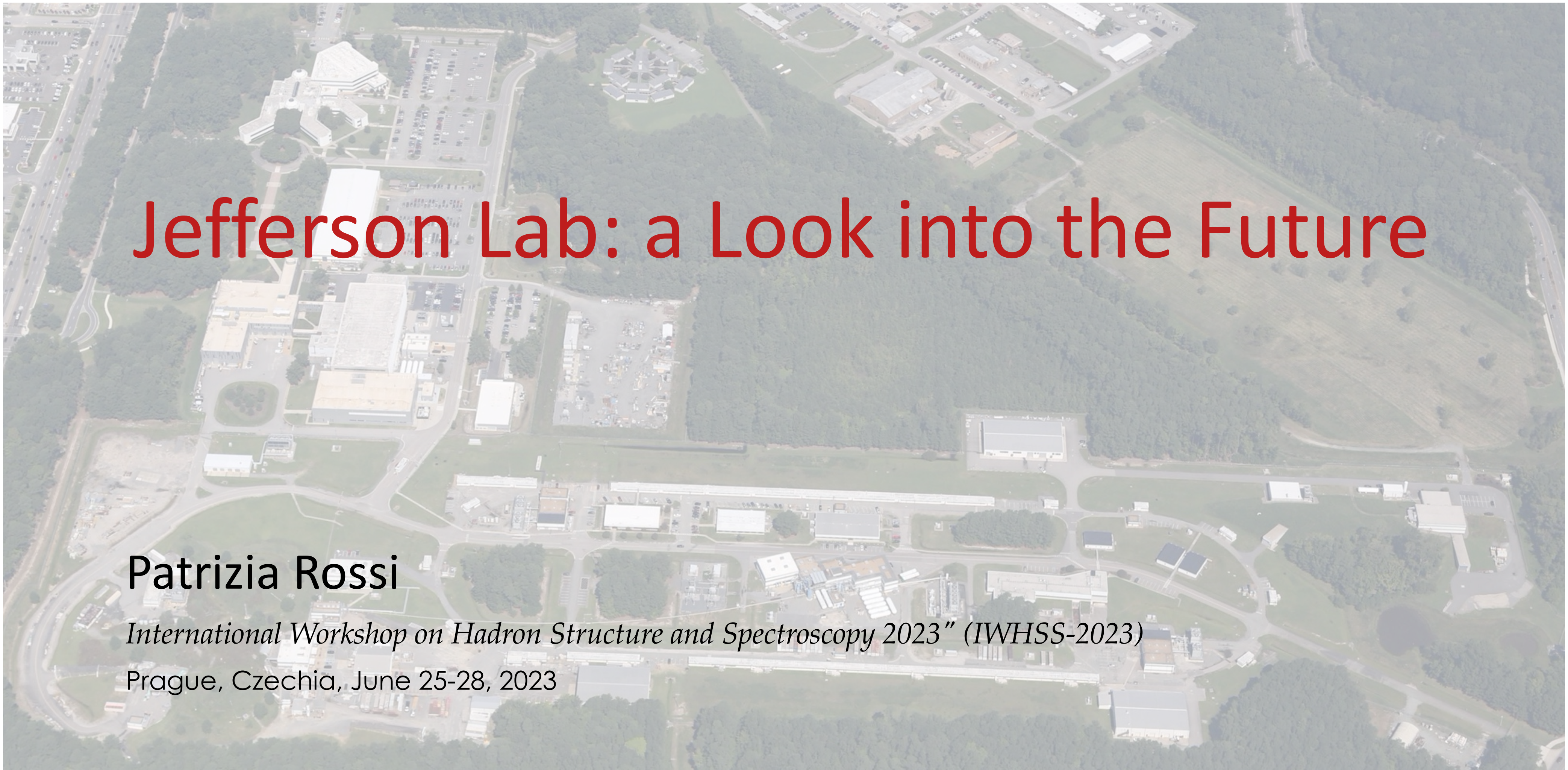


# Jefferson Lab: a Look into the Future

Patrizia Rossi

*International Workshop on Hadron Structure and Spectroscopy 2023" (IWHSS-2023)*

Prague, Czechia, June 25-28, 2023

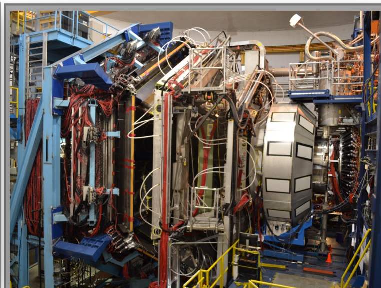
# Jefferson Lab and CEBAF


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

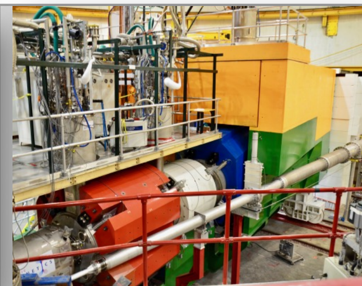
- **CW electron beam, $E_{max}$ = 12 GeV, $Pol_{max}$ ~ 90%**
- **High intensity linearly polarized photon beam**
- Range of beam energies & currents delivered to four exp. halls simultaneously
- **Physics program centered around the non-perturbative dynamics** to understand the rich variety of effects manifested in hadronic structure.
- **Discover evidence for physics beyond the standard model**

# Present, Near and Further Future

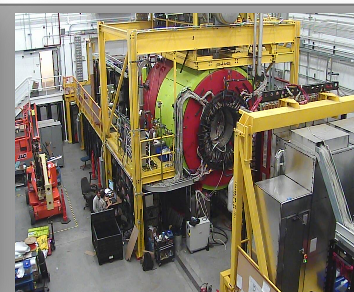
Hall A: SBS & BB



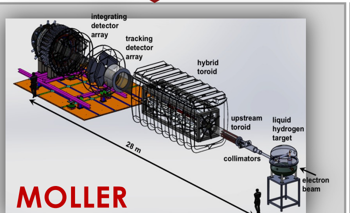
Hall B: CLAS12



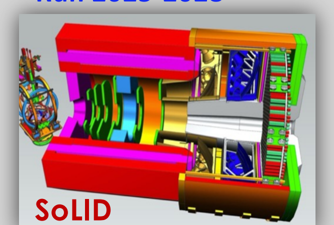
Hall C: HMS-SHMS



Hall D: GlueX



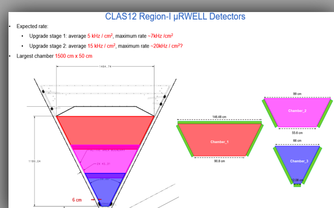

**Under costruction**
**Run 2025-2028**



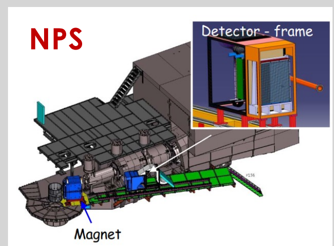

**DOE Science Review**
**R&D ongoing**

**Luminosity Upgrade**

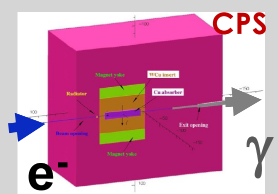
Stage -1: **2x10$^{35}$cm$^{-2}$ s$^{-1}$**
**3 years**
Stage -2: > **10$^{37}$cm$^{-2}$ s$^{-1}$**
**7-10 years**



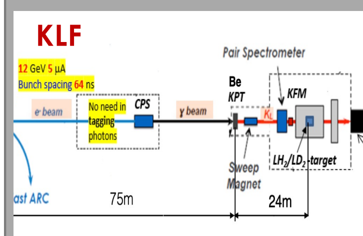

**On going, started in 2022**




**Run in August 2023**




**Under Construction**
**Run 2028 ->**



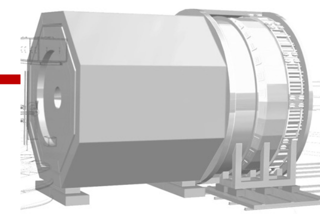

**Under Construction**
**Run 2026 -~2028**

- **Program @ 12 GeV started in 2017. ~1/3 of approved exps completed**
- **It covers a broad range of topics across Nuclear Physics and beyond:**
  - Hadron Spectra
  - Hadron Structure (transverse-longitudinal-3D),
  - Hadrons and Cold Nuclear Matter
  - Low Energy tests of SM and Fund. Sym.
- **By ~2030 complete ~85% approved program with base detectors + new equipment**

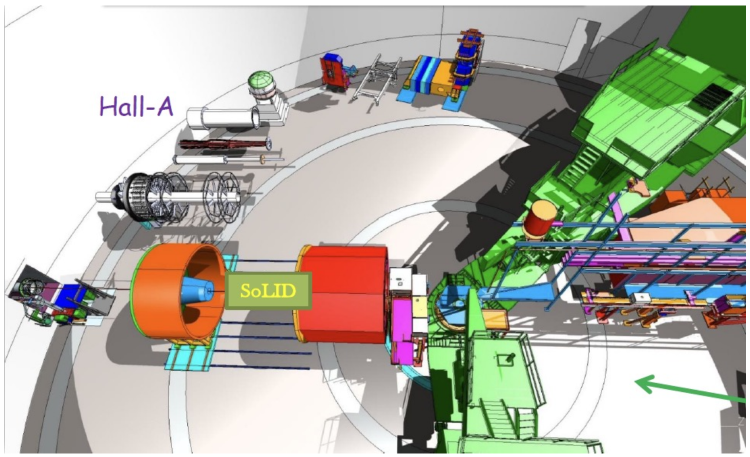
  …not including SoLID
  …not including new proposals
  ***CEBAF is a facility in high demand !***
- Jlab beyond 2030
  - **SoLID**
  - **Positron Beam at 12 GeV**
  - **CEBAF energy upgrade to 22 GeV**

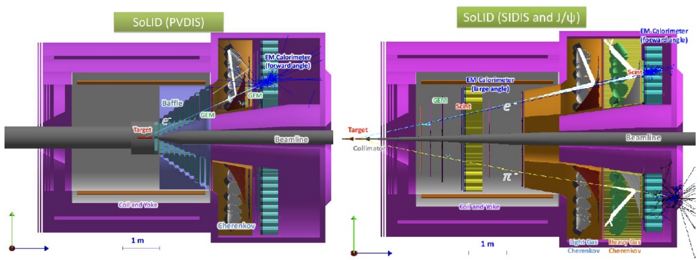
Jefferson Lab

# Solenoidal Large Intensity Device



High Intensity $(10^{37} \sim 10^{39} cm^{-2}s^{-1})$
Large Acceptance, $4\pi$ Coverage



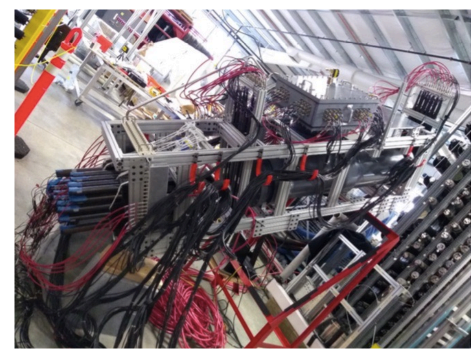

## Physics Programs

- *Parity Violation DIS*
- *Near-Threshold J/ψ Production*
- *Semi-Inclusive DIS w/ polarized targets*
- *Deep Exclusive Reactions (DEMP, TCS, DDVCS)*

- Precision **lepto-quark couplings** at unique mass and sensitivity scales
- Superior sensitivity to the differential el/γ production x- section of J/ψ near threshold (**proton mass**)
- **3D momentum imaging** of the nucleon
- **Spatial 3D structure** of the nucleon

## Project Status

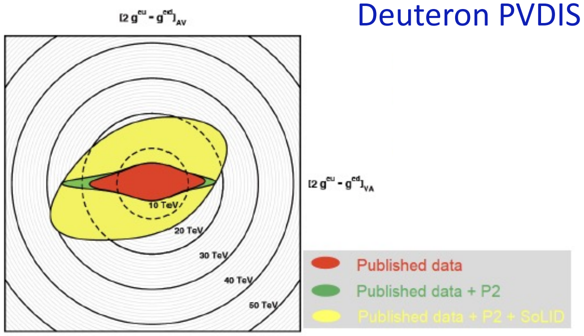
- DOE Science Review (2021) Feedback: positive report, recommend to move to next step
- Detector pre-R&D funded by DOE started in 2020 & on-going
- CLEOII Magnet Test Completed

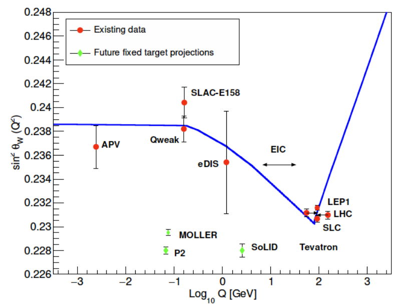


- GEM readout and DAQ testing for high rates
- Cherenkov test for high rates/high background
- Acquire test data while running

# Physics with SoLID: some Highlights

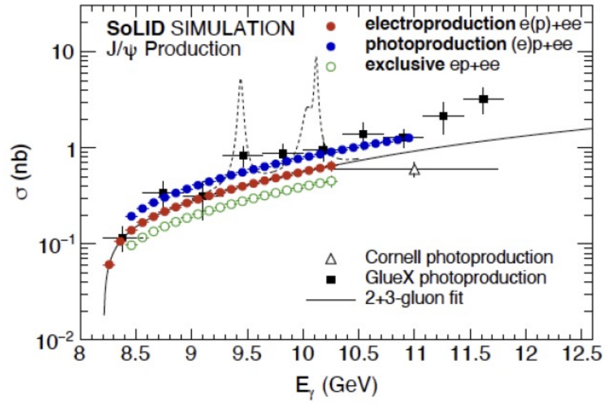
## Deuteron PVDIS measurement




- Sub-1% precision over broad kinematic range
- Sensitive to Standard Model test at high energy scale

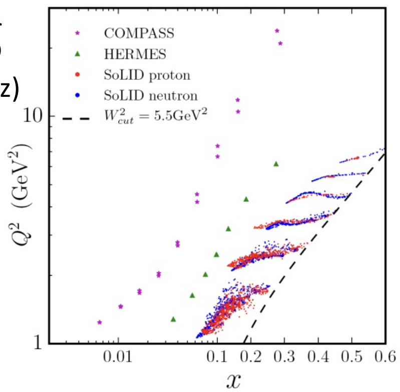
## J/Ψ production

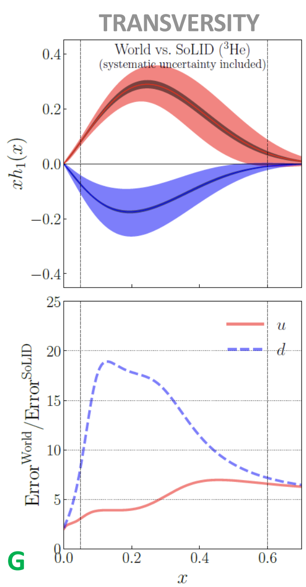


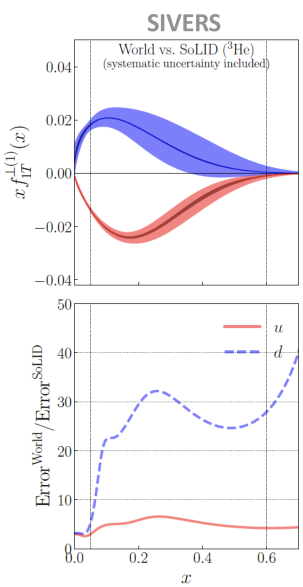

- Each measurement has a corresponding t-dependent differential cross section measurement

## SIDIS with Transversely Polarized $^3$He and Proton

- Wide phase-space & high-statistics for 4D binning in (x, $p_T$, $Q^2$, z)



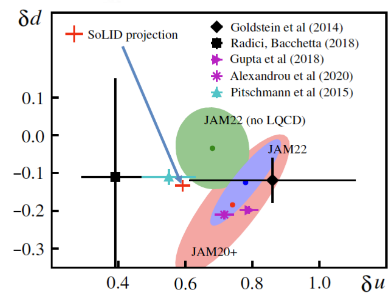




SoLID White-Paper, arXiv 2209.13357, accepted by J. Phy. G

## Tensor charge

$$\delta u = \int_0^1 dx\ \left(h_1^u(x) - h_1^{\bar{u}}(x)\right)$$

$$\delta d = \int_0^1 dx\ \left(h_1^d(x) - h_1^{\bar{d}}(x)\right)$$




- SoLID projection: stat+syst included

J. Cammarotaet al, PRD 102, 054002 (2020) (JAM20+)
L. Gamberget al., PRD106(2022)3,034014 (JAM22)

D'Alesioet al., Phys. Lett. B 803 (2020)135347
H. Gao, T. Liu and Z. Zhao, PRD 97, 074018 (2018)
Z. Ye, et al, Phys. Lett. B 767, 91 (2017)

# 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**

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

White Paper: https://arxiv.org/abs/2306.09360

Contents

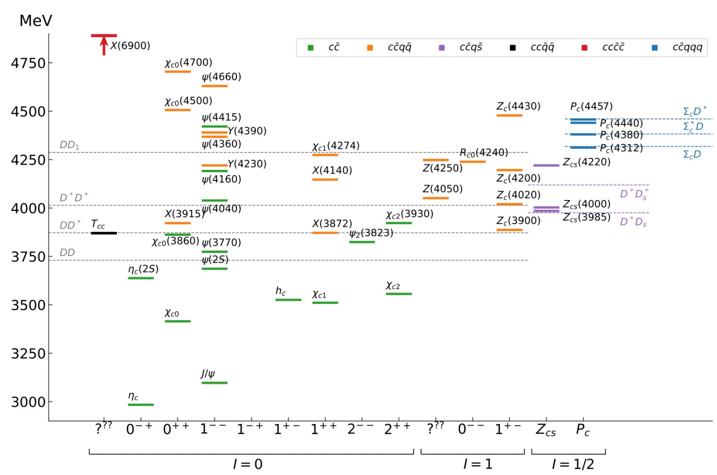


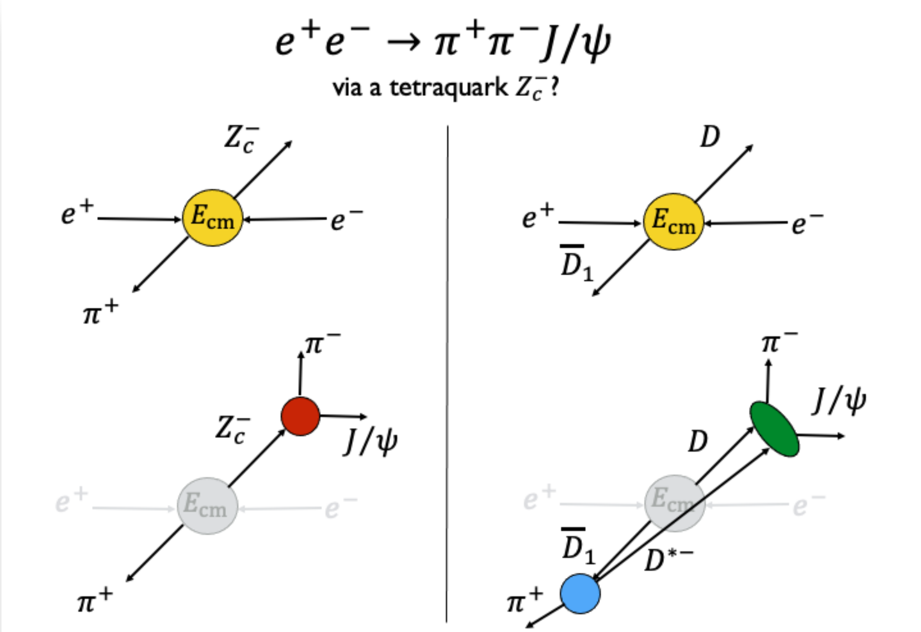
- Initial scientific case for upgrading CEBAF to 22 GeV
- Result of a community effort, incorporating insights from a series of workshops conducted between March 2022 and April 2023.
- It will be presented at the US LRP of NP

Jefferson Lab

# Photoproduction of Hadrons with Charm Quarks

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



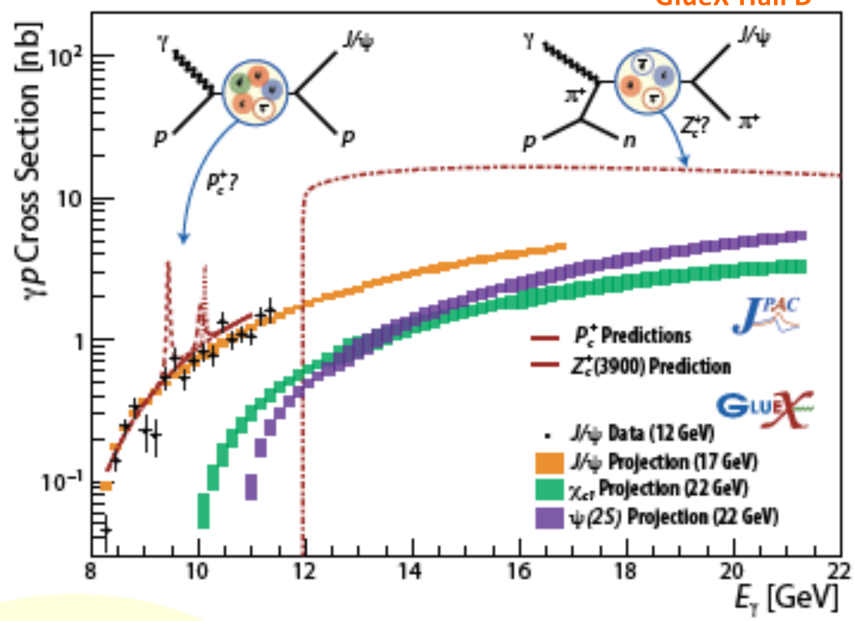


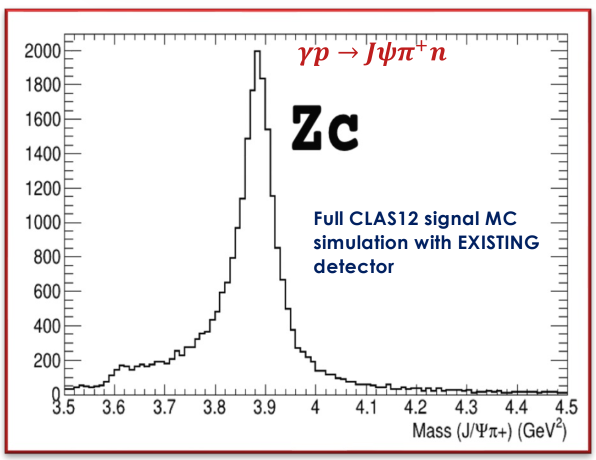

- **Many "XYZ" states observed in B decays, $e^+e^-$ colliders**
- **Scarce consistency between various production mechanisms**
- **Significant theoretical interest and progress, but internal structure not understood yet**

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

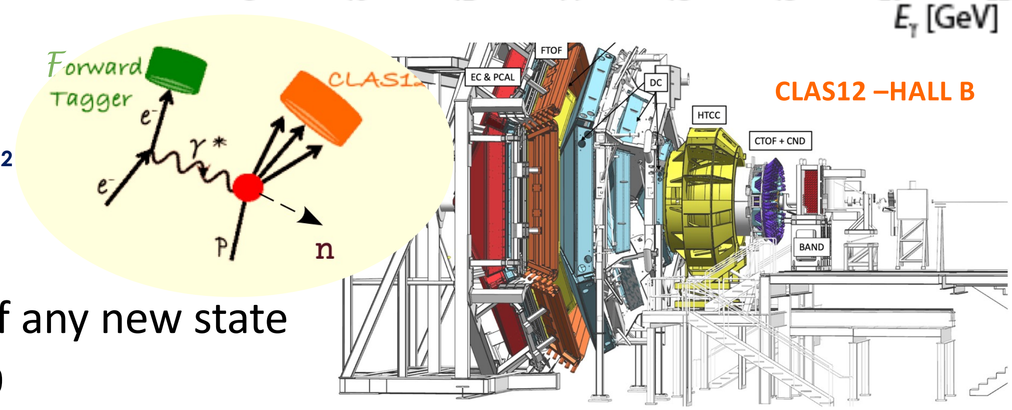
- **Never direcly produced using γ/lepton beam**
- Direct probe of the $Z_c \rightarrow J/\psi\pi$ coupling without re-scattering effects
- **Photoproduction** tool already used to validate the existence of **charmed 5quark**.
- With an energy upgraded CEBAF, this line of investigation can be **extended to other exotic candidates.**

GlueX-Hall D



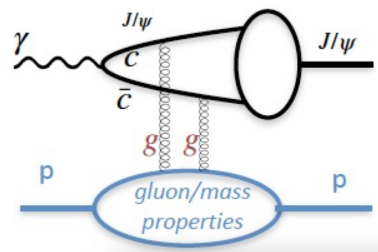

$e^-$ 2.5-4.5° →
$Q^2$<0.03 (GeV/c)$^2$



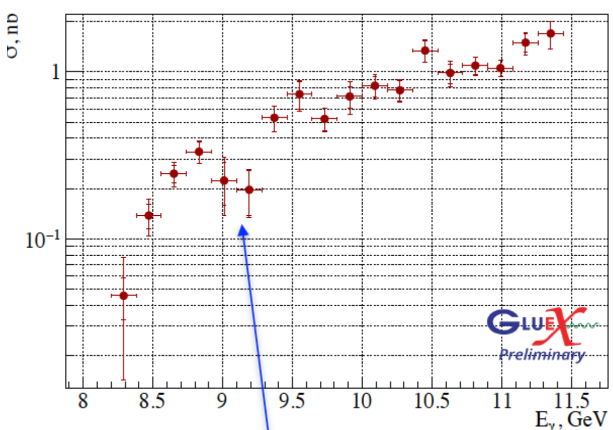

- **$Q^2$ evolution** of any new state produced

# J/ψ photoproduction near threshold

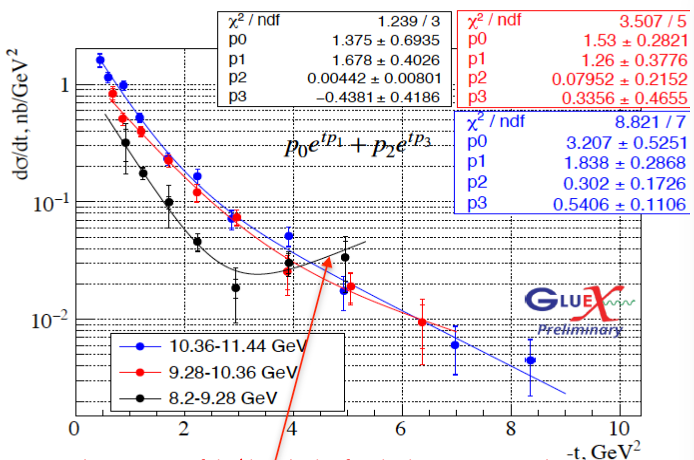
- **Near-threshold J/ψ photoproduction:**
  a tool to access the gluonic content of the nucleon
  (mass radius, nucleon mass, gravitational FFs, etc )



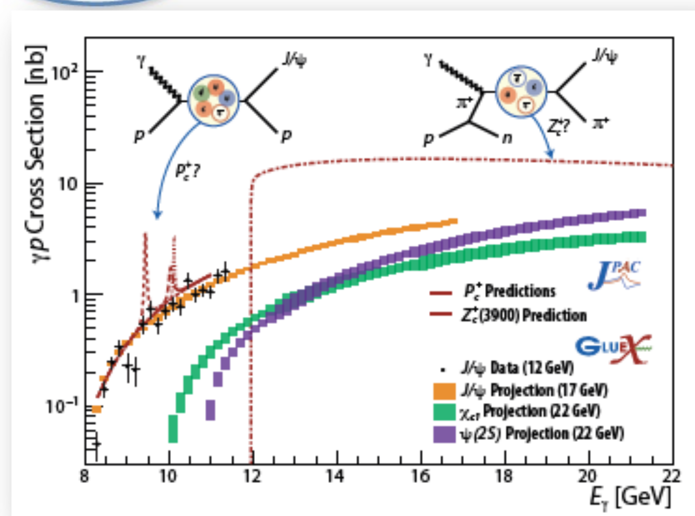

..based on some assumptions (mainly gluon exchange)




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




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



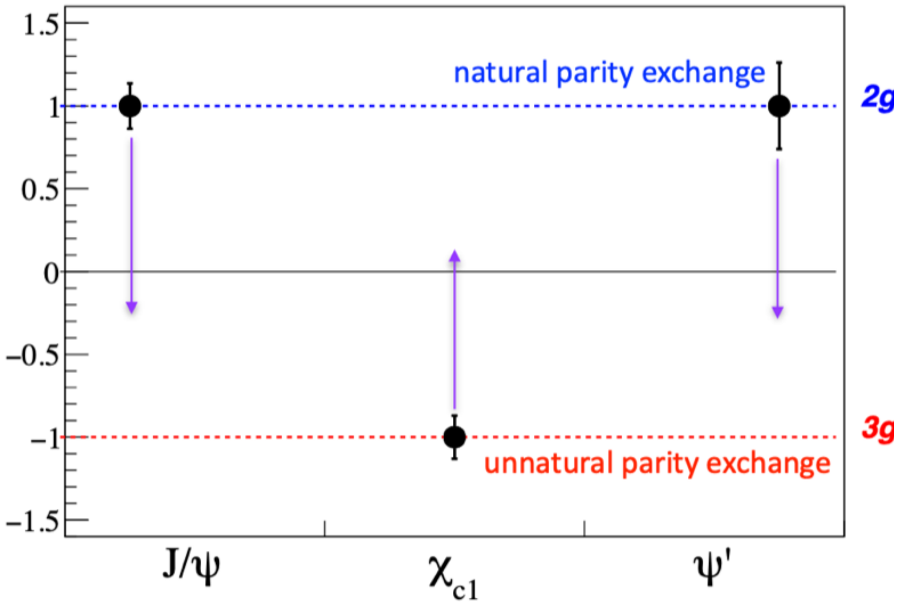

- In general, consistent with the t-channel production via gluon-exchange but current experimental precision is not sufficient to completely rule out alternative interpretation of the data.

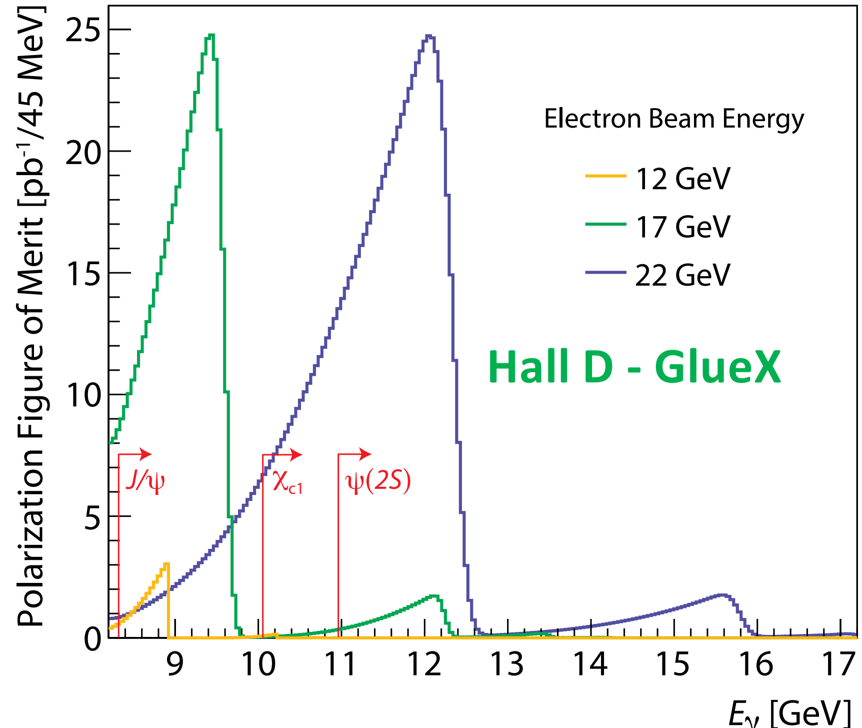
- Similar precision with the SoLID detector in Hall A

# J/ψ Photoproduction – Polarization

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

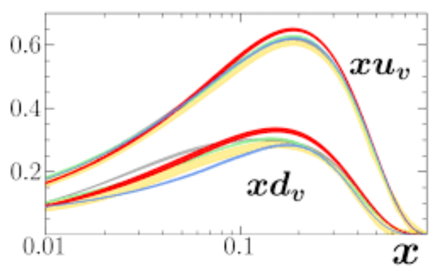
$$naturality \times (-1)^J = P$$

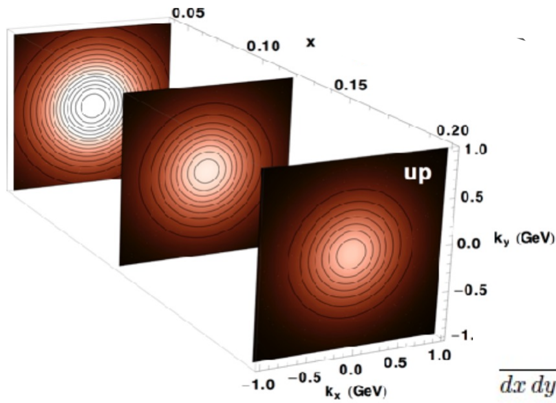


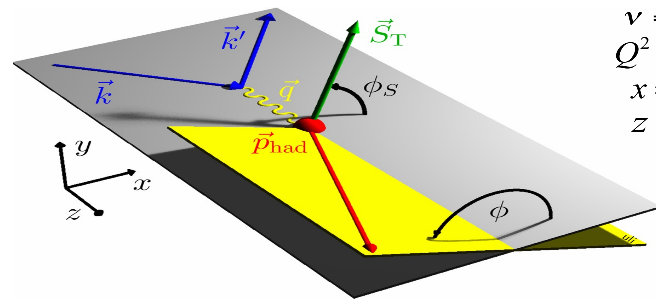




Any deviation from the expected naturality (+ or -1) indicates contribution of mechanism different from what is needed to study mass properties of the proton

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




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

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

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

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

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

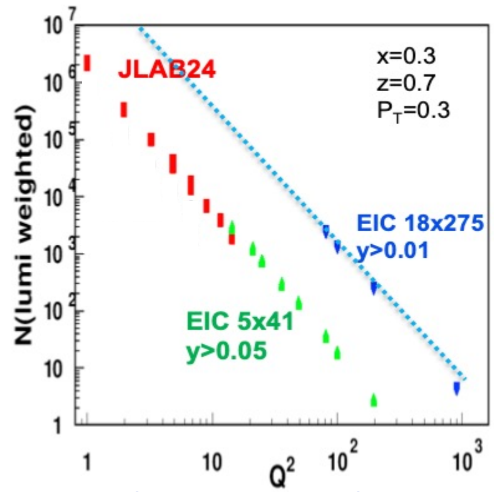
**Complexity in the extraction**

**High statistics**
**Wide kinematical range**

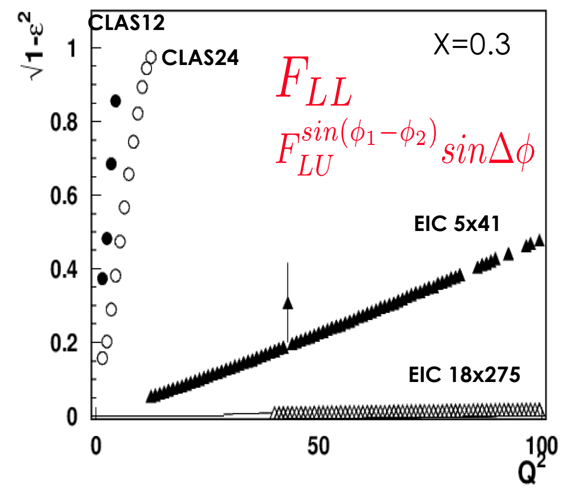
# The Nucleon Structure in 3D

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

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



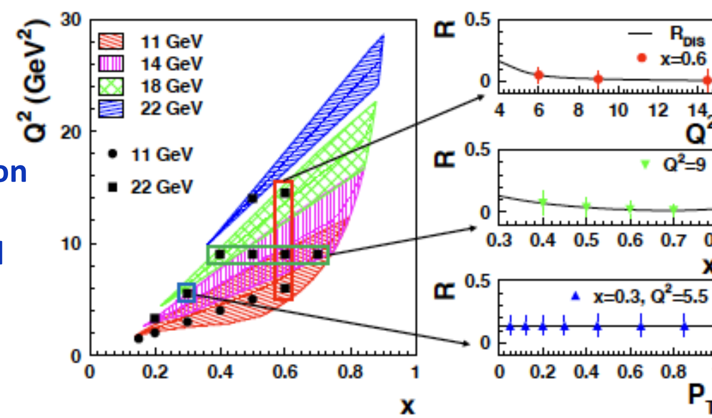

ε = ratio of long. and trans. photon flux



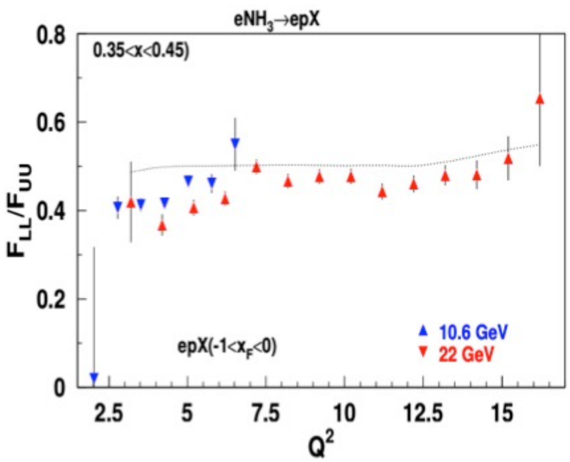

- Complementarity with EIC

$R=\sigma_L/\sigma_T$

- Unique determination of R essential to properly understand SIDIS measuements
- Needed by EIC



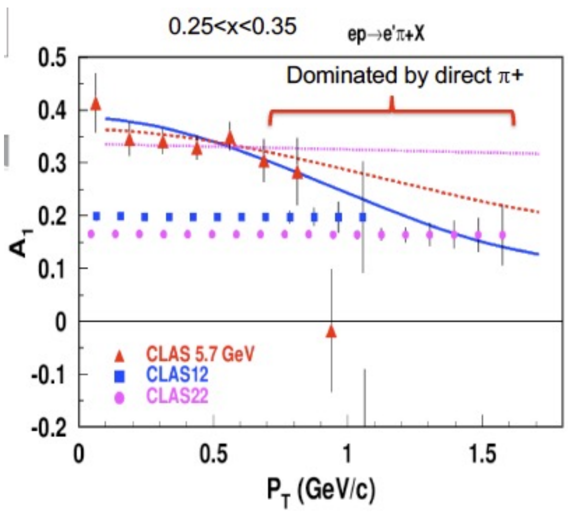
# SIDIS Enhanced Multi-D Phase Space @ 22 GeV



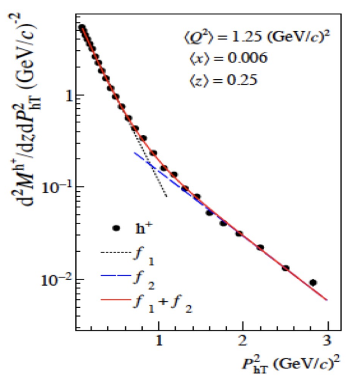

- **$Q^2$ evolution studies possible**

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**

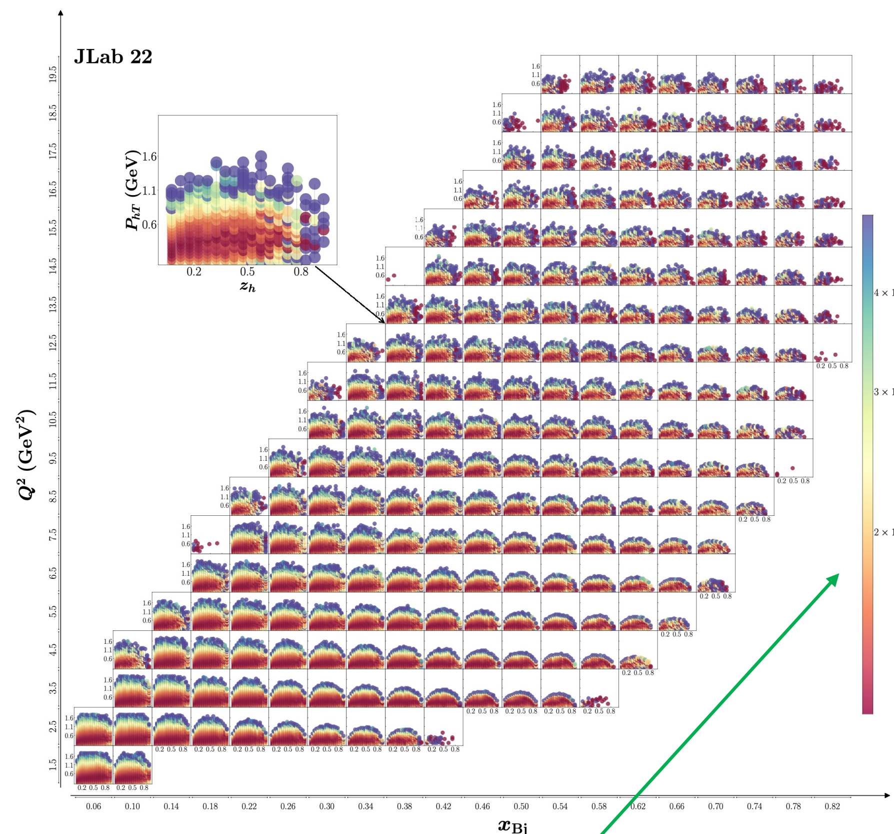



- **Enhanced $P_T$ Range**




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

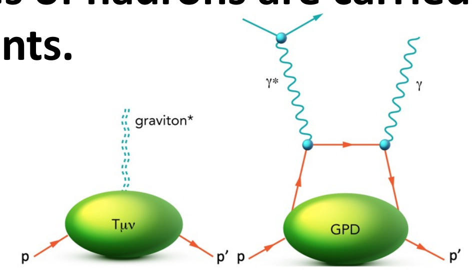
**Projections for 100 days of running with L= $10^{35}$ cm$^{-2}$s–1 using the existing CLAS12 simulation/reconstruction chain**



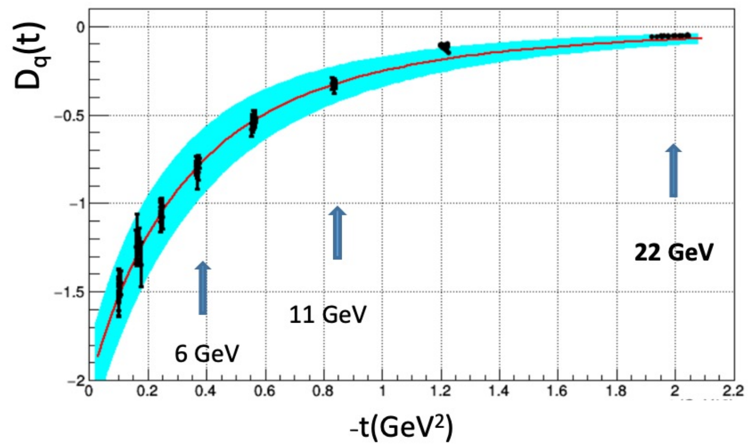

**Expected uncertainties for SIDIS cross sections in 4D bins**

# Mechanical Properties of the Proton

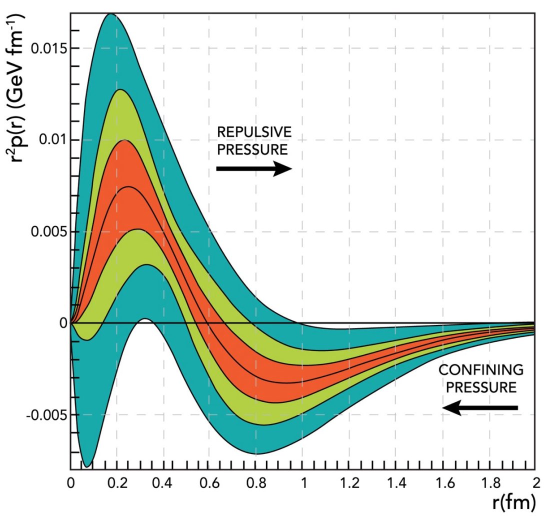
**GFFs : describe how energy, spin, and various mechanical properties of hadrons are carried by quark and gluon constituents.**




A massless spin-2 field would couple to the stress–energy tensor in the same way that gravitational interactions do

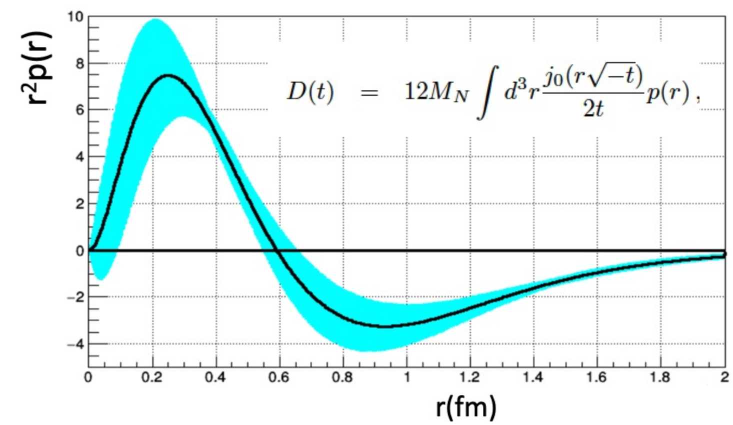



**GFF D(t)**: describes the pressure distribution in the nucleon, accessible through measurements of the CFFs of DVCS




- First experimental extraction of the D(t) term and the determination of the pressure distribution inside the proton obtained with JLab-CLAS DVCS data @ 6 GeV

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

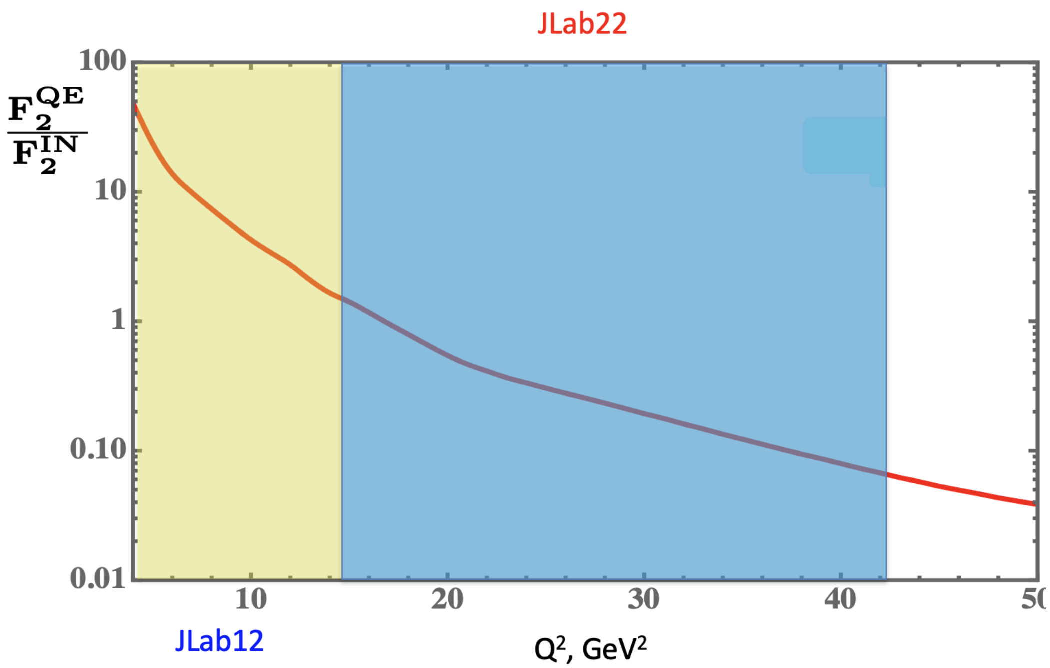


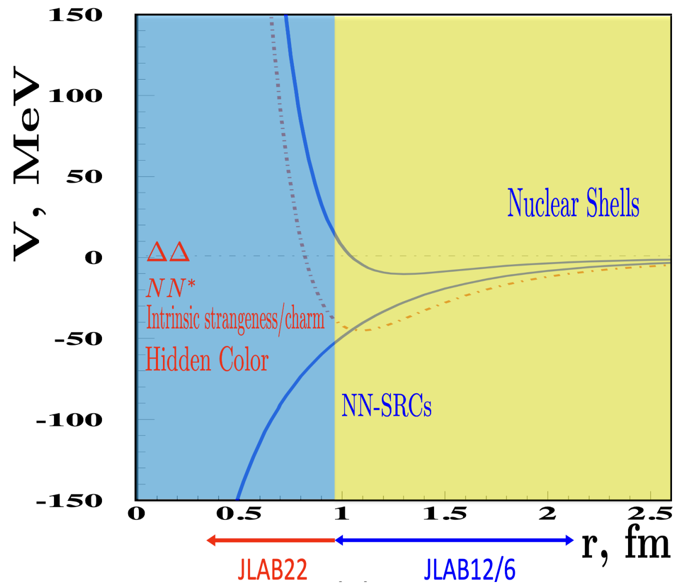
# Nuclear Dynamics at Extreme Conditions

**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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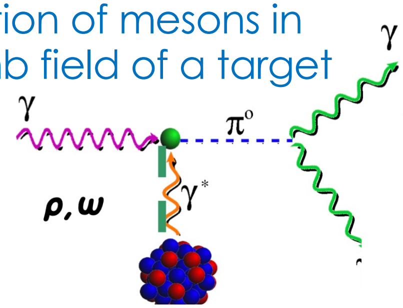
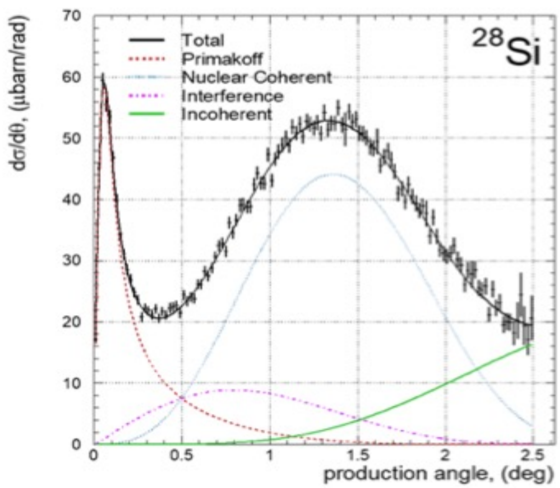
# QCD Confinement and Fundamental Symmetries

- $\gamma$/e-production of mesons in the Coulomb field of a target

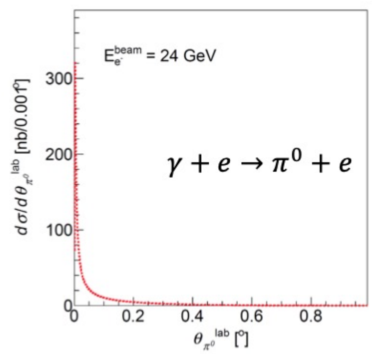



PrimEx-II: $\gamma + {}^{28}Si \rightarrow \pi^0 + {}^{28}Si$




Science 368, 506-509 (2020)

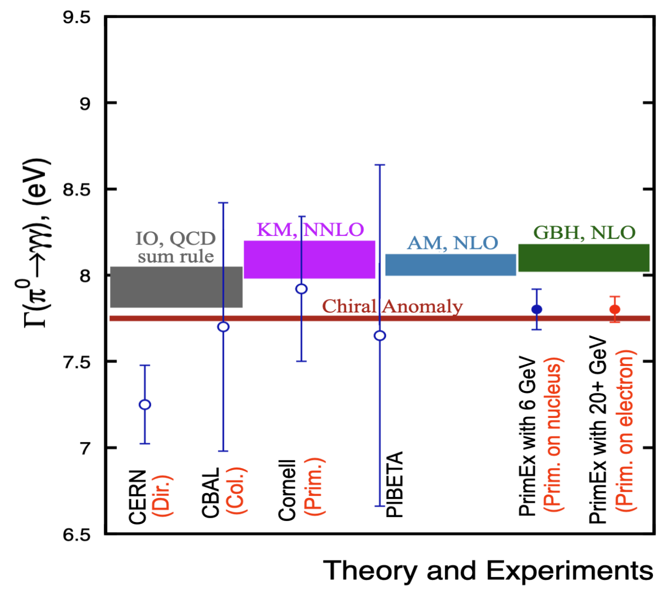
- **$\pi^0$ Primakoff production off an electron target**




| Measurement | Reaction | $E_{th}$ (GeV) |
|---|---|---|
| $\Gamma(\pi^0 \rightarrow \gamma\gamma)$ | $\gamma + e \rightarrow \pi^0 + e$ | 18.0 |
| $F(\pi^0 \rightarrow \gamma^*\gamma)$ | $e + e \rightarrow \pi^0 + e + e$ | 18.1 |

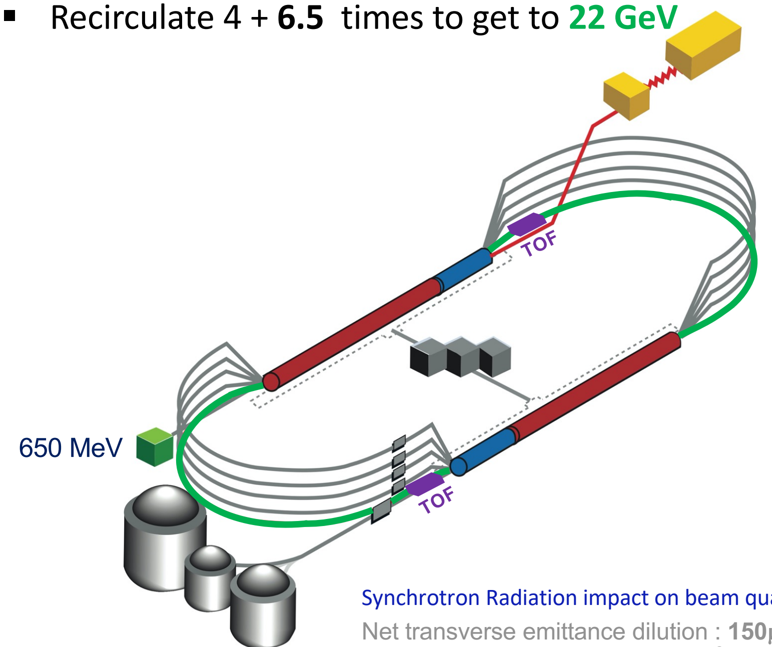
**$\pi^0$ Primakoff off an e- target: eliminate nuclear bkg**

- **$\pi^0$ radiative decay width**: can be predicted at ≈ 1% precision in the low energy QCD



# 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**

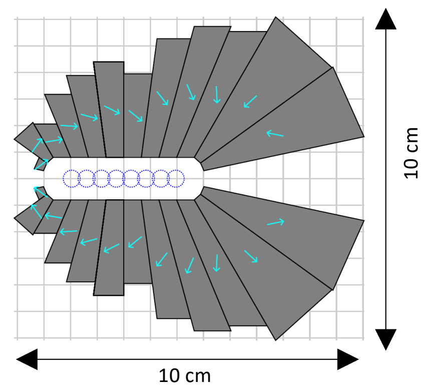



Synchrotron Radiation impact on beam quality

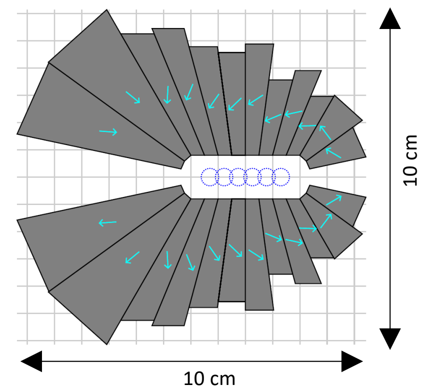
Net transverse emittance dilution : **150µm**
Net natural energy spread : **$2\times10^{-3}$**
Net synchrotron radiated energy: **1 GeV**

**Enabling Technology:**

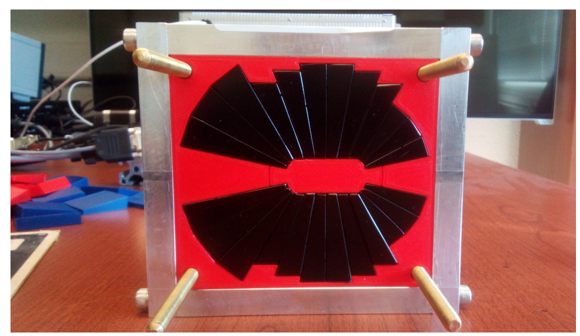
Novel **permanent magnets** CBETA- like (power & cost savings)




**Focusing Magnet BF** $L_{QF}$= 1.67 m

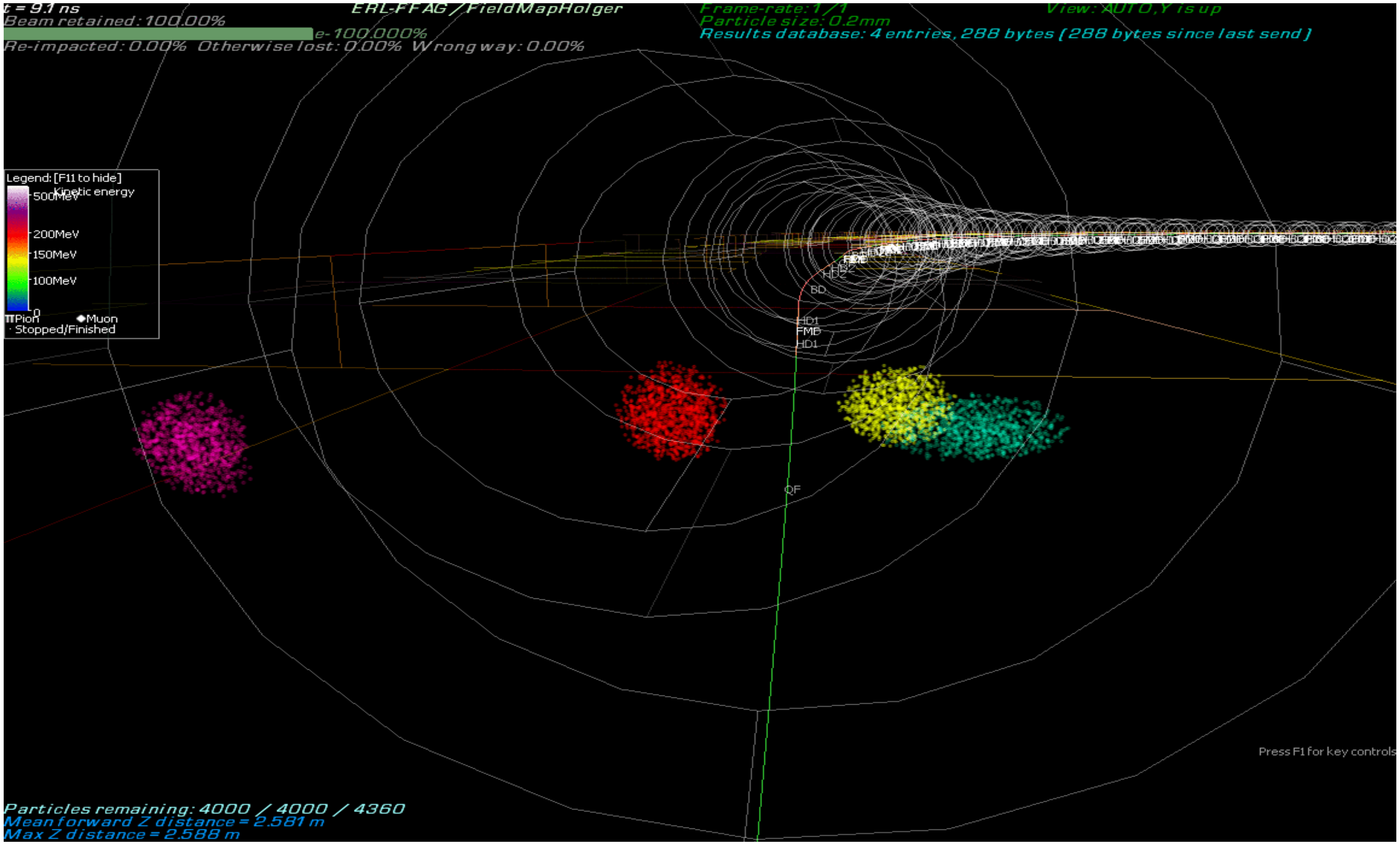



**Defocusing Magnet BD** $L_{BD}$= 1.24 m



- **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

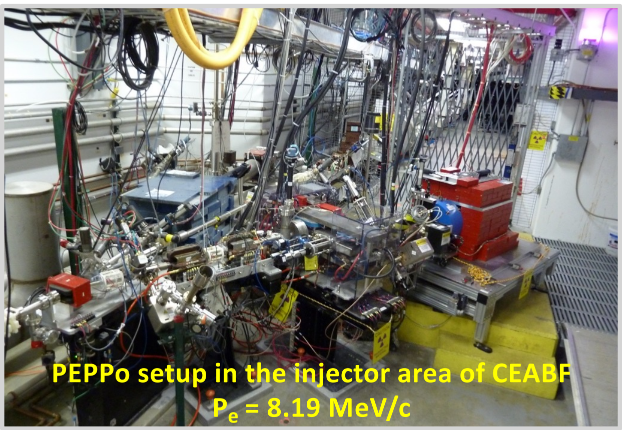




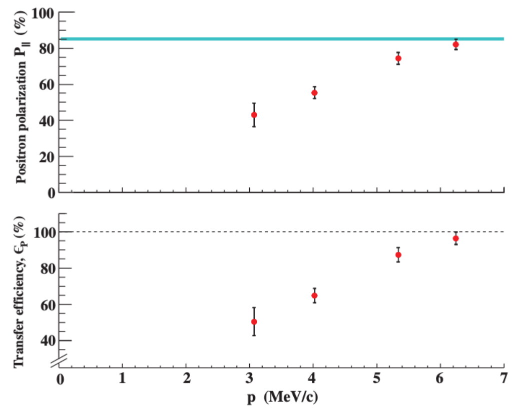

Courtesy A. Bogacz

# 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 $\mu A$ unpolarized positron beams.



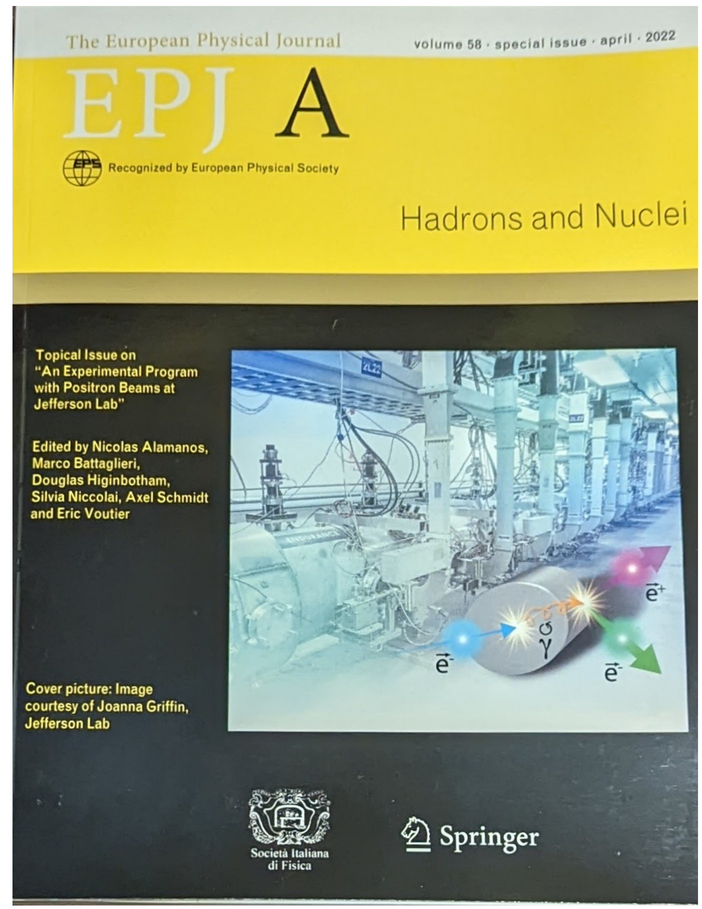

- Demonstrated for the first time the efficient transfer of polarization from $e^-$ to $e^+$




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
- Proposals and LoIs submitted to the JLab Program Advisory Committee

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

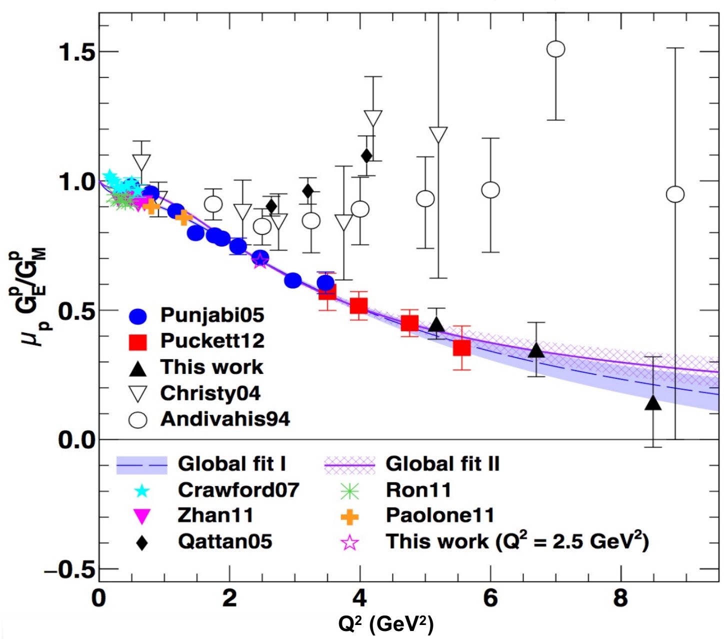


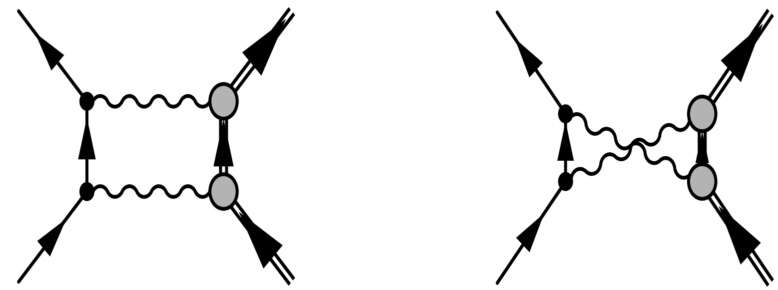
# One Detailed Example: Understanding Two Photo Exchange

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.*



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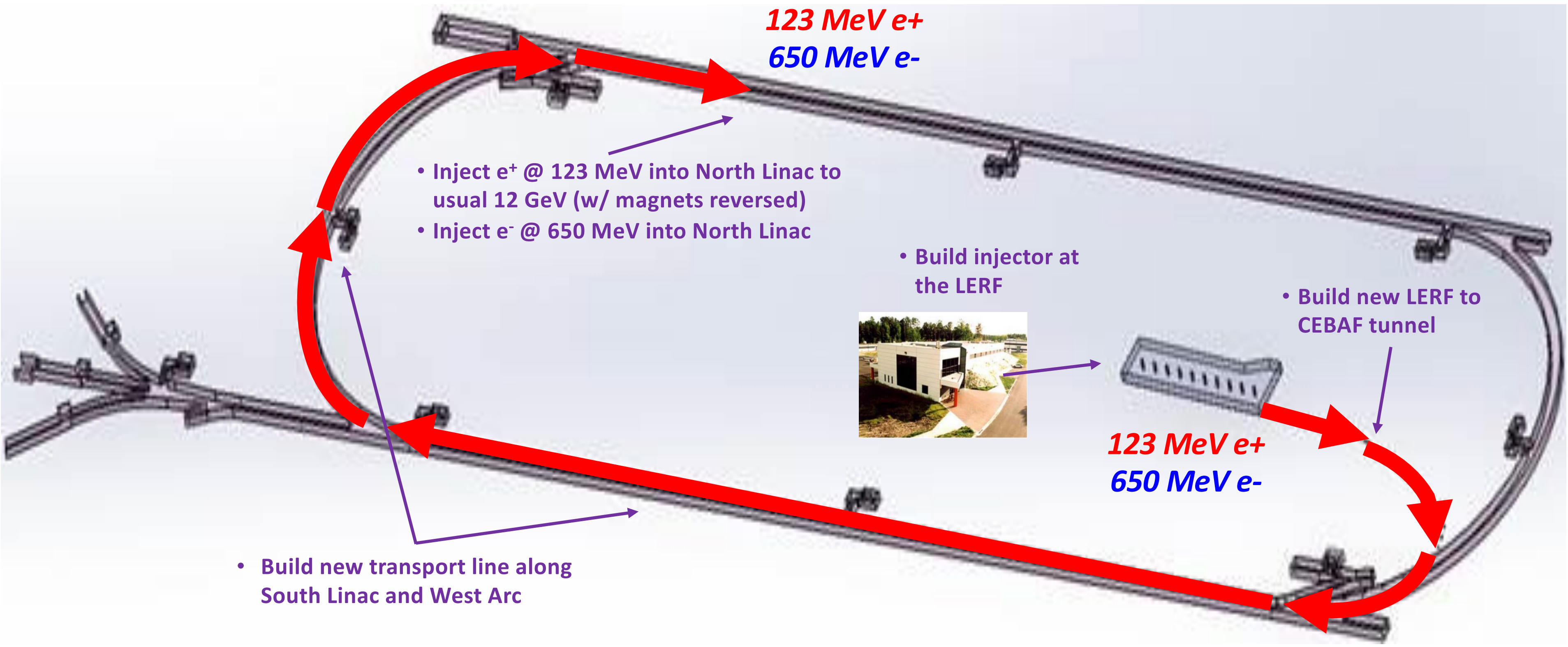
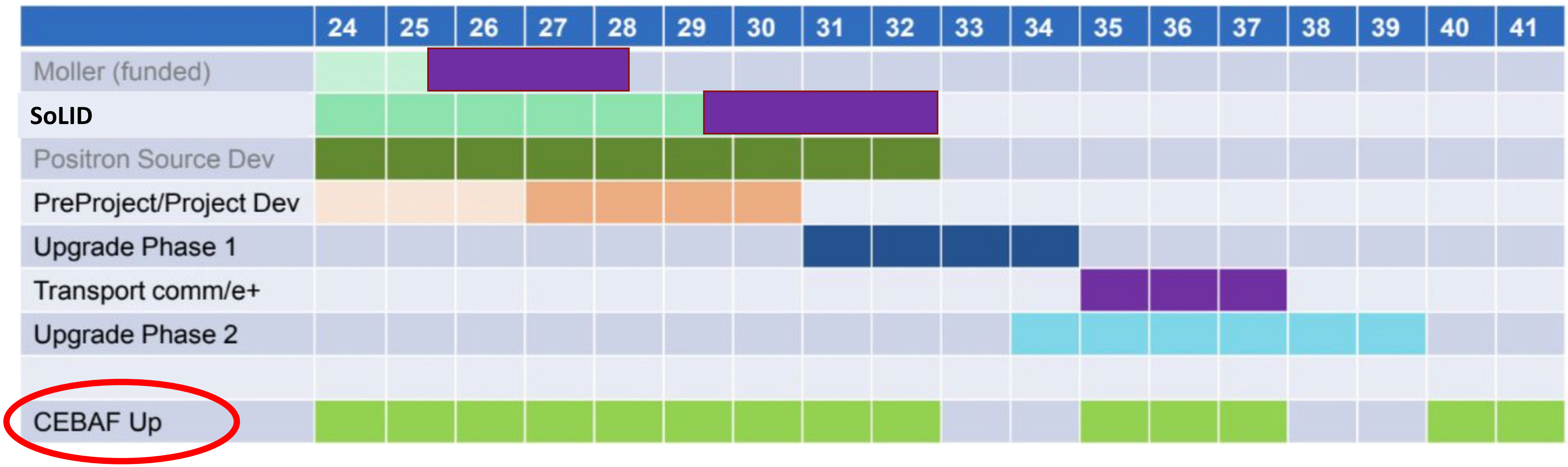
# Low Energy Recirculator Facility (LEFRF) As The New Injector Facility for CEBAF



# VERY ROUGH Timeline

Gantt chart 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

- 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, and beyond including SoLID

- 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 will be presented at the NP Long Range Plan, currently under discussion

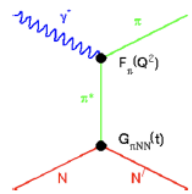
# Backup

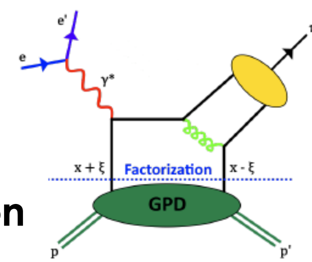
# Pion Structure Studies with Exclusive Measurements

- 1) Determine the pion form factor, $F_\pi$ to high $Q^2$
- $F_\pi$ is a key QCD observable
- Measure $F_\pi$ 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**

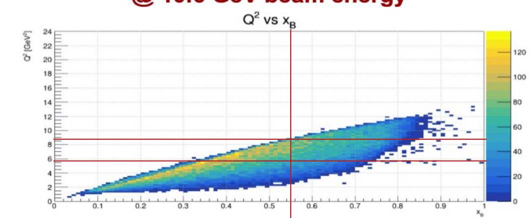
- $\sigma_L$ scales to leading order as $Q^{-6}$
- $\sigma_T$ expectation as $Q^{-8}$
- As $Q^2$ becomes large: $\sigma_L >> \sigma_T$

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

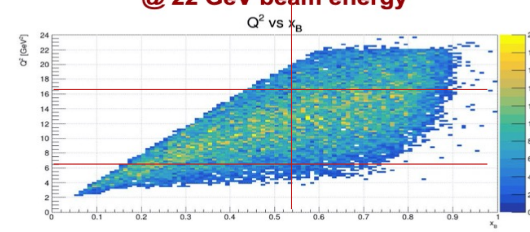
$F_\pi$ asymptotic behavior rigorously calculable in pQCD
$F_\pi$ $Q^2$<0.3 measured

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

@ 10.6 GeV beam energy



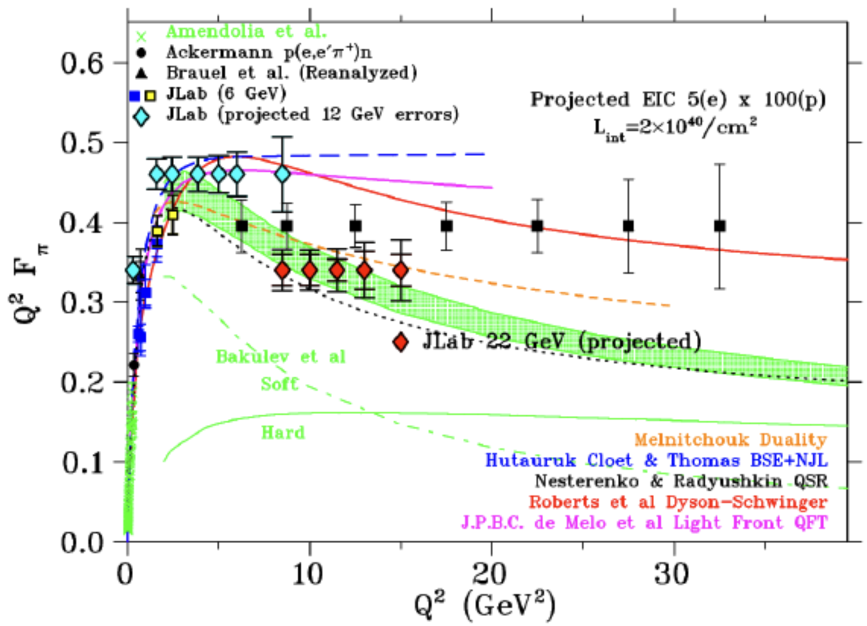

@ 22 GeV beam energy




**All these studies require $\sigma_L/\sigma_T$ separation**

# JLab22 $F_\pi$ 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 $F_\pi$ values to $Q^2 = 13\ GeV^2$
  - Larger error point at $Q^2 = 15\ GeV^2$




- JLab energy upgrade and Hall C upgrade provides <u>much improved</u> overlap of $F_\pi$ data between JLab and EIC

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



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# Partonic Structure and Spin

## Nucleon Strangeness

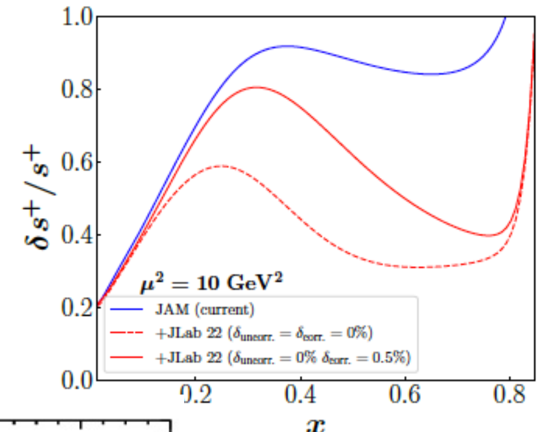
- The nucleon strange sector is largely unexplored with an up to 80% uncertainty in the $s^+ = s + \bar{s}$ PDF

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

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

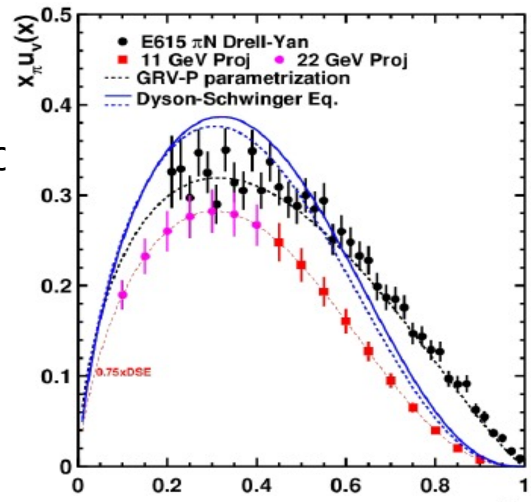
PVDIS @ 22 GeV with the SoLID

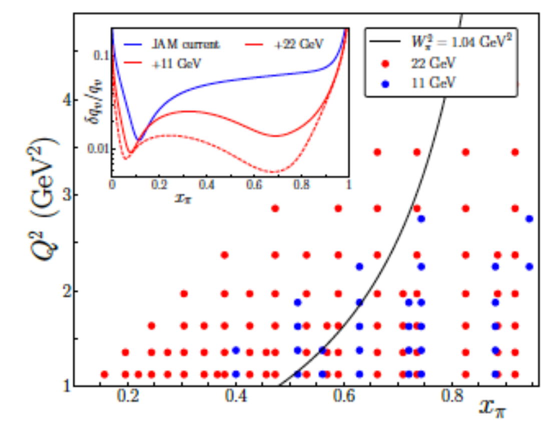
~100 days, 40 μA beam split between 40 cm D and H targets




## Meson structure

- Available phase space significantly increased
  ➔ large improvement in the determination of the valence structure of the pion
  ➔ kin. coverage to smaller $x_\pi$ 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 $x_\pi$ region

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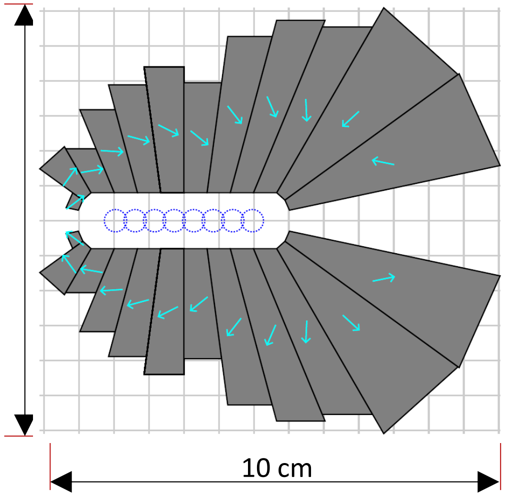
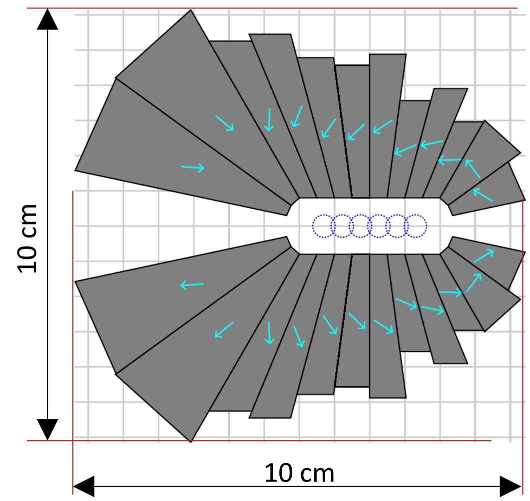
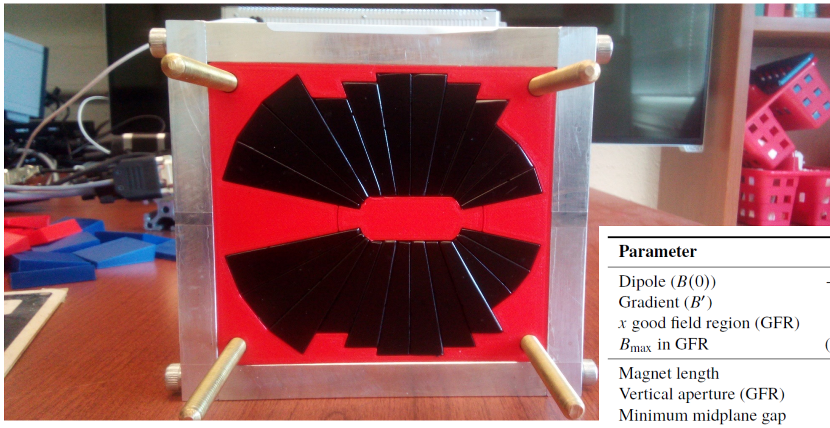
# Permanent Magnet Design – Open Mid-plane Geometry




**Focusing Magnet BF**
$G_F$= -41.13 T/m
$L_{QF}$= 1.67 m
$B_F$= -0.812 T

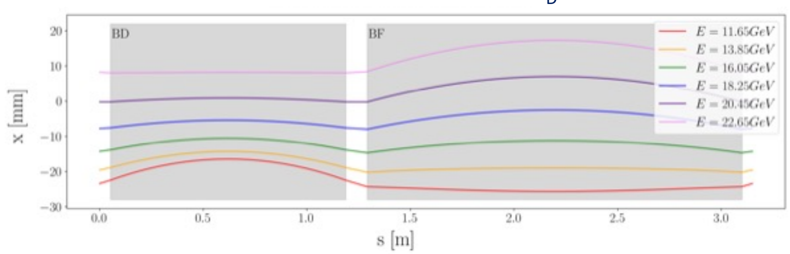



**Defocusing Magnet BD**
$G_D$= 43.44 T/m
$L_{BD}$= 1.24 m
$B_D$= -0.593 T



Courtesy A. Bogacz

| Parameter | Value | Unit |
|---|---|---|
| Dipole ($B(0)$) | –0.9512 | T |
| Gradient ($B'$) | 55.54 | T/m |
| $x$ good field region (GFR) | ±10.5 | mm |
| $B_{max}$ in GFR | (–)1.536 | T |
| Magnet length | 45 | mm |
| Vertical aperture (GFR) | ±7.5 | mm |
| Minimum midplane gap | ±3 | mm |
| Material | NdFeB | |
| Grade | N42EH | |
| $B_r$ | 1.28–1.33 | T |
| $\mu_0 H_{cJ}$ | 2.9 | T |




orbits

- **Each cell: 1 BF +1 BD, total length = 3.15 m**
- **Each arc: 70 cells**

- **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**

# CEBAF @ 22 GeV

| Pass number | Beam Energy [GeV] | $\epsilon_N^x$ [mm mrad] | $\sigma_{\frac{\Delta E}{E}}$ [%] |
|---|---|---|---|
| 1 | 2.8 | 1.0 | 0.01 |
| 2 | 5.0 | 2 | 0.02 |
| 3 | 7.2 | 4 | 0.02 |
| 4 | 9.4 | 12 | 0.03 |
| 5 | 11.5 | 20 | 0.03 |
| 6 | 13.7 | 21 | 0.04 |
| 7 | 15.8 | 23 | 0.05 |
| 8 | 17.9 | 26 | 0.06 |
| 9 | 19.9 | 34 | 0.08 |
| 10 | 21.9 | 49 | 0.11 |
| 10.5 | 22.9 | 61 | 0.12 |

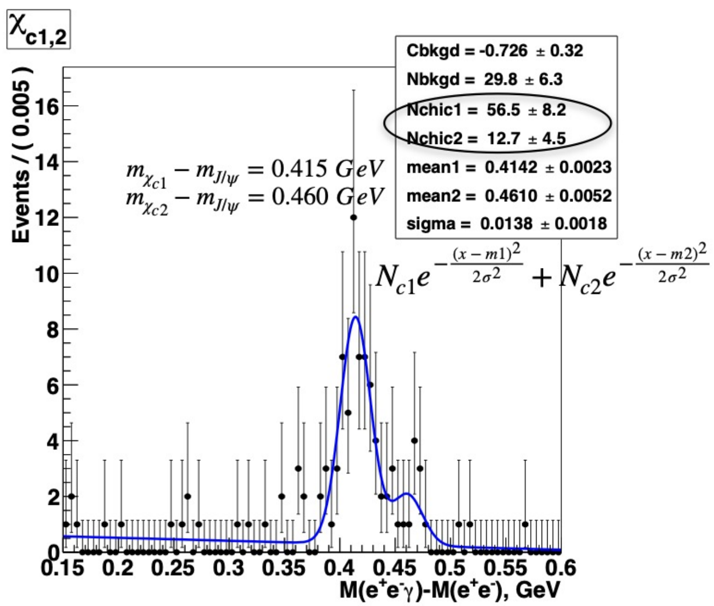
Table 1: The horizontal and longitudinal emittances diluted by synchroton radiation as delivered at various passes. Here, $\sigma_{\frac{\Delta E}{E}} = \sqrt{\frac{\Delta\epsilon_E^2}{E^2}}$.

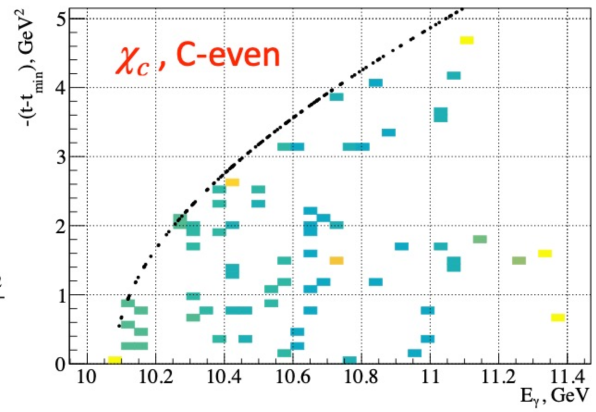
Synchrotron Radiation impact on beam quality

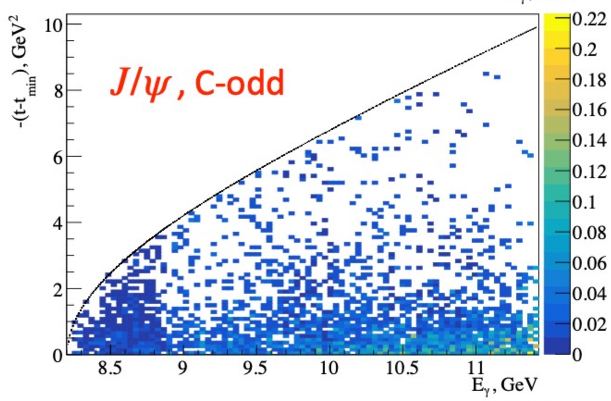
- Net transverse emittance dilution (normalized): **150μm**
- Net natural energy spread: **$2\times10^{-3}$**
- Net synchrotron radiated energy: **1 GeV**

# Higher Charmonium States, $\chi_c$ and $\psi'$ with GlueX

$$\gamma p \to \chi_c p \to (J/\psi\gamma)p \to (e^+e^-\gamma)p$$




$$weight = \frac{1}{L(E_\gamma)}$$

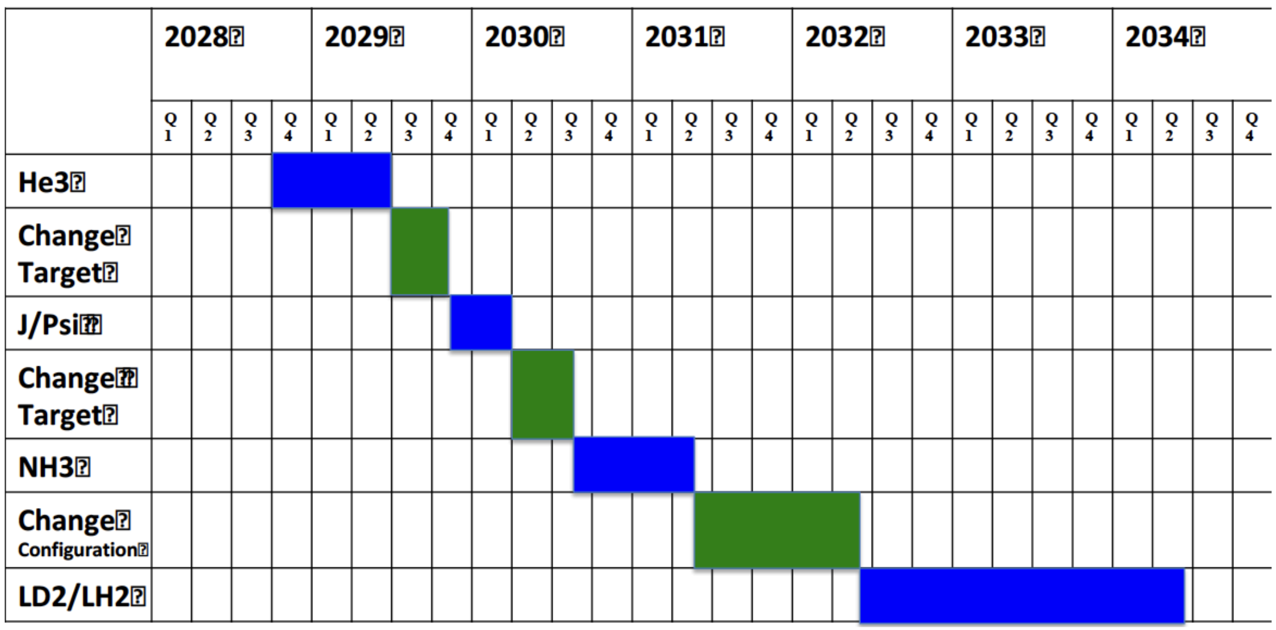
- $\chi_{c1}(3511)$ and $\chi_{c2}(3556)$, $1^{++}$ and $2^{++}$ $(1P)$, $E_\gamma^{thr} = 10.1$ GeV
- C-even charmonium states require 3g-exchange
- Dramatic difference in $(E_\gamma, t)$ distribution w.r.t $J/\psi$

- GlueX has observed also a small number of $\psi'(3686)$ $(2S)$ states in $\gamma p \to \psi' p \to (e^+e^-)p$, $\quad E_\gamma^{thr} = 10.9$ GeV

# SoLID Timeline

➢ **Tentative Run-Plan (2021 Science Review):**

- ❑ Start with standard dependencies (polarized $^3He$, $LH_2$)
- ❑ Minimize switchover time (radiation level)
- ❑ Assuming starting data taking from FY2029 and ~ 50% efficiency)



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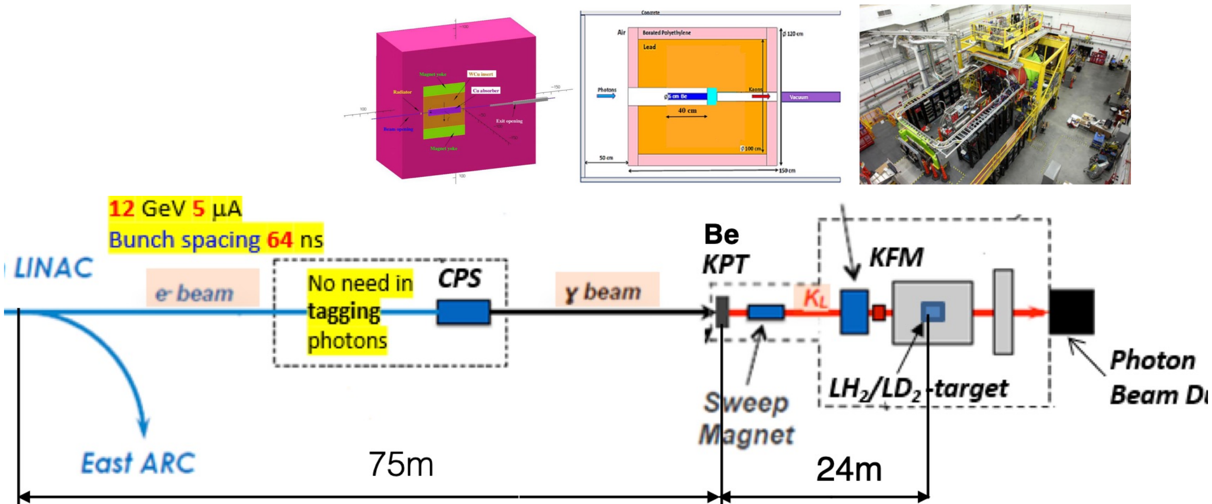
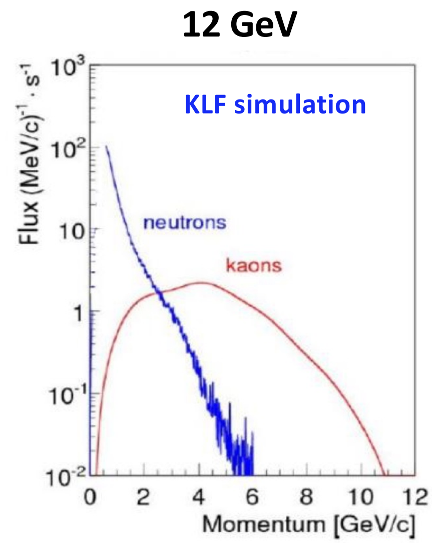
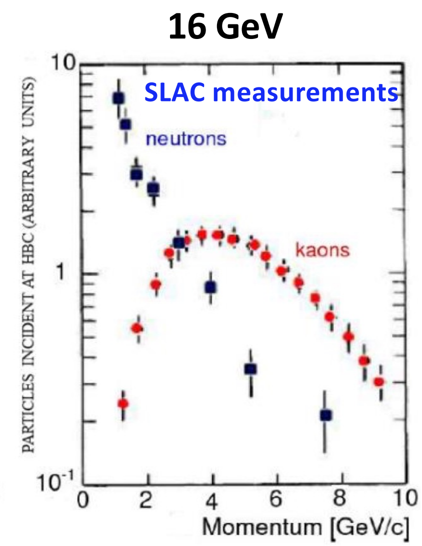
# K-Long Facility in Hall D




$K_L$ beam facility is under construction

- Commencing 2026-2027
- Exciting possibilities to elucidate strange quark sector
- Technical design/prototyping/construction

$$N(K_L)/sec \sim 10^4 \;\rightarrow\; \frac{N(K_L)_{JLAB}}{N(K_L)_{SLAC}} \sim 10^3$$

## Proposals to PAC51

- p-DVCS@CLAS12 - CLAS12 and PWG endorsed – PR12+23-002
  Beam charge asymmetries for deeply virtual Compton scattering on the proton at CLAS12
  *E. Voutier, V. Burkert, S. Niccolai, R. Paremuzyan*
- Coulomb corrections in DIS - PWG endorsed – PR12+23-003
  Measurement of deep inelastic scattering from nuclei with electron and positron beams to constrain the impact of Coulomb corrections in DIS
  *D. Gaskell, N. Fomin, B. Henry*
- A' search - PWG endorsed – PR12+23-005
  A dark photon search with a JLab positron beam
  *B. Wojtsekhowski, A. Gasparian, N. Liyanage, B. Raydo*
- p-DVCS@NPS - PWG endorsed – PR12+23-006
  Deeply virtual Compton scattering using a positron beam in Hall C
  *C. Muñoz Camacho, M. Mazouz*
- TPE@CLAS12 - CLAS12 and PWG endorsed – PR12+23-008
  A direct measurement of hard two-photon exchange with electrons and positrons at CLAS12
  *A. Schmidt, J.C. Bernauer, V. Burkert, E. Cline, I. Korover, T. Kutz, N. Santiesteban*
- $e^+$ Super-Rosenbluth – PR12+23-012
  A measurement of two-photon exchange in unpolarized elastic positron-proton and electron-proton scattering
  *J. Arrington, M. Nycz, S.N. Santiesteban, M. Yurov*

## Letters-of-Intent to PAC51

- p-GPs - PWG endorsed – LOI12+23-001
  Measurement of the generalized polarizabilities of the proton with positron and polarized electron beams
  *N. Sparveris*
- Axial form factor - PWG endorsed – LOI12+23-002
  The axial form factor of the nucleon from weak capture of positrons
  *D. Dutta*
- Dark Bhabha – LOI12+23-005
  A hopefully amplitude-level search for a Dark Photon in Bhabha scattering
  *D. Mack*
- TPE in polarization transfer – LOI12+23-008
  Polarization transfer in positron-proton elastic scattering
  *A. Puckett, J.C. Bernauer, A. Schmidt*
- Dispersive effects in DIS – LOI12+23-015
  Energy dependence of dispersive effects in unpolarized inclusive elastic electron/positron-nucleus scattering the impact of Coulomb correct
  *P. Gueye, J. Arrington, P. Giuliani, D. Higinbotham*

# SoLID

6 approved proposals:

**E12-10-006:**Single Spin Asymmetries on Transversely Polarized3He

**E12-11-007:**Single and Double Spin Asymmetries on Longitudinally Polarized3He

**E12-11-108:**Single Spin Asymmetries on Transversely Polarized Proton

**E12-10-007:** Precision Measurement of Parity-Violation in Deep Inelastic Scattering Over a Broad Kinematic Range

**E12-12-006:**Near Threshold Electroproduction of J/Psi at 11 GeV

**E12-22-004**:Measurement of the Beam Normal Single Spin Asymmetry in Deep Inelastic Scattering using the SOLID Detector (the effect of two- photon exchange in DIS via BNSSA and possible effects beyond the parton-model description that may enhance the asymmetry.)

6 RUN Groups proposals

E12-10-006A: Dihadron Electroproduction in DIS with TransverselyPolarized 3He Target at 11 and 8.8 GeV

E12-11-108A/E12-10-006B:Target Single Spin Asymmetry Measurements in the Inclusive Deep-Inelastic $\vec{N}(e,e^\prime)$ Reaction onTransversely Polarized Proton and Neutron ($^3$He) Targets using the SoLID Spectrometer

E12-12-006A: Timelike Compton Scattering on the proton in e+e- pair production with SoLID at 11 GeV

E12-10-006C: Measurement of Deep Exclusive pi- Production using a Transversely Polarized 3He Target and the SoLID Spectrometer

E12-11-108B/E12-10-006D: K+/- Production in Semi-Inclusive Deep Inelastic Scatteringusing Transversely Polarized Targets and the SoLID Spectrometer

E12-11-007A/E12-10-006E: A Precision Measurement of Inclusive g2n and d2n with SoLID on a Polarized 3He Target at 8.8 and 11 GeV

1 Conditionally approved

PR12-22-002: It is about PV EMC.

Previous LOIs

LOI12-21-002: Measurement of the Tensor Observable Azz using SoLID

LOI-12-21-004: Measurement of the Deuteron Tensor Structure Function b1 with SoLID

LOI12-16-007: Parity Violating DIS on polarized 3He.

2 LOIs submitted to PAC51

LOI12-23-012 A Measurement of Double Deeply Virtual Compton Scattering in the di-muon channel with the SoLID Spectrometer

LOI12-23-006 A Measurement of the N to Delta Transition Form Factors with the SoLID detector