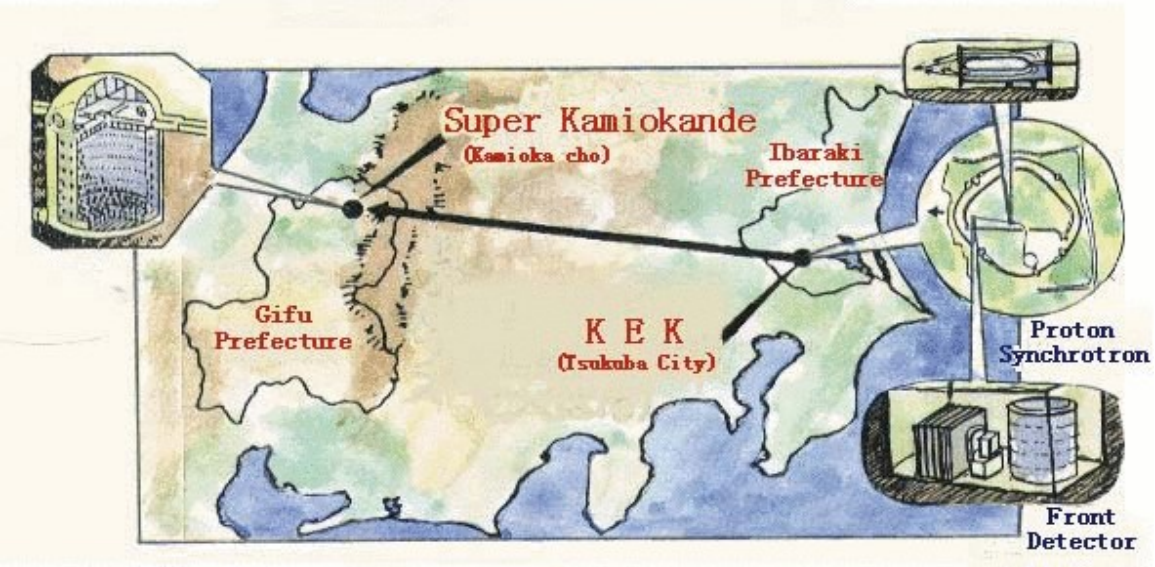
# K2K Beam and Near Detectors




Ana Y. Rodríguez for the K2K Collaboration

IFAE/Universidad Autònoma de Barcelona

May 30th, NuInt 07

# Outline

- Experiment Overview
- Beam Line
  - Primary proton beam
  - Target station
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- Near Detector
  - 1 Kton
  - SciFi
  - SciBar / Lead Glass
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- Oscillation measurement
- Summary

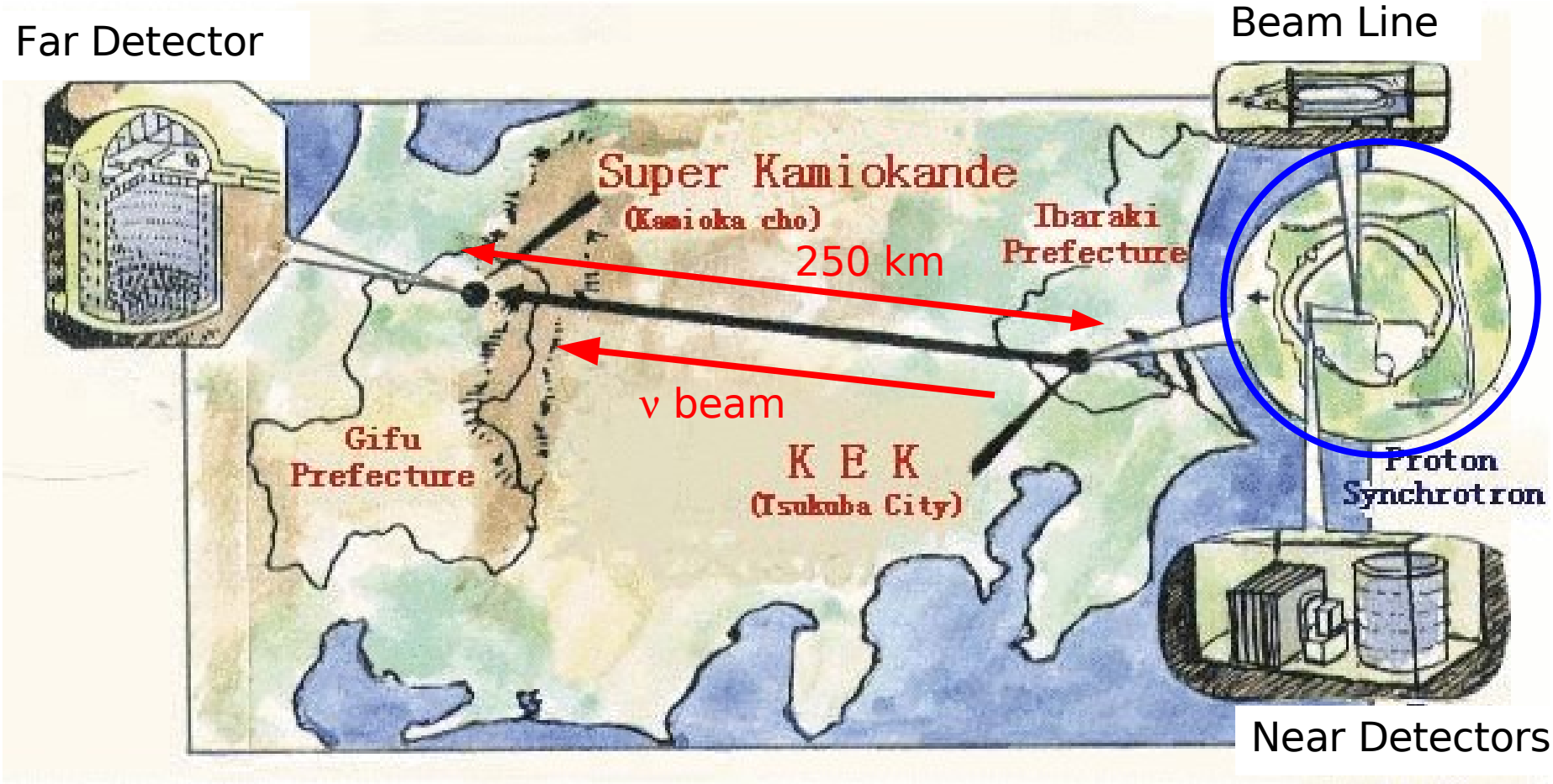
# Collaboration

JAPAN: High Energy Accelerator Research Organization (KEK)
Institute for Cosmic Ray Research, University of Tokyo
Kobe University, Kyoto University, Niigata University
Okayama University, Tokyo University of Science, Tohoku University
KOREA: Chonnam National University, Dongshin University
Korea University, Seoul National University
U.S.A.: Boston Univerrsity, University of California, Irvine
Duke University, University of Hawaii, Manoa
Massachusetts Institute of Technology
State university of New York at Stony Brook
University of Washington at Seattle
POLAND: Warsaw University, Solton Institute

Since 2002
JAPAN: Hiroshima University, Osaka University
CANADA: TRIUMF, University of British Columbia
EUROPE: Rome, Saclay, Barcelona, Valencia, Geneva
RUSSIA: INR-Moscow

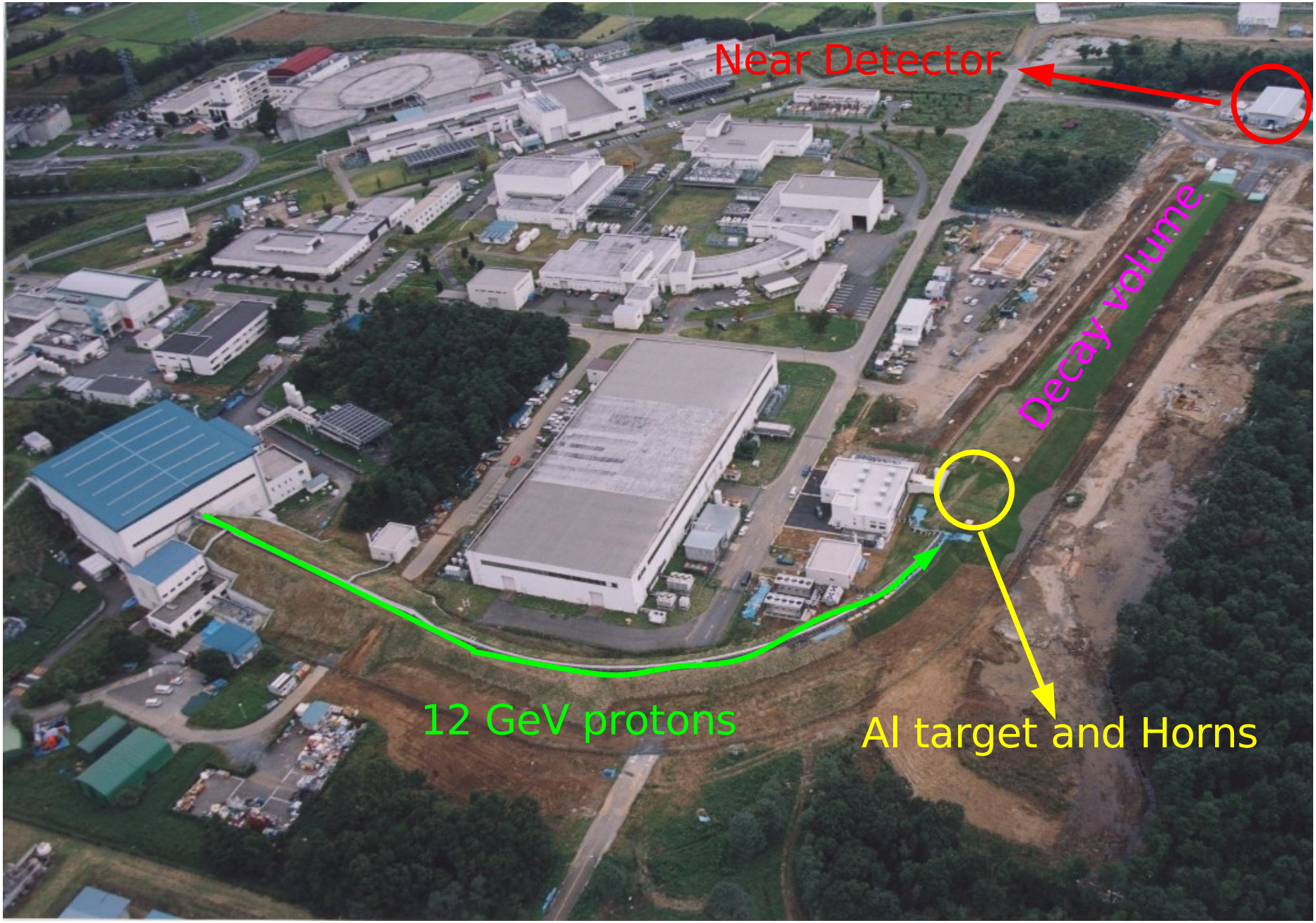
# Experiment Overview

- K2K is the first long baseline neutrino experiment
- Proposed to confirm atmospheric neutrino oscillations
- Data taken from June 1999 to November 2004



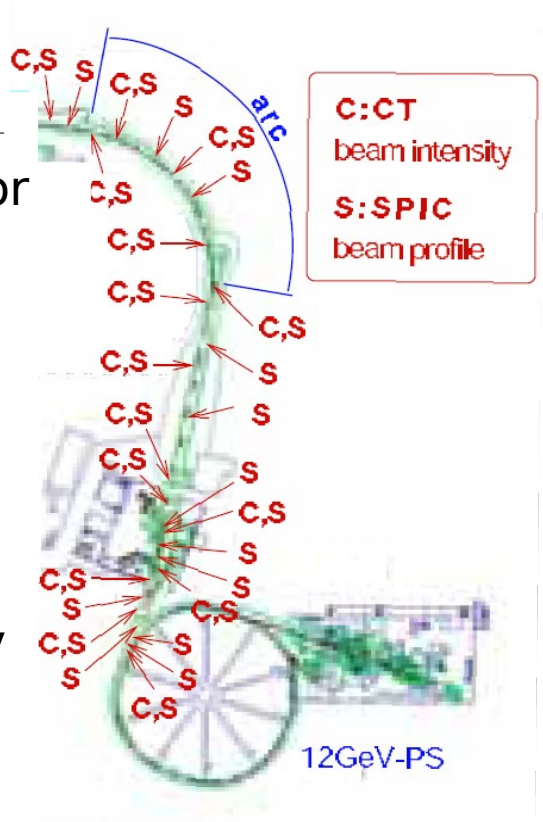
# Experiment Overview – Near Site





# Primary Proton Beam

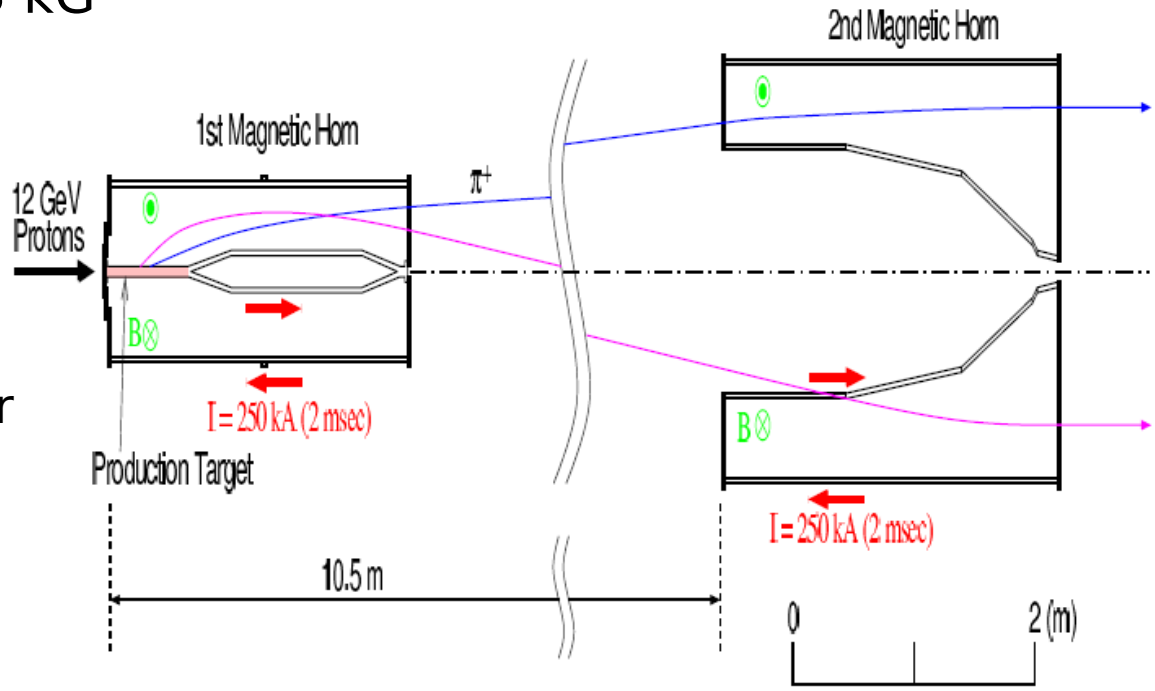
toward Far Detector




- protons accelerated to a kinetic energy of 12 GeV
- extracted in a 1.1 μs single turn
  - 9 bunches spaced 125 ns
  - repetition cycle 2.2 s
- 13 CT monitor the beam intensity
  - 85% overall transportation efficiency
  - before the target 5 x $10^{12}$ protons per extraction
- 28 SPICs monitor the profile and position of the beam

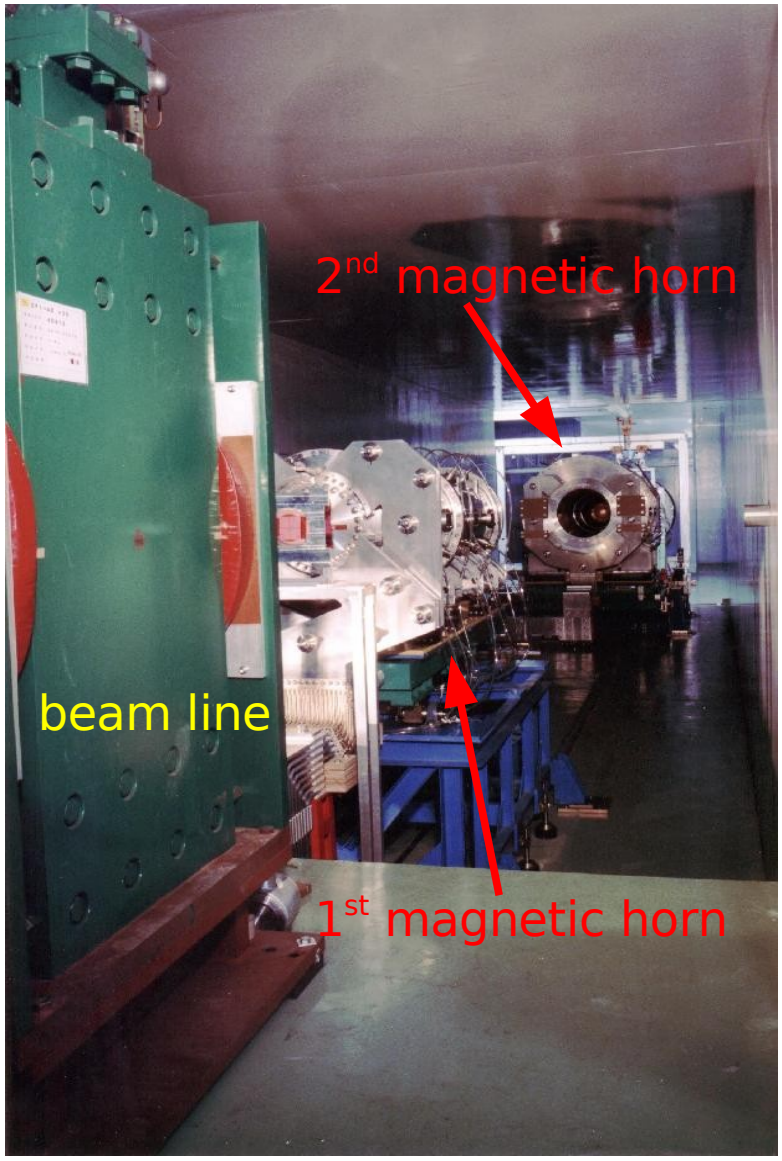
# Target Station

- The production target is an Al rod
- Two magnetic horns focus mainly $\pi^+$
  - $\pi^+$ momentum ~ 2-3 GeV/c → $E_\nu$ ~ 1-1.5 GeV
- Neutrino flux with horns magnets is 22 times greater than without
- Maximum magnetic field 33 kG

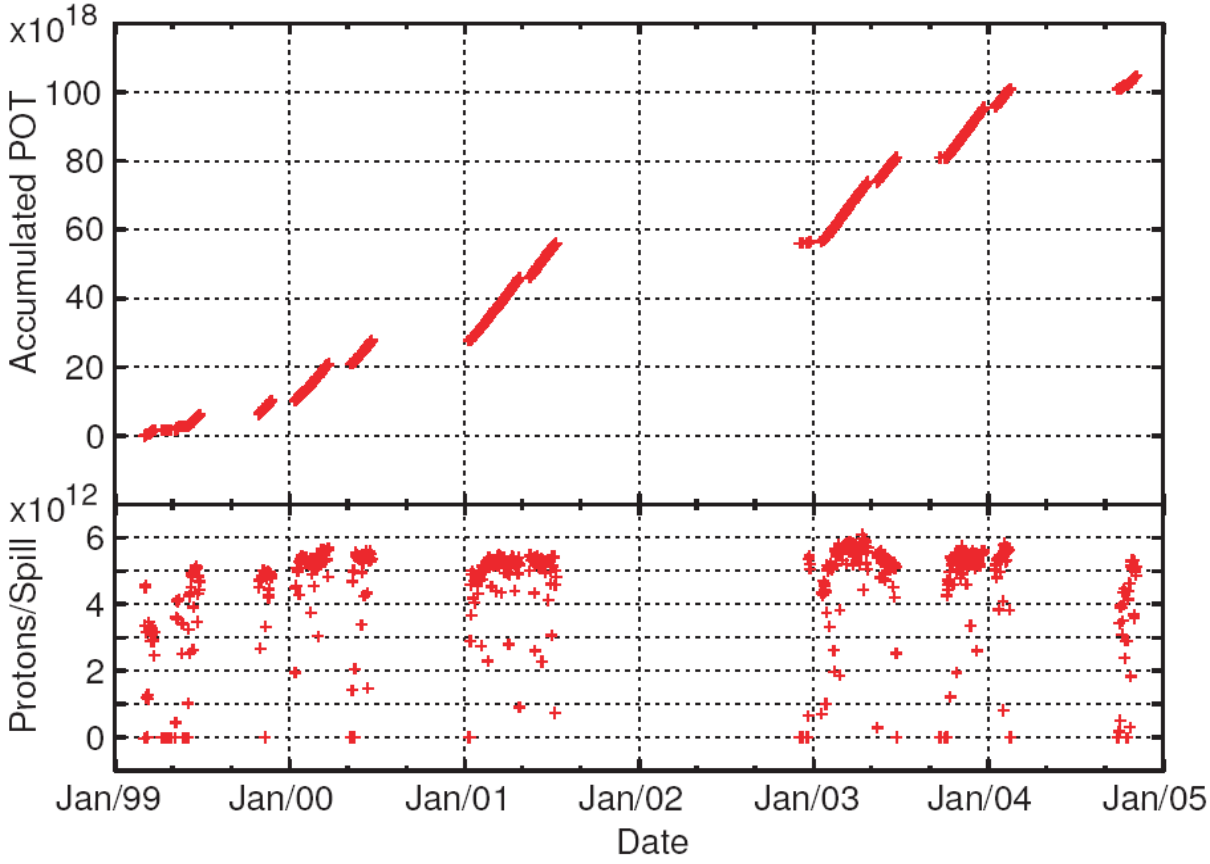



- Target:
  66 cm length, 3 cm diameter
- First horn:
  2.37 m length, 0.70 m diameter
- Second horn:
  2.76 m length, 1.65 m diameter
- Pulsed current:
  2 msec duration and 250 kA amplitude

# Target Station




$10^{20}$ POT were delivered to the production target



# Decay Volume and Beam Dump

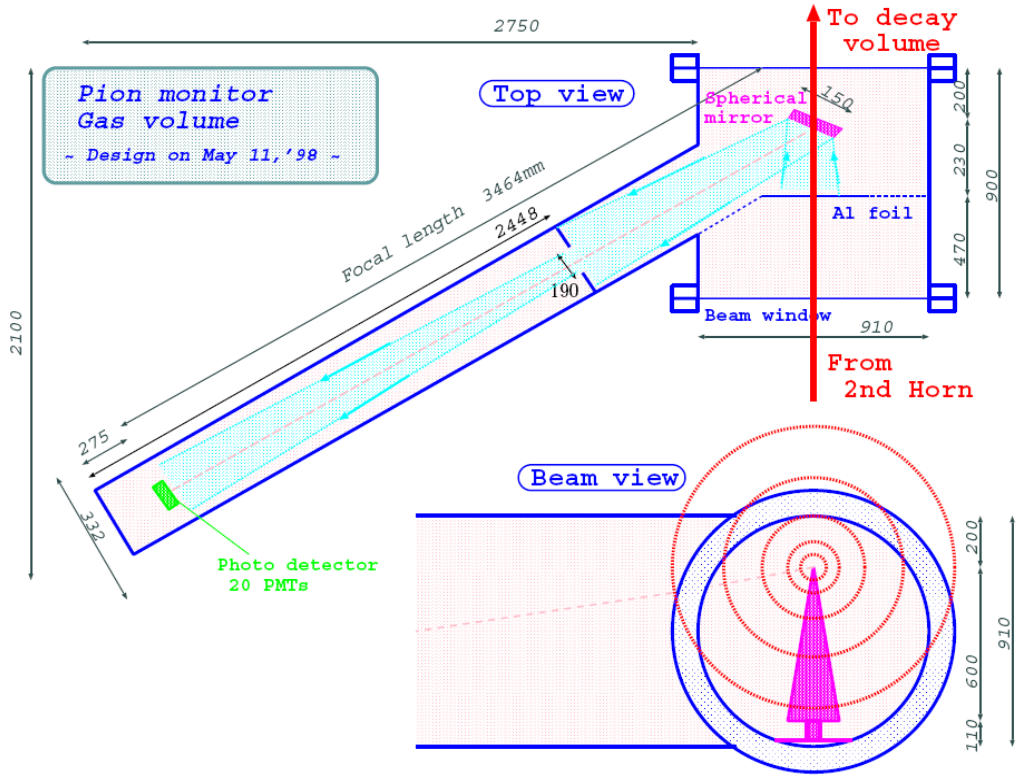


- 200 m decay volume: $\pi^+ \rightarrow \mu^+ \nu_\mu$
- cylindrical in shape and separated in three section with different dimensions
- filled with helium gas at 1 atm

- a beam dump stop all particles except neutrinos
  - a 3.5 m thick iron, 2 m thick concrete, and a region of soil 60 m long

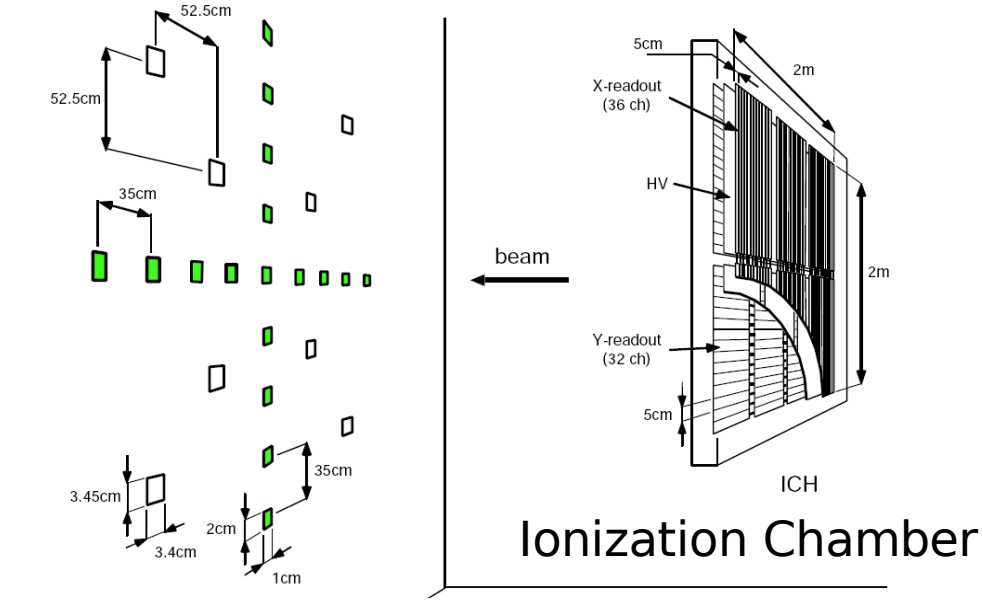
# Beam Monitors

- A pion monitor PIMON was installed to measure the momentum and angular distributions of pions
  - two occasions downstream the magnetic horns
  - gas Čerenkov imaging detector
    - gas vessel
    - spherical mirror
    - array of PMTs
  - confirm the validity of the far-to-near ratio given by Cho-CERN model and HARP



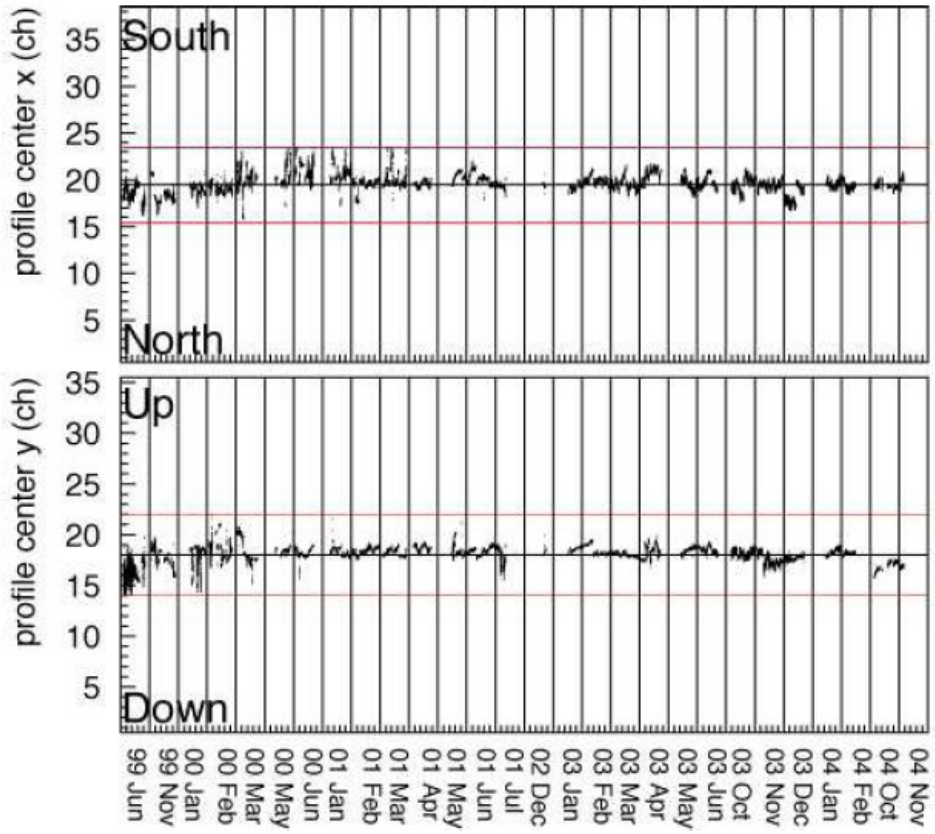
# Beam Monitors

- A muon monitor MUMON was installed to measure the profile center of muons which corresponds to that of neutrinos
  - downstream the iron and concrete shields
  - $10^4$ muons/cm$^2$/spill with momentum greater than 5.5 GeV/c

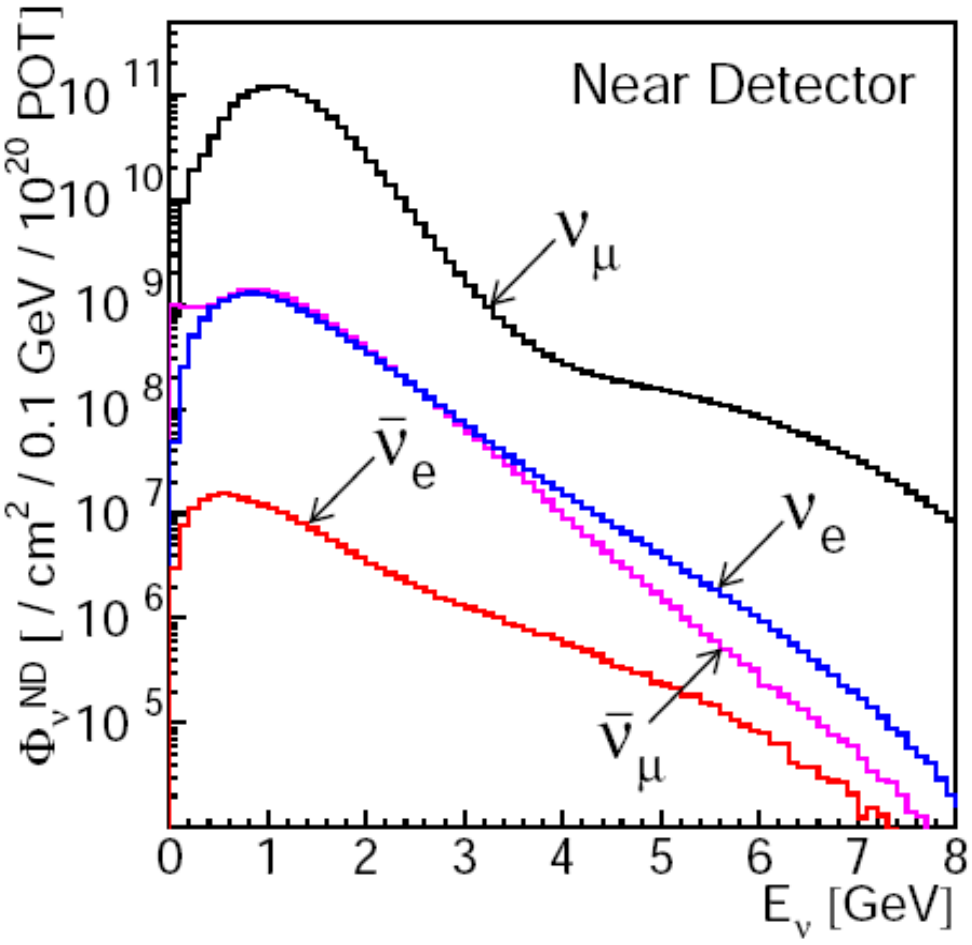



Ionization Chamber

Silicon Pads Detectors



# Neutrino Flux at ND




97.3% muon neutrinos from decayed positive pions

Contamination

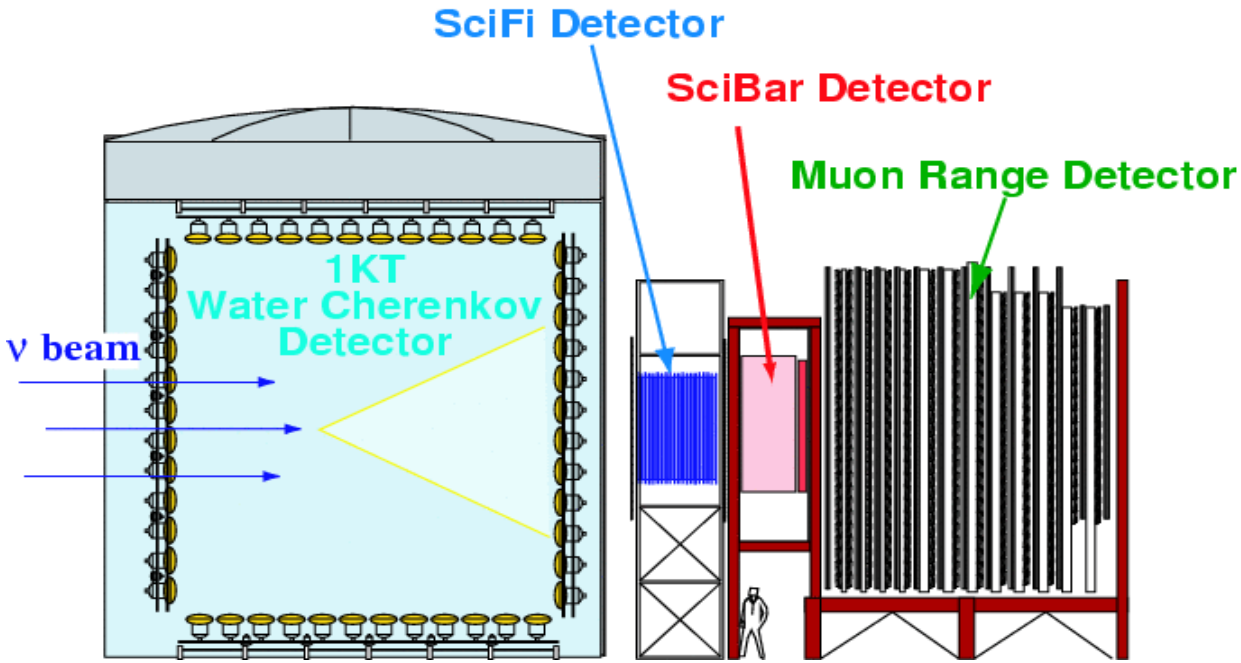
| | |
|---|---|
| $\nu_e/\nu_\mu$ | ~ 0.013 |
| anti-$\nu_\mu/\nu_\mu$ | ~ 0.015 |
| anti-$\nu_e/\nu_\mu$ | ~ 1.8 x 10-4 |

# Near Detector

- 1 Kiloton Water Čerenkov Detector

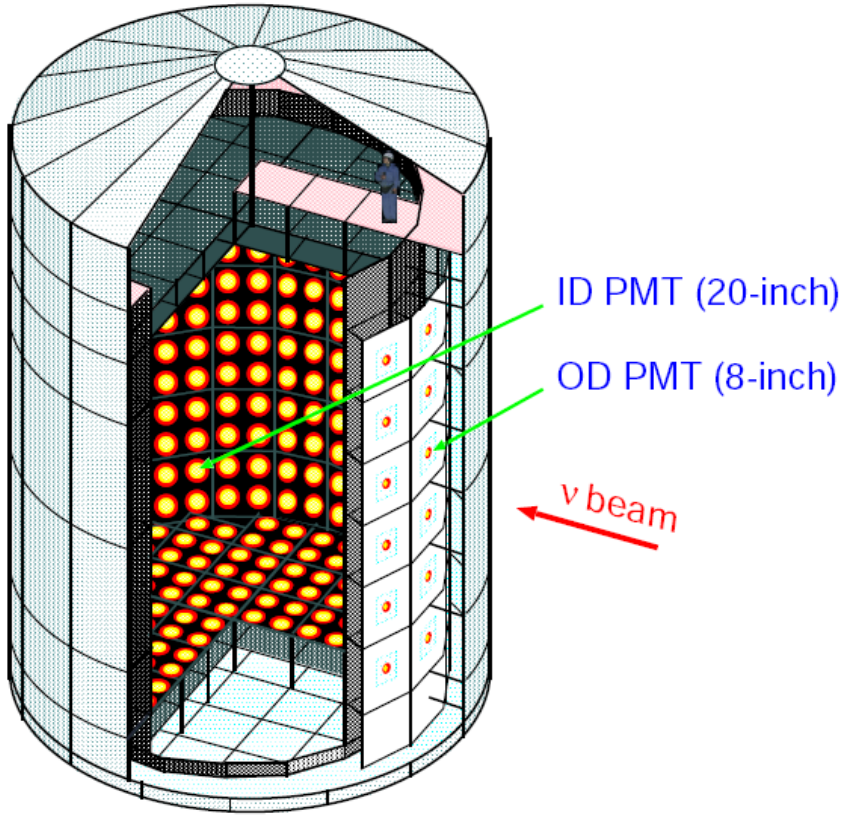
Fine Grain Detector:

- Scintillating-Fiber/water target tracker
- Since summer 2003, fully active carbon Scintillator-Bar tracker before Lead Glass calorimeter
- Muon Range Detector (MRD)

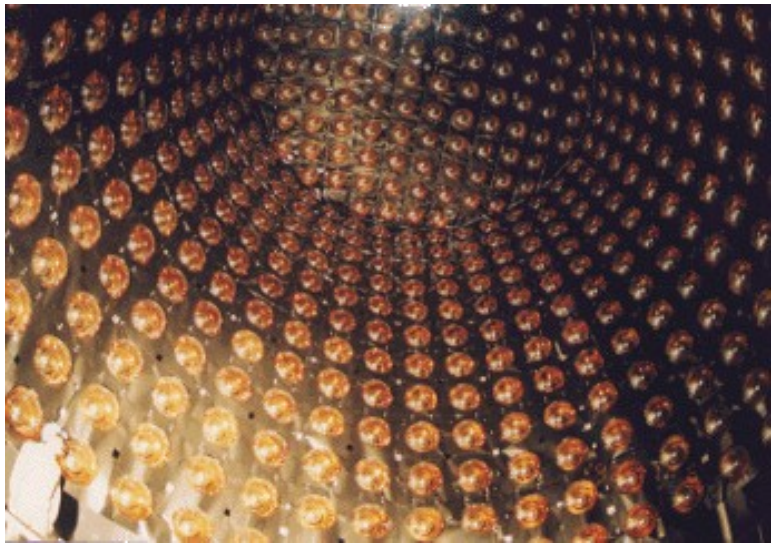



# 1 kton

- Primary role to measure the $\nu_\mu$ interaction rate and the $\nu_\mu$ energy spectrum
  - 10.8 m diameter and height
  - 1 kton pure water
  - optically separated into the inner detector (680 PMTs, 40% coverage)
  - and the outer detector (68 PMTs)

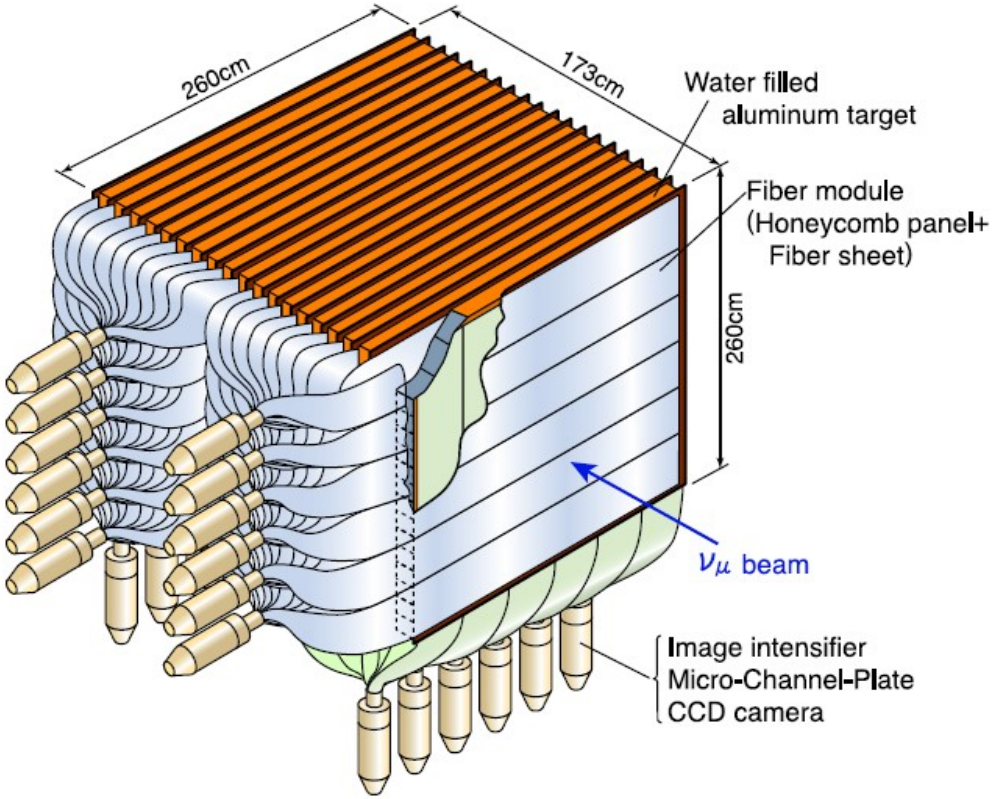



  - Vertex single-ring resolution ~15 cm
  - Vertex multi-ring resolution ~ 40 cm
  - Capability of particle ID:
    0.3% (3.3%) of $\nu_\mu$ ($\nu_e$) CCQE events are misidentified as e-like (μ-like)

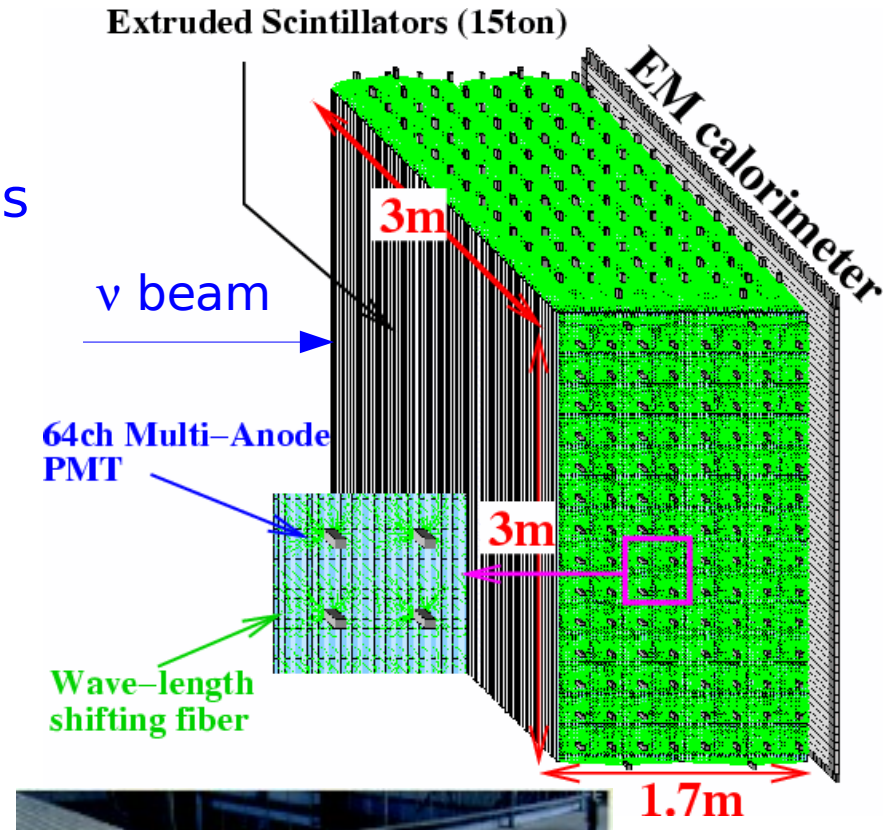


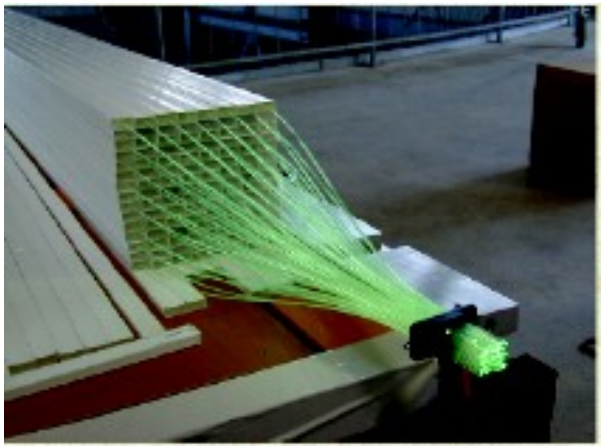
- Design to improve the measurement of the neutrino energy and to study the neutrino interactions with high detection efficiency

  - Track-finding efficiency 70% for ~ tracks 30 cm long
  - 6 tons total mass
  - 260 x 260 x 173 $cm^3$ volume
  - 20 layers placed 9 cm apart
  - each layer has 1 horizontal and 1 vertical sheets of scintillating fibers
  - 19 layers of water in aluminum tanks



- Design to improve the measurement of the neutrino energy and to study the neutrino interactions with high detection efficiency for low momentum particles
  - Minimum reconstructible length 8cm
    - 450 MeV/c threshold for protons
    - 100 MeV/c for muons
  - Single track-finding efficiency 99%
  - Full active fine-segmented
  - 15 tons total mass ($C_8H_8$)
  - 1.7 x 3 x 3 $m^3$ volume
  - 14848 bars, size 300 x 2.5 x 1.3 cm
  - 64 X+Y layers with 116 bars per view
  - Electron catcher of lead and scintillating fibers



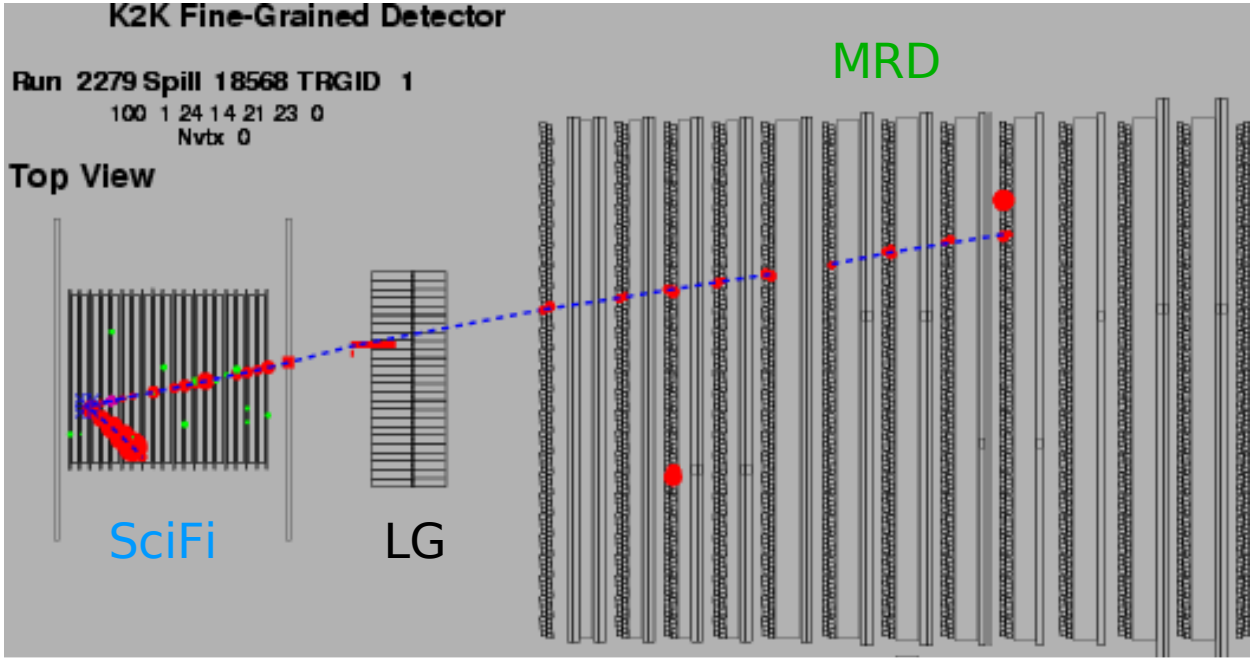
# Lead Glass Calorimeter

- Its purpose is to distinguish electrons from muons by measuring the energy deposited

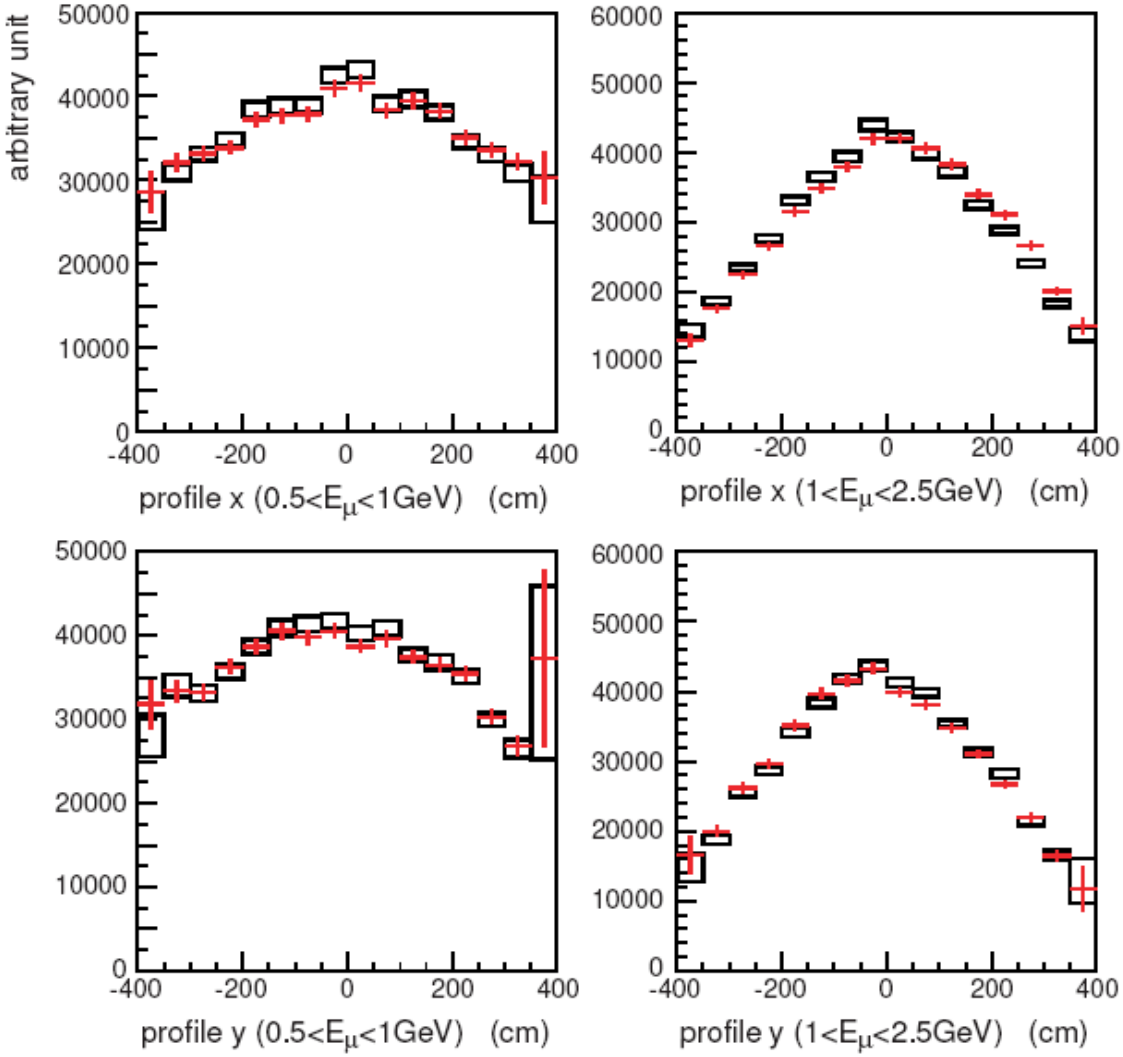
  - 600 cells of 12 x 12 x 34 $cm^3$
  - The energy resolution was estimated by using an electron beam
    - 10% at 1 GeV

- Two purposes
  - monitor the stability of the neutrino beam direction, profile, and spectrum
  - Identify muons produced in the upstream detectors and measure the energy and angle with combination of other fine grain detectors

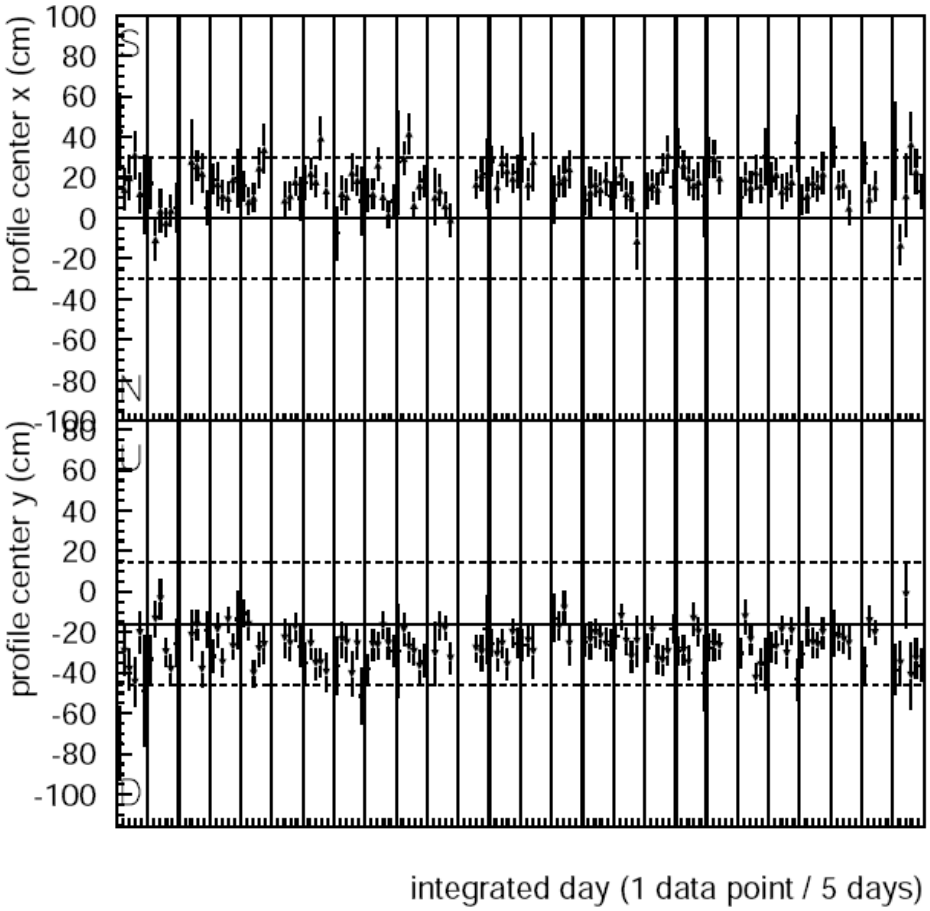
- 915 tons total mass
- 12 layers of iron
- 13 sets of vertical and horizontal drif-tube layers
- covering the muon energy up to 2.8 GeV
- Track-finding efficiency 66% (95%) for tracks with 1 (2) traversed iron plate(s)



## Neutrino beam profiles measured by MRD




## Stability of the neutrino beam direction measured by MRD

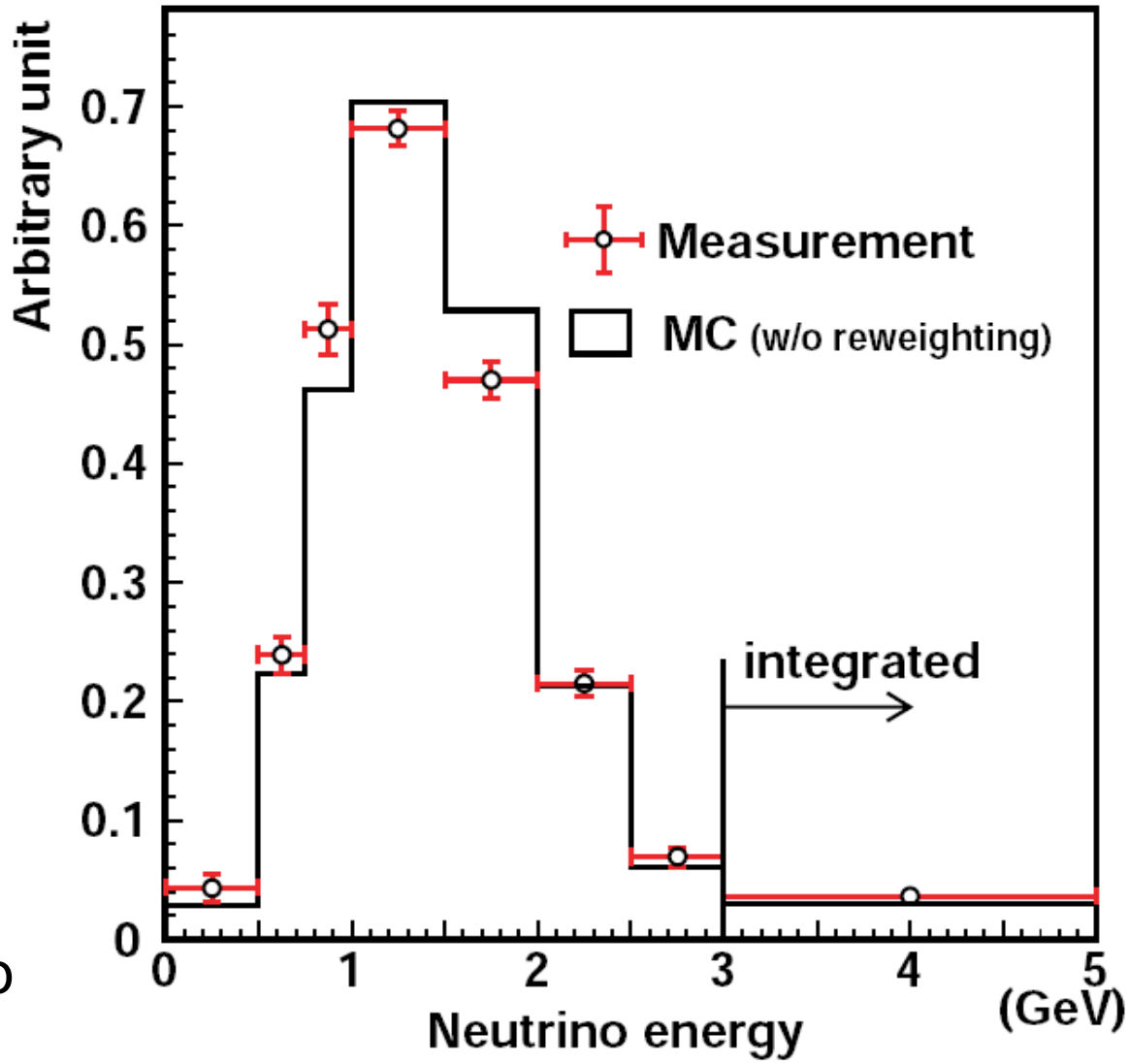


# Near Detector

Neutrino energy spectrum measured at the Near Detector assuming CCQE

The spectrum is fitted by using a $\chi^2$ method to compare $(p_\mu, \theta_\mu)$ distributions measured in the 1 kton and Fine Grain Detector to MC expectations

The ratio of non-CCQE to CCQE and the energy scale parameters are also included.



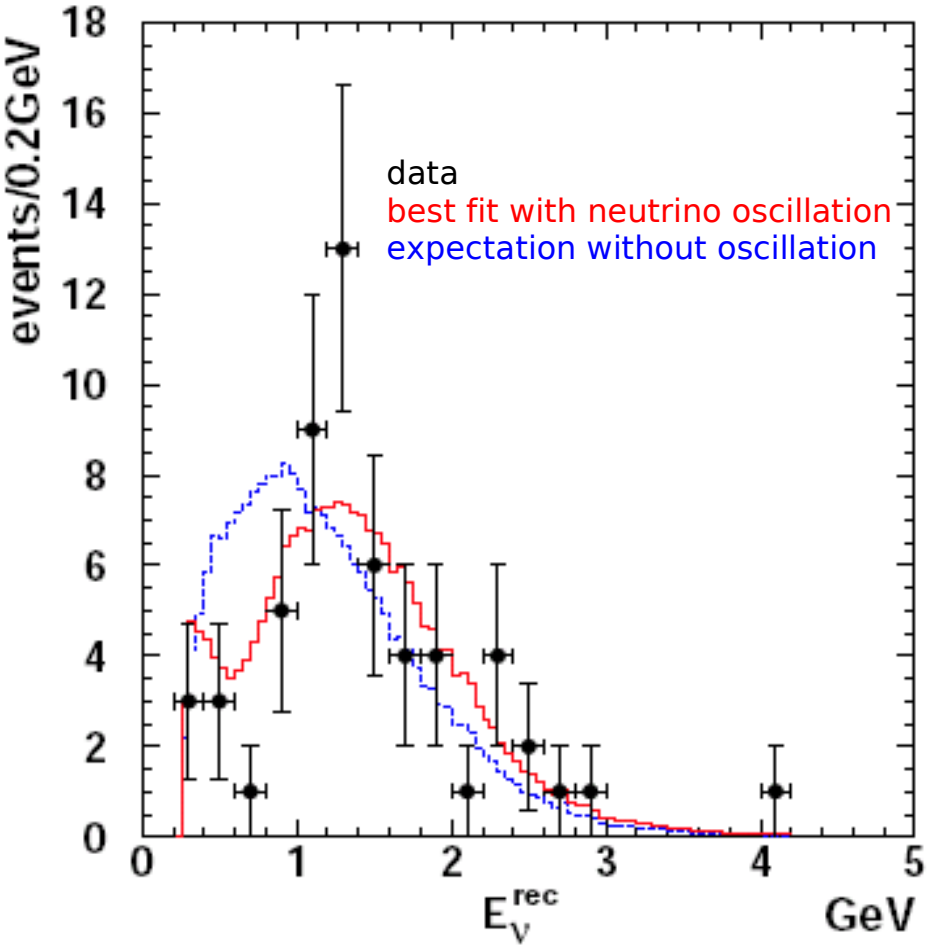
# Oscillation Measurement

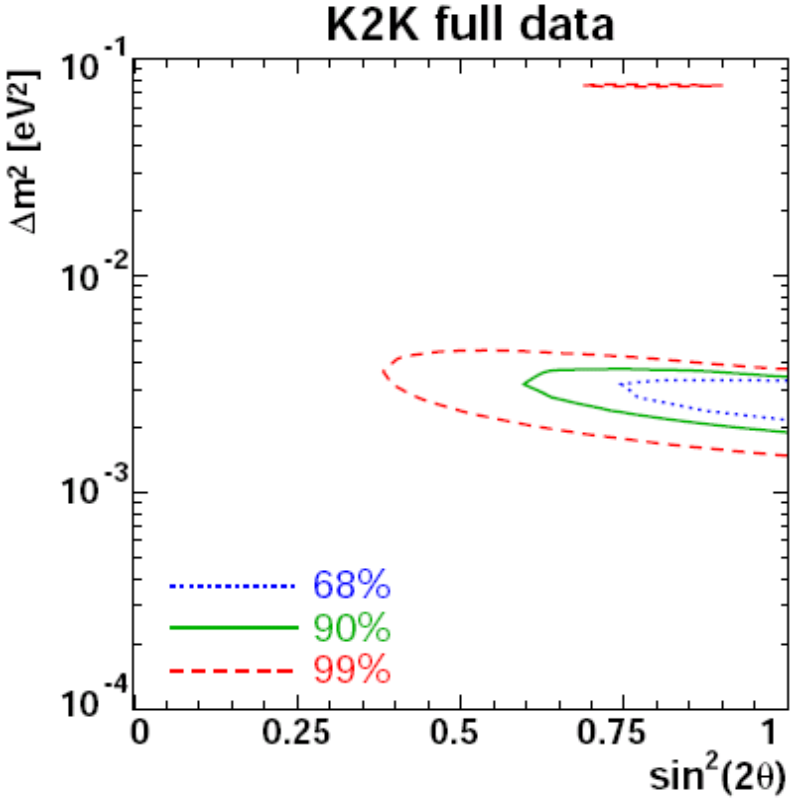
- 112 beam-originated observed events with an expectation of 158±9
- 58 quasi-elastic candidates

Oscillation $\nu_\mu \rightarrow \nu_\tau$

$$P(\nu_\mu \rightarrow \nu_\tau) = \sin^2 2\theta \sin\left(\frac{1.27\Delta m^2(eV^2)L_\nu(km)}{E_\nu(GeV)}\right)$$

- $\Delta m^2$ ($eV^2$) = 2.8 x $10^{-3}$
- $\sin^2 2\theta = 1$

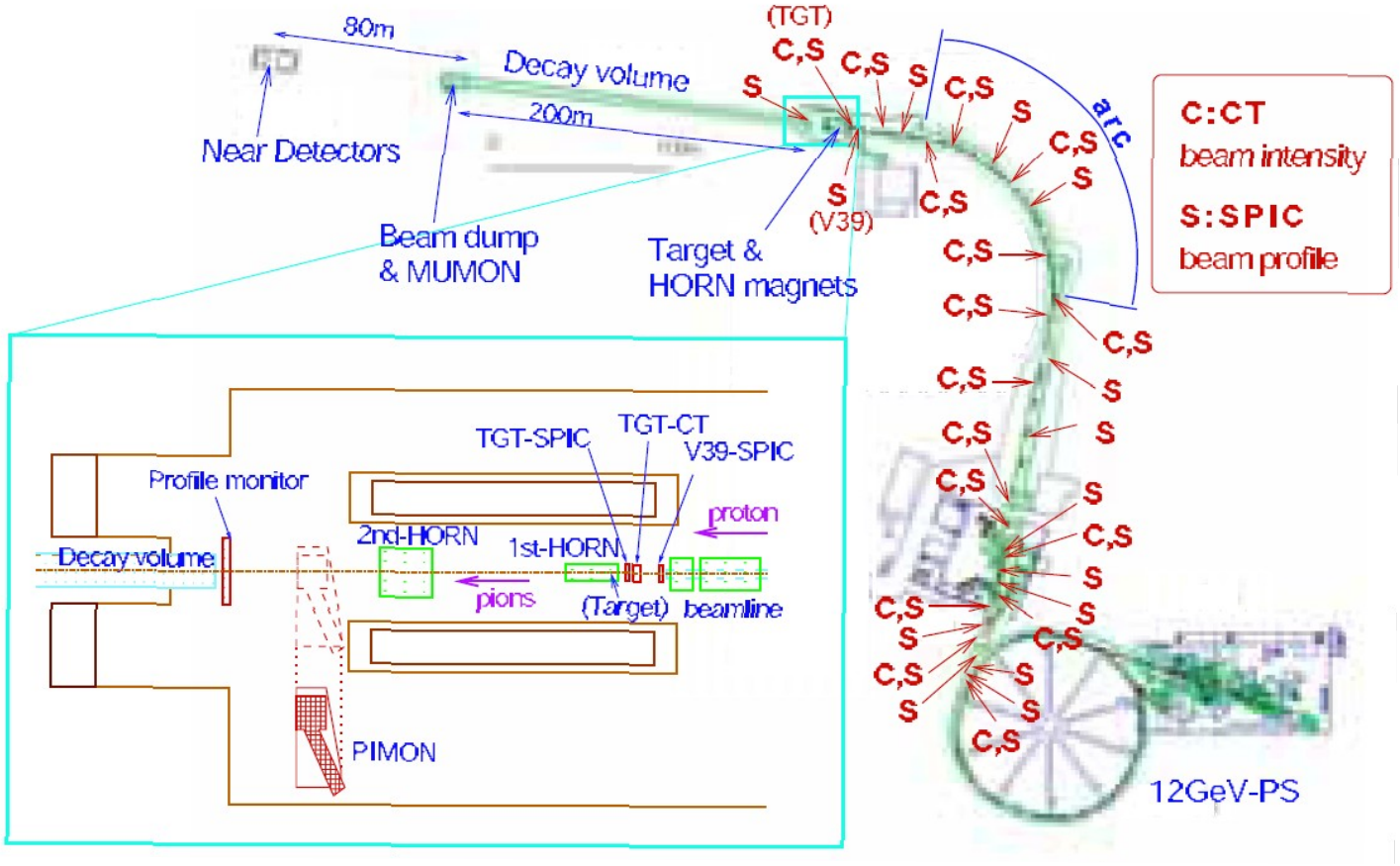


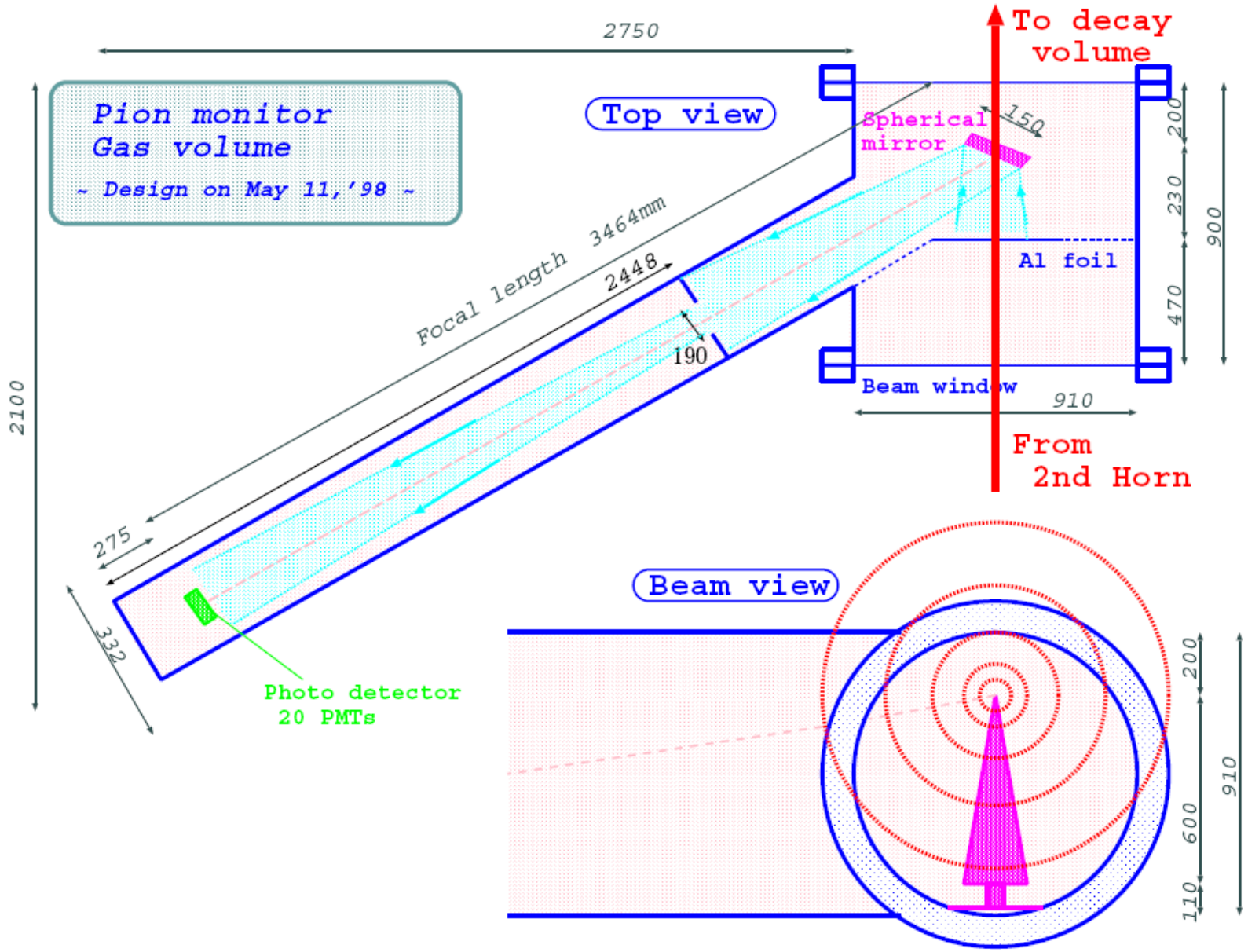
# Summary

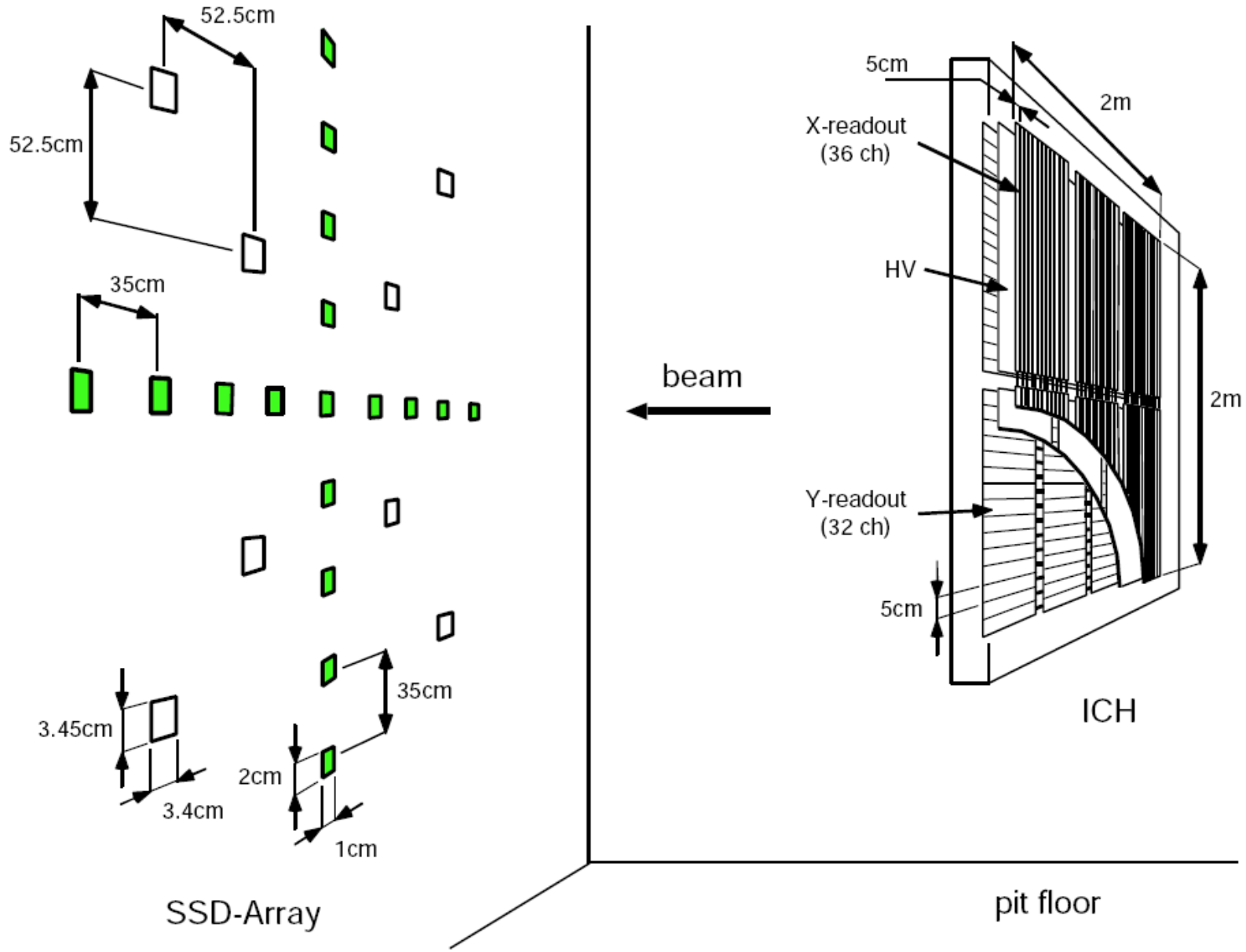
- K2K is the first long baseline neutrino experiment
- Data taken from June 1999 to November 2004
- During the overall period $10^{20}$ POTs were delivered on target according to the expectation
- The Near Detector capabilities suffice to measure the neutrino rate and neutrino energy spectrum
- K2K neutrino oscillation measurement confirm the atmospheric neutrino oscillation

# Beam Line




- protons accelerated to a kinetic energy of 12 GeV
- extracted in a 1.1 μs single turn
- hit the target generating $\pi^+$
- magnetic horns focus $\pi^+$ to a decay volume $\pi^+ \rightarrow \mu^+ \nu_\mu$
- a beam dump stop all the particles except the $\nu_\mu$
- beam monitors control the energy spectrum and direction of $\pi^+$ and $\mu^+$


Pion monitor
Gas volume
~ Design on May 11,'98 ~
Top view
2750
2100
Focal length 3464mm
2448
190
275
332
Photo detector
20 PMTs
Spherical
mirror
150
Al foil
Beam window
910
To decay
volume
From
2nd Horn
200
230
470
900
Beam view
200
600
110
910


52.5cm
52.5cm
35cm
3.45cm
3.4cm
2cm
35cm
1cm
SSD-Array
beam
5cm
2m
X-readout
(36 ch)
HV
2m
Y-readout
(32 ch)
5cm
ICH
pit floor