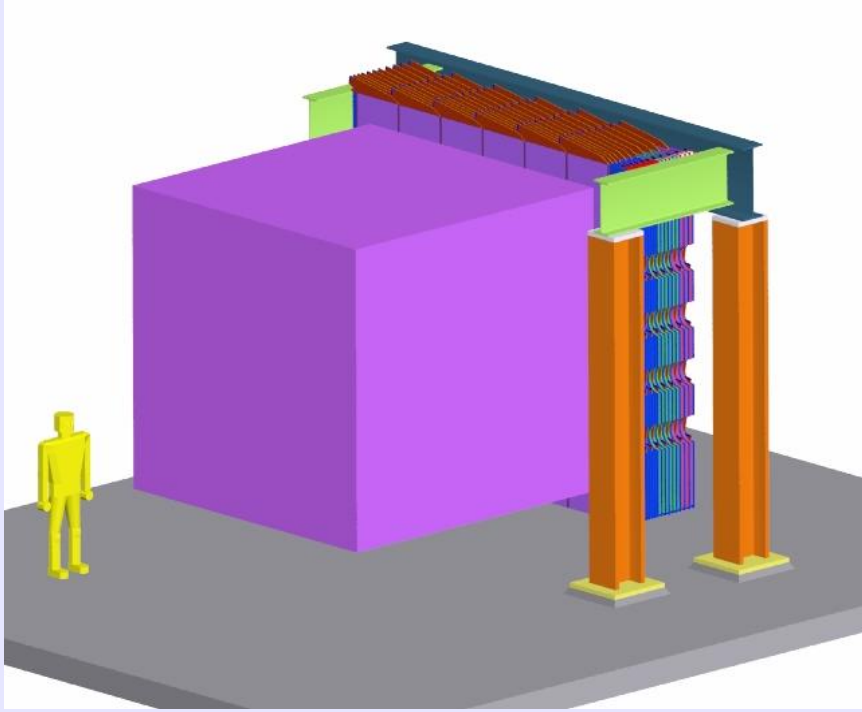
FINeSSE, Δs Measurement through the Neutrino-Nucleon Neutral Current Scattering

I Physics of Δs
II FINeSSE
III Scibath pilot detector beam test
IV Δs measurement
V Conclusion



Teppei Katori,
Indiana University Cyclotron Facility

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

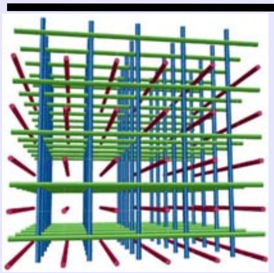
W. Metcalf, M. O. Wascko
Louisiana State University, Baton Rouge

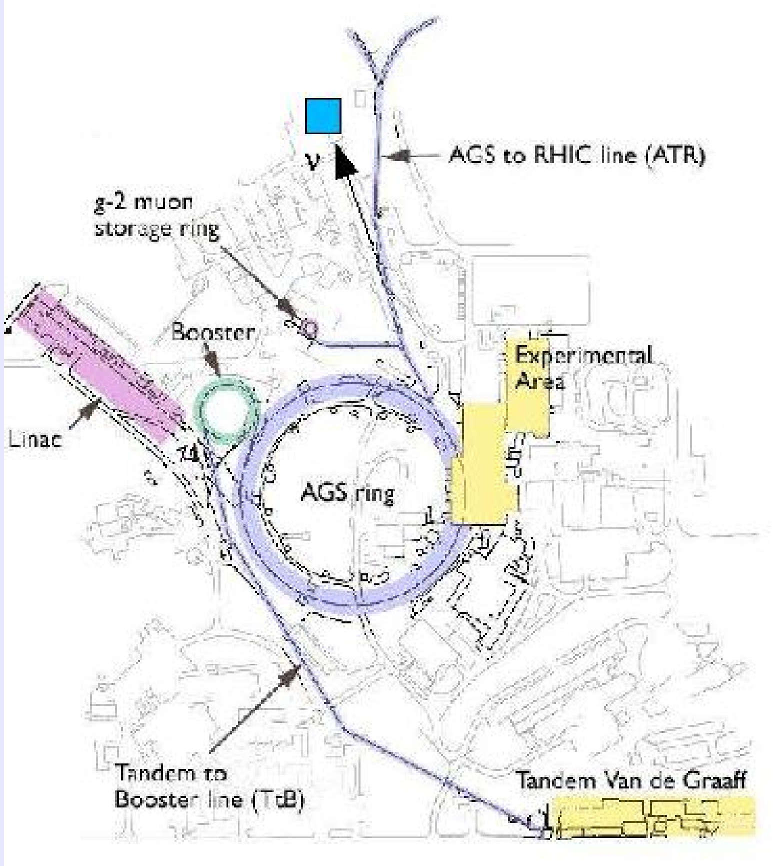
V. Papavassiliou, S.F. Pate
New Mexico State University, Las Cruces

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

FINeSSE

Fine-grained
Intense
Neutrino
Scattering
Scintillator
Experiment





I Physics of Δs

1. What is Δs?

Δs

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

→ $Q^2 = 0$ of the Nucleon Neutral Current Weak Axial Vector IsoScalar Form Factor (property of the elastic scattering)

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

isospin

$$ = -\left(\frac{G_F}{\sqrt{2}}\right)^{\frac{1}{2}} \bar{u}(p')\left(-G_A^{T=0}(Q^2)\gamma_\mu\gamma_5\tau + G_A^s(Q^2)\gamma_\mu\gamma_5\right)u(p) $$

isovector isoscalar

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

I Physics of Δs

1. What is Δs?

Δs

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

→ $Q^2 = \infty$ of integration of the polarized parton distribution function

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

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

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

Δs is the connection between
Elastic Scattering (ES) experiment
and
Deep Inelastic Scattering (DIS) experiment

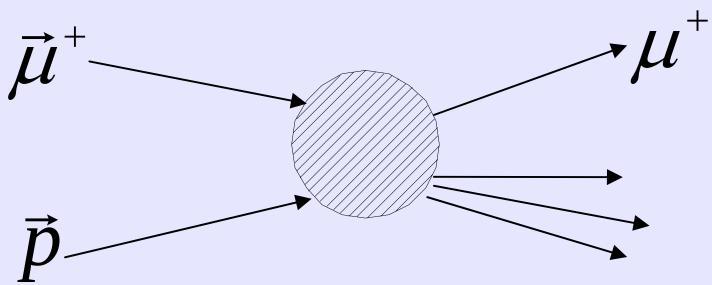
I Physics of Δs

2. How to measure Δs?

Inclusive leptonic DIS

ex) EMC, SMC

"Spin Crisis"

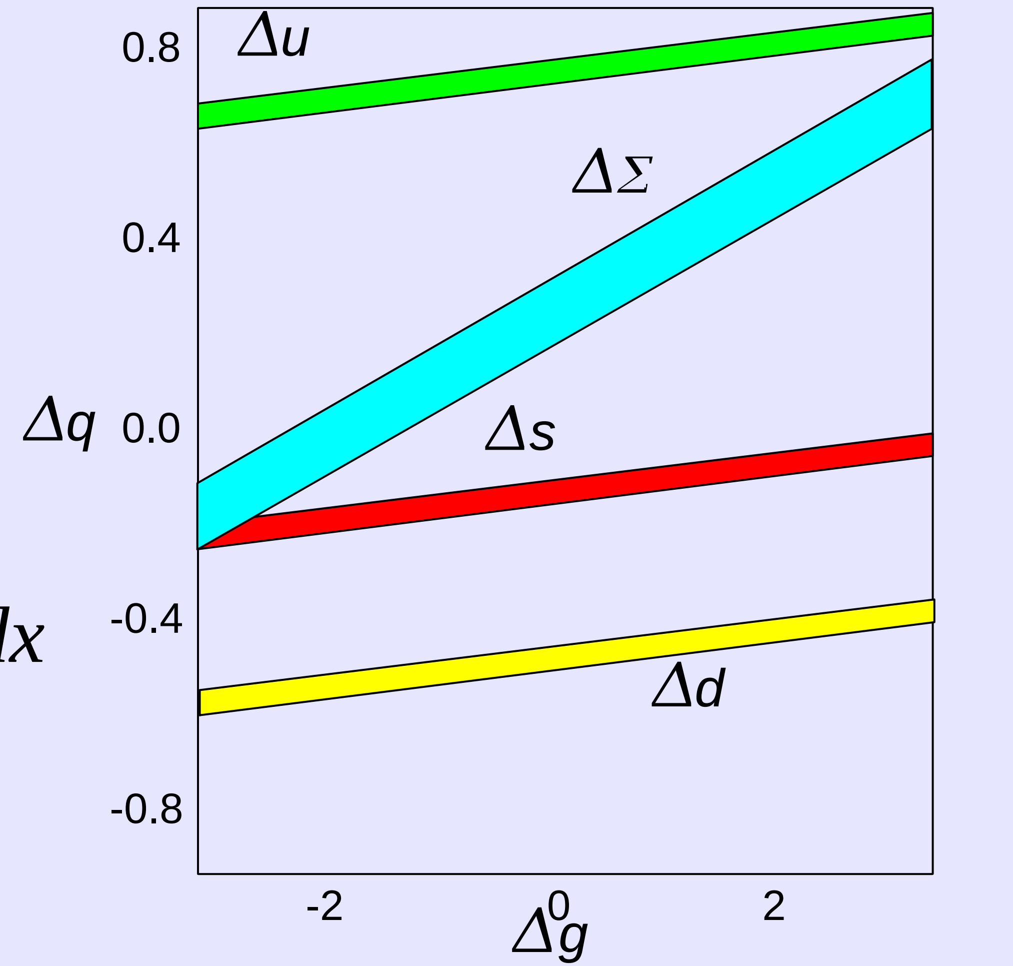


$$\Gamma_1 = \int_0^1 g_1(x)dx = \frac{1}{2}\sum e_q^2 \int_0^1 \Delta q(x)dx$$

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

$$\boxed{\Delta s \sim -0.10 \pm 0.06}$$

SU(3)$_f$ assumption



Spin Muon Collaboration
(Phys.Rev.D**56**(1997)5330)

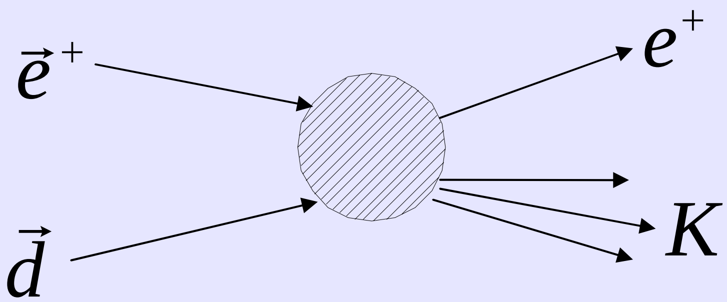
I Physics of Δs

2. How to measure Δs?

Semi-Inclusive leptonic DIS

ex) HERMES

"Spin Disaster"

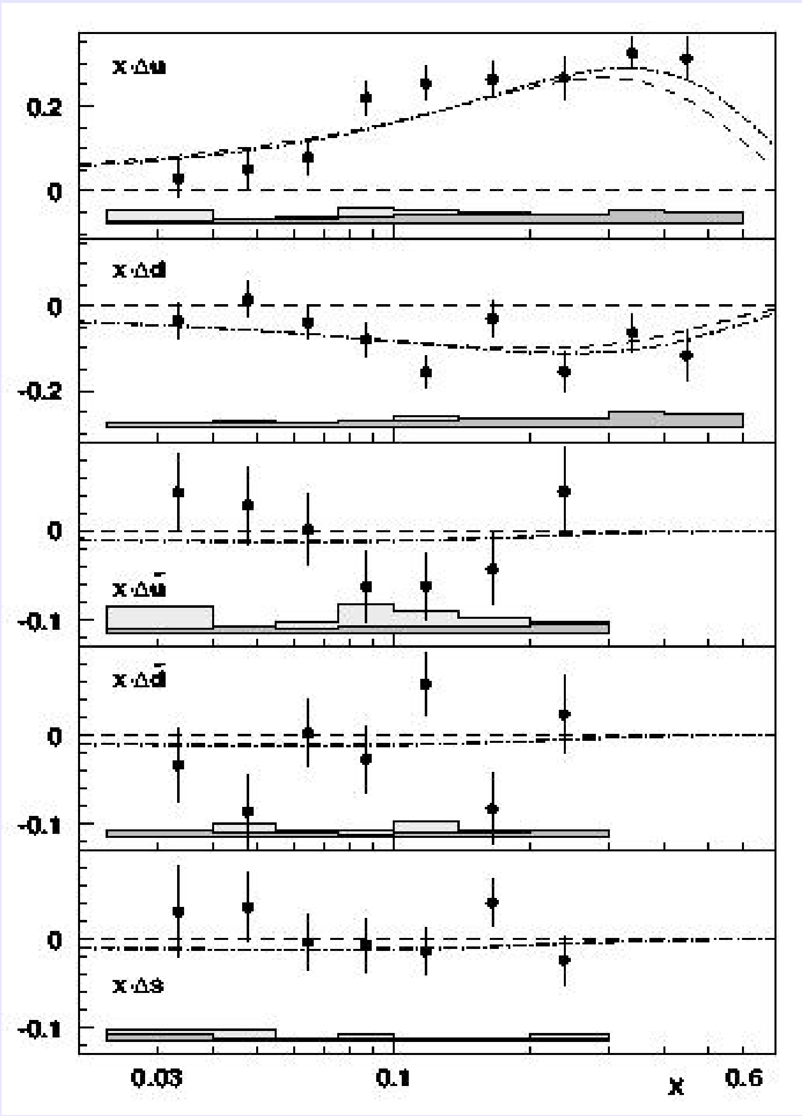


$$\Delta s = \int_{x=0.023}^{x=0.30} \Delta s(x)dx$$

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

no extrapolation to x=0

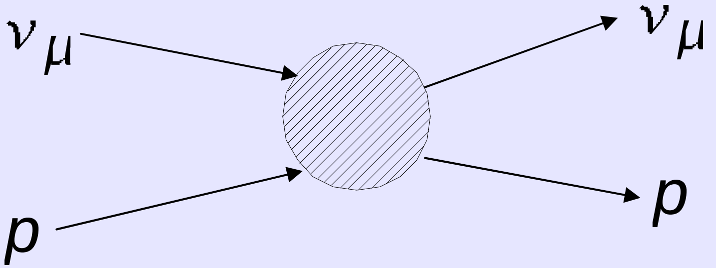
no extrapolation to $Q^2 = \infty$



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

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

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

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

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

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

I Physics of Δs

2. How to measure Δs?

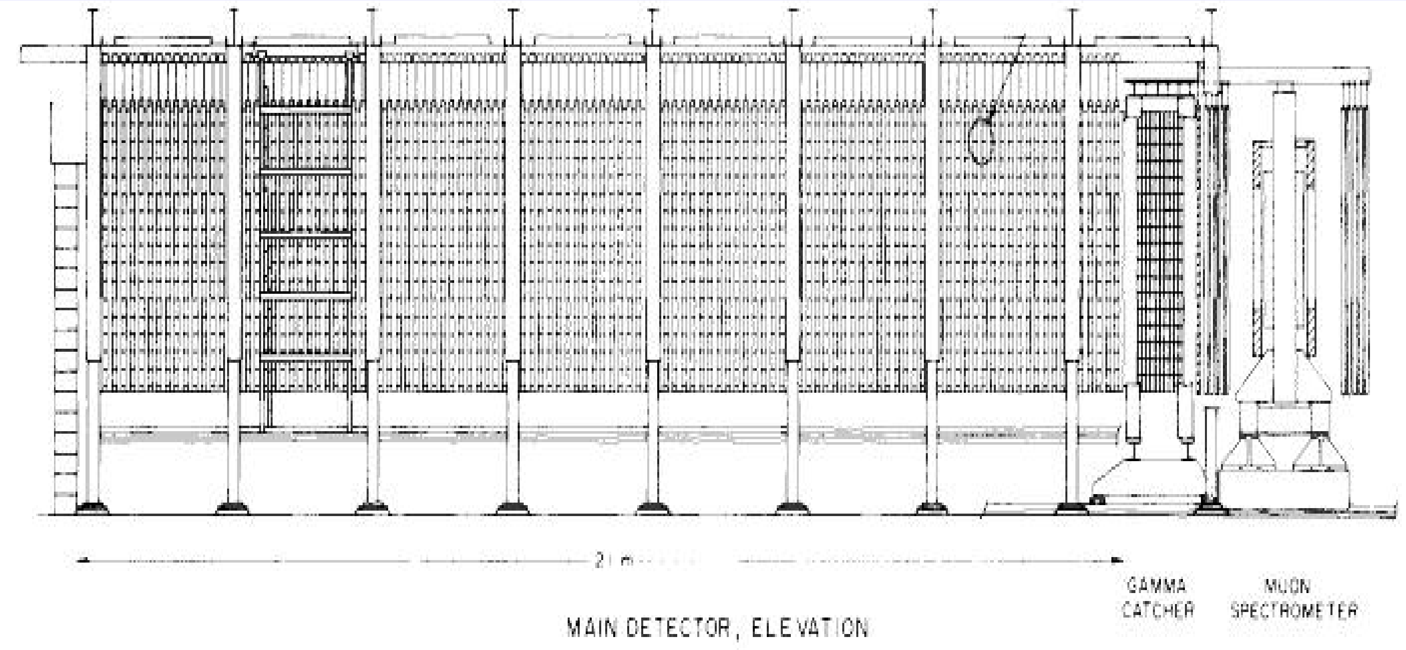
Neutrino ES

ex) BNL E734

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

$$= -0.15 \pm 0.09$$

Garvey et al.('93)



with Parity Violating electron (PVe) scattering experiment data

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

Pate ('04)

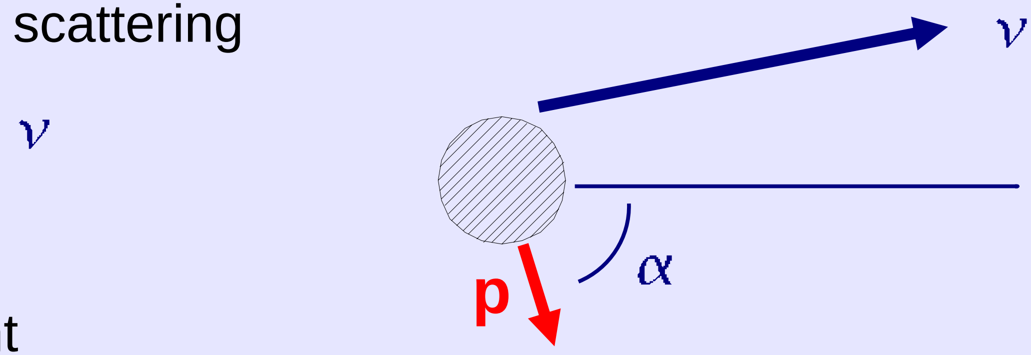
low statistics
large background
extrapolation from relatively high Q^2 → **FINeSSE**
large error from G^s_M (task for PVe)

II FINeSSE

1. Motivation

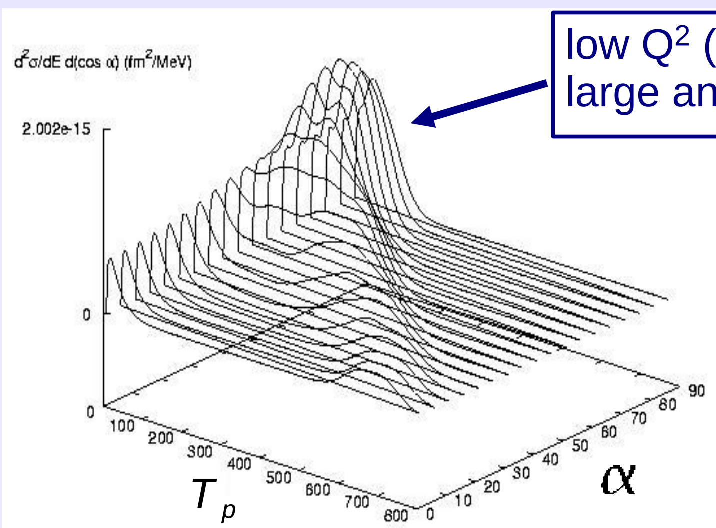
Physics

- Measurement of Low E neutrino-nucleon Neutral Current proton (NCp) elastic scattering and Charge Current Quasi-Elastic (CCQE) scattering



Detector Requirement

- active high resolution detector
- sufficiently low threshold
- good performance for large angle event



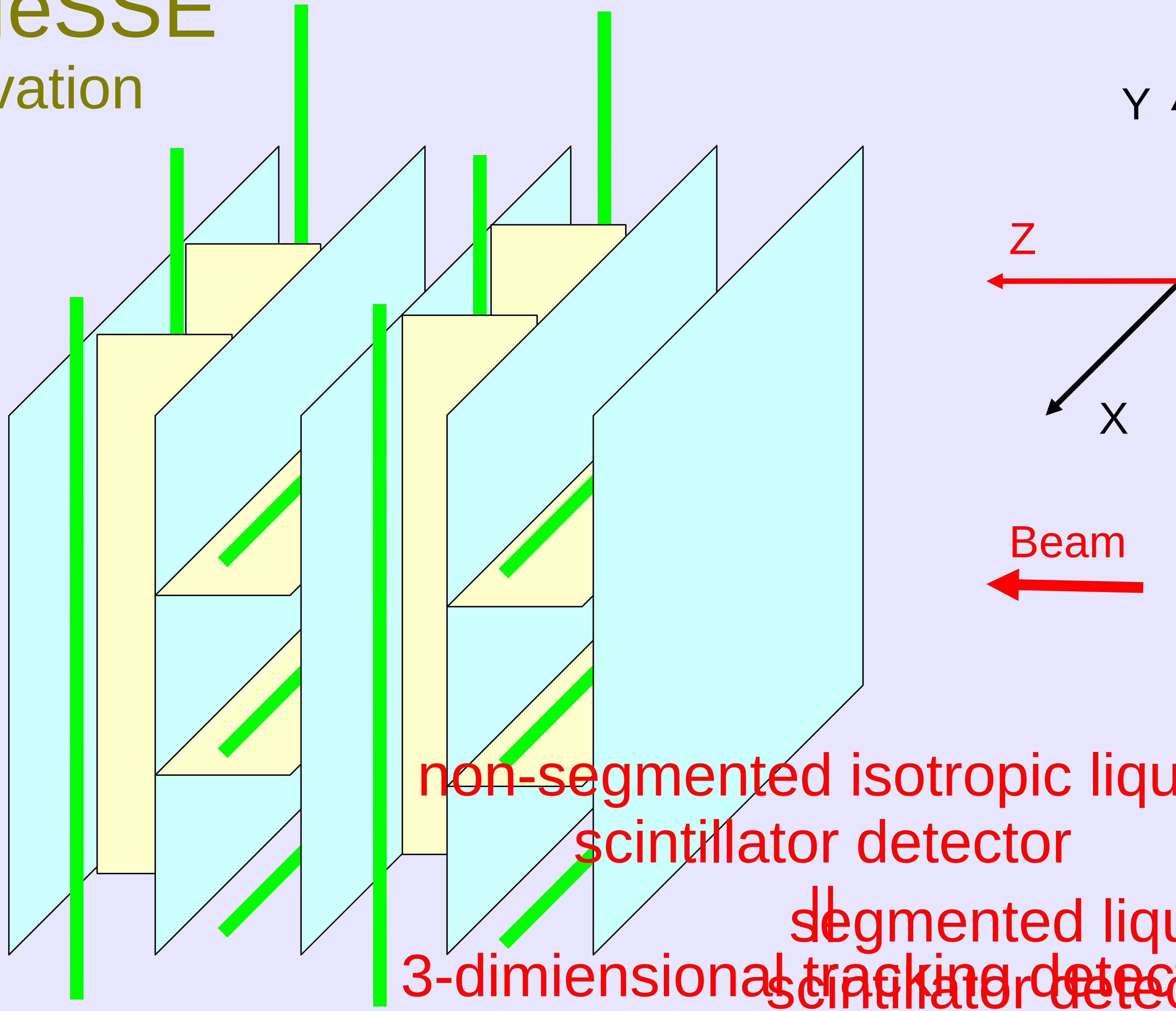
low Q^2 ($=2M_PT_P$) and large angle event

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

non-segmented isotropic liquid scintillator detector

II FINeSSE

1. Motivation



non-segmented isotropic liquid scintillator detector

||

segmented liquid scintillator detector

3-dimiensional tracking detector

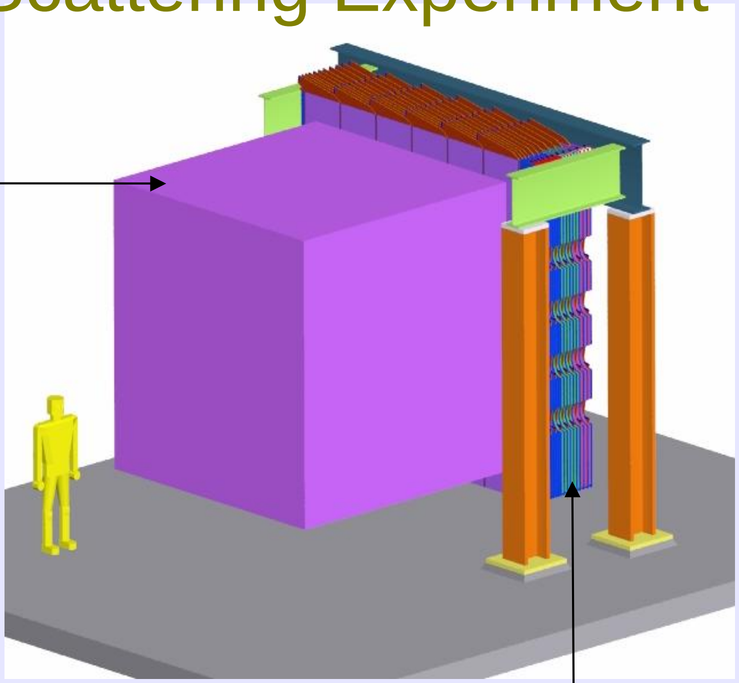
II FINeSSE

2. Fine-grained Neutrino Scintillator Scattering Experiment

FINeSSE detector

The Vertex Detector

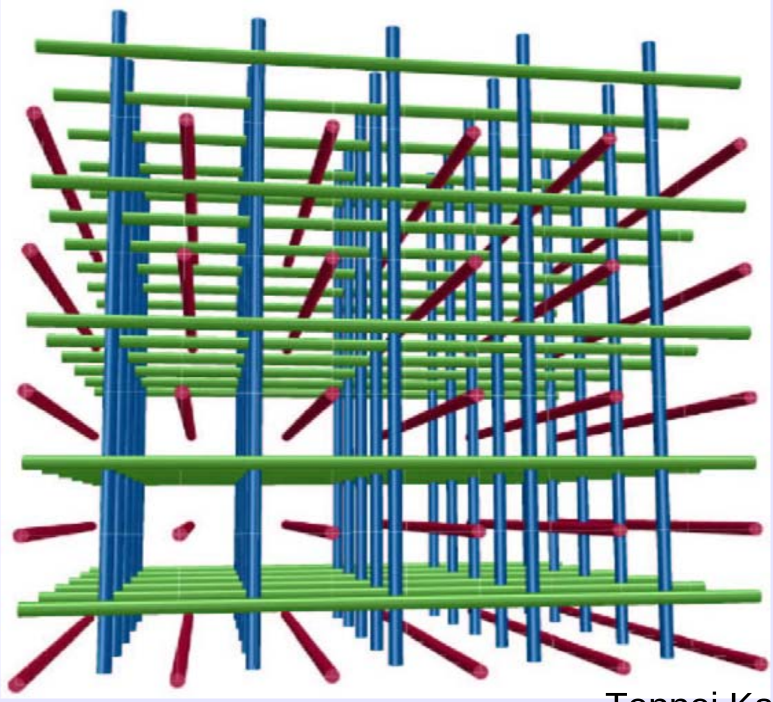
- to precisely track low-energy protons
- $(2.5m)^3$ active liquid scintillator volume
- 19200 (80x80x3) 1.5 mm WLS fibers
on 3cm spacing with 3 orientations

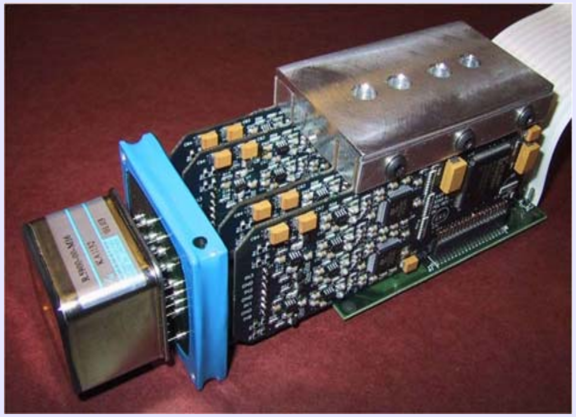


The Muon Rangestack

- 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

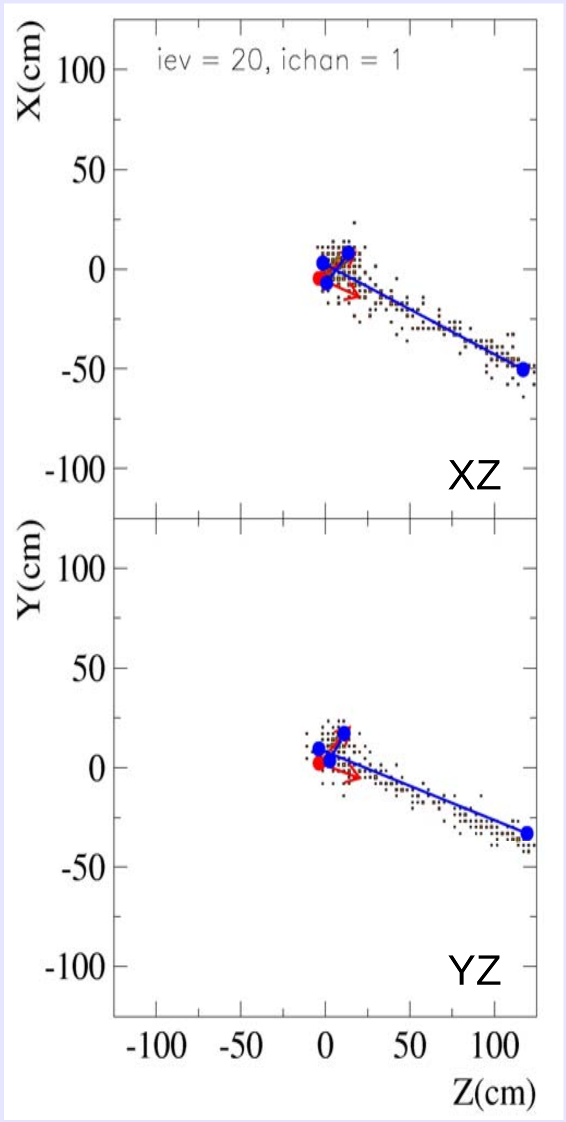
simulated hits and reconstructed tracks in the Vertex Detector

■ fiber hits,
(size $\propto$ # γ collected)

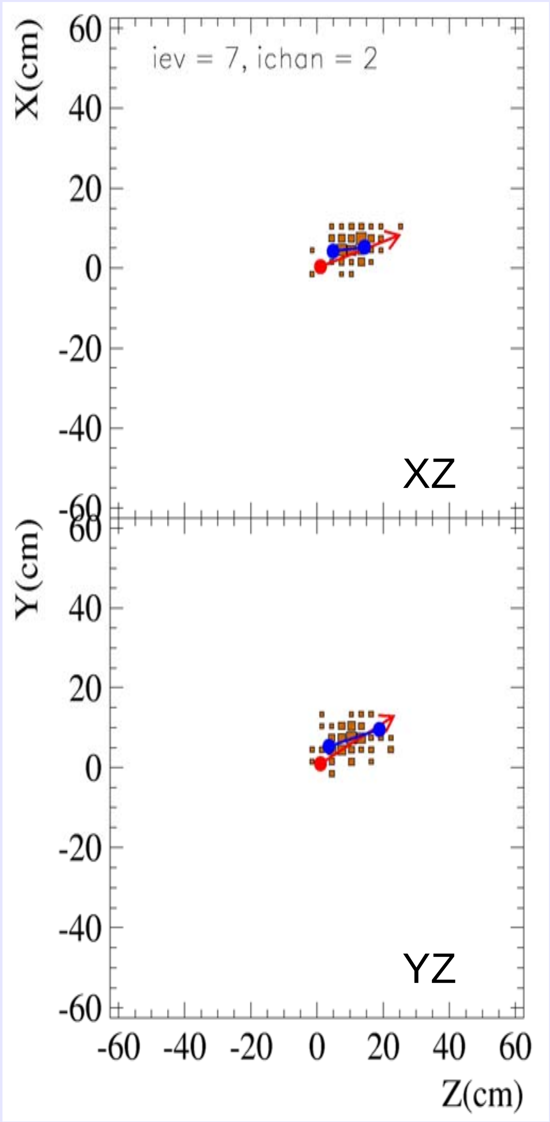
generated

reconstructed

CCQE event



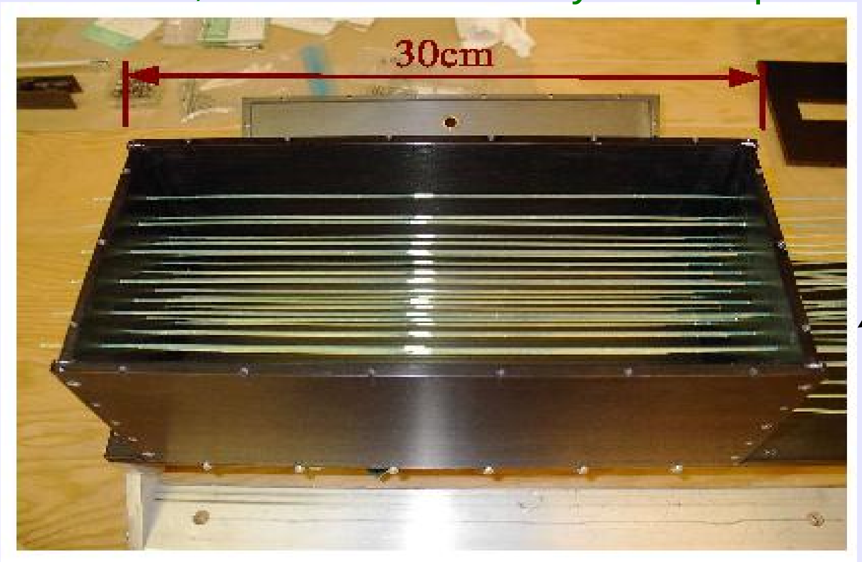
NCp event



III Scibath pilot detector beam test

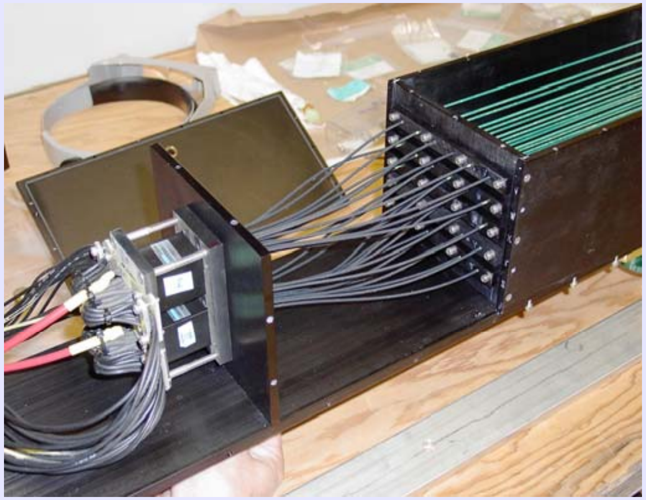
1. Pilot type detector

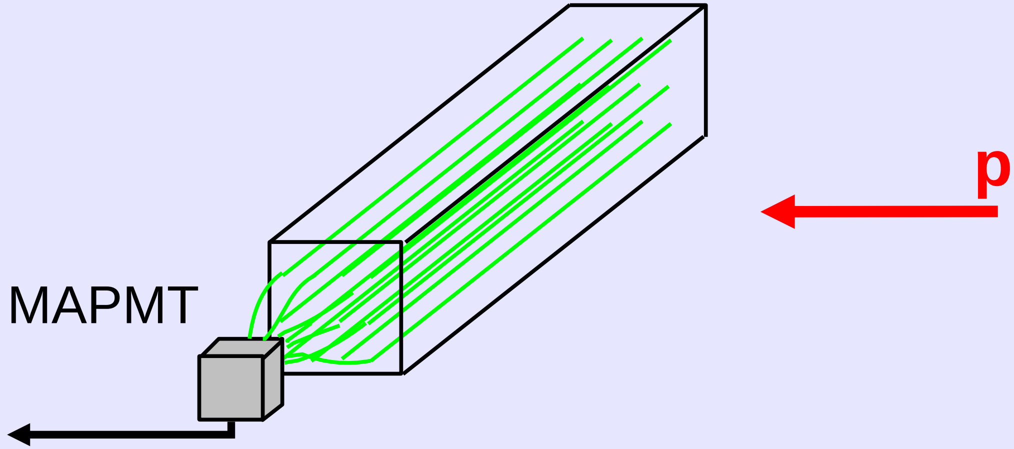
1-dimension, 30 WLS fibers array in the liquid scintillator



Read out by
16ch. MAPMT
(H8711)

Fiber and MAPMT coupling



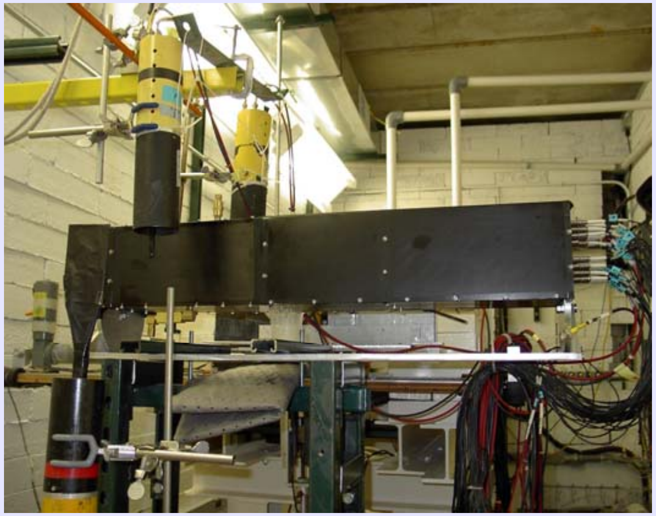


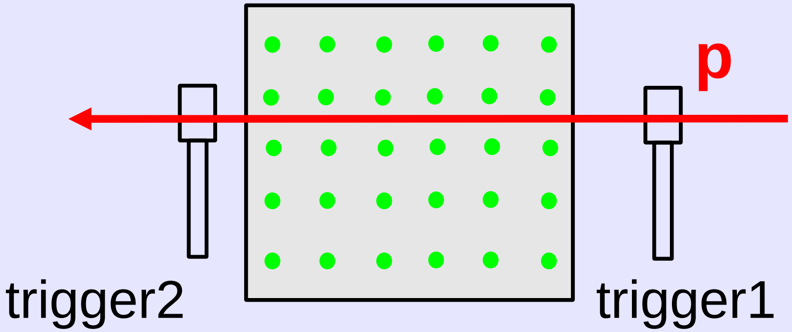
Prototype “Scibath” have been tested by using 200MeV proton beam at Indiana University Cyclotron Facility (IUCF), Radiation Effect Research Program (RERP)

III Scibath pilot detector beam test

2. Light yield

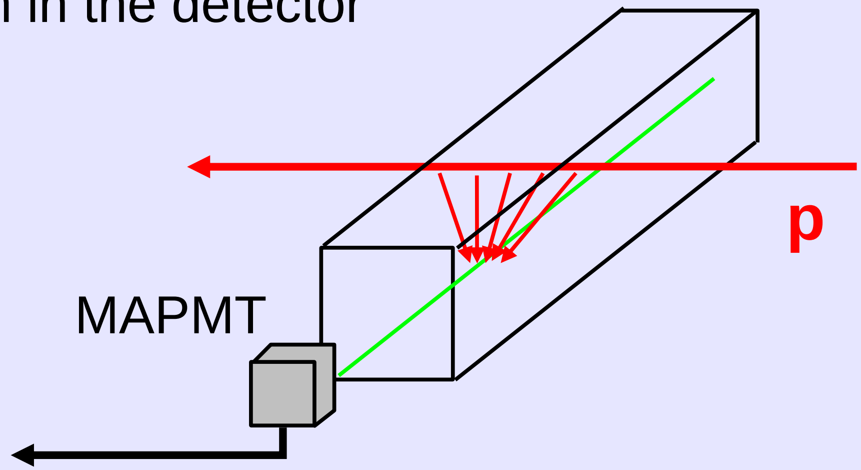
Beam test setup,
RERP@IUCF

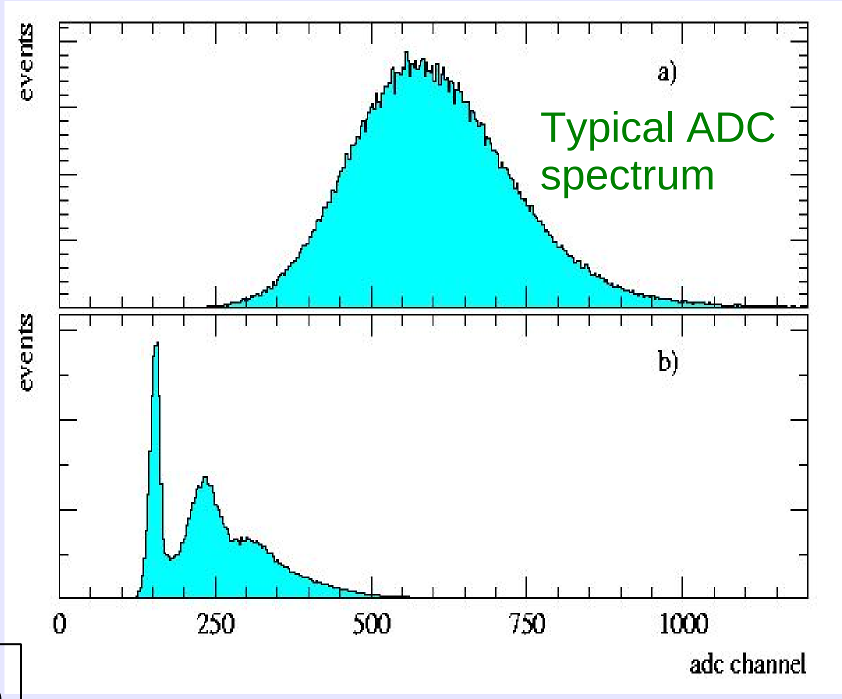




Light Yield

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





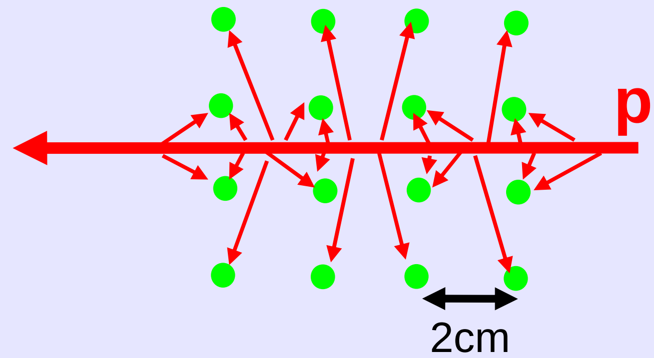
17± 2p.e./fiber for near tracks with 200MeV proton

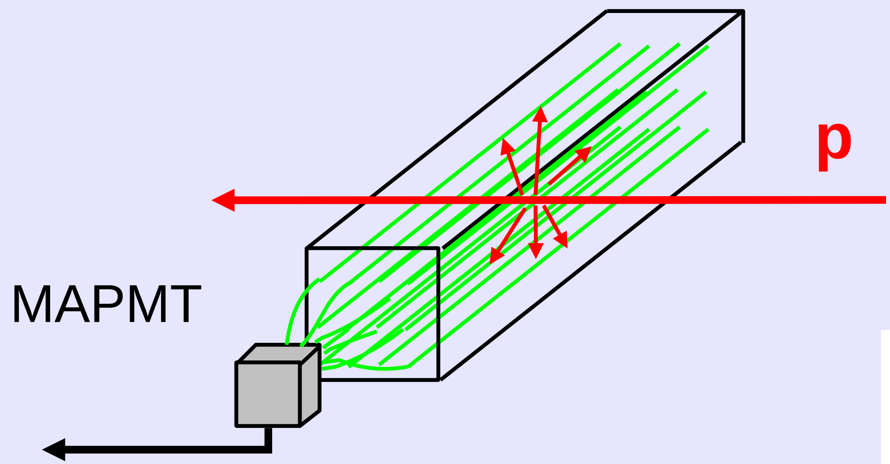
III Scibath pilot detector beam test

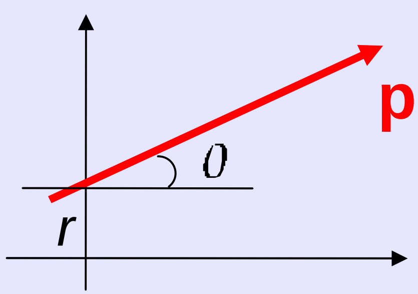
3. Position resolution

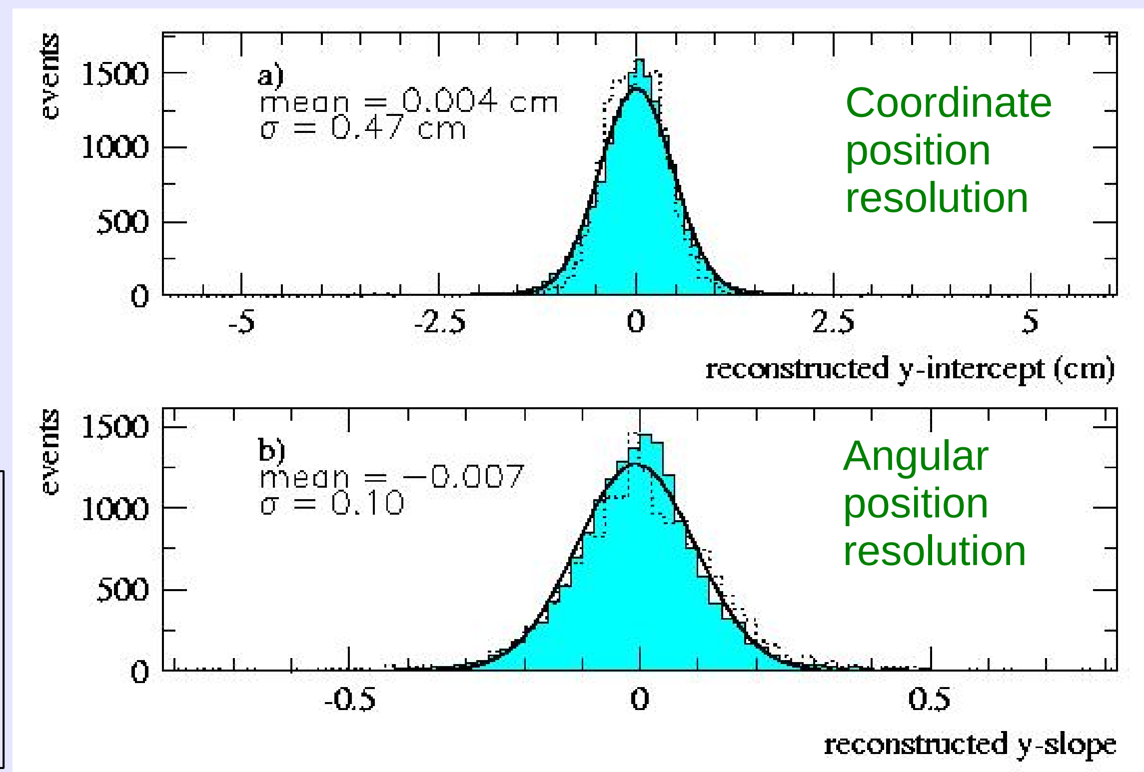
Position Resolution

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}

IV Δs measurement

1. NCp/CCQE ratio

FINeSSE ratio scheme

Ideally speaking, we want to measure

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

but this is tough! so instead, we measure,

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

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

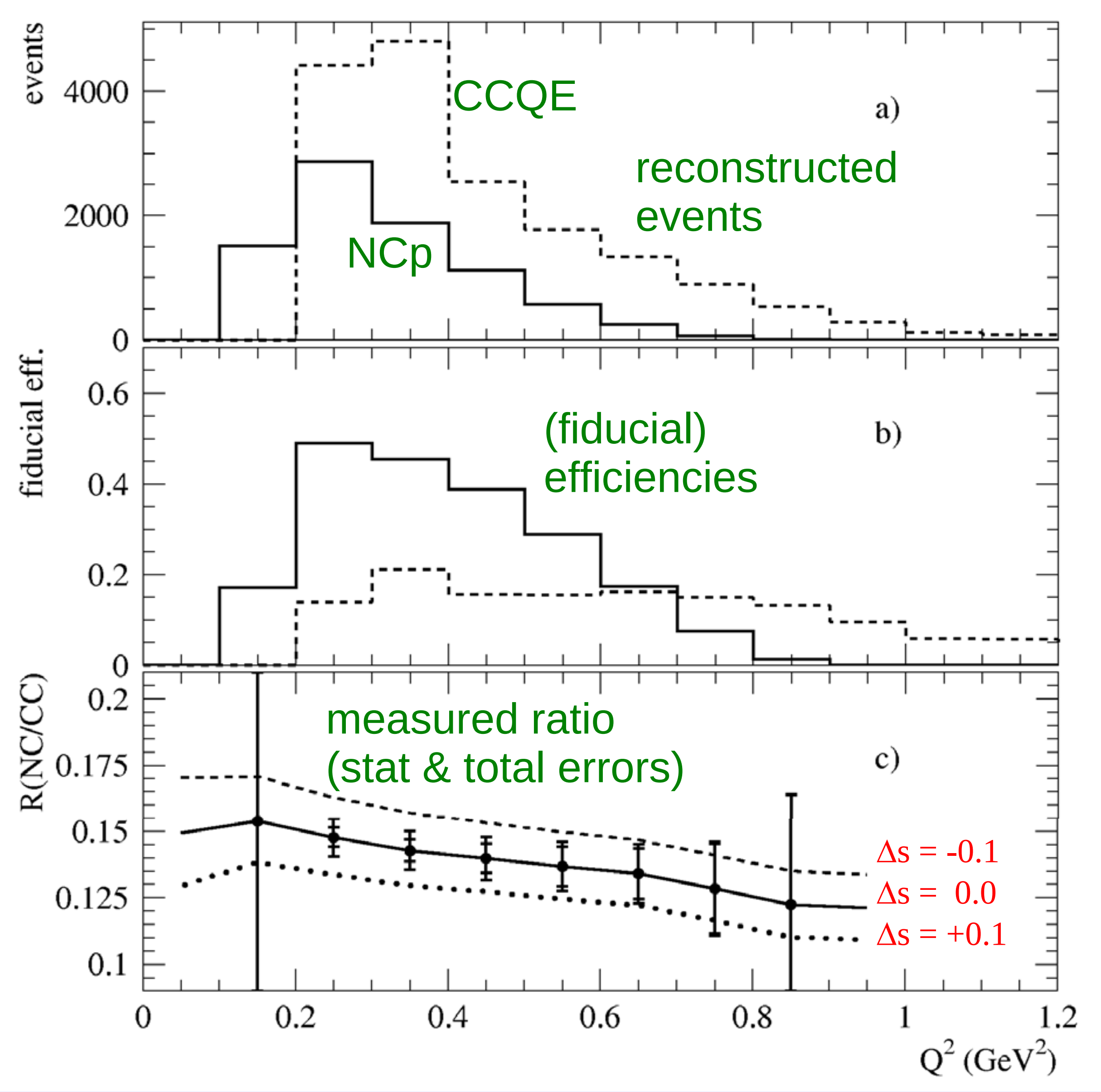
Maieron and Alberico('03, unpublished)

IV Δs measurement

1. NCp/CCQE ratio

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

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



IV Δs measurement

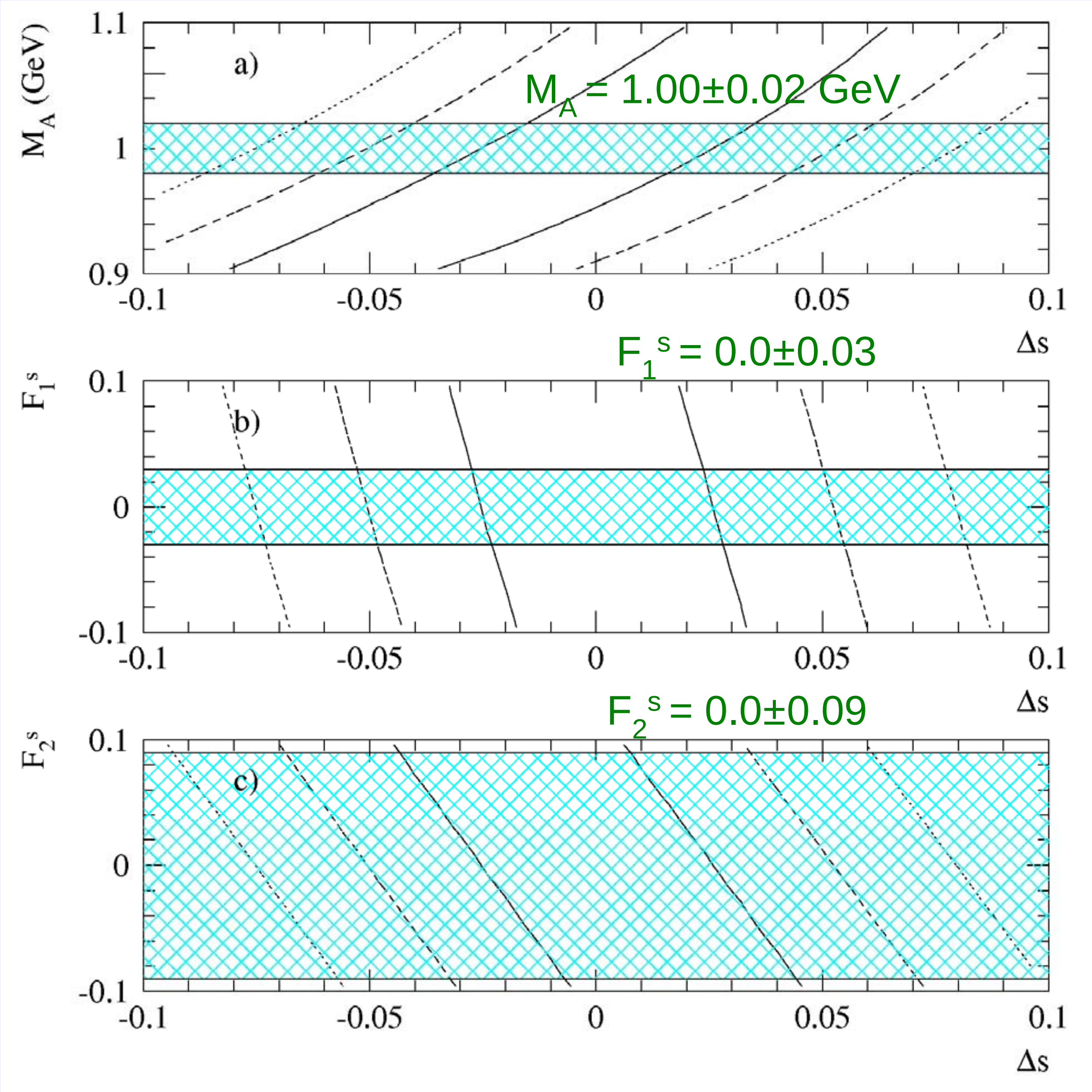
2. Δs and other strange quark form factors

$$R_\nu(NCp/CCQE)$$

also depends on M_A, F_1^s and F_2^s

Form factor uncertainties is evaluated from G0 experiment expected errors

$$\boxed{\sigma(\Delta s) = \pm 0.02(sys)}$$



FINeSSE, Δs Measurement through the Neutrino-Nucleon Neutral Current Scattering

Conclusion

I. Δs is a great interest property from the community

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

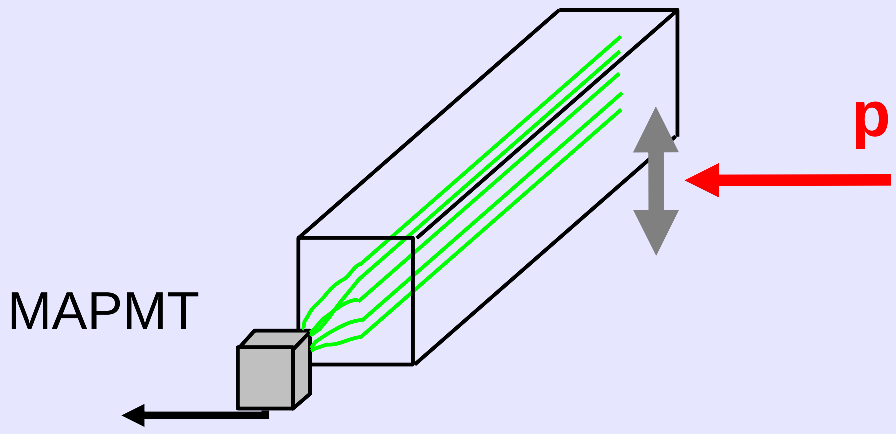
III. FINeSSE is experimentally capable to measure Δs with the smallest error

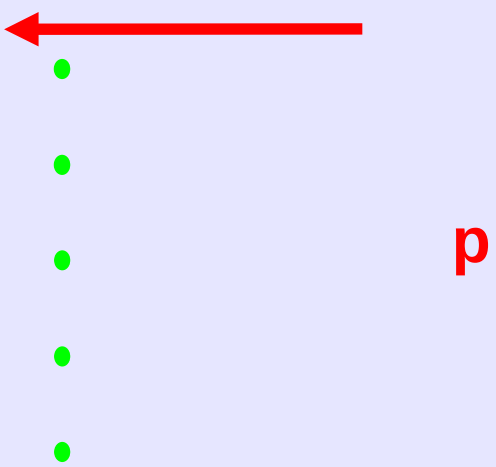
Thank you for your attention!

More?

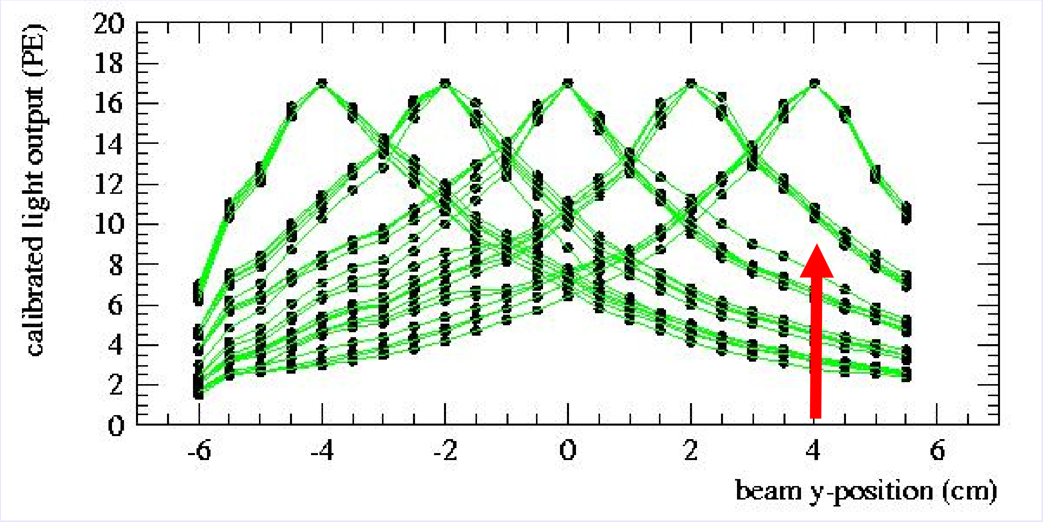
III Scibath pilot detector beam test

3. Second beam test





Blue-Green fiber scan plot data

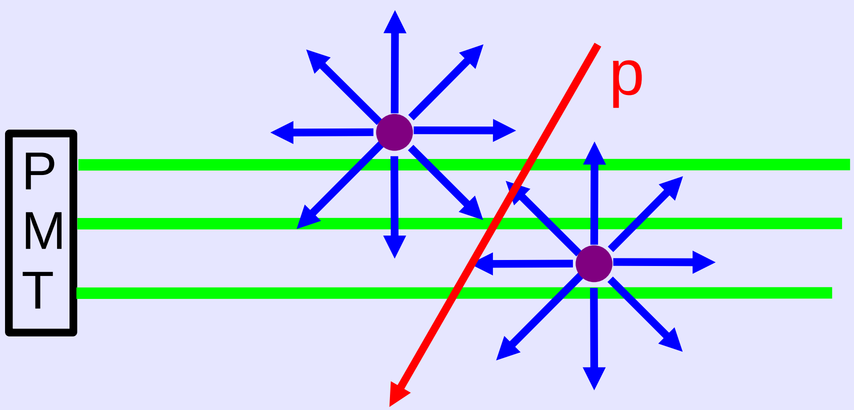


III Scibath pilot detector beam test

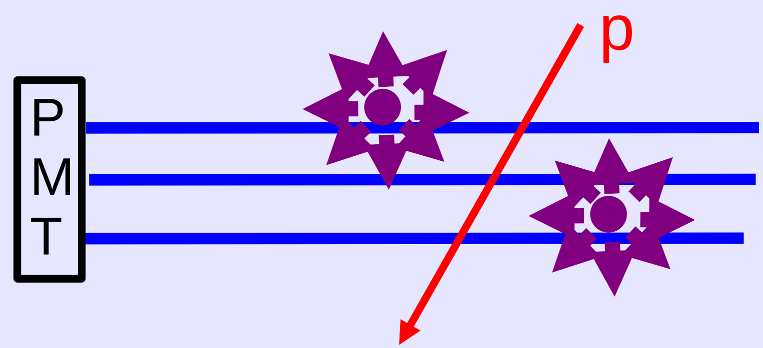
3. Second beam Test

Trick of Non-Wave Length Shifting

We remove the Wave Length Shifter (POPOP) from liquid scintillator (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

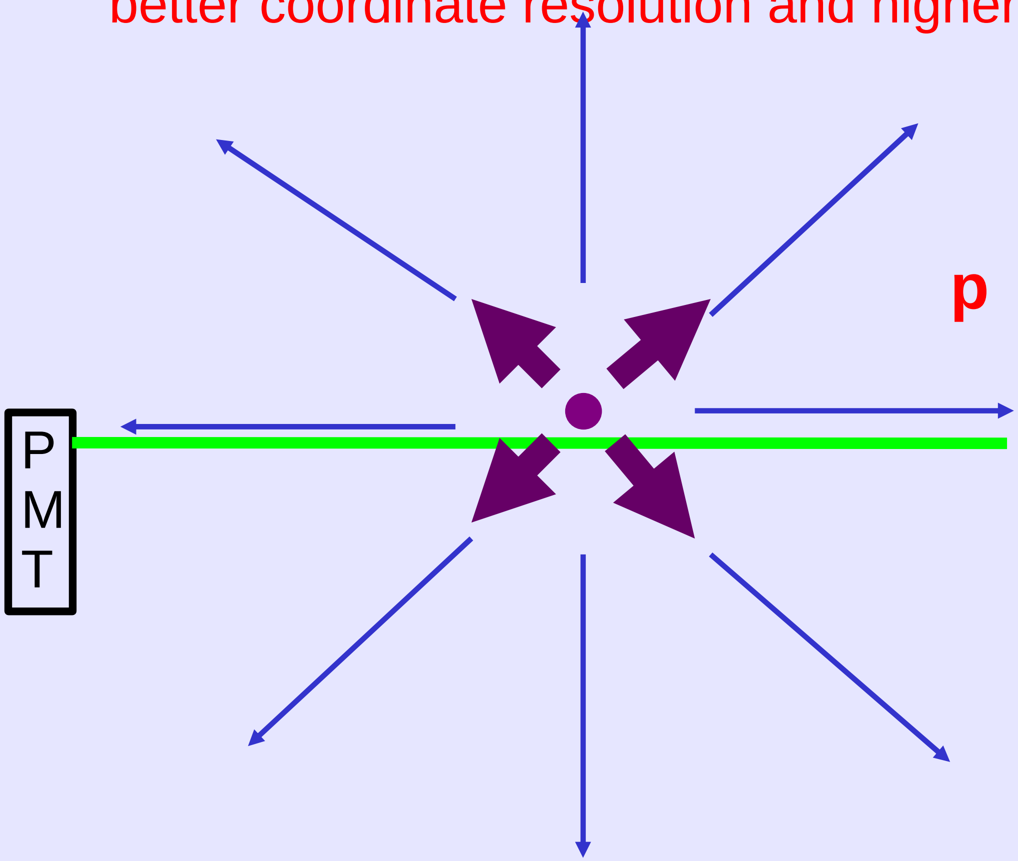
(1) Non-WLS liquid scintillator has shorter attenuation length
→ nicely localize light output
(2) Non-WLS liquid scintillator has locally higher light output
→ higher amount of light to the nearest fiber
(3) UV-Blue fiber sends blue light to MAPMT
→ higher quantum efficiency
(4) UV process is faster
(5) UV light is less reflective

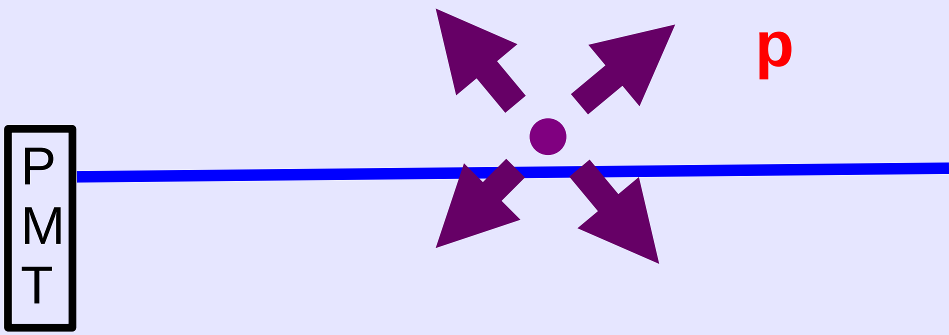
II-III Scibath pilot detector beam test

3. Second beam Test

Trick of Non-Wave Length Shifting

We remove the Wave Length Shifter (POPOP) from liquid scintillator (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

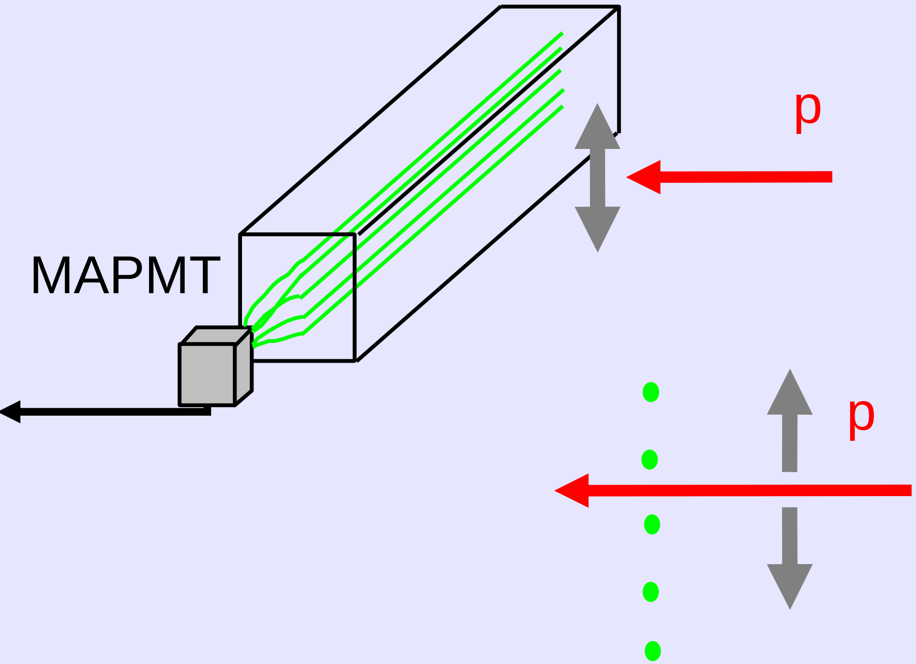
p → UV → Blue → Green → PMT

new scheme

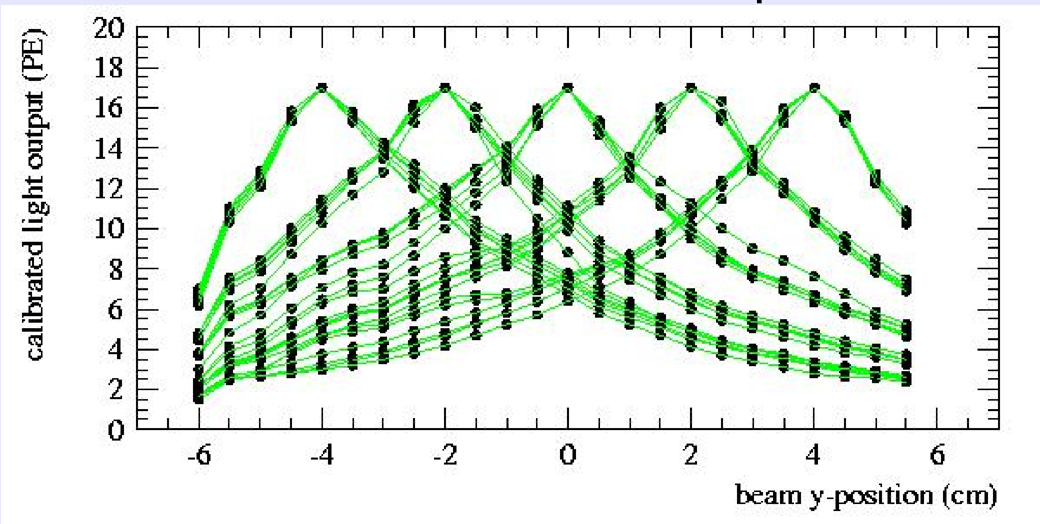
p → UV → Blue → PMT

III Scibath pilot detector beam test

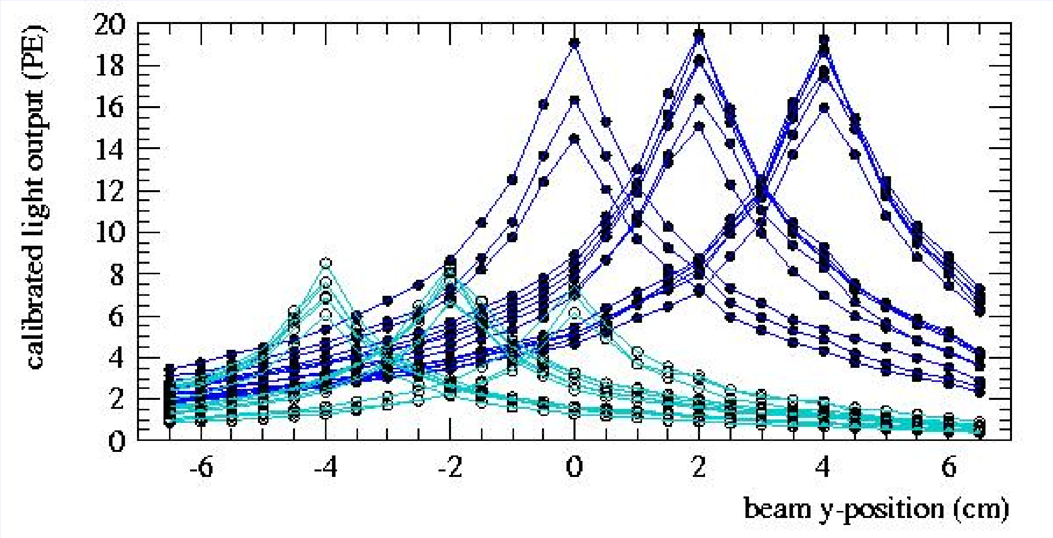
3. Second beam test



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

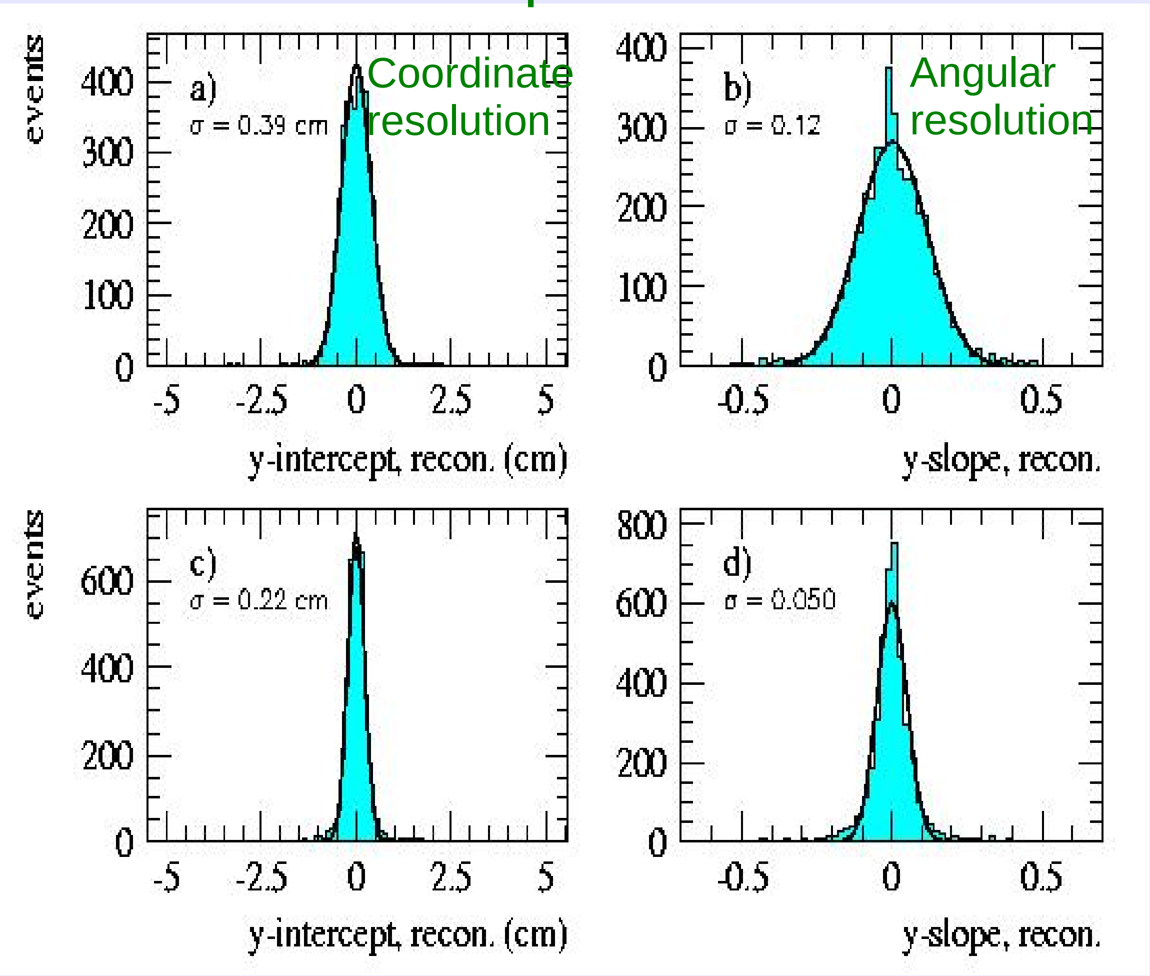
↓

better position resolution

IIII Scibath pilot detector beam test

3. Second beam test

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!