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"An investigation of the spin structure of the proton in deep inelastic scattering of polarised muons on polarised protons"

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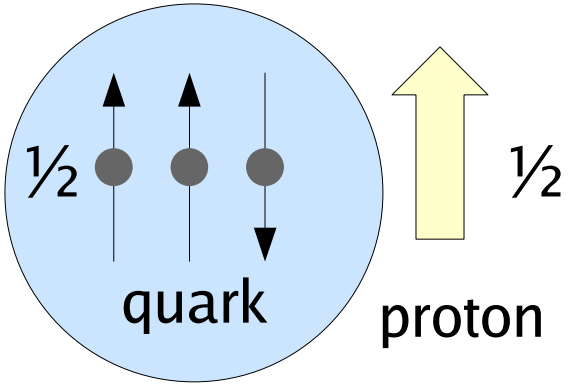
1. Introduction

The proton is not elementary particle. It has internal structure.
It basically consists of 3 quarks.

- spin of the proton 1/2
- spin of the quark 1/2



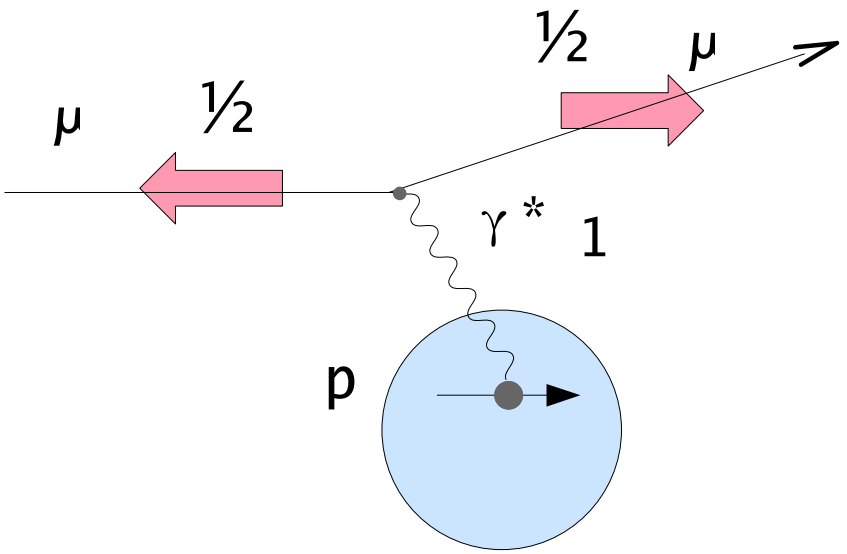
How is the spin structure of proton?

If two quarks have spin in up direction,
and a quark has in down direction,
the total spin is 1/2.

$$\tfrac{1}{2} + \tfrac{1}{2} - \tfrac{1}{2} \overset{?}{=} \tfrac{1}{2}$$

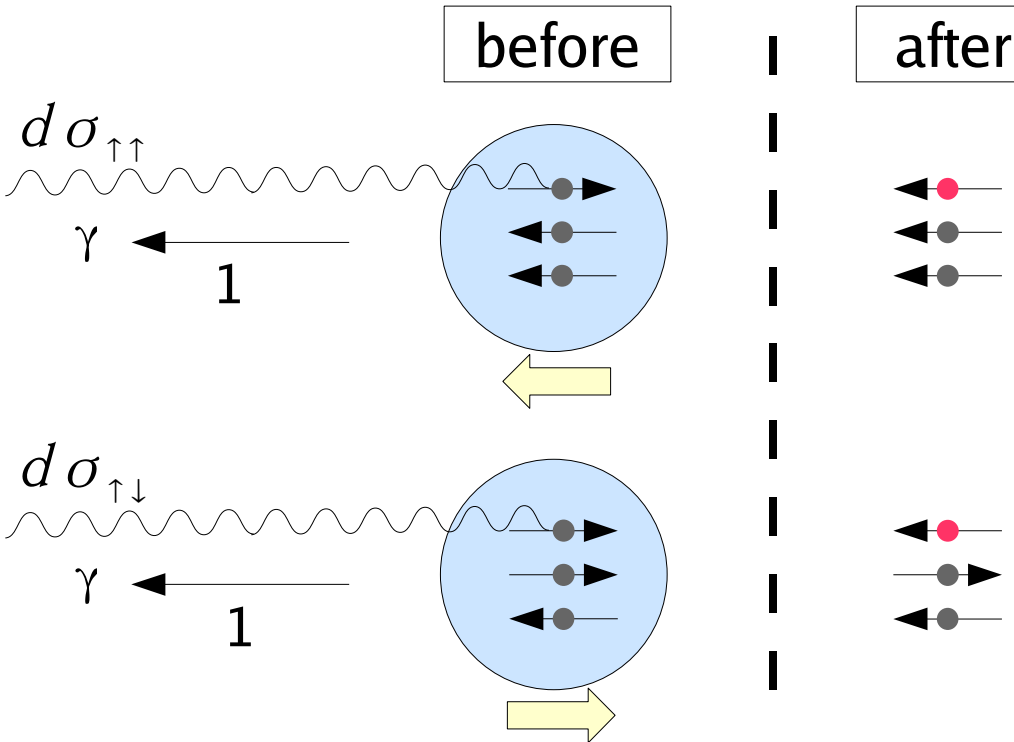
It is important to check whether this picture is correct.

2. Polarized deep inelastic scattering



The muon scatters off a quark exchanging the virtual photon.
When the muon is polarized, the virtual photon is also polarized.

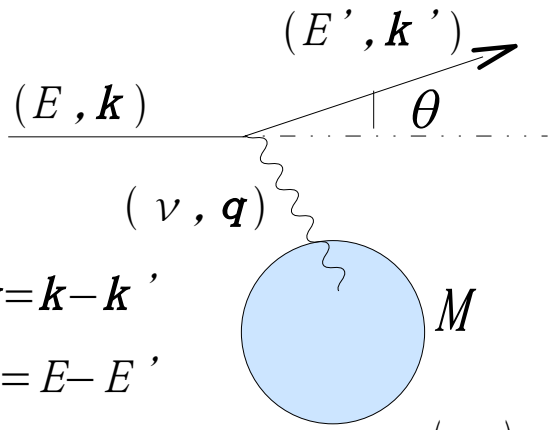
muon spin : ½
spin of the virtual photon : 1



The quark can absorb the virtual photon if the quark spin flips.
So the quark spin must be antiparallel to the spin of the virtual photon.

Asymmetry is defined as follows:

$$A=\frac{d\sigma^{\uparrow\downarrow}-d\sigma^{\uparrow\uparrow}}{d\sigma^{\uparrow\downarrow}+d\sigma^{\uparrow\uparrow}}$$



$q = k - k'$

$\nu = E - E'$

$Q^2 = -q^2 = 4\,EE'\sin^2\left(\frac{\theta}{2}\right)$

F_1 : spin independent structure function

g_1 : spin dependence of distribution of quark momentum in proton

Bjorken x

$$x = \frac{Q^2}{2\,M\nu} \qquad (0 < x < 1)$$

x has no dimension.
x means the ratio of quark momentum to proton momentum.

$$A = \frac{D\,g_1}{F_1} \rightarrow g_1 = \frac{A\,F_1}{D} \rightarrow \int_0^1 g_1^p\,dx$$

D : depolarization factor

in quark-parton model

$$\int_0^1 g_1^p\,dx = \frac{1}{2}\left(\frac{4}{9}\Delta u + \frac{1}{9}\Delta d + \frac{1}{9}\Delta s\right) = \frac{1}{12}\left[\underbrace{(\Delta u - \Delta d)}_{a_3} + \frac{1}{3}\underbrace{(\Delta u + \Delta d - 2\Delta s)}_{\sqrt{3}\,a_8} + \frac{4}{3}\underbrace{(\Delta u + \Delta d + \Delta s)}_{\sqrt{\frac{3}{2}}\,a_0}\right]$$

$a_3 = 1.254 \pm 0.006$ neutron β decay

$a_8 = 0.397 \pm 0.020$ hyperon weak decay

This value can be extracted.

$$\Delta u = \int_0^1 (u^{\uparrow}(x) - u^{\downarrow}(x))\,dx$$

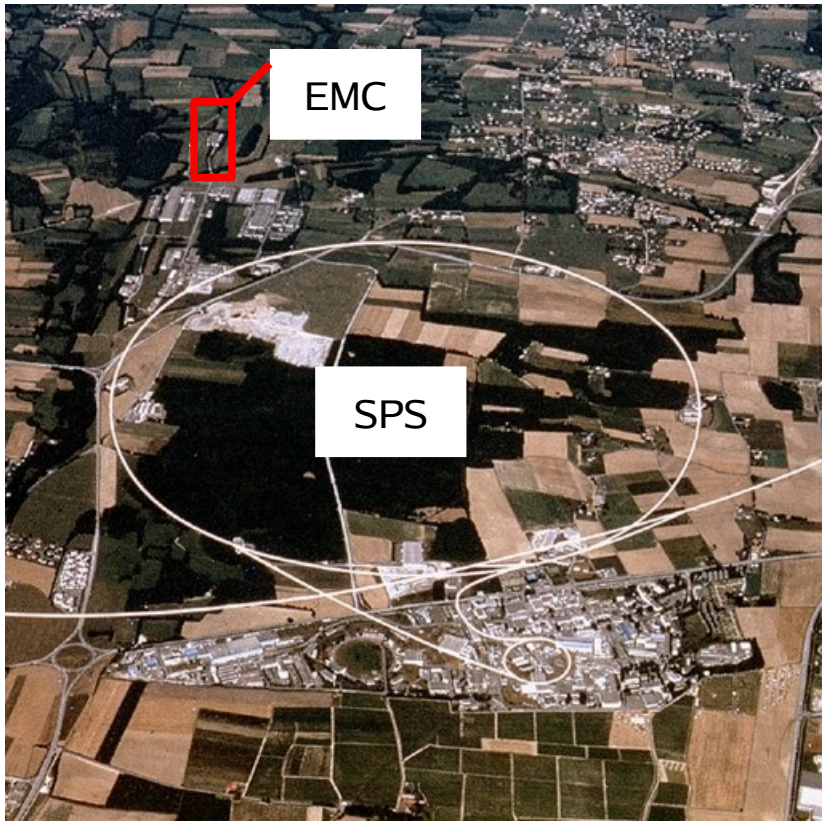
$u^{\uparrow}(x)$: probability of u quarks with spin parallel to the proton spin

$u^{\downarrow}(x)$: probability of antiparallel

$$\langle S_z \rangle_{quarks} = \frac{1}{2}(\Delta u + \Delta d + \Delta s) = \frac{1}{2}\sqrt{\frac{3}{2}}\,a_0$$

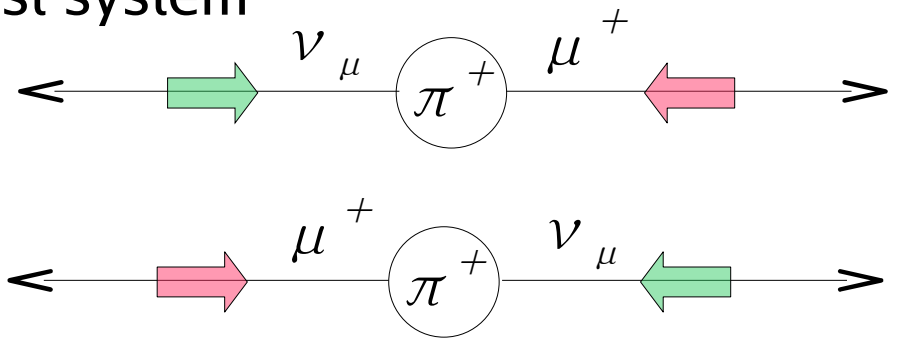
3. EMC experiment

The experiment was carried out at CERN, Geneva.

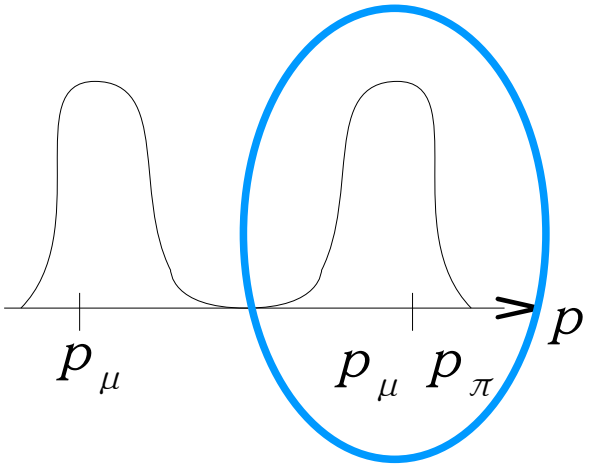


$$\pi^+ \rightarrow \mu^+ \nu_\mu$$

Rest system



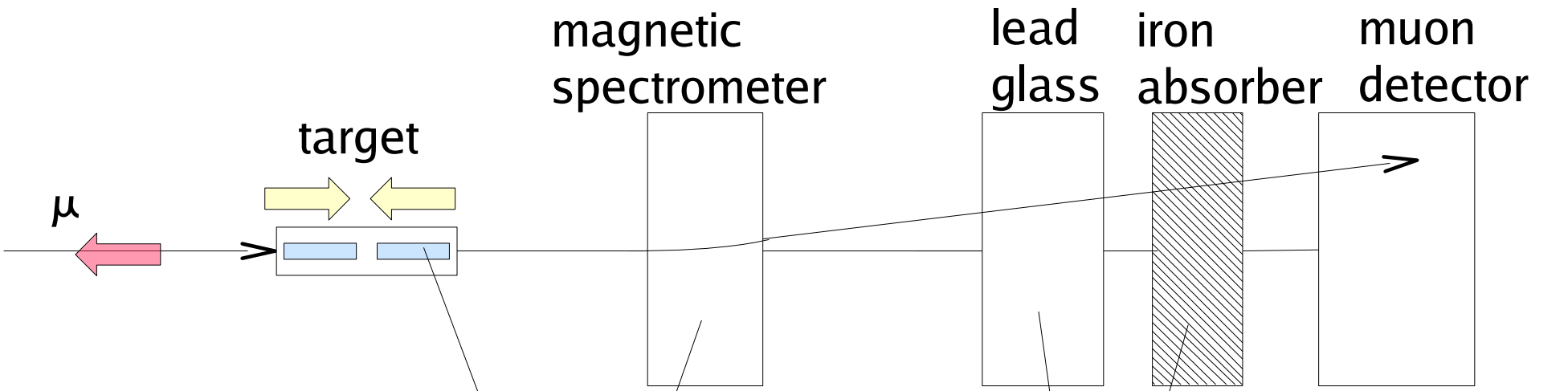
Lab system



proton beam : 450GeV
pion beam : 110 , 130 , 210 GeV
muon beam :
polarized positive muons
muon energy 100 , 120 , 200 GeV

Muon beam polarization
typically 0.79±0.06

EMC experiment



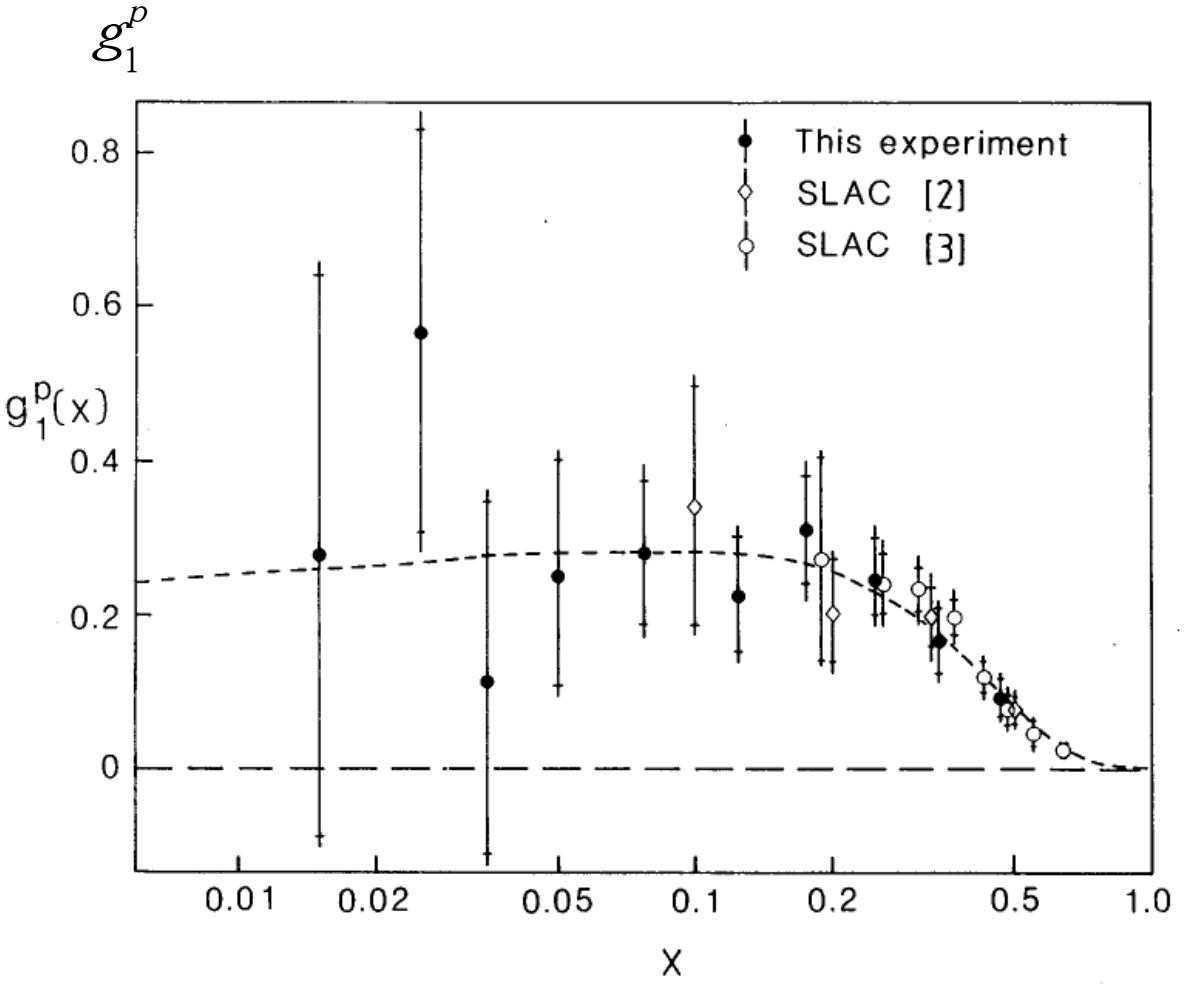
target :
two cells
(parallel , antiparallel)
free protons in the NH_3
polarization ~77%

measure γ

momentum analyzed
scattered muon
forward hadrons

absorb
γ , hadrons

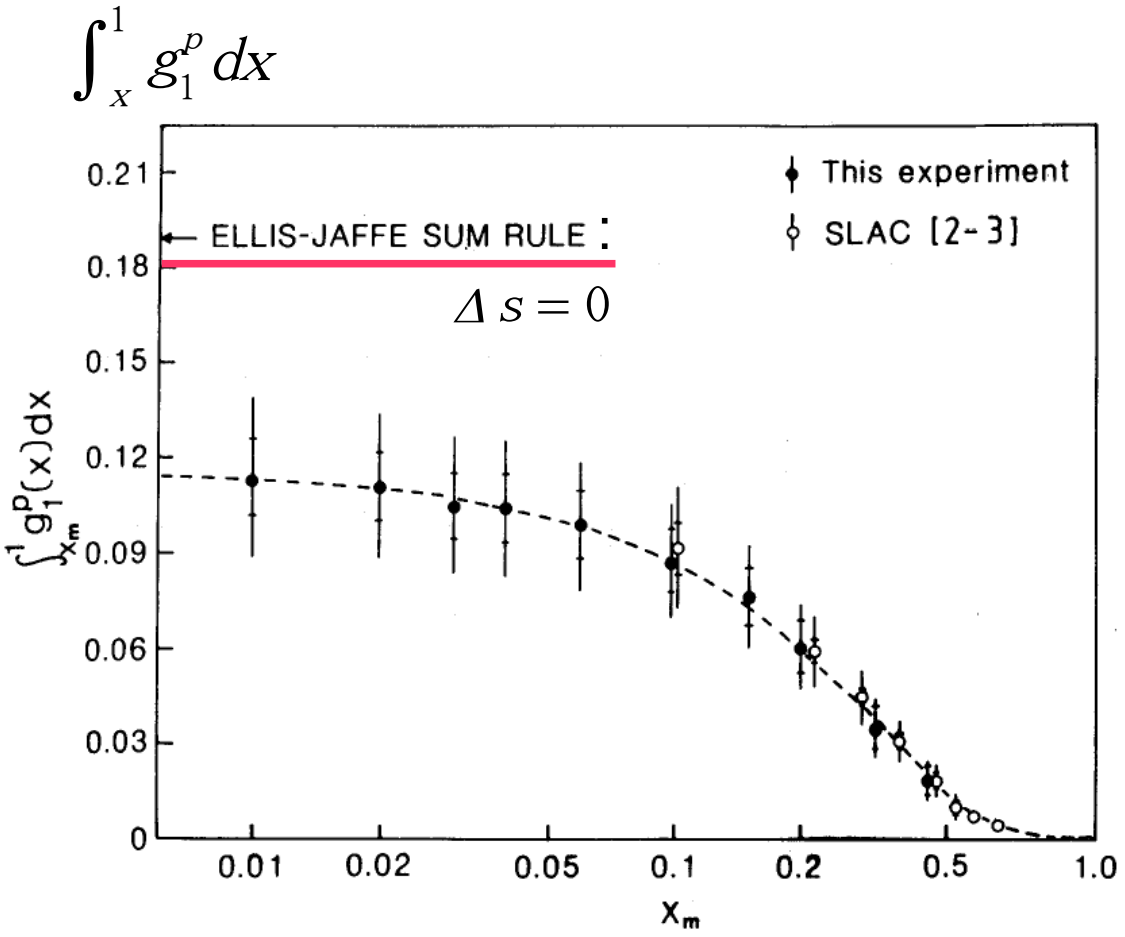
4. Result



The horizontal axis is Bjorken scale in logarithmic scale.
The dashed curve is the value based on a quark-parton model.

x = 0.1 ~ 0.7 : SLAC (1970's)
x = 0.01 ~ 0.7 : EMC (1989)

x coverage was extended.



The horizontal axis is Bjorken scale in logarithmic scale.

$$\int_0^1 g_1^p\,dx = 0.126 \pm 0.010 \pm 0.015$$

statistical error

systematic error

quark spin contribution to the proton spin

$$a_0 = 0.098 \pm 0.076 \pm 0.113$$

$$\langle S_z \rangle_{quarks} = \frac{1}{2}\sqrt{\frac{3}{2}}\,a_0$$

$$= +0.060 \pm 0.047 \pm 0.069$$

Quark spin contribution to the proton spin is only (12±9±14)% .

5. Summary

- The proton basically consists of 3 quarks.
- It is important to study the contribution of the quark spin to the proton spin.
- Polarized deep inelastic scattering was carried out by EMC.
  beam : polarized (~80%) positive muon 100, 120, 200GeV
  target : polarized (~77%) proton
- The contribution of the quark spin to the proton spin was found to be small: (12±9±14)%

→ There must be something else which contribute to the proton spin; gluon spin, orbital angular momentum of quarks and gluons, ・・・.
Related experiments are being carried out at COMPASS-CERN, SLAC, HERMES-DESY, Belle-KEKB, RHIC-spin-BNL, J-lab etc.