T2K

S.Mine (University of California, Irvine)
for T2K collaboration

- Physics goals:
  - discovery of $\nu_\mu \rightarrow \nu_e$ appearance
  - precise measurement of ν_μ disappearance
  - discovery of CP violation (phase-2)

this talk

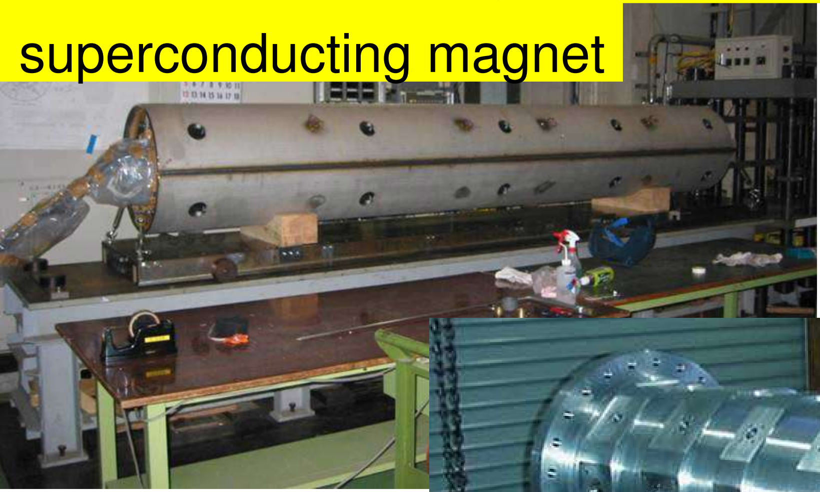
- Schedule:
  - J-PARC (~0.7MW 40GeV PS)
    - construction: 2001~2007
    - operation: 2008~
  - T2K (approved in 2003)
    - construction: 2004~2008
    - experiment: 2009 ~

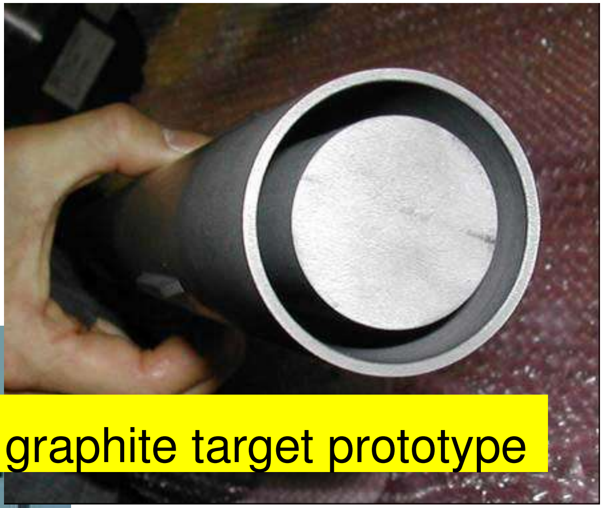
T2K collaboration

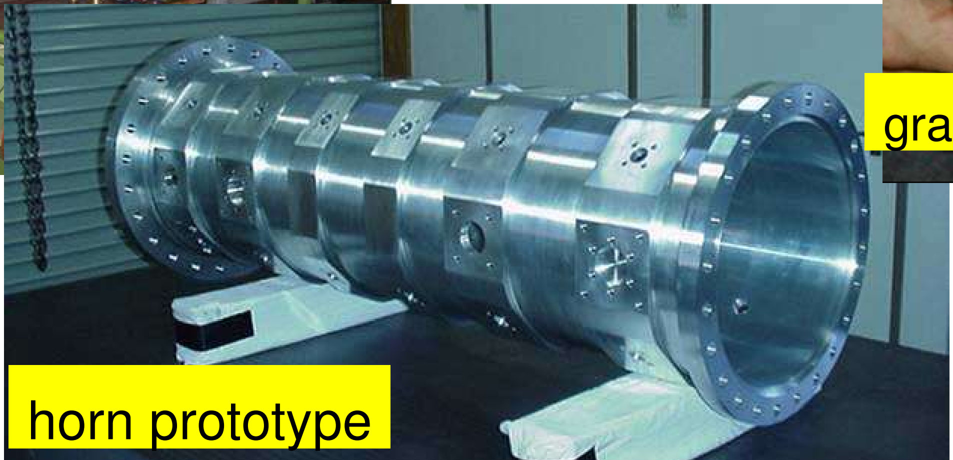
12 countries
~60 institutions
~180 collaborators

Accelerator/Beam line status

J-PARC



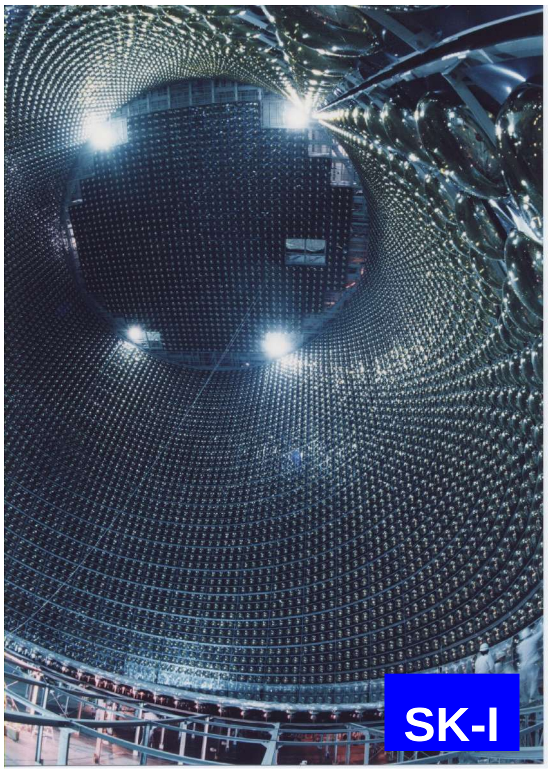


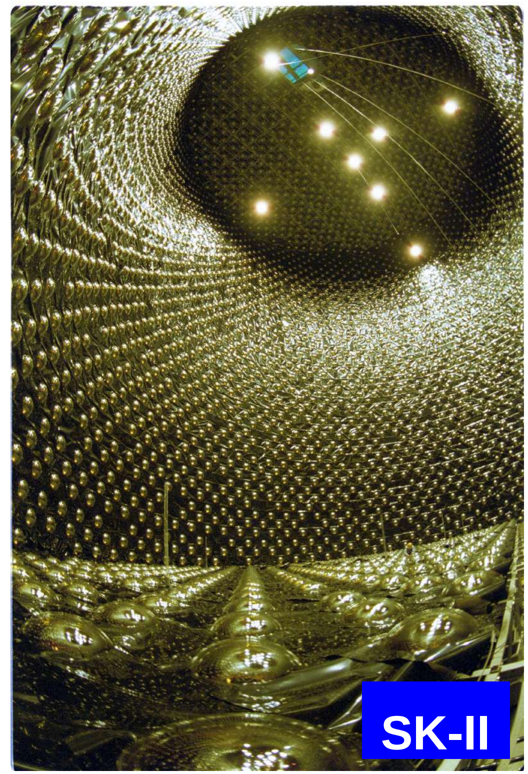


Super-Kamiokande history

1996	1997	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007

SK-I (1996–2001) · accident (2001) · SK-II (2002–2005) · reconstruction (2005–2006) · SK-III (2006–)



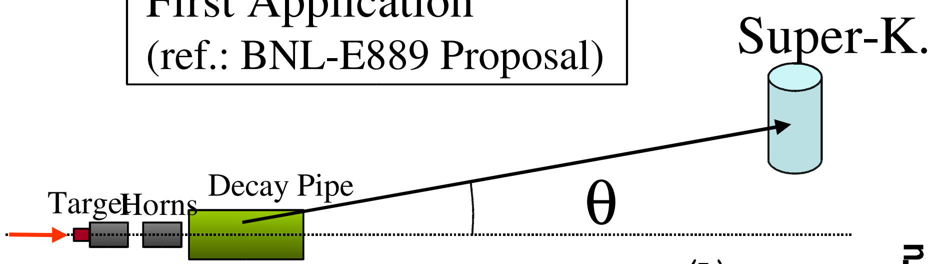


plastic vessel

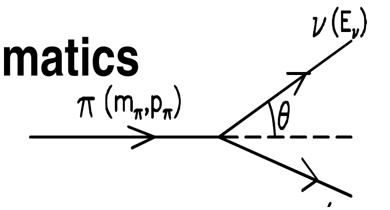
SK-I		SK-II
11,146	number of inner detector PMTs	5,182
40 %	photocathode coverage	19 %

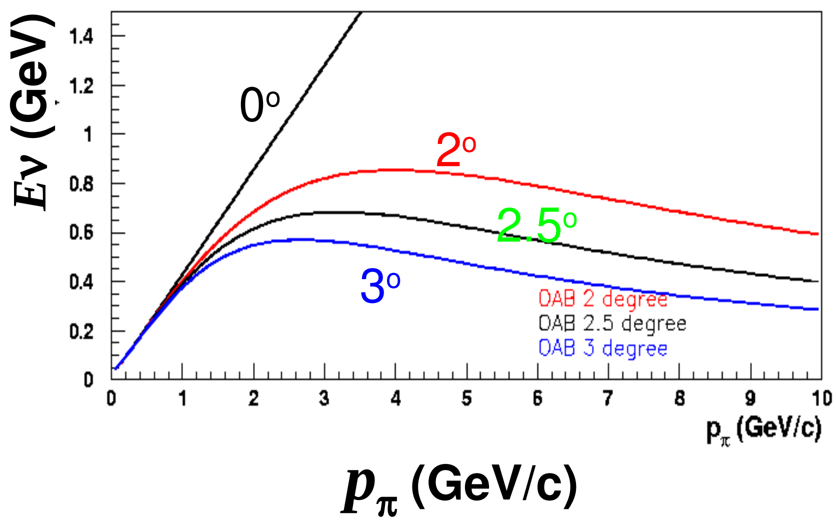
Narrow intense beam: Off-axis beam

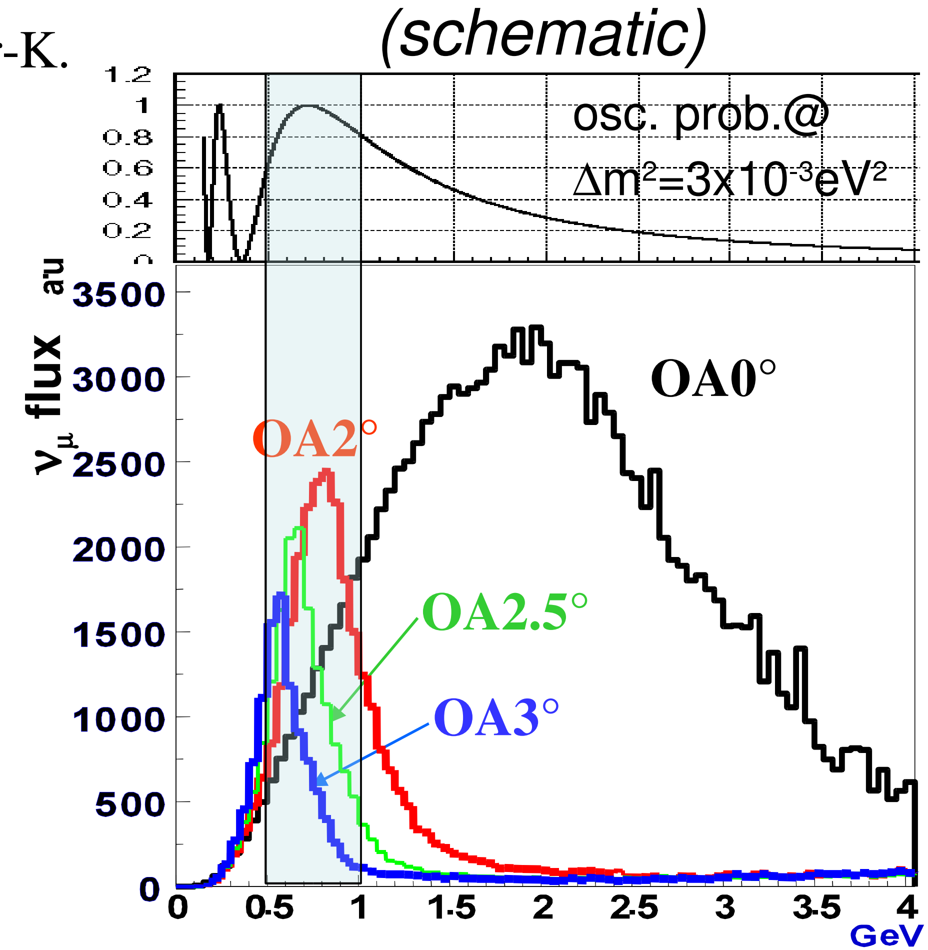
First Application
(ref.: BNL-E889 Proposal)



π decay Kinematics

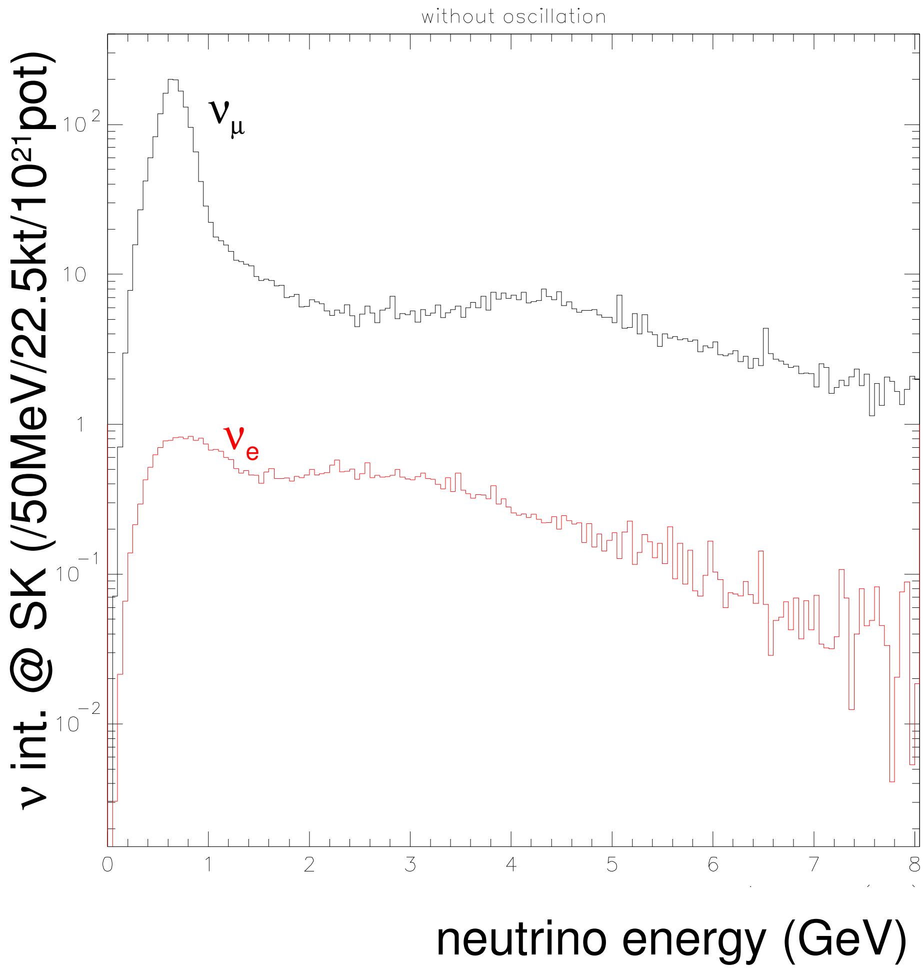






ν interaction @ SK

(w/o oscillation)



- 2.5° off-axis beam (40GeV)
- NEUT
- ν int.(22.5kt/10^{21}pot) ~ 2200(ν_μ)
- ν_e/ν_μ at peak ~0.4%

10^{21}pot~1year

3 flavor oscillation (simplified)

- ν_μ disappearance

  $P(\to) = 1 - 4C_{23}^2 S_{23}^2 C_{13}^4 \cdot \sin^2 \quad {}_{32} - P(\to)_e$

- ν_e appearance

  $P(\to)_e = 4C_{13}^2 S_{13}^2 S_{23}^2 \cdot \sin \quad {}_{31}$

  $P(\nu_\mu \rightarrow \nu_e) = \sin^2\theta_{23} \sin^2 2\theta_{13} \sin^2(1.27 \Delta m_{13}^2 L/E)$

- beam $\nu_e \rightarrow \nu_e$ oscillation

  $P({}_e \to)_e = 1 - 4C_{13}^2 S_{13}^2 \sin^2 \quad {}_{13}$

$\Delta m_{12}^2=0,\ \Delta m_{12}^2 << \Delta m_{13}^2 = \Delta m_{23}^2$

$\Delta m_{23}^2 = 2.5\times10^{-3} eV^2, \theta_{23} = \pi/4$

no matter effect

CP phase $\delta=0$

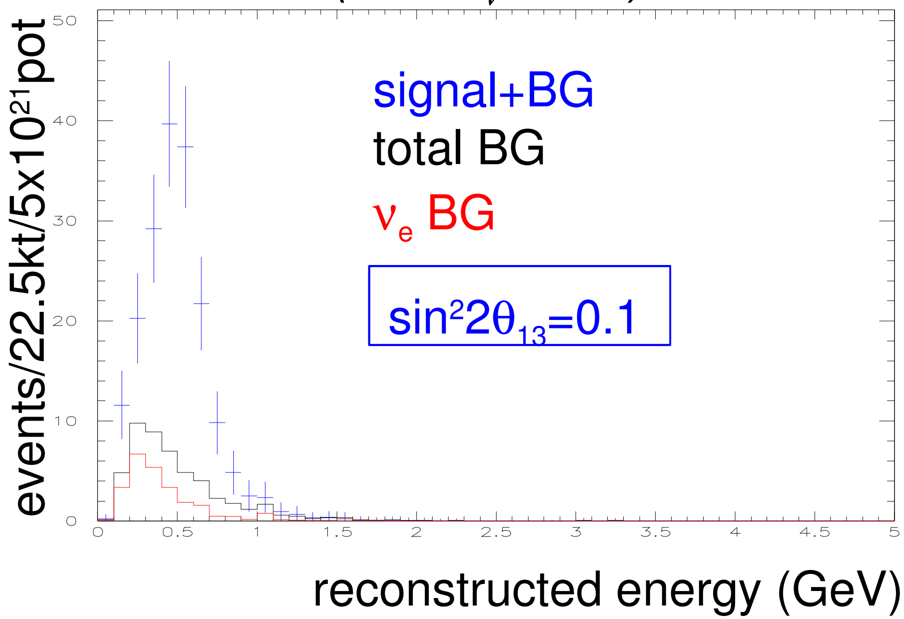
in this analysis unless noted

Selection criteria for ν_e appearance

(SK-I detector simulator & reconstruction used)

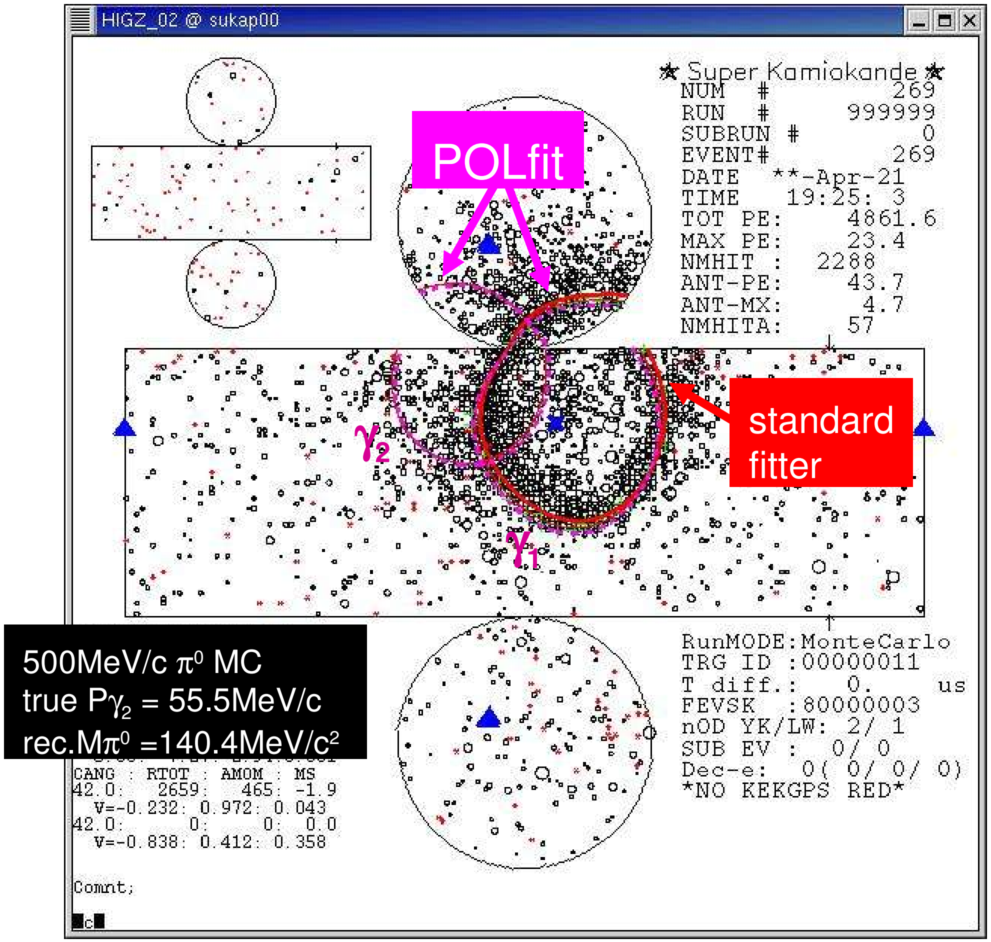
- Standard SK cuts:
  - fully contained(FC) in fiducial volume(FV), visible energy>100MeV
  - single-ring
  - PID(e/μ)
  - no decay-e
  - $0.35<E_\nu^{rec}<0.85$GeV

(w/o E_ν^{rec} cut)



- Further π^0 cuts:
  - $\cos\theta_{\nu e}<0.9$
  - Mγγ & ΔL cuts of POLfit

POLfit (π^0 fitter)



force to find 2nd γ-ring

↓

identify and reject asymmetric decay π^0 BG in 1R-e sample

- input:
  vertex, 1st ring dir., total E_{vis}
- output:
  $M_{\gamma\gamma}$, $\Delta L(\pi^0\text{like-elike})$

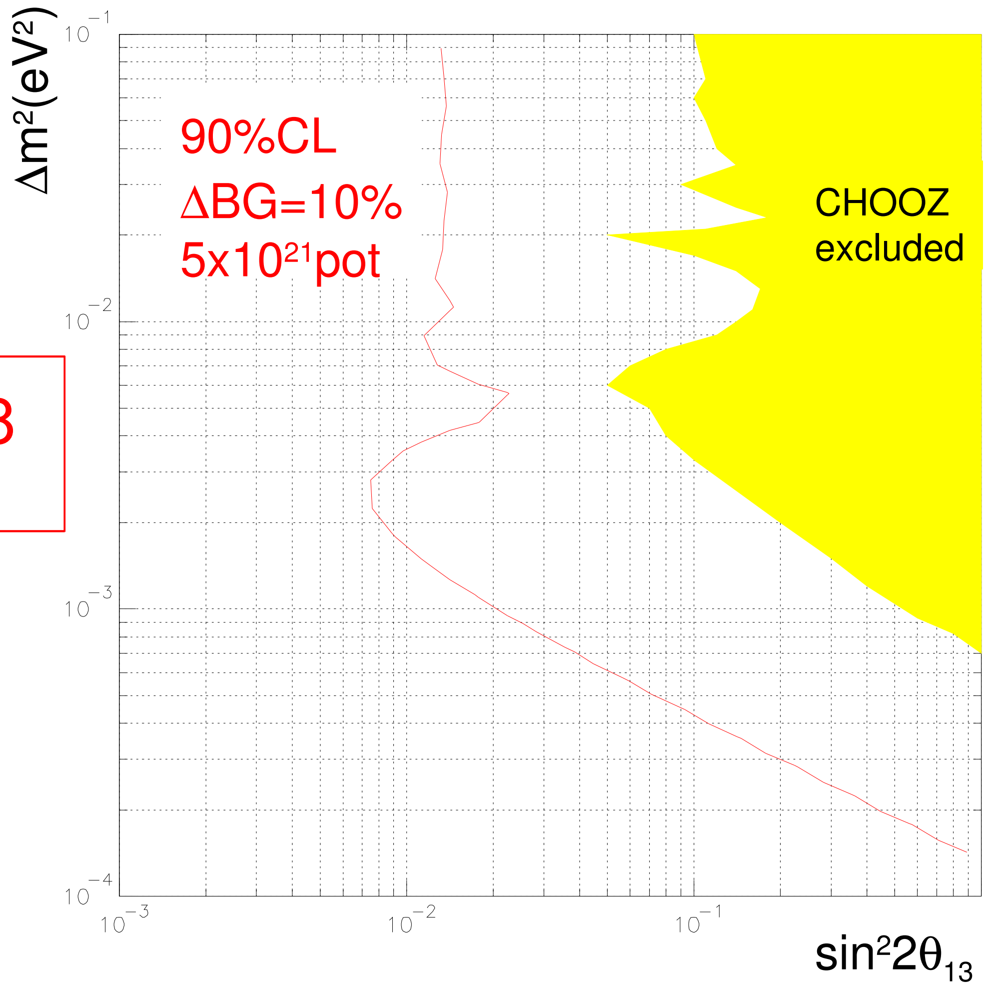
Events vs. selections

(events / 22.5kt / 5×10^{21}pot)

($\sin^2 2\theta_{13}$=0.1)

	ν_μCC BG	ν_μNC BG	beam ν_e BG	ν_e(CC) signal
FCFV, E_{vis}>100	2215	847	184	243
1R-e, no decay-e	12(0.5%)	156(18%)	71(39%)	187(77%)
$0.35<E_\nu^{rec}<0.85$	1.8(0.1%)	47(6%)	21(11%)	146(60%)
$\cos\theta_{\nu e}<0.9$, $M\gamma\gamma<100$, $\Delta L<80$	0.7+9(0.3%)		13(7%)	103(42%)

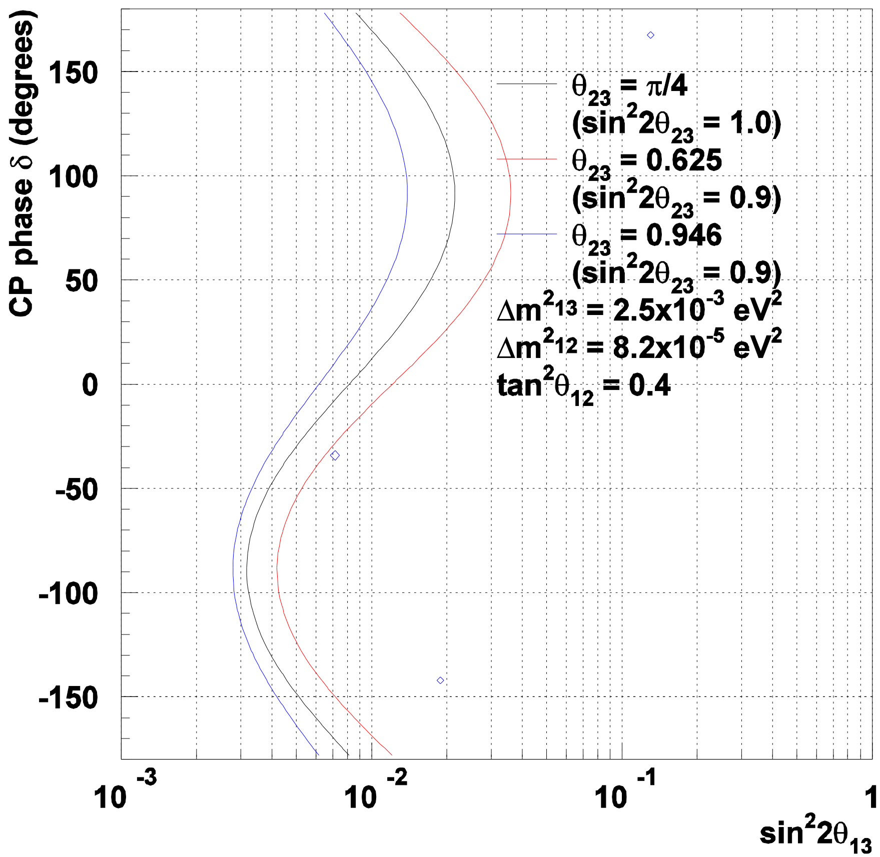
ν_e sensitivity

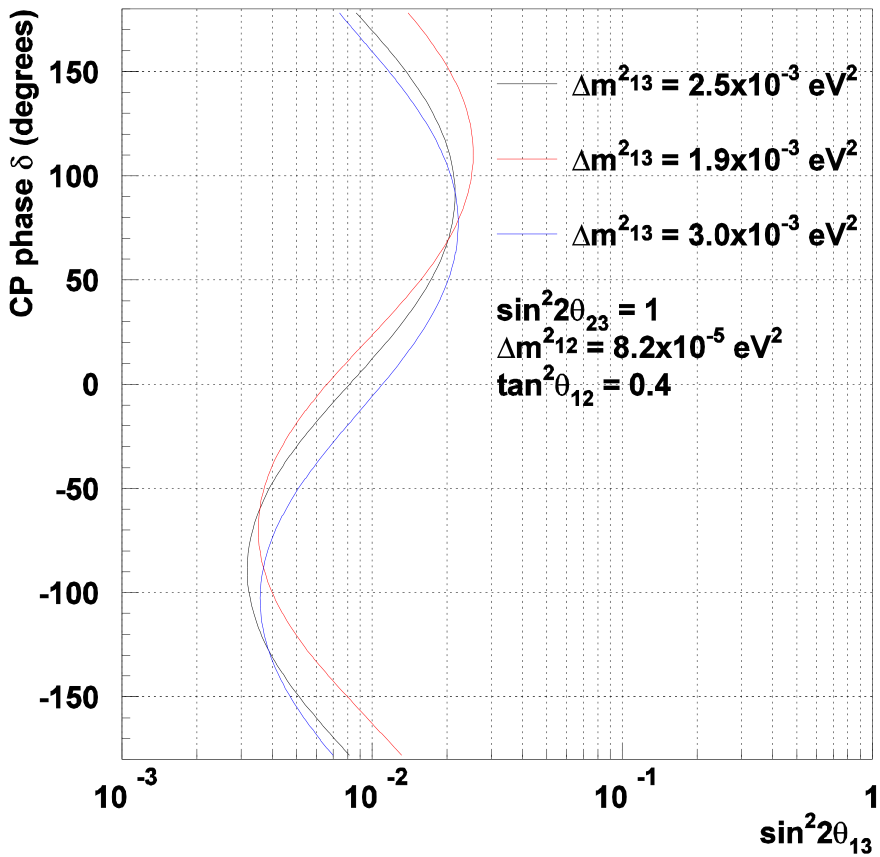


$\sin^2 2\theta_{13} \sim 0.008$
$@2.5\times10^{-3}eV^2$

ν_e sensitivity as a function of CP-phase δ

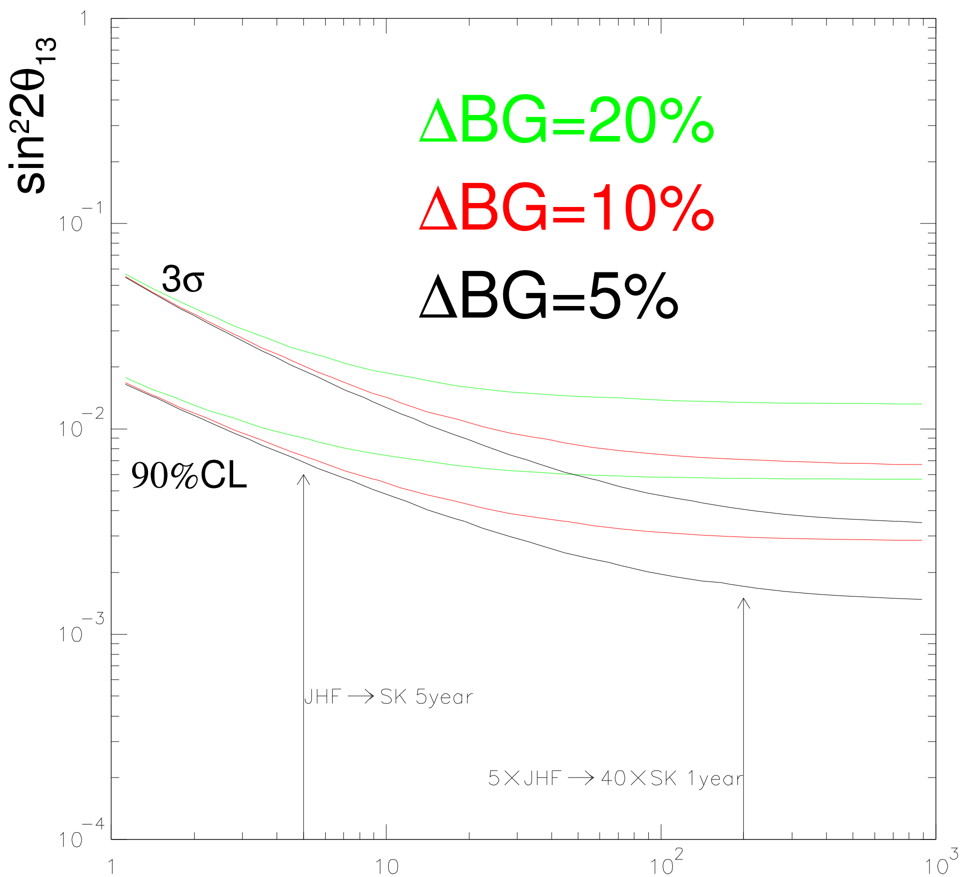
(90%CL, 5×10^{21}pot, ΔBG=10%)





ν_e sensitivity vs. exposure

(dependence on background uncertainty)



exposure (22.5kt •10^{21}pot)

ΔBG sources:

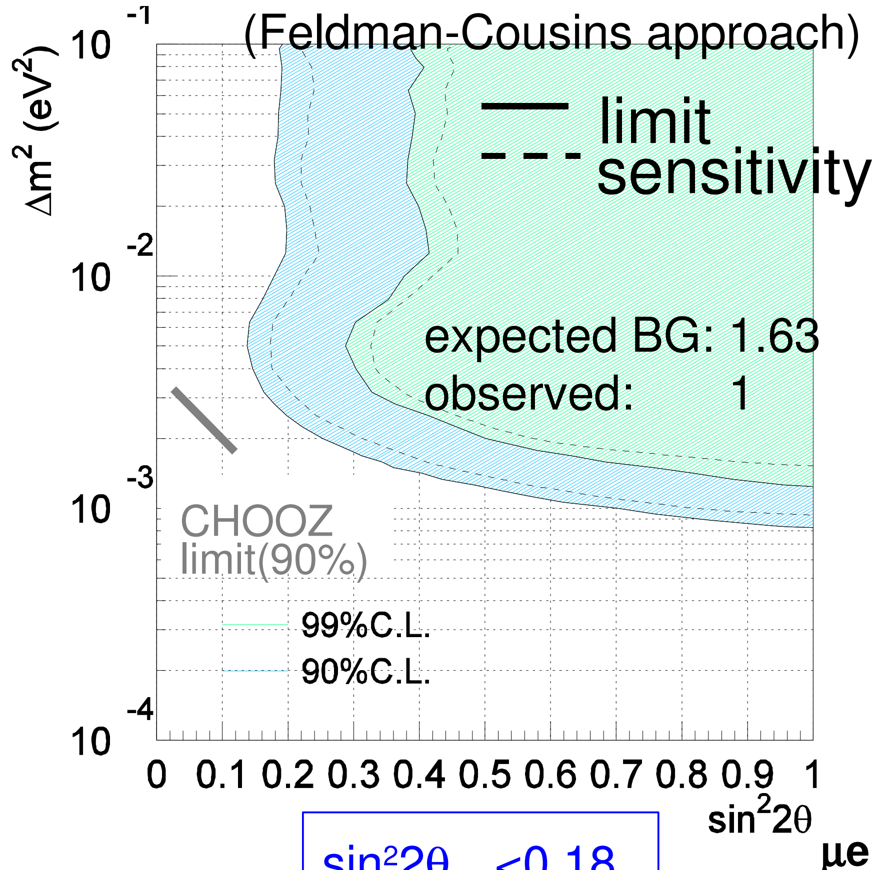
- SK itself
  - π^0 rejection efficiency
  - e/μ separation
  - decay-e
  - fiducial volume
  - energy scale
  - etc.
- π^0 production
- beam ν_e

} NDs

K2K ν_e search @ SK

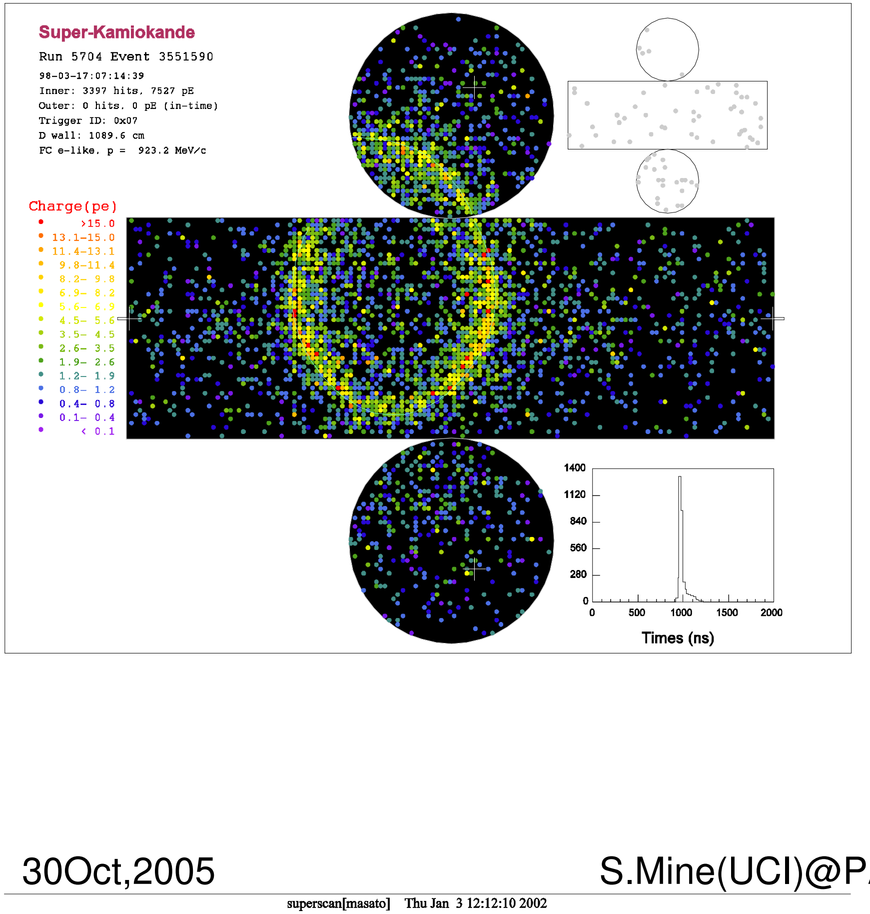
K2K1+K2K2 DATA:

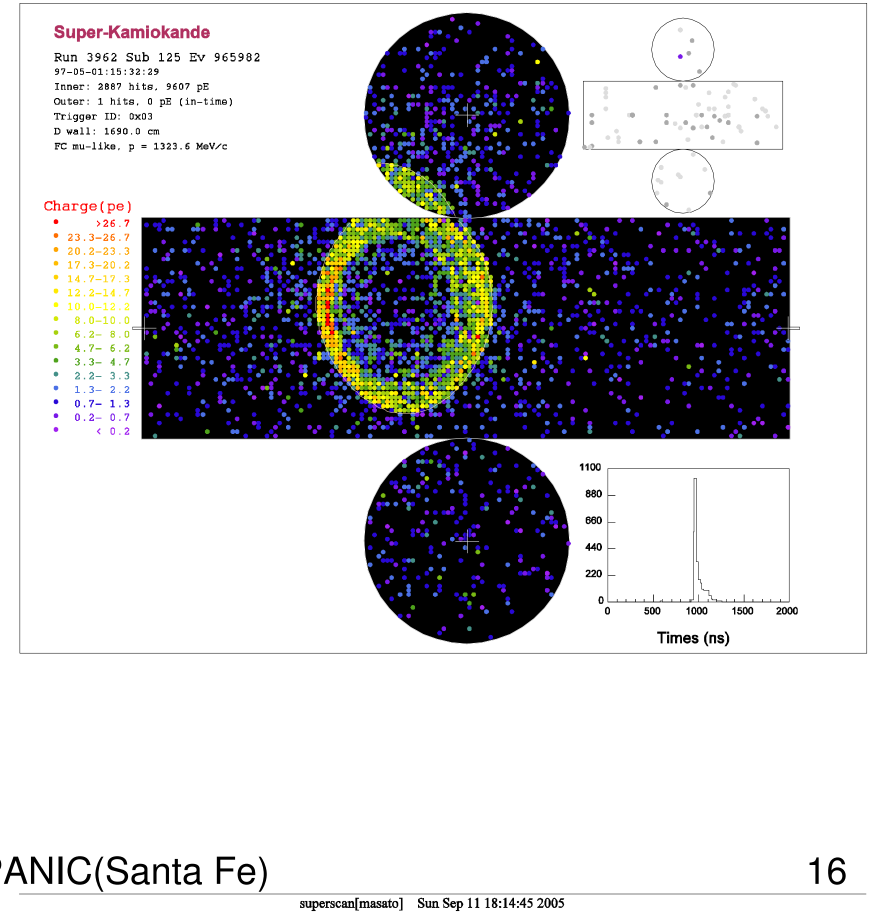
FCFV	112 ev
Single Ring	67
PID(e/μ)	9
tight e –ID	8
E_{vis}>100 MeV	7
No e from μ→e	5
POLfit cut(e/π^0)	1
exp'd BG:	1.63
ν_μ int.	1.25
beam ν_e	0.38



$\sin^2 2\theta_{\mu e} < 0.18$
@2.8×10^{-3}eV^2

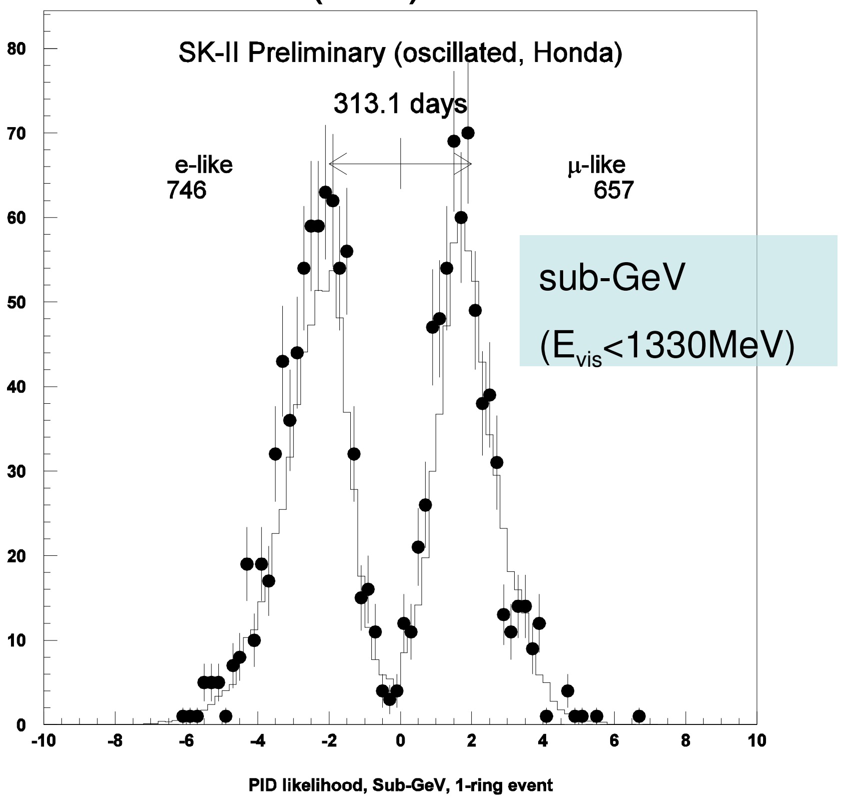
e/μ separation @ SK

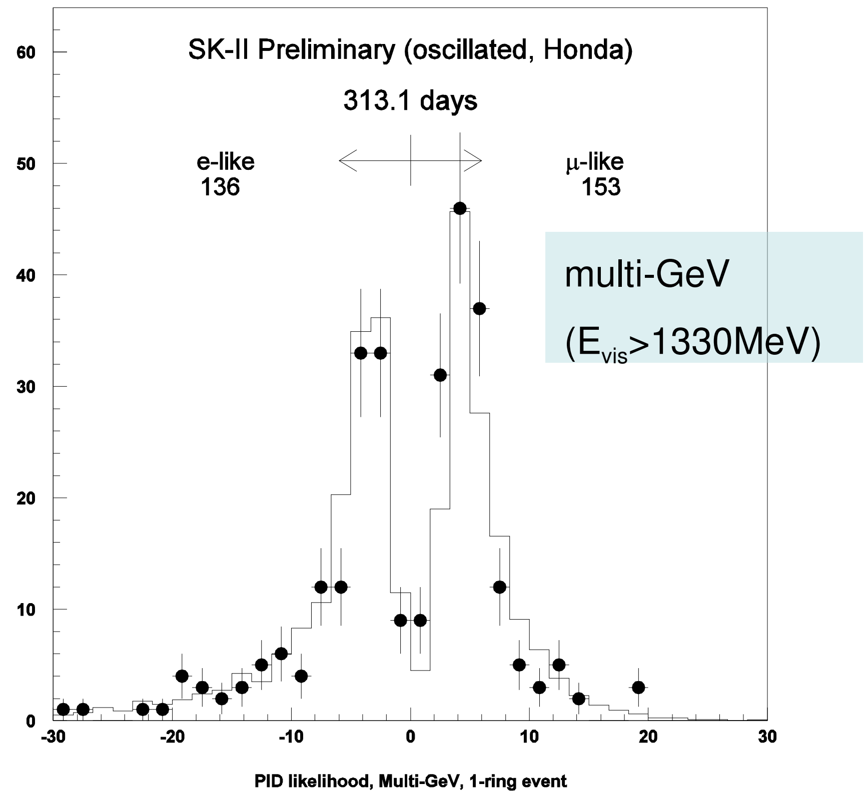




e/μ separation @ SK

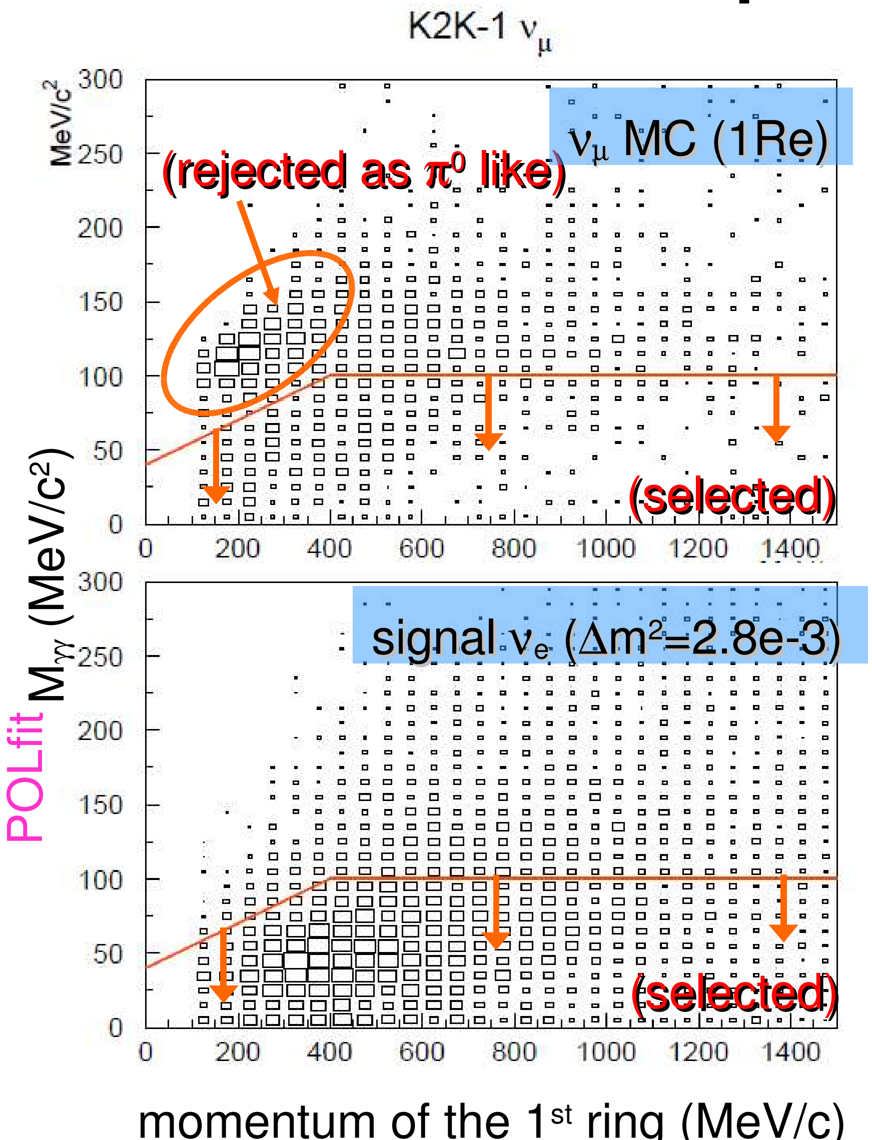
- ● atm-ν DATA(1R)
- — atm-ν MC(1R)



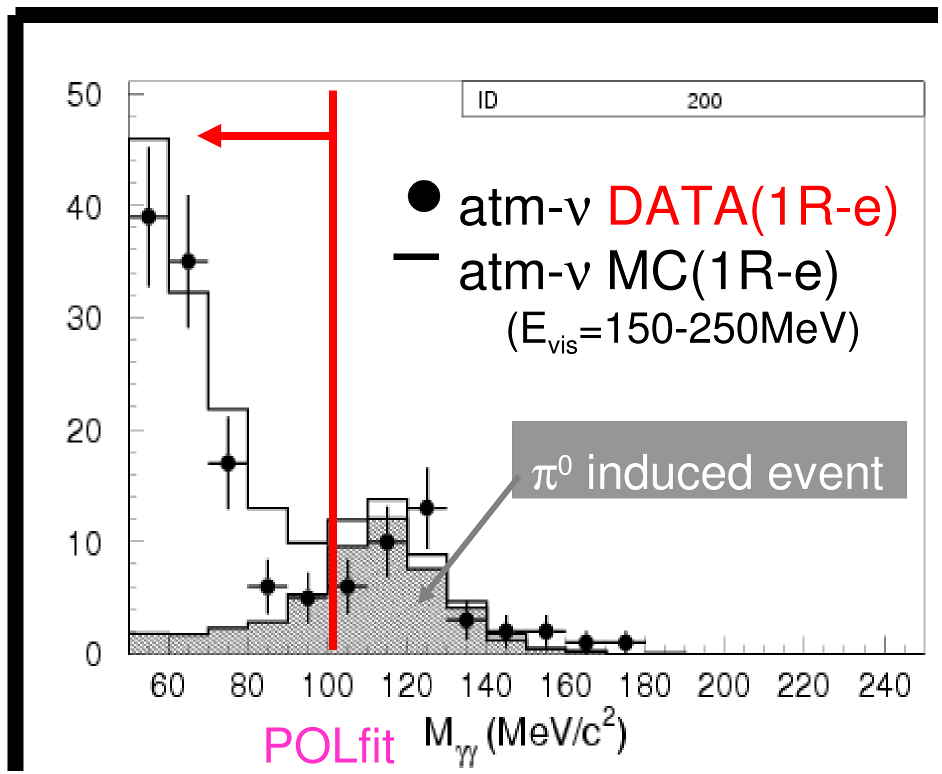


An experiment with test beams also confirmed PID capability: PL B374(1996)238

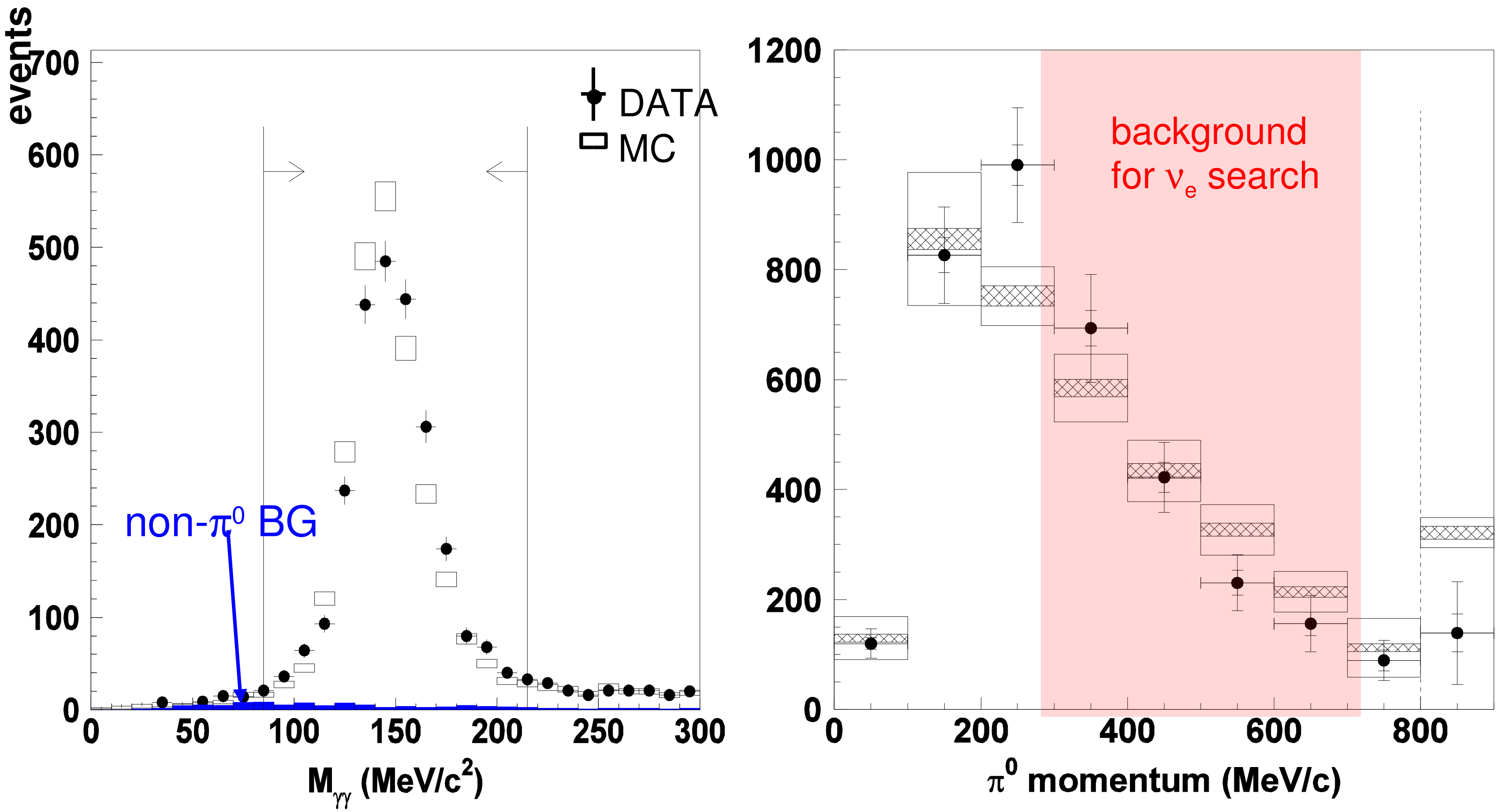
e/π^0 separation @ SK



70% π^0 rejection and
30% signal efficiency loss
for 1R-e sample for K2K



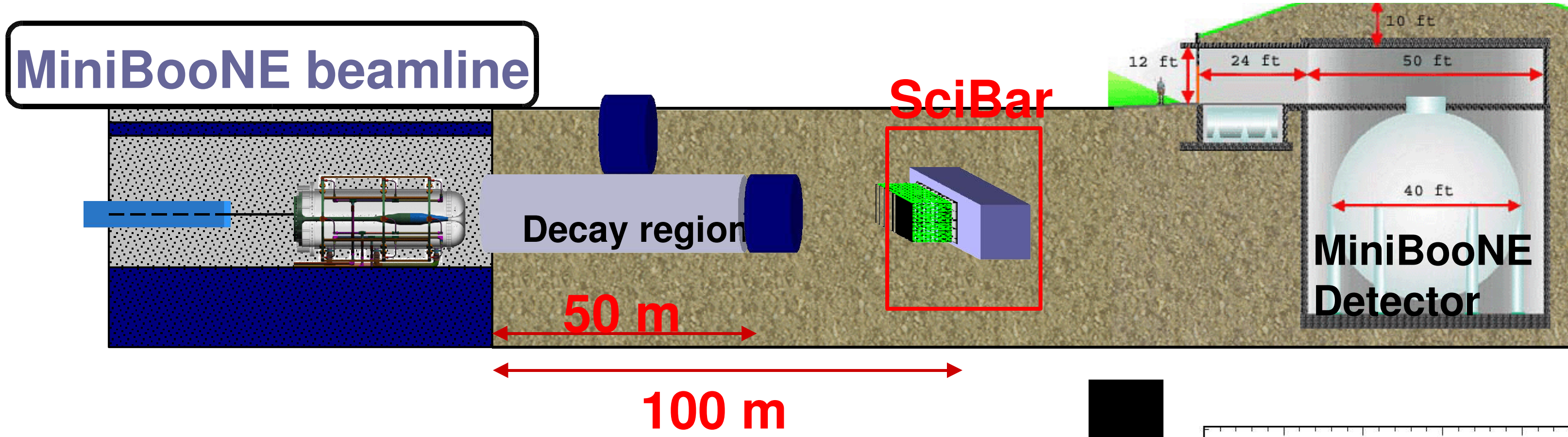
NC π^0 measurement @ K2K-1KT



$\sigma(NC1\pi^0)/\sigma(CCall)=0.064\pm0.001\pm0.007$ (0.065 by NEUT): Phys.Lett.B619:255,2004

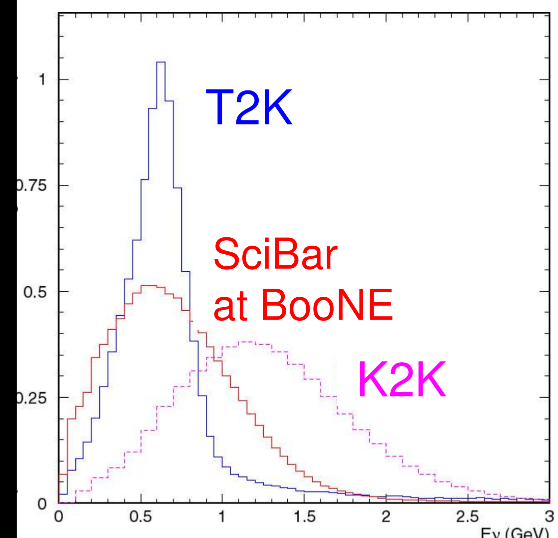
SciBooNE

(K2K-SciBar detector at FNAL Booster Neutrino Beam line)



- Cross section measurements for T2K
  - for both neutrinos and anti-neutrinos
- MiniBooNE near detector

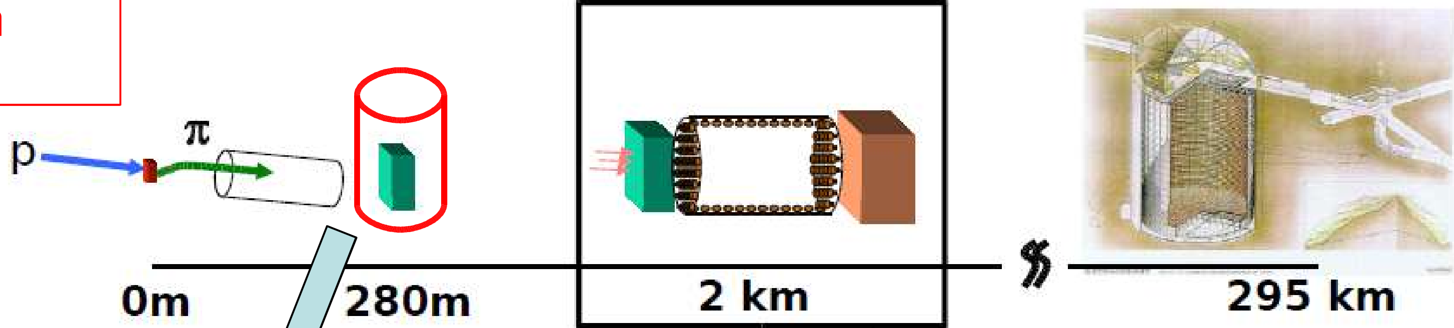
It will be proposed to FNAL soon
(cheap/quick experiment)



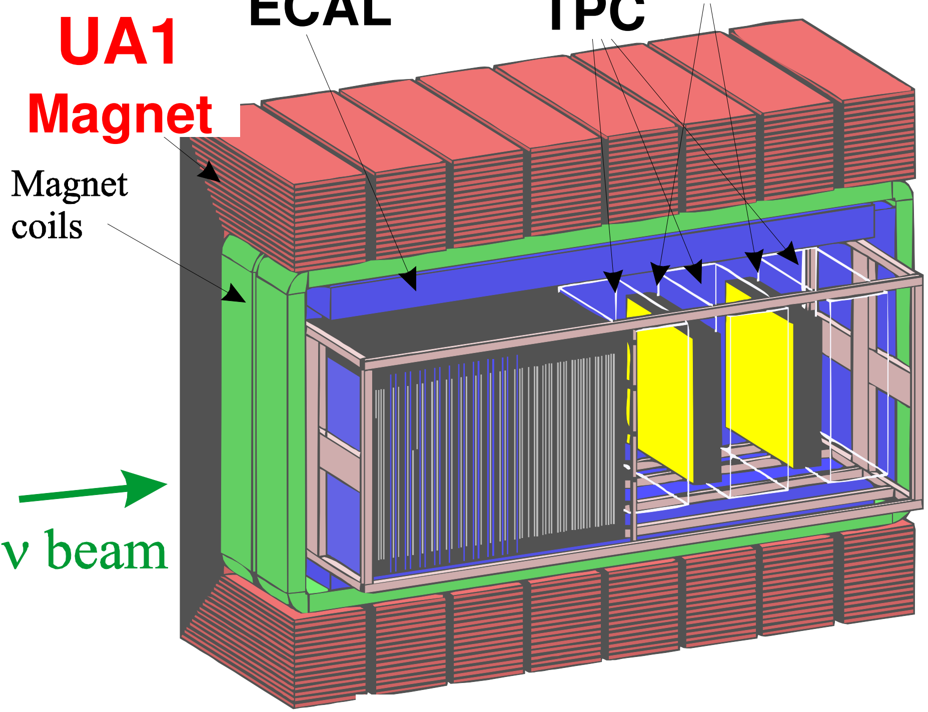
Eν (GeV)

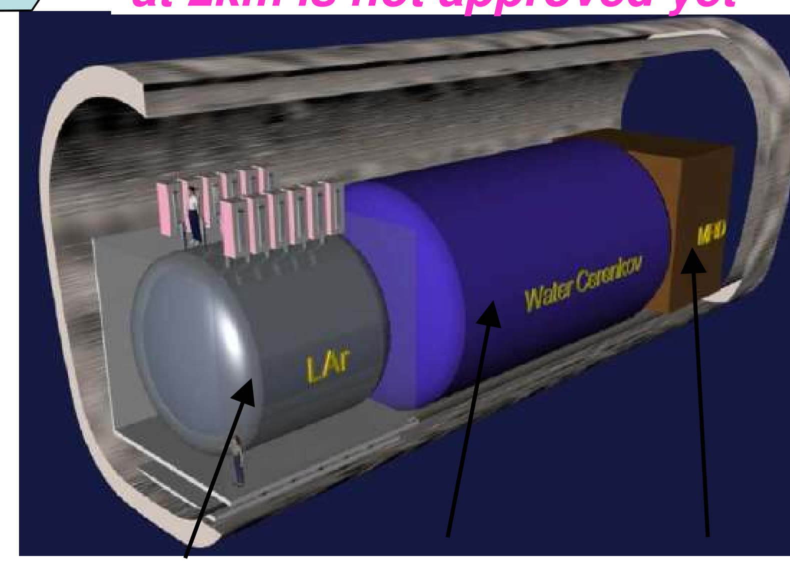
ND280: Conceptual Design Report

T2K near detectors



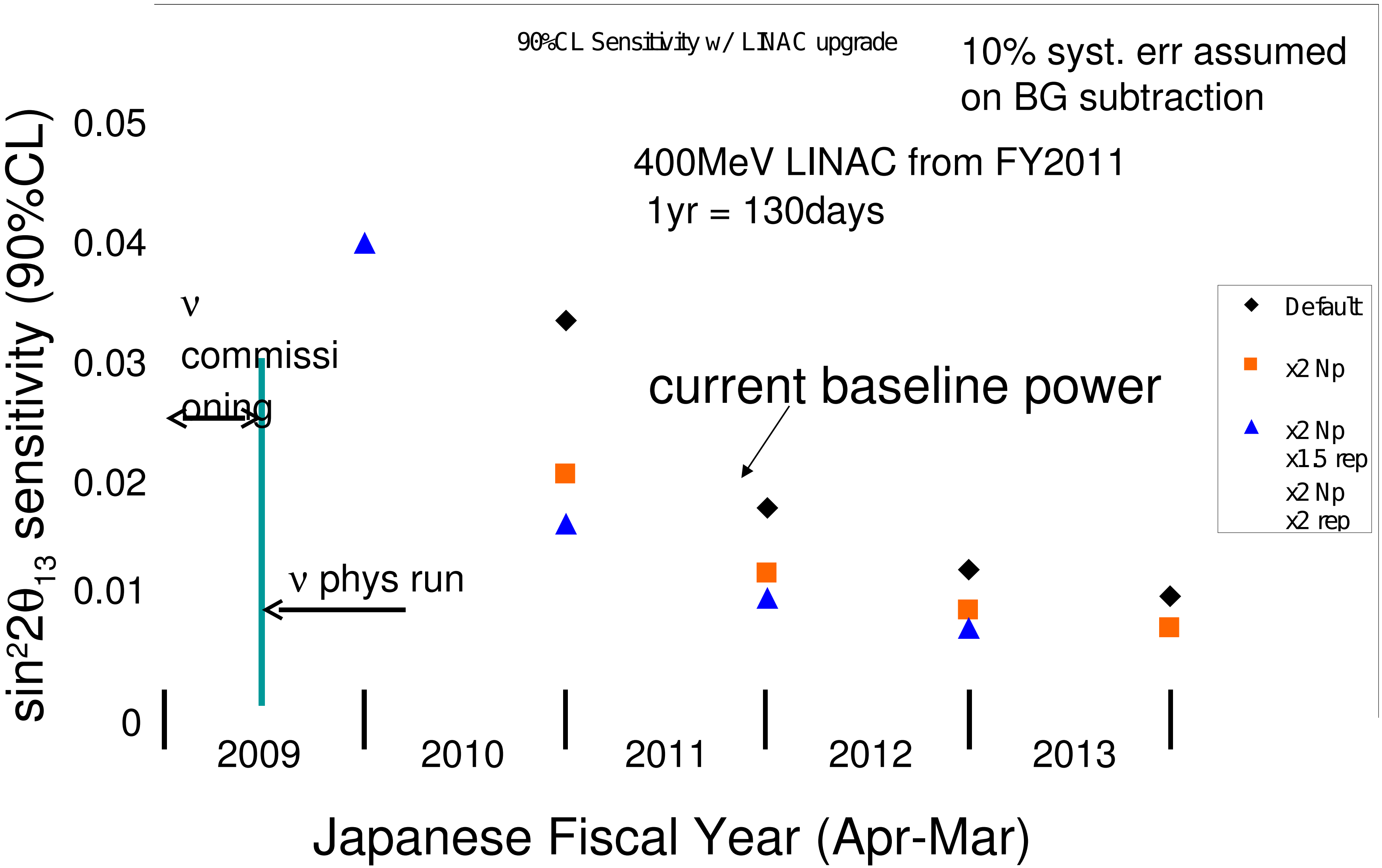
The Experimental facility at 2km is not approved yet





ν_e sensitivity vs. calendar time

(possibility of beam power upgrade)



Summary

- T2K is approved and the construction is on schedule
- Neutrino experiment will start in 2009
- θ_{13} sensitivity (phase-1):

  - the latest ν MC & SK1 final tools

  - SK is ideal for separating μ/e/π^0, K2K has demonstrated background rejection in ν_e search

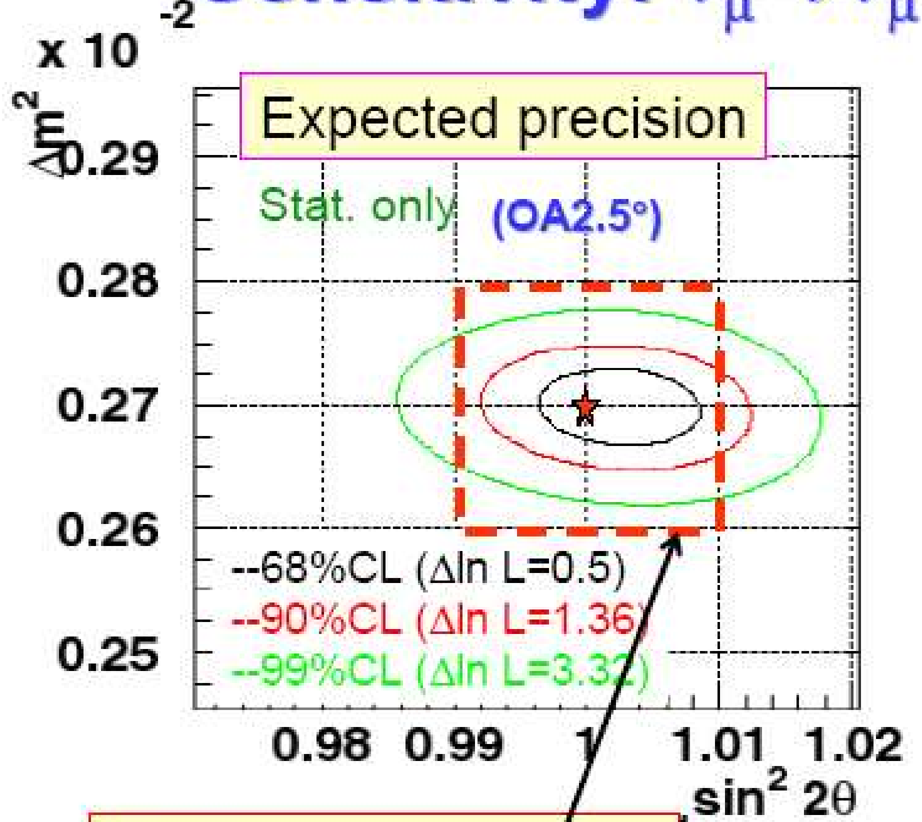
  - ~10times improvement from CHOOZ

  - background should be understood < ~10%:
    - reconstruction @ SK
    - π^0 production and beam ν_e @ NDs

- Seriously considering to increase beam power

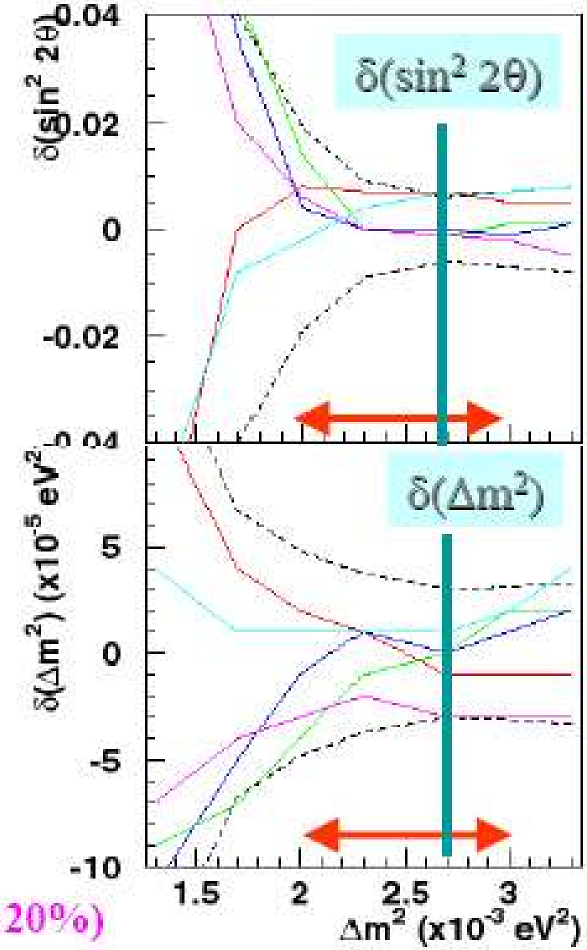
supplement

Sensitivity: $\nu_\mu \to \nu_\mu$ disappearance



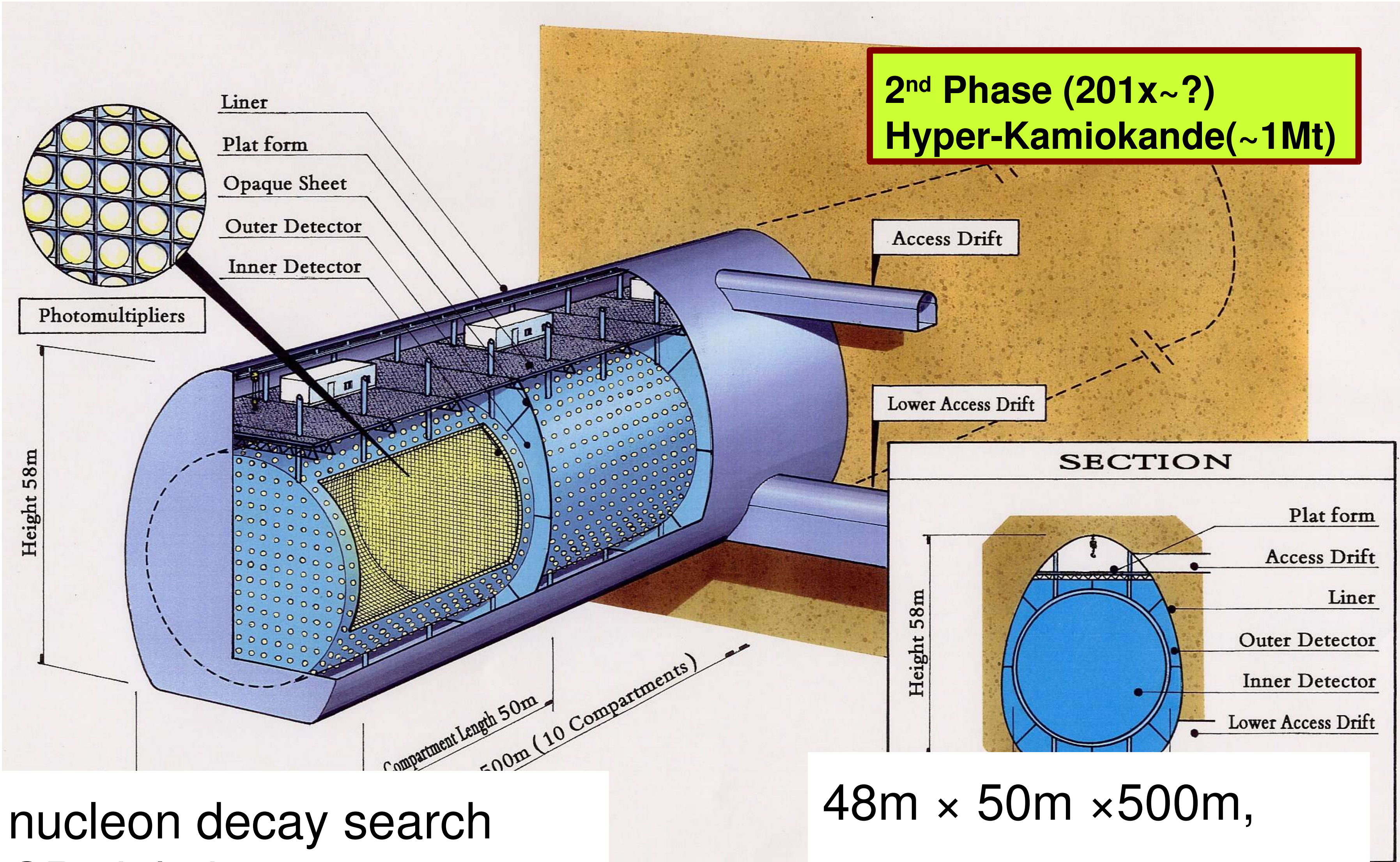
Goal
$\delta(\sin^2 2\theta_{23}) \sim 0.01$
$\delta(\Delta m_{23}^2) \sim < 1 \times 10^{-4}$

Effect of systematic error on param meas.



Stat. error
norm (+5%)
NQE (+5%)
E_{SK} (+1%)
beam shape (±20%)

Phase 2 (if θ_{13} can be measured.)

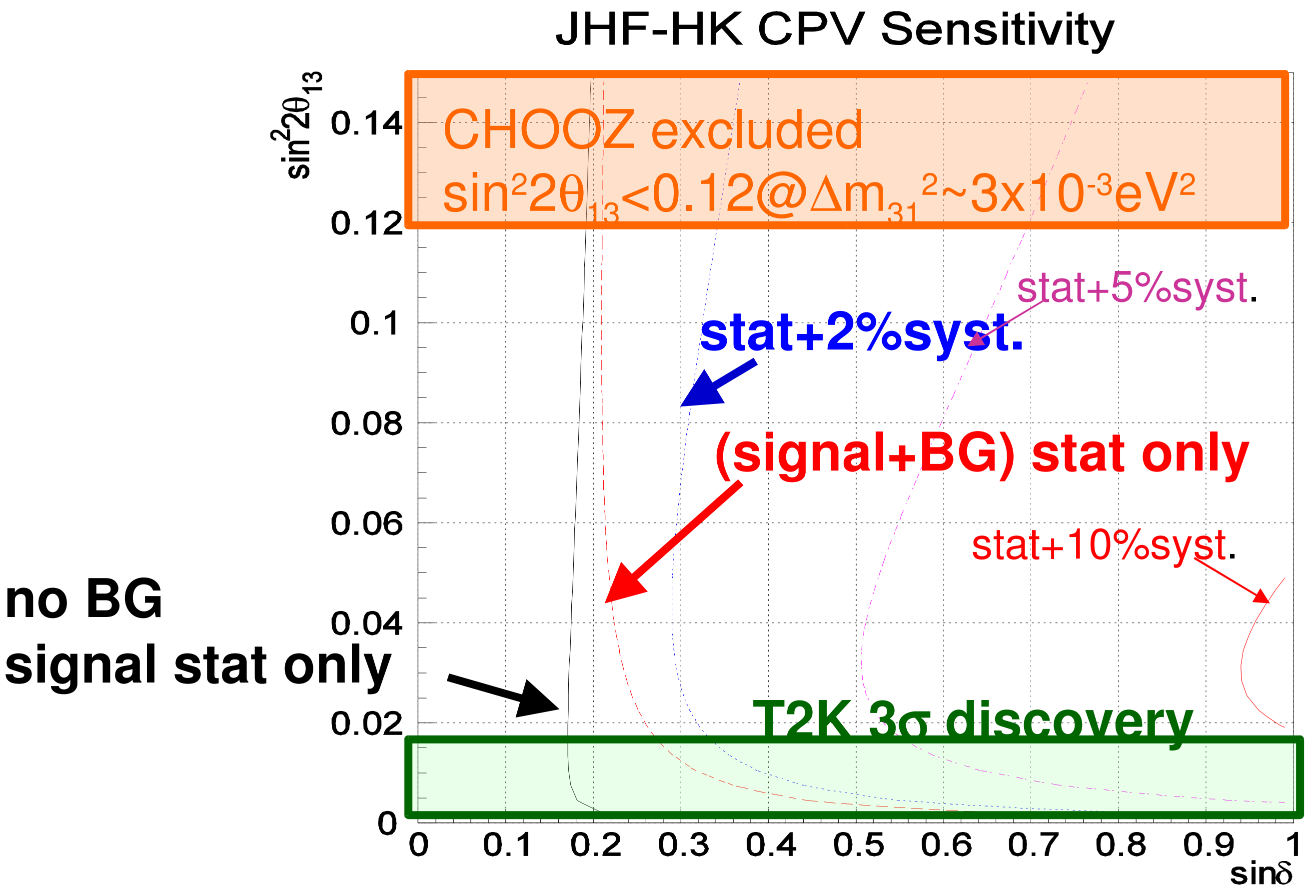


nucleon decay search
CP violation measurement

48m × 50m ×500m,

Total mass = 1 Mton

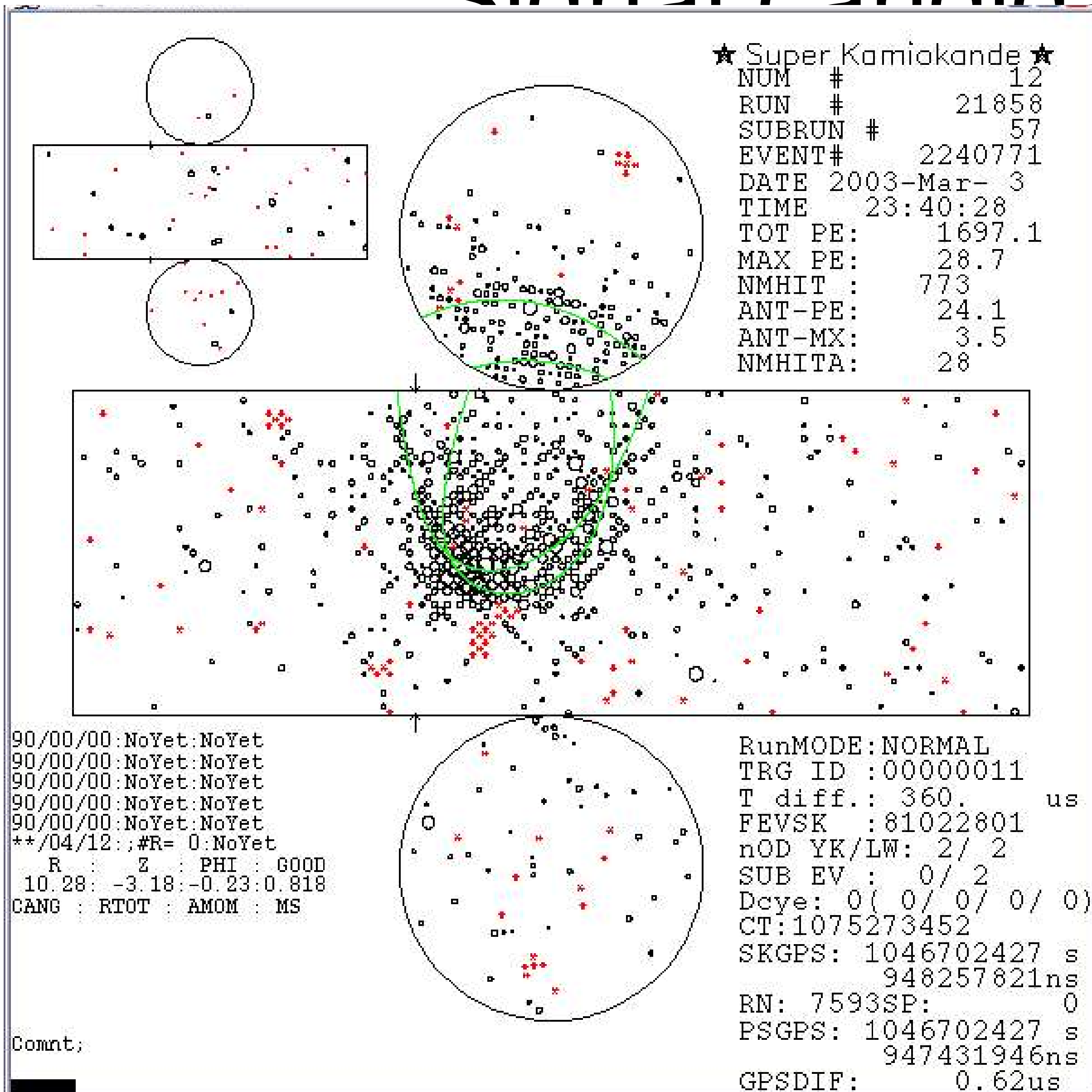
Search for CP violation



4MW, 540kt
2yr for ν_μ
6.8yr for $\bar{\nu}_\mu$

3σ CP sensitivity : |δ|>20° for $\sin^2 2\theta_{13}$>0.01 with 2% syst.

Signal candidate:



RUN: 21858

EVENT: 2240771

$E_{\gamma 1}$: 266.7MeV

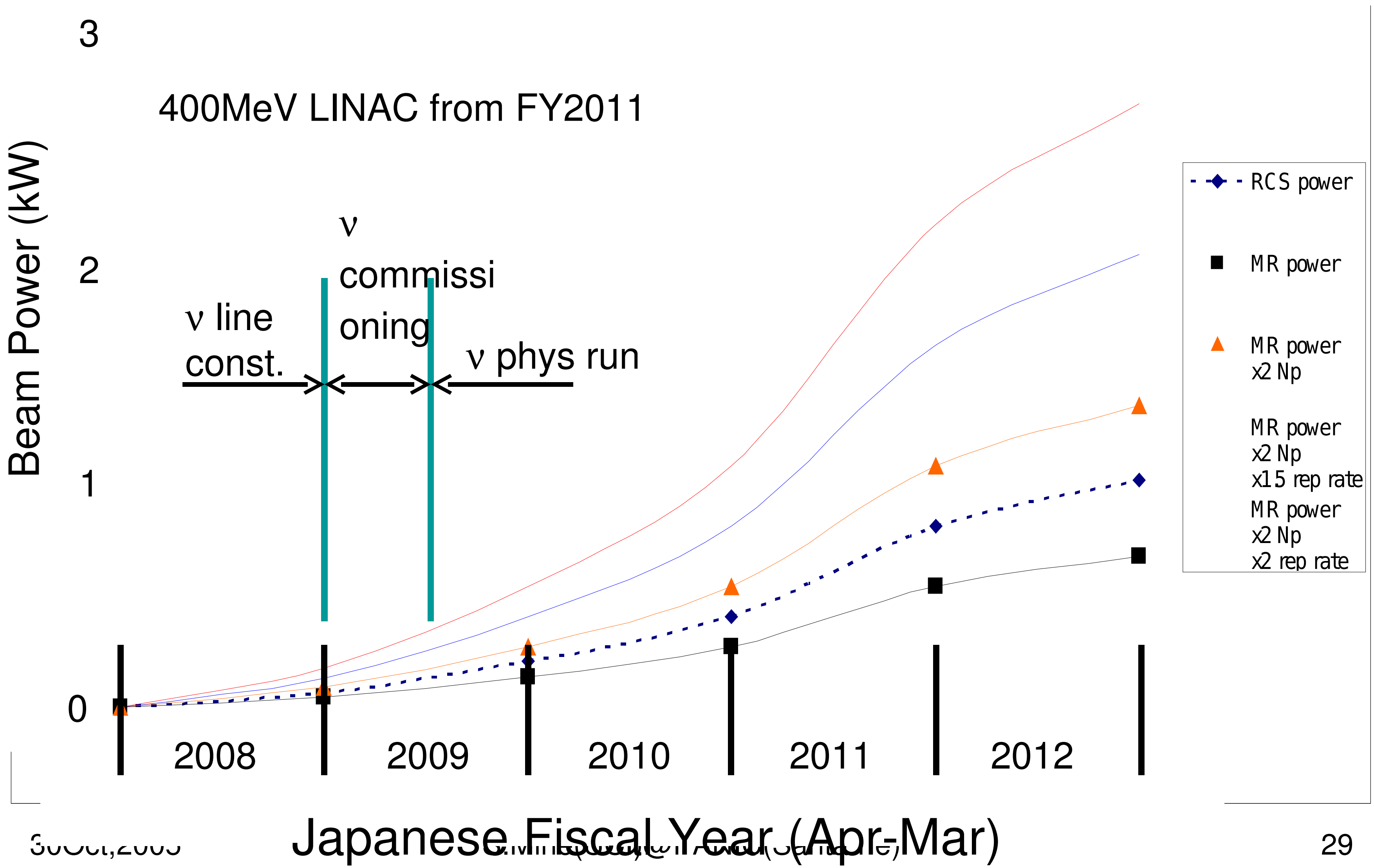
$E_{\gamma 2}$: 170.8MeV

$\theta_{\gamma\gamma}$: 22.5 deg.

$M_{\gamma\gamma}$: 83.1MeV/c^2

Looks multi-ring event.

Possibility of beam power upgrade



- ν_μ disappearance

$$P(\rightarrow)=1-4(C_{12}^2C_{23}^2+S_{12}^2S_{13}^2S_{23}^2-2C_{12}C_{23}S_{12}S_{13}S_{23}\cos)S_{23}^2C_{13}^2\cdot\sin^2 {}_{23}$$

$$-4(S_{12}^2C_{23}^2+C_{12}^2S_{13}^2S_{23}^2+2C_{12}C_{23}S_{12}S_{13}S_{23}\cos)S_{23}^2C_{13}^2\cdot\sin^2 {}_{13}$$

$$-4(C_{12}^2C_{23}^2+S_{12}^2S_{13}^2S_{23}^2-2C_{12}C_{23}S_{12}S_{13}S_{23}\cos)$$

$$¿(C_{12}^2C_{23}^2+S_{12}^2S_{13}^2S_{23}^2+2C_{12}C_{23}S_{12}S_{13}S_{23}\cos)\cdot\sin^2 {}_{12}$$

- ν_e appearance

$$P(\rightarrow {}_e)=4C_{13}^2S_{13}^2S_{23}^2\cdot\left(1+\frac{2a}{m_{13}^2}(1-2S_{13}^2)\right)\cdot\sin^2 {}_{31}$$

$$+8C_{13}^2S_{12}S_{13}S_{23}(C_{12}C_{23}\cos -S_{12}S_{13}S_{23})\cdot\cos {}_{32}\cdot\sin {}_{31}\cdot\sin {}_{21}$$

$$-8C_{13}^2C_{12}C_{23}S_{12}S_{13}S_{23}\sin \cdot\sin {}_{32}\cdot\sin {}_{31}\cdot\sin {}_{21}$$

$$+4S_{12}^2C_{13}^2(C_{12}^2C_{23}^2+S_{12}^2S_{23}^2S_{13}^2-2C_{12}C_{23}S_{12}S_{23}S_{13}\cos)\cdot\sin^2 {}_{21}$$

$$-8C_{13}^2S_{13}^2S_{23}^2\cdot\frac{aL}{4E}(1-2S_{13}^2)\cdot\cos {}_{32}\cdot\sin {}_{31}$$

δ→-δ, a→-a for anti.-ν

- beam ν_e

$$P({}_e\rightarrow {}_e)=1-4C_{13}^2S_{13}^2\cdot\left(C_{12}^2\sin^2 {}_{13}+S_{12}^2\sin^2 {}_{23}\right)+4S_{12}^2C_{12}^2C_{13}^4\sin^2 {}_{12}$$