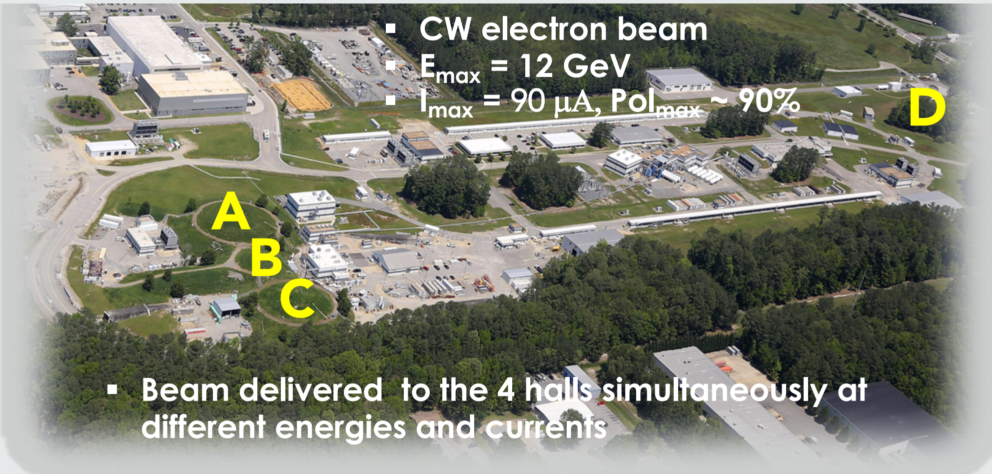
Jefferson Lab at 20+ GeV

Patrizia Rossi

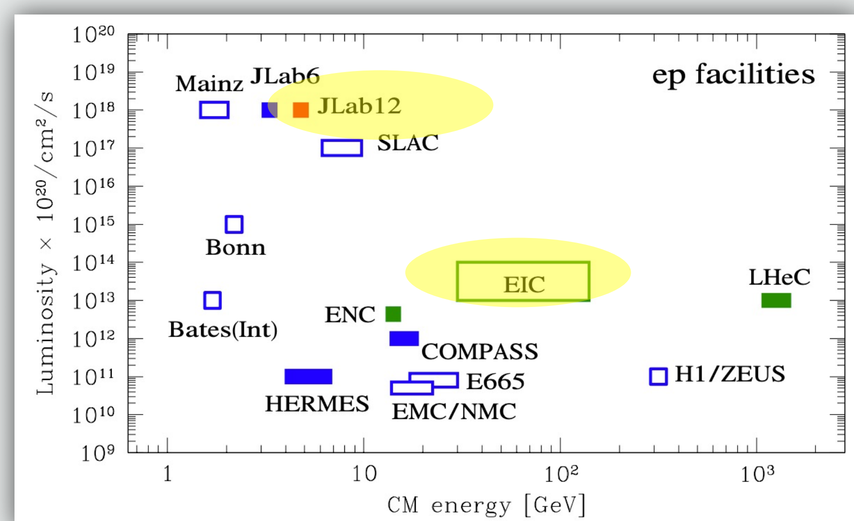
14th Conference on the Intersections of
Particle and Nuclear Physics (CIPANP 2022)

Orlando -FL – 29 August - 4 September 2022

Jefferson Lab's Science and Technology vision



- **High intensity tagged photon beam at 9 GeV**
- **Experiments at ultra-high luminosities, up to 10^{39} e-nucleons /cm²/ s**



Jefferson Lab

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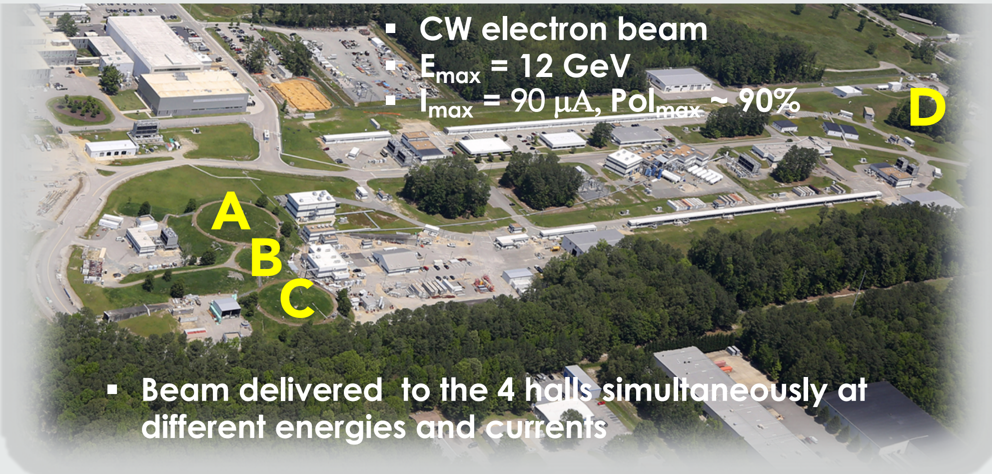

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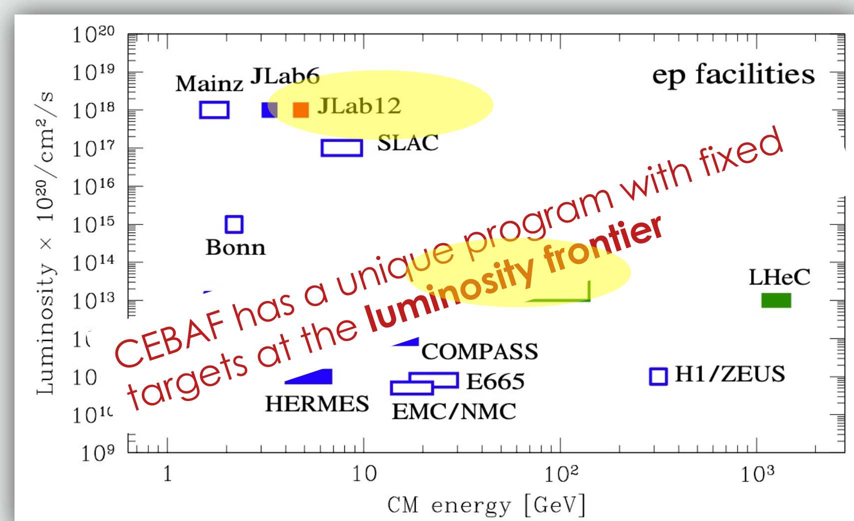

Jefferson Lab

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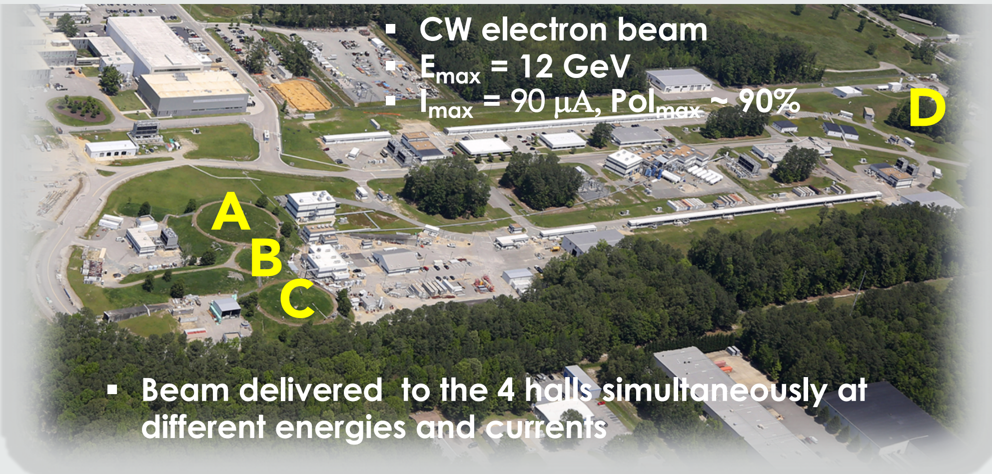

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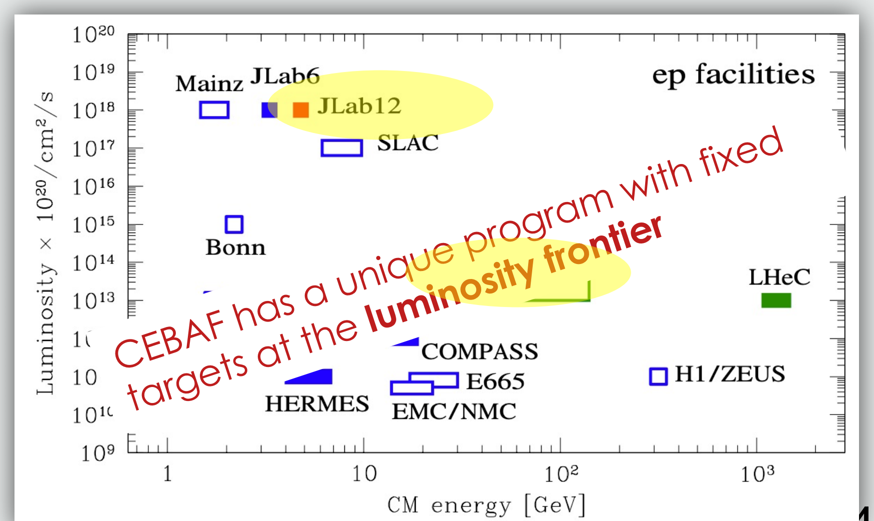


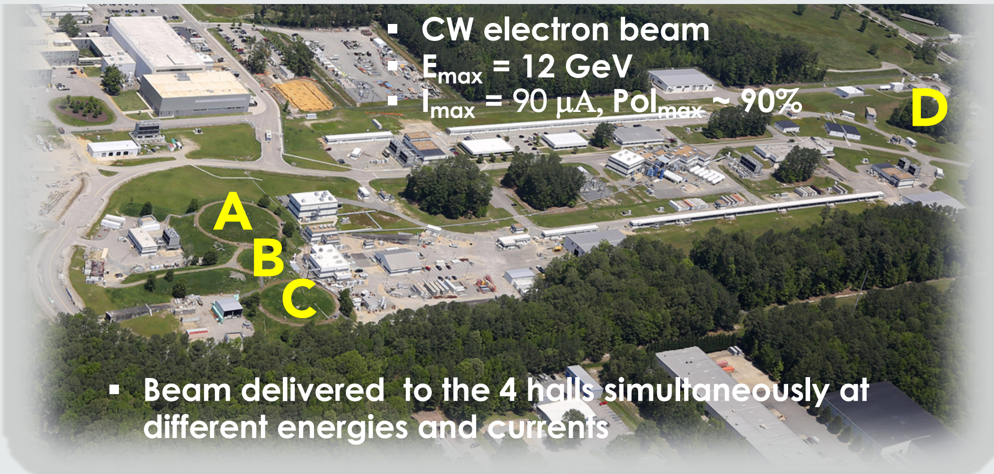
Broad Scientific Program

- Spectroscopy
- Nucleon Structure: Forms Factors, PDFs, TMDs, GPDs
- Cold Nuclear Matter
- Fundamental Symmetries
  - What is the role of gluonic excitations in the spectroscopy of light mesons?
  - Where is the missing spin in the nucleon?
  - What is the relation of short-range nuclear structure and parton dynamics?
  - Can we discover evidence for physics BSM?

Jefferson Lab is facing a time of change

- **Ensuring that the 12 GeV scientific program is successful**
- **Moving EIC forward**
- **Exploring the long-term scientific opportunities at CEBAF**
- **Stewarding best-in-class accelerator technology**
- **Diversifying Jefferson Lab's scientific mission with a significant role in Advanced Computing**

Jefferson Lab's Science and Technology vision



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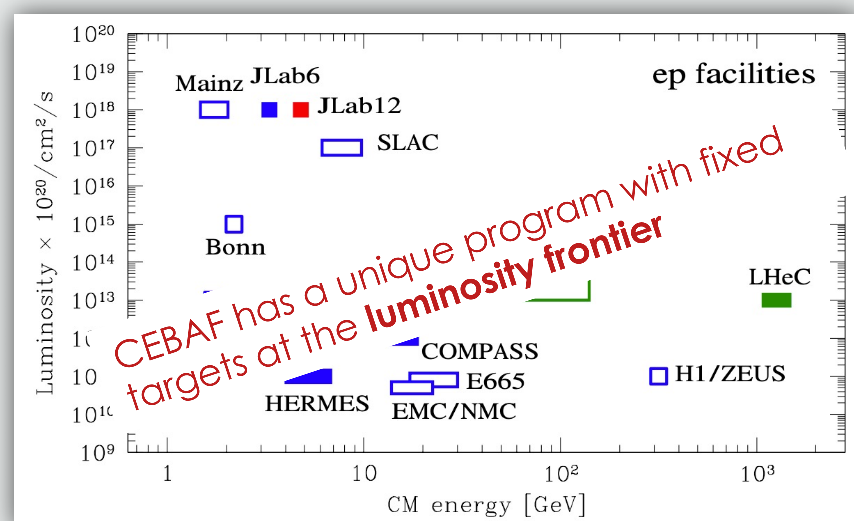

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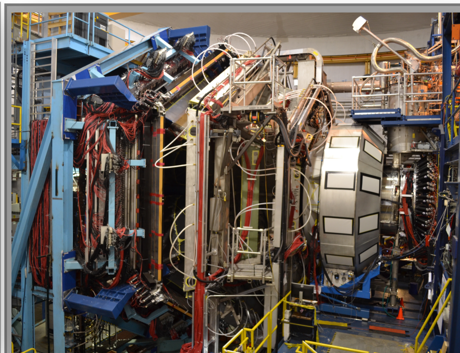
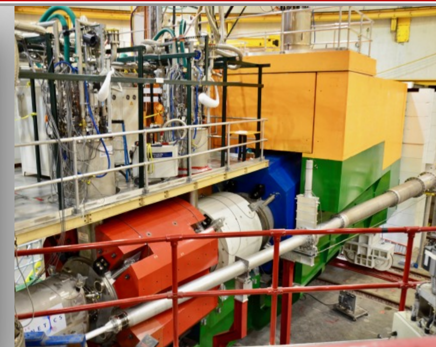
Today and Tomorrow

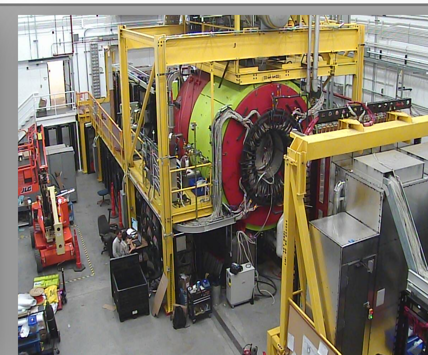
Hall A: SBS & BB



Hall B: CLAS12



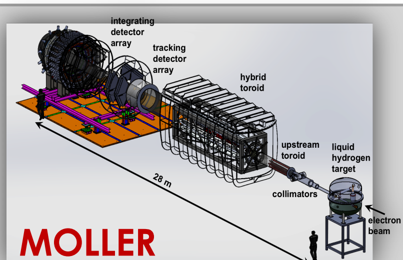
Hall C: HMS-SHMS



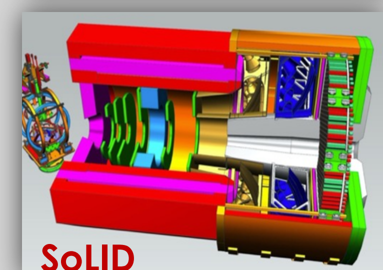
Hall D: GlueX

The 12 GeV Experimental Program is in full swing

33 Experiments completed out of 91 approved



MOLLER



SoLID

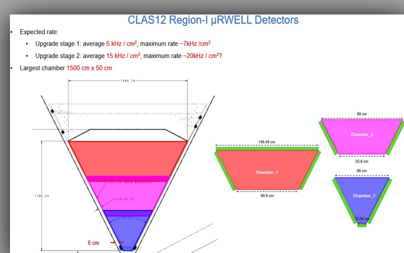
Luminosity Upgrade

Stage -1: **$2x10^{35}cm^{-2}\ s^{-1}$**

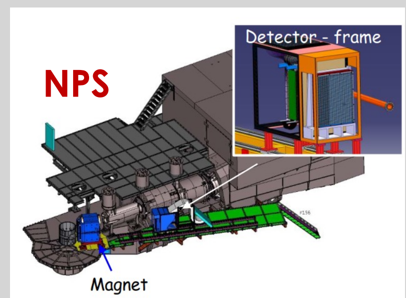
3 years

Stage -2: > **$10^{37}cm^{-2}\ s^{-1}$**

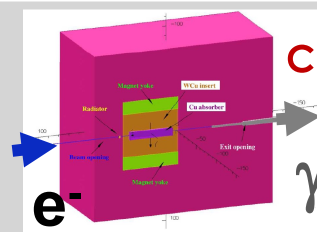
7-10 years



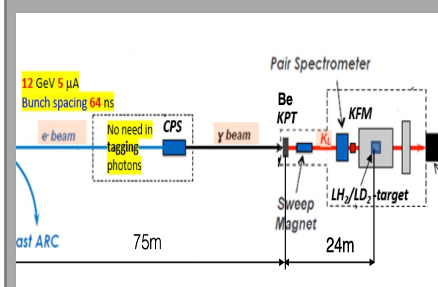
NPS



CPS



KLF



~8 years at ~30 weeks/year

Jefferson Lab

Future Opportunities at CEBAF

- **Higher energy**
- **Positron beam**
- **High Luminosity**

https://indico.jlab.org/event/520/

https://indico.knu.ac.kr/event/566/

APCTP Focus Program in Nuclear Physics 2022: Hadron Physics Opportunities with JLab Energy and Luminosity Upgrade

Jul 18 – 23, 2022
APCTP, Pohang

Overview
Timetable
Participant List

The electroproduction of mesons and photons has been shown to be a powerful tool for studies of the interaction of elementary particles and their dynamics at short and long distances. In particular, studies of the orbital motion of partons encoded in transverse space and momentum distributions of partons, like Generalized Parton Distributions (GPDs) and Transverse Momentum Distributions (TMDs), have been widely recognized as key objectives of the JLab 12 GeV program. Studies of azimuthal distributions of hadrons and photons in exclusive and semi-inclusive DIS (SIDIS) provide access to variety of observables widely recognized as key objectives of the COMPASS measurements, various activities at RHIC and KEK, the LHC fixed target projects (LHC spin, SMOG2@LHCb) and a driving force behind the construction of the future Electron Ion Collider (EIC). Studies of the ground and excited nucleon state structure in terms of nucleon elastic form factors, PDFs, and the N→N* (nucleon to nucleon resonances) transition electro-excitation amplitudes offer a unique complementary opportunity to explore the evolution of active components in the structure of the ground and excited state nucleons at distances where the transition from quark-gluon confinement to the perturbative QCD regime is expected and where the dominant part of hadron mass emerges. These studies are of particular importance to address key open problems of the Standard Model on emergence of hadron mass and quark-gluon confinement. The upgraded to 24 GeV JLab, with much wider kinematical coverage, in particular at large Q^2, will be crucial to extend all ongoing projects at JLab, in particular studies of the 3D structure of hadrons and hadronization, pin down interaction dependent parts, providing missing deeper access to quark- gluon dynamics and opening new opportunities on studies of the charm sector and significant improvement in secondary beam capabilities.

Starts Jul 18, 2022, 9:00 AM
Ends Jul 23, 2022, 1:00 PM

APCTP, Pohang
Classroom 308

Physics with CEBAF at 12 GeV and Future Opportunities

J. Arrington[1], M. Battaglieri[2,15], A. Boehnlein[2], S.A. Bogacz[2], W.K. Brooks[10], E. Chudakov[2], I. Cloët[3], R. Ent[2], H. Gao[4], J. Grames[2], L. Harwood[2], X. Ji[5,6], C. Keppel[2], G. Krafft[2], R. D. McKeown[2,8,*], J. Napolitano[7], J.W. Qiu[2,8], P. Rossi[2,14], M. Schram[2], S. Stepanyan[2], J. Stevens[8], A.P. Szczepaniak[12,13,2], N. Toro[9], X. Zheng[11]

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[13]Center for Exploration of Energy and Matter, Indiana University, Bloomington, Indiana 47403, USA
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v1 [nucl-ex] 30 Nov 2021

Abstract

We summarize the ongoing scientific program of the 12 GeV Continuous Electron Beam Accelerator Facility (CEBAF) and give an outlook into future scientific opportunities. The program addresses important topics in nuclear, hadronic, and electroweak physics including nuclear femtography, meson and baryon spectroscopy, quarks and gluons in nuclei, precision tests of the standard model, and dark sector searches. Potential upgrades of CEBAF are considered, such as higher luminosity, polarized and unpolarized positron beams, and doubling the beam energy.

Keywords:

Progress in Particle and Nuclear Physics: In Press

https://www.ectstar.eu/workshops/opportunities-with-jlab-energy-and-luminosity-upgrade/

OPPORTUNITIES WITH JLAB ENERGY AND LUMINOSITY UPGRADE

26 September 2022 — 30 September 2022

ECT* - Villa Tambosi
Strada delle Tabarelle, 286
Trento - Italy

Organizers

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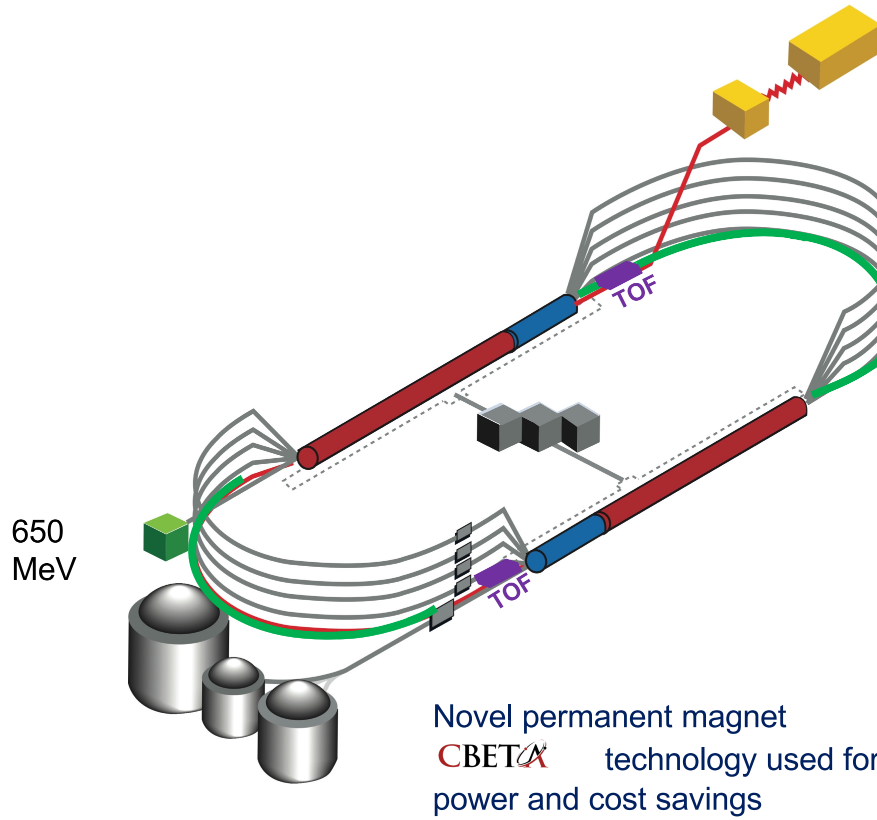
OBJECTIVE:

gather theorists and experimentalists to discuss the physics opportunities and technical options for each of the possible upgrade scenarios: energy, positron, luminosity

CEBAF FFA Upgrade – 'Currently under Study'

- **Starting with 12 GeV CEBAF as a baseline**
- **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+4 times to get to about 18 GeV**



Courtesy Alex Bogacz

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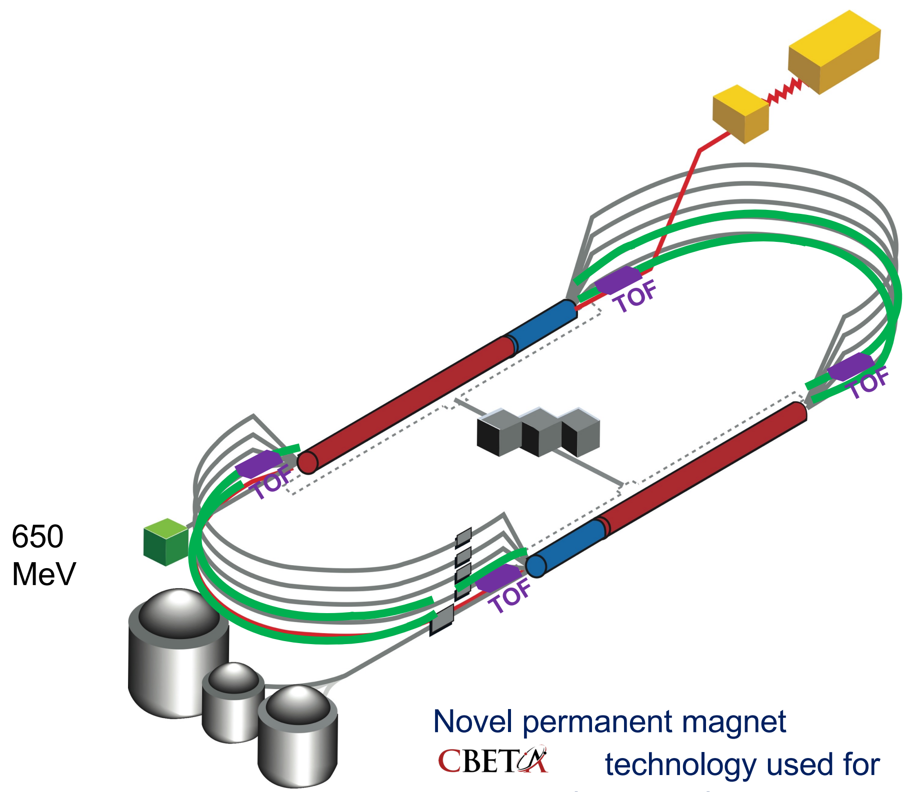
- **Recirculate 3 times to get about 24 GeV**

Pass Arithmetic: **5** -1 + 4 + 3 = **11**



Novel permanent magnet CBETA technology used for power and cost savings

Courtesy Alex Bogacz

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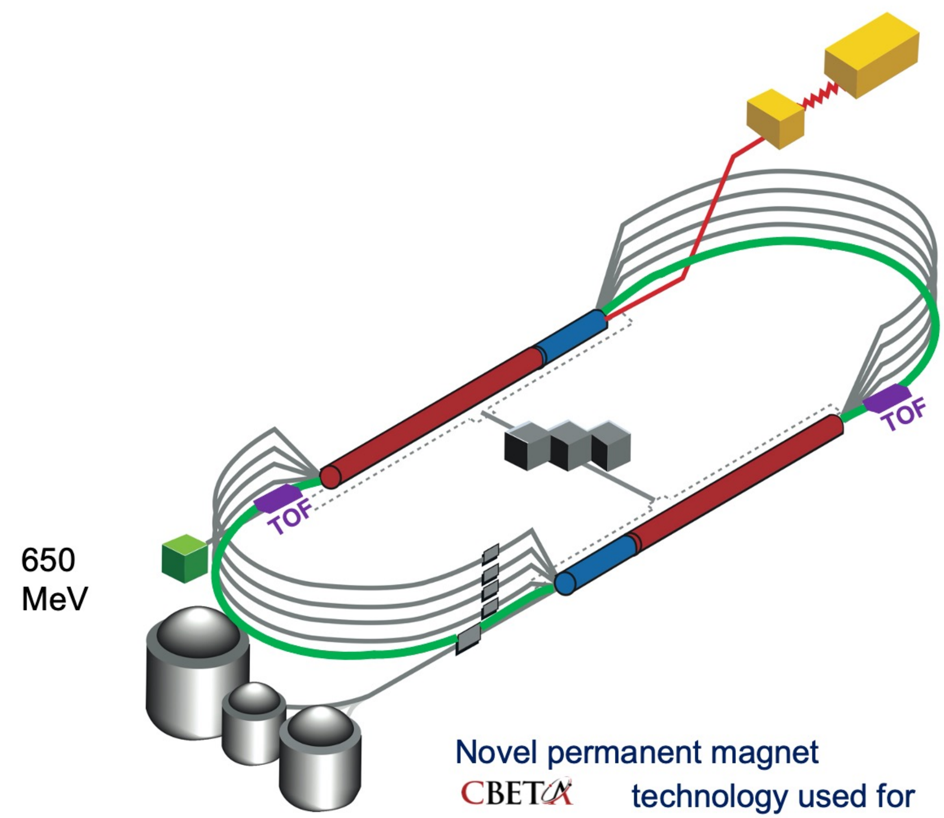
Pass Arithmetic: **5** -1 + 4 + 3 = **11**

- **Recirculate 4 + 6 times to get to about 22 Ge**

Pass Arithmetic: **5** -1 + 6 = **10**



Novel permanent magnet CBETA technology used for power and cost savings

Courtesy Alex Bogacz

Higher Energy

https://www.jlab.org/conference/hews22#

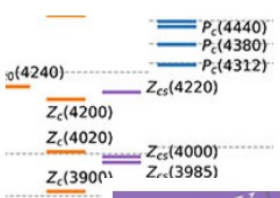
View | New draft | Revisions

HIGH ENERGY WORKSHOP SERIES 2022

We are pleased to announce an upcoming series of summer workshops being organized jointly between the laboratory and the Jefferson Lab Users Organization (JLUO) to probe the science that would be opened up by a higher energy electron beam (~20-24 GeV) at Jefferson Lab. We are particularly interested in identifying key measurements that are not possible to access at 12 GeV, that initially utilize largely existing or already-planned Hall equipment, and that leverage the unique capabilities of luminosity and precision possible at Jefferson Lab in the EIC era.

High Energy Workshop Series 2022

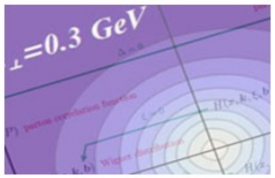
- **5 workshop series**



Hadron Spectroscopy with a CEBAF Energy Upgrade
June 16 & 17

Marco Battaglieri, Sean Dobbs, Derek Glazier, Alessandro Pilloni, Justin Stevens, Adam Szczepaniak

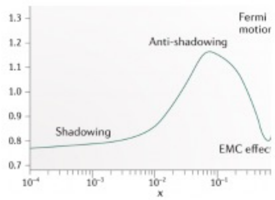
Recent observations in heavy-quark spectroscopy have provided numerous candidates for hadronic resonances which



The Next Generation of 3D Imaging
July 7 & 8

Harut Avagyan, Carlos Munoz Camacho, Jian-Ping Chen, Xiangdong Ji, Jianwei Qiu, Patrizia Rossi

Studies of azimuthal distributions of hadrons and photons in exclusive and semi-inclusive Deep Inelastic Scattering measurements, providing access to a variety of observables helping to elucidate the way the properties of the proton



Science at Mid x: Anti-shadowing and the Role of the Sea
July 22,23

John Arrington, Mark Dalton, Thia Keppel, Wally Melnitchouk, Jianwei Qiu

An upgrade of CEBAF at Jefferson Lab beyond 20 GeV will open up key science that is not possible to access at 12 GeV. One kinematic regime where this is most possible is in the "middle" Bjorken x regime around x~0.1, where the available momentum transfers at 12 GeV have heretofore limited or prevented several exciting measurements. Here, for example, the long-standing mystery of anti-shadowing may now be probed for the first time in decades. The strange sea may

Physics Beyond the Standard Model
August 1

Marco Battaglieri, Bob McKeown, Xiaochao Zheng

Possibilities for testing the Standard Model and searching for new physics beyond the Standard Model enabled by 20-24 GeV electron beams at CEBAF will be discussed. There will be opportunities for presentations and discussions where new ideas can be brought forward.

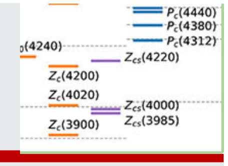
J/Psi and Beyond
August 16 & 17 9am - 1pm

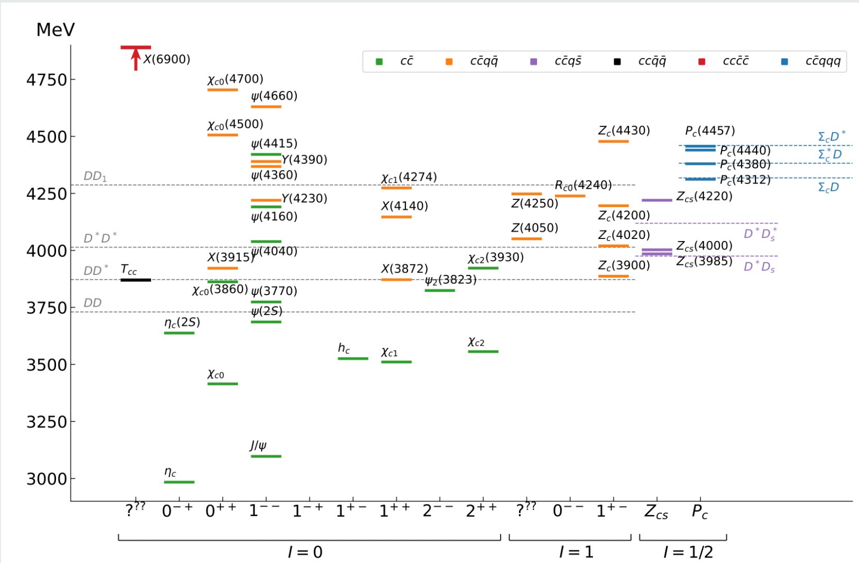
Ed Brash, Ian Cloet, Zein-Eddine Meziani, Jianwei Qiu

Measurements of J/psi near threshold with high statistics, for both electro and photoproduction at JLab with 12 GeV beam, has created tremendous interest in the community. A CEBAF energy increase (to ~24 GeV) will allow us to ask new questions and provide opportunities for addressing long-standing puzzles in nuclear and particle physics, thus enhancing the physics output of all four experimental halls, using existing (Halls B, C, and D) and future (SoLID in Hall A) equipment. This focused one-day workshop aims to (1) identify the key new measurements which could be made possible via an energy increase, and (2) specify the corresponding new questions that could be answered and the outstanding puzzles that could be addressed. For example, what is the impact of Psi(2S) data near and above its threshold in exploring the size change of the probe through a comparison with the threshold J/psi production data? With the enhanced Q lever-arm in J/psi electro-production that comes with higher energy beam, do we expect an improvement in probing the trace anomaly (which is central to the origin of proton mass)? Does having the J/psi produced precisely, especially with 19-20 GeV beam, help to address the tension that currently exi between JLab data and SLAC data from 40 years ago?

- **Short (~1-2 page) summaries of highlight science will contribute towards a white paper**

Hadron Spectroscopy



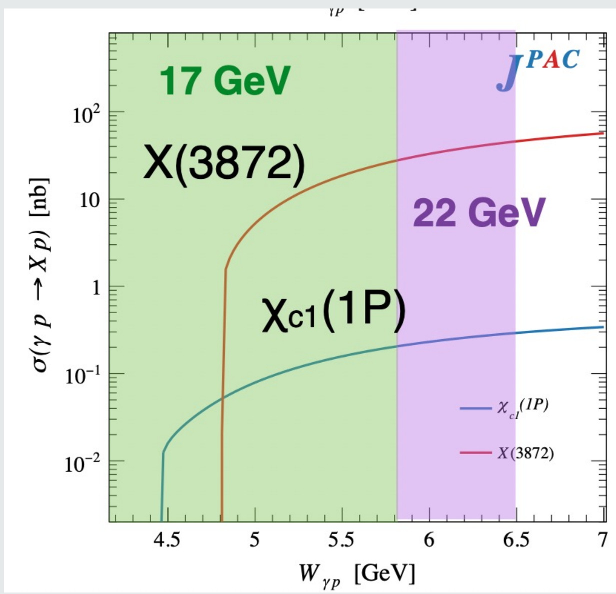


P. A. Zyla, et al., Review of Particle Physics, PTEP 2020 (8) (2020) 083C01

With CEBAF @ 20+ GeV the XYZ states and other charmonia can be studied

- states observed in B decays, e+e- colliders
- significant theoretical interest and progress, but internal structure not yet understood
- **never direcly produced** using photon/lepton beams

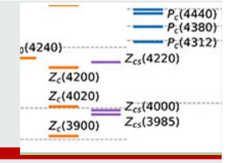
Predictions from JPAC



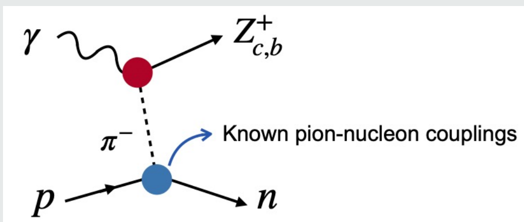
- **Photoproduction** provides an alternative mechanisms to study such states
- **Polarization** transfer observables offer new unexplored tools to establish their nature.

Jefferson Lab

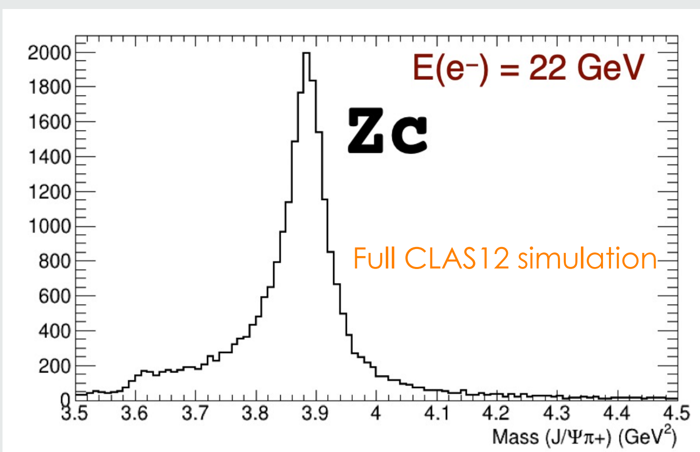
Hadron Spectroscopy

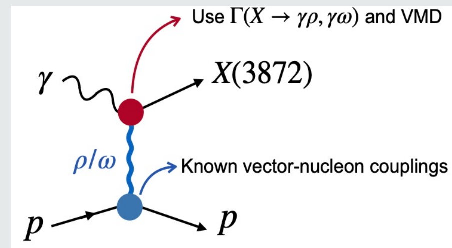


- Initial simulations from GlueX and CLAS12 demonstrate the capabilities of the existing detectors to measure these reactions
- Upgraded CEBAF energy ideally situated for near-threshold photo production of X and Z
- Electroproduction of N* resonances with increased Q^2 range will explore emergence of hadron mass



$$\gamma p \rightarrow J\psi\pi^+ n$$





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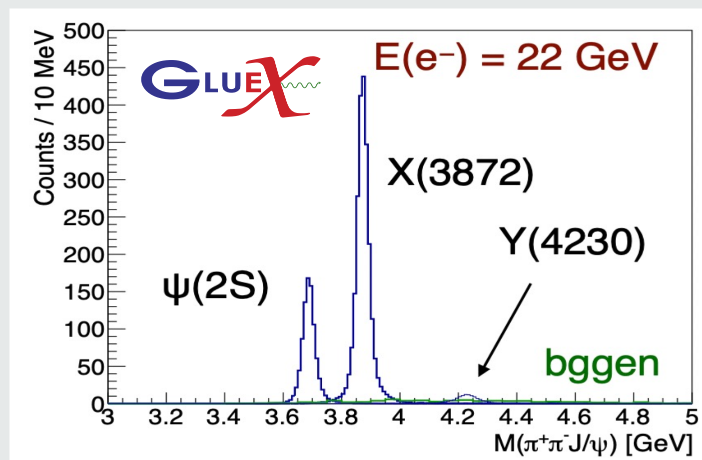
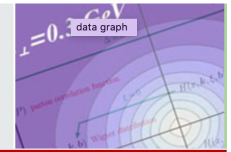


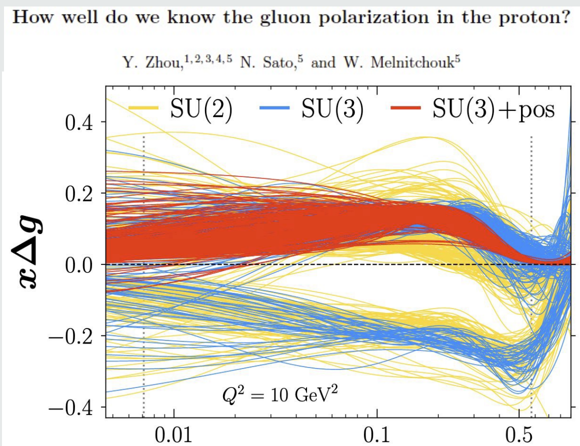
D. Glazier

S. Dobbs, P. Pauli

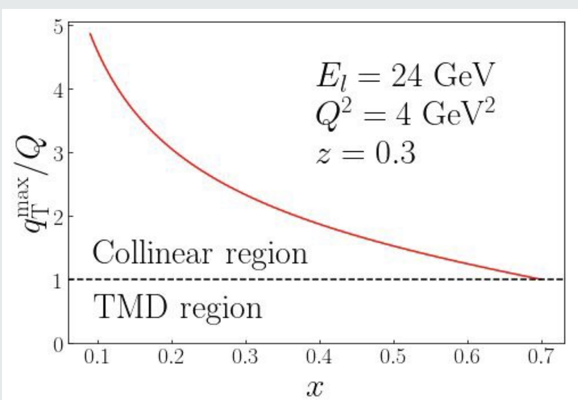


Gluon polarization

Accessing Gluon Polarization



arXiv:2201.02075v2

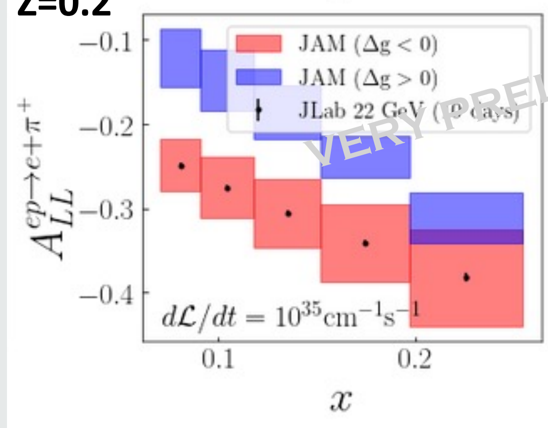


For 0.1<x<0.3 there is phase space with large P_T

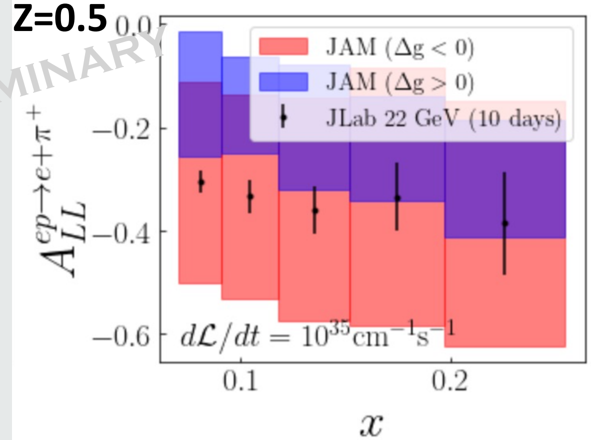
Gluon polarization is still elusive in the valence region

- **First simultaneous global QCD analysis of spin-averaged and spin-dependent PDFs (JAM Coll.), including single jet production data from unpolarized and polarized hadron collisions (STAR&PHENIX)**
- **Polarized jet data cannot discriminate between >0 & <0 solutions**
- **In the large PT region: solid theoretical framework based on the collinear factorization -> observables pol./unpol. can be written as convolution of collinear pdf and fragmentation function.**

Z=0.2



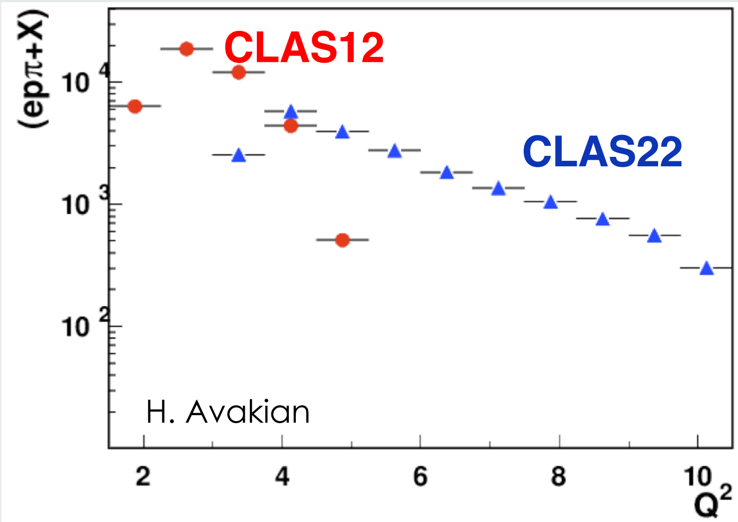
Z=0.5

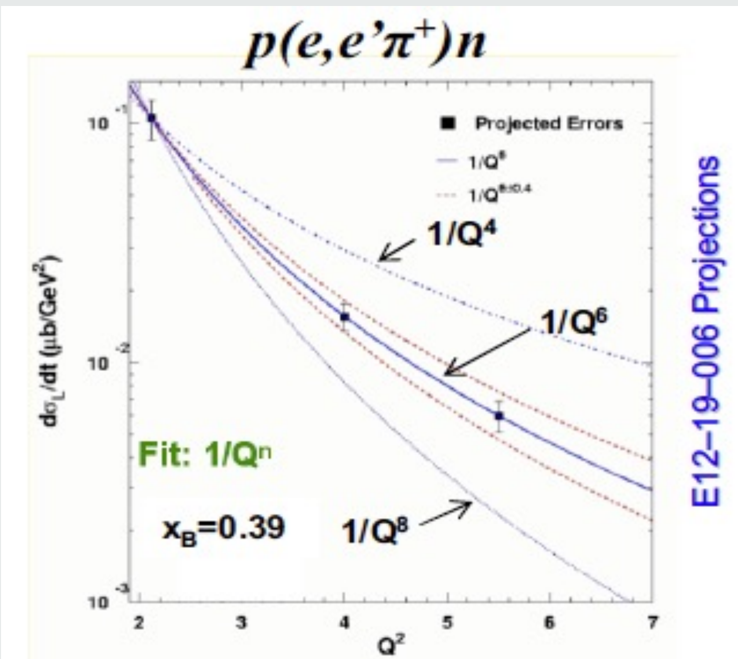


N. Sato

- **theory and exp are working together**

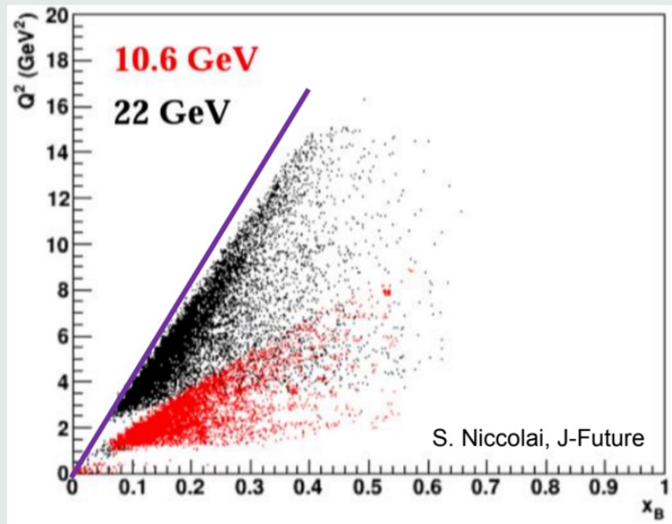
Enhancement of the Q^2 range



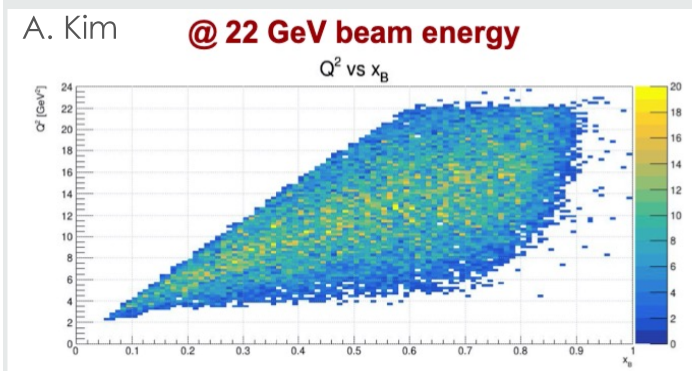


Increase of Q^2 range

- **Q^2 evolution studies possible:** QCD predicts <u>only</u> the Q^2 dep. of 3D PDFs



- **Possible to more cleanly separate pure twist-2 CFFs with suppressed higher twist (3) contributions**



- **The <u>relevant</u> Q^2 range for the Q^n scaling test significantly icreases with 18/22 GeV beam**

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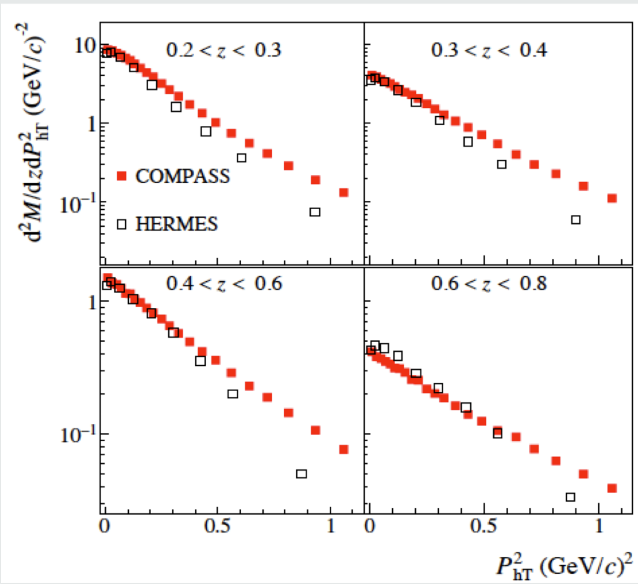
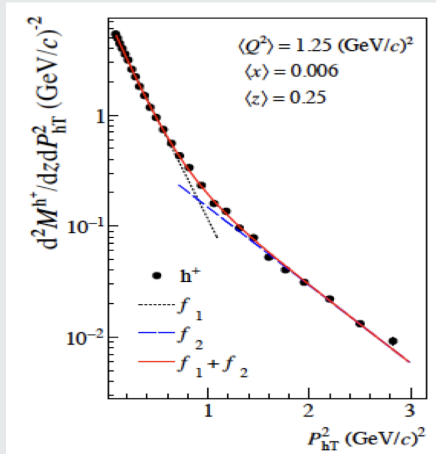
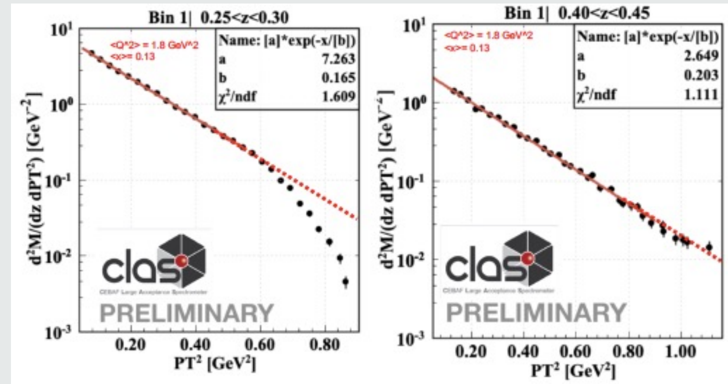
Enhancement of the P_T range





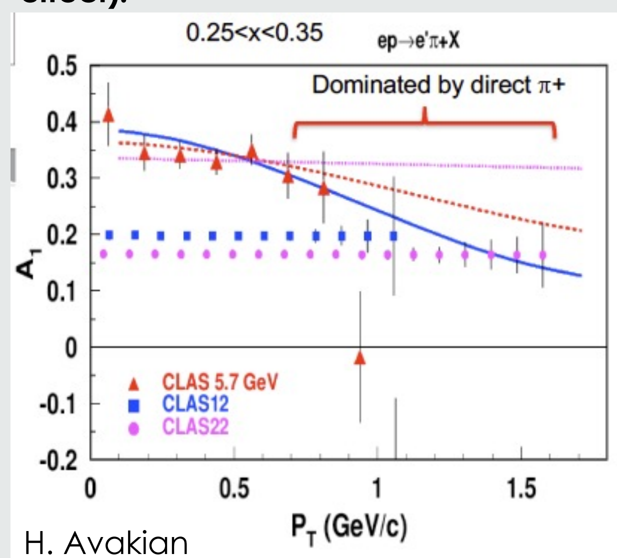
Increase P_T range



What is the origin of the "high" P_T (0.8-1.8) tail? Perturbative/non perturbative contributions?

- For some kinematic regions, at low z, the high P_T distribution appear suppressed: there is no enough energy in the system to produce hadron with high P_T (phase space effect).

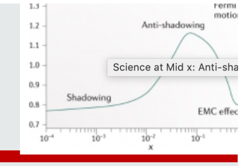
TMDs universal, so what is the origin of the differences observed ?

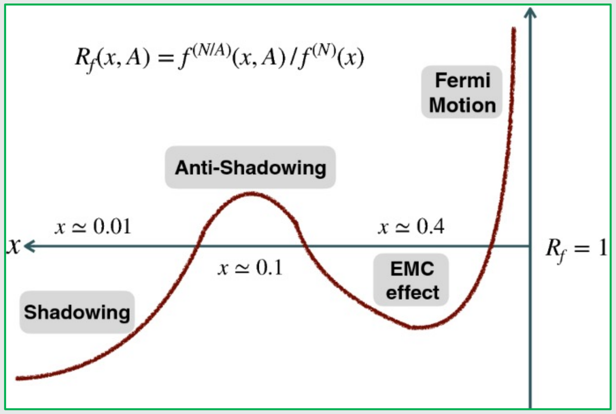


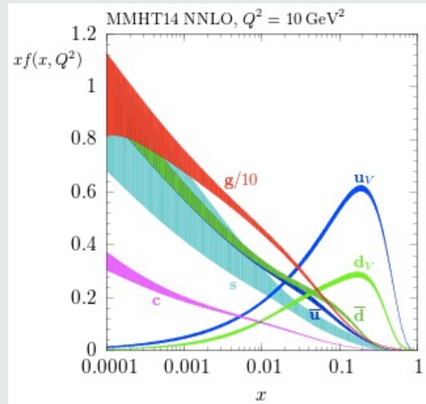
- **JLab: not enough energy to produce large P_T**
- **HERMES: not enough luminosity to access large P_T**

Larger P_T range and high luminosity is the key for a better insight into the problem

Anti-Shadowing







- **X~ 0.1 is a most dynamical rich regime of partonic structure in nucleon and nuclei**
  - Emergence of the gluon dominance
  - Interface between the sea and the valence, role of strange sea, …
  - Nuclear structure at the parton level, …
  - …

- Anti-Shadowing is the least studied nuclear structure function effect experimentally
  - flavor and spin dependence essentially uncharted
  - no tagged measurements
- Region near-equally dominated by valence quarks, sea-quarks, and gluons
  → many many models!!
- Transition between shadowing and the EMC regimes (where there is still much to learn) is a testing ground for ≠ descriptions
- In this intermediate region we can understand the nuclear force and the role of the pion

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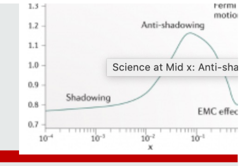
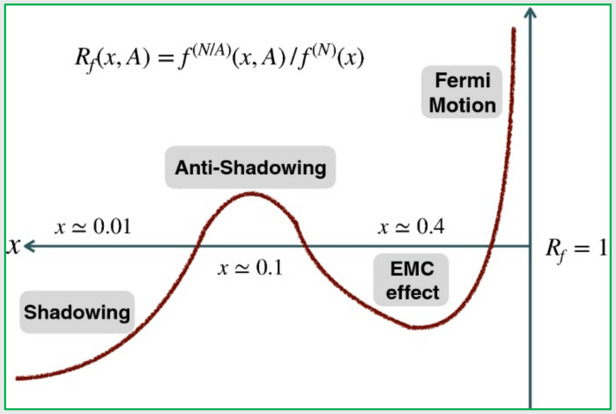
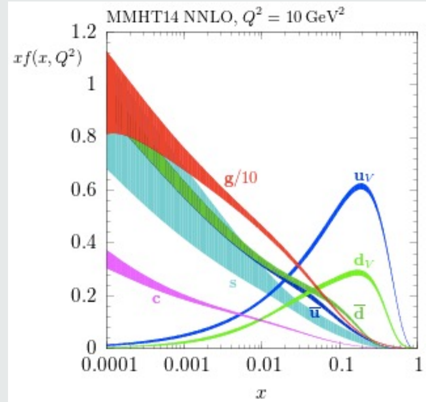
Anti-Shadowing







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What is needed

- High precision → high luminosity
- e-A (x, Q^2) range accessible
- Ability to change targets quickly,…
- Tensor polarized deuterium, mirror nuclei, polarized/unpolarized mapping across A, N, Z,
- Nuclear tagging → links between nuclear dynamic & quark structure

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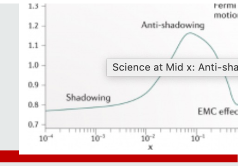

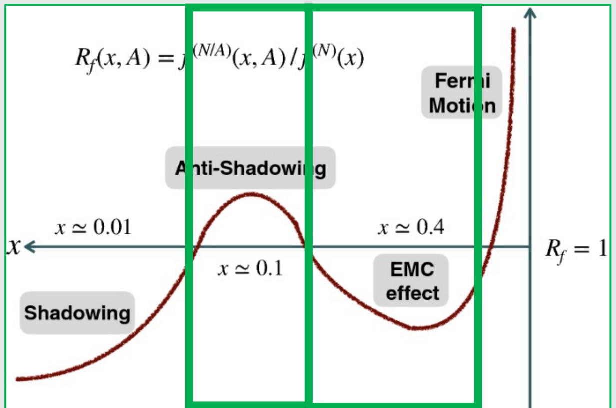

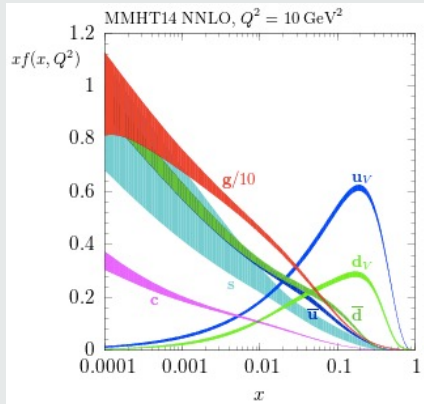

~22 GeV ⟸ 12 GeV

- **JLab at ~22 GeV is an anti-shadowing regime machine !**

- **X~ 0.1 is a most dynamical rich regime of partonic structure in nucleon and nuclei**
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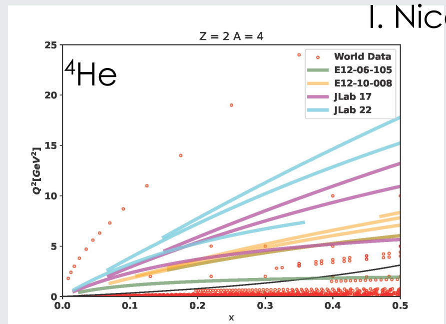
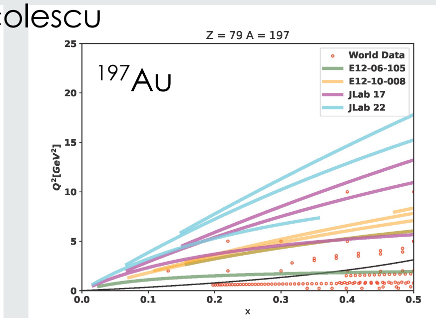
- ing across A, N, Z,
- clear tagging → links between nuclear dynamic & quark structure

ALL Possible @ Jlab 22 GeV

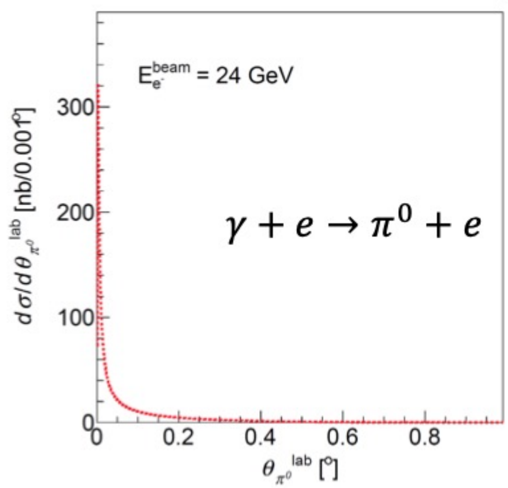
I. Nicolescu





Physics Beyond the Standard Model

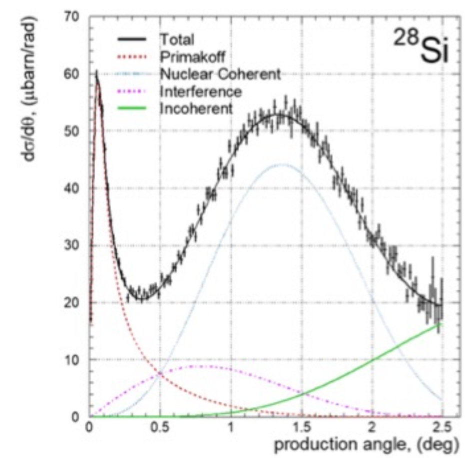
Topic	Presenter	Highlight/Comment
SoLID PVDIS on deuteron	A. Emmert	Prelim. Study → reduced uncertainty in $\sin^2\theta_W$
BSM in PVDIS experiments	S. Mantry	e → μ study underway
Primakov effect experiments	L. Gan	γ + e → π +e, new gauge boson searches
BDX experiment	M. Spreafico	Prelim. Study → expanded reach
BSM with secondary beams	M. Bondi	Competitive with current hadron facilities



L. Gan

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

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



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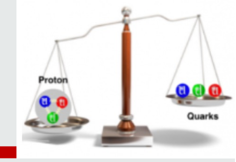
π^0 Primakoff production off an electron target will eliminate all nuclear backgrounds

Jefferson Lab

J/ψ photoproduction

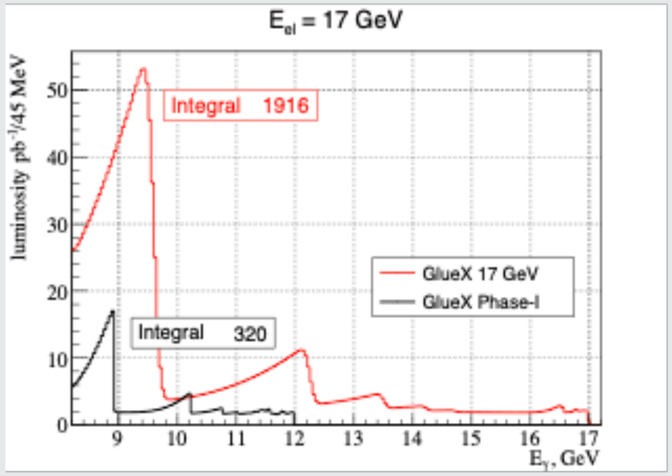


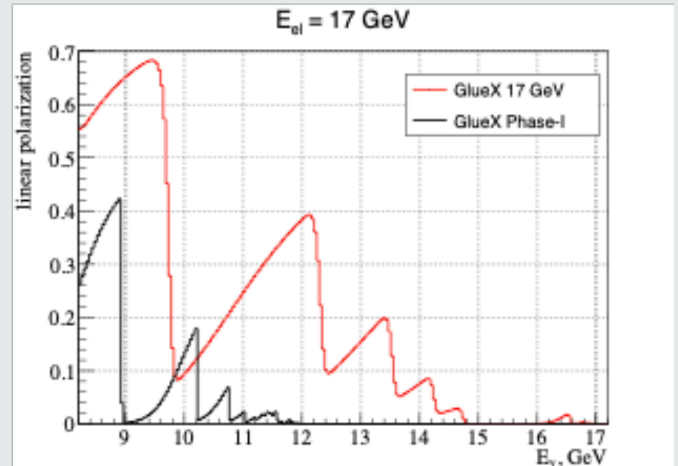
Golden process to unveil:

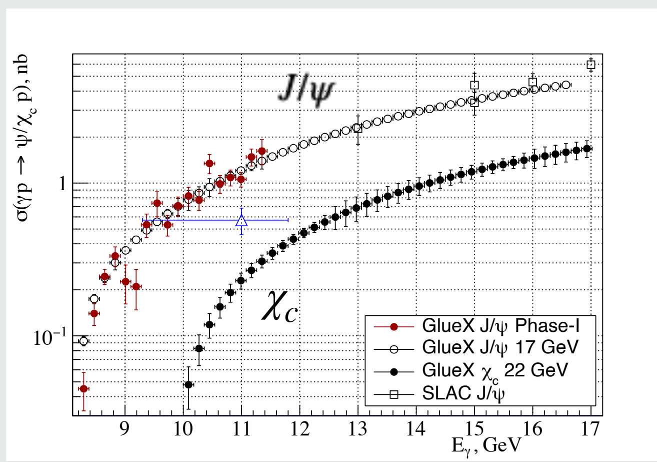
- *the nucleon mass structure*
- *pentaquark state involving the charm quarks*
- *poorly constrained gluon distribution of the nucleon at large x (> 0.1).*

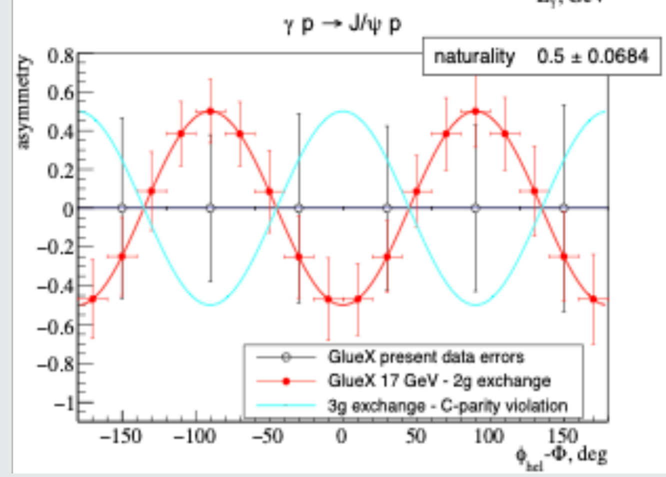
Substantial increase of the flux in the coherent peak allows precise cross section measurements covering the whole region down to threshold

Significant increase of the linear polarization allows to do important polarization measurements in the threshold region







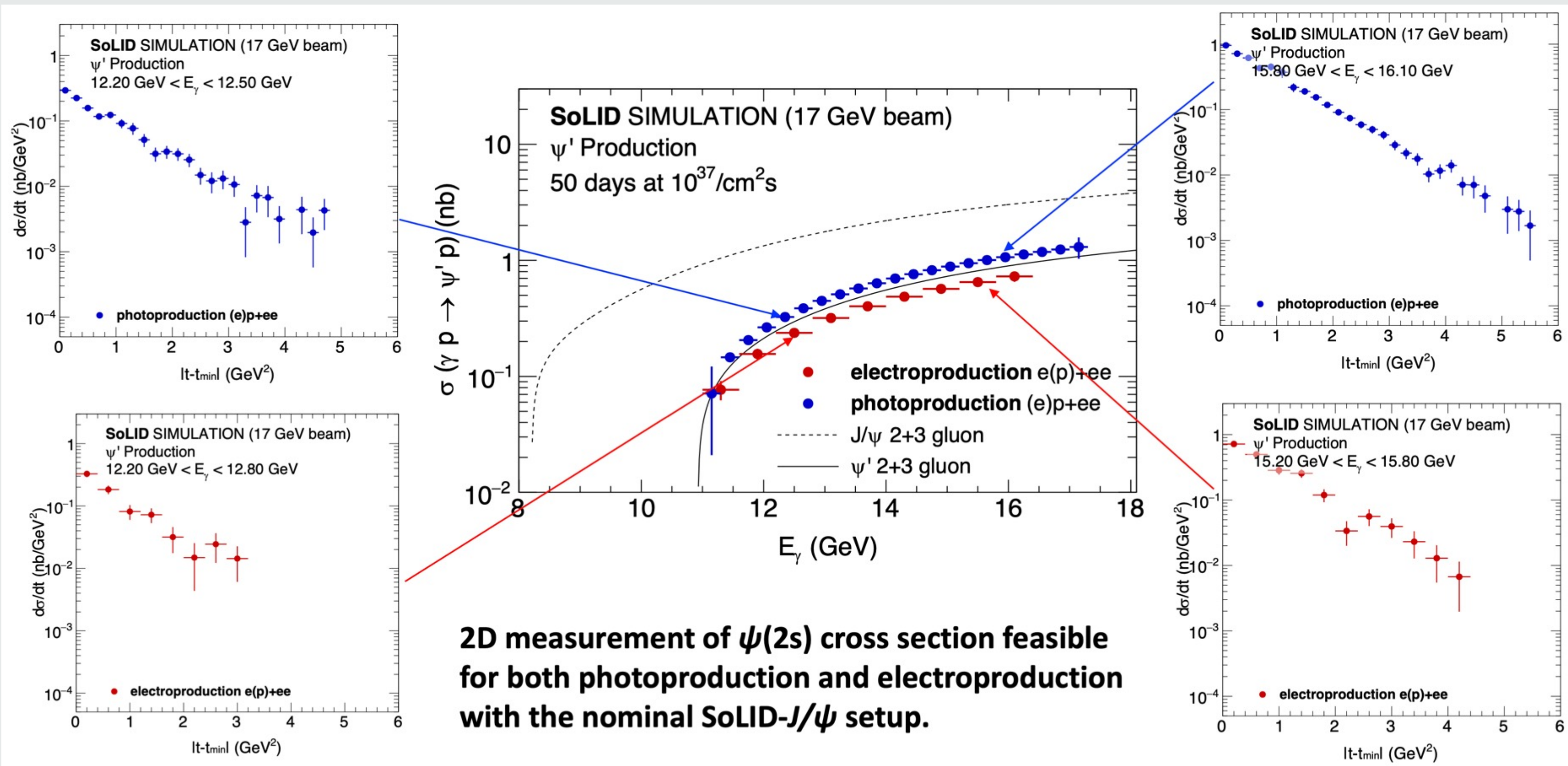


L. Pentchev

Jefferson Lab

J/ψ away from the threshold

- **Complementary probe to probe the gluonic field in the proton**
- **Better constrain on model dependencies and factorization assumptions**



S. Joosten

Jefferson Lab

Conclusions

- **CEBAF 20+ GeV upgrade is technical feasible**
- **There is a strong science for such an upgrade:**
  - Many new charmonium states, so-called "XYZ states," could be directly observed/tested at JLab
    – Fundamental question on how hadrons are emerged?
  - Uniquely determine the sign of gluon polarization
    – Critically important for understanding the "proton spin"
  - Significant enhancement of x, Q^2, P_T range
    – Critically important for better interpretation of the current theory
  - Explore the anti-shadowing phenomenon
    – a chance to solve the multi-decade mystery
  - Allow π^0 Primakoff production off an electron target
    – help eliminate nuclear background
  - Precision charmonium production near threshold in lepton-hadron collisions
    – as a precision probe of fundamental hadron properties and its tomography