Status of the T2K experiment

Yuichi Oyama
(KEK/J-PARC)
for T2K collaboration

Feb-27-2020
CNNP2020@Cape Town, South Africa

Neutrino mixing matrix

- Study of neutrino mixing is one of the most active areas in recent particle physics.

The flavor eigenstates are mixtures of the mass eigenstates.
Assuming 3 generations of neutrinos, the mixing matrix has 6 parameters.

2 mass square differences (Δm^2_{21}, Δm^2_{32}), $\Delta m^2_{ij}=m^2_i-m^2_j$
3 mixing angles (θ_{12}, θ_{23}, θ_{13})
1 CP violation phase, δ_{CP}.

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta_{CP}} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta_{CP}} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

- The mixing between 2nd and 3rd generation was established with atmospheric/long-baseline neutrinos around 2000. Prof. Kajita (Super-Kamiokande collaboration) won the Nobel prize in 2015.

- The mixing between 1st and 2nd generation was established with solar/reactor neutrinos around 2000. Prof. McDonald (SNO collaboration) won the Nobel prize in 2015.

- Observation of mixing between 1st and 3rd generations began in 2010s.

Neutrino oscillation parameters from PDG2019

- Δm^2_{21} and θ_{12} are

  $\Delta m^2_{21} = (7.53 \pm 0.18) \times 10^{-5} \mathrm{eV}^2$, $\sin^2\theta_{12} = 0.307 \pm 0.013$ $\theta_{12} \sim 34^o$

- $|\Delta m^2_{32}|$ and θ_{23} are

  $|\Delta m^2_{32}| = (2.444 \pm 0.034) \times 10^{-3}\, \mathrm{eV}^2$, $\sin^2\theta_{23} = 0.512^{+0.019}_{-0.022}$

  (for normal mass ordering, octant I) $\theta_{23} \sim 45^o$

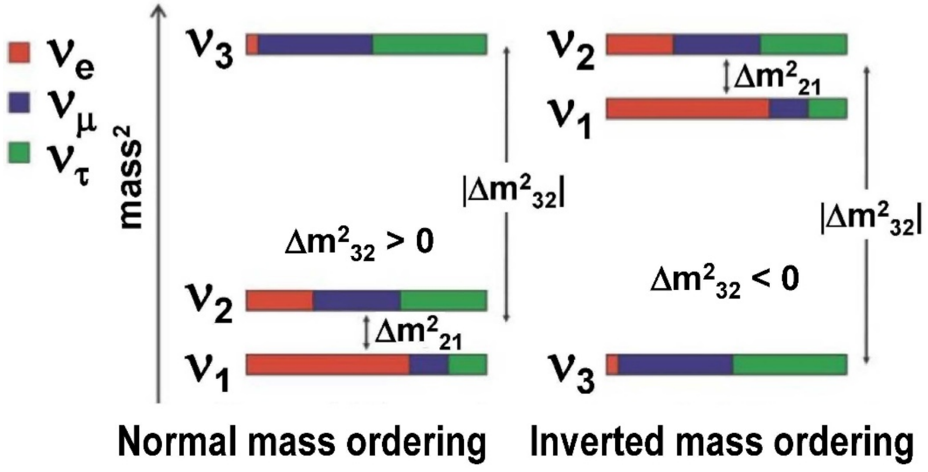
- First non-zero indication of θ_{13} was reported by T2K in 2011. Present constraint given by reactor experiments is

  $\sin^2\theta_{13} = 0.0218 \pm 0.0007$ $\theta_{13} \sim 8^o$

- At present, weak constraints on δ_{CP} have been obtained.

  $\delta_{CP} = (1.37^{+0.18}_{-0.16})\pi$ radian

- Further constraints on δ_{CP} as well as mass ordering, sign of Δm^2_{32}, can be studied by long-baseline neutrino oscillation experiments.



ν_μ disappearance in long-baseline experiments

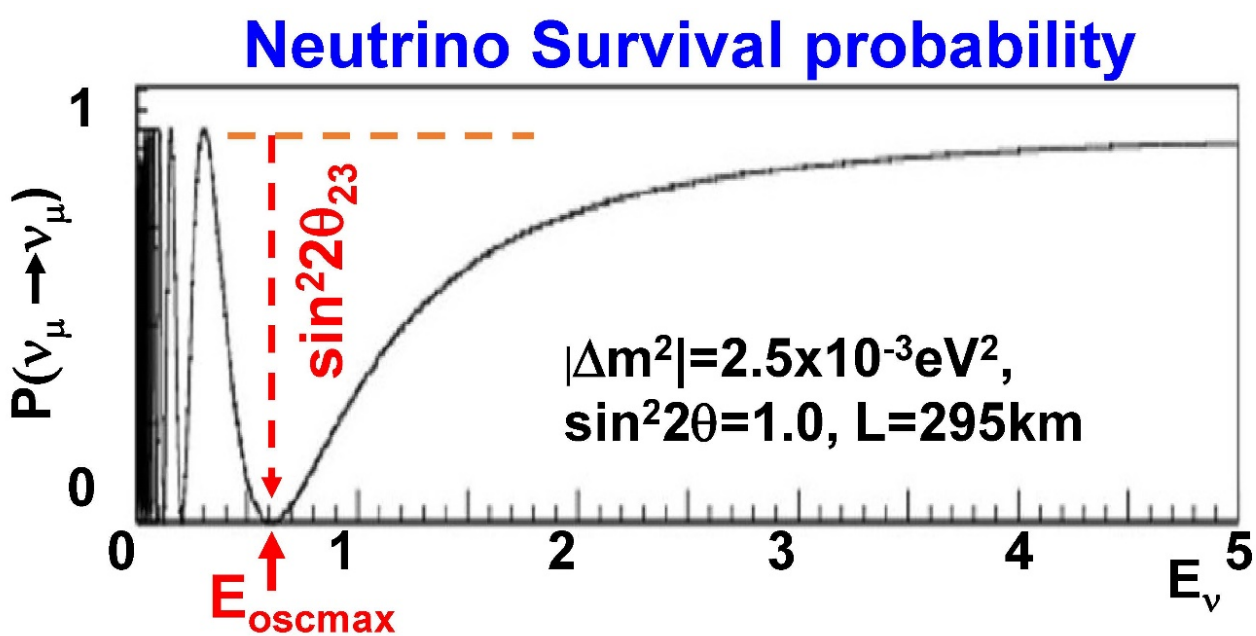
- The survival probability that ν_μ remain as ν_μ can be written as

$$P(\nu_\mu \to \nu_\mu) \approx 1 - \cos^4\theta_{13}\sin^2 2\theta_{23}\sin^2\left(\frac{\Delta m^2_{32}L}{4E_\nu}\right) - \sin^2 2\theta_{13}\sin^2\theta_{23}\sin^2\left(\frac{\Delta m^2_{32}L}{4E_\nu}\right)$$
$$\approx 1 - \sin^2 2\theta_{23}\sin^2\left(\frac{\Delta m^2_{32}L}{4E_\nu}\right)$$

- $|\Delta m^2_{32}|$ can be determined from position of the oscillation maximum E_{oscmax};

$$\frac{|\Delta m^2_{32}|L}{4E_{oscmax}} = \frac{\pi}{2}$$

- $\sin^2 2\theta_{23}$ can be determined from depth of the dip in the energy distribution.



ν_e appearance in long-baseline experiments

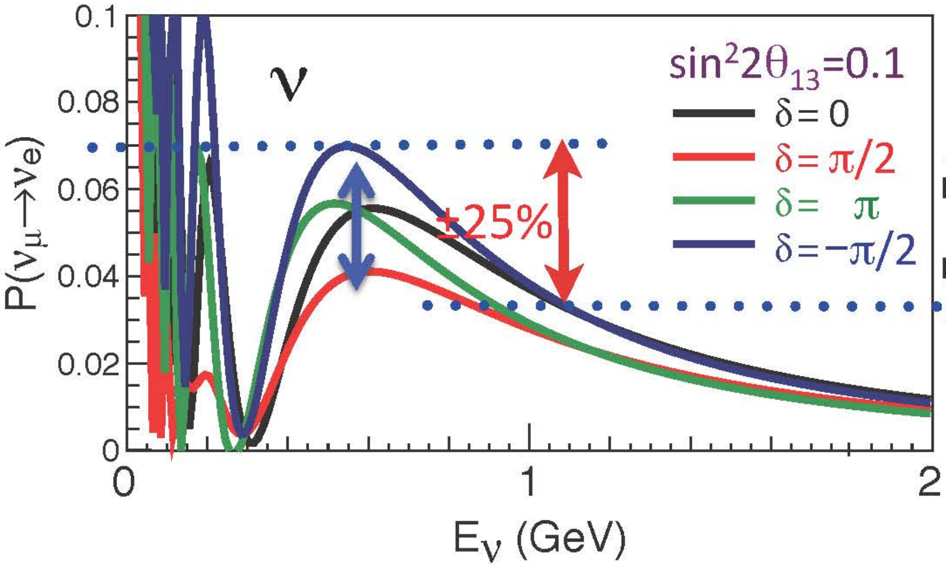
- **The probability of ν_e appearance can be written as**

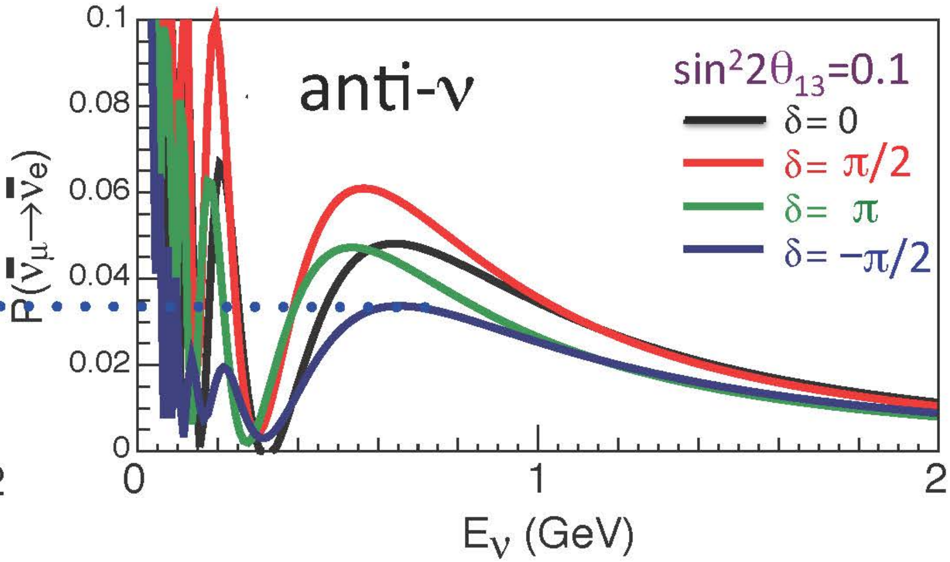
$$P(\nu_\mu \to \nu_e) \approx \sin^2\theta_{23}\sin^2 2\theta_{13}\sin^2\left(\frac{\Delta m^2_{32}L}{4E_\nu}\right)\left(1+\frac{4\sqrt{2}G_F n_e E}{\Delta m^2_{31}}(1-2\sin^2\theta_{13})\right)$$
$$\mp \sin 2\theta_{12}\sin 2\theta_{23}\sin 2\theta_{13}\cos\theta_{13}\sin\delta_{CP}\sin^2\left(\frac{\Delta m^2_{32}L}{4E_\nu}\right)\sin^2\left(\frac{\Delta m^2_{21}L}{4E_\nu}\right)$$

- for neutrino, + for anti-neutrino

These probabilities are used to study δ_{CP} and mass hierarchy.

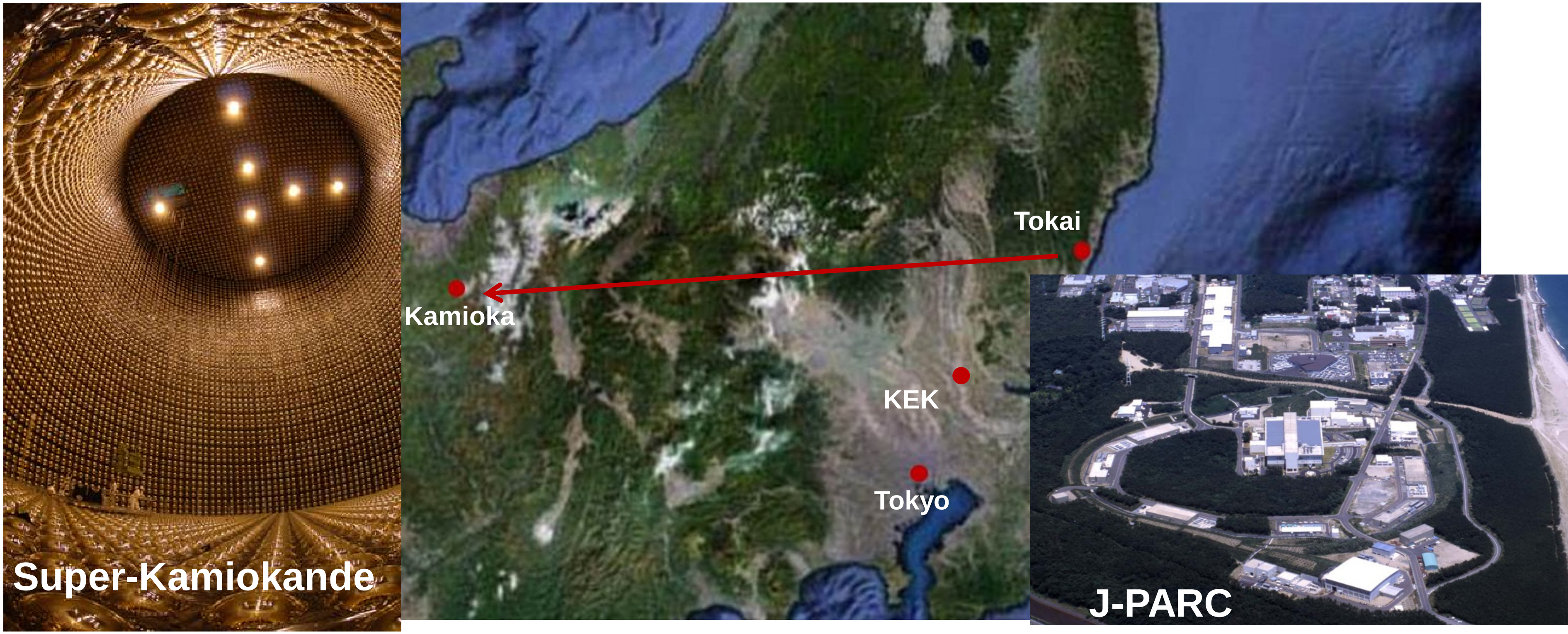
- **Oscillation probabilities $P(\nu_\mu \to \nu_e)$ and $P(\bar{\nu}_\mu \to \bar{\nu}_e)$**



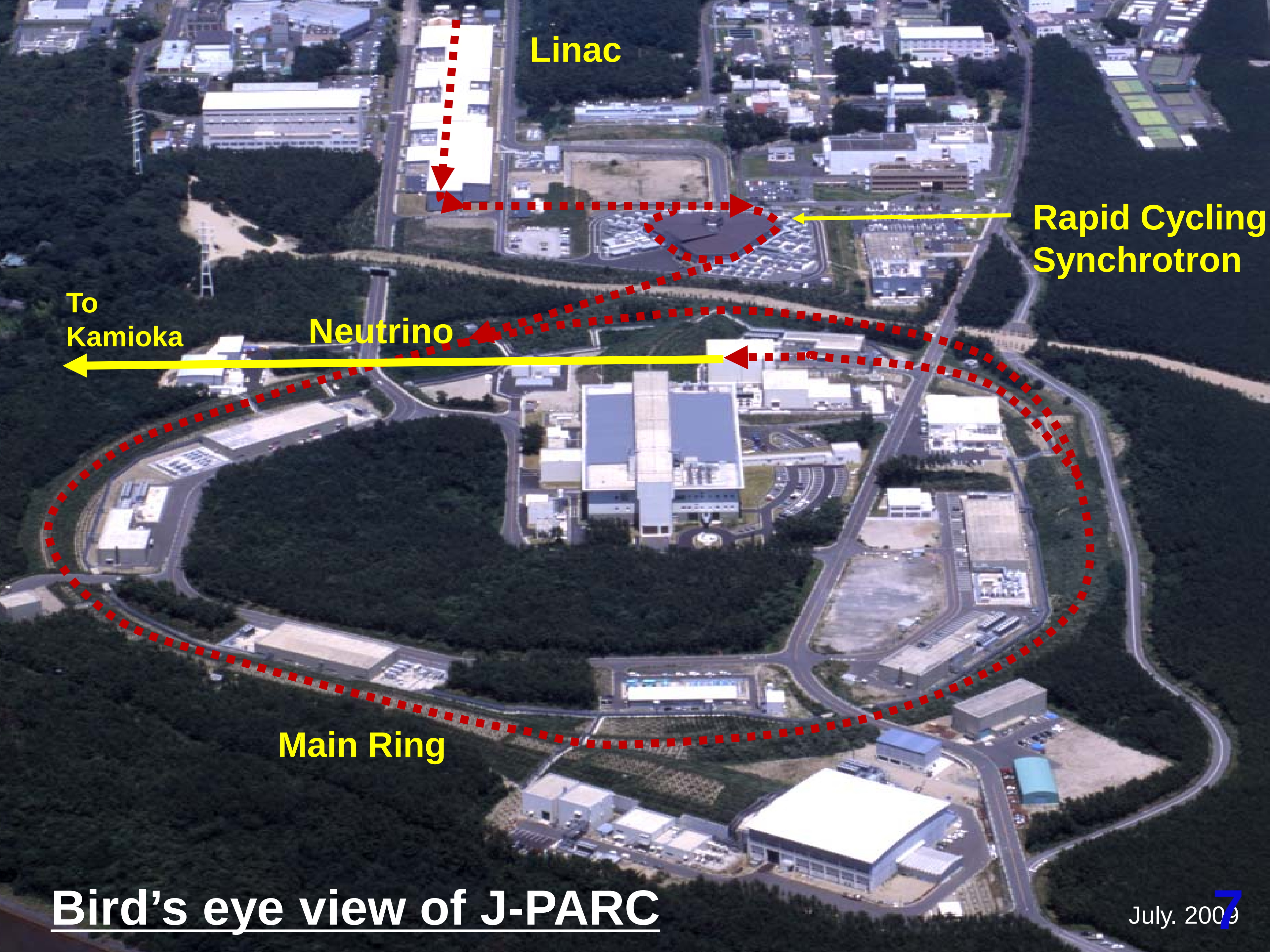


If $P(\nu_\mu \to \nu_e) < P(\nu_\mu \to \nu_e)$, $\delta_{CP} > 0$
If $P(\nu_\mu \to \nu_e) > P(\bar{\nu}_\mu \to \bar{\nu}_e)$, $\delta_{CP} < 0$

T2K experiment

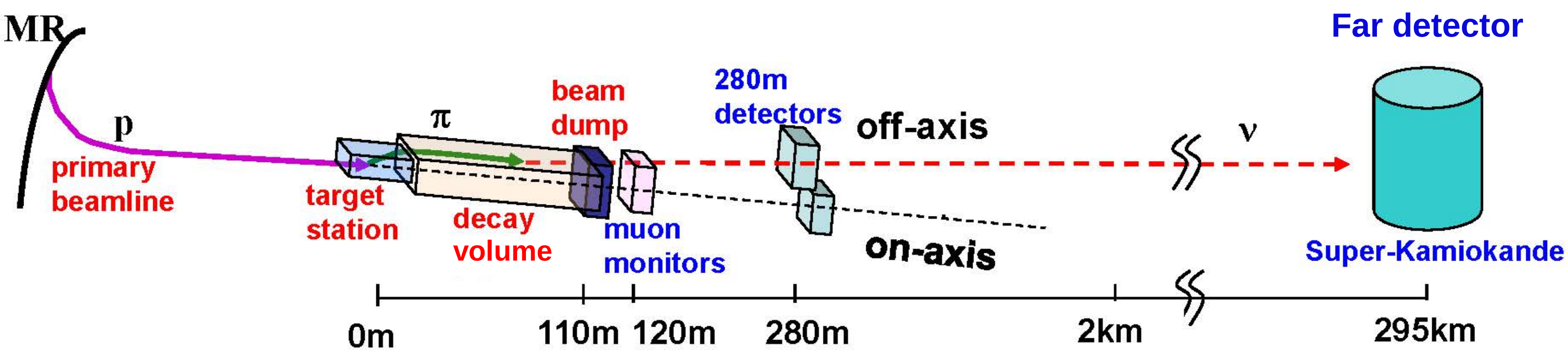


- Second generation long-baseline neutrino-oscillation experiment; from Tokai to Kamioka. The experiment started in 2009.
- High intensity almost pure ν_μ beam from J-PARC is shot toward the Super-Kamiokande (SK) detector 295 km away.



Bird's eye view of J-PARC

T2K Beam line and Detectors



Beamline

- Primary beamline
- Target station
- Decay Volume
- Beam dump @ ~110 m downstream

Detectors

- Muon monitors@ ~120 m downstream
- Near detectors@ ~280 m downstream.
- Far detector@ 295 km downstream (Super-Kamiokande)

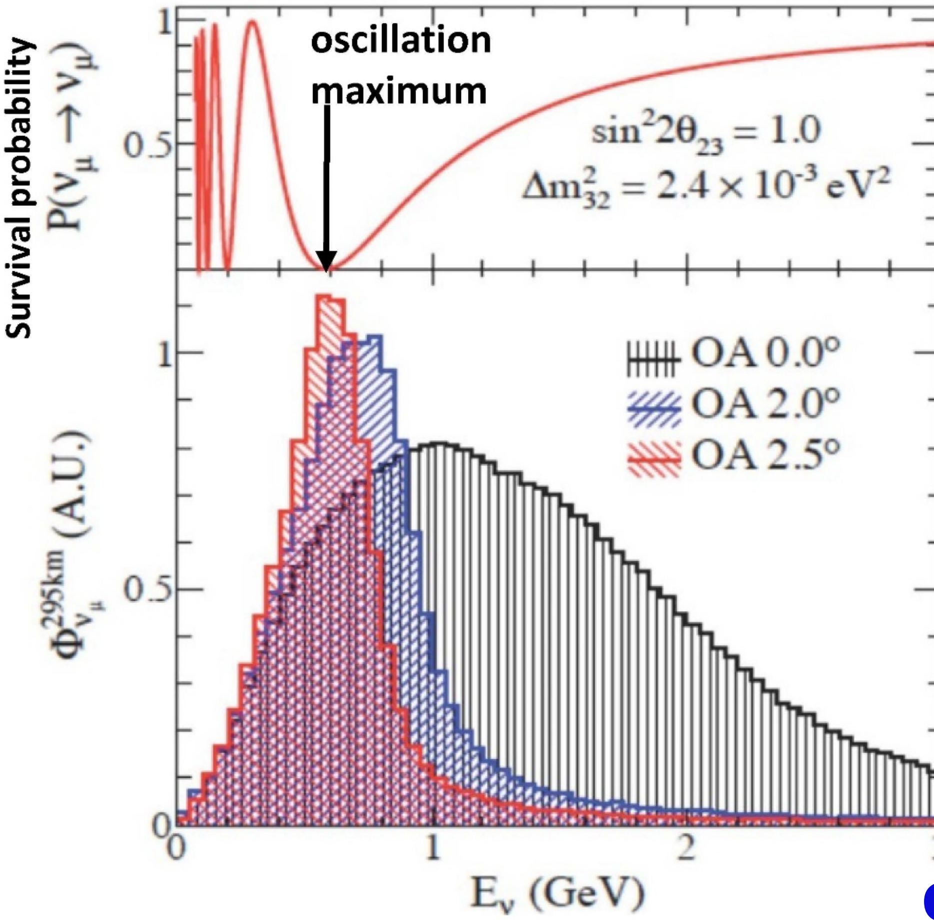
Off-axis beam : the center of the beam direction is adjusted to be 2.5º off from the SK direction.

Off-axis beam

The center of the beam direction is adjusted to be 2.5^o off from the SK direction. Neutrino energy spectrum becomes quasi-monochromatic. The peak energy is ~0.6 GeV.

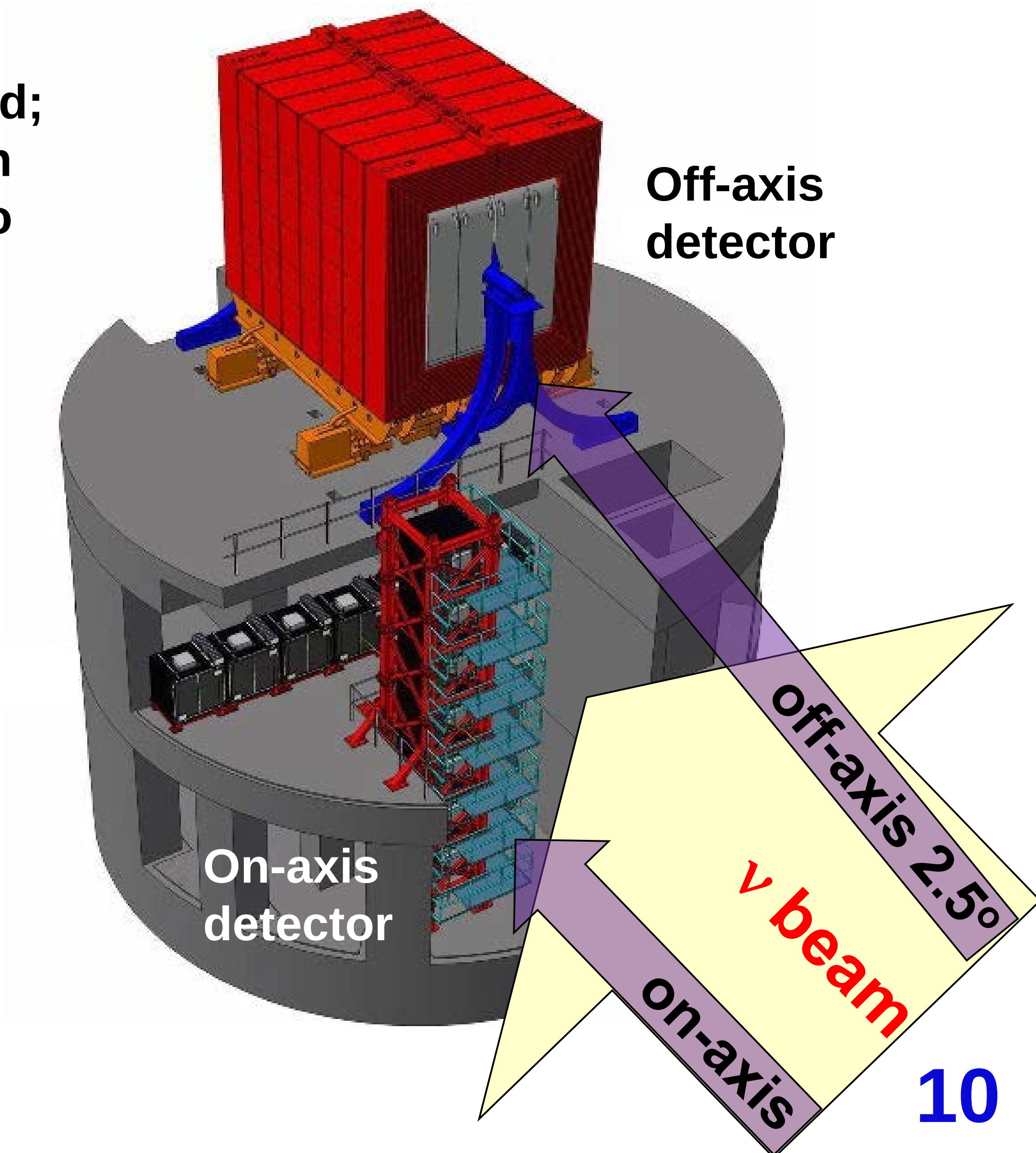
Merits of the off-axis beam are:

- The neutrino energy peak agrees with the oscillation maximum.
- Because of the suppression of high energy (> 1 GeV) neutrinos, non-CCQE background events (including NCπ^0 events) are reduced.
- Water Cherenkov detector has better performance for single charged particle events.



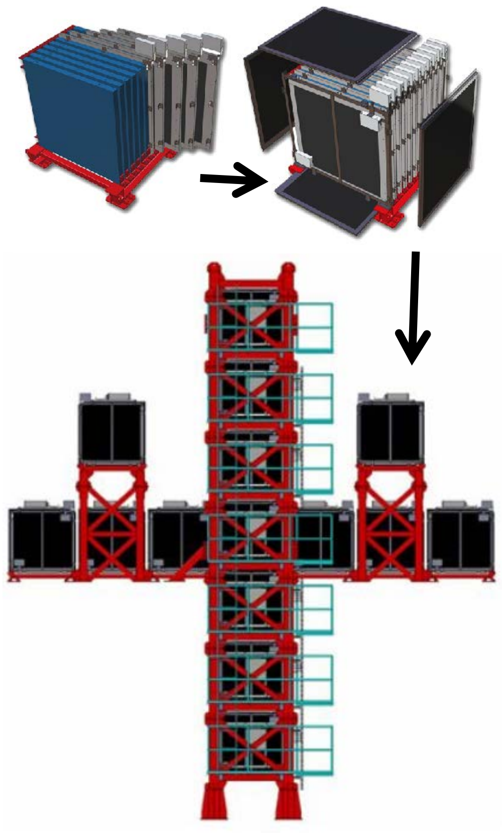
Near Detectors at 280m downstream

- **Two detectors were installed; they are On-axis Detector in the direction of the neutrino beam center, and Off-axis detector in the direction of Super-Kamiokande.**

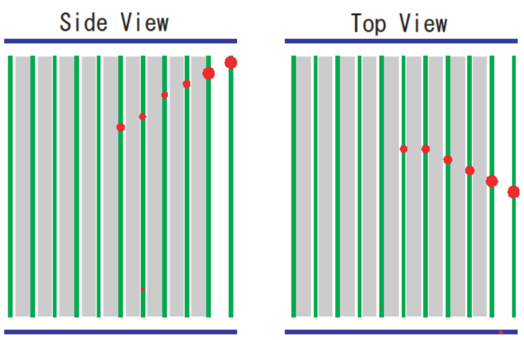


On-axis detector (INGRID)

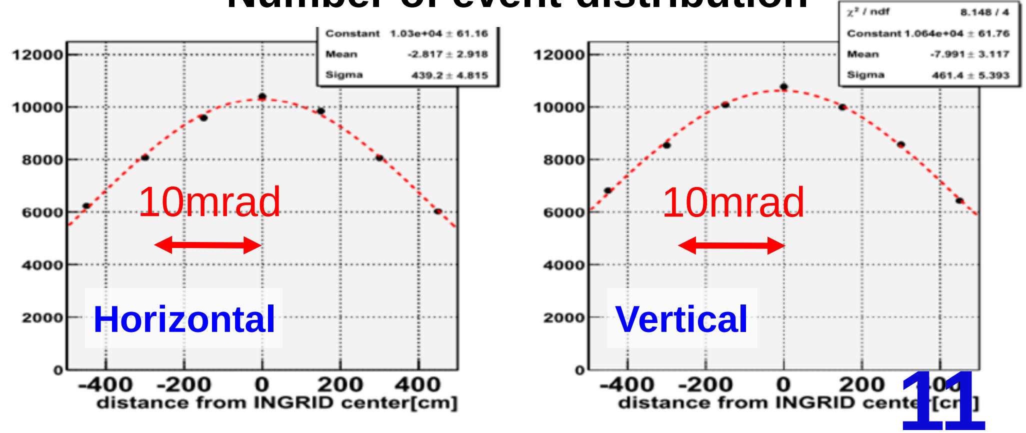
- Consists of 16 modules; 7 horizontal, 7 vertical, and 2 off-diagonal. Each module is 1m x 1m x 1m cube.
- Each module is “sandwich” of 11 scintillator layers and 10 iron layers. They are surrounded by 4 veto planes.
- The neutrino beam center is obtained from horizontal/vertical distribution of the neutrino event rate. The nominal accuracy is ~0.1 mrad.



INGRID event view



Number of event distribution

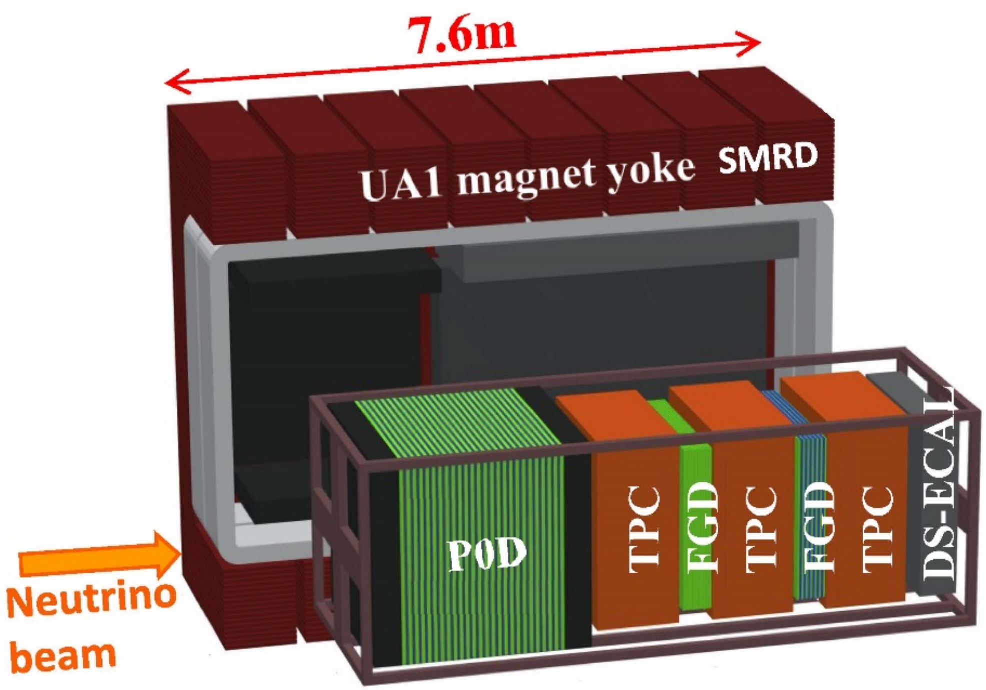


Off-axis detector (ND280)

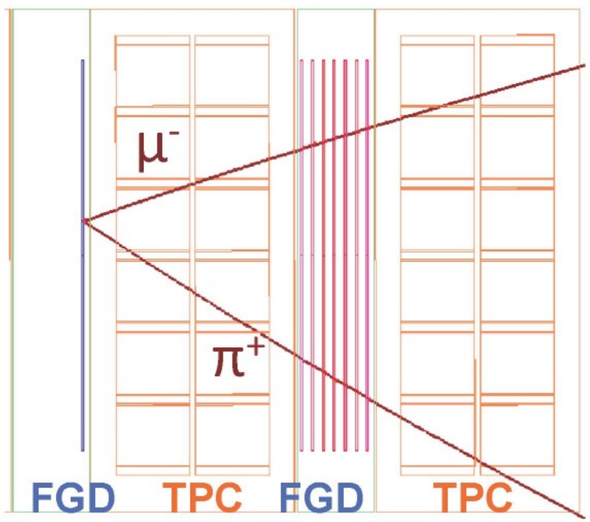
- ND280 is made from following components.
  - -2 FGDs (Fine-Grained Detectors)
  - -3 TPCs (Time Projection Chambers)
  - -P0D (π^0 detector)
  - -ECAL (Electromagnetic CALorimeters)
  - -SMRD(Side Muon Range Detector).

  All components are in 0.2 T of magnetic field.

- Neutrino flux as well as neutrino interactions can be studied from the reconstructed track information.

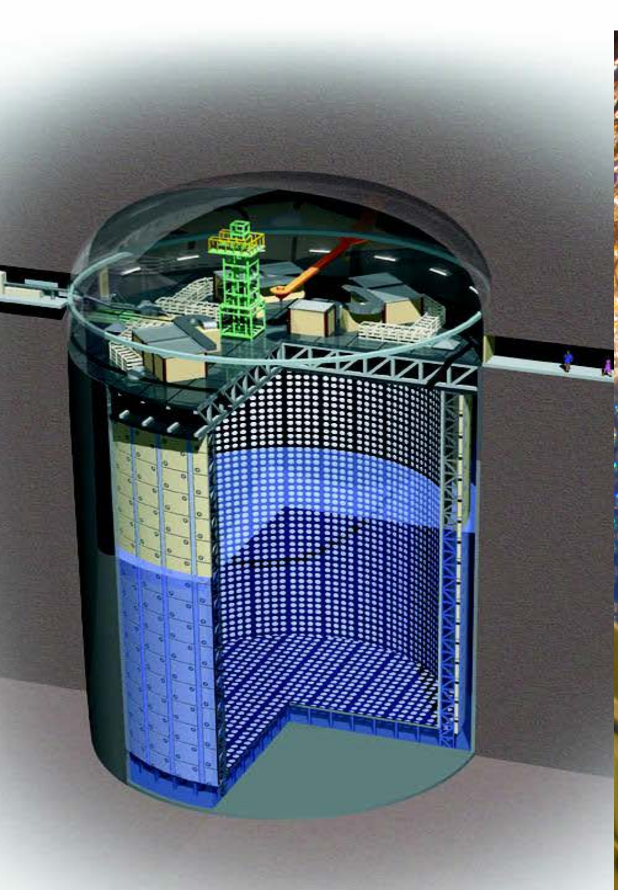


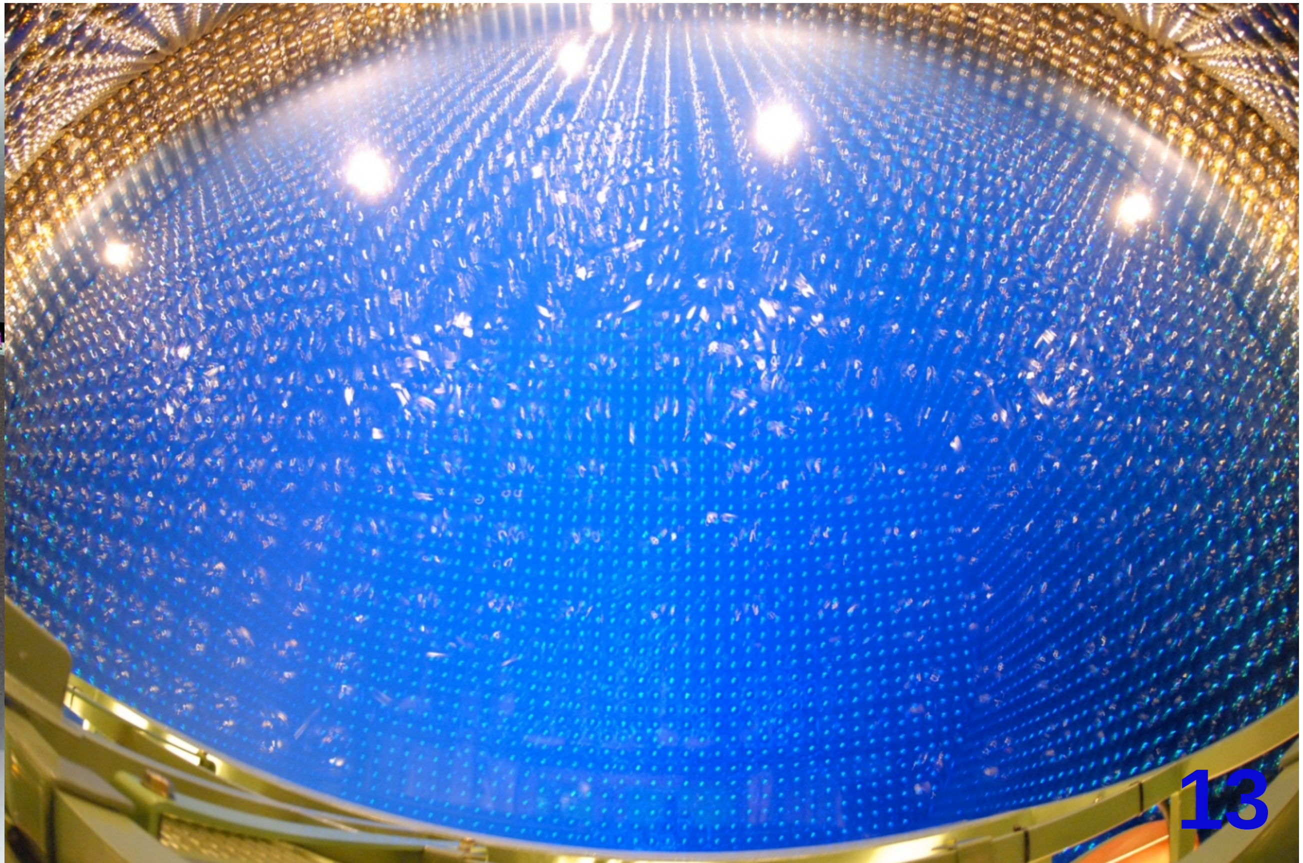
CC1π



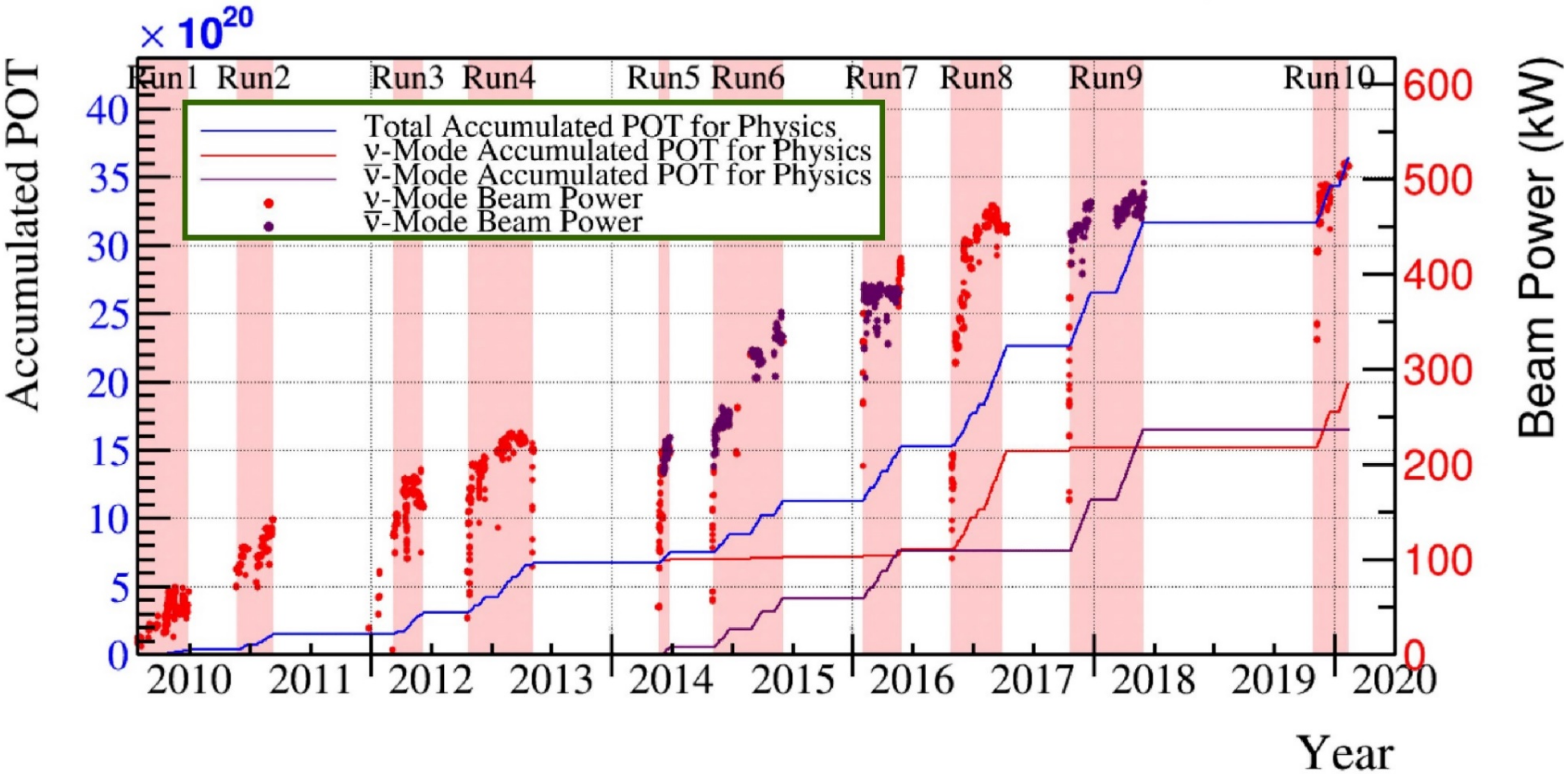
Far detector : Super-Kamiokande (SK)

- **50kt water Cherenkov detector. The fiducial volume of the inner detector is 22.5 kton, and is viewed by 11129 20-inch diameter PMTs. Outer water layer surrounding the inner volume is viewed by 1885 8-inch diameter PMTs.**
- **Located at 1000 m underground in Kamioka mine, Japan. The distance from J-PARC is 295 km.**





History of the T2K neutrino beam until February 2020

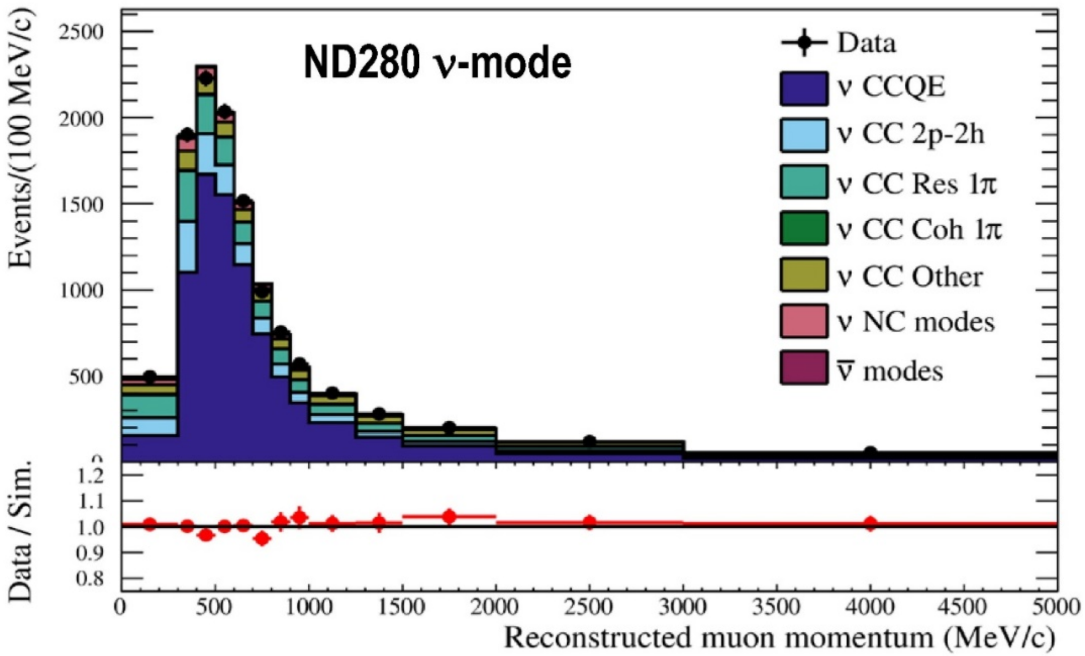


- **Physics run started in January 2010. Anti-neutrino beam running (reverse horn current direction) started in June 2014. At middle of February 2020, the maximum beam power achieved is 523kW.**
- **Integrated POT (protons on target) until middle of February 2020: 1.99×10^{21} (ν) + 1.65×10^{21} ($\bar{\nu}$) = 3.64×10^{21} (total).**

Systematic errors on expected number of events

- Neutrino oscillation parameters are extracted from a comparison of SK data and expectations. The systematic error on the expectation is very important.
- The expectations are constrained to be consistent with ND280. This reduces the neutrino flux and cross section uncertainties and the systematic error on the expectation at SK.

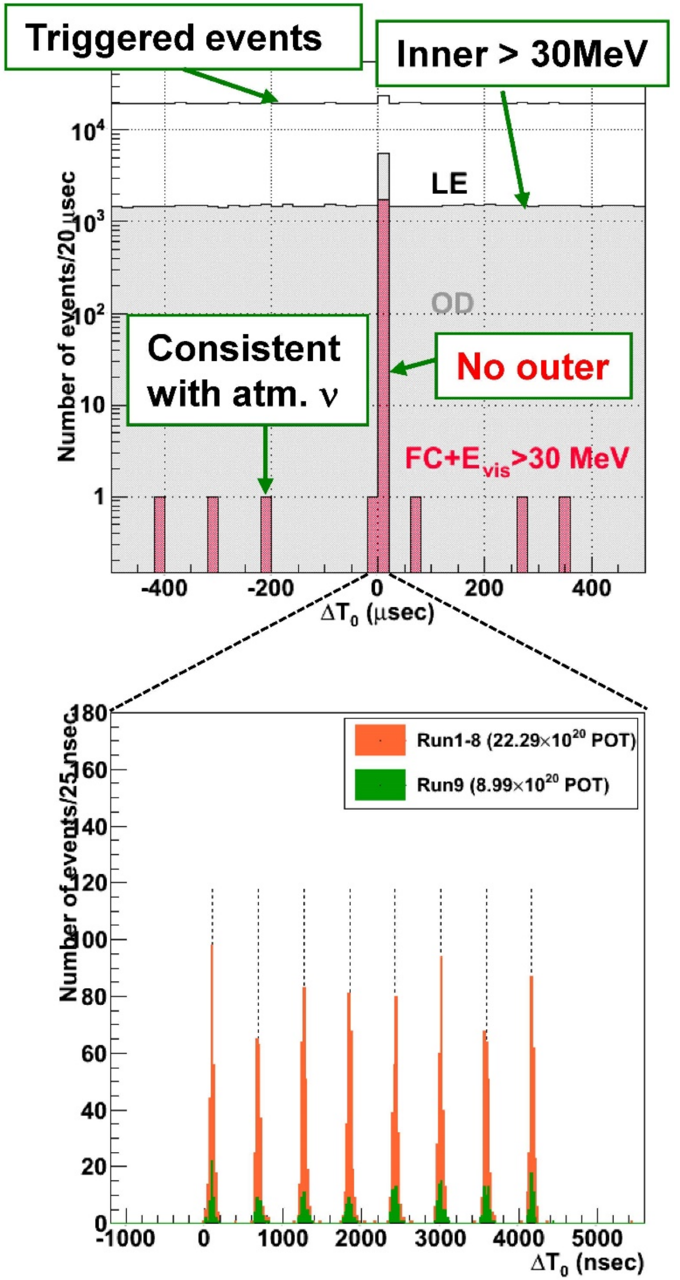
An example of data-expectation comparison in ND280



event	Without ND280	With ND280
ν μ-like single ring	14.6%	5.1%
ν e-like single ring	16.9%	8.8%
ν̄ μ-like single ring	12.5%	4.5%
ν̄ e-like single ring	14.4%	7.1%

Super-Kamiokande Event Selection

- **Data recorded between Jan. 2010 and May 2018 are used. It corresponds to 1.49x10^{21} (ν) + 1.64x10^{21} ($\bar{\nu}$).**



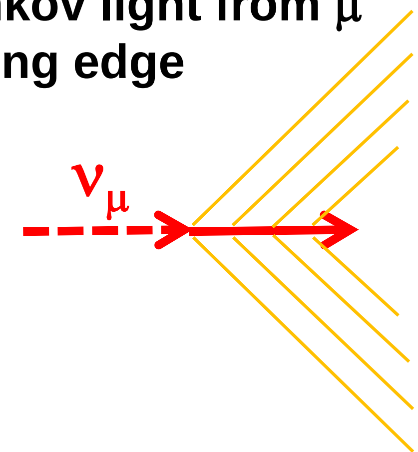
Event Selection Criteria

1. **Total energy deposit in the inner detector is larger than 30 MeV equivalent.**
2. **No outer detector activity**
3. **The event time agrees with ~5 μsec beam period in 2.48 sec accelerator cycle. (8 bunch structure can be found.)**
4. **1 Ring events → μ/e particle identification is applied**

μ/e identification in Super-Kamiokande

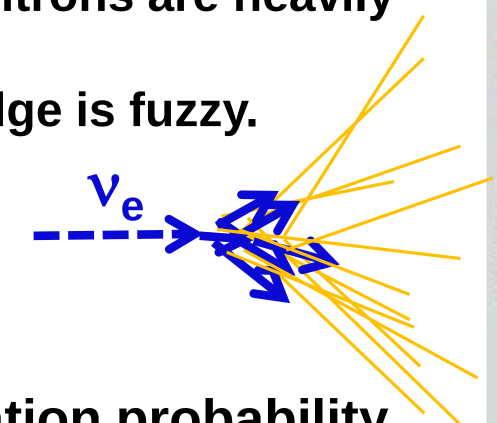
$\nu_\mu \rightarrow \mu$

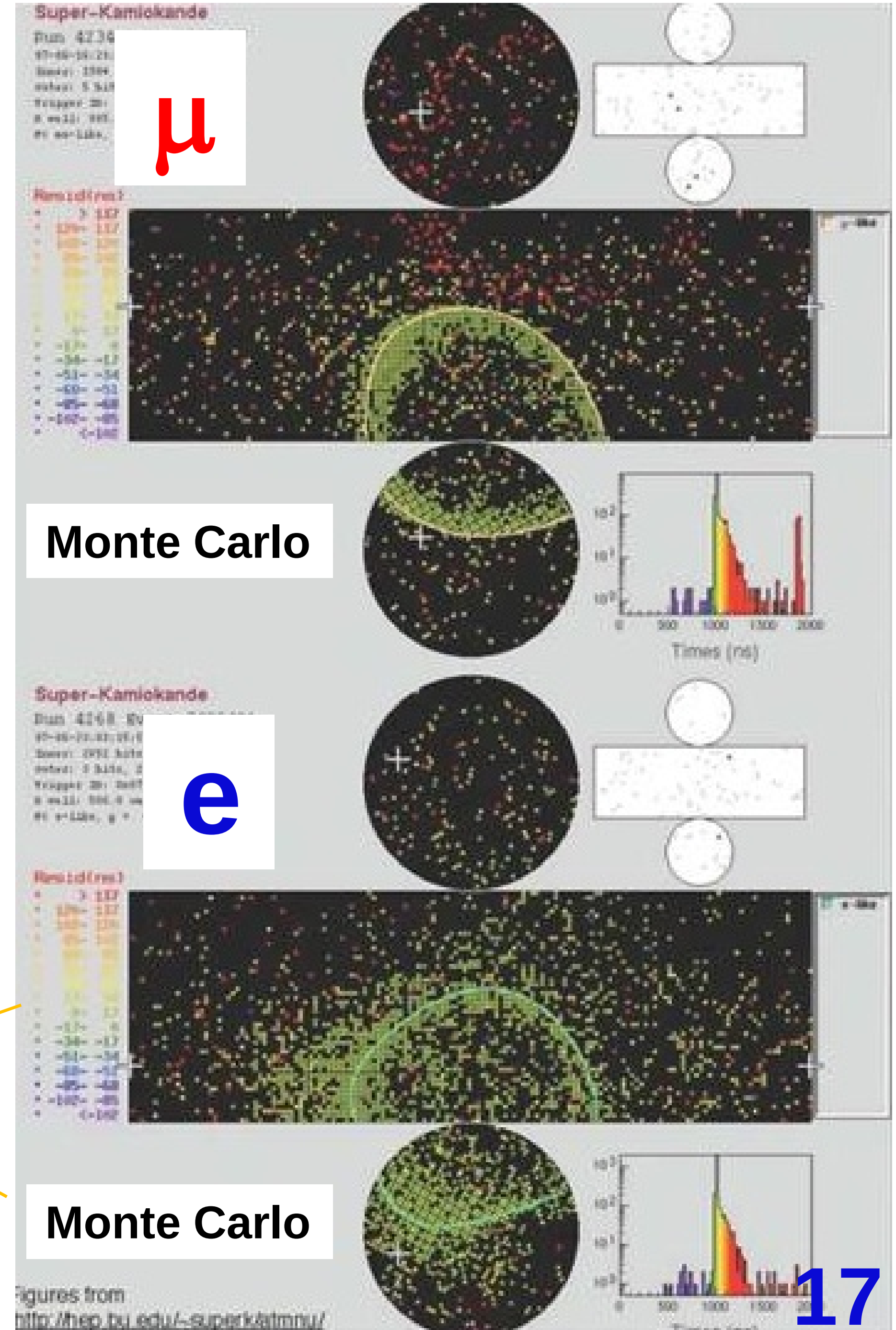
Only direct Cherenkov light from μ
Clear Cherenkov ring edge



$\nu_e \rightarrow e$

Cherenkov light from e-m shower.
Electrons and positrons are heavily scattered.
Cherenkov ring edge is fuzzy.





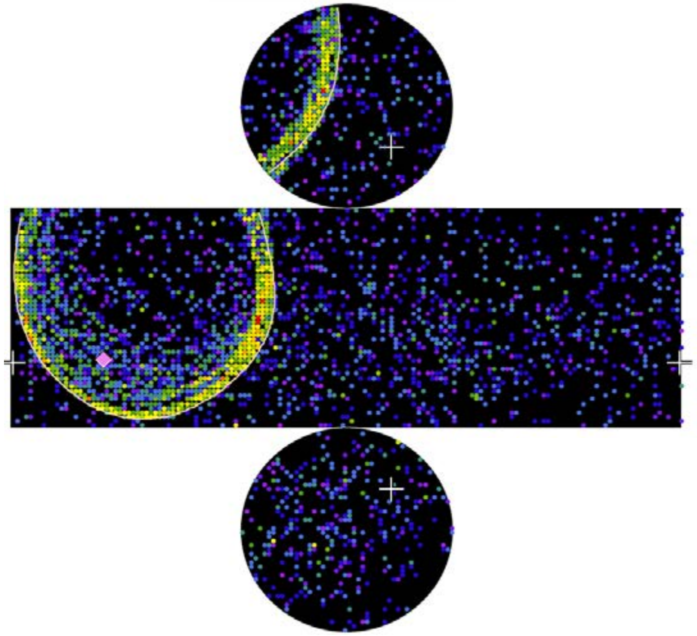
- **μ/e misidentification probability is less than 1 %.**

Event Selection

Examine Particle ID of 1 ring events

ν_μ selection

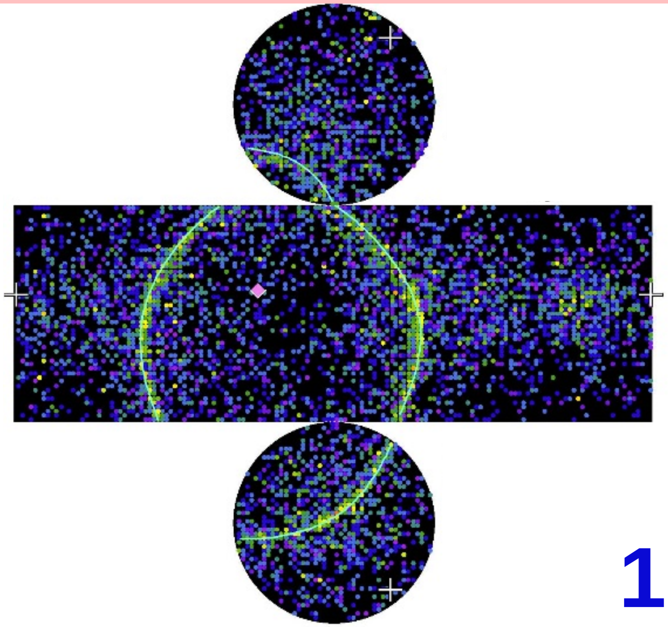
- μ-like PID
- $p_\mu > 200$ MeV/c
- Michel electron 1 or 0



ν_e selection

- e-like PID
- $p_e > 100$ MeV/c
- $E_{rec} < 1250$ MeV
- π^0 rejection

π^0 rejection : Forced 2nd ring is assumed. Invariant mass and likelihood for π^0 are examined.

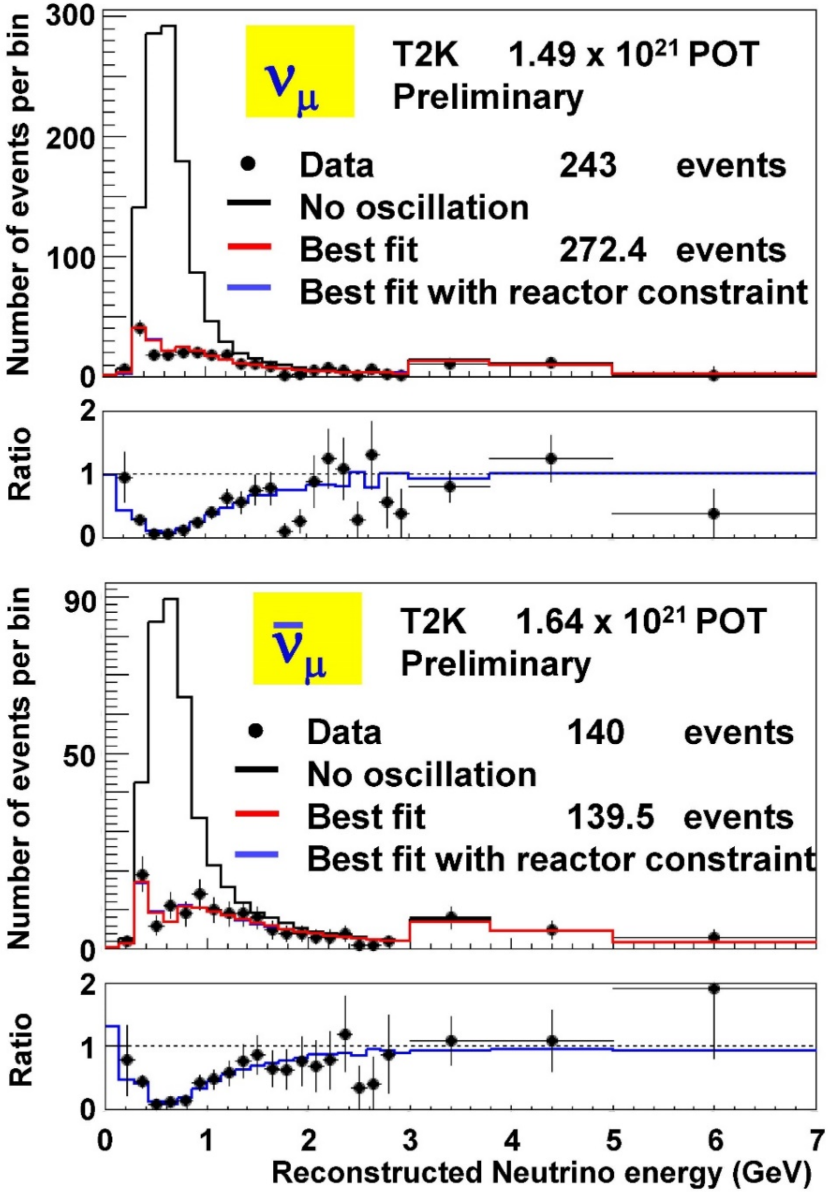


Results of ν_μ and $\bar{\nu}_\mu$ disappearance

- **Disappearance of muon neutrino events as well as a distortion of neutrino energy spectrum is obvious for both ν_μ and $\bar{\nu}_\mu$.**
- **Oscillation parameters for anti-neutrinos well agree with the parameters for neutrinos within statistical errors.**
- **These results are updates of past publications.**

PRL 112, 181801(2014),
PRD 91, 072010(2015)
for 6.57x10^{20} POT, **120** ν_μ data

PRL 116, 181801(2016)
for 4.01x10^{20} POT, **34** $\bar{\nu}_\mu$ data

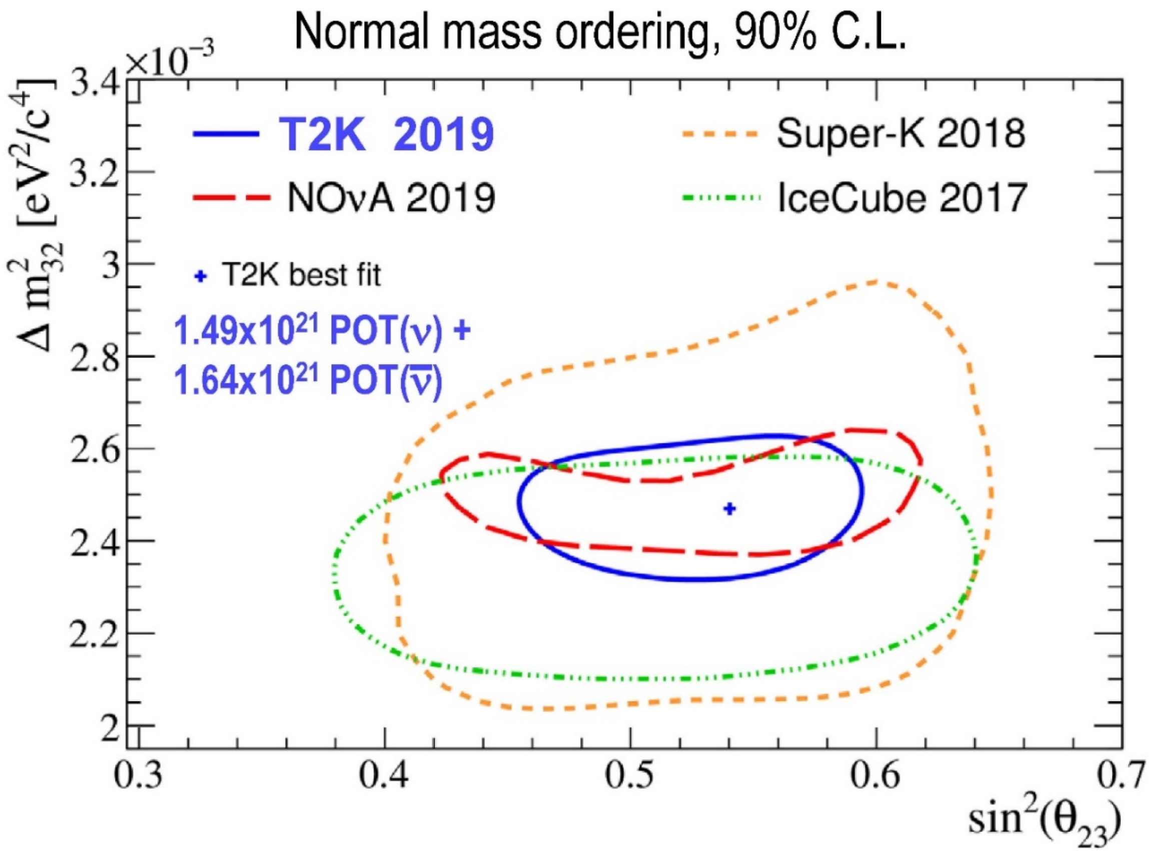


Constraints on $\sin^2\theta_{23}$ - $|\Delta m^2_{32}|$ plane

- **Constraints on $|\Delta m^2_{32}|$ and $\sin^2\theta_{23}$ are obtained.**
- **The best fit parameters are**

  $|\Delta m^2_{32}|$ = 2.47 x 10^{-3} eV^2
  $\sin^2\theta_{23}$ = 0.541

- **The T2K results well agree with other experiments, and give most stringent constraints on $\sin^2\theta_{23}$. It does not contradict with the maximal mixing ($\sin^2\theta_{23}$=0.5).**
- **The constraint for inverted mass ordering is almost similar to that for normal mass ordering.**

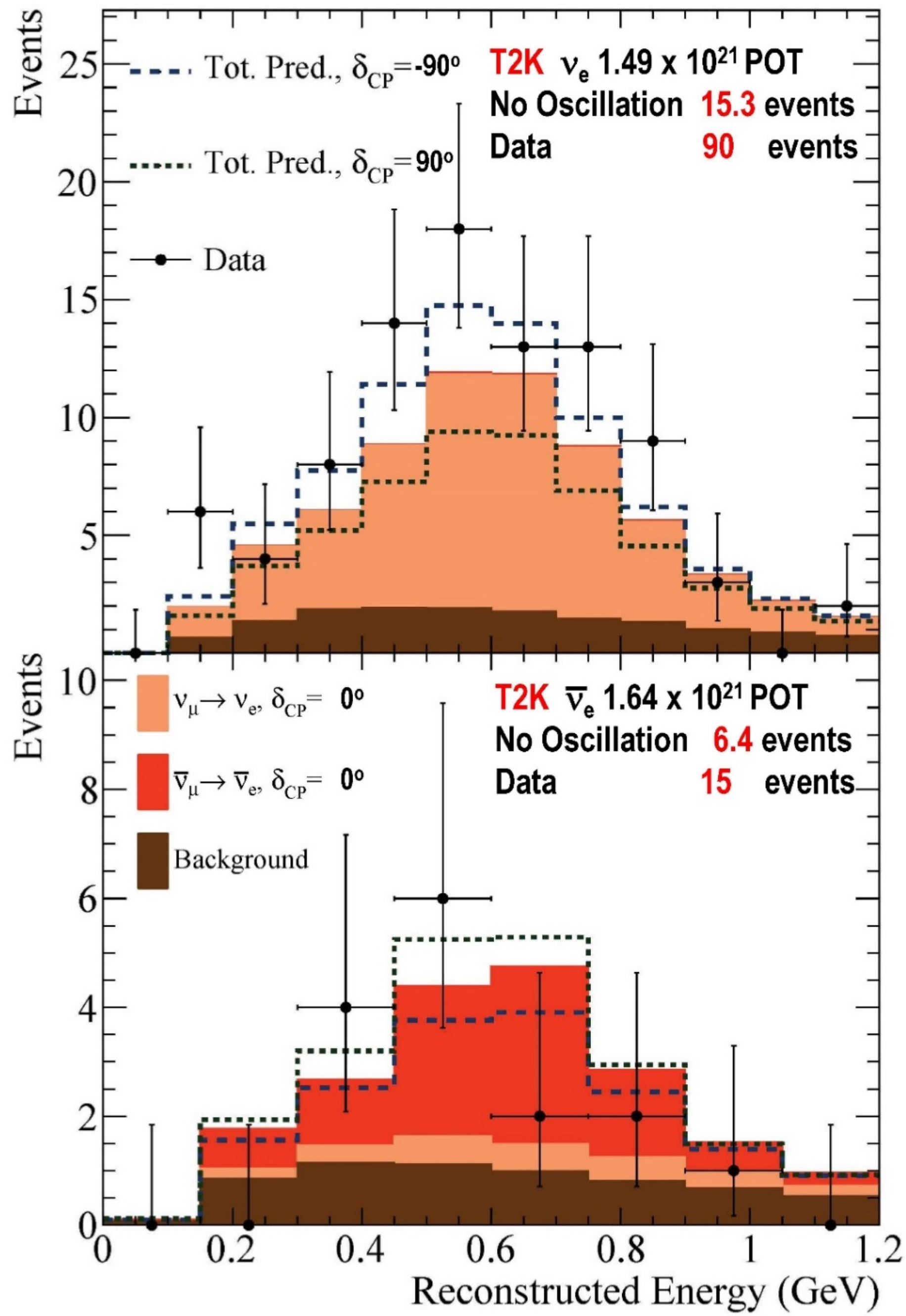


Results of ν_e and $\bar{\nu}_e$ appearance

- For ν_e appearance, **90** events are found where expectation for no oscillation is **15.3**. It is certainly ν_e appearance signal.

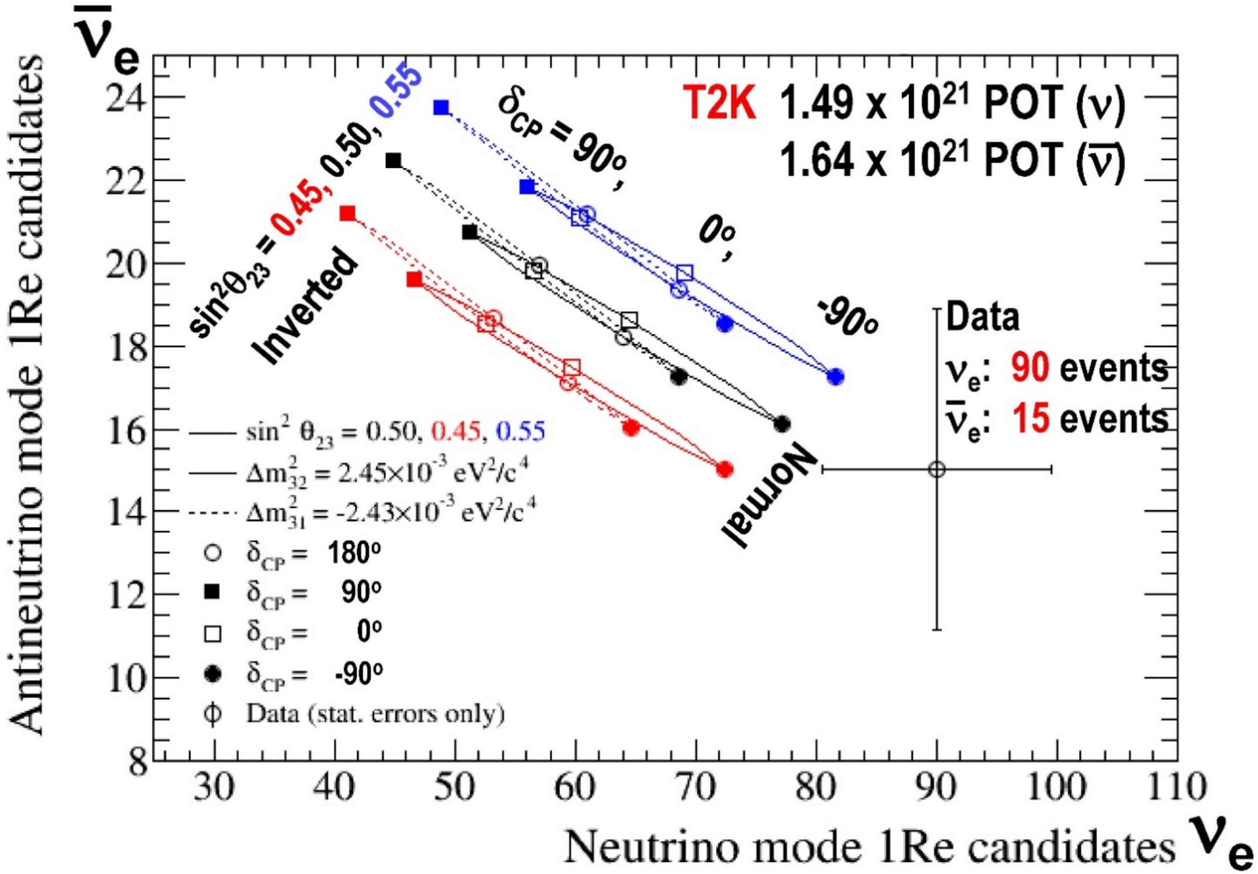
  (In addition to 75 CCQE events, 15 $CC1\pi^+$ events are also employed in the ν_e analysis to improve the statistics.)

- For $\bar{\nu}_e$ appearance, **15** events are found where expectation for no oscillation is **6.4**. To claim a significant appearance signal, more statistics is needed.



ν_e VS $\bar{\nu}_e$

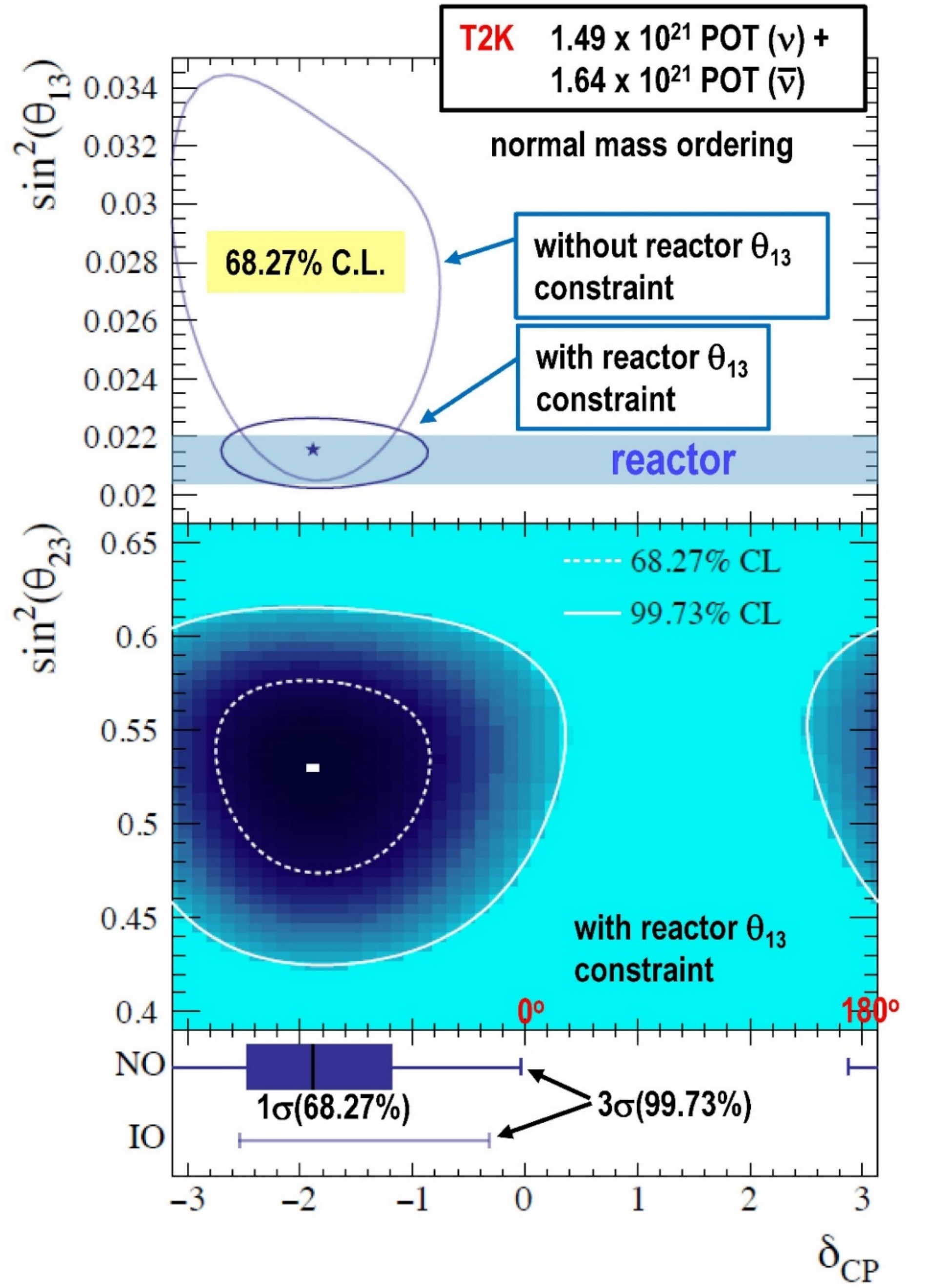
- Number of ν_e and $\bar{\nu}_e$ signals are compared with expectations in the 2-dimensional plane.



- More electron neutrinos, and less electron anti-neutrinos are observed.
  - Negative δ_{CP} (δ_{CP} ~ -90°) is favored over positive δ_{CP}.
  - Normal mass ordering is favored over Inverted mass ordering.

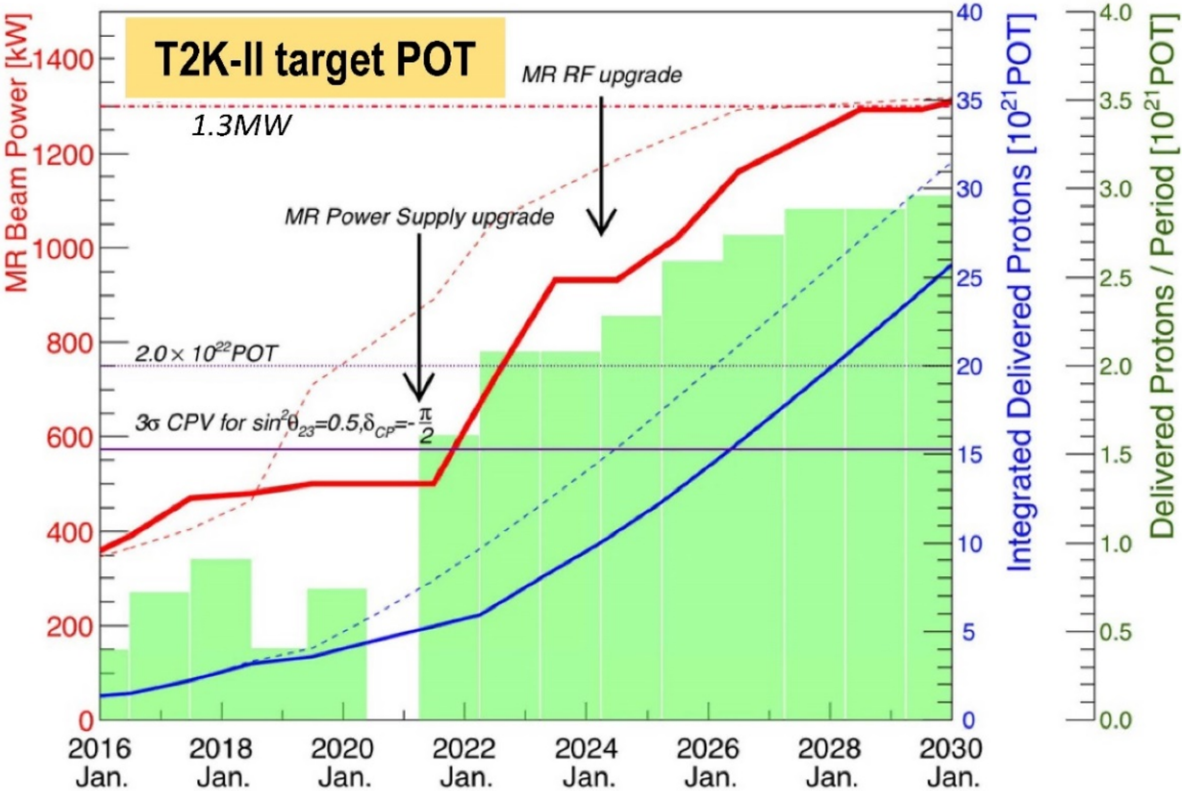
Constraints on δ_{CP} and the mass ordering

- **Constraints on δ_{CP} are calculated.**
- **The statistical probability of normal mass ordering (NO) is 88.9%, and that of inverted mass ordering (IO) is 11.1%. NO is favored over IO.**
- **The best fit value for NO with 1σ error is $-108^{o}\,{}^{+40^{o}}_{-33^{o}}$.**
- **The 3σ allowed intervals are $-195^{o} < \delta_{CP} < -2^{o}$ for NO and $-145^{o} < \delta_{CP} < -18^{o}$ for IO.** (=165°)
- **For CP-conserving cases, (NO,0°),(IO,0°) and (IO,180°) are outside of 3σ region. (NO,180°) is outside of 2σ region. All CP-conserving cases are excluded with more than 2σ.**



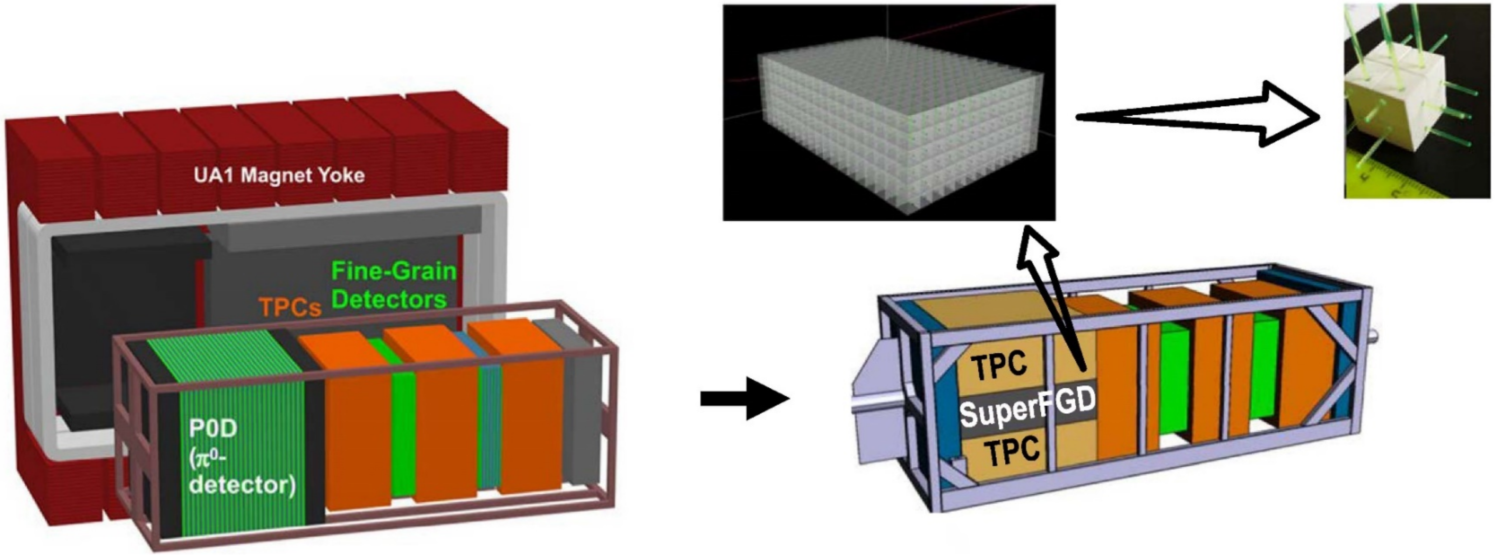
Future (beam upgrade)

- Upgrades of the J-PARC Main Ring components as well as the neutrino beamline components are in progress. Most of the work will be done in the long shutdown in 2021.
- The beam power will be upgraded from ~500kW to >1000kW around 2025. After all upgrades are completed, 30×10^{20} POT data will be stably accumulated every year. Note that accumulated POT between 2010 and 2020 was 36×10^{20} POT.



Future (ND280 upgrade)

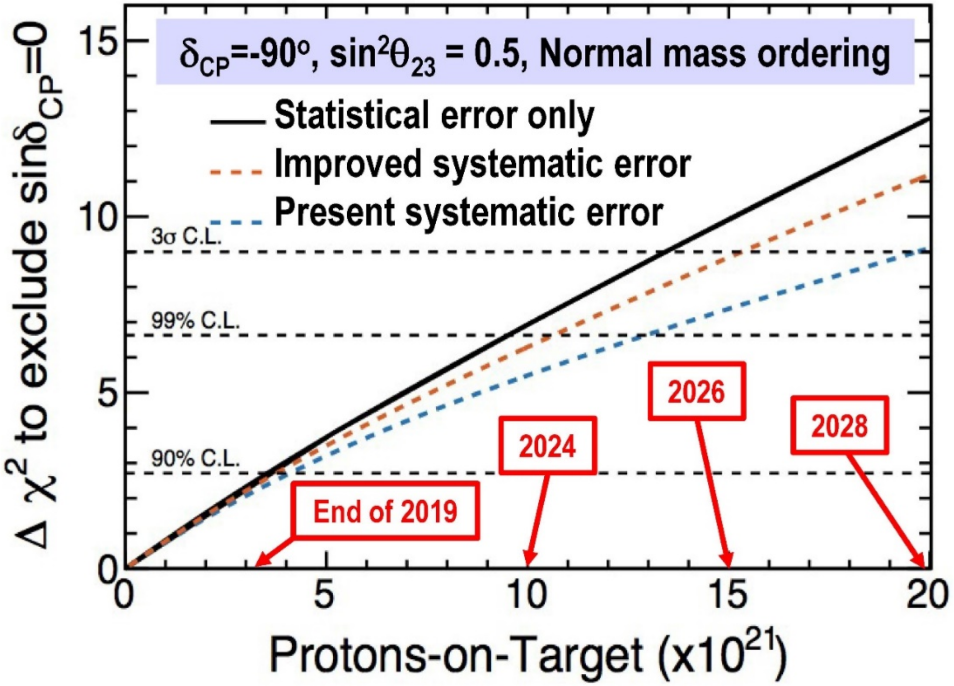
- Upgrade of the near detector (ND280) is also planned during the long accelerator shutdown in 2021.
- The main component of the upgrade is SuperFGD, that will be installed in the center of the ND280 detector.



- It is consist of ~2 million optically independent 1cm x 1cm x 1cm plastic scintillator cubes. The signal is read out along three orthogonal directions by wavelength shifting fibers.
- This high granularity detector will improve the understanding of the neutrino-nucleus interaction as well as the neutrino flux. And it will contribute to a reduction of the systematic errors.

Future (sensitivity)

- Potential capability for the discovery of CP violation is estimated as a function of Protons of Target.

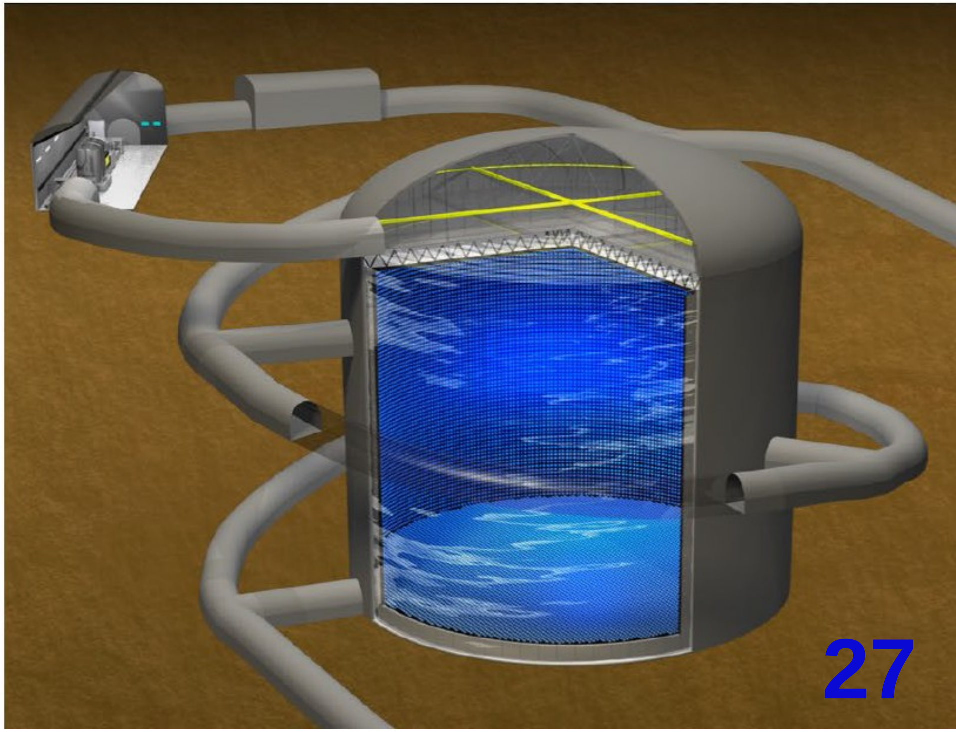


- At present the statistical error for the appearance signals is dominant. However, the reduction of systematic error will become important after a large accumulation of POT.

- The statistical errors will be improved by the beam power upgrade. The systematic errors will be improved by the near detector upgrade. And we hope that we can discover the CP violation in 2020s.

Future (Far detector)

- **Hyper-Kamiokande is the next generation far detector (from a viewpoint of T2K experiment). It has ~186 ktons of fiducial volume which is about 8 times larger than Super-Kamiokande.**
- **Because of** *a political reason*, **some T2K upgrade in Tokai site is a part of Hyper-Kamiokande project. It includes IWCD (Intermediate Water Cherenkov Detector, ~1km downstream from the target).**
  (A small fraction of the very big money is reasonably large money.)
- **A part (~5%) of total budget was approved by the Japanese Diet in January 2020, and will be used in the coming fiscal year. Since the Japanese budget is year-by-year basis, approval of ~5% in the first year certainly means GREEN LIGHT.**
- **More about Hyper-Kamiokande project will be reported by Dr. Federico Nova this afternoon.**



Summary

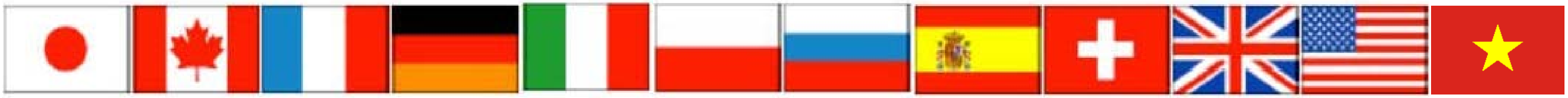
- At middle of February 2020, the maximum beam power achieved is **523kW**, and total POT is **3.64×10^{21}**.
  Analysis based on **1.49×10^{21}** (ν) + **1.64×10^{21}** ($\bar{\nu}$) is obtained.
- Results from $\nu_\mu/\bar{\nu}_\mu$ disappearance well agree with other experiments.
  It does not contradict with the maximal mixing ($\sin^2\theta_{23}$=0.5).
- From $\nu_e/\bar{\nu}_e$ appearance analysis, **normal** mass ordering is favored over inverted mass ordering. **Negative δ_{CP}** is favored.
- The best fit value for δ_{CP} with 1σ error is **$-108^{o}\,{}^{+40^{o}}_{-33^{o}}$** (normal mass ordering).
- **All CP-conserving cases are excluded with more than 2σ.**
- The beam power upgrade as well as the near detector upgrade are in progress. **We hope that we can discover the CP violation in 2020s.**

Thank you very much

The T2K collaboration includes about 500 physicists from 12 countries (Canada, France, Germany, Italy, Japan, Poland, Russia, Spain, Switzerland, UK, USA, Vietnam).

Backup

The T2K collaboration



The T2K collaboration includes about 500 physicists from 12 countries (Canada, France, Germany, Italy, Japan, Poland, Russia, Spain, Switzerland, UK, USA, Vietnam).

Main Ring

- Third (and final) stage accelerator. Proton Synchrotron of 1568m circumference.

- The 30 GeV proton beam is extracted to the neutrino beamline.

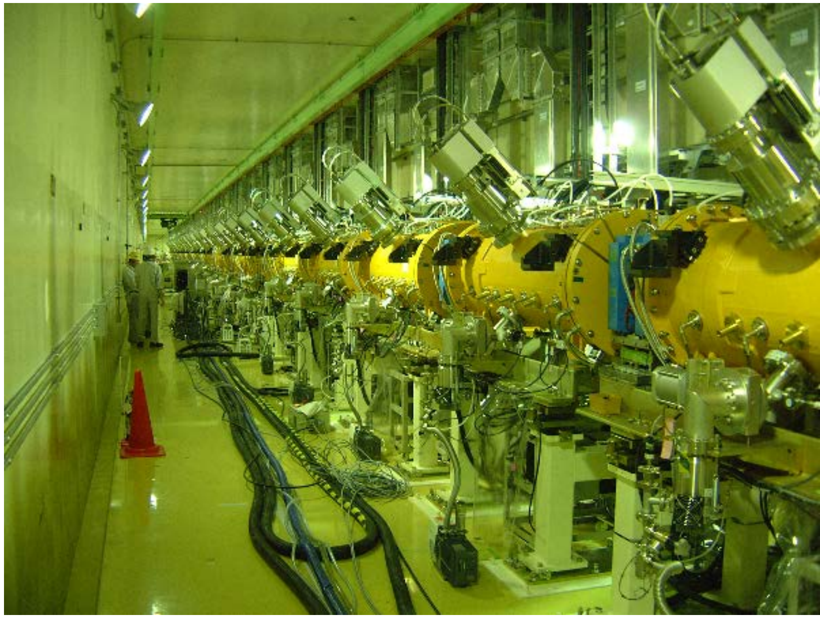
Proton beam from J-PARC

- The design value of the proton beam from J-PARC is as follows;

E_{proton} :	30GeV
Beam power:	750kW
Proton per Second:	1.6×10^{14}

Linac

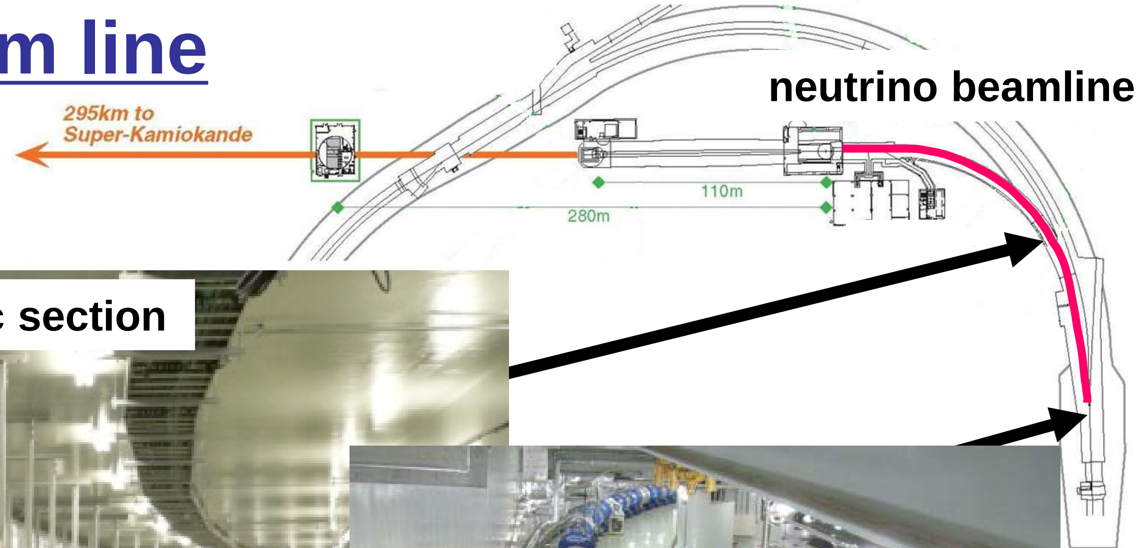
- First stage accelerator, 330m in length.
- Protons are accelerated to 400 MeV.



RCS (Rapid Cycling Synchrotron)

- Second stage accelerator, Proton Synchrotron of 348m circumference.
- Protons are accelerated up to 3 GeV.

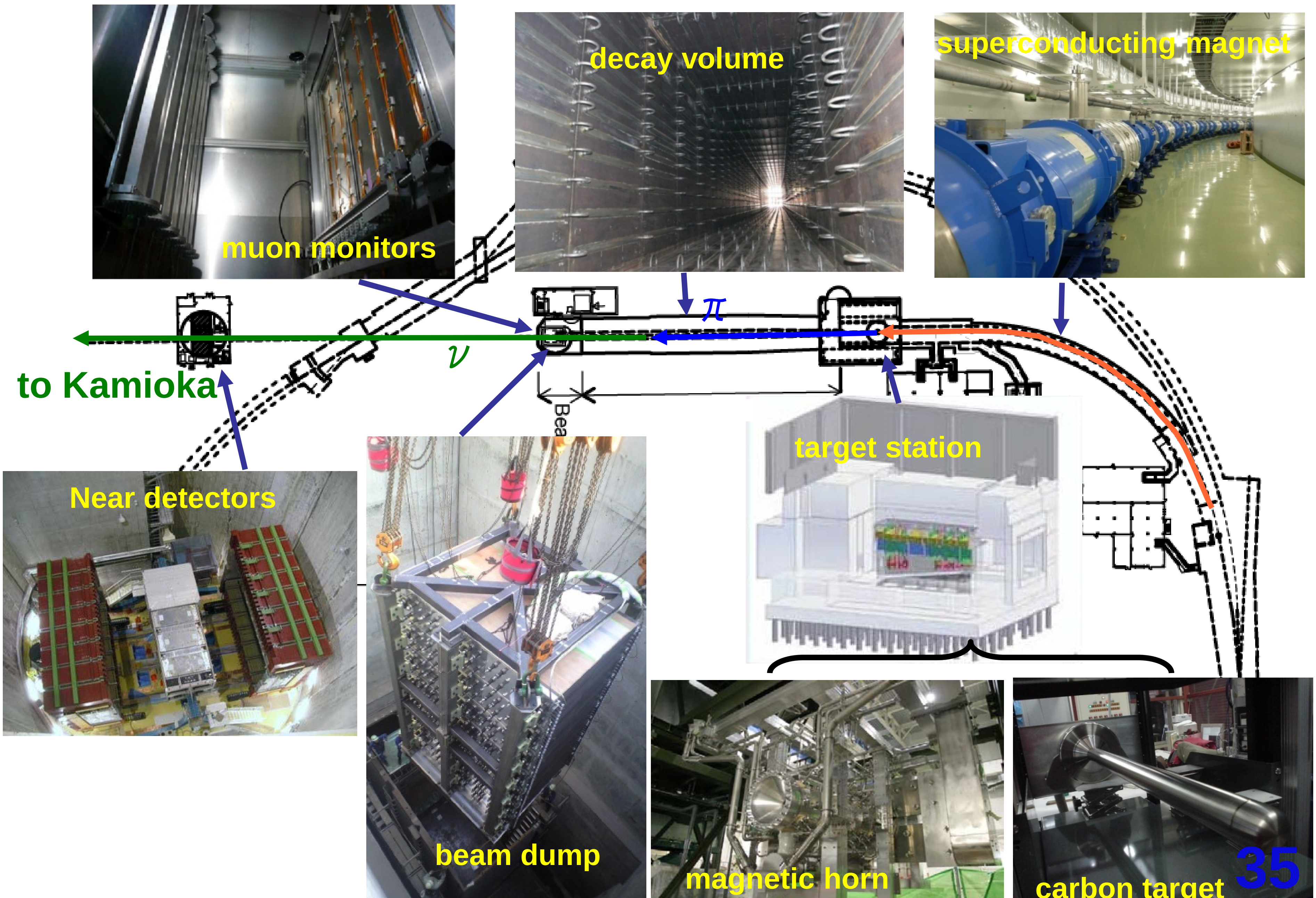
Primary Proton beam line



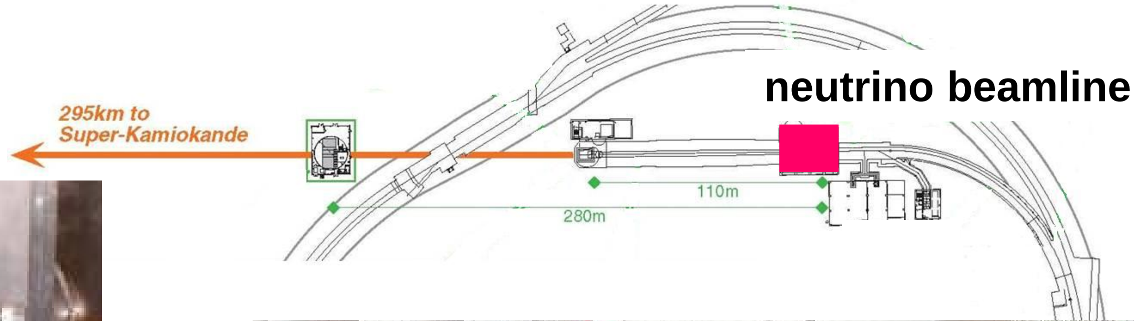
Superconducting magnet in Arc section

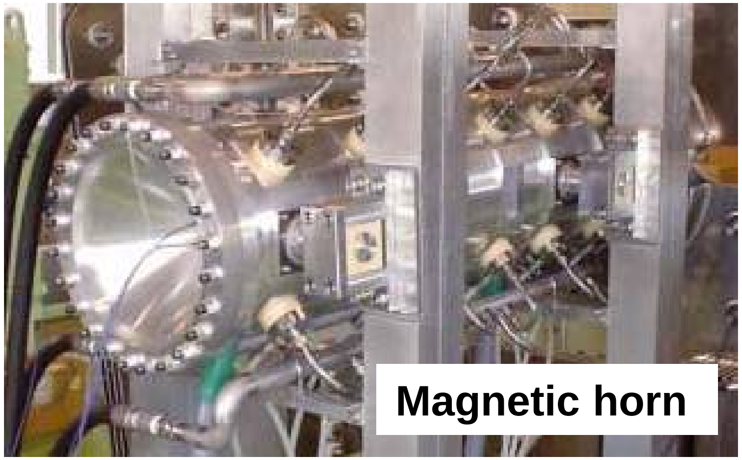
Normal-conducting magnet in Preparation section

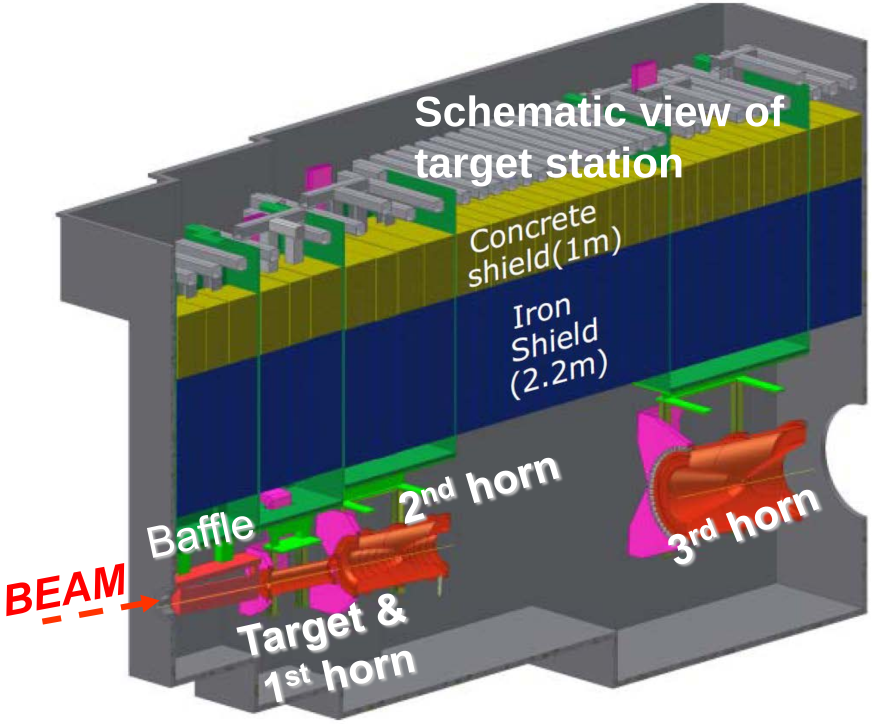
Neutrino beam line and components



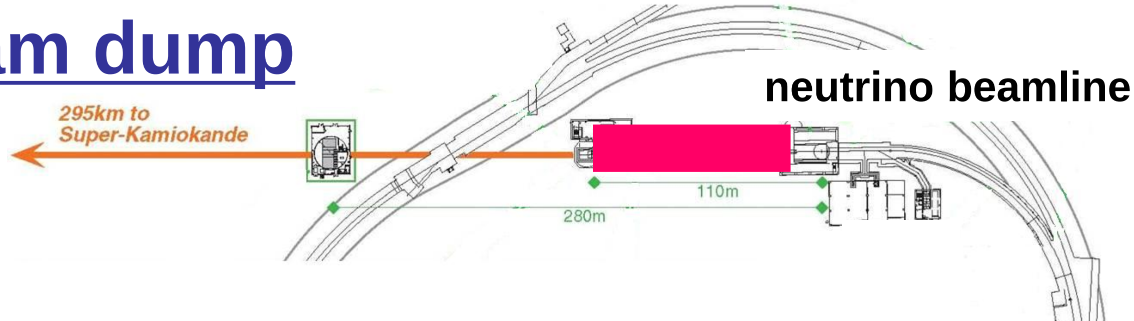
Target Station



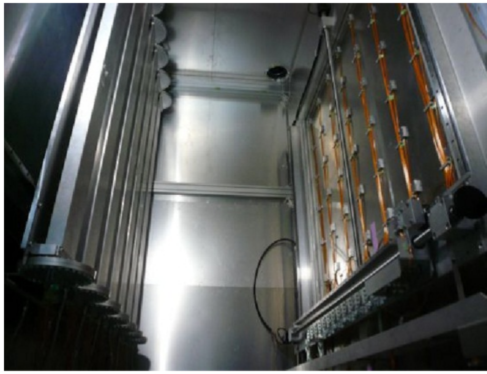


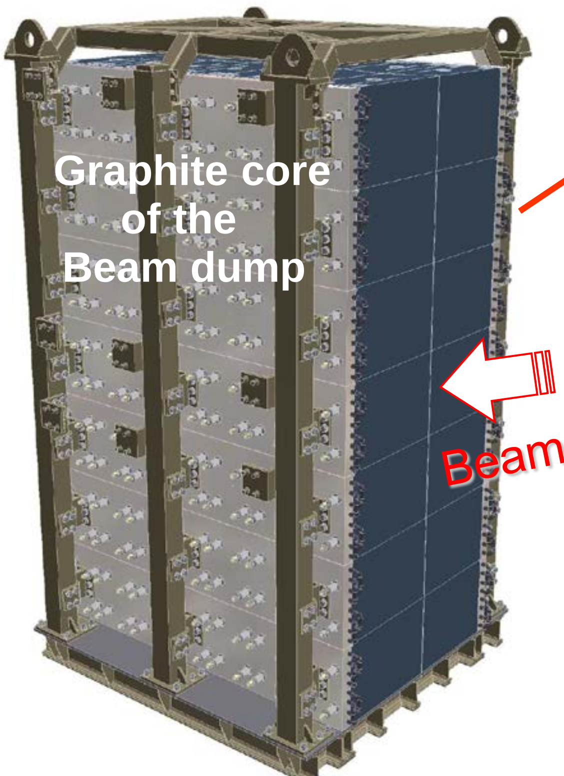


Decay pipe and Beam dump



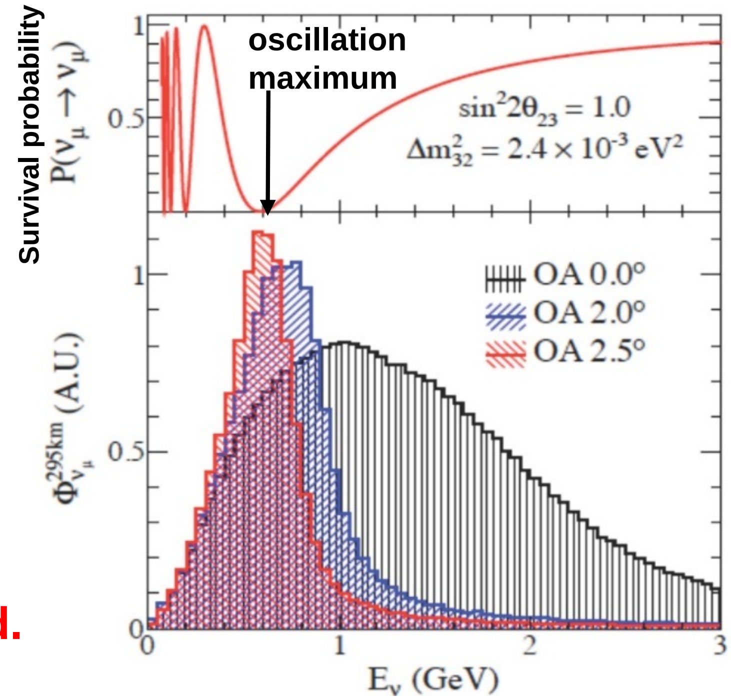
Muon monitors in Muon Pit





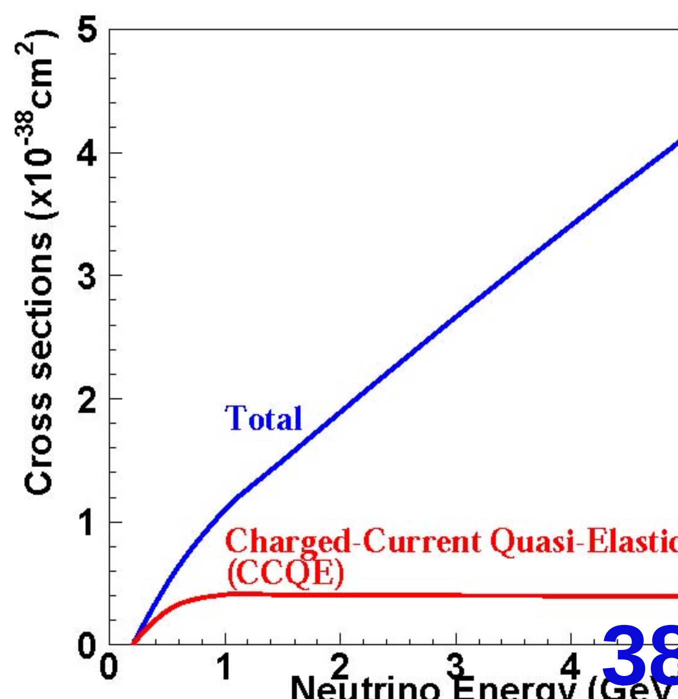
Off-axis beam

The center of the beam direction is adjusted to be 2.5^o off from the SK direction.
Neutrino energy spectrum becomes quasi-monochromatic. The peak energy is ~0.6 GeV.



Merits of the off-axis beam are:

- The neutrino energy peak agrees with the oscillation maximum.
- High energy (> 1 GeV) neutrinos are suppressed.
  - Neutrino energy spectrum is calculated from CCQE events; $\nu_\mu + n \rightarrow \mu + p$. Fraction of CCQE events is small in high energy range and some of non-CCQE events are serious background for the CCQE selection.
  - Neutral Current (NC) π^0 events are background for the ν_e appearance search. NCπ^0 events are reduced by the suppression of high energy neutrinos.
- Water Cherenkov detector has better performance for single charged particle events.

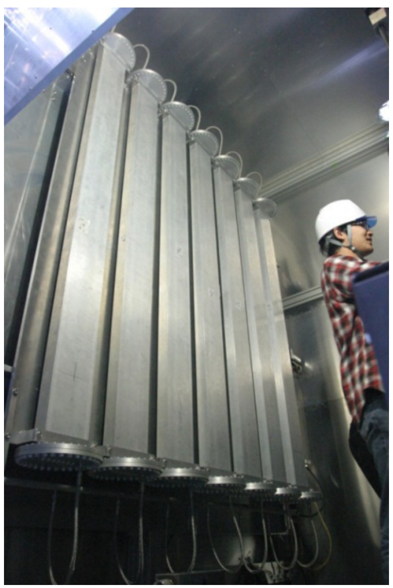


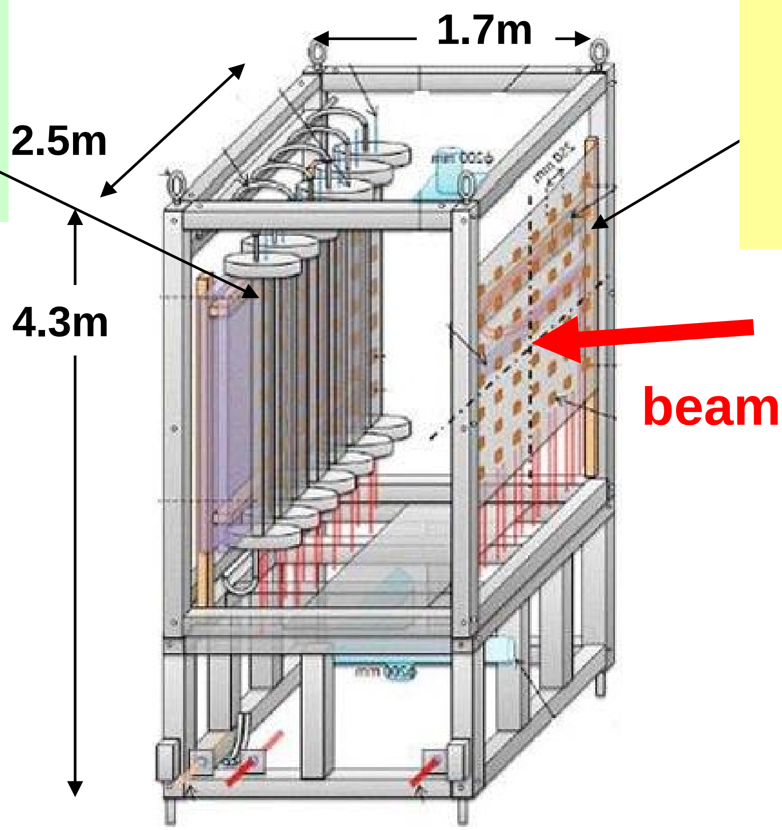
Muon monitors

- Two types of muon monitors are installed downstream of the beam dump for redundancy.

Ionization chamber

7x7 channels
Ar+2%N_2gas (~Mar. 2015)
He+1%N_2gas (May~ 2015)



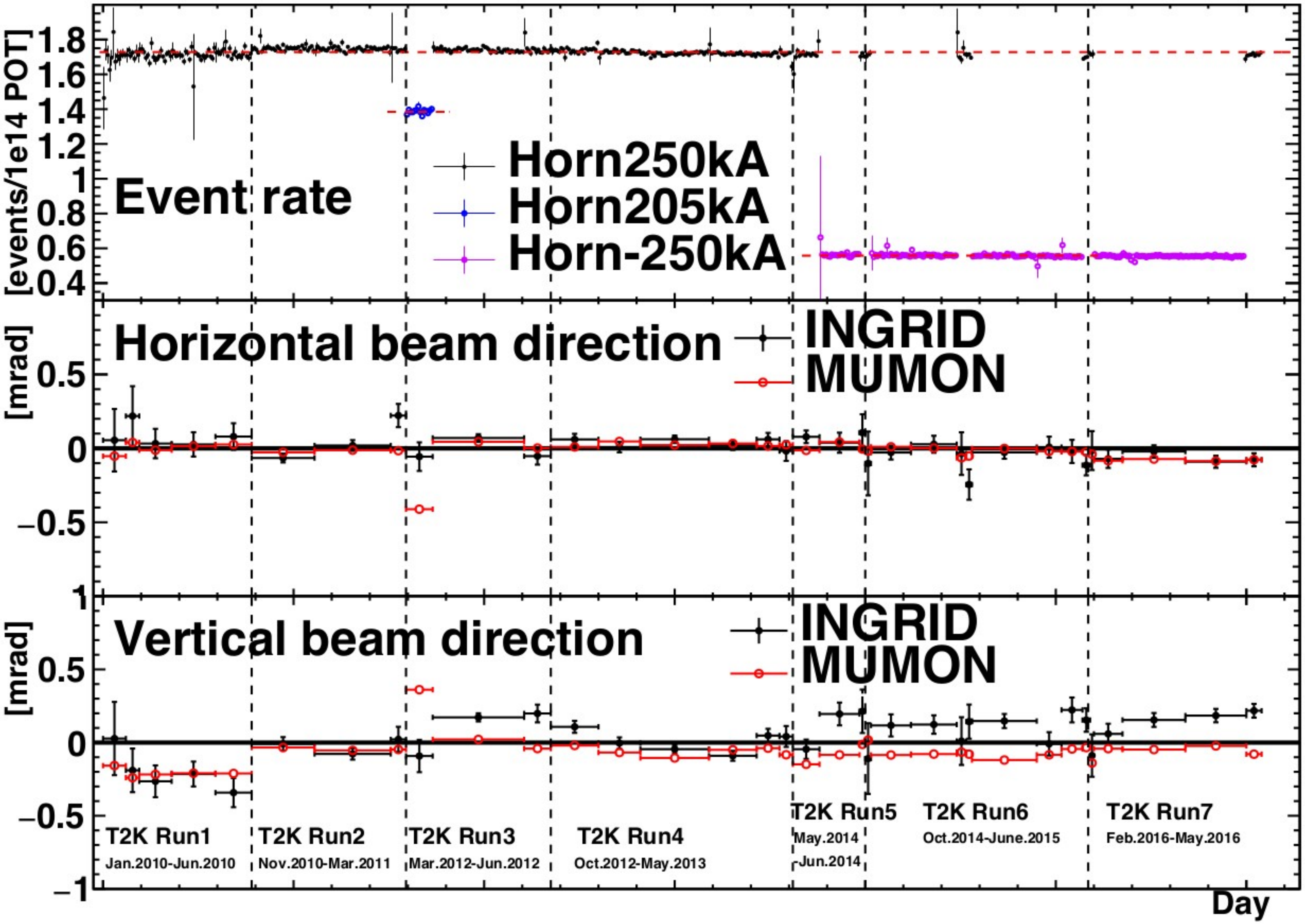


Semiconductor array

7 x 7 channels of Silicon PIN photo diode

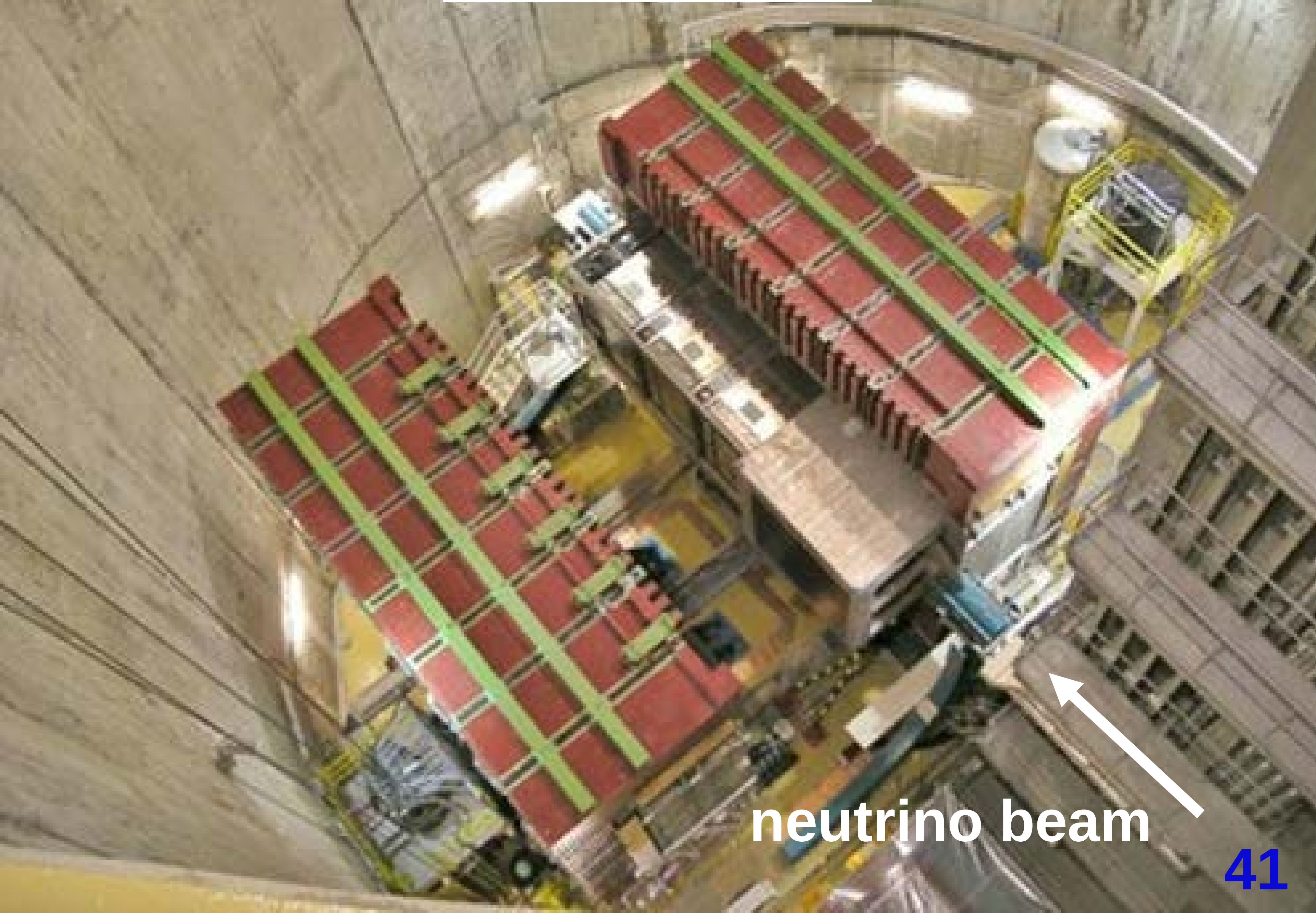
- Confirm the position of the beam center with < 3cm resolution on a bunch by bunch basis. This corresponds to < 0.3mrad beam direction accuracy.

Stability of event rate and beam direction



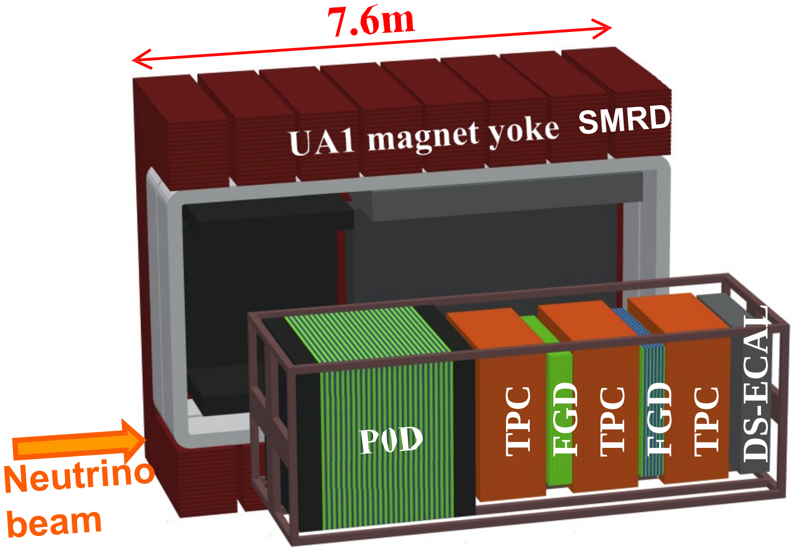
- Event rate is stable over neutrino and anti-neutrino periods.
- Beam direction is much stable than our requirement, 1mrad.

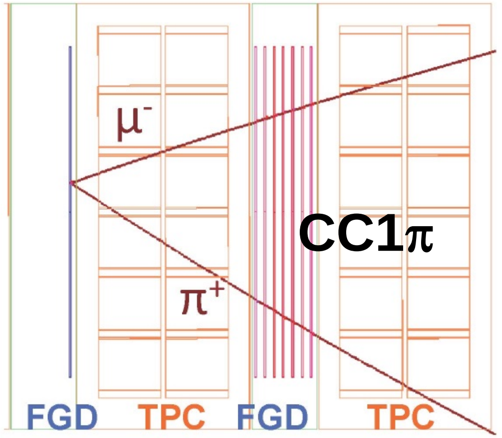
ND280 detector



Off-axis detector (ND280)

- **ND280 is made from several components.**
- **2 FGDs (Fine-Grained Detectors) consist of scintillator bars and one has water as a target material.**
- **3 gas-filled TPCs (Time Projection Chambers) track charged particles.**
- **All components are in 0.2 T of magnetic field. The magnets were previously used in UA1 and NOMAD.**
- **Charged particles are deflected by the magnetic field. The curvature of the track recorded by TPC are used to determine the momentum of the particles.**
- **Neutrino flux as well as neutrino interactions can be studied from the reconstructed track information.**
- **Other components are P0D (π^0 detector), ECAL(Electromagnetic CALorimeter) and SMRD(Side Muon Range Detector).**

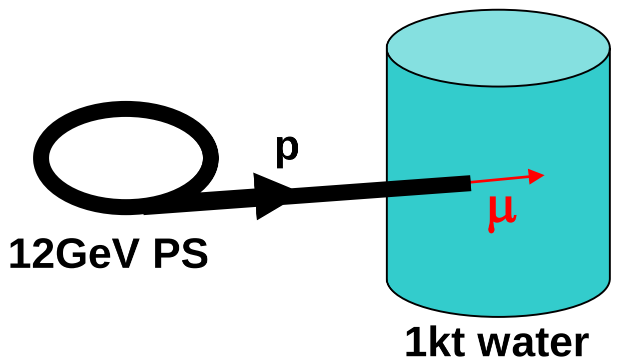




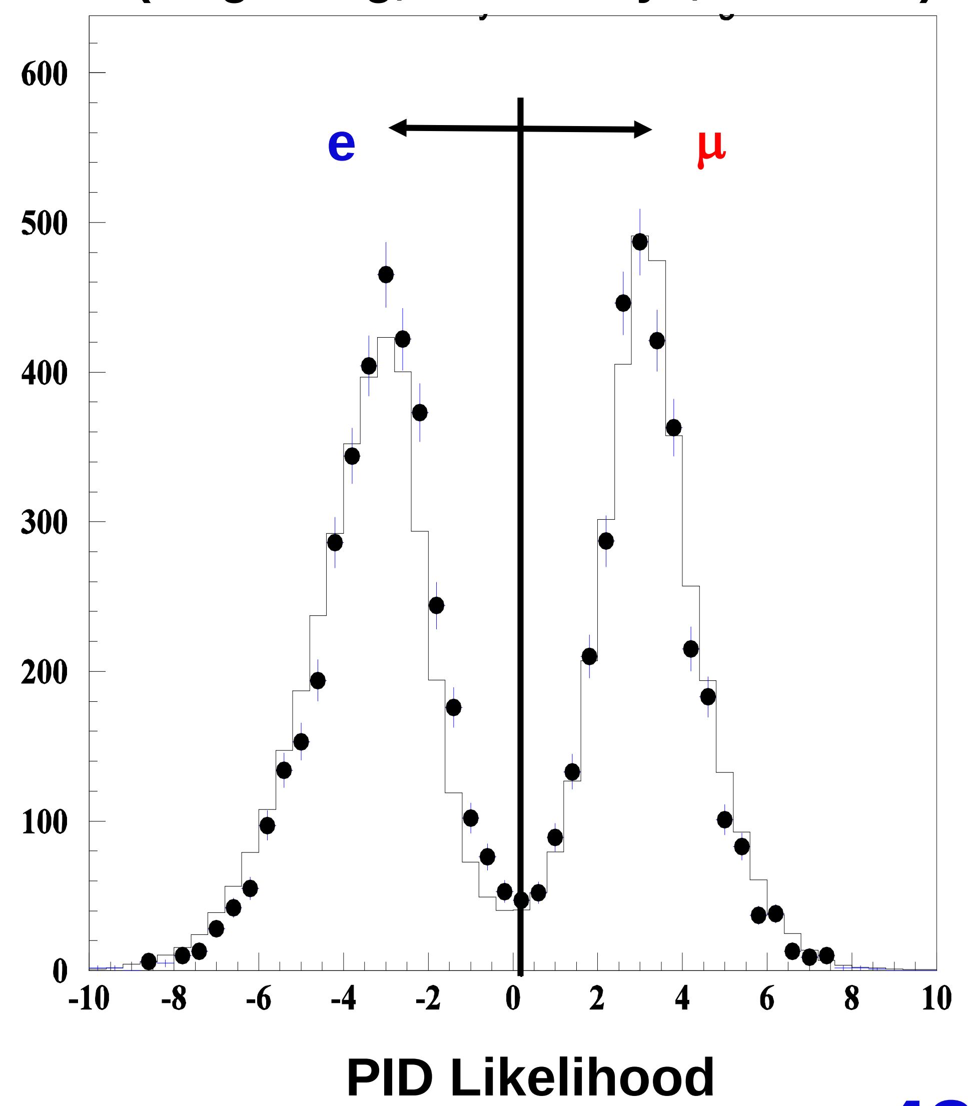
μ/e identification in Super-Kamiokande

"PID likelihood" is defined, and is applied to atmospheric neutrino events.
The separation is clear.

- The excellent (>99 %) particle identification capability was also confirmed by a beam test using KEK 12GeV Proton Synchrotron.
  S.Kasuga et al., PL.B374,238(1996)



SK atmospheric neutrino data
(single ring, 1489.2 days, Sub-GeV)

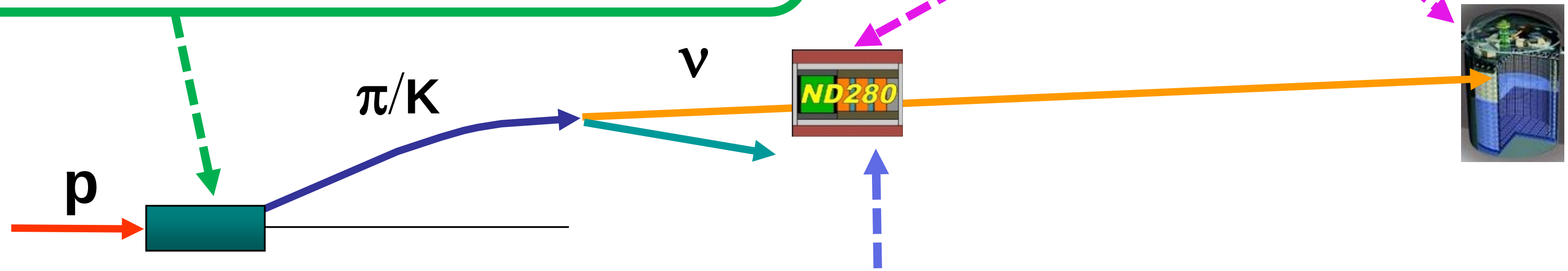


Expected number of neutrino events

- **Calculation of expected number of events in Super-Kamiokande is essentially important. It is because neutrino oscillations are examined from a comparison between data and expectations.**
- **Monte Carlo simulation and their systematic errors are:**

Neutrino flux calculation has systematic errors due to uncertainty of π/K productions at the target

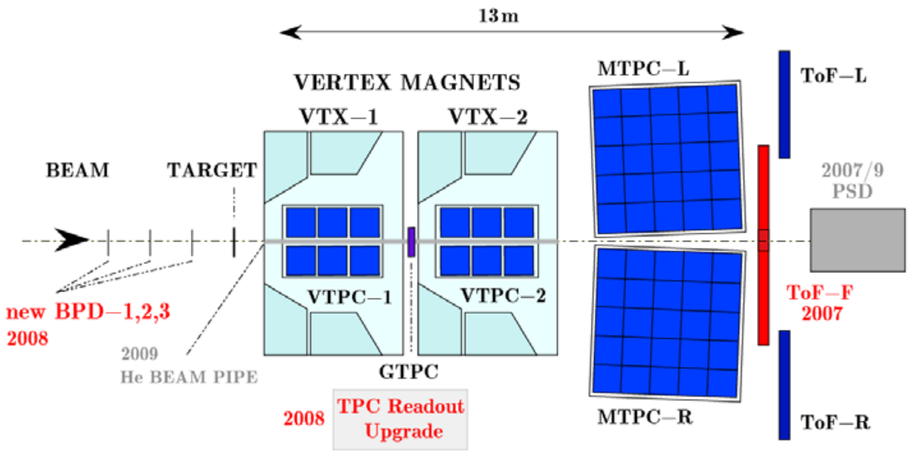
Simulation of event generation is affected by systematic errors related to neutrino interactions.



Data and expectation are compared at ND280, and systematic errors in neutrino flux and neutrino interactions can be reduced. The reduced systematic errors can be applied to calculations in the far detector.

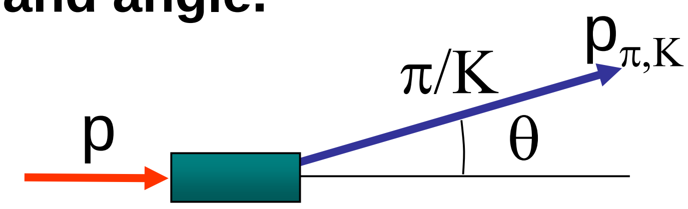
π/K production measurement

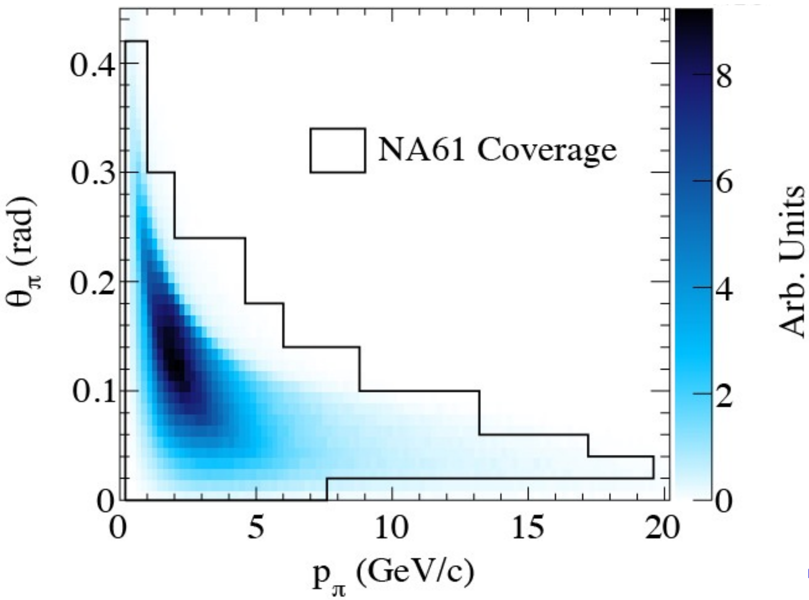
- Some of T2K members join CERN NA61/SHINE : "Study of hadron productions in hadron-nucleus and nucleus-nucleus collisions at CERN SPS"



- The energy of the proton beam is adjusted to the T2K proton beam, 30 GeV. Thin (2 cm) carbon plate is used as target. The carbon material is same as T2K

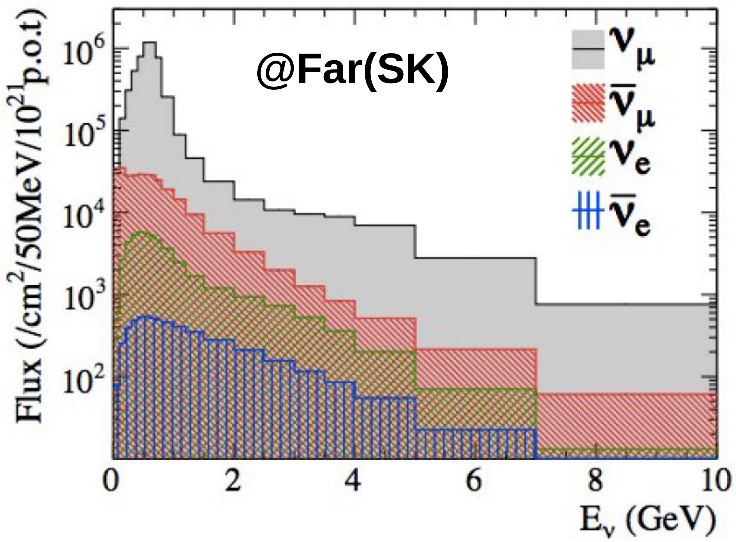
- Production of pions and kaons are precisely measured by TPC and TOF. Their fluxes are measured as a function of momemtum and angle.



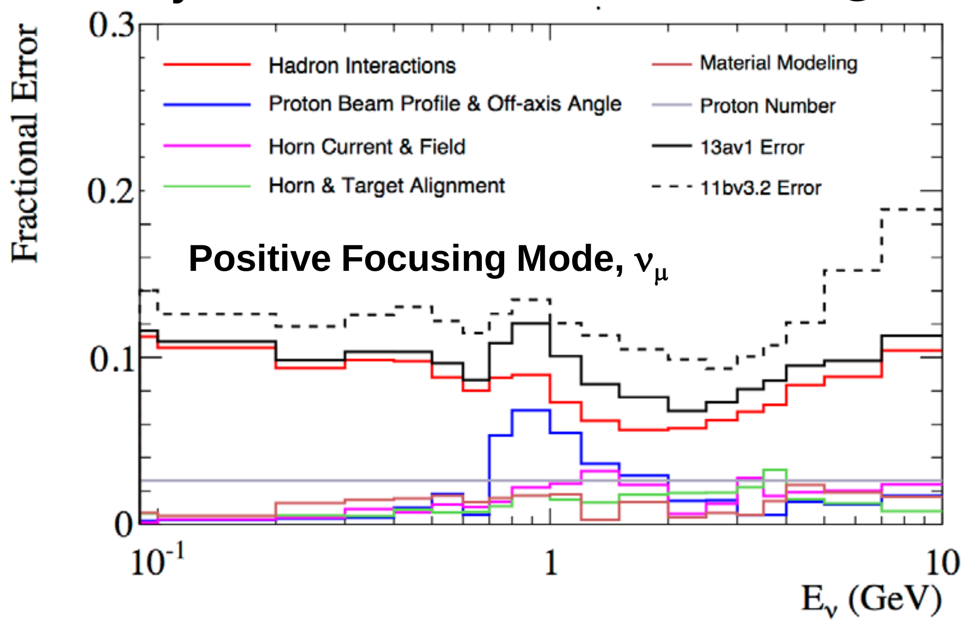


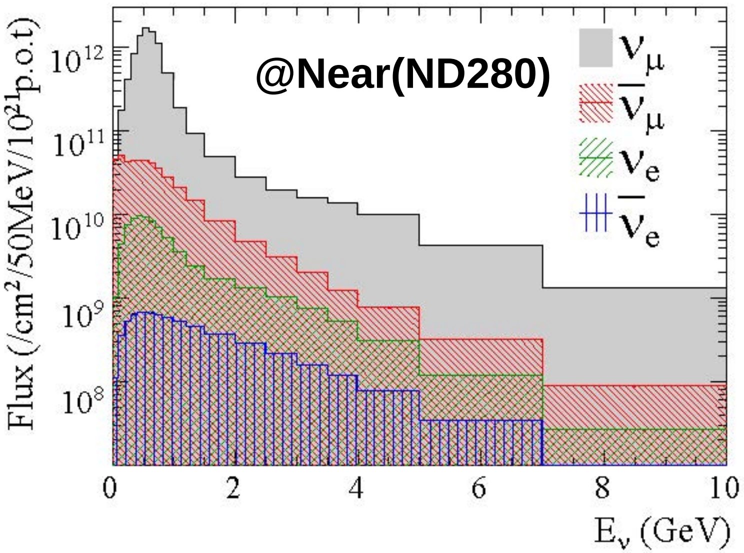
Expected neutrino fluxes at SK and ND280

- **From p/K production data, neutrino flux at Far(SK) and Near(ND280) detectors can be calculated from decay kinematics.**



Systematic errors of neutrino flux @SK



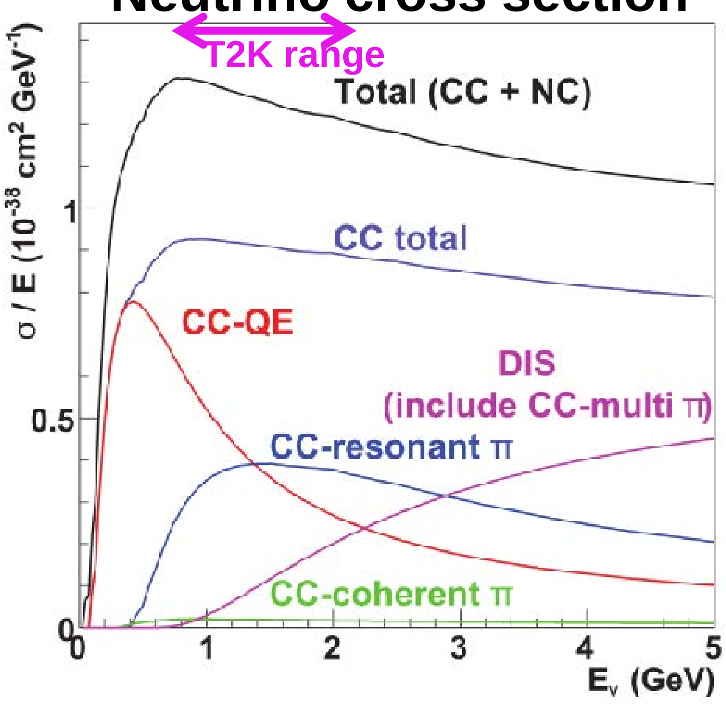


- **Systematic errors on neutrino fluxes @SK in 0.1GeV~5GeV range are 10~15%.**
- **However, fluxes at two detectors are highly correlated, and the some of the systematic errors are common.**
- **An extrapolation of ND280 analysis can reduce systematic errors in SK.**

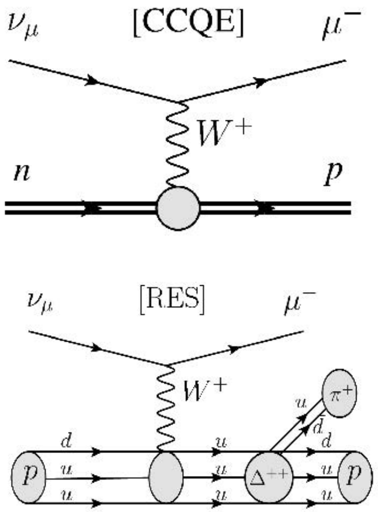
Neutrino Interactions

- In the neutrino interaction simulation, model parameters, such as axial vector mass, are tuned by using external neutrino data. Results from MiniBooNe are used as primary inputs.

Neutrino cross section



In the T2K neutrino energy range, contributions from CCQE and CC1π interactions are dominant.



Charged Current Quasi-Elastic

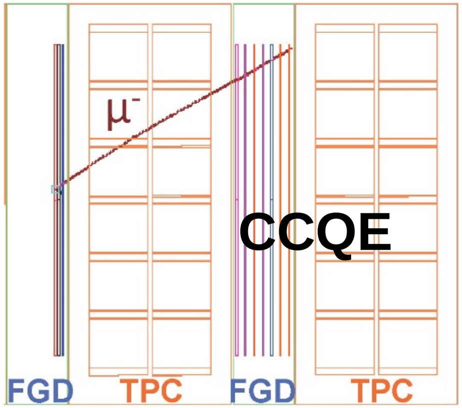
Charged Current 1π Resonant Production

- At present, nominal systematic errors for the neutrino cross section are larger than ~10%.

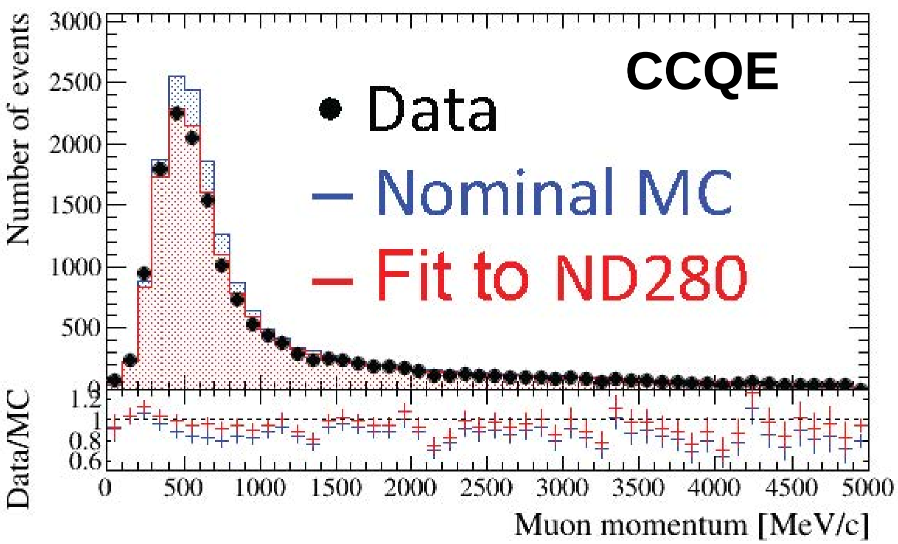
ND280 analysis

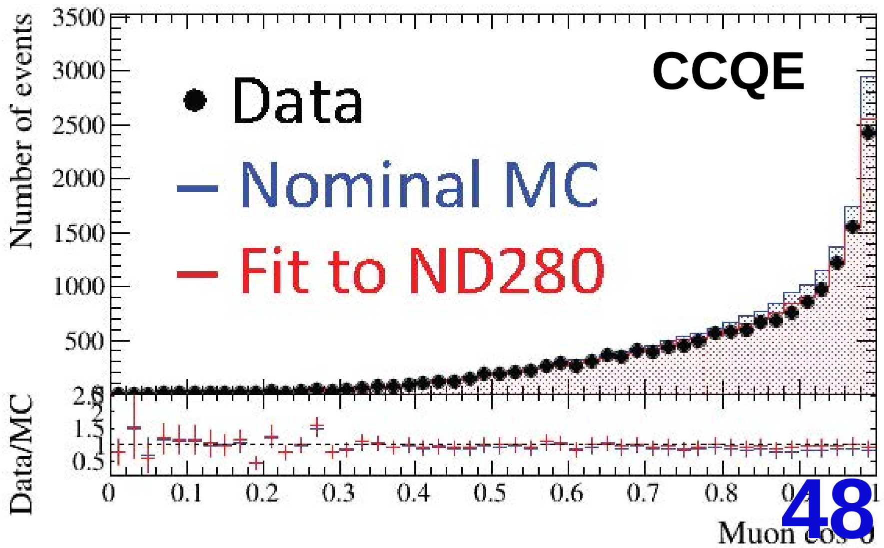
- **CCQE events, CC1π events, and CC_{dis} events are selected based on track topologies in ND280 FGD/TPC.**
- **p_μ and $\cos\theta_\mu$ distribution are carefully compared between the data and the simulation. All systematic errors related to cross sections and neutrino fluxes are adjusted from the comparison.**

CCQE : Charged Current Quasi Elastic
CC1π : Charged Current 1π resonant production
CC_{dis} : Charged Current Deep Inelastic Scattering

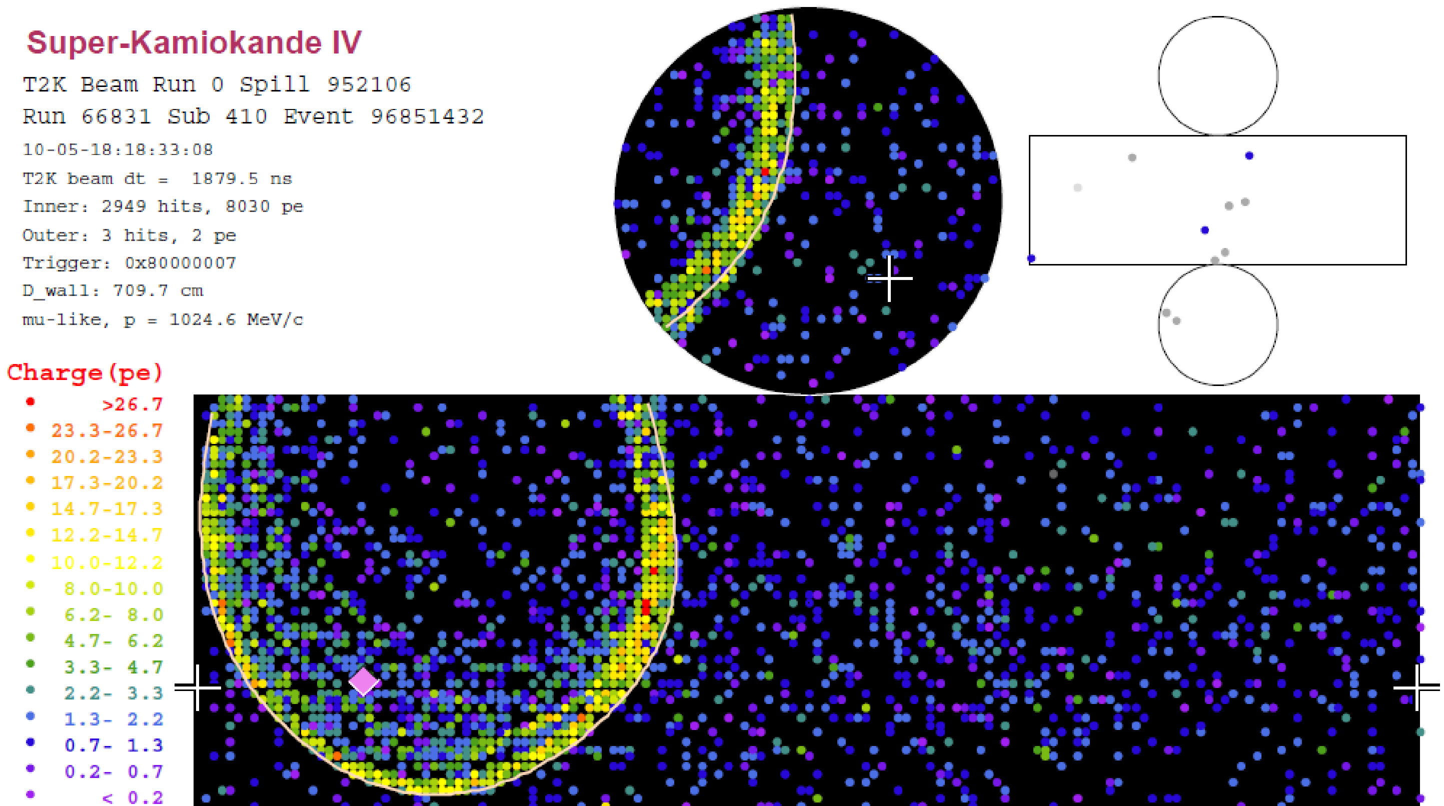


- **The agreements are excellent after the parameter adjustment. The adjusted parameters can be also applied for SK.**



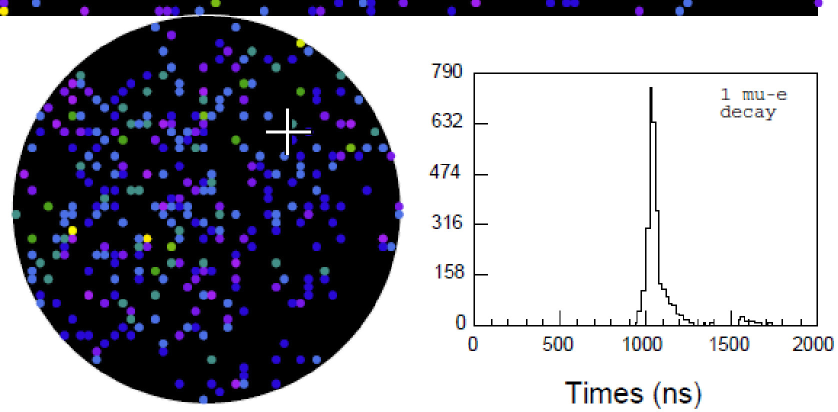


Typical single muon ring event

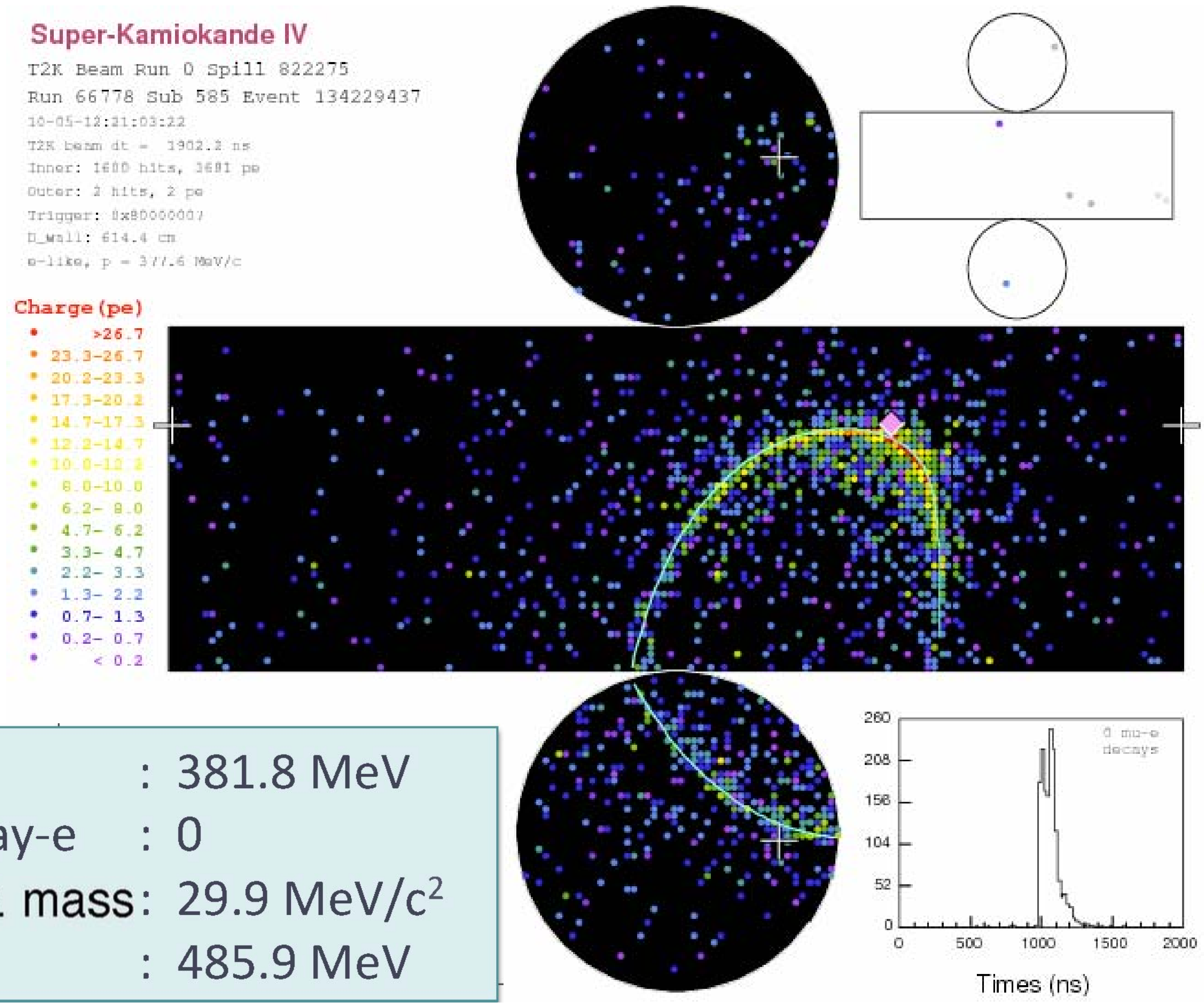


Pμ = 1025 MeV/c

1 decay-e

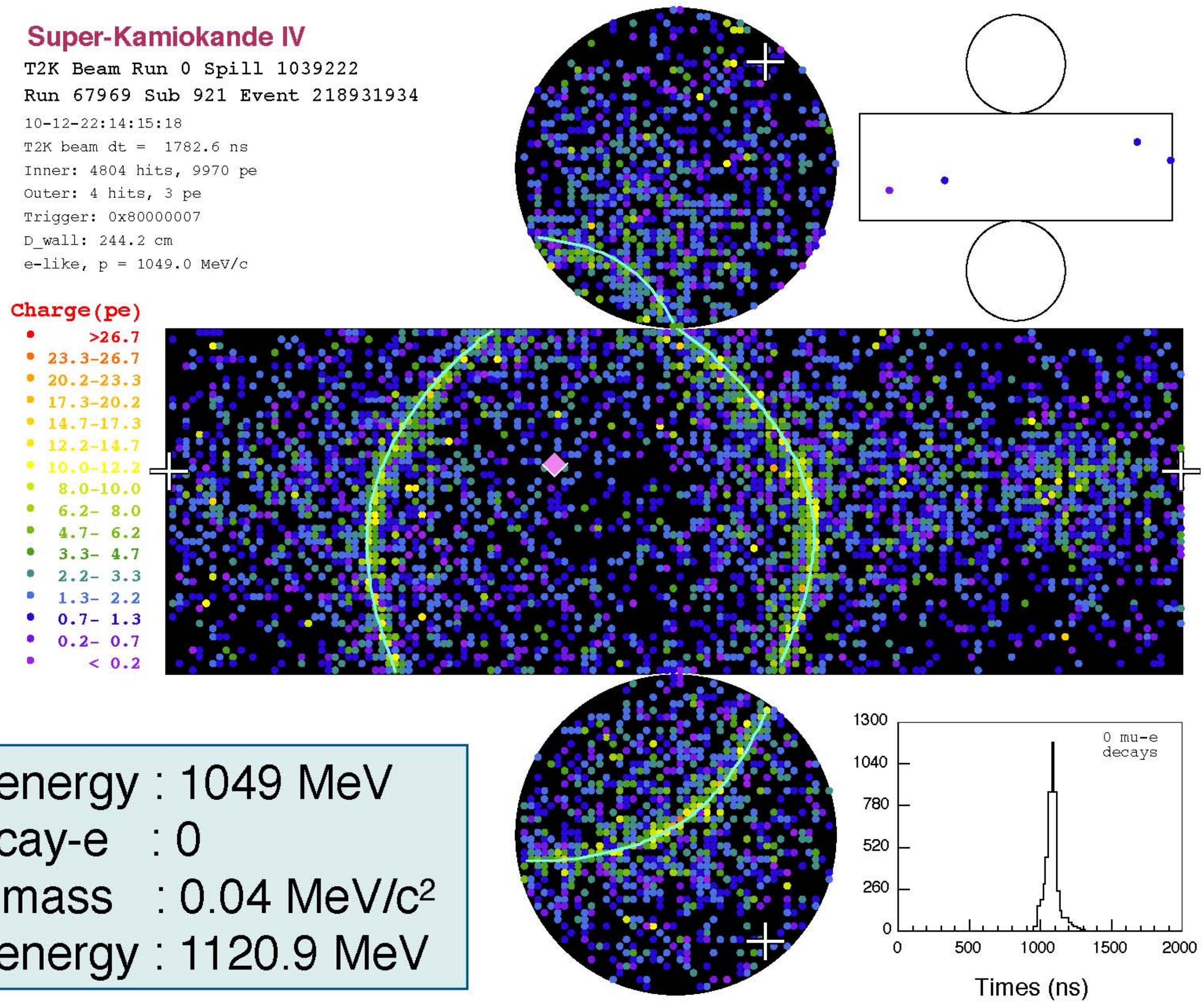


Possible electron neutrino candidate(1)



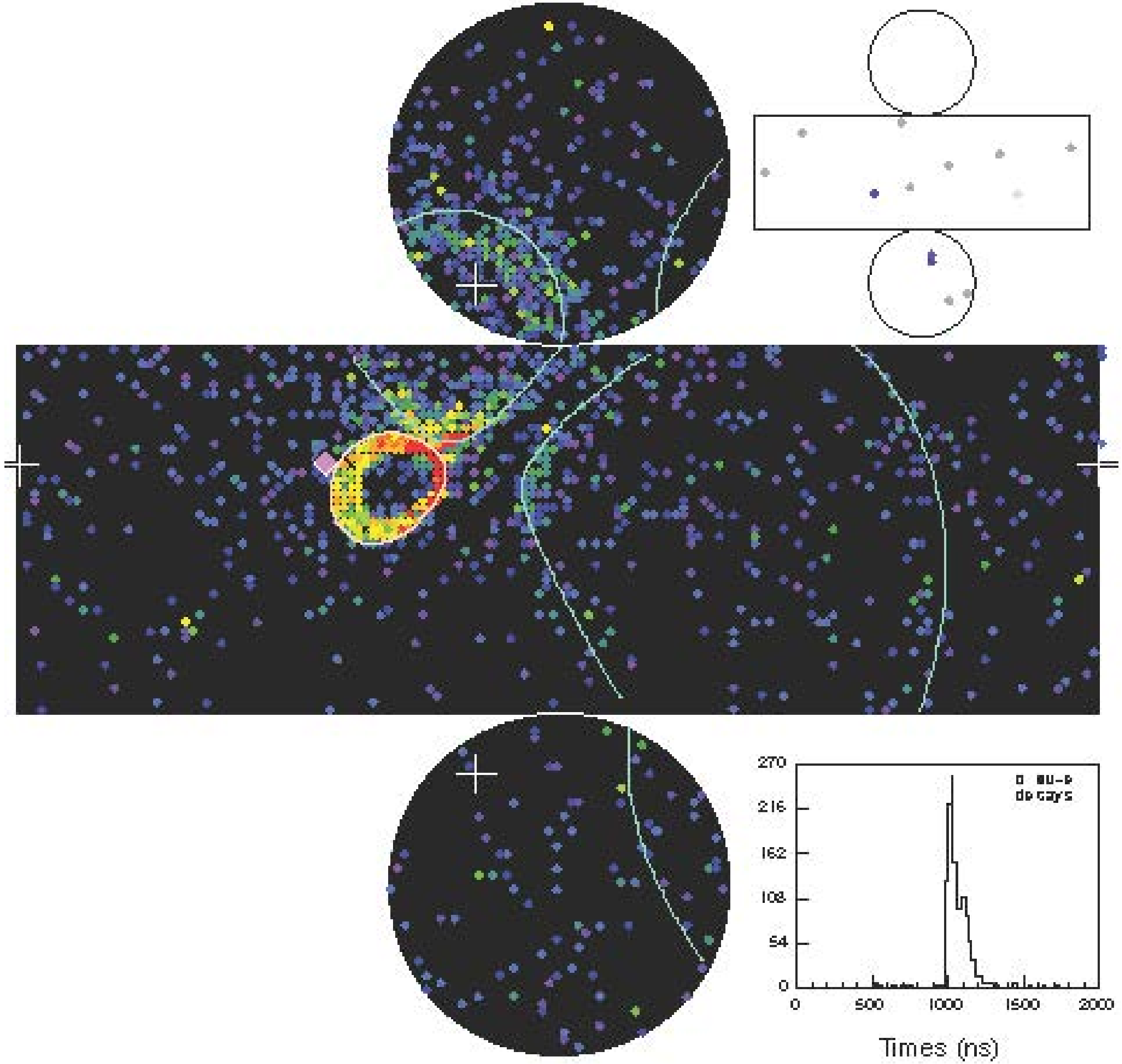
Evis	:	381.8 MeV
Ndecay-e	:	0
2γ Inv. mass	:	29.9 MeV/c^2
E_ν^{rec}	:	485.9 MeV

Possible electron neutrino candidate(2)



visible energy : 1049 MeV
# of decay-e : 0
2γ Inv. mass : 0.04 MeV/c²
recon. energy : 1120.9 MeV

First anti-neutrino beam event



End