Aug 25, 2004

NP04, KEK

Determining Strangeness Quark Spin in Neutrino-Nucleon Scattering at J-PARC

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1. Introduction

u, *d*, and *s* Quark Spin in the Nucleon: $\Delta u, \ \Delta d, \ \Delta s$
Worldwide studies with accelerators

1.1 EMC experiment at CERN (1988) $\mu + p$
J. Ashman et al. Phys. Lett. B206 (1988) 364,
Nucl. Phys. B328 (1989) 1

Quark Spin in the Proton $\Delta\Sigma = \Delta u + \Delta d + \Delta s$

Proton Spin Problem

$$\frac{1}{2}\Delta\Sigma = 0.06 \pm 0.047 \pm 0.068 \leq \frac{1}{2}$$

12 ± 9± 14 % ⇨ **20 – 30 % of Proton Spin**

These papers obtained rather large number of citations in accelerator-based particle physics experiments ≈ 1200

Experiments on the Proton Spin and related measurements

Fixed Target Experiments:

CERN	EMC, SMC, COMPASS	mu 160 GeV	pol p,d	DIS
DESY-HERA	HERMES	e 28 GeV	pol p,d	DIS
SLAC		e 50 GeV	pol 3He, p,d	DIS
JLAb	Hall A	e 6 GeV	pol 3He	DIS
	Hall B	e 6 GeV	pol p,d	Resonance Reg.
	Hall C	e 6 GeV	pol p,d	Resonance Reg.
MIT/Bates	SAMPLE	e 0.2 GeV	p,d	Elastic Scatt. PV
JLAB	G0	e 6 GeV	p,d	Elastic Scatt. PV
JLAB	HAPPEX	e 6 GeV	p,d	Elastic Scatt. PV
Mainz-MAMI		e 0.88 GeV	p,d	Elastic Scatt. PV
BNL	E734	nu 1.3 GeV	p	Elastic Scatt. NC

Collider Experiments:

BNL-RHIC	PHENIX	p+p 100 or 250 GeV	gluon spin, sea quark
	STAR	p+p 100 or 250 GeV	gluon spin, sea quark
KEK B-factory	BELLE	e + e, 8 on 3.5 GeV	fragmentation function

$\Delta u, \ \Delta d, \ \Delta s$ in flavor SU(3) of Octet Baryon

Neutron beta decay and hyperon weak decays:

$$(g_A/g_V)_{\mathrm{np}} = 3(\Delta u - \Delta d) = F + D = 1.2695 \pm 0.0029$$ **:Neutron lifetime**

$$(g_A/g_V)_{\Lambda p} = 2\Delta u - \Delta d - \Delta s = F + D/3 = 0.718 \pm 0.015$$

$$(g_A/g_V)_{\Xi\Lambda} = \Delta u + \Delta d - 2\Delta s = F - D/3 = 0.25 \pm 0.05$$

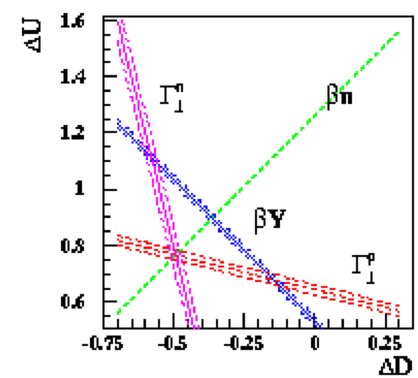
$$(g_A/g_V)_{\Sigma n} = 3(\Delta d - \Delta s) = F - D = |0.340 \pm 0.017|$$

Polarized deep inelastic electron (muon) scattering:

$$\Gamma_1^p = \frac{1}{2}\left(\frac{4}{9}\Delta u + \frac{1}{9}\Delta d + \frac{1}{9}\Delta s\right) = 0.119$$

$$\Gamma_1^n = \frac{1}{2}\left(\frac{1}{9}\Delta u + \frac{4}{9}\Delta d + \frac{1}{9}\Delta s\right) = -0.053$$

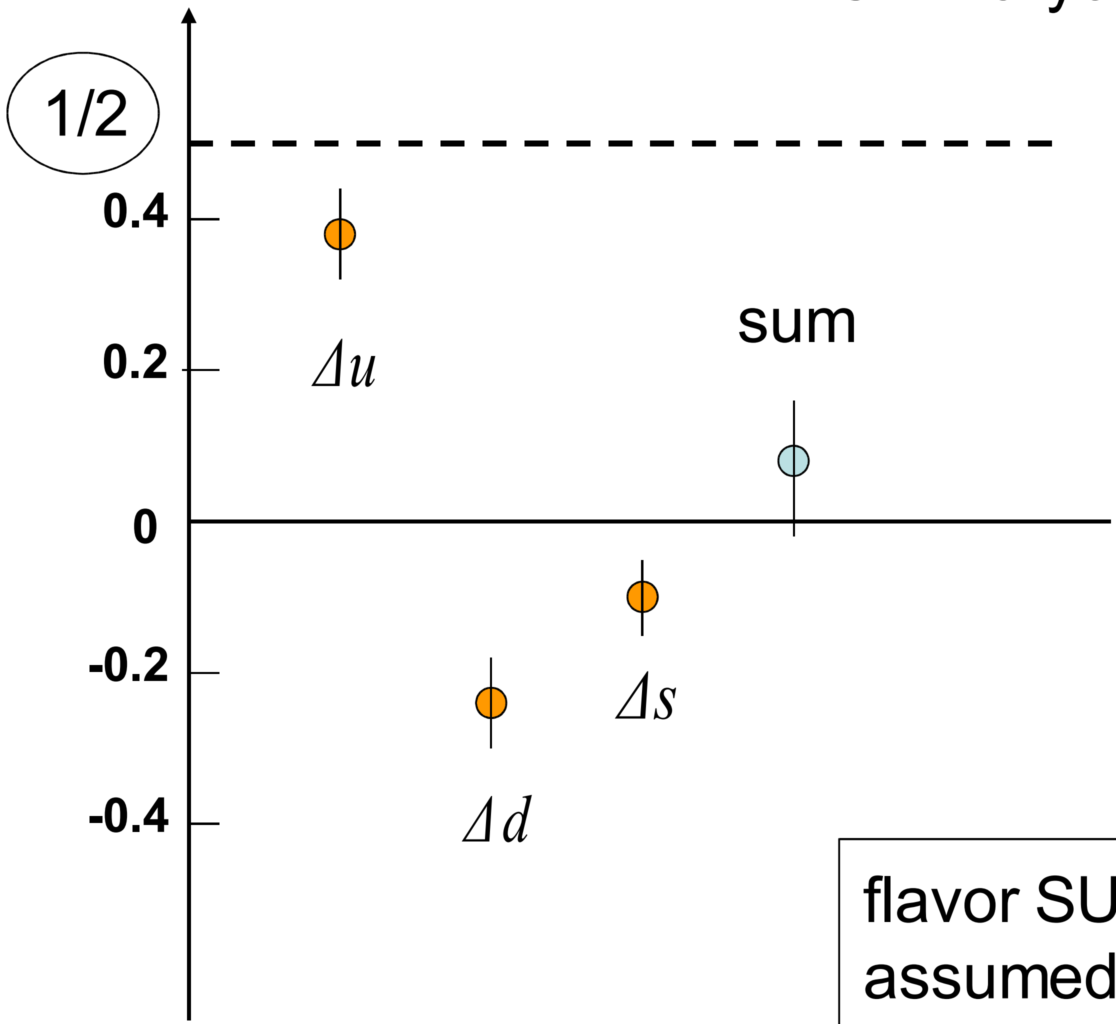
$\Delta q(x), \ 0 < x_{\mathrm{BJ}} < 1,$



$$\Delta\Sigma = \Delta u + \Delta d + \Delta s = 0.213 \pm 0.138$$ 21%

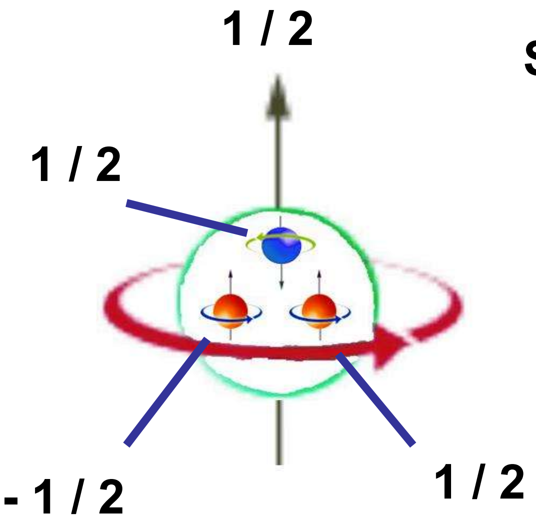
$$\Delta S = -0.124 \pm 0.046$$

EMC + Baryon weak decays



flavor SU(3) symmetry assumed

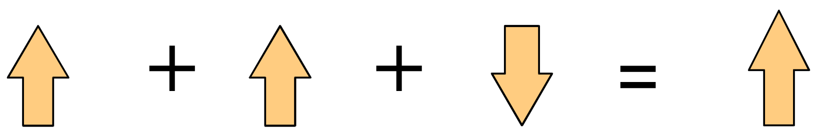
Spin of the Proton

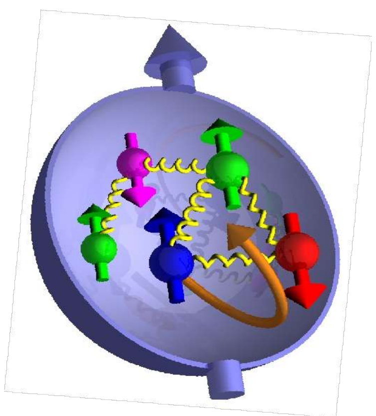


SU(6) Quark Wave Functions of Baryons

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

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





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

gluon spin, orbial angular momentum,
important to understand the quark spin part well

Impact of Δs Measurement

- Spin Flavor Structure of the Proton
  - Beyond Flavor SU(3) assumption

- Neutron EDM J.Ellis and R.A.Flores PLB377(96)83
  - Neutron-EDM predicted using q-EDM and Δq

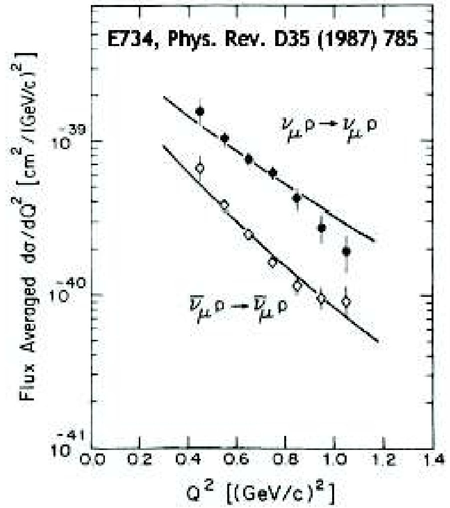
$$d_n = \eta^E (\Delta u \; d_u^E + \Delta d \; d_d^E + \Delta s \; d_s^E)$$
$$¿ \, m_u \Delta u + m_d \Delta d + m_s \Delta s$$

- Dark Matter J.Ellis and M. Karliner Lecure at Erice School 95 hep-ph/9601280
  - Better determination of Dark-Matter reaction

$$\sigma(\chi \; p \rightarrow \chi \; p) \propto \frac{4}{9} \Delta u + \frac{1}{9} (\Delta d + \Delta s) \; (\text{photino}) \; \text{or}$$
$$\propto \frac{17}{36} \Delta u + \frac{5}{36} (\Delta d + \Delta s) \; (\text{pure } U(1) \text{ gaugino})$$

Neutrino-nucleon elastic scattering cross section
from viewpoint of strange quark spin Δs in the proton

E734



L.A. Ahrens et al., Phys. Rev. D35 (1987) 785,
G.T. Garvey et al., Phys. Rev. C48 (1993) 761

BNL734 experiment with
Neutrino beam from AGS on proton,
ν **(mean energy 1.3 GeV) ,** $\bar{\nu}$ **(1.2 GeV)**
ν **0.5 E19 POT,** $\bar{\nu}$ **2.5E19 POT**
elastic scattering
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

How to measure:

$$\frac{d\sigma}{dQ^2} = \frac{G_F^2}{2\pi}\frac{E_\nu^2}{Q^2}\left[A \pm B\, W + C\, W^2 \right],$$

$+$ for ν,
$-$ for $\bar{\nu}$

$$W = 4\left(E_\nu / M_p - \tau\right), \quad \tau = Q^2 / 4 M_p^2$$

$$A = \frac{1}{4}\left[G_1^2 (1+\tau) - \left(F_1^2 - \tau\, F_2^2\right)(1-\tau) + 4\,\tau\, F_1 F_2 \right],$$

$$B = -\frac{1}{4}\left[G_1 \left(F_1 + \tau\, F_2\right)\right],$$

$$G_1(Q^2) = \frac{-0.631}{(1 + Q^2 / M_A^2)^2} + \frac{G_1^s(Q^2)}{2}$$

$$C = \frac{1}{16}\frac{M_p^2}{Q^2}\left[G_1^2 + F_1^2 + \tau\, F_2^2 \right],$$

$$G_1^s(Q^2 = 0) = \Delta s$$

beam:

ν beam only: sensitive to both *G* and G^2

ν and $\bar{\nu}$ beams: cross section difference

⇨ linear in *G*

target:

proton (LiqScintillator subtraction)

- clear interpretation of *G*

nuclear target

- corrections for nuclear effects
- high statistics

νN Elastic Scattering Exp at J-PARC

evaluation by Saito

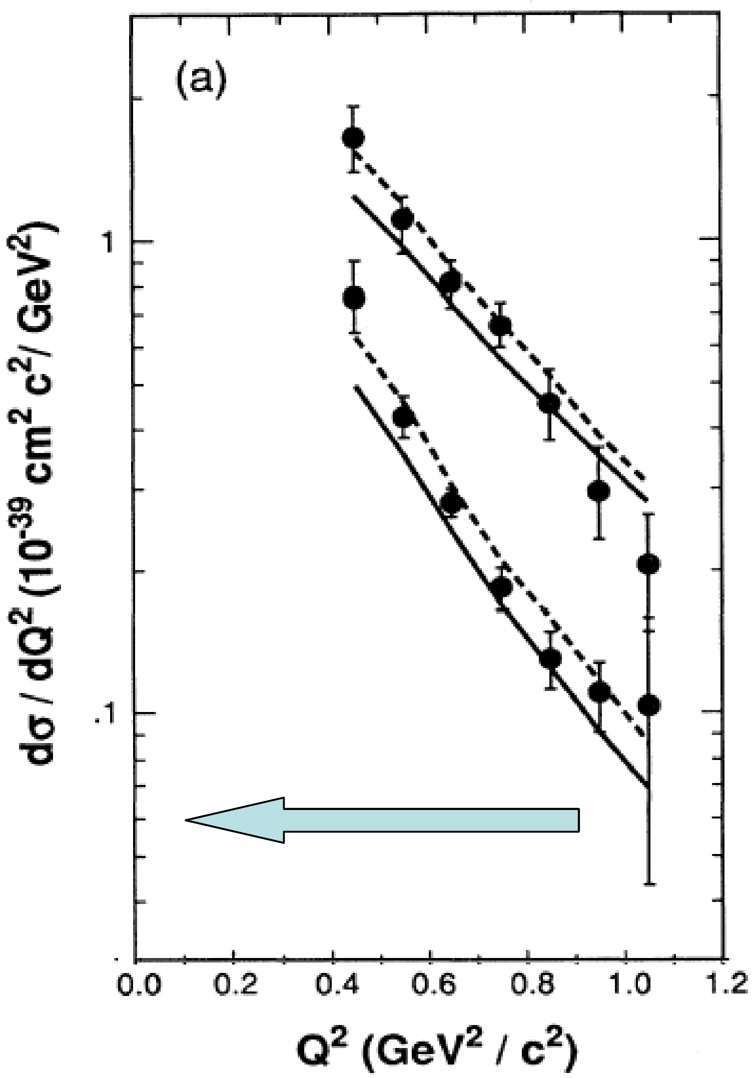
Conditions:

- On-axis at near detector hall of T2K
- LiqScintillator with different **H/C** mixture for pure proton signal   (subtraction method)
  - e.g Bicron BC510A (H/C=1.212) and BC-533 (H/C=1.96)
  - Pure Carbon can be extracted for νA cross section
  - e.g. 5x5x5m^3
- 1.0E21 POT possible in one year (130 days)
  - 30 times BNL-E734
  - ν and $\bar{\nu}$ beams

Sensitivity for Δs

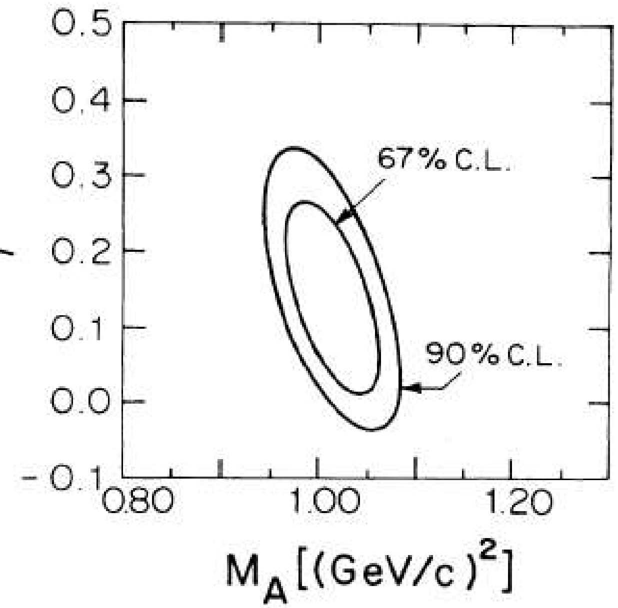
Conditions:

- Similar Detection Efficiency to E734:
  - 7.6% for neutrino-N elastic
  - 5.4% for anti-neutrino-N elastic
- with lower Q^2 cut-off : 0.1 GeV^2
  - Achievable with more uniform detector
- 25 times more statistics but pure proton only 1/6
  - Factor 2 reduction in statistical error
- Systematic control improvements to ~5%
  - E734, 7.6% dominated by Beam Flux and Nuclear Effects
  - Possible to remove Nuclear Effects which could be larger in lower Q^2 region



Comparison with BNL-E734

- If Δs is the only parameter to be determined
  - E734: $\Delta s = -0.10 \pm 0.08$
  - J-PARC: $\Delta s = -0.10 \pm 0.03$



- If Δs and M_A are both free parameters
  - E734: $\Delta s = -0.10 \pm 0.27$
  - J-PARC: $\Delta s = -0.10 \pm 0.12$
  - N.B. other analysis of E734 provided better precision:

TABLE II. The fit results for the strange form factors $G_1^s(0) = \Delta s$, $F_1^s = -\frac{1}{6}\langle r_s^2 \rangle$, and $F_2^s(0) = \mu_s$, and the axial-vector dipole mass M_A.

Fit	$G_1^s(0)$	F_1^s	$F_2^s(0)$	M_A	χ^2/N_{DOF}
I	0	0	0	1.086±0.015	14.12/14
II	−0.15±0.07	0	0	1.049±0.019	9.73/13
III	−0.13±0.09	0.49±0.70	−0.39±0.70	1.049±0.023	9.28/11
IV	−0.21±0.10	0.53±0.70	−0.40±0.72	1.012±0.032	8.13/11

Conclusions

- Δs is strangeness quark spin in the proton
- Physics with proton spin problem, neutron EDM, dark matter
- 'Proton spin problem' is an important subject for particle physics and is studied worldwide. Strange quark has been suggested to be negatively polarized but need closer examination
- Neutrino scattering provides Δs while $\int_0^1 \mathrm{dx}\ \Delta s(x)$ from DIS requires extrapolation to unmeasured region
- Neutrino beam at J-PARC provides a unique possibility to measure Δs through axial vector form factor (G_A^s) with neutral current elastic scattering cross section
- The case of proton target (LiqScintillator subtraction) was estimated
- Design and detector tests are planned