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Strangeness spin in the proton studied with neutrino scattering

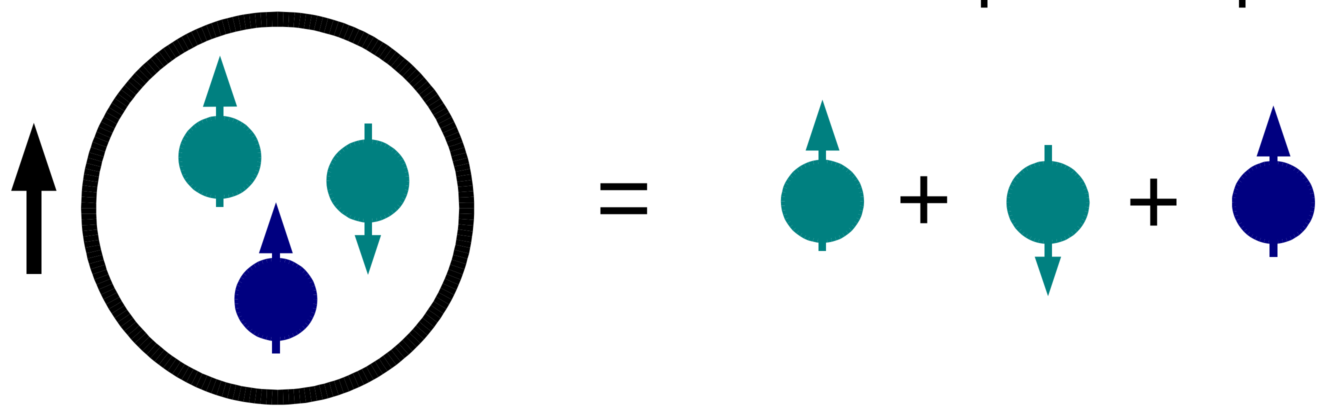
Yoshiyuki Miyachi
Tokyo Institute of Technology

Contents

- **Introduction**
  - Spin structure of nucleon
  - Proton spin problem: Deep Inelastic Scattering
  - Form factor measurement with neutrino beam
- **FINeSSE, J-PARC**
- **Summary**

Spin structure of nucleon

Nucleon spin: ½ = sum of quarks spin



$$\frac{1}{2} = \frac{1}{2}\Delta\Sigma = \frac{1}{2}\left(\Delta u + \Delta d + \Delta s + \Delta\bar{u} + \Delta\bar{d} + \Delta\bar{s}\right) \qquad \Delta q = q^{\uparrow} - q^{\downarrow}$$

The most naive case: $\Delta\Sigma = \Delta u + \Delta d + \Delta s = 1$

Naive Parton model: Assuming SU(3) flavor symmetry, taking axial current

$$\Delta\Sigma = \Delta u + \Delta d + \Delta s = a_0$$

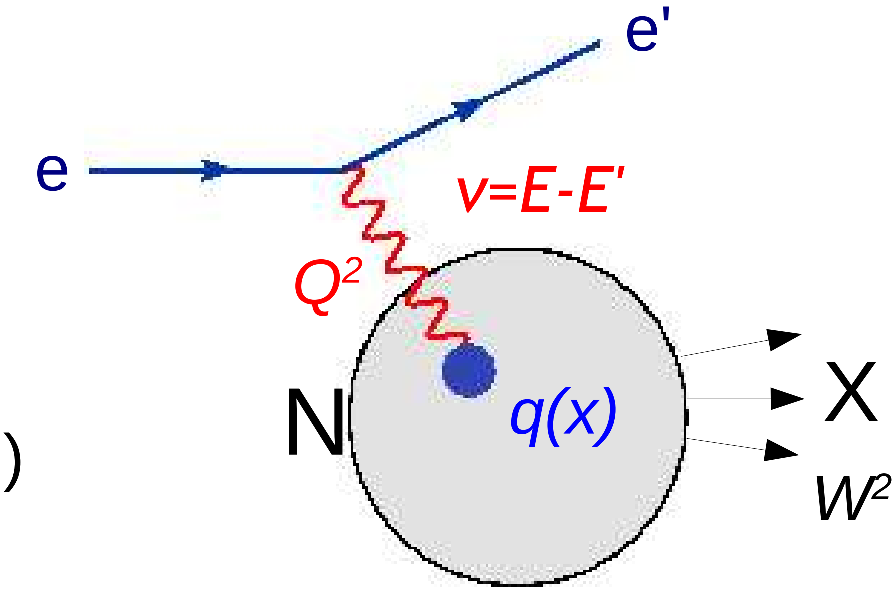
$$\Delta u - \Delta d = a_3$$

$$\Delta u + \Delta d - 2\Delta s = a_8$$

From weak decay:
$a_3 = 1.26,$
$a_8 = 0.58$

if Δs = 0, $\Delta\Sigma$ = a_8 = 0.58

Deep Inelastic Scattering and PDF



Deep Inelastic Scattering (DIS):

$$e + N \rightarrow e' + X$$

Q^2>1GeV^2, W^2>10GeV^2

= Σ_q(e-q elastic scattering)

Parton Distribution Function (PDF): *q(x)*

Probability distribution of finding quark inside nucleon which carries momentum fraction $x=Q^2/2M\nu$.

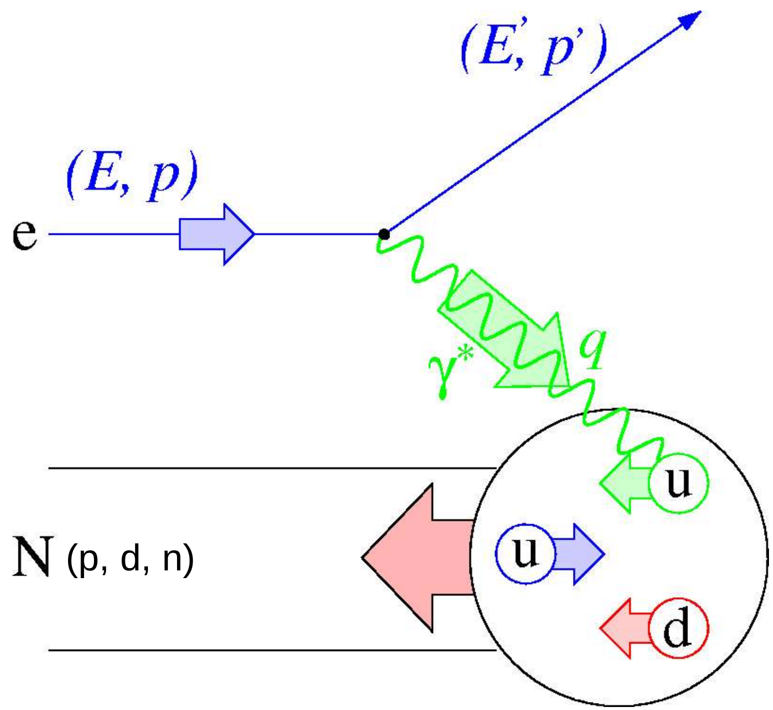
$$\frac{d^2\sigma}{dx\,dy} = \frac{2\pi\alpha^2 s}{Q^4}\left(x y^2 F_1(x) + (1-y) F_2(x)\right)$$

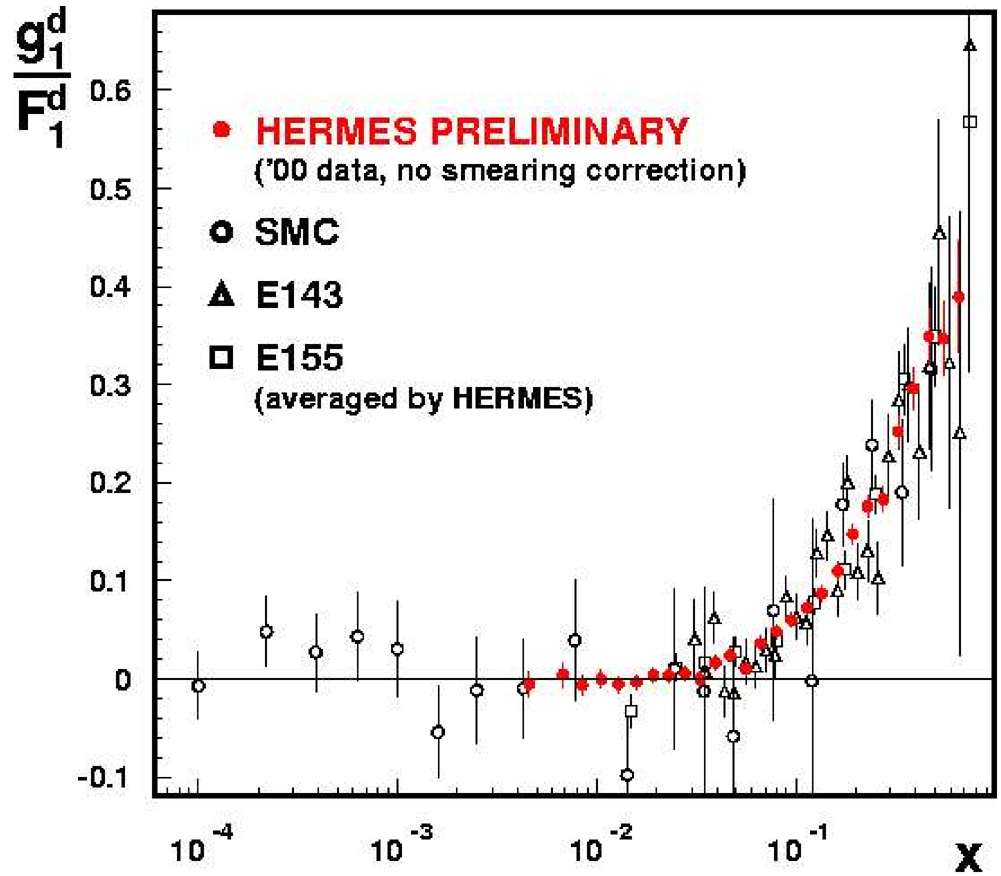
$$F_1(x) = \frac{1}{2}\sum_q e_q^2 q(x) \qquad F_2(x) = 2x F_1(x)$$

Polarized DIS measurement

$$\vec{l} + \vec{N} \rightarrow l' + X$$

$$A_1 = \frac{\sigma_{1/2} - \sigma_{3/2}}{\sigma_{1/2} + \sigma_{3/2}} = \frac{g_1}{F_1} = \frac{\sum_q e_q^2 \Delta q(x)}{\sum_q e_q^2 q(x)}$$





$$g_1(x) = \frac{1}{2} \sum_q e_q^2 \Delta q(x)$$

$$\Delta q(x) = q^{\uparrow}(x) - q^{\downarrow}(x)$$

Quark spin contribution

EMC finding: "Spin Puzzle" (Nucl. Phys. B328 (1989) 1)

$$\int_0^1 dx\, g_1^p(x) = \frac{1}{9} a_0 + \frac{1}{12} a_3 + \frac{1}{36} a_8 = 0.126 \pm 0.01 \pm 0.015$$

From weak decay: $a_3 = 1.26, \quad a_8 = 0.58$

assuming flavor SU(3)

$$a_0 \sim 0.1$$

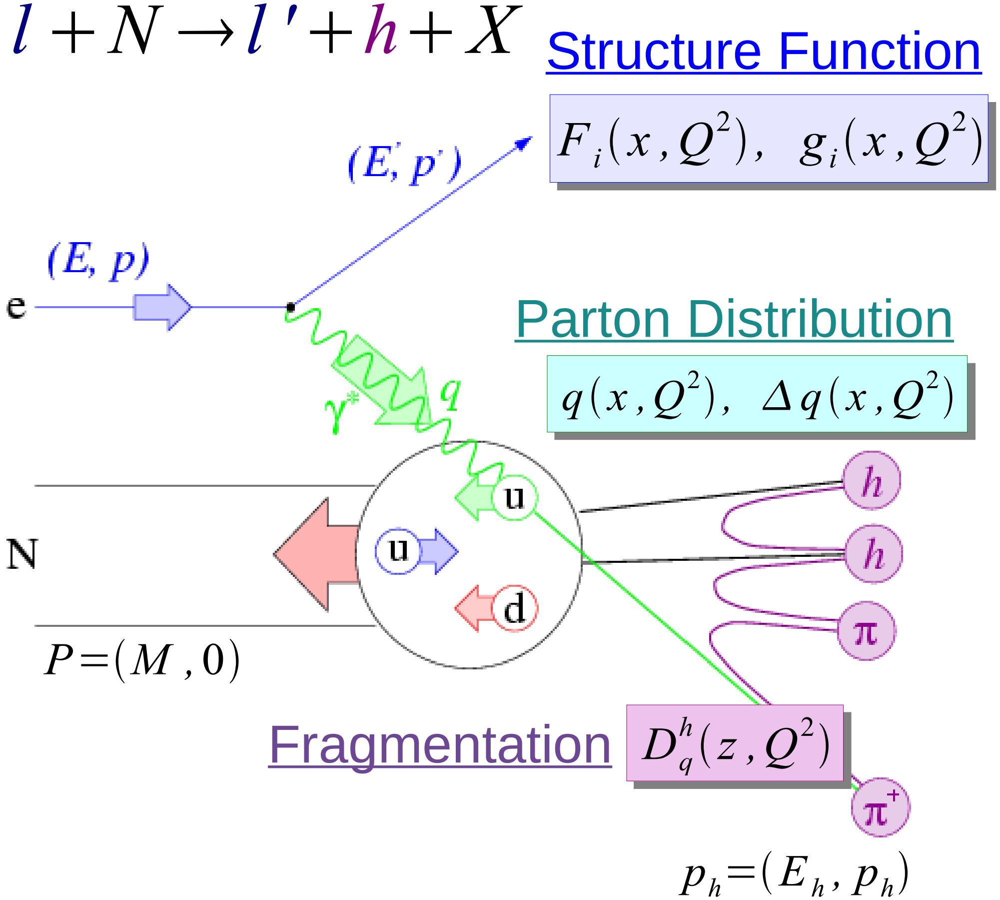
$$\Delta\Sigma = 0.1, \quad \Delta s + \Delta\bar{s} \sim -0.19$$

axial anomaly: $a_0 = \Delta\Sigma - 3\frac{\alpha_s}{2\pi}\Delta G \quad \Delta G > 0$

Hadron coincidence measurement

Semi-inclusive measurement of DIS

$$\vec{l} + \vec{N} \rightarrow l' + h + X$$



Measure hadron(s) in coincidence with the scattered lepton

$$\frac{d^3 \Delta\sigma^h}{dx\, dz\, dQ^2} \propto \sum_i e_q^2 \Delta q(x, Q^2) D_q^h(z, Q^2)$$

$$z = \frac{P \cdot p_h}{P \cdot q} = \frac{E_h}{\nu}$$

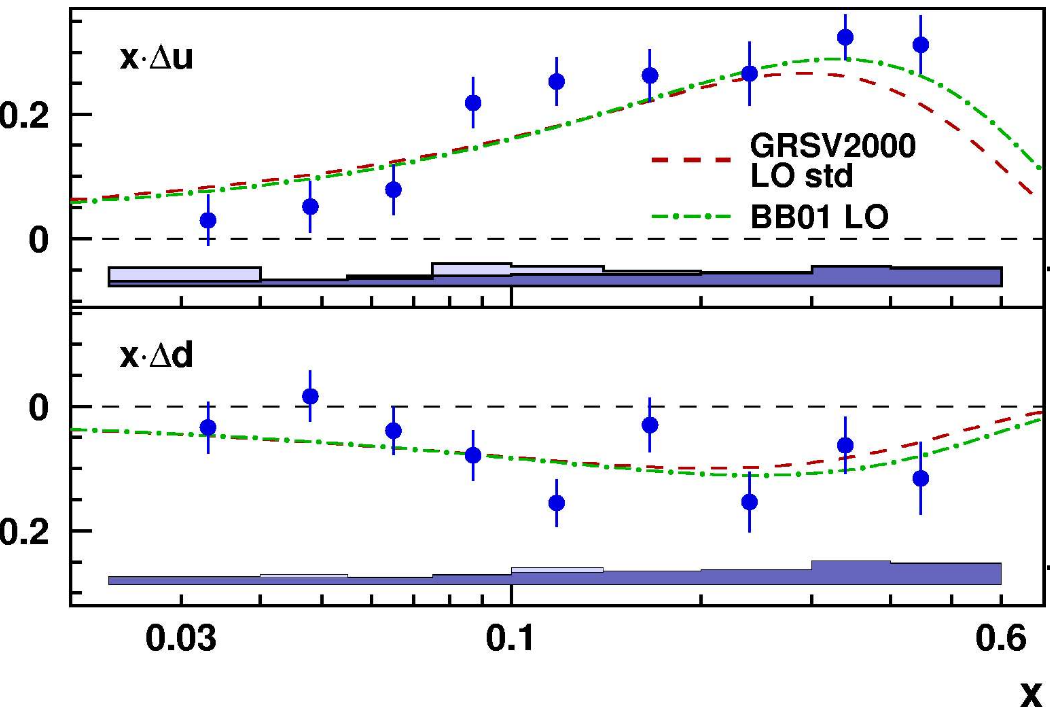
Flavor Tagging:

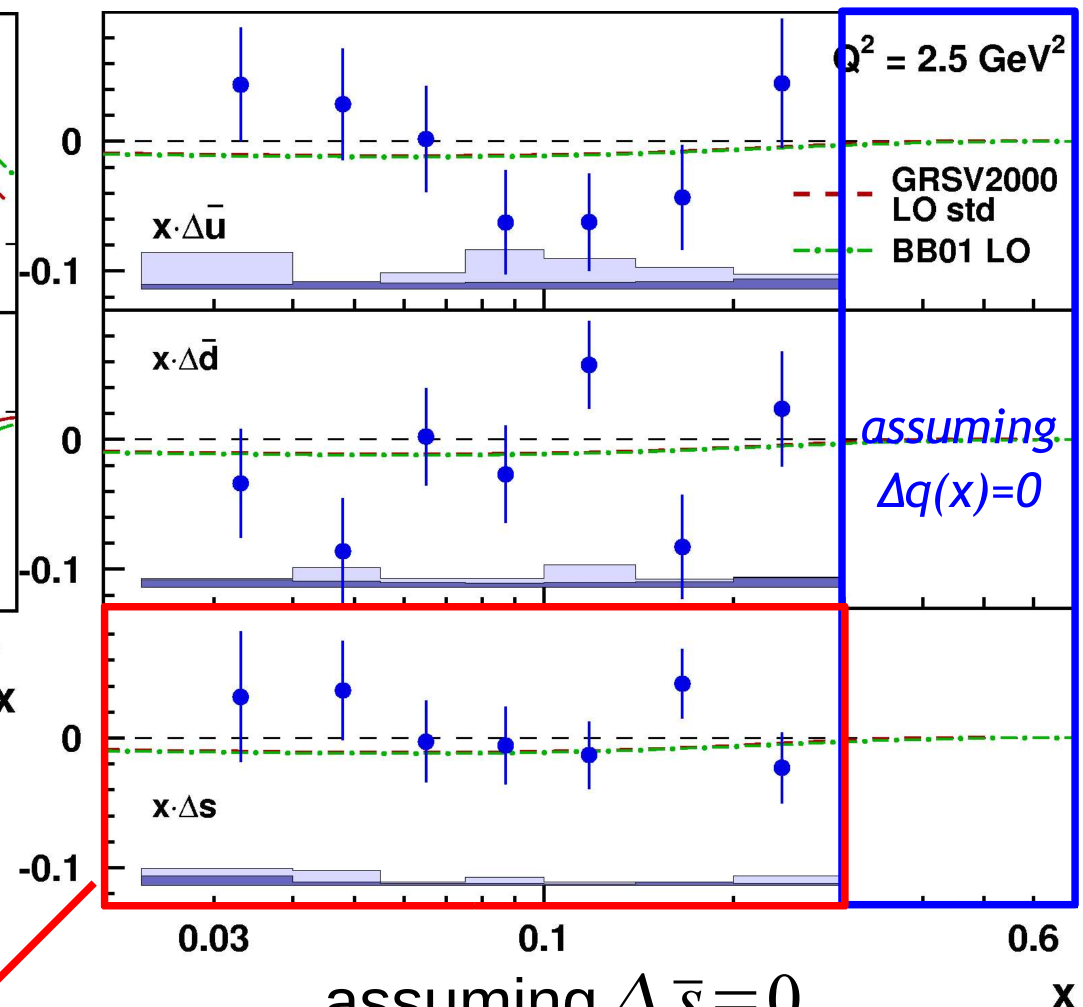
Hadron carries information on

quark flavor

through fragmentation function

Results from HERMES $Q^2 = 2.5\,\mathrm{GeV}^2$





assuming $\Delta \bar{s} = 0$

$$\Delta q = \int_{0.023}^{0.6} dx\, \Delta q(x) \qquad Q^2 = 2.5\,\mathrm{GeV}^2$$

$$\Delta u = 0.601 \pm 0.039 \pm 0.049$$
$$\Delta d = -.226 \pm 0.039 \pm 0.050$$
$$\Delta \bar{u} = -.002 \pm 0.036 \pm 0.023$$
$$\Delta \bar{d} = -.054 \pm 0.033 \pm 0.011$$
$$\Delta s = 0.028 \pm 0.033 \pm 0.009$$

Free from SU(3) flavor symmetry assumption

Neutrino-Nucleon scattering

$$\frac{d\sigma}{dQ^2}=\frac{G_F^2}{2\pi}\frac{Q^2}{E_\nu^2}\left(A\pm BW\pm CW^2\right)$$

$$W=\frac{4E_\nu}{m_p}-\frac{Q^2}{m_p^2}$$

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

$$\tau=\frac{Q^2}{4m_p^2}$$

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

$$C = \frac{1}{16}\frac{m_p^2}{Q^2}\left(G_1^2+F_1^2+\tau F_2^2\right)$$

NC-EL/CC-QE

Neutral Current

$$F_{1,2}=\left[\left[\frac{1}{2}-\sin^2\theta_W\right]\left[F_{1,2}^p-F_{1,2}^n\right]-\sin^2\theta_W\left[F_{1,2}^p+F_{1.2}^n\right]-\frac{1}{2}F_{1,2}^s\right.$$

$$G_1=\left[-\frac{G_A}{2}\tau_z+\frac{G_A^s}{2}\right]$$

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

τ_z=1 for proton, -1 for neutron

Neutrino scattering and Δs

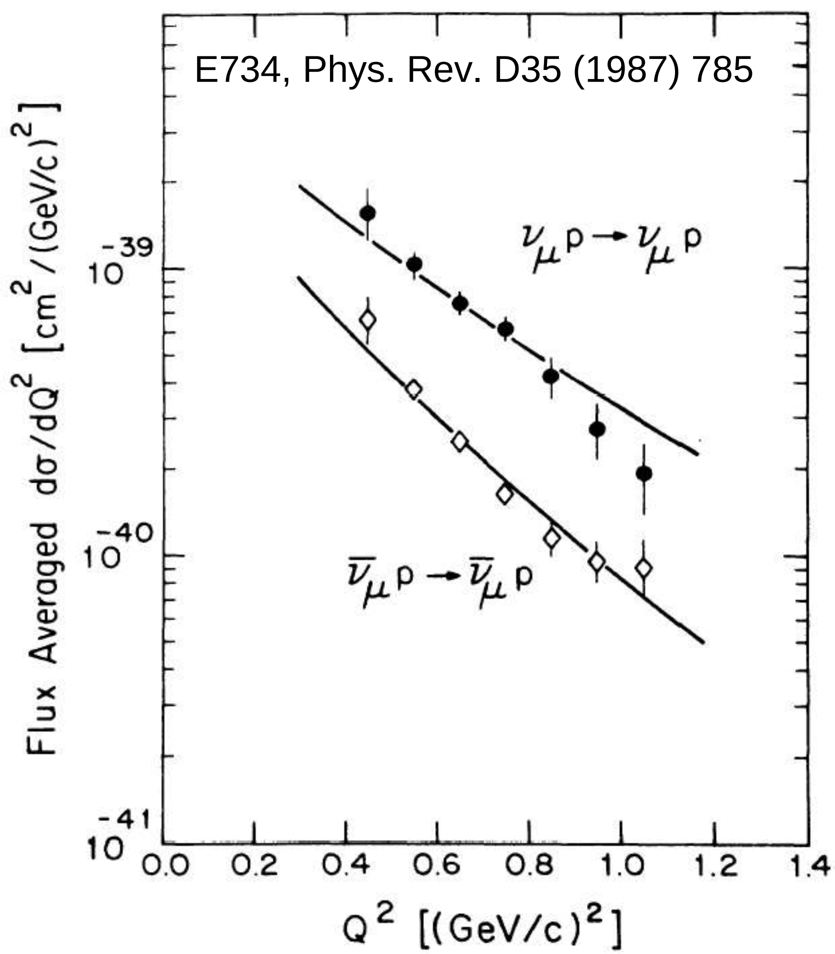
- **Neutral current cross section → strange axial form factor**
- **From $G_A^s(Q^2)$ to Δs**

$$G_A^s(Q^2 \to 0) = \Delta s = -0.21 \pm 0.10$$

Further analysis: (Alberico *et al.*)

$$R_{NC/CC}^{\nu} = 0.152 \pm 0.007 \pm 0.017$$
$$R_{NC/CC}^{\bar{\nu}} = 0.218 \pm 0.012 \pm 0.023$$
$$R_{NC}^{\nu/\bar{\nu}} = 0.302 \pm 0.019 \pm 0.037$$

$$0.5 < Q^2 < 1.0\,\mathrm{GeV}^2$$



-0.21 < Δs < 0

strong correlation with the axial mass M_A

Strangeness spin in nucleon

ϕ production in $p\bar{p}$ annihilation: polarized strangeness

DIS inclusive measurement: $\Delta s = \int_0^1 ds(x)\,dx = -0.13 \pm 0.06$

required SU(3) flavor symmetry and several assumptions

DIS semi-inclusive measurement: $\Delta s = \int_{0.023}^{0.6} ds(x)\,dx = 0.03 \pm 0.03$

Unknown contribution from the low x region (same in inclusive measurement)

Neutrino scattering: $-0.2 < \Delta s < 0$

global strange form factors analysis resulted in the positive solution, too.
(with parity violating electron scattering data)

Baryon magnetic moment: $\Delta s \sim -0.2$

Lattice calculation: $\Delta s \sim -0.1$

Precise determination $\delta(\Delta s) < 0.04$ is important.

Using superbeams

Axial Form Factor Measurement

Methods to extract Δs

NC cross section:

$$\sigma^{NC}(Q^2) \rightarrow G_A^s(Q^2) \xrightarrow[Q^2 \rightarrow 0]{} G_A^s(0)$$

NC cross section p/n ratio:

$$R^{\nu}_{p/n}(Q^2) = \frac{(d\sigma/dQ^2)^{NC}_{(\nu,p)}}{(d\sigma/dQ^2)^{NC}_{(\nu,n)}}$$

NC/CC asymmetry:

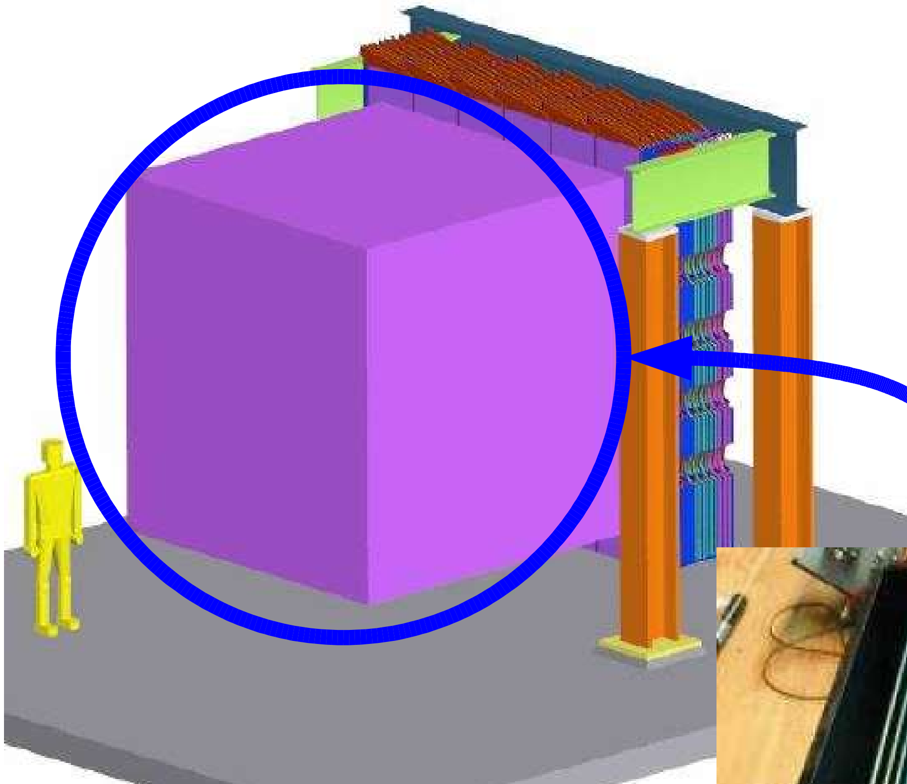
$$A(Q^2) = \frac{(d\sigma/dQ^2)^{NC}_{\nu} - (d\sigma/dQ^2)^{NC}_{\bar{\nu}}}{(d\sigma/dQ^2)^{CC}_{\nu} - (d\sigma/dQ^2)^{CC}_{\bar{\nu}}}$$

NC/CC ratio:

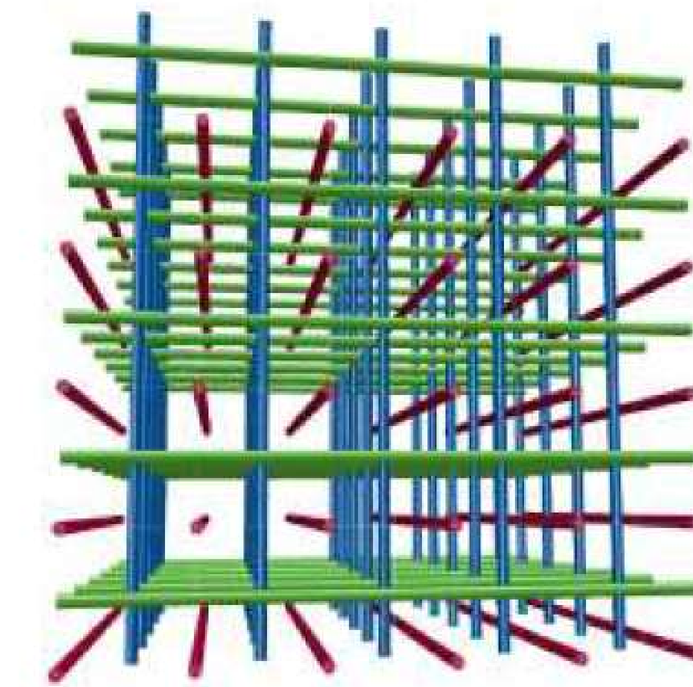
$$R_{NC/CC}(Q^2) = \frac{(d\sigma/dQ^2)^{NC}_{\nu}}{(d\sigma/dQ^2)^{CC}_{\nu}}$$

FINeSSE

Fermilab Intense Neutrino Scattering Scintillator Experiment



Liq. Scintillator readout with WS fibers

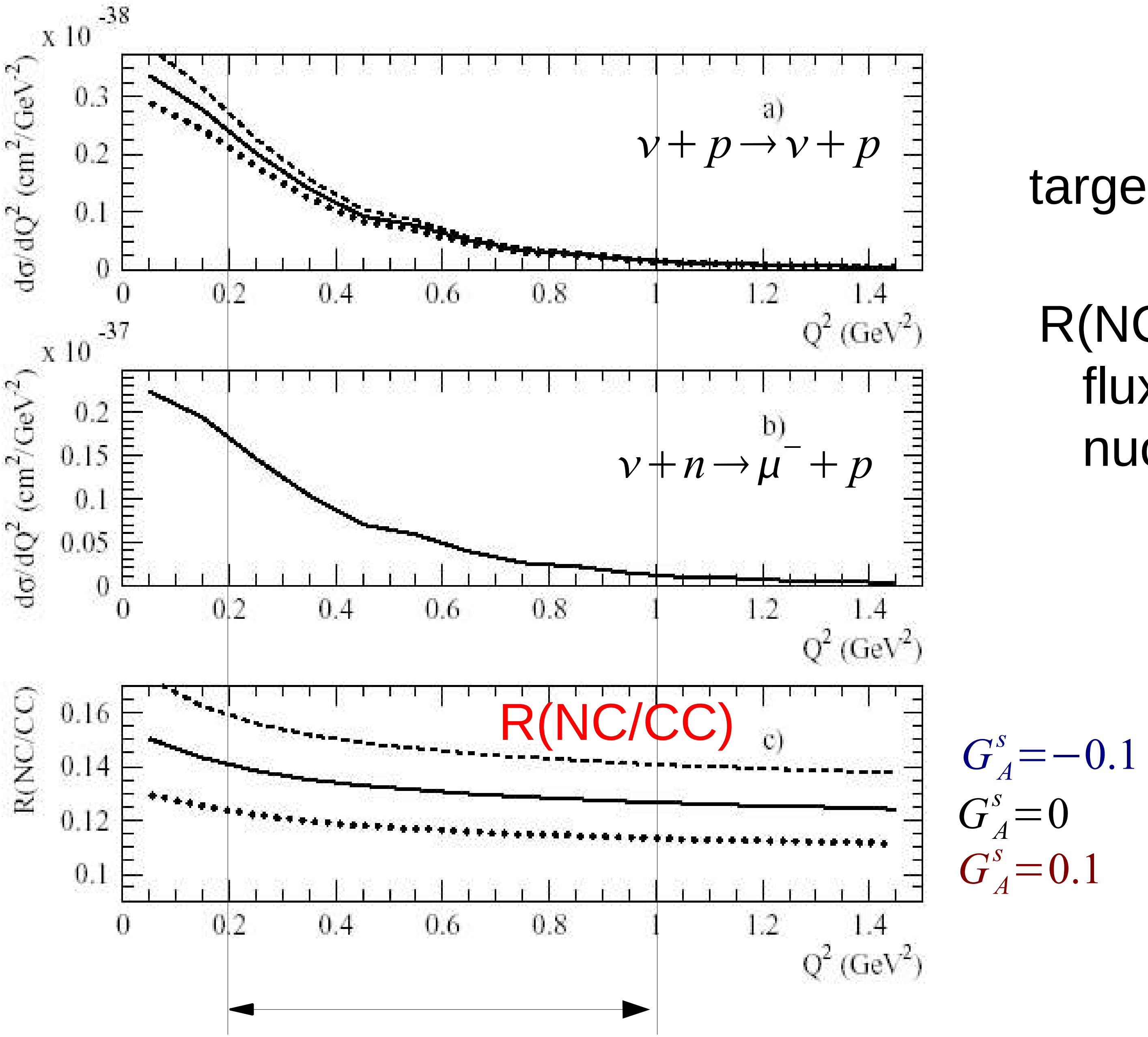


FINeSSE detector Prototype

Proposal:	Fermilab
LOI:	BNL

R(NC/CC) measurement -FINeSSE-

Monte Carlo Estimation

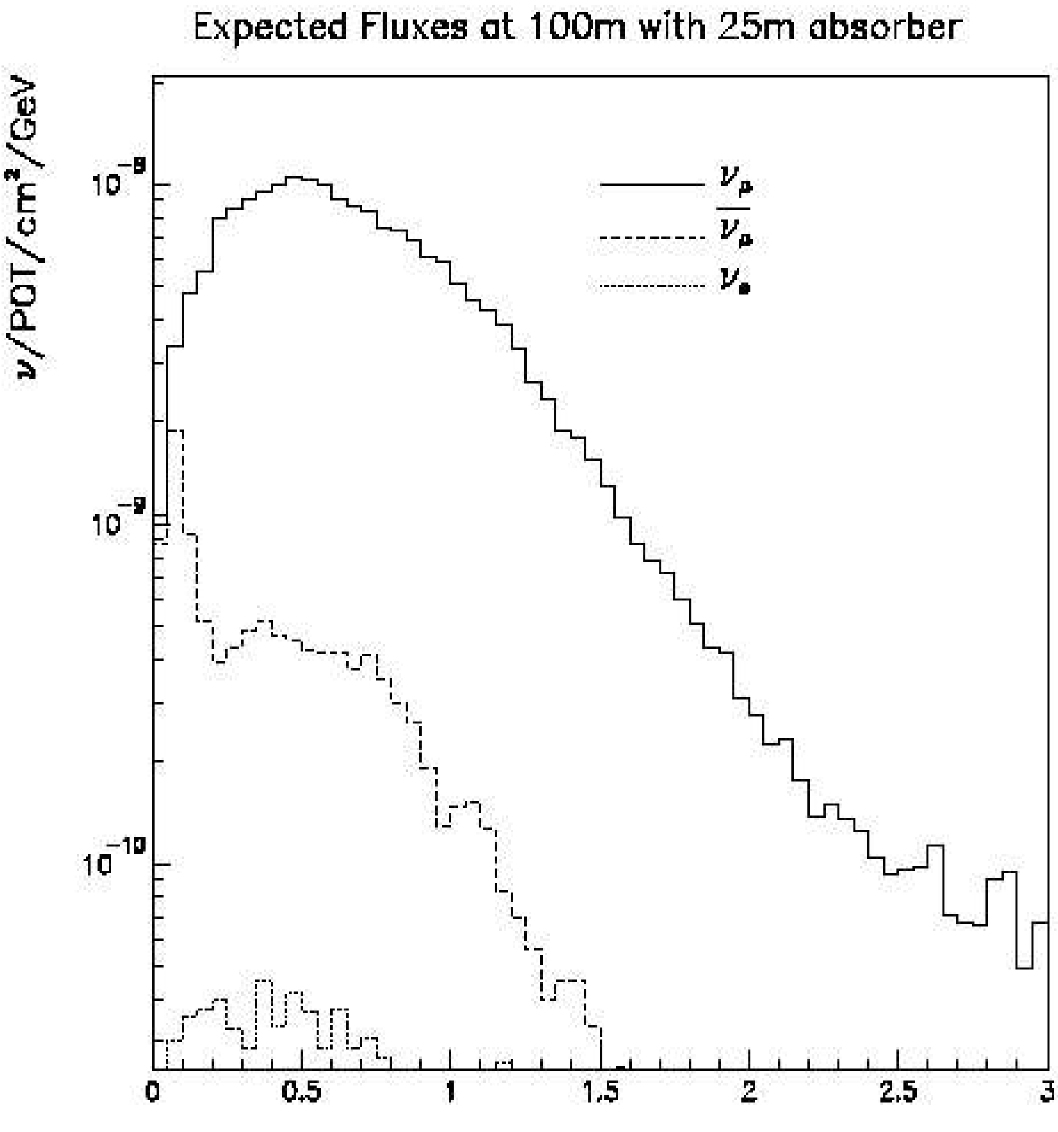


target: C in Liq. Scinti.

R(NC/CC) cancels:
- flux
- nuclear effects

from FINeSSE LOI

FINeSSE at Fermilab hep-ex/0402007



Fermilab Booster
used for MiniBooNE

6E+20 POT in 2 years

R(NC/CC) measurement:

<u>FINeSSE</u>	<u>E734</u>
$0.2 < Q^2 < 1.0$	$0.5<Q^2<1.0$
stat. error: 2%	5%
sys. error: 5%	11%

↓

$$\delta(\Delta s) < 0.04$$

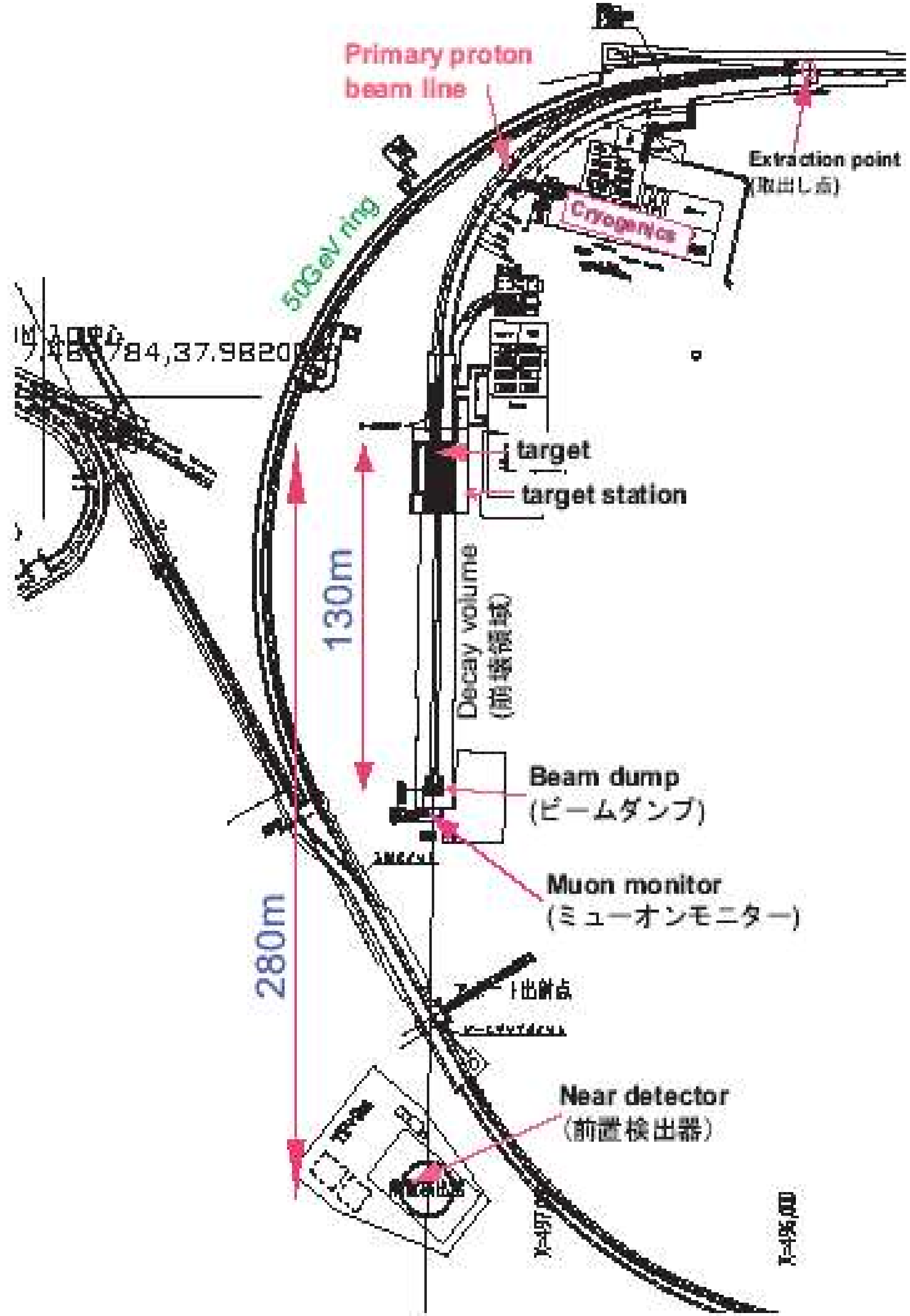
What should be considered?

- **Nuclear Effects**
  - Target: Carbon in the liquid scintillator.
  - Is it canceled in the ratio R(NC/CC) over the entire Q^2 range?
- **Q^2 extrapolation**
  - rely on the dipole form factor.
    - uncertainty below Q^2=0.2 GeV^2
  - Nuclear effects in the very low Q^2 region

J-PARC

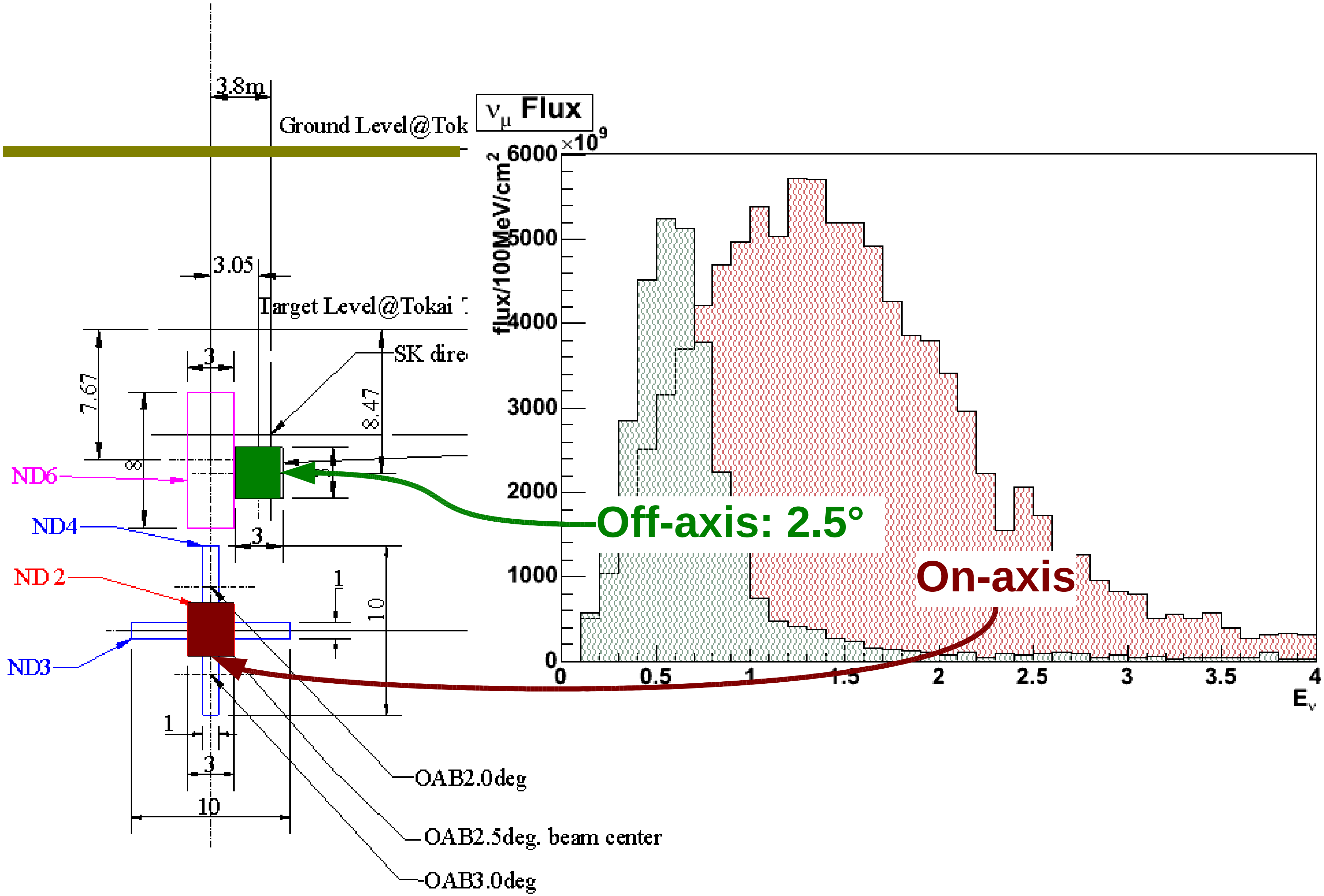
J-PARC ν-beam line

- **Neutrino beam**
  - peak around 1 GeV for “on-axis”, 0.8 GeV for “off-axis”
  - 10^{21} POT/year
  - with anti-neutrino beam
    - neutrino anti-neutrino asymmetry measurement

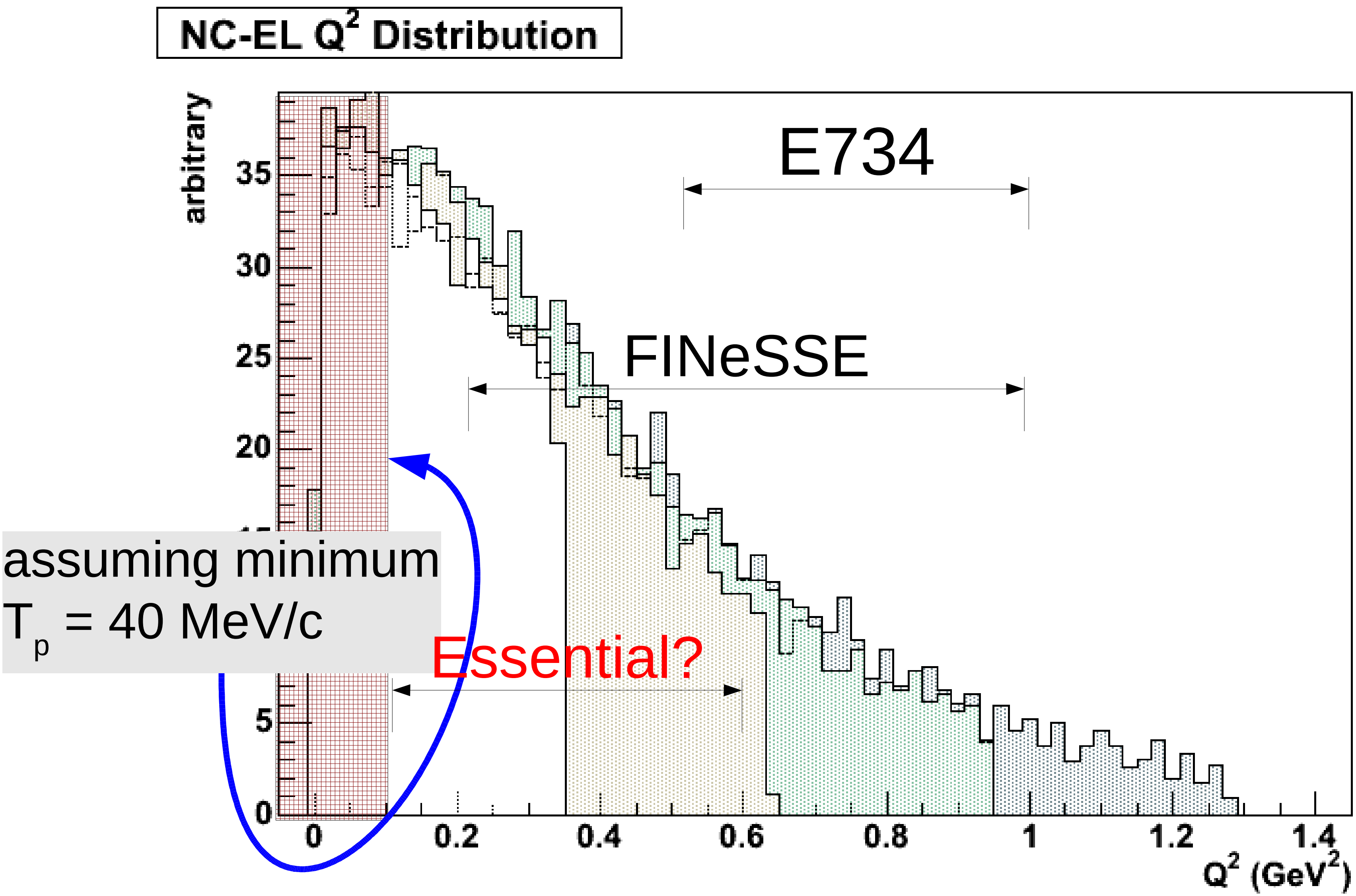


Neutrino Flux

(Neutrino Flux Monte Carlo Data)



Neutral current elastic scattering



$E_\nu =$ 0.4 0.6 0.8 1.0 GeV

monochromatic energy

What can we do?

- **Elastic scattering measurement**
  - NC, CCQE: σ or R(NC/CC) measurement
  - Neutrino anti-neutrino asymmetry measurement
  - background control: neutral π production, neutron
- **Nuclear effects**
  - Use different mixture of H/C? Liquid Scintillator?
  - Hydrogen target if possible. Hydrogen TPC?
- **Q^2 extrapolation**
  - G_a^s at Q^2=0 gives Δs: need to extrapolate Q^2=0
  - as low Q^2 as possible: precise reconstruction of recoil proton

Summary

- **Strangeness spin in the nucleon**
  - has been studied with various probes
  - statistical and systematic uncertainties
- **Neutrino scattering**
  - Unique tool for studying strangeness spin: nucleon axial form factor measurement
  - Key points: nuclear effects, Q^2 extrapolation
  - Measurement at J-PARC: studies are on going.