

# Первый осцилляционный результат эксперимента T2K

А.О. Измайлов

ИЯИ РАН

(от имени коллаборации T2K)

4 июля 2011

# Параметры осцилляций и PMNS матрица

## Слабые состояния

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos\theta_{23} & \sin\theta_{23} \\ 0 & -\sin\theta_{23} & \cos\theta_{23} \end{pmatrix} \begin{pmatrix} \cos\theta_{13} & 0 & \sin\theta_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -\sin\theta_{13}e^{i\delta} & 0 & \cos\theta_{13} \end{pmatrix} \begin{pmatrix} \cos\theta_{12} & \sin\theta_{12} & 0 \\ -\sin\theta_{12} & \cos\theta_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

SK, K2K, MINOS

CHOOZ, MINOS

Solar, KamLand

$$7.38 \times 10^{-5} \text{ eV}^2 < \Delta m_{12}^2 < 7.80 \times 10^{-5} \text{ eV}^2$$

$$0.84 < \sin^2 2\theta_{12} < 0.89$$

$$0 < \sin^2 2\theta_{13} < 0.15$$

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

$$2.3 \times 10^{-3} \text{ eV}^2 < \Delta m_{23}^2 < 2.56 \times 10^{-3} \text{ eV}^2$$

$$0.92 < \sin^2 2\theta_{23} < 1.0$$

$$\Delta m_{12}^2 + \Delta m_{23}^2 + \Delta m_{31}^2 = 0$$

$\theta_{13} - ?$

$\delta_{CP} - ?$

$$\Delta m_{12}^2, \Delta m_{23}^2 \neq \Delta m_{31}^2$$

Inverted or normal mass hierarchy?

# Основные цели T2K

## Фаза I

- Поиск осцилляций  $\nu_\mu \rightarrow \nu_e$ , чувствительность  $\sin^2 2\theta_{13} \approx 0.01$

$$P_{\nu_\mu \rightarrow \nu_e} \approx \sin^2(\theta_{23}) \sin^2(2\theta_{13}) \sin^2\left(1.27 \frac{\Delta m_{31}^2 L}{E}\right)$$

- Измерение параметров осцилляций нейтрино  $\sin^2 2\theta_{23}$  и  $\Delta m_{23}^2$  в процессе  $\nu_\mu \rightarrow \nu_\mu$  с высокой точностью и при большой статистике (~50 K2K)

$$P_{\nu_\mu \rightarrow \nu_\mu} \approx 1 - \sin^2(2\theta_{23}) \sin^2\left(1.27 \frac{\Delta m_{23}^2 L}{E}\right)$$

- Поиск переходов в стерильные  $\nu_{\text{sterile}}$

## Фаза II

### Работа с антинейтринным пучком

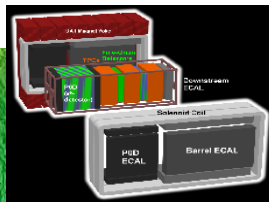
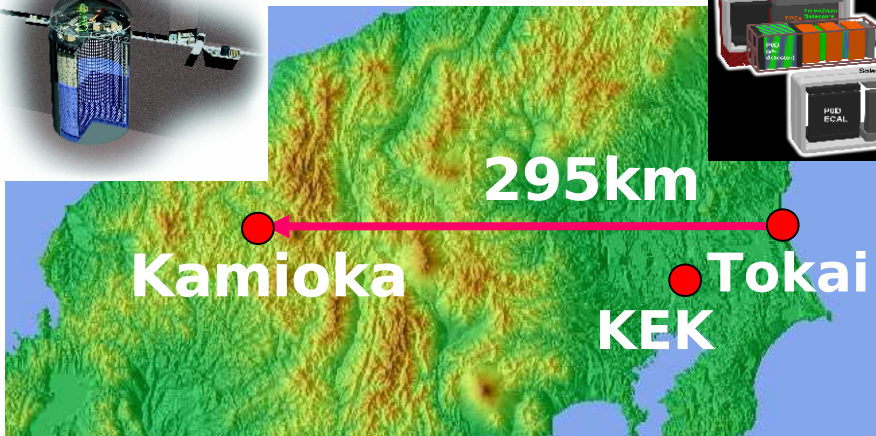
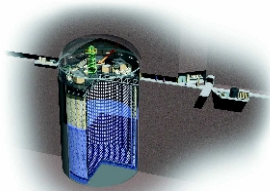
- Поиск CP-нарушения в лептонном секторе
- Определение иерархии масс массовых состояний нейтрино

# Коллаборация Т2К



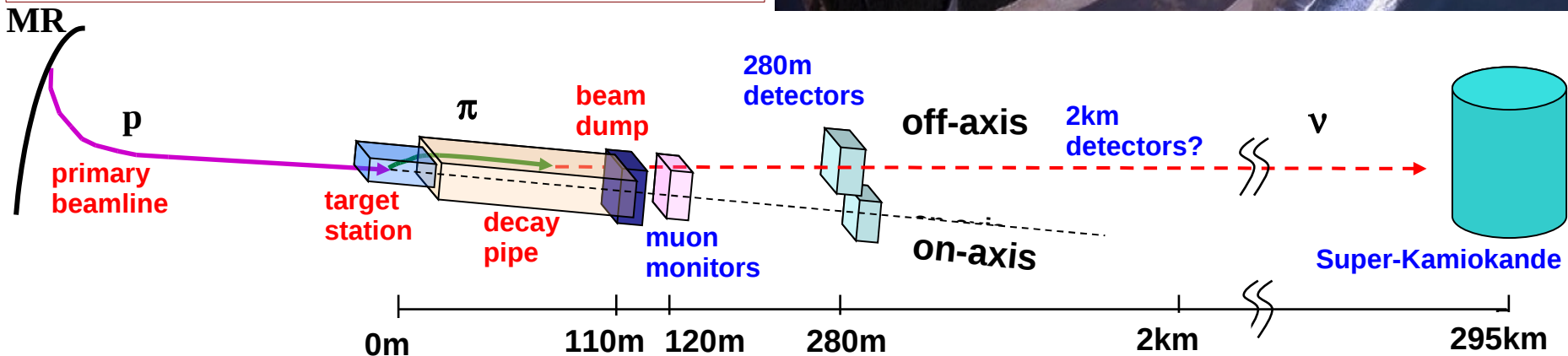
**~500 участников, 59 институтов, 12 стран**

# Эксперимент T2K (Tokai to Kamioka)

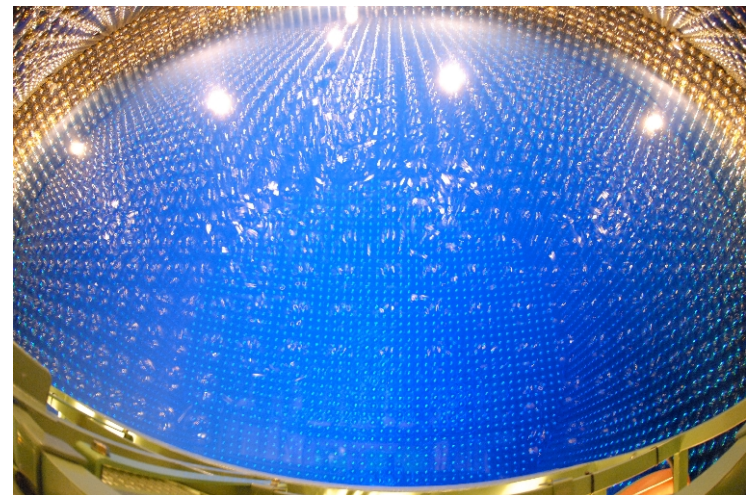
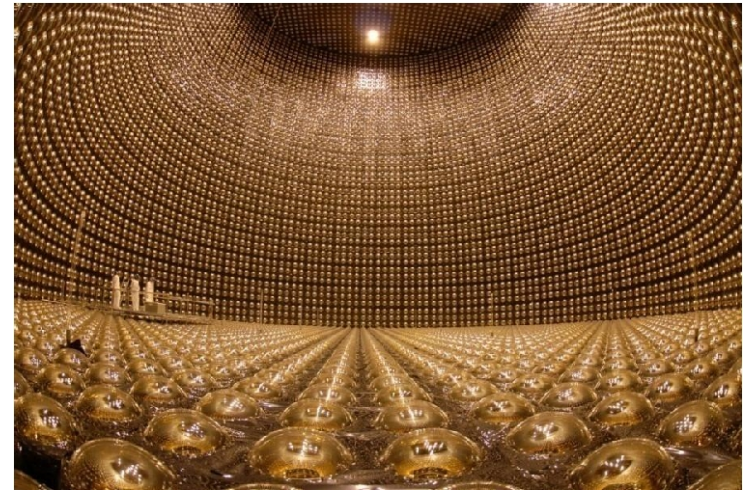
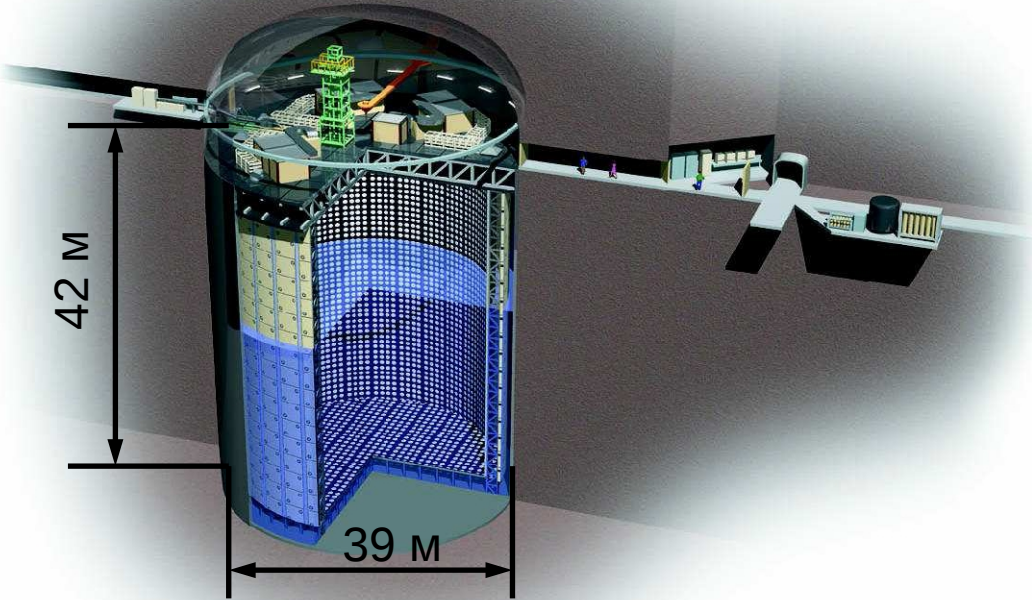


30 GeV JPARC PS intense proton beam used to create muon neutrino beam

Far detector - Super-Kamiokande



## Far detector Super-Kamiokande



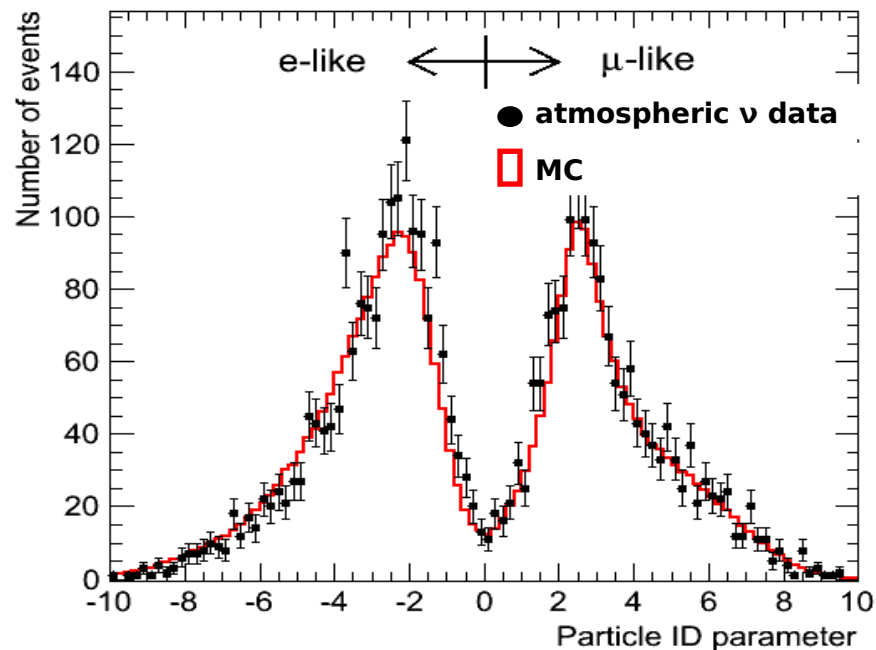
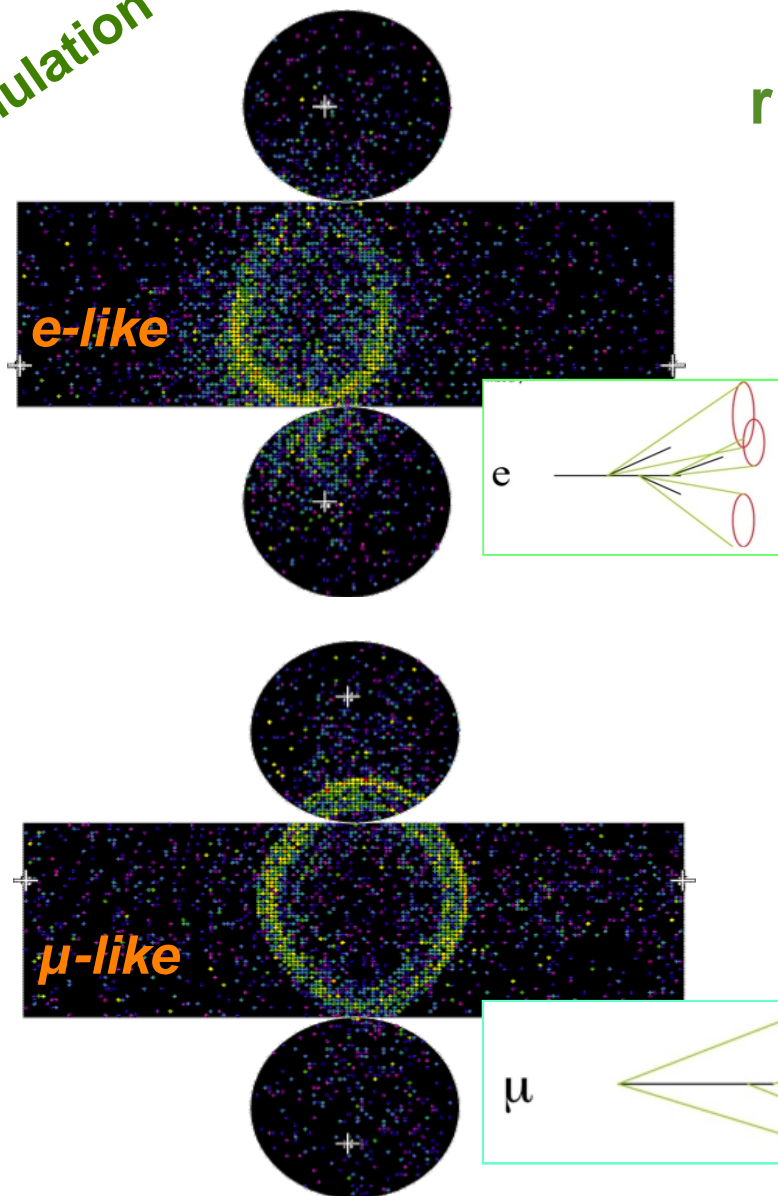
50kT (22.5 kT FV) water Cherenkov detector  
11146 20-inch PMTs (Inner Detector)  
Fully recovered since July 2006  
Dead-time less DAQ system (2008~)

Detector performance is well-matched at sub GeV  
**Excellent performance for single particle event**  
**Good e-like(shower ring) /  $\mu$ -like separation**

# Electron-like and muon-like events separation at SK

simulation

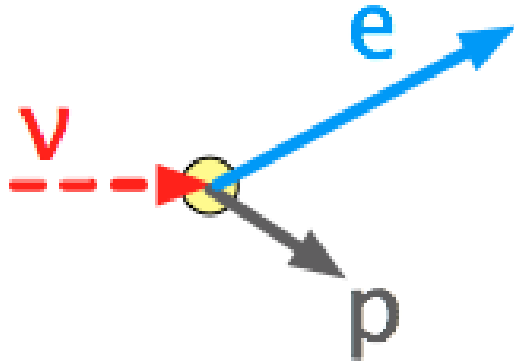
## Particle ID using ring shape & opening angle



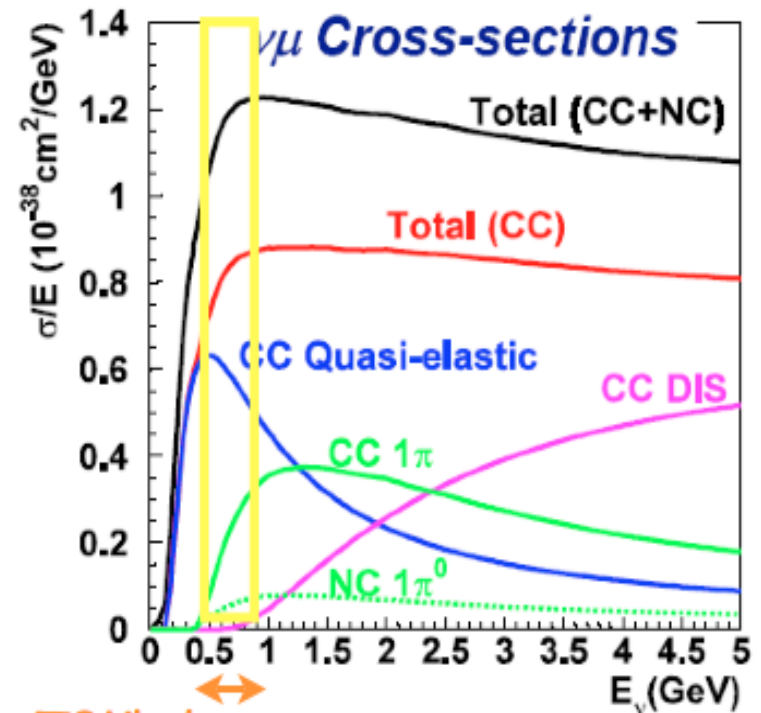
*Probability that  $\mu$  is mis-identified as electron is ~1%*

# Neutrino interactions in T2K

CCQE interactions dominant at T2K energy



T2K nu signal:  $\nu + n \rightarrow e(\mu) + p$



T2K's beam energy

High energy neutrino interactions cause background events in T2K  
(e.g. CC1pi for  $\nu_\mu$  disappearance, intrinsic  $\nu_e$  and NC1pi for  $\nu_e$  appearance )



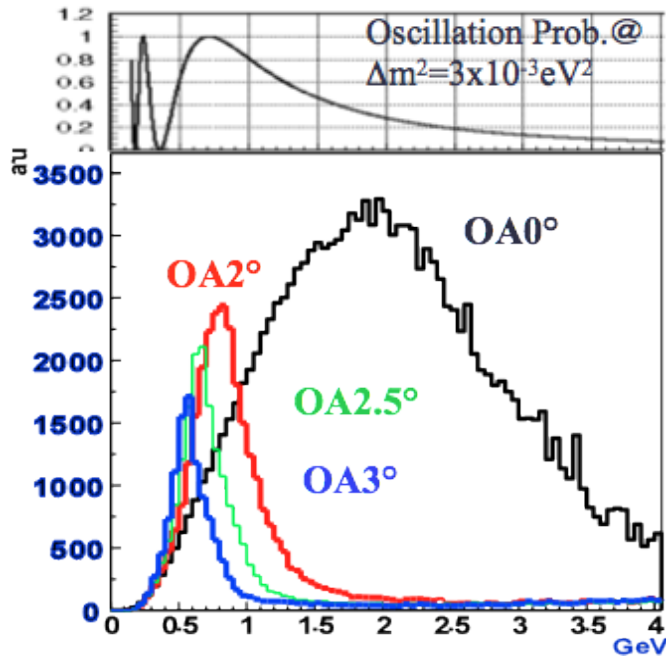
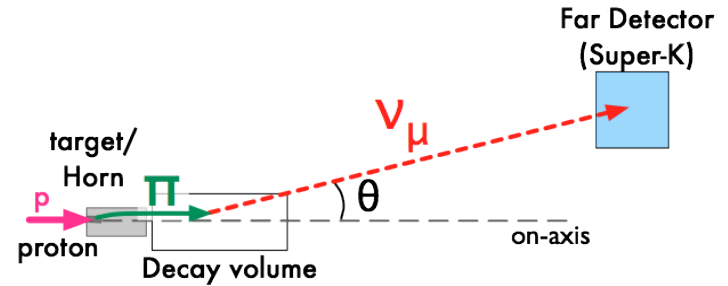
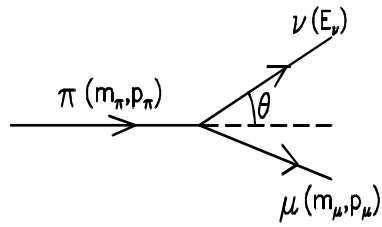
need to reduce high energy tail



off-axis conception



# T2K off-axis conception



Optimize beam energy for oscillation max  
 $E_\nu \sim 600 \text{ MeV}$

--> T2K utilizes  $2.5^\circ$  off-axis angle

--> small high energy tail

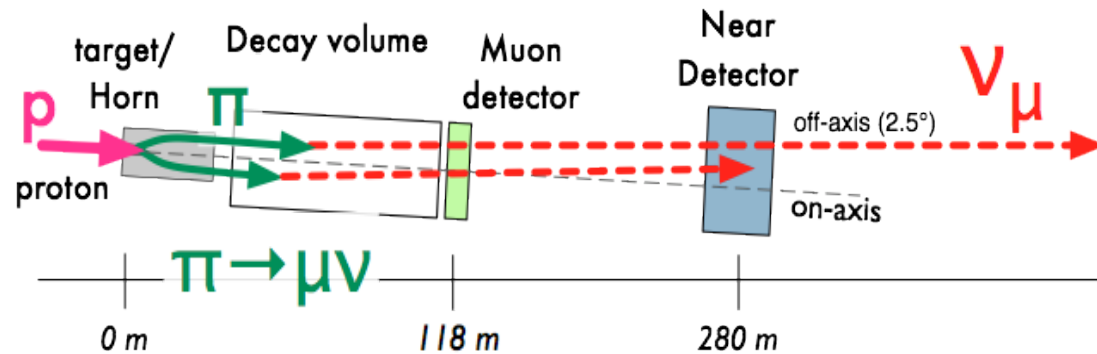
--> background reduction

Crucial to carefully monitor neutrino beam direction

--> keep peak energy stable



# “Pre-oscillation” beam monitoring



## Muon monitor

- spill-by-spill monitoring

## On-axis detector INGRID

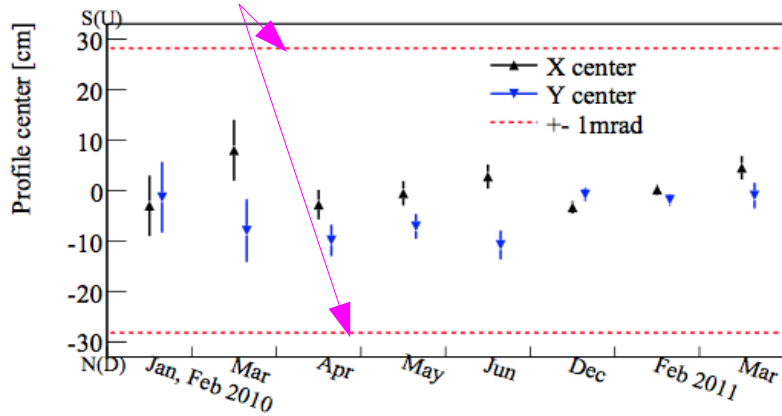
- actual nu beam day-by-day monitoring

## Off-axis detector

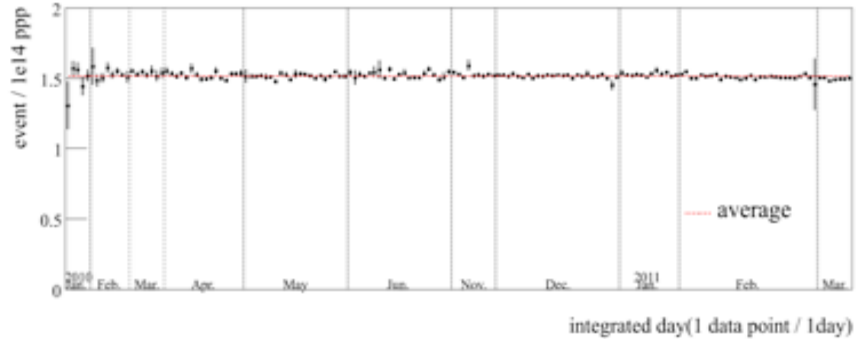
- nu energy spectrum
- nu<sub>e</sub> contamination
- nu cross-sections

# Neutrino beam stability

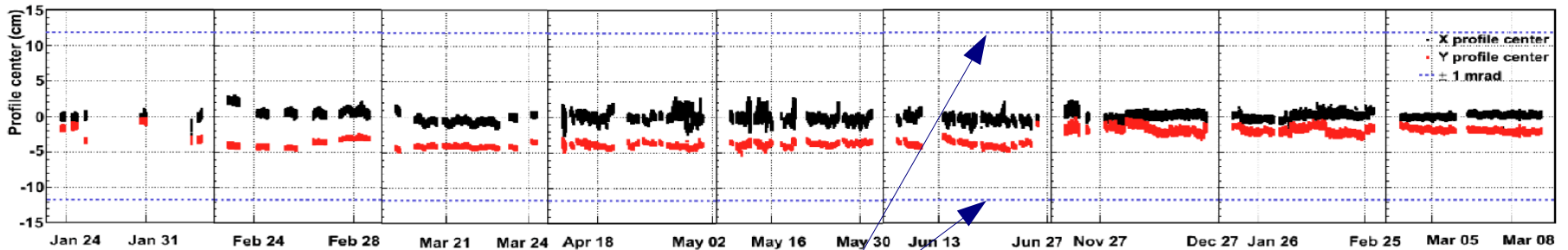
**< 1 mrad**



**INGRID beam direction stability**



**INGRID  $\nu$  int. rate stability**



**Muon-monitor beam direction stability < 1mrad** <sup>12</sup>

# ND280 Off-axis детектор

## UA1 CERN магнит

магнитное поле 0.2 Т вес около 900 т

## Детектор для изучения СС взаимодействий:

- **Fine Grained Detector (FGD)**
  - измерение потока нейтрино,  $E_\nu$  спектра, ароматного состава пучка с помощью СС взаимодействий
  - водная и сцинтилляционная мишени
- **Time Projection Chamber (TPC)**
  - определение импульса заряженных частиц
  - идентификация частиц путем измерения  $dE/dx$

## $\pi^0$ -детектор (P0D)

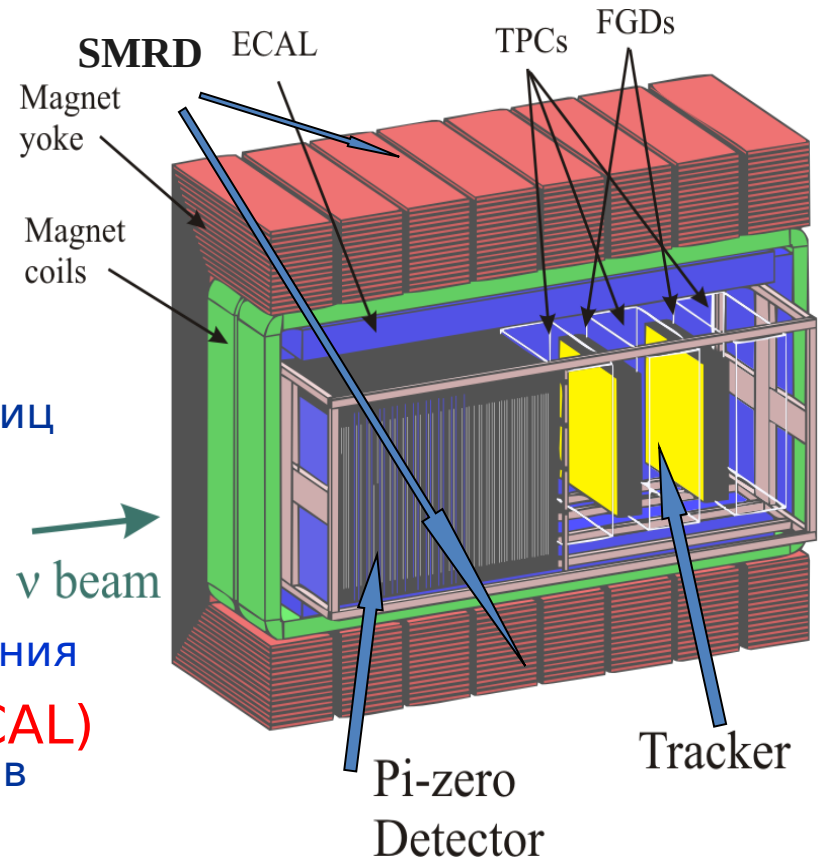
- изучение NC-  $\pi^0$  реакций
- использование воды для измерения сечения реакции на кислороде

## Электромагнитный калориметр (ECAL)

- Детектирование фотонов от  $\pi^0$  распадов в P0D, TPC и FGD
- восстановление треков и идентификация заряженных частиц

## Side Muon Range Detector (SMRD)

- измерение импульсов мюонов, вылетающих под большими углами
- триггер для калибровки космическими частицами внутренних детекторов
- вето-детектор



SMRD, INGRID, P0D & ECAL – utilizing Hamamatsu MPPC photosensors: ~ 64k channels

# Measurements in off-axis T2K ND280

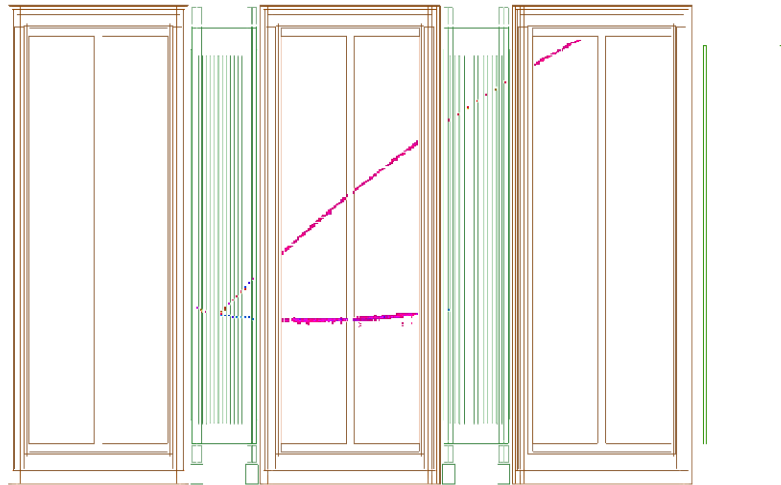
An impact for the present analysis  $\leftarrow$   $\nu\mu$  CC events rate measurement

Tracker system TPC+FGD

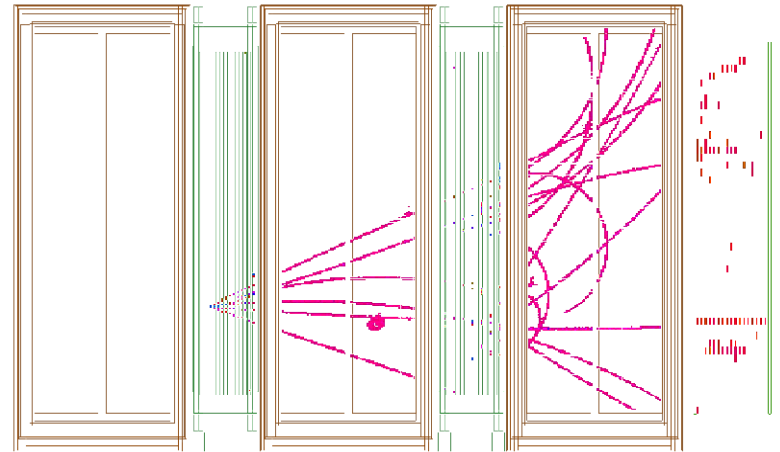
--  $< 10\%$  dEdX resolution

--  $10\%$  momentum resolution at  $1\text{GeV}/c$

Event number : 24083 | Partition : 63 | Run number : 4200 | Spill : 0 | SubRun number : 6 | Time : Sun 2010-03-21 22:33:25 JST | Trigger: Beam Spill

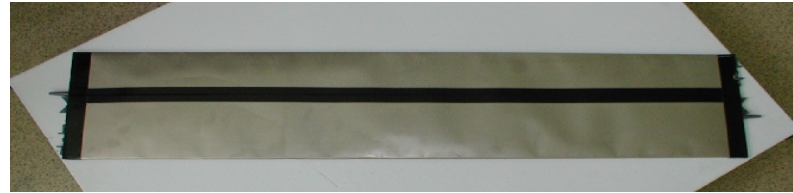
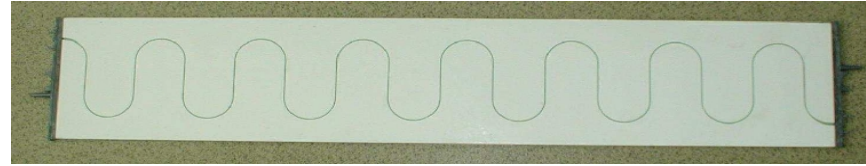
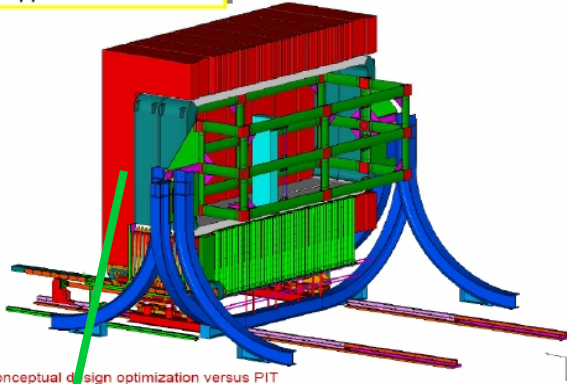


Event number : 110264 | Partition : 63 | Run number : 4200 | Spill : 0 | SubRun number : 25 | Time : Mon 2010-03-22 14:06:35 JST | Trigger: Beam Spill

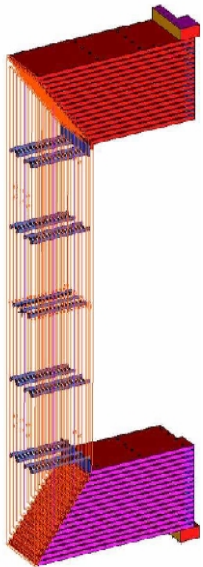


# Детектор мюонного пробега (SMRD)

MAGNET conceptual design:  
Basket support structure



Conceptual design optimization versus PIT



## Задачи и структура SMRD

- Регистрация CC-QE мюонов, вылетающих под большими углами к оси нейтринного пучка
- Идентификация фоновых событий
- Калибровка внутренних детекторов
- Воздушные прослойки UA1 магнита, оборудованные сцинтилляционными счетчиками

SMRD счетчики разработаны и созданы в ИЯИ РАН

- ~2200 индивидуальных сцинтилляционных счетчиков
- светосбор с двух торцов сцинтиллятора: Y11 (d=1мм) WLS оптоволоконно S-формы, Hamamatsu MPPC фотодетекторы
- суммарный световыход 25-50 р.е./MIP (~1.5 МэВ) для центра счетчика T=20-22 С
- эффективность регистрации MIP >99.9%
- $\sigma_x < 10$  см;  $\sigma_t \sim 1$  нс

# Изготовление SMRD счетчиков в ИЯИ РАН

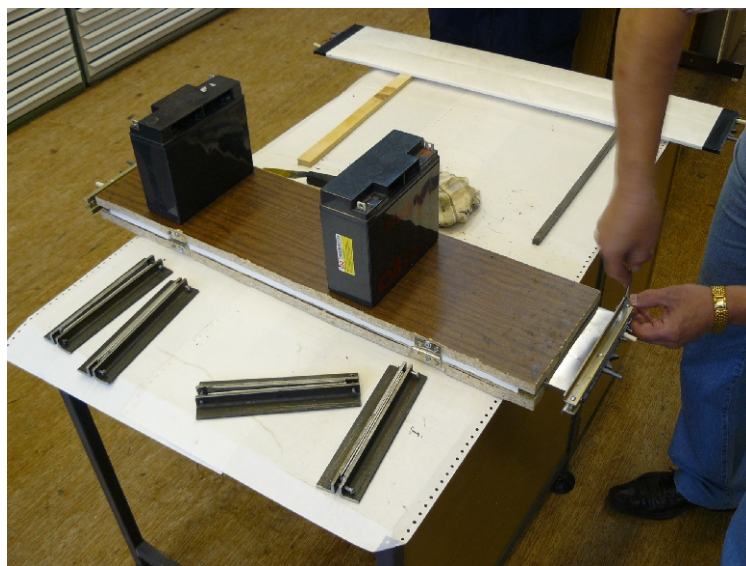
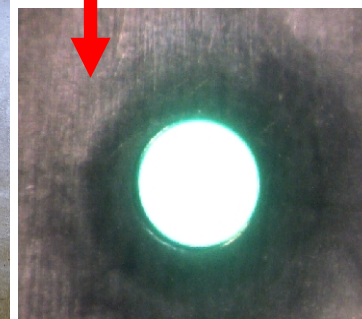
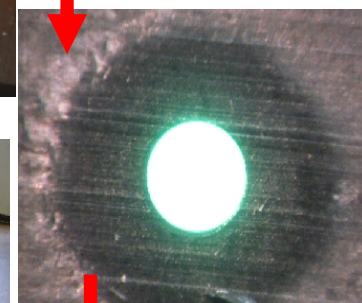
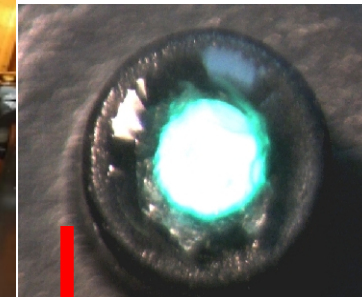
Обработка сцинтилляционных пластин



Нарезание канавки S-формы



Полировка WLS  
оптоволокон



Вклеивание оптоволокон и боковых панелей



Подготовка контейнеров из нержавеющей стали



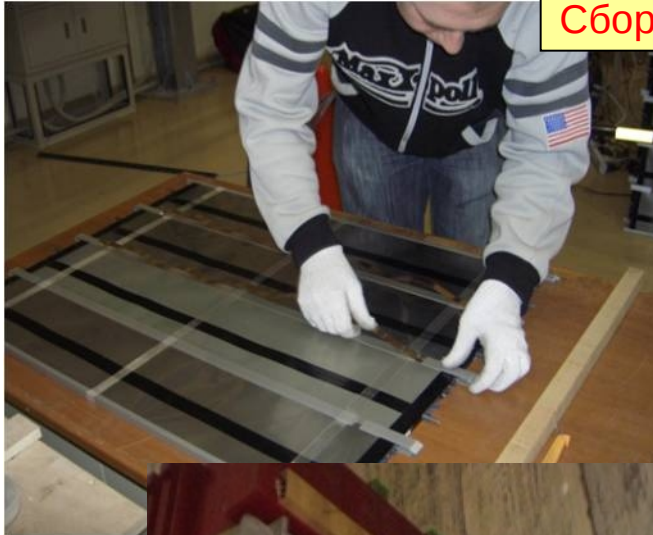
# Готовые SMRD счетчики в ИЯИ РАН перед отправкой в J-PARC

Все ~2200 счетчика созданы и протестированы в ИЯИ РАН и отправлены в J-PARC двумя партиями: в сентябре 2008 и марте 2009



# Установка SMRD модулей в магнит

Сборка индивидуальных счетчиков в модули



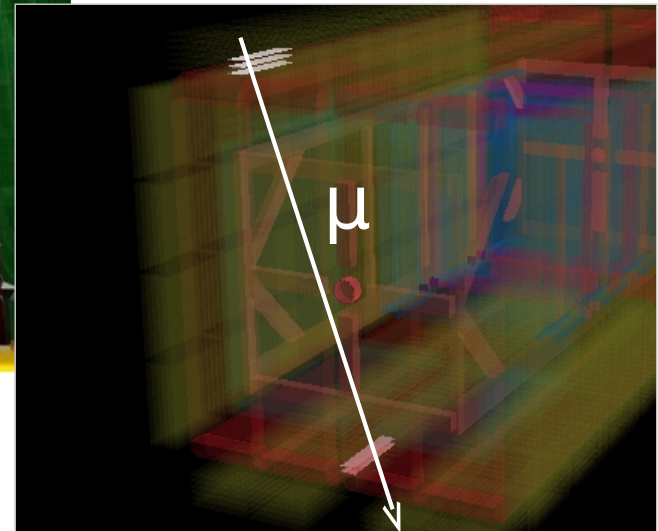
Работа по установке SMRD модулей в магнит

# SMRD детектор

Установка всех SMRD модулей в магнит завершена в июле 2009 года

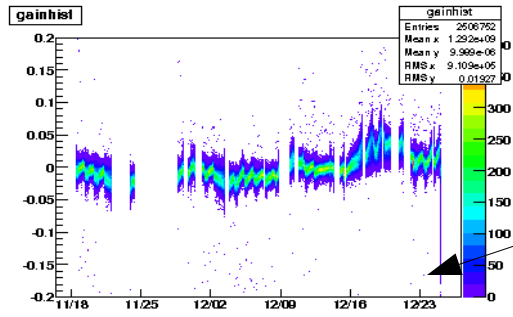


Событие от  
космического мюона,  
зарегистрированное в  
SMRD



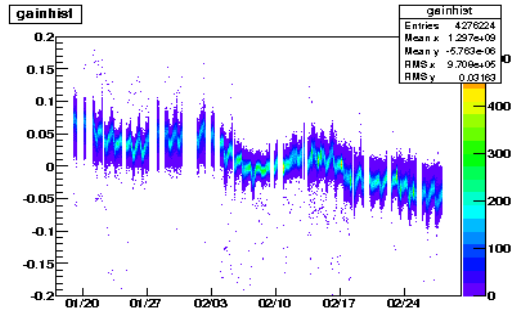
# SMRD детектор

- Калибровка детектора
- Мониторинг работы детектора
- Время-амплитудная (elx & fiber time-walk) для SMRD (также POD & ECal)

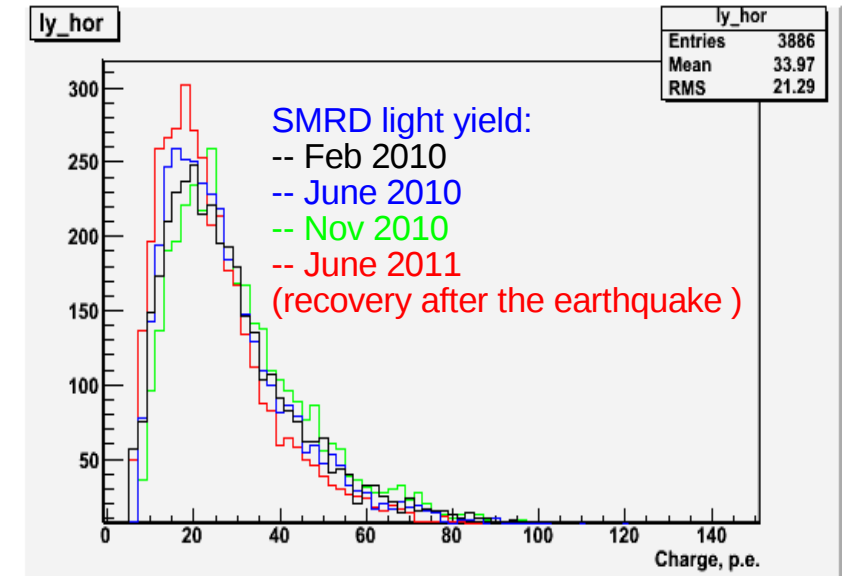
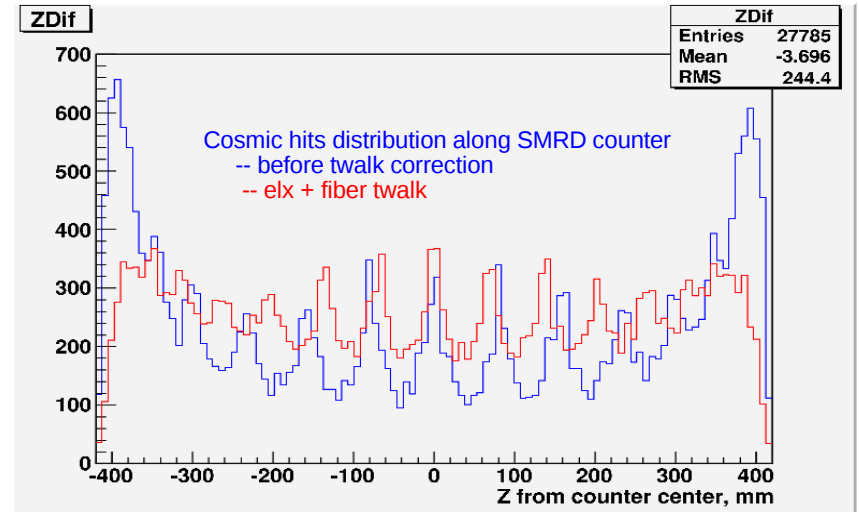
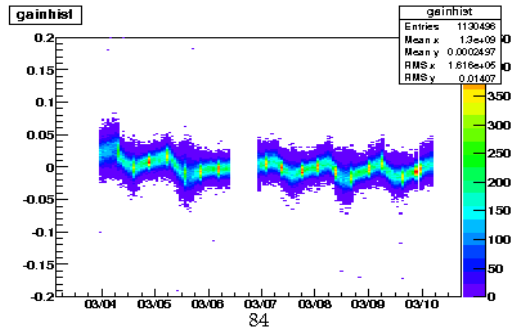


SMRD MPPC gain variations

2009-2011 Operations

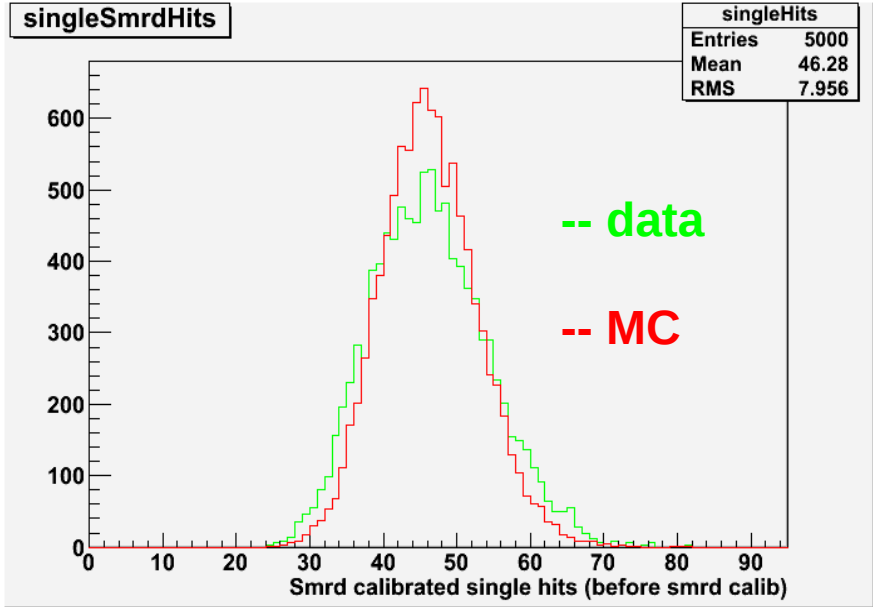
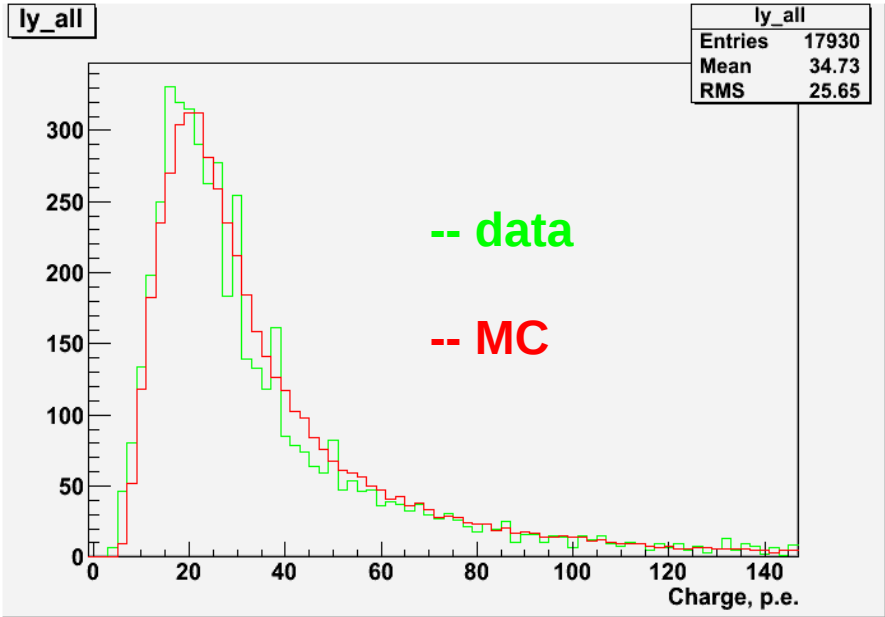


problems with 10 channels out of 4016



# SMRD MC tuning

Tune MC to match SMRD performance (cosmic data)



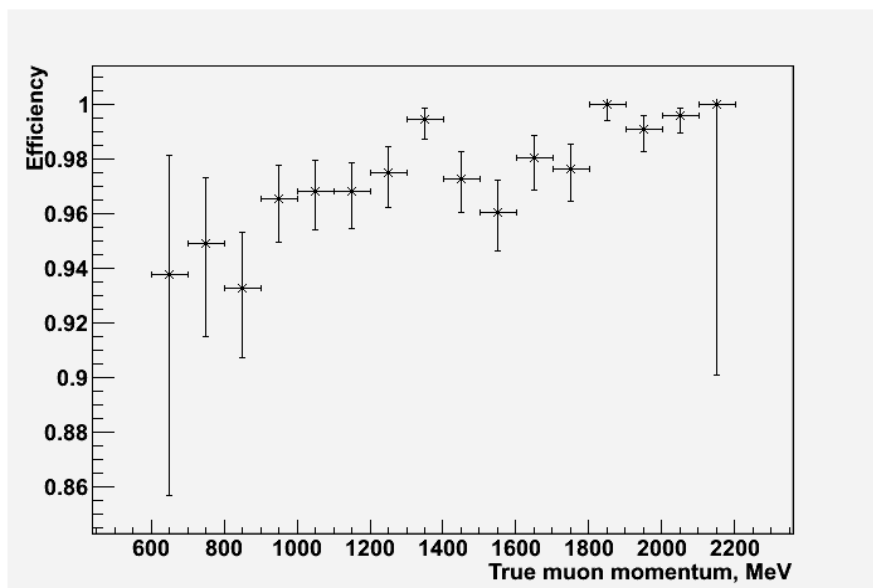
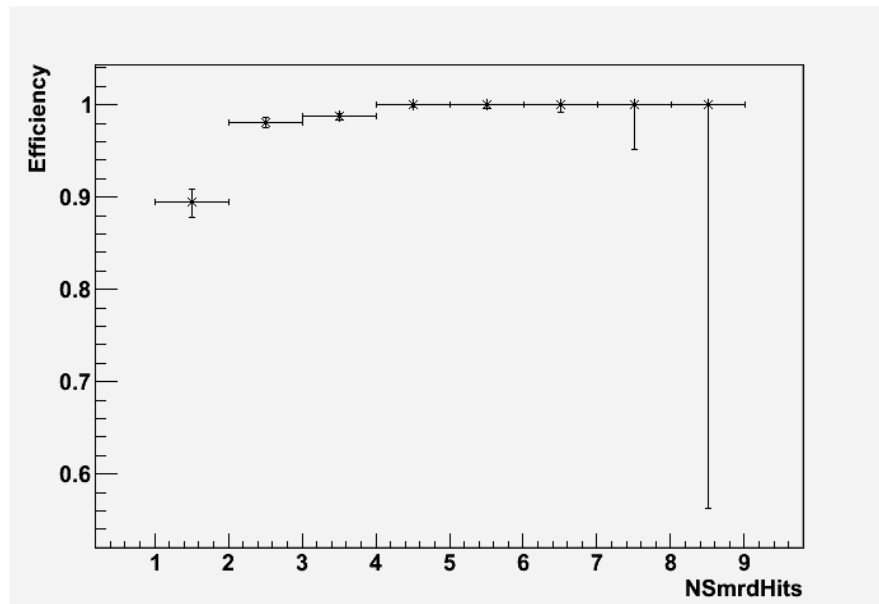
SMRD L.Y., single hits contributors from double-sided hits

SMRD all single hits (not double-sided)

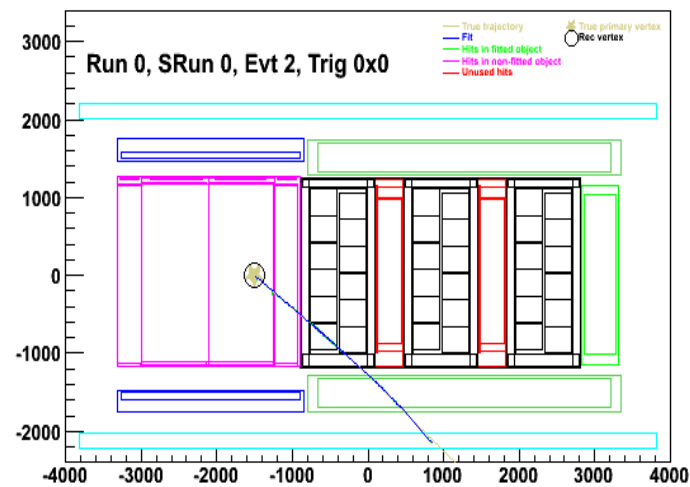
T=19-21 C

# Реконструкция событий в SMRD

- Сшивка SMRD событий с внутренними детекторами ND280 <-- Kalman Filter
- Возможность использования одиночных хитов в SMRD
- Высокая эффективность сшивки



YZ Projection



# FGD-(TPC)-SMRD tracks analysis

## Analysis of FGD-(TPC)-SMRD tracks:

### Goal:

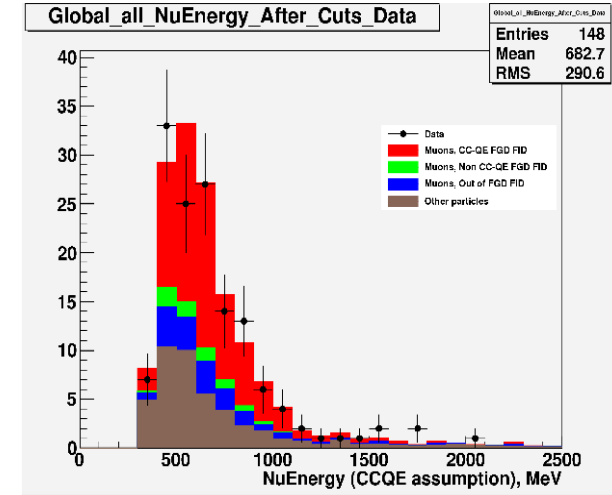
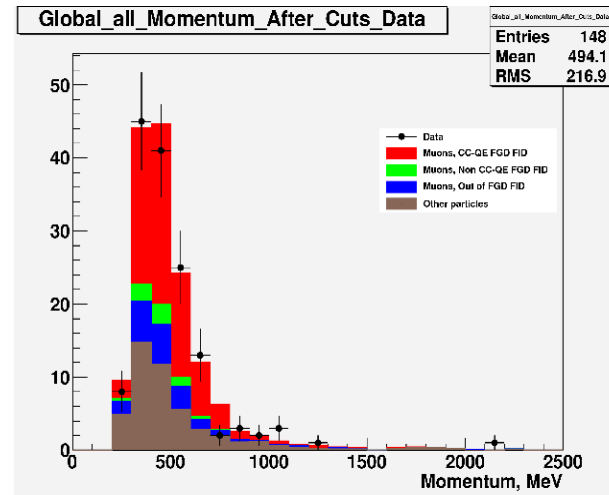
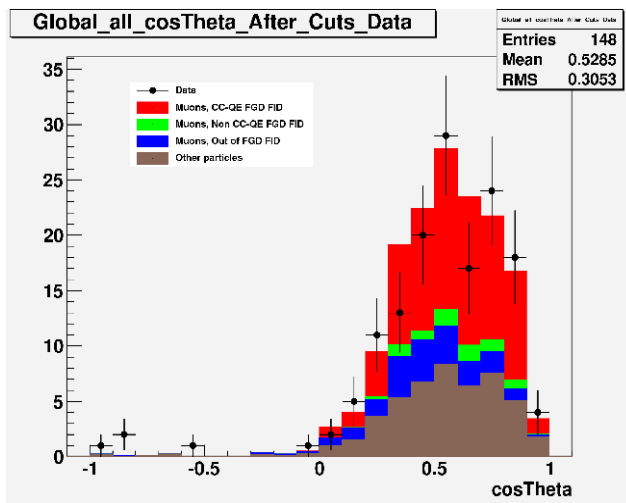
- recovery of high-angle muon tracks
  - FGD iso reconstruction efficiency still limits this --> future improvements expected
- independent estimation of muon/nu kinematic parameters (w/o TPC info)

### Method:

- SMRD constituent presence provides muon PID
- select:
  - FGD-SMRD tracks
  - FGD-TPC-SMRD tracks when TPC info is not reliable (too short TPC tracks)
- estimate muon momentum via energy loss calculation

### Current results for 2010a data ( $2.94 \times 10^{19}$ POT):

- improved reconstruction algorithm allows filtering even single SMRD hits
- able to reconstruct muon momentum with  $\sim 20\%$  sigma
- muon selection purity: 68%; CCQE selection purity: 52%
- total 148 events selected



Kinematic parameters

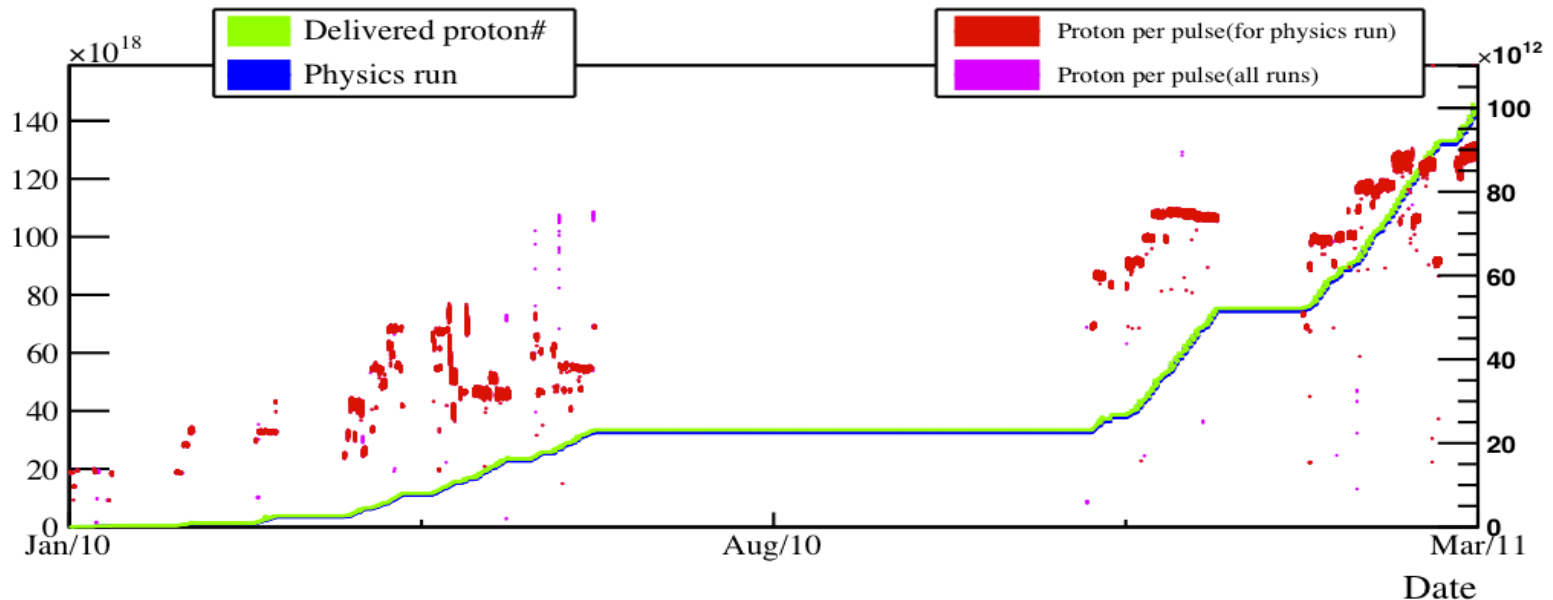
Поиск  $\nu_{\mu} \leftrightarrow \nu_e$  осцилляций



# Number of POT used in analysis

# of bunch : 6 → 8

rep. rate : 3.64s → 3.2s → 3.04s



## Run 1 (Jan. '10 - June '10)

- $3.23 \times 10^{19}$  p.o.t. for analysis
- 50kW stable beam operation

## Run 2 (Nov. '10 - Mar. '11)

- $11.08 \times 10^{19}$  p.o.t. for analysis
- ~145kW beam operation

Total # of protons used for this analysis is  $1.43 \times 10^{20}$  pot (2% of T2K goal)  
Stopped at Match 11 2011 because of Great Eastern Japan Earthquake

## Nu\_mu--> Nu\_e oscillations analysis

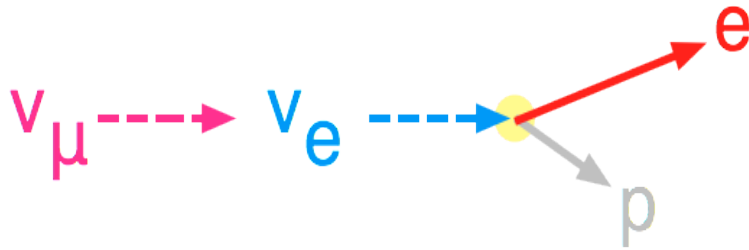
1. Apply SK Nu\_e selection cuts for events in far detector

Cuts established and fixed for initial data taking conditions (using MC samples) prior to data analysis to avoid any bias

2. Compare the observed events number with the expectation for  $\sin^2 2\theta_{13} = 0$  to search for Nu\_e appearance

# Background signals for Nu\_e appearance search

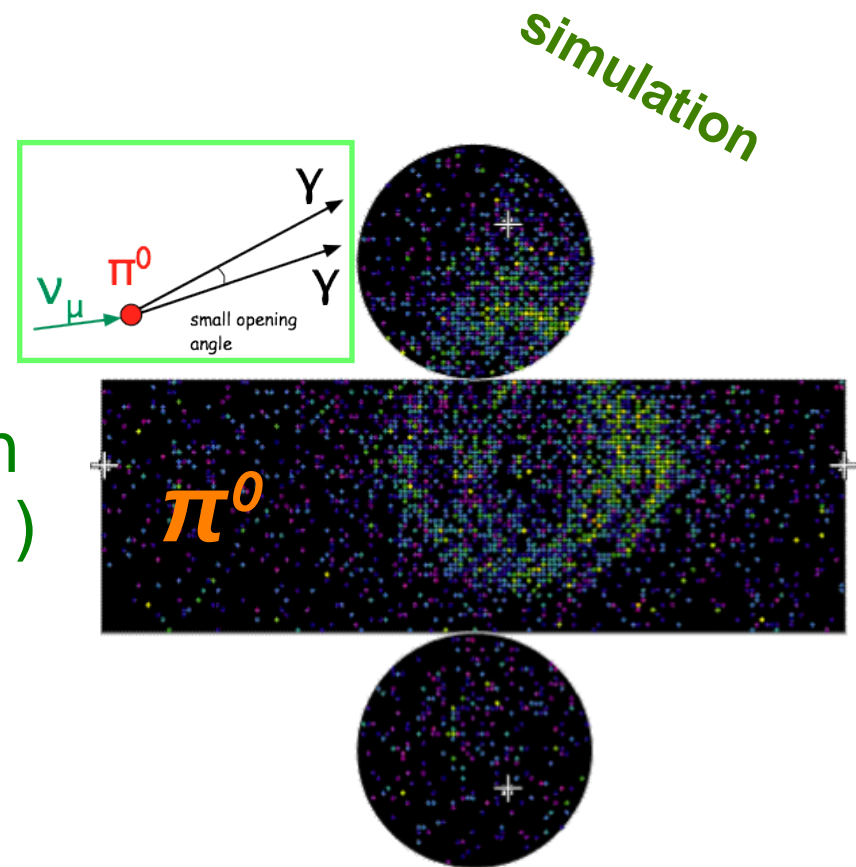
Signal: single CCQE electron event



Background:

-- Nu\_e contamination  
in the primary Nu\_mu beam  
(from muon & kaon decays )

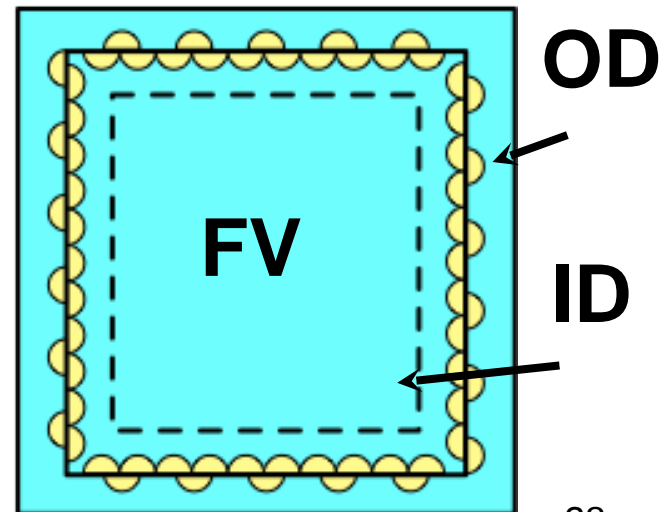
-- pi-0 from NC interactions



# Super-Kamiokande Nu<sub>e</sub> events selection cuts

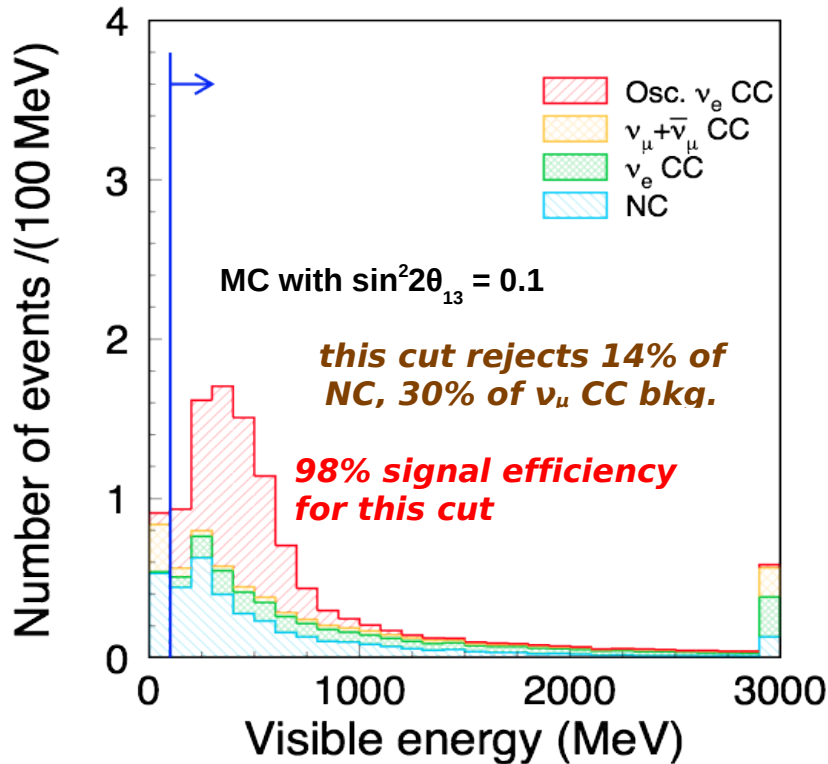
## 7 Nu<sub>e</sub> selection cuts

1. T2K beam timing & Fully contained (FC) events  
(synchronized with the T2K beam timing, no activities in the OD --> clusters with >15 PMT)
2. In fiducial volume (FV)  
(distance between recon. vertex and wall > 200 cm)
  - \* Poor vertex reconstruction accuracy for events too close to the ID walls
  - \* Events from outside the ID rejection
  - \* Total 22.5kton FV
3. Single electron  
Exactly one Cherenkov ring  
Ring is e-like



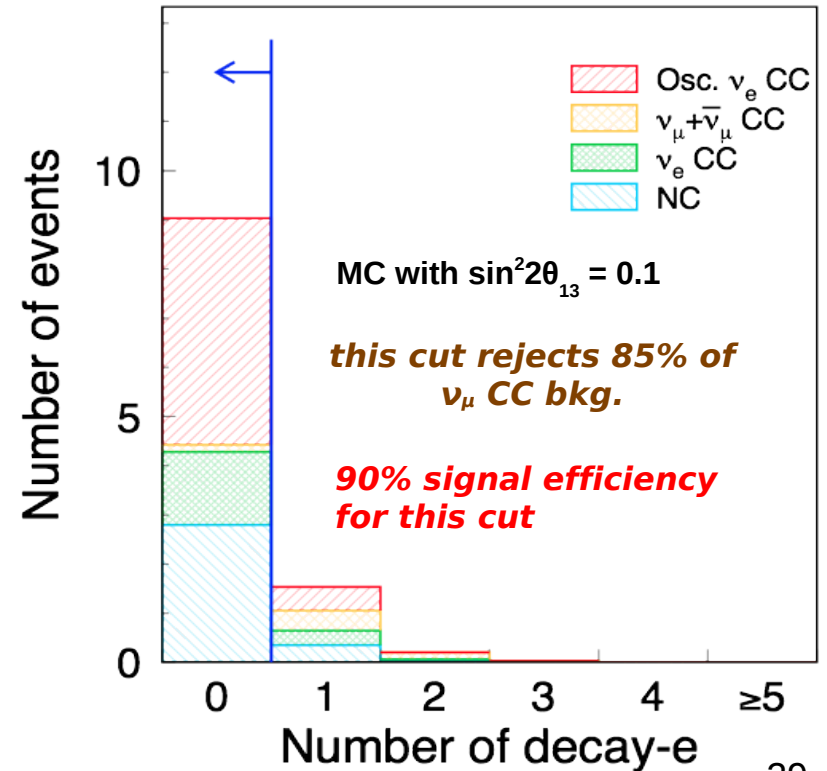
#### 4. Energy deposited in ID (visible energy) > 100 MeV

- \* Reject low energy events:  
NC events and decay electrons  
from invisible muons



#### 5. No decay electrons (no delayed electron signal)

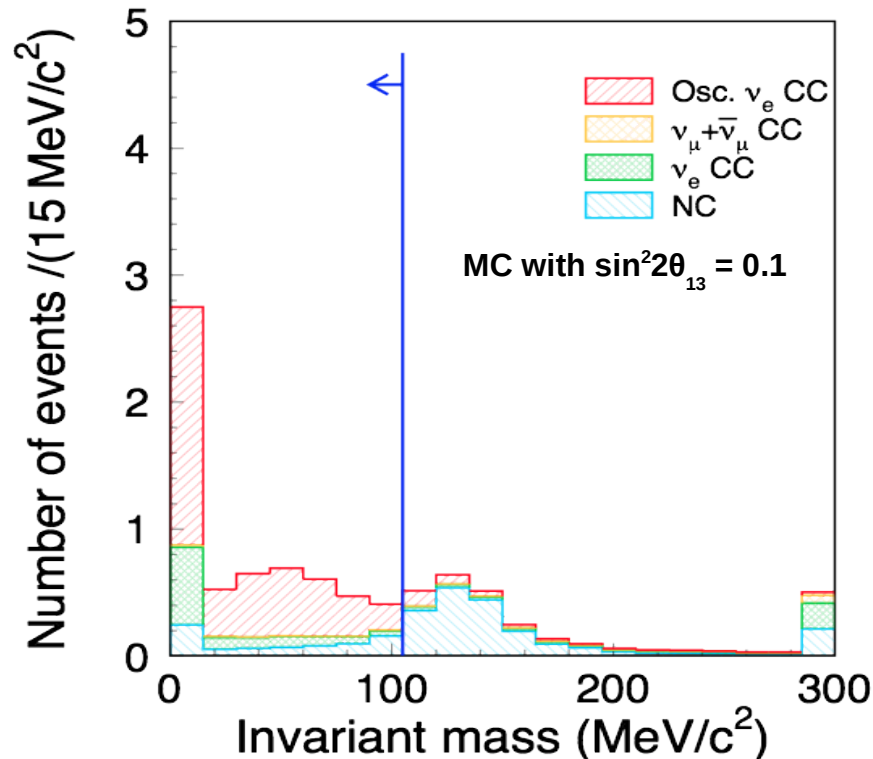
- \* Reject events with muons or pions which are invisible or mis-identified as electron ( $\nu_\mu$  events or CC non-QE events)



## 6. Reconstructed invariant mass < 105 MeV

### \* Suppress NC $\pi^0$ background

*Find 2nd e-like ring by forcing to fit light pattern under the 2 e-like rings assumption, and then reconstruct invariant mass of these 2 e-like rings*

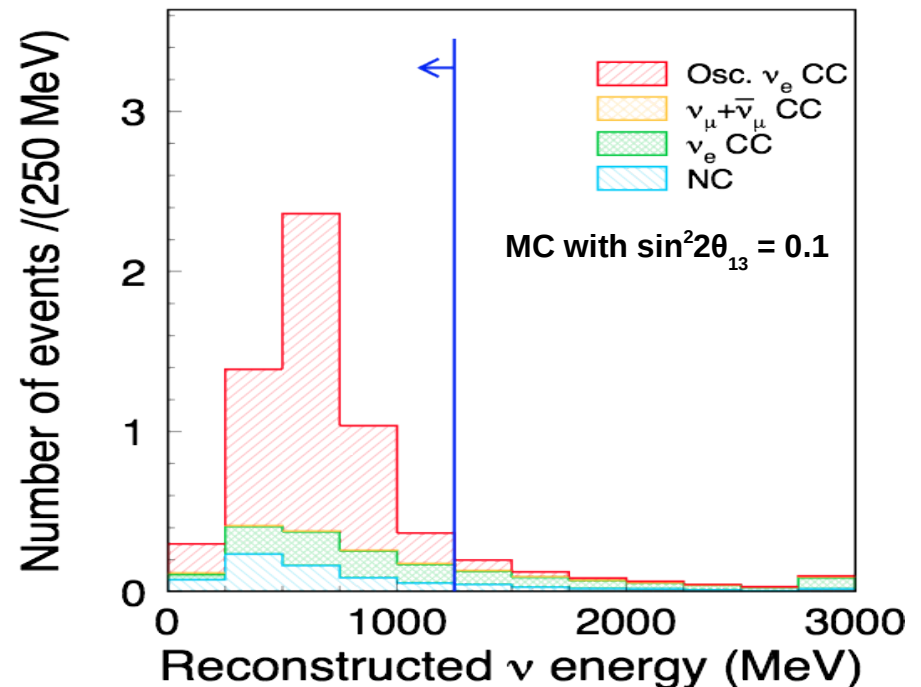


## 7. Reconstructed $\nu_e$ energy < 1250 MeV

### \* Reject intrinsic beam $\nu_e$

**backgrounds at high energy**

\* Signal ( $\nu_\mu \rightarrow \nu_e$ ) has a sharp peak at  $E \sim 600$  MeV



**After all the selection criteria**  
**background rejection :**  
**77 % for beam  $\nu_e$ ,**  
**99 % for NC**  
**signal efficiency : 66 %**  
**for the number of events in FV**

# Expected events Nu\_e number at Super-K

$$N_{SK}^{exp} = R_{ND}^{\mu, Data} \times \frac{N_{SK}^{MC}}{R_{ND}^{\mu, MC}} \frac{\int \Phi_{\nu_{\mu}(\nu_e)}^{SK}(E_{\nu}) \cdot P_{osc.}(E_{\nu}) \cdot \sigma(E_{\nu}) \cdot \epsilon_{SK}(E_{\nu}) dE_{\nu}}{\int \Phi_{\nu_{\mu}}^{ND}(E_{\nu}) \cdot \sigma(E_{\nu}) \cdot \epsilon_{ND}(E_{\nu}) dE_{\nu}} \frac{M^{SK}}{M^{ND}} \cdot POT^{SK}$$

(flux) x (osc. prob.) x (x-section) x (efficiency) x (det. mass)

## Signal Nu\_e events

$$\frac{N_{SK \nu_e sig.}^{MC}}{R_{ND}^{\mu, MC}} = \frac{\int \Phi_{\nu_{\mu}}^{SK}(E_{\nu}) \cdot P_{\nu_{\mu} \rightarrow \nu_e}(E_{\nu}) \cdot \sigma(E_{\nu}) \cdot \epsilon_{SK}(E_{\nu}) dE_{\nu}}{\int \Phi_{\nu_{\mu}}^{ND}(E_{\nu}) \cdot \sigma(E_{\nu}) \cdot \epsilon_{ND}(E_{\nu}) dE_{\nu}} \cdot \frac{M^{SK}}{M^{ND}} \cdot POT^{SK}$$

## Background from intrinsic Nu\_e contamination

Background from intrinsic Nu\_e events at Super-K is predicted using nu beam simulation based on NA61 measurements (pions) and FLUKA simulation (kaons)

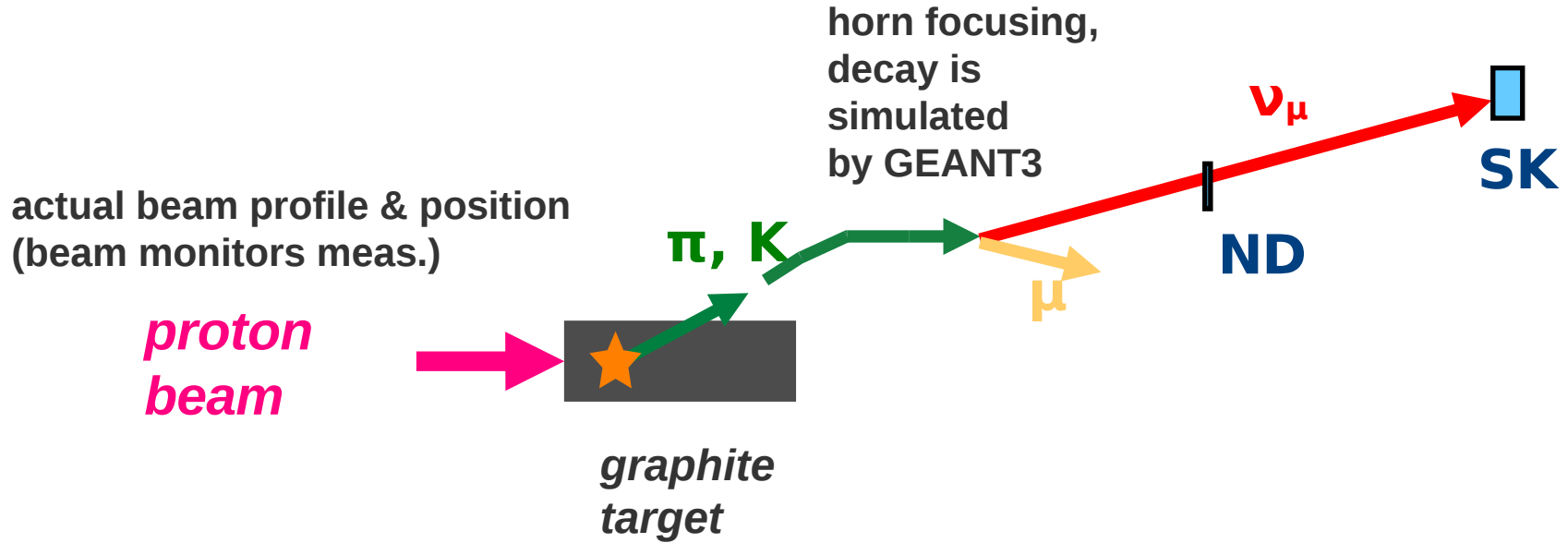
$$N_{SK beam \nu_e bkg.}^{exp} = R_{ND}^{\mu, Data} \times \frac{N_{SK beam \nu_e bkg.}^{MC}}{R_{ND}^{\mu, MC}} \frac{N_{SK beam \nu_e bkg.}^{MC}}{R_{ND}^{\mu, MC}} = \frac{\int \Phi_{\nu_e}^{SK}(E_{\nu}) \cdot P_{\nu_e \rightarrow \nu_e}(E_{\nu}) \cdot \sigma(E_{\nu}) \cdot \epsilon_{SK}(E_{\nu}) dE_{\nu}}{\int \Phi_{\nu_{\mu}}^{ND}(E_{\nu}) \cdot \sigma(E_{\nu}) \cdot \epsilon_{ND}(E_{\nu}) dE_{\nu}} \cdot \frac{M^{SK}}{M^{ND}} \cdot POT^{SK}$$

## Background from pi0 from Nu\_mu NC interactions

$$N_{SK NC bkg.}^{exp} = R_{ND}^{\mu, Data} \times \frac{N_{SK NC bkg.}^{MC}}{R_{ND}^{\mu, MC}}$$



# Neutrino flux prediction

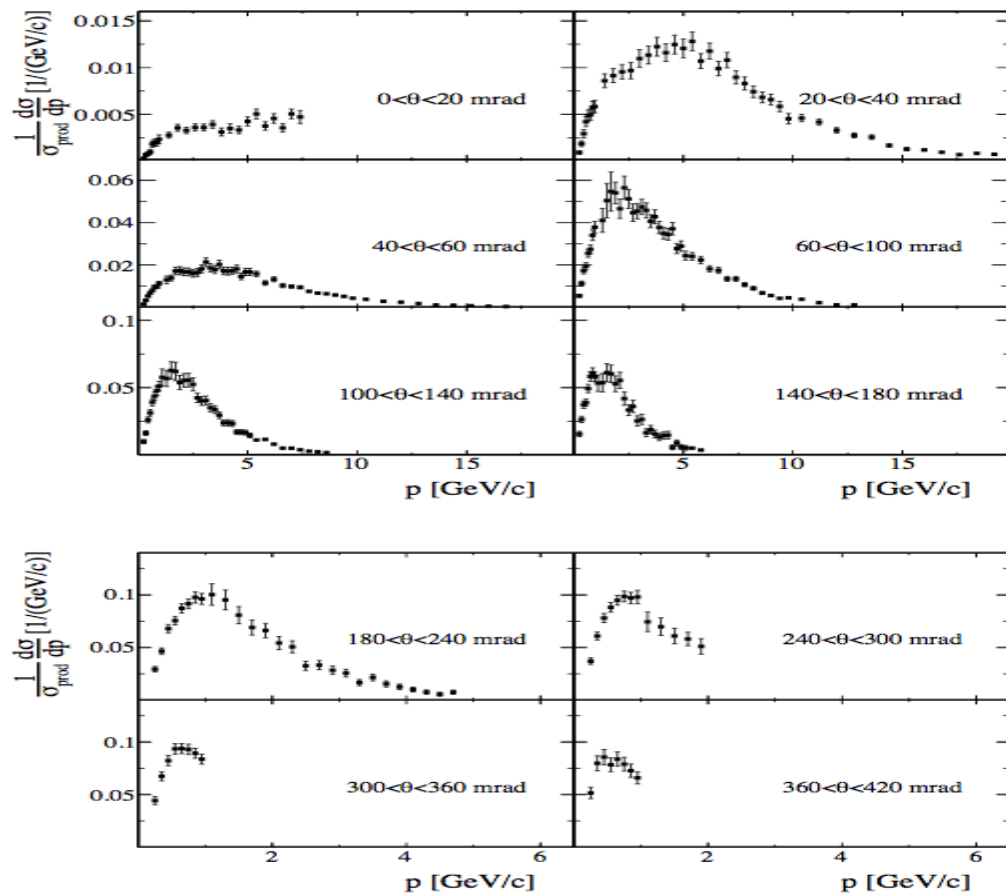


## Hadron production by 30GeV proton beam on carbon target

- Use CERN NA61/SHINE pion measurement (large acceptance: >95% coverage of  $\nu$  parent pions)
- Kaon, pion outside NA61 acceptance, other interaction in the target were based on FLUKA simulation
- Secondary interaction x-sections outside the target were based on experimental data

# NA61/SHINE contribution for T2K

31 GeV/c protons on carbon target  
2007 data with thin target



N.Abgrall et al., arXiv:1102.0983 [hep-ex]  
submitted to Phys.Rev.C (2011)

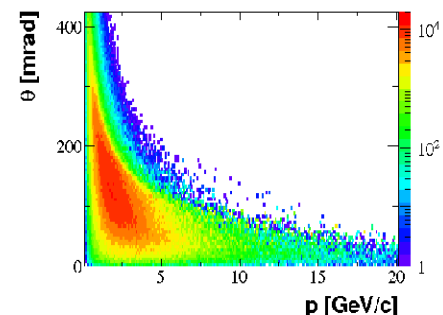


Figure 1: (Color online) The prediction from the T2K beam simulation: the  $\{p, \theta\}$  distribution for positively charged pions weighted by the probability that their decay produces a muon neutrino passing through the SK detector.

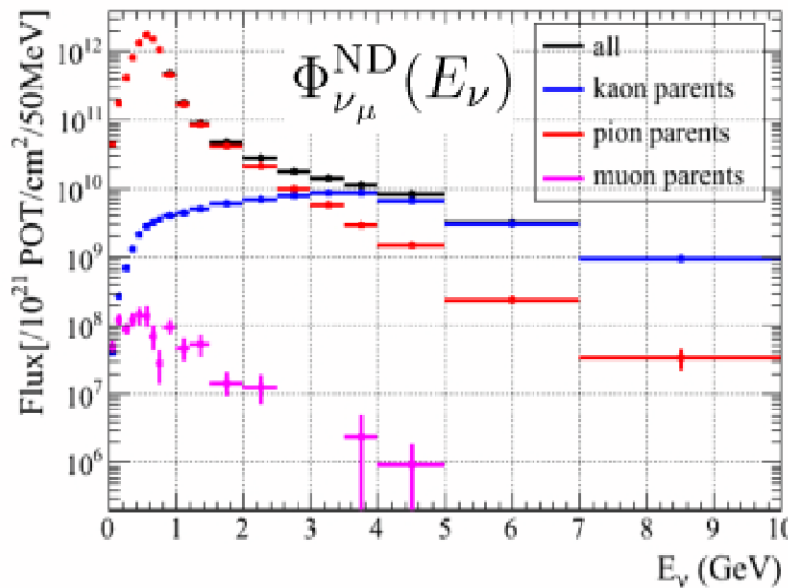
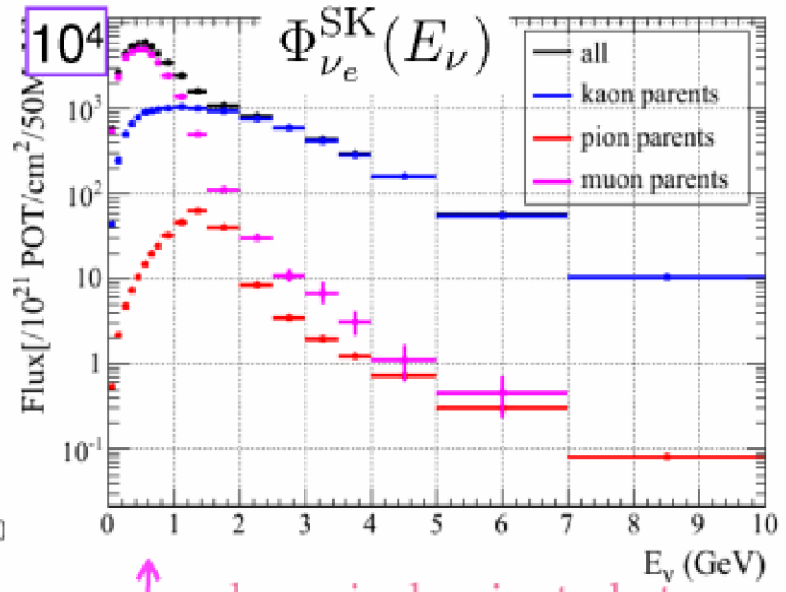
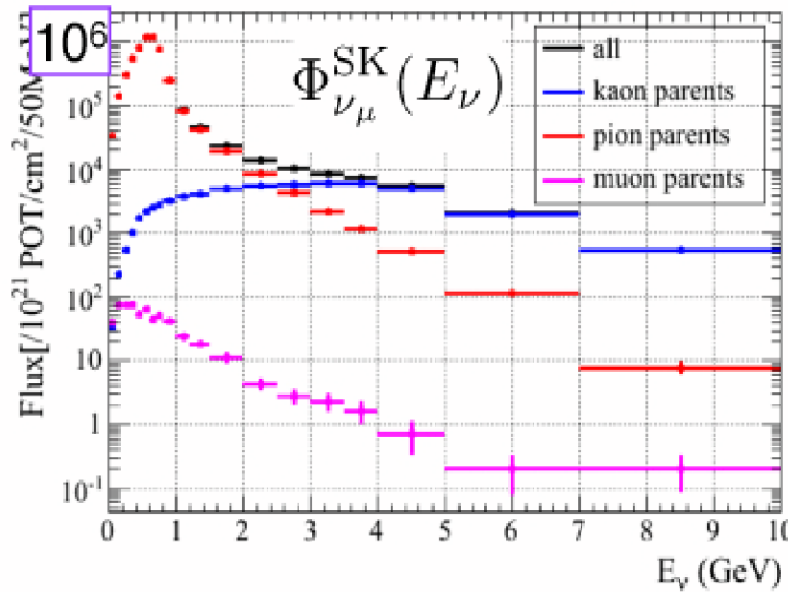
**Systematic uncertainty was evaluated in each  $(p, \theta)$  bin typically 5-10%**

**The normalization uncertainty is 2.3% on the overall  $(p, \theta)$**

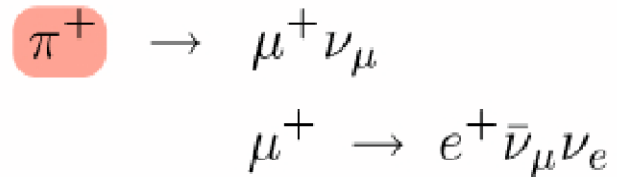
**→ propagate the systematic uncertainty in each  $(p, \theta)$  bin into the estimation of the expected number of events in T2K**

# Flux predictions

## Predicted neutrino flux (center value)



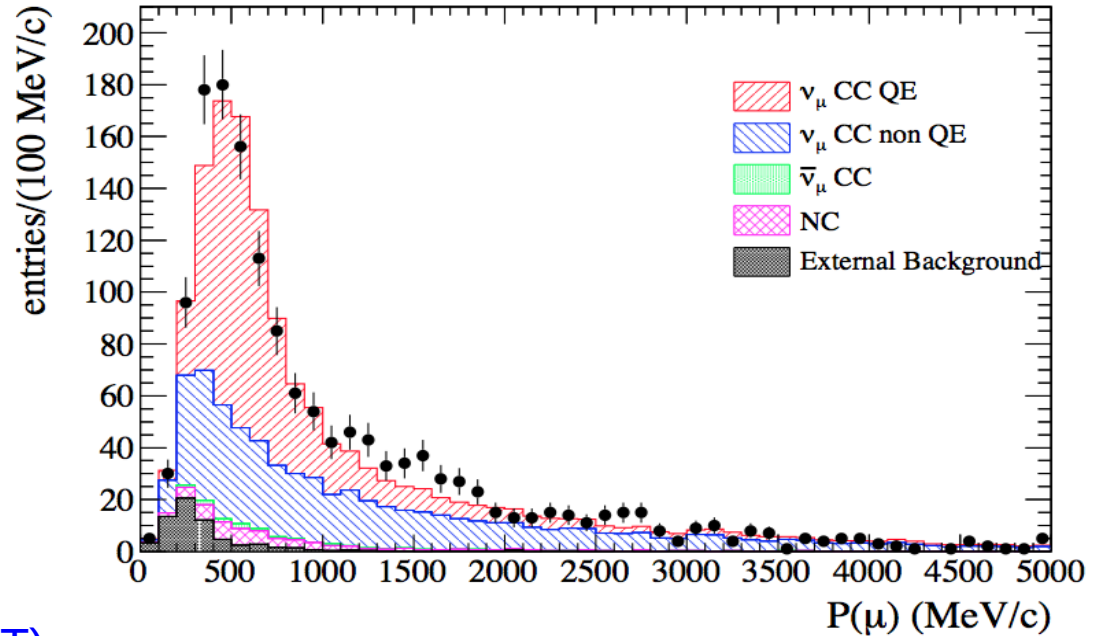
↑  $\mu$  decay is dominated at low energy



NA61 pion measurement predicts the beam  $\nu_e$  from pion origin

# ND280 input to present analysis

- CC inclusive measurements in ND280 tracker: FGD+TPC
- 98% CC, 50% CCQE
- Analysis based on 2010a data (Jan2010 -June 2010)
- $2.9 \times 10^{19}$  POT
- data is consistent with MC based on NA61 (flux) and nu interactions simulation (NEUT)



$$R_{ND}^{\mu, Data} = 1529 \text{ events} / 2.9 \times 10^{19} \text{ p.o.t.}$$

$$\frac{R_{ND}^{\mu, Data}}{R_{ND}^{\mu, MC}} = 1.036 \pm 0.028(\text{stat.})_{-0.037}^{+0.044}(\text{det. syst.}) \pm 0.038(\text{phys. syst.})$$

*The expected number of events with  $1.43 \times 10^{20}$  p.o.t.*

	Beam $\nu_e$ background	NC background	Oscillated $\nu_\mu \rightarrow \nu_e$ (solar term)	Total
<i>The expected # of events at SK</i>	<b>0.8</b>	<b>0.6</b>	<b>0.1</b>	<b>1.5</b>

$$N_{\text{SK tot.}}^{\text{exp}} = 1.5 \text{ events}$$

# Systematic uncertainty of the expected event number

error source	syst. error
(1) $\nu$ flux	$\pm 8.5\%$
(2) $\nu$ cross section	$\pm 14.0\%$
(3) Near detector	$+5.6\%$ $-5.2\%$
(4) Far detector	$\pm 14.7\%$
(5) Near det. statistics	$\pm 2.7\%$
Total	$+22.8\%$ $-22.7\%$

$$\sin^2 2\theta_{13} = 0$$

$$N_{SK}^{exp} = R_{ND}^{\mu, Data} \times \frac{N_{SK}^{MC}}{R_{ND}^{\mu, MC}} \frac{\int \Phi_{\nu_{\mu}(\nu_e)}^{SK}(E_{\nu}) \cdot P_{osc.}(E_{\nu}) \cdot \sigma(E_{\nu}) \cdot \epsilon_{SK}(E_{\nu}) dE_{\nu}}{\int \Phi_{\nu_{\mu}}^{ND}(E_{\nu}) \cdot \sigma(E_{\nu}) \cdot \epsilon_{ND}(E_{\nu}) dE_{\nu}}$$

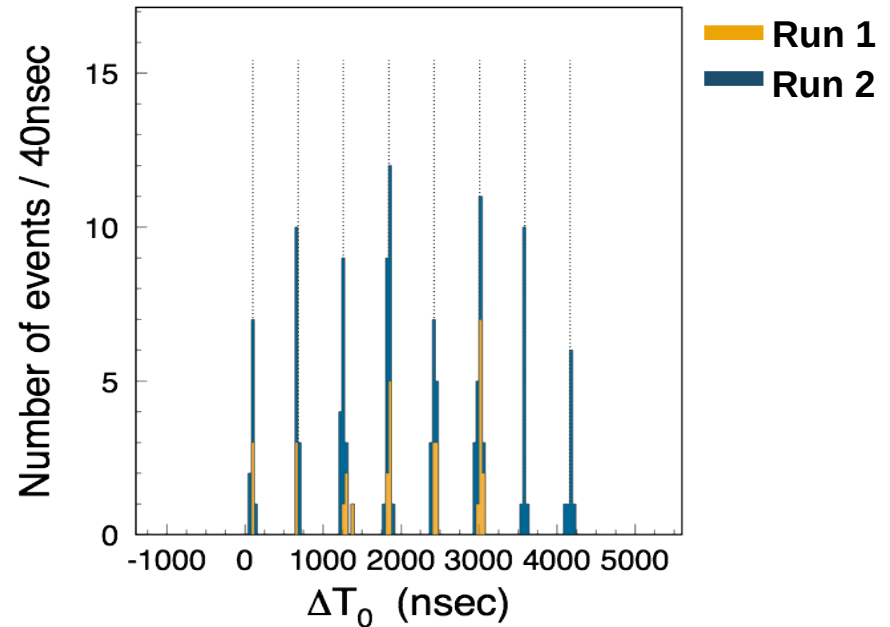
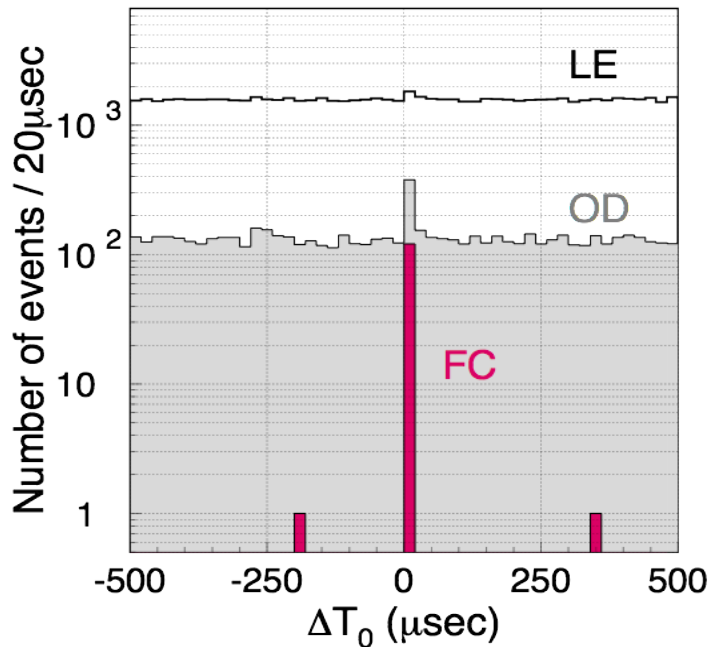
The expected number of events in Super-K:

$$N_{SK}^{exp} = 1.5 \pm 0.3 \text{ events}$$

# T2K events in Super-Kamiokande and results

## Events in beam timing

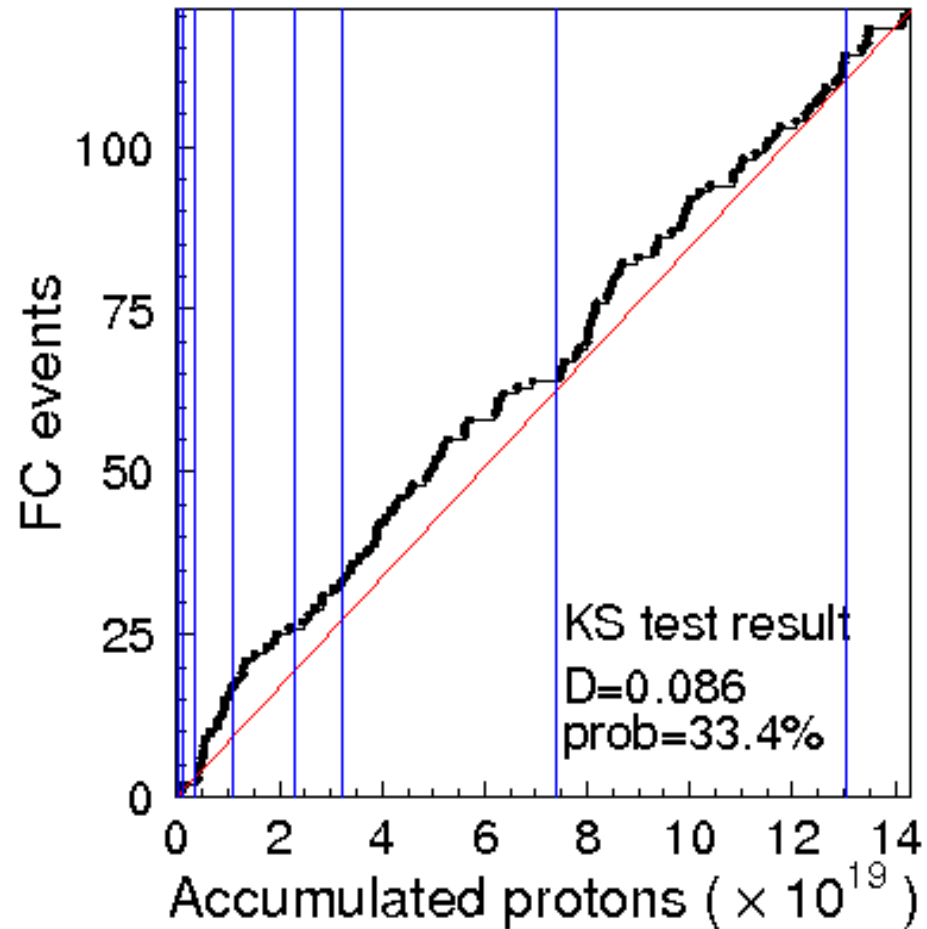
**Clear beam structure !**



Number of events in on-timing windows (-2 ~ +10 μsec)

Class / Beam run	RUN-1	RUN-2	Total	Exp. BG
POT (x 10 <sup>19</sup> )	3.23	11.08	14.31	
<b>Fully-Contained (FC)</b>	33	88	<b>121</b>	0.023

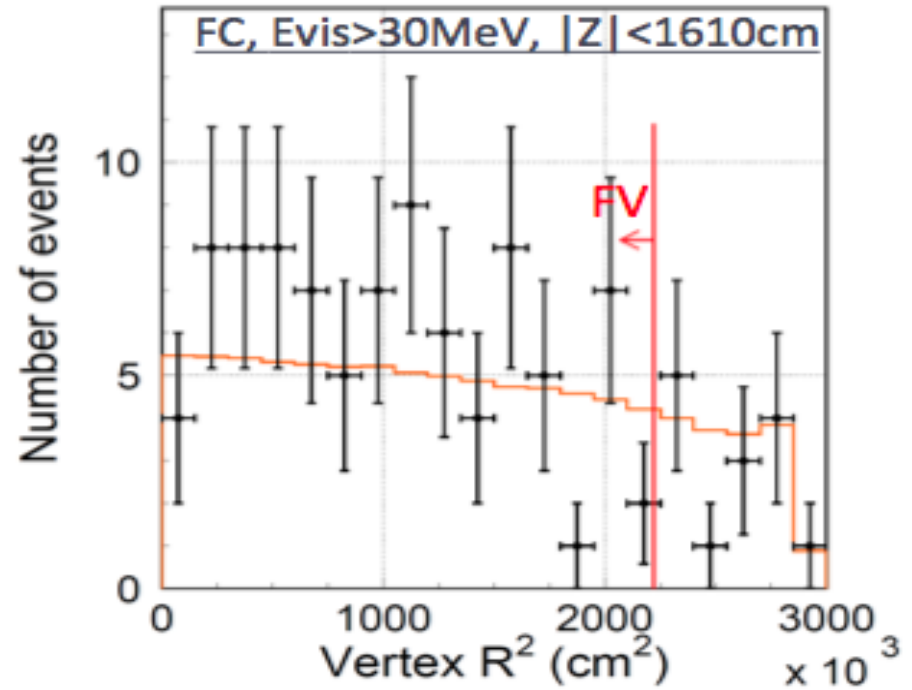
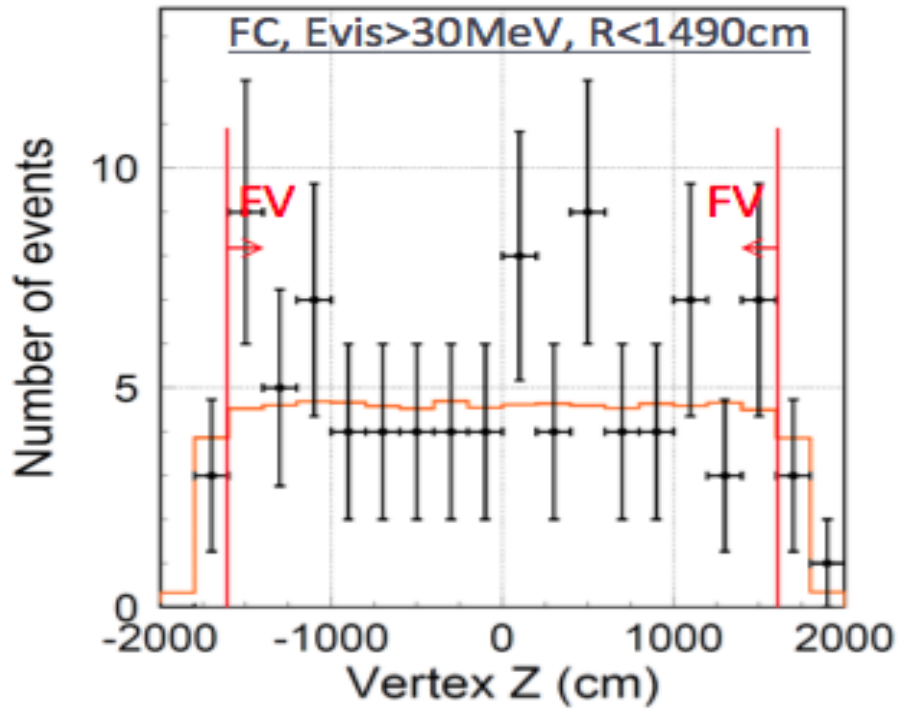
# Super-K FC events vs POT





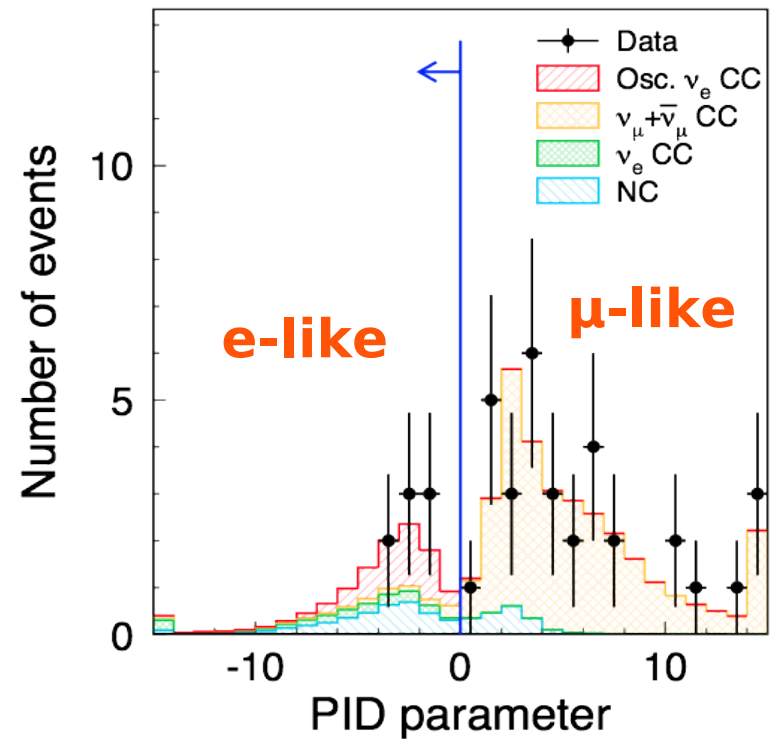
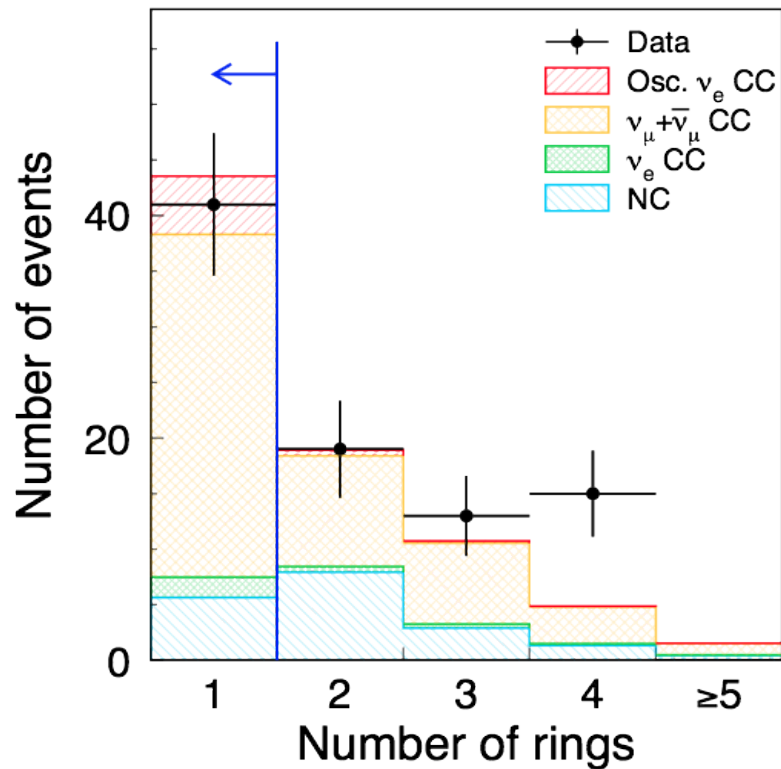
# SK cuts application

## Fiducial volume cut & fully contained FC



# Single ring and e-like ring

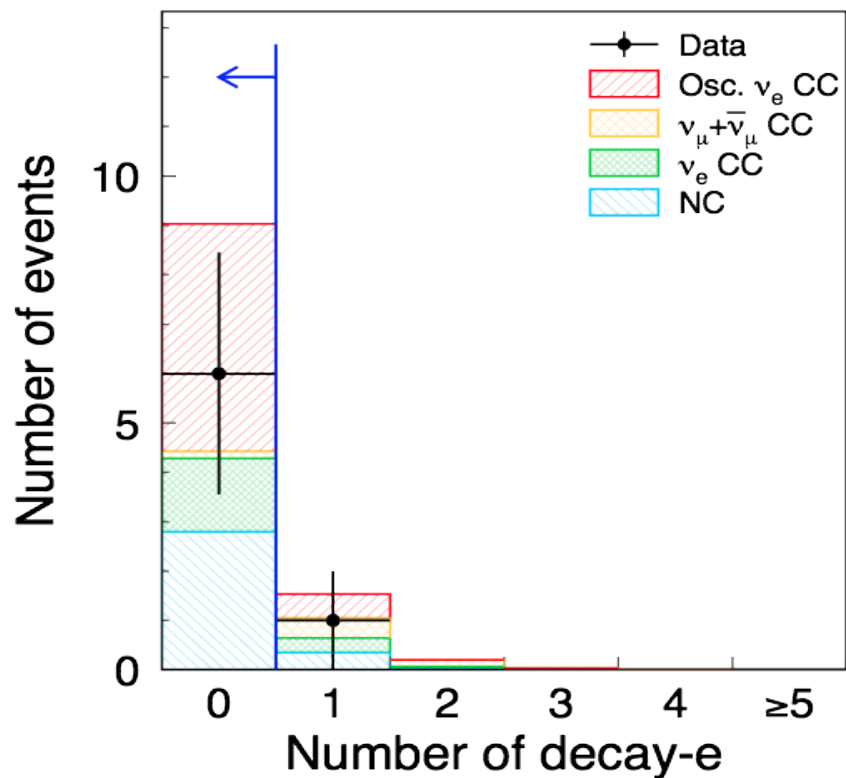
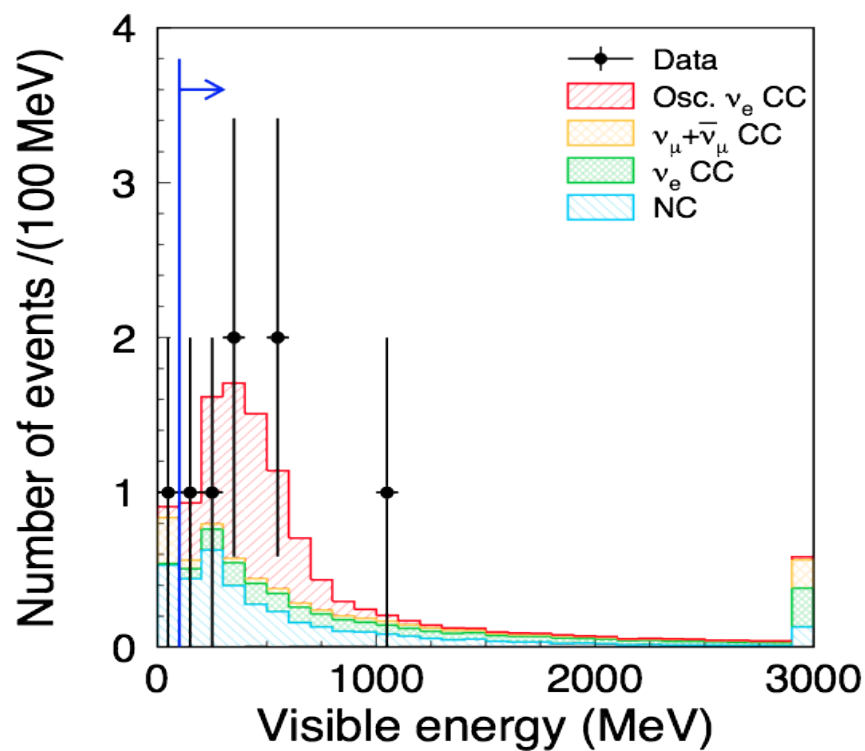
MC with  $\sin^2 2\theta_{13} = 0.1$



$E_{\text{visible}} > 100 \text{ MeV}$

No decay electron

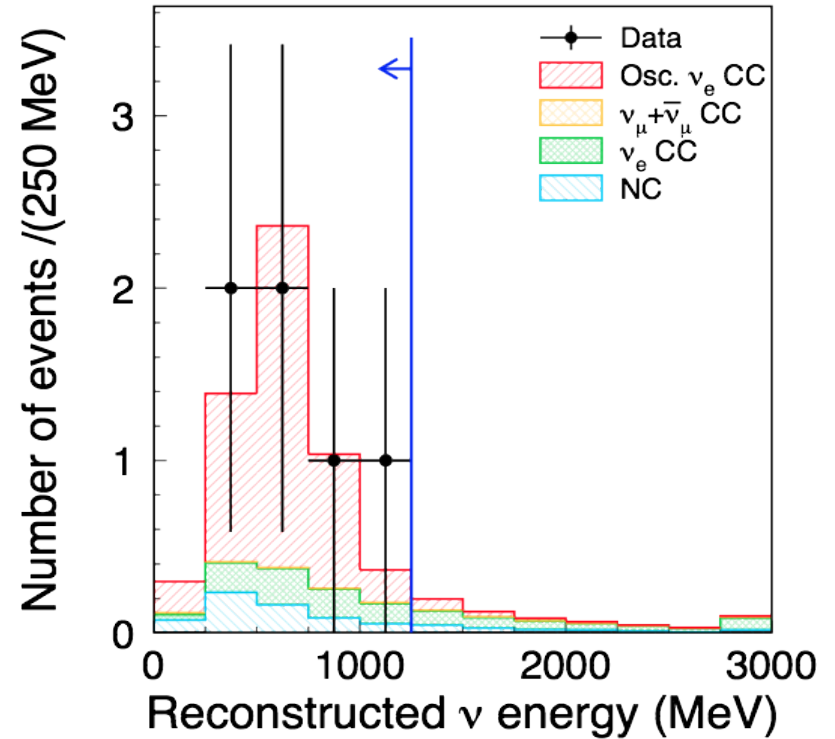
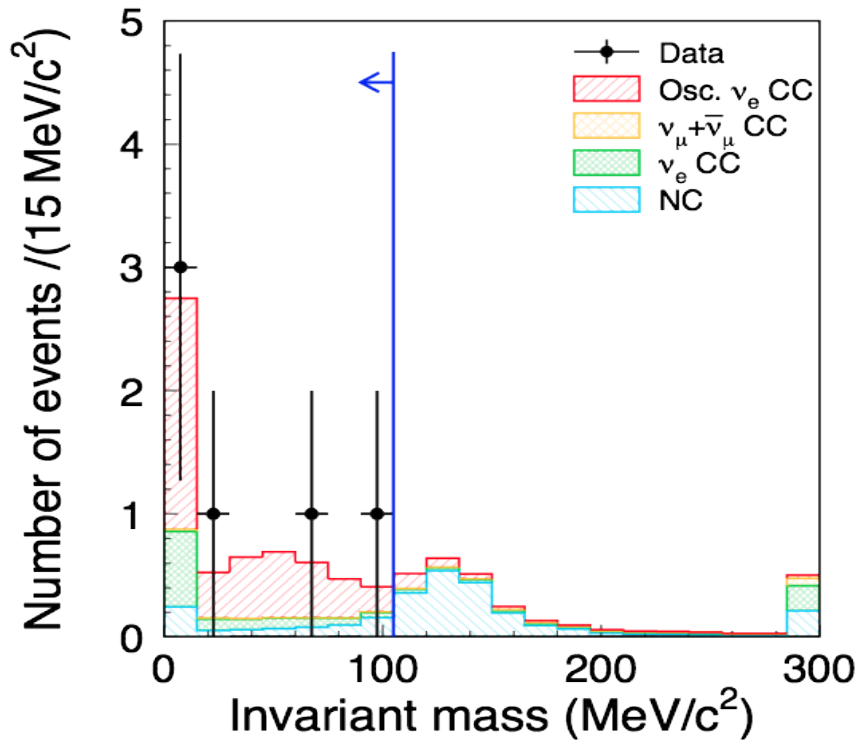
MC with  $\sin^2 2\theta_{13} = 0.1$



Invariant mass  $< 105$  MeV

Reconstructed  $\text{Nu}_e$  energy  
 $< 1250$  MeV

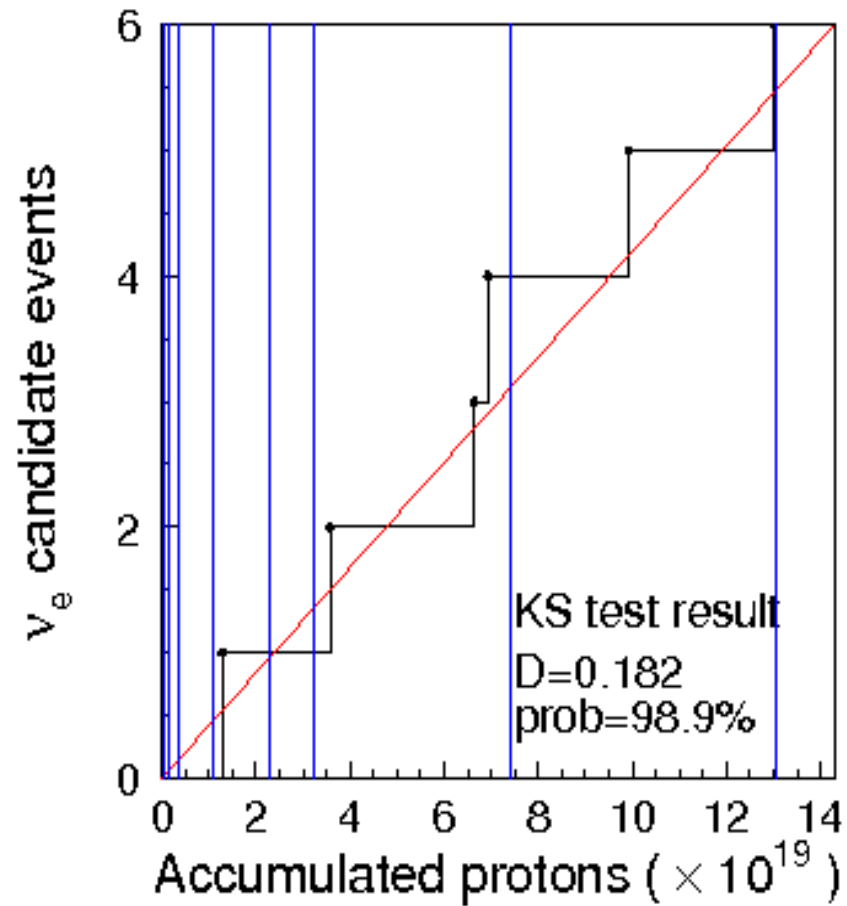
MC with  $\sin^2 2\theta_{13} = 0.1$



**After all SK Nu<sub>e</sub> selection cuts...  
6 events remained !!!**

**(N<sub>exp</sub> = 1.5 ± 0.3 at sin<sup>2</sup>2θ<sub>13</sub> = 0)**

# Selected Nu\_e events vs POT



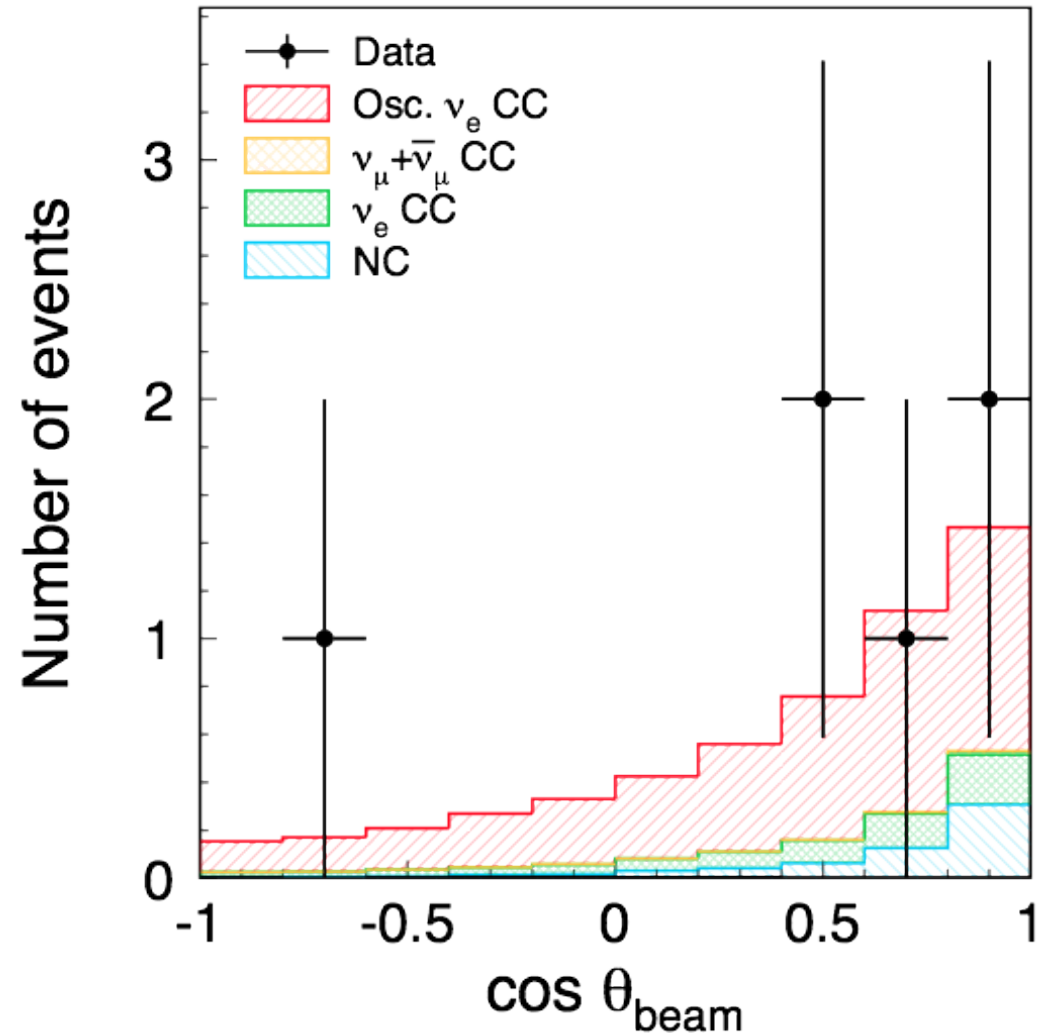
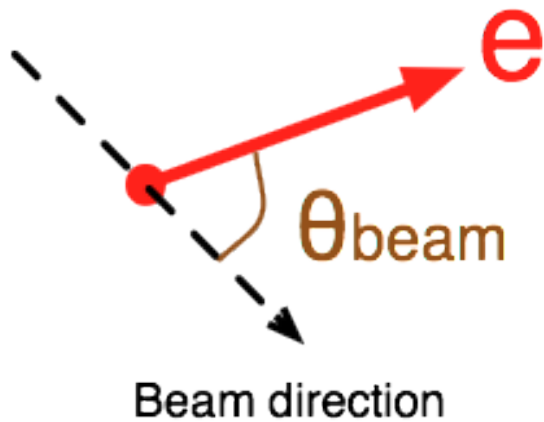
# Number of events for each Nu\_e selection step

	Expected					Data
	BG total	$\nu_\mu + \bar{\nu}_\mu$ CC	$\nu_e$ CC	NC	$\nu_\mu \rightarrow \nu_e$ CC	
Interactions inside the FV	141.44	67.30	3.17	70.98	0.13	–
FCFV	73.76	52.44	3.03	18.29	0.12	88
Single-ring	38.42	30.85	1.92	5.66	0.11	41
Electron-like PID	6.65	1.02	1.91	3.72	0.11	8
$E_{\text{vis}} > 100 \text{ MeV}$	5.81	0.72	1.90	3.19	0.11	7
No decay-e	4.50	0.14	1.56	2.79	0.10	6
POLfit mass $< 105 \text{ MeV}/c^2$	1.92	0.04	1.12	0.76	0.09	6
Reconst. $\nu$ energy $< 1250 \text{ MeV}$	1.40	0.03	0.76	0.61	0.09	6
Efficiency from Interactions [%]	1.0	$< 0.1$	24.0	0.9	73.9	
Efficiency from FCFV [%]	1.9	0.1	25.0	3.4	76.4	

--

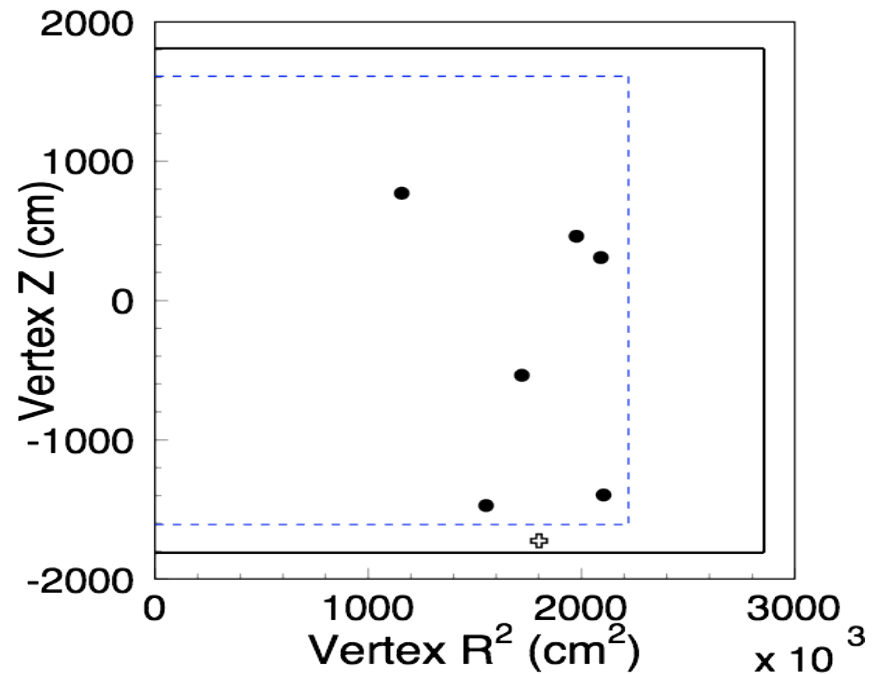
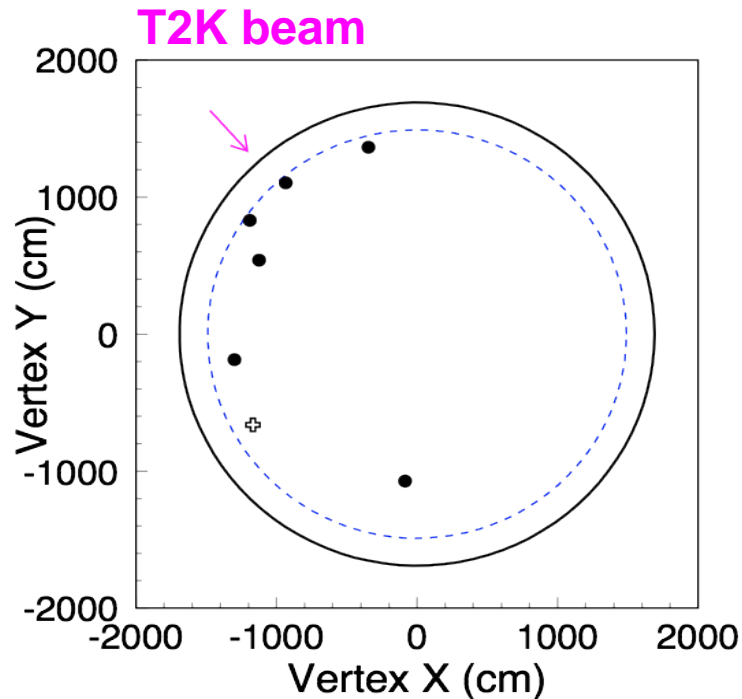
$\sin^2 2\theta_{13} = 0$  is assumed in MC simulation for this table

# Angle distribution for selected Nu\_e events





# Vertex distribution in SK FV



\* **Vertexes clustering at large  $R$   $\rightarrow$  make some additional checks**

\* **Check distribution of events outside FV  $\rightarrow$  no indication of BG contamination**

\* **Check distribution of events in OD  $\rightarrow$  no indication of BG contamination**

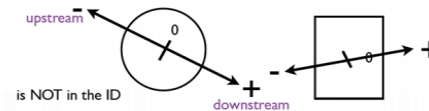
\* **K.S. of the  $R^2$  distribution gives  $p \sim 0.03$**

# Some checks of vertexes distribution

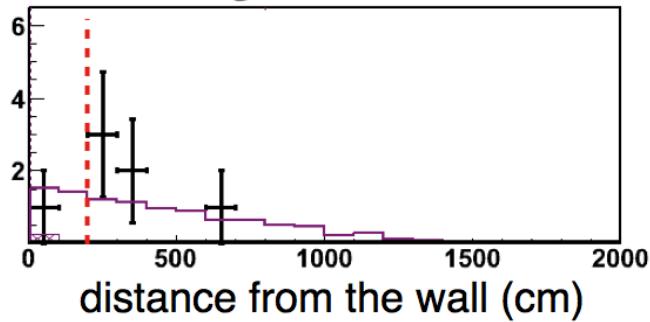
Blank histogram: MC  
 Hatched histogram: MC w/ true vertex being not in the ID.  
 Cross: T2K Data  
 SK Nu<sub>e</sub> selection cuts w/o FCFV

OD (outer detector) vertexes distribution  
 MC with “full” oscillations;  
 $\sin^2 2\theta_{13} = 0.1$

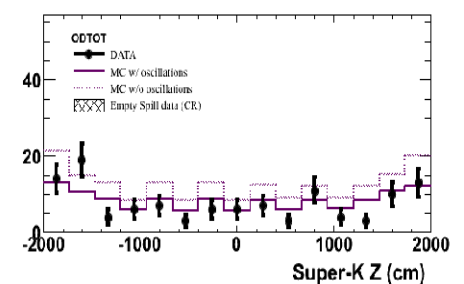
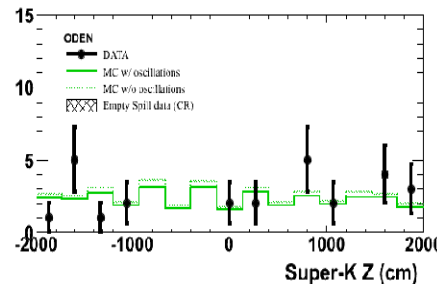
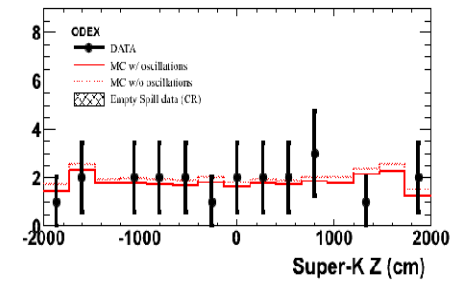
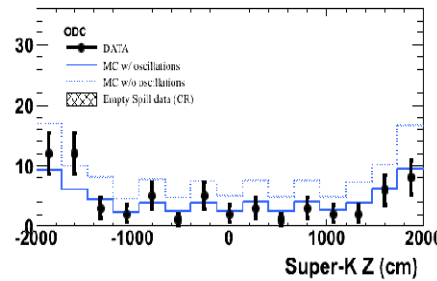
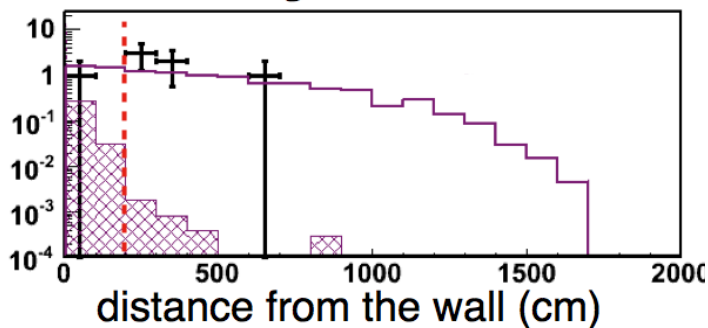
## Beam Z



DWALL,  $\nu_e$  Candidate Sample



DWALL,  $\nu_e$  Candidate Sample



# First T2K results for $\nu_e$ appearance search

**$1.43 \times 10^{20}$  pot analyzed (2% of T2K goal)**

**The observed number of events: 6**

**The expected number of events:  $1.5 \pm 0.3$  ( $\sin^2 2\theta_{13} = 0$ )**

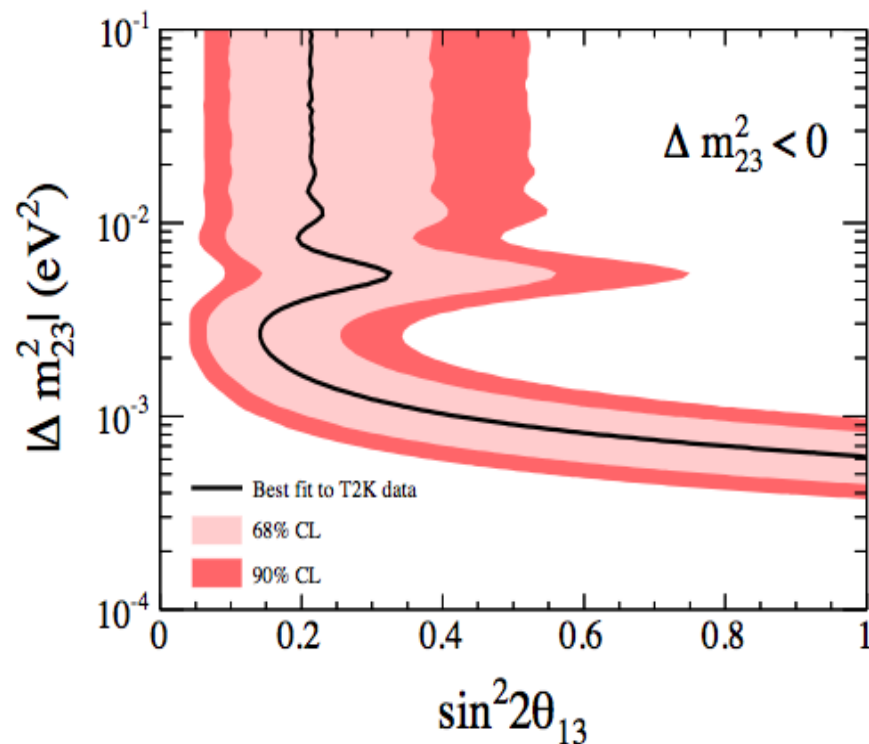
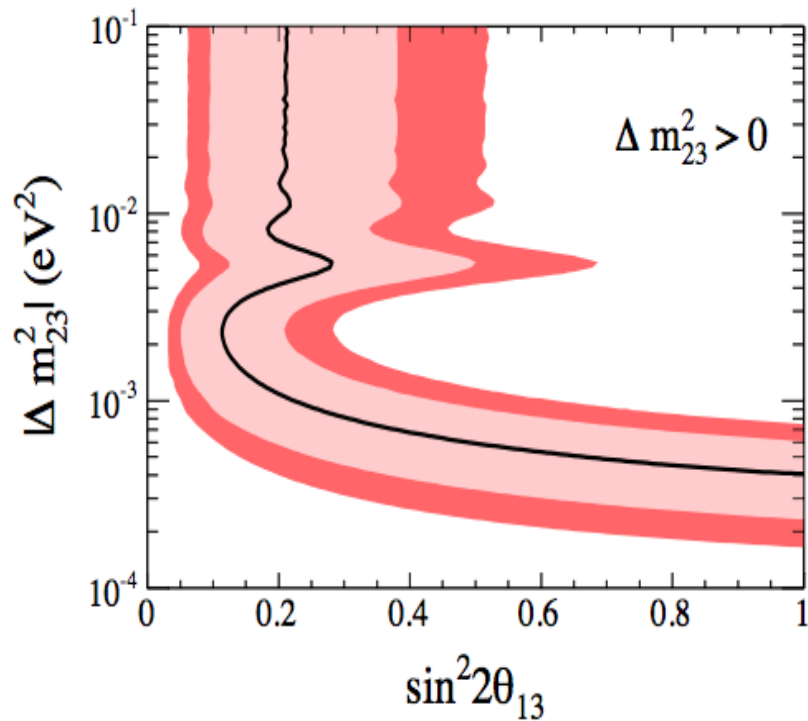
No oscillation hypothesis leads to 0.07 probability to observe 6 or more events ( $2.5 \sigma$ )

Indication of  $\nu_e$  appearance in  $\nu_\mu \rightarrow \nu_e$  transitions !

# Allowed region for $\sin^2 2\theta_{13}$ vs $\Delta m_{23}^2$

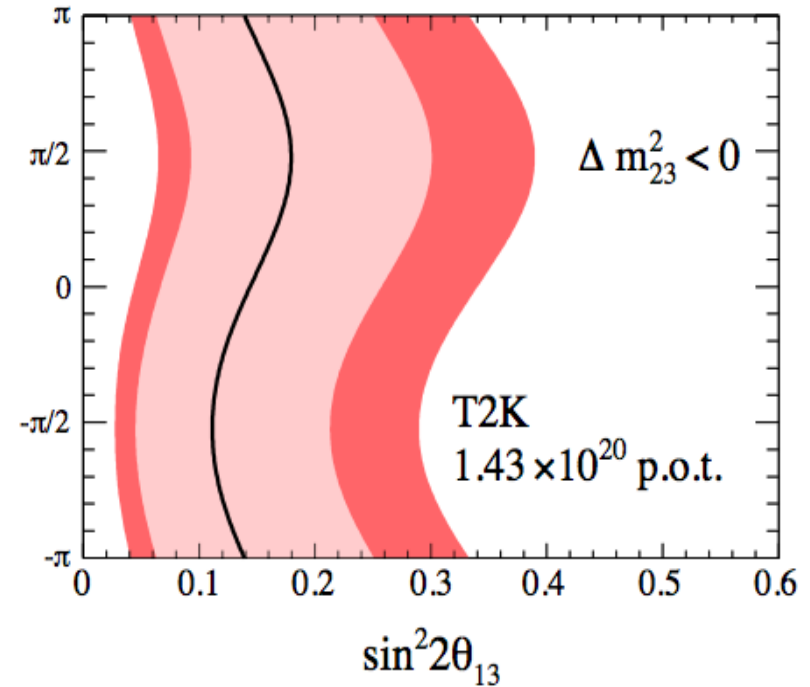
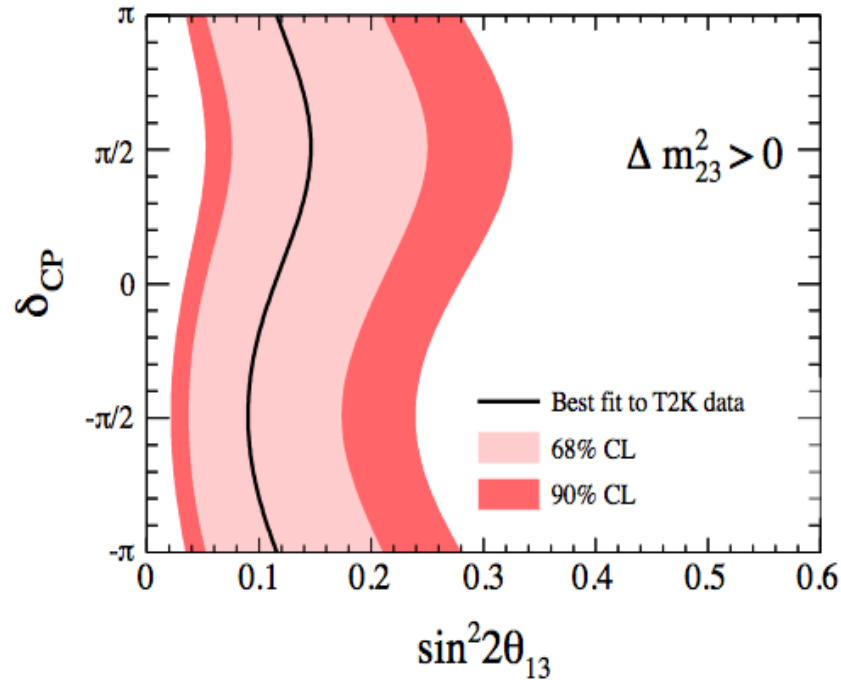
## Feldman-Cousins method

$$\sin^2 2\theta_{23} = 1.0 \text{ and } \delta_{CP} = 0$$



# Allowed region for $\sin^2 2\theta_{13}$ vs $\delta_{CP}$

$\Delta m_{23}^2 = 2.4 \times 10^{-3} \text{ eV}^2$  and  $\sin^2 2\theta_{23} = 1.0$



**90% C.L. interval & Best fit point (assuming  $\Delta m_{23}^2 = 2.4 \times 10^{-3} \text{ eV}^2$ ,  $\sin^2 2\theta_{23} = 1$ ,  $\delta_{CP} = 0$ )**

$0.03 < \sin^2 2\theta_{13} < 0.28$

$\sin^2 2\theta_{13} = 0.11$

$0.04 < \sin^2 2\theta_{13} < 0.34$

$\sin^2 2\theta_{13} = 0.14$

# Заключение

- Создан ближний детектор ND280 эксперимента T2K, важным элементом которого является детектор мюонного пробега SMRD, разработанный и созданный в ИЯИ РАН
  - световыход 25-50 ф.э. (центр счетчика, MIP),  $T=20-22$  С
  - эффективность регистрации MIP > 99%
  - стабильная работа детектора в течении 2009-2011 гг.
- Выполнена калибровка детектора, настройка MC SMRD, а также сшивка SMRD с “внутренними” детекторами ND280
- Показана возможность использования SMRD детектора для реконструкции/анализа нейтринных событий без участия время-проекционных камер
- Ближний детектор ND280 позволяет восстанавливать спектр нейтрино T2K

- В эксперименте T2K получено первое указание на появление  $\nu_e$  в результате  $\nu_\mu \rightarrow \nu_e$  осцилляций:
- зарегистрировано 6 событий от электронных нейтрино, ожидаемое число (отсутствие осцилляций) –  $1.5 \pm 0.3$  события
  - $2.5\sigma$  significance 99.3%
  - $0.03(0.04) < \sin^2 2\theta_{13} < 0.28(0.34)$  (90% C.L.) для нормальной (“обратной”) иерархии масс
  - возобновление работы эксперимента после устранения последствий землетрясения, продолжение изучения  $\nu_\mu \rightarrow \nu_e$  осцилляций
  - лето 2011, результат  $\nu_\mu \rightarrow \nu_\mu$  для  $1.43 \times 10^{20}$  p.o.t

## Доклады на конференциях:

1. TIPP09 Цукуба, Япония, 12-17 марта 2009
2. ИТЭФ, научная сессия-конференция секции ЯФ ОФН РАН «Физика фундаментальных взаимодействий», 23-27 ноября 2009
3. INSS 2010, Йокогама-Токай, 23-31 августа 2010, Япония
4. 11<sup>th</sup> NNN workshop, Тояма, Япония, 13-16 декабря 2010
5. 15 Ломоносовская конференция, 18-24 августа 2011

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всего - 15

в реферируемых изданиях - 10:

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