An Investigation of The Spin Structure of The Proton in Deep Inelastic Scattering of Polarised Muons on Polarised Protons

高エネルギー偏極ミューオンの偏極陽子標的による
深非弾性散乱からの陽子スピン構造の研究

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The European Muon Collaboration

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CONTENTS

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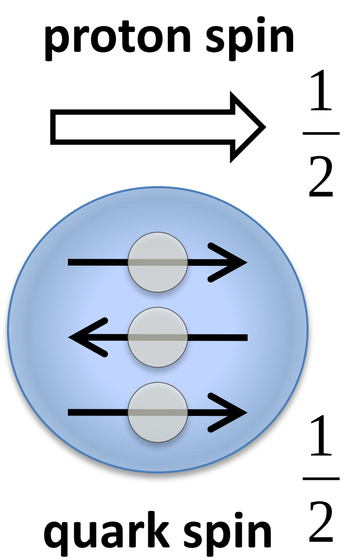
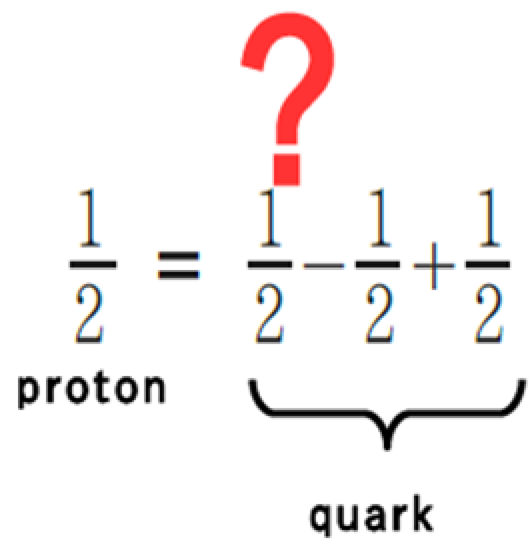
1. Introduction

- The proton has spin $\frac{1}{2}$.
- The proton basically consists of three quarks.
- Each of the quarks has spin $\frac{1}{2}$.

Are these three quarks the origin of the spin of the proton?

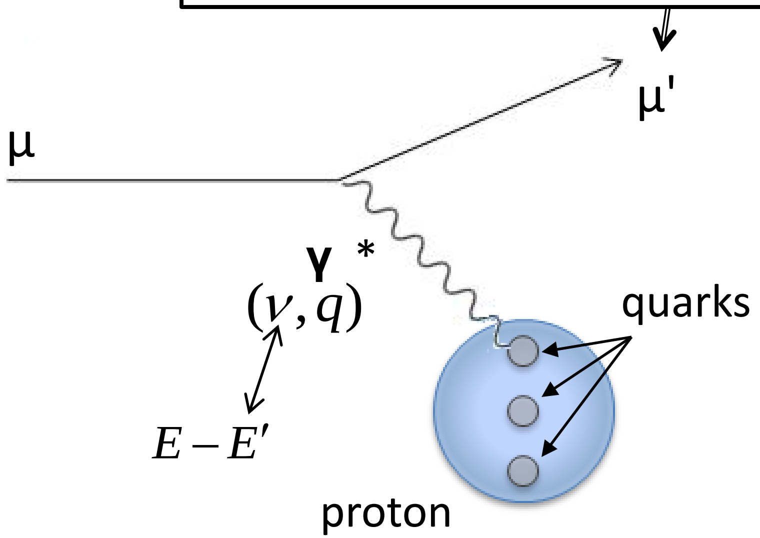
This experiment tested it by measuring the high energy muon-proton scattering.





2. Deep Inelastic Scattering

Measured values → •Scattering angles / •Energies } of the scattered muons(μ')



elastic / inelastic scattering

elastic scattering : $x = 1$

inelastic scattering : $0 < x < 1$

Bjorken x

$$0 < x = \frac{Q^2}{2M\nu} \leq 1$$

What is "deep inelastic scattering"

It happens when

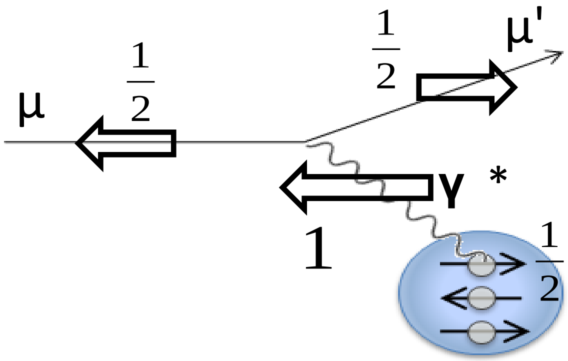
$$0 < x < 1$$

$Q \geq 1\,\mathrm{GeV}$, $\nu \geq 10\,\mathrm{GeV}$ (In experiment)

||

elastic scattering of the muon and the quark

Asymmetry in muon-proton scattering cross section



In this experiment

the incident muon
the target proton

are polarised

Asymmetry "A"

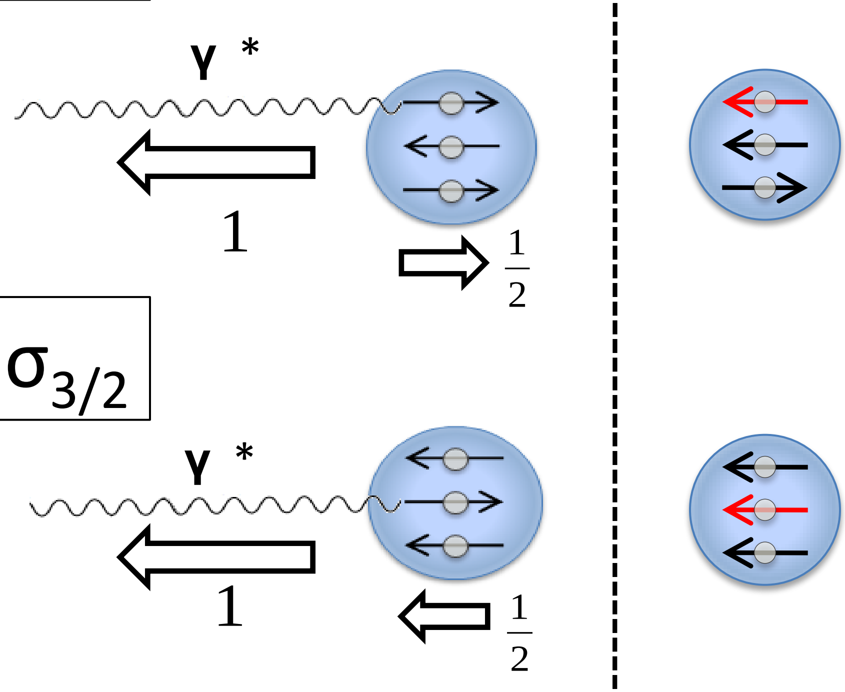
$$A = \frac{d\sigma^{\overset{\rightarrow}{\leftarrow}} - d\sigma^{\overset{\rightarrow}{\rightarrow}}}{d\sigma^{\overset{\rightarrow}{\leftarrow}} + d\sigma^{\overset{\rightarrow}{\rightarrow}}}$$

muon
proton

Asymmetry in virtual photon absorption cross section

$\sigma_{1/2}$

before absorption | after absorption



$\sigma_{3/2}$

The asymmetry A is approximately expressed in terms of asymmetry in the virtual photon absorption cross section A_1

$$A \approx DA_1$$

where D is a depolarisation factor from the μ to the γ *, and

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}}$$

virtual photon
proton

Structure Function

F_1 (x) : spin independent structure function

$$F_1 = \frac{1}{2}\sum_f e_f^2 (q_f^{\uparrow}(x) + q_f^{\downarrow}(x))$$

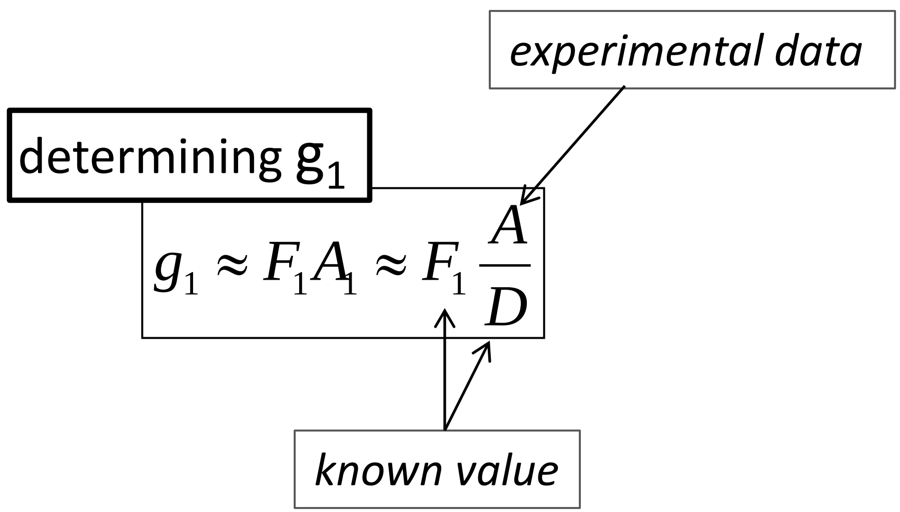
g_1 (x) : spin dependent structure function

$$g_1 = \frac{1}{2}\sum_f e_f^2 (q_f^{\uparrow}(x) - q_f^{\downarrow}(x))$$

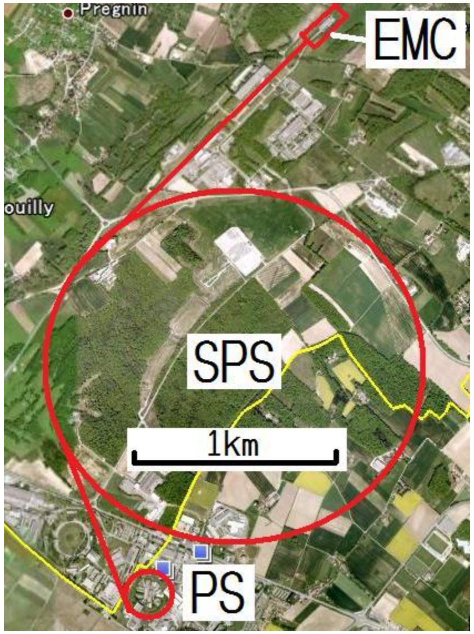
$q^{\uparrow(\downarrow)}(x)$: distribution function for quarks

whose spin is prallel(antiparallel) to the spin of the proton

$(f = \mathrm{u, d, s})$



3. Experimental Method

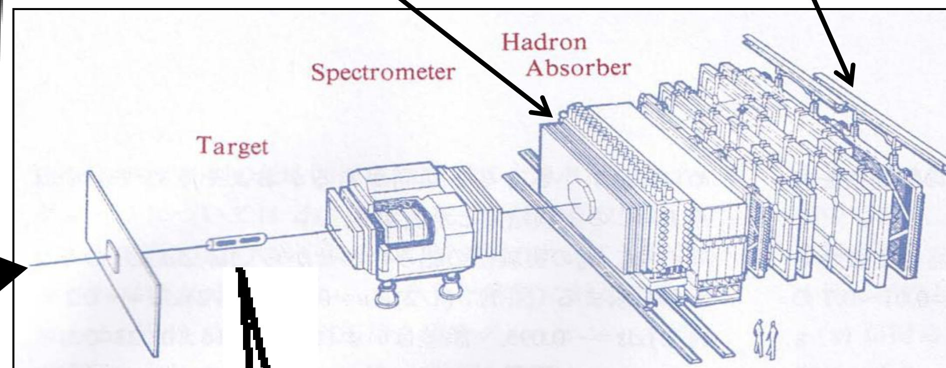


"CERN" in Switzer land

detect scattered muons

remove hadrons

μ^+

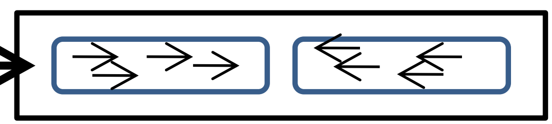


Proton beam energy : 450 GeV
Muon beam energies : 100, 120, 200 GeV

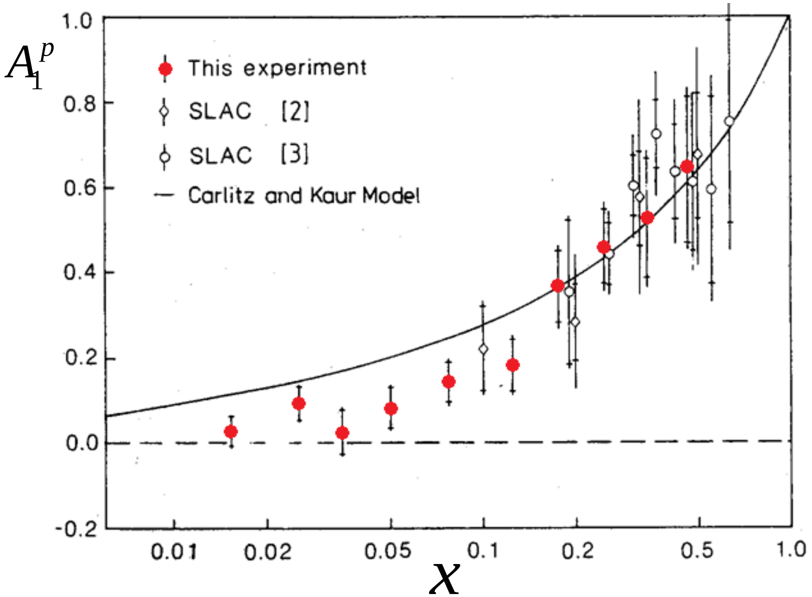
$$p + A \to \pi^+ + X$$

$$\hookrightarrow \mu^+ + \nu_\mu$$

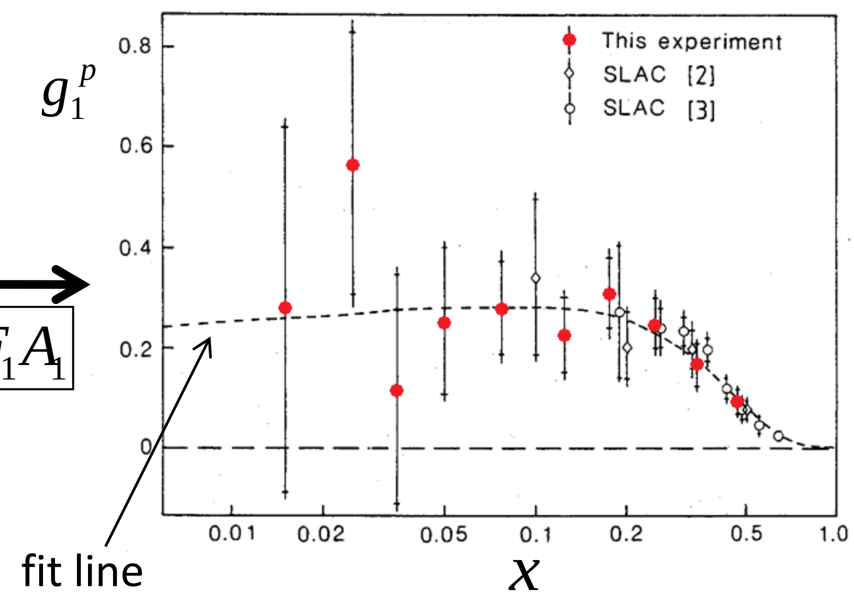
μ

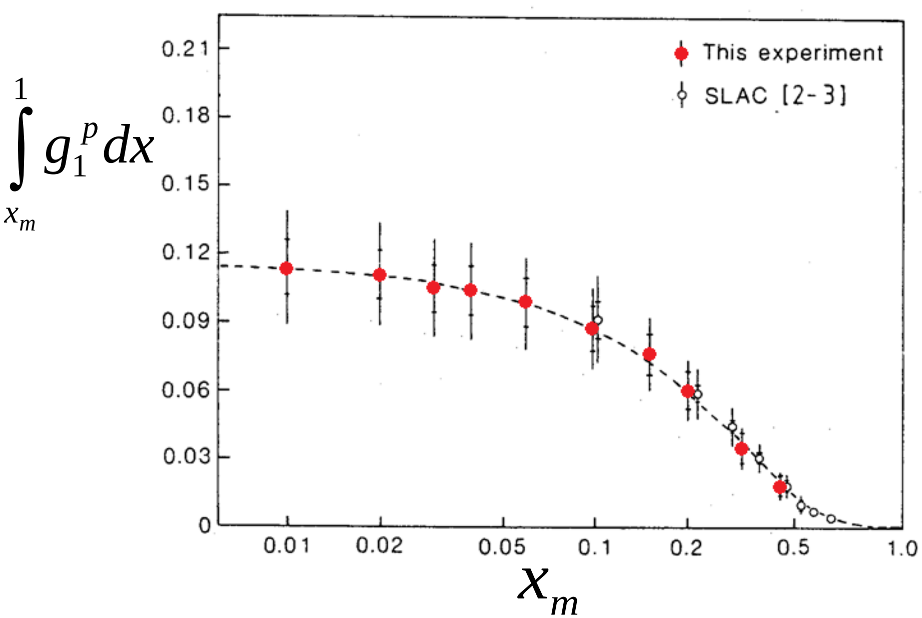


4. Result



$$g_1 \approx F_1 A_1$$





systematic error

$$\int_0^1 g_1^p(x)dx = 0.126 \pm 0.010 \pm 0.015$$

statistical error

$$g_1^p = \frac{1}{2}\sum_f e_f^2 (q_f^\uparrow(x) - q_f^\downarrow(x)) \qquad \Delta q = \int_0^1 dx (q^\uparrow(x) - q^\downarrow(x))$$

$$\int_0^1 g(x)_1^p \, dx = \frac{1}{2}\left(\frac{4}{9}\Delta u + \frac{1}{9}\Delta d + \frac{1}{9}\Delta s\right) = \frac{1}{12}\left[(\Delta u - \Delta d) + \frac{1}{3}(\Delta u + \Delta d - 2\Delta s) + \frac{4}{3}(\Delta u + \Delta d + \Delta s)\right]$$

This experiment

$(\Delta u - \Delta d) \rightarrow a_3 = 1.254 \pm 0.006$ (neutron β-decay)

$(\Delta u + \Delta d - 2\Delta s) \rightarrow \sqrt{3}\, a_8 = 0.397 \pm 0.020$ (hyperon weak decay)

$(\Delta u + \Delta d + \Delta s) \rightarrow \sqrt{3/2}\, a_0$

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

$$\langle S_z \rangle_{quarks} = 0.060 \pm 0.047 \pm 0.069 << \frac{1}{2}$$

⇒ Quarks carry only (12±9±14)% of the spin of the proton

5. Summary

- This experiment tested the contribution of the quarks spin to the proton spin.
- The method is the measurement of the spin structure function in deep inelastic scattering.
- The contribution of the quarks spin is only (12±9±14)%.

⇩

There must be another origin of the proton spin.

- gluon spin,
- Orbital angular momentum of quarks, and/or
- Orbital angular momentum of gluons

A lot of investigations of spin origin are carried out all over the world.

ex.) SMC-CERN , SLAC , HERMES-DESY , COMPASS-CERN, RHIC-BNL , JLab , Belle-KEKB, etc…

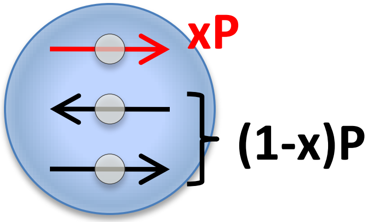
以下補足

Bjorken x

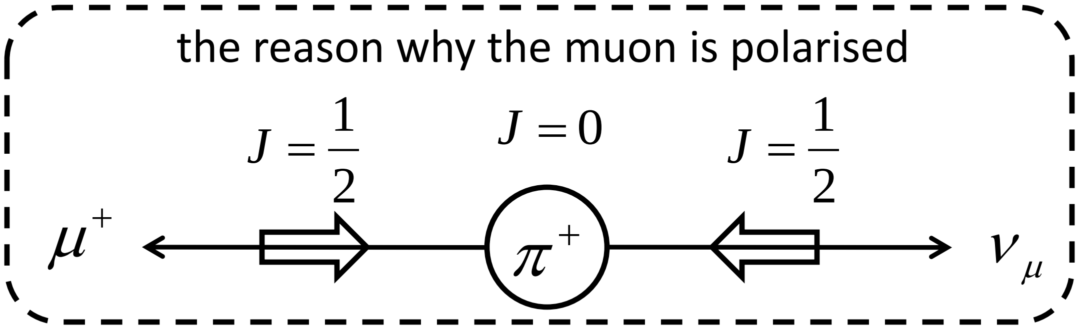
$$x = \frac{Q^2}{2M\nu} \quad (0 < x \le 1)$$

↓

"x" is the fraction of the momentum of the proton carried by the struck quark.



Proton momentum : **P**


the reason why the muon is polarised
J = 1/2
J = 0
J = 1/2
μ+
π+
νμ