J-PARC neutrino beam and the T2K

Design, Goal and Construction status

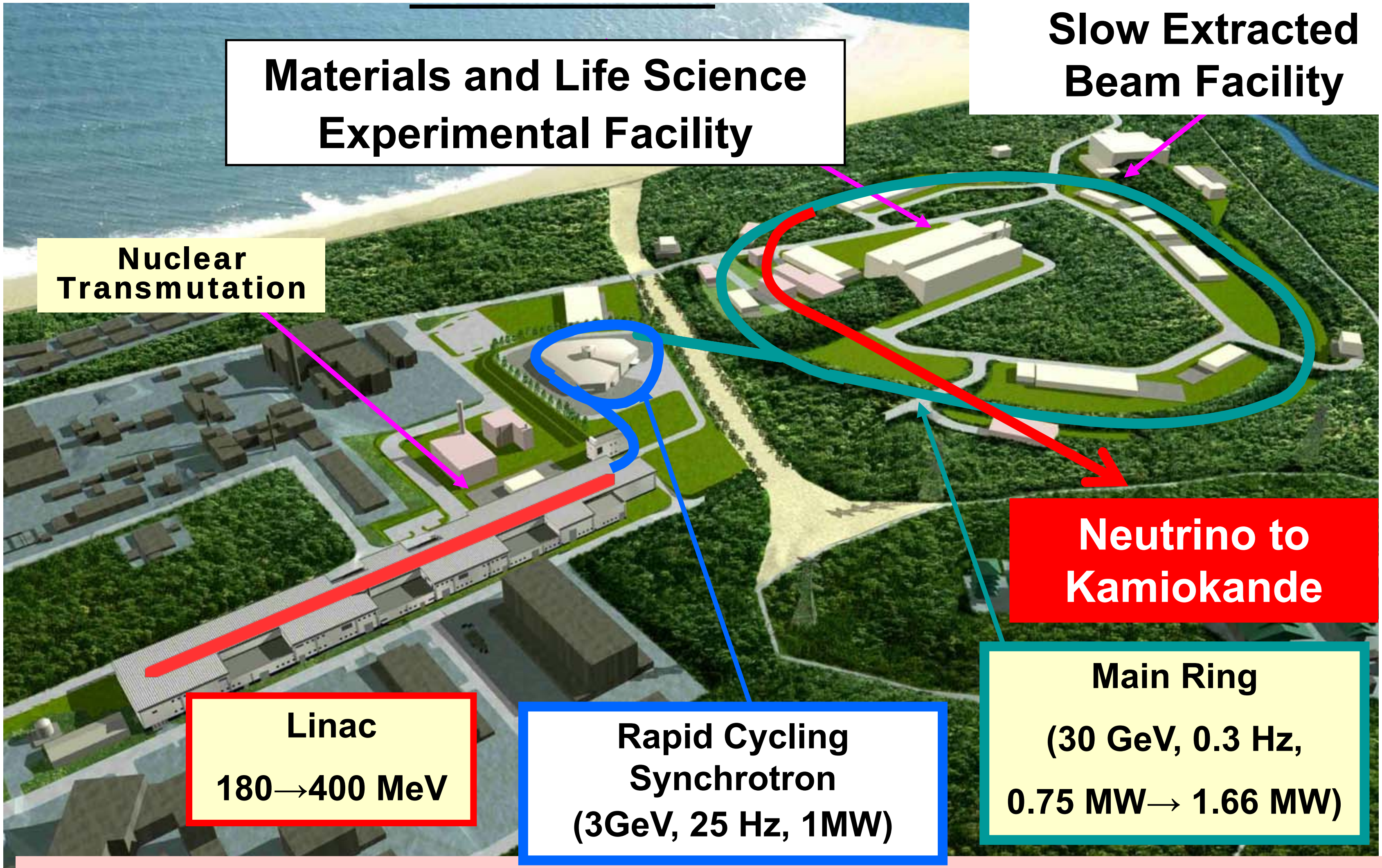
3rd CHIPP Swiss neutrino workshop

November17-19, 2008

Koichiro Nishikawa

KEK

J-PARC



J-PARC = Japan Proton Accelerator Research Complex

Joint Project between KEK and JAEA


E133°
E135°
Kobe
Osaka
Kyoto
Kanazawa
Kanazawa
Tsu
Nagoya
Gifu
Gifu
E137°
Super-K
Nagano
Nagano
Japan
Kofu
Shizuoka
→Talk by Dr. Y Suzuki
295km
Honshu
N37°
Mito
J-PARC
© 2007 Europa Technologies
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Streaming 100%
Talk by Dr. D. Wark

T2K Collaboration

~400 members from 12 Countries

Canada, France, Germany, Italy, Japan, Korea, Poland, Russia, Spain, Switzerland, UK, US

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Goal of T2K

- Neutrino flavor oscillation
  - Explicit demonstration of flavor oscillation with the best possible sensitivity
    - Search of ν_e appearance in ν_μ beam
      - The last of the three mixing angles
      - Possible tool for CPV search in leptons
  - Precision measurement of ν_μ disappearance parameters
    - How close the θ_{23} to $\pi/4$: maximal mixing?

- Opening future direction

  Various options, but the choice depends on :
  - Physics results available
  - Technologies in high power proton beam handling
  - Understanding of sources of systematic errors
  - Detector R/D

Importance of $\nu_\mu \rightarrow \nu_e$ appearance oscillation

δ : CP Violation in Lepton Sector

$$P_{\alpha\beta} = \delta_{\alpha\beta} - 4\sum_{j>i} \mathrm{Re}(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}) \sin^2 \frac{(m_j^2 - m_i^2)L}{4E_\nu}$$

$$\mp 2\sum_{j>i} \mathrm{Im}(U^*_{\alpha i} U_{\beta i} U_{\alpha j} U^*_{\beta j}) \sin \frac{(m_j^2 - m_i^2)L}{2E_\nu}$$

ν disappearance 1- P_{ee} : $\alpha=\beta$ $|U_{\alpha i}|^2$ Real

→CPV cannot be observed

CPV in $\nu_\mu \rightarrow \nu_e \propto \sin\theta_{12} \sin\theta_{23} \sin\theta_{13} \Delta m^2_{12}$ (L/E) $\sin\delta$

$\nu_\mu \rightarrow \nu_e$ appearance and CPV in the mixing

Main features of T2K

Super-K exist at the distance 295km and $\Delta m^2 \sim 2.5 \times 10^{-3}$ eV ^{2}

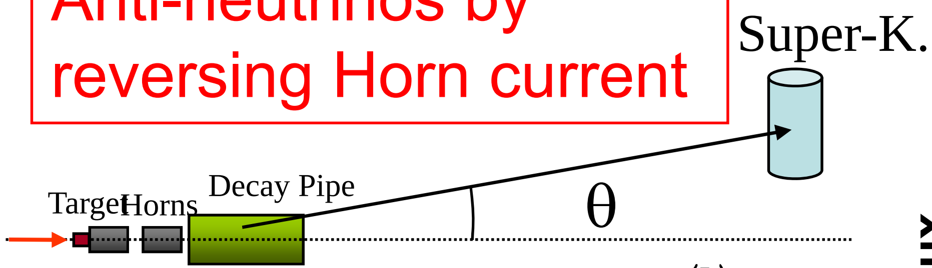
1. Super-K water Cherenkov detector is the superb detector for low E neutrinos (small number of charged particles in final state), backed by twenty years of experience
2. New high power accelerator at J-PARC
3. Oscillation max. at sub-GeV neutrino energy, matched well for Super-K performance
   - QE dominant in sub-GeV
     - Event-by event $E\nu$ reconstruction by kinematics
4. New beam design
   - Small high energy tail
     - small BKG in νe search and $E\nu$ reconstruction for oscillation pattern studies
   - Almost monochromatic
     - Extra E(rec.) requirement on ν_e appearance signal

Low semi-narrow band beam and neutrino event reconstruction

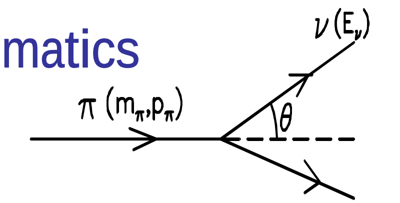
Energy and Lepton ID

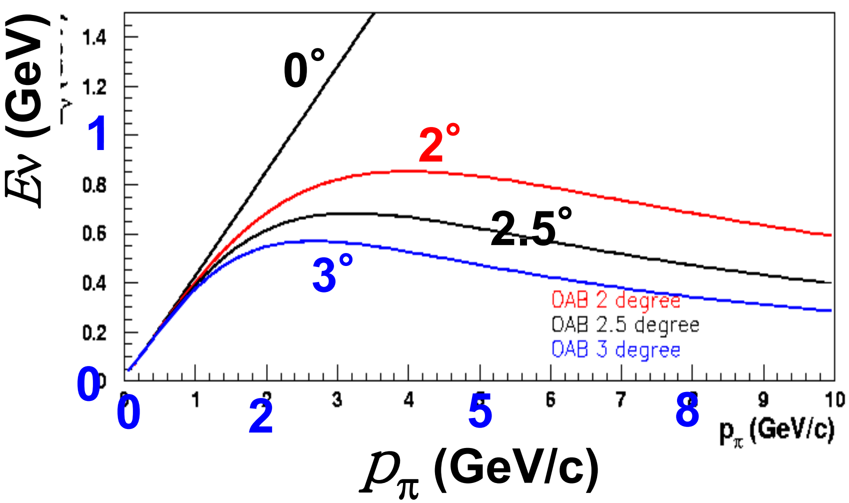
Narrow intense beam: Off-axis beam

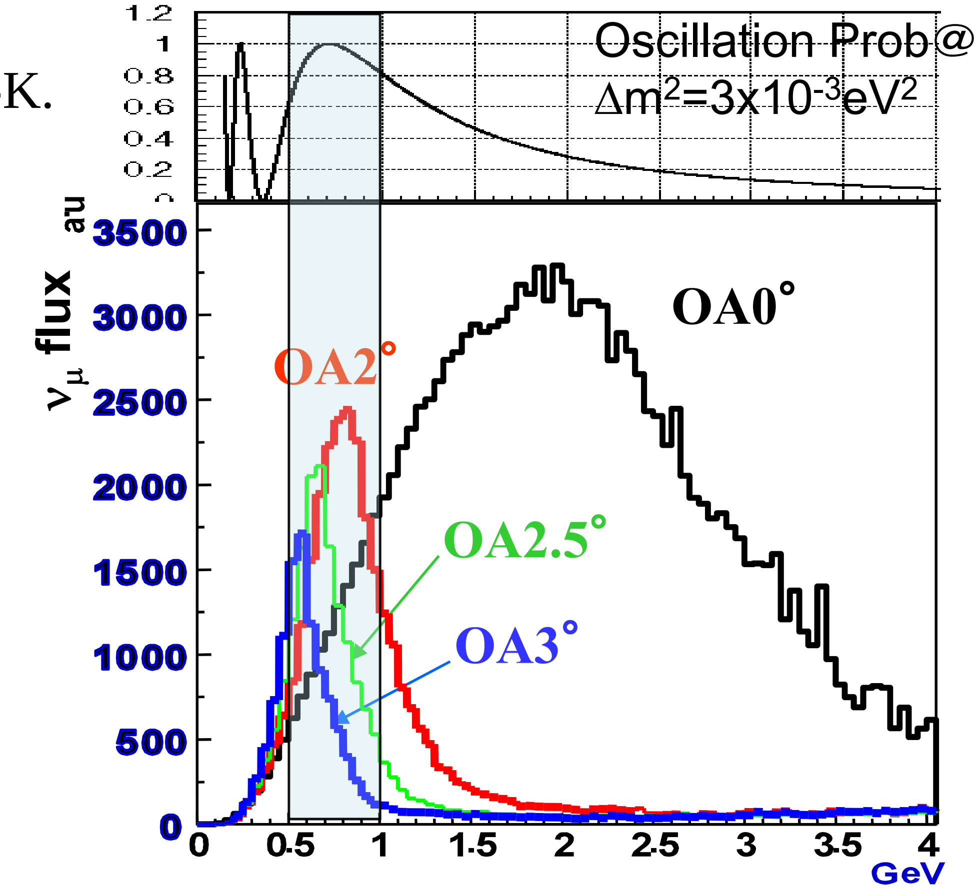
Anti-neutrinos by reversing Horn current



π decay Kinematics







- **Quasi Monochromatic Beam**
- **x 2~3 intense than NBB**
- **Tuned at oscillation maximum**

Statistics at SK

(OAB 2.5 deg, 1 yr, 22.5 kt)

~ 2200 ν_μ tot

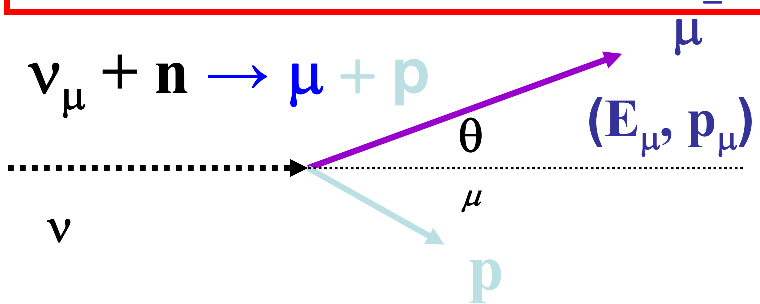
~ 1600 ν_μ CC

ν_e ~0.4% at ν_μ peak

Eν determination at low E

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

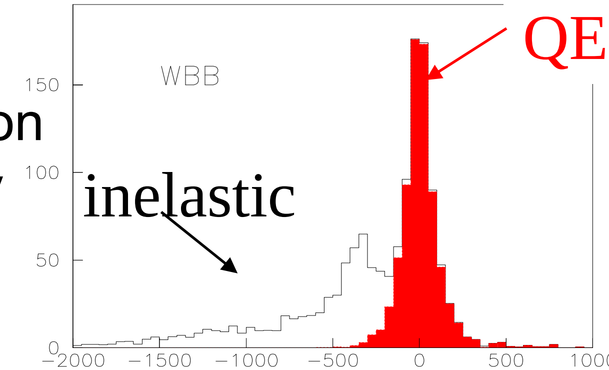
δE ~ 60 MeV δE/E ~ 10%



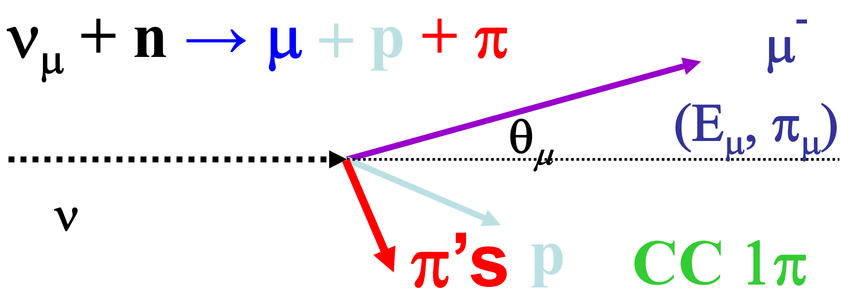
Quasi-Elastic process

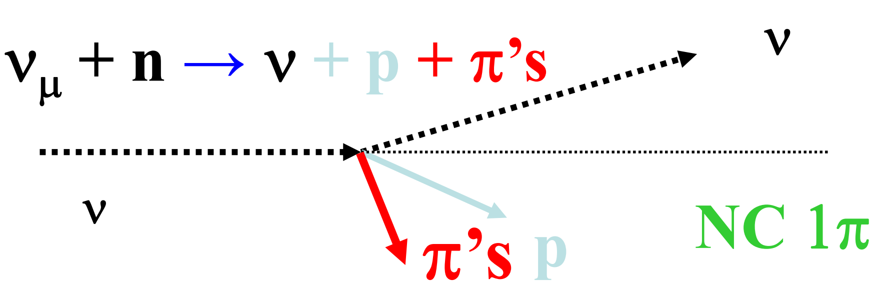
QE fraction

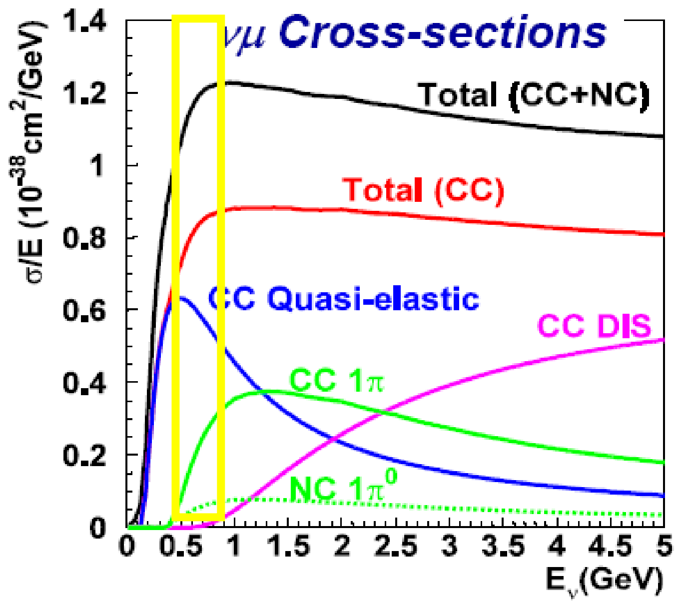
Inelastic from high energy



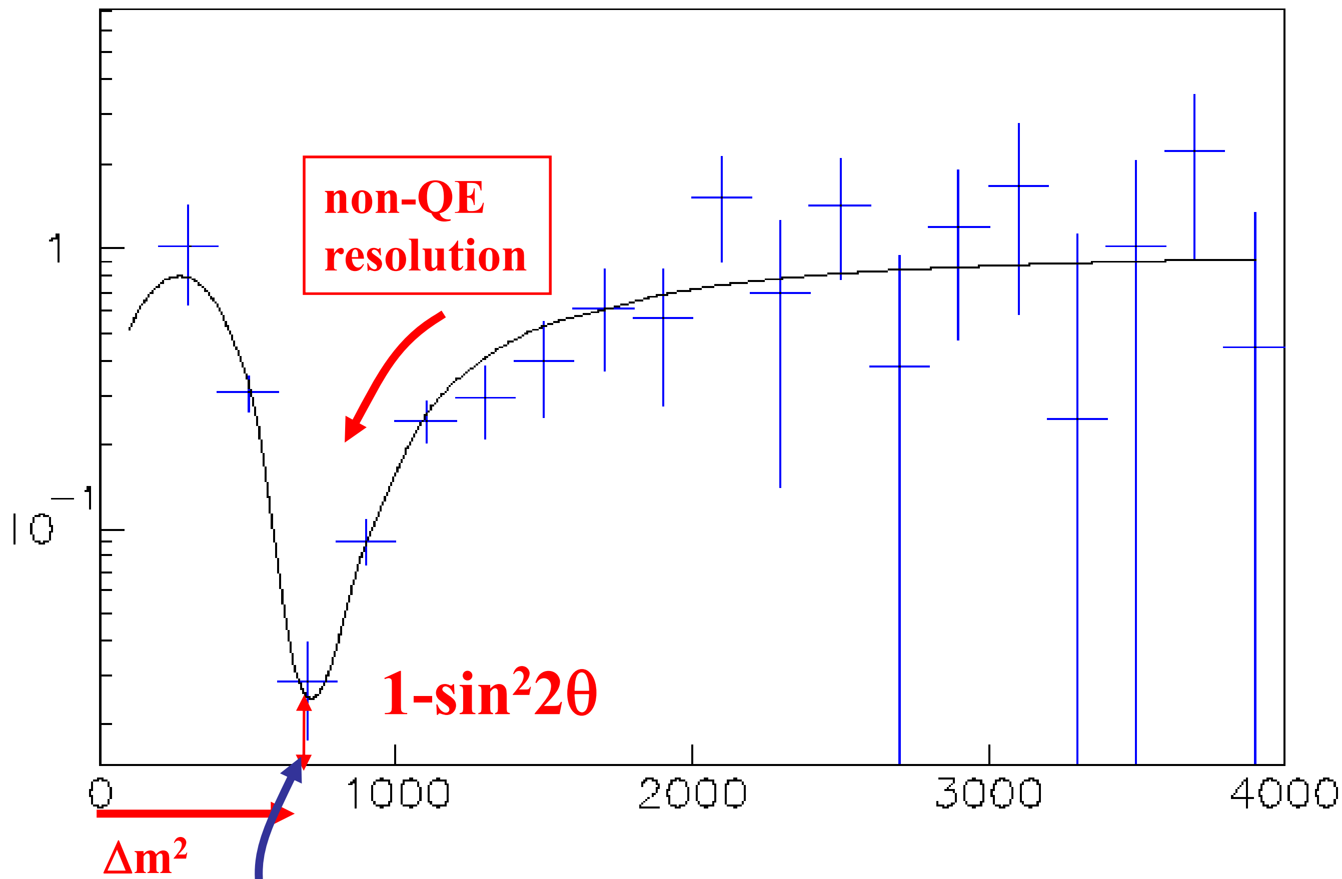
E (reconstructed) – E (true)



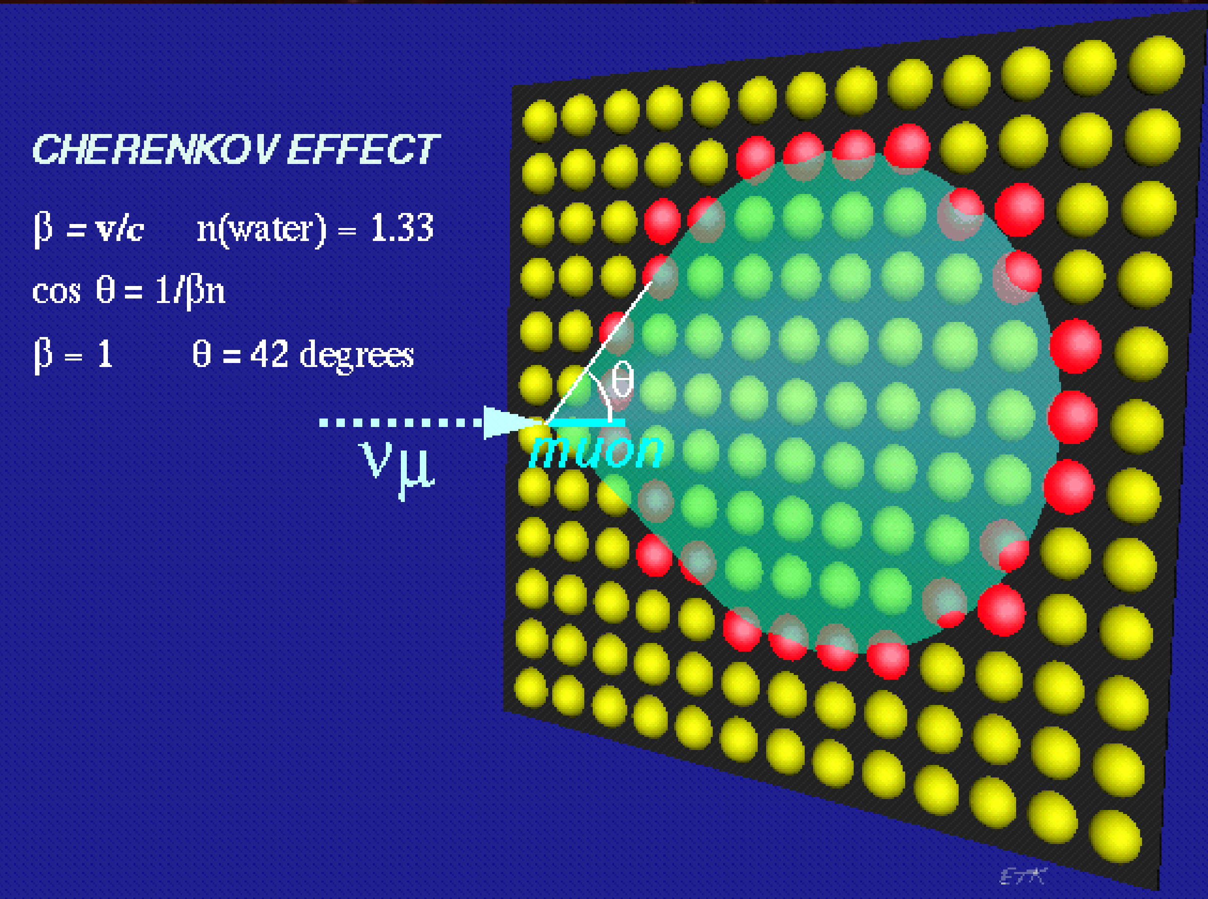


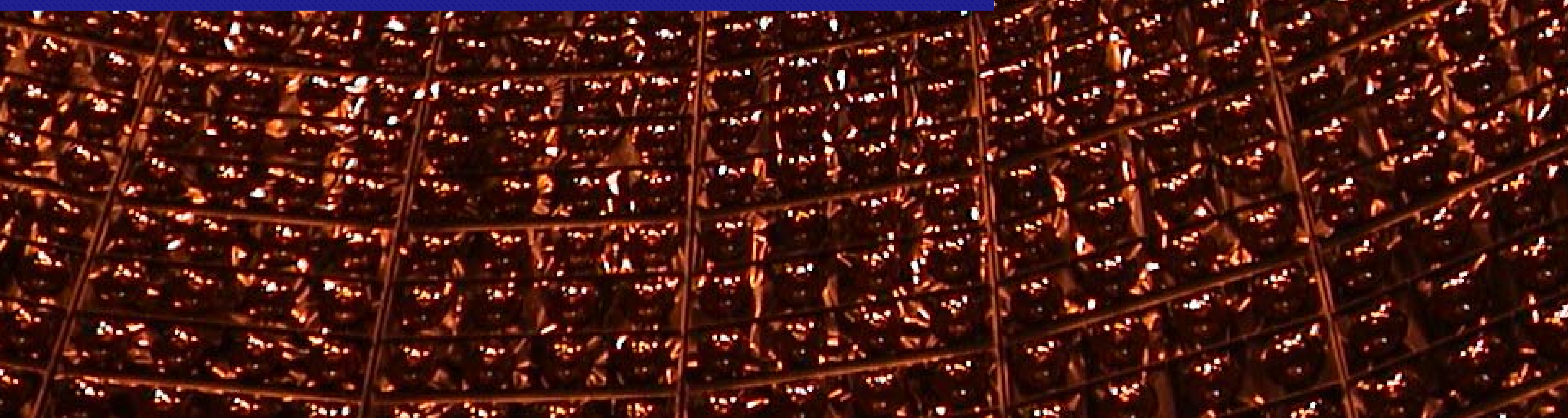


Good E_ν determination capability and Disappearance measurements



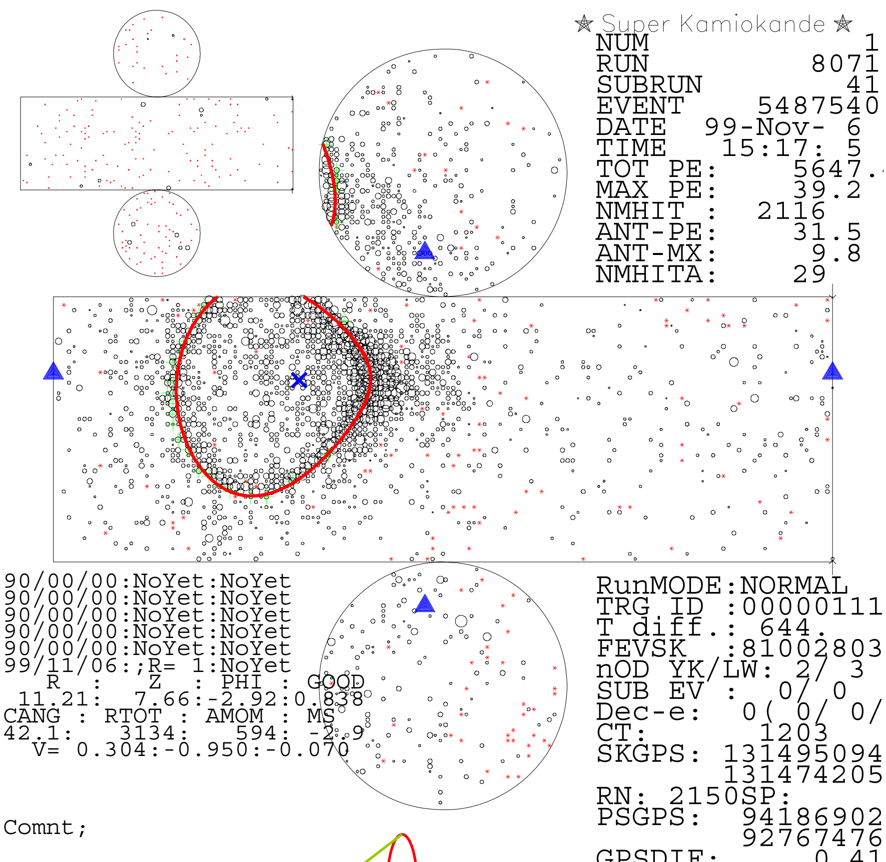
± 10% bin
High resolution : less sensitive to systematics


CHERENKOV EFFECT
β = v/c   n(water) = 1.33
cos θ = 1/βn
β = 1   θ = 42 degrees
θ
νμ
muon

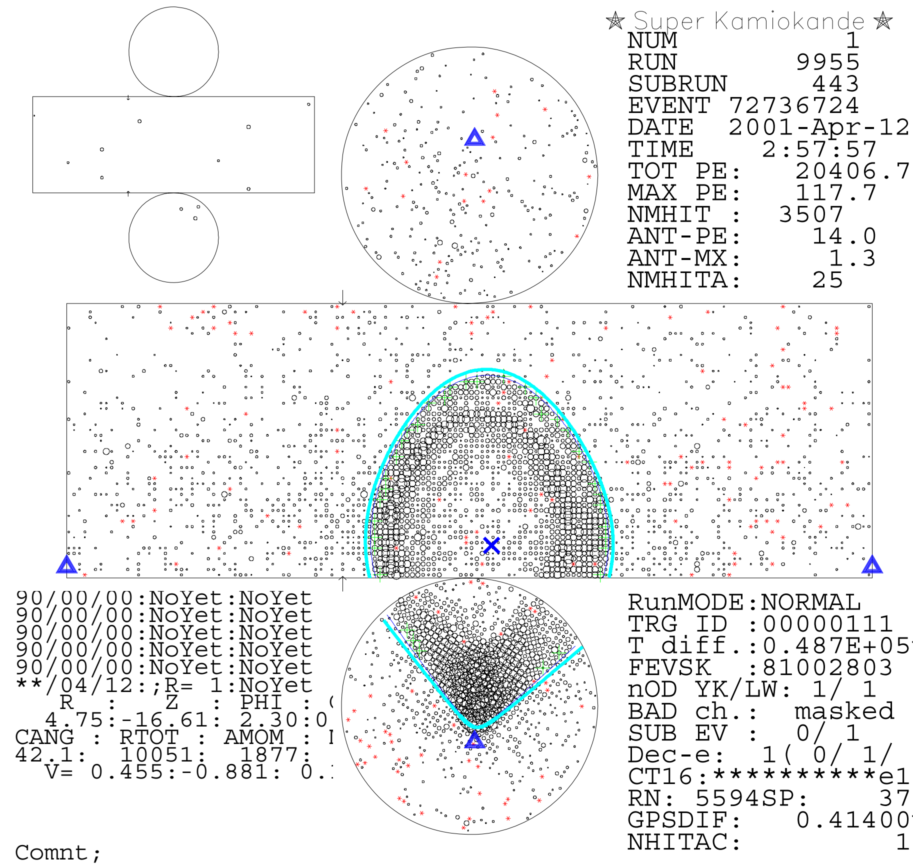


PID in Super-Kamiokande

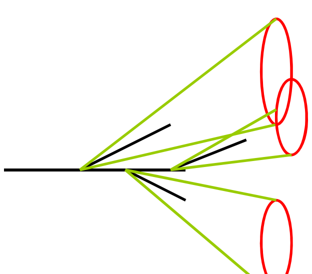
e-like



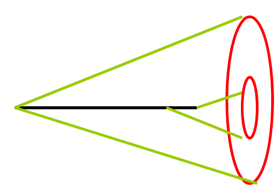
μ-like



e

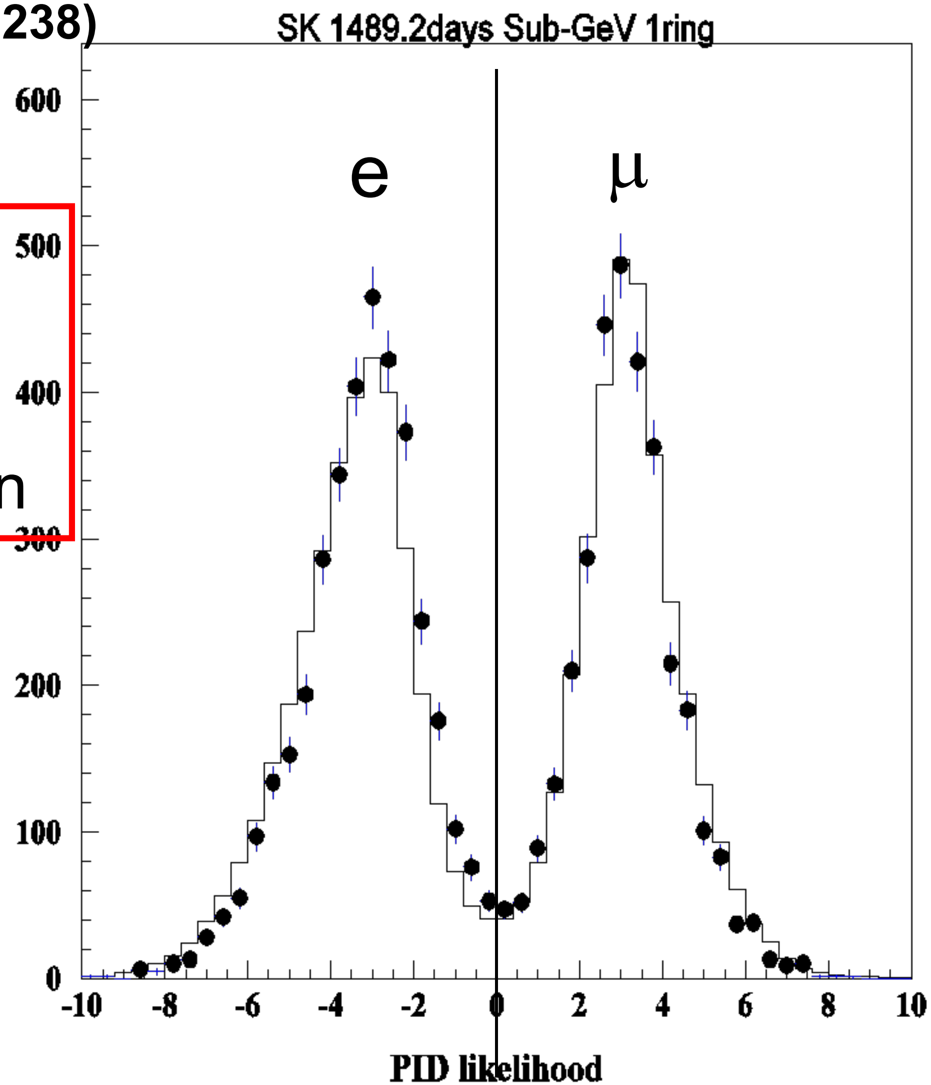


μ



Particle ID (e & μ) (in single ring events)

- **An experiment with test beams confirmed the particle ID capability (PL B374(1996)238)**



Water Cherenkov detector works best for low E ν's
(simple final state)
with good energy resolution

One of the critical experimental issues Prediction of beam at Near and Far sites

- Only the product（Flux times cross section）as a function of E can be measured

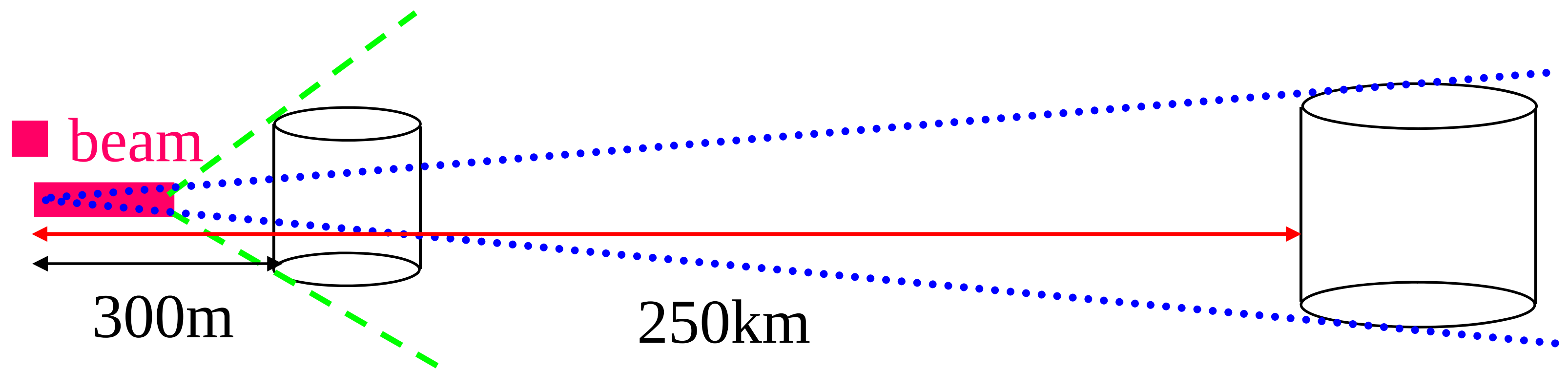
$$N_{obs}^{near}(E_\nu) = F^{near}(E_\nu) \cdot \sigma(E_\nu)$$

$$N_{obs}^{far}(E_\nu) = F^{far}(E_\nu) \cdot \underline{P(\nu_\alpha \to \nu_\beta)} \cdot \sigma(E_\nu)$$

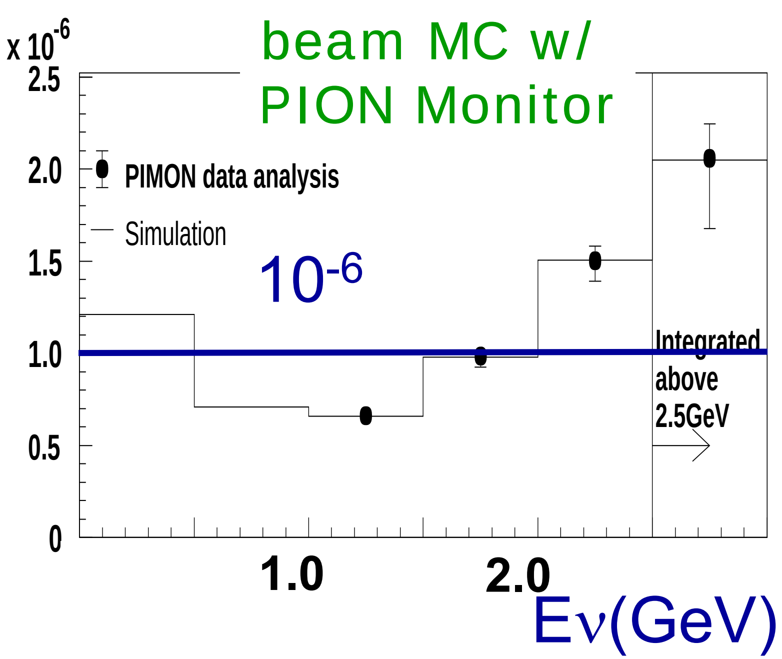
$P(\nu_\alpha \to \nu_\beta)$ is the object to measure

1. $F^{near}(E_\nu)$, $F^{far}(E_\nu)$ different from $1/r^2$ unless decay at rest
   - Different spectrum due to finite decay length and acceptance at two distances
   - Hadron production expt. (NA61) (Dr. B. Popov talk)
2. $\sigma(E)$ poorly known at low-medium energy
   - Two measurements at different distances can reduce the effect of ambiguities of cross sections (ND280)

Neutrino spectrum difference at far and near



Far/Near Ratio in K2K

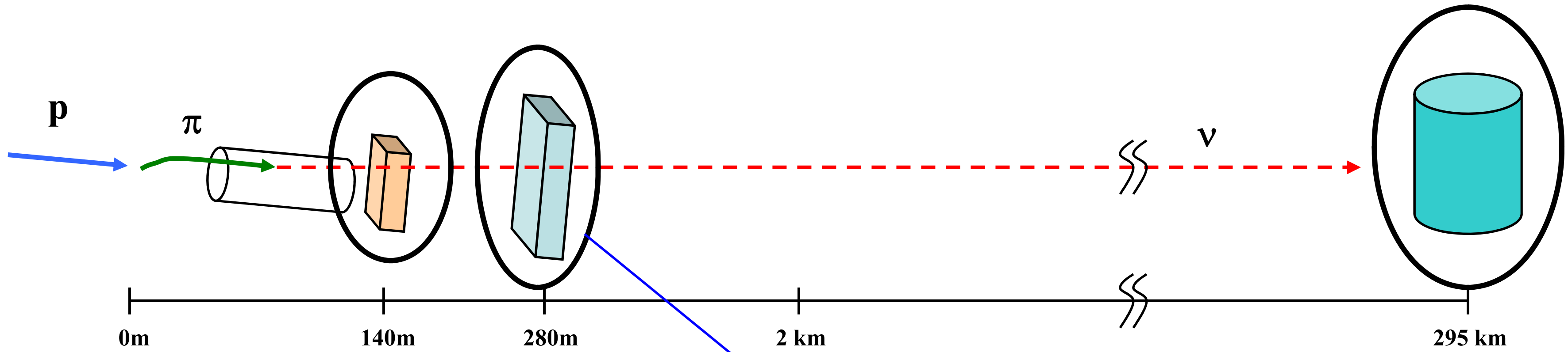


Angular acceptance
(well collimated for HE)

Finite decay volume length
(less decay for HE)

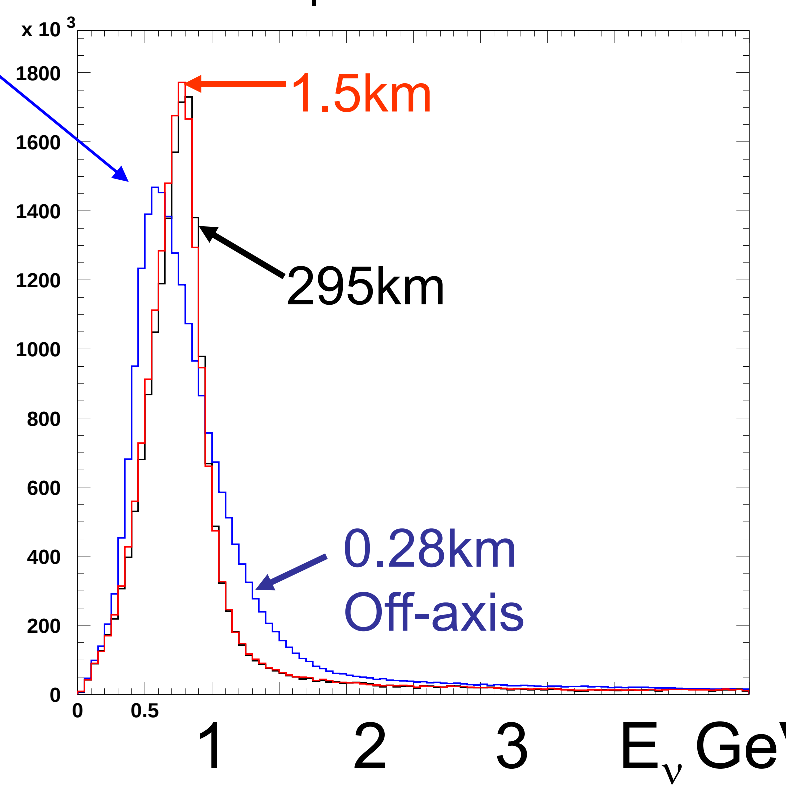
Distributions for mesons
1<p <4 GeV/c, θ < 250 mrad

T2K setup

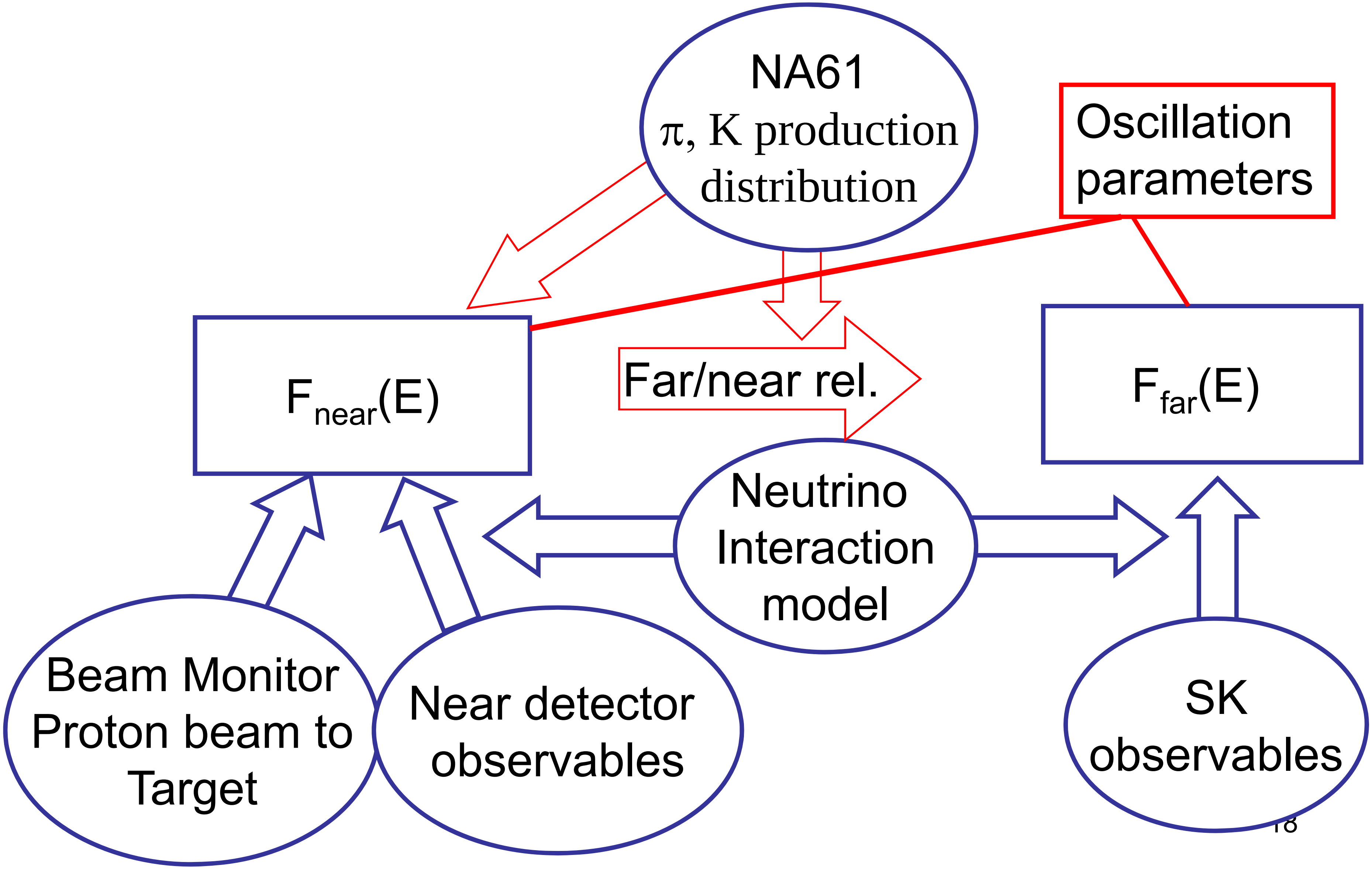


- Neutrino beamline
- Muon monitors @ ~140m
  - Fast (spill-by-spill) monitoring of beam direction/intensity ($\pi \rightarrow \mu\ \nu$)
- ND280 @280m
  - Flux/spectrum/νe bkg- off-axis
  - intensity/direction - on-axis
- Far detector @ 295km
  - Super-Kamiokande

Neutrino spectra at diff. dist



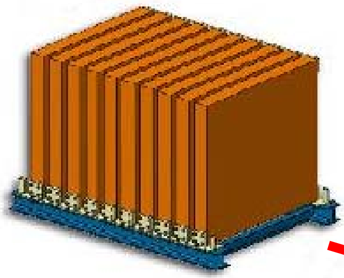
A possible flows of the analysis
(to be developed)



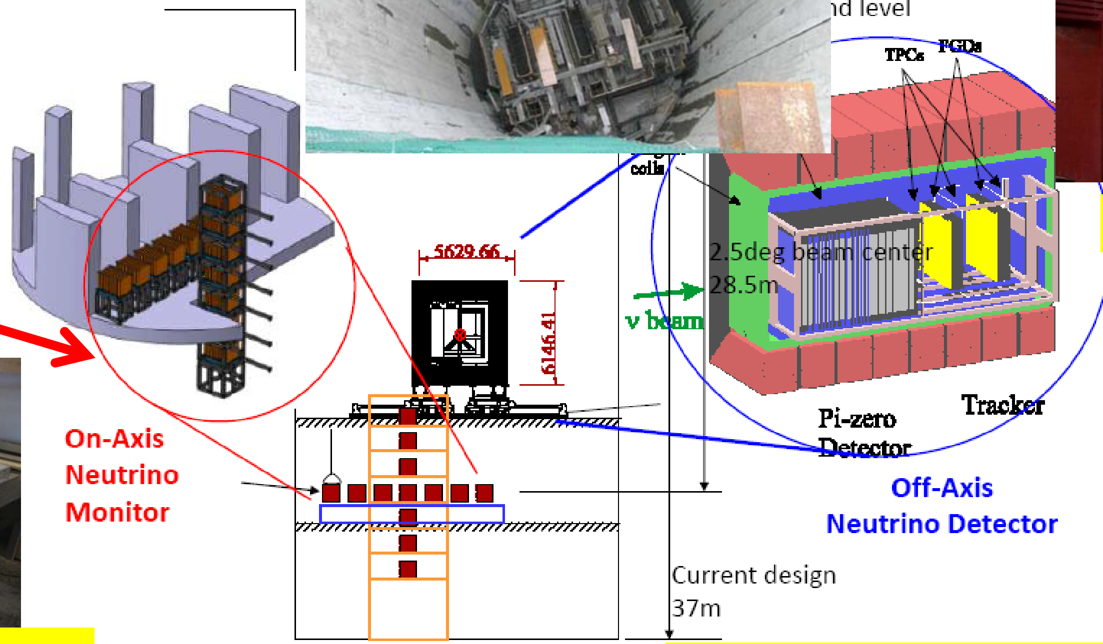
280n ctors

On-axis detector (INGRID)

Iron+Scibar Sandwich



In production, ready in Apr.2009

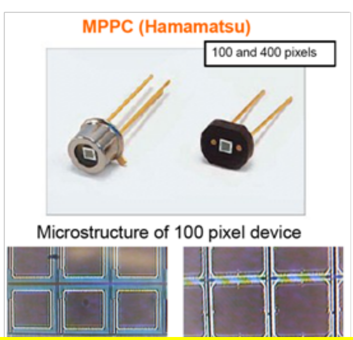


Installed in Apr-Jun.2008

FGD

FGD

All are in production



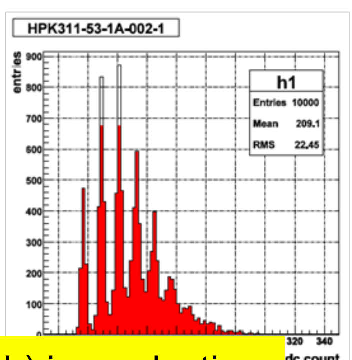
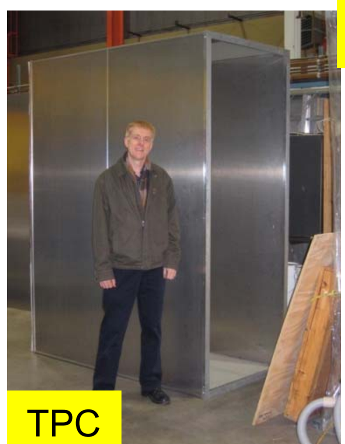


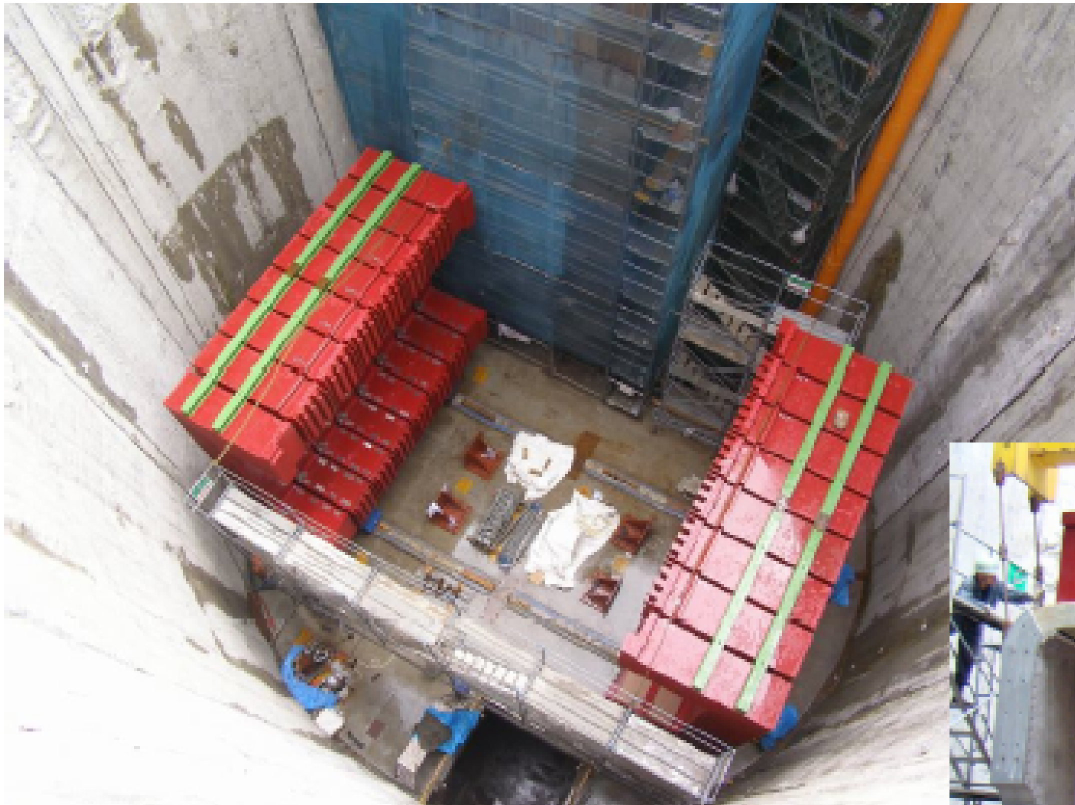
Photo-sensor (~60k ch) in production



TPC

ECAL

Installation at ND280 (Apr-Jun 08)



Yoke re-assembly

Magnet Installation Completed
June 15, 2008
On time and budget!

Swiss contributions
Bern, ETH, Geneva

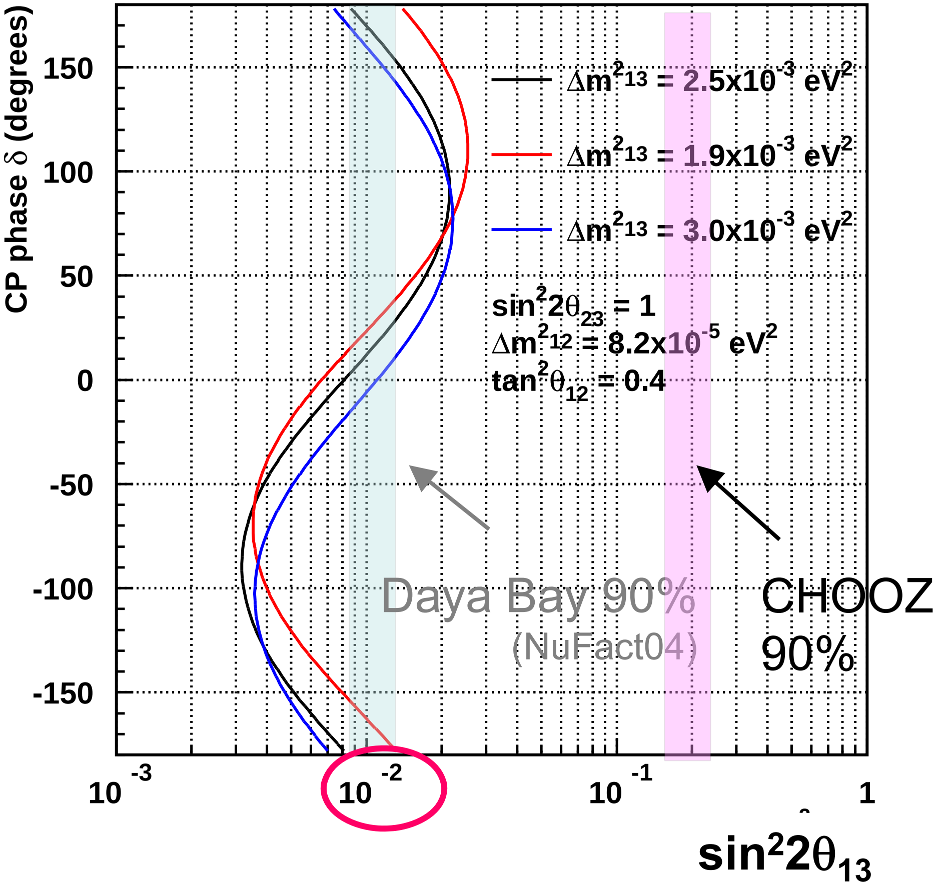
- TPC mechanics, testing, and assembly
- Major contributions to NA61
- Major contributions to UA1 magnet
- Analysis

T2K Physics Sensitivity

to be updated with real data soon

ν_e appearance

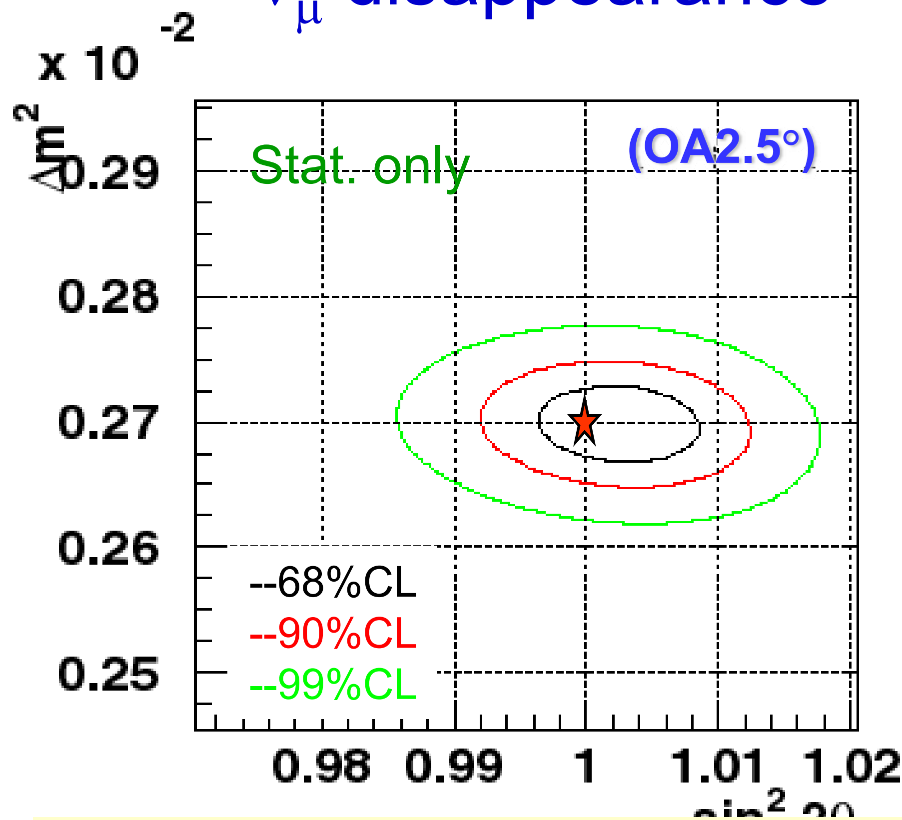
(Strong δ dependence)



>10 times improvement from CHOOZ

δ, Neutrino $\leftrightarrow$ Anti-neutrino, Reactor

ν_μ disappearance



Goal

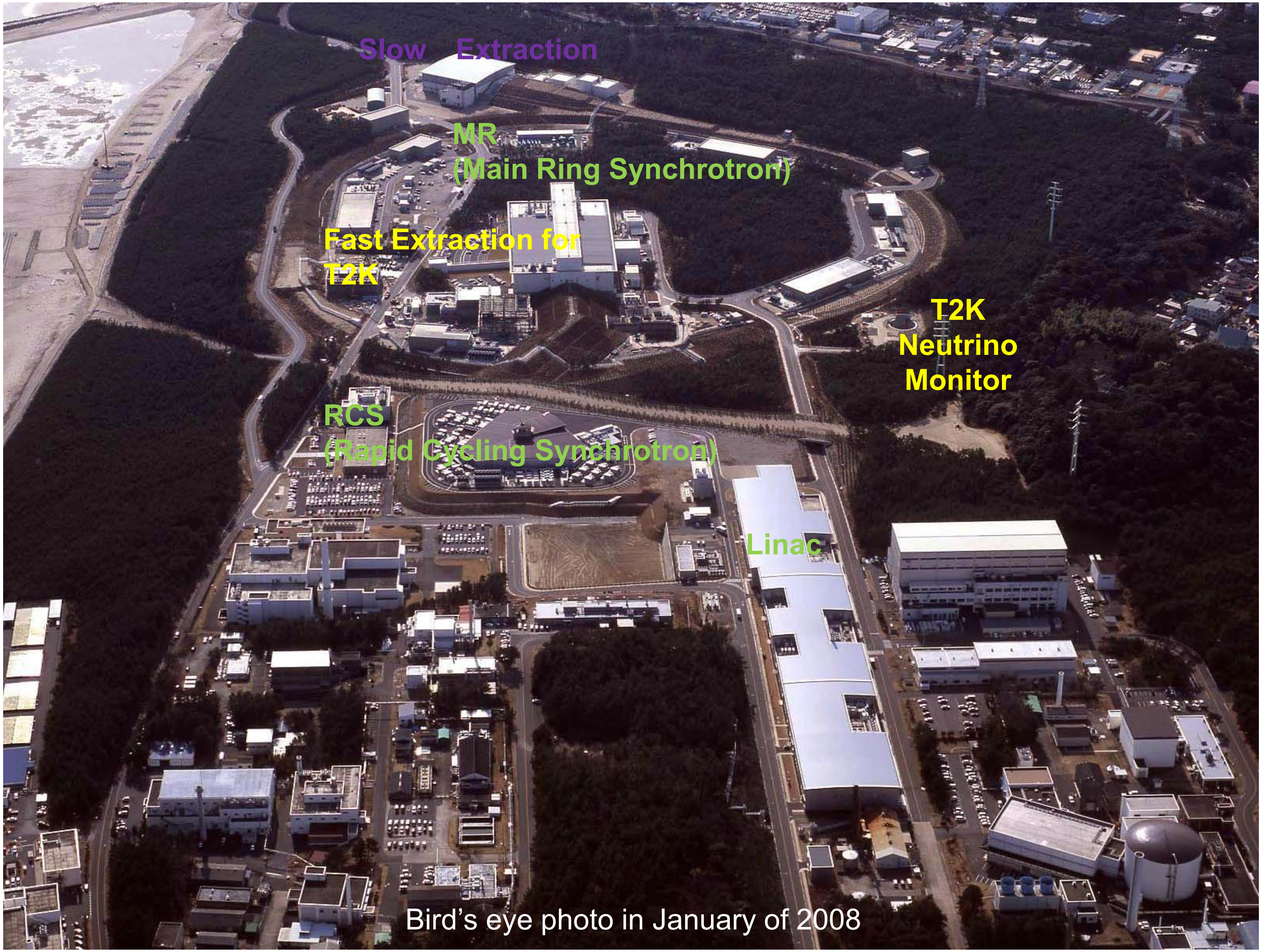
$\delta(\sin^2 2\theta_{23}) \sim 0.01$

(0.08 MINOS EPS2007)

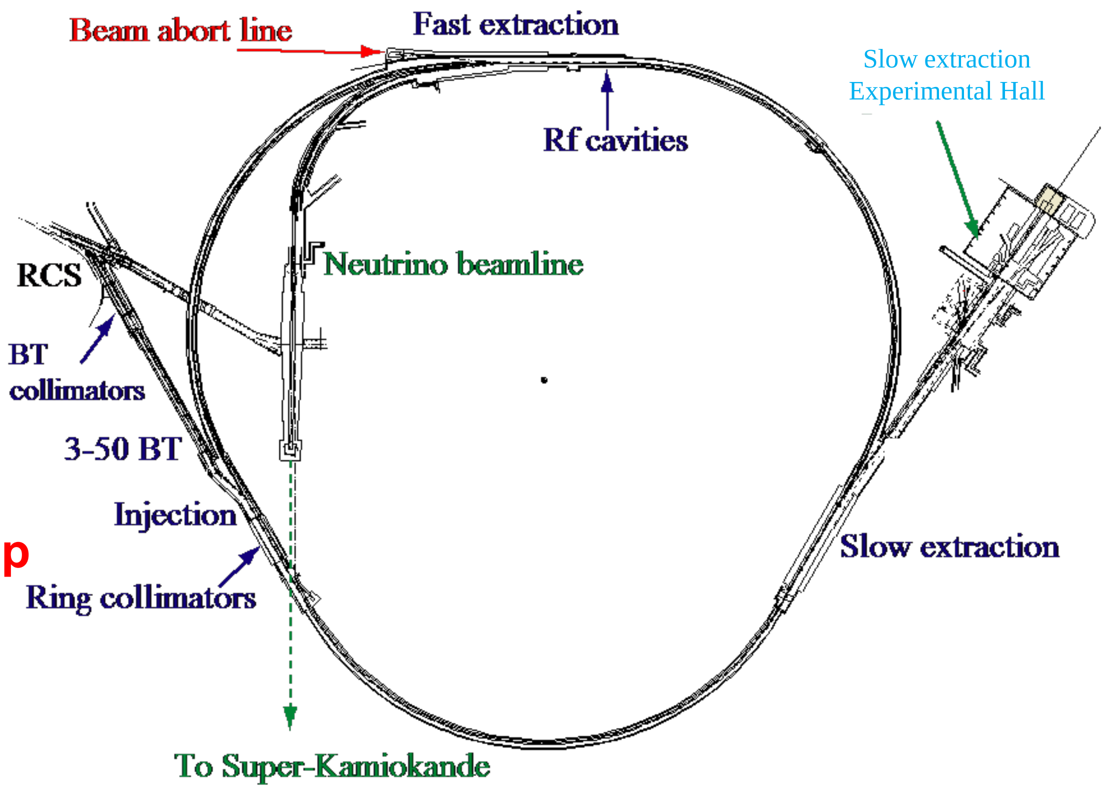
$\delta(\Delta m_{23}{}^2) \sim < 5 \times 10^{-5}\ \mathrm{eV}^2$

Construction status

J-PARC Accelerator and Experimental Facility



Overview of MR



Circumference	**1567.5 m**
Repetition rate	**～0.3 Hz@Start Up**
Injection energy	**3 GeV**
Extraction energy	**30 GeV**
Superperiodicity	**3**
h	**9**
No. of bunches	**8 (6 in day 1)**
Transition γ	**31.7(imaginary)**
Typical tune	**22.4, 20.8**
Transverse emittance	
At injection	**~54 πmm-mrad**
At extraction	**~10 πmm-mrad**
Beam power	**0.75MW goal for the first stage**

\+ Injection and Extraction
Rooms for improvement

Problems to be cleared and Achievements (Changing daily)

Achievements

- LINAC+RCS High power demonstration
  - RCS 213kw equiv. operation for 70 seconds
    - (Limited capacity of beam dump)
    - 1.77×10^{13} protons per pulse, 2 bunch/pulse, 25Hz
  - RCS 353kw equiv. operation for one pulse
    - 2.93×10^{13} protons per pulse, 2 bunch/pulse, 25Hz
- MR
  - ～1 hour operation with 3.64 sec cycle time
  - 3GeV (RF capture), 4×10^{11} protons/bunch, single bunch, controlled abort after 1 sec
  - Various optics measurement/tuning has been done

Work in progress

- Leakage Magnetic Field from Septum Magnet
  - Additional Magnetic Shielding is Designed and Attached
- Effect of Magnet Power Supply Ripple
  - Cable Re-Configuration, Additional Noise Filtering and Feed Back Tuning are underway

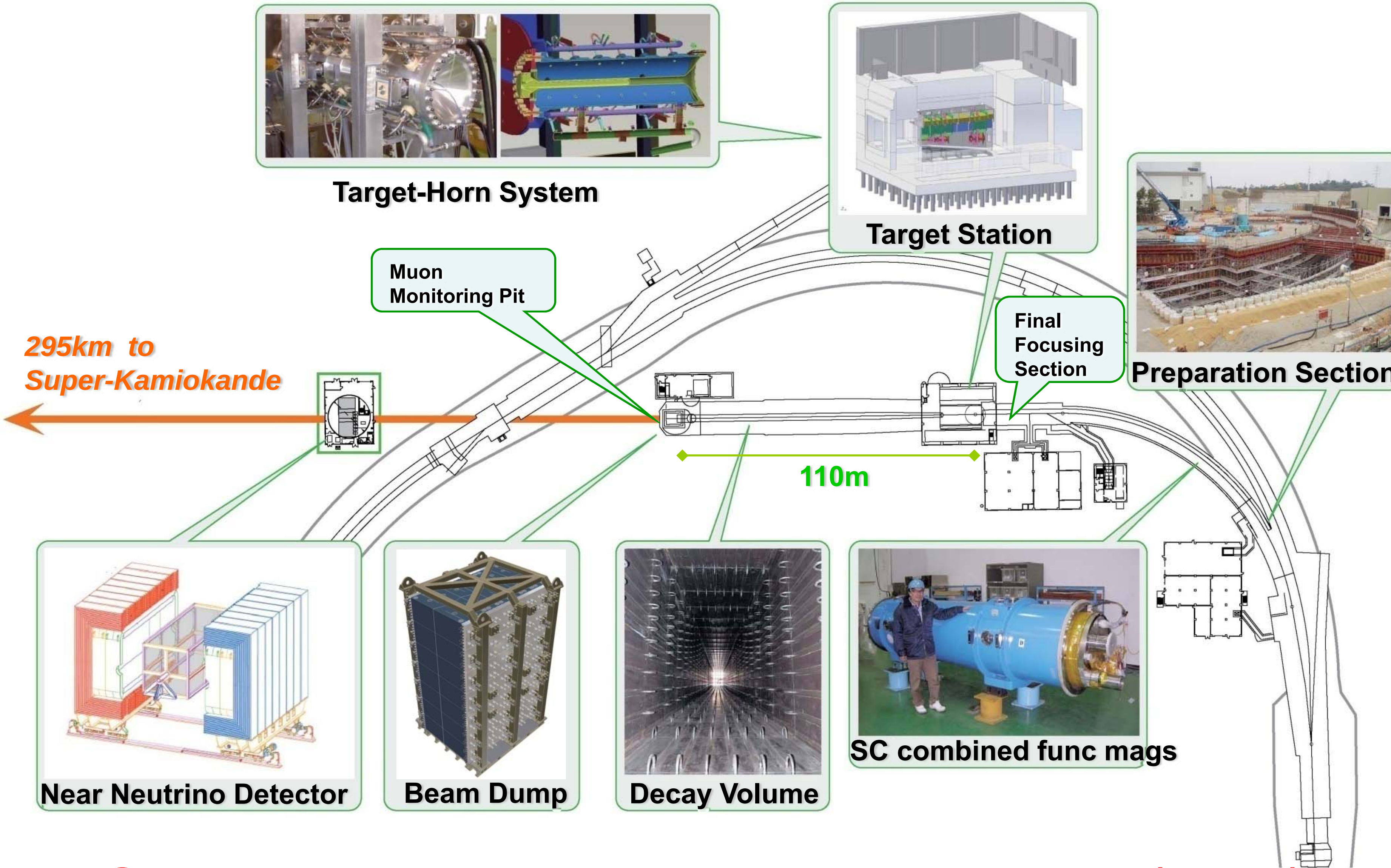
MR Schedule

- Intermission: July08-Nov08
  - Install rest of the fast extraction devices
  - Install slow extraction devices
  - Various tuning/preparation for acceleration/extraction
- Beam Commissioning: Dec08-Feb09
  - Fast extraction system (for beam dump)
  - Acceleration to 30GeV
  - Slow extraction
- Intermission: March09
  - Integrate neutrino beam facility to other radiation restricted area
  - 5th RF system installation
- Beam Commissioning: Apr09-
  - Neutrino beam facility commissioning with beam (Beam Power < 7.2kw Apr-June)

Installed Kicker Magnet

*Accelerator Team is doing their best to provide 100kw × 10^7sec proton power on target by summer 2010 (> CHOOZ limit by appearance expt.)
and Power improvement toward ～MW after that

Neutrino Beamline at J-PARC



Construction: Apr. 2004 ~ Mar. 2009 (5yrs)

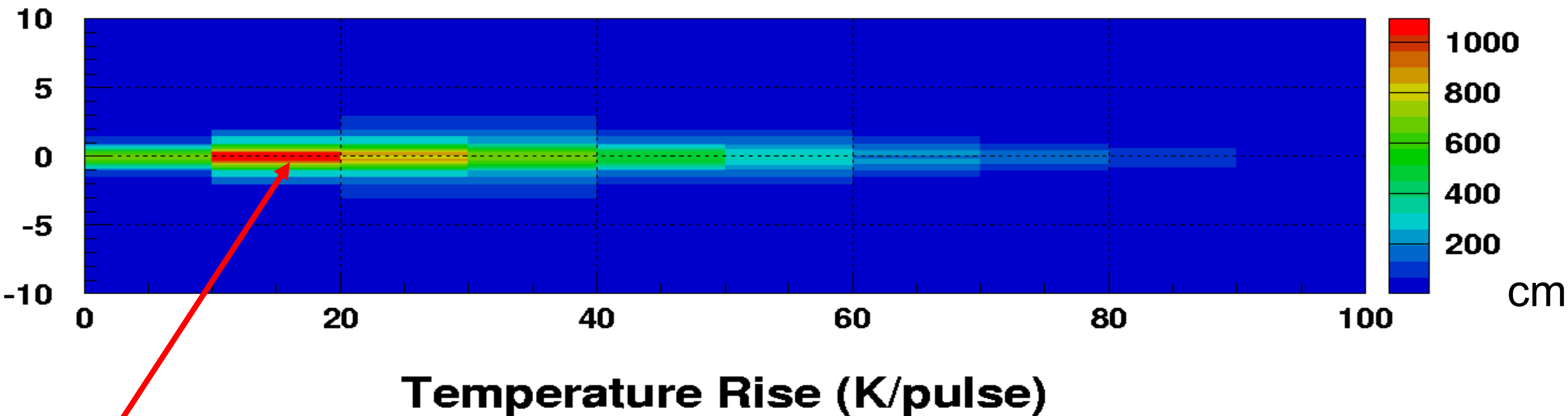
Handling of high power proton beam 0.75 MW fast-ext'ed beam !

w/ 5μs pulse

Residual rad.

> 1000Sv/h

When this beam hits an iron block,



1100º

(cf. melting point 1536º)

✓ Material heavier than iron would melt.

✓ Thermal shock stress $\approx E\alpha\Delta T \approx 3GPa$

(cf. Fe limit ~300 MPa)

Material heavier than Ti might be destroyed. 29

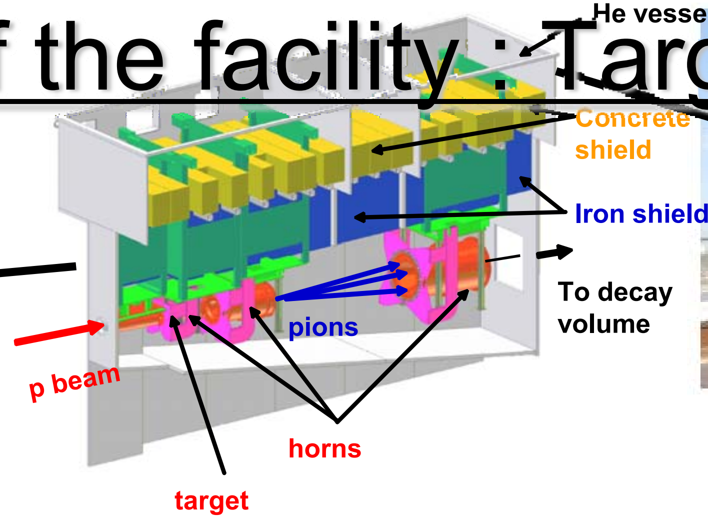
MW Neutrino Beam Line

- Heating by dEdX
  - Water cooling and He cooling (where possible)

- Shock wave and high radiation
  - Remote handling
  - Graphite for target and dump core (< 10ppm O_2)
  - Tritium, NOx production
  - Minimum number of beam windows

  One piece enclosure from entrance to the target area to beam dump, filled with He

The heart of the facility : Target Station



- Installation of the helium vessel(~470ton, 1000m^3) finished, passed vacuum test.
- Target and horn are being prepared for installation

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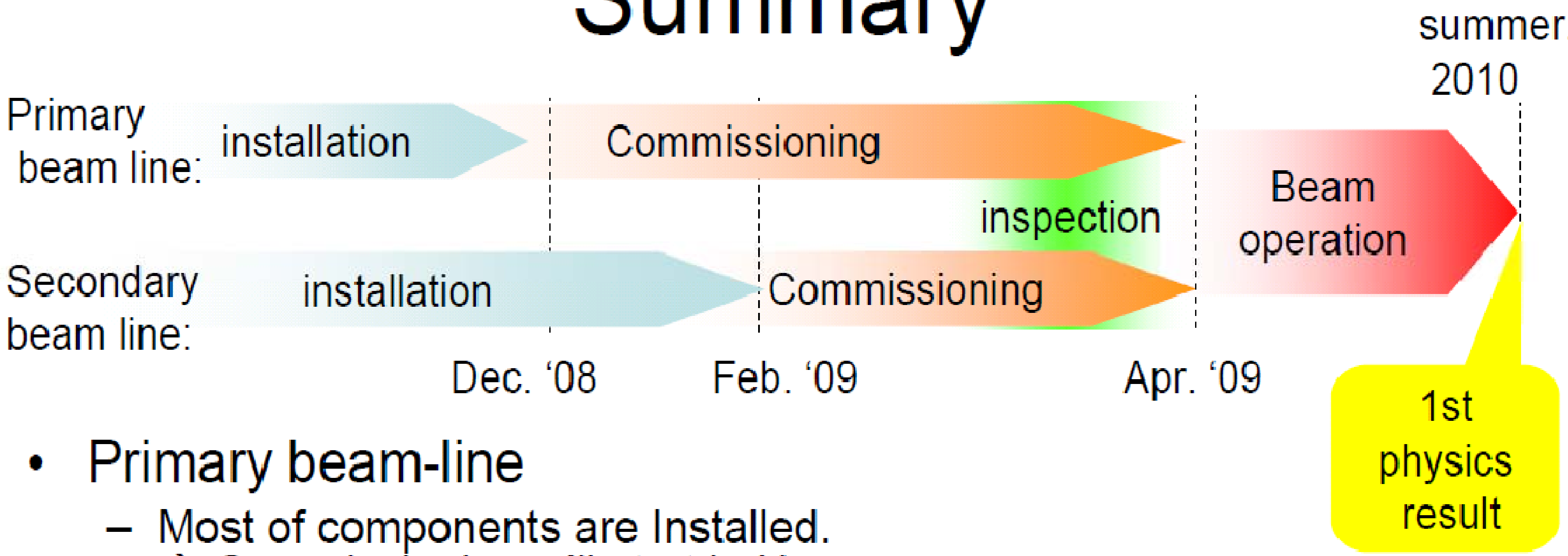
Summary of Status

	Conceptual Design	Engineering Design	Real Production	Installation
Proton Beam monitor				Feb.~
Superconducting magnets				Feb~
Cryogenics				Apr~
Normal Conducting magnets				
Vacuum system				
Target				Aug.~
Horn				Aug.~
Target Station				
Beam Window				Jul~
Decay Volume				
Beam Dump				Aug~
Muon monitor				

- All components are in production/installation phase
- Installations are starting as scheduled

Summary



- Primary beam-line
  - Most of components are Installed. → Commissioning will start in Nov.
- Secondary beam-line
  - Heavy Installation work in Oct. ~ Nov.
  - Commissioning of Horns will be starts in Feb.
- DAQ/Interlock
  - All the hardware is prepared. → System commissioning in Dec

Neutrino beam-line construction on schedule for the commissioning from Apr.

→ 1st physics result in 2010 summer with 100kW×10^7sec beam

Summary

In one year

- Entire J-PARC accelerator complex will be commissioned soon, still many technical problems to be overcome
- Construction of T2K beam line is on time and will be commissioned in April 2009
- Aiming for first results in 2010

In several years

- T2K will provide vital information on θ_{13}, needed to define next step

- New accelerator and beam line have been build based on Super-Kamiokande
- Future experiment will be build based on new accelerator, new beam line and the results from T2K

Thank you for your attention!

First few years