RCNP研究会「J-PARCハドロン実験施設のビームライン整備拡充に向けて」
11月12日＠RCNP

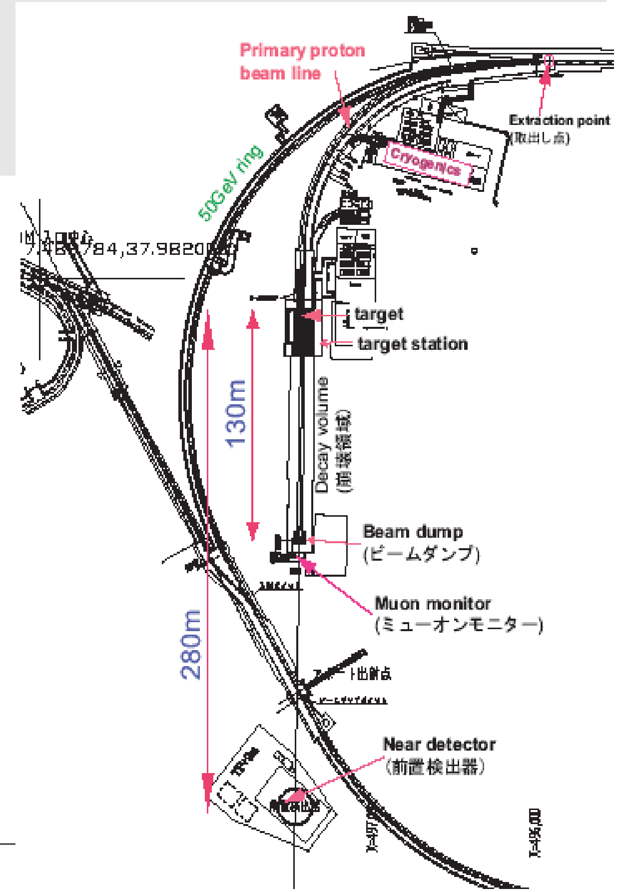
# ニュートリノ・原子核散乱による 陽子内ストレンジクォークスピンΔsの測定

*Yoshiyuki Miyachi, Tokyo Tech*

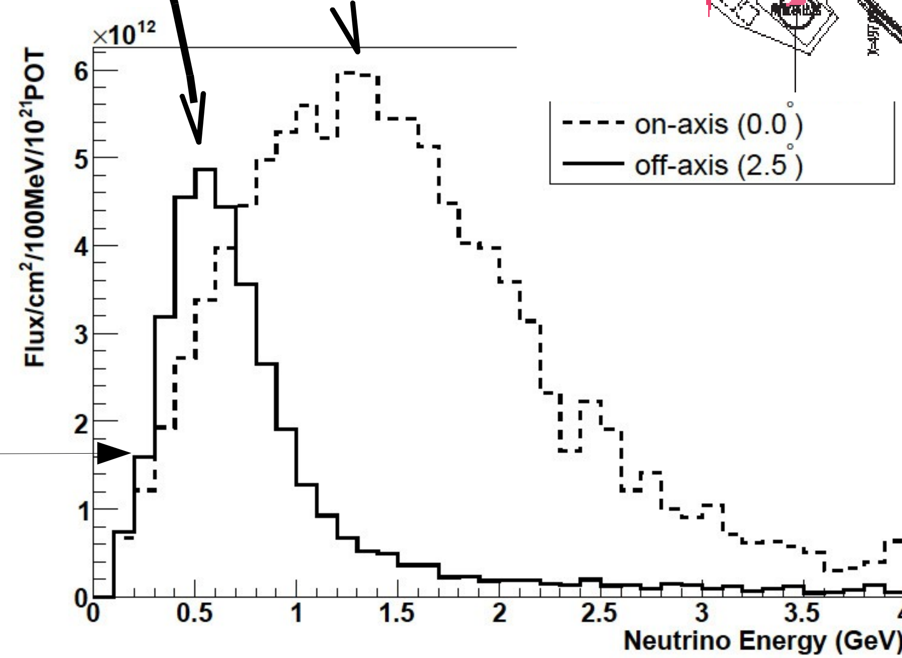
- Proton Spin Problem and Δs
  - SU(3) flavor symmetry
  - Nucleon Form Factors
- Neutrino Scattering and Δs
  - E734, FINeSSE, SciBooNE
  - Experiment at J-PARC
- Summary

# J-PARC ν-beam line

- **Beam flux**
  - 1 GeV for "on-axis"
  - < 1GeV for "off-axis"
- **$10^{21}$ POT/year (130 days)**
- **anti-neutrino beam**
  - neutrino anti-neutrino asymmetry measurement

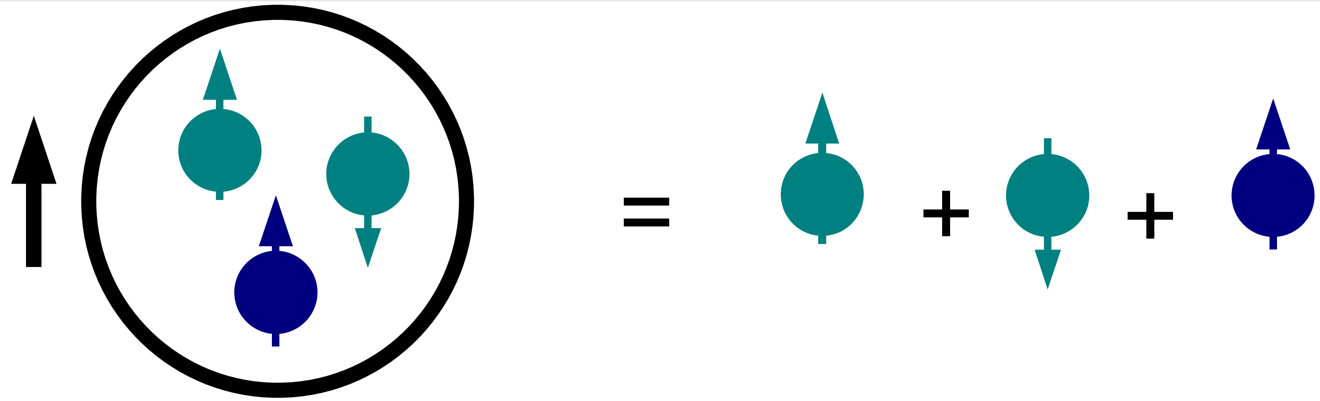



Expected ν flux (MC data)



# Proton spin

**Proton spin:**



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

**The most naive case:**

$$\Delta\Sigma=1$$

**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:
$a_3=1.26$,
$a_8=0.58$

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

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

# Proton spin problem and Δs

## - EMC results -

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

## Polarized DIS:

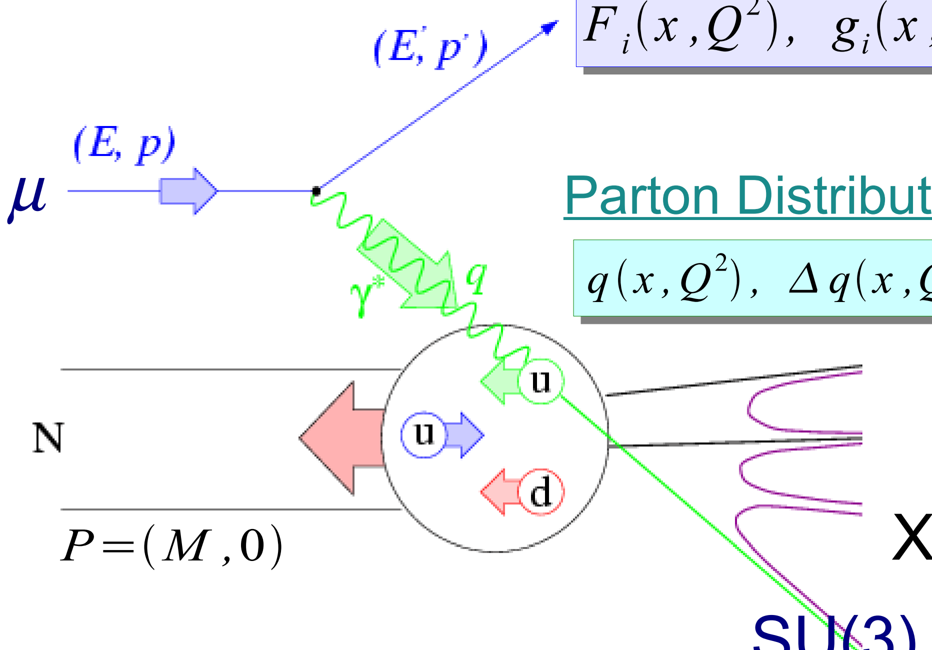
$$\vec{\mu} + \vec{N} \rightarrow \mu' + X$$

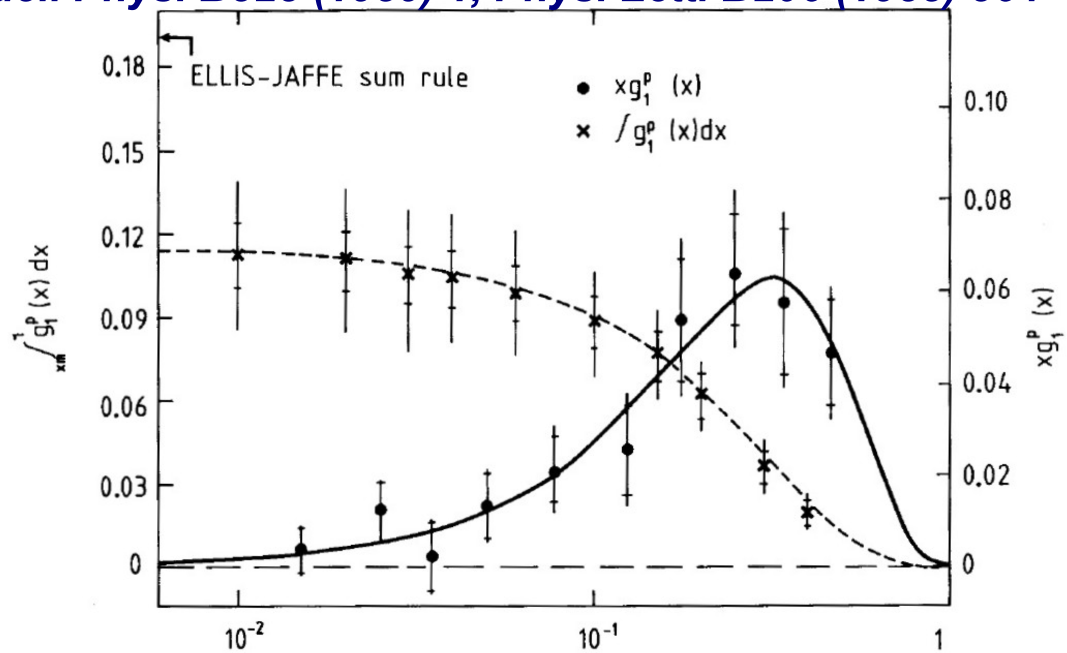
Structure Function

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

Parton Distribution

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




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

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

SU(3) flavor symmetry

$$a_3 = 1.26, \; a_8 = 0.58$$

$$a_0 = \Delta u + \Delta d + \Delta s = 0.12 \longrightarrow \Delta s = -0.19$$

# Updated results on $g_1$ and $\Delta s$

*Phys. Rev. D 75 (2007) 012007*

$$\int_{0.021}^{0.9} g_1^d(x, 5\,\mathrm{GeV}^2)\,dx =$$
$$0.0436 \pm 0.0012 \pm 0.018 \pm 0.0008 \pm 0.0026$$

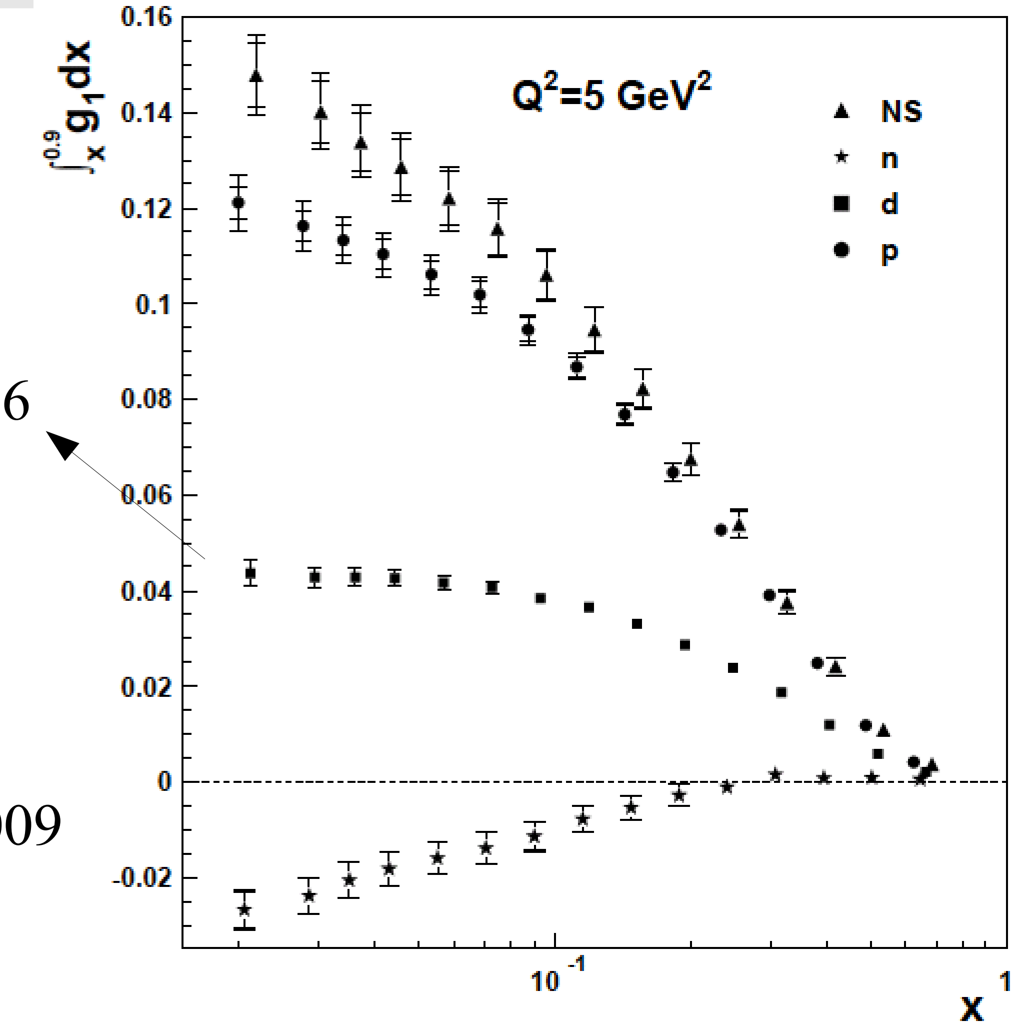
Assumption:

" High $x$ contribution = 0

" Saturation in the lower $x$ region

" SU(3) flavor symmetry:

$$\Delta s(5\,\mathrm{GeV}^2) = -0.085 \pm 0.013 \pm 0.008 \pm 0.009$$




*Phys. Lett. B 647 (2007) 8*:

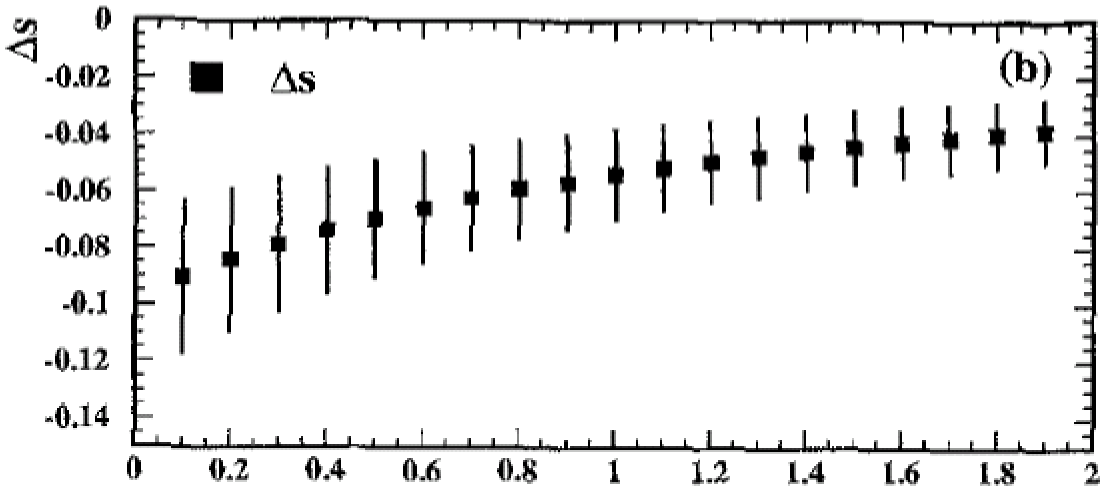
Assuming SU(3) flavor symmetry

$$\Delta s(\infty) = -0.08 \pm 0.01 \pm 0.02$$

# SU(3) violation and impact on Δs

$$\Delta s = 3\Gamma_1^p - \frac{3}{2}D\left(F/_D + \frac{1}{9}\right)$$

J. Lichtenstadt and H. J. Lipkin, Phys. Lett. B353 (1995) 119




SU(3): symmetry ↔ violation

E. Leader et. al., Phys. Lett. B488 (2000) 283

| $a_8$ | $-(\Delta s + \Delta\bar{s})$ |
|---|---|
| 0.40 | $0.02 \pm 0.01$ |
| 3F − D | $0.06 \pm 0.01$ |
| 0.86 | $0.15 \pm 0.02$ |

χQM calculation:

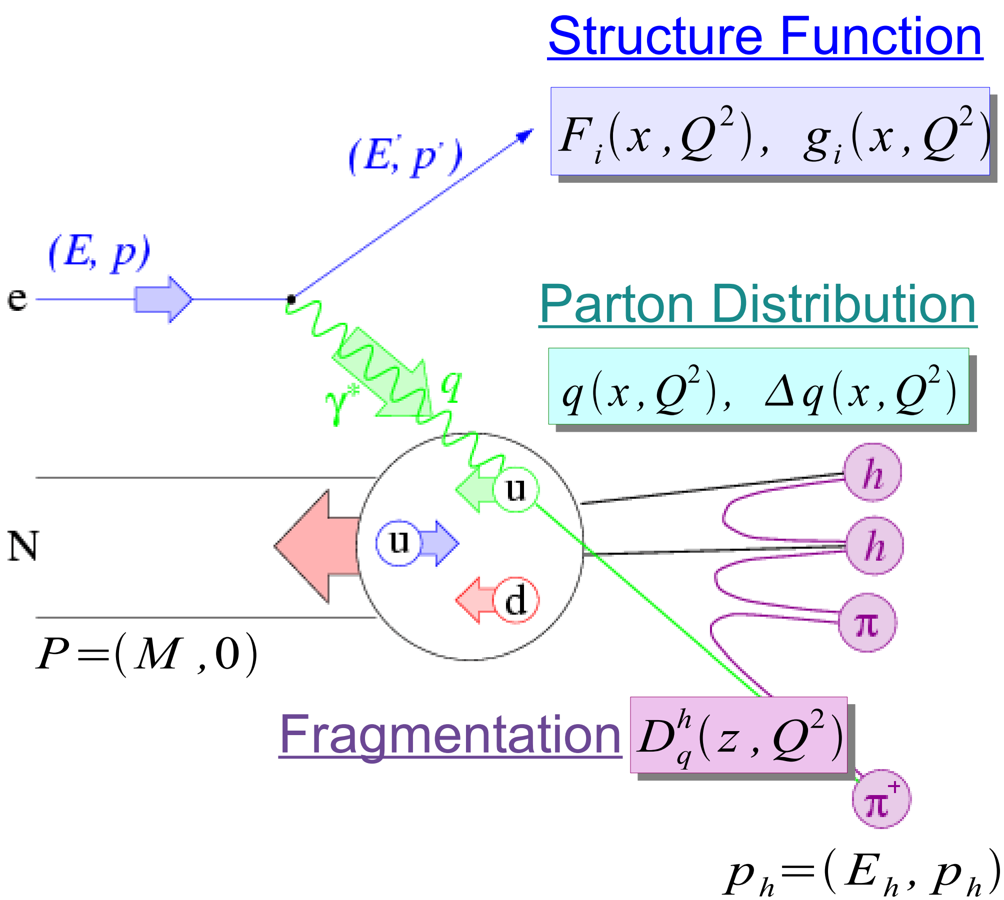
(X. Song et. al, Phys. Rev. D55 (1997) 2624-2629)

SU(3) symmetry: Δs = -0.1

SU(3) breaking: Δs = -0.05

# Flavor tagging in DIS

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




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

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

Flavor Tagging:

Hadron carries information on
quark flavor
through fragmentation function

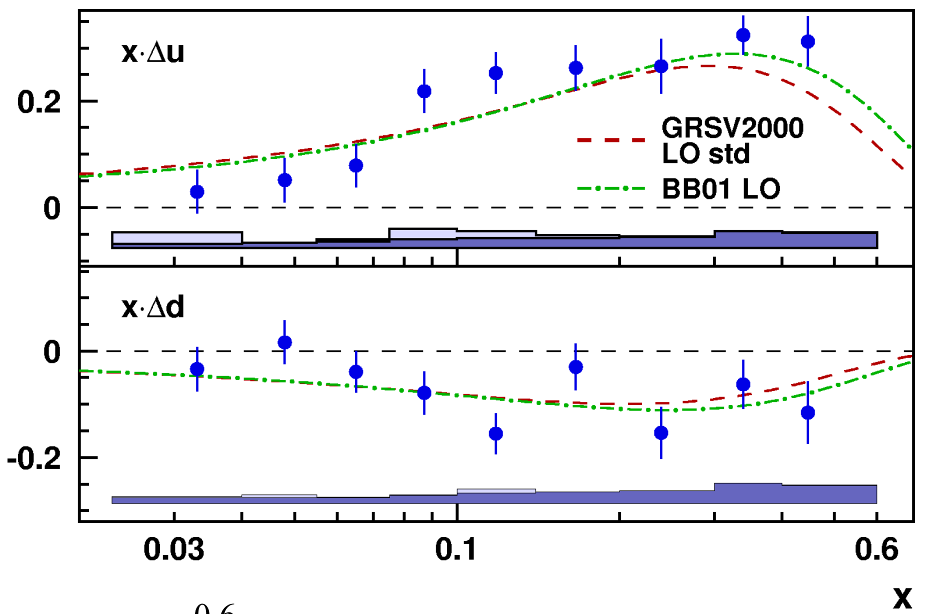
# Strangeness spin inside proton

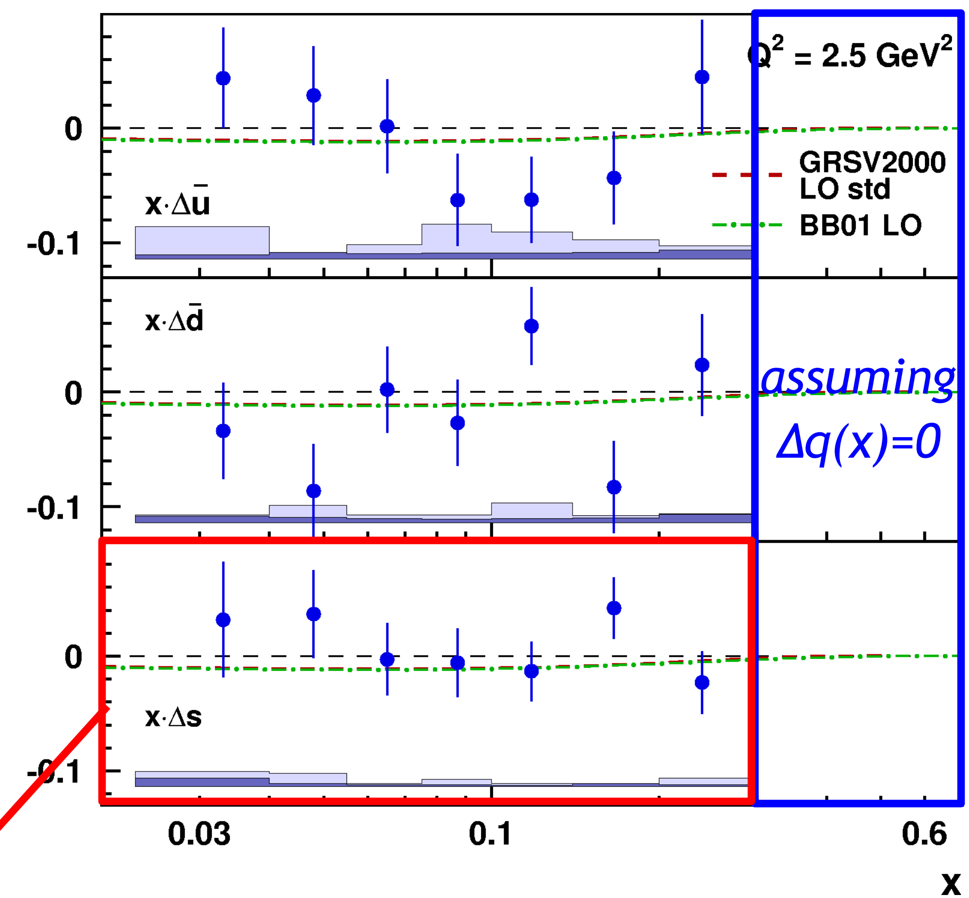
$\vec{e}+\vec{N}\rightarrow e'+h+X$

## - HERMES results -

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

*Phys. Rev D 71 (2005) 012003*




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

$$\Delta u=0.601\pm0.039\pm0.049$$

$$\Delta d=-.226\pm0.039\pm0.050$$

$$\Delta\bar{u}=-.002\pm0.036\pm0.023$$

$$\Delta\bar{d}=-.054\pm0.033\pm0.011$$

$$\Delta s=0.028\pm0.033\pm0.009$$

- without SU(3) symmetry assumption
- only partial moments are available
- “LO” extraction

# Neutrino-Nucleon scattering

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

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

$$A=\frac{1}{4}\left[G_1^2(1+\tau)-\left(F_1^2-\tau F_2^2\right)(1-\tau)+4\tau F_1F_2\right]$$

$$\tau=\frac{Q^2}{4\mathrm{m}_p^2}$$

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

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

NC-EL/CC-QE

## Neutral Current

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

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

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

# Neutrino scattering and $\Delta$s

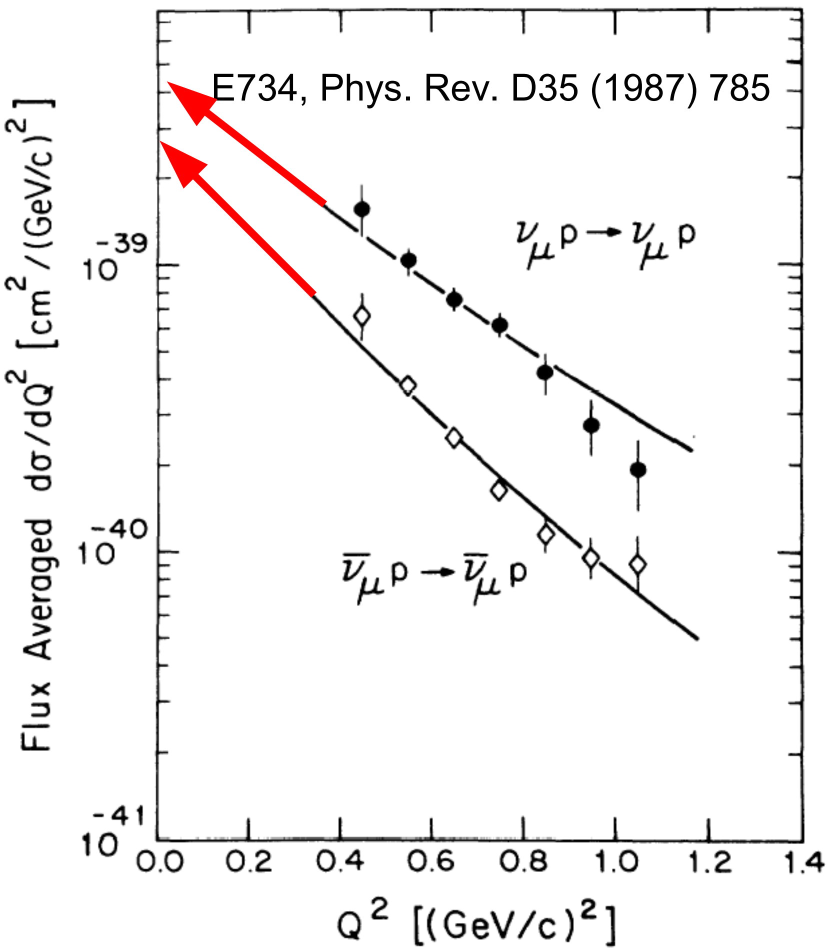
## - E734 results -

- **Neutral current elastic scattering cross section**
  - Liquid scintillator + Drift Tube 170 t
  - 0.5E19 POT for neutrino
  - 2.5E19 POT for anti-neutrino
- **From $G_A^s(Q^2)$ to $\Delta s$**
  - $G_A^s(Q^2 \to 0) = \Delta s = -0.21 \pm 0.10$
- **Further analysis based on E734**

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

$$R^{\bar{\nu}}_{NC/CC} = 0.218 \pm 0.012 \pm 0.023$$

$$R^{\nu/\bar{\nu}}_{NC} = 0.302 \pm 0.019 \pm 0.037 \qquad 0.5 < Q^2 < 1.0\ GeV^2$$



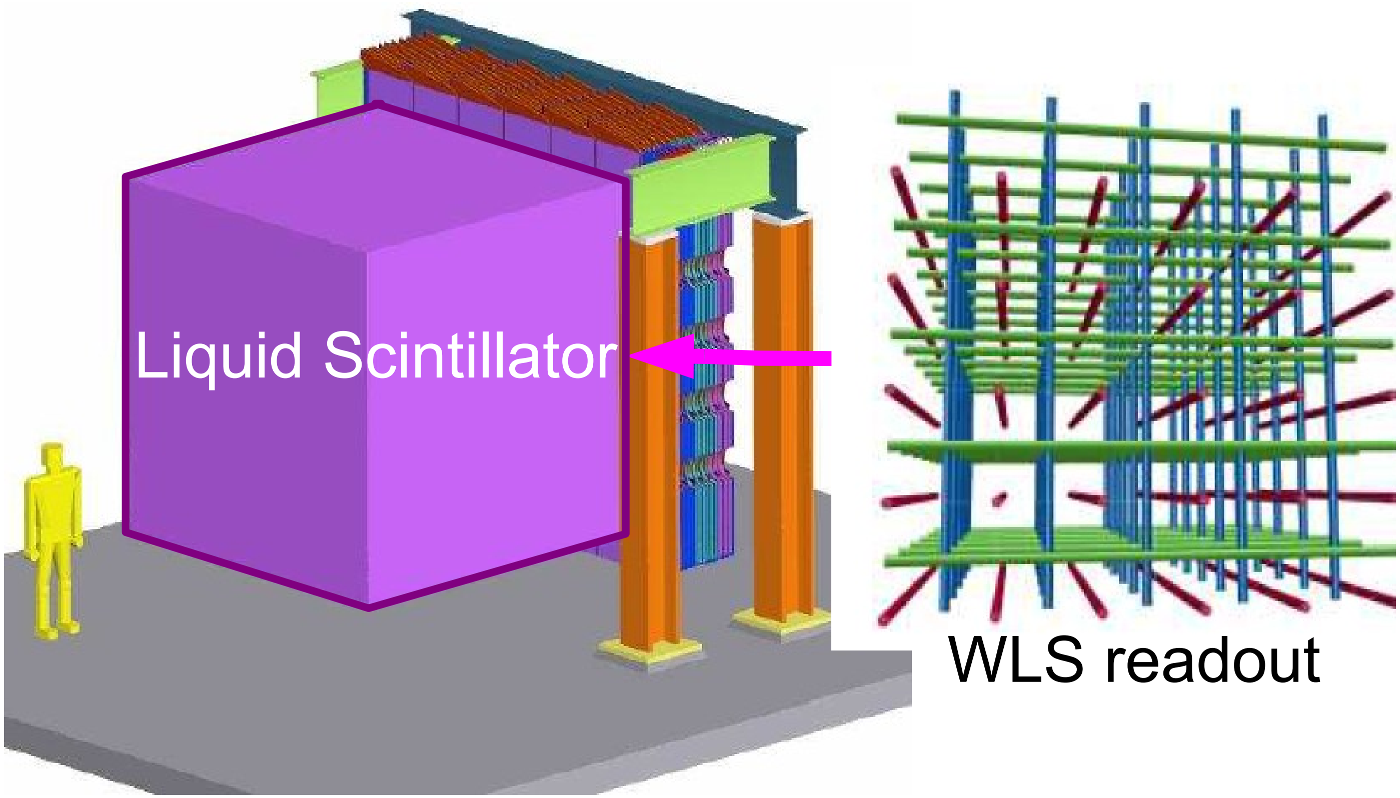

-0.21 < $\Delta$s < 0

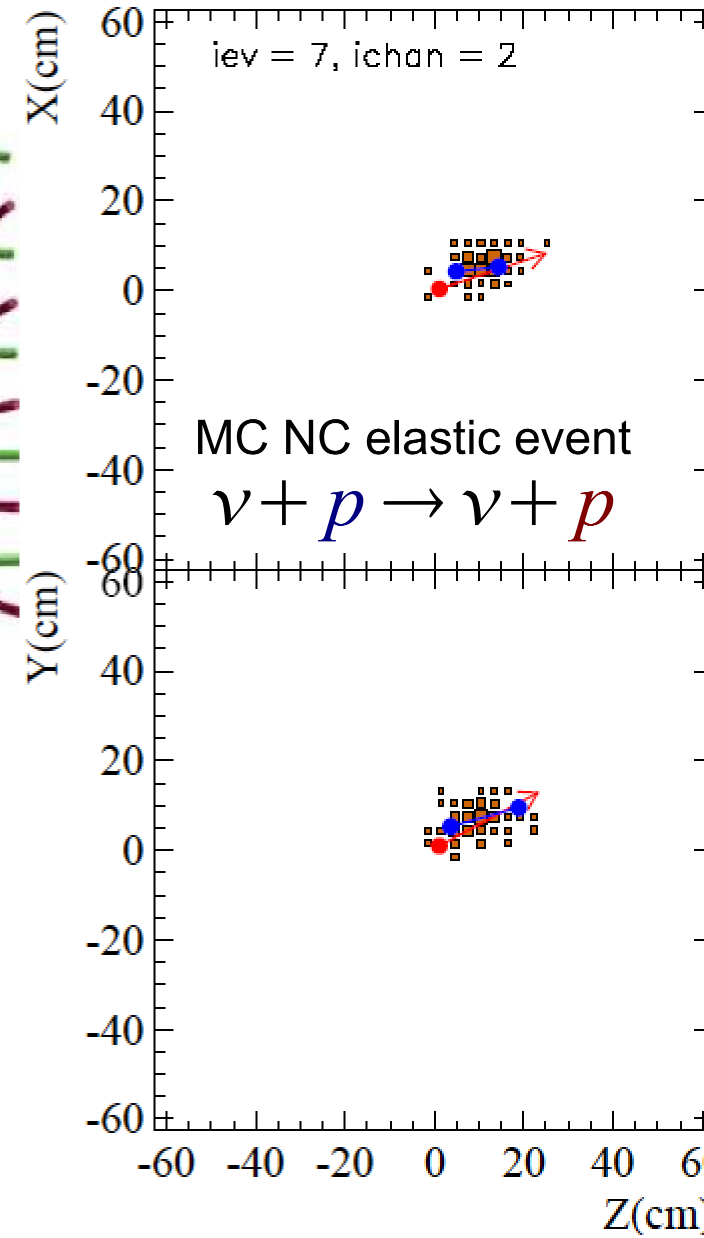
strong correlation with the axial mass $M_A$

$Q^2$ dependence of $G_s^A$

# FINeSSE @ FNAL

*FINeSSE Proposal, hep-ex/0402007*



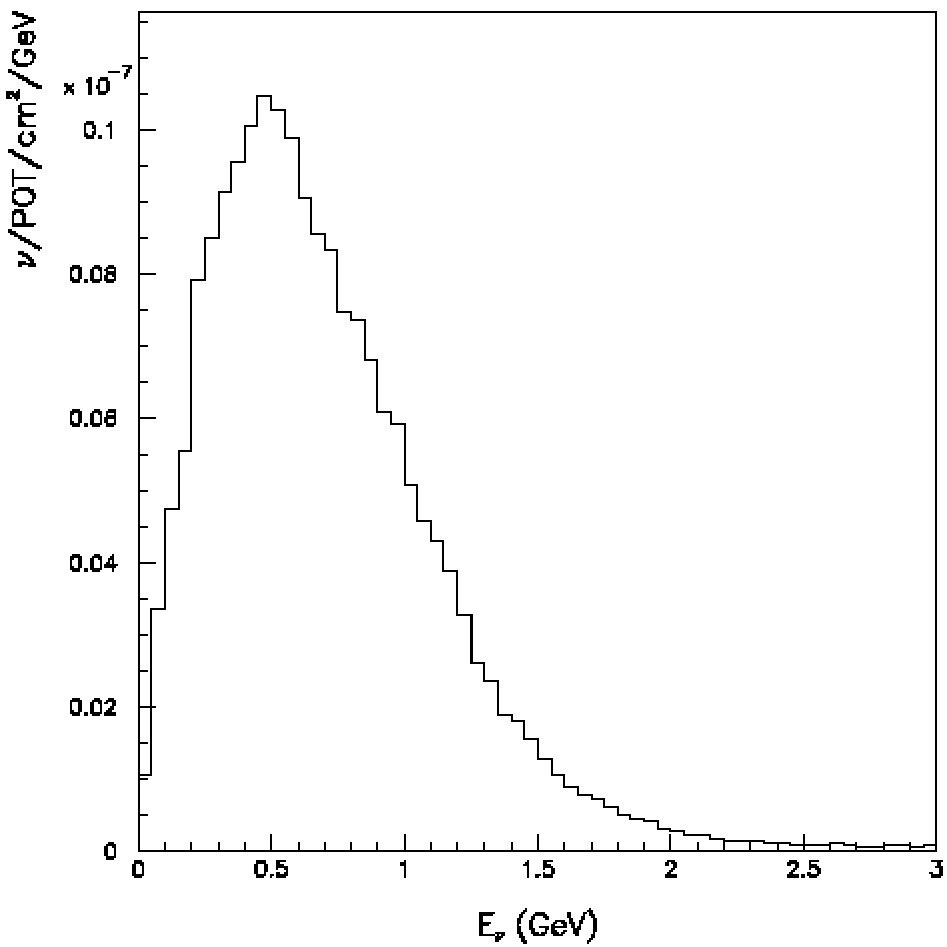




- Target: C in SciBath
- **R(NC/CC) measurement**
  cancellation of **flux** and **nuclear effect**

# FINeSSE @ FNAL

*FINeSSE Proposal, hep-ex/0402007*

FNAL booster neutrino beam-line



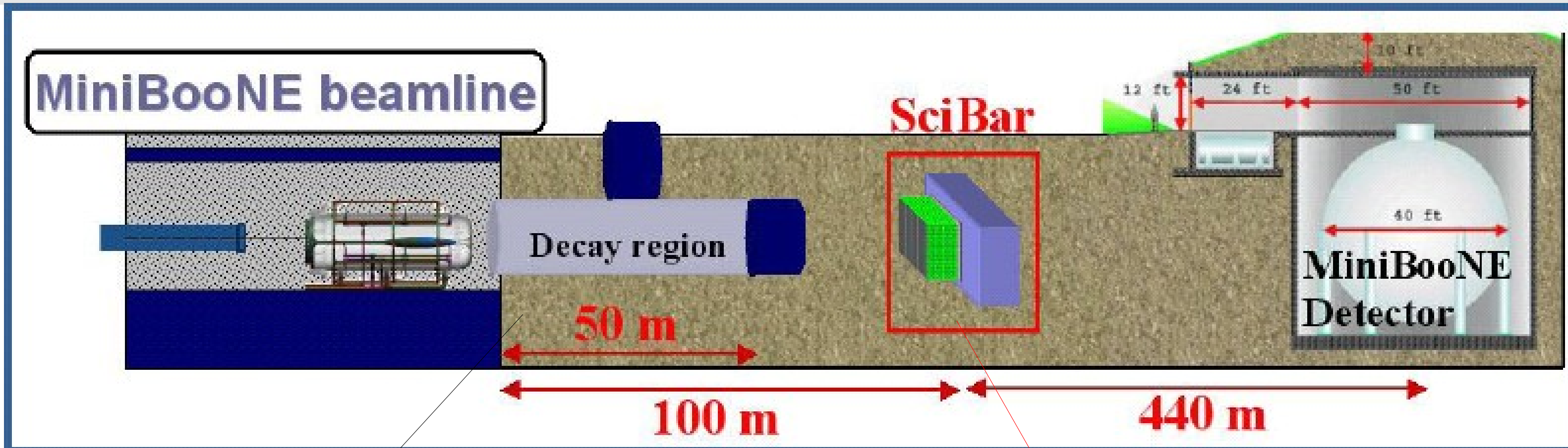

$\nu_\mu$ 6E20 POT

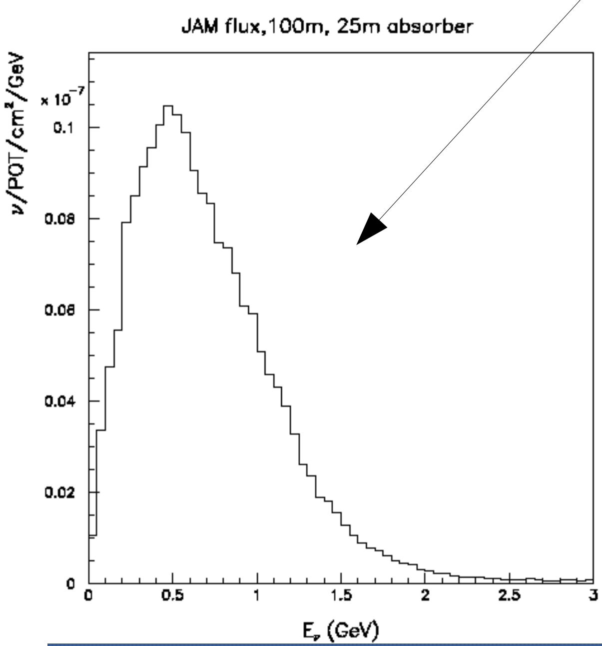
| $\nu$ Reaction | 9 ton |
|---|---|
| CC QE, $\nu_\mu n \to \mu^- p$ | 146,610 |
| NC EL, $\nu_\mu N \to \nu_\mu N$ | 59,184 |
| CC $\pi^+$, $\nu_\mu p \to \mu^- p \pi^+$ | 66,690 |
| CC $\pi^0$, $\nu_\mu n \to \mu^- p \pi^0$ | 13,932 |
| CC $\pi^+$, $\nu_\mu n \to \mu^- n \pi^+$ | 11,664 |
| NC $\pi^0$, $\nu_\mu p \to \nu_\mu p \pi^0$ | 11,394 |

| quantity, $Q$ | prefactor | relative error, $\Delta Q/Q$ | contribution to $\Delta R/R$ |
|---|---|---|---|
| $N_{\rm NC}$ | 1 | 1.2% | 1.2% |
| $N_{\rm CC}$ | 1 | 1.0% | 1.0% |
| $\mathcal{F} = \frac{N_{\rm NC}^{\rm free}}{N_{\rm NC}^{\rm C}}$ | 0.27 | 5% | 1.4% |
| $\frac{\epsilon_{\rm CC}}{\epsilon_{\rm NC}}$ | 1 | 3% | 3.0% |
| $\sum_i \epsilon_{{\rm NC},i} N_{{\rm NC},i}$ | 0.35 | 10% | 3.5% |
| $\sum_i \epsilon_{{\rm CC},i} N_{{\rm CC},i}$ | 0.29 | 10% | 2.9% |
| Total experimental error | | | 5.8% |

→ $\delta(\Delta s) = 0.04$ (sta. + sys.), (+ 0.025 from form factors)

# SciBooNE @ FNAL




- SciBooNE anticipates
  - ~1e20 POT ν
  - ~1e20 POT anti-ν

" SciBar/EC detector from K2K
" Muon Range Detector

Primary physics goal:
precise cross section measurements of non-QE ν-interaction, anti-ν interaction

Proposal approved Dec. 2005

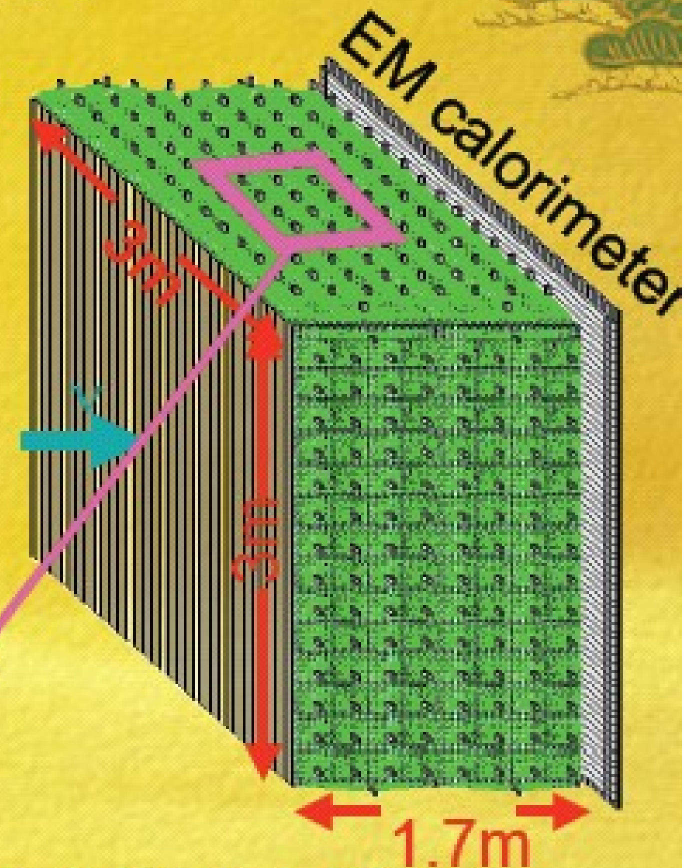
(NuFact06, H. Tanaka)

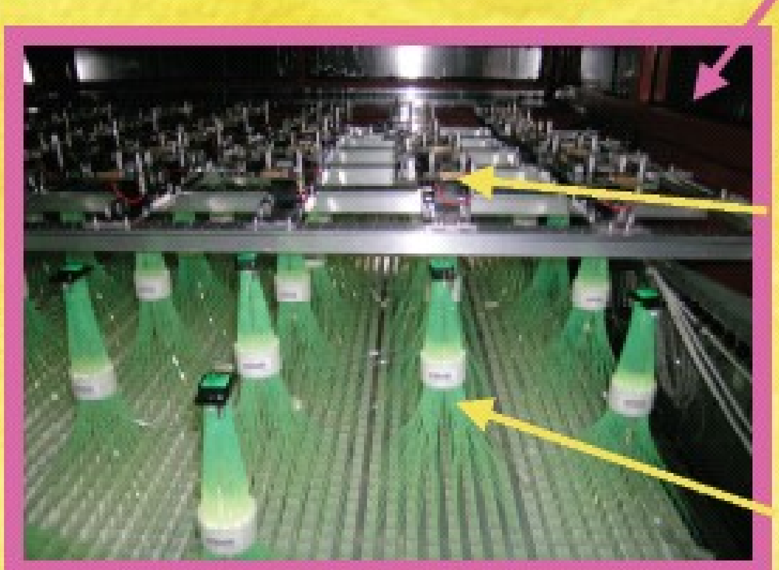
# SciBar Detector

- Extruded scintillators with WLS fiber readout
- Scintillators are the neutrino target
- 2.5 x 1.3 x 300 $cm^3$ cell
- ~15,000 channels
- Identify short tracks (>8cm)
- Distinguish a proton from a pion by dE/dx
- Total 15 tons

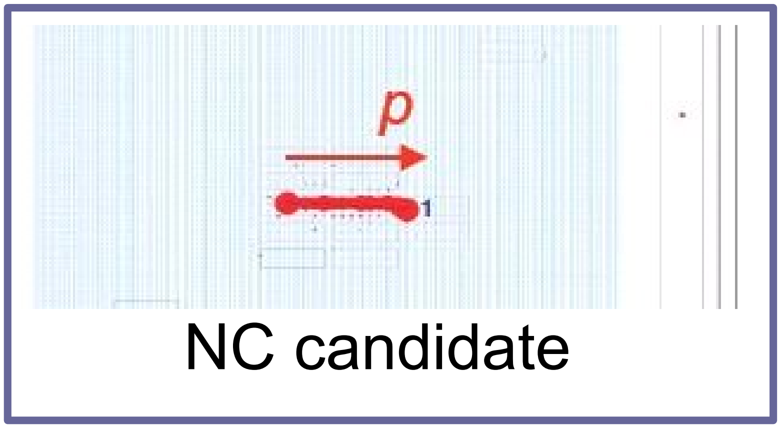
➔ High track finding efficiency (>99%)

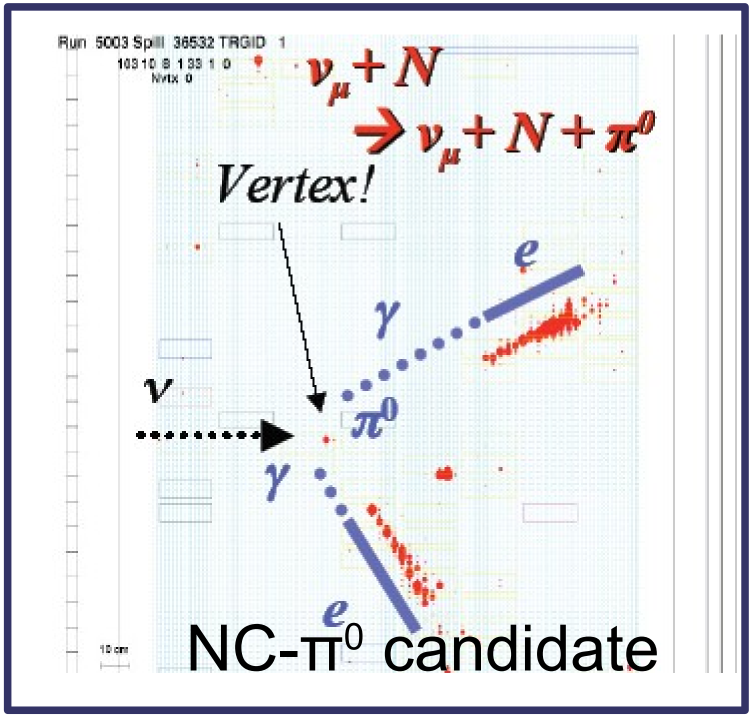
➔ Clear identification of ν interaction process



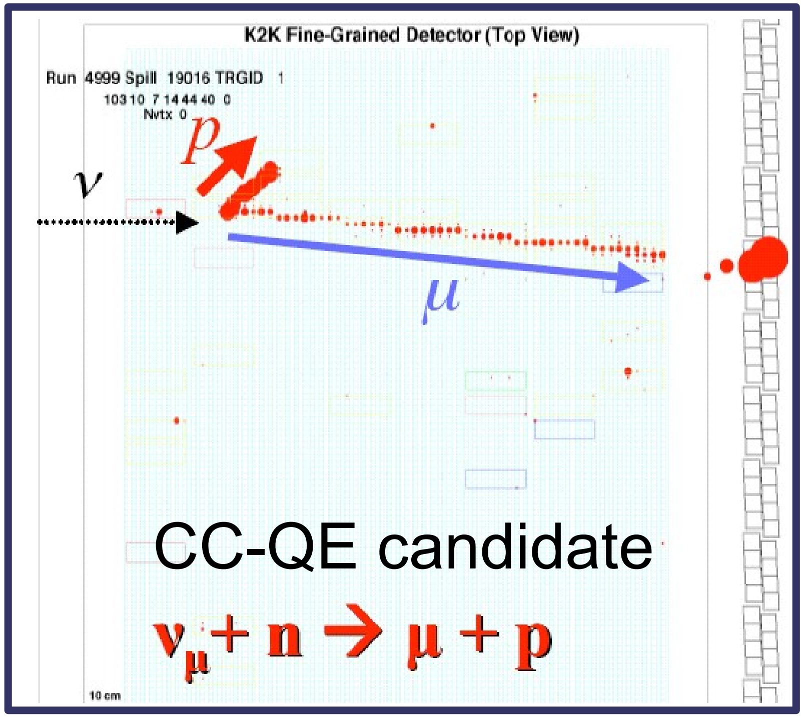
# SciBar Event Display with K2K data




$$R(NC/CC) = \frac{N^{\nu + p \rightarrow \nu + p}}{N^{\nu + n \rightarrow \mu + p}}$$

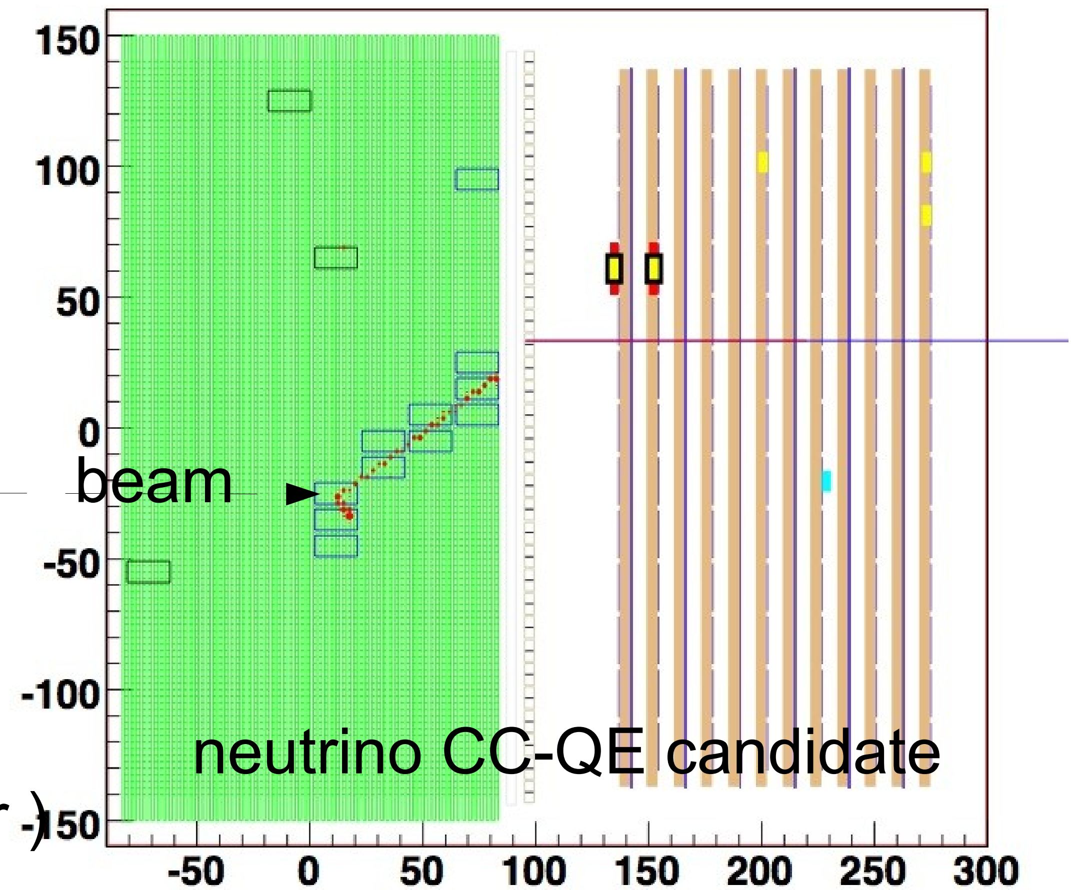
Neutron background should be carefully studies.



# SciBooNE: status and plan

- SciBar and EC were moved from KEK to FNAL (Jul. 2006)
- Civil construction started (Sep. 2006)
- Commissioning done (Apr. 2007)
- Physics RUN : ( May 2007 ~ )
  with anti-neutrinos ( ~ Aug. 2007 )
  3.4E19 POT ( ~ July 22nd)
- Detector live time: 96.5%
- Calibration of the detectors is on going.
- Physics RUN with neutrino started (Oct. ~ : 1 year, 1E20POT ν, ν-bar )
- R(NC/CC) study is planned.

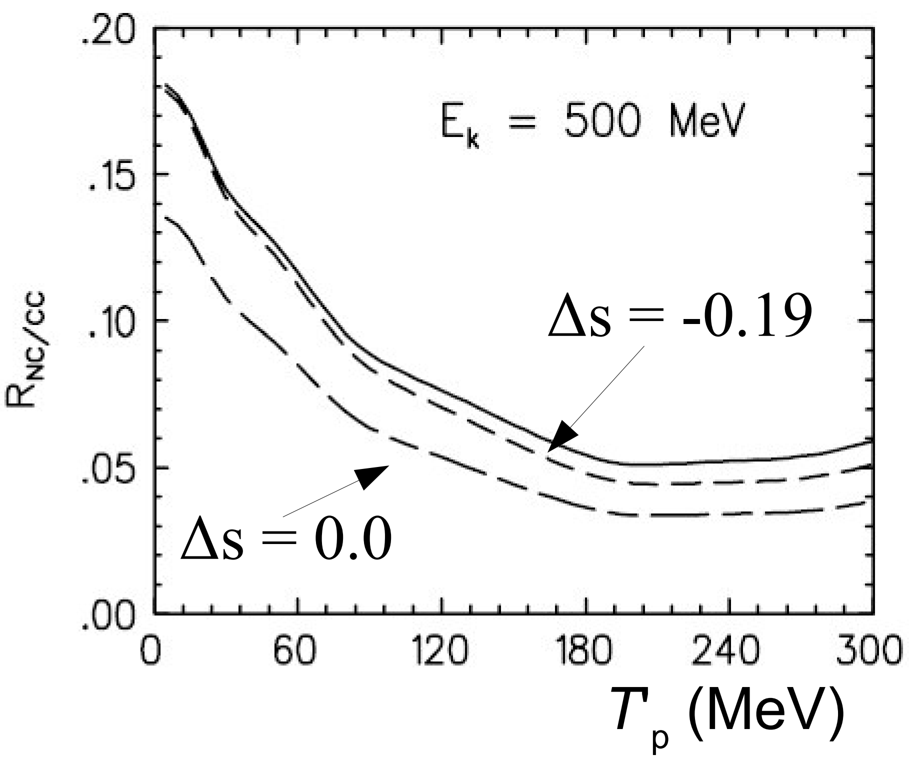
SciBooNE Event Display:
with anti-neutrino beam



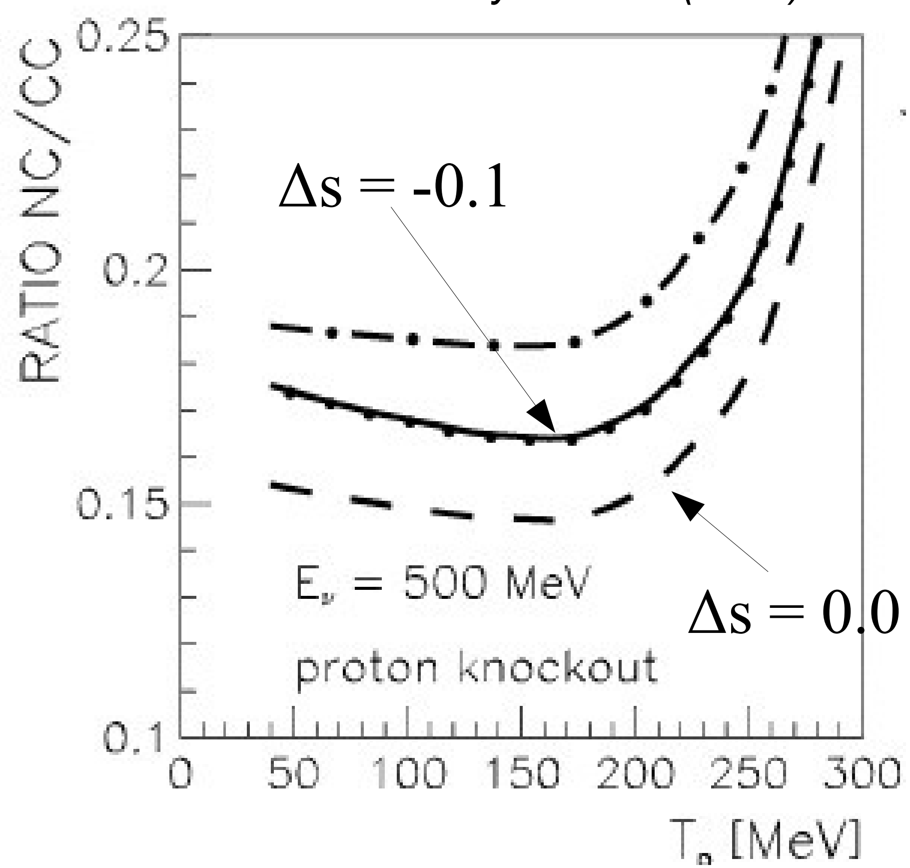

- One page "proposal" was submitted to FNAL on Δs measurement as extension of SciBooNE
http://www.fnal.gov/directorate/Longrange/Steering_Public/community_letters.html

# R(NC/CC) and Δs

*B. I. S. van der Ventel and J. Piekarewicz, Phys. Rev. C73 (2006) 025501*



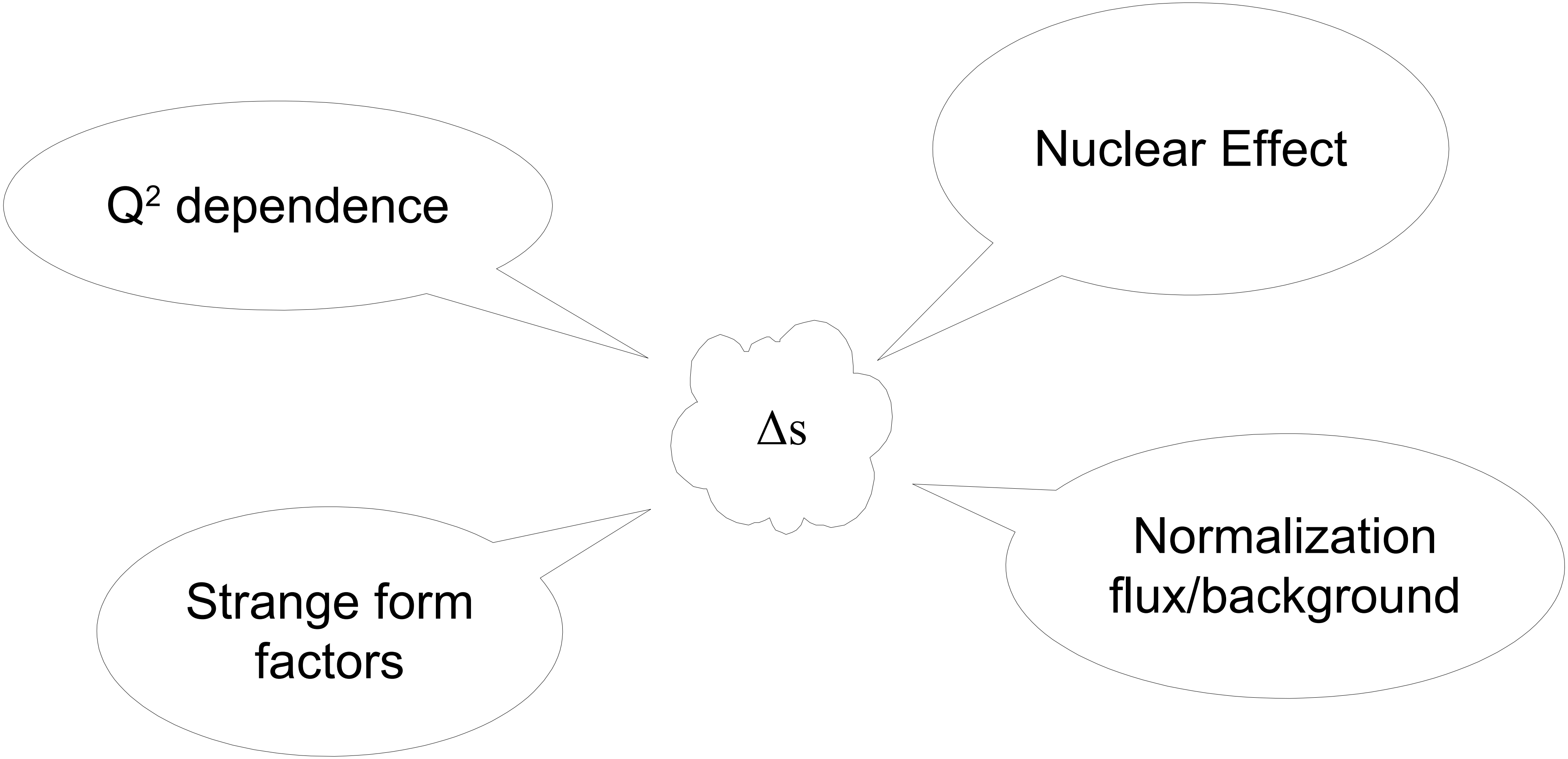

*A. Meucci et al., Nucl. Phys. A 773 (2006) 250*




a relativistic plane-wave impulse-approximation.

a relativistic distorted-wave impulse-approximation

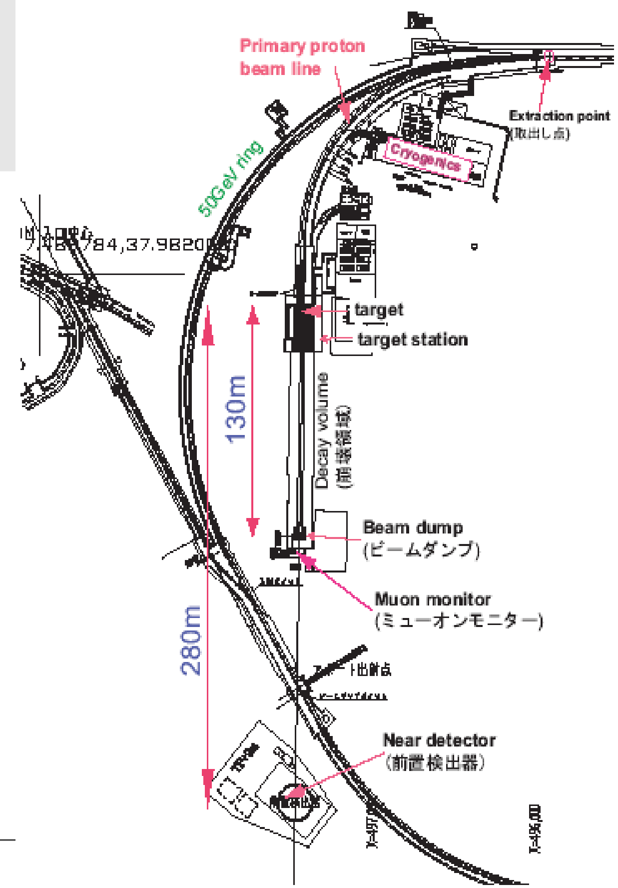
Both were calculated for $^{12}C$.



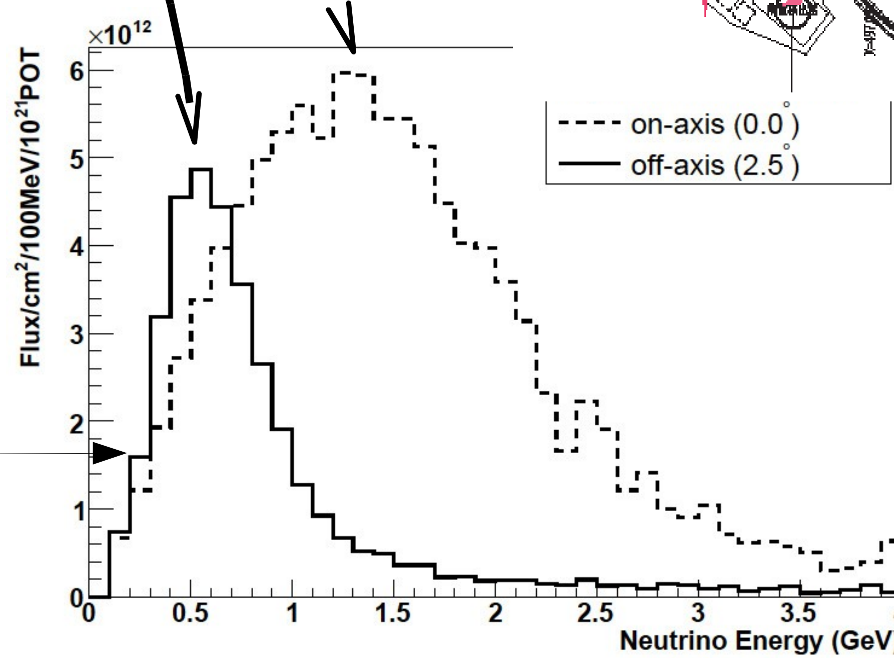

Accurate measurement of **NC ν-H** in $0.1 < Q^2 < 0.4$ GeV$^2$ which is covered by the electron scattering.

# J-PARC ν-beam line

- **Beam flux**
  - 1 GeV for "on-axis"
  - < 1GeV for "off-axis"
- **$10^{21}$ POT/year (130 days)**
- **anti-neutrino beam**
  - neutrino anti-neutrino asymmetry measurement




Expected ν flux (MC data)



# Methods of $\Delta s$ measurement

- **Nuclear effect (ex. C target):**
  - Nuclear model uncertainty on $\Delta s$ extraction
- **R(NC/CC) measurements:**
  - Neutrino flux should be canceled. It also suppresses the nuclear effect.
  - Is there any model dependence uncertainty?
- **ν-H scattering extraction:**
  - Using two targets with different mixture of H and C
    - Separation of ν-H and ν-C scattering becomes possible
  - Neutrino flux information is needed to extract the cross section.

# Extraction of $N_{NC}^{H}$

## Nuclear effect free extraction:

Using two liquid scintillators with different mixture of H and C:

| BICRON: | H/C | ρ(g/cm³) | $\rho^{H}$(g/cm³) | $\rho^{C}$(g/cm³) |
|---|---|---|---|---|
| BC501A | 1.212 | 0.874 | 0.112 | 0.688 |
| BC533 | 1.96 | 0.8 | 0.080 | 0.794 |

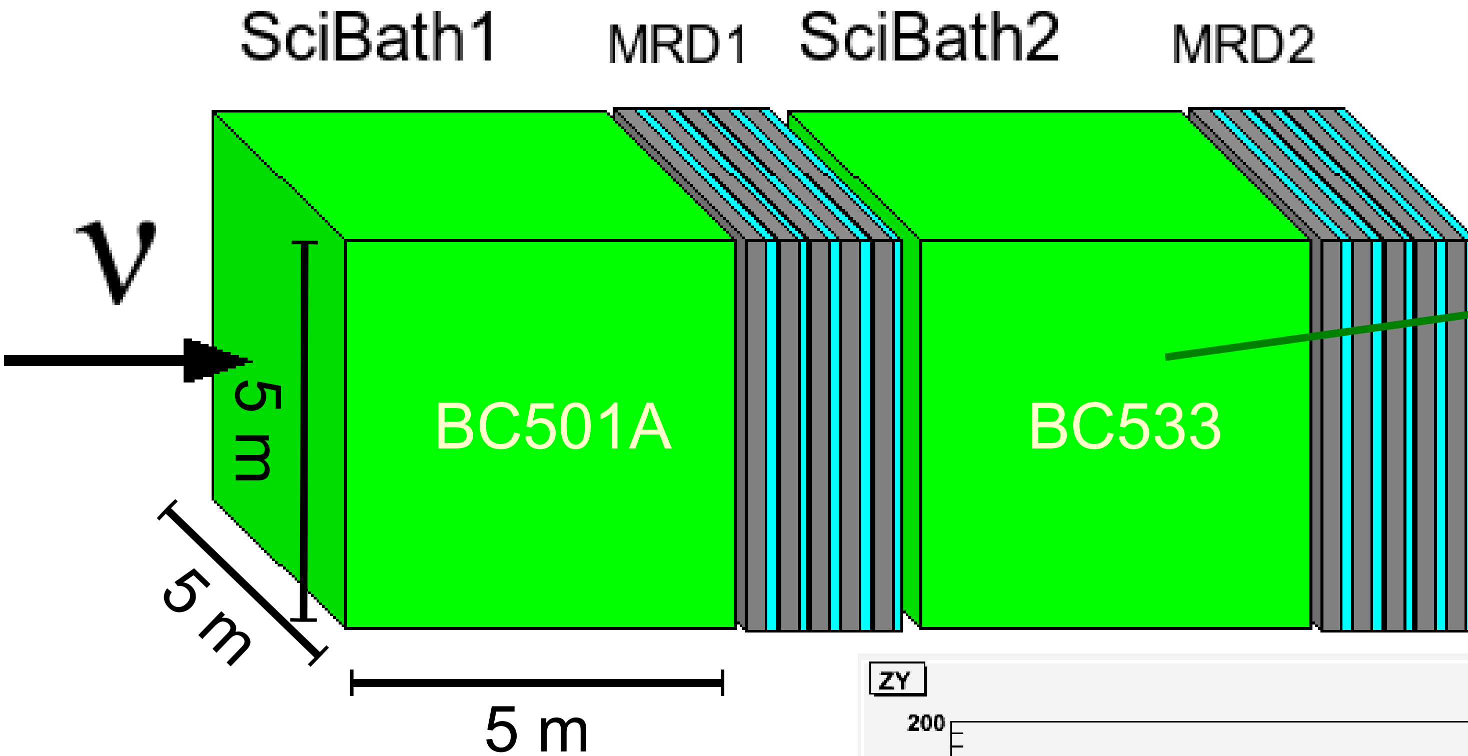
$$N_{NC}^{H} = 23.4 \times N_{NC}^{BC533} - 20.3 \times N_{NC}^{BC501A}$$

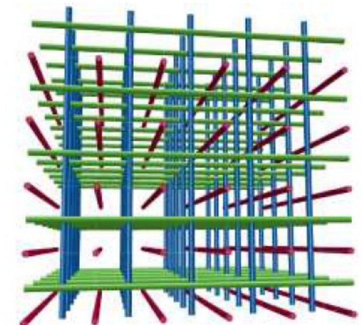
( ~ 15% *$N_{NC}$ )

$$N_{NC}^{C} = -2.36 \times N_{NC}^{BC533} + 3.30 \times N_{NC}^{BC501A}$$

(FINeSSE: δ(Δs)~0.04 with 6E20 POT + 9 t)

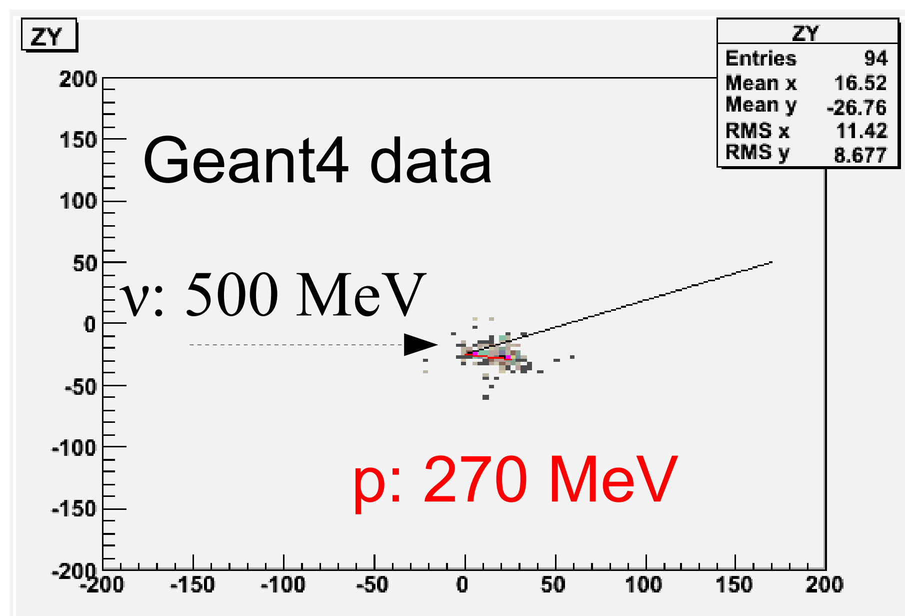
# Dual SciBath configuration



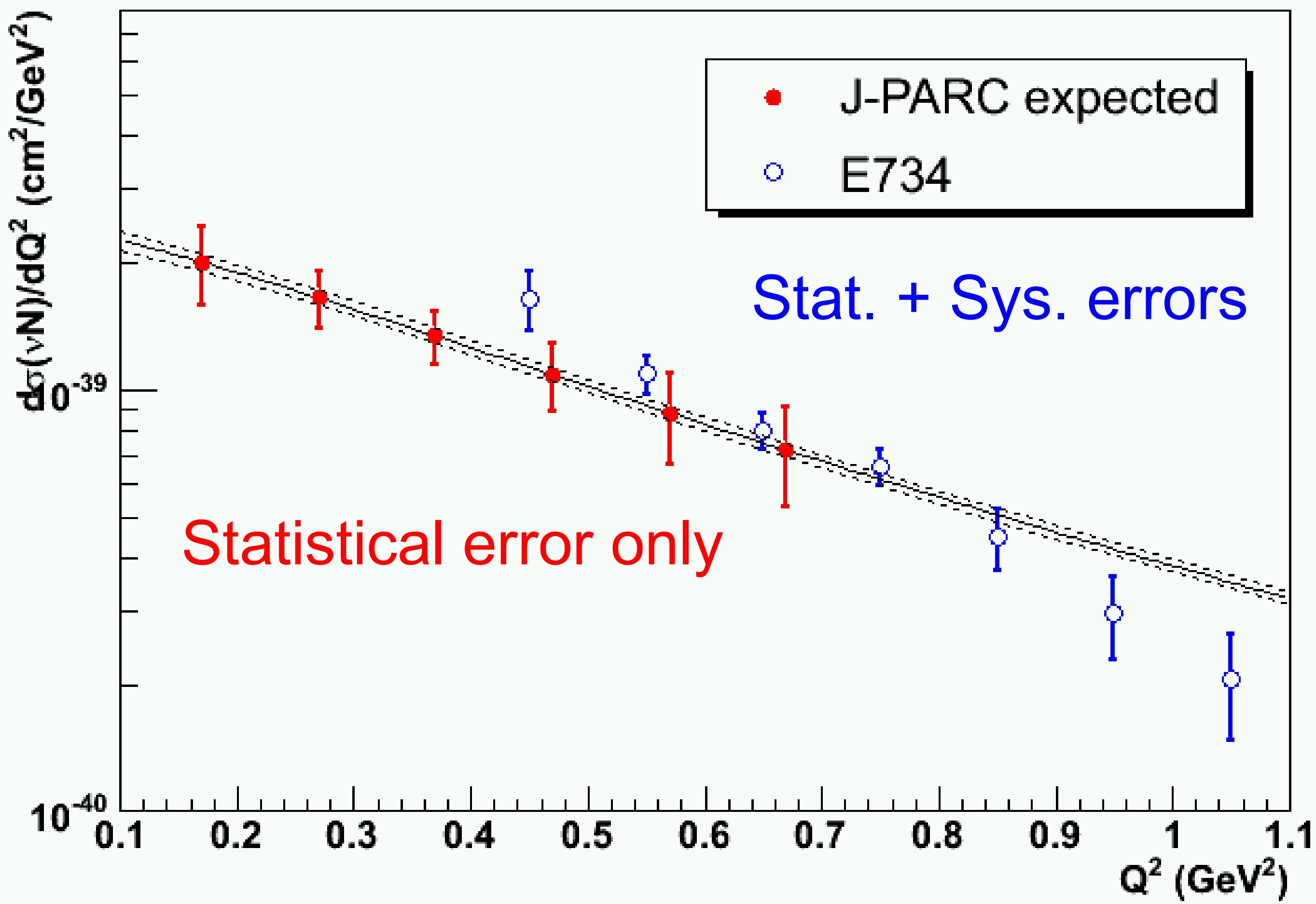



WLS readout

Fiducial volume:
$3x3x3\ m^3$



# Expected sensitivity




1E21 POT (off-axis)
+ 2 * 27 t SciBath

$\delta(\Delta s) = 0.03$
(dipole form factor)

Expected sensitivity assuming the dipole approximation:

$$\delta(\Delta s) = 0.03$$

Systematic errors must be studied carefully. (Normalization, Background)

# Summary

- **Proton spin problem**
  - Δs is a key for understanding of sea quark contribution
    - HERMES, COMPASS: Δs = -0.08 ± 0.02 with SU(3) symmetry
    - HERMES SIDIS: Δs = 0.03 ± 0.03 ( partial, no SU(3) symmetry)
  - Flavor SU(3) symmetry? breaking?
  - Strange nucleon form factor can constrain directly Δs
- **Neutrino scattering: NC elastic scattering**
  - E734 NC cross section measurements : -0.2 < Δs < 0.0
  - FINeSSE proposed R(NC/CC) measurement : δ(Δs) = 0.04
  - SciBooNE: Data taking was started in 2007
    - R(NC/CC) study is planned using 1E20 POT.
  - Key points: nuclear effects in R(NC/CC), $Q^2$ extrapolation

# Summary

- **Δs measurement at J-PARC**
  - Aim to measure NC cross section on H, not R(NC/CC)
  - Sensitivity study based on
    - 1E21POT neutrino beam at 280m away from the production target
    - Dual SciBath detector (BC501A and BC533)
    - **δ(Δs) ~ 0.03** expected (with dipole form factor assumption)
    - Normalization and background contributions to the systematic error to be studied.
    - $Q^2$ extrapolation ($Q^2$ dependence) also has to be carefully studied.