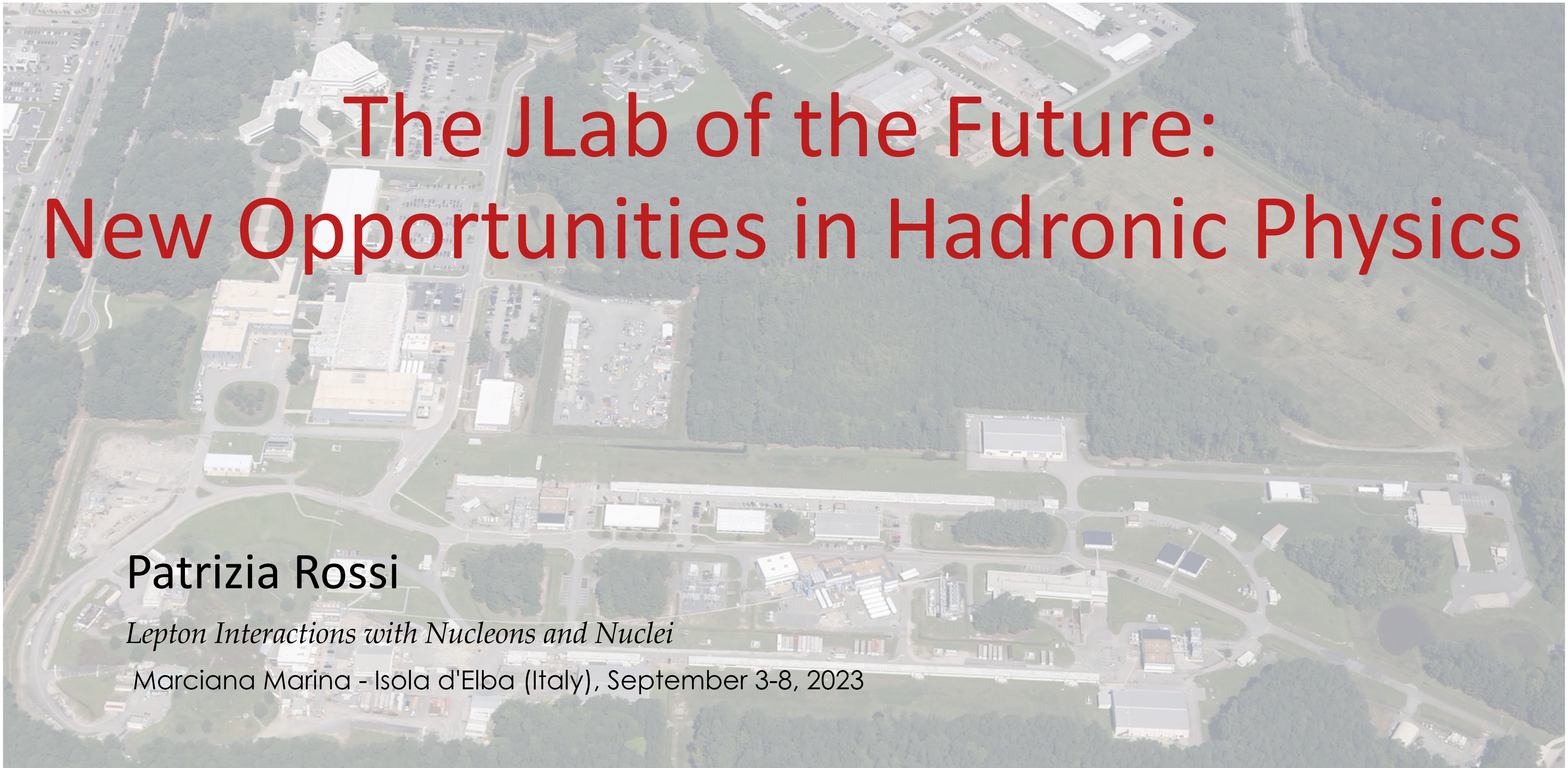


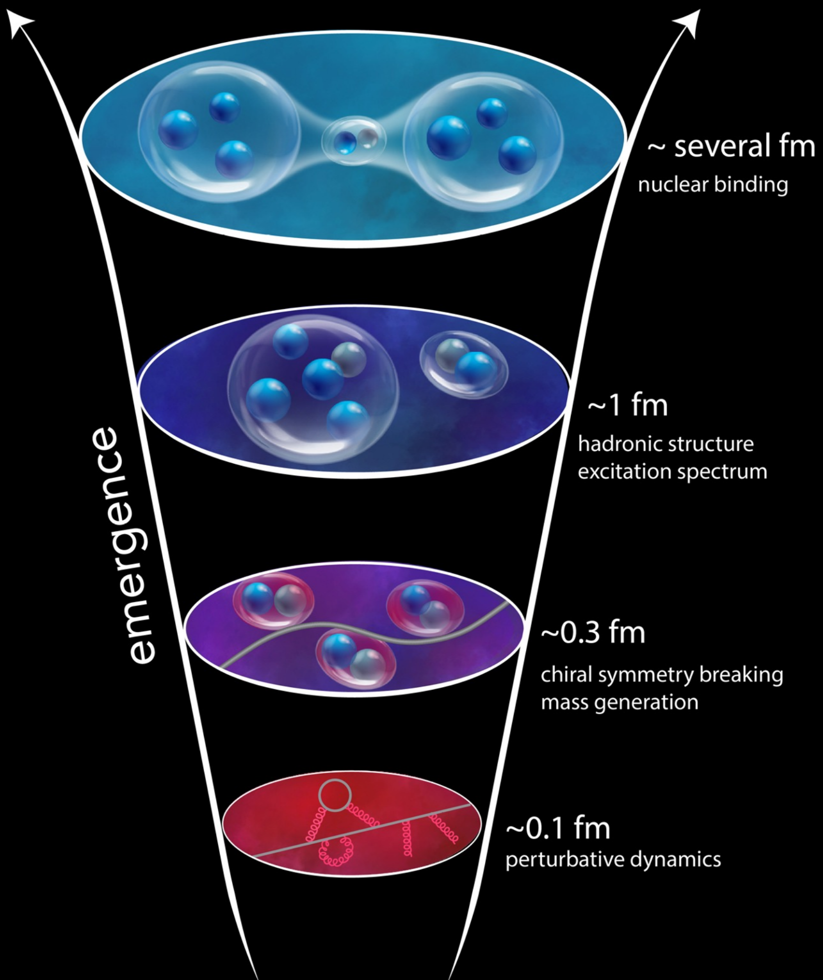
The JLab of the Future: New Opportunities in Hadronic Physics

Patrizia Rossi

Lepton Interactions with Nucleons and Nuclei

Marciana Marina - Isola d'Elba (Italy), September 3-8, 2023

TJNAF is managed by Jefferson Science
Associates for the US Department of Energy

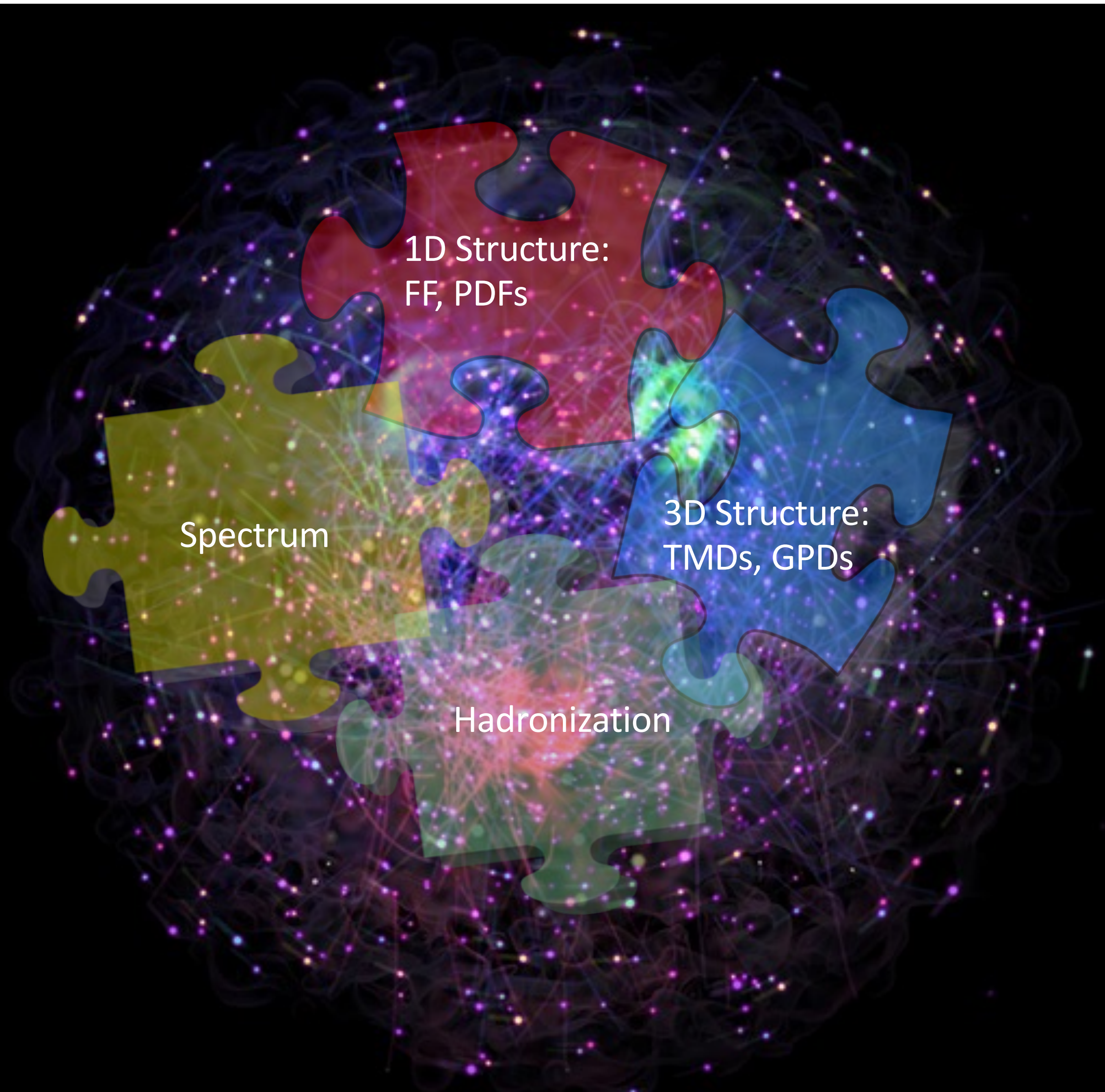


The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe." -- *More is different*, P. W. Anderson [Science 177, 393 (1972)].

Jefferson Lab's Mission

- **Study the emergence of hadron structure & the quarks and gluons <u>dynamics</u> in the non-pQCD regime**

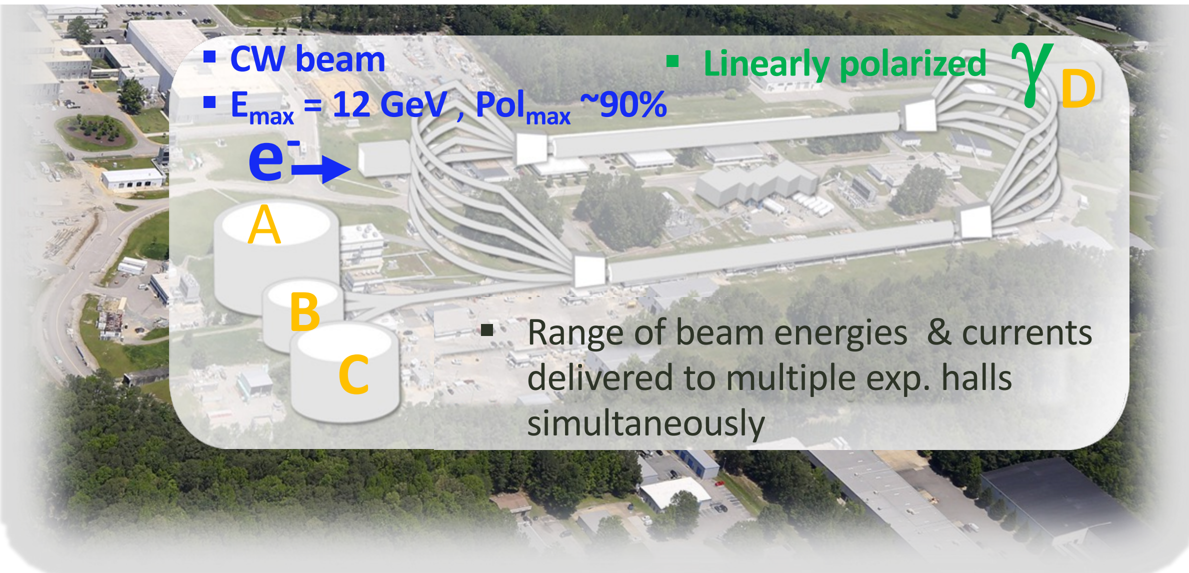
- **Search for Physics BSM**



- Complex and multifaced problem requiring multiple observables sensitive to different characteristics of the hadron structure

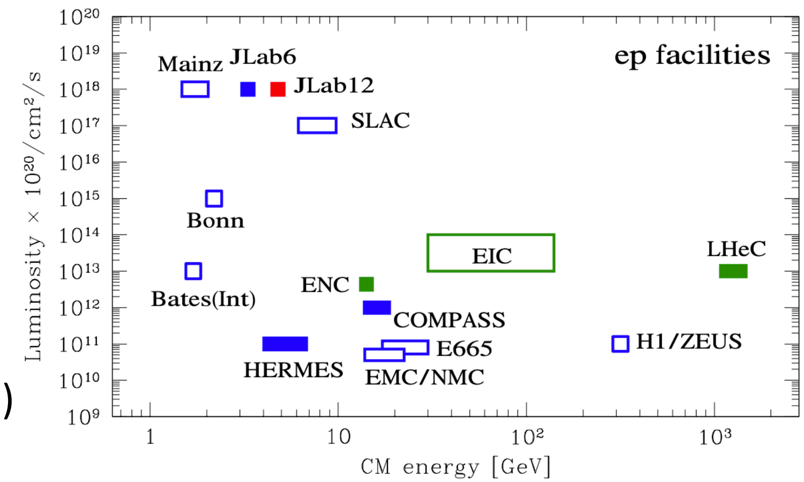
- Precise measurements → LUMINOSITY

Jefferson Lab and CEBAF



Fixed target experiments at the "luminosity frontier"

(up to 10^{39} e-N /cm²/ s)



- **12 GeV scientific era is going strong** (started in 2017)
  - High-profile results emerging from 12 GeV program
  - At least a decade of running in the future
- Looking toward exciting future scientific opportunities that could be obtained through cost-effective upgrades

- CEBAF @ 22 GeV

- Positron beam @ 12 GeV

What a 22 GeV Upgrade will bring?

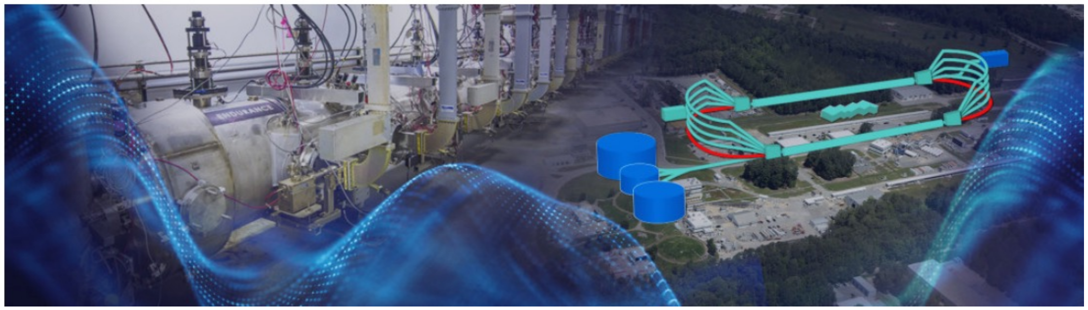
- **A NEW territory to explore → cross the critical threshold into the region where $c\bar{c}$ states can be produced in large quantities, and with additional light quark degrees of freedom.**
- **A BETTER (and needed) insight into our current program → enhancement of the phase space**
- **A BRIDGE between JLab @ 12 GeV and EIC → test and validation of our theory from lower to higher energy and with high precision**

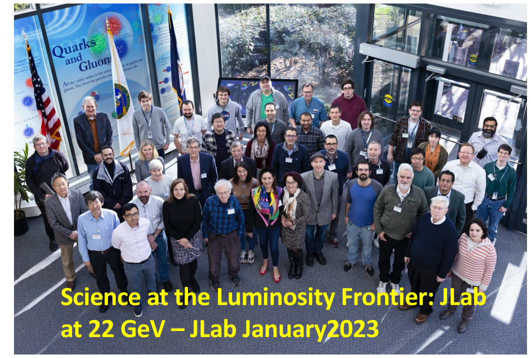
The physics program will:

- **Leverage on the uniqueness of CEBAF HIGH LUMINOSITY**
- **Utilize largely existing or already-planned Hall equipment**
- **Take advantage of recent novel advances in accelerator technology**

JLab Energy Upgrade Development

SCIENCE AT THE LUMINOSITY FRONTIER: JEFFERSON LAB AT 22 GEV

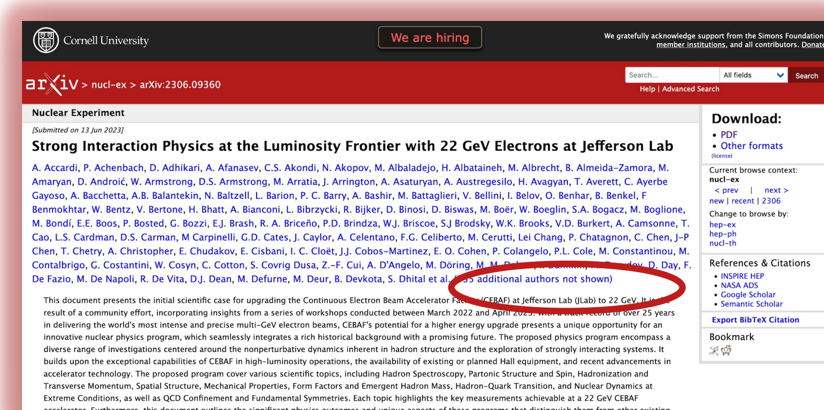




- **Strong Interaction Physics at the Luminosity Frontier with 22 GeV Electrons**

2306.09360 [nucl-ex] *444 authors*

- J-Future - Messina (Italy) 28–30 Mar 2022
- High Energy workshop series 2022 - Jefferson Lab, June - August 2022
- Hadron Physics Opportunities with JLab Energy Upgrade – Pohang (S. Korea), July 2022
- Opportunity with JLab Energy and Luminosity Upgrade- ECT* Trento (Italy), September 2022
- Science at the Luminosity Frontier: JLab at 22 GeV – Jefferson Lab, January 2023



Cornell University | We are hiring

arXiv > nucl-ex > arXiv:2306.09360

Nuclear Experiment

[Submitted on 13 Jun 2023]

Strong Interaction Physics at the Luminosity Frontier with 22 GeV Electrons at Jefferson Lab

A. Accardi, P. Achenbach, D. Adhikari, A. Afanasev, C.S. Akondi, N. Akopov, M. Albaladejo, H. Albataineh, M. Albrecht, B. Almeida-Zamora, M. Amaryan, D. Androić, W. Armstrong, D.S. Armstrong, M. Arratia, J. Arrington, A. Asaturyan, A. Austregesilo, H. Avagyan, T. Averett, C. Ayerbe Gayoso, A. Bacchetta, A.B. Balantekin, N. Baltzell, L. Barion, P. C. Barry, A. Bashir, M. Battaglieri, V. Bellini, I. Belov, O. Benhar, B. Benkel, F Benmokhtar, W. Bentz, V. Bertone, H. Bhatt, A. Bianconi, L. Bibrzycki, R. Bijker, D. Binosi, D. Biswas, M. Boër, W. Boeglin, S.A. Bogacz, M. Boglione, M. Bondí, E.E. Boos, P. Bosted, G. Bozzi, E.J. Brash, R. A. Briceño, P.D. Brindza, W.J. Briscoe, S.J Brodsky, W.K. Brooks, V.D. Burkert, A. Camsonne, T. Cao, L.S. Cardman, D.S. Carman, M Carpinelli, G.D. Cates, J. Caylor, A. Celentano, F.G. Celiberto, M. Cerutti, Lei Chang, P. Chatagnon, C. Chen, J-P Chen, T. Chetry, A. Christopher, E. Chudakov, E. Cisbani, I. C. Cloët, J.J. Cobos-Martinez, E. O. Cohen, P. Colangelo, P.L. Cole, M. Constantinou, M. Contalbrigo, G. Costantini, W. Cosyn, C. Cotton, S. Covrig Dusa, Z.-F. Cui, A. D'Angelo, M. Döring, ... D. Day, F. De Fazio, M. De Napoli, R. De Vita, D.J. Dean, M. Defurne, M. Deur, B. Devkota, S. Dhital et al. (... additional authors not shown)

This document presents the initial scientific case for upgrading the Continuous Electron Beam Accelerator Fa... (CEBAF) at Jefferson Lab (JLab) to 22 GeV. ... result of a community effort, incorporating insights from a series of workshops conducted between March 2022 and April ... over 25 years in delivering the world's most intense and precise multi-GeV electron beams, CEBAF's potential for a higher energy upgrade presents a unique opportunity for an innovative nuclear physics program, which seamlessly integrates a rich historical background with a promising future. The proposed physics program encompass a diverse range of investigations centered around the nonperturbative dynamics inherent in hadron structure and the exploration of strongly interacting systems. It builds upon the exceptional capabilities of CEBAF in high-luminosity operations, the availability of existing or planned Hall equipment, and recent advancements in accelerator technology. The proposed program cover various scientific topics, including Hadron Spectroscopy, Partonic Structure and Spin, Hadronization and Transverse Momentum, Spatial Structure, Mechanical Properties, Form Factors and Emergent Hadron Mass, Hadron-Quark Transition, and Nuclear Dynamics at Extreme Conditions, as well as QCD Confinement and Fundamental Symmetries. Each topic highlights the key measurements achievable at a 22 GeV CEBAF accelerator. Furthermore, this document outlines the significant physics outcomes and unique aspects of these programs that distinguish them from other existing

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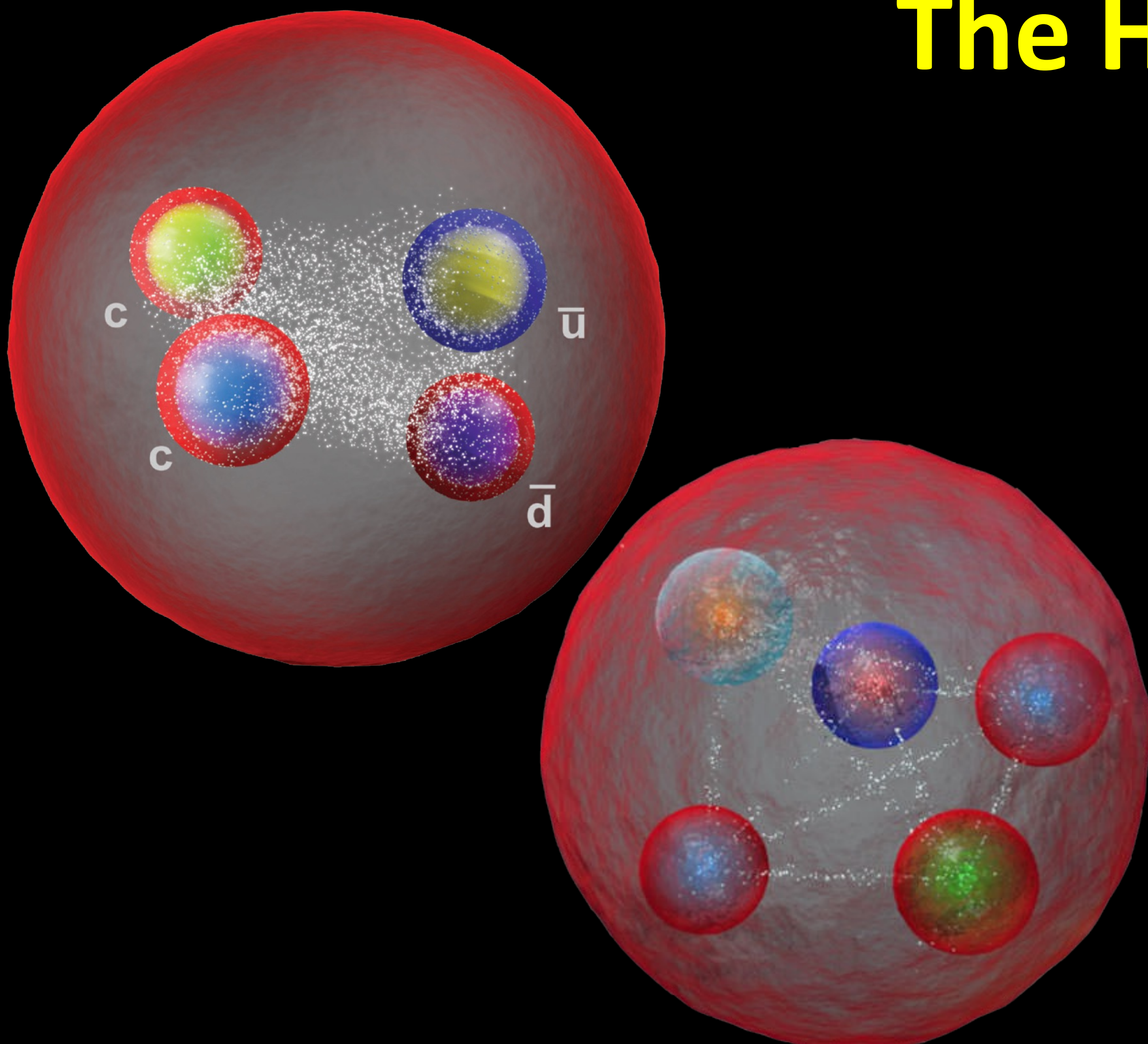
Broad community interest in this science

Strong Interaction Physics at the Luminosity Frontier with 22 GeV Electrons at JLab

Contents

Presented at the Resolution Meeting of the NP Long Range Plan in July 2023

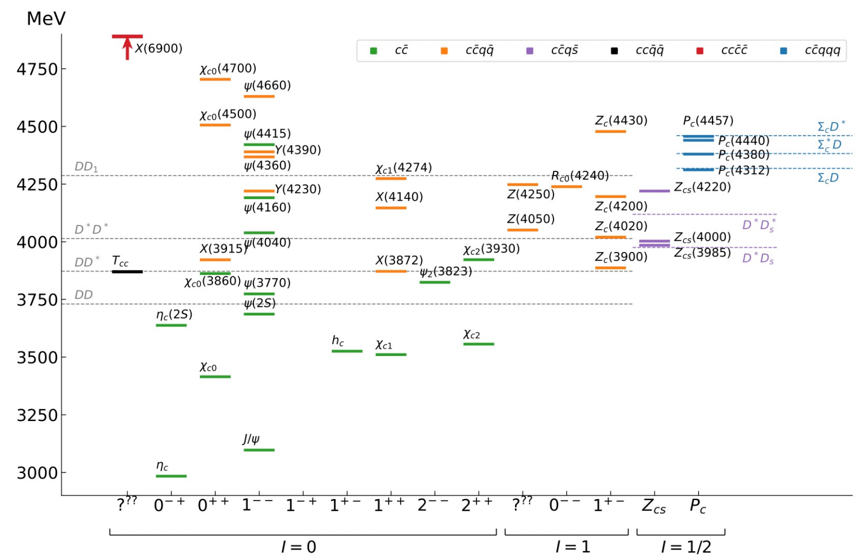
The Hadron Spectra



With an energy upgrade a unique production environment of charmed exotic states can be probed

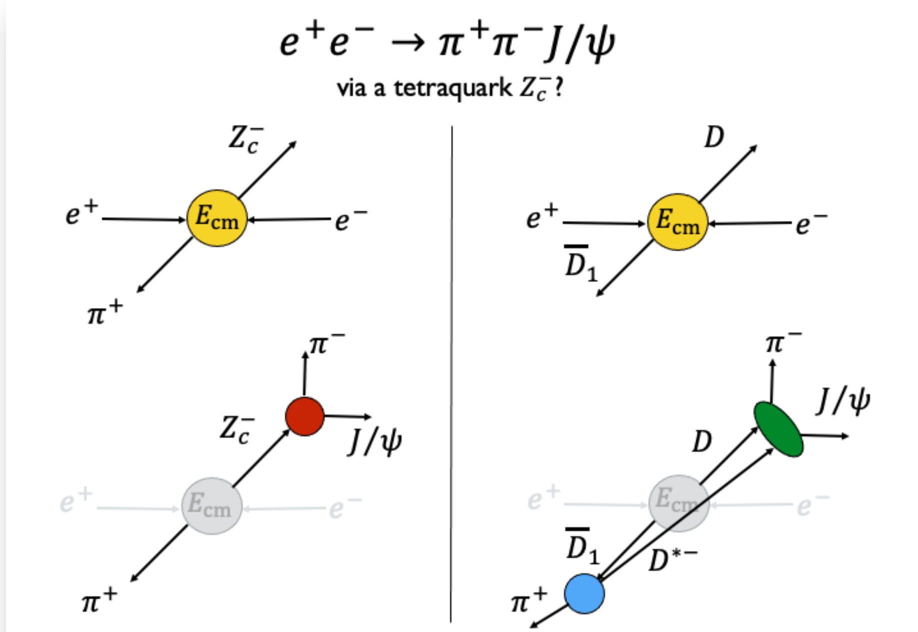
Photoproduction of Hadrons with Charm Quarks

Potentially decisive information about the **nature of some 5-quark and 4-quark (XYZ)** candidates



JPAC Collaboration, arXiv:2112.13436

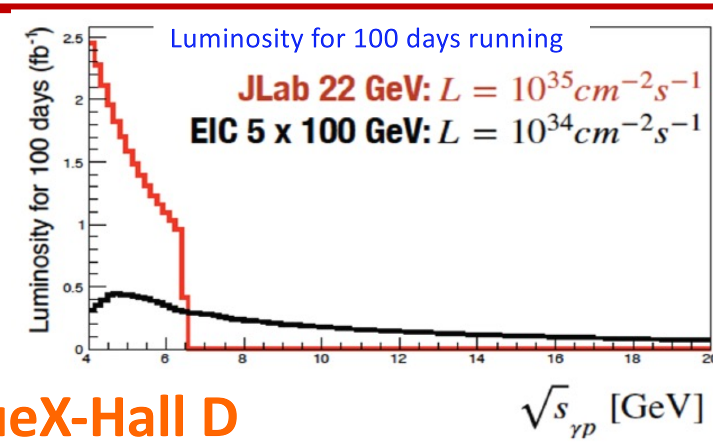
- **Many "XYZ" states observed in B decays, e^+e^- colliders**
- **Scarce consistency between various production mechanisms**
- **Significant theoretical interest and progress, but internal structure not understood yet**



Interpretation of data is complicated by nonresonant $D^{*-}D \to J/\psi\pi^-$ scattering that can produce peaks in invariant mass spectra for certain choices of $E_{\rm cm}$ and π^+ momentum that result in a $D^{*-}D$ interaction. These peaks are effects of initial state kinematics and do not require a resonance in $\pi^- J/\psi$.

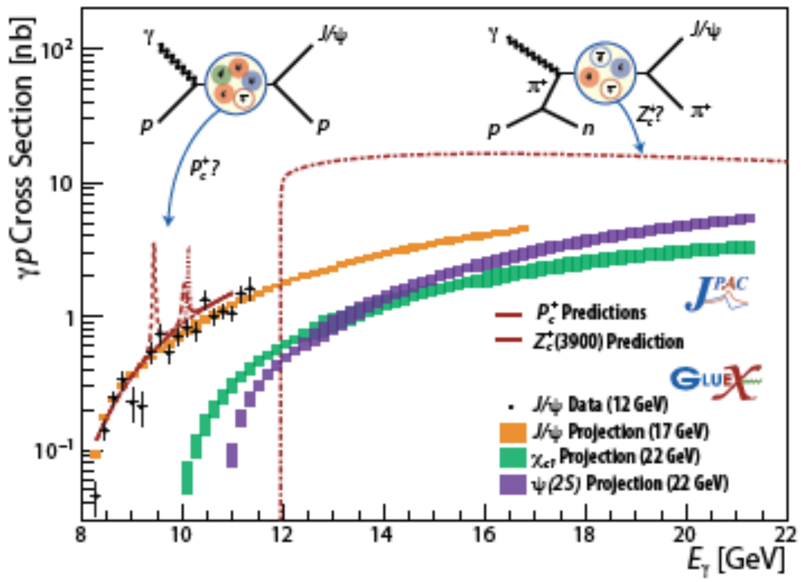
Spectroscopy of Exotic States with $c\bar{c}$

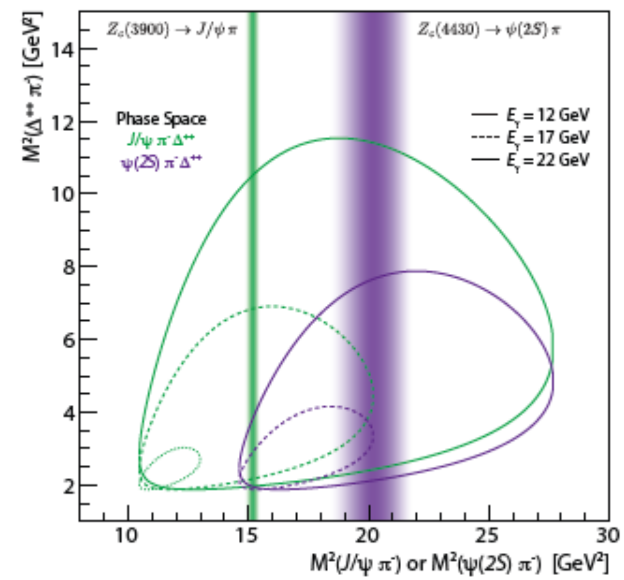
- **Never direcly produced using γ/lepton beam**
- Direct probe of the $Z_c \rightarrow J/\psi\pi$ coupling without re-scattering effects



GlueX-Hall D

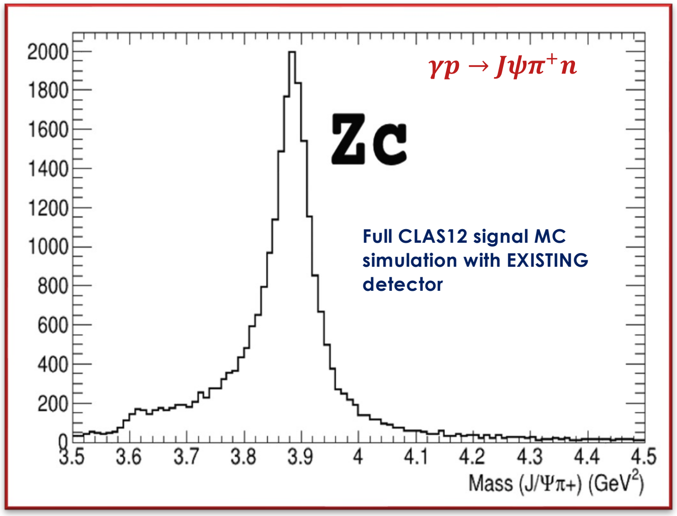
- **Photoproduction** tool already used to validate the existence of **charmed 5quark**.
- With an energy upgraded CEBAF, this line of investigation can be **extended to other exotic candidates.**



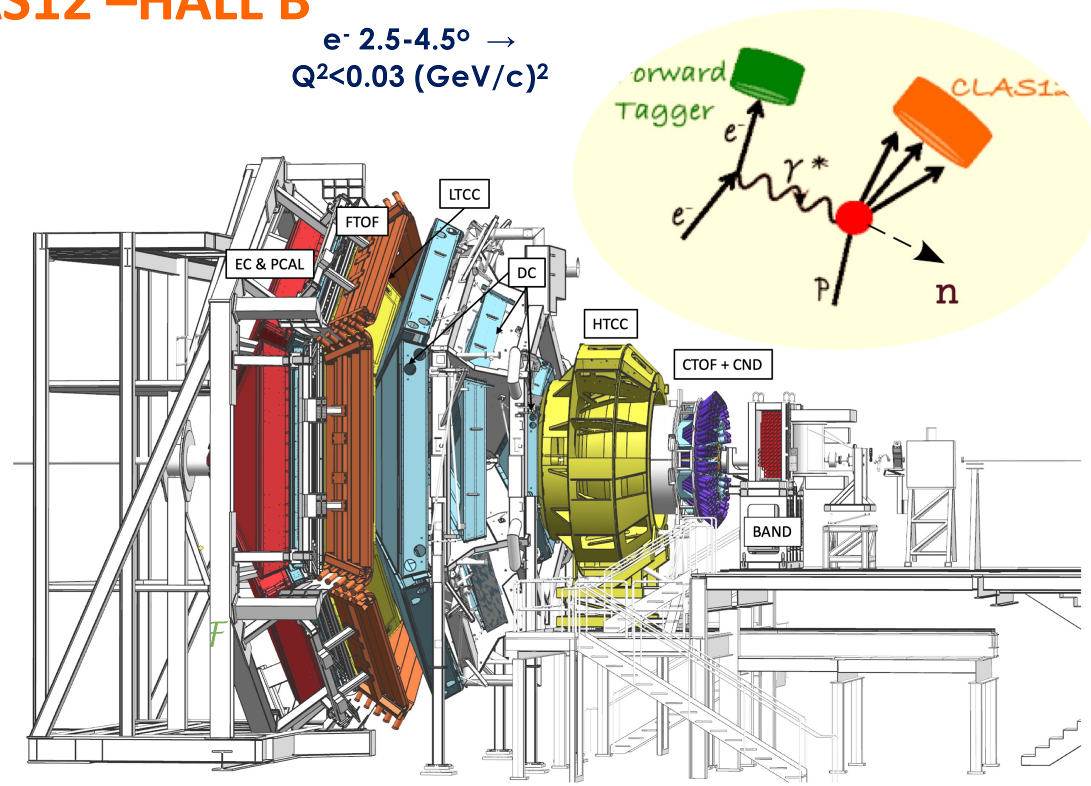


Spectroscopy of Exotic States with $c\bar{c}$

CLAS12 –HALL B

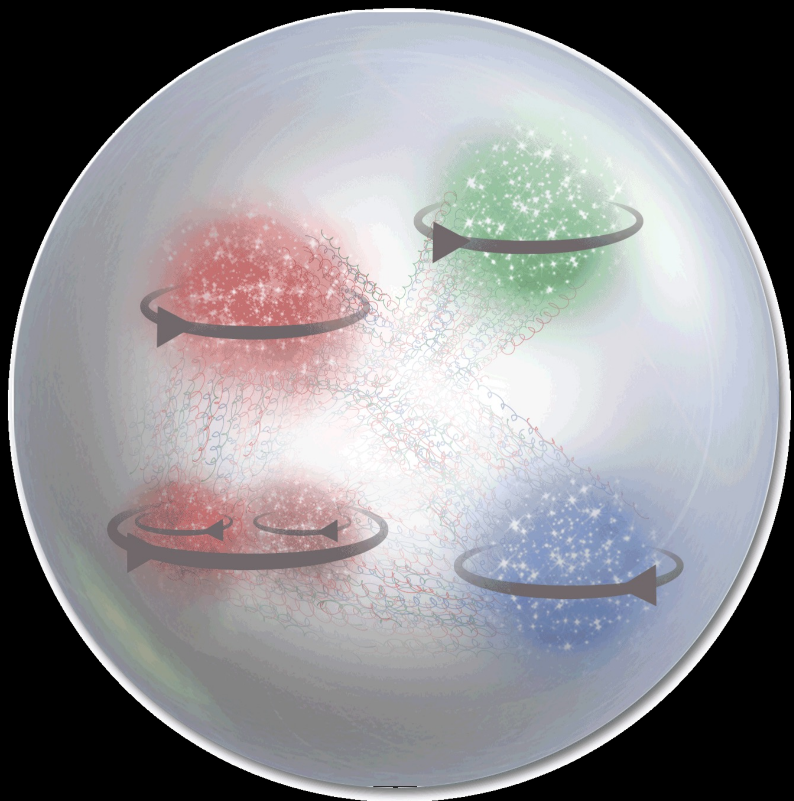


e^- 2.5-4.5° →
Q^2<0.03 (GeV/c)²



- **Q^2 evolution** of any new state produced

Nucleon's Structure

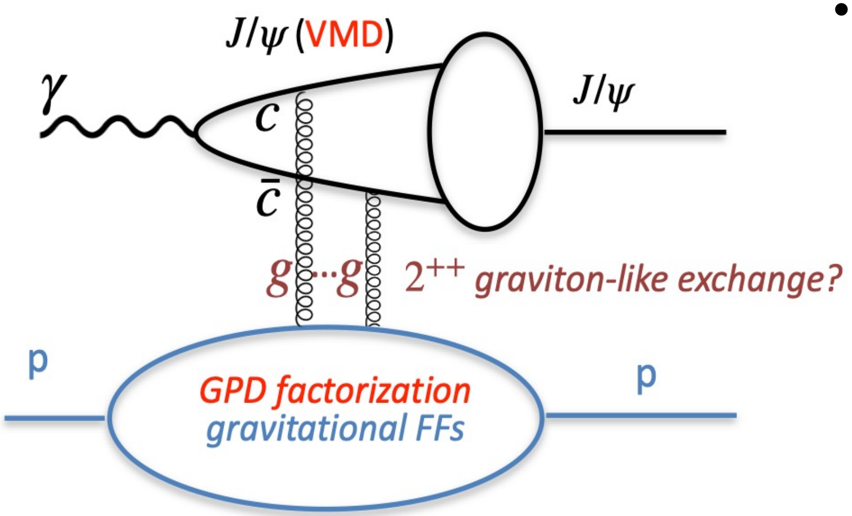


Better Insights into Quarks and Gluon Dynamics

- Distribution of Mass
- Distribution of Forces and Pressure
- Transverse Structure of the Nucleon

These properties emerge from the complex dynamics of its fundamental constituents

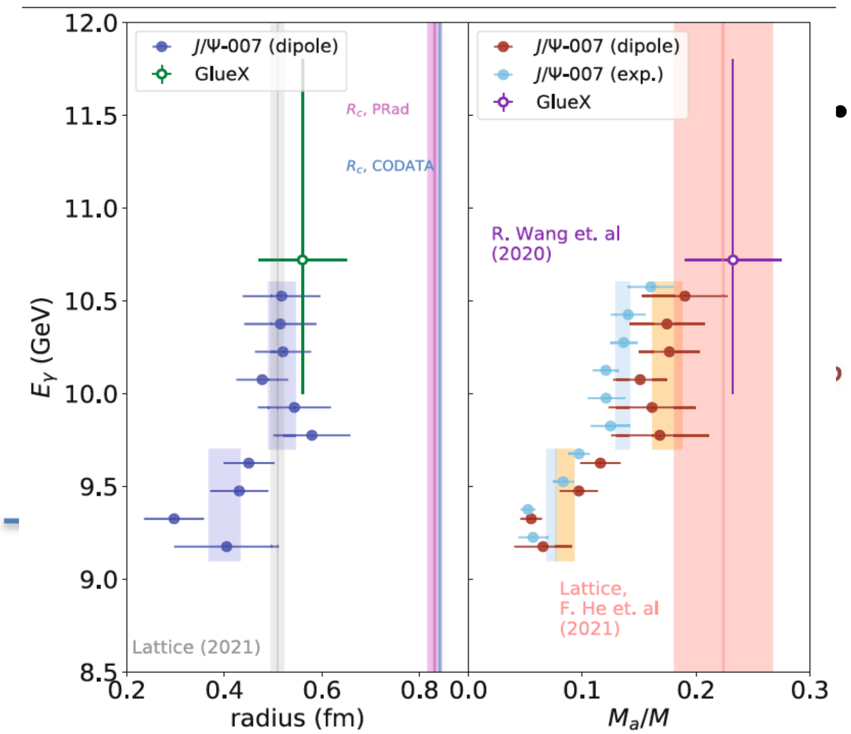
J/ψ photoproduction close to threshold



Gluonic properties of the nucleon

- Relation to nucleon gravitational form factors (GFF)
  Guo PRD103(2021); Mamo PRD104; Hatta PRD100
  - Relation to EMT *trace anomaly* and nucleon mass
  Kharzeev (1996-1999); Ji (1995)
  - Proton mass radius
  Kharzeev PRD104(2021)

J/ψ photoproduction close to threshold



Nature **volume 615**, pages 813–816 (2023)

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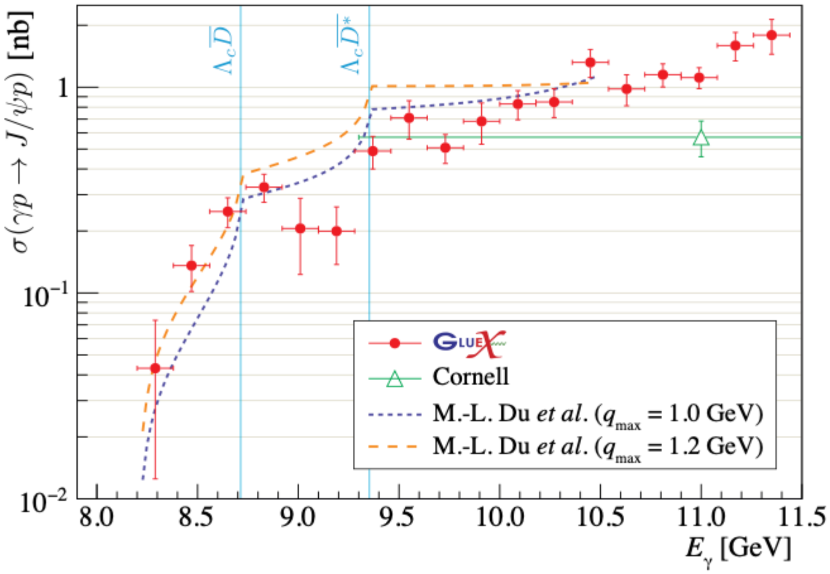
  - Proton mass radius
    Kharzeev PRD104(2021)

…But under certain assumptions

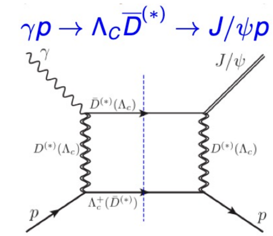
- VMD relates $\gamma p \to J/\psi p$ to elastic $J/\psi p \to J/\psi p$
- $m_C \to \infty$ interaction via gluon exchange
- GPD factorization valid at threshold

Detailed studies of the reaction $\gamma p \to J/\psi p$ are needed in order to verify the validity of the assumptions

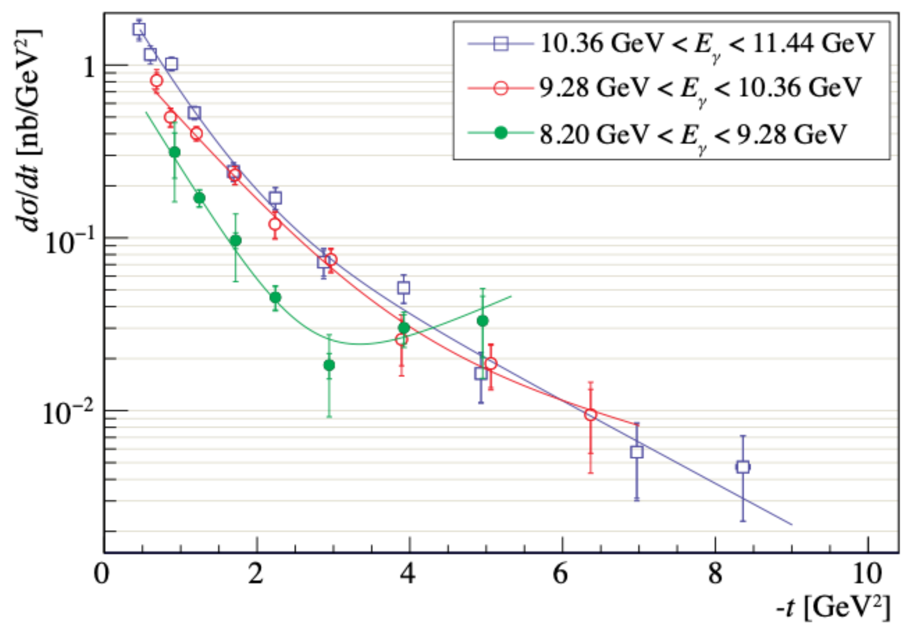
J/ψ photoproduction near threshold: GlueX Results



PHYSICAL REVIEW C 108, 025201 (2023)



- Cusps at the thresholds of $\Lambda_C \overline{D}$, $\Lambda_C \overline{D}*$
- Production via open-charm and rescattering?
- This mechanism is not a 2-gluon exchange and may reduce the relation between $\gamma p \to J/\psi p$ and GFF of the nucleon

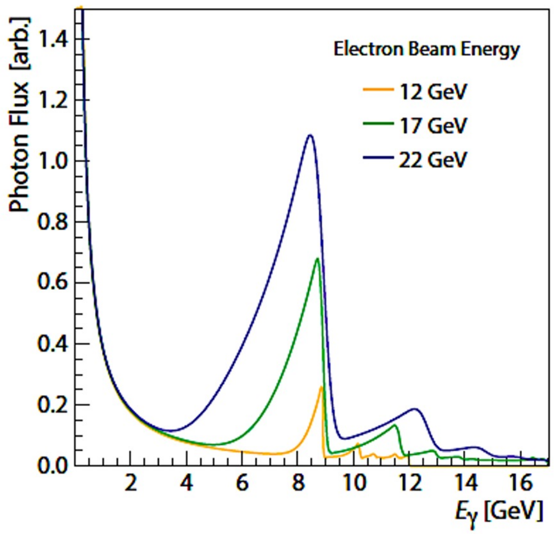


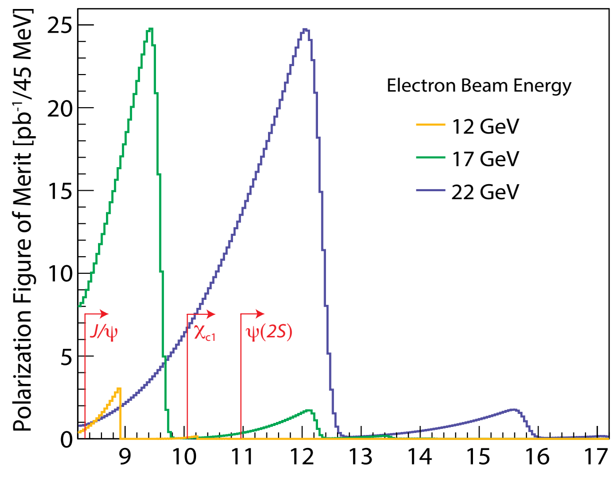
- Exponential slopes indicating t-channel generally consistent with the gluon-exchange mechanism
- Enhancement of $d\sigma/dt$ for lowest energy -> other mechanisms into the game

ab

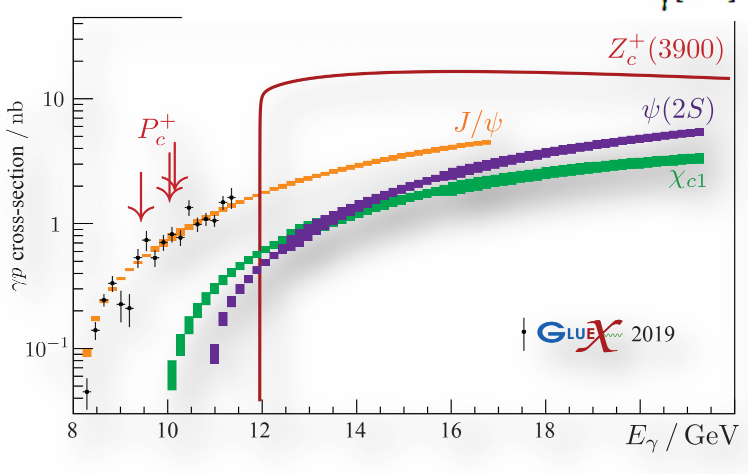
J/ψ photoproduction with GlueX @ Higher Energies

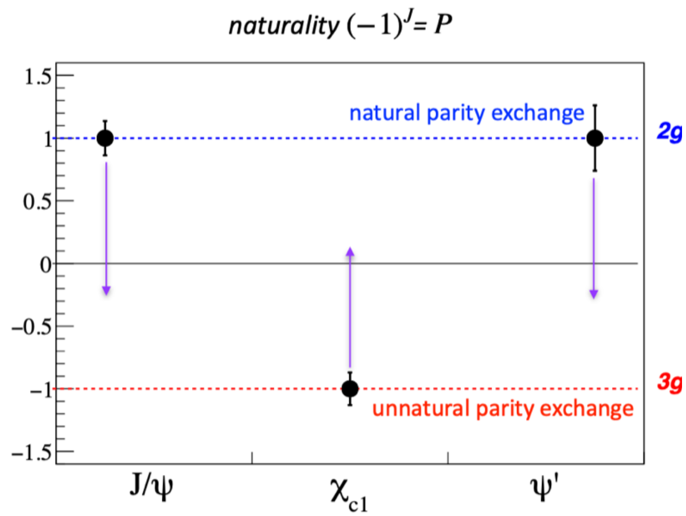
- Increasing the electron beam energy results in a larger fraction of useful high-energy photons





- Energy upgrade gives significant increase of polarization FOM, allowing unique studies of the gluon exchange for J/ψ and higher charmonium states





- Any deviation from the expected naturality (+ or -1) indicates contribution of mechanism different from what is needed to study mass properties of the proton

Jefferson Lab

Global Properties of the Nucleon

- The structure of hadrons is probed by exploring their interactions with the fundamental currents $\mathbf{J}^{\mu}_{\mathbf{em}}$ $\mathbf{J}^{\mu}_{\mathbf{weak}}$ $\mathbf{T}^{\mu\nu}_{\mathbf{grav}}$
- The matrix elements of these currents are described in terms of **Form Factors**
- The most fundamental information corresponds to the form factors at zero-momentum transfer

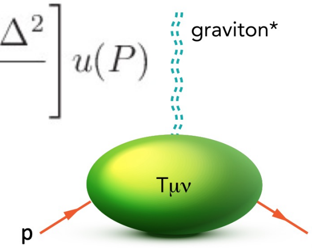
em:	$\partial_\mu J^\mu_{\rm em} = 0$	$\langle N'\vert J^\mu_{\rm em}\vert N\rangle \to Q = 1.602176487(40) \times 10^{-19}$C $\mu = 2.792847356(23)\mu_N$
weak:	PCAC	$\langle N'\vert J^\mu_{\rm weak}\vert N\rangle \to g_A = 1.2694(28)$ $g_p = 8.06(55)$
gravity:	$\partial_\mu T^{\mu\nu}_{\rm grav} = 0$	$\langle N'\vert T^{\mu\nu}_{\rm grav}\vert N\rangle \to m = 938.272013(23)$ MeV$/c^2$ $J = \frac{1}{2}$ $D = ?$

DOI: 10.1142/S0217751X18300259

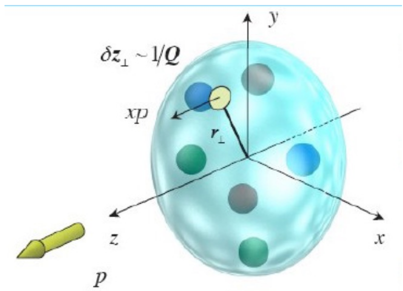
- All well known except the D-term
- It reflects the internal dynamics of the system through the distribution of forces

Nucleon Gravitational FFs and Generalized Parton Distributions

- **Matrix elements of QCD EMT** $\langle P'|T^{\mu\nu}|P\rangle = \bar{u}(P')\left[A(t)\gamma^{(\mu}\bar{P}^{\nu)} + B(t)\frac{\bar{P}^{(\mu}i\sigma^{\nu)\alpha}\Delta_\alpha}{2M} + D(t)\frac{\Delta^\mu\Delta^\nu - g^{\mu\nu}\Delta^2}{4M}\right]u(P)$



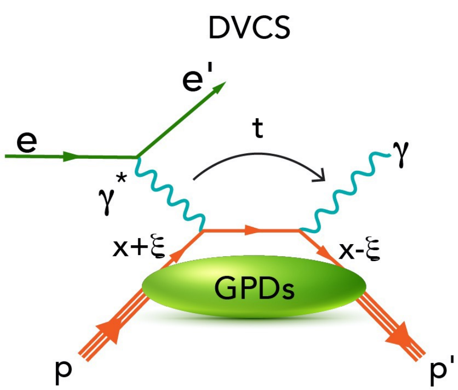
For a spin ½ hadron there are 3 independent Form Factors associated with scattering off a graviton



- **Generalized Parton Distributions:** multidimensional description of nucleon structure (longitudinal momentum versus transverse position)

H, E, $\tilde{H}$, $\tilde{E}$

  - A massless spin-2 field would couple to the stress–energy tensor in the same way that gravitational interactions do → **D –term accessible through DVCS measurements**



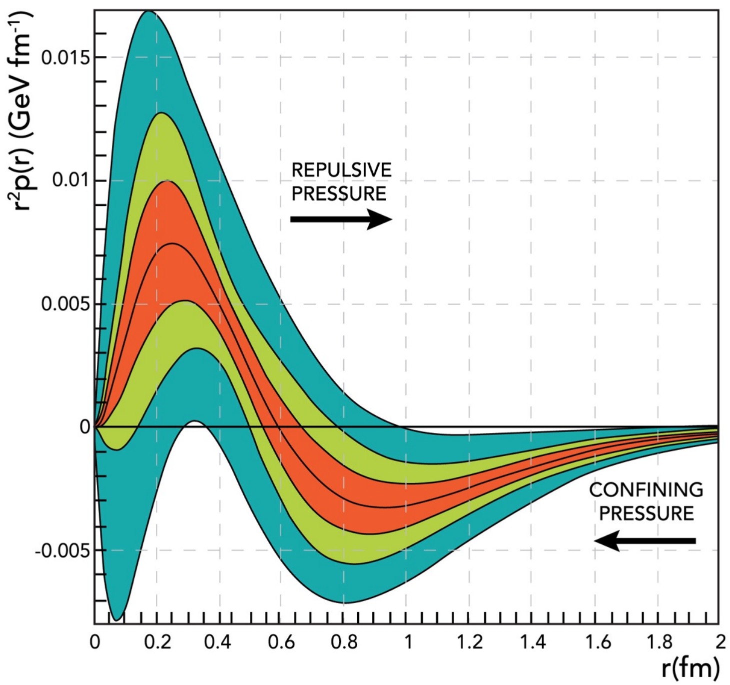
$$\mathrm{Re}\mathcal{H}(\xi,t) + i\mathrm{Im}\mathcal{H}(\xi,t) = \int_{-1}^{1} dx \left[\frac{1}{\xi - x - i\epsilon} - \frac{1}{\xi + x - i\epsilon}\right] H(x,\xi,t)$$

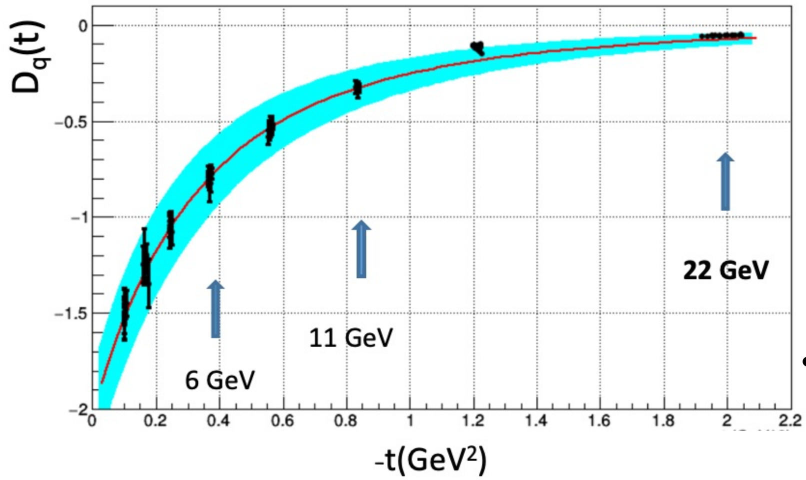
$$\mathrm{Re}\mathcal{H}_q(\xi,t) \;=\; \frac{1}{\pi}\int_{-1}^{1} dx \mathrm{P}\frac{\mathrm{Im}\mathcal{H}_q(x,t)}{\xi - x} + 2\int_{-1}^{1} dz \frac{D_q(z,t)}{1-z}$$

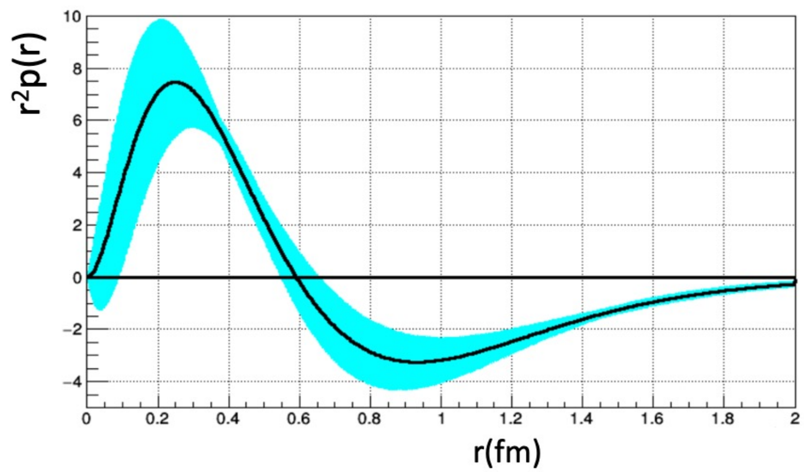
- D-term related to the subtraction constant in the dispersion relation (at fixed t) for the Compton Form Factor

Mechanical Properties of the Proton

- (quark) D(t) term and determination of the pressure distribution inside the proton from JLab-CLAS DVCS data @ 6 GeV







- **Large -t range required to perform the Fourier transform with controlled uncertainties ➜ high luminosity**

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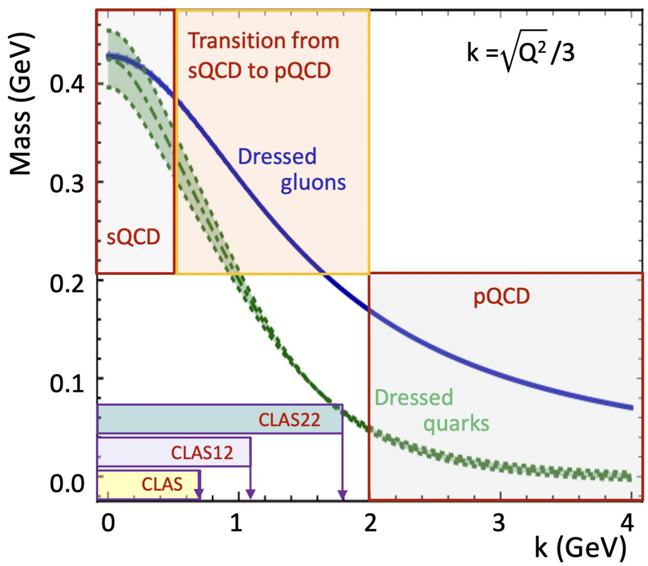
Bound 3 Quark Structure of N*s and Emergence of Mass

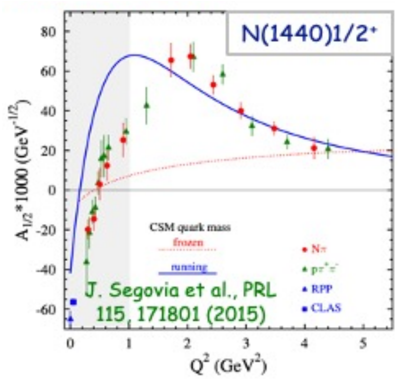
Continuum Schwinger Method

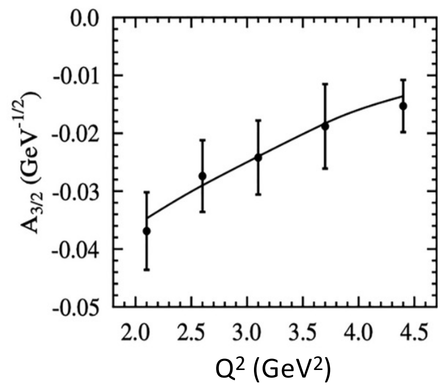
- The solution of the QCD equations of motion for q/g fields reveals existence of dressed q/g with momentum-dependent masses.



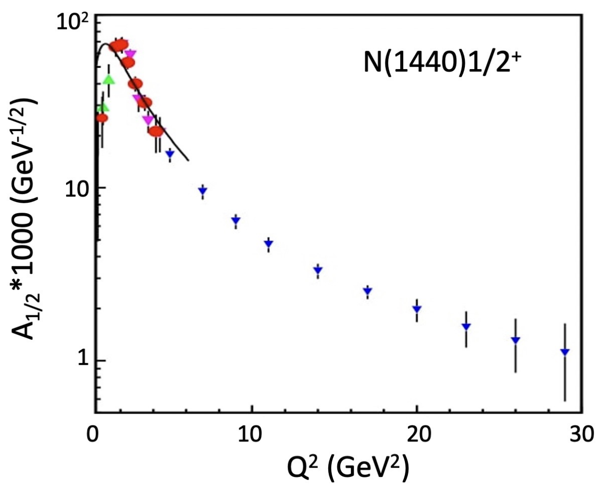
- **JLab22 is the only foreseeable facility to extend these measurements up to 30 GeV²**

CLAS results



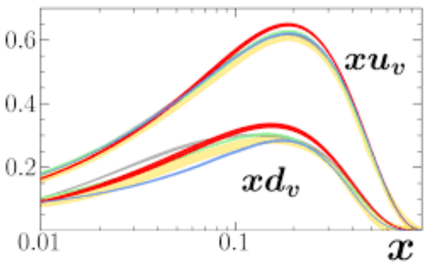


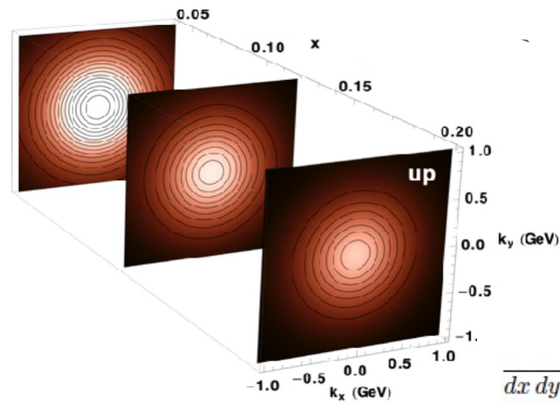
V.I. Mokeev et al. PR C 108, 025204

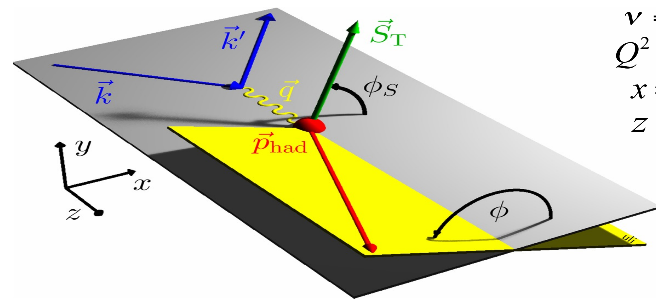


- Q^2 evolution of the $\gamma_v pN^*$ electrocouplings could offer an insight into hadron mass generation and the emergence of the N* structure from QCD

3D Picture of the Nucleon in Momentum Space (TMD)







$$\nu = E - E'$$
$$Q^2 = 4EE' \sin(\theta/2)$$
$$x = Q^2 / 2M\nu$$
$$z = E_h / \nu$$

$\sigma = f(x, Q^2, z, P_T)$

$$\frac{d\sigma}{dx\,dy\,d\phi_S\,dz\,d\phi_h\,dP_{h\perp}^2} = \frac{\alpha^2}{x\,y\,Q^2}\frac{y^2}{2(1-\varepsilon)}\Big\{F_{UU,T} + \varepsilon F_{UU,L} + \sqrt{2\varepsilon(1+\varepsilon)}\cos\phi_h\,F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}$$
$$+ \lambda_e\sqrt{2\varepsilon(1-\varepsilon)}\sin\phi_h\,F_{LU}^{\sin\phi_h} + S_L\Big[\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_h\,F_{UL}^{\sin\phi_h} + \varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\Big]$$
$$+ S_L\lambda_e\Big[\sqrt{1-\varepsilon^2}\,F_{LL} + \sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_h\,F_{LL}^{\cos\phi_h}\Big]$$
$$+ S_T\Big[\sin(\phi_h-\phi_S)\Big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\Big) + \varepsilon\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}$$
$$+ \varepsilon\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)} + \sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_S\,F_{UT}^{\sin\phi_S}$$
$$+ \sqrt{2\varepsilon(1+\varepsilon)}\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] + S_T\lambda_e\Big[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}$$
$$+ \sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_S\,F_{LT}^{\cos\phi_S} + \sqrt{2\varepsilon(1-\varepsilon)}\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\}$$

A more complete picture of the nucleon
…but there is no free lunch

- **More functions in the x-section**
- **More variables for each function**

Complexity in the extraction

High statistics
Wide kinematical range

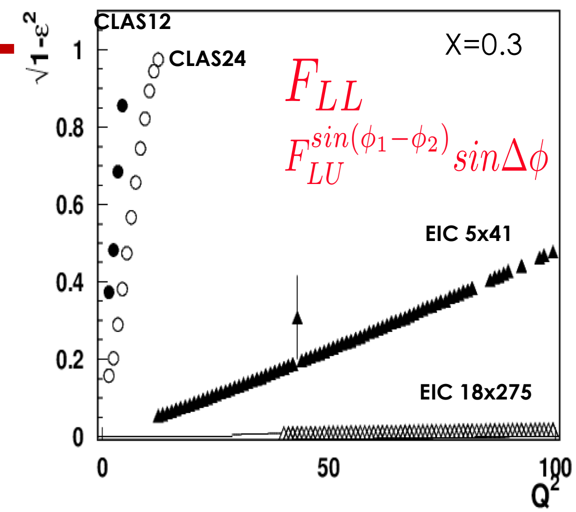
The Nucleon Structure in 3D

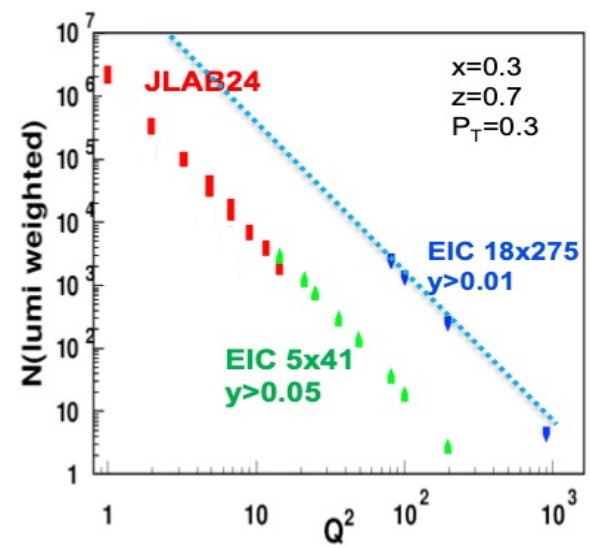
$$\frac{d\sigma}{dx\,dy\,d\phi_S\,dz\,d\phi_h\,dP_{h\perp}^2}$$
$$= \frac{\alpha^2}{x\,y\,Q^2}\,\frac{y^2}{2\,(1-\varepsilon)}\Bigg\{F_{UU,T} + \varepsilon\,F_{UU,L} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}$$
$$+ \lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h} + S_L\Big[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h} + \varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\Big]$$
$$+ S_L\,\lambda_e\Big[\sqrt{1-\varepsilon^2}\,F_{LL} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\Big]$$
$$+ S_T\Big[\sin(\phi_h-\phi_S)\Big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\Big) + \varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}$$
$$+ \varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}$$
$$+ \sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big] + S_T\lambda_e\Big[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}$$
$$+ \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Bigg\}$$

- <u>At large x</u> fixed target experiments are sensitive to ALL Structure Functions

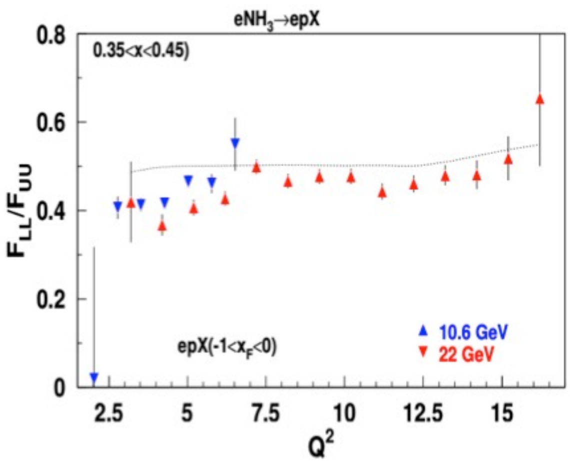
- Complementarity with EIC

ε = ratio of long. and trans. photon flux





SIDIS Enhanced Multi-D Phase Space @ 22 GeV

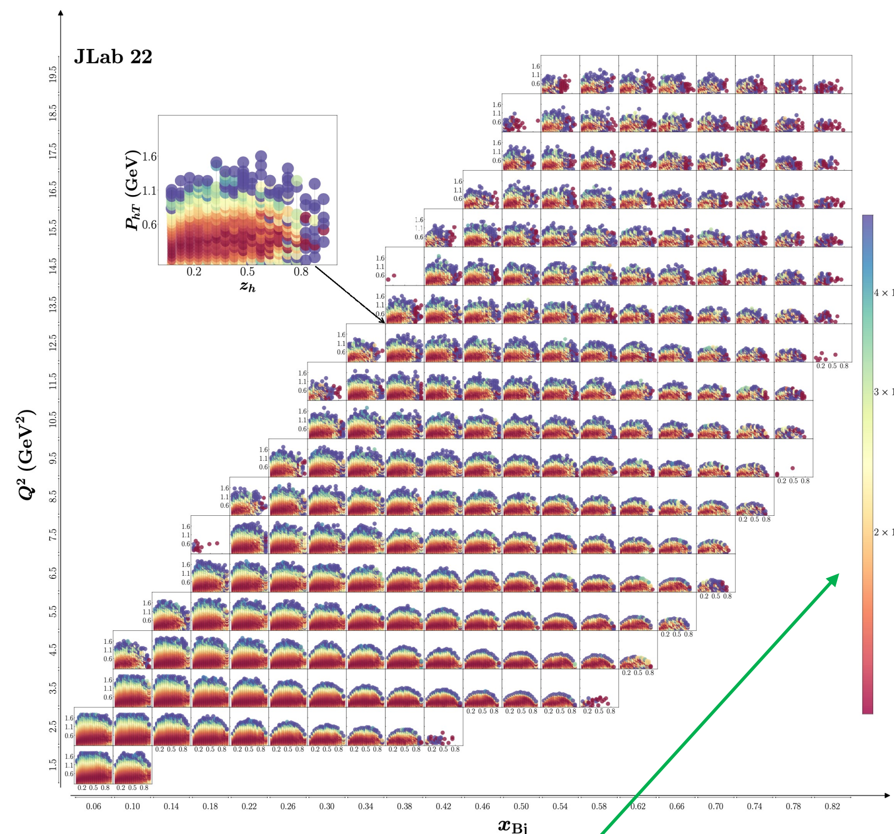


- **Q^2 evolution studies possible**

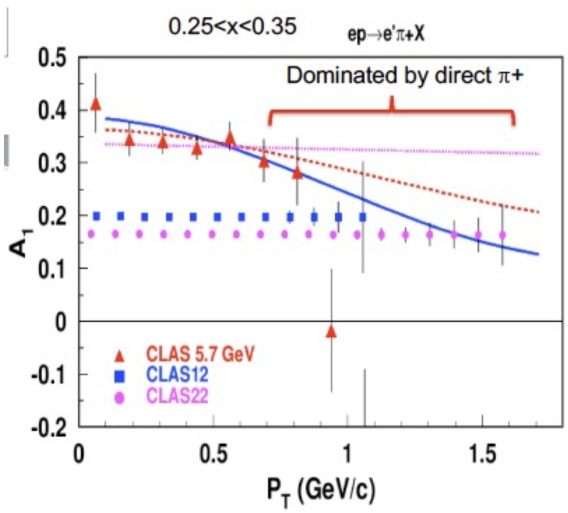
QCD predicts only the Q^2 dependence

- Increase significant the range of high Q^2 allowing:
  - **Studies of evolution properties**
  - **Disentangle leading/sub-leading contributions**
  - **Validate/test the phenomenology**

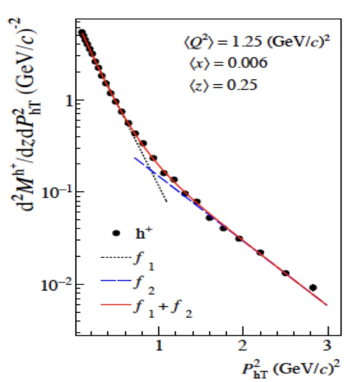
Projections for 100 days of running with L= 10^{35} $cm^{-2}s^{-1}$ using the existing CLAS12 simulation/reconstruction chain



Expected uncertainties for SIDIS cross sections in 4D bins



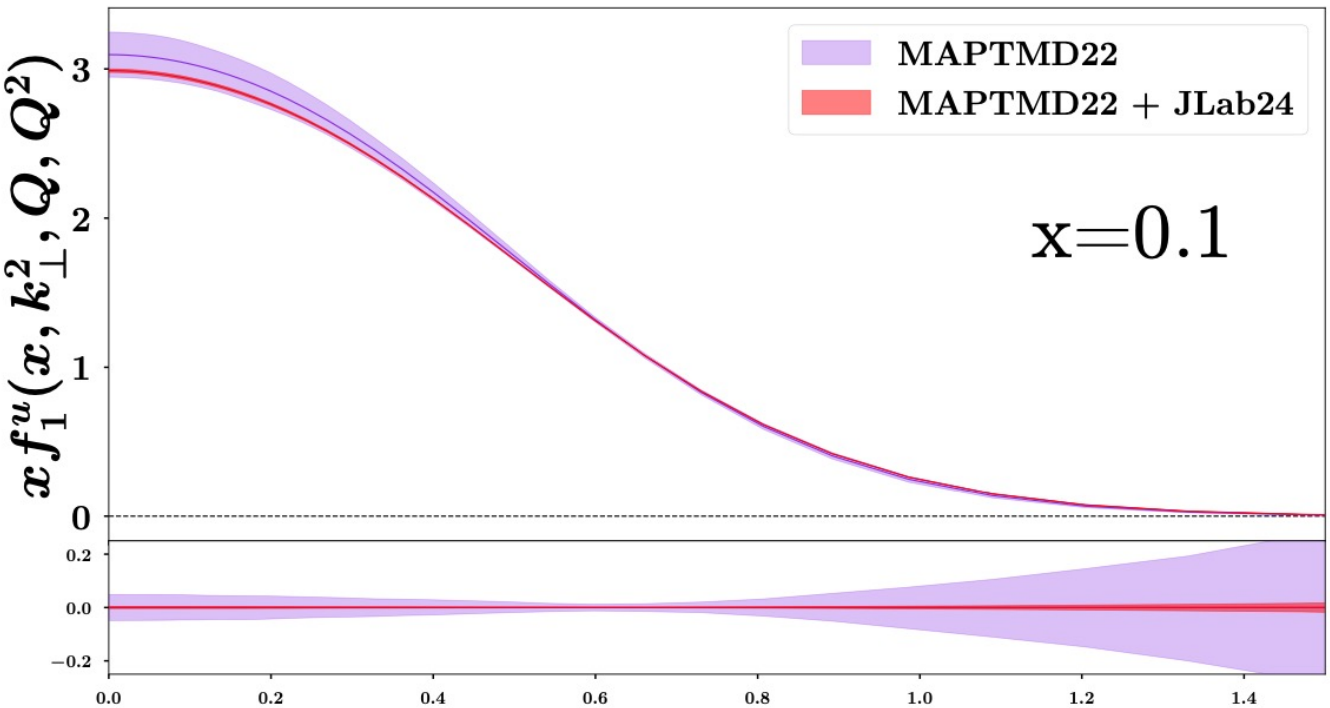
- **Enhanced P_T Range**



- **What is the origin of the "high" PT tail?** Perturbative/non pert. contributions?

Impact of SIDIS data at 22 GeV

❑ **Spin-averaged TMD - up quark:**

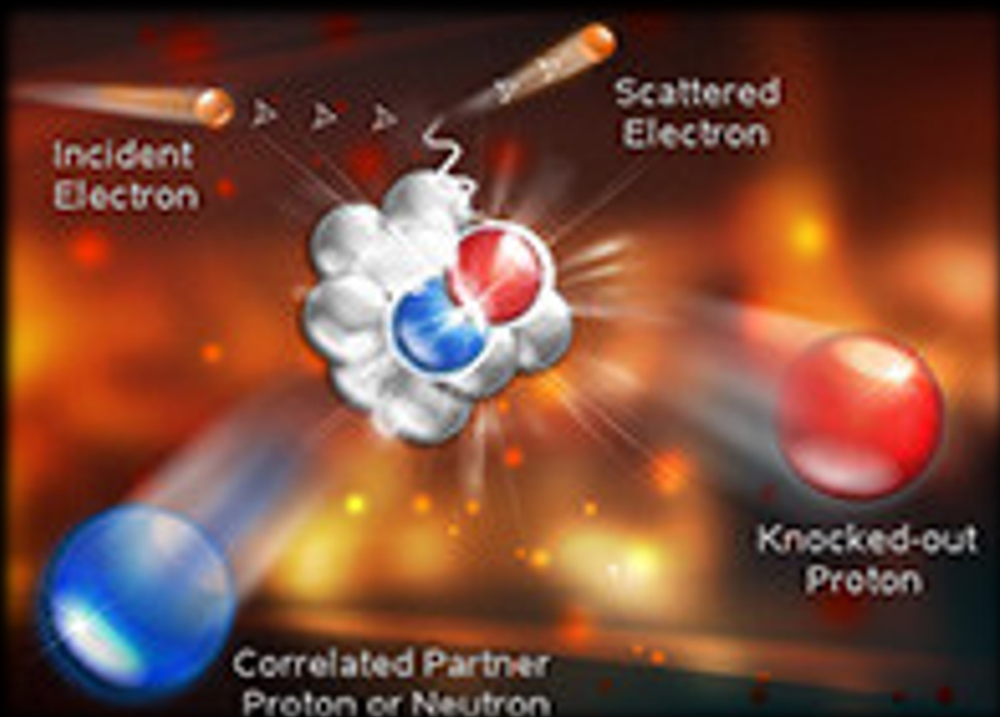


A. Bacchetta 2023

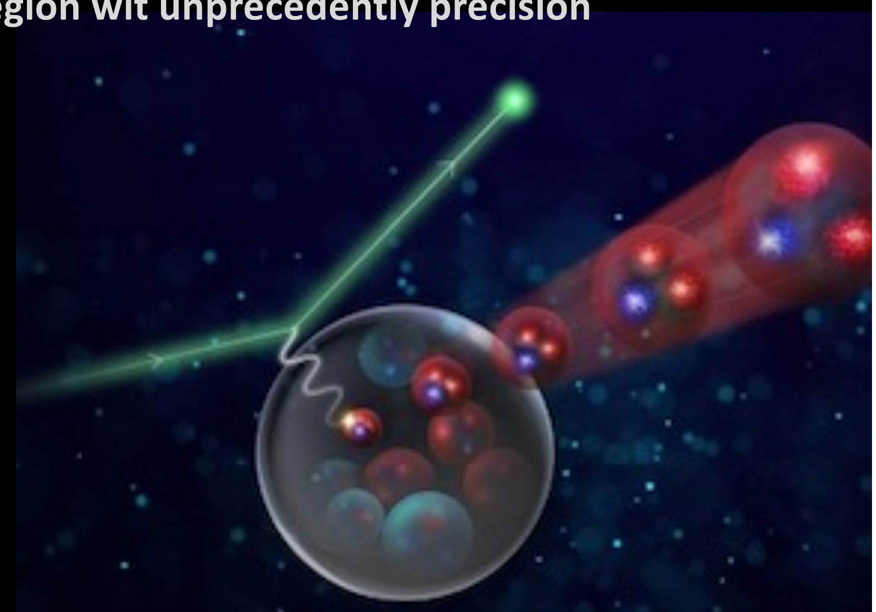
Simulated JLab data: $Q^2 > 1.4\ \mathrm{GeV}^2; \quad 0.2 < z < 0.7; \quad P_{hT}^{\pi^+} < \min[\min[0.2Q, 0.5zQ] + 0.3\ \mathrm{GeV}, zQ]$

Jefferson Lab

Nuclear Dynamics



- **Exploring nuclear forces dominated by nuclear repulsion**
- **Investigation of nuclear-medium effects**
  - **antishadowing and the transition to the EMC region wit unprecedently precision**
- **SRC**

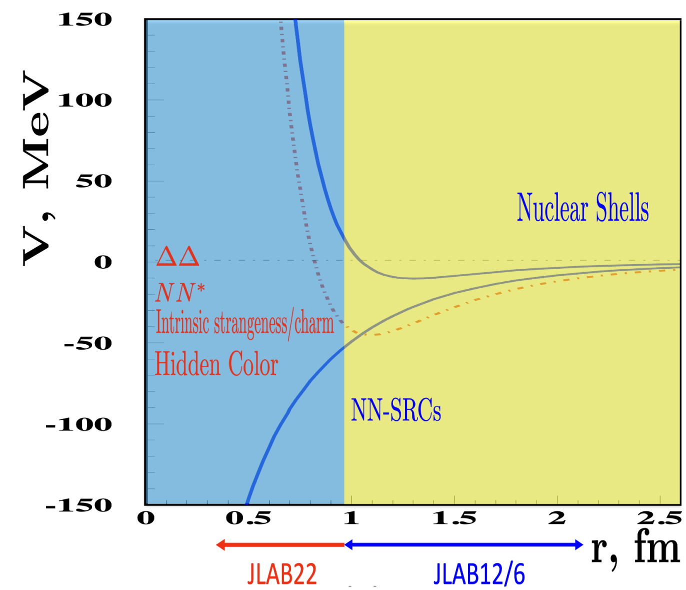


- **Hadronization and Color Tranparency**

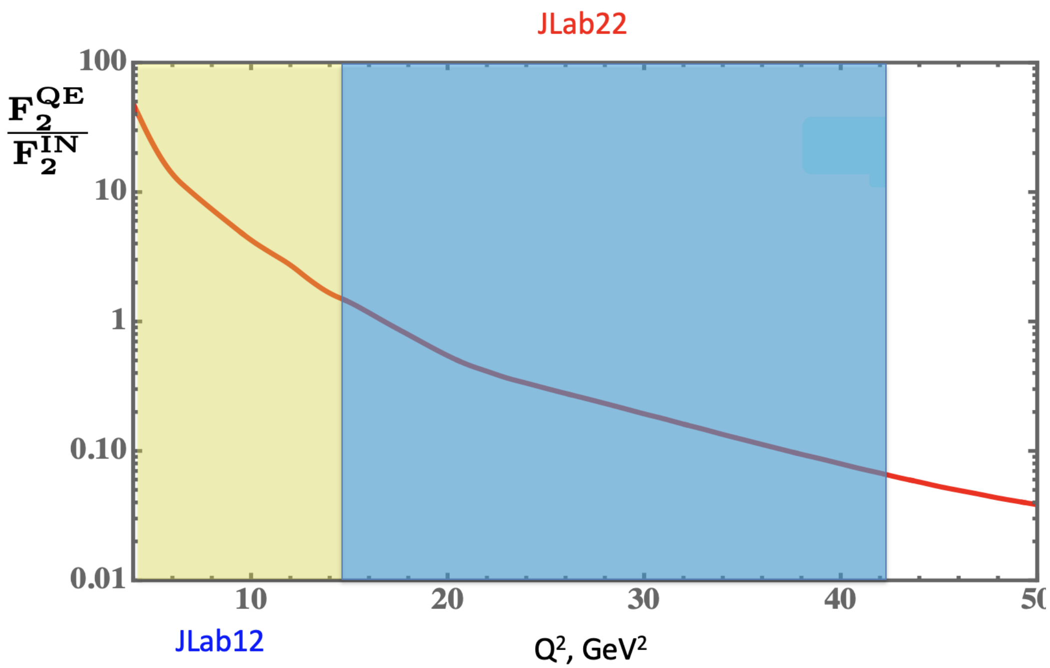
Nuclear Dynamics at Extreme Conditions

The dynamics of the nuclear repulsive core is still poorly understood

- Crucial for understanding the dynamics of transition between hadronic to quark-gluon phases of matter
  - ➔ **evolution of the universe**
  - ➔ **dynamics of superdense matter at the cores of neutron stars**



A 22 GeV upgrade will provide reach to the nuclear forces dominated by nuclear repulsion



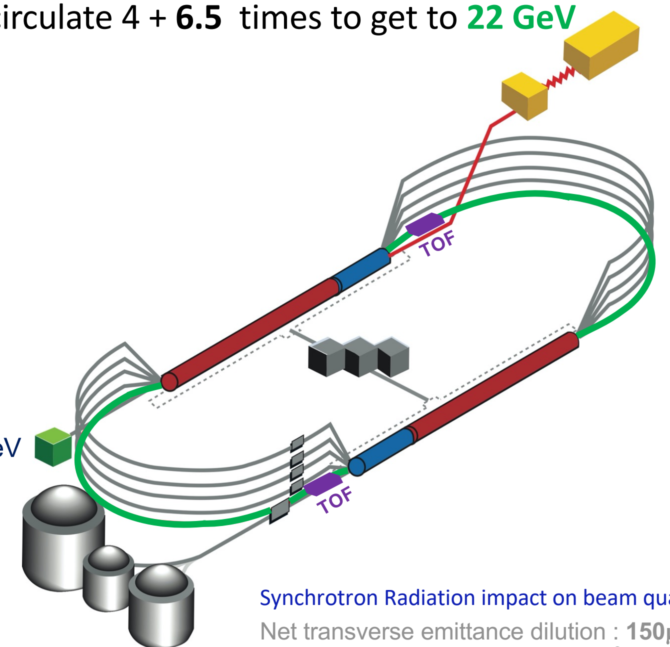
- **Superfast Quarks**

  The high Q^2 reach will allow
  - the suppression of quasi-elastic contributions,
  - the first-ever direct study of nuclear DIS structure function at Bjorken x > 1.2 (r~ 0.5 fm,)

Jefferson Lab

CEBAF FFA Upgrade – Baseline under Study

- Starting with 12 GeV CEBAF
- NO new SRF
- NEW 650 MeV injector
- Remove the highest recirculation pass and replace them with **two FFA arcs** including TOF chicane
- Recirculate 4 + **6.5** times to get to **22 GeV**

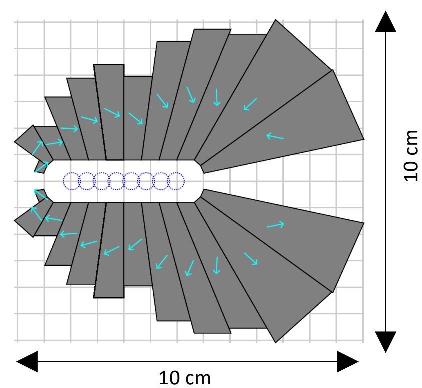


Synchrotron Radiation impact on beam quality

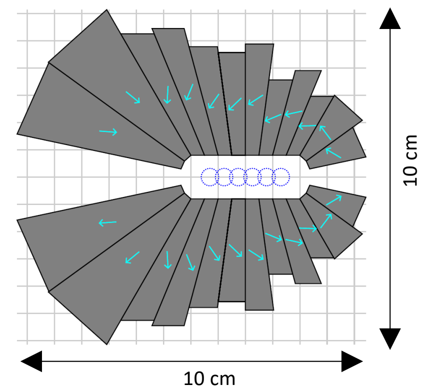
Net transverse emittance dilution : **150µm**
Net natural energy spread : **2×10^{-3}**
Net synchrotron radiated energy: **1 GeV**

Enabling Technology:

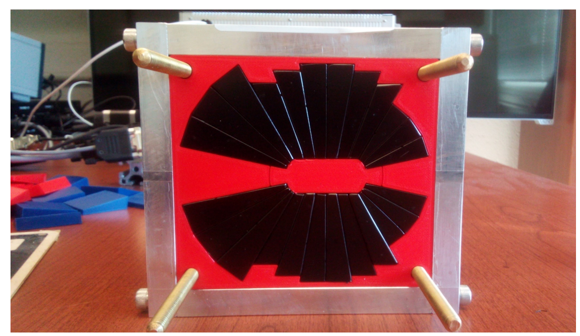
Novel **permanent magnets** CBETA- like (power & cost savings)



Focusing Magnet BF L_{QF}= 1.67 m

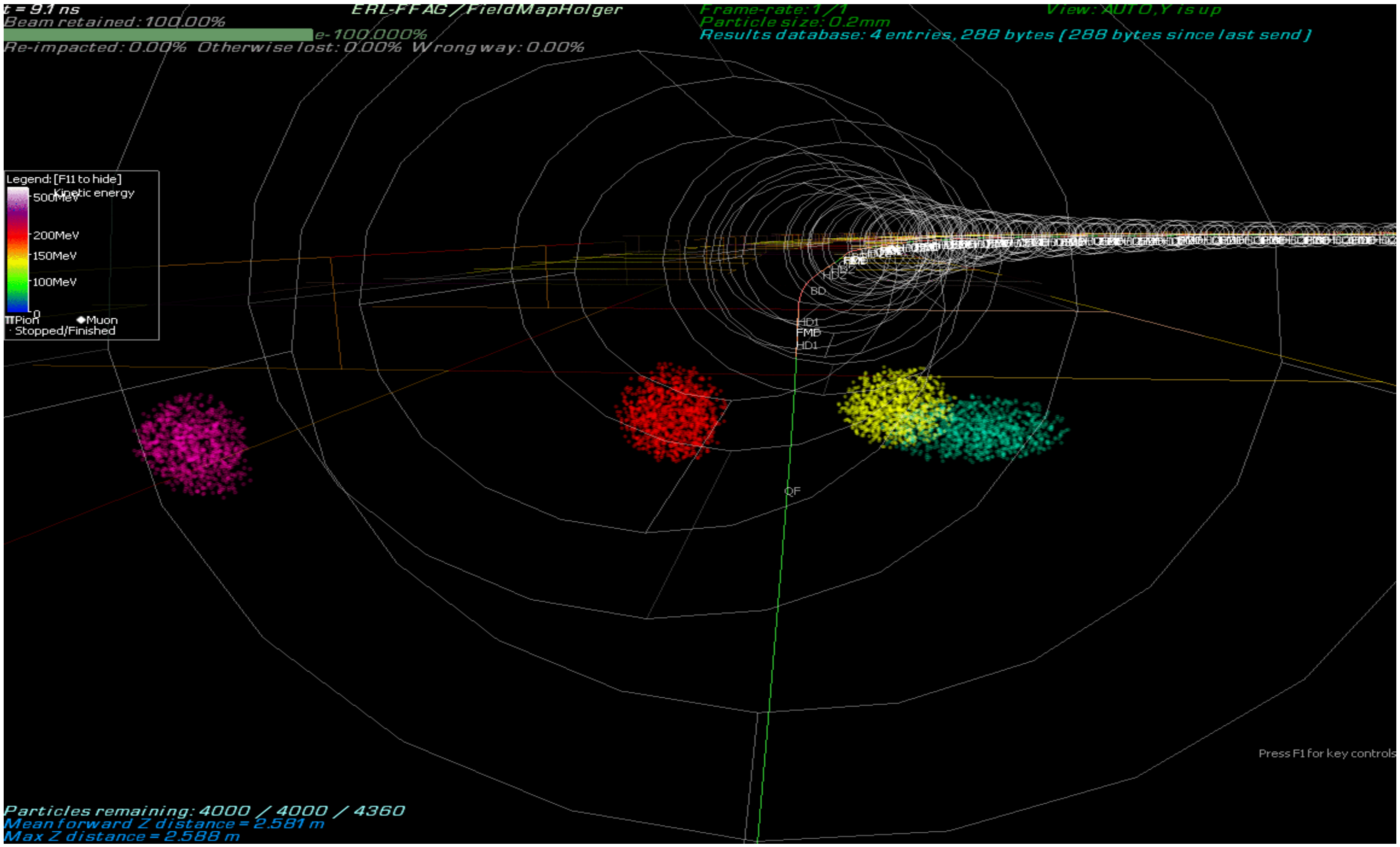


Defocusing Magnet BD L_{BD}= 1.24 m



- **A prototype open midplane BF magnet was built and evaluated for mechanical integrity**
- **Magnetic measurement confirmed a robust design with >1.5 Tesla in good field region, 10^{-3} field accuracy**
- **Radiation resilience tests will be carried out at CEBAF**

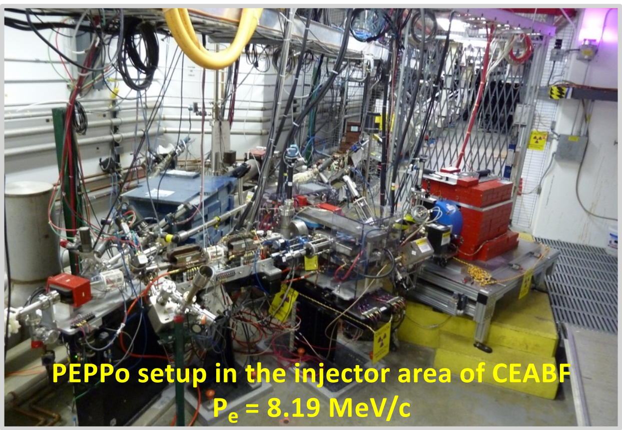
Multi-Bunch Dynamics in CBETA FFA Arc



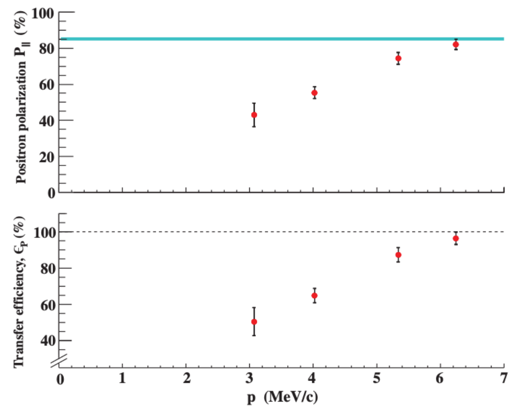
Courtesy A. Bogacz

A Positron Program with CEBAF at 12 GeV

- Dedicated R&D program to add a positron source capable to produce 100 nA polarized and 1 μA unpolarized positron beams.



- Demonstrated for the first time the efficient transfer of polarization from e^- to e^+

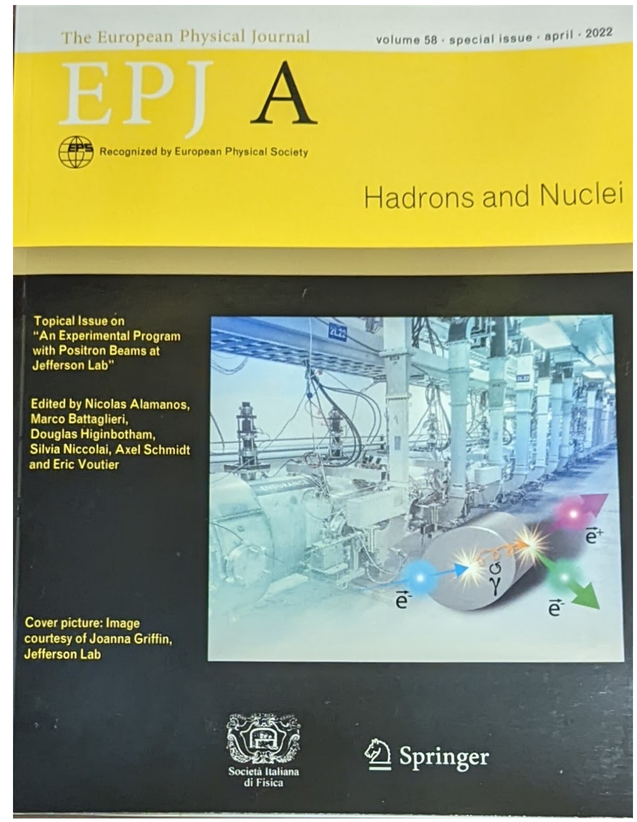


Phys. Rev. Lett. 116, 214801

- A Positron Program White Paper has been published in 2022
- Experimental program accessible to positron beams:
  e.m. Form Factors, PDFs, GPDs, physics BSM, measurement of weak neutral-current couplings, LFV
- 6 Proposals and 5 LoIs submitted to the JLab Program Advisory Committee in July 2023

- **Topical issue on An Experimental Program with Positron Beams at Jefferson Lab**
  Eur. Phys. J. A 58 (2022) 3, 45

JLab PWG = ***~250 Physicists***

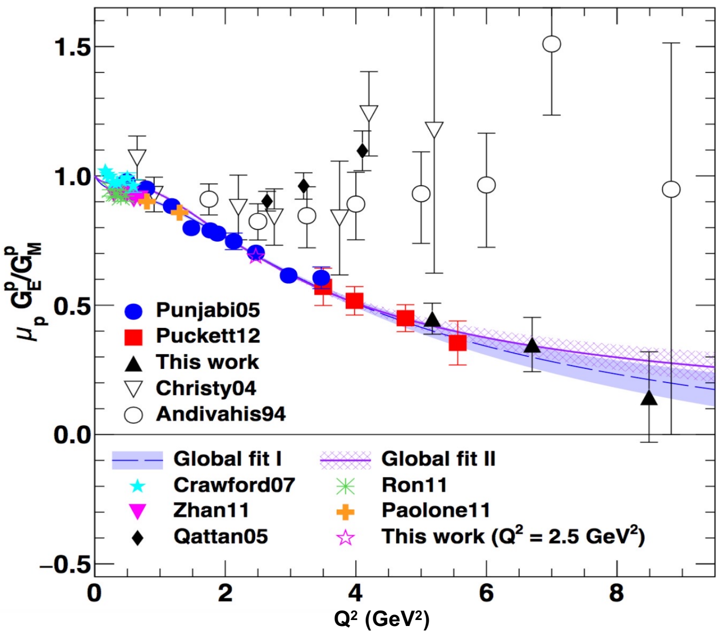


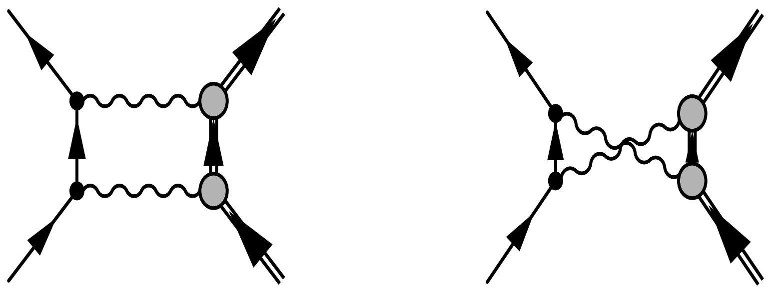
One Detailed Example: Understanding Two Photo Exchange

P.A.M. Guichon, M. Vanderhaeghen, PRL 91 (2003) 142303 P.G. Blunden, W. Melnitchouk, J.A. Tjon, PRL 91 (2003) 142304

Measurements of **polarization transfer** observables in **electron elastic scattering off protons question** the **validity** of the **1γ exchange approximation** of the electromagnetic interaction.

A.J.R. Puckett et al. PRC 96 (2017) 055203





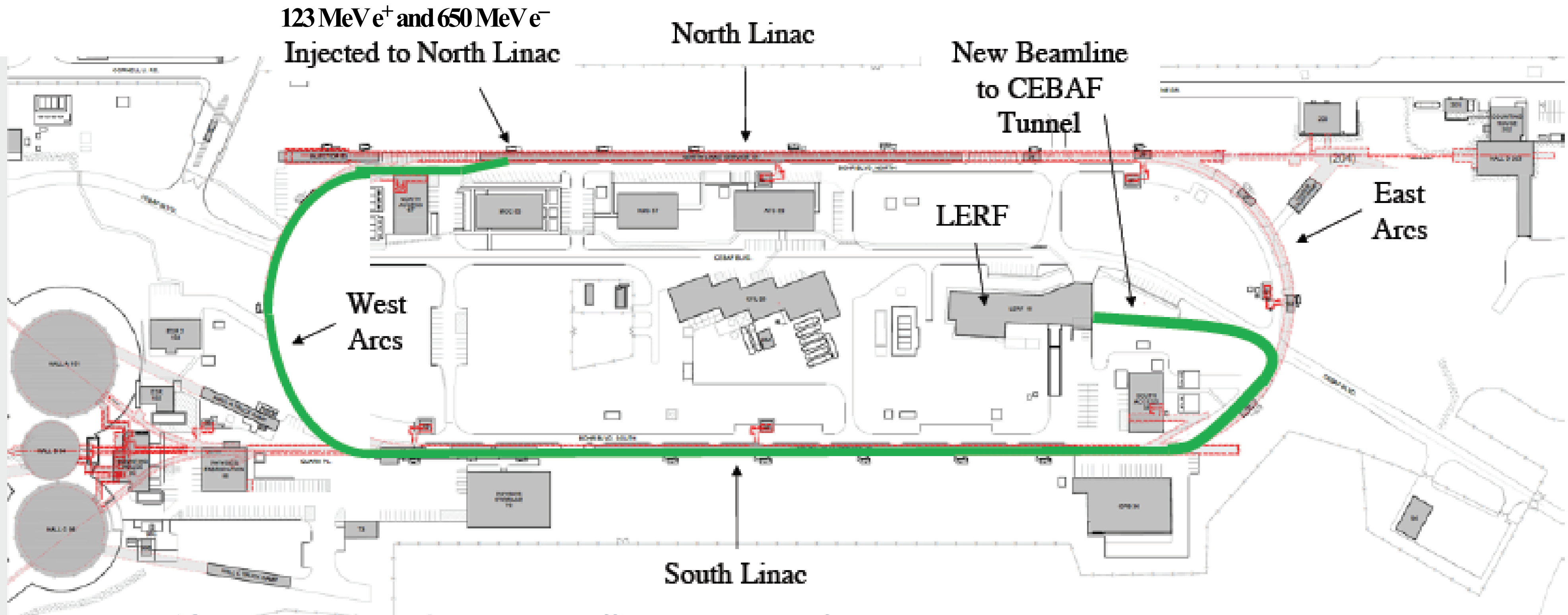
Two-photon exchange (TPE) is likely the cause of the form factor discrepancy at high Q^2.

$$\sigma \sim |\mathcal{M}_{1\gamma}|^2 \pm 2\mathrm{Re}\left[\mathcal{M}_{1\gamma}\mathcal{M}_{2\gamma}\right] + \ldots,$$ **elastic scattering cross section**

$$R_{2\gamma} \equiv \frac{\sigma_{e^+p}}{\sigma_{e^-p}} = 1 + 4\frac{\mathrm{Re}\left[\mathcal{M}_{1\gamma}\mathcal{M}_{2\gamma}\right]}{|\mathcal{M}_{1\gamma}|^2} + \ldots$$ **positron-proton/electron-proton cross section**

***e^+ @ JLab** has a the unique opportunity to bring a **definitive answer** about TPE.*

Electron/positron injector vault is required for 12 GeV e+ and 22 GeV e-



'Green beamline' is a cost-effective option for staging positron and energy upgrades:

123 MeV e^+ for 12 GeV CEBAF

650 MeV e^- for 22 GeV CEBAF Energy Upgrade

Conclusions and Outlook

- QCD manifests fascinating complexity
  - Large research facilities like CEBAF are required to understand the implications of QCD in experiments
- CEBAF will remain the prime facility for fixed target electron scattering at the luminosity frontier
  - A groundbreaking experimental program has been developed stretching well into the 2030s with existing or planned new equipment
- A new round of upgrades to CEBAF are presently under technical development: an energy upgrade to 22 GeV and an intense polarized positron beams
  - This scientific program can provide a unique insight into the non-pQCD dynamics
  - It is complementary to the envisioned EIC program
  - It has been presented at the NP Long Range Plan
  - **Strong support by a Broad Community**