Jefferson Lab in the EIC Era

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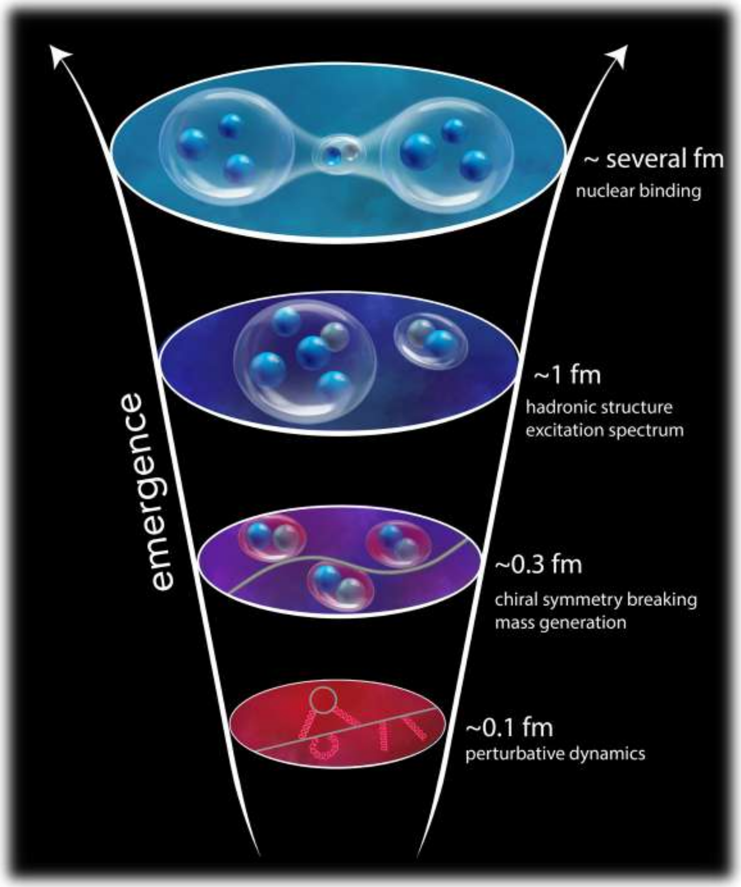
10th International Conference on Physics Opportunities at an ElecTron-Ion-Collider (POETIC2023)

ICTP-SAIFR São Paulo (Brazil), May 2-6, 2023

Introduction: An Asymmetric Path



"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)].

Non-pQCD: Lattice Calculations

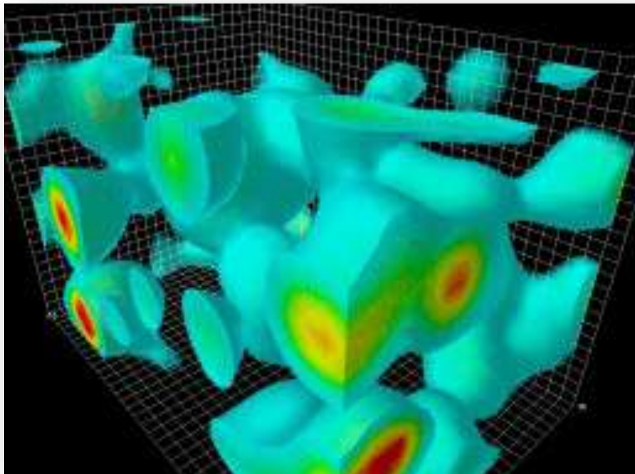
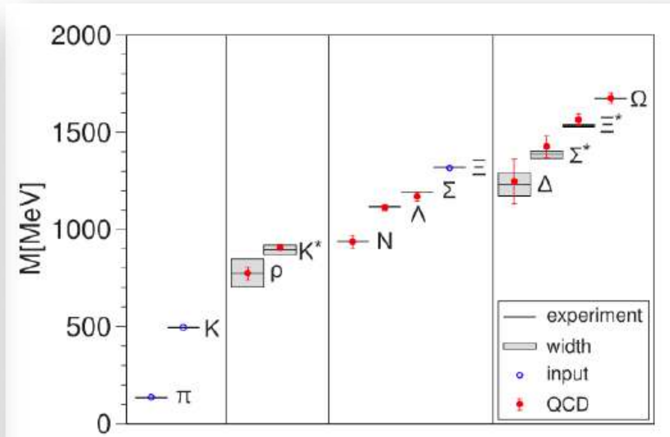


Figure from the CSSM Lattice Collaboration



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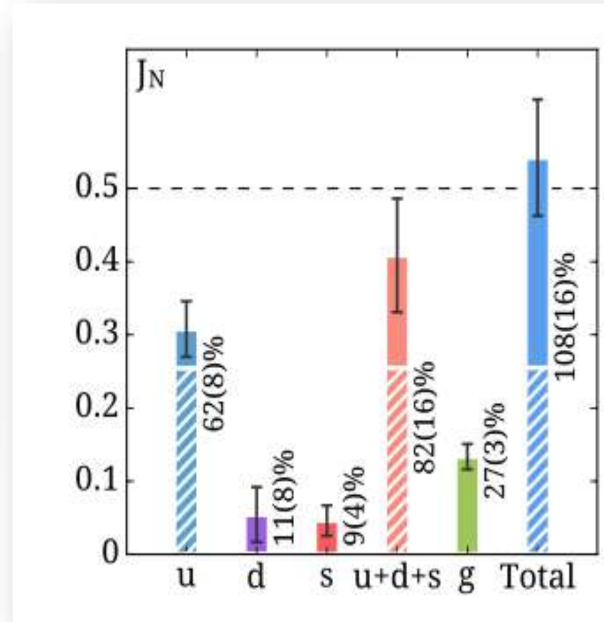


Phys.Rev.Lett. 119 (2017) 14, 142002

Remarkable results by LQCD!

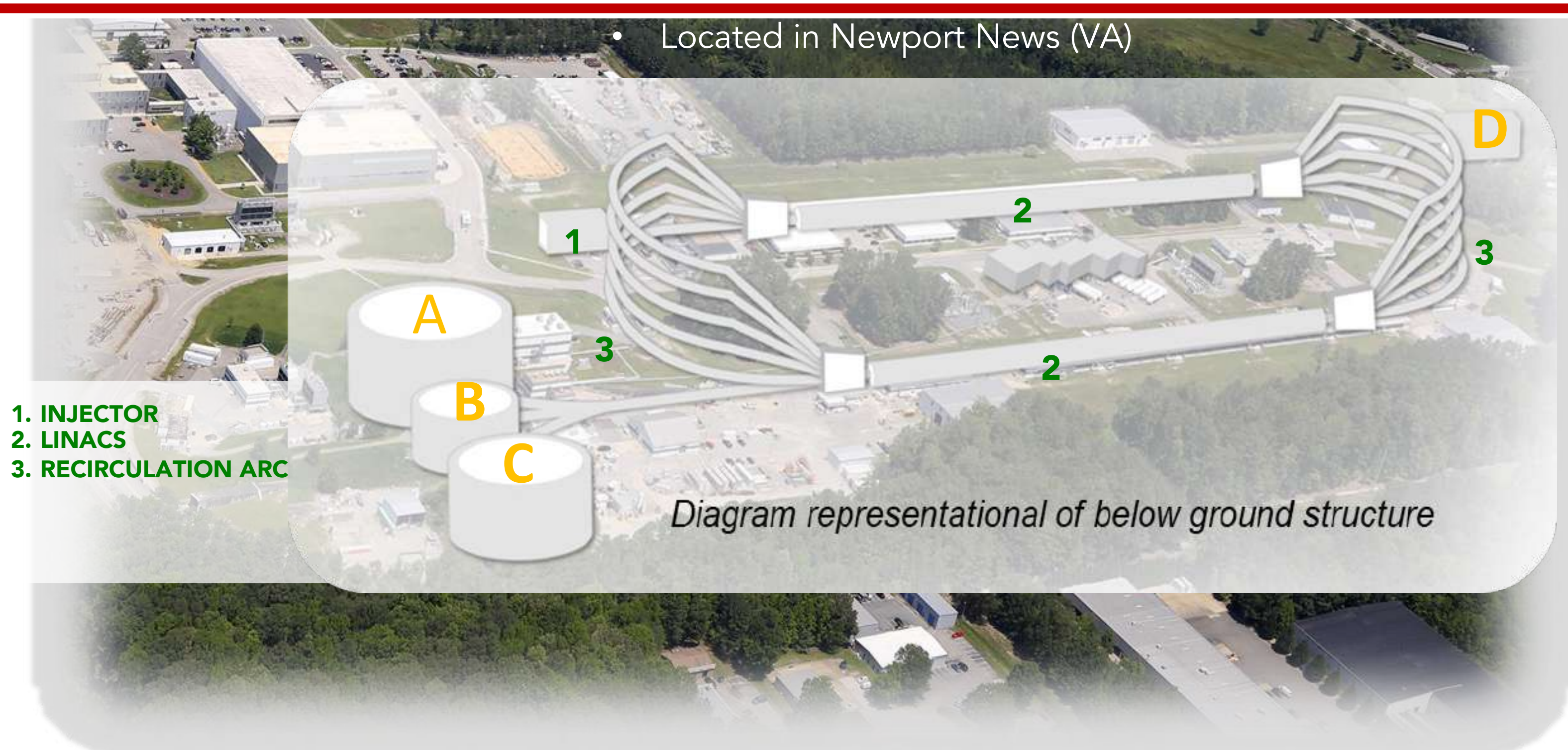
However:

- **Currently there is no formulation of lattice QCD that allows us to simulate the real-time dynamics of a quark-gluon system**
- **It is computationally intensive**

Jefferson Lab and CEBAF

- Explore the fundamental nature of confined states of quarks and gluons → **Non-perturbative regime of QCD**

Jefferson Lab and CEBAF



- Upgrade completed in September 2017
  - **CW electron beam, E_{max} = 12 GeV, Pol_{max} ~ 90%**
- High intensity polarized photon beam at 9 GeV (Hall D)
- Range of beam energies & currents delivered to multiple exp. halls simultaneously

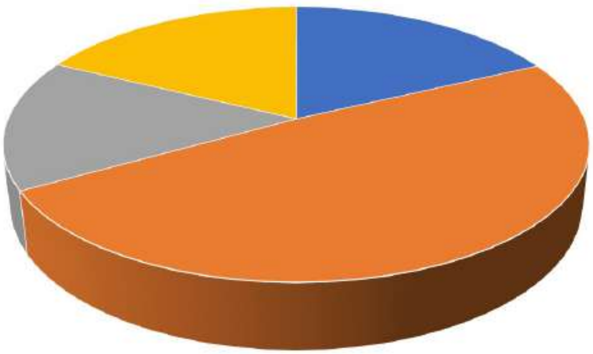
Fixed target experiments at the "luminosity frontier"
(up to 10^{39} e-N /cm^2/ s)

Jefferson Lab and CEBAF

- Explore the fundamental nature of confined states of quarks and gluons → **Non-perturbative regime of QCD**
- Discover evidence for physics beyond the standard model

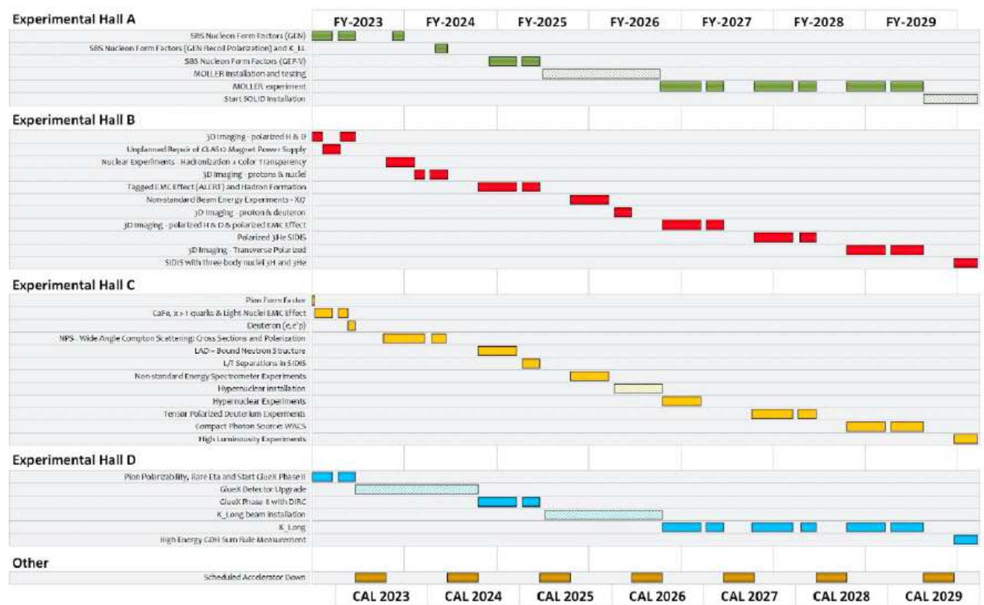
Jefferson Lab Physics Program

- Probe the emergence of hadron structure & the dynamics **non-pQCD**



- **1D-3D Nucleon Structure**
- **Hadrons & Cold Nuclear Matter**
- **Hadron Spectra**
- **Test of SM & Fundamental Sym.**

- **Complex problem which demands different approaches and measurements to access multiple observables**



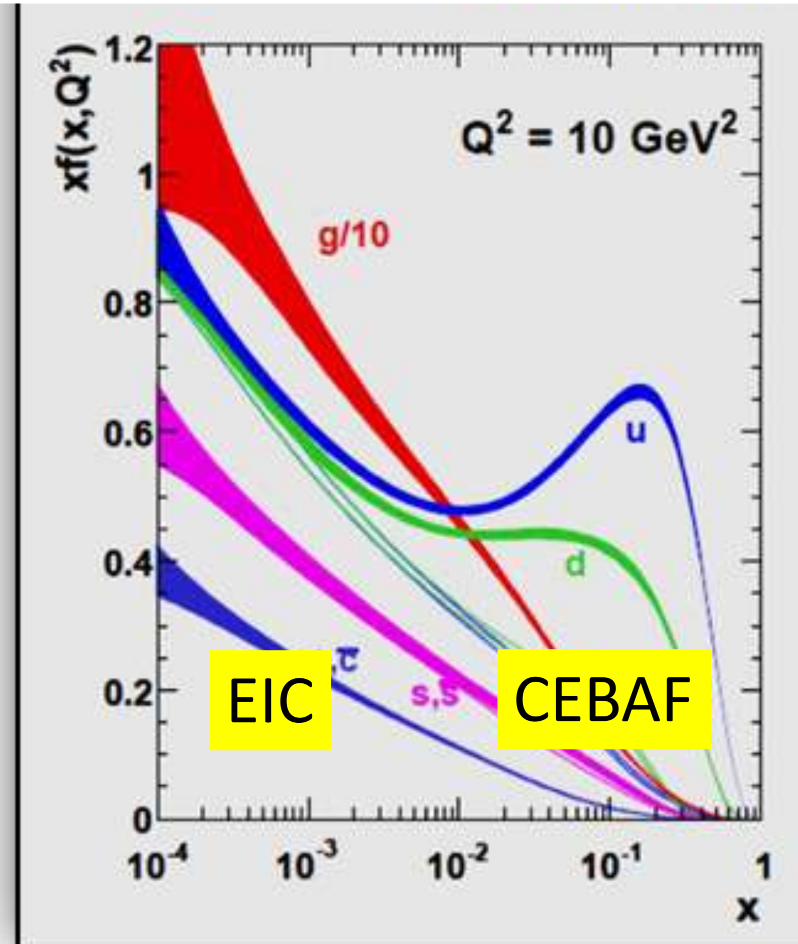
- **86% complete in FY29 without SoLID, 70% complete with SoLID** (assuming optimal running operation)

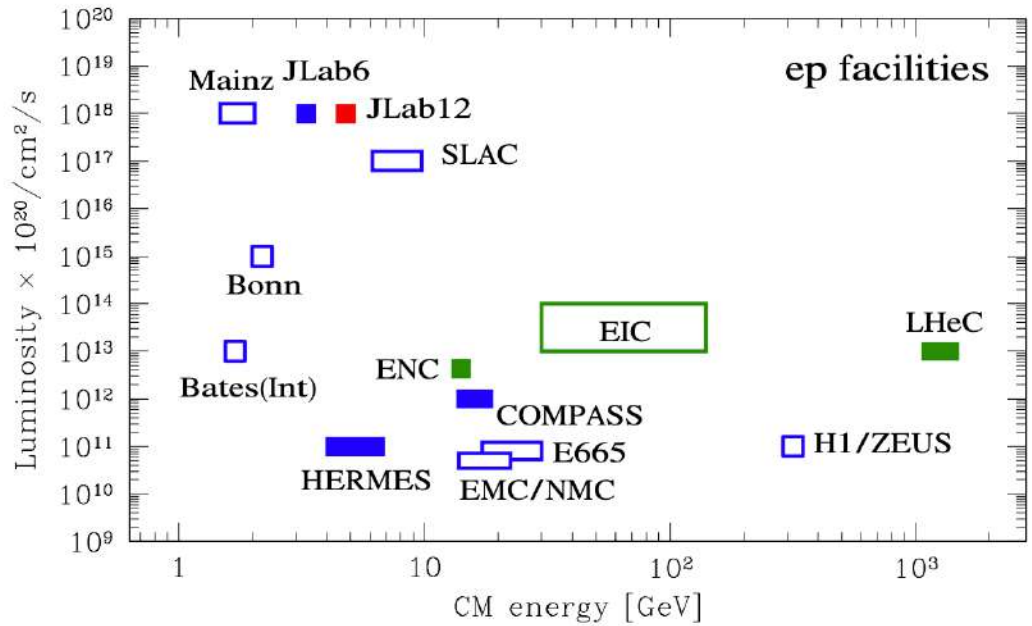
...not including new proposals

- **~90 approved experiment, ~1/3 executed**

Jefferson Lab

EIC-CEBAF: Two Complementary Facilities



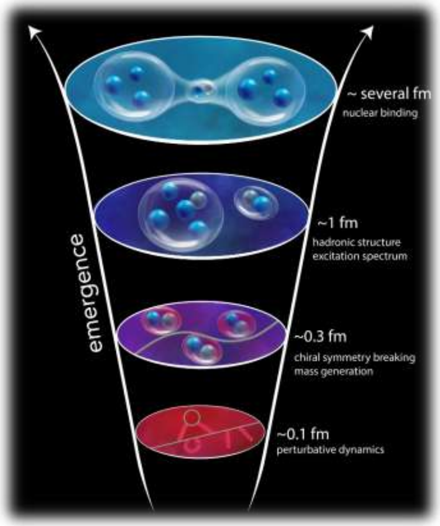


Moving a step farther:

- Double CEBAF energy
- Positron beam

Jefferson Lab

Why CEBAF @ 22 GeV?



- A medium energy electron accelerator at the luminosity frontier is
  - critical to understanding the rich variety of **non-perturbative** effects manifested in hadronic structure
  - complementary to high energy facilities that illuminate the perturbative dynamics and discover the fundamental role of gluons in nucleons and nuclei

What a 22 GeV upgrade would bring:

- **some important thresholds would be crossed → charm, nuclear distances, in fundamental symmetries, etc..**
- **An energy window which sits between JLab @ 12 GeV and EIC**
  → test and validation of our theory from lower to higher energy and with high precision
- **A rich physics program is under development, leveraging on existing or already-planned infrastructure and on the uniqueness of CEBAF HIGH LUMINOSITY**

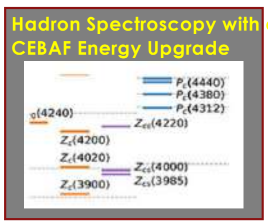
Science Case for an Energy Upgrade

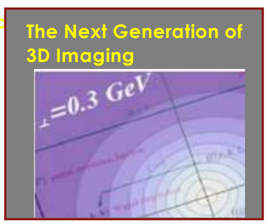
International Workshops

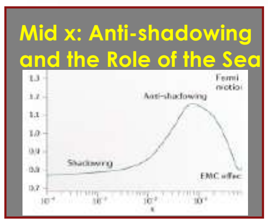
March-Sep 2022

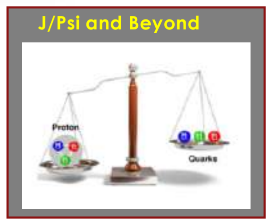
Summer Series @ Jlab

Jun-Aug 2022









Science at the Luminosity Frontier: JLab at 22 Gev

January 23-25, 2023

- Spectra and structure of heavy and light hadrons asprobes of QCD
- Sea and valence partonic structure and spin
- Form Factors, Generalized Parton Distributions and Energy-Momentum Tensor
- Fragmentation, Transverse Momentum and Parton correlations
- Hadron-quark transition and nuclear dynamics at extreme conditions
- Low-energy tests of the Standard Model and Fundamental Symmetries

https://www.jlab.org/conference/luminosity22gev

- **Physics case summarized in a short document sent to the LRP writing committee**
- **Longer document is in preparation**
  - **It will be circulated within the community**
  - **Goal is to post it on (ArXiv) by the end of May**

APS April Meeting 2023
Apr 15 & 16, 2023

B15/K16 Mini-Symposium:
Opportunities with Jlab Upgrades in Energy, Luminosity and a Positron Beam

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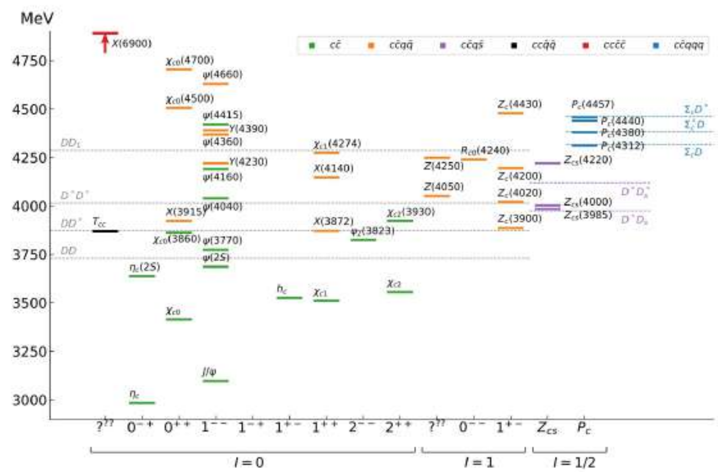
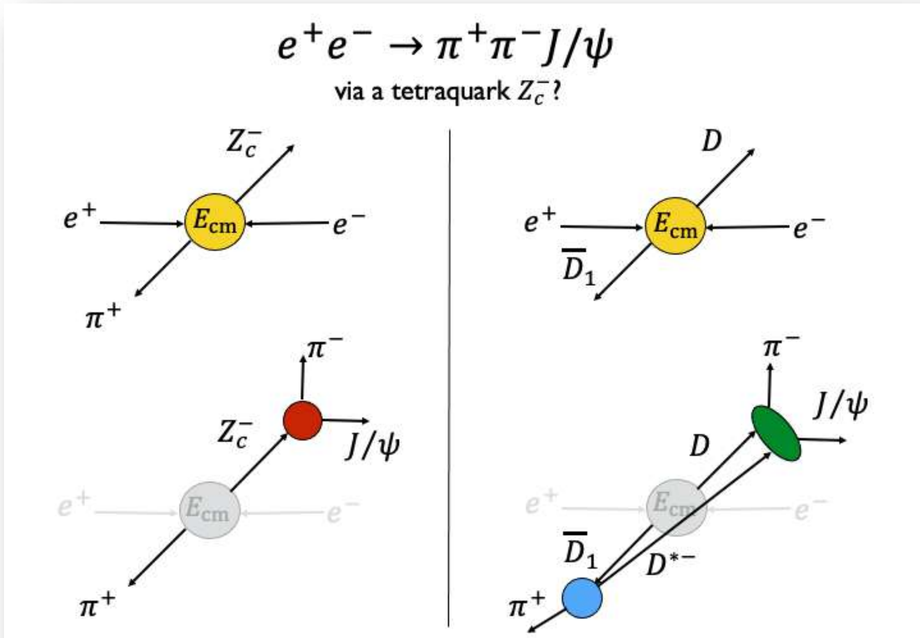
Spectroscopy of Exotic States with $c\bar{c}$

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

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



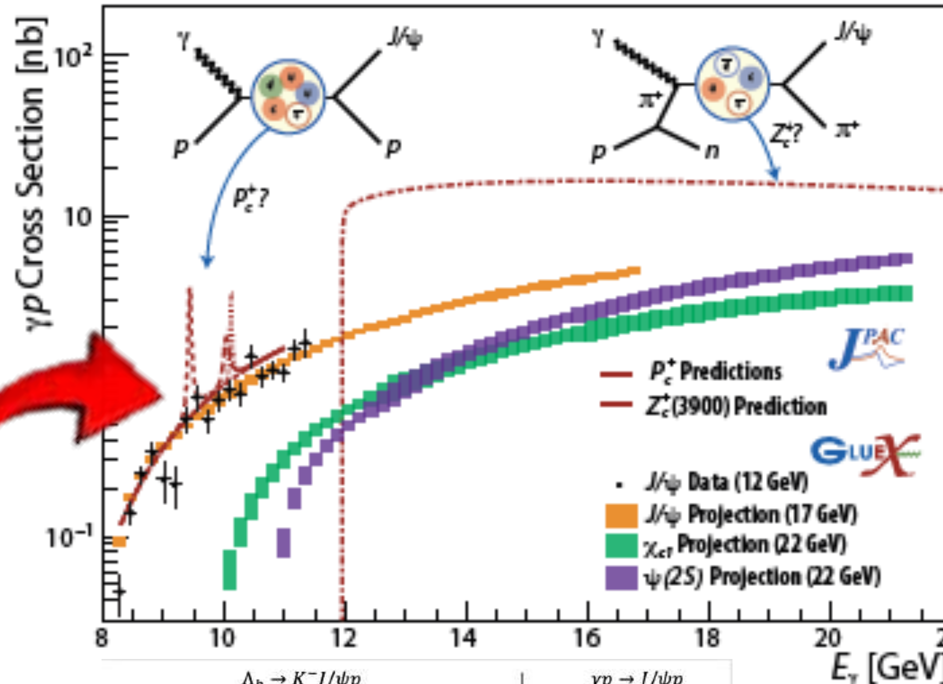
- **Many "XYZ" states observed in B decays, e^+e^- colliders**
- **Scarce consistency between various production mechanisms**
- **Significant theoretical interest and progress, but internal structure not understood yet**

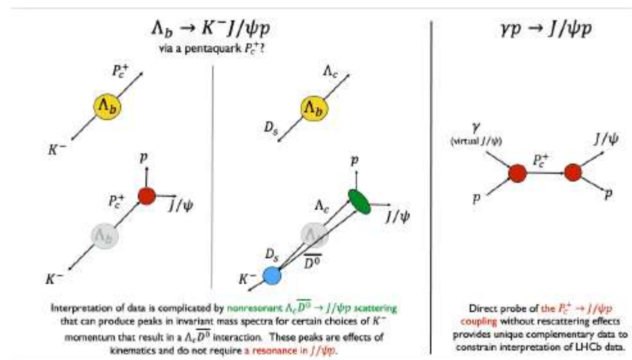


Interpretation of data is complicated by nonresonant $D^{*-}D \to J/\psi\pi^-$ scattering that can produce peaks in invariant mass spectra for certain choices of E_{cm} and π^+ momentum that result in a $D^{*-}D$ interaction. These peaks are effects of initial state kinematics and do not require a resonance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

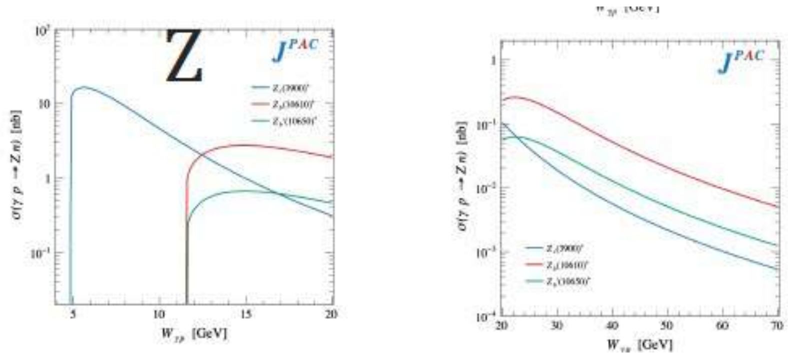
Spectroscopy of Exotic States with $c\bar{c}$

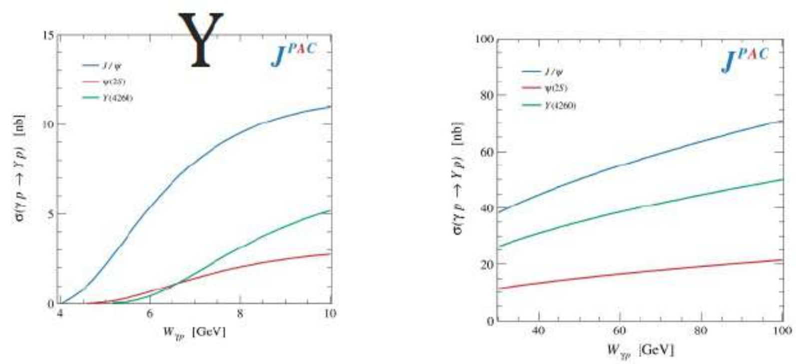
- **Never direcly produced using γ/lepton beam**
- Direct probe of the $Z_c \rightarrow J/\psi\pi$ coupling without re-scattering effects
- **Photoproduction** tool already used at 12 GeV to validate the existence of **charmed pentaquark**.
- With an energy upgraded CEBAF, this line of investigation can be **extended to other exotic candidates.**

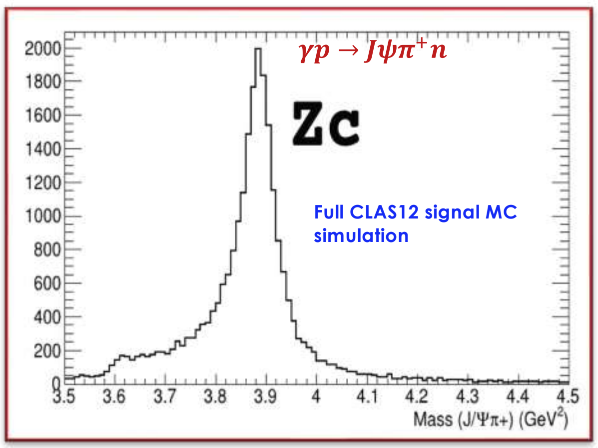




Spectroscopy of Exotic States with $c\bar{c}$

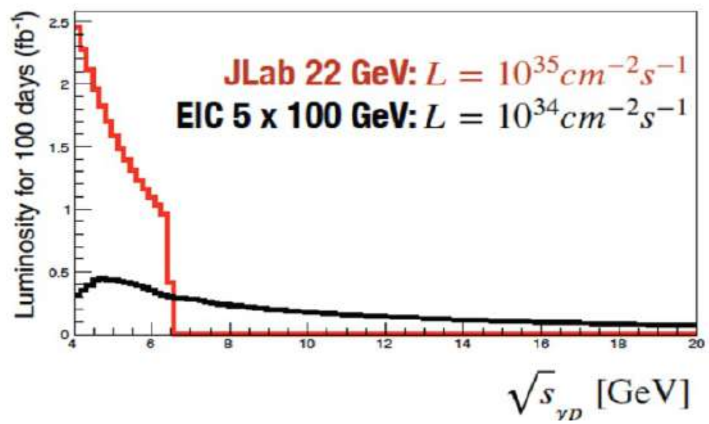






Simulations from GlueX & CLAS12 with existing detectors

- Diffractive production, dominated by Pomeron (2-gluon) exchange. Benefits from higher energies at the EIC



- Luminosity for 100 days running for JLab22 and EIC (5x100 GeV configuration).of the proton

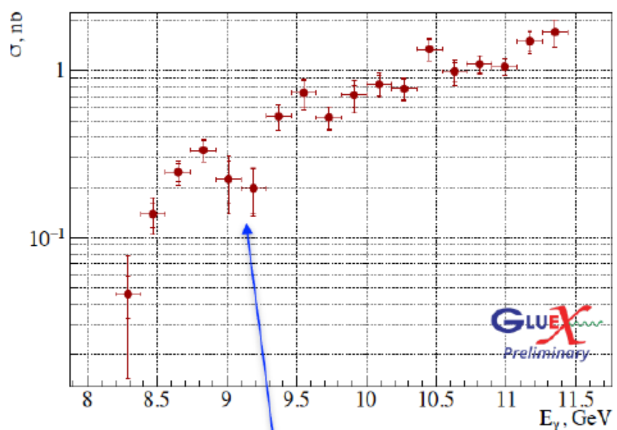
J/ψ photoproduction near threshold

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

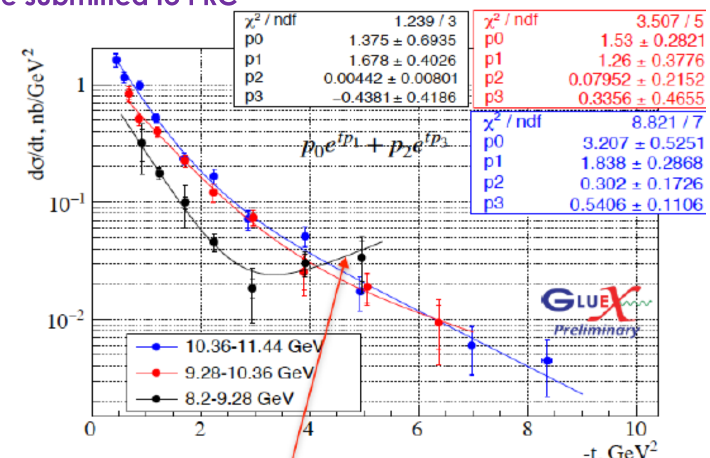
- **gluon GPD**
- **mass radius of the proton,**
- **anomalous contribution to the proton mass.**

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

GlueX final results to be submitted to PRC

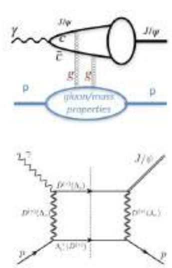


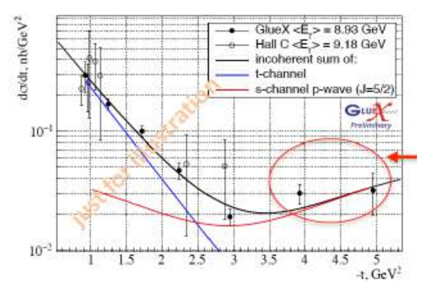
Possible structure at $\Lambda_c\overline{D}^{(*)}$ threshold σ(8.6-9.6) GeV



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

- **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





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

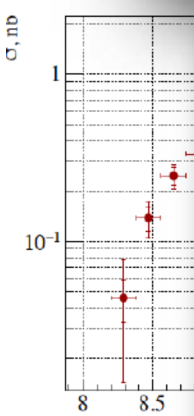
J/ψ photoproduction near threshold

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

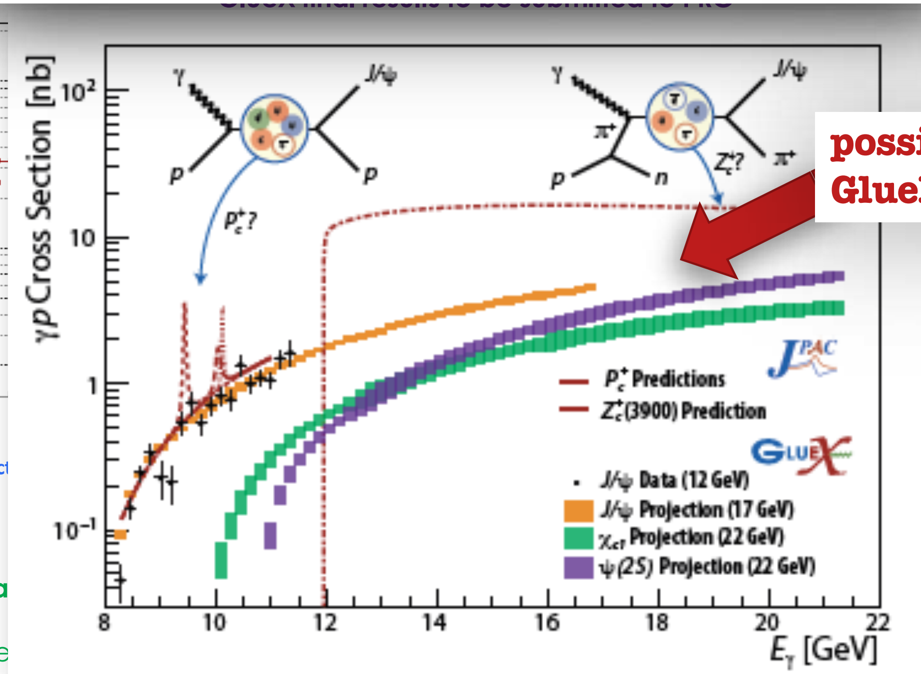
- gluon GPD
- mass radius of th
- anomalous contr

me assumptions
xchange)

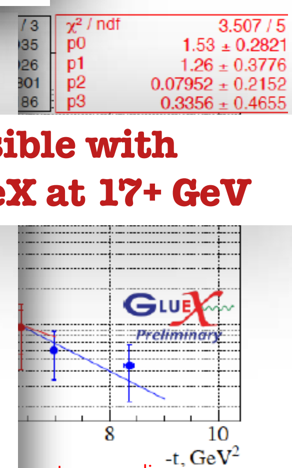
Need precise measurements (high statistics) to develop accurate theoretical models to understand the mechanism



Possible struct

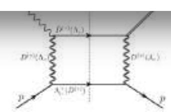


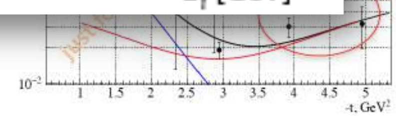
possible with GlueX at 17+ GeV



west energy slice

- **CANNOT be explained by t-cha EXCHANGE) alone**
- Can have contribution from ope exchange to both σ and $d\sigma/dt$ at high t

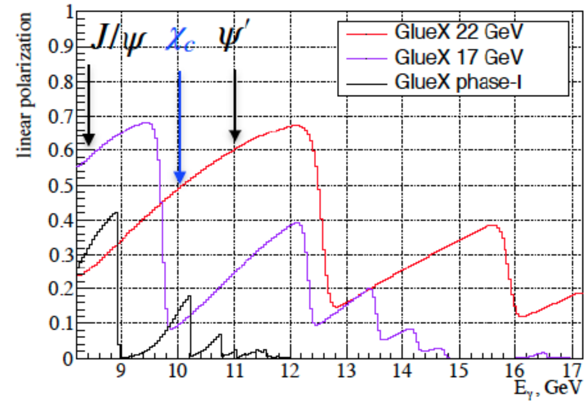




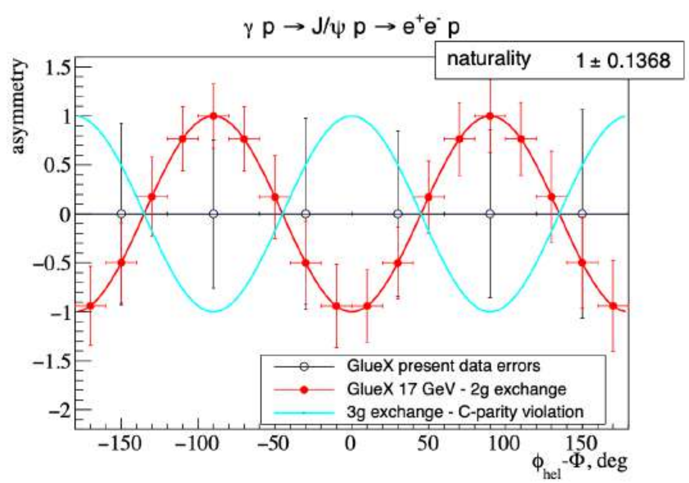
- Can we interpret this as a possible evidence for a s-channel resonance (?) *Pc*

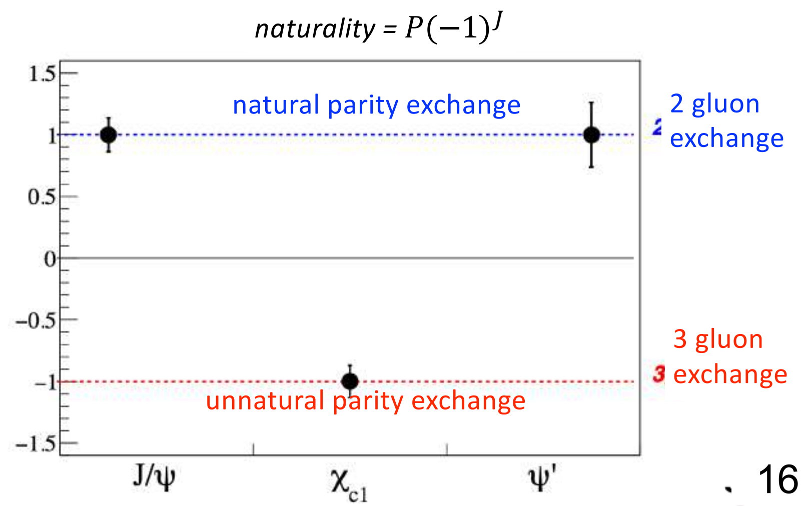
J/ψ photoproduction in Hall D - polarization

Energy upgrade gives significant increase of photon linear polarization

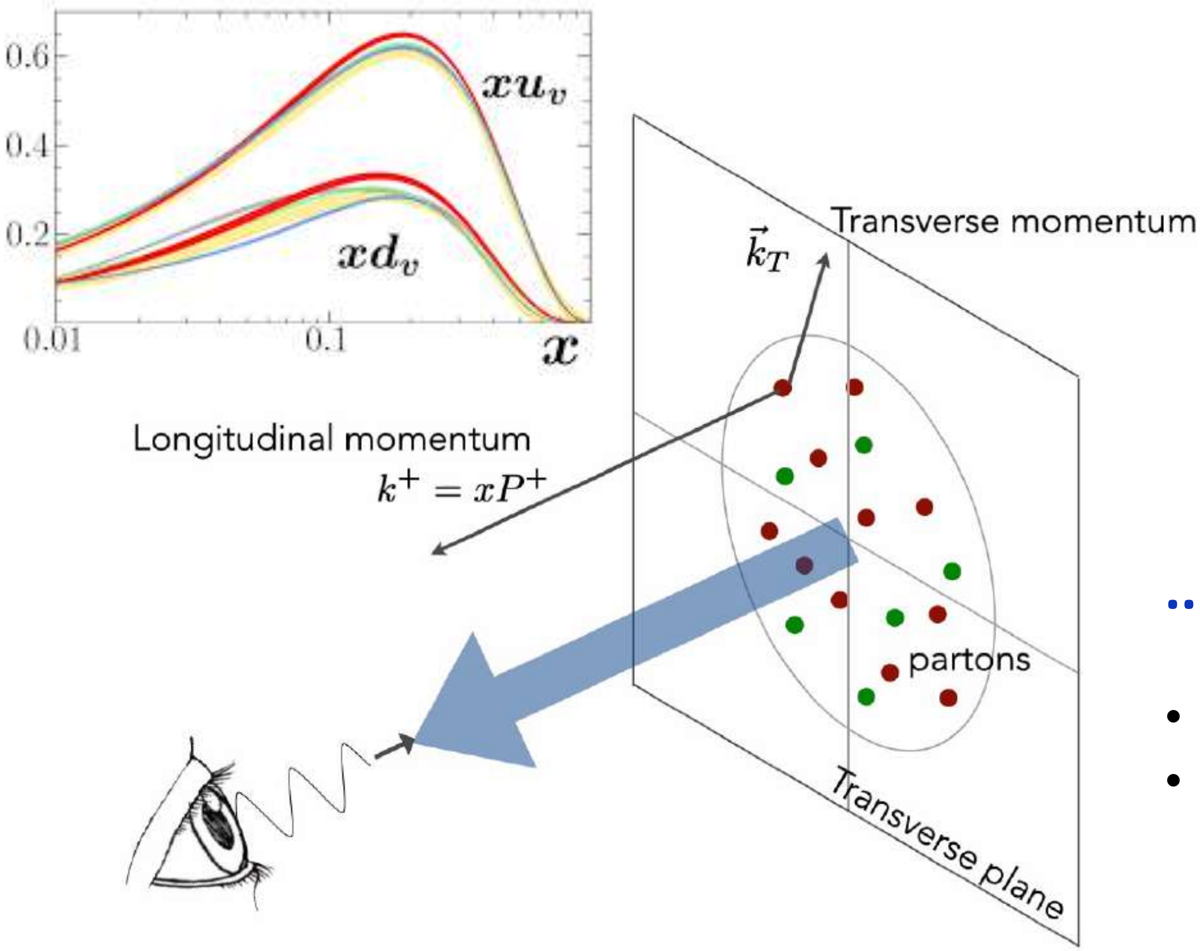


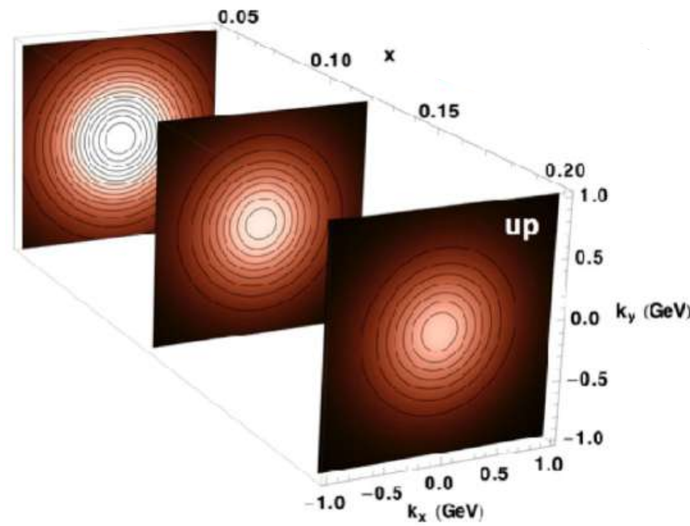
… allowing unique studies of the gluon exchange for J/ψ and higher charmonium states





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



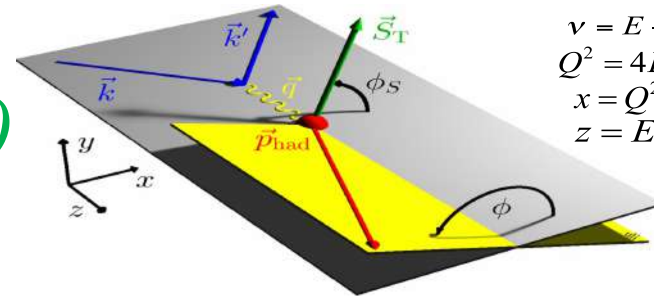


....but there is no free lunch

- **More functions in the x-section**
- **More variables for each function**
  - **→ Complexity in the extraction**
  - **→ High statistics required**

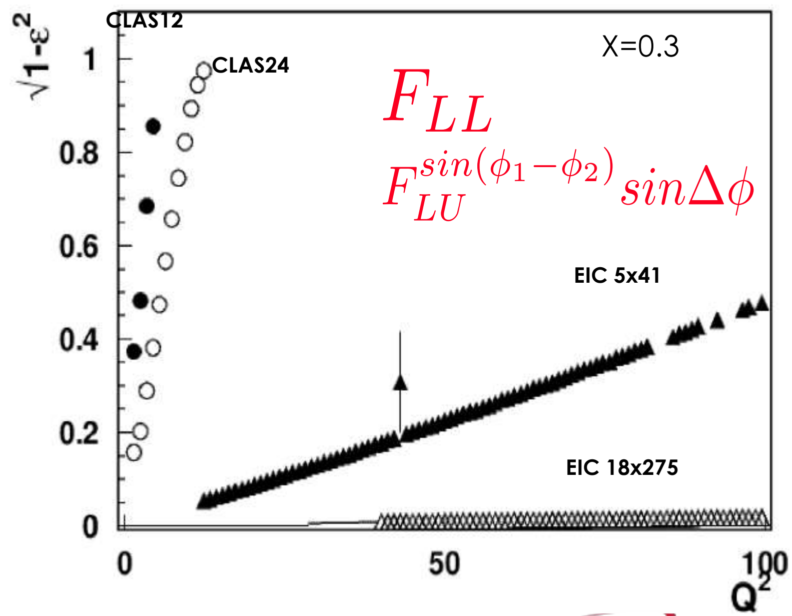
The Nucleon Structure in 3D

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



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

ε = ratio of longitudinal and transverse photon flux



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

- **At large x fixed target experiments are sensitive to ALL Structure Functions**

Jefferson Lab

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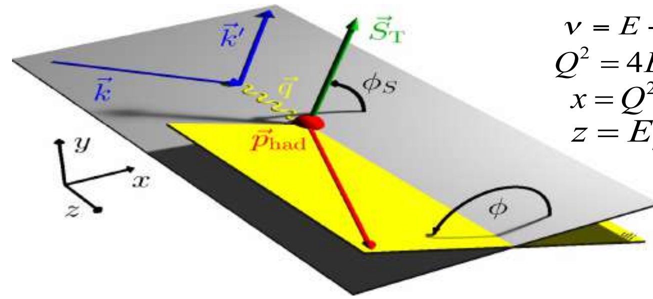
$$\sigma = f(x, Q^2, z, P_T)$$



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$$+ \lambda_e \sqrt{2\varepsilon(1-\varepsilon)}\, \sin\phi_h\, \cancel{F_{LU}^{\sin\phi_h}} + S_L \Big[\sqrt{2\varepsilon(1+\varepsilon)}\, \sin\phi_h\, F_{UL}^{\sin\phi_h} + \varepsilon \sin(2\phi_h)\, F_{UL}^{\sin 2\phi_h} \Big]$$
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$$+ S_T \Big[\sin(\phi_h - \phi_S) \Big(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon F_{UT,L}^{\sin(\phi_h-\phi_S)} \Big) + \varepsilon \sin(\phi_h + \phi_S)\, F_{UT}^{\sin(\phi_h+\phi_S)}$$
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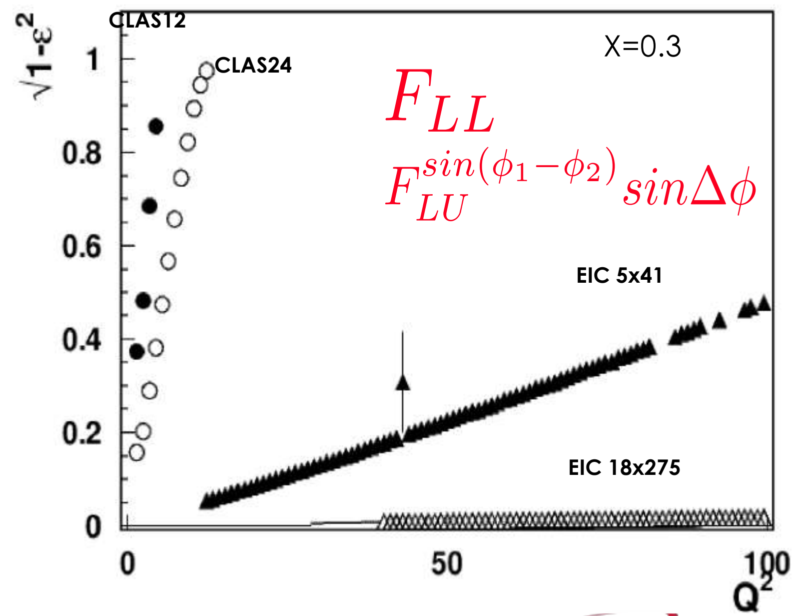
$$+ \sqrt{2\varepsilon(1+\varepsilon)}\, \sin(2\phi_h - \phi_S)\, F_{UT}^{\sin(2\phi_h-\phi_S)} \Big] + S_T \lambda_e \Big[\sqrt{1-\varepsilon^2}\, \cos(\phi_h - \phi_S)\, \cancel{F_{LT}^{\cos(\phi_h-\phi_S)}}$$
$$+ \sqrt{2\varepsilon(1-\varepsilon)}\, \cos\phi_S\, \cancel{F_{LT}^{\cos\phi_S}} + \sqrt{2\varepsilon(1-\varepsilon)}\, \cos(2\phi_h - \phi_S)\, \cancel{F_{LT}^{\cos(2\phi_h-\phi_S)}} \Big] \Big\}$$

ε = ratio of longitudinal and transverse photon flux



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Jefferson Lab

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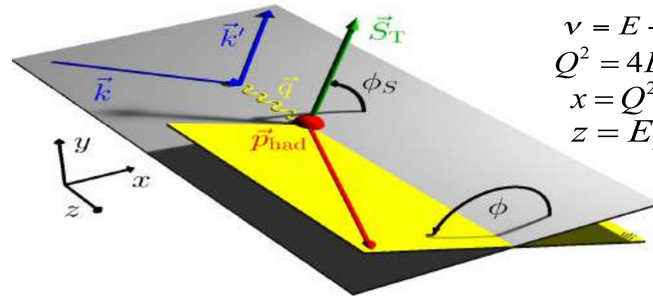

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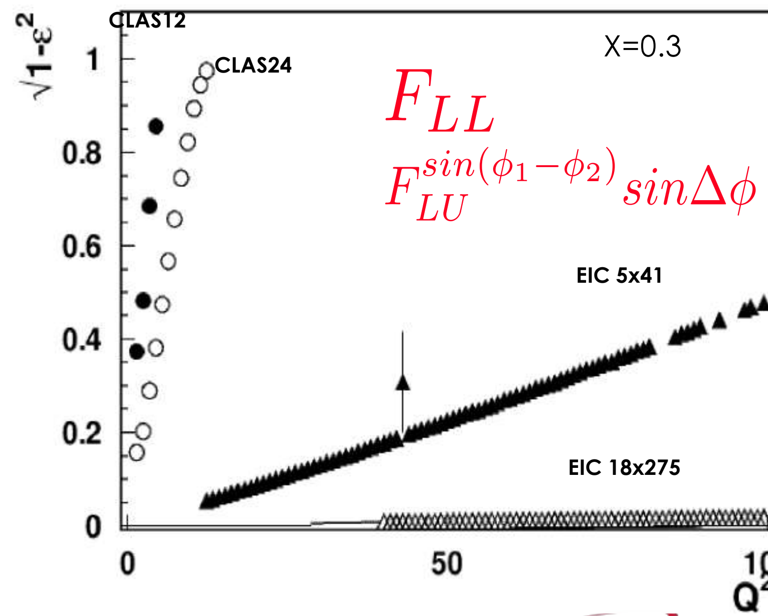
$$+ S_L\lambda_e\left[\sqrt{1-\varepsilon^2}\,\cancel{F_{LL}} + \sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_h\,\cancel{F_{LL}^{\cos\phi_h}}\right]$$
$$+ S_T\Bigg[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)} + \varepsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\right) + \varepsilon\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}$$
$$+ \varepsilon\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)} + \sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_S\,F_{UT}^{\sin\phi_S}$$
$$+ \sqrt{2\varepsilon(1+\varepsilon)}\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Bigg] + S_T\lambda_e\Bigg[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S)\,\cancel{F_{LT}^{\cos(\phi_h-\phi_S)}}$$
$$+ \sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_S\,\cancel{F_{LT}^{\cos\phi_S}} + \sqrt{2\varepsilon(1-\varepsilon)}\cos(2\phi_h-\phi_S)\,\cancel{F_{LT}^{\cos(2\phi_h-\phi_S)}}\Bigg]\Bigg\}$$

ε = ratio of longitudinal and transverse photon flux



- **At large x fixed target experiments are sensitive to ALL Structure Functions**

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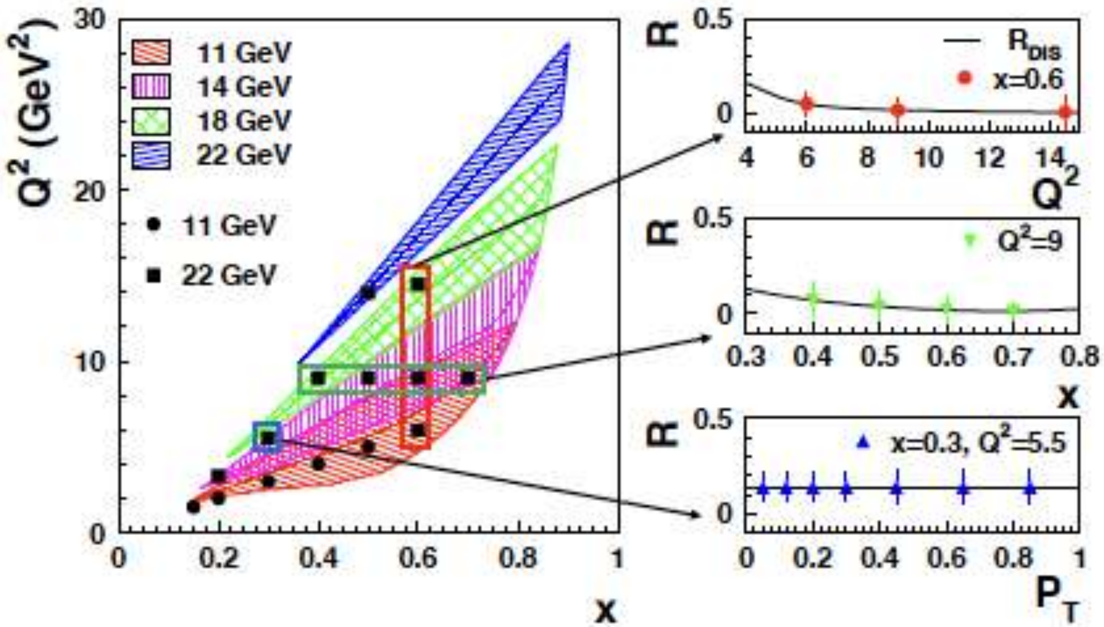
Structure Functions Separation



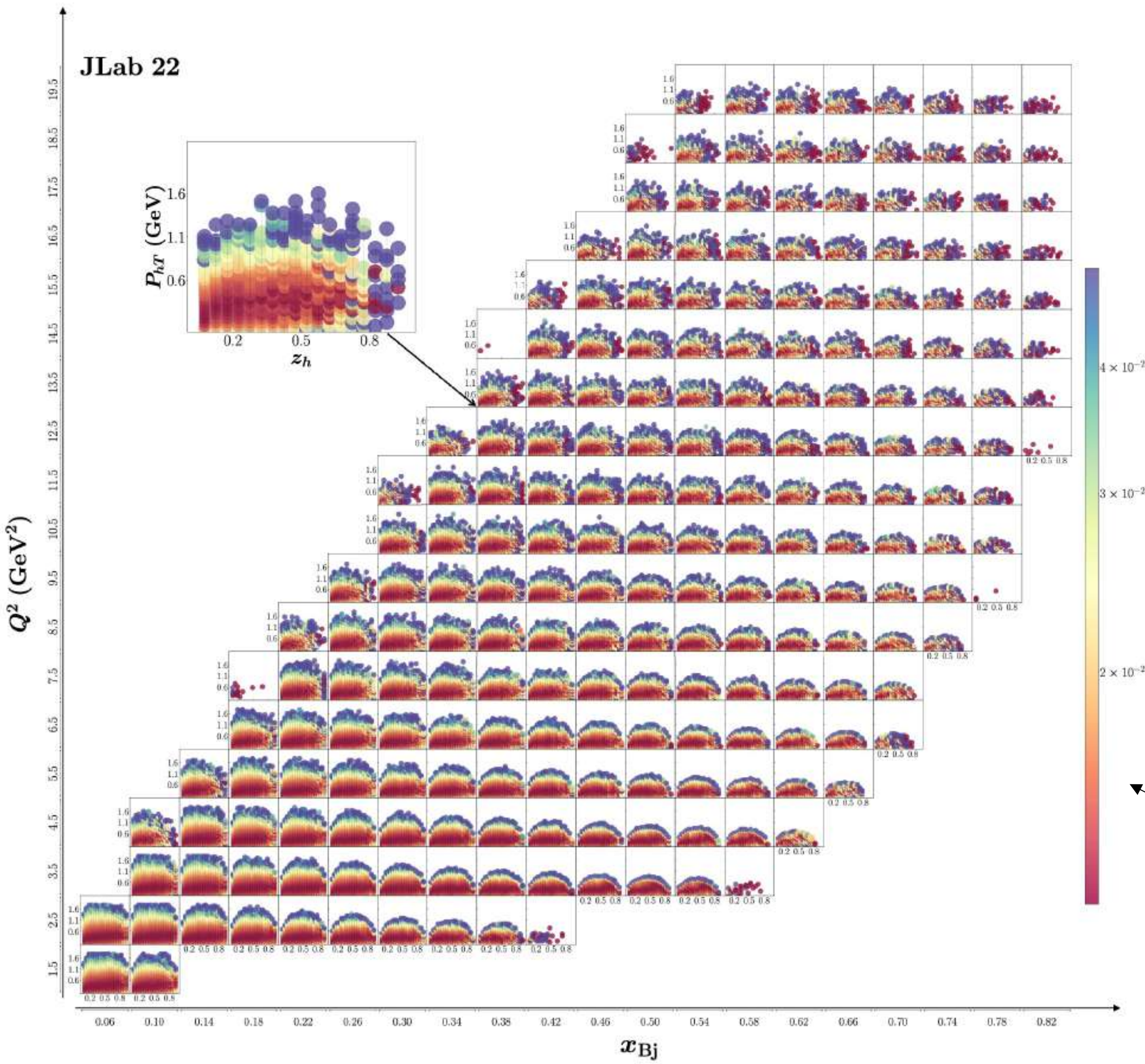
$R=\sigma_L/\sigma_T$

- **R for SIDIS is <u>assumed</u> to be similar to that of DIS but *never been thoroughly checked***

<u>A combined 11 and 22 GeV SIDIS program</u>

will provide a unique determination of the ratio of longitudinal to transverse photon SIDIS cross sections essential to properly understand SIDIS multiplicities, Sivers and Collins effects,…

Multi-D phase space at 22 GeV kinematics



- Multi-dimensional coverage of P_T access give access to fine binning of all observables
- Projections using the existing CLAS12 simulation/reconstruction chain for 100 days of running with L= 10^{35} $cm^{-2}s{-1}$

Expected uncertainties for SIDIS cross sections in 4D bins

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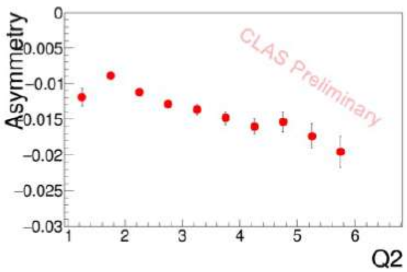
Luminosity: a "Must"

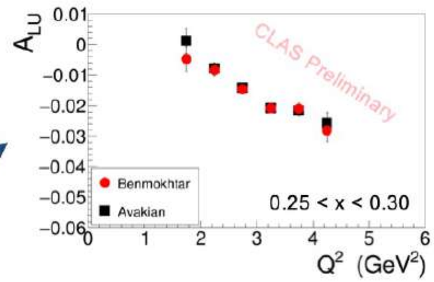
- **High Luminosity**

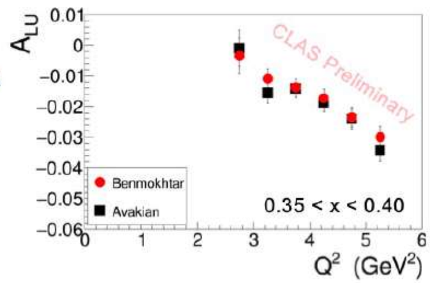
  CRUCIAL for measurements in multi-dimensional phase space
  - **interpretation of the results**
  - **validate and improve our understanding of parton dynamics**

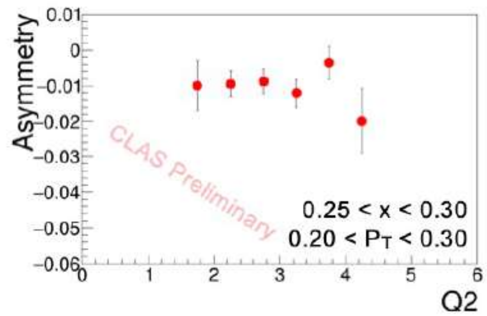
H. Avakian- T. Hayward

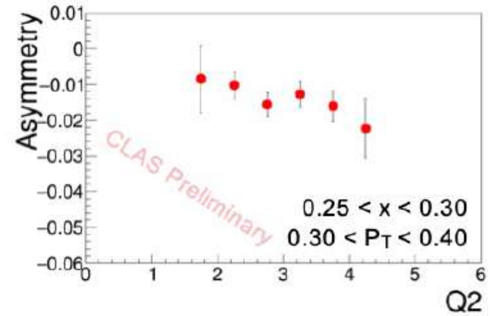


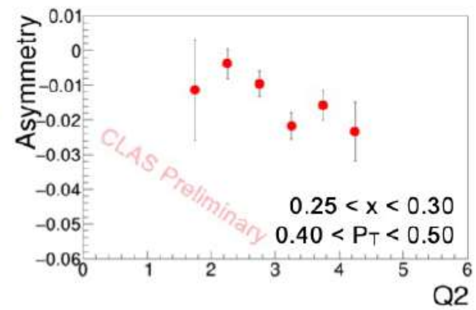
All plots $x_F < 0$.











clas
$ep \to e'pX$

Onward to 4D

Observing the expected Q^2 behavior for subleading twist objects may require high precision multidimensional bins… or maybe our theory is wrong.

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Luminosity: a "Must"

- **High Luminosity**

  CRUCIAL for measurements in multi-dimensional phase space
  - **interpretation of the results**
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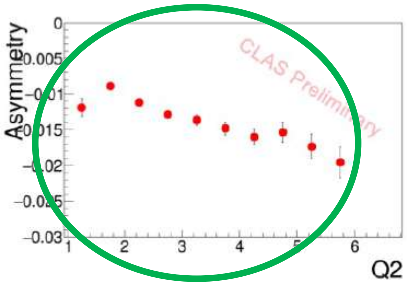

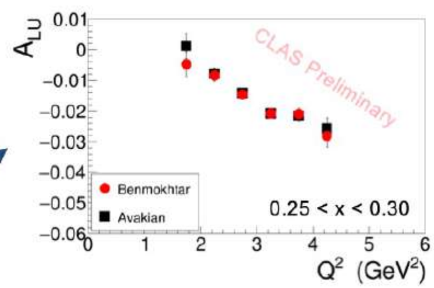

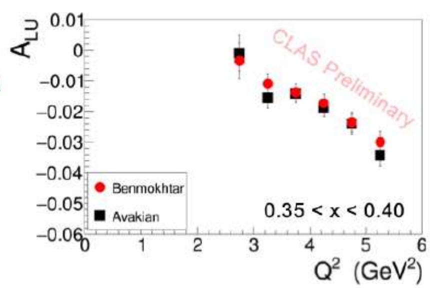

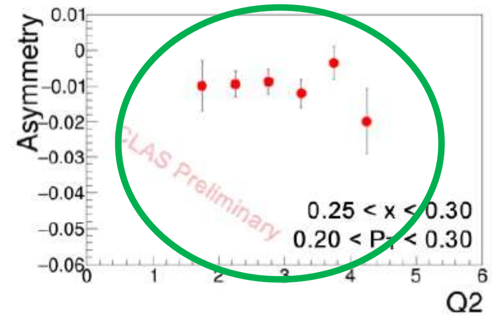

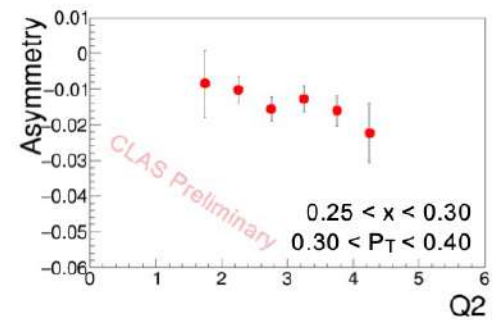

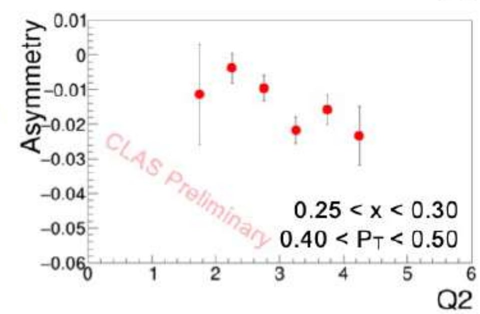

All plots $x_F < 0$.

clas
$ep \rightarrow e'pX$

Onward to 4D

Observing the expected Q^2 behavior for subleading twist objects may require high precision multidimensional bins… or maybe our theory is wrong.

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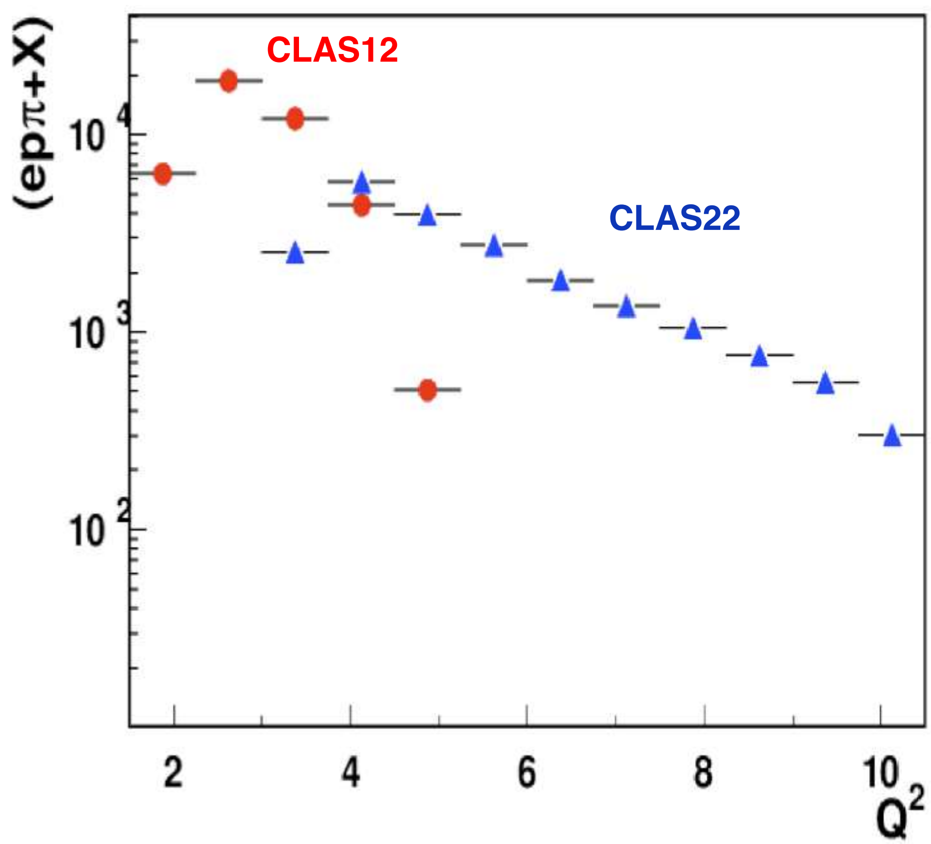
Enhancement of Q^2 Range



- **Q^2 evolution studies possible**

  QCD predicts only the Q^2 dependence

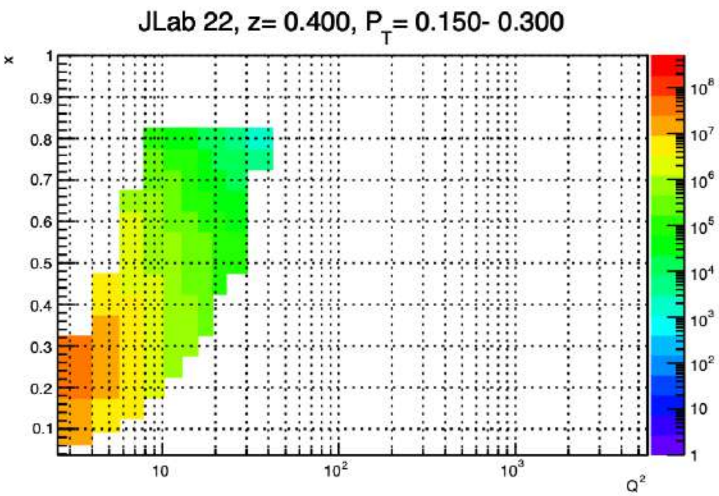
Increase significant the range of high Q^2 where

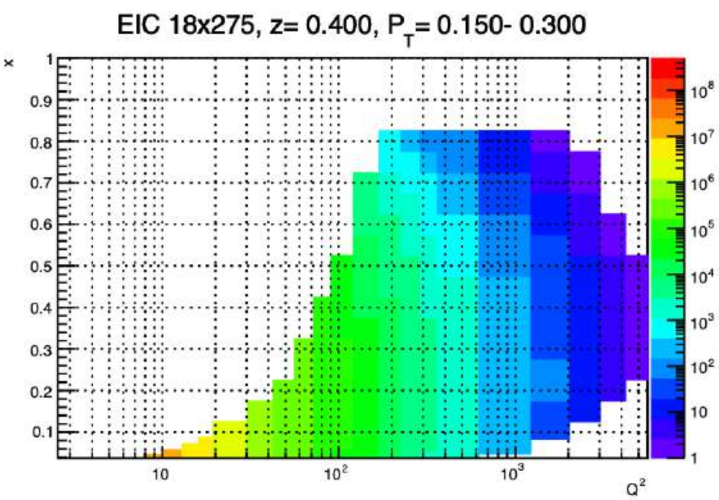
- **theory is supposed to work better**
- **Bigger change of observables vs Q^2**

allowing

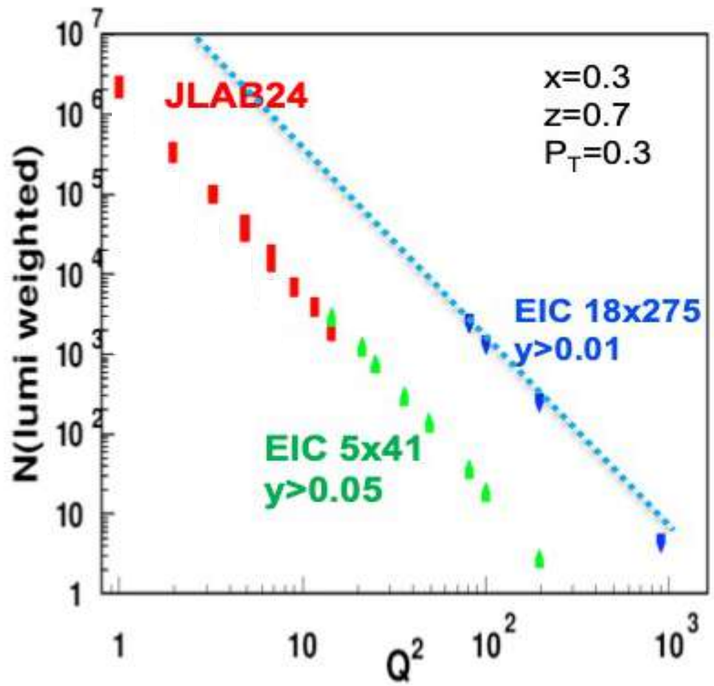
- **studies of evolution properties**
- **Disentangle leading/sub-leading contributions**
- **Validate/test the phenomenology**

SIDIS Phase Space





Counts / year



x-section from Bacchetta et al, 1703.10157

Beautiful Complementarity !

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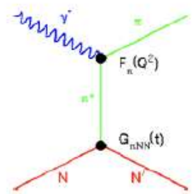
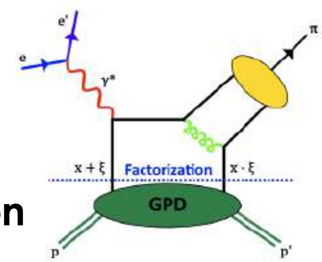
Pion Structure Studies with Exclusive Measurements

- 1) Determine the pion form factor, F_π to high Q^2
- F_π is a key QCD observable
- Measure F_π indirectly using pion cloud of the proton via $p(e, e'\pi^+)n$

$$|p\rangle = |p\rangle_0 + |n\pi^+\rangle + \ldots$$

- 2) Study the hard-soft factorisation regime
- Determine region of validity of hard-exclusive reaction mechanism
- Can only extract GPDs where factorisation applies





One of the most stringent tests of factorization is the x-section Q^2 dependence

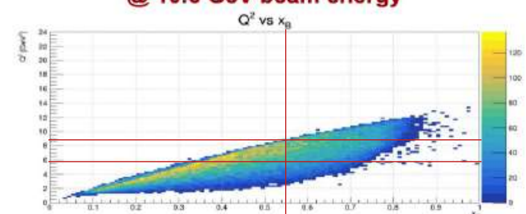
- σ_L scales to leading order as Q^{-6}
- σ_T expectation as Q^{-8}
- As Q^2 becomes large: $\sigma_L >> \sigma_T$

- Pion FF good observable for study of interplay between hard and soft physics in QCD

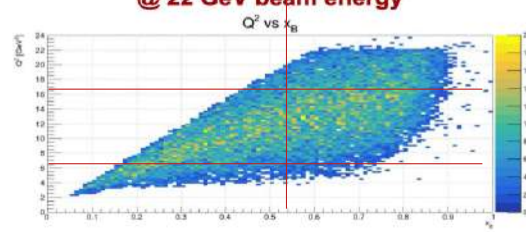
F_π asymptotic behavior rigorously calculable in pQCD
F_π Q^2<0.3 measured

$$\frac{d\sigma_L}{dt} \propto \frac{-tQ^2}{(t-m_\pi^2)} g_{\pi NN}^2(t) F_\pi^2(Q^2,t)$$

@ 10.6 GeV beam energy



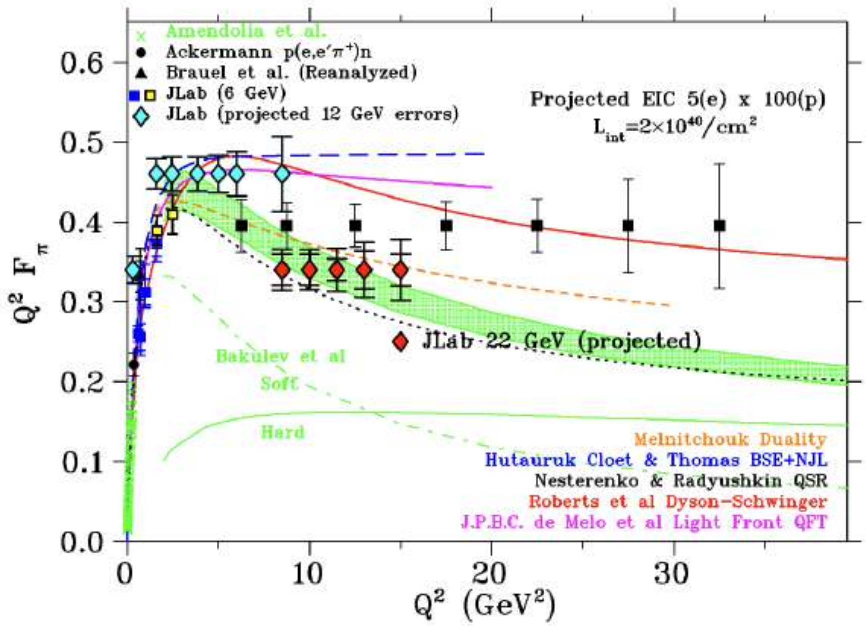
@ 22 GeV beam energy



All these studies require σ_L/σ_T separation

JLab22 F_π Data in the EIC Era

- L-T separations not possible at the EIC
- JLab will remain **only** source of quality L-T separated data!
- Phase 2 with upgraded HMS (VHMS)
  - Extends region of high quality F_π values to $Q^2 = 13\ GeV^2$
  - Larger error point at $Q^2 = 15\ GeV^2$



- JLab energy upgrade and Hall C upgrade provides much improved overlap of F_π data between JLab and EIC

Talk by S. Kay
APS GHP 2023
14/04/23

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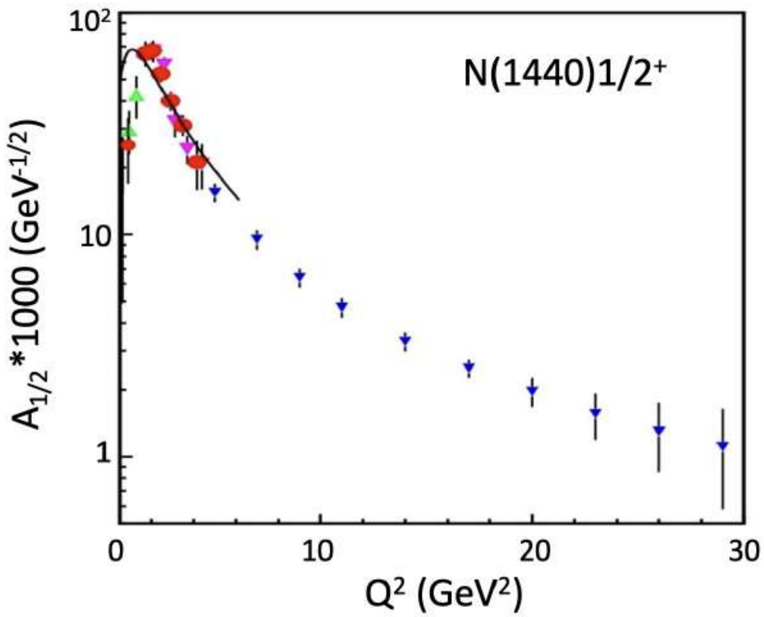
Bound 3 Quark Structure of N*s and Emergence of Mass



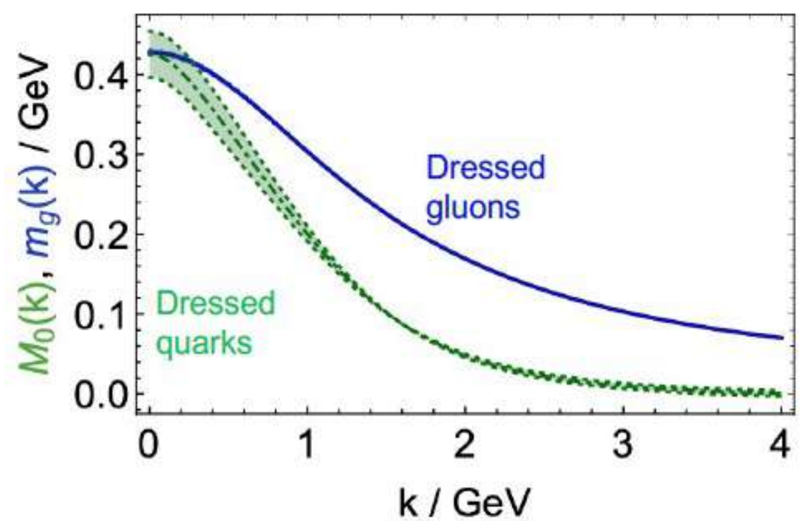
- Q^2 evolution of the $\gamma_v pN^*$ electrocouplings could offer an insight into hadron mass generation and the emergence of the N* structure from QCD

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

Continuum Schwinger Method

C.D. Roberts, Symmetry 12, 1468 (2020), AAPS Bull 31, 6 (2021)

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



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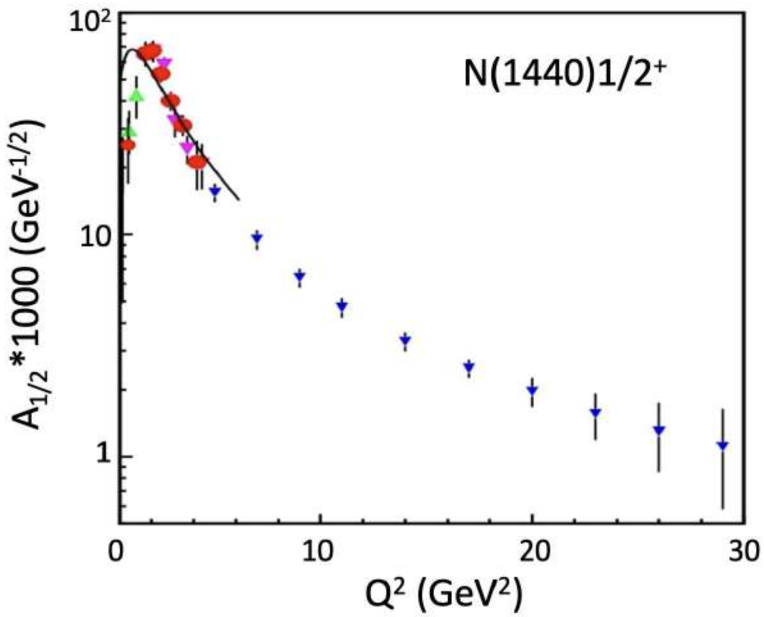

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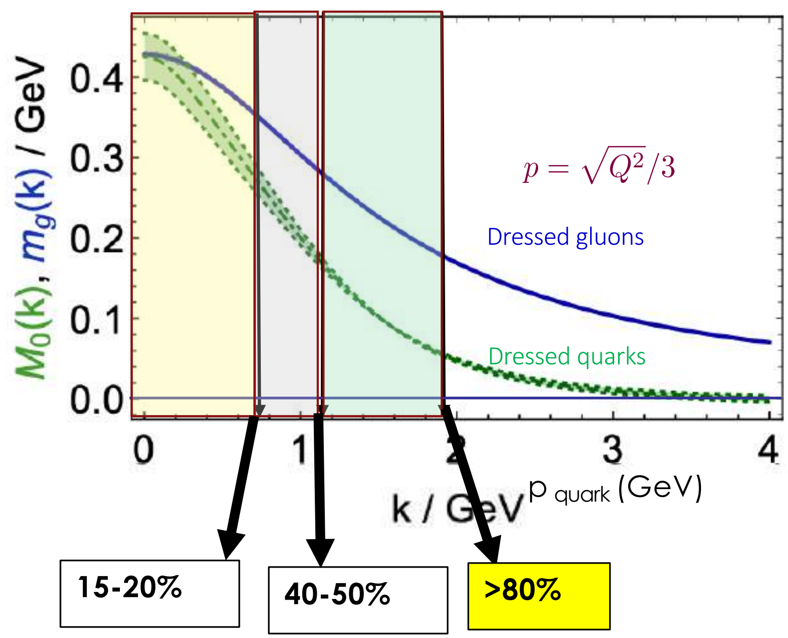


- **Q2 range(<35 GeV2) where the dominant portion of hadron mass is expected to be generated**

Partonic Structure and Spin

Nucleon Strangeness

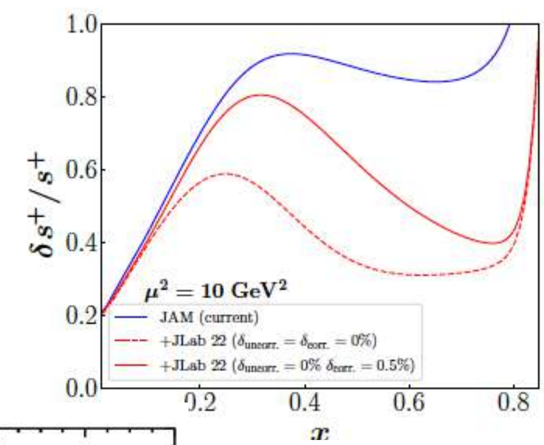
- The nucleon strange sector is largely unexplored with an up to 80% uncertainty in the $s^+ = s + \bar{s}$ PDF

Substantial improvement with a reduction in the s+ uncertainty that can reach more than a factor two at large-x

- **Precision extraction of $\sin^2\theta_W$**

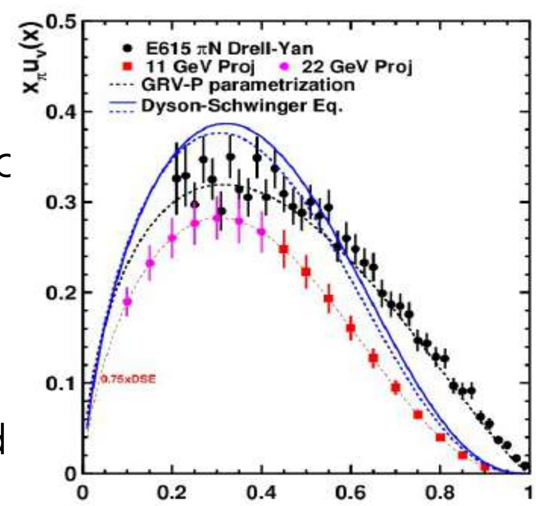
PVDIS @ 22 GeV with the SoLID

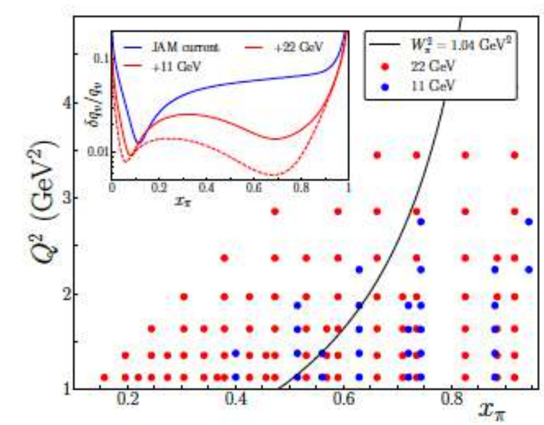
~100 days, 40 µA beam split between 40 cm D and H targets



Meson structure

- 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





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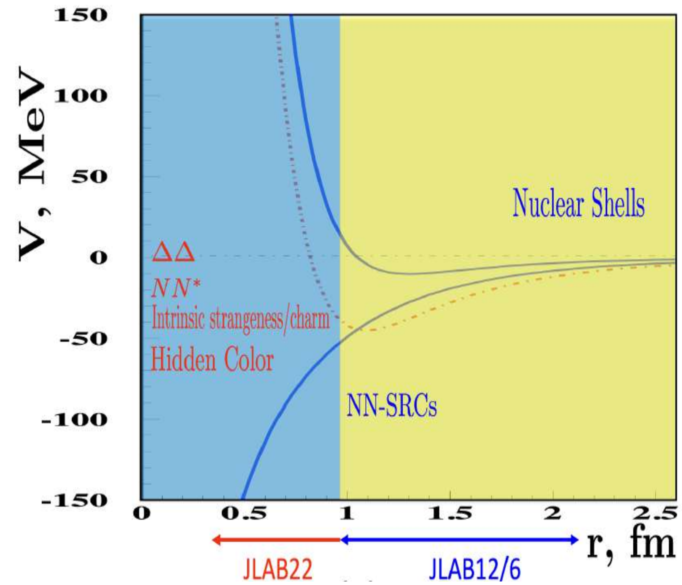
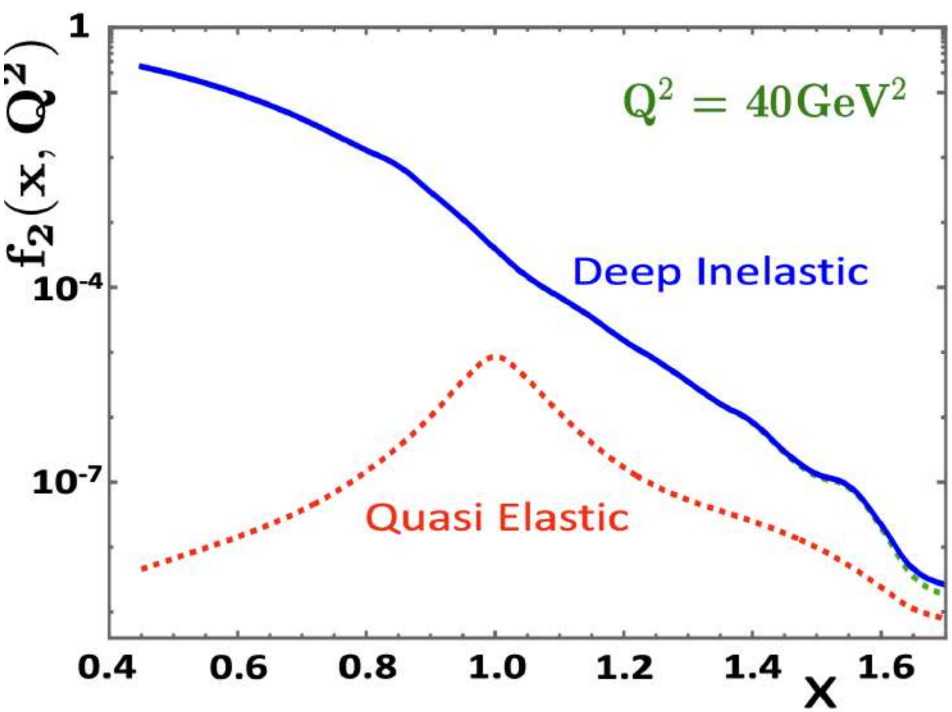
Nuclear Dynamics at Extreme Conditions

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,)

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CEBAF FFA Upgrade – Baseline under Study

- Starting with 12 GeV CEBAF
- NO new SRF (1.1 GeV per linac)
- New 650 MeV recirculating injector
- Remove the highest recirculation pass (Arc 9 & A) and replace them with two FFA arcs including time-of-flight chicanes
- Recirculate 4 + **6.5** times to get to **22 GeV**

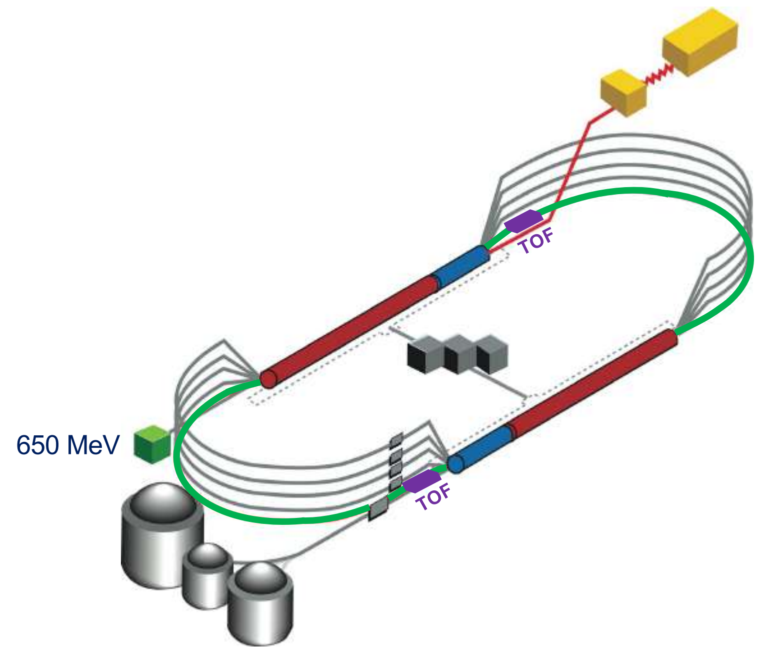
Pass Arithmetic: **5** -1 + **6.5** = **10.5**

Synchrotron Radiation impact on beam quality

Net transverse emittance dilution (normalized): **150μm**

Net natural energy spread: **2×10^{-3}**

Net synchrotron radiated energy: **1 GeV**

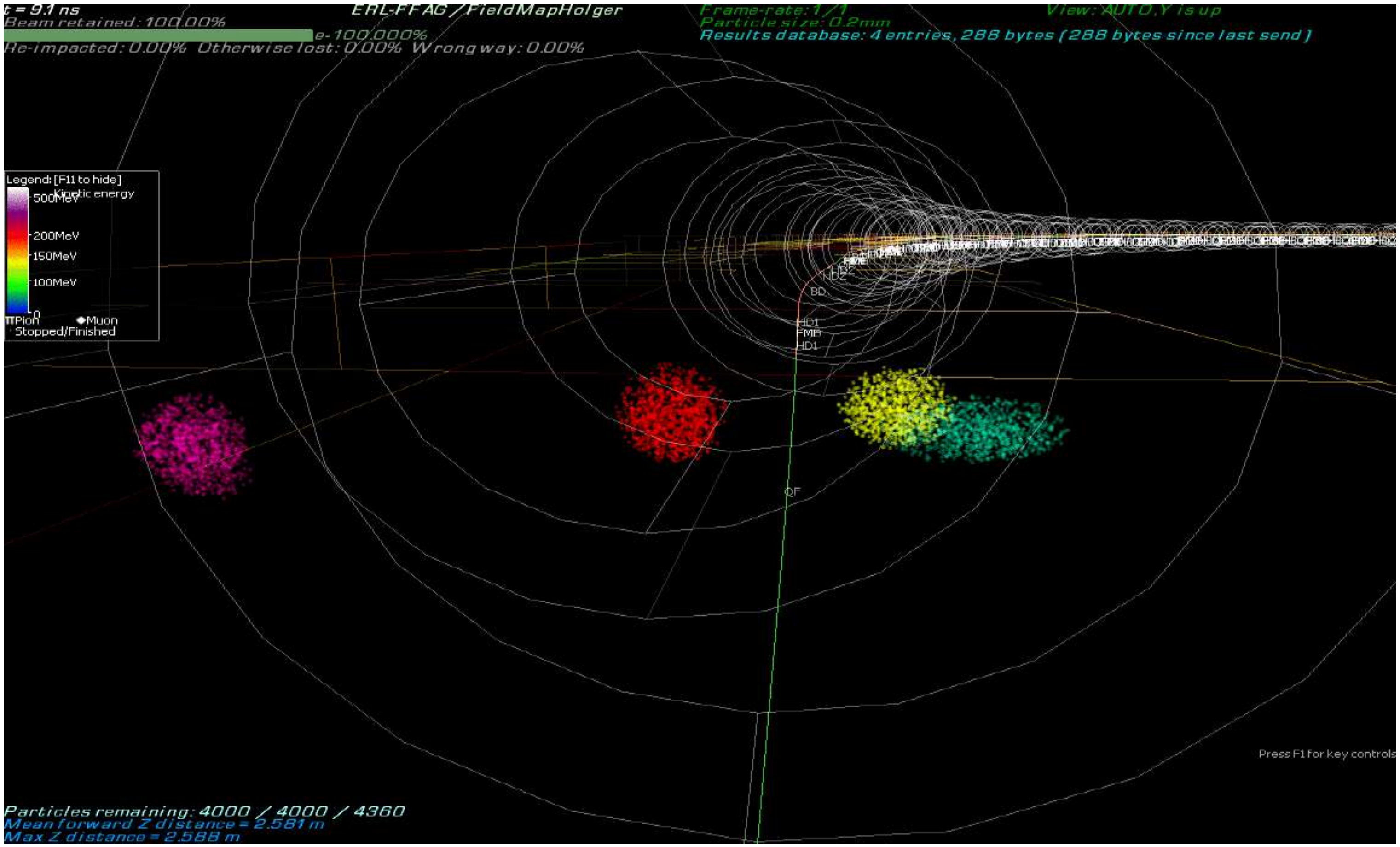


Enabling Technology:

Novel permanent magnets, CBETA-like used for power and cost savings

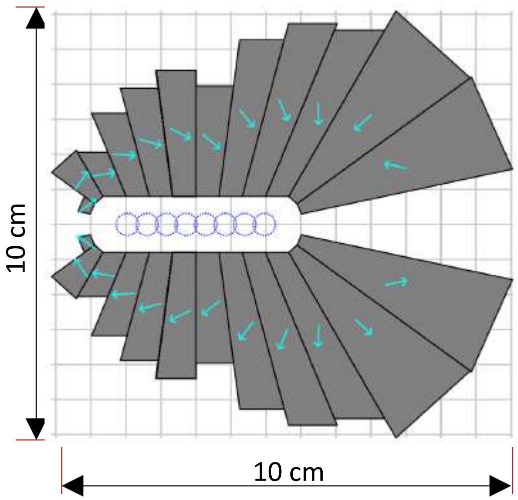
Courtesy A. Bogacz

Multi-Bunch Dynamics in CBETA FFA Arc



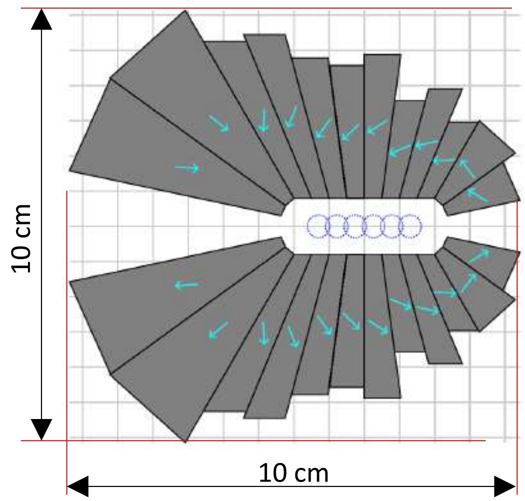
Courtesy A. Bogacz

Permanent Magnet Design – Open Mid-plane Geometry



Focusing Magnet BF

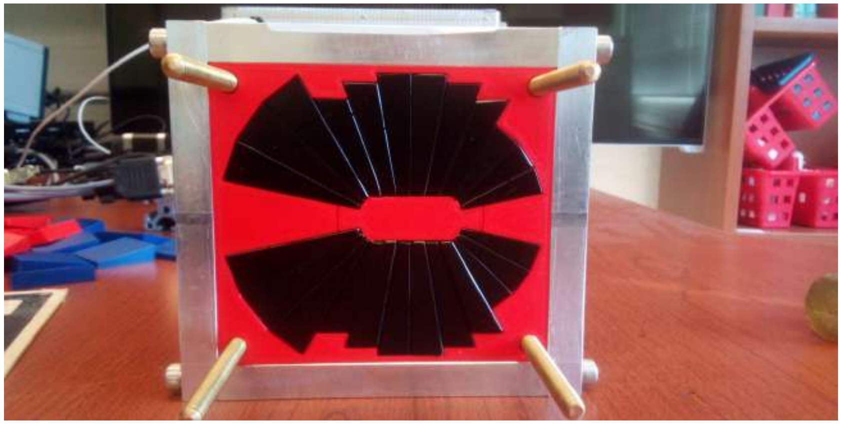
G_F= -41.13 T/m
L_{QF}= 1.67 m
B_F= -0.812 T



Defocusing Magnet BD

G_D= 43.44 T/m
L_{BD}= 1.24 m
B_D= -0.593 T

CBETA magnets: from 38cm^2 to 78cm^2

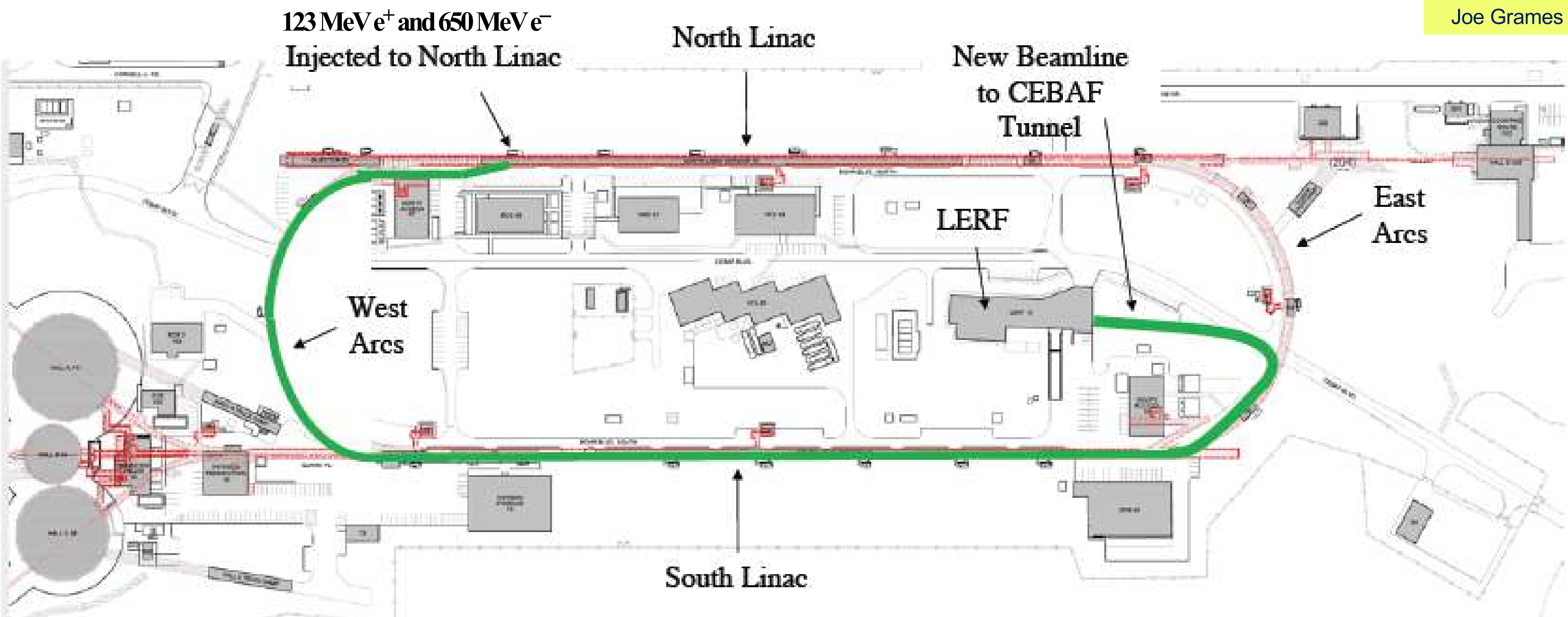


A prototype open midplane BF magnet was built and evaluated for mechanical integrity. Magnetic measurement confirmed a robust design with >1.5 Tesla in good field region, 10^{-3} field accuracy. Radiation resilience tests will be carried out at CEBAF.

Courtesy A. Bogacz

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

Joe Grames



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

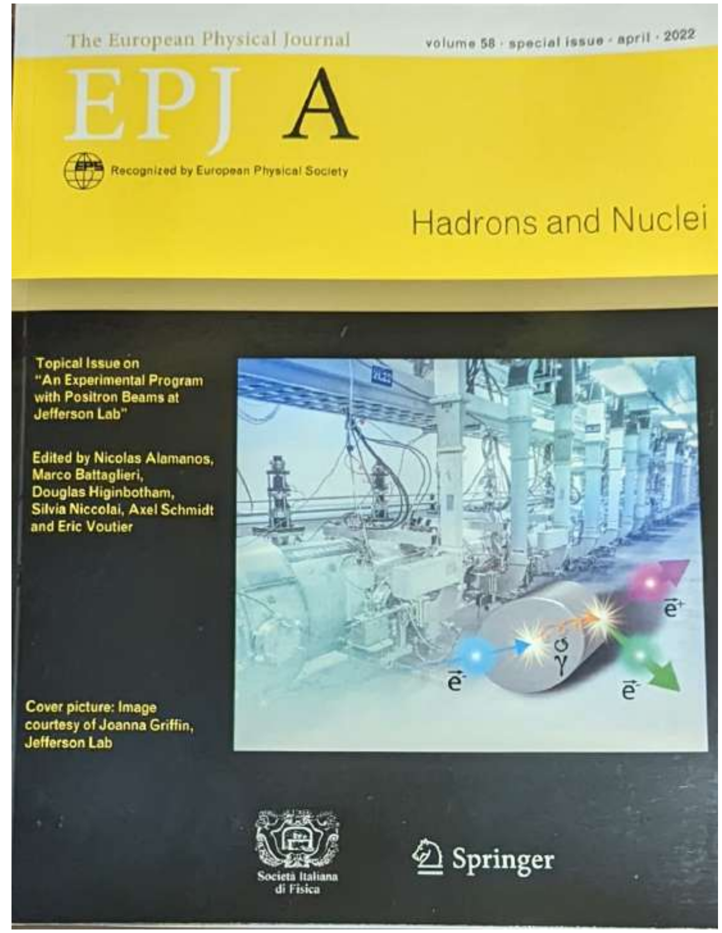
123 MeV e^+ for 12 GeV CEBAF

650 MeV e^- for 22 GeV CEBAF Energy Upgrade

Positron Program White Paper

Experiment Label (EPJ A)	Short Name	Hall	Detector	Target	Polarity	p (GeV/c)	P (%)	I (μA)	Time (d)	PAC Grade
				Two Photon Exchange Physics						
57:144	$H(e,e'p)$	B	CLAS12$^+$	H_2	$+/-_s$	2.2/3.3/4.4/6.6	0	0.060	53	
57:188	$H(\vec{e},e'\vec{p})$	A	ECAL/SBS	H_2	$+/-_p$	2.2/4.4	60	0.200	121	
57:199	r_p	B	PRad-II	H_2	$+$	0.7/1.4/2.1	0	0.070	40	
	r_d			D_2		1.1/2.2		0.010	39	
57:213	$\vec{H}(e,e'p)$	A	BB/SBS	$N\vec{H}_3$	$+/-_s$	2.2/4.4/6.6	0	0.100	20	
57:290	$H(e,e'p)$	A	HRS/BB/SBS	H_2	$+/-_s$	2.2/4.4	0	1.000	14	
57:319	SupRos	A	HRS	H_2	$+/-_p$	0.6−11.0	0	2.000	35	
58:36	$A(e,e')A$	A	HRS	He	$+/-_p$	2.2	0	1.000	38	
				Nuclear Structure Physics						
57:186	p-DVCS	B	CLAS12	H_2	$+/-_s$	2.2/10.6	60	0.045	100	C2
57:226	n-DVCS	B	CLAS12	D_2	$+/-_s$	11.0	60	0.060	80	
57:240	p-DDVCS	A	SoLID$^\mu$	H_2	$+/-_s$	11.0	(30)	3.000	100	
57:273	He-DVCS	B	CLAS12/ALERT	^{4}He	$+/-_s$	11.0	60			
57:300	p-DVCS	C	SHMS/NPS	H_2	$+$	6.6/8.8/11.0	0	5.000	77	C2
57:311	DIS	A/C	HRS/HMS/SHMS		$+/-_s$	11.0				
57:316	VCS	C	HMS/SHMS	H_2	$+/-_s$		60			
				Beyond the Standard Model Physics						
57:173	C_{3q}	A	SoLID	D_2	$+/-_s$	6.6/11.0	(30)	3.000	104	D
57:253	LDM	B	PADME ECAL/HCAL	C $PbW0_4$	$+$	11.0	0	0.100	180 120	
57:315	CLFV	A	SoLID$^\mu$	H_2	$+$	11.0				
								Total (d)	1121	

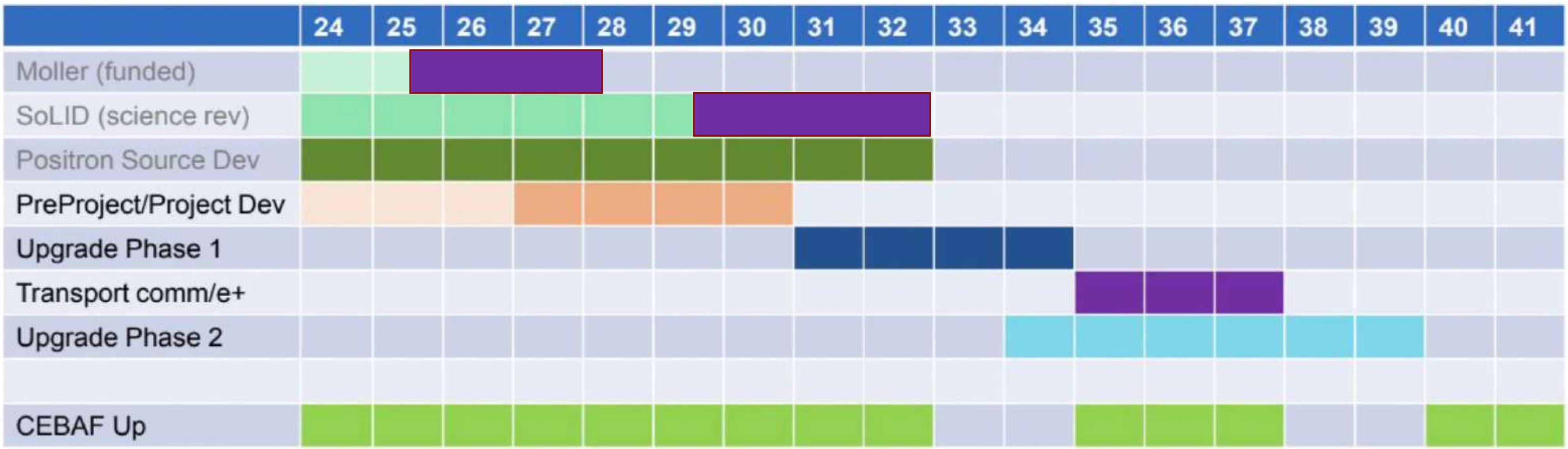
CLAS12$^+$ ≡ CLAS12 implemented with an Electromagnetic Calorimeter in the Central Detector
SoLID$^\mu$ ≡ SoLID complemented with a muon detector
$+$ Secondary positron beam
$-_s$ Secondary electron beam
$-_p$ Primary electron beam
(30) Do not require polarization but would take advantage if available at the required beam intensity



https://doi.org/10.1140/epja/s10050-022-00699-6

VERY ROUGH Timeline for Positrons and the 22 GeV Upgrade

Gantt chart made by David Dean to give a rough idea when these project could become a reality.



Phase 1 includes building the positron source and the tunnel & beamline connecting the source to main machine.
Phase 2 includes the new permanent magnets to allow 22 GeV within current CEBAF footprint.

NOTE: Plan was formulated so that these projects are ramping up as the EIC project cost is ramping down.

Conclusions and Outlook

- Understanding the strong interaction dynamics of non-pQCD and ``how'' hadrons/nuclei emerge from fundamental QCD principles, is a complex problem which demands different approaches and precise measurements of multiple observables
- With a fixed-target program at the "luminosity frontier", large acceptance detection systems, as well as high-precision spectrometers, CEBAF offers unique opportunities to shed light on the nature of QCD and the emergence of hadron structure
- With CEBAF at higher energy some important thresholds would be crossed and an energy window which sits between JLab @ 12 GeV and EIC would be available. This can provide a unique insight into the non-pQCD dynamics.
- Positrons are an exciting addition to the Jefferson Lab 12 GeV program under development
- A strong science case for these upgrades is emerging and it is supported by JLab management, staff and user community. It will complement/enhance the EIC program

THANK YOU!