Meson Structure at the EIC

Temple EIC User Meeting

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Richard Trotta, Jon Arrington, Yulia Furletova, Stephen Kay, Cynthia Keppel, Rolf Ent, Tim Hobbs, Tanja Horn, Dmitry Romanov, Arun Tadepalli, Rik Yoshida, and the meson structure working group

Jefferson Lab

THE CATHOLIC UNIVERSITY OF AMERICA

5 key EIC measurements from EPJA article

1. Measurement of pion and kaon structure functions and their GPDs
    - insights into quark and gluon energy contributions to hadron masses
2. Measurement of open-charm production
    - settle question of whether gluons persist or disappear within pions in the chiral limit
3. Measurement of the charged-pion form factor up to Q2~35 GeV
    - Quantitatively related to emergent-mass acquisition from DCSB
4. Measurement of the behavior of (valence) u-quarks in the pion and kaon
    - quantitative measure of the contributions of gluons to NG boson masses and differences between the impacts of emergent and Higgs-driven mass generating mechanisms.
5. Measurement of the fragmentation of quarks into pions and kaons
    - a timelike analog of mass acquisition, which can potentially reveal relationships between DCSB and confinement mechanism

Pion and Kaon Structure White Paper

- At low t values, the cross-section displays behavior characteristic of meson pole dominance.
  - Using the Sullivan process can provide reliable access to a meson target in this region
- Empirically, this can be studied through data covering a range in low t and compare
  - Pion, -t<0.6 GeV2
  - Kaon, -t <= 0.9 GeV2

Pion and Kaon Structure White Paper

- For p(e,e'π^+n)X, the final state neutron moves with an energy near that of the initial proton beam
    - The Zero Degree Calorimeter (ZDC) must reconstruct the energy and position well enough to constrain both scattering kinematics and 4-momentum of pion
- For p(e,e'K$^+$□)X, the decay products of the □ must be tracked through the very forward spectrometer
- Geometric acceptance - standard Pythia and accept forward particles
    - Can now do real detection
- But need to find how to distinguish decay products? (e.g. □)

Structure functions

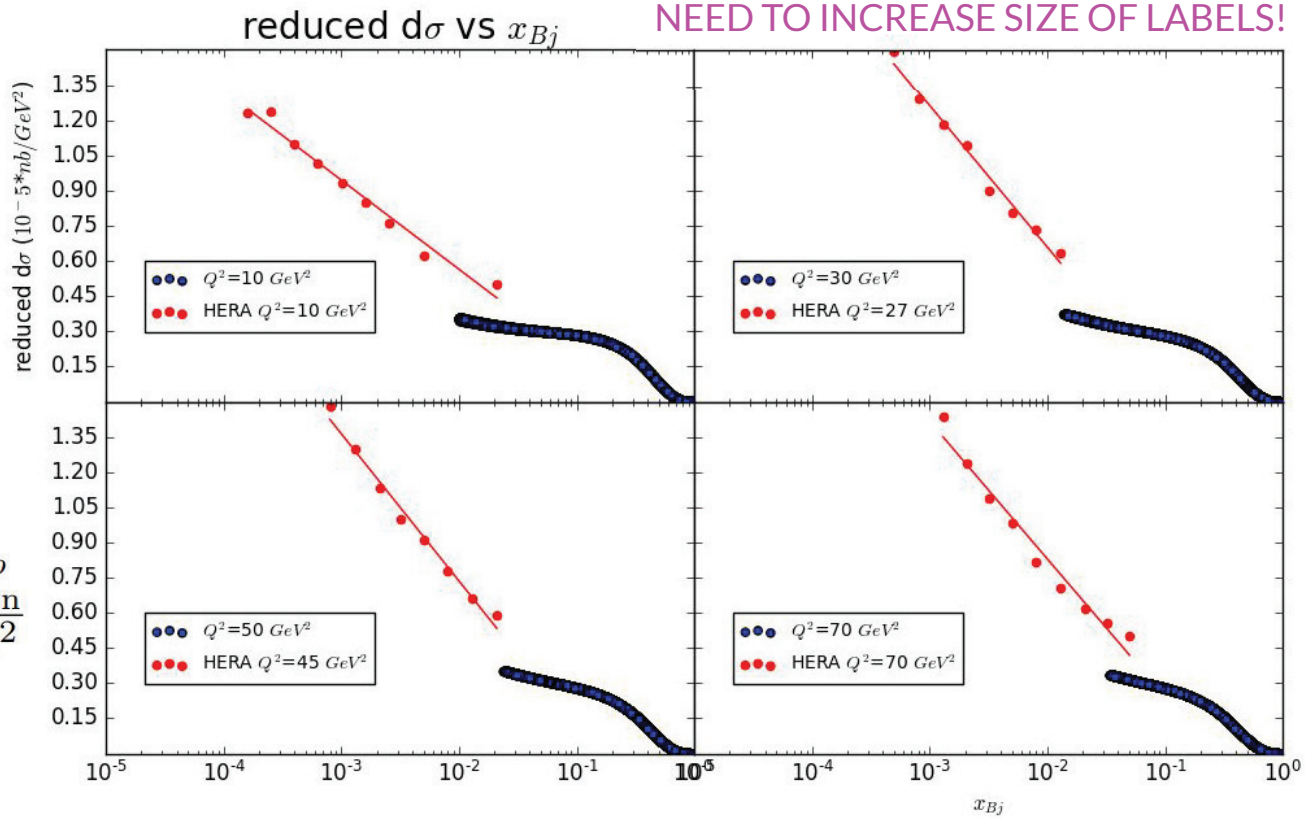
- For projections use a Fast Monte Carlo that includes the Sullivan Process
  - PDFs, form factor, fragmentation function projections
- Progress with generator development since EPJA article:
  - fixes made in generator to remove fixed-target leftovers
  - now can make pion structure function (pion SF) projections
- Current final states: pi/p, pi/n, k/□
- Beam energies: 18 on 275, 10 on 100, 5 on 100

Validation: Reduced cross section compared with HERA

- HERA data from *ZEUS collab, Eur. Phys. J. C 21 (2001)*
- Proton beam = 100 GeV/c
- Electron beam = 5 GeV/c
- x_{Bj}=(0.01-1.0)
- Q^2=(10-100)

$$\tilde{\sigma}^{e^+p} = \left[\frac{2\pi\alpha^2}{xQ^4}Y_+\right]^{-1} \frac{d^2\sigma^{e^+p}_{\text{Born}}}{dx\ dQ^2}$$

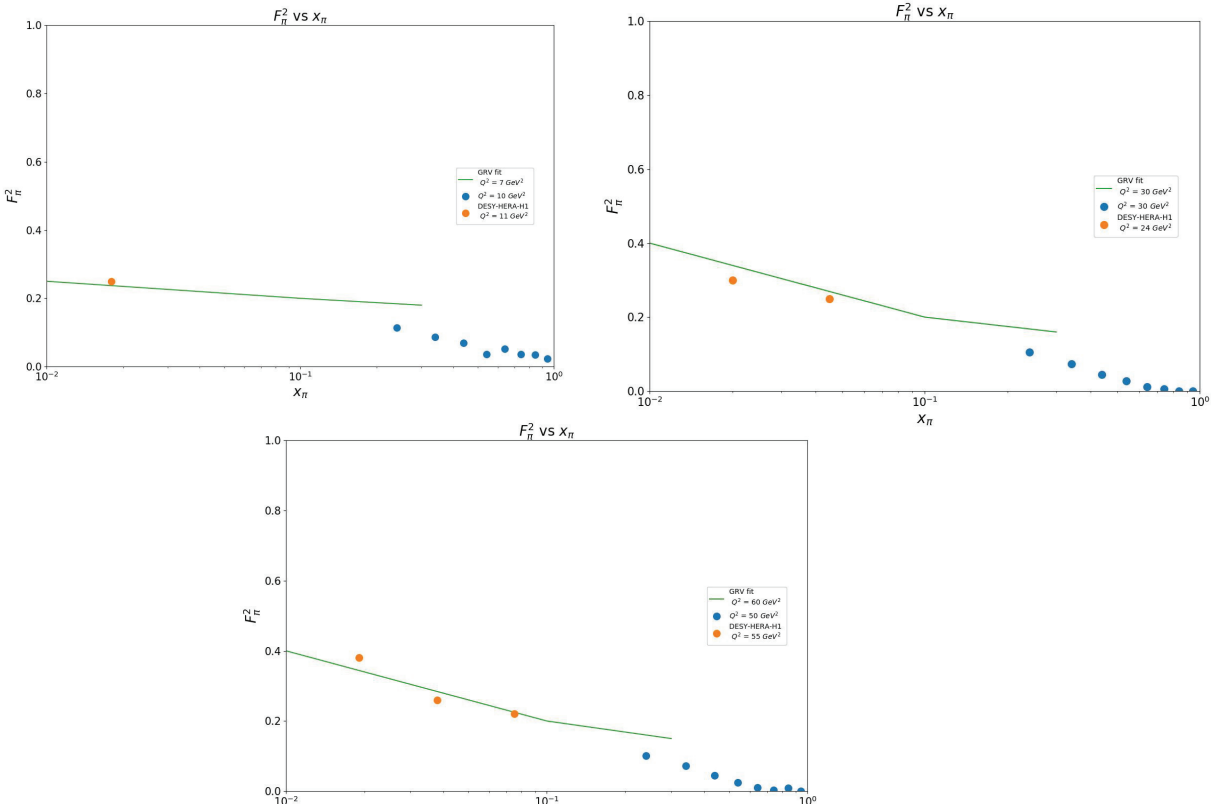
NEED TO INCREASE SIZE OF LABELS!



Validation: F2π with GRV fit/DESY-HERA-H1 data

NEED TO INCREASE SIZE OF LABELS!

- F2π = (0.461)*F2P
  - (ZEUS Parameterization)
- DESY-HERA-H1 data and GRV fit (for three points) were eyeballed from plots
  - *J. Lan et. al., arXiv preprint (2019) arXiv:1907.01509*
- HERA F2pi data appear to be consistent with the MC projections though the x-dependence seems stronger at higher x



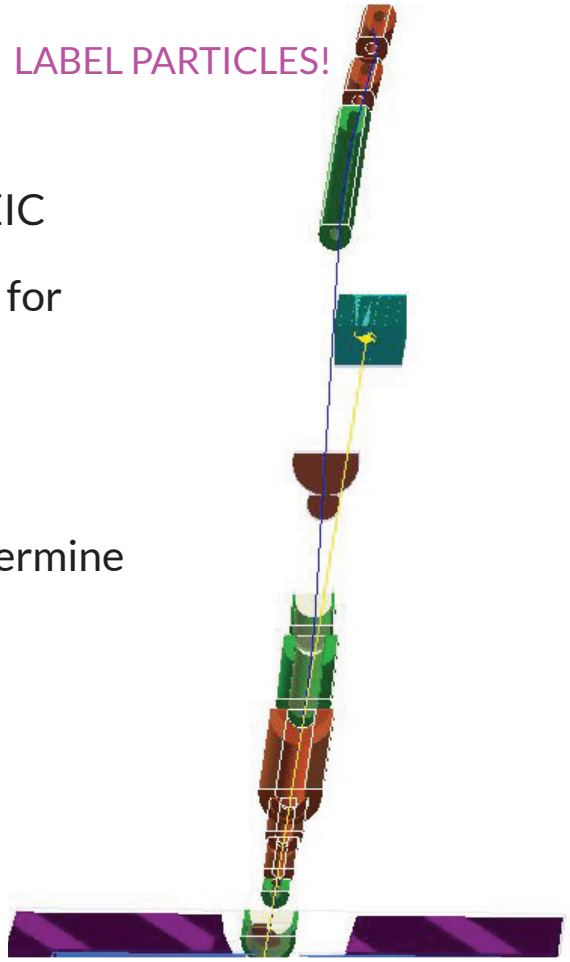
GEANT4 for EIC

- Meson structure MC outputs lund files for use in GEANT4
- Detector MC updated with eRHIC specifics (crossing angle changes primarily)
- Updating electron beam line
    - Solenoid centered at zero - this cannot be changed as it affects the beamline
    - IR region was the same size for JLEIC and eRHIC design, so can use JLEIC detector in eRHIC beam line.
    - Modulo beam line required changes in end caps, crossing angles

e+p->π+p+e'

LABEL PARTICLES!

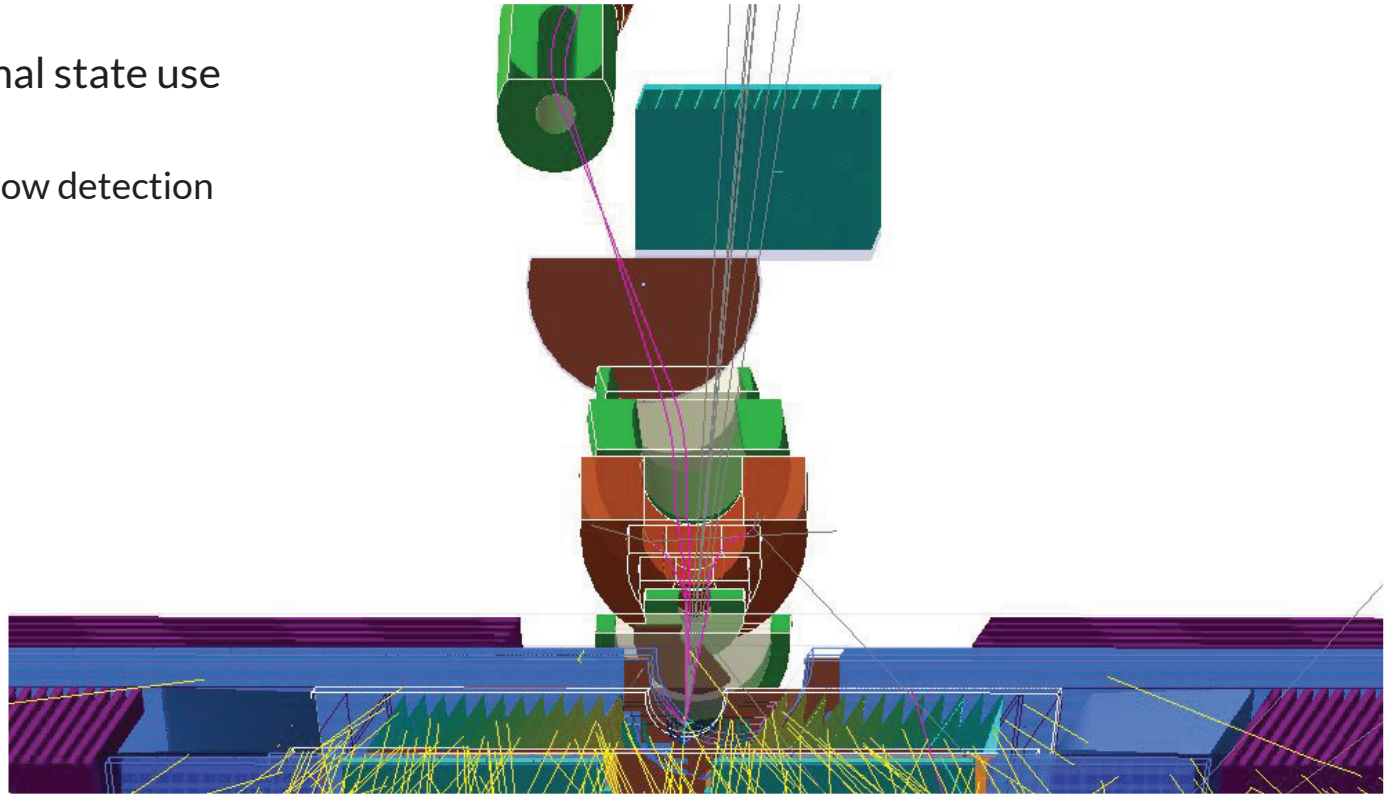
- Have the beamline CAD - generally looks similar to JLEIC
- Currently only have Roman Pots in forward region - ok for DVCS, but need more detectors for meson structure measurements
- General approach: put virtual detectors at different z-locations in between the magnets - based on this determine what space is needed for these additional detectors
- Yulia is sending me some slides to include



e+p->π+n+e'

LABEL PARTICLES!

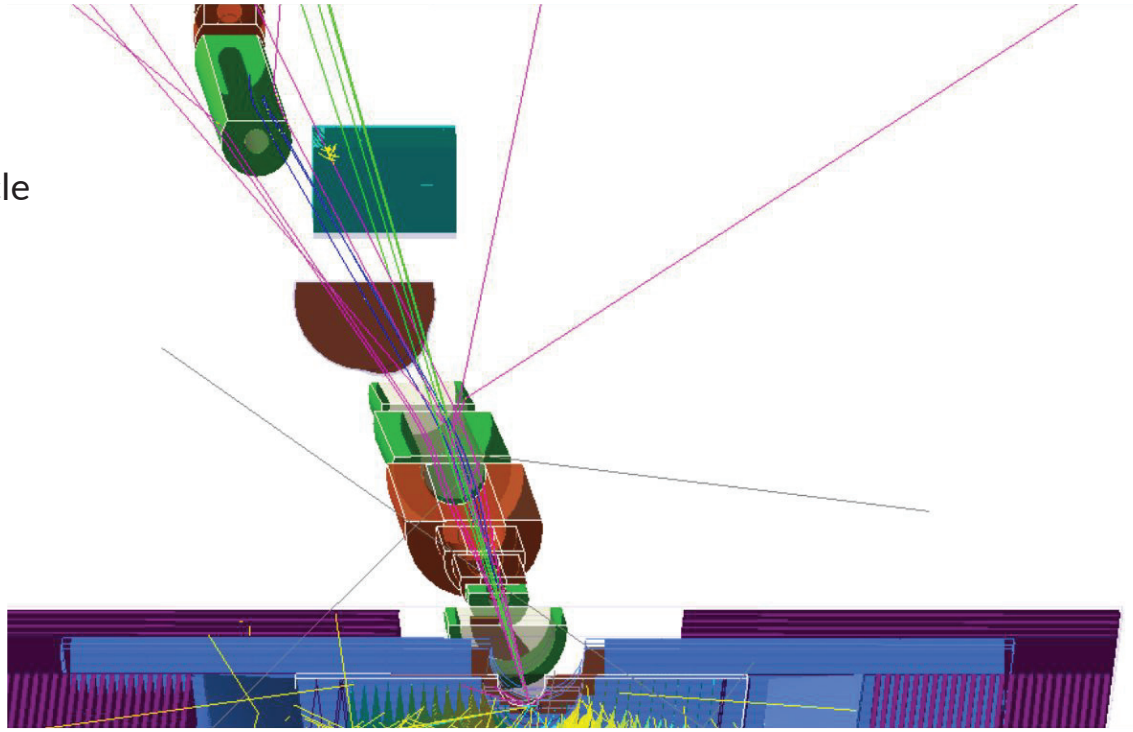
- For neutron final state use ZDC
  - need to know detection fractions



e+p->K+Λ+e’

LABEL PARTICLES!

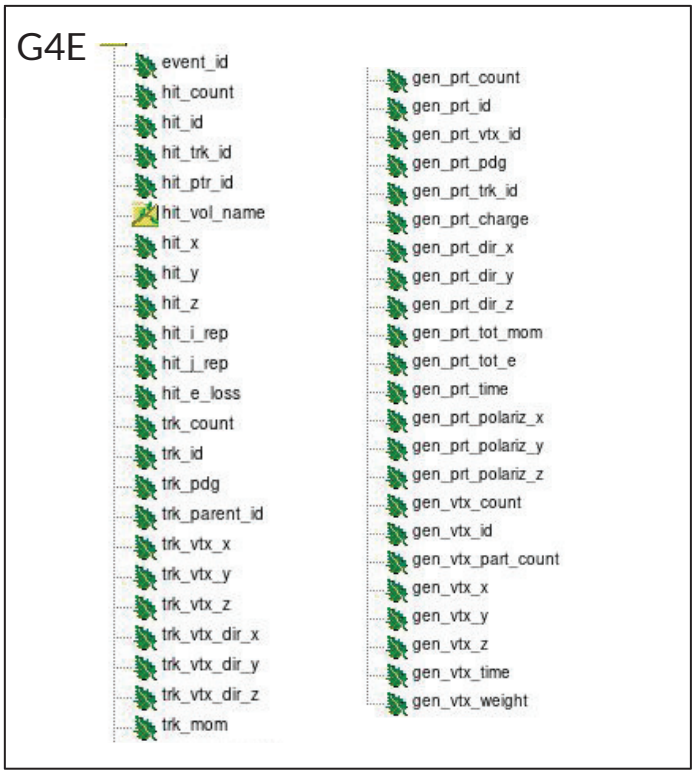
- For Lambda/Sigma
  - need to know detection fractions
  - need detection of particle (i.e. decay state ID)



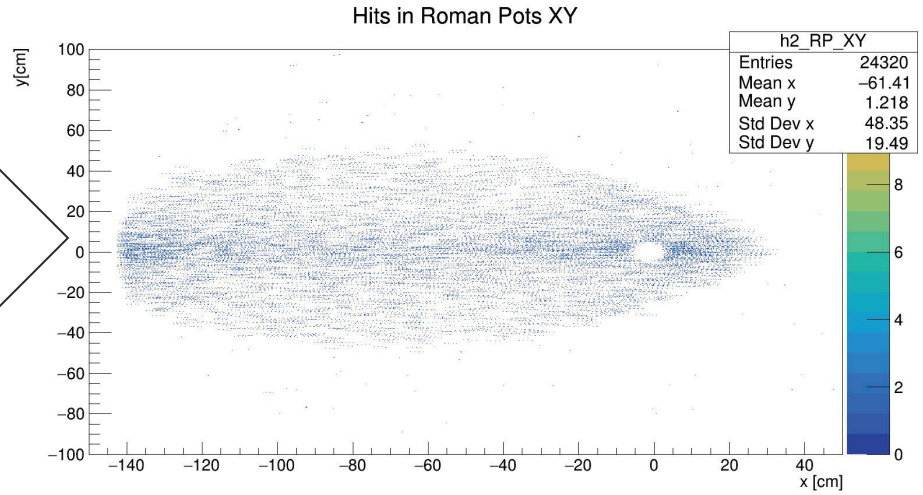
Future projections

- New meson_structure eJANA plugin
  - Minor issues (e.g. huge G4E ROOT files, ~21 GB for only 80k ran)
  - I have it working locally and a jupyter notebook has been developed
- Future use of G4E with MC and what we would like to do near and far future

18 on 275 (Proton detection fraction ~100%,)

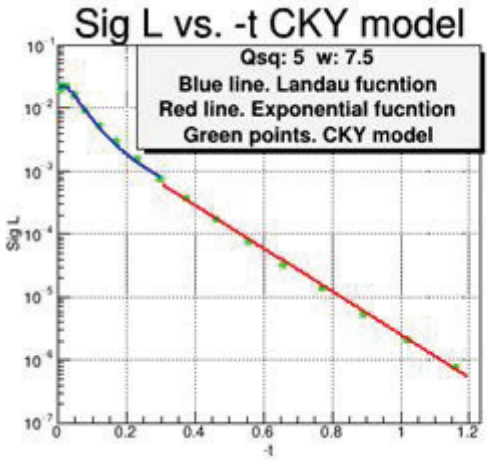


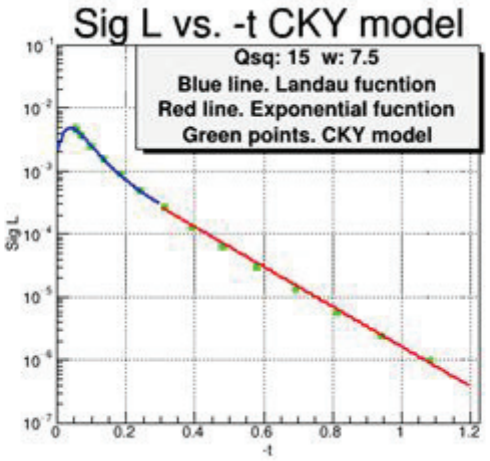
eJANA

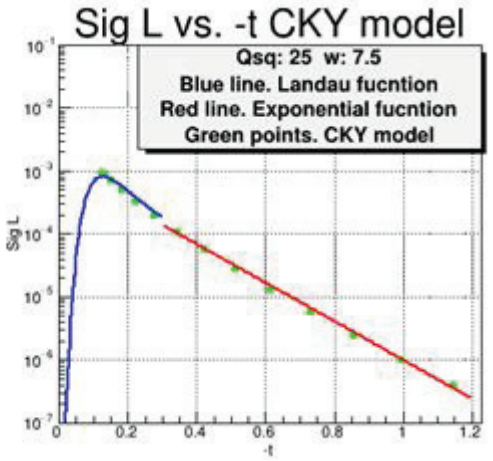


DEMP Event Generator

- Want to examine **exclusive** reactions too for π form factor studies
  - p(e,e'π^+n) exclusive reaction is reaction of interest, treat p(e,e'π^+)X SIDIS events as background
- Regge-based p(e,e'π^+)n model of T.K. Choi, K.J. Kong, B.G. Yu (CKY) arXiv: 1508.00969
  - MC event generator has been created by parameterizing the CKY σ_L,σ_T for 5<Q2<35, 2<W<10, 0<-t<1.2

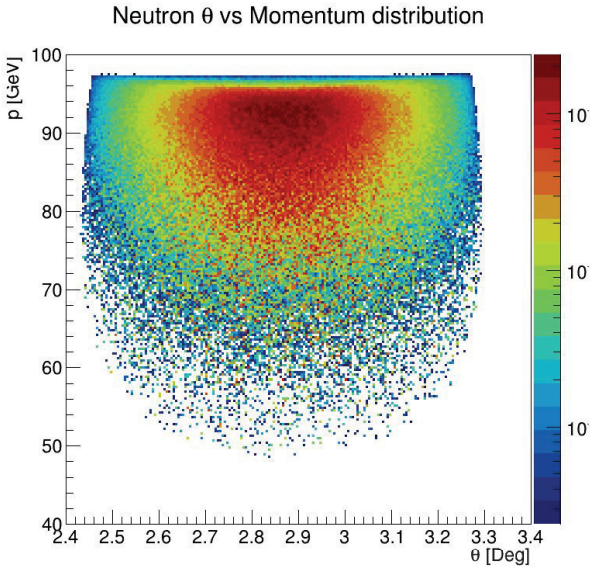


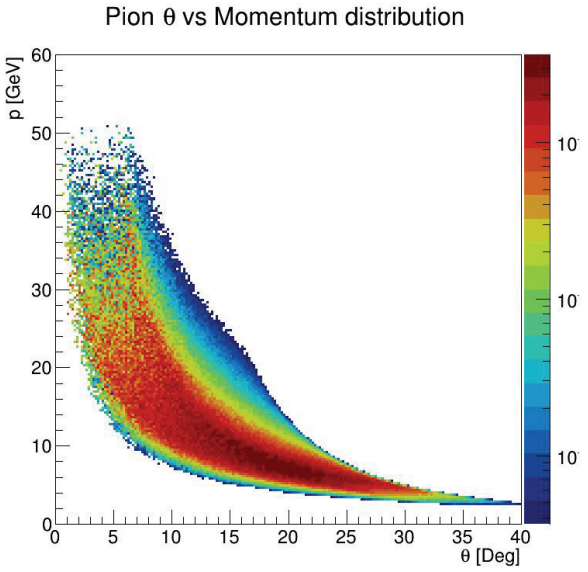


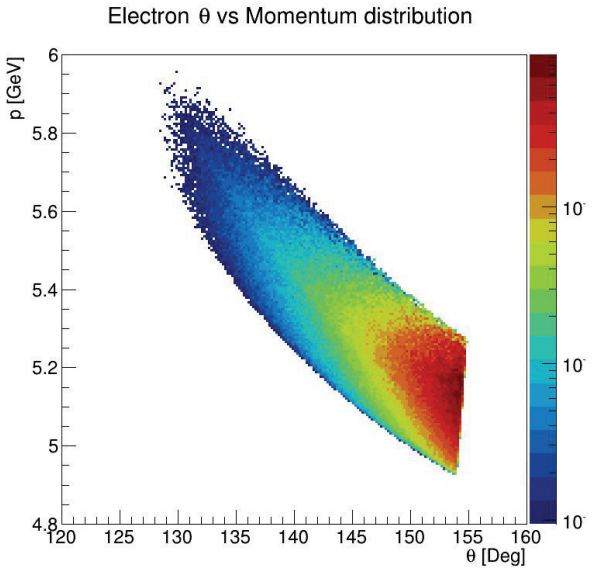


n, π^+ and e' Acceptance (-t < 0.5 GeV²)

- 5 (e^-) on 100 (p) GeV collisions, 50 mrad crossing angle assumed
- Events weighted by cross section



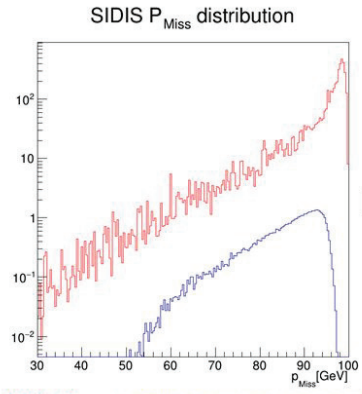




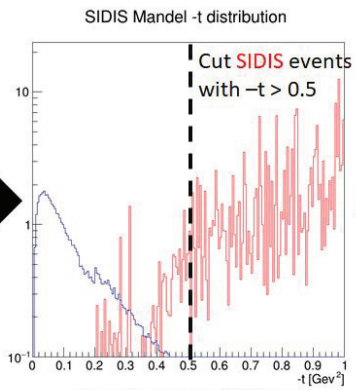
Neutrons - within 0.2° of outgoing proton beam, offset is due to crossing angle

Dealing with p(e,e'π^+)X Events

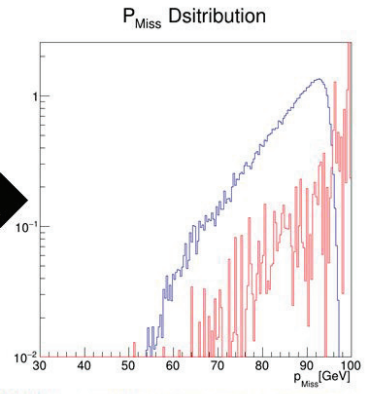
- Used Duke event generator to generate p(e,e'π^+)X SIDIS events as background
  - /work/eic/evgen/SIDIS_Duke on JLab ifarm
- SIDIS events dominate over exclusive events
  - However, distributed over a wider momentum range and are primarily at large -t
- Compare neutron from DEMP events with missing 4-mometum from SIDIS events



SIDIS P_{Miss} vs DEMP neutron 4 momentum, **no cuts**



-t distribution for SIDIS and DEMP events. SIDIS primarily at high -t



SIDIS P_{Miss} vs DEMP neutron 4 momentum -t and θ cuts remove large number of SIDIS events

Connecting G4EMC with EIC paper

- Tim Hobbs slide on F2pi parameterization
- Connect work done with EPJA article, just bring it all together

Procedure for use??

- Quick slide on use in Jypter for people to try out, Dimitri and I need to update

Conclusion and Outlook

- Come up with a method to distinguish decay products, e.g. □ and Σ
- Currently have π with proton and neutron final states and K with □
  - Need to include K with Σ
- Make Analyzer plugin for physics variables including smearing
- Implement virtual detectors and determine detection fractions
- First rough projection of detection fraction
- Determine where detectors should go

EXTRA

EIC fast Monte Carlo

- C++ based fast MC which outputs root files and text file for GEANT4 input

Cpp Script(TDISMC_EIC.cpp)-requires as input: range of Q2 and x and uses a header file for beam energy, beam polarization, structure function parameterization, physical constants, etc.

Calls 4 quantities…

1. CTEQ6 PDF table
2. f2π with various parameterization (the header file defines the structure function)
3. F2N, nucleon structure function (the header file defines the structure function)
4. Beam smearing function

Event generation

Random number generation uses TRandom3 (run3.SetSeed(#))

- Defining electron and proton/deuterium beam…
  - kbeamMC=kbeam*ran3.Gaus(1,eD/k), where eD/k=7.1e-4 is the fractional energy spread normalized emittance value
  - kbeamMCx=kbeamMC*ran3.Gaus(0,Θex), where Θex is smearing
  - PbeamMC=Pbeam*ran3.Gaus(0, iDp/p), where iDp/p=3e-4
  - PbeamMCx=PbeamMC*ran3.Gaus(0, Θix)

Collider vs. fixed target

Careful with kinematic definitions

- Original code was written for fixed target – found and fixed several instances with restrictions that apply to fixed target, but not to collider
- Examples:
  - Measurable proton range (for fixed target given by TPC – imposes limits on k, z)
  - Removed fixed target restrictions on x for structure function calculations

GRV

- GRV fit explained

Collider vs. fixed target

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Kinematic Variables

$$Q^2 = Q^2_{max}\,uu + Q^2_{min}(1 - uu)$$

$$uu = ran3.Uniform(\,)$$

$$x_{Bj} = (x_{min})^{1-uu}(x_{max})^{uu}$$

$$x_\pi = \frac{x_{TDIS}}{1-(p2)_z}$$

$$(p2)_z = gRandom -> Uniform(1)$$

$$y_\pi = \frac{(pScatPion)_{rest}(qVirt)_{rest}}{(pScatPion)_{rest}(kIncident)_{rest}}$$

$$t_\pi = E^2_\pi - |pScatPion.v3|^2$$

$$x_D = x_{Bj}\left(\frac{M_{proton}}{M_{ion}}\right)$$

$$y_D = \frac{Q^2}{x_D(2p\bullet k)}$$