Meson Structure at the EIC

Temple EIC User Meeting

March 19th, 2020

Richard Trotta, 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 EJPM

1. Measurement of pion and kaon structure functions
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

Pion and Kaon Structure White Paper

- For p(e,e'π^+)n, 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^+)□, 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 41

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

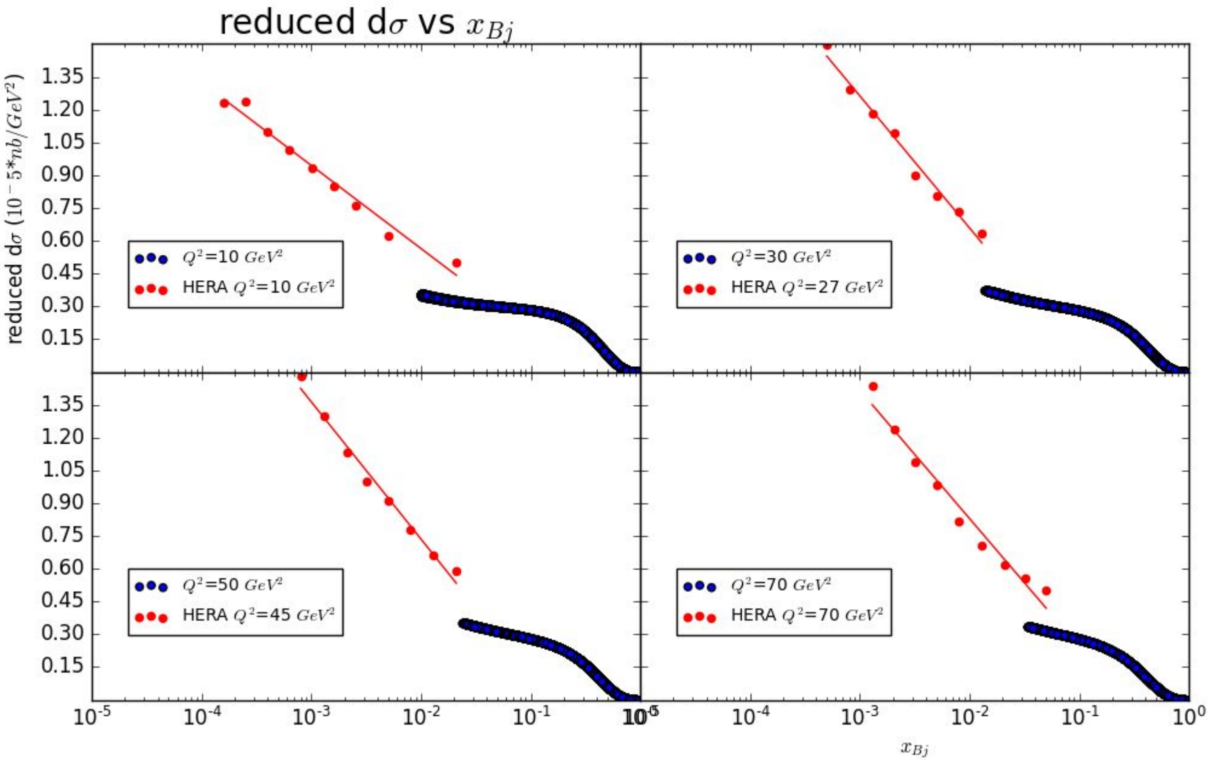
Careful with kinematic definitions

- 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

Validation: Reduced cross section compared with HERA

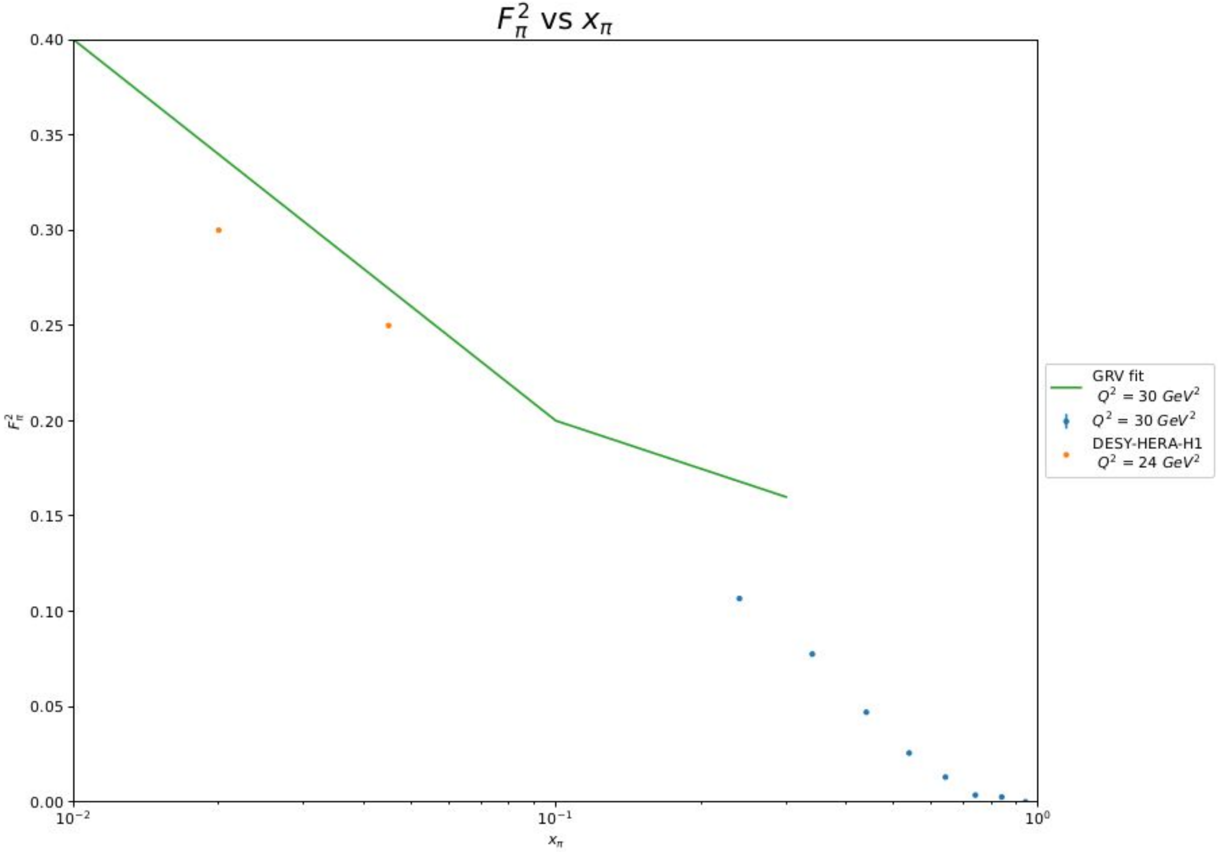
- HERA data from *ZEUS collab, Eur. Phys. J. C 21 (2001)*
- Proton beam = 100 GeV/c
- Electron beam = 5 GeV/c
- x_{Bj}=(0.01-1.0)
- Q^2=(10-100)

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



Validation: F2π with GRV fit/DESY-HERA-H1 data [Q^2= 30(30/24) GeV]

- 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



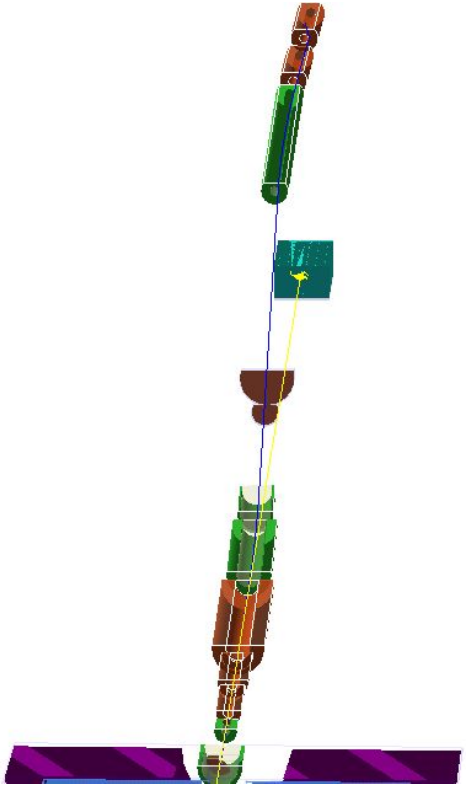
GEANT4 for EIC

- 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

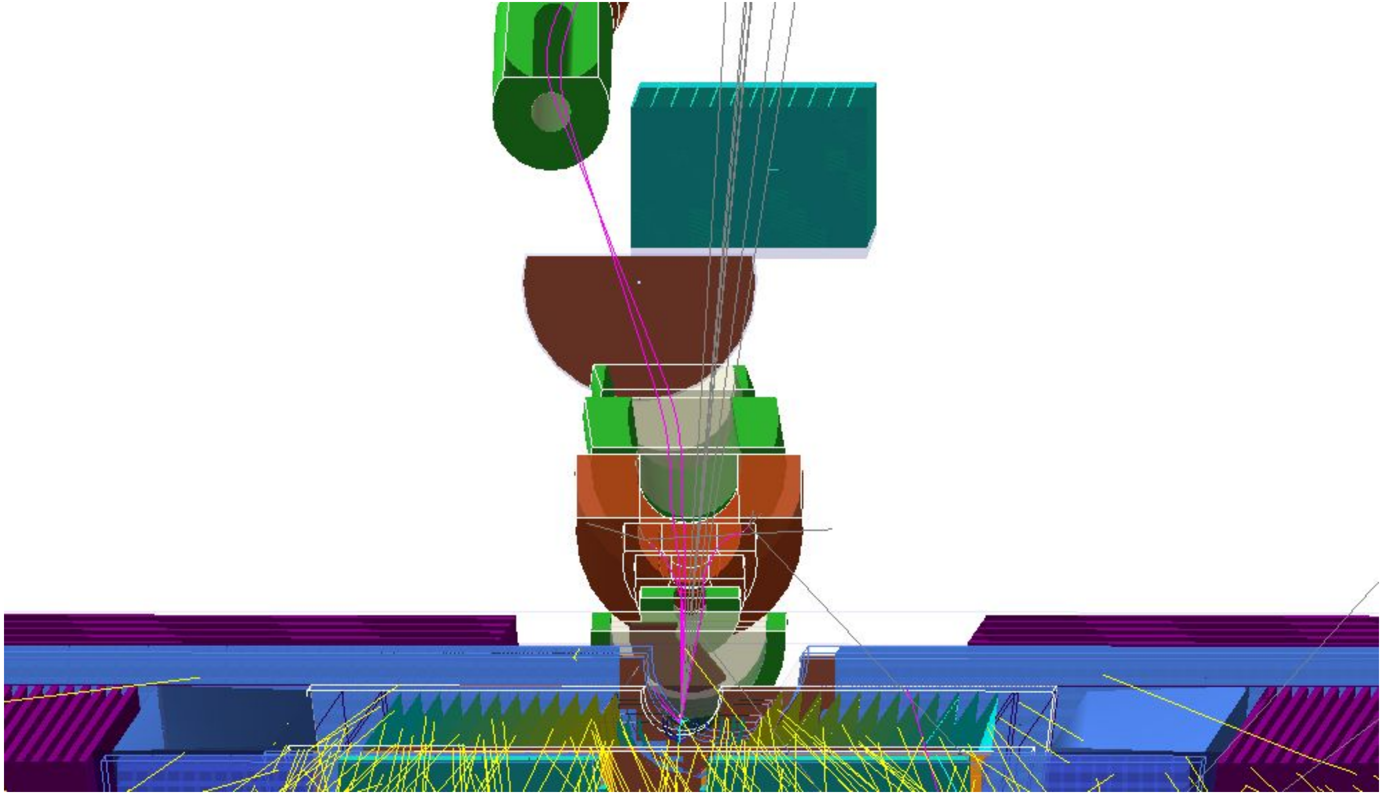
GEANT4 for EIC

- For neutron final state use ZDC -> need to know detection fractions, for Lambda/Sigma need in addition detection of particle
- 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

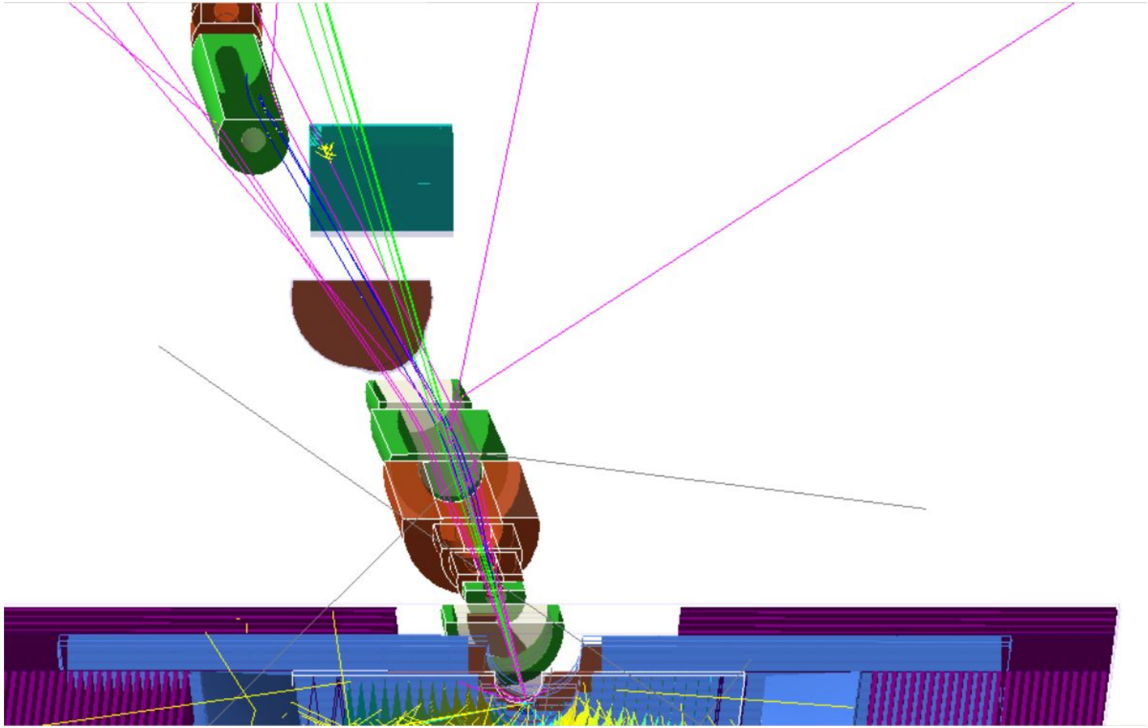
$e^+p \rightarrow \pi^+p^+e'$

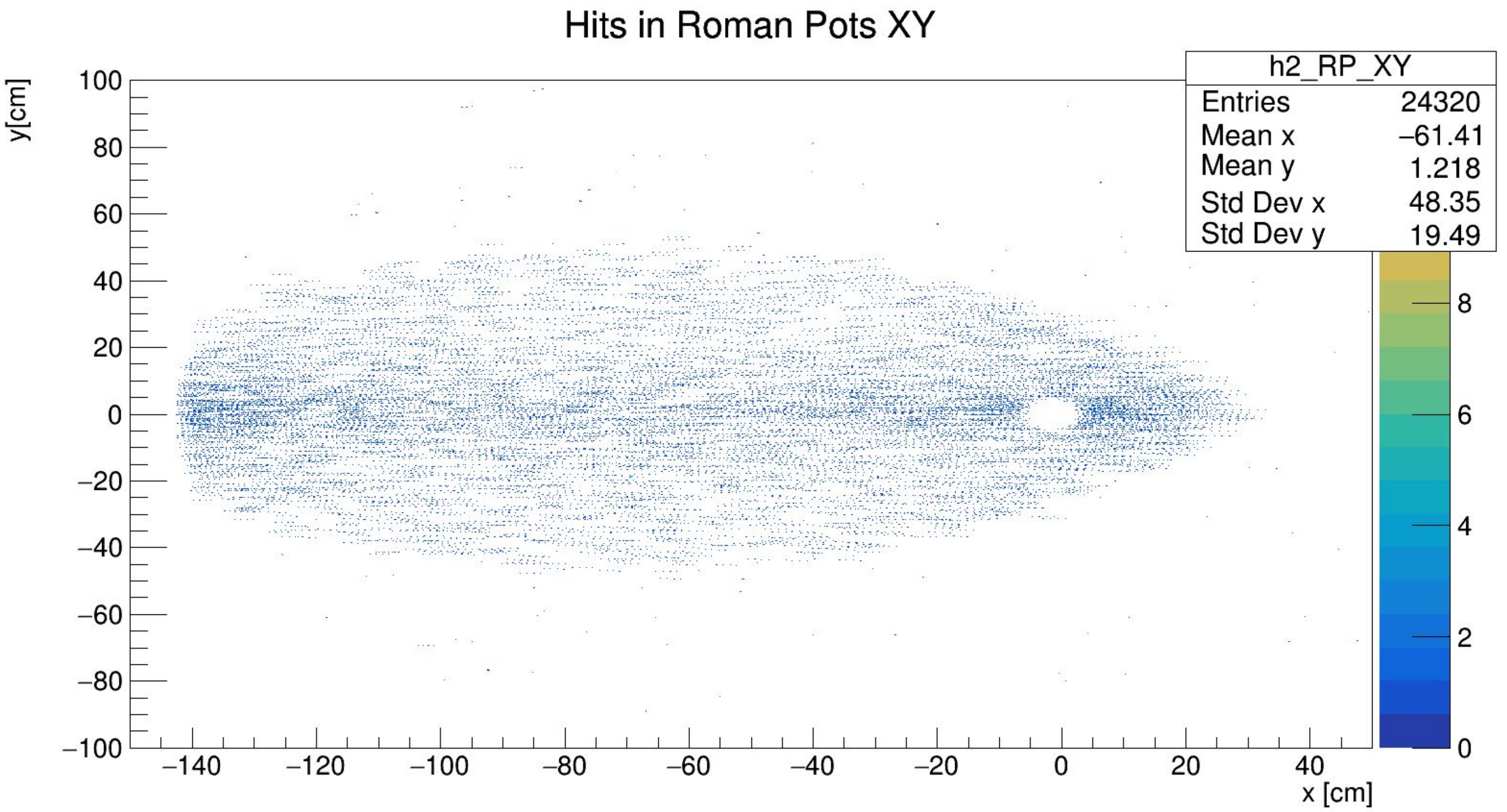


$e^+p \rightarrow \pi^+n^+e'$



e+p->K+□+e’




Hits in Roman Pots XY
h2_RP_XY
Entries 24320
Mean x −61.41
Mean y 1.218
Std Dev x 48.35
Std Dev y 19.49
y[cm]
x [cm]
100
80
60
40
20
0
−20
−40
−60
−80
−100
−140
−120
−100
−80
−60
−40
−20
0
20
40
8
6
4
2
0

Future projections

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

DEMP Event Generato

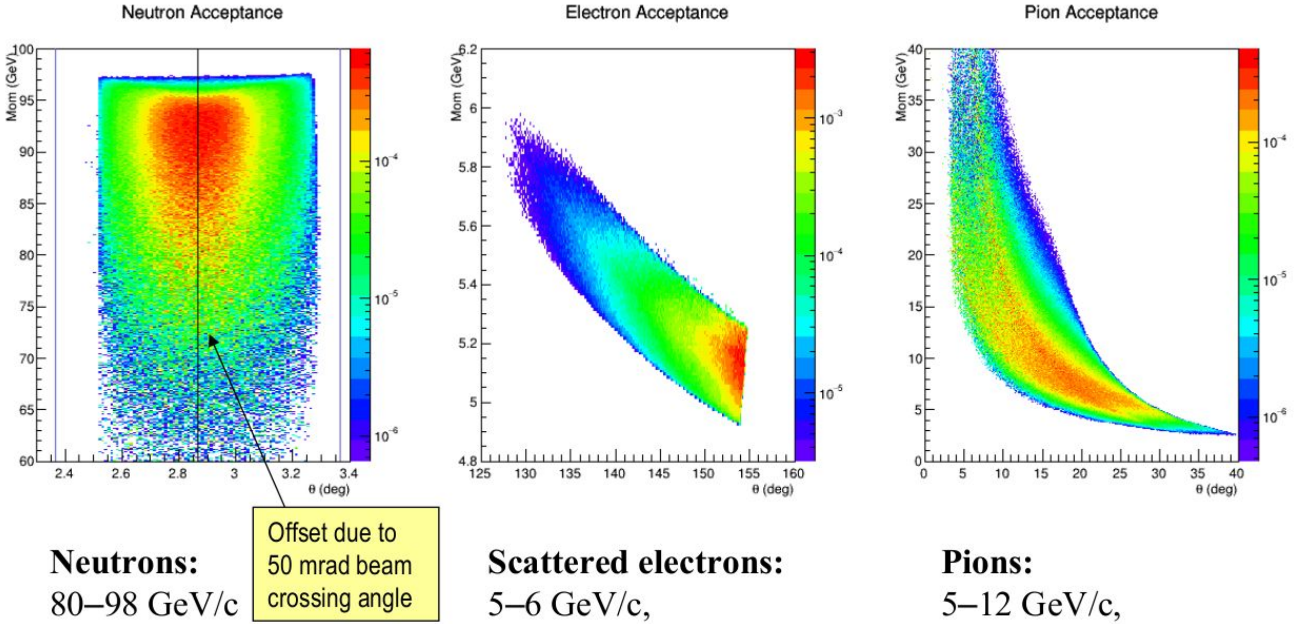
- Initially looked at p(e,e'π^+)n model by C. Weiss, V. Guzey, (2008)
    - An extrapolation of a soft model cross section to high Q2
    - However, many event required to be generated with W2~Q2, where the model is unreliable
- Regge-based p(e,e'π^+)n model of T.K. Choi, K.J. Kong, B.G. Yu (CKY) arXiv: 1508.00969 appears to behave better over a range of kinematics
    - 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

DEMP π^+, n, e' Acceptance for $-t$<0.5 GeV^2

University of Regina

Garth Huber, huberg@uregina.ca

5(e$^-$) x 100(p) GeV Collisions → E_{cm}=44.7 GeV



Neutrons:
80–98 GeV/c
<0.2° of outgoing proton beam

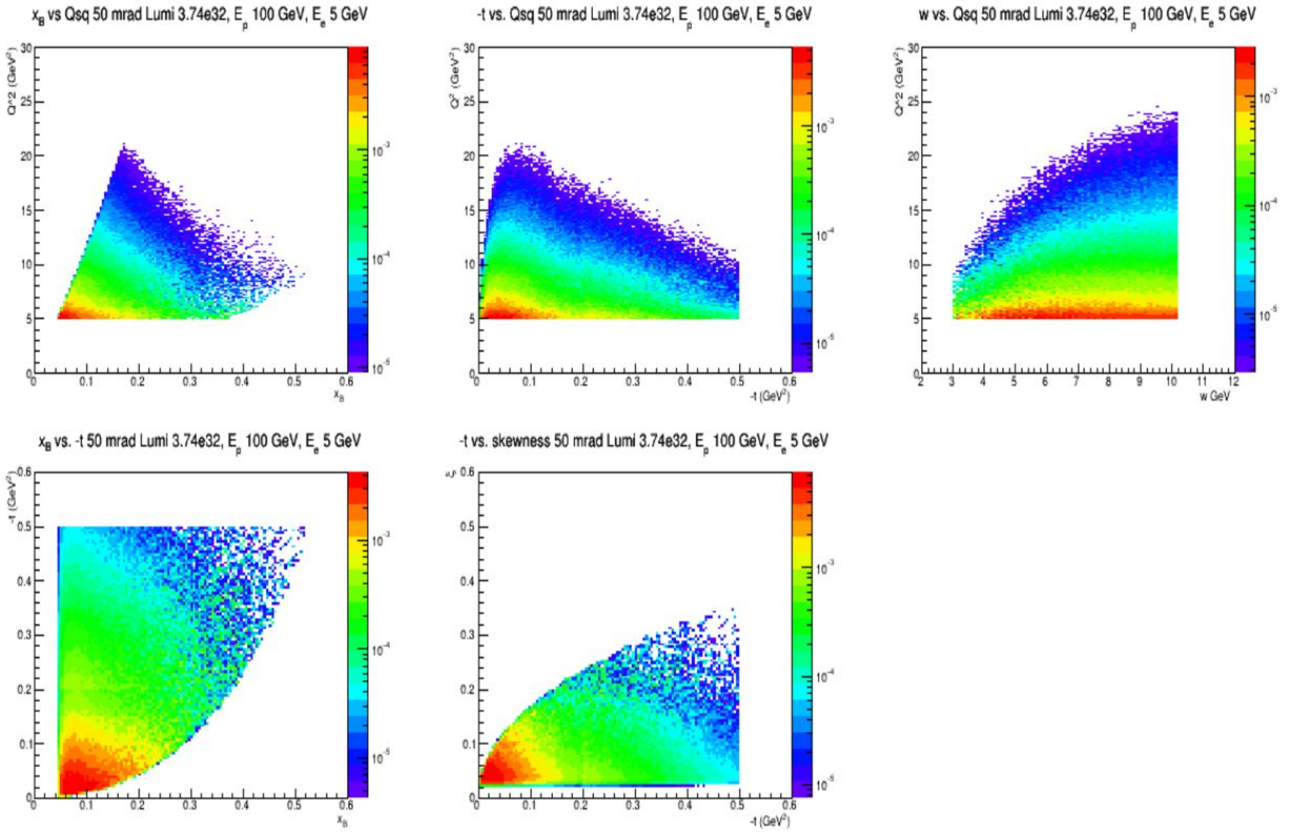
Scattered electrons:
5–6 GeV/c,
25-45° from outgoing e beam

Pions:
5–12 GeV/c,
7-30° from p beam

Assure exclusivity of *p(e,e'π^+n)* reaction by detecting neutron

e–π–n triple coincidences, weighted by cross section

DEMP Kinematic Coverage for 5x100

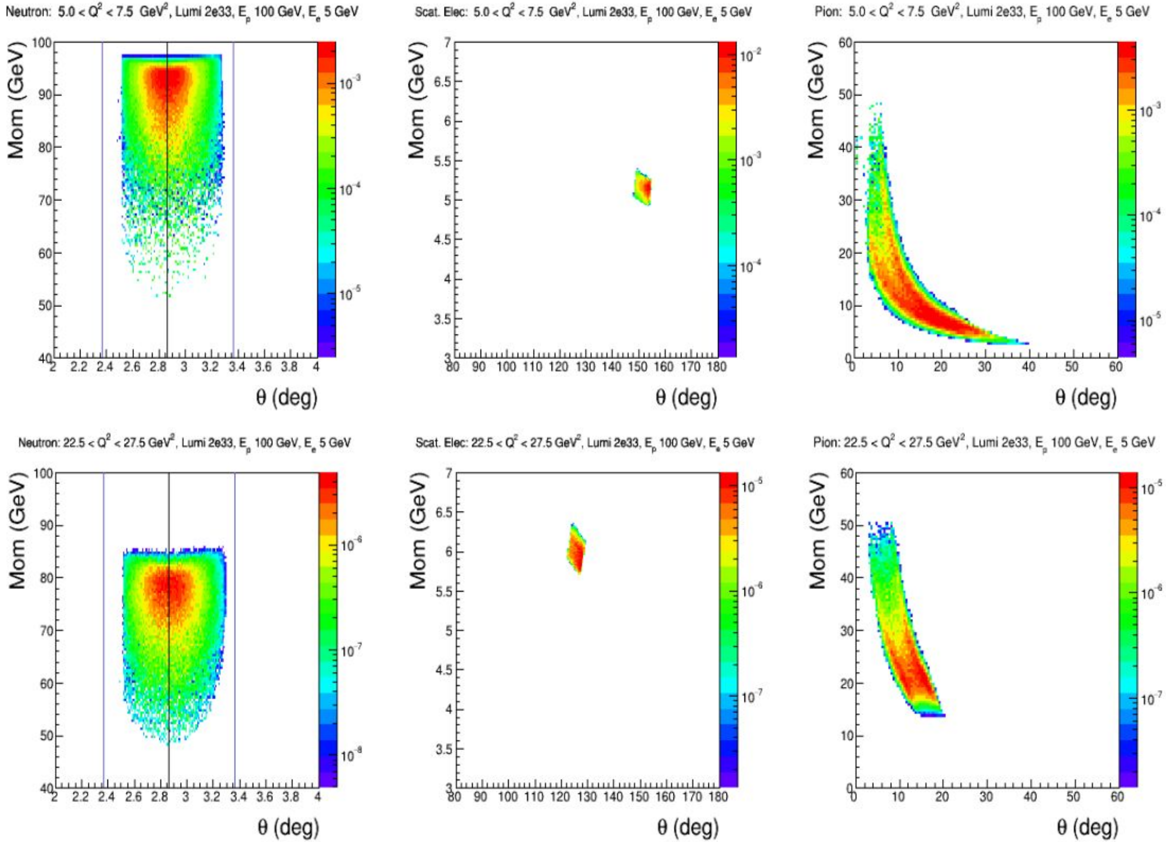


e–π–n triple coincidences, weighted by cross section

Garth Huber, huberg@uregina.ca

Acceptance for Q^2=6 and 25 GeV^2

University of Regina



e–π–n triple coincidences, weighted by cross section

Garth Huber, huberg@uregina.ca

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

Conclusion and Outlook

- 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
- 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

EXTRA

Breaking Down Important Scripts

Currently have different scripts for different physics processes

- TDISMC_EIC.cpp : pion structure function with ep scattering
- TDISMC_EICn.cpp : pion structure function with eD scattering
- TDISMC_EICK.cpp : kaon structure function with ep scattering

All gather physics from here

- cteq/ : cteqpdf.h and data based call files (c++ wrapper)
- cteq-tbls/ : nucleon PDFs table
- tim_hobbs/ : various regularization form for pion FF

Edit kinematics (x range, Q2 range, number of events, pbeam, kbeam)

- inputs/ : kinematics.input

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

Kinematic Variables

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

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

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

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

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

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

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

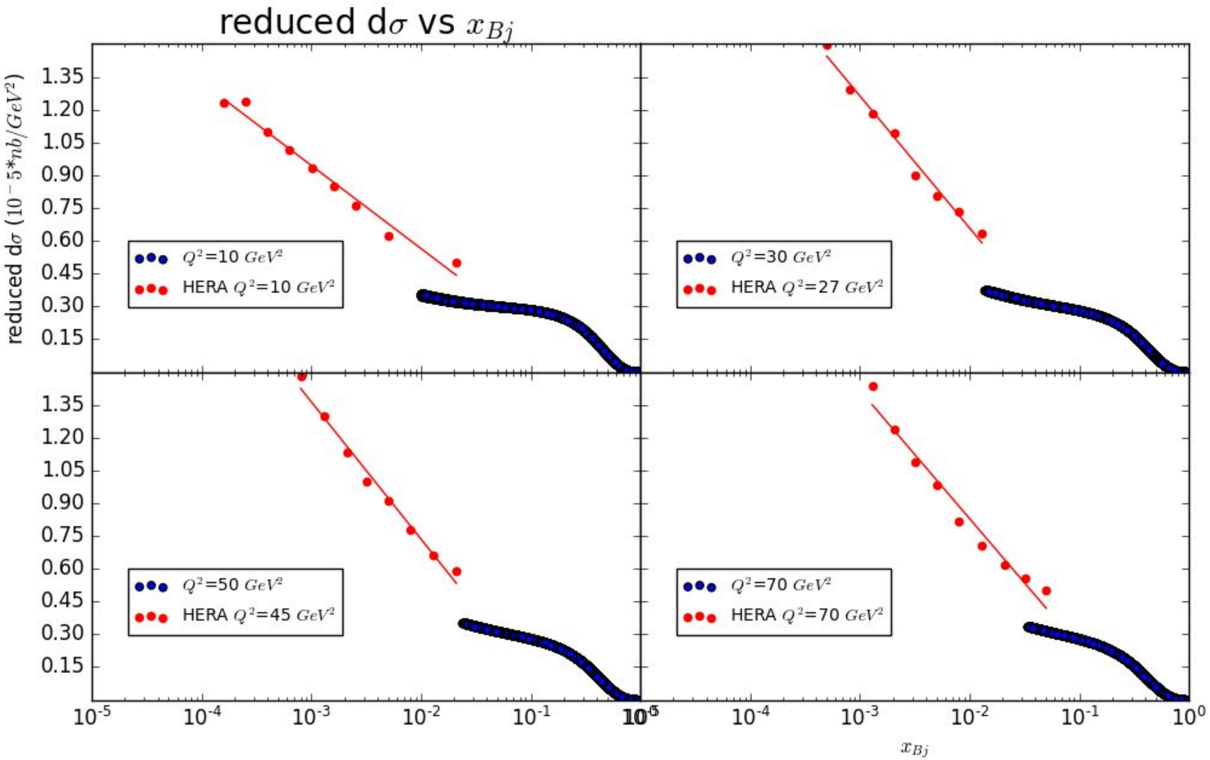
$$x_D = x_{Bj}\left(\frac{M_{proton}}{M_{ion}}\right)$$

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

Validation: Reduced cross section compared with HERA

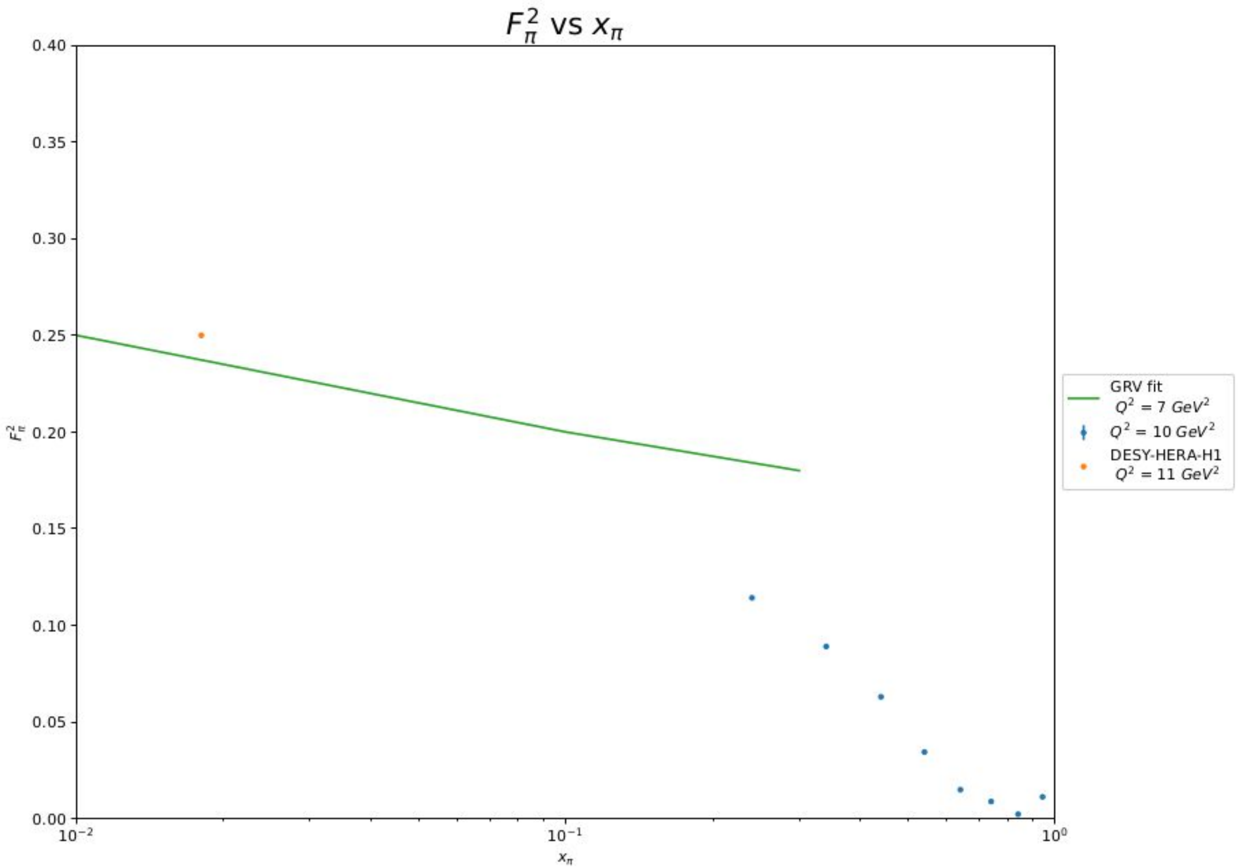
- HERA data from *ZEUS collab, Eur. Phys. J. C 21 (2001)*
- Proton beam = 100 GeV/c
- Electron beam = 5 GeV/c
- x_{Bj}=(0.01-1.0)
- Q^2=(10-100)

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

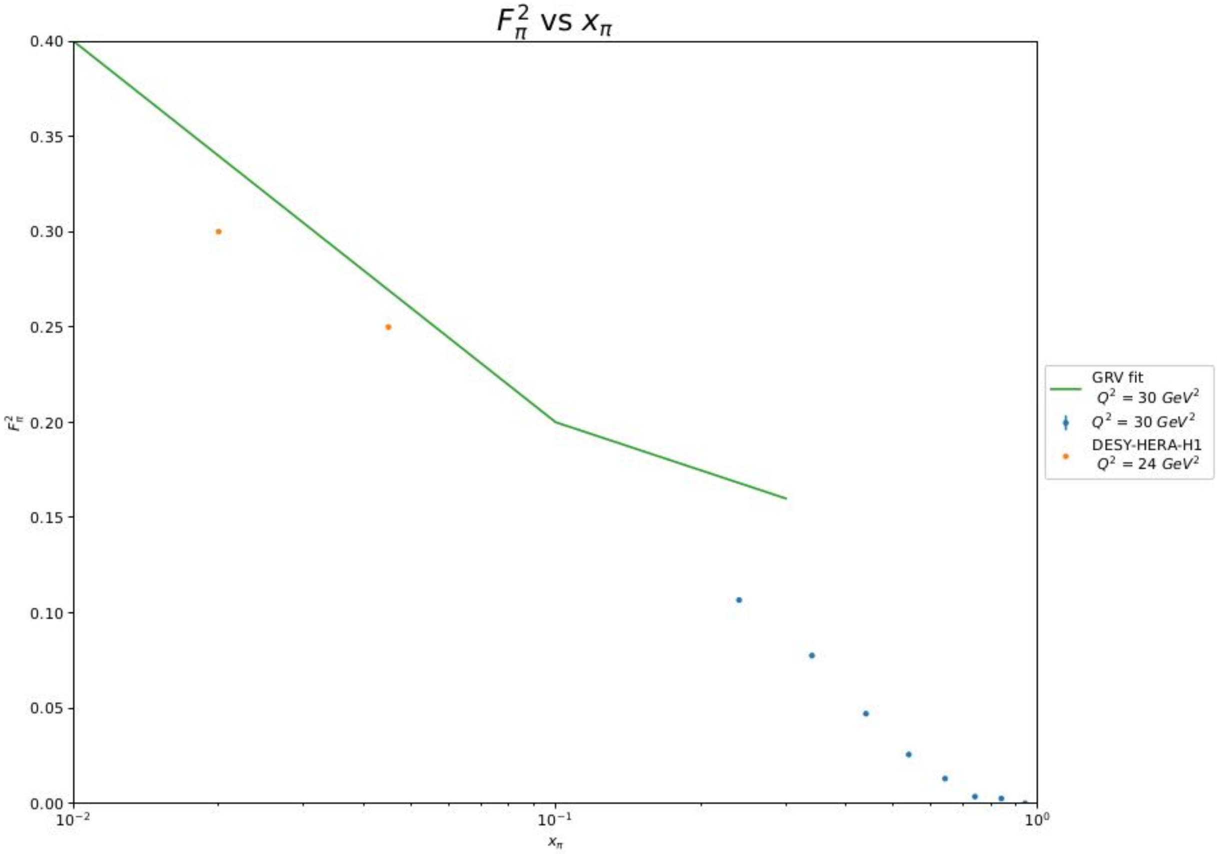


Validation: F2π with GRV fit/DESY-HERA-H1 data [Q^2= 10(7/11) GeV]

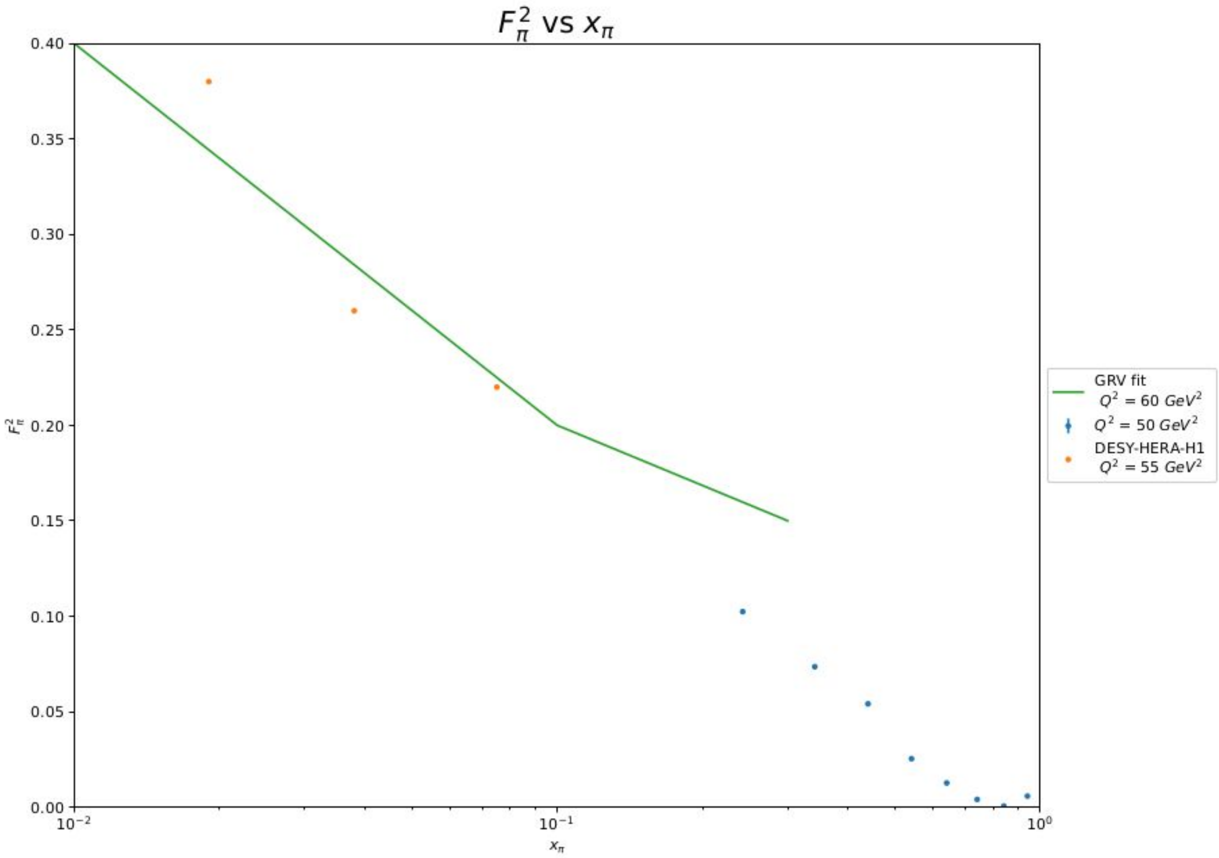
- F2π = (0.461)*F2P
  - (ZEUS Parameterization)
- DESY-HERA-H1 data and GRV fit (for three points) were eyeballed from plots
  - *J. Lan et. al., arXiv preprint (2019) arXiv:1907.01509*
- HERA F2pi data appear to be consistent with the MC projections though the x-dependence seems stronger at higher x



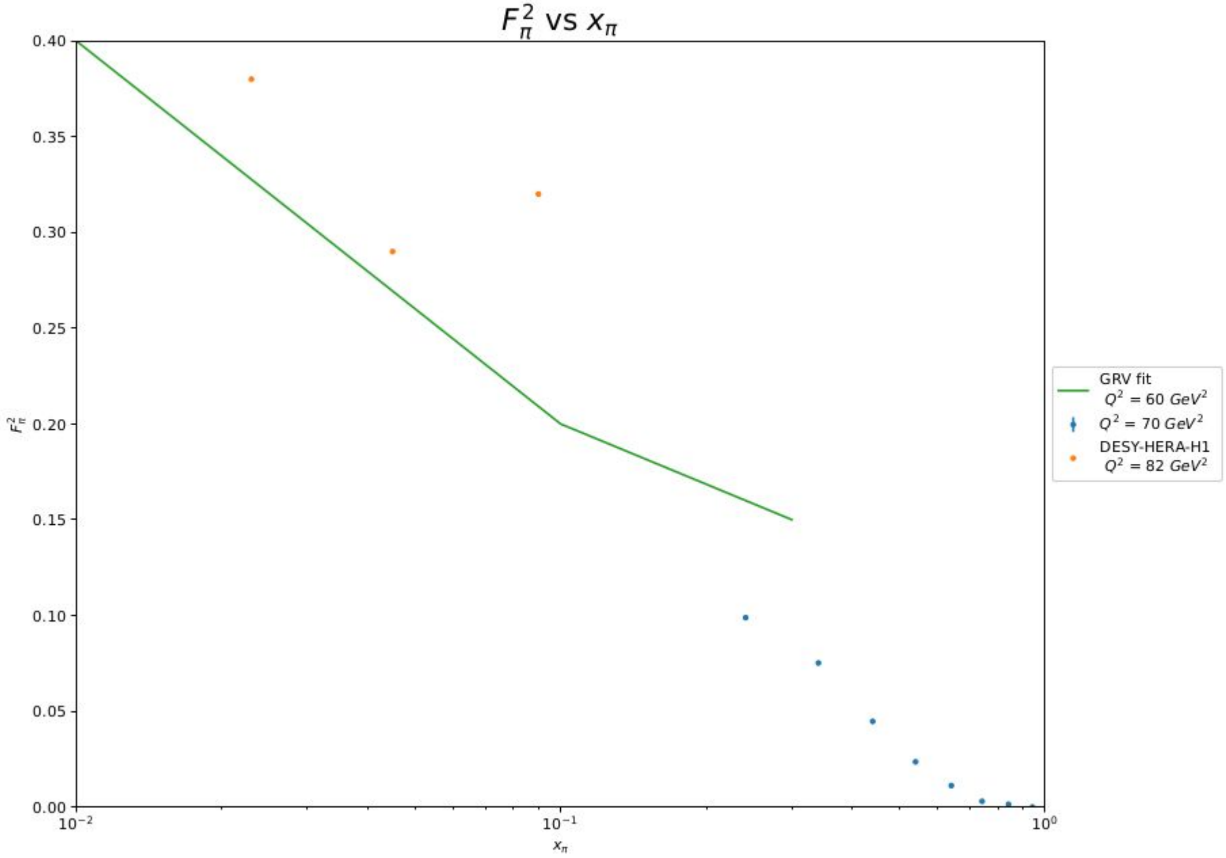
F2π with GRV fit/DESY-HERA-H1 data [Q^2= 30(30/24) GeV]



F2π with GRV fit/DESY-HERA-H1 data [Q^2= 50(60/55) GeV]



F2π with GRV fit/DESY-HERA-H1 data [Q^2= 70(60/82) GeV]



Projected F2π uncertainties – Rik's analytical estimates vs. MC

- The calculated values for f2π, xpi, and the stat uncertainty are very similar especially at low x.
- The high x comparison falls off as my calculated stat uncertainties stay below 1%

Richard	**Q2=10 GeV2**	**no cuts**							
F2pi	nan	0.114	0.089	0.063	0.034	0.015	0.009	0.002	0.011
xpi	nan	0.25	0.35	0.45	0.55	0.65	0.75	0.85	0.95
stat uncern %	nan	0.45%	0.51%	0.54%	0.64%	0.69%	0.67%	0.71%	0.82%
Rik	**Q2=9 GeV2**	**no cuts**							
F2pi	0.152	0.140	0.110	0.088	0.060	0.039	0.020	0.008	nan
xpi	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	nan
stat uncern %	0.42%	0.45%	0.50%	0.55%	0.28%	0.80%	1.90%	3.00%	nan

Q^2 vs x_{Bj} Phase Space