T2K experiment status

- **Jean-Michel POUTISSOU**

- **TRIUMF**

T2K experiment

- Overview
- Challenges
- Experimental set up
- Analysis strategy
- Early results and prospects

Neutrino oscillation

- Neutrino changes its flavor while propagating in vacuum/matter.
  → Neutrinos have masses = **Evidence for physics beyond the Std. Model.**

Flavor eigenstates: ν_e, ν_μ, ν_τ

$$\begin{pmatrix}\nu_e\\ \nu_\mu\\ \nu_\tau\end{pmatrix} = U_{MNS}\begin{pmatrix}\nu_1\\ \nu_2\\ \nu_3\end{pmatrix}$$

Mass eigenstates: m_1, m_2, m_3

Atmospheric & accelerator | Reactor & accelerator | Solar & reactor

$$U_{MNS} = \begin{pmatrix}1 & 0 & 0\\ 0 & +c_{23} & +s_{23}\\ 0 & -s_{23} & +c_{23}\end{pmatrix}\begin{pmatrix}+c_{13} & 0 & +s_{13}e^{-i\delta}\\ 0 & 1 & 0\\ -s_{13}e^{i\delta} & 0 & +c_{13}\end{pmatrix}\begin{pmatrix}+c_{12} & +s_{12} & 0\\ -s_{12} & +c_{12} & 0\\ 0 & 0 & 1\end{pmatrix} \approx \begin{pmatrix}0.8 & 0.5 & s_{13}e^{-i\delta}\\ 0.4 & 0.6 & 0.7\\ 0.4 & 0.6 & 0.7\end{pmatrix}$$

$\theta_{23} = 37^\circ \sim 45^\circ$
$\Delta m_{23}^2 \approx 2.4 \times 10^{-3}$ eV^2

$\theta_{13} < 10^\circ$ by CHOOZ

$\theta_{12} \approx 34.4^\circ \pm 1.3^\circ$
$\Delta m_{12}^2 \approx 8 \times 10^{-5}$ eV^2

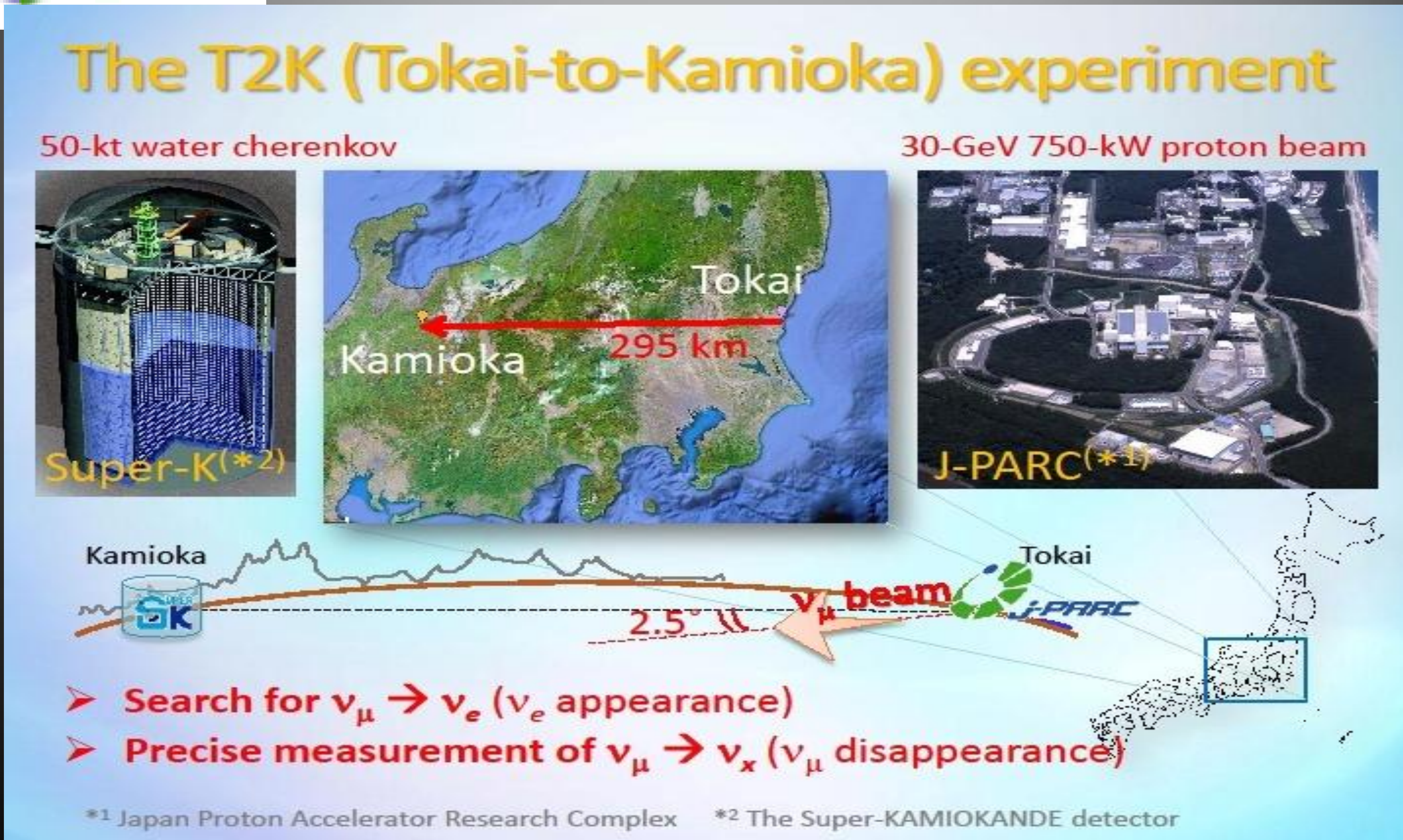
$c_{ij} = \cos\theta_{ij}$, $s_{ij} = \sin\theta_{ij}$
$\Delta m_{ij}^2 \equiv m_i^2 - m_j^2$

- Mass hierarchy ($m_1 < m_2 < m_3$ or $m_3 < m_1 < m_2$)?
- Size of the mixing angle θ_{13}?
- Size of the CP phase δ? ... Ability to measure CP violation depends on $\sin\theta_{13}$.

→ **Important to measure θ_{13}.**

T2K concepts

- ν_μ disappearance experiment:
  - $P(\nu_\mu \to \nu_x) \sim \sin^2 2\theta_{23} \sin^2(\Delta m^2_{32} L/4E_\nu)$
  - Measure Δm^2_{32} and θ_{23})
  - Goals for (3.75MW*10^7s)
    - $\delta(\Delta m^2_{23}) < 1*10^{-4}[eV^2]$
    - $\delta(\sin^2 2\theta_{23}) \sim 0.01$
  - L is fixed by SK at 295 km
  - E_ν is defined by the J-PARC beam properties
- ν_e appearance experiment:
  - $P(\nu_\mu \to \nu_e) \sim \sin^2 2\theta_{13} \sin^2\theta_{23} \sin^2(\Delta m^2_{32} L/4E_\nu)$
  - Determine θ_{13}

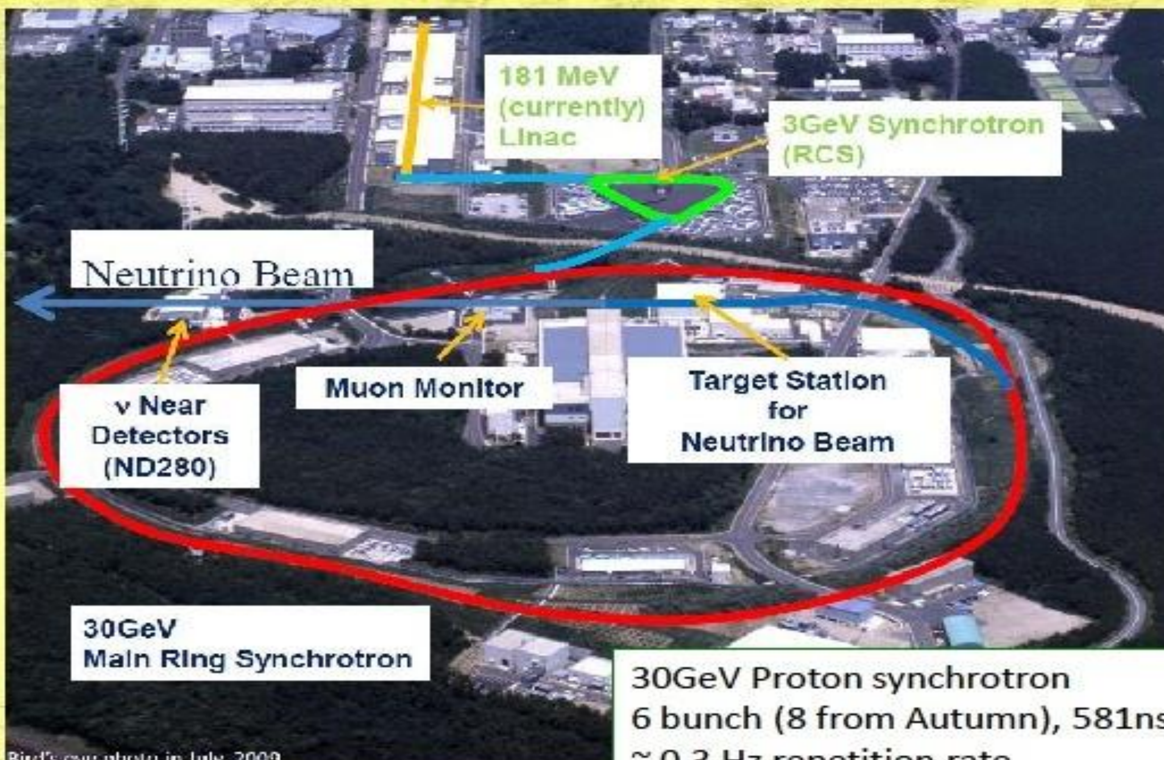

The T2K (Tokai-to-Kamioka) experiment
50-kt water cherenkov
30-GeV 750-kW proton beam
Super-K(*2)
Tokai
295 km
Kamioka
J-PARC(*1)
Kamioka
Tokai
ν_μ beam
2.5°
J-PARC
➤ Search for $\nu_\mu \rightarrow \nu_e$ (ν_e appearance)
➤ Precise measurement of $\nu_\mu \rightarrow \nu_x$ (ν_μ disappearance)
*1 Japan Proton Accelerator Research Complex
*2 The Super-KAMIOKANDE detector

T2K

J-PARC

13

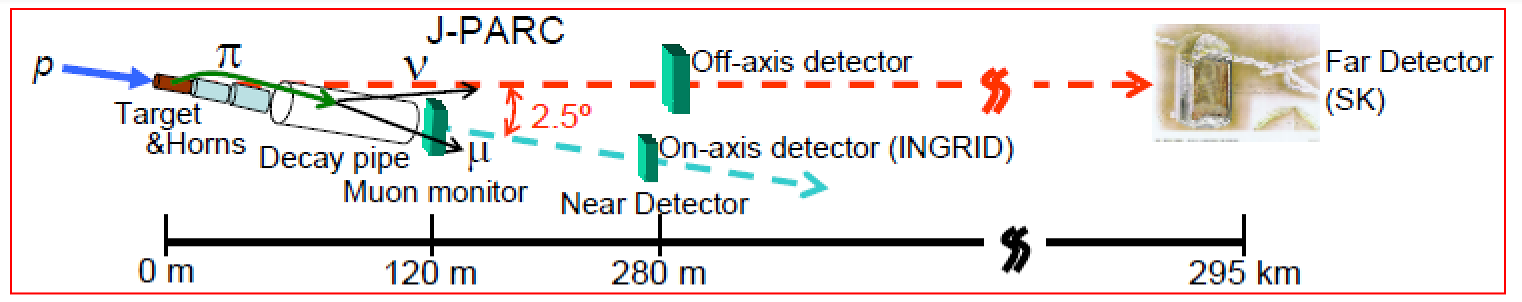
Experimental setup:
J-PARC Accelerator and Experimental Facility



30GeV Proton synchrotron
6 bunch (8 from Autumn), 581ns interval
~ 0.3 Hz repetition rate
Construction finished 2008 JFY

J-PARC complex

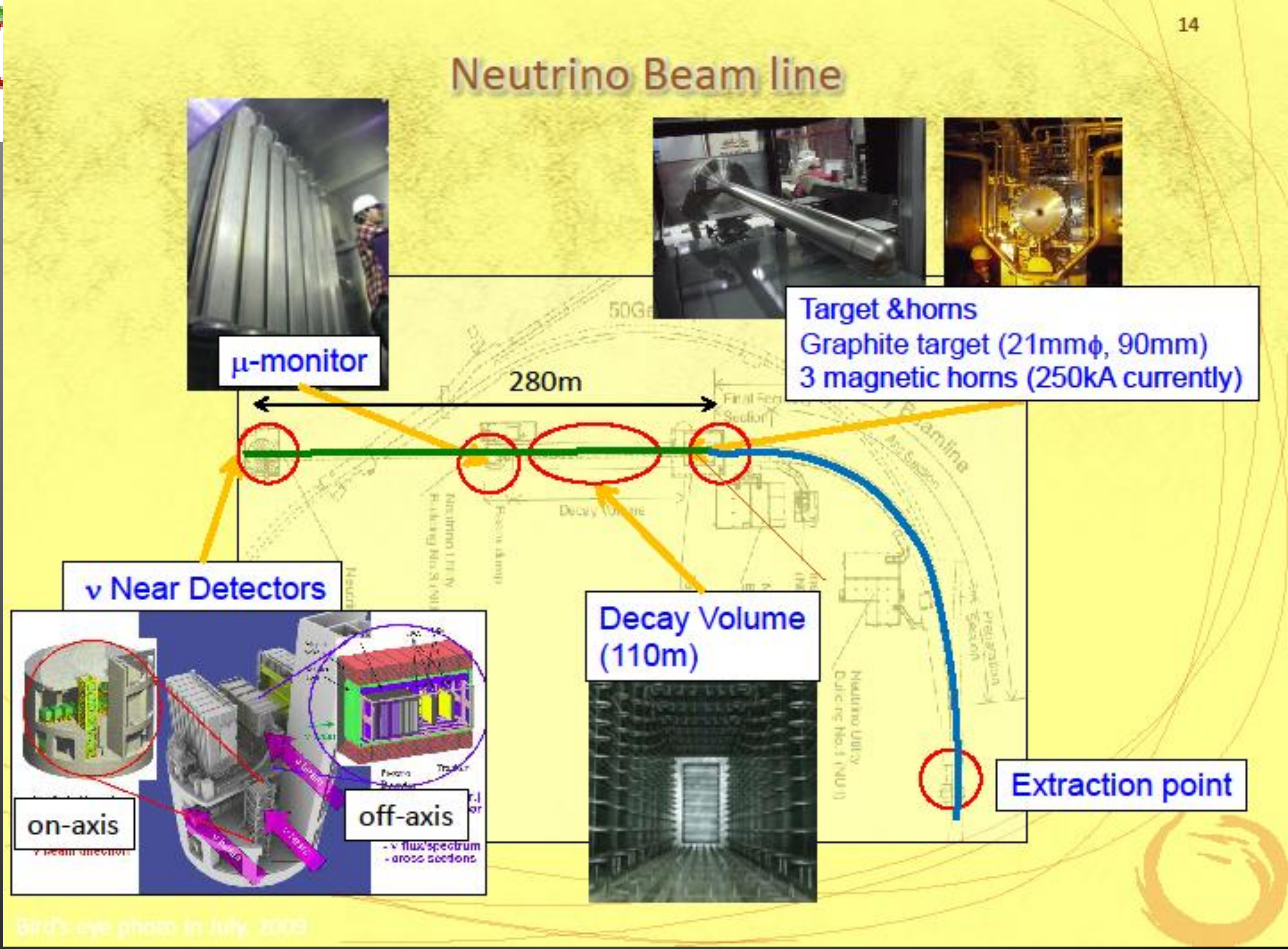
T2K components



Proton beam(fast extracted)
Pion(Kaon) production (90cm carbon target)
Pion(kaon) focusing (Three horns)
Pion(Kaon) decay section(110 m, helium filled)
Hadron asbsorber (carbon/iron)
Muon beam monitoring (Silicon/Ion chambers/emulsion)
On-Axis(Ingrid) /off axis neutrino beam monitors
Far detector (SK)

T2K neutrino beam

- derived from Proton energy 30Gev
- Fast extraction (Beam on/beam off ~ 1.5 *10-6)
- Optimized to the first oscillation maximum(.7GeV).
- Narrow band energy beam by using off axis position
- Highest possible intensity at J-PARC (750KW-4MW)

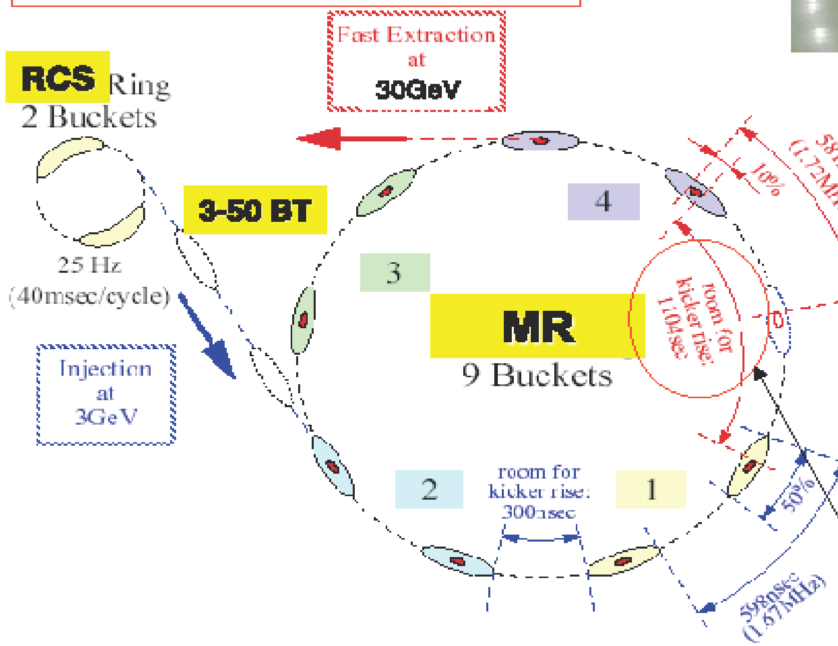


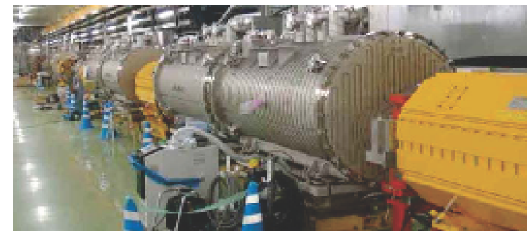
14
Neutrino Beam line
μ-monitor
280m
Target &horns
Graphite target (21mmϕ, 90mm)
3 magnetic horns (250kA currently)
ν Near Detectors
on-axis
off-axis
Decay Volume
(110m)
Extraction point

Accelerator complex

New FX kicker magnets

Original injection scheme:
4 batch injection from the RCS to MR
-> 8 bunch operation in the MR

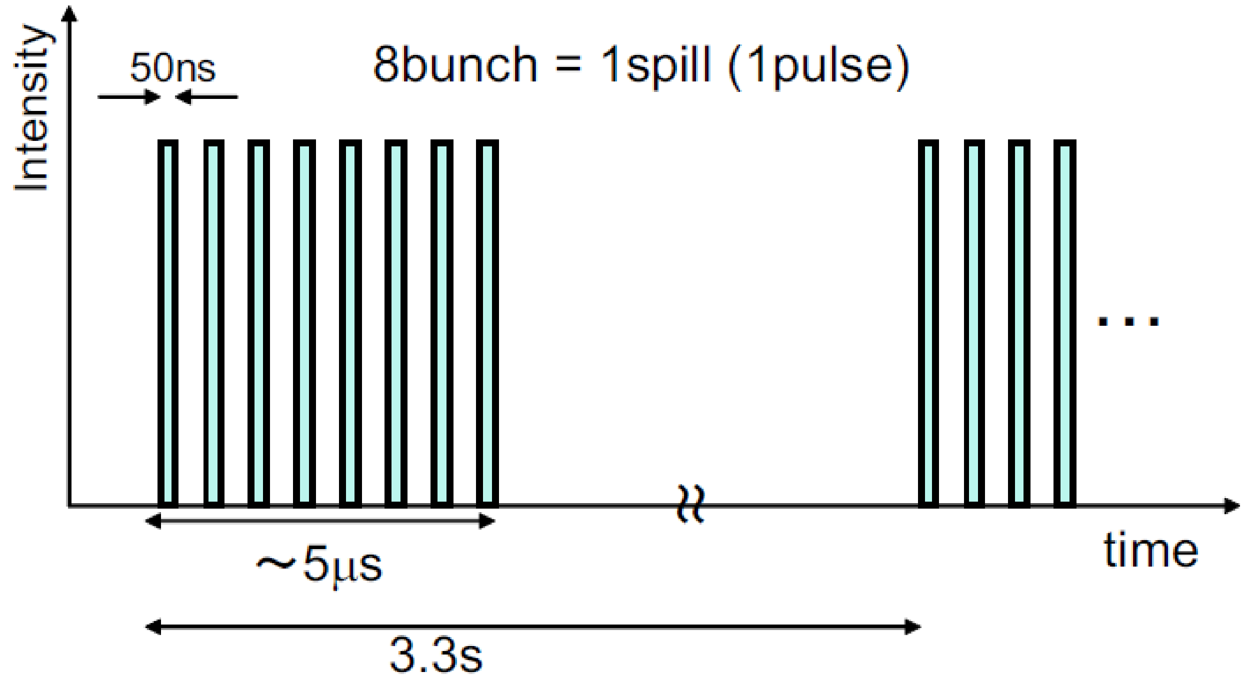




Harmonic number of the MR is nine and one vacant bucket makes the room for the rise time of kicker.

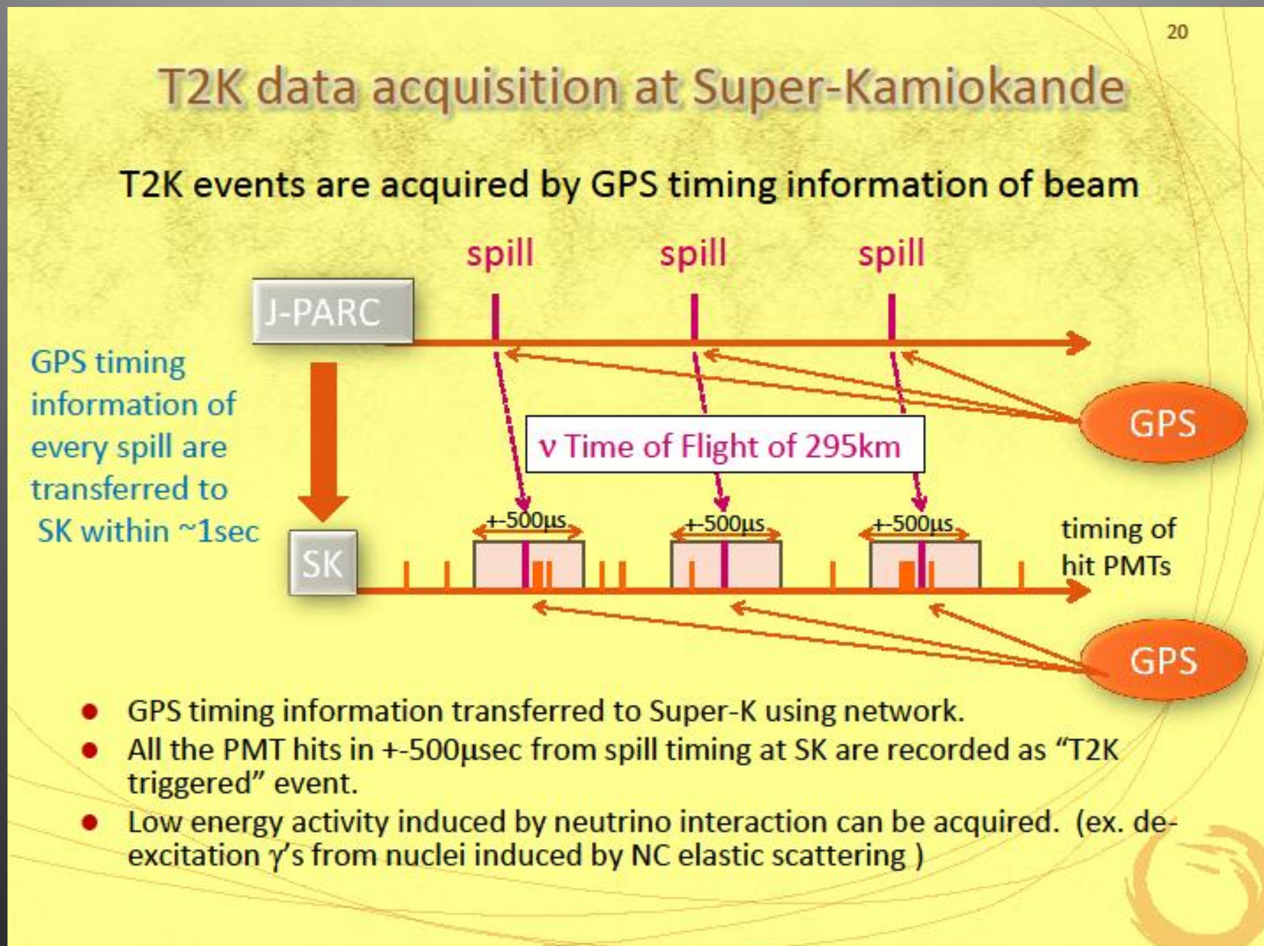
Before the 2010 summer shutdown, the MR operated with 6 bunches.
It is limited by the performance of extraction kicker magnets.
The pulse rise time of 1.6 μsec is too long to receive 8 bunches.
→Shorter rise time than 1 μsec is required.
We replace the kicker system with new one in 2010 summer shutdown.

Timing sequence

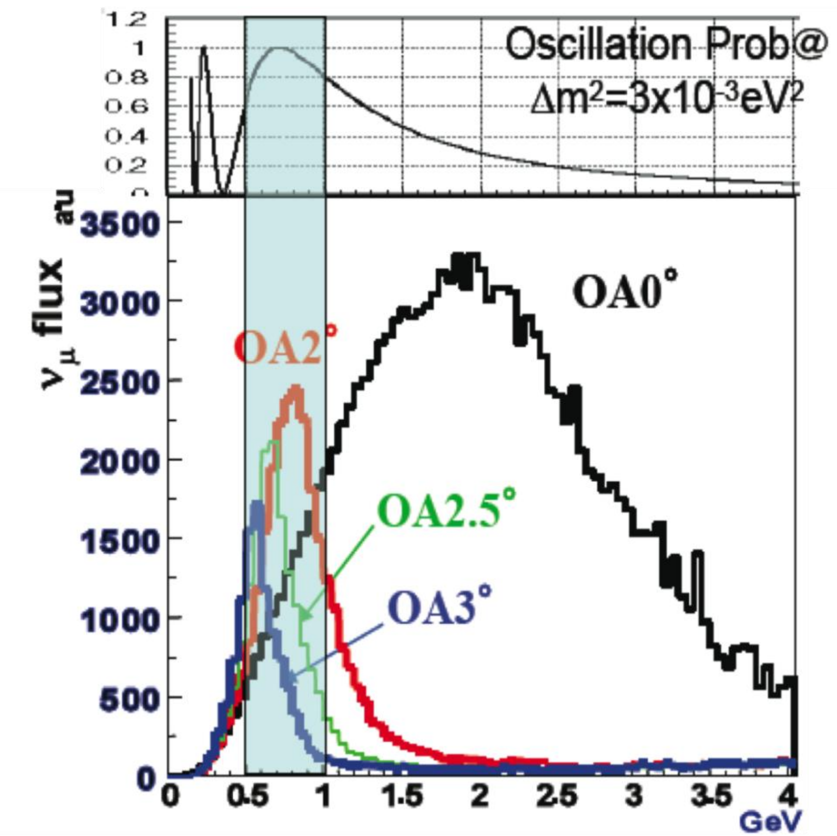


5: Bunch structure of the fast extracted beam to J-PARC neutrino beamline

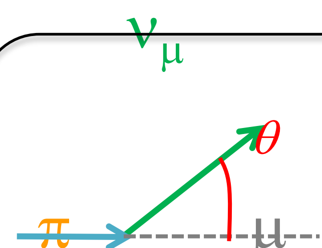
Timing critical



Off Axis beam concept

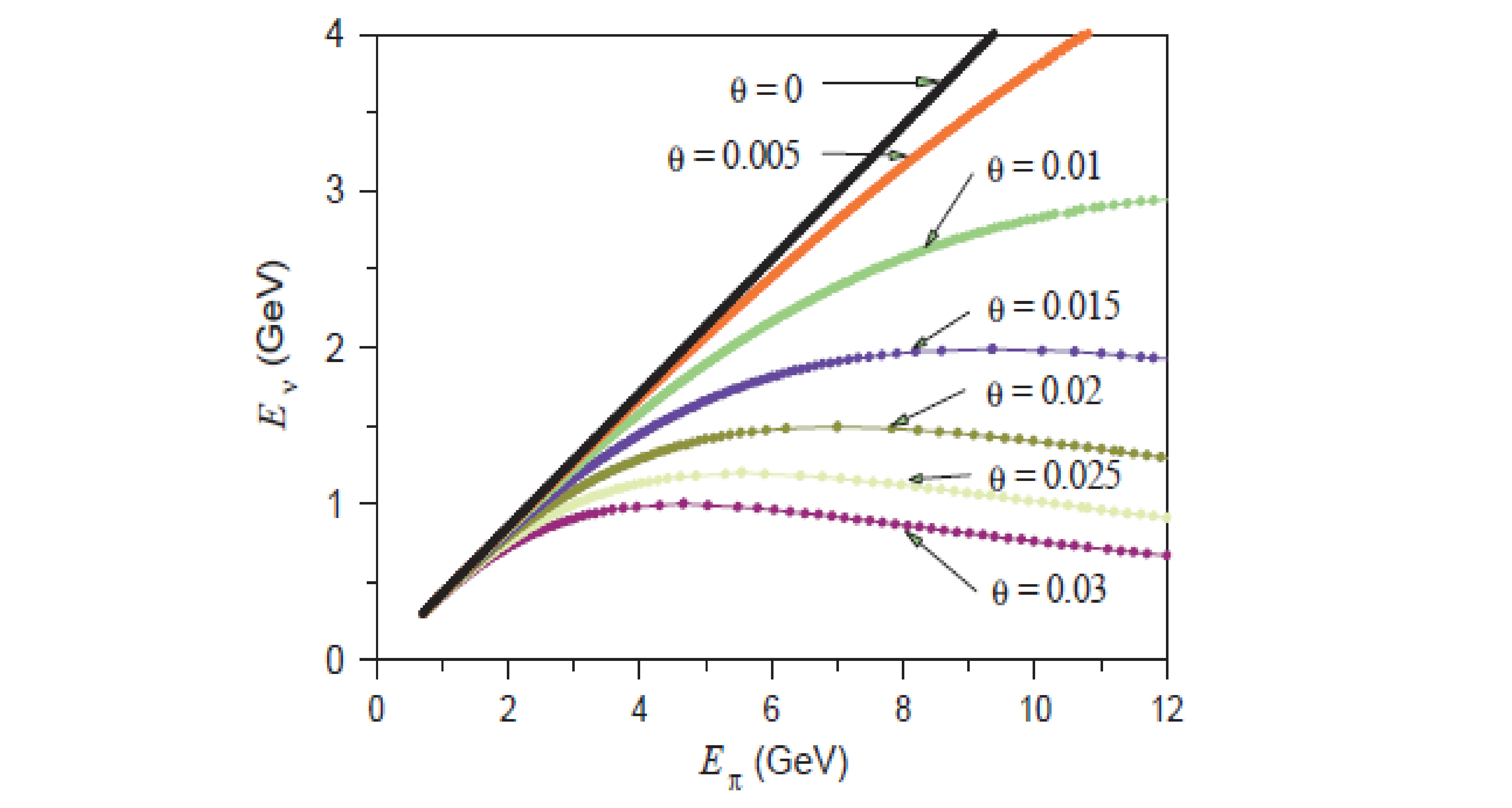


Off-axis beam



$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2(E_\pi - p_\pi \cos\theta)}$$

Off Axis beam kinematics



Neutrino facility in J-PARC

Special Features

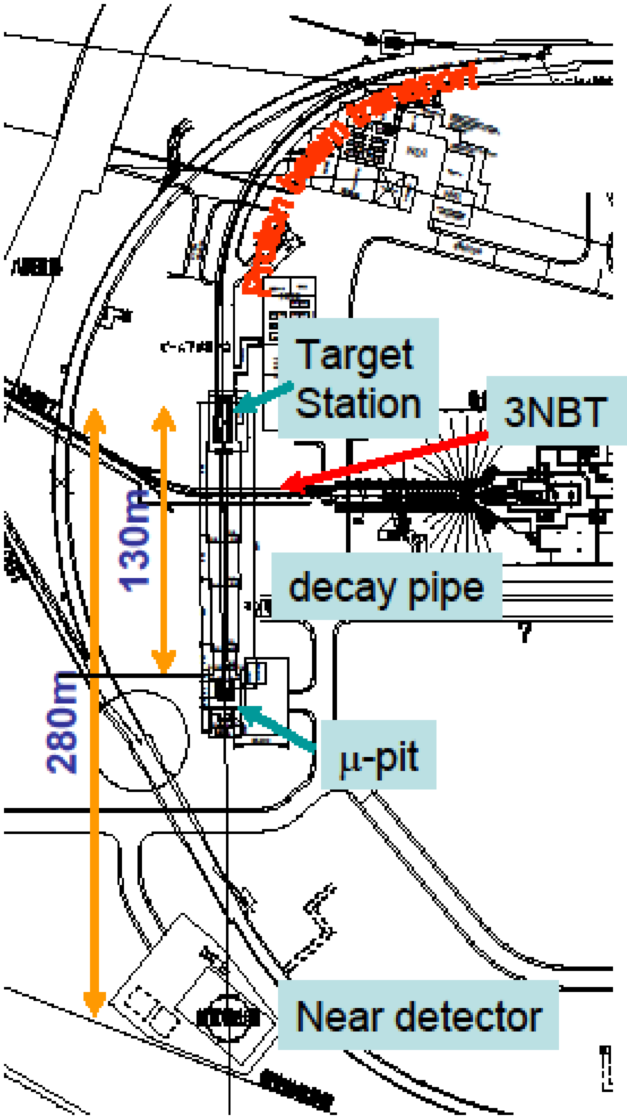
- Superconducting combined function magnets
- Off-axis beam

Components

- Primary proton beam line
  - Normal conducting magnets
  - Superconducting arc
  - Proton beam monitors
- Target/Horn system
- Decay pipe (130m)
  - Cover OA angle 2~3 deg.
- Beam dump
- muon monitors
- Near neutrino detector

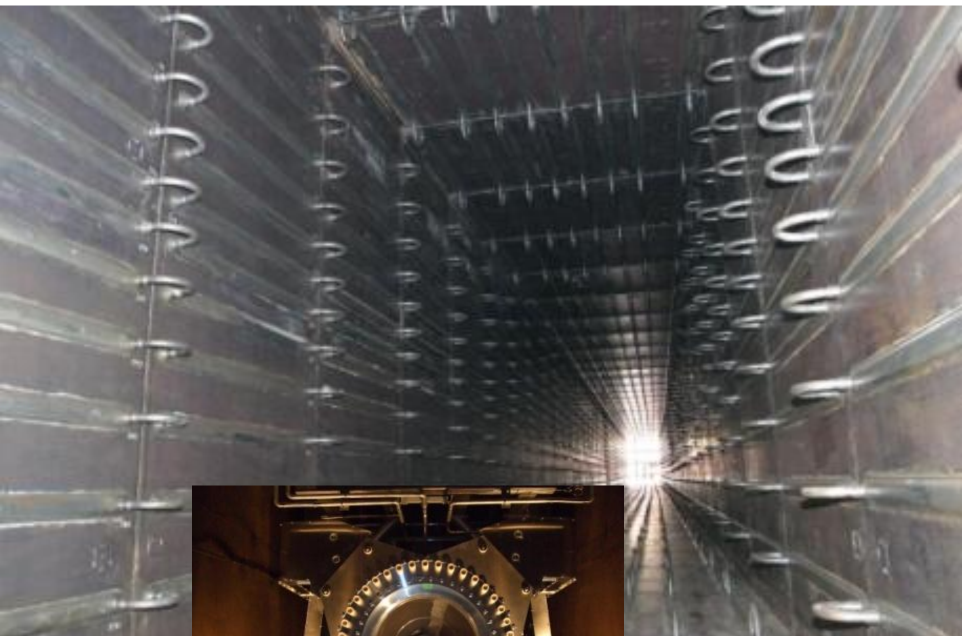
Construction: JFY2004~2008

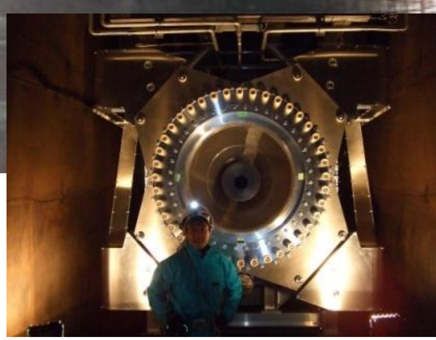
T.Kobayashi (KEK)



4

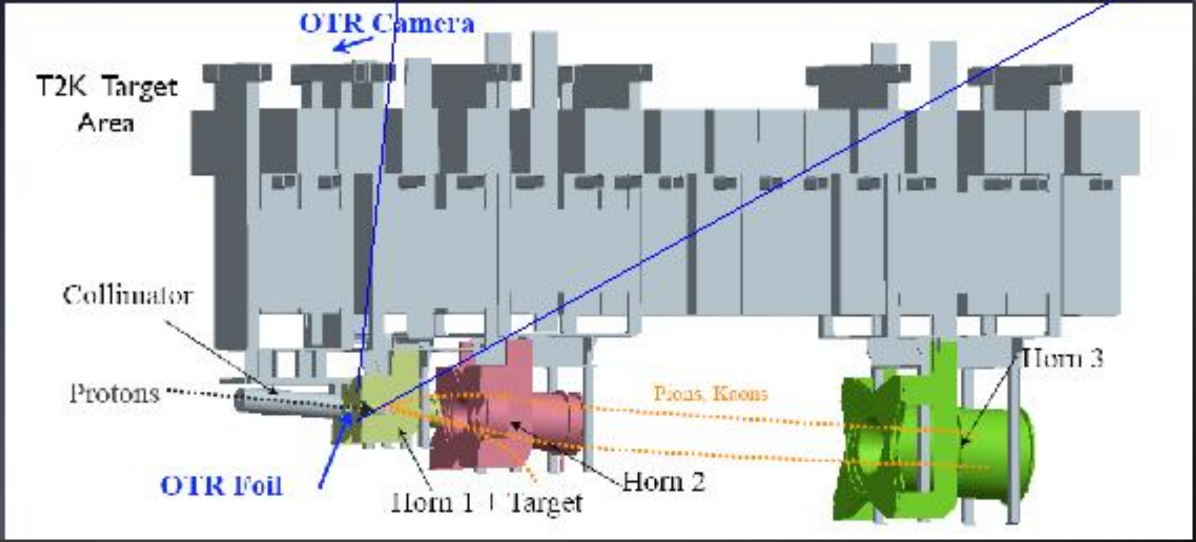
Neutrino Beamline





Optical Transition Radiation Monitor (OTR)

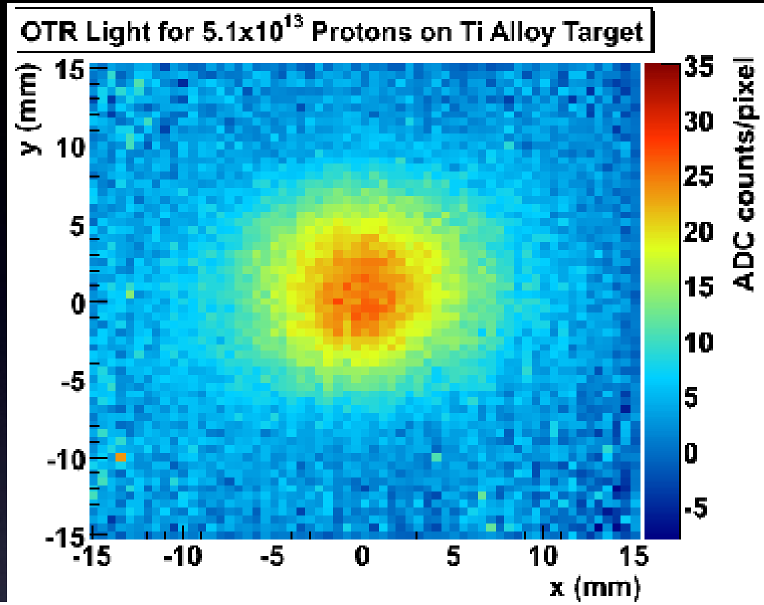
- OTR detector is directly upstream of T2K target.
- Measures the proton beam width and position just before impact.
  - Cannot place conventional beam monitors in this position; wouldn't survive radiation.

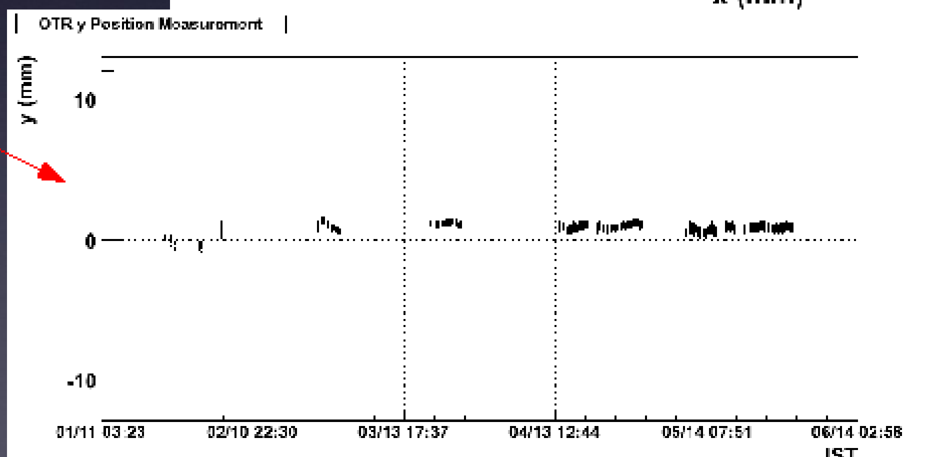


Thomas Lindner
TRIUMF, 7-15-2010

OTR Performance

- Understanding beam position and width is important for our ν flux predictions.
- OTR has been working well and providing important feedback on proton beam.
  - Already providing good feedback on proton beam position.



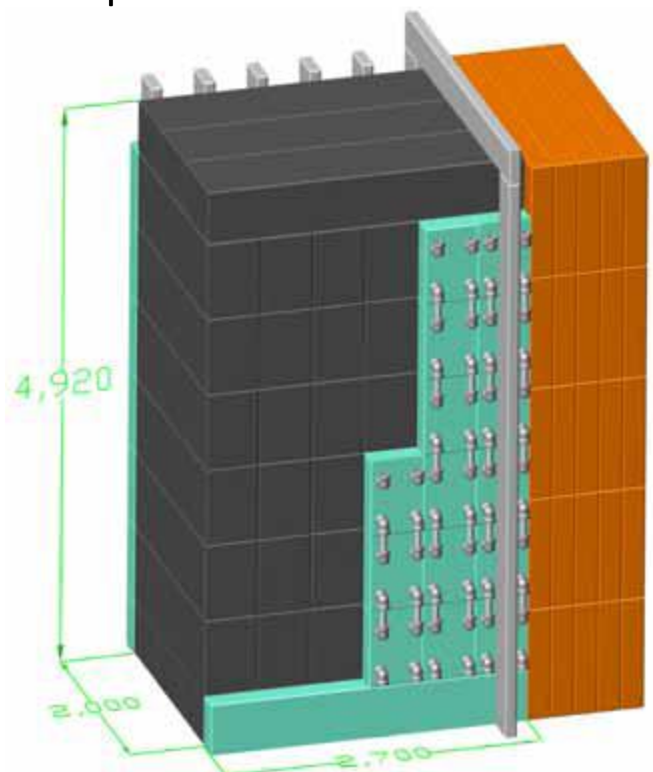


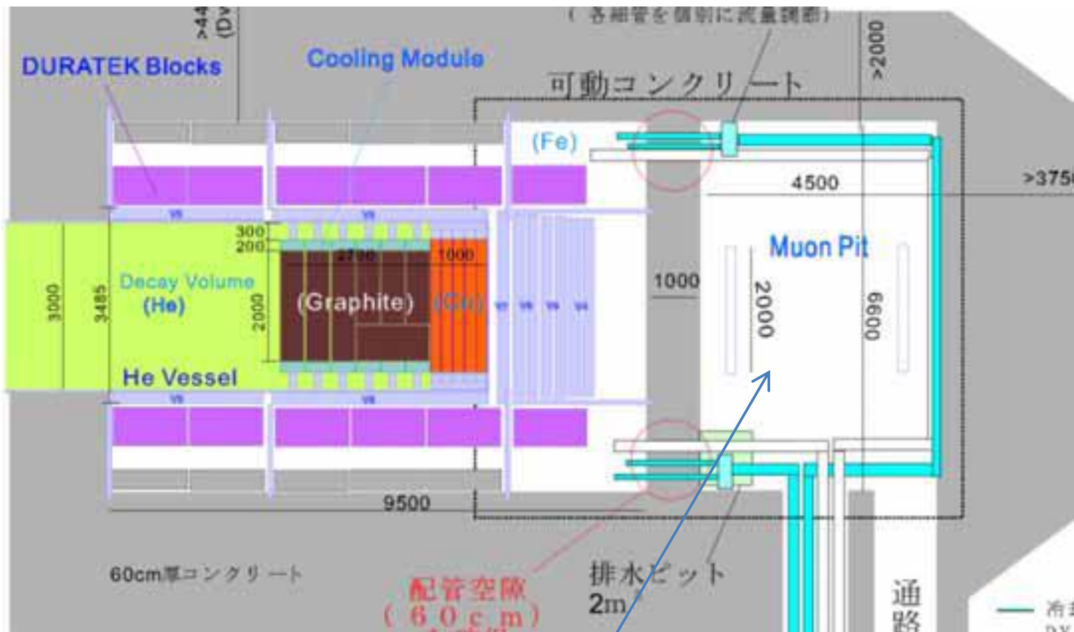
TRIUMF Contribution:
A. Konaka, D. Morris

Thomas Lindner
TRIUMF, 7-15-2010

Beam dump area

- Dump designed to accommodate 4MW beam power





Muon monitors location

Off Axis beam advantages

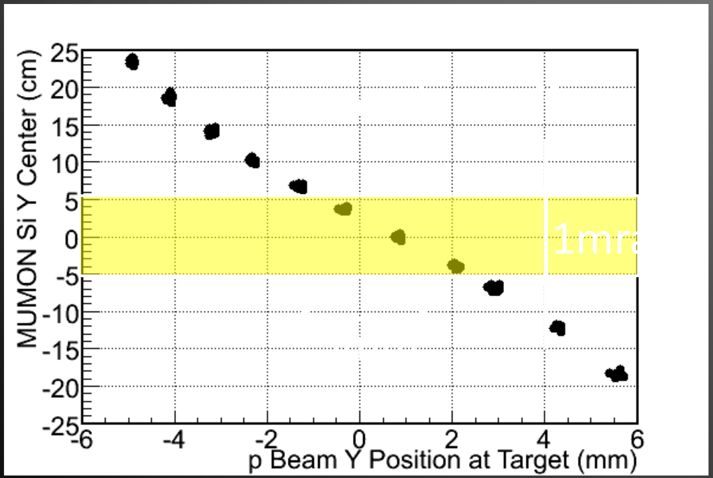
- Narrow band energy distribution
- Maximum ν_μ flux at the oscillation maximum
- Minimized high energy tail
- Low ν_e contamination

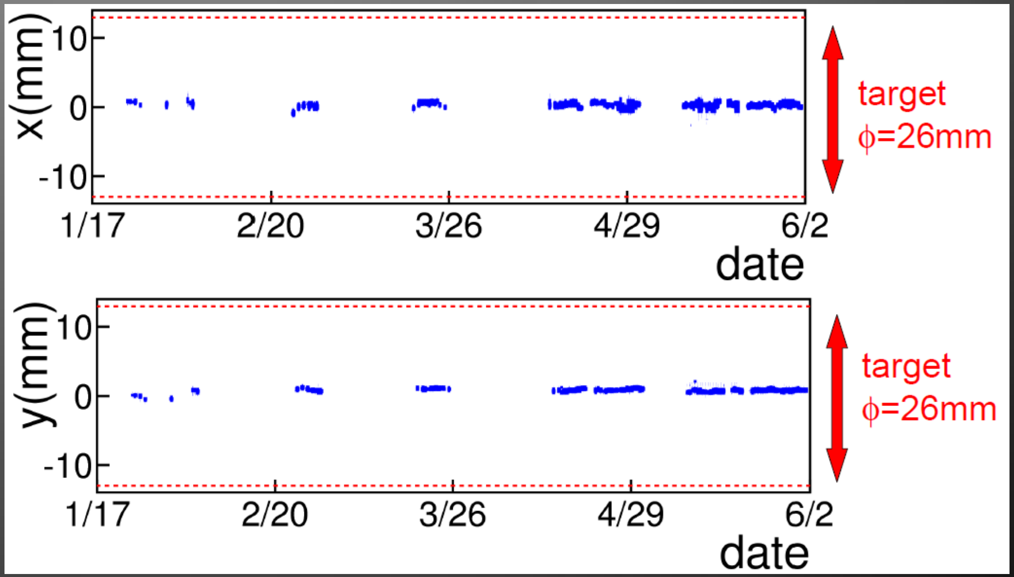
Muon monitors

Proton beam stability

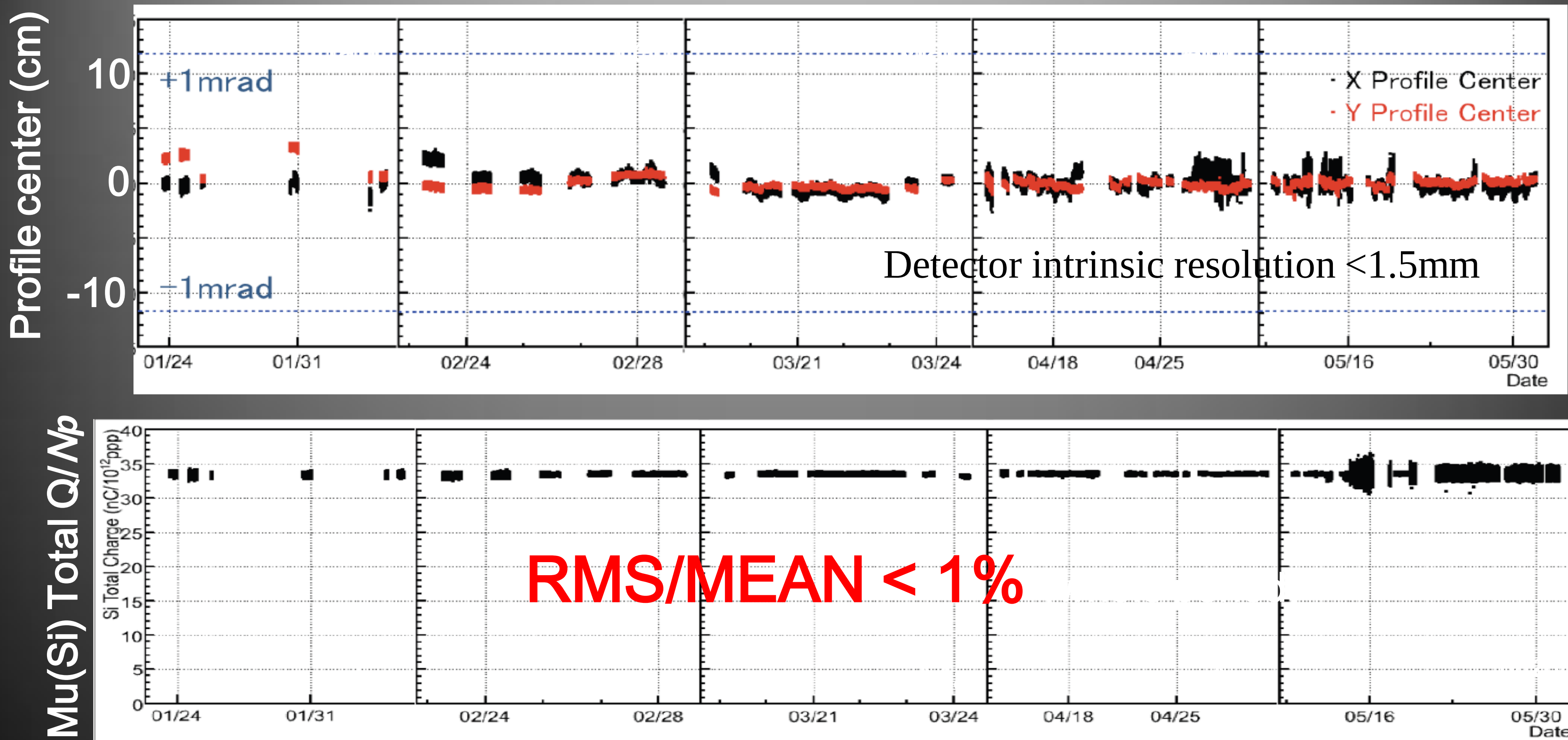
- Beam position on target have to be controlled < 1mm
  - To control direction of secondary beam within 1mrad
  - To avoid destroying the target from non uniform thermal stress on target (at higher power)
- Succeeded to control <1mm during long term operation

Correlation btw p beam position on target vs MUMON center



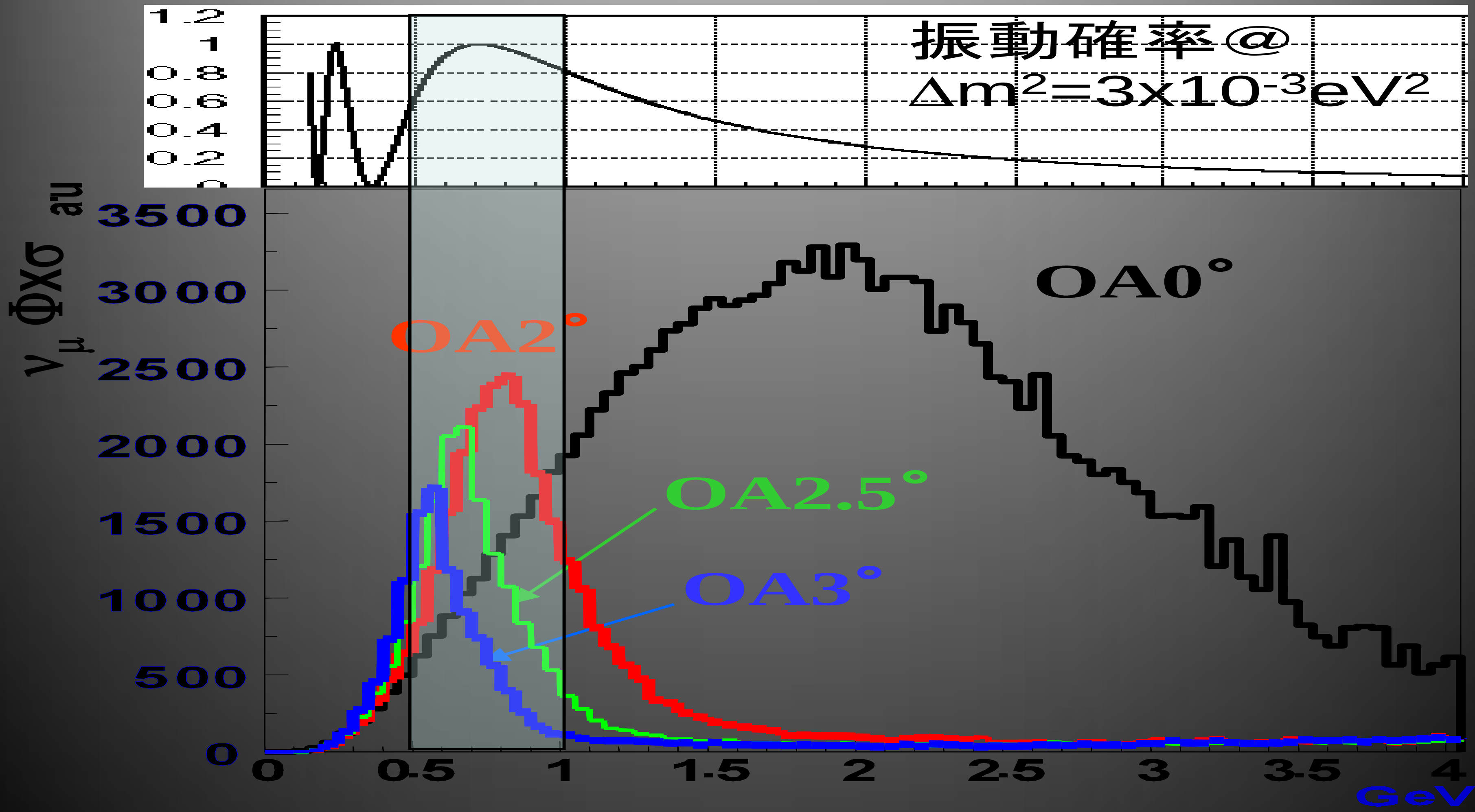


Beam direction & intensity stability
measured by Muon monitor



- Beam direction is controlled well within 1mrad
- Secondary beam intensity (normalized by proton intensity) stable within 1%
  - (reflects stability of targeting, horn focusing, etc)
- Stable well within our physics requirements

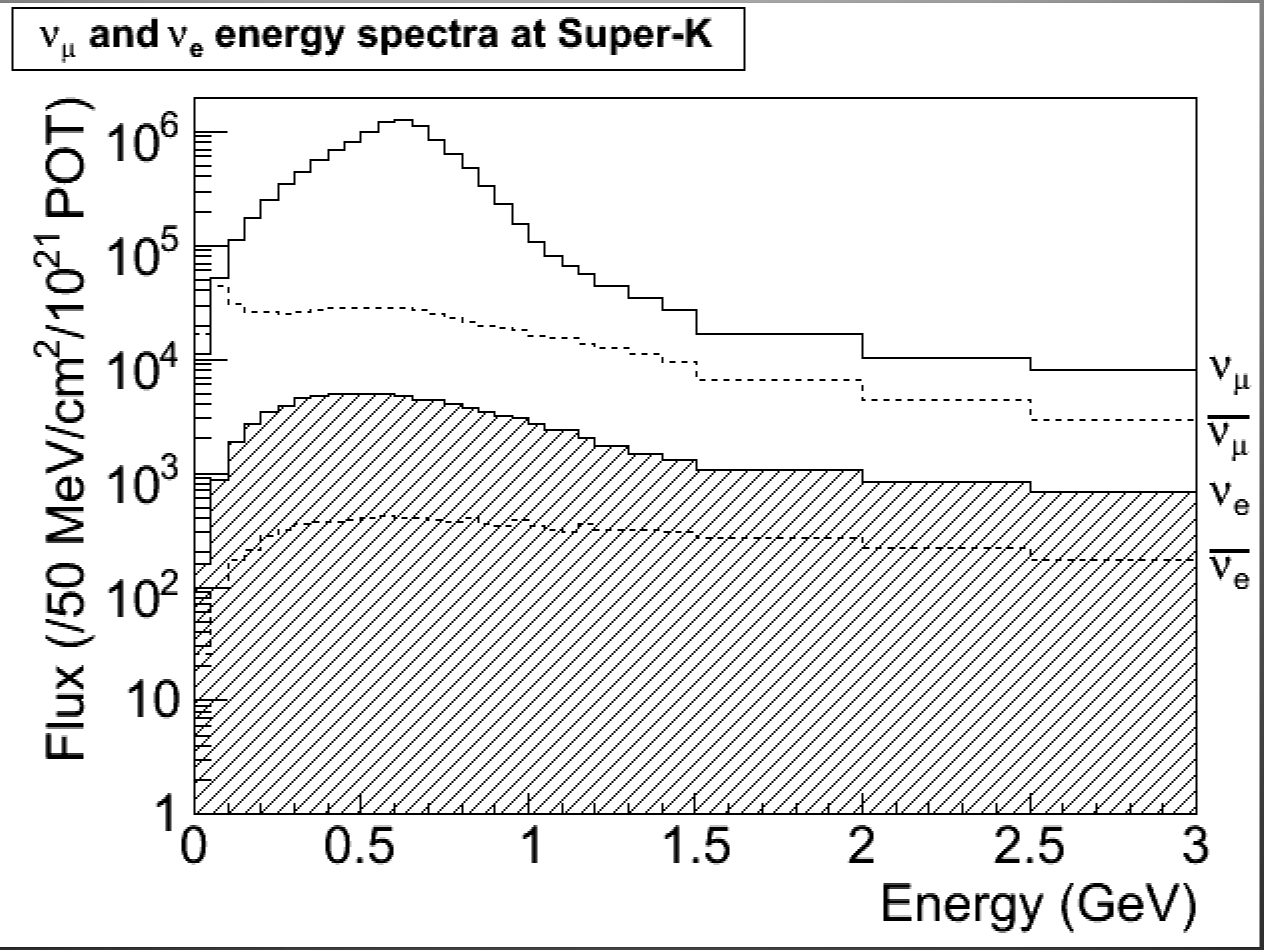
Off Axis beam

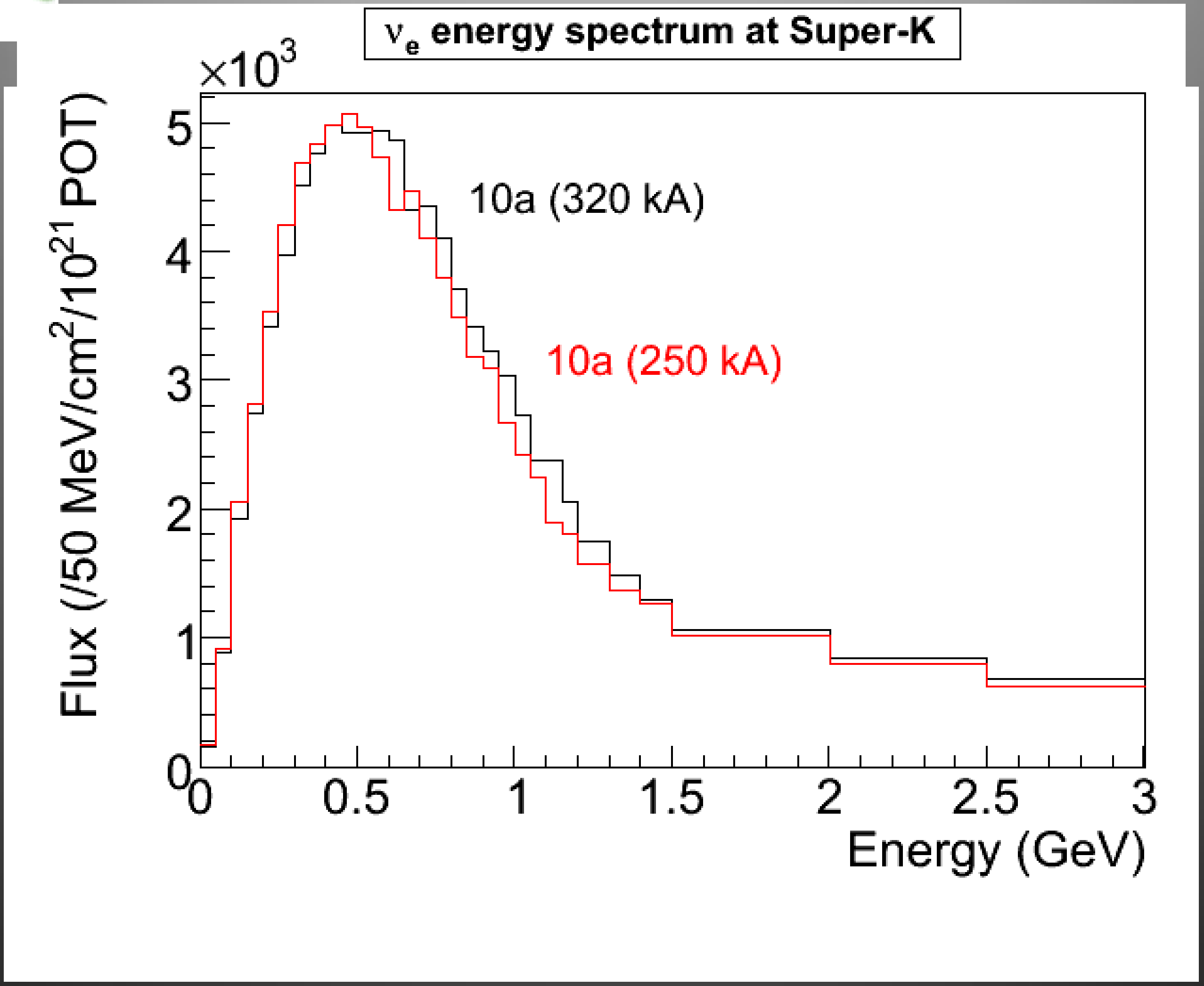


Neutrino flux estimation

- Proton beam intensity on target:
  - Redundant intensity monitors
  - Spill selection
- Proton beam properties on target:
  - Beam profile monitors
  - OTR in front of target
- Hadron production models:
  - Established codes like Fluka08 and GCalor
  - Validation data from NA61 with replicate target
- Simulation of the horn focusing system
- Decay tunnel and beam dump.

Reference spectra at SK

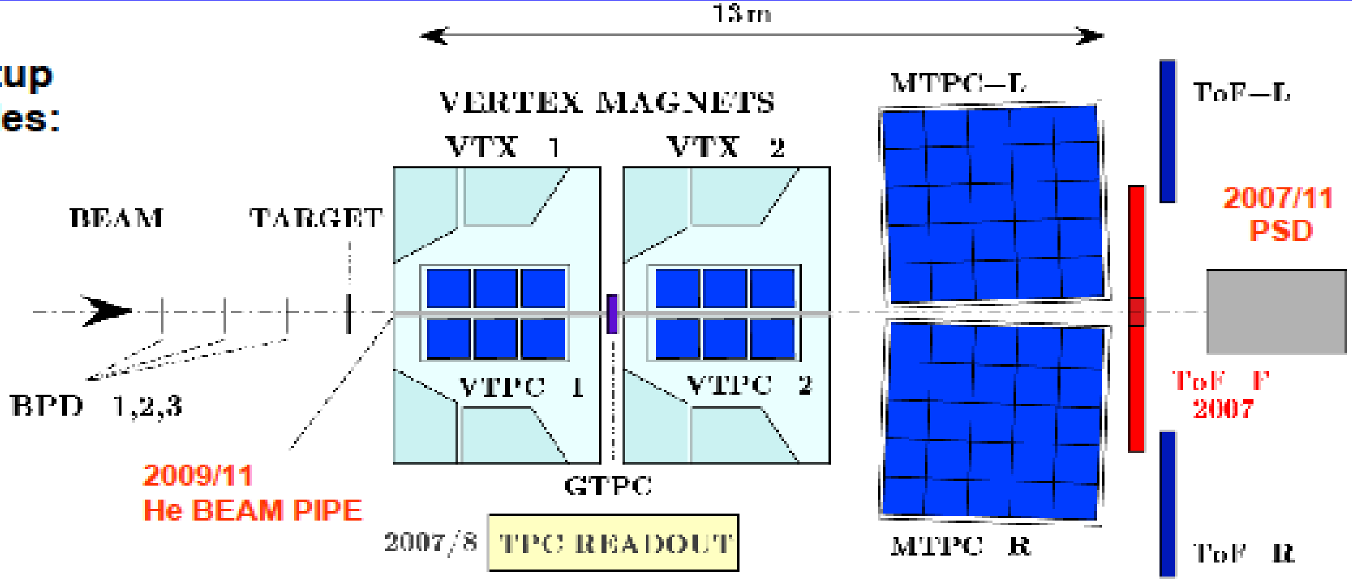




ν_e energy spectrum at Super-K
$\times 10^3$
Flux (/50 MeV/cm^2/10^{21} POT)
10a (320 kA)
10a (250 kA)
0
1
2
3
4
5
0
0.5
1
1.5
2
2.5
3
Energy (GeV)

NA61/SHINE – Fixed Target Experiment at CERN SPS

NA49 Setup + Upgrades:



- **Large Acceptance Spectrometer for charged particles: (TPCs as main tracking devices; 2 dipole magnets with bending power of max 9 Tm over 7 m length** (2007-Run: 1.14 Tm); **new ToF-F to entirely cover T2K acceptance; high momentum resolution; good particle identification)**

Data taking for T2K:	**Year**	**Target**	**Statistics**	**Status**
	2007	**thin C**	**670k triggers**	***Preliminary pion spectra***
	2007	**replica**	**230k triggers**	***First analysis loop***
	2009			***Under calibration***

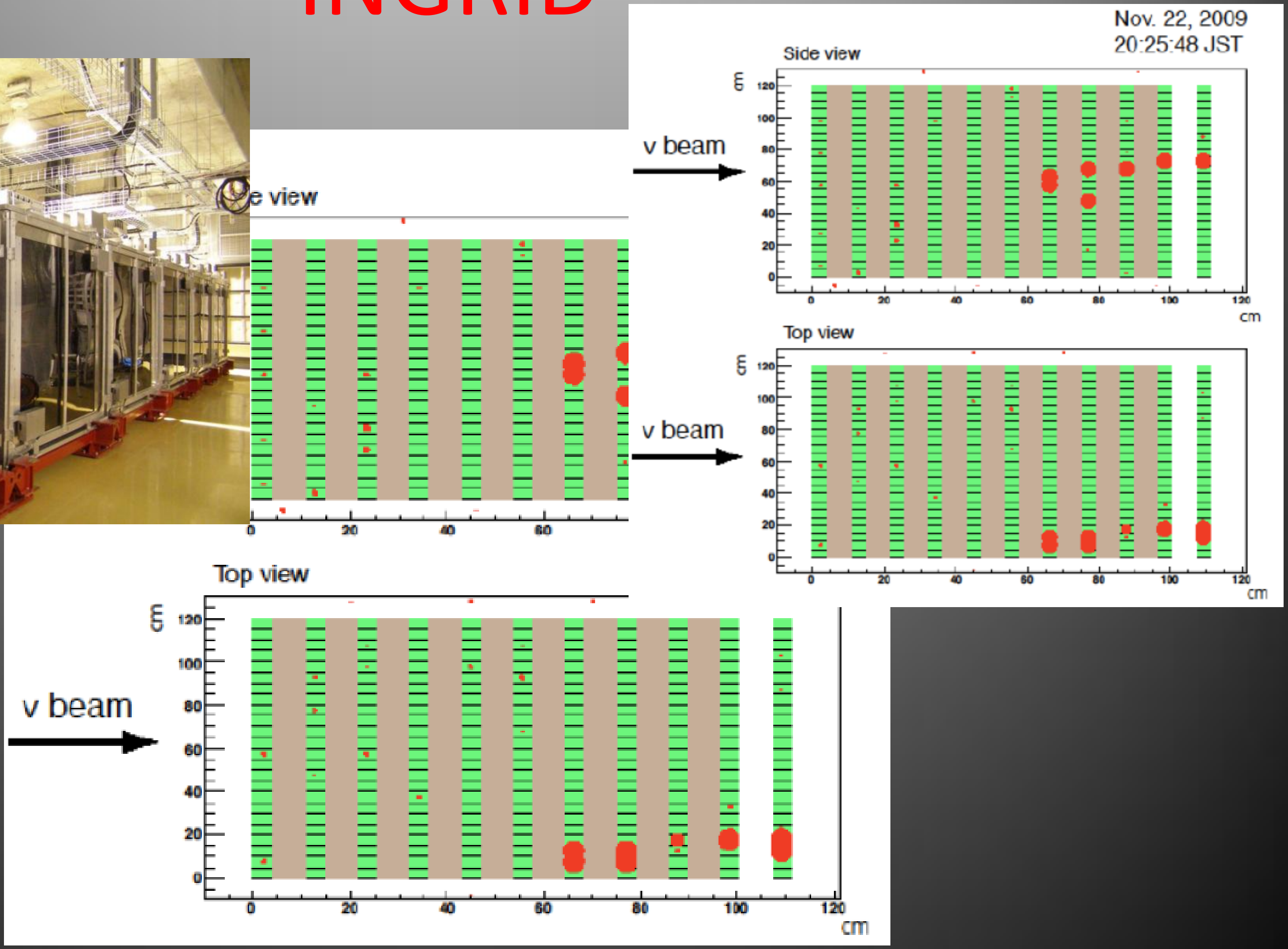
Neutrino Beam MC

- Determine muon flux @ dump monitors
  - High energy muons (>5 Gev)
  - Spil by spill direction and intensity monitoring
  - Horn focusing stability
- Determine ν flux on Axis @ INGRID
  - Beam profile and position
  - High energy neutrino rate consistency check
- Determine ν flux off axis @ND280
  - Neutrino energy spectrum
  - Neutrino species composition
  - Neutrino flux
- Determine ν flux off axis @SK
  - Far to near ratio (critical systematic uncertainty)
  - Oscillation analysis
- Neutrino vector files generated for each subsystems

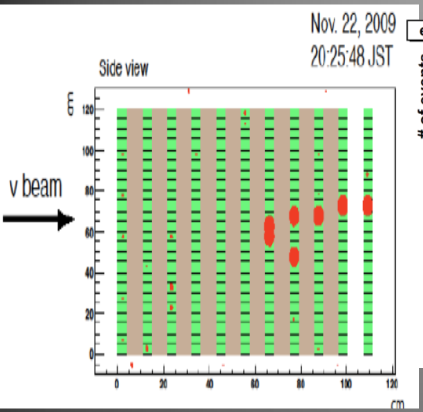
Neutrino flux validation

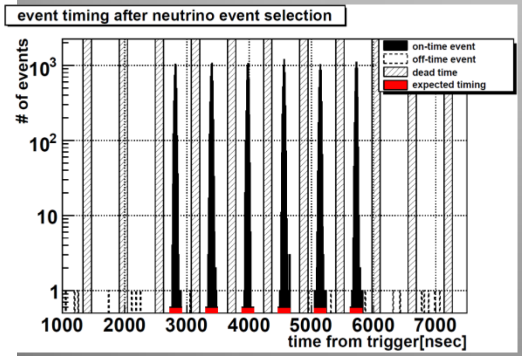
- Dump muon monitors:
  - High energy (>5 GeV/c)
- On Axis INGRID (Scint/ Iron tracker)
  - Iron target and High energy threshold
  - One scintillator only module
- Off Axis : ND280 detector complex
  - On Carbon target
  - On water target (SK target material)

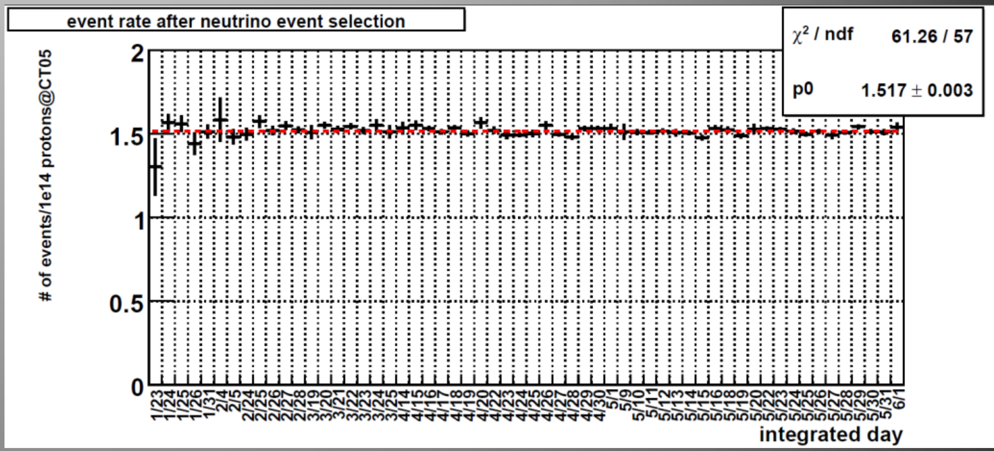
INGRID

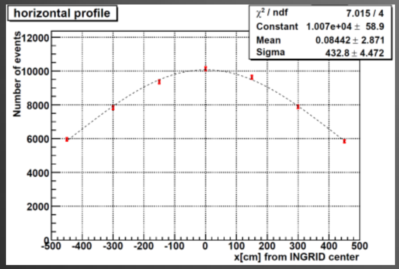

Nov. 22, 2009
20:25:48 JST
Side view
ν beam
Top view
ν beam
e view
Top view
ν beam
cm

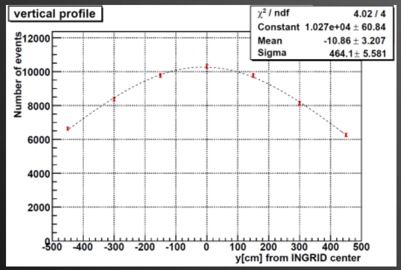
INGRID measurements

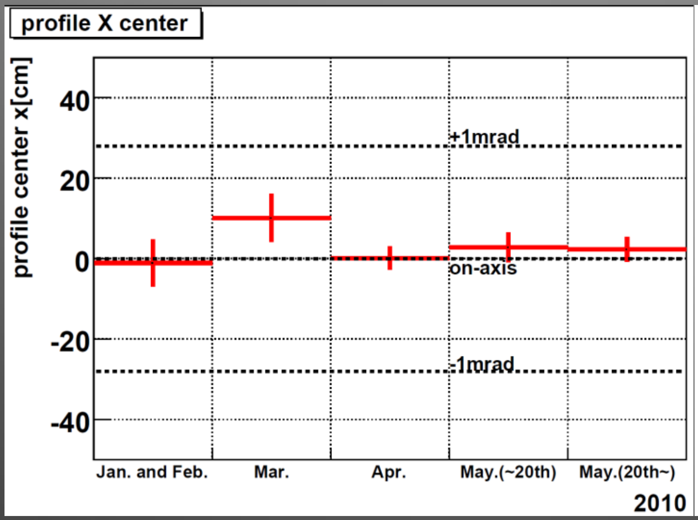


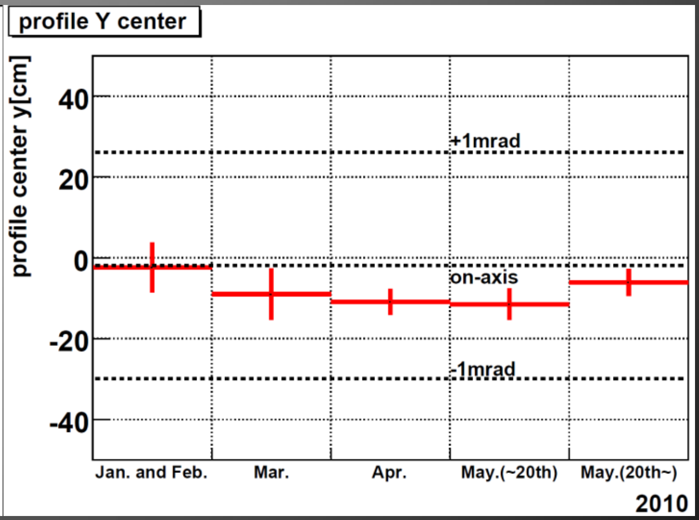












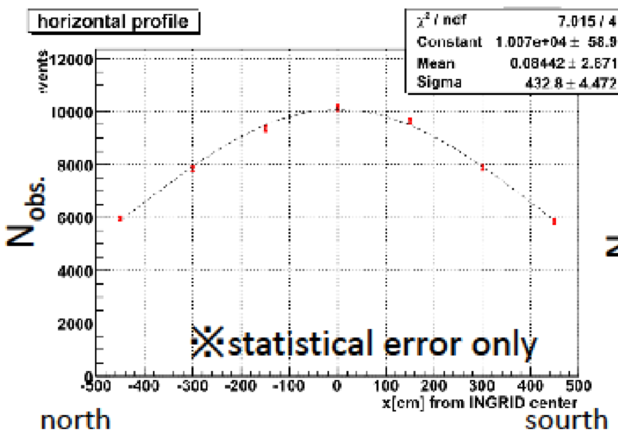
- Bunch structure clearly seen as expected
- Event rate is stable
- Beam direction well controlled within requirement (<1mrad)

Ingrid beam profile

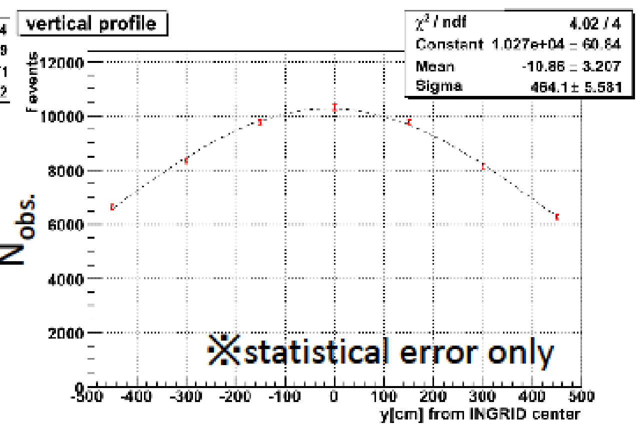
Beam profile

Run32(April)

Horizontal



Vertical



center: 0.1 +- 2.9 cm

σ :433 +- 4 cm

center: -10.9 +- 3.2 cm

σ :464 +- 6 cm

Clear beam profile was observed

28

Number of neutrino events

- $N_\nu(E) \sim \Phi_\nu(E) * \sigma_\nu(E) * \varepsilon(E) *$ Target (H_2O in SK)

- Neutrino flux
  - MC
  - Validation
  - Hadron production
  - Diff energy spectrum

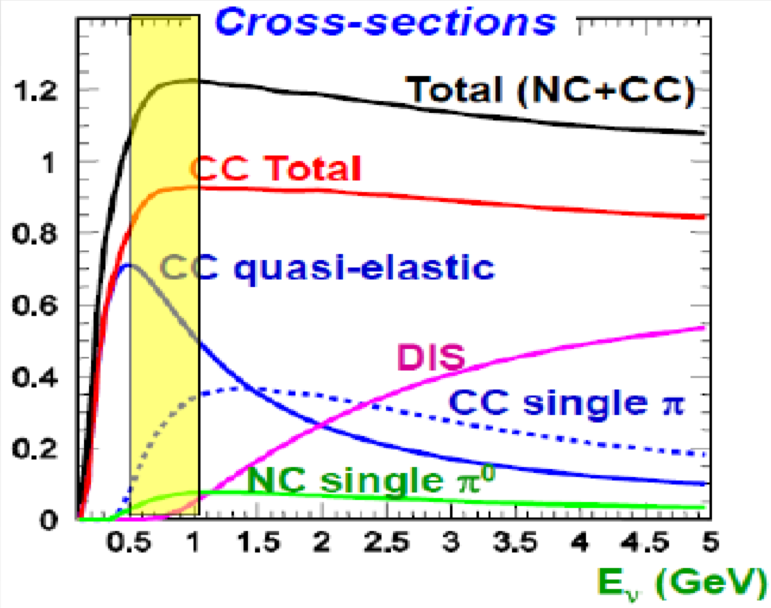
  for CC and NC events

Cross section ($10^{-38}cm^2$)

- Poorly known at 1GeV
- signal via CC
- Background NC related

Neutrino cross-section

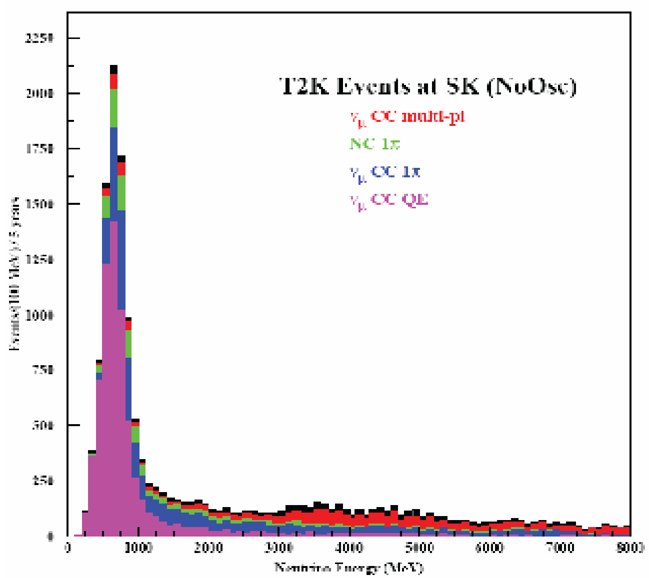
- Dominant channel @ T2K energy: CCQE



Claudio Giganti - Blois2010

Neutrino spectrum

T2K Events w/ and w/o Oscillations



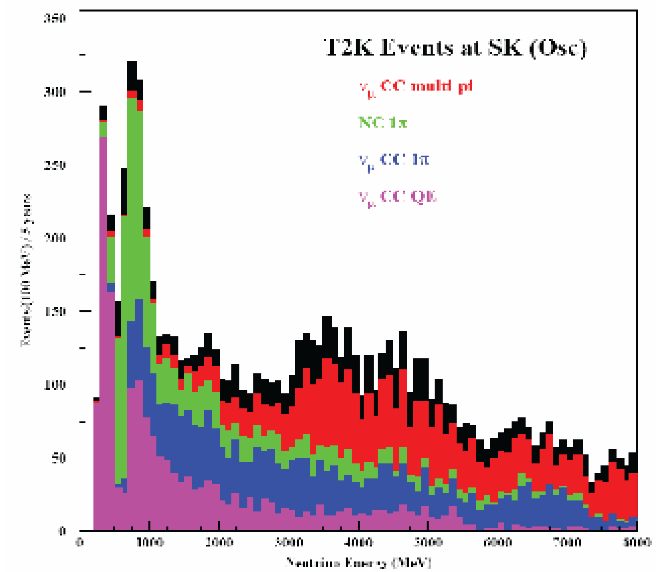


Figure courtesy D. Casper

SK sample is mainly non-QE, need to understand feed-down from high energies!

Neutrino Signals

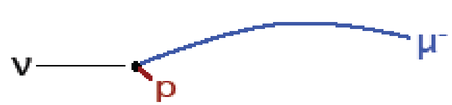
- **Golden mode**: Charged-Current Quasi Elastic (CCQE)

$$\nu_l + n \longrightarrow p + l^-$$

- Flavor of l^- is the ν flavor
- Energy and θ of l^- give a good measurement of the ν energy

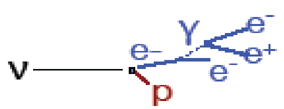
ν_μ signal

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



ν_e signal

$$\nu_e + n \rightarrow p + e^-$$



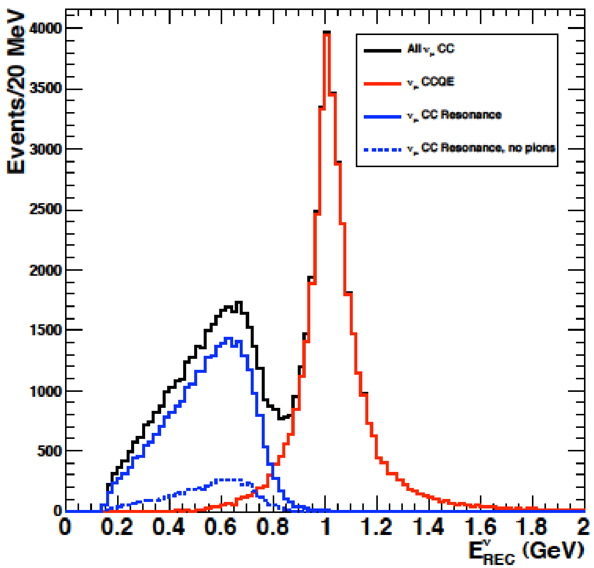
19

What is measured

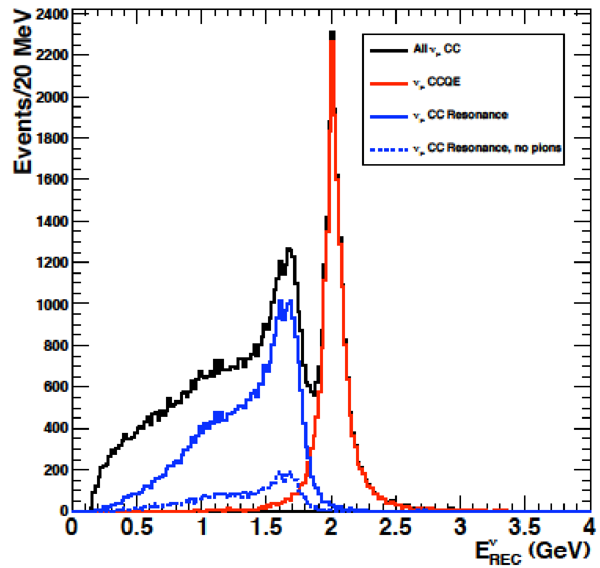
- Charged current reaction Muon type or electron type
- Lepton defines neutrino flavor
- Lepton momentum related to neutrino momentum only for two body reactions
  - CCQE (smearing by Fermi momentum)
  - Final state interaction

Kinematic Reconstruction: Background

"kinematic" reconstruction of 1 GeV ν_μ CC in **Genie**



"kinematic" reconstruction of 2 GeV ν_μ CC in **Genie**



- Why not deal only with "topology"?
  - Kinematics determined largely by "underlying" event, not topology
  - Need accurate model of background rates and how often they can topologically mimic CCQE

Number of lepton events

- CC and NC processes
-
- $N_{\lambda}(E_{\lambda}) \sim \Phi_{\nu\lambda}(E_{\nu}) * \sigma_{\iota}(E_{\lambda}) * \varepsilon(E_{\lambda}) *$ Target
- Composition
- Muon(electron) momentum -
  - CCQE signal
  - Fermi momentum
  - non CCQE contributions

Energy dep efficiencies

- purity

-cuts

Issues

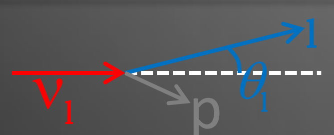
- Neutrino energy
- Neutrino type
- Backgrounds

Neutrino energy

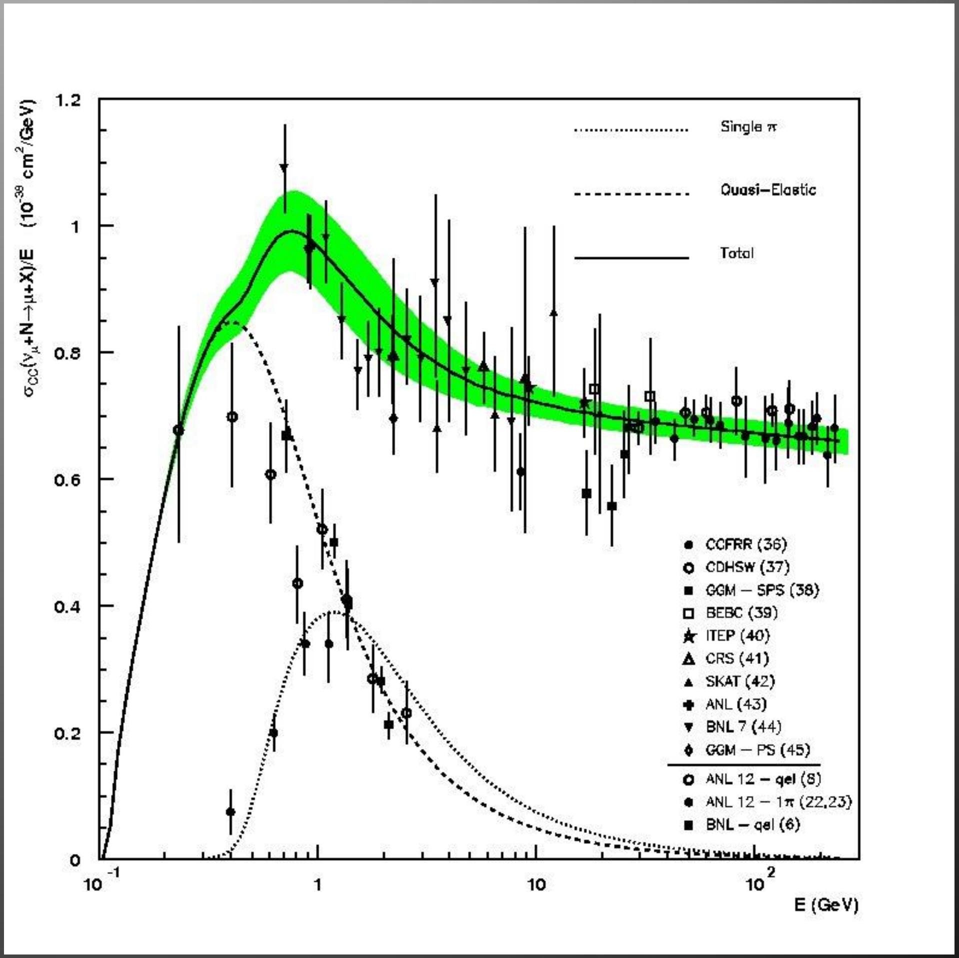
- What is measured is lepton momentum.
- Use CCQE to convert to neutrino energy
  - Fermi momentum smearing
  - Final state interaction
- Ccqe is only a fraction of the processes contributing to the lepton production
  - CC1p
  - CCp0
  - Ccnp
  - Misidentified lepton
  - -Misidentified NC events

Neutrino beam energy

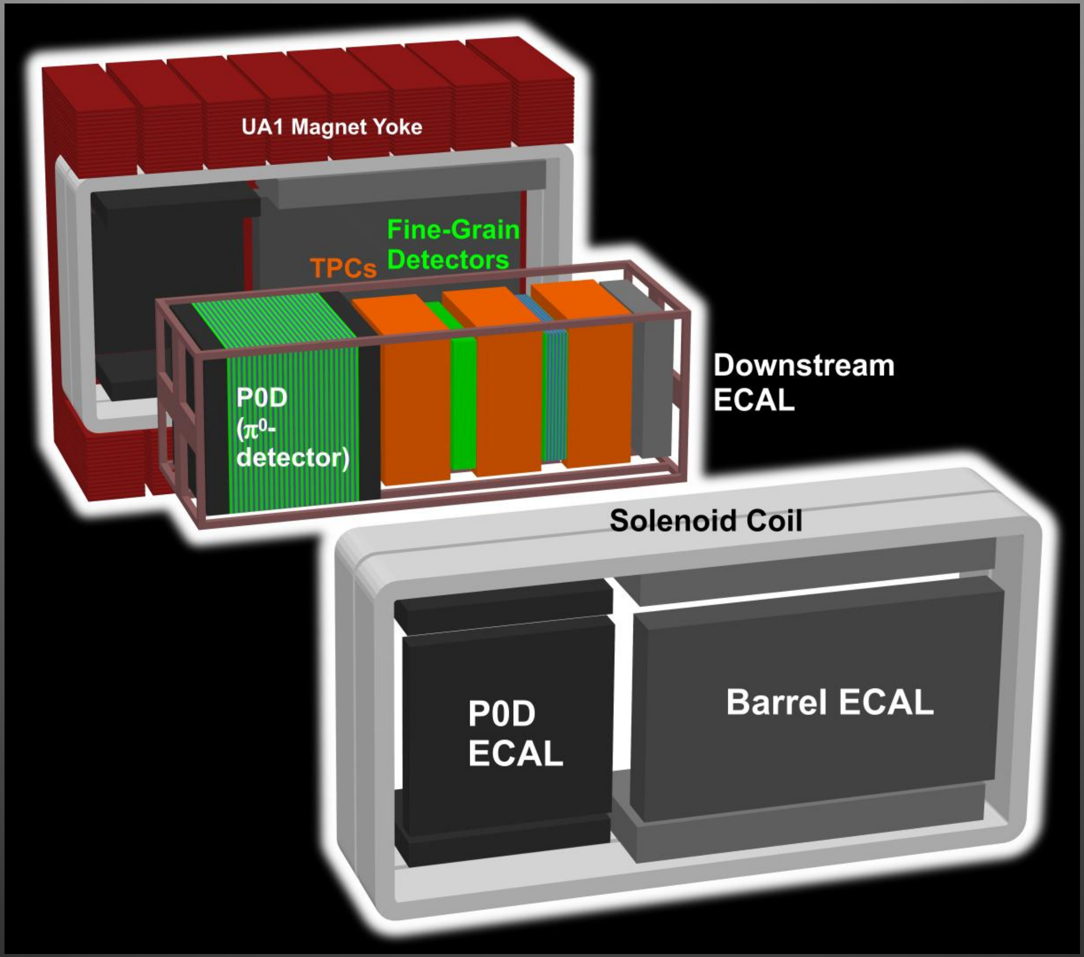
Use quasi elastic events for which P_l and θ_l determine E_ν



$$E_\nu^{rec} \approx \frac{m_n E_l - m_l^2/2}{m_n - E_l + p_l \cos\theta_l}$$



ND280 Off Axis detectors



Role of ND280 OA detectors

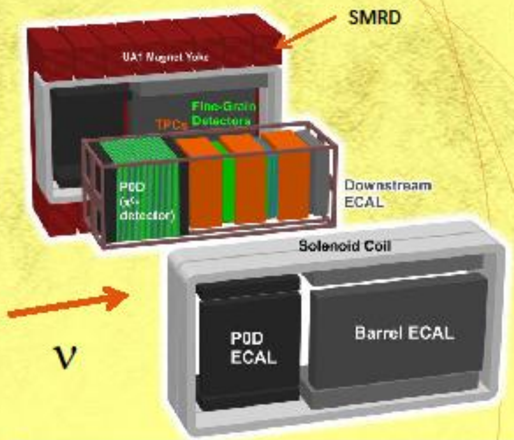
- Neutrino flux and Energy spectrum for ν_μ and ν_e components of the beam (FGD and TPC)
- Charge current cross sections both for signal and background processes (FGD and TPC)
- Pizero production cross sections on water (POD .FGD,ECAL)
- Cosmics and neutrino induced pit/magnet interactions

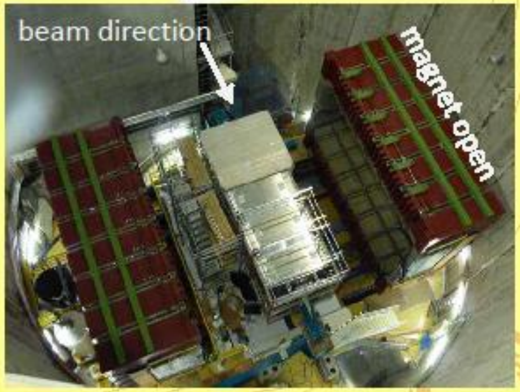
ND 280 components

- (UA1/Nomad) Magnet (.2Tesla field)
- 2 Fine grain detectors
- 3Time projection chambers
- POD
- ECAL
- SMRD

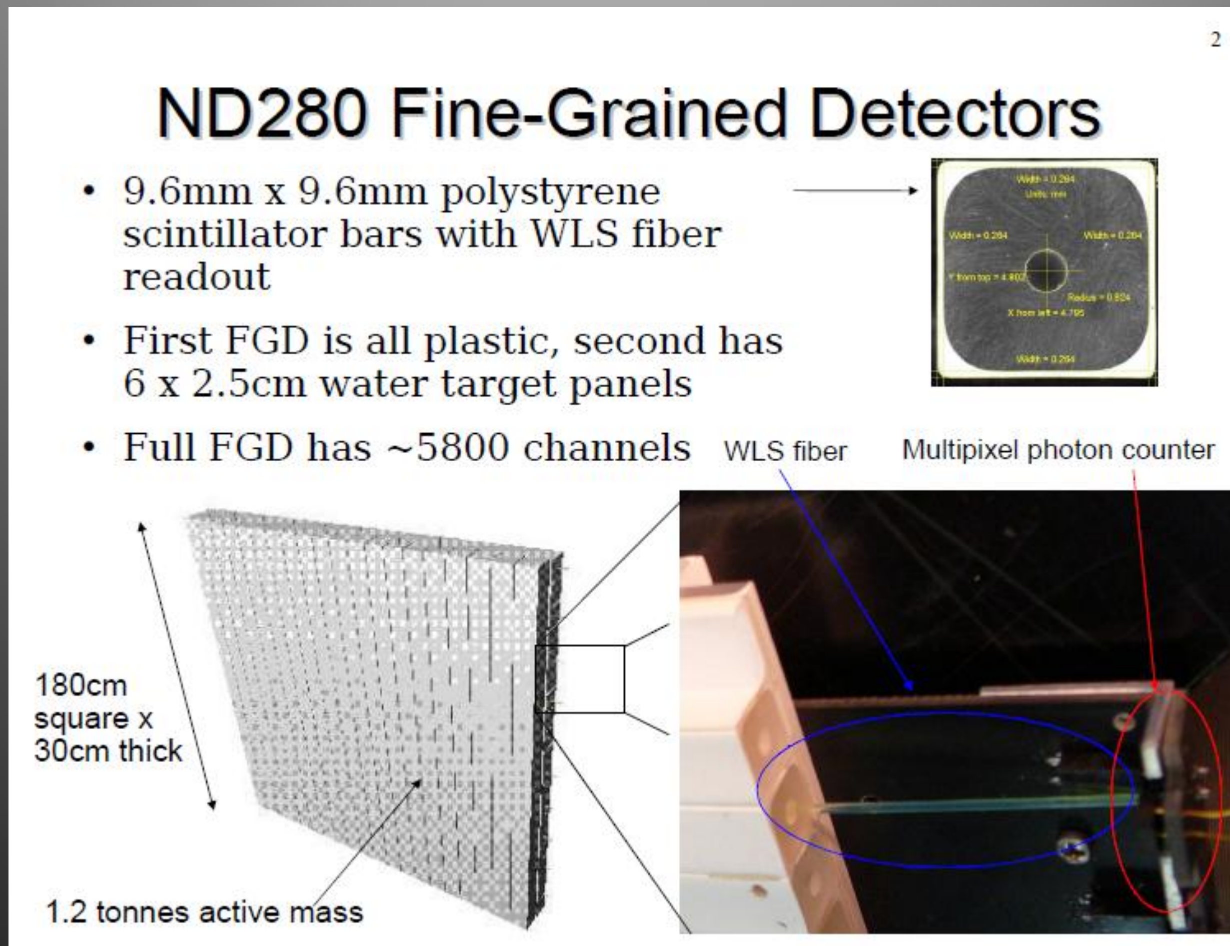
Off-Axis Detector

- Measure neutrino flux and cross section
- UA1 Magnet 0.2 T field
- Tracker Region: Fine Grained Detectors (FGDs) & TPCs
  - Particle Tracking (p,θ) & identification
- P0D
  - Measure NC π^0 rate
- Includes a water target in P0D and FGD2
  - Understand interactions on H_20 target
- ECAL (Downtream Currently Installed)
  - Surrounds tracker and P0D
  - Capture EM energy
  - Rest of ECAL is to be installed this summer
- SMRD
  - Muon ranging instrumentation in the magnet yoke





Fine Grain Detector



New technology

Multi-Pixel Photon Counters (MPPC) Readout

45

- MPPC is an array of silicon photodiodes operating just above the avalanche breakdown voltage.
  - Output from MPPC is a sum of charge from each individual pixel avalanche.
  - Similar characteristics to PMTs, but smaller, cheaper and insensitive to magnetic fields.
- ND280 has chosen to use MPPC as the photosensors for all scintillator detectors.
  - Using ~50,000 MPPCs for ND280; first large-scale use of these devices.

Hamamatsu MPPC
Active area: 1.3x1.3 mm^2
Number of pixels: 667

Thomas Lindner
TRIUMF, 7-15-2010

Fine Grain detector

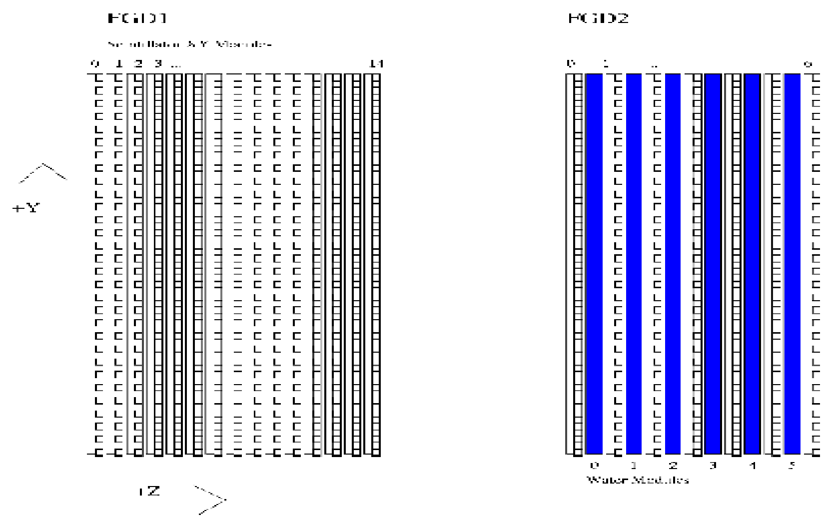
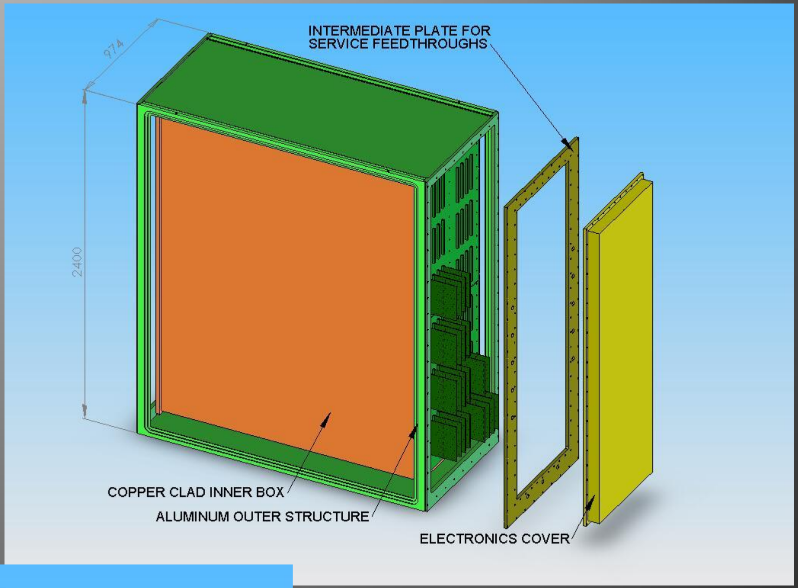


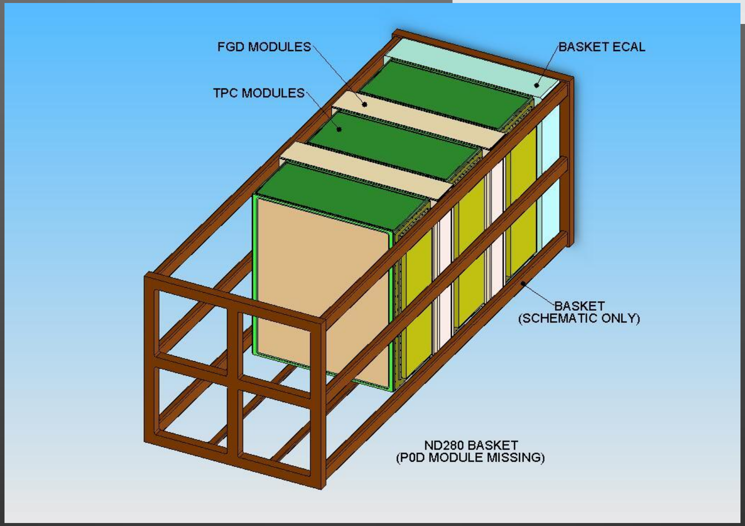
Figure 2: numbering convention for scintillator and water modules.

TPC`s

- Charged Lepton identification
  - ν_e component of the beam
- Charged Lepton momentum measurement to 10% resolution at 1GeV/c
  - Muon momentum scale to 2%
- Charged Pion identification
- Only low mass detector in the ND280

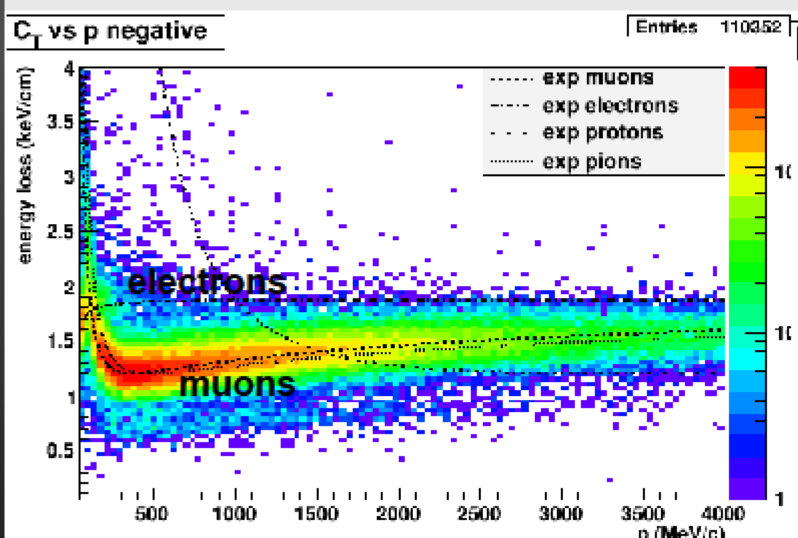
TPC details

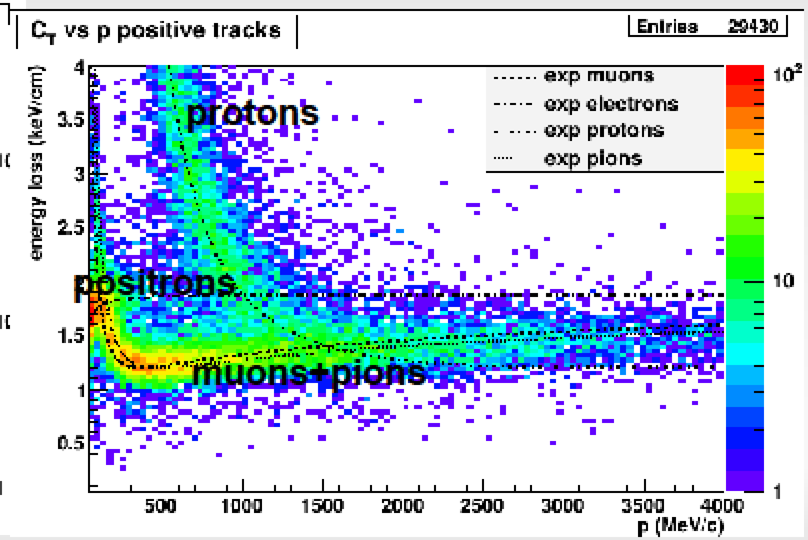

INTERMEDIATE PLATE FOR SERVICE FEEDTHROUGHS
974
2400
COPPER CLAD INNER BOX
ALUMINUM OUTER STRUCTURE
ELECTRONICS COVER


FGD MODULES
TPC MODULES
BASKET ECAL
BASKET (SCHEMATIC ONLY)
ND280 BASKET (P0D MODULE MISSING)

PID performances

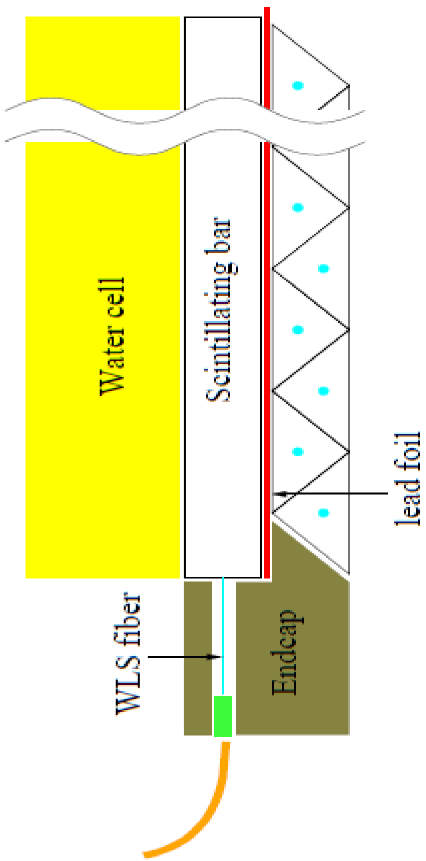
- Look at ALL the reconstructed tracks during beam triggers in the first T2K physics run
- Divided in positive and negative tracks
- Negative: mainly muons, some electrons
- Positive: protons, MIPs, electrons





5

POD



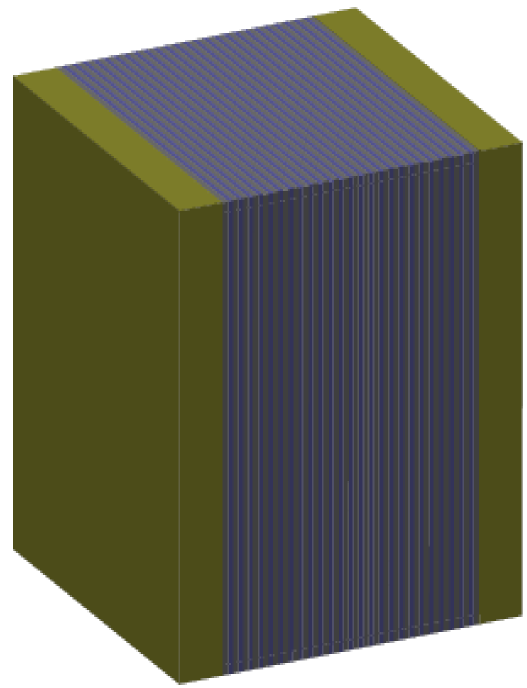


Figure 6.7: The P0D detector viewed from the upstream end. The central region of the P0D is constructed of alternating water target and scintillator tracking layers. The upstream and downstream regions are composed of lead radiator and scintillator tracking layers.

POD

- Measure NC π^0 production in water
- Systematic level of 10% on SK background

- Alternating water planes (3cm) and scintillator tracking planes (3cm), X and Y planes with thin lead sheet in between (0.6cm)
- Front and back module s without water

ECAL

- Electromagnetic calorimeter surrounding the main tracker detectors
- Pizero detector
- 32 layers of scintillator (1cm thick,4cm wide)
- 31 layers of lead 1.75cm thick

Reactions involved

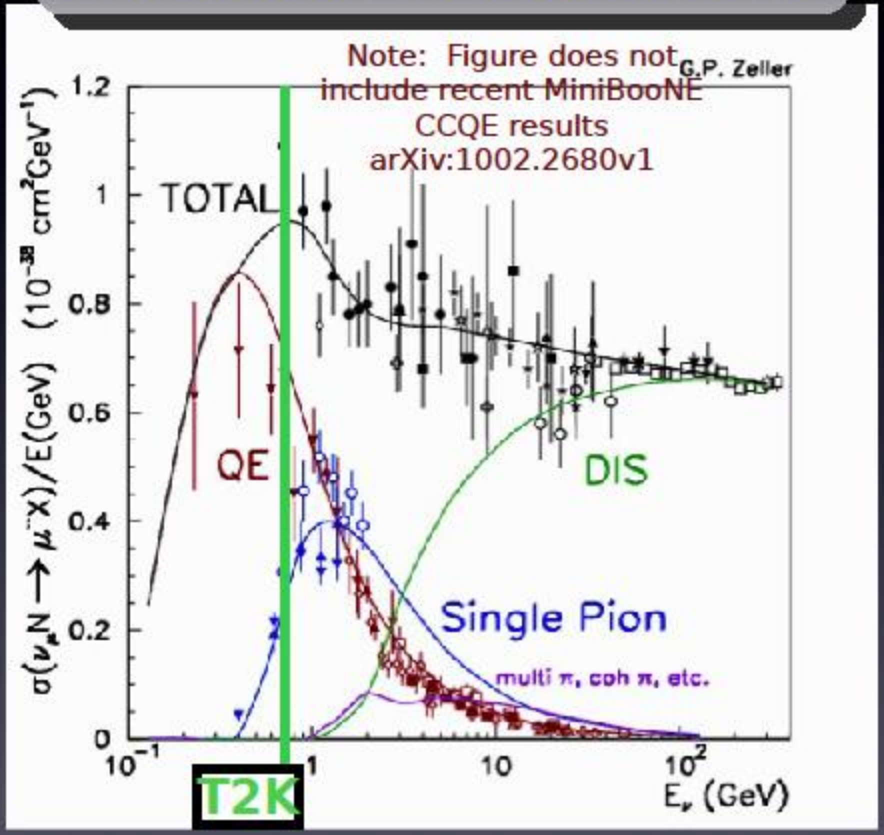
Int. Mode	Fraction
$CC - QE$	65 %
$CC - 1\pi$	20 %
$CC - coh\pi$	1 %
$CC - n\pi$	3 %
$NC - 1\pi$	7 %
$NC - N\pi$	7 %

Table 2.2: Fraction of interaction modes around oscillation maximum ($0.35GeV < E_{\nu}^{rec} < 0.8GeV$) for the 1 ring muon-like event as predicted by the NEUT Monte Carlo.

GeV Neutrino Interactions

- GeV Neutrinos are detected through a variety of processes.
- Signal mode for our measurement is Charged Current Quasi-Elastic (CCQE):
  - $\nu_{\mu/e} + n \rightarrow \mu^-/e^- + p$
  - Allows flavor tagging of the neutrino via the charged lepton.
  - Dominant process at T2K oscillation maximum.

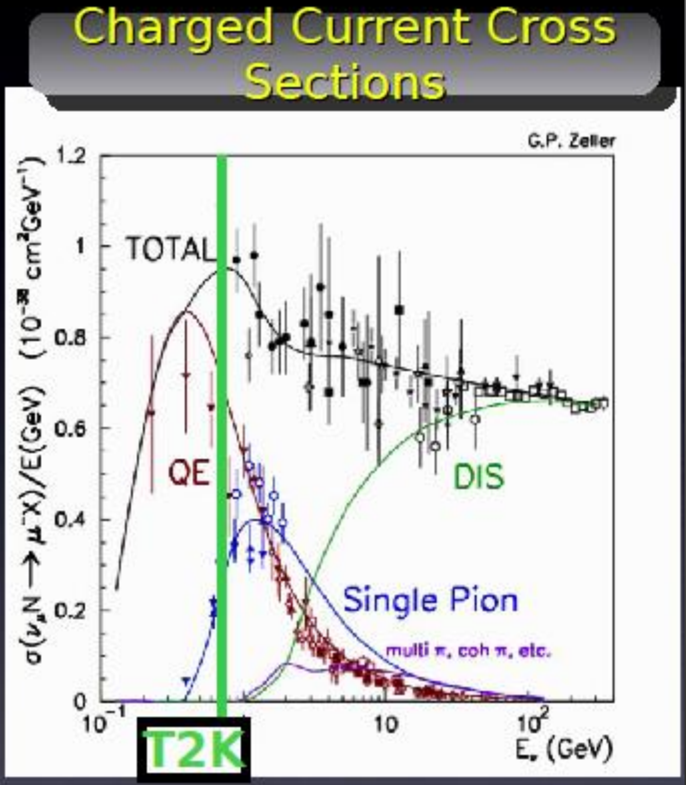
Charged Current Cross Sections



Sub-GeV Neutrino Interactions

Interaction background processes:

- Largest ν_μ background to CCQE ν_μ measurements at Super-K is $CC\pi^+$
  - $\nu_{\mu/e} + N \rightarrow \mu^-/e^- + N + \pi^+$
  - comparable size to CCQE
- Largest ν_μ background to ν_e search at Super-K is $NC\pi^0$
  - $\nu_{\mu/e} + N \rightarrow \nu_{\mu/e} + N + \pi^0$
  - Only $\pi^0 \rightarrow \gamma\gamma$ detected in the final state
  - γ and e^- are indistinguishable



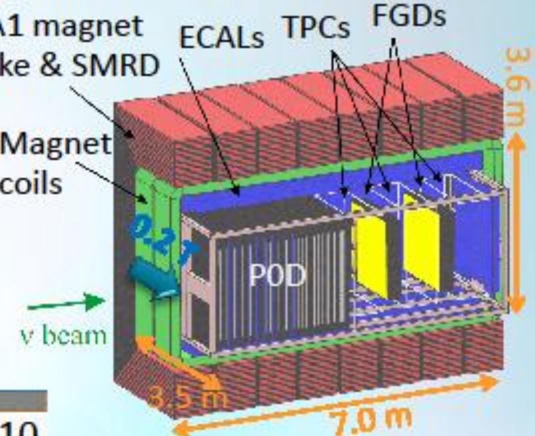
What are we expecting to see in the near detector

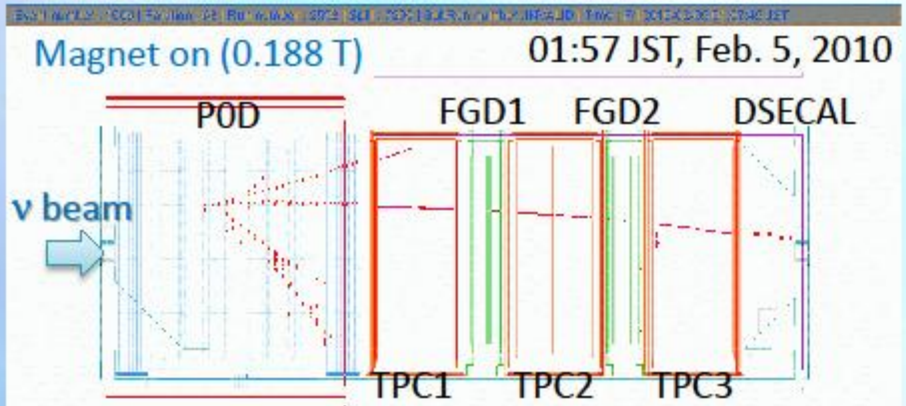
Int. Mode	Fraction	Events/10^{21} POT/ton
$CC - QE$	38 %	65038
$CC - p\pi^+$	11 %	17846
$CC - p\pi^0$	3 %	4887
$CC - n\pi^+$	3 %	5107
$CC - Coherent\ \pi^+$	1 %	2189
$CC - multi\ \pi$	7 %	11943
$CC - DIS$	8 %	13057
$NC - Elastic\ n$	9 %	15671
$NC - Elastic\ p$	8 %	13581
$NC - n\pi^0$	2 %	2837
$NC - p\pi^0$	2 %	3519
$NC - p\pi^-$	1 %	1931
$NC - n\pi^+$	1 %	2300
$NC - Coherent\ \pi^0$	1 %	1099
$NC - multi\ \pi$	2 %	3639
$NC - DIS$	2 %	4022

Table 2.1: Total number of events predicted by the NEUT Monte Carlo for the Near Detector, per ton and per $10^{21} POT$. The Fractions of different interaction modes are also shown.

Neutrino event in ND280

- Measure Φ_ν^{ND} and σ_ν
  - P0D: π^0 Detector → NC π^0 rate
  - TPC: Time Projection Chamber → PID (dE/dx)
  - Magnetic field 0.2 T } p_l
  - FGD: Fine Grain Detector → θ_l
  - ECAL: Electromagnetic CALorimeter
  - SMRD: Side Muon Range Detector

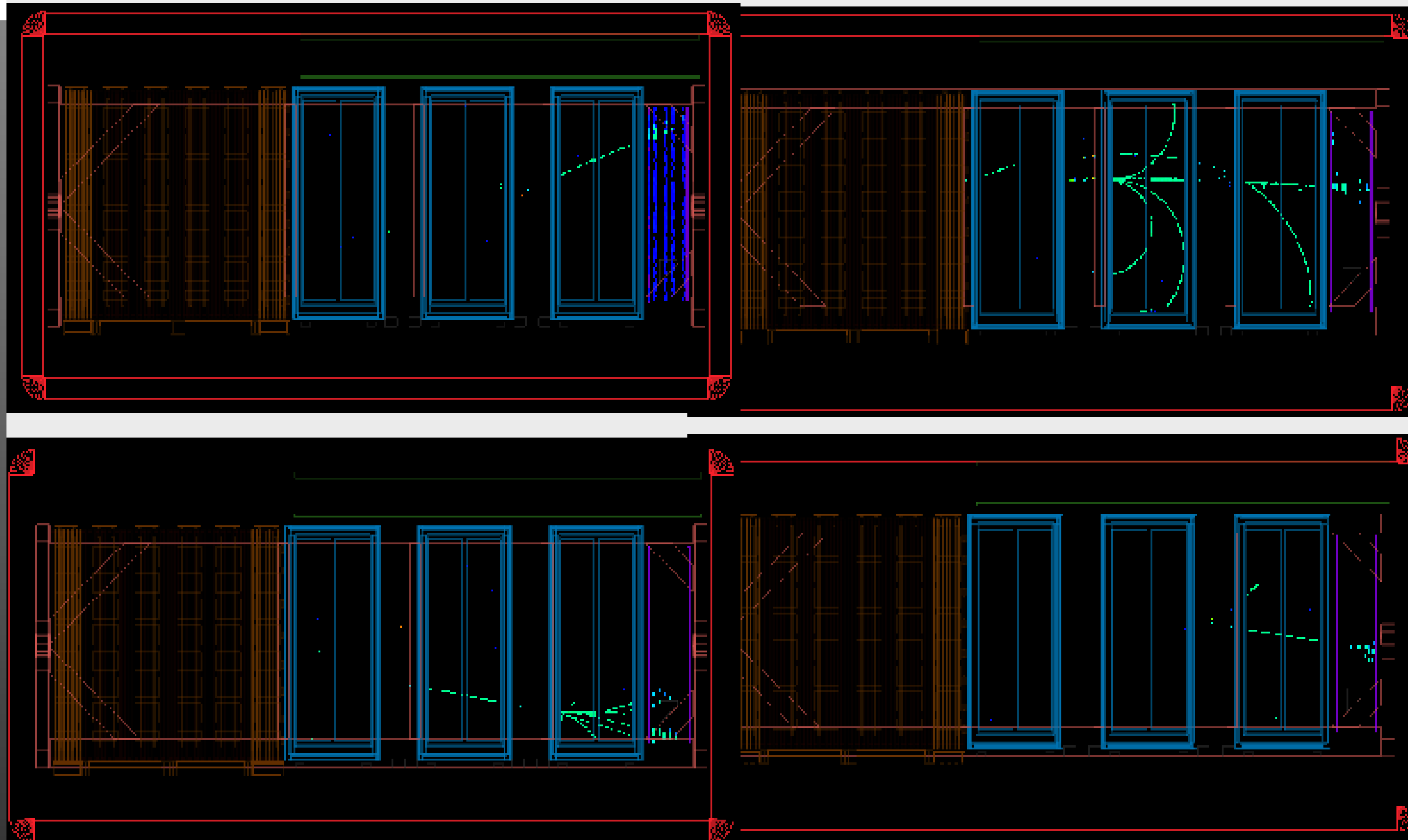




Detected the neutrino event w/ the full setup.

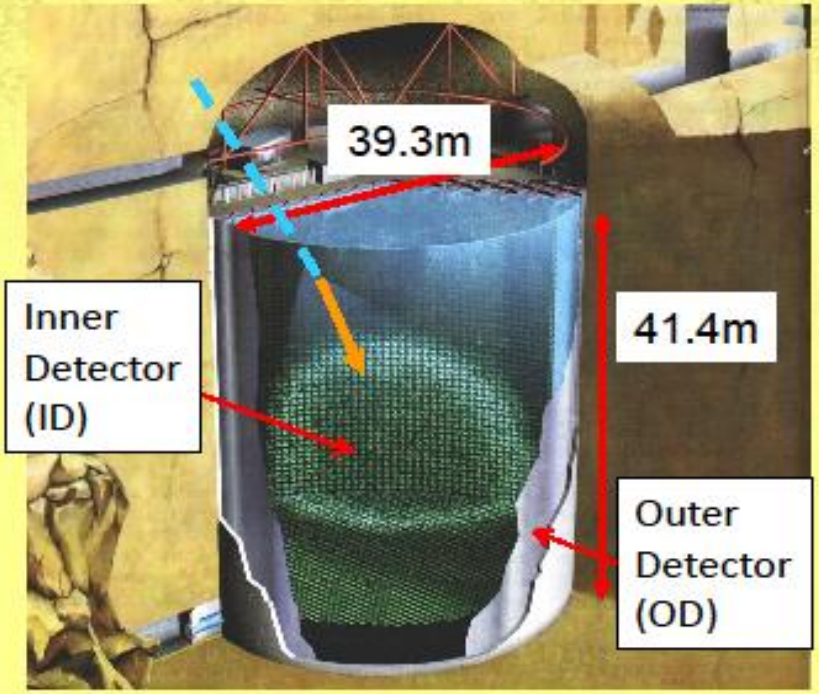
Calibration of the detectors is ongoing.

Look at ν_e sample



13

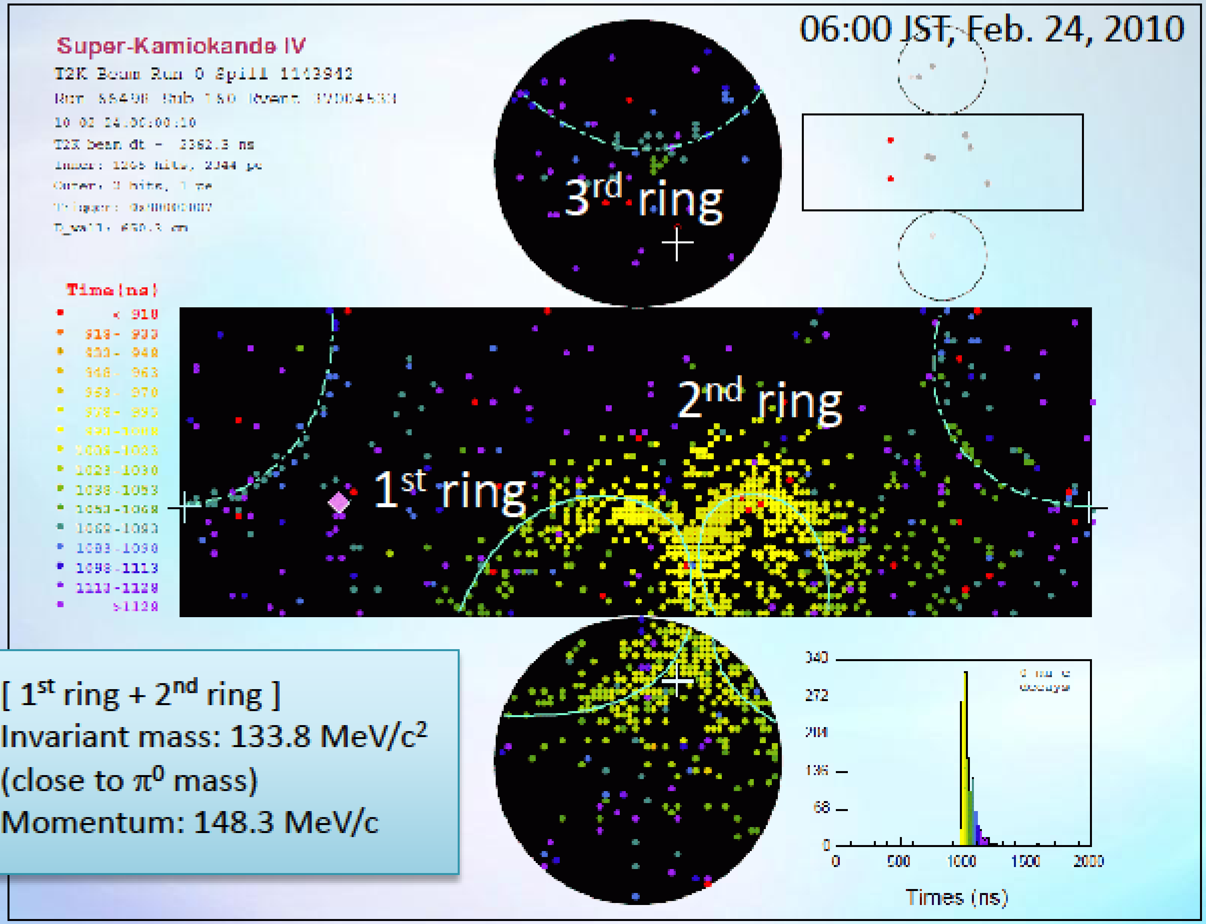
Far detector: Super-Kamiokande IV



- Water Cherenkov detector
- Deep underground (1000m, 2700 m.w.e), Kamioka-mine, Japan.
- Cylindrical shape,50kton water (22.5 kton fid.vol)
- Optically separated Inner Detector/ Outer Detector
- ID : 11129 20inch PMTs (~40% photo-coverage)
- OD: 1885 8inch PMTs
- SK-IV started Aug.2008 with new frontend electronics.

- 4π acceptance, very efficient π^0/e separation.
- High Particle ID (μ/e) power (~99% at 600MeV/c)
- Good energy reconstruction.
- Methods are established.

T2K 1st neutrino event in Super-K

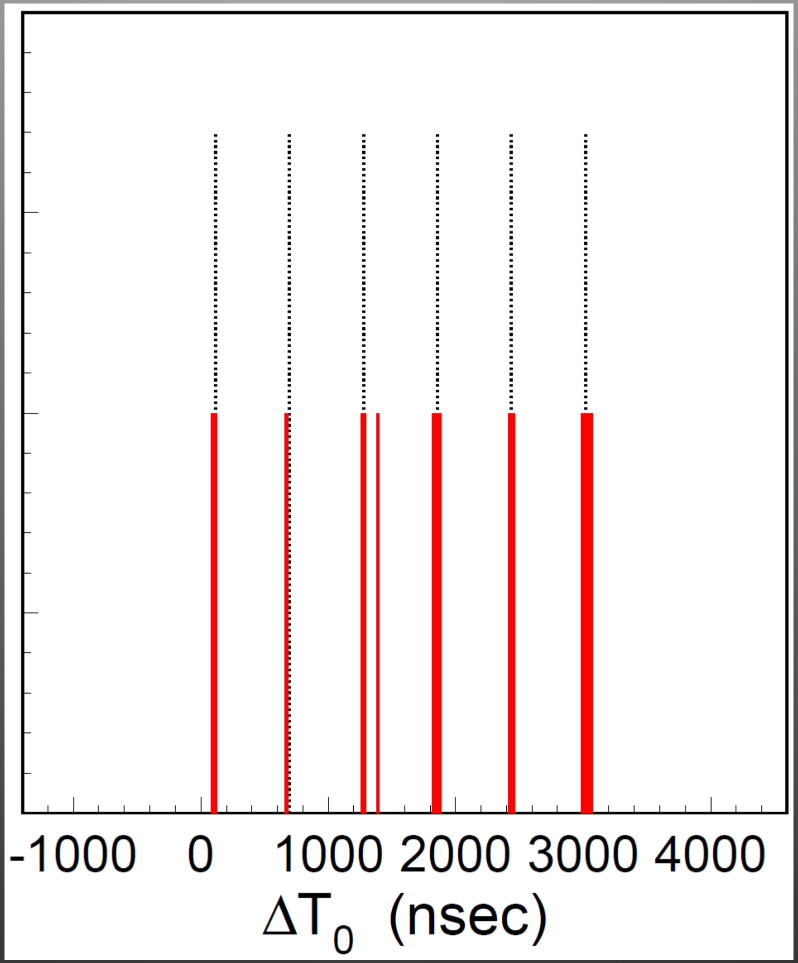


[1st ring + 2nd ring]
Invariant mass: 133.8 MeV/c^2
(close to π^0 mass)
Momentum: 148.3 MeV/c

Number of events at SK [With FC]

Class / Beam run	29-31	32	33	34	ALL
POT (x 10^{19})	0.34	0.76	1.21	0.93	**3.23**
Fully-Contained (FC)	2	15	9	7	**33**
+ fiducial volume cut + visible ene. > 30MeV (FCFV)	2	11	8	2	**23**

Delta-T distribution at SK



Analysis strategy

Beam

- # Proton
- MC flux simulation
- Validation

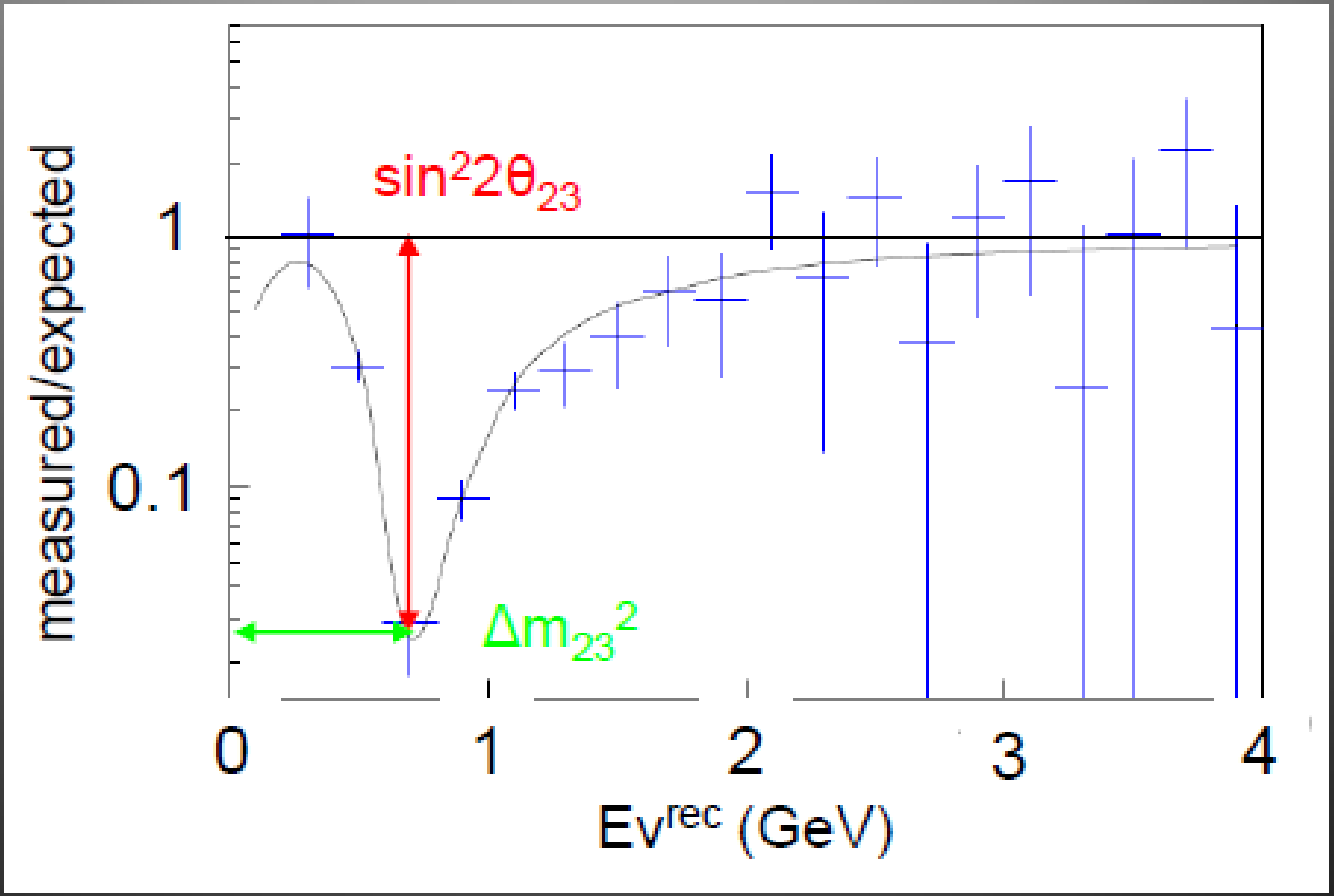
ND280

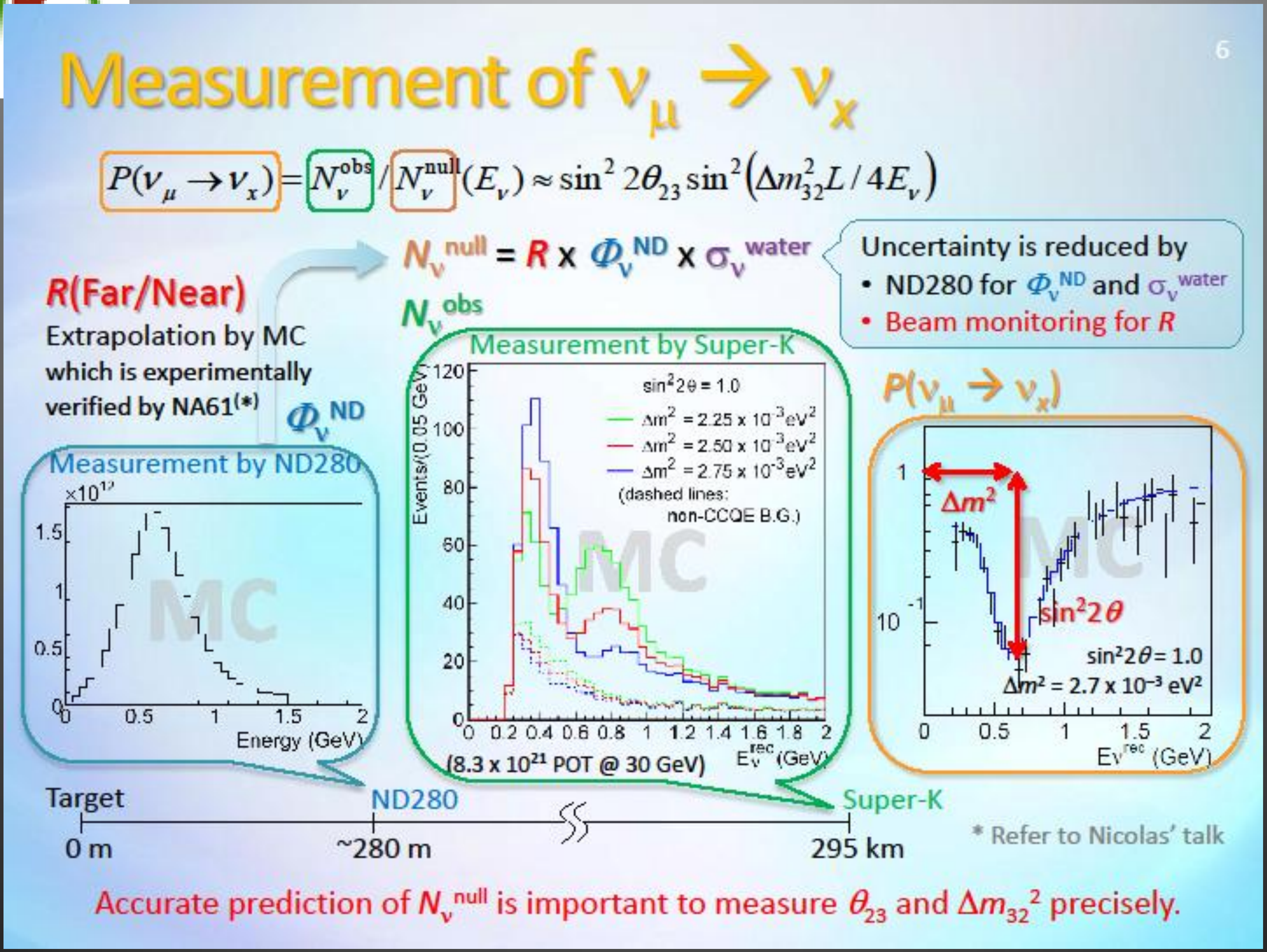
- Flux
- Cross section
- Efficiencies

SK

- Flux(N/F ratio)
- Cross section
- Efficiencies

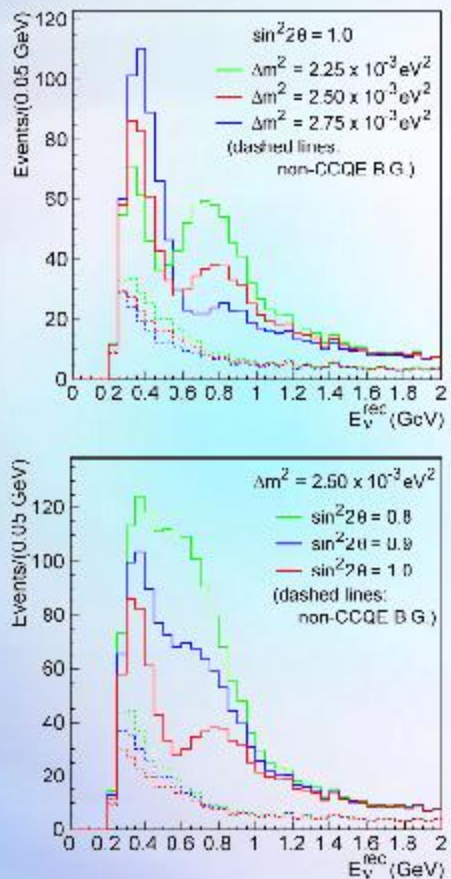
ν_μ disappearance

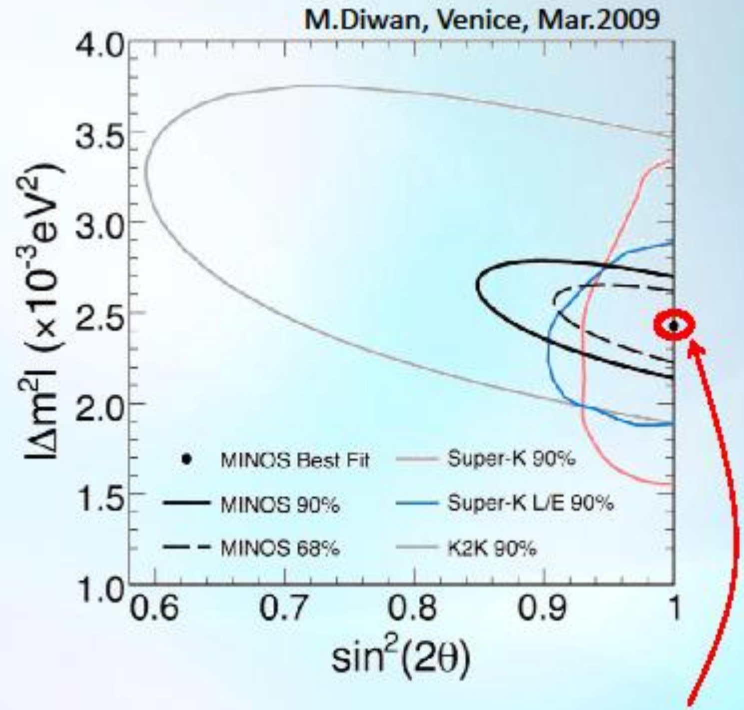



6
Measurement of νμ → νx
P(νμ → νx) = Nν^obs / Nν^null (Eν) ≈ sin² 2θ23 sin²(Δm²32 L / 4Eν)
Nν^null = R x Φν^ND x σν^water
Uncertainty is reduced by
• ND280 for Φν^ND and σν^water
• Beam monitoring for R
R(Far/Near)
Extrapolation by MC
which is experimentally
verified by NA61(*)
Φν^ND
Nν^obs
Measurement by ND280
×10¹²
Energy (GeV)
MC
Measurement by Super-K
Events/(0.05 GeV)
sin²2θ = 1.0
Δm² = 2.25 x 10⁻³eV²
Δm² = 2.50 x 10⁻³eV²
Δm² = 2.75 x 10⁻³eV²
(dashed lines:
non-CCQE B.G.)
(8.3 x 10²¹ POT @ 30 GeV)
Eν^rec (GeV)
P(νμ → νx)
Δm²
sin²2θ
sin²2θ = 1.0
Δm² = 2.7 x 10⁻³ eV²
Eν^rec (GeV)
Target
ND280
Super-K
0 m
~280 m
295 km
* Refer to Nicolas' talk
Accurate prediction of Nν^null is important to measure θ23 and Δm32² precisely.

Sensitivity to Δm_{23} and θ_{23}

30 GeV, 8.3 x 10^{21} POT

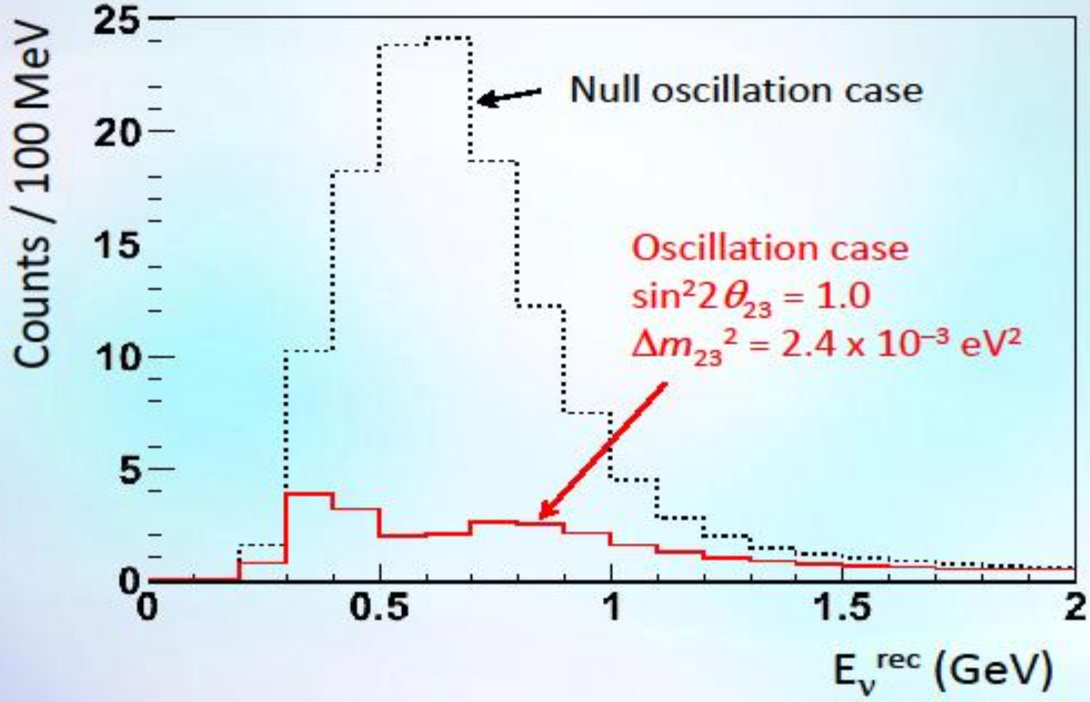




$\delta(\sin^2 2\theta_{23}) \approx 0.01$, $\delta(\Delta m_{23}^2) < 10^{-4}$ eV^2

Sensitivity to Δm_{23} and θ_{23}

100 kW x 1 x 10^7 sec

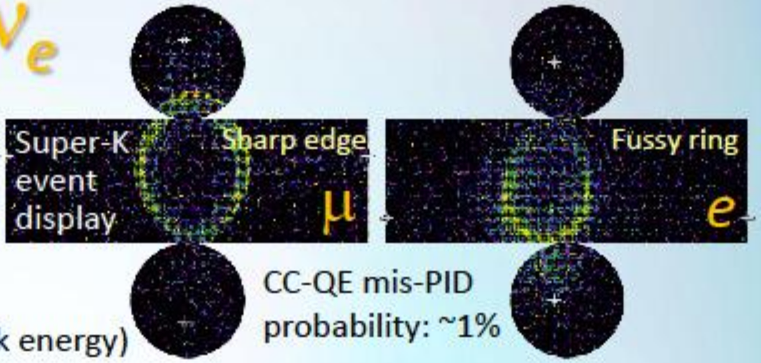


→ $\delta(\sin^2 2\theta_{23}) \approx 0.1$, $\delta(\Delta m_{23}^2) \approx 4 \times 10^{-4}$ eV² (90% CL)

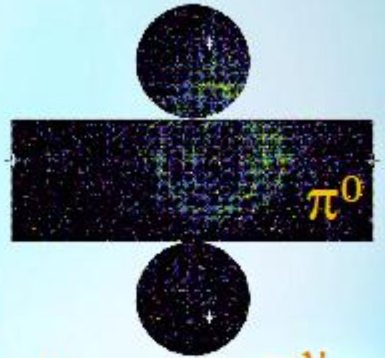
(Statistical error only)

Search for $\nu_\mu \rightarrow \nu_e$

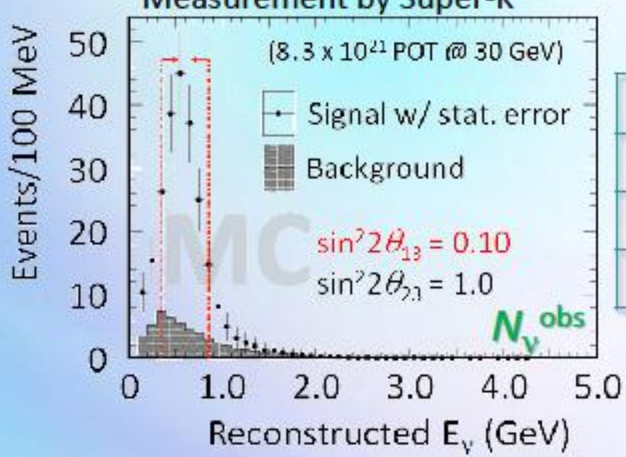
- ν_e signal
  - 1-ring e-like event (CC-QE)
- Background
  - Beam ν_e contamination
    (~0.4% of ν_μ at ν_μ spectrum peak energy)
  - Miss-reconstructed NC(*) π^0 event
    (mainly from high *E* νs ← reduced by the off-axis beam)



CC-QE mis-PID probability: ~1%



Measurement by Super-K



Expected num. of events in 0.35-0.85 GeV

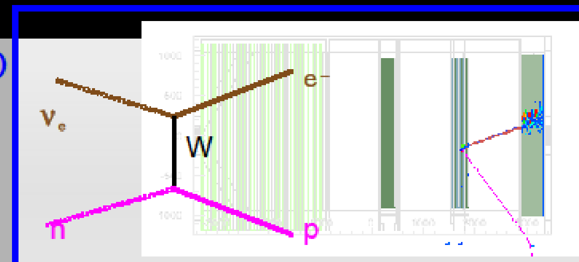
$\sin^2 2\theta_{13}$	0.1	0.01
Signal	143	14
Beam ν_e BG	16	16
BG from ν_μ	10	10

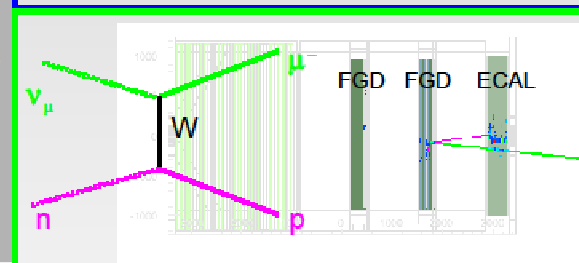
($\sin^2 2\theta_{13} < 0.13$ by CHOOZ)

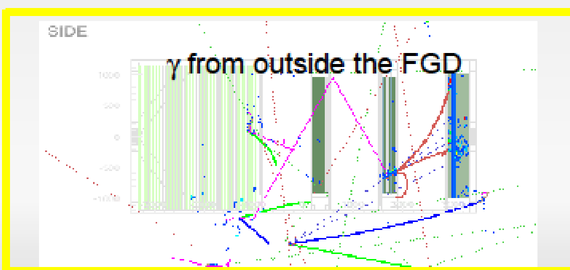
* NC: Neutral Current

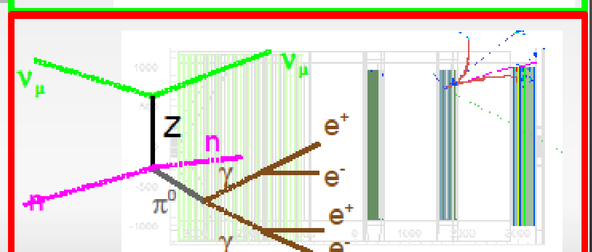
ν_e analysis

- Signal: CC ν_e interactions in the FGD
- 3 sources of backgrounds:
  - ν_μ interactions in the FGD with misid muons → negligible in the MC, to be measured on the data
  - CC/NC ν_μ interactions in the FGD with γ → electrons in the TPC
  - Interactions outside the FGD with γ converting in the FGD









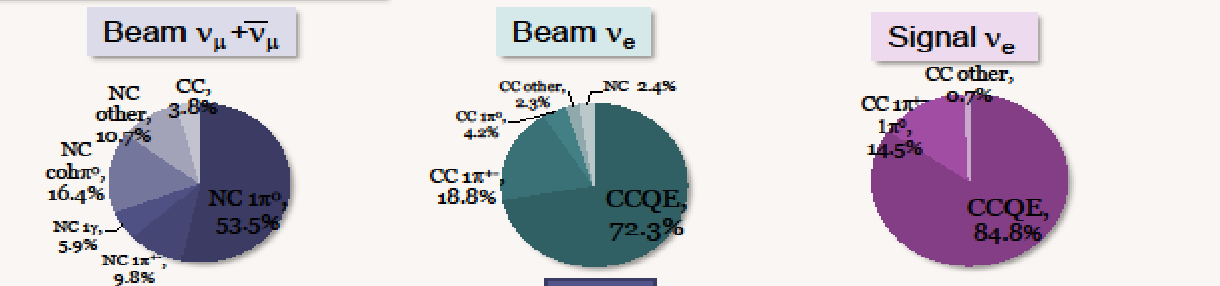
11

ν_e analysis

11

Break down of final events

Neutrino interaction mode



Final state

beam ν_μ	Frac.
NC$1\pi^0$	77 %
NC$1\pi^\pm$	8.6 %
NC1γ	5.2 %
NC other	6.0 %
CC	3.8 %

beam ν_e	Frac.
1e	94.6 %
1e + 1p$^\pm$	2.6%
1e + 1P	0.4%
NC	2.4%

signal ν_e	Frac.
1e	98.5 %
1e + 1p$^\pm$	1.5 %

Systematic error of $1\pi^0$ and 1e efficiencies are important

ν_e Events

- Appearance of ν_e events in the far detector is dominated by mixing angle θ_{13}
- Largest background from ν_e in the beam at J-PARC
- Select events that have
  - Vertex > 2m from tank wall
  - Direction < 25 degrees of beam
  - <16 hits in outer tank
  - Single e-like ring, no decay e,
  - Low π_0 likelihood and invariant mass
  - 0.35 GeV <E < 0.85 GeV

Signal and Background for 5x10^{21} protons on target

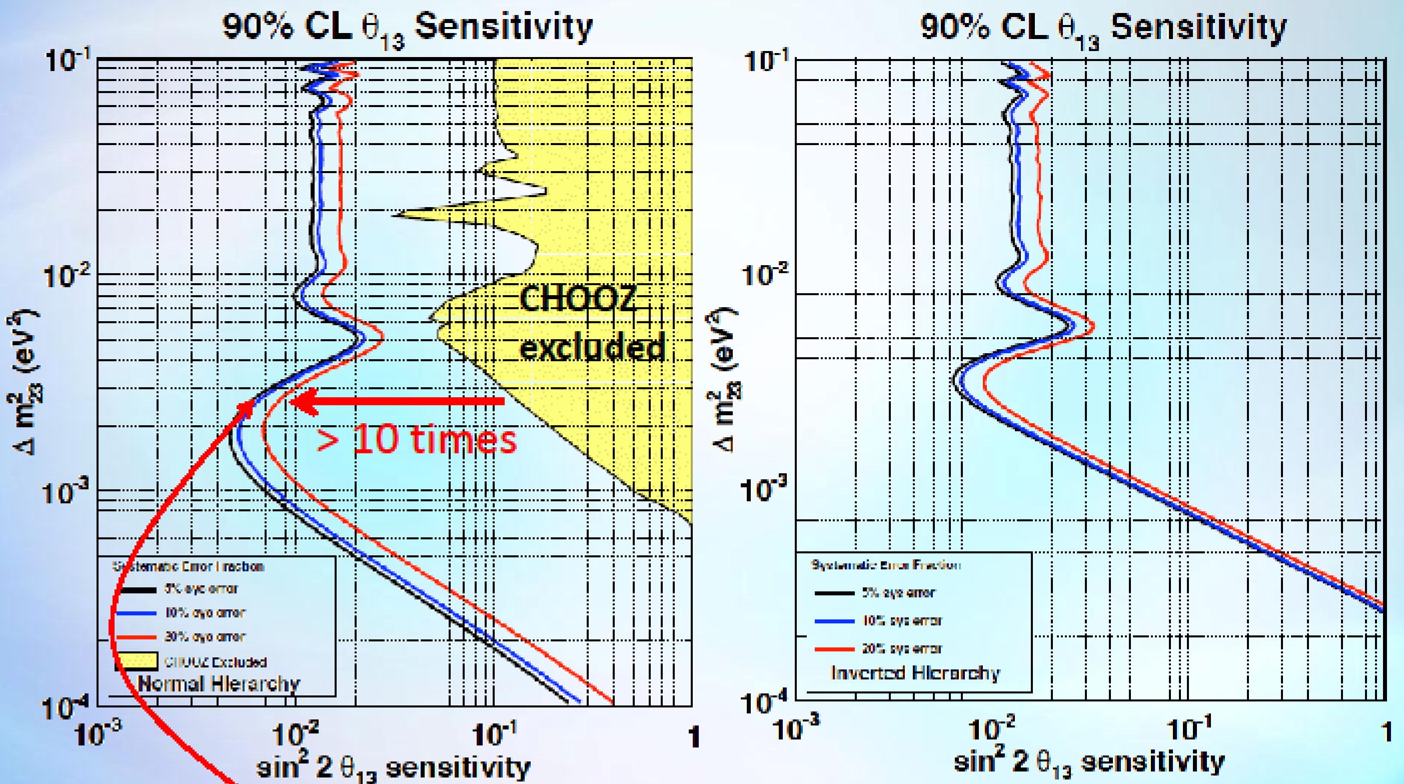
Parameters	ν_μ CC Bkg	ν_μ NC Bkg	Beam ν_e Bkg	ν_e Signal
Δm_{13}^2=2.4e10^{-3}, $\sin^2 2\theta_{13}$=0.1	0.4	9.7	15	143

26

T2K sensitivity to θ_{13}

30 GeV, 8.3×10^{21} POT

$\delta_{CP} = 0$

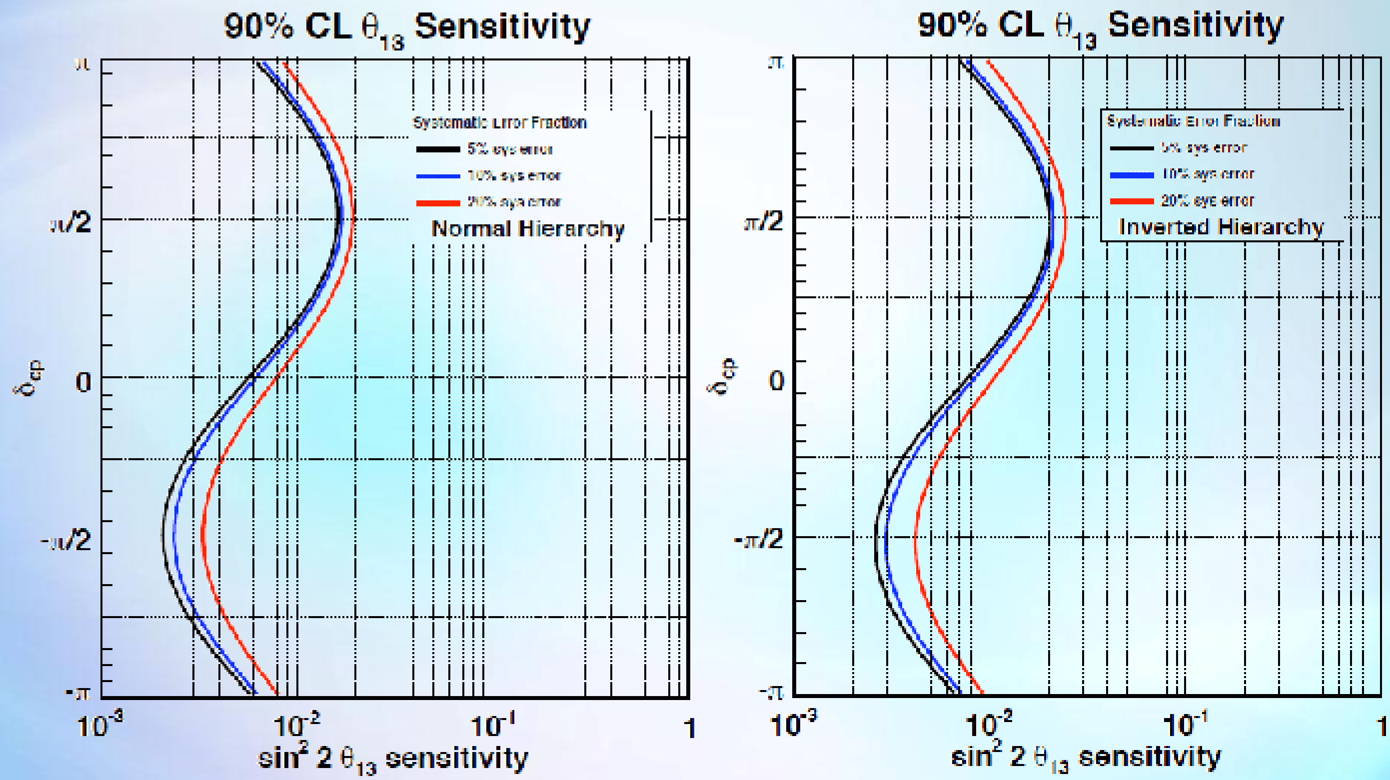


0.0060 @ $\Delta m_{23}^2 = 2.4 \times 10^{-3}$ eV^2
(for a 10% sys. error)

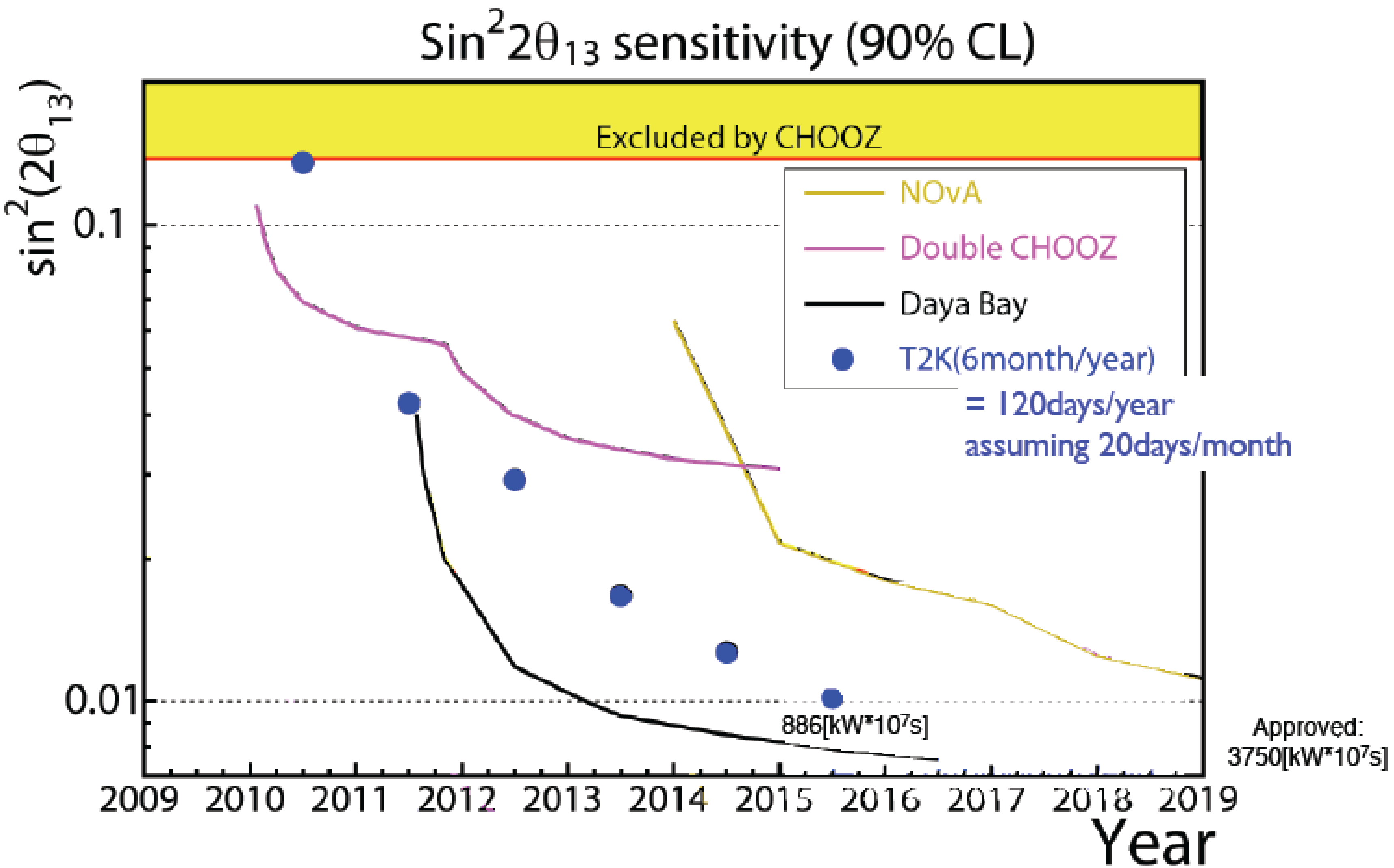
T2K sensitivity to θ_{13}

30 GeV, 8.3×10^{21} POT

$\Delta m_{23}^2 = 2.4 \times 10^{-3}\ eV^2$



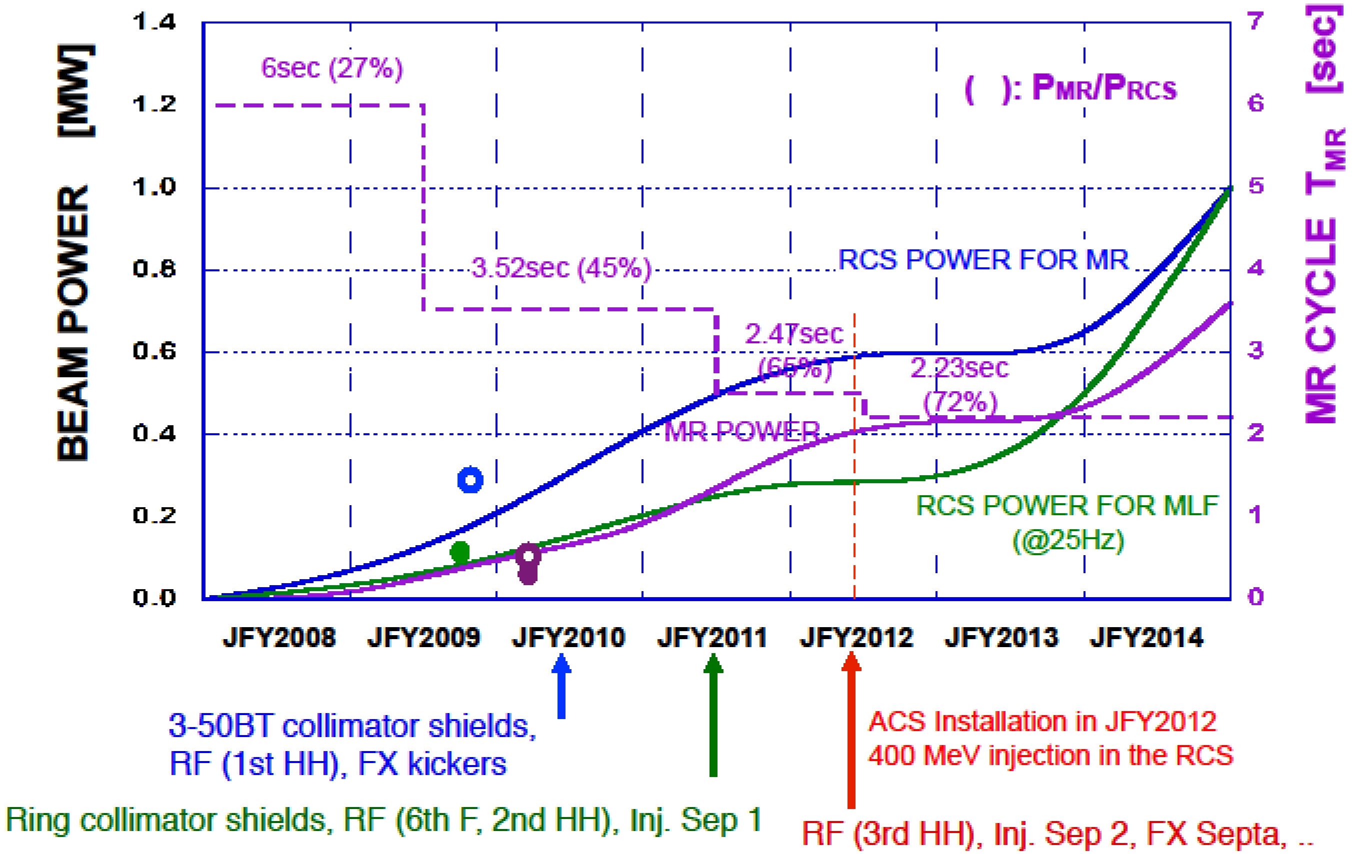
International competition



Request beam time of more than 10^7 sec(=~120days) per year in order to keep leading international competition

Power upgrade plan of RCS and MR(FX)

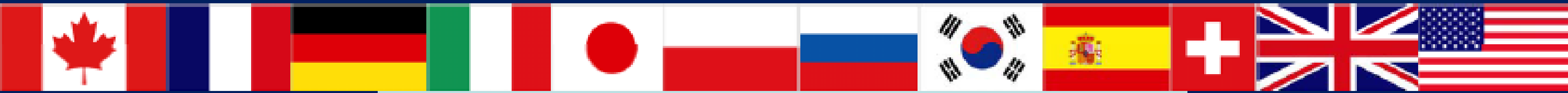
For 8 bunches, 30 GeV at MR: $P_{MR}=1.6 \times (P_{RCS}/ T_{MR})$



Systematic errors goals

- –Neutrino flux:< 5%
- –Energy spectrum width : < 10%
- –Non-QE/QE:< 5–10%
- –NC-1π0, beam-ve:< 10%
- –SK energy scale:< 2%

The T2K Collaboration



~500 members, 62 institutes, 12 countries

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U. B. Columbia
U. Regina
U. Toronto
U. Victoria
York U.

France
CEA Saclay
IPN Lyon
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LPNHE Paris

Germany
U. Aachen

Italy
INFN, U. Roma
INFN, U. Napoli
INFN, U. Padova
INFN, U. Bari

Japan
Hiroshima U.
ICRR Kamioka
ICRR RCCN
KEK
Kobe U.
Kyoto U.
Miyagi U. Edu.
Osaka City U.
U. Tokyo

Poland
A. Soltan, Warsaw
H.Niewodniczanski, Cracow
T. U. Warsaw
U. Silesia, Katowice
U. Warsaw
U. Wroklaw

Russia
INR

S. Korea
N. U. Chonnam
U. Dongshin
U. Sejong
N. U. Seoul
U. Sungkyunkwan

Spain
IFIC, Valencia
U. A. Barcelona

Switzerland
U. Bern
U. Geneva
ETH Zurich

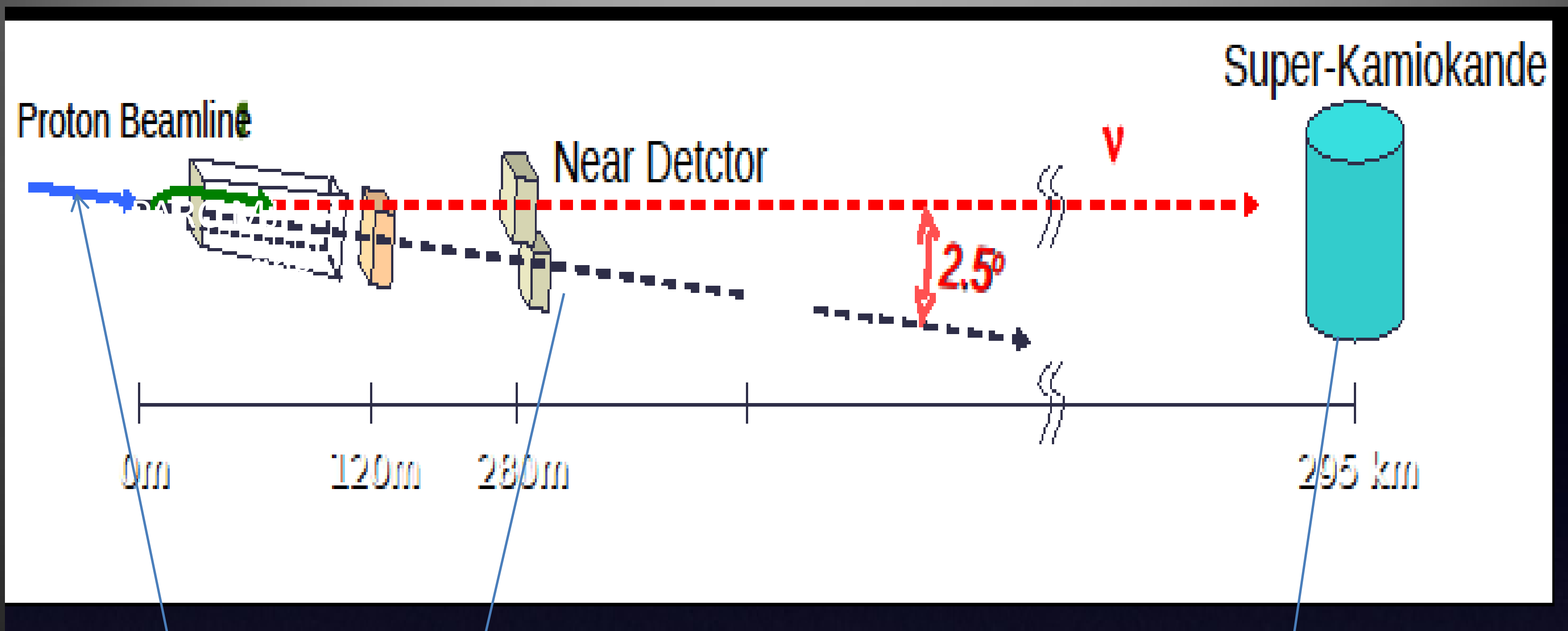
United Kingdom
Imperial C. London
Queen Mary U. L.
Lancaster U.
Liverpool U.
Oxford U.
Sheffield U.
Warwick U.
STFC/RAL
STFC/Daresbury

USA
Boston U.
B.N.L.
Colorado S. U.
Duke U.
Louisiana S. U.
Stony Brook U.
U. C. Irvine
U. Colorado
U. Pittsburgh
U. Rochester
U. Washington

End

- Many collaborators contributed slides to this talk
- Thank you/Merci/спасибо

T2K experiment



J-PARC complex at Tokai

Kamioka mine(W-Japan)

Neutrino mixing