Mauro Mezzetto
Istituto Nazionale di Fisica Nucleare,
Sezione di Padova

"JHF "

- **Introduzione**
- **JPARC**
- **JPARC neutrino experiment**
- **Close detectors**
- **Long term perspectives**

Napoli, 30 giugno 2003.

ν oscillations are the most important discovery in hep of the last 15 years.

They measure fundamental parameters of the standard model. Mixing angles, neutrino masses and the CP phase δ_{CP} are fundamental constants of the standard model.

They are a probe of the GUT scales . The smallness of neutrino masses is connected to the GUT scale through the see-saw mechanism.

They are directly linked to many fields in astrophysics and cosmology : baryogenesis, leptogenesis, galaxies formation, dynamic of supernovae explosion, power spectrum of energy anisotropies, etc.

They open the perspective of the measure of **leptonic CP violation.**

If you are skeptical about that ....

Experimental articles with more than 500 cites in the last 15 years in the QSPIRES database (at 04/04/03):

1	SK	Evidence for Oscillation of Atmospheric Neutrinos.	1705
2	SCP	Measurements of Ω and Λ from 42 High Redshift SN.	1311
3	SST	Observational Evidence from SuperNovae for an Accelerating Universe and a Cosmological Constant.	1293
4	COBE	Structure in the COBE DMR First Year Maps.	1036
5	CDF	Observation of TOP Quark Production in $\overline{p}-p$ Collisions.	930
6	D0	Observation of the Top Quark.	889
7	SK	Atmospheric ν_μ/ν_e Ratio in the MultiGeV Energy Range.	751
8	Chooz	Initial Results from CHOOZ.	683
9	Boomerang	A Flat Universe from High Resolution Maps of the CMB.	644
10	Chooz	Limits on Neutrino Oscillations from the CHOOZ Experiment.	635
11	Kamiokande	Observation of a Small Atmospheric ν_μ/ν_e Ratio.	628
12	CLEO	First Measurement of the Rate for the Inclusive $b \rightarrow s\gamma$.	618
13	SNO	Measurement of the rate of ν_e + d –> p + p + e- ...	592
14	Homestake	Measurement of the Solar ν_e Flux ...	565
15	LSND	Evidence for $\overline{\nu}_\mu \rightarrow \overline{\nu}_e$ Oscillations from LSND.	563
16	SK	Measurement of a Small Atmospheric ν_μ/ν_e Ratio.	561
17	CDF	Evidence for TOP Quark Production in $\overline{p}-p$	550
18	SK	Study of the Atm. ν Flux in the MultiGeV Energy Range.	547
19	IMB	The ν_e and ν_μ Content of the Atmospheric Flux.	535
20	SK	Solar Neutrino Data Covering Solar Cycle 22.	504
21	LSND	Neutrino Oscillations from LSND.	500

Most of the parameters are waiting to be measured

δm^2_{12} ✓ SOLARS+KAMLAND $5\ 10^{-5} < \delta m^2_{12} < 3\ 10^{-4}\ eV^2$

θ_{12} ✓ SOLARS+KAMLAND $0.2 < \sin^2(\theta_{12}) < 0.5$

Addressed by a SuperBeam/Nufact experiment

δm^2_{23} ✓ ATMOSPHERICS $\delta m^2_{23} = 2.6 \pm 0.4\ eV^2$

θ_{23} ✓ ATMOSPHERICS $0.9 < \sin^2 2(\theta_{23}) < 1$

θ_{13} ☐ CHOOZ LIMIT $\theta_{13} < 14^0$

δ_{CP} ☐

Mass hierarchy ☐

Σm_ν ☐ BETA DECAY END POINT $\Sigma m_\nu < 6.6$ eV

Dirac/Majorana ☐

The capital importance of θ_{13}

Present limit from CHOOZ: $\sin^2 2\theta_{13} \leq 0.1$. Both solar and atmospheric results are compatible with $\theta_{13} = 0$.

Solar+Atmospherics favor a near bi-maximal mixing matrix (VERY DIFFERENT from CKM matrix!)

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

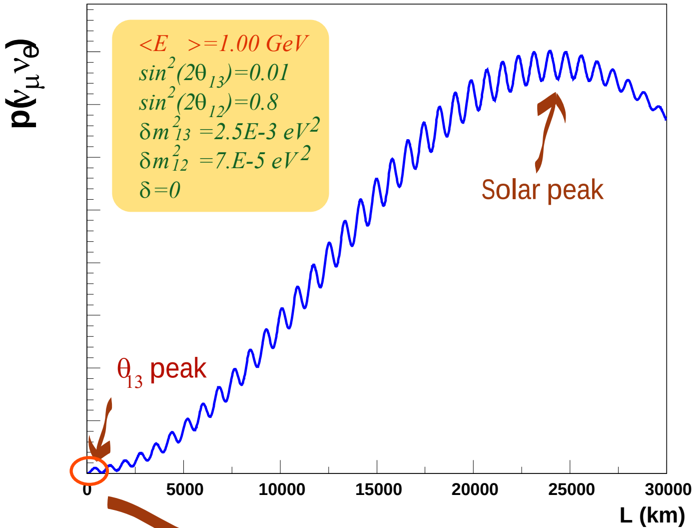
$\theta_{13} \rightarrow 0 \quad \Rightarrow$ The 3x3 matrix is a trivial product of two 2x2 matrixes.

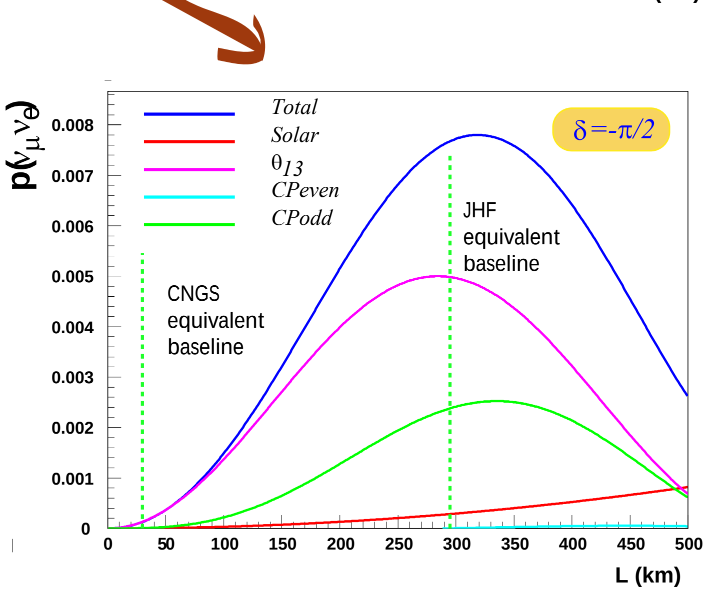
θ_{13} drives $\nu_\mu \rightarrow \nu_e$ subleading transitions $\Rightarrow$

the necessary milestone for any subsequent search:

neutrino mass hierarchy and leptonic CP violation searches.

Subleading $\nu_\mu - \nu_e$ oscillations





$p(\nu_\mu \to \nu_e)$ developed at the first order of matter effects

$$p(\nu_\mu \to \nu_e) = 4c_{13}^2 s_{13}^2 s_{23}^2 \sin^2 \frac{\Delta m_{13}^2 L}{4E} \qquad \theta_{13} \text{ driven}$$

$$+ 8c_{13}^2 s_{12} s_{13} s_{23} (c_{12} c_{23} cos\delta - s_{12} s_{13} s_{23}) \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \quad \text{CPeven}$$

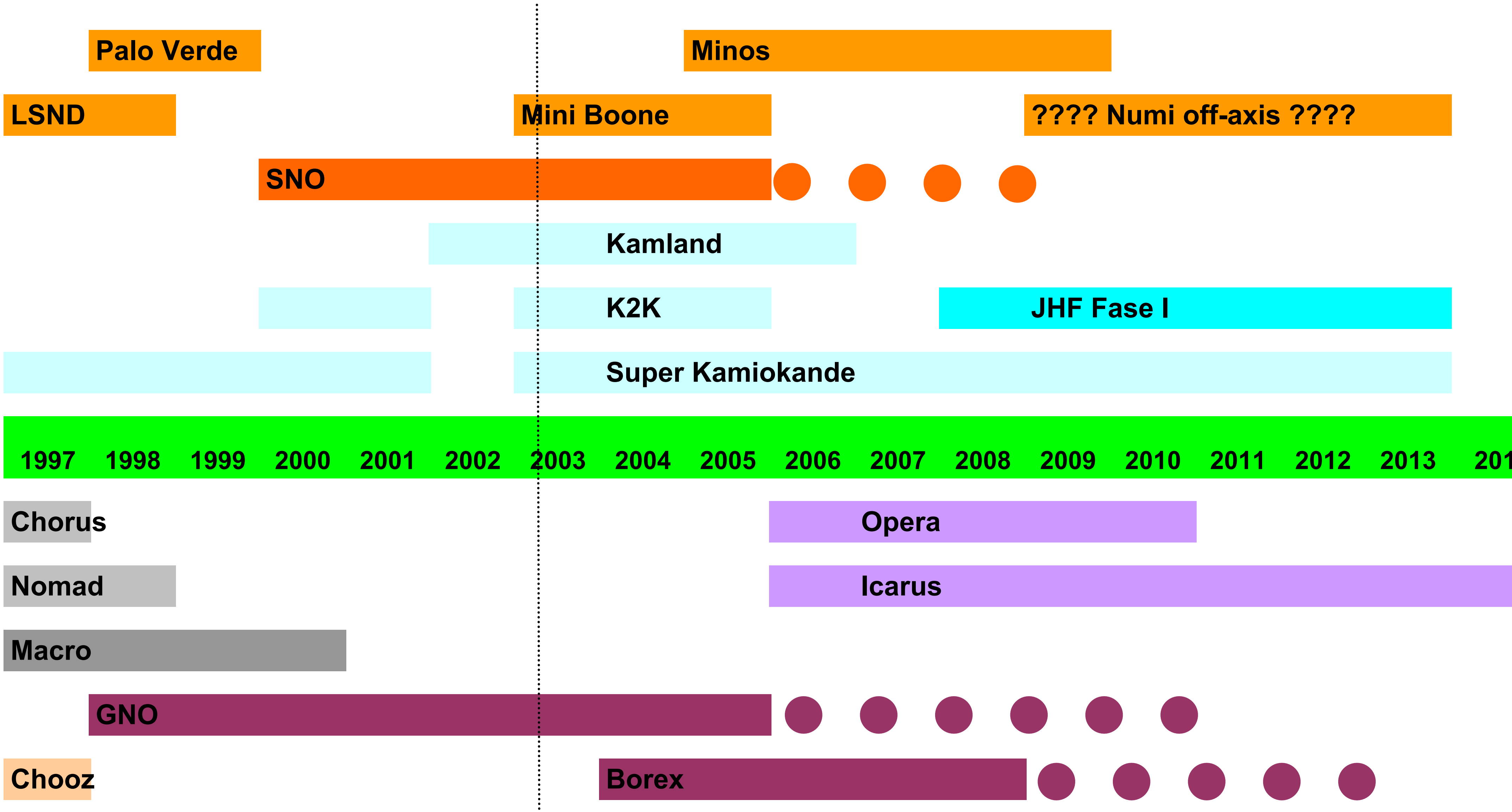
$$- 8c_{13}^2 c_{12} c_{23} s_{12} s_{13} s_{23} \sin\delta \sin \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \sin \frac{\Delta m_{12}^2 L}{4E} \qquad \text{CPodd}$$

$$+ 4s_{12}^2 c_{13}^2 \{c_{13}^2 c_{23}^2 + s_{12}^2 s_{23}^2 s_{13}^2 - 2c_{12} c_{23} s_{12} s_{23} s_{13} cos\delta\} \sin \frac{\Delta m_{12}^2 L}{4E} \quad \text{solar driven}$$

$$- 8c_{12}^2 s_{13}^2 s_{23}^2 \cos \frac{\Delta m_{23}^2 L}{4E} \sin \frac{\Delta m_{13}^2 L}{4E} \frac{aL}{4E} (1 - 2s_{13}^2) \quad \text{matter effect (CP odd)}$$

where $a = \pm 2\sqrt{2} G_F n_e E_\nu = 7.6 \cdot 10^{-5} \rho[g/cm^3] E_\nu [GeV] \quad [eV^2]$

Neutrino Oscillation Experiments



Time is an important issue

Sensitivity to to θ_{13} as a function of the year

	2004	2005	2006	2007	2008	2009
CHOOZ	**<0.14**	**<0.14**	**<0.14**	**<0.14**	**<0.14**	**<0.14**
MINOS		➔	<0.085	<0.06	<0.049	<0.042
CNGS*			➔	<0.067	<0.047	<0.039
CNGSx1.5*			➔	<0.056	<0.039	<0.033
Low energy CNGS				➔	<0.040	<0.028
JHF					➔	<0.013

* Designed for ν_τ appearance

Experimental possibilities to detect θ_{13}

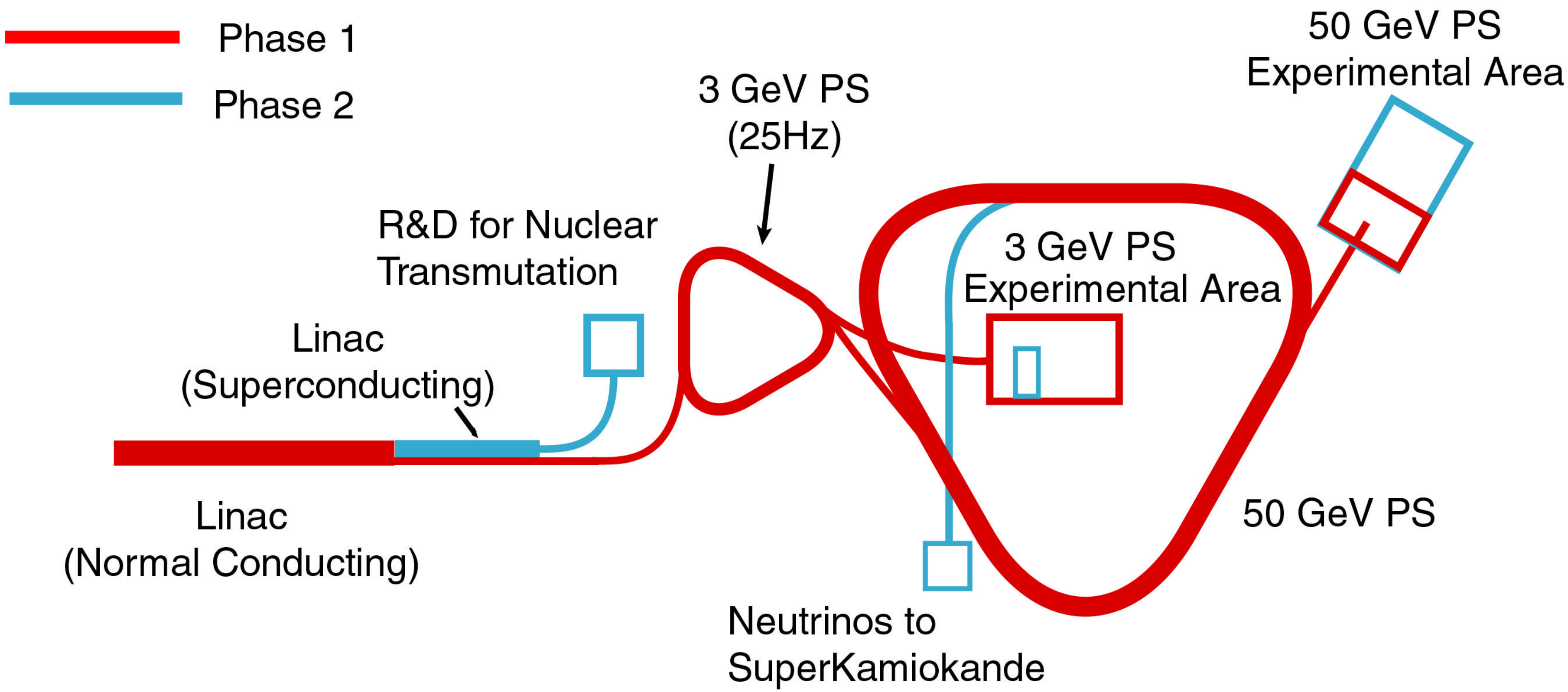
ν_e appearance

Collaboration	Proposed by	Configuration	Sensitivity ($\times$ Chooz)	Timescale
Numi off-axis	FNAL	Numi upgraded, medium energy beam, 50 kton detector on surface, technology not yet chosen	25	> 2009
Gulf of Taranto	Dydak	CNGS low energy, 6000 PMT in the sea, 1000 m depth	20	?
BNL to Homestake	BNL	AGS upgraded, detect first and second maximum, UNO detector	20	???
SPL to Frejus	CERN	Low energy, UNO detector	100	???

Other ways

Source	Collaboration	Effect	Sensitivity ($\times$ Chooz)	Comments
Atmospherics	Monolith	MSW resonance	4	400 kton/years
Reactors	Theoreticians	ν_e Disappearance	10	
Reactors	Experimentalists	ν_e Disappearance	4	
SuperNovae	Several groups	MSW	> 100	LVD, SK, SNO

Phase 1 and Phase 2



Ð Phase 1 + Phase 2 = 189 billion Yen (= $1.89 billion if $1 = 100 Yen).

Ð Phase 1 = 133.5 billion Yen for 6 years (= 2/3 of 189 billion Yen).

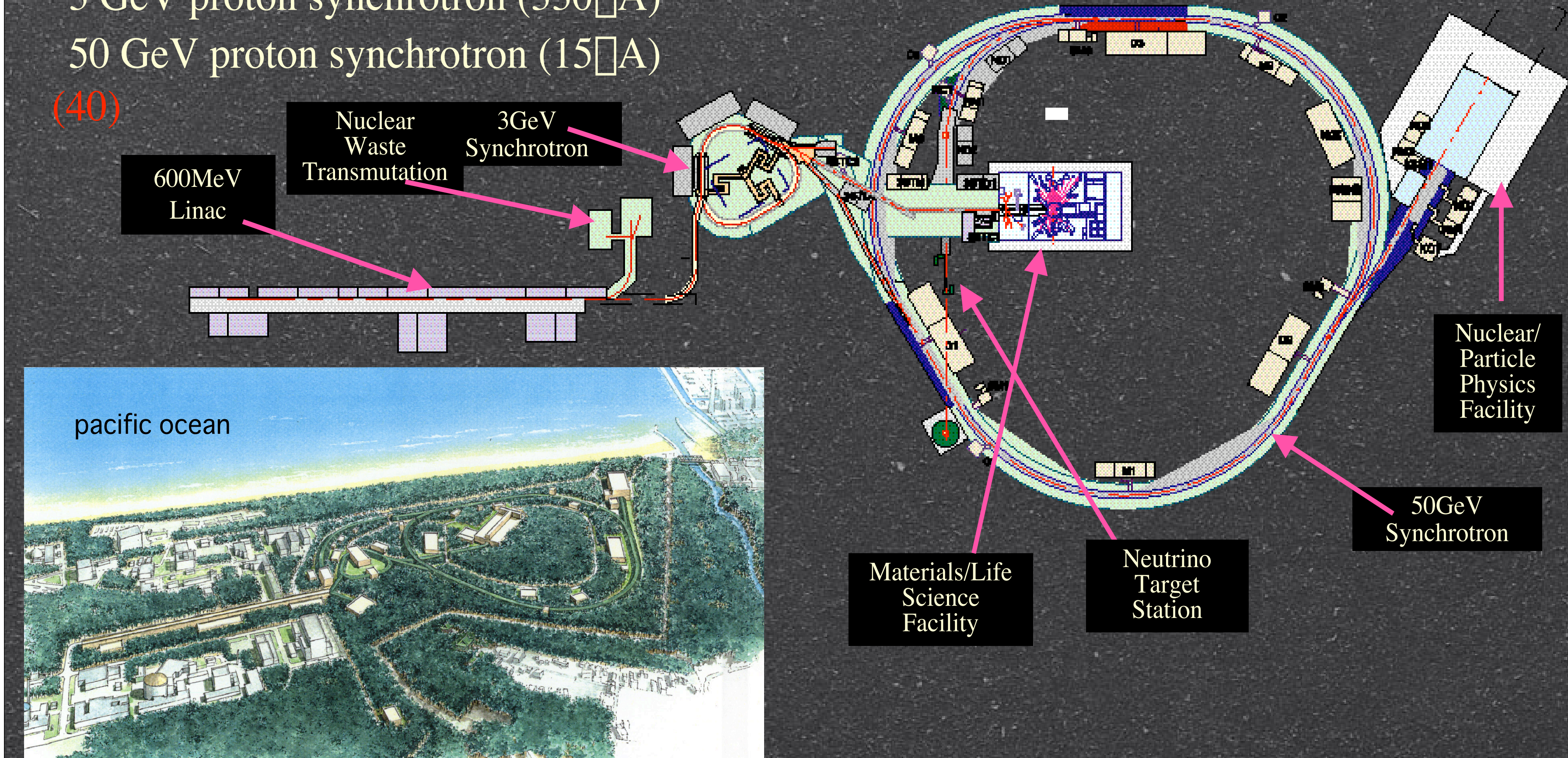
Ð Construction budget does not include salaries.

Proton Driver

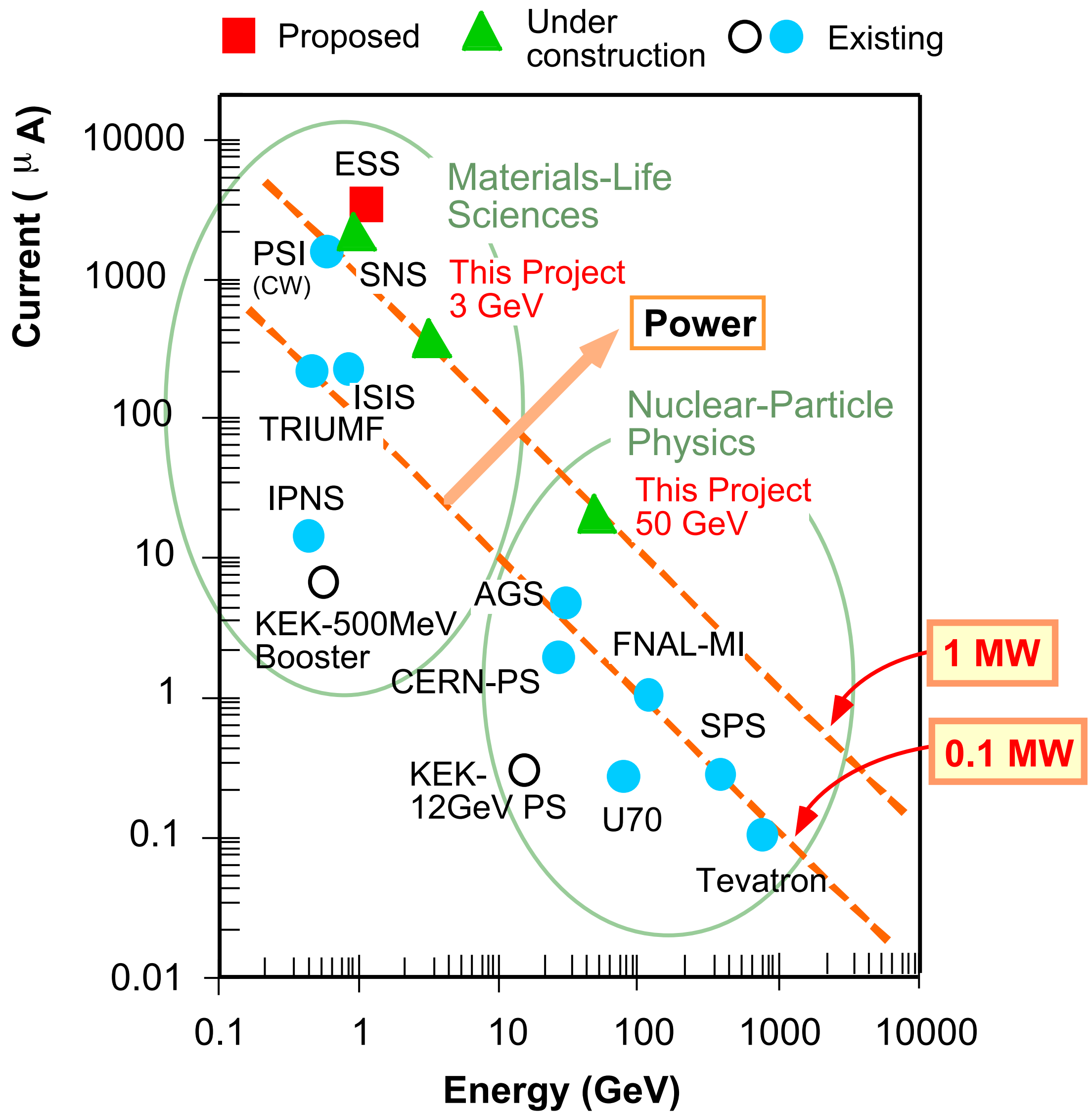
J-PARC = Japan Proton Accelerator Research Complex

400 (200) MeV proton linac
3 GeV proton synchrotron (330□A)
50 GeV proton synchrotron (15□A)
(40)

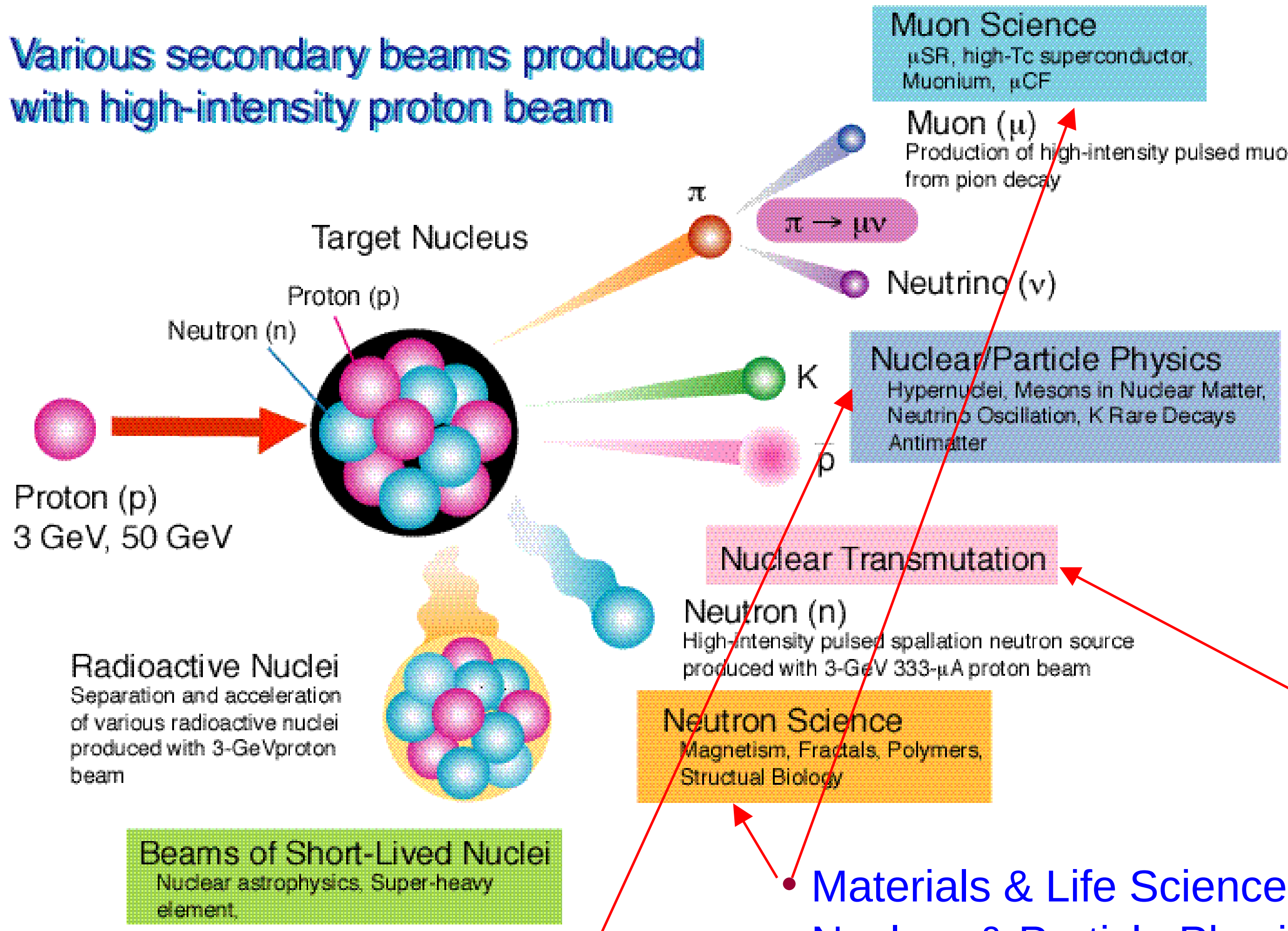
At Tokai



World’s Proton Accelerators

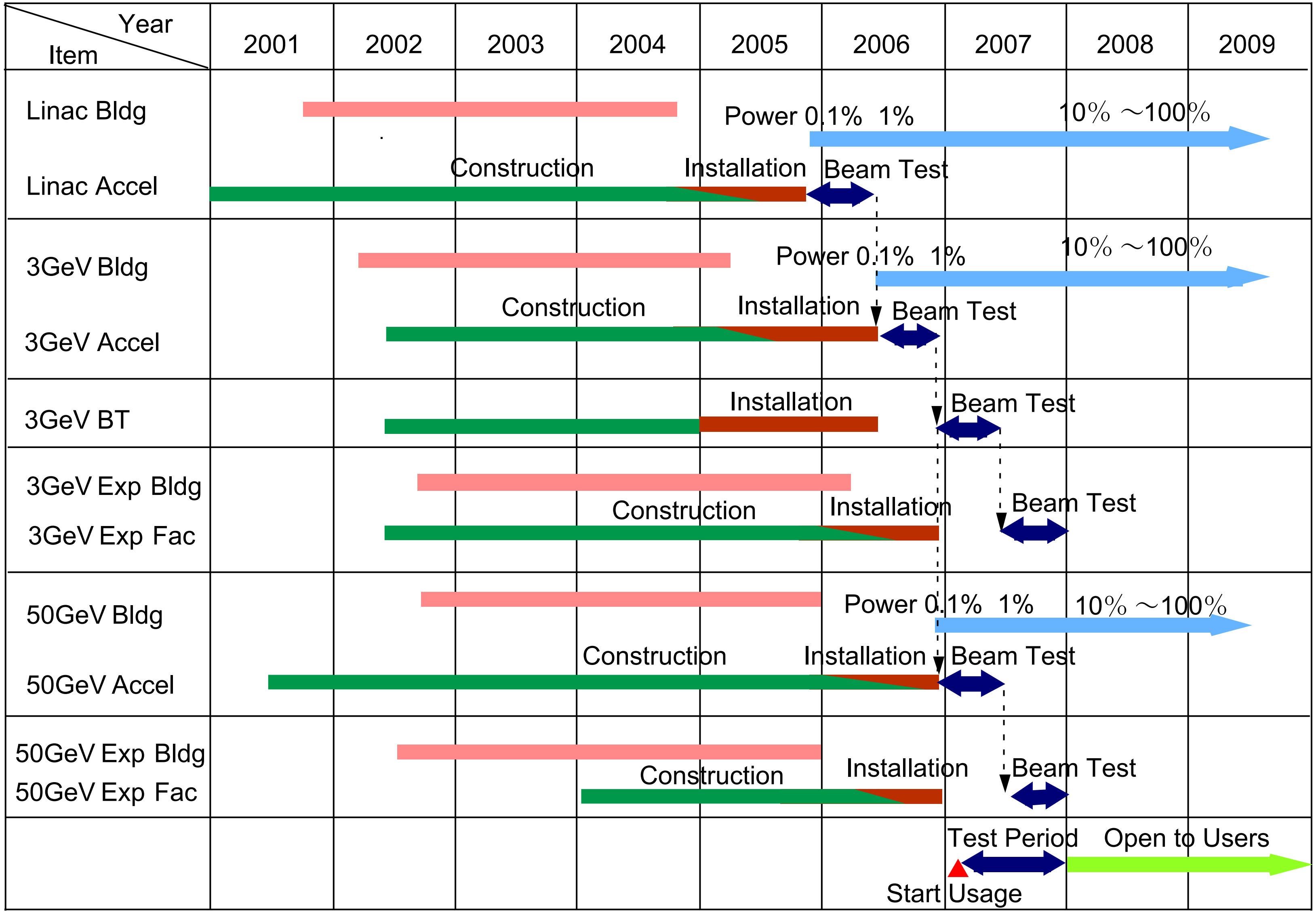


Why Do We Need High Intensity Protons?



- Materials & Life Sciences at 3 GeV
- Nuclear & Particle Physics at 50 GeV
- R&D toward Transmutation at 0.6 GeV

Beam Commissioning

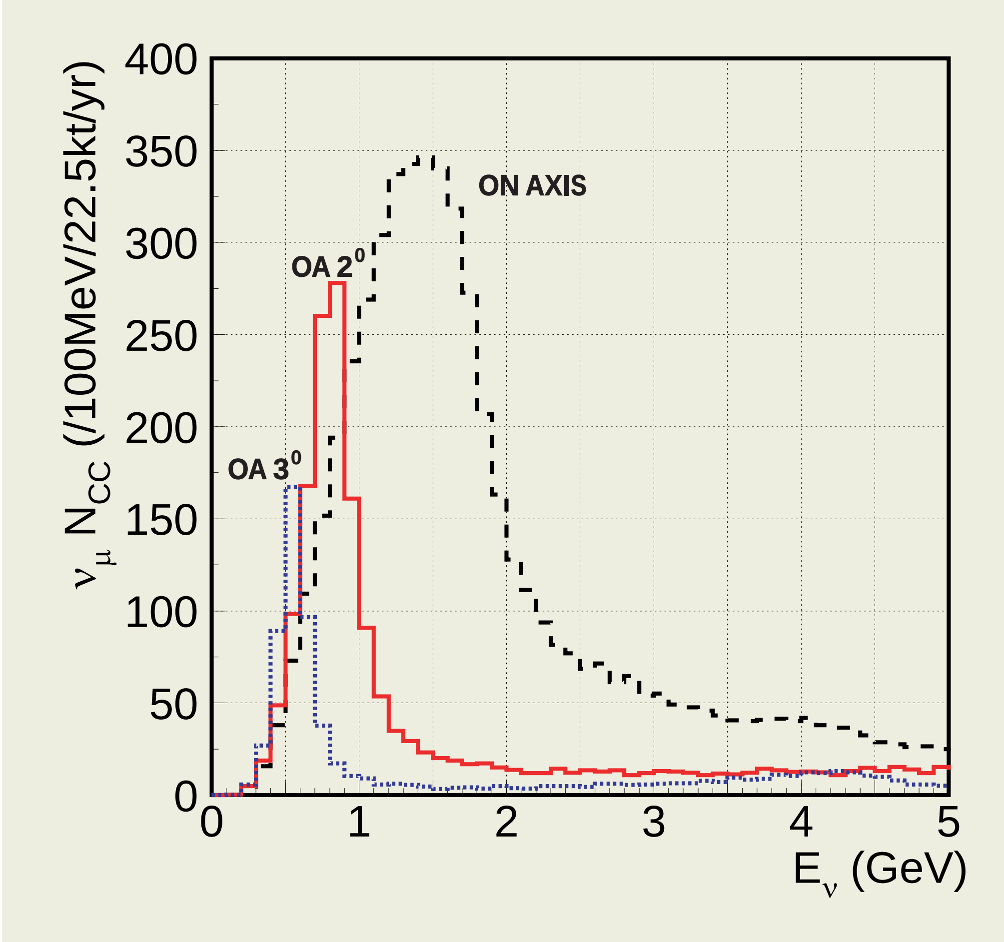


Present Status

JPARC-Japan Proton Accelerator Complex

Neutrino beam from the 50 GeV - 0.75 MW proton beam at the Hadron Facility at Jaeri, Japan.

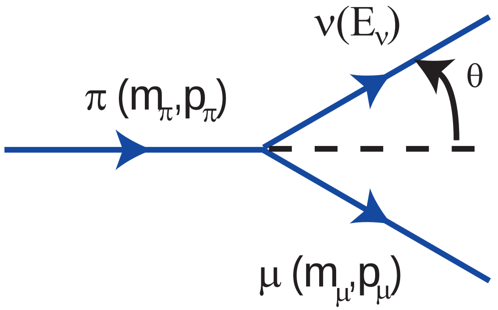
Taken off-axis to better match the oscillation maximum at the SuperKamiokande location (295 km).



K2K		JPARCnu
$6 \cdot 10^{12}$	Protons per pulse	$3 \cdot 10^{14}$
2.2 s	Cycle	3.4 s
12 GeV	Proton energy	50 GeV
40	Events in SK per year (no osc.)	2200
1.5	Mean neutrino energy	0.8

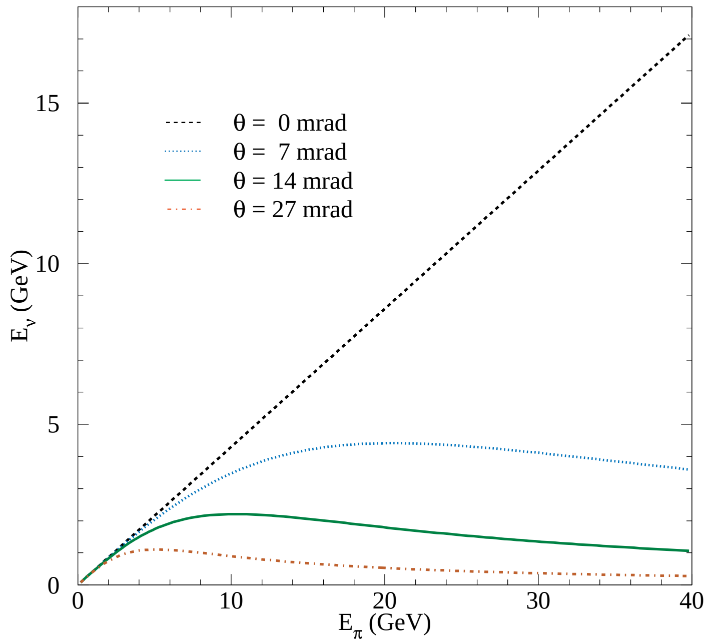
Off Axis Neutrino Beams. BNL-E889 proposal: http://minos.phy.bnl.gov/nwg/papers/E889

Decay Kinematics

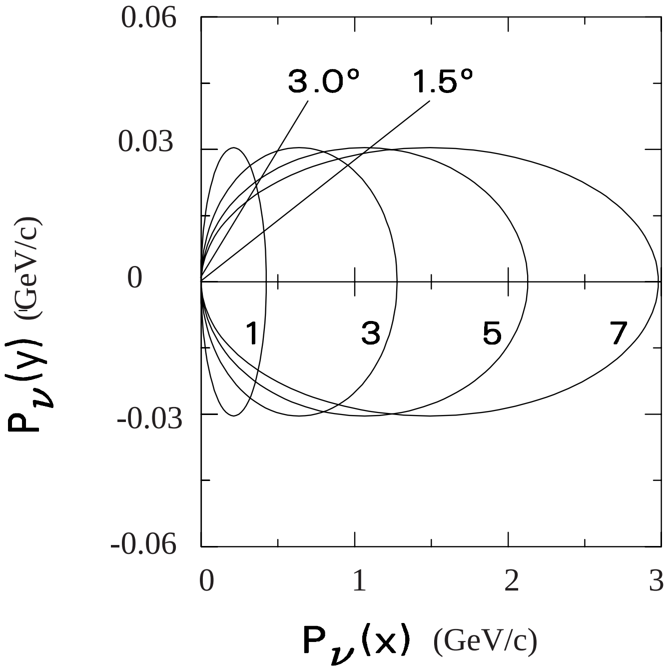


From momentum energy conservation:

$$E_\nu = \frac{m_\pi^2 - m_\mu^2}{2(E_\pi - p_\pi cos\theta)}$$



A qualitative argument:

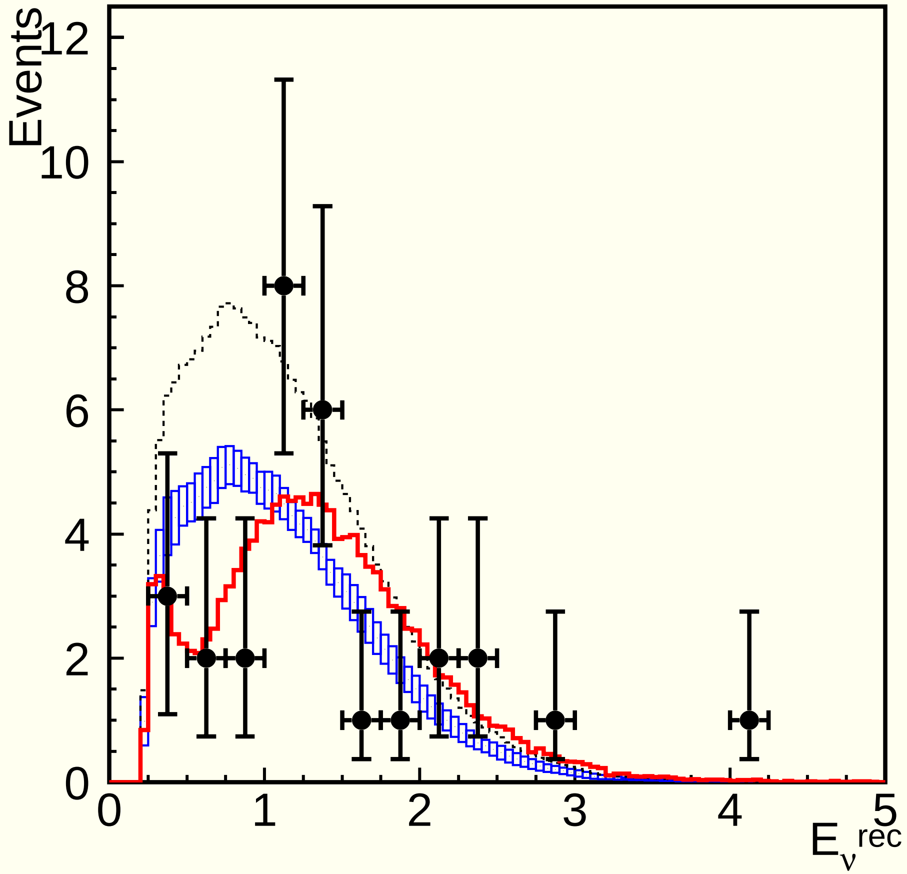


- Transverse momentum, Lorentz invariant: $m_\pi - m_\mu$.
- Longitudinal momentum is Lorentz boosted.
- At an angle θ there is an accumulation of lower energies neutrinos

- **Maximum neutrino flux at 0°.**
- **Off axis is the most efficient way to have a narrow band beam.**
- ν_e **come from 3 body decays (kaons or muons) while off-axis is optimized on the pion 2 body decay$\Rightarrow$ the** ν_e **contamination below the peak is reduced.**

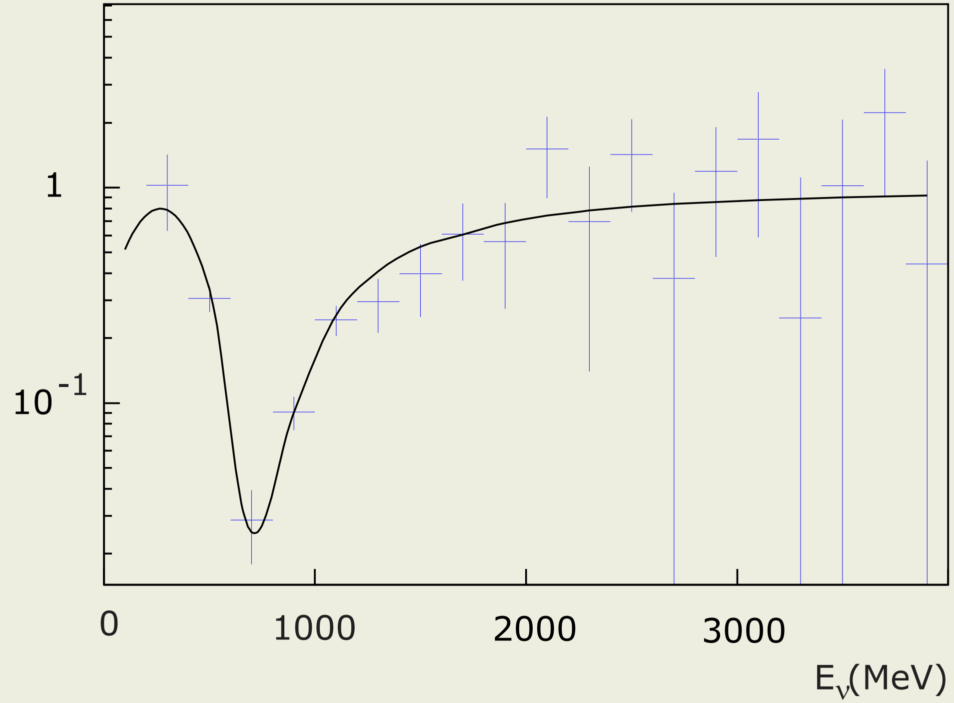
JHF: ν_μ disappearance

K2K at half of its statistics:



JHF in 5 years

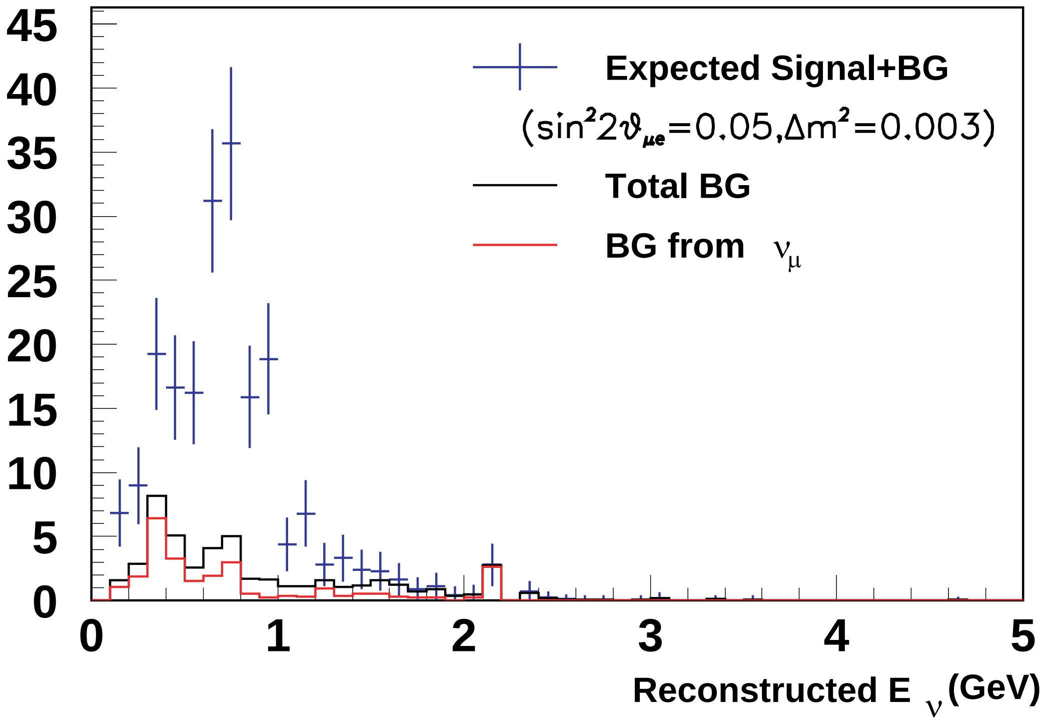
- δm^2_{23} with a resolution of 10^{-4} eV^2.
- $\sin^2 2\theta_{23}$ at $1 \div 2$ %.



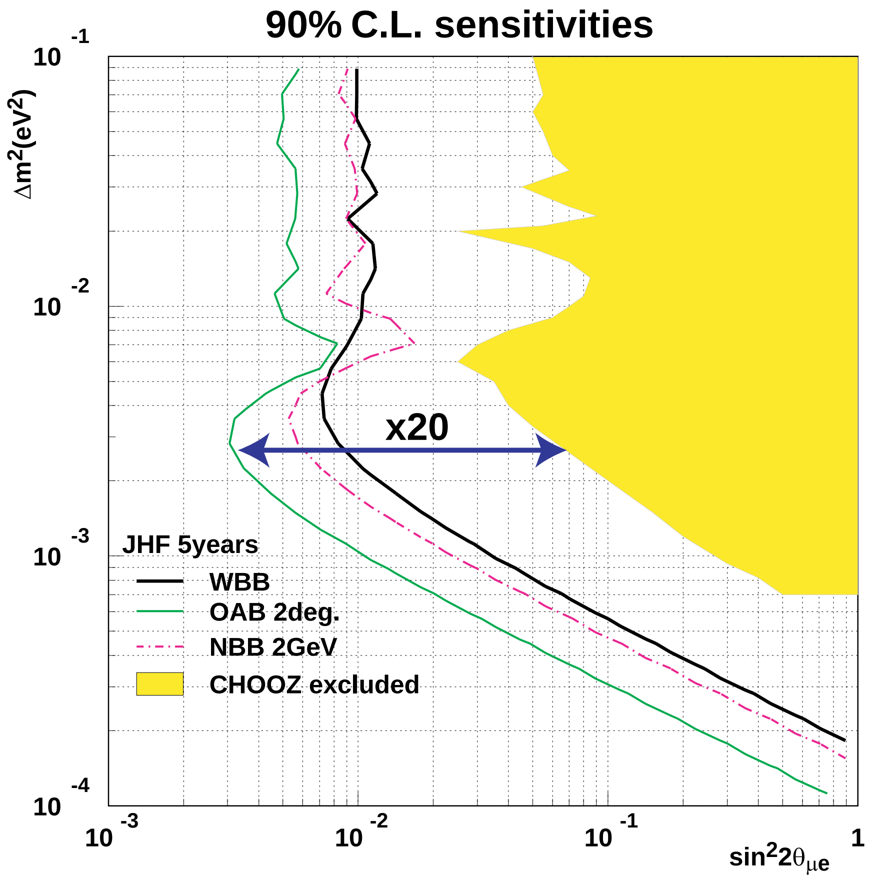
Ratio of the measured ν_μ spectrum with respect to the non-oscillation prediction in case of oscillation.

JHF ν_e appearance

OAB 2°	ν_μ CC	ν_μ NC	ν_e CC	Osc. ν_e
Generated in F.V.	10713.6	4080.3	292.1	301.6
1R e-like	14.3	247.1	68.4	203.7
e/π^0 separation	3.5	23.0	21.9	152.2
0.4 GeV$< E_{rec} < 1.2$ GeV	1.8	9.3	11.1	123.2



Sensitivity to θ_{13}



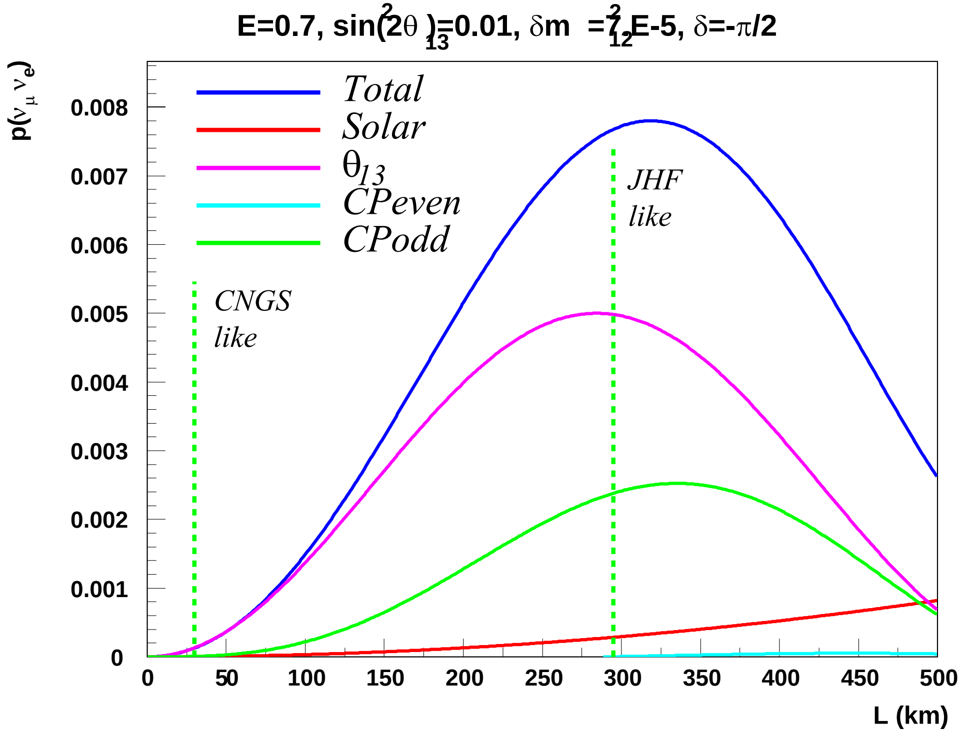
Degeneracies, correlations and ambiguities.

δ / θ_{13} degeneracy:

θ_{13} and δ are strongly degenerate in $p(\nu_\mu \to \nu_e)$.

In a neutrino run, positive δ values tend to cancel the θ_{13} oscillating term. The effect rises if δm^2_{12} rises.

Should we paradoxically conclude that this is a problem? Certainly NOT: δ_{CP} is A SIGNAL. With an antineutrino run the sign of the CP violating term (obviously) reverses, and for large values of δ_{CP} and δm^2_{12} JHF could fit BOTH θ_{13} and δ_{CP}.



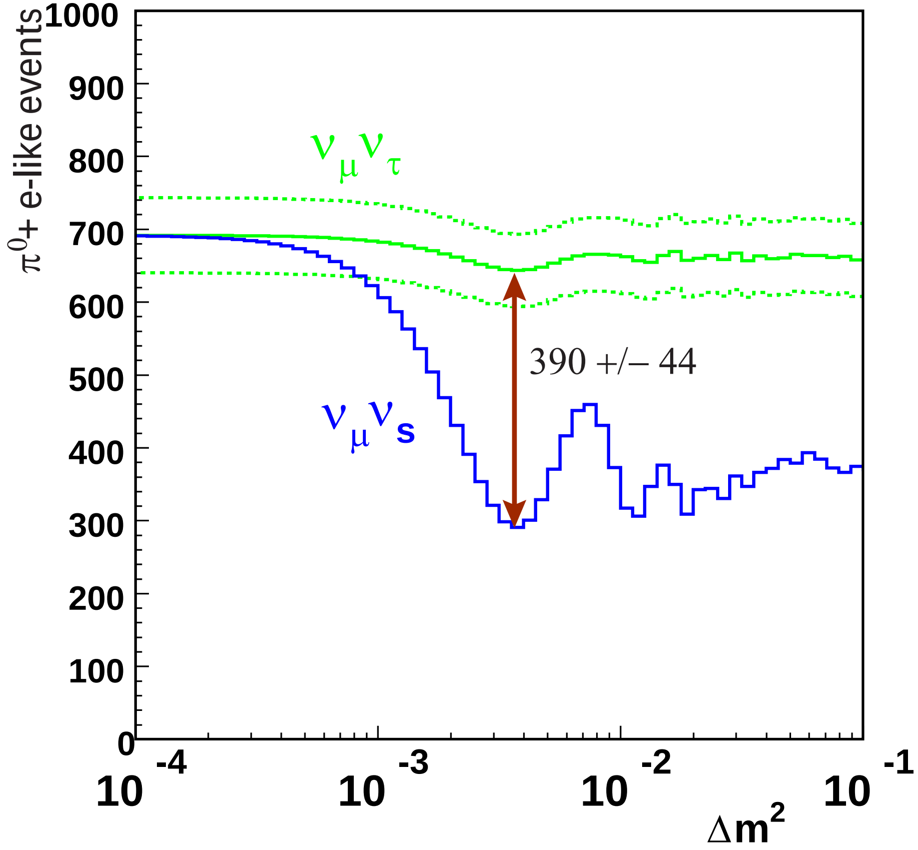
- $\theta_{23} / \pi/2 - \theta_{23}$ **ambiguity**: ν_μ disappearance measures $\sin^2(2\theta_{23})$ while $p(\nu_\mu \to \nu_e)$ depends by $\sin^2(\theta_{23})$. For $\theta_{23} \neq \pi/2$ this creates two different solutions.
- **sign of δm^2_{23} ambiguity**: Changing the sign of δm^2_{23} $p(\nu_\mu \to \nu_e)$ changes, mainly for the matter effects. This creates two different solutions (small effect on JHF).

Separazione $\nu_\tau - \nu_{\text{sterili}}$

Tag delle correnti neutre con i π° (metodo Vissani-Smirnov), usato anche in SK ($\nu + N \rightarrow \nu + N + \pi^\circ$)

Le sistematiche sulla sezione d'urto di produzione risonante di π° in eventi di NC verranno fortemente ridotte dal close detector di K2K e dai close detectors di JHF.

Limite alla frazione di ν_s a circa 0.1 (90% CL).



The role of close detectors

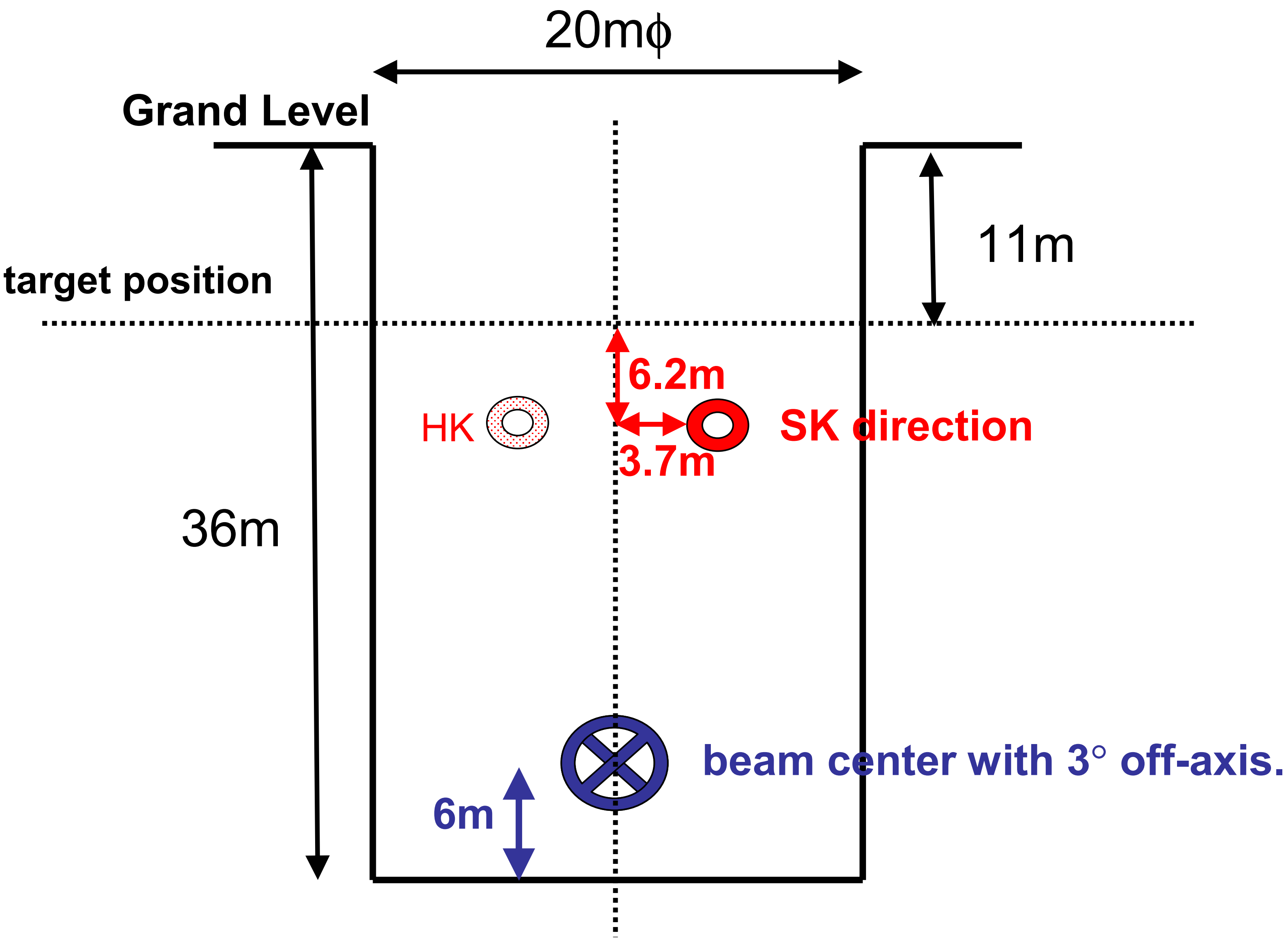
The need is not (only) to subtract backgrounds with 2%, 5% or 10% systematic error.

The need is to ground to solid rock the discovery of the elusive subleading ν_e appearance.

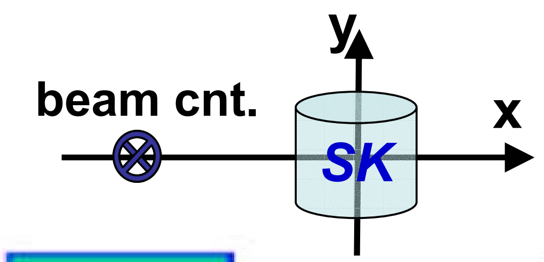
Fluxes , particle identification and background subtractions should be computed with redundant experimental informations and the minimum need of MonteCarlos.

- ν_μ (10%) and ν_e (3%) flux predictions with the minimum far/near bias.
- Measure of the single π° resonant cross sections. Possibly as function of the energy. They are the main backtround for the ν_e appearance (CC) and the experimental sample for the sterile neutrino appearance (NC).
- Evaluation of the quasi-elastic/resonance ratio, the major uncertitude of the reconstruction of the energy of the events.
- Measure of the particle identification algorithms in a close-detector similar to SuperKamiokande.
- Direction of the horn focused pions:
  - $\delta < E_\nu > \simeq 25\, MeV/\mathrm{mrad} \rightarrow \delta(\Delta m^2) = 10^{-4}\, eV^2/\mathrm{mrad}$
  - $\delta\Phi_\nu/\Phi = 4\%/\mathrm{mrad} \rightarrow \delta(\sin^2 2\theta) = 0.001 - 0.005$

2. The detector hall at 280m from the target

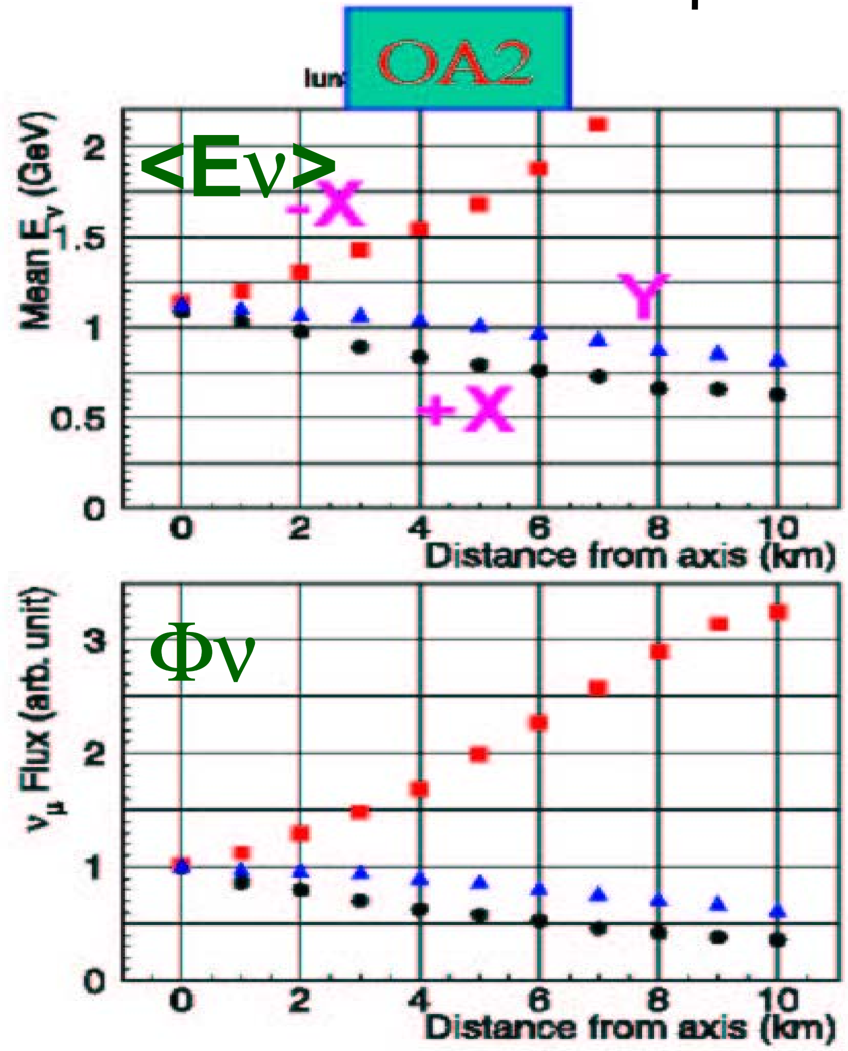


3. ND280 at on-axis (ND280on)



- Off-axis beam systematic
  - $\langle E\nu \rangle$~80MeV/km
    ~25MeV/mrad
    $\rightarrow$ $\delta(\Delta m^2)=1\times10^{-4}eV^2$
  - $\delta\Phi\nu$~13%/km
    ~4%/mrad
    $\rightarrow\delta(\sin^2 2\theta)=0.001\sim0.005$
    for $\sin^2 2\theta=1.0\sim0.9$

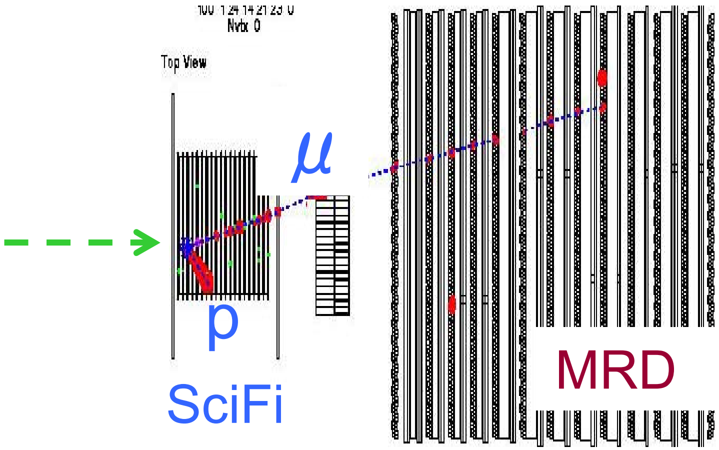
possible systematic error.

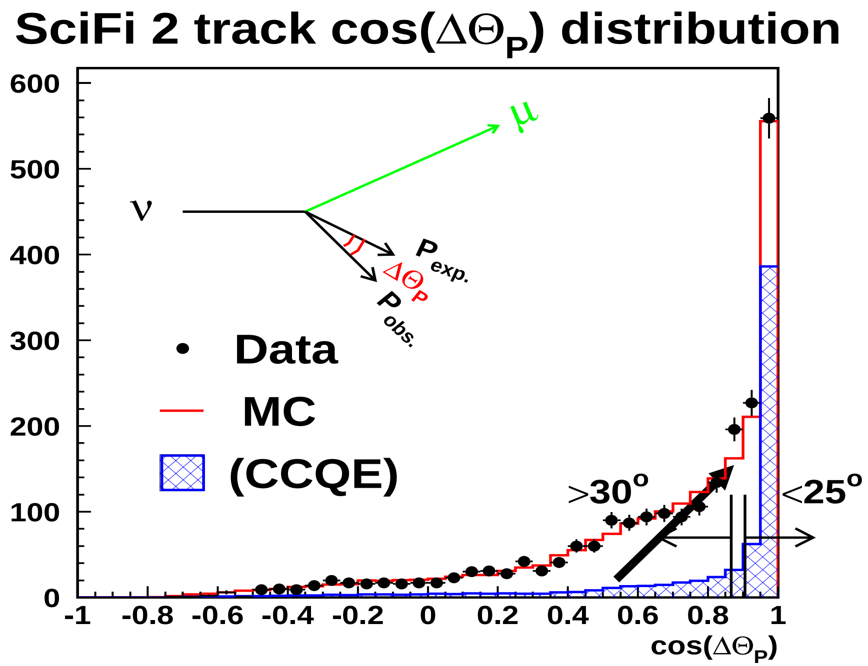


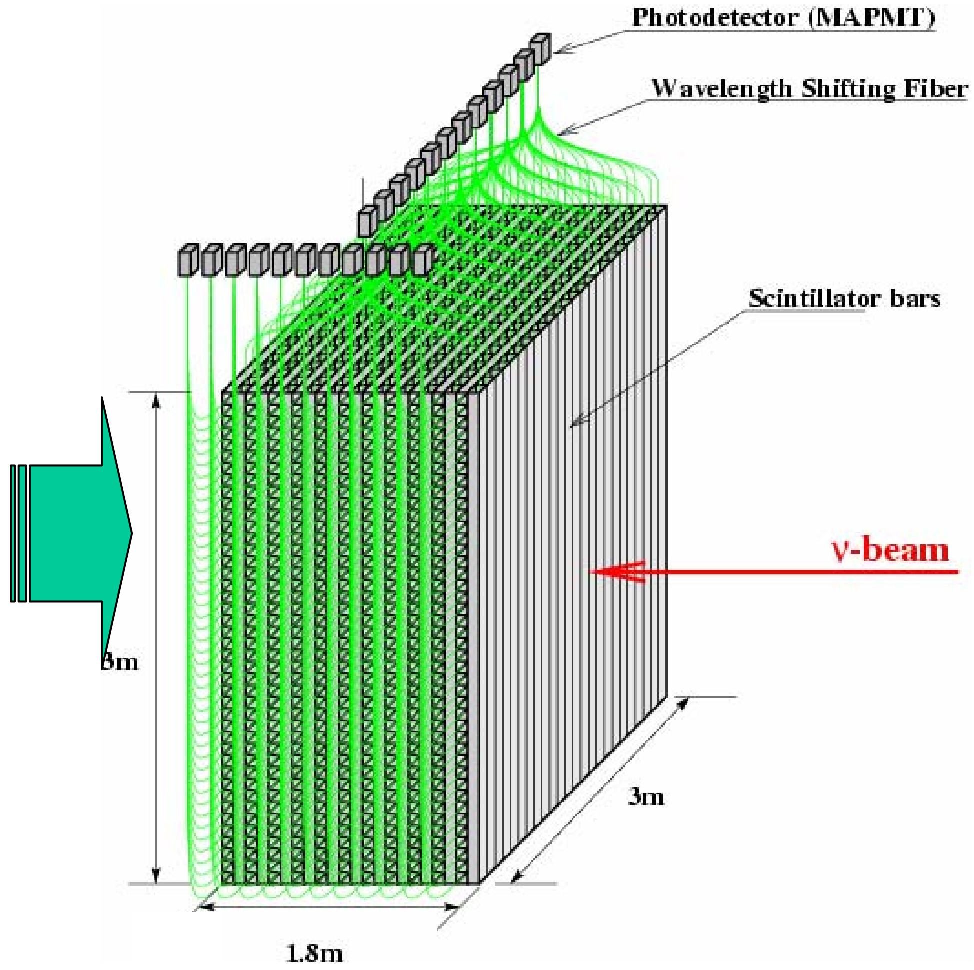
ND280on Purpose:

- monitor the beam direction.
- monitor the beam flux:
  Nν and Eν

Fine grained detector (fully active scintillator ?)

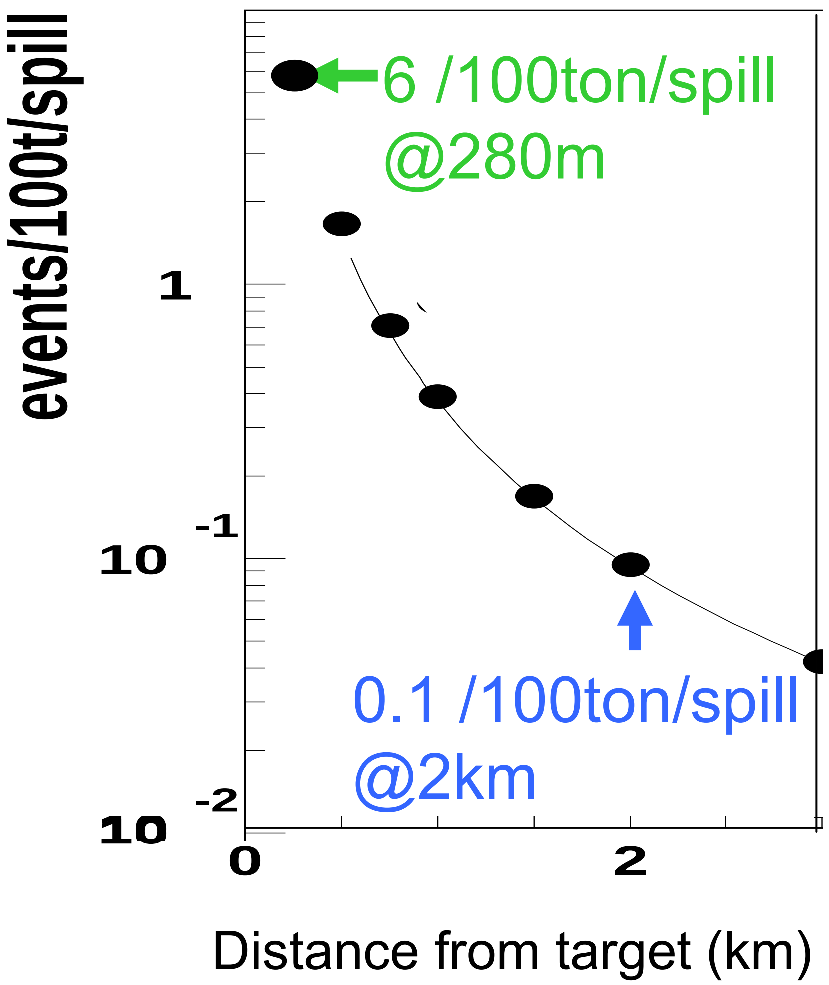


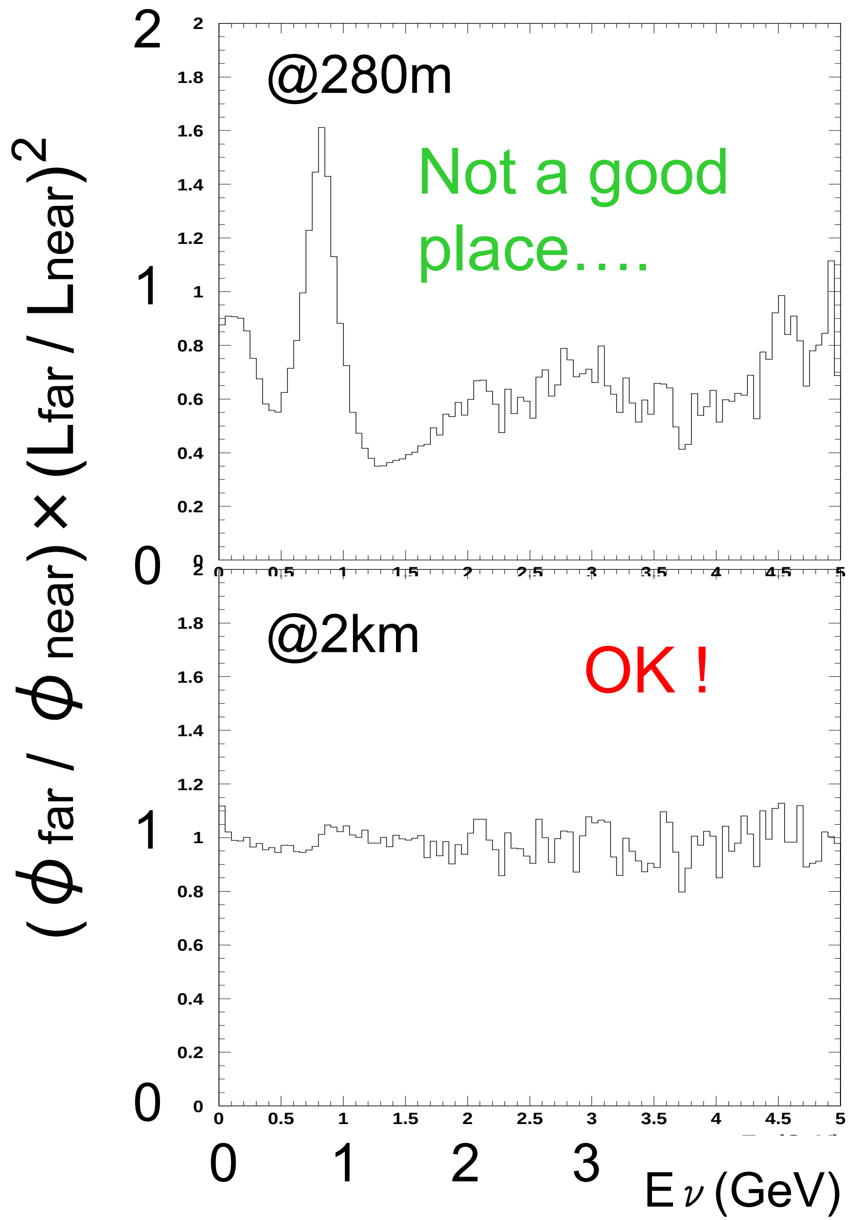




Very important to understand the details of ν interactions.

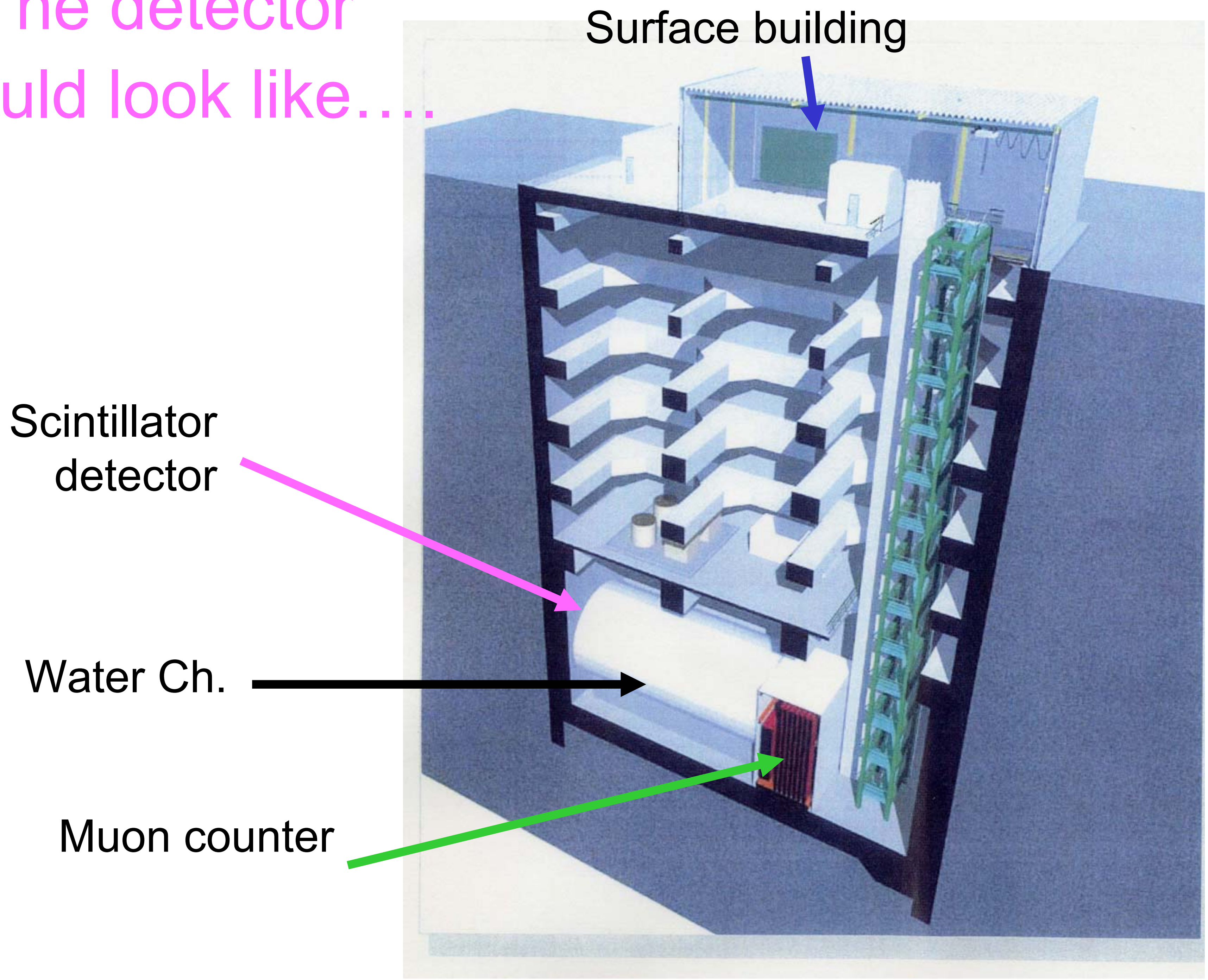
Event rate & Far/near ratio



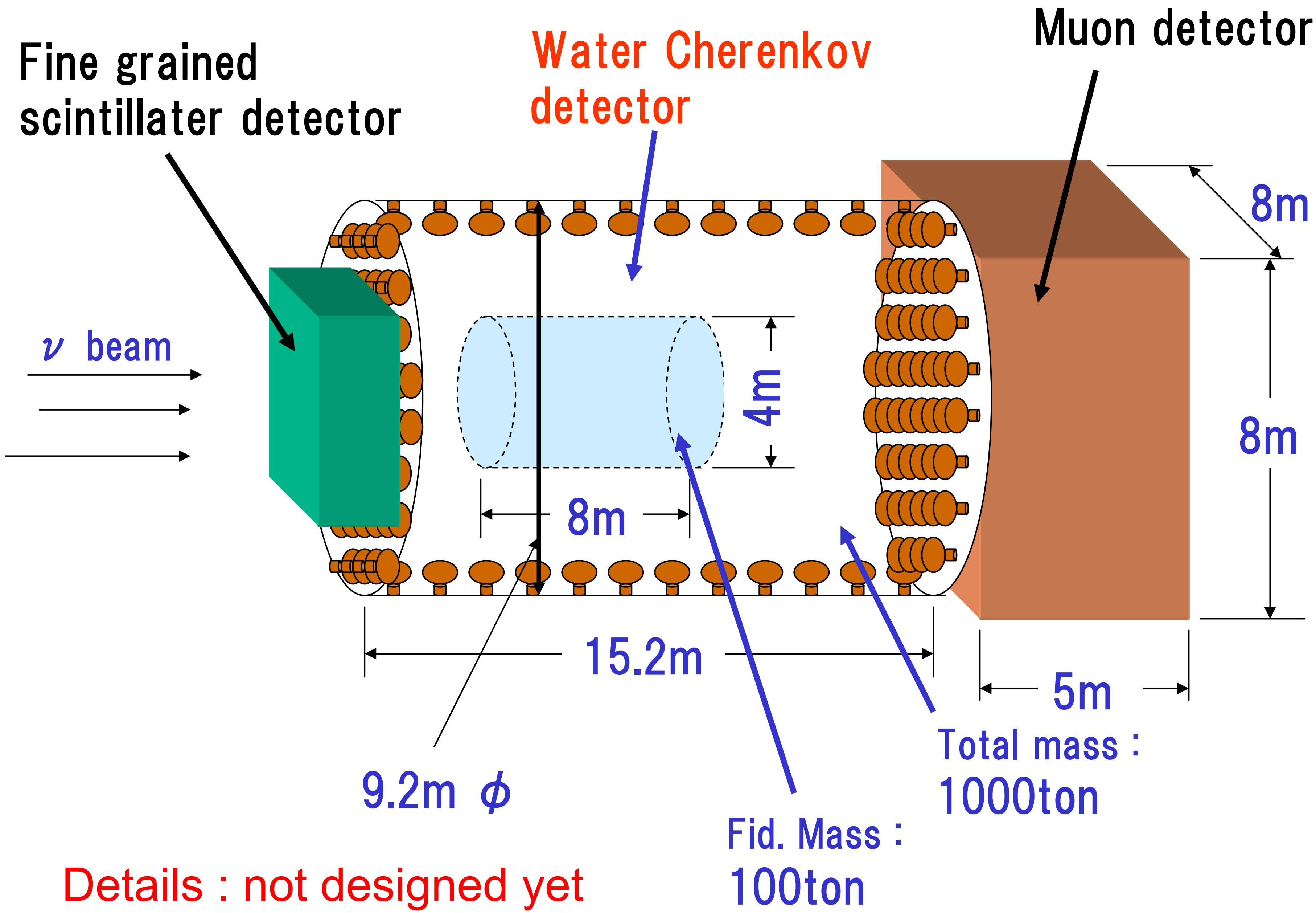


Water Cherenkov : Impossible @280m (Total mass > 100 tons)

The detector should look like….



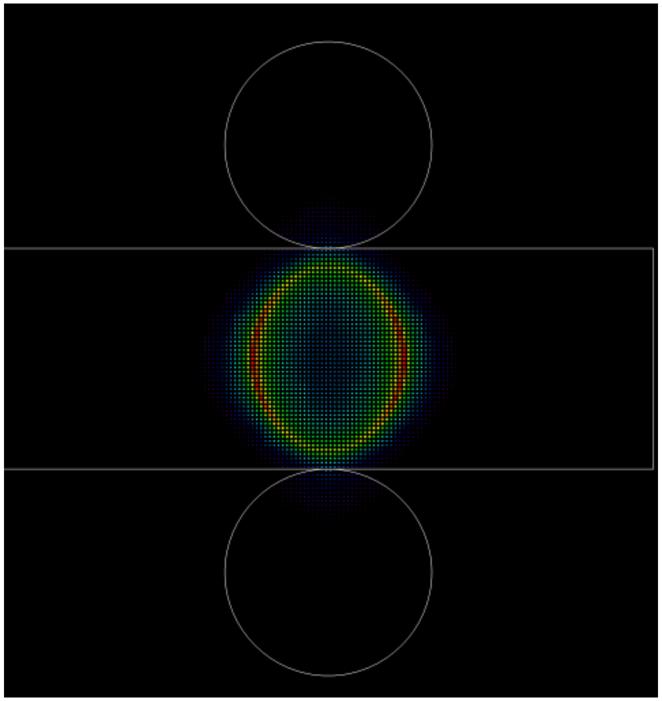
Near detector @2km



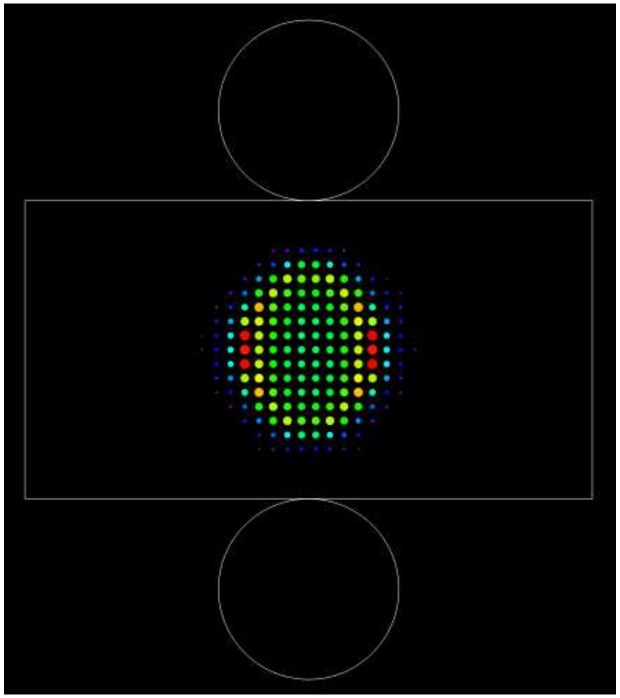
Details : not designed yet

2km Intermediate Detector

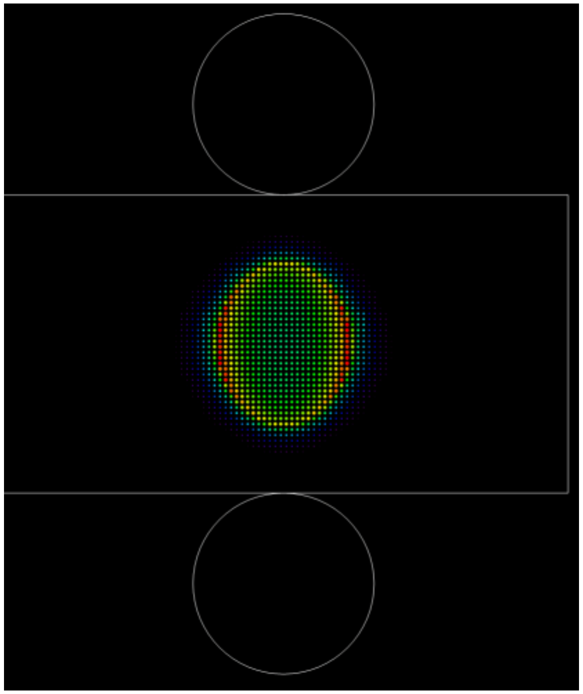
Electron simulation



Super-Kamiokande



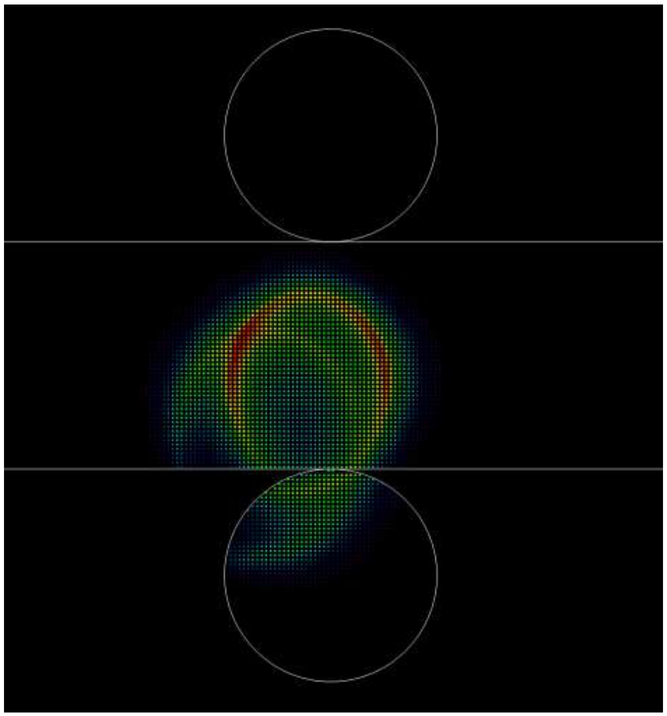
Intermediate detector
20 inches



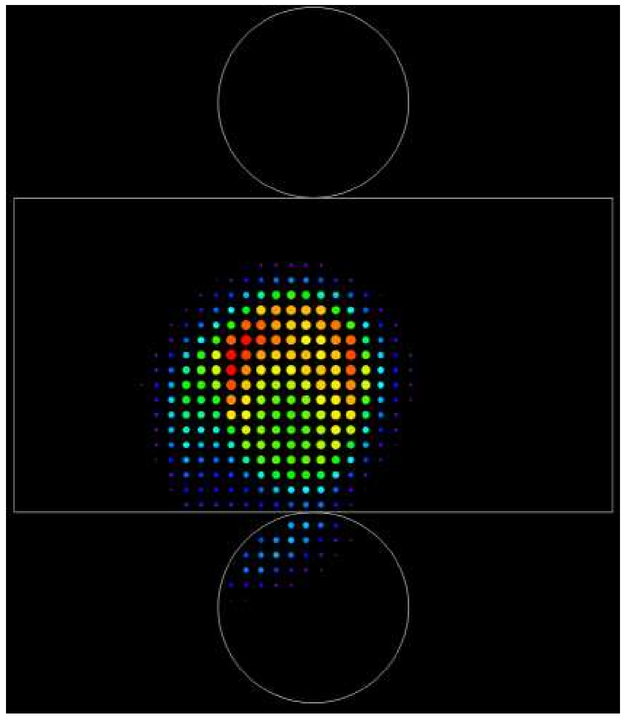
Intermediate Detector
8 inches

2km Intermediate Detector

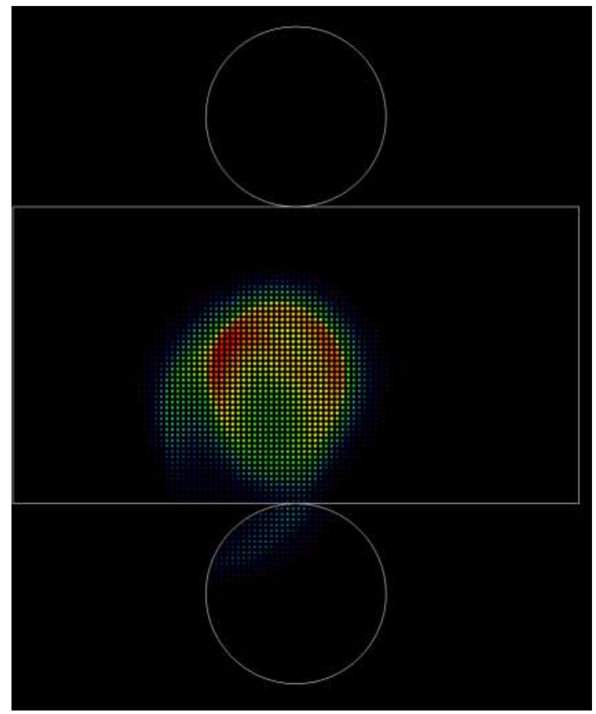
π^0 simulation



Super-Kamiokande



Intermediate detector
20 inches



Intermediate Detector
8 inches

Upgrade degli algoritmi di ricostruzione degli eventi in SK

1) Ricostruzione di E_ν con una precisione di 80 MeV

2) Miglioramento di un fattore 30 della reiezione e/π°

Gli algoritmi di SK ad oggi porterebbero il fondo dei π° al 2.5% delle ν_μ^{CC} con una efficienza sugli elettroni dell'80%.

D'altra parte ad oggi SK non ha bisogno di reiezioni spinte dei π° negli eventi atmosferici o per la ν_μ disappearance di K2K.

Gli algoritmi sono provati sul MC di SK tunato sui dati di K2K

3) Separazione e/μ a 10^{-4}.

Il fascio dei neutrini di JHF, stato finanziario

Il fascio dei neutrini é stimato a **213 OkuYen**. La spesa copre:

- Fast estraction dal PS
- Linea di trasporto dei protoni con magneti SC
- Target, Horn, Reflector, Decay tunnel
- Tutti i sistemi di monitor
- Due stazioni di close detectors, una a 280 m e l'altra a 2 km.

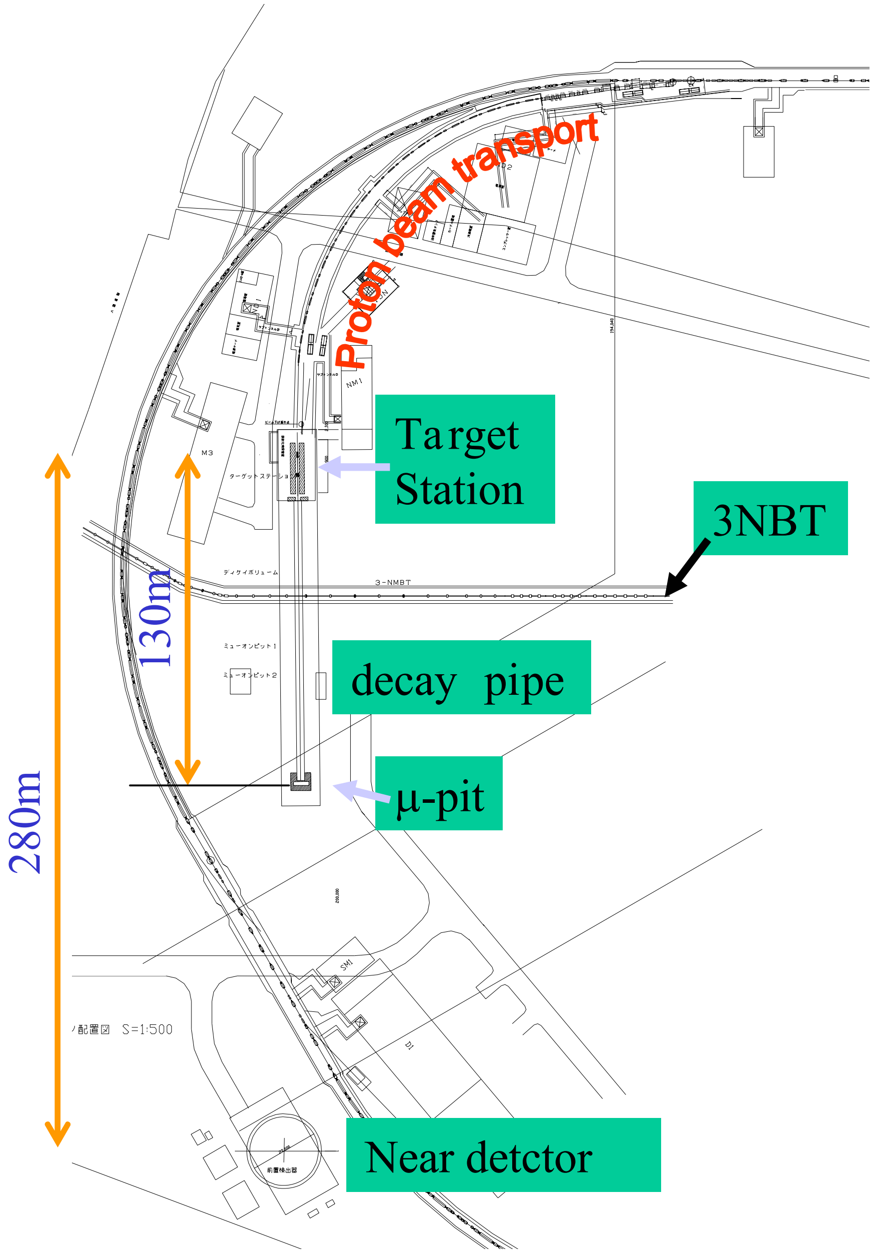
I giapponesi contano di essere finanziati per **163 OkuYen** (76% del totale). Il finanziamento dovrebbe essere deciso autunno quest'anno.

Gli enti finanziatori richiedono che i mancanti 50 OkuYen vengano raccolti formando una ampia collaborazione internazionale.

La riparazione di SuperKamiokande é a carico della collaborazione SuperKamiokande.

E' richiesto aiuto tecnico su tutti gli aspetti della costruzione del fascio dei neutrini e viene lasciata alla collaborazione internazionale la responsabilitá dei close detectors.

Al momento nessun rivelatore é stato appaltato e c'é ampio margine di manovra.



- Ceiling of 163 Oku-yen (1 Oku-yen ~ 1 M$)
  - *Is it an absolute ceiling?*
  - *It is about the cost of neutrino beam line + 280 m detector.*
  - *No contingency at all.*
- How to get funding for the 2 km detector?
  - *We wish to get additional funding for the experimental hall + detector.*
  - *If it is allowed to request it from KEK for JFY 2004 budget depends on the forthcoming negotiation with MEXT (Monkasho).*
  - *One of the necessary conditions is the availability of the candidate site for the 2 km detector.*
  - *Also, realistic design and cost estimation of the detector hall are needed.*

Schedule

- End of June: KEK → MEXT (Monkasho)
- End of August: MEXT → Ministry of Finance
- End of December: Decision of JFY 2004 budget

Schedule

- FINAL READY-TO-CONSTRUCT design for **whole neutrino facility**
  - Oct. 2003~Mar.2004
- Design of Target station / Beam dump (μ-mon) / 280m hall
  - have to be finalized by the end of Dec. 2003
- Schedule from JFY2004(not yet finally fixed)
  - 4 year budget plan (JFY2004~JFY2007)
  - Aim to complete beam line by Sep. 2007
  - Commissioning in later half of JFY2007
  - 280m hall construction will be the last (~Sep.2007?)

Letter of Intent
Neutrino Oscillation Experiment at JHF

Summary

The first stage of a next-generation long baseline neutrino oscillation experiment is proposed to explore the physics beyond the Standard Model. The experiment will use the high intensity proton beam from the JHF 50 GeV proton synchrotron (JHF PS), and Super-Kamiokande as a far detector. The baseline length will be 295 km. The beam power of JHF PS is capable of delivering 3.3×10^{14} 50 GeV protons every 3.5 seconds (0.75 MW). The experiment assumes 130 days of operation at full intensity for five years. The high intensity neutrino beam is produced in an off-axis configuration. The peak neutrino energy is tuned to the oscillation maximum of ~0.8 GeV to maximize the sensitivity to neutrino oscillations.

The merits of this experiment can be summarized as follows:

- The off-axis beam can produce the highest possible intensity with a narrow energy spread. The oscillation maximum will be ~0.8 GeV for the distance of 295 km and $\Delta m^2 \sim 3 \times 10^{-3} eV^2$. The corresponding angle of the beam line axis relative to the direction of far detector is about 2 degrees.
- The far detector, Super-Kamiokande (SK), already exists. Experience in operating SK, including analysis tools, already exists. SK has excellent performance in detecting low-energy neutrinos.
- The neutrino events at sub-GeV are dominated by charged current quasi-elastic interactions, hence the neutrino energy E_ν can be reconstructed by two body kinematics.

The expected sensitivities in the first stage, assuming 0.75 MW and 130 days operation for five years are:

- Discovery of $\nu_\mu \to \nu_e$ at $\Delta m^2 \sim 3 \times 10^{-3} eV^2$ down to $sin^2 2\theta_{13} \sim 0.006$. This is a factor of twenty improvement in sensitivity over past experiments.
- Precision measurements of oscillation parameters in ν_μ disappearance down to $\delta(\Delta m^2_{23}) = 10^{-4}$ eV^2 and $\delta(\sin^2 2\theta_{23}) = 0.01$.
- Search for a sterile component in ν_μ disappearance by detecting neutral current events.

With successful completion of the first stage, a second stage of the experiment can be envisaged. In the second stage with the 1 Mt Hyper-Kamiokande detector and upgraded 4 MW PS, CP violation in the lepton sector can be probed, if $\sin^2 2\theta_{13}$ is in the discovery range of the first stage of the experiment. Sensitivity to proton decay is significantly extended up to 10^{35} ($(2 \sim 3) \times 10^{34}$) years lifetime for the $p \to e^+\pi^0$ ($p \to \bar{\nu}K^+$) mode.

Japan

KEK
Y. Hayato, A. K. Ichikawa, T. Ishida, T. Ishii, J. Kameda, T. Kobayashi, K. Nakamura, Y. Oyama, M. Sakuda, M. Tanaka, Y. Totsuka, M. Yoshida
ICRR, University of Tokyo
Y. Itow, T. Kajita, K. Kaneyuki, Y. Koshio, M. Miura, S. Moriyama, M. Nakahata, T. Namba, Y. Obayashi, C. Saji, M. Shiozawa, Y. Suzuki, Y. Takeuchi
Hiroshima University
I. Endo, M. Iinuma, T. Takahashi
Kobe University
S. Aoki, T. Hara, A. Suzuki
Kyoto University
T. Nakaya, K. Nishikawa
Miyagi University of Education
Y. Fukuda
Osaka City University
T. Okusawa, K. Yamamoto
Tohoku University
T. Hasegawa, K. Inoue, M. Koga, J. Shirai, F. Suekane, A. Suzuki
University of Tokyo
H. Aihara, M. Iwasaki, M. Yokoyama

Canada

University of Alberta
P. Kitching, J. McDonald, M. Vincter
University of Regina
R. Tacik
University of Toronto
J. Martin
TRIUMF
M. Barnes, E. Blackmore, J. Doornbos, P. Gumplinger, R. Helmer, R. Henderson, A. Konaka, G. Marshall, J. Macdonald, J.M. Poutissou, G. Wait, S. Yen
University of Victoria
R. Kowalewski
York University
S. Bhadra, S. Menary

France

CEA SACLAY - DSM/DAPNIA - Service de Physique des particules
J. Bouchez, C. Cavata, J. Mallet, L. Mosca, F. Pierre

Italy

INFN - University of Bari
G. Catanesi, E. Radicioni
INFN - University of Napoli
V. Palladino
INFN - University of Padova
M. Mezzetto
INFN - University of Roma
U. Dore, P. Loverre, L. Ludovici

Korea

Kangwon University
S.K. Nam
Kyungpook National University
W. Kim
KyungSang National University
I.G. Park
Dongshin University
M.Y. Pac
SungKyunKwan University
Y.I. Choi
Seoul National University
S.B. Kim, K. Joo
Chonnam Naitonal University
J.Y. Kim, I.T. Lim
Yonsei University
Y. Kwon

Poland

Warsaw University
D. Kielczewska

Russia

Institute for Nuclear Research RAS
A.V. Butkevich, Yu.G. Kudenko, V.A. Matveev, S.P. Mikheyev

Spain

University of Barcelona
E. Fernandez, F. Sanchez
University of Valencia
J. Burguet, J.J. Gomez Cadenas, A. Tornero

Switzerland

University of Geneva
A. Blondel, S. Gilardoni

UK

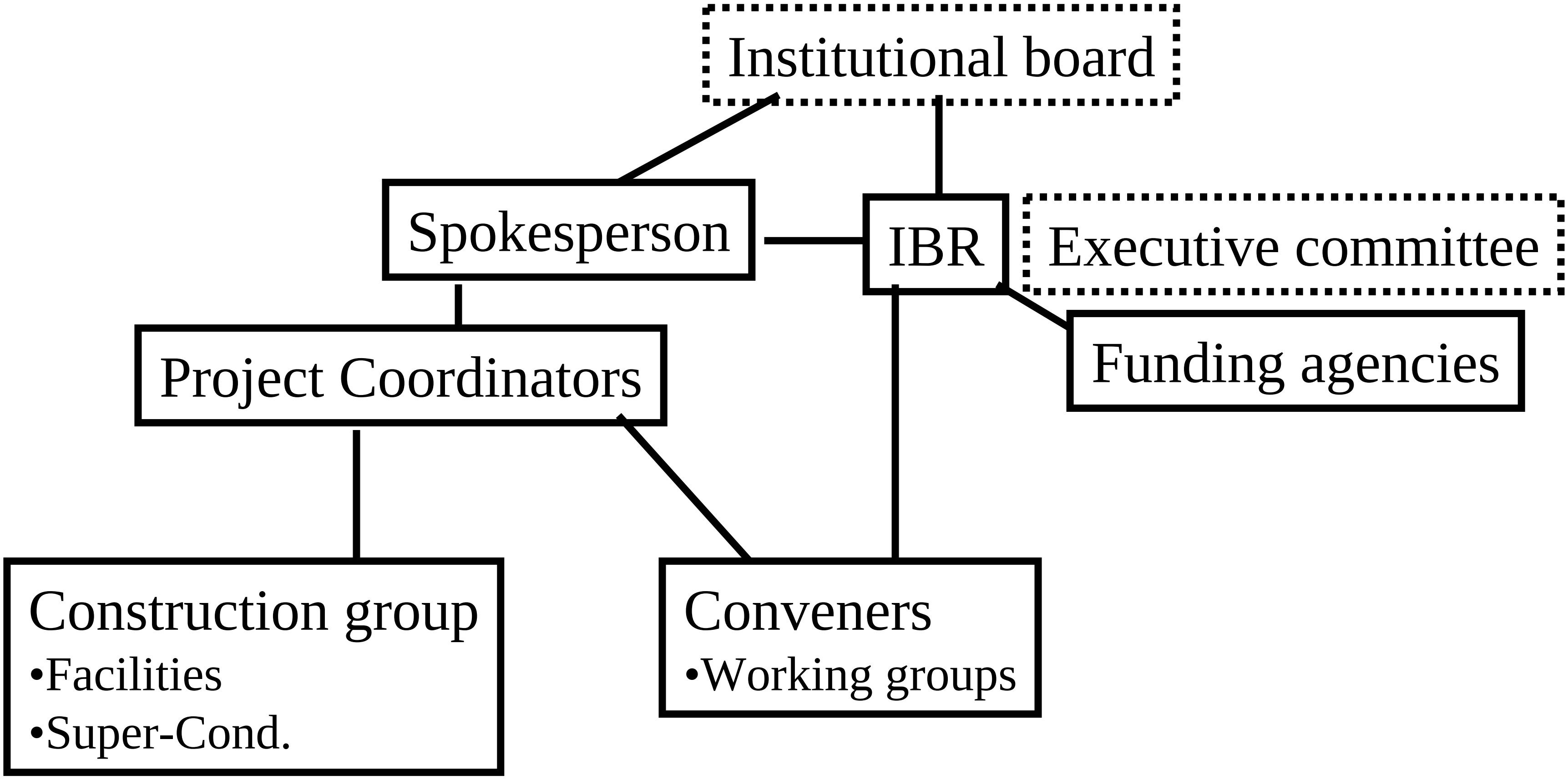
Rutherford Appleton Laboratory
D.L. Wark
Imperial College London
P. Dornan, K. Long
Queen Mary Westfield College London
P. Harrison
University of Liverpool
J.B. Dainton, A. Mehta, C. Touramanis

USA

Argonne National Laboratory
M. Goodman
Boston University
E. Kearns, J.L. Stone, L.R. Sulak, C.W. Walter
Brookheavn National Laboratory
M. Goldhaber, M. Harrison, P. Wanderer
University of California, Berkeley and Lawrence Berkeley National Laboratory
K. M. Heeger, Kam-Biu Luk
University of California, Irvine
W.R. Kropp, S. Mine, M.B. Smy, H.W. Sobel, M.R. Vagins
California State University Dominguez Hills
K. Ganezer, J. Hill, W. Keig
University of Hawaii
J.G. Learned, S. Matsuno
Los Alamos National Laboratory
T.J. Haines
Louisiana State University
R. Svoboda
Massachusetts Institute of Technology
K. Scholberg
The University of Pennsylvania
E.W. Beier, W.J. Heintzelman, N. McCauley. S.M. Oser
The University of Rochester
A. Bodek, H. Budd, K. McFarland, P. Slattery, M. Zielinski
The State University of New York at Stony Brook
C.K. Jung, K. Kobayashi, C. McGrew, A. Sarrat, C. Yanagisawa
University of Washington
R.J. Wilkes

Contact Person : Koichiro Nishikawa (Kyoto University)
Email : nishikaw@scphys.kyoto-u.ac.jp, Tel : 81-75-753-3859

Minimum organization



IBR

- Spokesperson — K. Nishikawa
- Construction group representative — T. Kobayashi
- National/Regional representatives

Canada	A. Konaka, J.M. Poutissou	China	To be named
Italy	M. Mezzetto	France	F. Pierre
Korea	S.B. Kim	Poland	D. Kielczewska
Russia	Y. Kudenko	Spain	F. Sanchez
Switzerland	A.Blondel	UK	D. Wark
USA	G. Beir, C.K. Jung*, H. Sobel		

- KEK representative — K. Nakamura
- ICRR representative — Y. Suzuki

Leptonic CP

Two conditions to make Leptonic CP detectable:

- Solar LMA confirmed
- $\theta_{13} \geq 0.5^0$ (see the following).

A big step from a θ_{13} search:

$$\text{from } p(\nu_\mu \to \nu_e) \neq 0 \text{ to } \begin{cases} p(\nu_\mu \to \nu_e) \neq p(\overline{\nu}_\mu \to \overline{\nu}_e) & \text{(direct CP)} \\ p(\nu_\mu \to \nu_e) \neq p(\nu_e \to \nu_\mu) & \text{(T search)} \end{cases}$$

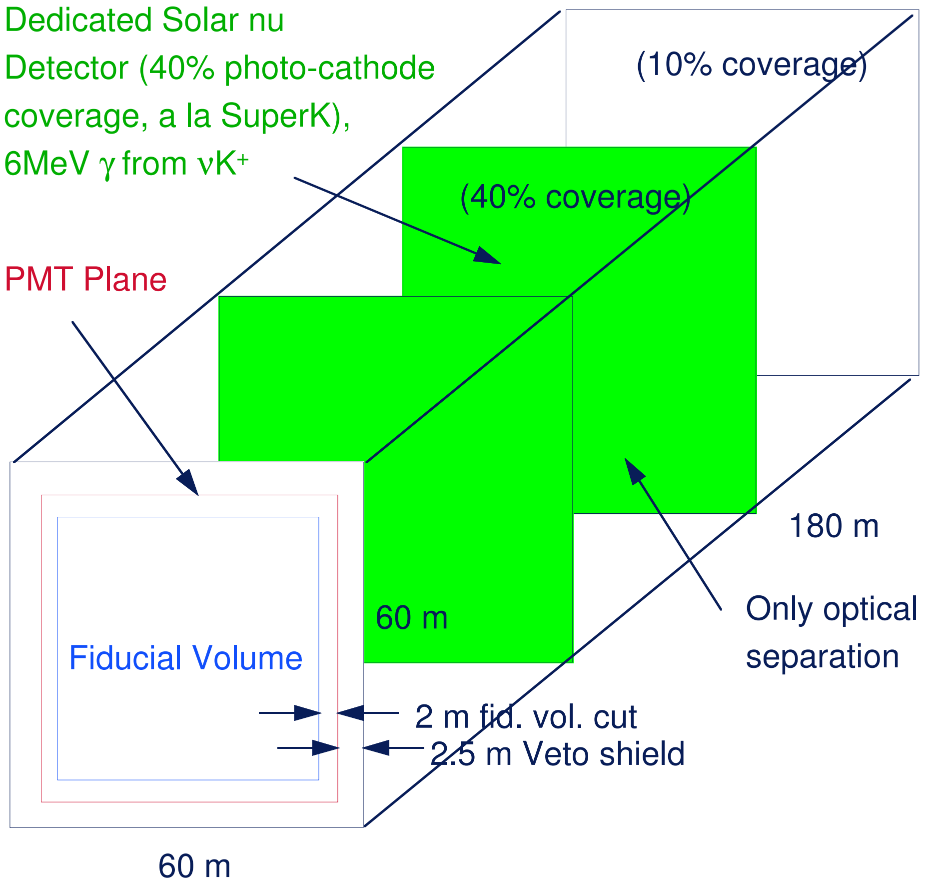
This will require:

1. Neutrino beams of novel conception.

Super Beams
Neutrino Factory
Beta Beams

2. Detectors of unprecedent mass
3. Improved control of systematics $\Rightarrow$ Dedicated experiments on neutrino cross-sections, hadron production, particle ID.

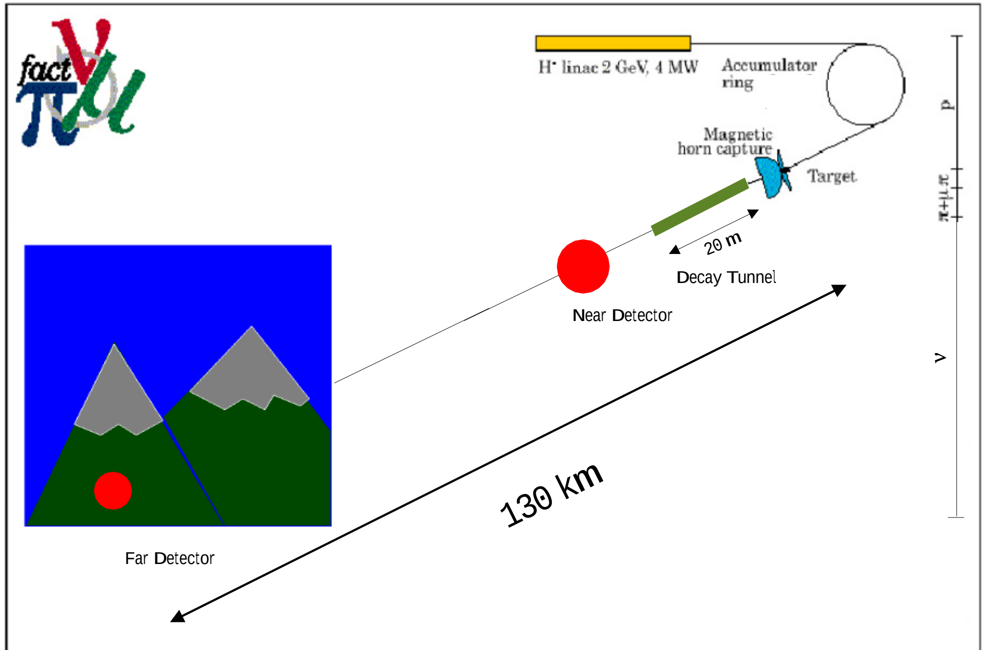
UNO detector



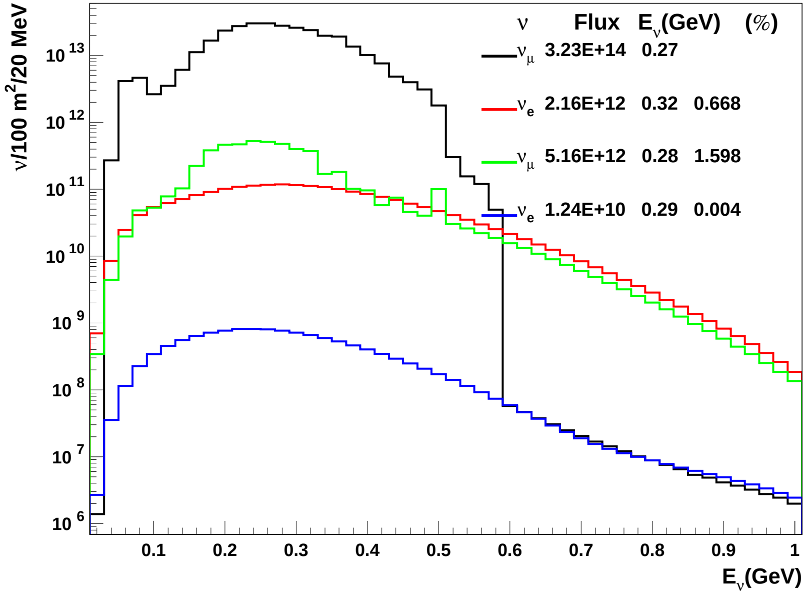
- Fiducial volume: 440 kton: 20 times SuperK.
- 60000 PMTs (20”) in the inner detector, 15000 PMTs in the outer veto detector.
- **The killer detector for proton decay, atmospheric neutrinos, supernovae neutrinos.**
- Energy resolution is poor for multitrack events but quite adequate for sub-GeV neutrino interactions.
- It would be hosted at the Frejus laboratory, 130 km from CERN, in a $10^6\ m^3$ cavern to be excavated.

SPL-SuperBeam at CERN

A feasibility study of the CERN possible developments



Possible Low Energy Super Beam Layout

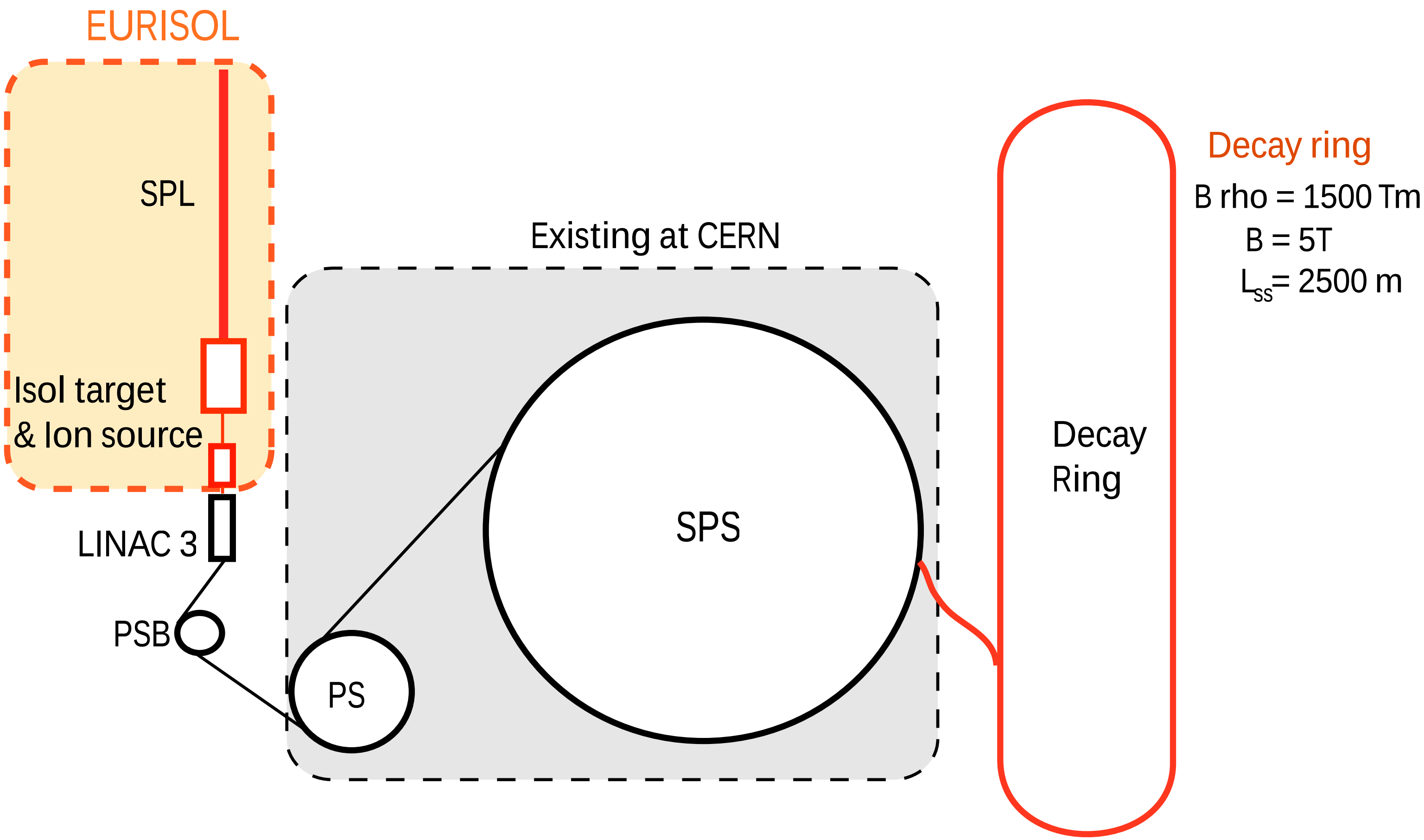


Flux intensities at 50 km from the target

Flavour	Absolute Flux $(\nu/10^{23}\mathrm{pot/m^2})$	Rel. Flux (%)	$\langle E_\nu \rangle$ (GeV)
ν_μ	$3.2 \cdot 10^{12}$	100	0.27
$\overline{\nu}_\mu$	$2.2 \cdot 10^{10}$	1.6	0.28
ν_e	$5.2 \cdot 10^{9}$	0.67	0.32
$\overline{\nu}_e$	$1.2 \cdot 10^{8}$	0.004	0.29

Beta Beam

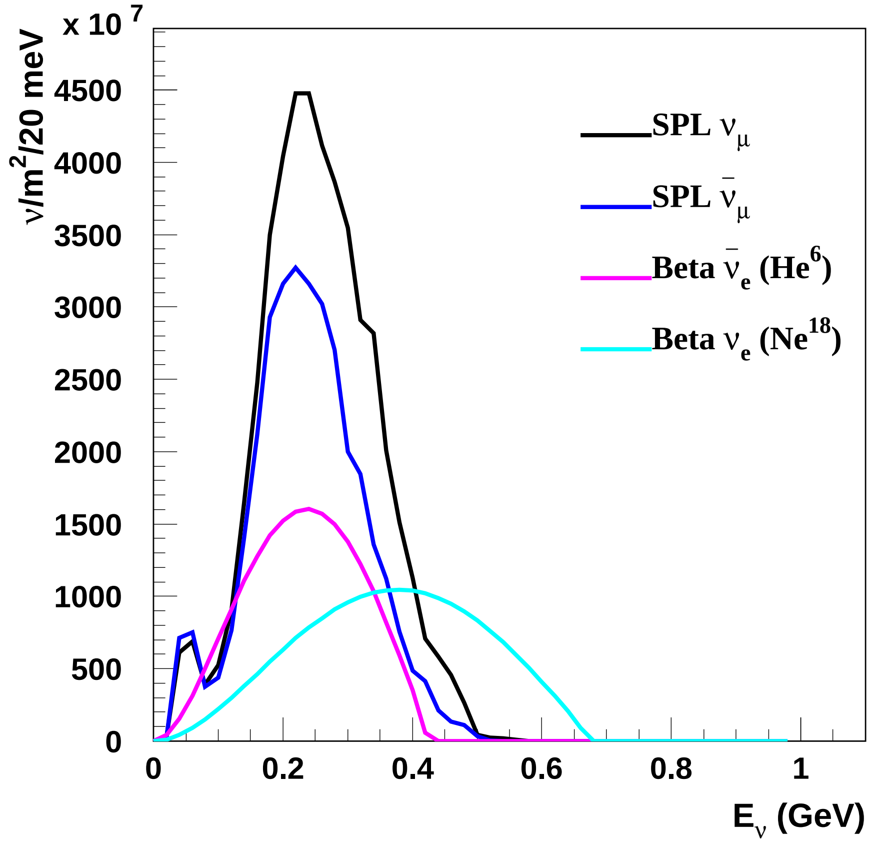
M. Lindroos and collaborators, see http://beta-beam.web.ch/beta-beam



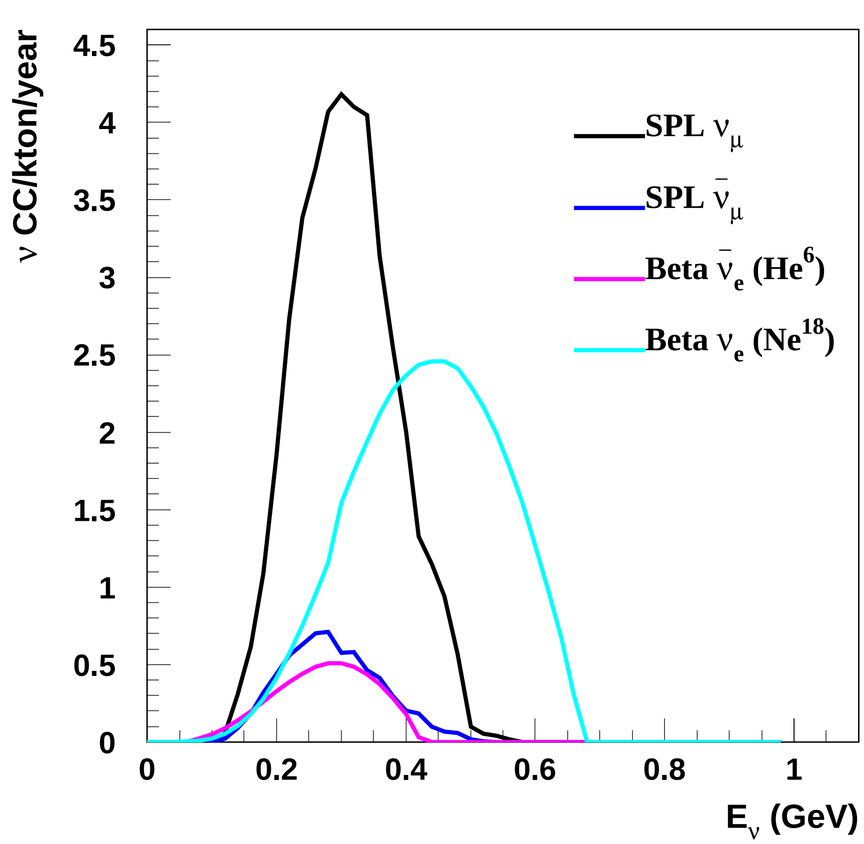
- 1 ISOL target to produce He^6, 100 μA, $\Rightarrow 2.9 \cdot 10^{18}$ ion decays/straight session/year. $\Rightarrow \overline{\nu}_e$.
- 3 ISOL targets to produce Ne^{18}, 100 μA, $\Rightarrow 1.2 \cdot 10^{18}$ ion decays/straight session/year. $\Rightarrow \nu_e$.
- The 4 targets could run in parallel, but the decay ring optics requires:

$$\gamma(Ne^{18}) = 1.67 \cdot \gamma(He^6).$$

Fluxes



CC Rates



	Fluxes @ 130 km $\nu/m^2/yr$	$< E_\nu >$ (GeV)	CC rate (no osc) events/kton/yr	$< E_\nu >$ (GeV)	Years	Integrated events (440 kton $\times$ 10 years)
SPL Super Beam						
ν_μ	$4.78 \cdot 10^{11}$	0.27	41.7	0.32	2	36698
$\overline{\nu}_\mu$	$3.33 \cdot 10^{11}$	0.25	6.6	0.30	8	23320
Beta Beam						
$\overline{\nu}_e$ ($\gamma = 60$)	$1.97 \cdot 10^{11}$	0.24	5.2	0.28	10	28880
ν_e ($\gamma = 100$)	$1.88 \cdot 10^{11}$	0.36	39.2	0.43	10	172683

Interesting features of a low energy conventional neutrino beam.

ν beam:

- $\langle E_{\nu_\mu} \rangle \simeq 0.25$ GeV $\Rightarrow$ L $\sim$ 100 km $\Rightarrow$ **NO MATTER EFFECTS**.
- ν_e production by kaons largely suppressed by threshold effects.

ν_e in the beam come only from μ decays.

$$\pi^+ \longrightarrow \mu^+\nu_\mu, \quad \mu^+ \downarrow e^+\nu_e\overline{\nu}_\mu$$

$\Rightarrow$ they can be predicted from the measured ν_μ CC spectrum both at the close and at the far detector **with a small systematic error of** $\sim 2\%$**.**

Detector Backgrounds

- Good e/π^0 separation following the large $\pi^0 \rightarrow \gamma\gamma$ opening angle
- Good e/μ separation in a Čerenkov detector because μ are produced below or just above the Čerenkov threshold.
- Charm and τ production below threshold.

Less exiting aspects of a low energy neutrino beam

- Cross sections are small $\Rightarrow$ large detectors are necessary in spite of the very intense neutrino beam.
- $\overline{\nu}_\mu$ production is disfavored for two reasons:
  - Smaller π^- multiplicity at the target.
  - $\overline{\nu}_\mu / \nu_\mu$ cross section ratio is at a minimum (1/5).
- Visible energy is smeared out by Fermi motion $\Rightarrow$ Counting Experiment.

The SuperBeam - BetaBeam synergy: CP, T and CPT

No other realistic scenario can offer CP, T and CPT searches at the same time in the same detector!!!!

CP Searches

- SuperBeam running with ν_μ and $\overline{\nu}_\mu$.
- Beta Beam running with ^{6}He ($\overline{\nu}_e$) and ^{18}Ne (ν_e).

T searches

- Compare Super Beam $p(\nu_\mu \rightarrow \nu_e)$ with Beta Beam ^{18}Ne $p(\nu_e \rightarrow \nu_\mu)$
- Compare Super Beam $p(\overline{\nu}_\mu \rightarrow \overline{\nu}_e)$ with Beta Beam ^{6}He $p(\overline{\nu}_e \rightarrow \overline{\nu}_\mu)$.

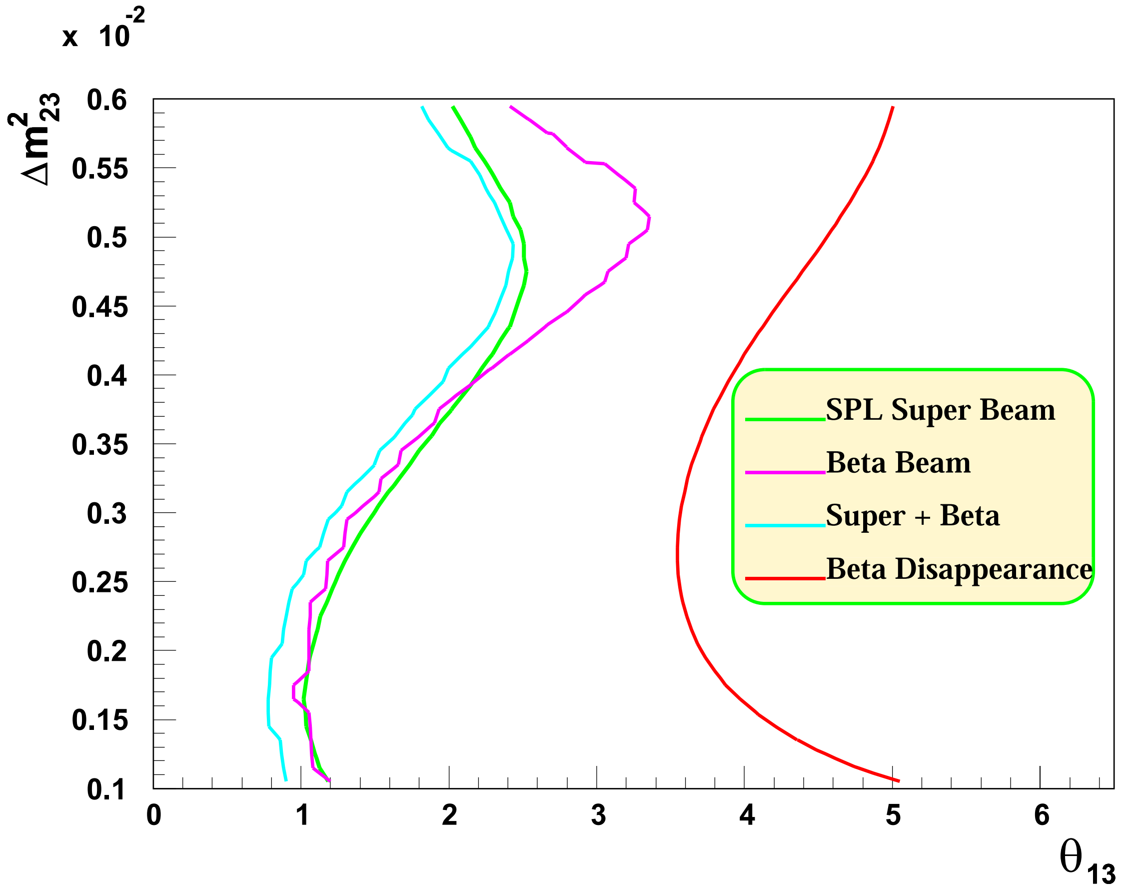
CPT searches

- Compare Super Beam $p(\nu_\mu \rightarrow \nu_e)$ with Beta Beam ^{6}He $p(\overline{\nu}_e \rightarrow \overline{\nu}_\mu)$.
- Compare Super Beam p($\overline{\nu}_\mu \rightarrow \overline{\nu}_e$) with Beta Beam ^{18}Ne $p(\nu_e \rightarrow \nu_\mu)$

The SuperBeam - BetaBeam synergy: a benchmark on θ_{13} sensitivity

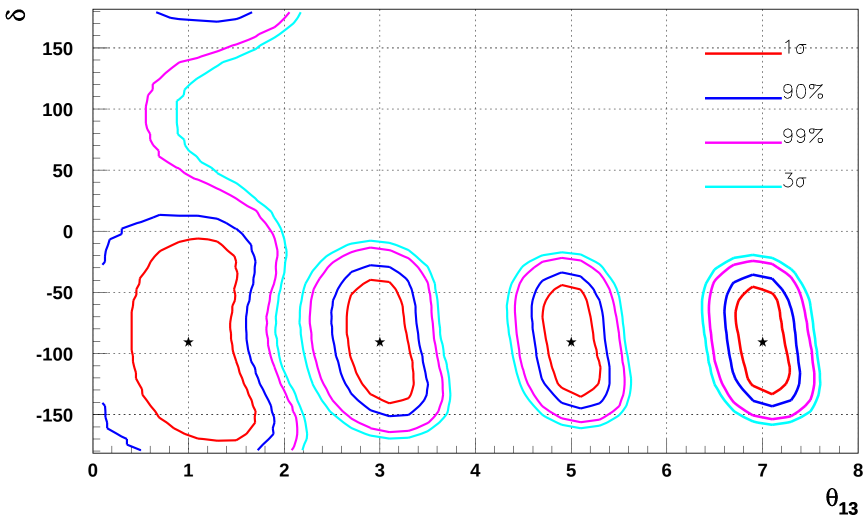
Computed for $\delta_{CP} = 0$ and 5 years running.

- Super Beam $\rightarrow 96\times$ CHOOZ.
- Super Beam + Beta Beam $\rightarrow 160\times$ CHOOZ.
- **Beta Beam can measure θ_{13} both in appearance and in disappearance mode. All the ambiguities can be removed for $\theta_{13} \geq 3.4^\circ$**

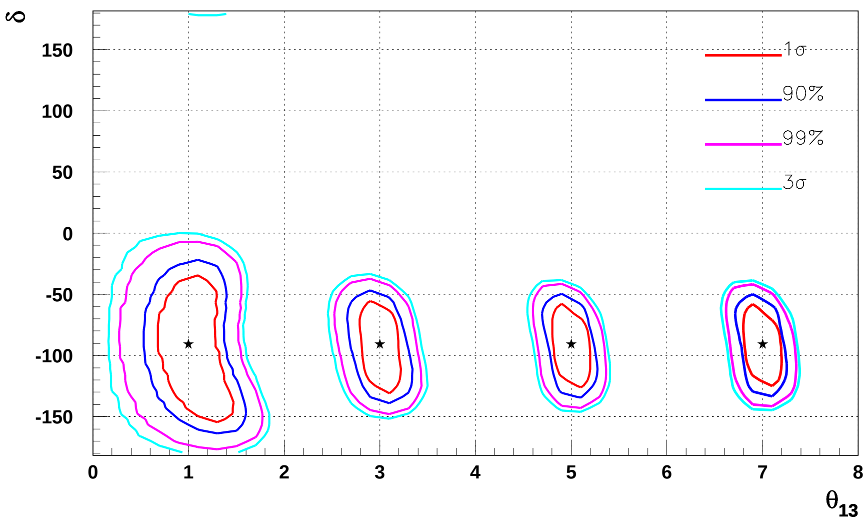


Beta Beam - Super Beam synergy: CP sensitivity

SUPER BEAM ONLY



SUPER BEAM + BETA BEAM



$$\delta m^2_{12} = 7 \cdot 10^{-5}\ eV^2, \quad \theta_{13} = 1^\circ, \quad \delta_{CP} = \pi/2$$

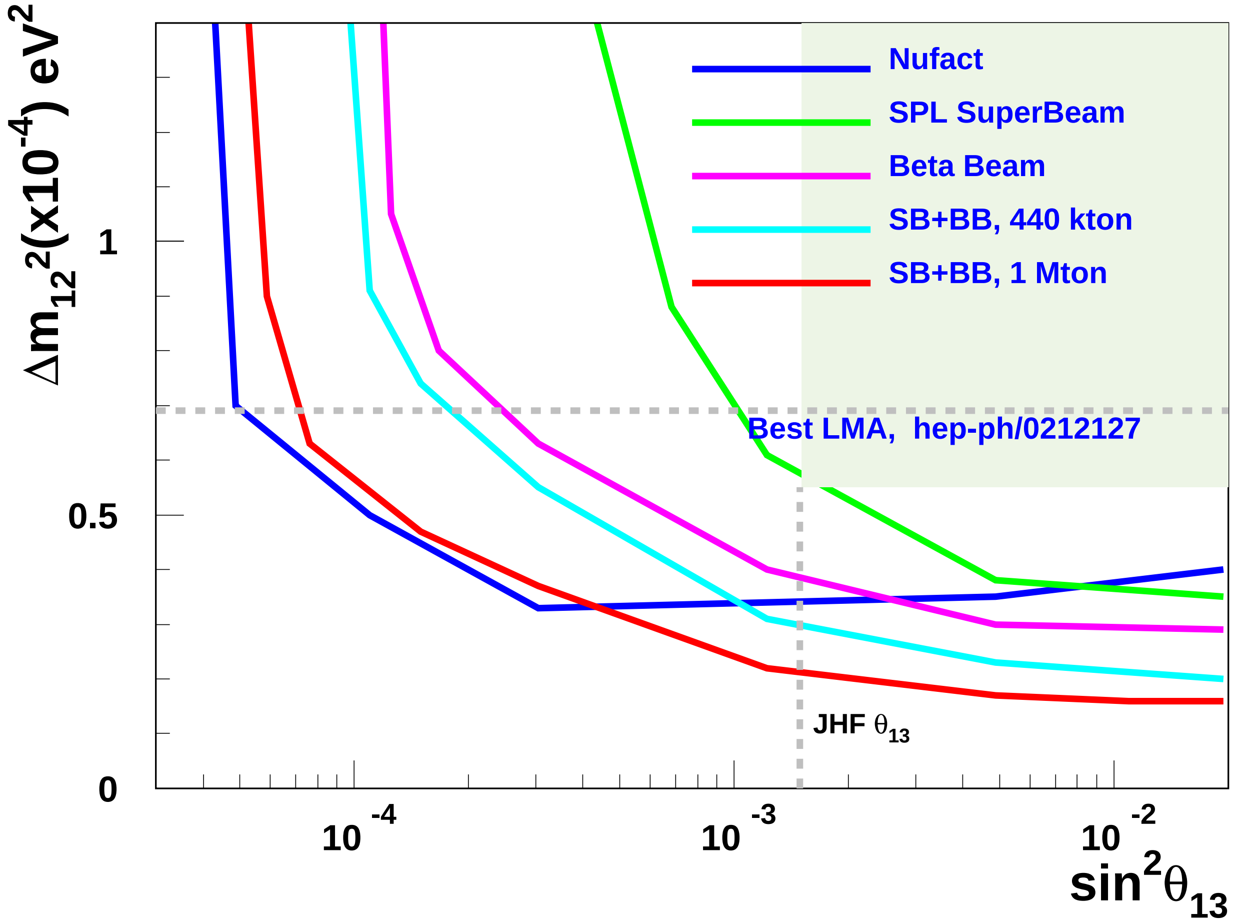
10 yrs (4400 kton/yr)	SuperBeam		Beta Beam	
	ν_μ	$\overline{\nu}_\mu$	$\overline{\nu}_e$ (He^6)	ν_e (Ne^{18})
	(2 yrs)	(8 yrs)	$\gamma = 60$	$\gamma = 100$
CC events (no osc, no cut)	36698	23320	28880	172683
Total oscillated	1.7	33.3	0.5	84.2
CP-Odd oscillated	-25.5	16.9	-11.9	41
Beam backgrounds	141	113	/	/
Detector backgrounds	37	50	1	299
Statistical Error	13.4	13.6	1.5	21.9
Error on θ_{23}	2.1	1.7	0.5	4.7
Error on δm^2_{12}	2.8	1.9	0.3	8.1
Total Error	13.9	14.6	1.7	25.7

A comparison of CP sensitivities: Beta Beam vs. Nufact

CP sensitivity, defined as the capacity to separate at 99%CL max CP ($\delta = \pi/2$) from no CP ($\delta = 0$).

Nufact sensitivity as computed in J. Burguet-Castell et al., Nucl. Phys. B **608** (2001) 301:

- 50 GeV/c μ.
- $2 \cdot 10^{20}$ useful μ decays/year.
- 5+5 years.
- 2 iron magnetized detectors, 40 kton, at 3000 and 7000 km.
- Full detector simulation, including backgrounds and systematics.



Conclusioni

- Il caso di fisica é di primaria importanza e complementare al programma del CNGS.
- I giapponesi sono alla ricerca di una ampia collaborazione internazionale.
- Indipendentemente dalla partecipazione italiana sará presente in JHF una larga collaborazione europea.
- L'intero settore dei close detectors, che costituisce la parte sperimentale qualificante di JHF rispetto a SuperKamiokande, é completamente aperto ad ogni proposta e collaborazione.
- La prospettiva a lungo termine potrebbe essere di riportare in Europa la leadership nella fisica dei neutrini costruendo un gigantesco upgrade di SuperKamiokande al Frejus dedicato anche allo studio della violazione di CP leptonica utilizzando fasci del CERN.