SciBar at FNAL Booster beam line

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NuInt05 @ Okayama

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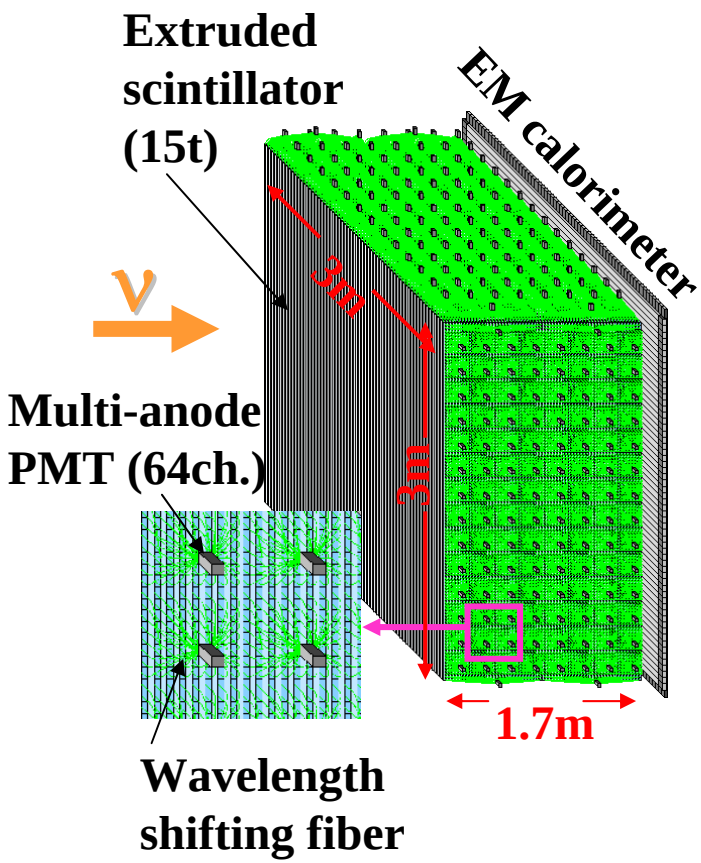
Introduction

- **Sci**ntillator **Bar** Detector
  - Fully active, Fine segmented scintillator tracker
  - Installed as a Near Detector in K2K Experiment
  - Used for
    - ν spectrum measurement
    - ν interaction study



Plan to bring SciBar to FNAL Booster Neutrino beam line!

Motivation

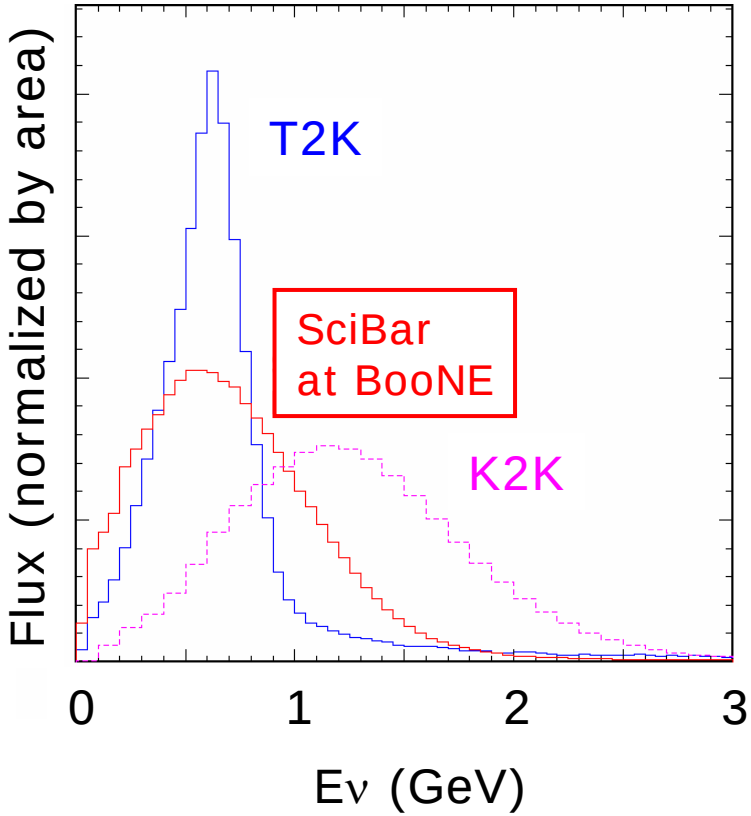
- **Neutrino cross section measurement for T2K**
  - **Similar energy to T2K**
  - **Direct σ measurement based on HARP result**

    In T2K, we have uncertainty on neutrino spectrum
  - **Earlier timescale**

    SciBar at BooNE: 2006-2007

    T2K : 2009-

Comparison of ν_μ flux spectra at K2K, T2K and BooNE



Motivation (cont'd)

- **Anti-neutrino cross section measurement**
  - **The first σ measurement below 1GeV with good final state separation**
  - **Helpful for T2K Phase-II**

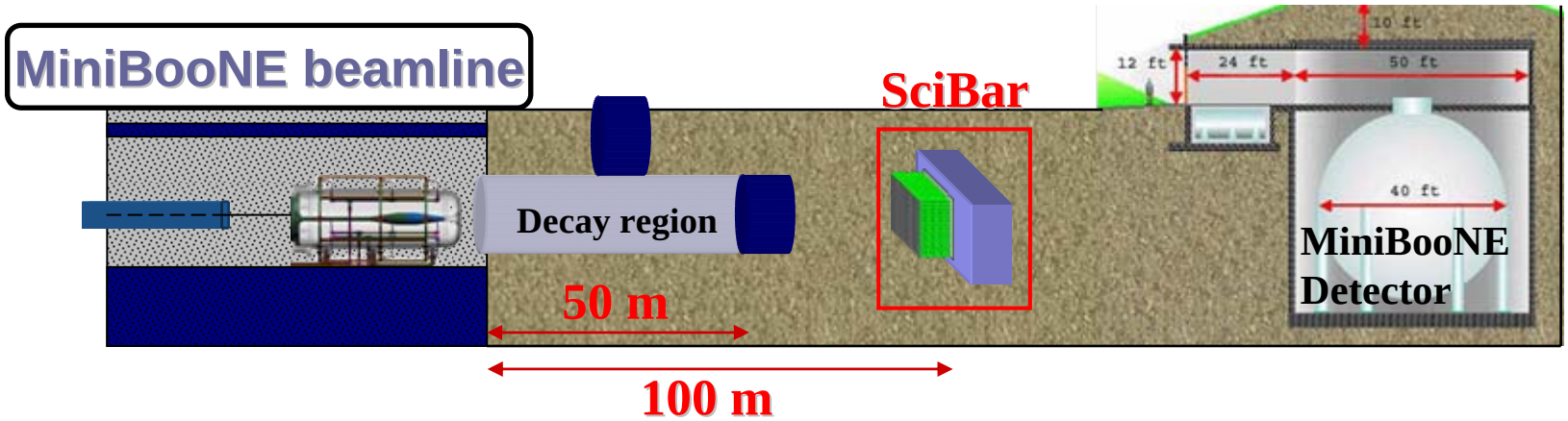
- **SciBar as a Near Detector of MiniBooNE**
  - **Constraint on the un-oscillated ν_μ flux**
  - **Background contamination measurement**
  - **Performance of SciBar has been understood in K2K**

Members

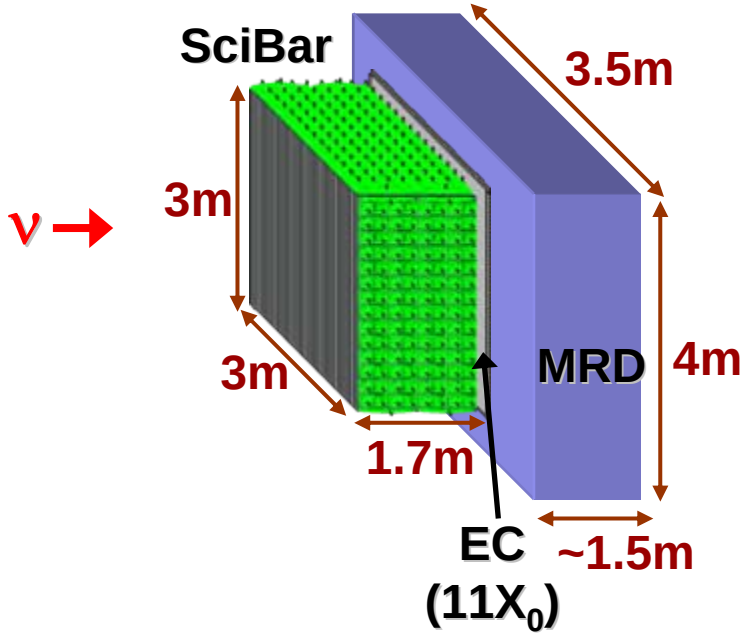
Barcelona	F. Sanchez, J. Alcaraz, S. Andringa, X. Espinal, G. Jover, T. Lux, F. Nova, A. Y. Rodriguez
Colorado	M. Wilking
Columbia	K. B. M. Mahn, J. Monroe, G. P. Zeller
FNAL	S. J. Brice, R. Stefanski
KEK	Y. Hayato
Kyoto	T. Nakaya, M. Yokoyama, H. Tanaka, K. Hiraide, Y. Kurimoto, Y. Kurosawa
LANL	R. Van de Water
LSU	M. O. Wascko
Rome	L. Ludovici, U. Dore, P. F. Loverre, C. Mariani
Valencia	J. J. Gomez-Cadenas, A. Cervera, M. Sorel, A. Tornero, J. Catala, P. Novella, E. Couce, J. Martin-Albo

10 institutes, ~40 people

Experimental setup



- Install at 100m from the target, on-axis position
- Bring SciBar and EC (including electronics) from KEK
- Arrange MRD (Iron+Scinti.) at FNAL



Physics cases

- Propose 1year run ($2x10^{20}$ protons on target)
- Neutrino run ($0.5x10^{20}$ POT)
  - CC-$1\pi^+$ cross section
  - NC-$1\pi^0$ cross section
  - Intrinsic ν_e contamination

# of interactions in FV
ν_μ ~78,000
ν_e ~ 700

- Anti-neutrino run ($1.5x10^{20}$ POT)
  - CC-QE cross section
  - neutrino BG contamination
  - CC-coherent π cross section

# of interactions in FV
$\bar{\nu}_\mu$ ~40,000
ν_μ ~22,000

Neutrino run

MRD matching sample (Pμ, θμ)

1 track

~13,500 events

QE~67%

2 track QE

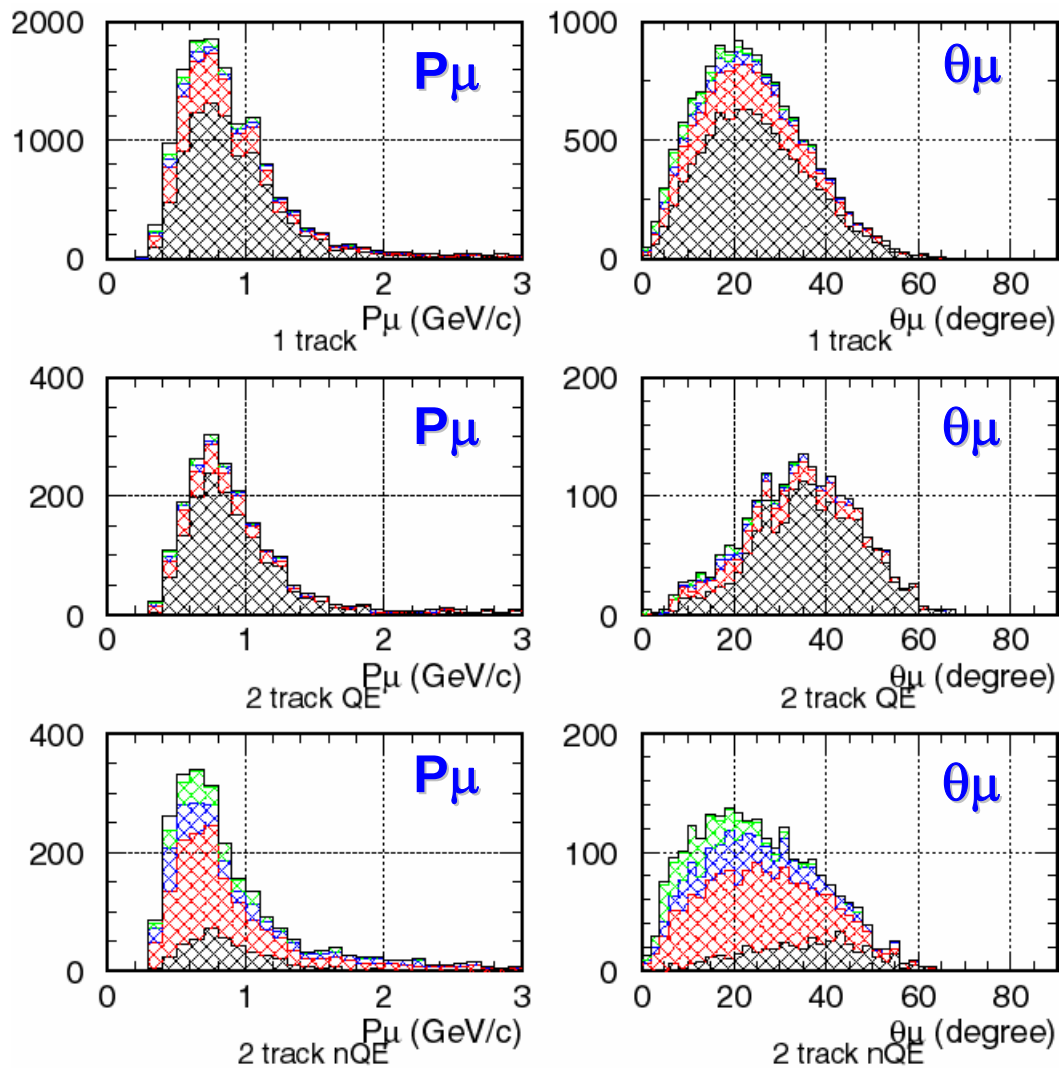
~1,970 events

QE~76%

2 track non-QE

~2,360 events

CC-1π~49%



CC-QE

CC-1π

CC-coh. π

CC-multi π

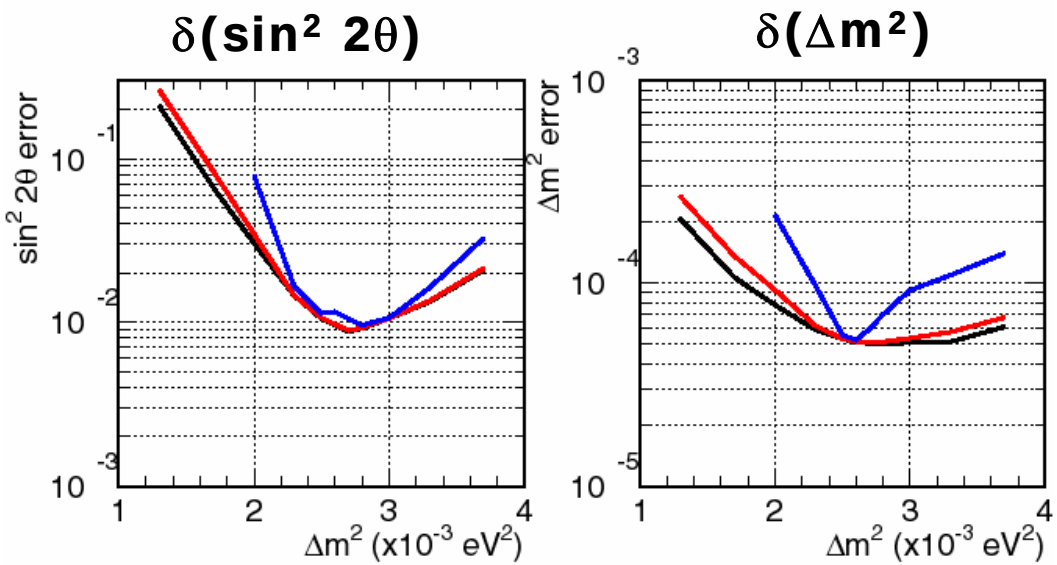
CC-1π^+ measurement

- CC-1π^+: $\nu + N \rightarrow \mu + N + \pi^+$

- Physics motivation
  - Dominant background to ν_μ disappearance in T2K
  - The uncertainty of nonQE/QE needs to be known to 5%

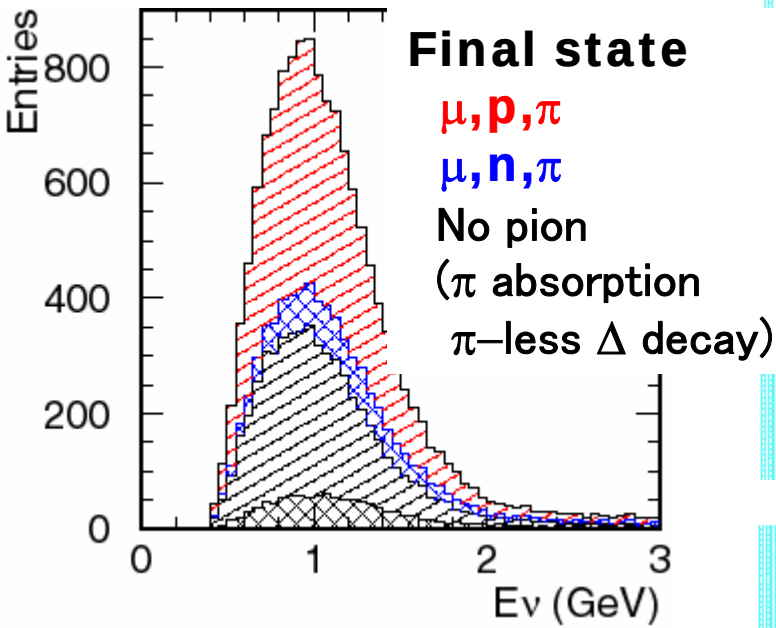
The ν_μ disappearance measurement error (90%CL)

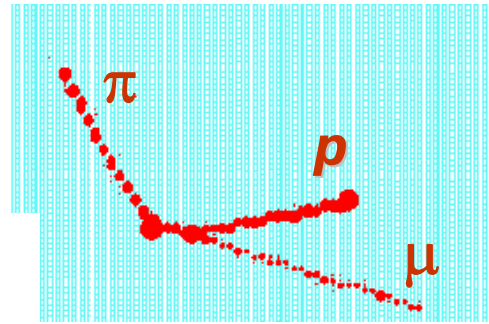
— stat. only
— δ(nQE/QE) = 5%
— δ(nQE/QE) = 20%

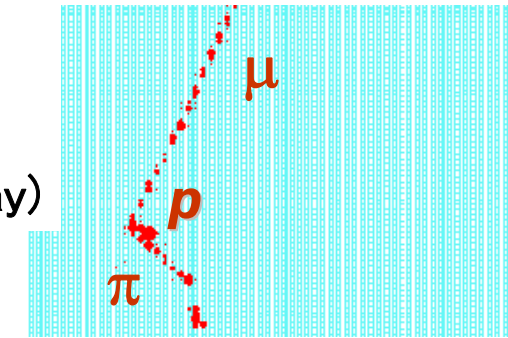


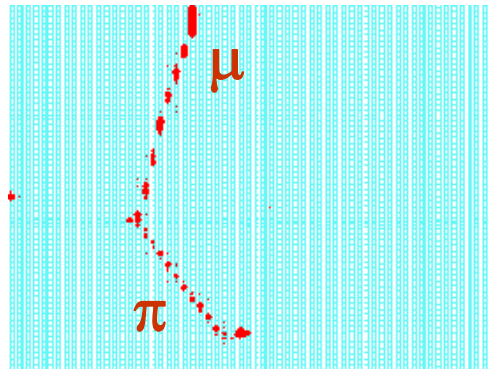
CC-1π^+ measurement (cont'd)

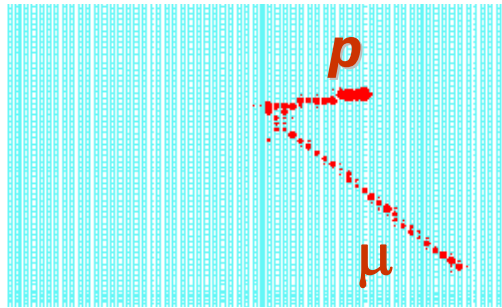
Eν distribution for CC-1π^+









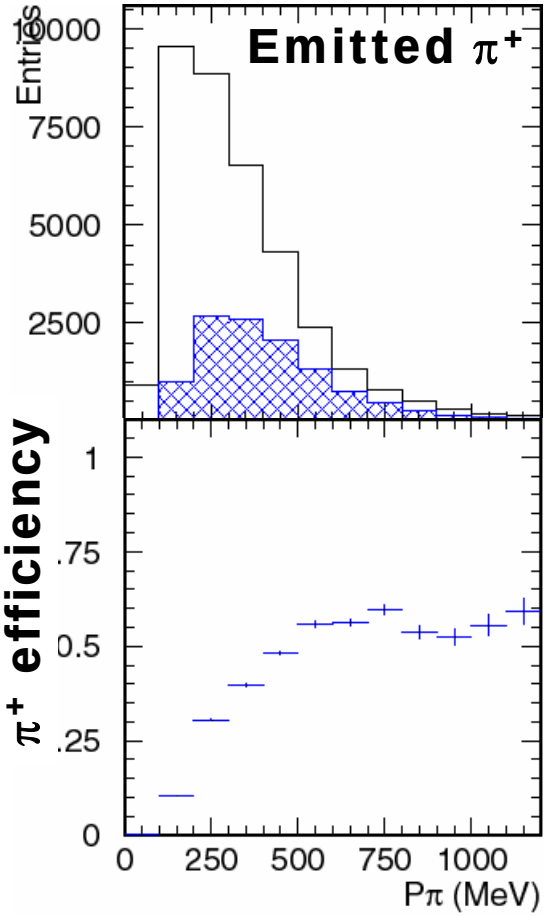


SciBar has an ability to separate the final state

Sensitive to the nuclear effect

CC-1π^+ measurement (cont'd)

π^+ detection efficiency as a function of Pπ^+



CC-1π^+ signature:
2-track, both are MIP-like

Selection criteria	#(CC-1π^+) [events]	Purity	Efficiency
Generated in FV	13,892	-------	100%
CC inclusive sample (SciBar+EC+MRD)	8,977	24.1%	64.6%
# of tracks =2	2,705	32.6%	19.5%
2nd track = MIP-like	1,355	46.8%	9.8%

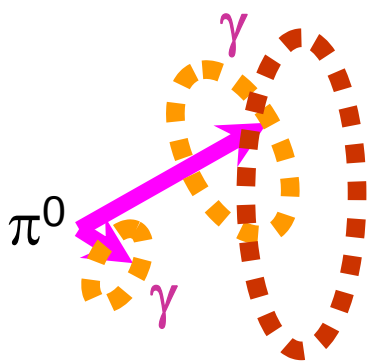
Additional vertex activity can separate $\nu+p\rightarrow\mu+p+\pi^+$ from $\nu+n\rightarrow\mu+n+\pi^+$

Statistics will allow a 5% measurement

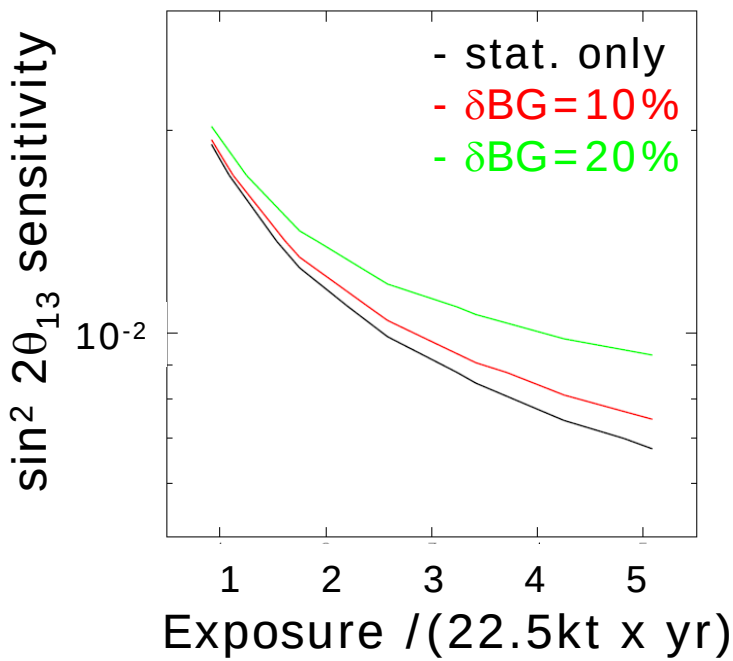
NC-1π^0 measurement

- NC-1π^0: $\nu + N \rightarrow \nu + N + \pi^0$
- Physics motivation
  - Dominant background to ν_e appearance in T2K
  - Need to be known to 10% level

2-ring merged to 1-ring in Cherenkov detector

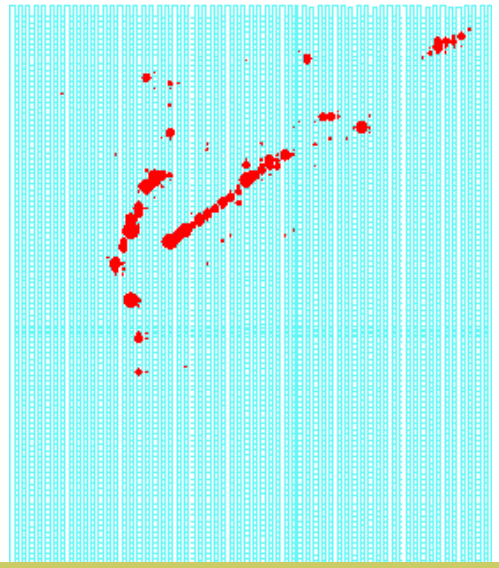


200~700MeV/c π^0s



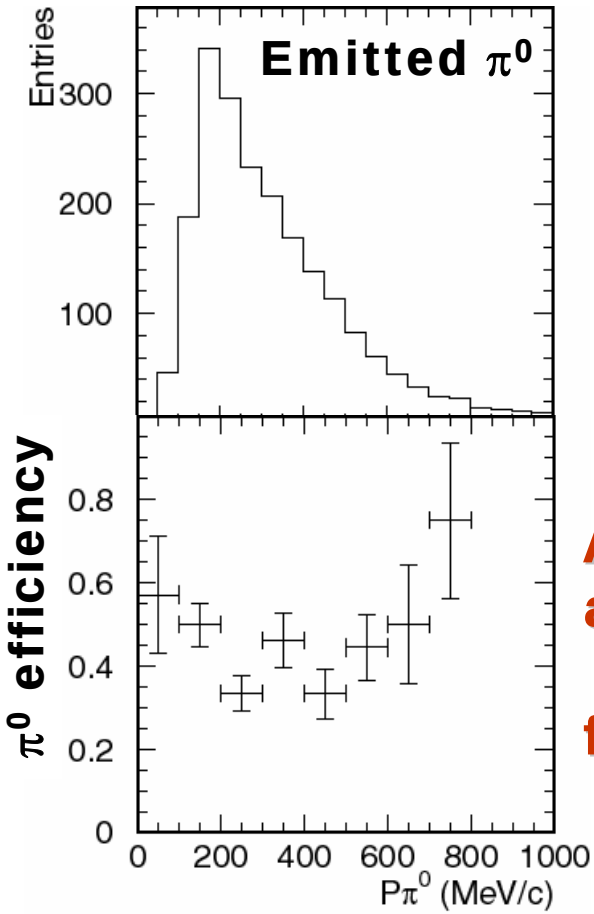
NC-1π^0 measurement (cont'd)

NC-1π^0 event display



π^0s are detected as two shower-like tracks in SciBar

π^0 detection efficiency as a function of Pπ^0



- Good efficiency for high-momentum π^0
- Reconstructed π^0 ~800events

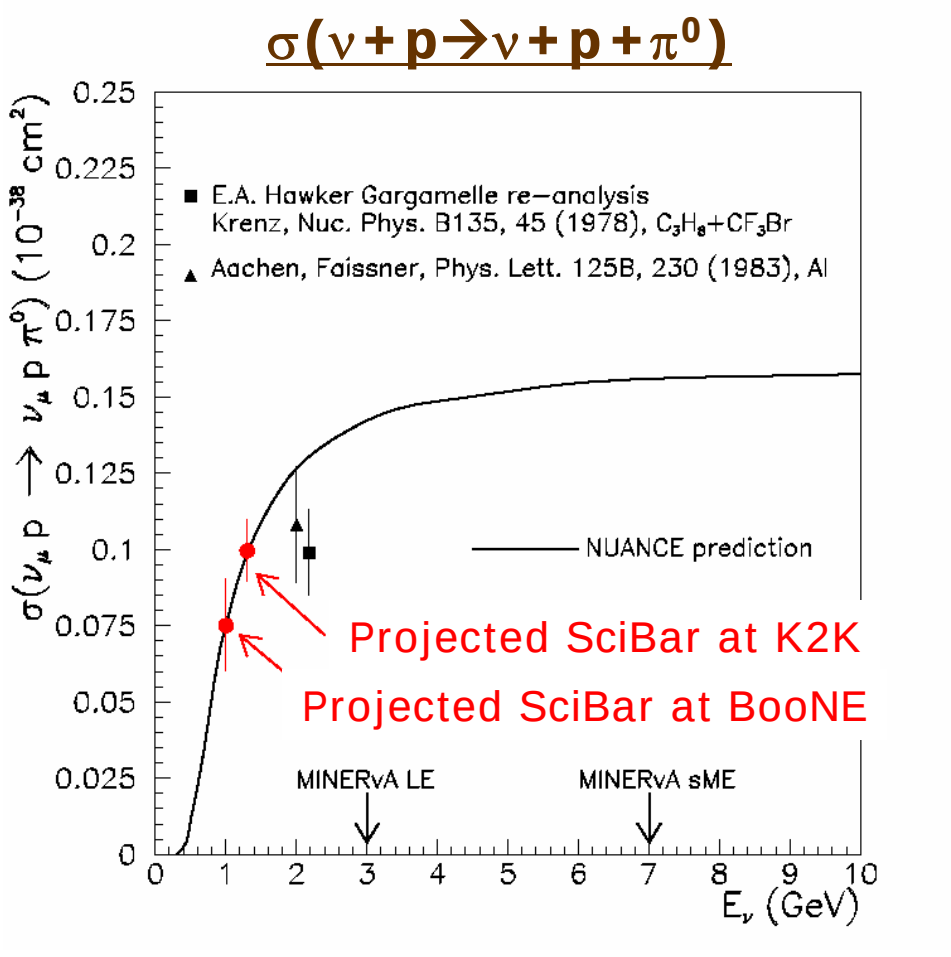
Additional vertex activity can separate

$\nu + p \rightarrow \nu + p + \pi^0$

from

$\nu + n \rightarrow \nu + n + \pi^0$

NC-1π^0 measurement (cont'd)



10% measurement can be obtained

Anti-neutrino run

MRD matching sample (Pμ, θμ)

1 track

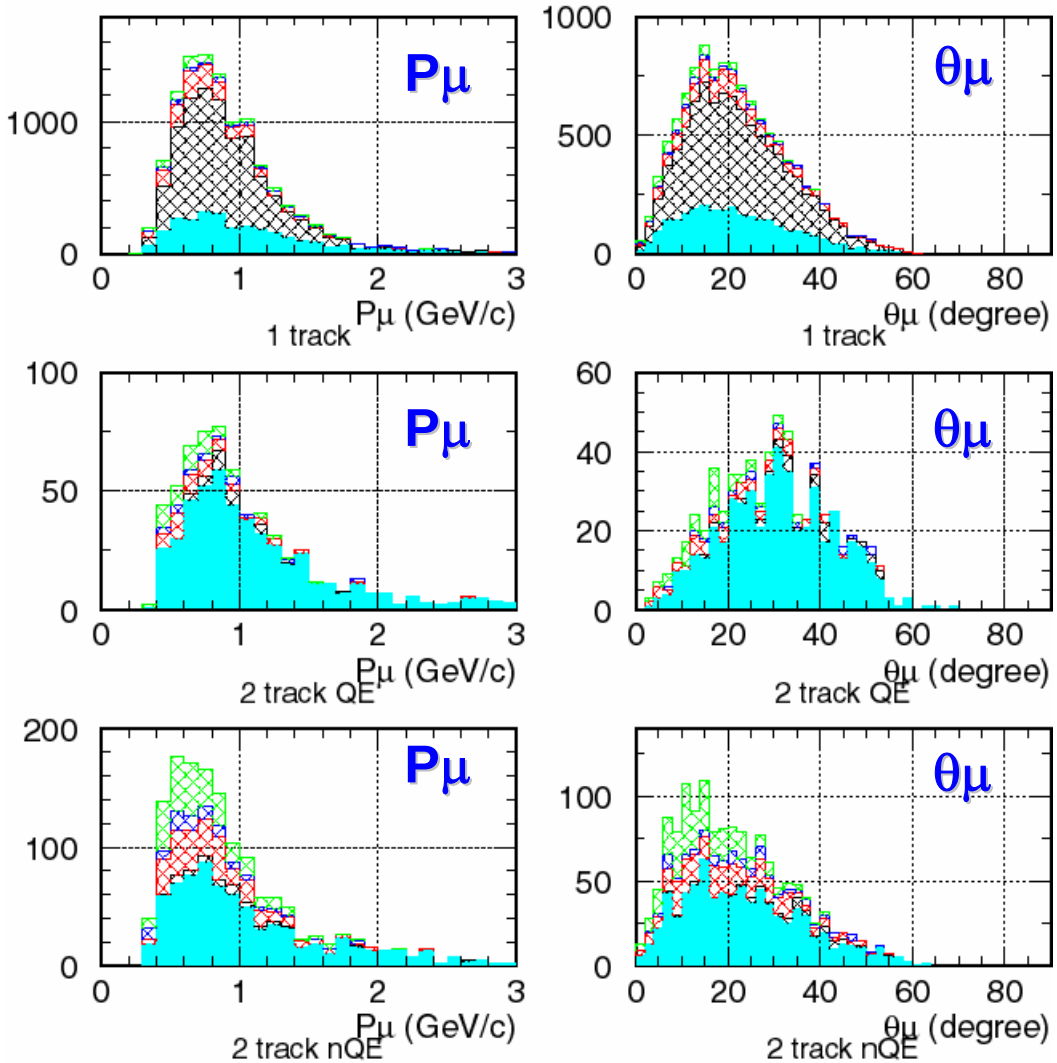
~17,000 events
QE~58%

2 track QE

~950 events
ν_μ BG~77%

2 track non-QE

~2,100 events
ν_μ BG~54%
CC-1π~18%
CC-coh. π~18%

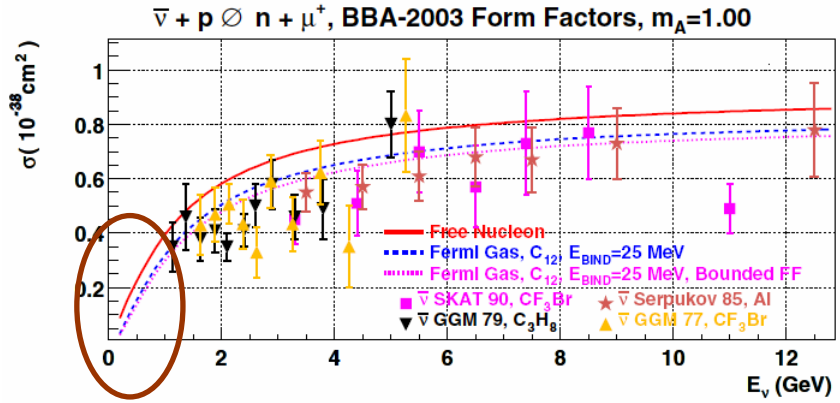


CC-QE
CC-1π
CC-coh. π
CC-multi π
ν_μ BG

Anti-neutrino CC-QE measurement

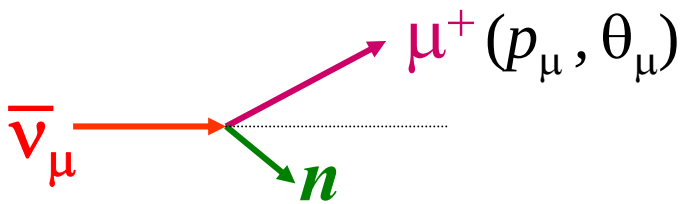
Physics motivation

- The first σ measurement with good final state separation
- It is important for T2K phase-II



No data

CC-QE: $\bar{\nu}_\mu + p \rightarrow \mu^+ + n$

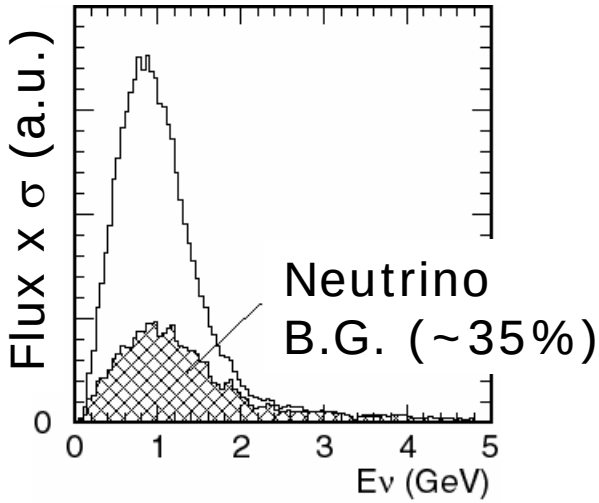


$$E_\nu^{rec} = \frac{m_N E_\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$

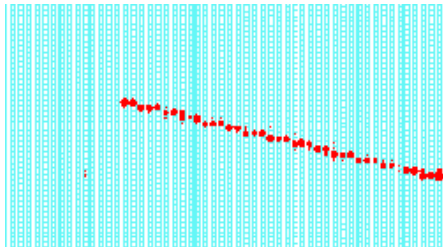
- **Detected as a 1-track event in SciBar**
- **Can reconstruct neutrino energy**

Anti-neutrino CC-QE and neutrino BG

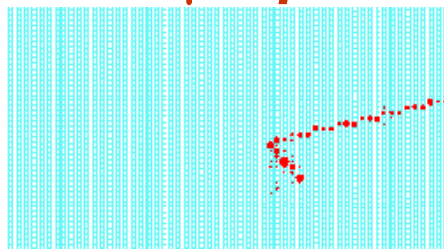
Anti-neutrino beam contains neutrino backgrounds

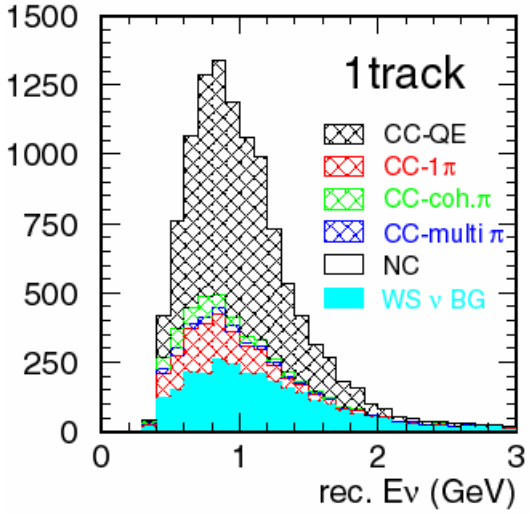


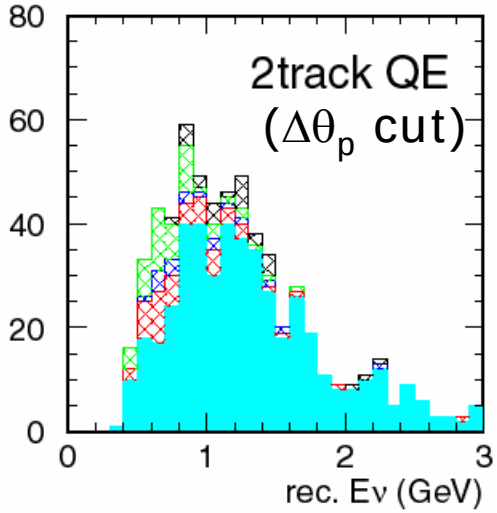
$\bar{\nu} + p \rightarrow \mu^+ + n$



$\nu + n \rightarrow \mu^- + p$





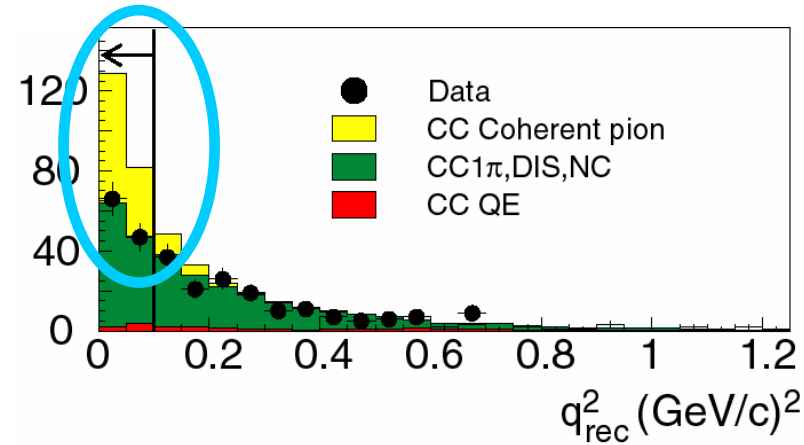


SciBar can separate anti-ν_μ QE from ν_μ QE

CC-coherent π measurement

- CC-coherent π: **ν+A→μ+A+π**

- Physics motivation
  - SciBar observed no CC-coherent π production in K2K beam (hep-ex/0506008)

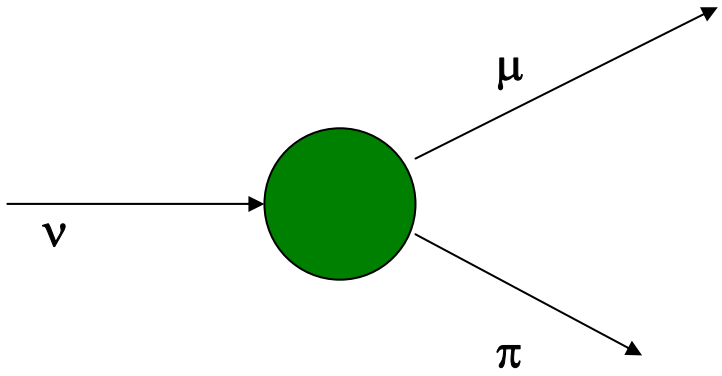


$$\frac{\sigma(CC-Coh\ \pi)}{\sigma(\nu_\mu CC)} < 0.60\times10^{-2}\ @\ 90\%CL$$

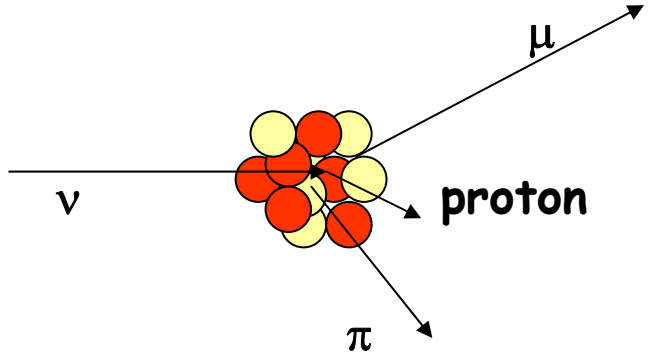
  - It will be a good check by using both neutrino and anti-neutrino beam

CC-coherent π measurement (cont'd)

CC-coherent π (ν+A→μ+A+π)



CC-1π (ν+p→μ+p+π)



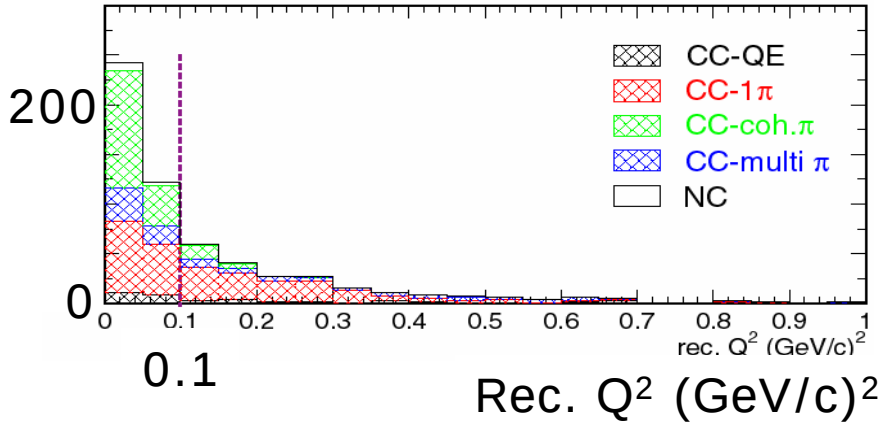
Coherent π signature

- **One muon and one pion in the final state**
- **Low momentum transfer**
- **No vertex activity due to proton**

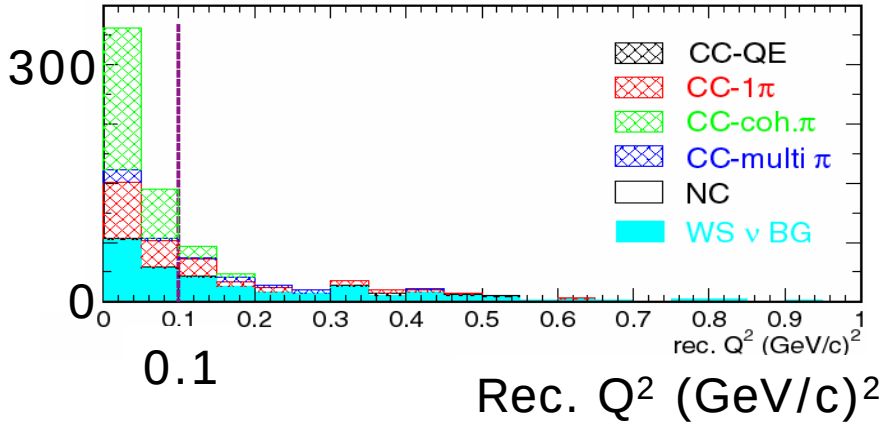
CC-coherent π measurement (cont'd)

Rec. Q^2 distribution of final sample

Neutrino Run(0.5×10^{20}POT)



Anti-neutrino Run(1.5×10^{20}POT)



#(coherent π)~160events
Efficiency = 0.11
Purity = 0.44

#(coherent π)~240events
Efficiency = 0.11
Purity = 0.49

we can measure in both neutrino and anti-neutrino beam

More physics cases

- **ν_μ disappearance**
  - Constraint on the un-oscillated ν_μ flux normalization and energy spectrum
- **Radiative delta decay ($\Delta \rightarrow N + \gamma$)**
  - First measurement of a neutrino-induced (or antineutrino-induced) radiative delta decay
- **NC-coherent π^0 cross section**
- **M_A measurement (CCQE, CC1π)**

… etc.

Summary & schedule

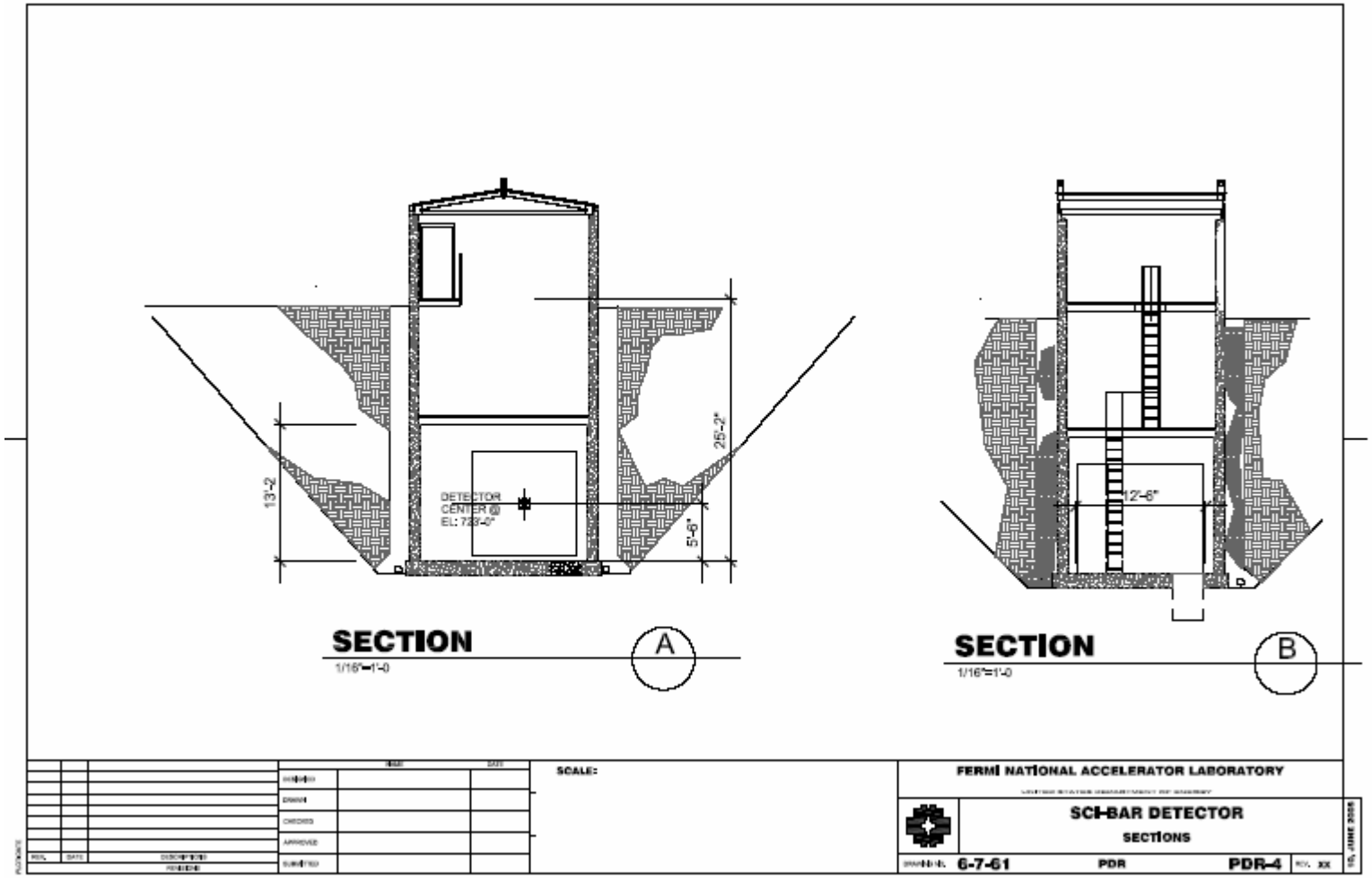
- We plan to bring SciBar to FNAL and measure neutrino/anti-neutrino cross sections.
- This measurement will be helpful for both T2K and MiniBooNE.

- Schedule
  - October 11th : Fermilab director's review
  - December 8th-10th: Fermilab PAC

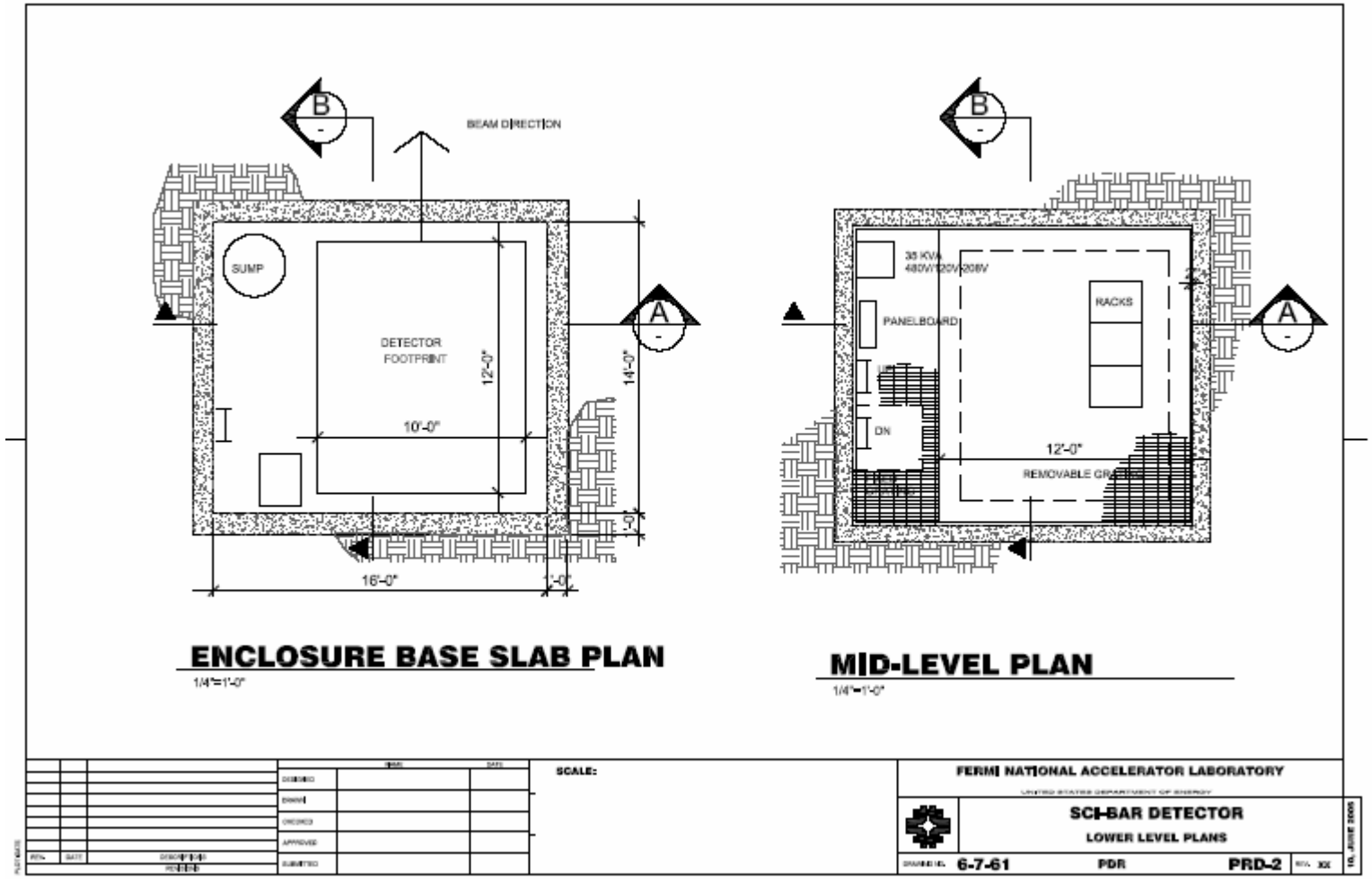
    disassemble → shipping → construction
  - 2006 fall -2007: data taking

Backup slides

SciBooNE detector hall (1)

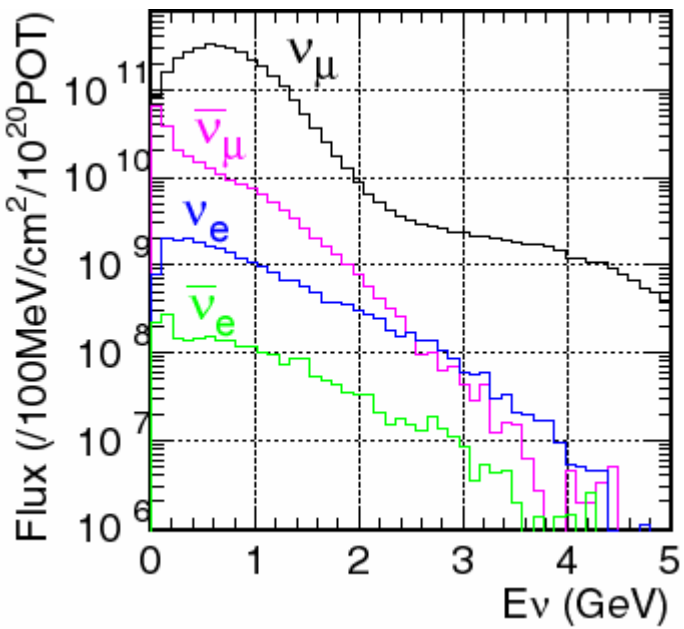


SciBooNE detector hall (2)

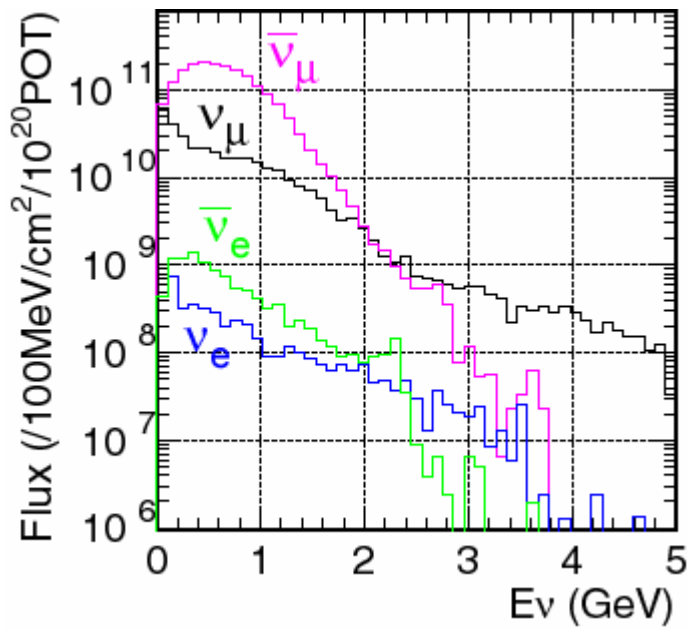


Expected neutrino flux spectra

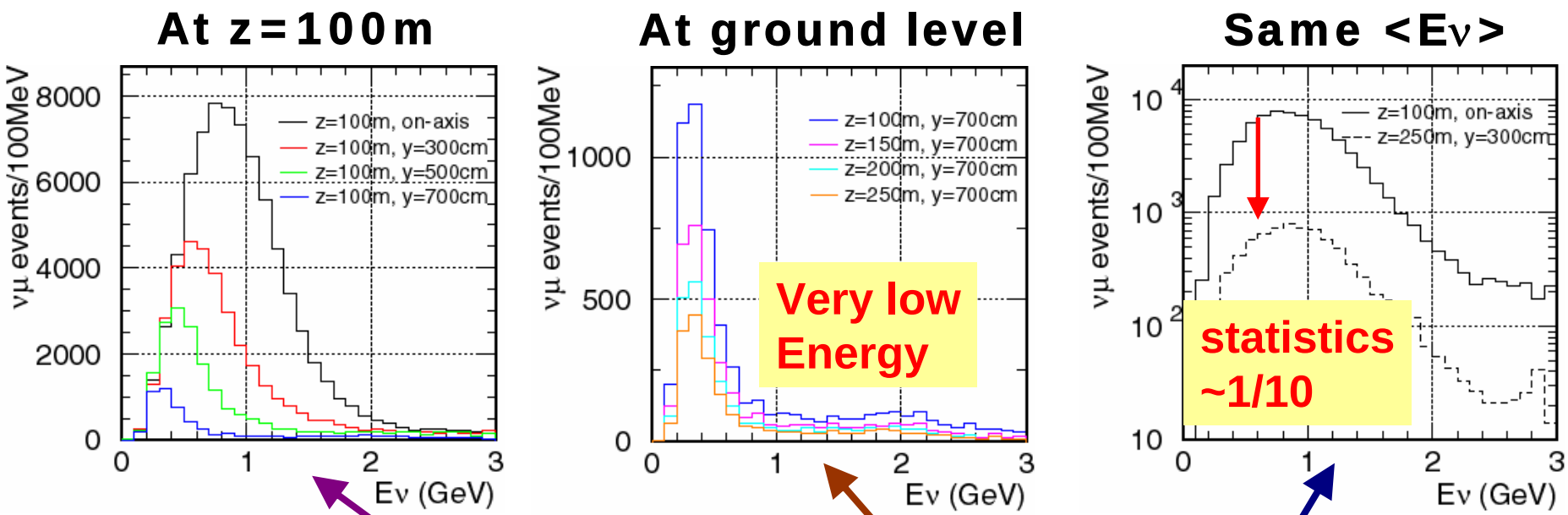
Neutrino Run



Anti-neutrino Run

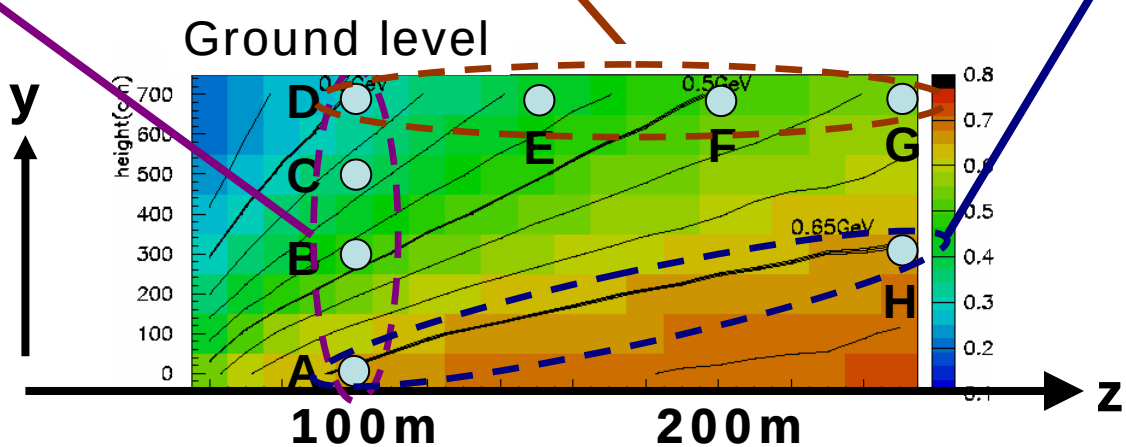


Expected ν_μ flux x σ spectra



Several detector locations: A~H

color means <Eν>



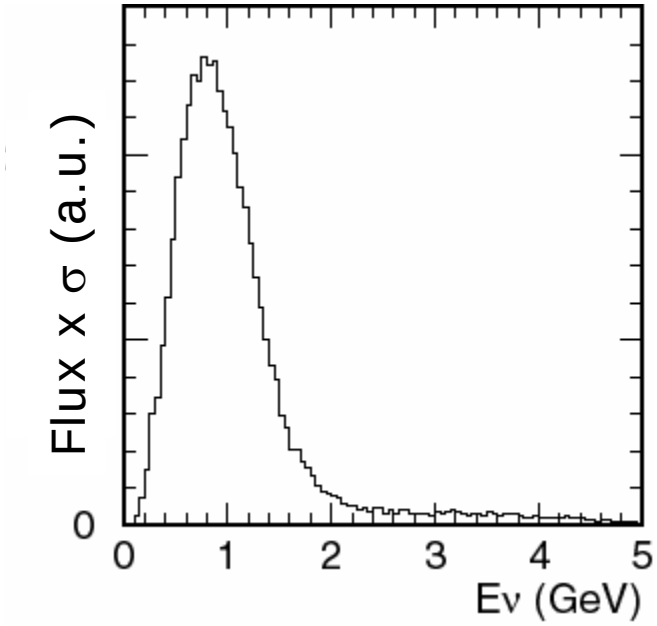
Comparison of several locations

location	A	B	C	D	E	F	G	H
Z Height	100m 0m	100m 3m	100m 5m	100m 7m	150m 7m	200m 7m	250m 7m	250m 3m
Cost	$505k	$431k	$292k	$219k	$219k	$219k	$219k	$431k
<Eν> peak E	0.92 0.76	0.76 0.58	0.64 0.42	0.60 0.30	0.60 0.30	0.61 0.32	0.61 0.32	0.94 0.87
$\#\nu_\mu$	78,397	37,230	19,357	6,001	3,791	2,807	2,200	8,112
$\#\overline{\nu}_\mu$	1,138	636	467	176	113	88	67	109
$\#\nu_e$	669	415	268	128	68	46	39	61
Statistics	☺	▲	X	X	X	X	X	X

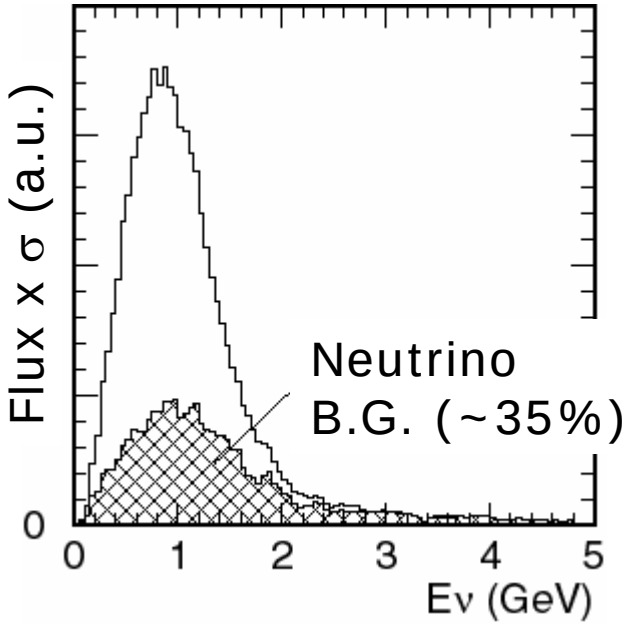
Expected # of interactions

Expected Proton Delivery Rate: (1~2)x10^{20} POT/year
➔ Assumed 1-year data taking at MiniBooNE beamline

Neutrino Run(0.5x10^{20}POT)



Anti-neutrino Run(1.5x10^{20}POT)



ν_μ: ~78,000 int.
ν_e: ~ 700 int.

$\bar{\nu}_\mu$: ~40,000 int.
ν_μ: ~22,000 int.

Neutrino mode (0.5×10^{20} POT)

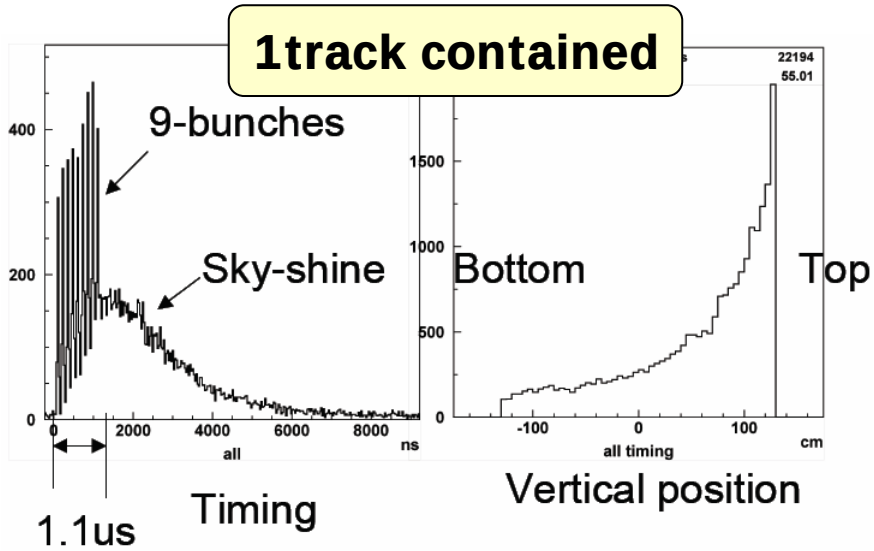
	# of $\nu\mu$ events
CC QE	32,238
CC resonant $1\pi^+$	14,317
NC elastic	13,976
CC multi-π	4,743
NC resonant $1\pi^0$	3,814
CC resonant $1\pi^0$	3,047
NC resonant $1\pi^{+/-}$	2,405
NC multi-π	1,650
CC coherent $1\pi^+$	1,466
NC coherent $1\pi^0$	741
Total	78,397

Antineutrino mode (1.5×10^{20} POT)

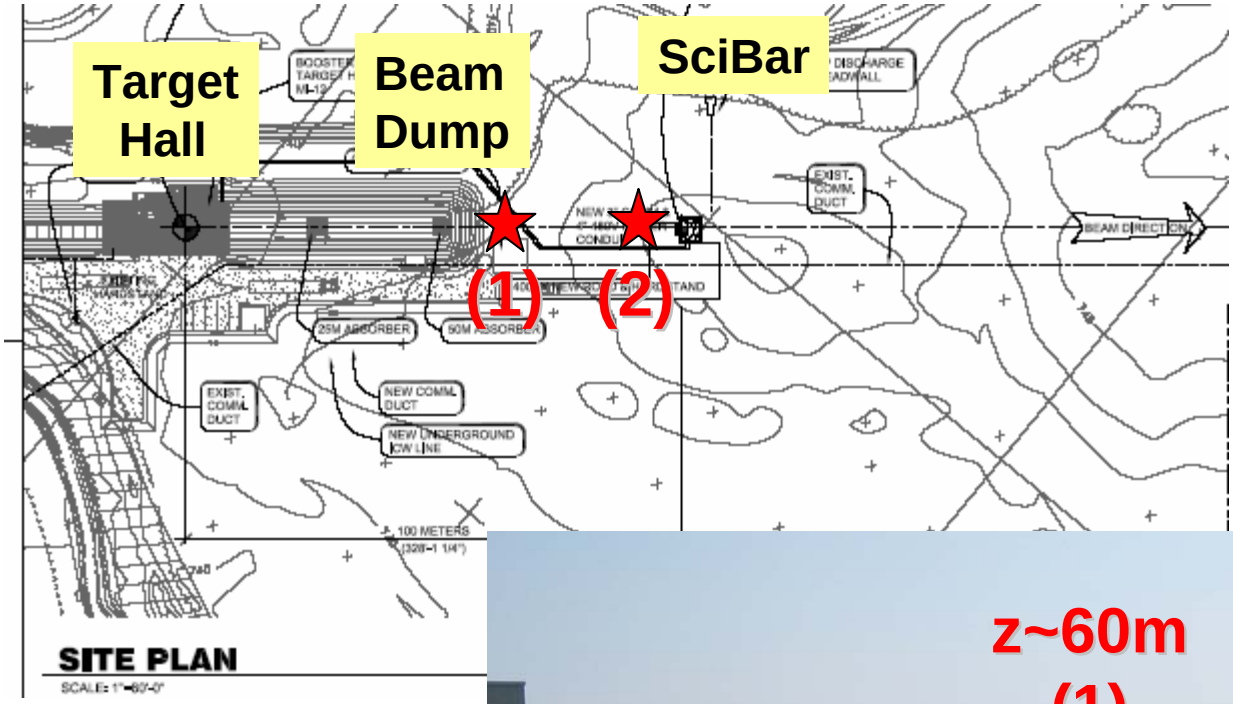
	# of ν_μ-bar events (RS)	# of ν_μ events (WS)
CC QE	18,214	7,674
NC elastic	7,410	3,446
CC resonant $1\pi^-$	4,252	0
CC resonant $1\pi^+$	0	4,363
CC coherent $1\pi^-$	2,105	0
CC coherent $1\pi^+$	0	384
NC resonant $1\pi^0$	2,025	1,104
CC multi-π	1,550	2,309
NC resonant $1\pi^{+/-}$	1,225	738
CC resonant $1\pi^0$	1,097	898
NC coherent $1\pi^0$	1,078	210
NC multi-π	688	823
Total	39,644	21,949

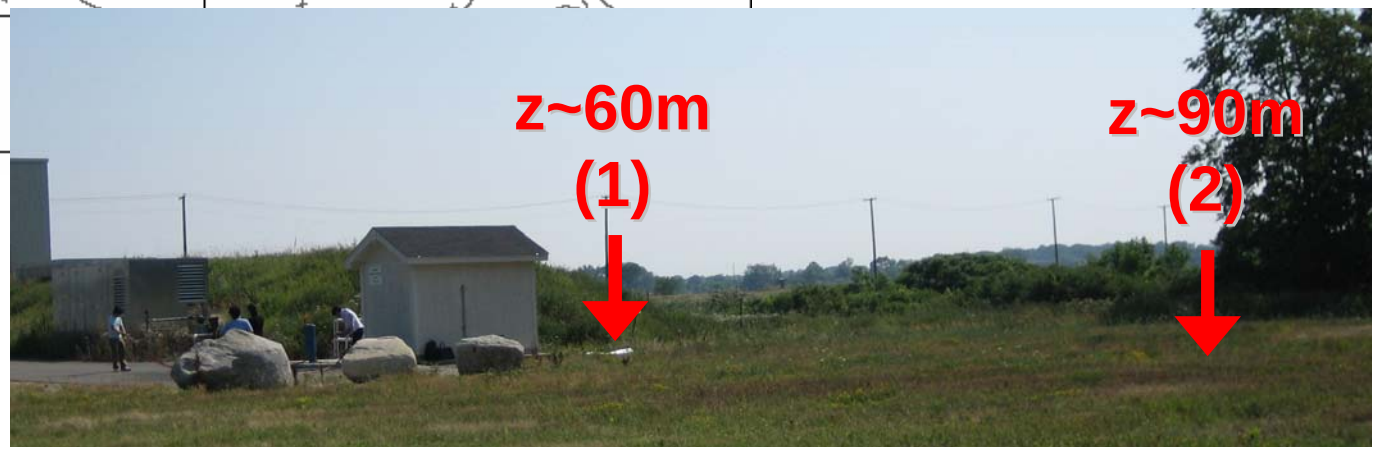
Beam related Background (1) ~Introduction~

- There exists beam related backgrounds at K2K near detector
  - From upward, upstream
  - Proton-like and gamma-like short tracks



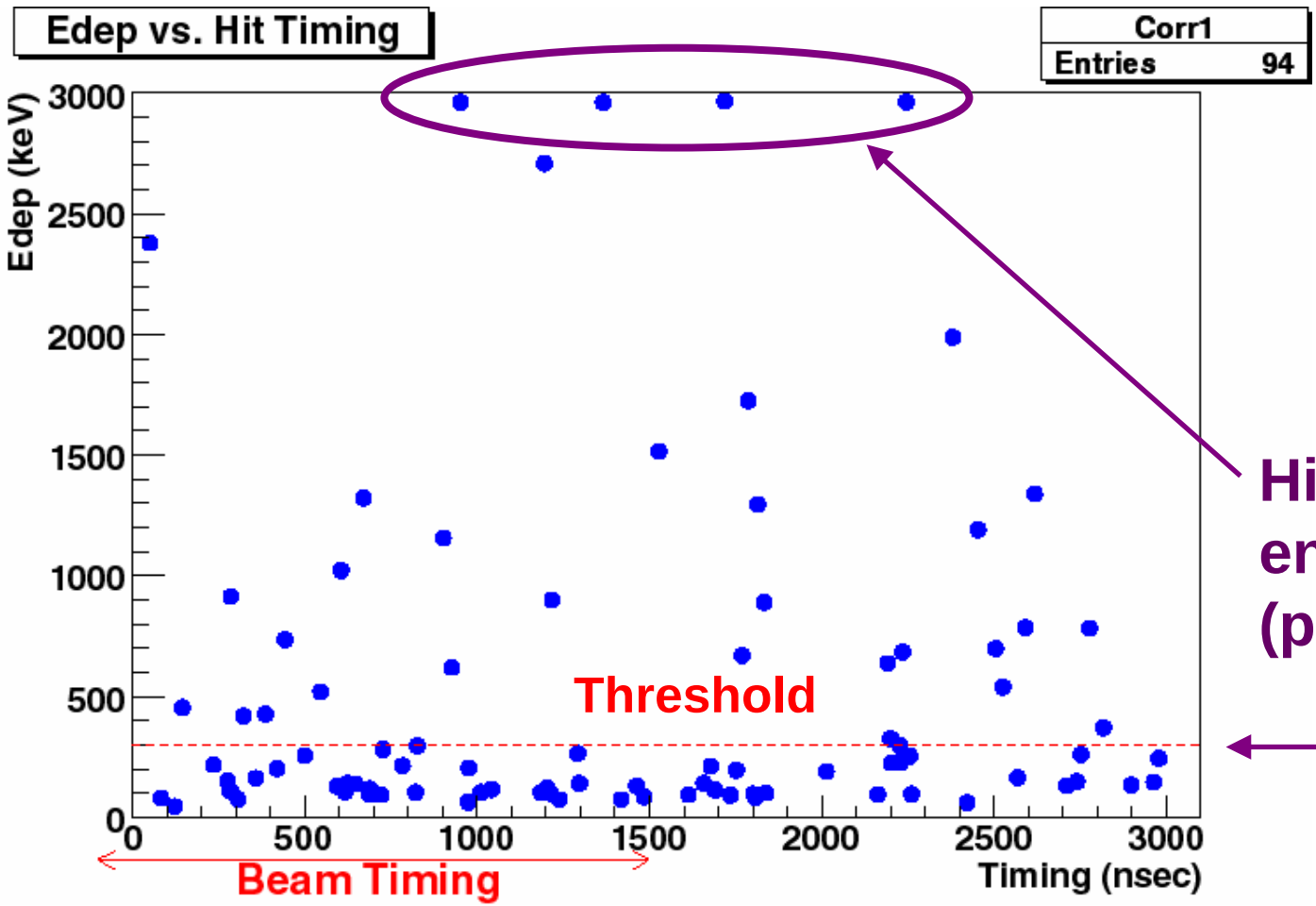
Beam related background (2)
~Measurement setup~





Scintillators were put on the ground

Beam related background (3)
~Energy deposit vs. Hit timing~



- z~60m
- On-timing (3μsec gate)
- 25,889 spills

Hits with large energy deposit (proton-like?)

Many low energy hits (gamma-like?)

Beam related background (4)
~Observed number of events at BNB~

	(1) z~60m		(2) z~90m	
	On-time	Off-time	On-time	Off-time
# of spills	25,889	10,072	33,441	10,233
Single hit Scinti. 1	16	0	14	0
Single hit Scinti. 2	37	0	20	1
coincidence	5	0	4	0

On-time: 1.5μsec gate at beam-timing
Off-time: 1.5μsec gate (~8msec after beam-timing)

The excess of hits at beam-timing was observed!

Beam related background (5) ~Comparison between BNB and K2K~

	Booster Neutrino Beam line		K2K Near Detector Hall	
POT/spill	$(4.0\sim4.5)\times10^{12}$		$\sim5\times10^{12}$	
Location	Z~60m Ground level	Z~90m Ground level	Top of SciBar	K2K-ND Hall Ground level
Single hit (Scinti. 1/2)	1) 38±10(stat) 2) 59±10(stat)	1) 26±7(stat) 2) 25±6(stat)	2.3	18
coincidence	8.0±3.6(stat)	4.9±2.5(stat)		

[# of events/spill/15tons]