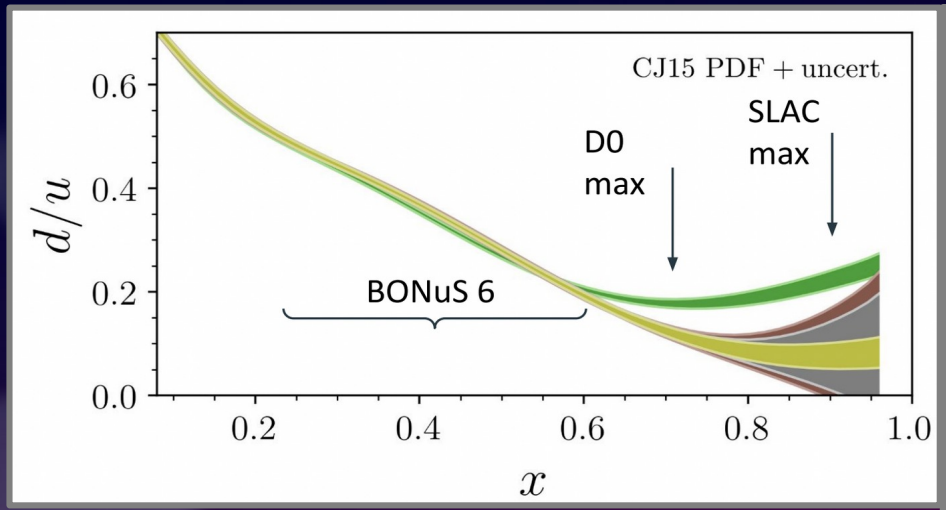
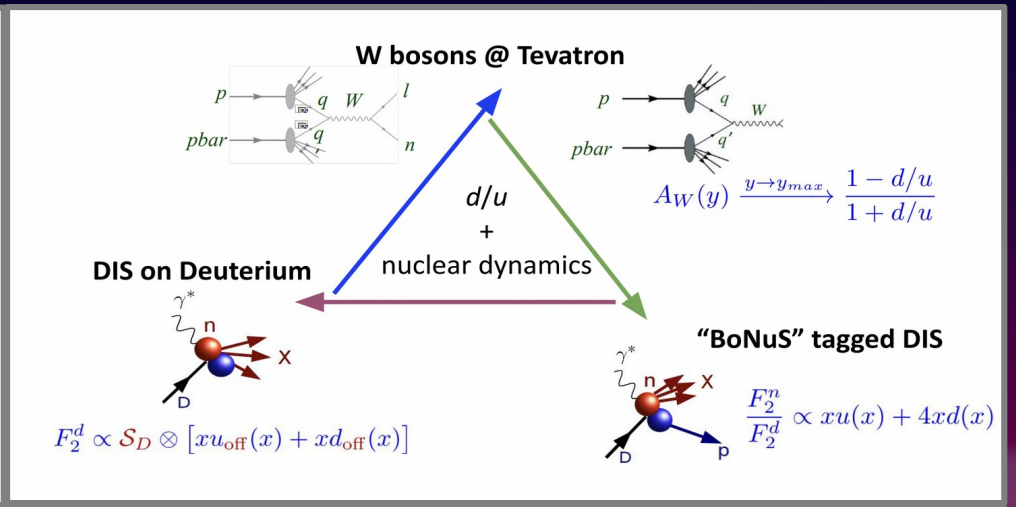
Inclusive measurements : What did we discuss at last week's symposium ?

Symposium : Nucleon and Nuclear Structure from Inclusive Measurements
Link : https://indico.phys.vt.edu/event/60/
Date : June 20 – 21, 2023
Venue : Jefferson Lab
Supported by : 4-VA, Office of the executive vice president and provost VT, Jefferson Lab
Organizers : Debaditya Biswas, Gabriel Niculescu, Ioana Niculescu, Marie Boer
Collaboration : Virginia Tech & James Madison University
Includes : Student Exchange Program

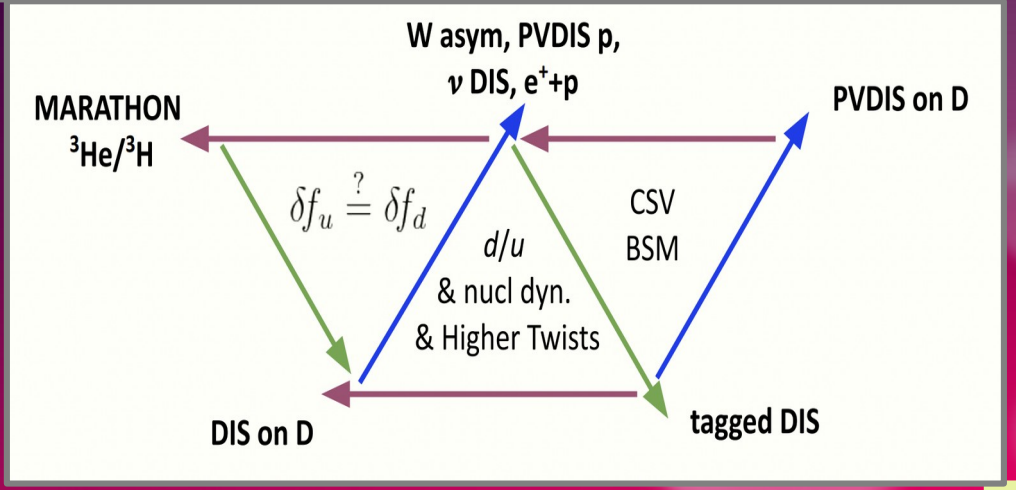
Debaditya Biswas (Deb)
Virginia Tech, VA, USA
Hall A/C Summer Collaboration Meeting 2023, Jefferson Lab, VA , USA

PDFs and nuclear structure in the CJ global analysis



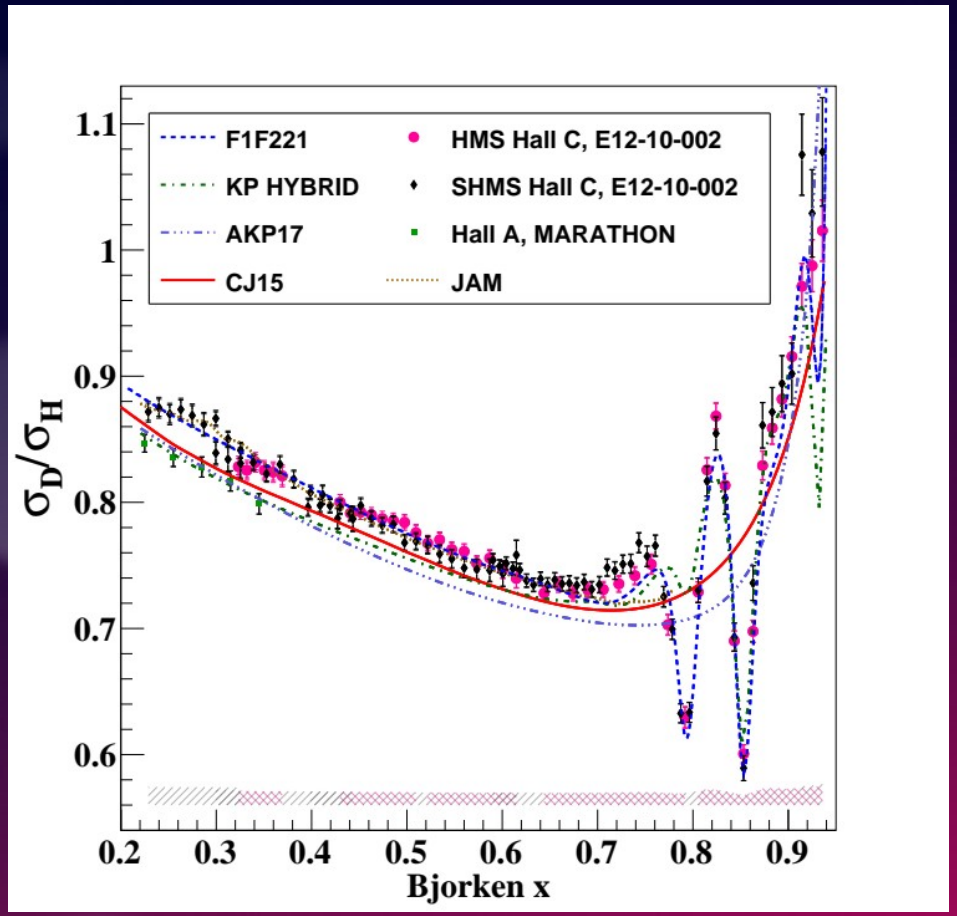


- Large uncertainty in large X
- The valence quark triangle can be extended using MARATHON data to explore the off-shell function (δf_u) is flavor independent or not (i.e. off-shell p~ off-shell n) ?
- Spectator tagging data is needed
- PVDIS is still relevant in BONuS12 / MARATHON era!
  - Proton : will contribute to d/u fit
  - Deuteron : can focus on CSV / BSM



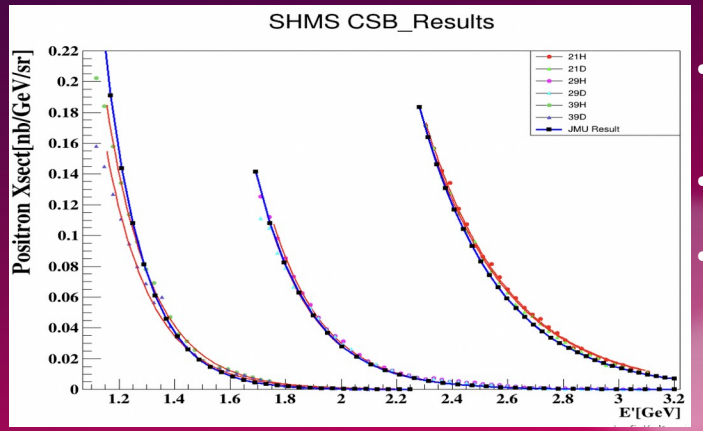
F_2 (E12-10-002)

Hall C – Final stage of data analysis, F_2^d/F_2^p paper soon to be published soon



- Final analysis done for the ratio paper
- Final work on the text in going on
- Absolute cross-section results : last stage of analysis
- Disagreement with the Marathon data : no smoking gun yet
- Will help reduce the uncertainty in the global fit specially at the large x
- One of the remaining work is to finalize HMS 59° data

Student exchange program between VT and JMU



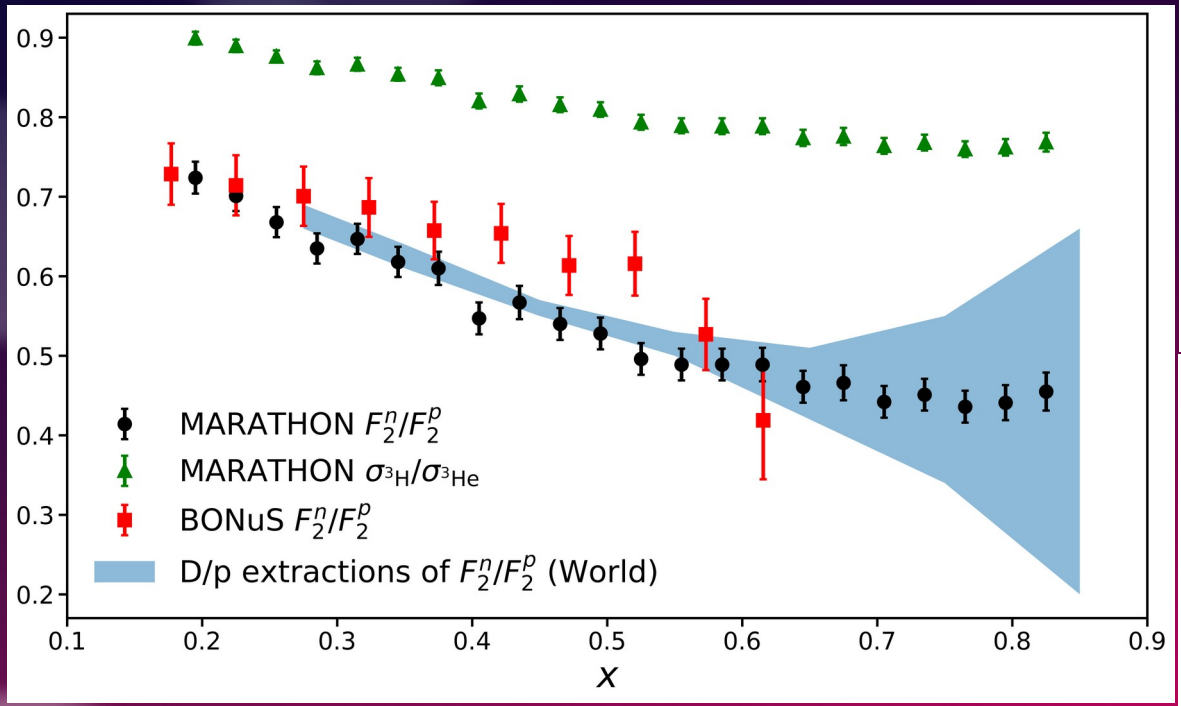
- Gyang C. : currently checking CSB
- Rechecking the SHMS results
- Then will do the same for HMS

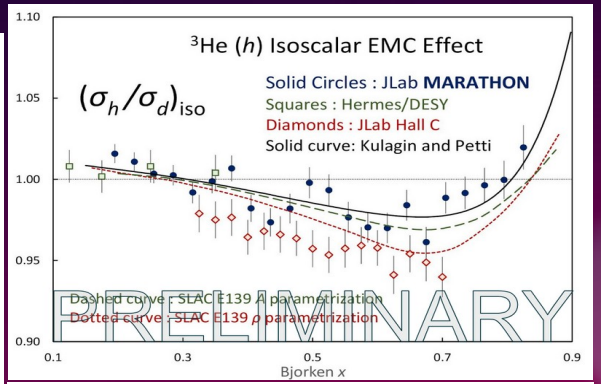
Speaker : William Henry, Gyang Chung

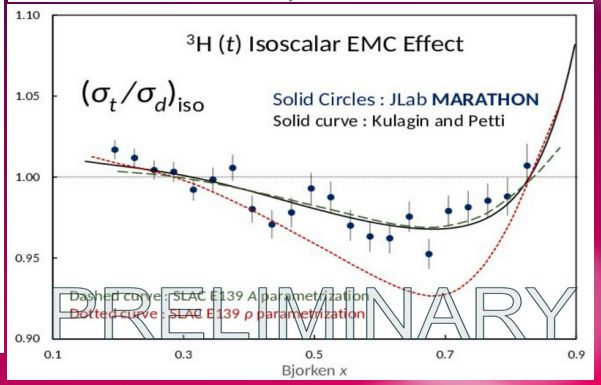
Marathon

PRL Publication of the F_2^n/F_2^p ratio, stay tuned for more publications

- Traditionally the F_2^n/F_2^p is derived from the proton to deuteron ratio
- This method rely on the knowledge of the nuclear effects in deuteron
- The knowledge of nuclear effects inside the deuteron is not well constrained at large X
- MARATHON measured this with A=3 mirror nuclei (^{3}He and ^{3}H)
- In the isospin symmetric world nuclear effects should largely cancel in the ratio







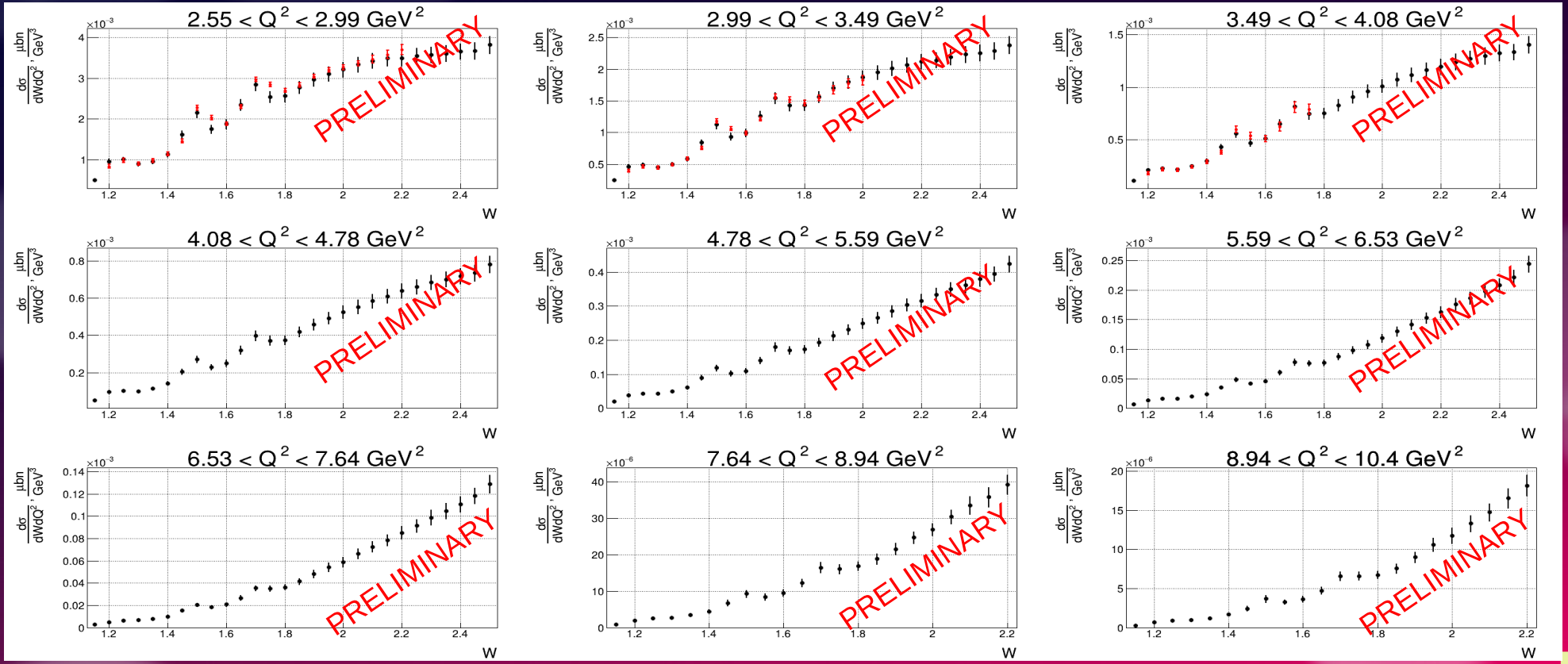
Speaker : Tyler Hague

CLAS12 : Inclusive electron scattering from proton

(with a focus on resonance region)

near publication results

4.0 GeV^2<Q^2<10 GeV^2 with coverage over W from threshold and up to the maximal value allowed by kinematics within any given Q^2-bin.
New opportunities for the insight into nucleon PDF in the resonance region and for exploration of quark-hadron duality.



Speaker : Valerii Klimenko

Spectator tagging: Inclusive measurements in controlled nuclear configuration

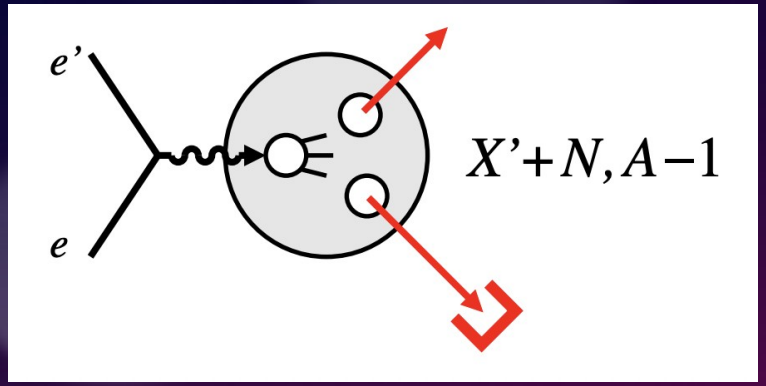
Spectator tagging with JLab: Fixed target view

complementary

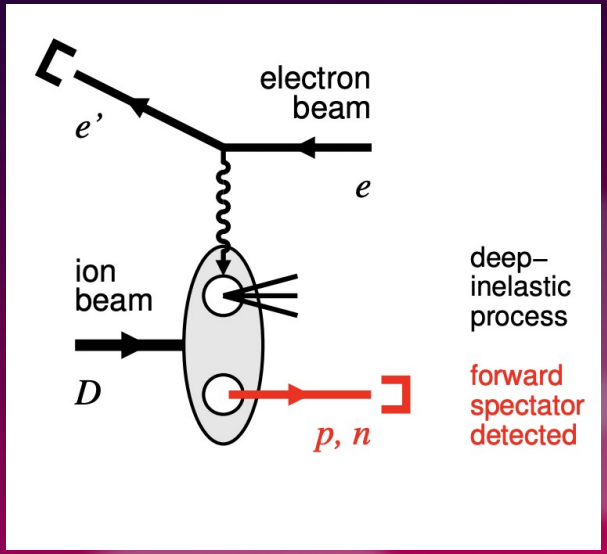
Spectator tagging with EIC: Collider frame view

JLab 12/22: High luminosity for x>0.5, spectator momenta p~300-500 MeV

EIC: Full DIS kinematics, x<0.1, far-forward detector coverage and resolution



- Part of the final state of high-energy process interacts with spectator → changes the spectator momentum distribution (keeping total cross section unchanged) → FSI need dedicated theory/ modeling in different kinematic regions



- Application of spectator tagging : Access free neutron through pole extrapolation, control the effective neutron polarization in polarized deuteron, maximize the tensor polarization, control strength of interaction in EMC effect
- Can be extended for breakup measurement to A>2 but requires substantial nuclear input : Spectral functions, decay amplitudes for specific final state, final-state interaction

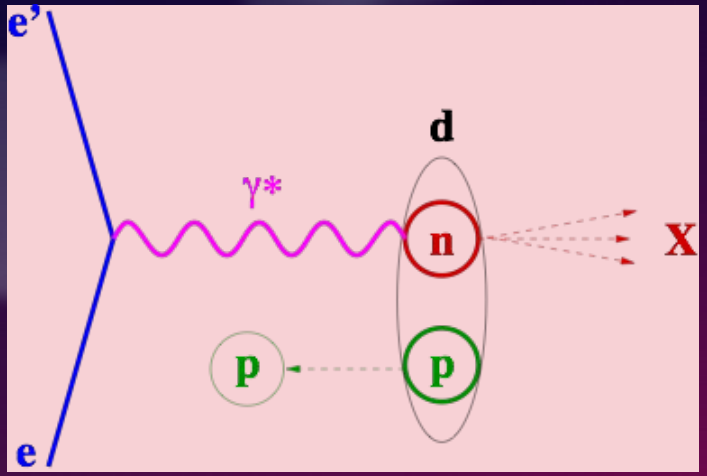
Speaker : Christian Weiss

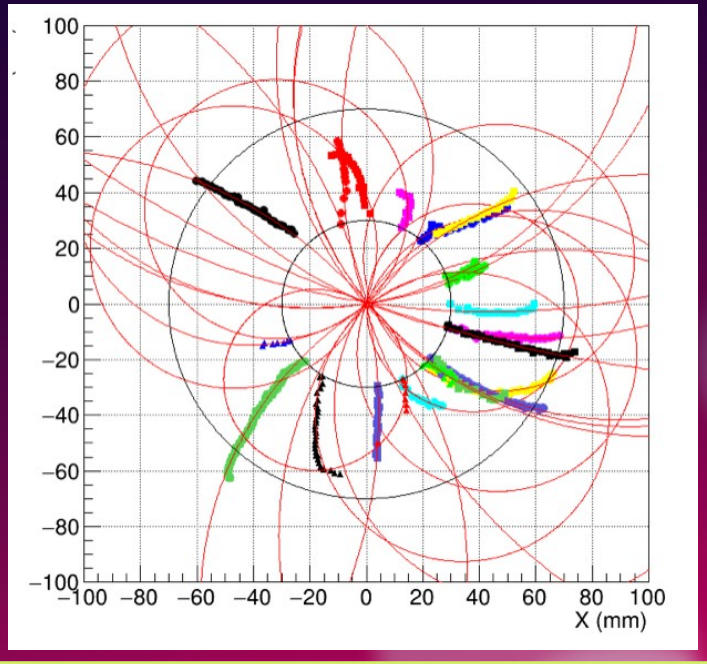
Proton tagging @ Jlab: CLAS BONuS 6/12, ALERT, HALL A TDIS
Neutron tagging @ Jlab : CLAS12 BAND

BONuS12 : neutron structure function

Analysis in progress

- Tagging of recoil spectator proton (RTPC detects the low energy recoils)
- Improved resolution of the invariant mass spectrum
- Completed data taking in summer 2020
- Calibration of the data set complete
- Results will compliment MARATHON up to X ~0.8
  - *With Beam energy to 22 GeV will push X to ~0.9*





New RTPC performed well
NIM paper soon to be submitted

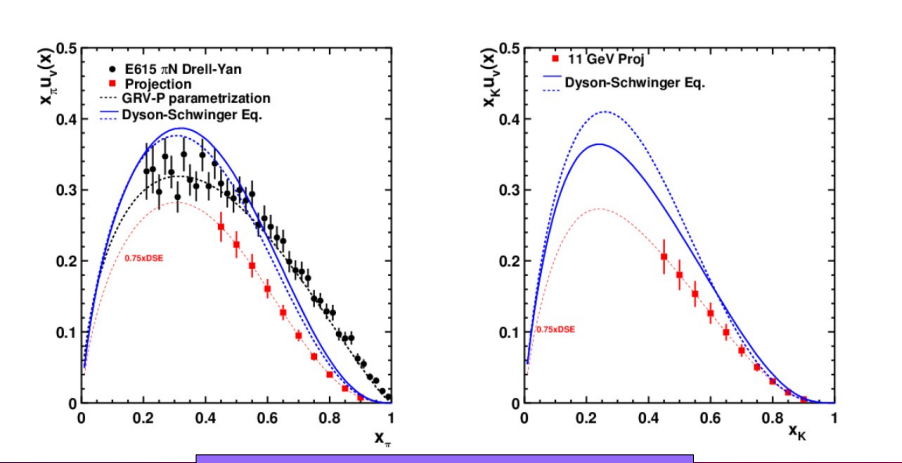
Speaker : Stephen Bueltmann

TDIS : Tagged Deep Inelastic Scattering

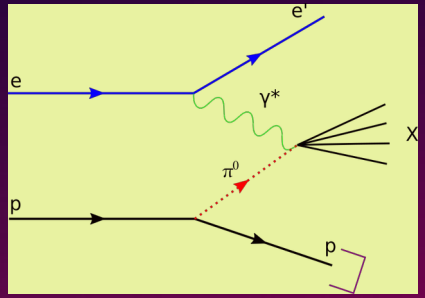
Proposed experiment and will be resubmitted to PAC 2023

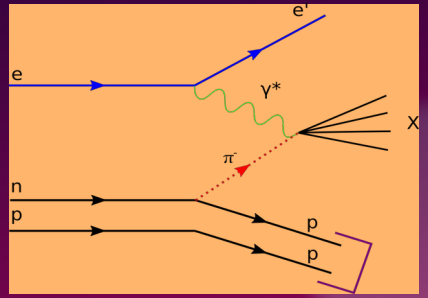
Fermi – Marshal (1947) : Nucleon stay at least 20% of time in virtual meson-nucleon state

- Understanding of the meson "cloud" is important for nucleon-nucleon interaction
- Especially the Pion cloud information is important to nucleon's long-range structure
- Even after data from Fermilab (Drell-Yan), RHIC (W production), HERA and COMPASS's (diffractive DIS) there still room for JLab to measure at intermediate and large *X*
- Experiment : A Low energy proton tagging in coincidence with the DIS scattered electron



Pion and Kaon structure





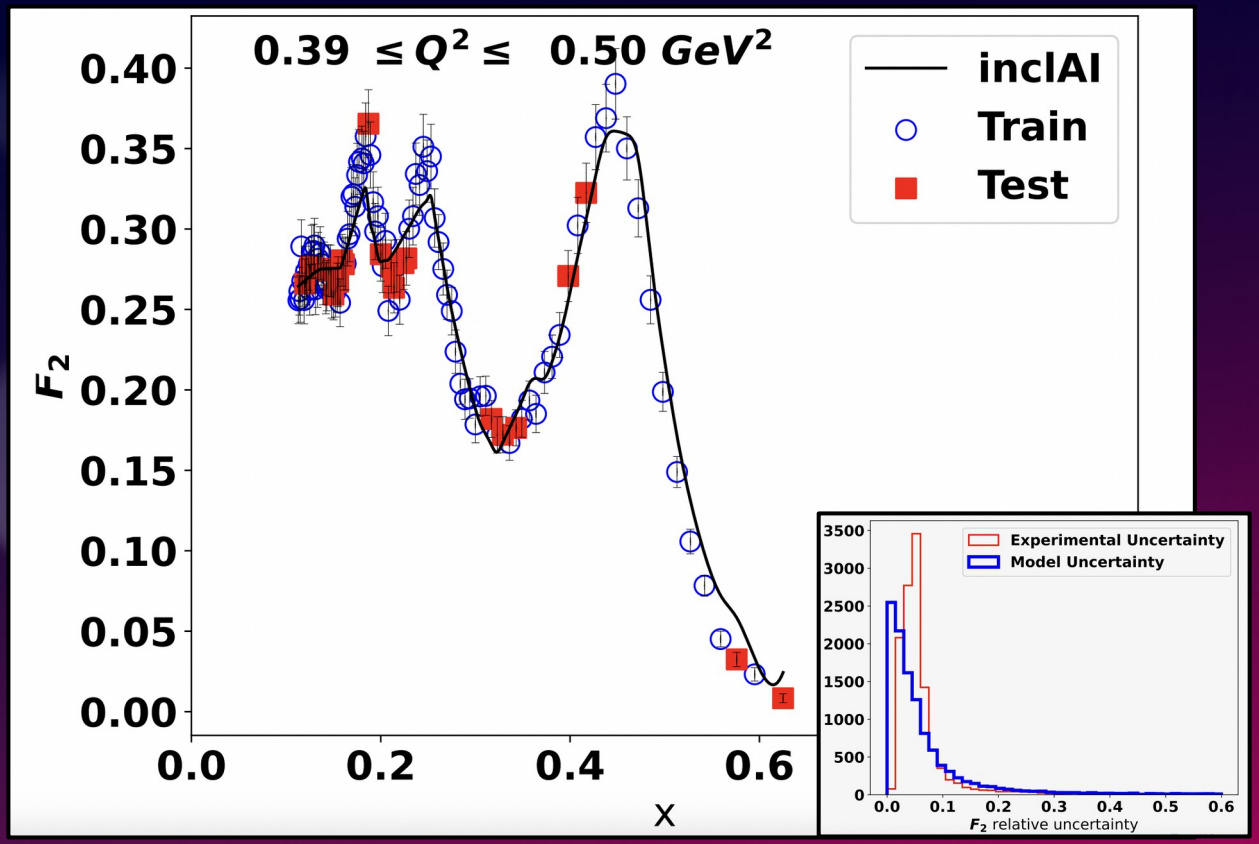
- Converged on a design since the original proposal: multi–Time Projection Chamber (mTPC)
- University of Virginia constructing 1st prototype mTPC chamber (N. Liyanage, H. Nguyen, S. Ali)
- JLab/Mississippi State (E. Christy, C. Cuevas, A. Nadeshani) preparing HV divider
- Two additional run group proposals were added

& Resonance region structure & F_2^n/F_2^p &
EMC effect in deuterium &
Form factor with Tagged proton

Speaker : Arun Tadepalli

Modeling F_2 with AI (Artificial Intelligence)

new tool



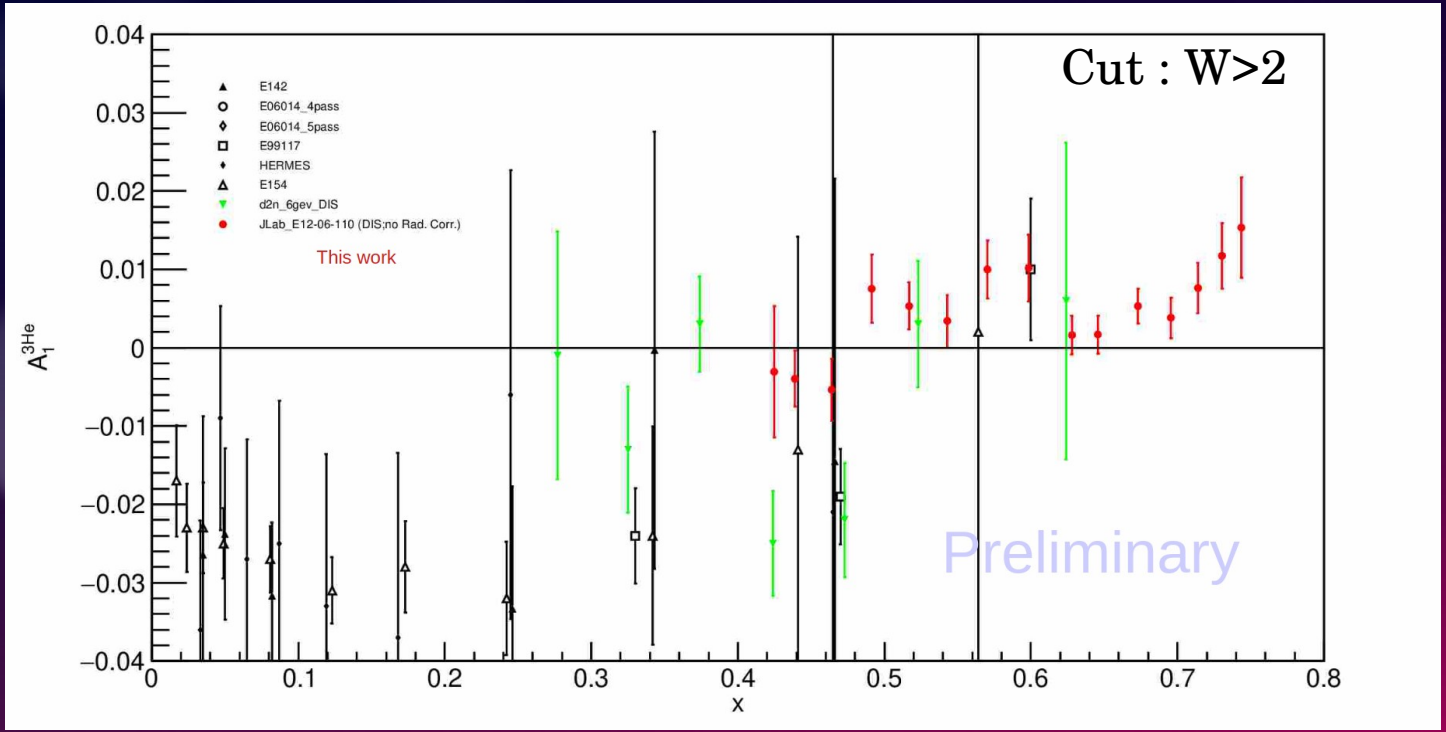
Sample Inclusive AI F_2 results for hydrogen

- Hydrogen and Deuterium results published in 2021
- Precision comparable with the data uncertainties
- Fast Process:10-100X+ speed
- Emerging Capabilities
  - Finding problem in existing data set
  - Extension to nuclei
- This work reminded us how important is to maintain the world data set and make it easily available for the community

Speaker : Gabriel Niculescu

Precision Measurement of the Neutron Asymmetry A1n at Large Bjorken X (E12-06-110)

Analysis in progress



$$A_1 = \frac{A_{\parallel}}{D(1+\eta\xi)} - \frac{\eta A_{\perp}}{d(1+\eta\xi)}$$

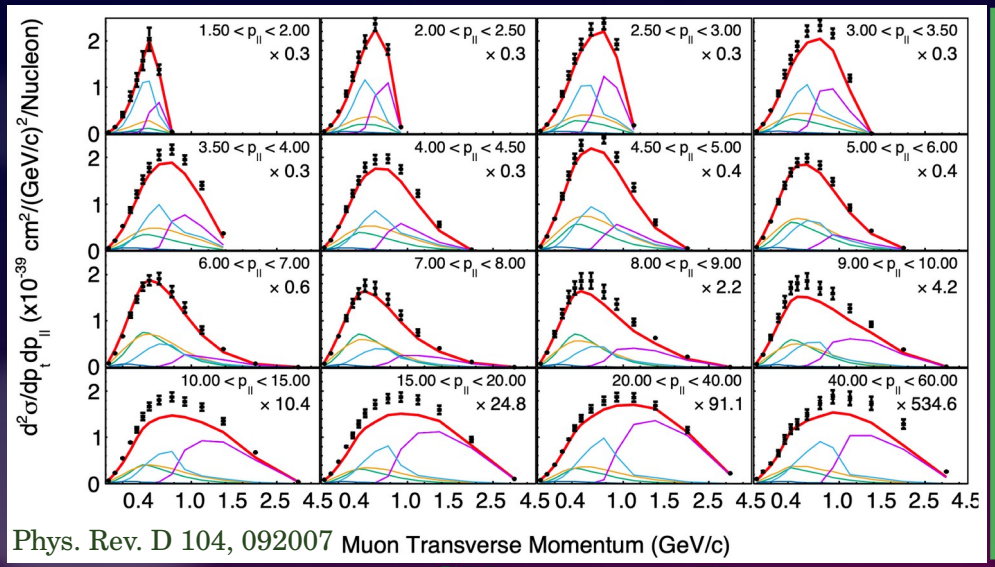
- Radiative corrections in progress
- Nuclear corrections remain to do

- Understanding nucleon spin from quark and gluon spin and orbital angular momentum
- At high X sea contribution is negligible and the total spin should be carried out by valence quarks
- First : upgraded polarized ^{3}He target
- Achieved 50% polarization at 30 uAm
- After combining with precision proton data (CLAS12) high precision newutron data will allow polarized to unpolarized PDF ratios Δu/u (Δd/u) for large x

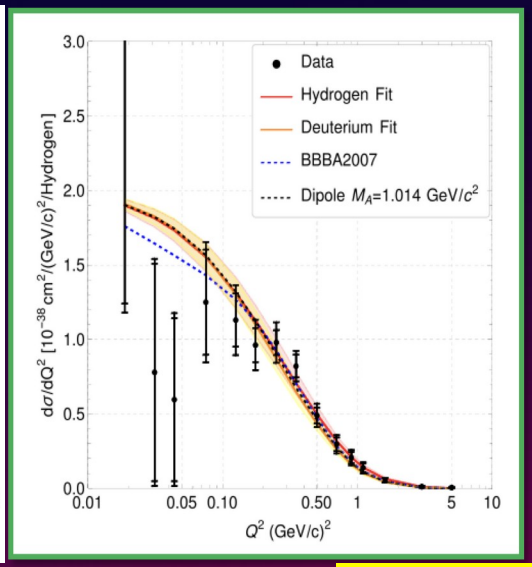
Speaker : Mingyu Chen.

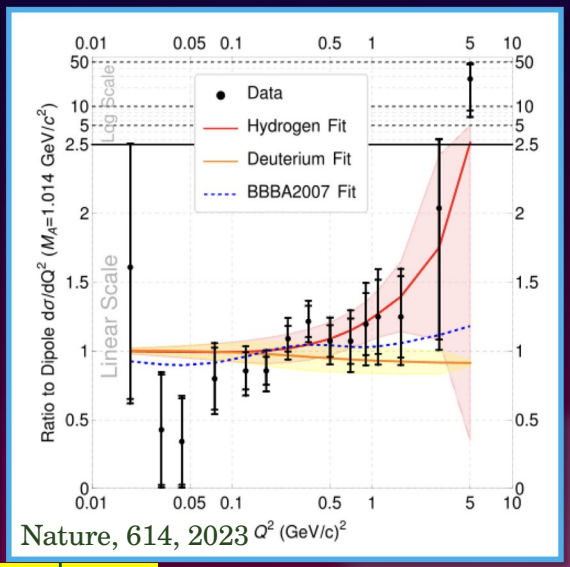
Minerva Results

what neutrino is doing here!



Phys. Rev. D 104, 092007





Nature, 614, 2023

$\nu_\mu + CH \rightarrow \mu^- + X$

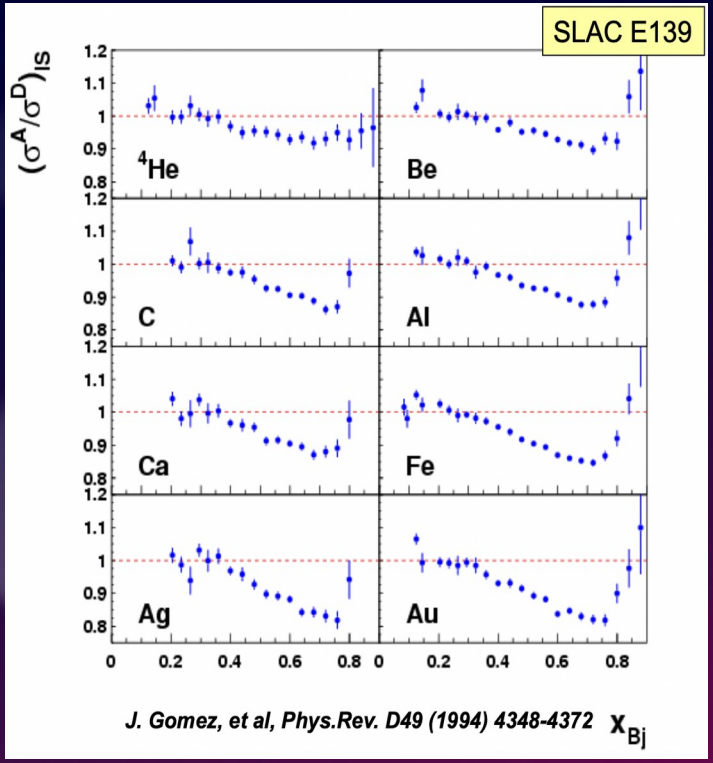
- In few regions under and over prediction compared to Minerva Tune v1 (Genie Generator + local modifications)
- Underlying processes like QE, Soft DIS, True DIS, etc. contribute to the prediction in this mismodeling
- Exclusive, Semi-inclusive measurements
- Required to investigate complex regions

$\bar{\nu}_\mu + p \rightarrow \mu^+ + n$

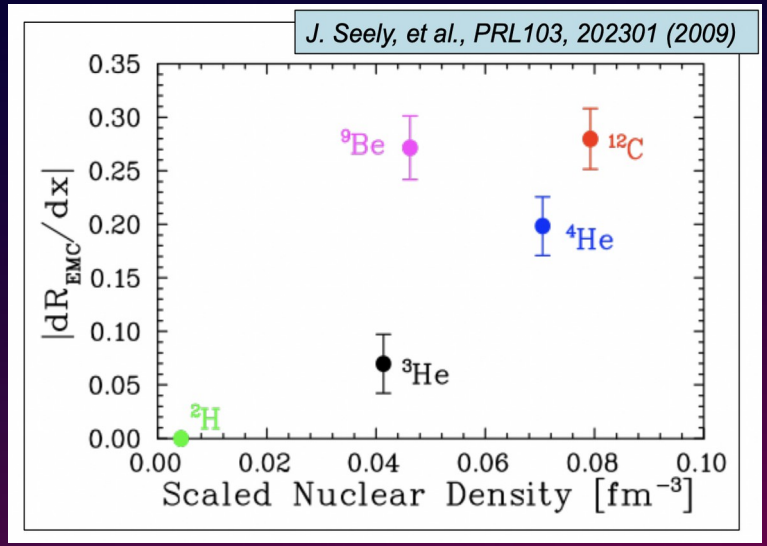
- Opportunity to measure both vector and axial vector form factors
- Reportedly first statistically significant measurement of elastic anti neutrino-proton scattering cross section (~5000 proton elastic scattering)
- Fitted cross section to export the axial form factor and compared it with different models

Speaker : Zubair Dar

The EMC Effect and Connections to a Possible Nuclear Dependence of R



- Universal x-dependence
- Little Q2 dependence
- EMC effect increases with A
- Nuclear dependence is one way to investigate the origin



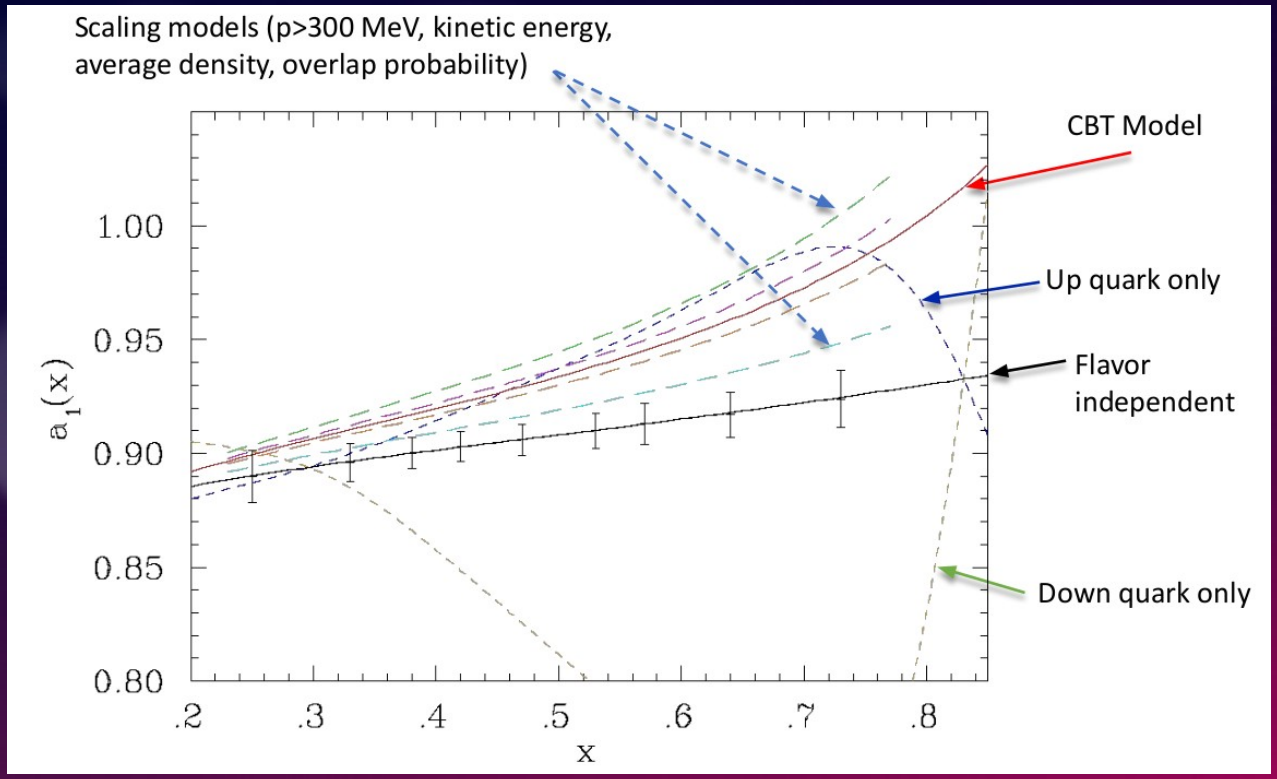
- Be does not scale well with the average density !
- EMC effect is driven by local density not the average nuclear density
- Now the question is : What drives the local nuclear density in nucleus → Short Range Correlation

- Two Recent Experiments E12-10-008, E12-06-105 (x>1) To explore the EMC – SRC effects
- Large Number of targets
- Completed data taking this year
- Analysis is underway, stay tuned for the preliminary results
- EMC effect provides information about the nuclear PDFs
- In that context $R=\sigma_L/\sigma_T$ and the LT separated data becomes important
- Proposed E12-14-002 will provide the information about R

Speaker : Dave Gaskell

PVEMC: Flavor Dependence of Nuclear PDF Modification

Proposed Experiment



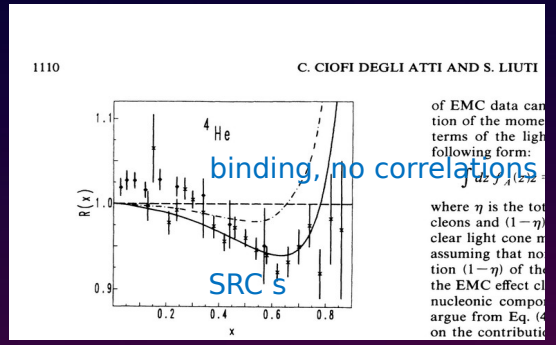
- parity-violating DIS measurement using the SoLID spectrometer and a 48Ca target
- precise measurement of the flavor dependence of the EMC effect over the full x
- provide a completely new observable
- will constraints on the d- and u-quark distributions for heavy neutron-rich nuclei
- important in understanding of the flavor structure of the pdfs in heavy nuclei

Flavor dependence: Is EMC effect different for up and down quarks?

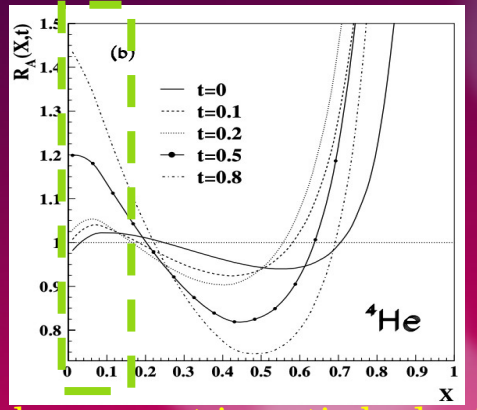
Speaker : Rakitha Beminiwattha

The EMC effect in QCD

- Short range correlations impact on the EMC effect has been known for long
- But do we know what their quark and gluon structure?
- To understand this both nucleon medium modifications and off-shell effects resultiing from the combination of x-rescaling (binding) and the **transverse** motion of quarks need to be included
- How: QCD correlation functions and gauge links give us the key to interpret the EMC effect
- New observables: Deeply Virtual Compton Scattering (DVCS) from nuclei



C. Ciofi degli Atti, S. Liuti Phys.Rev.C 41 (1990) 1100
C. Ciofi degli Atti, S. Liuti *Phys.Rev.C* 44 (1991) R1269
C. Ciofi degli Atti, SL, PLB (1989)
F. Gross, S. Liuti, PRC45 (1992)



Enhancement in anti-shadowing region due to transverse motion

Speaker : Simonetta Liuti

Student exchange program between VT and JMU

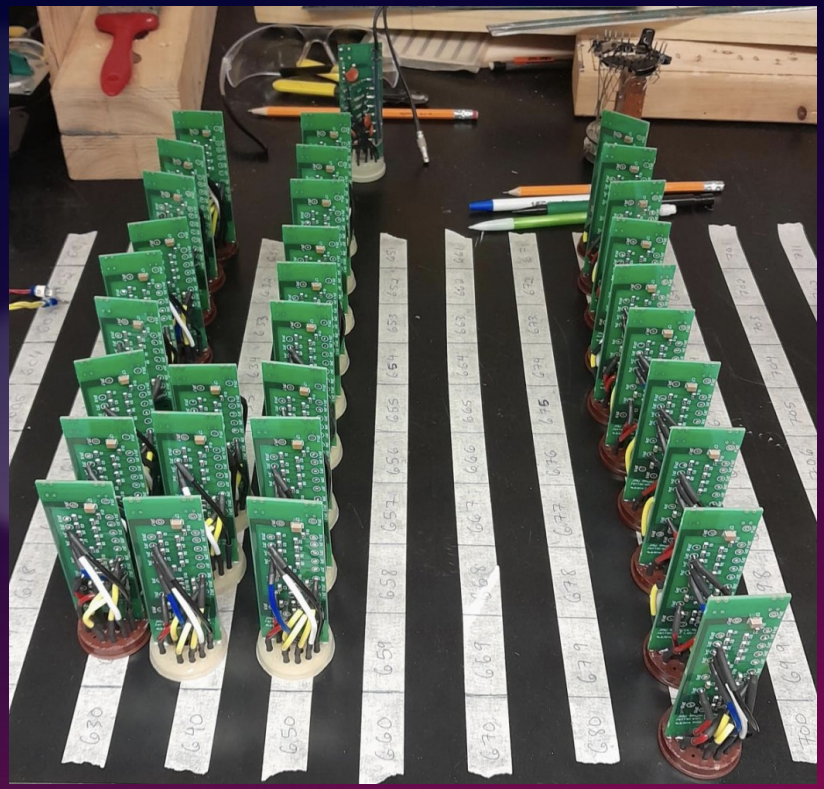
Hard Exclusive Diphoton Photoproduction

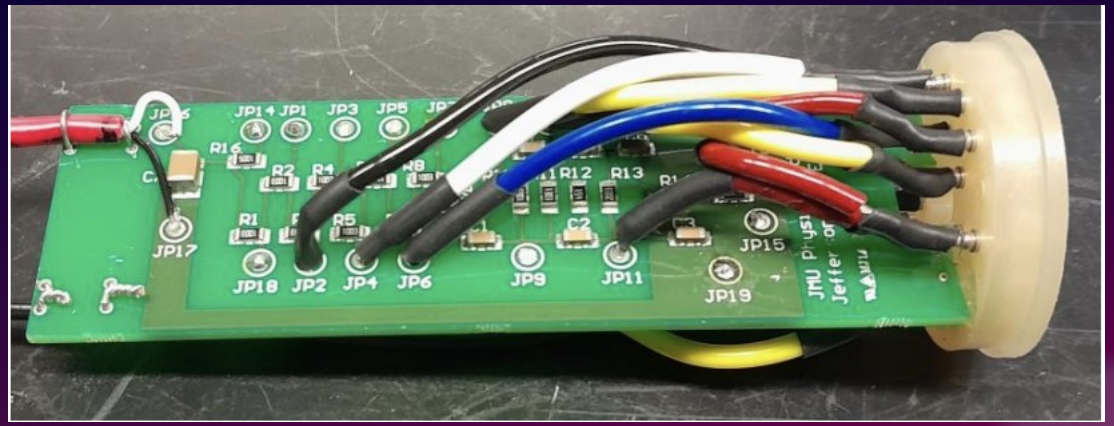
- currently running impact studies of hard exclusive diphoton photoproduction comparing the use of 11GeV and 8.5GeV electron beams as well as real versus quasi real photon beams
- simulation is running as expected
- theoretical applications include Paris/Warsaw group and JLab LDRD group
- future research potential
  - study of beam asymmetry through GlueX in hall D (request to join collaboration has been made)
  - study of unpolarized cross section through TCS in hall C (Deb is working on GEANT4, Keirsten and Mary on analysis)

Speaker : Mary Conner, Keirsten Kekic

Student exchange program between VT and JMU

Assembling and Testing the Resistive Bases for the ECAL of JLab Hall A





- SBS ECAL made up to 193 super modules to be assembled for electron arm
- 1737 lead-glass blocks
- PMT HV bases been modified and are being tested before final assemble of the ECAL
- The bases are assembled and tested at JMU
- Assembled bases are scheduled to be delivered to Jlab this summer (2023)

Speaker : Mahmoud Gomina

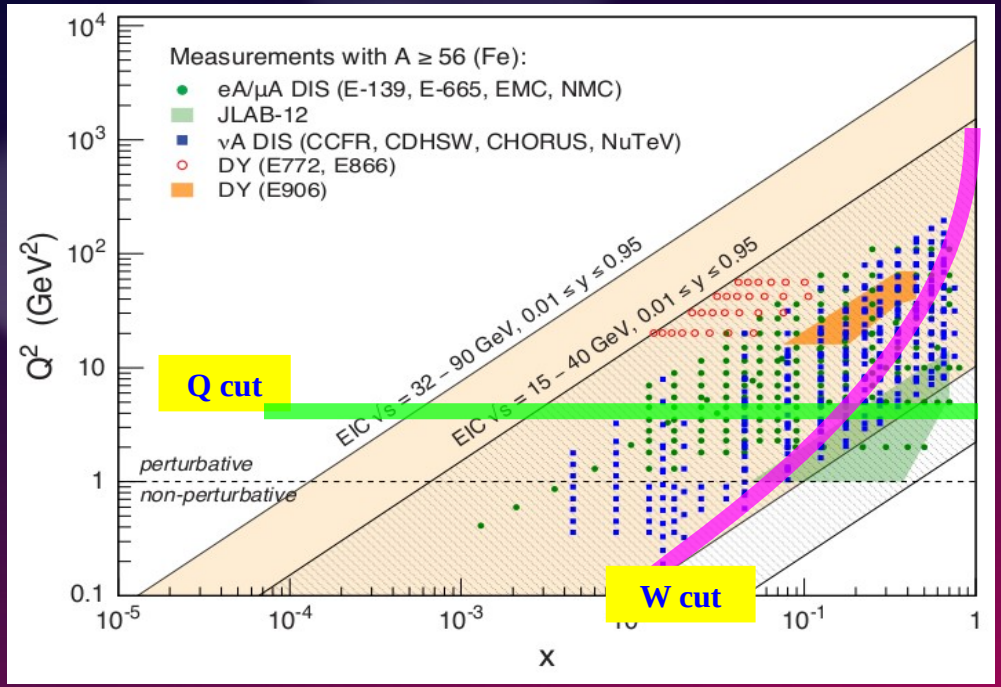
Nuclear PDF: nCTEQ : From PDF to underlying QCD

Proton PDF: $f_p(x,Q)$

generally NNLO; approaching ~1% precision; Boundary Conditions for nuclear PDF

Nuclear PDF: $f_A(x,Q)$

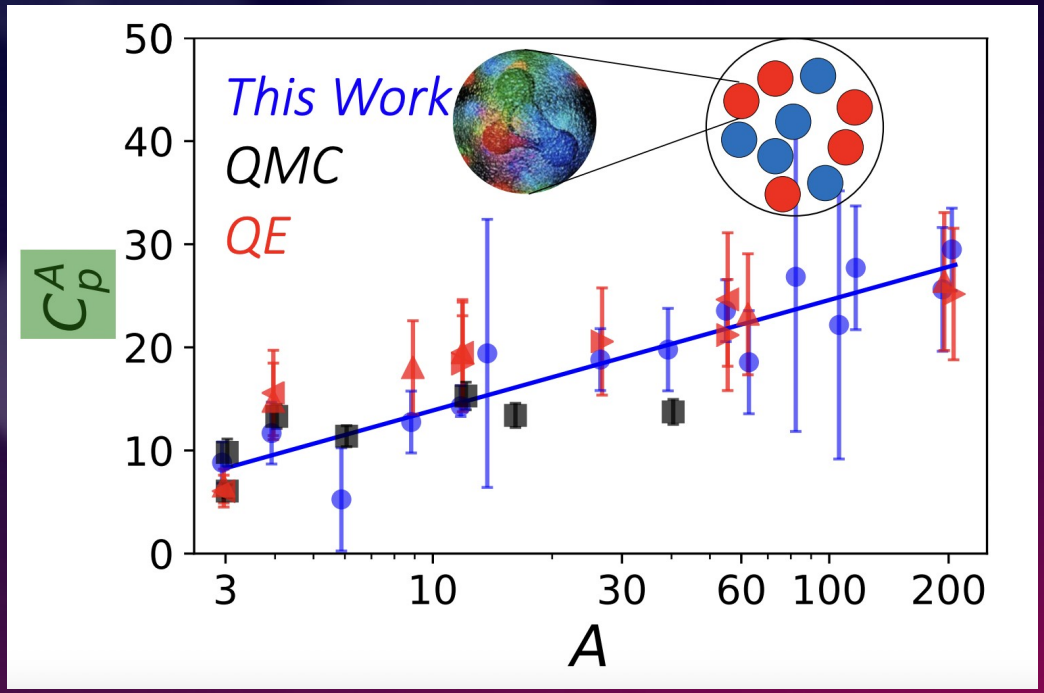
generally NLO; leverage proton PDF tools; recent progress encouraging *(e.g., PDG)*



- Newl JLab data (and others) provide extra constraints and probe the extreme regions of QCD
  - Low x : resummation, saturation, BFKL,..
  - Low W : resonance region, duality, …
  - Low Q : non-perturbative region, correlation effects,…
- Further studies are needed to explore full tomographic nuclear structure in spin, k_T, b_T
  - precision $f_A(x,Q)$ can serve as Boundary Condition for $f_A(x,Q,k_T,b_T,¾)$
  - include Lattice QCD info on moments and quasi-PDFs

Speaker : Fred Olness

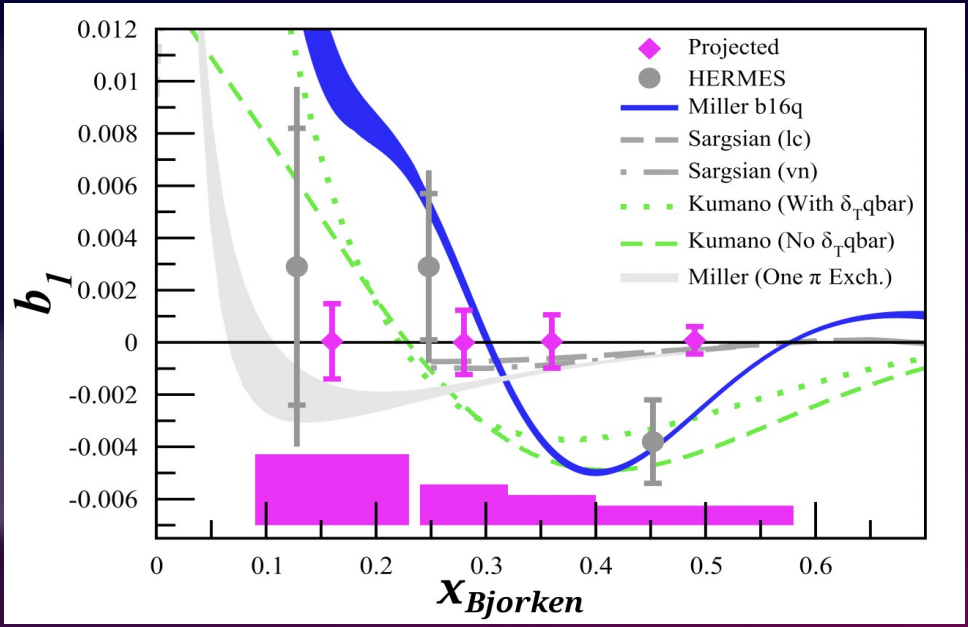
Nuclear PDF : Modification of quark-gluon distributions in nuclei by correlated nucleon pairs



- Fred conducted a fit of nuclear PDFs on world data. This original fit assumed a nuclear pdf of the following functional form:
  $f_{Nucleus} = f_{Proton}(A) + f_{Neutron}(A)$
- A relationship between SRC abundance taken from quasi-elastic scattering (a_2 is the observable) and the strength of the EMC effect is seen.
- This work re-parameterize Fred's fit to reflect the underlying physics of SRCs to extract the parameters.
- $f_{Nucleus} = (1\text{-}Cp)\, f_{FreeProton} + (Cp)\, f_{SRCProton} + (1\text{-}Cn)\, f_{FreeNeutron} + (Cn)\, f_{SRCNeutron}$
- The new fit does just as well as the old fit.
- The extracted parameters agree very well with a_2.

Speaker : Andrew Denniston

Solid Tensor-Polarized Targets for Tests of Nuclear Structure



Intend to improve uncertainty of HERMES 2005 data

- Deuteron is the simplest bound state in QCD
- But our understanding of this bound state is not complete
- Experiments like b1 and Azz can help understand deuteron better through measuring the Tensor Structure Function b1 and Azz
- Both experiment require a highly (> 30%) tensor-polarized deuterium target
- UNH group is developing the Tensor Polarized Targets for these experiments
- UNH group already demonstrated tensor polarization capability
- Showed the improvement to NMR signal fitting method
- Next talk by Allison Zec.

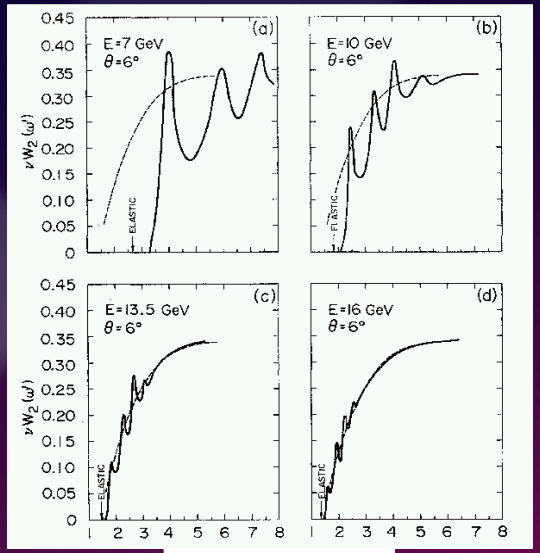
Speaker : Allison Zec

Quark-Hadron Duality and Beyond

- ✓ F_2^p
- ✓ F_1^p
- ✓ F_L^p
- ✓ F_2^n
- ✓ F_2^d
- ✓ F_2^C
- ✓ F_2^{Fe}
- ✓ F_2^{Au}
- ✓ A_1^p
- ✓ g_1^p
- ✓ g_1^d
- ✓ g_1^n
- ✓ g_1^{3He}

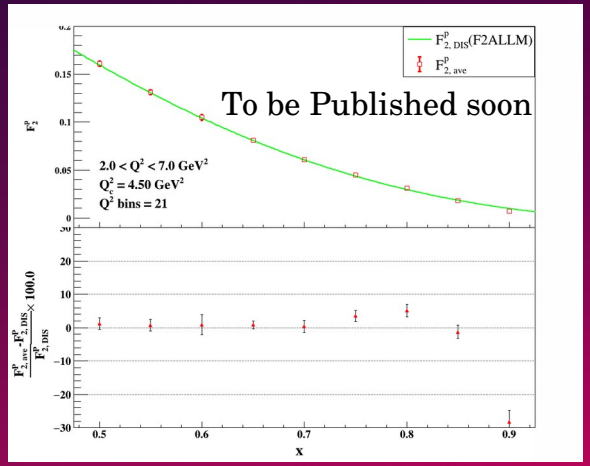
- ✓ SIDIS p π^+
- ✓ SIDIS p π^-
- ✓ SIDIS d π^+
- ✓ SIDIS d π^-

30+ years of data repeatedly indicated that duality is a fundamental and non trivial property of nucleon structure !



Bloom Gilman Duality

12 GeV Data, pushing to large Q^2



Speaker : Thia Keppel

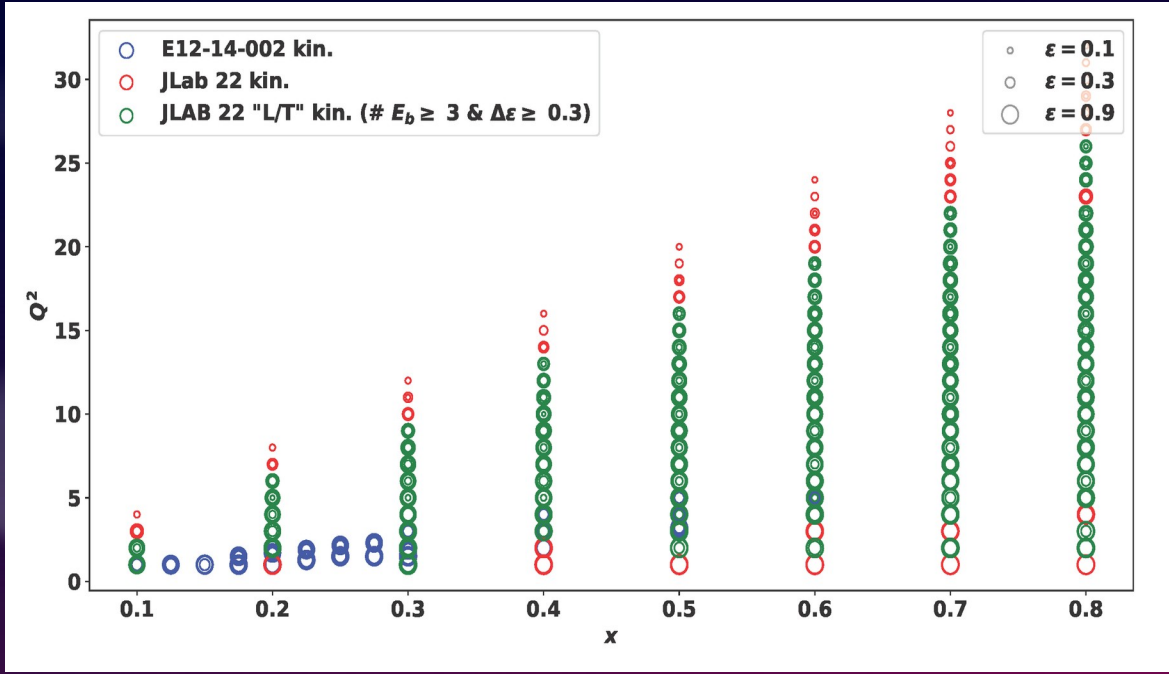
- What is the scaling curve ?
- Uncertainty at large x !
- Is it a clue to the nature of confinement ?
- " The 12 GeV future… Will duality hold also for meson structure functions?"
- Can we use duality to probe the large x region?

…… and also open questions like

- What else need to be measured in the context of duality?
- Can we test in 3D (TMD ?) ? If "yes", what quantities to measure?
- What is the underlying mechanish of duality?

JLAB @ 22 GeV

looking into the future …



- Higher energy will expand the kinematic regime
- High statistics measurements from fixed target experiments will complement EIC measurements.
- Measurements of : help extract gluon in nuclear PDFs
  - JLab/EIC overlap will provide important validation

Beam energy: 2.85---22.65 in 10 steps

HMS	**SHMS**
p: 0.5—7 GeV	**1 – 11 GeV**
theta: 10.5—80 deg.	**5.5 – 40 deg**

"JLab has a uniquely fundamental role to play in the EIC era in the realm of precision separation measurements between the longitudinal (σ_L) and transverse (σ_T) photon contributions to the cross section, which are critical for studies of both semi-inclusive and exclusive processes." - arXiv:2306.09360 (White paper)

Speaker : Ioana Niculescu

Summary

- For the sources of the figures / equations / works please check the original talks
- We had a successful workshop last week and discussed may important topics
- There were still many topics untouched in inclusive physics workshop
- Hard to do justice to this vast body of works of many smart people in 30 min
- So, feel free to discuss anything you like to add