# The 22 GeV Physics Program and the Project Development

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Positron Working Group Workshop

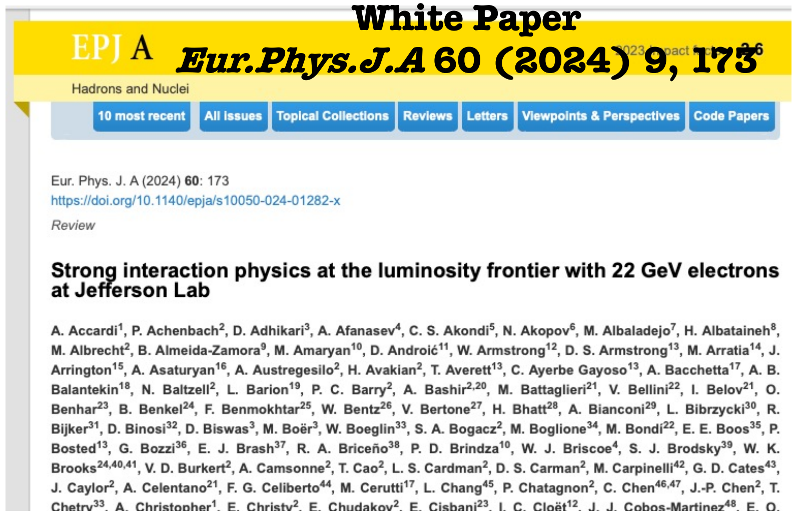
Jefferson Lab (USA) March 24 – 28, 2025

# The 22 GeV Physics Program

## WHY 22 GeV?

- A NEW territory to explore
- A BRIDGE between JLab @ 12 GeV and EIC
- CRITICAL to some measurement @ EIC
- A BETTER insight into our current program
- Bi-weekly meetings to refine the scientific case (2024)

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




Eur. Phys. J. A (2024) **60**: 173
https://doi.org/10.1140/epja/s10050-024-01282-x

*Review*

**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], D. Androić[11], W. Armstrong[12], D. S. Armstrong[13], M. Arratia[14], J. Arrington[15], A. Asaturyan[16], A. Austregesilo[2], H. Avakian[2], T. Averett[13], C. Ayerbe Gayoso[13], A. Bacchetta[17], A. B. Balantekin[18], N. Baltzell[2], L. Barion[19], P. C. Barry[2], A. Bashir[2,20], M. Battaglieri[21], V. Bellini[22], I. Belov[21], O. Benhar[23], B. Benkel[24], F. Benmokhtar[25], W. Bentz[26], V. Bertone[27], H. Bhatt[28], A. Bianconi[29], L. Bibrzycki[30], R. Bijker[31], D. Binosi[32], D. Biswas[3], M. Boër[3], W. Boeglin[33], S. A. Bogacz[2], M. Boglione[34], M. Bondí[22], E. E. Boos[35], P. Bosted[13], G. Bozzi[36], E. J. Brash[37], R. A. Briceño[38], P. D. Brindza[10], W. J. Briscoe[4], S. J. Brodsky[39], W. K. Brooks[24,40,41], V. D. Burkert[2], A. Camsonne[2], T. Cao[2], L. S. Cardman[2], D. S. Carman[2], M. Carpinelli[42], G. D. Cates[43], J. Caylor[2], A. Celentano[21], F. G. Celiberto[44], M. Cerutti[17], L. Chang[45], P. Chatagnon[2], C. Chen[46,47], J.-P. Chen[2], T. Chetry[33], A. Christopher[1], E. Christy[2], E. Chudakov[2], E. Cisbani[23], I. C. Cloët[12], J. J. Cobos-Martinez[48], E. O.

- LNF Workshop Dec 9-13, 2024


A document outlining the progress of the scientific case will be available within a few months


- 91 participants
- 62 plenary talks
- 6 parallel sessions

A lot of scientific discussions

...but also fun

Thanks Susan for the photos!

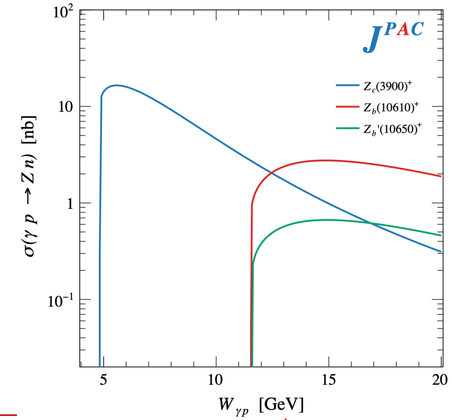




The path forward is clear

# 22 GeV: A New Window into the World of XYZ States

- This program suits perfect the 22 GeV upgrade: Thresholds for XYZ states open just above 12 GeV:
- Direct Production: Photons can directly produce XYZ states, unlike some other methods that rely on the decay of heavier particles.
- Complementary Information: Photoproduction can provide complementary information to what we learn about XYZ states from other production mechanisms, giving us a more complete picture.

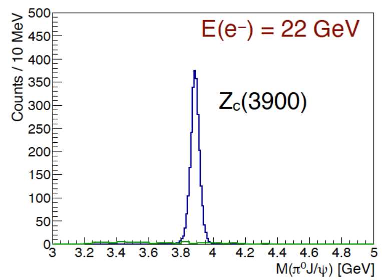



Measurements of X(Y) Z states at JLab with 22 GeV e- are feasible!

Simulations from GlueX & CLAS12 with existing detectors

**GlueX**

$\gamma p \to J/\psi\pi^0 p$, $J/\psi \to e^+e^-$




- Assumes 1 year @ 500 pb$^{-1}$, Br($Z_c \to \pi J/\psi$) = 5%
  - N($Z_c \to J/\psi\pi$) ≈ 2500 from $\gamma p \to Z_c^- \Delta^{++}$
- Can compare charged and neutral $Z_c$ production
  - Neutral production cross sections more uncertain

**CLAS12**

Courtesy of D. Glazier

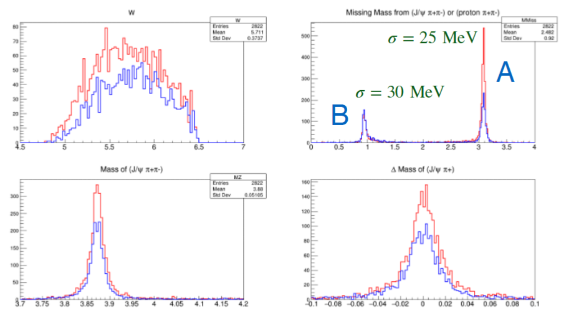
- CLAS12 has excellent PID
- Can measuring missing particles
- Simulations assuming $10^{35}$ cm$^{-2}$s$^{-1}$ luminosity for 50 days, zero-degree tagger

$X(3872) \to \pi^+\pi^- J/\psi$

A) Missing $J/\psi$ B) Missing proton

Acceptances:
X(3872) ≈ 1%
Zc(3900) ≈ 15%

Expected yields:
X(3872) = 2-3k
Zc(3900) = 25k




Next steps:

- Develop reasonable non-resonant background models to include in the MC
- Evaluate the contribution of open charm channels

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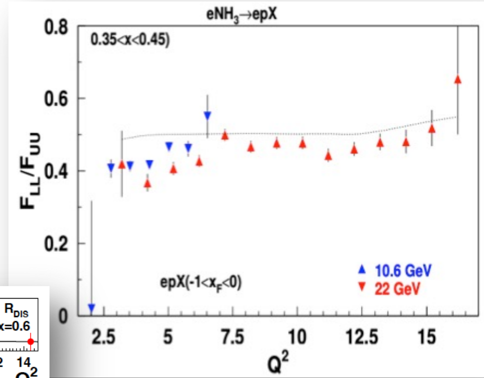
# Imaging Studies: the JLab Advantage

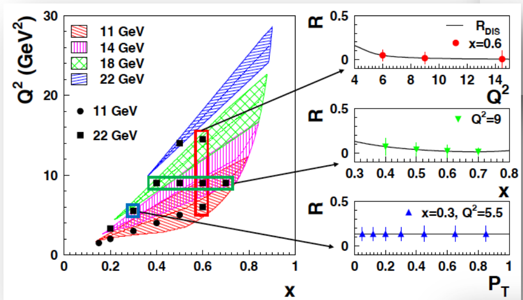
Jefferson LAB : IDEAL PLACE TO CARRY OUT IMAGING STUDIES in the non-perturbative region

**High Luminosity + High Polarized beam and target + High Resolutions State-of-the-art detectors + Versatile experimental setup + Multiparticles FS detection**




The increased energy will enable several advancements, including:

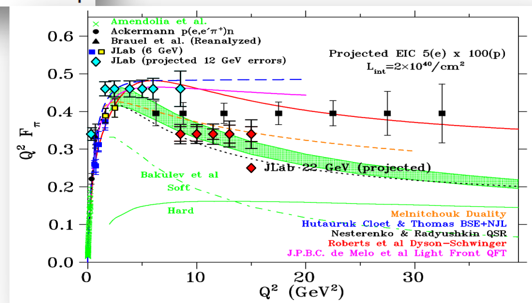
1. **Multidimensional** studies of the evolution of 3D observables with the energy scale ($Q^2$)




2. A unique opportunity to measure $\gamma^*_L$ and $\gamma^*_T$ contributions to observables at higher $Q^2$

3. A unique opportunity to evaluate the contribution of various processes (i.e. diffractive ρ,..) at higher $Q^2$

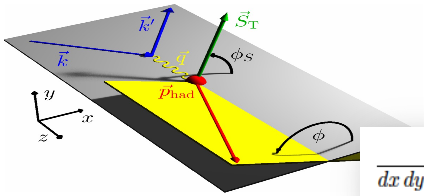
→ All the above will enable us to evaluate the assumption of the TMD factorization




→ 2. & 3. will serve as a bridge between lower energy experiments and EIC, providing critical information for interpreting EIC results

# Structure Functions and Depolarization Factor

$\nu = E - E'$
$Q^2 = 4EE' \sin(\theta/2)$
$x = Q^2 / 2M\nu$
$z = E_h / \nu$
$y = \frac{\nu}{E}$
$\mathbf{P_T} = \mathbf{z k_T} + \mathbf{k_T}$



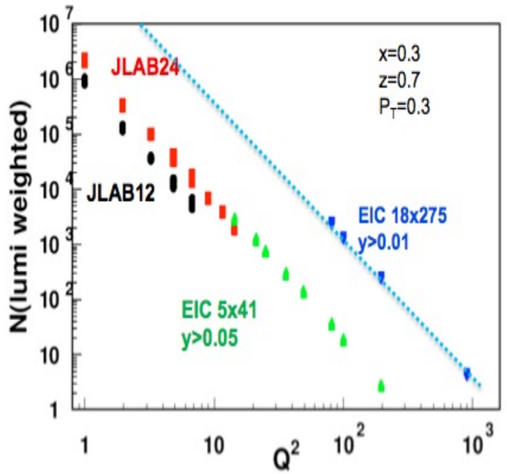
X-section for $\mathbf{eN \rightarrow e'hX}$

$$\mathbf{F_{ij}(x, Q^2, z, P_T, \phi, \phi_S) = TMD \otimes FF}$$

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

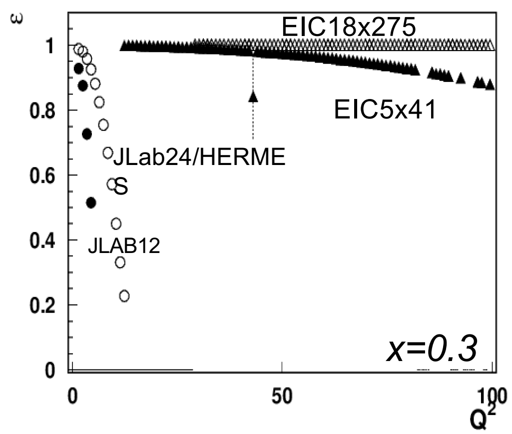
- Measurements of correlations of spin and transverse momenta provides direct access to details of QCD dynamics
- Full decomposition of SFs is needed to underlying the 3D PDFs

- Measurements of $F_{UU,T}$ and Sivers requires *separation*, evaluation of longitudinal photon (JLab)
- At higher energies (EIC), observables surviving the e→1 limit ($F_{UU}$, $F_{UL}$, Transversely pol. $F_{UT}$)




- At large x fixed target experiments are sensitive to ALL Structure Functions
- Combination of statistics and depolarization factors defines measurable SFs

ε=ratio of longitudinal and transverse photon flux



# Measurements of $\alpha_s$ with JLab@22 GeV

It is the most important quantity of QCD, key parameter of the SM, but (by far) the least known fundamental coupling: $\Delta\alpha_s/\alpha_s \simeq 10^{-2}$

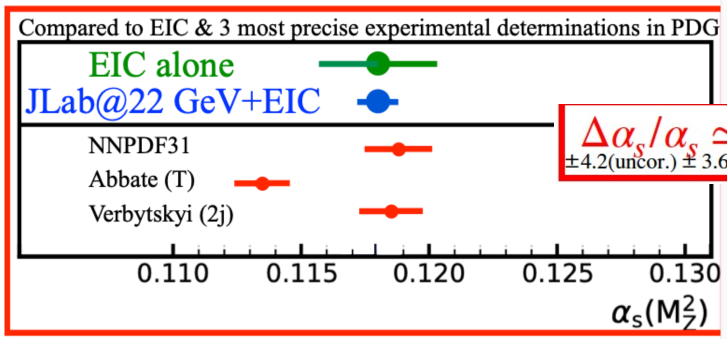
- Large efforts ongoing to reduce $\Delta\alpha_s/\alpha_s$
- No "silver bullet" experiment can exquisitely determine $\alpha_s$ ⇒ Strategy: combine many independent measurements

**Good prospects of measuring precisely $\alpha_s(M_Z)$ at JLab@22 GeV with Bjorken sum rule:**

Bjorken sum rule: $\Gamma_1^{p-n}(Q^2) \equiv \int g_1^{p-n}(x,Q^2)dx = \frac{1}{6} g_A \left[1 - \frac{\alpha_s}{\pi} \ldots\right]$

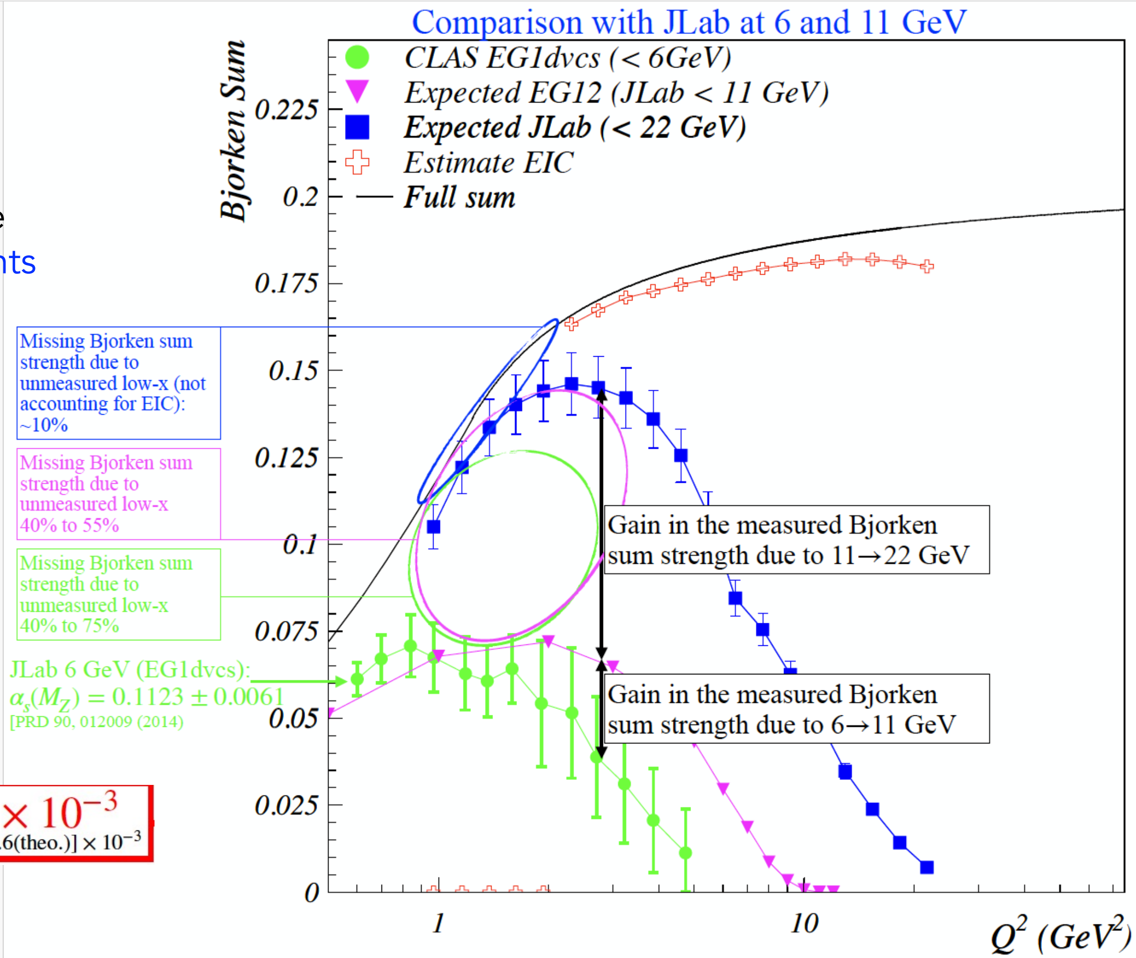
$Q^2$-dependence of $\Gamma^{p-n}(Q^2)$ provides $\alpha_s$.

Uncertainties from pQCD truncation and Higher-Twists remain small




$\Delta\alpha_s/\alpha_s \simeq 6.1 \times 10^{-3}$

$[\pm 4.2(\text{uncor.}) \pm 3.6(\text{cor.}) \pm 2.6(\text{theo.})] \times 10^{-3}$

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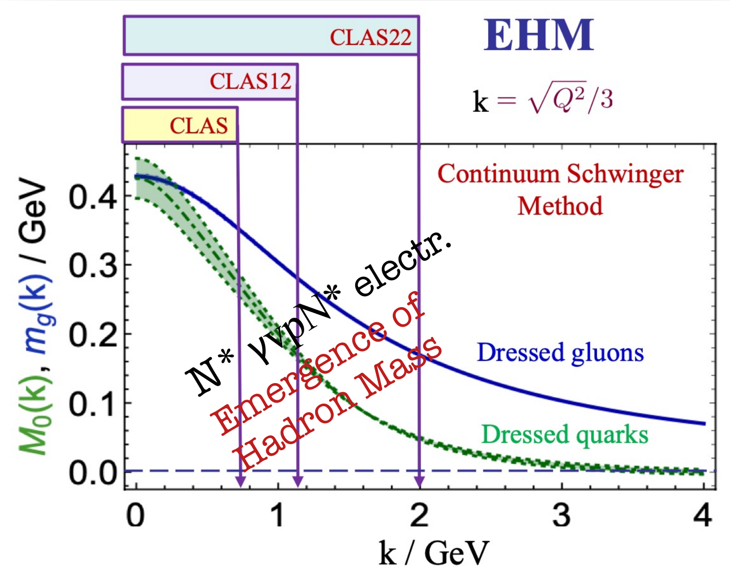
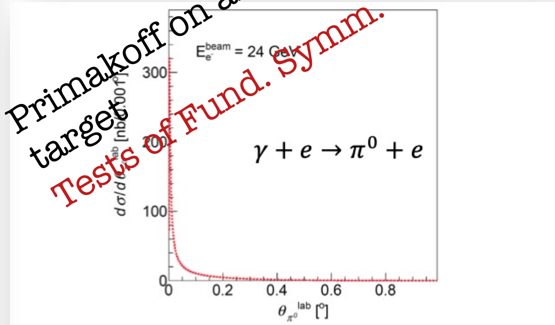
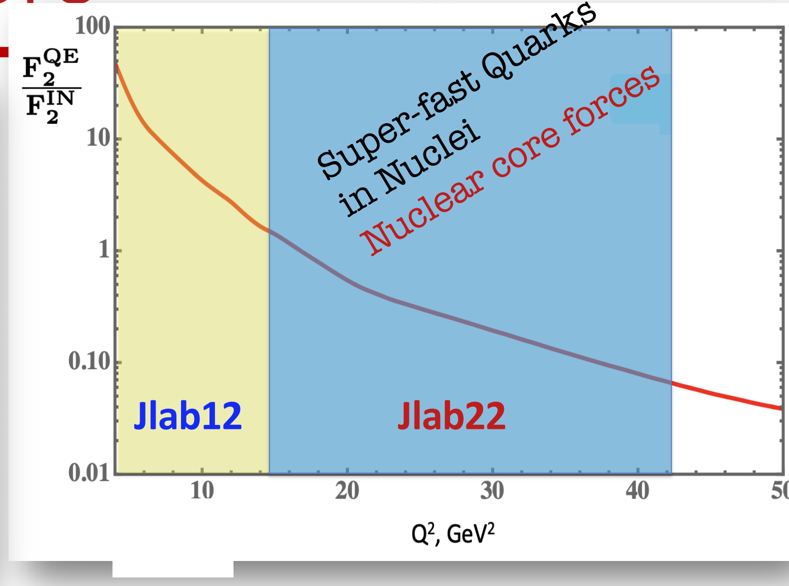
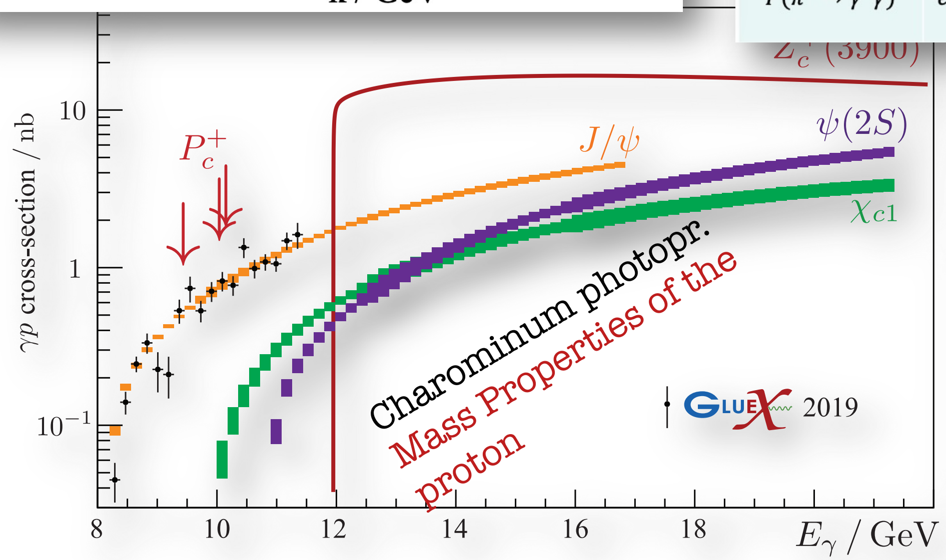
# ..And Many More

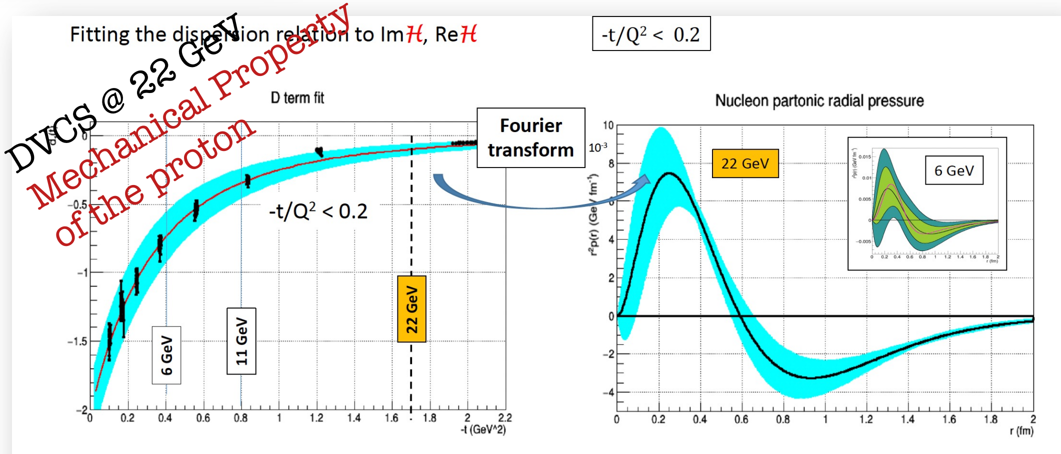



| Measurement | Reaction | $E_{th}$ (GeV) |
|---|---|---|
| $\Gamma(\pi^0 \to \gamma\gamma)$ | $\gamma + e \to \pi^0 + e$ | 18.0 |
| $F(\pi^0 \to \gamma^*\gamma)$ | $e + e \to \pi^0 + e + e$ | 18.1 |




22 GeV will cover a large range in -t and may discover existence of pressure domains.

# Path Forward

- Jefferson Lab continues to work with the community to articulate the scientific motivation for positron beams and for an increase in the maximum electron beam energy from 12 GeV to 22 GeV.
- Such capabilities could be realized in the future through a DOE construction project, which means that advance planning is important now to assess the key elements of a pre-conceptual project plan and the technical feasibility of the design.
- An overview of the DOE process for projects from establishing the mission need for a scientific capability (Critical Decision-0) through to project completion (Critical Decision-4) will be presented together with a brief look at early planning activities.

From A. Lung

# Department of Energy (DOE) Project Planning & Phases

Projects are planned in Phases which are “gated” by Critical Decision (CD) reviews and approval:

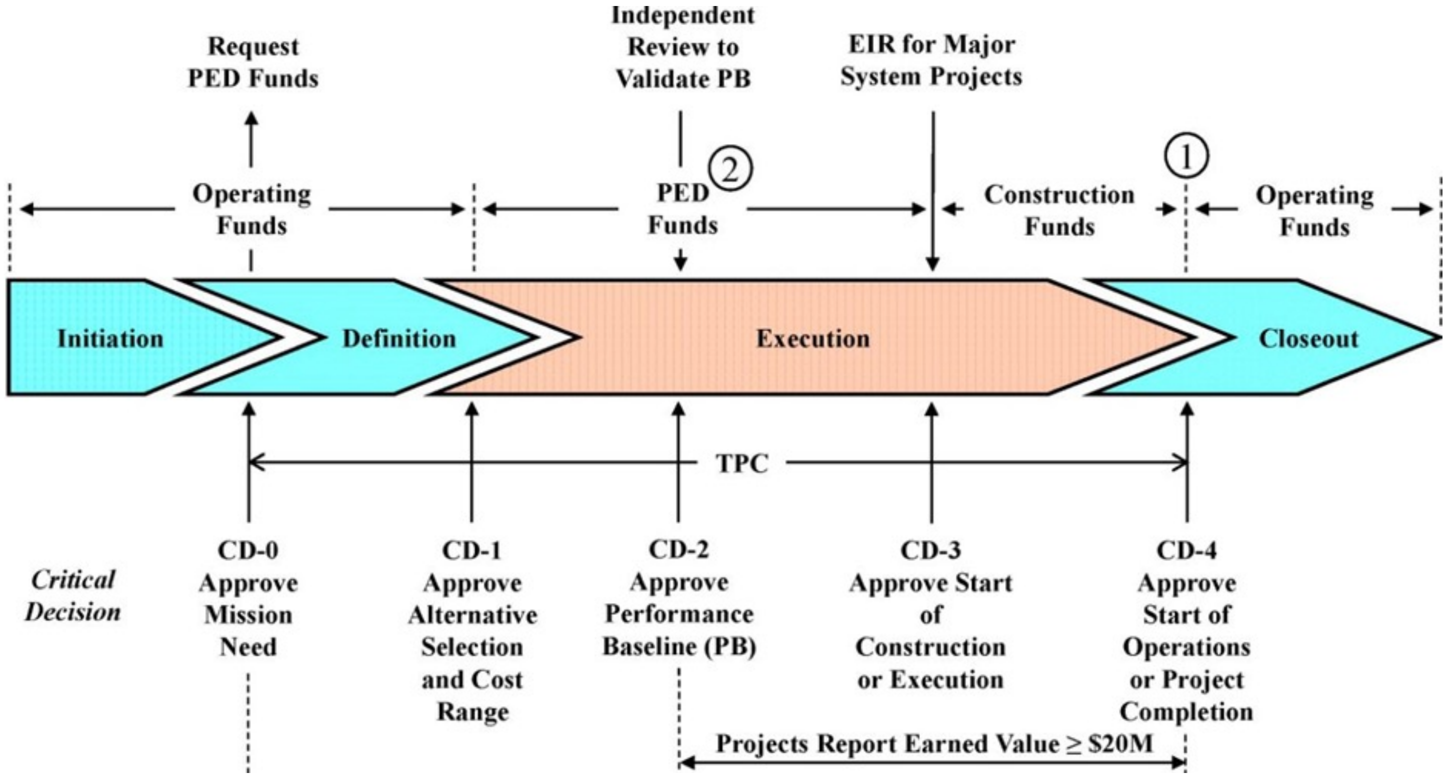
CD-0 Mission Need
– Science Case

CD-1 Cost Range

CD-2 Baseline

CD-3 Construction

CD-4 Completion
– Transition to Ops




*22 GeV Upgrade is in pre-project development mode.*

*Focus on science case and technical feasibility.*

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# Pre-R&D Studies are Critical to Initial Project Planning

Demonstrating technical feasibility is the foundation for defining the scientific capability as well as the range of cost, schedule, and scope.

- What has Jefferson Lab been doing in this arena?
  - Investing annually through Accelerator R&D ($K)

| Activities toward improving existing facility | Past Years | FY23 Actual | FY24 Est. | FY25 Est. | TOTAL ($K) |
|---|---|---|---|---|---|
| Positrons for CEBAF | 542 | 514 | 518 | 523 | 2,097 |
| 22 GeV CEBAF | 128 | 350 | 354 | 358 | 1,190 |
| Total | 670 | 864 | 872 | 881 | **3,287** |

  - *Requested an increase from DOE Nuclear Physics to $3M level annually*
  - *Investing in Lab Directed R&D (LDRD)*

| LDRD Awards - FY25 | Principal Investigator |
|---|---|
| High-intensity, polarized-beam prototype photogun for the Ce+BAF positron source | Max Bruker |
| Positron injector model integrator | Joe Grames |
| FFA@CEBAF permanent magnet resiliency in real radiation environment | Ryan Bodenstein |
| Total | ~$600K |

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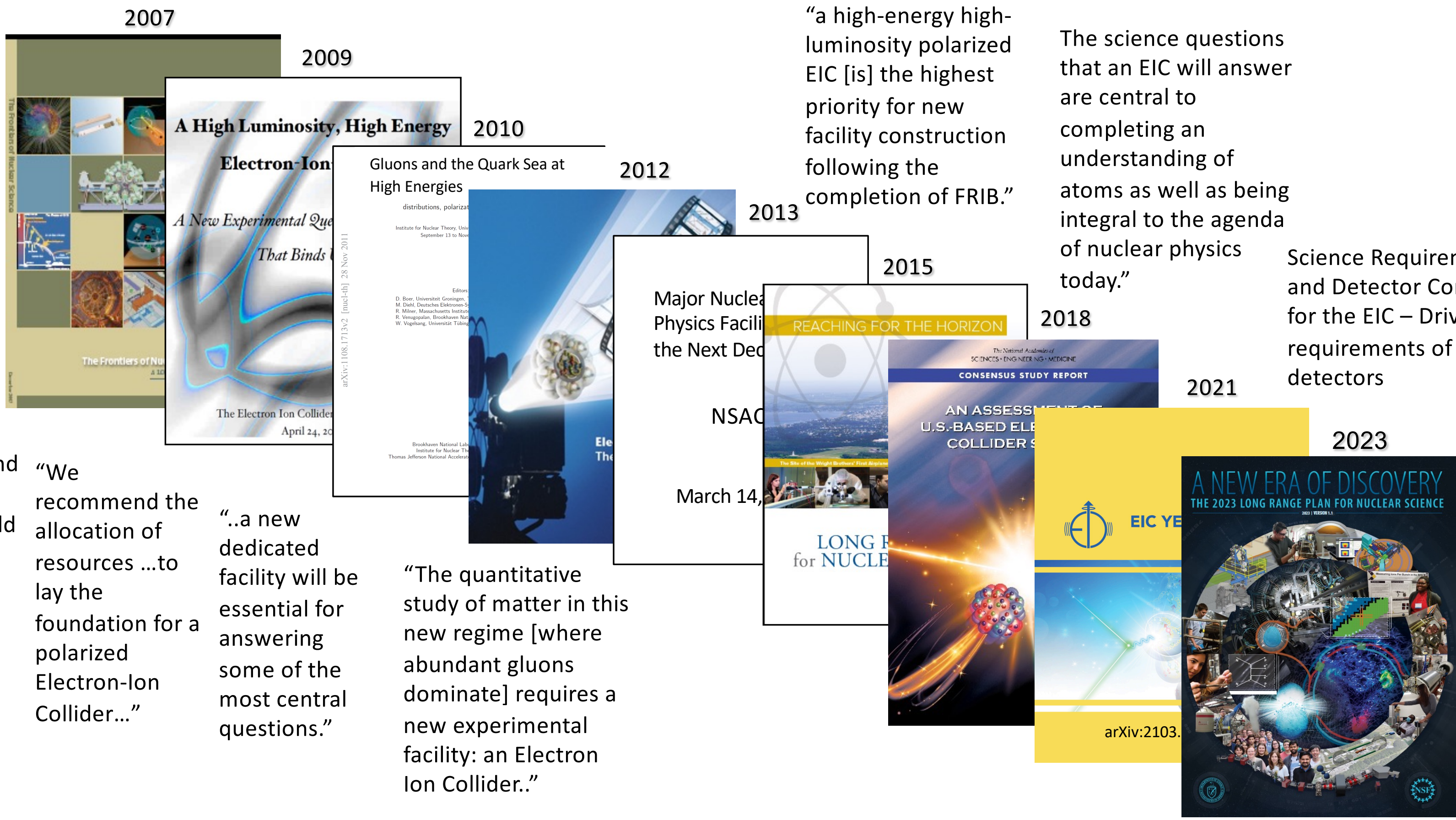
# Scientific Foundation for An Electron-Ion Collider was Built

## Long Range Plans; White Papers; NSAC Reviews; NAS Study; Yellow Report




"…essential accelerator and detector R&D [for EIC] should be given very high priority in the short term."

"We recommend the allocation of resources …to lay the foundation for a polarized Electron-Ion Collider…"

"..a new dedicated facility will be essential for answering some of the most central questions."

"The quantitative study of matter in this new regime [where abundant gluons dominate] requires a new experimental facility: an Electron Ion Collider.."

"a high-energy high-luminosity polarized EIC [is] the highest priority for new facility construction following the completion of FRIB."

The science questions that an EIC will answer are central to completing an understanding of atoms as well as being integral to the agenda of nuclear physics today."

Science Requirements and Detector Concepts for the EIC – Drives the requirements of EIC detectors

We recommend the expeditious completion of the EIC as the highest priority for facility construction.

**22 GeV would require similar activities, progression quicker to match size**

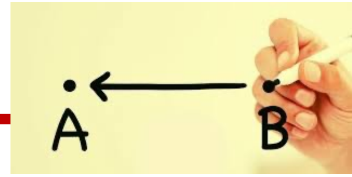
# Next Steps in Pre-Project Planning

- **Draft a Preliminary Technical Design Report (TDR)**
  - Capture the urgent questions that must be answered
  - Define and execute the plan to answer those questions through Pre-R&D, LDRD, modeling, etc
  - Update to full TDR as the results are known and the design matures

- **Continue to develop the most compelling science case**
  - Synthesize the most impactful results into language non-physicists understand
  - Users and Lab lead the way; highlight international collaborations

*Work during this preliminary phase advances the field of nuclear physics through technology development and a refined understanding of critical science questions.....and creates the foundation for a 22 GeV Project.*

# Steps and Milestones to Achieve the Goal




**Goal:** *strong* placement in next Long Range Plan

Working backwards…

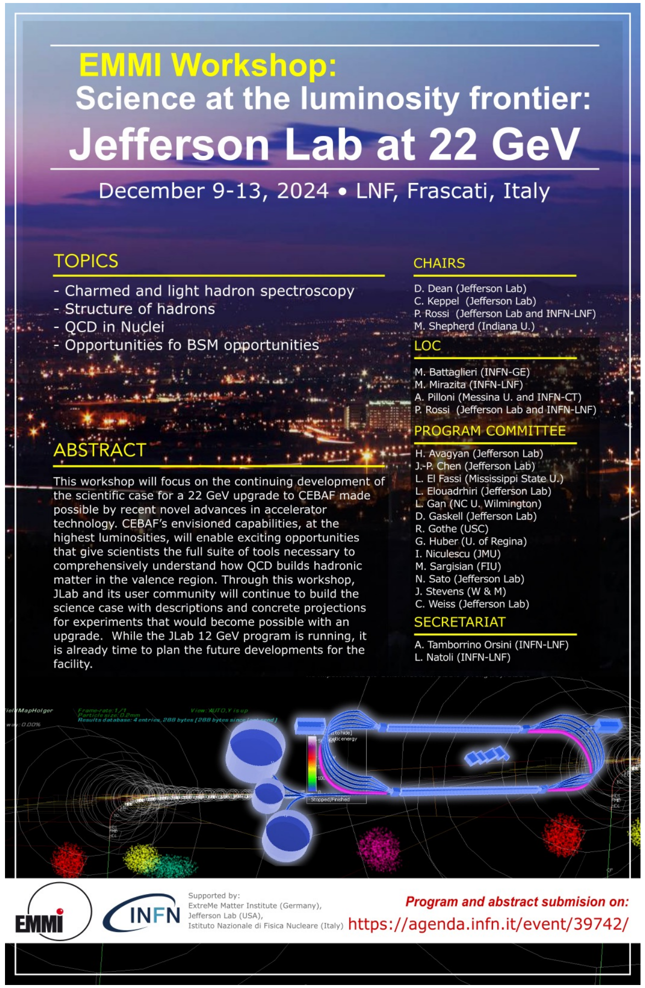
- Assume LRP every seven years, so look to 2029 town meetings – not actually a lot of time!
- **Prepare a strong TDR for ~2028, excellent physics case**
- Enable accelerator to make a major splash with technology demonstration in ~2027 (Nature, Science, press,…)
- **Earlier pTDR prepared in ~2026**
  - Communicates to DOE and science community
  - Capture the critical questions that must be answered – enables grant writers to point to the activity *(do NOT call it a "project"!!)*
  - Workshops and meetings to prepare
  - **A small study group (11 people) from Jab management, Physics, Accelerator and Theory Divisions, and 3 representatives of the user community,** meets monthly
- Laboratory to continue communication with funding agencies in parallel

## Development of the Science Case for the 22 GeV

- A document outlining the progress of the scientific case will be available within a few month to be prepared according to the following guidelines:
  1. capture the changes, refinements, and improvements of motivation, theoretical and experimental studies, since the white paper;
  2. set milestones for critical-path theoretical or experimental studies
  3. summarize, where possible, the anticipated global landscape 10-15 years from now, when the 22 GeV upgrade might begin producing results.
- Define the optimal strategy for restarting the "Open Discussion" series again in preparation for the next workshop, if not sooner
- Next workshop spring-summer 2026

# Summary – from Thia @ Frascati Workshop

- A lot of fascinating science – THANK YOU all!
- Exciting accelerator opportunity – nearly double the energy with no new cryomodules!
- The laboratory supports this effort
  - Funding some development
  - Organization and guidance
  - Communicating intent to funding agencies
- It will "take a village", all of us, to bring this to reality! Please…
  - Organize and attend topical and annual workshops, meetings
  - Contribute to the pTDR and TDR
  - Tell your friends ☺



# Backup Slides

# Notional CEBAF and EIC Efforts on One Chart

- Accelerator team has worked up an early schedule and cost estimate
  - 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 dev shown
- EIC Project is shown