

The First Neutrinos

in the T2K neutrino oscillation experiment

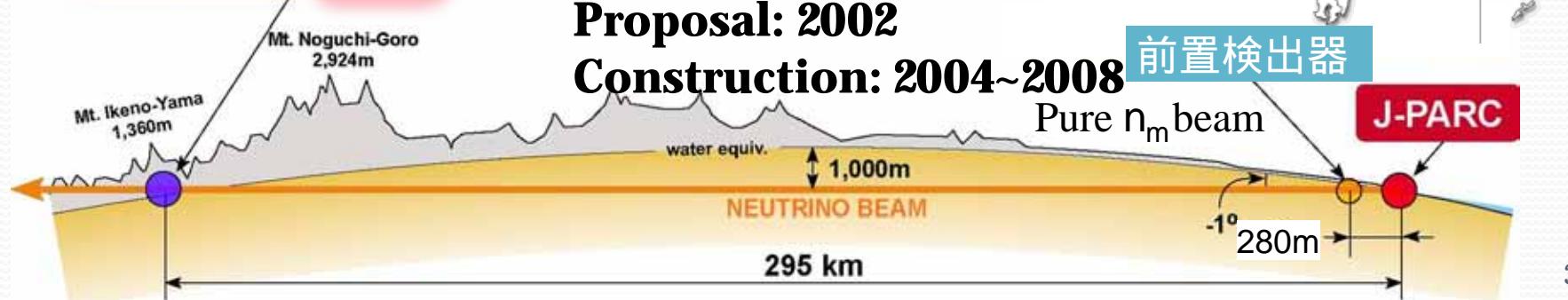
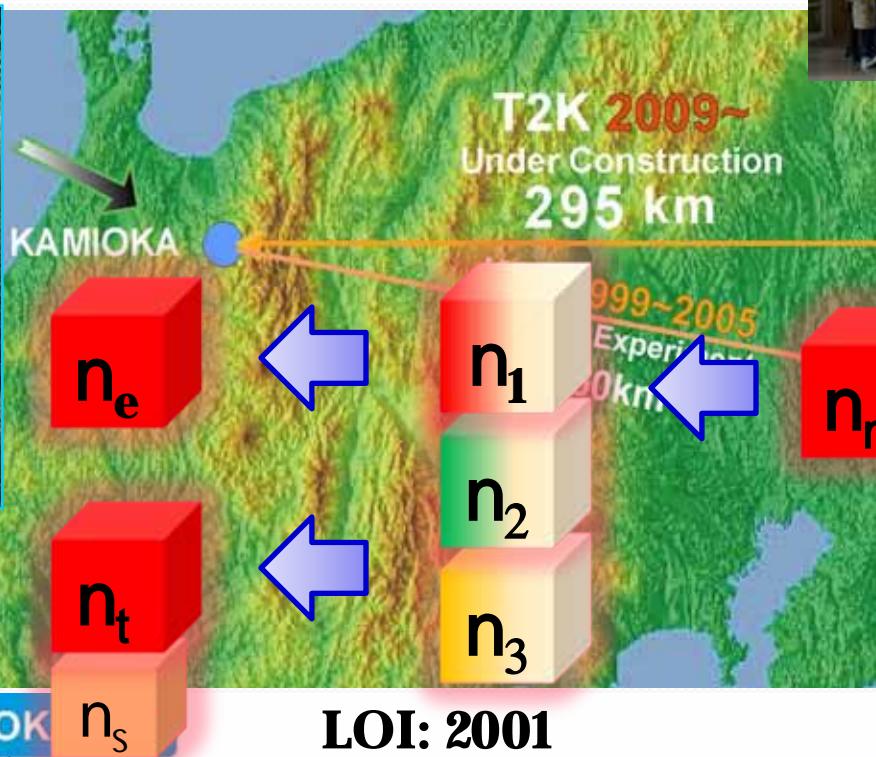
T. Nakaya (Kyoto University)

T2K



T2K Experiment

Tokai-to(2)-Kamioka

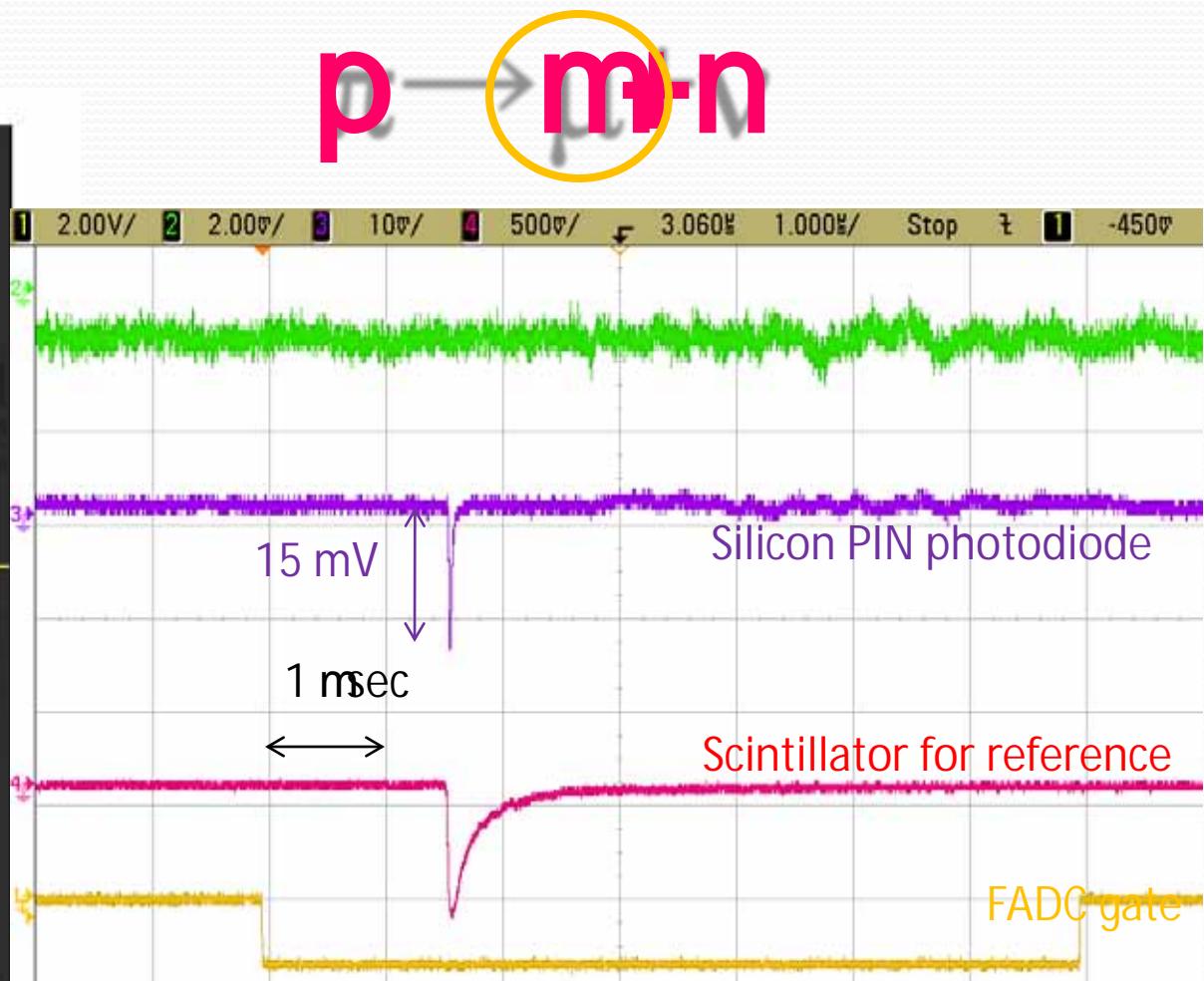
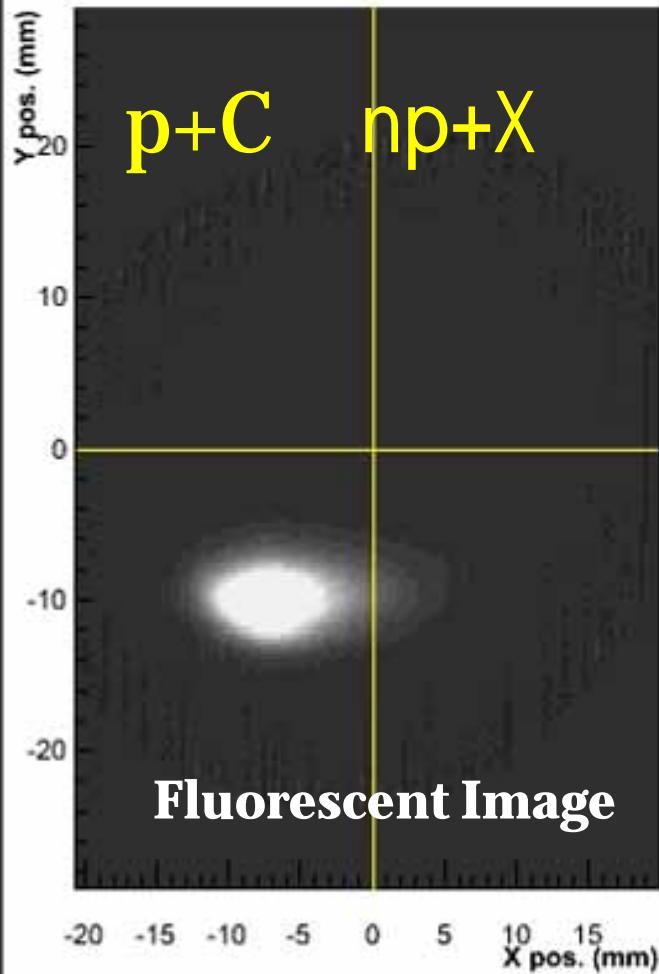


The First Neutrino Beam

April 23rd, 2009



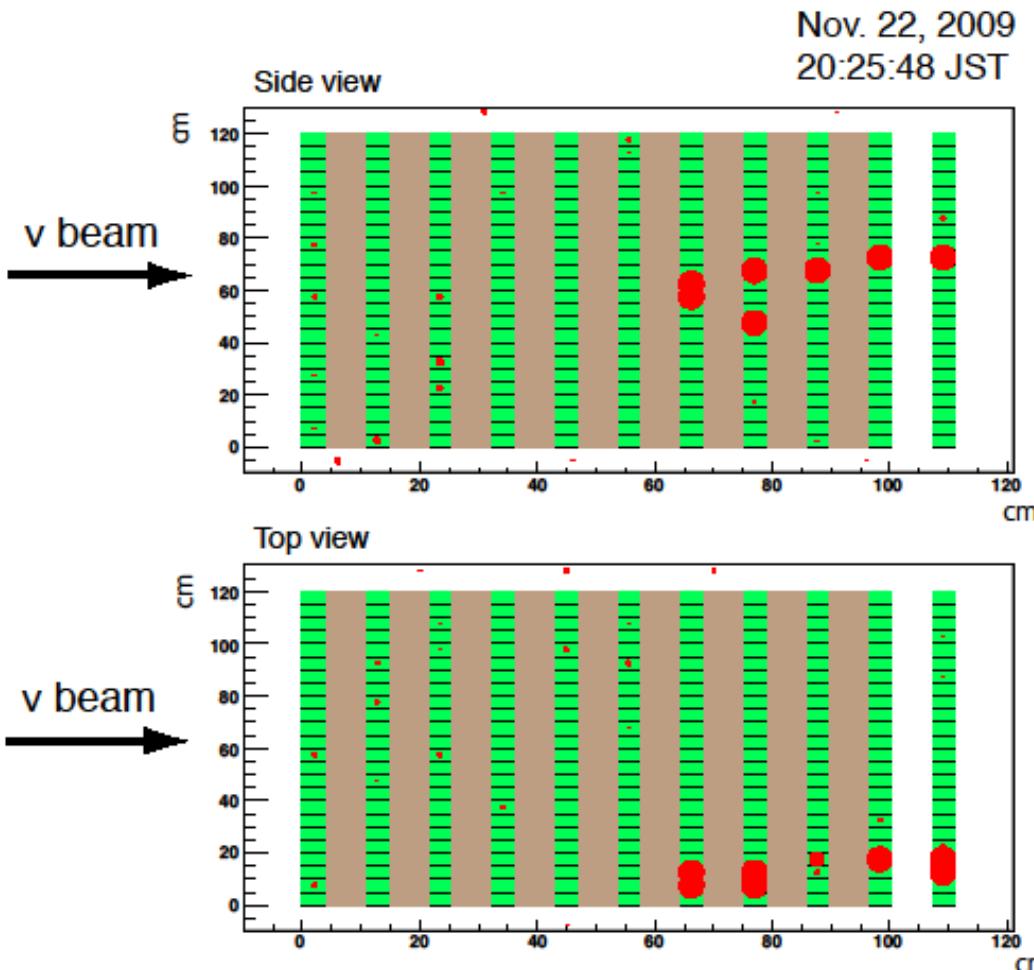
Proton Beam



First beam event in Muon monitor
and
evidence of neutrino production

The First Neutrino Events at the neutrino detector in J-PARC

November 22rd, 2009



INGRID Mod. 07

MR Run #27
Shot #19655
T2K Spill #241792

- Iron (6.5cm thick)
- Plastic scintillator (5cm wide, 1cm thick)
- Hit in plastic scintillator



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Science News

Share Blog Cite

With First Neutrino Events, Physicists Closer to Answering Why Only Matter in Universe

ScienceDaily (Nov. 27, 2009) — Physicists from the Japanese-led multi-national T2K neutrino collaboration have just announced that over the weekend they detected the first neutrino events generated by their newly built neutrino beam at the J-PARC (Japan Proton Accelerator Research Complex) accelerator laboratory in Tokai, Japan.

See Also:

Space & Time

- Dark Matter
- Astrophysics
- Cosmic Rays

Matter & Energy

- Quantum Physics

Protons from the 30-GeV Main Ring synchrotron were directed onto a carbon target, where their collisions produced charged particles called pions. These pions travelled through a helium-filled volume where they decayed to produce a beam of the elusive particles called neutrinos. These neutrinos then flew 200

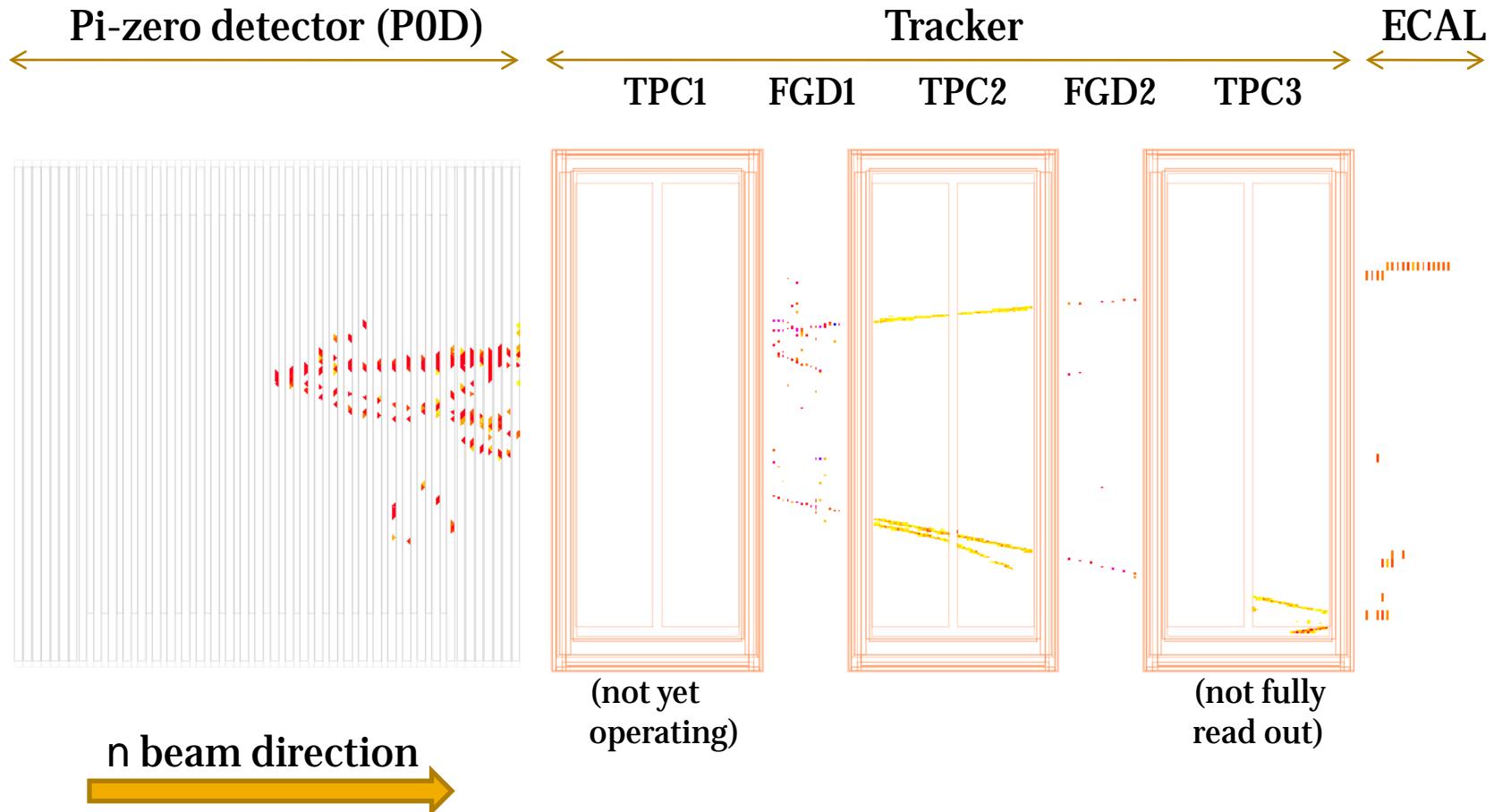


Arc-part tunnel for Neutrino Experimental Facility at the J-PARC accelerator laboratory in Tokai, Japan.
(Credit: Courtesy of J-PARC.)

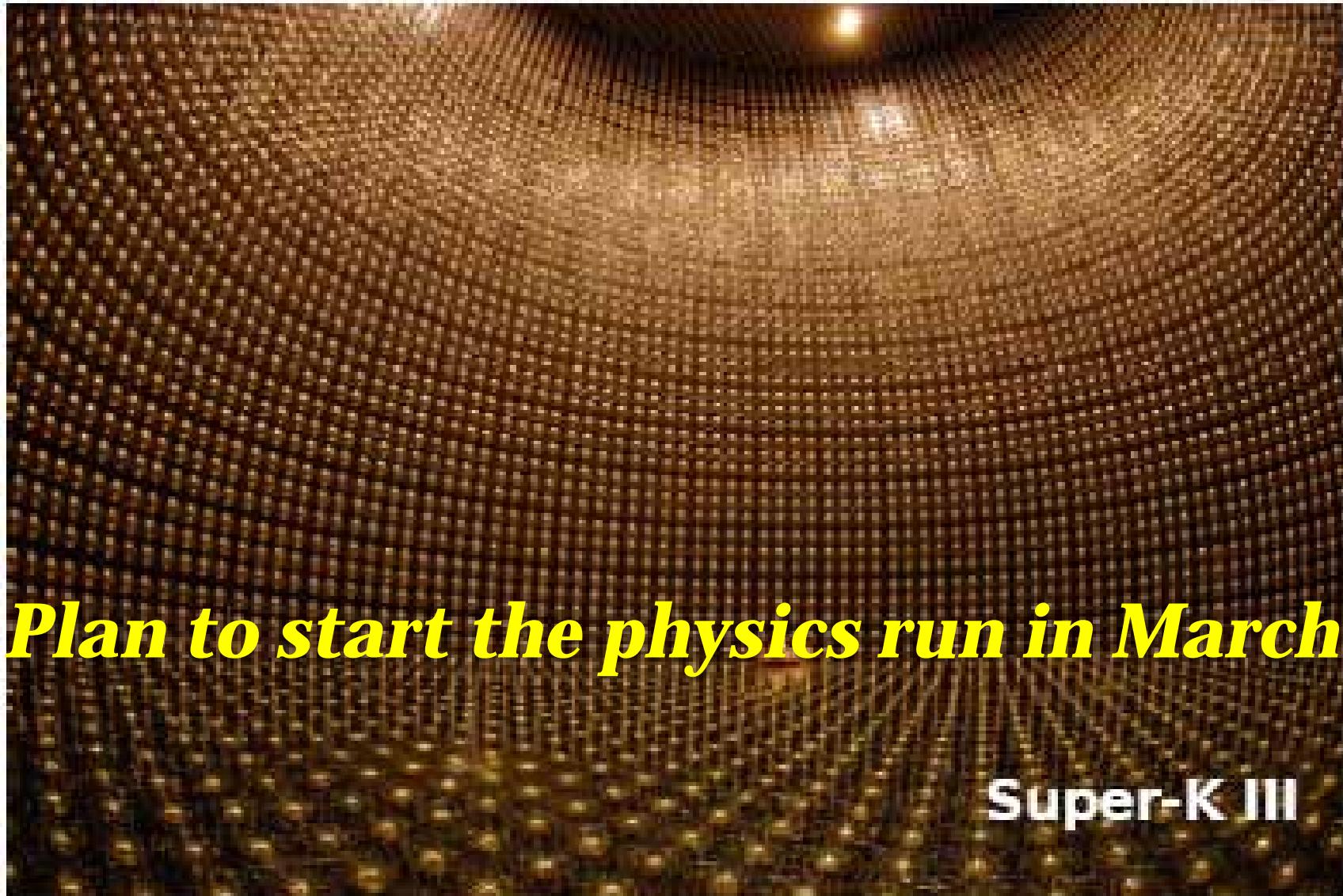
First neutrino interaction in ND280 off axis detector

December 19, 2009

Event number : 491 | Partition : INVALID | Run number : 1539 | Spill : INVALID | SubRun number :0 | Time : Sat 2009-12-19 07:40:13 JST | Trigger : 1



NO Super-K neutrino events yet. (Under beam/detector commissioning)



Plan to start the physics run in March!

Super-K III

Introduction

Neutrinos.

- Neutrinos are one of the most abundant particles in our universe.
 - No. 1: Photons (light) [$\sim 400\text{g/cm}^3$]
 - No. 2: Neutrinos ($\sim 300\text{n/cm}^3$)
although undetectable...
 - $n_{\text{Baryon}} \sim 0.000001/\text{cm}^3$



Neutrinos around us!

Supernova

Nobel Prize in Physics, year 2002

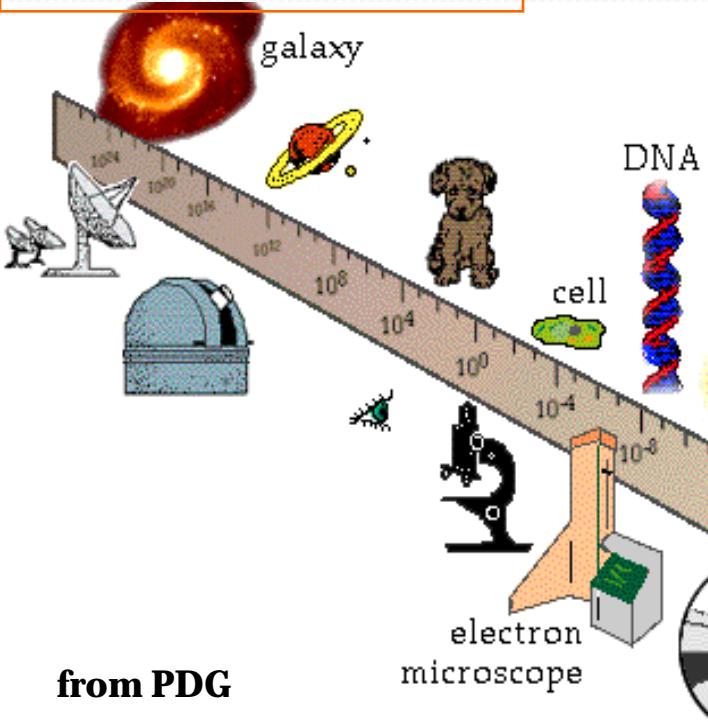


60 billion neutrinos
per sec•cm²



Elementary Particle Physics

100,000,000,000,
000,000,000,000m

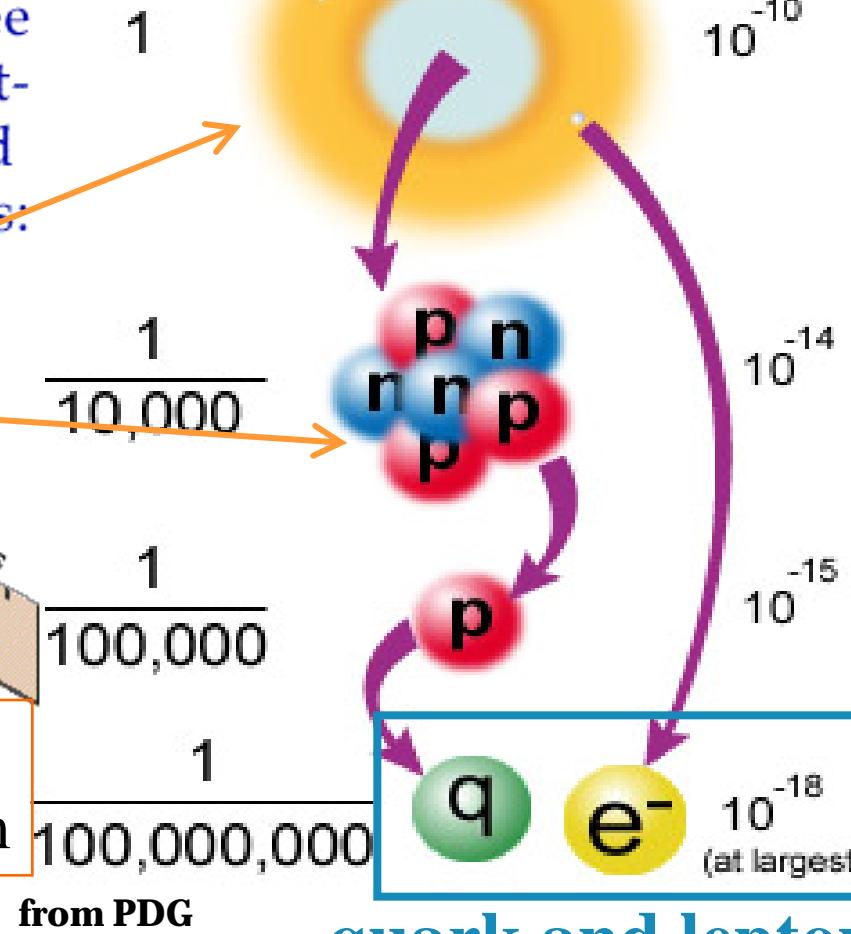


from PDG

0.000000000
0000000001m

How we see different-sized objects:

size in atoms and in meters

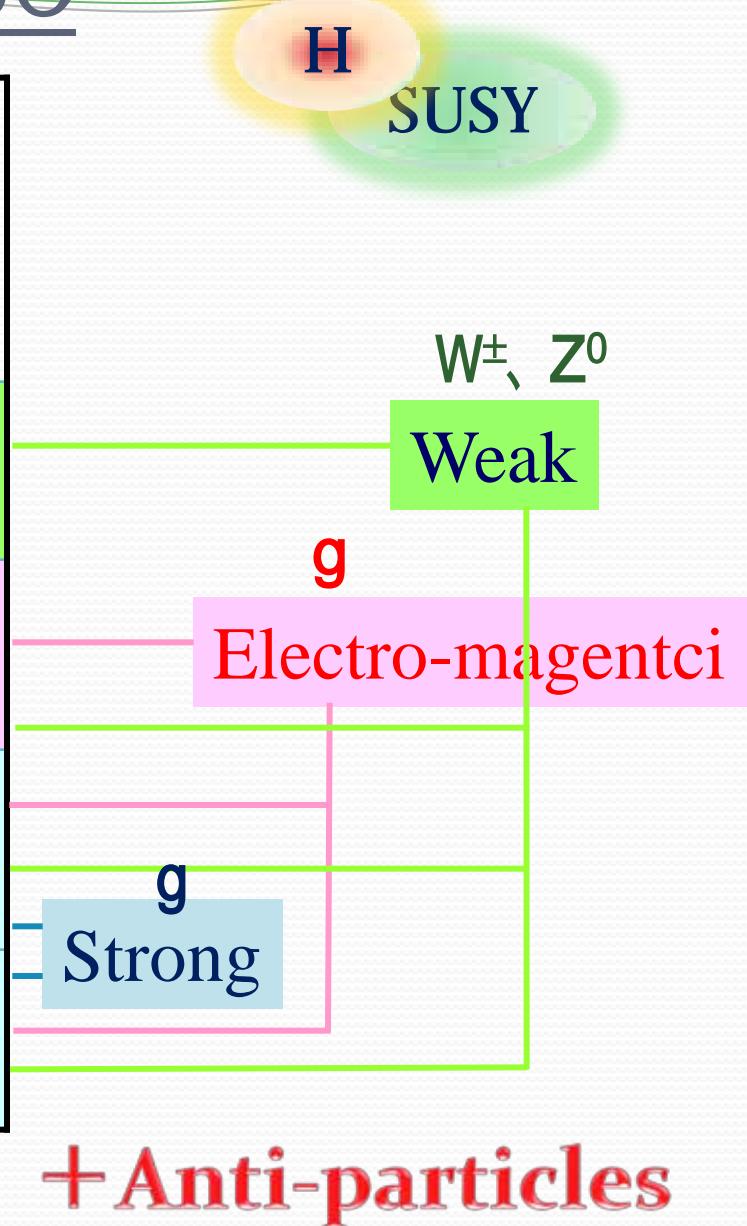


from PDG

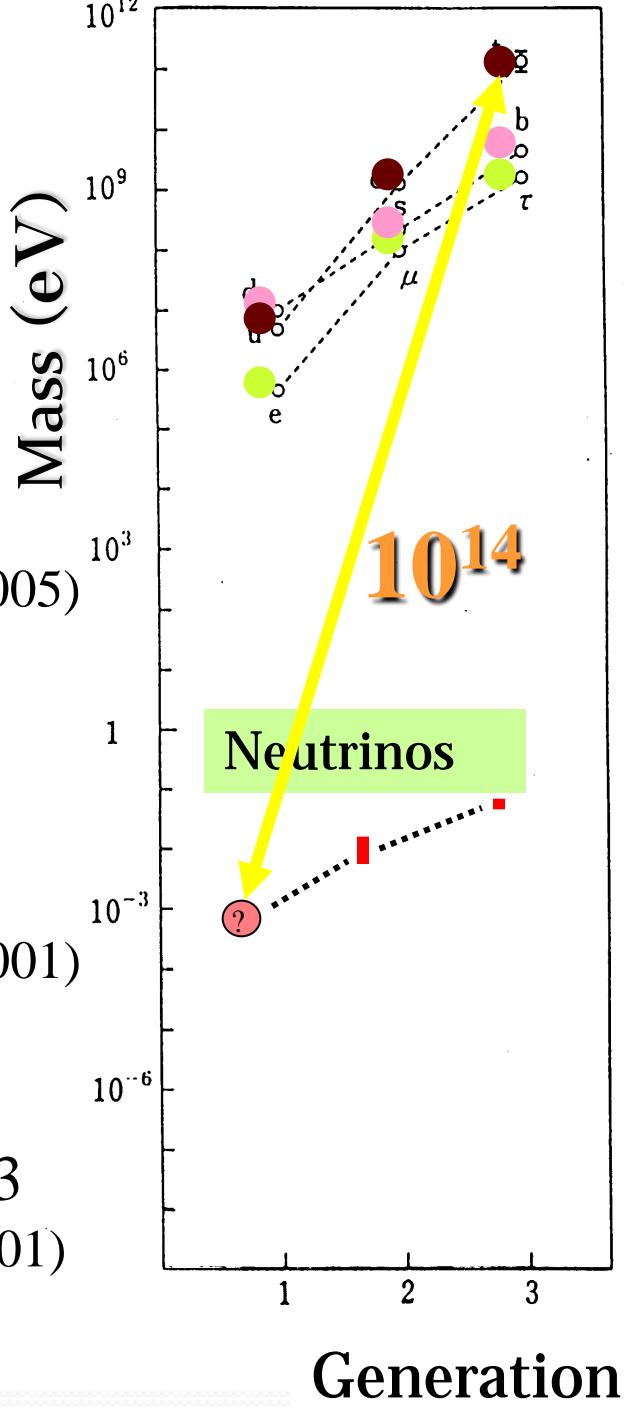
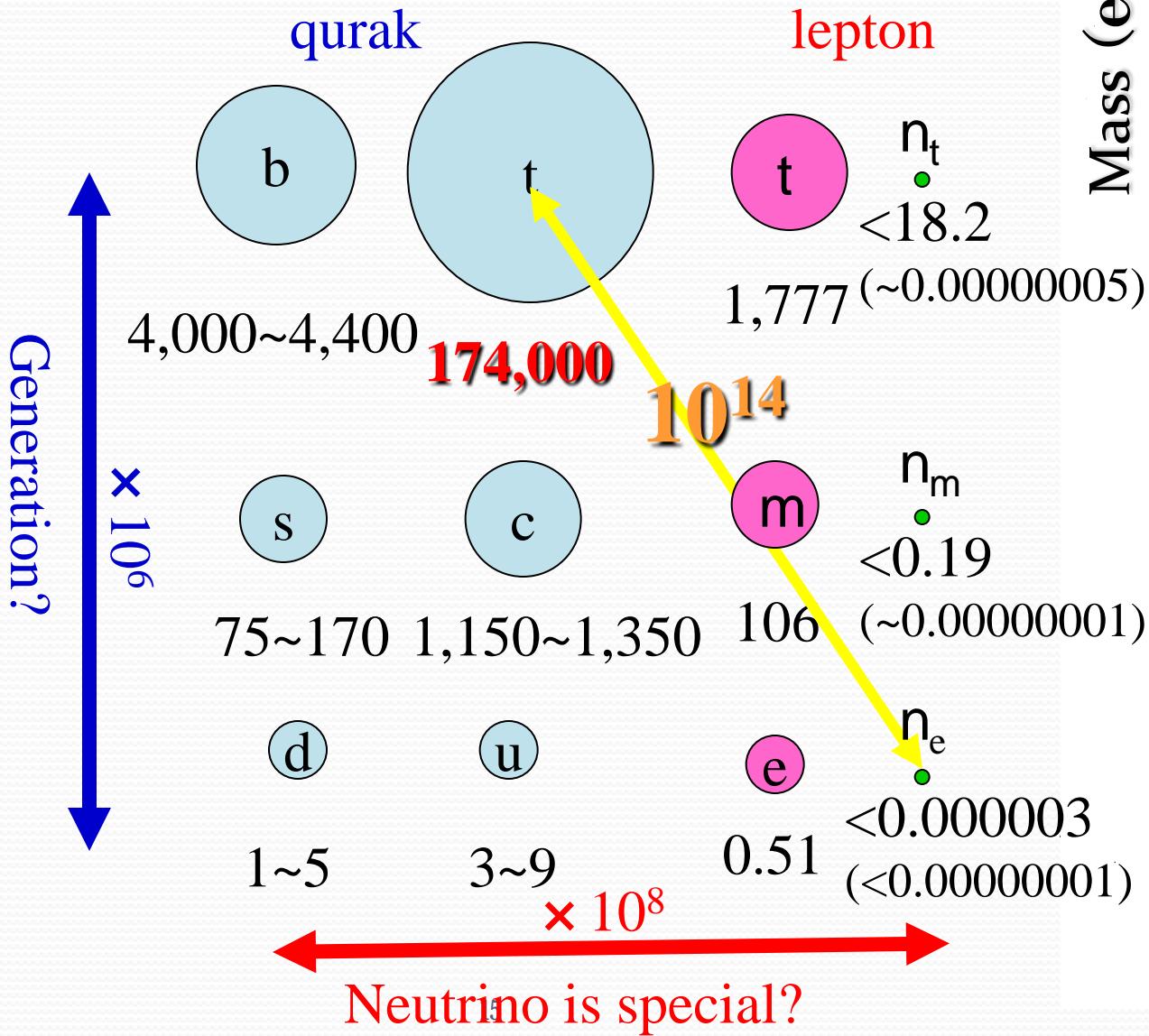
quark and lepton

Particles and Force

Charge	1 st Generati on	2 nd Genera tion	3 rd Genera tion
Lepton	n_e	n_μ	n_τ
Quark	u	c	t
-1/3	d	s	b

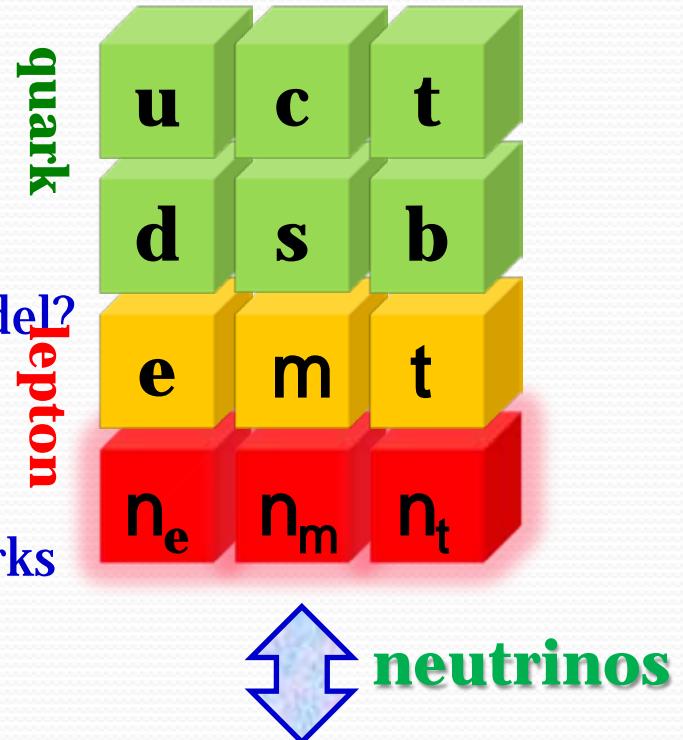


Mass(MeV) :



Neutrinos

- Only have weak interactions
 - Small mass
 - Origin in physics beyond the standard model?
 - Mixing
 - 3 neutrinos are mixed
 - Different mixing patterns from that of quarks
 - What symmetry exists?
 - No experimental information on the CP symmetry



*Much exciting to study
neutrinos after the discovery
of neutrino oscillation in 1998*

Mixing Matrix



Kobayashi-Maskawa matrix

- a) The weak neutrinos must be re-defined by a relation

$$\left. \begin{aligned} \nu_e &= \nu_1 \cos \delta - \nu_2 \sin \delta, \\ \nu_\mu &= \nu_1 \sin \delta + \nu_2 \cos \delta. \end{aligned} \right\} \quad (2 \cdot 18)$$

Weak state

The leptonic weak current (2·9) turns out to be of the same form with (2·1). In the present case, however, weak neutrinos are *not stable* due to the occurrence of a virtual transmutation $\nu_e \leftrightarrow \nu_\mu$ induced by the interaction (2·10). If the mass difference between ν_2 and ν_1 , i.e. $|m_{\nu_2} - m_{\nu_1}| = m_{\nu_2}^{(*)}$ is assumed to be a few Mev, the transmutation time $T(\nu_e \leftrightarrow \nu_\mu)$ becomes $\sim 10^{-18}$ sec for fast neutrinos with a momentum of \sim Bev/c. Therefore, a chain of reactions such as¹⁰⁾

$$\pi^+ \rightarrow \mu^+ + \nu_\mu, \quad (2 \cdot 19a)$$

$$\nu_\mu + Z(\text{nucleus}) \rightarrow Z' + (\mu^- \text{ and/or } e^-) \quad (2 \cdot 19b)$$

is useful to check the two-neutrino hypothesis only when $|m_{\nu_2} - m_{\nu_1}| \lesssim 10^{-6}$ Mev

state	$\bar{\zeta}n_m \div$	$\zeta V_m \quad V_{m2} \quad V_{m3} \div$	$\bar{\zeta}n_2 \div$
$\bar{\zeta}n_t \div \emptyset$	$\zeta V_{t1} \quad V_{t2} \quad V_{t3} \div$	$\bar{\zeta}n_3 \div \emptyset$	

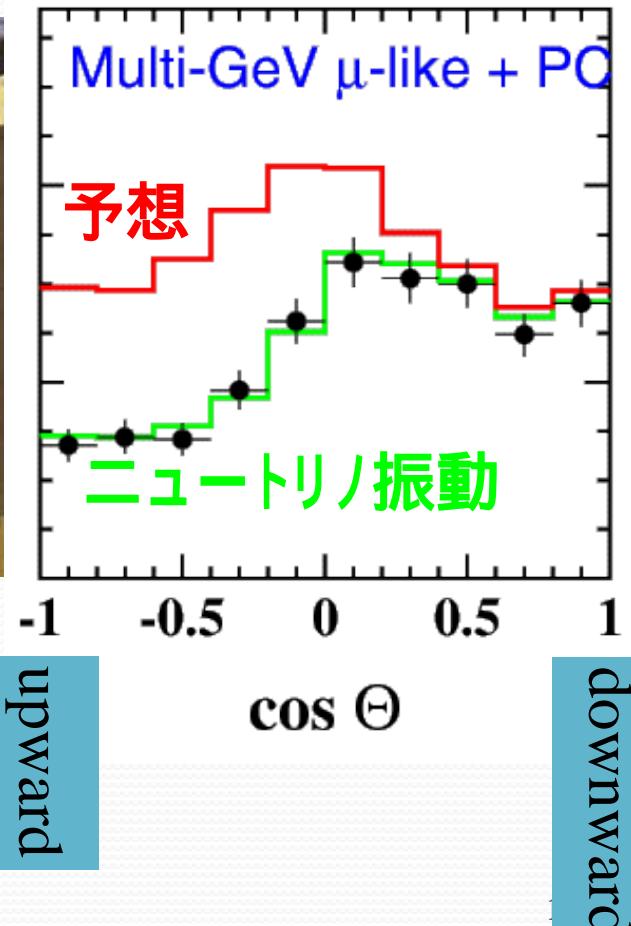
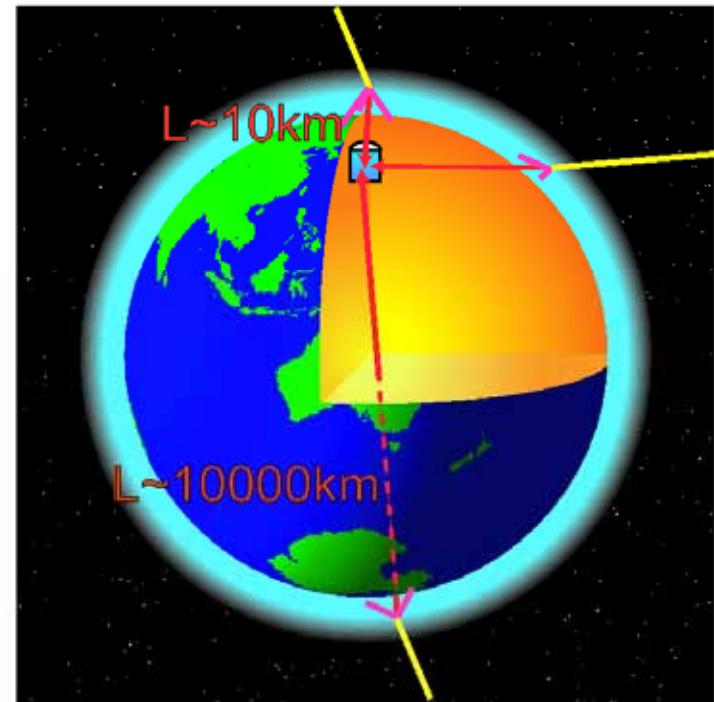
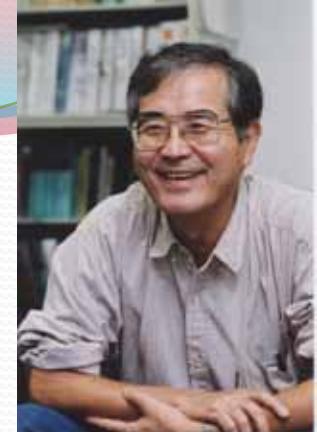
Particles

SAKATA

Mass state

Discovery of neutrino oscillation(1998)

Evidence of neutrino mass

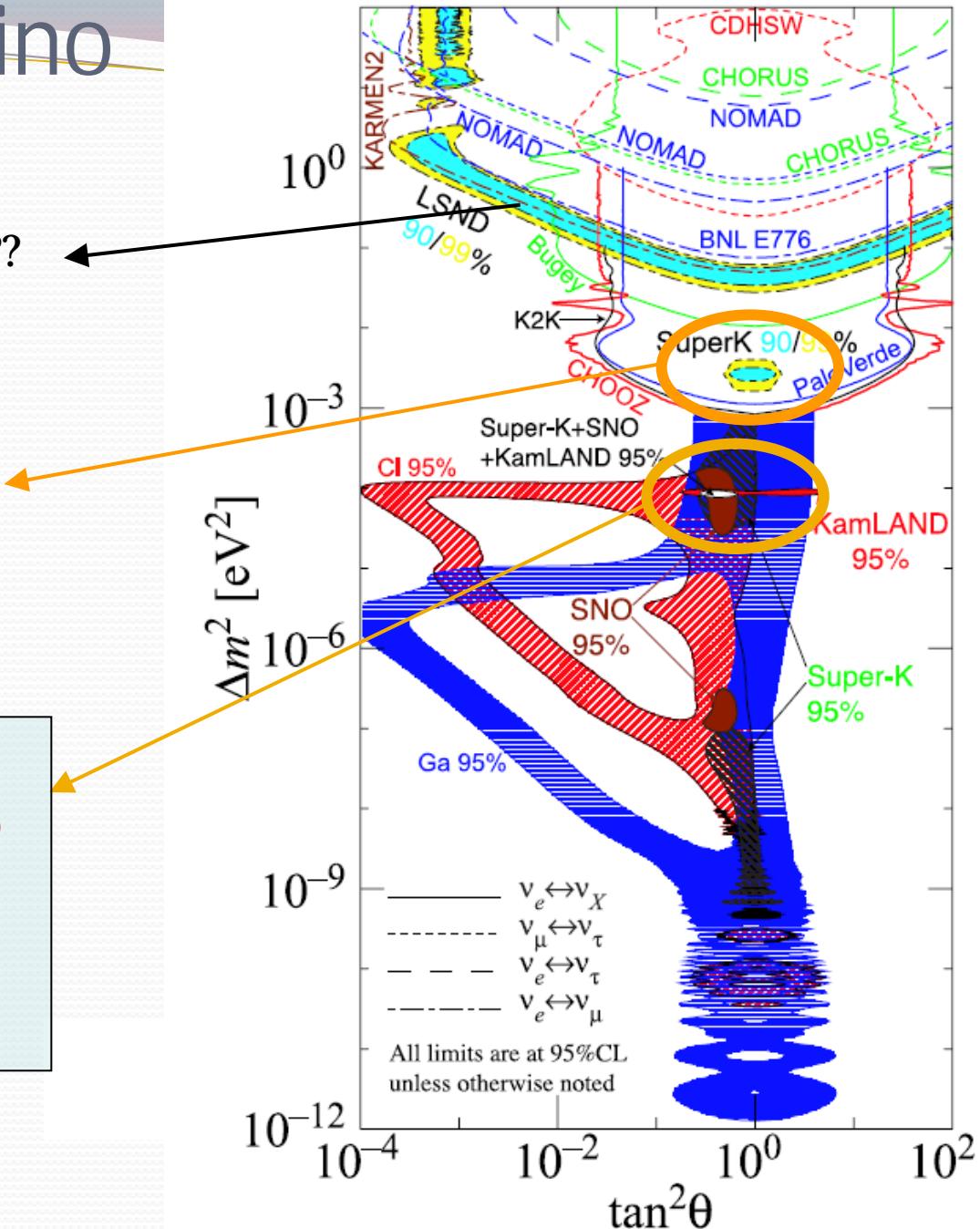


Status of Neutrino Oscillation

??? LSND anomaly ???

Atmospheric neutrinos
 n_m deficit (n_t appearance)
Dm₂₃ region
• Dm₂₃~2.5' 10⁻³eV²
• sin²2q₂₃~1.0

solar neutrinos
 n_e deficit (NO NC deficit)
Dm₁₂ region
• Dm₁₂~7.9' 10⁻⁵eV²
• sin²2q₁₂~0.82



Neutrino Oscillation

Maki-Nakagawa-Sakata matrix

$$\begin{matrix} \text{Weak State} \\ \bar{\nu}_e & \nu_e & \nu_m & \nu_t \end{matrix} = \boxed{\begin{matrix} \bar{\nu}_e & V_{e1} & V_{e2} & V_{e3} \\ \bar{\nu}_m & V_{m1} & V_{m2} & V_{m3} \\ \bar{\nu}_t & V_{t1} & V_{t2} & V_{t3} \end{matrix}} \begin{matrix} \nu_1 & \nu_2 & \nu_3 \end{matrix}$$

Δm_{12}^2

$\Delta m_{23}^2 \text{ } (\sim -m_{13}^2)$

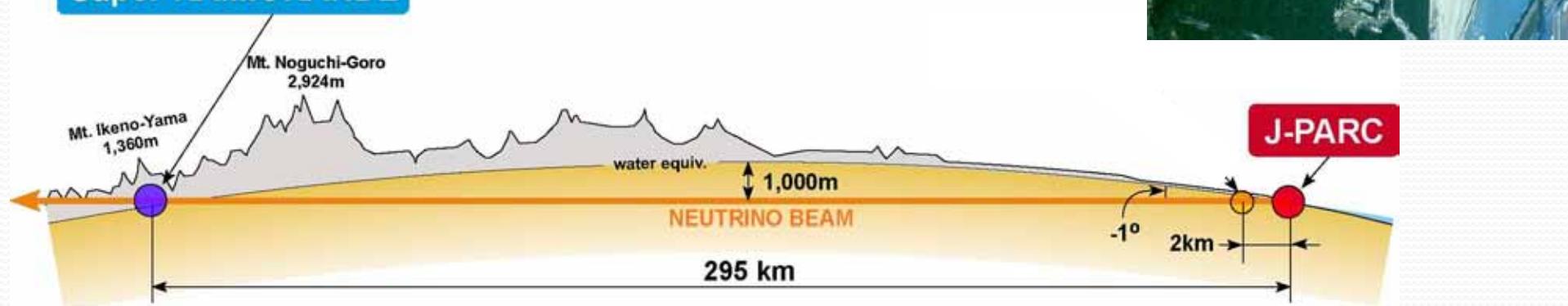
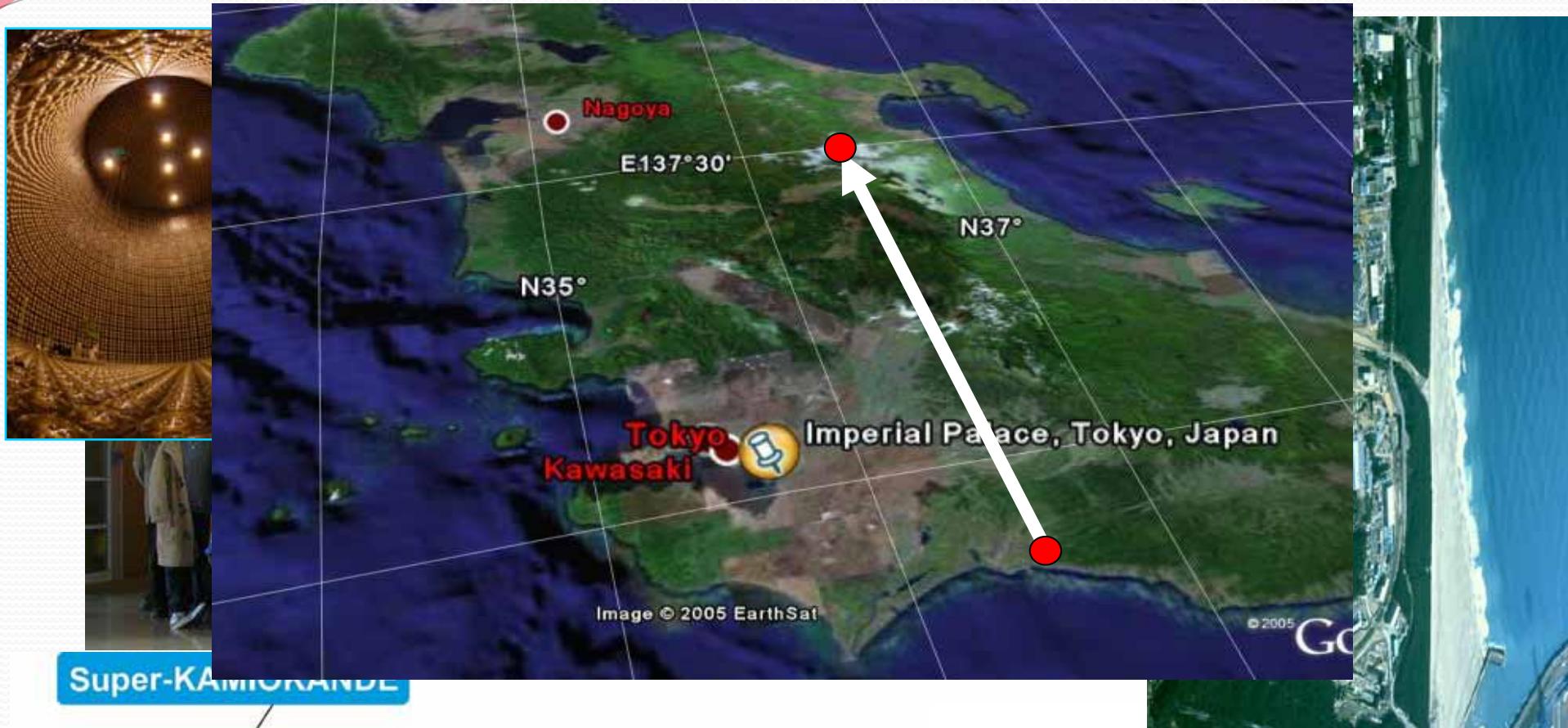
$|\mathbf{m}_2 - \mathbf{m}_1| \ll |\mathbf{m}_3 - \mathbf{m}_2|$

- Atmospheric Neutrinos Oscillation
- Solar Neutrino Oscillations

Status of Neutrino Experiments

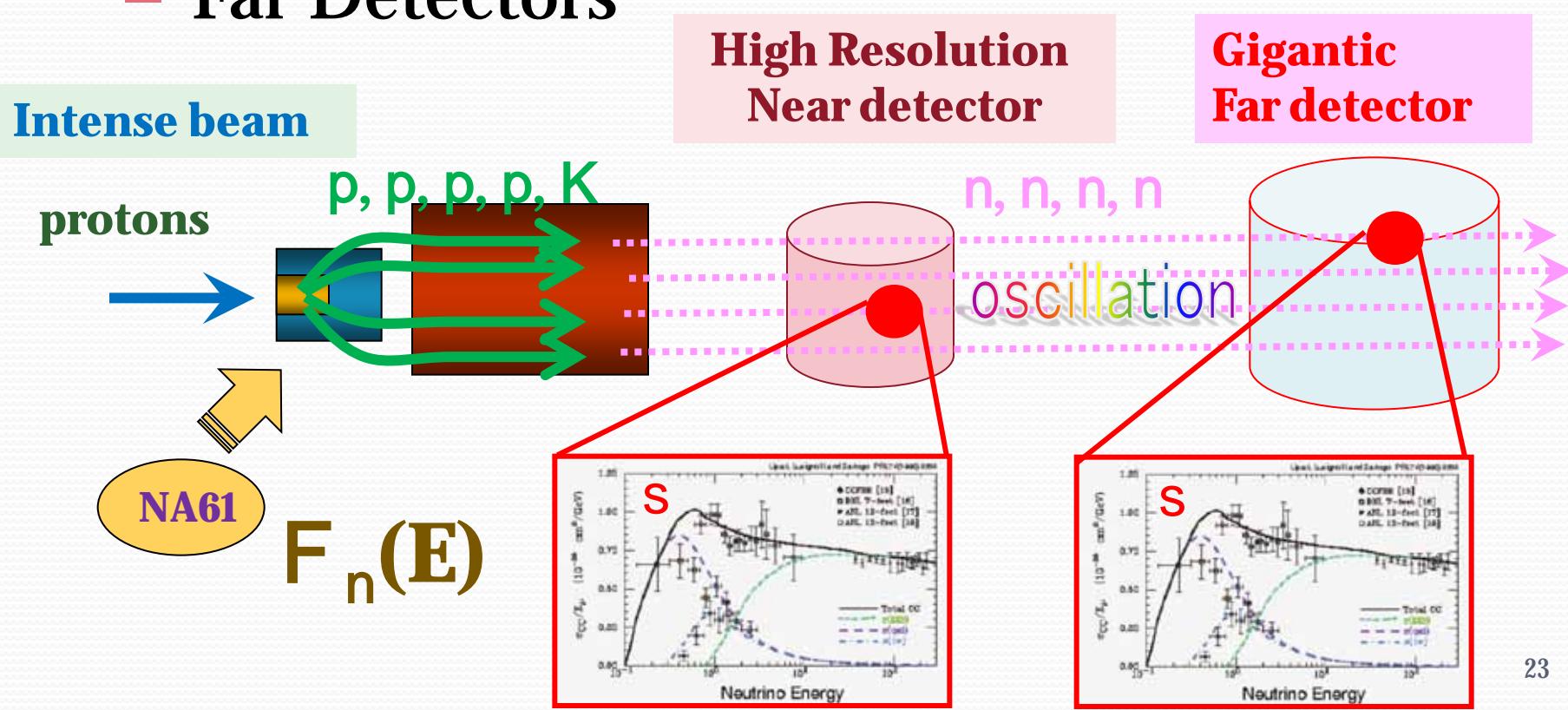
- Study of atmospheric neutrino oscillations with accelerator neutrinos.
 - Confirmation: K2K (Japan)、MINOS (US)、OPERA (Europe)
 - Δm_{23}^2 、 q_{23}
 - High Sensitive and High Precision experiments: **T2K**
 - Δm_{23}^2 、 q_{23} 、 q_{13} ⇒ CP study in future
- Study of solar neutrino oscillations with the reactor experiments
 - Confirmation and precision measurements: KamLAND
 - Δm_{12}^2 、 q_{12}
 - Observation of geo-neutrinos
 - New double beta decay measurements

T2K(Tokai-to[2]-Kamioka)

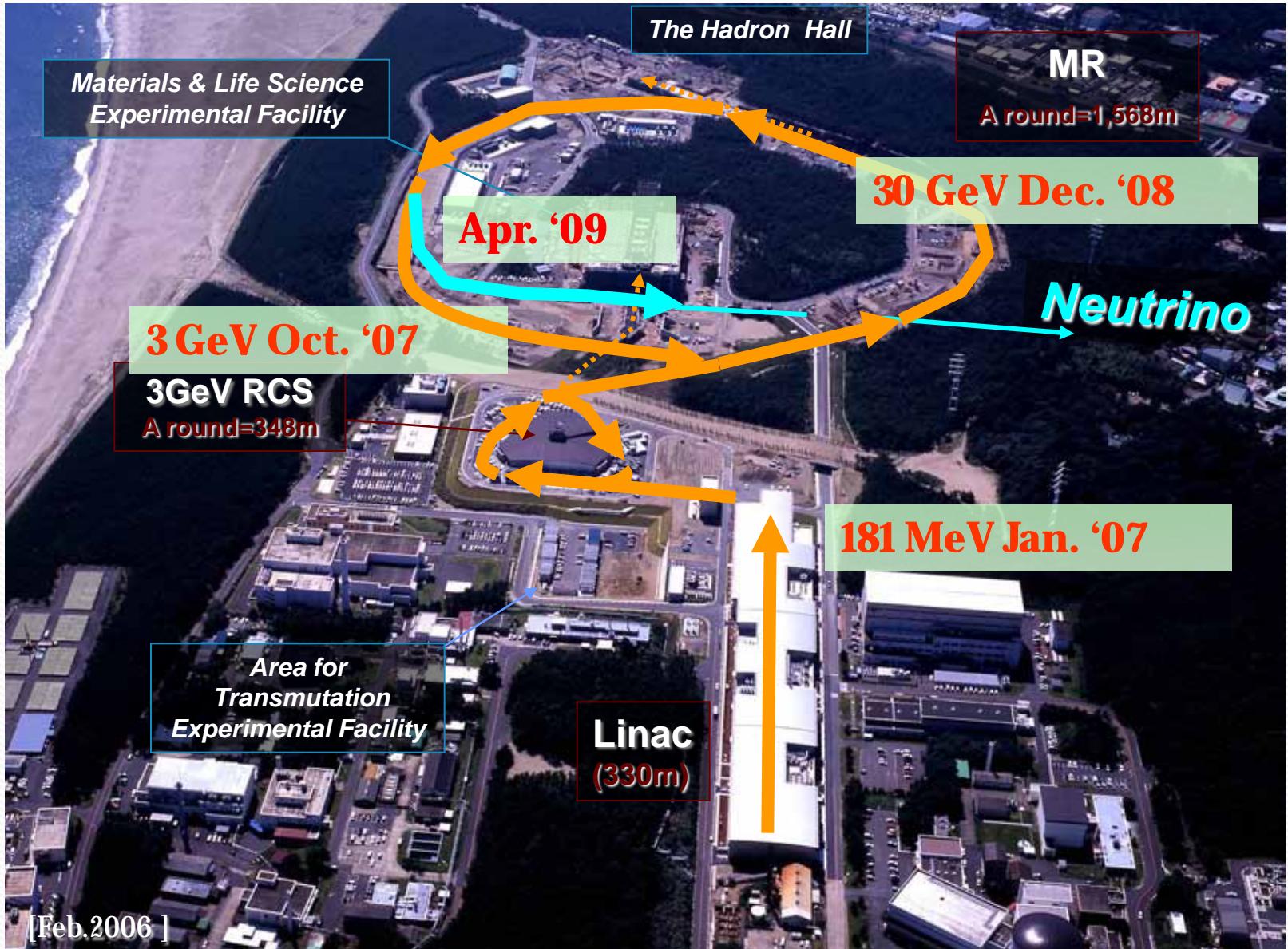


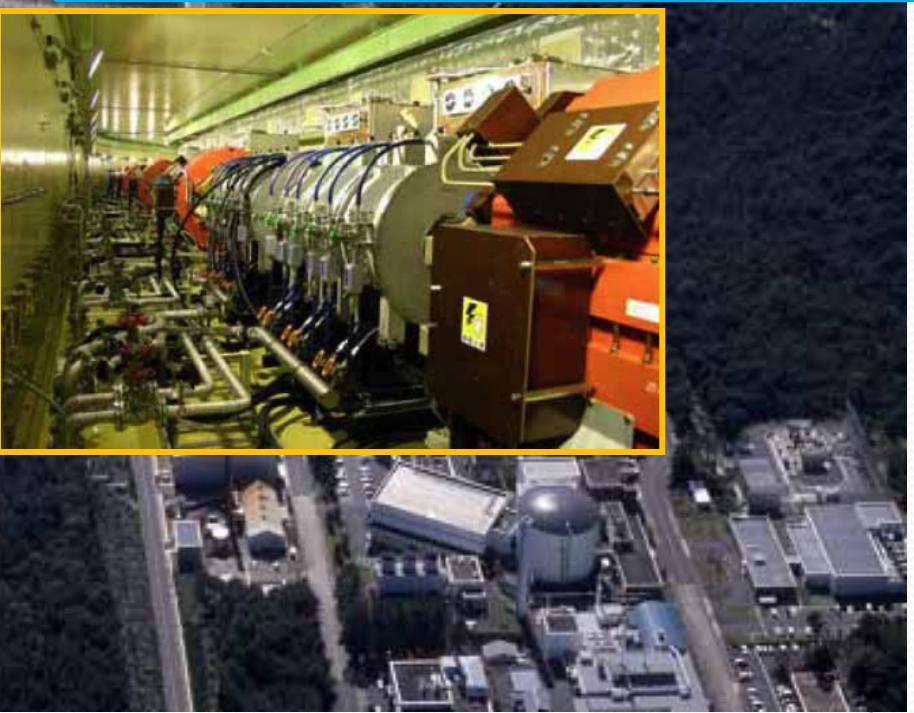
2. Components of the experiments.

- Accelerator/Neutrino Beams
- Near Detectors
- Far Detectors



J-PARC Accelerators





J-PARC Accelerator status

Run-26 (early October) for 2 weeks

- ❑ Linac beam: Peak current 5mA, pulse width 100~500ms
- ❑ RCS beam: 2 bunch, 20kW
- ❑ Purpose: Beam loss study at the downstream of charge stripping foil using extinction monitor (for μe conversion experiment)

Run-27 (end of October~early November) for 9 days

- ❑ Linac beam: 5mA and 500ms, or 15mA and 100ms
- ❑ RCS beam: 2 bunch, 100kW
- ❑ Purpose: Beam loss study

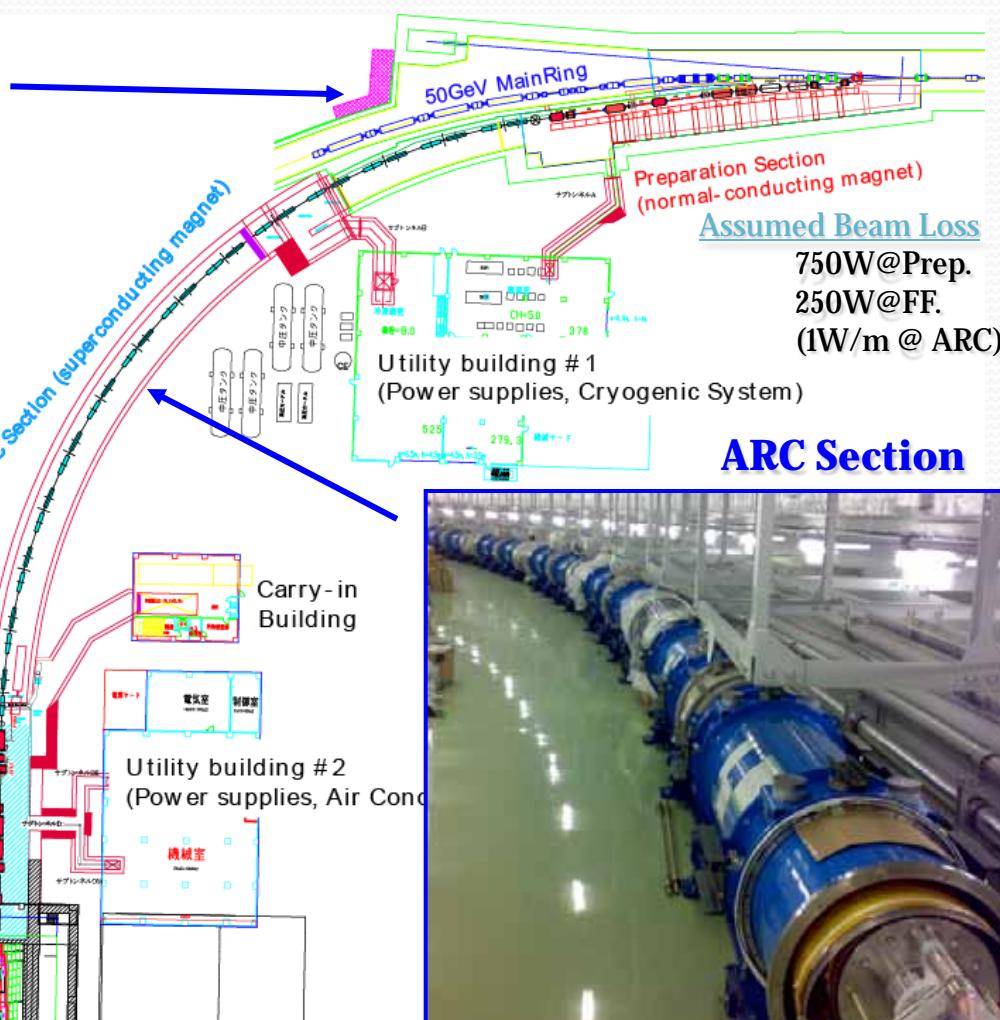
Run-28 (end of November) for 1 week

- ❑ Linac beam: 15mA and 500ms
- ❑ RCS beam: 2 bunch, RCS 300kW → MR100kW
- ❑ Purpose: Challenge to high power operation and beam loss study

Primary Beam-line for neutrinos



Preparation Section



ARC Section



Final Focusing Section

- Beam-line tunnel was completed in December 2006
- Installation finished in 2009

Proton beam monitors

Position: 20 x ESMs

Profile: 19 x SSEM s

Intensity: 5x CTs

- **Being assembled**
- **Installation started in prep sect**

ESM



CT



Loss: 50 x Ionization chambers

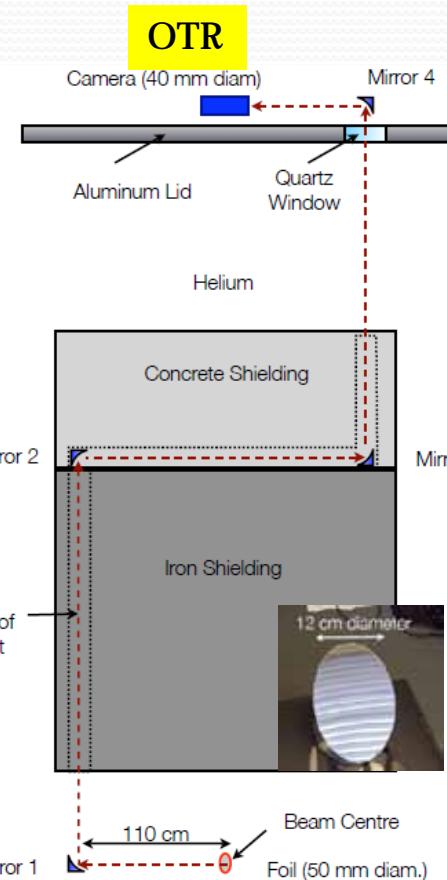
- **Twenty monitors are purchased in this FY**

SSEM



OTR detector (provided by Canada)

- **Provide all-time profile just in front of target**
- **Mirrors, rad-hard camera delivered**
- **Manufacturing, assembling in progress**



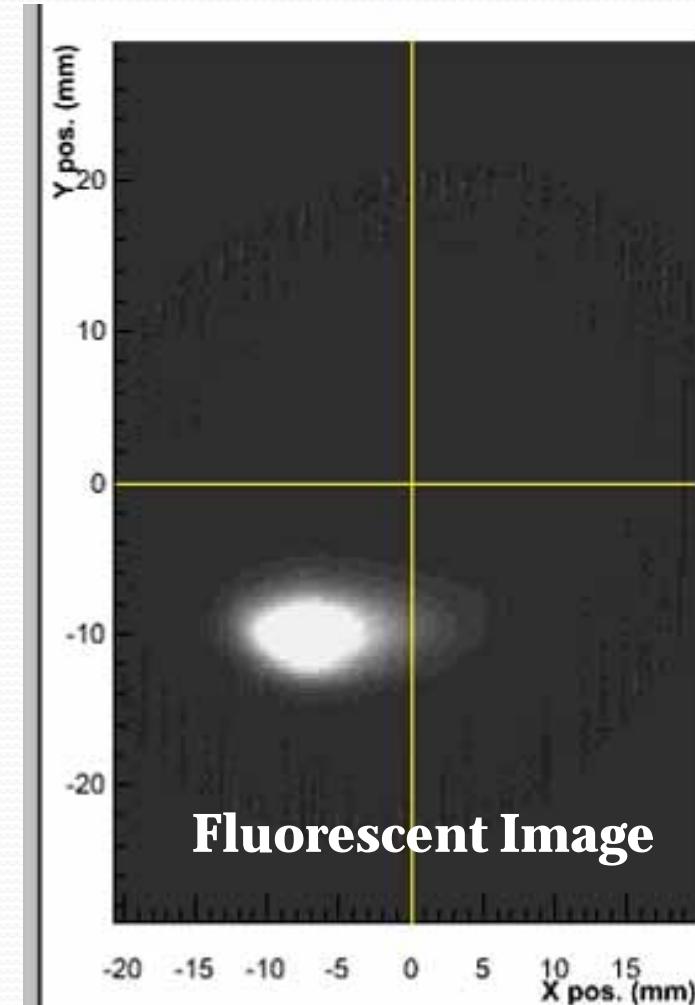
Installed monitor chamber



First shot of the proton beam

SSEM

(Segmented Secondary Emission Monitor)

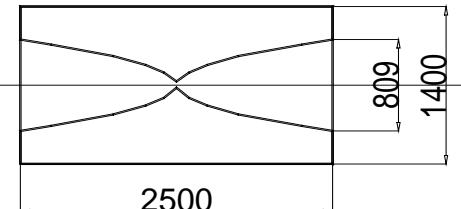
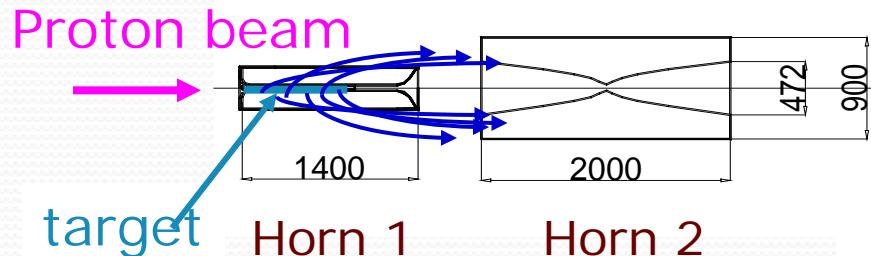


Neutrino Beam generation



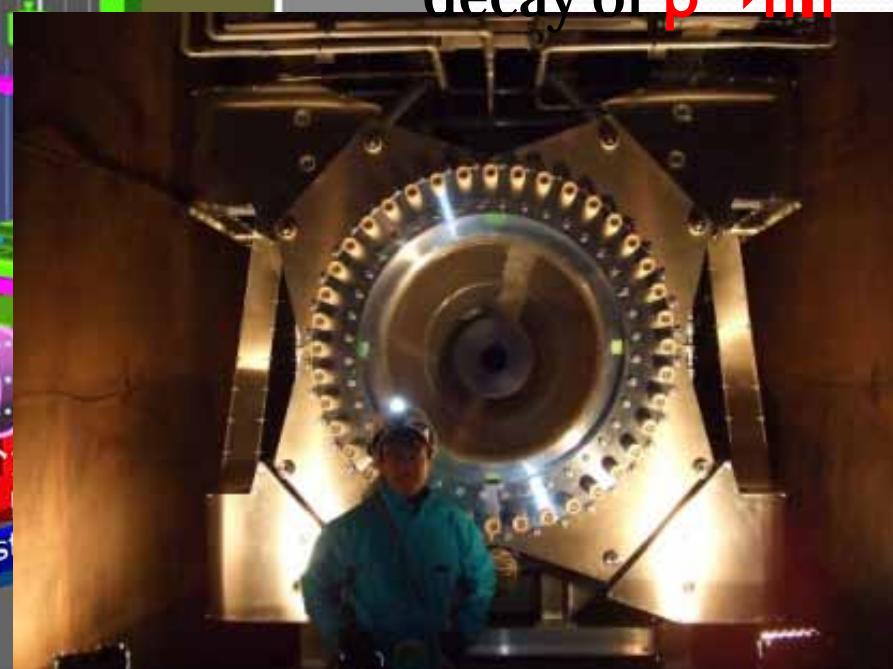
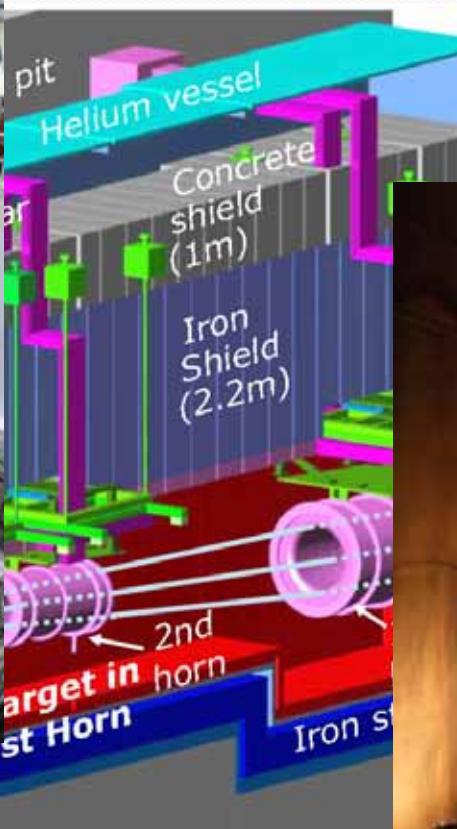
Ichikawa-san

Focusing many p^+



Horn 3

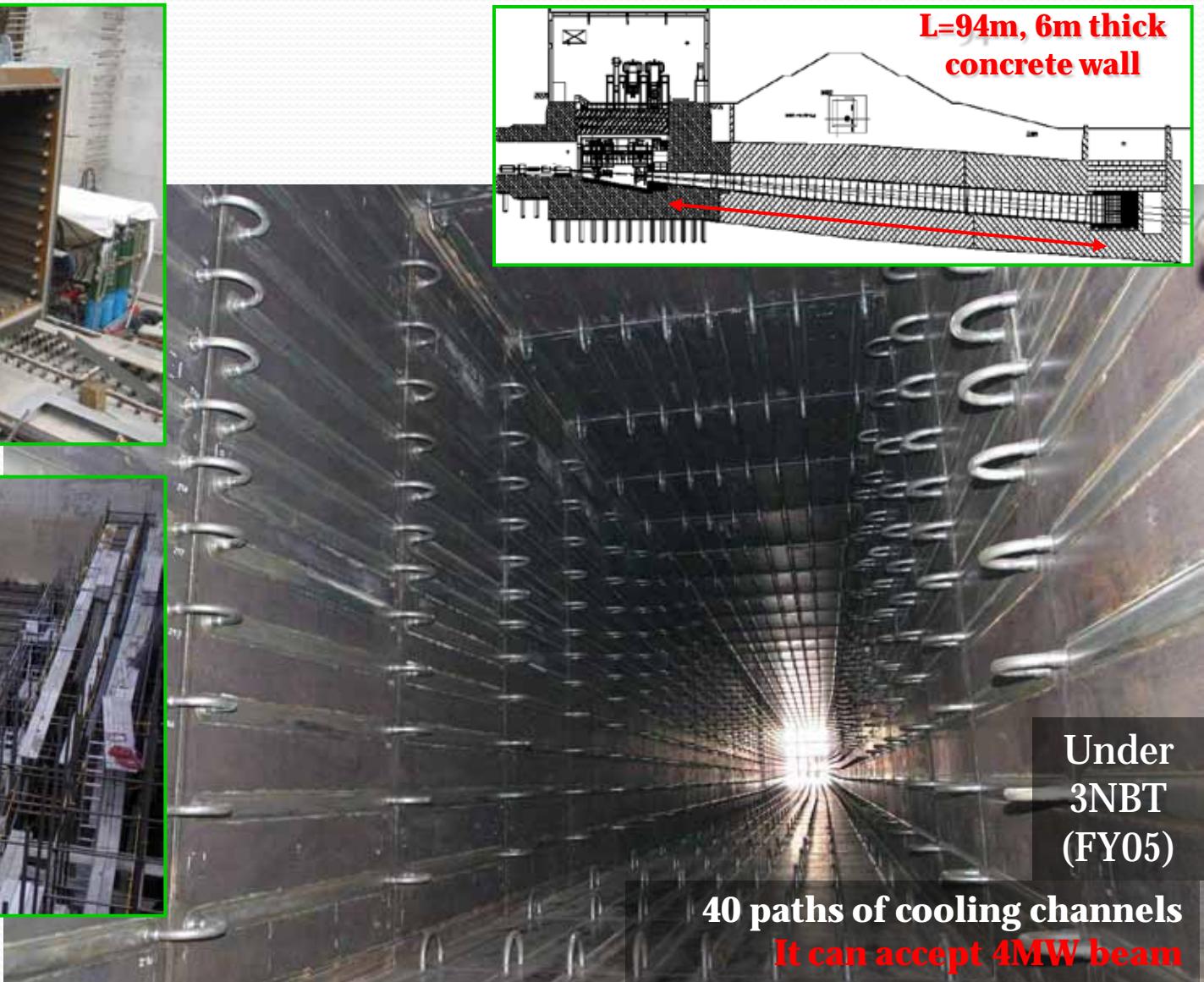
The neutrino beam
is produced from the
decay of $p \rightarrow m$



Decay Volume



2008/03/07



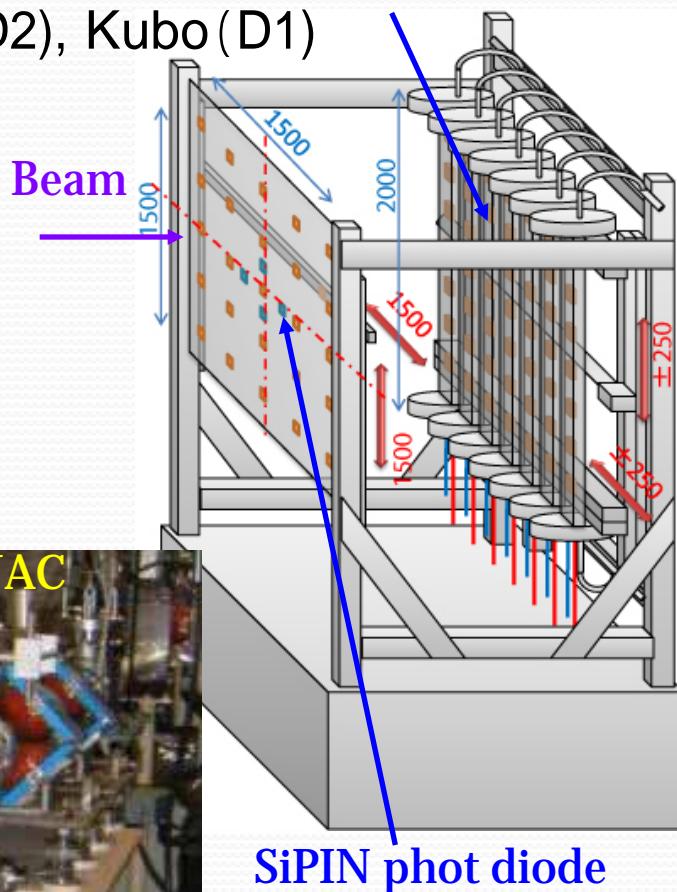
Muon monitor for the n beam

– $p \rightarrow m$ decay and μ measurement

Building by:

Matsuoka (D2), Kubo (D1)

Ion Chamber

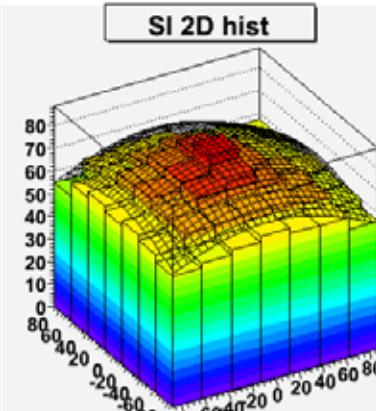
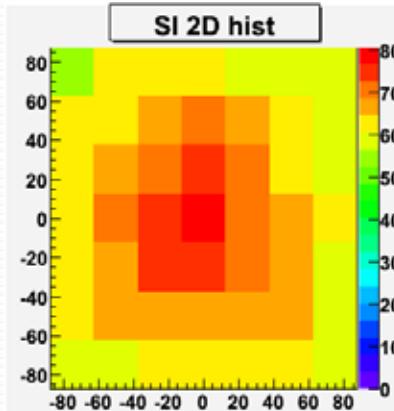


Feb. 14th, 2009



Horn focusing: Muon Monitor Signal

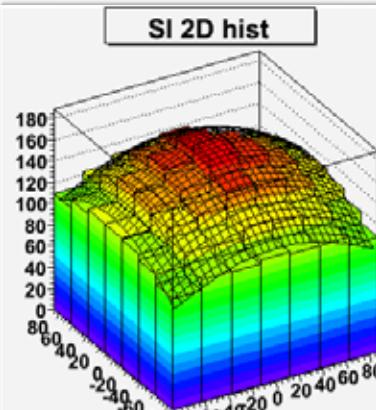
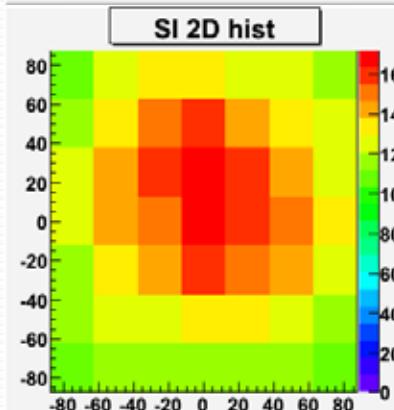
Horn off



SI Fit peak
73.2 pC

X CENTER Y CENTER
-4.84 cm **-2.54 cm**
X SIGMA Y SIGMA
135.5 cm **147.1 cm**

Horn on



SI Fit peak
159.3 pC

X CENTER Y CENTER
+3.60 cm **+8.35 cm**
X SIGMA Y SIGMA
118.1 cm **113.7 cm**

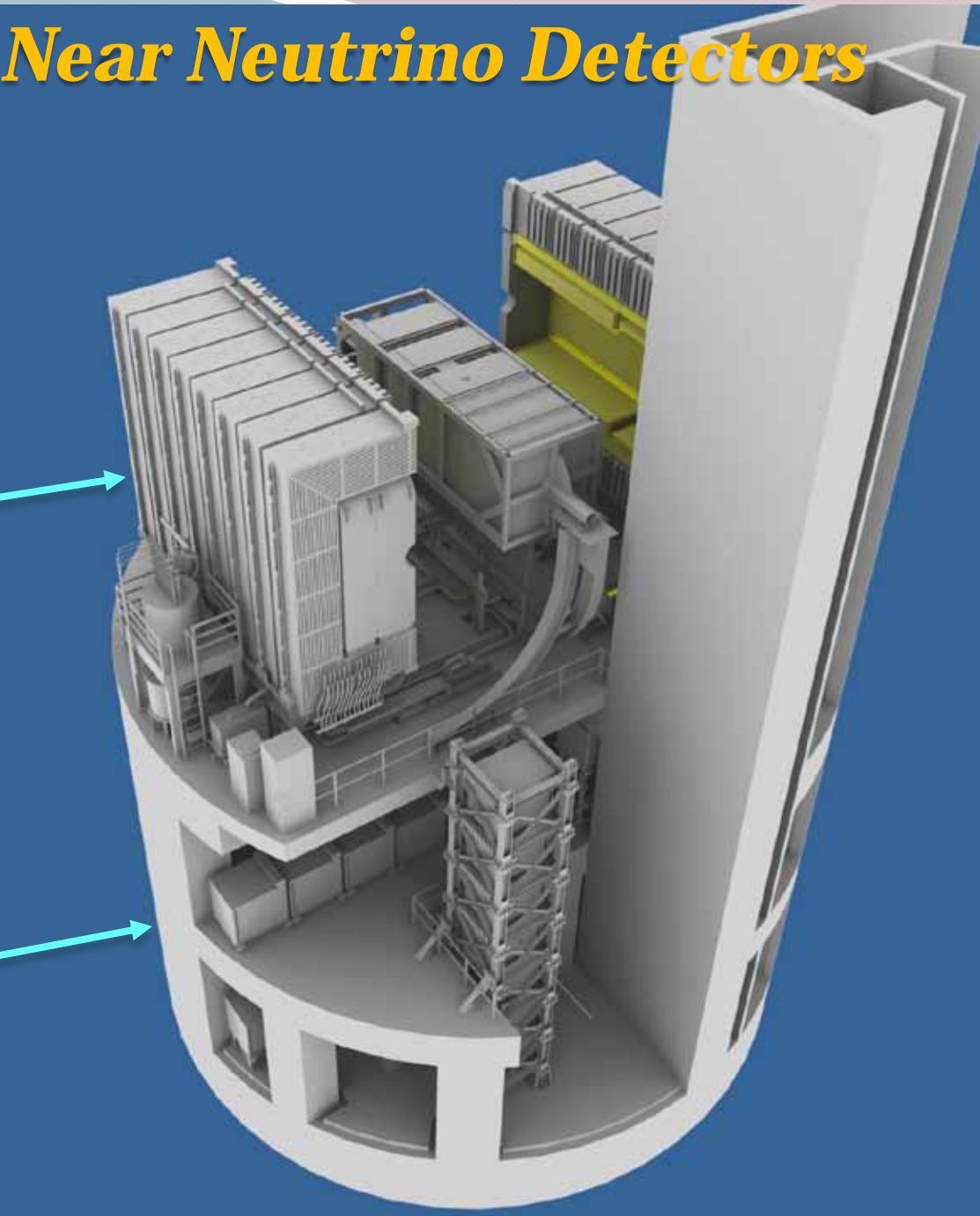
MUMON Silicon PIN photodiode array

Near Neutrino Detectors

Off-Axis



INGRID



Installation to NM pit

7/6 ~ 7/16 for horizontal modules

8/2 ~ 8/11 for vertical modules

Horizontal modules

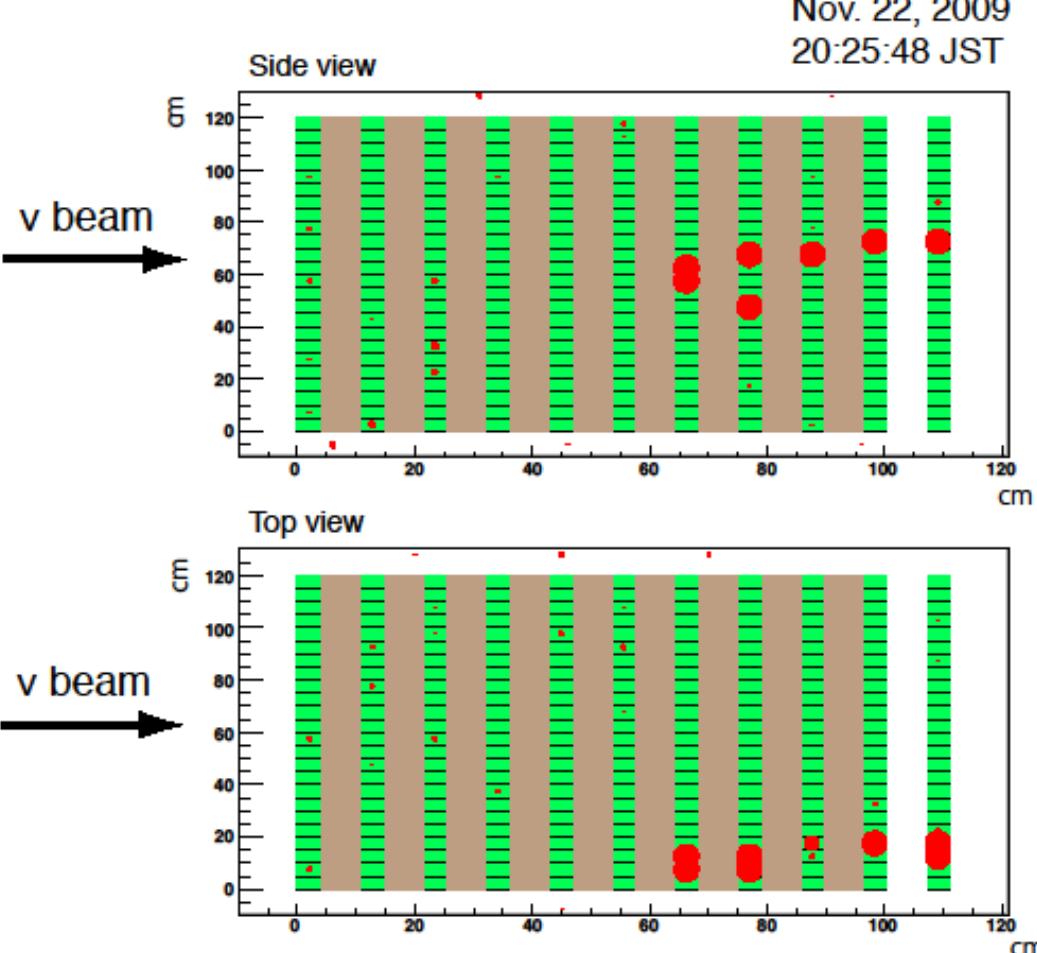


Vertical modules



All horizontal and vertical modules were Installed.

INGRID : First neutrino event candidate

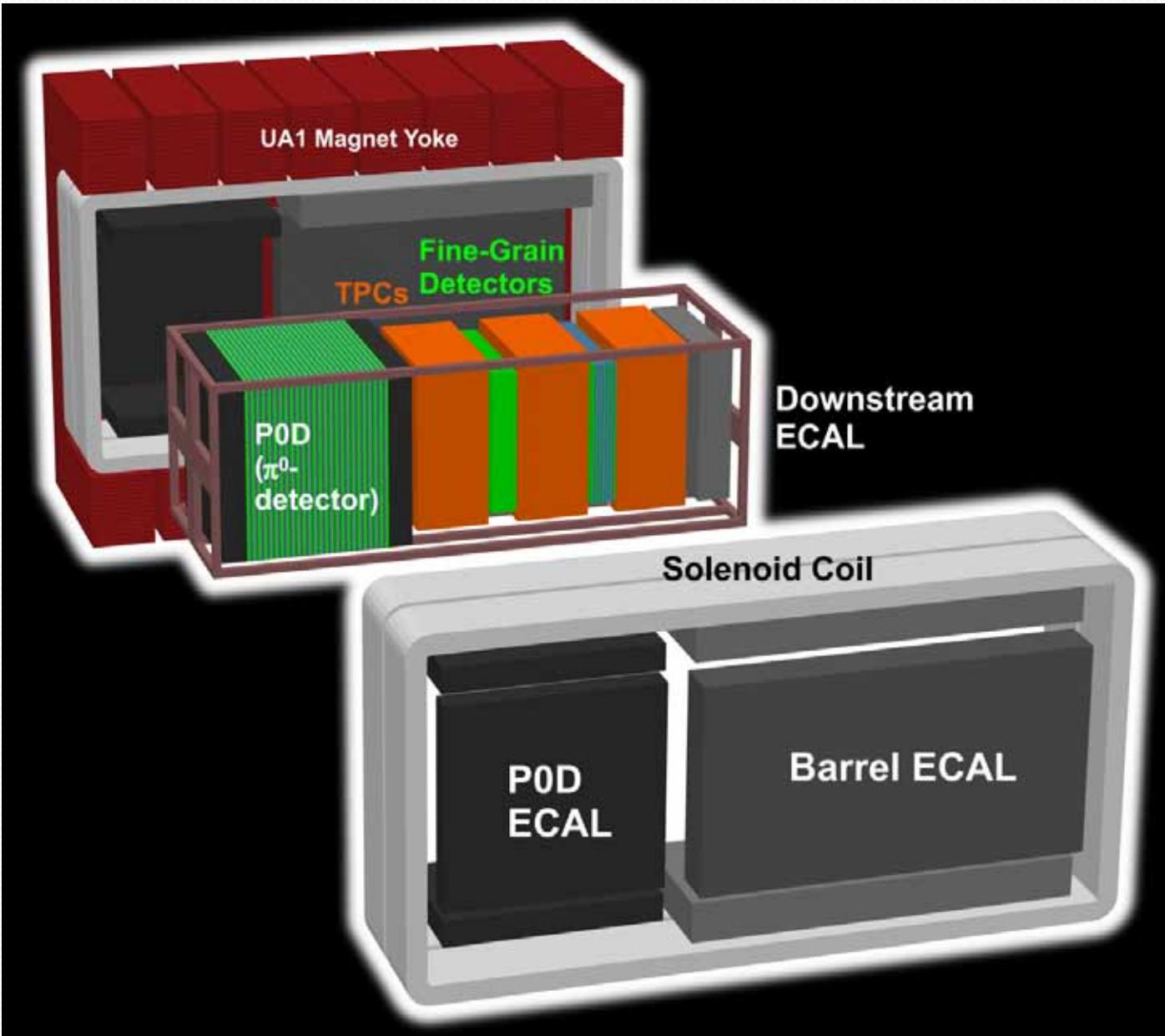


INGRID Mod. 07

MR Run #27
Shot #19655
T2K Spill #241792

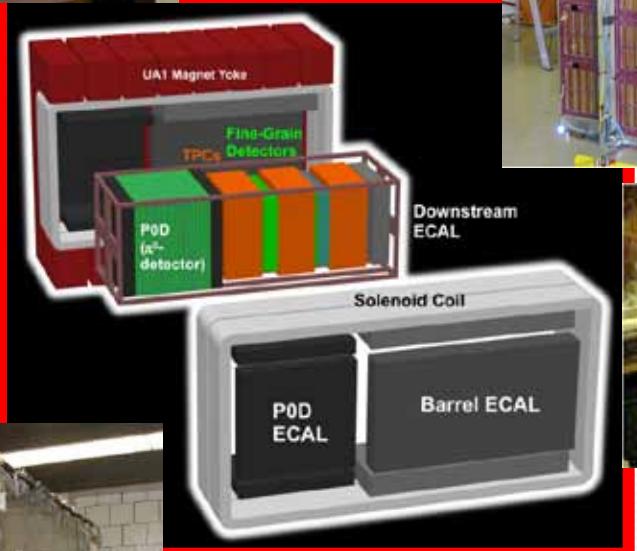
- Iron (6.5cm thick)
- Plastic scintillator (5cm wide, 1cm thick)
- Hit in plastic scintillator

280m Off-Axis Sub-Detectors



Off-axis Detectors

FGD(Canada, Japan)



TPC(Canada/France,
Spain, Swiss, Italy,
German)



Elec(UK,Fr)



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



POD(US)

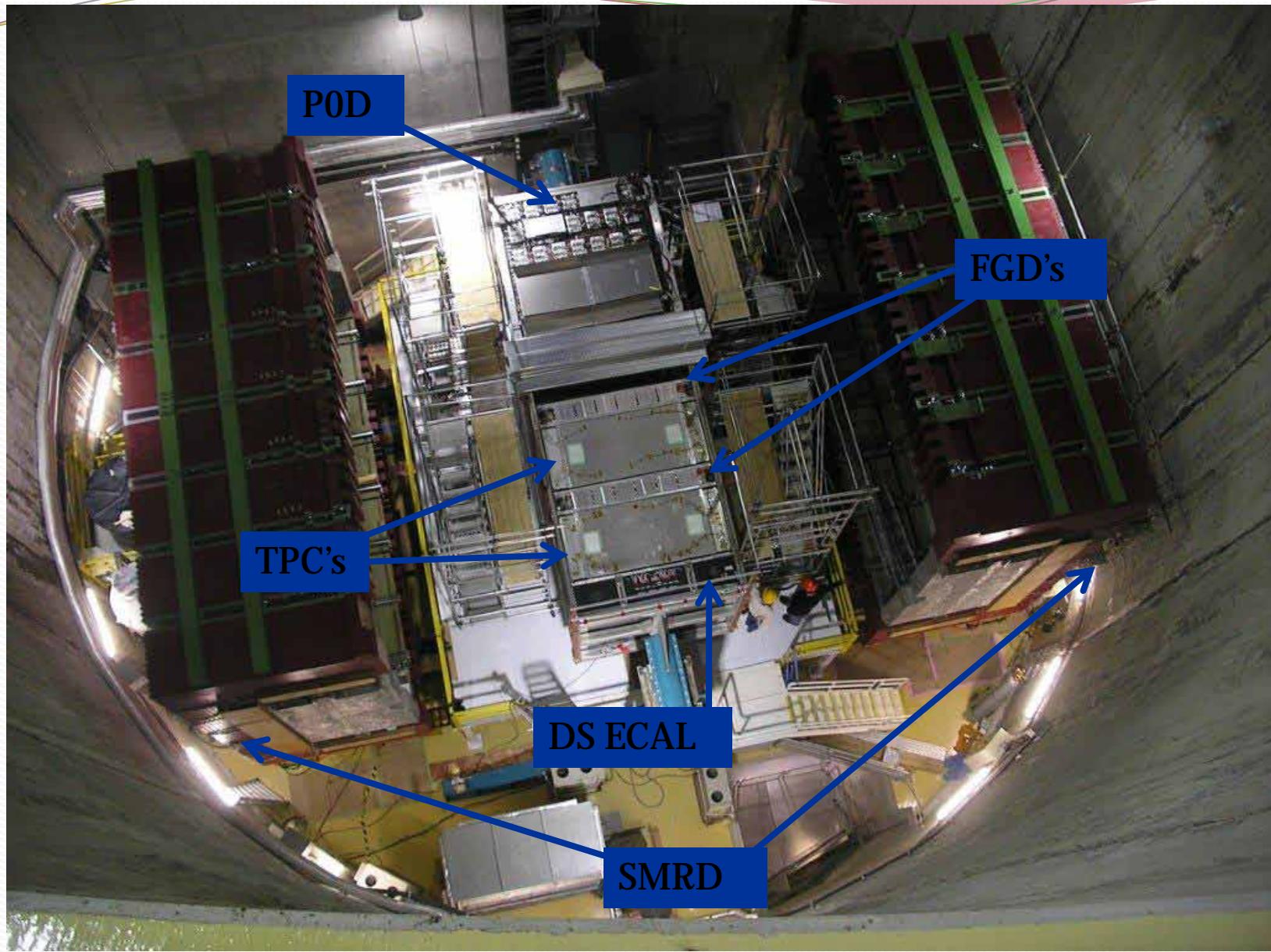


ECAL(UK)



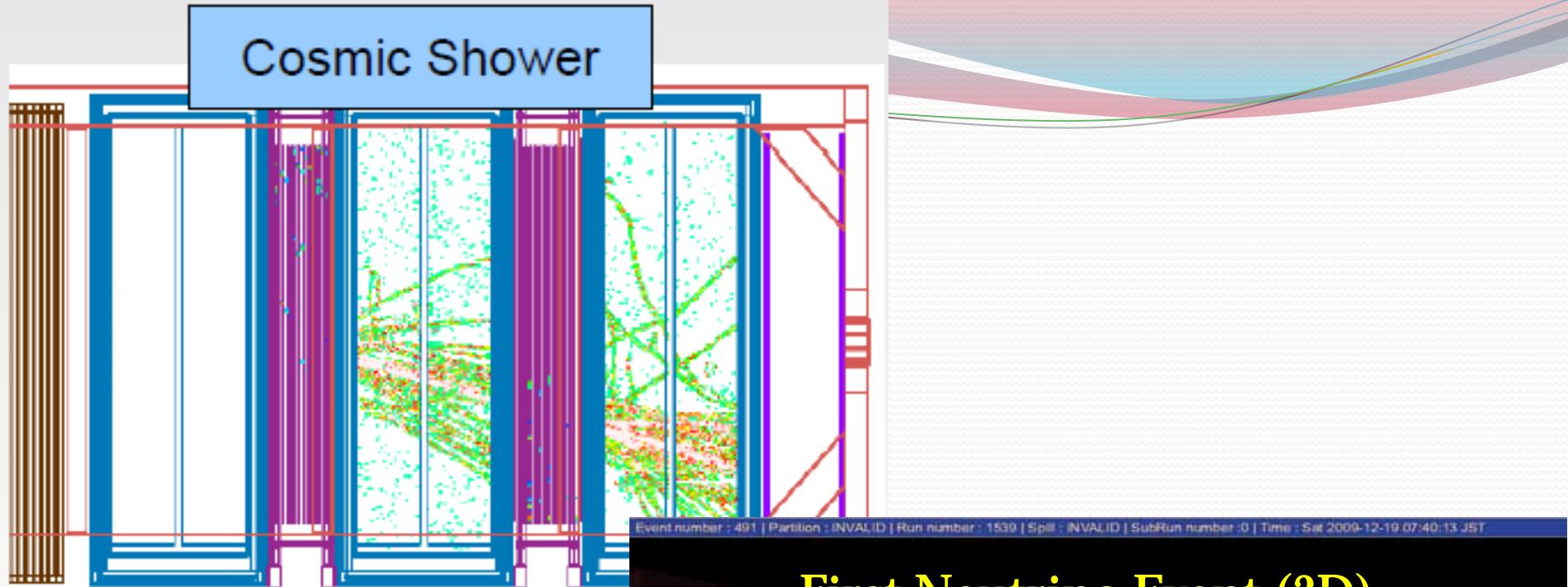
SMRD(Jp,US,Pol,Rus)

- The detectors were build in many countries and installed in J-PARC in 2009.

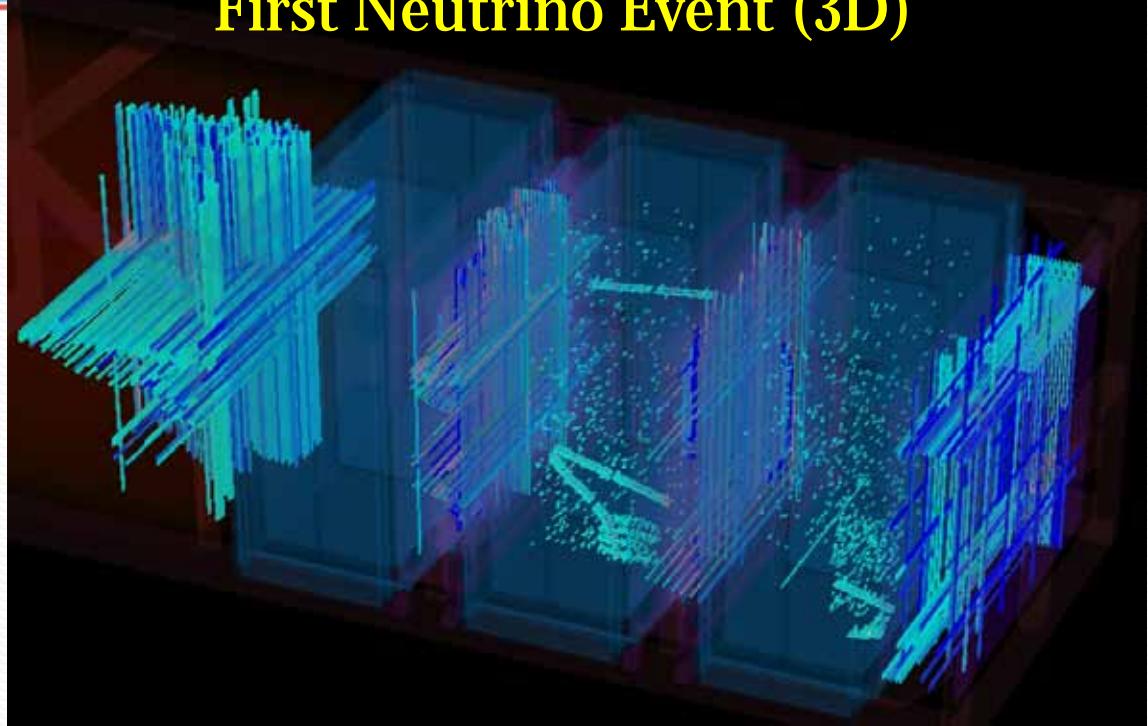




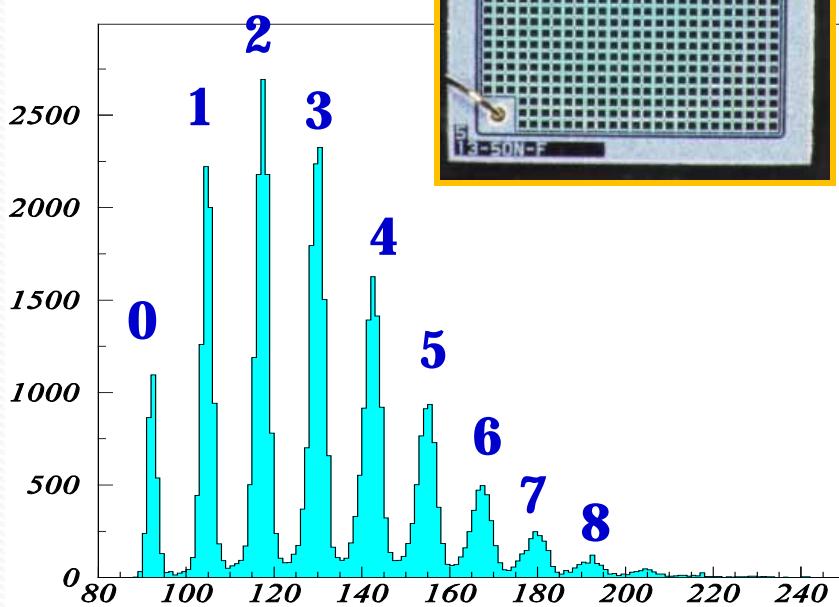
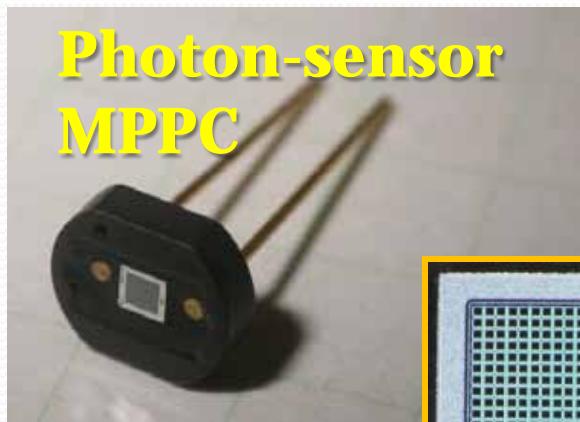
Cosmic Shower



First Neutrino Event (3D)



New developments of technology

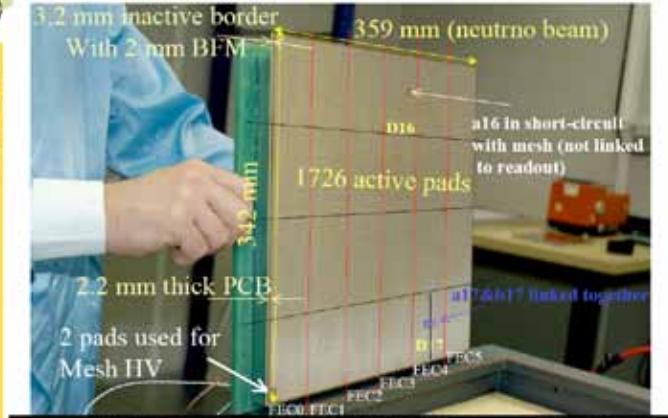


Large TPC and Micromegas



cees
sacly

MM1_001 (stiffener V2) (HARp tests 09/19/2007)

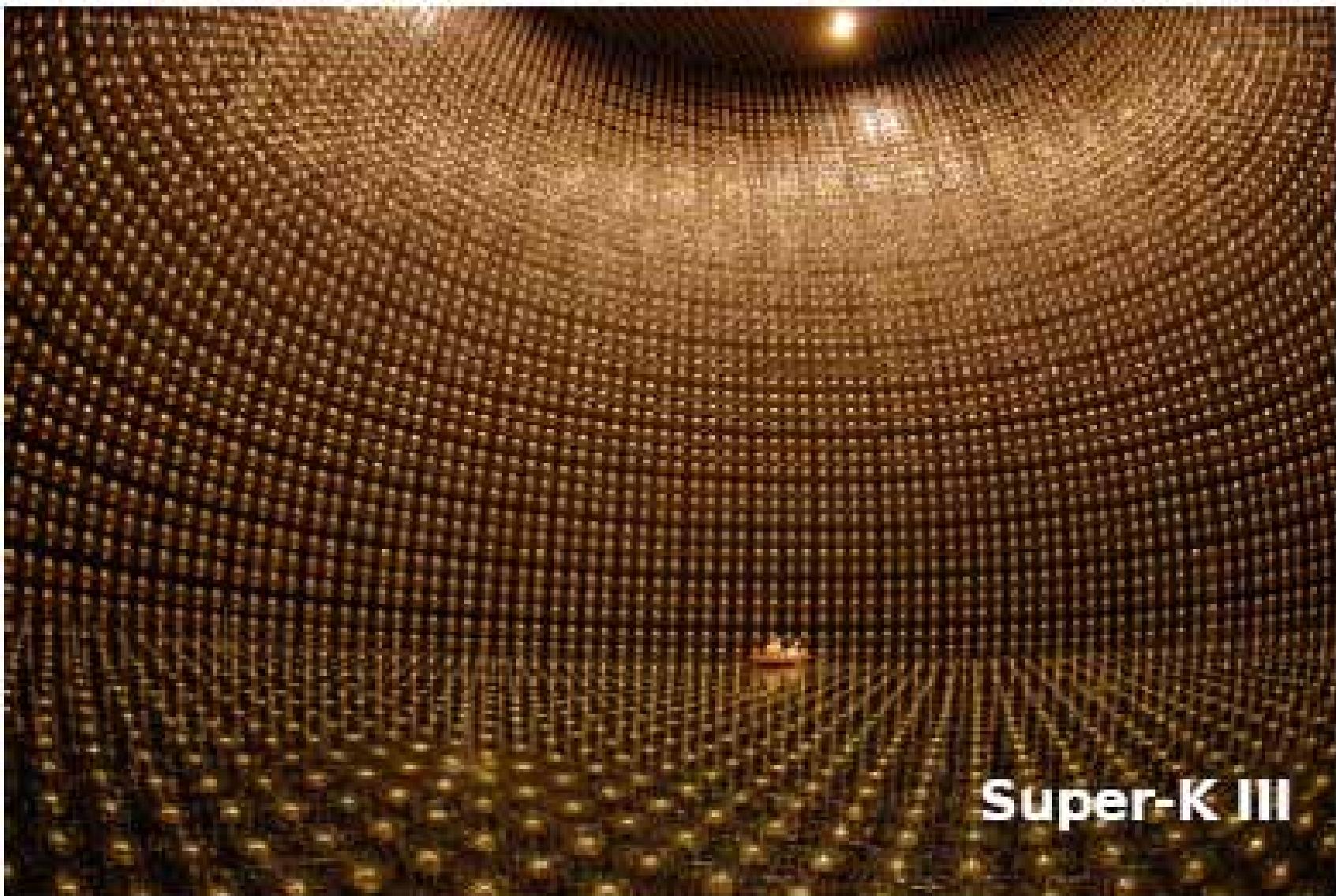


- a 30 µm thick 440 Lpi woven micromesh is embedded between 2 layers of pyralux
- 4 layers PCB with internal shielding layer & 6,9x9,7 mm pads with 7x9,8 mm pitch
- 126 µm amp. gap / 12 x ϕ 0,5 mm pillars per pad / « stretched » mesh procedure
- 93% of PCB surface is active area / less than 2 faulty pads per module



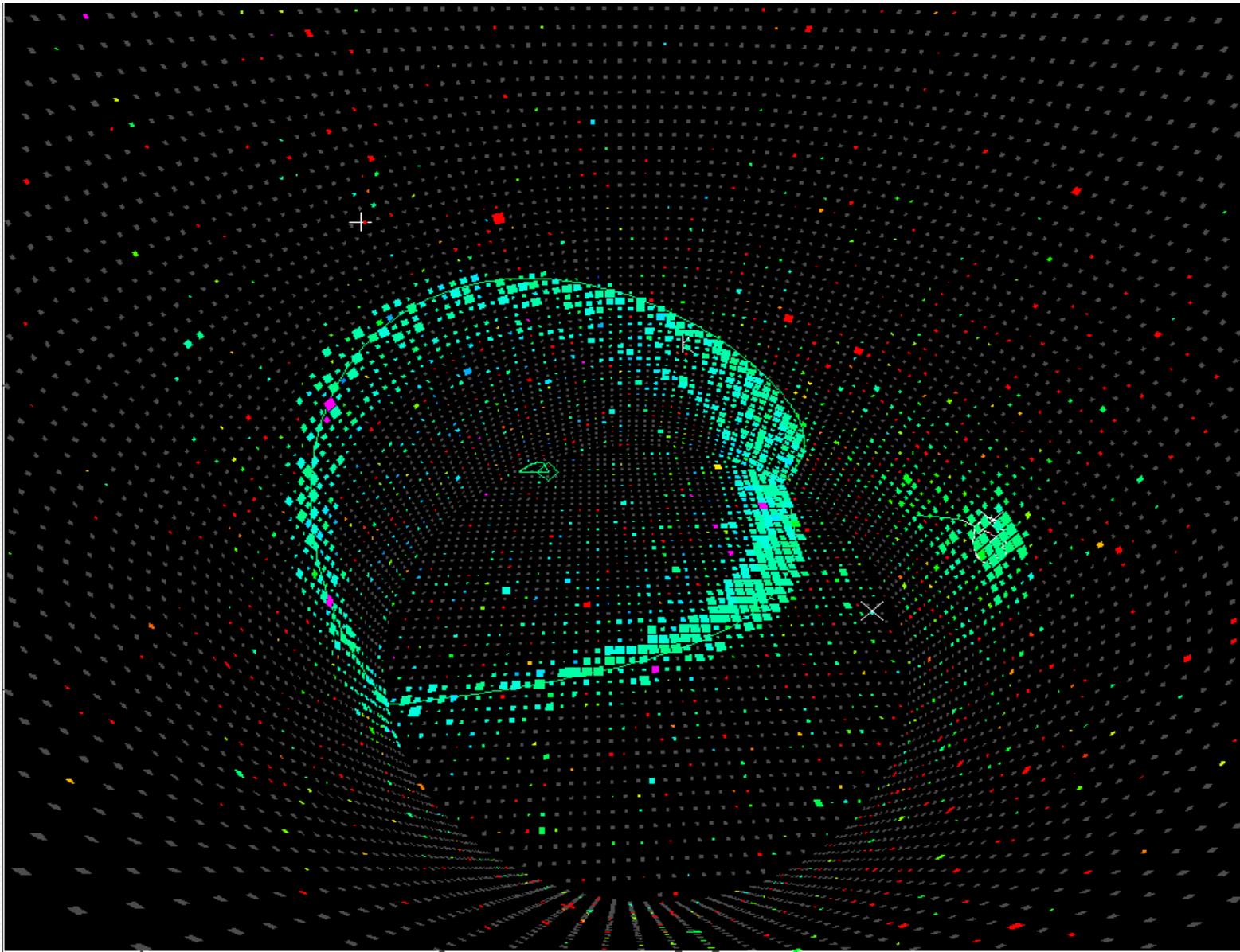
Total 120k channels

Super-Kamiokande IV



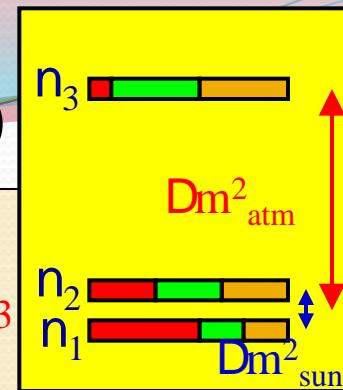
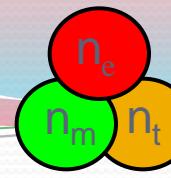
Super-K III

Neutrino Events (K2K)



- Start the experiment in April 2009.
- In 2009, beam-line & detector commissioning were performed.
- **100kW trial (so far 20kW is OK, but a trouble in 40kW)**
- Start the physics run in March 2010.
 - à fist result in summer 2010
- Beyond 100kW: 100 à 750kW(Design)
 - Beam loss control
 - Linac 400 MeV energy recovery and upgrade of the RCS injection system
 - **Important Physics result around 2012 (my personal view)**
- Long-term plan toward power frontier (~1.7 MW)
 - KEK roadmap
 - Anti- η running

T2K Measurements



Oscillation Probabilities when $Dm_{12}^2 \ll Dm_{23}^2 \gg Dm_{13}^2$

$\emptyset q_{23}$: n_m disappearance

$$P_{n_m \otimes n_x} \gg 1 - \frac{\cos^4 q_{13}}{\sim 1} \times \sin^2 2q_{23} \times \sin^2(1.27 Dm_{23}^2 L / E_n)$$

$\emptyset q_{13}$: n_e appearance

$$P_{n_m \otimes n_e} \gg \frac{\sin^2 q_{23}}{\sim 0.5} \times \sin^2 2q_{13} \times \sin^2(1.27 Dm_{23}^2 L / E_n)$$

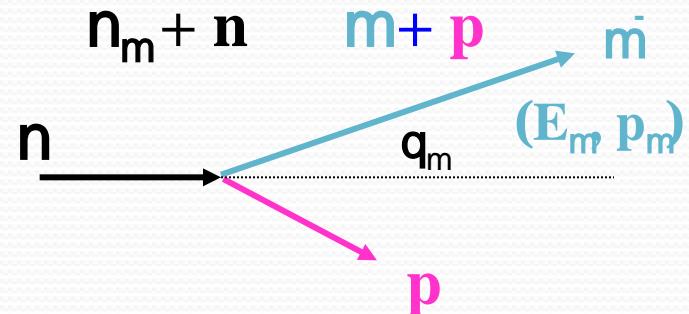
$\emptyset d$: CP violation (T2K-II)

$$A_{CP} = \frac{P(n_m \otimes n_e) - P(\bar{n}_m \otimes \bar{n}_e)}{P(n_m \otimes n_e) + P(\bar{n}_m \otimes \bar{n}_e)} @ \begin{array}{l} \sim 0.18 \text{ } (\sin^2 2q_{13} = 0.1) \\ \sim 0.58 \text{ } (\sin^2 2q_{13} = 0.01) \end{array}$$

$\times \sin d$

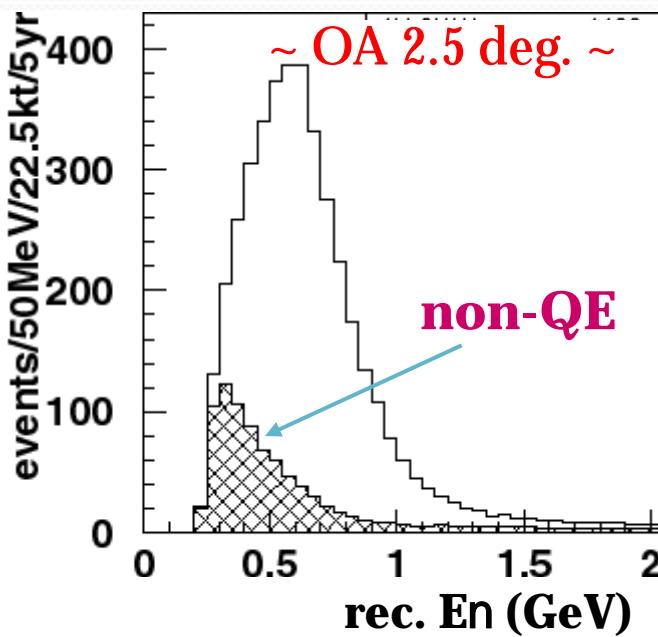
Measurement of q_{23} , Dm_{23}^2

Use 1 ring m -like events
 (= Quasi-Elastic enhanced sample) to
reconstruct neutrino energy.

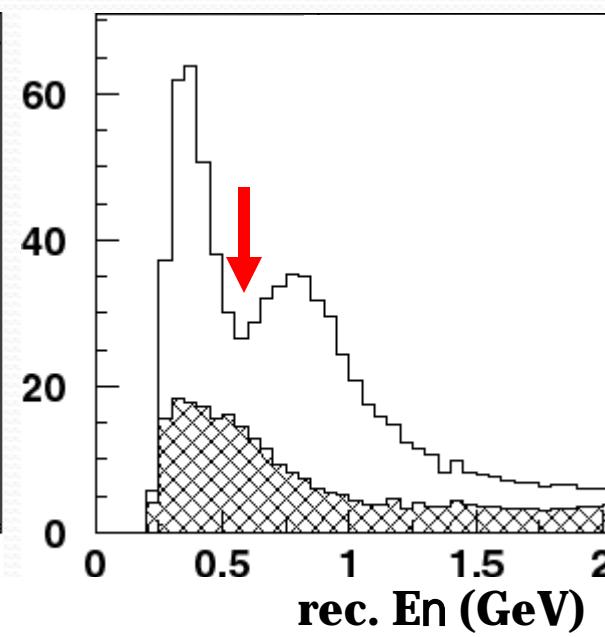


5 years

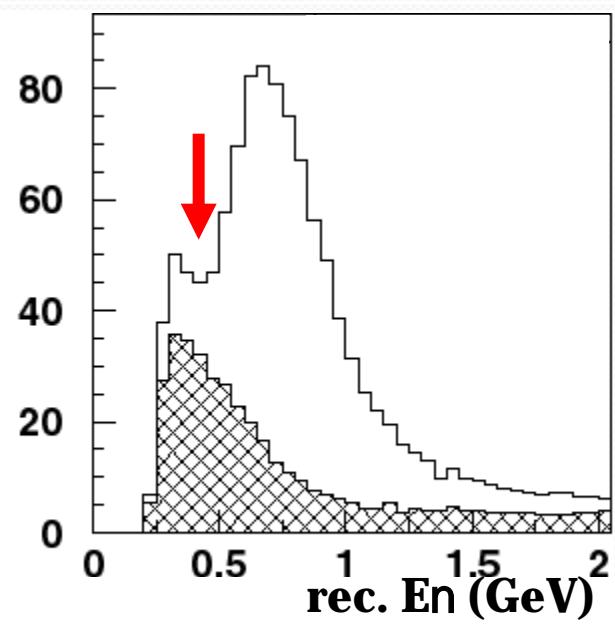
No oscillation



$Dm^2 = 2.5 \times 10^{-3} \text{ eV}^2$



$Dm^2 = 2.0 \times 10^{-3} \text{ eV}^2$



(assuming $\sin^2 2q_{23}=1.0$)

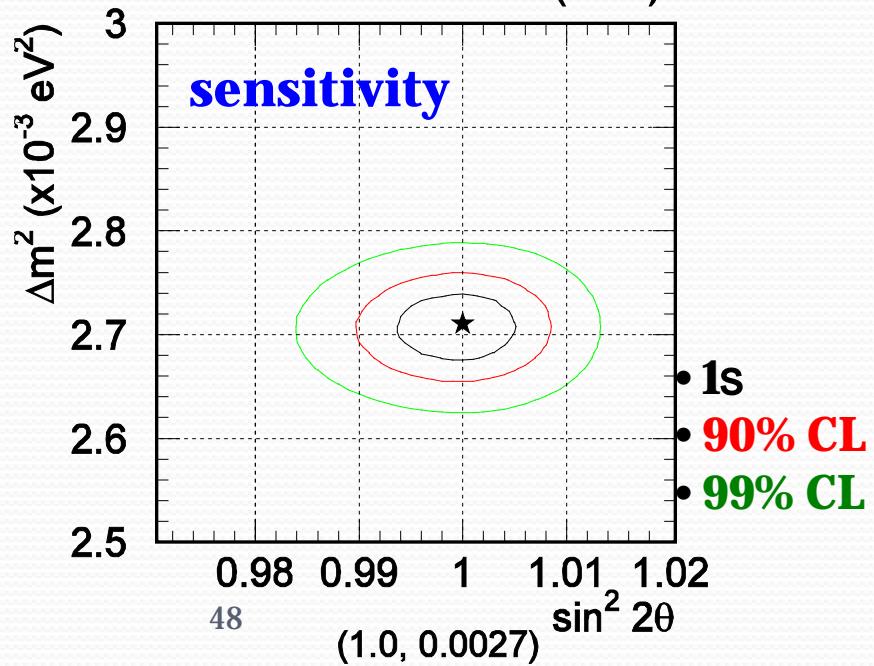
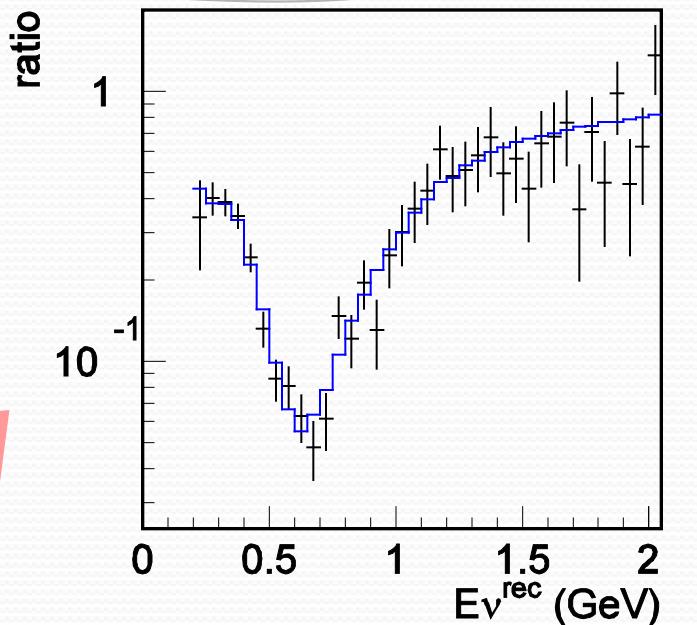
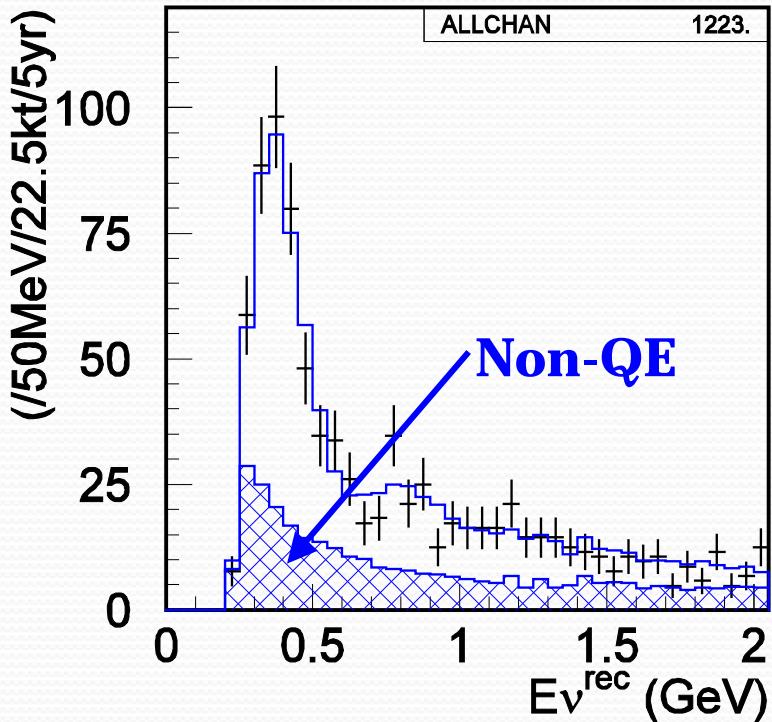
Ratio of E_η to non-oscillation

Oscillation parameter fit

Input:

$$\sin^2 2q_{23} = 1.00$$

$$Dm^2 = 2.7 \times 10^{-3} \text{ eV}^2$$



q_{13} measurement (n_e appearance search)

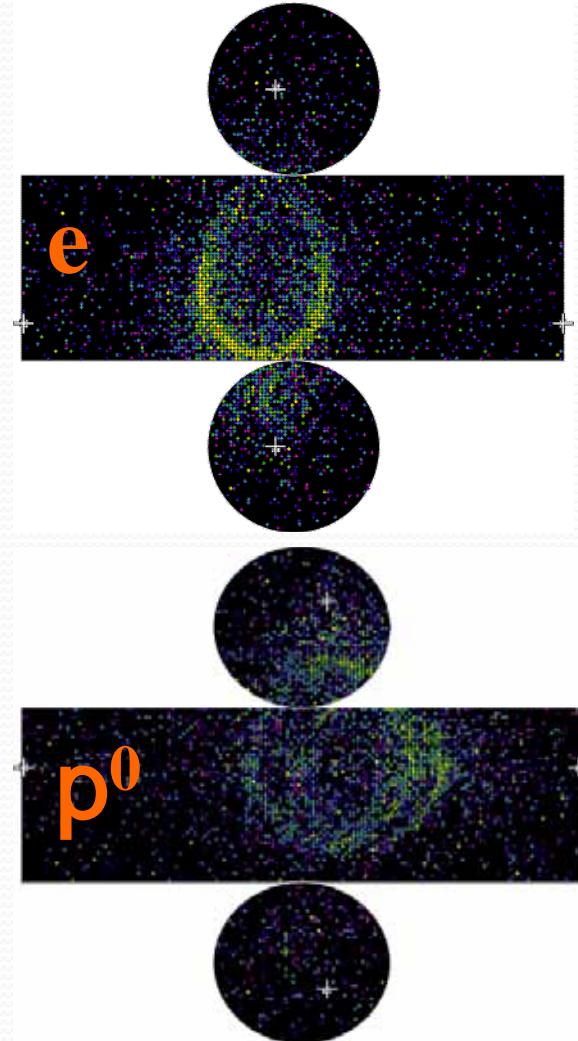
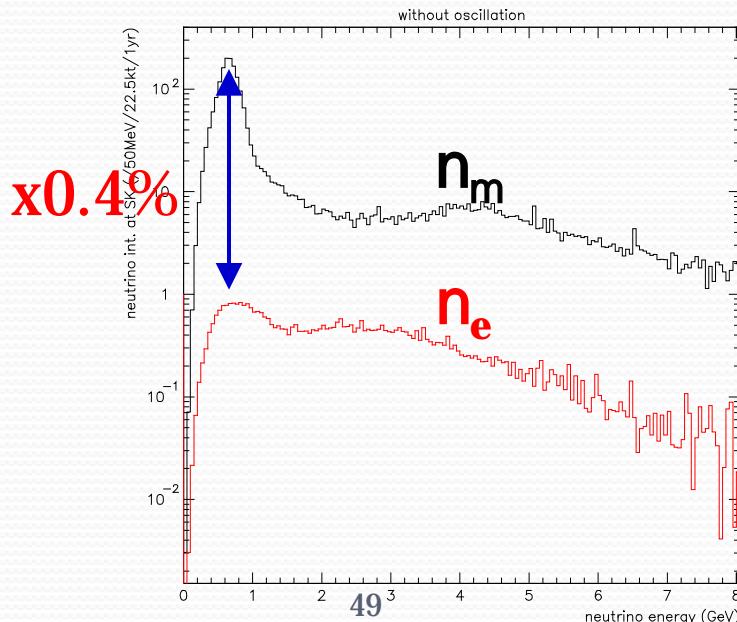
$\sin^2 2q_{23} = 1$ and $d=0$ are assumed.

Signal:

- 1ring e-like event (CC QE sample)

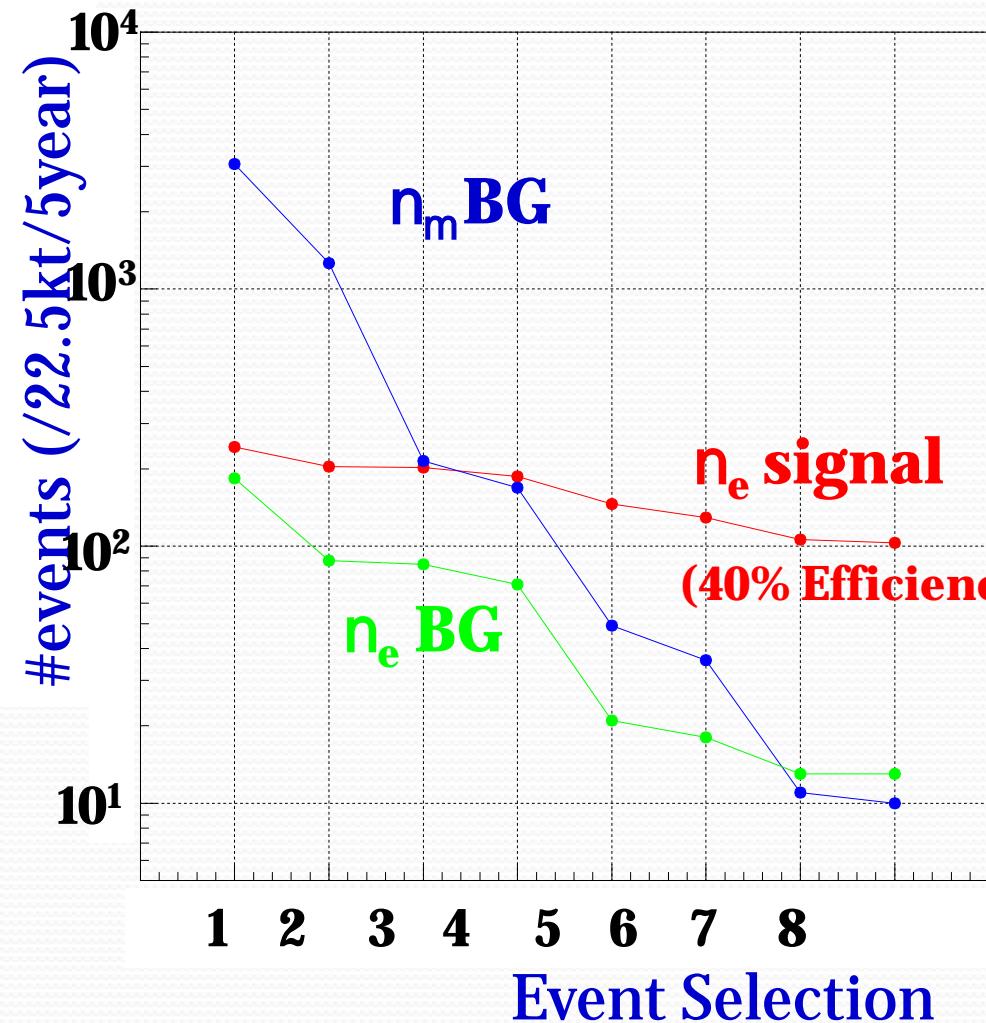
Background:

- beam n_e contamination (0.4% of n_m)
- mis-reconstructed p^0 event

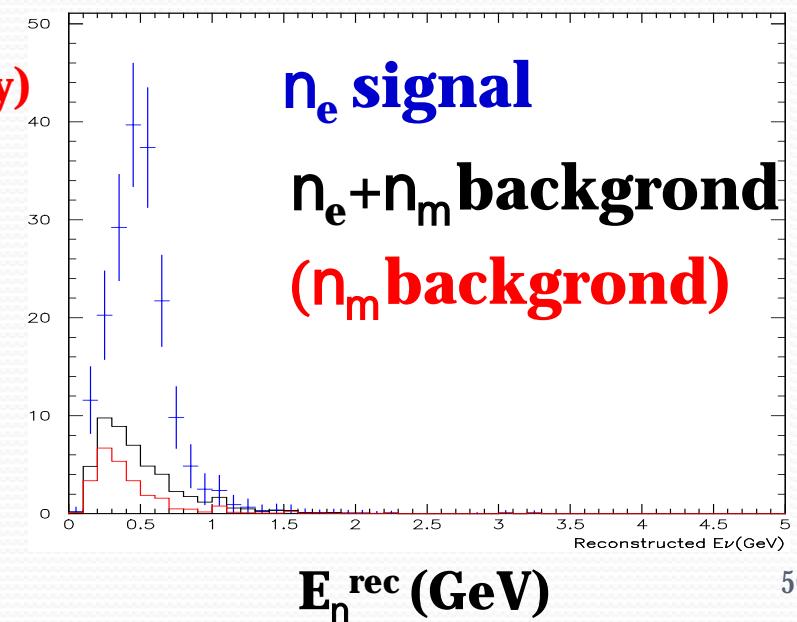


Background Suppression

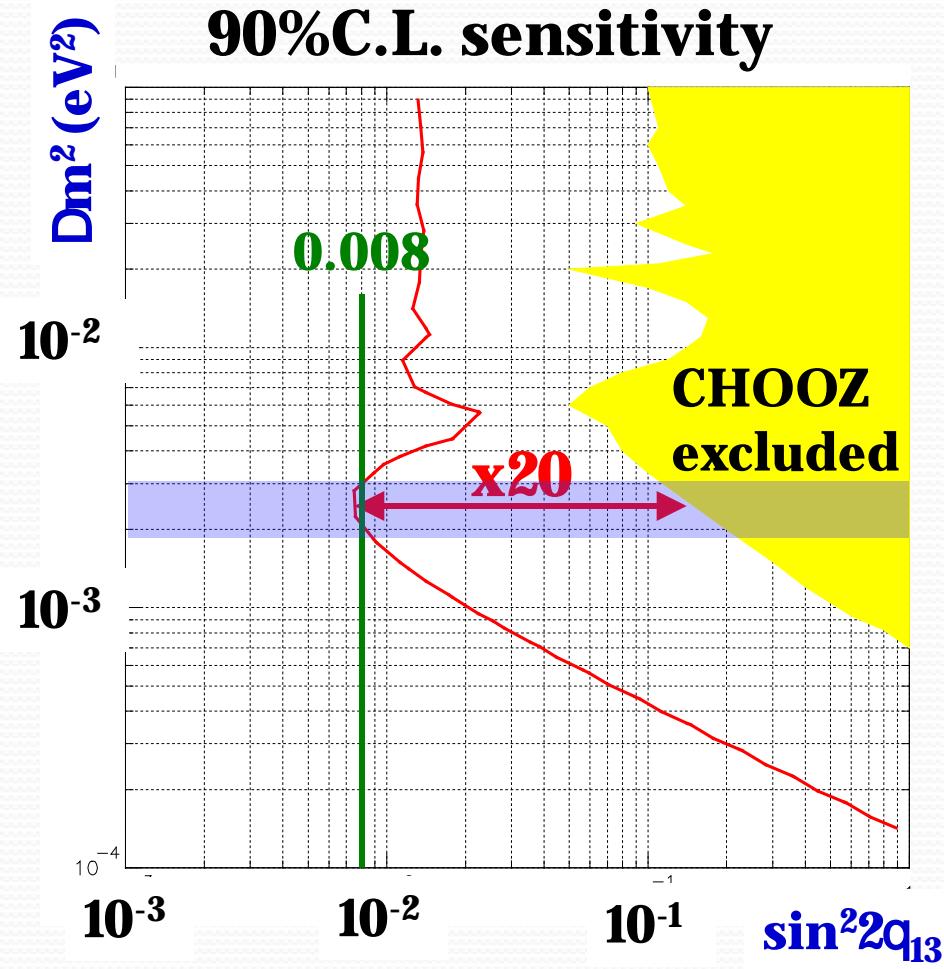
$(Dm^2=2.5 \times 10^{-3} \text{ eV}^2, \sin^2 2q_{13}=0.1)$



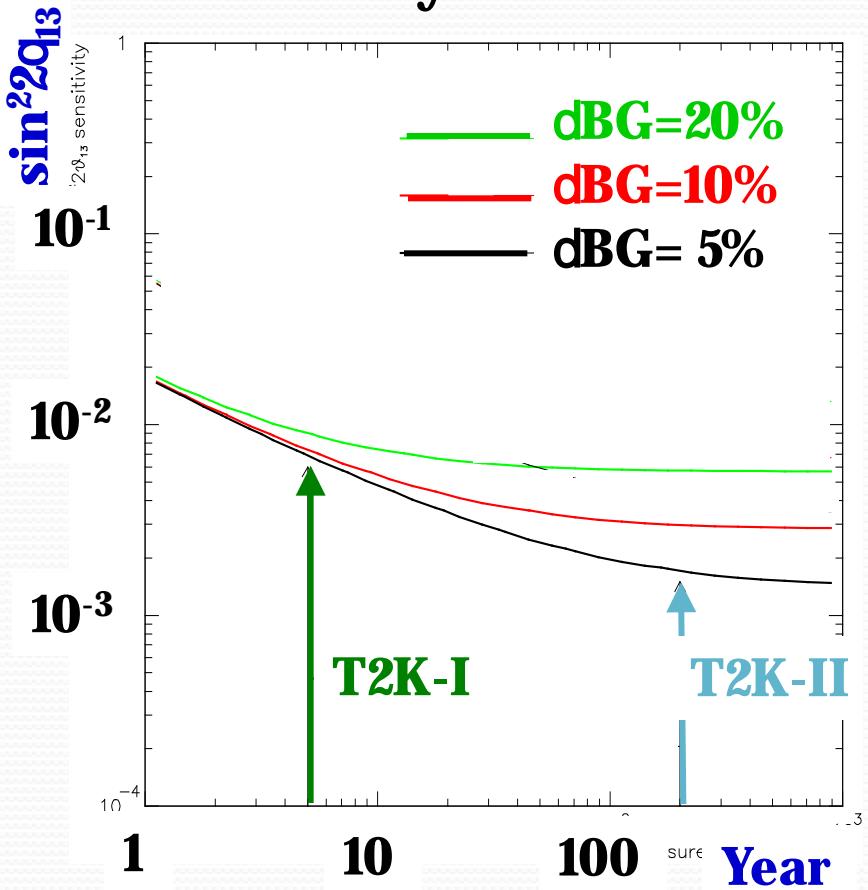
1. FCFV, $E_{\text{vis.}} > 100 \text{ MeV}$
2. single ring
3. e-like PID
4. no decay-electron
5. $0.35 < E_n^{\text{rec}} < 0.85 \text{ GeV}$
6. $\cos q_{ne} < 0.90$
7. $M_{p0} < 100 \text{ MeV}/c^2$ (p^0 fitter)
8. $\text{DL} < 80$ (p^0 fitter)



q_{13} Sensitivity (w/ $\text{dBG}_{\text{sys}}=10\%$)

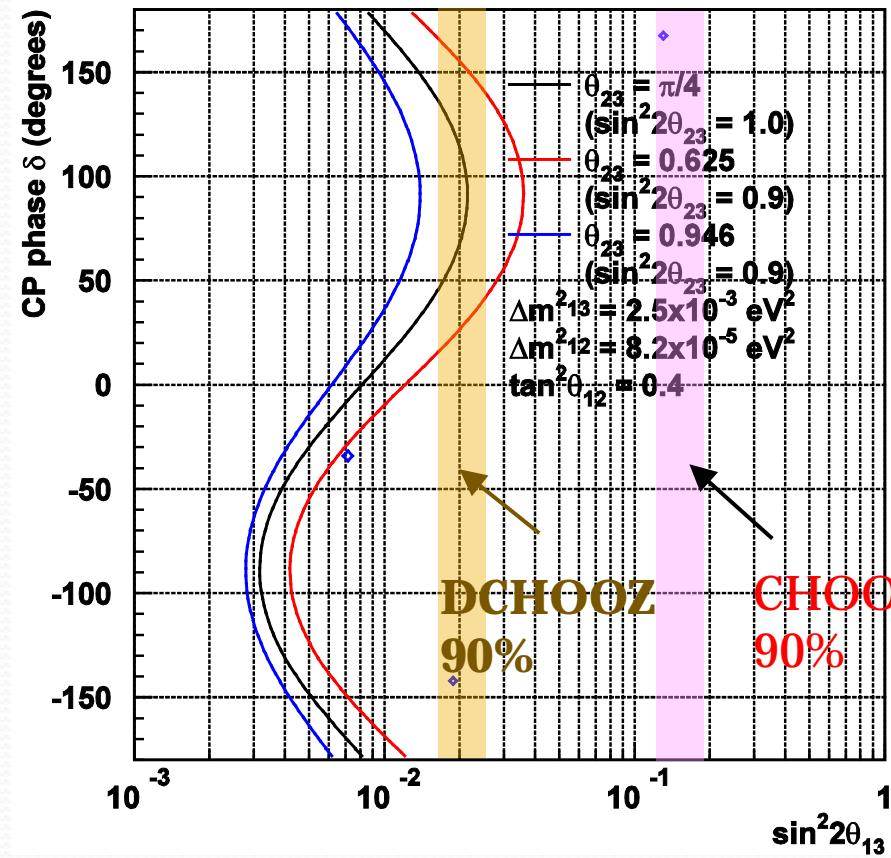
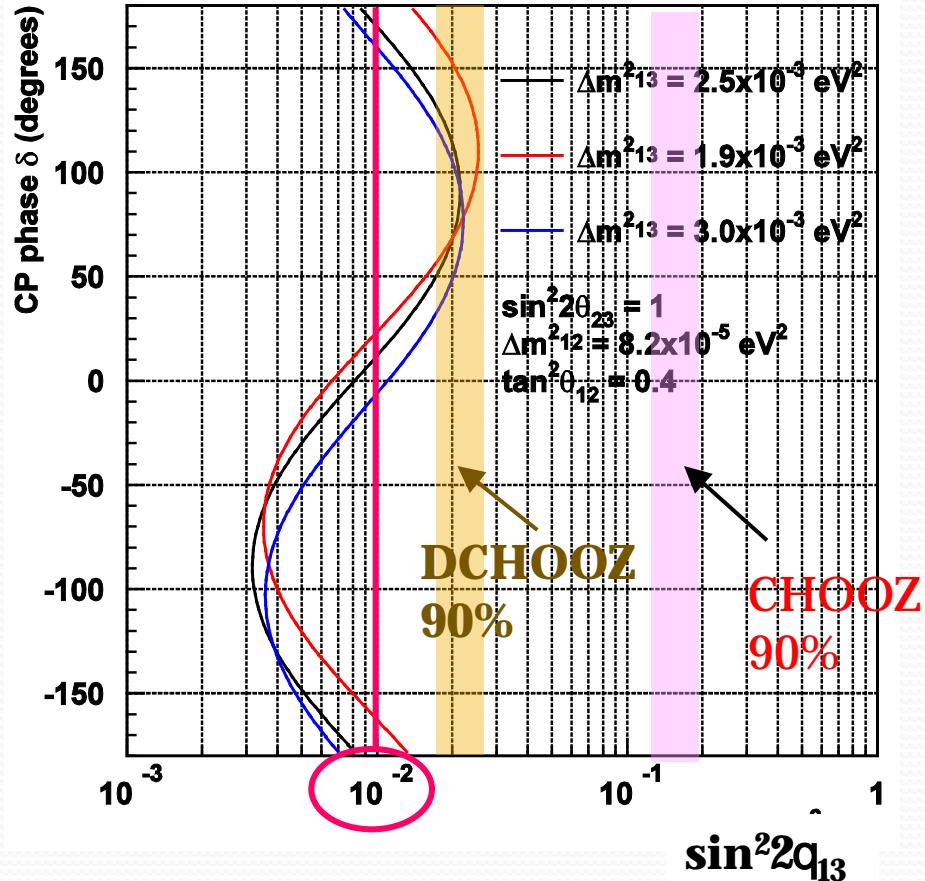


Sensitivity versus time



T2K Physics Sensitivity

n_e appearance (Strong d dependence)

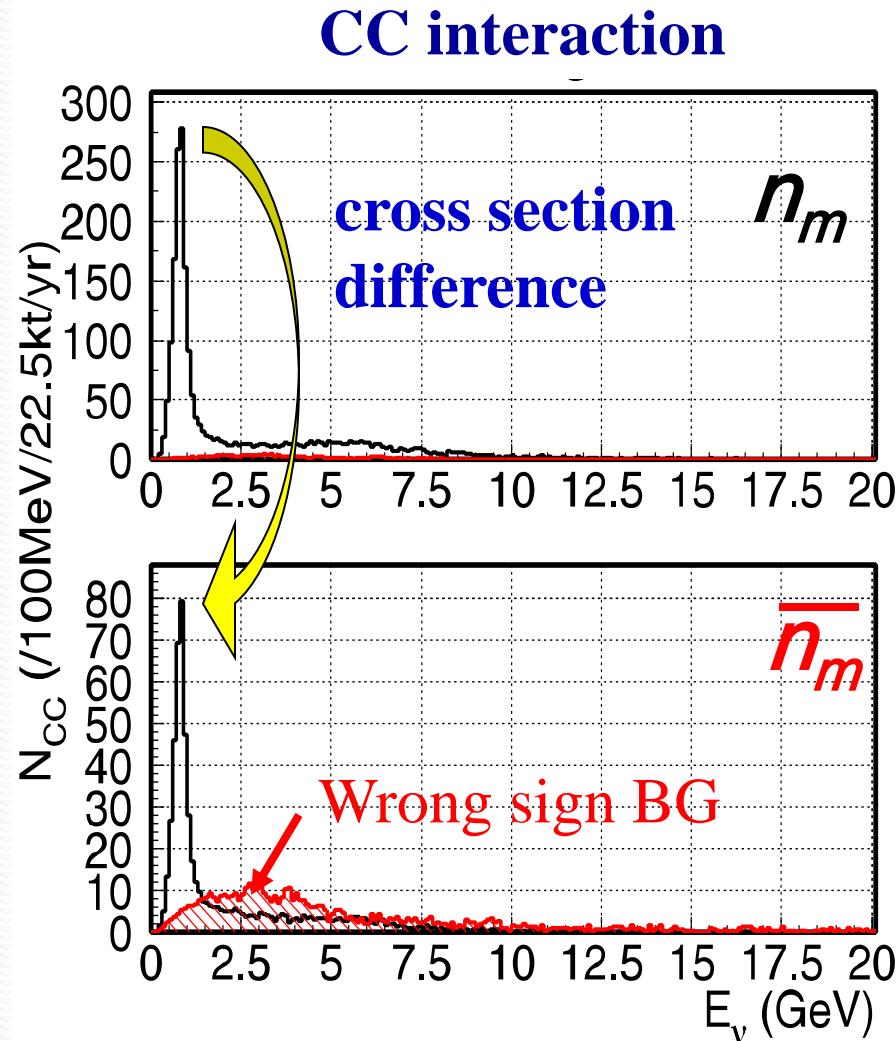
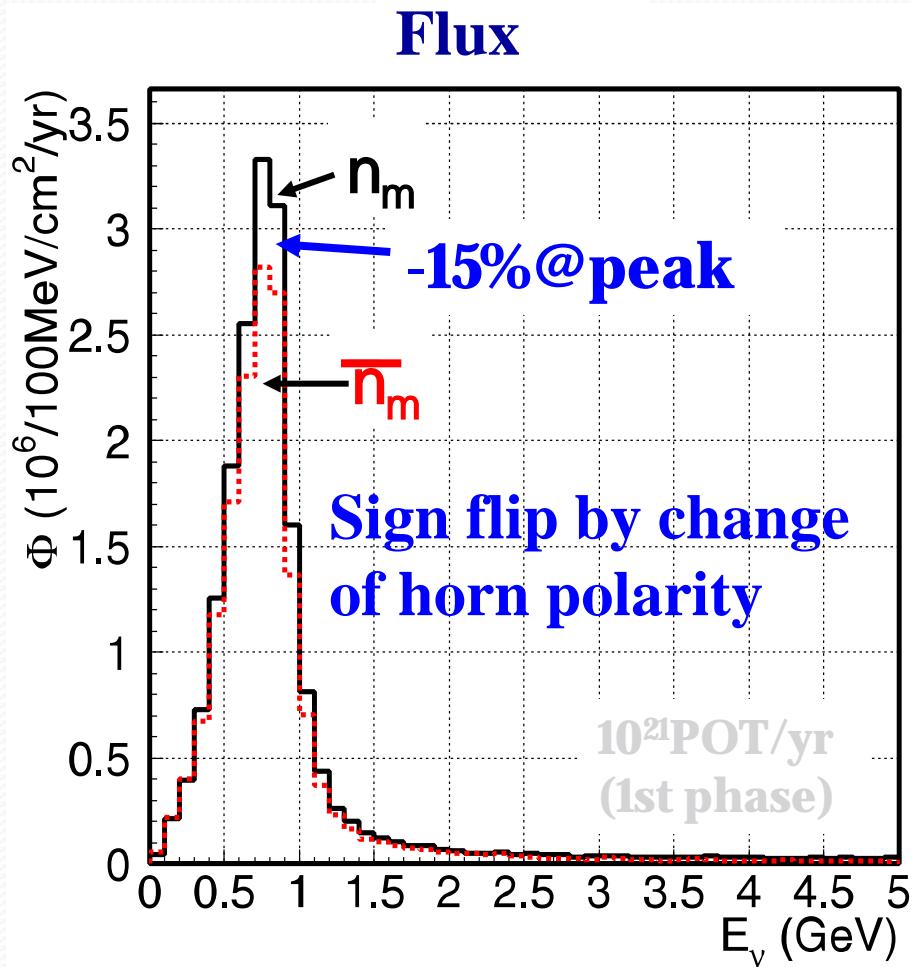


~10 times improvement from CHOOZ

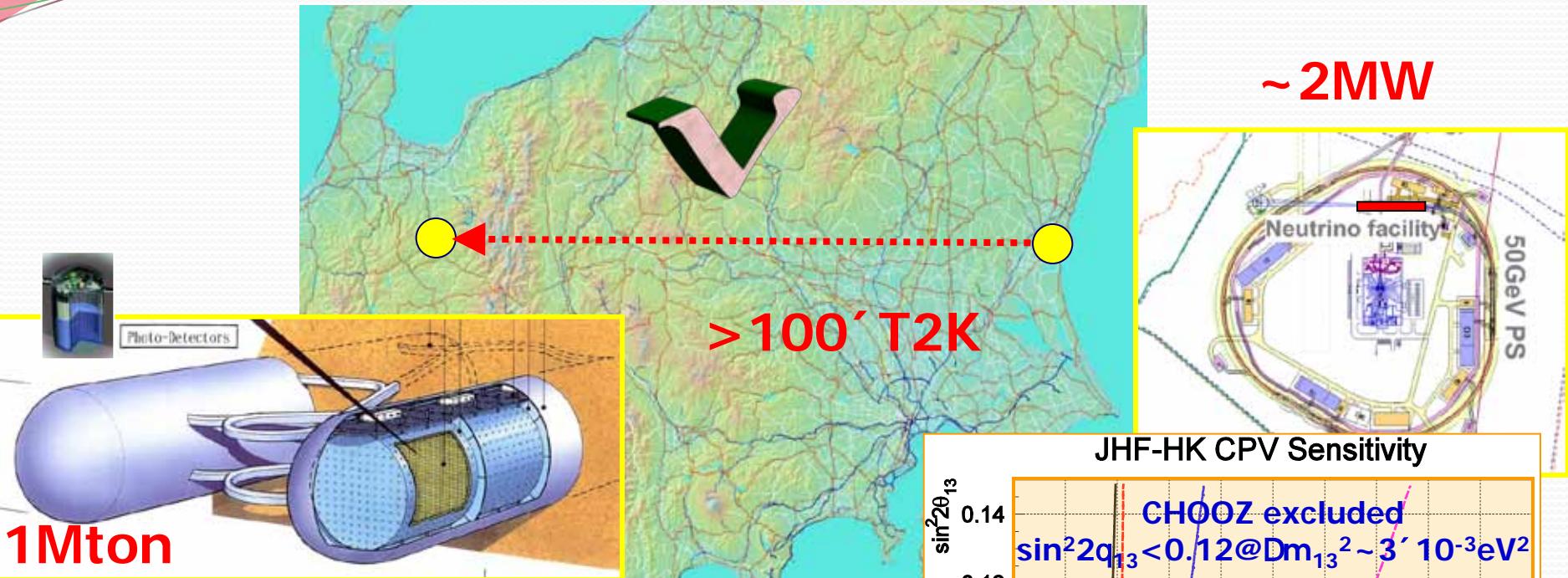
CP violation study

\bar{n} beam is an option

(Note: Old study with 2 ° off-axis)



Future Upgrade for the CP measurements

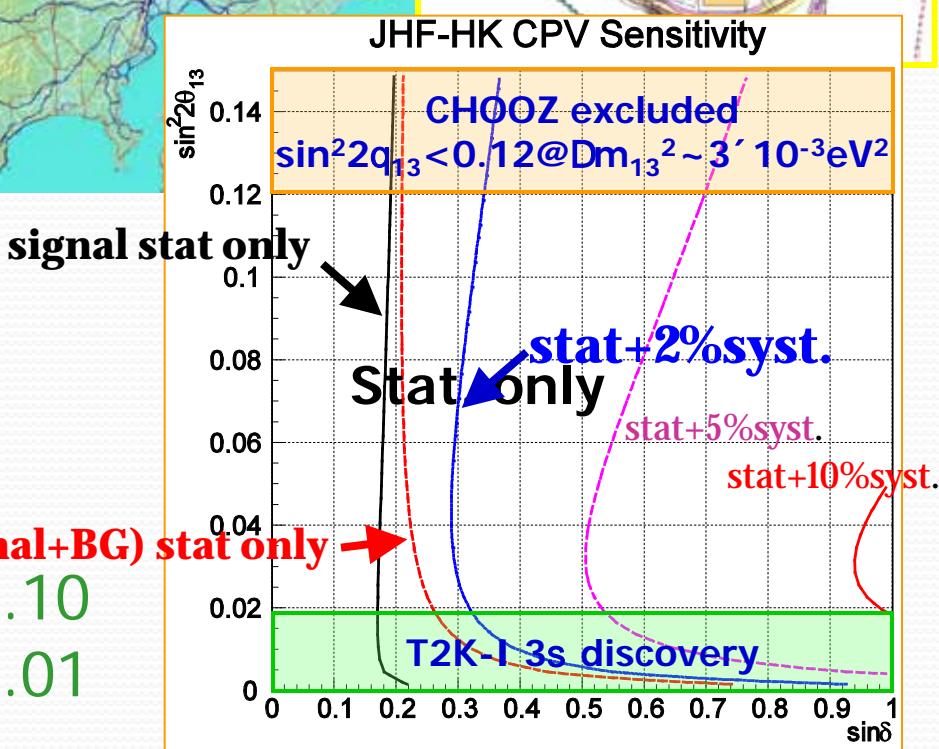


3s CP sensitivity : $|d| > 20^\circ$ for
 $\sin^2 2q_{13} > 0.01$ with 2% syst.

NOTE: CP violation

- $A_{CP} \sim 0.2$ sind @ $\sin^2 2q_{13} = 0.10$
- $A_{CP} \sim 0.6$ sind @ $\sin^2 2q_{13} = 0.01$

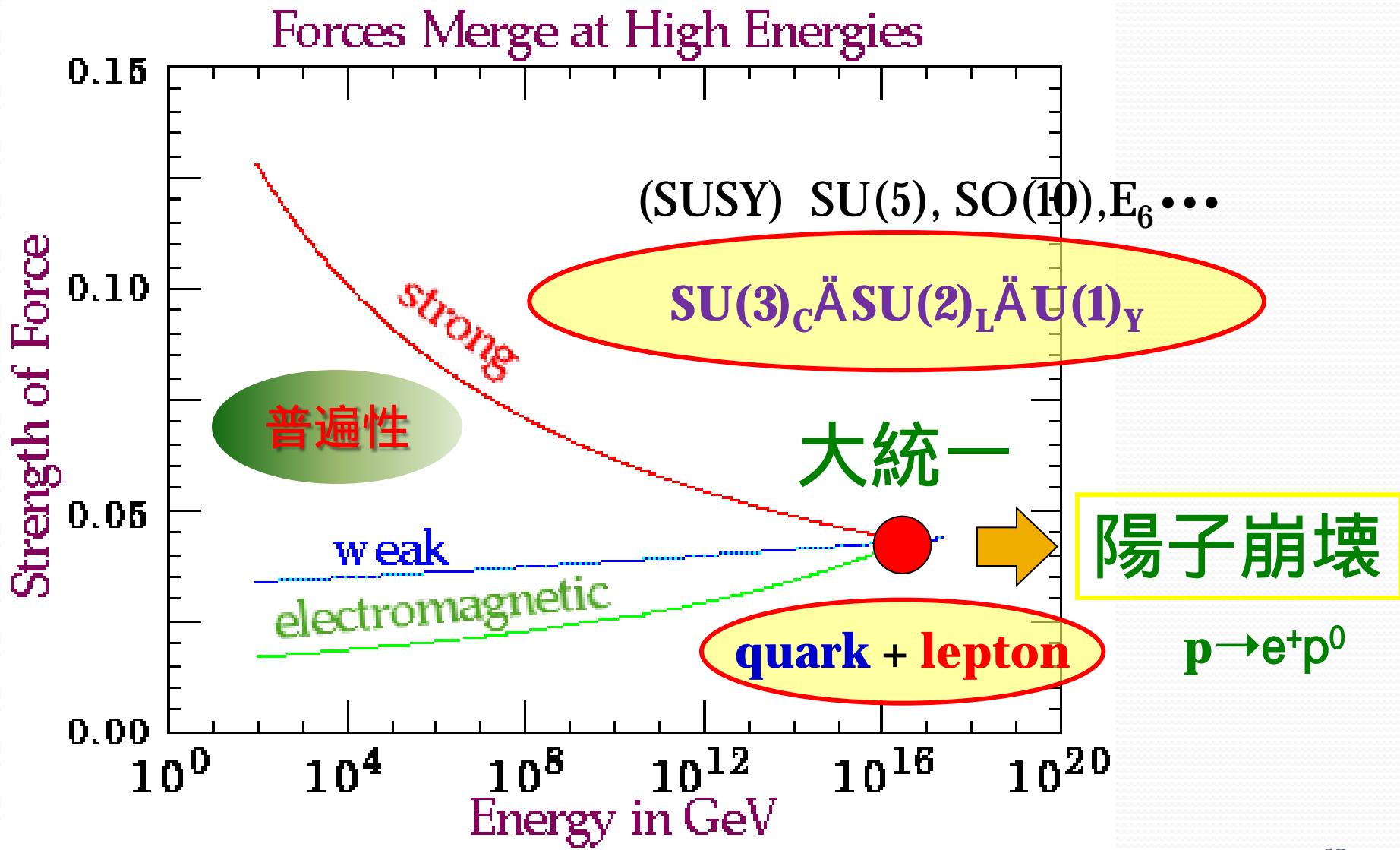
(signal+BG) stat only →



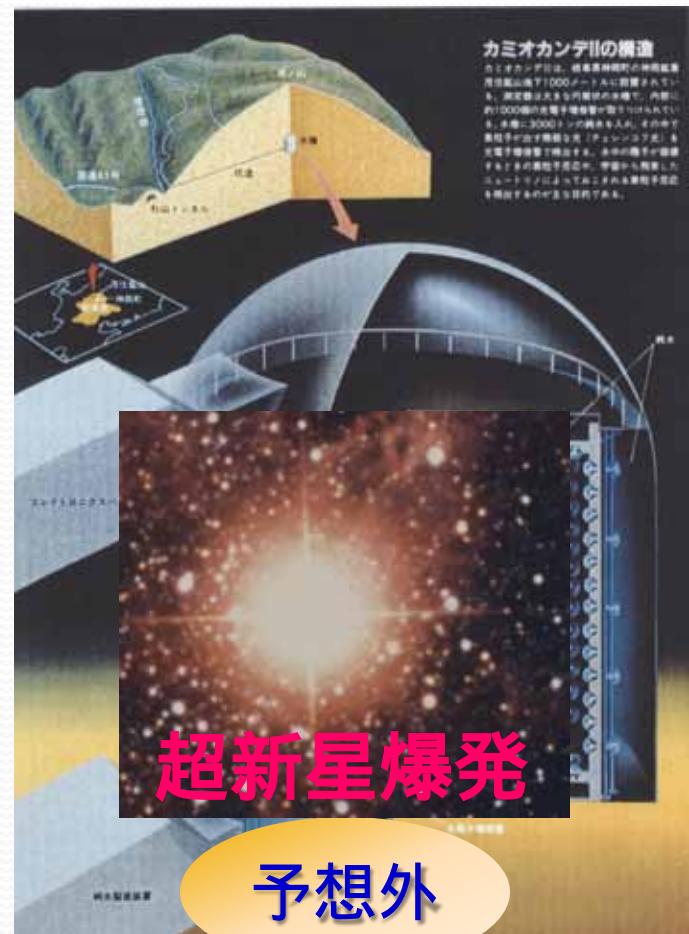
Summary

- The T2K neutrino oscillation experiment started in April 2009
- T2K is the front runner in neutrino experiments.
 - Many foreign researchers are in the collaboration.
- We soon have the new result in summer 2010.
 - First search for electron neutrino appearance.
 - Precise measurements of neutrino oscillations.
- We expect significant results around 2012.
 - Discovery of electron neutrino appearance?
 - Open the window to study CP violation in neutrinos.

大統一理論

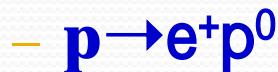


陽子崩壊の探索



大気ニュートリノが最大のバックグラウンド

– シグナル:



– バックグラウンド:



(注) n,pは測定器で見えない。

大気ニュートリノの研究を！

⇒ ニュートリノ振動発見へ

予想外

Test their real existence of atm. n (Reines, Miyake etc., 1960's)¹⁸

太陽ニュートリノ

– 太陽ニュートリノ観測の動機

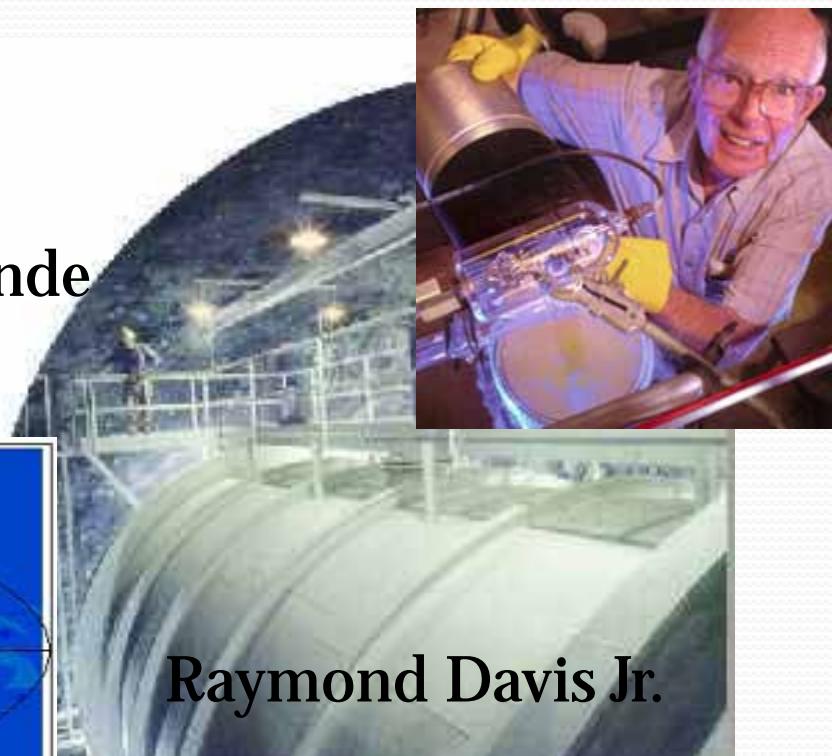
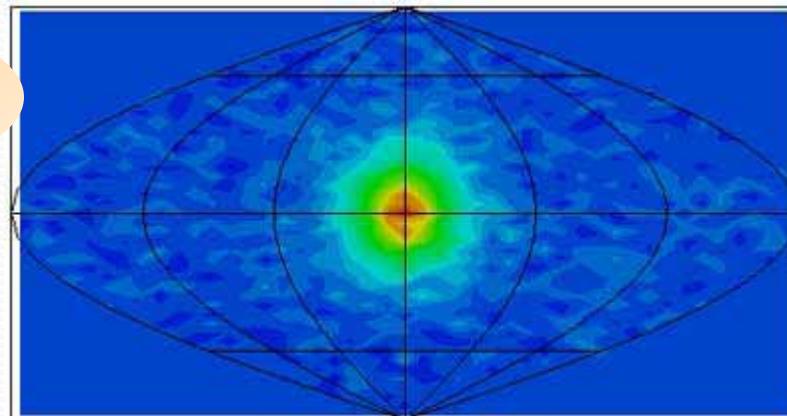
- Test the solar model (1960's) (J.N.Bahcall, "Neutrino Astrophysics", Cambridge University Press, 1989, page 488)

普遍性

– 太陽ニュートリノ観測

- 観測値が予想の $1/3$
- Kamiokande、Super-Kamiokande
観測値が予想の $\sim 40\%$

予想外



Raymond Davis Jr.

実験提案

Letter of Intent:
A Long Baseline Neutrino Oscillation Experiment
using the JHF 50 GeV Proton-Synchrotron
and the Super-Kamiokande Detector

February 3, 2000

—V1.0—

JHF Neutrino Working Group

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³Near Detector Contact Person: nakaya@scphys.kyoto-u.ac.jp

⁴Organizer: nishikaw@neutrino.kek.jp

JHFニュートリノ実験

中家 剛 (京大理)

1. Overview of the experiment
2. Physics Motivation
3. JHF facility and ν beam
4. Physics Sensitivity
5. Additional Options
6. Summary and Conclusion

日本物理学会シンポジウム
平成20年3月25日@近畿大学

日本が主導する
ニュートリノ振動・質量実験の現状と将来

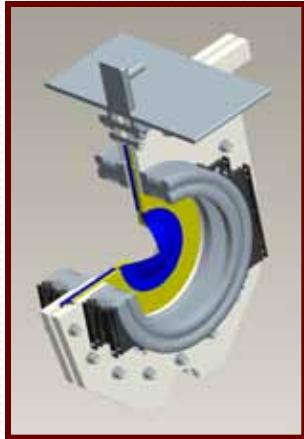
T2Kの物理

中家 剛(京都大学)
for the T2K collaboration

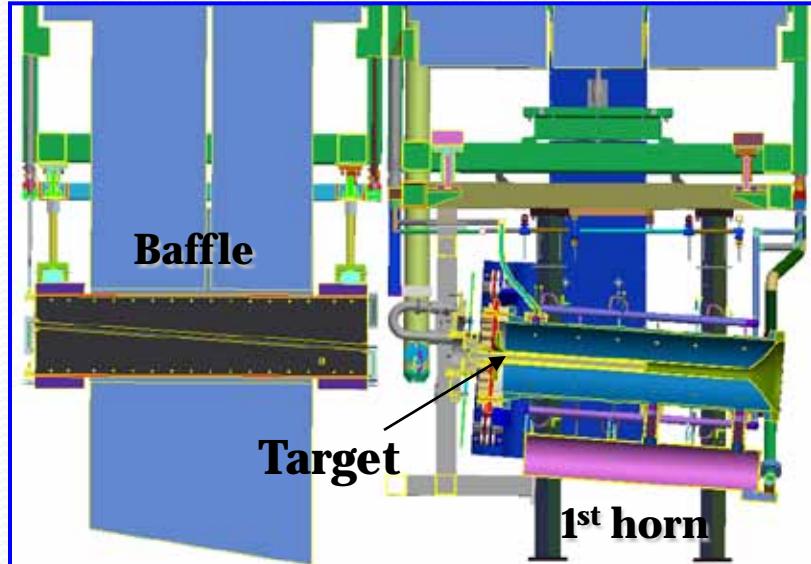
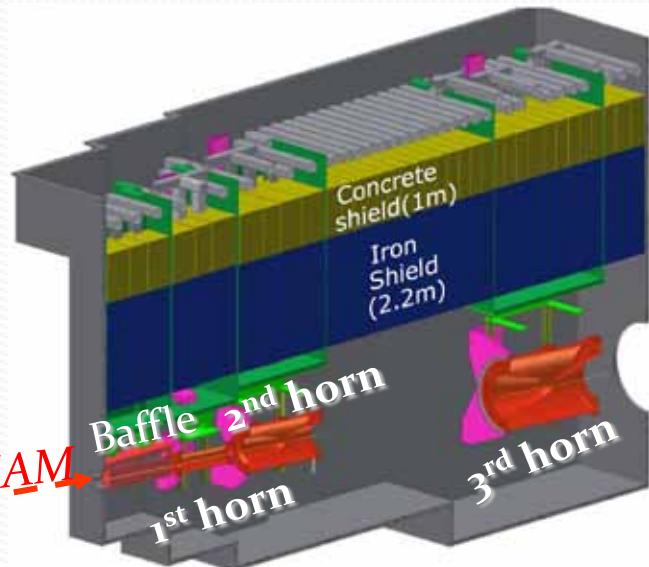
— The JHF-Kamioka neutrino
project: hep-ex/0106019

— Citation: 557

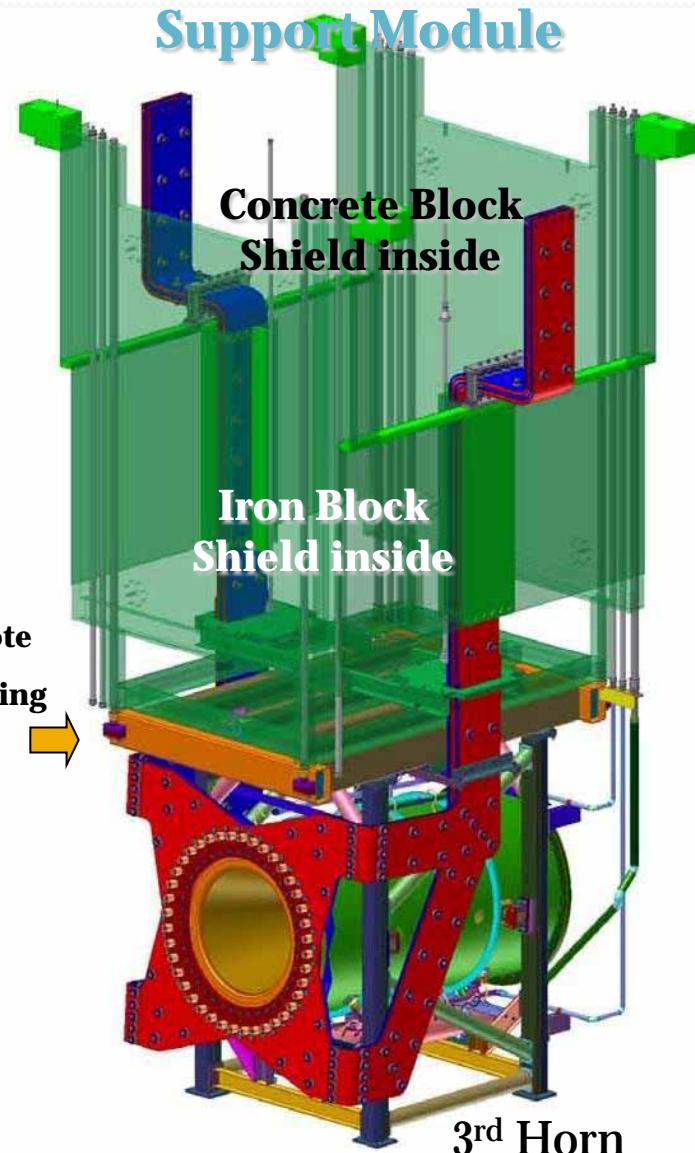
Apparatus in the TS vessel



Beam Window
With pillow seal

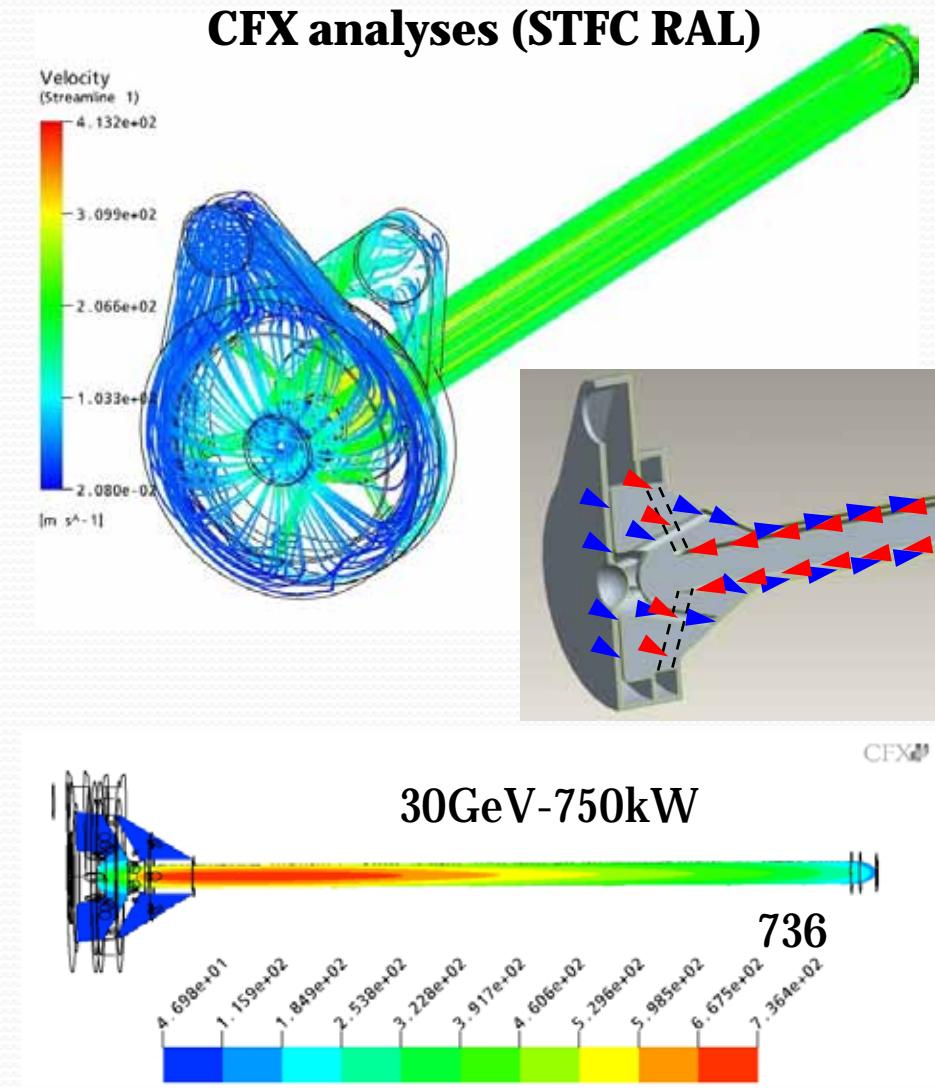


Remote
coupling



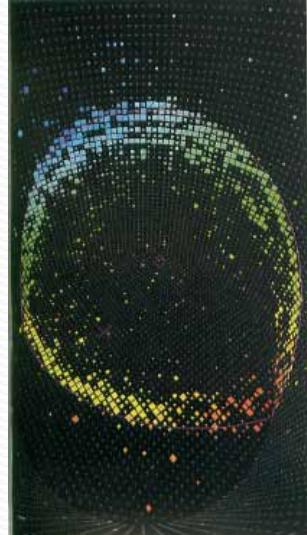


- Full prototype delivered in Dec. '07
- He gas flow test, achieve $650\text{Nm}^3/\text{h}$ (200m/s)



$\Delta T \sim 200\text{K}$ $\sim 7\text{MPa}$ (Tensile 27MPa)

注目の実験



超微小質量の巨大インパクト

短期集中連載：カミオカンデスーパー・カミオカンデ 物理学を変えた四半世紀 2

素粒子論の標準モデルを超えて……100ページ

中島林彦（編集部）／協力：戸塚洋二（東京大学）

盤石だと思われていた素粒子理論の標準モデルに、最初の大きな亀裂が走ったのは1998年のことだった。大ニュースの発信地は日本、しかも東京から遠くない。

福島県
ユーノード
200人
その
施設
成果
データ
日経サイ
SCIENTIFIC
AMERICAN
特集
革命前
物理學
史上最強の加速器
LHC稼働へ
国際ニアコライダ
日本の進むべき道に
下

あなたの体に
潜む“他者”

日本発の
微粒子ICタグ
歌声の科学

短期集中連載
物理学を変えた
ニュートリノ質量の
発見

超微小質量がもたらす驚き

- スーパー・カミオカンデは、宇宙線や太陽風で飛来する中性子（中性ニュートリノ）の精密観測によって、宇宙線に潜む「他者」の存在を想定した。
- ニュートリノ振動は、ある種類の核反応で、ニュートリノが非常に多く現れる現象で、ニュートリノは質量ゼロとする。（「ニュートリノは質量ゼロ」とする概念は、現在、ニュートリノが質量を持つことを示す）

超微小質量の巨大インパクト

高エネルギー加速器研究機構
日本原子力研究開発機構

大強度陽子加速器計画
「J-PARC」を徹底紹介

J-PARC（ジエイパーサー）は2008年末に稼働する。「J-PARC」では、電子を高精度まで加速して標的の原子核にぶつけ、中性子や中間子、ニュートリノなど、さまざまな「三次ビーム」を生成する。これらの強度は二段階を使い、既先端の電子線・素粒子実験を行ったり、燃料電池で走る車両のタンク内の構造を探りながらの走行を紹介する。J-PARCの全貌を紹介する。

**天
惡と使
魔**

ダン・ブラウン
越前敏弥訳
ANGELS & DEMONS
DAN BROWN

下→
したニュートリノの“変身”をとらえる
トーン2008年4月号

超微小質量がもたらす驚き

あなたの体に潜む“他者”

日本発の微粒子ICタグ
歌声の科学

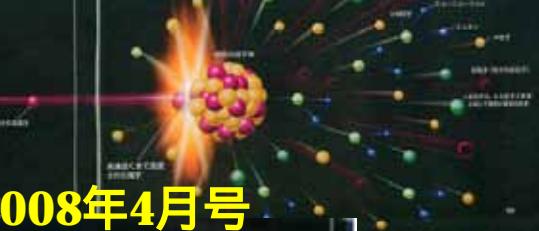
物理学者たる筆者たちが、じつは、これまでの常識を覆す驚きの事実を明らかにしている。それは、想像以上に、ニュートリノが質量をもたないとおきたい。しかし、新規の標準模型（暗黒と名づけている）を始め、ニュートリノ質量が標準模型の説明をこなすとあわかつていて、つまり、ニュートリノ振動と呼ばれている現象だけは、ニュートリノを質量ゼロの標準模型としてあわかつていて、つまり、ニュートリノ振動は標準模型の説明をこなすとあわかつていて、つまり、ニュートリノ振動は標準模型の説明をこなすとあわかつていて、つまり、ニュートリノ振動は標準模型の説明をこなすとあわかつていて、つまり、ニュートリノ振動は標準模型の説明をこなすとあわかつていて、つまり、

物質・生命のなぞに新加速器がせまる

大強度陽子加速器計画 「J-PARC」を徹底紹介

世界最高レベルの性能をもつ、多目的な大型の粒子加速器「J-PARC（ジエイパーサー）」が2008年末に稼働する。「J-PARC」では、電子を高精度まで加速して標的の原子核にぶつけ、中性子や中間子、ニュートリノなど、さまざまな「三次ビーム」を生成する。これらの強度は二段階を使い、既先端の電子線・素粒子実験を行ったり、燃料電池で走る車両のタンク内の構造を探りながらの走行を紹介する。

高エネルギー加速器研究機構
日本原子力研究開発機構



したニュートリノの“変身”をとらえる

トーン2008年4月号

トーン2008年4月号

トーン2008年4月号

トーン2008年4月号

トーン2008年4月号

トーン2008年4月号

トーン2008年4月号



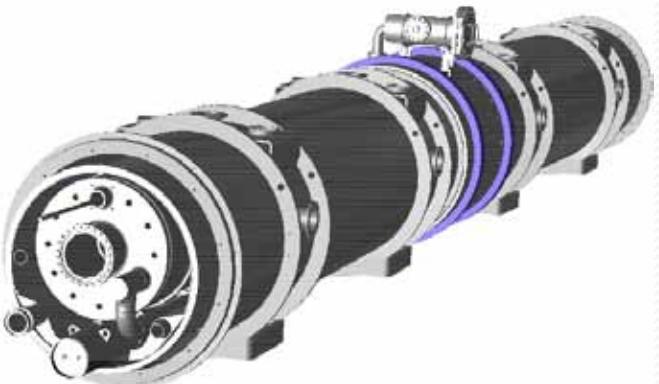
トーン2008年4月号

最後に

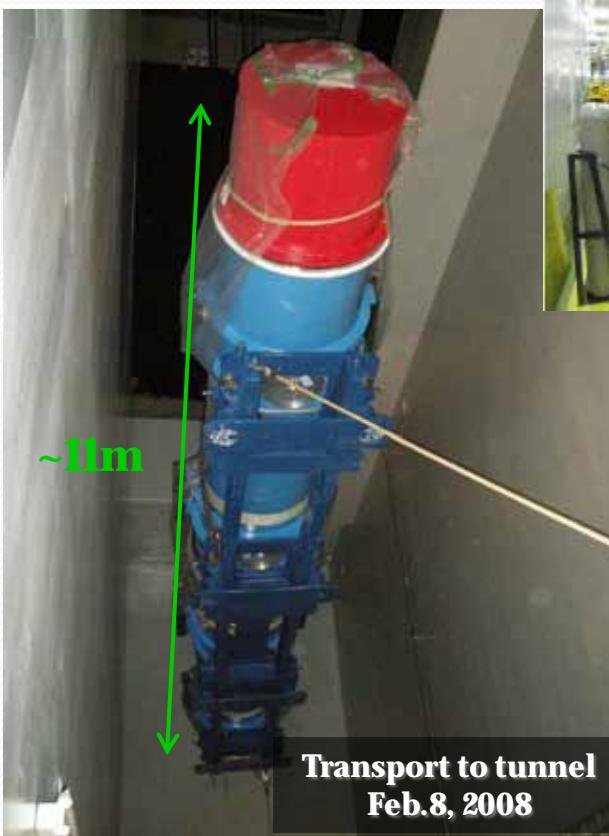
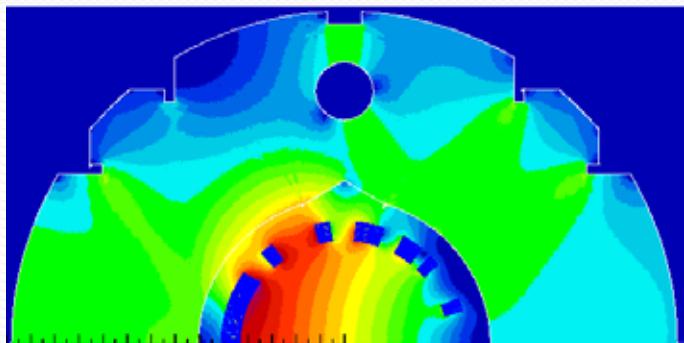
以下の現象が発見されるのも、夢ではない！

- － 牧・中川・坂田行列で予想していなかったCPの破れの発見。
- － ニュートリノ質量の大きさが、宇宙論から決定。
- － ニュートリノのマヨラナ性の発見(2重ベータ崩壊)。
- － 陽子崩壊の発見。
- － その他、今我々が予想していない…

Superconducting Magnets



Two magnets in cryostat "doublet"
14 doublets + 2 spare doublets
+ 4 corrector magnets by BNL



SCFM : Superconducting Combined Function Magnet

D: 2.6 T, Q: 18.6 T/m, Length: 3.3m, Current: 7,345A@ 50GeV

- 11 doublets in beam-line, Cryogenics installation on time.
- Entire system will be completed by December 2008