Experimental Advances in Pion and Kaon Structure Studies

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Teleworkshop on Strong QCD from Hadron Structure Experiments IV
07/06/21

Outline

- Meson Form Factors
- Jefferson Lab Hall C - Previous Measurements
- Jefferson Lab Hall C - Upcoming Program
  - Pion Form Factor
  - Kaon Form Factor
- On the Horizon - The EIC

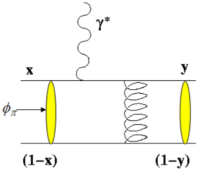
Meson Form Factors

- Pion and Kaon form factors (F_π, F_K) are key QCD observables
  - Describe the spatial distribution of partons within a hadron
- F_π and F_K of special interest in hadron structure studies
  - π - Lightest QCD quark system, crucial in understanding dynamic mass generation
  - K - Next simplest system, contains strangeness
- Clearest case for studying transition from perturbative to non-perturbative regime
- Existing data are good, but need to push Q^2 reach further

The Pion in pQCD 1/2

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

$$F_\pi(Q^2) = \frac{4_F \alpha_s(Q^2)}{Q^2} \left| \sum_{n=0}^{\infty} a_n \left(\log\left(\frac{Q^2}{\Lambda^2}\right)\right)^{-\gamma_n} \right|^2 \left[1 + O\left(\alpha_s(Q^2), \frac{m}{Q}\right)\right]$$



The Pion in pQCD 2/2

- At asymptotically high Q^2 ($Q^2 \rightarrow \infty$), the pion distribution amplitude becomes -
$$\phi_\pi(x) \rightarrow \frac{3f_\pi}{\sqrt{n_c}} x(1-x)$$
  - With $f_\pi = 93\ MeV$, the $\pi^+ \rightarrow \mu^+\nu$ decay constant
- F_π takes the form -
$$Q^2 F_\pi \rightarrow 16\pi\alpha_s(Q^2) f_\pi^2$$
- This only relies on asymptotitc freedom in QCD, i.e. $(\partial\alpha_s/\partial\mu) < 0$ as $\mu \rightarrow \infty$
- $Q^2 F_\pi$ should behave as $\alpha_s(Q^2)$, even for moderately large Q^2
- Pion form factor seems to be the best tool for experimental study of the nature of the quark-gluon coupling constant renormalisation

Eqns - G.P. Lepage, S.J. Brodsky, PLB 87, p359, 1979 | Closing Statement - A.V. Efremov, A.V. Radyushkin PLB 94, p245, 1980

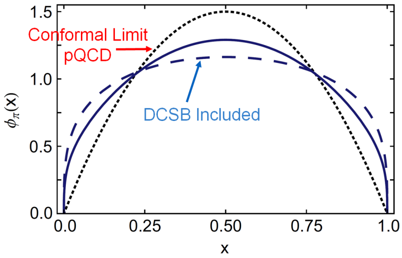
Implications for Pion Structure 1/2

- Previous pQCD derivation used normalisation of F_π based on the conformal limit of the pion's twist 2-PDA -

$$\phi_\pi^{cl}(x) = 6x(1-x)$$

- Gives F_π that are "too small"
- Incorporating the DCSB effects yields Pion PDA -

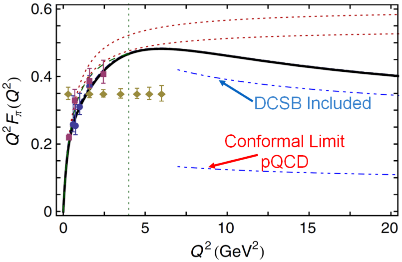
$$\phi_\pi(x) = \frac{8}{\pi}\sqrt{x(1-x)}$$



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

Implications for Pion Structure 2/2

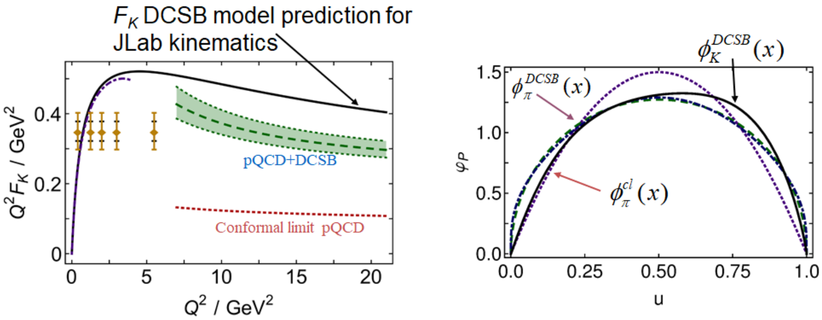
- Using this $\phi_\pi(x)$ in the pQCD expression brings the F_π calculation much closer to the data
- Underestimates the full computation by $\sim 15\%$ for $Q^2 \geqslant 8\ GeV^2$



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

Effects of DCSB on K^+ Properties

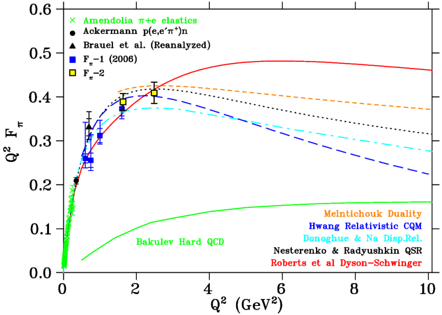
- K^+ PDA is also broad, concave and asymmetric
- Heavier s quark carries more bound state momentum than the u quark, shift is less then one might expect based on the difference in current quark masses.



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

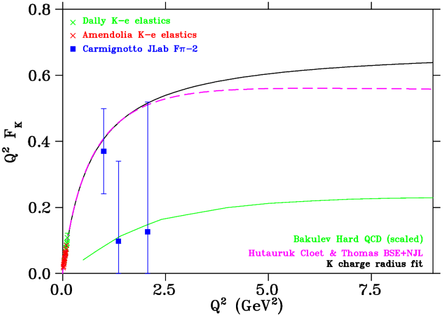
Pion Form Factor - Previous JLab Program

- 6 GeV era $F_\pi - 1$ and $F_\pi - 2$ very successful, best F_π experimental data we have for now
- Results differ from hard QCD calculation
- F_π to $\sim Q^2 = 2.45\ GeV^2$
- No pathological issue between elastic and electroproduction data observed



Kaon Form Factor - Previous JLab Program

- $F_\pi - 2$ also determined F_K at moderate Q^2
  - Not a dedicated F_K measurement
- F_K to $\sim Q^2 = 2.067\ GeV^2$
- Limited number of data points
- Large error bars
- No pathological issue between elastics and electroproduction

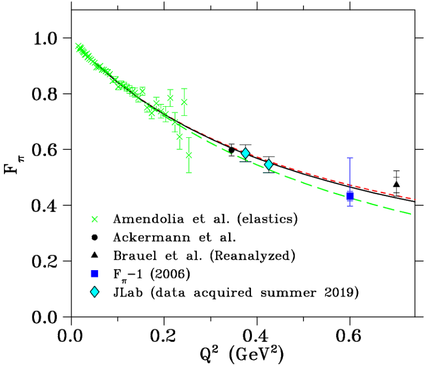


Meson Form Factors - Upcoming JLab Program

- E12-09-011 (Spokespeople: T. Horn, G Huber, P. Markowitz)
  - Ran in 2018-2019, analysis in progress
  - LT separated kaon cross section
  - Will attempt to extract F_K
- E12-19-006 (Spokespeople: D. Gaskell, T. Horn, G. Huber)
  - Low Q^2 part ran in June/July 2019
  - **Large experimental run this year (and in 2022)**
  - LT separated pion cross section
  - F_π to high Q^2 (8.5 GeV^2)
  - Pion reaction mechanism studies

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 used 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

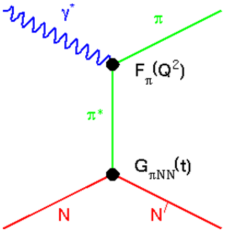
Measurement of F_π at Higher Q^2

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

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

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

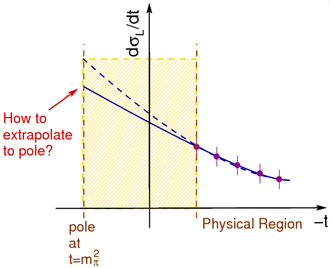
- Drawbacks of this technique -
  - Isolating σ_L experimentally challenging
  - Theoretical uncertainty in F_π extraction
    $\rightarrow$ Model dependent
    (smaller dependency at low -t)



Chew-Low Method to determine F_π

- $p(e, e'\pi^+)n$ 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

Measurement of F_π at JLab

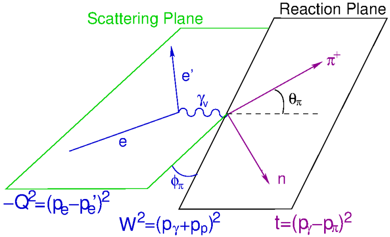
- The physical cross section for the electroproduction process is given by -

$$2\pi \frac{d^2\sigma}{dt d\phi} = \epsilon \frac{d\sigma_L}{dt} + \frac{d\sigma_T}{dt} + \sqrt{2\epsilon(\epsilon+1)}\frac{d\sigma_{LT}}{dt}\cos\phi + \epsilon\frac{d\sigma_{TT}}{dt}\cos 2\phi,$$

$$\epsilon = \left(1 + 2\frac{(E_e - E_{e'})^2 + Q^2}{Q^2}\tan^2\frac{\theta_{e'}}{2}\right)^{-1}$$

- $\epsilon \rightarrow$ Virtual photon polarisation

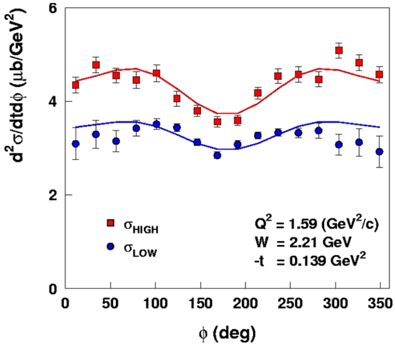
- L-T separation required to isolate σ_L from σ_T
- Need data at lowest $-t$ possible, σ_L has maximum pole contribution here



Measuring $\frac{d\sigma_L}{dt}$ at JLab

- Rosenbluth separation required to isolate σ_L
  - Fix W, Q^2 and $-t$, measure cross section at two beam energies
  - Carry out simultaneous fit at two different ϵ values to determine interference terms

- Careful control of point-to-point systematics crucial, $1/\Delta\epsilon$ error amplification in σ_L
- Spectrometer acceptance, kinematics and efficiencies must all be carefully studied and understood



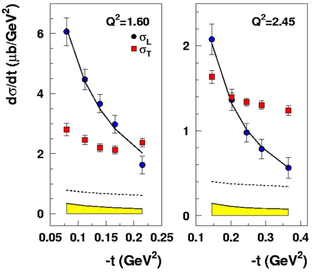
T. Horn, et al., PRL 97(2006) 192001

$F_\pi(Q^2)$ 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

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

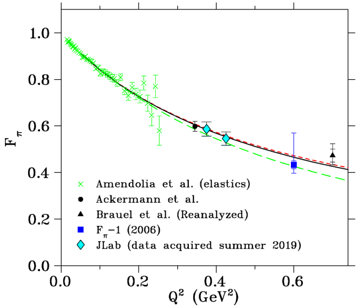


Error bars indicate statistical and random (pt-pt) systematic uncertainties in quadrature. Yellow band indicates the correlated (scale) and partly correlated (t-corr) systematic uncertainties.
$\Lambda_\pi^2 = 0.513, 0.491\ GeV^2$, $\Lambda_\rho^2 = 1.7\ GeV^2$
T. Horn, et al., PRL 97(2006) 192001

F_π Validation - Electroproduction Cross Check

- Low Q^2 data is an important test
  - Does electroproduction really measure the on-shell form factor?

- Test with $p(e, e'\pi^+)n$ measurements at same kinematics as $e\pi^+$ elastics
- New data points at $Q^2 = 0.375$ and 0.425 GeV^2, DESY (Ackermann) point at 0.35 GeV^2
- -t closer to pole than DESY data, 0.008 GeV^2 vs 0.013 GeV^2



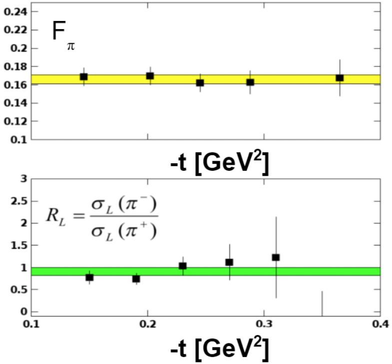
Amendolia, et al., NPB 277(1986) p168, P. Brauel, et al., ZPhysC (1979), p101, H. Ackerman, et al., NPB137 (1978), p294

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 -

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

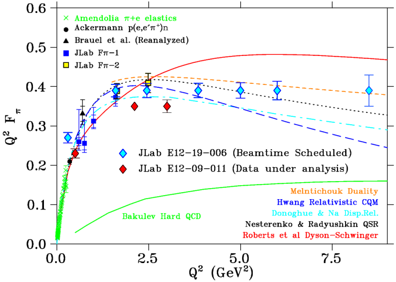
- Will test at $Q^2 = 1.6, 3.85, 6.0\ GeV^2$



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)

Current and Projected JLab F_π Data

- JLab 12 *GeV* program includes measurements of F_π to higher Q^2
- JLab HallC is the only facility worldwide that can perform this measurement
- New overlap points at $Q^2 = 1.6, 2.45$ will be closer to pole to constrain $-t_{min}$ dependence
- Check π^+/π^- ratios at modest Q^2 to test t-channel dominance



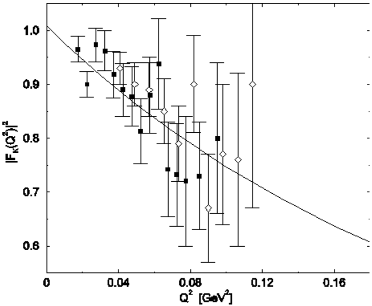
- New low Q^2 point will provide best comparison of the electroproduction extraction of F_π vs elastic $\pi + e$ data

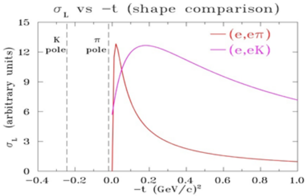
F_K Measurement at JLab

- 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





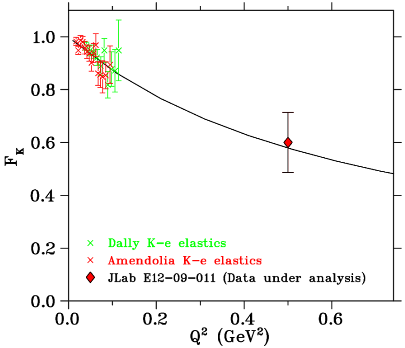
Amendolia, et al., PLB178(1986)435

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 -

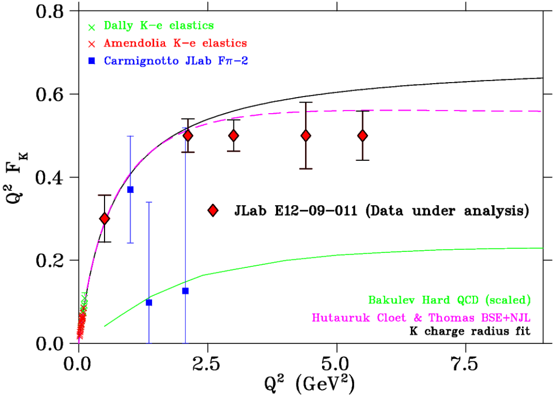
$$\frac{\sigma_L\left[p(e,e'K^+)\Sigma^0\right]}{\sigma_L\left[p(e,e'K^+)\Lambda^0\right]}$$

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



Current and Projected JLab F_K Data

- Points with projected errors shown below
- Data has all been acquired and analysis is in progress
- y positioning of points arbitrary



Form Factors at the EIC

- JLab measurements push the Q^2 reach of 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 $Q^2 = 10 - 40\ GeV^2$
- What is the size and range of interference between emergent mass and the Higgs-mass mechanism?
  $\rightarrow$ Need F_K data for $Q^2 = 10 - 20\ GeV^2$
- Beyond what is possible at JLab in the 12 GeV era
  - Need a different machine $\rightarrow$ **The Electron-Ion Collider (EIC)**

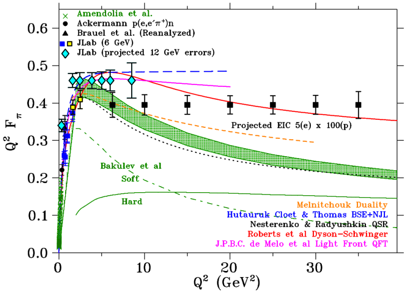
DEMP Studies at the EIC

- Measurements of the $p(e, e'\pi^+ n)$ reaction at the EIC have the potential to 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

EIC Kinematic Reach for F_π

Assumptions

- $5(e^-)$ on $100(p)$
- $\int \mathcal{L} = 20\ fb^{-1}yr^{-1}$
- Clean identification of $p(e, e'\pi^+ n)$
- Syst.Unc: 2.5% pt-pt, 12% scale
- $R = \sigma_L/\sigma_T = 0.013 - 0.14$ at lowest $-t$ from VR model
- $\delta R = R$ Syst.Unc in model subtraction to isolate σ_L
- π pole dominance at small $-t$ confirmed in $^2H\ \pi^+/\pi^-$ ratios



- Results look promising, but need further studies and further energy combinations

J Arrington et al 2021 J. Phys. G: Nucl. Part. Phys. 48 075106

Summary and Outlook

- New high Q^2 F_K data already acquired
  - Analysis in progress → Results ∼ 2023-2024
- Low Q^2 F_π data acquired
  - Analysis in progress → Results ∼ 2023-2024
- New high Q^2 F_π, experimental run this summer and in 2022
- EIC has the potential to push the Q^2 reach even further
- Work already featured in the EIC yellow report
- Now working closely with detector proto-collaborations
  - Carrying out feasibility studies
  - Existing DEMP event generator utilised
  - Kaon event generator in progress, hoping to test soon
  - **Activities are a priority for the ECCE Diffractive and Tagging group**

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?

S.J.D. Kay, D. Gaskell, T. Horn, G.M. Huber, P. Markowitz, V. Berdnikov, J. Roche, P. Stepanov, C. Yero, N. Heinrich, M. Junaid, V. Kumar , J. Murphy, R. Trotta, A. Usman

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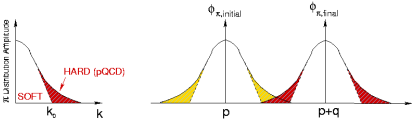
Backup Zone

Charged Meson Form Factors

- Simple $q\bar{q}$ valence structure of mesons makes them an excellent testing ground
- Pion form factor , F_π, is the overlap integral -

$$F_\pi(Q^2) = \int \phi_\pi^*(p)\phi_\pi(p+q)dp$$

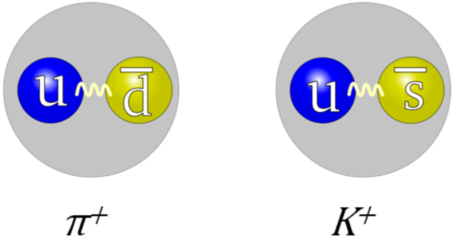


- Meson wave function can be split into ϕ_π^{soft} $(k < k_0)$ and ϕ_π^{hard}, the hard tail
  - Can treat ϕ_π^{hard} in pQCD, cannot with ϕ_π^{soft}
- Study of Q^2 dependence of form factor focuses on finding description of hard and soft contributions

Form Factors as a Model Test Case

- At very large Q^2, F_π and F_K can be calculated using pQCD
- What is the structure of π^+ or K^+ at all Q^2?
  - At what Q^2 do pQCD contributions dominate?
- Difficult to answer, both "hard" and "soft" components (e.g. gluonic effects) need to be considered
  - Non perturbative components of higher twist strongly cancel soft components, even at moderate Q^2
    Braun et al., PRD 61(2000)073004
- Many model calculations exists but...
  Reliable $F_\pi(Q^2)$ and $F_K(Q^2)$ data needed to establish the role of hard vs soft contributions at moderate Q^2
- Form Factor program is unique to JLab (until the EIC)

The Charged Kaon Form Factor



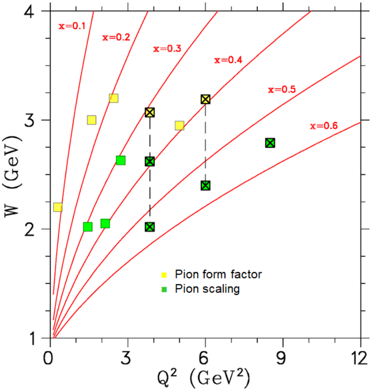
- In the hard scattering limit, pQCD predicts F_π and F_K will behave similarly -

$$\frac{F_K(Q^2)}{F_\pi(Q^2)} \rightarrow \frac{f_K^2}{f_\pi^2}$$

- Should compare the magnitude and Q^2 dependences of both form factors

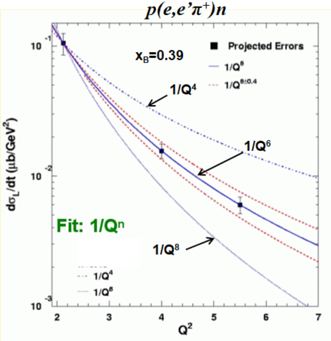
E12-12-006 - Optimised Run Plan

- Points along vertical lines allow F_π values at different distances from the pion pole
- Check model accounts for -
  - π^+ production mechanism
  - Spectator nucleon
  - Off-shell (t-dependent) effects
- Points along red curves allow $1/Q^n$ scaling tests at fixed x



$p(e,e'\pi^+)n$ Q^{-n} Hard-Soft Factorisation Test

- QCD counting rules predict the Q^{-n} dependence of the $p(e,e'\pi^+)n$ cross sections in Hard Scattering Regime -
  - σ_L scales to LO as Q^{-6}
  - σ_T scales as Q^{-8}
  - As Q^2 becomes large, $\sigma_L \gg \sigma_T$

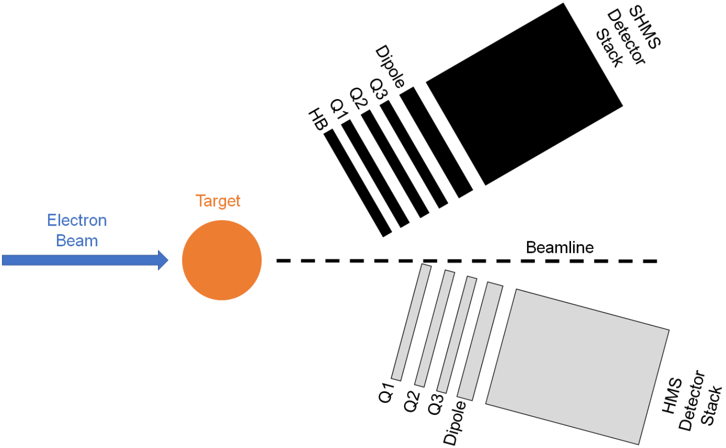


- Experimental validation of onset of hard scattering regime is essential for reliable interpretation of JLab GPD program results
  - If σ_L becomes large, it would allow leading twist GPDs to be studied
  - If σ_T remains large, it could allow for transversity GPD studies

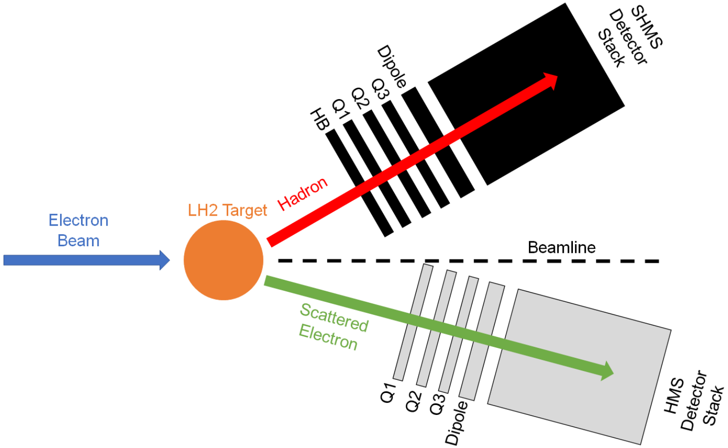
Hall C in the 12 GeV era

- Hall C is designed to measure precision differential cross sections and form factors
- Two advanced, rotatable, high resolution magnetic spectrometers
  - **HMS** - High Momentum Spectrometer
  - **SHMS** - Super High Momentum Spectrometer
- The SHMS was added as part of the 12 GeV upgrade program
  - The SHMS replaced the SOS
- Capable of operating at high rates across a wide range of configurations in angle and momentum

Hall C in the 12 GeV era



Hall C in the 12 GeV era - KaonLT Experiment



SHMS Detector Stack

- SHMS detects hadrons
- HMS detects electrons
- Wide angular and momentum range for each
- SHMS Aero and HGC used for PID
  - Aerogel $\rightarrow K/p$ separation
    - Four different n used
  - HGC $\rightarrow K/\pi$ separation

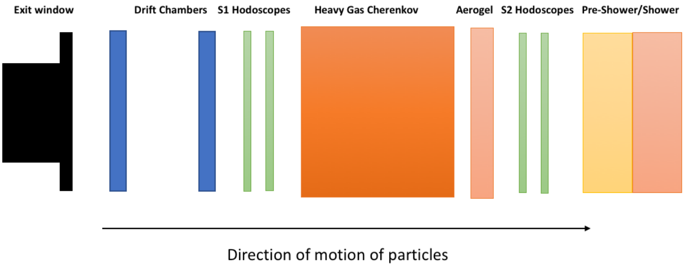


Image Credit - A. Usman University of Regina

Physics Settings - Acquired

- All physics settings for the kaon (E12-09-011) and 3 PAC days worth of settings for the pion (E12-19-006) already acquired through various beamtime periods in 2018/2019

E_{Beam}/GeV	Q^2/GeV^2	W/GeV	x	ϵ
10.6 & 8.2	5.5	3.02	0.40	0.53/0.18
10.6 & 8.2	4.4	2.74	0.40	0.72/0.48
10.6 & 8.2	3.0	3.14	0.25	0.67/0.39
10.6 & 6.2	3.0	2.32	0.40	0.88/0.57
10.6 & 6.2	2.115	2.95	0.21	0.79/0.25
4.9 & 3.8	0.5	2.40	0.09	0.70/0.45
4.6, 3.7 & 2.8	0.38	2.20	0.087	0.781/0.629/0.286

Physics Settings - To Be Acquired Form Factor Points

- Many physics settings still need to be acquired for the pion
- Long and complex experimental run
  - **Angles as small as** $\theta_{HMS} = 10.62^{\circ}$ **and** $\theta_{SHMS} = 5.50^{\circ}$
  - Hard work and contribution of our collaborators is **vital** and much appreciated!
- LD2 runs as well

E_{Beam}/GeV	Q^2/GeV^2	W/GeV	x	ϵ
11.0/8.8/6.7	1.60	3.00	0.165	0.817/0.689/0.408
11.0/6.7	1.60	3.00	0.165	0.817/0.408
11.0/8.8/8.0	2.45	3.20	0.208	0.709/0.505/0.383
11/9.9/8.8/8.0	3.85	3.07	0.311	0.666/0.572/0.436/0.301
11.0/8.0	3.85	3.07	0.311	0.666/0.301
11.0/9.9/8.0	5.00	2.95	0.390	0.633/0.530/0.238
11.0/9.9/9.2	6.00	3.19	0.392	0.452/0.304/0.184

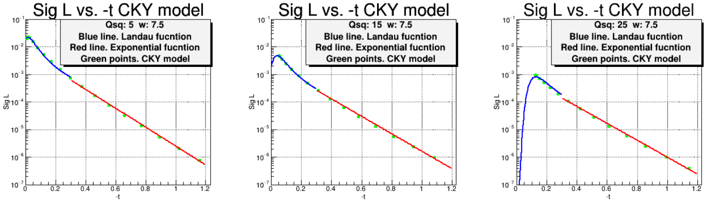
Upcoming Beamtime

- Many settings for E12-19-006 scheduled for Jun-Oct 2021
  - 4 months of beam! Lots of manpower will be needed

E_{Beam}/GeV	Q^2/GeV^2	W/GeV	x	ϵ	Note
8.0	2.45	3.20	0.208	0.383	
8.0	3.85	3.07	0.311	0.301	
9.9	3.85	3.07	0.311	0.572	
8.0	3.85	3.07	0.311	0.301	Deuterium
8.0	5.00	2.95	0.390	0.238	
9.9	5.00	2.95	0.390	0.5305	
9.2	6.00	3.19	0.392	0.184	
9.9	6.00	3.19	0.392	0.304	
6.0	3.85	2.02	0.546	0.582	Reaction mechanism
8.0	6.00	2.40	0.551	0.449	Reaction mechanism
8.0	6.00	2.40	0.551	0.449	Reat. Mech., Deut
9.2	8.5	2.79	0.552	0.156	Reaction mechanism

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 $5 < Q^2 < 35$, $2 < W < 10$, $0 < -t < 1.2$



Isolating σ_L from σ_T in an e-p Collider

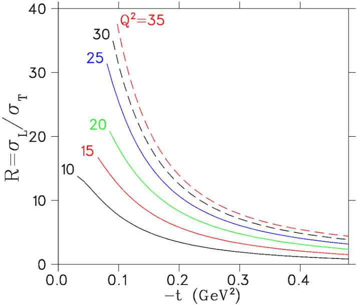
- For a collider -

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

  - 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 ($\sim 10\ GeV$), 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!



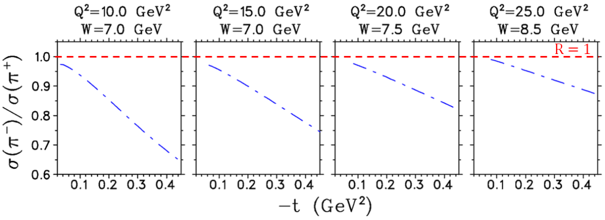
Predictions are assuming $\epsilon > 0.9995$ with the kinematic ranges seen earlier

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

- 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