Transverse double spin asymmetry in inclusive hadron production

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Abstract

The study of spin asymmetries is of fundamental importance to investigate the internal structure of nucleons. They provide an experimentally easy way to parametrize cross sections, intrinsically related to structure functions and transverse momentum dependent distributions and fragmentation functions. A central question in the understanding of *nucleon structure* is the *orbital* motion of *partons*: TMD PDFs and FFs are fundamental tools in order to solve the spin puzzle. After an extensive study of single target spin asymmetry A_{UT} in inclusive hadron productions, we will focus on the transverse double spin asymmetry A_{LT} in the same process. Predictions for A_{LT} have been derived for inclusive jet production ($lp \to jet\ X$) and SIDIS ($lp \to l^{'} h\ X$).

Contents

1 Physical motivations

An investigation of spin asymmetries that appear in the azimuthal distributions of various products of scattering processes play an essential role in current understanding of the spin structure of the nucleon.

In the last decades various measurements of azimuthal asymmetries were performed in SIDIS [10, 11, 12]. Such an observed non-zero modulation for single and double spin asymmetries was not completely understood in the framework of perturbative QCD. In fact, spin asymmetries are now described using parton distribution functions, non perturbative objects for which further theoretical and experimental investigations are strongly required. One of the commonly used frameworks to investigate non perturbative phenomenology is the formalism of transverse momentum dependent distribution functions (TMD PDFs) (see [5]).

Although the most prominent tools for the study of spin structure of the nucleon in the lepton-nucleon scattering experiments are the *exclusive* and semi-inclusive deep inelastic scattering processes (SIDIS), a valuable information can be obtained also from *inclusive* processes.

One of such an experimental observables measured a few decades ago is the transverse single spin asymmetry A_{UT} in inclusive hadron production from proton-proton scattering [6]. An observed large asymmetry triggered further investigation of inclusive processes also in lepton-nucleon scattering experiments (see [1], where such a measurement has been used also as a *model dependent* validity test for the TMD factorization *assumption*). Moreover, investigation of inclusive hadron production in lepton-proton scattering experiments, along with SIDIS results, might provide valuable input to deepen knowledge about asymmetries in inclusive hadron production form polarized proton-proton scattering.

Apart from TMDs approach, another formalism can be used for the description of inclusive hadron production. The latter is based on collinear factorization, which holds at enough large p_T, when the hard scale is p_T. In this regime, RHIC data could be described by collinear factorization plus twist-3 functions. The two approaches are compared in [7]. For the collinear approach, see [8, 9]. Inclusive hadron production in lepton-proton scattering, which is complementary to the proton-proton case, can also provide a way of testing simultaneously the TMDs and also the collinear approach for $p_T > 1GeV$.
In TMD framework the transverse single spin asymmetry A_{UT} is related to moments of the Sivers function $f_{1T}^{\perp}(x, k_T^2)$ (see fig. 1), while the double spin asymmetry A_{LT} provides sensitivity to the *worm-gear* PDF, $g_{1T}^{\perp}(x, k_T^2)$ (x is the collinear light-cone fraction of the impulse of the parent hadron carried by the parton; k_T is the transverse momentum of the parton).

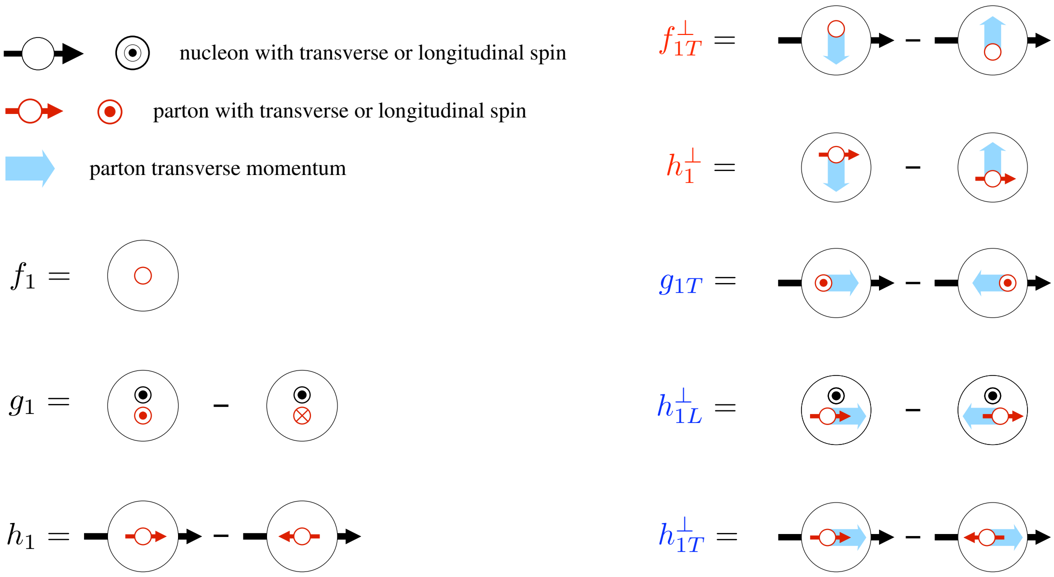

Figure 1: Probabilistic interpretation of twist-2 transverse-momentum-dependent distribution functions. To avoid ambiguities, it is necessary to indicate the directions of quark's transverse momentum, target spin and quark spin, specifying that the proton is moving out of the page, or alternatively the photon is moving into the page. Functions in blue are T-even and, as a consequence, universal. Functions in red are T-odd and not universal.

As pictorially explained in fig. 1 $f_{1T}^{\perp}$ is related to the probability of finding unpolarized quarks (with transverse momentum perpendicular to the hadron spin) in transversely polarized hadrons, while $g_{1T}^{\perp}$ is related to longitudinally polarized quarks in transversely polarized hadrons (see [5]). Both $f_{1T}^{\perp}$ and $g_{1T}^{\perp}$ have found to be non-zero in SIDIS (HERMES, JLab Hall A, COMPASS). Since we believe that these functions are responsible for the physical mechanism generating the asymmetries, we expect them to be non-zero also in the inclusive case.

Recently preliminary results of single target spin asymmetry in inclusive hadron production from lepton-nucleon scattering were obtained at HERMES. The extraction was based on data collected from 2002 to 2005 and the Maximum Likelihood fitting technique was used to obtain the $sin\ \phi_h$ azimuthal asymmetry moment.
This report deals with the first extraction of the double spin asymmetry A_{LT} in inclusive hadron production from scattering of longitudinally polarized lepton beam off transversely polarized hydrogen target at HERMES experiment, as a function of the transverse momentum of the detected hadron, p_T, and the Feynman variable, x_F. Compared with previous analysis of single target spin asymmetry we used a *combined* fitting technique that allows simultaneous extractions of single beam and target spin asymmetries together with the double spin asymmetry. Theoretical estimations about the behaviour of A_{LT} with p_T and x_F are available in [3] for inclusive jet production from lepton-nucleon scattering at higher energies relevant for Electron Ion Collider (EIC). Here, the size of A_{LT} is predicted to be smaller than the one for A_{UT} by two orders of magnitudes.
Predictions of A_{LT} in SIDIS experiments are also available (see [2]).

Azimuthal asymmetries discussed below are defined in terms of polarized cross sections differences, according to:

$$A_{UT}(\phi) = \frac{\sigma^{\uparrow} - \sigma^{\downarrow}}{\sigma^{\uparrow} + \sigma^{\downarrow}} \tag{1}$$

$$A_{LU}(\phi) = \frac{\overrightarrow{\sigma} - \overleftarrow{\sigma}}{\overrightarrow{\sigma} + \overleftarrow{\sigma}} \tag{2}$$

$$A_{LT}(\phi) = \frac{[\overrightarrow{\sigma}^{\uparrow} + \overleftarrow{\sigma}^{\downarrow}] - [\overleftarrow{\sigma}^{\uparrow} + \overrightarrow{\sigma}^{\downarrow}]}{[\overrightarrow{\sigma}^{\uparrow} + \overleftarrow{\sigma}^{\downarrow}] + [\overleftarrow{\sigma}^{\uparrow} + \overrightarrow{\sigma}^{\downarrow}]} \tag{3}$$

Here $\rightarrow$ and $\leftarrow$ denote the beam polarization, while $\uparrow$ and $\downarrow$ represent the target polarization. ϕ is defined to be the azimuthal angle between the hadron plane and the spin of the target (see fig. 2).

Table 1: Number of events collected in each year with (**f**-ending bit pattern) and without (**d**-ending bit pattern) cut on beam polarization.

Data	Bit pattern	π^+	π^-	K^+	K^-
03d1	0 x ffff ffff	1 989 672	1 696 773	172 674	95 136
03d1	0x ffff fffd	2 292 242	1 954 731	200 187	110 401
04d2	0 x ffff ffff	15 890 147	13 596 376	1 421 980	790 199
04d2	0x ffff fffd	16 771 258	14 349 457	1 498 649	832 582
05d2	0 x ffff ffff	29 294 679	25 048 242	2 611 985	1 470 133
05d2	0x ffff fffd	34 078 048	29 139 691	3 037 998	1 710 463

2 Event selection and statistic

Our analysis consists in a *combined* fit of target spin asymmetry A_{UT}, beam spin asymmetry A_{LU} and double spin asymmetry A_{LT}. As a consequence, we need to analyze data collected during years with both beam and target polarization (2003, 2004 and 2005). HTC tracking will be used. Effects of a cut on beam polarization ($P_b > 20\%$) are taken into account.

In the following we will outline the cuts applied to select proper experimental events:

- **Burst level cuts**
  1. the same as in the case of A_{UT} analysis
  2. g1.DAQ.bProdMethods, 0x00800 = 0 (*reasonable* beam polarization measurements)
  3. DQ Bit Pattern 0 x f f f f f f f **d** or 0 x f f f f f f f **f** (differences correspond to $|P_b| > 0$ and $|P_b| > 0.2$)
- **Event level cuts**
  1. Trigger 21 was fired
  2. Maximum momentum $p_{tot} < 28.2\ GeV$ for the sum of all tracks in the event
- **Track level cuts**
  1. Hadrons: $-100 < PID3 + PID5 - flux < 0$
  2. Momentum $2 < p_h < 15 GeV$ for each detected hadron
  3. Quality parameter: $smRICH.rQp > 0$
  4. Vertex z-position between: $18 < z < 18 cm$
  5. Long tracks within fiducial volume

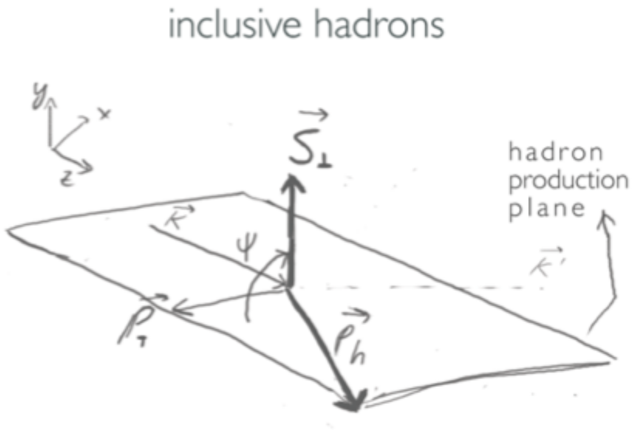

Figure 2: Inclusive hadron production $e\ p \to h\ X$. Only one hadron is detected, with transverse momentum p_T w.r.t. the lepton beam direction (z-axis).

The cut on beam polarization has a sensitive impact on the collected statistic. Applying the cut (**f**-ending bit pattern) we reduce by nearly 20% the number of events observed in each year. All the numbers of event are collected in Table 1.

3 Extraction method

In this section we will outline all the steps required to perform the combined fit of SSAs and DSA, starting from the phenomenological parametrization of the cross section in terms of A_{UT}, A_{LU}, A_{LT} and discussing the mathematical procedure necessary to properly take into account each contribution to the physical process.

3.1 Cross section and asymmetries

Let's consider the process of inclusive hadron production (see fig. 2) from the scattering of one lepton off a proton:

$$e\ p \to h\ X. \tag{4}$$

The differential cross section can be parametrized in terms of single and double spin asymmetries (the first index is related to *beam* polarization and the second one to *target* polarization):

$$d^{(n)}\sigma_{LT}(\mathbf{x}) = d^{(n)}\sigma_{UU}(\mathbf{x})[1 + P\ A_{LU}(\mathbf{x}) + S\ A_{UT}(\mathbf{x}) + P\ S\ A_{LT}(\mathbf{x})]\ , \tag{5}$$

where $d^{(n)}\sigma_{00}(\mathbf{x})$ is the unpolarized differential cross section, $\mathbf{x}$ represents all the kinematic variables involved, P is the beam polarization, S is the target polarization, A_{LU} is the single beam spin asymmetry, A_{UT} is the single target spin asymmetry and A_{LT} is the double beam-target spin asymmetry.

A smart (and in accord to theoretical evaluations of cross sections) way to access spin asymmetries is to decompose them in Fourier expansion, considering only terms of order 0 and 1:

$$A_{LT} = A_{LT}^{cos\ (0\phi)} cos\ (0\phi)\ + A_{LT}^{cos\ \phi} cos\ (\phi)\ + A_{LT}^{sin\ \phi} sin\ (\phi)\ + \ldots \quad (6)$$

$$A_{LU} = A_{LU}^{cos\ (0\phi)} cos\ (0\phi)\ + A_{LU}^{cos\ \phi} cos\ (\phi)\ + A_{LU}^{sin\ \phi} sin\ (\phi)\ + \ldots \quad (7)$$

$$A_{UT} = A_{UT}^{cos\ (0\phi)} cos\ (0\phi)\ + A_{UT}^{cos\ \phi} cos\ (\phi)\ + A_{UT}^{sin\ \phi} sin\ (\phi)\ + \ldots \quad (8)$$

The physically interesting ones are $A_{UT}^{sin\ \phi}$ and $A_{LT}^{cos\ \phi}$ and the remaining are expected to be zero. The nine *moments* ($A_{LT}^{cos\ (0\phi)}$, $A_{LT}^{cos\ \phi}$, ...) of the asymmetries will be *best fit parameters*.

The differential number of events collected in a small time interval $(\tau, \tau + d\tau)$ and small phase space $(x, x + dx)$ is

$$d^{(n)}N(\mathbf{x}, \tau) = L(\tau)\ d\tau\ d^{(n)}\sigma_{UU}(\mathbf{x})[1 + P\ A_{LU}(\mathbf{x}) + S\ A_{UT}(\mathbf{x}) + P\ S\ A_{LT}(\mathbf{x})]\ , \quad (9)$$

where $L(\tau)$ is the luminosity. The number density $d^{(n)}N$ can also be expressed as a function of beam polarization P and target polarization S, rather than τ, trough luminosity. Performing the substitution

$$\mathcal{L}(P', S')dP\ dS = \sum_{\substack{P'<P(\tau)<P'+dP \\ S'<S(\tau)<S'+dS}} L(\tau)d\tau\ , \quad (10)$$

we obtain

$$d^{(n)}N(\mathbf{x}, P, S) = [\mathcal{L}(P, S)dP\ dS]\ d^{(n)}\sigma_{UU}(\mathbf{x})[1 + P\ A_{LU}(\mathbf{x}) + S\ A_{UT}(\mathbf{x}) + P\ S\ A_{LT}(\mathbf{x})]\ . \quad (11)$$

The total number of events (as a function of the kinematics) that will be analyzed is built by four different physical contributions:

$$N(\mathbf{x}) = \overrightarrow{N}^{\uparrow}(\mathbf{x})\ +\ \overrightarrow{N}^{\downarrow}(\mathbf{x})\ +\ \overleftarrow{N}^{\uparrow}(\mathbf{x})\ +\ \overleftarrow{N}^{\downarrow}(\mathbf{x})\ , \quad (12)$$

where $\rightarrow$ / $\leftarrow$ denote positive and negative beam helicity states and $\uparrow$ / $\downarrow$ indicate up and down target polarization states. Each one is characterized by its own value of the luminosity. In order to perform the fit in the right way, it will be mandatory to take into account each sub-process with the correct *weight* in comparison with the others. We will discuss this topic in the next sections.

3.2 Extended Maximum Likelihood

The statistical basis of our fit technique is the framework of Extended Maximum Likelihood. In this section a brief review of its concepts will be given.

Suppose that N sets of independently measured quantities $\mathbf{x}_1, \ldots, \mathbf{x}_i, \ldots, \mathbf{x}_N$ with $\mathbf{x}_i = x_{1i}, ..., x_{ni}$ come from a probability density function (pdf) $p(\mathbf{x}; \theta)$, where $\theta = \theta_1, \ldots, \theta_m$ is the set of m unknown parameters. The pdf $p(\mathbf{x}, \theta)$ is normalized over the entire range of $\mathbf{x}$:

$$\int d\mathbf{x}\; p(\mathbf{x}, \theta) = 1 \; . \tag{13}$$

The parameter set θ can be estimated by maximizing the likelihood function $\mathcal{L}(\theta)$, which is the joint pdf for $\mathbf{x}_1, \ldots, \mathbf{x}_i, \ldots, \mathbf{x}_N$. The estimators $\hat{\theta}$ are the solution of the following m equations:

$$\nabla_\theta \; ln \; \mathcal{L}(\theta) = 0. \tag{14}$$

In the *standard* maximum likelihood fit method, the *likelihood function* $\mathcal{L}$ is

$$\mathcal{L}_{ML}(\theta) = \prod_{i\,:\,1}^{N} \; p(\mathbf{x}_i, \theta) \; . \tag{15}$$

In nuclear and particle physics experiments, the observed number of events often has *Poisson fluctuations* about its expected value $\hat{N}(\theta)$, which may depend on the parameters. Taking this into account, the standard maximum likelihood function is *extended* to include a poissonian term for the total number N:

$$\mathcal{L}_{EML}(\theta) = \frac{\hat{N}(\theta)^{N} \; e^{-\hat{N}(\theta)}}{N!} \; \prod_{i\,:\,1}^{N} \; p(\mathbf{x}_i, \theta) \; . \tag{16}$$

The negative log-likelihood function to be minimized is:

$$- \; ln \; \mathcal{L}_{EML}(\theta) = - \sum_{i:\,1}^{N} \; \mathcal{P}(\mathbf{x}_i, \theta) \; + \; \hat{N}(\theta) \; , \tag{17}$$

where $\mathcal{P}(\mathbf{x}_i, \theta) = p(\mathbf{x}, \theta) \; \hat{N}(\theta)$ is defined to be the *extended* pdf.
In our case the pdf $p(\mathbf{x}_i, \theta)$ is the differential cross section $d^{(n)}\sigma_{LT}(\mathbf{x})$. The last term in the negative log-likelihood function, $\hat{N}(\theta)$ allows us to properly take into account all the different configurations of beam and target polarization.

3.3 Normalization

In order to account for misbalances among the different physical states (the four configurations of polarization are not characterized by the same number of events and the same value of luminosity), we must express the total number of events (given by eq. 12) as a function of polarizations and luminosity values [1]:

$$N(\mathbf{x}) = N(\mathbf{x})(P,\ S,\ \mathcal{L})\ . \tag{18}$$

First of all we need to compute integrated luminosities [2]

$$\overrightarrow{\mathbb{L}}^{\uparrow} = \int_{P>0}\int_{S>0} dP\ dS\ \mathcal{L}(P,S) \tag{19}$$

$$\overrightarrow{\mathbb{L}}^{\downarrow} = \int_{P>0}\int_{S<0} dP\ dS\ \mathcal{L}(P,S) \tag{20}$$

$$\overleftarrow{\mathbb{L}}^{\uparrow} = \int_{P<0}\int_{S>0} dP\ dS\ \mathcal{L}(P,S) \tag{21}$$

$$\overleftarrow{\mathbb{L}}^{\downarrow} = \int_{P<0}\int_{S<0} dP\ dS\ \mathcal{L}(P,S)\ , \tag{22}$$

mean values of *beam* polarization weighted for the proper luminosity

$$\overrightarrow{\mathbb{P}}^{\uparrow} = \frac{\int_{P>0}\int_{S>0}\ dP\ dS\ P\ \mathcal{L}(P)}{\overrightarrow{\mathbb{L}}^{\uparrow}} \tag{23}$$

$$\overrightarrow{\mathbb{P}}^{\downarrow} = \frac{\int_{P>0}\int_{S<0}\ dP\ dS\ P\ \mathcal{L}(P)}{\overrightarrow{\mathbb{L}}^{\downarrow}} \tag{24}$$

$$\overleftarrow{\mathbb{P}}^{\uparrow} = \frac{\int_{P<0}\int_{S>0}\ dP\ dS\ P\ \mathcal{L}(P)}{\overleftarrow{\mathbb{L}}^{\uparrow}} \tag{25}$$

$$\overleftarrow{\mathbb{P}}^{\downarrow} = \frac{\int_{P<0}\int_{S<0}\ dP\ dS\ P\ \mathcal{L}(P)}{\overleftarrow{\mathbb{L}}^{\downarrow}}\ , \tag{26}$$

and mean values of *target* polarization weighted for the proper luminosity:

$$\overrightarrow{\mathbb{S}}^{\uparrow} = \frac{\int_{P>0,\ S>0}\ dP\ S\ \mathcal{L}(P)}{\overrightarrow{\mathbb{L}}^{\uparrow}} \tag{27}$$

$$\overrightarrow{\mathbb{S}}^{\downarrow} = \frac{\int_{P>0,\ S<0}\ dP\ S\ \mathcal{L}(P)}{\overrightarrow{\mathbb{L}}^{\downarrow}} \tag{28}$$

$$\overleftarrow{\mathbb{S}}^{\uparrow} = \frac{\int_{P<0,\ S>0}\ dP\ S\ \mathcal{L}(P)}{\overleftarrow{\mathbb{L}}^{\uparrow}} \tag{29}$$

$$\overleftarrow{\mathbb{S}}^{\downarrow} = \frac{\int_{P<0,\ S<0}\ dP\ S\ \mathcal{L}(P)}{\overleftarrow{\mathbb{L}}^{\downarrow}}\ , \tag{30}$$

Table 2: Coincidence rates measured by luminosity monitor.

Data / Bit pattern	$\overrightarrow{\mathbb{L}}^{\uparrow}$	$\overrightarrow{\mathbb{L}}^{\downarrow}$	$\overleftarrow{\mathbb{L}}^{\uparrow}$	$\overleftarrow{\mathbb{L}}^{\downarrow}$
03d1 **f**	2825601.757	2845673.945	0	0
03d1 **d**	3234350.987	3253045.833	0	0
04d2 **f**	10678408.377	10739278.317	10827273.451	10794727.219
04d2 **d**	11145013.287	11231317.075	11568212.832	11537821.278
05d2 **f**	59596786.396	59186562.219	90193638.909	89864022.205
05d2 **d**	69432539.246	69235990.698	103156203.867	102782042.586

Table 3: *Lumi constants* [mb^{-1}] for 2003, 2004 and 2005.

Data	2003	2004	2005
Lumi	949	969	267

Table 4: Values for mean beam polarization.

Data / Bit pattern	$\overrightarrow{\mathbb{P}}^{\uparrow}$	$\overrightarrow{\mathbb{P}}^{\downarrow}$	$\overleftarrow{\mathbb{P}}^{\uparrow}$	$\overleftarrow{\mathbb{P}}^{\downarrow}$
03d1 **f**	0.33880924	0.33888248	0	0
03d1 **d**	0.31556545	0.31586127	0	0
04d2 **f**	0.32736618	0.32720779	-0.41975374	-0.41975324
04d2 **d**	0.32079941	0.32032305	-0.40081790	-0.40072156
05d2 **f**	0.37170873	0.37195521	-0.30719823	-0.30714263
05d2 **d**	0.33581821	0.33510023	-0.28734509	-0.28723737

Table 5: Values for mean target polarization.

Data	$\overrightarrow{\mathbb{S}}^{\uparrow}$	$\overrightarrow{\mathbb{S}}^{\downarrow}$	$\overleftarrow{\mathbb{S}}^{\uparrow}$	$\overleftarrow{\mathbb{S}}^{\downarrow}$
03d1	0.795	-0.795	0	0
04d2	0.737	-0.737	0.737	-0.737
05d2	0.705	-0.705	0.705	-0.705

Then let's integrate on beam and target polarizations eq. 11:

$$\overrightarrow{N}^{\uparrow}(\mathbf{x}) = \int_{P>0}\int_{S>0} dP\ dS\ \frac{d^{(n)}N(\mathbf{x},P,S)}{d\mathbf{x}} = \\ = \overrightarrow{\mathbb{L}}^{\uparrow}\ \sigma_{UU}(\mathbf{x})[1 + \overrightarrow{\mathbb{P}}^{\uparrow}\ A_{LU}(\mathbf{x}) + \overrightarrow{\mathbb{S}}^{\uparrow}\ A_{UT}(\mathbf{x}) + \overrightarrow{\mathbb{P}}^{\uparrow}\ \overrightarrow{\mathbb{S}}^{\uparrow}\ A_{LT}(\mathbf{x})] \tag{31}$$

$$\overrightarrow{N}^{\downarrow}(\mathbf{x}) = \int_{P>0}\int_{S<0} dP\ dS\ \frac{d^{(n)}N(\mathbf{x},P,S)}{d\mathbf{x}} = \\ = \overrightarrow{\mathbb{L}}^{\downarrow}\ \sigma_{UU}(\mathbf{x})[1 + \overrightarrow{\mathbb{P}}^{\downarrow}\ A_{LU}(\mathbf{x}) + \overrightarrow{\mathbb{S}}^{\downarrow}\ A_{UT}(\mathbf{x}) + \overrightarrow{\mathbb{P}}^{\downarrow}\ \overrightarrow{\mathbb{S}}^{\downarrow}\ A_{LT}(\mathbf{x})] \tag{32}$$

$$\overleftarrow{N}^{\uparrow}(\mathbf{x}) = \int_{P<0}\int_{S>0} dP\ dS\ \frac{d^{(n)}N(\mathbf{x},P,S)}{d\mathbf{x}} = \\ = \overleftarrow{\mathbb{L}}^{\uparrow}\ \sigma_{UU}(\mathbf{x})[1 + \overleftarrow{\mathbb{P}}^{\uparrow}\ A_{LU}(\mathbf{x}) + \overleftarrow{\mathbb{S}}^{\uparrow}\ A_{UT}(\mathbf{x}) + \overleftarrow{\mathbb{P}}^{\uparrow}\ \overleftarrow{\mathbb{S}}^{\uparrow}\ A_{LT}(\mathbf{x})] \tag{33}$$

$$\overleftarrow{N}^{\downarrow}(\mathbf{x}) = \int_{P<0}\int_{S<0} dP\ dS\ \frac{d^{(n)}N(\mathbf{x},P,S)}{d\mathbf{x}} = \\ = \overleftarrow{\mathbb{L}}^{\downarrow}\ \sigma_{UU}(\mathbf{x})[1 + \overleftarrow{\mathbb{P}}^{\downarrow}\ A_{LU}(\mathbf{x}) + \overleftarrow{\mathbb{S}}^{\downarrow}\ A_{UT}(\mathbf{x}) + \overleftarrow{\mathbb{P}}^{\downarrow}\ \overleftarrow{\mathbb{S}}^{\downarrow}\ A_{LT}(\mathbf{x})] \tag{34}$$

In order to gain the goal stated in eq. 18 we must solve the system of the previous four equations for $\sigma_{UU}(\mathbf{x}),\ A_{LU}(\mathbf{x}),\ A_{UT}(\mathbf{x}),\ A_{LT}(\mathbf{x})$ as functions of $N(\mathbf{x})$, $\mathbb{P}$, $\mathbb{S}$ in different configurations.
An analytical solution of this system is available also in the very general case of different polarization values. With the assumption [3] (see tab. 5) $\overrightarrow{\mathbb{S}}^{\uparrow} = \overleftarrow{\mathbb{S}}^{\uparrow} = \mathbb{S}^{\uparrow}$ and $\overrightarrow{\mathbb{S}}^{\downarrow} = \overleftarrow{\mathbb{S}}^{\downarrow} = \mathbb{S}^{\downarrow}$ we obtain, for the A_{LT} asymmetry:

$$A_{LT} = \frac{\overrightarrow{n}^{\uparrow}(\overleftarrow{\mathbb{P}}^{\downarrow} - \overrightarrow{\mathbb{P}}^{\downarrow}) - \overrightarrow{n}^{\downarrow}(\overleftarrow{\mathbb{P}}^{\uparrow} - \overrightarrow{\mathbb{P}}^{\uparrow}) - \overleftarrow{n}^{\uparrow}(\overleftarrow{\mathbb{P}}^{\downarrow} - \overrightarrow{\mathbb{P}}^{\downarrow}) + \overleftarrow{n}^{\downarrow}(\overleftarrow{\mathbb{P}}^{\uparrow} - \overrightarrow{\mathbb{P}}^{\uparrow})}{\overrightarrow{n}^{\uparrow}\overleftarrow{\mathbb{P}}^{\uparrow}\mathbb{S}^{\downarrow}(\overleftarrow{\mathbb{P}}^{\downarrow} - \overrightarrow{\mathbb{P}}^{\downarrow}) + \overrightarrow{n}^{\downarrow}\overleftarrow{\mathbb{P}}^{\downarrow}\mathbb{S}^{\uparrow}(\overrightarrow{\mathbb{P}}^{\uparrow} - \overleftarrow{\mathbb{P}}^{\downarrow}) + \overleftarrow{n}^{\uparrow}\overrightarrow{\mathbb{P}}^{\uparrow}\mathbb{S}^{\downarrow}(\overrightarrow{\mathbb{P}}^{\downarrow} - \overleftarrow{\mathbb{P}}^{\downarrow}) + \overleftarrow{n}^{\downarrow}\overrightarrow{\mathbb{P}}^{\downarrow}\mathbb{S}^{\uparrow}(\overleftarrow{\mathbb{P}}^{\downarrow} - \overrightarrow{\mathbb{P}}^{\uparrow})}, \tag{35}$$

and similarly for A_{LU} and A_{UT}. Here n is the ratio $N(\mathbf{x})/\mathbb{L}$.

[1] let's return to the conventions of section 2, where $\mathbf{x}$ was the set of kinematic variables.
[2] integrated luminosity values can be obtained multiplying the coincidence rate measured by luminosity monitors given in tab. 2 with the *Lumi constants* (see tab. 3). Their definition is given in HERMES Wiki page ($https://hermes-wiki.desy.de/Main_Page$).
[3] it's a good approximation: true values differs only by 3%.

Inserting the asymmetries as functions of n, $\mathbb{P}$ and $\mathbb{S}$ inside the definition of the total number of events $N(\mathbf{x})$ we will take into account *properly* all the processes with different polarization states.

In the next section we will show the results obtained minimizing $-ln\mathcal{L}_{EML}(\mathbf{x})$ with respect to the nine moments of the asymmetries.

4 Results

In this section we will present plots of physically significant moments of asymmetries as functions of p_T (the transverse momentum of the detected hadron w.r.t. the beam direction) and x_F, the Feynman variable. For x_F we used a first-order approximation:

$$x_F = 2\frac{p_z^{CM}}{\sqrt{s}} \approx \frac{p_z^{lab}}{E_{beam}} . \tag{36}$$

Our analysis is monodimensional: when moments are plotted as functions of p_T, for example, they are integrated over all possible values of x_F (and viceversa). Errors on best-fit value are calculated according to Solmitz's covariance matrix [4].

4.1 Comparison with previous results on A_{UT}

We find a good qualitative agreement between the previous extraction of $A_{UT}(p_T, x_F)$ in inclusive hadron production at HERMES (fig. 3) and the present one [4](fig. 4). The current analysis is a combined fit over 2003, 2004, 2005. The previous one, instead, relies also on 2002 data (unpolarized beam).

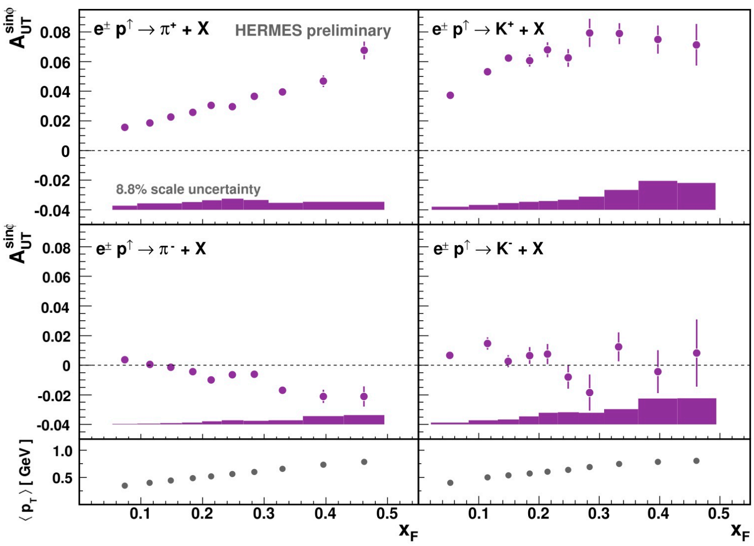

Figure 3: $A_{UT}^{sin\ \phi}$ as a function of x_F - previous HERMES measurement.

[4]in the previous analysis the rigorous definition of x_F is used.

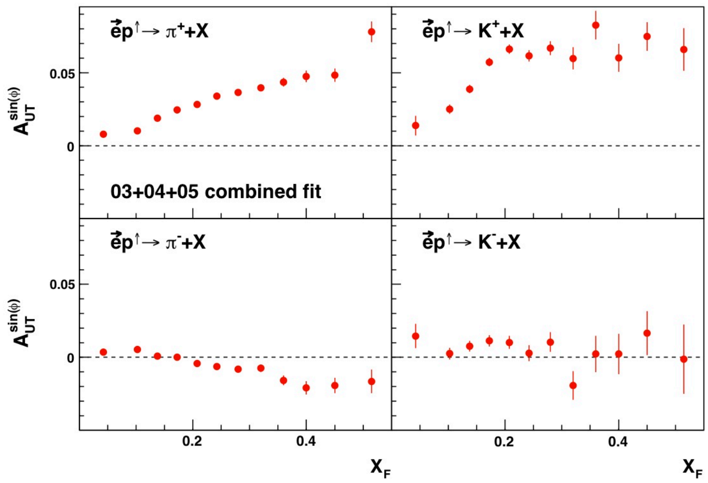

Figure 4: $A_{UT}^{sin\ \phi}$ as a function of x_F - current analysis.

4.2 Consistency on different years

Here we present results related to the $A_{LT}^{cos\ \phi}$ moment of the double spin asymmetry A_{LT} built with data collected in different years (2004 vs 2005). The goal of the following comparison (see figs. 5 and 6) is to study the time dependence of the extracted asymmetry amplitudes: they are statistically *compatible* over the two years of data taking 2004 and 2005, indicating reasonable consistency between two data taking years.

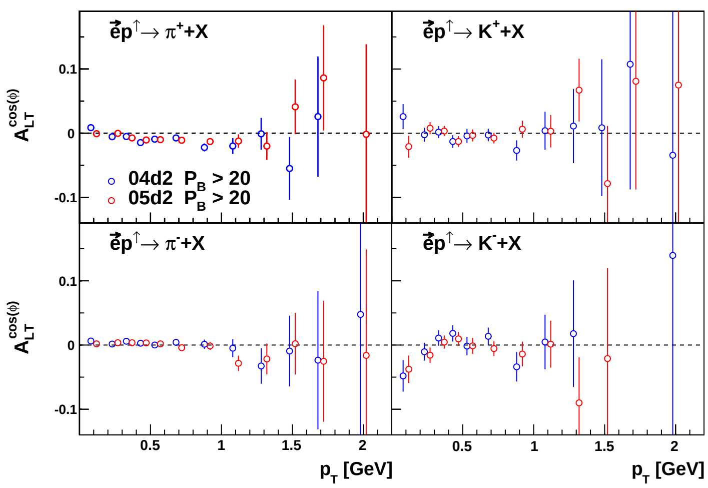

Figure 5: $A_{LT}^{cos\ \phi}$ as a function of p_T - 2004-**f** vs 2005-**f** .

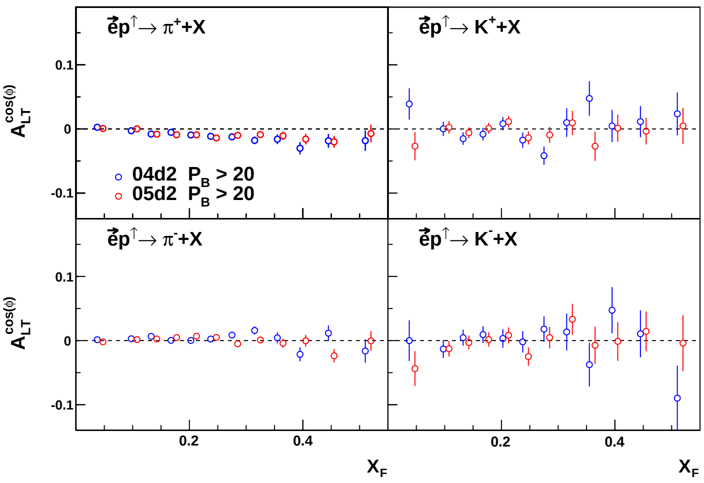

Figure 6: $A_{LT}^{cos\ \phi}$ as a function of x_F - 2004-**f** vs 2005-**f** .

4.3 Sensitivity to beam polarization

Here we present results related to the $A_{LT}^{cos\ \phi}$ moment of the double spin asymmetry A_{LT} built with data collected in 2005 with and without the cut on beam polarization ($P > 20\%$). The goal of the following comparison (see figs. 7 and 8) is to study the sensitivity of statistical precision of the results on beam polarization: the two sets are found to be statistically *compatible*. Statistical errors are unchanged because the rising of the statistics is compensated by the lowering of the mean polarization value.

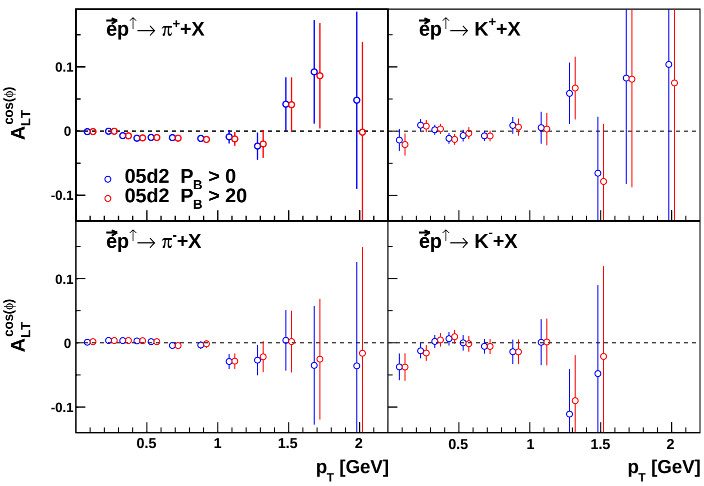

Figure 7: $A_{LT}^{cos\ \phi}$ as a function of p_T - 2005-**d** vs 2005-**f** .

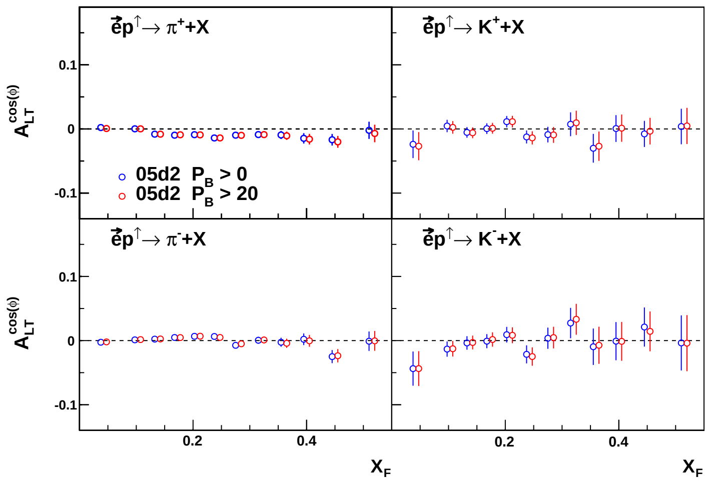

Figure 8: $A_{LT}^{cos\ \phi}$ as a function of x_F - 2005-**d** vs 2005-**f** .

4.4 Final results

In this paragraph *combined* preliminary results related to the $A_{LT}^{cos\ \phi}$ moment of the double spin asymmetry A_{LT} are shown. They are built with data collected in 2003, 2004 and 2005 with and without the cut on beam polarization ($P > 20\%$). The results for $A_{LT}^{cos\ \phi}$ moment are shown in figs. 9 and 10 in bins of transverse momentum of the hadron p_T and x_F respectively.

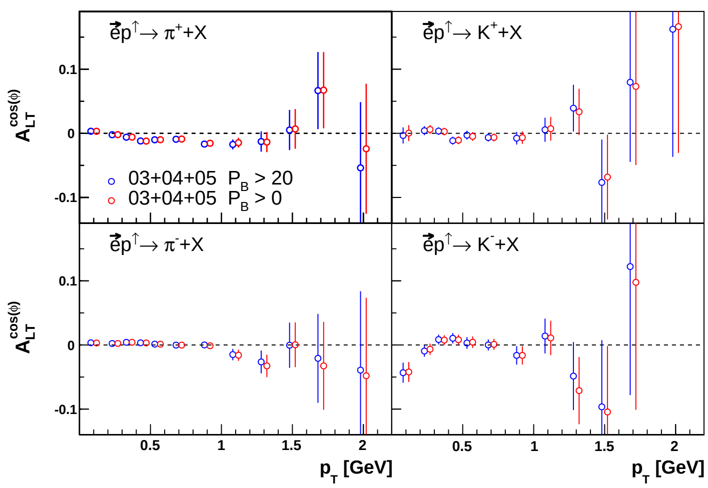

Figure 9: $A_{LT}^{cos\ \phi}$ as a function of p_T - 2003/04/05-**d** vs 2003/04/05-**f** .

A comparison of the moments from the data with cut on beam polarization with the ones without it does not indicate significative differences. The results for π^{+} show non-zero slightly negative behavior, particularly for the x_F dependence. The $A_{LT}^{cos\ \phi}$ moments for π^-, K^+ and K^- are compatible with zero throughout whole kinematic range.

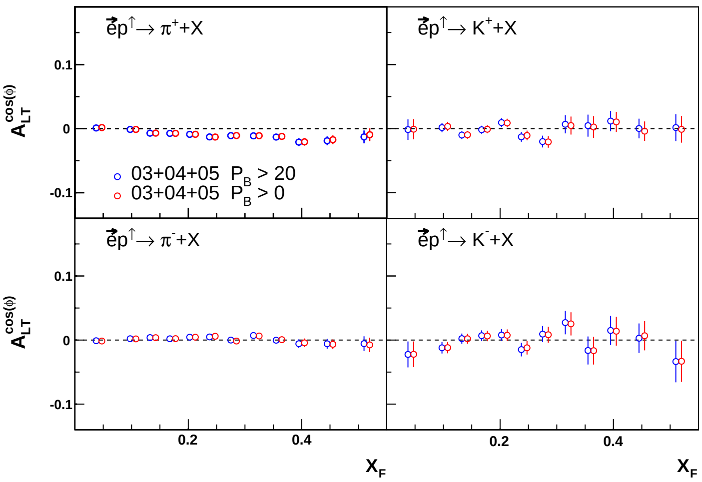

Figure 10: $A_{LT}^{cos\ \phi}$ as a function of x_F - 2003/04/05-**d** vs 2003/04/05-**f** .

5 Conclusions

Transverse double spin asymmetry A_{LT} in inclusive production of hadrons from scattering a longitudinally polarized lepton beam off transversely polarized hydrogen target was studied using HERMES data collected from 2003 to 2005. A combined extended maximum likelihood fit was performed which allowed to extract simultaneously azimuthal moments of single beam and target spin asymmetries together with the double spin asymmetry. The stability of the results over time was checked and the studies related to the sensitivity on the cut on beam polarization were performed.

The results of the $A_{LT}^{cos\ \phi}$ moment for π^+ show non-zero slightly negative behavior, particularly for the x_F dependence. The $A_{LT}^{cos\ \phi}$ moments for π^-, K^+ and K^- are compatible with zero throughout whole kinematic range. The magnitude of the $A_{LT}^{cos\ \phi}$ moment is approximatively five times smaller than the $A_{UT}^{sin\ \phi}$ moment of single target spin asymmetry. This is in contrary to the expectations from ref. [3], which suggests a highly suppressed (two orders of magnitude) amplitude compared to A_{UT}, although the predictions are made for larger values of center-of-mass energy. The observed non-zero signals for π^+ could indicate a sizable non-zero contribution from worm-gear $g_{1T}^{\perp}$ TMD, which was found to be responsible for A_{LT} asymmetry in SIDIS.

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