FINeSSE, Δs Measurement through neutrino scattering

I Physics of Δs
II FINeSSE
III Scibath pilot detector beam test
CEU Poster Session, Daniel Passmore
FR.081 : A 3D Liquid Scintillator Neutrino Detector
IV Δs measurement

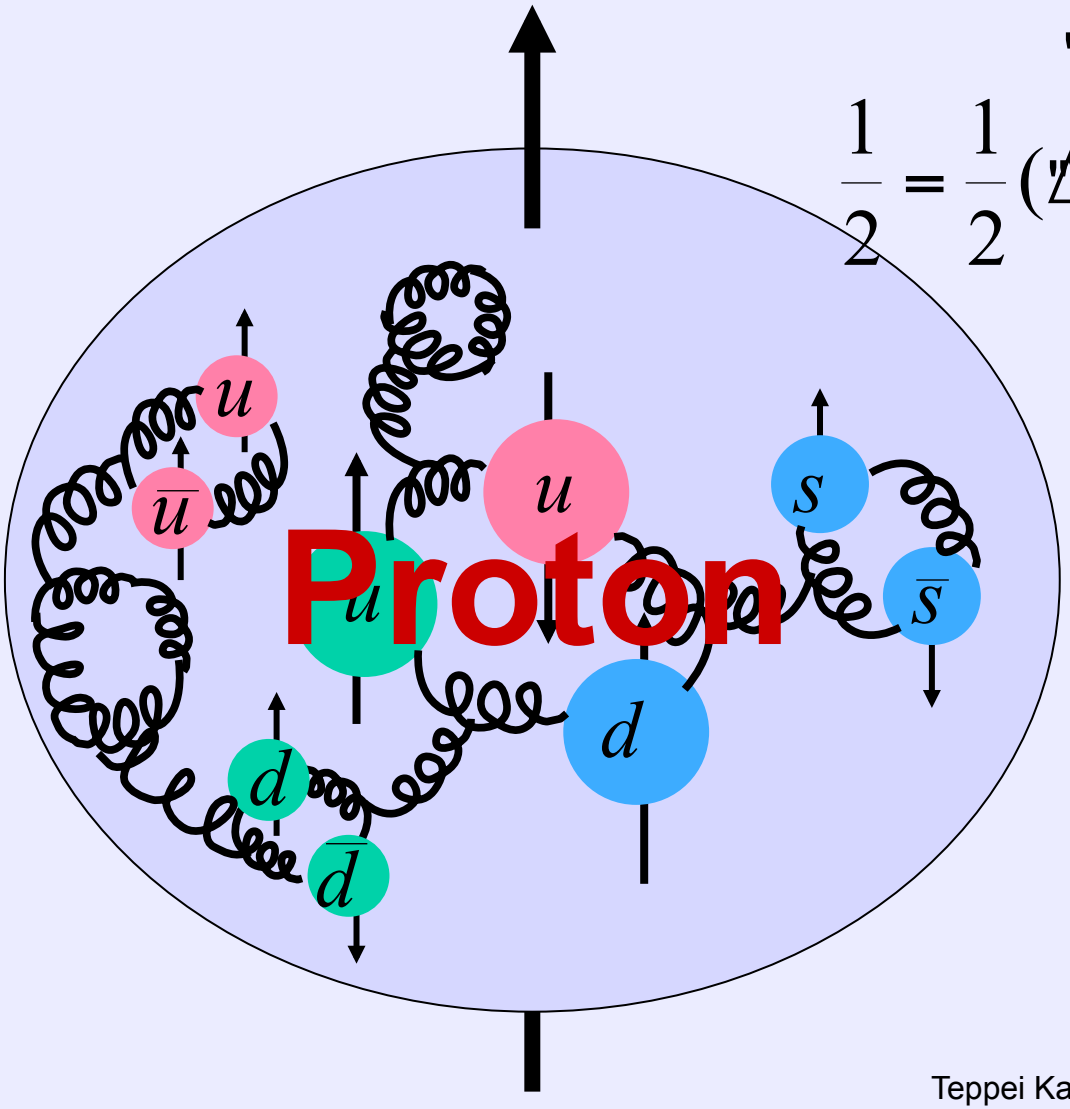
Teppei Katori
Indiana University
DNP 05 Fall meeting, Maui, Sept. 21, 05

I Physics of Δs

I Physics of Δs

1. What is Δs?

Δs : Strange Quark Spin Component in the Nucleon



"Nucleon spin sum rule"

"Nucleon spin"

$$\frac{1}{2} = \frac{1}{2}(\Delta u + \Delta d + \Delta s) + \Delta G + L_q + L_g$$

"Constituent quark model"

$$\frac{1}{2} = \frac{1}{2}(\Delta u + \Delta d + \Delta s)$$

Δs can be measured through

- Elastic Scattering

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

- Deep Inelastic Scattering

$$\Delta s = \int_0^1 \Delta s(x, Q^2 = \infty)\,dx$$

- Inclusive DIS ~ - 0.1
- Semi-Inclusive DIS ~ 0

Δs is the open question!

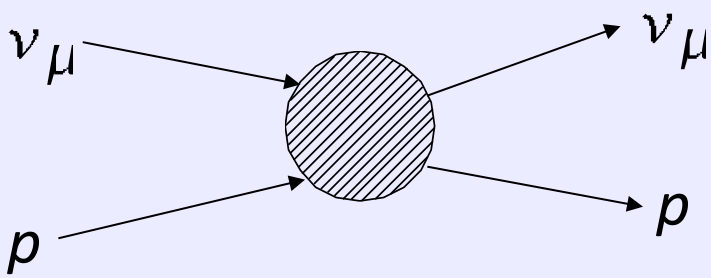
I Physics of Δs

2. How to measure Δs?

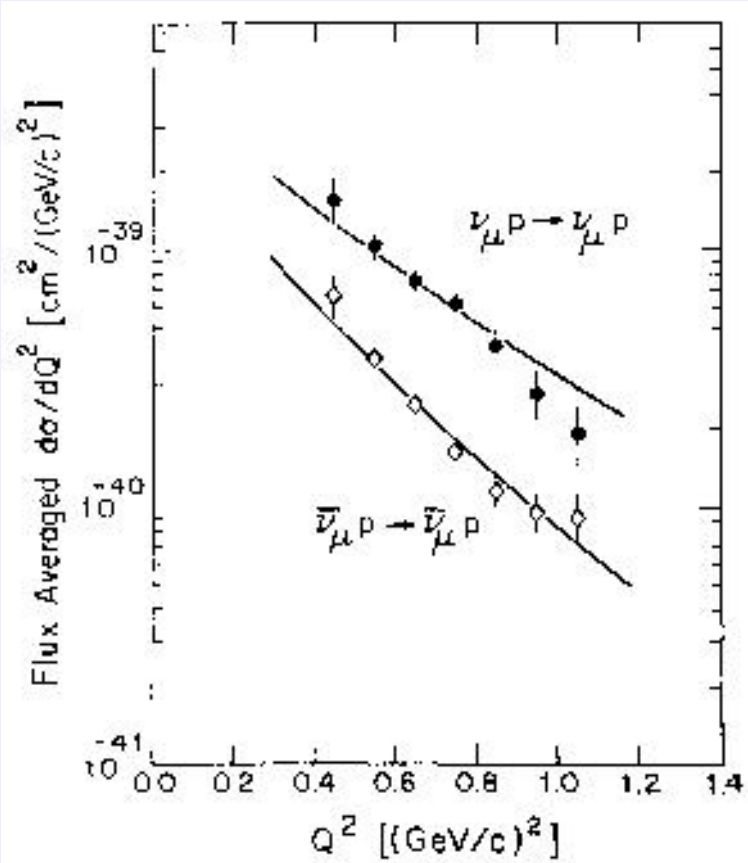
Neutrino NC Elastic Scattering

Clean, Theoretically Robust Method

ex) BNL E734



$$\Delta s = G_A^s(Q^2 = 0) = -0.15 \pm 0.09$$



L. A. Ahrens et al.
(Phys.Rev.D **35**(1987)785)

- no error from F^s_1 and F^s_2
- large systematics (flux, PID)
- extrapolation from relatively high Q^2

FINeSSE

- correct form factor error
- better experimental approach
- extrapolation from smaller Q^2

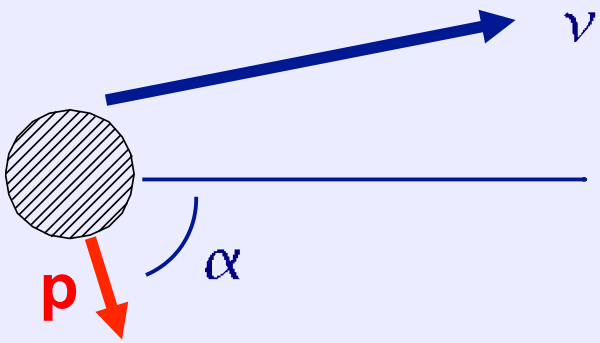
II FINeSSE

II FINeSSE

1. Motivation

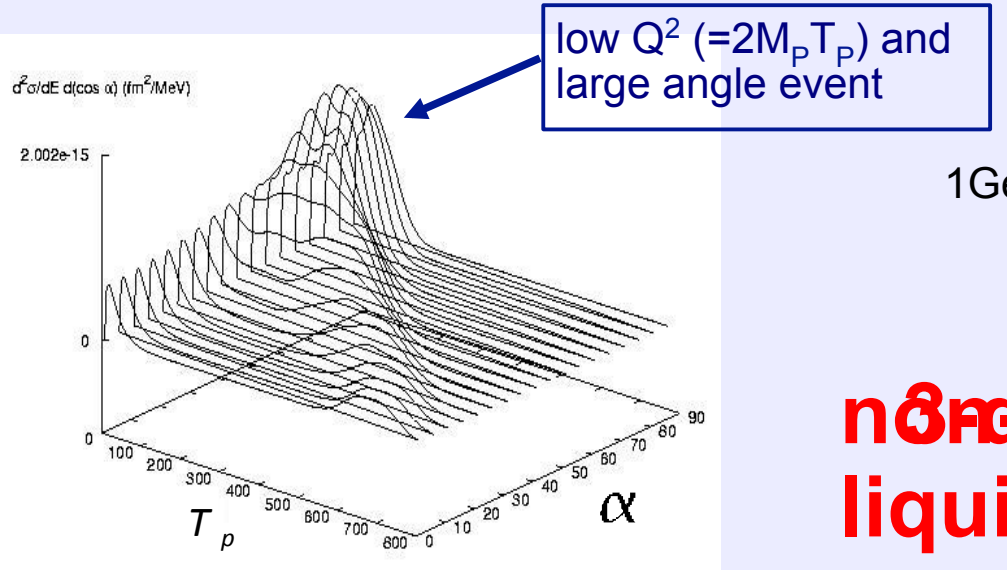
Physics

- Measurement of Low E
  Neutral Current proton (NCp) elastic scattering and
  Charge Current Quasi-Elastic (CCQE) scattering
- Low E (<1GeV) cross section measurement



Experimental Requirement

- Low E intense neutrino beam
- active high resolution tracking detector
- good performance for large angle event



low Q^2 (=$2M_PT_P$) and large angle event

1GeV neutrino XS for nucleon knockout from ^{12}C
van der Ventel and Piekarewicz
(Phys.Rev.C**69**(2004)035501)

3-dimensional tracking
liquid scintillator detector

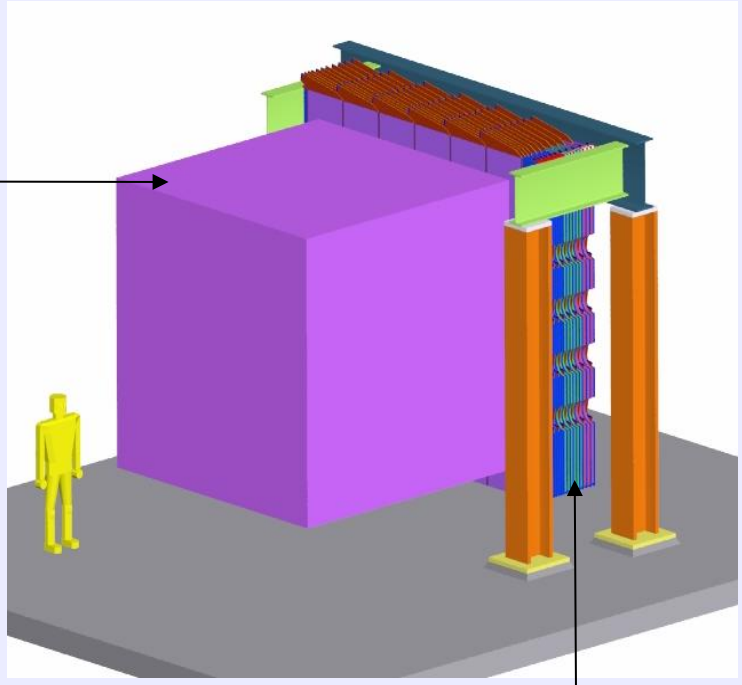
II FINeSSE

2. Fine-grained Intense Neutrino Scintillator Scattering Experiment

FINeSSE detector

The Vertex Detector

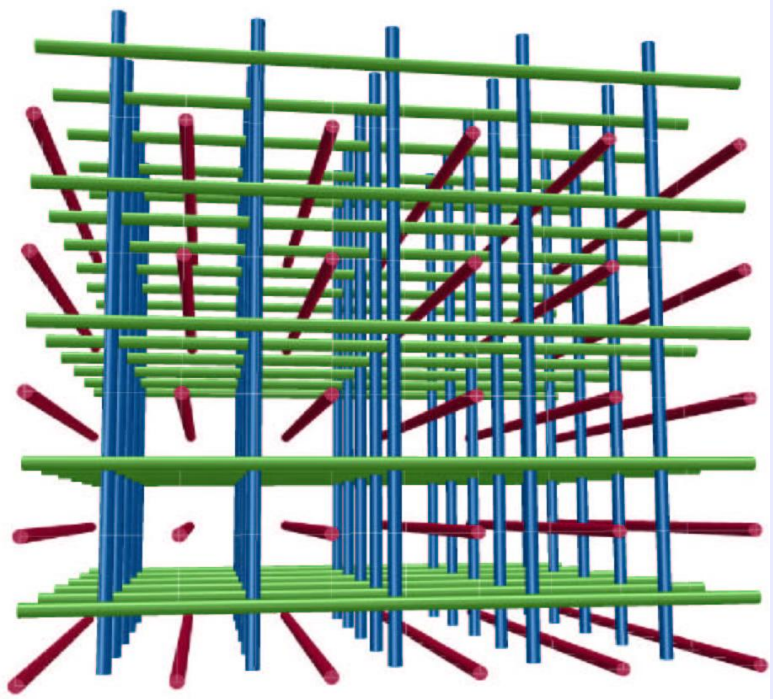
- to precisely track low-energy protons
- $(2.5m)^3$ active liquid scintillator volume
- 19200 (80x80x3) 1.5 mm WLS fibers on 3cm spacing with 3 orientations

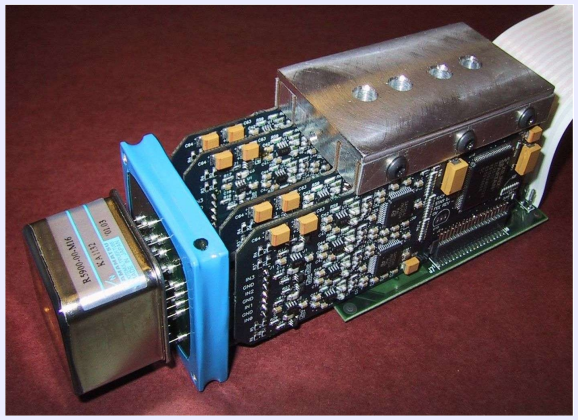


The Muon Rangestack

- to track and measure the energy of muons

Vertex Detector "Scibath" fiber orientation





Read out PMT and front-end electronics

II FINeSSE

3. FINeSSE physics

FINeSSE "Scibath" simulation

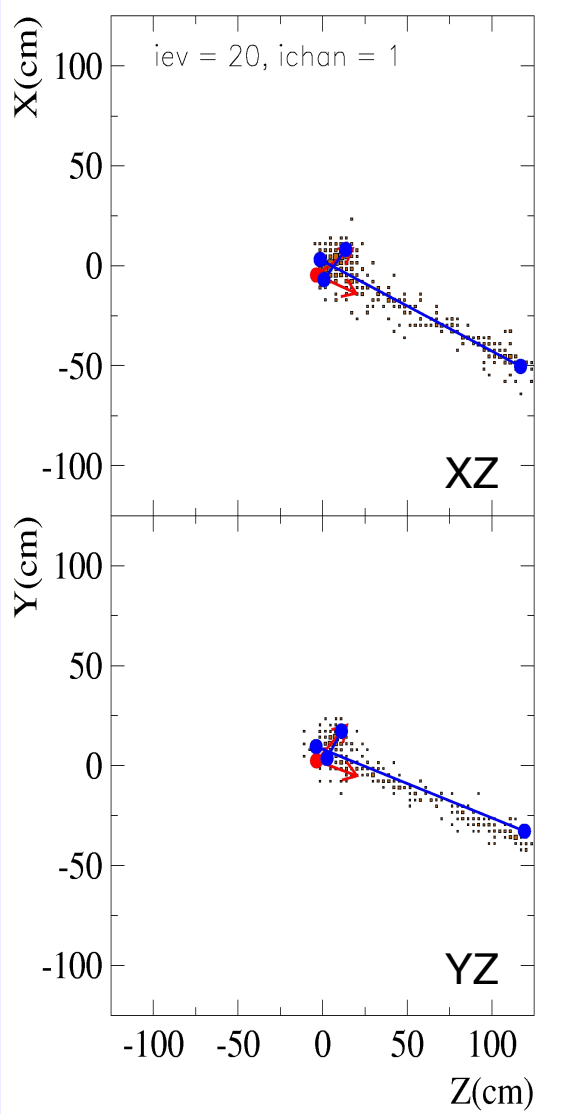
simulated hits and reconstructed tracks in the Vertex Detector

- fiber hits, (size ∝ # γ collected)

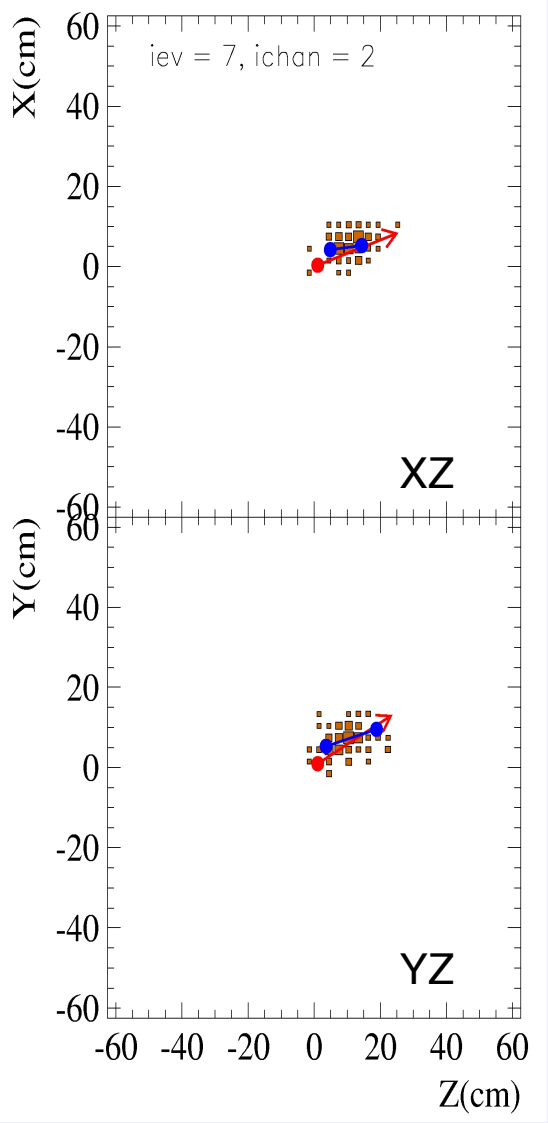
generated

reconstructed

CCQE event
T(mu)=820MeV
T(p)=150MeV



NCp event
T(p)=100MeV

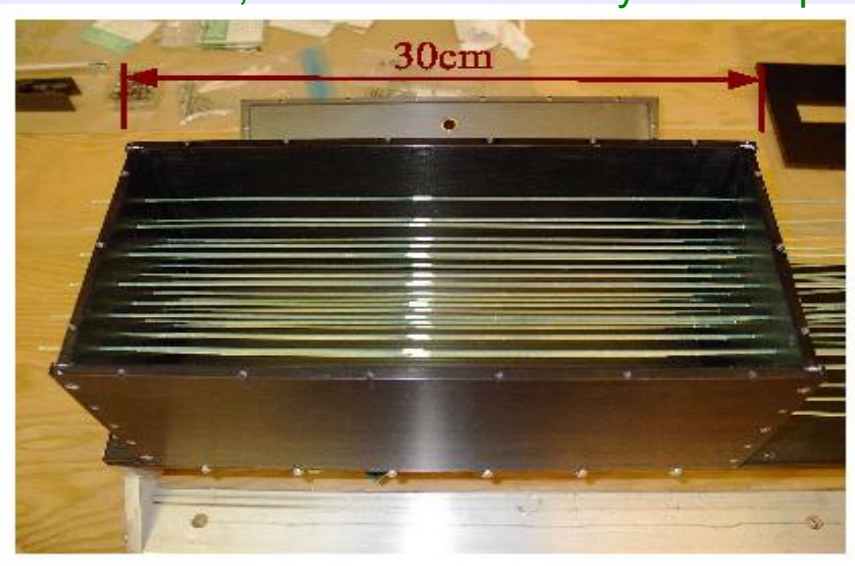


III Scibath pilot detector beam test

III Scibath pilot detector beam test

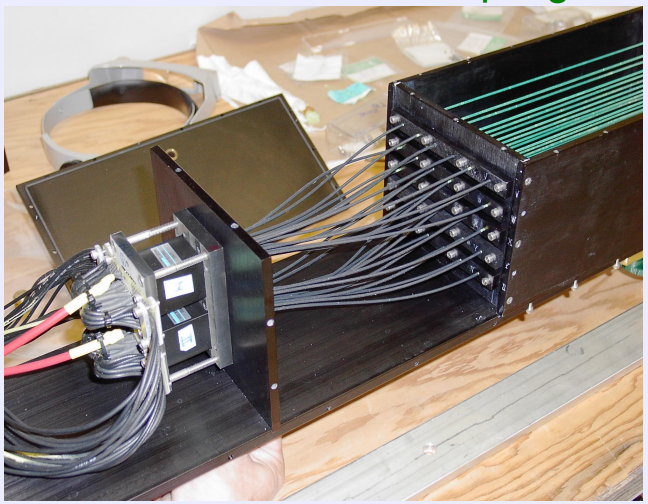
1. Pilot type detector

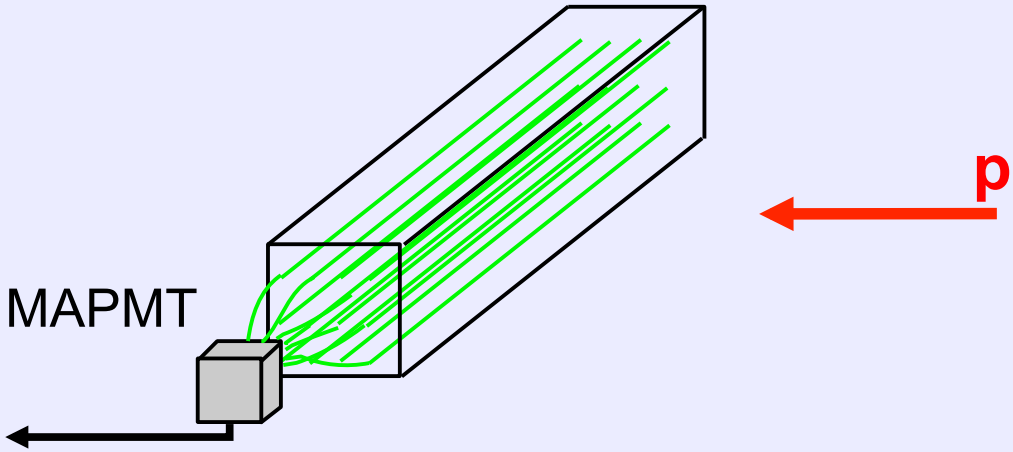
1-dimension, 30 WLS fibers array in the liquid scintillator



Read out by 16ch. MAPMT (H8711)

Fiber and MAPMT coupling





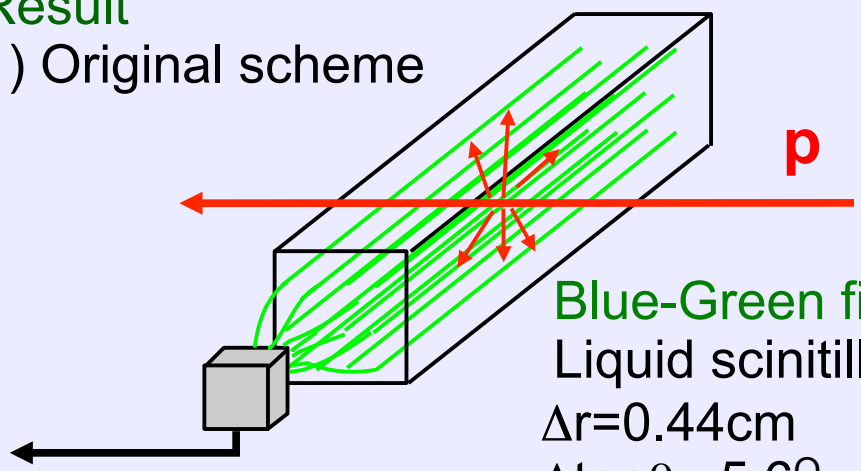
Prototype "Scibath" have been tested by using 200MeV proton beam at Indiana University Cyclotron Facility (IUCF), Radiation Effect Research Program (RERP)

III Scibath pilot detector beam test

2. Result

Result

1) Original scheme



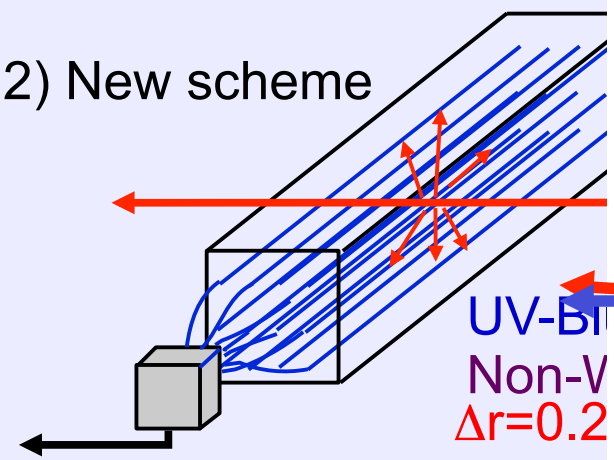
Blue-Green fib

Liquid scinitillat

Δr=0.44cm

Δtan

2) New scheme



Tru

tra

UV-Bl

Non-V

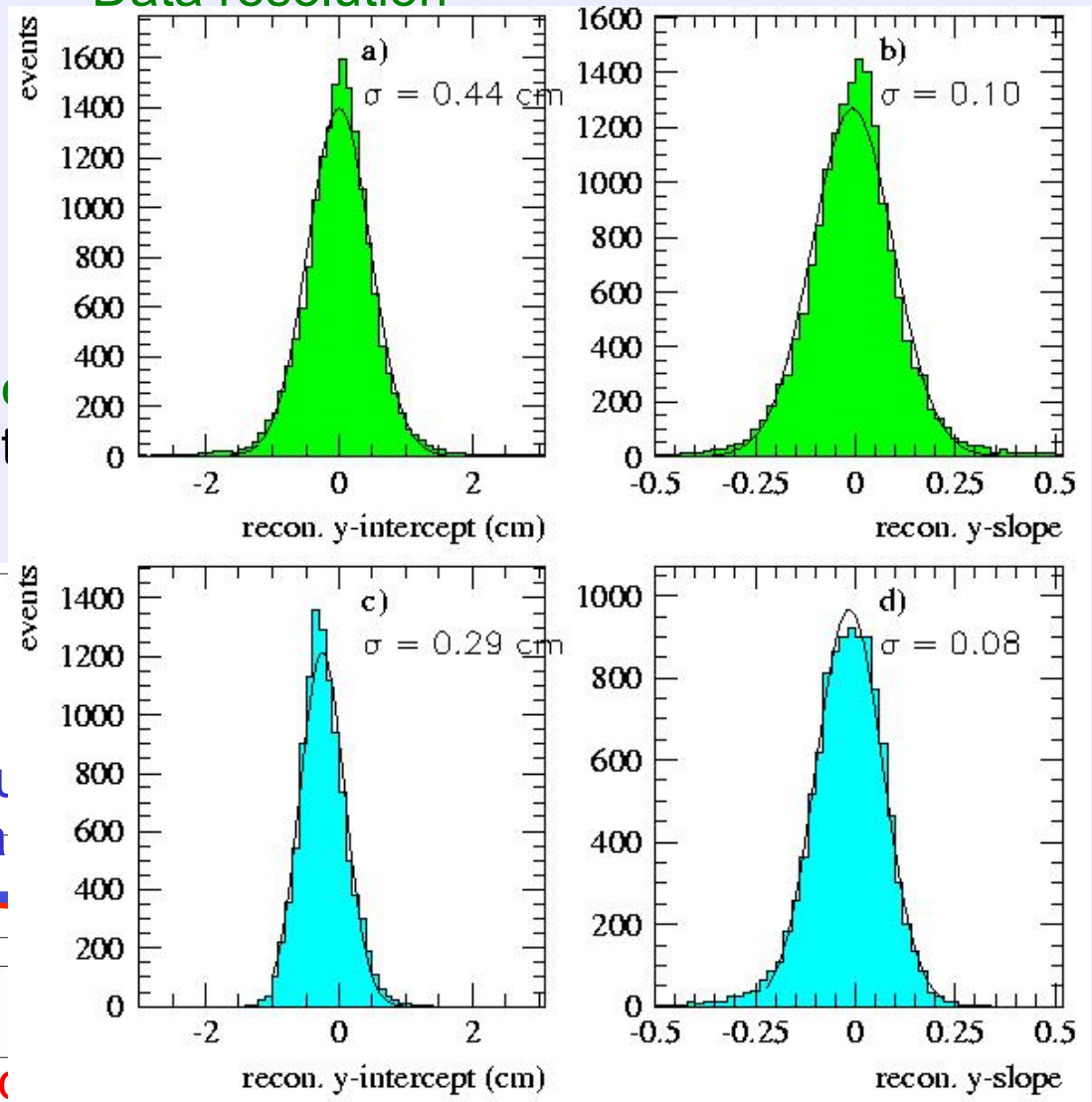
Δr=0.2

Δtanθ

Rec

proton track

Data resolution



new scheme give er position resolution!

CE ssmore

FR.081 : A 3D Liquid Scintillator Neutrino Detector

IV Δs measurement

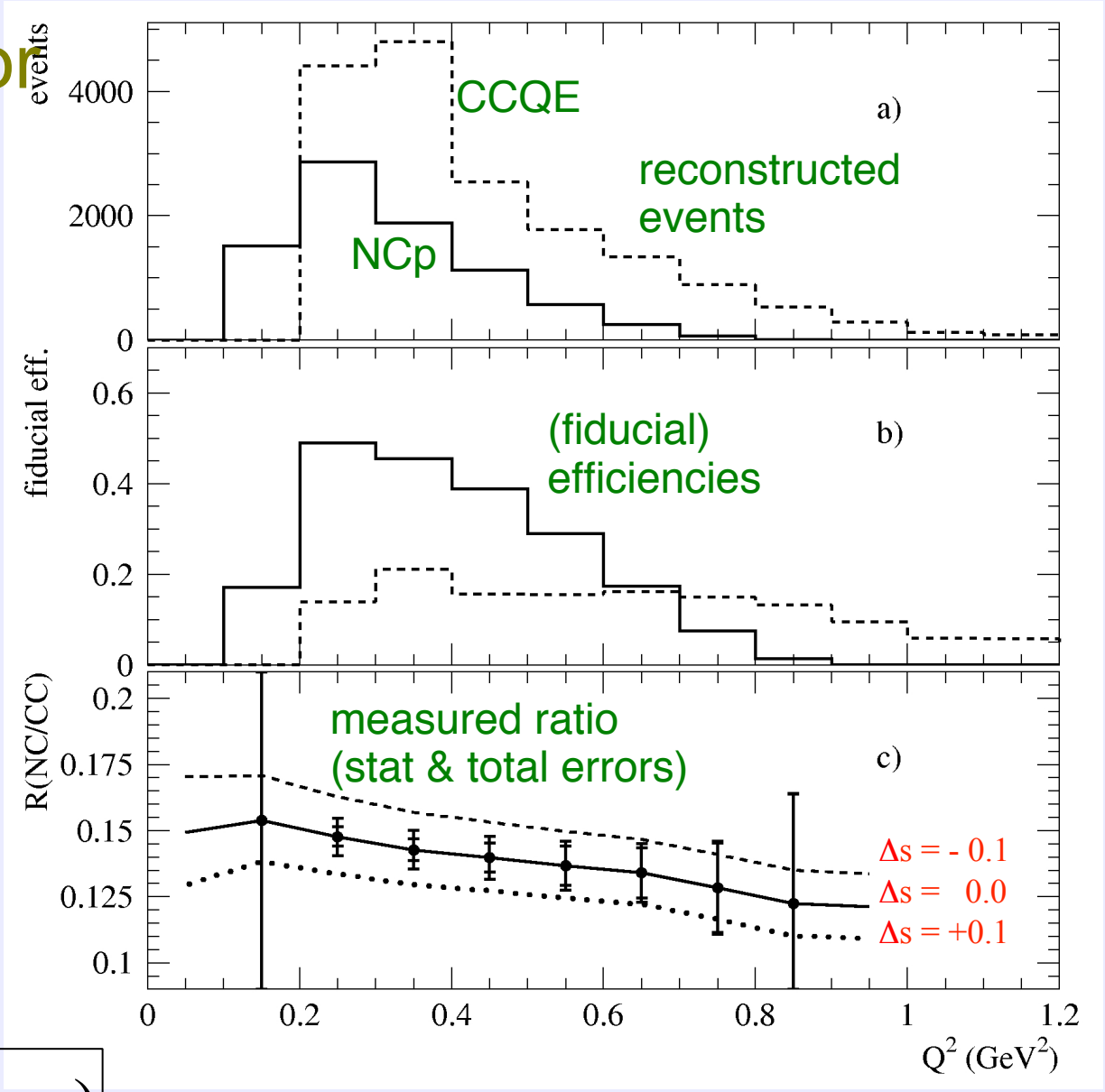
IV Δs measurement

1. Experimental error

Δs is measured from R_ν(NCp/CCQE)

Efficiency is high around Q^2 = 0.2 - 0.6 GeV^2 region

Experimental error can be extrapolated by using dipole parameterization for Q^2 dependence



$$\delta(\Delta s) = \pm 0.025(stat + sys)$$

IV Δs measurement

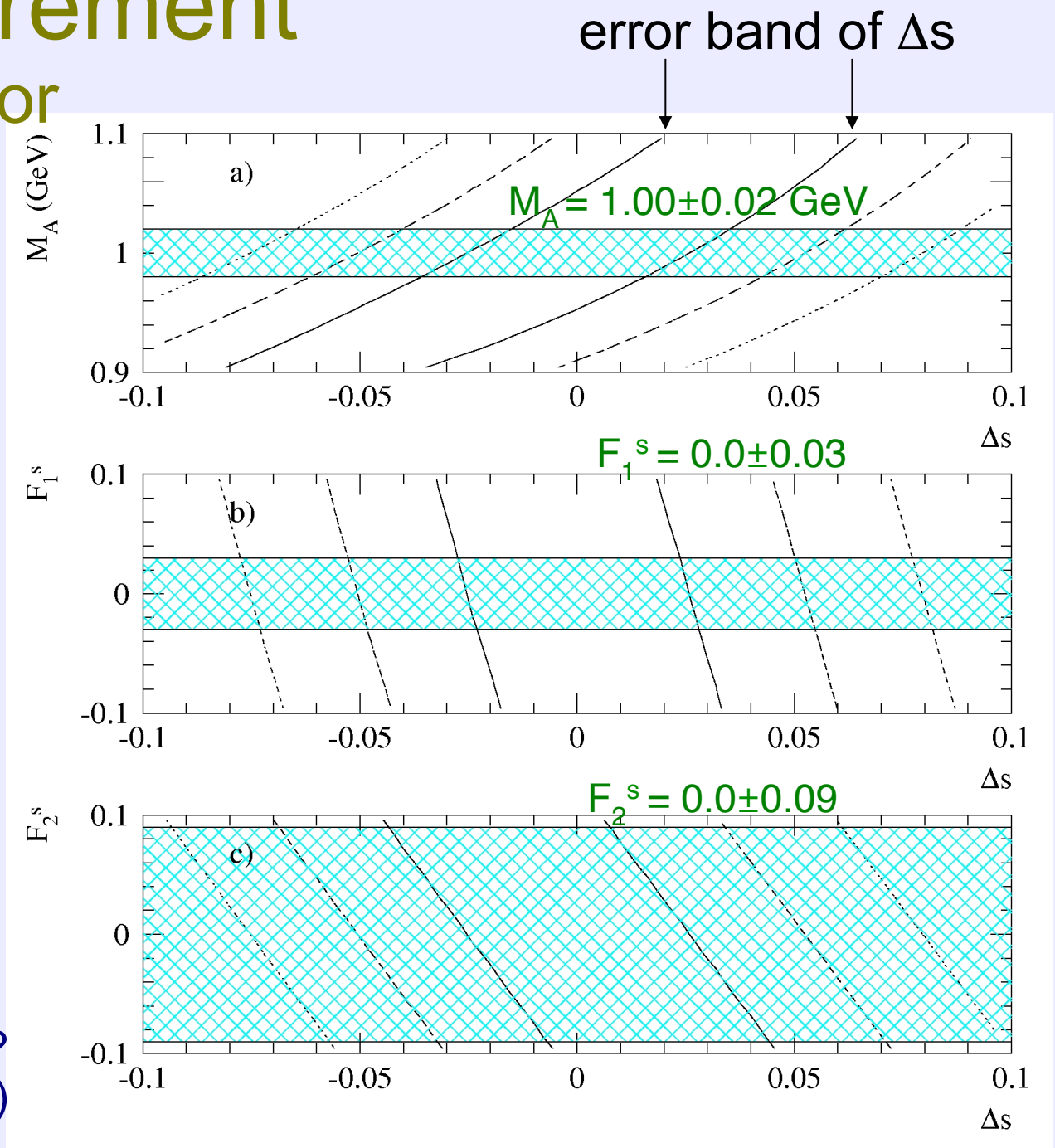
2. Form factor error

R_ν(NCp/CCQE) also depends on M_A, F_1^s and F_2^s

Form factor uncertainties is evaluated from G0 experiment expected errors

$$\delta(\Delta s) = \pm 0.02(sys)$$

F_1^s and F_2^s could be non-zero?
G0 collabo. (nucl-ex/0506021)



FINeSSE, Δs Measurement through neutrino scattering

Summary

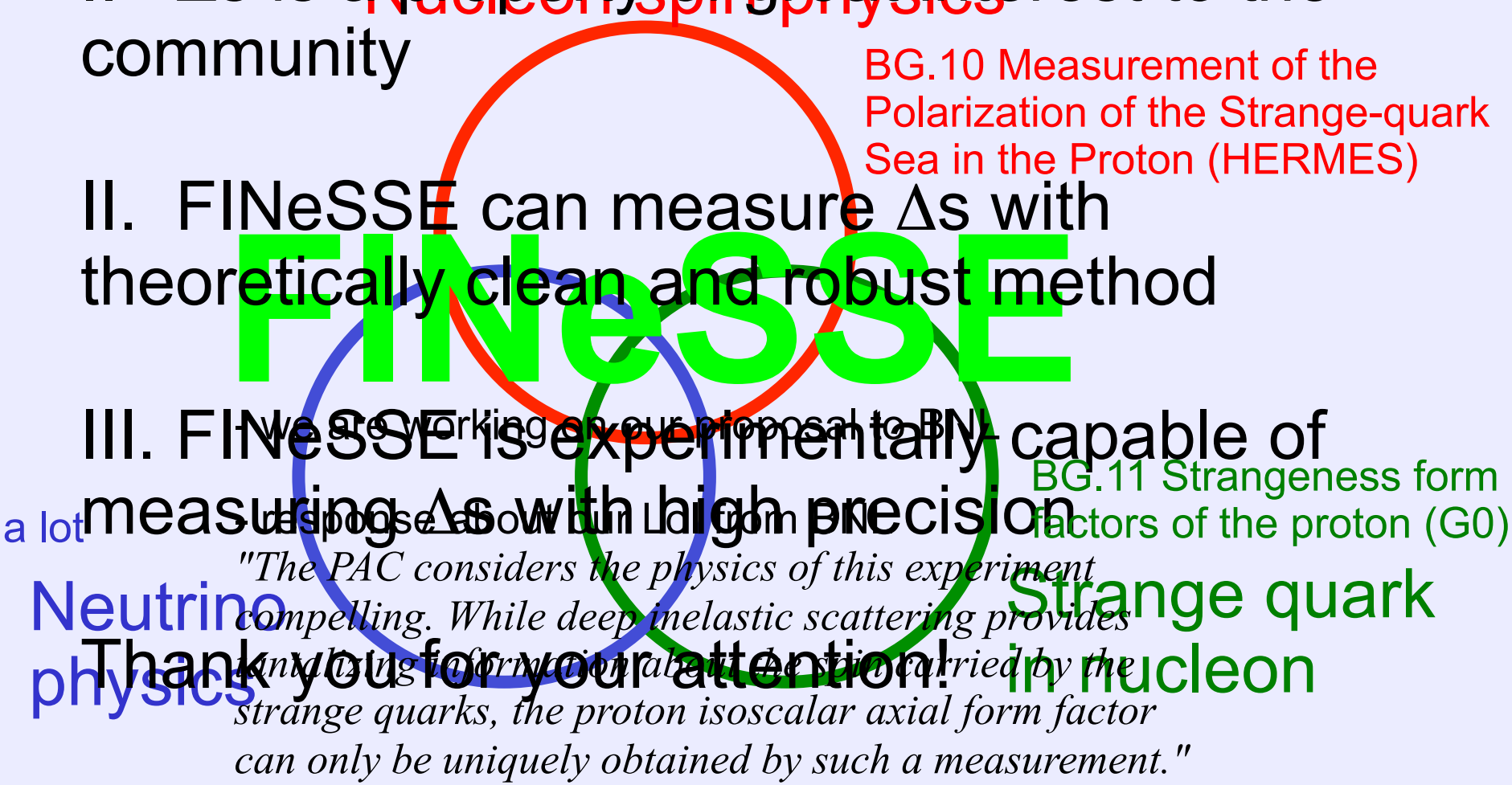
Conclusion

I. Δs is a property of great interest to the community

II. FINeSSE can measure Δs with theoretically clean and robust method

III. FINeSSE is experimentally capable of measuring Δs with high precision

Thank you for your attention!



- we are working on our proposal to BNL

- response above but LOI from PAC

"The PAC considers the physics of this experiment compelling. While deep inelastic scattering provides valuable information about the spin carried by the strange quarks, the proton isoscalar axial form factor can only be uniquely obtained by such a measurement."

FINeSSE Collaboration

L. Bugel, J. M. Conrad, M. Shaevitz, G. P. Zeller
Columbia University, Nevis Labs, Irvington

S. Brice, D. Finley, R. Stefanski
Fermi National Accelerator Laboratory, Batavia

J. C. Peng
University of Illinois, Urbana-Champaign

C. Horowitz, T. Katori, H.-O. Meyer, M. Novak, C. Polly, R. Tayloe, G. Visser
Indiana University Cyclotron Facility, Bloomington

C. Green, G. T. Garvey, W. C. Louis, G. McGregor, H. Ray, R. Van de Water
Los Alamos National Laboratory, Los Alamos

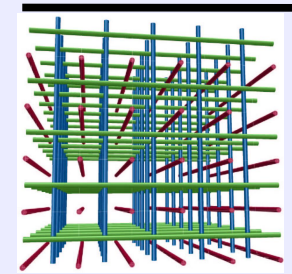
W. Metcalf, M. O. Wascko
Louisiana State University, Baton Rouge

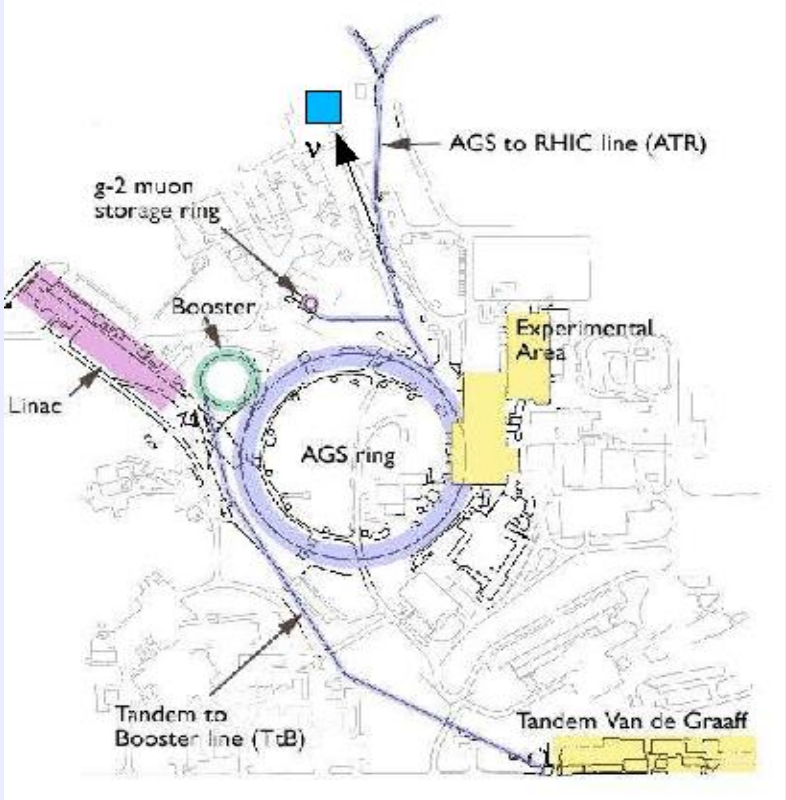
V. Papavassiliou, S.F. Pate
New Mexico State University, Las Cruces

A. Curioni, B. T. Fleming
Yale University, New Haven, Connecticut

FINeSSE

Fine-grained
Intense
Neutrino
Scattering
Scintillator
Experiment





More?

I Physics of Δs

1. What is Δs?

Δs

→ Strange Quark Spin Component in the Nucleon
(Axial Charge of Strange Quark)

→ $Q^2 = 0$ limit of the Nucleon Neutral Current Weak Axial Vector IsoScalar Form Factor (can be measured by elastic scattering)

$$ {}_N\langle p'|(J_A^Z)_\mu|p\rangle_N = -\left(\frac{G_F}{\sqrt{2}}\right)^{\frac{1}{2}} {}_N\langle p'|\bar{u}\gamma_\mu\gamma_5 u - \bar{d}\gamma_\mu\gamma_5 d - \bar{s}\gamma_\mu\gamma_5 s|p\rangle_N $$

$$ = -\left(\frac{G_F}{\sqrt{2}}\right)^{\frac{1}{2}} \bar{u}(p')\left(-\underbrace{G_A^{T=1}(Q^2)}_{\text{isovector}}\gamma_\mu\gamma_5\overset{\text{isospin}}{\tau} + \underbrace{G_A^s(Q^2)}_{\text{isoscalar}}\gamma_\mu\gamma_5\right)u(p) $$

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

I Physics of Δs

1. What is Δs?

Δs

→ Strange Quark Spin Component in the Nucleon

→ $Q^2 = \infty$ limit of the 1st moment of polarized strange quark PDF

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

$$\boxed{\Delta s = \int_0^1 \Delta s(x,Q^2 = \infty)dx}$$

$$G_A^s(Q^2 = 0) = \Delta s = \int_0^1 \Delta s(x,Q^2 = \infty)dx$$

this sum rule is the connection between
Elastic Scattering (ES) experiment
and
Deep Inelastic Scattering (DIS) experiment

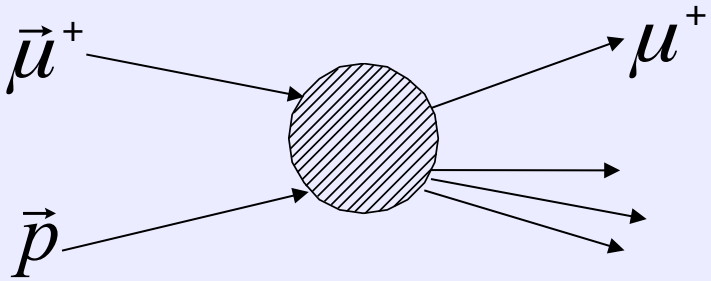
I Physics of Δs

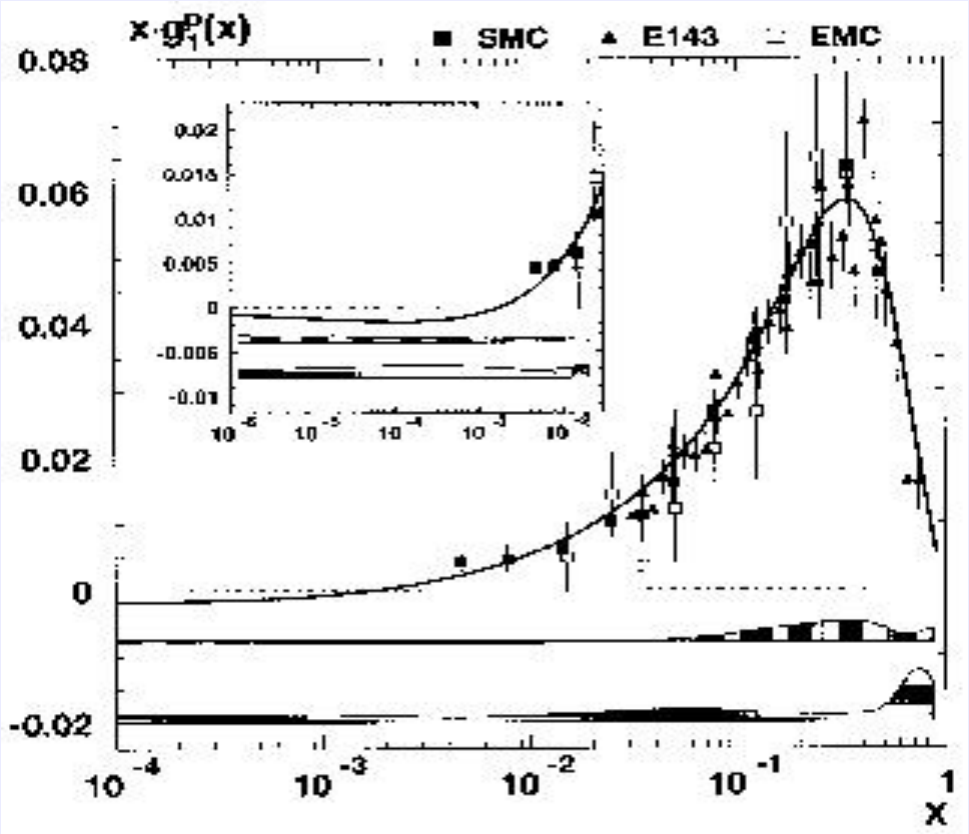
2. How to measure Δs?

Inclusive DIS

ex) SMC

"Spin Crisis"





Spin Muon Collaboration
(Phys.Rev.D**58**(1998)112002)

$$\Gamma_1 = \int_0^1 g_1(x)dx = \frac{1}{2}\sum e_q^2 \int_0^1 \Delta q(x)dx$$

$$= \frac{1}{2}\left[\frac{4}{9}\Delta u + \frac{1}{9}\Delta d + \frac{1}{9}\Delta s\right] = 0.13$$

$$\boxed{\Delta s = -0.12 \pm 0.06}$$

QCD fit

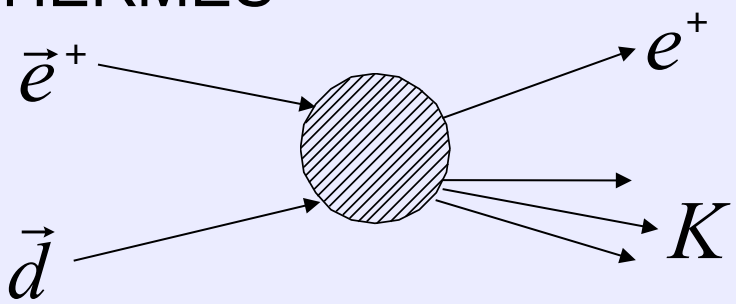
$SU(3)_f$ assumption

I Physics of Δs

2. How to measure Δs?

Semi-Inclusive DIS

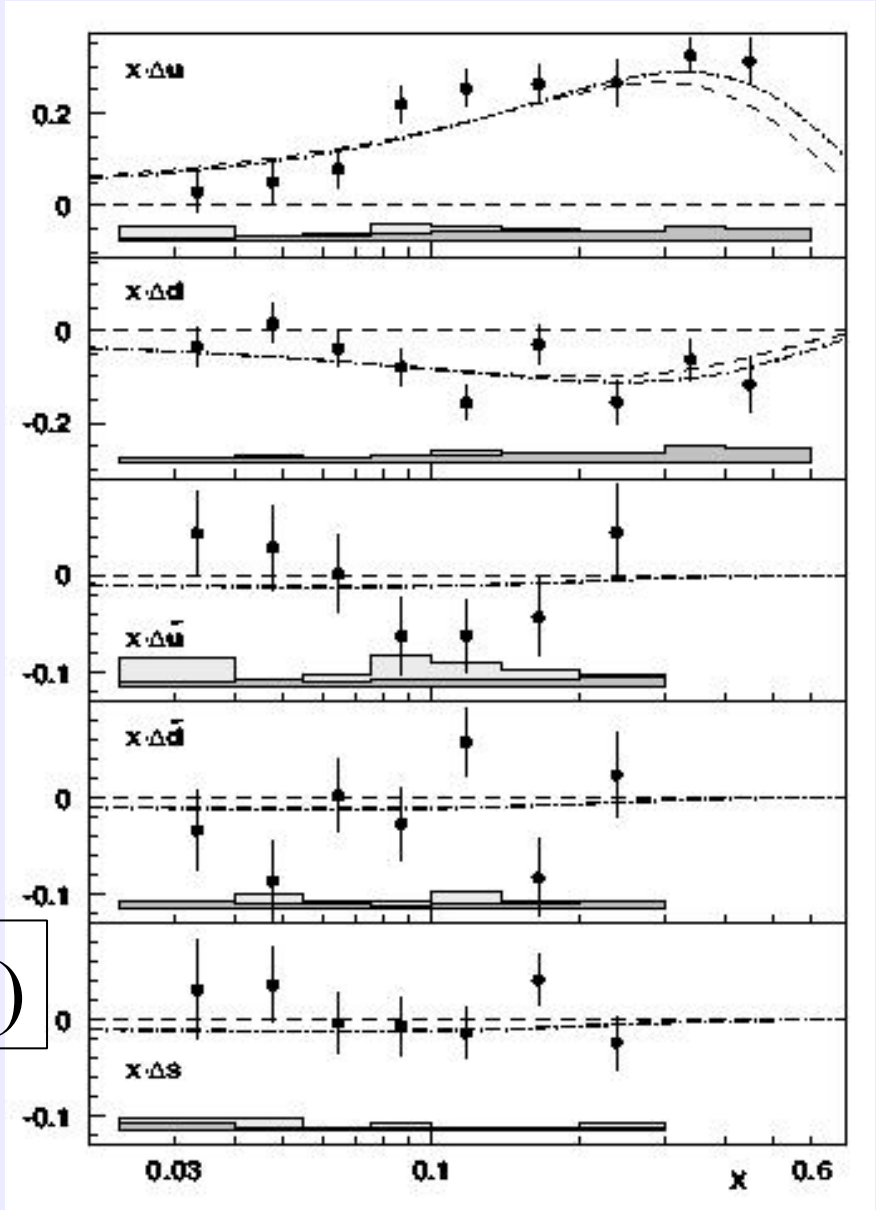
ex) HERMES



$$\Delta s = \int_{x=0.023}^{x=0.30} \Delta s(x)\,dx$$

$$\Delta s = +0.03 \pm 0.03(stat) \pm 0.01(sys)$$

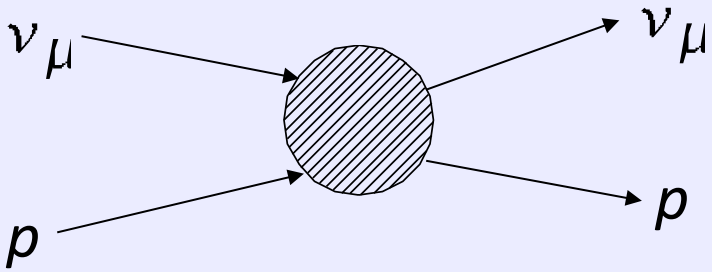
no extrapolation to x=0 and x=1



HERMES Collaboration
(Phys.Rev.Lett. **92**(2004)012005)

I Physics of Δs

2. How to measure Δs?



Neutrino ES

Clean, Theoretically Robust Method

Llewellyn-Smith formalism for Neutral Current Elastic Scattering

$$\frac{d\sigma^z}{dQ^2} = \frac{M^2 G_F^2}{8\pi E_\nu^2}\left[A^Z(Q^2) \pm B^Z(Q^2)\frac{(s-u)}{M^2} + C^Z(Q^2)\frac{(s-u)^2}{M^4}\right]$$

$$A^Z(Q^2) = \frac{Q^2}{M^2}\left\{\left(1+\frac{Q^2}{4M^2}\right)(G_A^Z)^2 - \left(1-\frac{Q^2}{4M^2}\right)(F_1^Z)^2 + \frac{Q^2}{4M^2}\left(1-\frac{Q^2}{4M^2}\right)(F_2^Z)^2 + \frac{Q^2}{M^2}[F_1^Z F_2^Z]\right\}$$

$$B^Z(Q^2) = \frac{Q^2}{M^2}[G_A^Z(F_1^Z + F_2^Z)]$$

$$C^Z(Q^2) = \frac{1}{4}\left\{(G_A^Z)^2 + (F_1^Z)^2 + \frac{Q^2}{4M^2}(F_2^Z)^2\right\}$$

information about Δs

$$\boxed{G_A^Z(Q^2) = \pm\frac{1}{2}G_A^{T=1}(Q^2) - \frac{1}{2}G_A^s(Q^2)}$$

I Physics of Δs

2. How to measure Δs?

Neutrino ES

ex) BNL E734

$$\Delta s = G_A^s(Q^2 = 0) = -0.15 \pm 0.09$$

Ahrens et al.('87)

with taking account form factor uncertainties from F^s_1, F^s_2 and M_A,

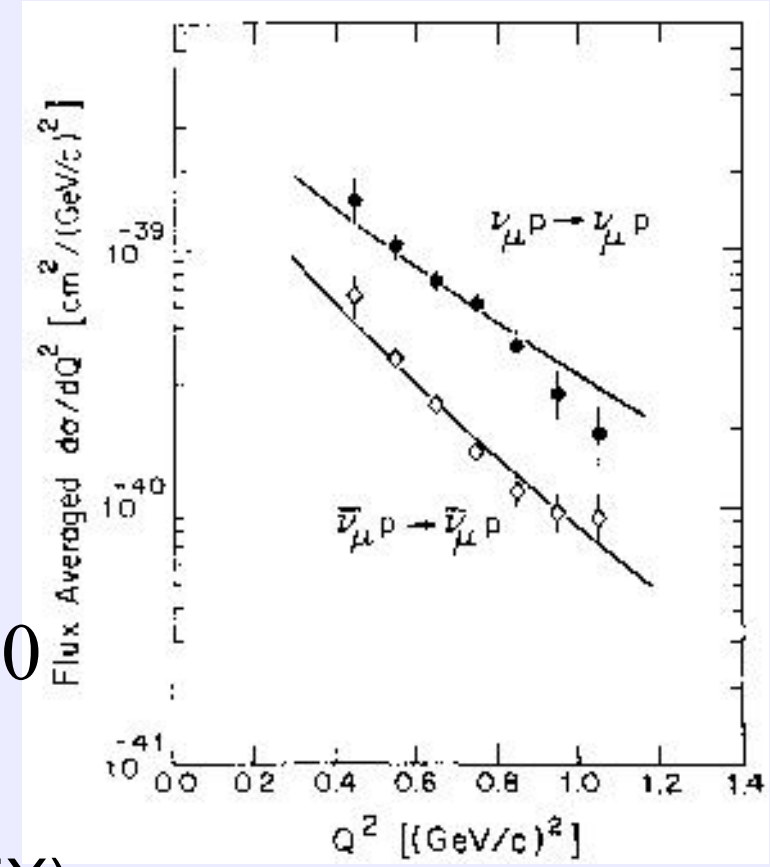
$$\Delta s = G_A^s(Q^2 = 0) = -0.21 \pm 0.10 \pm 0.10$$

Garvey et al.('93)

with Parity Violating electron (PVe) scattering experiment data (from HAPPEX)

$$G_A^s(Q^2 = 0.5GeV^2) = -0.09 \pm 0.05$$

Pate ('04)



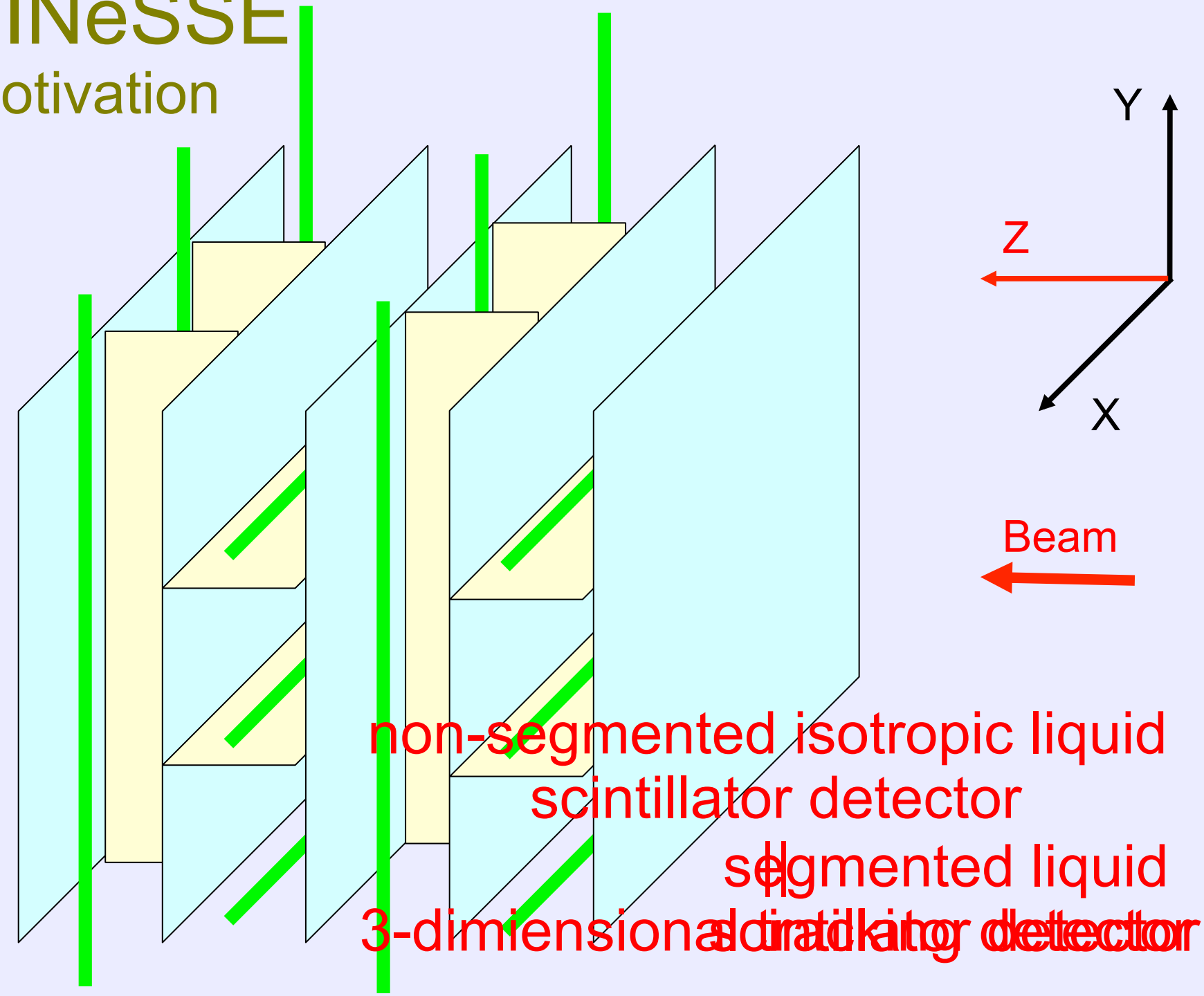
L. A. Ahrens et al. (Phys.Rev.D **35**(1987)785)

- low statistics
- large systematics → **FINeSSE**
- extrapolation from relatively high Q^2

- higher statistics
- better tracking system
- extrapolation from smaller Q^2

II FINeSSE

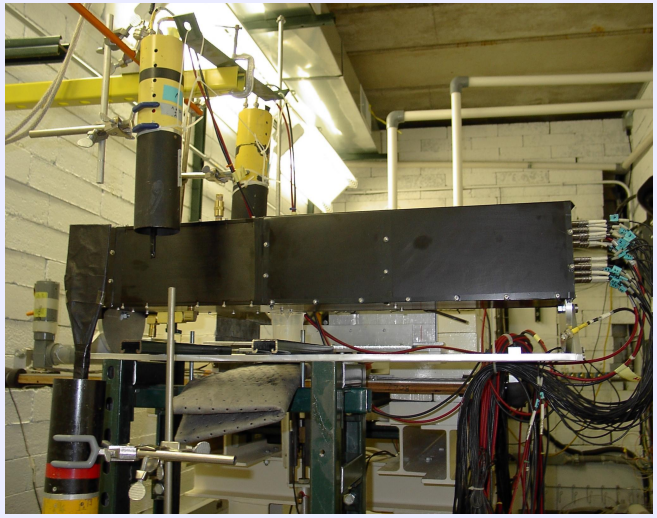
1. Motivation

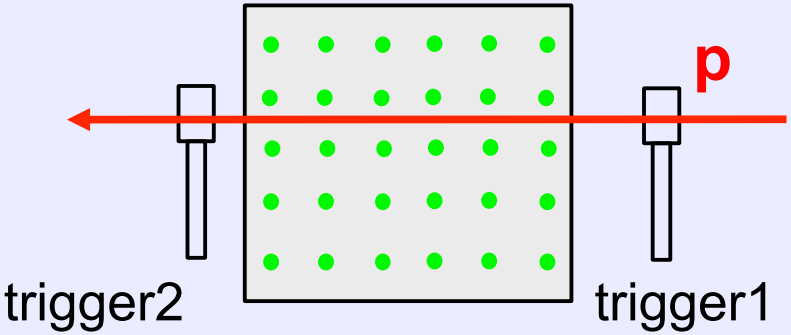


III Scibath pilot detector beam test

2. Light yield

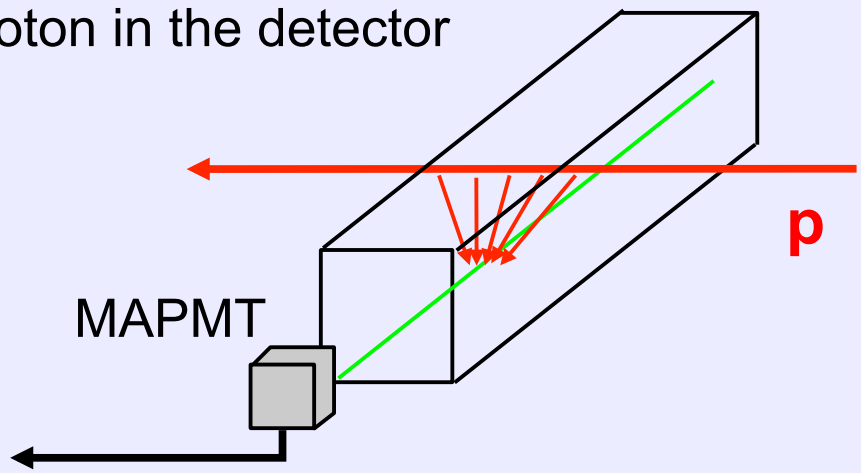
Beam test setup, RERP@IUCF

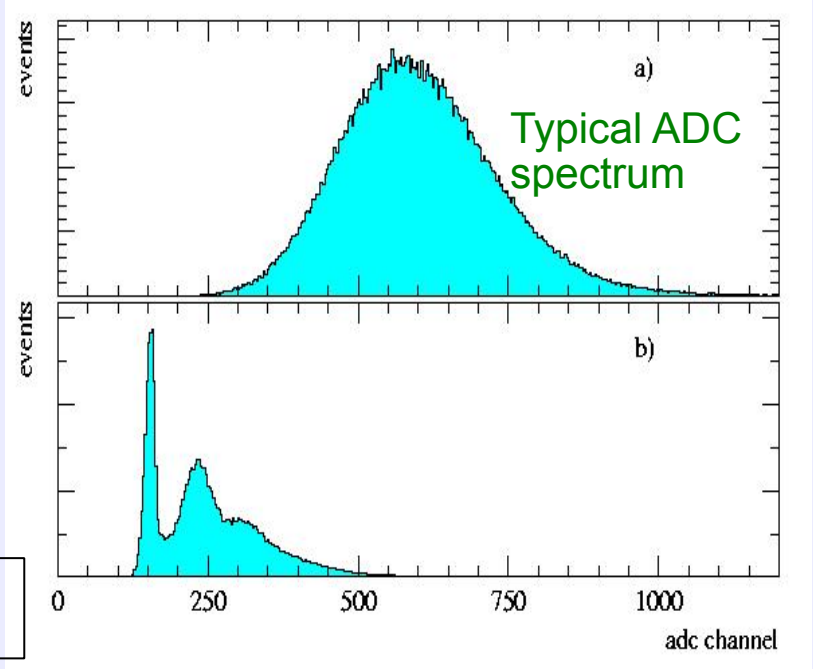




Light Yield

Detected light is the integration of all light from proton in the detector





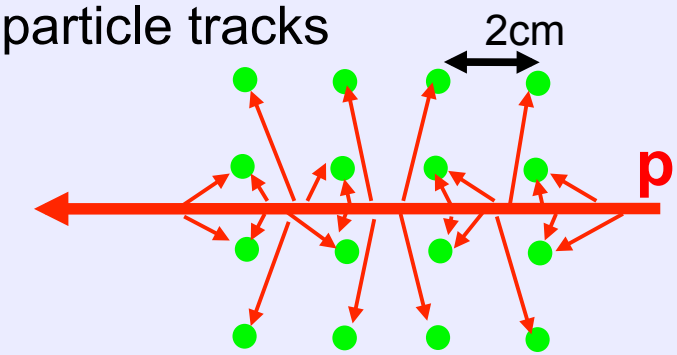
17±2p.e./fiber for near tracks with 200MeV proton

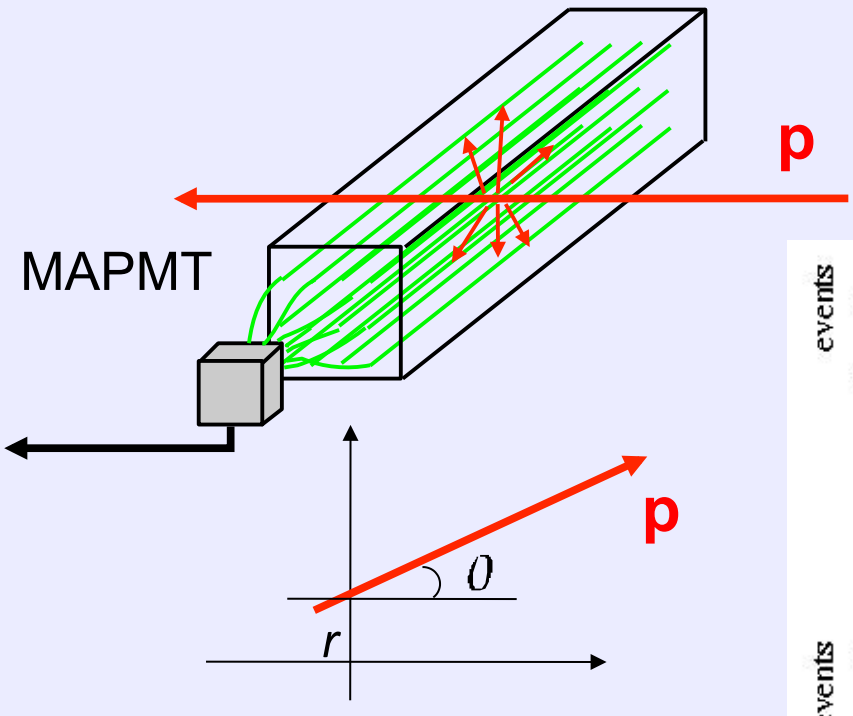
III Scibath pilot detector beam test

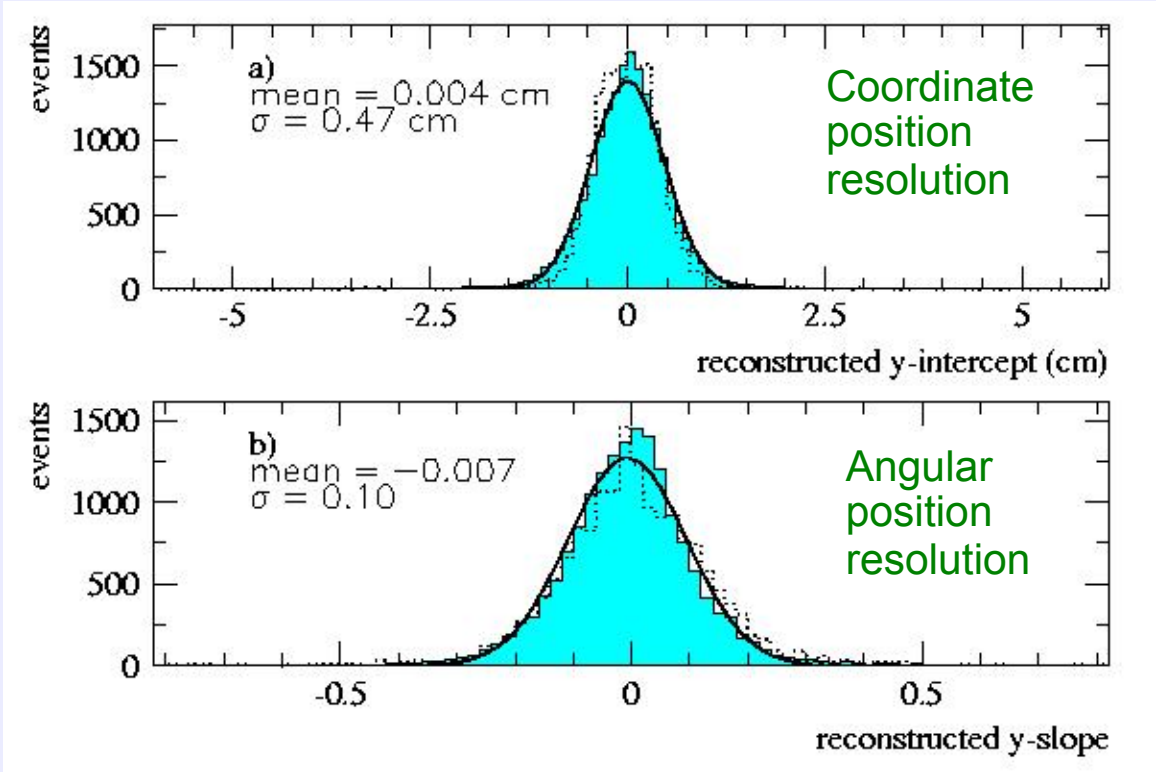
3. Position resolution

Position Resolution

All fibers' information is used to calculate single particle tracks (unlike segmented tracking detector)







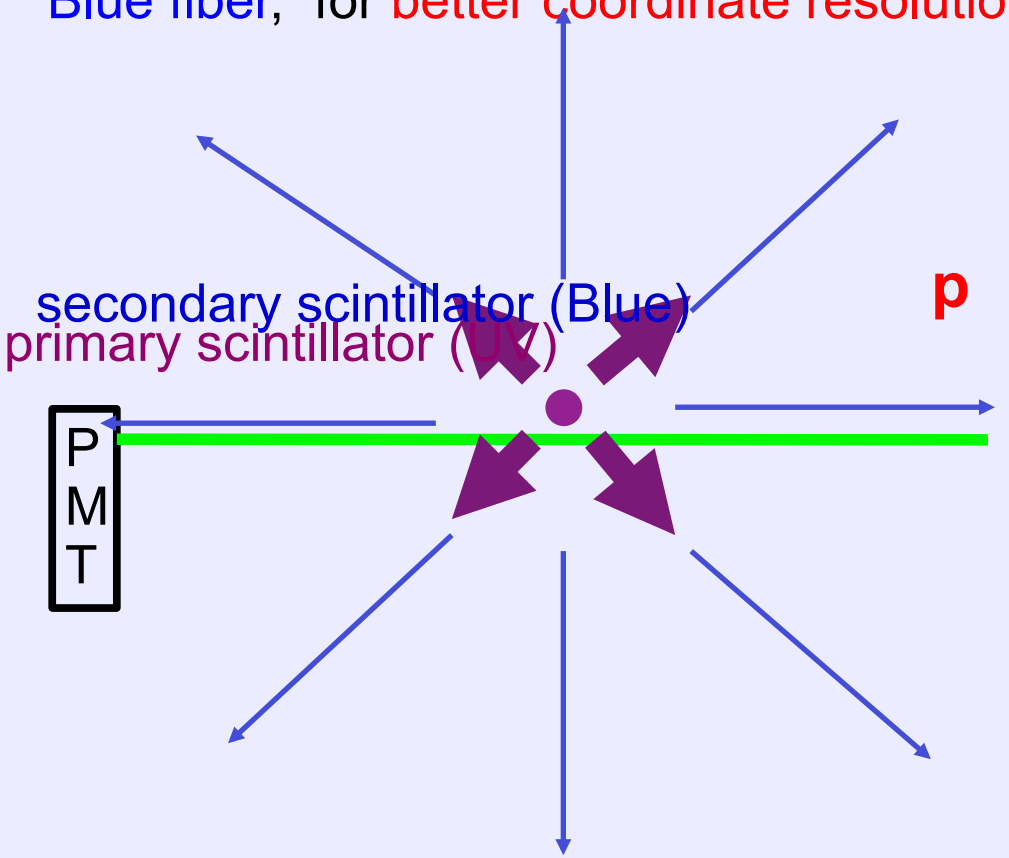
Coordinate Position Resolution
0.44cm
Angular Position Resolution
5.6^{O}

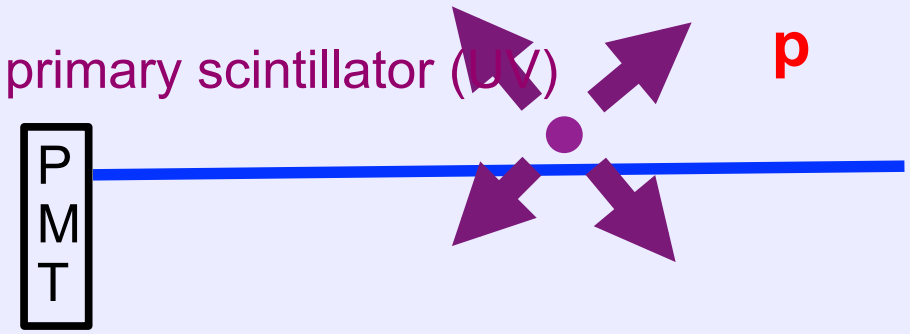
III Scibath pilot detector beam test

4. Non-WLS liquid scintillator

Trick of Non-Wave Length Shifting liquid scintillator

We remove the Wave Length Shifter (secondary scinctillator) from liquid scintillator and make Non-WLS liquid scintillator, and replace fiber from Blue-Green fiber to UV-Blue fiber, for better coordinate resolution and higher light output





traditional scheme of light transportation
p → UV → Blue → Green → PMT

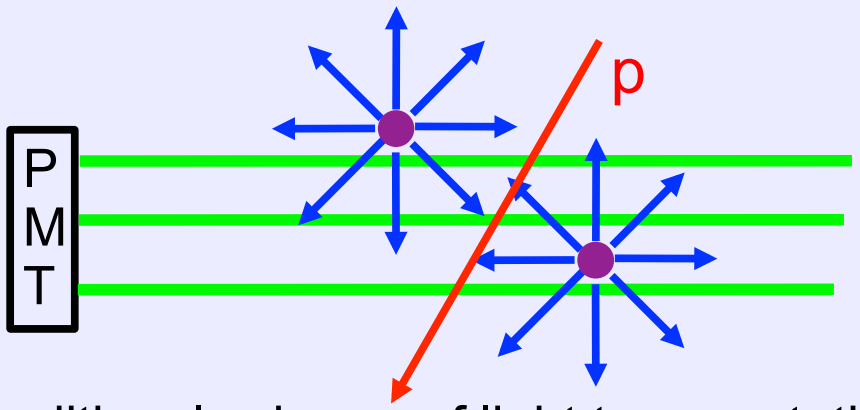
new scheme
p → UV → Blue → PMT

III Scibath pilot detector beam test

4. Non-WLS liquid scintillator

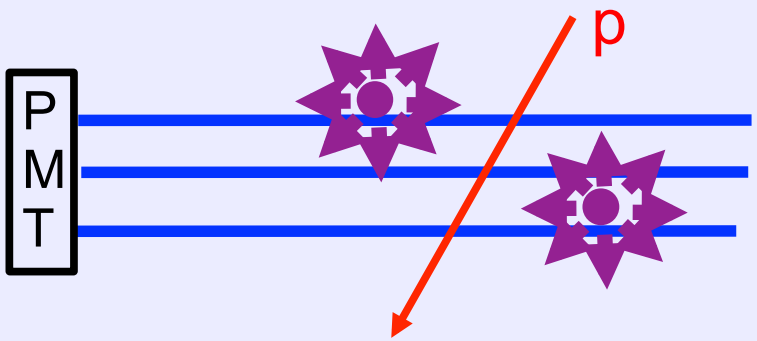
Trick of Non-Wave Length Shifting liquid scintillator

We remove the Wave Length Shifter (secondary scintillator) from liquid scintillator and make Non-WLS liquid scintillator, and replace fiber from Blue-Green fiber to UV-Blue fiber, for better coordinate resolution and higher light output



traditional scheme of light transportation

p → UV Blue → Green → PMT



new scheme

p → UV Blue → PMT

(1) Non-WLS liquid scintillator has shorter attenuation length
→ nicely localize light output

(2) Non-WLS liquid scintillator has locally higher light output
→ higher amount of light to the nearest fiber

(3) UV-Blue fiber sends blue light to MAPMT
→ higher quantum efficiency

(4) UV process is faster

(5) UV light is less reflective

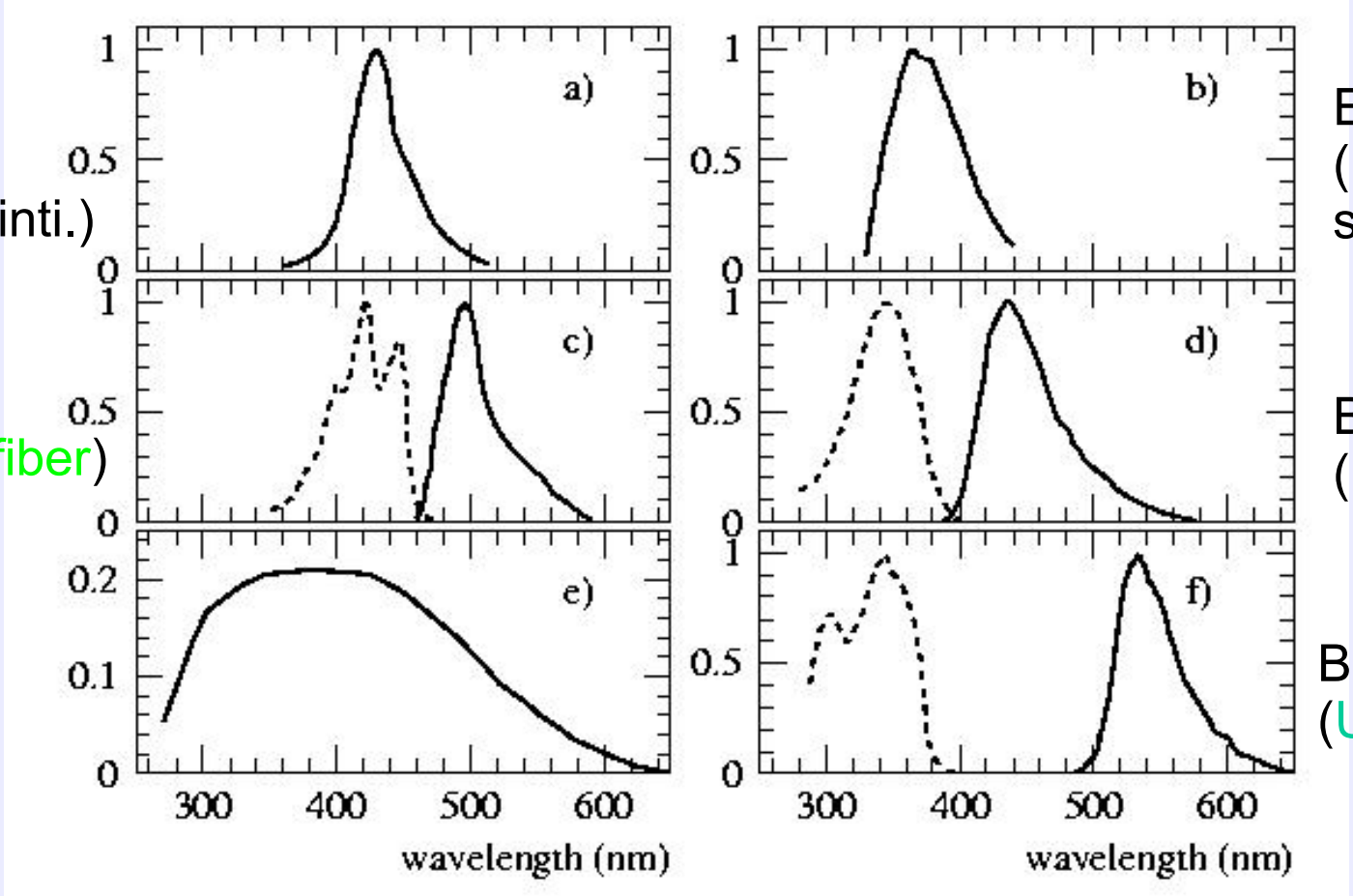
III Scibath pilot detector beam test

4. Non-WLS liquid scintillator

BCS-517H
(usual liq. scinti.)

BCF-91A
(Blue-Green fiber)

quantum
efficiency
of H8711



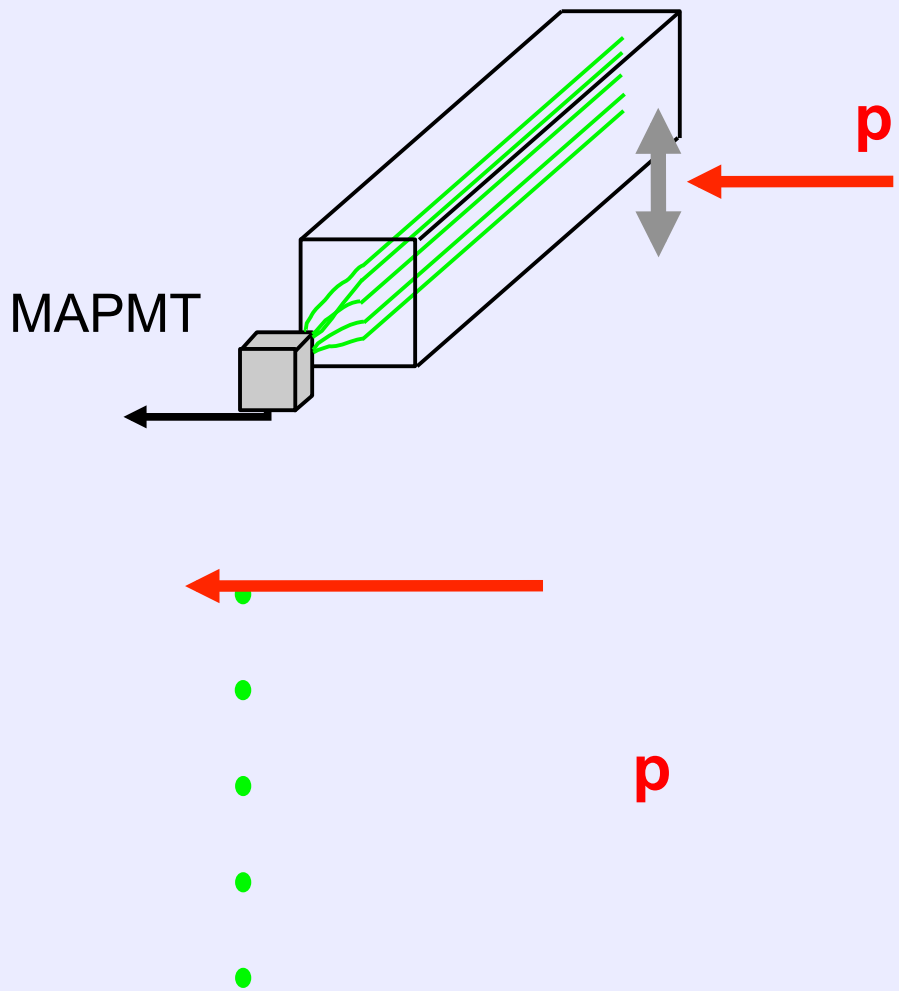
EJ-321L-NS
(Non-WLS liq.
scinti.)

BCF-99(1)
(UV-Blue fiber)

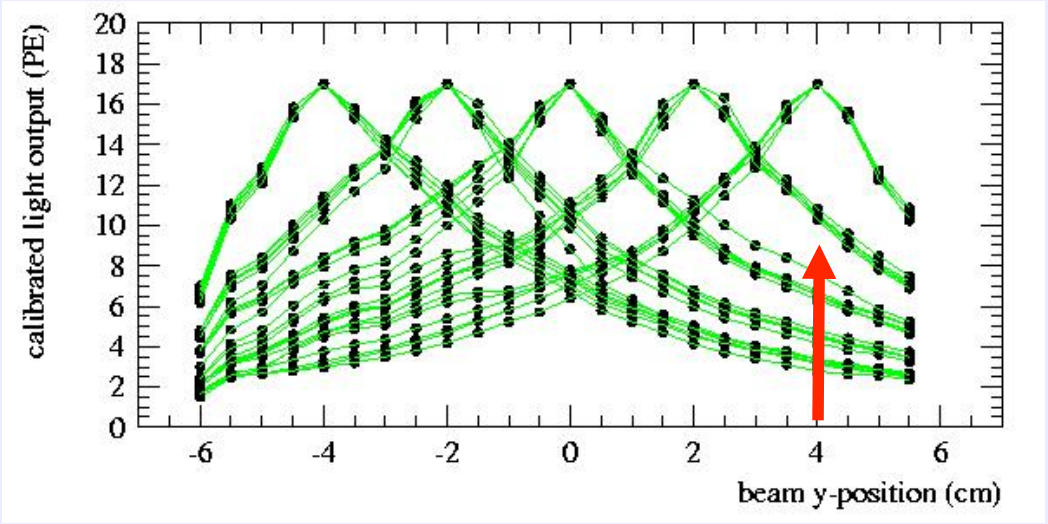
BCF-99(2)
(UV-Green fiber)

III Scibath pilot detector beam test

5. Scan plot

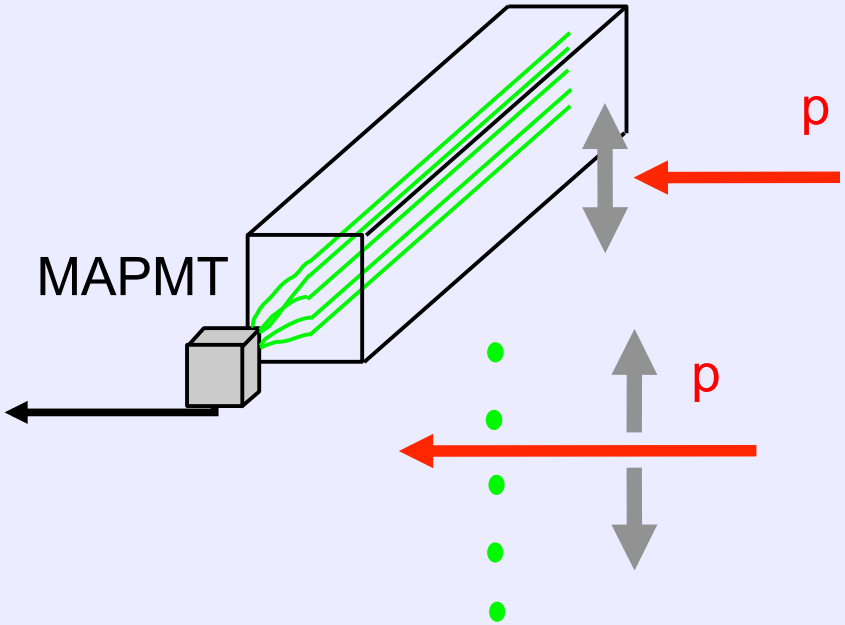


Blue-Green fiber scan plot data

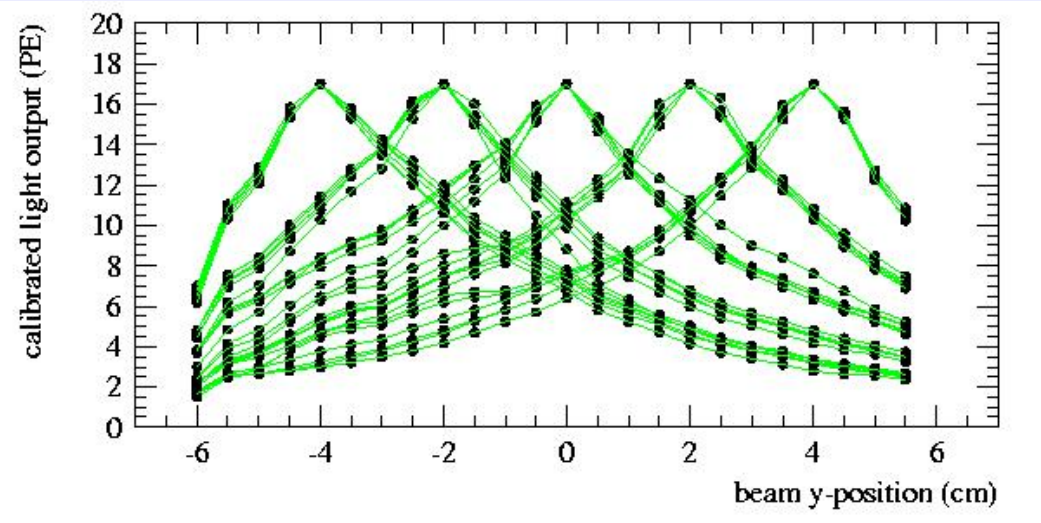


III Scibath pilot detector beam test

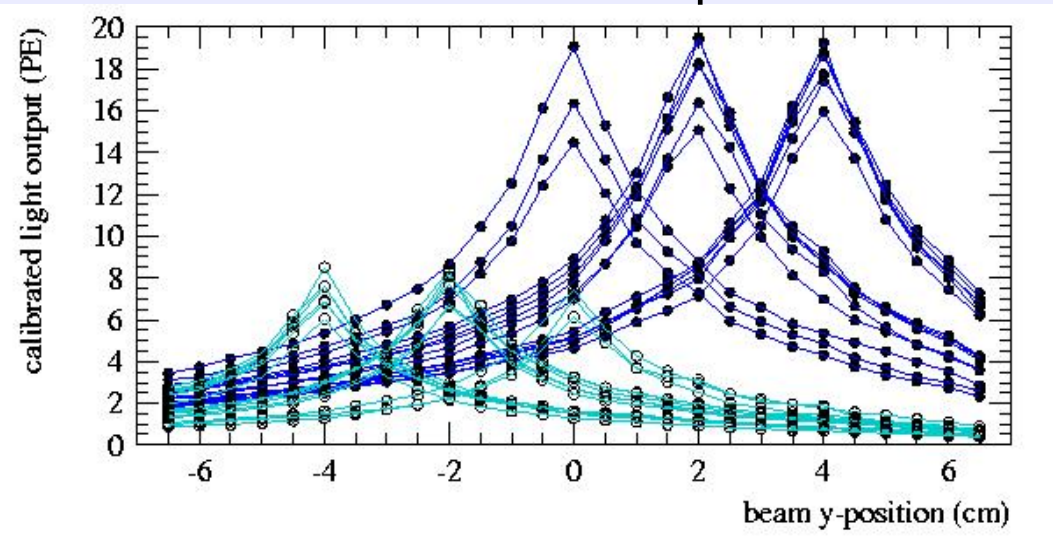
6. Second beam test



Blue-Green fiber scan plot data



UV-Blue fiber scan plot data



UV-Blue fiber makes sharper and narrower peak than Blue-Green fiber

↓

better light localization

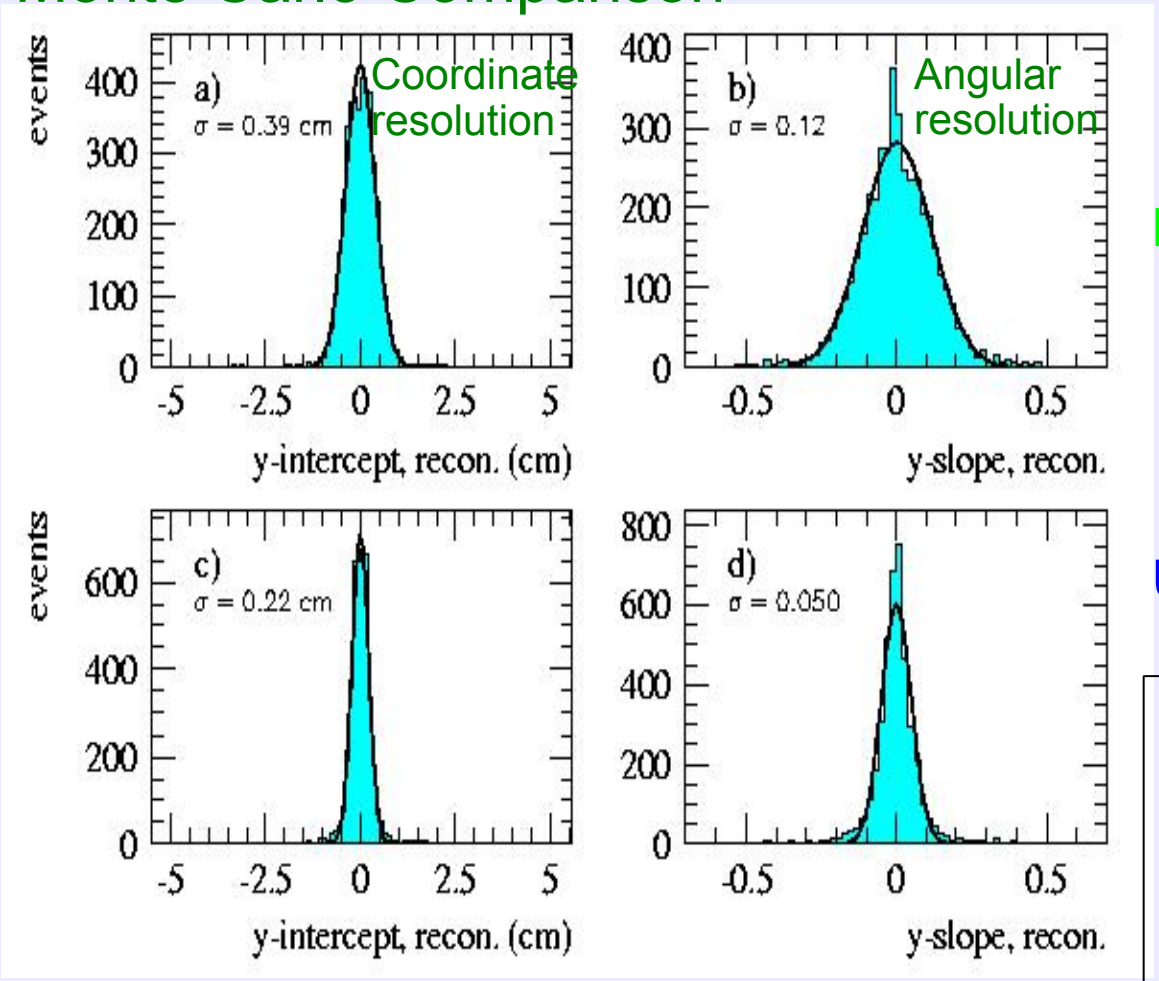
↓

better position resolution

III Scibath pilot detector beam test

7. Non-WLS scintillator position resolution

Monte Carlo Comparison



Blue-Green fiber resolution

~X2 better resolution

UV-Blue fiber resolution

combination of
UV-Blue fiber
and
Non-WLS Liquid Scintillator
gives
better position resolution!

IV Δs measurement

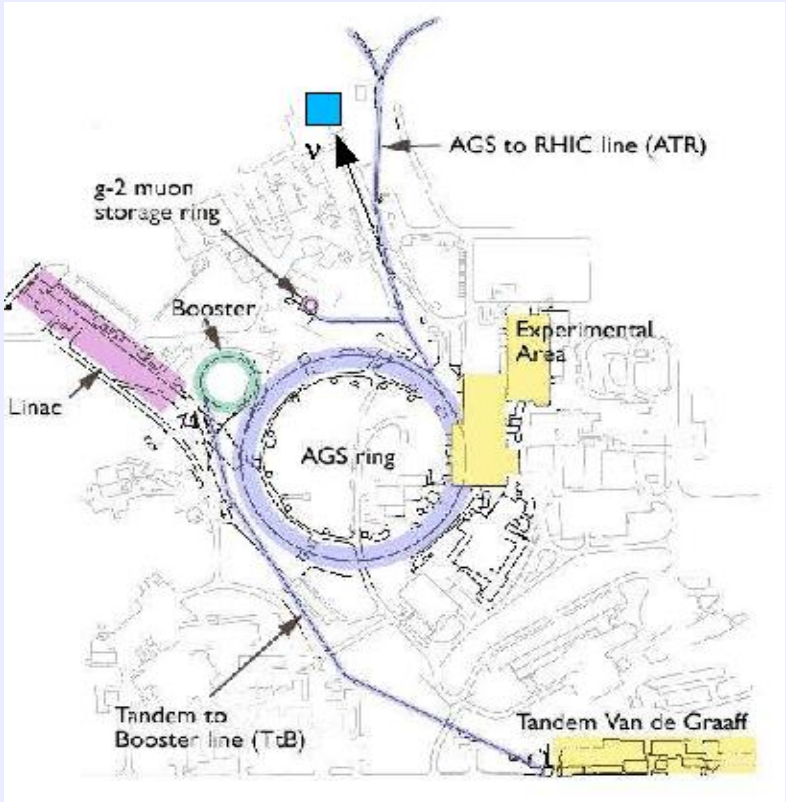
1. Neutrino beam

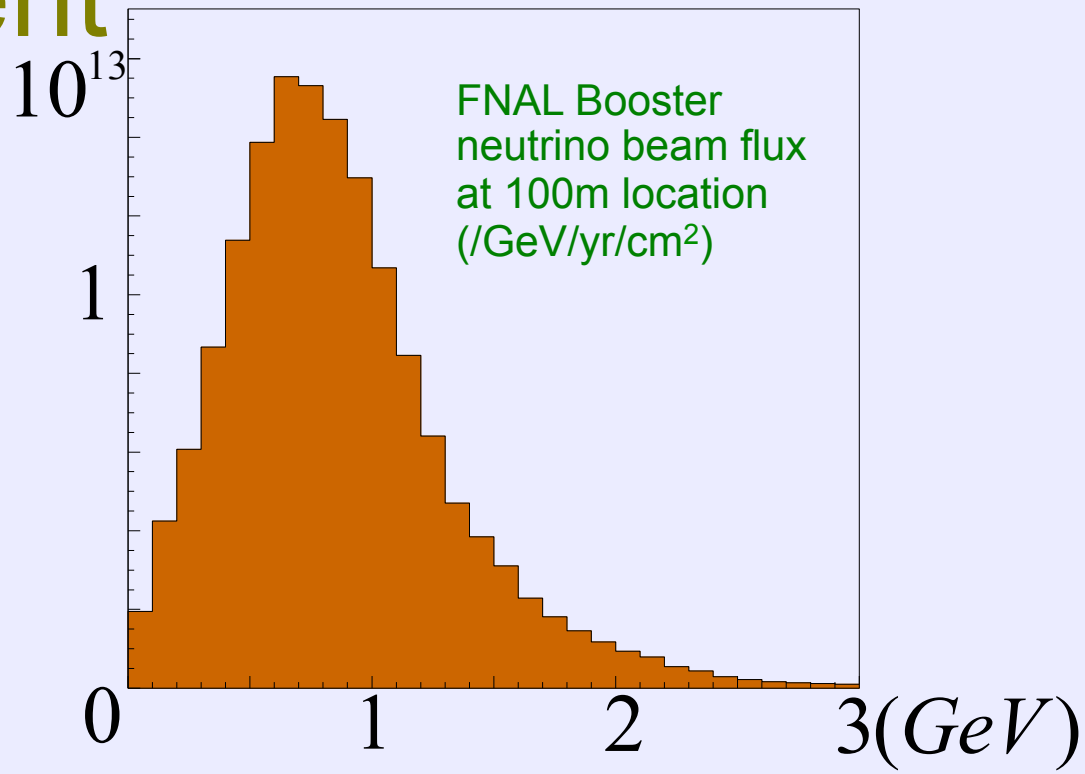
Neutrino beam requirement

- intense
- Low E (<1GeV)
- short high E tail

so candidate places are

- FNAL Booster
- BNL AGS
- JPARC





- We are working our proposal to BNL

- response about our LoI from BNL

"The PAC considers the physics of this experiment compelling. While deep inelastic scattering provides tantalizing information about the spin carried by the strange quarks, the proton isoscalar axial form factor can only be uniquely obtained by such a measurement."

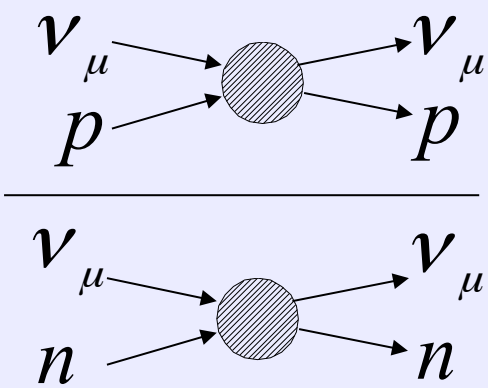
IV Δs measurement

2. Experimental error

FINeSSE ratio scheme

Ideally speaking, we want to measure

$$R_\nu(NCp/NCn) = \frac{\sigma(\nu p \to \nu p)}{\sigma(\nu n \to \nu n)} =$$



$\sigma(NCp) \uparrow$

non-zero Δs

$\sigma(NCn) \downarrow$

but this is difficult, so instead, we measure,

$$R_\nu(NCp/CCQE) = \frac{\sigma(\nu p \to \nu p)}{\sigma(\nu n \to \mu p)}$$

ratio of NC and CC cancel out neutrino flux uncertainty

Experimental error can be extrapolated from MC by using dipole parameterization for Q^2 dependence

$$\delta(\Delta s) = \pm 0.025(stat + sys)$$

IV Δs measurement

2. Nuclear effect

Since low Q^2 form factor dependence is crucial for Δs extraction, nuclear effect is the serious problem

$$R_\nu(NCp/CCQE) = \frac{\sigma(\nu p \rightarrow \nu p)}{\sigma(\nu n \rightarrow \mu p)}$$

- ratio of NC and CC cancel out neutrino flux uncertainty and nuclear effect uncertainty (relatively model independent)

$$\delta(\Delta s) = \pm 0.005$$

Maieron and Alberico (NuFact '03)

- Nuclear effect may be extracted from A(e,e'p) data

Martinez et al. ('05)

- Nuclear effect can be cancelled out by using 2 different H/C ratio scintillator

Saito (Pacific Spin '05)

III Scibath pilot detector beam test

4. Some additional work

Dirt neutron background

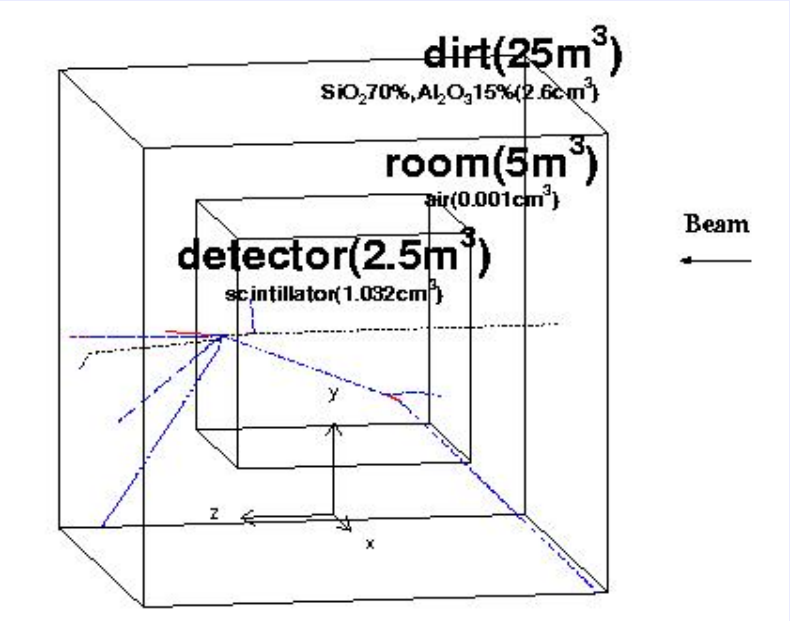
neutron is the most notorious background, because miss ID of neutrino-neutron NCE dilutes the effect of Δs for neutrino-proton NCE

isospin

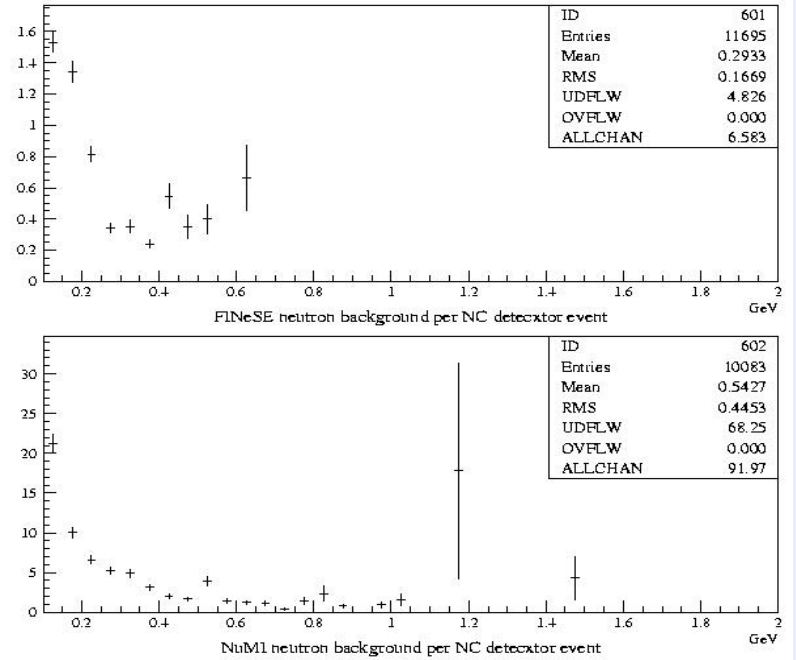
$$J_A^Z \rightarrow -G_A^{T=1}(Q^2)\gamma_\mu\gamma_5\tau + G_A^s(Q^2)\gamma_\mu\gamma_5$$

isovector isoscalar

configuration of the dirt neutron background



dirt neutron background rate



Booster

NuMI

→ High energy beam (=NuMI) has more dirt neutron background than low energy beam (=Booster)

III Scibath pilot detector beam test

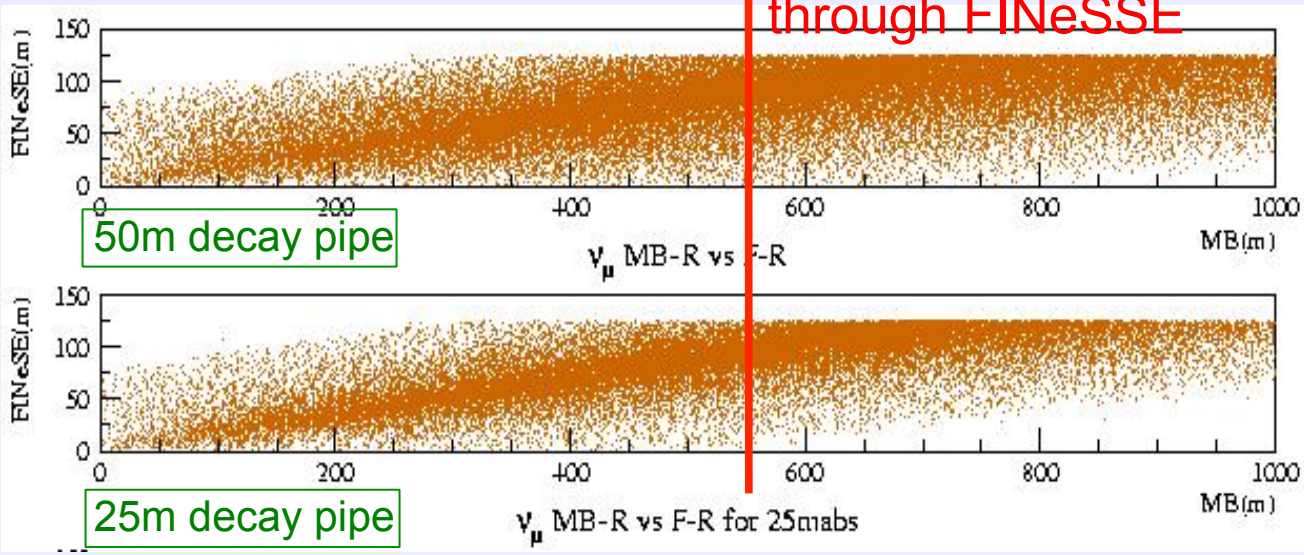
4. Some additional work

FINeSSE fiducial cut for FINeSSE - MiniBooNE coincidence

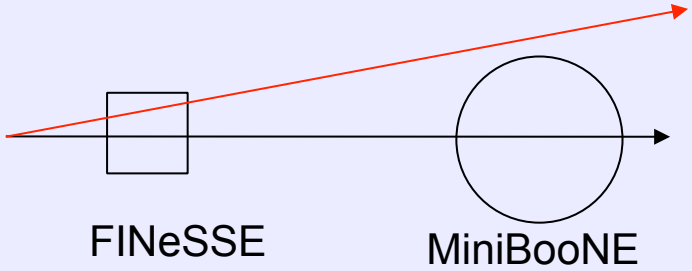
FINeSSE - MiniBooNE coincidence has an issue about parallax. Some fiducial cut for FINeSSE may be helpful to reject large angled neutrino which only pass through FINeSSE

MiniBooNE vs FINeSSE radius

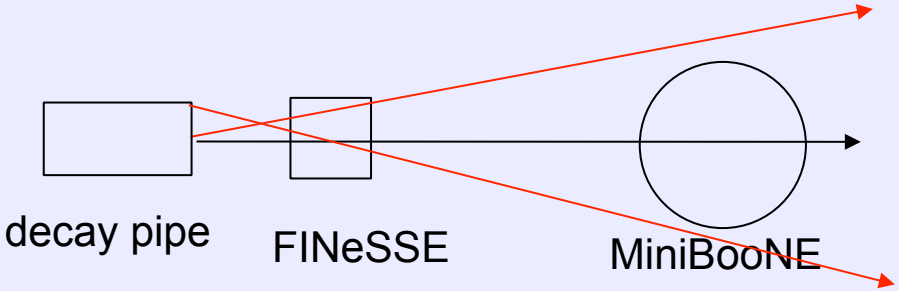
Neutrinos only pass through FINeSSE



MiniBooNE radius



This fiducial cut doesn't work very well since the beam pipe has a finite (~1m) radius



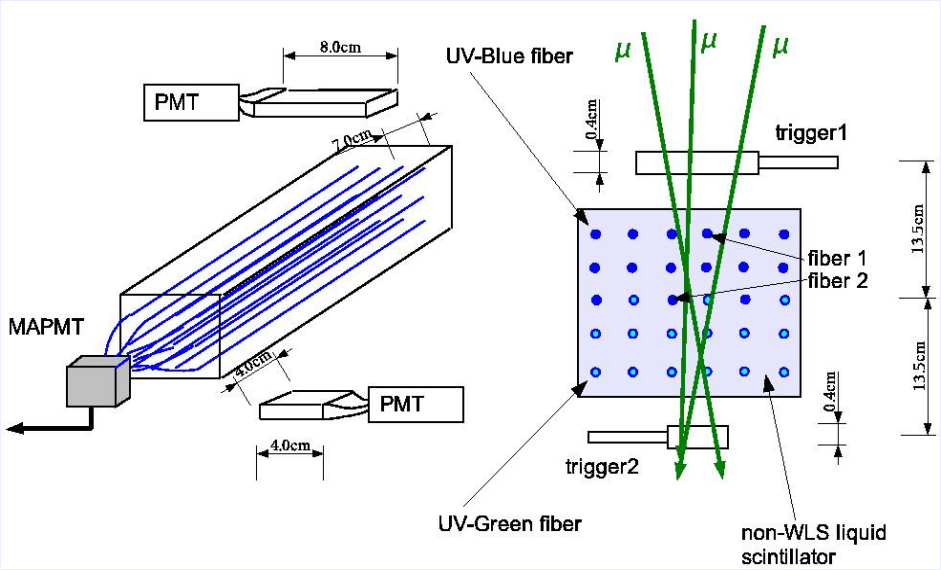
III Scibath pilot detector beam test

4. Some additional works

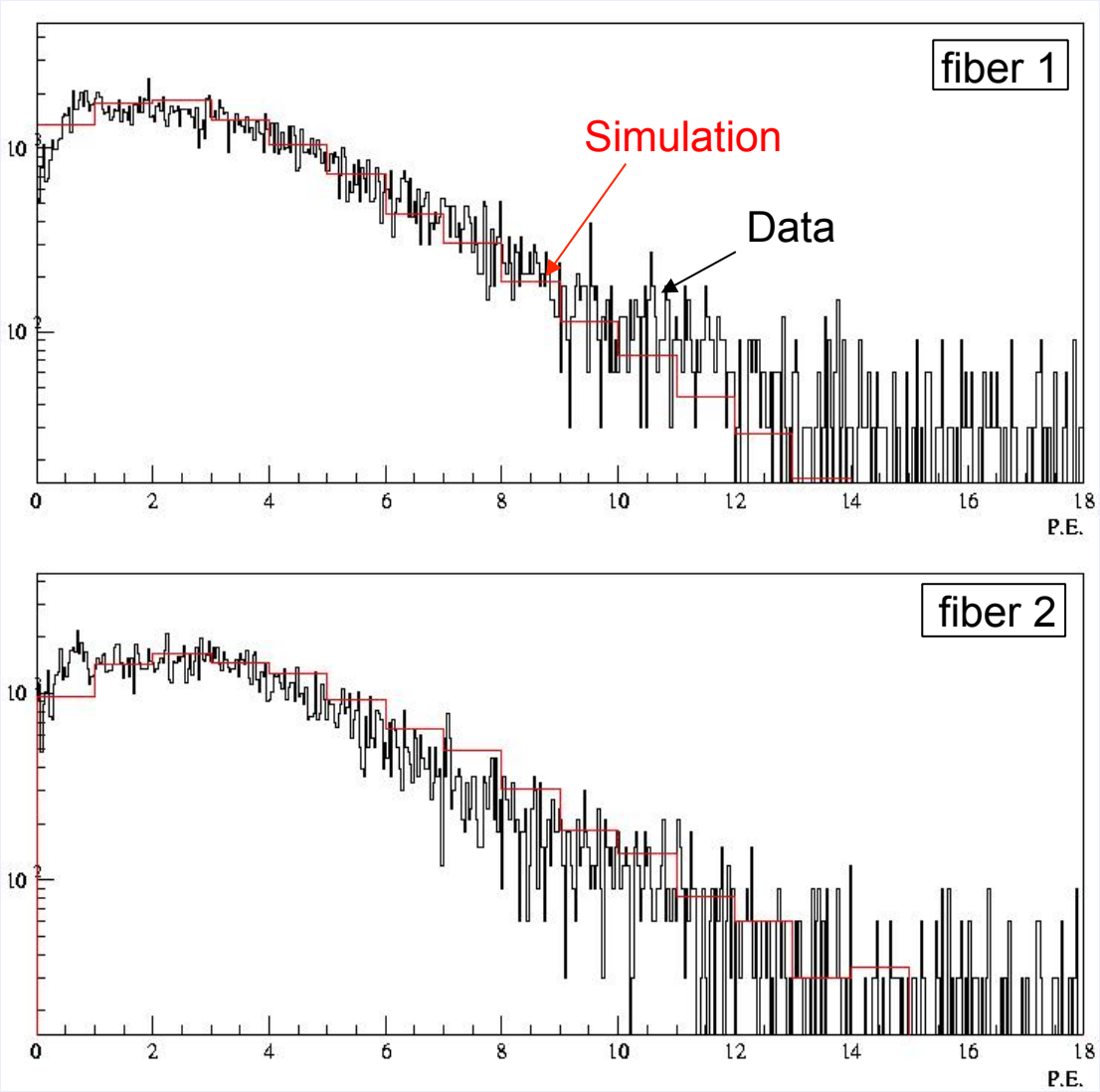
Cosmic muon measurement

cosmic muon spectra is measured for the calibration of Scibath pilot detector

Cosmic muon test setup



data-MC comparison



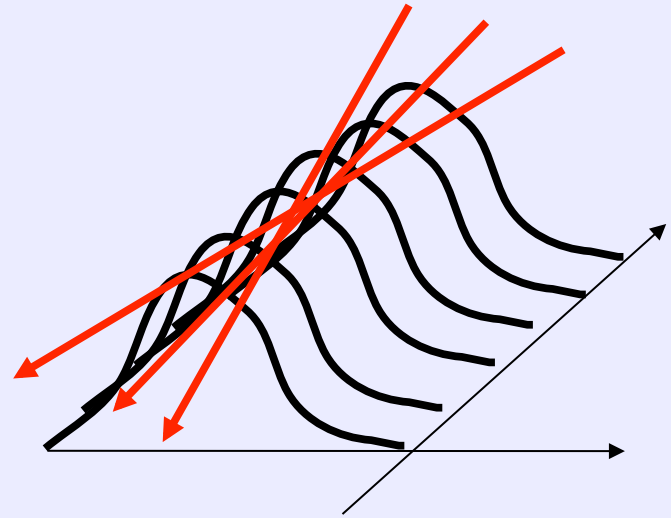
→ Cosmic muon spectrum is well described by MC which is designed for the proton beam test

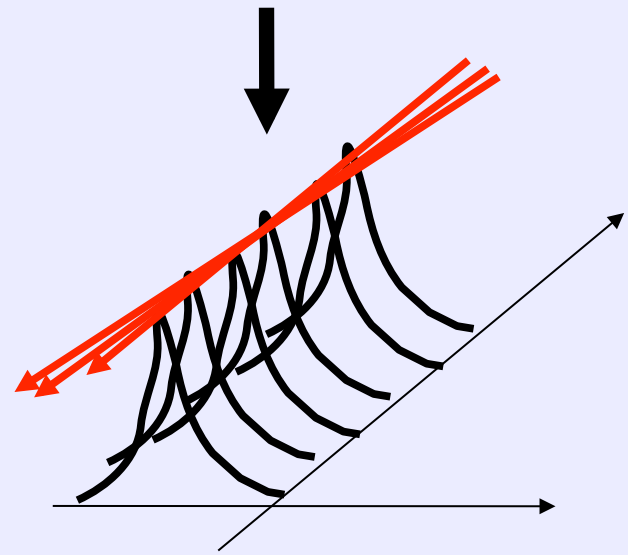
III Scibath pilot detector beam test

4. Some additional work

Track finding algorithm

Hough transformation (track fitting) need some “track finding” algorithm to maximize its power.
matrix inversion technique is the one appealing method.
However matrix which we are interested in is 6400X6400

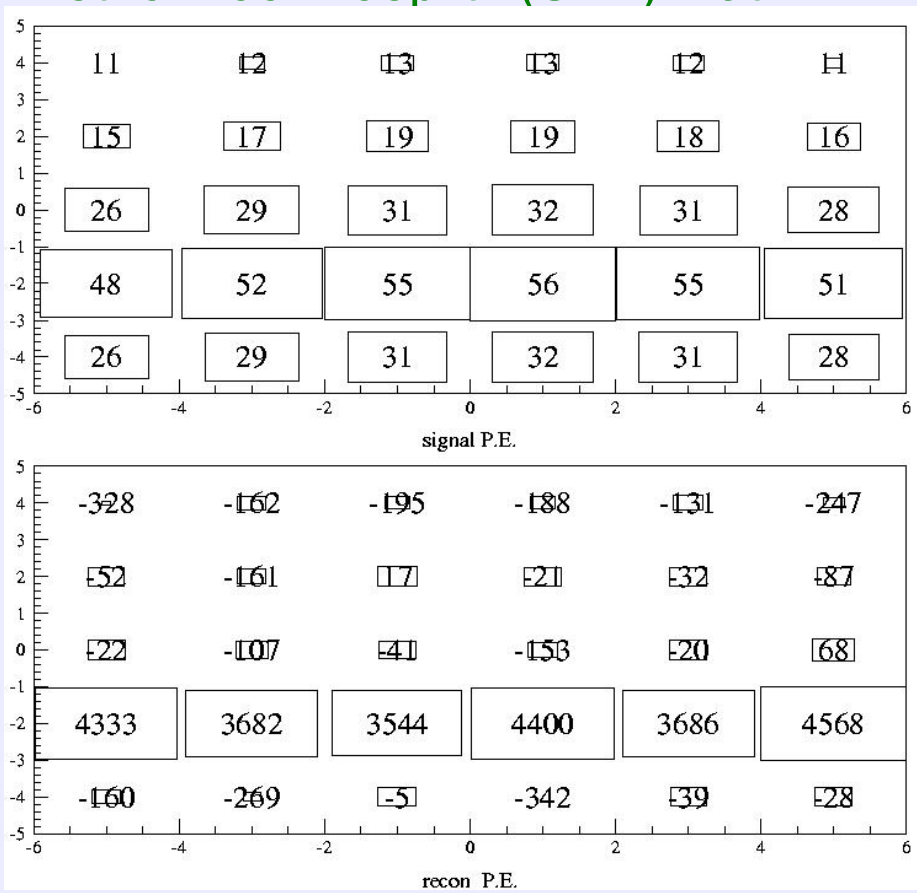




Inversion of Symmetric Block Toeplitz (SBT) matrix

measured light

reconstructed signal



in principle, we can use same process for full size FINeSSE scibath detector (in progress)