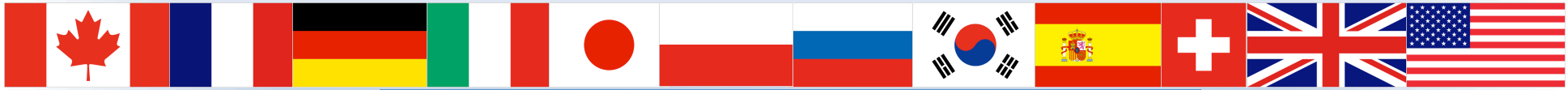
LABORATORIUM FÜR HOCHENERGIEPHYSIK
LHEP
UNIVERSITÄT BERN

The T2K experiment in the context of LBL neutrino physics

PPC 2010
IV INTERNATIONAL WORKSHOP ON THE INTERCONNECTION BETWEEN PARTICLE PHYSICS AND COSMOLOGY

M. Messina,
University of Bern and Albert Einstein Center for Fundamental Physics
on
behalf of the
T2K collaboration

The T2K Collaboration



~500 members, 61 Institutes, 12 countries

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

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CEA Saclay
IPN Lyon
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T2K goals

- **Discovery of ν_e appearance → determine θ_{13}**
  - Last unknown mixing angle to be measured
  - Opens the possibility to have CP violation in the lepton sector
- **Precise meas. of ν_μ disappearance → θ_{23}, Δm_{23}^2**
  - Is it really maximal mixing?
  - Anything unexpected?

Three neutrinos framework: accommodating (almost) all evidences

Reactor & accelerator

Solar & reactor

Atmospheric & accelerator

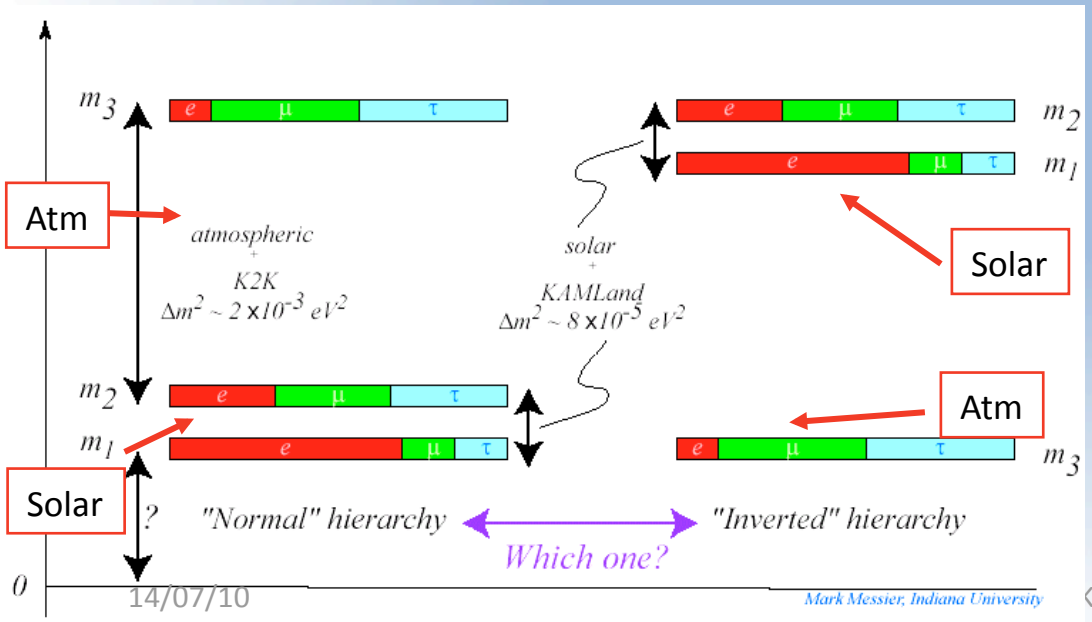
Flavor eigenstates

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

Mass eigenstates

$$U_{MNSP} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot diag \begin{pmatrix} e^{\frac{i\alpha_1}{2}} \\ e^{\frac{i\alpha_2}{2}} \\ 1 \end{pmatrix}$$

$\theta_{13} < 10^o$ CHOOZ/MINOS limit
$\theta_{13} \neq 0$? $\delta_{CP} \neq 0$?



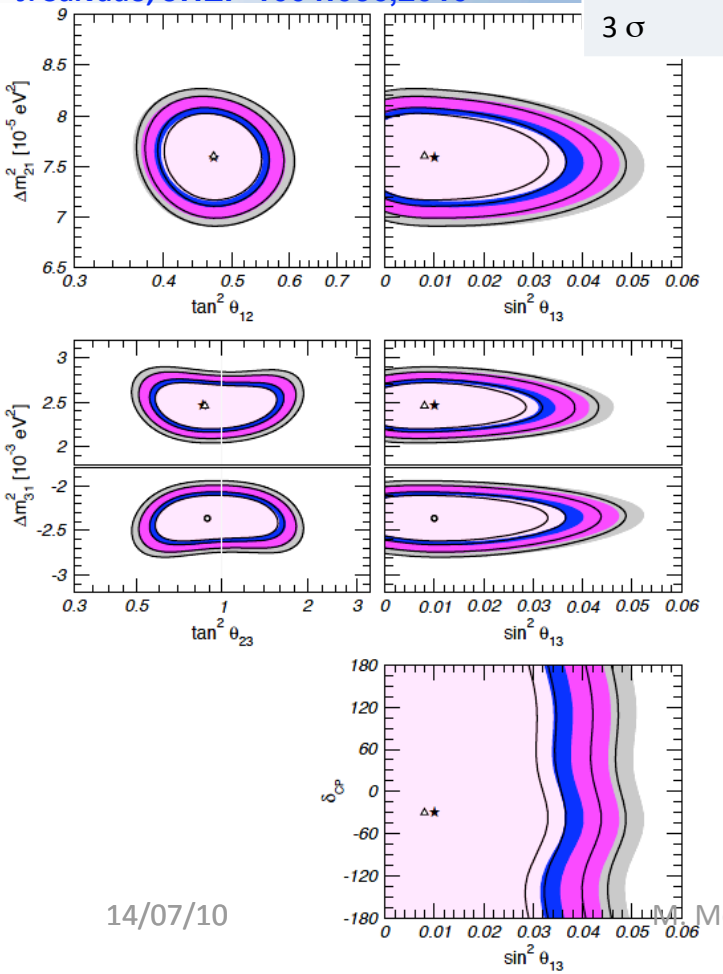
Standard parameterization: 3 angles + 2 mass square differences and possibly 1 Dirac phase and two Majorana phases.

State of art of the oscillation measurements

Parameters	$\Delta m^2(10^{-5}\,eV^2)$ solar	$\Delta m^2(10^{-3}\,eV^2)$ atmospheric	$\sin^2\theta_{12}$	$\sin^2\theta_{13}$	$\sin^2\theta_{23}$
Best fit	7.67	2.39	0.321	0.016	0.466
1 σ	7.48-7.83	2.31-2.50	0.294-0.331	0.006-0.026	0.408-0.539
2 σ	7.31-8.01	2.19-2.66	0.278-0.352	<0.036	0.366-0.602
3 σ	7.14-8.19	2.06-2.81	0.263-0.375	<0.046	0.331-0.644

M.C. Gonzalez-Garcia, M. Maltoni, J. Salvado, JHEP 1004:056,2010

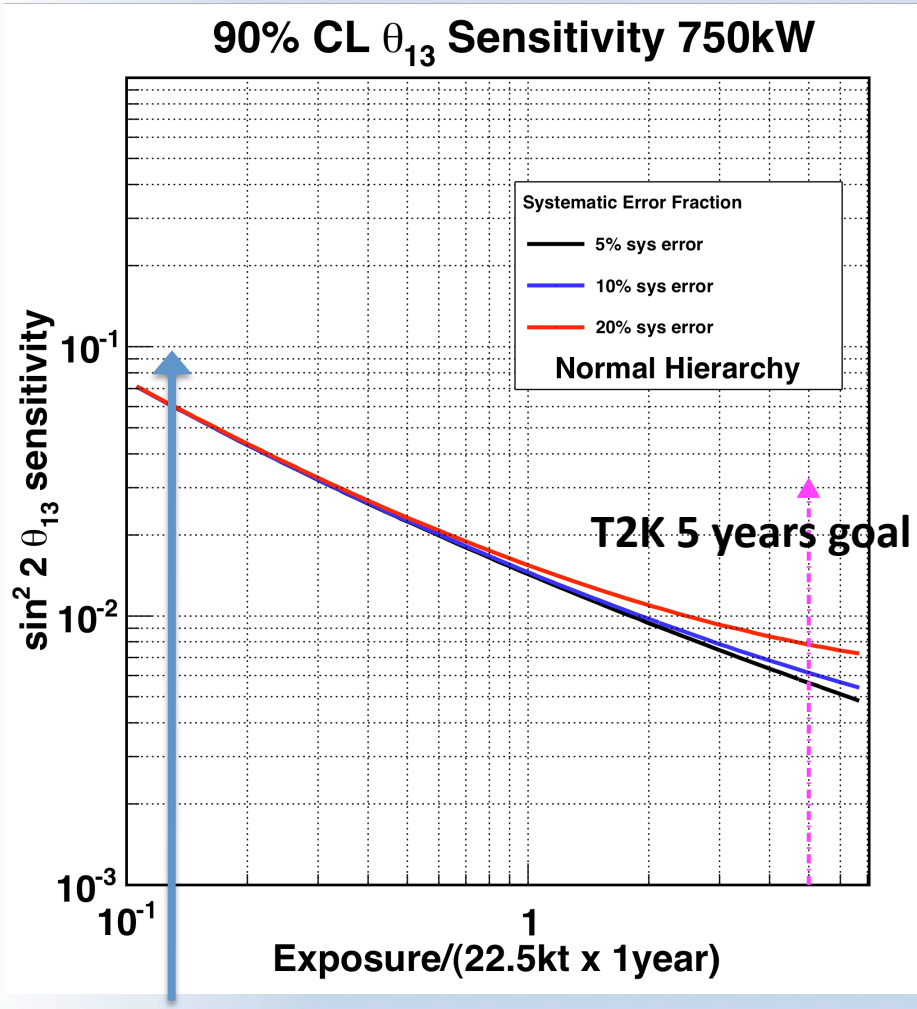
E. Lisi, Prog. in Part. and Nucl. Phys. 64 (2010) 171

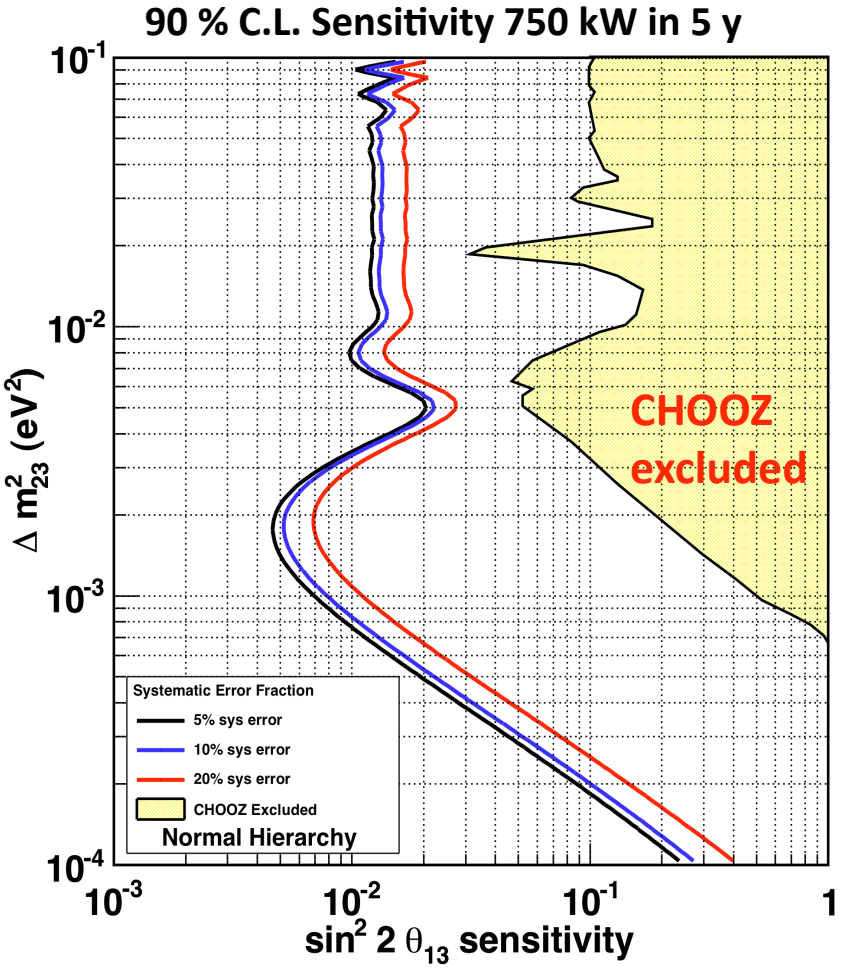


Open issues:

- θ_{13}
- CP violating phase
- mass hierarchy
- Is ν a Dirac or Majorana particle?

T2K sensitivity to θ_{13}

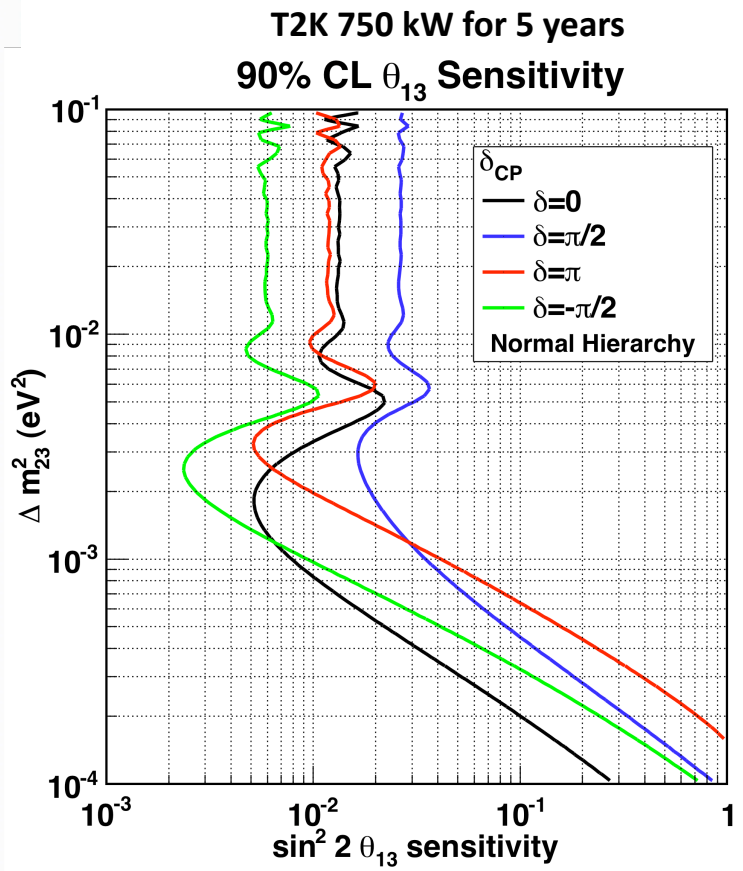




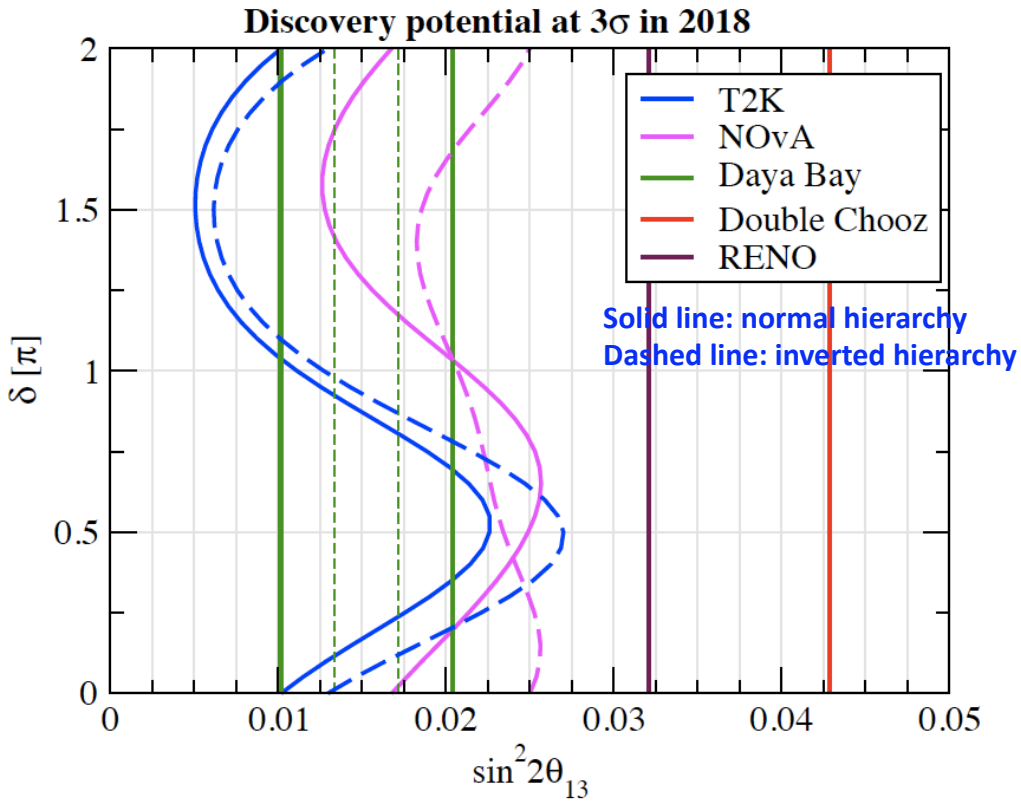
100 kW for 10^7 s (1 nominal year)

0.008 @ $\Delta m_{23}^2 = 2.4 \times 10^{-3}$ eV^2, $\delta_{CP} = 0$ and normal hierarchy 20% sys. error

Dependence on δ_{CP}

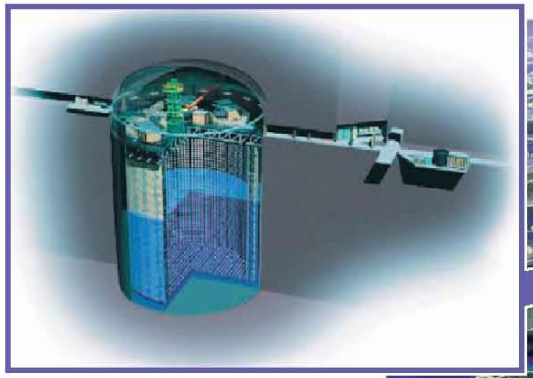


M. Mezzetto and T. Schwetz, arXiv:1003.5800.



T2K (Tokai to Kamioka) experiment

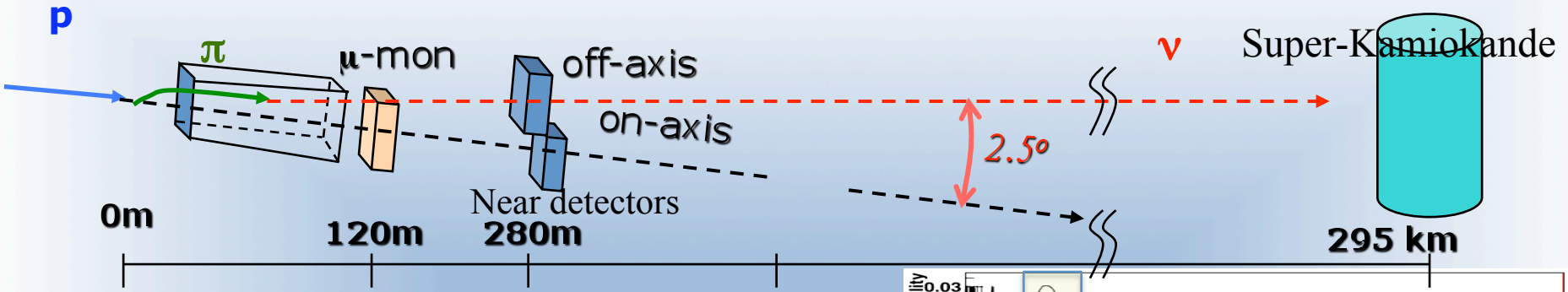
High intensity ν_μ beam from J-PARC to Super-Kamiokande



Super-Kamiokande
(ICRR, Univ. Tokyo)

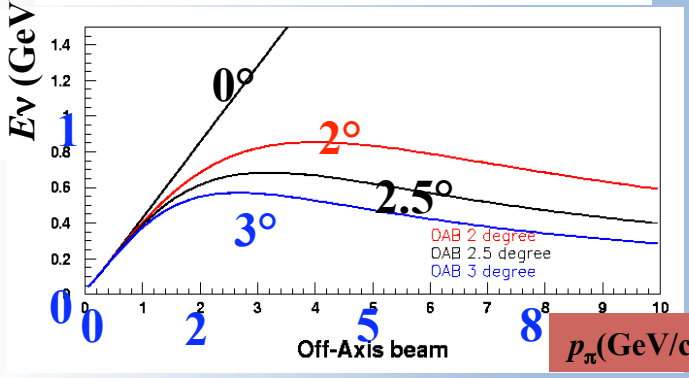
J-PARC Main Ring
(KEK-JAEA, Tokai)

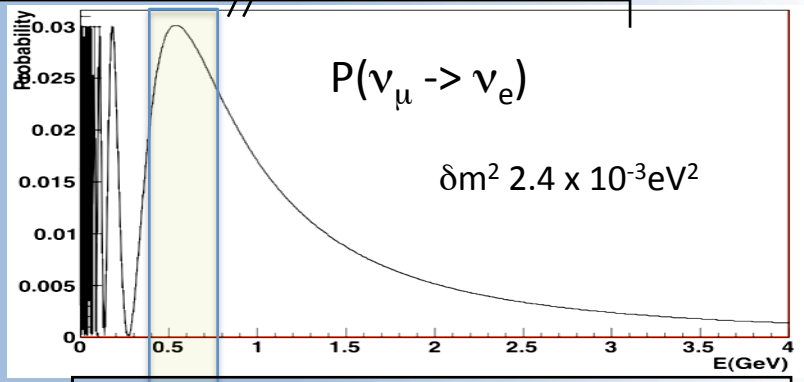
Off-axis beam: intense and narrow beam

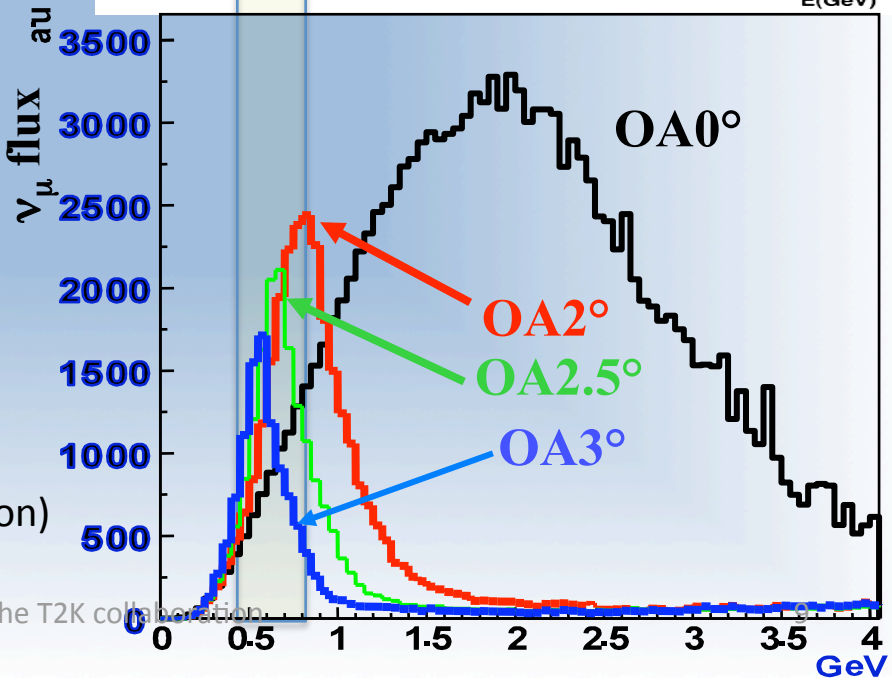


Meson (π/K) decay Kinematics

$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2(E_\pi - p_\pi \cos\vartheta)} \approx \frac{0.43 m_\pi \gamma_\pi}{(1+\gamma_\pi^2\vartheta^2)}$$

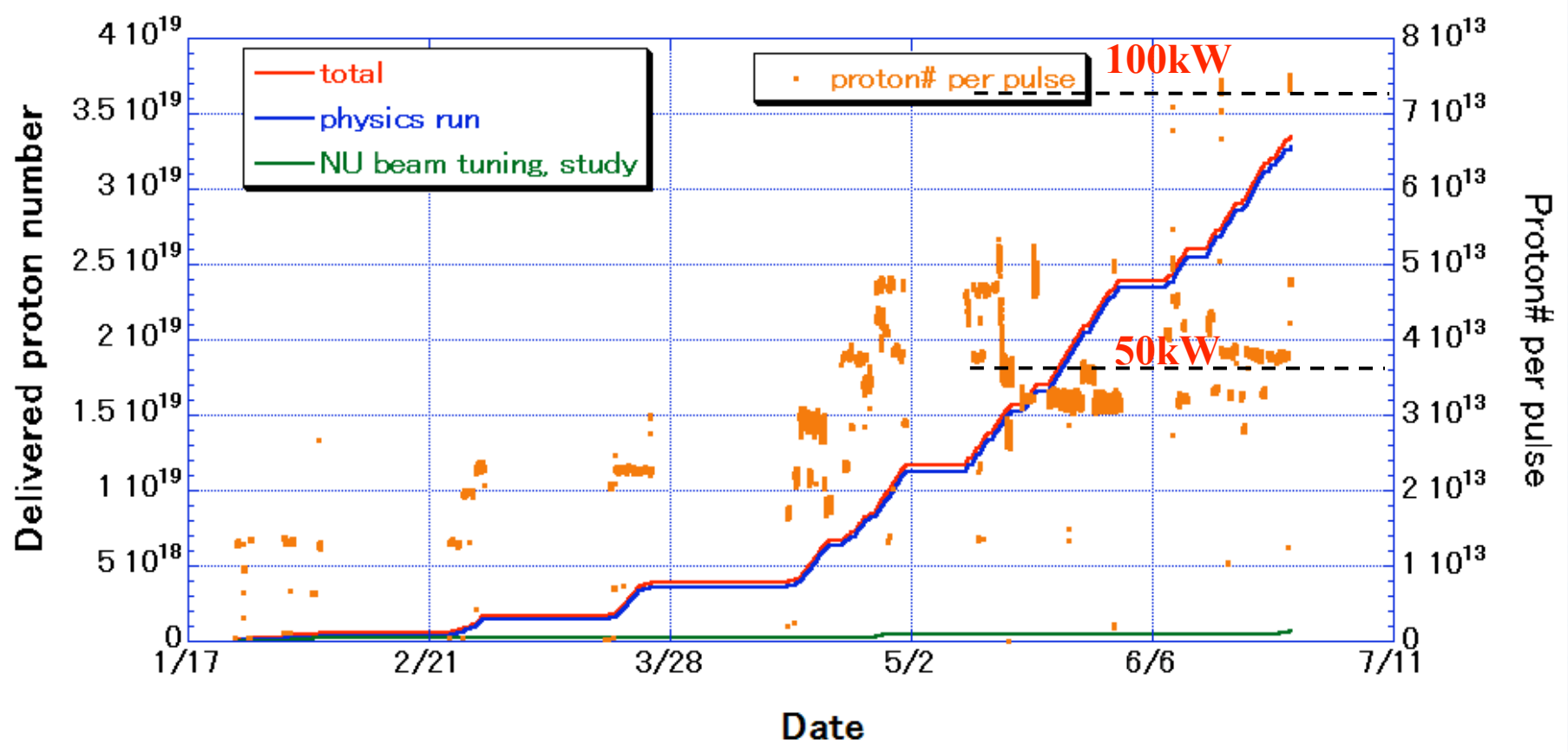






- 2.5 deg "Off-axis beam" (cf. BNL-E899 proposal)
- Near detectors @280m
- Far detector Super-Kamiokande
  - World largest Cerenkov light detector (**FV** 22.5 kton)
- Tuning MC beam with NA61 data

Started data taking for oscillation

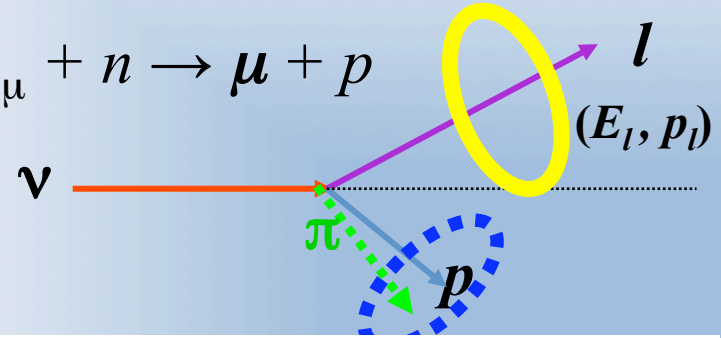


- Delivered # of protons: 3.28×10^{19} (Jan-June)
- Continuous run @ ~50kW level
- trial up to 100kW done

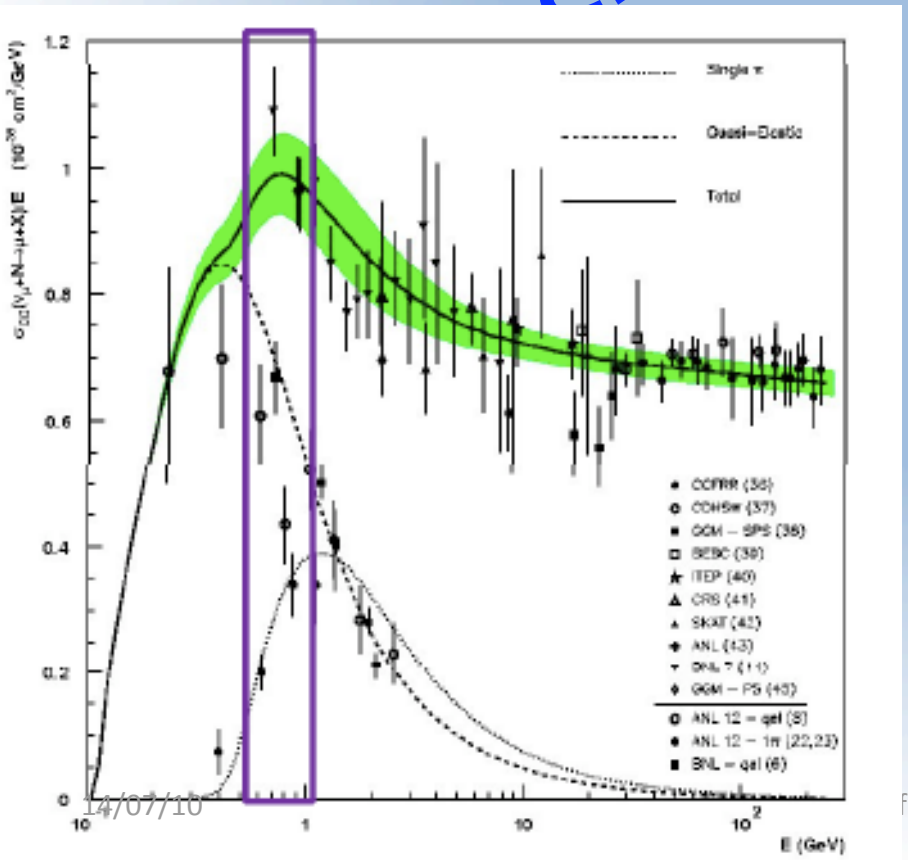
E_ν reconstruction in water Cherenkov

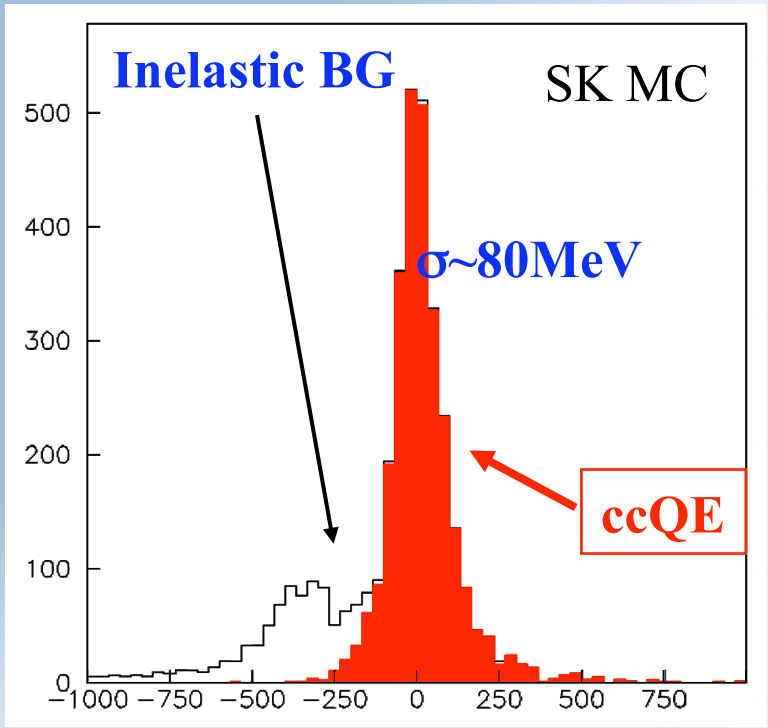
Assume CC Quasi Elastic (QE) reaction

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



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





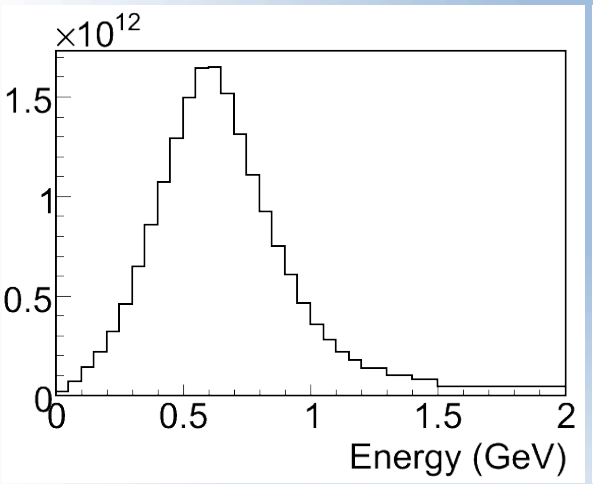
ν_μ Disappearance measurement

✓ The oscillation parameters θ_{23} Δm^2_{23} will be determined from the survival probability of ν_μ after traveling 295km.

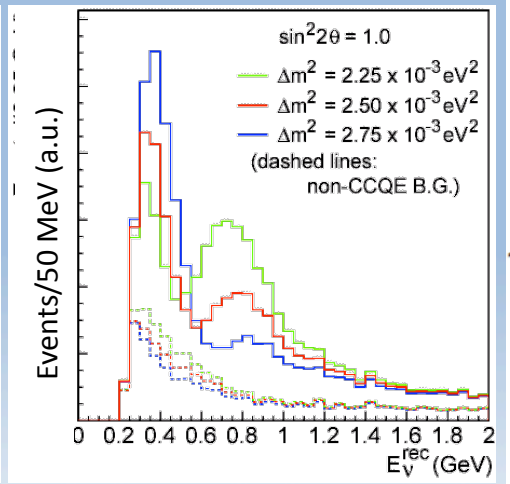
✓ This probability can be measured by comparing the neutrino spectra at the near and far site.

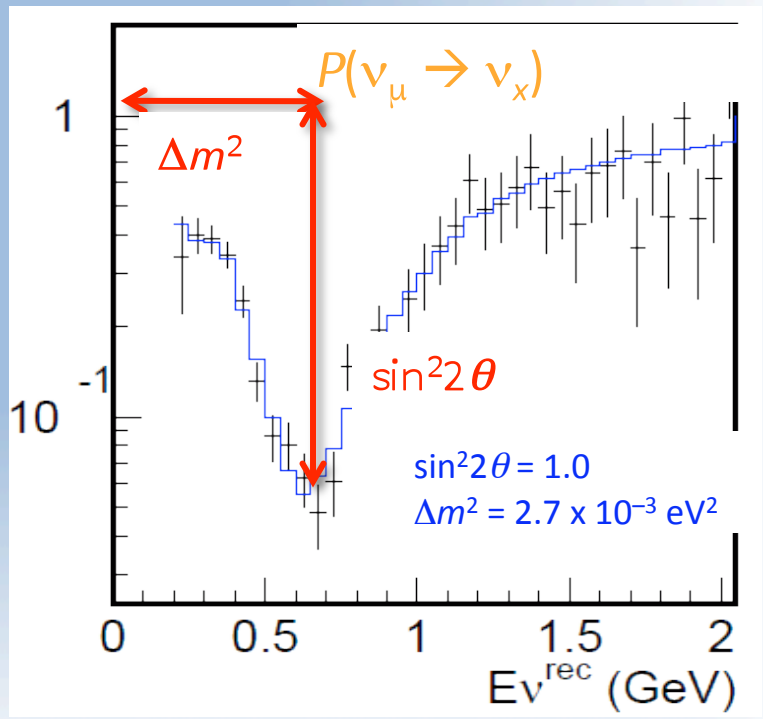
$$1 - P(\nu_\mu \rightarrow \nu_x) = N_\nu^{\text{obs}} / N_\nu^{\text{unosc}}(E_\nu) \approx 1 - \sin^2 2\theta_{23} \sin^2\left(\Delta m^2_{32} L / 4E_\nu\right)$$

Detected at by close detector



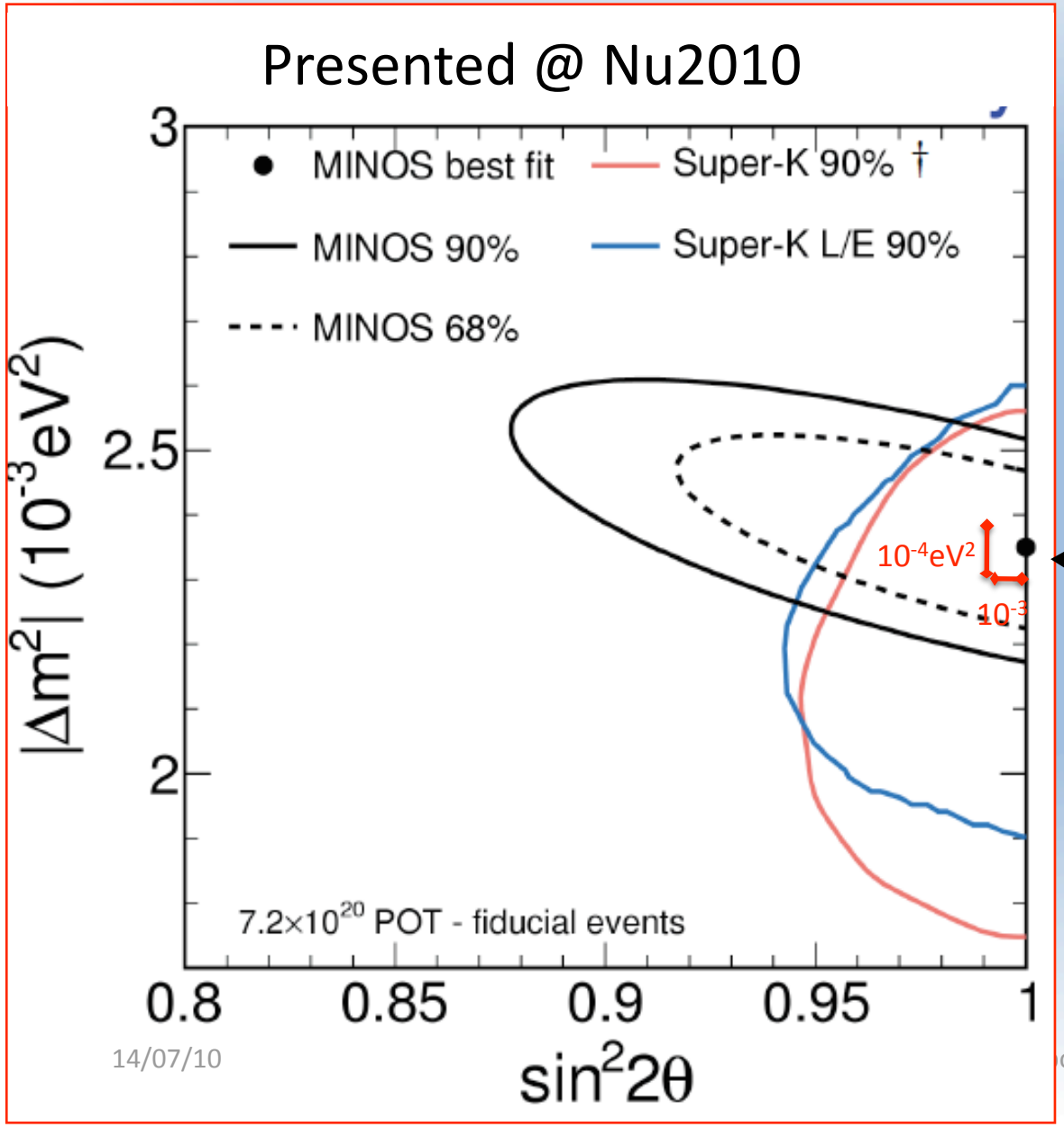
Detected at 295 km by SK





T2K aimed at precision for ν_μ -> ν_x

Presented @ Nu2010

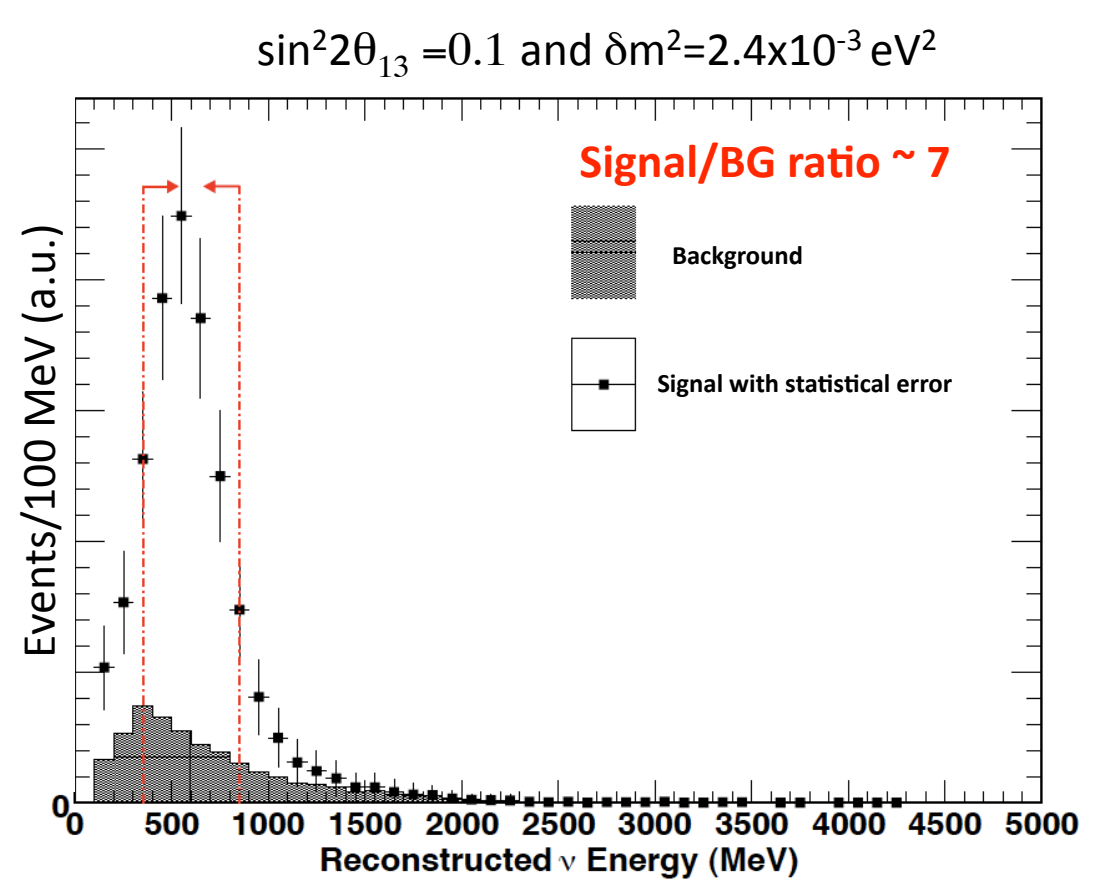


Goal @ 0.75MWx5x10^{7}s:

$\delta(\sin^2 2\theta_{23}) \sim 0.01$,
$\delta(\Delta m^2_{23}) < 1\times10^{-4}$ [eV^2]

the aimed precision is important for the determination of θ_{13} and the comparison with reactor experiments.
-reactor experiments are sensitive to
- $\sin^2(2\theta_{13})$
- accelerator experiments are sensitive to $\sin^2(\theta_{23})\sin^2(2\theta_{13})$

Detection of ν_e appearance: ν_μ -> ν_e

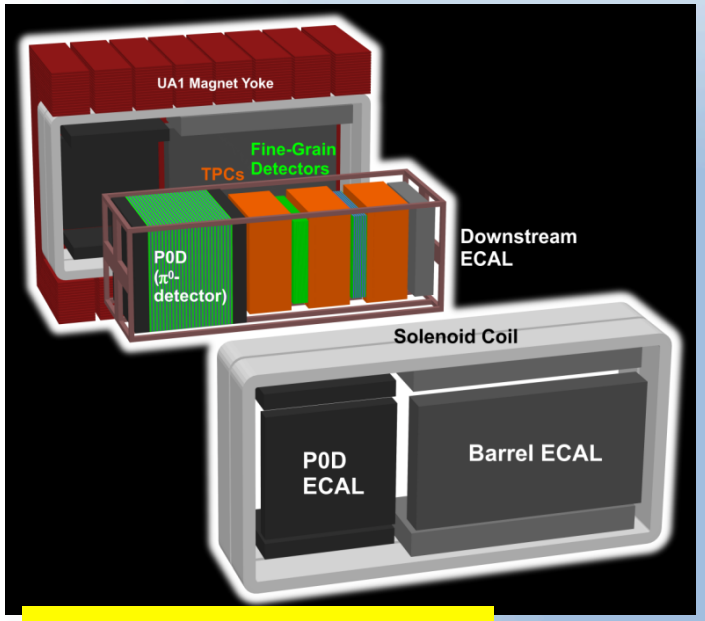


Main background

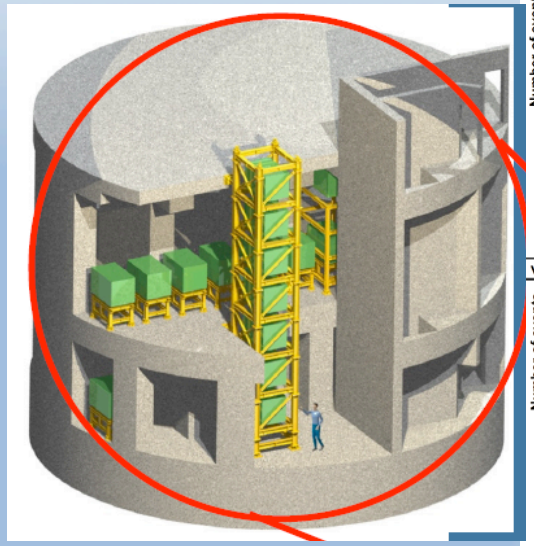
- ν_e contamination of the beam
  $\nu_e + n \rightarrow e^- + p$
- NC π^0 production
  $\nu_\mu + N \rightarrow \nu_\mu + p + \pi^0 \rightarrow \gamma + \gamma$

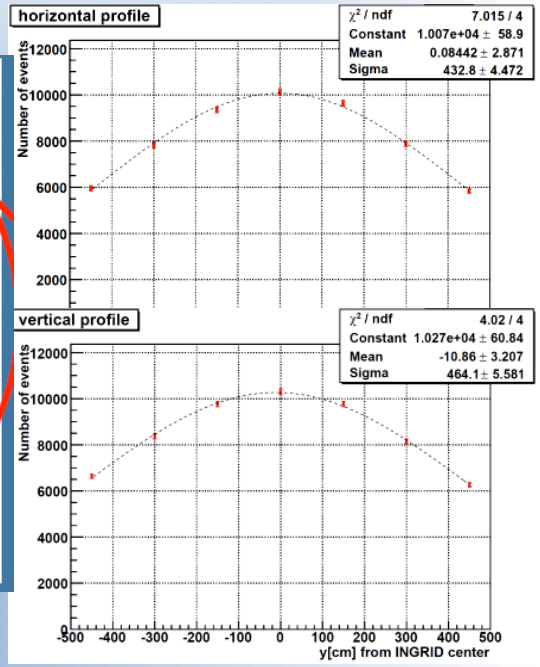
ND280 detectors

Off-axis detectors:
P0D+FGD+TPCs+ECAL+SMRD

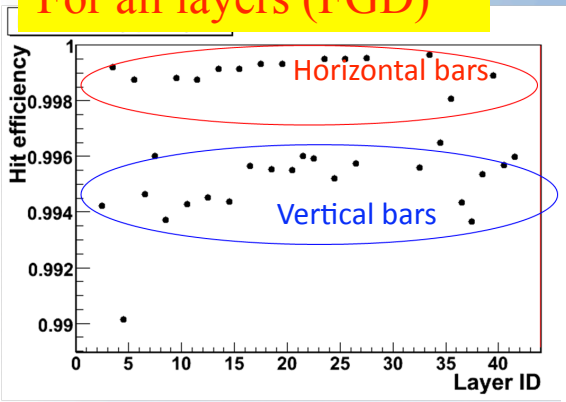


On axis detector: INGRID



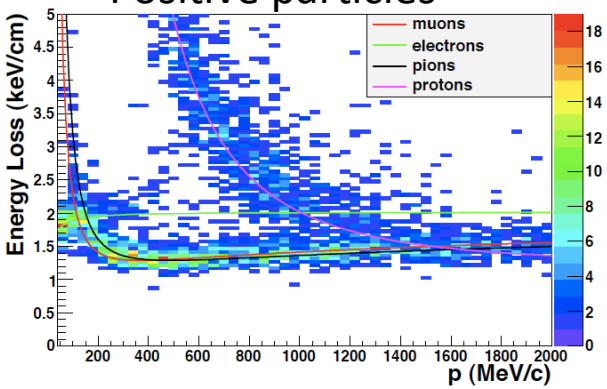


Hit Efficiencies >99%
For all layers (FGD)



dE/dx from TPC

Positive particles



Negative particles

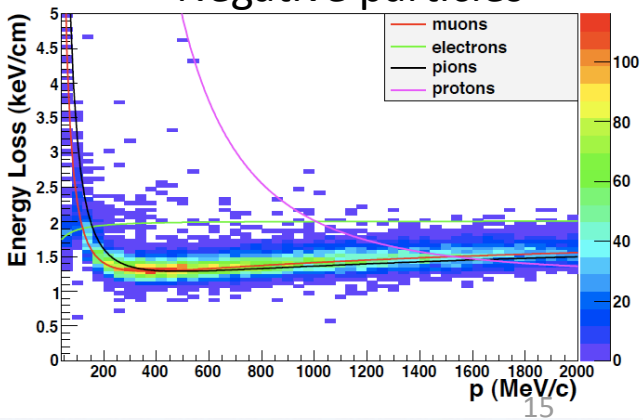
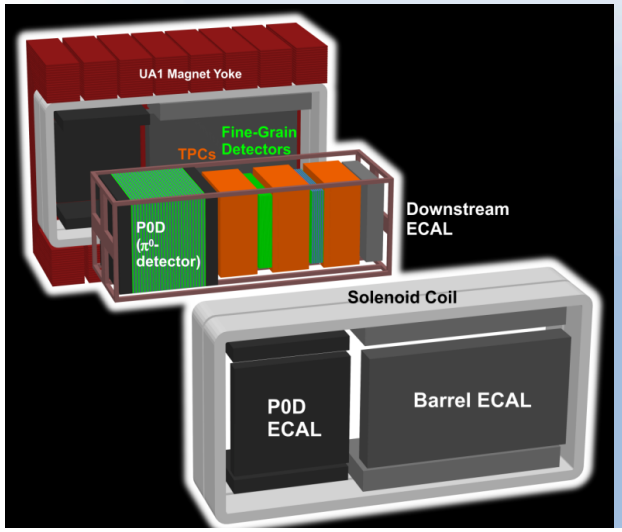
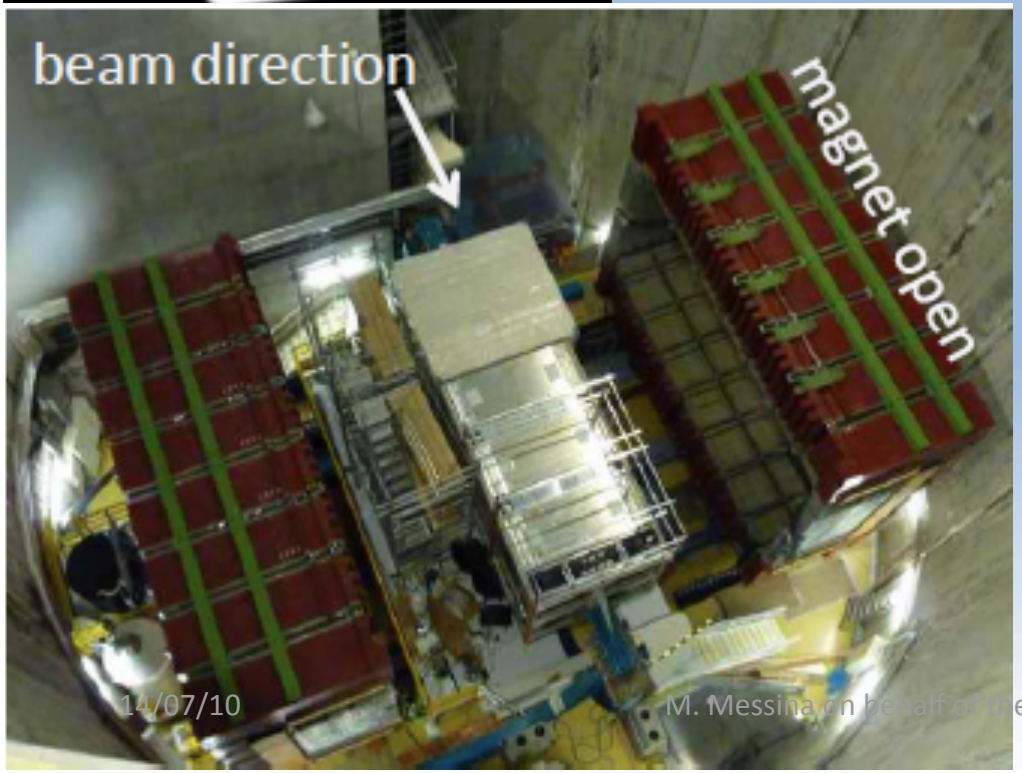
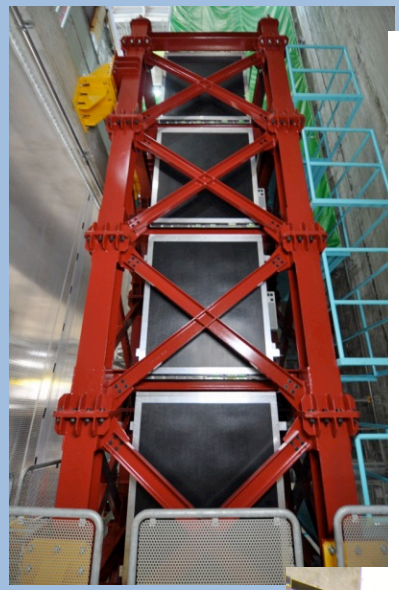
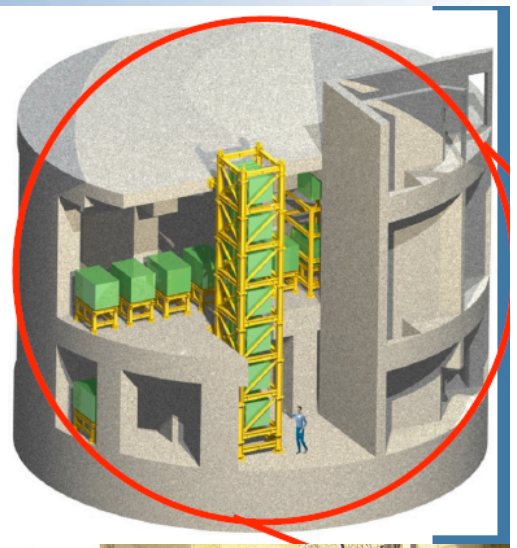


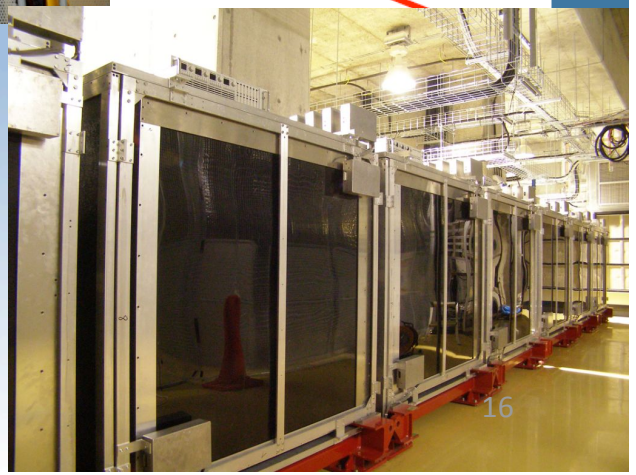
Photo gallery



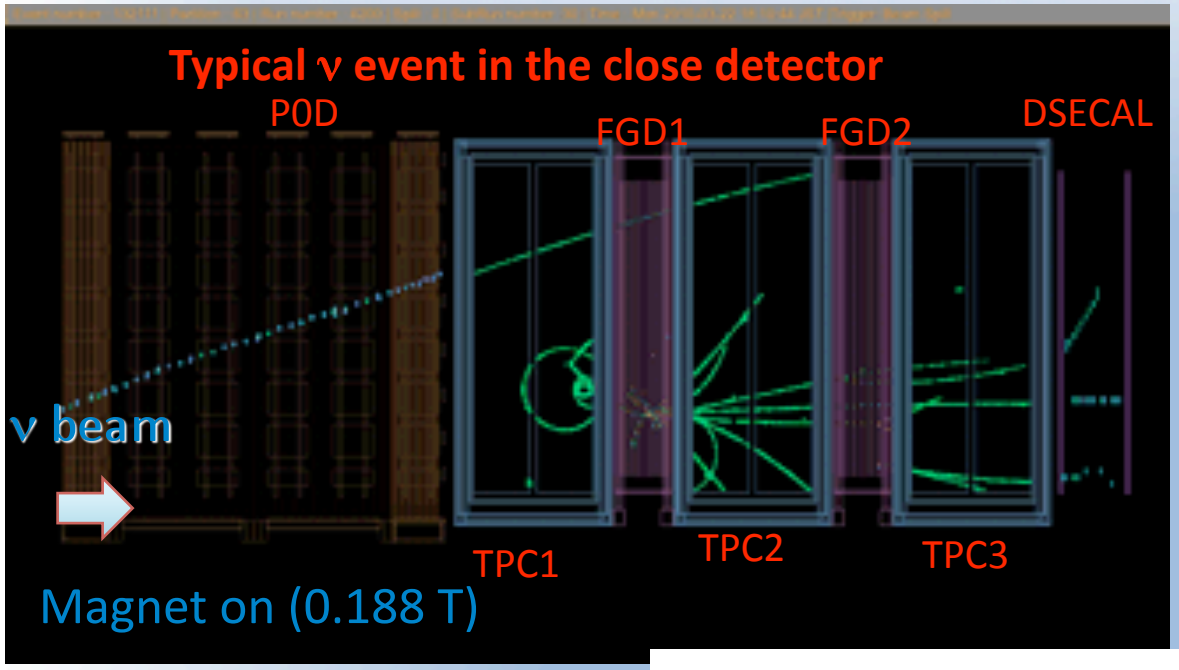


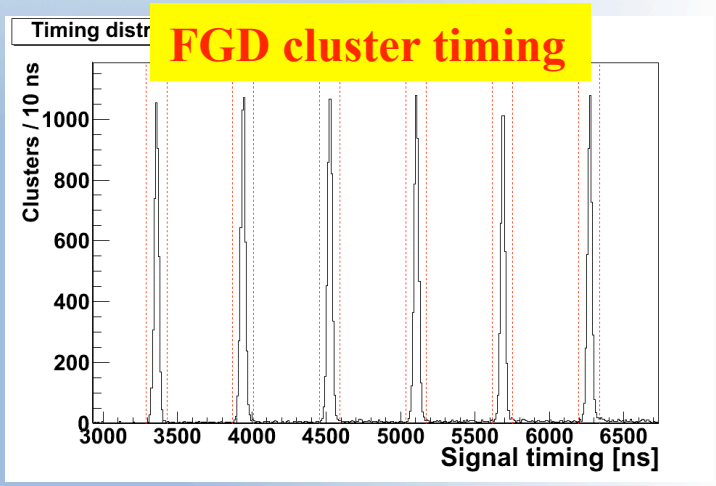




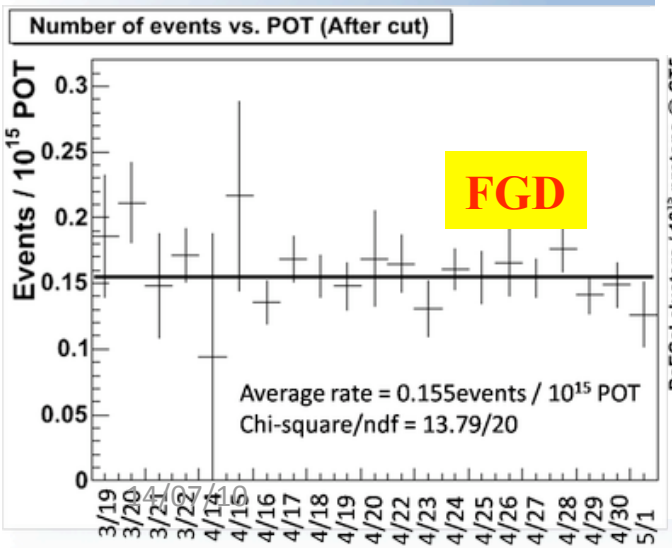


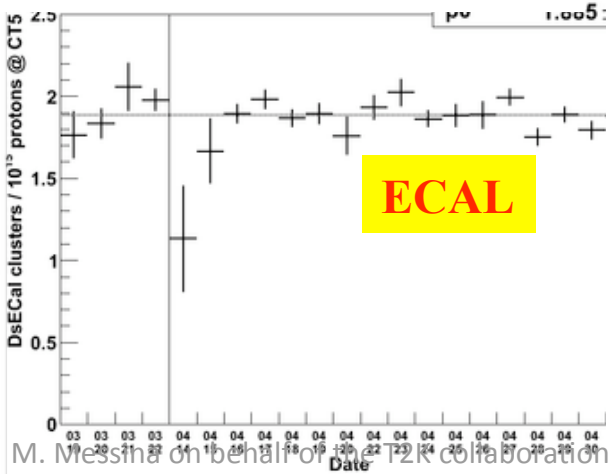
ND280 detectors performance

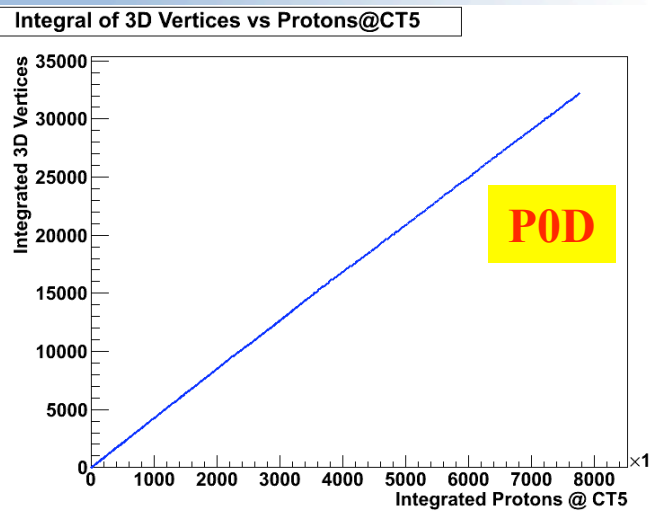




Events rate is stable

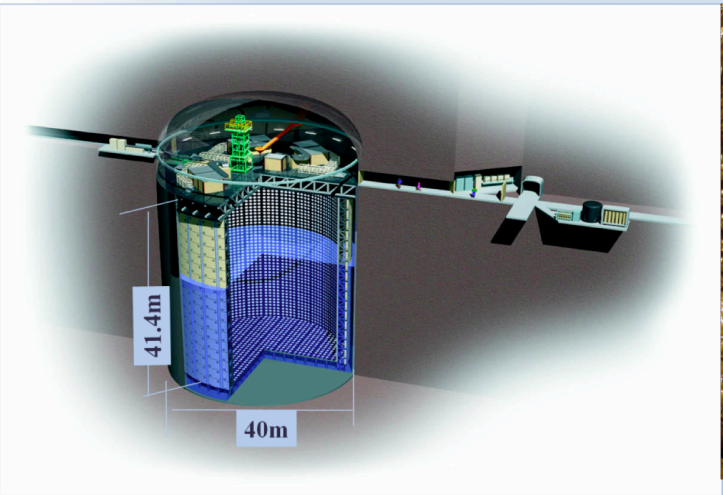


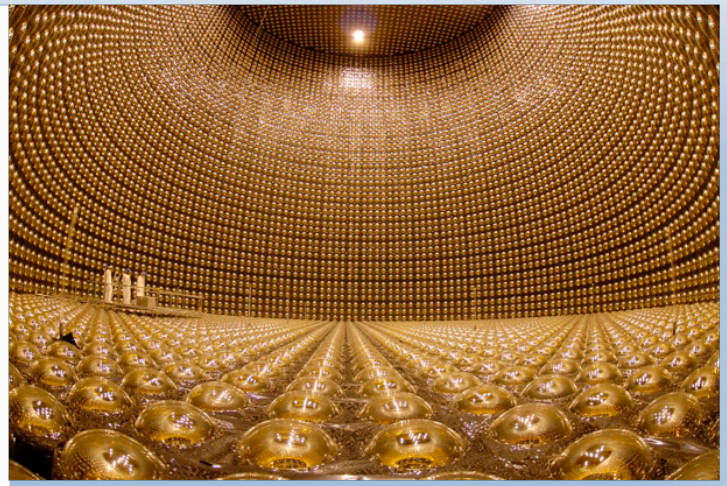




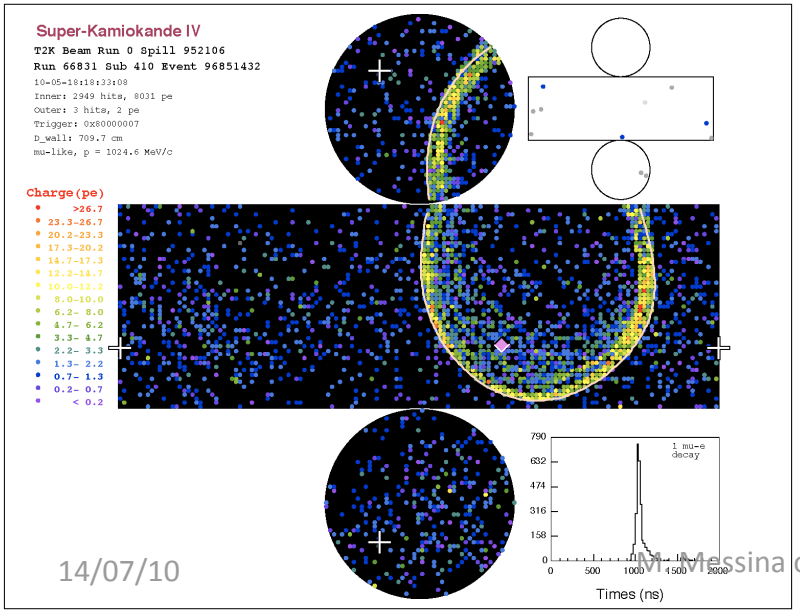
SuperKamiokande

and typical events

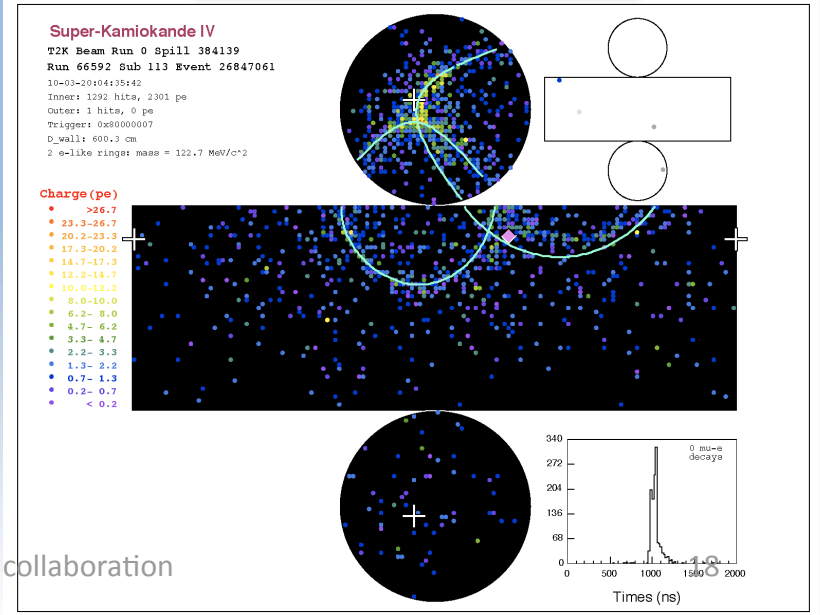




Single-ring μ-like event



Two-ring event



Far detector station: Super-Kamiokande

Events Selection

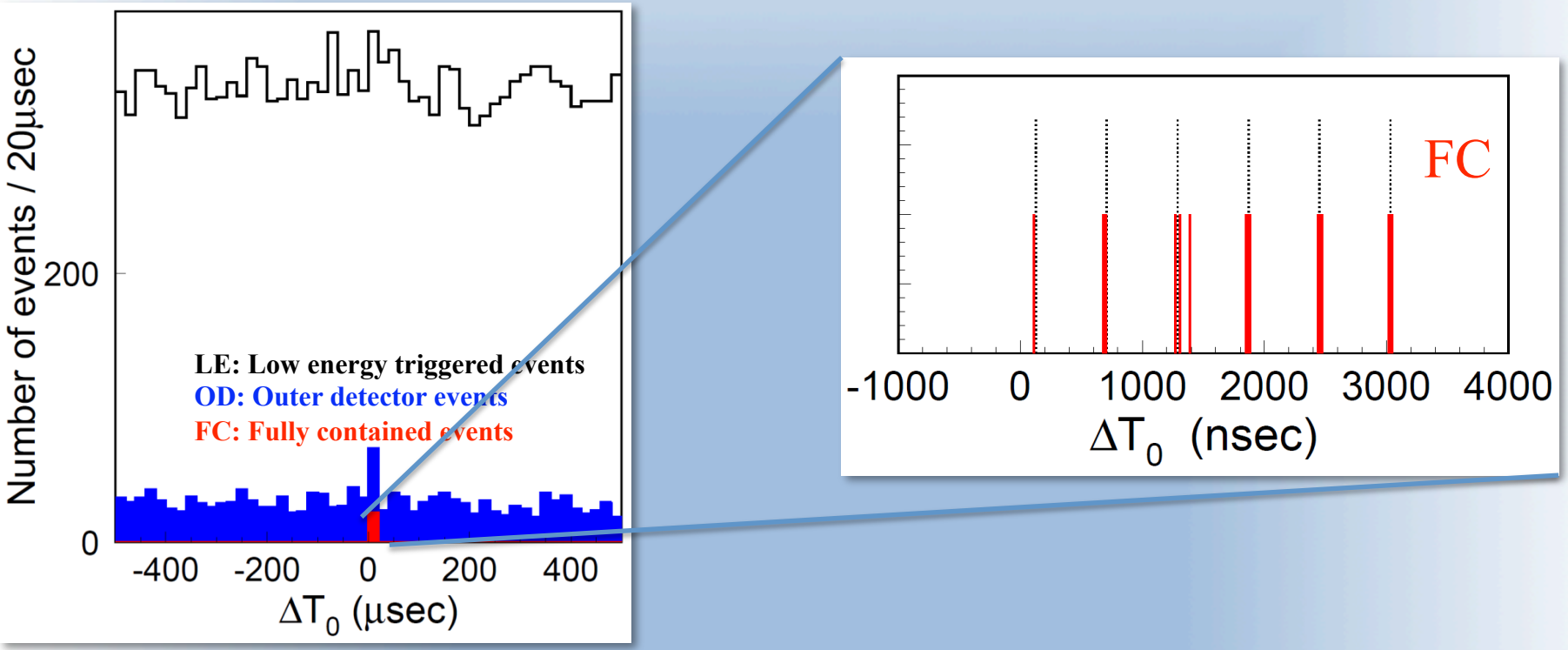
- J-PARC neutrino events selected by event timing using GPS
- SK analysis is very well established ->20yrs of experiences with water Cherenkov detector
- Event selection & cut values are fixed already

UNBIASED SELECTON

- Selection criteria

For ν_μ disappearance analysis	For ν_e appearance search
Timing coincidence w/ beam timing (+TOF)	
Fully contained (No OD activity)	
Vertex in fiducial volume (Vertex >2m from wall)	
Evis > 30MeV	Evis > 100MeV
# of ring =1	
μ-like ring	e-like ring
	No decay electron
	Inv. mass w/ forced-found 2nd ring < 105MeV
	E_ν^{rec} < 1250MeV

Observed events in SK



- Events time distribution in agreement with beam time structure
- 22 FC contained events observed up to middle of May.
- Expected BG: $<10^{-3}$evts

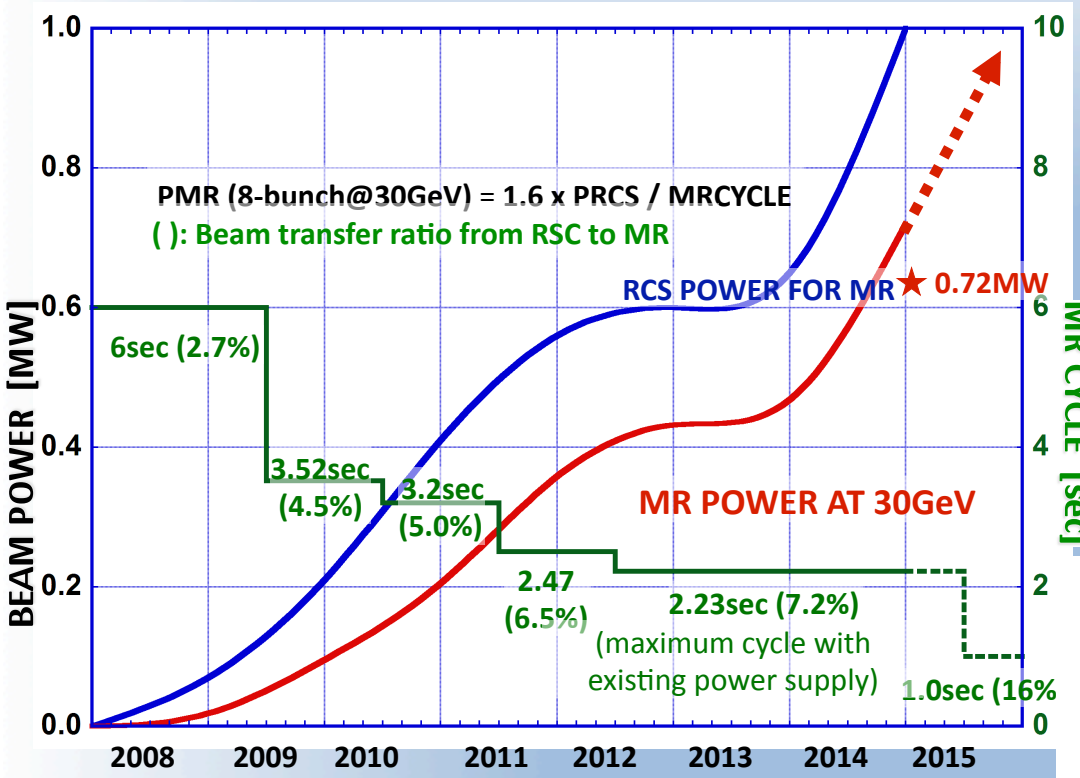
Summary and outlook

- Neutrino beam line completed in Mar. 2009 (on schedule)
- First beam on 23 April, 2009
- **Data recording for oscillation studies started in Jan. 2010**
  - Stable operation at ~50kW power intensity
  - 3.28E19 protons delivered up to the end of June 2010
  - 22 FC events observed in SK (far detector) up to middle of May.

- Ecal installation will be completed in summer shutdown
- After summer shutdown: from ~100 kW towards design power 0.75 MW
- Physics goal:
  - Integrated power 0.75 MW x 5×10^7sec (=3.75 MW$\times10^7$sec)
    - Discover ν_e appearance
      - $\sin^2 2\theta_{13}$ down to 0.018 (3σ sensitivity), 0.008 (90% CL sensitivity), with NH and $\delta CP=0$
    - Precise measurement of ν_μ disappearance
      - $\delta(\Delta m_{23}^2)\sim1\times10^{-4}$eV^2, $\delta(\sin^2 2\theta_{23})\sim1\%$

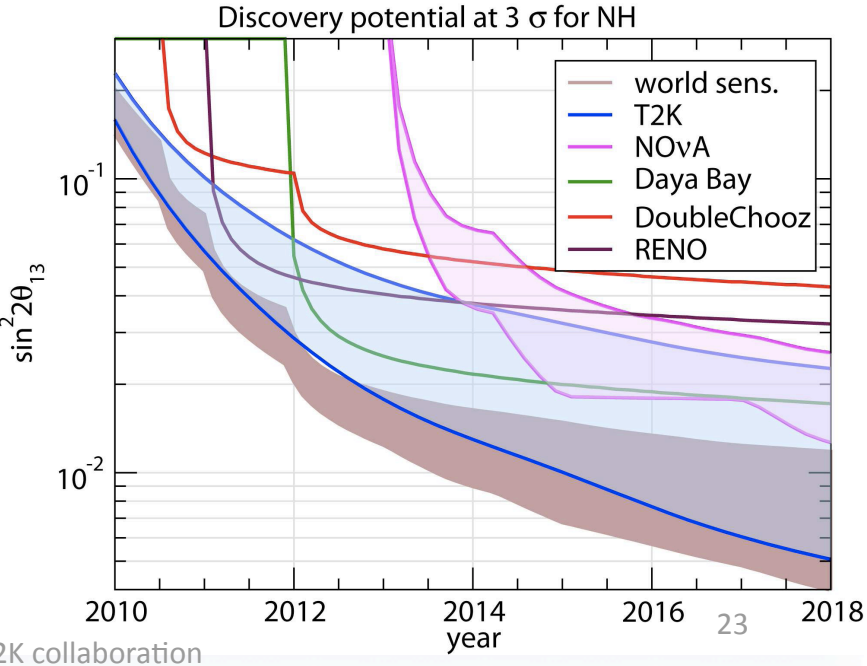
Backup slides

AN EXPECTED BEAM POWER CURVES FOR RCS AND MR FAST BEAM EXTRACTION



M. Mezzetto and T. Schwetz, arXiv:1003.5800.

The bands for the accelerator experiments describe the uncertainties due to the δCP phase



MR Power Improvement Scenario toward MW-class power frontier machine

Increase rep. rate (up to 2Hz) and/or increase # of protons

	Day1 (up to Jul.2010)	Next Step	KEK Roadmap
Power(MW)	0.1	0.45	1.66
Energy(GeV)	30	30	30
Rep Cycle(sec)	3.5	3-2	1.92～0.5
No. of Bunch	6	8	8
Particle/Bunch	1.2×10^{13}	$<4.1\times10^{13}$	$4.1\sim8.3\times10^{13}$
Particle/Ring	7.2×10^{13}	$<3.3\times10^{14}$	$3.3\sim6.7\times10^{14}$
LINAC(MeV)	181	181	400
RCS	h=2	h=2 or 1	h=2 or 1

Rapid cycle

add more RF and improve magnet power-supply