Extraction of the $\cos\phi$ and $\cos 2\phi$ cross-section moments of charged kaon SIDIS

Áron Kripkó, Stefan Diehl

Justus-Liebig University

akripko@jlab.org

March 5, 2025

Experimental Physics II

JUSTUS-LIEBIG-UNIVERSITÄT GIESSEN

Jefferson Lab

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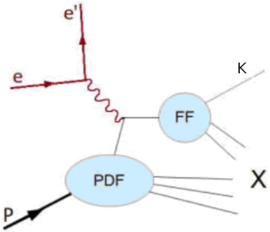
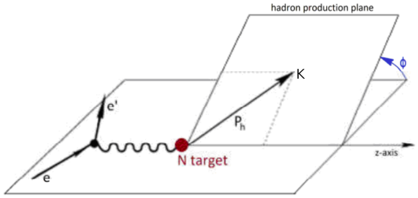
Physics motivation

- Kaon Sidis: $e^- p^+ \to e^- K^+ X$
- Moments, averaging beam polarisation, un-polarised target:
- $d\sigma = A_0(1 + A_{UU}^{\cos\phi} \cos\phi + A_{UU}^{\cos 2\phi} \cos 2\phi)$





Process (left) and kinematics (right) of single kaon SIDIS

Physics motivation

- Structure functions - moments - convolution of FFs and TMDs:
- $F_{UU} = \frac{Q^2(1-\epsilon)A_0}{\pi\alpha^2(1+\frac{\gamma^2}{2x_B})}$
- $\frac{F_{UU}^{\cos\phi}}{F_{UU}} = \frac{A_{UU}^{\cos\phi}}{\sqrt{2\epsilon(1+\epsilon)}} \quad - \quad F_{UU}^{\cos\phi} = \frac{2M}{Q}\zeta\left(-\frac{\hat{h}k_T}{M_h}xhH_1^{\perp} - \frac{\hat{h}p_T}{M}f_1D_1 + ...\right)$
- $\frac{F_{UU}^{\cos 2\phi}}{F_{UU}} = \frac{A_{UU}^{\cos 2\phi}}{\epsilon} \quad - \quad F_{UU}^{\cos 2\phi} = \zeta\left(-\frac{2(\hat{h}k_T)(\hat{h}p_T)-k_Tp_T}{MM_h}h_1^{\perp}H_1^{\perp} + ...\right)$
- Access to Boer-Mulders - $h_1^{\perp}$ - distribution of transversely polarized quarks in an unpolarized hadron
- Cahn effect - kinematic effect due to the intrinsic momentum of quarks in the nucleon

Particle ID and dataset - pion moments and kaon SSA notes

- Eventbuilder particle ID
- Fiducial cuts - Richards pion note
- Electron and hadron PID refinements from the pion note:
    - PCAL minimum energy deposition
    - ECAL sampling fraction cut
    - z-vertex position cut
    - Cut on vertex difference
    - $|\chi^2_{PID}| < 3$
- Use machine learning for Kaon ID
- QA cuts
- Topology: at least one good electron and at least one good Kaon
- Use inbending 10.6 GeV (2018) RG-A dataset:
    - 5032-5419

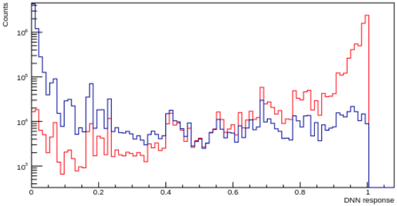
Kinematic cuts - pion moments and kaon SSA notes

- For optimal PID:
  - $y < 0.75$
  - $1.25 \text{ GeV} < p_K < 3 \text{ GeV}$
  - Only use forward detector for Kaons:
    - $5^\circ < \theta_K < 35^\circ$
    - $5^\circ < \theta_e < 35^\circ$
- To select the deep inelastic scattering region:
  - $W > 2 \text{ GeV}$
  - $Q^2 > 2 \text{ GeV}^2$
- To reject the kaons from the fragmentation region:
  - $x_F > 0$
  - $z > 0.3$
- To reduce the contamination from exclusive processes:
  - $M_X > 1.6 \text{ GeV}$
  - $z < 0.7$

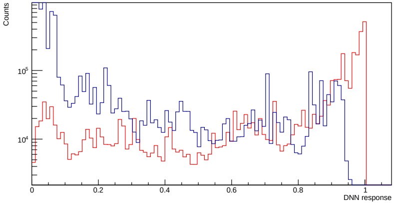
Machine learning

- Reduce pion contamination in the kaon sample
- Use most of the available detector information available:
  - EventBuilder PID
  - Momentum and β
  - Deposited energies in the 3 calorimeters
  - Calorimeter time information
  - Cluster moments and shower profiles
  - HTCC number of photoelectrons and time information
  - Energy depositions and time information in the 3 FTOF layers
- Significantly reduces the pion contamination in the kaon sample
- The results were cross-checked with an other MC sample and with the RICH

DNN response - pass 1 and 2

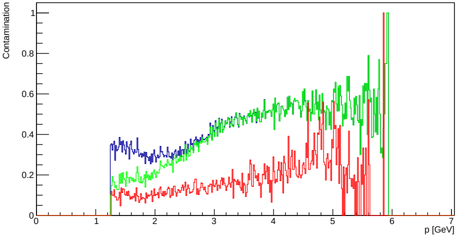


Pass 1 MC - ideal

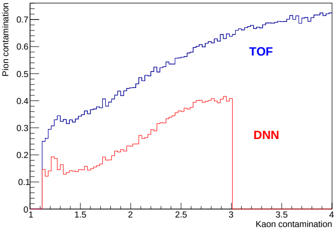


Pass 2 MC

Pion contamination - pass 1 and 2



Pass 1 MC - ideal, looser matching

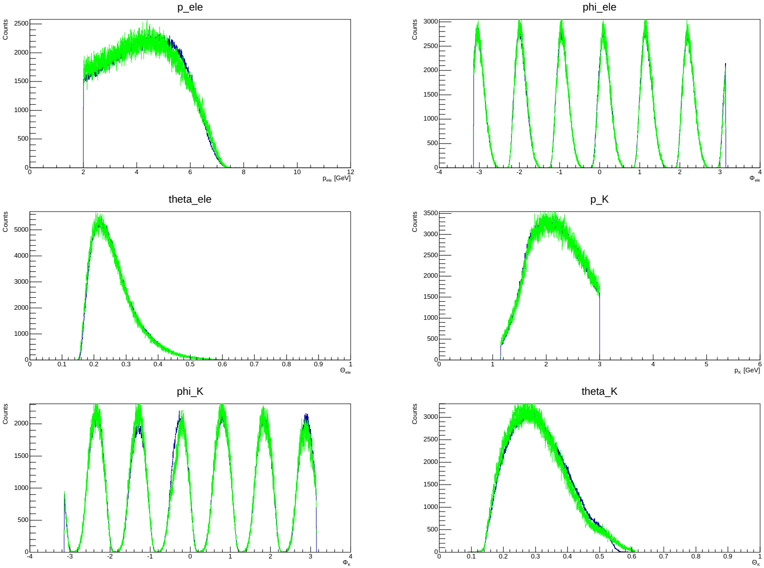


Pass 2 MC

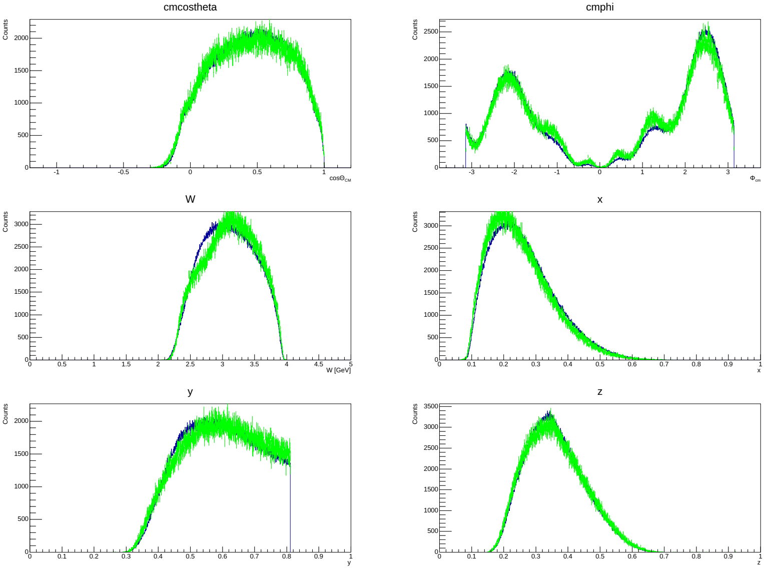
Monte-Carlo

- Good agreement with data
- 10% statistics to data - more in progress
- Low statistics - 1D binning in Q^2 for first look
- Use smearing to get realistic resolution
- Similar acceptance - can be used for unfolding

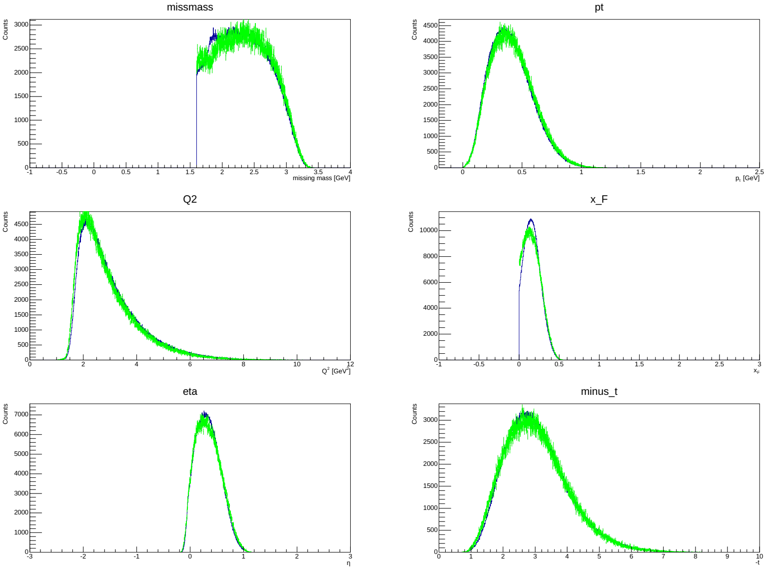
Kinematics - MC-data comparison



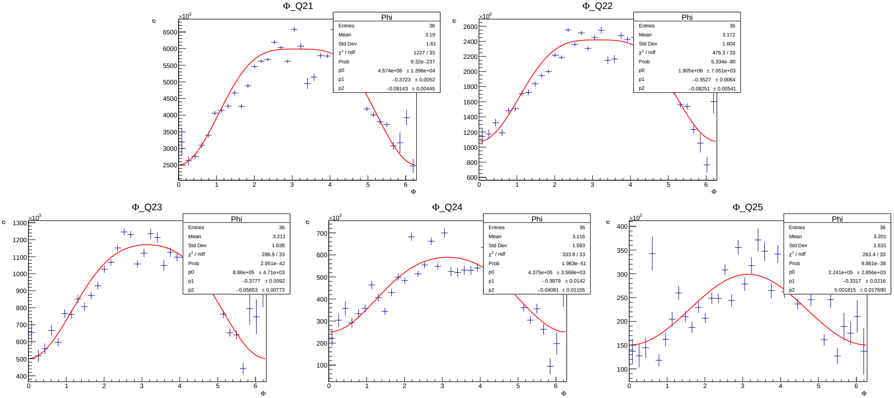
Kinematics - MC-data comparison



Kinematics - MC-data comparison



Φ distribution and fit examples - 36 bins - Q^2



Unfolding

- Use the same RooUnfold package as Richard
- Use Root interface instead of Python

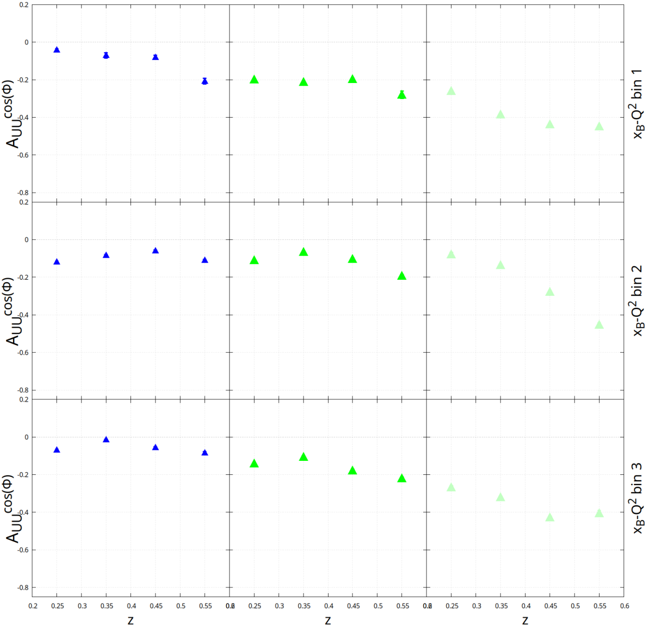
- Acceptance correction
- Bin migration effects
- Pion contamination

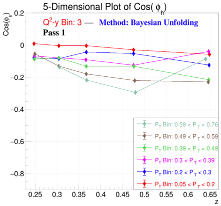
- Response matrix - matched generated and reconstructed MC
- Generated distribution - includes missed particles
- Reconstructed distribution - includes fakes (pions)

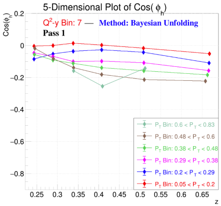
- Data $\rightarrow$ Acceptance (& bin migration) corrected distribution with subtracted pions

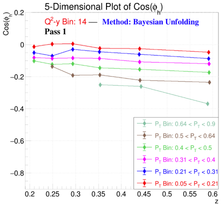
Cross-check with pions

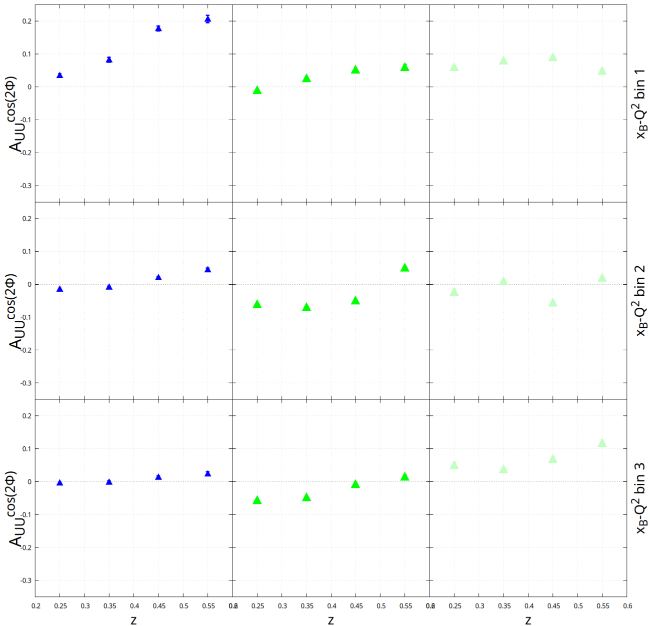
- Same framework and code as for kaons
- Binning to be compared Richards' scheme (3, 7, 14 - $Q^2 - y$):
  - $x_B < 0.2$ (average $Q^2 \sim 2.1$ GeV^2) $-$ $Q^2 < 2.4$ GeV^2 and $0.45 < y < 0.55$
  - $x_B > 0.2$ and $Q^2 < 3.3$ GeV^2 $-$ 2.4 GeV$^2 < Q^2 < 2.9$ GeV^2 and $0.45 < y < 0.55$
  - $x_B > 0.2$ and $Q^2 > 3.3$ GeV^2 $-$ 3.7 GeV$^2 < Q^2 < 5.3$ GeV^2 and $0.45 < y < 0.55$
- 3 P_T bins:
  - $P_T < 0.33$ GeV
  - 0.33 GeV$< P_T < 0.66$ GeV
  - $P_T > 0.66$ GeV

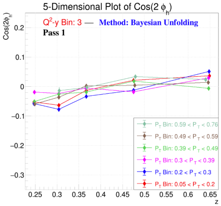

$A_{UU}^{\cos(\Phi)}$
x_B-Q^2 bin 1
x_B-Q^2 bin 2
x_B-Q^2 bin 3
z


5-Dimensional Plot of Cos(ϕ_h)
Q^2-y Bin: 3 — Method: Bayesian Unfolding
Pass 1
P_T Bin: 0.59 < P_T < 0.76
P_T Bin: 0.49 < P_T < 0.59
P_T Bin: 0.39 < P_T < 0.49
P_T Bin: 0.3 < P_T < 0.39
P_T Bin: 0.2 < P_T < 0.3
P_T Bin: 0.05 < P_T < 0.2


5-Dimensional Plot of Cos(ϕ_h)
Q^2-y Bin: 7 — Method: Bayesian Unfolding
Pass 1
P_T Bin: 0.6 < P_T < 0.83
P_T Bin: 0.48 < P_T < 0.6
P_T Bin: 0.38 < P_T < 0.48
P_T Bin: 0.29 < P_T < 0.38
P_T Bin: 0.2 < P_T < 0.29
P_T Bin: 0.05 < P_T < 0.2


5-Dimensional Plot of Cos(ϕ_h)
Q^2-y Bin: 14 — Method: Bayesian Unfolding
Pass 1
P_T Bin: 0.64 < P_T < 0.9
P_T Bin: 0.5 < P_T < 0.64
P_T Bin: 0.4 < P_T < 0.5
P_T Bin: 0.31 < P_T < 0.4
P_T Bin: 0.21 < P_T < 0.31
P_T Bin: 0.05 < P_T < 0.21


$A_{UU}^{cos(2\Phi)}$
x_B-Q^2 bin 1
x_B-Q^2 bin 2
x_B-Q^2 bin 3
z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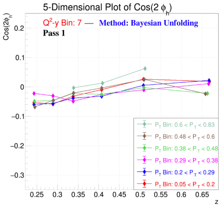
z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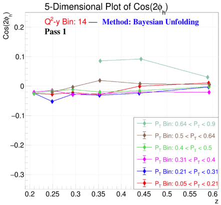
z


5-Dimensional Plot of Cos(2ϕ_h)
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Pass 1
Cos(2ϕ_h)
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P_T Bin: 0.5 < P_T < 0.64
P_T Bin: 0.4 < P_T < 0.5
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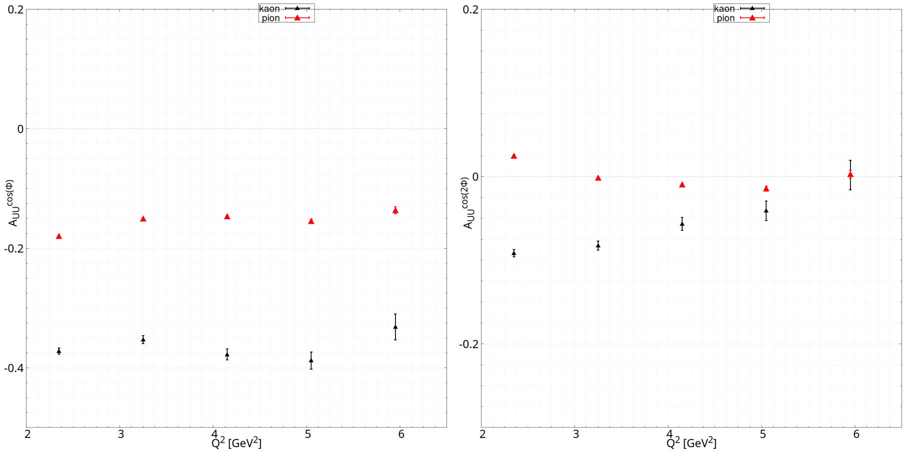
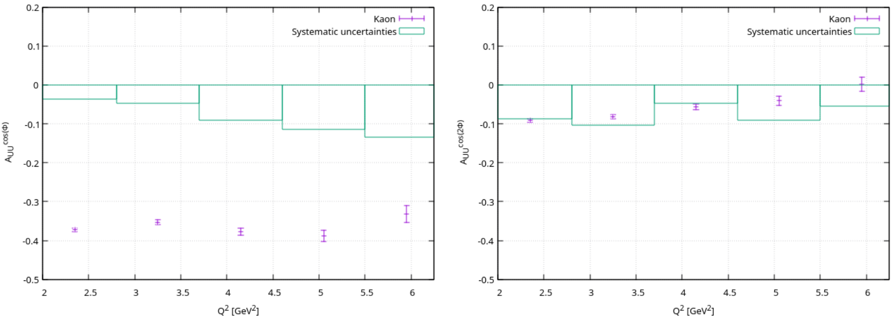
z


kaon
pion
$A_{UU}^{\cos(\Phi)}$
Q^2 [GeV^2]
0.2
0
-0.2
-0.4
2
3
4
5
6
kaon
pion
$A_{UU}^{\cos(2\Phi)}$
Q^2 [GeV^2]
0.2
0
-0.2
2
3
4
5
6

Systematic uncertainties - first estimates

- Effect of the fiducial cuts
- Difference between the MC and data
- Acceptance effects
- Bin migration and resolution effects
- Contamination of the kaon sample with pions

Total systematic uncertainty



Summary

- First look into kaon SIDIS cross-section cos moments
- Unfolding framework implemented and tested for pions
- Q^2-behavior is reasonable
- First generous systematic uncertainty estimates
- More MC statistics is needed in the future
- Framework for multidimensional analysis is implemented
  - work to be done