νFact02
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Super muon-neutrino beam

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2. "Super-beam" long baseline experiments
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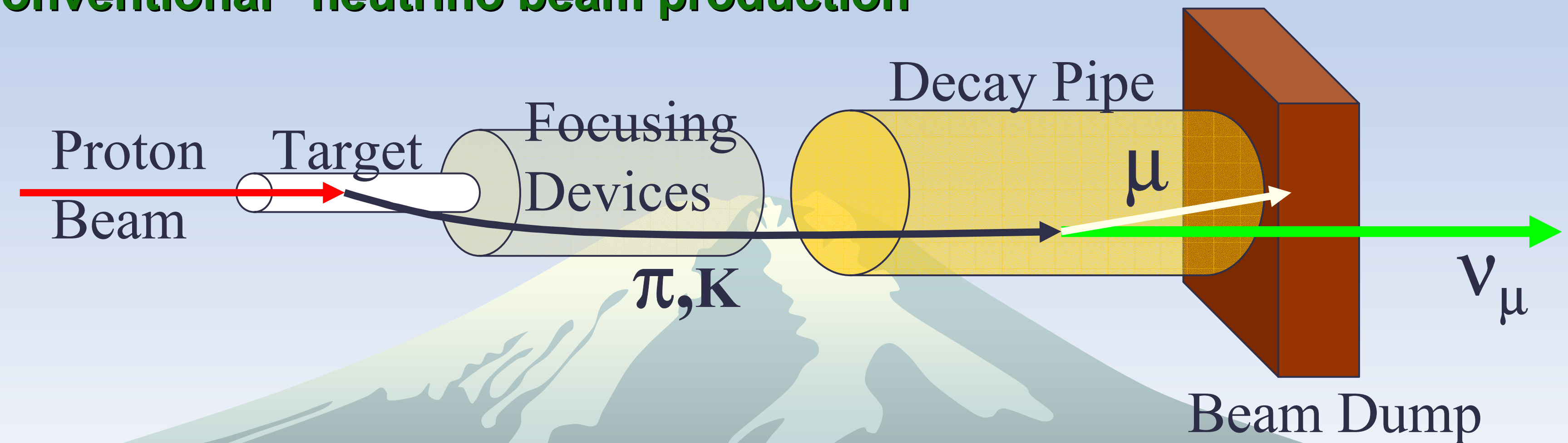
Next goals of LBL experiments

- Establish 3 flavor framework (or find something new)
  - Discovery of ν_e appearance (θ_{13}>0?)
    - At the same Δm^2 as ν_μ disapp. →Firm evidence of 3gen. mix.
    - Open possibility to search for CPV
  - Confirmation of $\nu_\mu \rightarrow \nu_\tau$
    - Appearance
    - NC measurement
  - Precision measurements of ocs. params.
    - $\Delta m_{23}, \theta_{23} / \Delta m_{13}, \theta_{13}$
    - Test exotic models (decay, extra dimensions,….)
- Sign of Δm^2
- Search for CPV in lepton sector
  - Give hint on Matter/Anti-matter asymmetry in the universe

What's super muon-neutrino beam?

"Conventional" neutrino beam production



with MW-class proton beam

- Pure ν_μ beam ($\gtrsim$99%)
- ν_e ($\lesssim$1%) from $\pi\rightarrow\mu\rightarrow e$ chain and K decay(K_{e3})
- $\nu_\mu/\bar{\nu}_\mu$ can be switched by flipping polarity of focusing device

For high precision LBL experiments

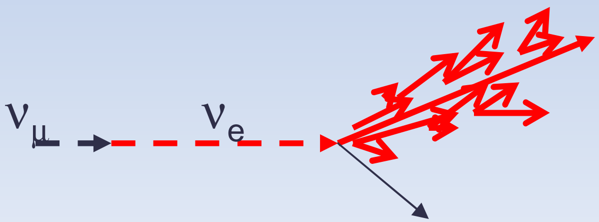
"Super beam LBL experiments" ≈ "2nd generation LBL experiments w/ high intensity conventional beam"

- High statistics
  - Beam intensity ≲100kW → ≳MW (super beam)
  - **AND/OR** detector mass ~10kt → 100~1,000kt
- Designed and optimized after the knowledge of Super-Kamiokande/K2K results
- Primary goal: ν_e app. → CPV, sign of Δm^2

- Japan: JHF(off-axis)→SK/HK
- FNAL: Off-axis NuMI, Proton driver upgrade,
- BNL: Super AGS(off-axis)→?
- CERN: SPL→Furejus, Off-axis CNGS

Next critical path
$\nu_\mu \rightarrow \nu_e$ appearance

Signal

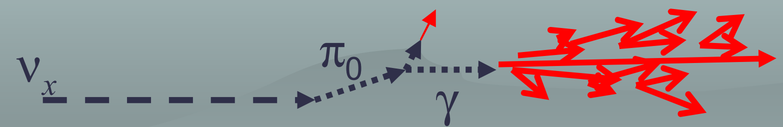


Single EM shower

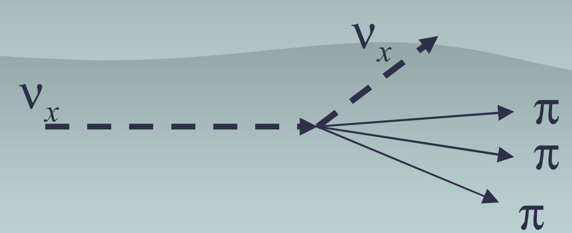
Backgroud

1. Beam intrinsic ν_e contamination
   Identical signature w/ signal
   Different energy distribution

2. NC π_0 production



3. NC multi pion production

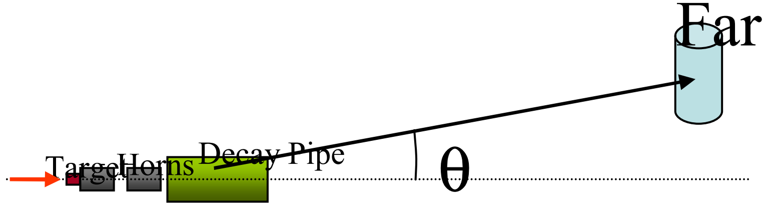


Key for ν_e appearance experiment

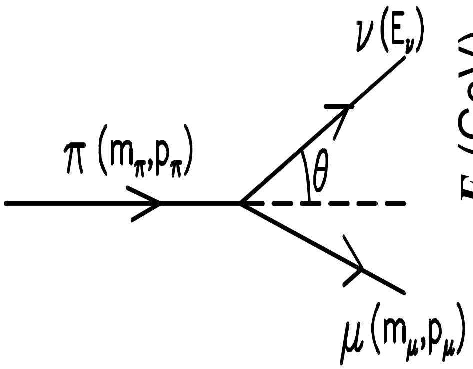
- High statistics
- Small background contamination (beam)
  - intrinsic ν_e → short decay pipe,…
  - off-axis, … → less high energy tail → less inelastic
- Background rejection (beam+detector)
  - event topology ($e \Leftrightarrow \pi_0$)
  - narrow spectrum beam w/ neutrino energy reconstruction → additional kinematical constraint
- Small systematic error on background estimation
  - near/far spectrum difference
  - cross section
  - detector response

High intensity narrow band beam
-- Off-axis (OA) beam --

(ref.: BNL-E889 Proposal)

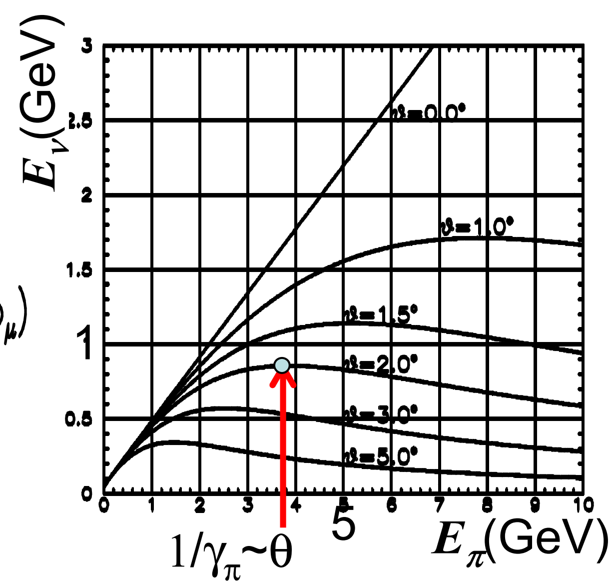


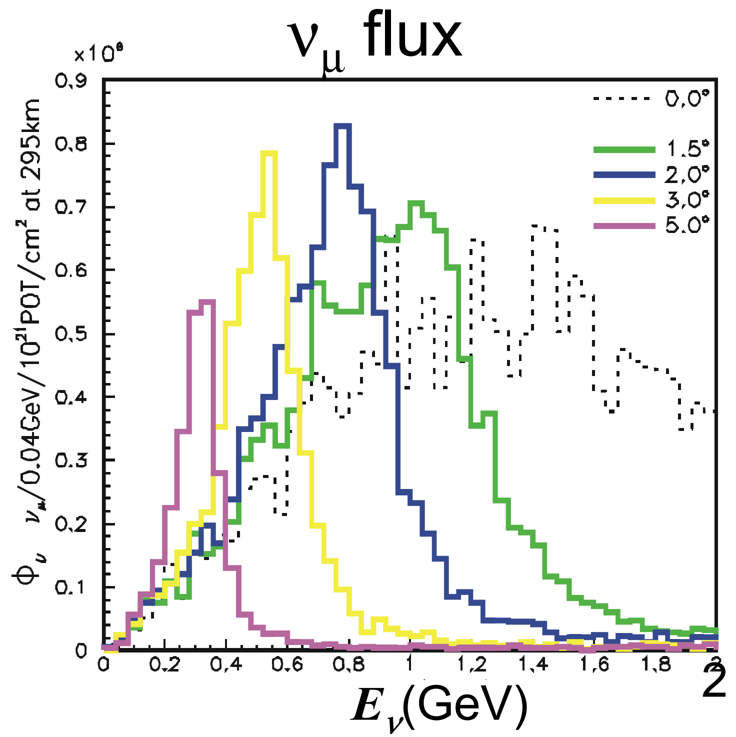
Decay Kinematics



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

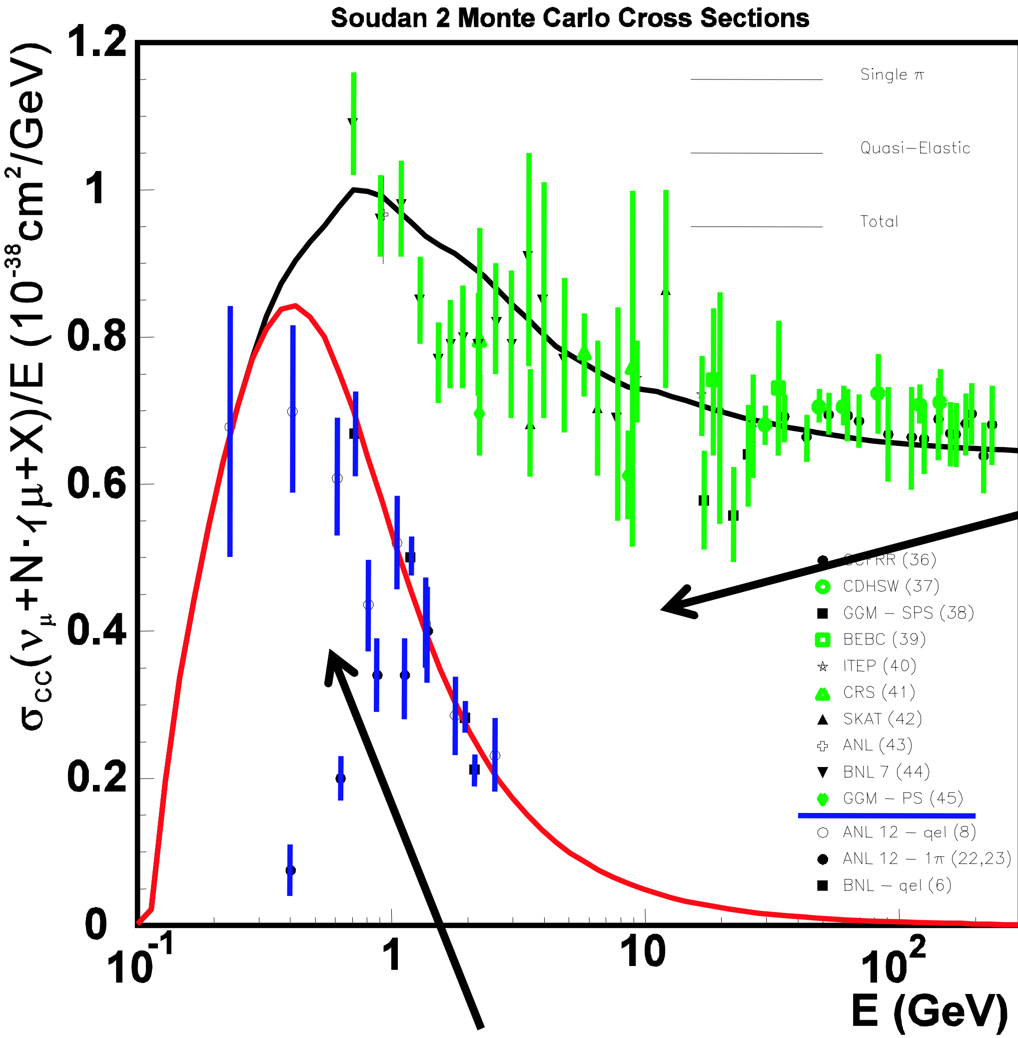
$$E_\nu^{max}[\text{GeV}] \approx \frac{30}{\theta[\text{mrad}]}$$





- ➤Increase statistics @ osc. max.
- ➤Decrease background from HE tail

Charged current cross sections



Inelastic

- $NC\pi_0$
- multi π
- ….

CCqe (ν_μ+n→μ+*p*)

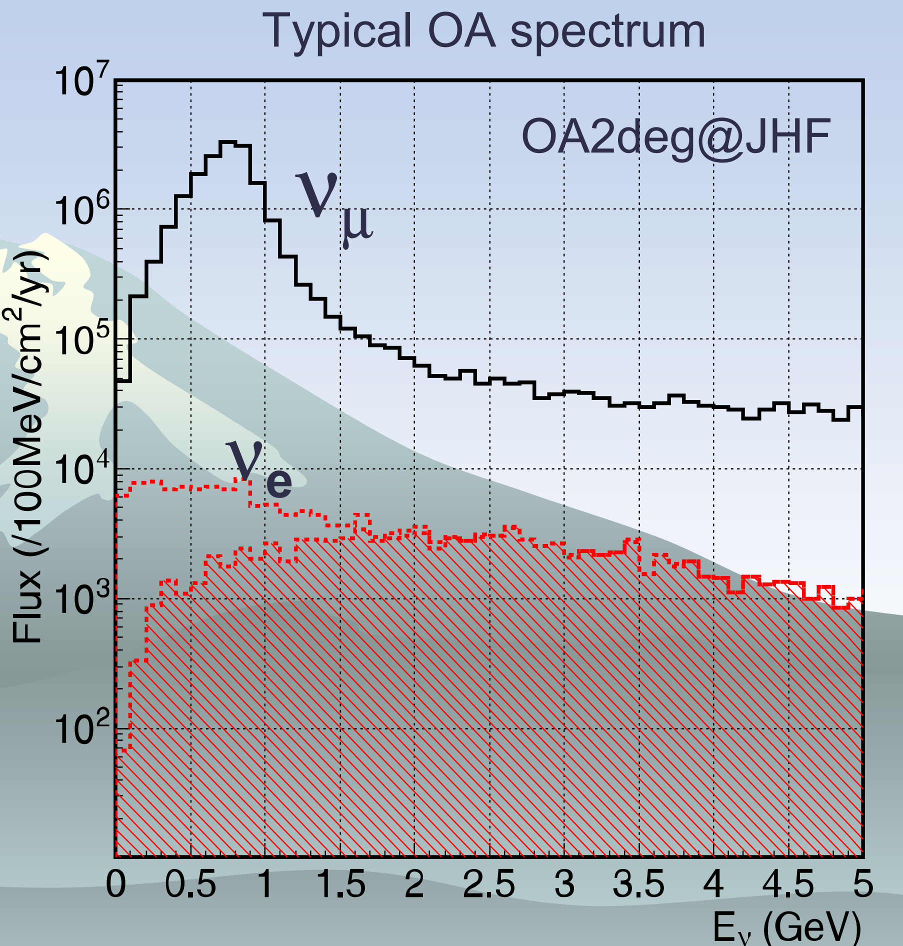
CCqe dominate ≲1GeV

Inelastic dominate ≳1GeV

Backgroud

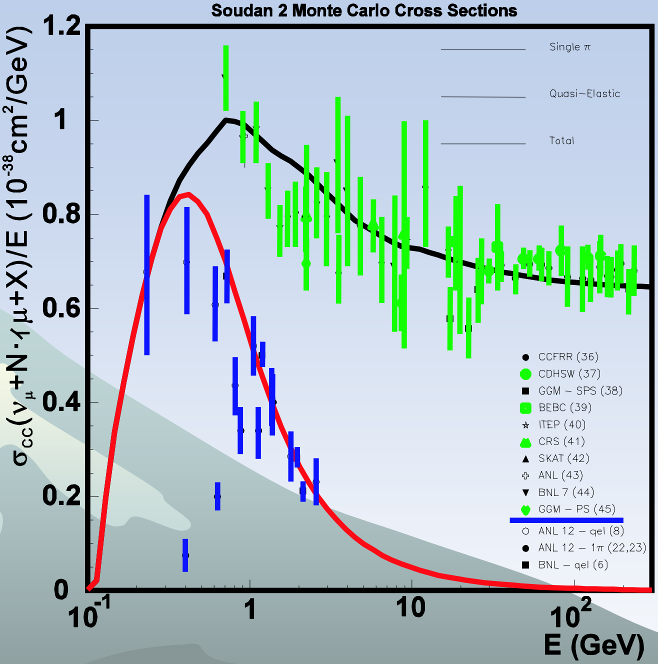
Background rejection

- Event topology
  - π_0: for example,
    - additional EM activity?
    - vertex displacement (γ flight)
    - angular distribution
  - intrinsic beam ν_e: no way
- E_ν distribution
  - Signal peaked at osc. max.
  - Fake "ν_e" event by π_0&beam ν_e broad



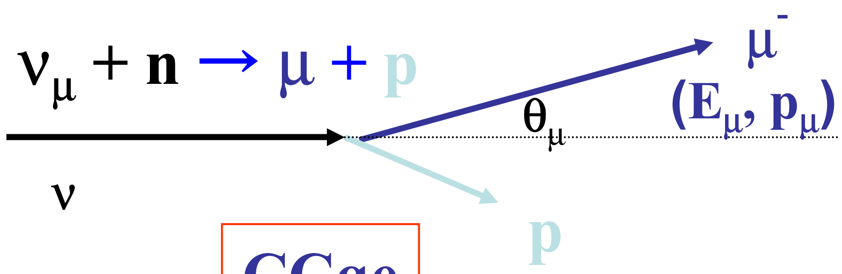
E_ν reconstruction

- ≲1GeV
  - 2-body kinematics of dominant CCqe
  - Water Ch. works well
- ≳1GeV
  - Inelastics (nuclear resonances) dominate
  - (Fine grain) sampling calorimeter. Resolution?
  - Full reconstruction of secondary particles?

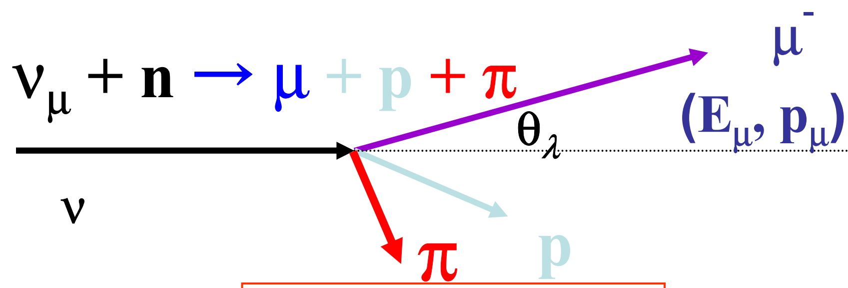


E_ν reconstruction $\lesssim$1GeV region

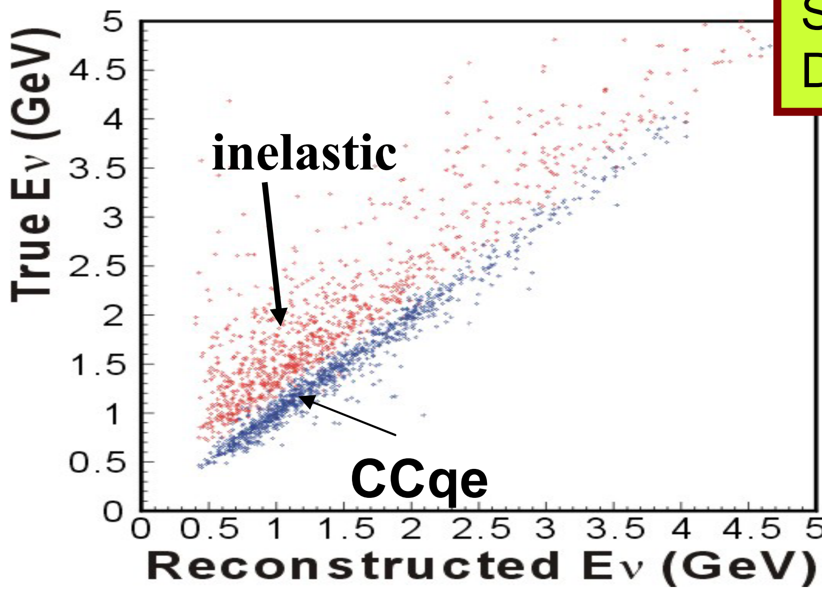
CC quasi elastic reaction ⇔ $$E_\nu = \frac{m_N E_\mu - m_\mu^2/2}{m_N - E_\mu + p_\mu \cos\theta_\mu}$$



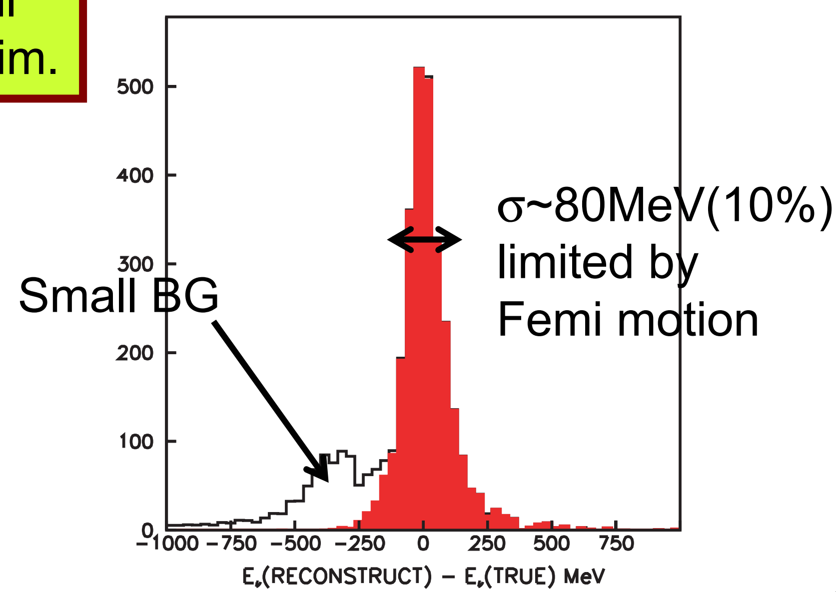
CCqe



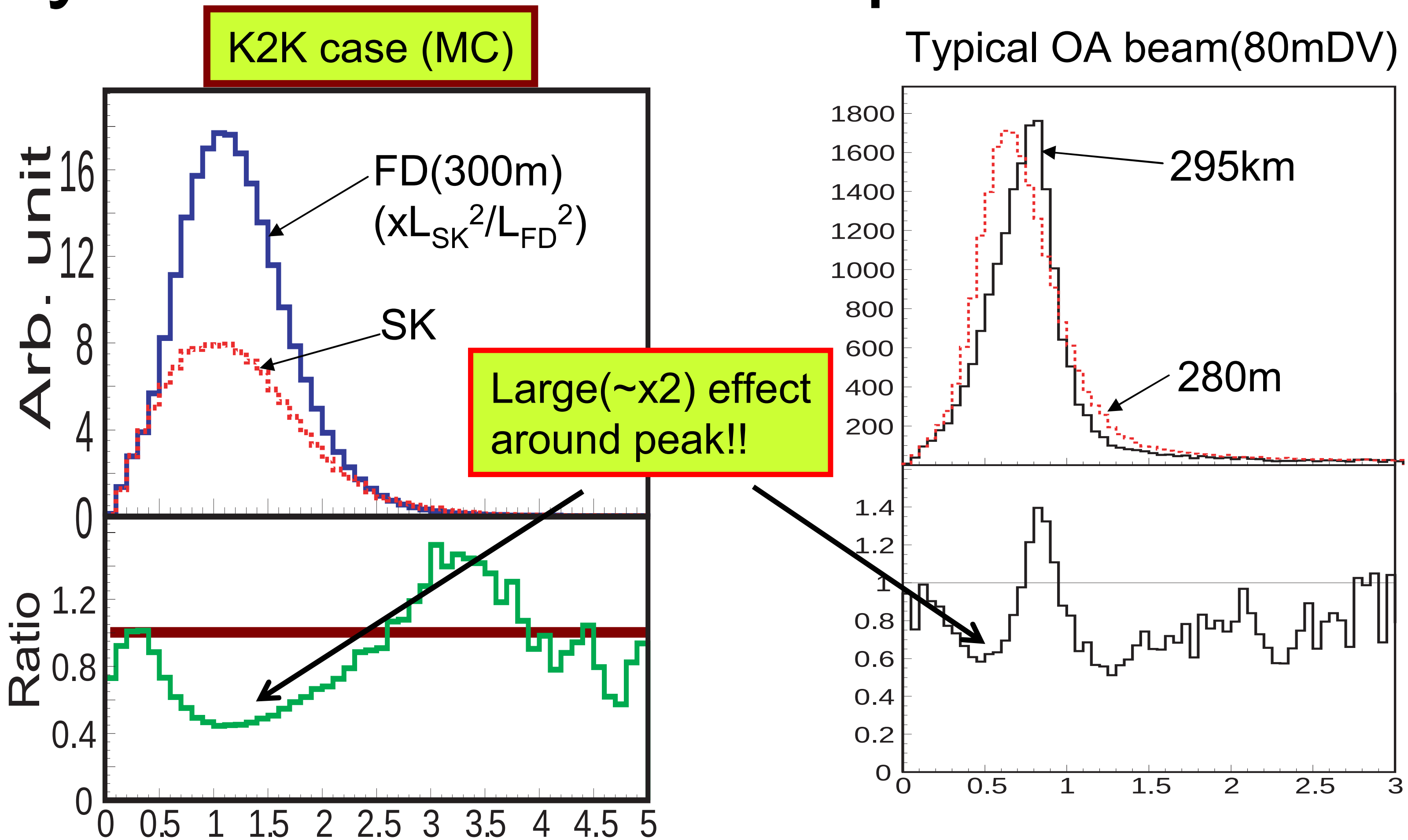
Inelastic (BG)



SK Full Det. Sim.



Syst. error: far/near spectrum diff.



Important not only for ν_μ disappearance, but also **for sig/BG estimation for ν_e search**

(“super-beam”) LBL experiments

	E_p (GeV)	Power (MW)	Beam	$\langle E_\nu \rangle$ (GeV)	L (km)	M_{det} (kt)	ν_μCC (/yr)	ν_e @peak
K2K	12	0.005	WB	1.3	250	22.5	~50	~1%
MINOS(LE)	120	0.41	WB	3.5	730	5.4	~2,500	1.2%
CNGS	400	0.3	WB	18	732	~2	~5,000	0.8%
JHF-SK	**50**	**0.75**	**OA**	**0.7**	**295**	**22.5**	**~3,000**	**0.2%**
JHF-HK	50	4	OA	0.7	295	1,000	~600,000	0.2%
OA-NuMI	120	0.3	OA	~2	730?	20kt?	~1,000?	0.5%
OA-NuMI2	120	1.2	OA	~2	730?	20kt?	~4,000?	0.5%
AGS→??	28	1.3	WB/OA	~1	2,500?	1,000?	~1,000?	
SPL-Furejus	2.2	4	WB	0.26	130	40(400)	650(0)	0.4%
OA-CNGS	400	0.3	OA	0.8	~1200	1,000?	~400	0.2%

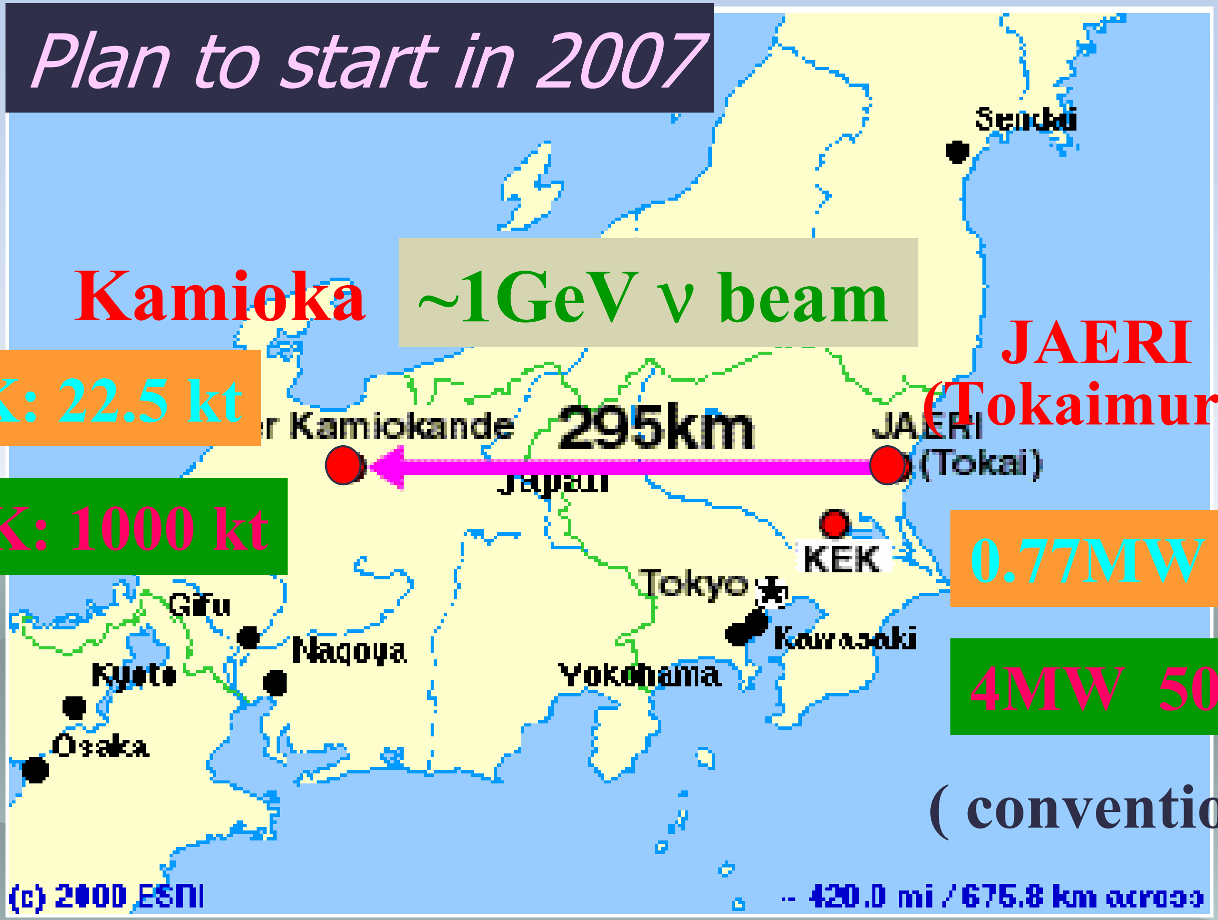
The plans are in very different phases. Most are in optimization phase.
JHF-SK most advanced

- budget request submitted
- EXISITING real detector

JHF-Kamioka Neutrino Project

(hep-ex/0106019)

Plan to start in 2007



Kamioka

~1GeV ν beam

JAERI (Tokaimura)

Super-K: 22.5 kt

Hyper-K: 1000 kt

0.77MW 50 GeV PS

4MW 50 GeV PS

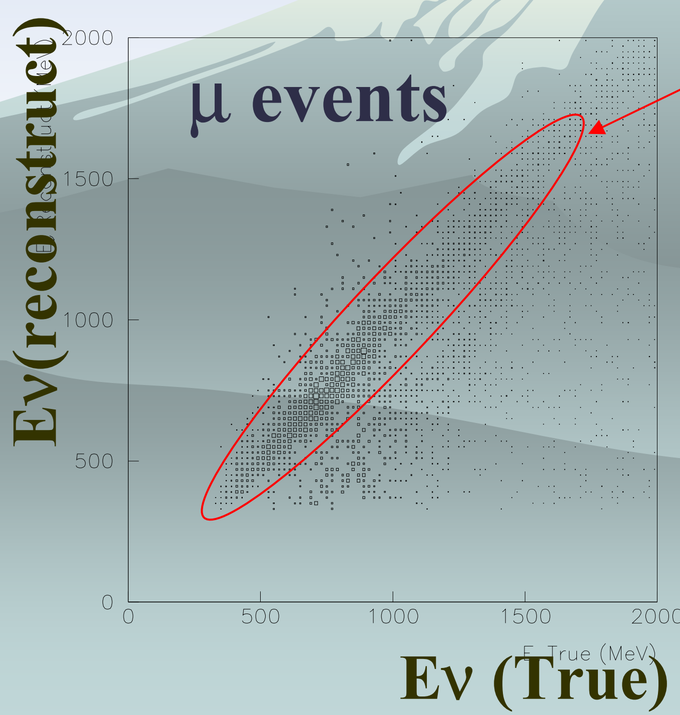
(conventional ν beam)

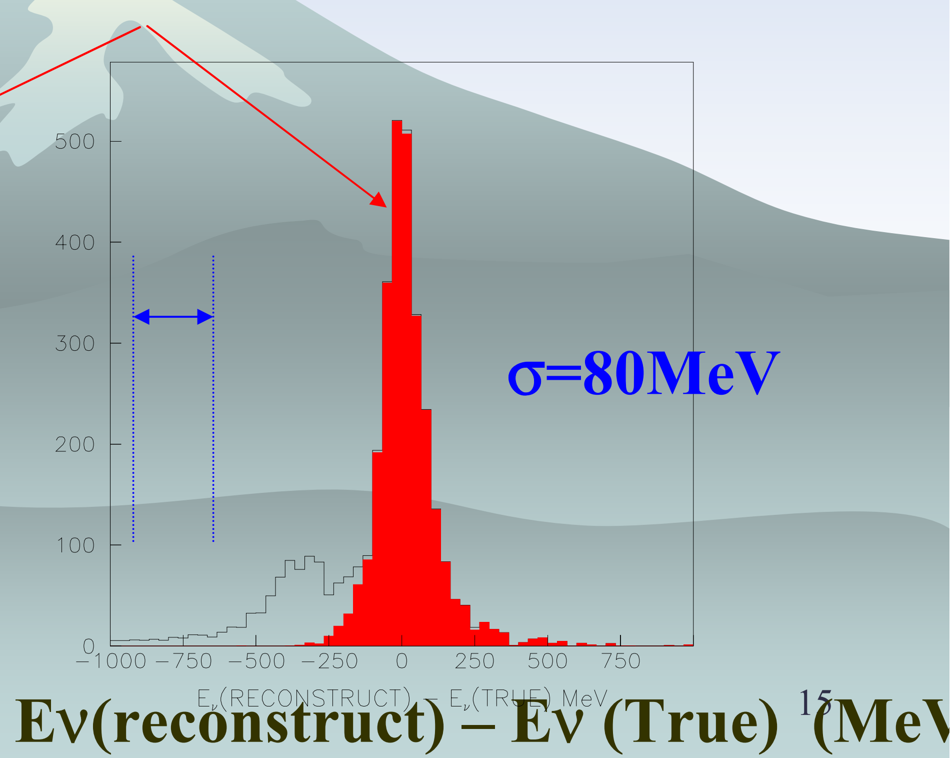
Phase-I (0.77MW + Super-Kamiokande)

Phase-II (4MW+Hyper-K) ~ Phase-I × 200

Principle of JHF-Kamioka project

- **Intense Narrow Band Beam by "off-axis".**
- **Beam energy is at the oscillation maximum.**
  - High sensitivity, less background
- ~1 GeV ν beam for **Quasi-elastic** interaction.



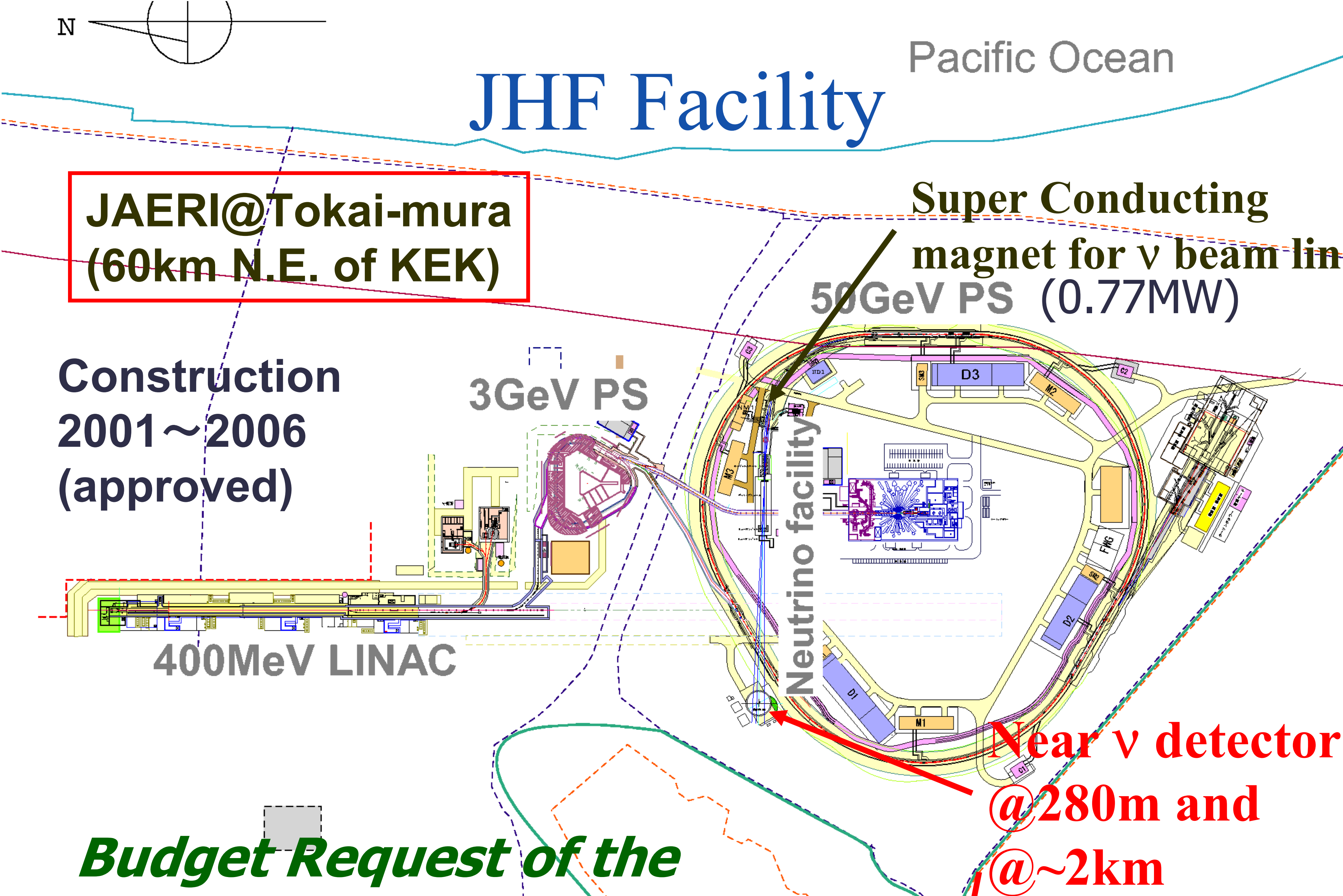


JHF Facility

JAERI@Tokai-mura (60km N.E. of KEK)

Super Conducting magnet for ν beam line

Construction 2001～2006 (approved)



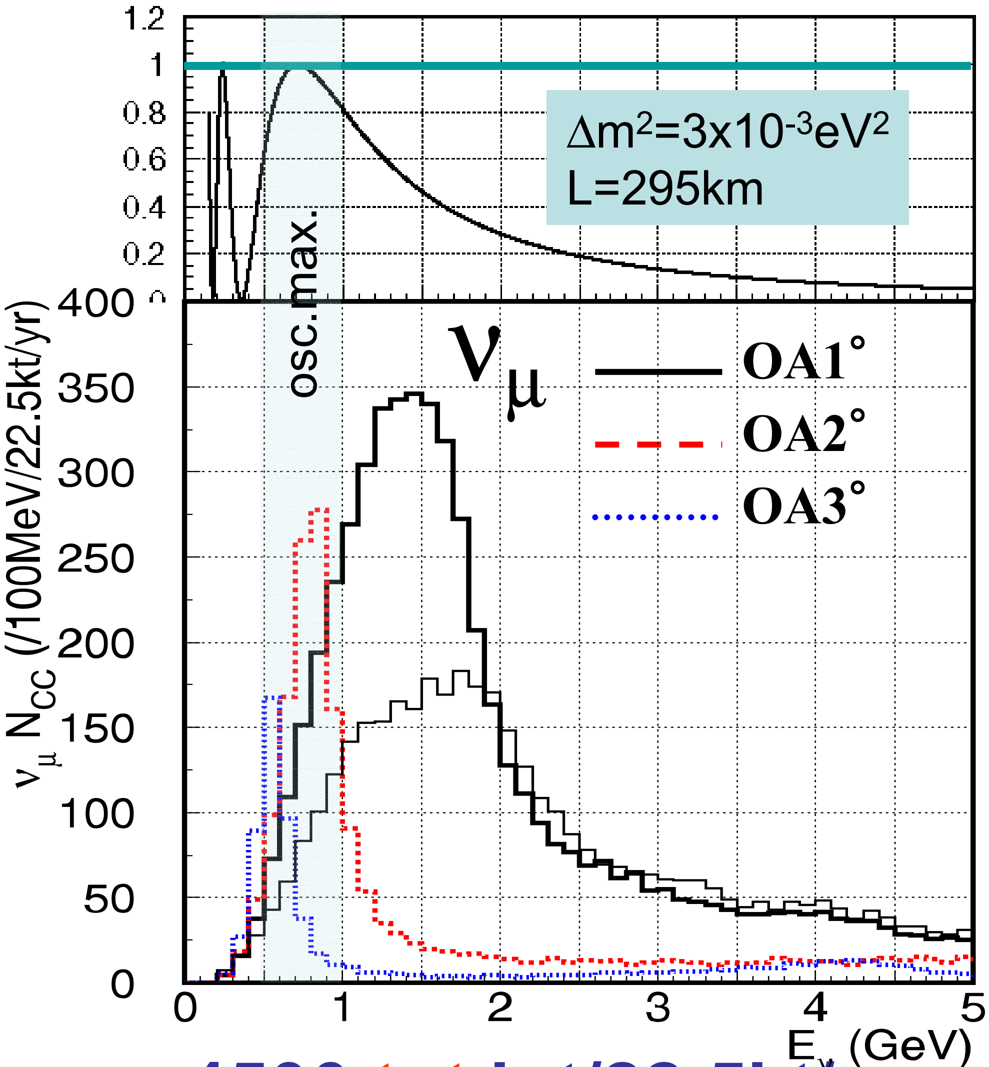
Near ν detectors @280m and @~2km

Budget Request of the ν beam line submitted

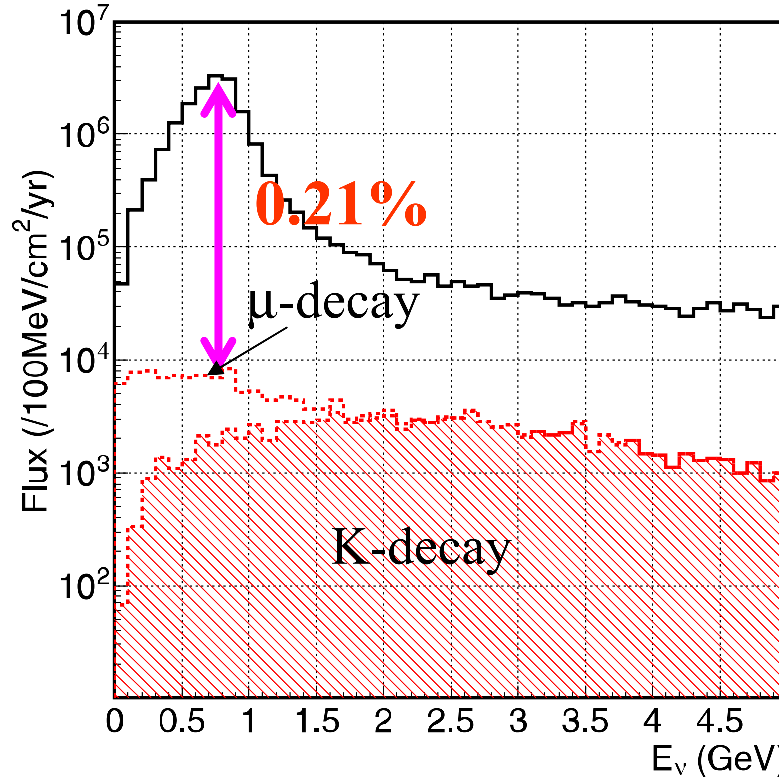
10^{21}POT(130day)≡ "1 year"

Expected spectrum

Osc. Prob.=$\sin^2(1.27\Delta m^2 L/E_\nu)$



ν_e contamination



Very small ν_e/ν_μ @ ν_μ peak

~4500 tot int/22.5kt/yr

~3000 CC int/22.5kt/yr

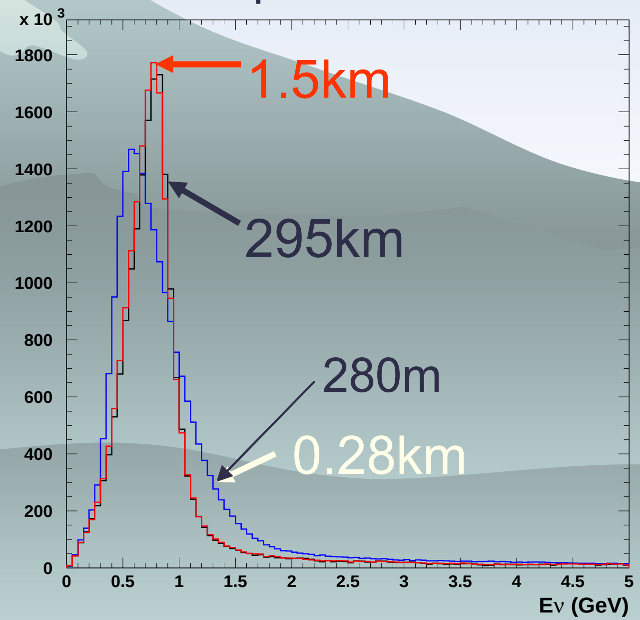
Detectors at near site

- **Muon monitors @ ~140m**
  - Behind the beam dump
  - Fast (spill-by-spill) monitoring of beam direction/intensity

- **First Front detector** "Neutrino monitor" @280m
  - Intensity/direction
  - Neutrino interactions

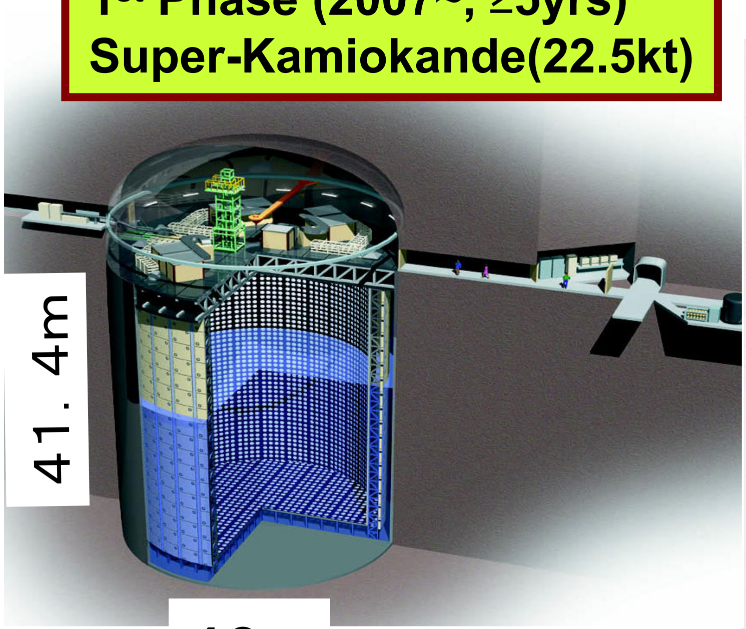
- **Second Front Detector @ ~2km**
  - **Almost same E_ν spectrum as for SK**
  - Absolute neutrino spectrum
  - Precise estimation of background
  - **Investigating possible sites**

Neutrino spectra at diff. dist

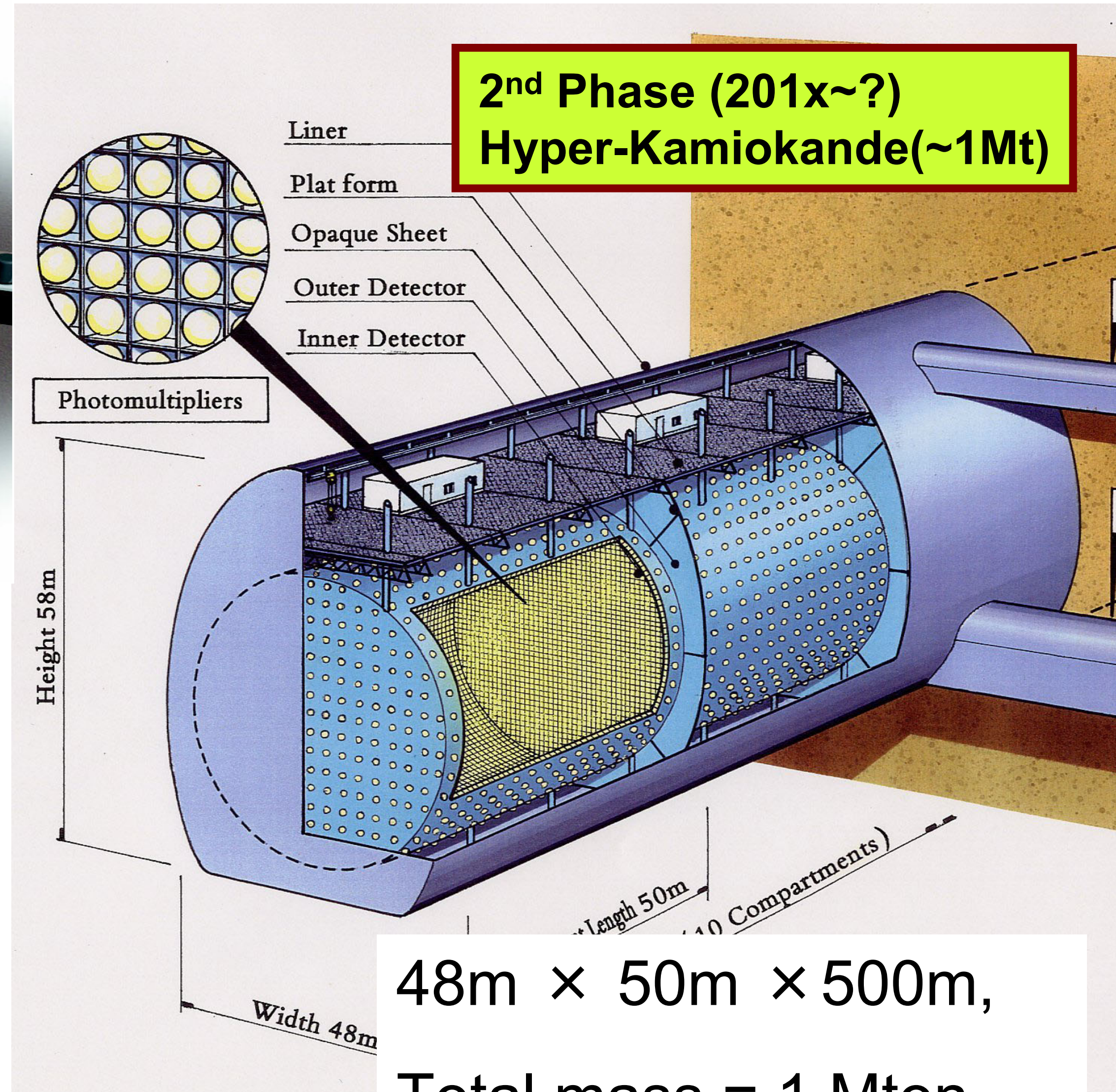


Far Detectors

1st Phase (2007~, ≥5yrs)
Super-Kamiokande(22.5kt)



2nd Phase (201x~?)
Hyper-Kamiokande(~1Mt)



48m × 50m ×500m,

Total mass = 1 Mton

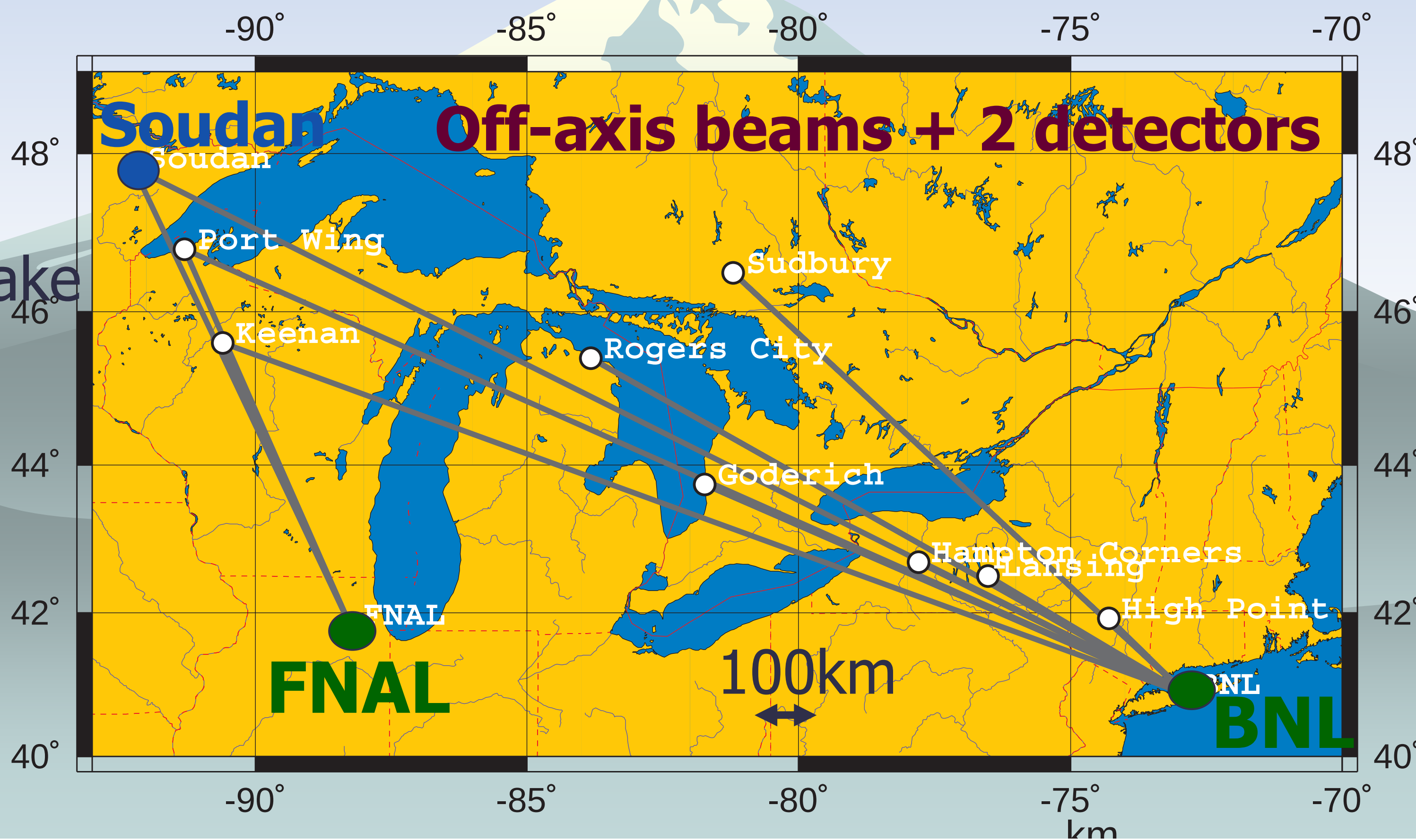
USA: FNAL and BNL plan

- BNL: Super AGS (1.3MW, LOI submitted)
- FNAL: Super NUMI (1.6 MW) or the new proton driver.

(hep-ex/0205040,0204037,hep-ph/0204208)

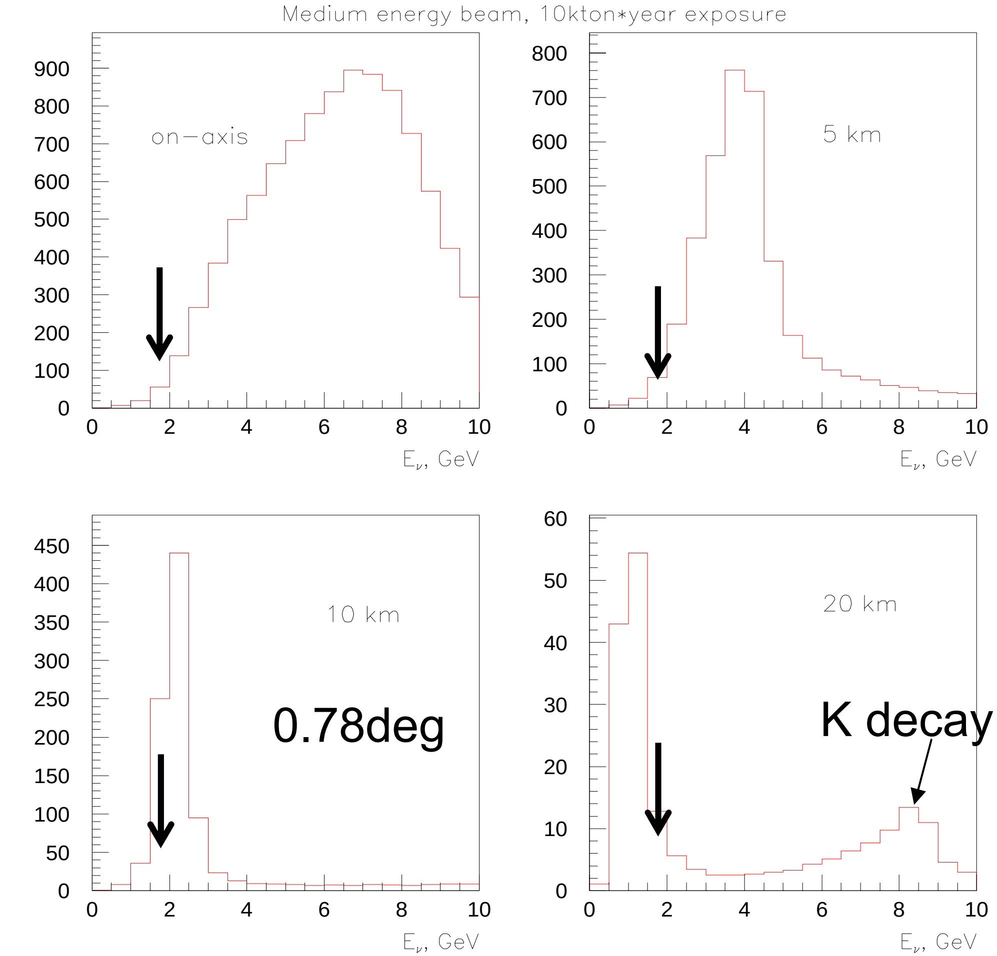
Homestake

WIPP



OA-NuMI

A. Para, M. Szleper, hep-ex/0110032



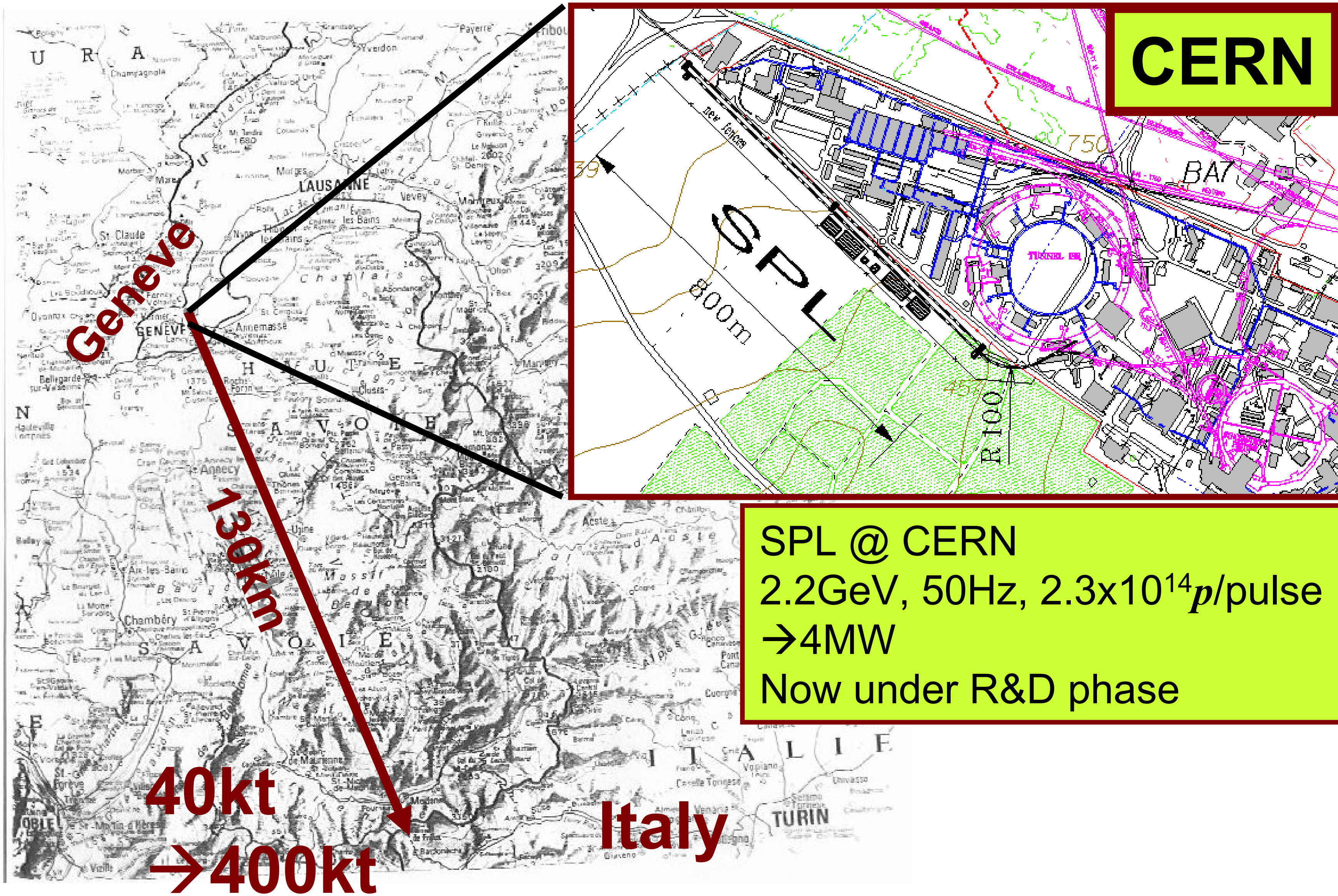
Osc. max. @ 730km

1.8GeV ($\Delta m^2=3\times10^{-3}eV^2$)

Features

- Nuclear resonance region
  → Inelastic background
  → Energy reconstruction?
- Too large angle→ Kaon peak
- Beam goes 3.5deg downward
  → hard to place 2nd near det.
  → Far/near ratio?
  Para/Szleper's prescription using Matrix (hep-ex/0110001)

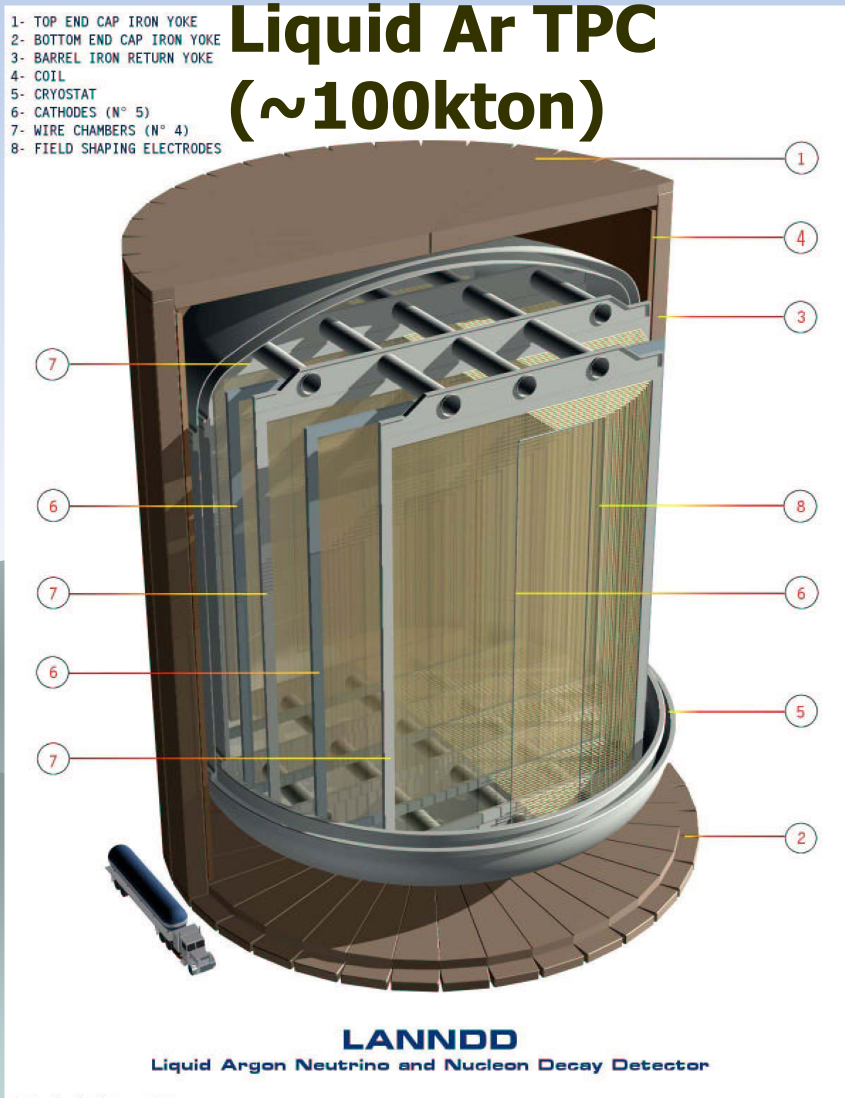
Europe: SPL→Furejus



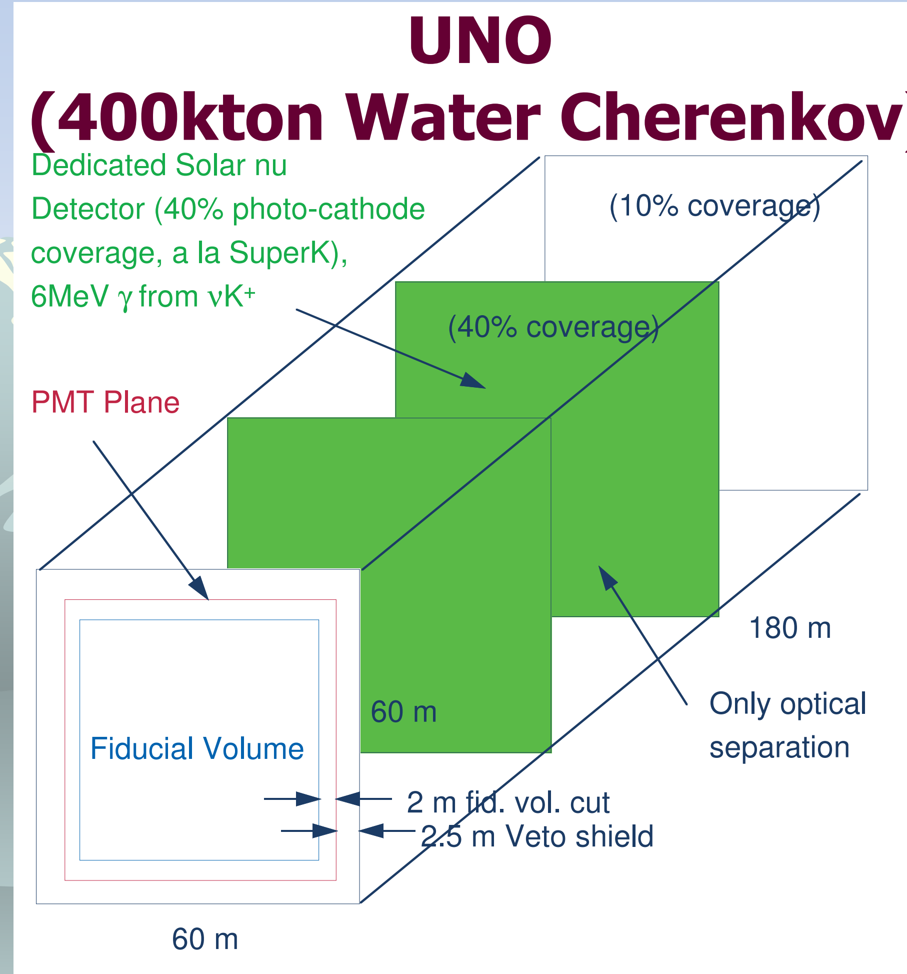
SPL @ CERN
2.2GeV, 50Hz, 2.3x10^{14} p/pulse
→4MW
Now under R&D phase

Detectors

Liquid Ar TPC (~100kton)

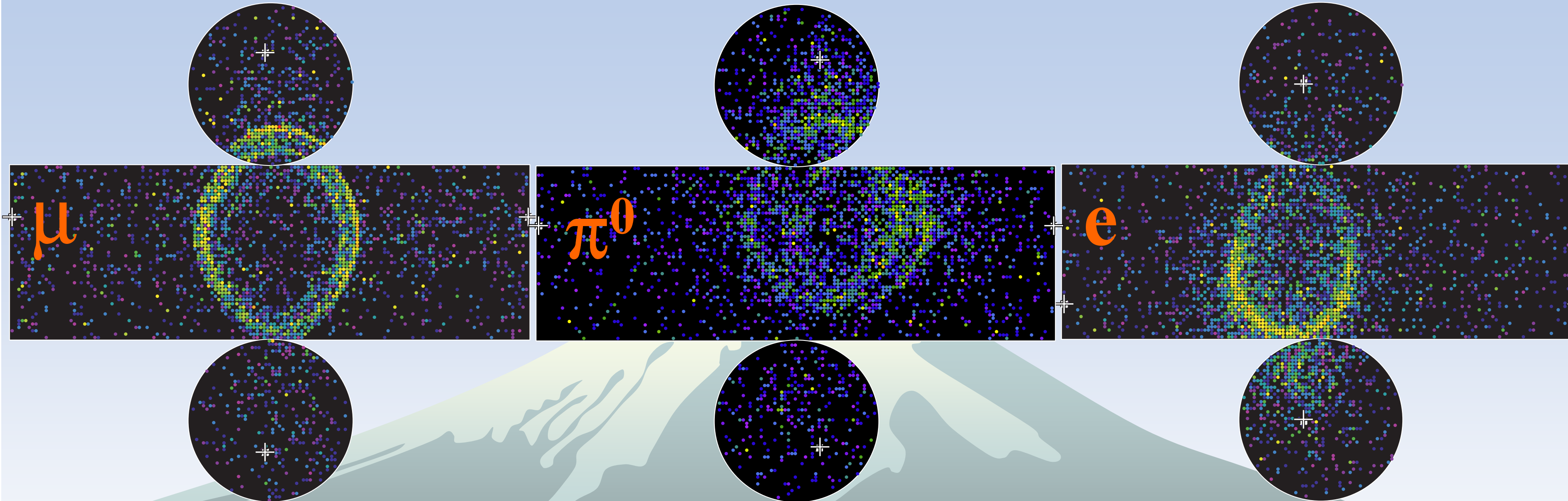


UNO (400kton Water Cherenkov)



Physics Sensitivity

ν_e appearance in JHF-Kamioka (phase 1)



Backgrounds

1.8 events | 9.3 events | 11.1 events

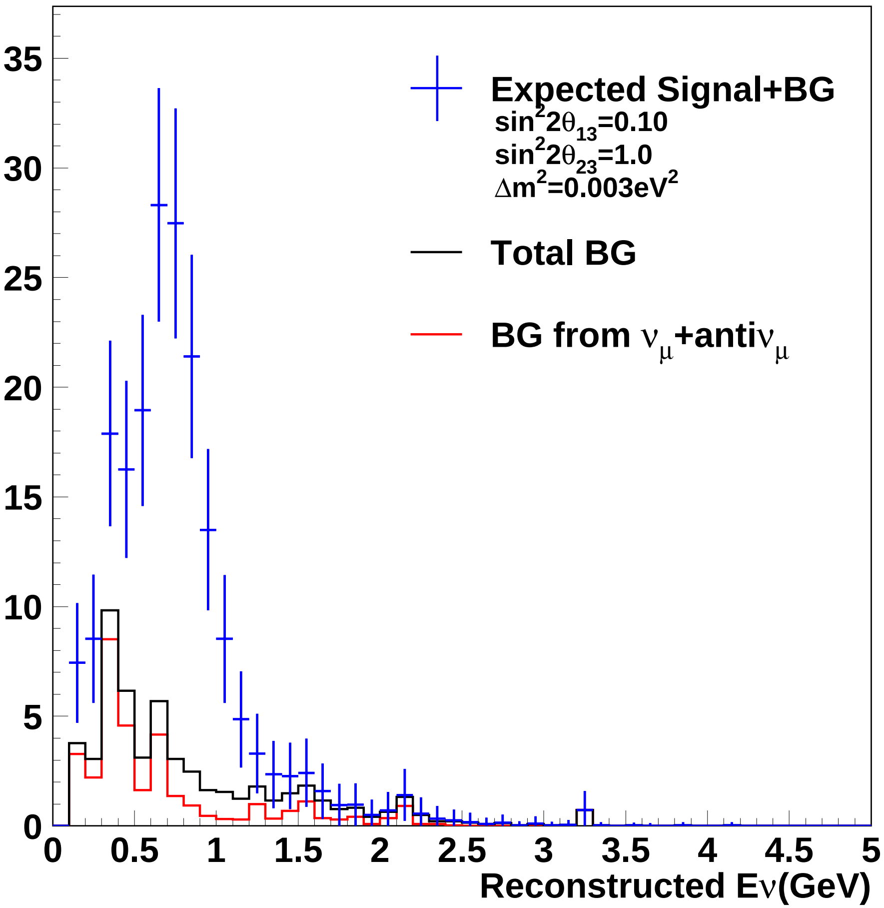
Signal

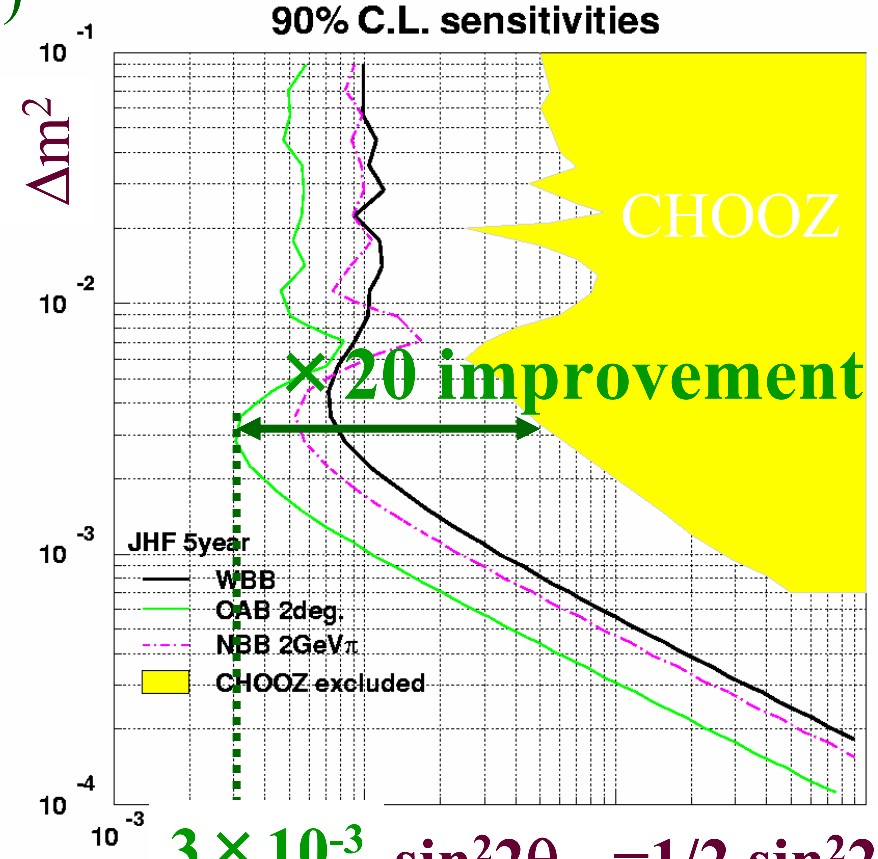
123.2 events @ $\sin^2 2\theta_{13}=0.1$, $\Delta m^2=3\times 10^{-3}\text{eV}^2$

(5 years running)

ν_e appearance (continue)

$\sin^2 2\theta_{\mu e}=0.05$ ($\sin^2 2\theta_{\mu e} \equiv 0.5\sin^2 2\theta_{13}$)



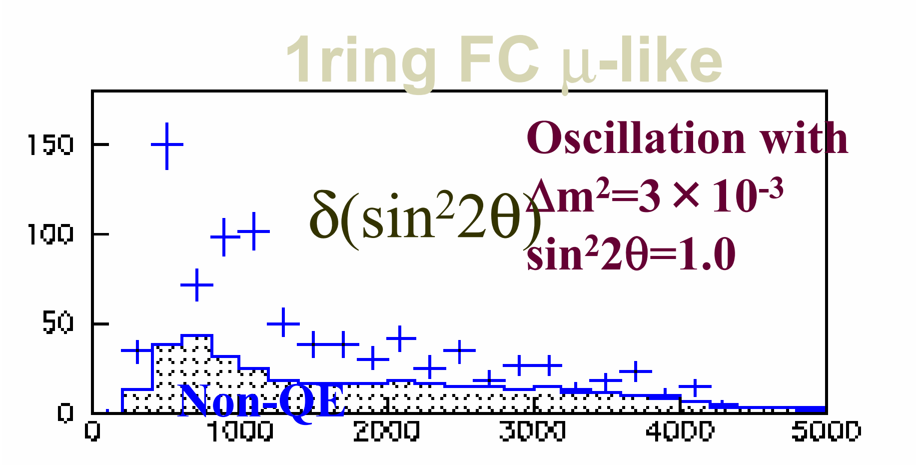


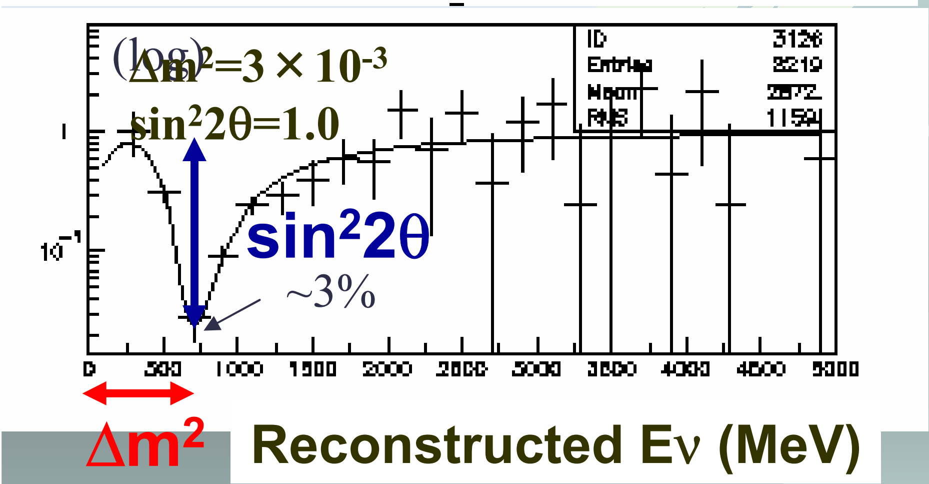
3×10^{-3}

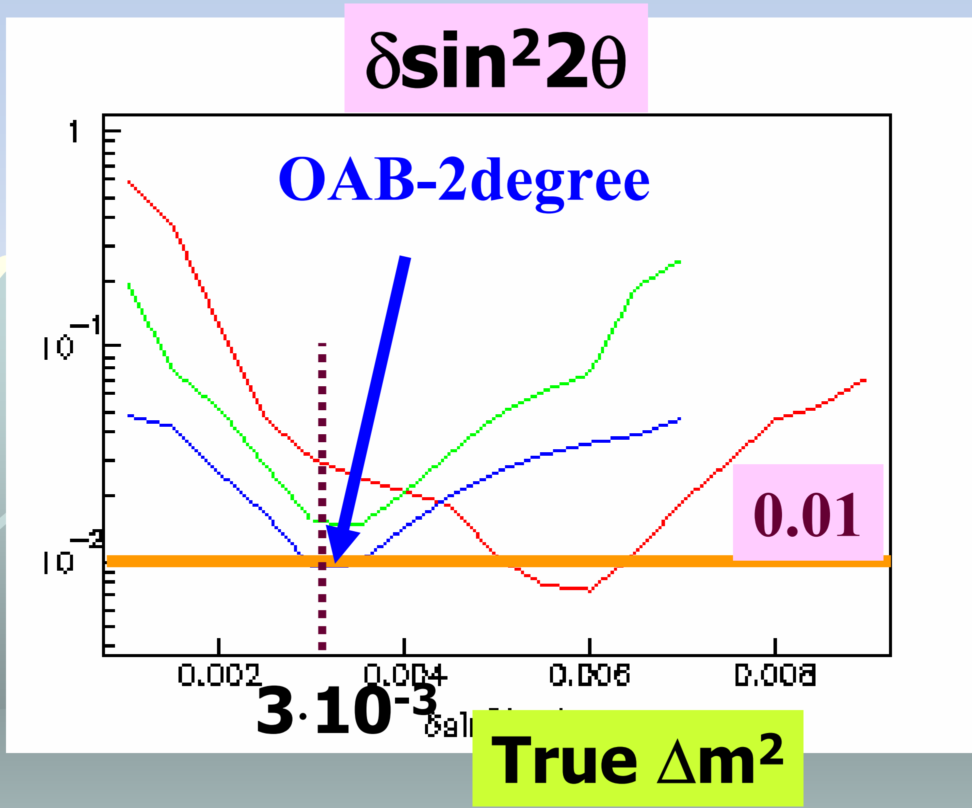
$\sin^2 2\theta_{\mu e} = 1/2 \cdot \sin^2 2\theta_{13}$

$\sin^2 2\theta_{13} < 0.006$ (90% C.L.)

ν_μ disappearance



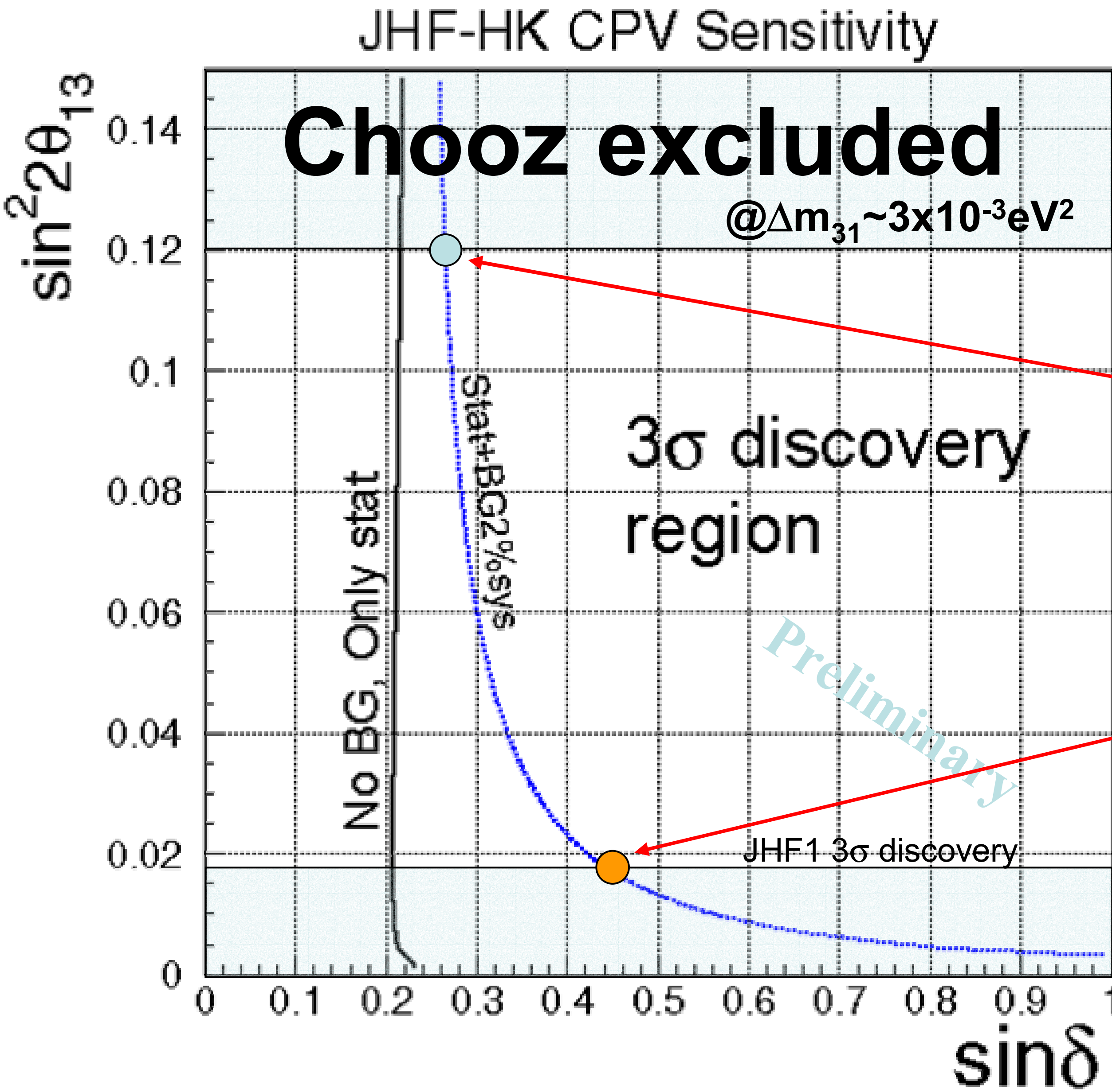




$\delta\sin^2 2\theta_{23} \sim 0.01$

$\delta\Delta m_{23}^2 \quad < 1\times 10^{-4} eV^2$

Sensitivity(3σ) to CPV(2nd phase)



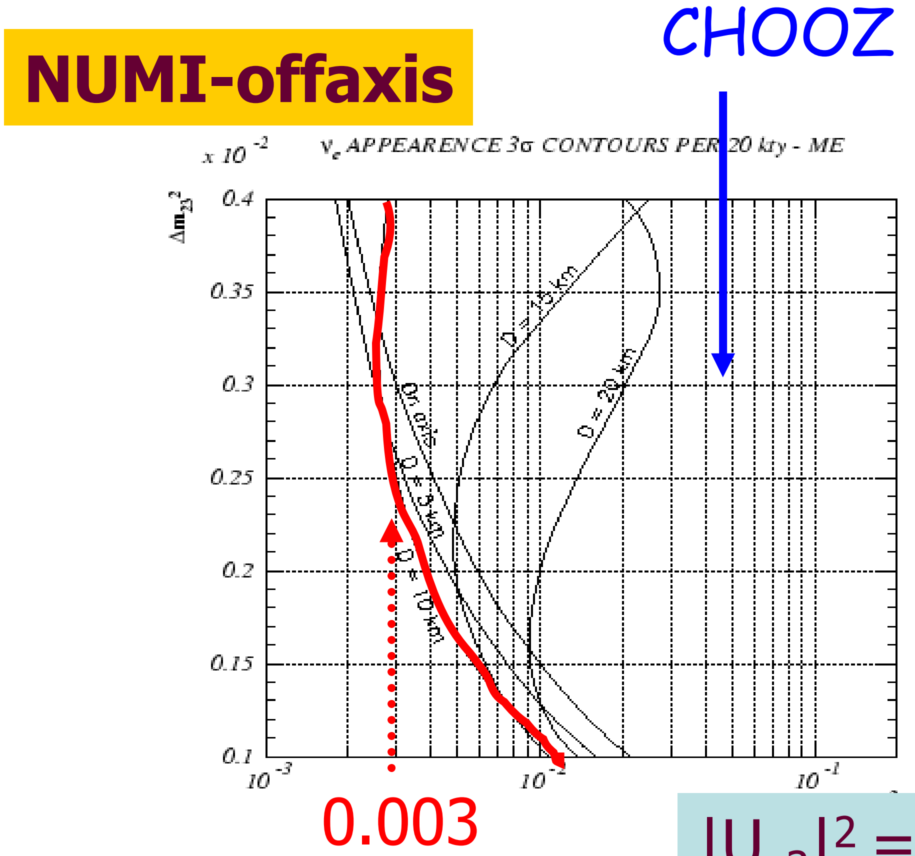
4MW,1Mt
2yr for ν_μ
6.8yr for $\bar{\nu}_\mu$

δ>~14deg

δ>~27deg

US Super ν beam

- They are studying the physics potential of several options, which are competitive to JHF-Kamioka project.



$|U_{e3}|^2 = 1/4 \cdot \sin^2 2\theta_{13}$

Possibility to discriminate sign of Δm^2 (Matter effect)

hep-ex/0206025

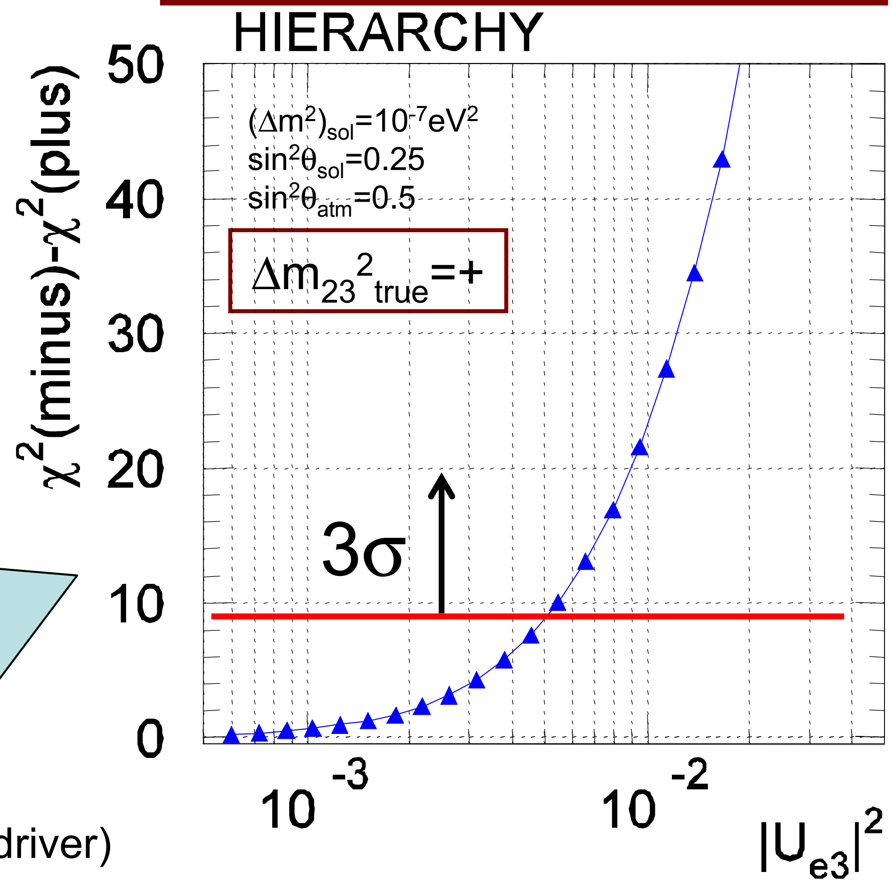
- Small matter effect in JHF-SK (~1GeV-295km)
- Other longer baseline projects could play complementary role

Running time

ν_μ:ν_μ~1:3

(cross sec. diff)

OA-NuMI MC study



For example,

~5yrs of OA-NuMIx20kt(w/ proton driver)

Summary

- Exciting topics in 2nd generation LBL experiments.
  - ne appearance
  - CPV, sign of Δm^2, ……
- Several "super-beam" experiments are under consideration
  - US, Europe and Japan
  - They are in very different stages.
- Earliest beam is expected in 2007 at JHF-Kamioka project
  - Accelerator construction started in 2001.
  - Budget request for ν facility submitted this year.

Summary (II)

- Physics sensitivity of JHF-Kamioka project
  - $\sin^2\theta_{13} \lesssim 0.006$ (90%CL)
  - $\delta(\Delta m^2) \lesssim 3\%$, $\delta(\sin^2\theta_{23}) \sim 1\%$
  - can discover CPV if $\delta \gtrsim 20^o$ (in 2nd phase)
- Experiments are complementary each other
  - JHF-Kamioka hard to see matter effect
  - ➔ Longer baseline/higher energy experiments
- νFact will come after the (at least) 1st round of super-beam experiments (10~20yrs)
  - If $\sin^2\theta_{13} \lesssim 0.01$, JHF-SK may not see, but JHF-HK may.
  - But sensitivity to CPV in JHF-HK reduces
  - ➔ CPV in νFact?

Future Prospect

2002 : JHFn budget request&approval

2003 : start construction

2005 : K2K final results

2007 JHF1

$\sin^2 2\theta_{13} > 0.018$?

201x

3σ discovery → JHF2
CPV
precision meas. θ_{13}
Proton decay

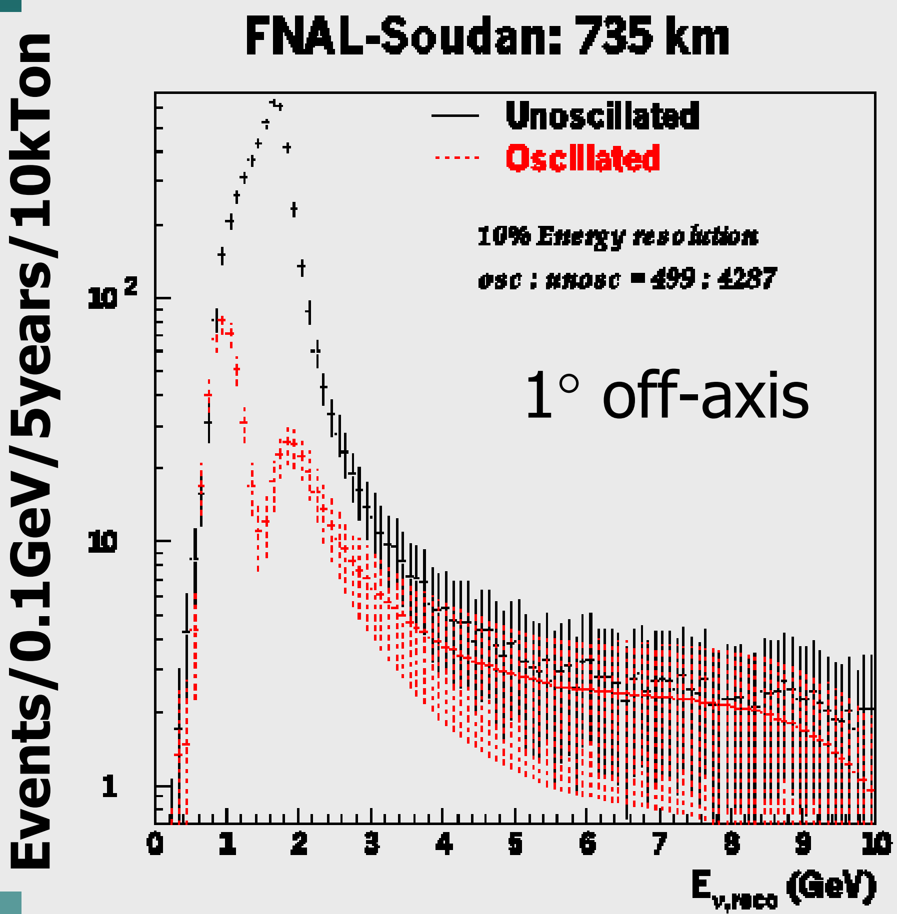
Hint? → JHF2
Search $\theta_{13} < 10^{-3}$
Proton decay

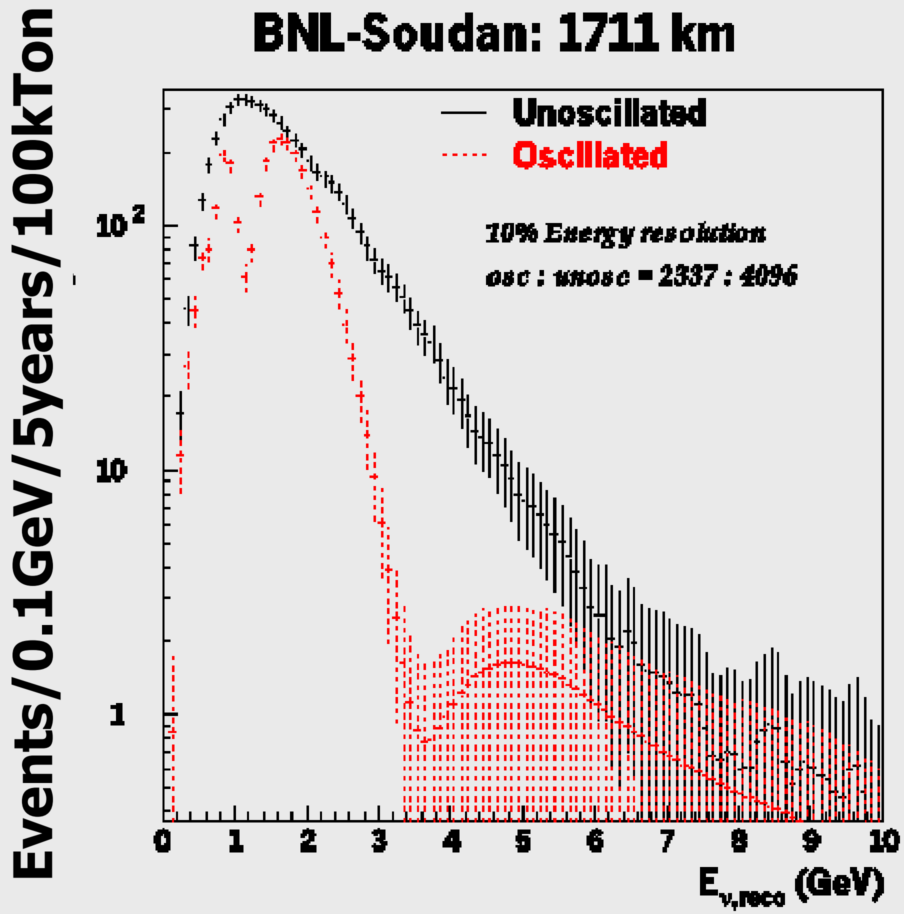
20xx Future SuperBeam, VLBL, ν-fact for very small θ_{13}, CPV, sign of Δm^2

(Super) Neutrino Beams

	$\langle E\nu \rangle$ (GeV)	L (km)	#CC ν/kt/yr	$L/L_{osci.}$*	$f(\nu_e)$ @peak
K2K	1.3	250	2	0.47	~1%
NuMi (High E)	15	730	3100	0.12	0.6%
NuMi (Low E)	3.5	730	469	0.51	1.2%
CNGS	17.7	732	2448	0.10	0.8%
JHF-I	0.7	295	133	1.02	0.2%
Numi off-axis	2.0	730	~80	0.89	0.5%
JHF-II	0.7	295	691	1.02	0.2%
SPL	0.26	130	16.3	1.21	0.4%

FNAL, BNL to Soudan





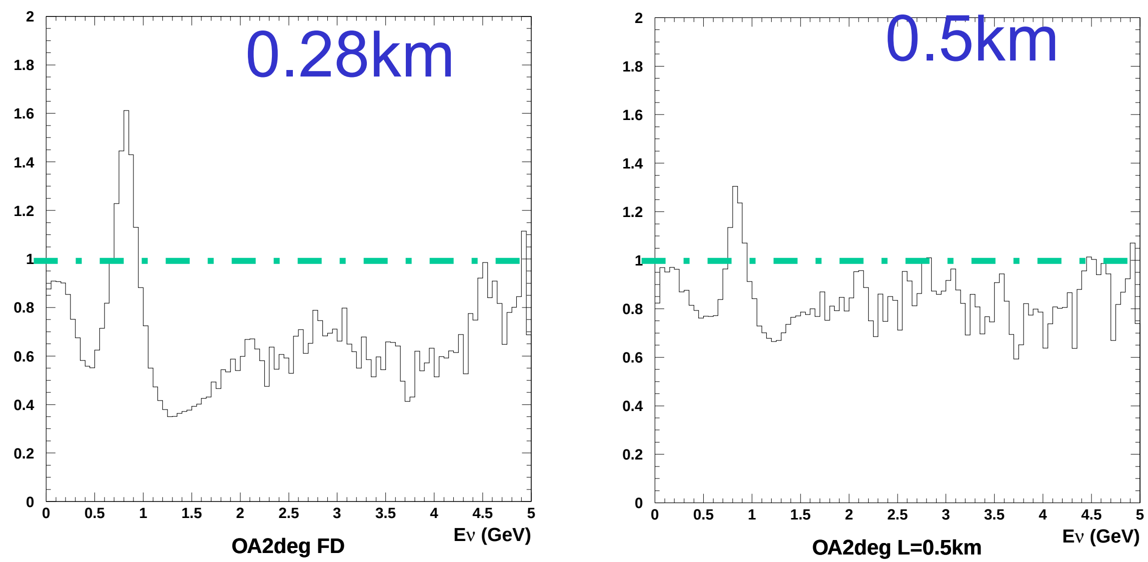
- Water Cherenkov like Super-K

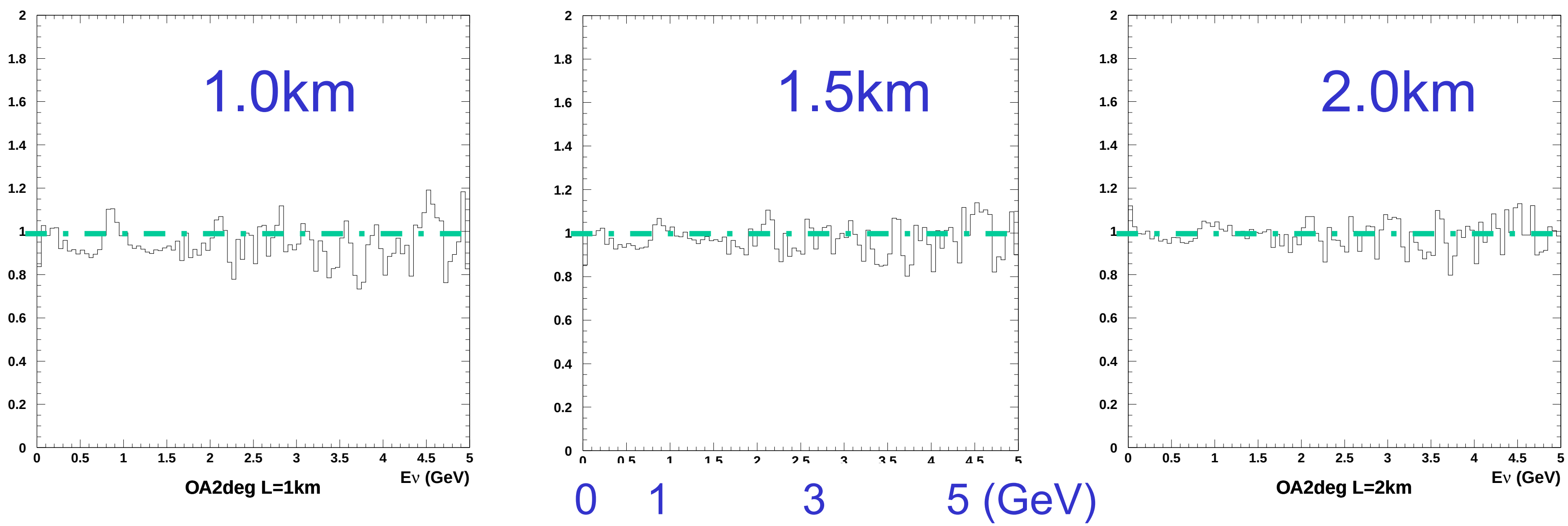
Far/near spectrum ratio

$$\frac{\Phi_{far}(E_\nu)\cdot L_{far}^2}{\Phi_{near}(E_\nu)\cdot L_{near}^2}$$

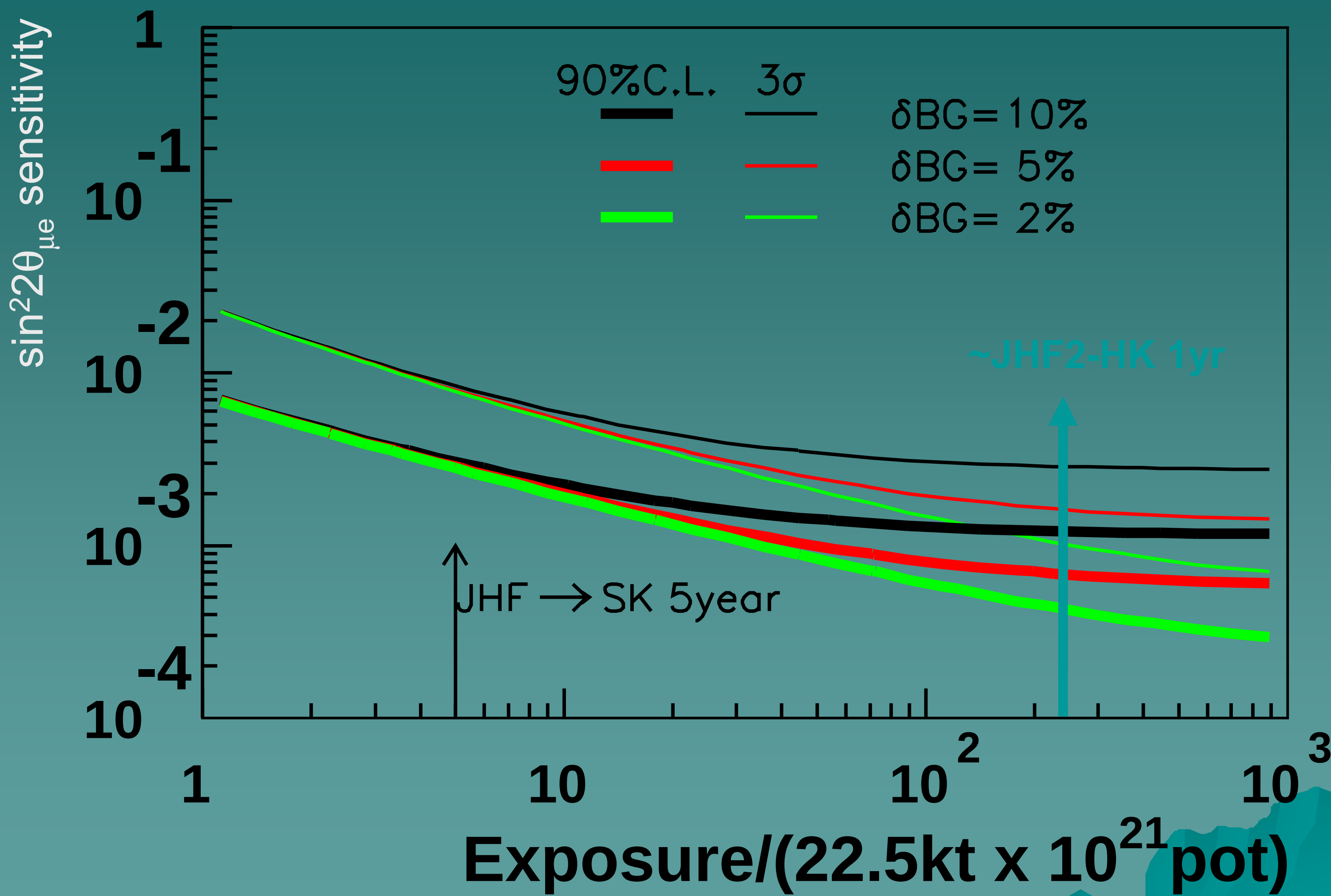
Decay pipe len.
L_{DV}=80m

want near det.
@ ≳10xL_{DV}





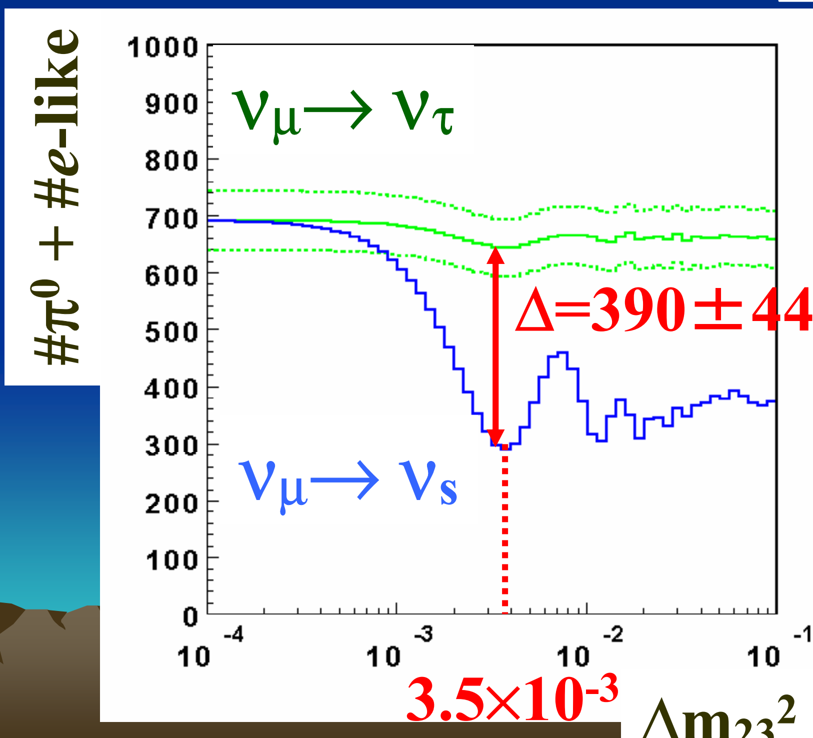
Sensitivity for Mixing Angle

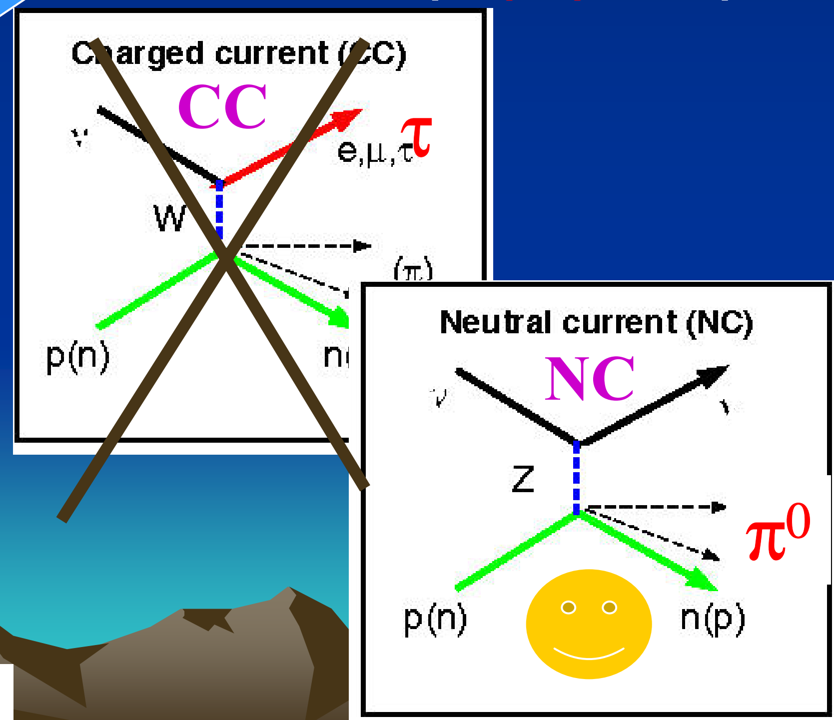


$\nu_\mu \to \nu_\tau$ confirmation w/ NC interaction

- NC π^0 interaction ($\nu + N \to \nu + N + \pi^0$)
  - $\nu_\mu \to \nu_e$ CC + NC(~0.5CC) ~0 ($\sin^2 2\theta_{\mu e}$~0)
    - ν_μ CC + NC(~0.5CC) ~0 (maximum oscillation)
    - ν_τ **NC**

#π^0 is sensitive to ν_τ flux. ⇒ **Limit on ν_s ($\delta f(\nu_s)$~0.1)**





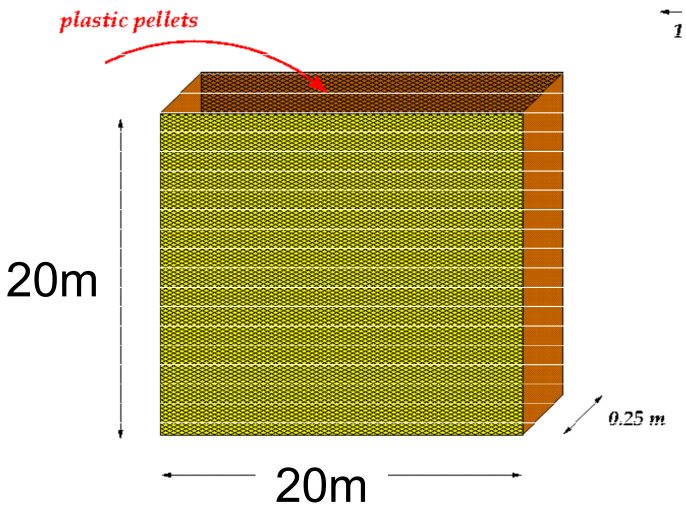
(High Intensity) Proton Accelerators

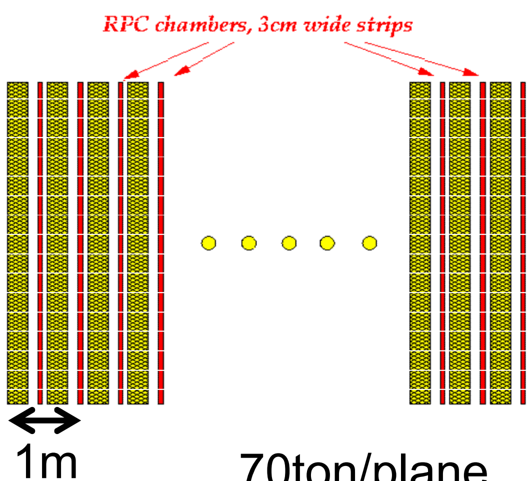
	Power (MW)	Energy (GeV)	Intensity (10^{12} ppp)	Rep. rate (Hz)
KEK-PS	0.005	12	6	0.45
AGS	0.14	24	60	0.6
FNAL-MI	0.41	120	40	0.53
SPS	0.3	400	35	0.16
JHF-I	0.77	50	330	0.29
Super-AGS	1.3	28	120	2.5
FNAL-proton driver-I	1.2	16	30	15
SPL	4	2.2	230	50
JHF-II	4	50		

Not the construcion stage yet, but R&D stage.

Some ideas for OA-NuMI detector (under consideration)

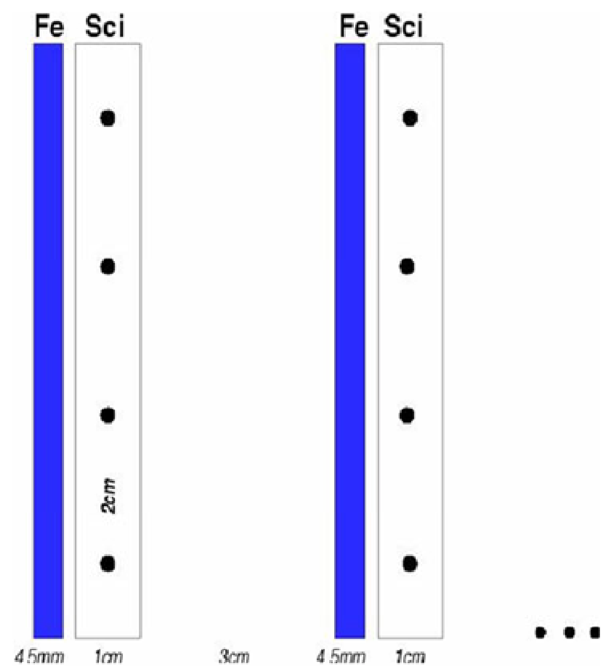
Plastic pellets +RPC (A.Para)





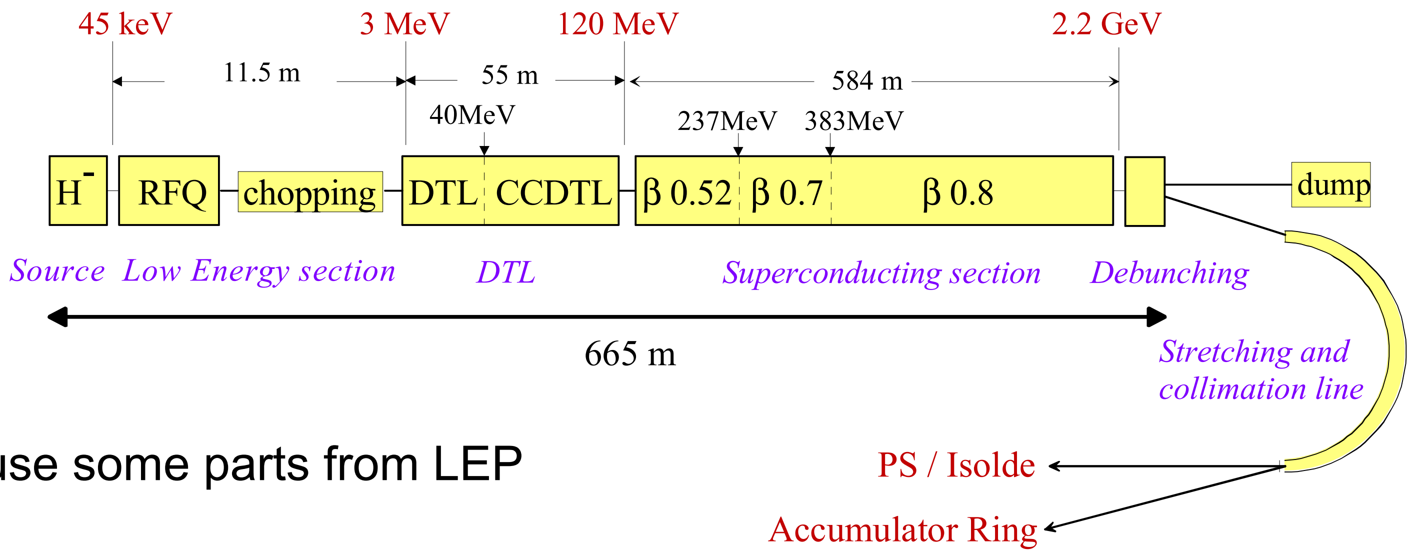
70ton/plane

SOMINOS(Fe+Sci) Szleper+Velasco



5kt, 12m dia., 875planes

Super Proton Linac (SPL) @ CERN



Reuse some parts from LEP

Parameter	Value	Unit
Mean beam power	4	MW
Kinetic energy	2.2	GeV
Repetiton rate	**50**	Hz
Pulse duration	3.3	μs
Pulse intensity	**2.27** $\times 10^{14}$	p/pulse

Under R&D phase