2009年9月5日
高エネ委
研計小委

T2Kの現状と将来のJ-PARC νビームアップグレード

小林　隆

IPNS, KEK

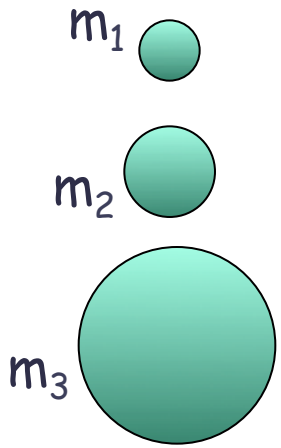
ニュートリノの３世代混合

フレーバー固有状態

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

ユニタリー行列

質量固有状態



$$U_{MNS} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & +c_{23} & +s_{23} \\ 0 & -s_{23} & +c_{23} \end{pmatrix} \begin{pmatrix} +c_{13} & 0 & +s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & +c_{13} \end{pmatrix} \begin{pmatrix} +c_{12} & +s_{12} & 0 \\ -s_{12} & +c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

大気、加速器　　(大気)、加速器　　太陽、原子炉

ニュートリノ振動をつかさどる6個のパラメータ

θ_{12}, θ_{23}, θ_{13}, δ

Δm_{12}^2, Δm_{23}^2, Δm_{13}^2

未知！

$$\Delta m_{ij}^2 = m_i^2 - m_j^2$$

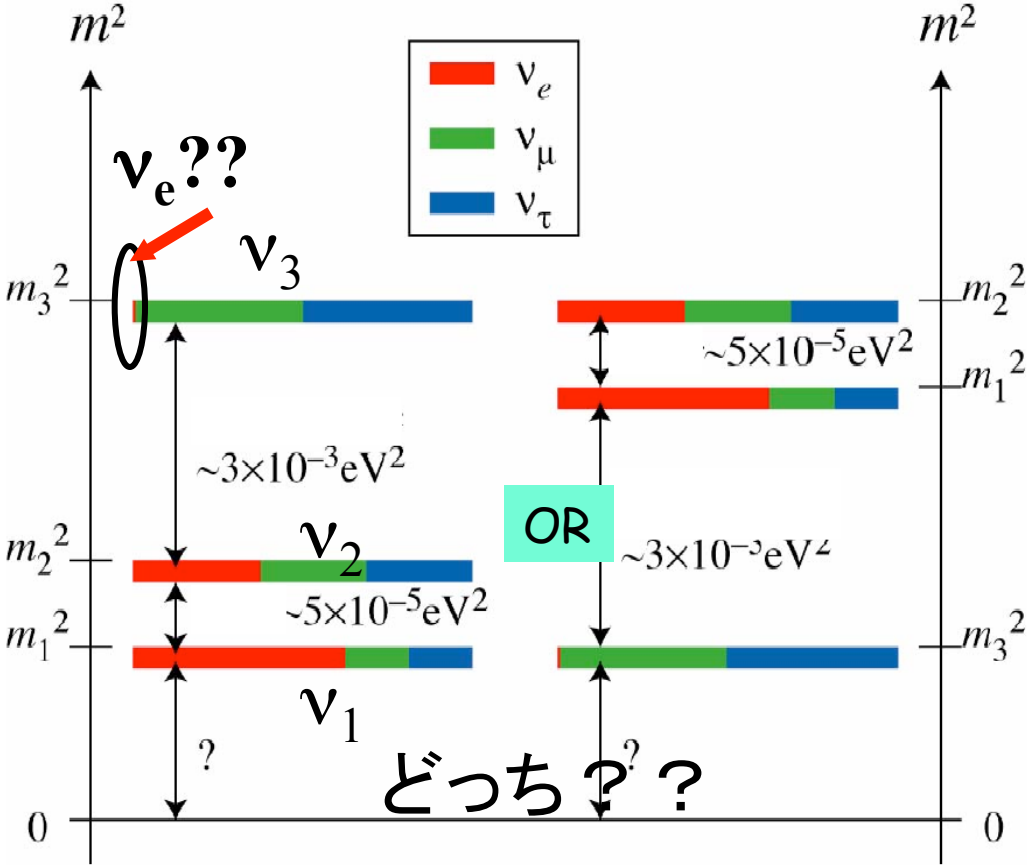
$$c_{ij} = \cos(\theta_{ij}), \quad s_{ij} = \sin(\theta_{ij})$$

これまでわかったこと、わかってないこと

太陽＋原子炉
- θ_{12}~33°
- Δm_{12}^2~0.00008eV^2

大気＋加速器
- θ_{23}~45°
- Δm_{23}^2~0.0025eV^2

未知！！
- **θ_{13}<10°**
- **(Δm_{13}^2~Δm_{23}^2)?**
- **δ ???**



NEUTRINOS

$$U_{MNSP} \sim \begin{pmatrix} 0.8 & 0.5 & ? \\ 0.4 & 0.6 & 0.7 \\ 0.4 & 0.6 & 0.7 \end{pmatrix}$$

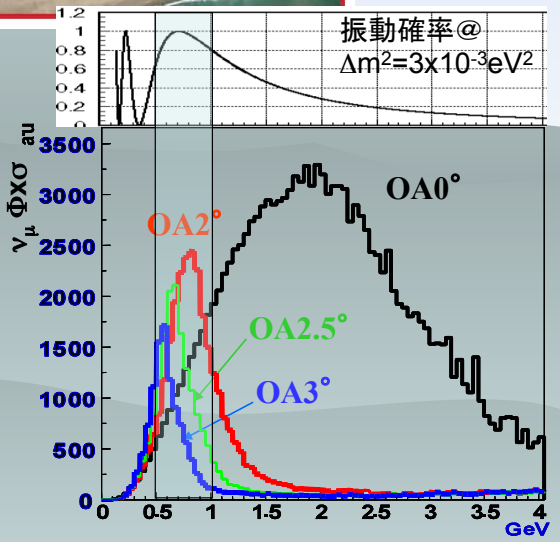
QUARKS

$$V_{CKM} \sim \begin{pmatrix} 1 & 0.2 & 0.005 \\ 0.2 & 1 & 0.04 \\ 0.005 & 0.04 & 1 \end{pmatrix}$$

クォーク(小林益川)とも顕著な違い

Tokai-to-Kamioka (T2K) long baseline neutrino oscillation experiment

- Goal
  - **νe 出現の発見➔θ_{13}決定**
  - νμ 消失の精密測定.
- Intense narrow spectrum νμ beam from J-PARC MR
  - Off-axis w/ 2~2.5deg
  - Tuned at osci. max.
- SK: largest, high PID performance



1600ν_μCC/yr/22.5kt (2.5deg)

最も重要かつ緊急な課題: θ_{13}. なぜ?

CPV & sign(Δm^2) will be probed thru ν_e appearance in accel LBL

$$P(\nu_\mu \to \nu_e) = 4C_{13}^2 S_{13}^2 S_{23}^2 \sin^2 \frac{\Delta m_{31}^2 L}{4E} \times \left(1 + \frac{2a}{\Delta m_{31}^2}(1 - 2S_{13}^2)\right) \quad \textbf{Leading}$$

$$+8C_{13}^2 S_{12}S_{13}S_{23}(C_{12}C_{23}\cos\delta - S_{12}S_{13}S_{23}) \cos\frac{\Delta m_{32}^2 L}{4E} \sin\frac{\Delta m_{31}^2 L}{4E} \sin\frac{\Delta m_{21}^2 L}{4E}$$

$$-8C_{13}^2 C_{12}C_{23}S_{12}S_{13}S_{23} \sin\delta \sin\frac{\Delta m_{32}^2 L}{4E} \sin\frac{\Delta m_{31}^2 L}{4E} \sin\frac{\Delta m_{21}^2 L}{4E} \quad \textbf{CP-odd}$$

+ other terms..

$\delta \to -\delta$, $a \to -a$ for $\bar{\nu}_\mu \to \bar{\nu}_e$

Matter eff.: $a = 7.56\times10^{-5}[\mathrm{eV}^2]\cdot\left(\frac{\rho}{[\mathrm{g/cm}^3]}\right)\cdot\left(\frac{E}{[\mathrm{GeV}]}\right)$

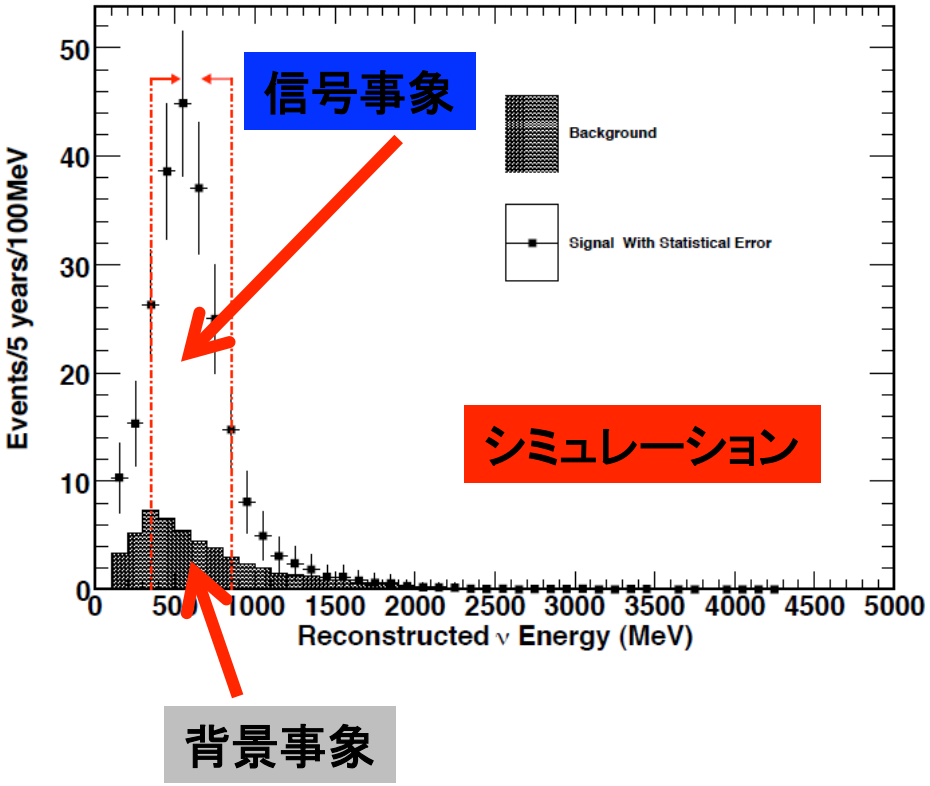
CP非保存の効果 $\propto \sin\delta \cdot s_{12} \cdot s_{23} \cdot s_{13}$

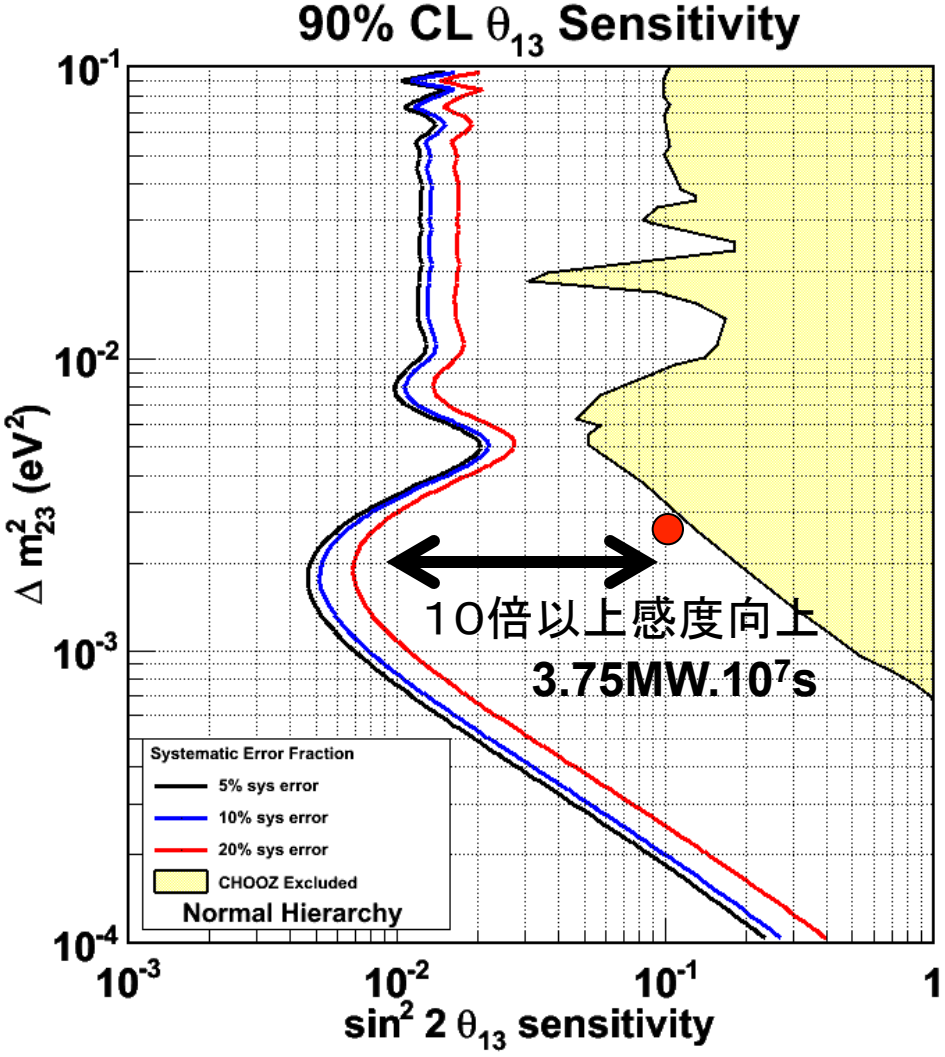
(where $\sin\theta_{12}$~0.5, $\sin\theta_{23}$~0.7, $\sin\theta_{13}$<0.2)

The size of θ_{13}
Decide future dir.!

$\nu_\mu \rightarrow \nu_e$振動で予想される信号と感度

電子ニュートリノ候補事象



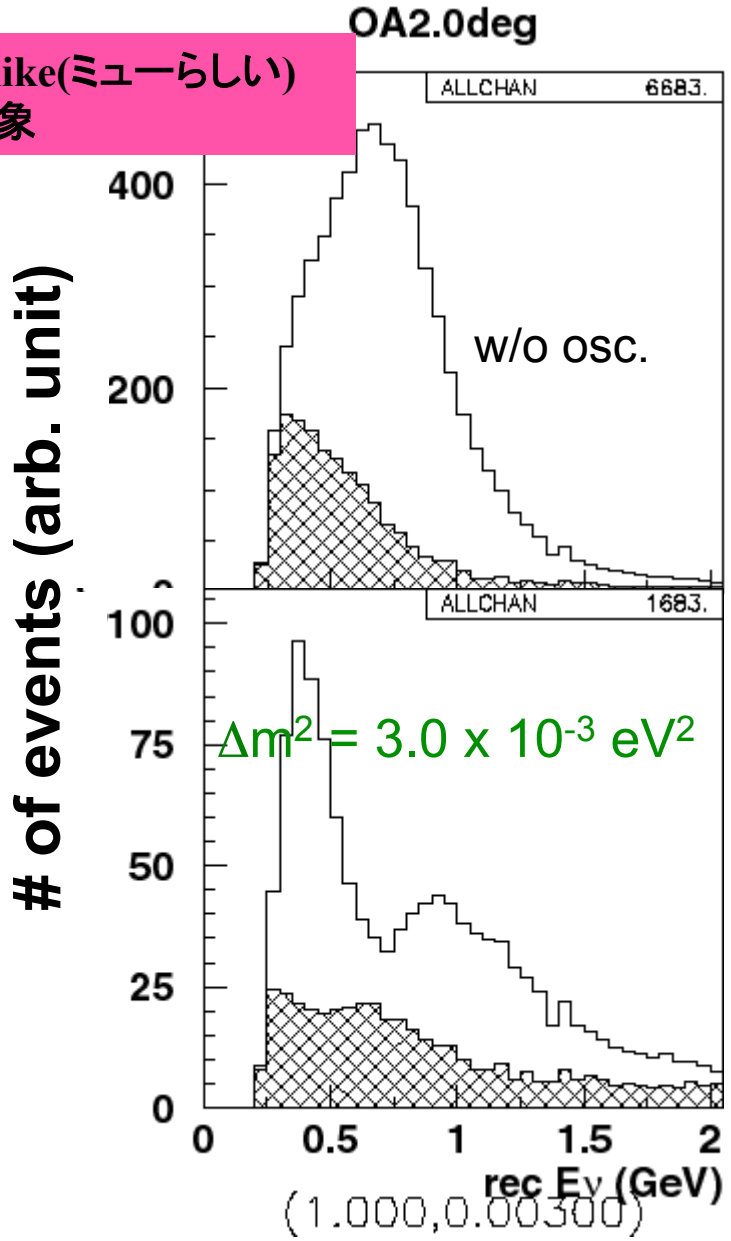


$\sin^2 2\theta_{13}$=0.1, 2.5deg, 750kWx5yr

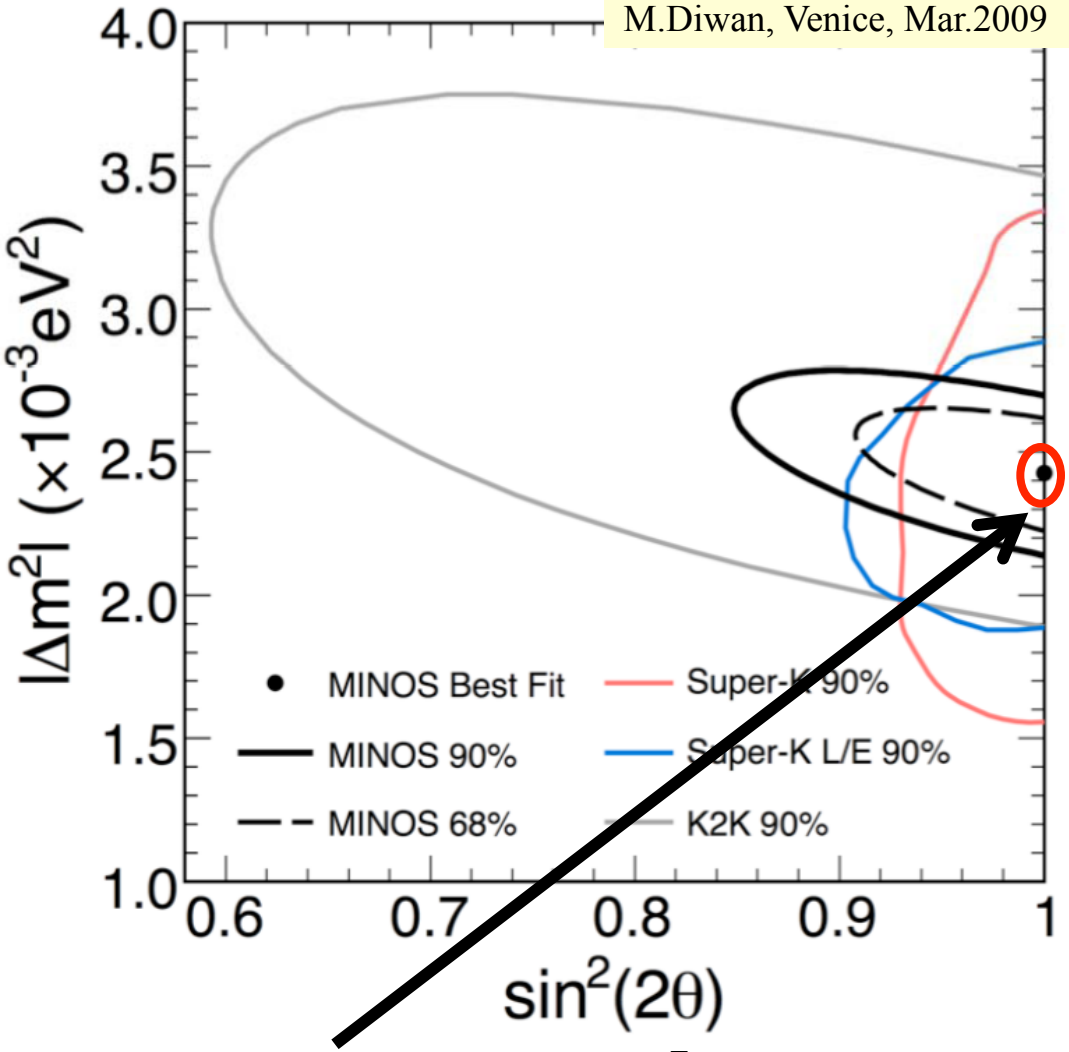
$\sin^2 2\theta_{13}$	νμ(CC+NC)	Beam νe	Osc'd νe
0.1	10	17	143

θ_{23}, Δm^2_{23} 精密測定：μニュートリノ消失

μ-like(ミューらしい)事象



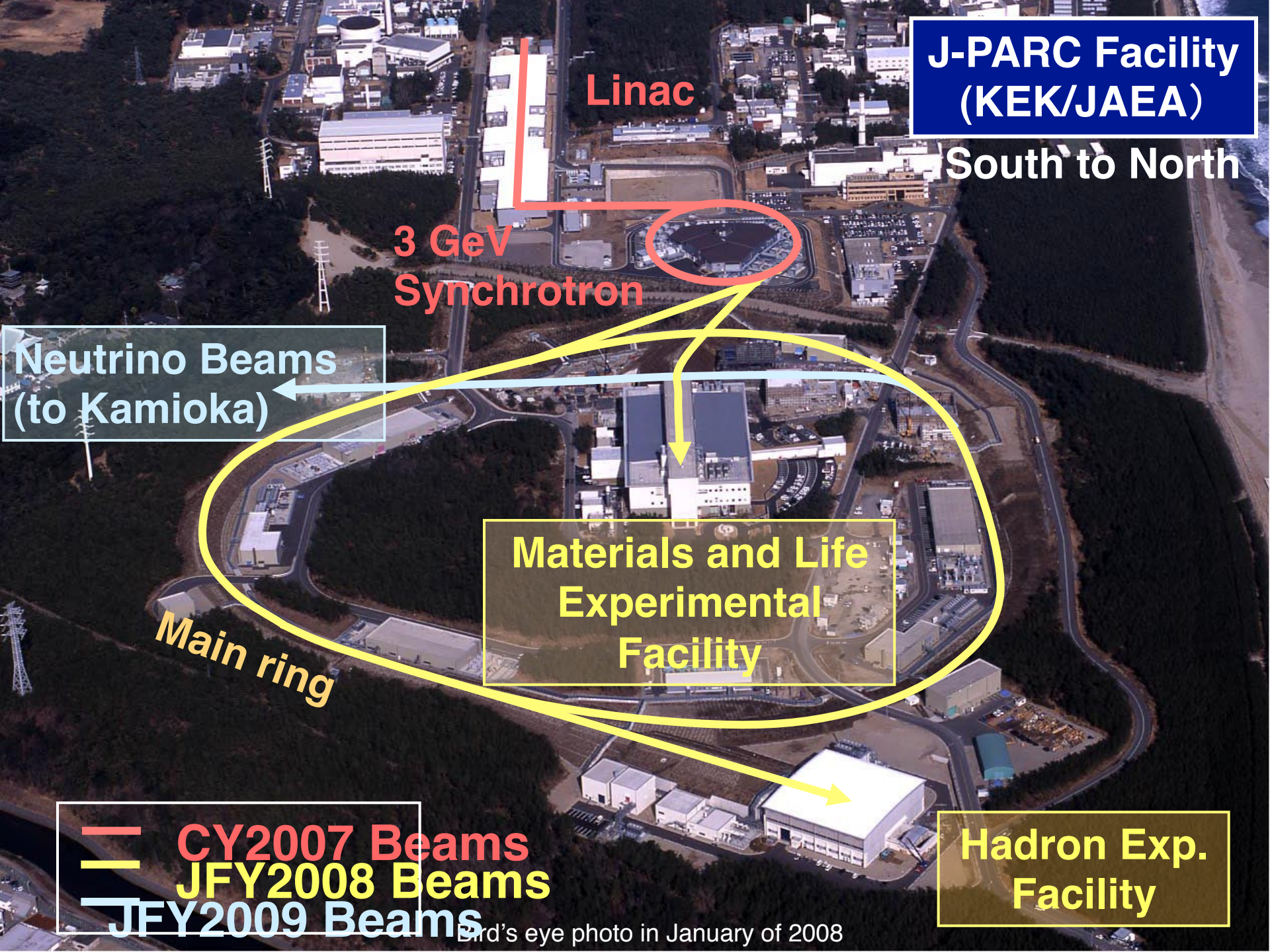
M.Diwan, Venice, Mar.2009



Goal @ 3.75MW.10⁷s:

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

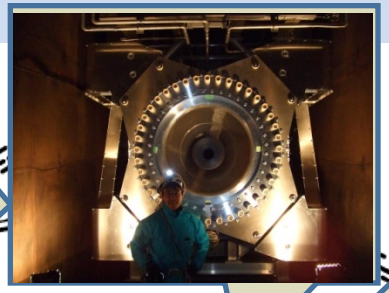
$\delta(\Delta m^2_{23}) < 1\times10^{-4}$ [eV²]


J-PARC Facility
(KEK/JAEA)
South to North
Linac
3 GeV
Synchrotron
Neutrino Beams
(to Kamioka)
Materials and Life
Experimental
Facility
Main ring
Hadron Exp.
Facility
CY2007 Beams
JFY2008 Beams
JFY2009 Beams
Bird's eye photo in January of 2008

ニュートリノ施設

ニュートリノモニター棟

電磁ホーン

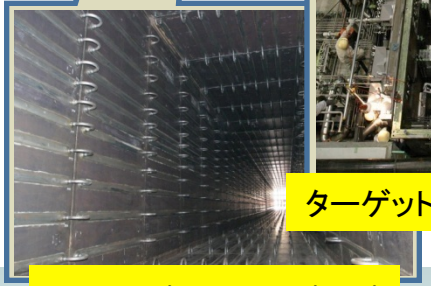


標的(グラファイト)

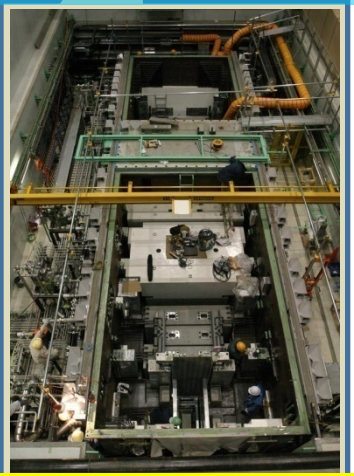
- 建設ほぼ終了
- 機器の立ち上げ調整中
- 2009年4月からビーム受入れ開始

CERNから寄贈された
UA1磁石(1000ton).
ニュートリノモニター棟内に
設置済み

ビームダンプ



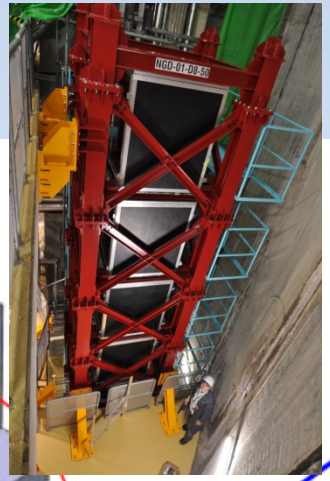
Decay volume completed



ターゲットステーション完成

一次陽子ビームライン(超伝導)

Near neutrino detectors



- Intensity
- Profile (dir)

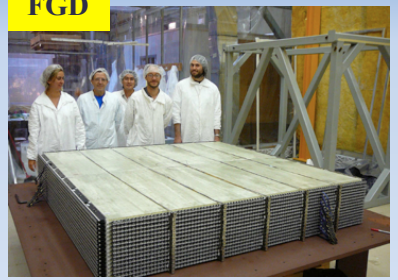
All 14 mod. inst. completed

- Neutrino flux
- Spectrum
- νe contami.
- Cross sect

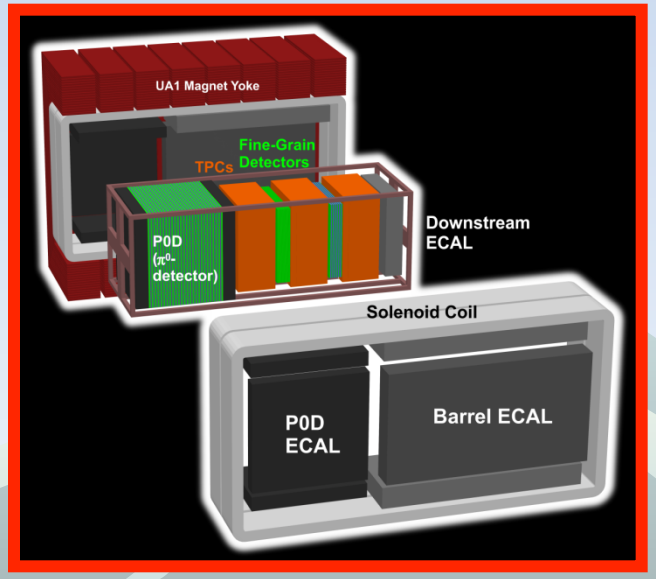
10

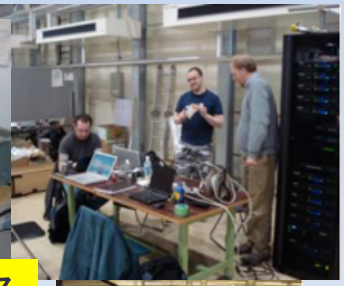
Off-axis 検出器

FGD



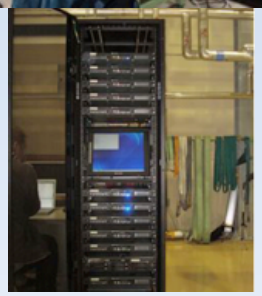
TPC





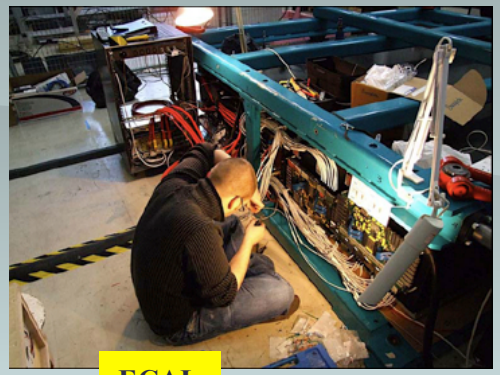
エレクトロニクス

12-FEM board stack-up before burn-in phase



- 製作、組立、試験進行中。
- 9月ごろ設置開始
- 冬以降のビームに備える

P0D



ECAL

SMRD

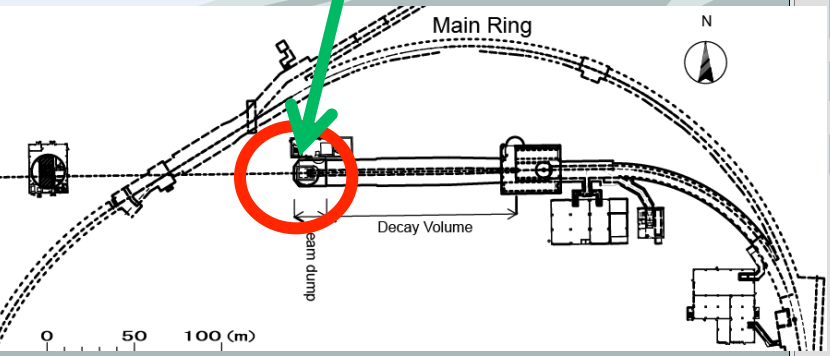
11

T2K beamline started operation!

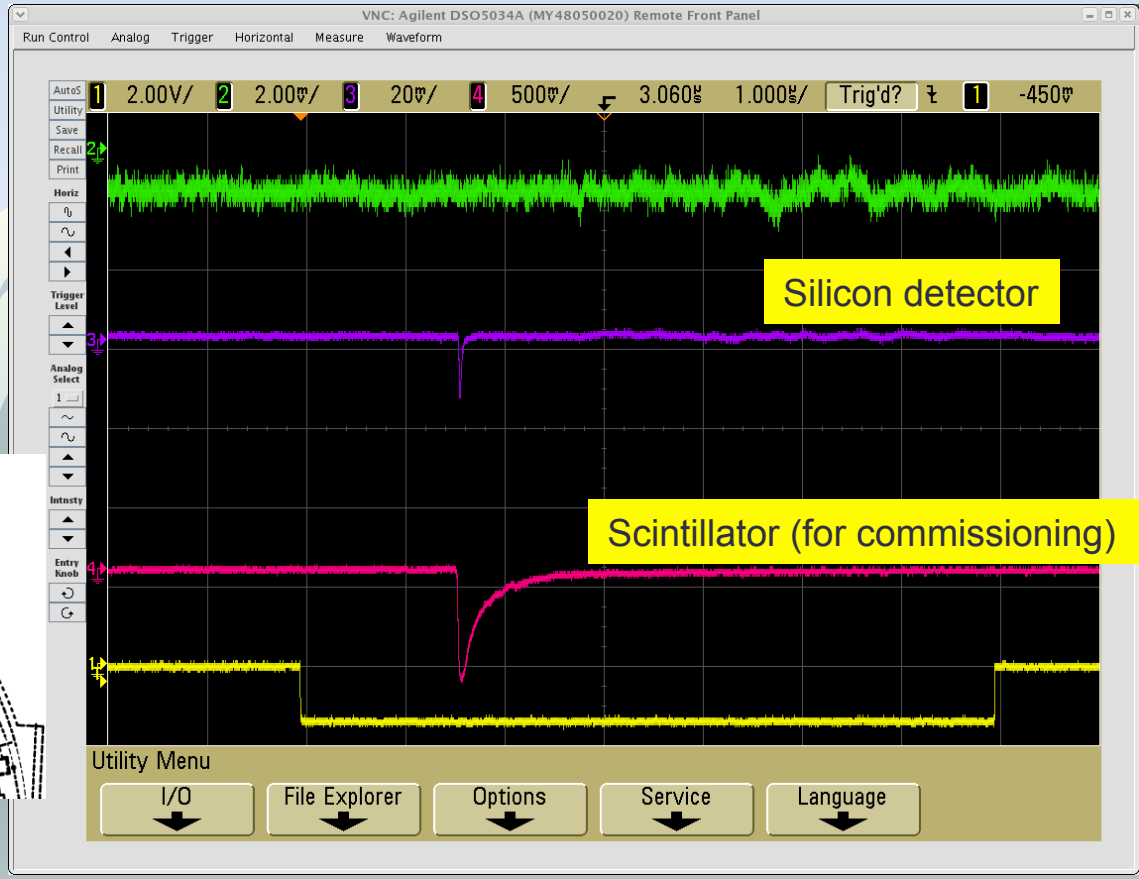
First shot after turning on SC magnets at 19:09, Apr.23, 2009

Muon monitors
(installed behind beam dump)

Ionization Chambers Silicon detectors



Muon monitor signal



First observation of muons produced in neutrino beamline

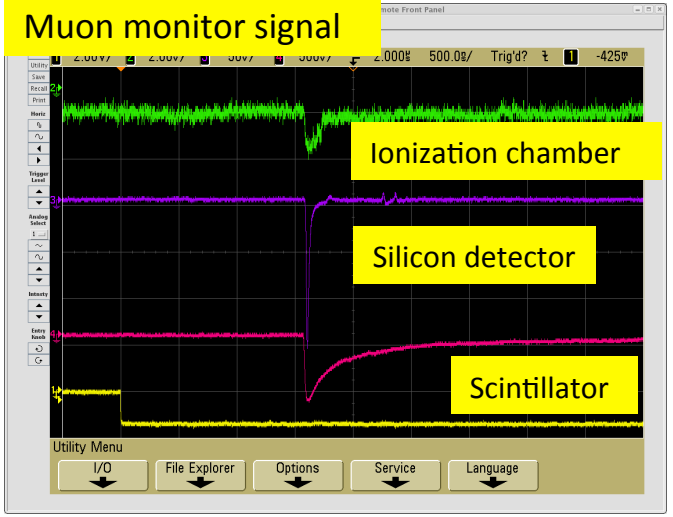
J-PARC Neutrino Facility Start Operation

First beam: Apr.23, 2009

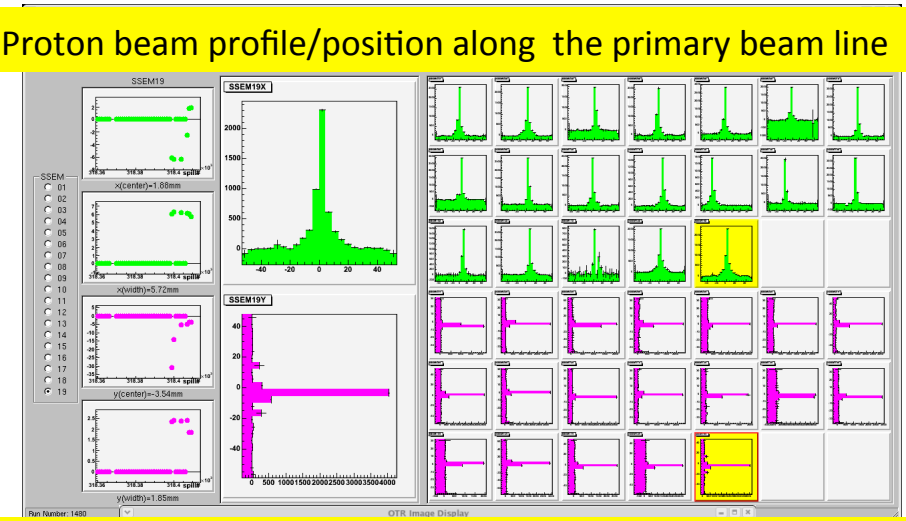
~4x1011p/bunch, 1bunch (~0.1% beam)
Only 1st horn, 1 INGRID mod.

All components worked well!

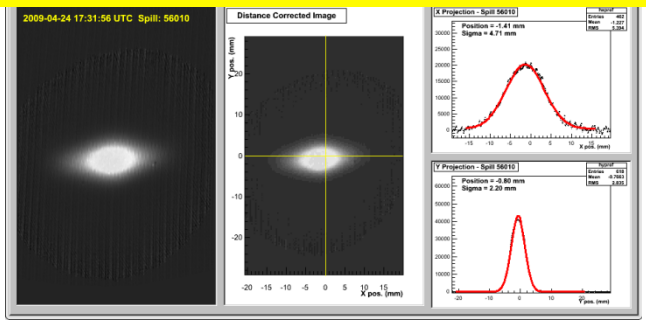
Muon monitor signal



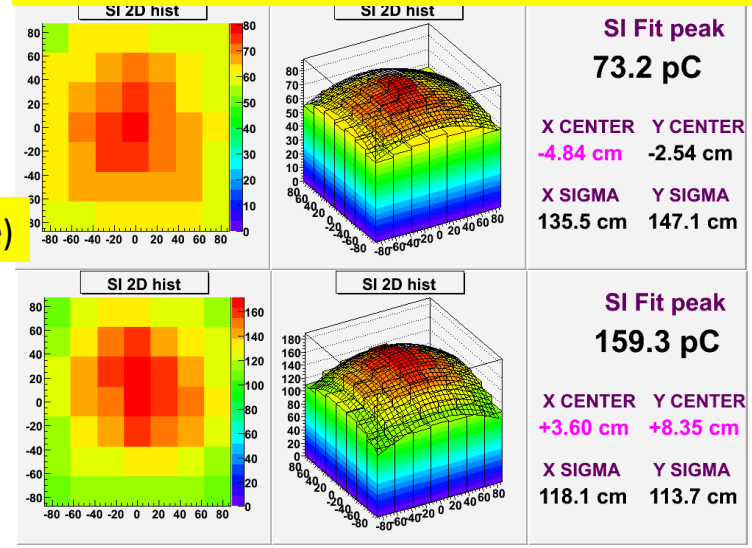
Proton beam profile/position along the primary beam line



Proton profile just in front of the target (fluorescence plate)



Muon monitor signal with/without Horn Magnet



Horn Off

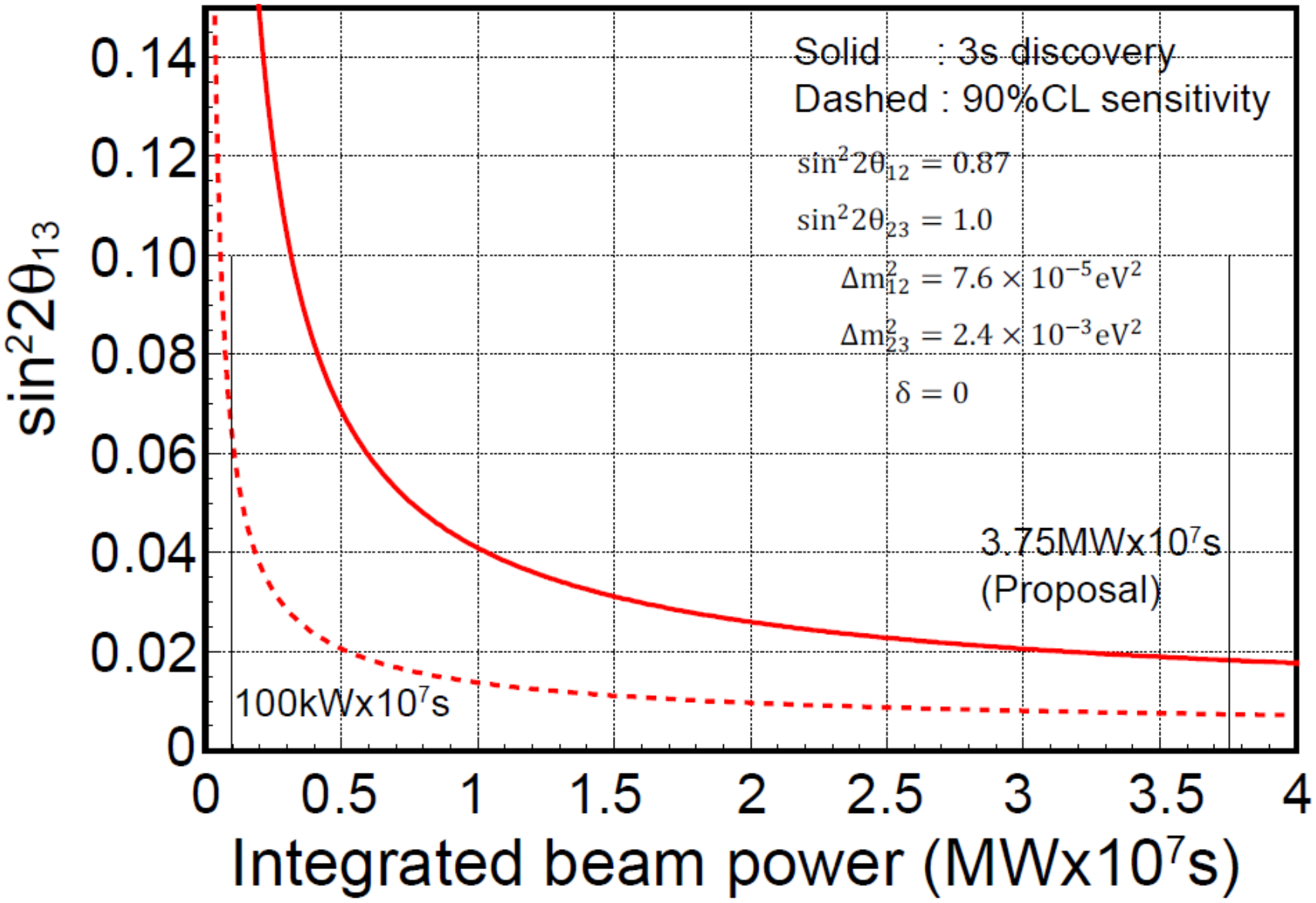
Horn 273kA

今後

- June~Sept, 2009 (during scheduled shutdown)
  - Horn 2 and 3 installation and operation test
  - On-axis INGRID detector completion
  - Ready to accept beam on Oct. 10
- Fall~Winter, 2009
  - Beam/Detector commissioning
- Winter JFY2009 ~ 2010
  - Want to accumulate O(100kW x10^7s) by Summer 2010
  - **First physics results in 2010**
  - **→ Exceed sensitivity of present world record result from Chooz experiment**
- After that
  - Physics data taking with > a few 100kW
  - **Next milestone: 1~2MW.yr before as soon as possible**

- Final goal: 3.75MW.yr (approved by PAC)

θ_{13} sensitivity



Accelerator issues to realize design spec

- LINAC
  - RFQ discharge → 2nd ver. End of 2010
  - Energy 181MeV → 400MeV: 2012~2013
  - Ion source/RFQ: 30mA → 50mA
  - …
- RCS
  - RF core buckling problem (being attacked w/ UT group)
  - Injection bump mag. PS: →400MeV
  - …
- MR
  - Shorten Kicker rise time 6bunch→8bunch (being replaced)
  - Replace injection/extraction devices with full aperture (60pi.mm.mrad)
  - Power supply ripple problem
  - RF improvement (add fundamental/hh,
  - …
- All
  - Control beam loss (drastic improvement of collimator, tune control devices etc)

(1)T2K and beyond:
3-step Power Upgrade Scenario

Based on the assumption that three machine issues will be solved in a few years

- **Short term plan (2009~2010)**
  - **FY2009 → Establish 30 kW run and 100kW trial**
  - **FY2010 → Establish 100kW (10^7 sec) and 300kW trial**
- **Middle term plan (2011~in a few years??)**
  Achieve design beam power (750kW)
  - **Understanding/solving space charge effect and collimator scenario/aperture**
  - **Improvement of MR magnet power supply to increase repetition rate**
  - **Linac 400 MeV energy recovery and upgrade of the RCS injection system**
- **Long-term plan toward power frontier (>MW)**
  - **KEK roadmap**

Quest for the Origin of Matter Dominated Universe

One of the Main Subject of the KEK Roadmap

T2K (2009~)

Discovery of the ν_e Appearance

Neutrino Intensity Improvement

Huge Detector R&D

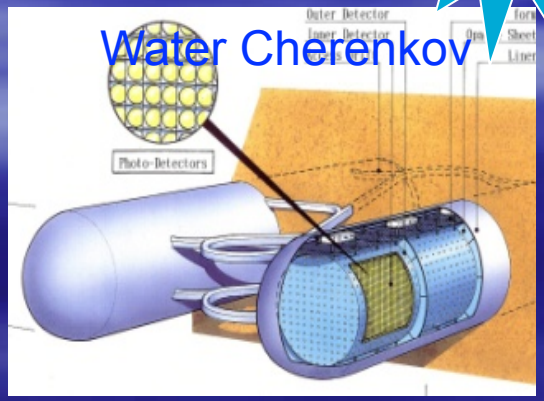
Establish Huge Detector Technology

Construction of Huge Detector

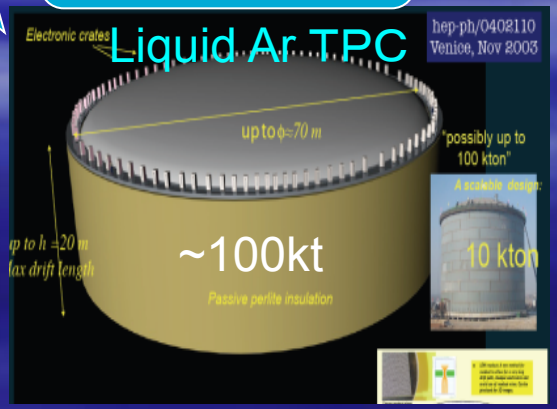
Discovery of Lepton CP Violation Proton Decay

~Mt

Water Cherenkov



Liquid Ar TPC



Technically Feasible MR Power Improvement Scenario — KEK Roadmap —

	Day1 (up to Jul.2010)	Next Step	KEK Roadmap	Ultimate
Power(MW)	0.1	0.45	1.66	?
Energy(GeV)	30	30	30	
Rep Cycle(sec)	3.5	3-2	1.92	
No. of Bunch	6	8	8	
Particle/Bunch	1.2×10^{13}	$<4.1\times10^{13}$	8.3×10^{13}	
Particle/Ring	7.2×10^{13}	$<3.3\times10^{14}$	6.7×10^{14}	
LINAC(MeV)	181	181	400	
RCS	h=2	h=2 or 1	h=1	

After 2010, plan depends on financial situation

Item to be Modified from DAY1 toward High Intensity

- No. of Bunch in MR(6→8)
  - Fast Rise Time Extraction Kicker Magnet
- Increase Repetition Rate (3.5Sec→1.92Sec)
  - RF and Magnet Power Supply Improvement
- RCS h=1 Operation (longer beam bunch to decrease space charge effect)
  - RF Improvement
- LINAC 400MeV Operation (avoid severe space charge effect at RCS injection)

h=2: 2 bunches×4cycle injection to MR
h=1:Single bunch with doubled no. of proton×8cycle injection

まとめ

- 最重要課題：電子ニュートリノ出現を検出し世界に先駆けてθ_{13}の測定
  - ニュートリノ物理の今後の方向性を決めるθ_{13}
  - 感度$\sin^2 2\theta_{13} > 0.008$ (90%), ~0.018 (3σ)
- 2009年4月23日～　実験開始
  - 4，5月ビームコミッショニング
    - 約1000分の1の強度、
    - 第1ホーン、INGRID1モジュール
- 秋以降ビームコミッショニング再開
  - 第2，3ホーン、INGRIDすべて稼働。
  - Off-axis冬から稼働
- 冬から物理測定を開始したい
- マイルストーン
  - **O(100kW.10^7sec)** を2010年夏までに、
  - **1~2MW.10^7sec**程度を数年内、遅くとも2014年ごろまで
  - 最終的に**3.75MW.10^7sec**
- **加速器の改良がクリティカル**