Update on the extraction of cos moments for kaon SIDIS

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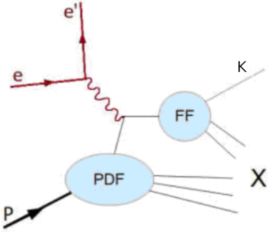
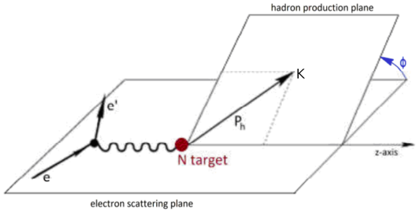
Physics motivation

- 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:
- $F_{UU} = \frac{Q^2(1-\epsilon)A_0}{\pi\alpha^2(1+\frac{\gamma^2}{2x_B})}$
- $\frac{F_{UU}^{\cos\phi}}{F_{UU}} = \frac{A_{UU}^{\cos\phi}}{\sqrt{2\epsilon(1+\epsilon)}} \quad - \quad F_{UU}^{\cos\phi} = \frac{2M}{Q}\zeta\left(-\frac{\hat{h}k_T}{M_h}xhH_1^{\perp} - \frac{\hat{h}p_T}{M}f_1 D_1 + \ldots\right)$
- $\frac{F_{UU}^{\cos 2\phi}}{F_{UU}} = \frac{A_{UU}^{\cos 2\phi}}{\epsilon} \quad - \quad F_{UU}^{\cos 2\phi} = \zeta\left(-\frac{2(\hat{h}k_T)(\hat{h}p_T)-k_T p_T}{MM_h}h_1^{\perp}H_1^{\perp} + \ldots\right)$
- 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

- Eventbuilder particle ID
- Fiducial cuts
- 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

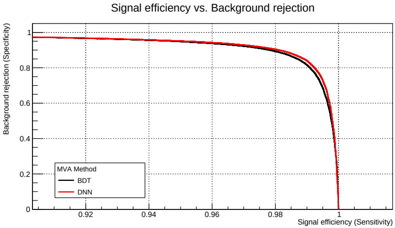
Kinematic cuts

- 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:
  - $M_X > 1.6\ \text{GeV}$
  - $z < 0.7$

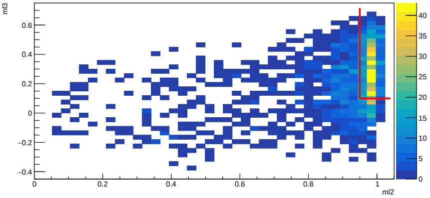
Machine learning

- Reduce pion contamination in the kaon sample
- Use most of the available detector information:
  - Momentum and β
  - θ and ϕ
  - ECAL energy depositions
  - ECAL path/time
  - χ^2_{PID}
  - FTOF energy
  - FTOF path/time
- These inputs are smeared and shifted before training to match data
- Significantly reduces the pion contamination in the kaon sample
- The results were cross-checked with an other MC sample
- DNN - 3 hidden layers, tanh activation function
- BDT - secondary cross check or further tightening

ROC curves and return values



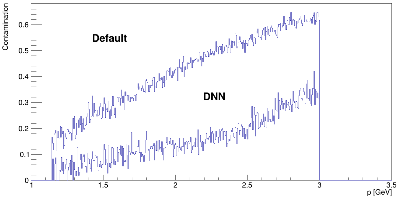
ROC Curves



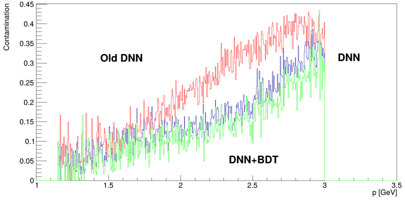
Return values

- Cuts at 0.95 and 0.1
- DNN is slightly better
- BDT can be used for ML related systematics

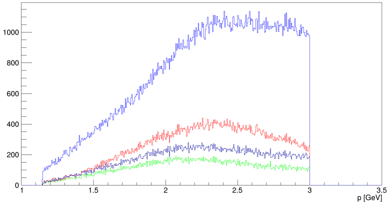
Pion contamination



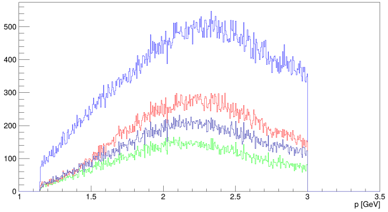
Pion contamination



Contamination with other methods



Detected kaons

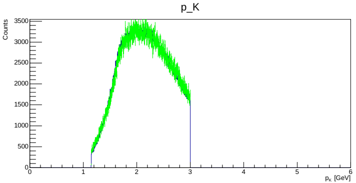


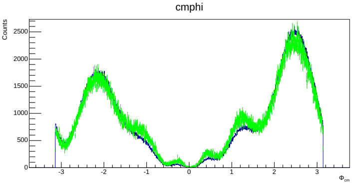
Real kaons

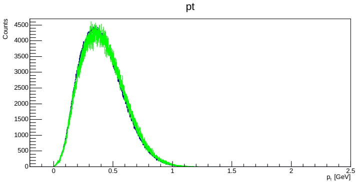
Monte-Carlo

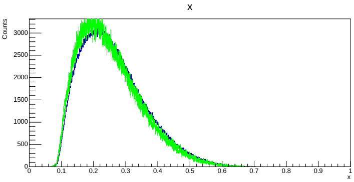
- Good agreement with data
- $\sim 50\%$ statistics to data - more needed
- Low statistics - 1D binning for first look
- Use smearing to get realistic resolution
- Similar acceptance - can be used for unfolding

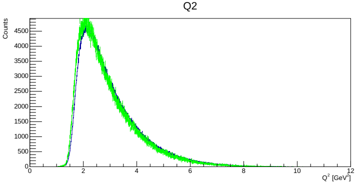
Kinematics - MC-data comparison

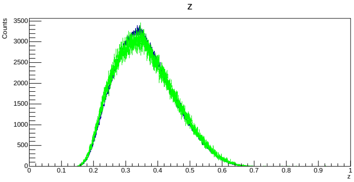




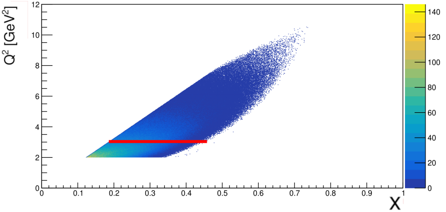


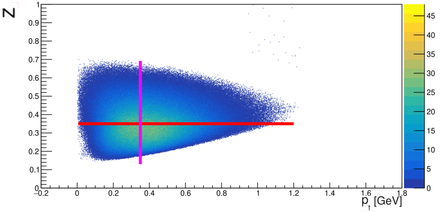






Binning





- 4 bins for multi-D
- 4-9 bins with identical widths for 1D or in the last dimension

Unfolding - acceptance corrections and bin migration

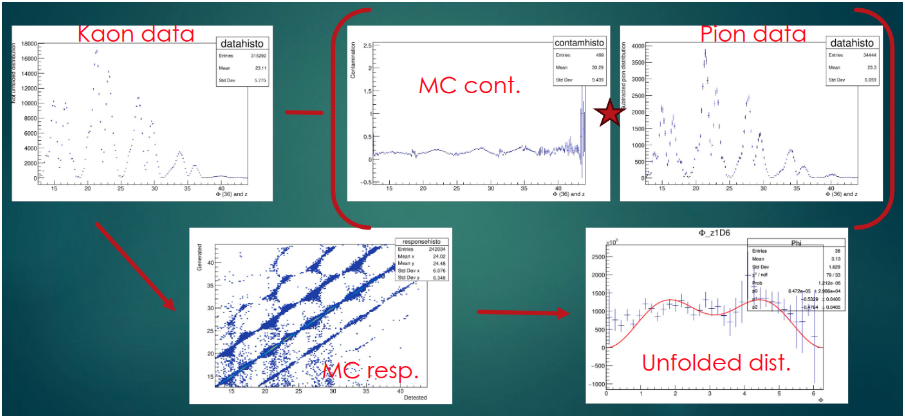
- Use the ROOTs RooUnfold package

- Acceptance correction
- Bin migration effects
- Pion contamination - handled before unfolding - MC scaled
- Φ is momentum dependent - pion data is scaled

- Response matrix - matched generated and reconstructed MC
- Generated distribution - includes missed particles
- Reconstructed distribution - does not includes fakes (pions)

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

Unfolding and analysis procedure



Pion contamination - subtraction

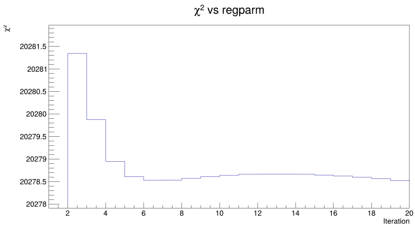
- ϕ is *p*-dependent
- Contamination is *p*-dependent

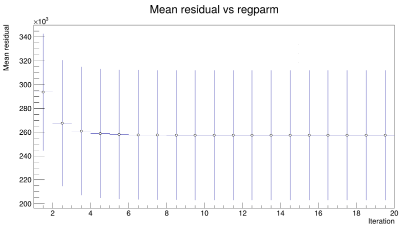
- After DNN $\sim 15\%$ of the kaons are pions
- Kaon distribution from data in flattened bin
- Pion distribution from data in flattened bin - scaled to have same *p*-distribution
- Misidentified pions from MC in flattened bin - scaled to have same *p*-distribution
- "Pure" kaon data is then unfolded with MC response only using matched kaons

- Assume that kaon contamination in pions are negligible
- Assume that MC contamination is accurate

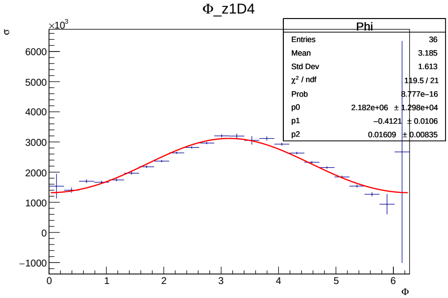
Bayesian unfolding

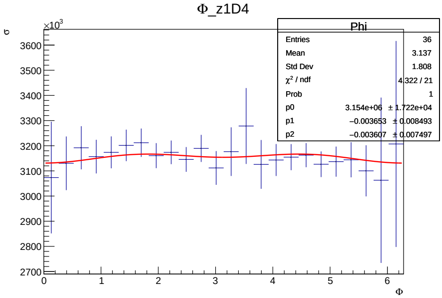
- Multiple unfolding methods implemented - best is Bayesian
- Flattened bins - correction factor for every kinematic and ϕ bin
- Number of iterations optimized for every binning scheme
- Example for Q^2 kaon binning scheme:



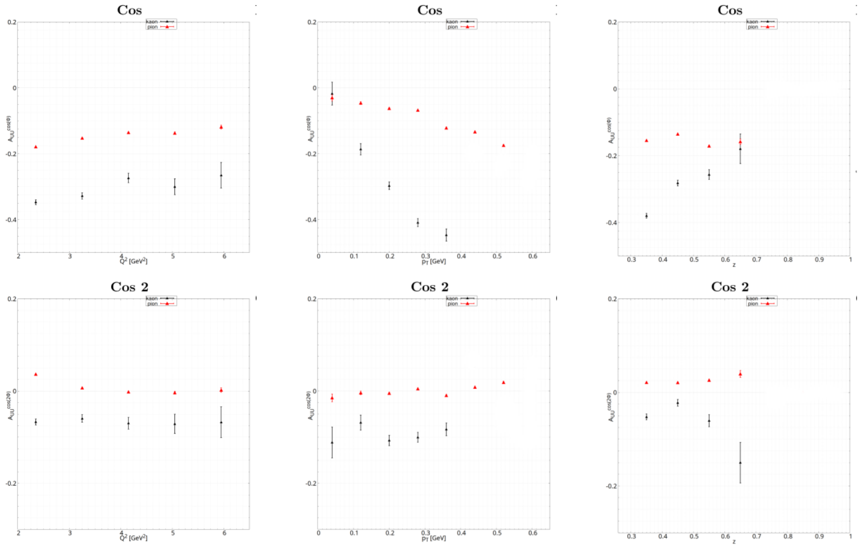


- $d\sigma = A_0(1 + A_{UU}^{\cos\phi}\cos\phi + A_{UU}^{\cos 2\phi}\cos 2\phi)$ - fit unfolded phi distribution
- Closure test - repeat whole process but on MC - should be flat
- Advanced closure test in progress - Injected moments

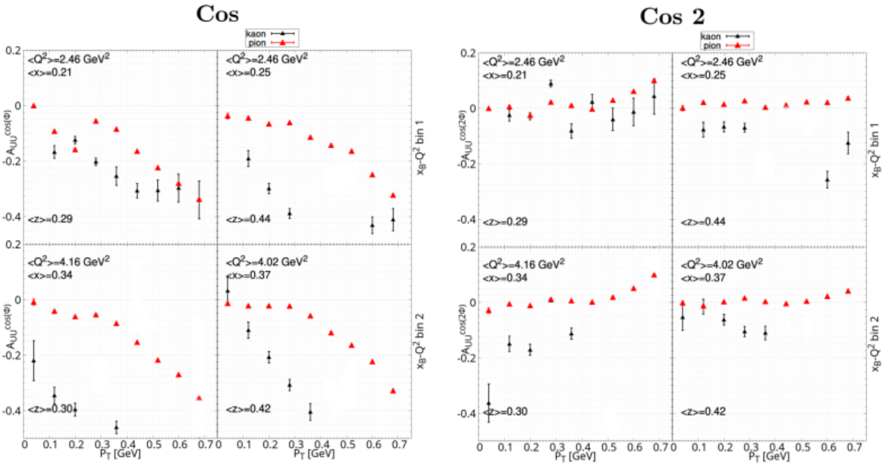




Results - Q^2 - p_T - z



Outlook - multi-D results



Summary and outlook

- Unfolding framework implemented and now stable
- Pion contamination is under control - new, optimized DNN
- 1D binning is possible

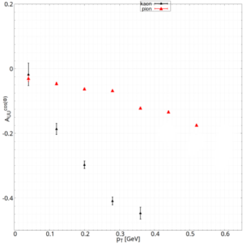
- More MC statistics is needed in the future - multi-D
- Closure tests are promising
- Systematic studies are in progress

- At least 10 times more MC is needed

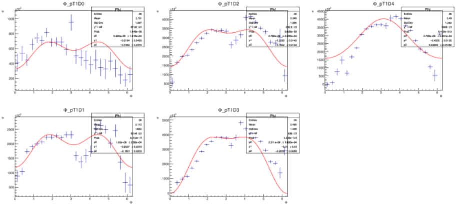
Backup

Results - p_T

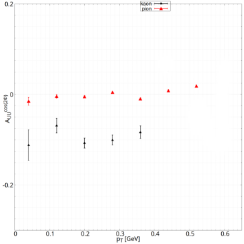
Cos



Data Fit



Cos 2



Closure Test