JLUO meeting on NSAC long range plan

Thursday 8 Sep 2022, 08:00 → 15:20 US/Eastern

Online via Zoom

Carlos Munoz Camacho (IJCLab, Orsay (CNRS/IN2P3))

Theory

Input to LRP process:

What theory can do as it relates to the future experimental program, including developments and outlook in event generators

Jianwei Qiu
Jefferson Lab, Theory Center

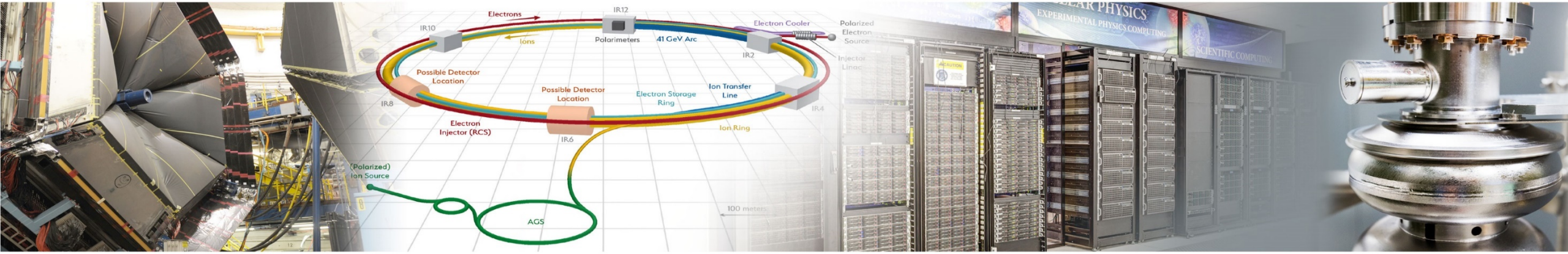
Jefferson Lab

U.S. DEPARTMENT OF ENERGY | Office of Science

JSA

Jefferson Lab's Science and Technology Vision

Stuart's presentation at DOE S&T Review



Nuclear Physics at CEBAF

Vibrant 12 GeV research program, operating >30 weeks/yr, supporting ~1,700 annual users

MOLLER Project & SoLID proposal

Future opportunities in fixed-target, high-luminosity complementary to EIC

Theory and computation supporting NP goals

Electron-Ion Collider

Partnering with BNL in the management, design, and construction of the Electron-Ion Collider Project

Leadership in EIC scientific program

Leadership of the Generic EIC–related Detector R&D Program

Computational Science & Technology

Vision for world-leading computational program

Developing concept of a High Performance Data Facility focused on the unique challenges and opportunities for data-intensive applications and near real-time computing needs

Development of AI and ML for Science

Accelerator Science & Technology

Accelerator component production for DOE/SC projects, including LCLS-II and LCLS-II HE at SLAC, SNS PPU at ORNL, and PIP-II at FNAL

Develop CEBAF upgrade concepts

Accelerator R&D including materials, coatings, SRF, cryogenics

S&T thrusts are synergistic and mutually supportive

What theory can do as it relates to the future experimental program?

- **JLab/Theory website [https://www.jlab.org/theory/theory-research]**

  The Jefferson Lab Theory Center pursues frontline research in all areas of QCD and hadron physics, commits to the lab mission to provide the theoretical underpinnings of its experimental program, and develops the theoretical tools necessary to extract physics knowledge from the current and future experimental data. Through expertise across a broad range of nuclear physics, Theory Center staff members provide leadership for national and international nuclear physics research efforts.

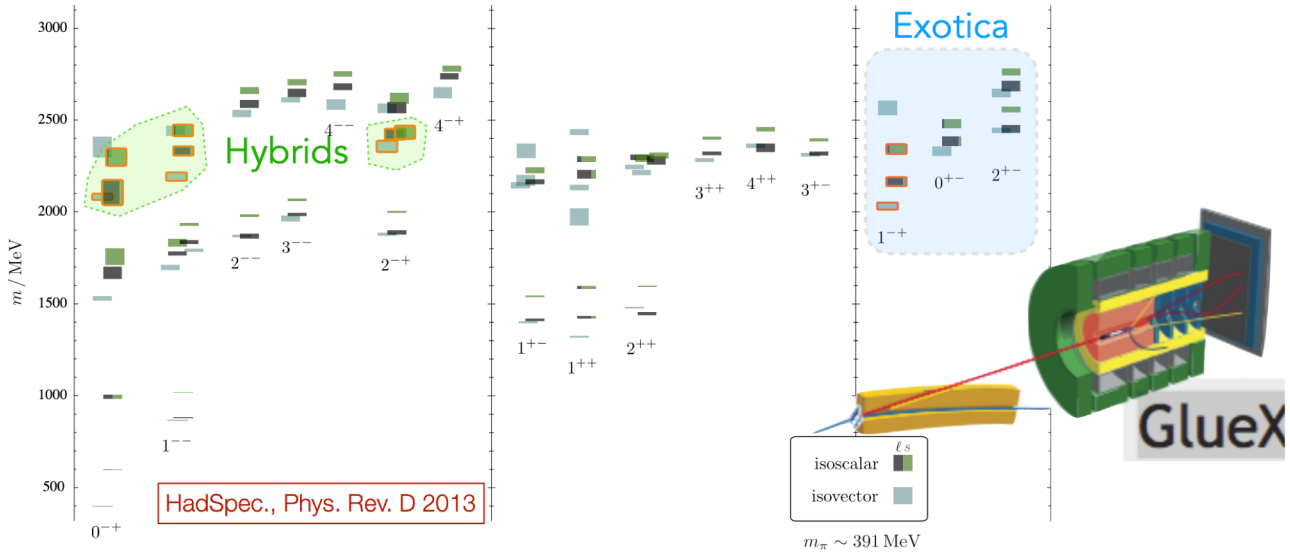
- **The Theory Center's current research focuses on the following thrust areas:**
  - Hadron spectroscopy from lattice QCD;
  - Application of analytical methods to hadron spectroscopy (JPAC);
  - Partonic structure of hadrons and nuclei;
  - Hadron & nuclear structure from lattice QCD;
  - Hadron & nuclear structure and effective field theories;
  - Structure and electroweak response of nuclei.

- **Theory Center also conducts supporting research in areas such as:**
  - Physics beyond the Standard Model;
  - Artificial intelligence & machine learning;
  - Quantum information science & quantum computing.

Hadron spectroscopy from lattice QCD

Developing an understanding of which constructions of quarks and gluons appear in the spectrum of hadrons, with that understanding being rooted in first-principles QCD through the lattice QCD calculations

- **Applying finite-volume formalisms to relate the discrete spectrum of states computed in lattice QCD calculations to the continuous scattering amplitudes measured in experiments**
- **Focusing on studying excited hadrons as they appear in experiment, as short-lived resonances which decay into lighter stable hadrons.**



- Clear evidence for meson states that are quark-gluon hybrids or have exotic quantum numbers

Enabled by early adoption of GPUs in LQCD

Jefferson Lab

Hadron spectroscopy from lattice QCD

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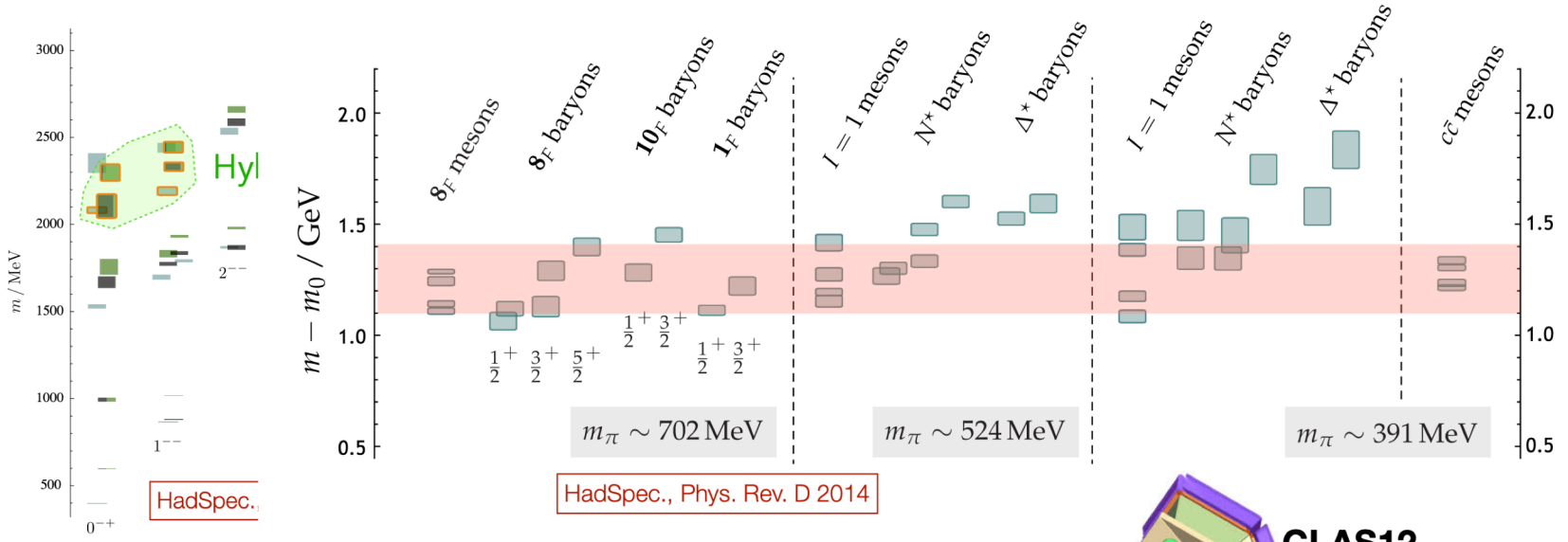
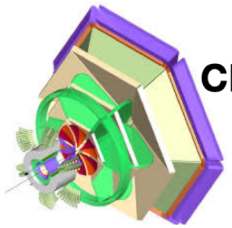


- Clear evidence for me hybrids or have exotic
- Identified common scale for gluon excitation amongst mesons and baryons



CLAS12

Hybrid baryons spurred new experimental effort

Jefferson Lab

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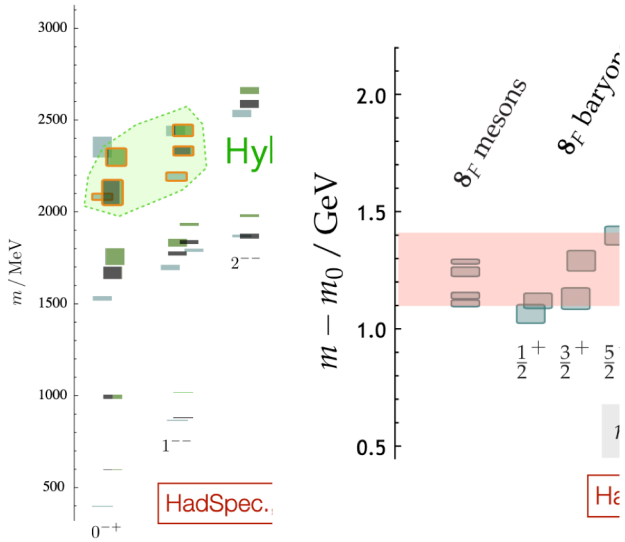

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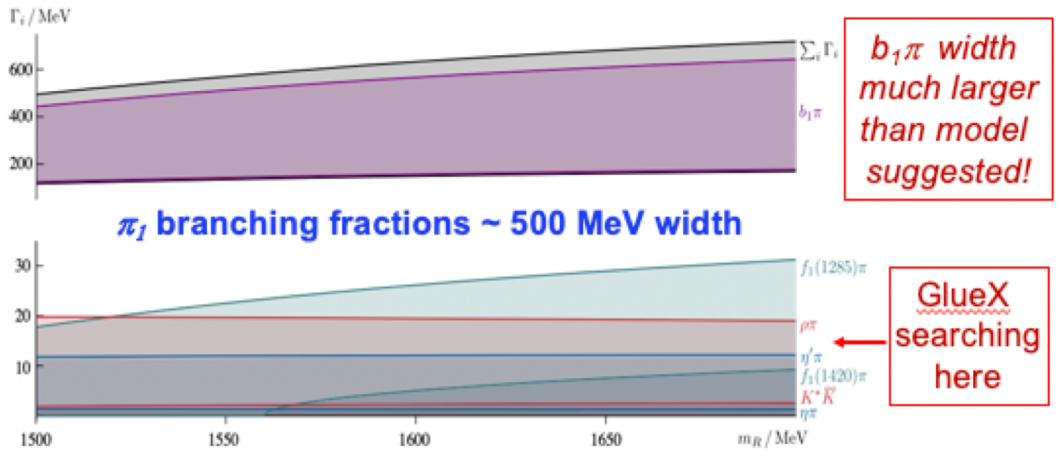
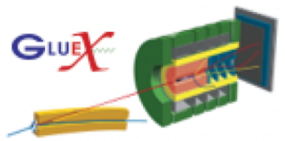
Where to look?



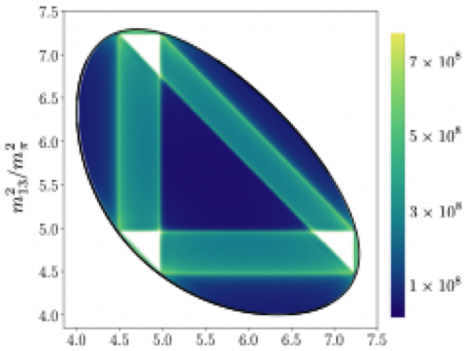
PHYSICAL REVIEW D **103,** 054502 (2021)

Decays of an exotic 1^{-+} hybrid meson resonance in QCD

Hadron Spectrum Collaboration



Beyond two-particle decay



3-body amplitudes (Dalitz plot)

PRL Editor's Suggestion

Hadron Spectrum Collaboration

Phys. Rev. Lett. 126 (2021) 012001

Jefferson Lab

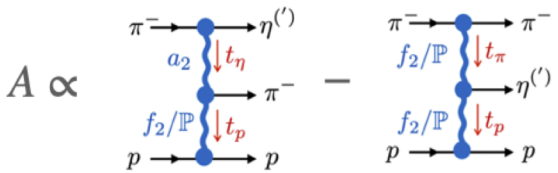
Application of analytical methods to hadron spectroscopy (JPAC)

Developing theoretical and phenomenological understanding of production and decays of hadron resonances

- **JPAC – Joint Physics Analysis Center:**

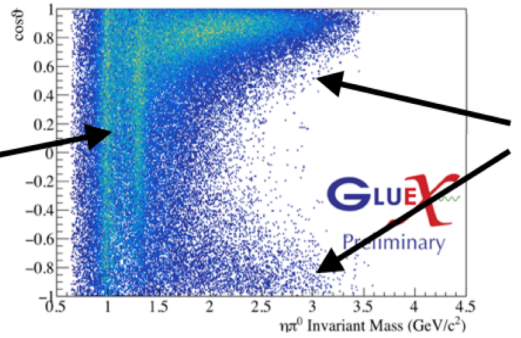
  Joint efforts between theorists and experimentalists, providing support to *CLAS12, GlueX, …*

- **Search for the exotic hybrid at JLab and future EIC:**

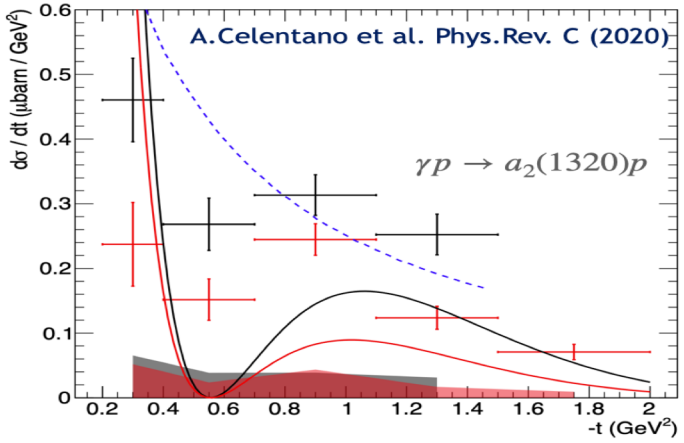


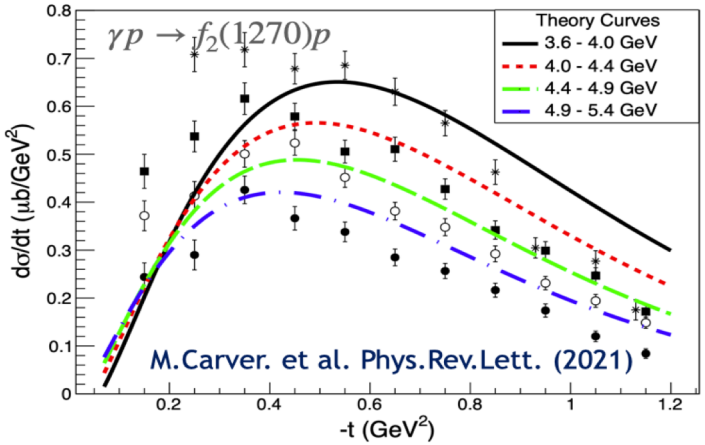
L.Bibrzycki et al, arXiv:2104.10646

(Exotic) resonance production region



Regge region





JPAC predictions (Solid lines) *PRD 2020*

Jefferson Lab

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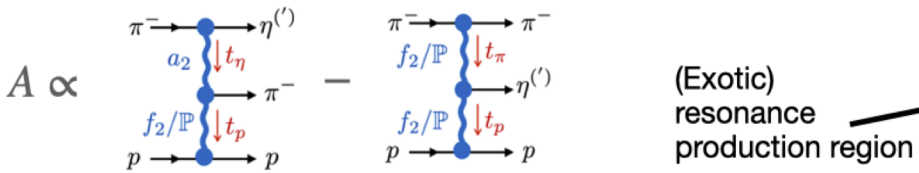

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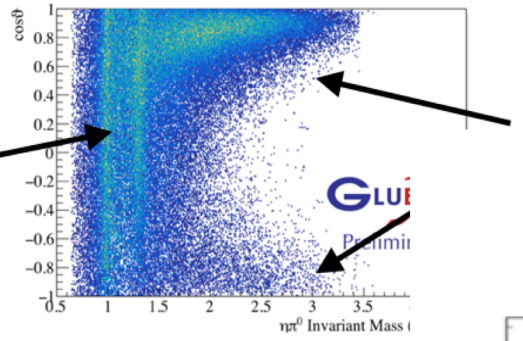
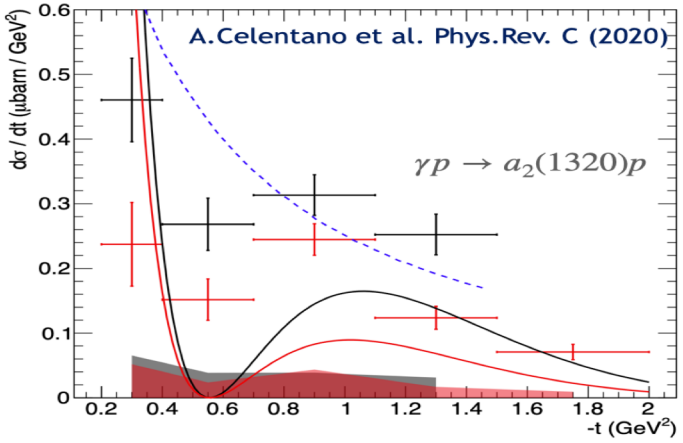
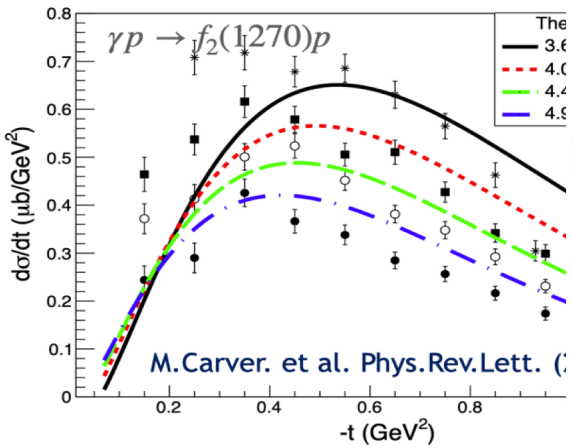
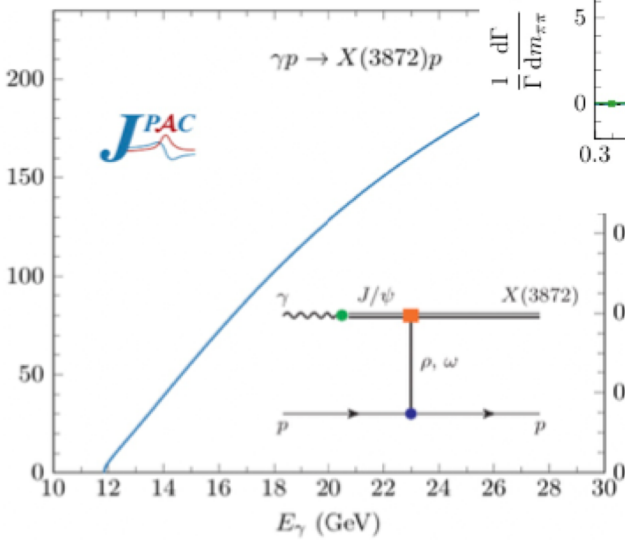


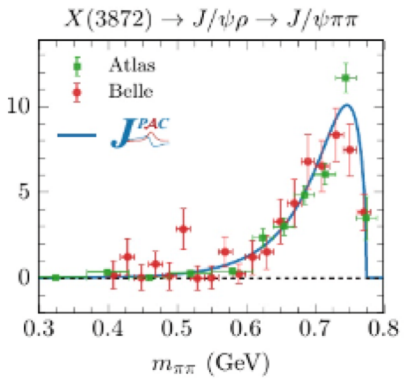
XYZ at JLab

Enough phase space/luminosity







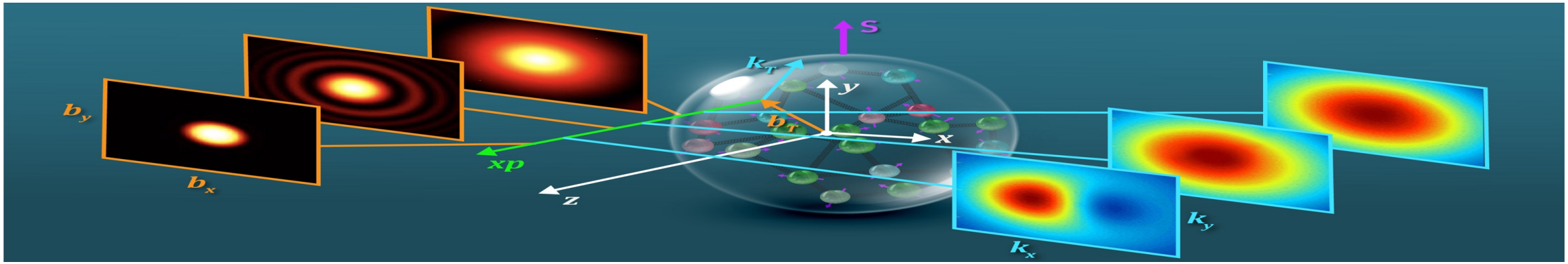


JPAC predictions (Solid lines) *PRD 2020*

Jefferson Lab

Partonic structure of hadrons and nuclei

Developing new formalisms and techniques to quantify three-dimensional partonic structure of hadrons through various quantum correlation functions (QCFs), PDFs, FFs, TMDs, GPDs, multi-parton correlations, ...



NO quarks and gluons can be seen in isolation!

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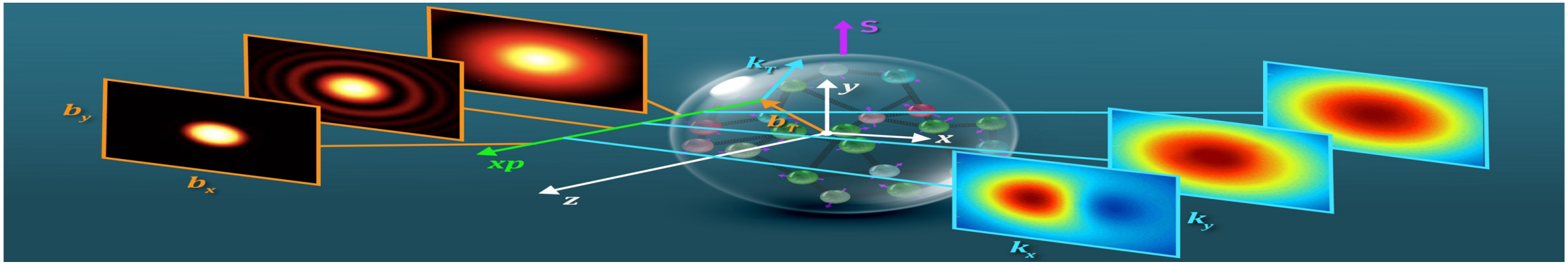


NO quarks and gluons can be seen in isolation!

Lattice QCD data

Experimental data

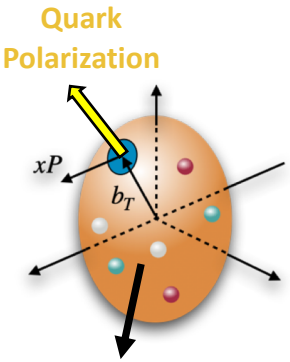
Factorization Theory

$$= \int \cdots \int$$

PQCD Calculation

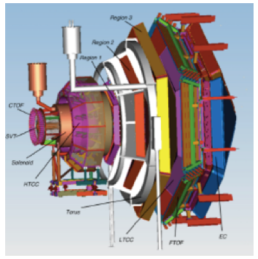
$\otimes$

Quantum Correlation Functions Unknown



Bayesian inference
Theory/Phenomenology
AI/ML, Computation

Extract QCFs



Jefferson Lab
KEK
CERN
BROOKHAVEN NATIONAL LABORATORY
Fermilab

SciDAC5-Project: Comparing theory & Experimental data at event-level

Jefferson Lab

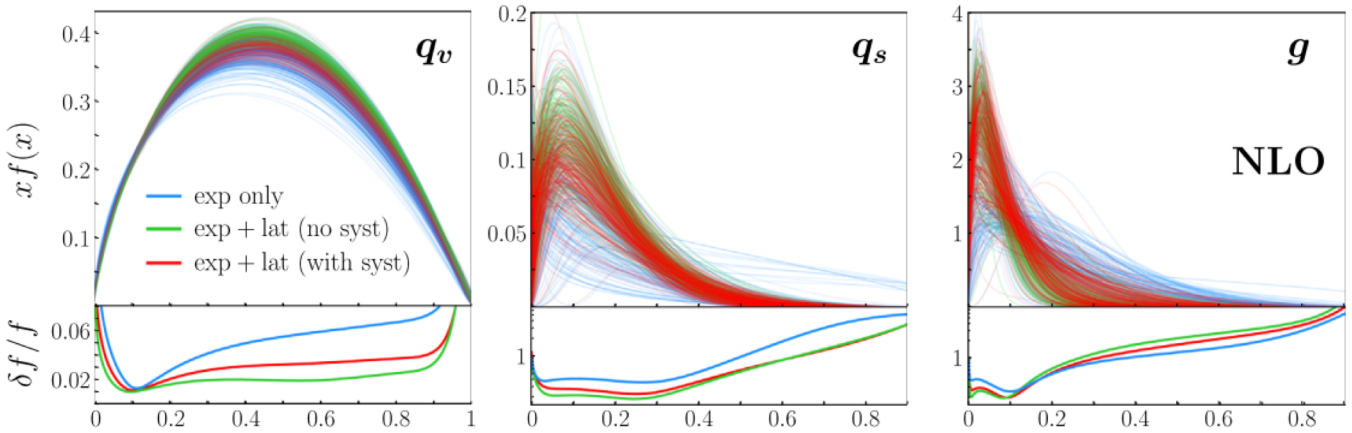
Partonic structure of hadrons and nuclei

- **Combined analysis of LQCD and EXP data:**

  Phys.Rev.D 105 (2022) 114051

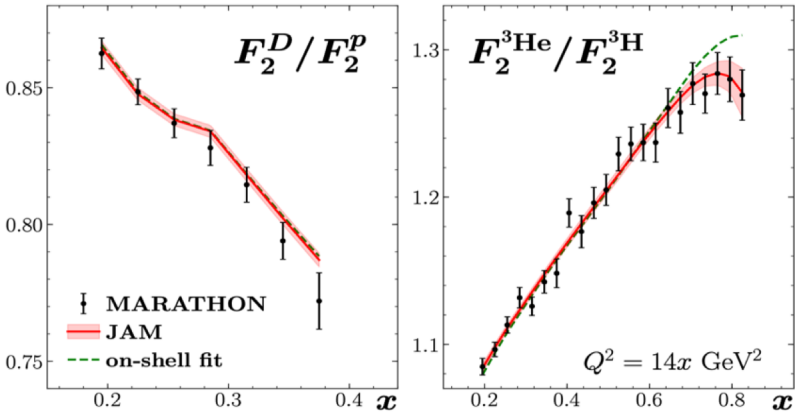
  - First global QCD analysis and extraction of pion PDFs with lattice data and experimental data
  - Polarized and unpolarized PDFs

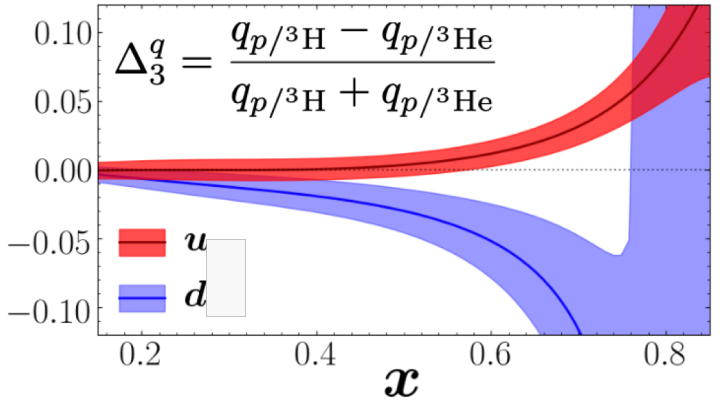
  Phys. Rev. D103 (2021) 016003



- **Support JLab experimental data analysis:**
  - Combining collider W/Z data and MARATHON d/p, helium-3, tritium DIS data

  Phys.Rev.Lett. 127 (2021) 24, 242001





Joint Theory + Experiment publication

  - Evidence for isovector nuclear EMC effect in A=3 system from QCD analysis including MARATHON data

JHEP 08 (2022) 103

- **Develop new observables for extracting the x-dependence of GPDs – 3D tomography**

Jefferson Lab

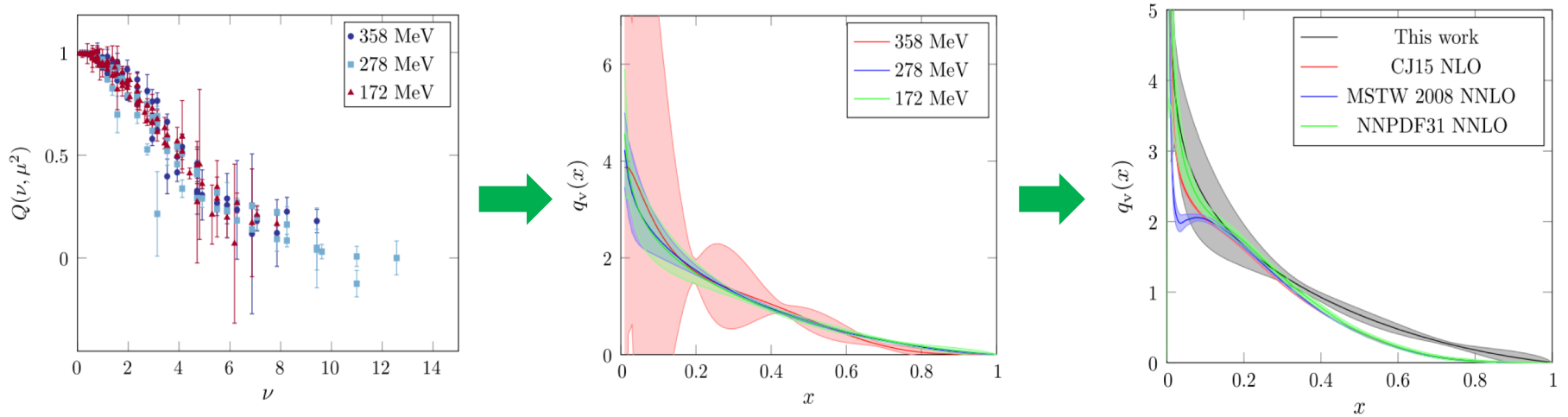
Hadron & nuclear structure from lattice QCD

Exploiting lattice QCD to calculate the key measures of partonic structure to reveal the distribution of momentum, spin and mass amongst the primordial quarks and gluons, …

- **Exploiting new ideas in artificial intelligence and statistical methods to ensure that key physics emerges with the minimum of bias**
- **Working to ensure that experiment and computation can together provide the most faithful description of the internal structure of hadrons**

❑ **LQCD calculation at the physical point:**

Phys. Rev. Lett. 125 (2020) 232003 **HadStruc Collaboration**



Gluon PDF

Phys.Rev.D 104 (2021) 094516

Transversity PDF

Phys.Rev.D 105 (2022) 034507

…

On-going calculation for extracting GPDs

Ioffe-time distribution $\nu = P.z$

Neural-network was used to aid the analysis to extract PDFs

JHEP 03, 2021

❑ **Generating new LQCD configurations better suited for hadroni structure calculations:**

A new SciDAC5-Project on LQCD

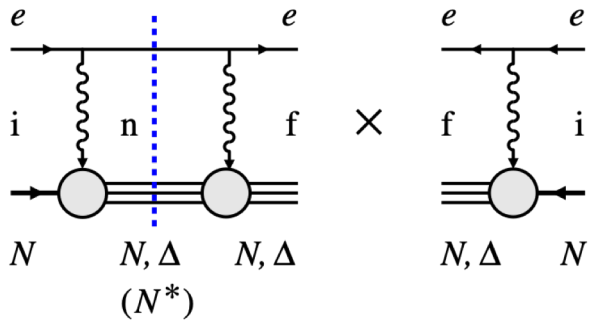
Jefferson Lab

Hadron & nuclear structure and effective field theories

Pursuing a focused research program using methods such as Chiral EFT, large-N_c QCD, and others, to explain large-distance hadron structure and interactions, particularly structures measured at JLab, …

❑ The $1/N_c$ expansion:

- **Two-photon exchange in electron/positron-hadron scattering: Systematic analysis using 1/Nc expansion and chiral EFT methods, including spin effects. Relevant to JLab positron program**



- **Calculated transverse normal single-spin asymmetry in inclusive electron scattering e+N(pol)$\rightarrow e'$+X with two-photon exchange**

To be measured at JLab Hall A

- **Resonance excitation in hard exclusive processes and transition GPDs: Systematic analysis of N-Delta transition in pseudoscalar/vector production using 1/Nc expansion**

❑ Chiral EFT:

Nucleon form factors: Analysis combining dispersion theory and chiral EFT methods with predictive power. Relevant to PRad, JLab positron program, muon scattering MUSE

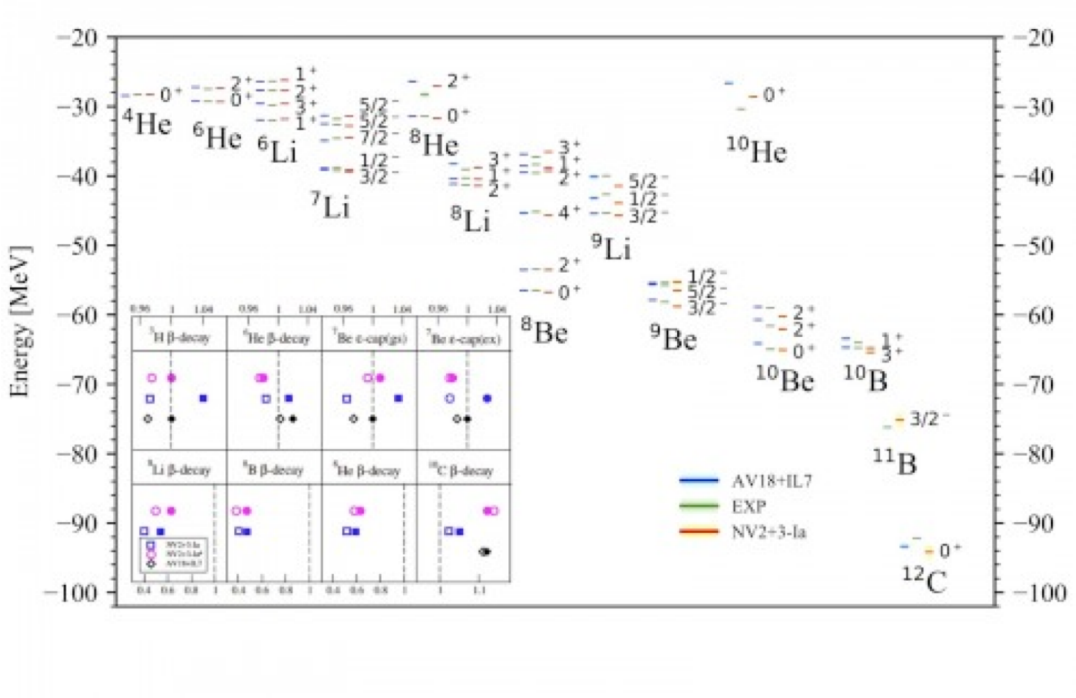
Structure and electroweak response of nuclei

Understanding the structure and dynamics of nuclei in terms of the many-body (primarily, two- and three-body) strong forces governing the interactions among their constituents, i.e., the nucleons, …

Understanding the response of nuclei to electromagnetic and weak probes in terms of the coupling of these probes to individual nucleons and to many-body clusters of nucleons

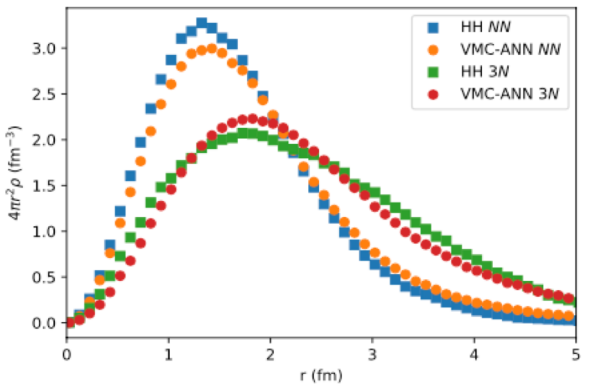
❑ Light nuclei spectra:

- **χEFT for 2N and 3N interactions with Δ's**
- **Contact 3N interaction constrained by ^{3}He/^{3}H binding**



❑ Artificial neural network-VMC with π/EFT:

- π/EFT used for validating new quantum many-body method
- Comparison VMC-ANN with the HH method



^{6}Li point nucleon density

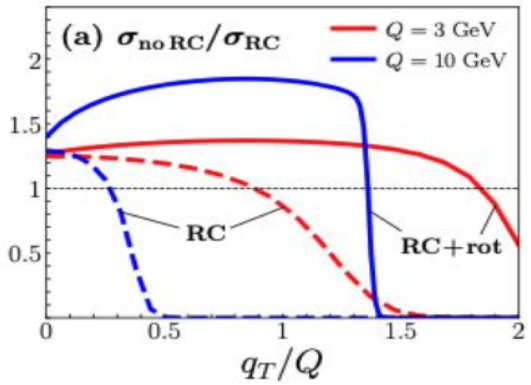
Nucleus	ANN E (MeV)	HH E (MeV)
^{2}H	−2.242(1)	−2.242
^{3}H	−8.232(1)	−8.475
^{3}He	−7.564(1)	−7.811
^{4}He	−27.903(1)	−28.17
^{6}He	−27.46(2)	−27.41(8)
^{6}Li	−30.82(3)	−31.00(8)

Binding energies up to A = 6 nuclei

Jefferson Lab

Hadron/nuclear structure – JLab/EIC

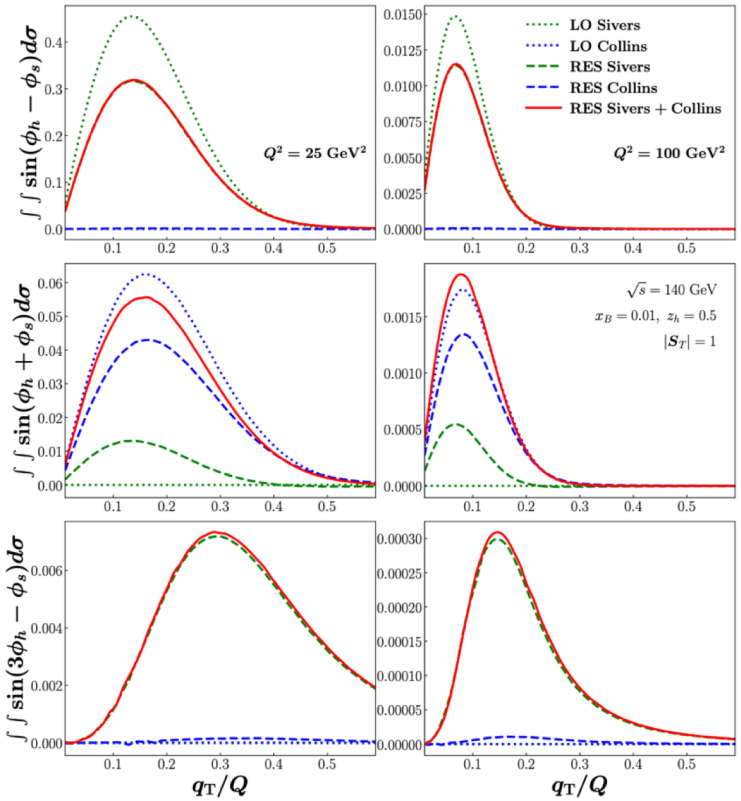
❑ QED at SIDIS (JLab/EIC):



JHEP 11 (2021) 157

Phys.Rev.D 104 (2021) 9, 094033

- **Presented a new factorized approach to semi-inclusive deep-inelastic scattering which treats QED and QCD radiation on equal footing**
- **Provided a systematically improvable approximation to the extraction of transverse momentum dependent parton distributions**



New young members

- Yang-Ting Chien (bridged with Georgia State): Jet and jet stricture at the EIC, …
- Felix Ringer (Joint with ODU):
  - AI/ML and QC for NP at JLab/RHIC/EIC, …

Jefferson Lab

Hadron/nuclear structure – JLab/EIC

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JHEP 11 (2021) 157
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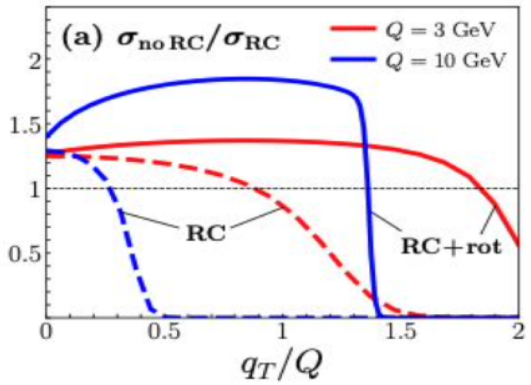

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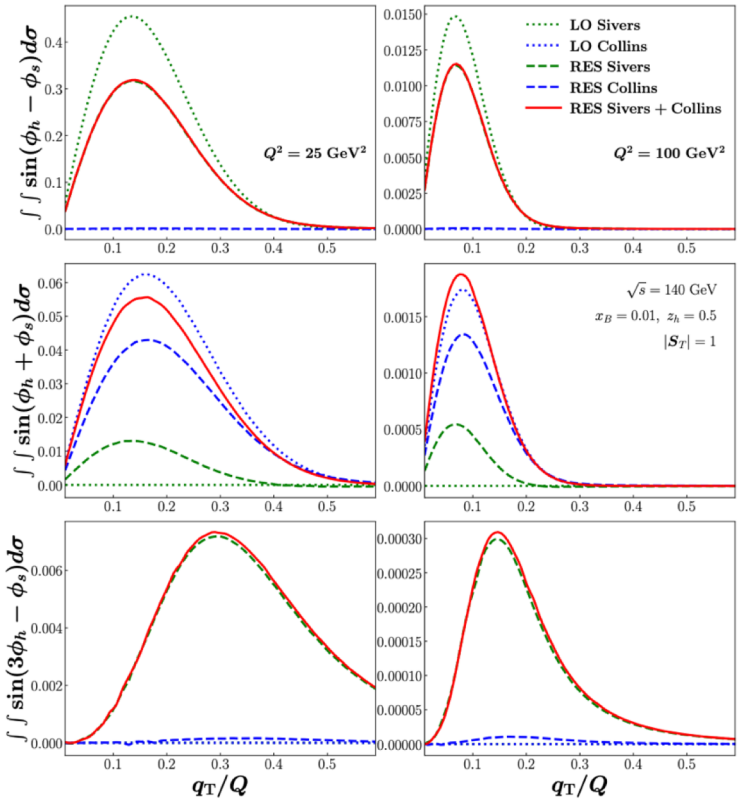
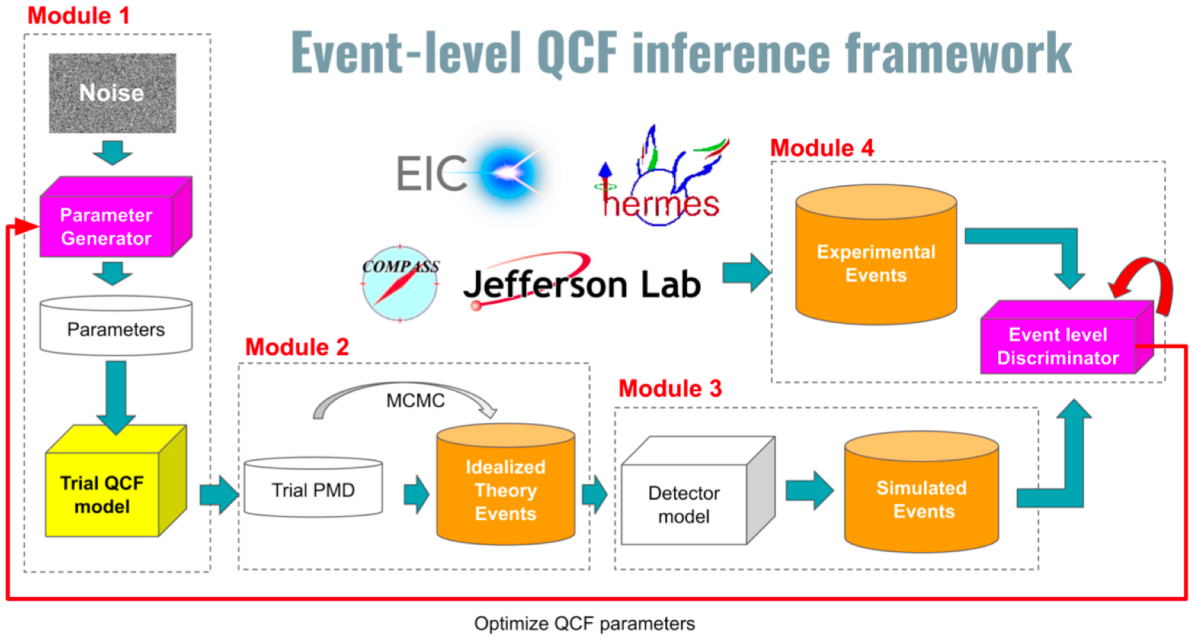


❑ Femtoscale Imaging of Nuclei using Exascale Platforms:



Synergy between CST, Physics, Theory

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Jefferson Lab

Summary and Outlook

- JLab NP Theory is a fully integrated part of JLab science program

  (providing strong theory support to experimental programs, PAC proposals, many on-going dialogs, discussions, collaborations with experimental colleagues)

- JLab NP Theory has vigorous research program "precisely" aligned with NSAC 2015 LRP & plays critical roles in JLab 12 GeV and EIC program, and ready to contribute to the next LRP

  (strongly tied to the goals of JLab12 and the future EIC)

- Excellent synergy locally with experimenters/PHY and computing experts/CST, as well as people in neighboring universities, …

  (a strong team with many outstanding and balanced expertise)

Thanks!