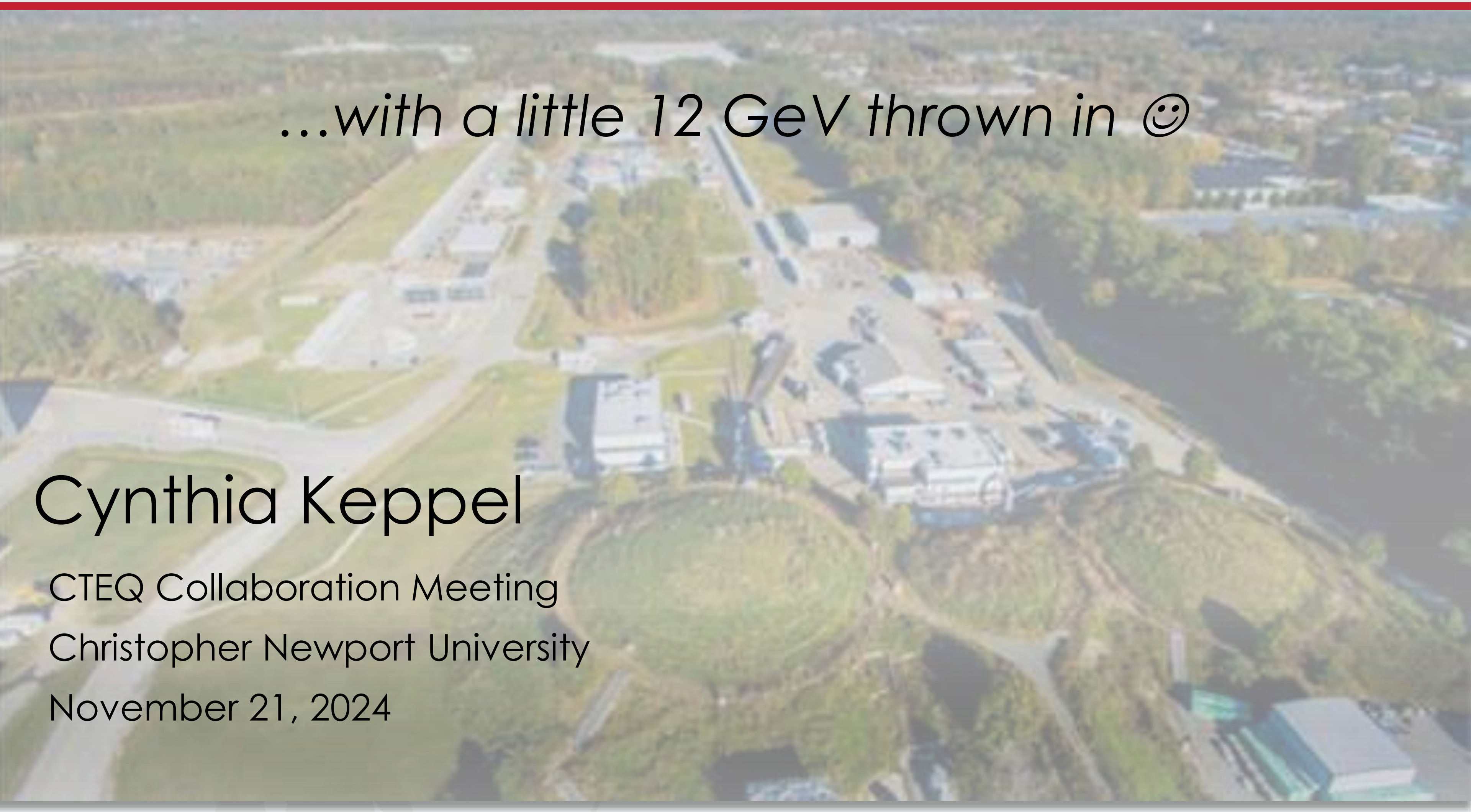
Future Opportunities at JLab with 12 GeV Positrons and 22 GeV Electrons



…with a little 12 GeV thrown in ☺

Cynthia Keppel

CTEQ Collaboration Meeting
Christopher Newport University
November 21, 2024

The combined positron to 22 GeV GeV upgrade is a rather new opportunity at Jefferson Lab….

The community did a lot of work (science workshops, accelerator studies, cost estimating, profile development,…) to quickly prepare for the NSAC Long Range Plan

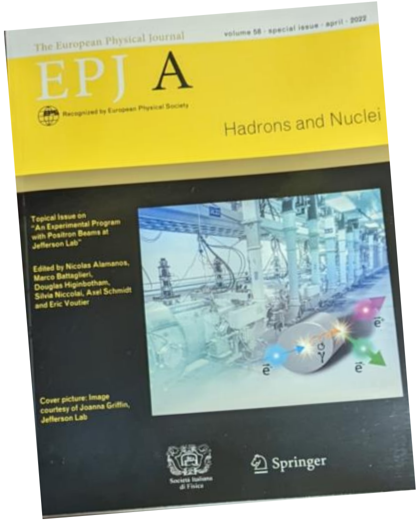
- *Critical just to be mentioned favorably!*

"The staged upgrade plan for CEBAF foresees...[]…an energy upgrade of CEBAF to more than 20 GeV….. exciting new technology could enable a cost-effective method to double the energy of CEBAF, allowing wider kinematic reach for nucleon femtography studies in the existing tunnels and with no new cryomodules required."

"To investigate the other XYZP states, higher beam energy is required; the tetraquark candidate Z_c states would Z_c be copiously produced at a high-luminosity, fixed-target electron machine operating above 20 GeV."

"The role of two-photon exchange can be determined by measurements using a positron beam, which could be realized at Jefferson Lab with a modest accelerator upgrade."

Science at the Luminosity Frontier: Jefferson Lab Upgrade Development



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EPJ A
Recognized by European Physical Society
Hadrons and Nuclei

Topical Issue on "An Experimental Program with Positron Beams at Jefferson Lab"

Edited by Nicolas Alamanos, Marco Battaglieri, Douglas Higinbotham, Silvia Niccolai, Axel Schmidt and Eric Voutier

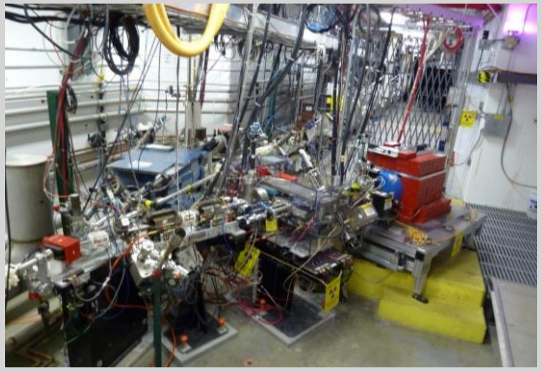
Cover picture: Image courtesy of Joanna Griffin, Jefferson Lab

Società Italiana di Fisica
Springer

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

Strong Interaction Physics at the Luminosity Frontier with 22 GeV Electrons at JLab
Eur.Phys.J.A 60 (2024) 9, 173

2009 1st dedicated workshop



2012-16 PEPPo demonstrates 82% e+ polarization

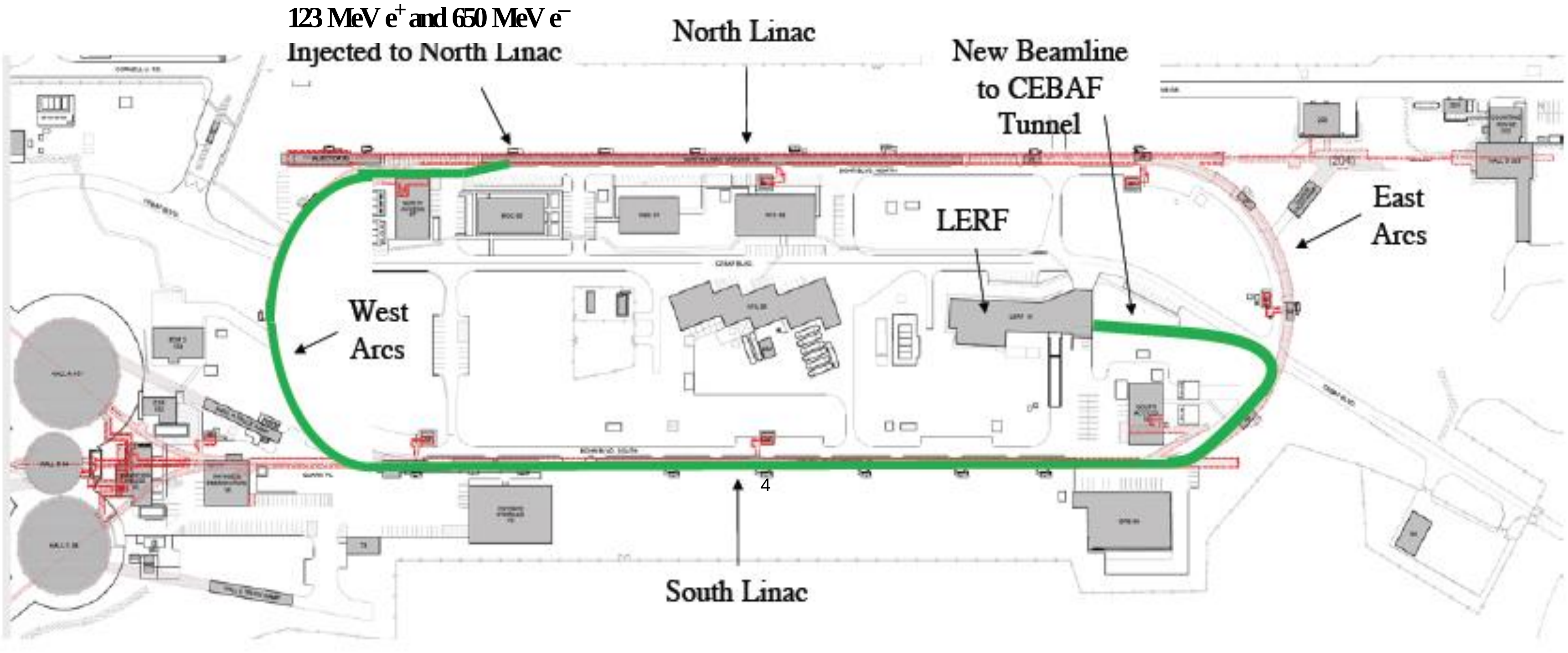
Many workshops along the way

Broad community interest in this science

Jefferson Lab

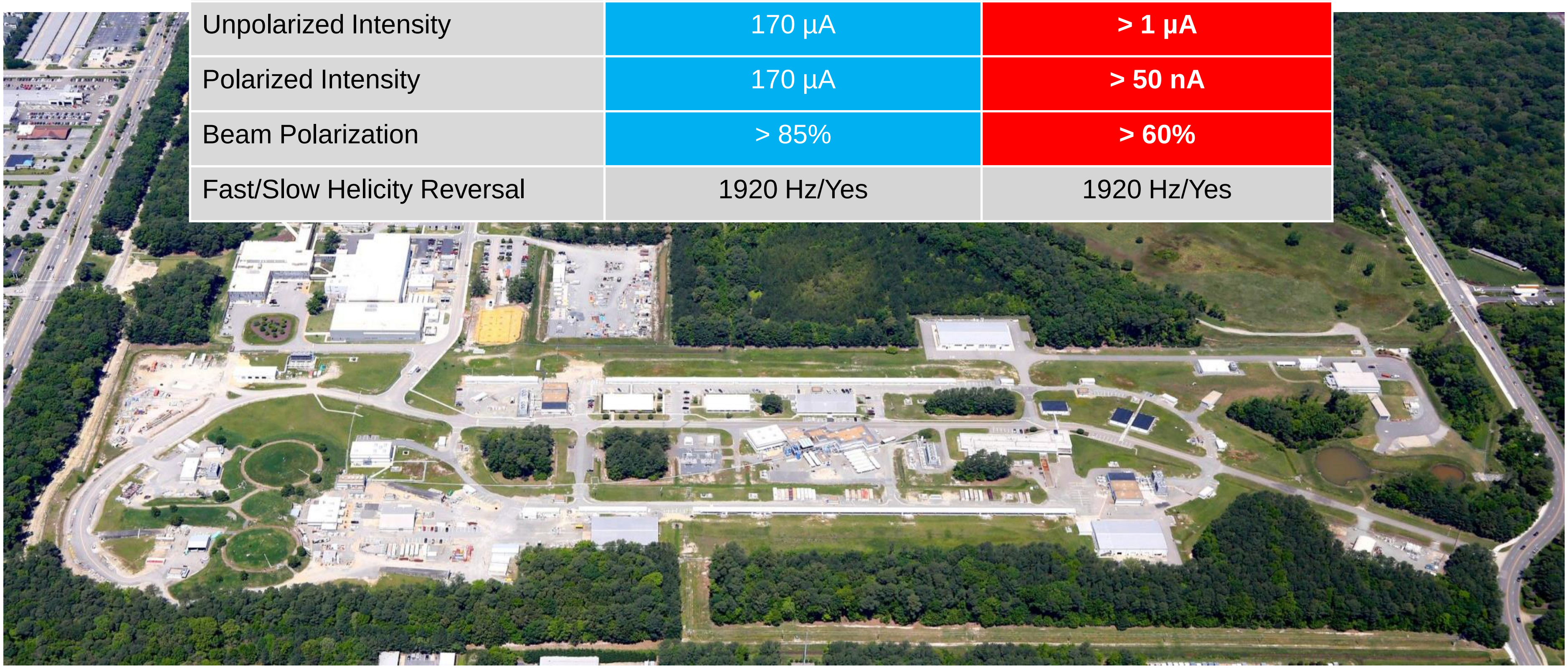
JEFFERSON LAB ACCELERATOR PHASED UPGRADE

- A staged upgrade program at the luminosity frontier (up to 10^{39} e-N /cm^2/ s), capitalizing on novel accelerator science and technology
- Phase 1: Polarized positrons in a former FEL (“LERF”) with transport to CEBAF (proposed 12 GeV science program)
- Phase 2: Recirculating injector energy upgrade to 650 MeV electrons
- Replace one set of arcs on each side with new FFA permanent magnet arcs to upgrade to 22 GeV – ***no new RF needed! No new cryomodules needed!***



12 GeV Ce^{+}BAF: Polarized Positron Beams

Machine Parameter	**Electrons**	**Positrons**
Hall Multiplicity	4	**1 or 2**
Energy (ABC/D)	11/12 GeV	11/12 GeV
Beam Repetition	249.5/499 MHz	249.5/499 MHz
Duty Factor	100% cw	100% cw
Unpolarized Intensity	170 µA	**> 1 µA**
Polarized Intensity	170 µA	**> 50 nA**
Beam Polarization	> 85%	**> 60%**
Fast/Slow Helicity Reversal	1920 Hz/Yes	1920 Hz/Yes



(C1) APPROVED POSITRON SCIENCE PROGRAM

6 Experiments, 10+ LOIs, even more ideas!

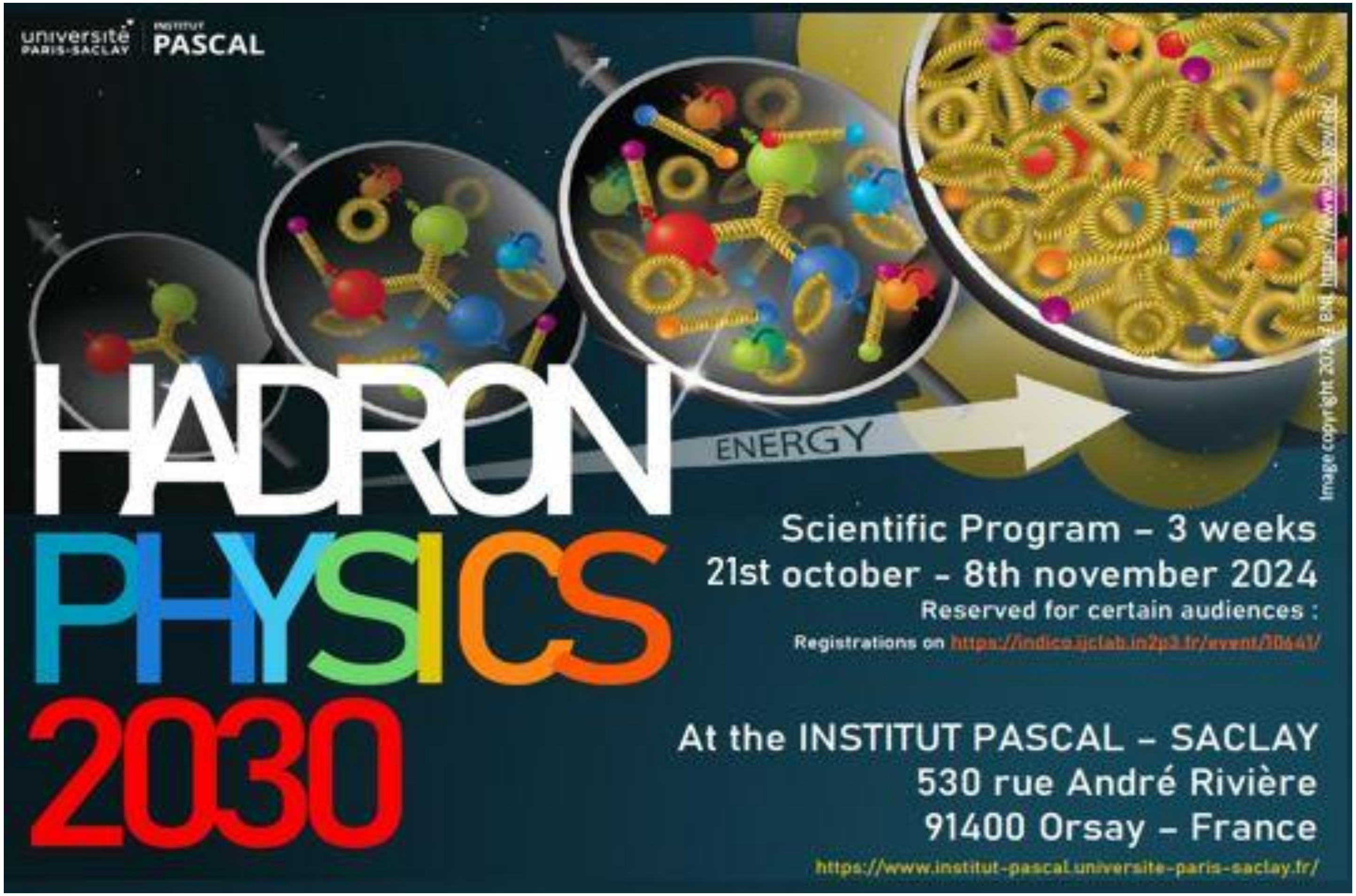
NUMBER	TITLE	PHYSICS THEME	CONTACT PERSON	HALL	DAYS AWARDED	SCIENTIFIC RATING	PAC DECISION
PR12+23-002	Beam Charge Asymmetries for Deeply Virtual Compton Scattering on the Proton at CLAS12	GPDs	Eric Voutier	B	100	A-	C1
PR12+23-003	Measurement of Deep Inelastic Scattering from Nuclei with Electron and Positron Beams to Constrain the Impact of	TPE	Dave Gaskell	C	9.3	A-	C1
PR12+23-006	Deeply Virtual Compton Scattering using a positron beam in Hall C	GPDs	**Carlos Muñoz Camacho**	C	137	A-	C1
PR12+23-008	A Direct Measurement of Hard Two-Photon Exchange with Electrons and Positrons at CLAS12	TPE	Axel Schmidt	B	55	A	C1
PR12+23-012	A measurement of two-photon exchange in unpolarized elastic positron–proton and electron–proton scattering	TPE	Michael Nycz	C	56	A-	C1
PR12+24-005	A Dark Photon Search with a JLab positron beam	FS	Bogdan Qojtsekhowski	B	55	A-	C1

Approved 210 days Hall B & 202 days in Hall C for 357 total PAC days

(PAC day = two calendar day)

The JLab Positron Working Group offers review for new experimental proposals.

- https://indico.ijclab.in2p3.fr/event/10641/



université PARIS-SACLAY
INSTITUT PASCAL

HADRON PHYSICS 2030

Scientific Program – 3 weeks
21st october – 8th november 2024
Reserved for certain audiences :
Registrations on https://indico.ijclab.in2p3.fr/event/10641/

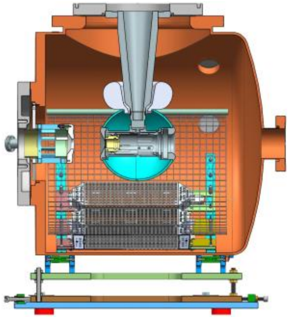
At the INSTITUT PASCAL – SACLAY
530 rue André Rivière
91400 Orsay – France
https://www.institut-pascal.universite-paris-saclay.fr/

Pol. e^+ Injector Critical Risk Areas mA e^- Source, High Power Targets, Capture Cavity

Conceptual Development

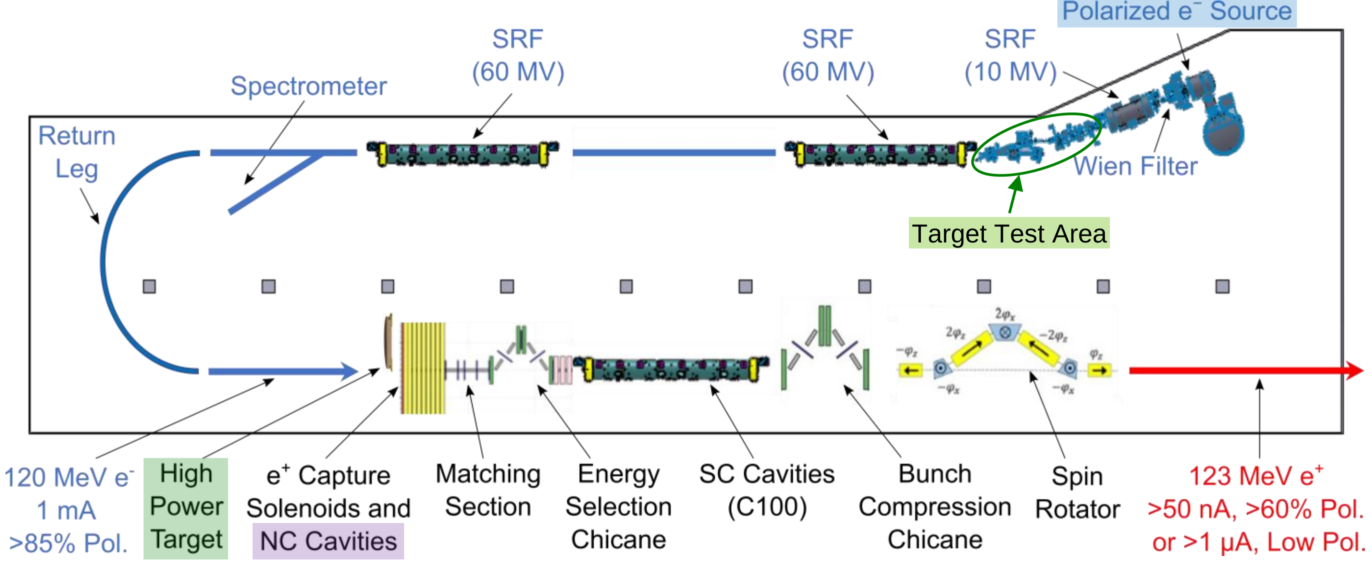
- Improve design of e^+ injector
- Develop pCDR

- High current e^- source (<10 mA @ 10 MeV)
- Up to 90% polarization
- Long life time



- M. Bruker, IPAC’24, MOPC52
- JLab LDRD “A high-intensity, polarized-beam prototype photogun for the Ce$^+$BAF positron source”,
  PI: M. Bruker, proposal awarded, FY25-FY26

Scheme of e^+ Injector at LERF



Polarized e^- Source

SRF (60 MV)

SRF (60 MV)

SRF (10 MV)

Spectrometer

Return Leg

Wien Filter

Target Test Area

120 MeV e^-
1 mA
>85% Pol.

High Power Target

e^+ Capture Solenoids and NC Cavities

Matching Section

Energy Selection Chicane

SC Cavities (C100)

Bunch Compression Chicane

Spin Rotator

123 MeV e^+
>50 nA, >60% Pol.
or >1 μA, Low Pol.

S. Habet, PhD Thesis, Dec 2023

	Simul.	Goal
Energy [MeV]	123	
Current [nA]	170	> 50
Polarization [%]	65	> 60
$\sigma_{\Delta p/p}$[%]	0.6	< 1
σ_z [ps]	2	< 4
$\varepsilon_{nx}, \varepsilon_{ny}$ [m·rad]	1.5e-3	< 4e-5

A. Ushakov “Positron Beams for 12 GeV CEBAF”, Hadron Physics 2030

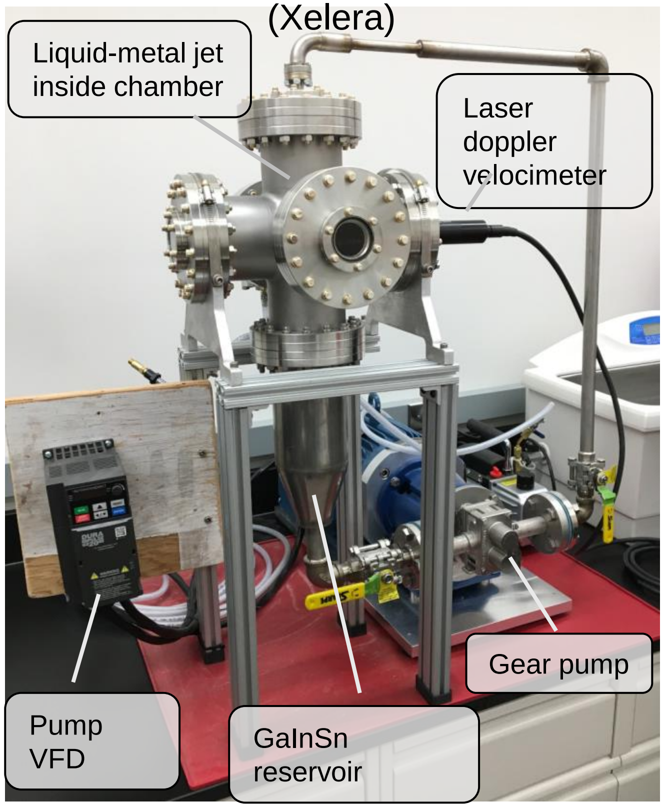
Development and Test of Liquid Metal Targets

Two target concepts are considered

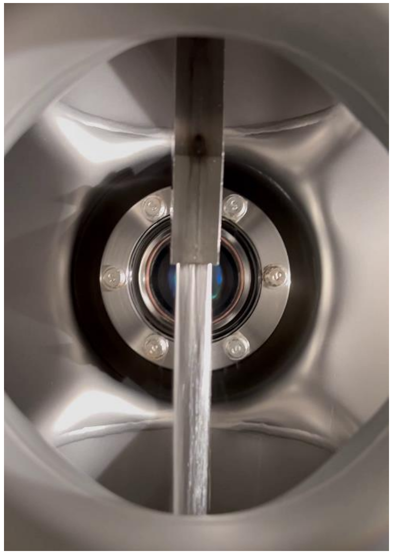
1. Solid high-Z target (i.e. tungsten)
   ⇒ next slide
2. Liquid metal targets (GaInSn, PbBi)

- Liquid Metal Targets are developed by Xelera Research LLC
- DOE Small Business Innovation Research (SBIR) Phase 2, Oct 2024 – Sep 2026
- Planned test of GaInSn target at JLab with up to 10 mA @ 10 MeV e^- beam
- Liquid PbBi target is proposed for future for drive e^- beam with 1 mA @ 120 MeV

Prototype of GaInSn Test Stand (Xelera)



Example of GaInSn jet with speed ~8 m/s



N. Taylor et al., IPAC’24, TUPC83

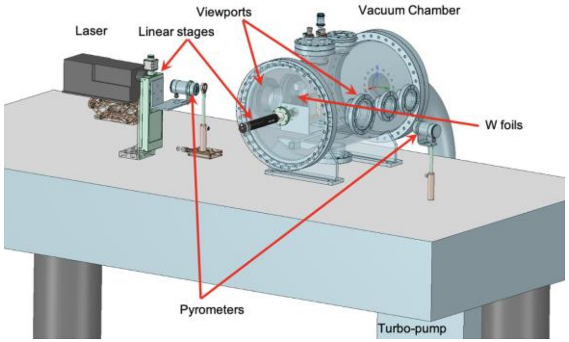
Concept of Tungsten Target, CFD Simulations, Prototype Testing (S. Covrig)

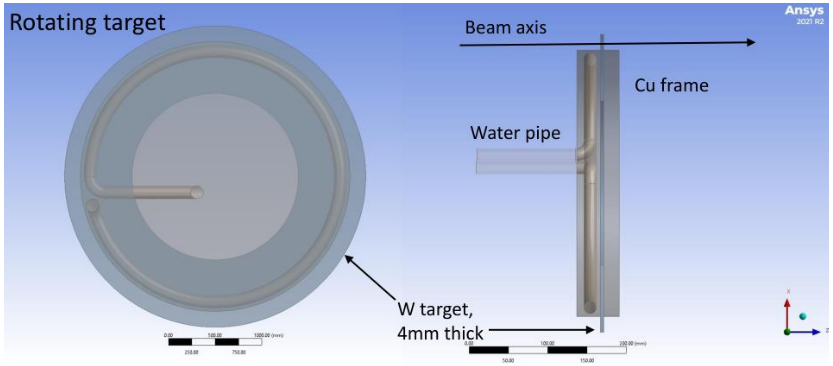
Design goal: target should be able to take 1 mA, 120 MeV CW e^- beam current and have a lifetime of 6 months (or longer)

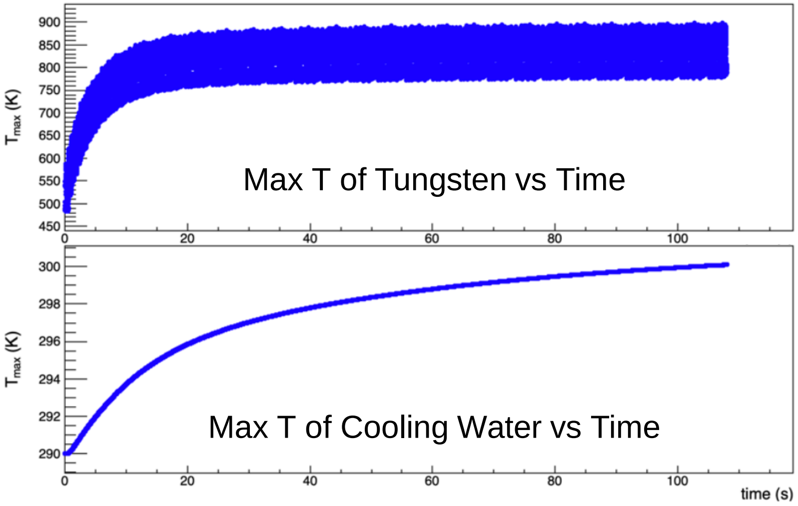
- Focus on assessing with CFD solid high-Z targets (tungsten, W-alloys, etc.)
- Implemented full time-dependent CFD simulations
- Initial calculations have shown that the rotating W target (4mm thickness, 10 Hz rot. frequency, >30 cm diameter) can take 20 kW beam power and peak target temperature $T_{max} < 1000$ K
- Started looking at target engineering, radiological issues, shielding

- DOE FY2024 R&D for Next Generation Nuclear Physics Accelerator Facilities (funded, FY25-FY26)

Tungsten Target Test



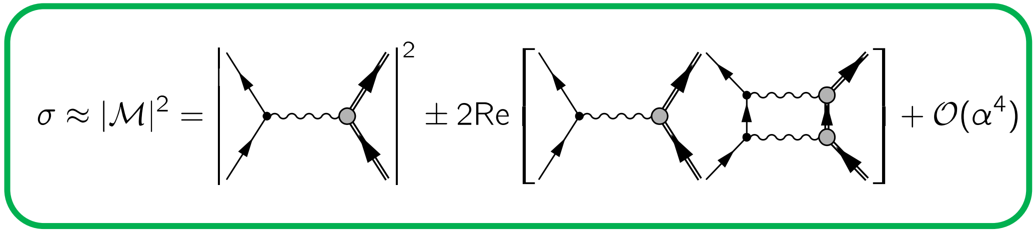



Max T of Tungsten vs Time

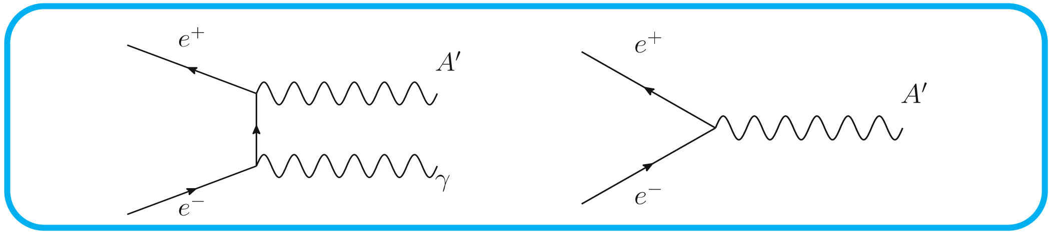
Max T of Cooling Water vs Time

Positrons open the door to understanding a range of physics that can’t be accessed with electrons alone.

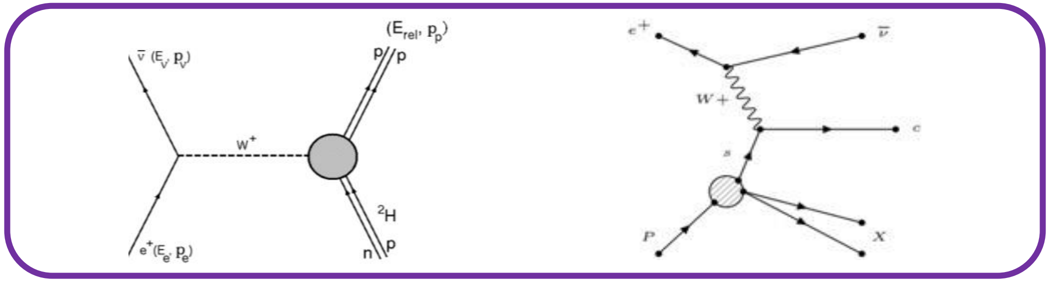
- **Beam charge asymmetries**
  - Two-photon exchange
  - Deeply Virtual Compton Scattering



- **Annihilation processes**
  - Light dark matter searches

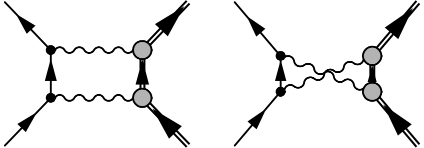


- **Charged-current processes**
  - Inverse beta-decay
  - Access strangeness with charm-tagging
  - Charged lepton flavor violation
  - Axial Form Factor



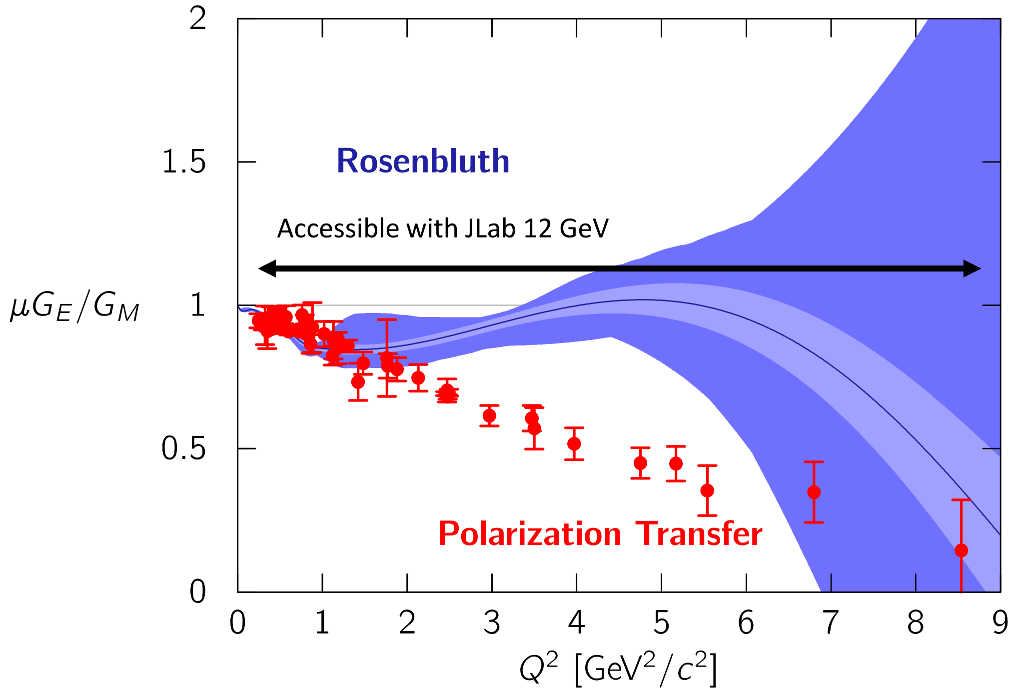
Along with many other new ideas!

Two-photon exchange may be the cause of the proton form factor discrepancy.

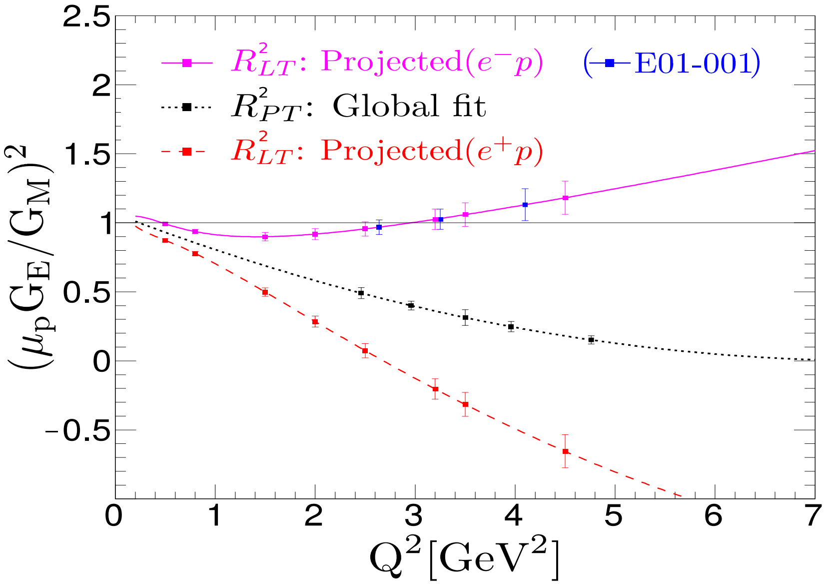


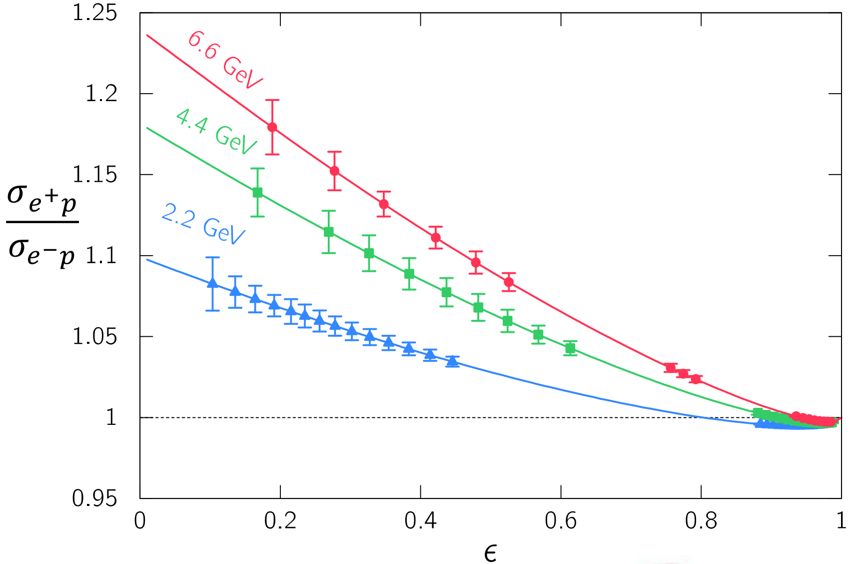
Two-photon exchange —

- A challenge to calculate
- Leading contribution has opposite effect for e^+
- Measurements of $\sigma_{e^+}/\sigma_{e^-}$ isolate TPE
- Results to date inconclusive



Requires precision measurements

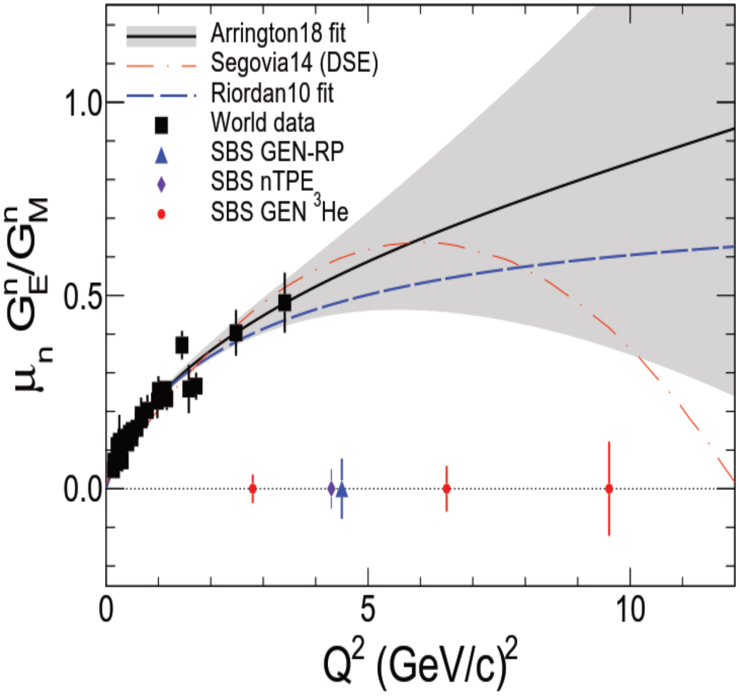




Hall A Today

Just completed Neutron Electric Form Factor Experiments (part of the SBS program)

- 60cm long polarized helium cell at 50% polarization at 45 uA
- *Highest Figure-of-merit **ever** achieved!*
- 6 graduate students on the experiment.



This experiment will clearly differentiate between fundamental approaches to QCD.

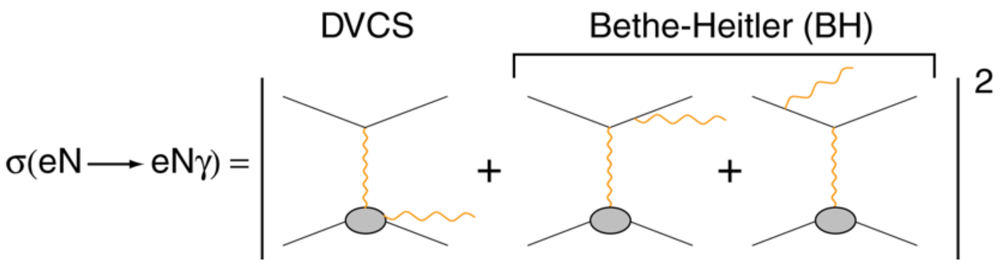
Gary is installing target oven

Kate with the 3He target cell

Hunter is excited about the first NMR measurement

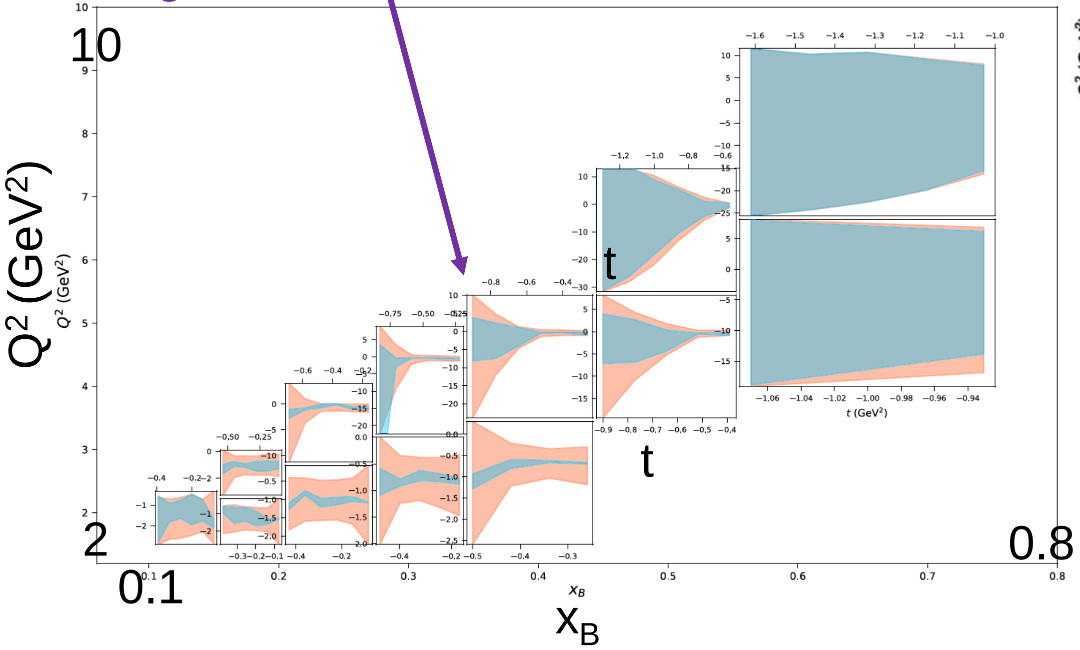
Currently installing GEp (to start early 2025)

Polarized positrons are an excellent tool for separating DVCS from background

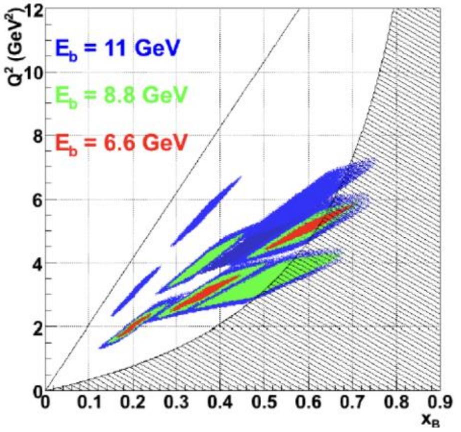


- Lepton beams of opposite charge separate Interference from DVCS
- Lepton beams of opposite helicity separate spin (in)dependent contributions
- **Clean isolation of DVCS, constraints on GPDs**

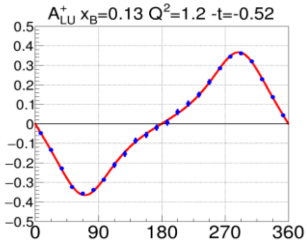
Positron data would dramatically improve GPD global fits.



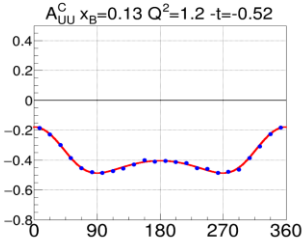
JLab Today: Pioneering mechanical properties of the Nucleon via GPDs (Gravitational Form Factors, Pressure Distribution, Gluonic Radius,…!)

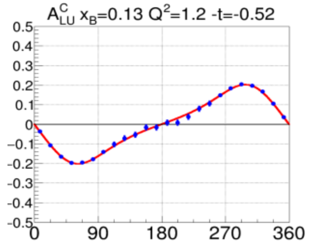


Anticipated Reach



Anticipated precision for beam charge/spin asymmetries

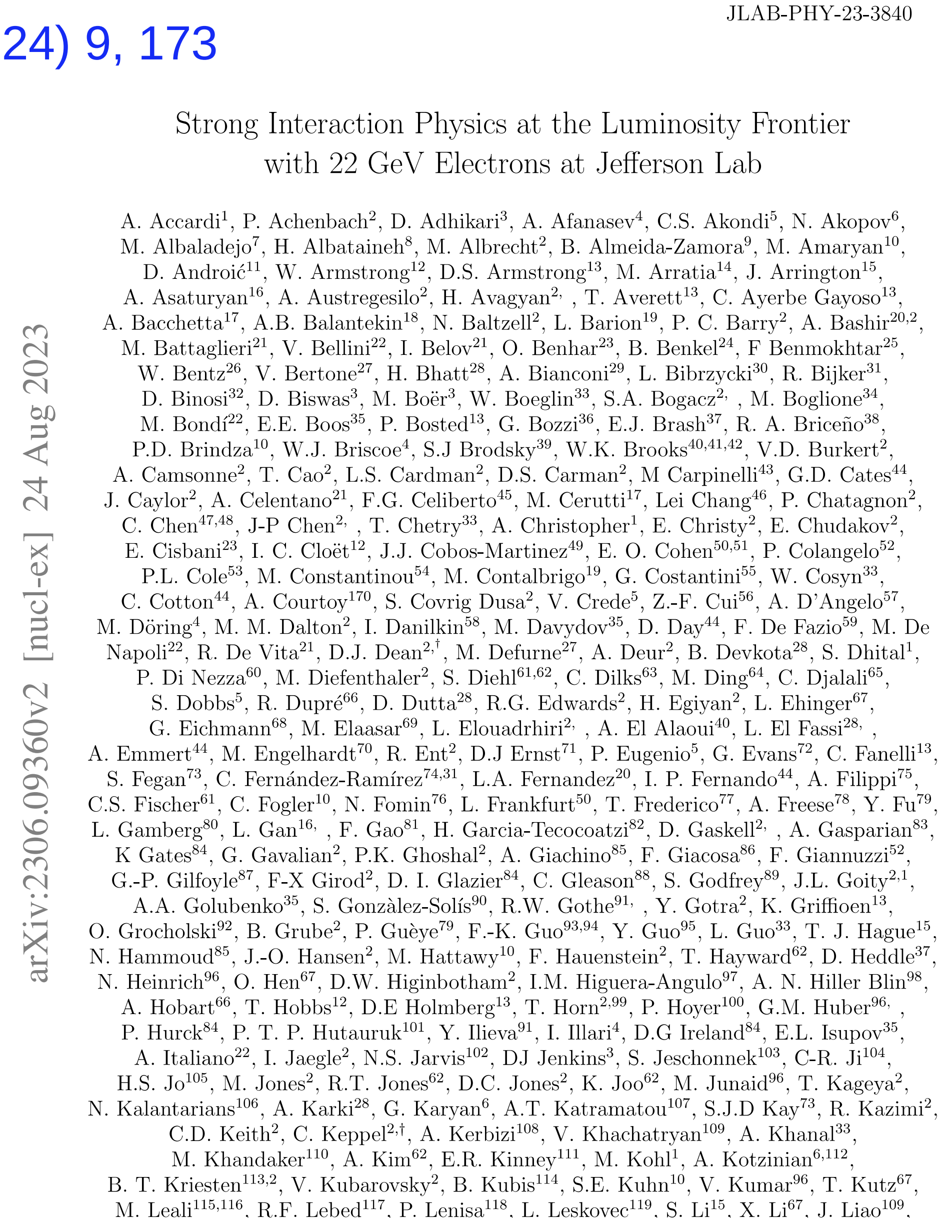




Strong Interaction Physics at the Luminosity Frontier with 22 GeV Electrons at JLab

Eur.Phys.J.A 60 (2024) 9, 173

140+ pages, ~450 authors with many powerful experiments *using existing or planned equipment* - just a few examples….



JLAB-PHY-23-3840

arXiv:2306.09360v2 [nucl-ex] 24 Aug 2023

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

A. Accardi[1], P. Achenbach[2], D. Adhikari[3], A. Afanasev[4], C.S. Akondi[5], N. Akopov[6],
M. Albaladejo[7], H. Albataineh[8], M. Albrecht[2], B. Almeida-Zamora[9], M. Amaryan[10],
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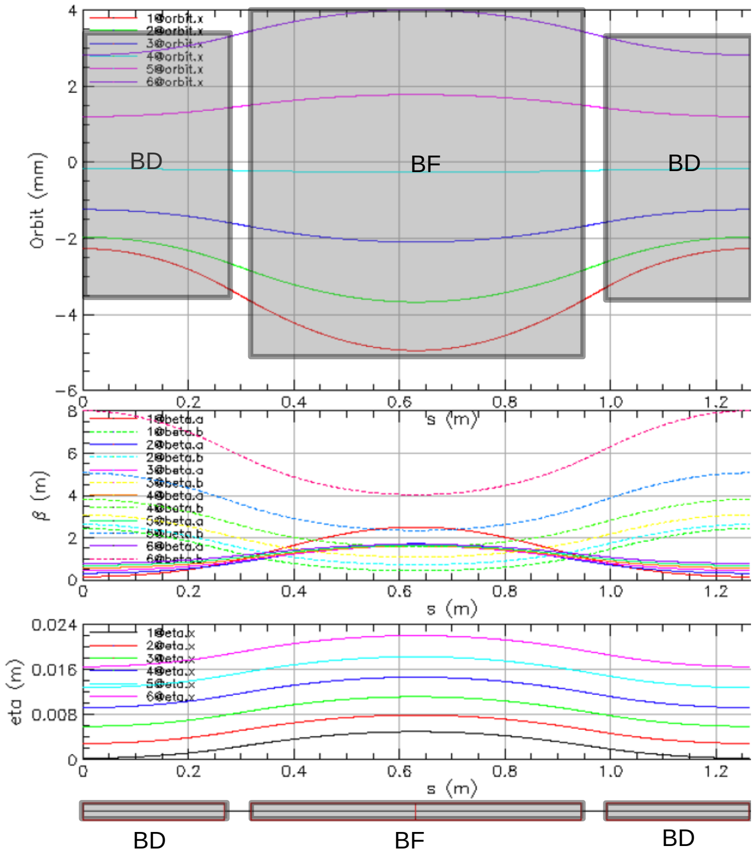
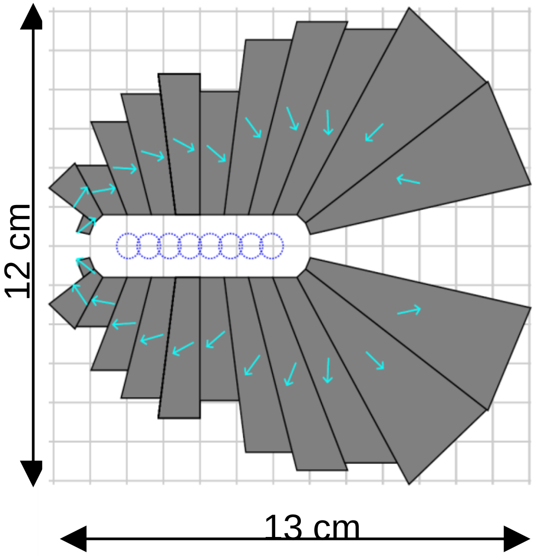
Compact FFA Cell – How Does it Work?

- Large momentum acceptance FFA (Fixed Field, Alternating Gradient) cell is configured with combined function permanent magnets capable of transporting multiple energy beams through the same string of magnets **(six beams with energies spanning a factor of two)**





Focusing Magnet BF

G_F= -41.13 T/m

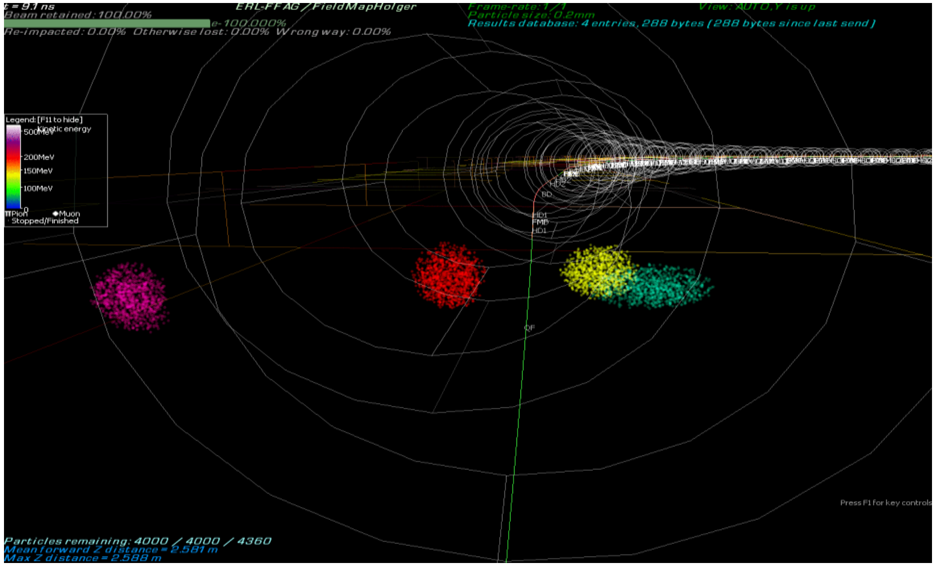
L_{QF}= 1.67 m

B_F= -0.812 T

- Closely spaced orbits for all six beams (~ 1 cm)
- Extremally low dispersion (a few mm) in a combined function lattice – virtue of FFA technology
- Self similar beta functions for different energy beams
- Arc composed of 75 cells, L_{cell} = 3.15 m

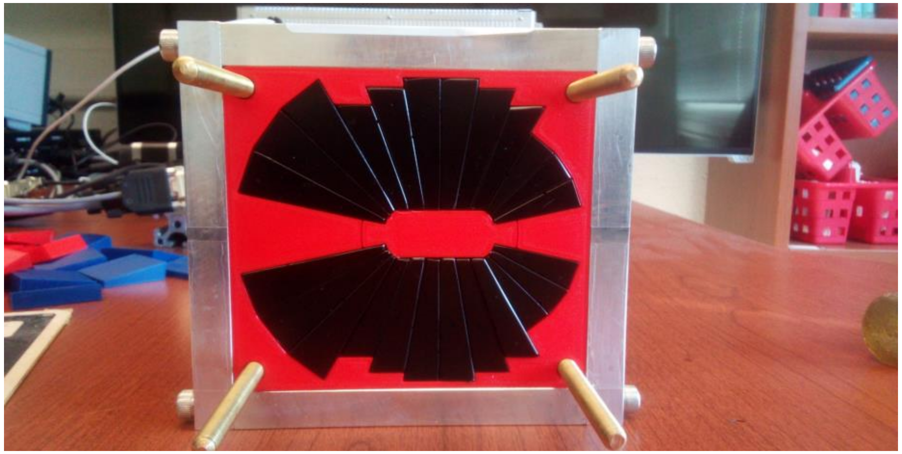
Multi-Energy Beam Dynamics in FFA Arc

CBETA 2019-2022 the first multi-turn SRF ERL (150 MeV)

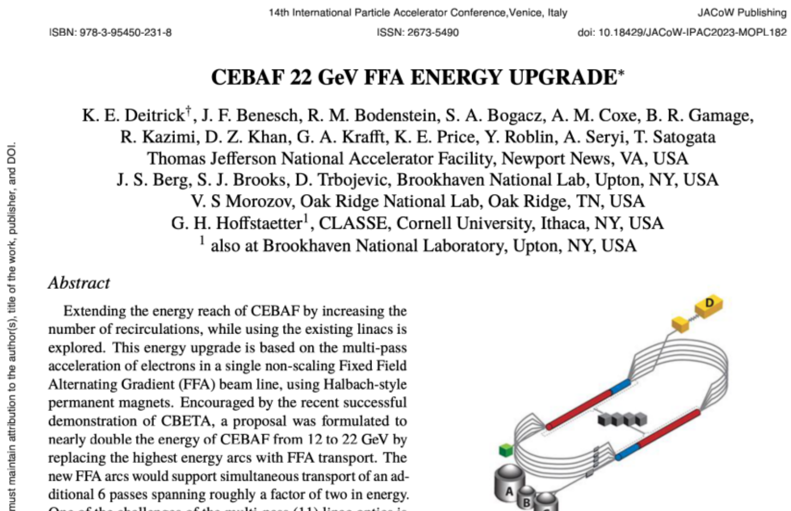


Stephen Brooks, BNL

Scaling to higher energy at Jlab…



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. JLab radiation resilience tests in CEBAF began October 2023.



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CEBAF 22 GeV FFA ENERGY UPGRADE*

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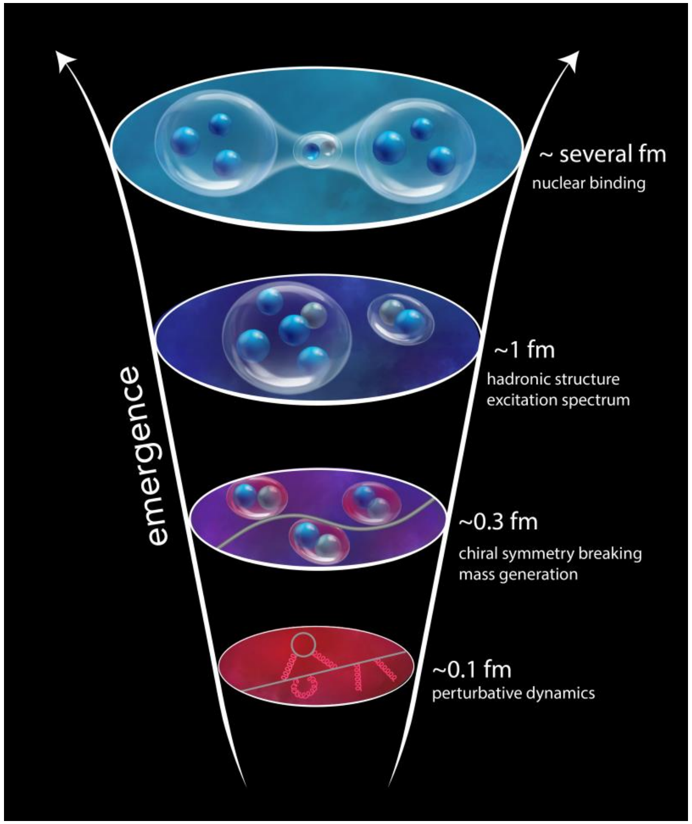
Abstract

Extending the energy reach of CEBAF by increasing the number of recirculations, while using the existing linacs is explored. This energy upgrade is based on the multi-pass acceleration of electrons in a single non-scaling Fixed Field Alternating Gradient (FFA) beam line, using Halbach-style permanent magnets. Encouraged by the recent successful demonstration of CBETA, a proposal was formulated to nearly double the energy of CEBAF from 12 to 22 GeV by replacing the highest energy arcs with FFA transport. The new FFA arcs would support simultaneous transport of an additional 6 passes spanning roughly a factor of two in energy.

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Why CEBAF @ 22 GeV?

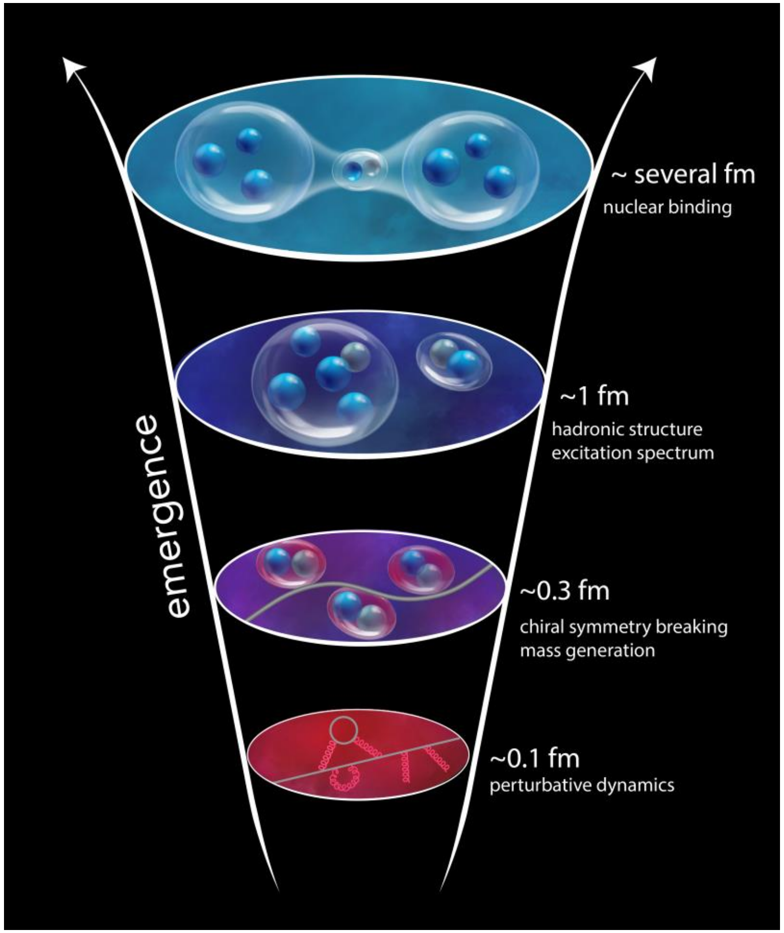
"The ability to reduce everything to simple fundamental laws does not imply the ability to start from those laws and reconstruct the universe."
-- *More is Different*, P. W. Anderson [Science 177, 393 (1972)]



In this landmark paper P.W. Anderson established complexity as a fundamentally important subject of inquiry. He highlighted profound limitations of reductionist approaches in understanding nature's complexity, and he set in motion new lines of investigation that have led to, for instance, condensed matter physics and systems biology.

Levels at which different processes occur require our close and careful attention: **understanding the dynamics at a given level often requires more than simply being able to characterize the dynamics at lower levels. Complexity is fundamentally important in its own right.**

Why CEBAF @ 22 GeV?



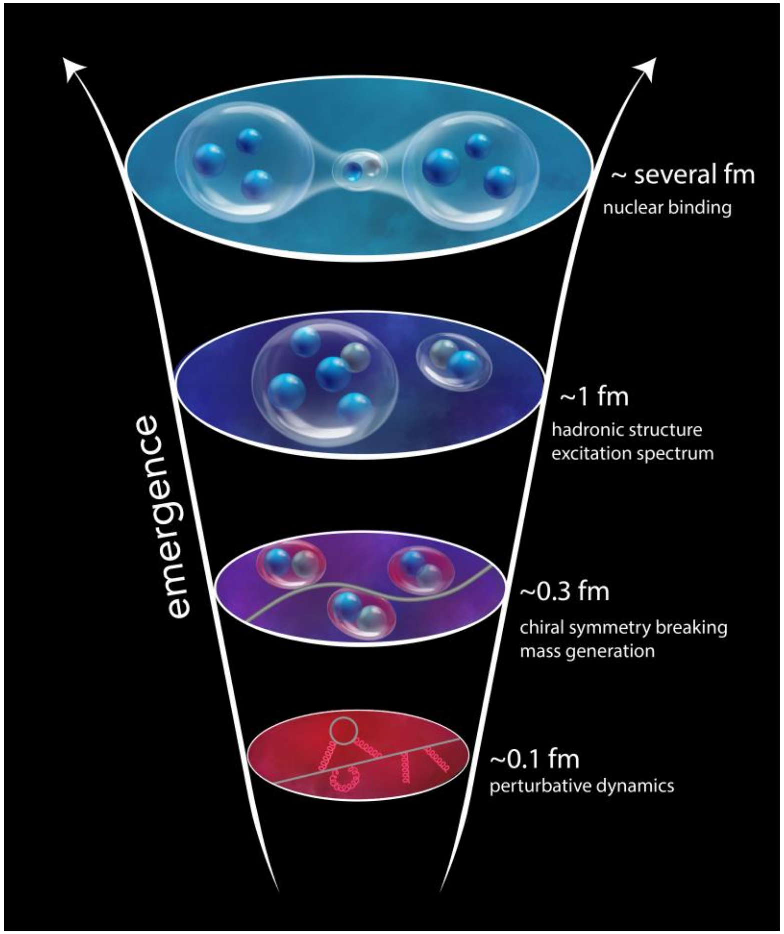
Studying the Complexity in Quantum Chromodynamics

Need to understand strong interaction dynamics *at multiple levels*, from asymptotically free fundamental quark and gluon constituents to

- the structure of (bound) nucleons, to
- nucleon-nucleon interactions, and to
- the nuclear medium

Understanding the dynamics at each level is a complex, non-pQCD problem which demands different approaches and measurements to access multiple observables across multiple scales

What a 22 GeV Upgrade Brings

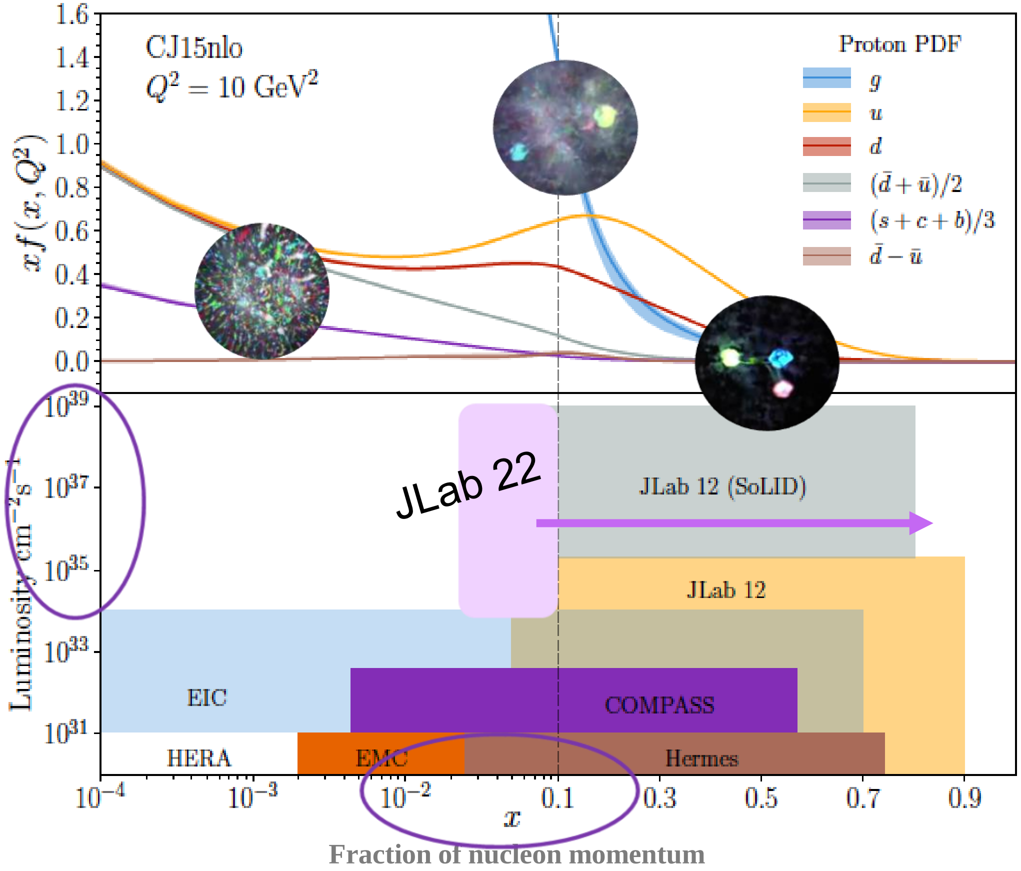


A NEW territory to explore → cross the critical threshold into the region where $c\bar{c}$ states can be produced in large quantities, and with additional light quark degrees of freedom

A BRIDGE between JLab @ 12 GeV and EIC → testing and validation of QCD from lower to higher energy, through multiple phenomena, and with high precision

A BETTER insight into our current program → enhancement of the phase space

JLab 12 to 22 GeV:
Probing Nucleon Valence Structure at High Luminosity



Physics with CEBAF at 12 GeV and Future Opportunities
Prog. Part. Nucl. Phys. 127 (2022) 103985

(See Deb's talk)

Partonic structure in the valence region _defines_ the hadron

- Baryon number, charge, flavor content, total spin, …

- Large x, low Q^2 evolves to low x, high Q^2 via pQCD, extract shape and strength ***from data***

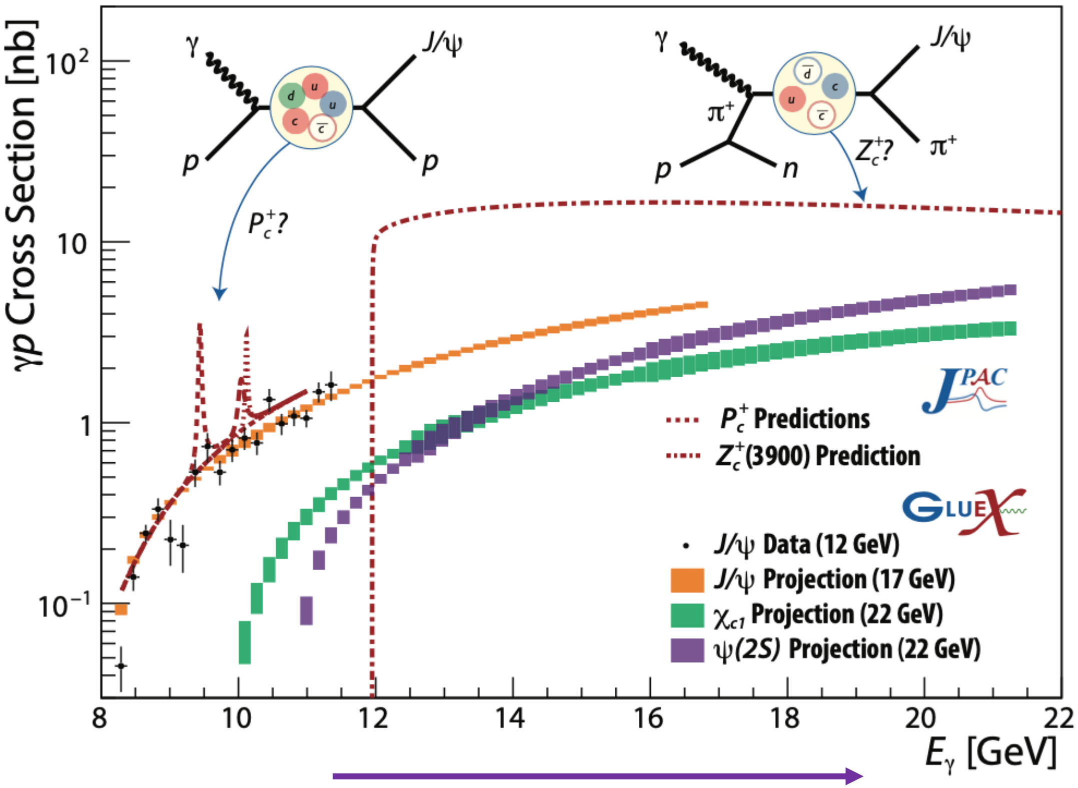
Precision measurements (2D,3D) in the valence regime requiring high luminosity are the purview of JLab, providing overlap with EIC into the low x region

Spectroscopy of Exotic States with charm

Photoproduction of hadrons with charm quarks: a new tool for discovery in QCD

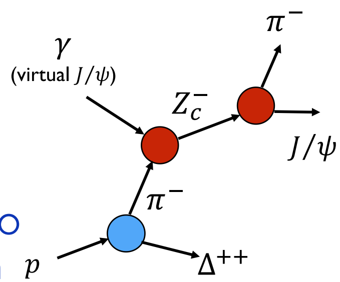
→ a unique method to probe the **gluonic structure of the proton**
→ potentially decisive information about the **nature of some 5-quark and 4-quark** candidates

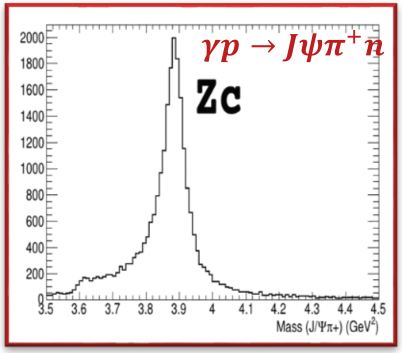
- Tetraquark candidates, **XYZ states**, observed in B decays, e^+e^- colliders but their internal structure is ***not yet understood***
- **Never direcly produced** using γ/lepton beams ➞ **Polarized photoproduction alternative mechanism to study such states**



Thresholds crossed and t range opens up at higher energy

Direct (photon) probe of the $Z_c \to J/\psi\pi$ coupling without rescattering effects provides unique complementary data to constrain interpretation of e^+e^- data.





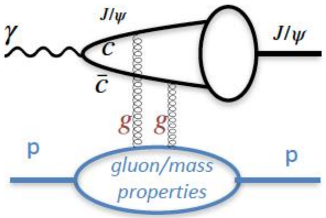
Initial simulations demonstrate the **capabilities of the existing detectors to measure these reactions**

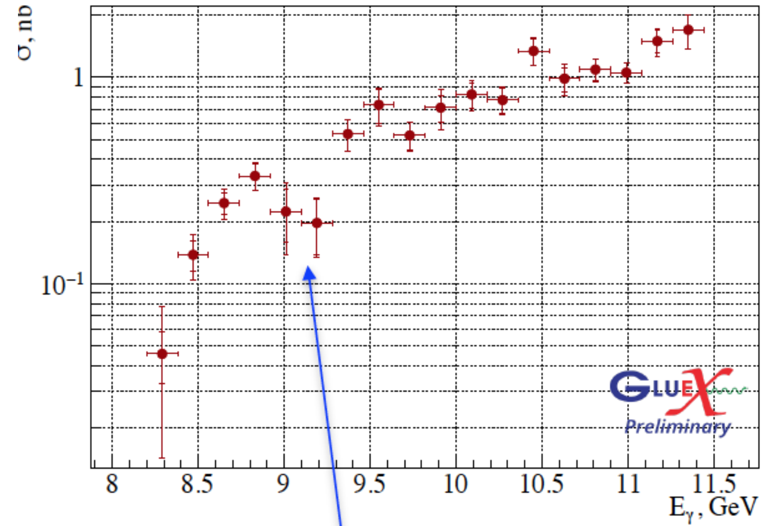
J/ψ photoproduction near threshold

Used to study important aspects of the gluon structure of the proton

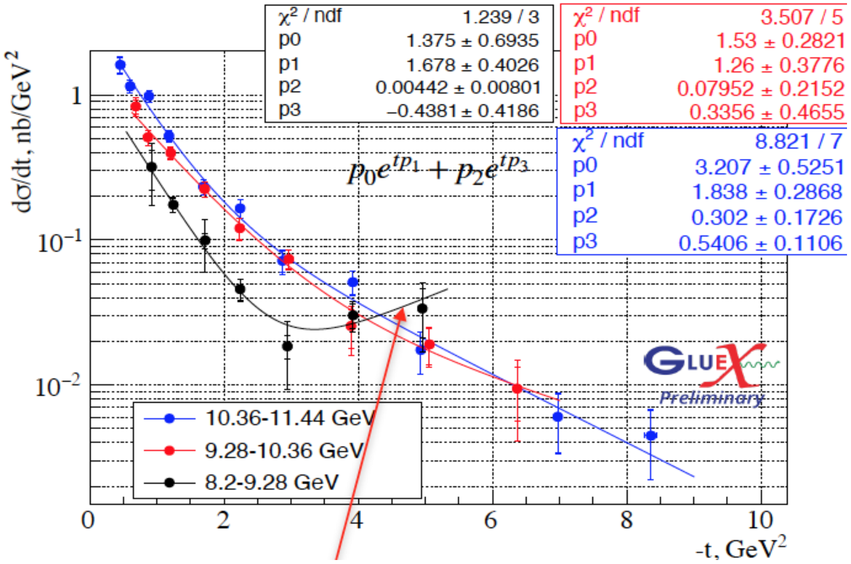
- **gluon GPD, gravitational FF**
- **mass radius of the proton,**
- **anomalous contribution to the proton mass.**

..based on some assumptions (mainly 2-g exchange)

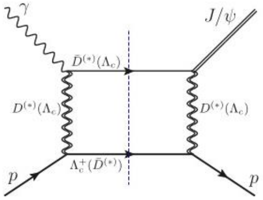




Possible structure at $\Lambda_c\overline{D}^{(*)}$ threshold σ(8.6-9.6) GeV



- **CANNOT be explained by t-channel (GLUON EXCHANGE) alone**
- Can have contribution from open-charm exchange to both σ and $d\sigma/dt$ at high t



Enhancement of dσ/dt at high t for the lowest energy slice

- **Can we interpret this as a possible evidence for a s-channel resonance (?) *Pc***

Phys. Rev. C 108 (2023) 2, 025201

Nucleon Structure in 3D

SIDIS cross section

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

$$\frac{d\sigma}{dx\,dy\,d\phi_S\,dz\,d\phi_h\,dP_{h\perp}^2}
= \frac{\alpha^2}{x\,y\,Q^2}\,\frac{y^2}{2\,(1-\varepsilon)}\Bigg\{F_{UU,T} + \varepsilon\,F_{UU,L} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi}$$

$$+\,\lambda_e\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\sin\phi_h\,F_{LU}^{\sin\phi_h} + S_L\left[\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_h\,F_{UL}^{\sin\phi_h} + \varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right]$$

$$+\,S_L\,\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]$$

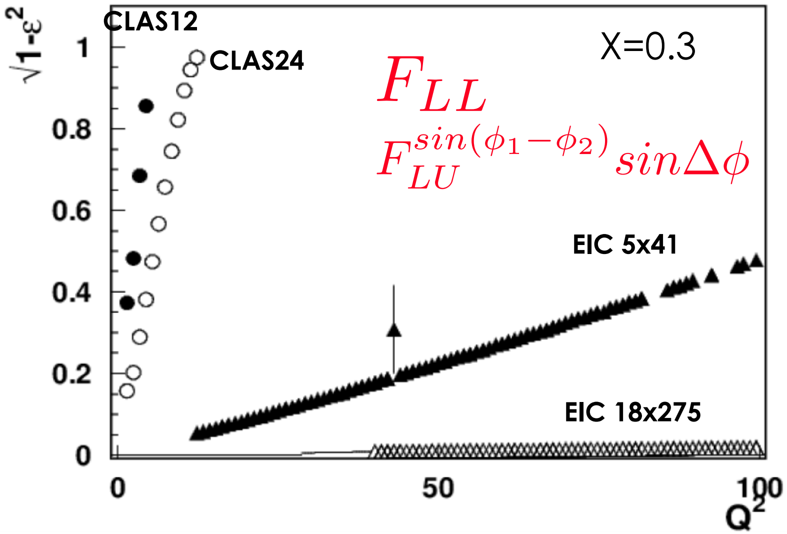
$$+\,S_T\Bigg[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon\,F_{UT,L}^{\sin(\phi_h-\phi_S)}\right) + \varepsilon\,\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}$$

$$+\,\varepsilon\,\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin\phi_S\,F_{UT}^{\sin\phi_S}$$

$$+\,\sqrt{2\,\varepsilon(1+\varepsilon)}\,\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Bigg] + S_T\lambda_e\Bigg[\sqrt{1-\varepsilon^2}\,\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}$$

$$+\,\sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos\phi_S\,F_{LT}^{\cos\phi_S} + \sqrt{2\,\varepsilon(1-\varepsilon)}\,\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Bigg]\Bigg\}$$

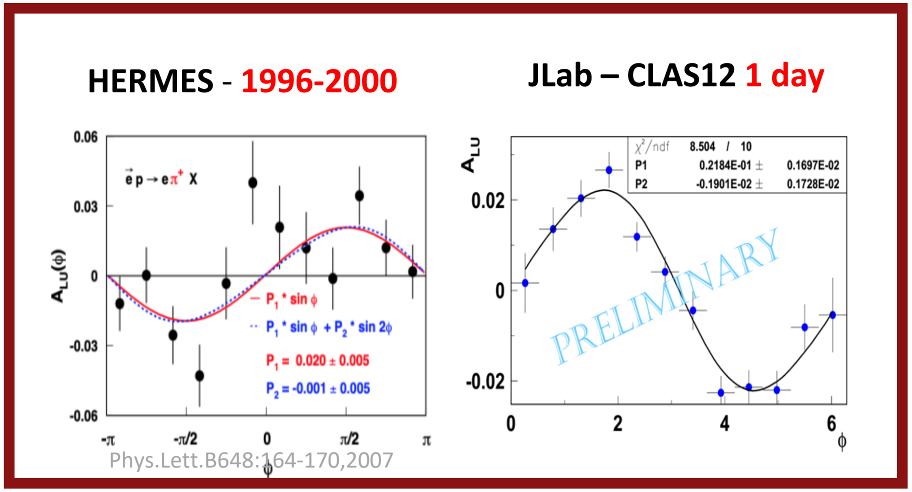
- Separation of SFs highly non-trivial!



A combined 11, 22 GeV and EIC SIDIS program

will increase our ability to measure a variety of SIDIS SFs across an enhanced multidimensional phase space – the only way to test and validate our understanding and interpretation of SIDIS reactions.

TMDs: High Statistics Crucial!

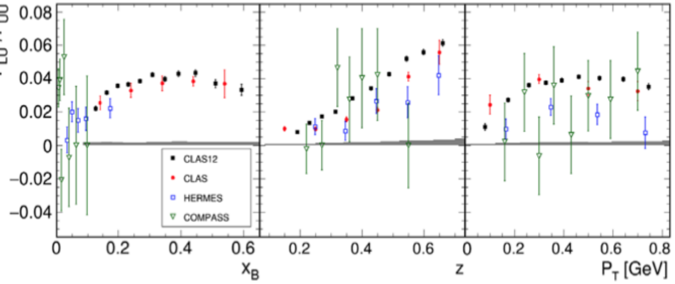

HERMES - 1996-2000

JLab – CLAS12 1 day

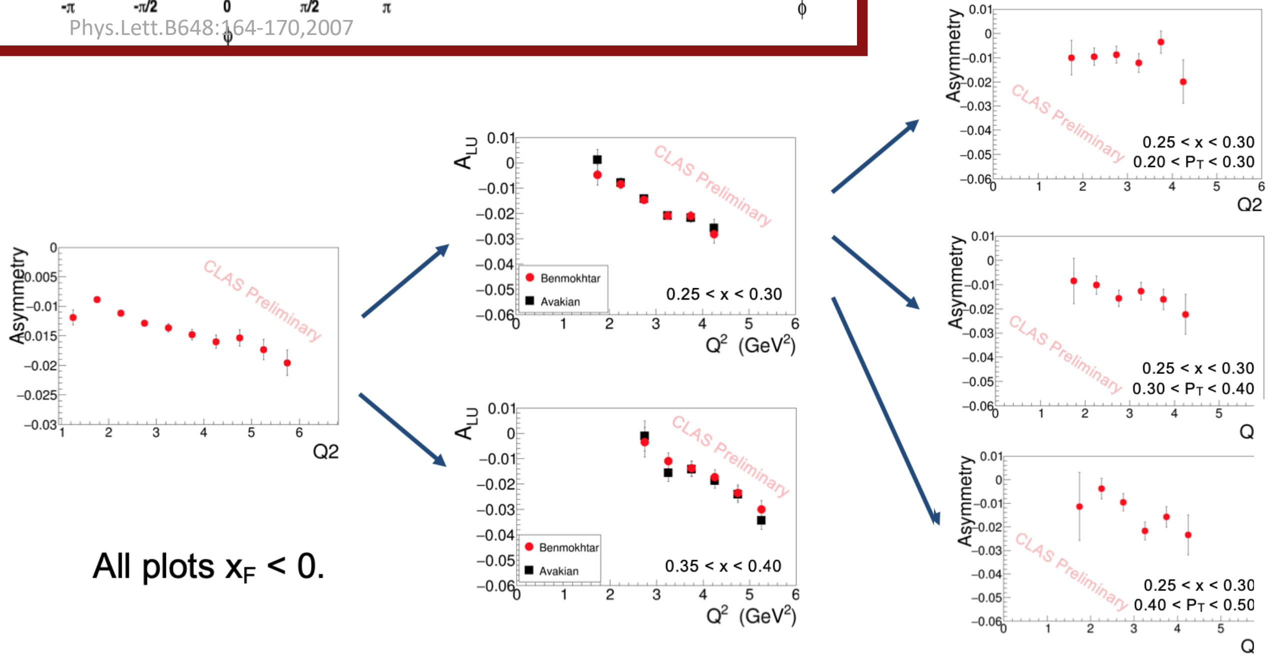
Phys.Lett.B648:164-170,2007

Phys. Rev. Lett. 128, 062005 (2022). (2022)

ep→e'π+ X



F_{LU} contains information on quark-gluon correlations



All plots $x_F < 0$.

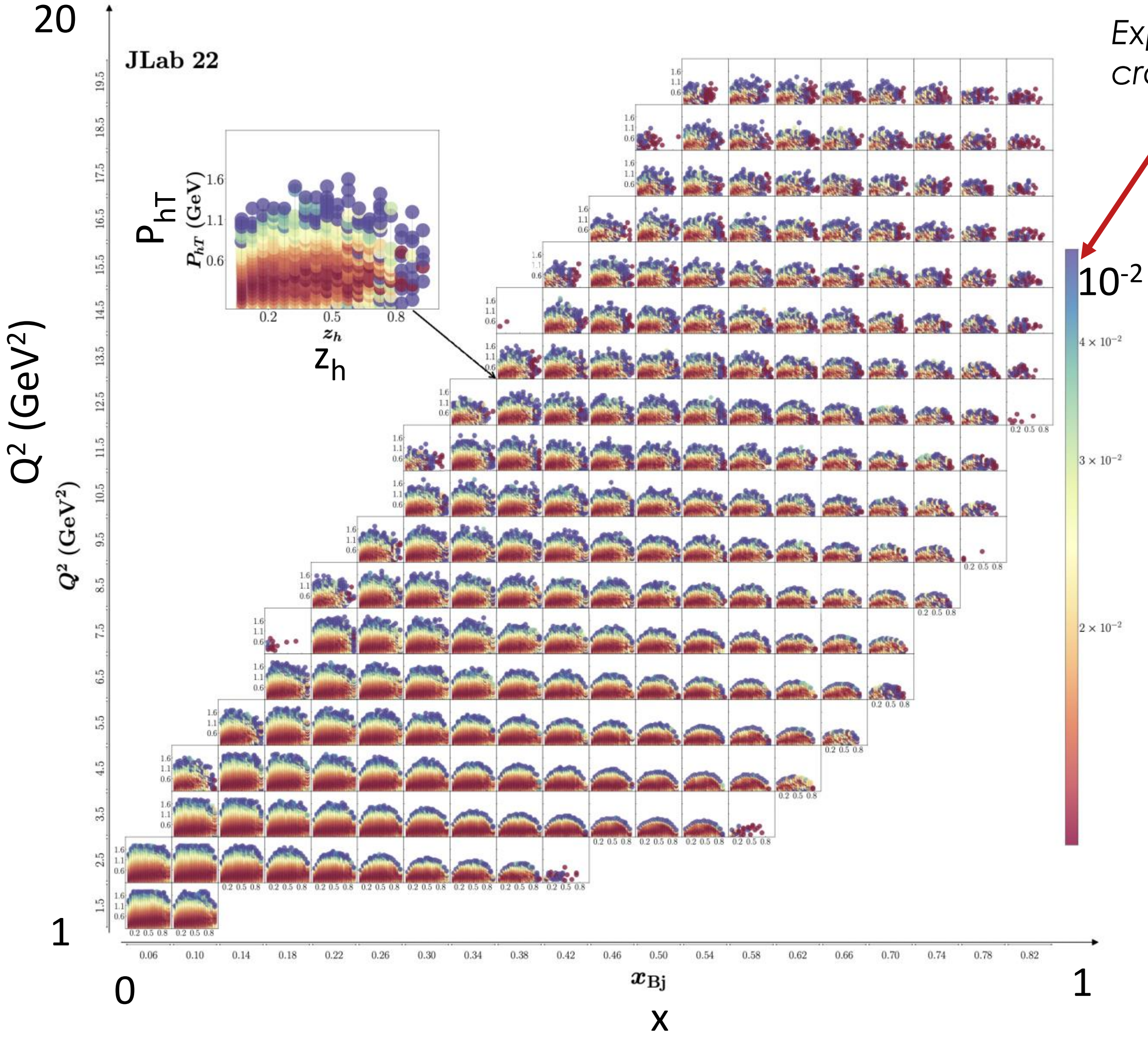
clas

ep → e'pX

Onward to 4D

- QCD predicts only the Q^2 dependence
- Studies of the Q^2 behavior requires high precision and multi-dimensional analysis

SIDIS Phase Space at 22 GeV



Expected uncertainties for SIDIS cross sections in 4D bins

Significantly increase the kinematic range to validate/test the theory/phenomenology

Multi-dimensional coverage of P_T gives access to fine binning of all observables

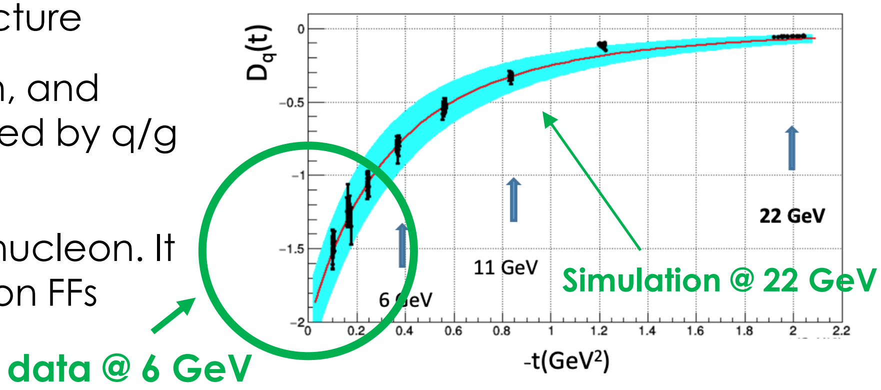
Projections using the existing CLAS12 simulation/reconstruction chain for 100 days of running with L= 10^{35} cm^{2}s^{-1}

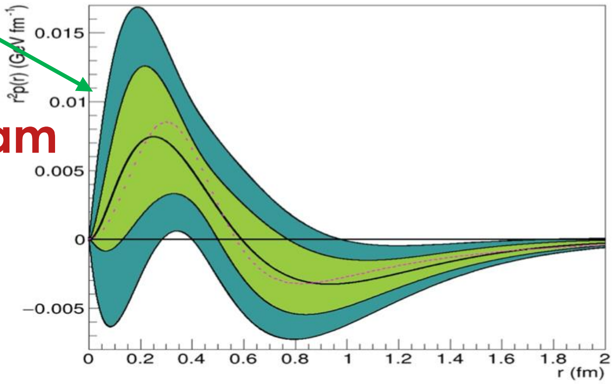
Spacial Structure & Mechanical Properties of the Proton

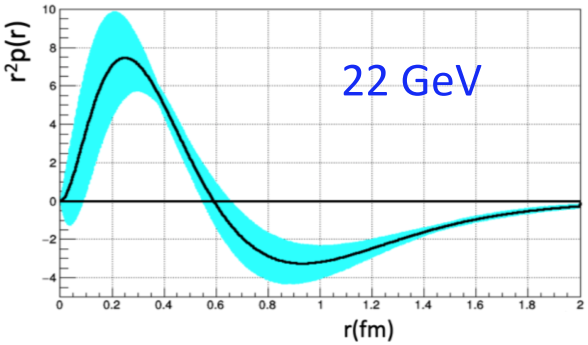
- Form Factors: source of information on hadron structure
- Gravitational FFs (GFFs) : describe how energy, spin, and various mechanical properties of hadrons are carried by q/g constituents.
- GFF D(t): describes the pressure distribution in the nucleon. It is accessible through measurements of the Compton FFs measured in **Deeply Virtual Compton Scattering**

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

➜ **The 22 GeV beam energy is crucial to this program**







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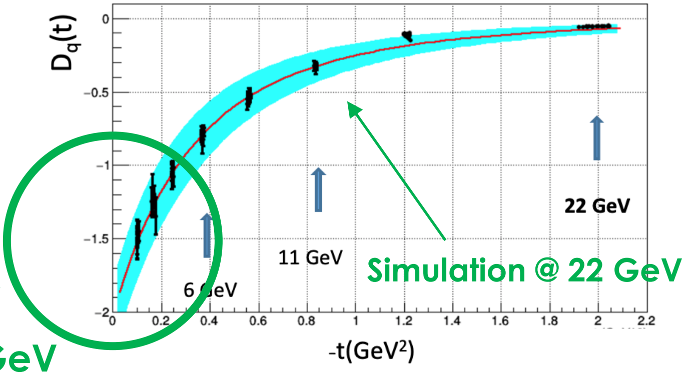
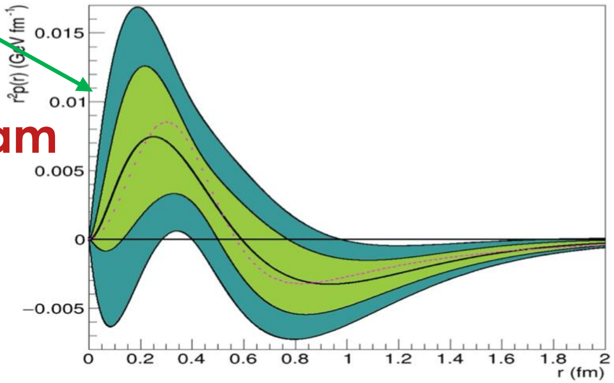


Simulation @ 22 GeV

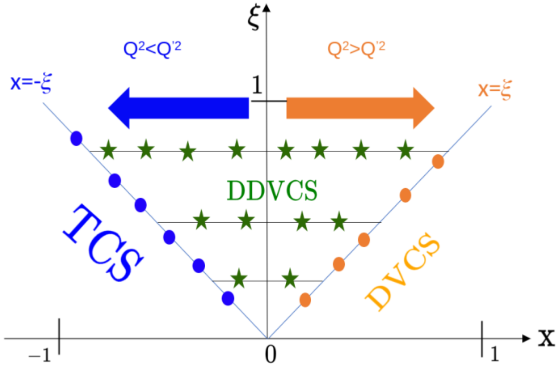
data @ 6 GeV

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

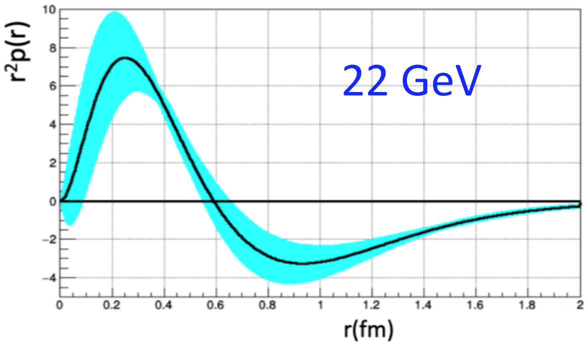


➜ **The 22 GeV beam energy is crucial to this program**

Double DVCS (DDVCS): e+p→e′ +(l+l−)+p, l=e or μ



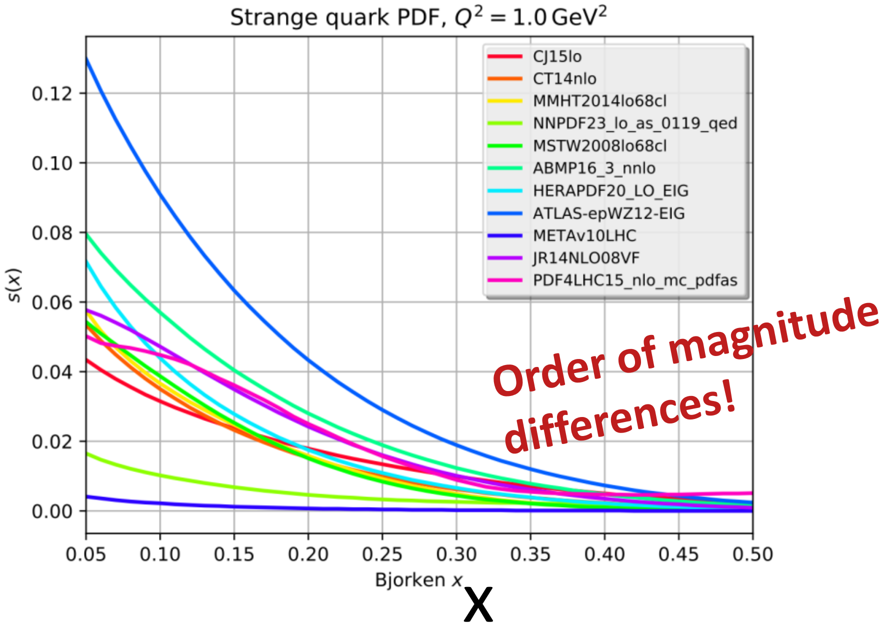
NEVER been measured (very small cross section).➜ **JLAB with high luminosity will be the only place to measure this reaction.**



Unambiguous Access to Strange Quarks

Current Situation

- **di-muon production in neutrino-nucleus scattering** – *nuclear corrections introduce significant uncertainty*
- **W and Z rapidity distributions**
- **W+c production**
- **Semi-inclusive K production:** *choice of fragmentation function negates inclusion in global fits*
- *JLab12 Q^2 too low for PDF analysis*



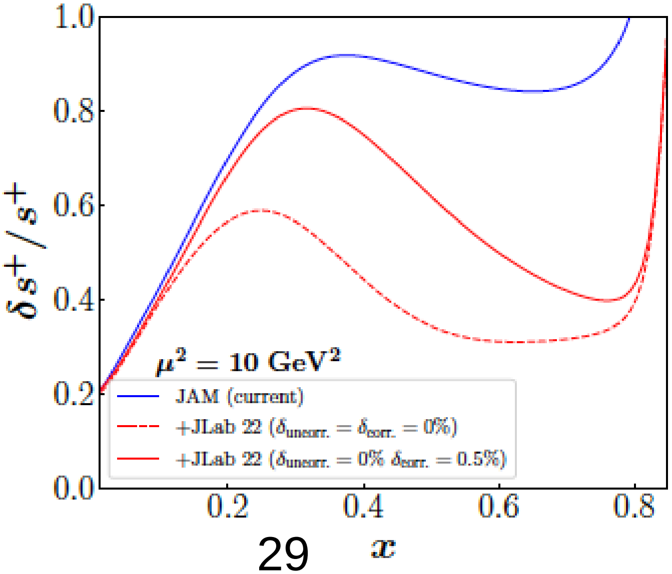
Order of magnitude differences!

Parity-violating DIS

- **Parity-violating DIS allows strange contribution to be isolated from combined with p,n data**

$$s + \bar{s} \approx 3(5F_2^{\gamma Z p} - F_2^{\gamma p} - F_2^{\gamma n}) \qquad \text{LO}$$

- **Valence regime provides <u>strength and shape</u>**
- **Substantial improvement with a reduction in the uncertainty that can reach *<u>more than a factor two at large-x</u>***

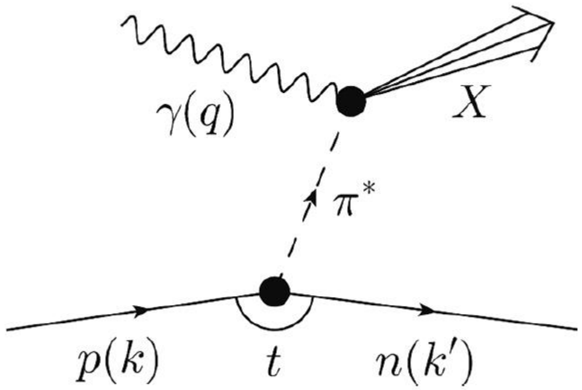


~100 days, 40 µA beam split between 40 cm D and H targets

Partonic Structure of Mesons

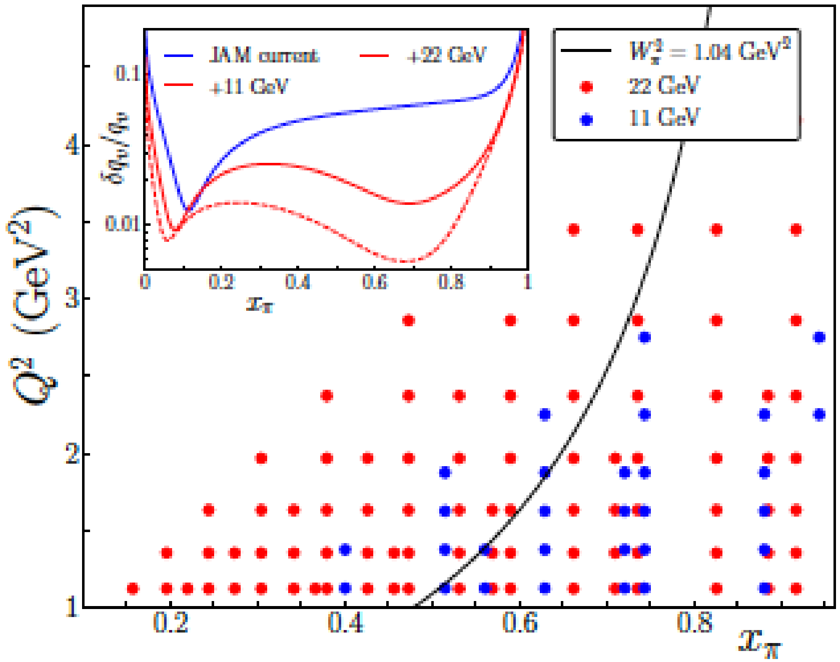
Meson structure

- Tagged deep inelastic scattering (TDIS) provides a mechanism to access the meson structure via the Sullivan process .
- A cut of W^2 π > 1.04 GeV^2 (to avoid contributions from resonances in a pion analysis,) eliminates most of the data at 11 GeV.

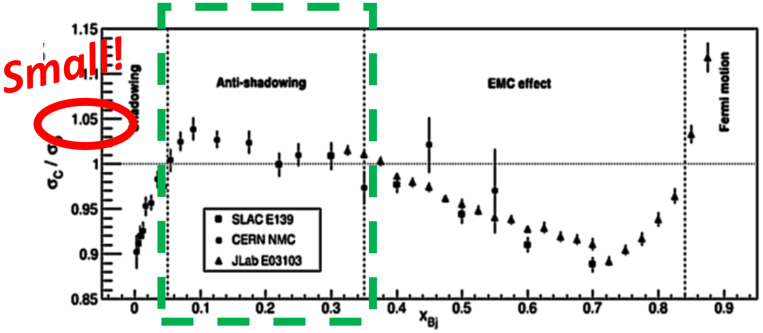


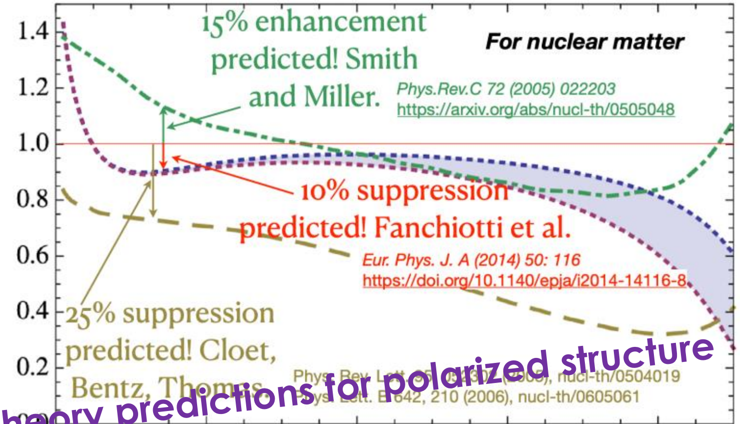
At 22 GeV:

- Available phase space significantly increased
  ➔ large improvement in the determination of the valence structure of the pion
  ➔ kin. coverage to smaller x_π region to probe the sea content of mesons
- Overlap the existing π induced DY data
  ➔ test the universality of PDFs in the mid to large x_π region
  ➔ pion PDF predicted to be broader than the proton PDF



Anti-shadowing: solving a multi-decade puzzle



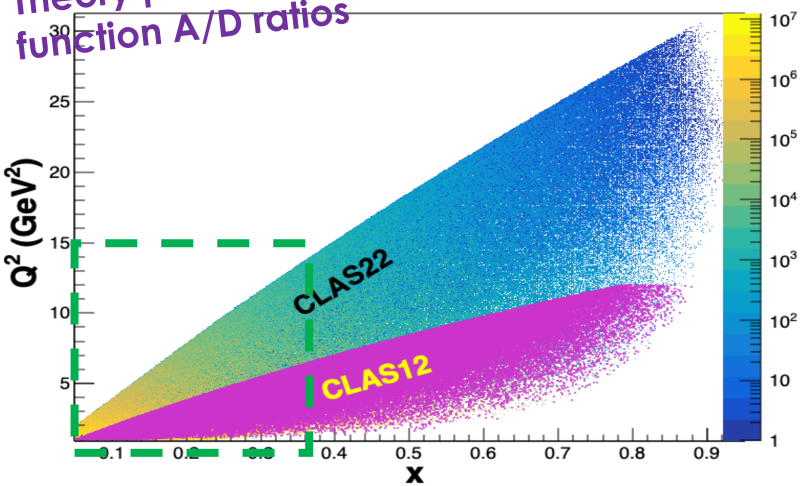


15% enhancement predicted! Smith and Miller. Phys.Rev.C 72 (2005) 022203 https://arxiv.org/abs/nucl-th/0505048

10% suppression predicted! Fanchiotti et al. Eur. Phys. J. A (2014) 50: 116 https://doi.org/10.1140/epja/i2014-14116-8

25% suppression predicted! Cloet, Bentz, Thomas. Phys. Rev. Lett. [illegible], nucl-th/0504019; Phys. Lett. B 642, 210 (2006), nucl-th/0605061

Theory predictions for polarized structure function A/D ratios



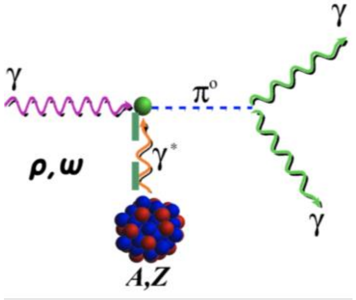
With a 22 GeV e- beam JLab can access the anti-shadowing region (x~0.1-0.3) at moderate Q^2

- Region extremely interesting, near-equally dominated by valence quarks, sea-quarks, and gluons → many many models!!
- Anti-Shadowing is the *least studied* nuclear structure function effect experimentally – ***small effect requiring precision and high luminosity***
  - flavor dependence essentially uncharted
  - spin dependence essentially uncharted (~50% differences in predictions)
  - no tagged measurements
  - no L/T separations

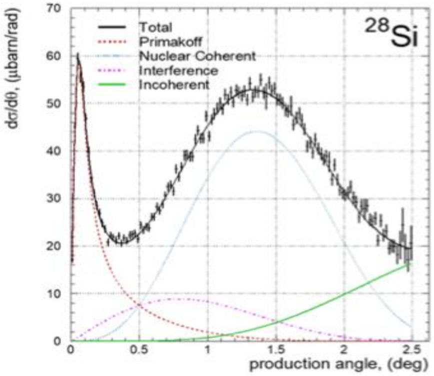
A rigorous testing ground between shadowing, EMC regimes – models and theory must describe **ALL**

Jefferson Lab

QCD Confinement and Fundamental Symmetries



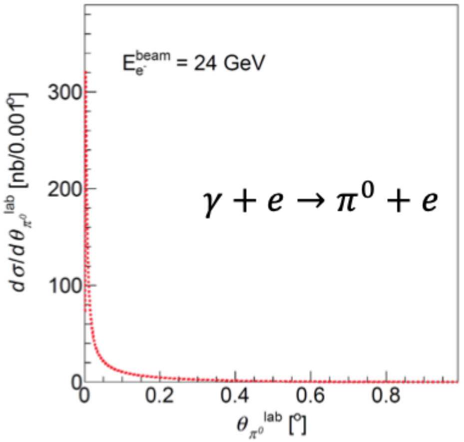
PrimEx-II: $\gamma + {}^{28}Si \rightarrow \pi^0 + {}^{28}Si$



Science 368, 506-509 (2020)

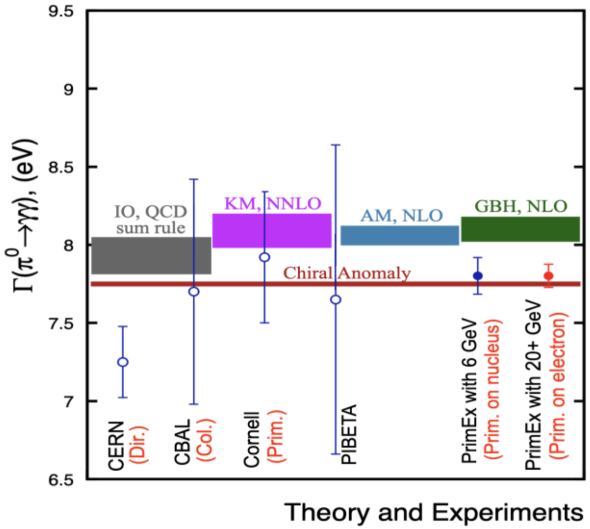
- **π^0 Primakoff production off an electron target**

Higher energy will allow for η'



The threshold for photo- or electroproduction of π^0 off an electron target is 18 GeV

$\Gamma(\pi^0 \rightarrow \gamma\gamma)$ can be predicted at ≈ 1% precision



Stringent test of low-energy QCD

- **Primakoff production off nuclear target**

A 22 GeV upgrade will greatly enhance the Primakoff experiments for more massive mesons off nuclear target

➡ **first Primakoff measurement of Γ(η' → γγ)** with ~3.5% precision to study the U(1)A anomaly coupling to the gluon field,

➡ **improve the measurement of Γ(η → γγ)** to a 2% accuracy to determine the light-quark mass ratio

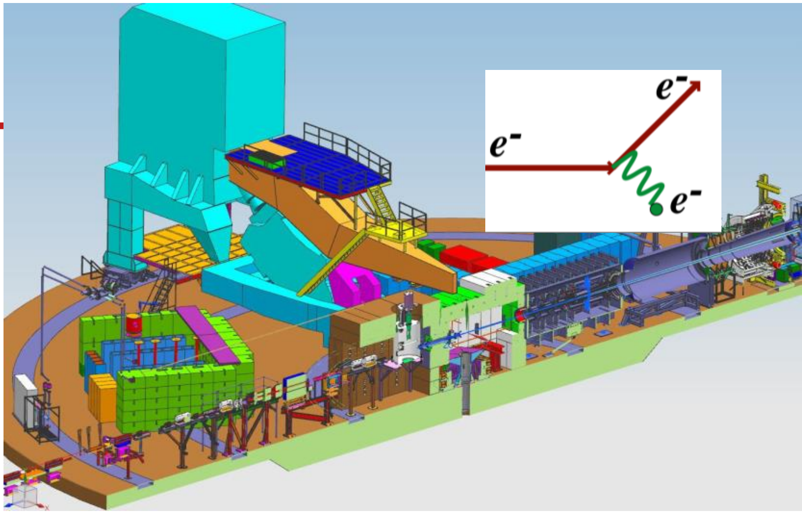
MOLLER Scattering at Jefferson Lab – installation in a year!

$$\delta(\sin^2\theta_W) = \pm\, 0.00023\ (\text{stat.})\ \pm\, 0.00012\ (\text{syst.})$$

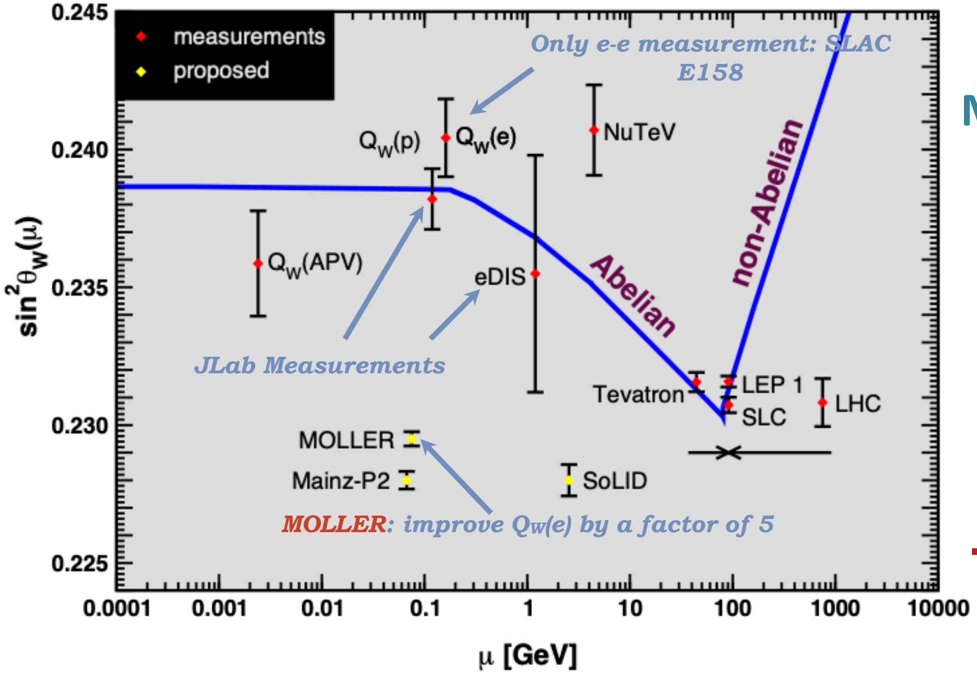
$$\Rightarrow \quad \sim 0.1\%$$

- **Unique (purely leptonic) new physics reach**
- **Special opportunity with JLab high luminosity**

Search for new flavor diagonal neutral currents



Look for tiny but measurable deviations from precisely calculable predictions for SM processes

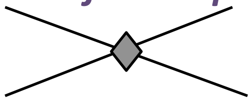


Only e-e measurement: SLAC E158

JLab Measurements

MOLLER: improve Qw(e) by a factor of 5

A_{new}



$$\frac{1}{\Lambda^2}\mathcal{L}_6$$

MOLLER Reach $\Lambda^{ee}_{RR-LL} \sim 38\ \text{TeV}$

- **Unique discovery space: beyond that of a 500 GeV lepton collider**
- **Precursor to HiLumi LHC $\sin^2\vartheta_W$ – complementary precision electroweak physics**
- **Impacts the current discrepancy on the W mass (Fermilab vs LHC)**

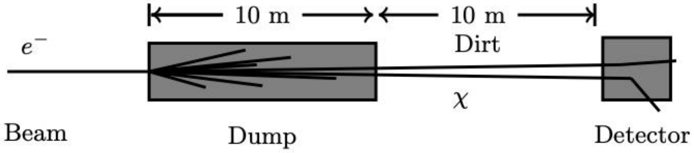
Upgrade Outlook

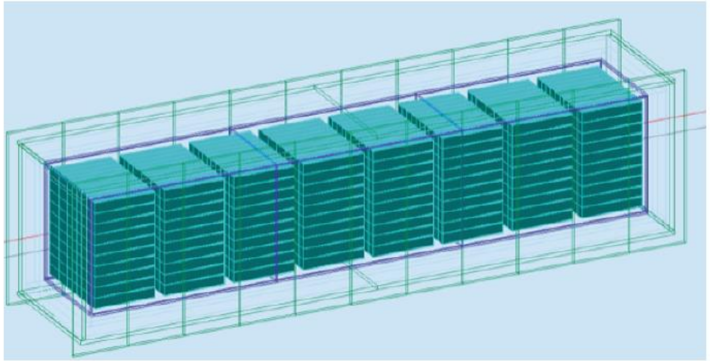
- Understanding structure and dynamics in non-pQCD and the strong interaction is a complex problem **requiring multiple observables using different approaches and measurements**
- The CEBAF uniqueness to run electron and positron scattering experiments at the luminosity frontier provides a powerful tool
- Proposals are being accepted by the Program Advisory Committee for positron science (6 approved and more to come!)
- A very strong science case for an upgrade is emerging – come join the fun!
  - 22 GeV workshop at LNF-INFN in Frascati December 9-13, 2024 https://www.jlab.org/conference/dec24luminosity22gev

Polarized gluon distribution, standard model tests, longitudinal/transverse separations, hadron formation in nuclei, meson form factors, probing the light quark sea,……. and more!

BDX and Secondary Beam Capability Behind Hall A

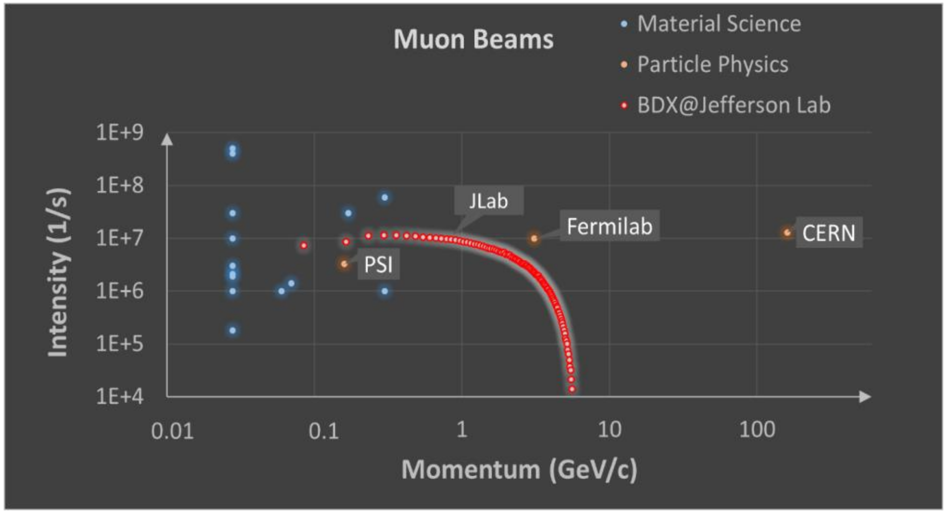
The Beam Dump Experiment (BDX) at Jefferson Laboratory (JLab) is an electron-beam thick- target experiment to search for Light Dark Matter (LDM) particles in the MeV-GeV mass range





Muons and neutrinos that penetrate the shielding form **high-intensity secondary beams.**

(M. Battaglieri et al., *Secondary Beams at High-Intensity Electron Accelerator Facilities*, Instruments 8, 1 (2024), https://doi.org/10.3390/instruments8010001.)



Is this a new JLab (HEP) Physics program? Look for 'BDX and Beyond' workshop being planned at JLab for this Fall/Winter!

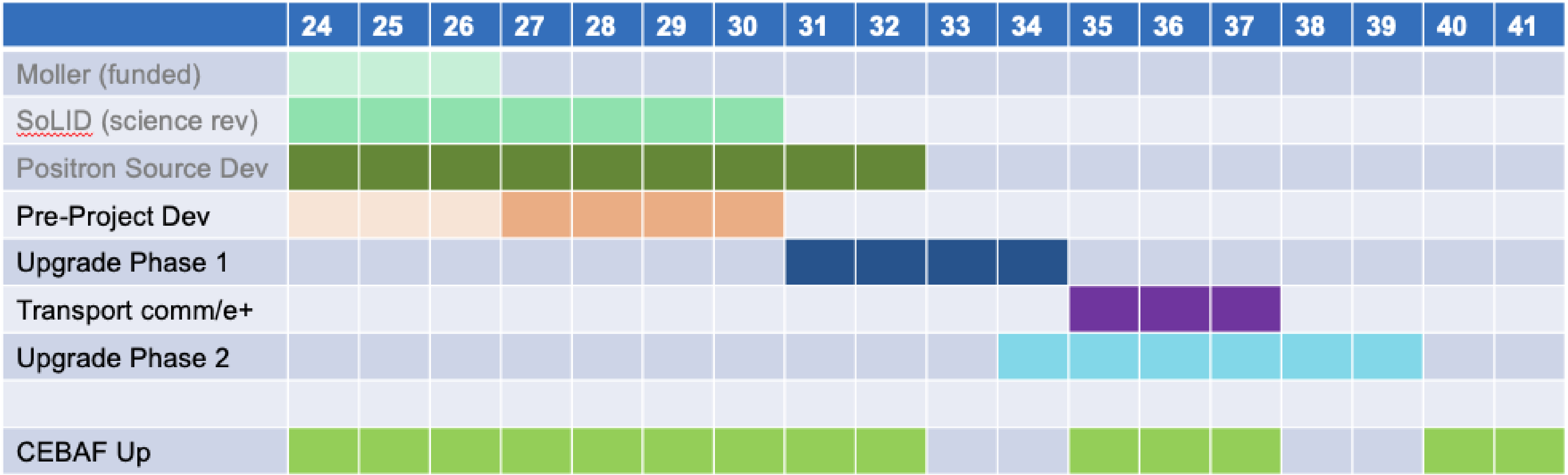
Thank you!

Thank you for listening, and thanks also to the scientific community working on developing this exciting science!

More info!

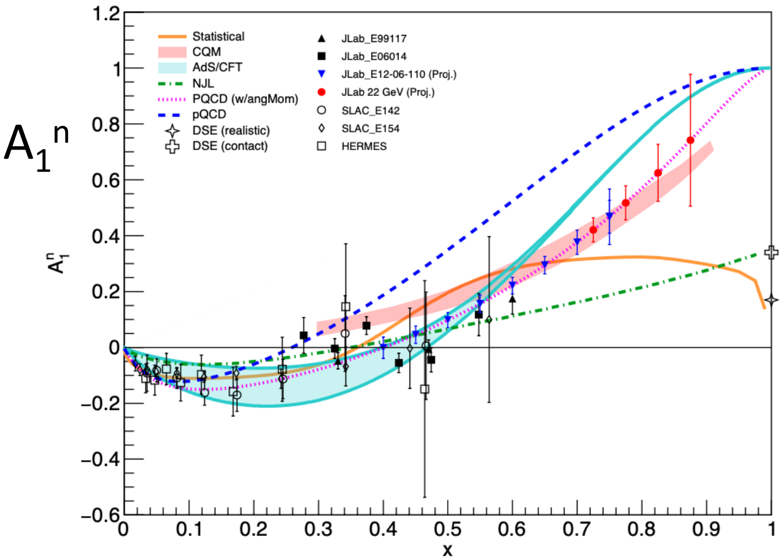
Notional CEBAF & upgrade schedule (FY24 – FY42)

- Accelerator and engineering team have worked up an early schedule and cost estimate – in revision
  - Schedule assumptions based on a notional timing of when funds might be available (near EIC ramp down based on EIC V3 profile)
  - For completeness, Moller and SoLID (part of 12 GeV program) are shown; positron source development also shown



	24	25	26	27	28	29	30	31	32	33	34	35	36	37	38	39	40	41
Moller (funded)	🟩	🟩	🟩															
SoLID (science rev)	🟩	🟩	🟩	🟩	🟩	🟩	🟩											
Positron Source Dev	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩									
Pre-Project Dev	🟧	🟧	🟧	🟧	🟧	🟧	🟧											
Upgrade Phase 1								🟦	🟦	🟦	🟦							
Transport comm/e+												🟪	🟪	🟪				
Upgrade Phase 2											🟦	🟦	🟦	🟦	🟦	🟦		
CEBAF Up	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩	🟩			🟩	🟩	🟩			🟩	🟩

Polarized Structure Functions and α_s

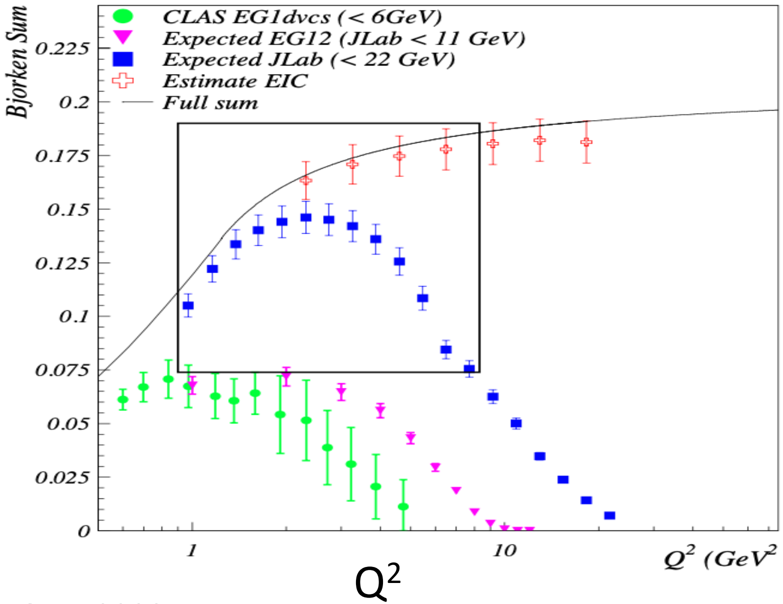


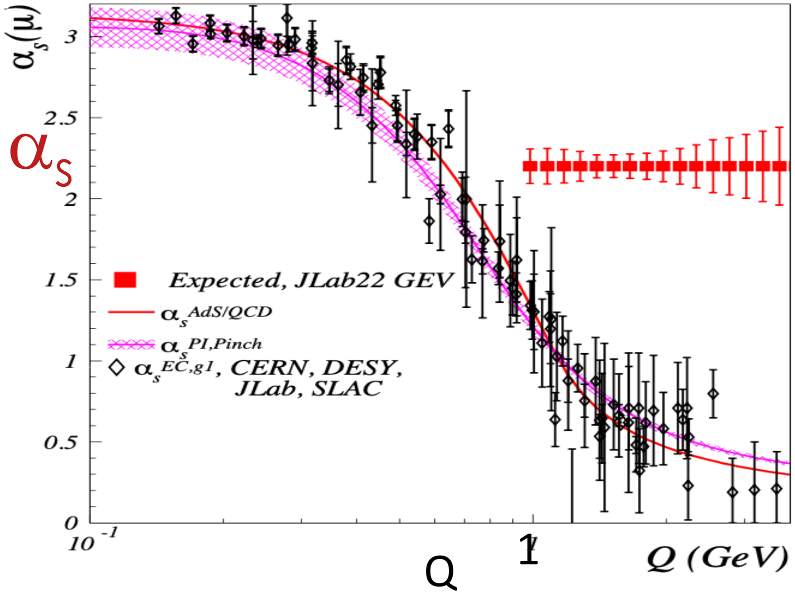
Extend the precision and kinematic reach of polarized structure functions

Bjorken Sum Rule $\Gamma_1^{p-n}(Q^2) \equiv \int \left(g_1^p(x,Q^2) - g_1^n(x,Q^2)\right)\, dx.$

The strong coupling constant is a key parameter of the Standard Model

Its current uncertainty is the least precise among all fundamental couplings

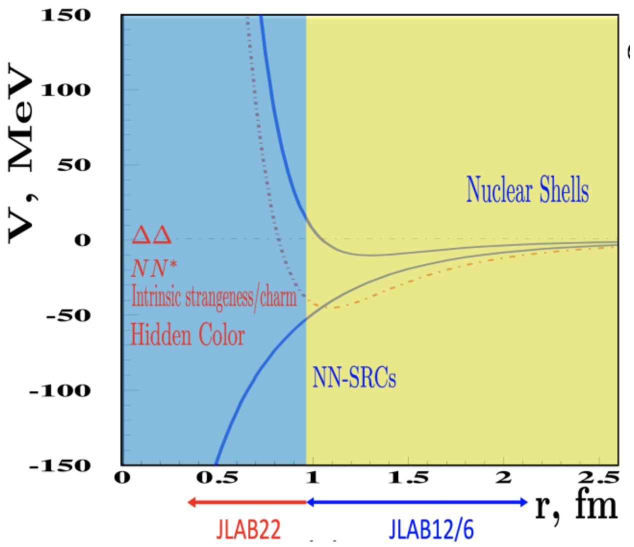




Nuclear Dynamics at Extreme Conditions

The dynamics of the nuclear repulsive core is still poorly understood

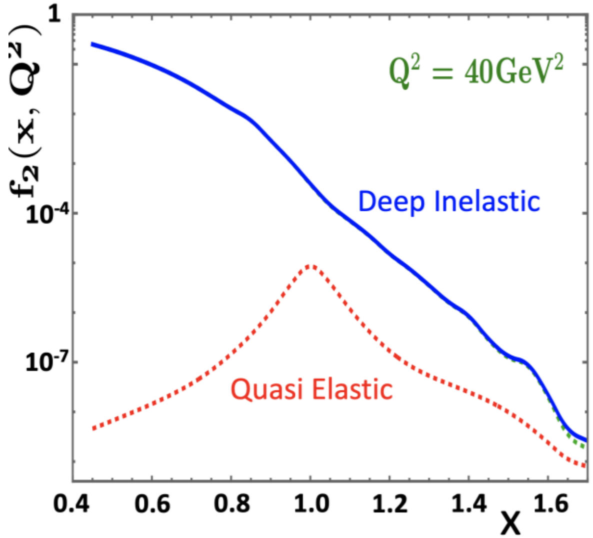
A 22 GeV upgrade will provide reach to the nuclear forces dominated by nuclear repulsion



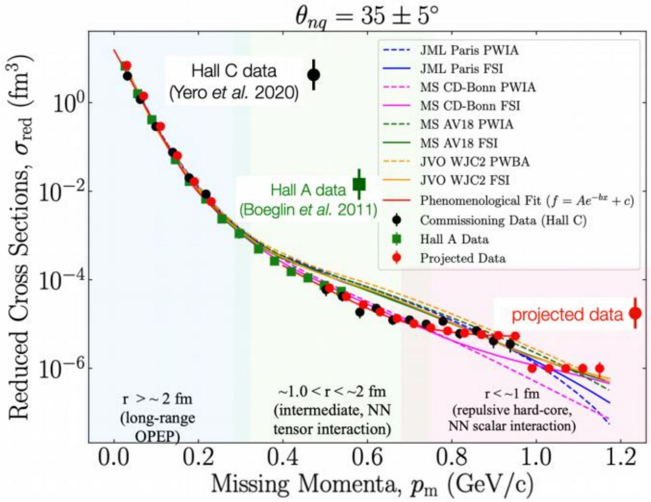
Superfast Quarks

The high Q^2 reach will allow

- the suppression of quasi-elastic contributions,
- the first-ever study of nuclear DIS structure function at Bjorken x > 1.2 (r~ 0.5 fm,)



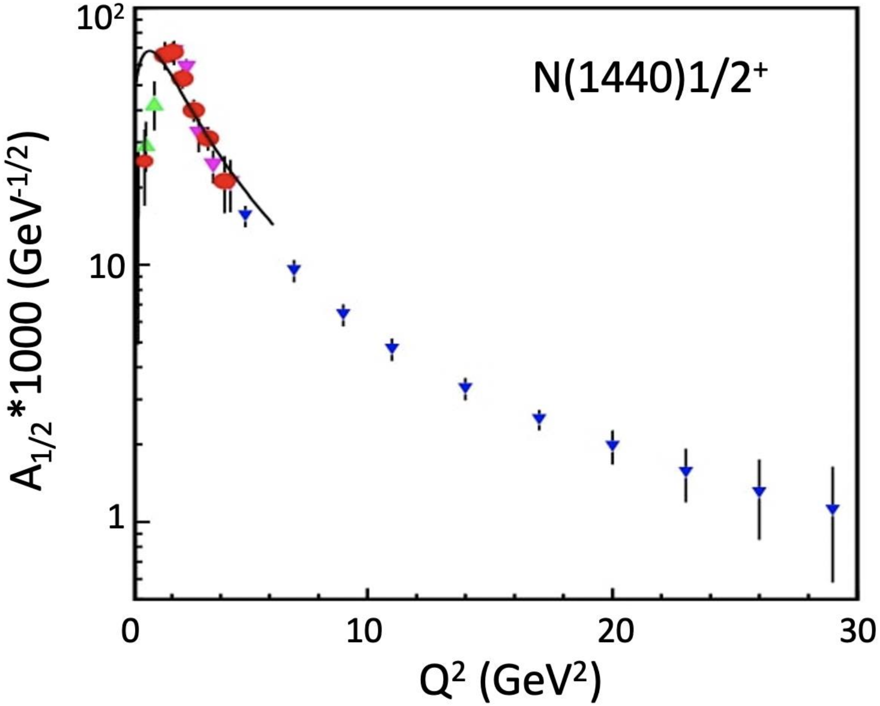
Exploring Deuteron at Very Large Internal Momenta (> 800 MeV/c – non-nucleonic & hidden color components)



- non-relativistic theory reproduces data up to pm ~ 0.7 GeV/c
- no model reproduces data (non-nucleonic degrees of freedom?, quarks?) pm > 0.7 GeV/c

Jefferson Lab

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

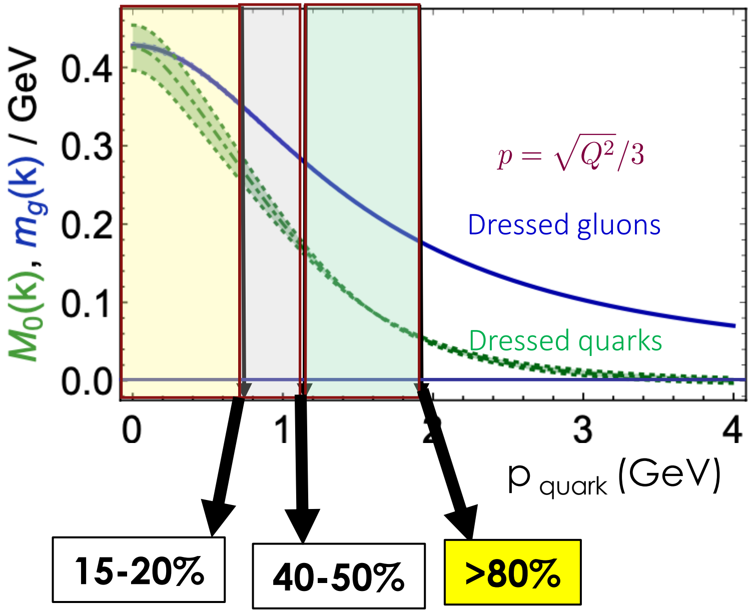


- Q^2 evolution of the γvpN* electrocouplings could offer an insight into hadron mass generation and the emergence of the N* structure from QCD

- **Simulations indicate JLab22 is the only foreseeable facility to extend these measurements up to 30 GeV^2**

Continuum Schwinger Method

QCD equations of motion for q/g fields reveal existence of dressed q/g with momentum-dependent masses.



6 GeV **12 GeV** **22 GeV**

Q² range(<35 GeV²) where the dominant portion of hadron mass is expected to be generated