Meson Structure at the EIC

Temple EIC User Meeting

March 19th, 2020

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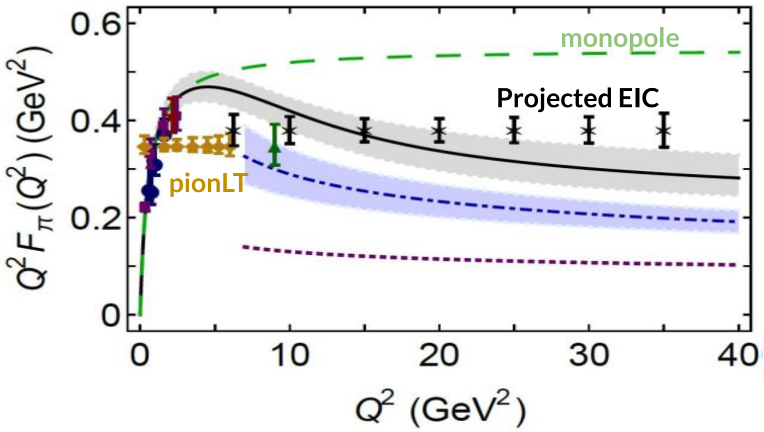
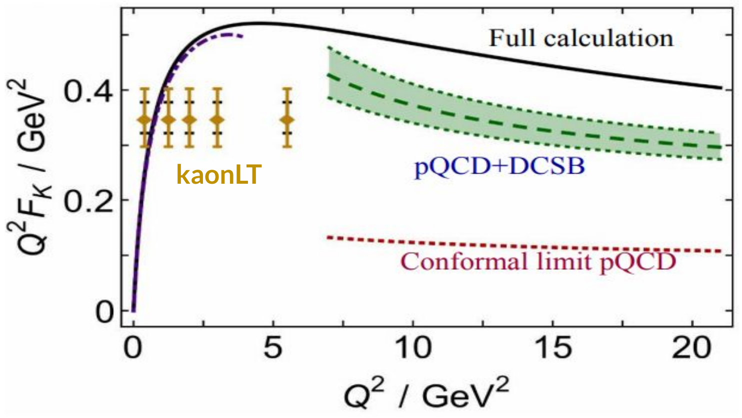
Jefferson Lab

THE CATHOLIC UNIVERSITY OF AMERICA

5 key EIC measurements from EPJA article

1. Measurement of pion and kaon structure functions and their GPDs
2. Measurement of open-charm production
3. Measurement of the charged-pion form factor up to Q2~35 GeV
4. Measurement of the behavior of (valence) u-quarks in the pion and kaon
5. Measurement of the fragmentation of quarks into pions and kaons





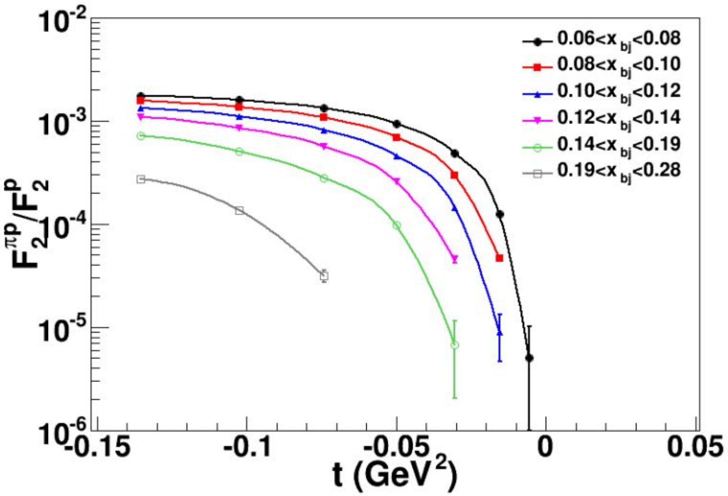
Pion and Kaon Structure White Paper

- 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

- Geometric acceptance - standard Pythia and accept forward particles
    - Can now do real detection

EIC Capabilities

- $L_{EIC} = 10^{34} = 1000 \times L_{HERA}$
- Fraction of proton wave function related to pion Sullivan process is roughly 10^{-3} for a small –t bin (0.02).
  - pion data at EIC should be comparable or better than the proton data at HERA, or the 3D nucleon structure data at COMPASS
- By mapping pion (kaon) structure for –t < 0.6 (0.9) GeV^2, we gain at least a decade as compared to HERA/COMPASS.



Particle Detection

- 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
  - Constraining neutron energy around 3.5% will assure an achievable resolution in x
- For p(e,e'K^+□)X, the decay products of the □ must be tracked through the very forward spectrometer
  - Distinguishing decay products is crucial

Process	Forward Particle	Geometric Detection Efficiency (at small -*t*)
$^1H(e, e' \pi^+)\ n$	n	>20%
$^1H(e, e' K^+)\ \Lambda$	Λ	50%
$^1H(e, e' K^+)\ \Sigma$	Σ	17%

Timeline since EPJA Publication

<table>
<tr><th><u>Event</u></th><th><u>Date</u></th><th><u>Notes</u></th></tr>
<tr><td>EPJA Publication</td><td>July 19th, 2019</td><td>Final revisions Sep. 16th, 2019</td></tr>
<tr><td>First Meson structure WG meeting</td><td>Jan. 27th, 2020</td><td>Integrate into YR
Science Motivation - mass mechanism in pion/kaon as way to understand QCD, puzzles about gluon content, large x
Check if can adequately do the meson structure physics with the EIC at BNL</td></tr>
<tr><td>Meson structure WG meeting</td><td>Feb. 25th, 2020</td><td>Detection fractions
Can detect forward-going particles, but how to distinguish decay products, e.g. lambda
Structure functions
progress with generator development since EPJA article: now can make pion SF projections</td></tr>
<tr><td>Meson structure WG meeting</td><td>March 16th, 2020</td><td>Detection fractions checks
Proton and neutron done
for K/Lambda: checking Lambda decay
Virtual planes are ready - working on analysis chain with reconstruction for K-Lambda</td></tr>
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Structure functions

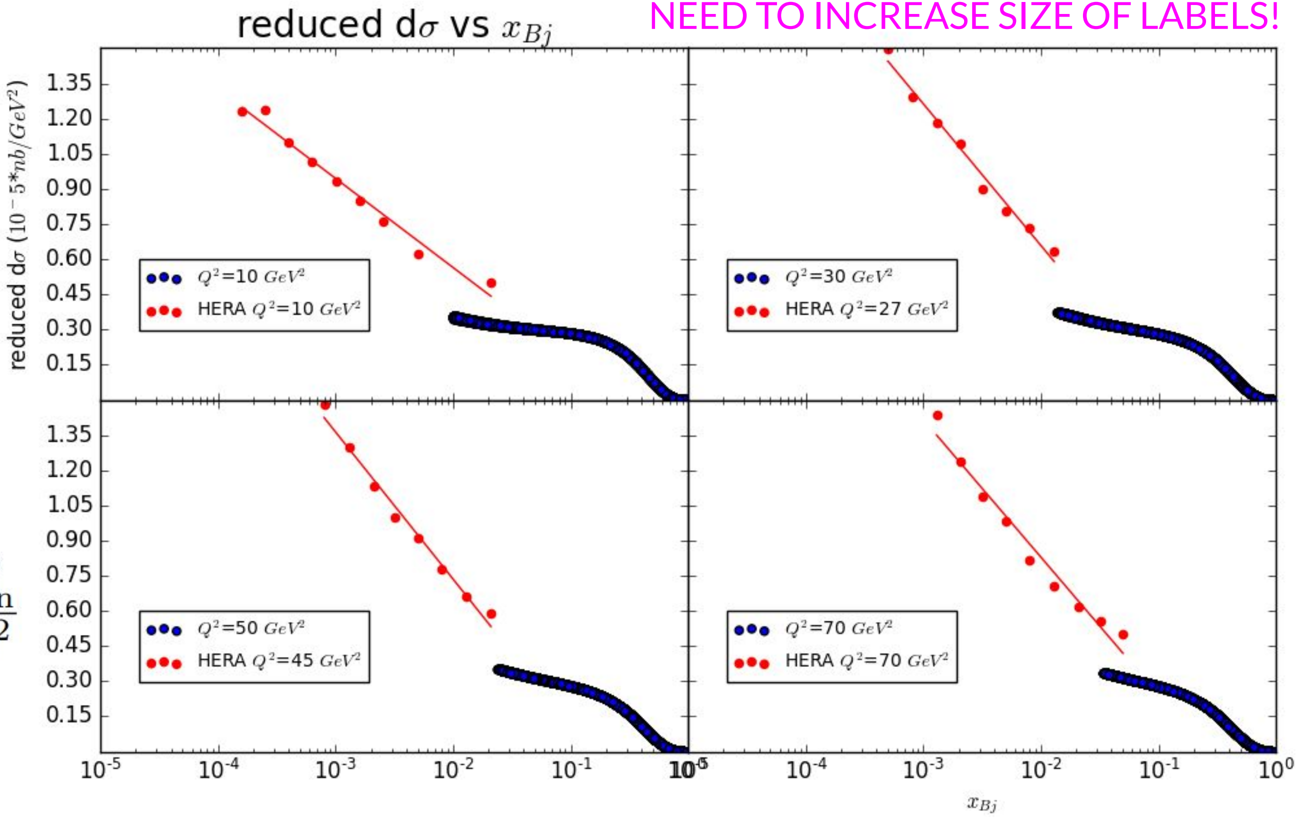
- For projections use a Fast Monte Carlo that includes the Sullivan Process
  - PDFs, form factor, fragmentation function projections
- Progress with generator development since EPJA article:
  - fixes made in generator to remove fixed-target leftovers
  - now can make pion structure function (pion SF) 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)

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

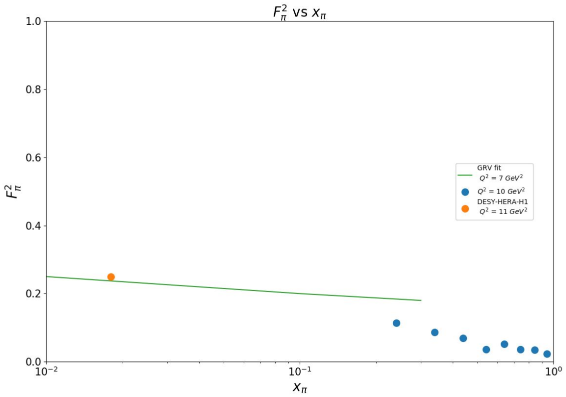
NEED TO INCREASE SIZE OF LABELS!

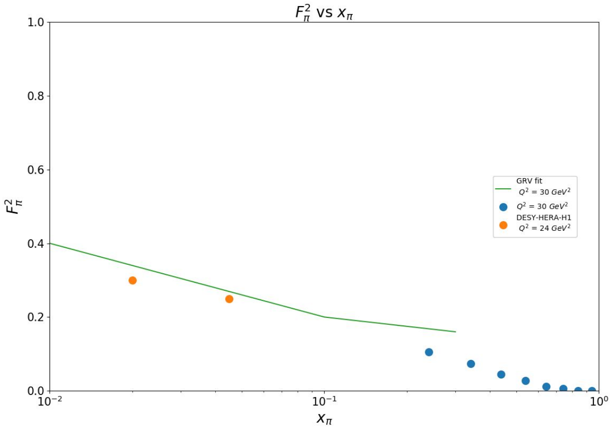


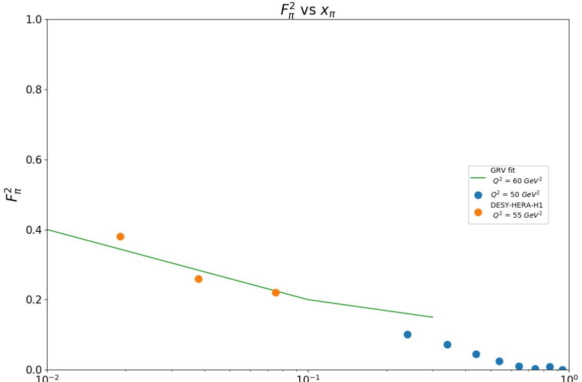
Validation: F2π with GRV fit/DESY-HERA-H1 data

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





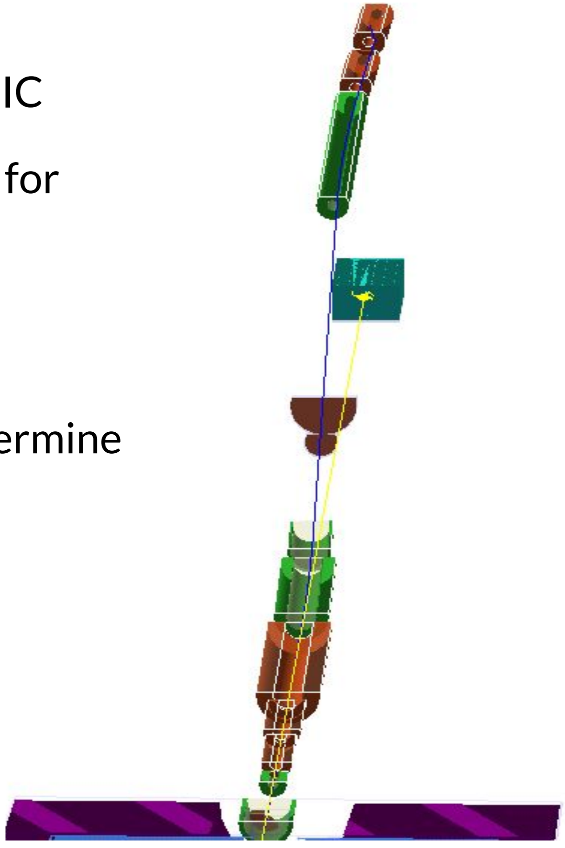


GEANT4 for EIC

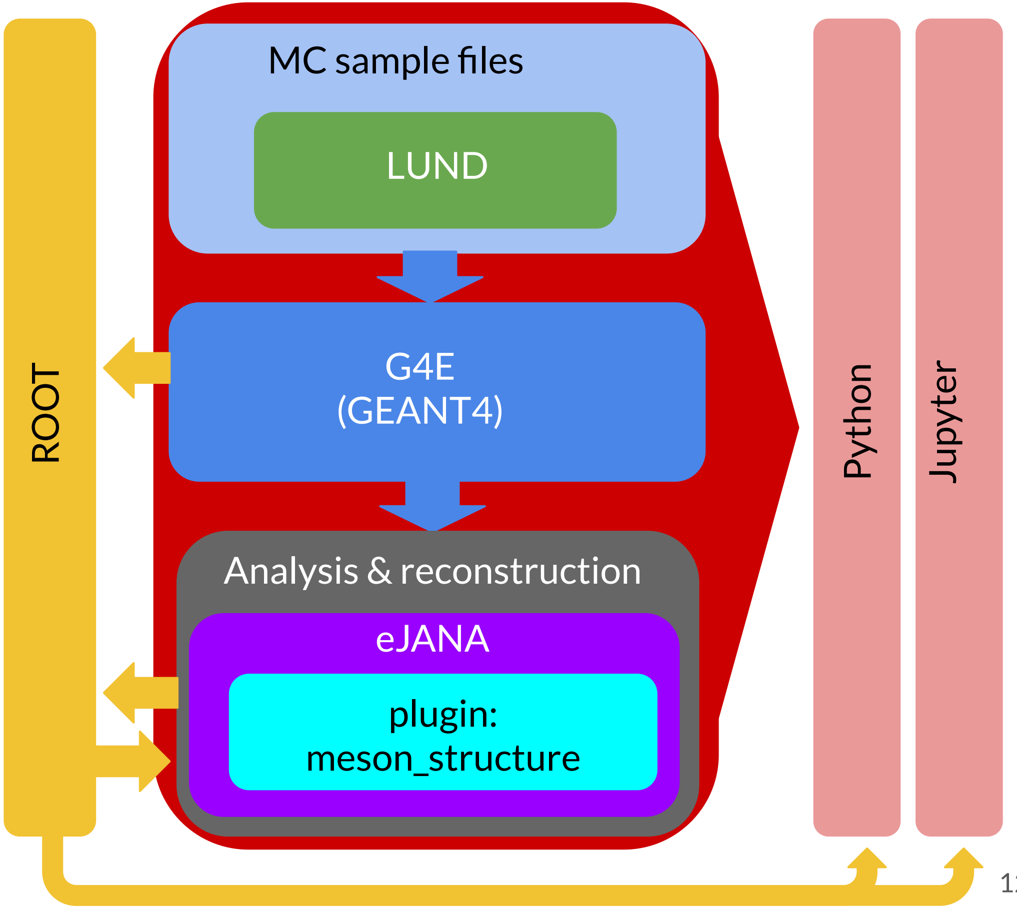
- Meson structure MC outputs lund files for use in GEANT4
- Detector MC updated with eRHIC specifics (crossing angle changes primarily)
- Updating electron beam line
    - Solenoid centered at zero - this cannot be changed as it affects the beamline
    - IR region was the same size for JLEIC and eRHIC 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' (systematic checks)

- 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

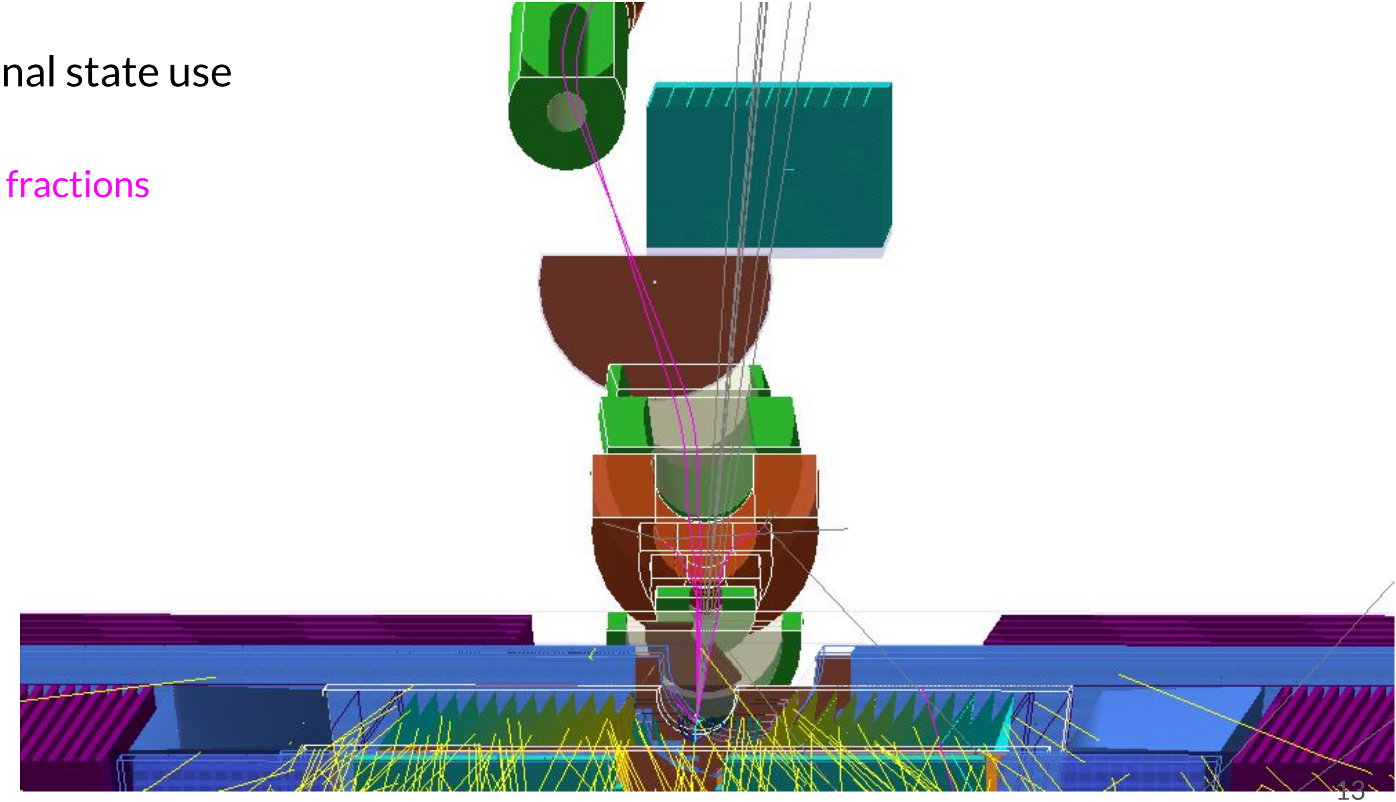


Analysis procedure



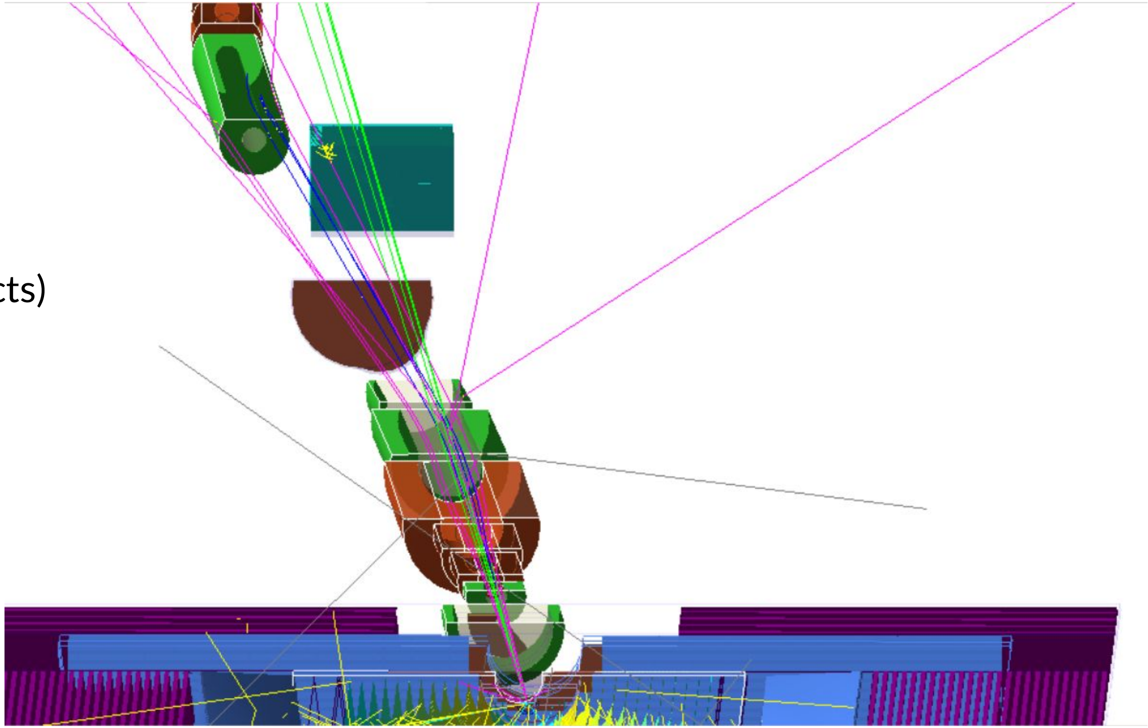
e+p->π+n+e'

- For neutron final state use ZDC
  - detection fractions



e+p->K+□+e’

- For Lambda/Sigma
  - need to know detection fractions
  - need particle reconstruction (i.e. determine decay products)



Future projections

- Future use of G4E with MC and what we would like to do near and far future

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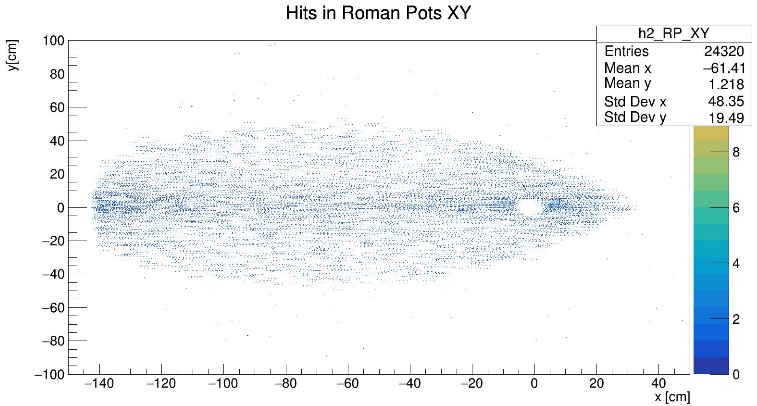
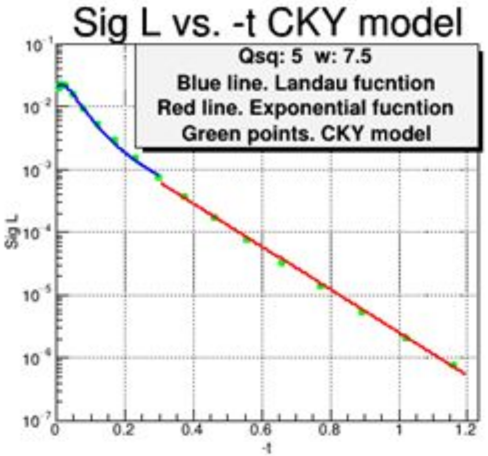
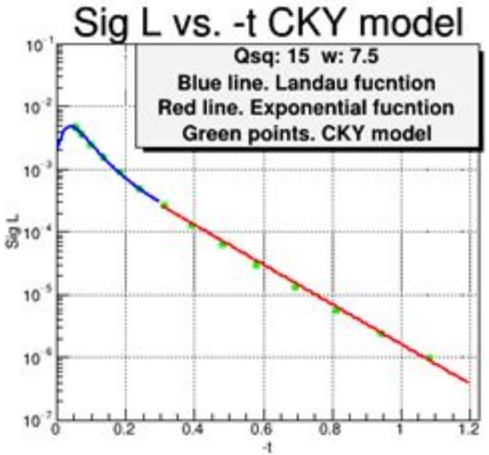


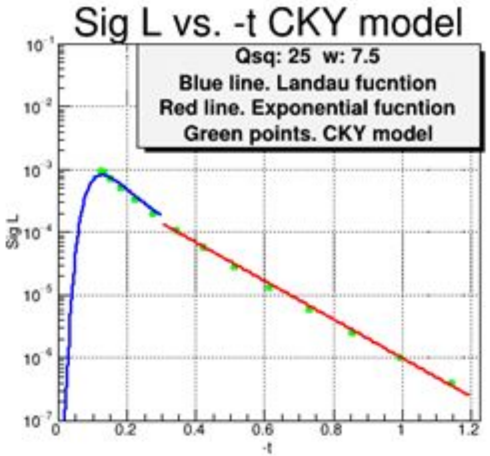
PLOTS OF MOMENTUM/ANGULAR DISTRIBUTION FOR SCATTERED ELECTRON !

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



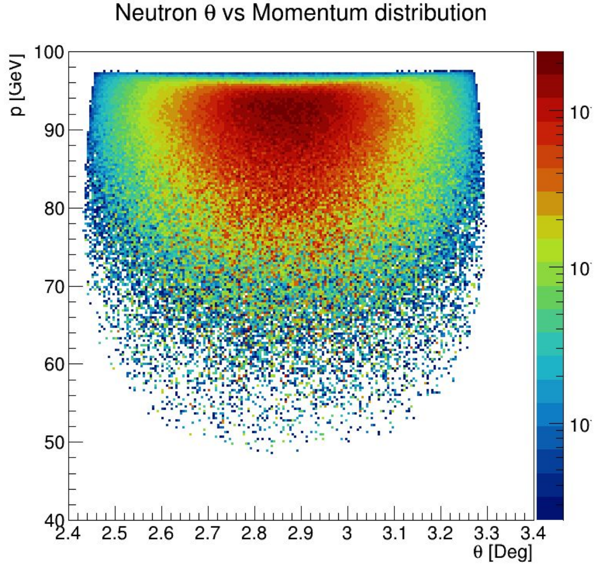


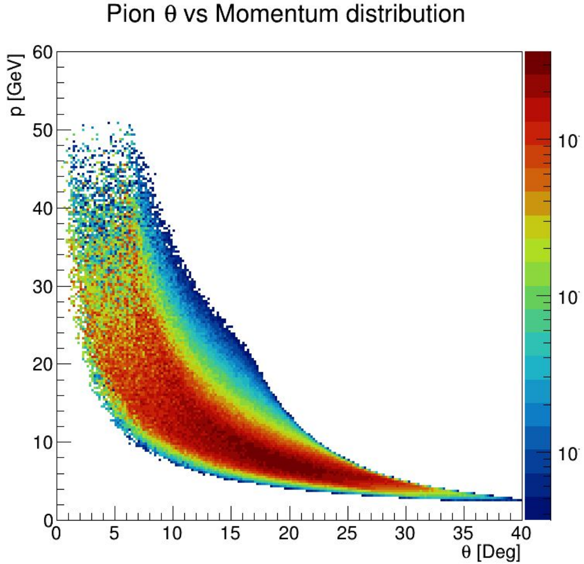


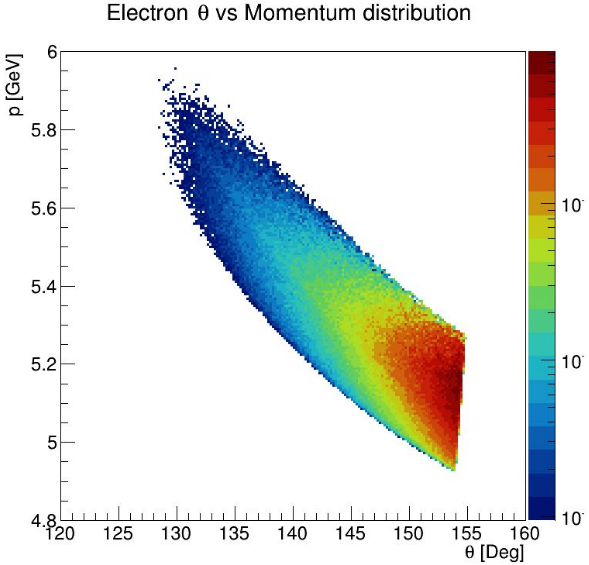
n, π^+ and e' Acceptance (-t < 0.5 GeV^2)

UPDATE CROSSING ANGLE!

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







Neutrons - within 0.2^o 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

Connecting G4EMC with EIC paper

- Tim Hobbs slide on F2pi parameterization
- Connect work done with EJWP to show interesting physics we can look at, depends on what Yulia and I get done before Temple

Procedure for use??

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

Timeline to come

Event	Date	Event	Date	Event	Date
EPJA Publication	July 19th, 2019	Next Meson structure WG meeting	March 30th, 2020	**Status reports at EICUGM**	**August 3-7, 2020**
First Meson structure WG meeting	Jan. 27th, 2020	Next Detector WG meeting	April 13th, 2020	Third workshop at CUA	Sep. 17-19, 2020
Meson structure WG meeting	Feb. 25th, 2020	Second workshop at U of Pavia	May 22-24, 2020	Week with pion and kaon structure focus	Oct. 5-9, 2020
Meson structure WG meeting	March 16th, 2020	workshop on meson structure at EIC at CFNS/SBU	June 1-5, 2020	Fourth workshop at UCB/LBL	Nov. 19-21, 2020

Conclusion and Outlook

- Currently have π with proton and neutron final states and K with □
  - Need to include K with Σ
- Particle reconstruction for □ (and Σ)
- Implement virtual detectors and determine detection fractions for all final states
- Make Analyzer plugin for physics variables including smearing
- 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,Ѳex), where Ѳex is smearing
  - PbeamMC=Pbeam*ran3.Gaus(0, iDp/p), where iDp/p=3e-4
  - PbeamMCx=PbeamMC*ran3.Gaus(0, Ѳix)

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

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

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

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

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

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

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

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

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

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