TRANSVERSE DOUBLE SPIN ASYMMETRY IN INCLUSIVE HADRON PRODUCTION AT HERMES

Summer Student Program 2012

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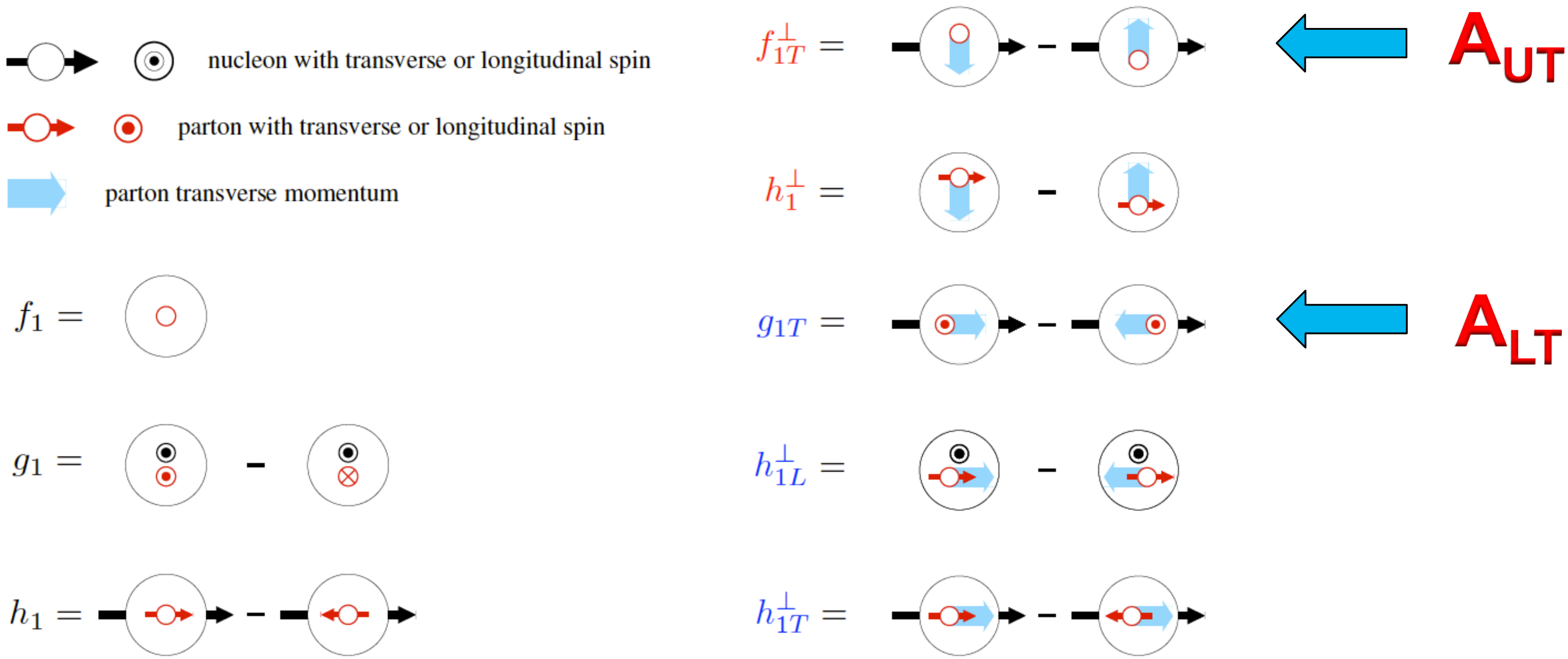
Transverse double spin asymmetry in inclusive hadron production

DESY - HERMES, 06/09/2012

PHYSICAL MOTIVATION

- > Why measure ***single*** and ***double spin asymmetries*** in the inclusive case ?
- > Investigation of the **spin structure** of the nucleon
- > Commonly used framework for SIDIS: ***TMDs approach***

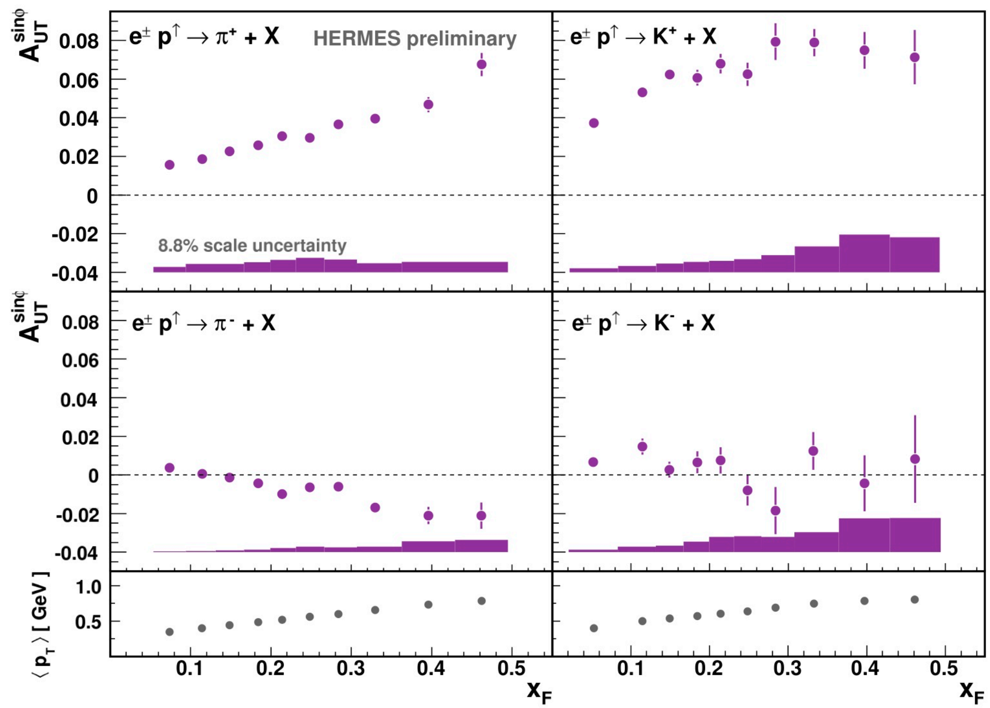


- > Additional information about TMDs can be accessed trough inclusive hadron production $ep^{\uparrow} \rightarrow hX$

INTRODUCTION

> Azimuthal ***Single*** Target Spin Asymmetry → ***preliminary results*** obtained at HERMES

$$ep^{\uparrow} \rightarrow hX$$

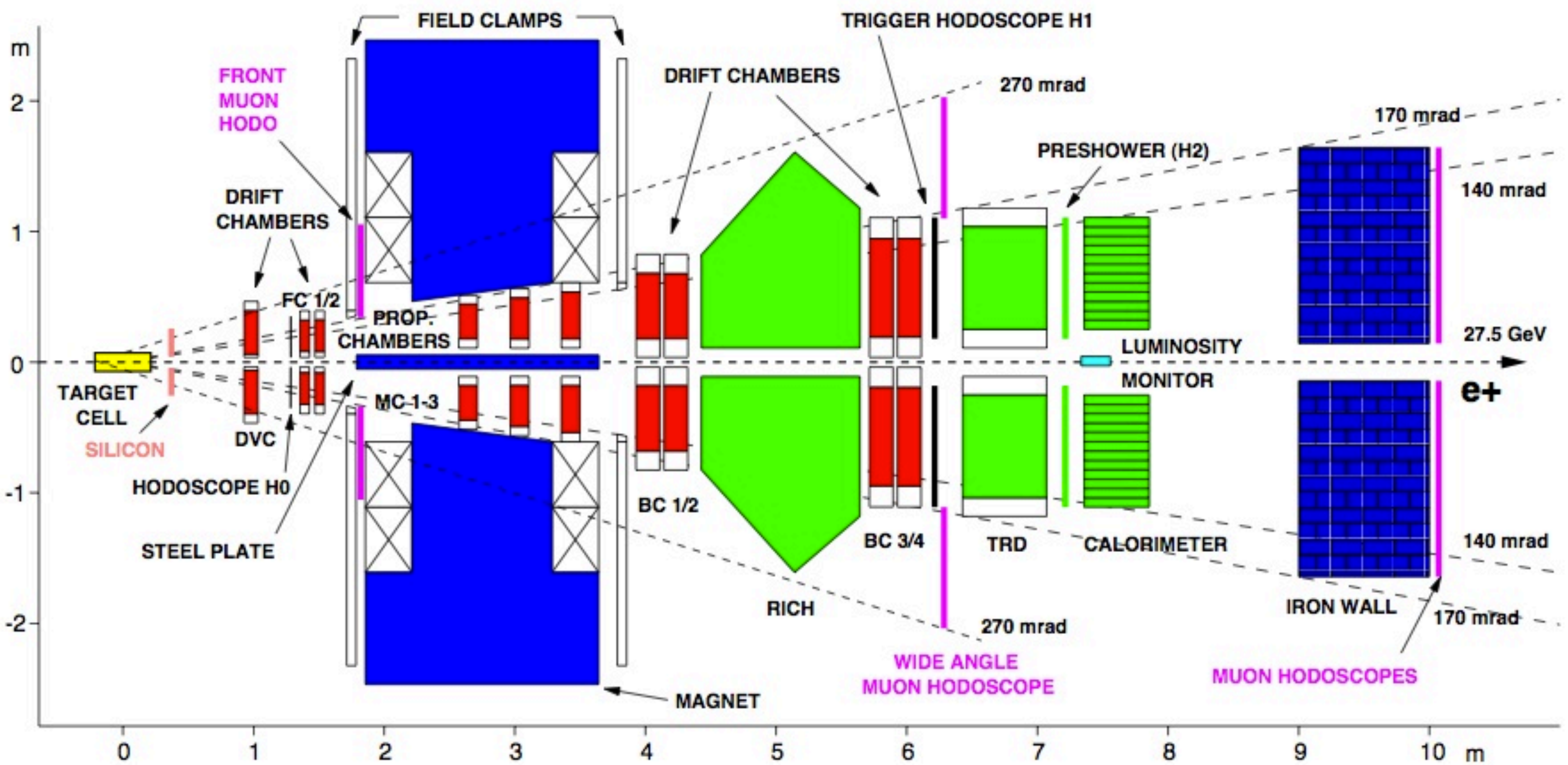


> Transverse ***Double*** Spin Asymmetry

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

HERMES EXPERIMENT

- Fixed target experiment: data taking 1995 – 2007
- Longitudinally polarized HERA lepton beam (27.6 GeV)
- Transversely polarized target (2002 - 2005)



COLLECTED STATISTICS

- Analyzed data sample: 2003, 2004, 2005 with transversely polarized hydrogen target and longitudinally polarized lepton beam
- Identified hadrons: $2 < p_h < 15$ GeV

DATA	BEAM POL	π^+	π^-	K^+	K^-
2003	$\mid P_b \mid > 20$	1 989 672	1 696 773	172 674	95 136
	$\mid P_b \mid > 0$	2 292 242	1 954 731	200 187	110 401
2004	$\mid P_b \mid > 20$	15 890 147	13 596 376	1 421 980	790 199
	$\mid P_b \mid > 0$	16 771 258	14 349 457	1 498 649	832 582
2005	$\mid P_b \mid > 20$	29 294 679	25 048 242	2 611 985	1 470 133
	$\mid P_b \mid > 0$	34 078 048	29 139 691	3 037 998	1 710 463

EXTRACTION METHOD / 1

> **Cross section parametrization**

$$d\sigma_{LT}(\phi) = d\sigma_{UU}[1 + P_B A_{LU}(\phi) + S_T(\phi) A_{UT}(\phi) + P_B S_T A_{LT}(\phi)]$$

> **Fourier decomposition of asymmetries**

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

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

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

physical

9 parameters in our fit

EXTRACTION METHOD / 2

> Extended ML fit

The number of observed events could have a ***Poisson fluctuation about its expected value N(θ)***, which may depend on the **parameters** (the nine **moments of spin asymmetries**)

$$\mathscr{L}(\boldsymbol{\theta}) = \boxed{\frac{[\mathbb{N}(\boldsymbol{\theta})]^N e^{-\mathbb{N}(\boldsymbol{\theta})}}{N!}} \prod_i^N p(\mathbf{x}_i;\boldsymbol{\theta})$$

Extended pdf

$$\mathscr{P}(\mathbf{x};\boldsymbol{\theta}) \equiv p(\mathbf{x};\boldsymbol{\theta})\mathbb{N}(\boldsymbol{\theta})$$

$$-\ln \mathscr{L}_{EML}(\boldsymbol{\theta}) = -\sum_i^N \ln \mathscr{P}(\mathbf{x}_i;\boldsymbol{\theta}) + \boxed{\mathbb{N}(\boldsymbol{\theta})}$$

Since we are performing a fit with **different physical settings** (2 beam pol states x 2 target pol states = ***4 total configurations***, each one with its own luminosity value) the normalization factor N is very important:

it allows to ***account*** for possible ***misbalances*** in ***different physical configurations***

EXTRACTION METHOD / 3

- Derivation of the normalization factor ***N*** as a function of the **moments**, **polarization** and **luminosity**:

$$N = \overrightarrow{N}^{\uparrow} + \overleftarrow{N}^{\uparrow} + \overrightarrow{N}^{\downarrow} + \overleftarrow{N}^{\downarrow}$$

We should find the ***expression of the asymmetries*** as functions of the four ***number densities*** and ***polarizations.***

$$\overrightarrow{N}^{\uparrow} / \overrightarrow{L}^{\uparrow} = \sigma_{UU}[1 + \overrightarrow{P}^{\uparrow} A_{LU} + S^{\uparrow} A_{UT} + \overrightarrow{P}^{\uparrow} S^{\uparrow} A_{LT}]$$

$$\overrightarrow{N}^{\downarrow} / \overrightarrow{L}^{\downarrow} = \sigma_{UU}[1 + \overrightarrow{P}^{\downarrow} A_{LU} + S^{\downarrow} A_{UT} + \overrightarrow{P}^{\downarrow} S^{\downarrow} A_{LT}]$$

$$\overleftarrow{N}^{\uparrow} / \overleftarrow{L}^{\uparrow} = \sigma_{UU}[1 + \overleftarrow{P}^{\uparrow} A_{LU} + S^{\uparrow} A_{UT} + \overleftarrow{P}^{\uparrow} S^{\uparrow} A_{LT}]$$

$$\overleftarrow{N}^{\downarrow} / \overleftarrow{L}^{\downarrow} = \sigma_{UU}[1 + \overleftarrow{P}^{\downarrow} A_{LU} + S^{\downarrow} A_{UT} + \overleftarrow{P}^{\downarrow} S^{\downarrow} A_{LT}]$$

Assumptions:

$$\overrightarrow{S}^{\uparrow} = \overleftarrow{S}^{\uparrow} = S^{\uparrow}$$

$$\overrightarrow{S}^{\downarrow} = \overleftarrow{S}^{\downarrow} = S^{\downarrow}$$

OUR GOAL:

N(moms, pol, lum)

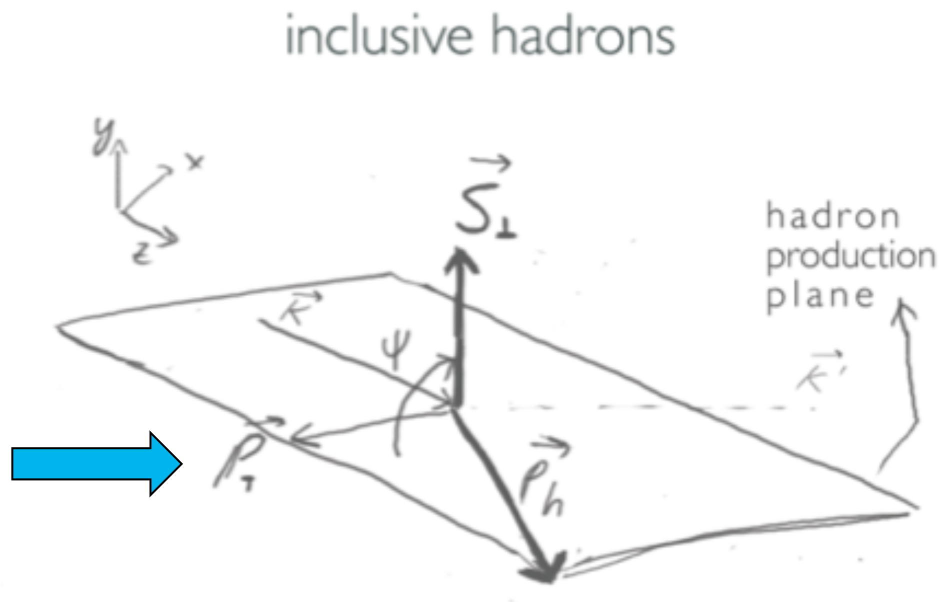
- E.g.: proper expression of A_{LT} from the analytical solution of the system

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

$$n = N/L$$

PHYSICAL DEPENDENCE OF ASYMMETRIES

> ***Transverse momentum of the detected hadron***
>
> (w.r.t. beam direction)



> ***Feynman variable***

$$x_F = 2p_z^{CM}/\sqrt{s} \quad \longrightarrow \quad x_F \approx p_z/E_{Beam}$$

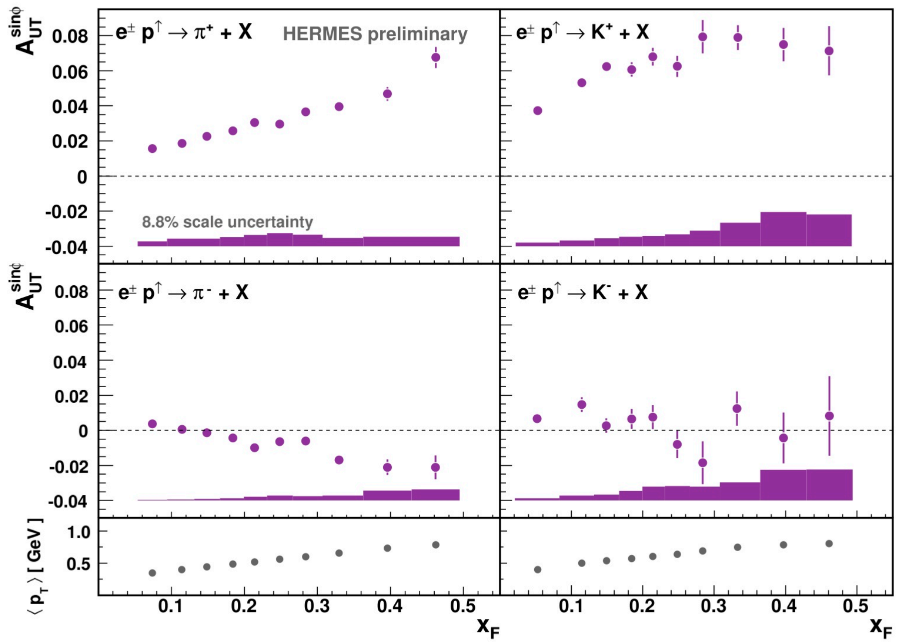
PLOTS

- ***Comparison*** of extraction method with results on A_{UT}
- ***Consistency*** of the results for different data taking ***years***
- ***Sensitivity*** to the cut on ***beam polarization***
- ***Final results***

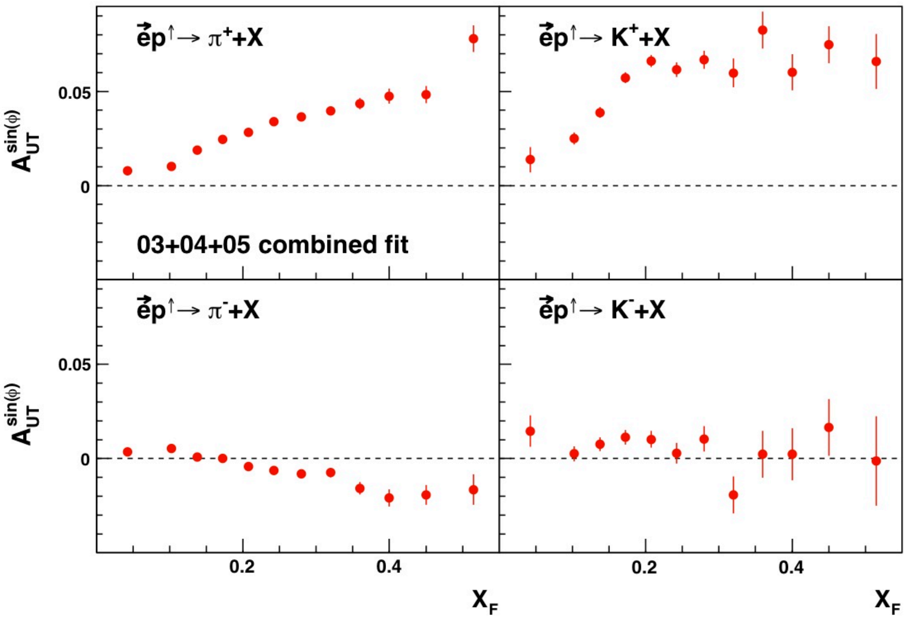
PLOTS / 1

> ***Comparison*** of extraction method with results on A_{UT}

PLOTS - Comparison with results on A_{UT}



Qualitative agreement between two measurements



Combined results on 03 04 05

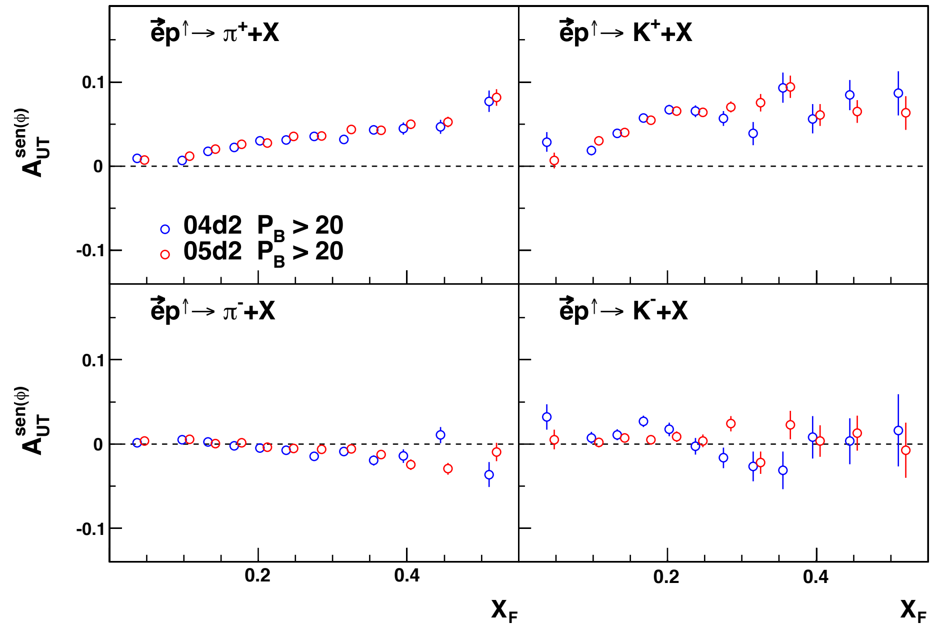
PLOTS / 2

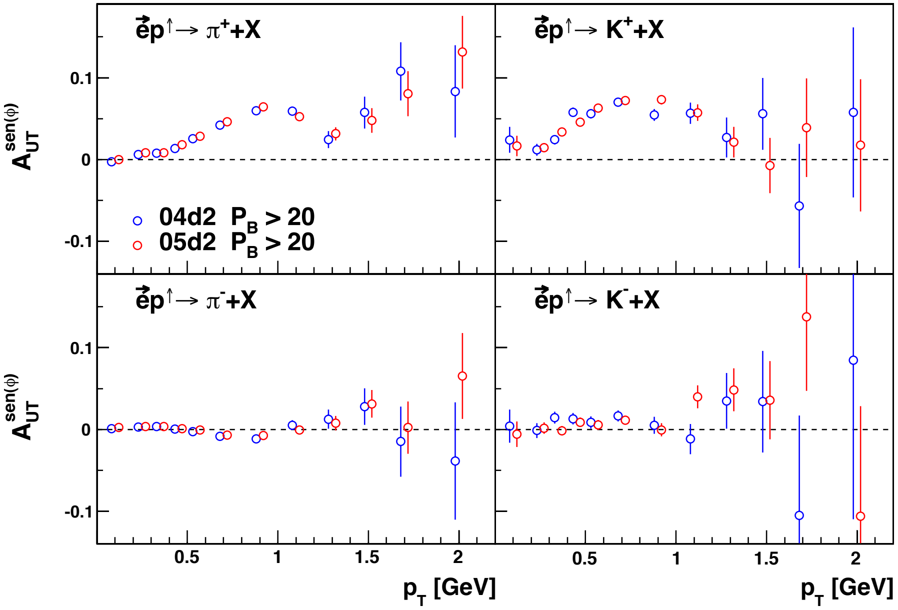
> ***Consistency*** of the results for different data taking ***years***

PLOTS - RESULTS FOR DIFFERENT YEARS

- A_{UT} **sine** modulation

  with cut on beam polarization





Consistent between 04 and 05

PLOTS / 3

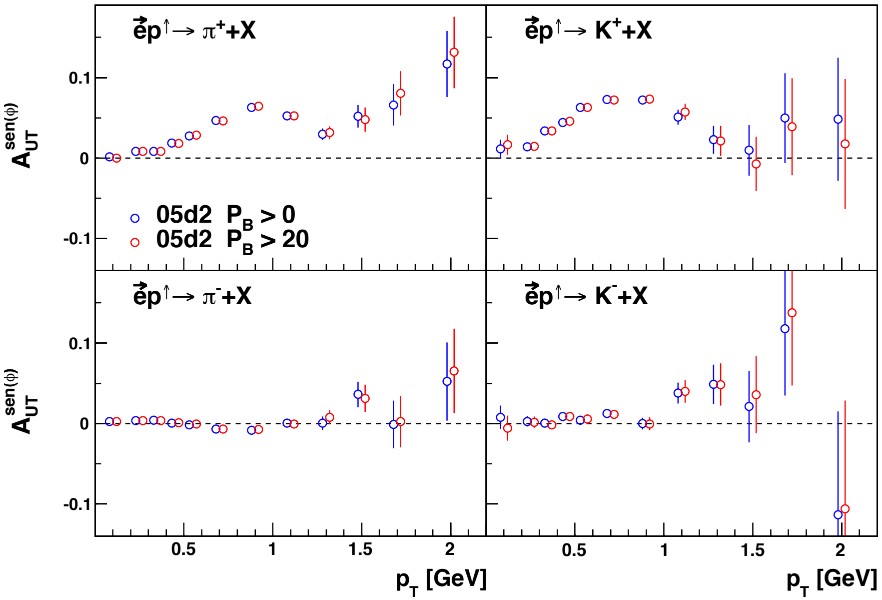
- *Sensitivity* to the cut on *beam polarization*

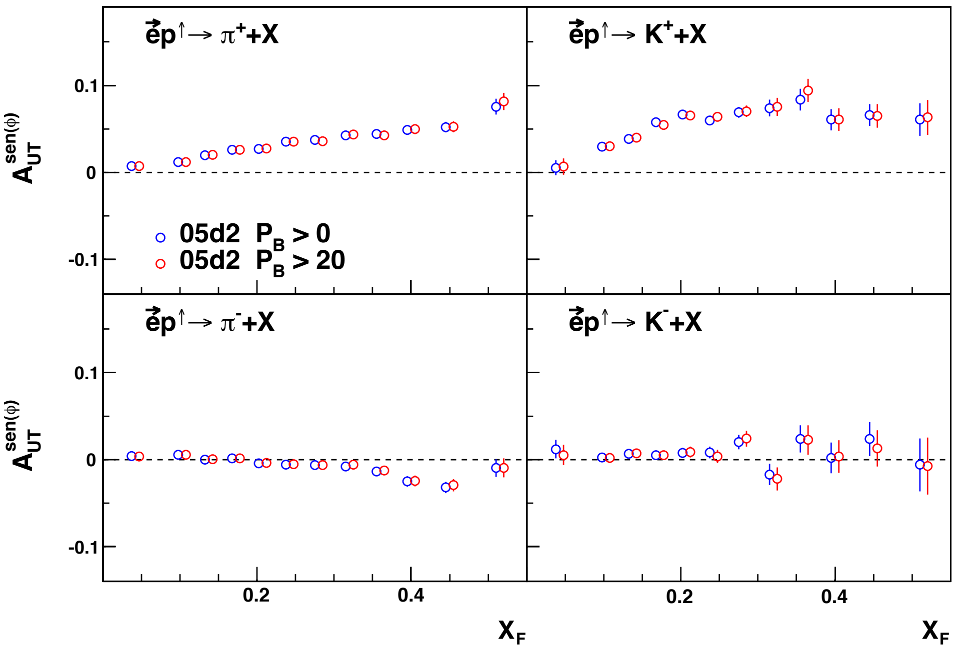
PLOTS - SENSITIVITY ON BEAM POLARIZATION

2005 dataset

> A_{UT} **sine** modulation

with and without cut on beam polarization





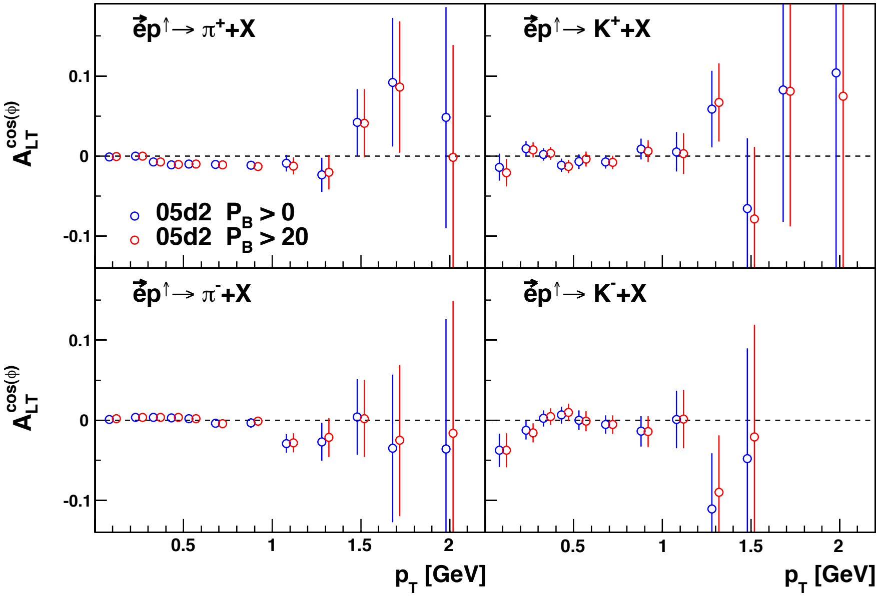
Results are consistent

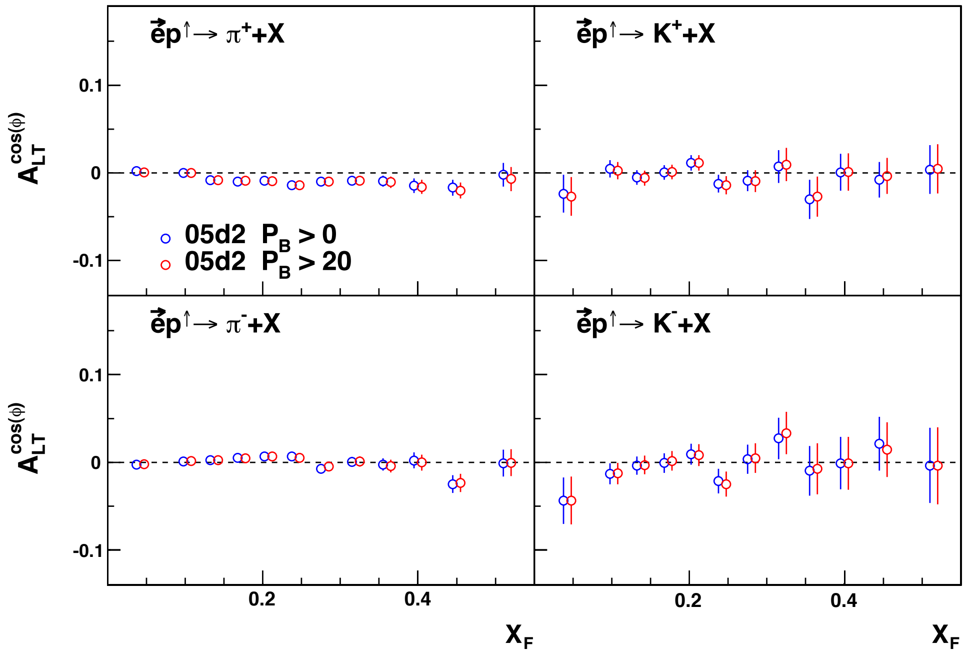
PLOTS - SENSITIVITY ON BEAM POLARIZATION

2005 dataset

> A_{LT} **cosine** modulation

with and without cut on beam polarization





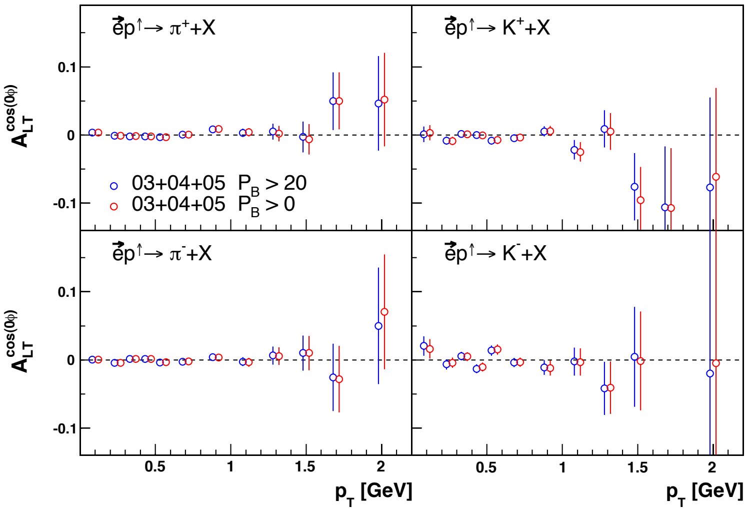
Statistical errors are unchanged

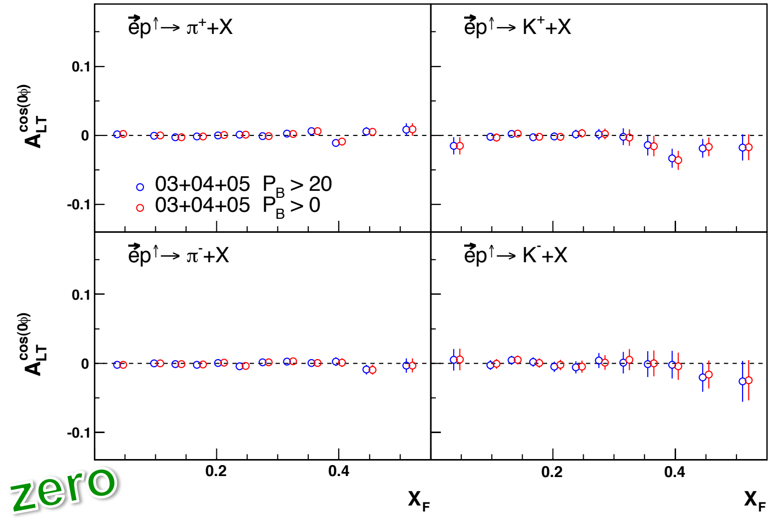
PLOTS / 4

> *Final results*

PLOTS - FINAL RESULTS

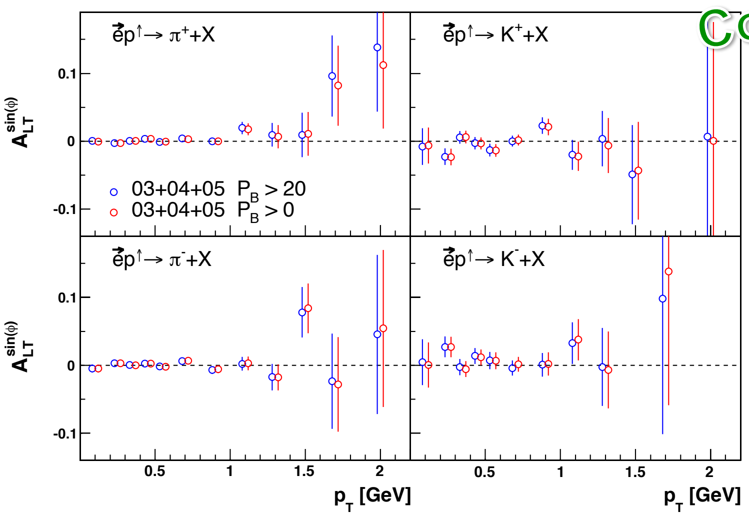
> A_{LT} **constant** and **sine** moment – combined dataset

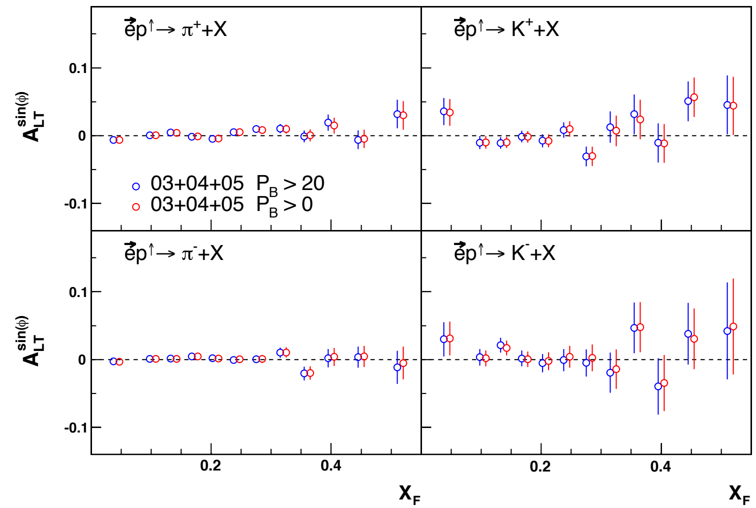




constant

Consistent with zero



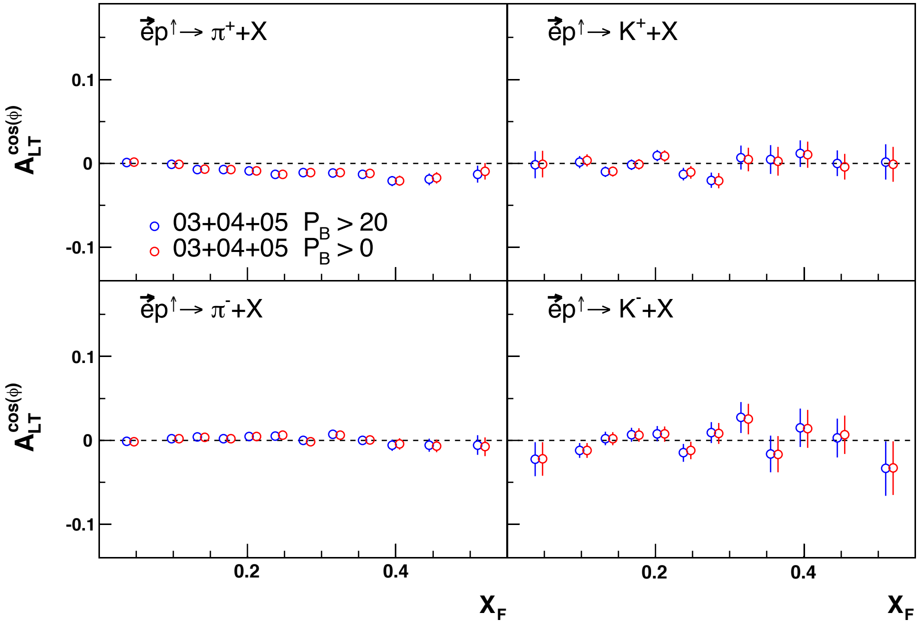


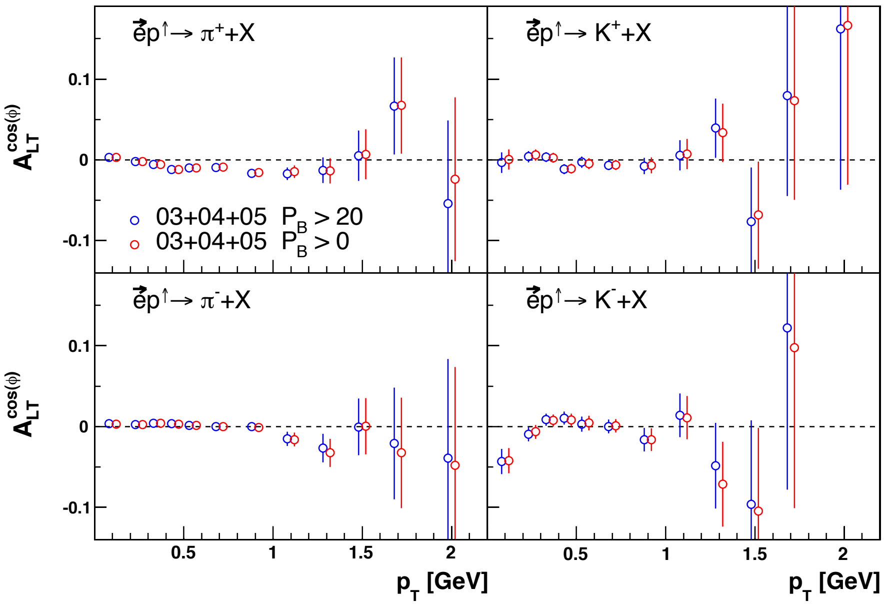
sine

PLOTS - FINAL RESULTS

> A_{LT} **cosine** modulation

with and without cut on beam polarization for combined dataset





Sligthly negative values for π^{+} .

Compatible with zero for π^{-}, K^{+}, and K^{-}

CONCLUSION

- ***non-zero A_{LT} found for π^+***
- In contrary to (some) ***expectation of a highly suppressed*** (two orders of magnitude compared to A_{UT}) ***amplitude***
- Is this a ***sign of a non-zero worm-gear*** function?

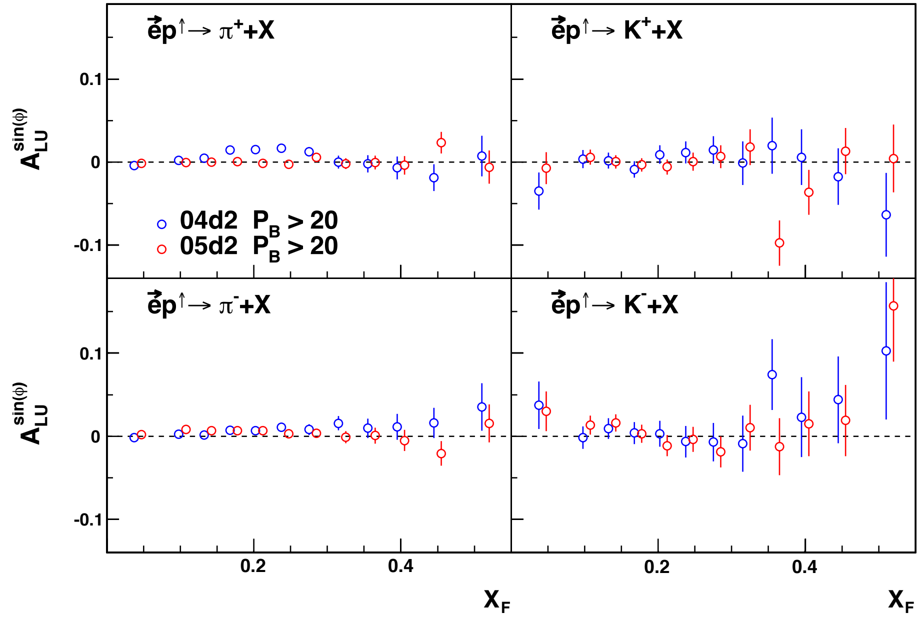
> ***Thank you for your attention !***

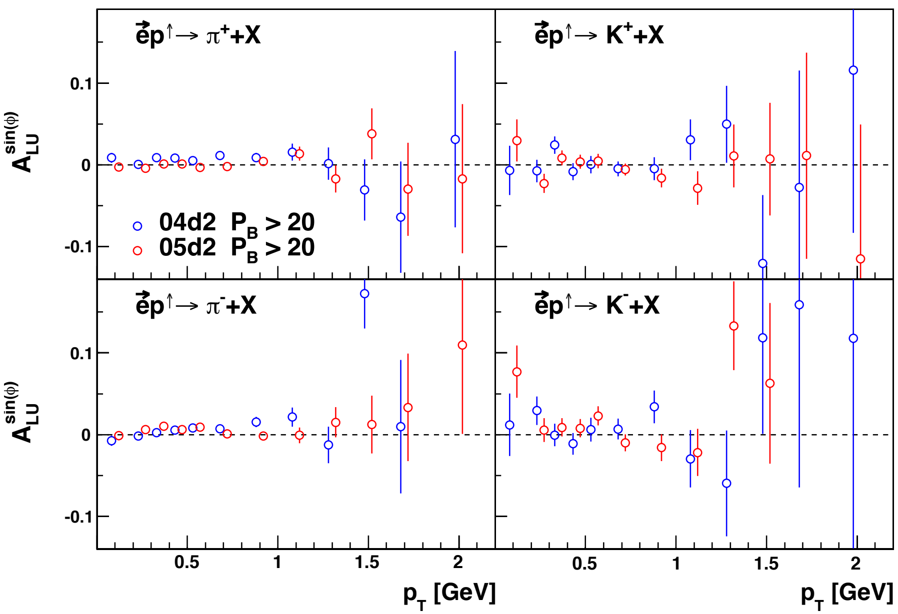
BACKUP SLIDES

PLOTS - RESULTS FOR DIFFERENT YEARS

> A_LU **sine** modulation

with cut on beam polarization



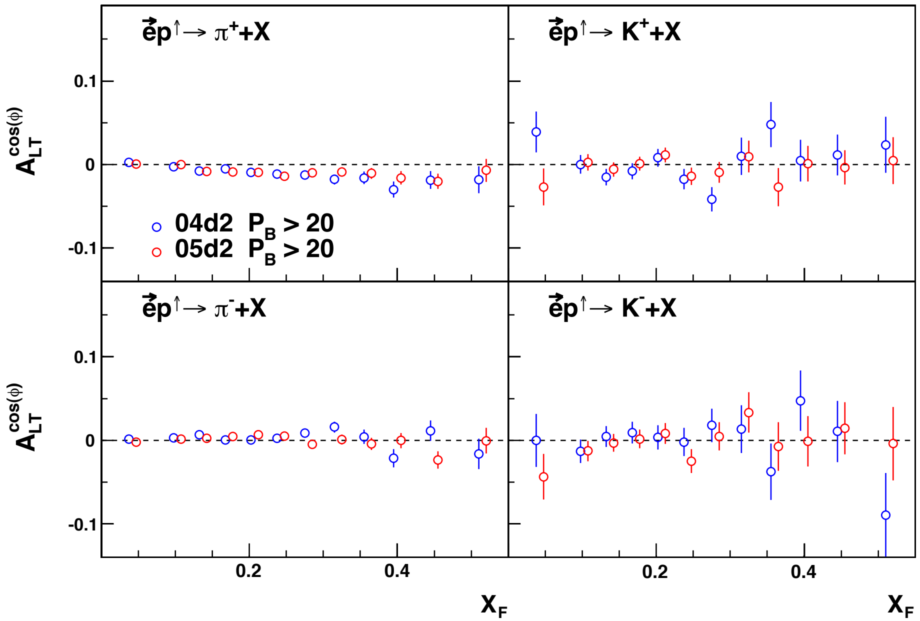


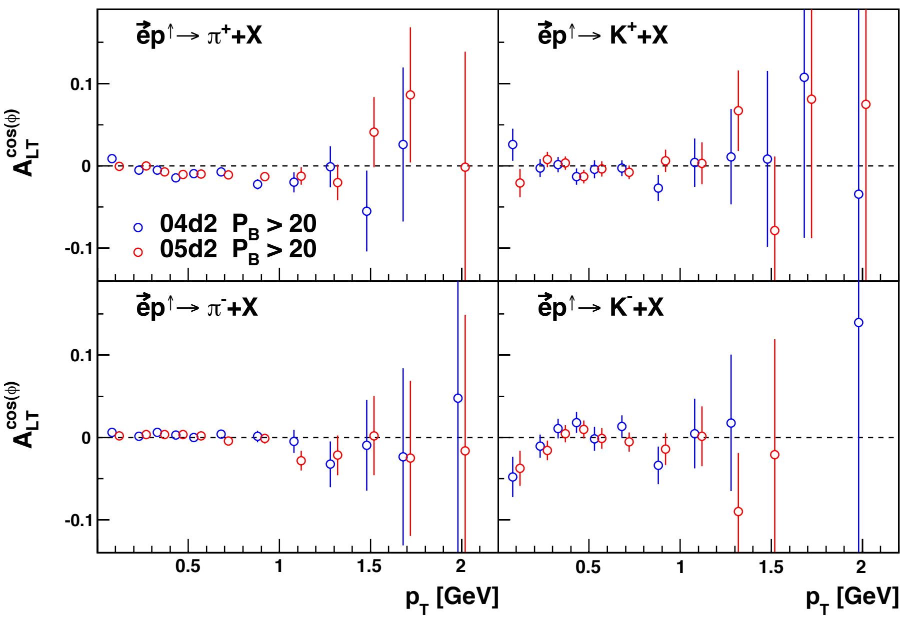
Expected to be zero

PLOTS - RESULTS FOR DIFFERENT YEARS

> A_LT **cosine** modulation

with cut on beam polarization

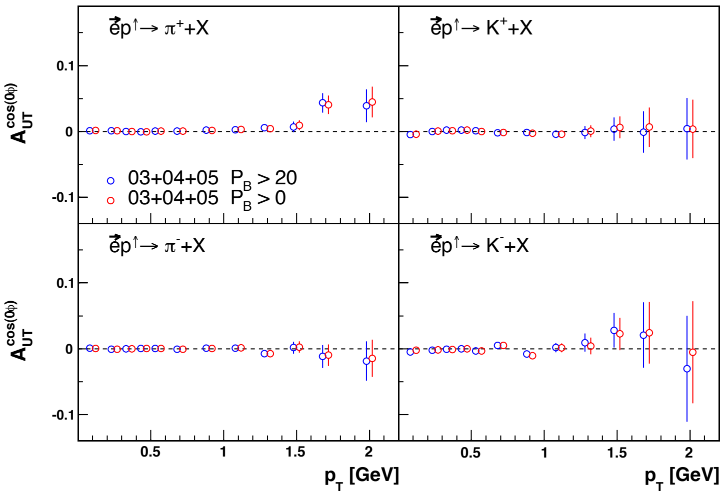


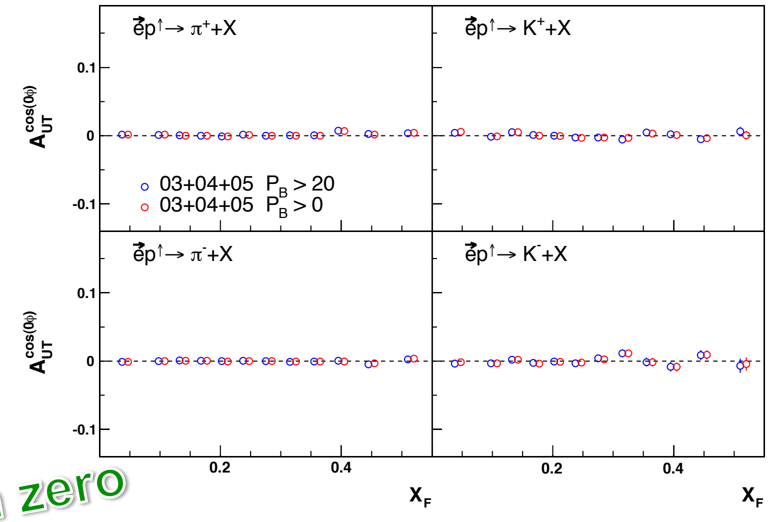


Is found to be compatible with zero on both 04 and 05

PLOTS - FINAL RESULTS

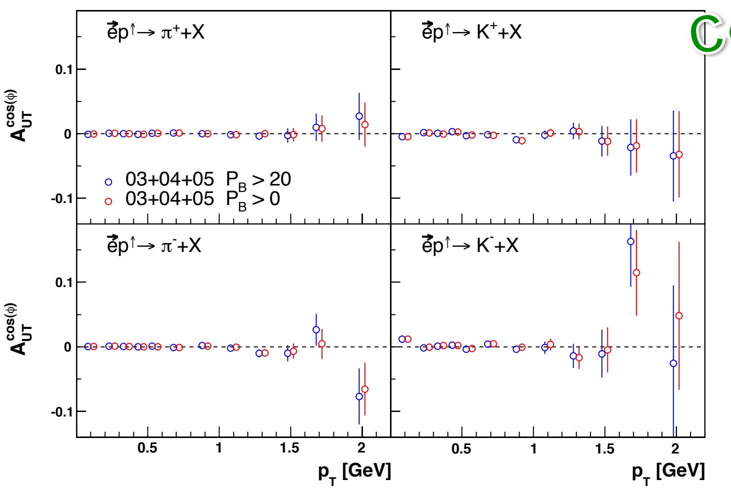
> A_UT **constant** and **cosine** moment - using cut on beam polarization



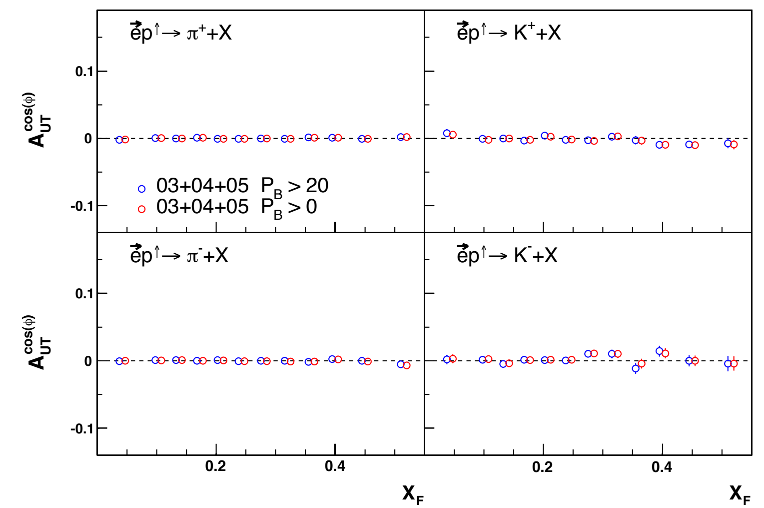


constant

Consistent with zero



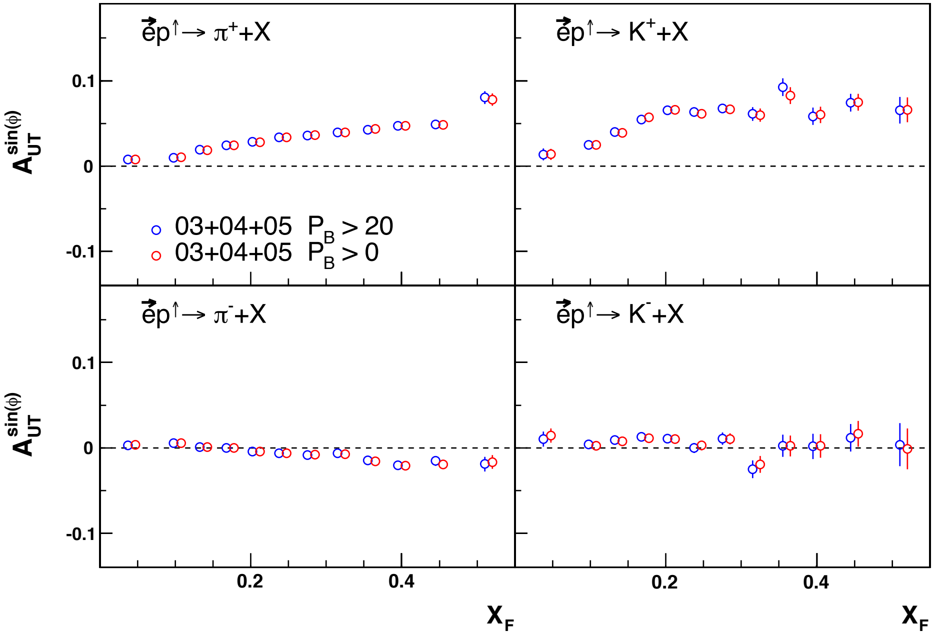
cosine

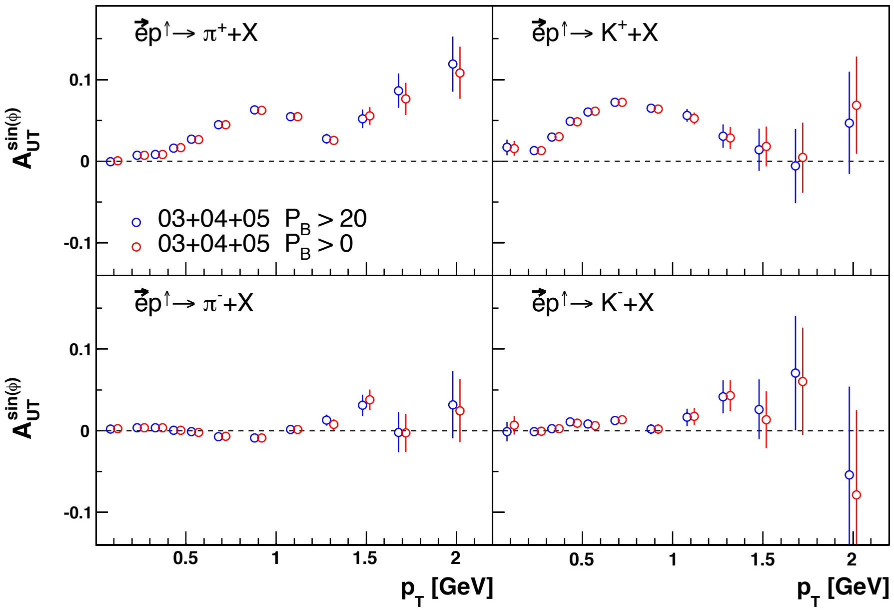


PLOTS - FINAL RESULTS

> A_UT **sine** modulation

with cut on beam polarization



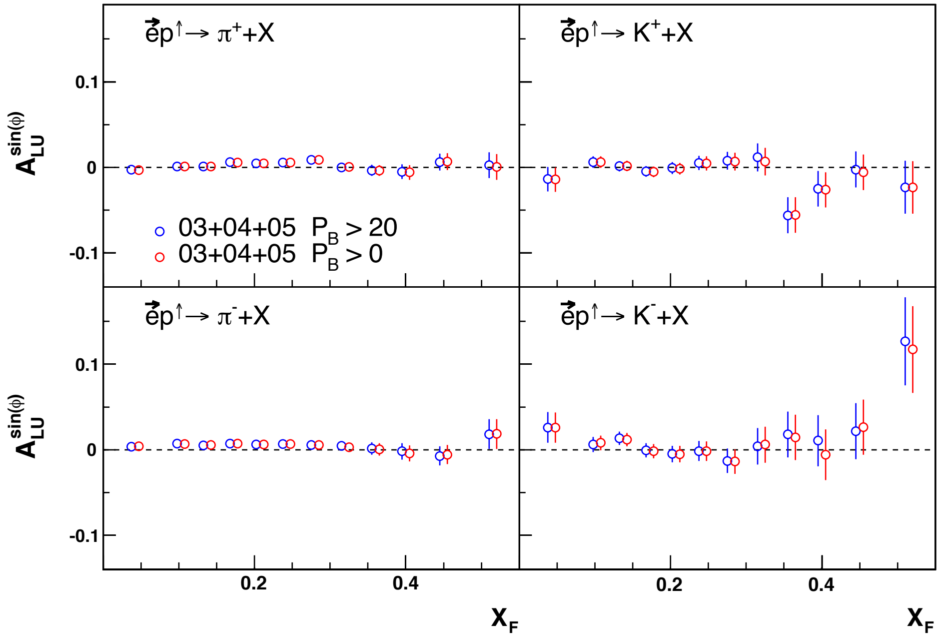


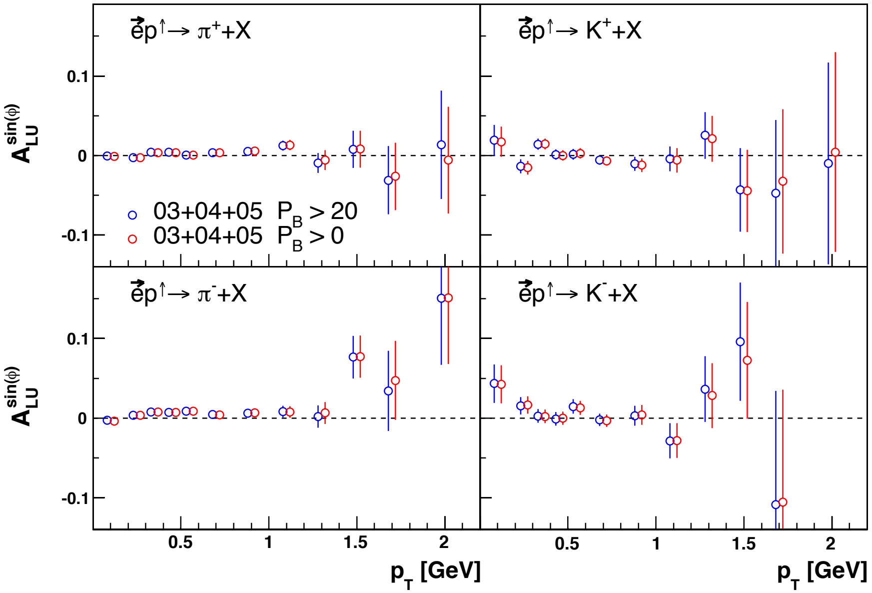
Consistent

PLOTS - FINAL RESULTS

> A_LU **sine** modulation

with cut on beam polarization





Expected to be zero