Neutrino Oscillation Working Group Summary: Experiments

Mark Messier

NuFact'05

25 June 2005

Disclaimer!

In the next three talks we will be summarizing ~46 talks given over 5 days -- Apologies in advance for any oversights and errors

Review of experimental data

T. Kajita: Review of results using non-terrestrial sources

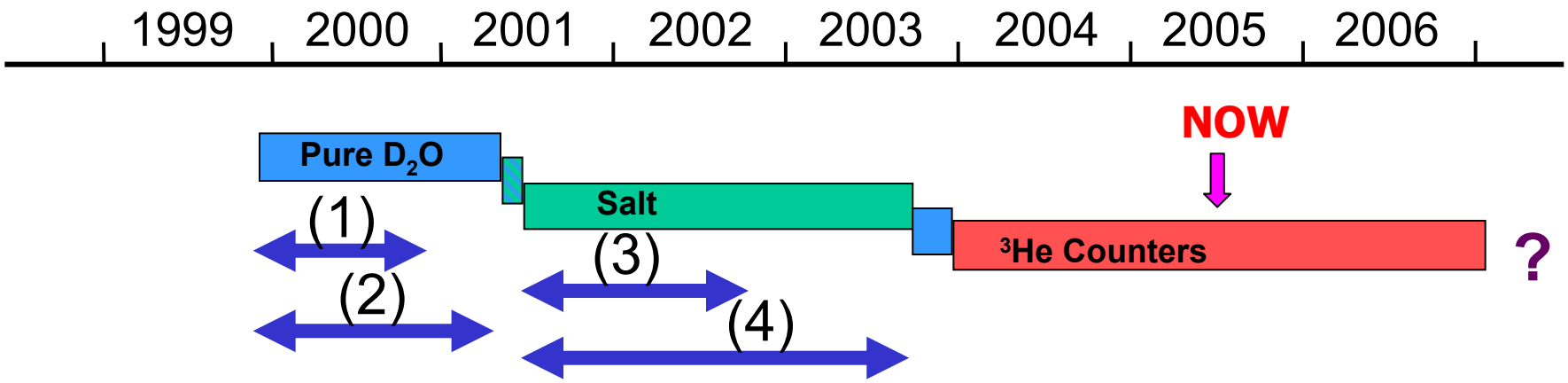
L. Hsu: KamLAND

L. Ludovici: K2K

A. Marchionni: MINOS

I. Stancu: MiniBooNE

History of SNO



(1) ν_{e+}+d→e^-+p+p (CC)

(also compared with SK ν+e→ν+e)

(2) ν_xd→$\nu_x$pn,
n+d→t+γ(6.25MeV) (NC)

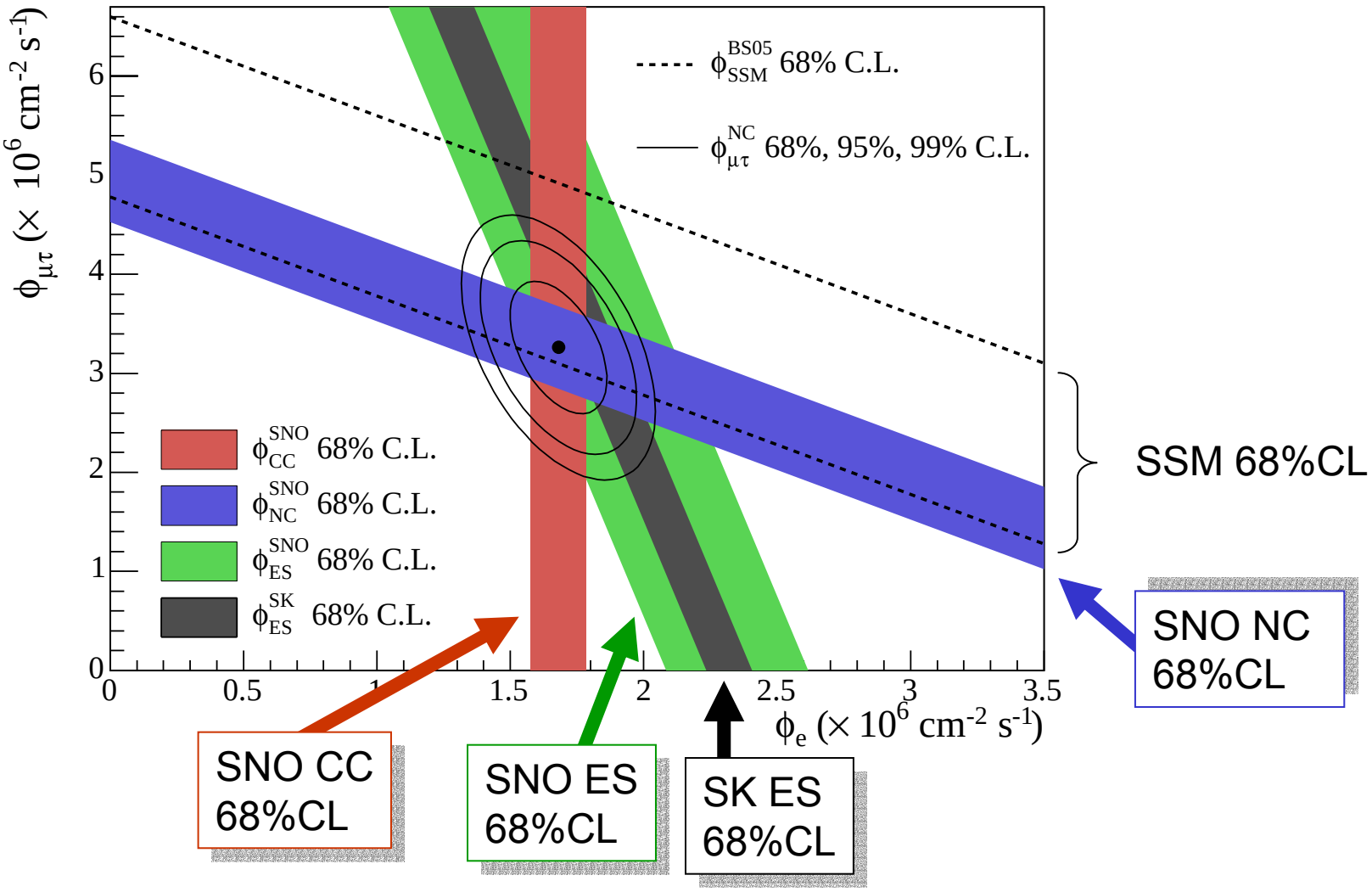
& ν_e+d→e^-+p+p (CC)

(3) ν_x+d→ν_x+p+n,
n+^{35}Cl→^{36}Cl+γ's(Σ8.6MeV) (NC)

& ν_e+d→e^-+p+p (CC)

(4) *New!*
Same as (3), but with improved stat. and syst.

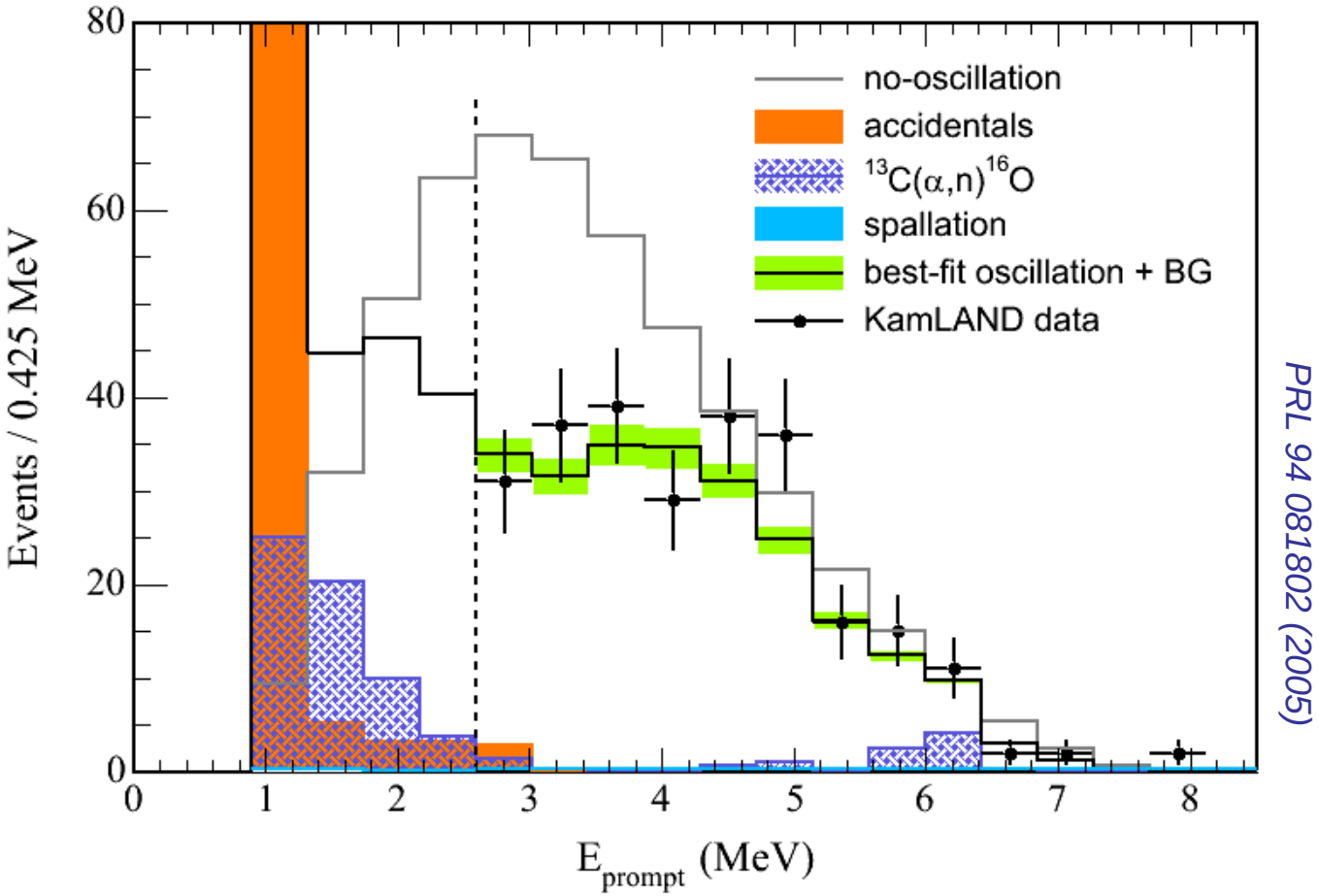
ν_e and (ν_μ+ν_τ) fluxes



All the data are consistently explained within the standard oscillation

Observation of Spectral Distortion

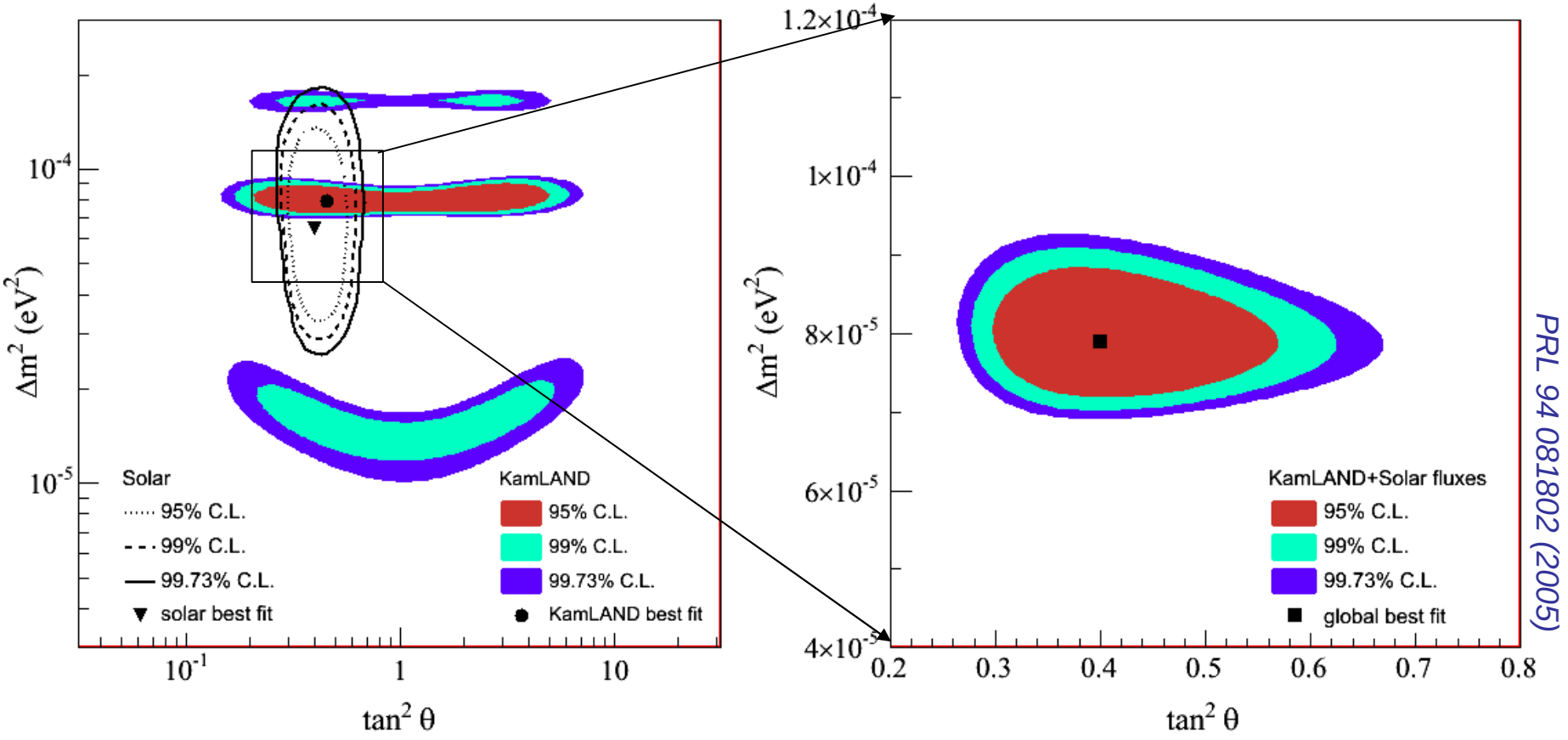
Measurement of Energy Spectrum Distortion Due to $\bar{\nu}_e$ Oscillation (Latest KamLAND Result)



PRL 94 081802 (2005)

Unparalled Sensitivity to Δm^2_{12}

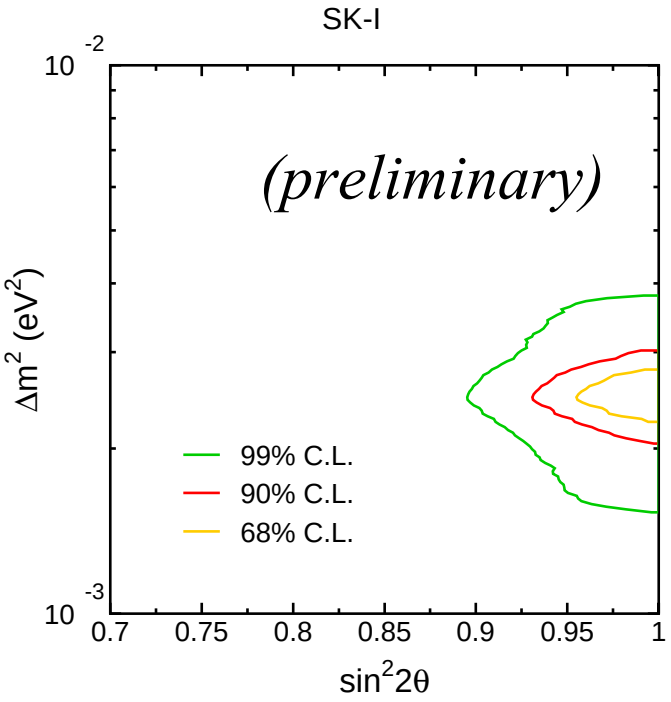
Extract Oscillation Parameters and Combine with Solar Data

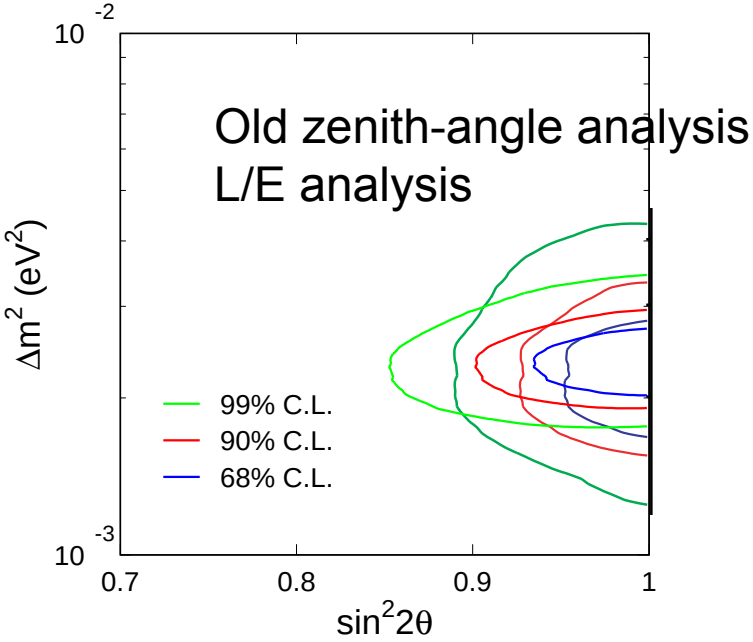


PRL 94 081802 (2005)

Solar + KamLAND: $\Delta m^2_{12} = 7.9^{+0.6}_{-0.5} \times 10^{-5}$ eV^2, $\tan^2\theta_{12} = 0.4^{+0.10}_{-0.07}$

Allowed region from the finer binning analysis



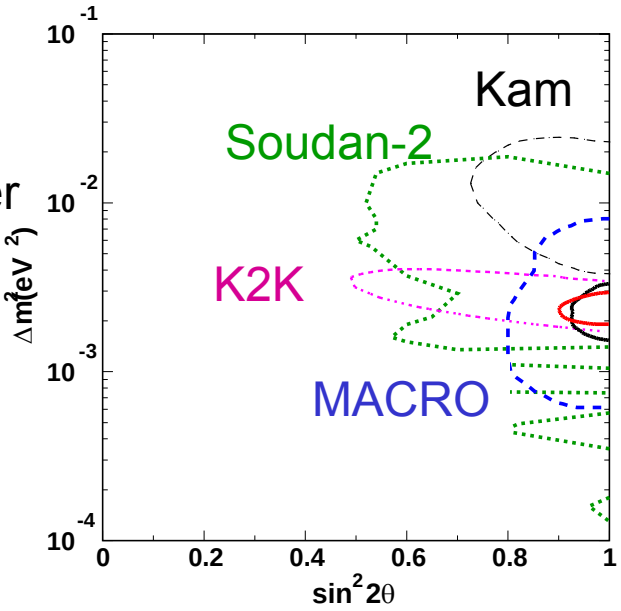


90% CL allowed region:

$\sin^2 2\theta > 0.93$

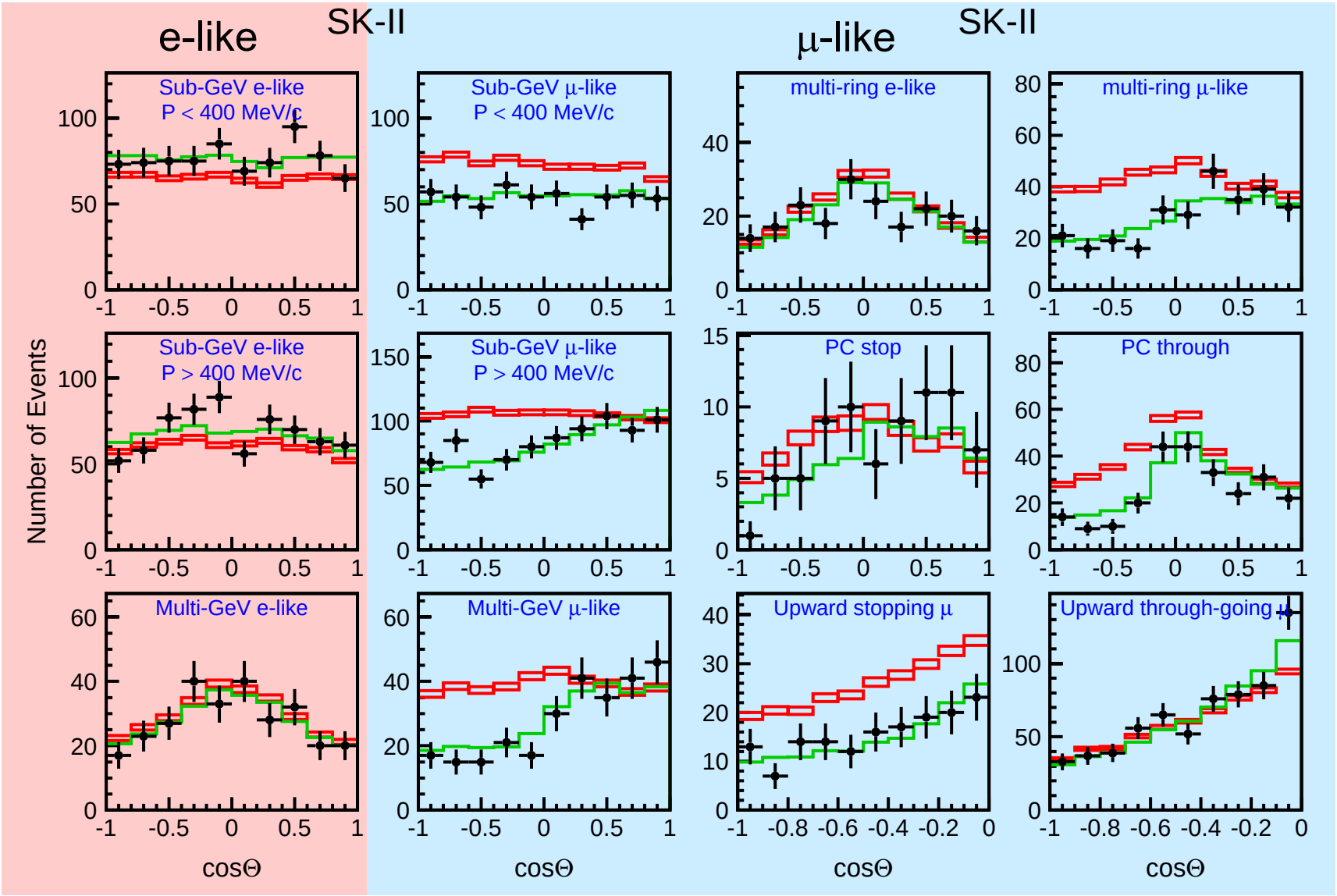
$2.0 < \Delta m^2 < 3.0 \times 10^{-3} \mathrm{eV}^2$

Also consistent with all the other data

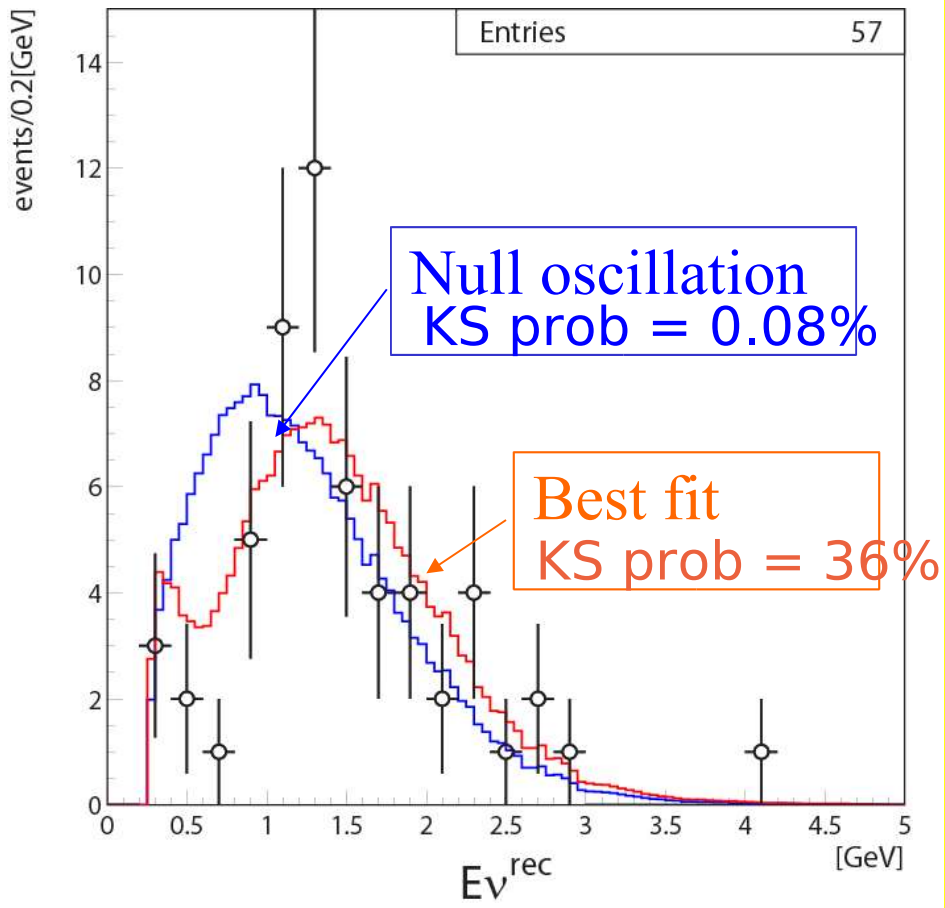


SK-II atmospheric neutrino data

FC&PC: 627days, Up-going muons: 609days



Fit and Data are Consistent



Best likelihood for:

$\sin^2 2\dot{\theta} = 1.51$

$\Delta m^2\,[eV^2] = 2.19\times10^{-3}$

$\mathrm{Prob}\{\sin^2 2\dot{\theta}>1.5\}|_{\mathrm{BestFit}} = 13\%$

Best fit (physical region):

$\sin^2 2\dot{\theta} = 1.00$

$\Delta m^2\,[eV^2] = 2.79\times10^{-3}$

Expected neutrino interactions at the best fit is 103.8, to be compared with 107 observed.

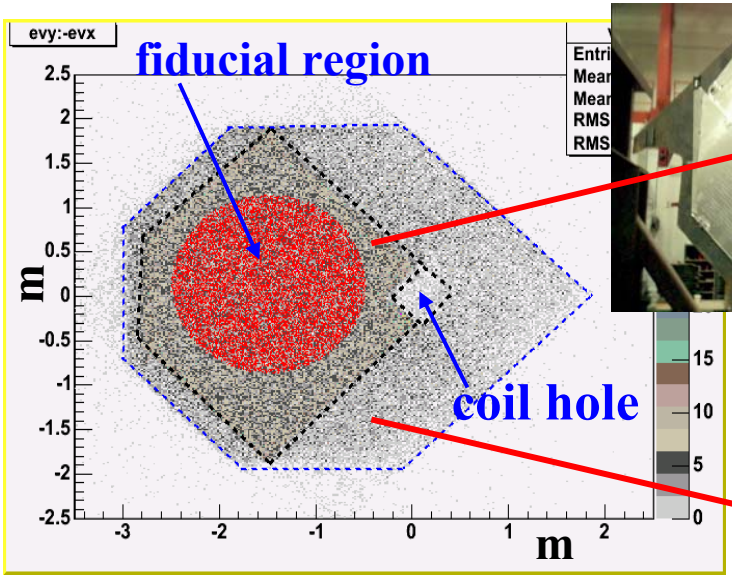
From LogL differences w.r.t. the best fit:

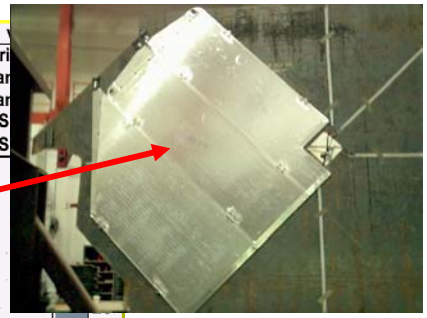
Prob{No Oscill} = 0.0050% (4.0σ) (shape+norm.)

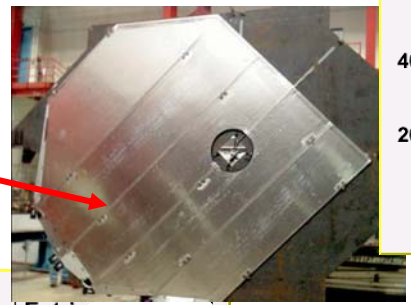
= 0.74% (2.6σ) (shape only)

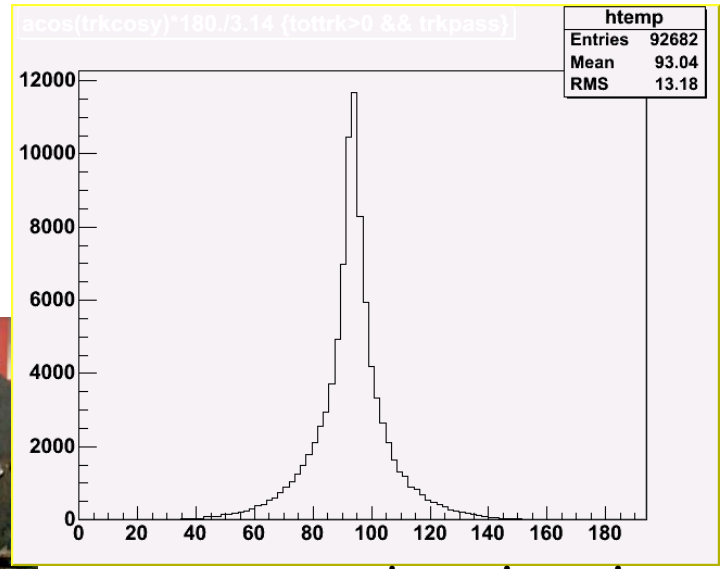
= 0.26% (3.0σ) (norm. only)

Distributions in Near Detector

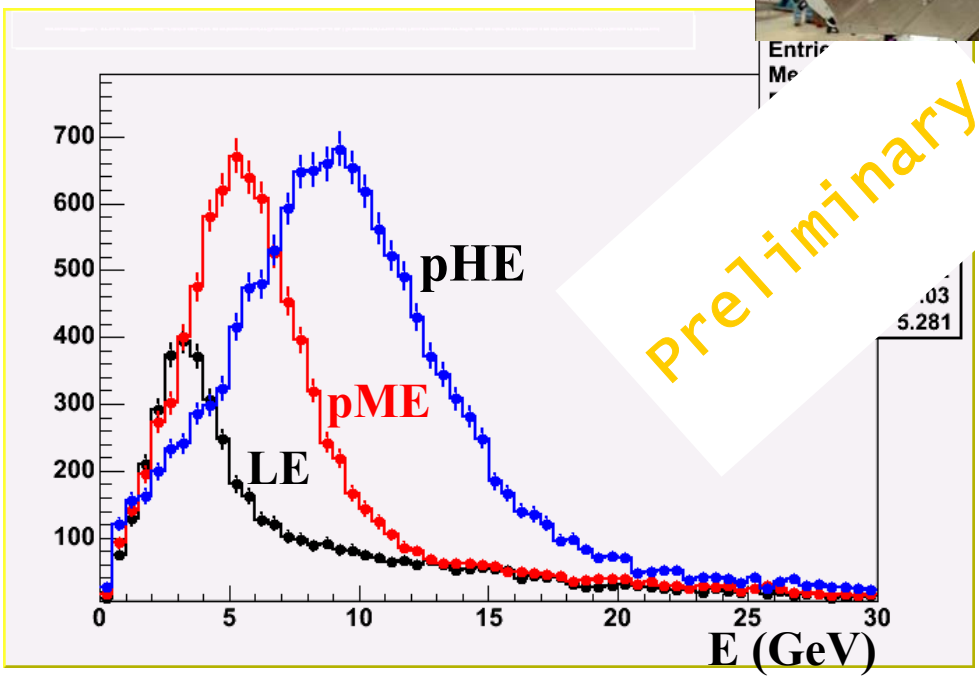








reconstructed track angles with respect to vertical

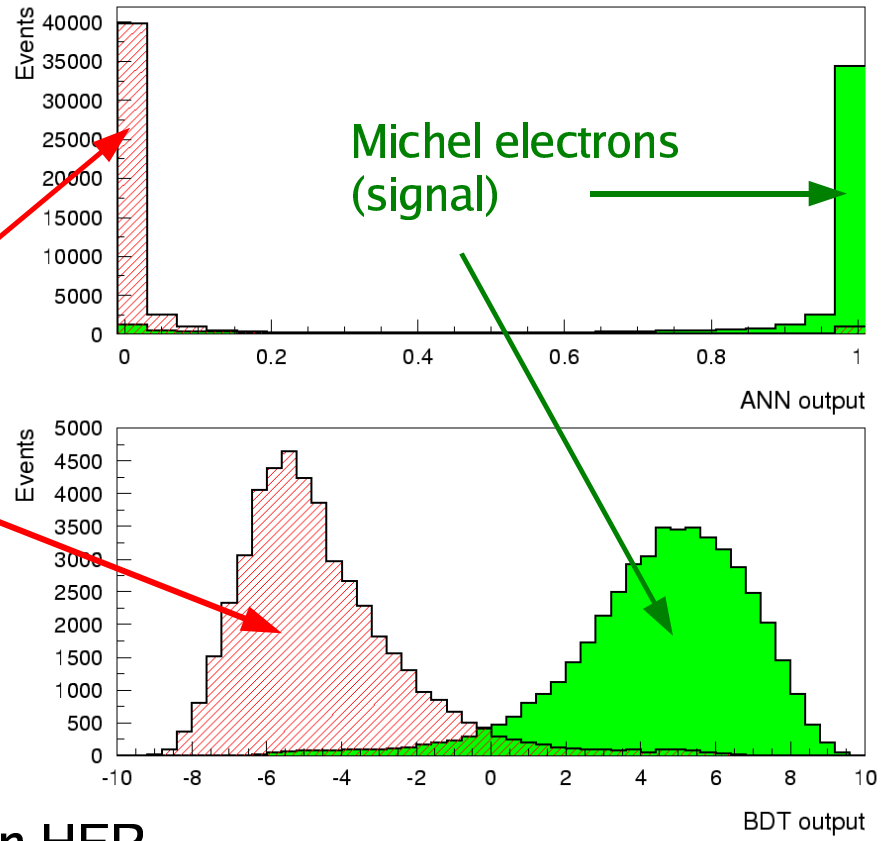


Preliminary

Near Detector, LE beam configuration

- **expect 1×10^{7} ν interactions in a cylindrical fiducial region of 1 m radius and 4 m length for 2.5×10^{20} pot**

PID: ANNs versus BDTs



- ANNs:
  - relatively established technique for PID in HEP
  - very effective for small number of input variables
  - quite tedious to train (many parameters... art)

- BDTs:
  - can easily handle large numbers of input variables
  - relatively easy to train
  - invariant under monotonous variable transformations

Next Generation Experiments

M. Bonesini: Hadroproduction data parameterisation for fast neutrino beam calculations

G. De Lellis: OPERA

J. Kisiel: ICARUS

J. Nelson: NOvA

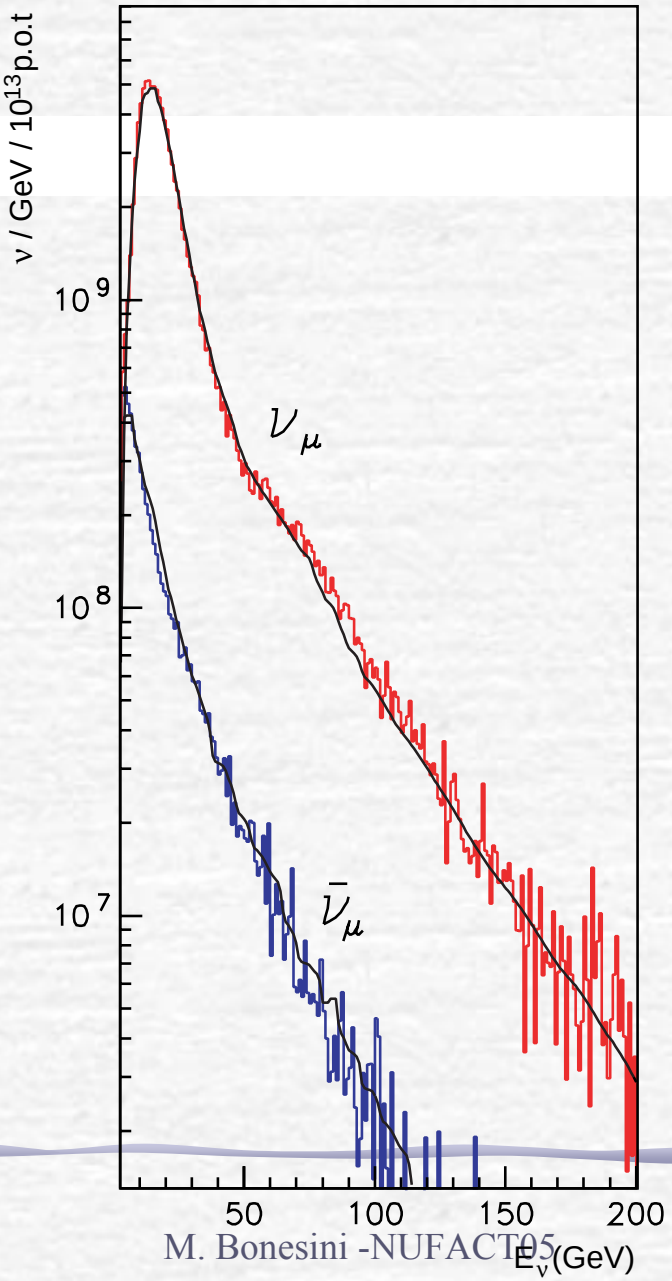
Y. Yamada: T2K phases I & II

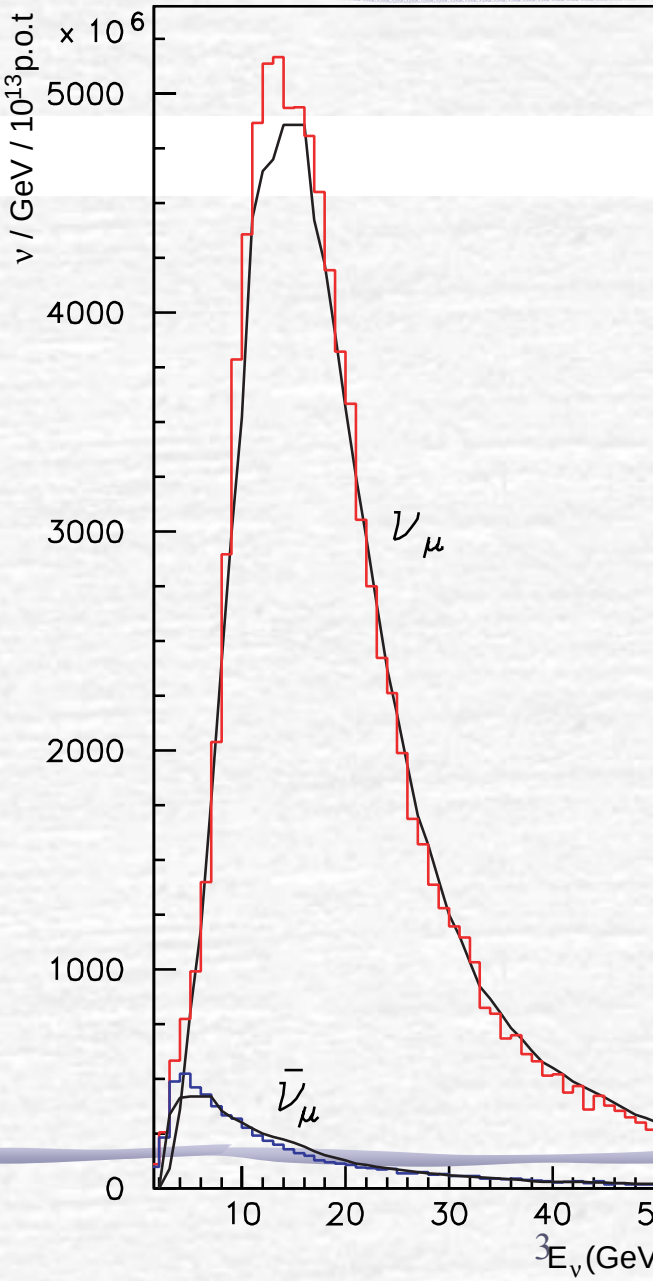
M. Fechner: Background extrapolation from T2K 2 km detector

WANF: Comparison with CHARM II data

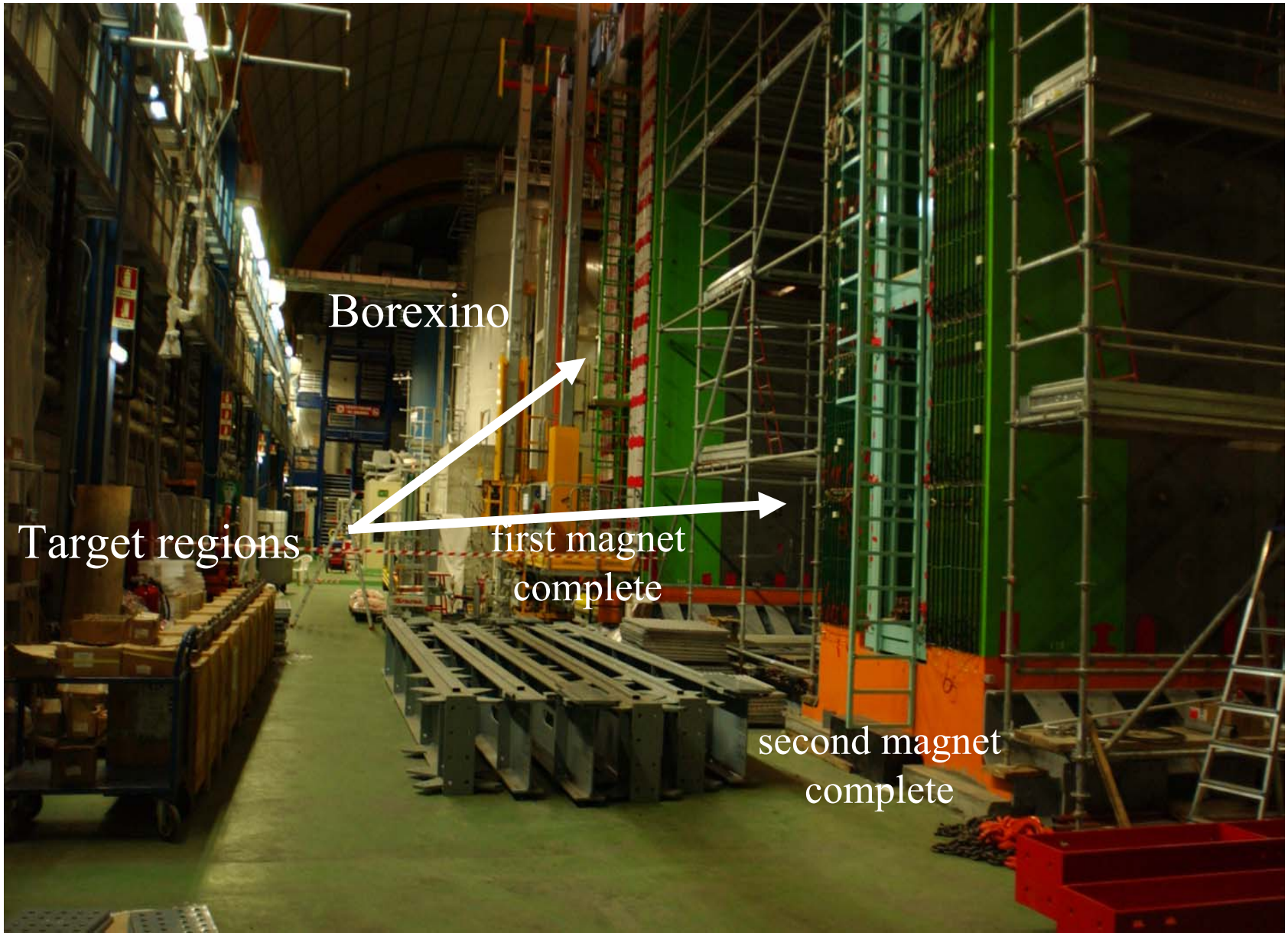
e CHARM II collab., Eur. Phys. J. C11
999), 18

- 450 GeV p on Be
- 8 mrad acceptance
- Detector at 881 m
- Positive focusing
  - ν_μ beam (10^5 pot)
  - CHARM II data
  - Anti- ν_μ contamination



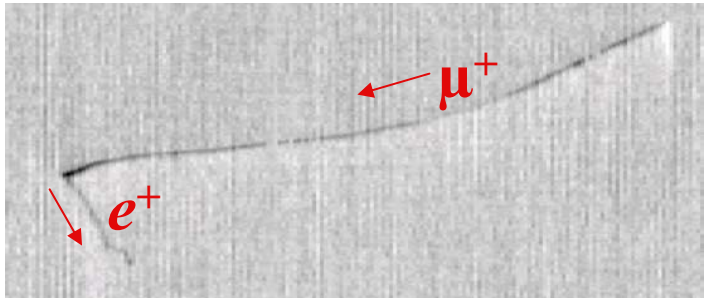


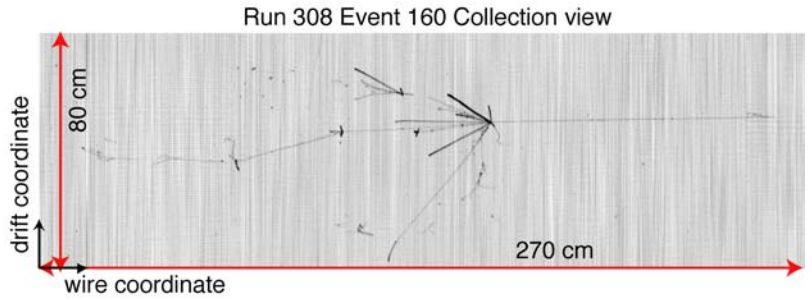
Detector picture as in June 2005

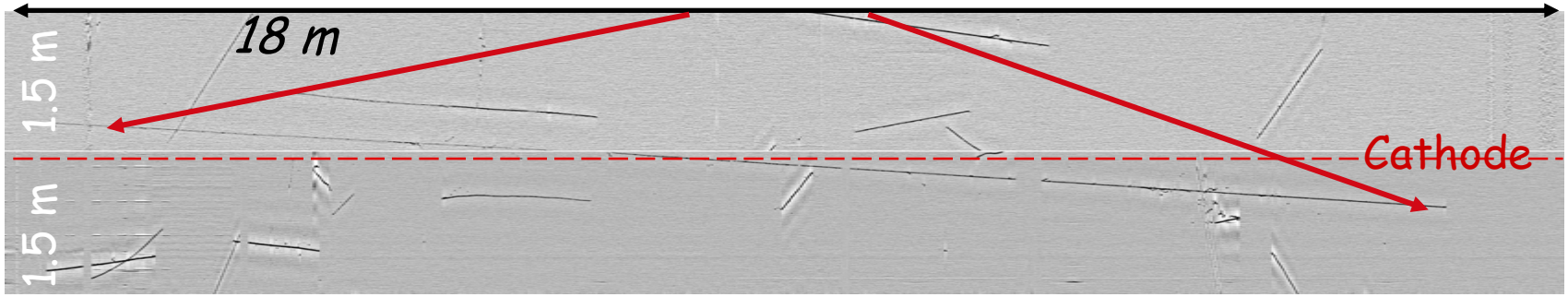


Status of the ICARUS detector

- 2001: successful test of the T300 module in Pavia (100 days of data taking, ~29000 triggers on tape, different topologies: long (up 18 m !) muon tracks, hadronic and EM interactions, muon bundles,…







$\nu_\mu \rightarrow \nu_\tau$ *sensitivity*

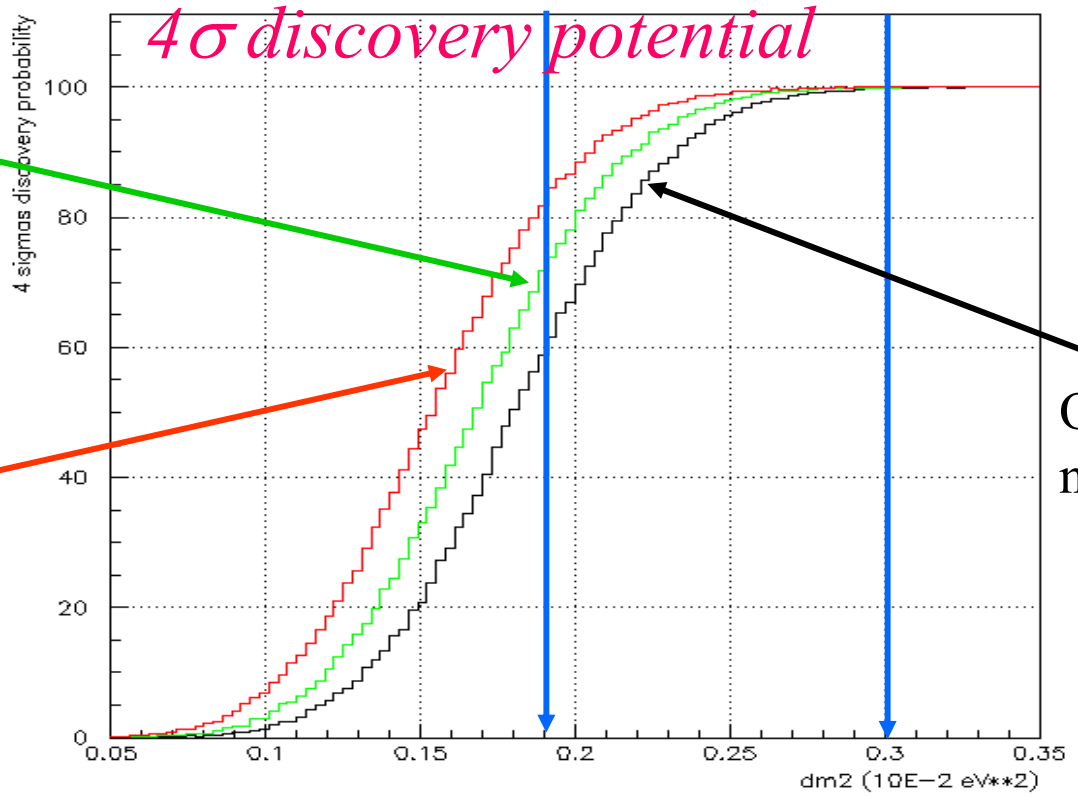
full mixing, 5 years run @ 4.5 x10^{19} pot / year

	signal (Δm^2=1.9x10^{-3}eV^2)	signal (Δm^2=2.4 x10^{-3}eV^2)	signal (Δm^2=3.0x10^{-3}eV^2)	BKGD
OPERA 1.8 kton	6.6	10.5	16.4	0.7
+ brick finding + 3 prong decays	8.0	12.8	19.9	1.0

Opera with expected background improvements

-30%

Opera, half background



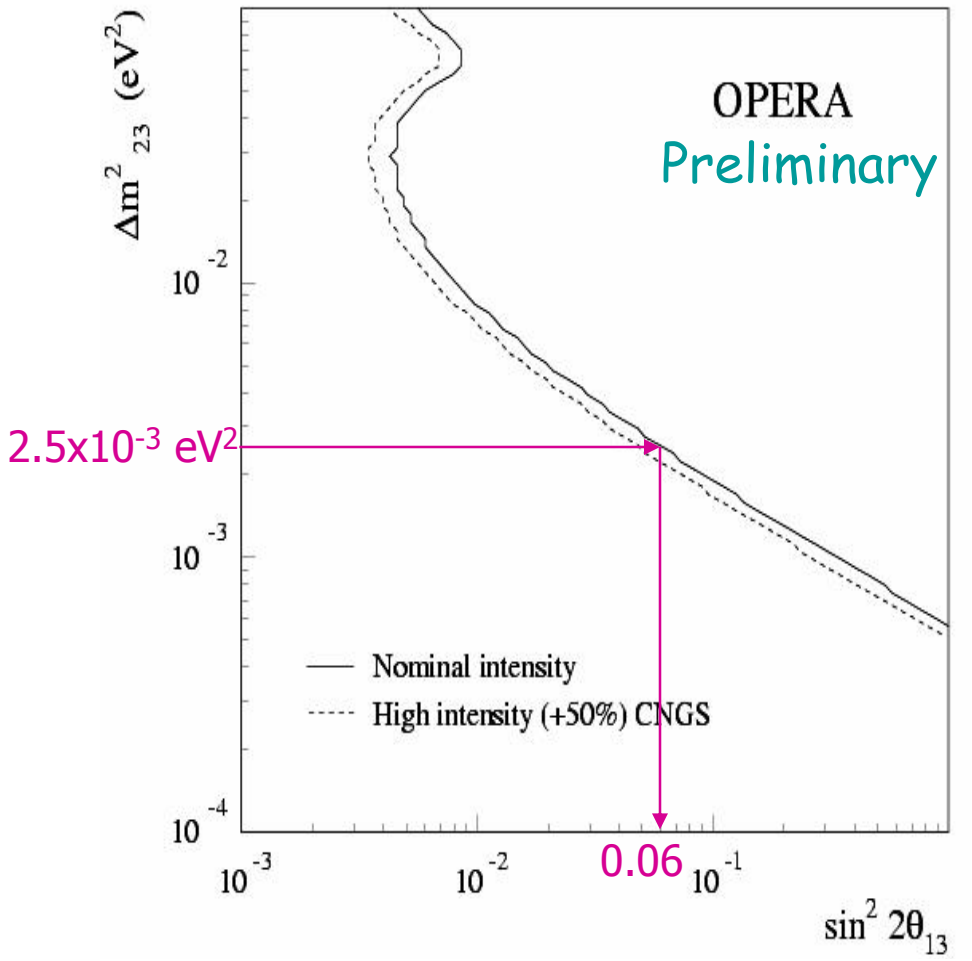
Opera nominal

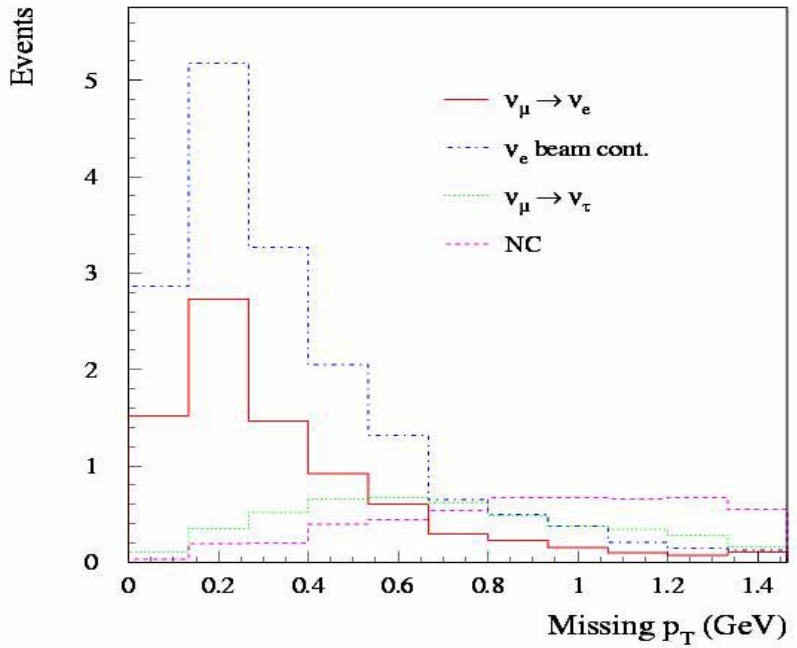
SK 90% CL (L/E analysis)

OPERA sensitivity to θ_{13}

Simultaneous fit of E_e, missing p_T and E_{vis} distributions

10% syst. in ν_e contamination



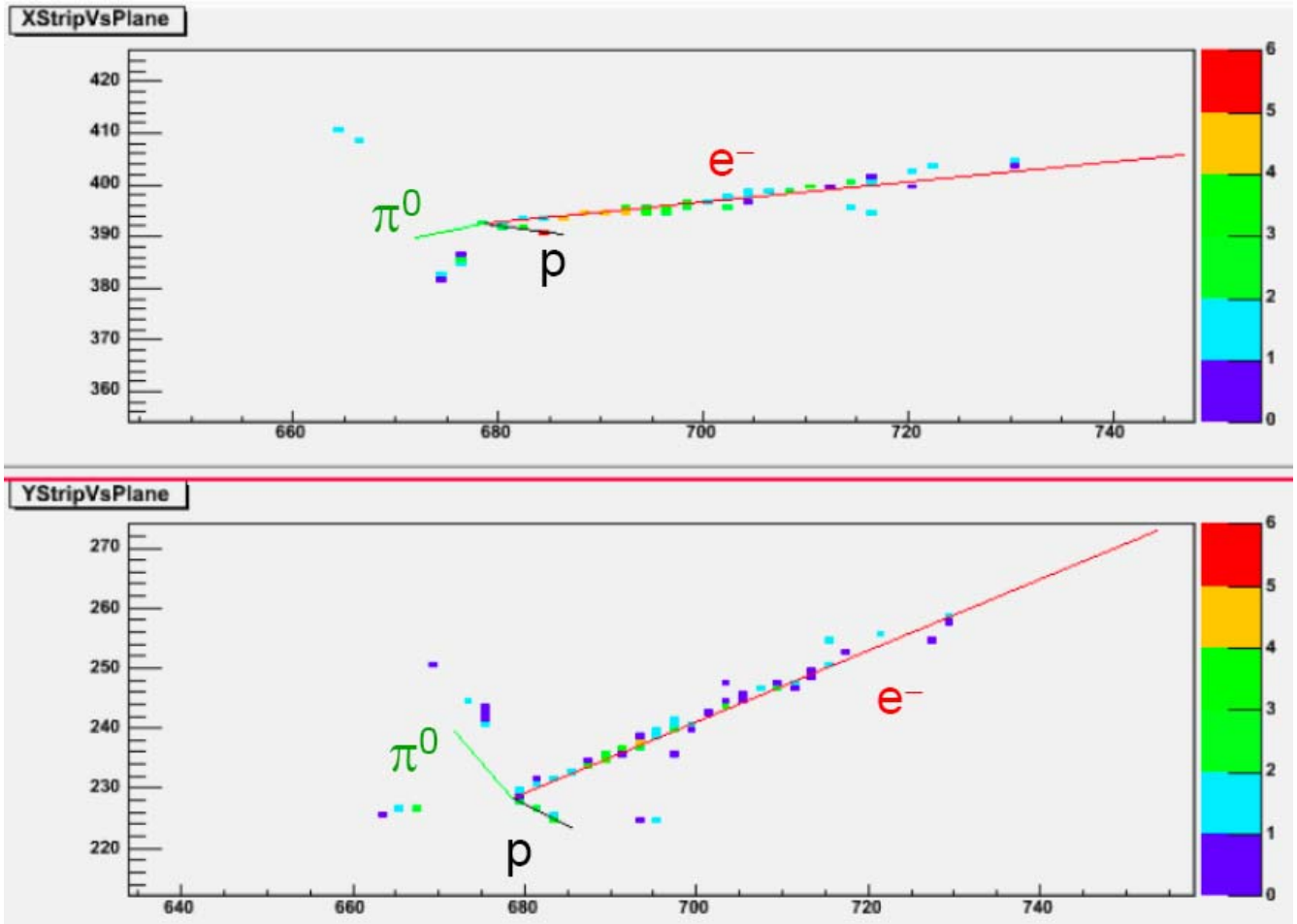


Limits at 90% CL for

$\Delta m^2 = 2.5\text{x}10^{-3}$ eV^2 full mixing

	$\sin^2 2\theta_{13}$	θ_{13}
CHOOZ	**<0.14**	**11^0**
OPERA	**<0.06**	**7.1^0**

Example MC Event
1.65 GeV $\nu_e N \rightarrow e p \pi^0$



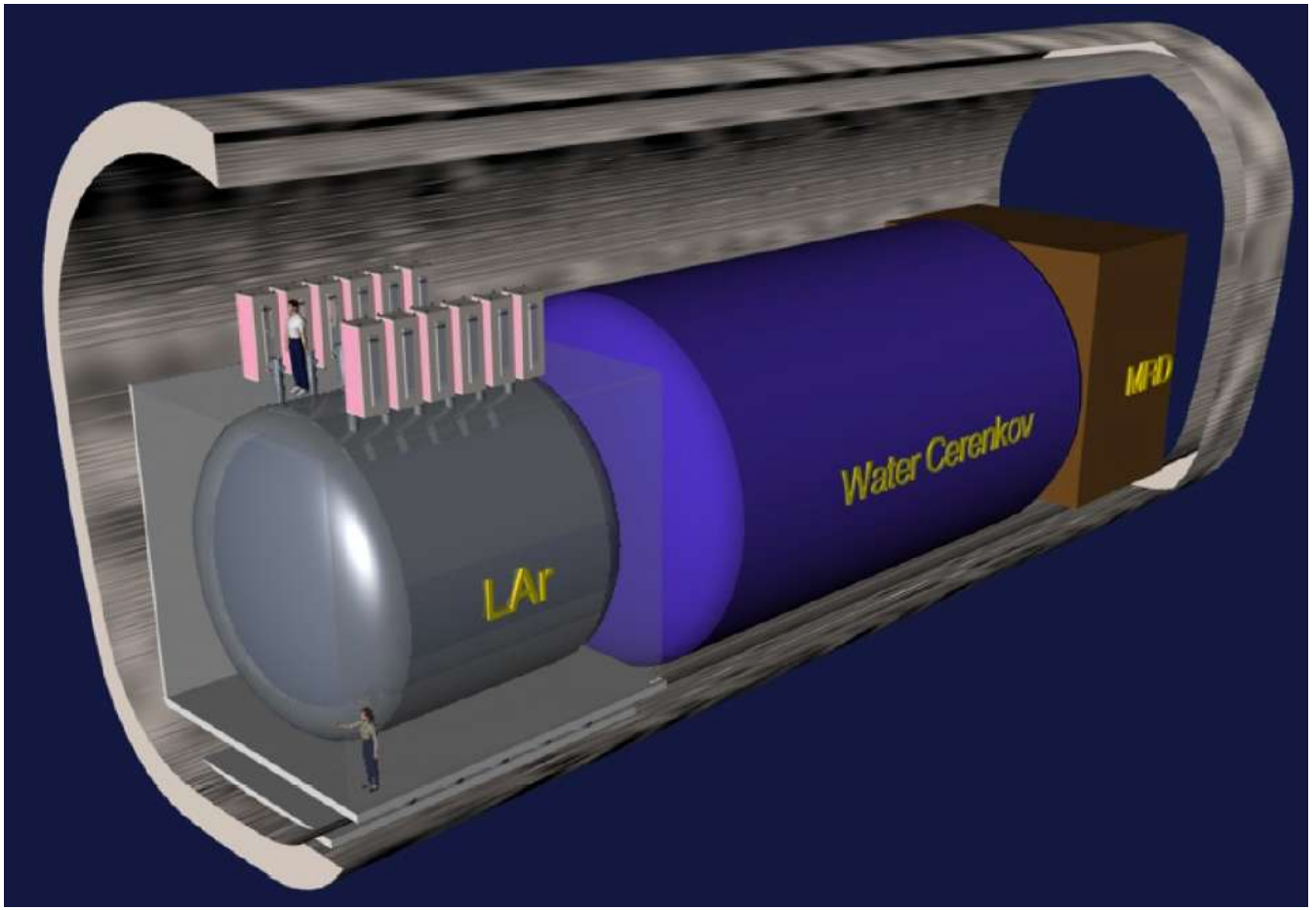
Half Block Prototype Being Built

J-PARC status

- Buildings for LINAC and 3GeVPS finished.
- North-east part of tunnel for 50GeVPS finished.
- South-west part of tunnel will finish in FY2006.
- First beam on 50GeV PS in FY2008

2KM Detector Configuration

The 2KM detector is made of three sub-systems.



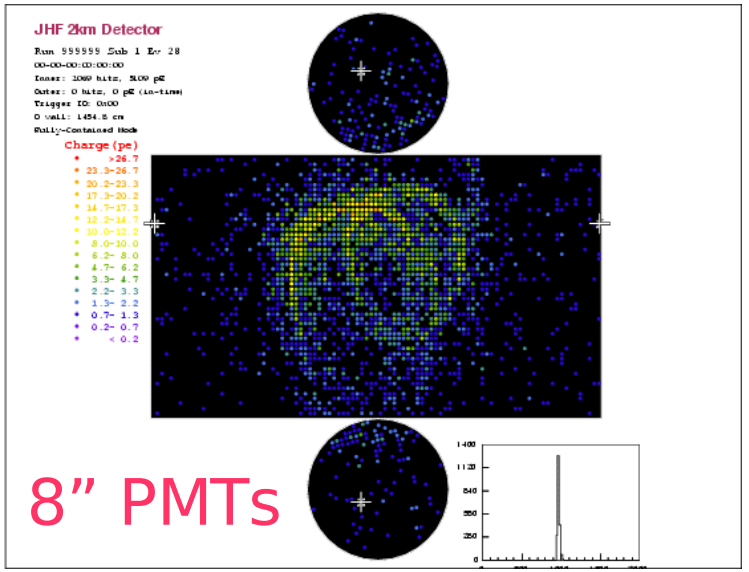
ν Direction

Muon Ranger:
Measure high energy tail of neutrino spectrum.

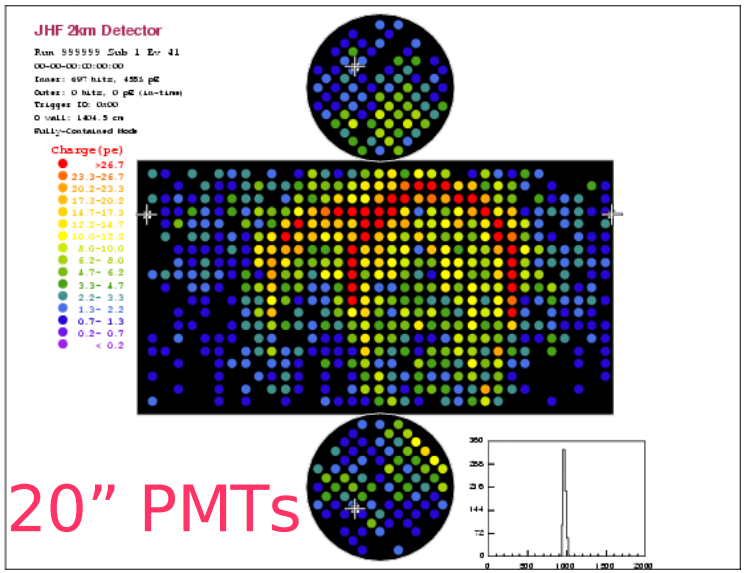
Liquid Argon Detector:
exclusive final states
frozen water target

Water Cherenkov Detector:
Same detector technology as SK
~ 1 interaction/spill/1kton

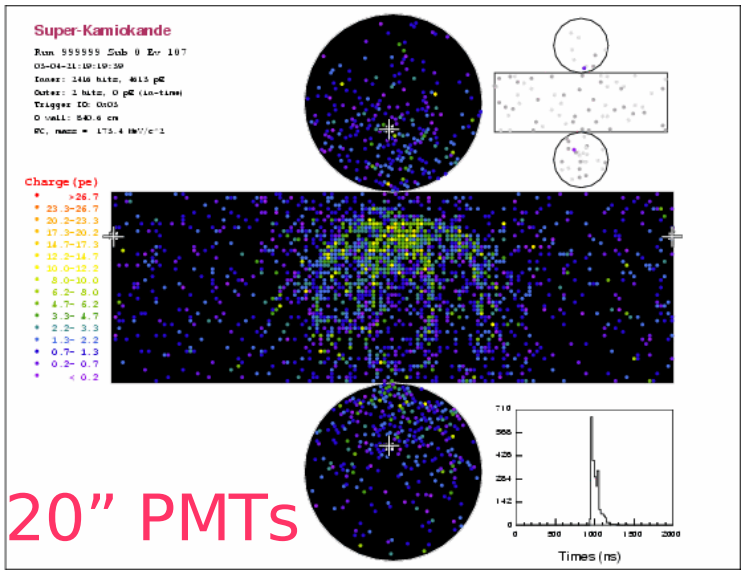
2KM : 5660 PMTs



2KM : 841 PMTs



SK : 11146 PMTs

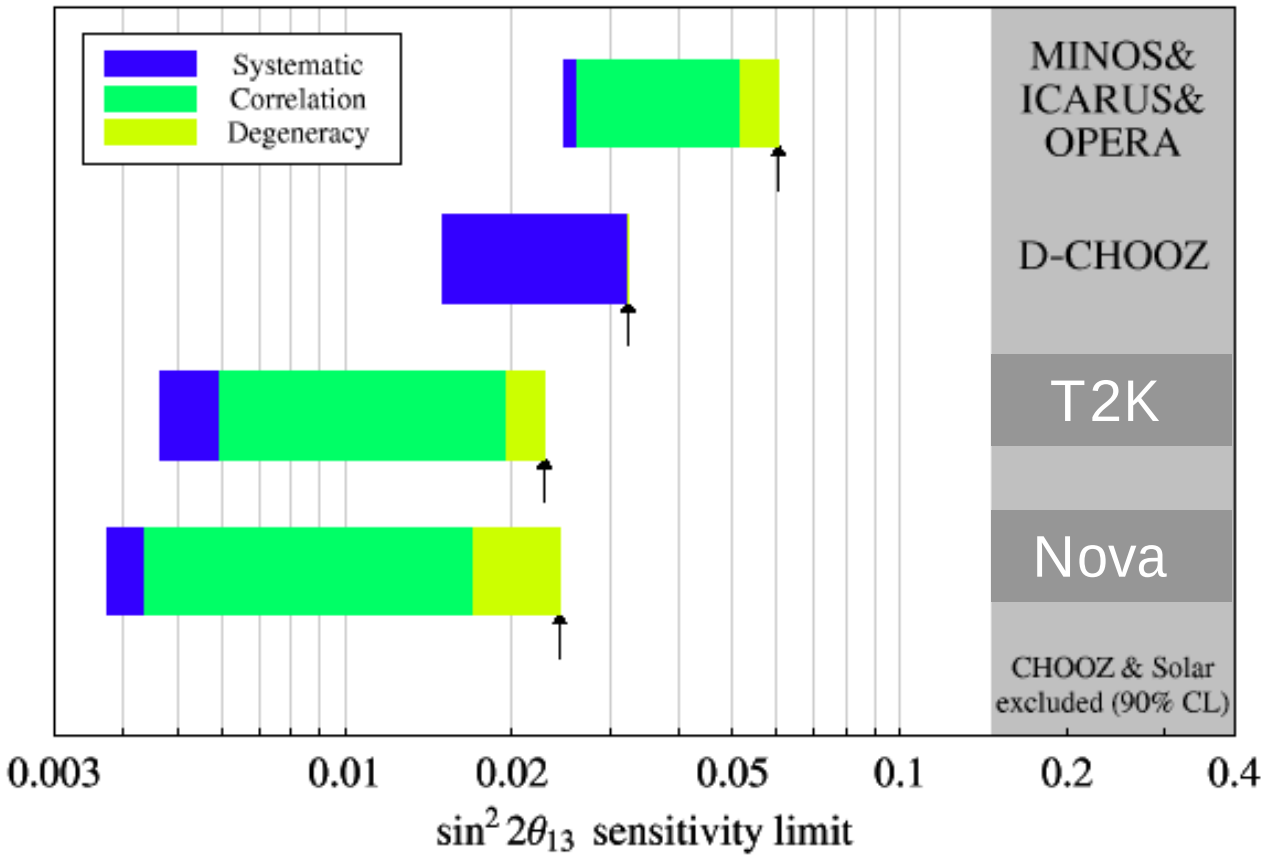


Studies show that 5660 8” PMTs best match SK performance :

- Ring counting
- Particle ID
- Fid. Vol. Determination
- e/π^0 separation

$\sin^2(2\theta_{13})$ at LBL & reactors

$\Delta m^2 = 2.0\ 10^{-3}\ eV^2$



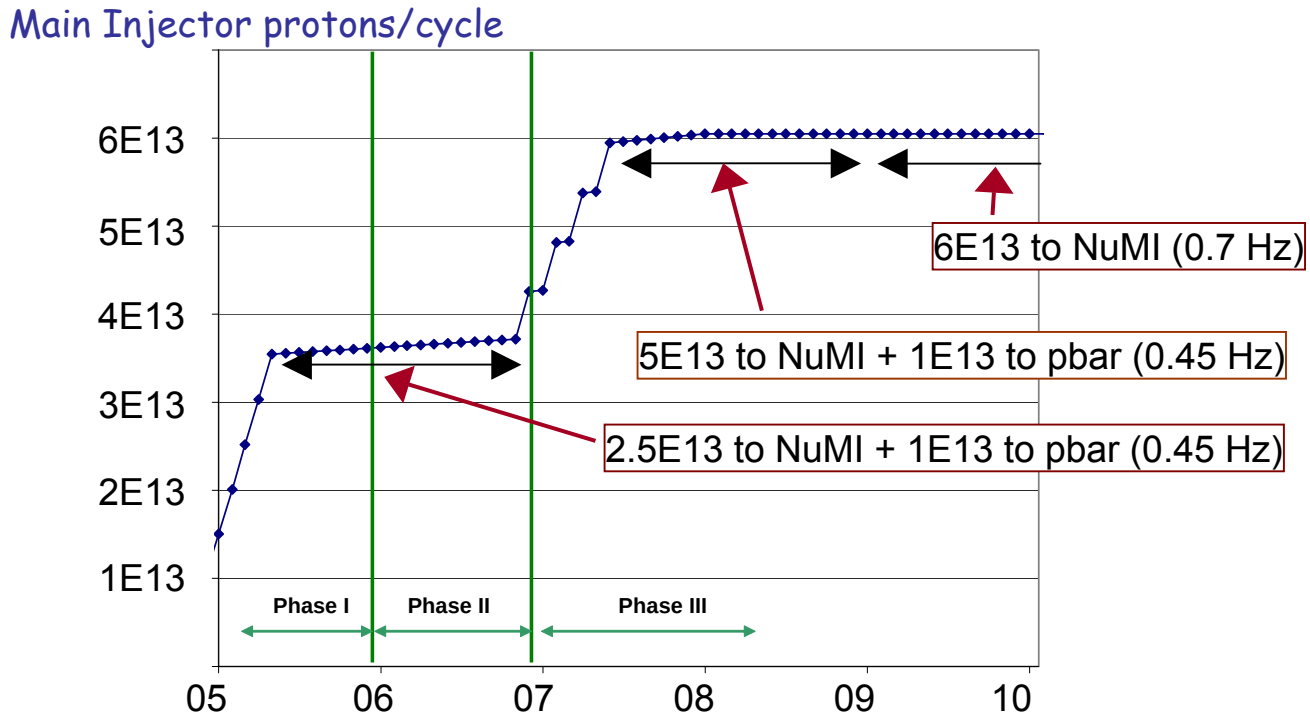
5 years

3 years

5 years

P. Huber et. al. hep/0403068

Evolution of Beam Intensities and Rates to NuMI



NuMI flux to MINOS ~ 2 x 10^{20} protons/year (now)

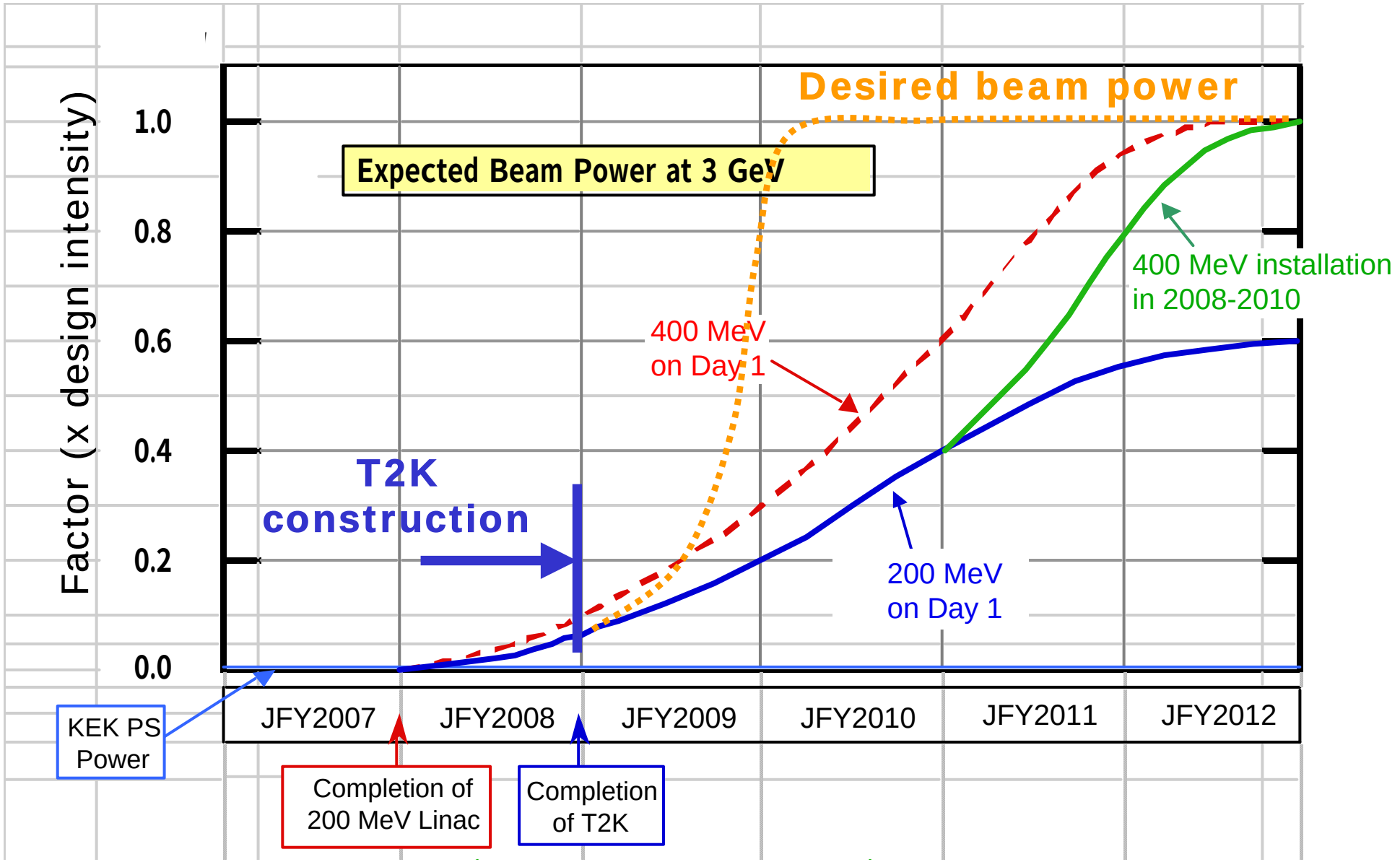
`Proton Plan' (remove existing limitations) gives NuMI

~ 4 x 10^{20} protons/year before collider turn-off in 2009

~ 6 x 10^{20} protons/year after collider turn-off in 2009

Proton Driver (new Linac) ~ 25 x 10^{20} - whenever PD exists

Expected Beam Power



Neutrino Detectors

J. Nelson: Magnetized iron calorimeter

D. Casper: Water Cherenkov

S. Pordes: FLARE (Fermilab Liquid Argon Experiment)

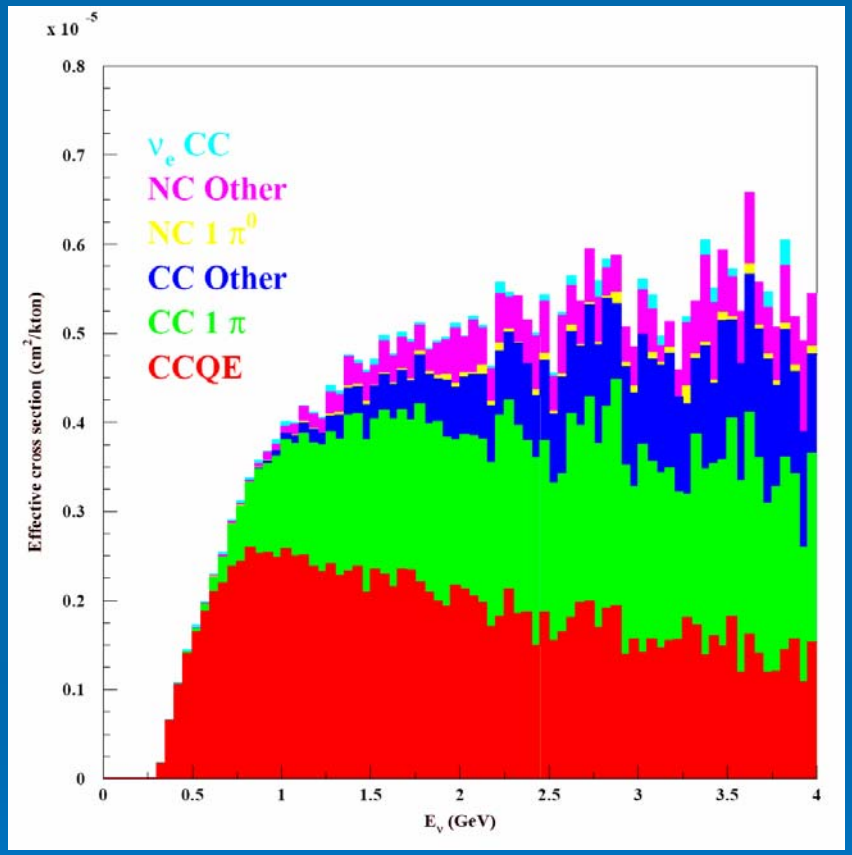
A. Rubbia: Very large liquid argon detectors

N. Mondal: India-based Neutrino Observatory (INO)

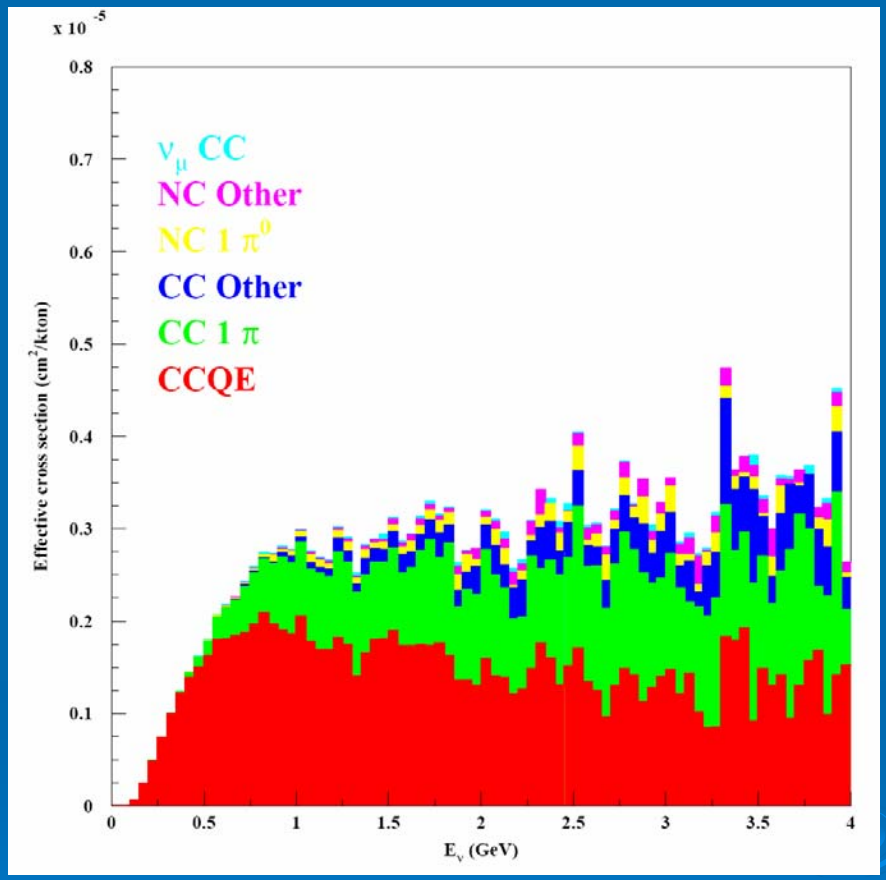
Y. Yoshizawa: Recent developments in Hamamatsu Photonics

E. Flyckt: Large PMT's for Megaton detectors

Signal and Backgrounds



1-ring μ-like sample



1-ring e-like sample

50kt NOvA Sampling Detector
Solid Scintillator + PMT

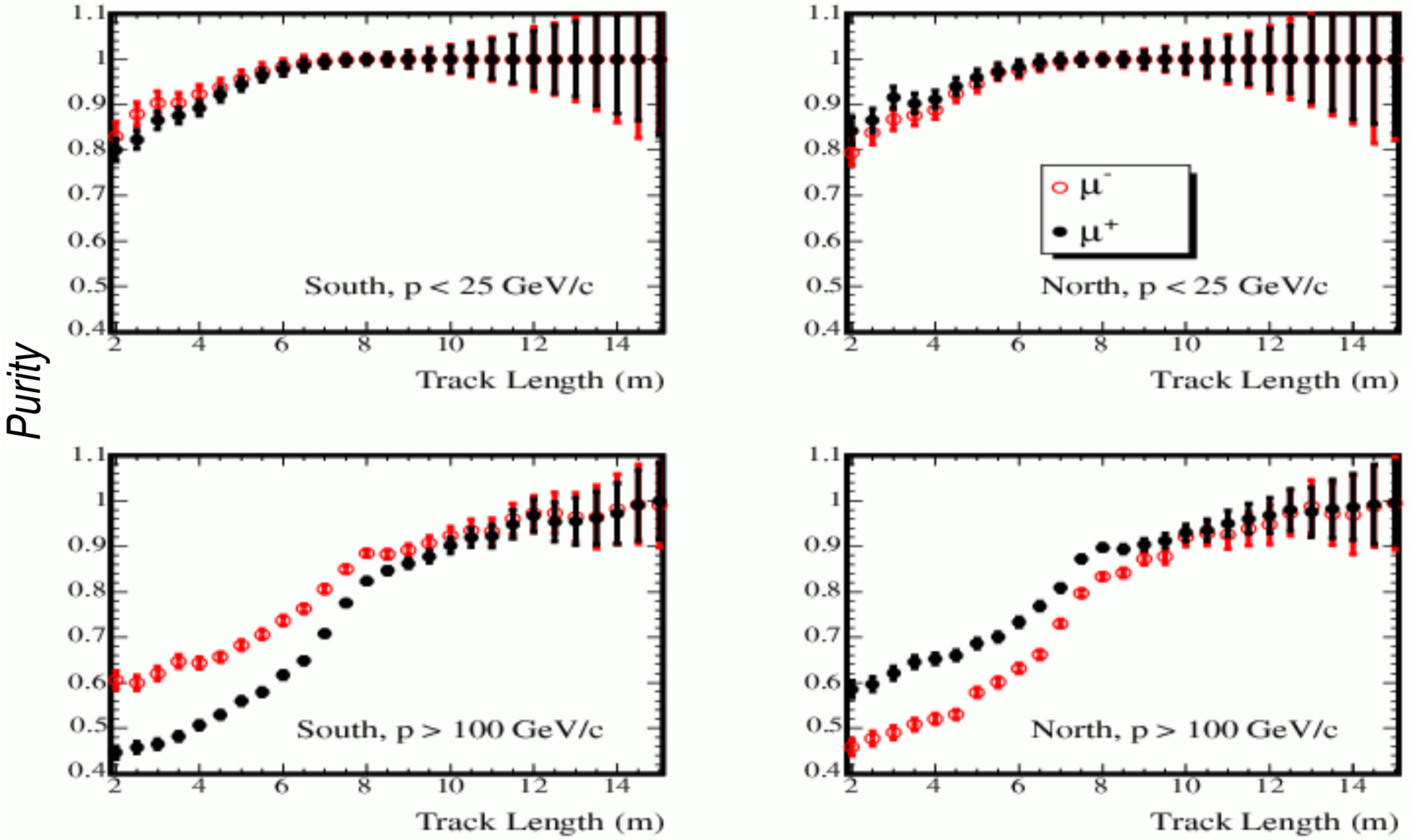
~400m^2 and 1000 samples

Not fully loaded costs – only to show scaling

Use absolute costs from NOvA talk (next slide)

	Solid PMT		Solid APD	Liquid APD
Scintillator	22.3		27.3	14.2
optical fibers	12.0		12.0	12.0
Scintillator Assembly	25.7		21.4	13.5
Photodetector	7.5		1.7	1.7
Electronics (not DAQ)	15.3		8.4	8.4
Sum	82.8	$M	70.8	49.8

MINOS charge sign measurement



Brian Rebel, PhD Thesis, Indiana University

towards a Large Liquid Argon TPC for the NuMI Off-axis Beam

Present Concept: Tank, Argon, Electrodes, Readout.

Monte-Carlo studies (efficiency ~ 80% in active/fiducial region)

Issues to/under study:

- Initial `purification' of Argon (dealing with air in Tank)
- Effects of materials used on electron drift lifetime
- Electrode mechanics
- Signal processing (from wire up to DAQ)
- Data Acquisition (from spill based to always live)
- Simulations
- Automated reconstruction (rejection of cosmic rays, event identification)

urls: http://www-off-axis.fnal.gov/flare/ &
http://www-off-axis.fnal.gov/notes/notes.html

U.S. Department of Energy
and the
National Science Foundation

Professor Frederick Gilman
Chair, HEPAP
Carnegie-Mellon University
5000 Forbes Avenue
Pittsburgh, PA 15213

Professor Richard F. Casten
Chairman, NSAC
Wright Nuclear Structure Laboratory
Yale University
New Haven, CT 06520

Charge 3

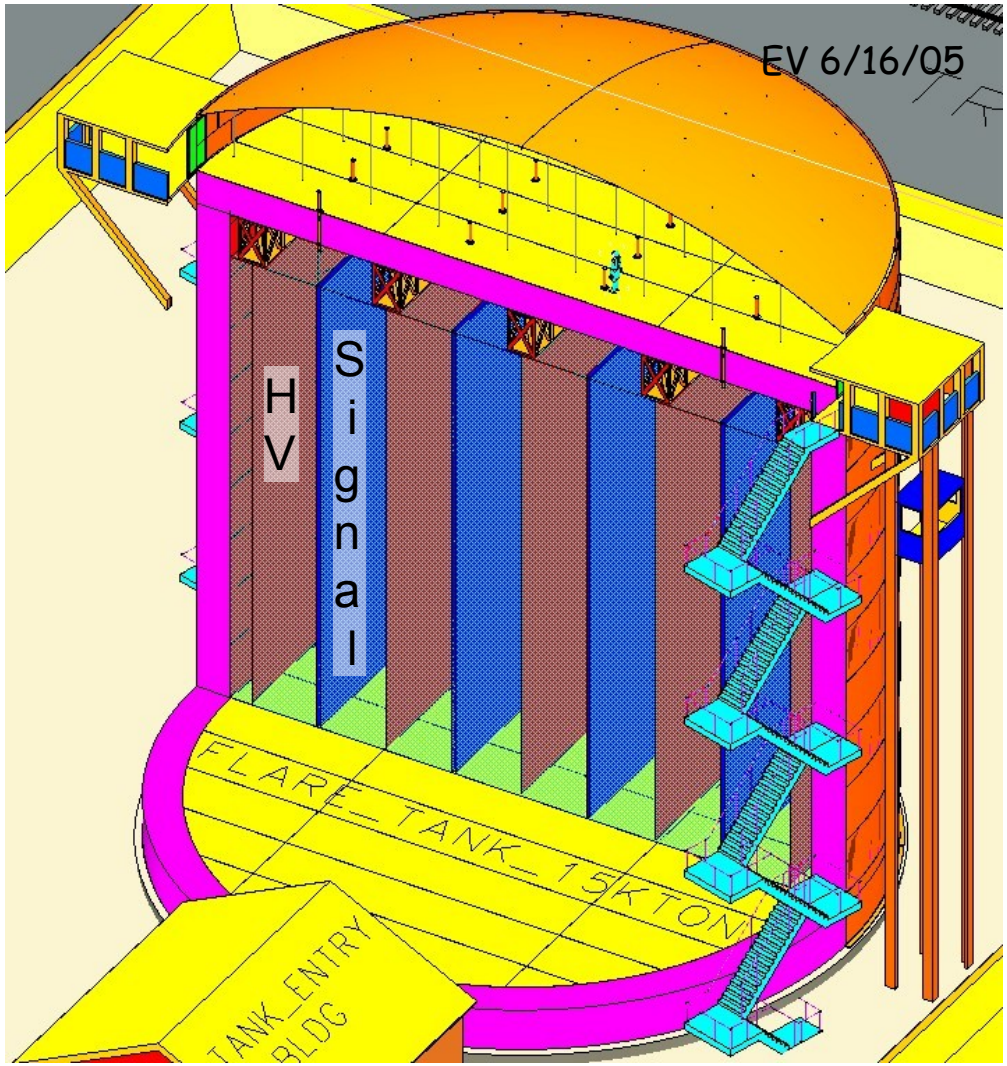
We request that NuSAG address the APS Study's suggestion that the U.S. participate in *"A timely accelerator experiment with comparable $\sin^2 2\theta_{13}$ sensitivity [to the recommended reactor experiment, i.e. $\sin^2 2\theta_{13}$=0.01]* and sensitivity to the mass-hierarchy through matter effects."

The options to be considered should include, but not be limited to:

- U.S. participation in the T2K experiment in Japan
- Construction of a new off-axis detector to exploit the existing NUMI beamline from Fermilab to Soudan, as proposed by the Nova collaboration
- As above but using a large liquid argon detector.

Large Liquid Argon TPC for the NuMI Off-axis Beam is part of NuSAG charge

towards a Large Liquid Argon TPC for the NuMI Off-axis Beam



3D `Model' cutaway
15 kt detector

Changes from standard LNG tank:

inner tank wall thickness increased
- LAr is 2 x density of LNG;

trusses in inner tank to take load of the wires:

penetrations for signals from inner tank to floor supported from roof of outer tank;

Tentative coil parameters

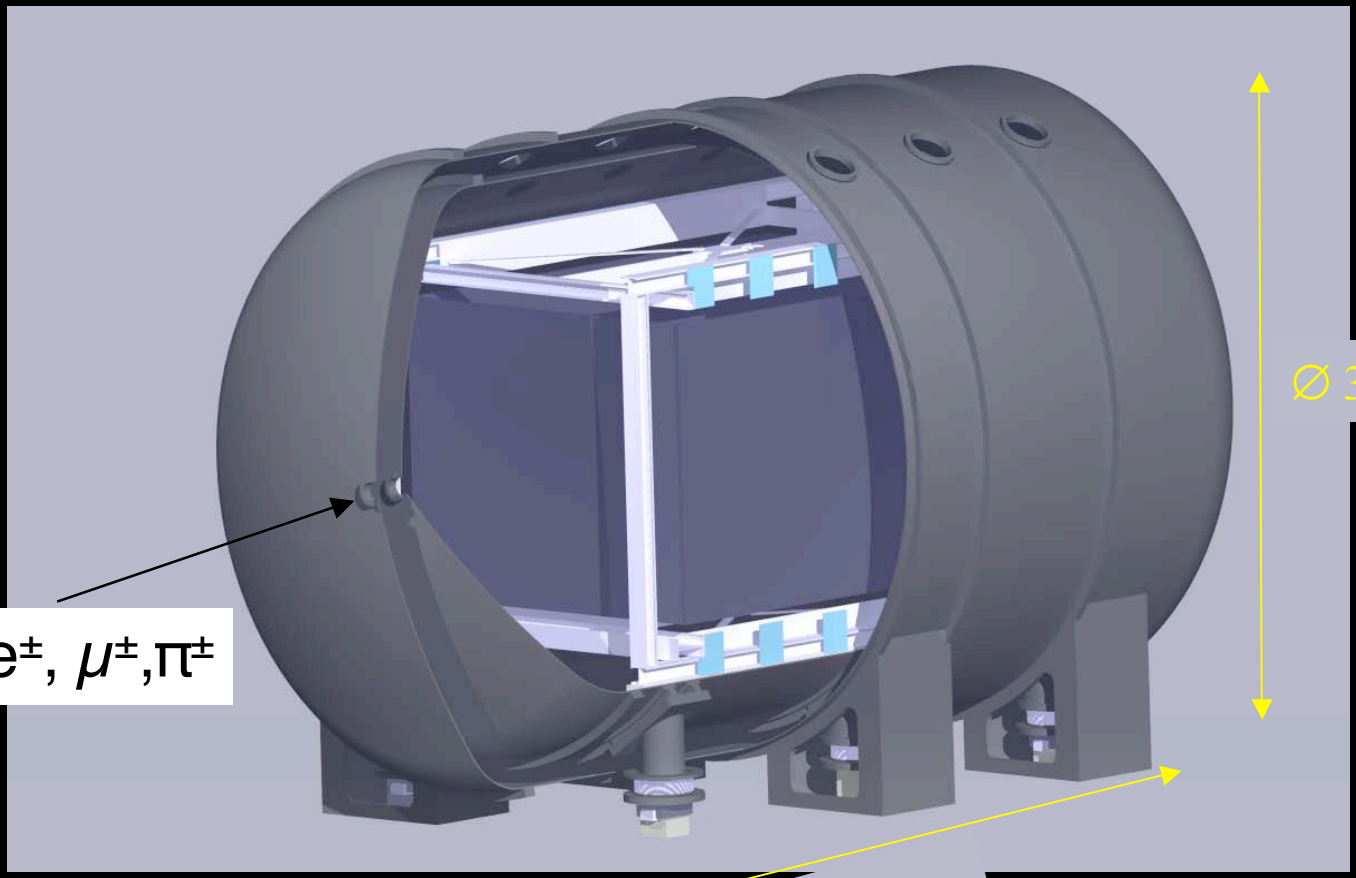
Other examples: ALEPH, CDF, ATLAS Toroids, AMS-II

	10 kton LAr			100 kton LAr			ATLAS solenoid	CMS
Magnetic induction (T)	0.1	0.4	1.0	0.1	0.4	1.0	2.0	4.0
Solenoid diameter (m)	30			70			2.4	6
Solenoid length (m)	10			20			5.3	12.5
Magnetic volume (m^3)	7700			77000			21	400
Stored magnetic energy (GJ)	0.03	0.5	3	0.3	5	30	0.04	2.7
Magnetomotive force (MAt)	0.8	3.2	8	1.6	6.4	16	9.3	42
Radial magnetic pressure (kPa)	4	64	400	4	64	400	1600	6500
Coil current (kA)	30 (I/I_c=50%)						8	20
Total length conductor (km)	2.5	10	25	12	57	117	5.6	45
Conductor type	NbTi/Cu normal superconductor, T=4.4K							

(Detailed magnetic, mechanical, thermal and quench analysis yet to be performed…)

(5) Conceptual study of a 50 ton (magnetized) LAr TPC

We are contemplating a magnetized prototype for calorimetry and charge discrimination studies.

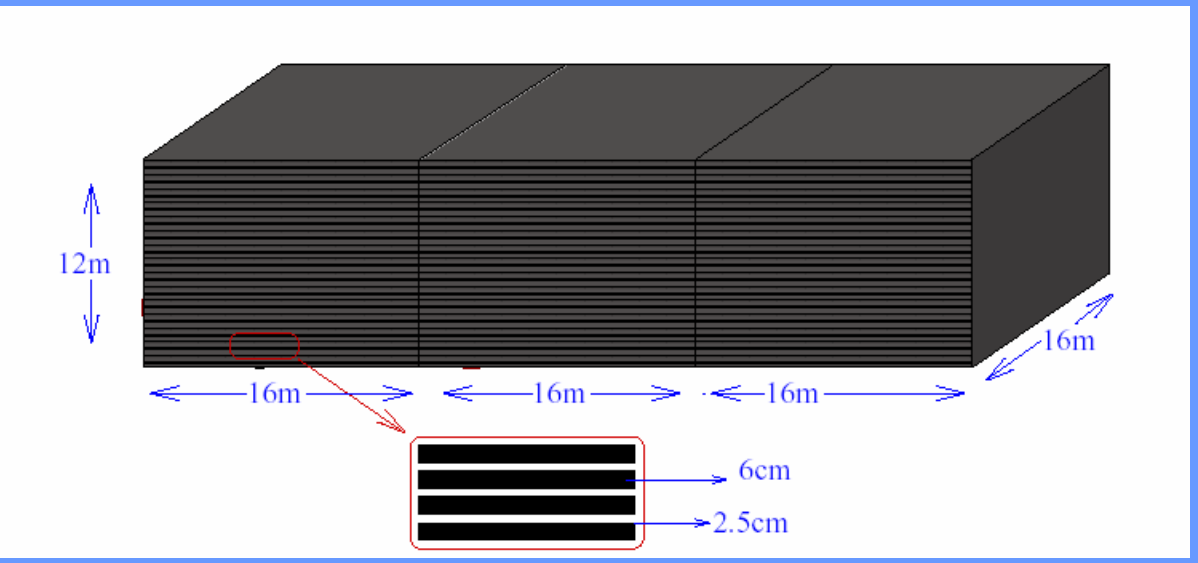


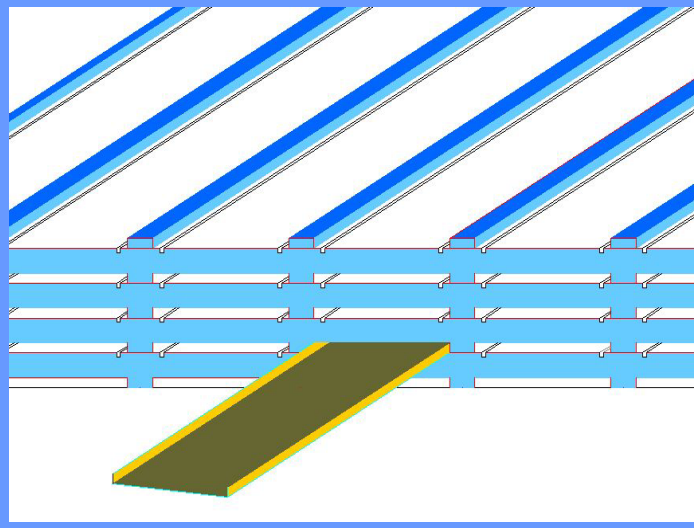
Length = 5 m ≈ 6.3λ ≈ 36X_0
Radius = 1.8 m ≈ 2.25λ ≈ 20R_M

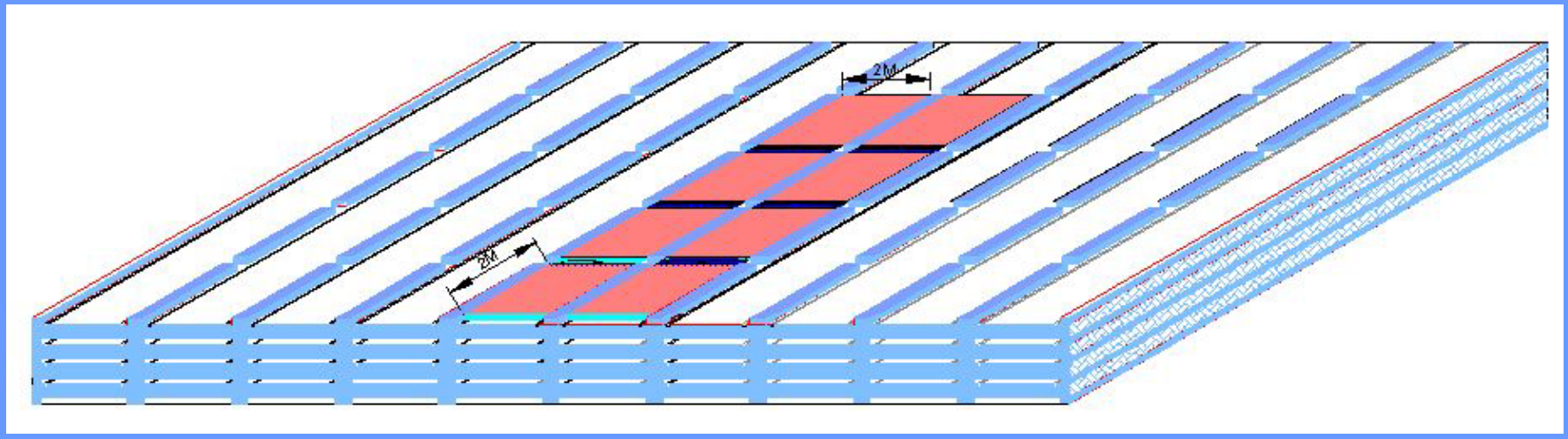
Tendering for cryostat done

Measurement campaign at CERN, KEK or FNAL?

INO Detector Concept

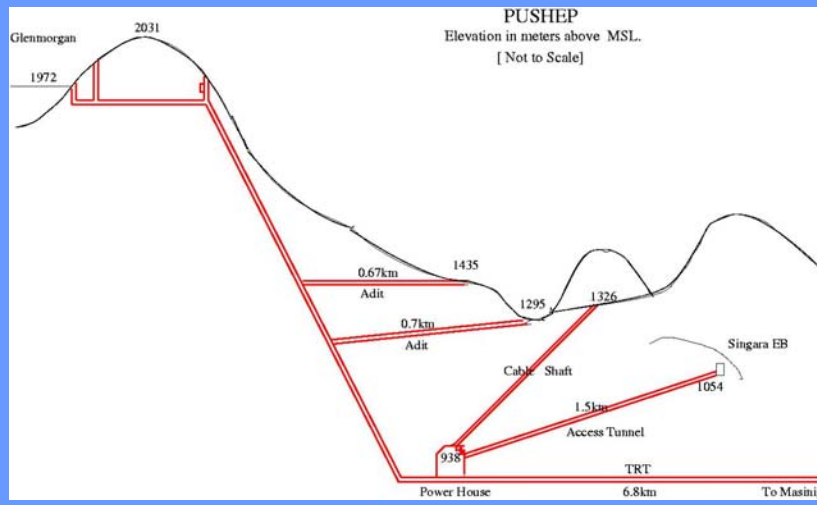




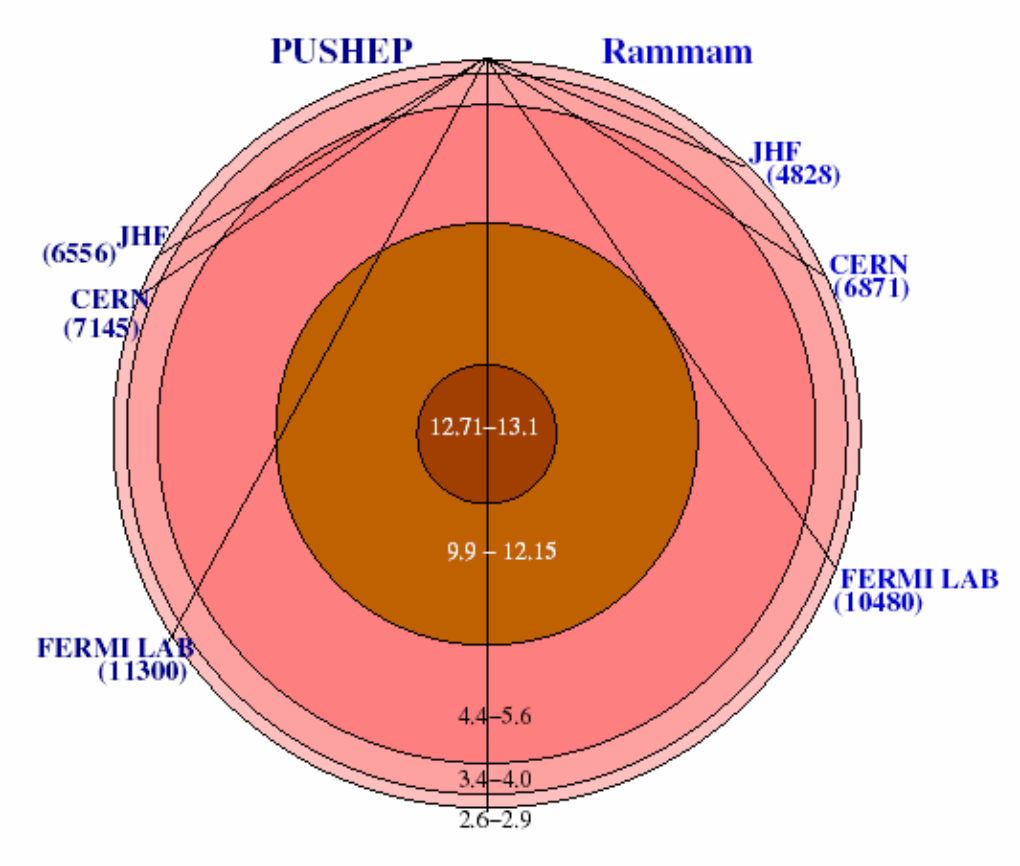


Possible INO sites

- PUSHEP (Pykara Ultimate Stage Hydro Electric Project) in South India
- or
- RAMMAM Hydro Electric Project Site



Physics with Neutrino beam from NUFACT – Phase II



- Determination of θ_{13}
- Sign of Δm^2_{23}
- Probing CP violation in leptonic sector
- Matter effect in $\nu_\mu \rightarrow \nu_\tau$ oscillation

Reactor Experiments

S. Dazeley: Double CHOOZ

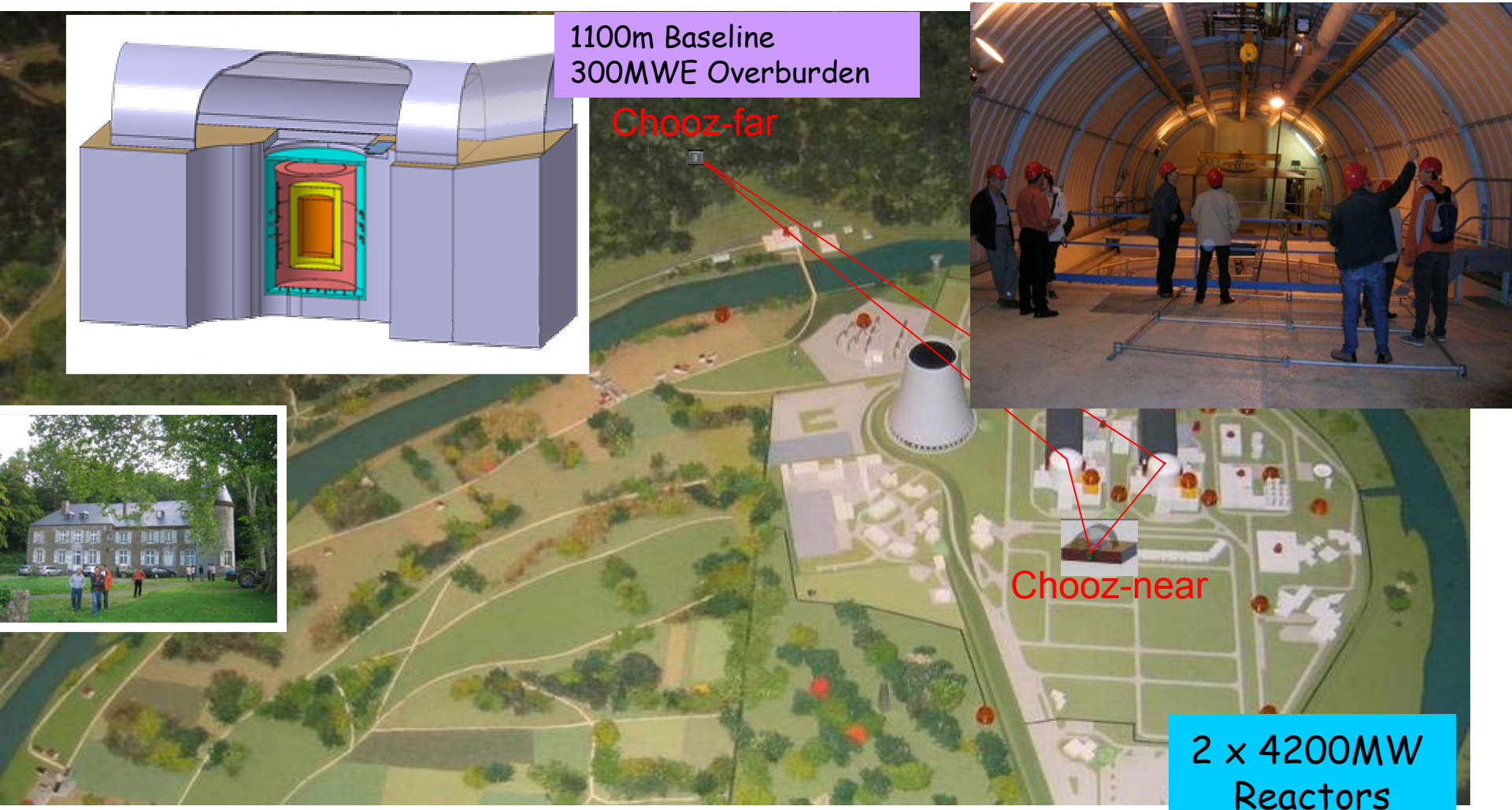
Y. Sakamoto: KASKA

J. Cao: Daya Bay

J. dos Anjos: Angra

TBC (too busy to come?): Braidwood

The Chooz Site

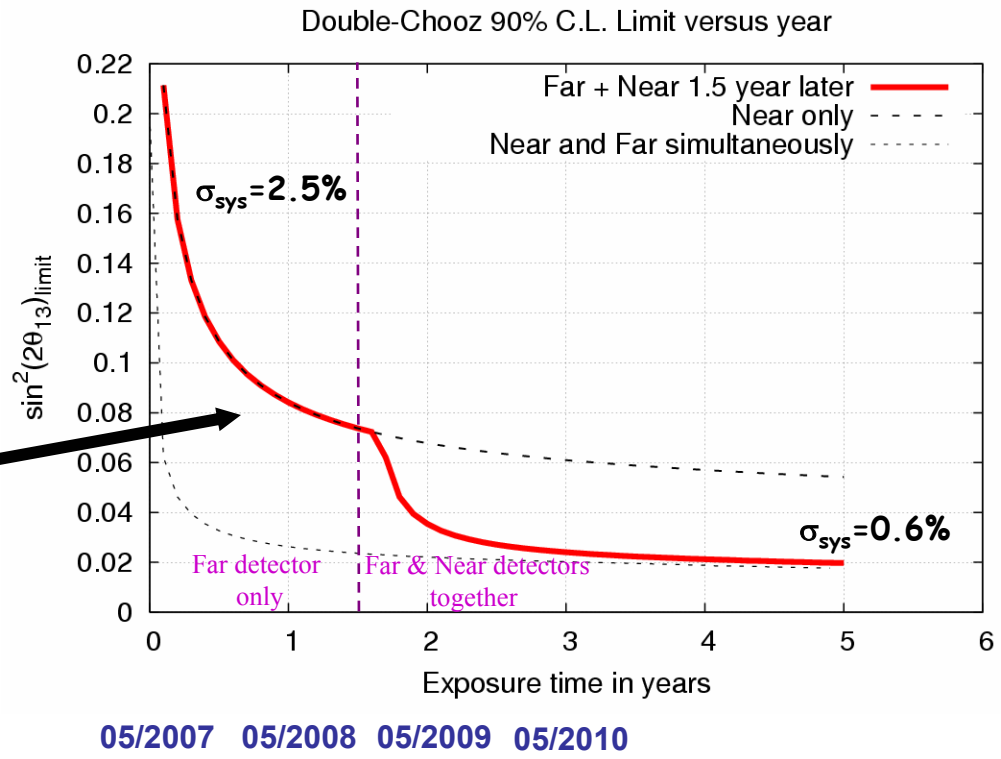


Systematics detail

	Double Chooz Goal
Solid angle	0.2%
Volume	0.2%
Density	0.1%
Fraction H atoms	0.1%
Neutron Efficiency	0.2%
Neutron Energy cut	0.2%
Time cut	0.1%
Dead time	0.2%
Acquisition	0.1%
Background	0.2%
Total	0.6%

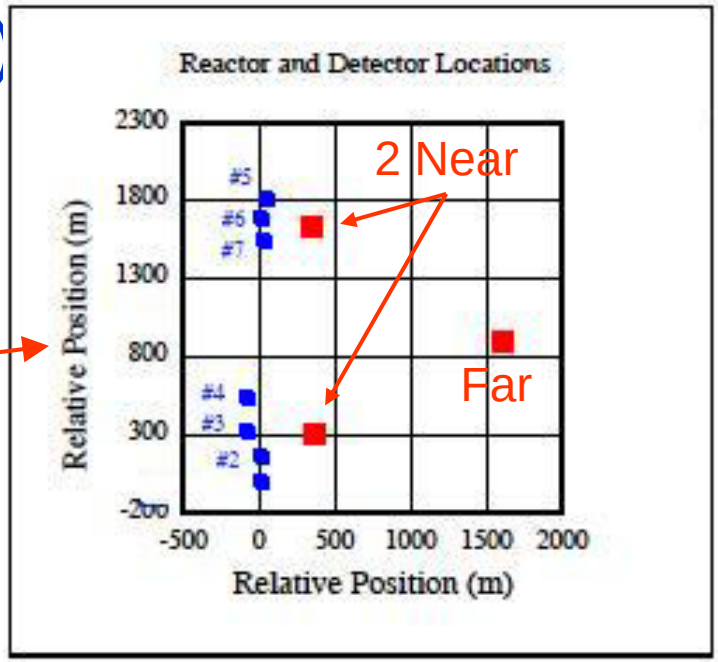
Expected Sensitivity 2007-2012

- **Far Detector starts in 2007**
- **Near detector follows 16 months later**
- **Double Chooz can surpass the original Chooz bound in 6 months**
- **90% C.L. contour if $\sin^2(2\theta_{13})=0$**
- **$\Delta m^2_{atm} = 2.8\ 10^{-3}\ eV^2$ is supposed to be known at 20% by MINOS**

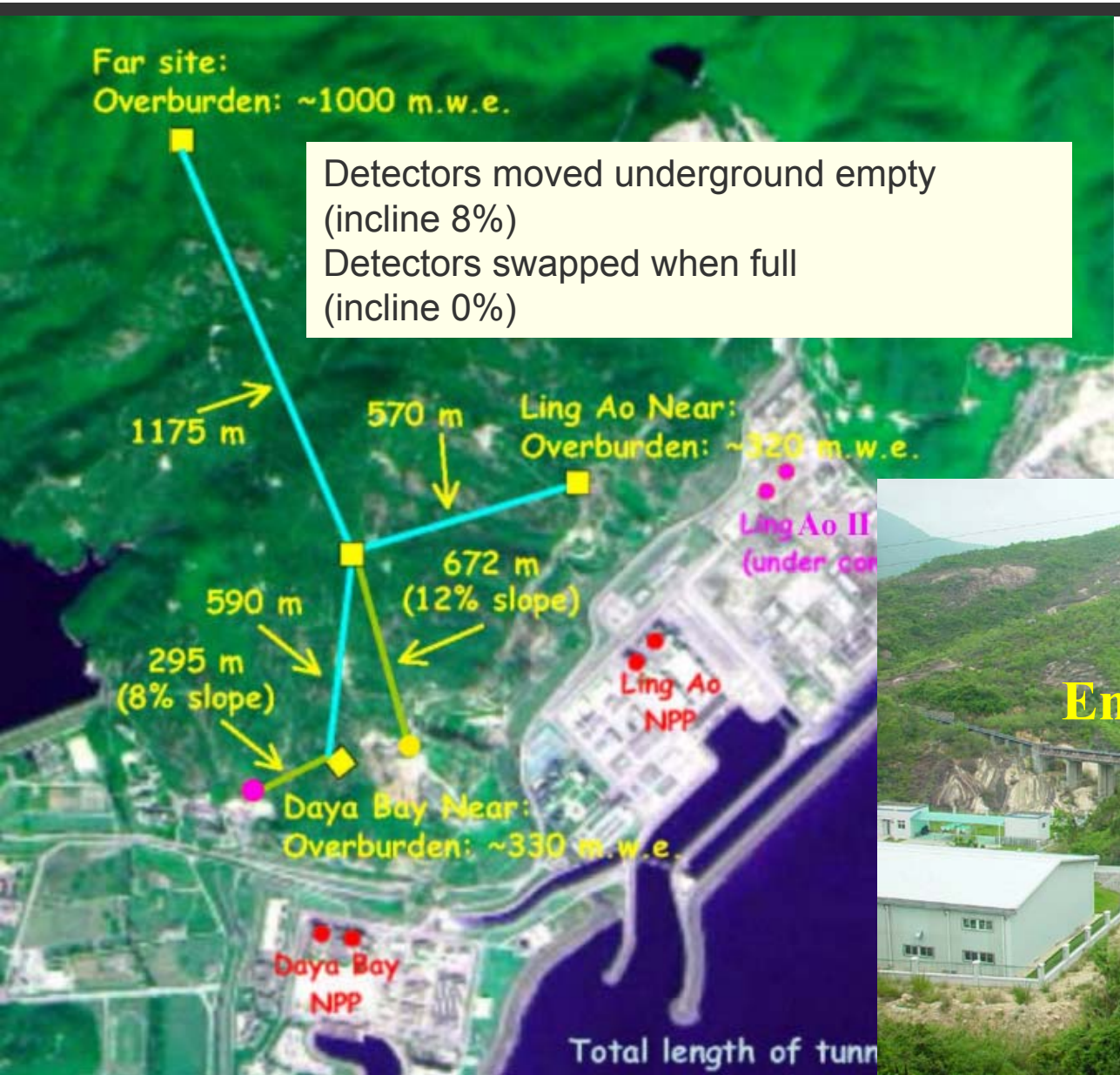


The neutrino source

- Kashiwazaki-Kariwa Nuclear Power Station
  - World's largest reactor complex: 24.3GWth (8.2GWe)
  - Tokyo Electric Power Co.
  - K-K supplies 20% of total consumption of Tokyo area.
- 7 reactors in two clusters (3+4)



Tunnel Design



Horizontal tunnel
(approved by NPP)

0% slope to transport detector easily

Portal elevation 13m

Tunnel elevation –10m

View of the Experimental Layout