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Transverse Spin Physics by HERMES

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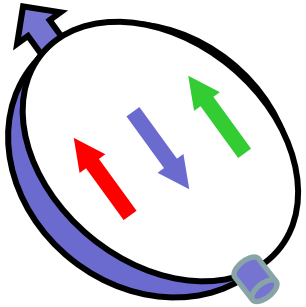
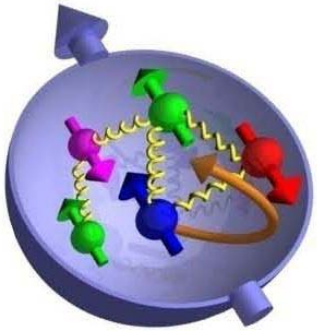
Spin Structure of the Nucleon



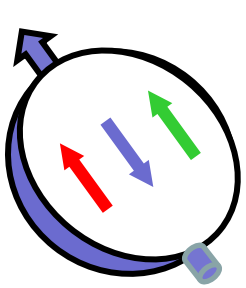


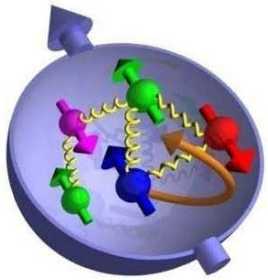
Proton spin, 1/2 :
determined by the specific heat of hydrogen molecular (1927)

Hydrogen atom, proton spin and electron spin, 21 cm wavelength, astronomy

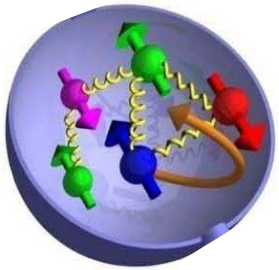
Application, MRI (Magnetic Resonance Imaging) for medical use

Spin Structure of the Nucleon





Polarized nucleon



Unpolarized nucleon

Correlation between Quark Spin and its Transverse Momentum in Unpolarized nucleon

Spin-orbit interaction

Milestones, HERMES

2001 Deeply Virtual Compton Scattering and Exclusive Hadron Productions — Phys. Rev. Lett. 87 (2001) 182001

2005 Extraction of Collins Asymmetry — Phys. Rev. Lett. 94 (2005) 012002

2007 Quark Spin Contribution to the Nucleon Spin

$33 \pm 3.9\,\%$ — Phys. Rev. D 75 (2007) 012007

2009 Extraction of Sivers Asymmetry — Phys. Rev. Lett. 103 (2009)152002

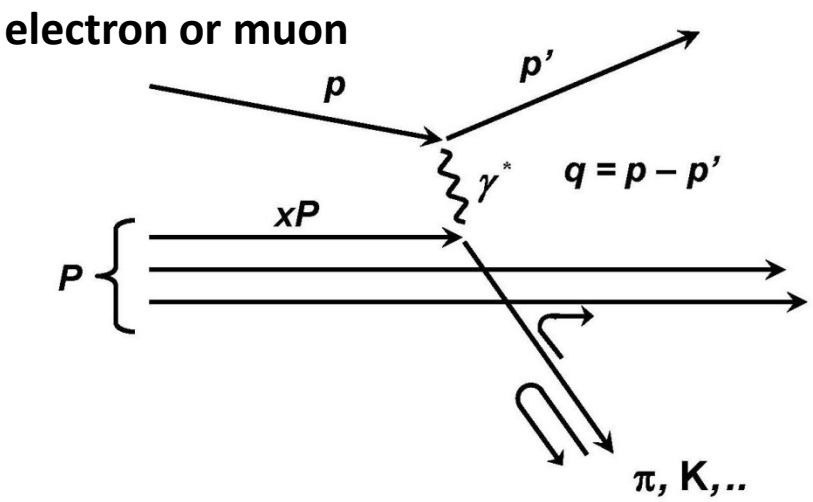
2013 Extraction of Azimuthal Angle Dependence with Unpolarized Targets

Azimuthal distributions of charged hadrons, pions, and kaons produced in deep-inelastic scattering off unpolarized protons and deuterons
A. Airapetian et al., Phys. Rev. D 87 (2013) 012010

2014 Inclusive measurement of hadrons, A_{UT}

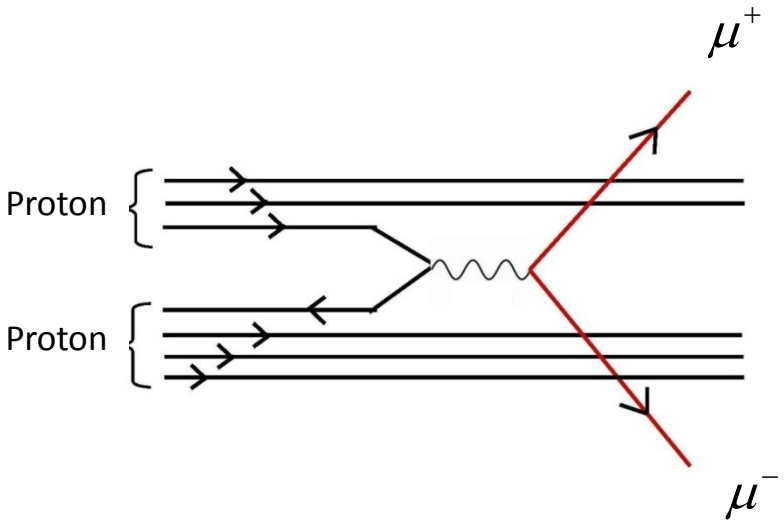
Transverse target single-spin asymmetry in inclusive electroproduction of charged pions and kaons *A. Airapetian et al., Phys. Lett. B 728 (2014) 183-190*

Deep inelastic scattering



Space-like virtual photon

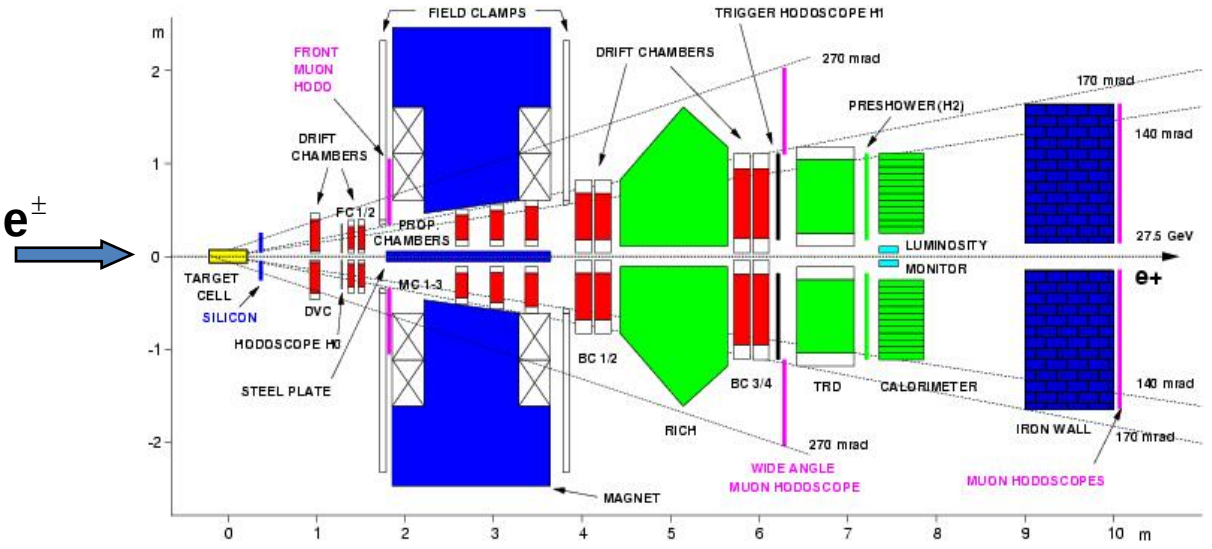
Drell-Yan process



Time-like virtual photon

HERMES Experiment at DESY－HERA

E_e = 27.6 GeV

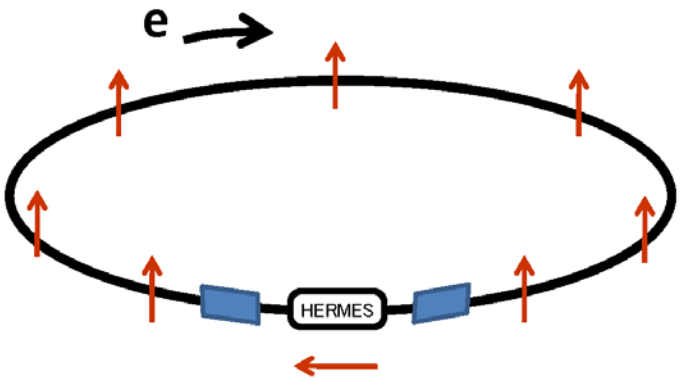


Proton, Deuteron Targets

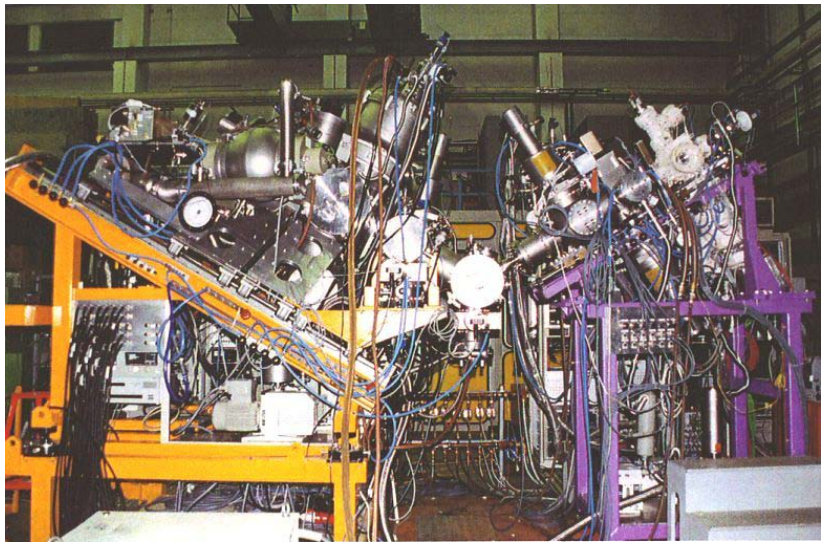
Pion, Kaon, Proton Identification with RICH

HERMES Experiment at DESY－HERA

Polarized electron (positron) beam



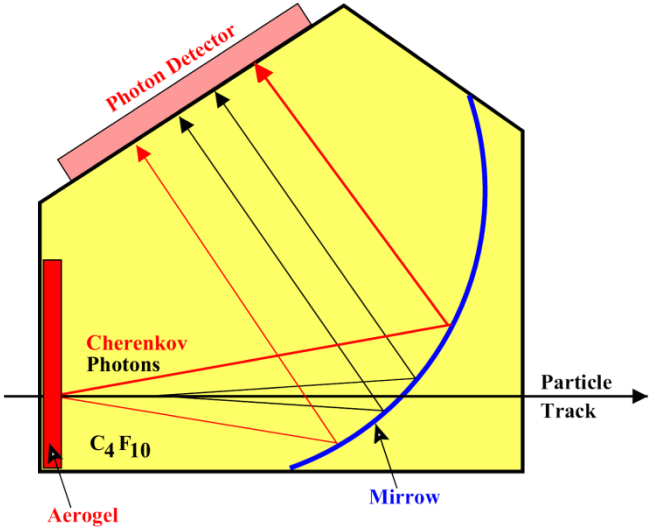
Polarized internal targets

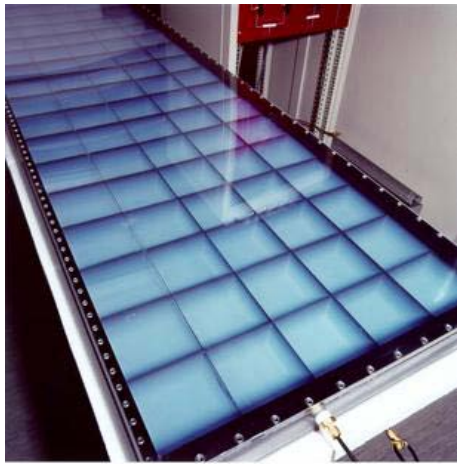


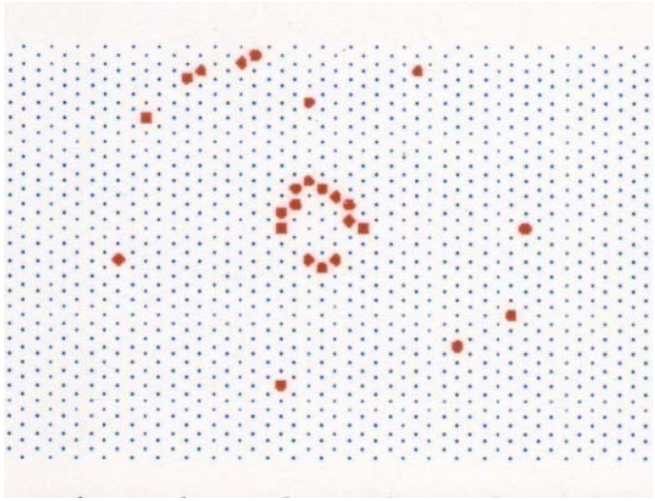
Hadron Identification

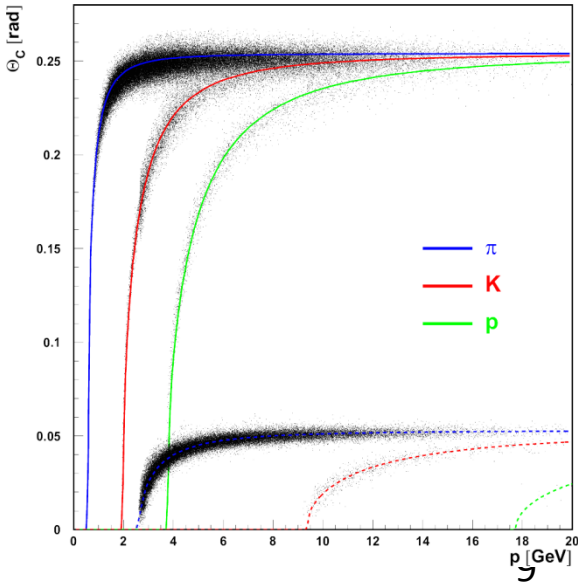
RICH

radiator: Aerogel, C_4F_{10}



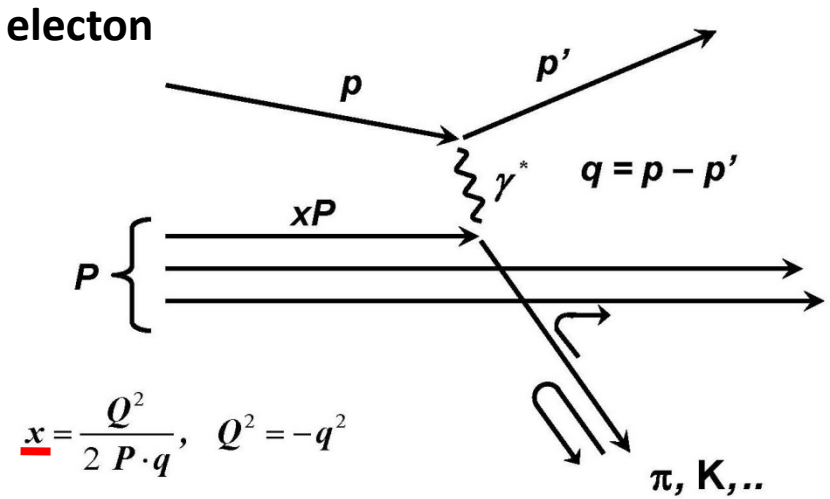






Event by event measurement

Deep inelastic scattering



$$x = \frac{Q^2}{2\,P\cdot q}, \quad Q^2 = -q^2$$

Event by event

Hadron coincidence

$$Q^2 > 1\ GeV^2,\ W^2 > 10\ GeV^2,$$
$$0.023 < x < 0.4, \quad 0.1 < y < 0.95$$

Bjorken *x* is Lorentz Invariant Quantity $$x = \frac{Q^2}{2P \bullet q}$$

$$x = \frac{Q^2}{2M\nu}$$ in a fixed target experiment, in Lab frame

Bjorken *x* is the momentum fraction of the parton in Breit frame

$$E_{\gamma^*} = 0$$

Physics of 1st moment

nth moment

$$\int_0^1 dx\ x^{n-1} F_1(x,Q^2)$$

Integration over *x* from 0 to 1

The 1st moment is the quantity we like to determine

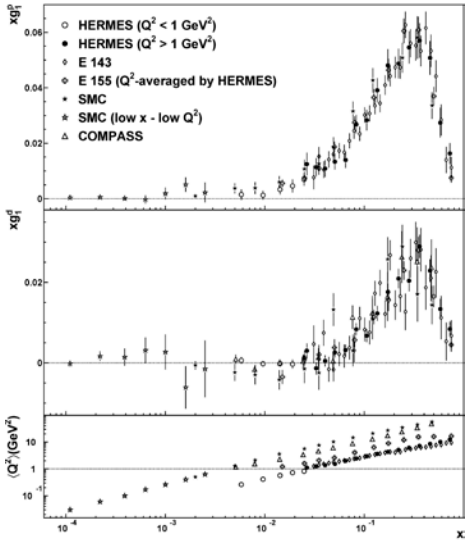
$$\int_0^1 dx\ F_1(x,Q^2)$$

Example: Violation of Gottfried Sum Rule: NMC

$$\int_0^1 dx\ g_1(x,Q^2), \qquad \int_0^1 dx\ u(x,Q^2)$$

Analysis of Quark Spin Contribution to the Nucleon Spin

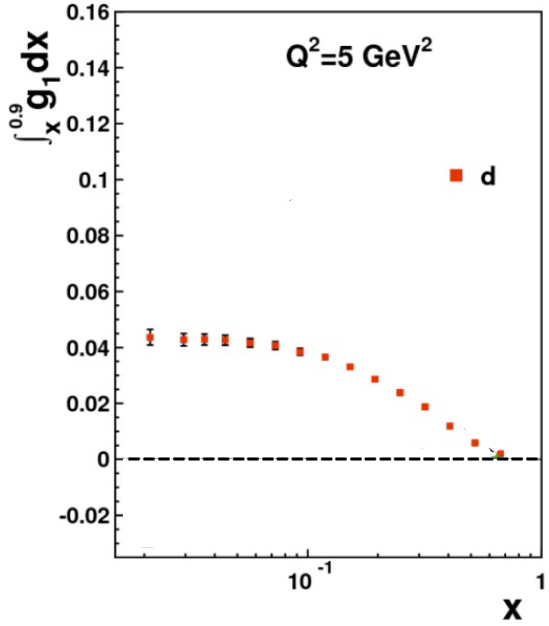
Longitudinal spin structure

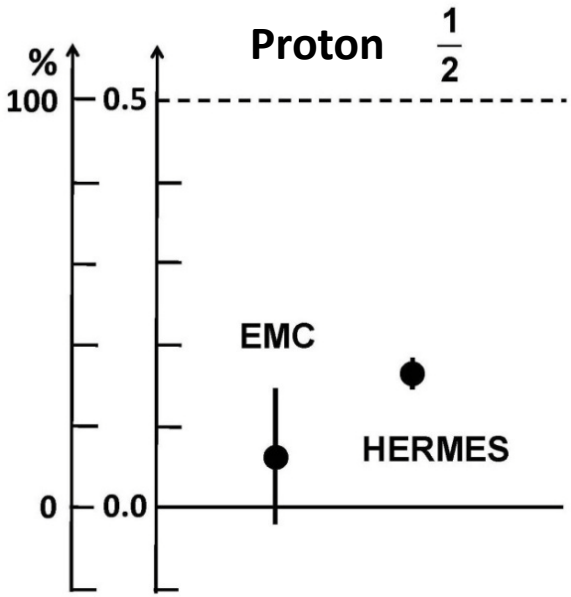


- Quark spin contributions to the proton spin

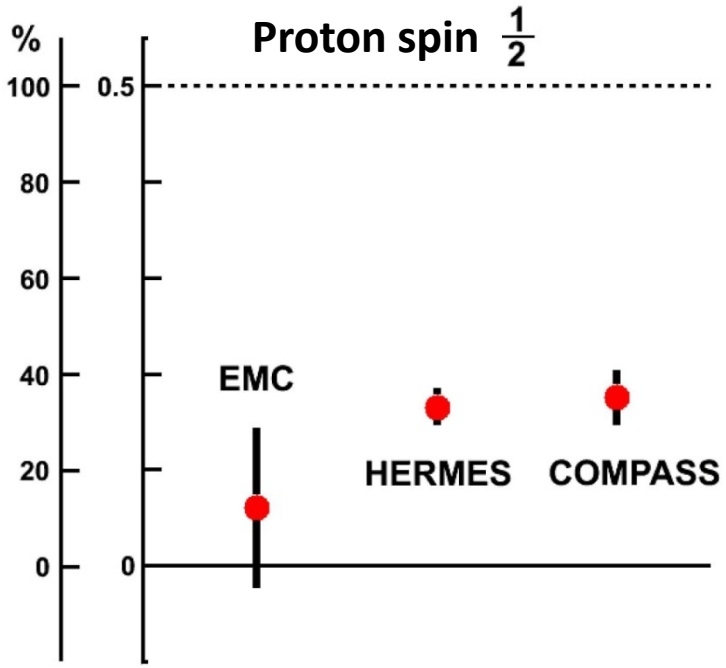
The 1st moment

$$\frac{1}{2}\int_0^1 dx\ (u^{\uparrow}(x)-u^{\downarrow}(x))+(d^{\uparrow}(x)-d^{\downarrow}(x))+(s^{\uparrow}(x)-s^{\downarrow}(x)) = \frac{1}{2}(\Delta u+\Delta d+\Delta s)$$





33 ± 3.9 %



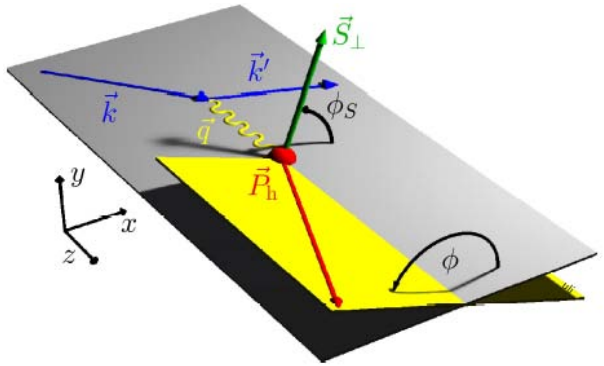
33 ± 3.9 %

Transverse Spin Physics

Event by event

Azimuthal Angle dependence, Transversely Polarized Target

Transversely polarized nucleon

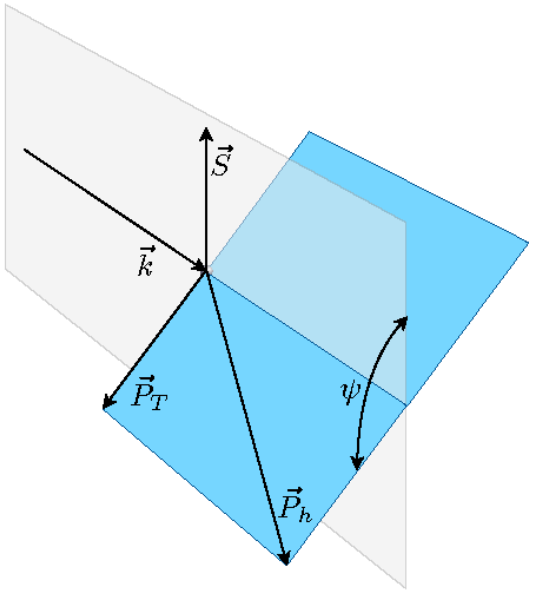


$$(\phi - \phi_s), \quad (\phi + \phi_s)$$

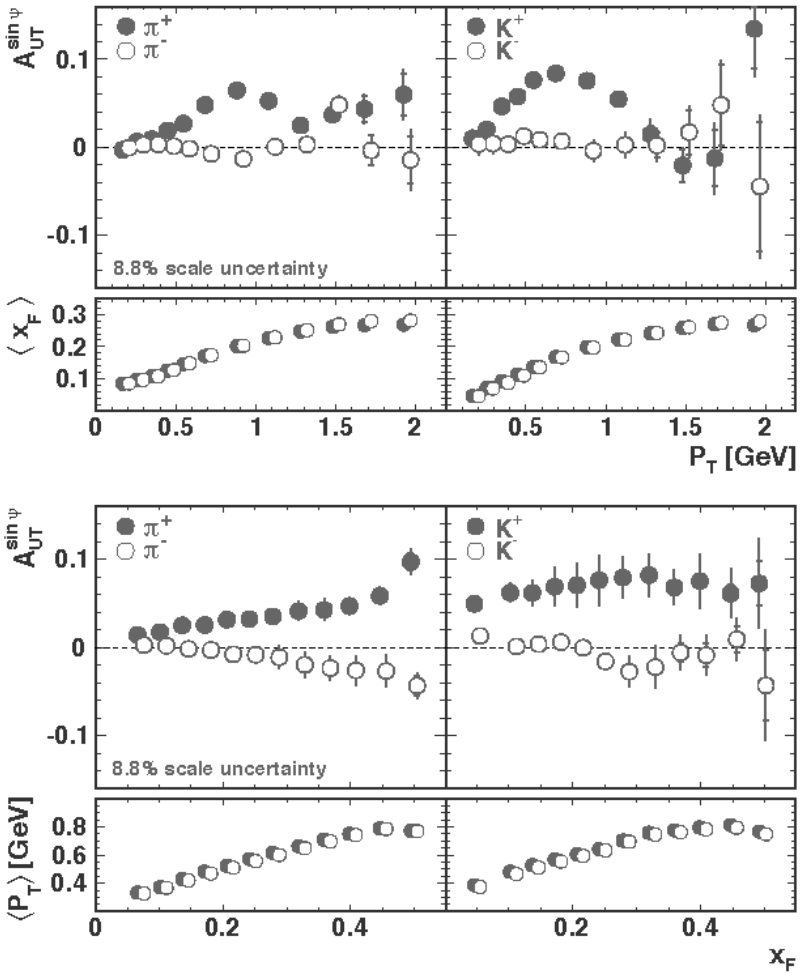
Sivers asymmetry, Collins asymmetry

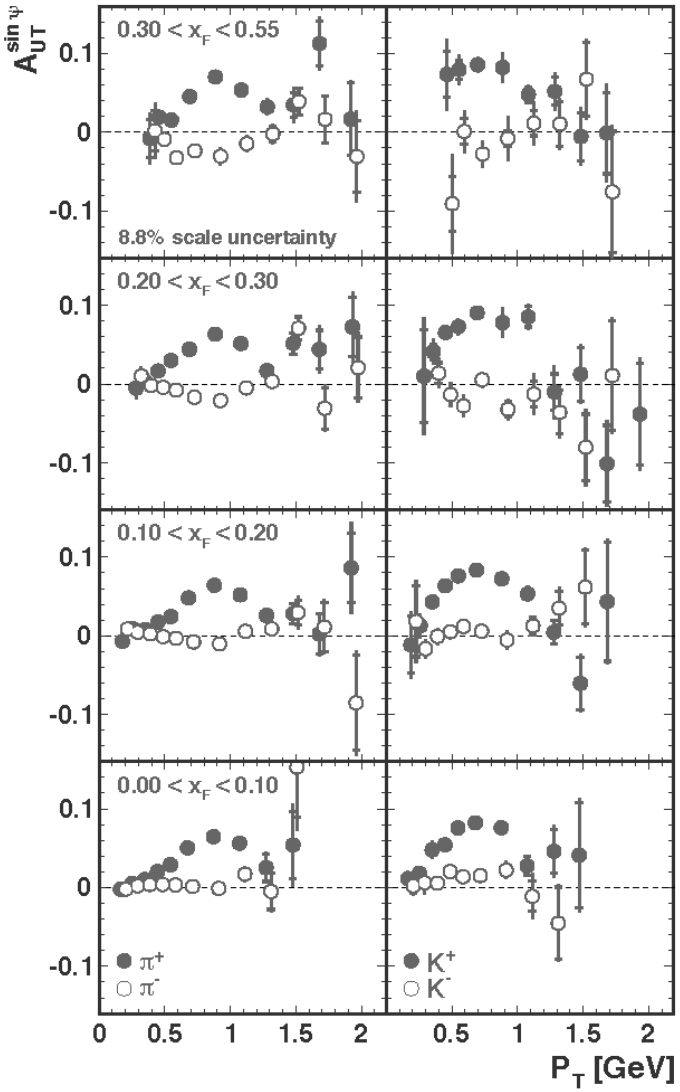
2014 **Transverse target single-spin asymmetry in <u>inclusive</u> electroproduction of charged pions and kaons**

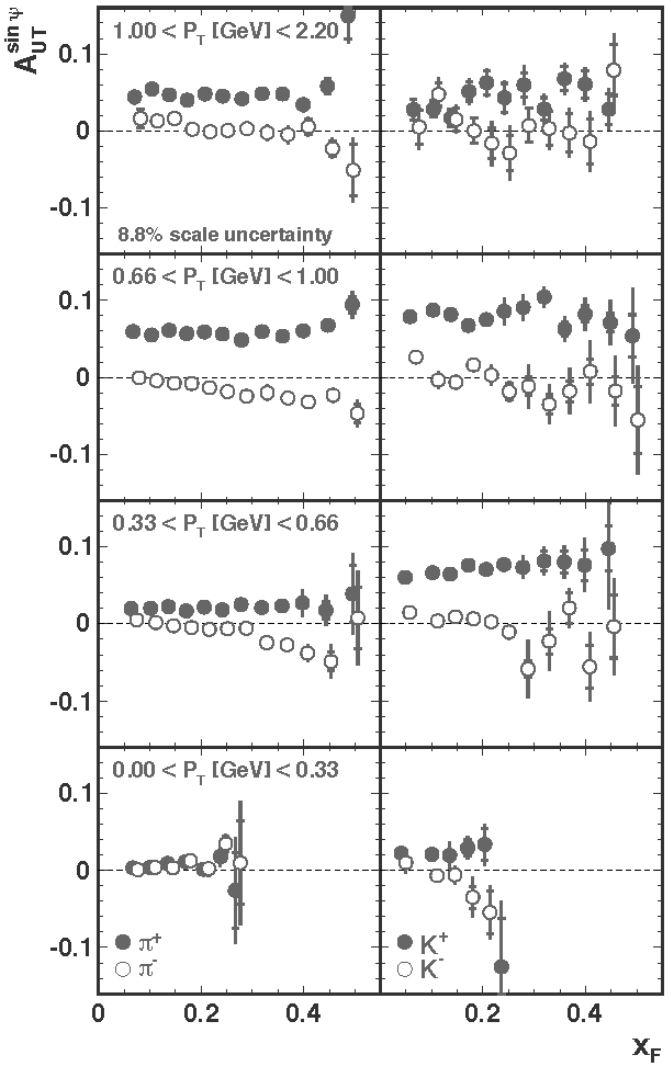
A. Airapetian et al, Phys. Lett. B 728 (2014) 183-190

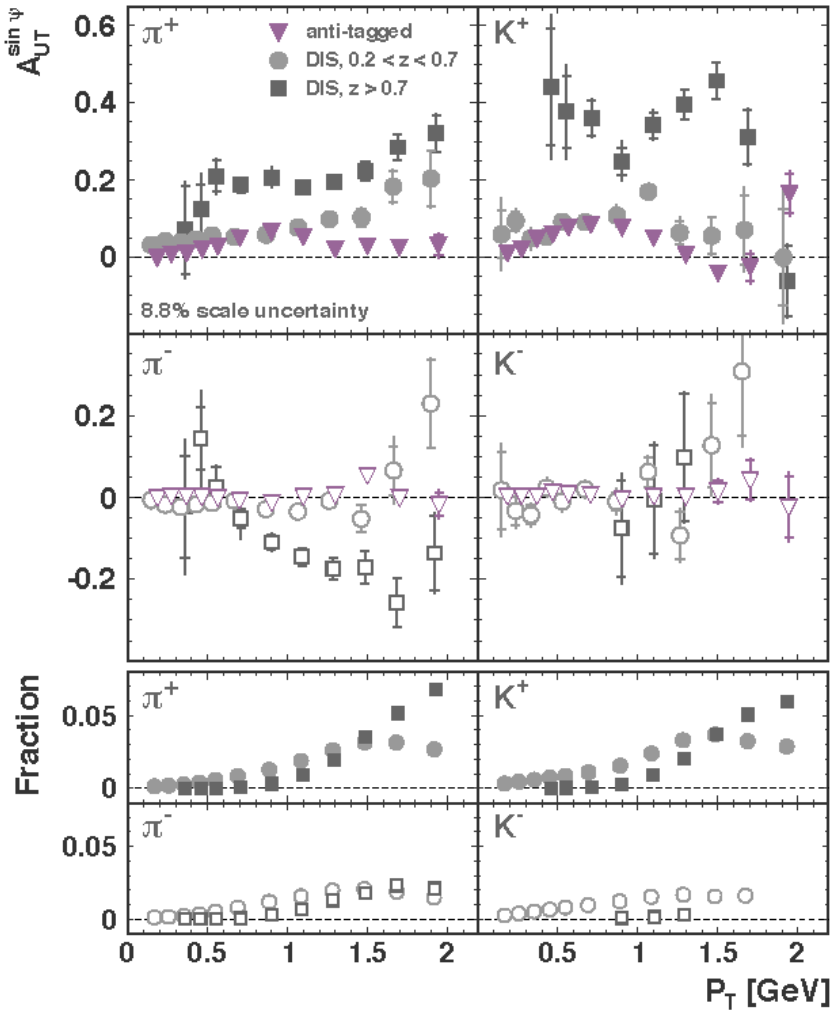


A_{UT}


$A_{UT}^{\sin\psi}$
π^+
π^-
K^+
K^-
0.1
0
-0.1
8.8% scale uncertainty
$\langle x_F \rangle$
0.3
0.2
0.1
0
0.5
1
1.5
2
P_T [GeV]
$A_{UT}^{\sin\psi}$
π^+
π^-
K^+
K^-
0.1
0
-0.1
8.8% scale uncertainty
$\langle P_T \rangle$ [GeV]
0.8
0.6
0.4
0
0.2
0.4
x_F


$A_{UT}^{\sin\psi}$
0.30 < x_F < 0.55
8.8% scale uncertainty
0.20 < x_F < 0.30
0.10 < x_F < 0.20
0.00 < x_F < 0.10
π^+
π^-
K^+
K^-
P_T [GeV]


$A_{UT}^{\sin\psi}$
1.00 < P_T [GeV] < 2.20
8.8% scale uncertainty
0.66 < P_T [GeV] < 1.00
0.33 < P_T [GeV] < 0.66
0.00 < P_T [GeV] < 0.33
π^+
π^-
K^+
K^-
x_F


$A_{UT}^{\sin\psi}$
π^+
anti-tagged
DIS, 0.2 < z < 0.7
DIS, z > 0.7
K^+
8.8% scale uncertainty
π^-
K^-
Fraction
P_T [GeV]

Summary

-- Physics of the 1st moment. Integration over x.
Event by event determination of $x,\ Q^2, \phi, \ldots$
is important

-- Longitudinal polarized DIS → quark spin contributions to the proton spin, **33 ± 3.9 %**

-- Transverse spin and transverse motion of quarks are key elements to understand the structure of the nucleon.
Sivers asymmetry and Collins asymmetry have been measured.

-- Transverse target single-spin asymmetry in inclusive electroproduction of charged pions and kaons (2014)

-- Azimuthal asymmetry with unpolarized nucleons has been found.
→ Boer-Mulders function and Cahn effect (2013)