HERMES results on transverse target single-spin asymmetries in inclusive electroproduction of charged pions and kaons

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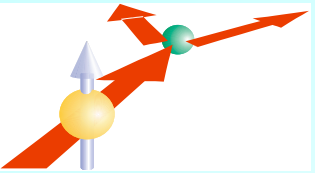
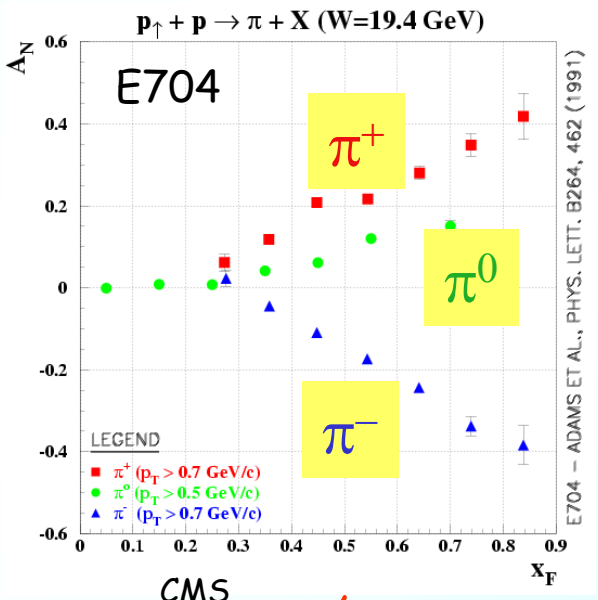
(on behalf of the hermes Collaboration)

Motivation: A_N in $p^{\uparrow}p$



$$A_N = [\sigma(\uparrow)-\sigma(\downarrow)]/[\sigma(\uparrow)+\sigma(\downarrow)]$$

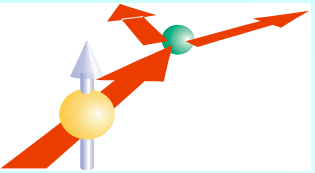
- Large A_N were observed in $\overset{(-)}{p}{}^{\uparrow}\, p \rightarrow h\, X$ reactions at ANL, BNL, FNAL, RHIC for $\sqrt{s}$ = 4.9–500 GeV



CMS

$x_F = p_{long}/p_{long,max}$

Motivation: A_N in p↑p

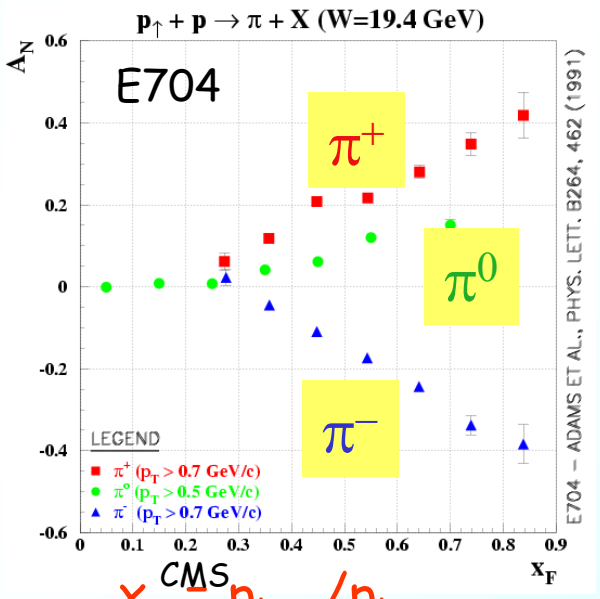


$$A_N = [\sigma(\uparrow)-\sigma(\downarrow)]/[\sigma(\uparrow)+\sigma(\downarrow)]$$

- Large A_N were observed in $p^{\uparrow} p \rightarrow h^{(-)} X$ reactions at ANL, BNL, FNAL, RHIC for $\sqrt{s}$ = 4.9–500 GeV
- Possible origins:
  - Sivers DF (was invented to explain A_N)
  - Collins FF + transversity DF
  - higher-twist multiparton correlations
  - Combinations of above

  But: sign problem (Kang et al., PRD83 (2011) 094001)

- For consistent partonic description: Need flavor dependent $A_N(E, x_F, p_T)$



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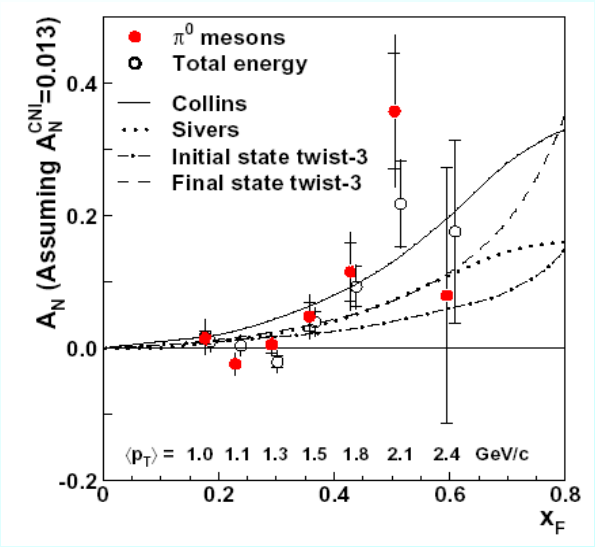
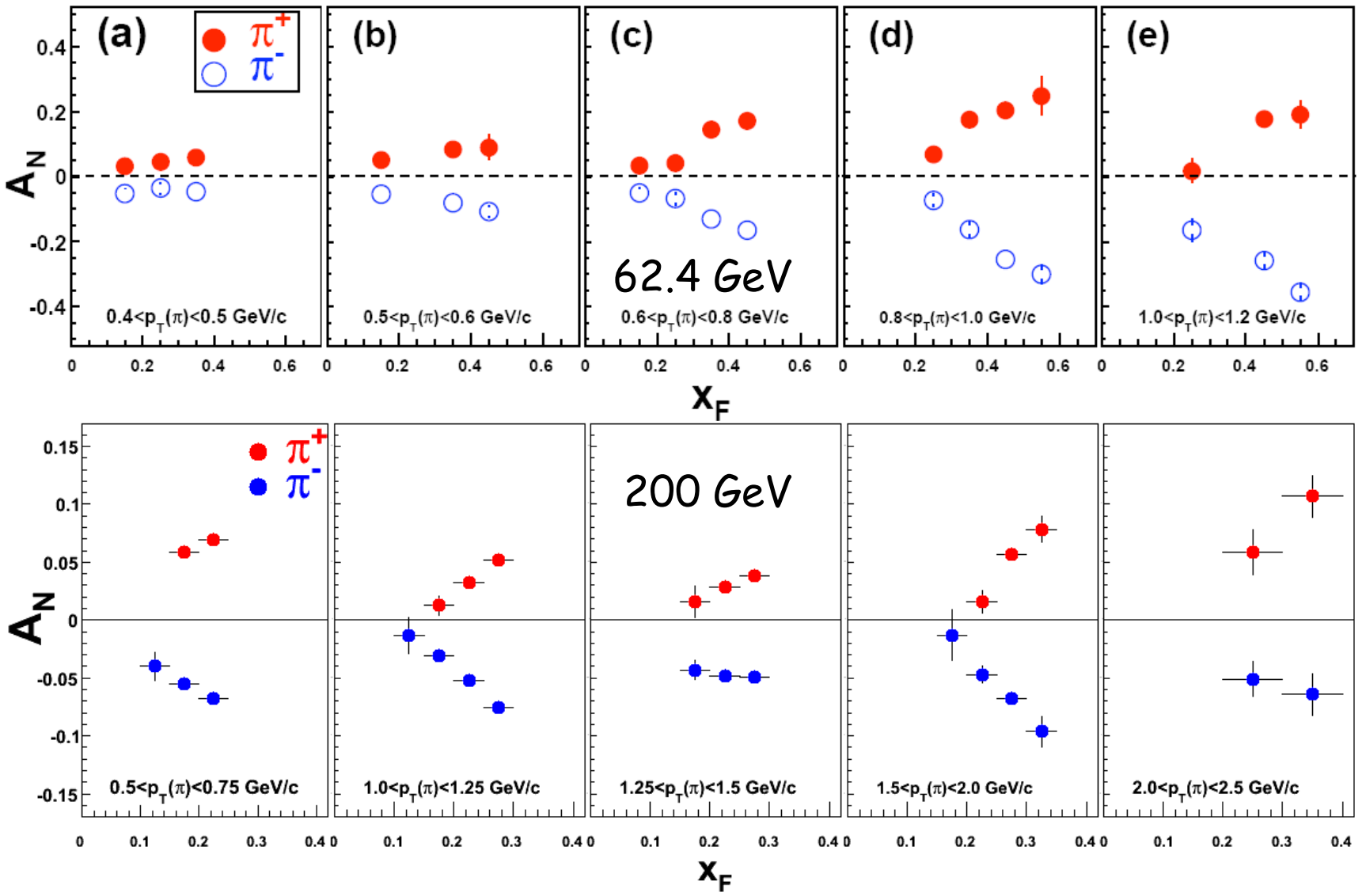
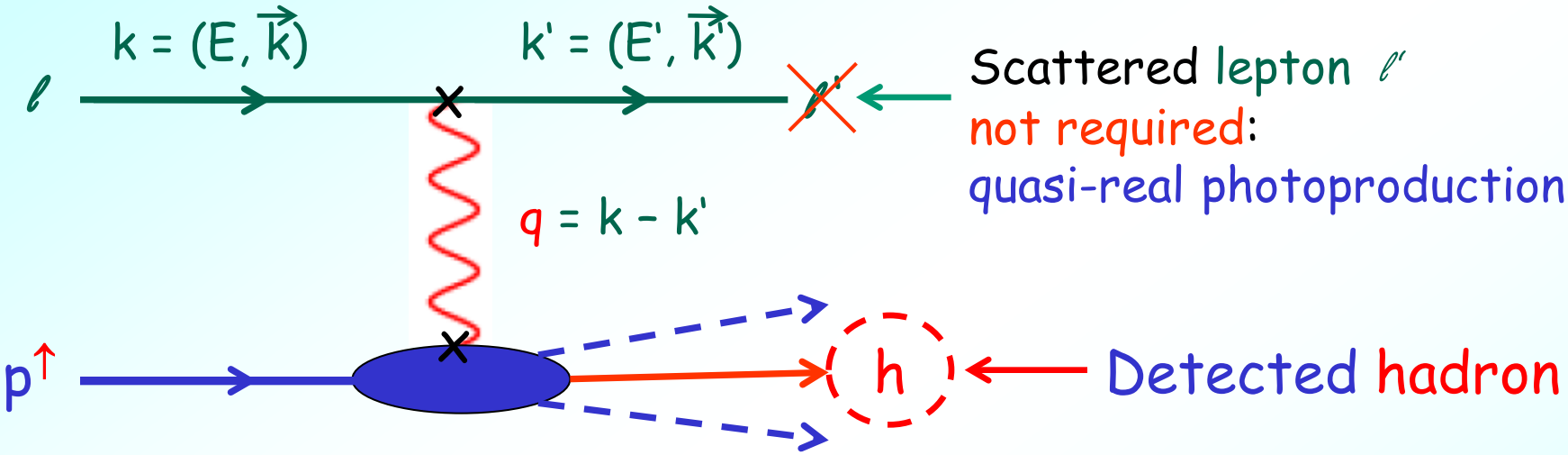


Example: A_N for charged pions in p↑p

I. Arsene et al., Phys. Rev. Lett. 101 (2008) 042001



Inclusive hadron electroproduction

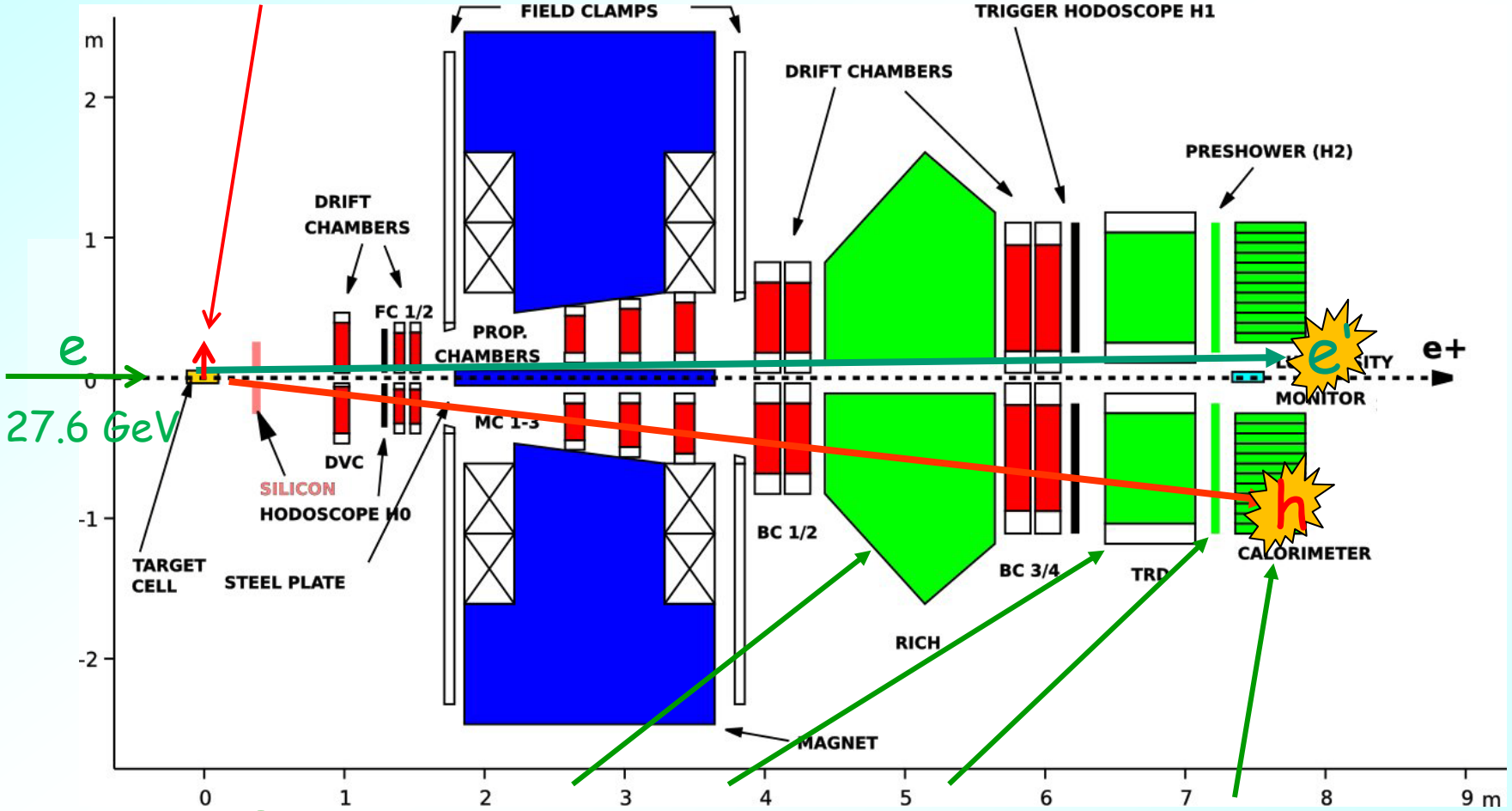


Relevant kinematic variables:

- Feynman variable $x_F = P^h_{long}/P^h_{long,max}$ (in ep CMS)
- Transverse hadron momentum P_T (w.r.t e direction)
- Azimuthal hadron angle Ψ

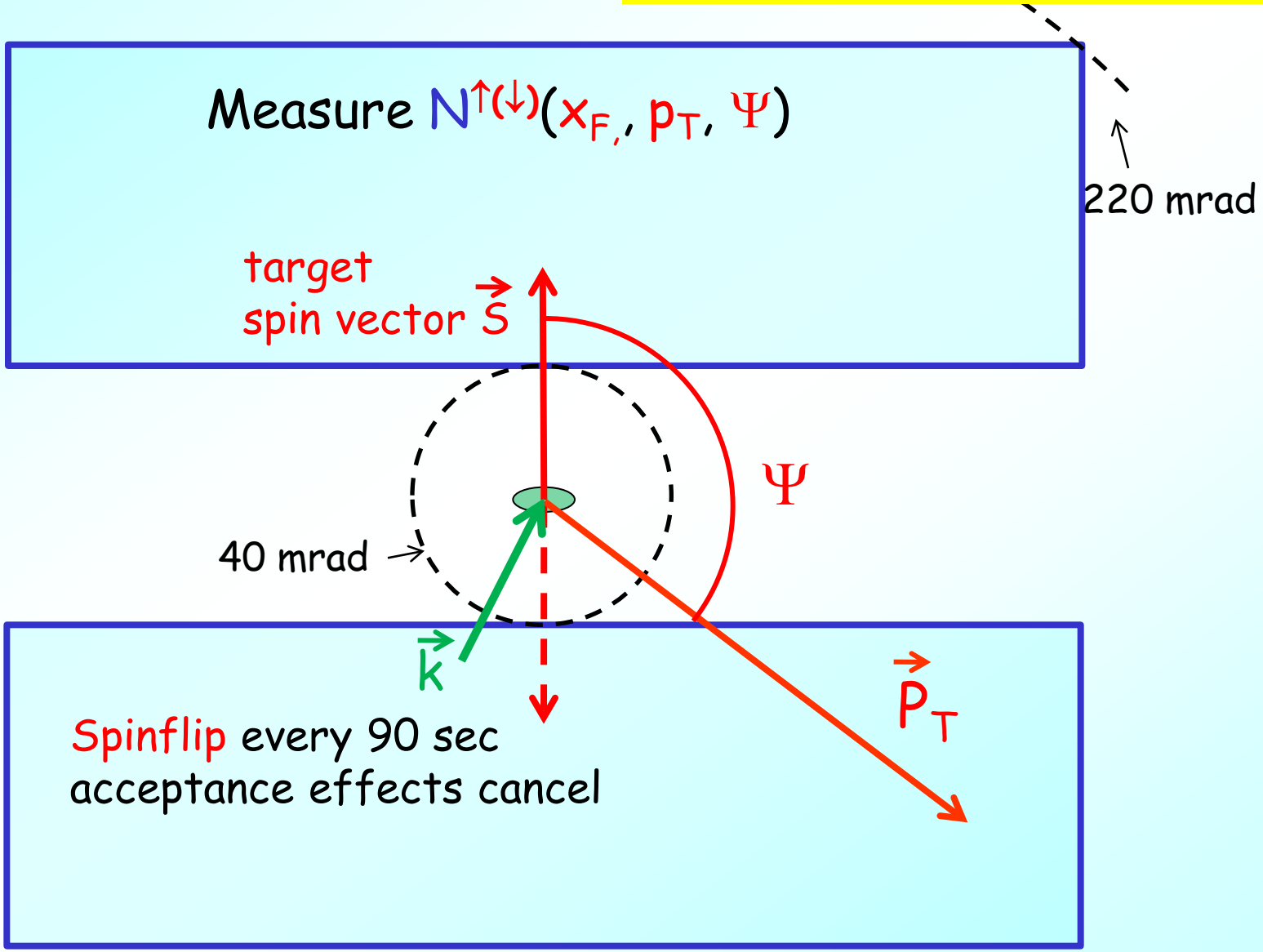
HERMES Spectrometer

Transversely polarized H gas target, $S_T \cong 0.71$ (2002-2005)

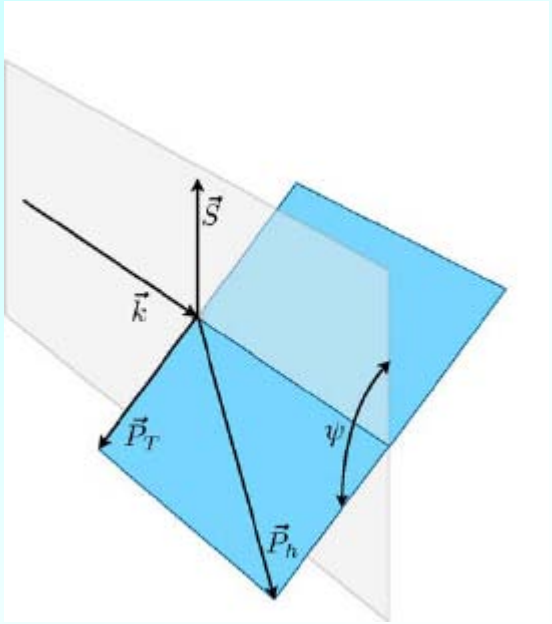


- PID: RICH, TRD, Preshower, Calorimeter
  lepton contamination in hadron sample < 0.1 %

HERMES front view

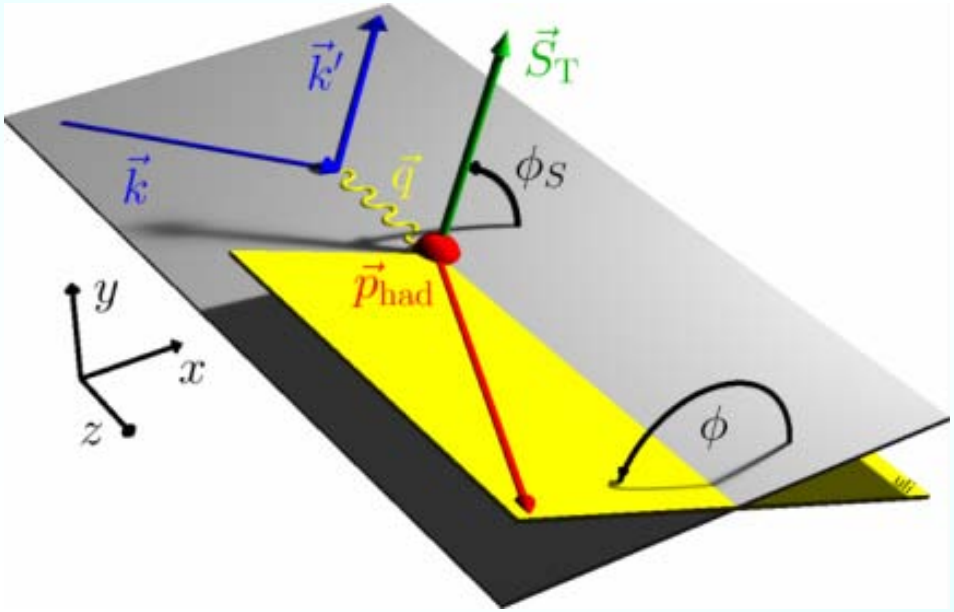


Definition of angle Ψ



Inclusive hadron electroproduction:

Ψ: azimuthal angle between upwards target spin direction and hadron production plane around beam direction



SIDIS:

$\Psi \approx \phi - \phi_S$ (Sivers angle)

TTSA in inclusive hadron electroproduction

TTSA: Tranverse target single-spin asymmetry

Inclusive hadron electroproduction:
$e^{\pm} p^{\uparrow} \rightarrow h X$

Azimuthal asymmetry:

Asymmetry amplitude

$$A(x_F, P_T, \Psi) = \frac{\sigma_{UT}(x_F, P_T, \Psi)}{\sigma_{UU}(x_F, P_T)} = A_{UT}^{\sin\Psi}(x_F, P_T) \sin\Psi$$

A_{XY}: beam target polarisation

$$A_N = \frac{\sigma_L - \sigma_R}{\sigma_L + \sigma_R} = -\frac{2}{\pi} A_{UT}^{\sin\Psi}$$ (left-right asymmetry)

(for ideal detector with full 2π coverage)

x_F dependence (1D projection)

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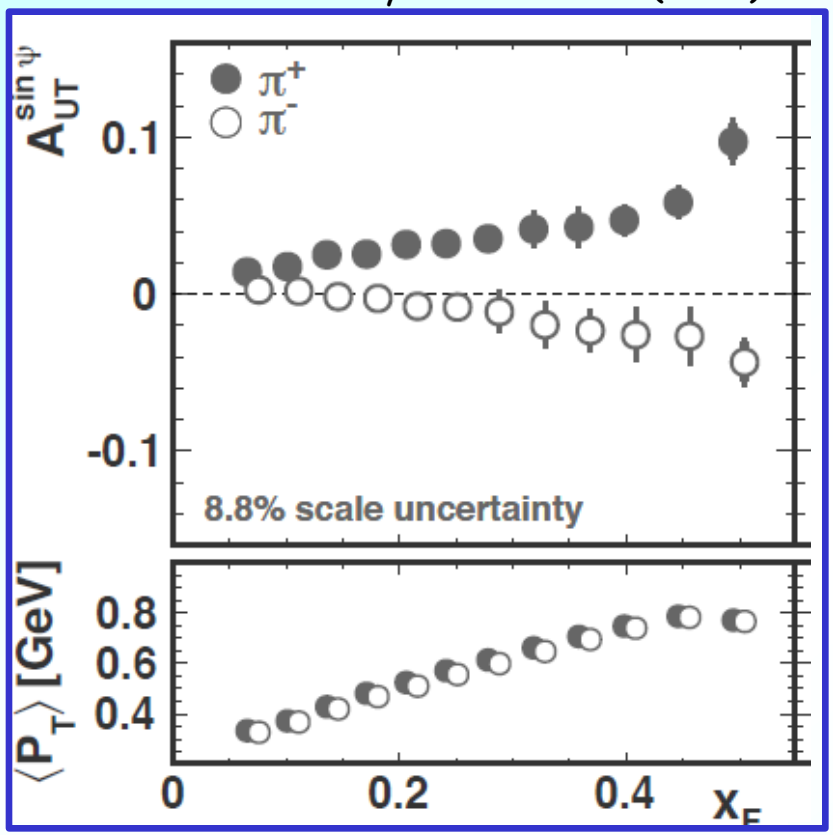
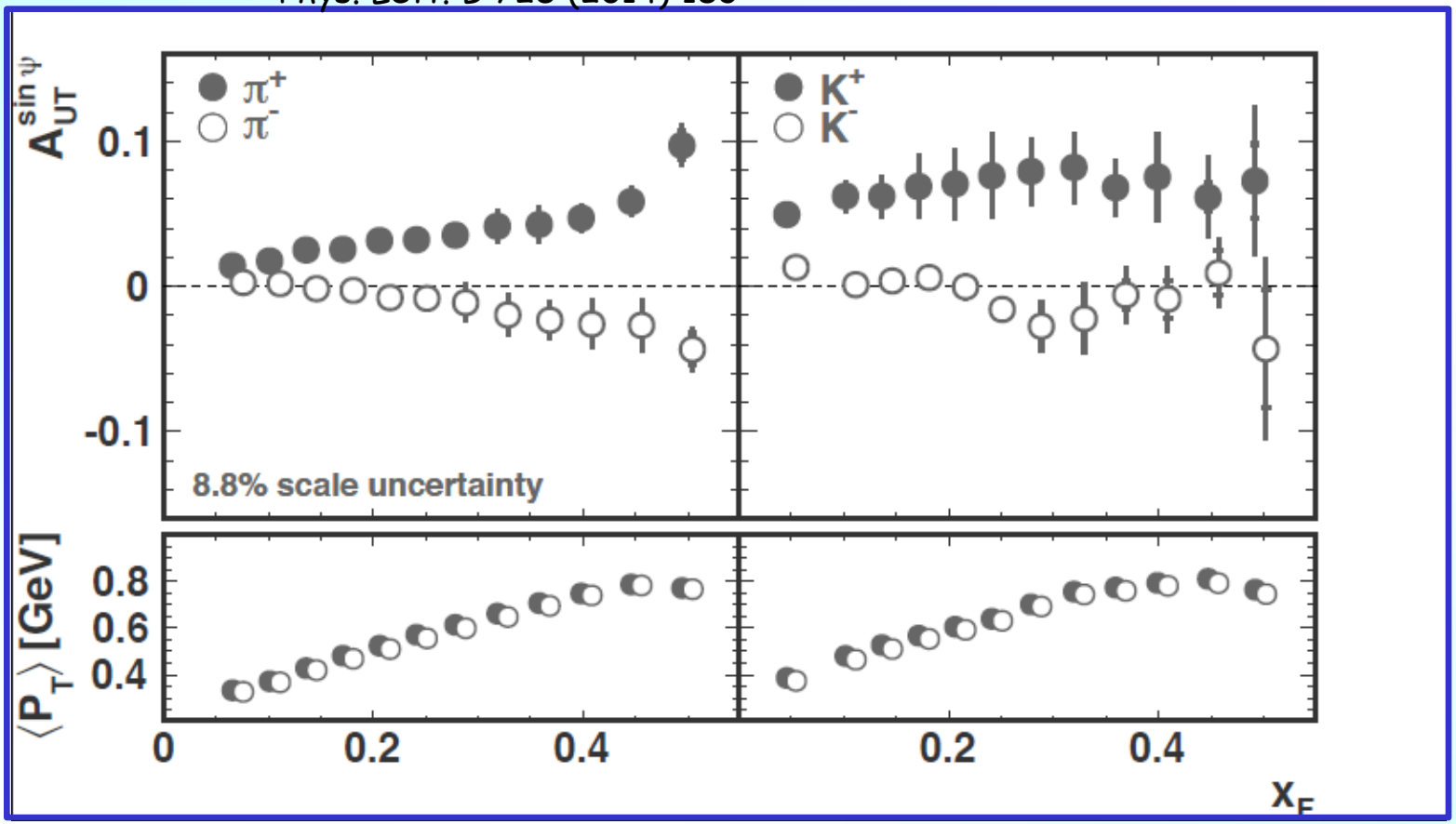


- π^+: positive; nearly linear rise with x_F up to ~ 10 %
- π^-: negative; similar trend, smaller magnitude (up to ~ 4 %)

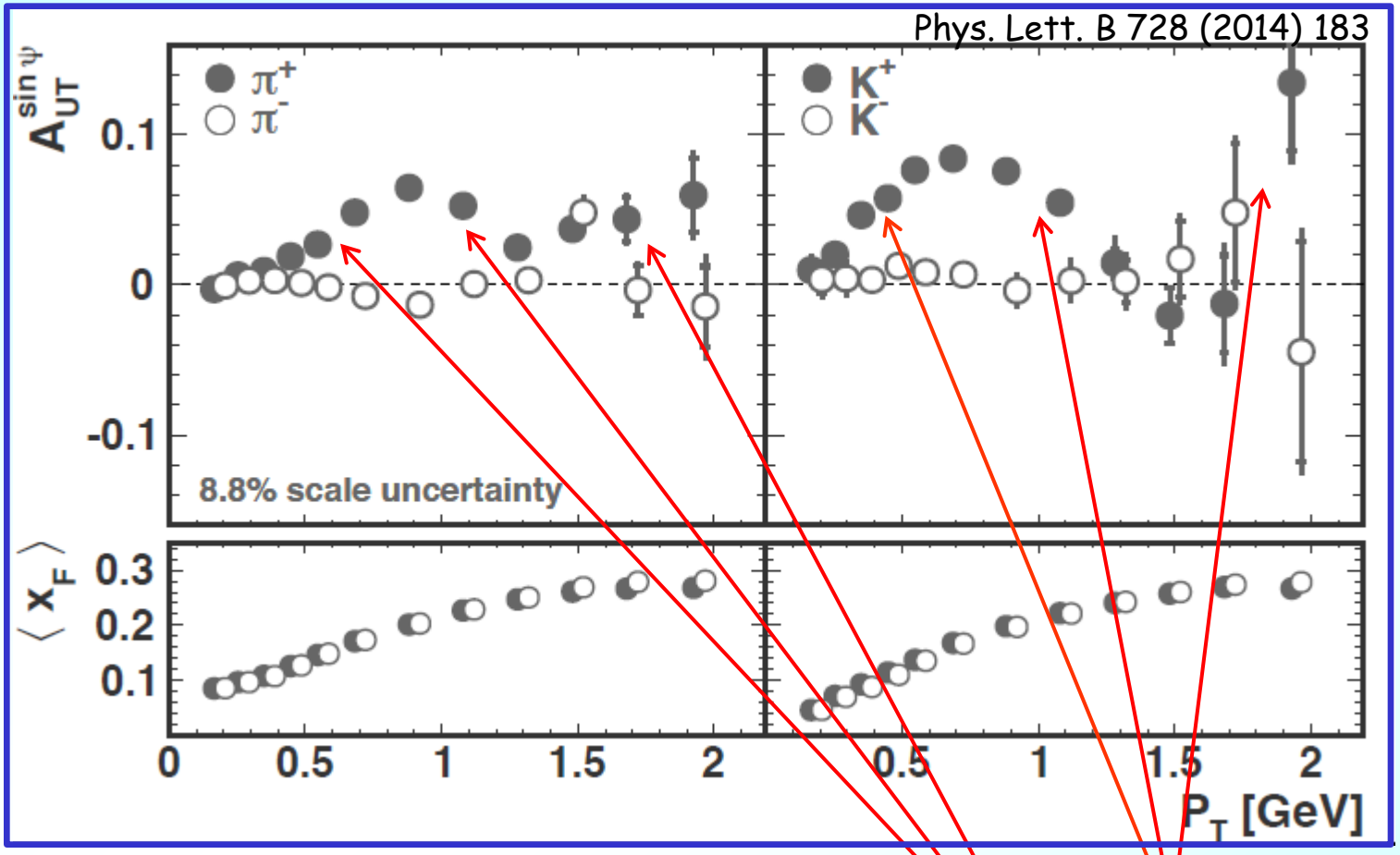
x_F dependence (1D projection)

Phys. Lett. B 728 (2014) 183



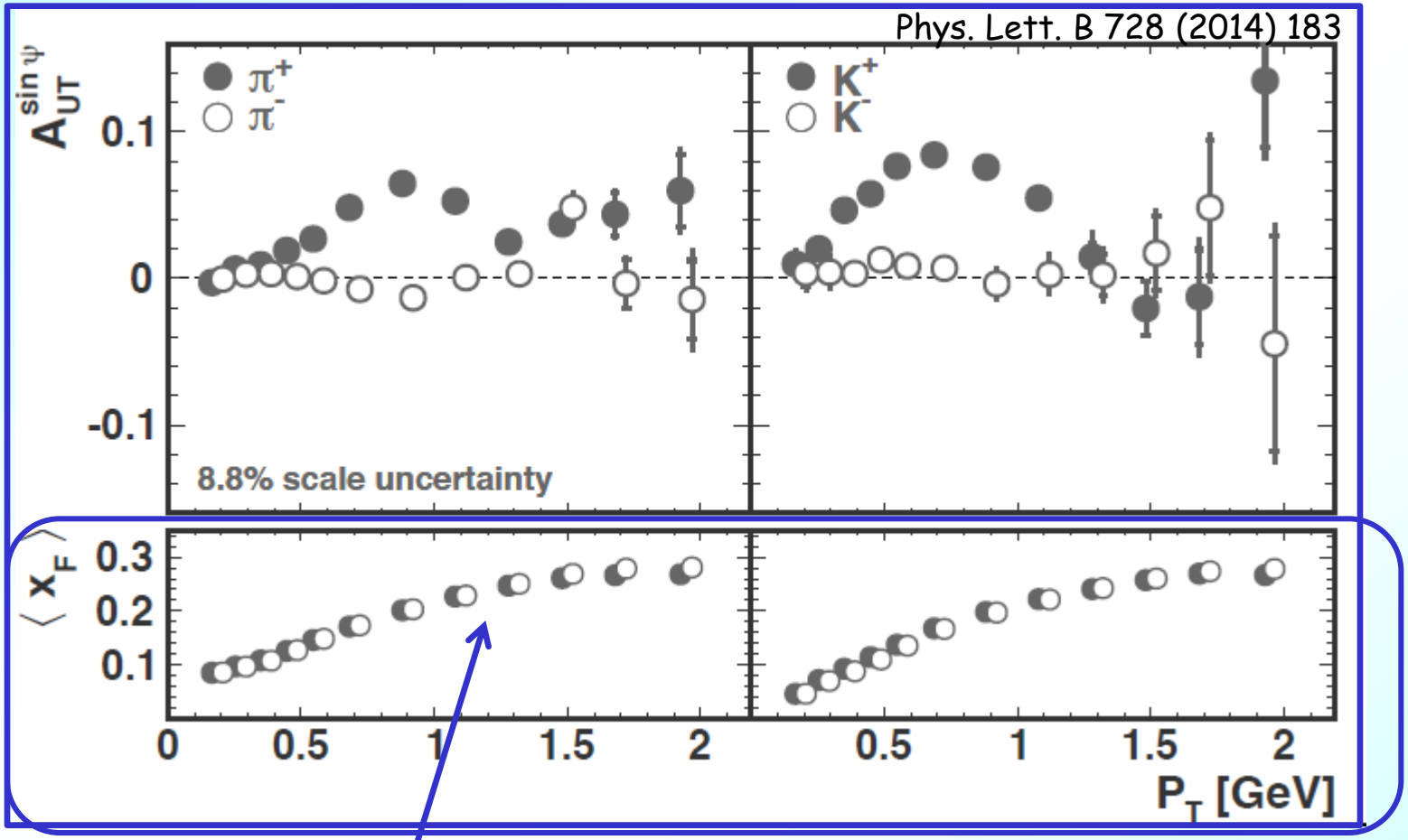
- π^+: positive; nearly linear rise with x_F up to ~ 10 %
- π^-: negative; similar trend, smaller magnitude (up to ~ 4 %)
- K^+: about constant at ~ 7 %
- K^-: ≈ 0
- Kaons behave differently than pions

P_T dependence (1D projection)



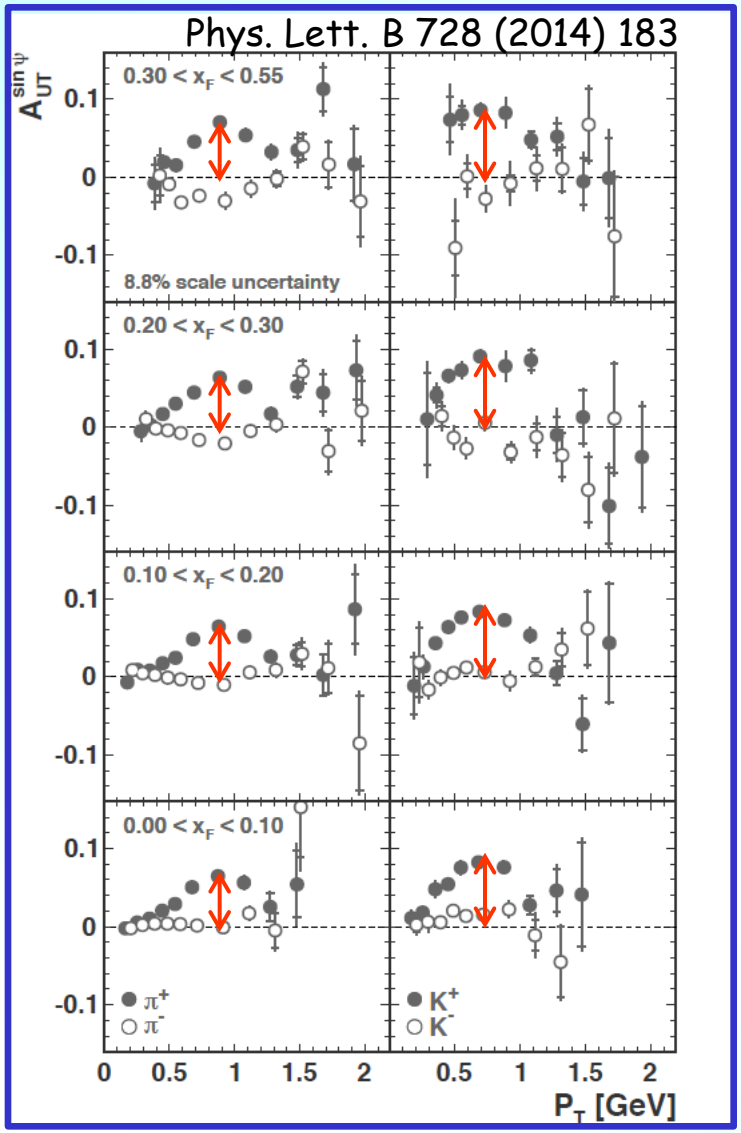
- Rather complicated behaviour for π^+ and K^+

P_T dependence (1D projection)



- Rather complicated behaviour for π+ and K+
- P_T and x_F strongly correlated; important to look at 2D

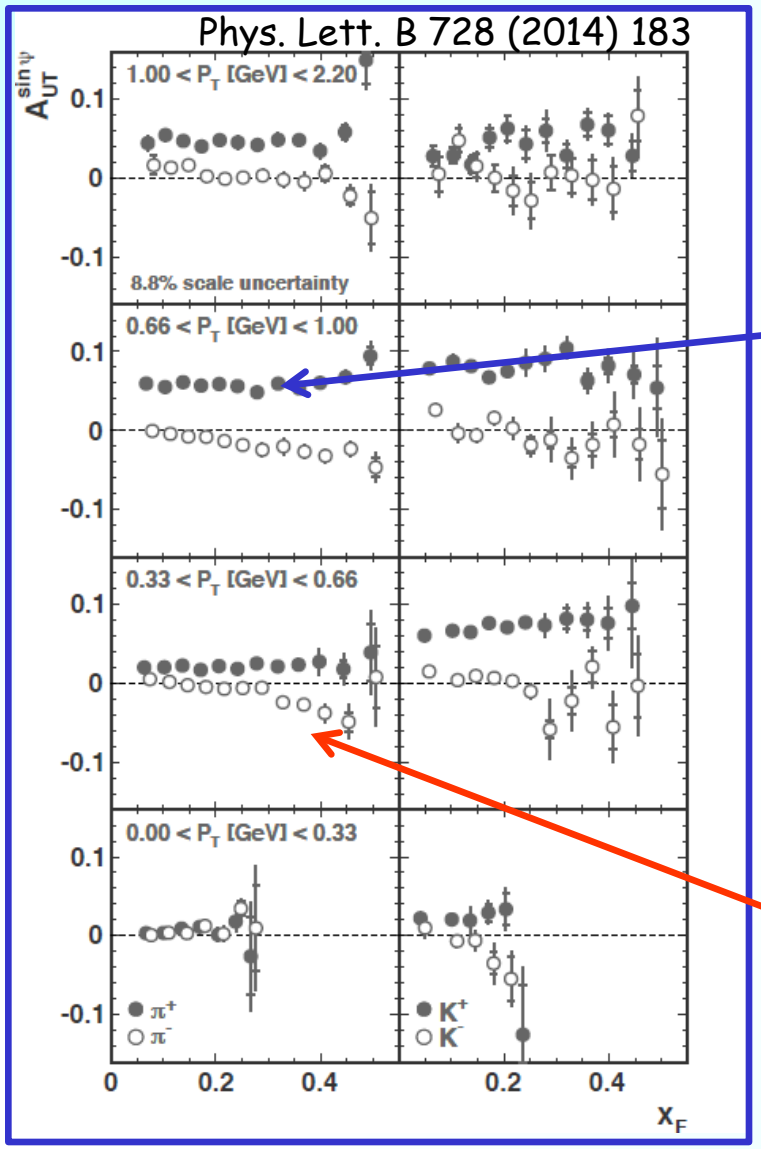
P_T dependence (2D extraction)



- π^+, K^+:
  Very similar P_T dependence for all four x_F intervals; amplitude positive, maximal for $P_T \cong .8$ GeV

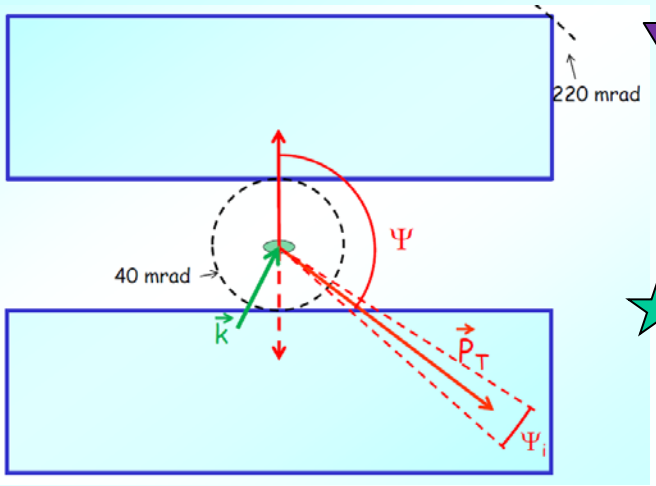
- π^-:
  Amplitude mostly negative, magnitude increases with x_F

x_F dependence (2D extraction)



- π^+, K^+:
  very small dependence on x_F
- x_F dependence observed in 1D extraction is mainly reflection of the P_T dependence
- π^-:
  $A_{UT}^{\sin\Psi}$ negative for x_F >.2
  magnitude increases with x_F

Details: sub-samples



▼ anti-tagged category: e' not in acceptance
- trigger on hadron, low efficiency ε, P^h-dependent, $\langle\varepsilon\rangle \cong 0.3$
- hard scale: P_T

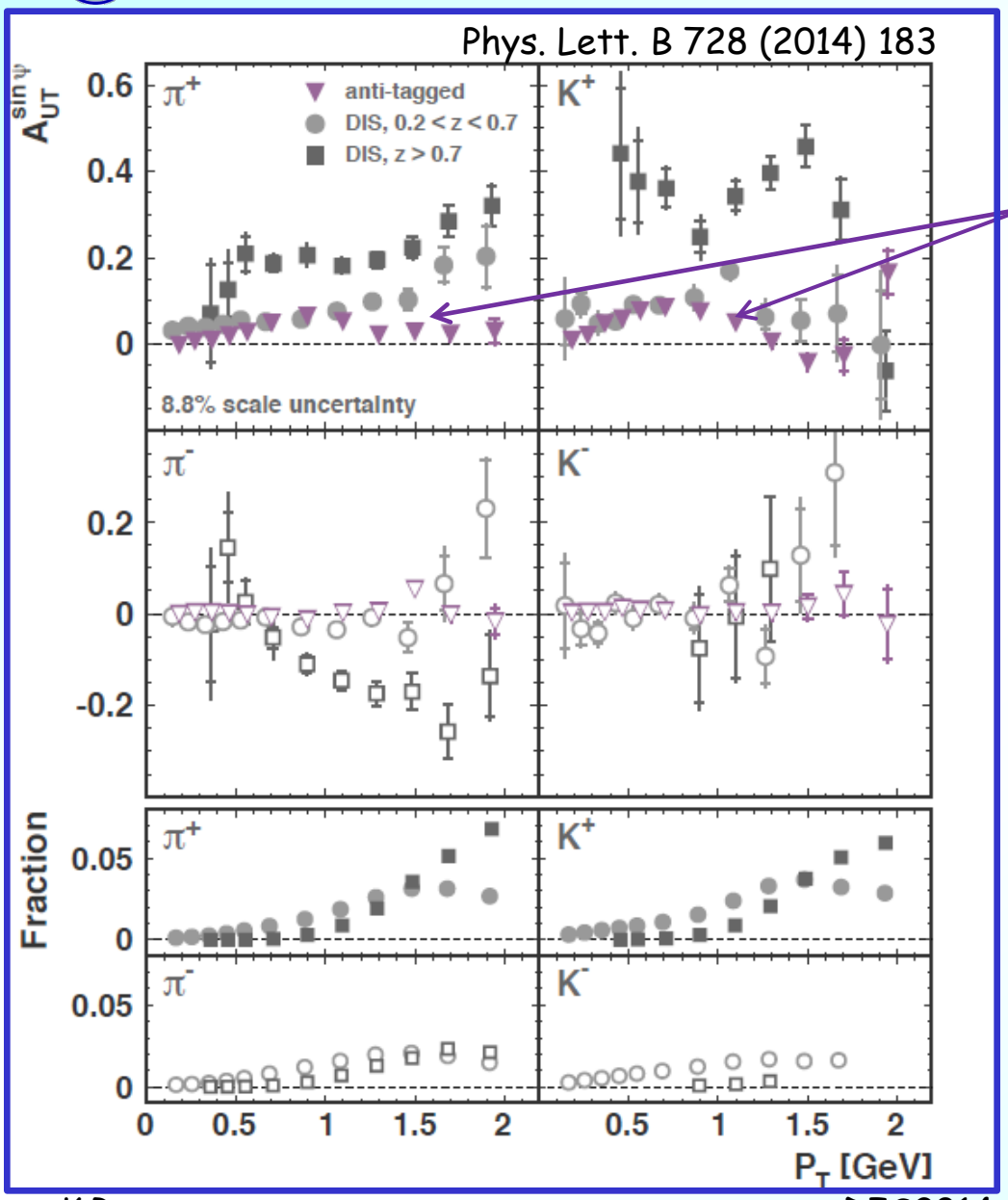
★ tagged category: e' in acceptance, $\varepsilon \cong 1$
-part of this category: DIS events
($Q^2 > 1$ GeV^2, $W^2 > 10$ GeV^2, $0.023 < x < 0.4$, $0.2 < y < 0.95$)
- hard scales: Q, P_T; $Q^2 > P_T^2$

Sub-samples: ● DIS, $0.2 < z < 0.7$ (used for determination of TMDs)
■ DIS, $z > 0.7$ (´quasi-exclusive')

	π^+	π^-	K^+	K^-
raw tracks	60	50	5.1	2.8
ε-corr. tracks	172	142	14.5	7.3
▼ anti-tagged	170.5	140.7	14.3	7.2
● DIS, $0.2 < z < 0.7$	0.69	0.49	0.12	0.05
■ DIS, $z > 0.7$	0.061	0.037	0.013	0.001

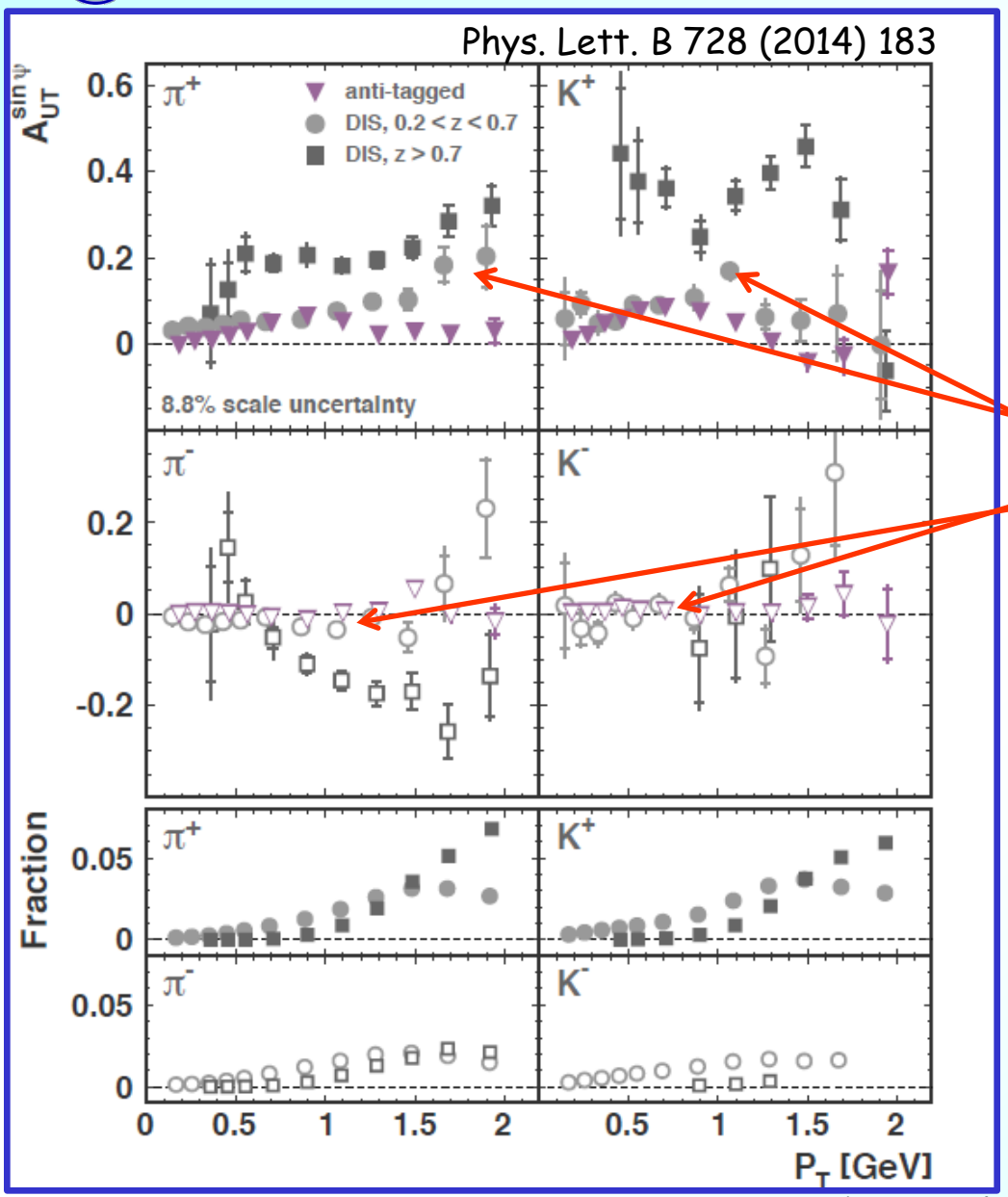
$* 10^6$

P_T dependence for 3 sub-samples



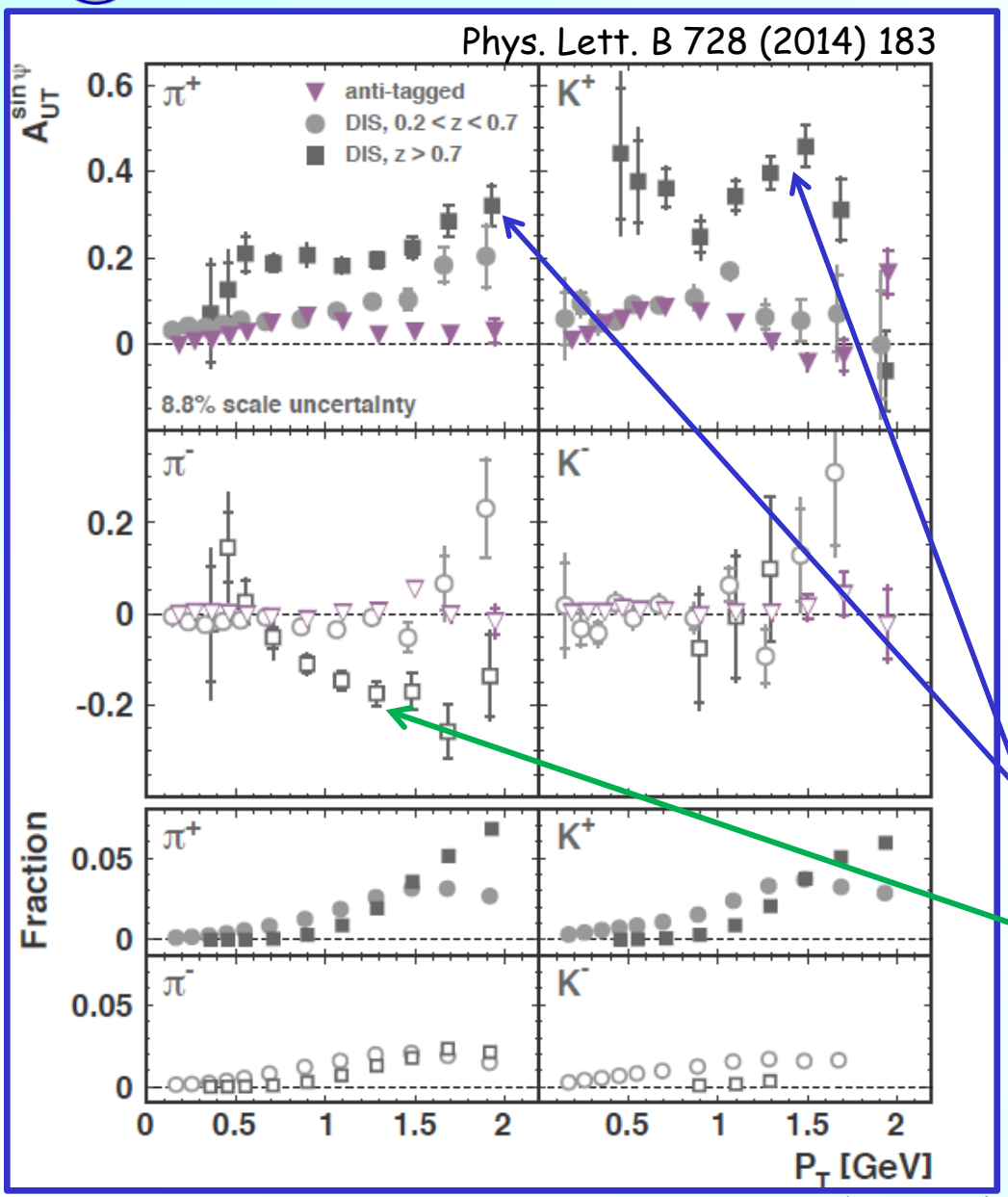
▼ anti-tagged
decrease with P_T for $P_T > 0.8$ GeV
➡ Higher-twist

P_T dependence for 3 sub-samples



- anti-tagged
  decrease with P_T for $P_T > 0.8$ GeV
  → Higher-twist
- DIS, $0.2 < z < 0.7$
  π^+, K^+: increase with P_T up to ~20%
  π^-, K^-: compatible with zero
  → Sivers

P_T dependence for 3 sub-samples



▼ anti-tagged

decrease with P_T for $P_T > 0.8$ GeV

➡ Higher-twist

● DIS, $0.2 < z < 0.7$

π^+, K^+: increase with P_T up to ~20%

➡ Sivers

■ DIS, $z > 0.7$

π^+, K^+: very large asymmetries up to >40%

π^-: large negative asymmetry up to ~ -20%

(favoured fragm. of struck quark;

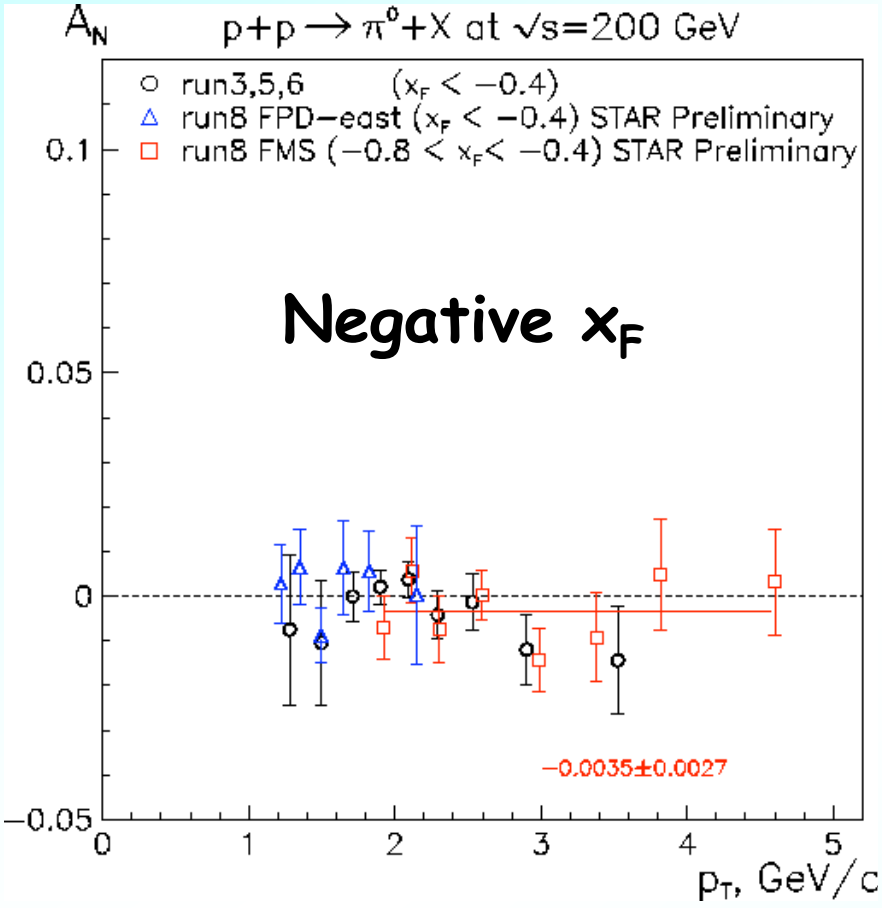
➡ d-quark Sivers function ?)

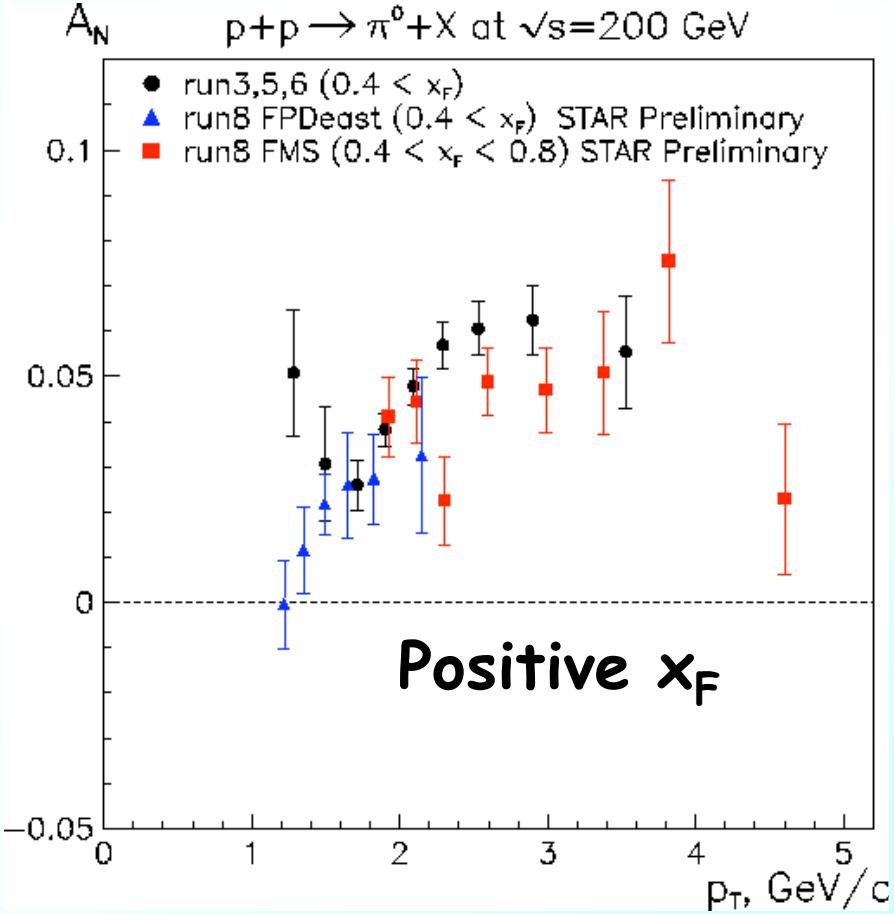
Conclusion

- HERMES has measured with high precision single-spin asymmetries in inclusive hadron electroproduction $e + p^{\uparrow} \rightarrow h + X$ from a transversely polarised proton target
- Substantial single-spin asymmetries are observed for positive pions and kaons
- 1D x_F dependence of amplitudes is mainly a reflection of underlying P_T dependence
- Complicated P_T dependence of amplitudes caused by contributions of sub-samples:
  -decrease with P_T for quasi-real photoproduction
  -increase with P_T for DIS samples
  -very large asymmetries for ´quasi-exclusive' events

Backups

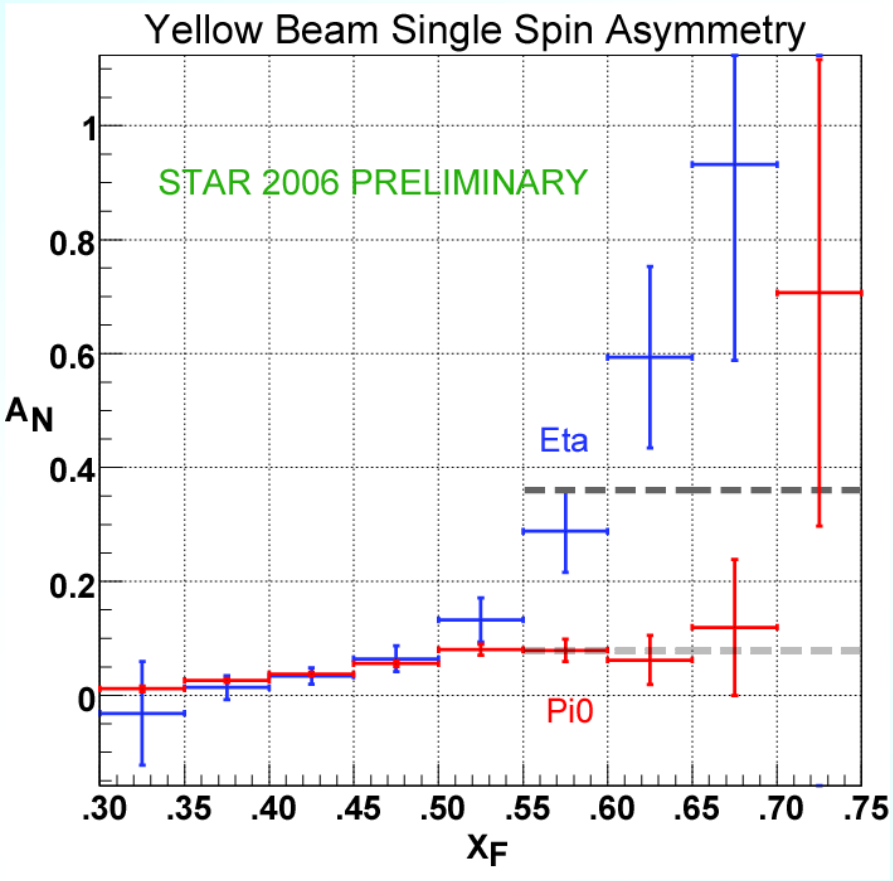
A_N for π^0 in p↑p





Consistent with zero for all p_T

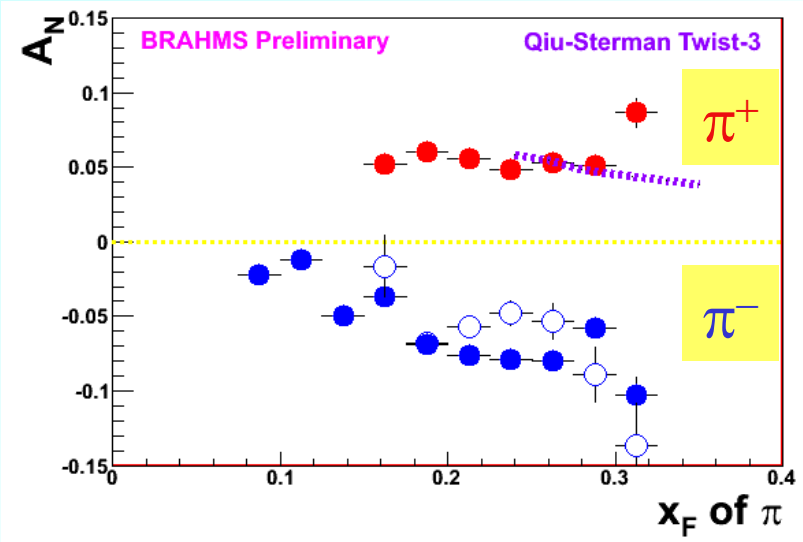
A_N for π^0 and η in p↑p

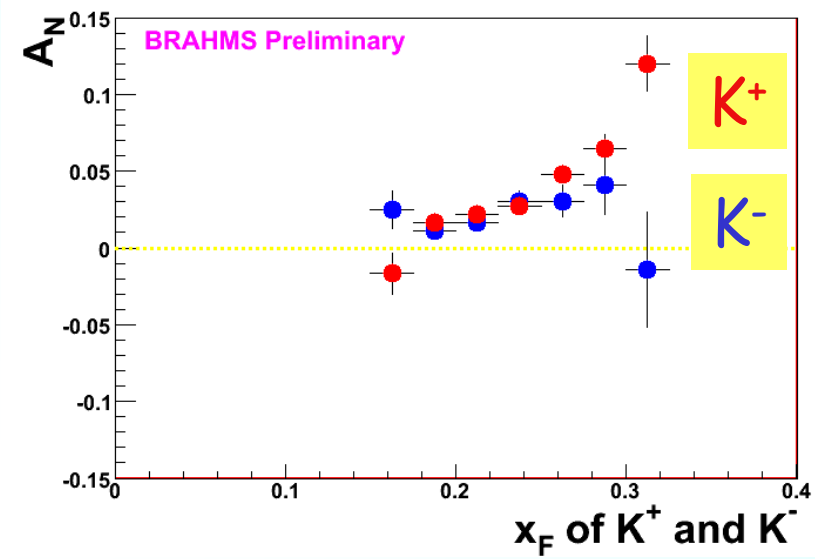


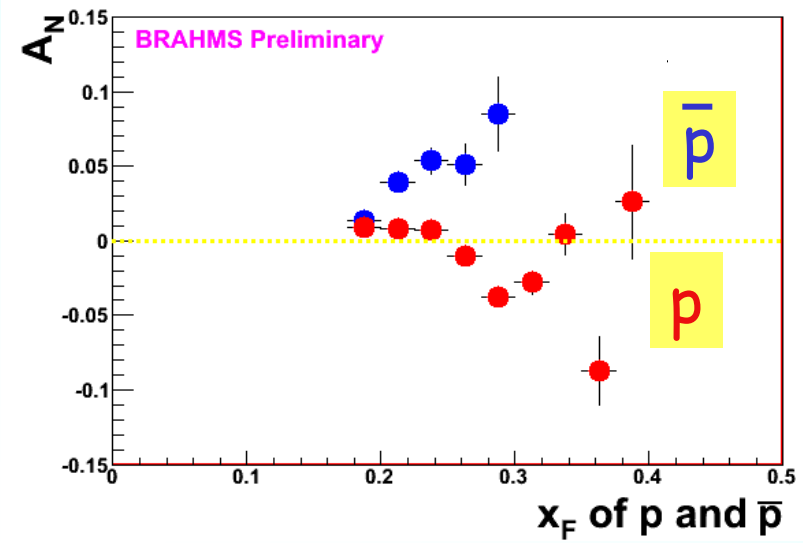
Very large asymmetry for η

A_N for identified hadrons in p↑p

$\sqrt{s}$ = 200 GeV







- $A_N(\pi^+)$ positive ~ $A_N(\pi^-)$ negative
- $A_N(K^+)$ ~ $A_N(K^-)$ positive
  (in disagreement with expectation from valence quark fragmentation)
- $A_N(p)$ ~ 0, $A_N(\bar{p})$ positive
- More data and theoretical input needed

Inclusive hadron TSA

Interpretation: non-trivial due to missing hard scale - except for high p_T (factorisation?)

Model predictions:

M. Anselmino et al., PRD 81 (2010) 034007

pions

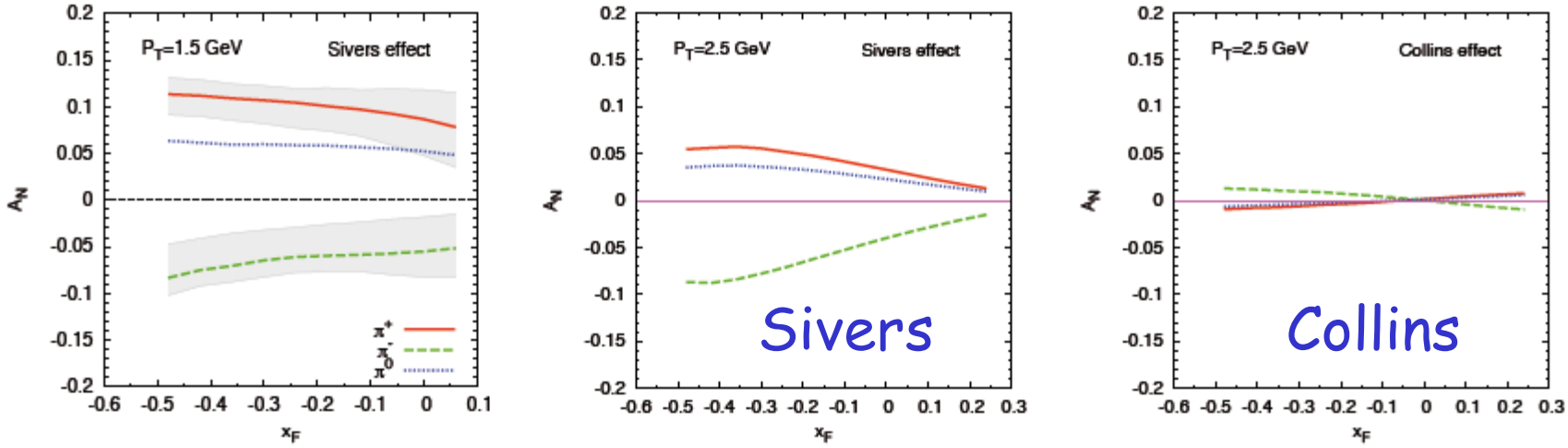


FIG. 2: Estimates of A_N vs. x_F for the $p^\uparrow \ell \to \pi X$ process at HERMES ($\sqrt{s} \simeq 7$ GeV). Left panel: Sivers effect at $P_T = 1.5$ GeV; central panel: Sivers effect at $P_T = 2.5$ GeV; right panel: Collins effect at $P_T = 2.5$ GeV.

HERMES Experiment

Data taking: 1995-2007

27.6 GeV e+/e- beam of HERA
polarisation ≤ 60 %

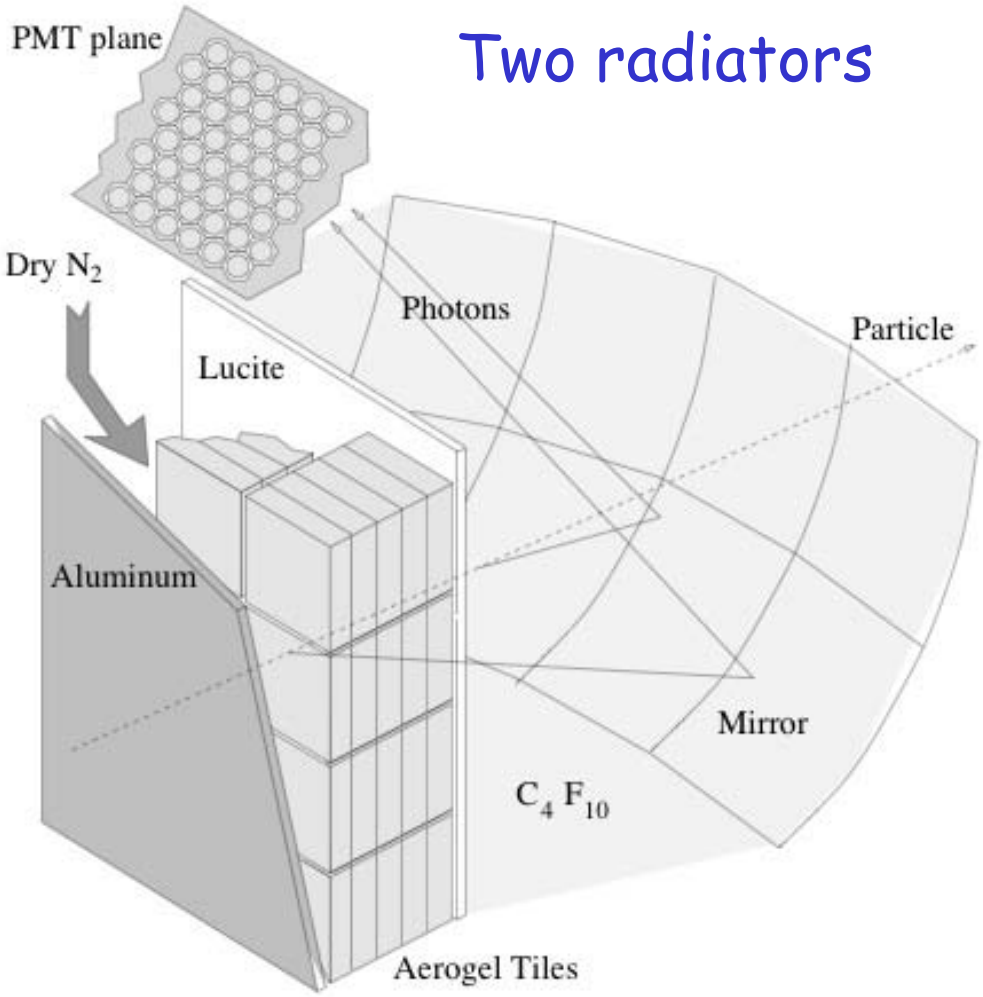
Internal gas targets

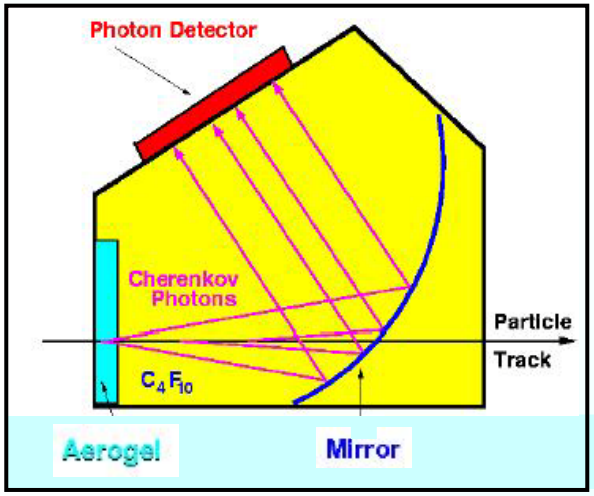
polarized : $\vec{}^{1}H$, $\vec{}^{1}H^{\uparrow}$, $\vec{}^{2}H$, $\vec{}^{3}He$

unpolarized: ^{1}H, ^{2}H, ^{3}He, ^{4}He,
N, Ne, Kr, Xe

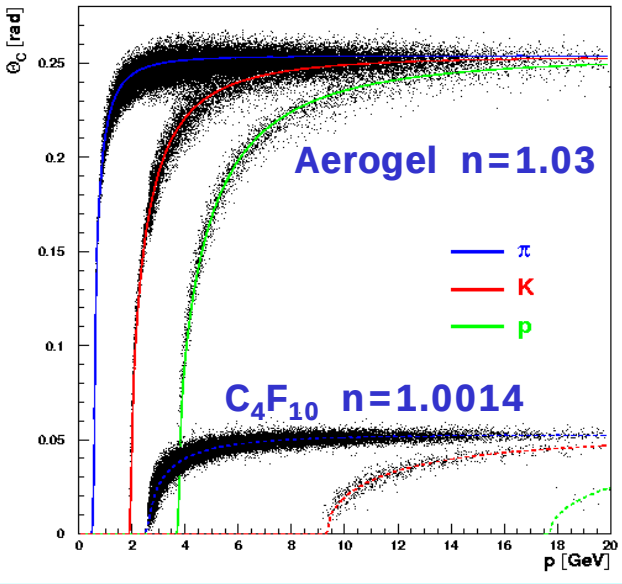
HERMES spectrometer - RICH

Two radiators





hadron separation



Hadron: π ~ 98%, K ~ 88% , P ~ 85%