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Study of Strange Quark in the Nucleon with Neutrino Scattering

T.-A. Shibata

Tokyo Institute of Technology

Contents:

3. Physics Motivation

    --- Quark Structure of the Nucleon

    --- Proton Spin Problem and Strange Quark Spin Δs

2. Strange Quark with Neutrino Scattering, G_A^s

3. Flavor Decomposition of Quark Helicity Distributions $\Delta q(x)$

4. Conclusions

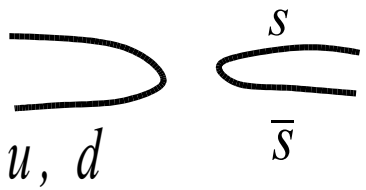
Strangeness in the nucleon, s(x)

- π N scattering σ term:

$$\langle p|s\bar{s}|p\rangle \approx 0.2$$

- OZI suppressed φ production

$$|p\rangle = |uud\rangle + \varepsilon|(uud)(s\bar{s})\rangle$$

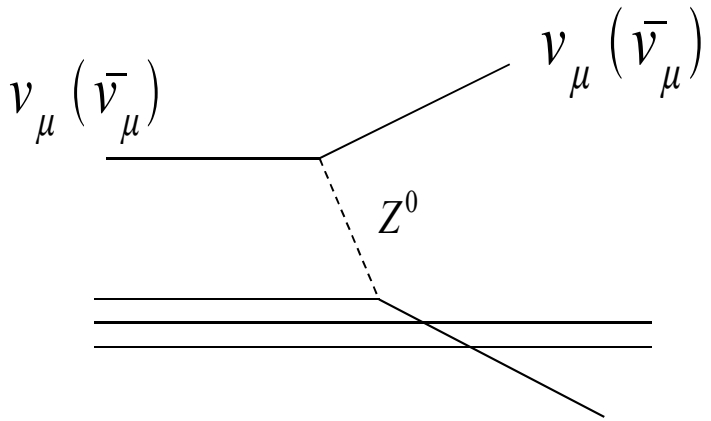


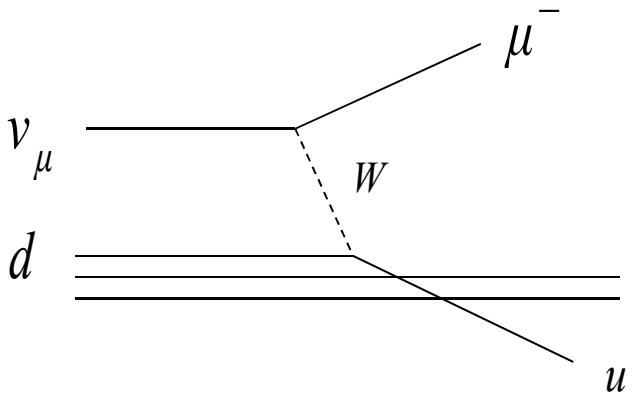
- Neutrino scattering

Strange quark polarization in the nucleon, Δs(x)

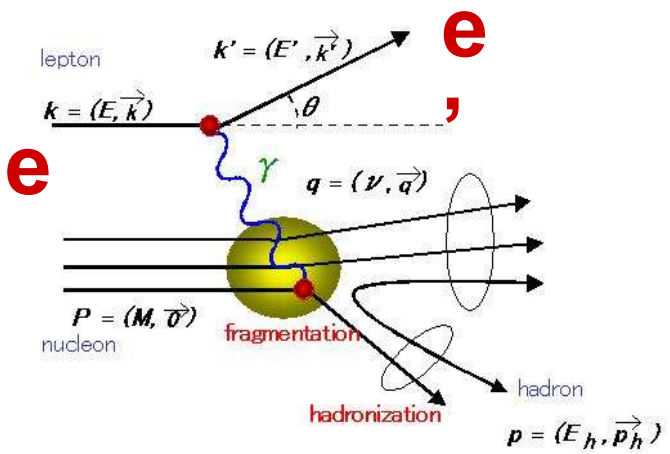
- **Polarized deep inelastic scattering (inclusive)** $\Delta s \approx -0.1$
- ν **N elastic scattering** $\Delta s \approx -0.15$
- **Baryon magnetic moments** $\Delta s \approx -0.2$
- **Lattice calculations** $\Delta s \approx -0.1$
- **Polarized deep inelastic scattering (hadron detection)** $\Delta s \approx 0$

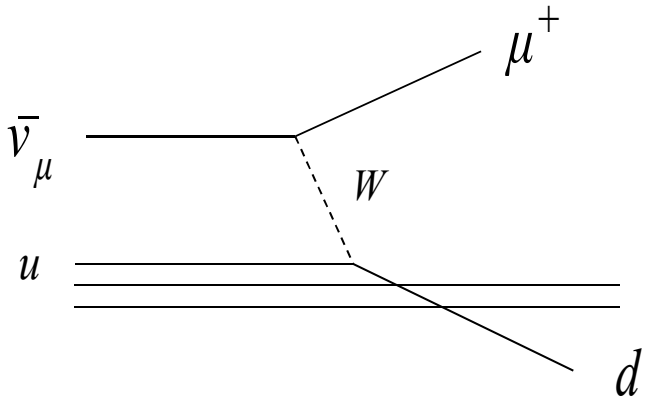
Neutrino Scattering





cf.





lepton number conservation, charge conservation

- Selective reactions on quark flavor

  Distinction between quark and antiquark

$$\nu + d \to \mu^- + u \qquad \nu + \bar{u} \to \mu^- + \bar{d}$$

$$\bar{\nu} + u \to \mu^+ + d \qquad \bar{\nu} + \bar{d} \to \mu^+ + \bar{u}$$
$$(s)$$

- (anti-)Neutrino is ∓ 100 polarized

  Selective reactions with quark helicity (spin)

electron (muon) deep inelastic scattering:

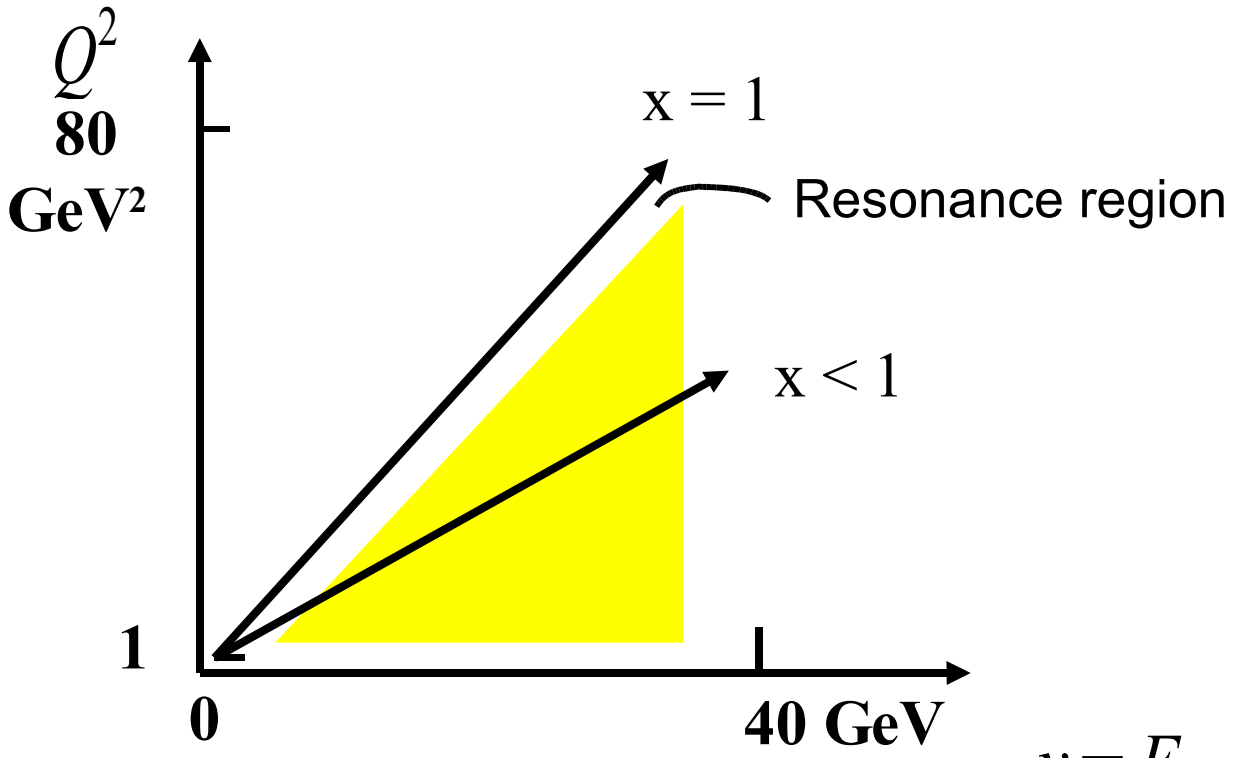
$$F_2(x) = x\left[\frac{4}{9}(u(x)+\bar{u}(x)) + \frac{1}{9}(d(x)+\bar{d}(x)) + \frac{1}{9}(s(x)+\bar{s}(x))\right]$$

neutrino scattering

$$F_{3^{\bar{\nu}p}}(x) = u(x) - \bar{d}(x) - \bar{s}(x),$$

$$\frac{d\sigma^{\bar{\nu}(\nu)}}{dxdy} = \frac{G^2 s}{2\pi} F_2(x)\left[\frac{1+(1-y)^2}{2} \mp \frac{1-(1-y)^2}{2}\frac{x F_3(x)}{F_2(x)}\right]$$

Bjorken $x = \dfrac{Q^2}{2\,m\,\nu}$

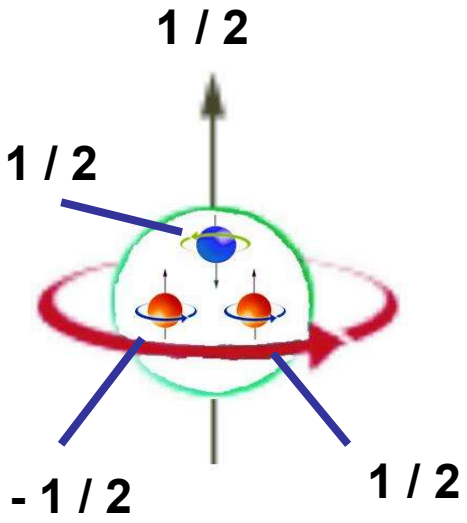


‘Proton Spin Problem’ by EMC and Neutrino Cross Sections

Spin of Proton

SU(6) Quark Wave Functions of Baryons

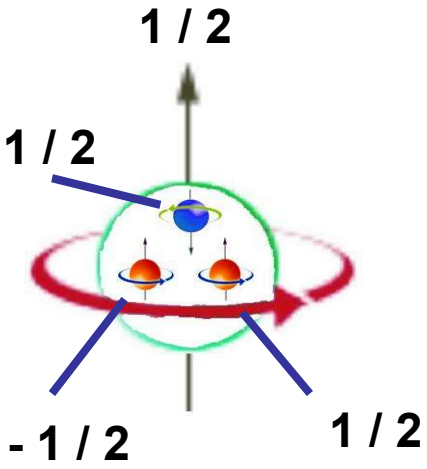
Sum of Spins of u u d Quarks = Spin of Proton

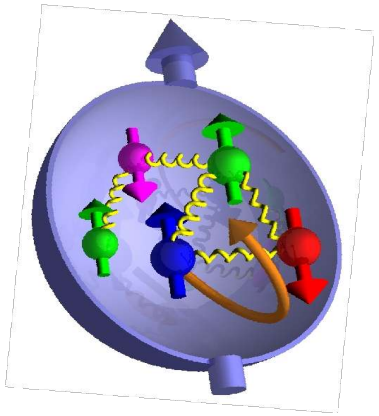


$$\frac{1}{2}+\frac{1}{2}+\left(-\frac{1}{2}\right)=\frac{1}{2}$$

Spin of Proton

$$\frac{1}{2}=\frac{1}{2}\sum_{q}(\Delta q+\Delta\bar{q})+\Delta G+L_q+L_G$$





EMC Experiment (1988)

$$\frac{1}{2}(\Delta u+\Delta d+\Delta s)=0.06\pm0.047\pm0.068\ (12\pm9\pm14)\ \leq\ \frac{1}{2}$$

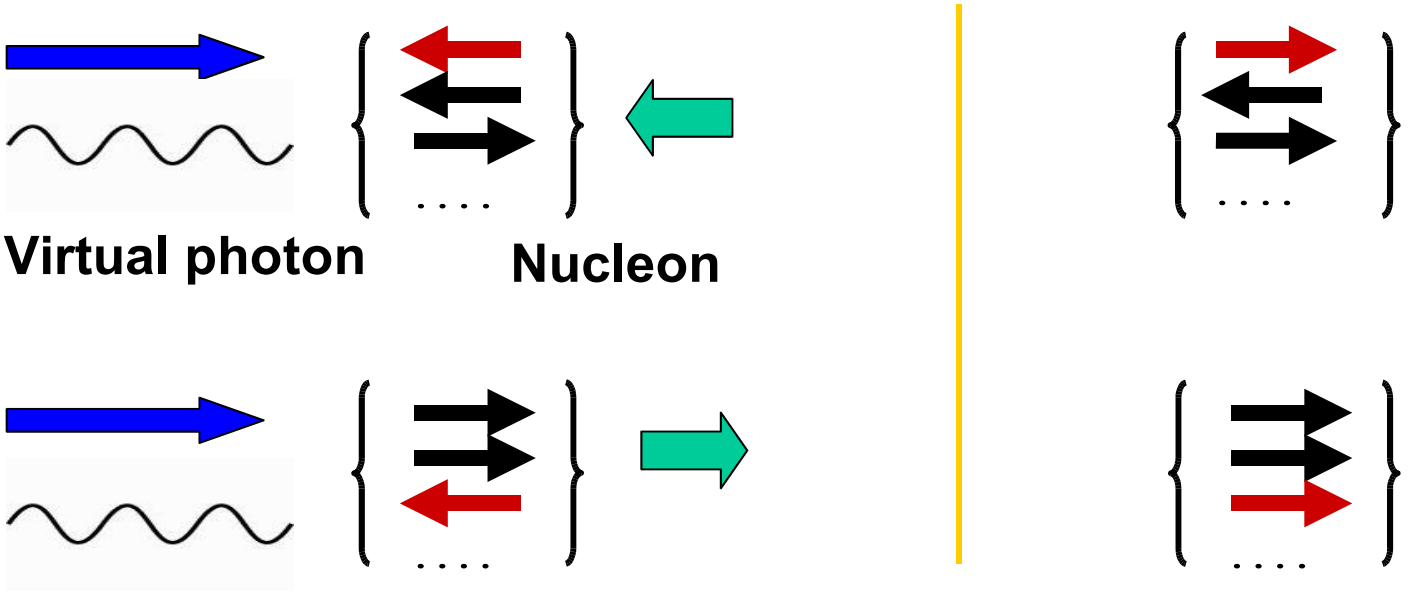
20 – 30 % of Nucleon Spin
Slightly negative Δs

How was it measured?

Quark Helicity Distributions, Flavor Separation

Double-spin asymmetry $\vec{e} + \vec{N} \rightarrow e' + X$

Polarized beam and polarized target



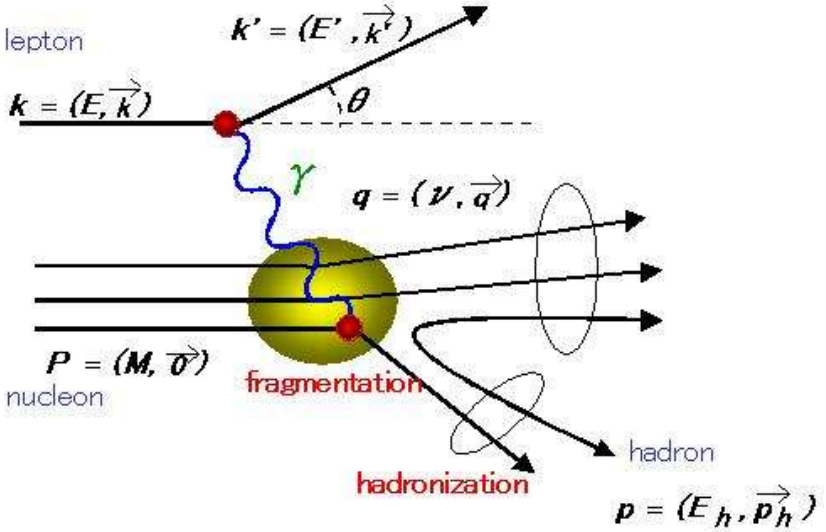
$$A_1(x,z) = \frac{\sigma^{\rightarrow}_{\leftarrow}(x) - \sigma^{\rightarrow}_{\rightarrow}(x)}{\sigma^{\rightarrow}_{\leftarrow}(x) + \sigma^{\rightarrow}_{\rightarrow}(x)}$$

Asymmetry, Polarized Quarks

$$\sigma_h(x,z) \propto \sum_q e_q^2\, q(x)\; D_q^h(z)$$

(quark distribution) x
(fragmentation function)

$$A_1(x,z) = \frac{\sigma^{\rightarrow}_{\leftarrow}(x) - \sigma^{\rightarrow}_{\rightarrow}(x)}{\sigma^{\rightarrow}_{\leftarrow}(x) + \sigma^{\rightarrow}_{\rightarrow}(x)}$$

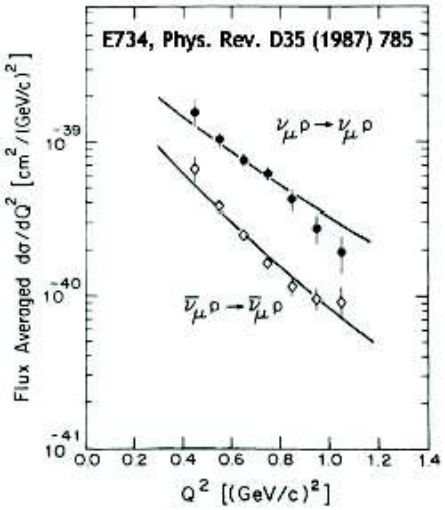


$$q(x) = q^{\leftarrow}(x) + q^{\rightarrow}(x)$$ **Quark Density Distribution**

$$\Delta q(x) = q^{\leftarrow}(x) - q^{\rightarrow}(x)$$ **Quark Helicity Distribution**

After EMC experiment, low energy neutrino-nucleon cross sections attracted attention from viewpoint of strange quark contriutions to the nucleon spin.

G.T. Garvey et al., Phys. Rev. C48 (1993) 761
Reanalysis of BNL734 experiment
Neutrino beam from AGS on proton,
ν (mean energy 1.3 GeV) , $\bar{\nu}$ (1.2 GeV)
νp and $\bar{\nu} p$ elastic events.
axial vector dipole mass M_A needs to be determined



G.T. Garvey et al., Prog. Part. Nucl. Phys. 34 (1995) 245.
Neutral current neutrino-proton and -neutron scattering cross section
Strange form factors. Axial vector form factor $G_A^s(Q^2=0)=\Delta s$
$E_\nu =$ 0.1 – 0.25 GeV , ν + p, ν + n elastic cross sections
LSND at LAMPF

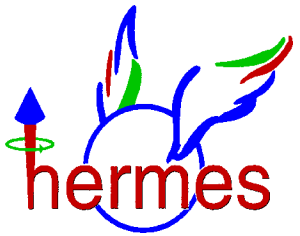
SAMPLE, G0 Experiments

Flavor Separation of Quark Helicity Distributions

$$\Delta u(x),\ \Delta d(x),\ \Delta \bar{u}(x),\ \Delta \bar{d}(x),\ \Delta s(x)$$

as a function of x

$$\Delta u(x),\ \Delta d(x),\ \Delta \bar{u}(x),\ \Delta \bar{d}(x),\ \Delta s(x)$$



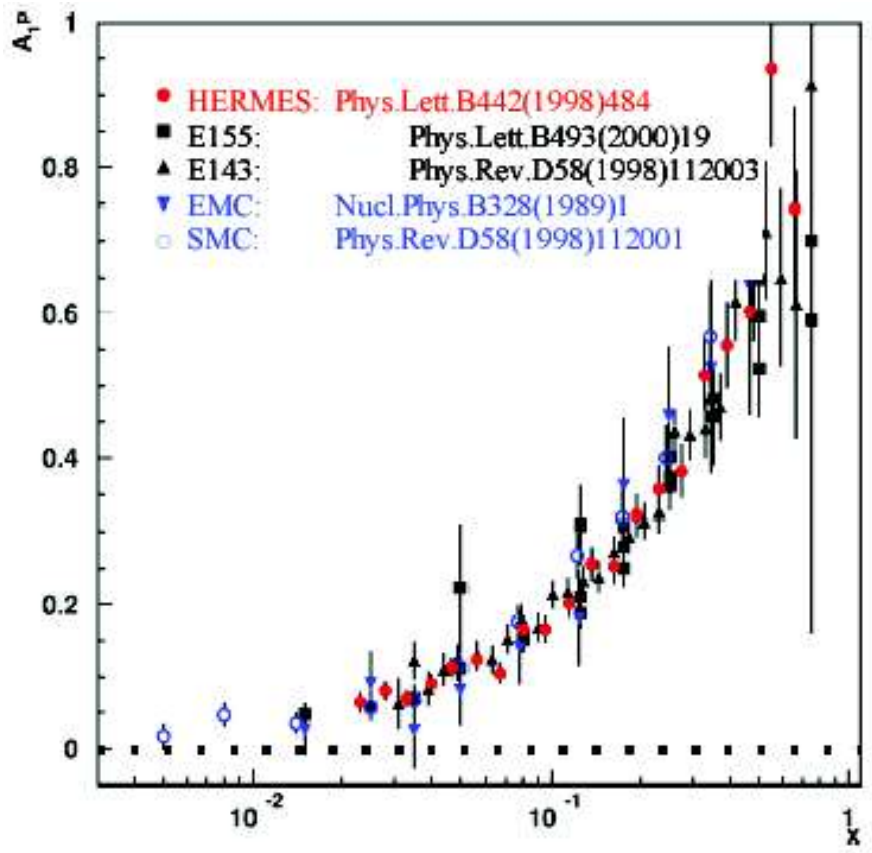
A. Airapetian et al., HERMES

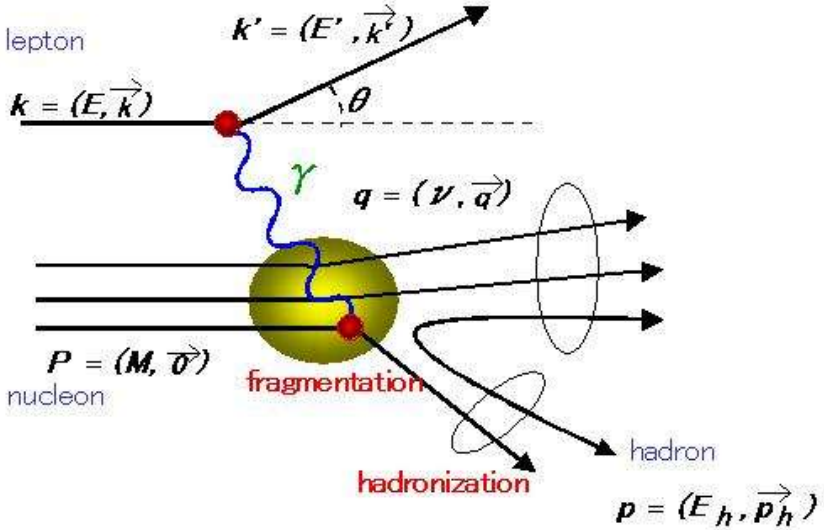
'Flavor Decomposition of the Sea Quark Helicity Distributions in the Nucleon from Semi-inclusive Deep-inelastic Scattering'
Phys. Rev. Lett. 92 (2004) 012005
hep-ex/0307064

'Quark Helicity Distributions in the Nucleon for up-, down-, and strange-quarks from Semi-inclusive Deep-inelastic Scattering'
submitted to Phys. Rev. D
hep-ex/0407032

Precision measurements of asymmetry $A_{1,p}(x)$

$$A_1(x,z)=\frac{\sigma^{\rightarrow}_{\leftarrow}(x)-\sigma^{\rightarrow}_{\rightarrow}(x)}{\sigma^{\rightarrow}_{\leftarrow}(x)+\sigma^{\rightarrow}_{\rightarrow}(x)}$$





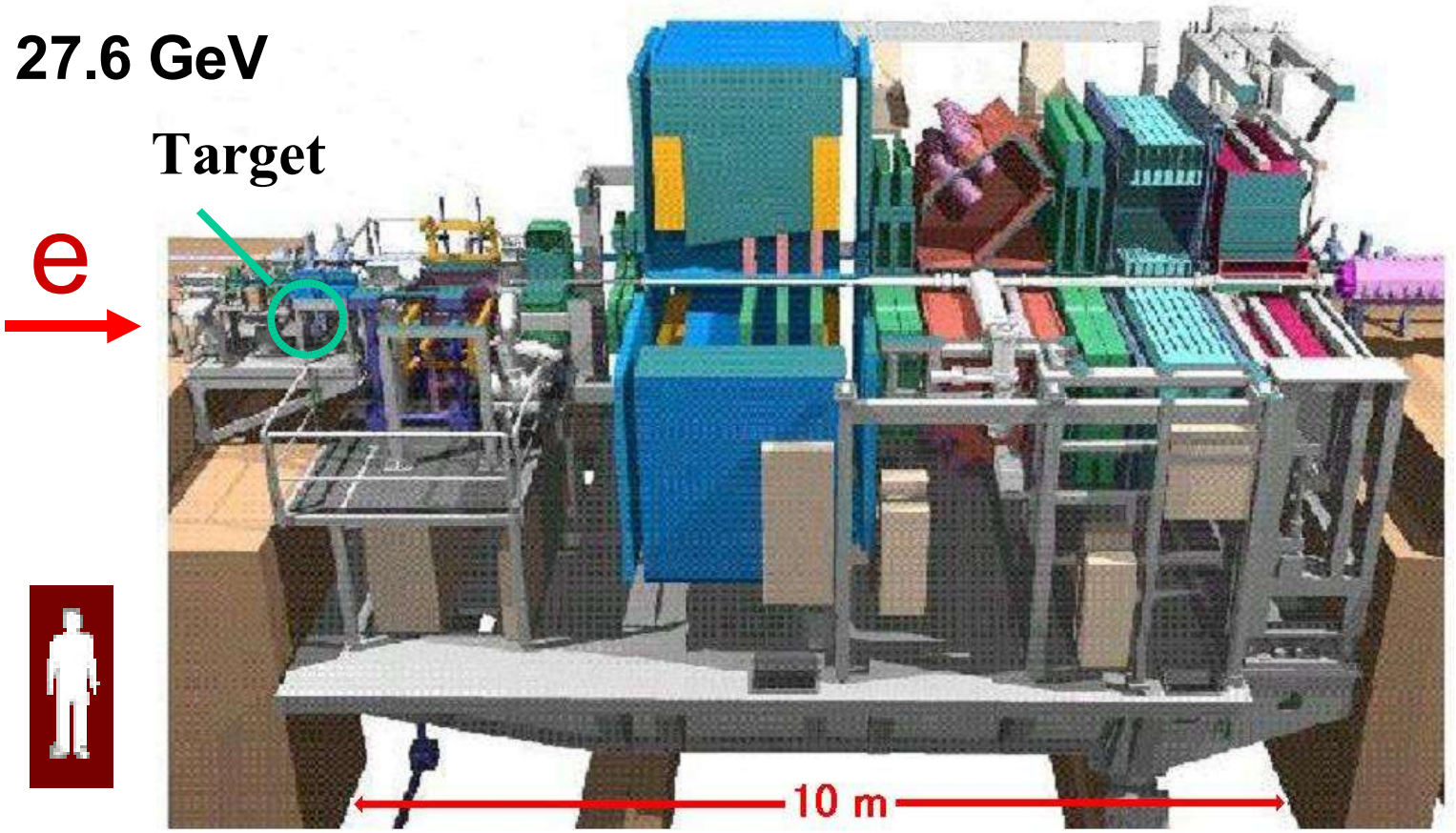
Hadron identification
at 2-15 GeV/c
with RICH

Detector

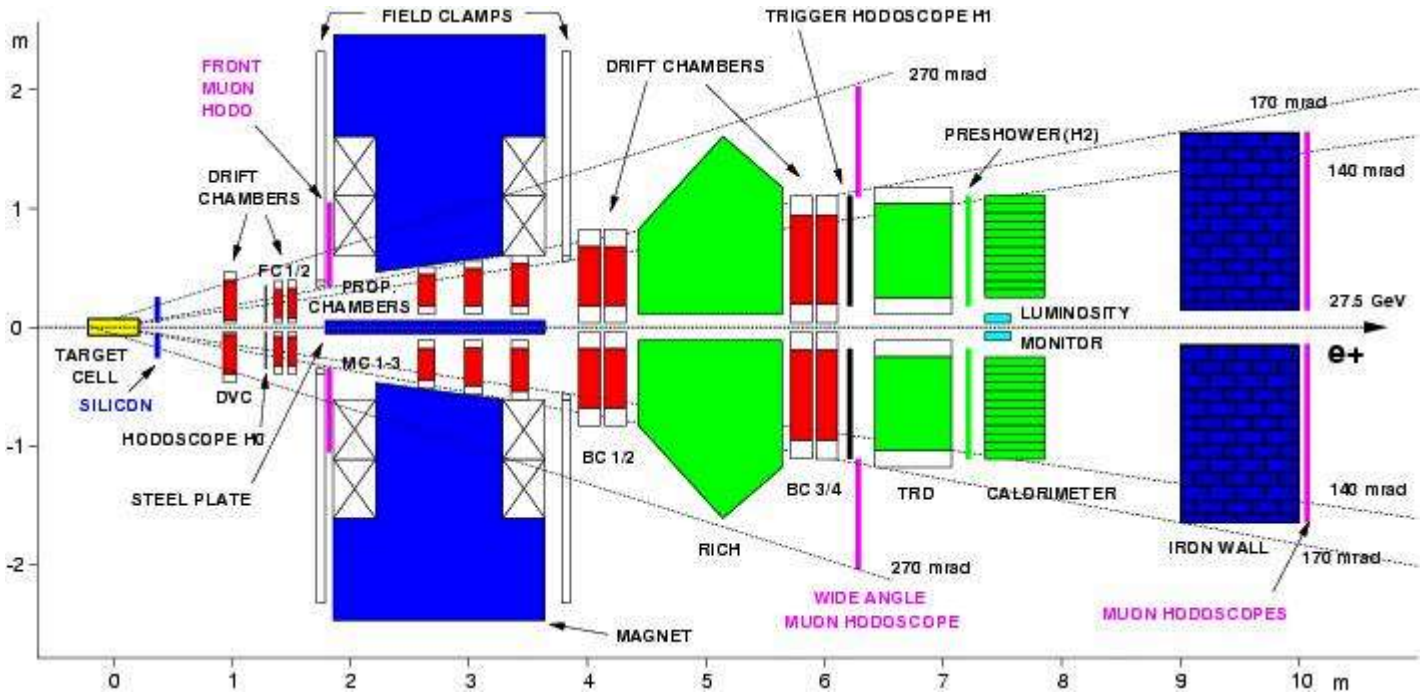
HERMES @DESY- HERA
1995 --

Polarized Internal gas targets
(H, D, ^{3}He)

27.6 GeV



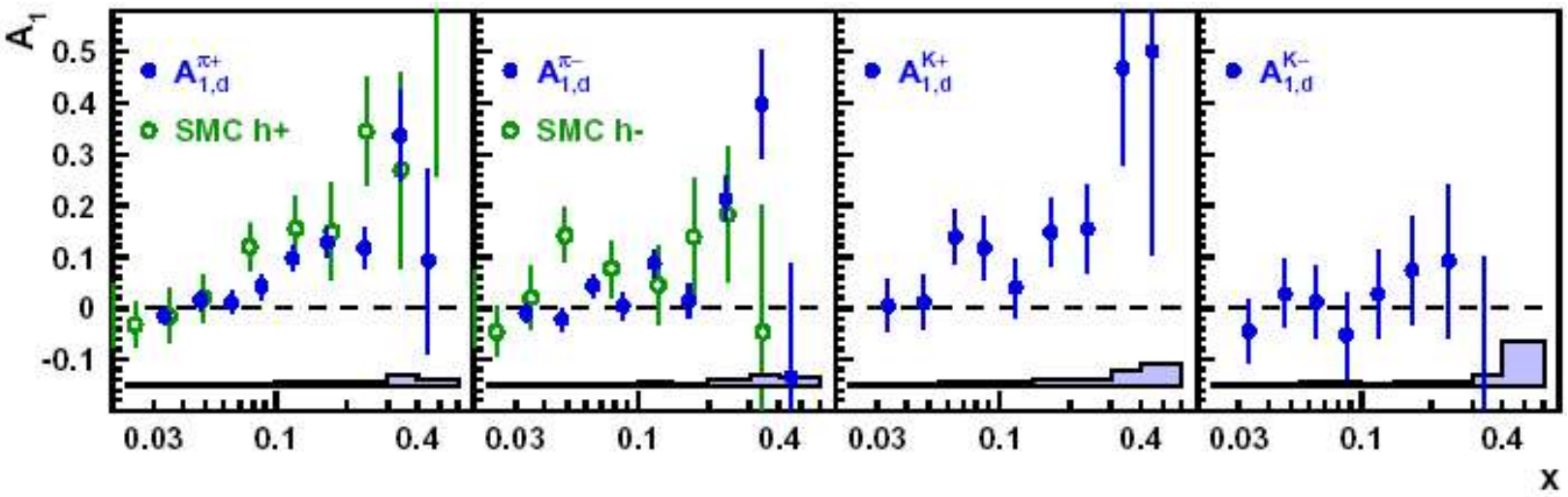
HERMES Spectrometer



$A_{1,d}^{h}(x)$ Asymmetry, Hadron detection

Deuterium Target

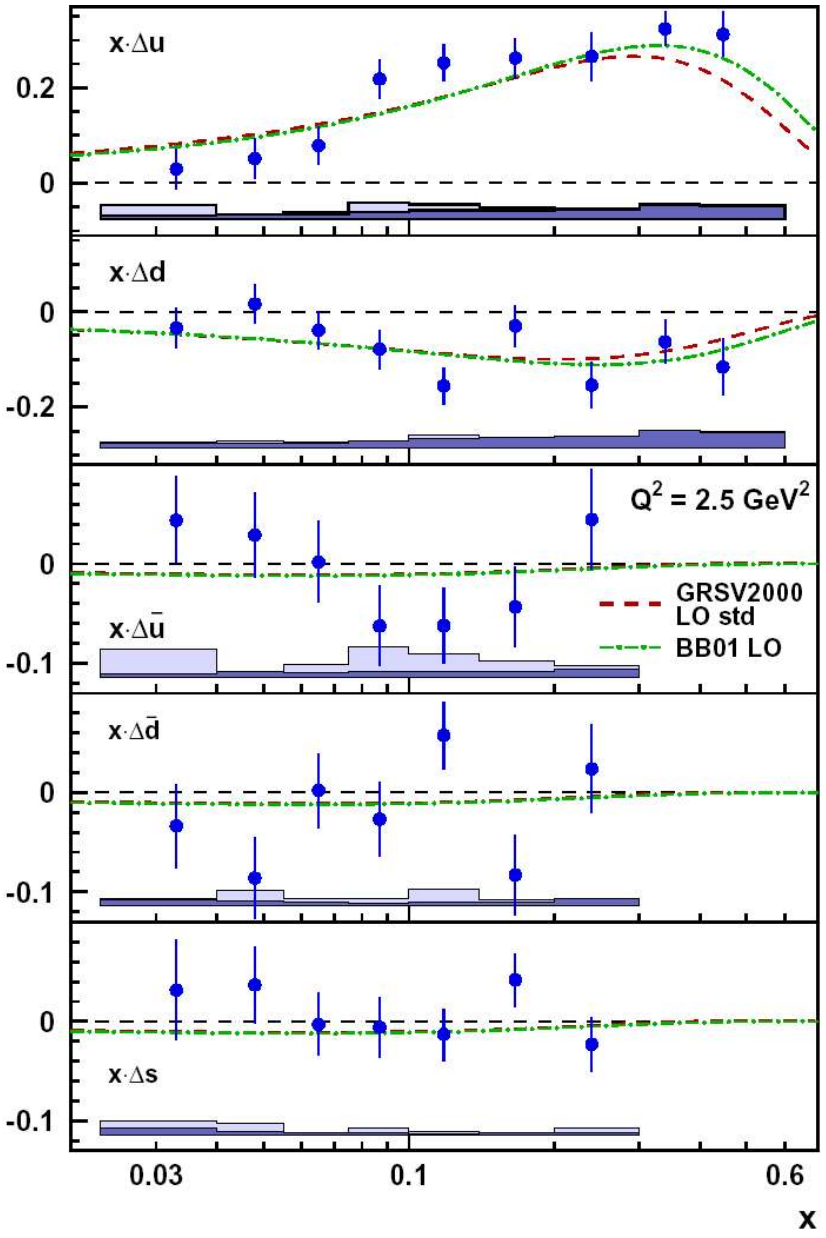
π^+ π^- K^+ K^-



x

A_1 increases with x

$$A_{1,d}^{K^+} > A_{1,d}^{K^-}$$



hermes

Systematic Errors:

Light Error Bar – Fragmentation Models

Dark Error Bar - Asymmetries

Positive	$\Delta u(x)$
Negative	$\Delta d(x)$
Nearly Zero	$\Delta \bar{q}(x)$

x **bin by bin analysis.**

SU(3) Symmetry not assumed.

Strangeness Helicity Distribution

$0.023 < x < 0.3$, x integral of $\Delta s(x)$, or $\Delta s(x) + \Delta \bar{s}(x)$

Integral: $+0.03 \pm 0.03\,(\text{stat.}) \pm 0.01\,(\text{syst.})$

in the measured region

Stepwise approach before Neutrino Factories:

'Strangeness with Neutrino Scattering' Working Group for J-PARC

feasibility studies,
compilation of existing data,
theoretical investigations, …

What is new with Neutrino Factories

- hydrogen and deuteron targets
  in counter experiments (non-bubble chamber)

- polarized hydrogen and deuteron targets

E_ν up to 30 GeV, ν and $\bar{\nu}$ beams with low contaminations,
small beam diameter, beam is polarized (!)

- Deep inelastic scattering on the nucleon at high energies

  quark and antiquark structure in the nucleon
  spin of quarks in polarized nucleon
  in particular, strangeness in the nucleon
  tests of fundamental sum rules
  combined analysis with e and muon scatterings

- Elastic scattering on the nucleon at low energies

  form factors both with ν and $\bar{\nu}$ beams

Conclusions

- **Neutral and charged current neutrino interactions are useful tools to study the properties of the nucleon.**
- **Neutrino reacts on the quark flavor selectively. Neutrino beam is 100% polarized. Selective reactions with quark helicity (spin).**
- **'Proton Spin Problem' is an important challenge for QCD (EMC,1988). Strange quark is suggested to be negatively polarized.**
- **Hadron detection in electron deep inelastic scattering (HERMES) provides flavor separation of quark helicity distributions** $\Delta q(x)$
- **Neutrino reaction is a promising approach to determine strange quark contributions to the nucleon spin** (G_A^s) **.**
- **At Neutrino Factories neutrino reactions on polarized targets are expected.**