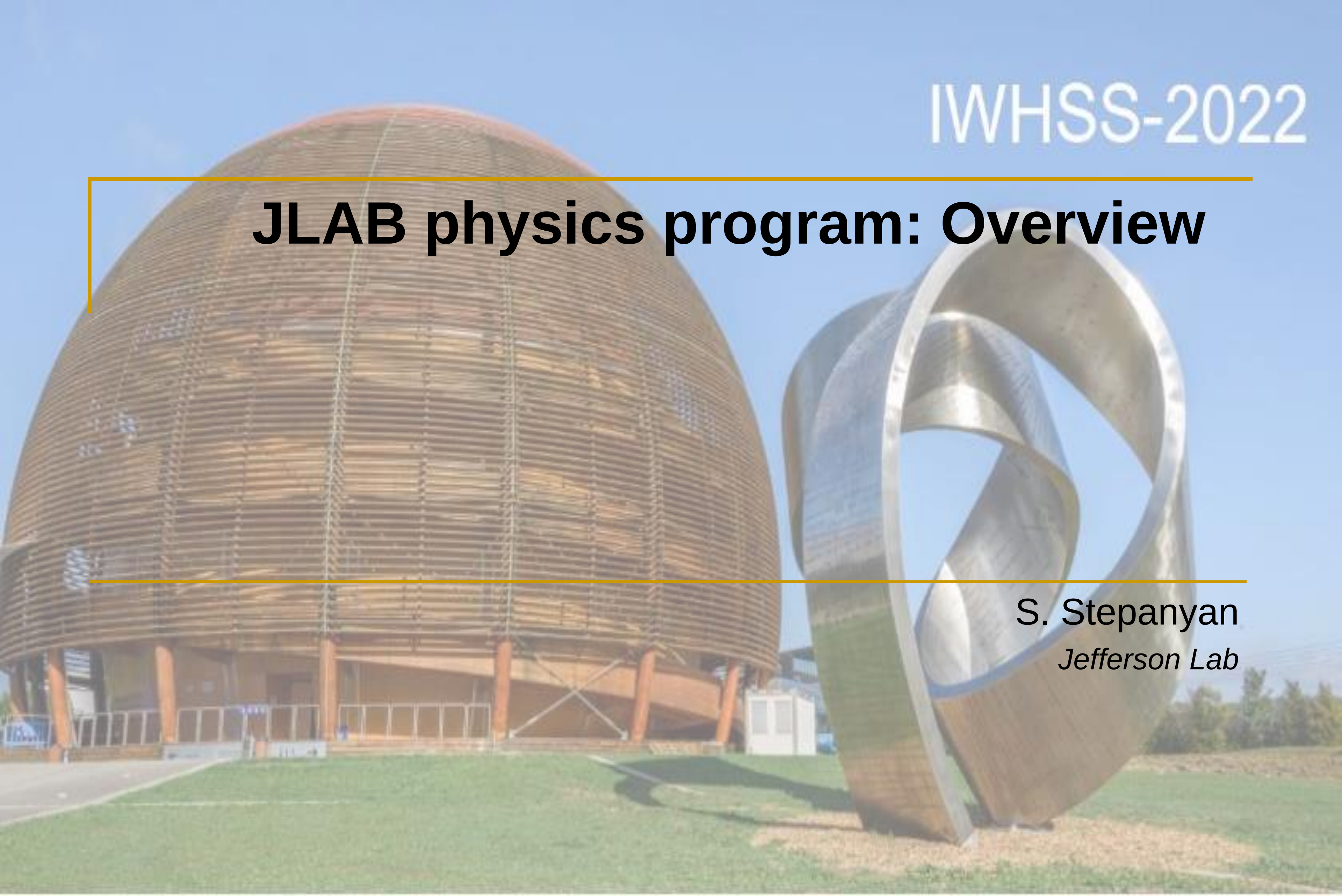


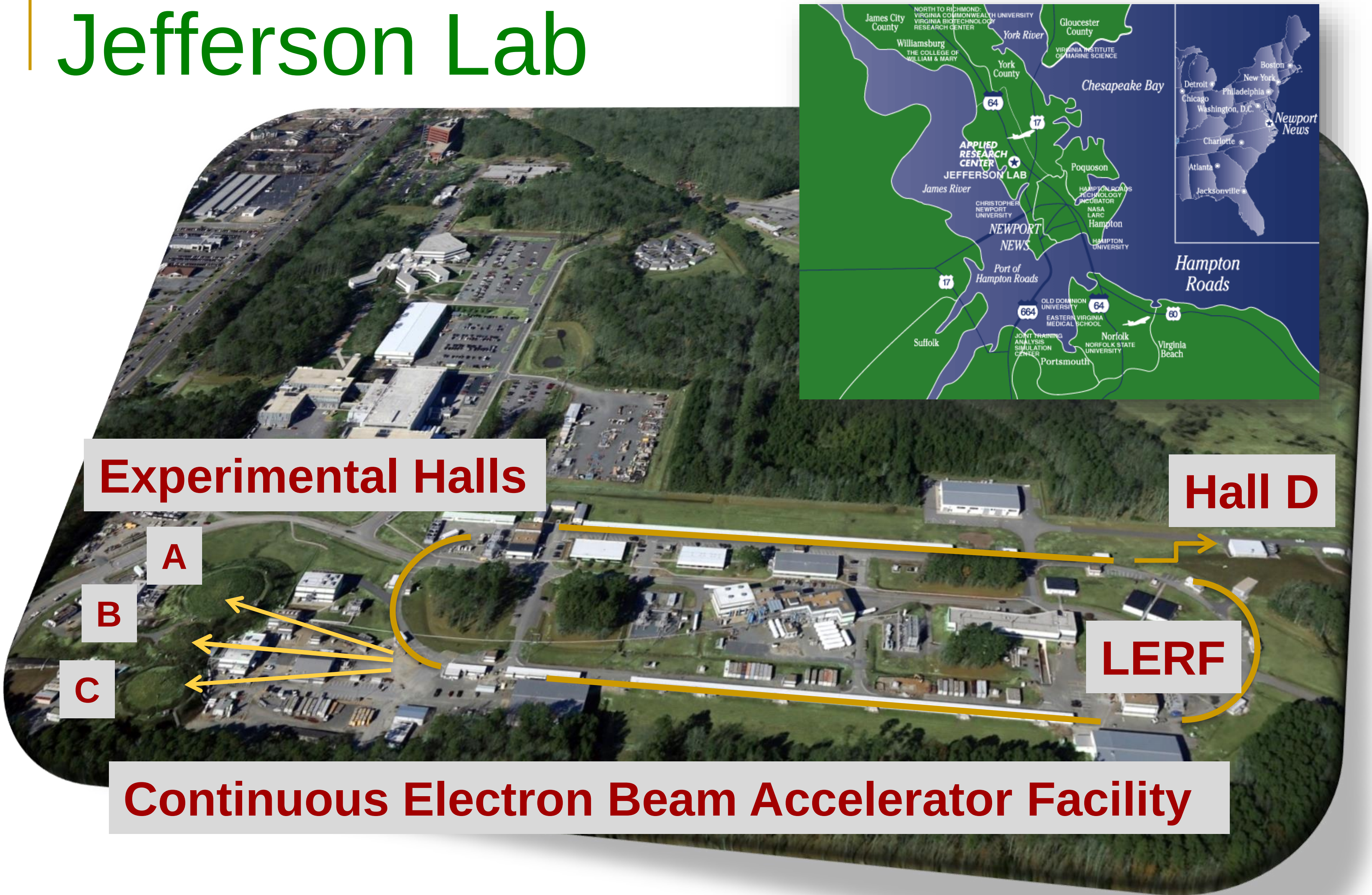
JLAB physics program: Overview

S. Stepanyan
Jefferson Lab

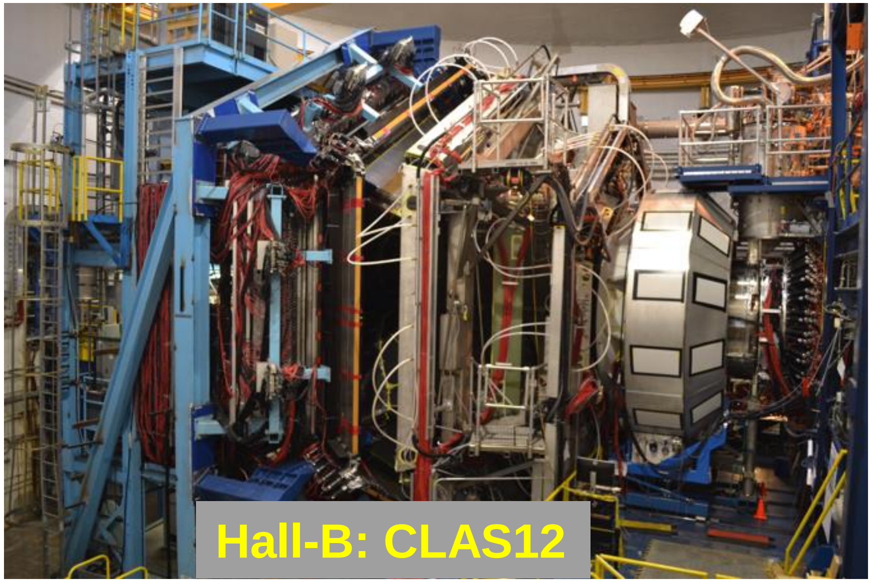
Outline

- Jefferson Lab CEBAF
- Overview of physics program
  - Elastic FF and polarized and unpolarized structure functions
  - 3-D structure, GPDs and TMDs
  - Hadron spectroscopy
  - QCD and nuclei
  - Physics beyond the Standard model
- Physics opportunities with positron beams
- Future energy upgrade
- Conclusion

Jefferson Lab

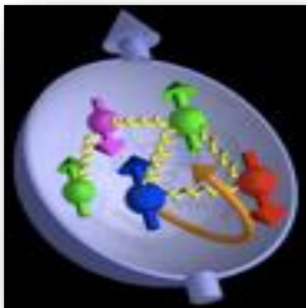


Experimental Setups

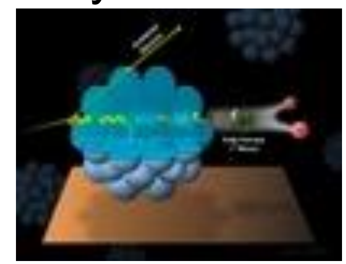


JLAB Physics program

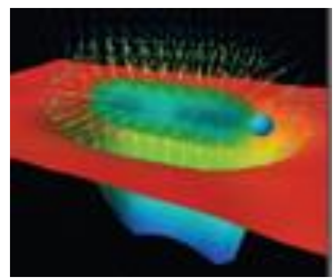
- Nucleon and nuclear structure studies, spatial and momentum tomography, form-factors …



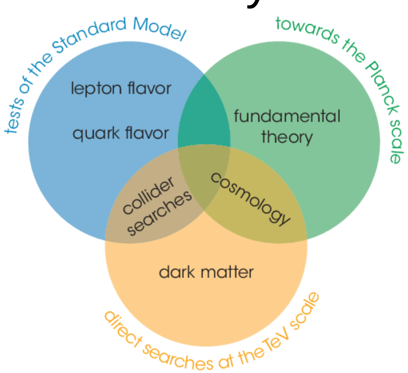
- Cold nuclear matter, NN correlations, hadronization, color transparency…



- Exploring origin of confinement – meson and baryon spectroscopy, exotics …



- Low-energy test of the Standard Model and fundamental symmetries.



Total of 86 approved experiments, 33 completed to date.

Recent overview and plans for future

https://arxiv.org/abs/2112.00060

- The 12 GeV Experimental Program is now in full swing.
- The overview includes recent results, updated projections, and plans for the future.
- It emphasizes the need for high-luminosity facilities (SoLID and CLAS12).
- Discusses the program with positron beams, and the possible energy upgrade to 20+ GeV.

Contents lists available at ScienceDirect

Progress in Particle and Nuclear Physics

journal homepage: www.elsevier.com/locate/ppnp

ELSEVIER

Review

Physics with CEBAF at 12 GeV and future opportunities

J. Arrington [a], M. Battaglieri [b,o], A. Boehnlein [b], S.A. Bogacz [b], W.K. Brooks [j], E. Chudakov [b], I. Cloët [c], R. Ent [b], H. Gao [d], J. Grames [b], L. Harwood [b], X. Ji [e,f], C. Keppel [b], G. Krafft [b], R.D. McKeown [b,h,*], J. Napolitano [g], J.W. Qiu [b,h], P. Rossi [b,n], M. Schram [b], S. Stepanyan [b], J. Stevens [h], A.P. Szczepaniak [l,m,b], N. Toro [i], X. Zheng [k]

[a] Lawrence Berkeley National Laboratory, Berkeley, CA 94720, USA
[b] Thomas Jefferson National Accelerator Facility, Newport News, VA 23606, USA
[c] Physics Division, Argonne National Laboratory, Lemont, IL 60439, USA
[d] Department of Physics, Duke University and Triangle Universities Nuclear Laboratory, Durham, NC 27708, USA
[e] Center for Nuclear Femtography, SURA, 1201 New York Ave. NW, Washington, DC 20005, USA
[f] Maryland Center for Fundamental Physics, Department of Physics, University of Maryland, College Park, MD 20742, USA
[g] Temple University, Philadelphia, PA 19122, USA
[h] William & Mary, Williamsburg, VA 23185, USA
[i] SLAC National Accelerator Laboratory, 2575 Sand Hill Road, Menlo Park, CA 94025, USA
[j] Universidad Técnica Federico Santa María, Valparaiso, Chile
[k] University of Virginia, Charlottesville, VA 22904, USA
[l] Physics Department, Indiana University, Bloomington, IN 47405, USA
[m] Center for Exploration of Energy and Matter, Indiana University, Bloomington, IN 47403, USA
[n] INFN, Laboratori Nazionali di Frascati, 00044 Frascati, Italy
[o] INFN, Sezione di Genova, 16146 Genova, Italy

ARTICLE INFO

Article history:
Available online xxxx

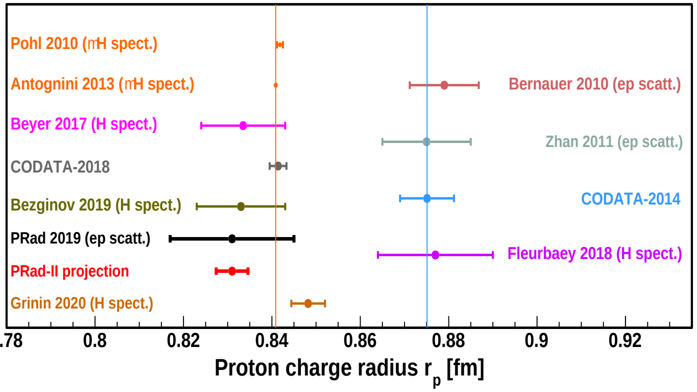
Keywords:
Electron Scattering
Quantum Chromodynamics
Hadronic Structure
Hadron Spectroscopy
Nuclear Structure
Standard Model Tests

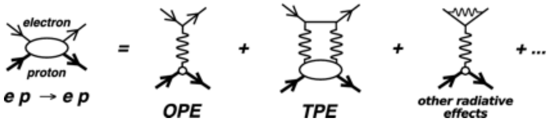
ABSTRACT

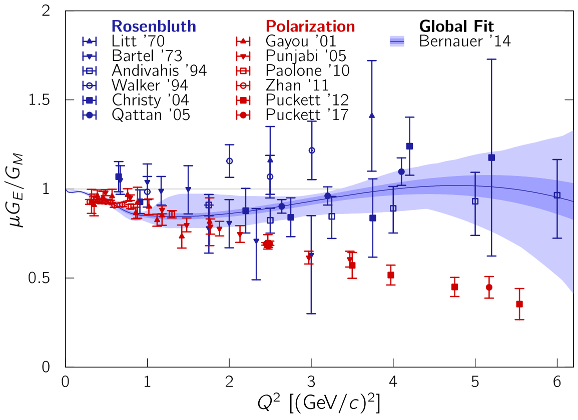
We summarize the ongoing scientific program of the 12 GeV Continuous Electron Beam Accelerator Facility (CEBAF) and give an outlook into future opportunities. The program addresses important topics in nuclear, hadronic, and electroweak physics, including nuclear femtography, meson and baryon spectroscopy,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

EM form factors

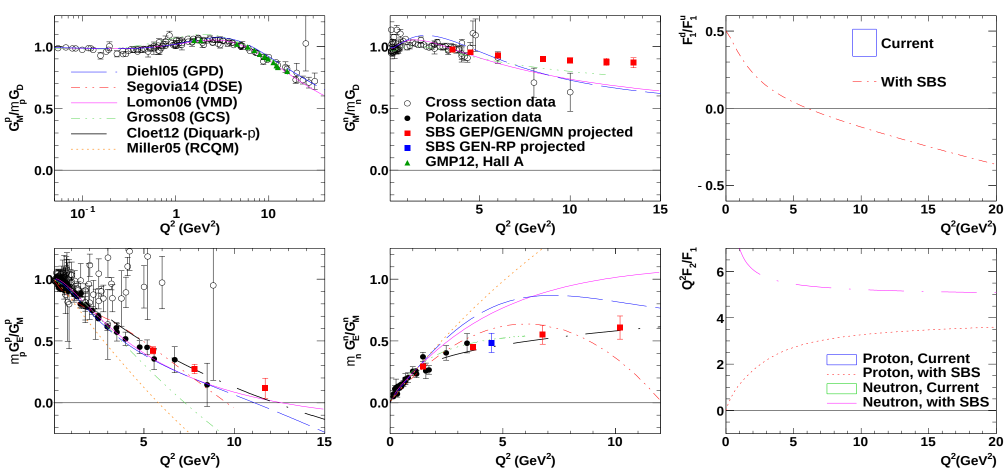
- Electron scattering has been a tool of choice for many decades for studies of the structure of the nucleon.
- However, at each new stage of experimental investigation, new challenges and inconsistencies arose.
- New experiments at Jefferson Lab address most of discrepancies, but some issues still remain:
  - the "proton radius puzzle", discrepancy between muonic-hydrogen and electron scattering;
  - the high Q^2 behavior of the proton elastic form factors $G_E(Q^2)$ and $G_M(Q^2)$ has also been a puzzle.







The SBS (Hall-A) form factor experiments.

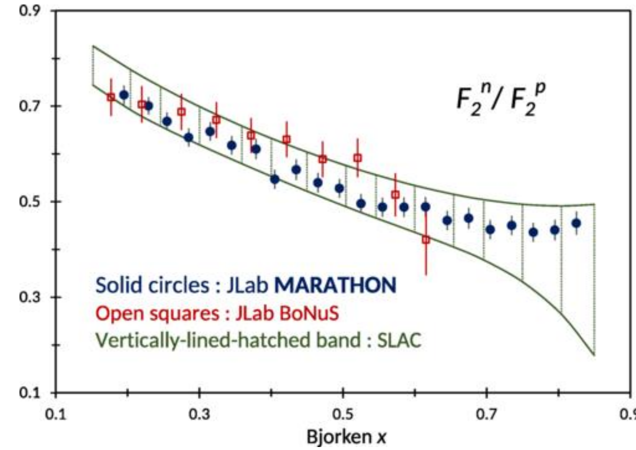


Jefferson Lab
Thomas Jefferson National Accelerator Facility

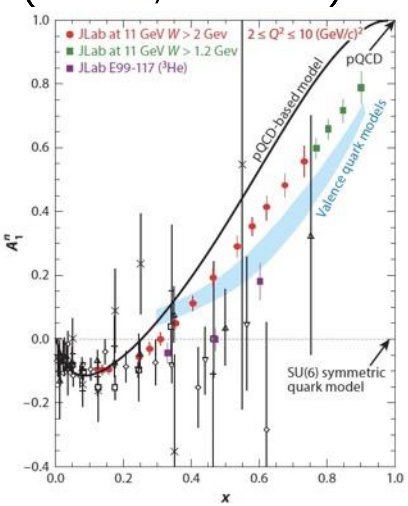
Structure of the valence quark distributions

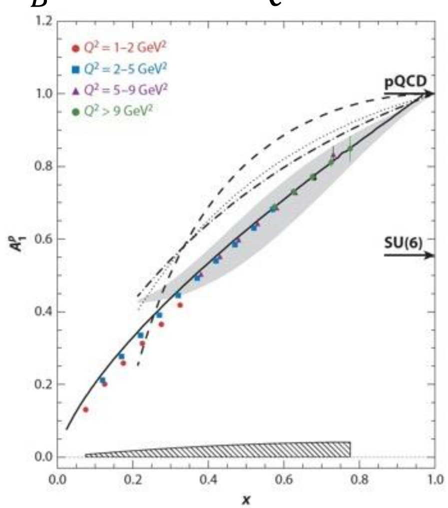
Precision measurements of F_2^n/F_2^p in the unpolarized DIS to constrain models for $(u+\bar{u})/(d+\bar{d})$. The SU(6) symmetry predicts F_2^n/F_2^p=2/3, the pQCD =3/7 at $x=1$.

- BoNus in Hall-B uses the low-energy spectator proton tagging: $en(p_s) \rightarrow e' p_s X$. New experiment with 11 GeV beam extends reach to $x_B \sim 0.8$.
- The *Marathon* experiment in Hall A measure inclusive scattering on two mirror nuclei with very similar wave functions, ^{3}He and ^{3}H.

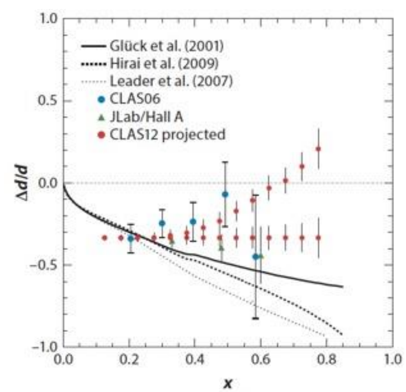


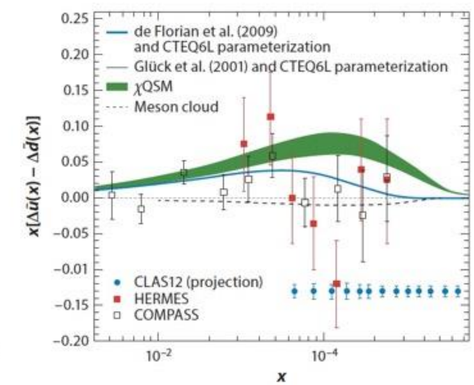
Study polarized parton distributions with high precision measurements of A_1^p, A_1^d, and A_1^{3He} (Hall-A, B and C) for $x_B \approx 0.8$ and $Q^2 \sim 10$ GeV^2.





Use global analysis to extract Δu and Δd, and the asymmetry of polarized see, $x\left[\Delta\bar{u}(x) - \Delta\bar{d}(x)\right]$.





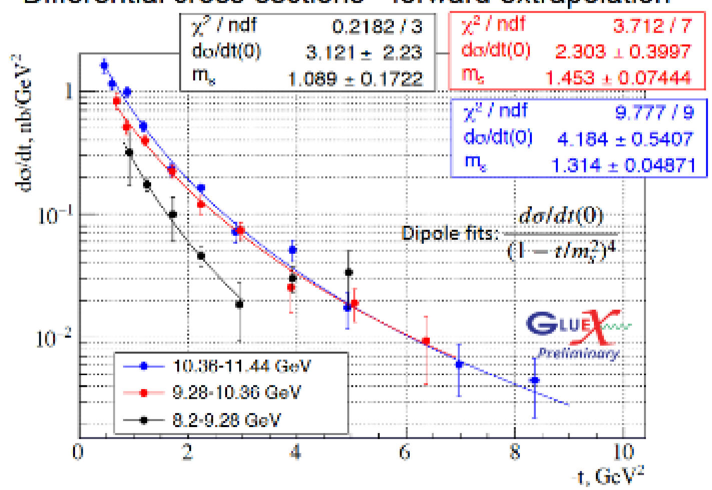
OFFICE OF SCIENCE

Jefferson Lab
Thomas Jefferson National Accelerator Facility

Protons gluonic FF – near threshold J/ψ production

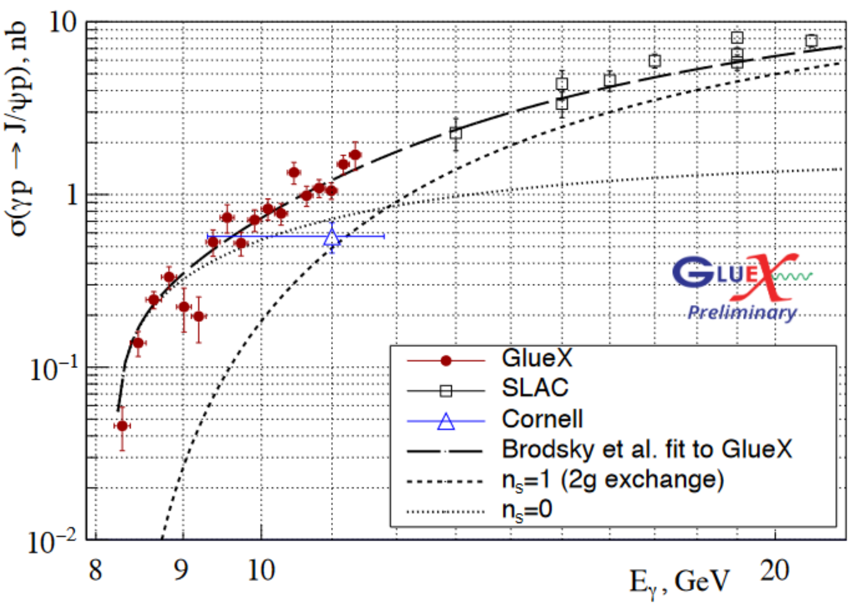
- Directly probe nucleon's gluonic field, access to the matter distribution, mass radius, and the trace anomaly of the EMT.
- Experiments in Hall C, and D (GlueX) already published results, the Hall-B CLAS12 (p, n) will follow.

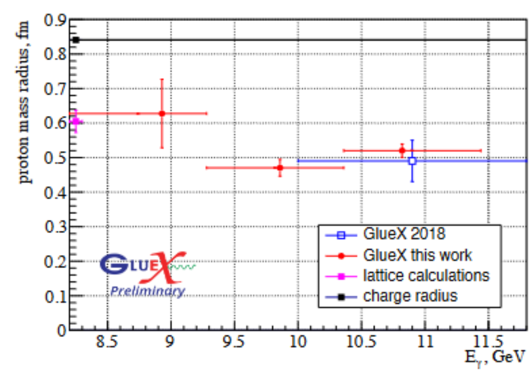
Differential cross-sections - forward extrapolation



E_γ, GeV	8.93	9.86	10.82
$q_{c.m.}$, GeV (J/ψp c.m.)	0.499	0.767	0.978
$d\sigma/dt(0)$, nb/GeV^2	3.121 ± 2.23	2.303 ± 0.400	4.184 ± 0.541
m_s, GeV	1.089 ± 0.172	1.453 ± 0.074	1.314 ± 0.049

Total cross section asymptotic - power counting



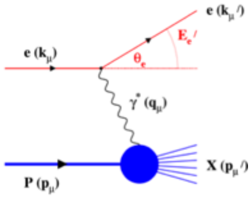


$$r_m = \frac{6}{m_p}\frac{dG}{dt}\bigg|_{t=0} = \frac{12}{m_s^2}$$

D.Kharzeev PRD104(2021)

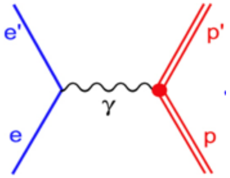
3-D Structure of the Nucleon: TMDs and GPDs

DIS Parton Distribution Functions

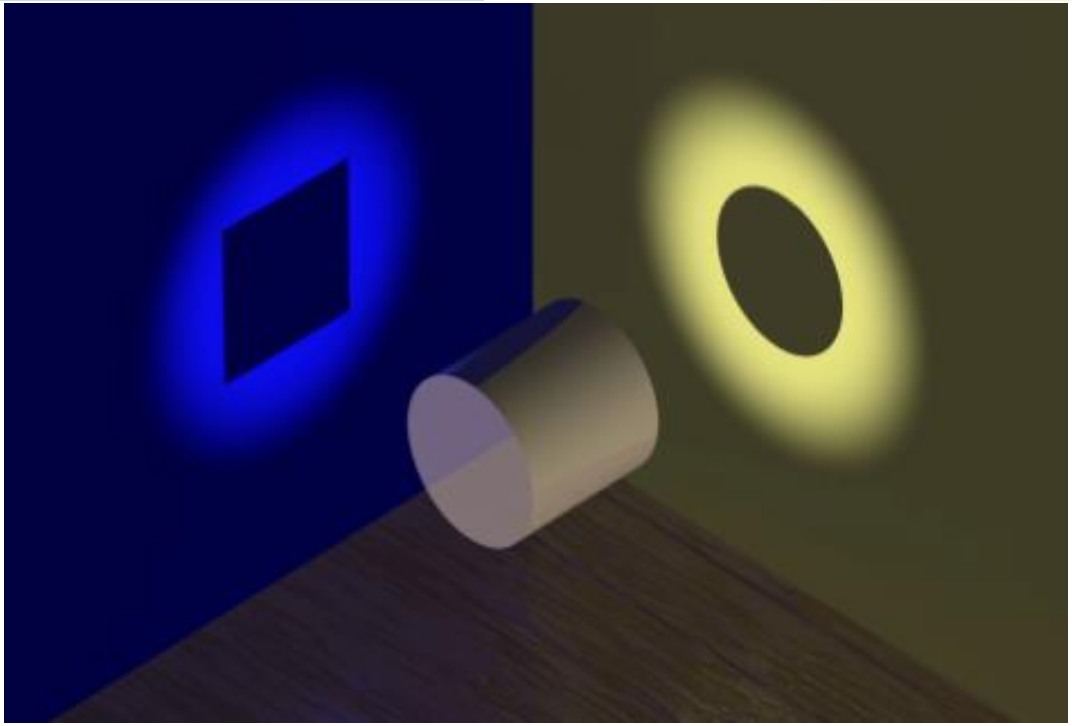


No information on the spatial location of the constituents

Elastic Form Factors



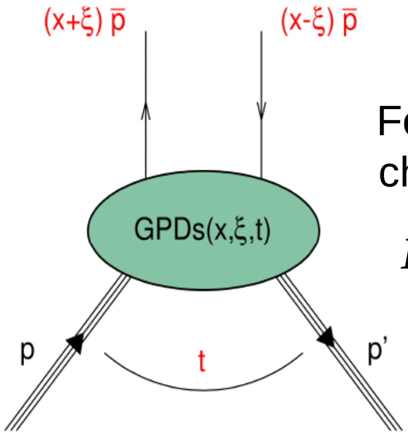
No information about the underlying dynamics of the system



Transverse Momentum Distributions & **Generalized Parton Distributions**
3-D imaging of the nucleon, the correlation of quark/antiquark transverse spatial and longitudinal momentum distributions, and on the quark angular momentum distribution

Nucleon tomography: GPDs

A major thrust of the JLab 12 GeV facility.



Four leading-twist chiral-even GPDs:

$$H^q; E^q; \tilde{H}^q; \tilde{E}^q$$

- GPDs → PDFs (in the limit $t \to 0$)

$$H^q(x,0,0) = q(x), -\bar{q}(-x)$$
$$\tilde{H}^q(x,0,0) = \Delta q(x), \Delta\bar{q}(-x)$$

- GPDs → FFs (first moments of GPDs)

$$\int_{-1}^{+1} dx H^q(x,\xi,t) = F_1^q(t) \qquad \int_{-1}^{+1} dx \tilde{H}^q(x,\xi,t) = g_A^q(t)$$
$$\int_{-1}^{+1} dx E^q(x,\xi,t) = F_2^q(t) \qquad \int_{-1}^{+1} dx \tilde{E}^q(x,\xi,t) = h_A^q(t)$$

Link to the energy-momentum tensor

$$\int_{-1}^{1} \mathrm{dx}\ \mathrm{x} \mathrm{H^q}(\mathrm{x},\xi,\mathrm{t}) = \mathrm{A^q}(\mathrm{t}) + \xi^2 \mathrm{D^q}(\mathrm{t})$$
$$\int_{-1}^{1} \mathrm{dx}\ \mathrm{x} \mathrm{E^q}(\mathrm{x},\xi,\mathrm{t}) = \mathrm{B^q}(\mathrm{t}) - \xi^2 \mathrm{D^q}(\mathrm{t})$$

the D-term characterizes the distribution of forces inside the nucleon

Polyakov, Physics Letters B, 2003

Nucleon tomography

$$\mathrm{H^q}(\mathrm{x},\mathrm{b}_\perp) = \int \frac{\mathrm{d}^2\Delta_\perp}{(2\pi)^2} e^{-i b_\perp \Delta_\perp} \mathrm{H^q}(\mathrm{x},0,-\Delta_\perp^2)$$

Burkardt, Int.J.Mod.Phys.A, 2002

Decomposition of the nucleon spin

$$\mathrm{J_Q} = \sum_q \frac{1}{2} \int_{-1}^{1} \mathrm{dx}\ \mathrm{x}(\mathrm{H^q}(\mathrm{x},\xi,0) + \mathrm{E^q}(\mathrm{x},\xi,0))$$

Ji, Phys. Rev. Lett, 1997

Compton Scattering and GPDs

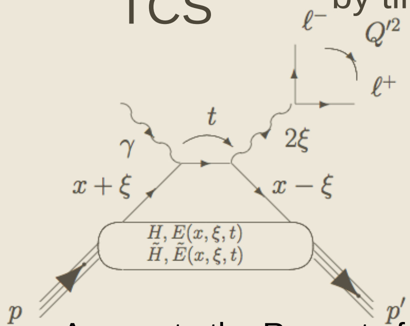
CLAS12 GPD studies

First experimental measurement with CALS12
PRL 127, 262501 (2021)

Started in 2001, PRL 87, 182002
Is the large part of the CLAS12 physics program

TCS

Hard scale is defined by time-like photons



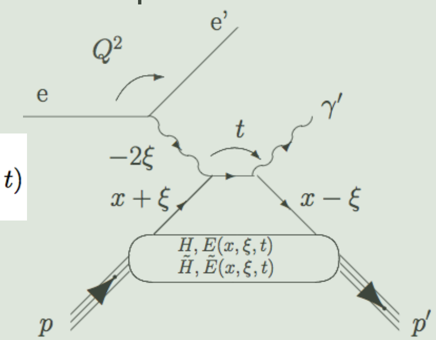
Access to the Re-part of the Compton amplitude

$$Re\ \mathcal{H}(\xi,t) = PV \int_{-1}^{1} dx\, C^{-}(\xi,x) H(x,\xi,t)$$

$$Im\ \mathcal{H}(\xi,t) = i\pi H(\xi,\xi,t)$$

DVCS

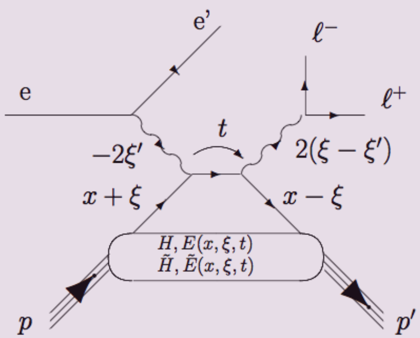
Hard scale is defined by space-like photon



µCLAS12, one of two proposed facilities capable of measuring

DDVCS

Both space-like and time-like photons can set the hard scale



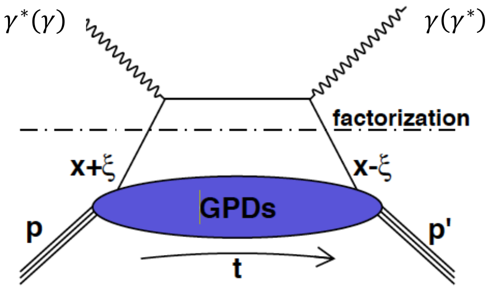
$$\int_{-1}^{+1} dx \frac{H(x,\xi,t)}{x-(2\xi'-\xi)+i\epsilon} + \ldots$$

$$H(2\xi'-\xi,\xi,t) + H(-(2\xi'-\xi),\xi,t)$$

σ-DDVCS is three orders of magnitude smaller than σ-DVCS
The main driver of the high luminosity upgrade

DVCS program

Program covers measurements of beam helicity, longitudinal and transverse polarized target asymmetries using detectors in Halls A, B, and C.

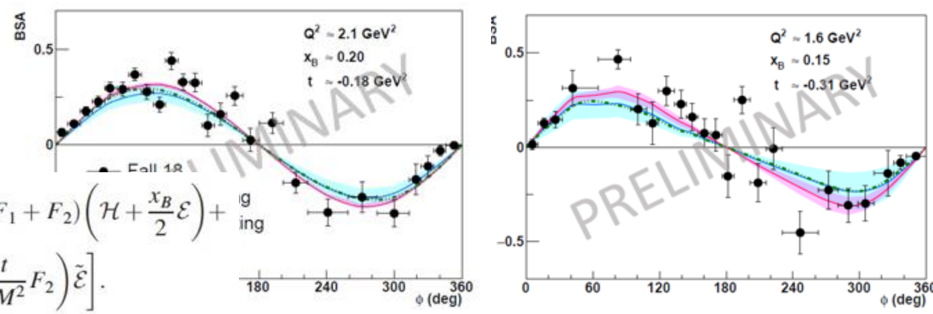


$$A_{LU} \propto F_1 Im\mathcal{H}$$
$$A_{UL} \propto F_1 Im\widetilde{\mathcal{H}}$$
$$A_{LL} \propto F_1 Re\widetilde{\mathcal{H}}$$
$$A_{UT} \propto F_1 Im\mathcal{E}$$

First BSA results from CLAS12

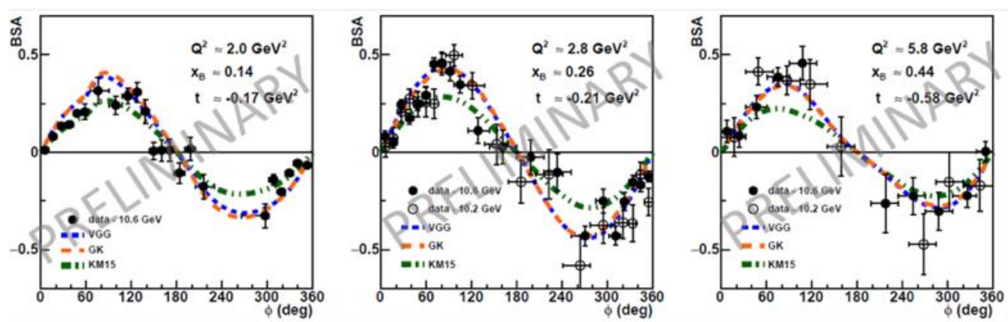
$$A_{LU} = \frac{a \sin\phi}{1 + c\cos\phi + d\cos 2\phi}$$

Fit with ANNs, constrained on 6 GeV data.



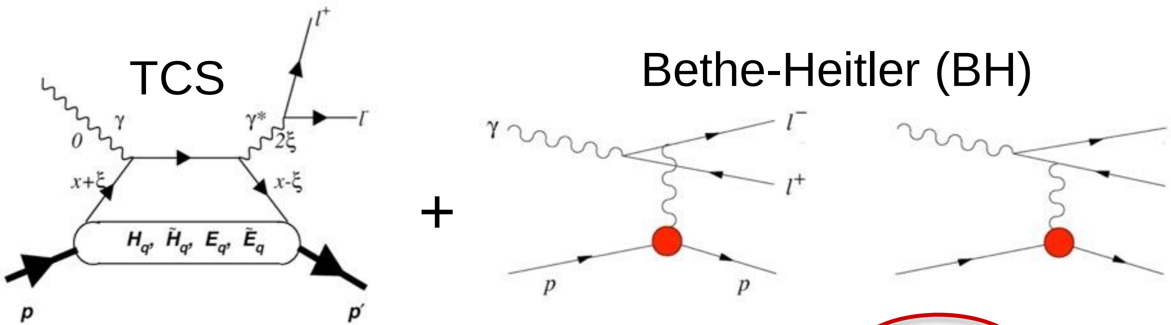
$$s_{1,\mathrm{LP}} \propto \Im\mathrm{m}\left[F_1\widetilde{\mathcal{H}} + \xi(F_1+F_2)\left(\mathcal{H} + \frac{x_B}{2}\mathcal{E}\right) + \ldots - \xi\left(\frac{x_B}{2}F_1 + \frac{t}{4M^2}F_2\right)\widetilde{\mathcal{E}}\right].$$

Comparisons with KM15 and VGG/GK models.



	Im **(DVCS, TCS)**	***Re*** **(DVCS, TCS)**
$\mathcal{H}$	$A_{LU}, A_{\odot U}$	σ, A_{UU}
$\widetilde{\mathcal{H}}$	A_{UL}	A_{LL}, A_{LT}
$\mathcal{E}$	A_{UT}	

First measurements of TCS with CLAS12

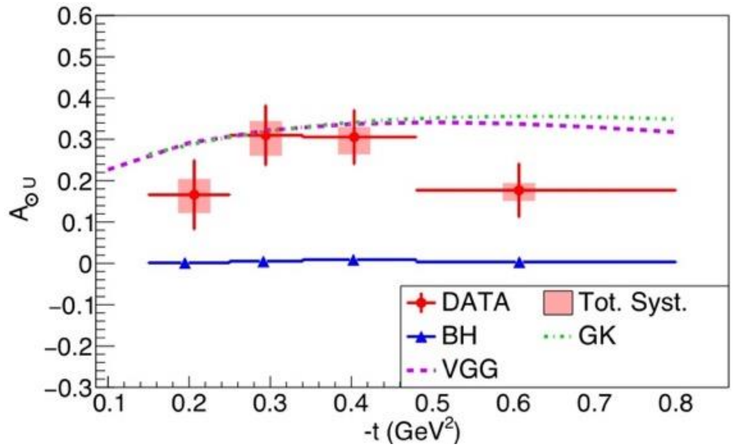


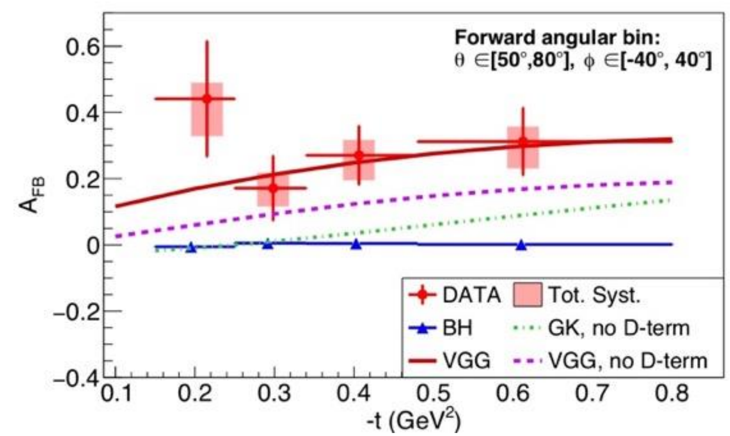
- BHA, $A_{\odot U} \sim \sin\varphi Im M^{--}$, universality of GPDs
- FB asymmetry, $A_{FB} \sim \cos\varphi Re M^{--}$, access to the EM FF $D^Q(t)$ (D-term).

$$\sigma(\gamma\mathbf{p} \to \mathbf{p'e^+e^-}) = \sigma_{\mathbf{BH}} + \sigma_{\mathbf{TCS}} + \sigma_{\mathbf{INT}}$$

$$A_{\odot U} = \frac{1}{P_b}\frac{N^+ - N^-}{N^+ + N^-} = \frac{d\sigma^+ - d\sigma^-}{d\sigma^+ + d\sigma^-} = \frac{-\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{m_p}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\frac{L_0}{L}\sin\phi\frac{(1+\cos^2\theta)}{\sin(\theta)}\mathrm{Im}\tilde{M}^{--}}{d\sigma_{BH}}$$

$$\mathbf{A_{FB}}(\theta_0,\phi_0) = \frac{\mathbf{d}\sigma(\theta_0,\phi_0) - \mathbf{d}\sigma(\pi-\theta_0,\pi+\phi_0)}{\mathbf{d}\sigma(\theta_0,\phi_0) + \mathbf{d}\sigma(\pi-\theta_0,\pi+\phi_0)} = \frac{-\frac{\alpha_{em}^3}{4\pi s^2}\frac{1}{-t}\frac{m_p}{Q'}\frac{1}{\tau\sqrt{1-\tau}}\frac{L_0}{L}\cos\phi_0\frac{(1+\cos^2\theta_0)}{\sin(\theta_0)}\mathrm{Re}\tilde{M}^{--}}{\mathbf{d}\sigma_{BH}(\theta_0,\phi_0) + \mathbf{d}\sigma_{BH}(\pi-\theta_0,\pi+\phi_0)}$$



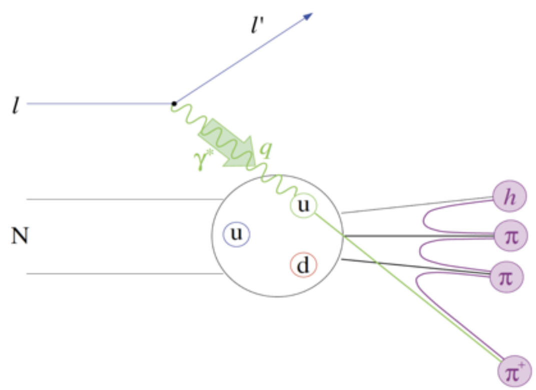


P. Chatagnon, et al. (CLAS Collaboration),"Phys. Rev. Lett. 127, 262501 (2021).

3D imaging in momentum space – SIDIS

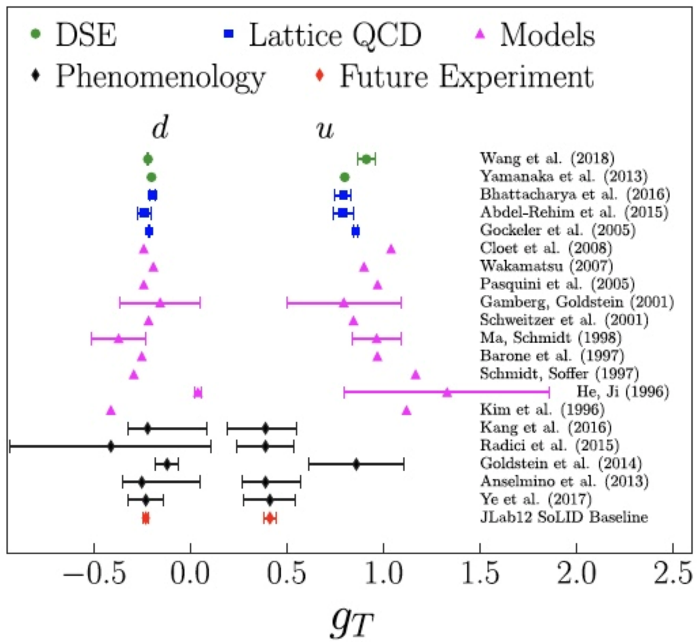
- Experiments in a wide kinematical region, with polarized beam and targets, variety of final states.
- Will study hadronization in both the target and current fragmentation regions

$$\sigma = F_{UU} + P_t F_{UL}^{\sin\phi} \sin 2\phi + P_b F_{LU}^{\sin\phi} \sin\phi \ldots$$



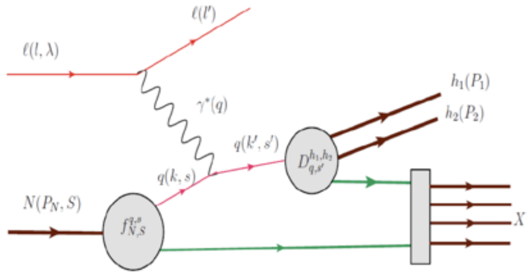
N \ q	U	L	T
U	f_1		$h_1^{\perp}$
L		g_1	$h_{1L}^{\perp}$
T	$f_{1T}^{\perp}$	g_{1T}	h_1 $h_{1T}^{\perp}$

Projected precision of extracted tensor charge for u and d quark from SoLID experiments with transversely polarized proton and ^{3}He targets.

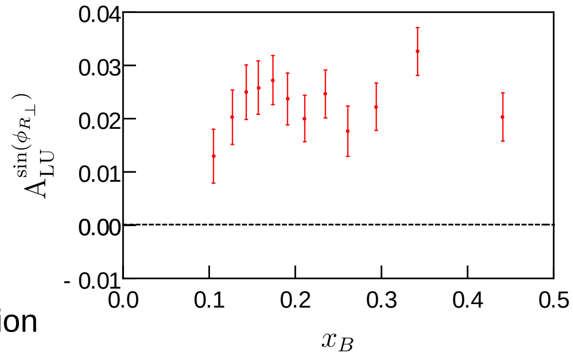


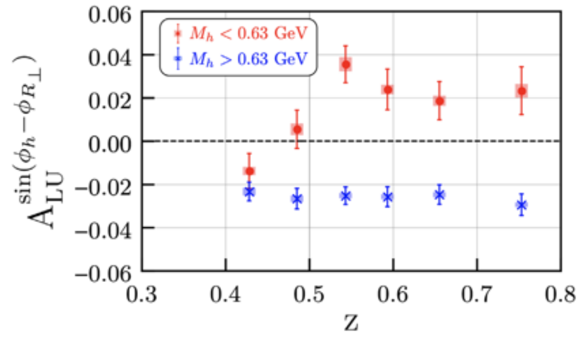
Di-hadron production in SIDS

BSA in the Process $ep \to e\pi^+\pi^- X$ with CLAS12



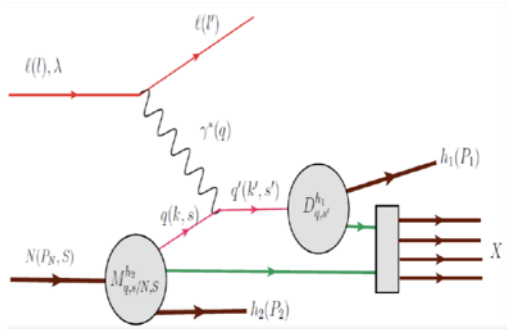
$$d\sigma_{LU} \propto W\lambda_e \sin(\phi_{R_\perp})\left[xe(x)H_1^{\sphericalangle}(z,M_h)+\frac{1}{z}f_1(x)\tilde{G}^{\sphericalangle}(z,M_h)\right]$$



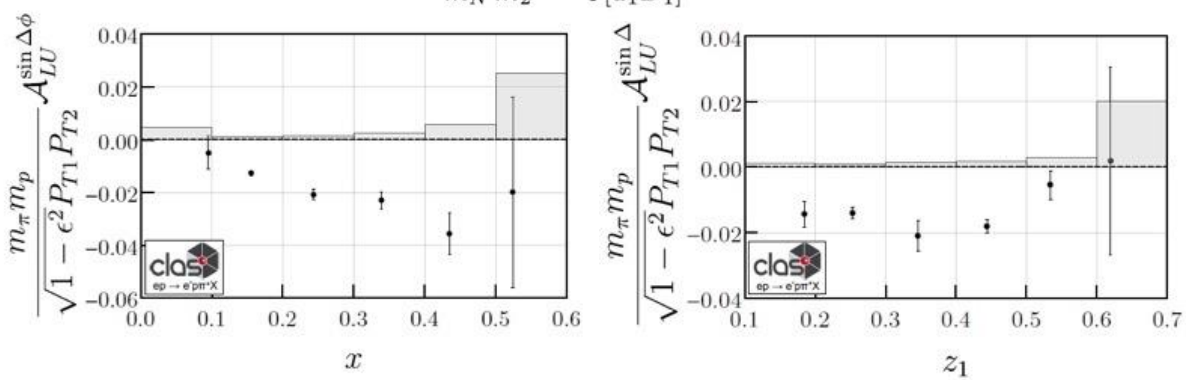


- Extraction of twist-3 collinear PDF $A_{LU}^{\sin(\phi_{R_\perp})} \sim \boldsymbol{e(x)}$
- Sensitive to the helicity-dependent two-pion fragmentation function $A_{LU}^{\sin(\phi_h-\phi_{R_\perp})} \sim \boldsymbol{G_1^\perp}$

BSA in back-to-back di-hadron production in the reaction $ep \to ep\pi^+ X$



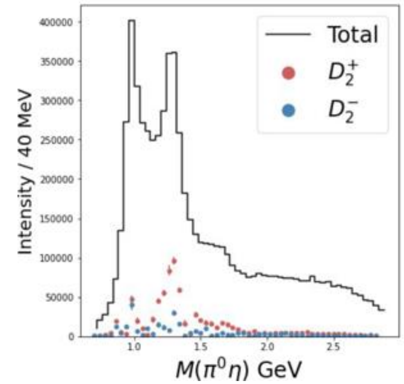
$$A_{LU} = -\sqrt{1-\epsilon^2}\frac{|\vec{P}_{T1}||\vec{P}_{T2}|}{m_N\, m_2}\frac{\mathcal{C}[w_5\, \hat{l}_1^{\perp h} D_1]}{\mathcal{C}[\hat{u}_1 D_1]}\sin\Delta\phi.$$



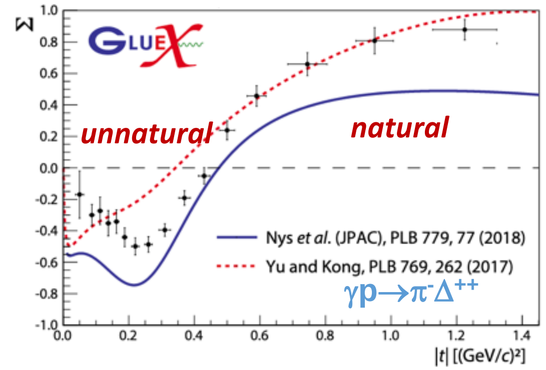
One of hadrons in CFR another in TFR, provides access to *leading twist* fracture functions, $\hat{l}_1^{\perp h}$ and $\hat{u}_1$.

Hadron spectroscopy

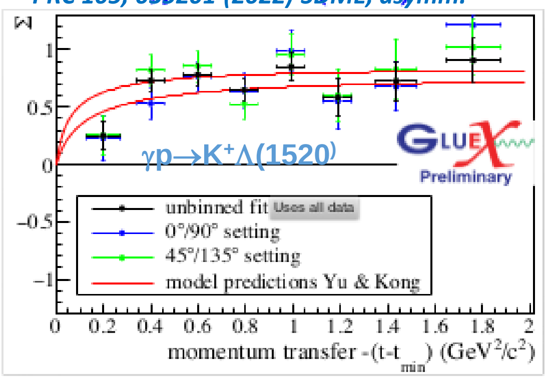
- Role of gluonic excitations, gluonic degrees of freedom – search for exotic states.
- Spectrum of excited nucleon states, transition FF.
- Strangeness production, polarization transfer



PRC 103, L02201 (2021) asymmetry

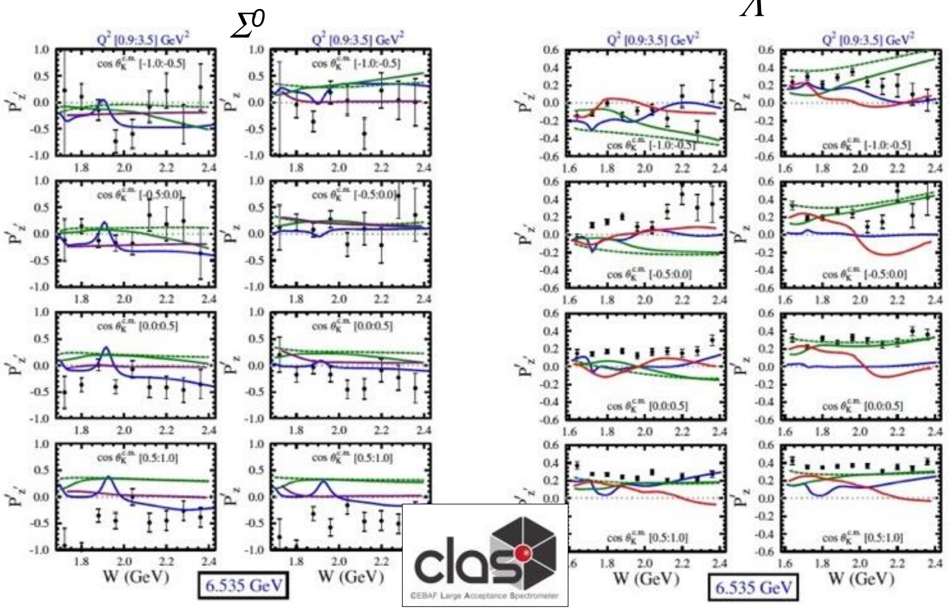


PRC 105, 035201 (2022) SDME, asymm.



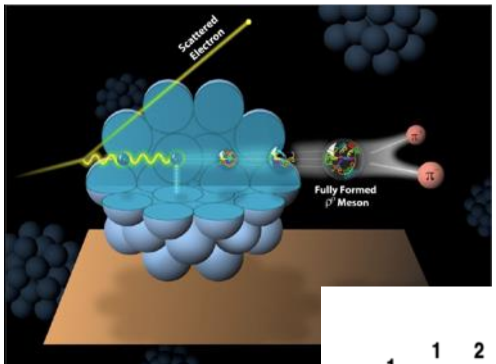
$$\frac{dN}{d\cos\theta_p} = N_0\left[1 + \alpha P_b P_Y' \cos\theta_p\right]$$

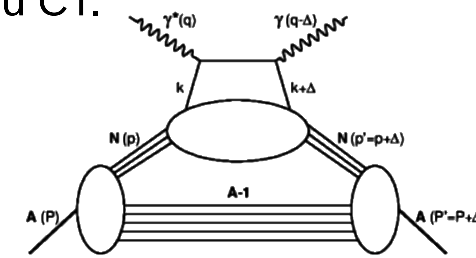
$$A = \frac{N^+ - N^-}{N^+ + N^-} = \nu_Y \alpha P_b P_Y' \cos\theta_p$$



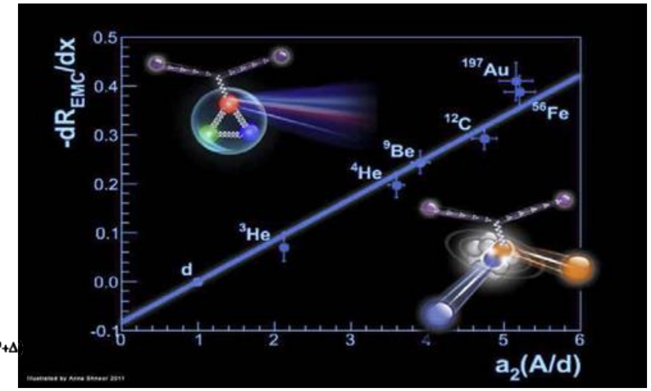
QCD and nuclei

- Nucleon modification, tagged EMC.
- Short range NN correlations.
- Quark/hadron propagation and CT.
- Nuclear DVCS

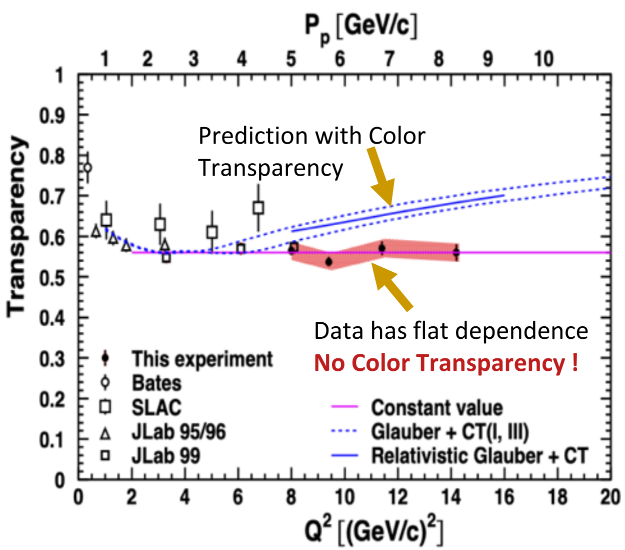




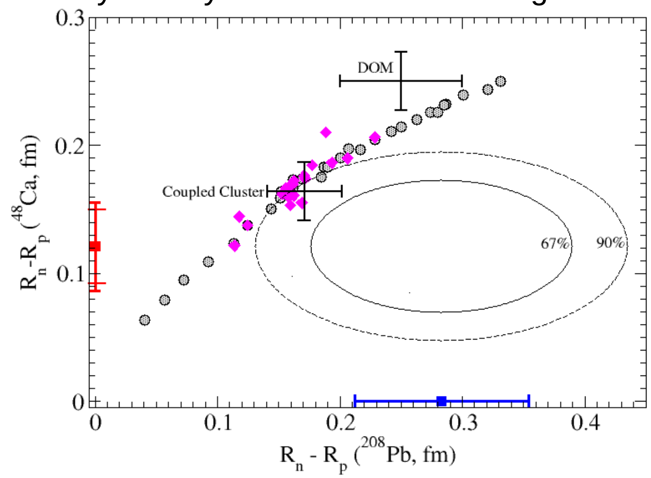
EMC-SRC correlation



Ruling out color transparency in quasi-elastic 12C(e,ep) up to Q^2 of 14.2 (GeV/c)2



PREX and CREX experiments: electroweak asymmetry in elastic *eA* scattering

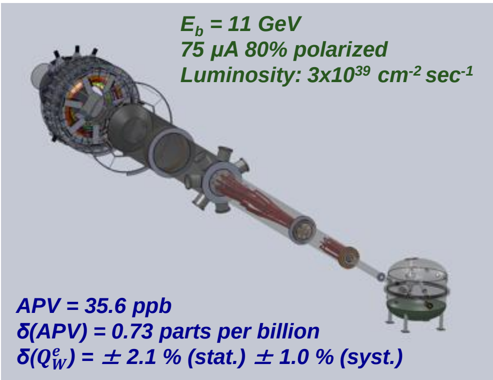


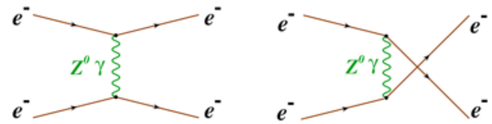
^{48}Ca : thin skin
^{208}Pb : thick skin

Implications for the EOS of neutron matter

Precision test of the SM electroweak interactions

PV Moller scattering: Purely leptonic probe – test of $\sin^2\theta_W$.

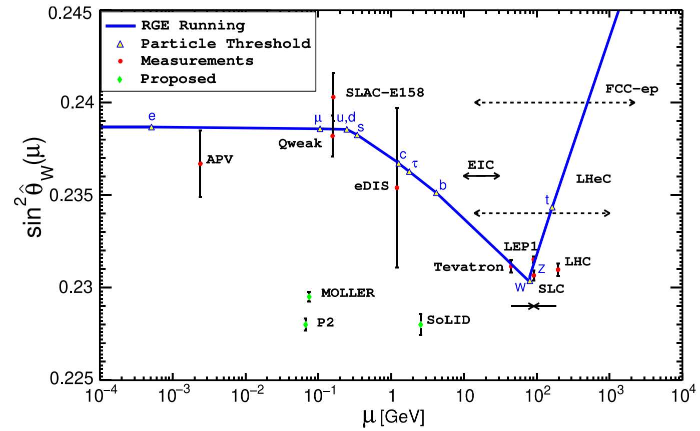




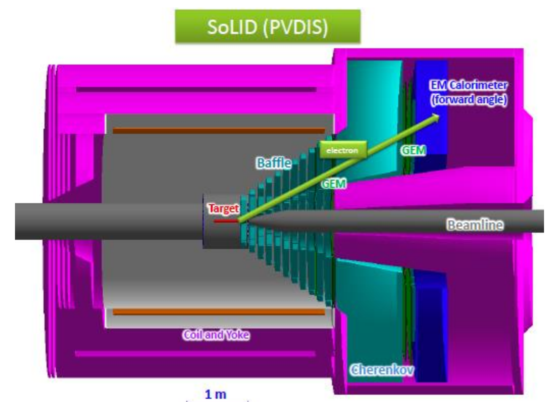
$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = mE\frac{G_F}{\sqrt{2}\pi\alpha}\frac{2y(1-y)}{1+y^4+(1-y)^4}Q^e_W$$

$$Q^e_W = -4g^V_e g^A_e = -(1-4\sin^2\theta_W)$$

The most precise measurement of weak mixing angle at low Q^2



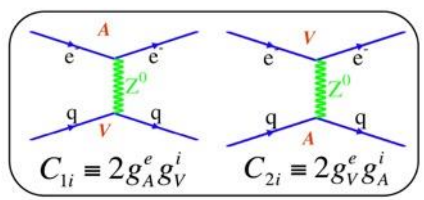
PV deep inelastic scattering: precision test of the SM prediction for hadronic axial-vector currents



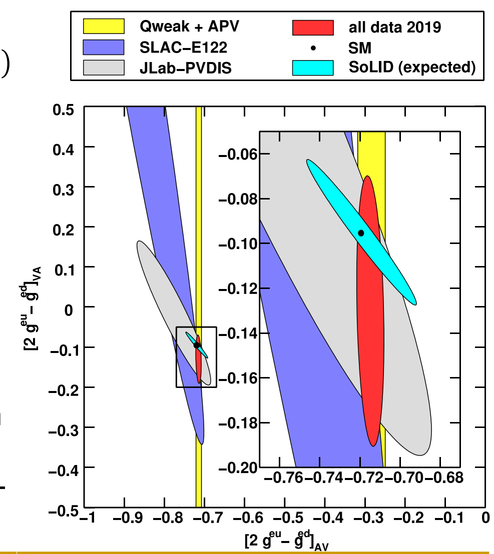
A Large Acceptance Detector, can handle high luminosity, 10^{39} cm^{-2} sec^{-1}

$$A_{PV} = \frac{\sigma_R - \sigma_L}{\sigma_R + \sigma_L} = \frac{G_F Q^2}{4\sqrt{2}\pi\alpha}\left(a_1(x,Q^2)Y_1(x,y,Q^2) + a_3(x,Q^2)Y_3(x,y,Q^2)\right)$$

$$a_1 = \frac{6}{5}(2C_{1u} - C_{1d}) \qquad a_3 = \frac{6}{5}(2C_{2u} - C_{2d})$$



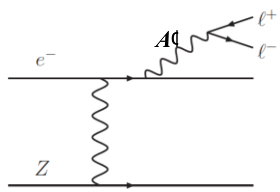
- BSM physics search - sensitive to contact interaction of high mass particles (~20 TeV – 40 TeV).
- Will help to disentangle dimension-6 from dimension-8 SM Effective Field Theory couplings.



Search for dark sectors

Hall-A

APEX



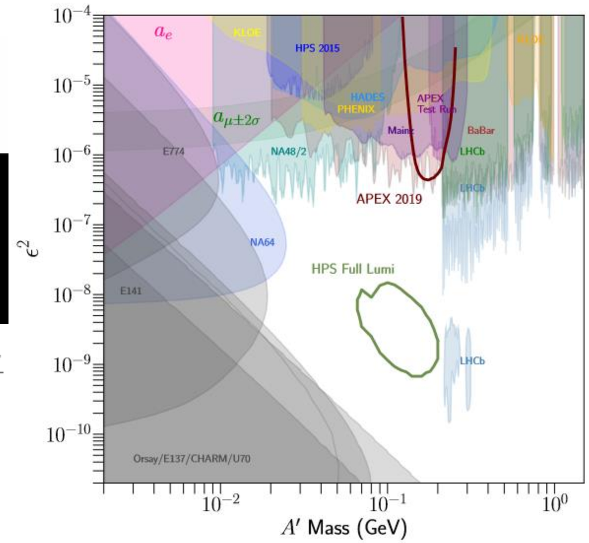
Direct Detection Search for X17

PRAD in Hall-B

Hall-B

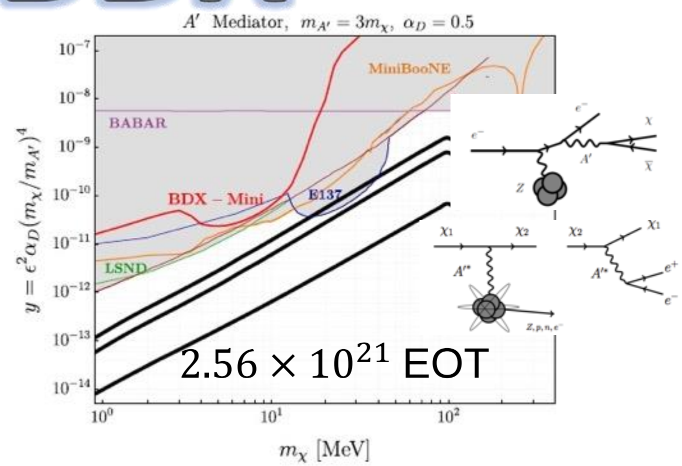
$$\frac{d\sigma(e^-Z\to e^-Z(A'\to l^+l^-))}{d\sigma(e^-Z\to e^-Z(\gamma^*\to l^+l^-))} = \frac{3\pi\epsilon^2}{2N_{eff}\alpha}\frac{m_{A'}}{\delta m}$$

$$c\tau \propto \frac{1}{\epsilon^2 m_{A'}}$$



BDX

Beyond Hall A beam dump



JEF with GluEx
$\gamma p \to \eta^{(\prime)} p'$ in Hall-D

Leptophobic

$\eta, \eta' \to B'\gamma \to \pi^0\gamma\gamma$, $(0.14 < m_{B'} < 0.62$ GeV)

$\eta' \to B'\gamma \to \pi^+\pi^-\pi^0\gamma$, $(0.62 < m_{B'} < 1$ GeV)

Leptophilic

$\eta, \eta' \to A'\gamma \to e^+e^-\gamma$.

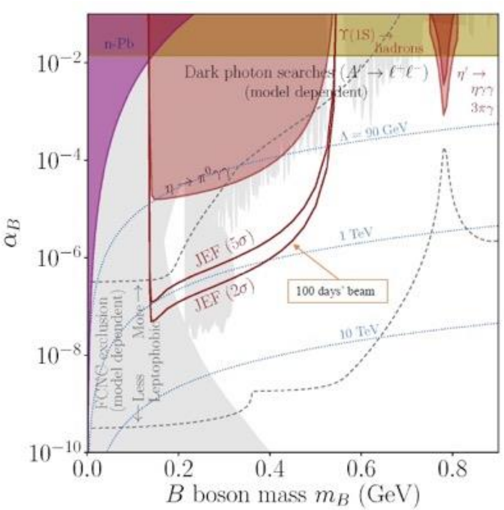
Hadrophilic

$\eta \to \pi^0 S \to \pi^0\gamma\gamma$, $\pi^0 e^+ e^-$, (10 MeV $< m_S < 2m_\pi$)

$\eta, \eta' \to \pi^0 S \to 3\pi$, $\eta' \to \eta S \to \eta\pi\pi$, $(m_S > 2m_\pi)$

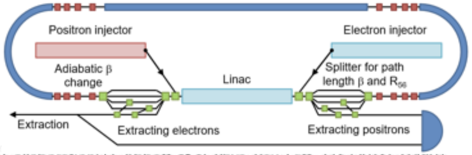
Axion-like:

$\eta, \eta' \to \pi\pi a \to \pi\pi\gamma\gamma$, $\pi\pi e^+e^-$

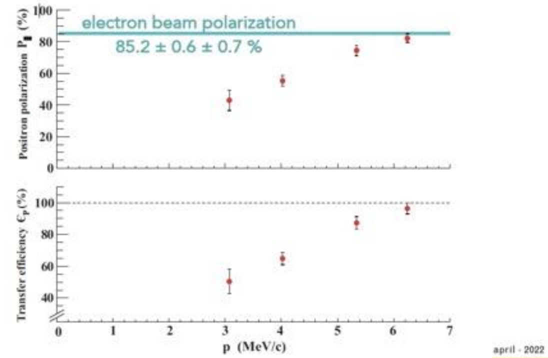


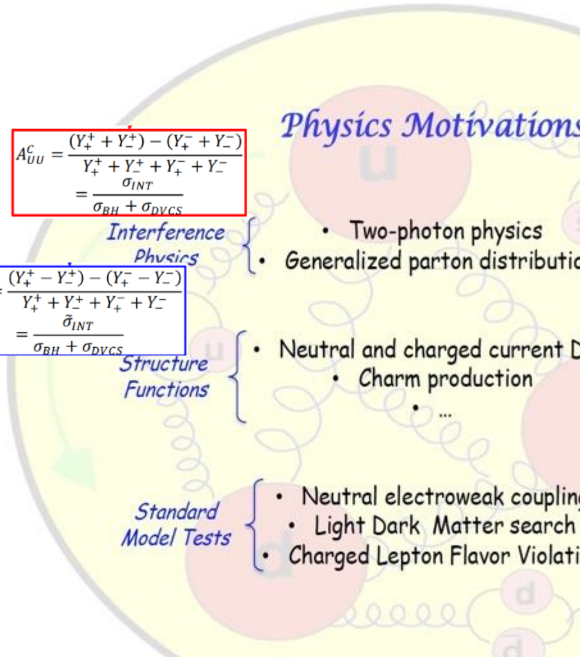
Physics with polarized positrons beams

A rich and exiting experimental program, will account for about five years of CEBAF running.



(PEPPo Collaboration) D. Abbott et al. Phys. Rev. Lett. 116 (2016) 214801





$$A_{UU}^{C} = \frac{(Y_+^+ + Y_-^+) - (Y_+^- + Y_-^-)}{Y_+^+ + Y_-^+ + Y_+^- + Y_-^-} = \frac{\sigma_{INT}}{\sigma_{BH} + \sigma_{DVCS}}$$

$$A_{LU}^{C} = \frac{(Y_+^+ - Y_-^+) - (Y_+^- - Y_-^-)}{Y_+^+ + Y_-^+ + Y_+^- + Y_-^-} = \frac{\tilde{\sigma}_{INT}}{\sigma_{BH} + \sigma_{DVCS}}$$

Interference Physics
- Two-photon physics
- Generalized parton distributions

Structure Functions
- Neutral and charged current DIS
- Charm production
- …

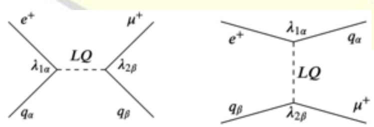
Standard Model Tests
- Neutral electroweak coupling
- Light Dark Matter search
- Charged Lepton Flavor Violation

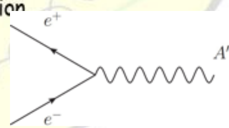
Two-photon contribution

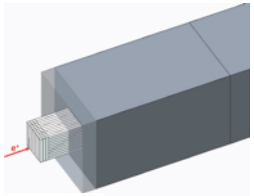
$$R_{2\gamma} = \frac{\sigma_{e+}}{\sigma_{e-}} \approx 1 + \delta_{2\gamma}$$

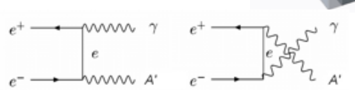
Weak neutral-current coupling

$$A_d^{e^+e^-} = -\frac{3G_F Q^2}{2\sqrt{2}\pi\alpha} Y(y) \frac{R_V\,(2g_{AA}^{eu} - g_{AA}^{ed})}{5 + 4R_C + R_S} = -1.06 \times 10^{-4}\,Q^2\,\frac{Y(y) R_V (2g_{AA}^{eu} - g_{AA}^{ed})}{1 + 0.8\,R_C + 0.2\,R_S}$$



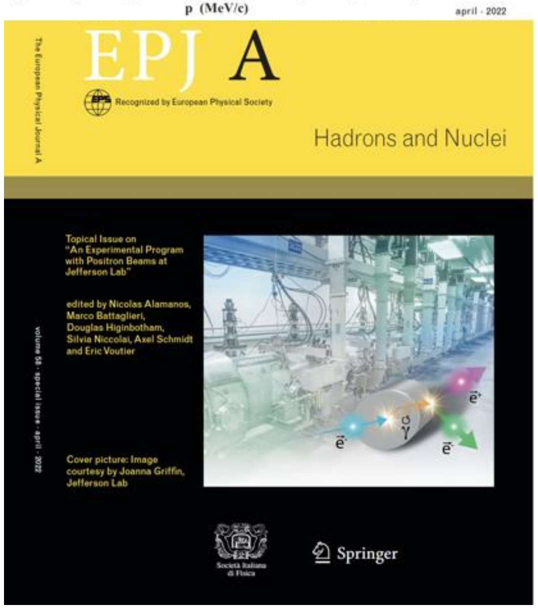






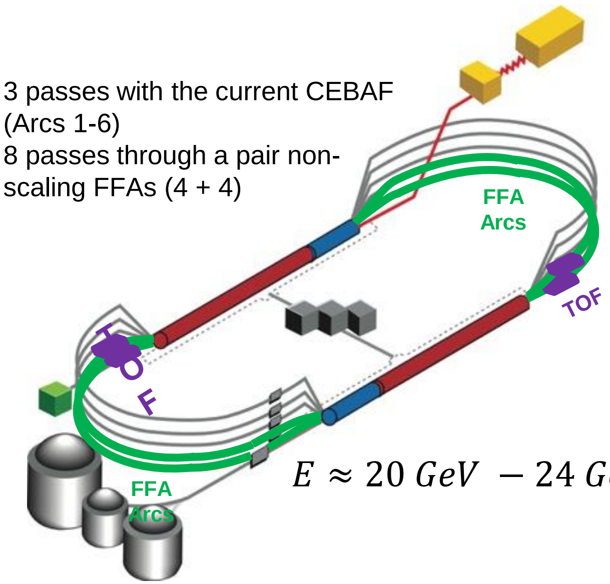
$$e^{\pm} + N \rightarrow \mu^{\pm} + X$$

$$L \approx 10^{39} cm^{-2} sec^{-1}$$



CEBAF energy upgrade

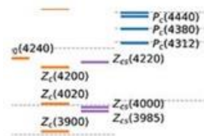
- 3 passes with the current CEBAF (Arcs 1-6)
- 8 passes through a pair non-scaling FFAs (4 + 4)



$$E \approx 20\ GeV\ - 24\ GeV$$

HIGH ENERGY WORKSHOP SERIES 2022

With the goal to probe the science that would be opened up by a higher energy electron beam (~20-24 GeV) at Jefferson Lab.

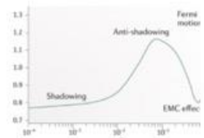


Hadron Spectroscopy with a CEBAF Energy Upgrade

June 16 & 17

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

Recent observations in heavy-quark spectroscopy have provided numerous candidates for hadronic resonances which are exotic in nature, the so-called XYZ and Pc states. With a CEBAF energy upgrade to 20-24 GeV these states and other charmonia may be studied in photoproduction and electroproduction measurements at JLab. This workshop aims to identify the key measurements made possible by such an upgrade, utilizing recent theoretical models for production and evaluating the detector performance requirements.

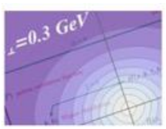


Science at Mid x: Anti-shadowing and the Role of the Sea

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 now be measured with minimal theoretical bias using parity-violating electron scattering. More generally, the interplay of the valence and sea regimes may be better disentangled. Novel tagged measurements may provide access to meson structure and the role of mesons in nuclei. All of these measurements leverage the unique capabilities of luminosity and precision possible at Jefferson Lab in the EIC era. This workshop seeks to enhance our knowledge of these topics and broadly identify exciting new science opened up in this middle x regime via experiments that initially utilize largely existing or already-planned Hall equipment.



The Next Generation of 3D Imaging

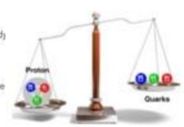
July 7 & 8

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 emerge dynamically from strong interactions, are recognized as key objectives of the JLab 12 GeV program, and driving force behind the construction of the future Electron Ion Collider (EIC). Jefferson Lab 12-GeV data already have remarkably higher precision at large parton fractional momenta x compared to the existing data and will be the main source of information on non-perturbative QCD in next decade. The major limitations in studies of the nucleon structure at JLab12 are the limited coverage of the kinematical region, where the non-perturbative sea is significant, and the limited phase space in accessing large momentum transfer and large transverse momenta of final state particles due to relatively low energy in the photon-nucleon CM system. These issues can be overcome by a JLab upgrade to 24 GeV.

The focus of this workshop will be threefold:

(1) Identify the flagship measurements that can be done only with 20+ GeV. **(2)** Identify the flagship measurements with 20+ GeV that can extend and improve the 11 GeV measurements, helping the physics interpretation through multidimensional bins in extended kinematics. **(3)** Identify the measurements with 20+ GeV that can set the bridge between JLab12 and EIC (complementarity)



J/Psi and Beyond

August 16 & 17 9am - 1pm

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

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 exists between JLab data and SLAC data from 40 years ago?

Physics Beyond the Standard Model

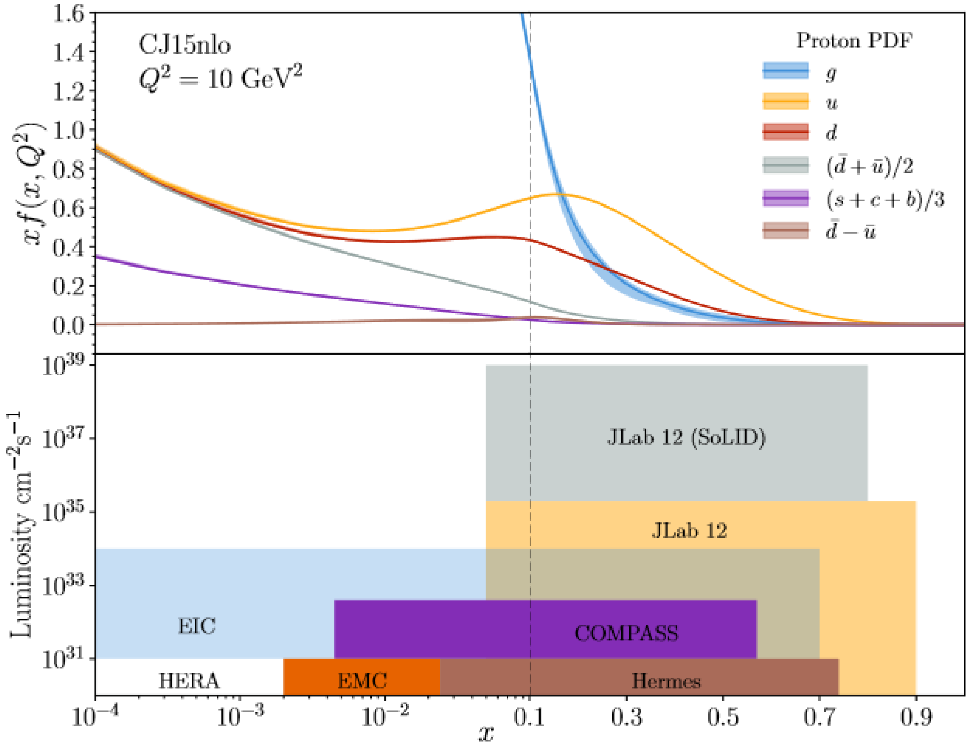
August 1

Marco Battaglieri, Bob McKeown, Xiaochao Zheng, Patrizia Rossi

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.

Complementarity with facilities worldwide

Jefferson Lab stays very relevant and complementary to other facilities with the high luminosity ($\sim 10^{39} cm^{-2} sec^{-1}$), high x reach of fixed target experiments.



Kinematic regions of Deep Inelastic Scattering and the comparative reach of different facilities.

- Precision measurements in the valence quark region requiring high luminosity are clearly the purview of CEBAF.
- The 20+ GeV energy upgrade will provide important overlap into the sea quark region where the EIC is designed to probe at low x.

To conclude

- Jefferson lab is the home of high luminosity experiments and will remain the prime facility for fixed target electron scattering for decades to come.
- JLAB started the execution of a vibrant physics program with up to 12 GeV electron beams and will continue for the next 10 years or so.
- New experiments yielded ground-breaking Nuclear Physics results in 3-D imaging of the nucleon, isospin decomposition of nucleon structure functions, near-threshold J/ψ production, proton charge radius measurement, and new information on neutron matter.
- There are exciting physics opportunities with positron beams, and machine upgrade is now under study.
- Looking forward to a new round of upgrades, building a case for high energy, ~24 GeV, machine.