Unpolarized Kaon electroproduction on Hydrogen and Deuterium target

Vallarino Simone
INFN Ferrara & University of Ferrara
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Semi-Inclusive Deep Inelastic Scattering (SIDIS)

$$e + p \rightarrow e' + H + X \qquad\qquad e + n \rightarrow e' + H + X$$

- Powerful tool to study the inner structure of nucleon, accessing to Transverse Momentum dependent Distribution functions (TMDs)
- The polarization in leptoproduction provides new dimensions for testing QCD
- Spin Asymmetries, in particular the large Single Spin Asymmetries (SSAs), can be related to TMDs
- Complementary measures with π and K can provide information about the Collins fragmentation mechanism
- These measures can be done with the CLAS12 detector, combining the high luminosity and the phase space extended after the 12 GeV upgrade
- To identify the high-momentum K a new Cherenkov detector for PID has been realized and installed in two sectors of CLAS12
- The proposal has been accepted and became the experiment E12-09-008 that is being performed by Run Group A (for Hydrogen) and B (for Deuterium)

SIDIS cross section

$$\frac{d\sigma}{dx\,dy\,d\psi\,dz\,d\phi_h\,dP_{h\perp}^2} =$$
$$\frac{\alpha^2}{xyQ^2}\frac{y^2}{2(1-\varepsilon)}\left(1+\frac{\gamma^2}{2x}\right)\Big\{F_{UU,T}+\varepsilon F_{UU,L}+\sqrt{2\varepsilon(1+\varepsilon)}\cos\phi_h\,F_{UU}^{\cos\phi_h}$$
$$+\varepsilon\cos(2\phi_h)\,F_{UU}^{\cos 2\phi_h}+\lambda_e\sqrt{2\varepsilon(1-\varepsilon)}\sin\phi_h\,F_{LU}^{\sin\phi_h}$$
$$+S_\parallel\left[\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_h\,F_{UL}^{\sin\phi_h}+\varepsilon\sin(2\phi_h)\,F_{UL}^{\sin 2\phi_h}\right]$$
$$+S_\parallel\lambda_e\left[\sqrt{1-\varepsilon^2}\,F_{LL}+\sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_h\,F_{LL}^{\cos\phi_h}\right]$$
$$+|\boldsymbol{S}_\perp|\Big[\sin(\phi_h-\phi_S)\left(F_{UT,T}^{\sin(\phi_h-\phi_S)}+\varepsilon F_{UT,L}^{\sin(\phi_h-\phi_S)}\right)$$
$$+\varepsilon\sin(\phi_h+\phi_S)\,F_{UT}^{\sin(\phi_h+\phi_S)}+\varepsilon\sin(3\phi_h-\phi_S)\,F_{UT}^{\sin(3\phi_h-\phi_S)}$$
$$+\sqrt{2\varepsilon(1+\varepsilon)}\sin\phi_S\,F_{UT}^{\sin\phi_S}+\sqrt{2\varepsilon(1+\varepsilon)}\sin(2\phi_h-\phi_S)\,F_{UT}^{\sin(2\phi_h-\phi_S)}\Big]$$
$$+|\boldsymbol{S}_\perp|\lambda_e\Big[\sqrt{1-\varepsilon^2}\cos(\phi_h-\phi_S)\,F_{LT}^{\cos(\phi_h-\phi_S)}+\sqrt{2\varepsilon(1-\varepsilon)}\cos\phi_S\,F_{LT}^{\cos\phi_S}$$
$$+\sqrt{2\varepsilon(1-\varepsilon)}\cos(2\phi_h-\phi_S)\,F_{LT}^{\cos(2\phi_h-\phi_S)}\Big]\Big\}$$

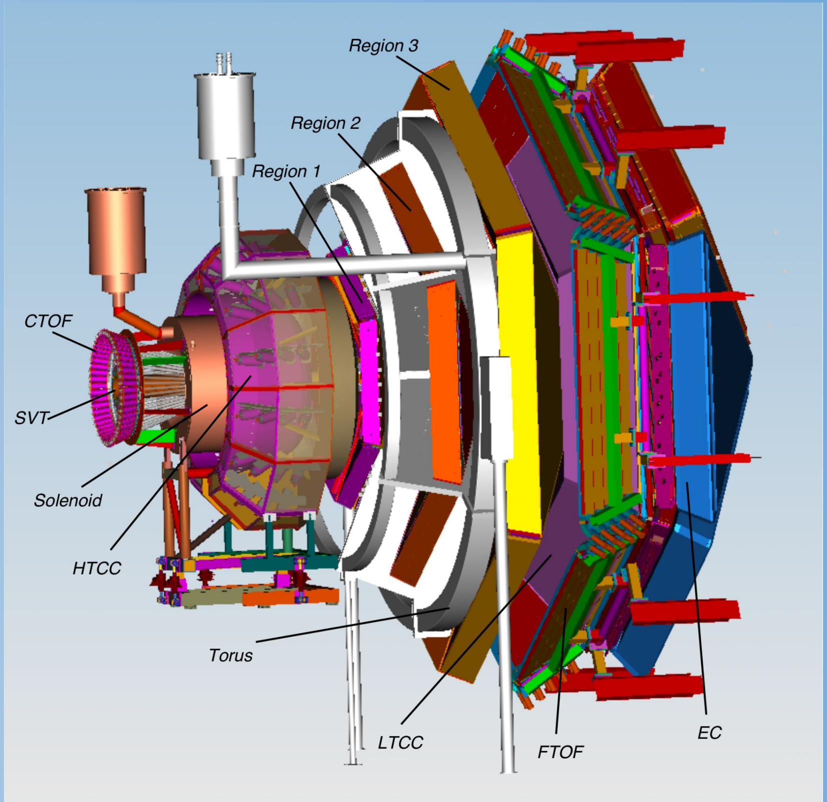
The aim of the experiment is to study the Boer-Mulders distribution functions, the Collins function and the Cahn effect, by measuring three terms of the cross section with unpolarized and longitudinally polarized beams, and with unpolarized H and D targets.

$$F_{UU}^{\cos\phi_h}=\frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\left(xh\,H_1^\perp+\frac{M_h}{M}\,f_1\frac{\tilde{D}^\perp}{z}\right)-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\left(xf^\perp D_1+\frac{M_h}{M}\,h_1^\perp\frac{\tilde{H}}{z}\right)\right]$$
$$F_{UU}^{\cos 2\phi_h}=\mathcal{C}\left[-\frac{2\,(\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T)\,(\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T)-\boldsymbol{k}_T\cdot\boldsymbol{p}_T}{M\,M_h}h_1^\perp H_1^\perp\right],$$
$$F_{LU}^{\sin\phi_h}=\frac{2M}{Q}\,\mathcal{C}\left[-\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{k}_T}{M_h}\left(xe\,H_1^\perp+\frac{M_h}{M}\,f_1\frac{\tilde{G}^\perp}{z}\right)+\frac{\hat{\boldsymbol{h}}\cdot\boldsymbol{p}_T}{M}\left(xg^\perp D_1+\frac{M_h}{M}\,h_1^\perp\frac{\tilde{E}}{z}\right)\right],$$

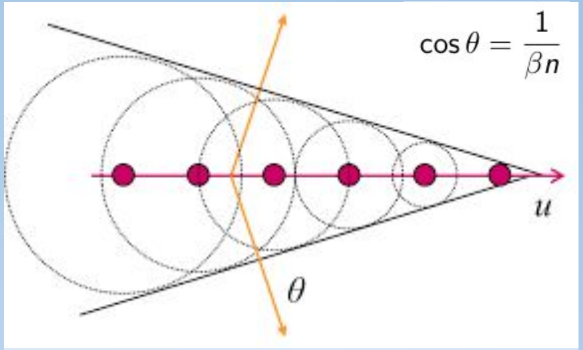
Where $h_1^\perp$ is the Boer-Mulders function, $H_1^\perp$ is the Collins function. The Cahn effect is related to the collinearity of quark process i.e. intrinsic transverse momentum.

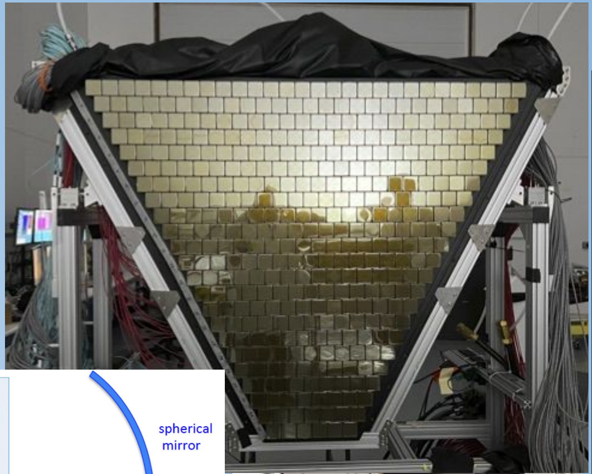
CLAS12 configuration

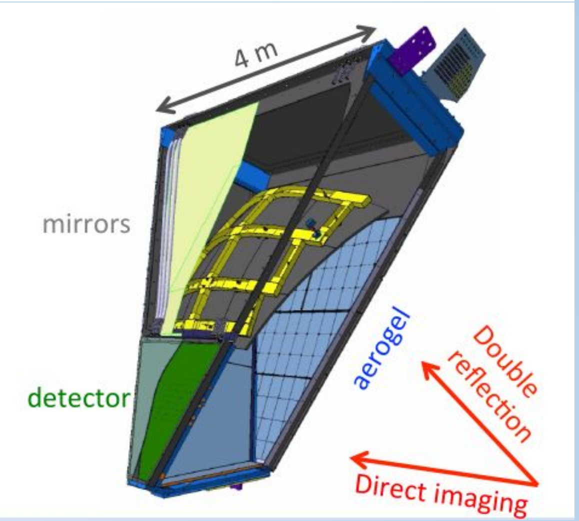
- Unpolarized targets of hydrogen or deuterium
- 11 GeV beam
- Toroidal magnetic field 2T (forward) and solenoid 5T (recoil).
- Standard production system, data acquisition and online monitoring
- The HTCC, LTCC and TOF system provides a good separation:
    - π/K up to 3 GeV/c
    - K/p in 2.5-5 GeV/c momentum range
- In the 3-8 GeV/c it is not possible to well separate π/K/p then an extension in PID momentum range is needed
- Two modules of Ring Imaging Cherenkov has been installed in sector 1 and 4 of the CLAS12 detector (completed in June 22)

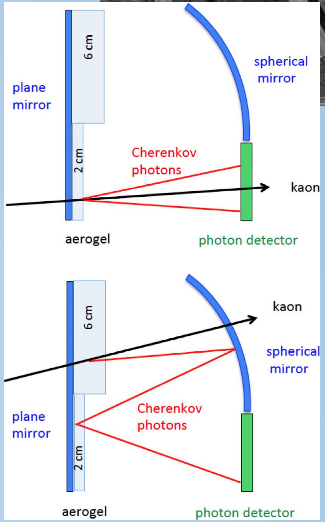


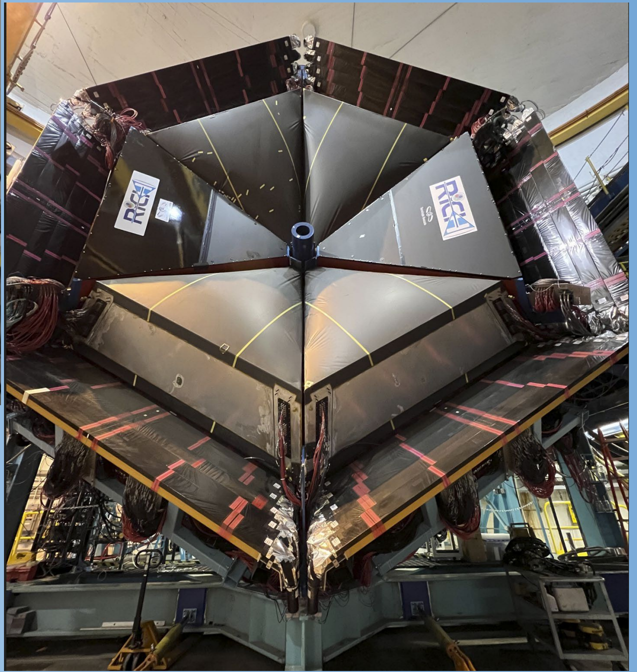
The CLAS12 Ring Imaging Cherenkov



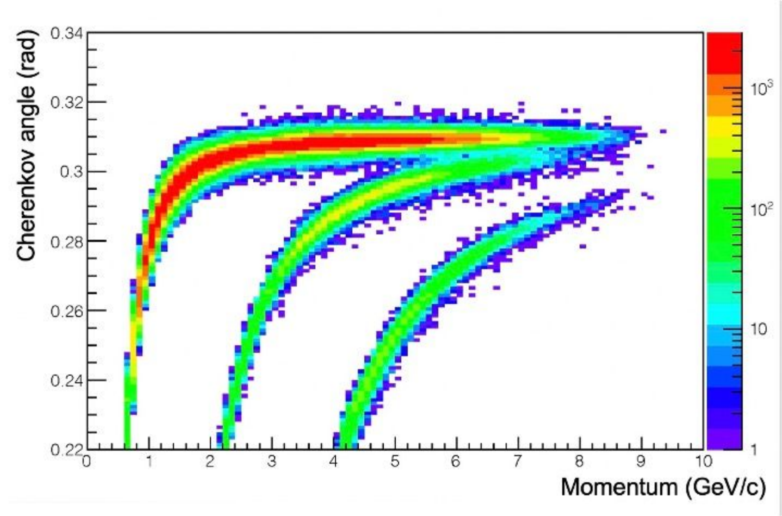


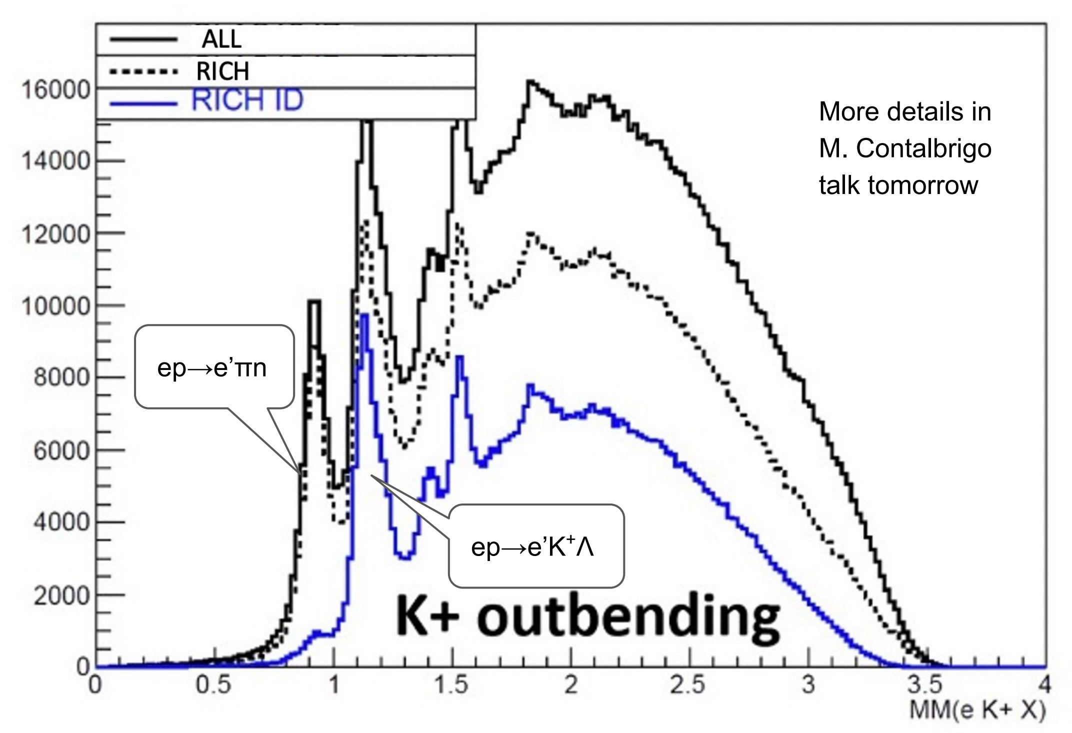






RICH preliminary performance





More details in M. Contalbrigo talk tomorrow

Left: hadron separation provided by RICH

Right: check with semi-inclusive channel

$$ep \rightarrow e'H^+X$$

Data analysis

Selection of *ep→e'KX* events, improved by the RICH

Definition of x_B, Q^2, z_k, P_T binning

Extraction of the cross section and the single spin asymmetry

$$\frac{d^5\sigma}{dx_B\, dQ^2\, dz_K\, d^2P_T}$$

Fit with:

$$A(1 + B\cos 2\phi + C\cos\phi)$$

$$SSA \propto \frac{N^+ - N^-}{N^+ + N^-}$$

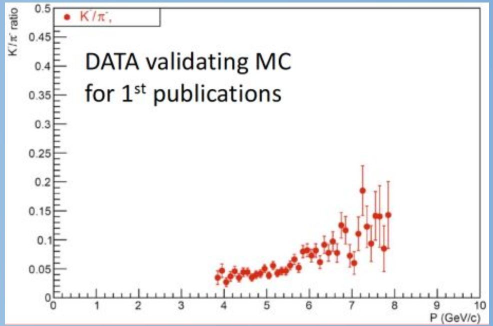
$$\frac{A'\sin\phi}{(1 + B'\cos 2\phi + C'\cos\phi)}$$

Extract $A^{\cos\phi}_{UU}$, $A^{\cos 2\phi}_{UU}$ and $A^{\sin\phi}_{LU}$ from fit parameters

Expected statistical and systematic errors

- The expected systematic errors have been evaluated using a fast Monte Carlo simulation of inclusive and semi-inclusive DIS with CLAS12 acceptance folded in.
- This SSA measurement is rather insensitive to uncertainties in acceptance and charge normalization
- Other sources include the longitudinal to transverse photo absorption cross section ratio and the beam polarization (for the sinϕ term)
- A source of systematic error is the possible contamination of single K sample with K from decays of exclusive K* meson
- The statistics for K is one order of magnitude less than π, as well as evaluated with MC and confirmed by the first data.
- To reduce the statistic errors the request is 54 beam days plus 2 commissioning days.

Item	$A_{UU}^{\cos 2\phi}$	$A_{UU}^{\cos\phi}$	$A_{LU}^{\sin\phi}$
beam polarization	-	-	3%
acceptance corrections	4%	4%	2%
radiative corrections	3%	3%	3%
fitting procedure	4%	4%	3%



Expected results

- This experiment will simultaneously collect SIDIS data with π and K using H and D targets.
- The extraction of cosϕ, cos2ϕ and sinϕ moments will provide information on Boer-Mulders function, the Collins function and the Cahn effect.
- The measurements for charged K with two targets, combined with π measurement, will allow the extraction of Collins analyzing power ratios, providing information about the polarized FFs and flavor sensitivity of PDFs.
- The measurements of azimuthal asymmetries will provide coinstains on the TMDs and will allow more precise test of factorization and the investigation of the Q^2 dependence, enabling to study the leading-twist and higher-twist nature of the corresponding observables.
- The measurement of the P_T dependence of Boer-Mulders asymmetry will allow to check of high P_T predictions and study transition from non-perturbative to perturbative regime.
- Combining analysis of CLAS12 data and HERMES measurement in high Q^2 domain will provide information on the Boer-Mulders funcion, that allows to study correlations between transverse spin and transverse momenta of quarks.

My role in this analysis

- Since november 2020 I am working with the CLAS12 RICH group, in particular I was involved in the second module assembling, installation and commissioning.
- I just started to study SIDIS and the SSA
- I will start to analyze the CLAS12 data looking for the Single Spin Asymmetry and extracting the $A^{\sin\phi}_{LU}$ term.

$$SSA \propto \frac{N^{+} - N^{-}}{N^{+} + N^{-}}$$

- The analysis will be performed on Run Group B data, which acquired ~43B triggers between 2019 and 2020. Also run group A data will be used to compare results from the two different targets.
- If possible I will go deep in this analysis and trying to extract the $A^{\cos\phi}_{UU}$, $A^{\cos2\phi}_{UU}$ terms.
- At the end of 2023 I will conclude my PhD with a thesis on RICH and its use on physics analysis like this one.

Thank you for your kindly attention

References

- [CLAS12 PAC 34 proposal] Studies of the Boer-Mulders Asymmetry in Kaon Electroproduction with Hydrogen and Deuterium Targets
- [Bacchetta et Al] Semi-inclusive deep inelastic scattering at small transverse momentum