Physics summary talk from 22GeV workshop

Patrizia Rossi

Hall A Collaboration Meeting

Jefferson Lab, January 27, 2023

SCIENCE AT THE LUMINOSITY FRONTIER: JEFFERSON LAB AT 22 GEV

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

Conference Date
January 23, 2023 to January 25, 2023

People registered ~ 240

Conference Location
CEBAF Center Auditorium. In-person attendance is strongly encouraged, but a Zoom link will be provided.

This workshop will focus on the continuing development of the scientific case for a 22 GeV upgrade to CEBAF made possible by recent novel advances in accelerator technology. CEBAF's envisioned capabilities, at the highest luminosities, will enable exciting opportunities that give scientists the full suite of tools necessary to comprehensively understand how QCD builds hadronic matter in the valence region. Through this workshop, JLab and its user community will continue to build the science case with descriptions and concrete projections for experiments that would become possible with an upgrade. We encourage our users and others interested to submit talks and ideas to the relevant topical organizers listed below.

Program

Introductory Session

08:30 **Welcome/Laboratory Perspective**
Speaker: David Dean (TJNAF)
20230123 upgrade ...

08:45 **Overview of the CEBAF Accelerator Upgrade (20+5)**
Speaker: Alex Bogacz (Jefferson Lab)
Accelerator_Upgra...

09:10 **The 22 GeV Luminosity Frontier: Theory Perspective (20+5)**
Speaker: Jianwei Qiu (Jefferson Lab)
20230123 upgrade ... 20230123 upgrade ...

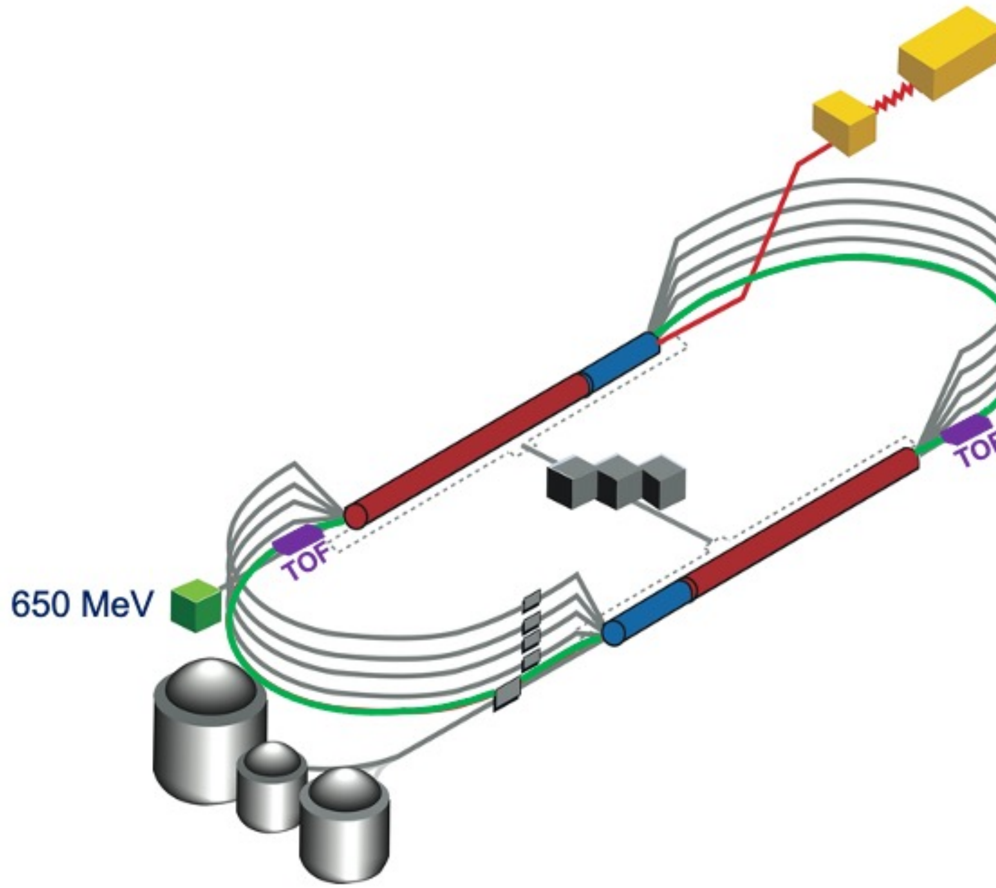
09:35 **Seeking the Origins of Structure (20+5)**
Speaker: Rolf Ent (JLab)
JLab_22GeV_0123...

+ 6 Sessions

- Spectra and structure of heavy and light hadrons as probes of QCD
  - Ralf Gothe (rwgothe@gmail.com)
  - Matt Shepherd (shepherd@jlab.org)
- Sea and valence partonic structure and spin
  - Jian-Ping Chen (jpchen@jlab.org)
  - Ioana Niculescu (ioana@jlab.org)
  - Nobuo Sato (nsato@jlab.org)
- Form Factors, Generalized Parton Distributions and Energy-Momentum Tensor
  - Latifa Elouadrhiri (latifa@jlab.org)
  - Garth Huber (Garth.Huber@uregina.ca)
  - Christian Weiss (weiss@jlab.org)
- Fragmentation, Transverse Momentum and Parton correlations
  - Harut Avagyan (avakian@jlab.org)
  - Dave Gaskell (gaskelld@jlab.org)
  - Nobuo Sato (nsato@jlab.org)
- Hadron-quark transition and nuclear dynamics at extreme conditions
  - Lamiaa El Fassi (elfassi@jlab.org)
  - Misak Sargisian (sargsian@fiu.edu)
- Low-energy tests of the Standard Model and Fundamental Symmetries
  - Liping Gan (ganl@uncw.edu)
  - Kent Paschke (paschke@jlab.org)

CEBAF FFA Upgrade – Baseline under Study

- Starting with 12 GeV CEBAF
- NO new SRF (1.1 GeV per linac)
- New 650 MeV recirculating injector
- Remove the highest recirculation pass (Arc 9 & A) and replace them with two FFA arcs including time-of-flight chicanes
- Recirculate 4.5 + **6** times to get to **22 GeV**



Pass Arithmetic: **5.5** -1 + **6** = **10.5**

Overview of the CEBAF Accelerator Upgrade 4

A. Bogacz

Session 2:

Spectra and structure of heavy and light hadrons as probes of QCD

- N* Structure and Transition Form Factors as Probe of Strong QCD

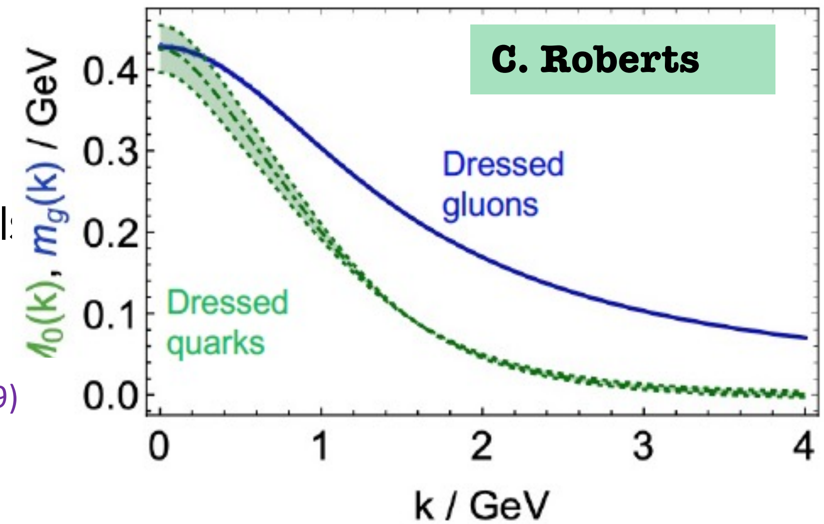
R. Gothe, D. Carman, V. Mokeev, C. Roberts

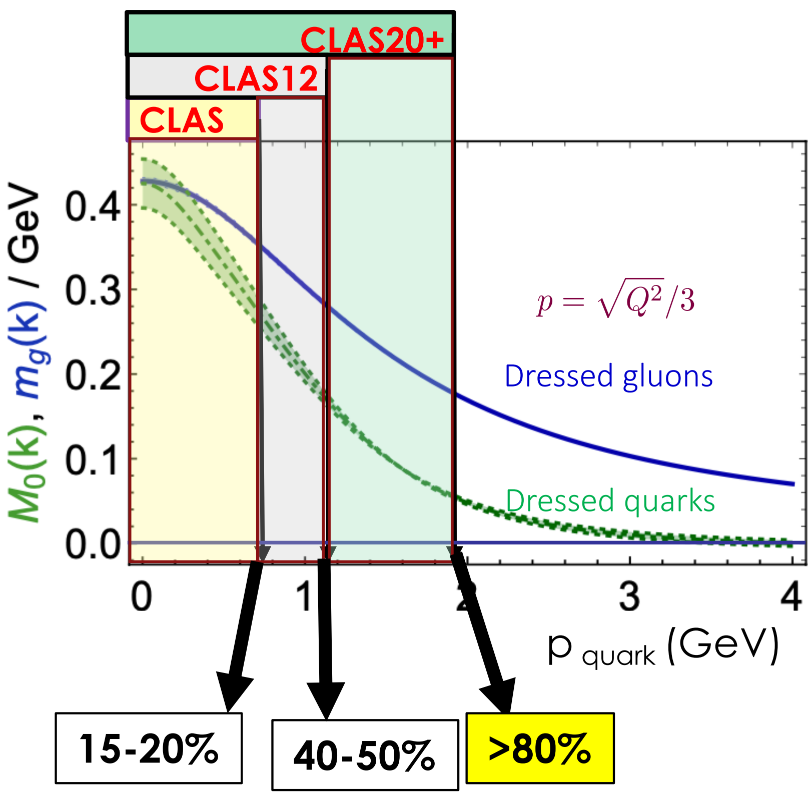
- Exotic charmonium: XYZ states
- Conventional charmonium

R. Mitchell, A. Pilloni, K. Mamo, L. Pentchev

Shedding Light on the Emergence of Hadron Mass

- **Functional QCD approach- Continuum Schwinger Method (CSM)**
  - In strong QCD regime, the solution of the QCD equations of motion for quark/gluon fields reveal existence of dressed q/g with momentum-dependent masses.
  - Results supported by LQCD O. Olivera et al., PRD 99, 094506 (2019)



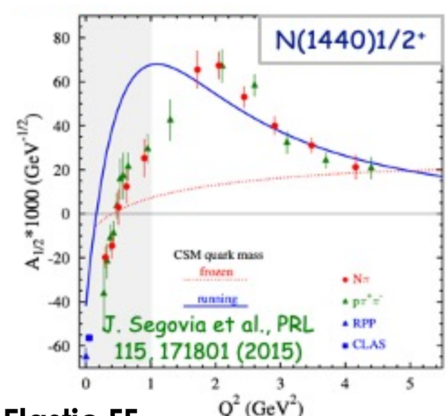


CEBAF @ 22 GeV:

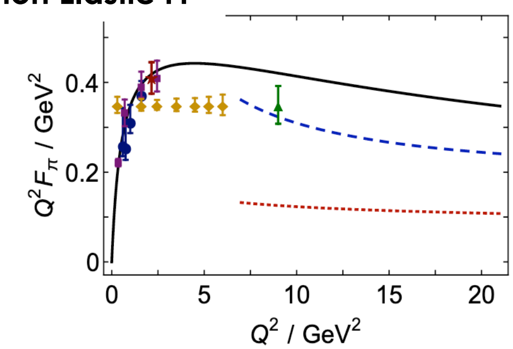
only foreseeable opportunity to explore N* electroexcitation within the Q^2 range(<35 GeV^2) where the dominant portion of hadron mass is expected to be generated

D. Carman
R. Gothe
V. Mokeev

$\gamma_v pN^*$ **Electrocouplings**



Pion Elastic FF



Experimental Status of Exotic Charmonium

Conclusions and Outlook

R. Mitchell

Heavy quark meson spectroscopy has expanded tremendously over the last decade.

Discoveries are being made almost monthly by LHCb, BESIII, Belle/Belle II, CMS, ATLAS, etc.

LHC will soon increase statistics; BESIII will soon have an upgrade; Belle II is just starting;
a super tau-charm factory (STCF) is potentially on the horizon, etc.

This Talk:

(I) Understanding the $X(3872)$
- known facts
- the global program
- the role of JLab 22 GeV

(II) Understanding the $Y(4230)$
- known facts
- the global program
- the role of JLab 22 GeV

(III) Understanding the $Z_c(3900)$
- known facts
- the global program
- the role of JLab 22 GeV

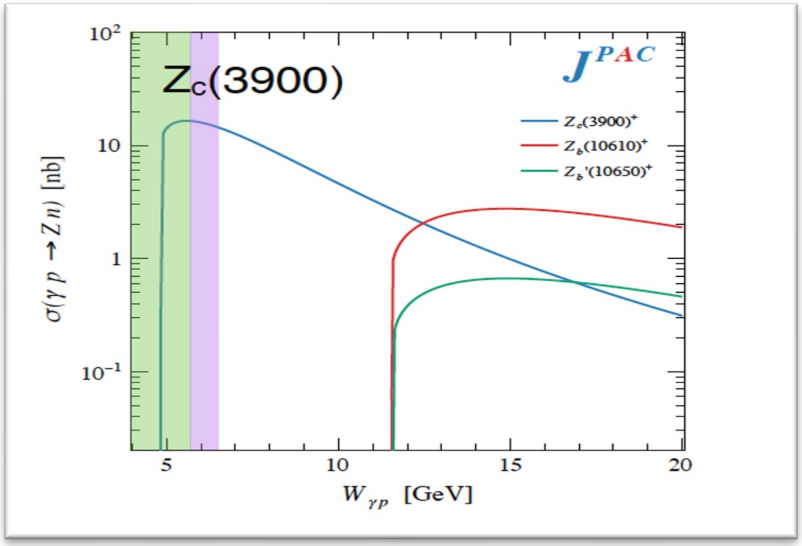
The JLab 22 GeV program could contribute:

- use the $X(3872)$ as a benchmark
- explore the intriguing results from COMPASS
- establish a connection between e^+e^- and γp cross sections
- look for the $Z_c(3900)$ in photoproduction with "simple" pion exchange

Photoproduction and the Nature of XYZ States

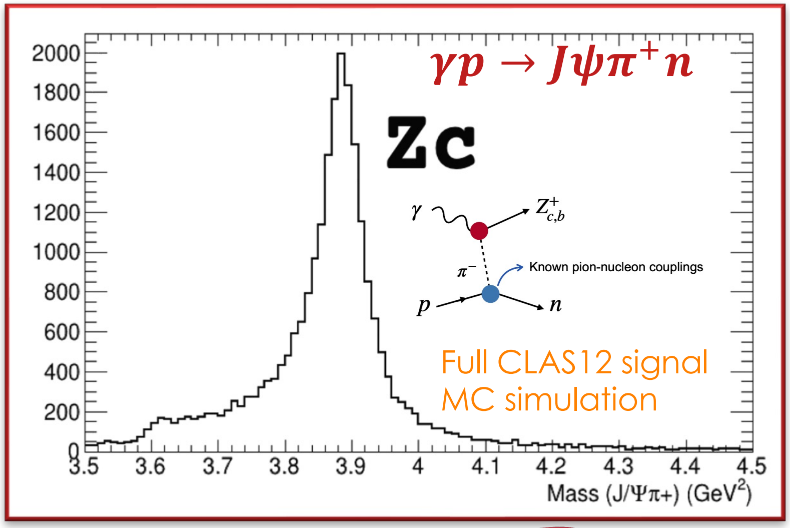
CEBAF @ 20+ GeV : XYZ states
& other charmonia

- Significant theoretical interest and progress, but internal structure not yet understood
- **Never direcly produced** using γ/lepton beams



A. Pilloni

- **Photoproduction provides an alternative mechanisms to study such states**
- Initial simulations from GlueX and CLAS12 demonstrate the **capabilities of the existing detectors to measure these reactions**



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Conventional Charmonium

New physics opportunities with conventional charmonium production at 22 GeV

- Defining the problem: The physics case for the exclusive threshold charmonium production and what are the experimental/theoretical challenges to be solved?
- Solution: How CEBAF energy upgrade is critical in solving these problems using existing GlueX detector?

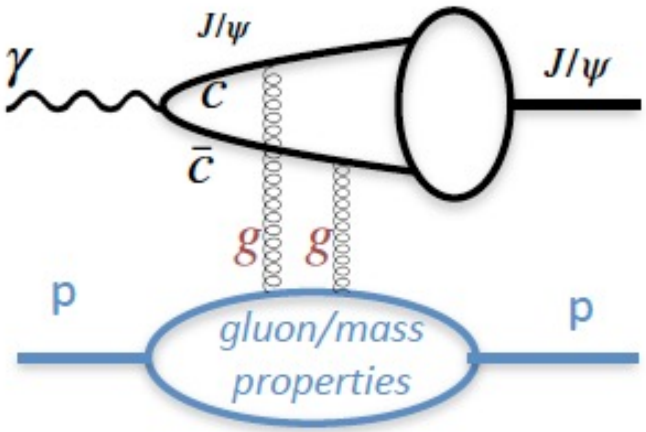
Will try to make realistic projections based on existing measurements

L. Pentchev (GlueX Collaboration)

Exclusive charmonium production and gluonic structure

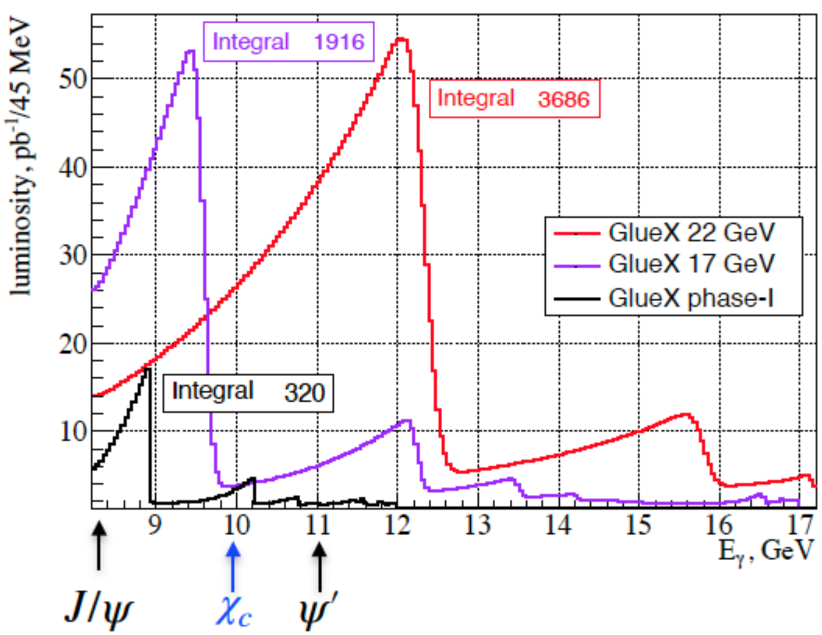
K. Mamo

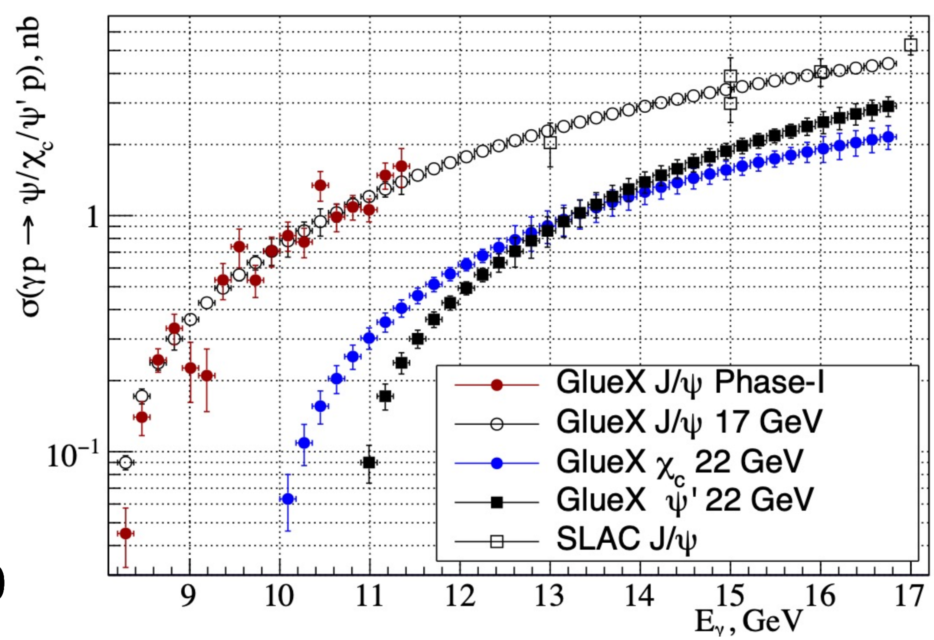
Charmonium threshold photo-production



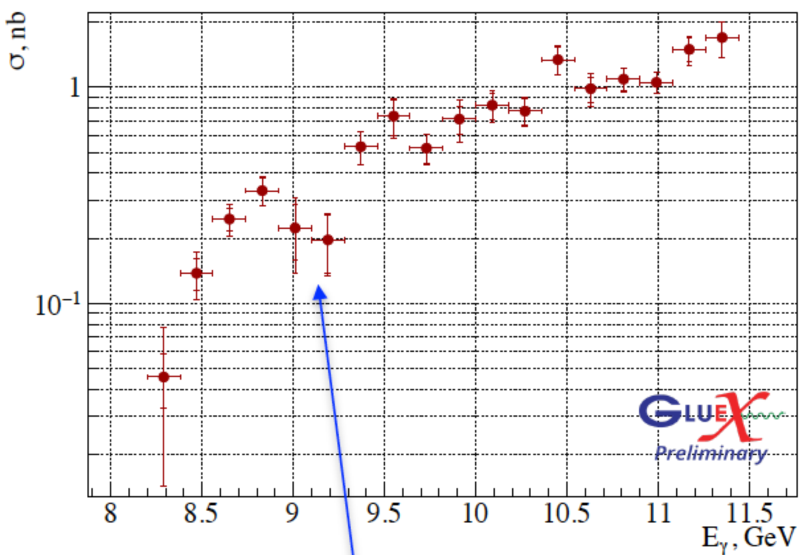
- Exclusive charmonium production near threshold probes gluon/mass properties of proton (mass radius, gravitational form factors, D-term, anomalous contribution to proton mass), however
… assuming factorization
… assuming two-gluon exchange

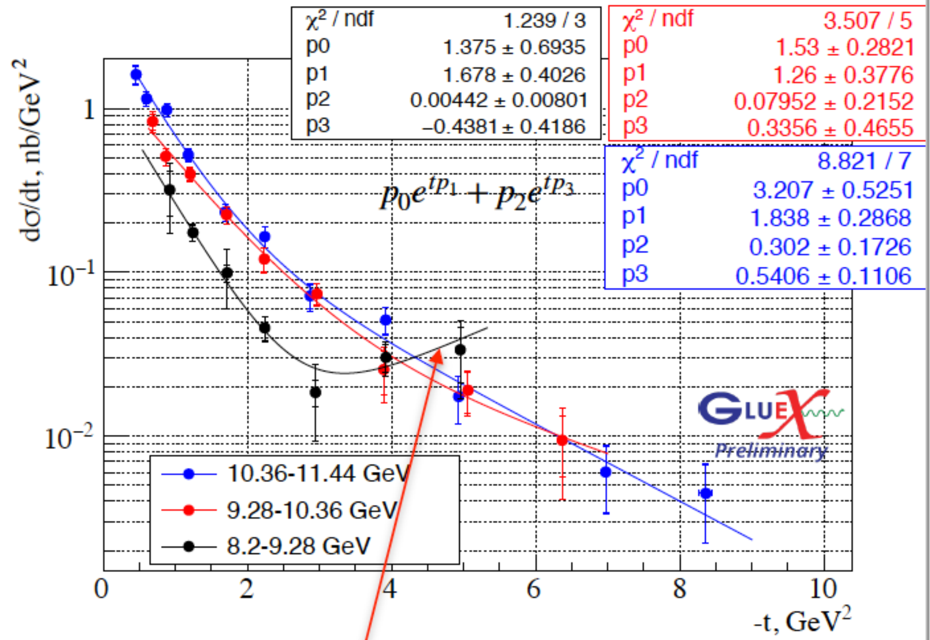
Energy increase gives higher fluxes and allows <u>detailed studies</u> of reaction mechanism using *J/ψ* and higher charmonium states





Preliminary GlueX results





- σ_{tot} increasing with energy approximately following the phase space,

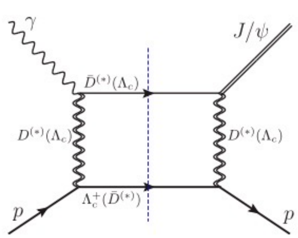
however:

- Possible structure in $\sigma(8.6-9.6GeV)$, the statistical significance of the two "dip" points is 2.6σ; if include look-elsewhere effect - 1.3σ

- t-slopes close to lattice predictions for the $A_g(t)$ gravitational form factor,

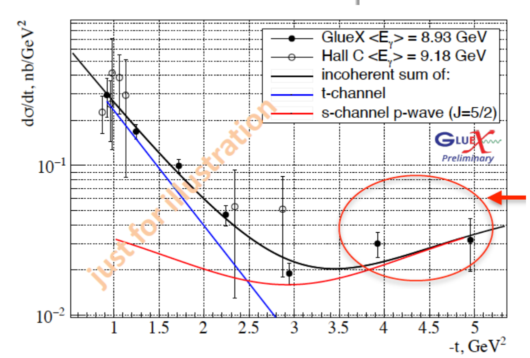
however:

- Enhancement of $d\sigma/dt$ at high t (for the lowest energy slice)



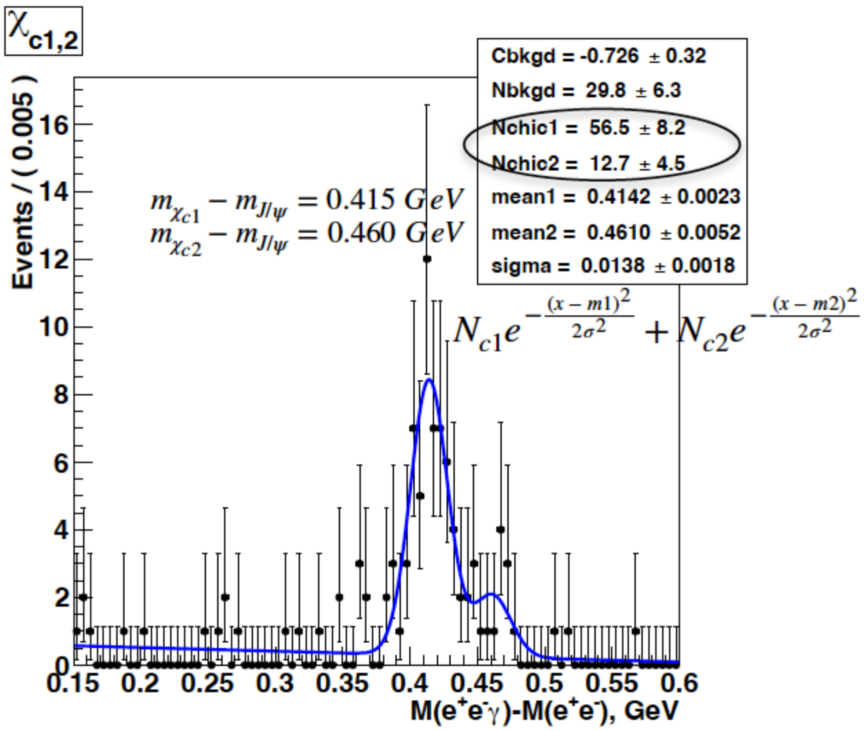
- **Possible structures in σ at $\Lambda_c\overline{D}^{(*)}$ thresh.**
- **CANNOT be explained by t-channel (GLUON EXCHANGE) alone**
- Can have contribution from open-charm exchange to both σ and $d\sigma/dt$ at high t

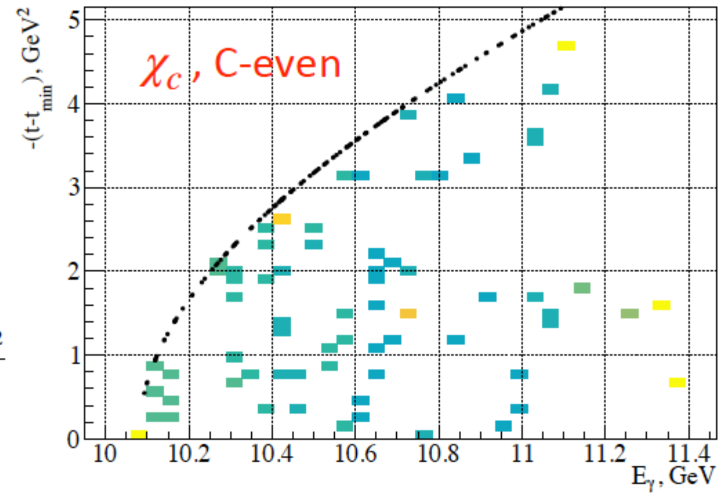
- **Can we interpret this as a possible evidence for a s-channel resonance (?) *Pc***

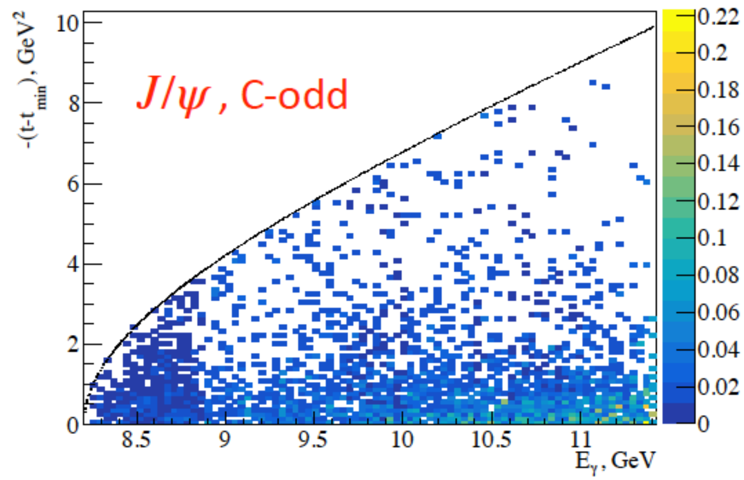


Higher Charmonium States with GlueX

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







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

- $\chi_{c1}(3511)$ 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_γ, t) distribution w.r.t J/ψ

- 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

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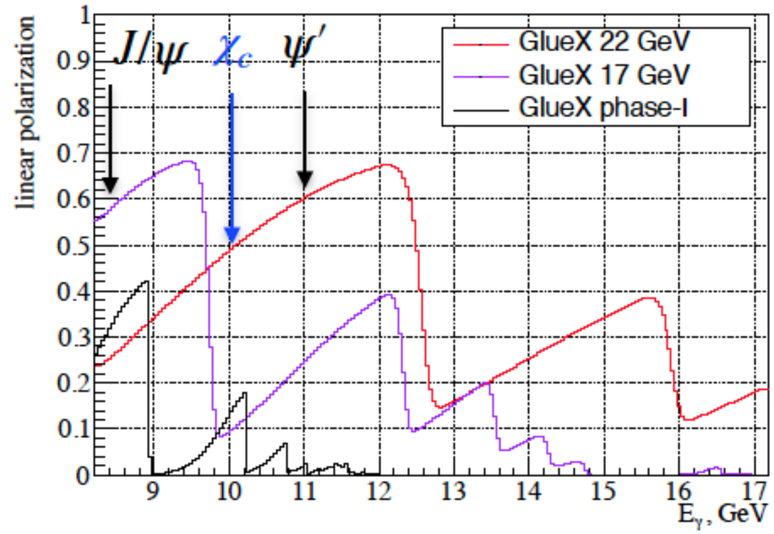
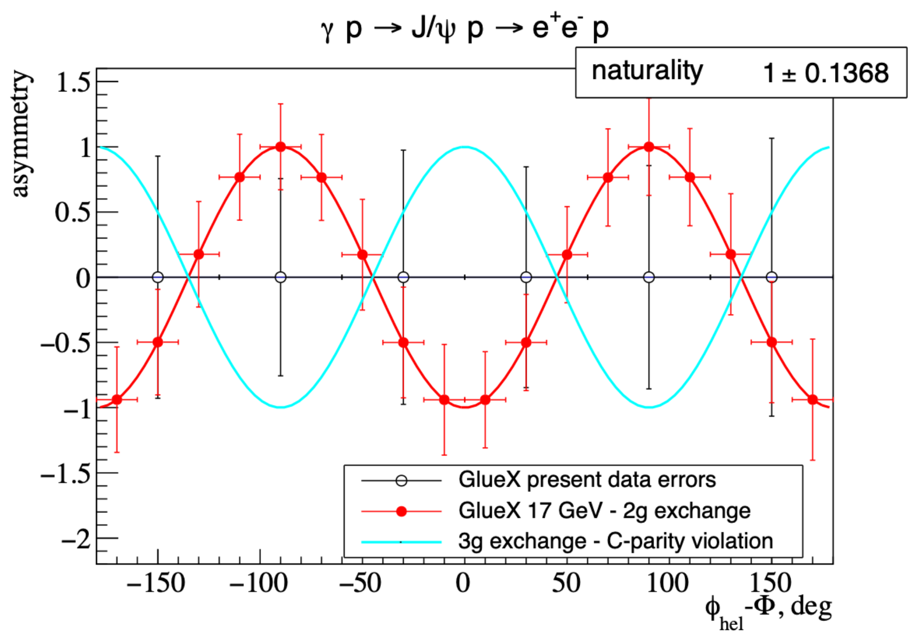
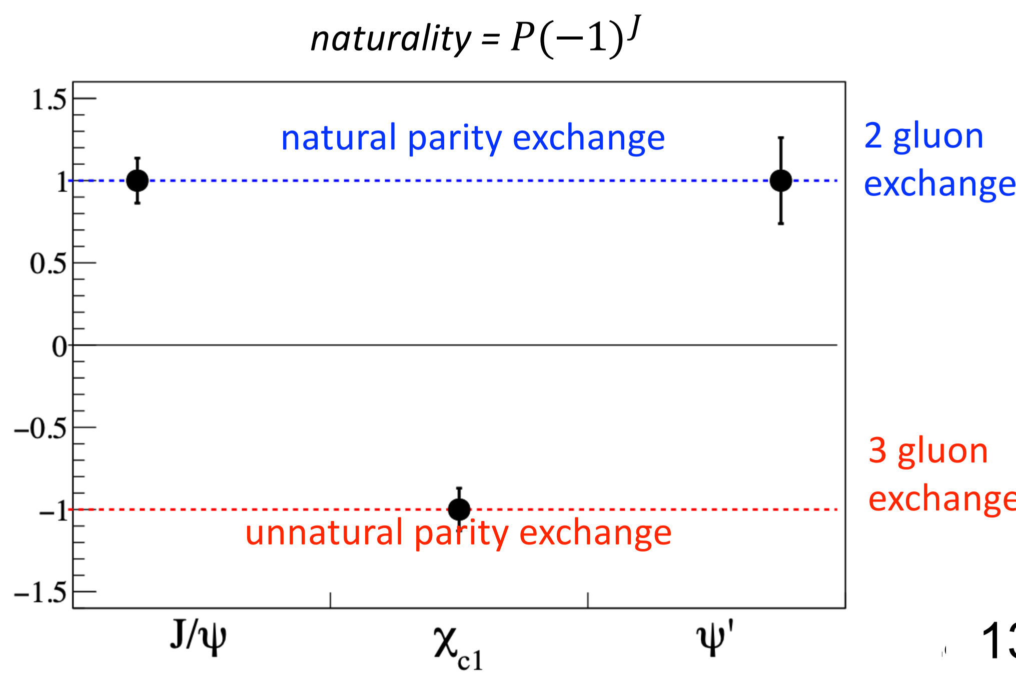
J/ψ photo-production in Hall D - polarization

Energy upgrade gives significant **increase** of **photon linear polarization**



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





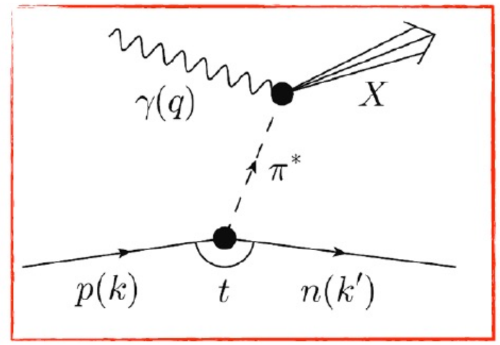
Session 3:

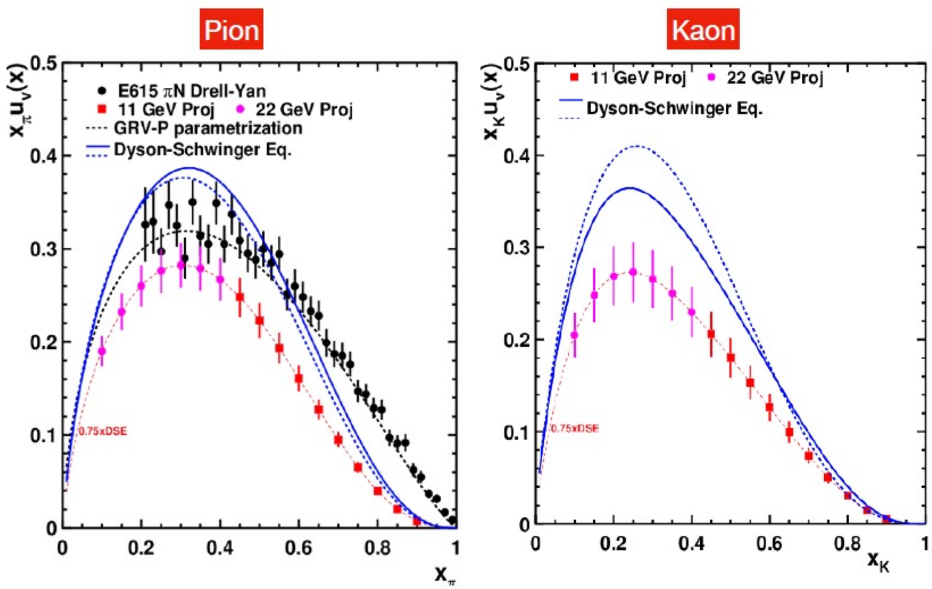
Sea and valence partonic structure and spin

- Nucleon sea structure A. Courtoy
- Pion structure P. Barry
- Probing light meson structure via spectator tagging R. Montgomery
- Exploring the anti-quark structure of the nucleon using SIDIS at higher beam energies A. Tadepalli
- The Unique opportunities of PVDIS at high energy M. Dalton
- Prospects for high precision determination of α_s with JLab at 22 GeV A. Deur
- Intrinsic sea in the proton J. Peng
- Nucleon sea structure (NNPDF) J. Roho
- *Flash talk* S. Kuhn

Meson Structure

- π/K structure not well known experimentally ➔ Need data!
- Interesting implications for PDFs/TMDs…
- Upcoming Tagged Deep Inelastic Scattering (TDIS) program: ➔ Meson SF via Sullivan process





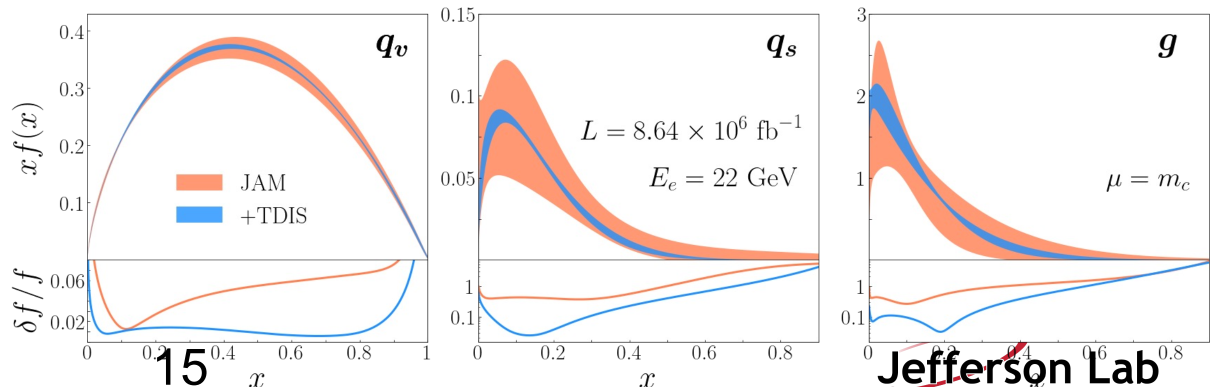
- 22GeV Projections:
  - 50 days' beam time
  - Time to keep error bars same as 11GeV proposals
- 11Gev limited $x_{\pi/K}$>=0.4
- 22GeV now $x_{\pi/K}$=0.1
- Same ranges for π and K
- 22GeV drastically expands x-range!
- Adds to sparse world data
- Especially kaon!

R. Montgomery

Impact on π PDFs with 22 GeV

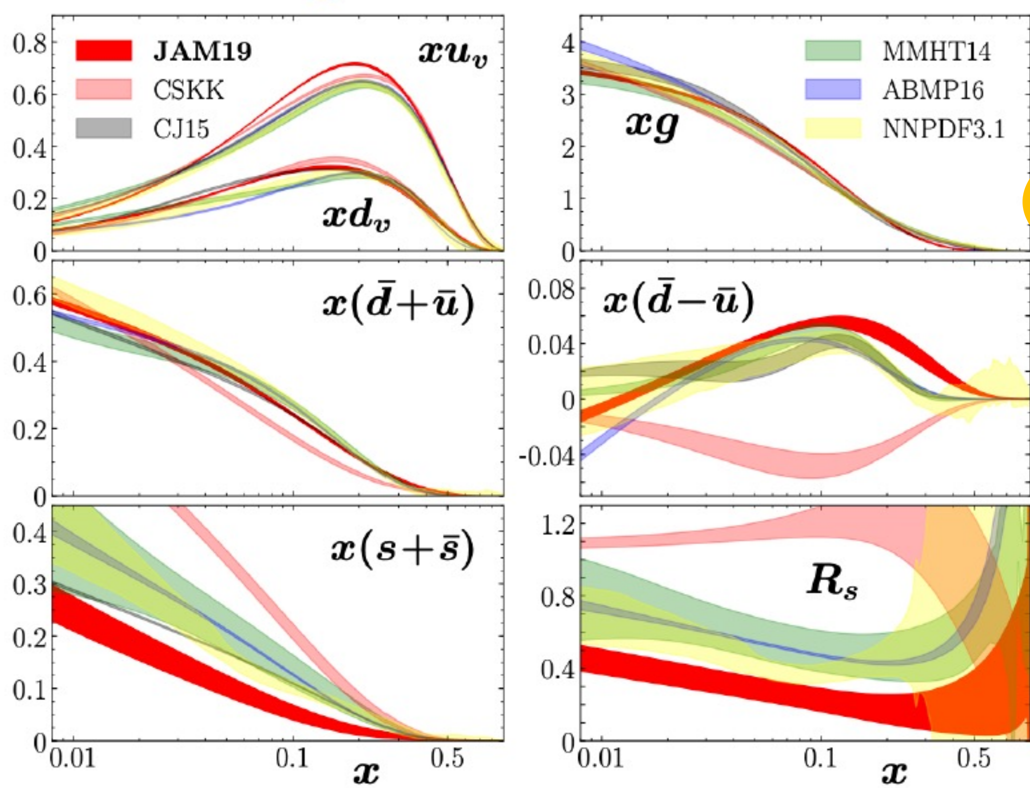
- Knowledge of pion PDFs increases dramatically with 22 GeV beam
- Assuming 1.2% systematic uncertainty

P. Berry



Unique opportunities of PVDIS at high energy

Knowledge of PDFs



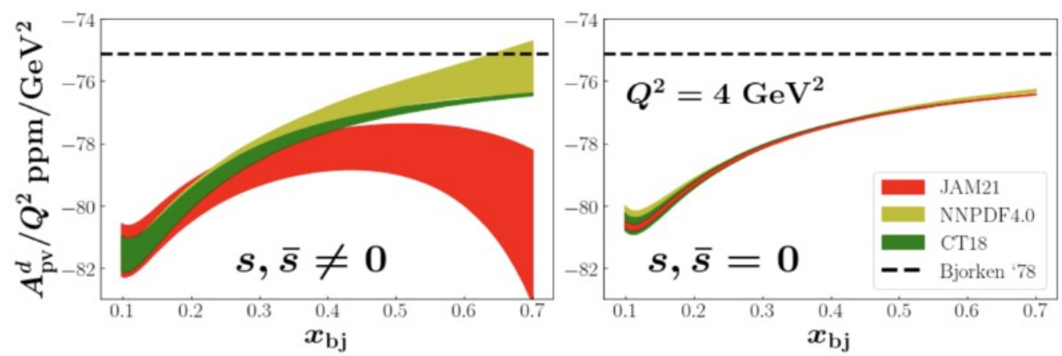
- **PVDIS used for precision extraction of $\sin^2\theta_W$ which is based on the assumption that there is no contribution from s and c.**

Strange quark uncertainties largest

$$R_s = \frac{s+\bar{s}}{\bar{u}+\bar{d}}$$

"Strange quark suppression"
Size of strange

Compare PV asymmetry with and without strange quarks.



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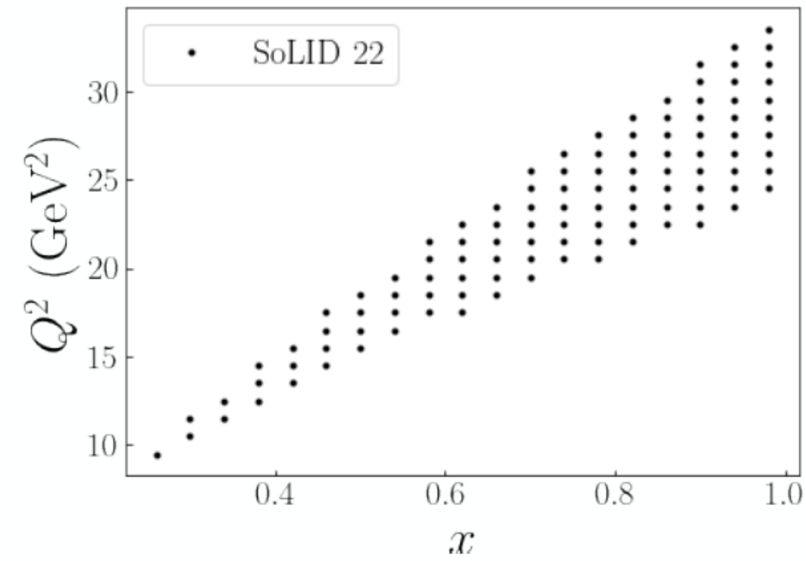
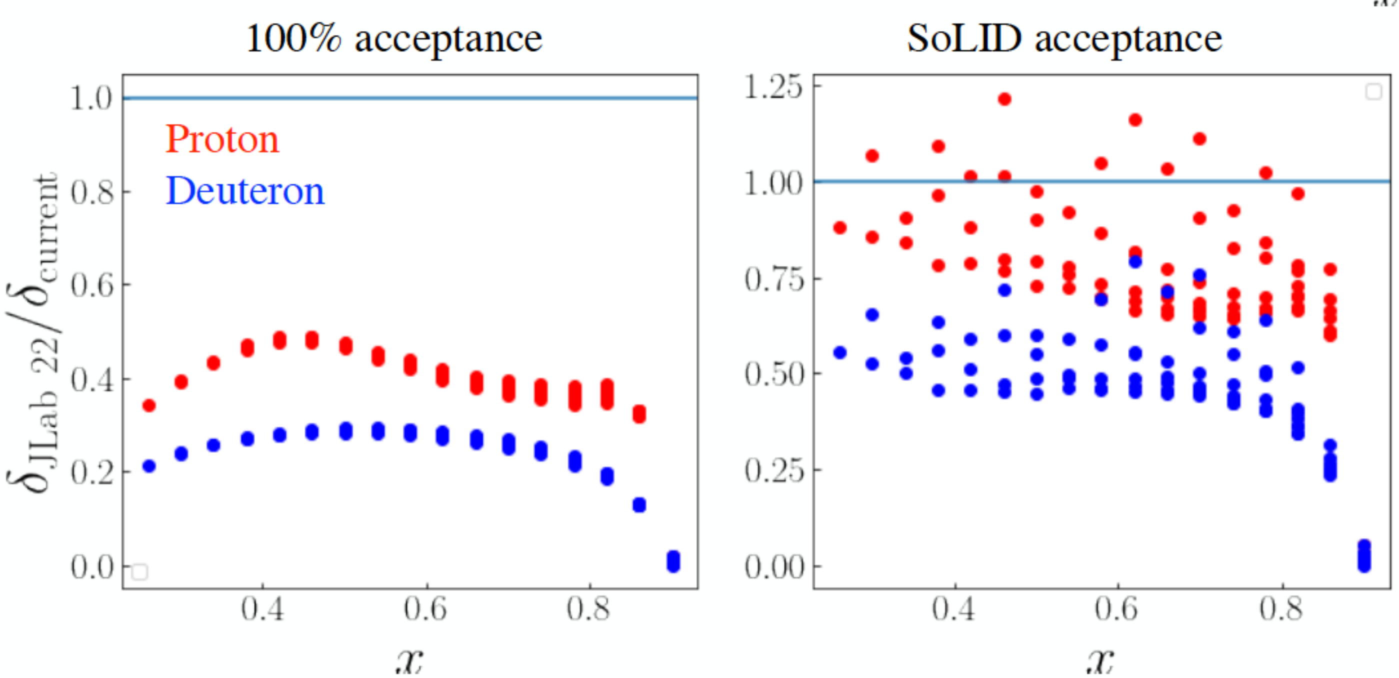
Impact on Strange Quark Puzzle

SoLID 22 GeV



Ratio of statistical uncertainties to current PDF uncertainties (JAM) on APV.



The only place in the world where this is possible.

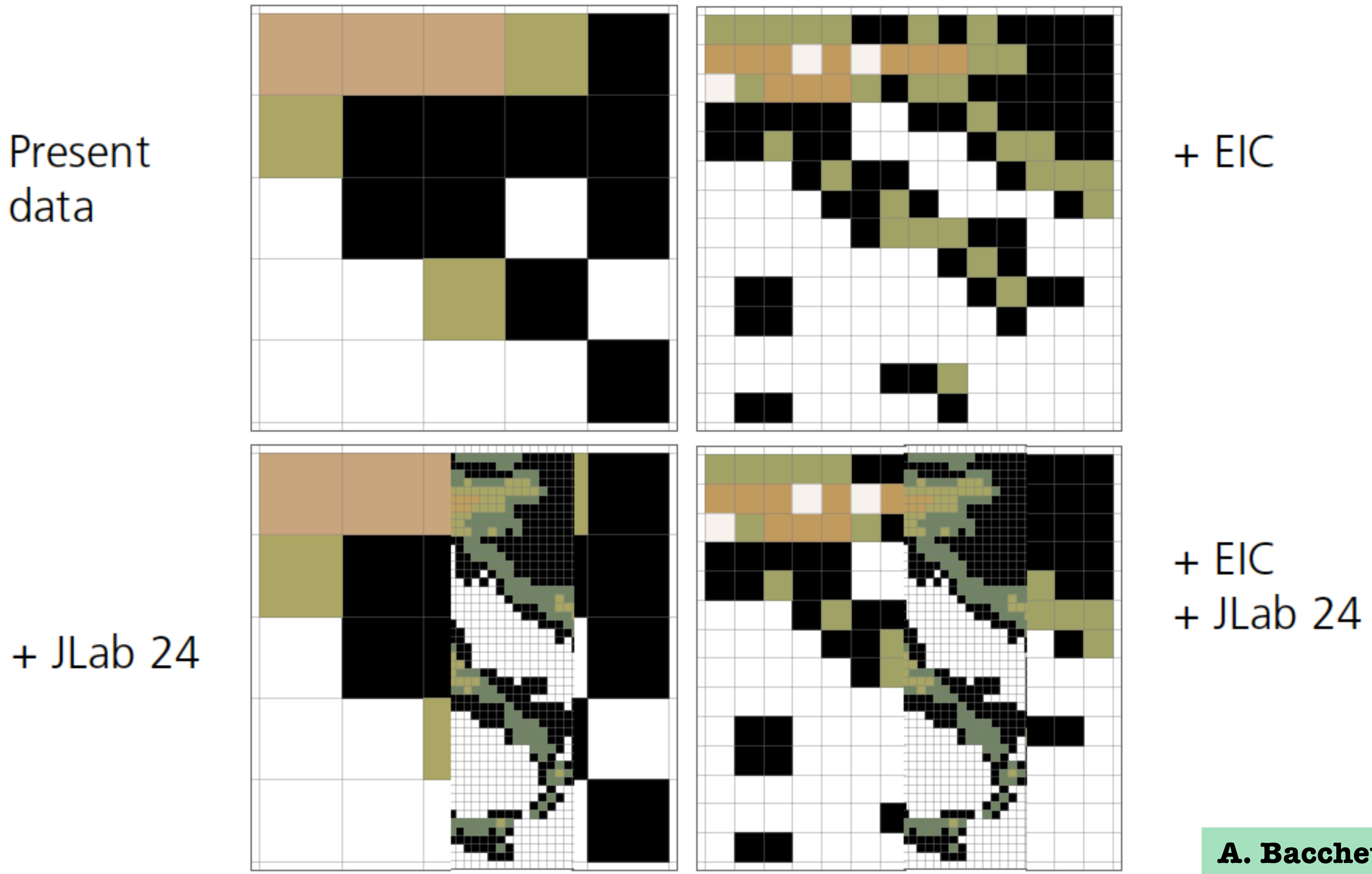
M. Dalton

Session 4:

Fragmentation, Transverse Momentum and Parton correlations

- Studies of SFs in SIDIS- theory A. Bacchetta
- Role of SIDIS Regions E. Boglione
- The relevance of Multidimensional binning in SIDIS B. Parsamyan
- Role of Vector Meson Decays A. Kerbizi
- Precision TMD studies – theory A. Vladimirov
- Role of R=sigma_L/sigma_T in SIDIS experiments E. Kinney
- Dihadron production with CLAS12 C. Dilks
- Independent Fragmentation and role of charge symmetry W. Armstrong
- *9 Flash talks* A. Moretti , A. Afanasev , A. Courtoy , E. Cohen , H. Avagyan, S. Diehl , T. Hayward , W. Cosyn , Y. Zhao

Improving our 3D Map



A. Bacchetta

Jefferson Lab

SIDIS Structure Functions

Bacchetta, Diehl, Goeke, Metz, Mulders, Schlegel, hep-ph/0611265

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

A. Bacchetta

SIDIS Structure Functions

Bacchetta, Diehl, Goeke, Metz, Mulders, Schlegel, hep-ph/0611265

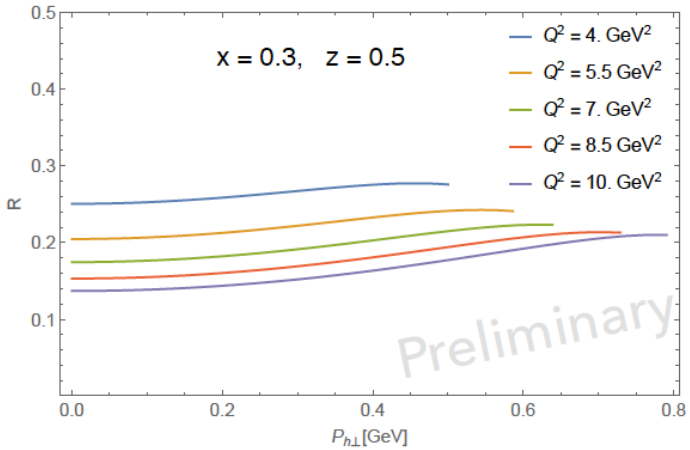
H.T.

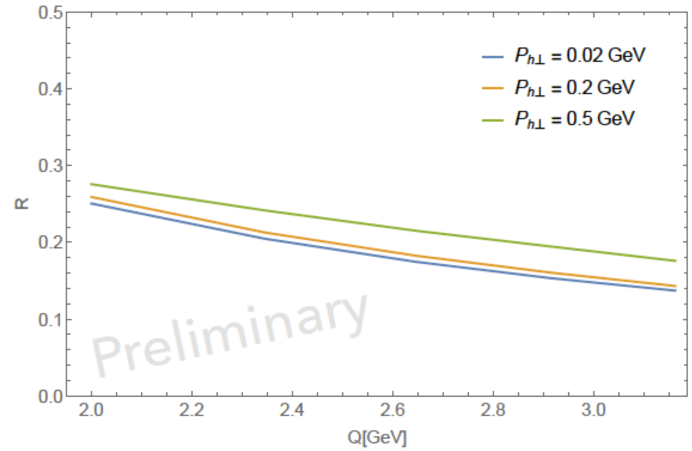
$$
\begin{aligned}
&\frac{d\sigma}{dx\,dy\,d\phi_S\,dz\,d\phi_h\,dP_{h\perp}^2} \\
&= \frac{\alpha^2}{x\,y\,Q^2}\,\frac{y^2}{2\,(1-\varepsilon)}\Bigg\{ F_{UU,T} + \varepsilon\,F_{UU,L} + \sqrt{2\,\varepsilon(1+\varepsilon)}\,\cos\phi_h\,F_{UU}^{\cos\phi_h} + \varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}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

A. Bacchetta

Jefferson Lab

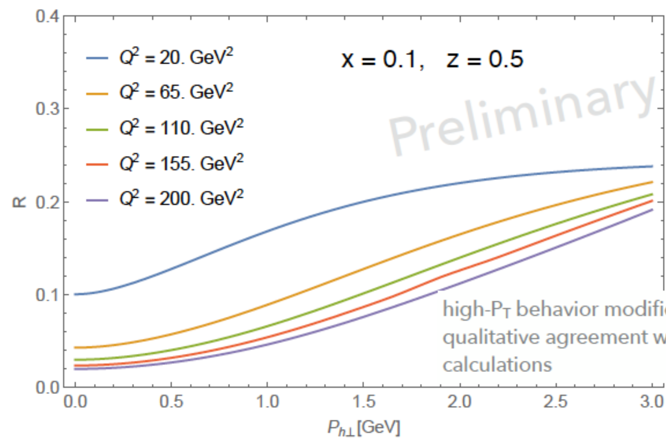
FUU,L



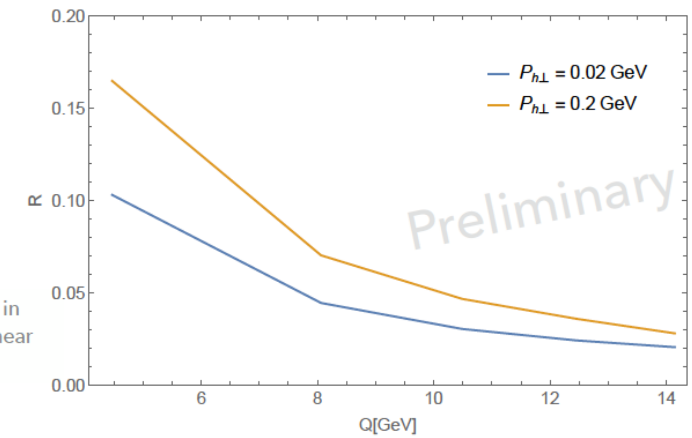


A. Bacchetta

Large size, even at small transverse momentum. Decreases less than 1/Q²



high-P_T behavior modified to be in qualitative agreement with collinear calculations



Smaller at small transverse momentum. Decreases 1/Q² more evident

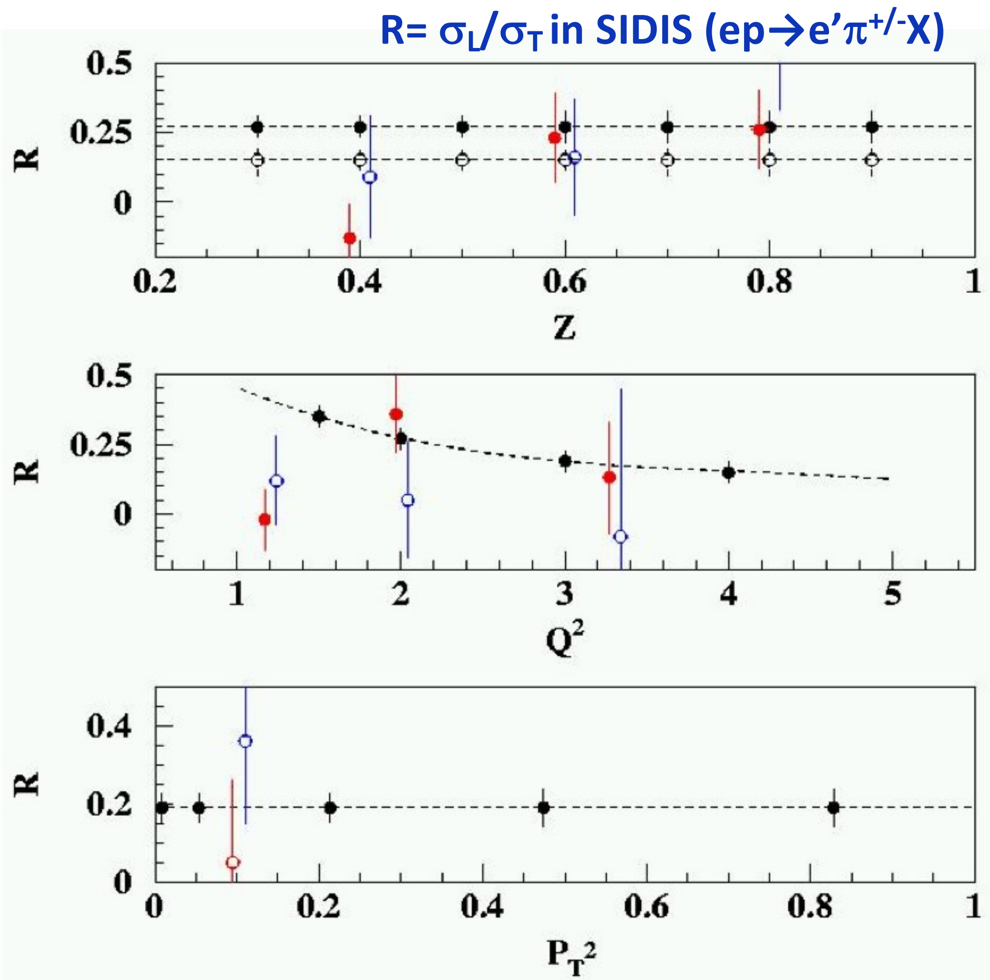
It has to be measured!!

Role of R=sigma_L/sigma_T in SIDIS experiments

$R=\sigma_L/\sigma_T$

E. Kinney

- DIS: R asymptotically scales like Q^2, at fixed x_B
- SIDIS: R is assumed to be similar to that of DIS but ***never been thoroughly checked***



- SHMS/HMS will allow precise L-T separations

- E12-06-104:
  Measurement of the Ratio R=sL/sT in Semi-Inclusive Deep-Inelastic Scattering
  Spokespersons: R. Ent, P. Bosted, E. Kinney, H. Mkrtchyan

- Is R in SIDIS same as DIS?
- Has R the same behavior at mid and large x?
- What is the R dependence on P_T?

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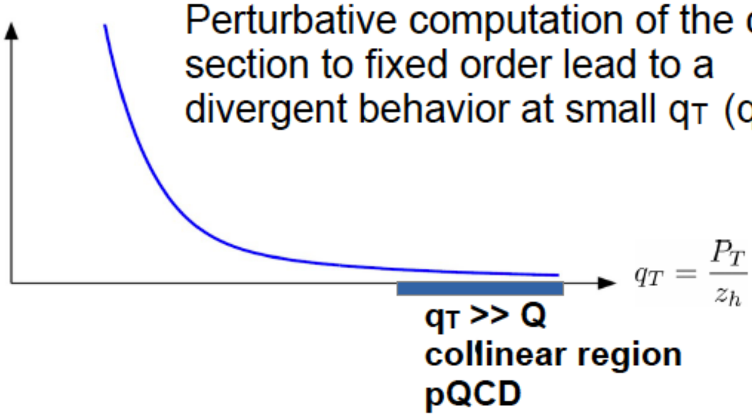
SIDIS Kinematical Regions

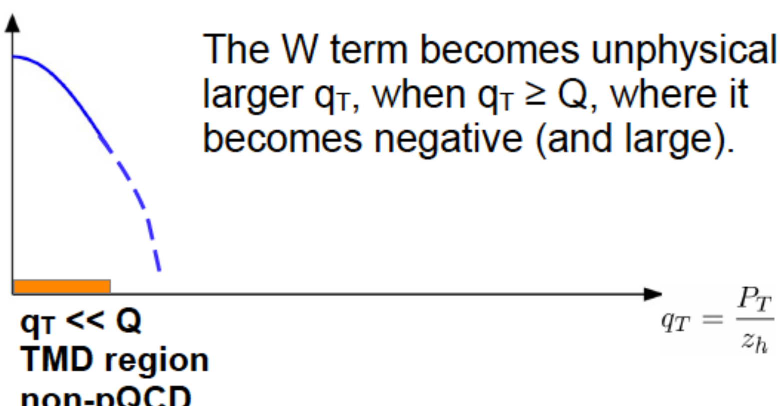
…… ***and their role in giving the correct theory interpretation to experimental measurements***

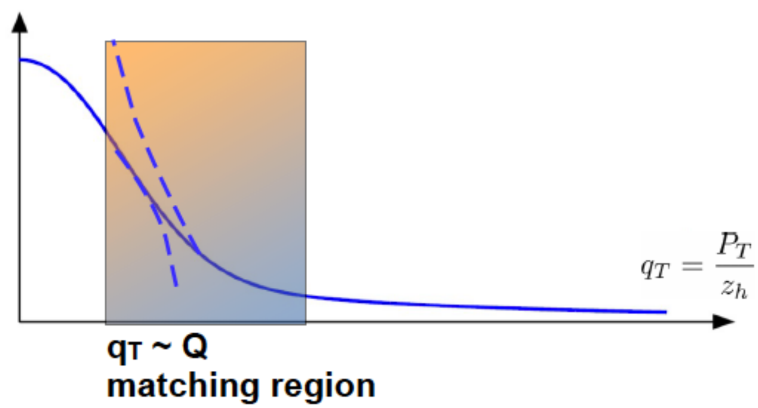
E. Boglione

Perturbative computation of the cross section to fixed order lead to a divergent behavior at small q_T ($q_T << Q$)



The W term becomes unphysical at larger q_T, when $q_T \geq Q$, where it becomes negative (and large).





Matching region is where TMD and collinear cross sections are expected to be matched

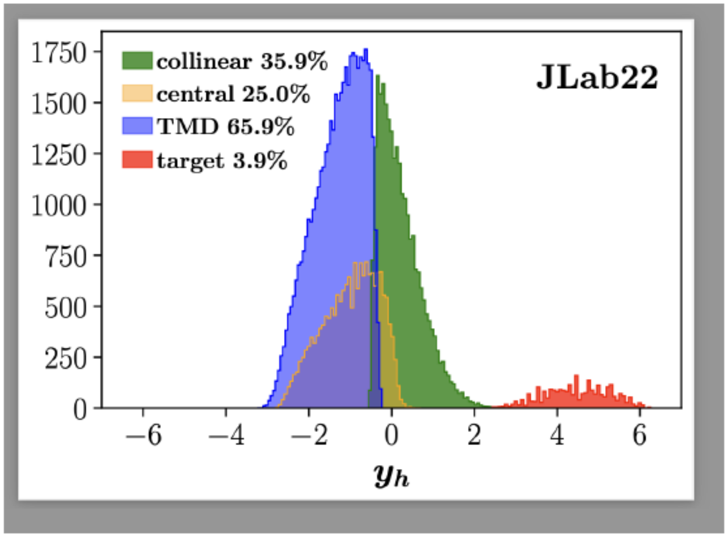
$$\sigma \simeq W + Y$$

The Y term corrects for the misbehavior of W as q_T gets larger, providing a consistent (positive) q_T differential cross section.

The Y term should provide an effective smooth transition to large q_T, where fixed order perturbative calculations are expected to work.

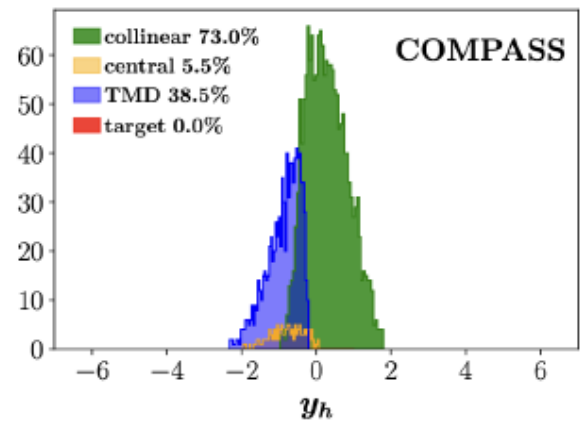
The Role of JLab @ 22 GeV

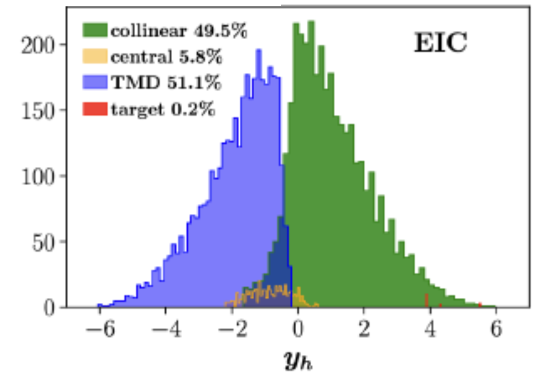
- How does QCD manifest itself in the "matching region"?
- Is the "matching region" just a transition region?
- Does this region need a new theoretical approach of its own, not just an attempt to stretch the TMD and collinear schemes to match each other?
- To learn about this new kinematic region we need new, high statistics data which populate this exact kinematics. **This is something that JLab22 could do in a unique way.**
- Jlab 22 experimental data will explore this intermediate region, helping us to study an energy and transverse momentum range which is crucial to improve the current understanding of QCD in term of factorization.



Phase space in rapidity y_h of produced hadron, with for TMD, collinear, central and target regions indicated.

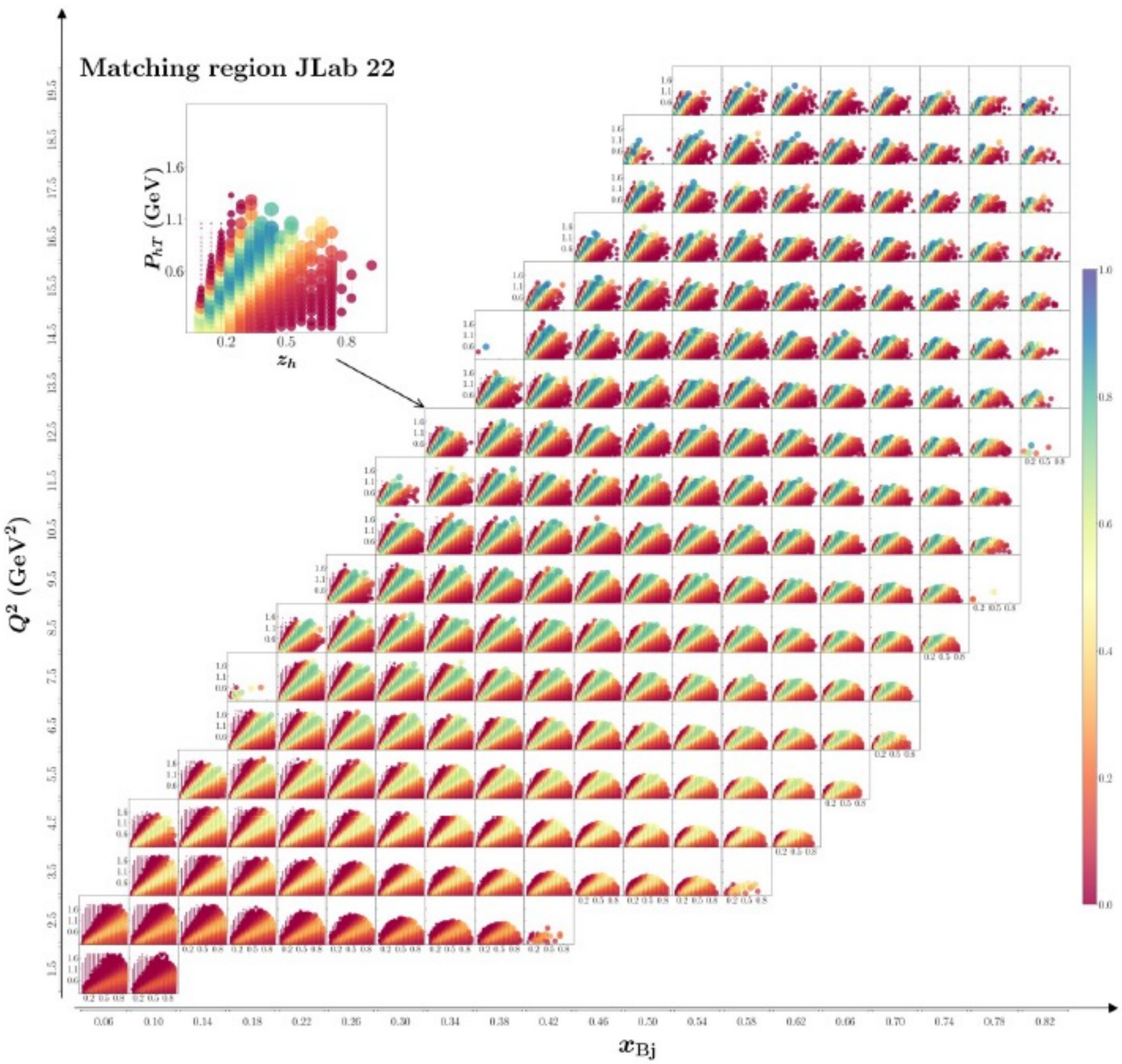
The legends show the percentage of all bins with corresponding affinity above 5%





E. Boglione

Affinity to Matching Region @JLab22



E. Boglione

- Very high statistics and fine binning will improve the 3D maps of hadron structure
- **TMD region** will be accessible (large Q, large z, **small P_T**)
- **Collinear region** will be accessible (large Q, moderate z, **large P_T**)
- A unique feature of Jlab22 is that it will offer an unprecedented insight onto the **matching region**, which cannot be explored in any other SIDIS experiment
- Extended reach in x will be crucial

Many thanks to Alexei Prokudin, who produced these plots in high speed mode

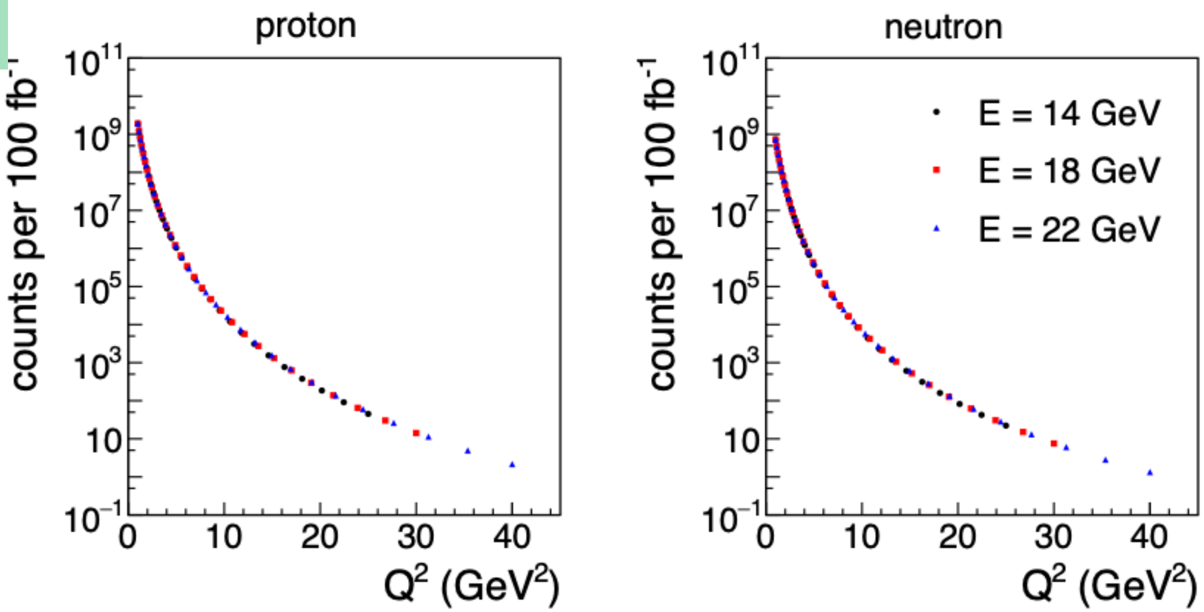
Session 5:

Form Factors, Generalized Parton Distributions and Energy-Momentum Tensor

- Electromagnetic Form Factor prospects (nucleon and pion/kaon) A. Pucket
- QCD energy-momentum tensor and the mechanical properties of hadrons P. Schweitzer
- DDVCS A. Camsonne
- Exclusive light meson production K. Joo
- Prospects for DVCS theory and GPD analysis S. Liuti
- Prospects for DVCS experiments V. Burkert

Form Factor Prospects with a 22 GeV CEBAF

A. Puckett



Luminosity (cm^{-2} s^{-1}, electron-nucleon)	fb^{-1}/day
10^{35} (NH_3/ND_3), polarized p/n	8.64
10^{37} (Helium-3 SEOP), polarized n	864
10^{38}-10^{39} (liquid hydrogen, deuterium)	8,600-86,000

Notes: assuming 2π azimuthal acceptance, Q^2 bin width $\approx Q^2$ spacing between points

- JLab high luminosity provides plenty of count rate up to max. accessible Q^2
- EIC ~100 fb^{-1} per YEAR (best-case)

- Prediction: SBS GEP measurement at 12 GeV^2, despite impressive precision and Q^2 reach will not conclusively establish a statistically significant zero crossing → JLab 22 will easily get us to 20-25 GeV^2 for G_E^p, G_E^n and to 30+ GeV^2 for G_M^p, G_M^n with excellent precision→ EIC will never be able to do this (see, however, https://arxiv.org/abs/2207.04378)

- ***If*** hadron elastic FFs at very large Q^2 continue to be theoretically interesting, JLab 22 GeV upgrade is the ONLY way to do these measurements!

EMT & the Mechanical Properties of Hadrons

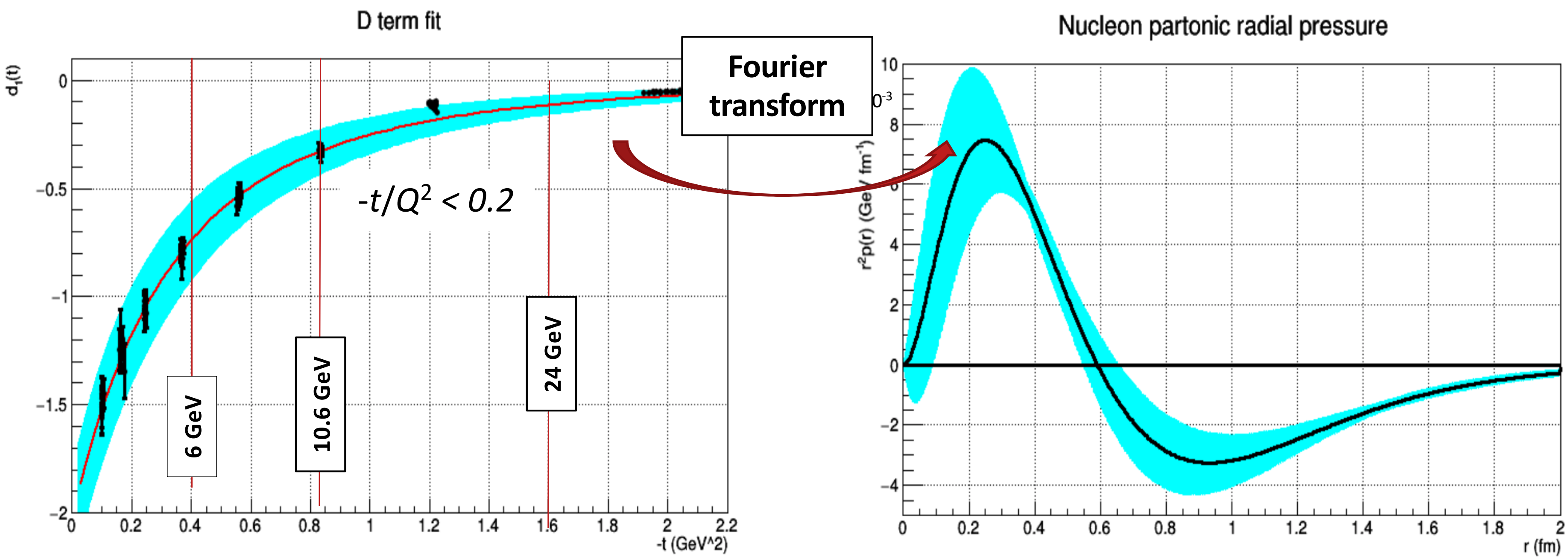
- In the standard EMT parametrization, there are three gravitational form factors one of this is the D-term which encodes the information on shear forces and pressure distribution inside the proton.
- It has been calculated in several models
- the JLab group reported the first determination of the pressure and shear forces on quarks inside the proton from experimental data on DVCS.

P. Schweitzer

From GFF Dq(t) to distribution of Forces (Pressure)

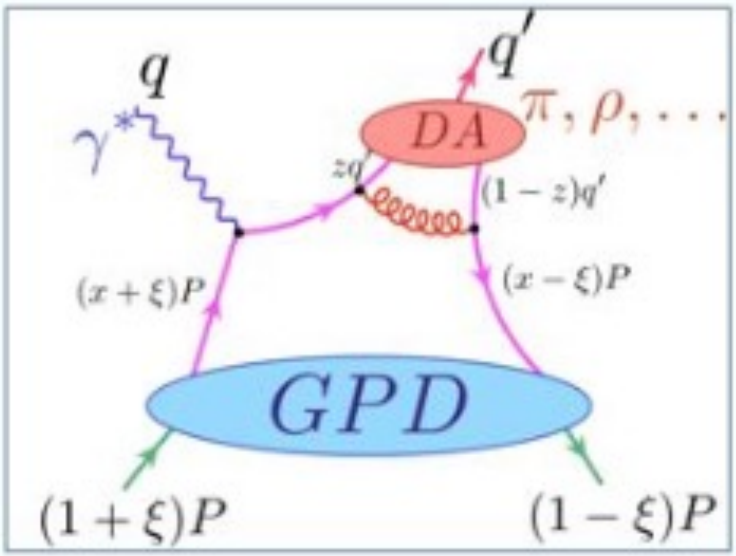
V. Burkert

Fitting the dispersion relation to $\mathrm{Im}\mathcal{H}(\xi,t)$, $\mathrm{Re}\mathcal{H}(\xi,t)$



22 GeV required to cover sufficient range in t for extraction of mechanical properties.

DVMP: L/T Separated π Cross Sections



- Validate the understanding of the hard-exclusive reaction towards 3D imaging. **The key to this validation is precision longitudinal-transverse (L/T) separated data.**
- **The handbag factorization, tells us that for asymptotically large Q^2 longitudinally polarized photons dominate**
- According to the handbag approach, the amplitudes for transverse photons are suppressed
  - σ_L scales to leading order as Q^{-6}
  - σ_T does not, expectation of Q^{-8}
  - As Q^2 becomes large: $\sigma_L \gg \sigma_T$

- High precision L/T separated data were taken at 6 GeV in Hall C provided clear evidence for strong contributions from transversely polarized virtual photons.

Experimental validation of onset of hard scattering regime is essential for reliable interpretation of JLab GPD program results

L/T Cross Section in Hall C

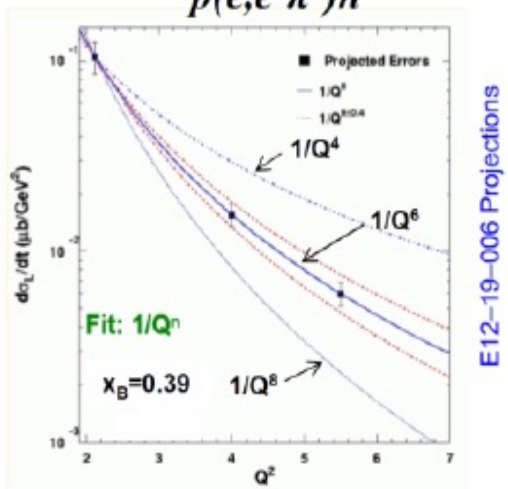
Light pseudoscalar mesons (π^+, K^+, π^0)

The Hall C Future Light Pseudoscalar Meson Team Leads
- Dave Gaskell, JLab
- Tanja Horn, CUA
- Stephen Kay, U. Regina
- Wenliang (Bill) Li, Stony Brook U.
- Pete Markowitz, FIU,
- Garth Huber, U. Regina

We welcome interested groups of collaborators for Hall C Future Studies

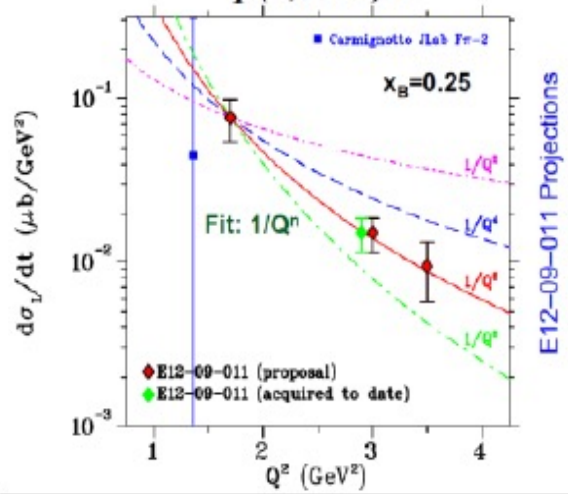
K. Joo

$p(e,e'\pi^+)n$



x	Q^2 (GeV²)	W (GeV)	$-t_{min}$ (GeV²)
0.31	1.45–3.65	2.02–3.07	0.12
	1.45–6.5	2.02–3.89	
0.39	2.12–6.0	2.05–3.19	0.21
	2.12–8.2	2.05–3.67	
0.55	3.85–8.5	2.02–2.79	0.55
	3.85–11.5	2.02–3.23	

$p(e,e'K^+)\Lambda$



x	Q^2 (GeV²)	W (GeV)	$-t_{min}$ (GeV²)
0.25	1.7–3.5	2.45-3.37	0.20
	1.7–5.5	2.45–4.05	
0.40	3.0–5.5	2.32–3.02	0.50
	3.0–8.7	2.32–3.70	

PHASE 1 SCENARIO

Q^{-n} scaling test range nearly doubles with 18 GeV beam and HMS+SHMS

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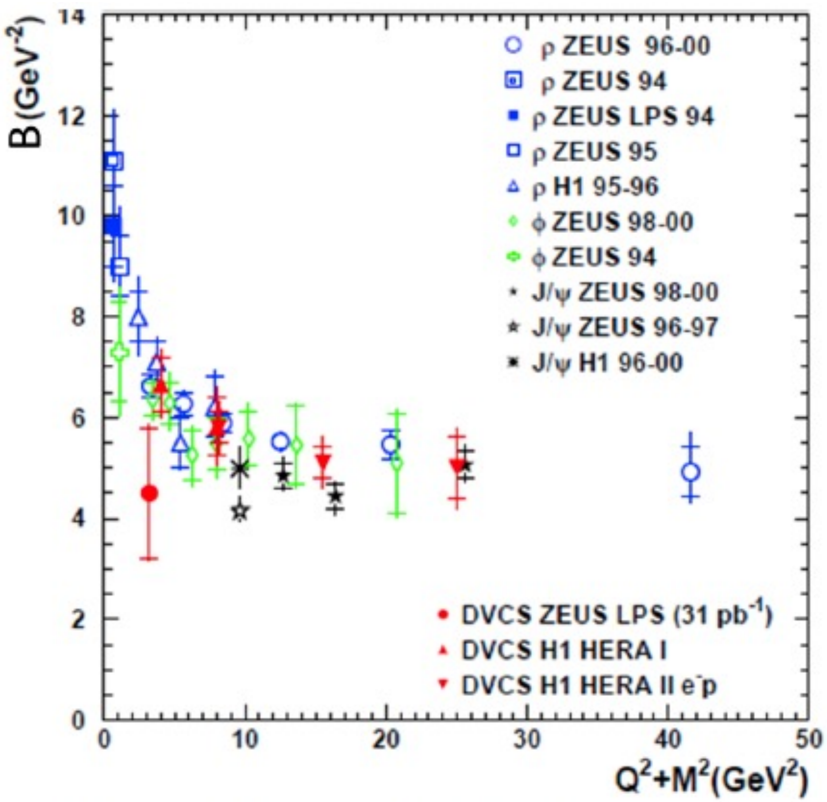
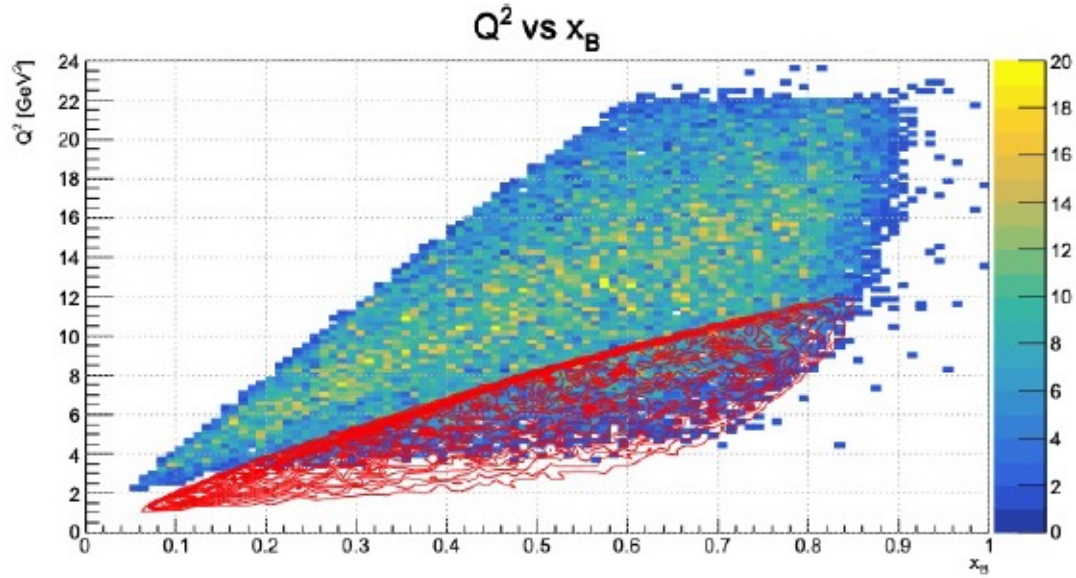
Exclusive ρ/ω/ϕ Production in Hall B



- Below $Q^2 = 10$ GeV^2 : decrease of the slope with Q^2 (related to meson production in large-size configurations which slowly dies out.
- Above $Q^2 = 10$ GeV^2: universal t-slope that can be attributed to the gluon GPD.



- At present 12 GeV kinematics, the small size regime is very questionable.
- At 20+ GeV one could go to higher Q2 (assuming sufficient luminosity) at moderate x and be much closer to the small size regime.

K. Joo

Jefferson Lab

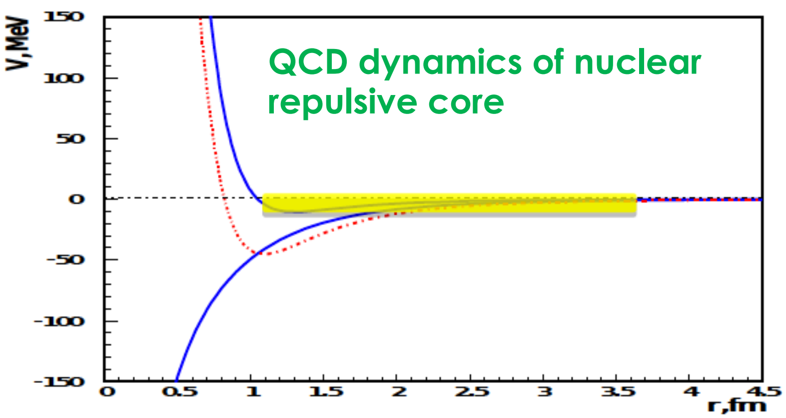
Session 6:

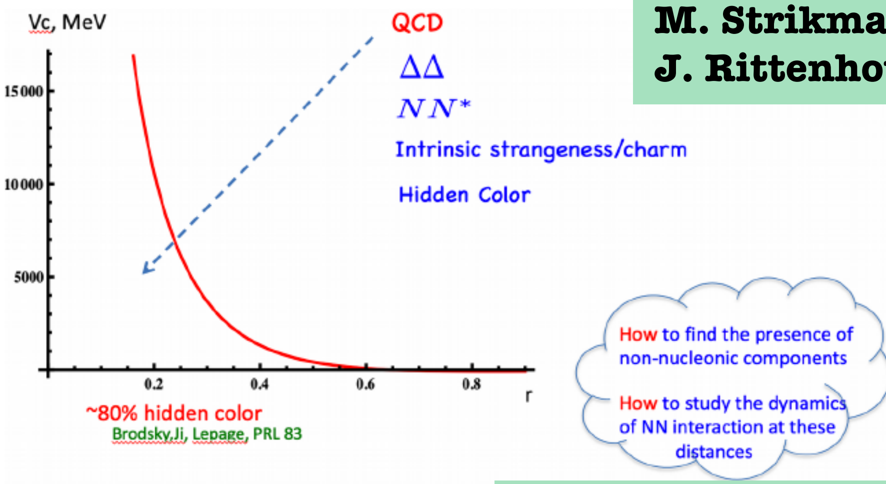
Hadron-quark transition and nuclear dynamics at extreme conditions

- Nuclear dynamics at short distances (Theory Overview)M. Strikman
- Tagged-DIS Medium Modifications Study T. Kutz
- Superfast Quarks J. Arrington
- Deuteron Disintegration at Large Missing Momenta C. Yero
- QCD and Nuclear Medium Effects (Theory Overview) G. Miller
- Color Transparency at 22 GeV H. Szumila-Vance
- Nuclear DVCS M. Yurov
- Spectator-tagged DVCS W. Armstrong
- Unpolarized EMC & anti-shadowing region Z. Ye
- Study of medium-modified spin structure functions in the EMC and antishadowing regions W. Brooks
- SIDIS in Nuclei S. Paul
- *2 Flash talks* J. Rittenhouse-West , S. Liuti

Investigation of the Nuclear Repulsive Core (< 0.5 fm)

- Crucial for understanding the dynamics of transition between hadronic to quark-gluon phases of matter
  - at high temperatures relevant to the evolution of the universe
  - at low temperatures and high densities relevant to the dynamics of superdense matter at the cores of neutron stars

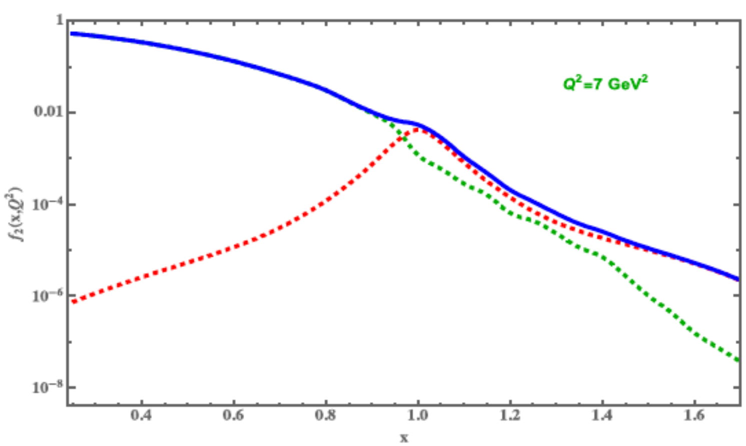


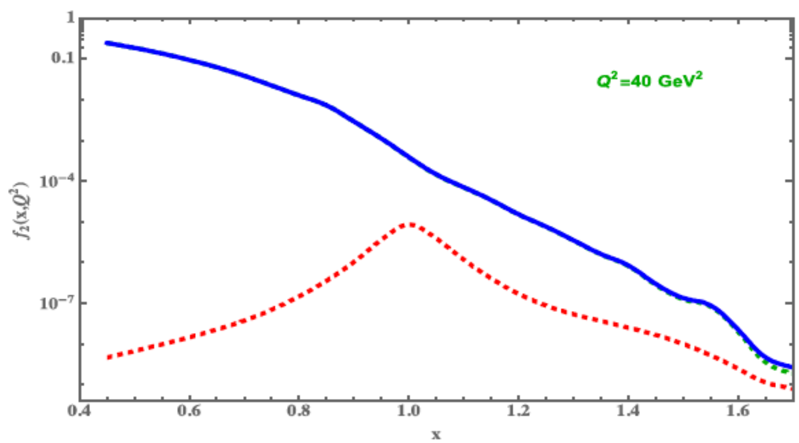


M. Strikman
J. Rittenhouse-West

- Probing super-fast quarks in deuteron

J. Arrington

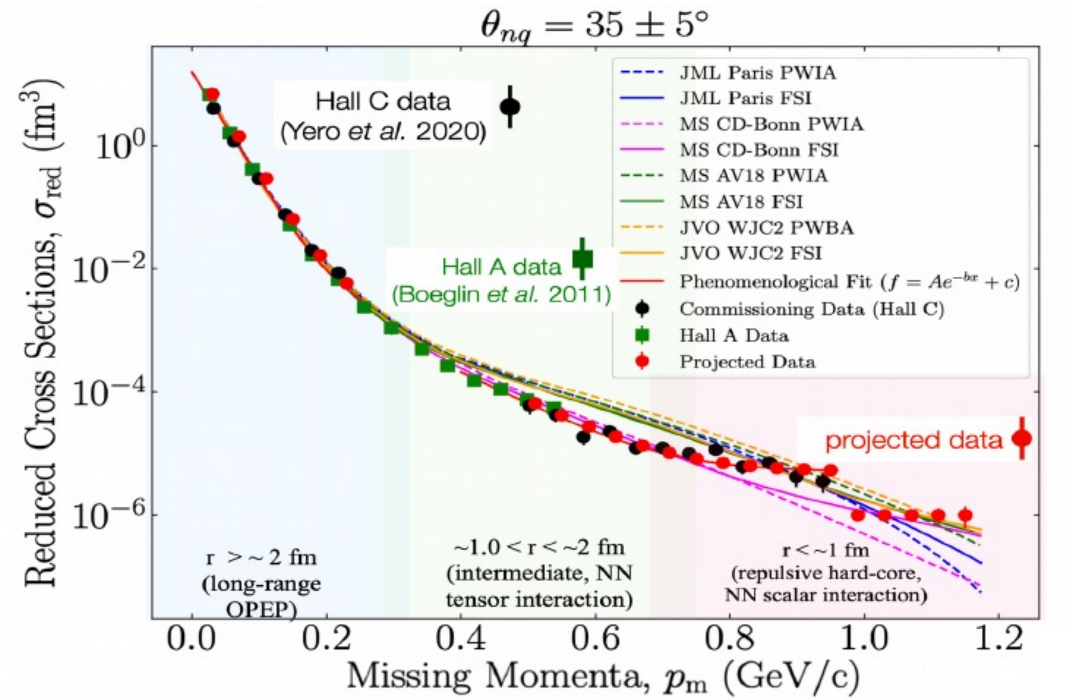




- DIS from nuclear targets at x > 1
- Q^2 above 30 GeV^2

High energies needed to isolate DIS at large x

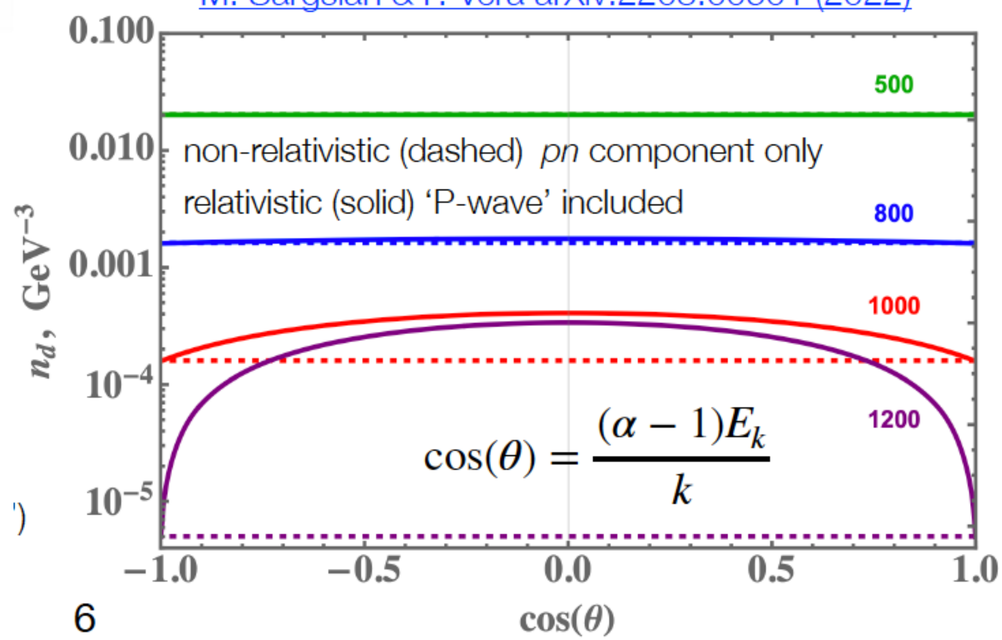
Deuteron at extremely Large Internal Momentum



C. Yero

- P-wave starts to dominate at k~ 800 MeV/c ➔angular dependence of momentum distributions (n_d) modified by non-nucleonic components

M. Sargsian & F. Vera arXiv:2208.00501 (2022)



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Triggered Questions

- Which role the upgrade will play in resolving the Color Transparency controversy between meson and baryon sectors?

  See G. Miller & H. Vance-Schmilla talks

- How the spectator tagging in JLab22 can access medium modifications and nuclear effects on quarks and gluons distributions?

  See W. Armstrong, T. Kutz, and M. Yurov talks

- What is the impact of the upgrade on accessing the anti-shadowing region and related medium modifications extended to the EMC region?

  See W. Brooks, S. Liuti, G. Miller, and Z. Ye talks

- How the 22 GeV upgrade would help improve our understanding about SIDIS production in Nuclei?

  See S. Paul talk

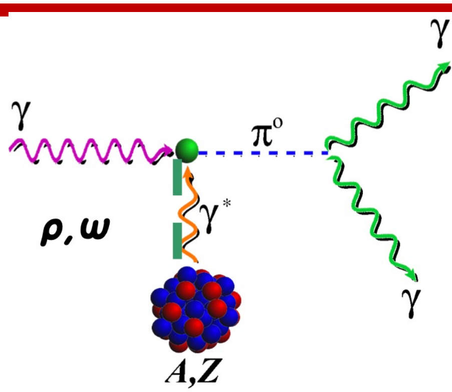
Session 7:

Low-energy tests of the Standard Model and Fundamental Symmetries

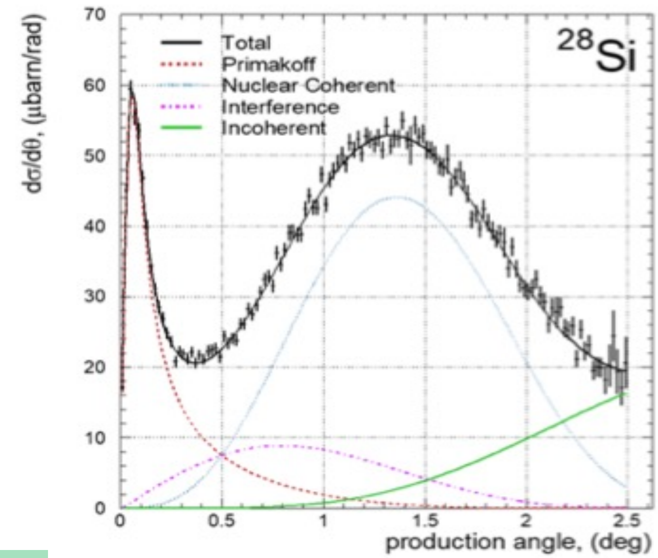
- Tests of low-energy QCD via light pseudoscalar mesons E. Passemar
- BSM physics of sub-GeV dark gauge bosons M. Pospelov
- Primakoff production of neutral pion off an atomic electron target A. Gasparian
- Search for sub-GeV dark gauge bosons via the Primakoff effect I. Jaegle
- Precision tests of fundamental symmetries via eta and eta' A. Somov
- Constraining new physics with PVDIS M. Nycz
- New opportunities at JLab using secondary beams M. Bondi

π^0 Primakoff production off an electron target

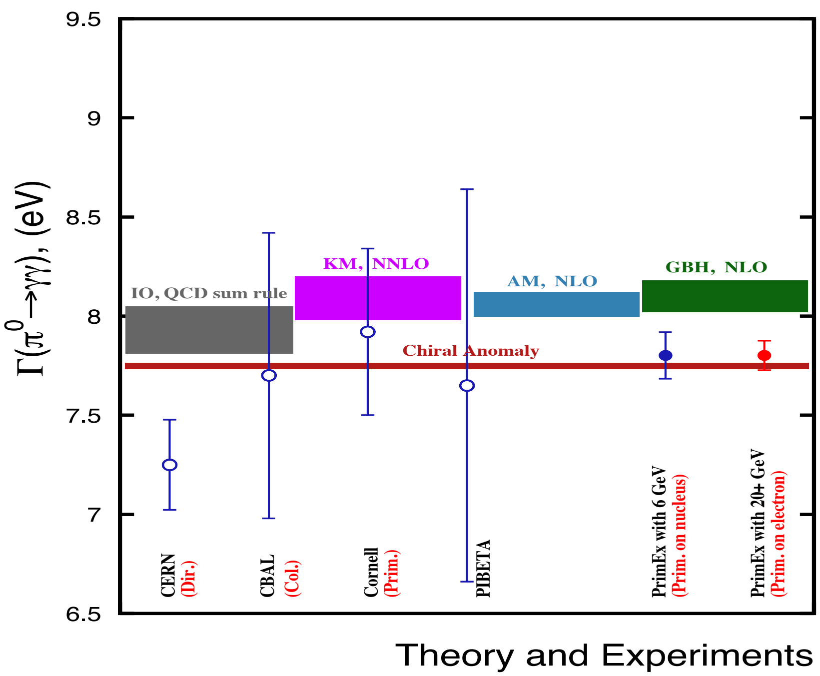
- **process of high-energy photo- or electro-production of mesons in the Coulomb field of a target**



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

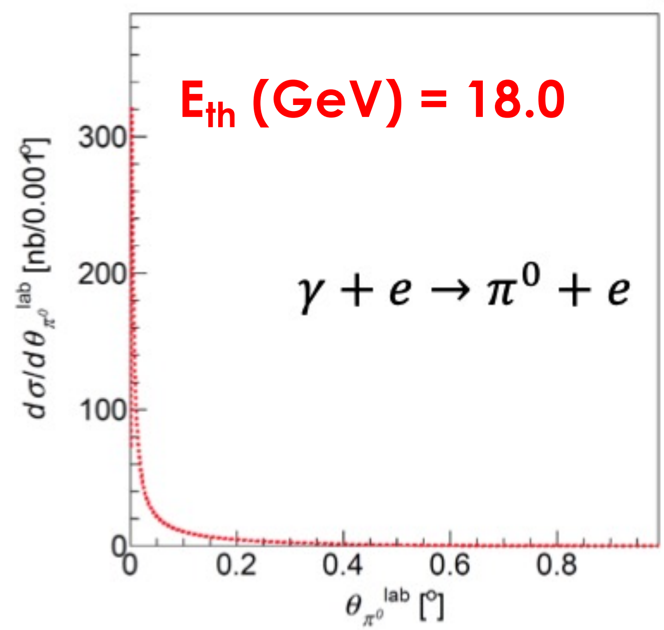


- π^0 **radiative decay width**: can be predicted at ≈ 1% precision in the low energy QCD



A. Gasparyan

Science 368, 506-509 (2020)

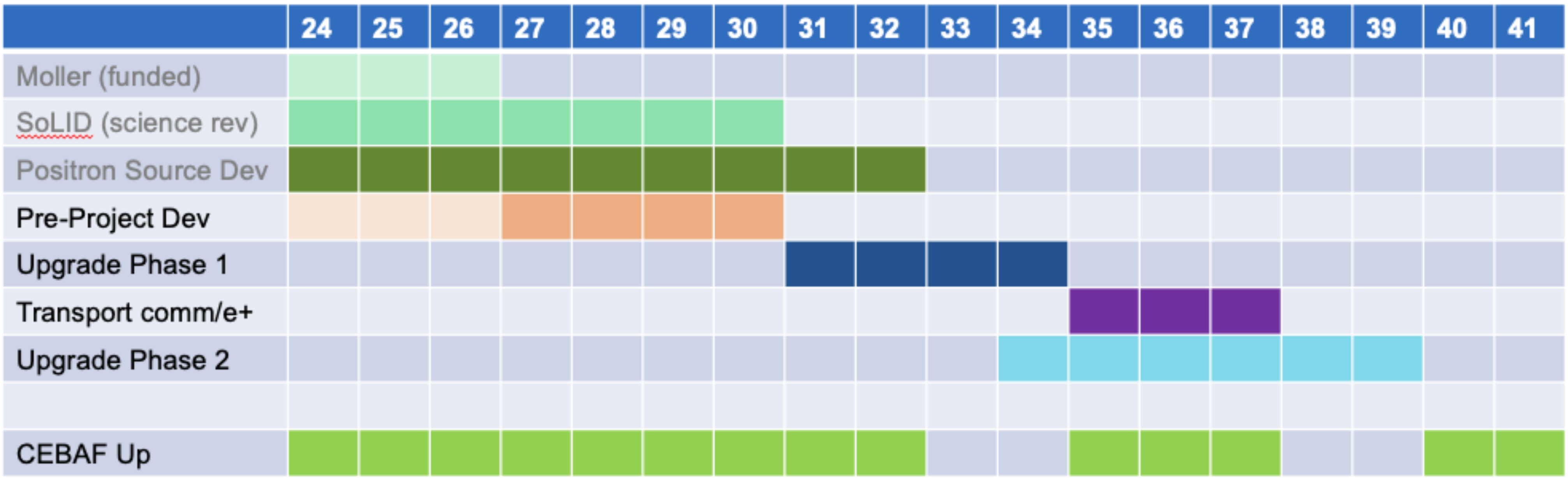


b

π^0 Primakoff off an e- target: eliminate nuclear bkg

Notional CEBAF & upgrade schedule (FY24 – FY42)

- 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



- FY23 $$
- Phase 1: tie LERF to CEBAF & injector for e+ — $101M ($78M – $152M)
- Phase 2: High Energy Upgrade (includes FFAs) — $244M ($188M – $366M)
- Total cost (Class 4 estimate) — $345M ($265M – $517M)

D. Dean

Summary and Outlook

- CEBAF 20+ GeV upgrade is technically feasible – Opportunity
- A very strong science case for such an upgrade is emerging:
  - New charmonium states, so-called "XYZ states," could be discovered/studied at JLab
    – *Fundamental question on how hadrons are emerged?*
  - Precision charmonium production near & beyond the threshold in lepton-hadron collisions
    – *as a precision probe of fundamental hadron properties and its tomography*
  - Open up a sweet region for determining the 3D structure – intrinsic confined motion
    – *Critically important for understanding how partons are confined in a bound hadron*
  - New opportunities for exploring 3D structure in position space – x-dependence of GPDs – *Tomography + moments of GPDs (gravitational form factors, angular momentum, …)*
  - Ideal facility to explore the anti-shadowing phenomenon
    – *a chance to solve the multi-decade mystery + look into the origin of nuclear force, …*
  - New and unique opportunities to search for physics beyond SM
- Capitalizing on past investment: We are obligated to explore new opportunity for CEBAF

J. Qiu

Backup

Opportunity with the NPS in Hall C

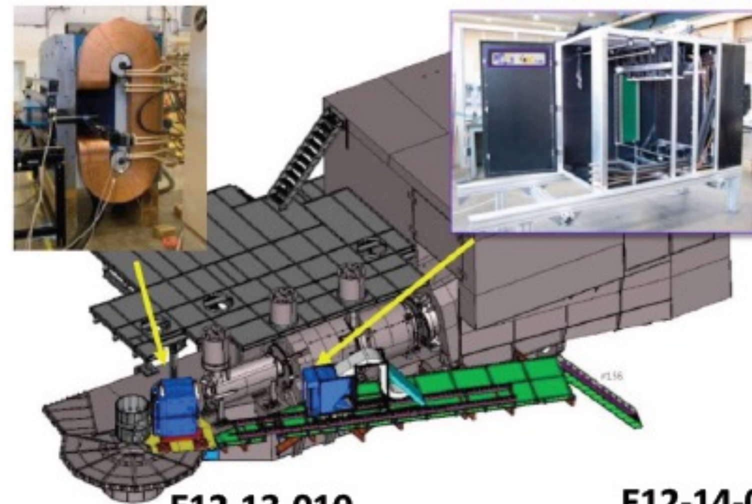
The NPS is a facility in Hall C, utilizing the well-understood HMS and the SHMS infrastructure, to allow for precision (coincidence) cross section measurements of neutral particles (γ and π^0).

Experiment	Exp #	Beam	Target	PAC Days	Rating
π^0 SIDIS	E12-13-007	$\vec{e}^-$	$L\,H_2$	(26)	A⁻
DVCS and Exclusive π^0	E12-13-010	$\vec{e}^-$	$L\,H_2$	53	A
Wide Angle Compton Scattering (WACS)	E12-14-003	e^-, γ	$L\,H_2$	18	A⁻
Wide Angle Exclusive π^0 photoproduction	E12-14-005	e^-, γ	$L\,H_2$	(18)	B
DVCS – days moved from Hall A	E12-06-114	$\vec{e}^-$	$L\,H_2$	35	A
A_{LL} & A_{LS} Polarization Observables in WACS at large s, t, and u	E12-17-008	CPS: $\vec{\gamma}$	$N\vec{H}_3$	46	A⁻
Timelike Compton Scattering (TCS) off a Transversely Polarized Proton	C12-18-005	CPS: $\vec{\gamma}$	$[N\vec{H}_3]_T$	35	C2

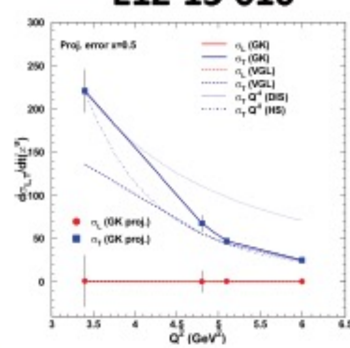
E12-13-010 will provide relative σ_L and σ_T contributions to the π^0 cross section up Q^2~6 GeV^2 to verify reaction mechanism (Julie Roche, Ohio U.)

E12-14-005 data will help confirm scaling in exclusive photoproduction of π^0 mesons and tests of the handbag mechanism (Dipangkar Dutta, Missispi State U.)

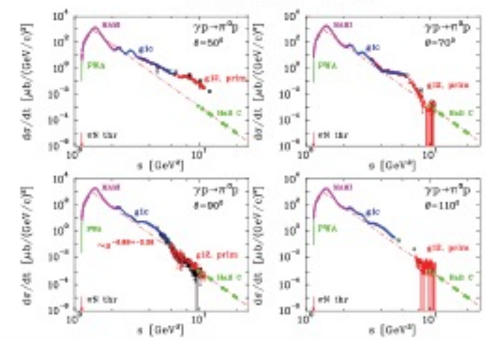
NSF MRI PHY-1530874



E12-13-010



E12-14-005



Q⁻ⁿ scaling test range increases with 18+ GeV beam and NPS – need to check in detail

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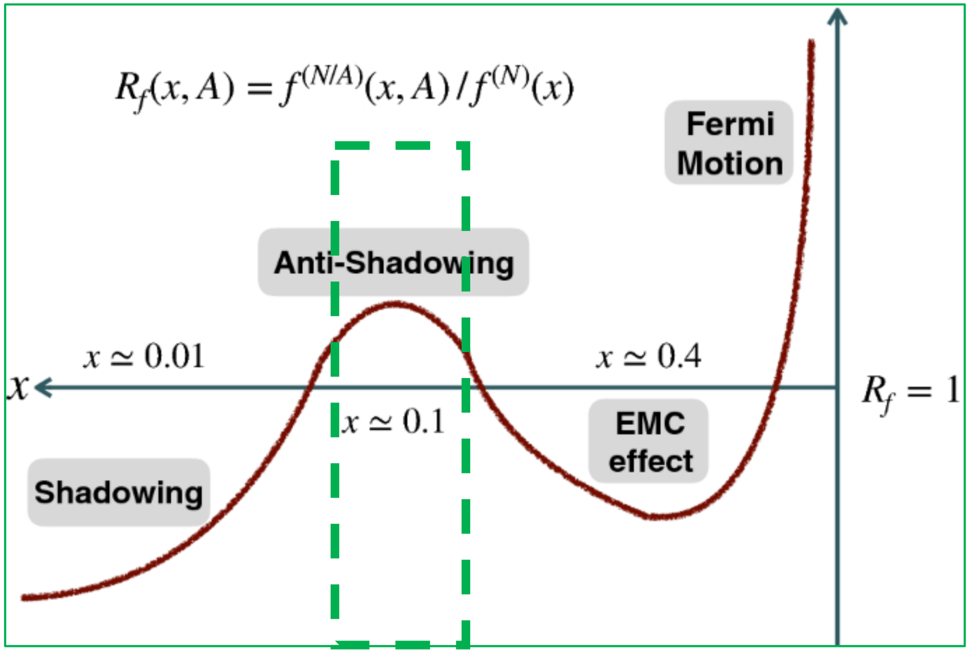
Anti-Shadowing

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



~22 GeV

- Region extremely interesting, near-equally dominated by valence quarks, sea-quarks, and gluons → many many models!!
- Anti-Shadowing is the least studied nuclear structure function effect exp.
  - flavor and spin dependence essentially uncharted
  - no tagged measurements
- The transition between shadowing and the EMC regimes ⟶ a testing ground for different descriptions

What is needed

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

ALL Possible @ Jlab 22 GeV

Prospects of DVCS @ 22 GeV at Jlab

- Hall A/C - High luminosity and precision DVCS data in valence quark region.
  - Precision scaling tests
  - High resolution imaging
  - Double the range in Q^2 from 11 GeV, at fixed range in t, x_B.

- Hall B/CLAS12 – Cover continuous Q^2 vs x_B space simultaneously at moderate luminosity
  - CLAS12 provides excellent particle identification
  - Large continuous kinematic coverage in same setting
  - Use longitudinally polarized solid targets with full solid angle coverage
  - Transversely polarized target concept developed (to access GPD E in Ji's spin sum rule)

- Combining 22 GeV DVCS data with previous 6 and 11 GeV data
  - construct more complete images of the protons valence quark domain
  - determine force, mass, and angular momentum distributions.

- TCS is measured simultaneously, direct access to *D*-term and test of universality

V. Burkert

Jefferson Lab