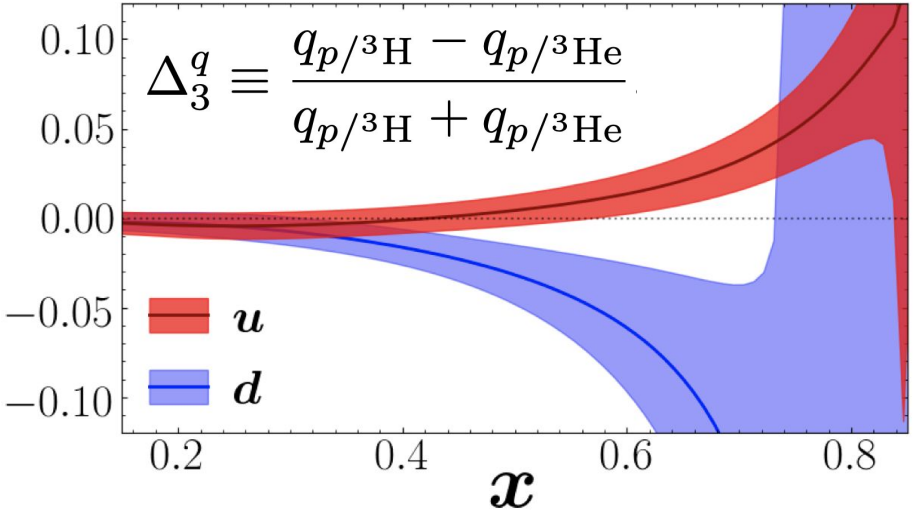
The Jefferson Lab Angular Momentum (JAM) Collaboration is an enterprise involving theorists, experimentalists, and computer scientists from the Jefferson Lab community using QCD to study the internal quark and gluon structure of hadrons and nuclei. Experimental data from high-energy scattering processes are analyzed using modern Monte Carlo techniques and state-of-the-art uncertainty quantification to simultaneously extract various quantum correlation functions, such as parton distribution functions (PDFs), fragmentation functions (FFs), transverse momemtum dependent (TMD) distributions, and generalized parton distributions (GPDs). Inclusion of lattice QCD data and machine learning algorithms are being explored to potentially expand the reach and efficacy of JAM analyses and our understanding of hadron structure in QCD.

Recent highlights

1. Isovector EMC effect with MARATHON data
2. Sea asymmetry with SeaQuest and STAR data
3. Polarized antimatter in the proton
4. Gluon polarization in the proton
5. Nucleon strangeness suppression
6. Pion PDFs with threshold resummation
7. Origin of single transverse-spin asymmetries



Isovector EMC effect



Coccuza, Melnitchouk, Metz, Sato (PRL)

- Global analysis including latest collider *W/Z* data and MARATHON *d/p*, helium, tritium DIS data
- *Evidence of different medium modifications for u and d quarks*
- *Naive modeling of nuclear PDFs, e.g. u/p/A = d/n/A (violates isospin for non-isoscalar A) is wrong*

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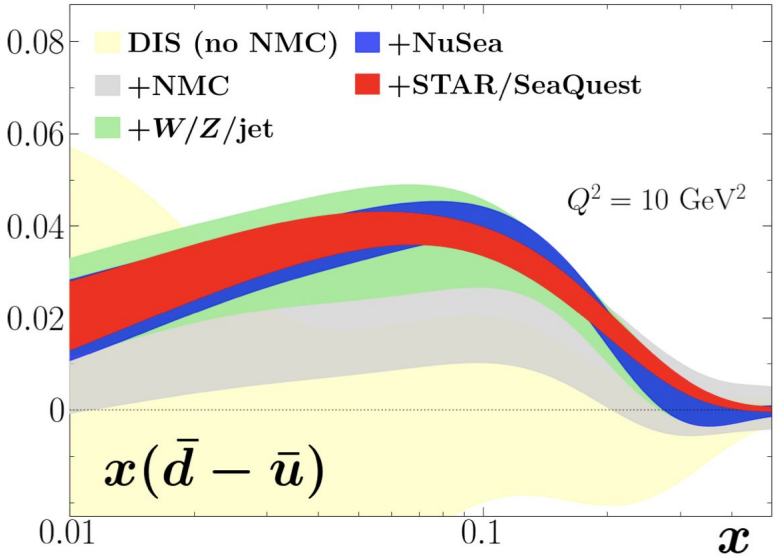
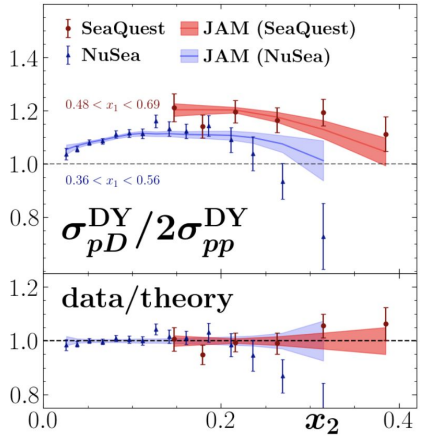
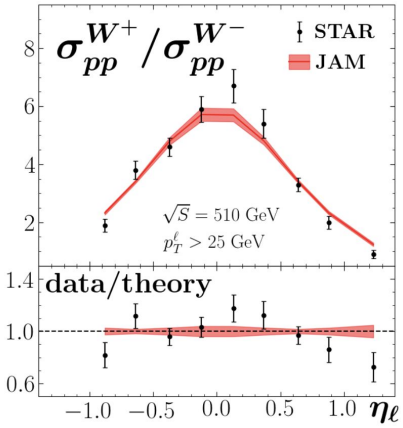
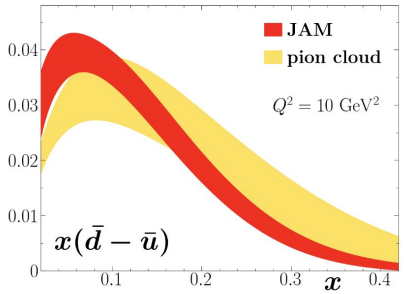
Nucleon sea asymmetry in high definition



Coccuza, Melnitchouk, Metz, Sato (PRD)







- First global analysis to include latest SeaQuest and STAR data
- Most precise phenomenological extraction of *dbar-ubar* asymmetry to date
- Dedicated historical progression of sea asymmetry from the EMC era

$$(\bar{d} - \bar{u})(x) = \left[\left(f_{n\pi^+} + f_{\Delta^0\pi^+} - f_{\Delta^{++}\pi^-}\right) \otimes \bar{q}_v^{\pi}\right](x),$$

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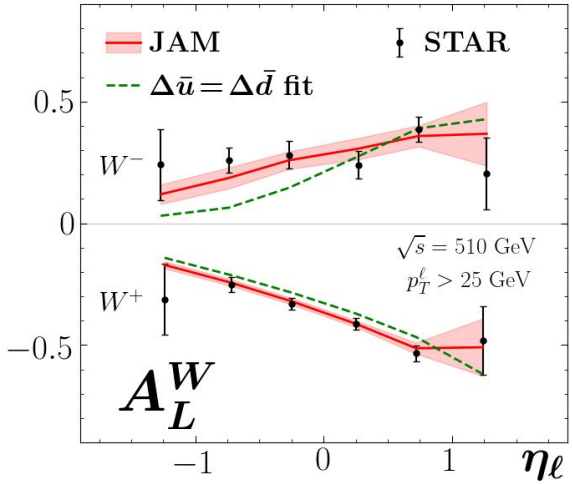
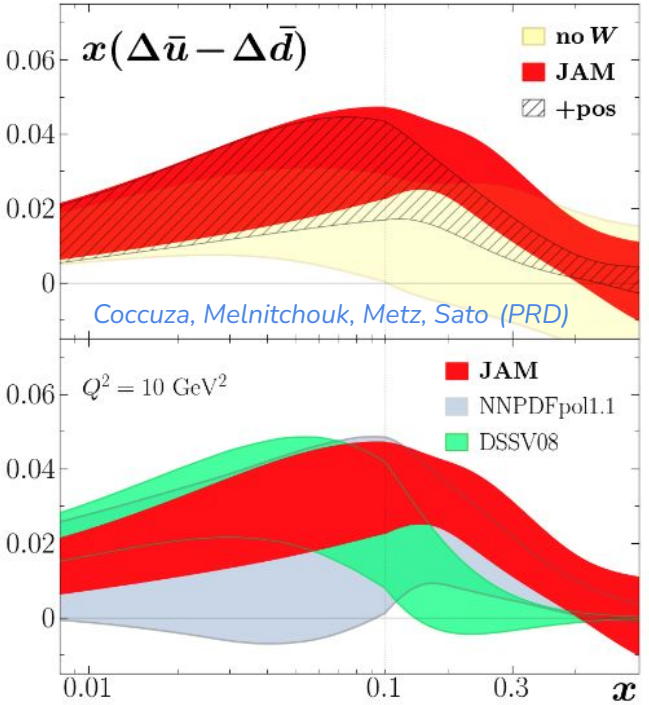


Polarized antimatter in the proton



- First simultaneous extraction of unpolarized and helicity PDFs and FFs in global analysis with inclusion of RHIC spin *W*+/- data
- Most precise phenomenological extraction of polarized *dbar-ubar* asymmetry to date

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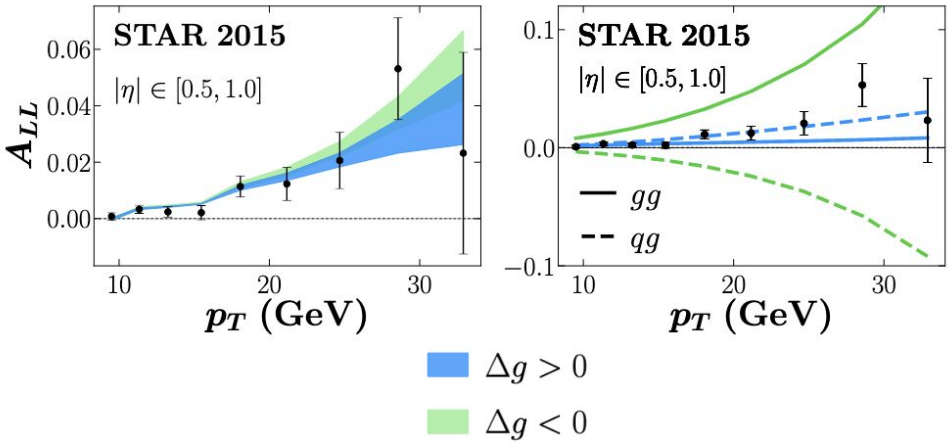
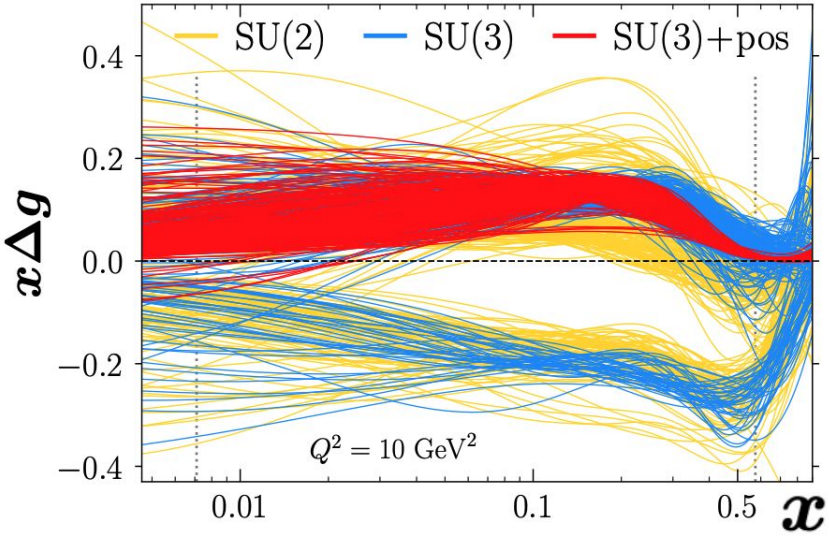


Negative gluon polarization?



Zhou, Melnitchouk, Sato (PRD)

- Inclusion of RHIC polarized jet data allows both positive and negative gluon helicity solutions (in absence of positivity constraints on unpolarized gluon PDF)
- *Gluon helicity currently not as well constrained as was believed (independent of theory bias)*

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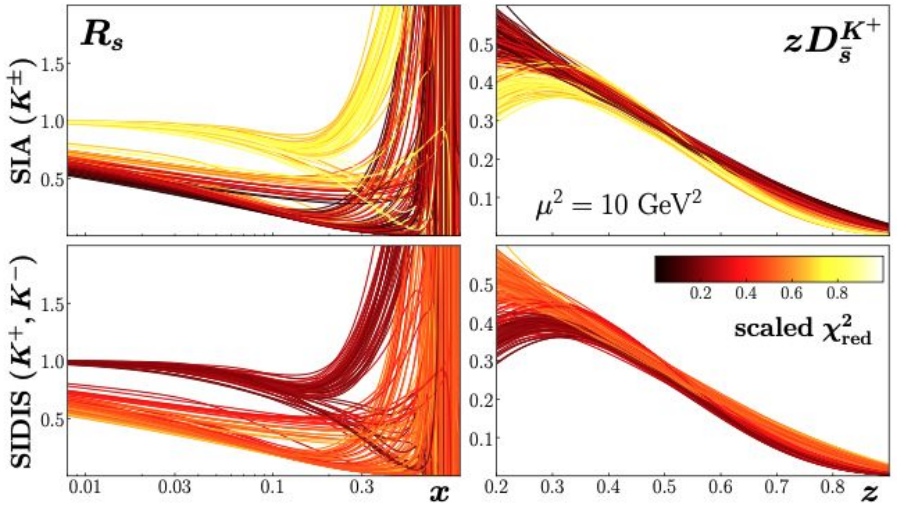
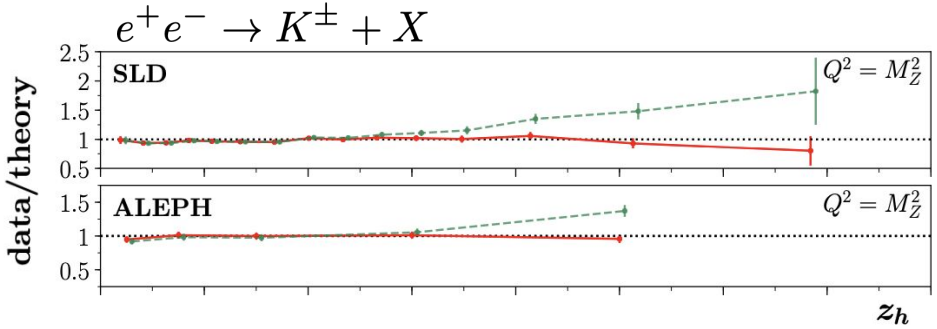
Strange suppression in the nucleon



Moffat, Melnitchouk, Rogers, Sato (PRD)



- New combined analysis of PDFs and FFs including unidentified charged hadron SIDIS and SIA data.
- Analysis indicates strong strange quark suppression
- Conclusion – strangeness at intermediate *x* is largely unconstrained

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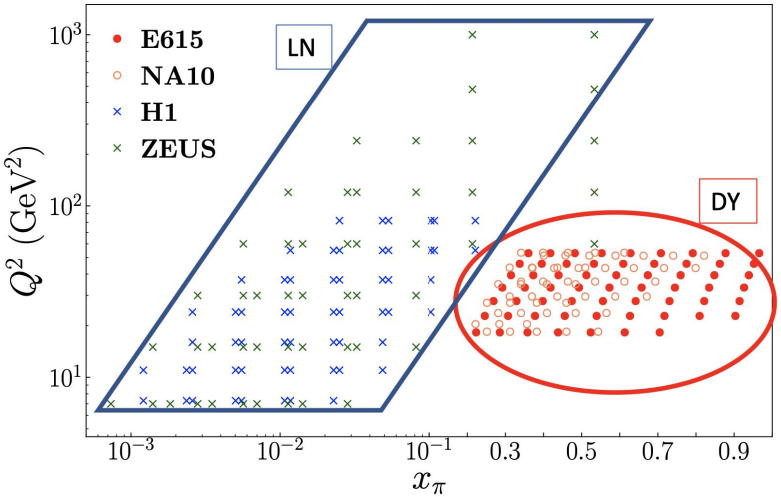
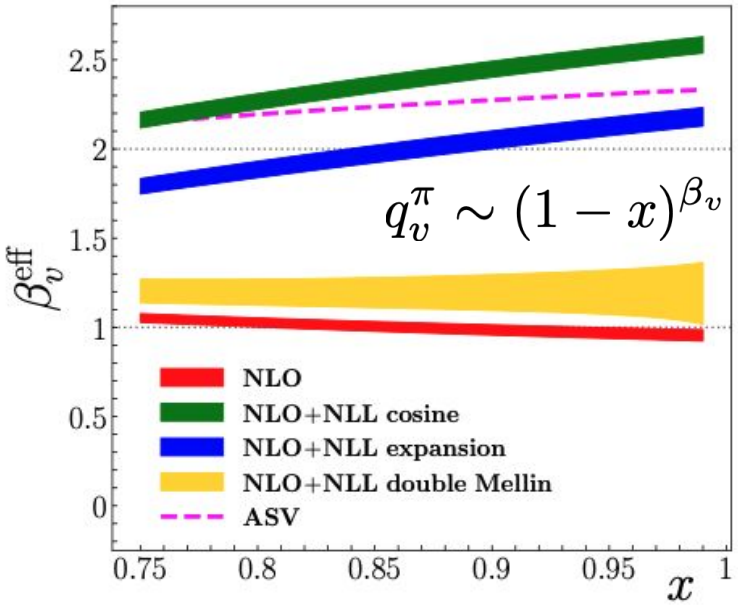


The structure of pions at large x



Barry, Ji, Melnitchouk, Sato (PRL)

- Inclusion of threshold resummation in DY shows consistency between NLO and resummation results for valence pion PDF at large *x*

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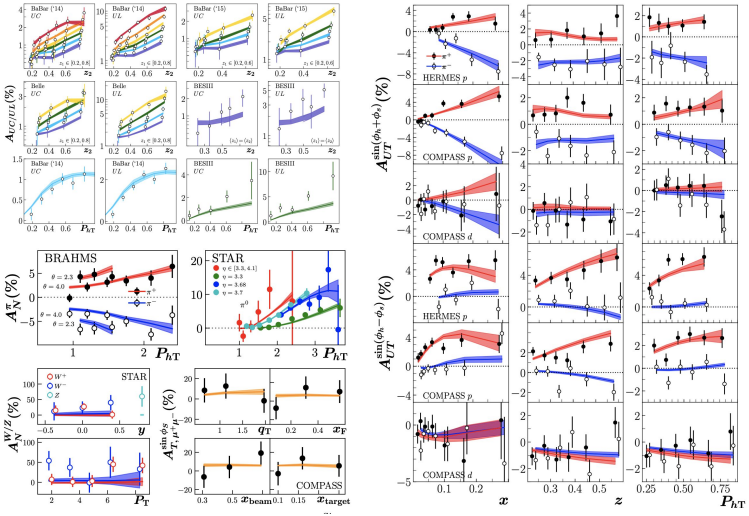
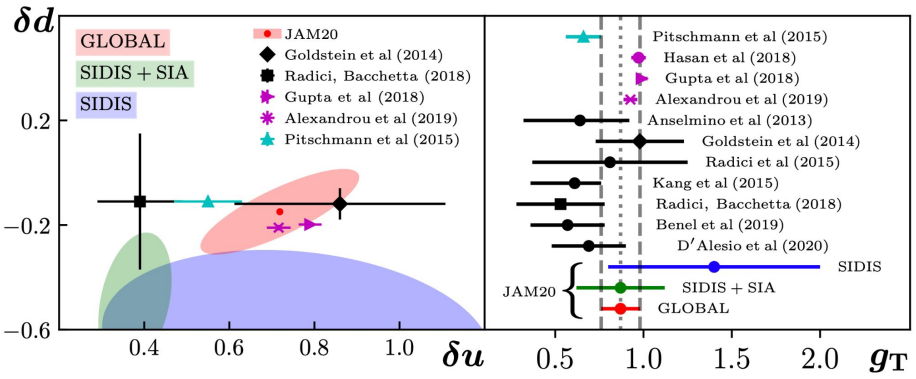


Simultaneous analysis of all SSAs



Cammarota, Gamberg , Kang, Miller, Pitonyak, Prokudin, Rogers, Sato (PRD)

- Exploratory study for a global analysis of all single-spin asymmetries from *ep*, *e+e-* add *pp* reactions using the parton model TMD with collinear twist-3 framework.
- Extracted flavor-dependent transversity in good agreement with LQCD for the first time.

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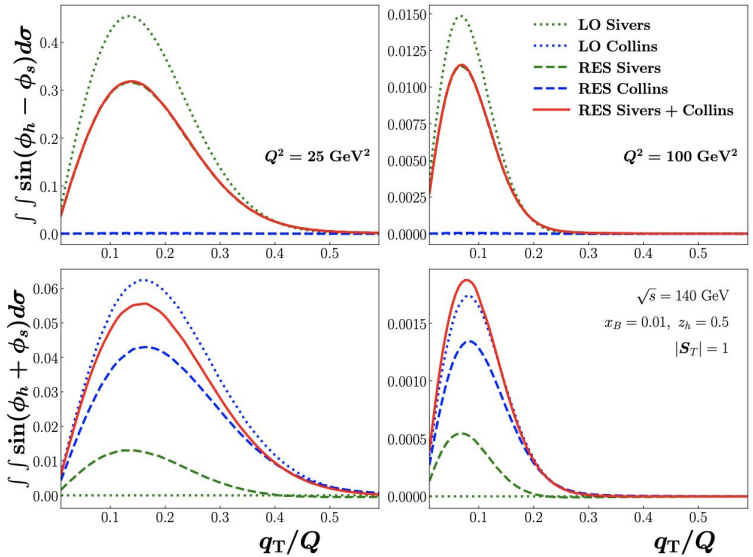
Challenges

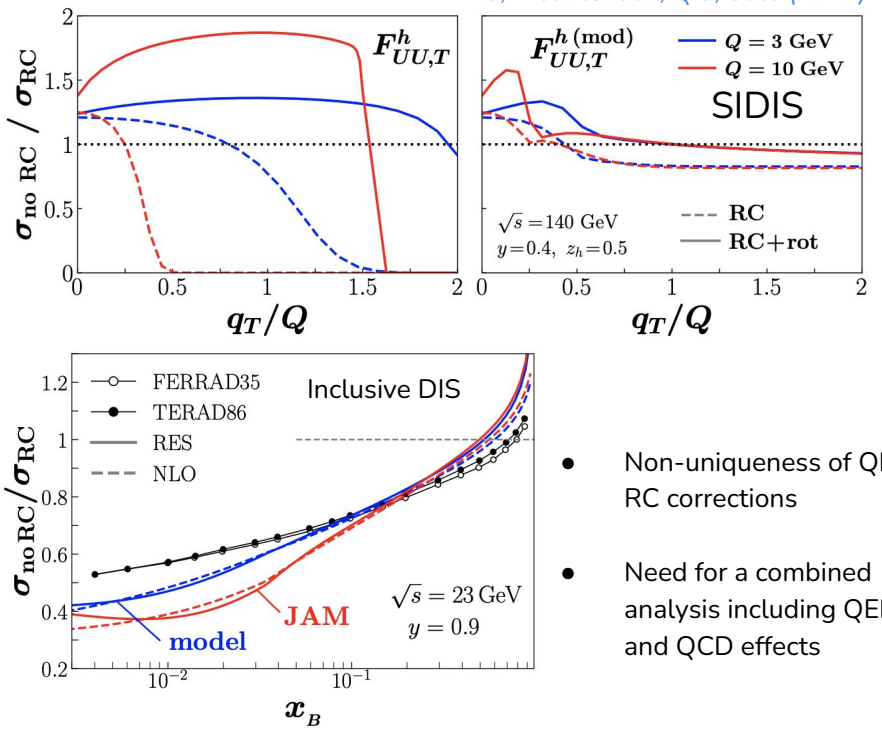
1. Inclusion of QED effects in global analysis
2. GPD phenomenology
3. End-to-end analysis framework



- Hybrid QED+QCD framework to study SSAs in SIDIS within global analysis
- *Crucial to control QED backgrounds in transverse spin asymmetries*

Towards a global analysis includes QED effects

Liu, Melnitchouk, Qiu, Sato (JHEP)



- Non-uniqueness of QED RC corrections
- Need for a combined analysis including QED and QCD effects

Challenges

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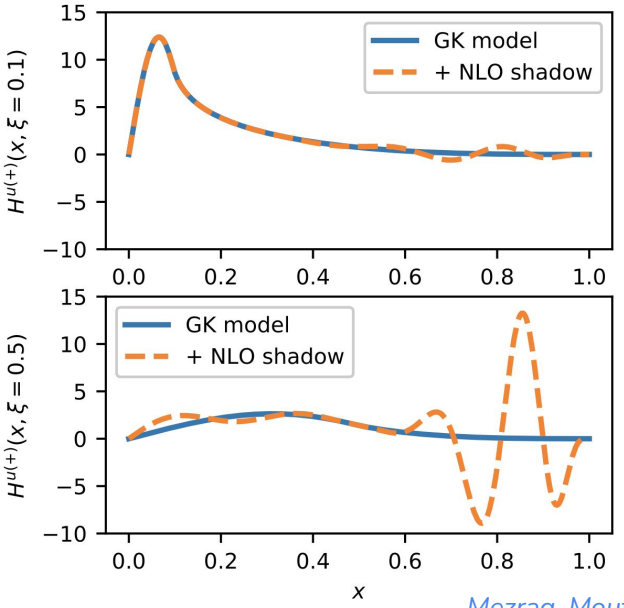
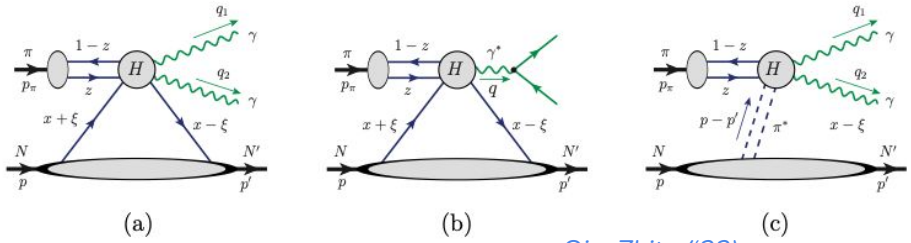
Deconvolution problem in DVCS/DVMP



Shadow GPDs analysis shows the inability to constraint GPDs uniquely away from the ridge.

Bertone, Dutrieux, Mezrag, Moutarde, Sznajder, ('21)

New processes to access GPDs away from the ridge



Qiu, Zhite ('22)

- Similar photon-induced processes measurable at Hall D can be explored
- Full realization of this program will bring GPD phenomenology into a new era

Challenges

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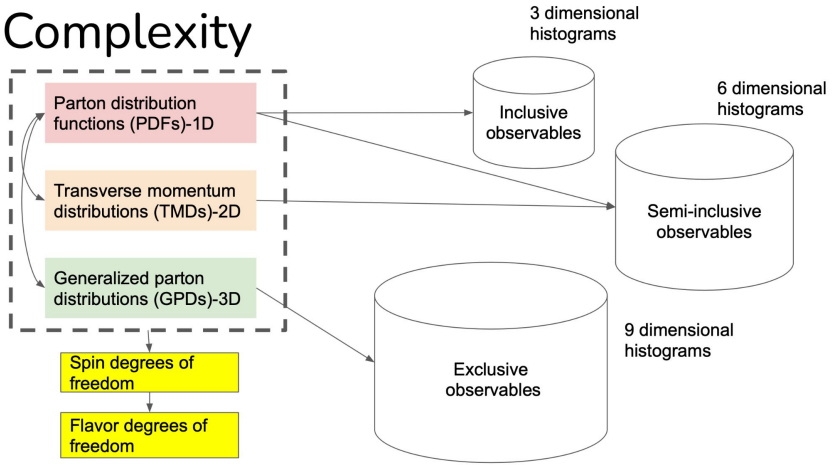
Complexity

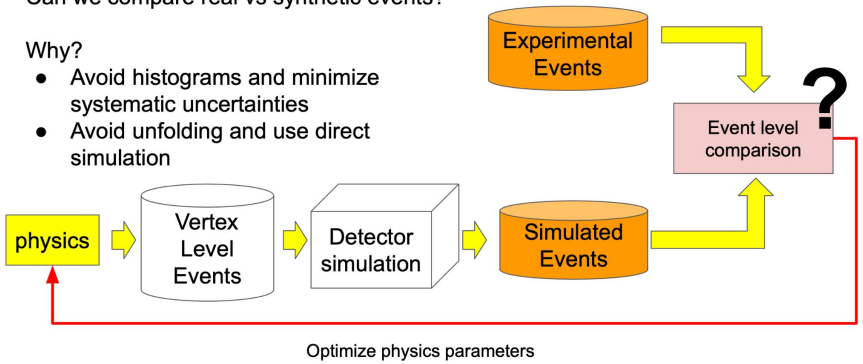


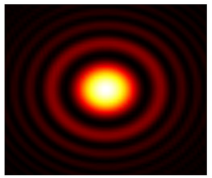
event-based analysis

Can we compare real vs synthetic events?

Why?

- Avoid histograms and minimize systematic uncertainties
- Avoid unfolding and use direct simulation





QuantOm Collaboration

Argonne NATIONAL LABORATORY

Jefferson Lab

VT

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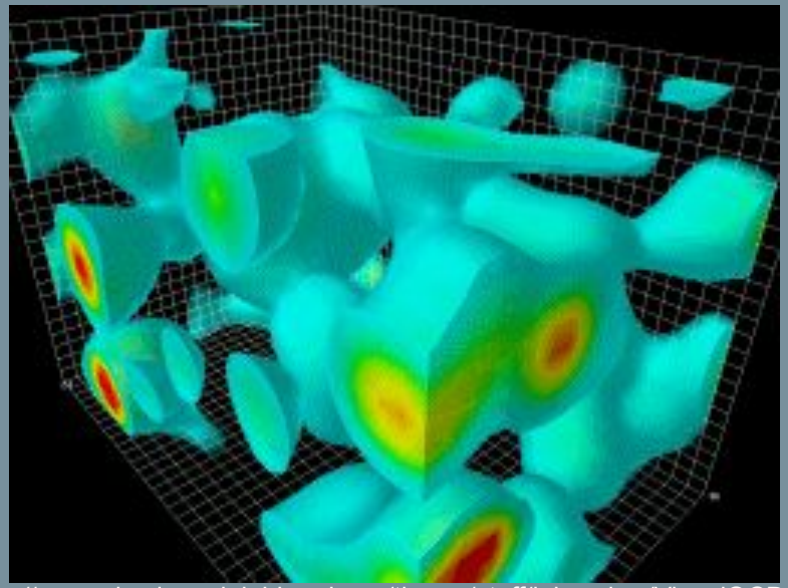
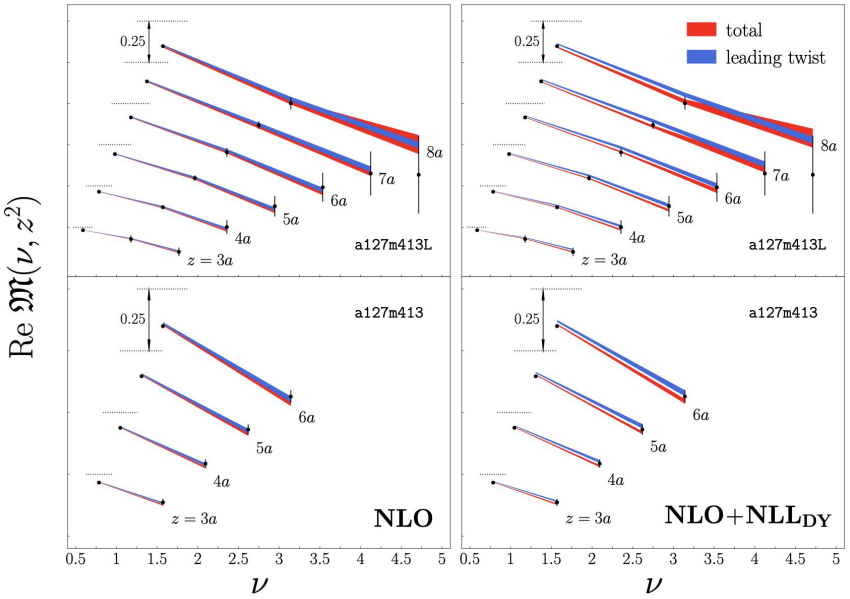
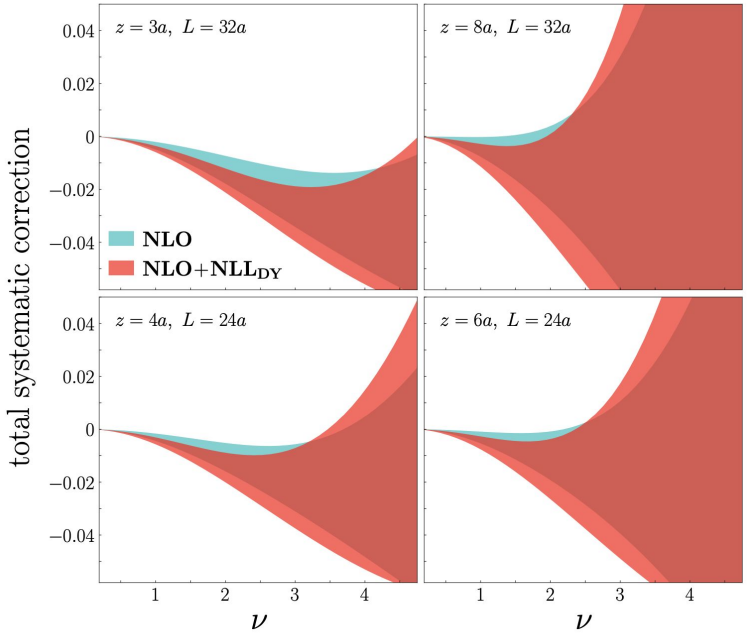


http://www.physics.adelaide.edu.au/theory/staff/leinweber/VisualQCD/Nobel/

Synergies with LQCD

Barry et al. (‘22)
JAM+HadStruct

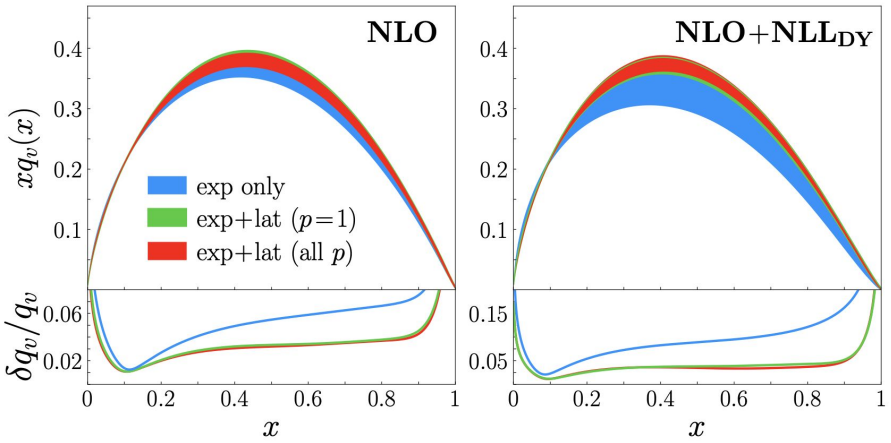


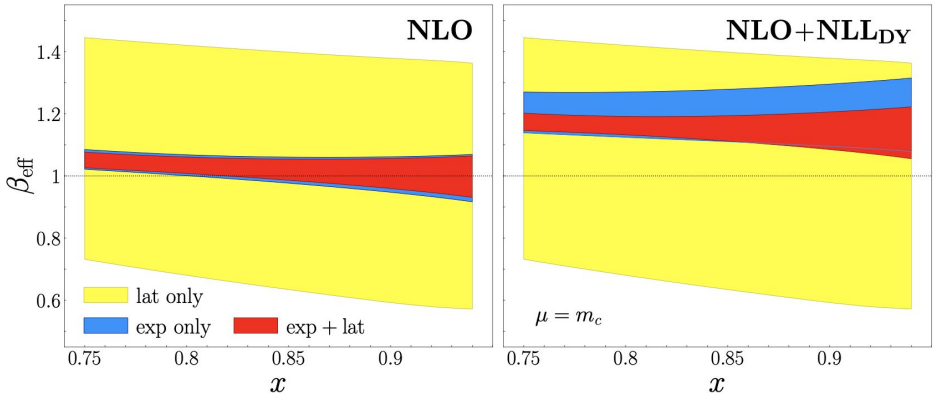


$$\mathrm{Re}\,\mathfrak{M}(\nu, z^2) = \int_0^1 \mathrm{d}x\; q_v(x, \mu_{\mathrm{lat}})\, \mathcal{C}^{\text{Rp-ITD}}\left(x\nu, z^2, \mu_{\mathrm{lat}}\right) + \boxed{z^2 B_1(\nu) + \frac{a}{|z|} P_1(\nu) + e^{-m_\pi (L-z)} F_1(\nu)}\,.$$

Experimental data can provide insights into LQCD systematics

Synergies with LQCD





- LQCD can aid hadron structure studies in cases where constraints from experiments are limited - *“lattice priors”*
- Theory Center has expertise from JAM & HadStruc and has started collaborative research work

Summary/Outlook

Are we getting ready for the EIC?

yes…but lot more work is needed

EIC is a community driven project:

everyone can really be part of it and contribute

Key to the success:

close collaboration between theory, experiment and computer science