

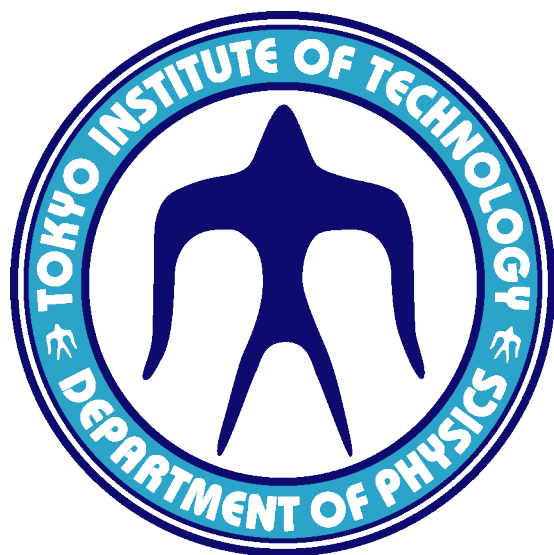
Workshop on Hadron Structure at J-PARC, November 30 – December 2, 2005

*Diabolical*

# Strange Spin measurements

at J-PARC

with  $\nu$ -N neutral current elastic scattering



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# Recent activities

## Presentations:

- NP04, Aug. 2 - 4, 2004, Tokai  
“Determining strangeness quark spin in neutrino scattering at J-PARC (**T.-A. Shibata**)”
- NP04 Neutrino session, Aug. 24 - 26, 2004, KEK  
“Strangeness Spin Contribution to the Nucleon Spin measured at J-PARC (**N. Saito**)”
- NuFact05, June 21 - 26, 2005, Rome  
“Study for the Neutrino Coherent Pion Production Experiment (**Y. Sakemi**)”
- NuInt05, September 26 – 29, 2005, Okayama  
“Strangeness in Nucleon -- a summary from electron scattering experiments and projection on neutrino scattering experiment (**Y. Miyachi**)”
- PANIC05, Neutrino Planning Satellite meeting, October 30, 2005, Santa Fe  
“Strangeness Spin Measurement at J-PARC(**Y. Miyachi**)”

**R&D:** Liquid scintillator test and detector simulation

## **Working group:**

<http://www.nucl.phys.titech.ac.jp/~sspin/>

## **Mailing list for the working group:**

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if you are interested, just send an empty E-mail to

[nu-spin-jparc-help@nucl.phys.titech.ac.jp](mailto:nu-spin-jparc-help@nucl.phys.titech.ac.jp)

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# Strangeness in nucleon

## $\pi$ -nucleon $\Sigma$ -term:

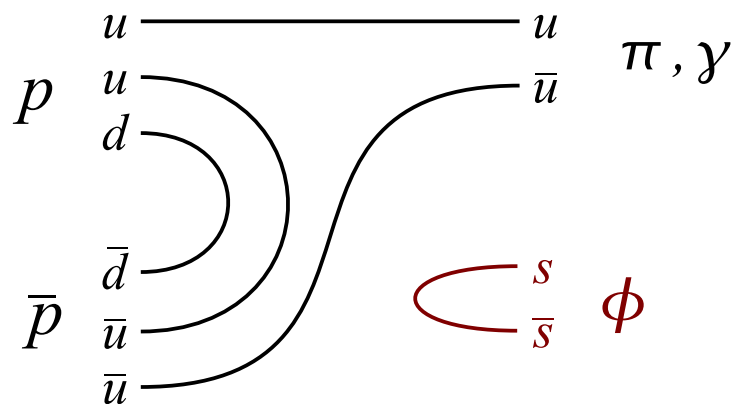
$$\Sigma = 64 \pm 8 \text{ MeV}$$

*Phys. Rev. C69 (2004) 035207*

strange scalar density

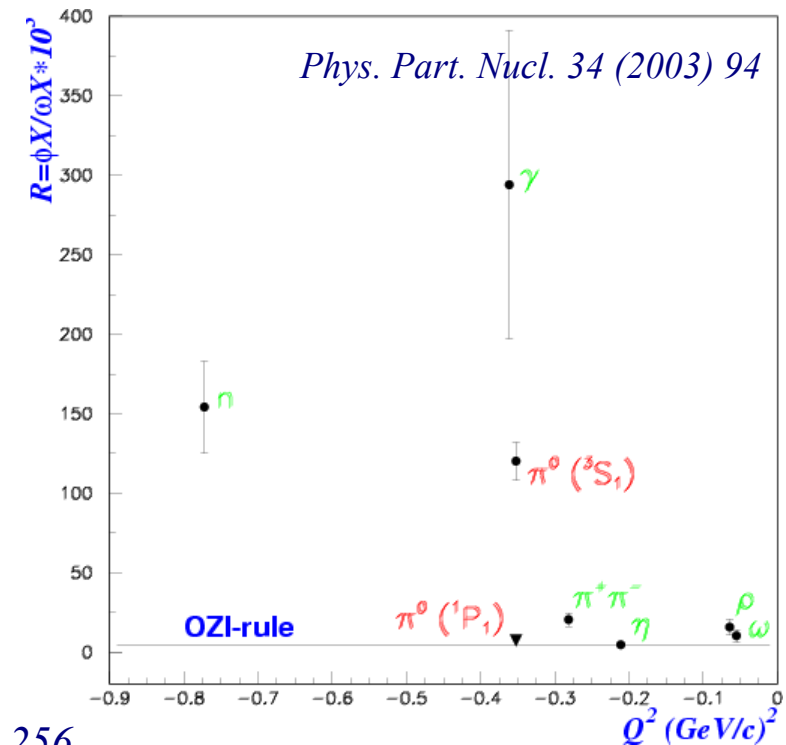
$$y = \frac{2 \langle p | \bar{s} s | p \rangle}{\langle p | \bar{u} u | p \rangle + \langle p | \bar{d} d | p \rangle} = 1 - \frac{\sigma_0}{\Sigma} \longrightarrow y \sim 0.5$$

## OZI rule breaking:



→ polarized strangeness?

*J. R. Ellis et. al, Phys. Lett. B 353 (1995) 319, Nucl. Phys. A 673 (2000) 256*



*Phys. Part. Nucl. 34 (2003) 94*


# Strange form factors

- electric and magnetic form factors -

## Parity violating electron proton elastic scattering:

$$e + p \rightarrow e' + p'$$

$$A_{PV} = \frac{d\sigma_R - d\sigma_L}{d\sigma_R + d\sigma_L}$$
$$= \frac{-G_F Q^2}{4\sqrt{2}\pi\alpha} \frac{\varepsilon G_E G_E^Z + \tau G_M G_M^Z - (1 - 4\sin^2\theta_W) \varepsilon' G_M G_A^e}{\varepsilon (G_E)^2 + \tau (G_M)^2}$$


$$\frac{dG_E^s(Q^2=0)}{dQ^2} = -\frac{1}{6}\rho_s^2, \quad G_M^s(Q^2=0) = \mu_s$$

SAMPLE, HAPPEX, PVA4, G0, E91004

# Resent results from Parity Violating Electron Scattering

## HAPPEX:

$$G_E^s + 0.080 G_M^s = 0.030 \pm 0.025 \pm 0.006 \pm 0.012 \quad (Q^2 = 0.099 \text{ GeV}^2) \quad \text{hep-ex/0506011}$$

$$G_E^s = -0.038 \pm 0.042 \pm 0.010 \quad (\text{with } ^4\text{He}) \quad (Q^2 = 0.091 \text{ GeV}^2) \quad \text{hep-ex/0506010}$$

## PVA4:

$$G_E^s + 0.225 G_M^s = 0.039 \pm 0.034 \quad (Q^2 = 0.230 \text{ GeV}^2) \quad \text{Phys. Rev. Lett. 93 (2004) 022002}$$

$$G_E^s + 0.106 G_M^s = 0.071 \pm 0.036 \quad (Q^2 = 0.108 \text{ GeV}^2) \quad \text{Phys. Rev. Lett. 94 (2005) 152001}$$

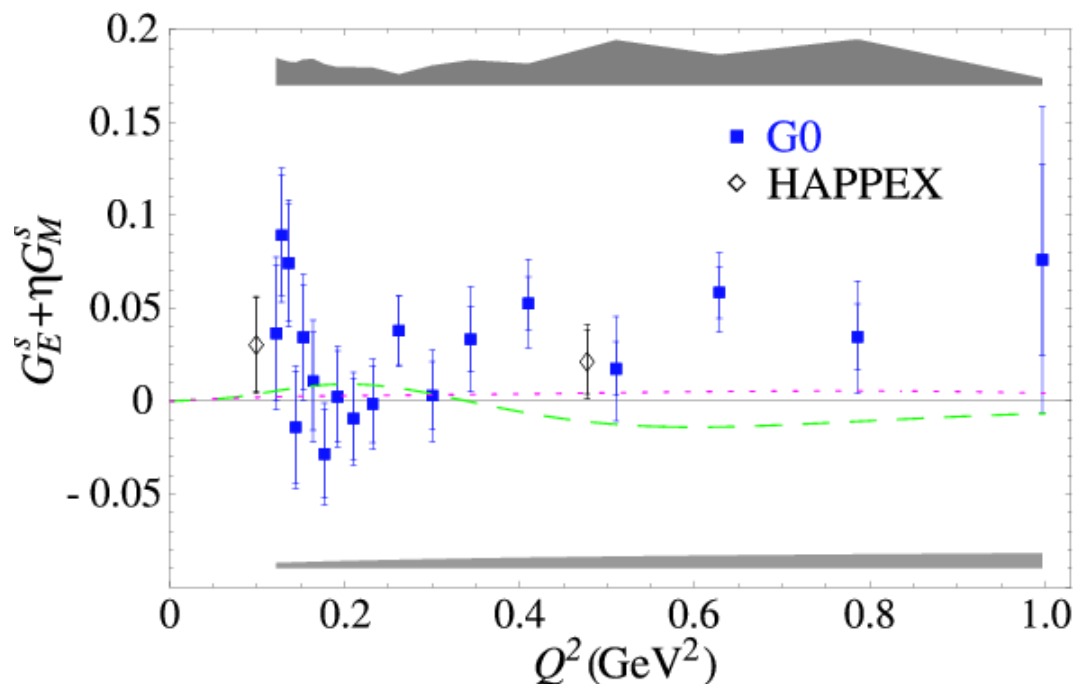
## G0: *Phys. Rev. Lett. 95 (2005) 092001*

$$G_E^s \neq 0$$

$$G_M^s \neq 0$$

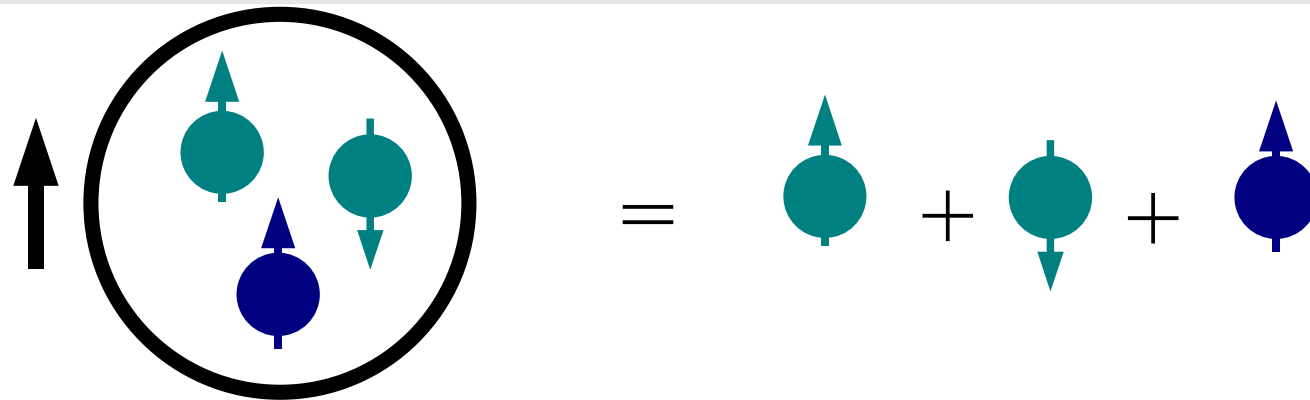
details in the next talk by J. Arvieux

$$\rightarrow G_A^s (= \Delta s) ?$$



# Proton spin problem

Proton spin:



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

The most naive case:

$$\Delta \Sigma = \Delta u + \Delta d + \Delta s = 1$$

Naive parton model:

Assuming SU(3) flavor symmetry, taking axial current matrix

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

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

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

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

$\Delta q$  corresponds to axial form factor  
 $\Delta q = G_A^q(Q^2=0)$

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

# Strangeness spin inside proton

- EMC results -

*Nucl. Phys. B328 (1989) 1, Phys. Lett. B206 (1988) 364*

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

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

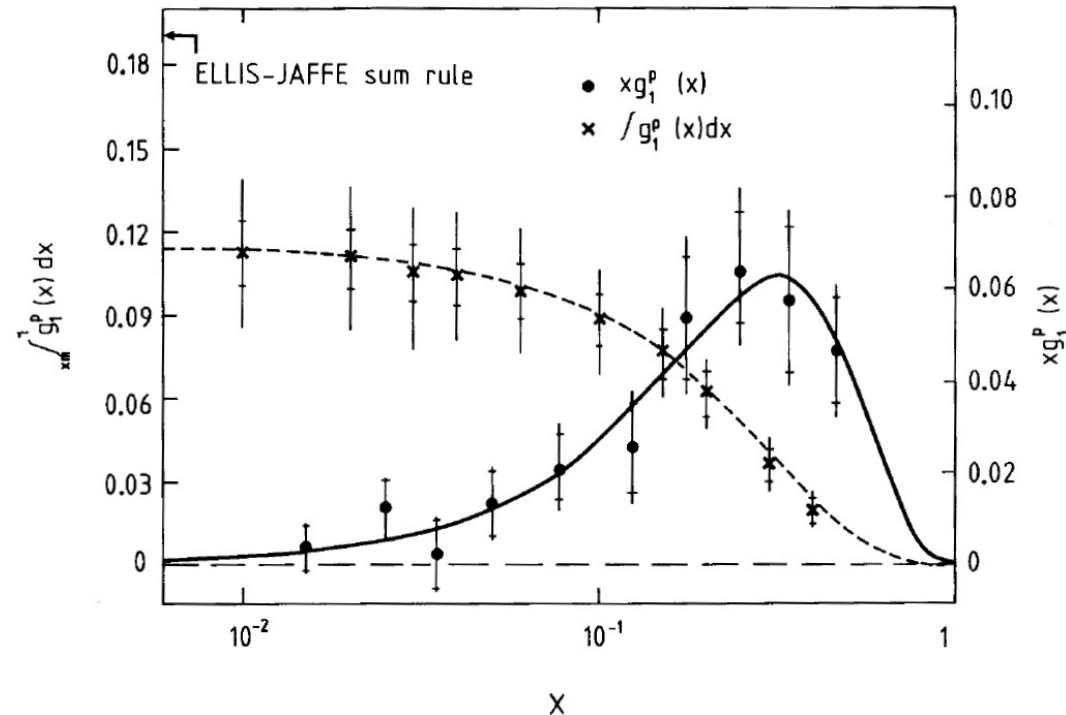
$$= 0.126 \pm 0.01 \pm 0.015$$

$$a_3 = 1.26, a_8 = 0.58$$

$$a_0 \sim 0.1$$

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

$$a_0 = \Delta \Sigma - 3 \frac{\alpha_s}{2\pi} \Delta G \quad \text{with } \Delta G > 0$$





# *Spin Physics is an important ingredient in particle physics.*

Spin Papers by EMC have about the same number of citation as  $J/\psi$ , top,  $W$ ,  $Z$  discoveries.

They are in Top5 among particle physics experiments using accelerators.

<i>J.J. Aubert et al., Phys.Rev.Lett.33 1404-1406,1974</i>	$J$	--- 1303
<i>J.E. Augustin et al., Phys.Rev.Lett.33:1406-1408,1974</i>	$\psi$	--- 1223
<i>CDF, F. Abe et al., Phys.Rev.Lett.74:2626-2631,1995</i>	$t$	--- 1182
<i>EMC, J. Ashman et al., Phys.Lett.B206 364,1988</i>		--- 1180
<i>EMC, J. Ashman et al., Nucl.Phys.B328 1,1989</i>		--- 1025
<i>UA1, G. Arnison et al., Phys.Lett.B122:103-116,1983</i>	$W$	--- 903
<i>UA1, G. Arnison et al., Phys.Lett.B126:398-410,1983</i>	$Z$	--- 845

**SPIRES-HEP database**

<http://www.slac.stanford.edu/library/topcites/2003/alltime.shtml>

# Flavor tagging in DIS

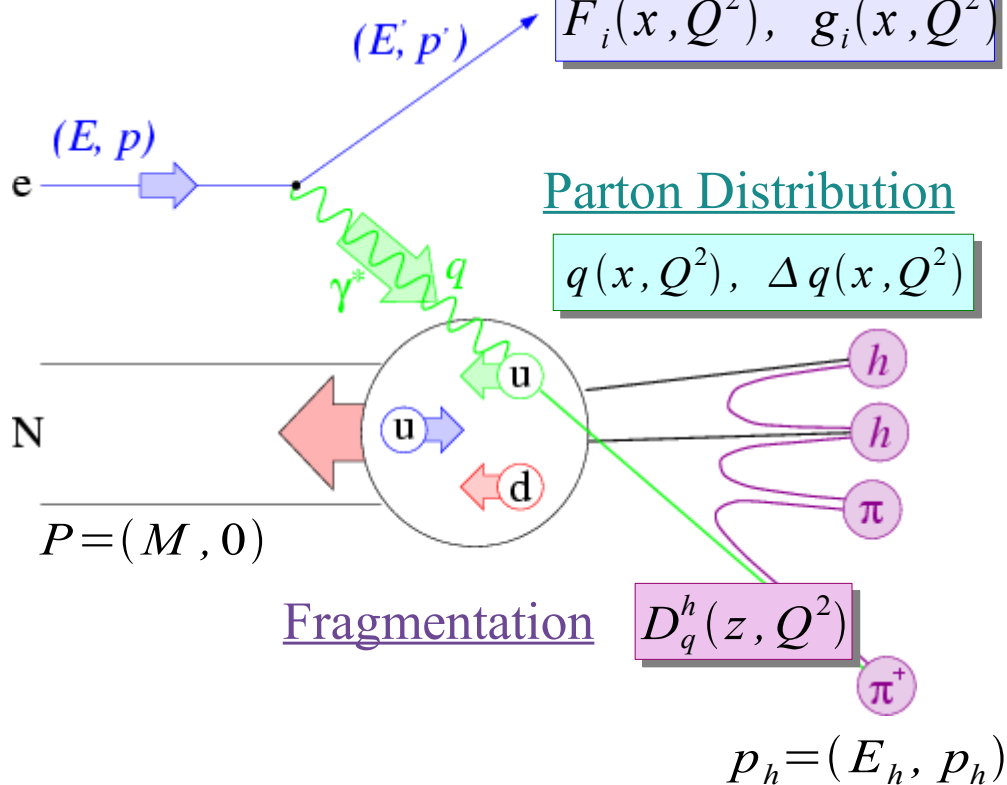
$$\vec{l} + \vec{N} \rightarrow l' + h + X$$

Structure Function

$$F_i(x, Q^2), \quad g_i(x, Q^2)$$

Parton Distribution

$$q(x, Q^2), \quad \Delta q(x, Q^2)$$



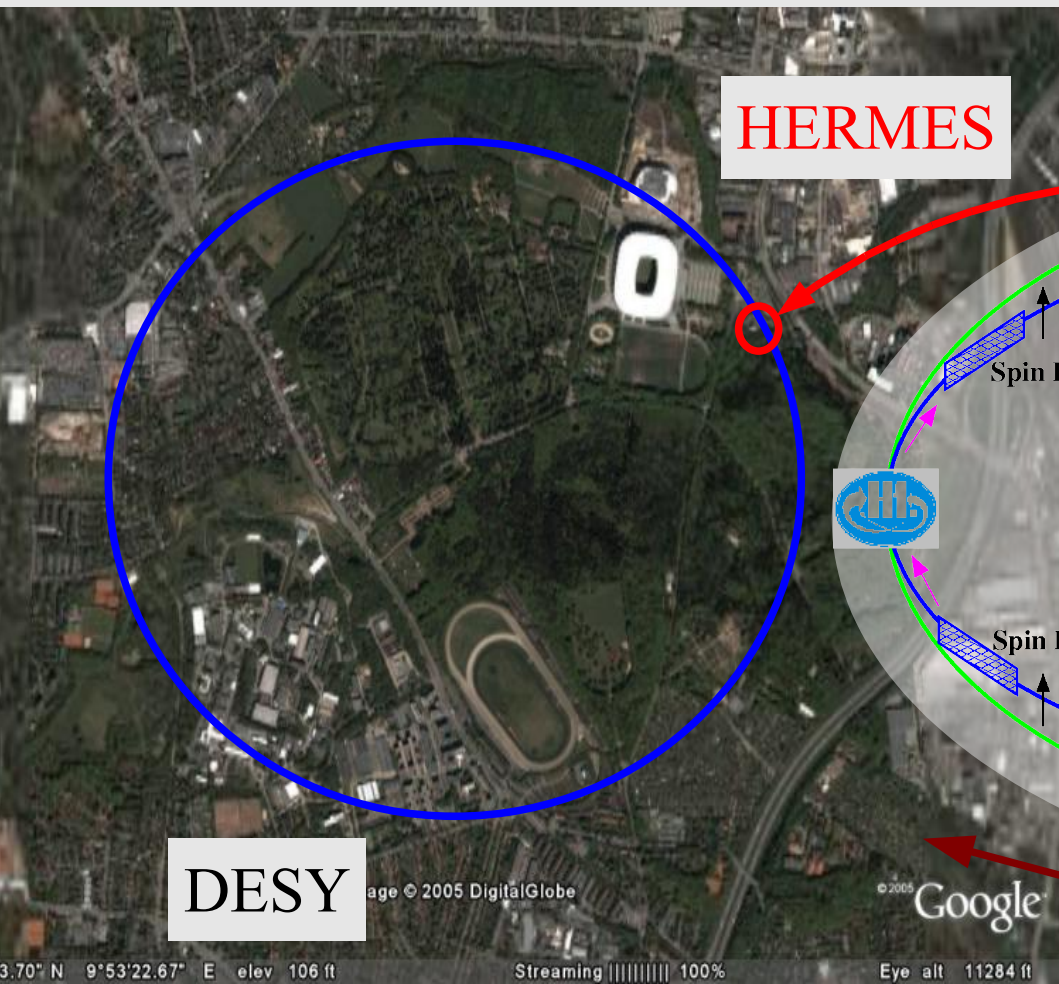
$$\frac{d^3 \Delta \sigma^h}{dx dz dQ^2} \propto \sum_i e_q^2 \Delta q(x, Q^2) D_q^h(z, Q^2)$$

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

Flavor Tagging:

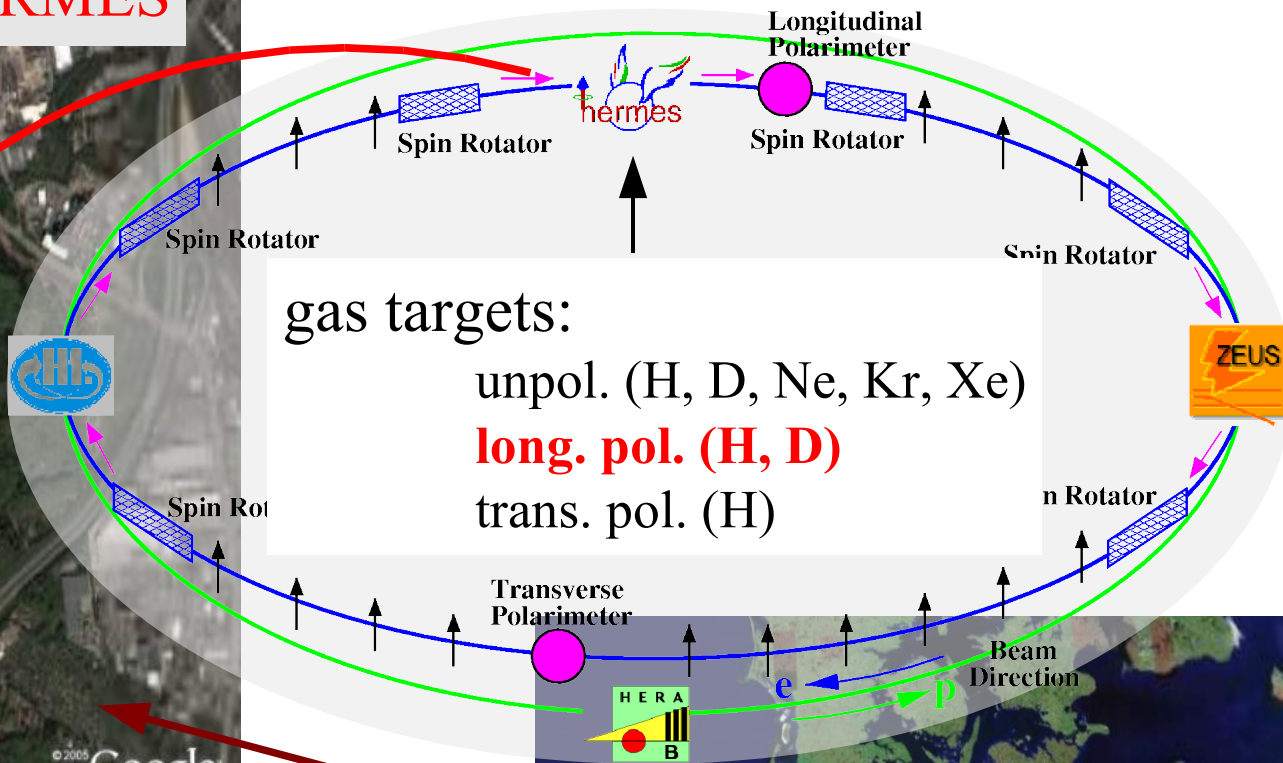
Hadron carries information on  
quark flavor  
through fragmentation function

# HERMES at DESY



HERMES

DESY



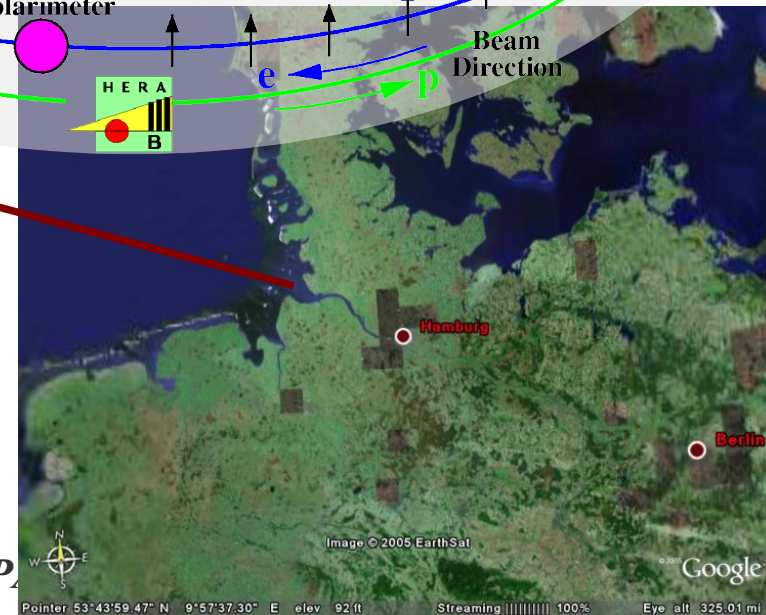
HERA:

**pol. electron/positron @ 27.5GeV**

polarization about 55%

December 1<sup>st</sup>, 2005, KEK

Workshop on Hadron Structure at J-PARC



# Strangeness spin inside proton

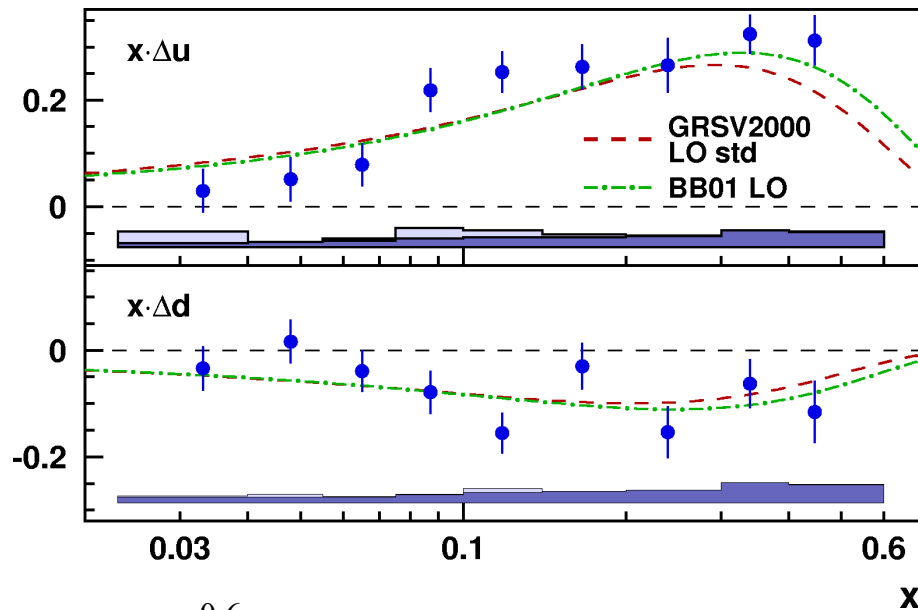


$$\vec{e} + \vec{N} \rightarrow e' + h + X$$

- HERMES results -

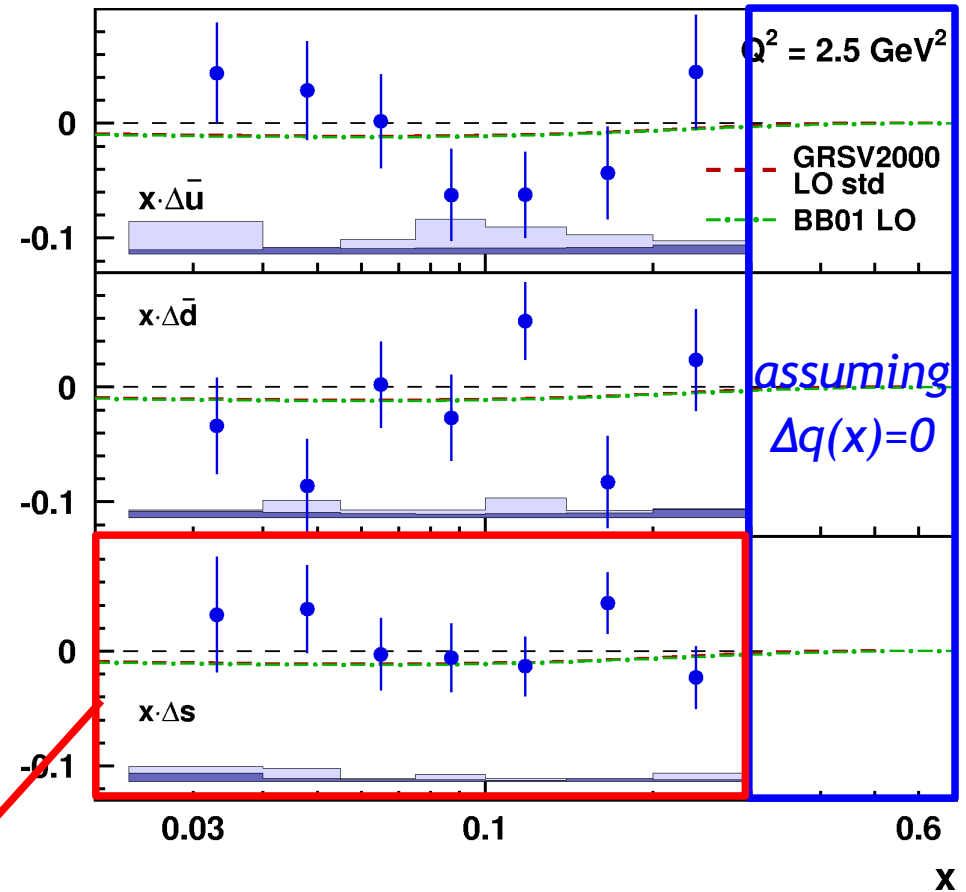
$\Delta \bar{s}(x) = 0$  assumed

*Phys. Rev D 71 (2005) 012003*



$$\Delta q = \int_{0.023}^{0.6} dx \Delta q(x) \quad Q^2 = 2.5 \text{ GeV}^2$$

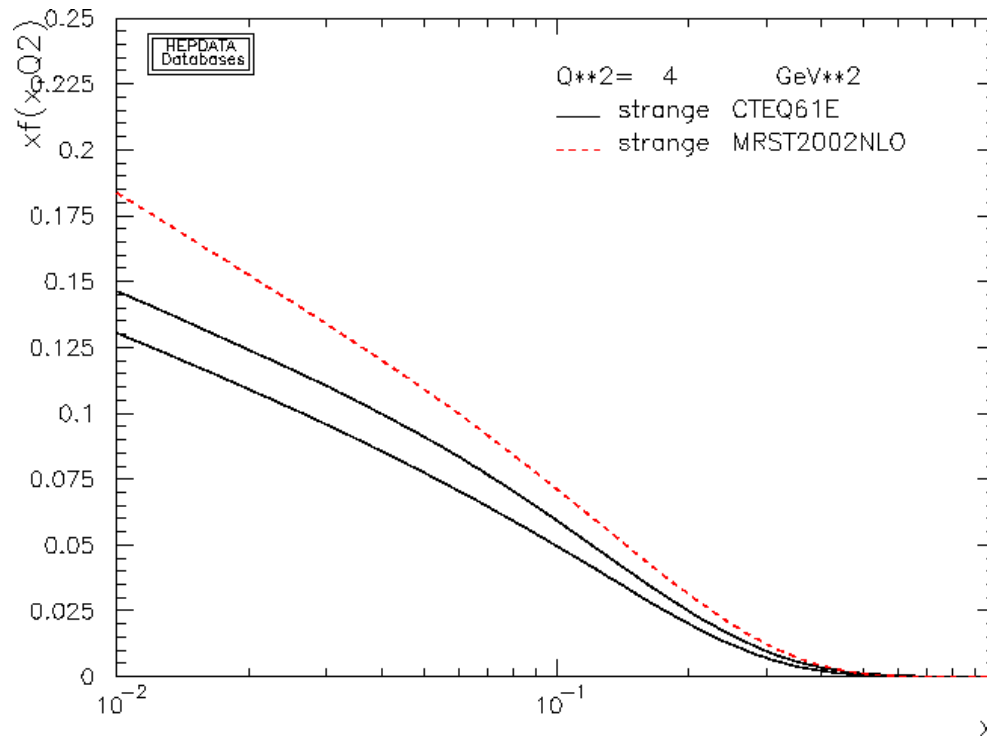
$$\begin{aligned} \Delta u &= 0.601 \pm 0.039 \pm 0.049 \\ \Delta d &= -.226 \pm 0.039 \pm 0.050 \\ \Delta \bar{u} &= -.002 \pm 0.036 \pm 0.023 \\ \Delta \bar{d} &= -.054 \pm 0.033 \pm 0.011 \\ \Delta s &= 0.028 \pm 0.033 \pm 0.009 \end{aligned}$$



Iso-scalar method also gave  $\Delta s(x) = 0$

# Strangeness outside the coverage

<http://durpdg.dur.ac.uk/hepdata/pdf3.html>



CTEQ5:

$$\int_{10^{-5}}^1 dx s(x) \sim 2$$

$$\int_{0.023}^{0.6} dx s(x) \sim 0.15$$

$$Q^2 = 2.5 \text{ GeV}^2$$

$$\int_{0.023}^{0.6} dx \Delta s(x) \sim 0 \quad \xrightarrow{\quad ? \quad} \quad \int_0^1 dx \Delta s(x) = ?$$

# Other impacts of $\Delta s$ measurements

- **Neutron EDM** (J. Ellis and R. A. Flores *PLB*377 (1996) 83)
  - n-EDM predicted using q-EDM and  $\Delta q$
  - $d_n \propto m_u \Delta u + m_d \Delta d + m_s \Delta s$
- **Dark Matter** (J. Ellis and M. Karliner hep-ph/9601280)
  - Better determination of Dark-Matter reaction

$$\sigma \propto \frac{4}{9} \Delta u + \frac{1}{9} (\Delta d + \Delta s) \quad \text{photino}$$

$$\sigma \propto \frac{17}{36} \Delta u + \frac{5}{36} (\Delta d + \Delta s) \quad \text{pure U(1) gaugino}$$

# Neutrino-Nucleon Scattering

**Measurement of strange spin inside nucleon**

via Neutral Current Elastic Scattering



# $\nu$ -Nucleon (Quesi)-Elastic Scattering

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

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

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

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

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

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

NC-EL/CC-QE

Neutral Current

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

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

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



# Neutrino scattering and $\Delta s$

- E734 results -

- **Neutral current cross section  $\rightarrow$  strange axial form factor**

- Liquid scintillator + Drift Tube 170 t
- 0.5E19 POT for neutrino
- 2.5E19 POT for anti-neutrino

- **From  $G_A^s(Q^2)$  to  $\Delta s$**

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

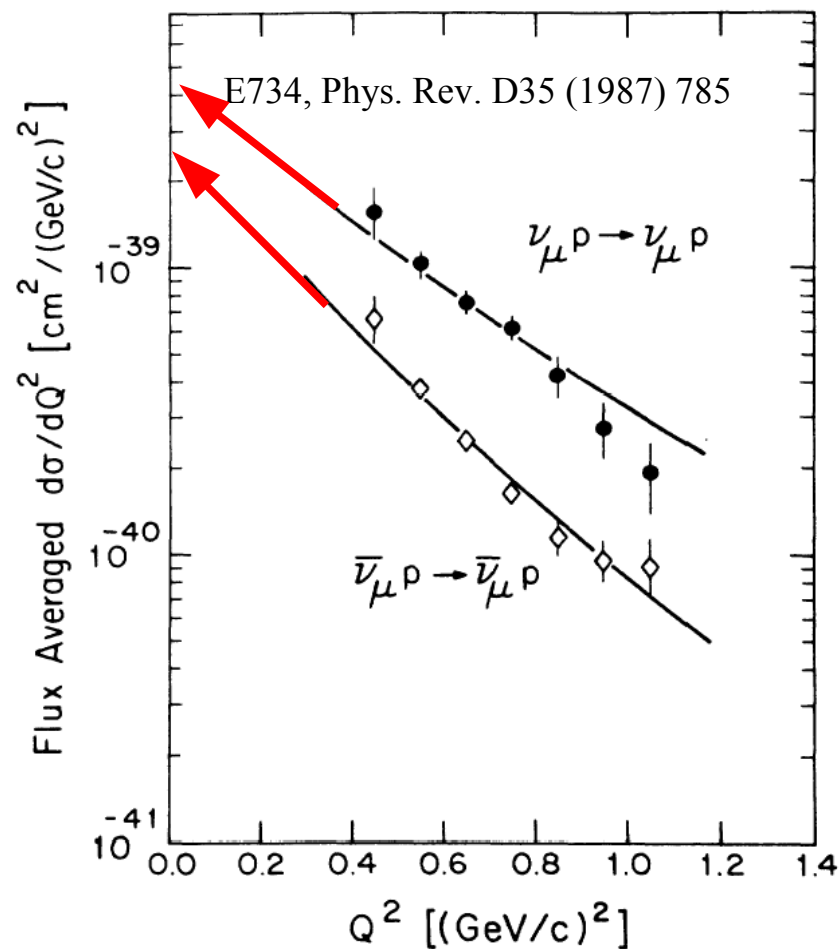
- **Further analysis: (Alberico et al.)**

$$R_{NC/CC}^\nu = 0.152 \pm 0.007 \pm 0.017$$

$$R_{NC/CC}^{\bar{\nu}} = 0.218 \pm 0.012 \pm 0.023 \quad 0.5 < Q^2 < 1.0 \text{ GeV}^2$$

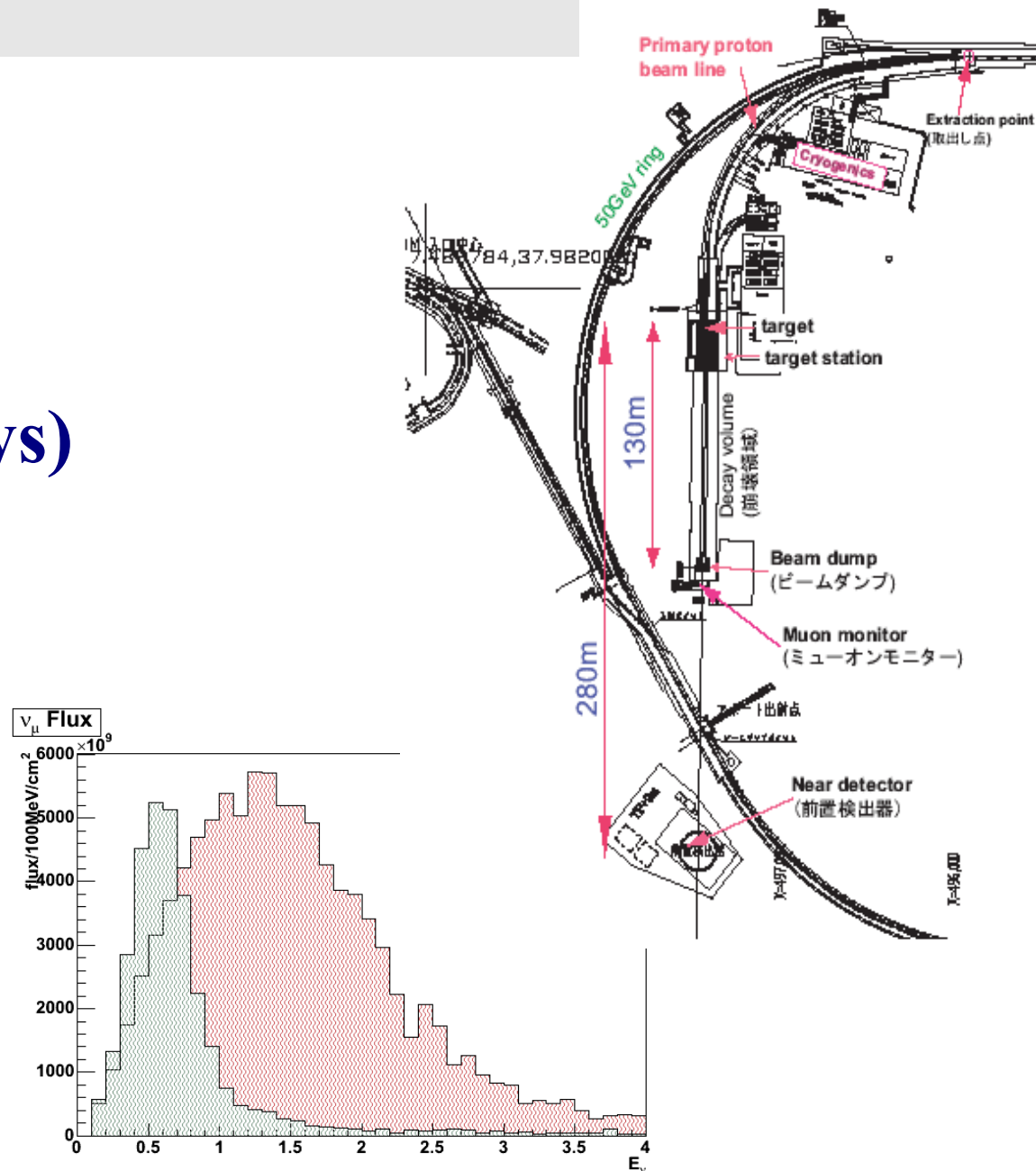
$$R_{NC}^{\nu/\bar{\nu}} = 0.302 \pm 0.019 \pm 0.037$$

$$-0.21 < \Delta s < 0 \quad \text{strong correlation with the axial mass } M_A$$

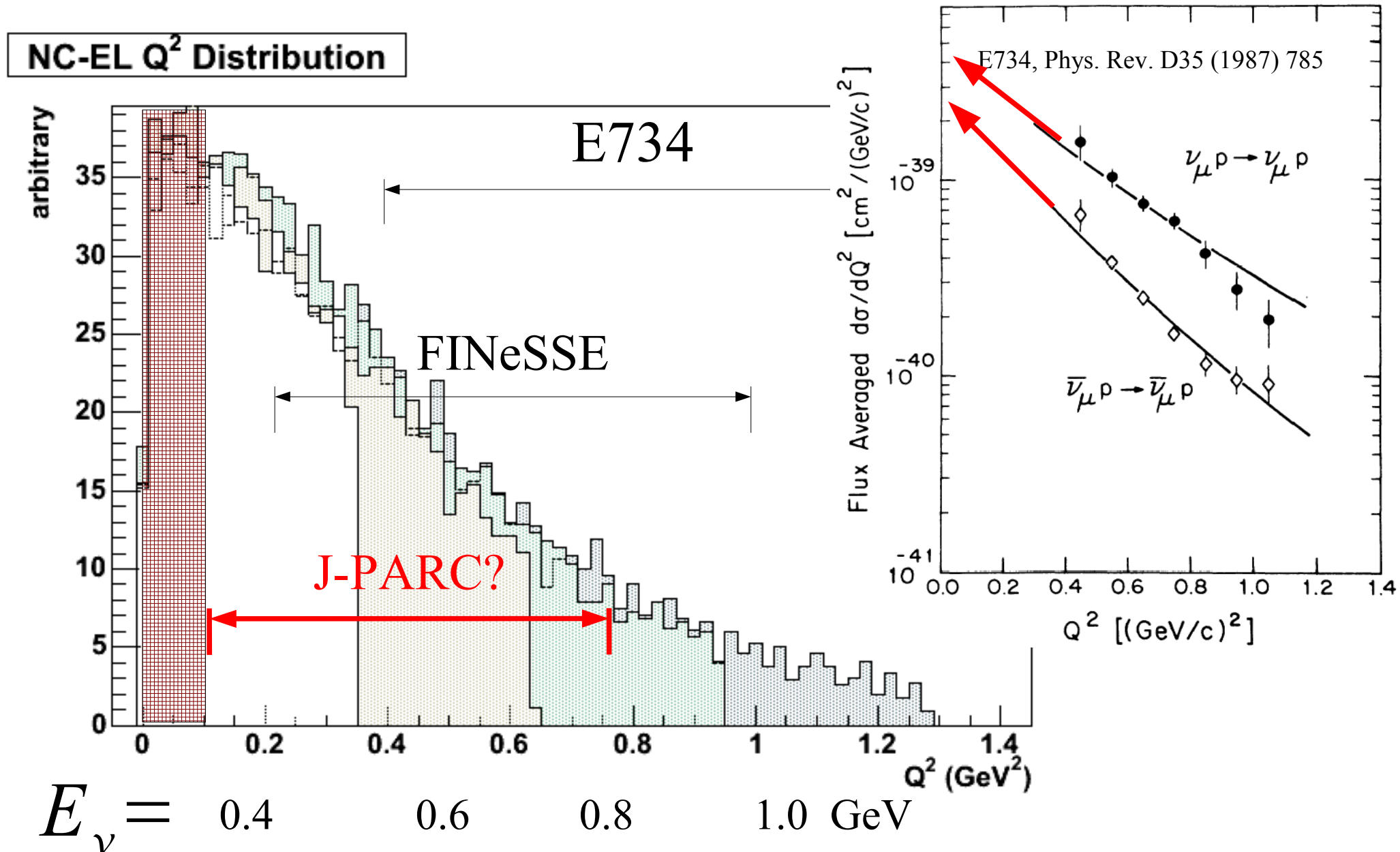


# J-PARC $\nu$ -beam line

- **Beam flux**
  - 1 GeV for “on-axis”
  - 0.8 GeV for “off-axis”
- **$10^{21}$  POT/year (130 days)**
  - 30 times BNL-E734
- **anti-neutrino beam**
  - neutrino anti-neutrino asymmetry measurement



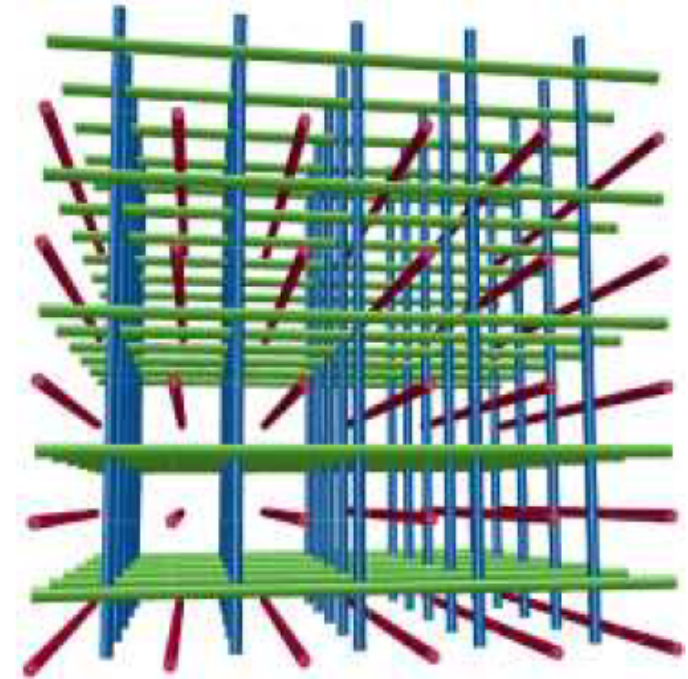
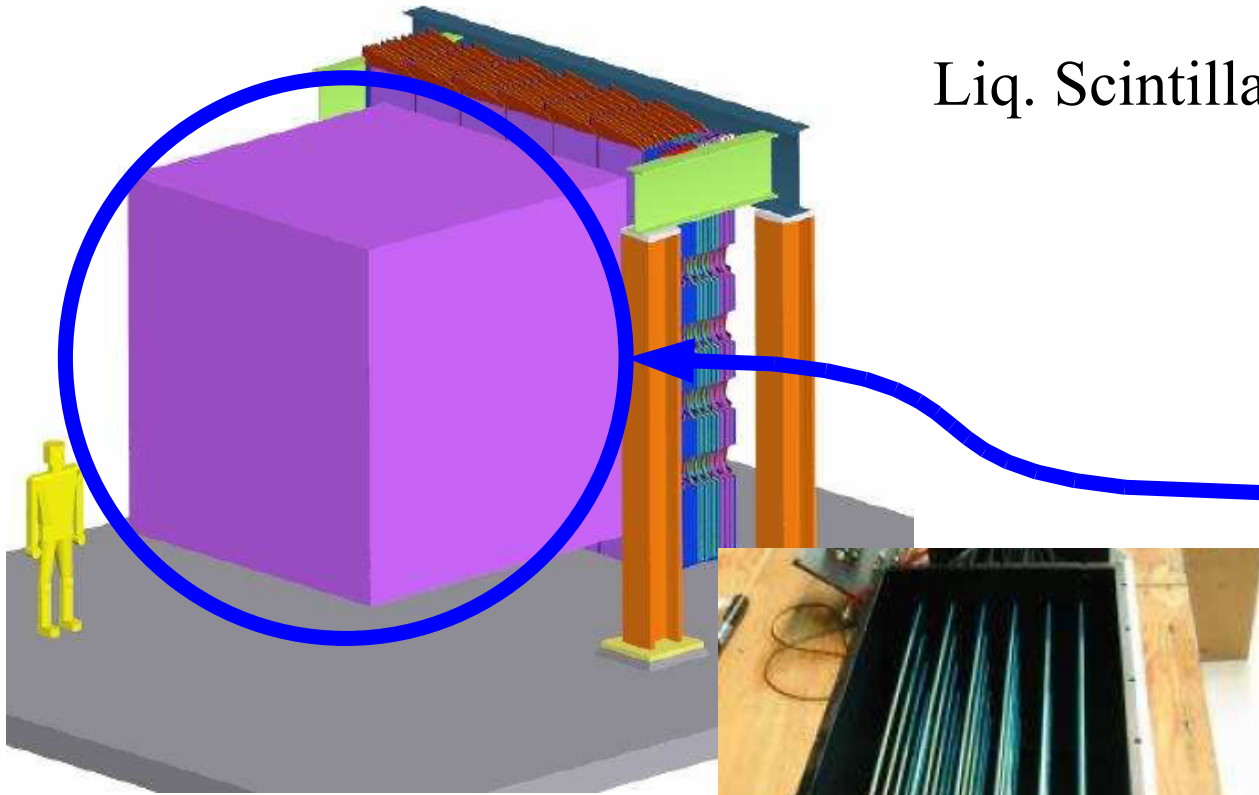
# Neutrino elastic scattering cross section



# FINeSSE

## Fermilab Intense Neutrino Scattering Scintillator Experiment

Liq. Scintillator readout with WS fibers



FINeSSE detector  
Prototype

Proposal: Fermilab  
LOI: BNL

→ *S. Pate's talk*

# Experiment at J-PARC

- **Off-axis beam line: peak energy  $< 1.0 \text{ GeV}^2$**
- **Liquid scintillator with different H/C mixture**
  - FINE SSE type detector
  - e.g. Bicron BC510A (H/C=1.212) and BC-533 (H/C=1.96)
    - Pure Carbon can be extracted for nA Xsection
  - e.g.  $5 \times 5 \times 5 \text{ m}^3 \sim 125 \text{ t}$
  - Recoil proton with  $T_p = 40 \text{ MeV}$ :  $Q^2 \sim 0.1 \text{ GeV}^2$ 
    - **High pressure hydrogen TPC dedicated for low  $Q^2$  measurements?**
- **$1\text{E}21$  POT possible in one year (130 days)**
  - 30 times BNL-E734



# Sensitivity at J-PARC

- Similar Detection Efficiency to E734:
  - 7.6% for neutrino-N elastic, 5.4% for anti-neutrino-N elastic
- However with lower  $Q^2$  cut-off : 0.1 GeV<sup>2</sup>
  - Achievable with more uniform detector
    - Hydrogen TPC was not included in this estimation.
- 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

$$\delta(\Delta s) = 0.08 \quad (\text{E734})$$

$$\delta(\Delta s) = 0.03 \quad (\text{J-PARC})$$

# Summary

- **Strangeness in the nucleon**
  - has been studied with various probes
    - $\pi$ -N  $\Sigma$ -term, OZI violation, Deep Inelastic Scattering, ...
  - Proton spin problem
    - Relates strange spin inside nucleon: positive? negative? zero?
- **Neutrino scattering**
  - Unique tool for studying strange spin inside nucleon
    - nucleon axial form factor measurement
  - Key points: nuclear effects,  $Q^2$  extrapolation to  $Q^2=0$
  - Measurement at J-PARC
    - $\delta(\Delta s) \sim 0.03$  expected (E734:  $\delta(\Delta s) \sim 0.08$ )