Pion and Kaon Form Factor Measurements at the EIC

Stephen JD Kay
University of Regina

EIC Detector 1 E/D WG
06/06/22

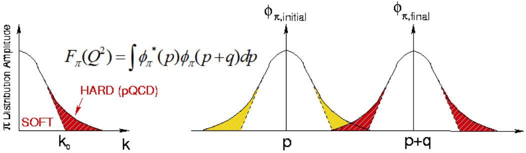
Outline

- Meson form factors
- Form factors at the EIC through DEMP
- Kaon form factors at the EIC - Outlook

Cover Image - Brookhaven National Lab, https://www.flickr.com/photos/brookhavenlab/

Meson Form Factors

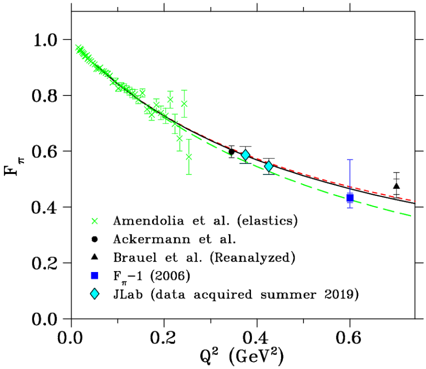
- Charged pion ($\pi^{\pm}$) and Kaon ($K^{\pm}$) form factors (F_π, F_K) are key QCD observables
  - Describe the spatial distribution of partons within a hadron



- Meson wave function can be split into ϕ_π^{soft} ($k < k_0$) and ϕ_π^{hard}, the hard tail
  - Can treat ϕ_π^{hard} in pQCD, cannot with ϕ_π^{soft}
  - Form factor is the overlap between the two tails (right figure)
- **F_π and F_K of special interest in hadron structure studies**
  - π - Lightest and simple QCD quark system
  - K - Another simple system, contains strange quark

Measurement of F_π - Low Q^2

- At low Q^2, F_π can be measured model independently
  - High energy elastic π^- scattering from atomic electrons in H
- CERN SPS - 300 GeV pions to measure F_π up to $Q^2 = 0.25\ GeV^2$
- Used data to extract pion charge radius - $r_\pi = 0.657 \pm 0.012\ fm$
- Maximum accessible Q^2 approximately proportional to pion beam energy
  - $Q^2 = 1\ GeV^2$ requires 1 TeV pion beam (!)



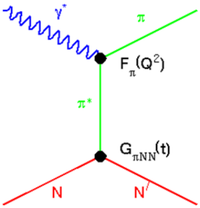
Amendolia, et al., NPB 277(1986) p168, P. Brauel, et al., ZPhysC (1979), p101, H. Ackermann, et al., NPB137 (1978), p294

Measurement of F_π at Higher Q^2

- To access F_π at high Q^2, must measure F_π indirectly
  - Use the "pion cloud" of the proton via $p(e,e'\pi^+)n$
- At small $-t$, the pion pole process dominates the longitudinal cross section, σ_L

- In the Born term model, F_π^2 appears as -

$$\frac{d\sigma_L}{dt} \propto \frac{-tQ^2}{(t-m_\pi^2)} g_{\pi NN}^2(t) F_\pi^2(Q^2,t)$$



- We do not use the Born term model
- Drawbacks of this technique -
  - Isolating σ_L experimentally challenging
  - Theoretical uncertainty in F_π extraction
    - Model dependent (smaller dependency at low -t)

Form Factors at the EIC

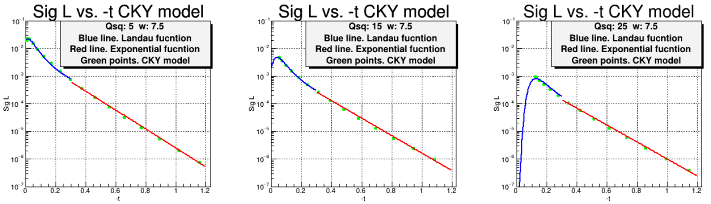
- Upcoming JLab measurements push the Q^2 reach of pion (F_π) and kaon (F_K) form factor data considerably
- Still can't answer some key questions regarding the emergence of hadronic mass however
- Can we get quantitative guidance on the emergent pion mass mechanism?
  $\rightarrow$ Need F_π data for $Q^2 = 10 - 40\ GeVc^{-2}$
- What is the size and range of interference between emergent mass and the Higgs-mass mechanism?
  $\rightarrow$ Need F_K data for $Q^2 = 10 - 20\ GeVc^{-2}$
- Beyond what is possible at JLab in the 12 GeV era
  - Need a different machine $\rightarrow$ **The Electron-Ion Collider (EIC)**

DEMP Studies at the EIC

- Measurements of the $p(e, e'\pi^+n)$ reaction at the EIC can potentially extend the Q^2 reach of F_π measurements even further
- A challenging measurement however
  - Need good identification of $p(e, e'\pi^+n)$ triple coincidences
  - Conventional L-T separation not possible $\rightarrow$ would need lower than feasible proton energies to access low ϵ
  - Need to use a model to isolate $d\sigma_L/dt$ from $d\sigma_{uns}/dt$
- Utilise new EIC software framework to assess the feasibility of the study with updated design parameters
  - Feed in events generated from a DEMP event generator
  - Multiple detector concepts to evaluate
- Event generator being modified to generate kaon events

DEMP Event Generator

- Want to examine exclusive reactions
  - $p(e, e'\pi^+ n)$ exclusive reaction is reaction of interest
    $\rightarrow p(e, e'\pi^+)X$ SIDIS events are background
- Generator uses Regge-based $p(e, e'\pi^+)n$ model from T.K. Choi, K.J. Kong and B.G. Yu (CKY) - arXiv 1508.00969
  - MC event generator created by parametrising CKY σ_L, σ_T for $5 < Q^2 < 35$, $2 < W < 10$, $0 < -t < 1.2$



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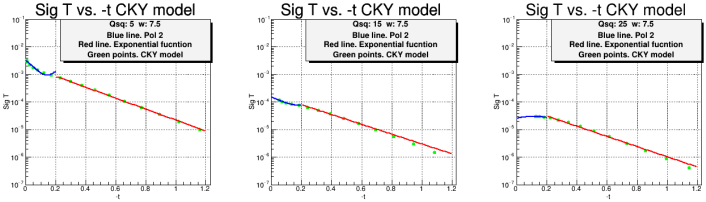
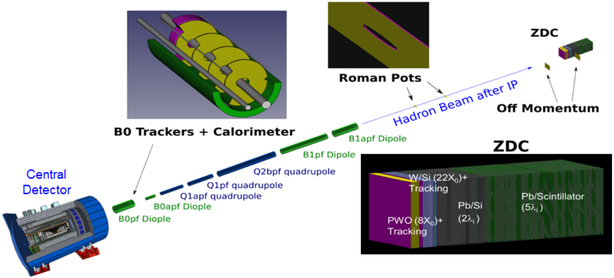


EIC Detector Overview



- Feed generator output into detector simulations
- Far forward detectors critical for form factor studies
- Current simulation effort has been focused on the EIC Comprehensive Chromodynamics Experiment (ECCE)
    - https://www.ecce-eic.org/

Selecting Good Simulated Events

- Pass through a full Geant4 simulation (ECCE)
  - More realistic estimates of detector acceptance/performance than earlier studies
- Identify $e'\pi^+n$ triple coincidences in the simulation output
- For a good triple coincidence event, require -
  - **Exactly** two tracks
    - One positively charged track going in the $+z$ direction (π^+)
    - One negatively charged track going in the $-z$ direction (e')
  - At least one hit in the zero degree calorimeter (ZDC)
    - For 5 (e', GeV) on 100 (p, GeV) events, require that the hit has an energy deposit over 40 GeV
- Both conditions must be satisfied
- Determine kinematic quantities for remaining events

Simulation Results - Neutron Reconstruction

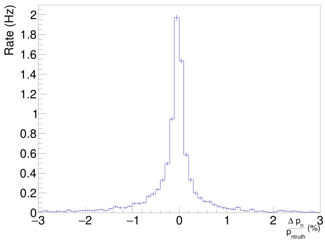
- High energy ZDC hit requirement used as a veto
  - ZDC neutron ERes is relatively poor though

$$\frac{35\%}{\sqrt{E}} \oplus 2\%$$

- However, position resolution is excellent, $\sim 1.5\ mm$
- Combine ZDC position info with missing momentum track to reconstruct the neutron track

$$p_{miss} = |\vec{p}_e + \vec{p}_p - \vec{p}_{e'} - \vec{p}_{\pi^+}|$$

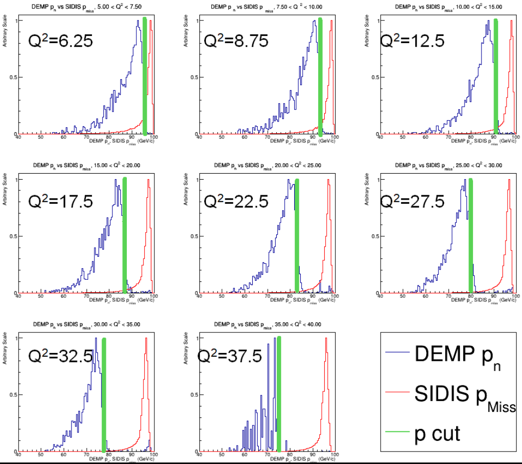
- Use ZDC angles, θ_{ZDC} and ϕ_{ZDC} rather than the missing momentum angles, θ_{pMiss} and ϕ_{pMiss}
- Adjust E_{Miss} to reproduce m_n
- After adjustments, reconstructed neutron track matches "truth" momentum closely



$\vec{p}_{miss}$ Cut - Q^2 bin dependent

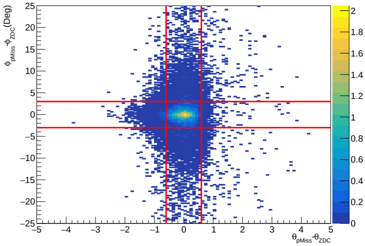
- Cut on $\vec{p}_{miss} \rightarrow \vec{p}_{miss} = \vec{p}_e + \vec{p}_p - \vec{p}_{e'} - \vec{p}_{\pi^+}$

- Cut varies by Q^2 bin
- Cuts simulate removal of SIDIS background
- SIDIS events at larger $\vec{p}$ and $-t$ thanDEMP events



$\Delta\theta$ and $\Delta\phi$ Cuts

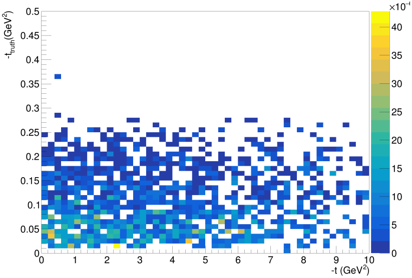
- Make use of high angular resolution of ZDC
- Compare hit θ/ϕ positions of neutron on ZDC to calculated θ/ϕ from p_{miss}
- If no other particles produced, quantities should be correlated
    - True for DEMP events
- Energetic neutrons from inclusive background processes will be less correlated
    - Additional lower energy particles produced



- $\theta_{pMiss} - \theta_{ZDC}$ and $\phi_{pMiss} - \phi_{ZDC}$ cut upon, in addition to other cuts
- $|\theta_{pMiss} - \theta_{ZDC}| < 0.6^{\circ}$, $|\phi_{pMiss} - \phi_{ZDC}| < 3.0^{\circ}$

Simulation Results - t Reconstruction

- Reconstruction of $-t$ from detected e' and π^+ tracks proved highly unreliable
  - $-t = -(p_e - p_{e'} - p_\pi)^2$
- Calculation of $-t$ from reconstructed neutron track matched "truth" value closely
  - $-t_{alt} = -(p_p - p_n)^2$
- Only possible due to the excellent position accuracy provided by a good ZDC



- Note that the x-axis $-t$ scale here runs to 10 GeV^2!

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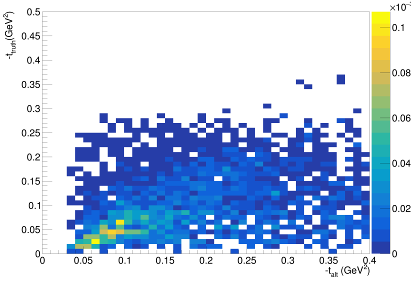
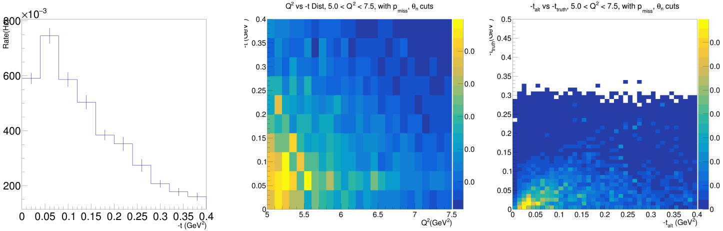


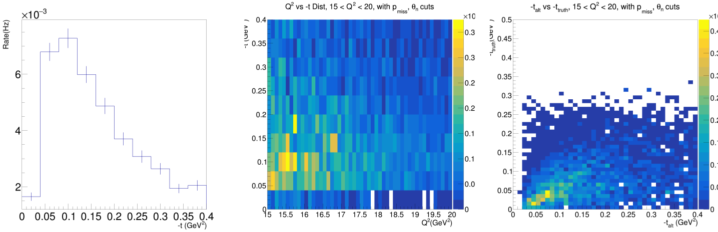
- x-axis $-t$ scale an order of magnitude smaller now!

Simulation Results - Q^2 $5 - 7.5$ GeV^2



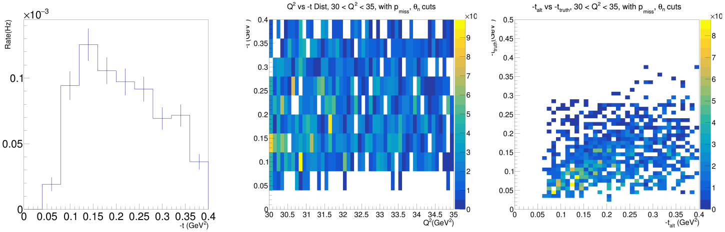
- Predicted $e'\pi^+n$ triple coincidence rate, binned in Q^2 and $-t$
  - 5 (e', GeV) on 100 (p, GeV) events
  - $\mathcal{L} = 10^{34} cm^{-2} s^{-1}$ assumed
  - $-t$ bins are 0.04 GeV^2 wide
  - Cuts on θ_n ($\theta_n = 1.45 \pm 0.5°$), $\vec{p}_{miss}$, $|\Delta\theta|$ and $|\Delta\phi|$
- $-t_{min}$ migrates with Q^2 as expected

Simulation Results - Q^2 $15-20$ GeV^2



- Predicted $e'\pi^+n$ triple coincidence rate, binned in Q^2 and $-t$
  - 5 (e', GeV) on 100 (p, GeV) events
  - $\mathcal{L} = 10^{34}cm^{-2}s^{-1}$ assumed
  - $-t$ bins are 0.04 GeV^2 wide
  - Cuts on θ_n $(\theta_n = 1.45 \pm 0.5^\circ)$, $\vec{p}_{miss}$, $|\Delta\theta|$ and $|\Delta\phi|$
- $-t_{min}$ migrates with Q^2 as expected

Simulation Results - Q^2 $30 - 35$ GeV^2



- Predicted $e'\pi^+n$ triple coincidence rate, binned in Q^2 and $-t$
  - 5 (e', GeV) on 100 (p, GeV) events
  - $\mathcal{L} = 10^{34} cm^{-2} s^{-1}$ assumed
  - $-t$ bins are 0.04 GeV^2 wide
  - Cuts on θ_n $(\theta_n = 1.45 \pm 0.5^\circ)$, $\vec{p}_{miss}$, $|\Delta\theta|$ and $|\Delta\phi|$
- $-t_{min}$ migrates with Q^2 as expected

Isolating σ_L from σ_T in an e-p Collider

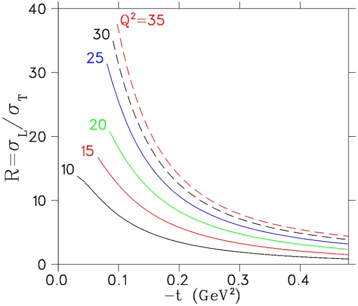
- For a collider -

$$\epsilon = \frac{2(1-y)}{1+(1-y)^2} \quad \text{with} \quad y = \frac{Q^2}{x(s_{tot} - M_N^2)}$$

  - y is the fractional energy loss
- Systematic uncertainties in σ_L magnified by $1/\Delta\epsilon$
  - Ideally, $\Delta\epsilon > 0.2$
- To access $\epsilon < 0.8$ with a collider, need $y > 0.5$
  - Only accessible at small s_{tot}
  - Requires low proton energies (~ 10 GeV), luminosity too low
- **Conventional L-T separation not practical, need another way to determine σ_L**

σ_L Isolation with a Model at the EIC

- QCD scaling predicts $\sigma_L \propto Q^{-6}$ and $\sigma_T \propto Q^{-8}$
- At the high Q^2 and W accessible at the EIC, phenomenological models predict $\sigma_L \gg \sigma_T$ at small $-t$
- Can attempt to extract σ_L by using a model to isolate dominant $d\sigma_L/dt$ from measured $d\sigma_{UNS}/dt$
- Critical to confirm the validity of the model used!



Predictions are assuming $\epsilon > 0.9995$ with the kinematic ranges seen earlier

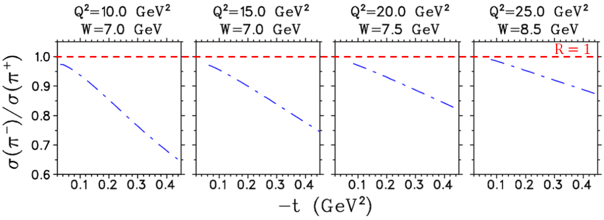
T.Vrancx, J. Ryckebusch, PRC 89(2014)025203

Model Validation via π^-/π^+ ratios

- Measure exclusive $^2H(e,e'\pi^+n)n$ and $^2H(e,e'\pi^-p)p$ in same kinematics as $p(e,e'\pi^+n)$
- π t-channel diagram is purely isovector $\rightarrow$ G-Parity conserved

$$R = \frac{\sigma\left[n(e,e'\pi^-p)\right]}{\sigma\left[p(e,e'\pi^+n)\right]} = \frac{|A_V - A_S|^2}{|A_V - A_S|^2}$$

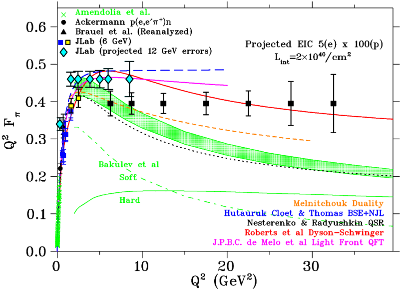
- R will be diluted if σ_T *not* small *or* if there are significant non-pole contributions to σ_L
- Compare R to model expectations



T.Vrancx, J. Ryckebusch, PRC 89(2014)025203

EIC F_π Data

- ECCE appears to be capable of measuring F_π to $Q^2 \sim 32.5\ GeV^2$
- **Error bars represent real projected error bars**
  - 2.5% point-to-point
  - 12% scale
  - $\delta R = R,\ R = \sigma_L/\sigma_T$
  - $R = 0.013 - 014$ at lowest $-t$ from VR model
- Uncertainties dominated by R at low Q^2
- Statistical uncertainties dominate at high Q^2

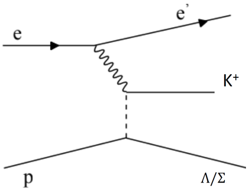


- Results look promising, need to test π^- too
- More details in upcoming ECCE NIM paper

F_K at the EIC - Challenges and Possibilities

- F_K at the EIC via DEMP will be extremely challenging

- Would need to measure two reactions
  - $p(e, e'K^+\Lambda)$
  - $p(e, e'K^+\Sigma)$
  - Need both for pole dominance tests



$$R = \frac{\sigma_L\left[p(e, e'K^+\Sigma^0)\right]}{\sigma_L\left[p(e, e'K^+\Lambda^0)\right]} \rightarrow R \approx \frac{g^2_{pK\Sigma}}{g^2_{pK\Lambda}}$$

- Consider just the Λ channel for now
  - Λ plays a similar role to neutron in π studies
  - Very forward focused, **but**, Λ will decay
    - $\Lambda \rightarrow n\pi^0$ - ~ 36 %
    - $\Lambda \rightarrow p\pi^-$ - ~ 64 %
  - Neutral channel potentially best option
    - **Very challenging 3 particle final state**

F_K at the EIC - Challenges and Possibilities

- Need to update DEMPGen with a kaon module
- Regina MSc student (Love Preet) is working on this module
  - Parametrisation based upon previous data and Vrancx/Ryckebusch Regge model guidance
  - `http://rprmodel.ugent.be/calc/`
- Use similar approach to pion model in generator
  - Need Λ and Σ modules
- In parallel, will begin studies of Λ reconstruction in ZDC
  - Can use particle gun
  - May need to use likelihood analysis for Λ reconstruction
  - Should also examine charged decay channel
- Kaon model updates and simulations will be focus over the summer

Form Factors at the EIC - Outlook

- EIC has the potential to push the Q^2 reach of F_π measurements into the 30 GeV^2 range
  - Can we measure F_K too?
- F_π work already featured in the EIC yellow report
- Worked closely with the ECCE proto-collaboration
  - Carrying out feasibility studies
  - Existing DEMP event generator utilised
  - Kaon event generator and simulations in progress
  - **Activities were a priority for the ECCE Diffractive and Tagging group**
  - Will continue to develop simulations with Detector 1 collaboration
- Results from simulation have been written up in an ECCE analysis note and NIM paper
  - Expect to see this soon!

R. Abdul Khalek et al. EIC Yellow Report. 2021. arXiv:2103.05419, Sections 7.2.1 and 8.5.1

Thanks for listening, any questions?

Meson Structure Working Group - S.J.D. Kay, G.M. Huber, Z. Ahmed, Ali Usman, John Arrington, Carlos Ayerbe Gayoso, Daniele Binosi, Lei Chang, Markus Diefenthaler, Rolf Ent, Tobias Frederico, Yulia Furletova, Timothy Hobbs, Tanja Horn, Thia Keppel, Wenliang Li, Huey-Wen Lin, Rachel Montgomery, Ian L. Pegg, Paul Reimer, David Richards, Craig Roberts, Dmitry Romanov, Jorge Segovia, Arun Tadepalli, Richard Trotta, Rik Yoshida

EIC-Canada

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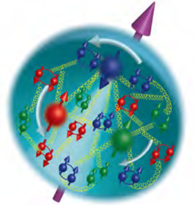
The University of Regina is situated on the territories of the nehiyawak, Anihsināpēk, Dakota, Lakota, and Nakoda, and the homeland of the Métis/Michif Nation. The University of Regina is on Treaty 4 lands with a presence in Treaty 6.

Backup Zone

Understanding Dynamic Matter

- Interactions and structure are not isolated ideas in nuclear matter
  - Observed properties of nucleons and nuclei (mass, spin) emerge from this complex interplay
  - Properties of hadrons are emergent phenomena



- Mechanism known as **D**ynamical **C**hiral **S**ymmetry **B**reaking (**DCSB**) plays a part in generating hadronic mass
- QCD behaves very differently at short and long distances (high and low energy)
  - How do our two distinct regions of QCD behaviour connect?
- **A major puzzle of the standard model to try and resolve!**
- How can we examine hadronic structure?

Image - A. Deshpande, Stony Brook University

The Pion in pQCD

- At very large Q^2, F_π can be calculated using pQCD

$$F_\pi(Q^2) = \frac{4}{3}\pi\alpha_s \int_0^1 dxdy \frac{2}{3}\frac{1}{yQ^2}\phi(x)\phi(y)$$

- As $Q^2 \rightarrow \infty$, the pion distribution amplitude, ϕ_π becomes -

$$\phi_\pi(x) \rightarrow \frac{3f_\pi}{\sqrt{n_c}}x(1-x)$$ $f_\pi = 93\ MeV$, $\pi^+ \rightarrow \mu^+\nu$ decay constant

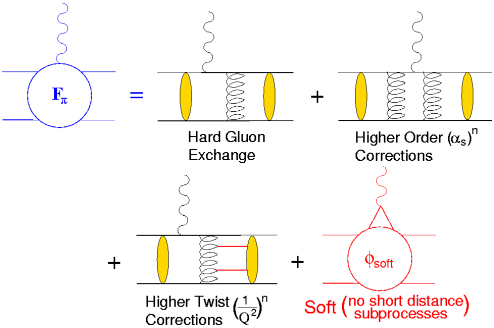
- F_π can be calculated with pQCD in this limit to be -

$$Q^2 F_\pi \xrightarrow[Q^2\rightarrow\infty]{} 16\pi\alpha_s(Q^2)f_\pi^2$$

- This is a **rigorous** prediction of pQCD
- Q^2 **reach of existing data doesn't extend into this region**
  - Need unique, cutting edge experiments to push into this region

Eqns - G.P. Lepage, S.J. Brodsky, PLB 87, p359, 1979

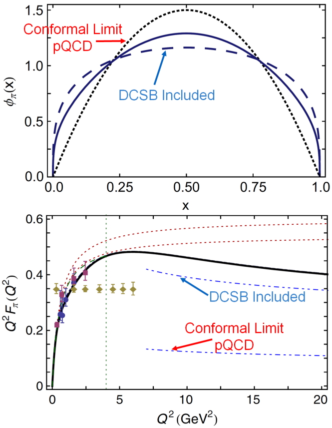
- At experimentally accessible Q^2, both the hard and soft components contribute



- Interplay of hard and soft contributions poorly understood
- Experiments can study the transition from soft to hard regime

Connecting Pion Structure and Mass Generation

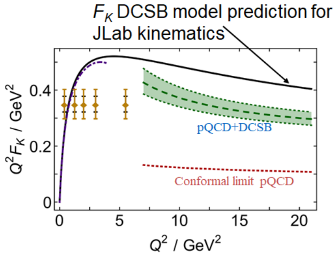
- ϕ_π as shown before has a broad, concave shape
- Previous pQCD derivation (conformal limit) did not include DCSB effects
- Incorporating DCSB changes $\phi_\pi(x)$ and brings F_π calculation much closer to the data
  - "Squashes down" PDA
- Pion structure and hadron mass generation are interlinked
- How can we measure F_π or F_K?

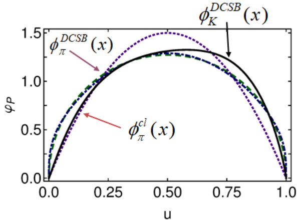


L. Chang, et al., PRL110(2013) 132001, PRL111(2013), 141802

What About the Kaon?

- K^+ PDA (ϕ_K) is also broad and concave, but asymmetric
- Heavier s quark carries more bound state momentum than the u quark

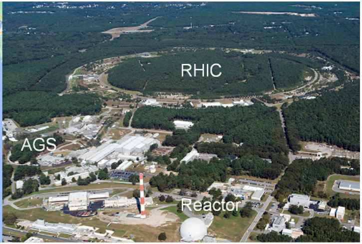




C. Shi, et al., PRD 92 (2015) 014035, F. Guo, et al., PRD 96(2017) 034024 (Full calculation)

The Electron-Ion Collider

- Major announcement in January 2020
  - Brookhaven National Lab (**BNL**) was chosen as the site of the future Electron-Ion Collider (**EIC**)
  - BNL is situated on Long Island, New York
  - Existing site of the Relativistic Heavy Ion Collider (**RHIC**) and the Alternating Gradient Synchrotron (**AGS**)



Upgrading RHIC - eRHIC

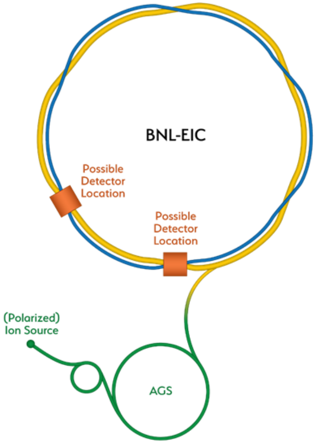


Image - Brookhaven National Lab

- Use existing RHIC
  - Up to 275 *GeV* polarised proton beams
  - Existing tunnel, detector halls, hadron injector complex (AGS)
- New 18 *GeV* electron linac
  - New high intensity electron storage ring in existing tunnel
- Achieve high $\mathcal{L}$, high E e-p/A collisions with full acceptance detectors
- High $\mathcal{L}$ achieved by state of the art beam cooling techniques

Upgrading RHIC - eRHIC

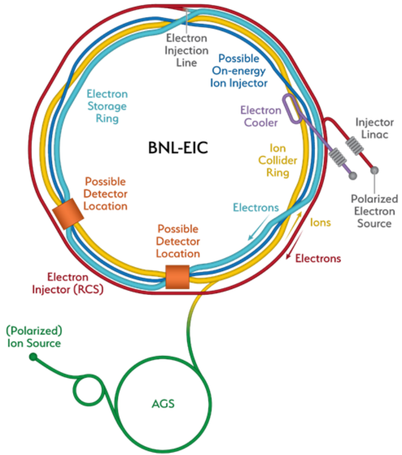
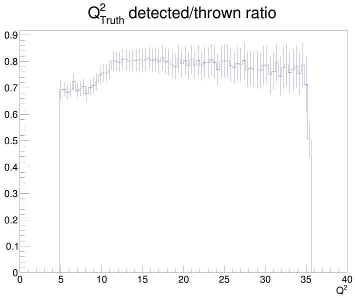


Image - Brookhaven National Lab

- Use existing RHIC
  - Up to 275 *GeV* polarised proton beams
  - Existing tunnel, detector halls, hadron injector complex (AGS)
- New 18 *GeV* electron linac
  - New high intensity electron storage ring in existing tunnel
- Achieve high $\mathcal{L}$, high E e-p/A collisions with full acceptance detectors
- High $\mathcal{L}$ achieved by state of the art beam cooling techniques

Simulation Results - Detection Efficiency

- Can examine truth quantities too, quick check of detection efficiency
- $\text{Efficiency} = \frac{\text{Accepted}}{\text{Thrown}}$
- Detection efficiency fairly high, $\sim 80\%$
- Nearly independent of Q^2
- Detection efficiency highest for low $-t$
  - Falls off rapidly with increasing $-t$
  - Dictated by size of ZDC



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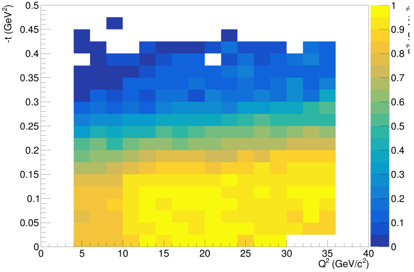
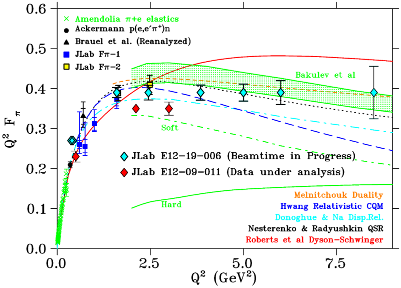


Current and Projected JLab F_π Data

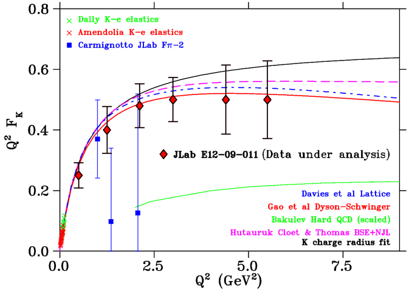
- JLab 12 *GeV* program includes measurements of F_π to higher Q^2
- JLab Hall C is the only facility worldwide that can perform this measurement
- Projected error bars show on plot, *y* positioning of points arbitrary
- Models all disagree!
  - Contributions from sea quarks and gluons highly uncertain at high Q^2



- **A world leading, high impact measurement**

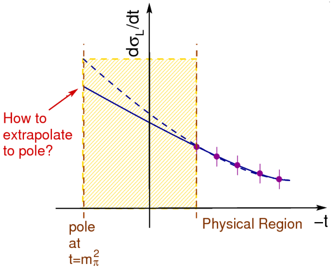
Current and Projected JLab F_K Data

- Data has all been acquired and analysis is in progress
- Projected errors bars, *y* positioning of points arbitrary
- **No existing data above $Q^2 \sim 2.25\ GeV^2$**
- Error bars on sparse existing data are very large
- Kaon structure even more poorly known than the pion



- $p(e, e'\pi^+)n$ data obtained away from $t = m_\pi^2$ pole
- "Chew Low" extrapolation method - must know analytical dependence of $d\sigma_L/dt$ in unphysical region

- Extrapolation method last used in 1972 by Devenish and Lyth
- Very large systematic uncertainties
- Failed to produce a reliable result
- Different polynomial fits equally likely in physical region
  - Form factor values divergent when extrapolated



- **We do not use the Chew-Low method**

Extracting F_π at JLab

- Only reliable approach for extracting F_π from σ_L is to use a model that incorporates the π^+ production mechanism and the spectator nucleon
- JLab F_π experiments so far use the VGL Regge model
  - Reliably describes σ_L across a wide kinematic domaon
- Ideally, want a better understanding of the model dependence of the result
- There has been considerable recent interest
  - T.K. Choi, K.J. Kong, B.G. Yu, arXiv 1508.00969
  - T. Vrancx, J. Ryckebusch, PRC 89(2014)025203
  - M.M. Kaskulov, U. Mosel, PRC 81(2010)045202
  - S.V. Goloskokov, P.Kroll, EPJC 65(2010)137
- **We aim to publish our experimentally measured cross section data so that updated values of F_π can be extracted as the models improve**

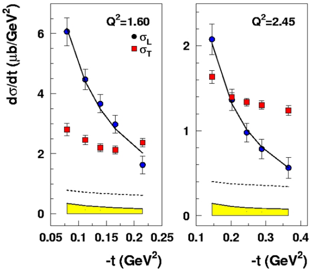
VGL - Vanderhaeghen-Guidal-Laget Model - Vanderhaeghen, Guidal, Laget, PRC 57(1998) 1454

$F_\pi(Q^2)$ from JLab Data

VGL model incorporates π^+ production mechanism and spectator neutron effects

- Feynman propagator - $\frac{1}{t-m_\pi^2}$ replaced by π and ρ Regge propagators
- Represents the exchange of a series of particles, compared to a single particle
- Free parameters - $\Lambda_\pi, \Lambda_\rho$ - Trajectory cutoff parameters
- At small $-t$, σ_L only sensitive to F_π

$$F_\pi = \frac{1}{1+Q^2/\Lambda_\pi^2}$$



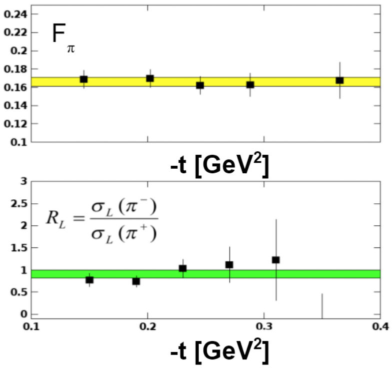
Error bars indicate statistical and random (pt-pt) systematic uncertainties in quadrature. Yellow band indicates the correlated (scale) and partly correlated (t-corr) systematic uncertainties.
$\Lambda_\pi^2 = 0.513, 0.491\ GeV^2$, $\Lambda_\rho^2 = 1.7\ GeV^2$
T. Horn, et al., PRL 97(2006) 192001

Two F_π Validation Methods

- Test #1 - Measure F_π at fixed Q^2/W, but vary $-t$
  - F_π values should not depend on -t
- Test #2 - π^+ t-channel diagram is purely isovector
- Use a deuterium target to measure $\sigma_L\,[n(e,e'\pi^-)p]$
- Examine the ratio -

$$R = \frac{\sigma_L\,[n(e,e'\pi^-)p]}{\sigma_L\,[p(e,e'\pi^+)n]} = \frac{|A_V - A_S|^2}{|A_V + A_S|^2}$$

- Will test at $Q^2 = 1.6, 3.85, 6.0\ GeV^2$



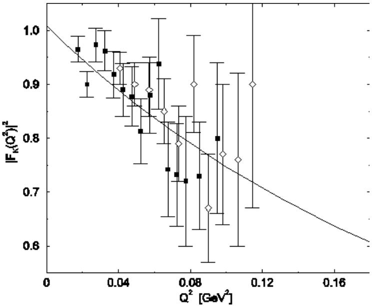
T. Horn, C.D. Roberts, J. Phys. G43 (2016) no.7, 073001
G. Huber et al, PRL112 (2014)182501
R. J. Perry et al., arXiV:1811.09356 (2019)

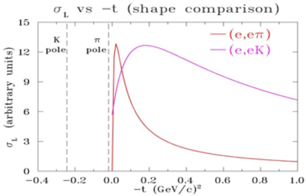
F_K Measurement at JLab

- Similar to F_π, elastic K^+ scattering from e^- used to determine F_K at low Q^2
- Can "kaon cloud" of the proton be used in the same way as the pion to extract F_k from electroproduction?
- Kaon pole further from kinematically allowed region

$$\frac{d\sigma_L}{dt} \propto \frac{-tQ^2}{(t-m_K^2)} g_K^2(T) F_K^2(Q^2,t)$$

- Issues are being explored and tested in JLab E12-09-011





Amendolia, et al., PLB178(1986)435

F_K Validation

- Again, low Q^2 data is an important test
- Due to experimental setup, can simultaneously study Λ^0 and Σ^0 channels
- Can conduct a pole dominance test through the ratio -

$$\frac{\sigma_L\left[p(e,e'K^+)\Sigma^0\right]}{\sigma_L\left[p(e,e'K^+)\Lambda^0\right]}$$

- Should be similar to ratio of $g^2_{pK\Lambda}/g^2_{pK\Sigma}$ if t-channel exchange dominates