

ニュートリノ散乱による Δs 測定

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

Proton spin problem and Δs

- EMC results -

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

Polarized DIS:

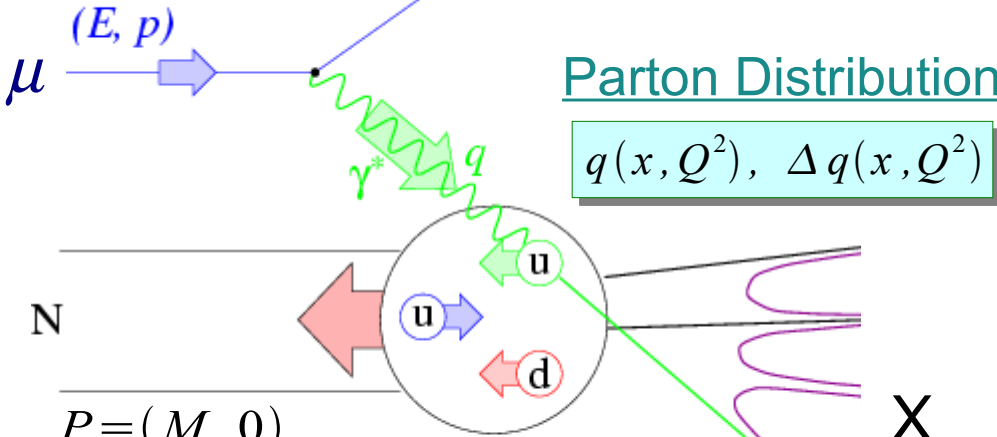
$$\vec{\mu} + \vec{N} \rightarrow \mu' + X$$

Structure Function

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

Parton Distribution

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

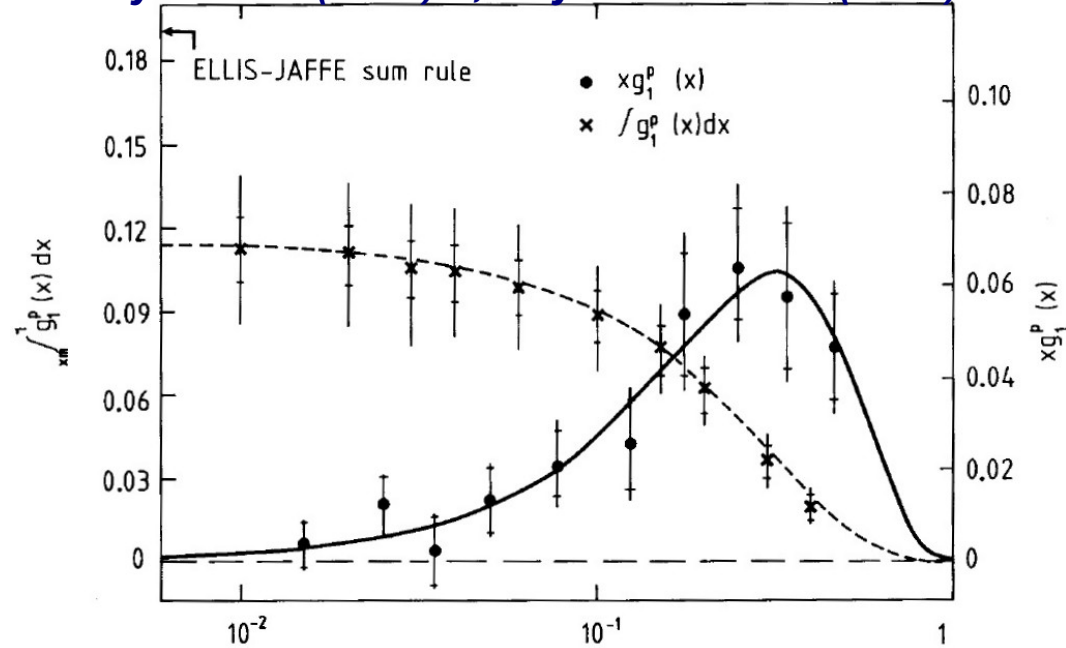


SU(3) flavor symmetry

$$a_3 = 1.26, a_8 = 0.58$$

$$a_0 = \Delta u + \Delta d + \Delta s = 0.12$$

$$\Delta s = -0.19$$



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

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

Updated results on g_1 and Δs



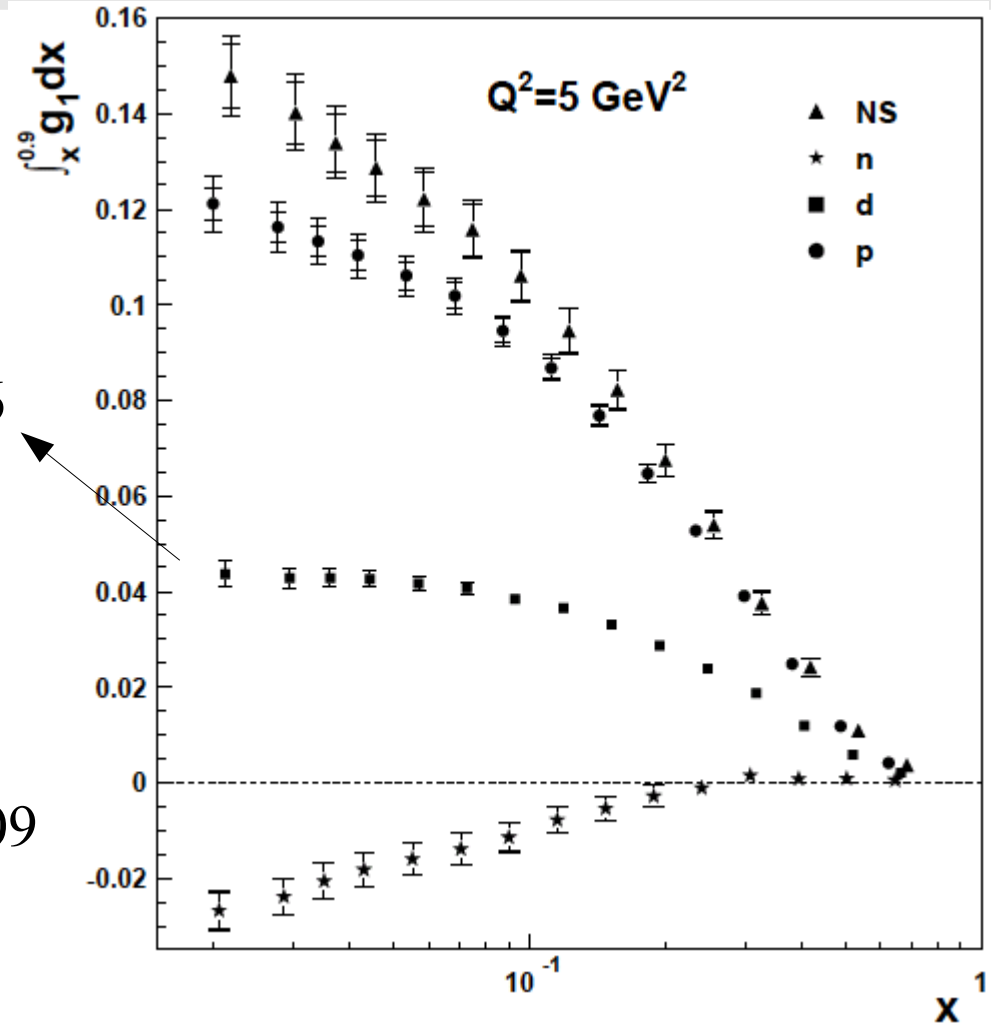
Phys. Rev. D 75 (2007) 012007

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

Assumption:

- " High x contribution = 0
- " Saturation in the lower x region
- " **SU(3) flavor symmetry:**

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



Phys. Lett. B 647 (2007) 8:

Assuming **SU(3) flavor symmetry**

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

Flavor tagging in DIS

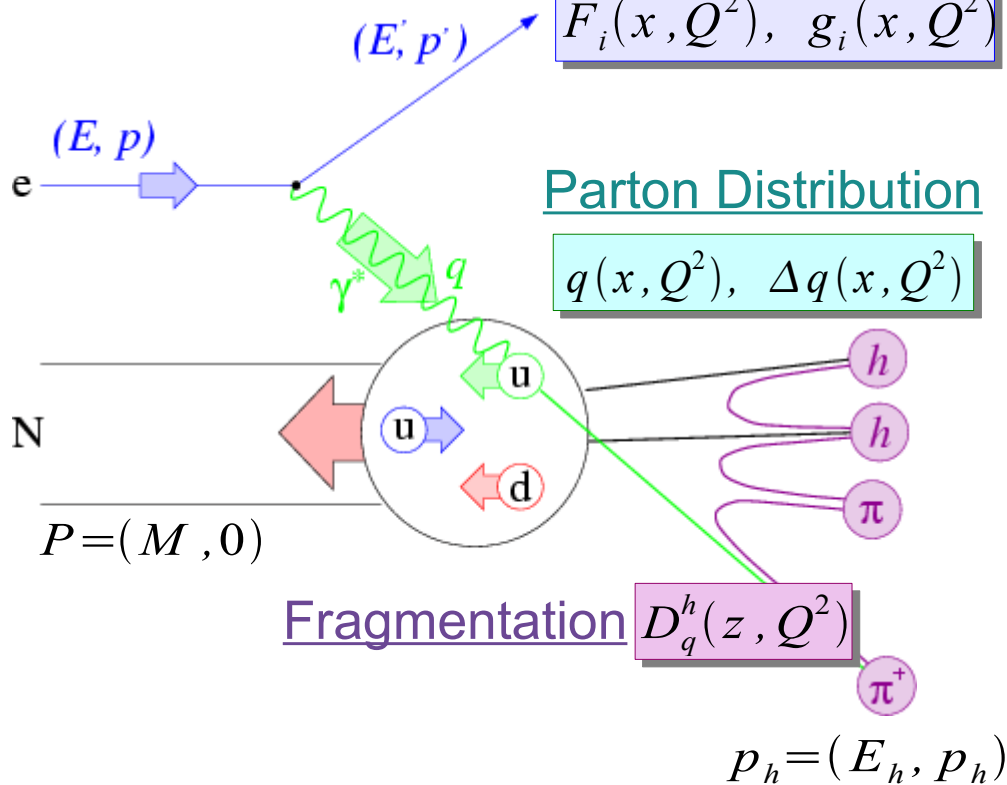
$$\vec{l} + \vec{N} \rightarrow l' + h + X$$

Structure Function

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

Parton Distribution

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



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

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

Flavor Tagging:

Hadron carries information on quark flavor through fragmentation function

Strangeness spin inside proton

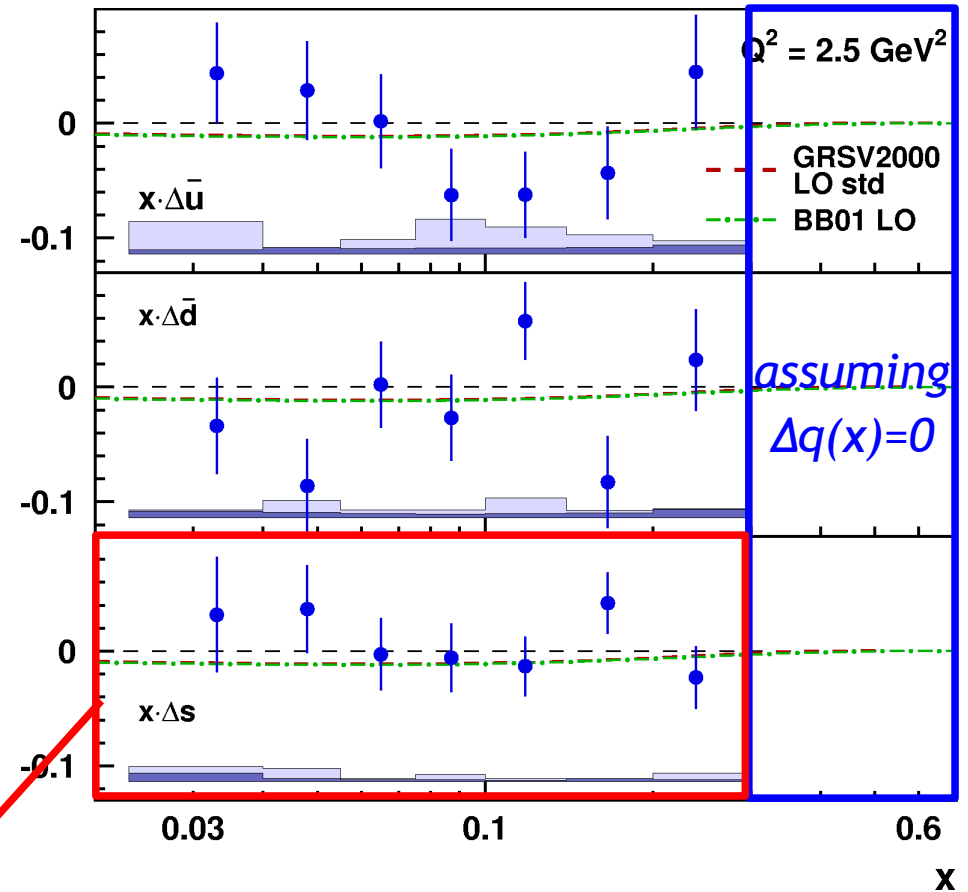
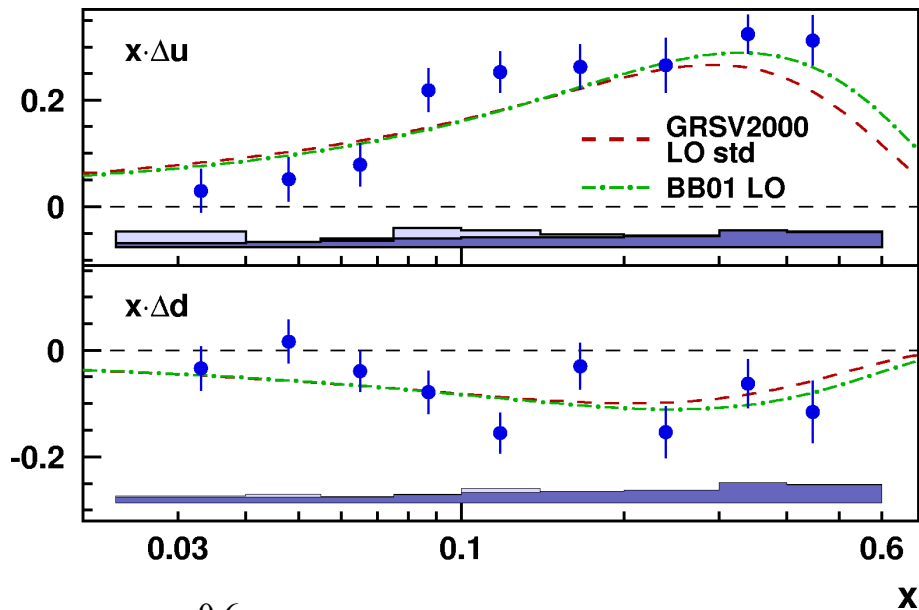


$$\vec{e} + \vec{N} \rightarrow e' + h + X$$

- HERMES results -

Phys. Rev D 71 (2005) 012003

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



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

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

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

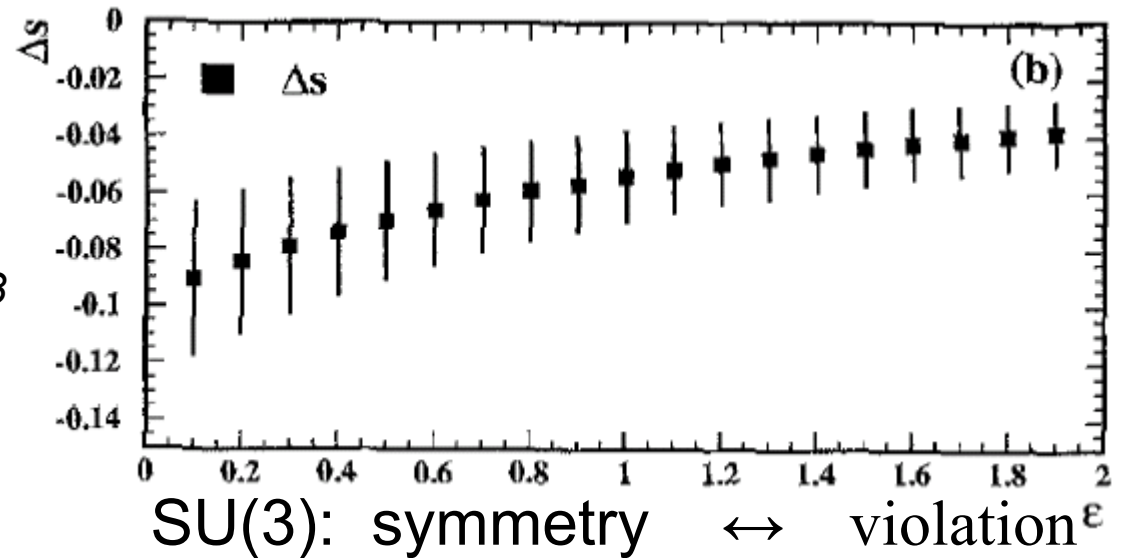
SU(3) violation and impact on Δs

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

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

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

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



χ QM calculation:

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

SU(3) symmetry: $\Delta s = -0.1$

SU(3) breaking: $\Delta s = -0.05$

Neutrino-Nucleon 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

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

$$G_1 = \left[-\frac{G_A}{2} \tau_z + \frac{G_A^s}{2} \right] \longrightarrow G_A^s (Q^2 = 0) = \Delta s$$

Neutrino scattering and Δ_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 Δ_s**

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

- **Further analysis based on E734**

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

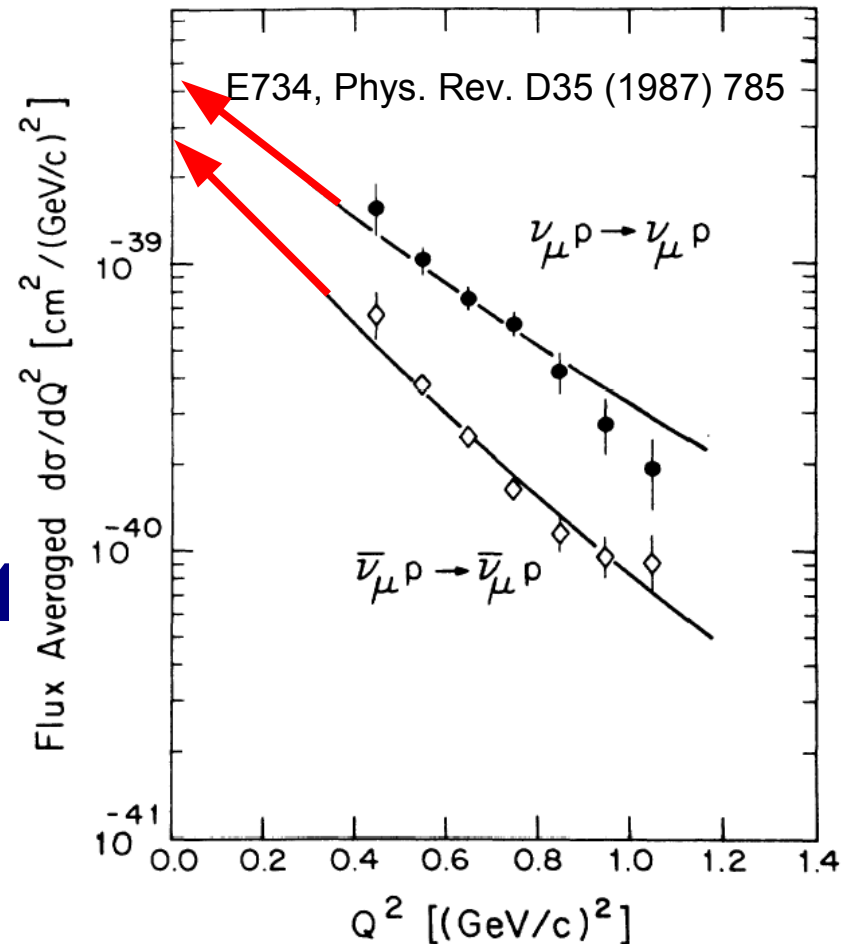
$$R_{NC/CC}^{\bar{\nu}} = 0.218 \pm 0.012 \pm 0.023$$

$$R_{NC}^{\nu/\bar{\nu}} = 0.302 \pm 0.019 \pm 0.037 \quad 0.5 < Q^2 < 1.0 \text{ GeV}^2$$

$$-0.21 < \Delta_s < 0$$

strong correlation with the axial mass M_A

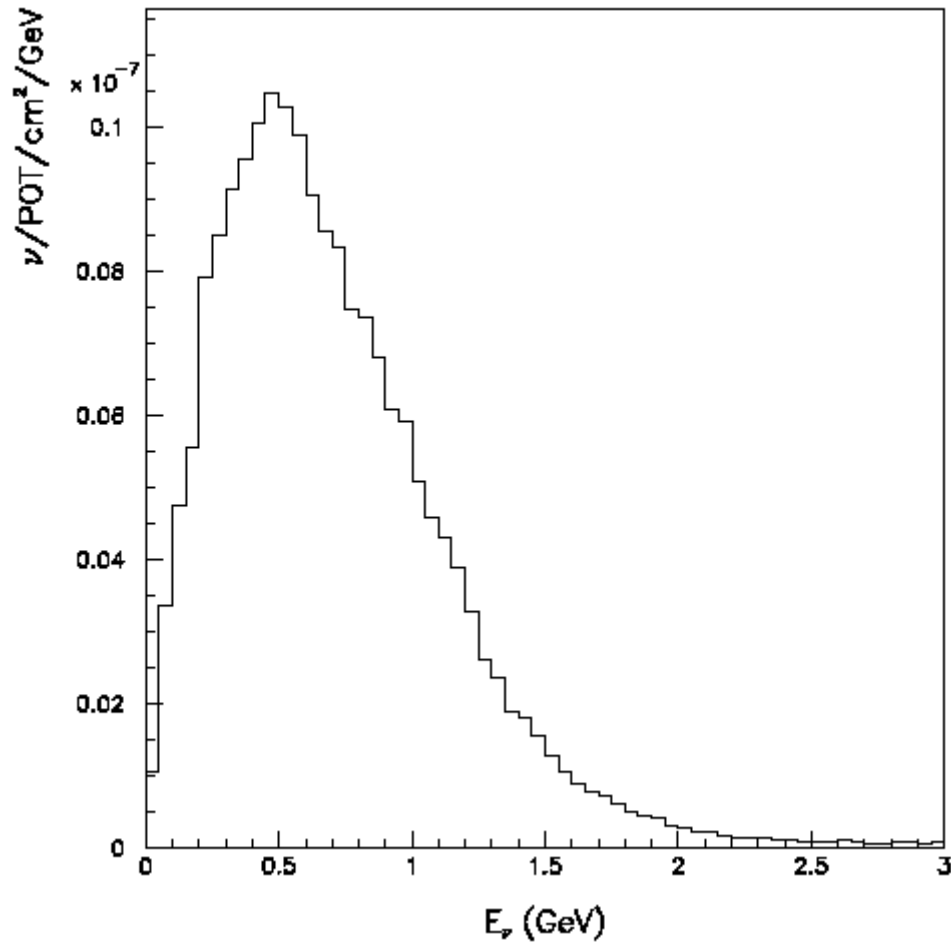
Q^2 dependence of G_s^A



FINeSSE @ FNAL

FINeSSE Proposal, hep-ex/0402007

FNAL booster neutrino beam-line



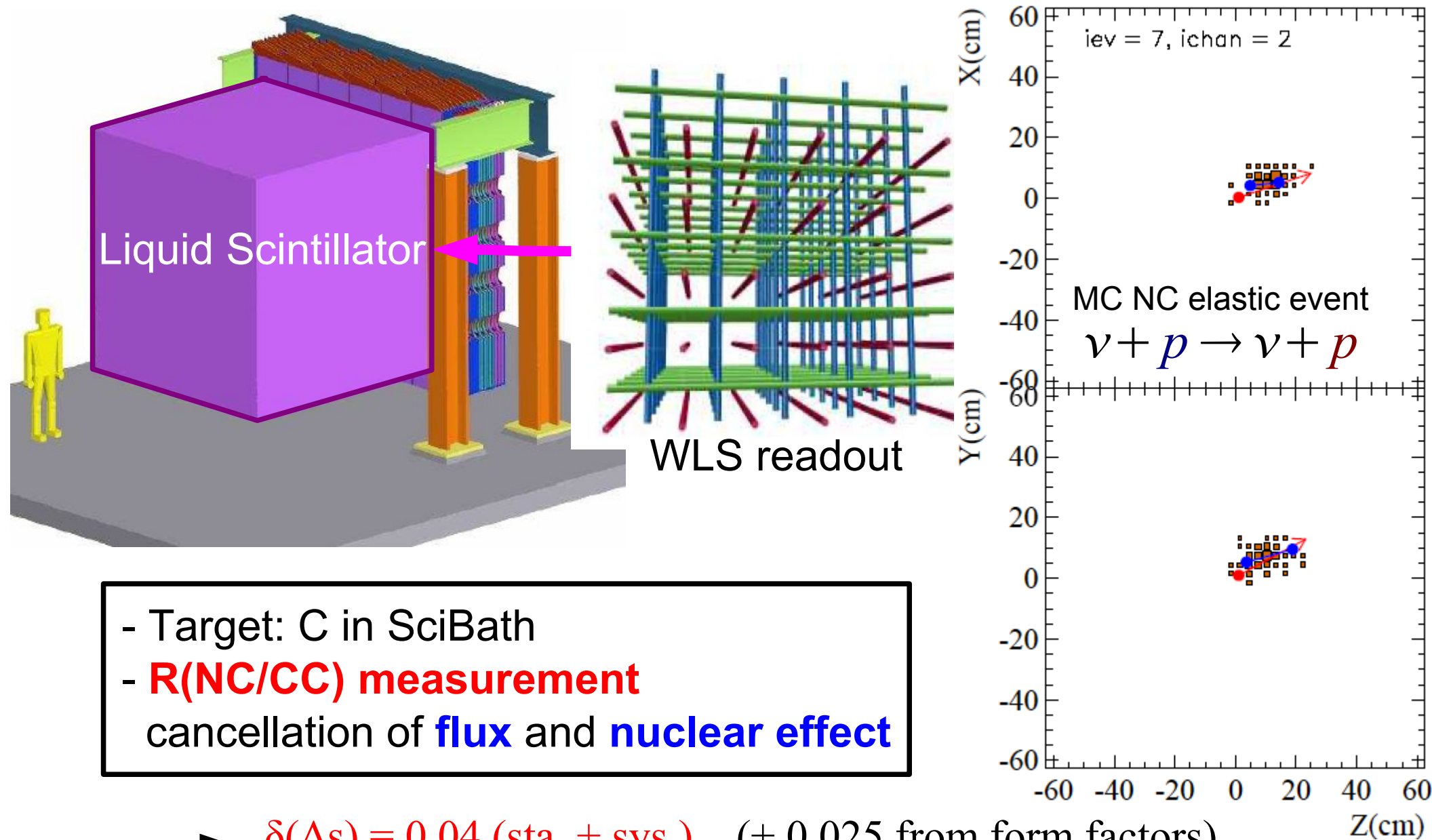
ν_{μ} 6E20 POT

ν Reaction	9 ton
CC QE, $\nu_{\mu}n \rightarrow \mu^{-}p$	146,610
NC EL, $\nu_{\mu}N \rightarrow \nu_{\mu}N$	59,184
CC π^{+} , $\nu_{\mu}p \rightarrow \mu^{-}p\pi^{+}$	66,690
CC π^{0} , $\nu_{\mu}n \rightarrow \mu^{-}p\pi^{0}$	13,932
CC π^{+} , $\nu_{\mu}n \rightarrow \mu^{-}n\pi^{+}$	11,664
NC π^{0} , $\nu_{\mu}p \rightarrow \nu_{\mu}p\pi^{0}$	11,394

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

FINeSSE SciBath detector

FINeSSE Proposal, hep-ex/0402007



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

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



MiniBooNE



v

SciBooNE@FNAL



Production target

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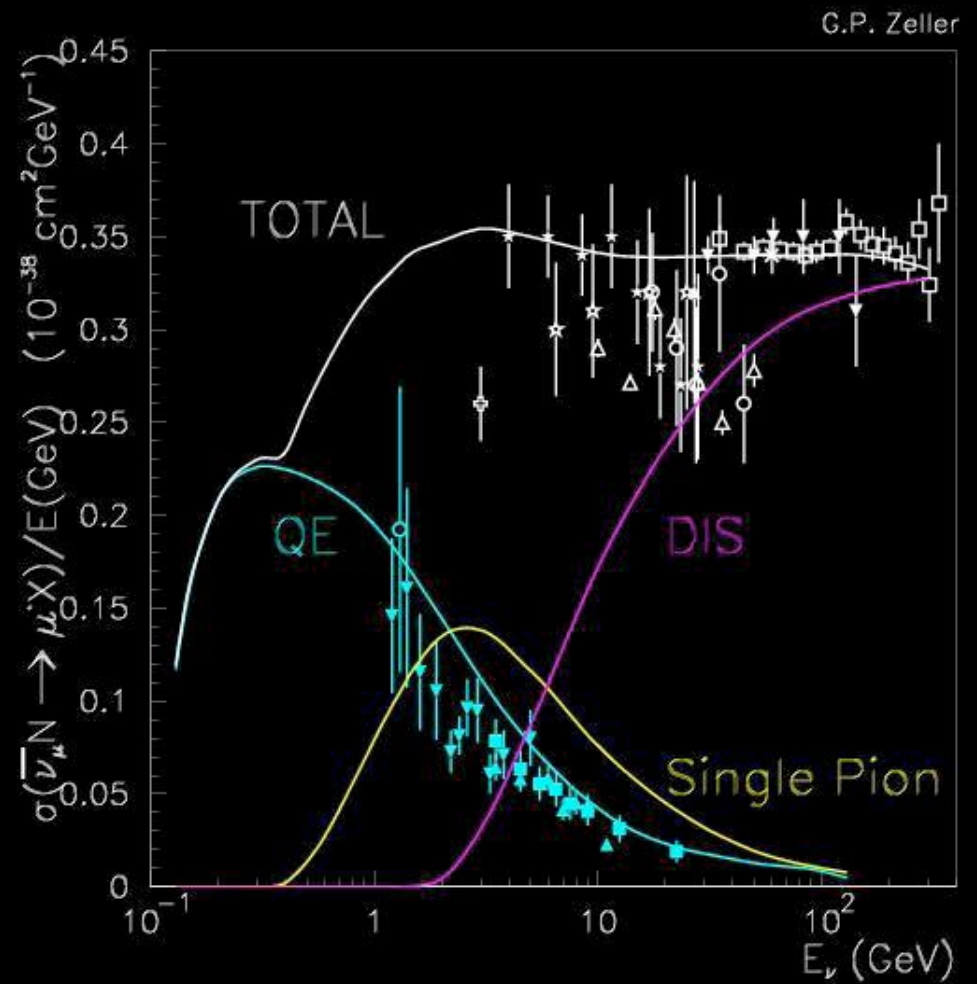
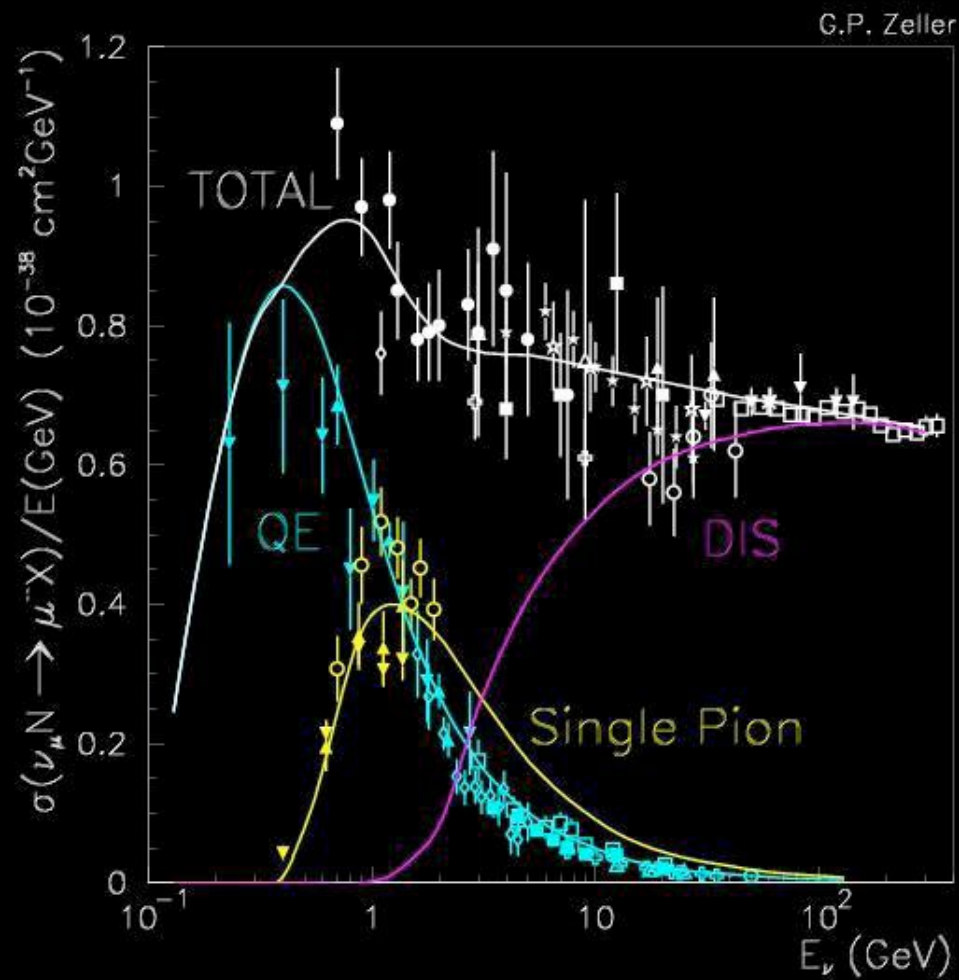
© 2007 Europa Technologies

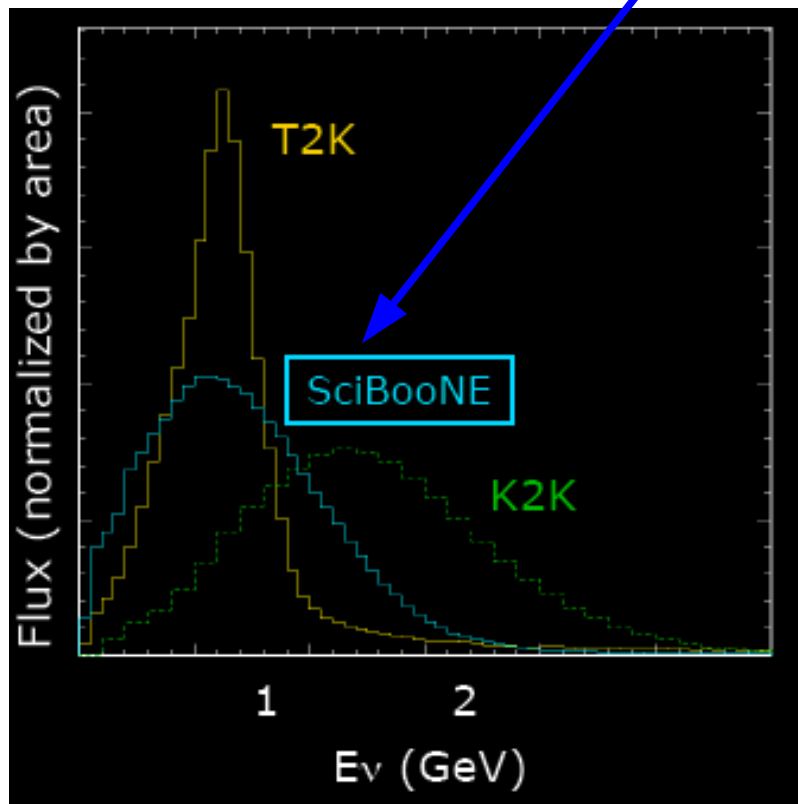
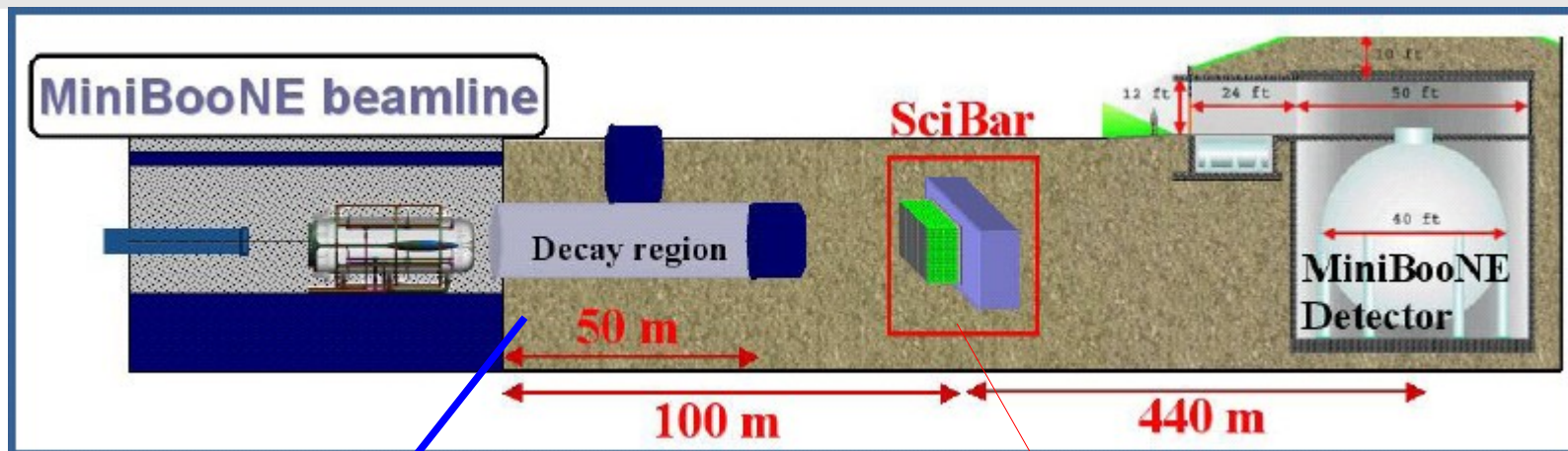
0 ポインタ 41° 50'08.51" N 88° 15'55.78" W

ストリーミング 100%

上空 1.04 km

Neutrino scattering cross section (CC)





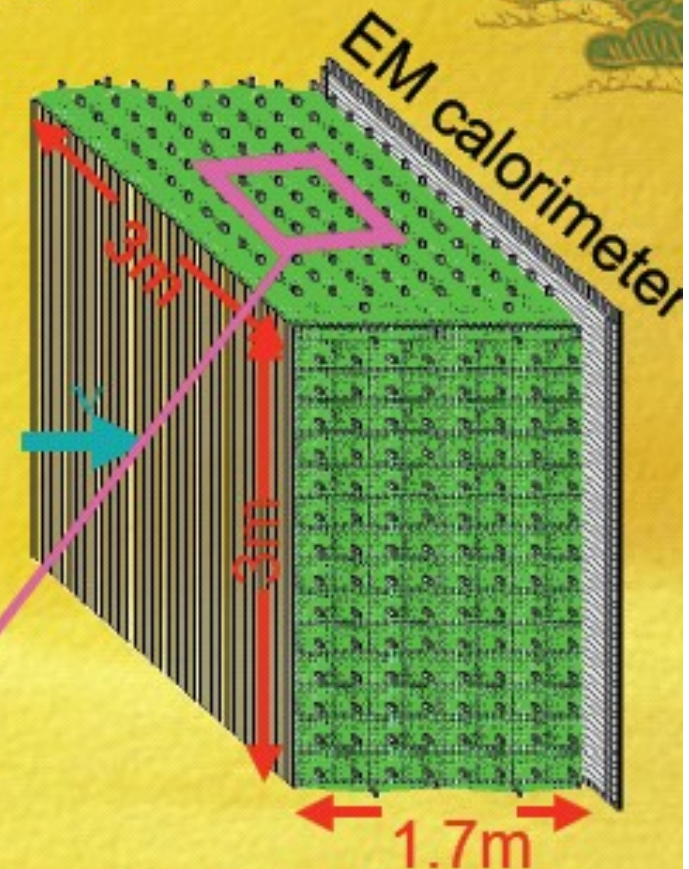
" SciBar/EC detector from K2K
" Muon Range Detector

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

- SciBooNE anticipates
 - $\sim 1e20$ POT ν
 - $\sim 1e20$ POT anti- ν

SciBar Detector

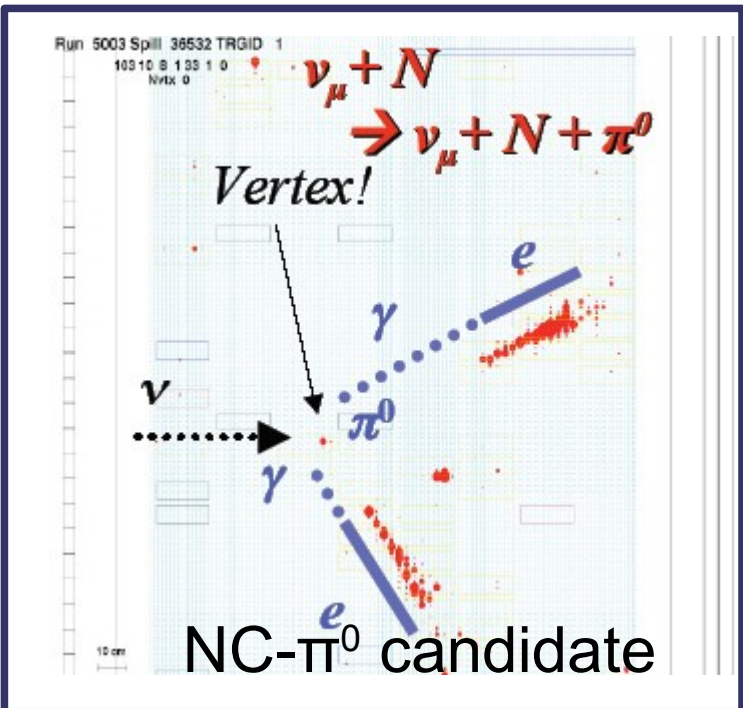
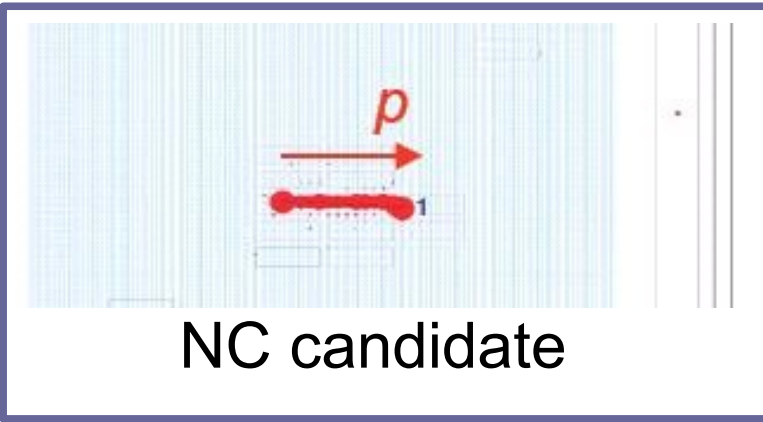
- Extruded scintillators with WLS fiber readout
- Scintillators are the neutrino target
- $2.5 \times 1.3 \times 300 \text{ cm}^3$ cell
- $\sim 15,000$ channels
- Identify short tracks ($>8\text{cm}$)
- Distinguish a proton from a pion by dE/dx
- Total 15 tons
- High track finding efficiency ($>99\%$)
- Clear identification of ν interaction process



Multi-Anode PMT
(64 channels)

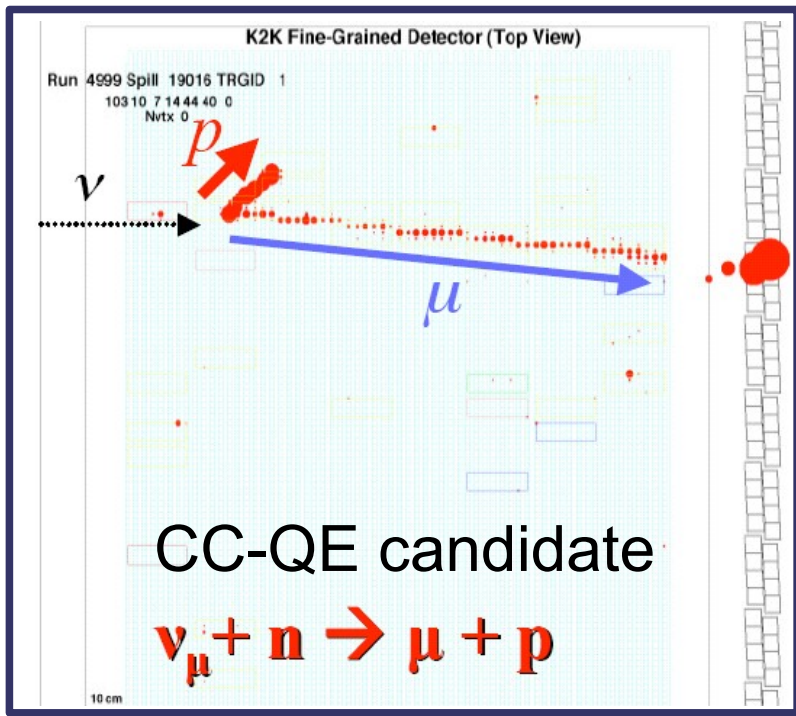
Wave-Length
Shifting fiber

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.



Expected yields

Channel	Number ν_μ
CCQE	39k
NCE	17k
CC $1\pi^+$	24k
CC $n\pi$	5k
NC $1\pi^0$	9k
Misc	2.1k
NCco $h\pi$	0.8k
CCco $h\pi$	1.2k?
TOTAL	98k

With 1E20 POT neutrino

1/3 of FINeSSE (59K)

FINeSSE: $\delta(\Delta s) \sim 0.04$

SciBooNE: $\delta(\Delta s) ?$

With 1E20 anti-neutrino

NCE $\sim 3k$

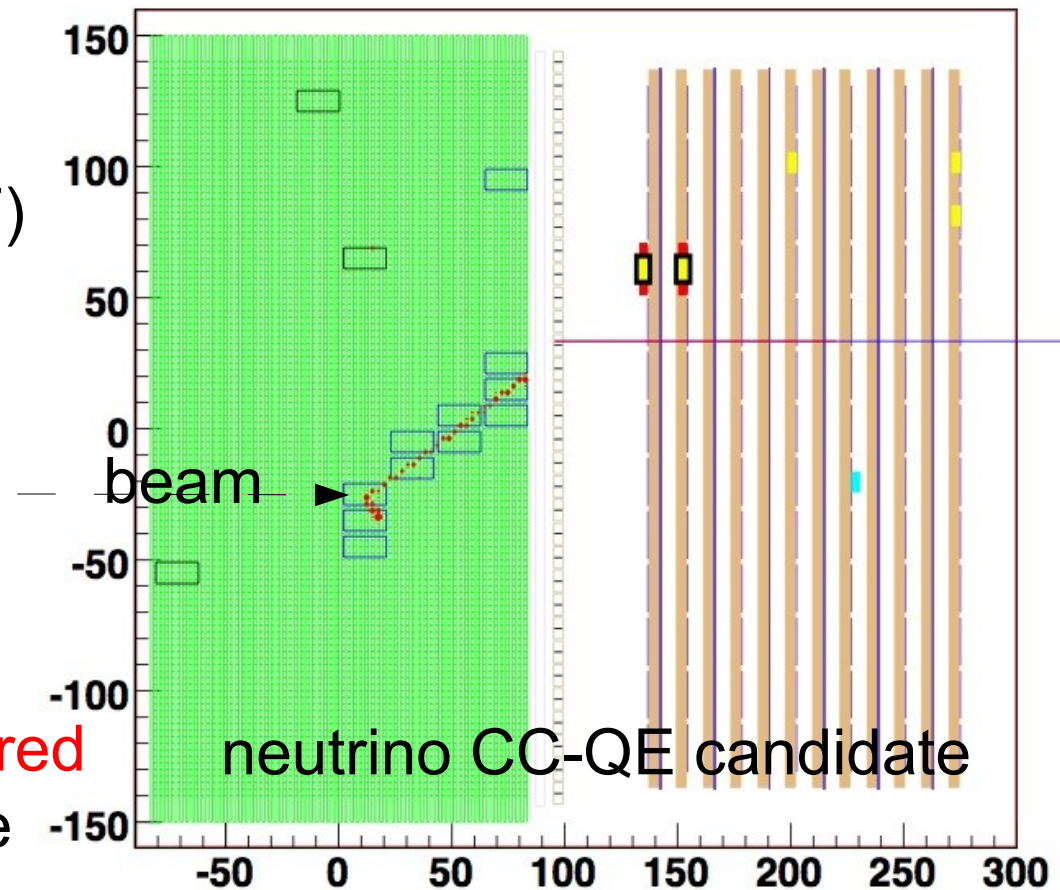
→ SciBooNE prolongation

- 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

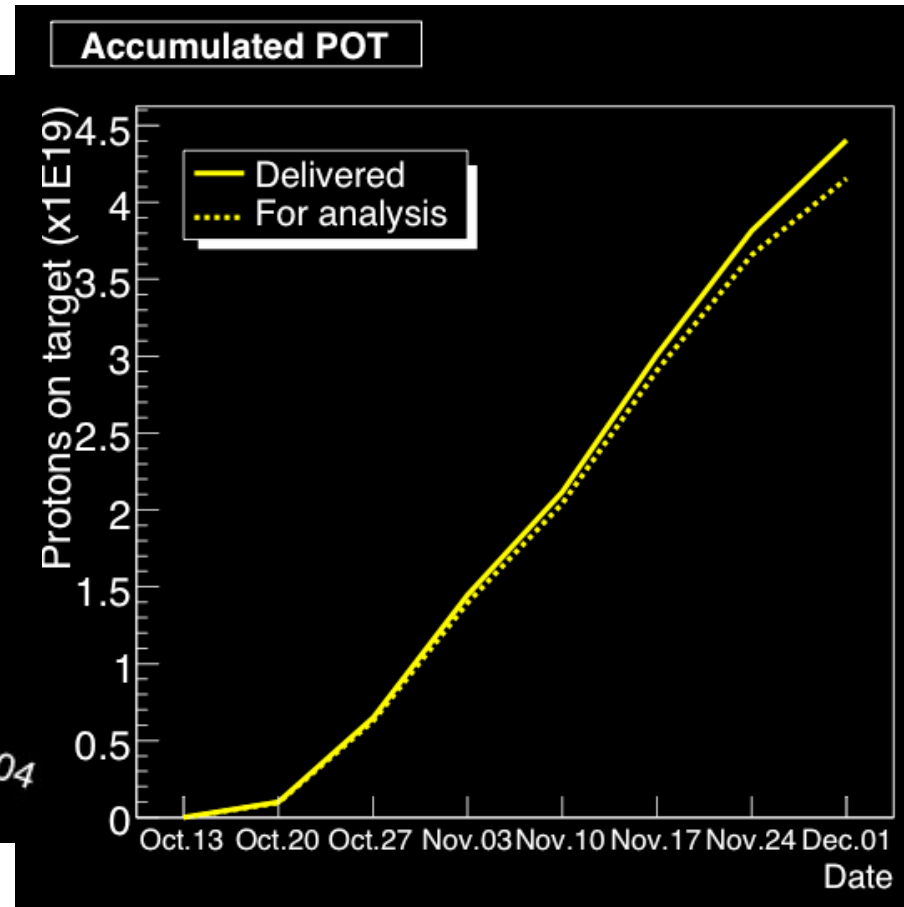
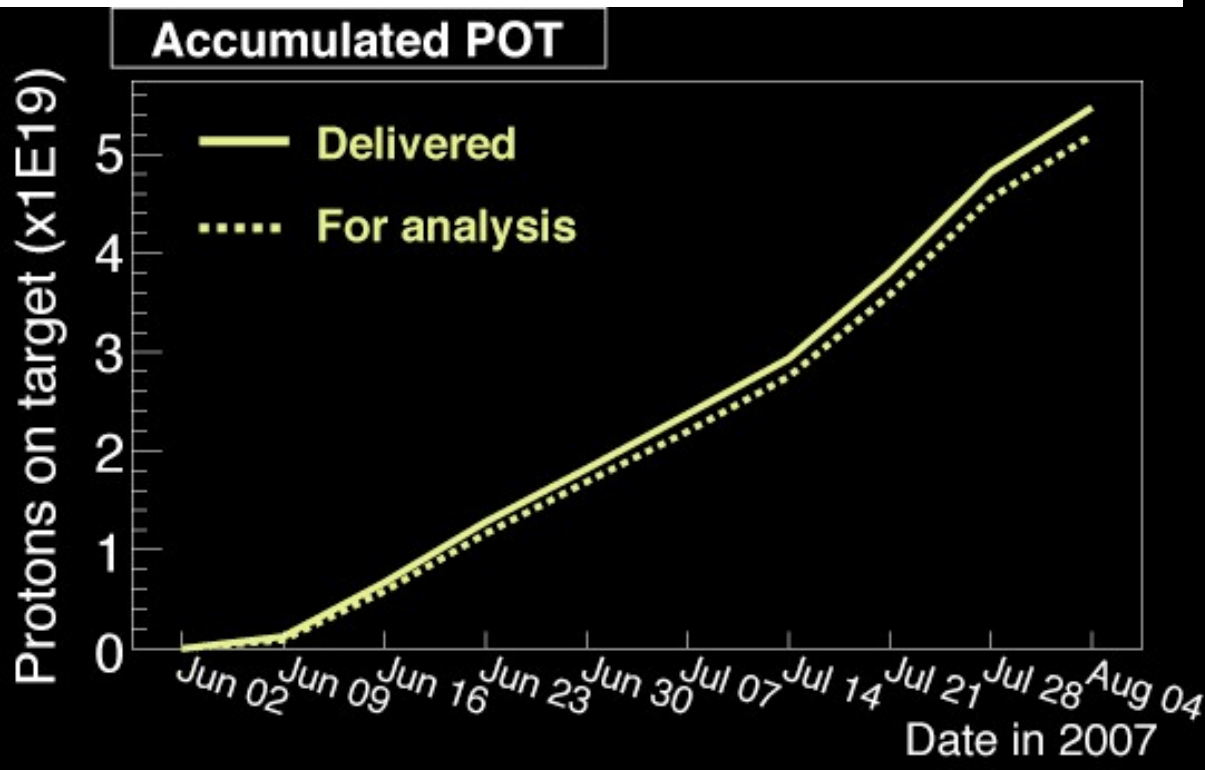
SciBooNE: status and plan

- SciBar and EC were moved from KEK to FNAL (Jul. 2006)
- Civil construction started (Sep. 2006)
- Commissioning done (Apr. 2007)
- Physics RUN : (May ~ Aug. 2007) with anti-neutrino mode
5E19 POT delivered
- Detector live time: 96.5%
- Calibration of the detectors is on going.
- Physics RUN with neutrino mode (Oct. 2007 ~) **4.3E19 POT delivered**
- Switch back to anti-neutrino mode (Spring 2008)
- R(NC/CC) study is on going.

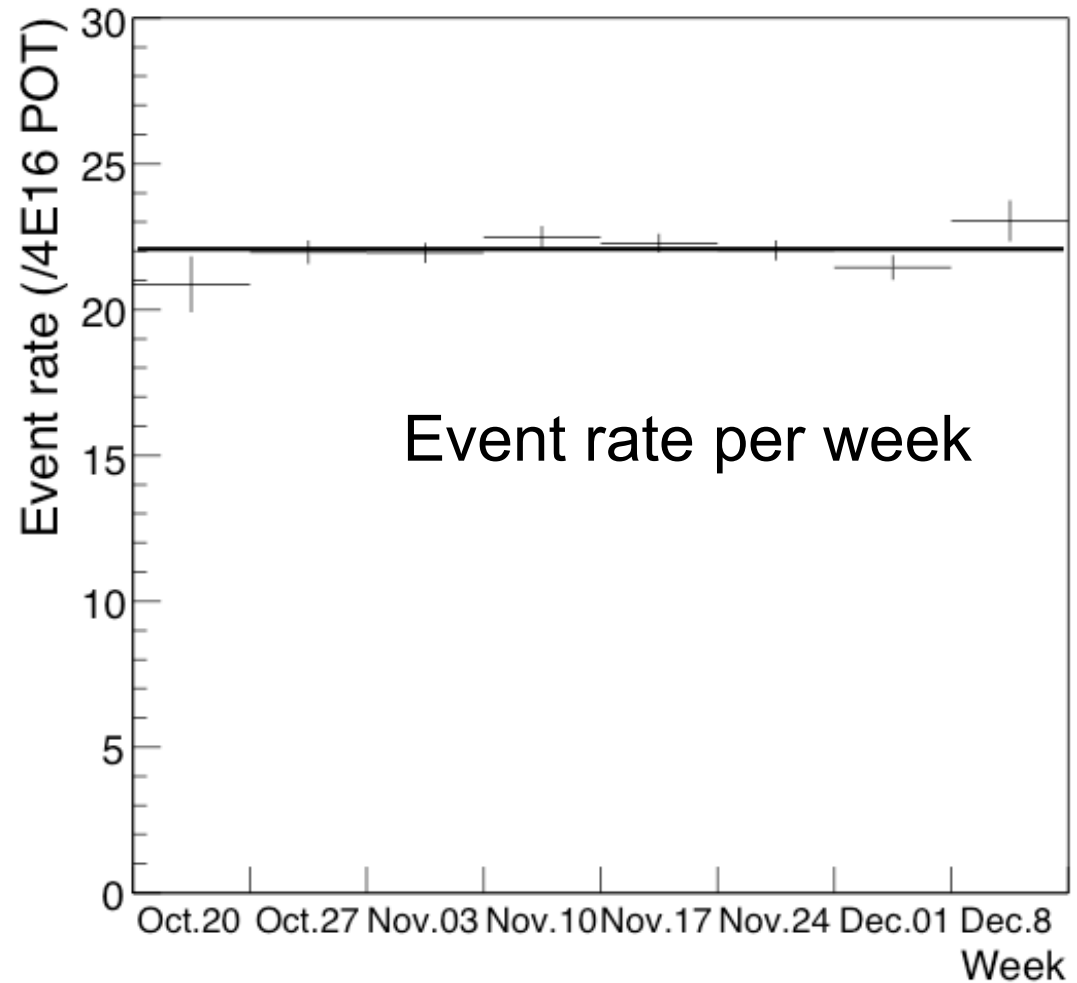
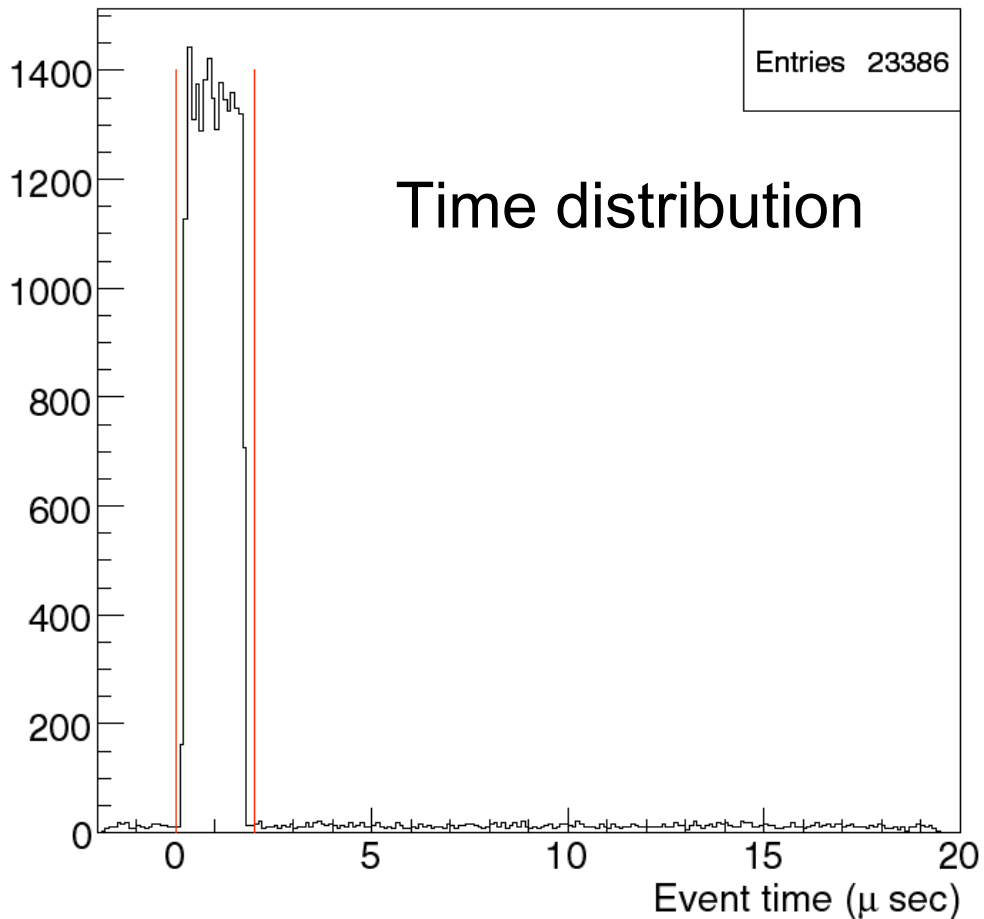
SciBooNE Event Display:
with anti-neutrino beam



Accumulated POT by SciBooNE



SciBar Performance



Nuclear effects on extraction of strange quark component

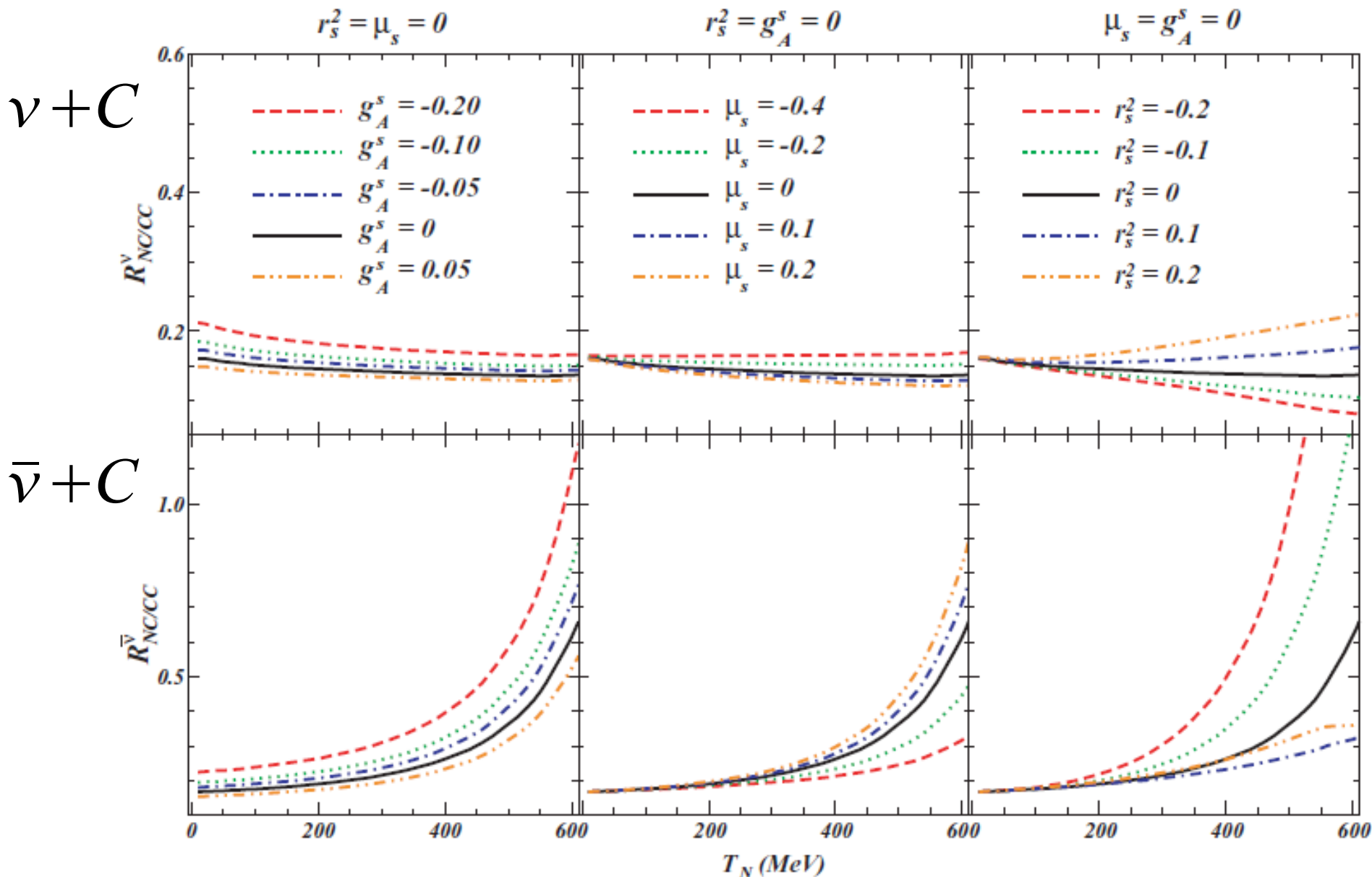
PHYSICAL REVIEW C 76, 055501 (2007)

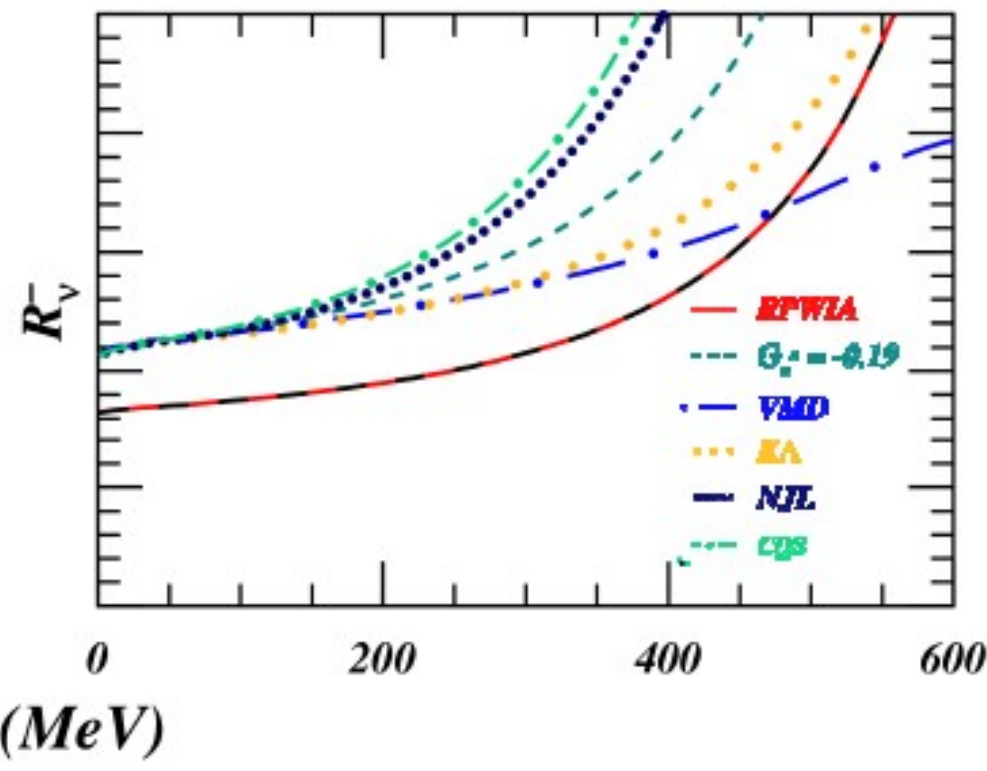
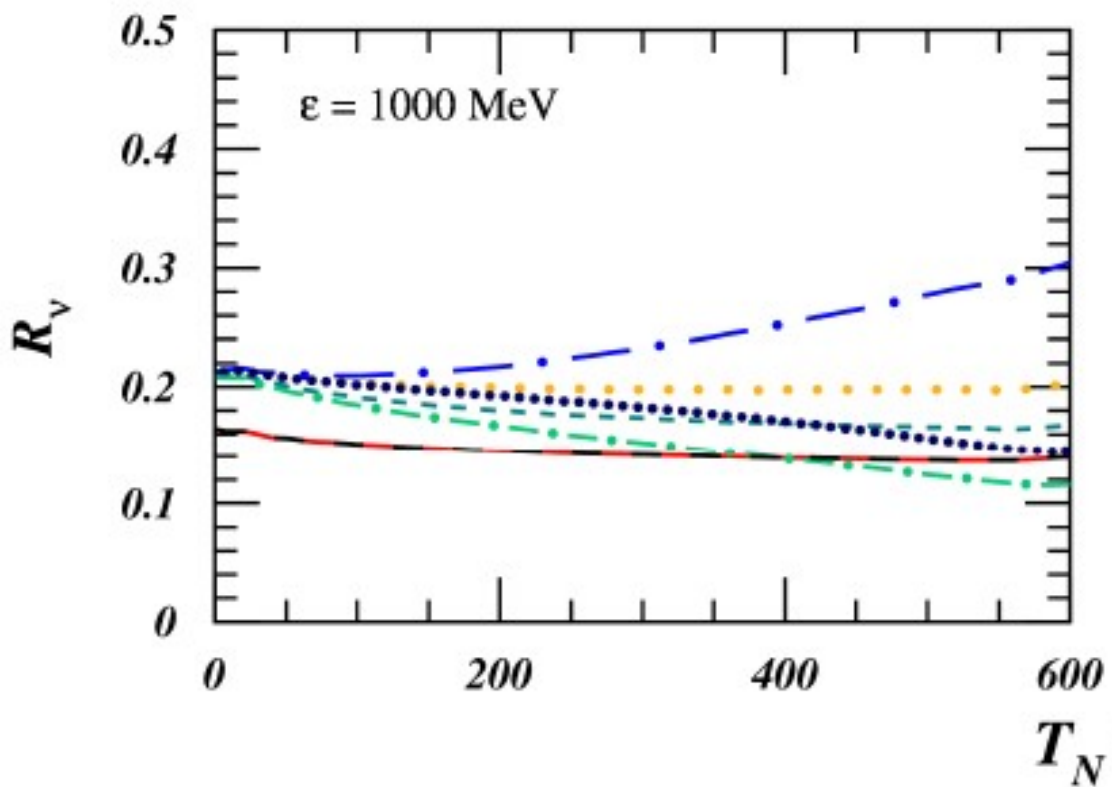
Strangeness content of the nucleon in quasielastic neutrino-nucleus reactions

N. Jachowicz, P. Vancraeyveld, P. Lava, C. Praet, and J. Ryckebusch

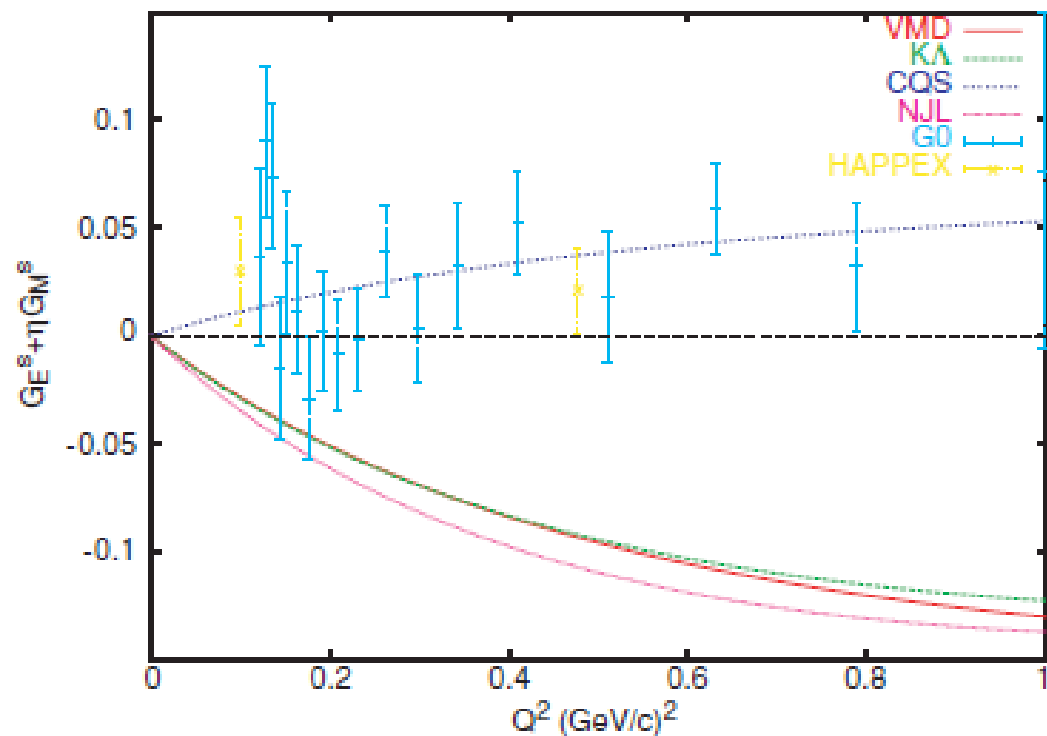
- nuclear binding : energy levels, missing momentum distributions for the bound nucleons
- Pauli blocking
- relativistic description
- final-state interactions
- full implementation of hadronic current with axial, and weak vector contributions and their interference terms, Q^2 dependence of the form factors

Nuclear target: A relativistic mean-field approach
 FSI: A relativistic multiple-scattering Glauber approach





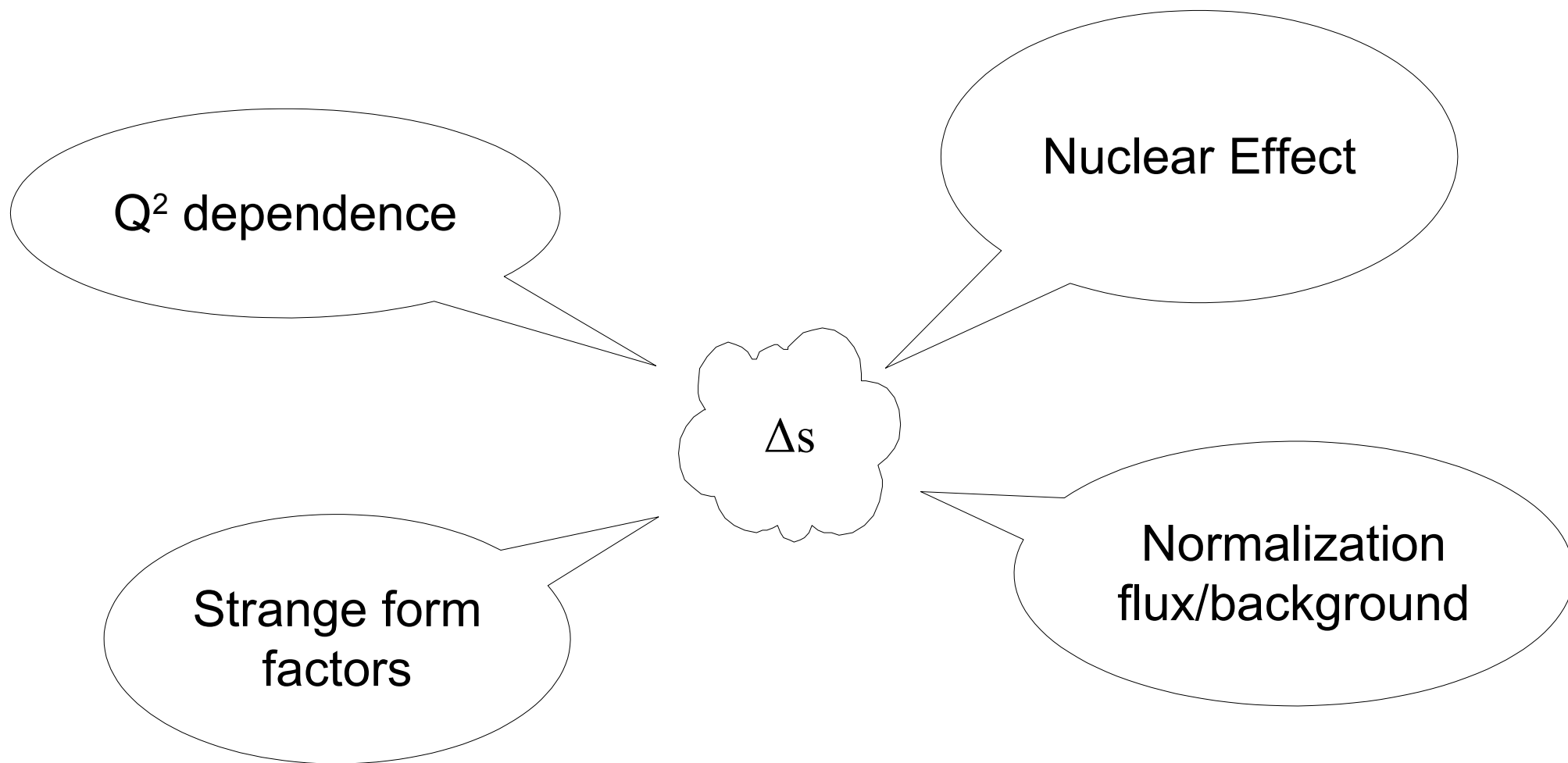
Comparison with other models...



PHYSICAL REVIEW C 76, 055501 (2007)

01/12@KEK

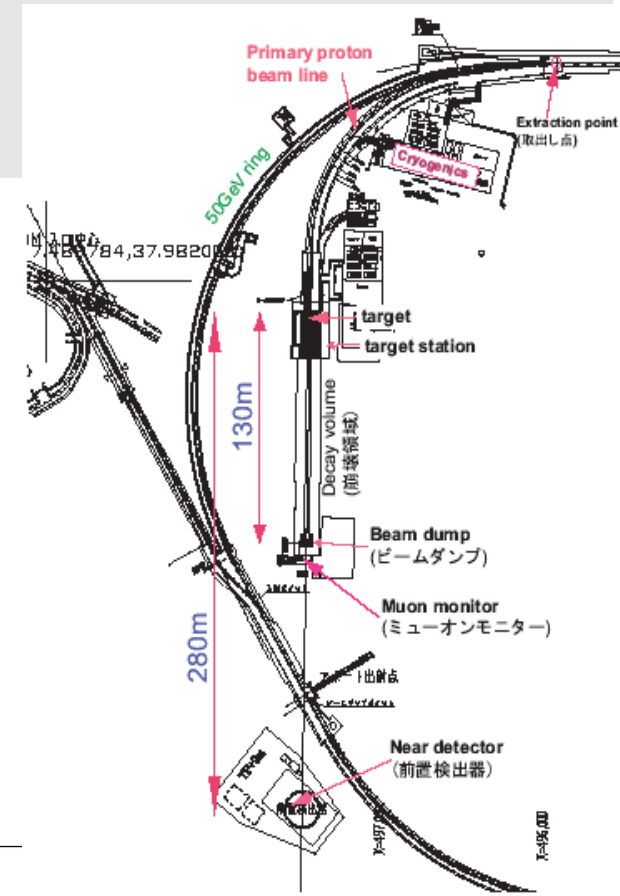
「核子の構造」



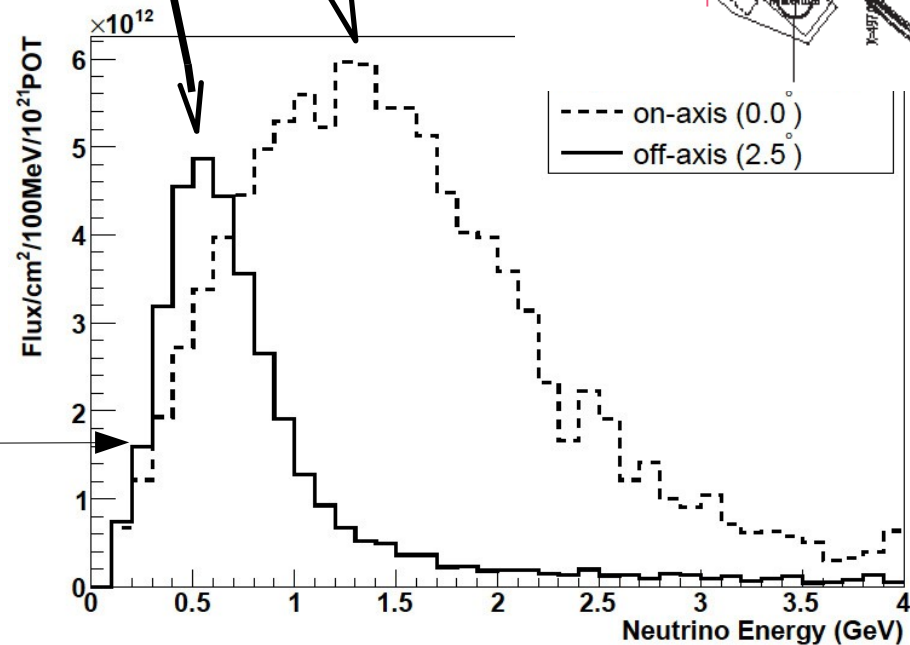
Accurate measurement of **NC ν -H** in $0.1 < Q^2 < 0.4 \text{ GeV}^2$
which is covered by the electron scattering.

J-PARC ν -beam line

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



Expected ν flux (MC data)



Methods of Δs measurement

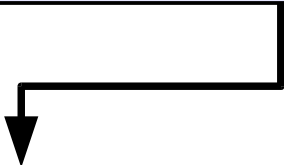
- **Nuclear effect (ex. C target):**
 - Nuclear model uncertainty on Δs extraction
- **R(NC/CC) measurements:**
 - Neutrino flux should be canceled. It also suppresses the nuclear effect.
 - Is there any model dependence uncertainty?
- **ν -H scattering extraction:**
 - Using two targets with different 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:

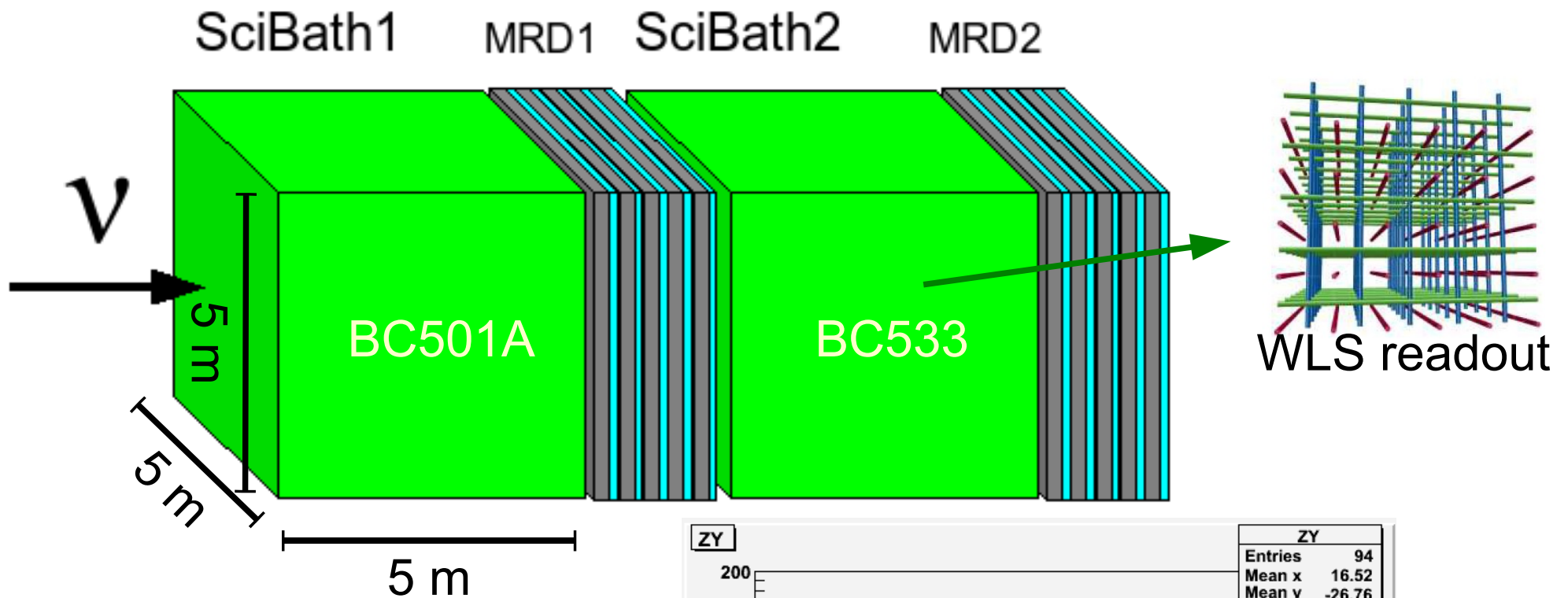
Using two liquid scintillators with different mixture of H and C:

<u>BICRON:</u>	<u>H/C</u>	<u>$\rho(\text{g/cm}^3)$</u>	<u>$\rho^H(\text{g/cm}^3)$</u>	<u>$\rho^C(\text{g/cm}^3)$</u>
BC501A	1.212	0.874	0.112	0.688
BC533	1.96	0.8	0.080	0.794

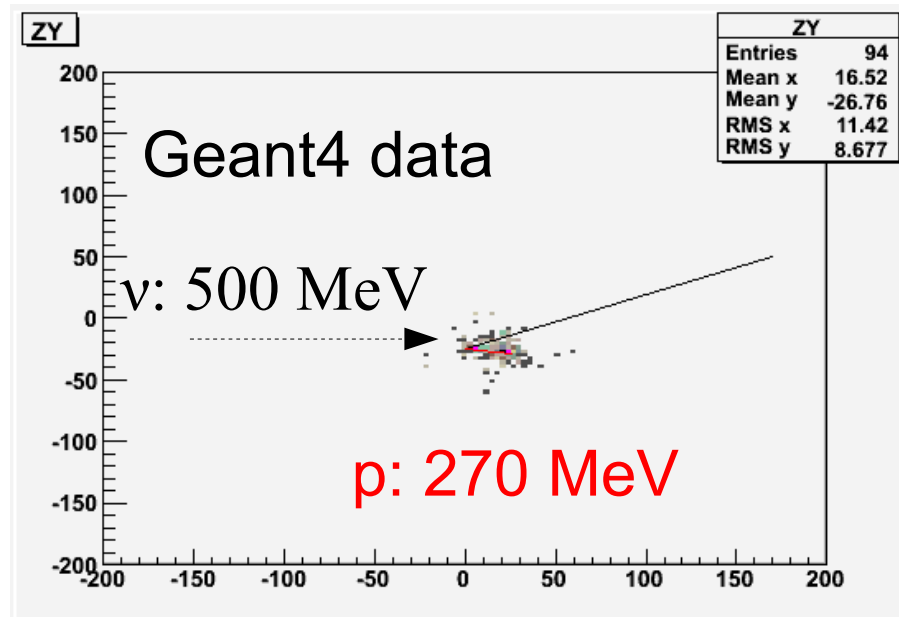

$$N_{NC}^H = 23.4 \times N_{NC}^{BC533} - 20.3 \times N_{NC}^{BC501A} \quad (\sim 15\% * N_{NC})$$
$$N_{NC}^C = -2.36 \times N_{NC}^{BC533} + 3.30 \times N_{NC}^{BC501A}$$

(FINeSSE: $\delta(\Delta s) \sim 0.04$ with $6E20$ POT + 9 t)

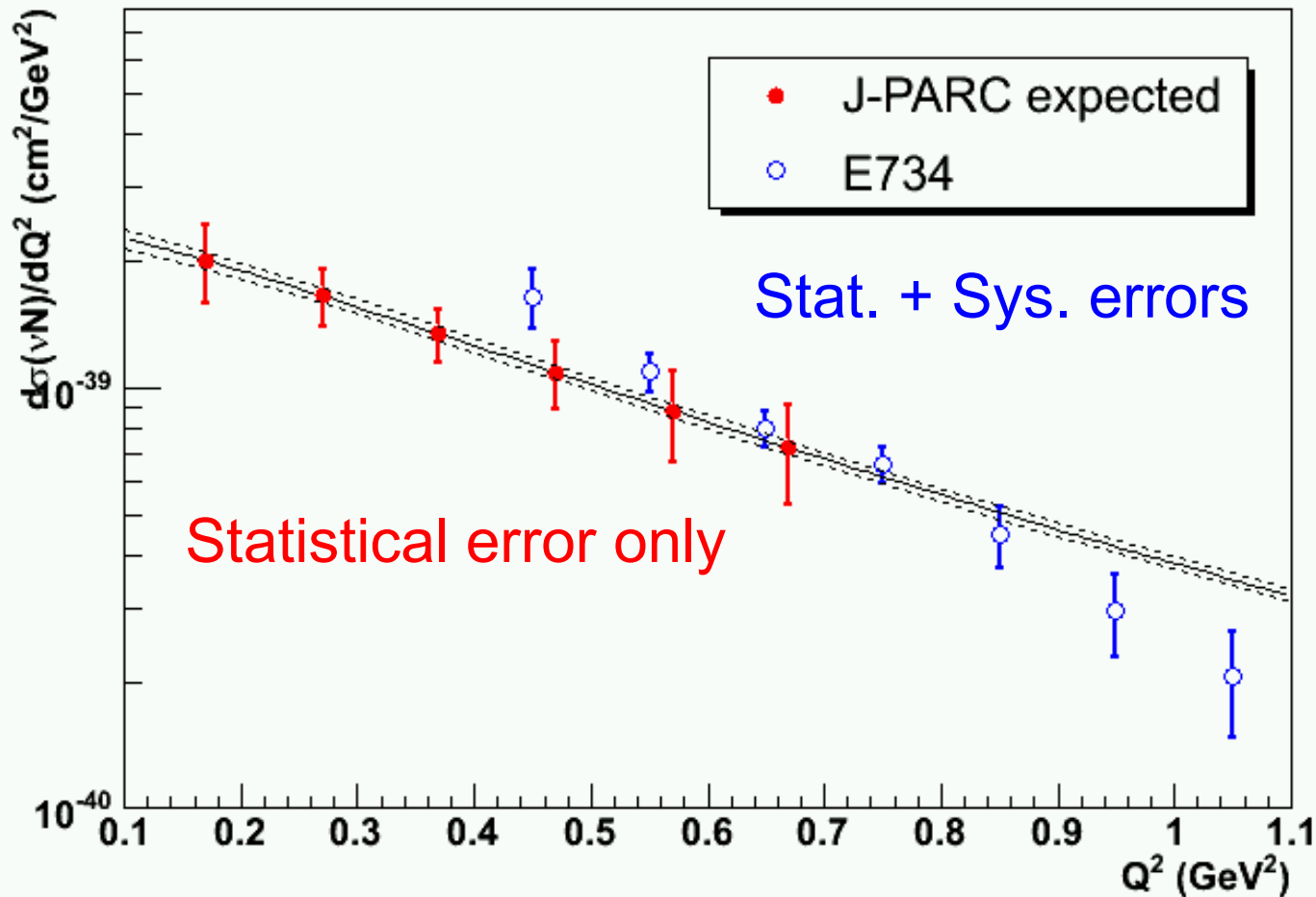
Dual SciBath configuration



Fiducial volume:
 $3 \times 3 \times 3 \text{ m}^3$



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**

- Δ_s is a key for understanding of sea quark contribution
 - HERMES, COMPASS: $\Delta_s = -0.08 \pm 0.02$ with SU(3) symmetry
 - HERMES SIDIS: $\Delta_s = 0.03 \pm 0.03$ (partial, no SU(3) symmetry)
- Flavor SU(3) symmetry? breaking?
- Strange nucleon form factor can constrain directly Δ_s

- **Neutrino scattering: NC elastic scattering**

- E734 NC cross section measurements : $-0.2 < \Delta_s < 0.0$
- FINeSSE proposed R(NC/CC) measurement : $\delta(\Delta_s) = 0.04$
- SciBooNE: Data taking was started in 2007
 - Smooth data taking. $1E20$ POT for both neutrino and anti-neutrino
 - R(NC/CC) study is on going. Feasibility study on Δ_s extraction

Summary

- **Prolongation of SciBooNE**

- http://www.fnal.gov/directorate/Longrange/Steering_Public/community_letters.html

- **Δs measurement at J-PARC**

- Measurement of 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

- $\delta(\Delta s) \sim 0.03$ 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.

END