INO/ICAL :Physics potential and status

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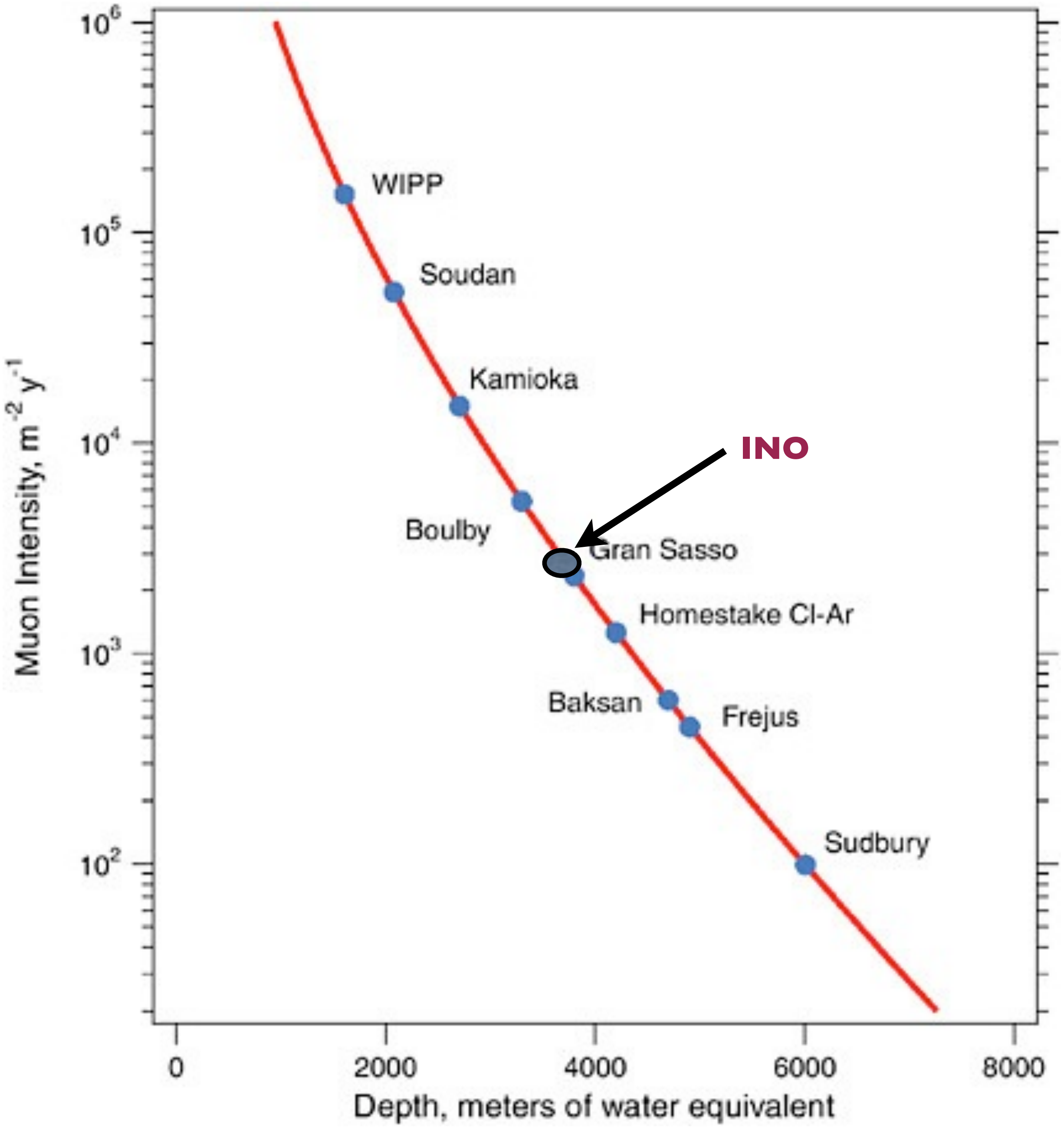
Fundamental Physics at the Intensity Frontier, Rockville, MD, Dec 01, 2011

Introduction....

The INO (Indian Neutrino Observatory) is a proposed large underground facility to be located in the southern part of India.



Accessed by a 2 km tunnel. Peak-tunnel distance 1317 m.

Flat terrain, good access roads, proximity to major city/airport (Madurai, 110 km).

Warm, winter 60 F, summer 100 F , Low rainfall, Low population density,

Introduction....

Underground facility with several caverns suitable for housing multi-disciplinary scientific experiments planned.

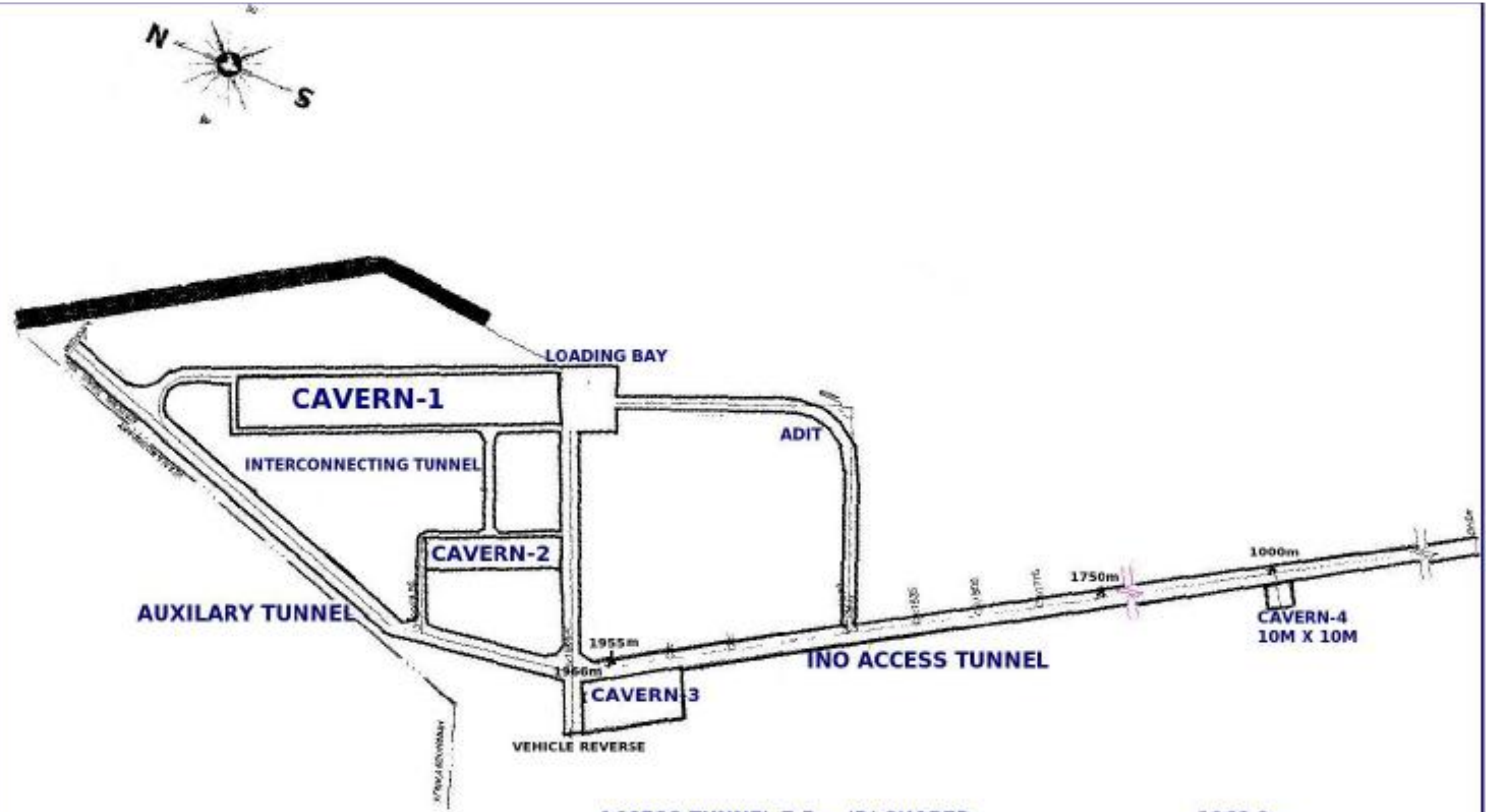
Surface support facility at site location, supplemented by the presence of NCHEP (National Center for High Energy Physics) at Madurai (110 km)

The flagship experiment will feature neutrino detection in ICAL, a 50-100 kT magnetized iron calorimeter detector

Neutrino-less Double Beta Decay and Dark Matter experiments planned for the future.

International Collaboration and participation sought and welcomed.
Current civil work and construction /fabrication schedule is 2012-2017

INO Cavern Layout...



ACCESS TUNNEL 7.5m, 'D' SHAPED :1966.0m
ADDITIONALLY DRIVEN INT. TUNNEL 5.5m 'D' SHAPED: 175.4m
AUXILARY TUNNEL 7.5m 'D' SHAPED : 224.6m
INTERCONNECTING TUNNEL 3.5m 'D' SHAPED : 72.5m
ADDITIONAL TUNNEL 7.5m 'D' SHAPED (future expn) : 50.0m

CAVERN -1 : 132m x 26M x 32.5m
CAVERN -2 : 55m x 12.5m x 8.6m
CAVERN -3 : 40m x 10m x 10m
CAVERN -4 : 10m x 10m x 10m

ICAL........Description and Salient Features

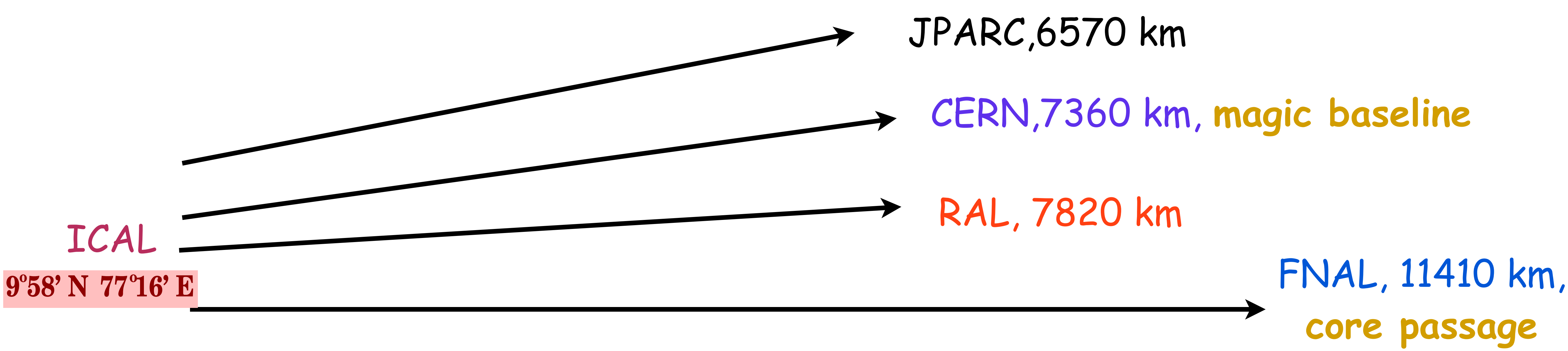
50-100 kT magnetized Iron Calorimeter

Modular Design tracking calorimeter, RPC as active detector medium

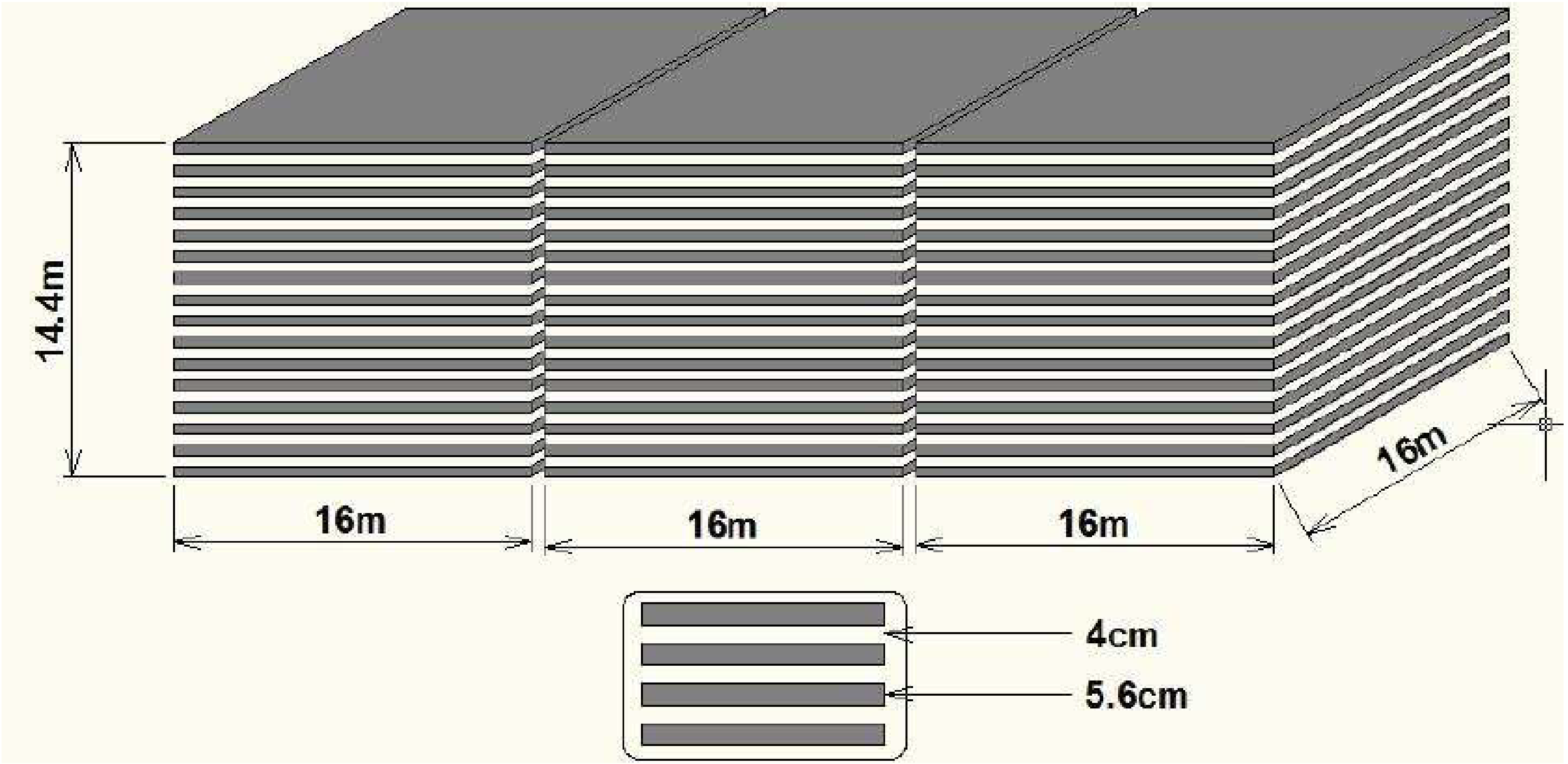
High efficiency charge identification for muons with E > 1 GeV, effective measurement and separation of muons and anti-muons produced by neutrinos and anti-neutrinos from the atmosphere or a (future) beam.

Good directionality with 1 nano-sec timing.

Distance from possible future beams offers opportunities for both planned and serendipitous discoveries if used as end detector.



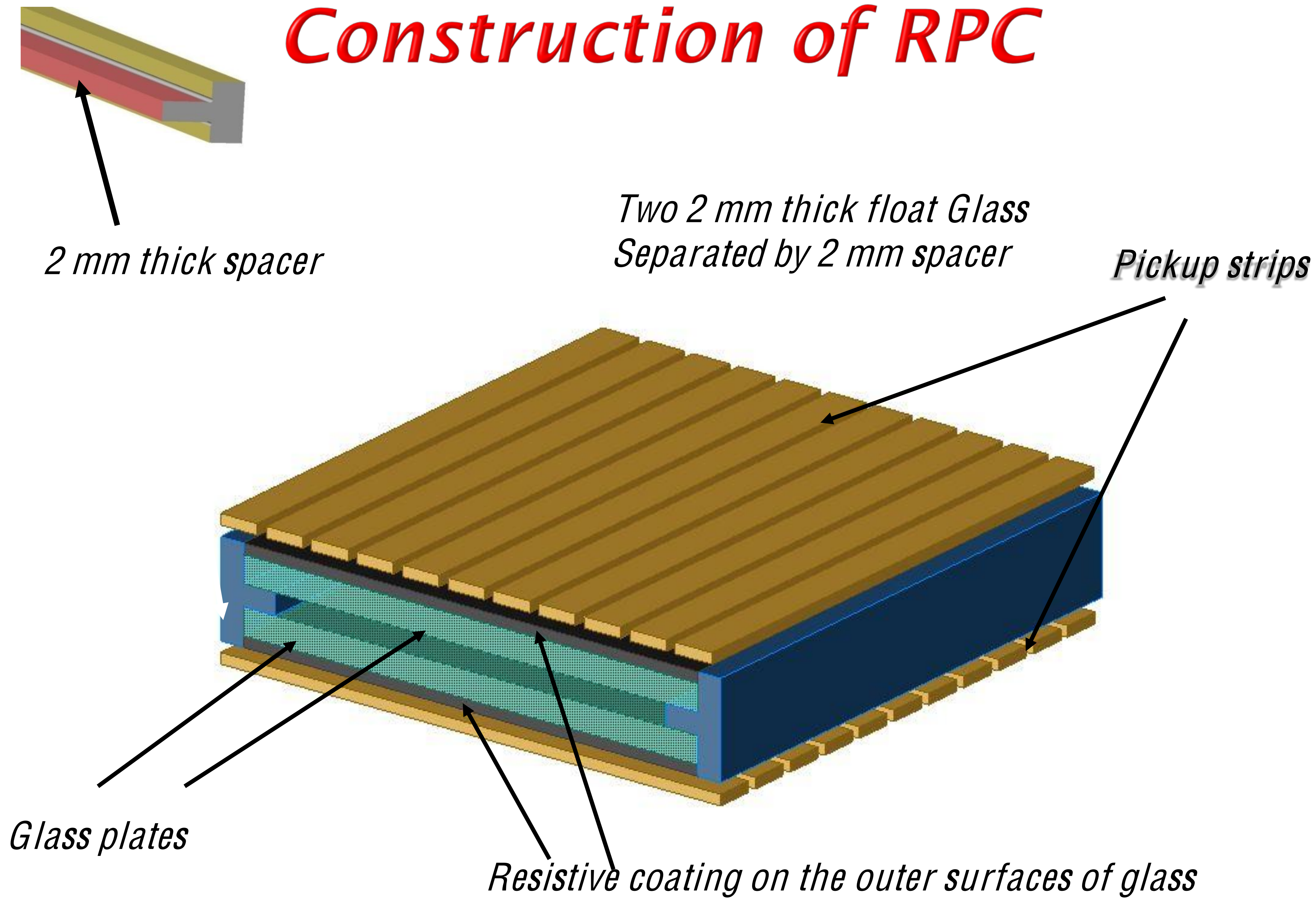
ICAL.......Description and Salient Features



No. of modules	3
Module dimension	16 m × 16 m × 14.4 m
Detector dimension	48 m × 16 m × 14.4 m
No. of layers	150
Iron plate thickness	∼ 5.6 cm
Gap for RPC trays	4.0 cm
Magnetic field	1.3 Tesla

ICAL........Description and Salient Features

Construction of RPC



ICAL.......Major Physics Goals...Oscillation parameters

Provide complementary measurements of atmospheric oscillation parameters by measuring ratio of N_up/N_down rates for muon neutrinos and anti-neutrinos.

TABLE I: Results of determination of θ_{23}

θ_{23}	CL	Source
$42.9^{\circ}{}^{+4.1^{\circ}}_{-2.8^{\circ}}$	1σ	global-fit[2]
$35.7^{\circ} - 54^{\circ}$	3σ	global-fit[2]
$45^{\circ}{}^{+10^{\circ}}_{-7.8^{\circ}}$	99%	SK [4]
$45^{\circ} \pm 9^{\circ}$	90%	MINOS (ν) [4]
$34^{\circ}{}^{+6^{\circ}}_{-4^{\circ}}$ or $56^{\circ}{}^{+4^{\circ}}_{-6^{\circ}}$	90%	MINOS ($\bar{\nu}$) [5]
$39^{\circ} - 51^{\circ}$	2σ	T2K [32]
$36^{\circ} - 54^{\circ}$	2σ	NOνA [32]
$40^{\circ} - 50^{\circ}$	2σ	INO (1 Mton·yr)

TABLE II: Results of determination of Δm^2_{31}

$\Delta m^2_{32}(10^{-3}\mathrm{eV}^2)$	CL	Source
$-2.36 \pm 0.07(\pm 0.36)$	1 (3)σ	global-fit [2]
$+2.47 \pm 0.12(\pm 0.37)$	1 (3)σ	global-fit [2]
$2.5^{+0.52}_{-0.60}$	99%	SK 3ν [4]
$2.35^{+0.11}_{-0.08}$	90%	MINOS ν [5]
$3.36^{+0.45}_{-0.40}$	90%	MINOS $\bar{\nu}$ [5]
2.5 ± 0.04	2σ	T2K [32]
$2.5^{+0.07}_{-0.04}$	2σ	NOνA [32]
2.5 ± 0.07	2σ	INO (1 Mton·yr)

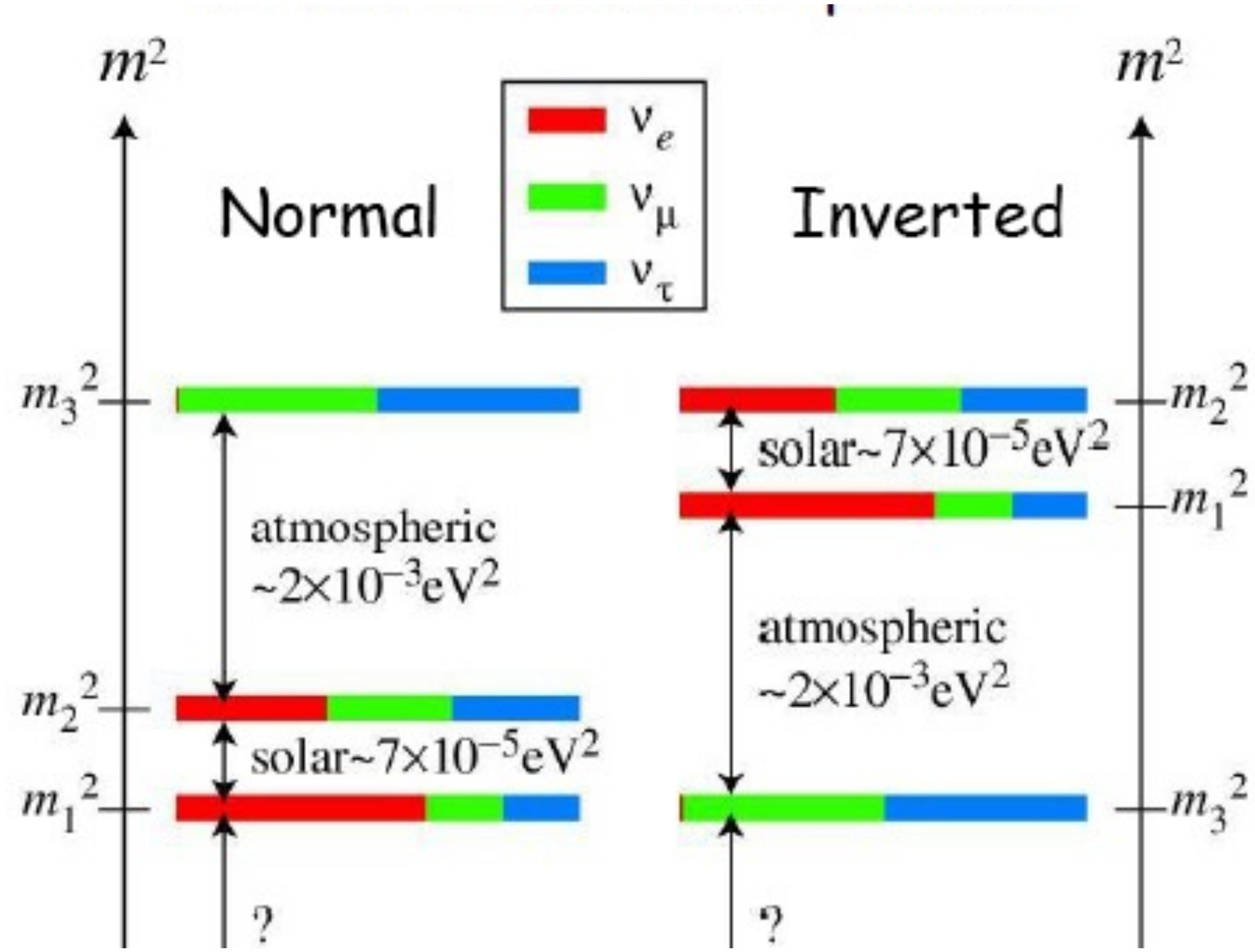
Samanta and Smirnov, arXiv 1012.0360

ICAL

NOva results shown are for 5 yr run

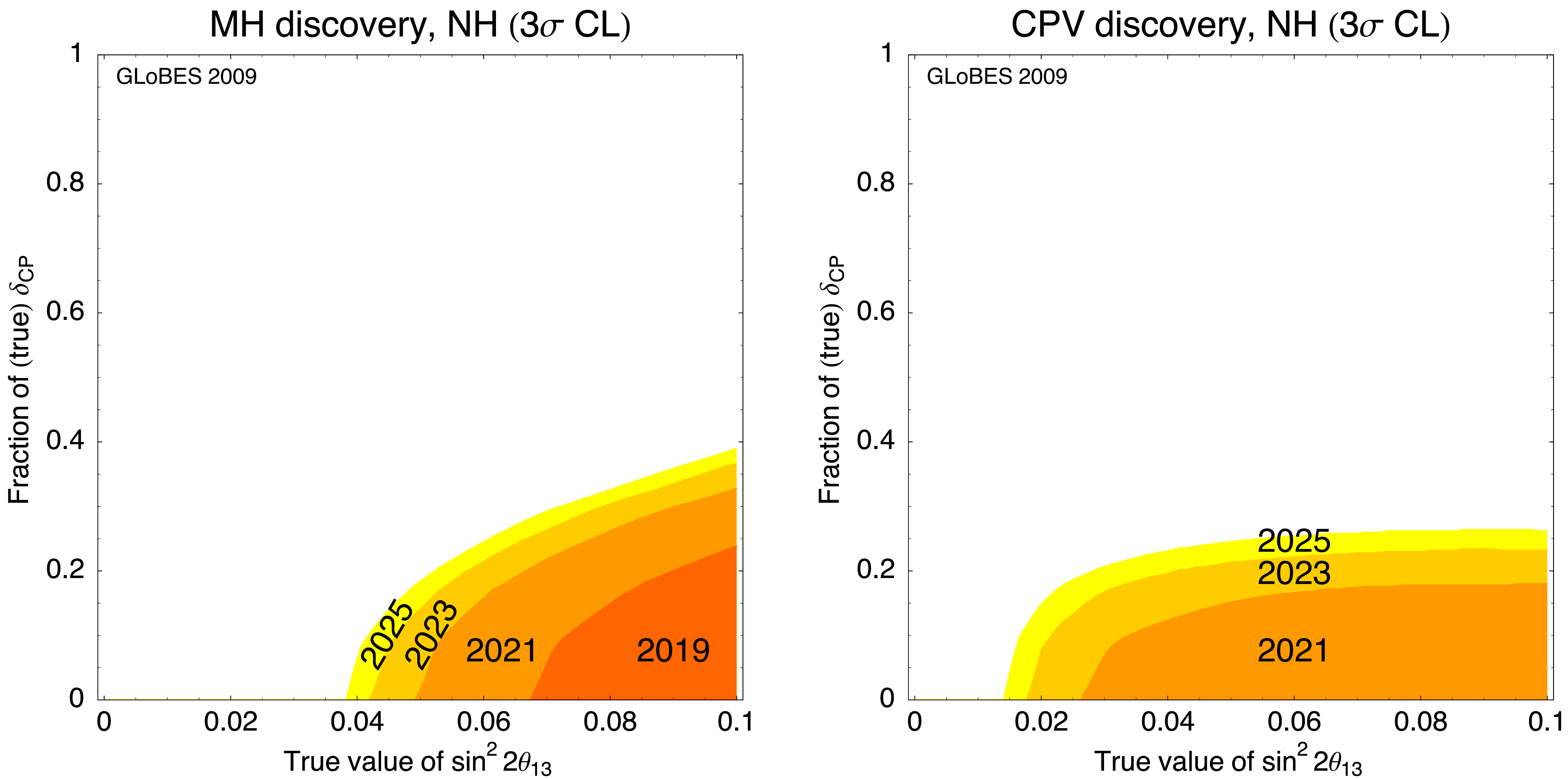
ICAL.......Major Physics Goals...Mass Hierarchy

Determination of the mass hierarchy vital to BSM physics efforts



Detection of CPV in the lepton sector similarly vital. (Not an ICAL phase I goal)

Mass hierarchy and CPV ....future LBL sensitivities



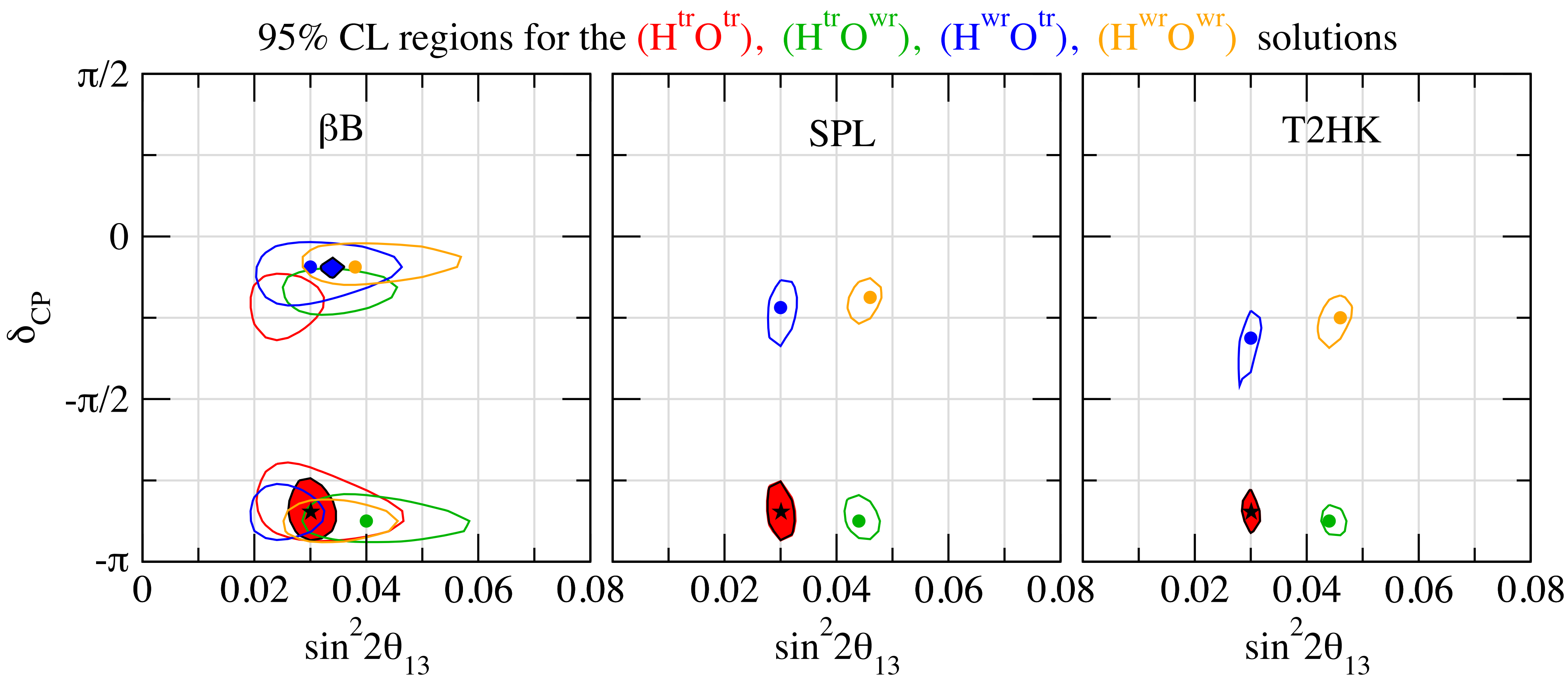
Huber, Lindner, Schwetz and Winter, arXiv 0907.1836

Sensitivities with existing experiments + NuMI upgraded to 2.3 MW and T2K upgraded to 1.7 MW.

Measurements difficult due to presence of degeneracies in LBL, large fraction of CP angle range inaccessible.

Previous work has established that atm data when combined with LBL data is a effective degeneracy resolver

Huber, Maltoni, and Schwetz hep-ph 0501037



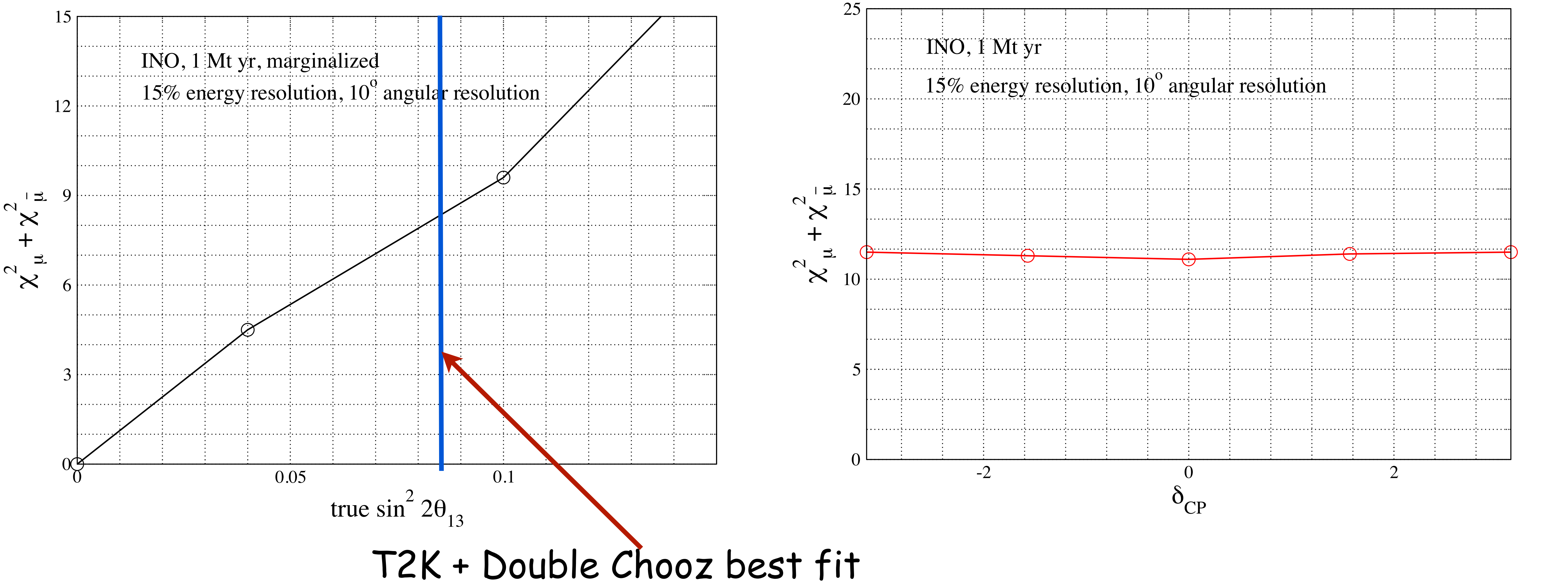
440 kT Water Ckv detectors in each case, 10 yr run , collecting both beam and atmospheric data.

Atm alone lacks precision and high statistics, but has wide-band in L and E and consequent access to matter effects. LBL alone with present baselines lack sufficient matter effects.

Eight-fold/Four-fold degeneracy collapses when atmospheric data added to LBL.

Campagne, Maltoni, Mezetto and Schwetz hep-ph 0603172

ICAL........Major Physics goals... Hierarchy Sensitivity for 1 Mt-yr



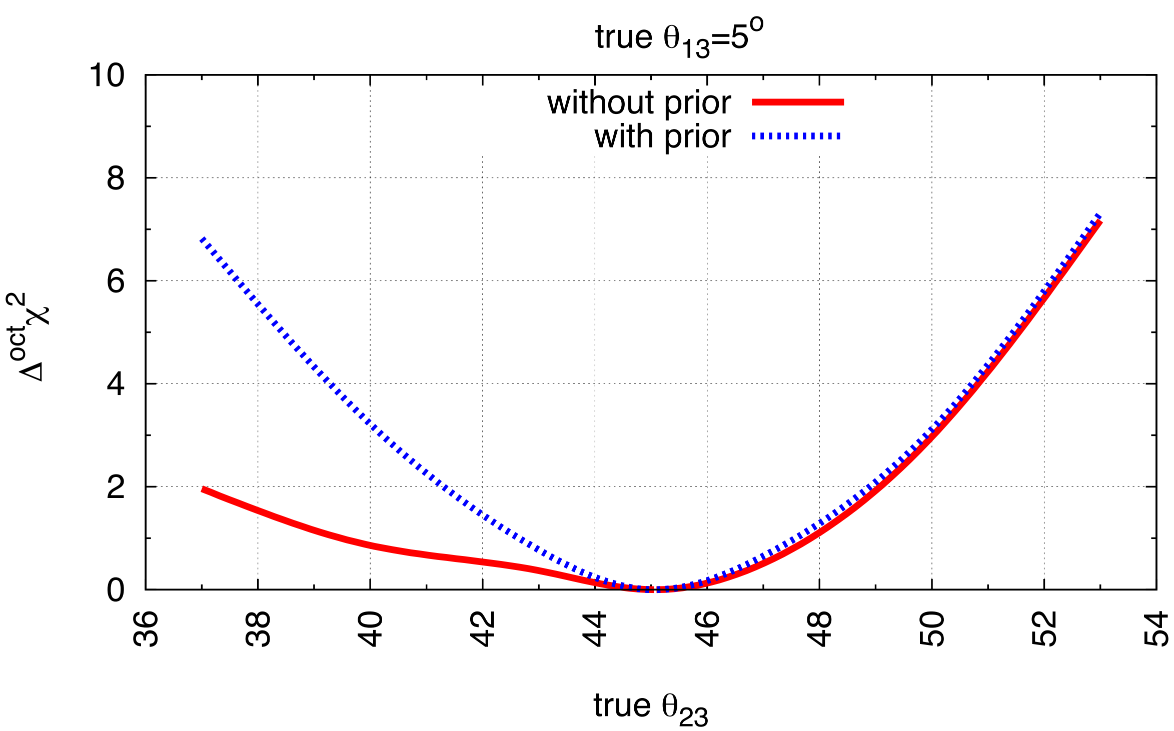
> 2 sigma (almost 3 sigma) sensitivity at T2K + DC value

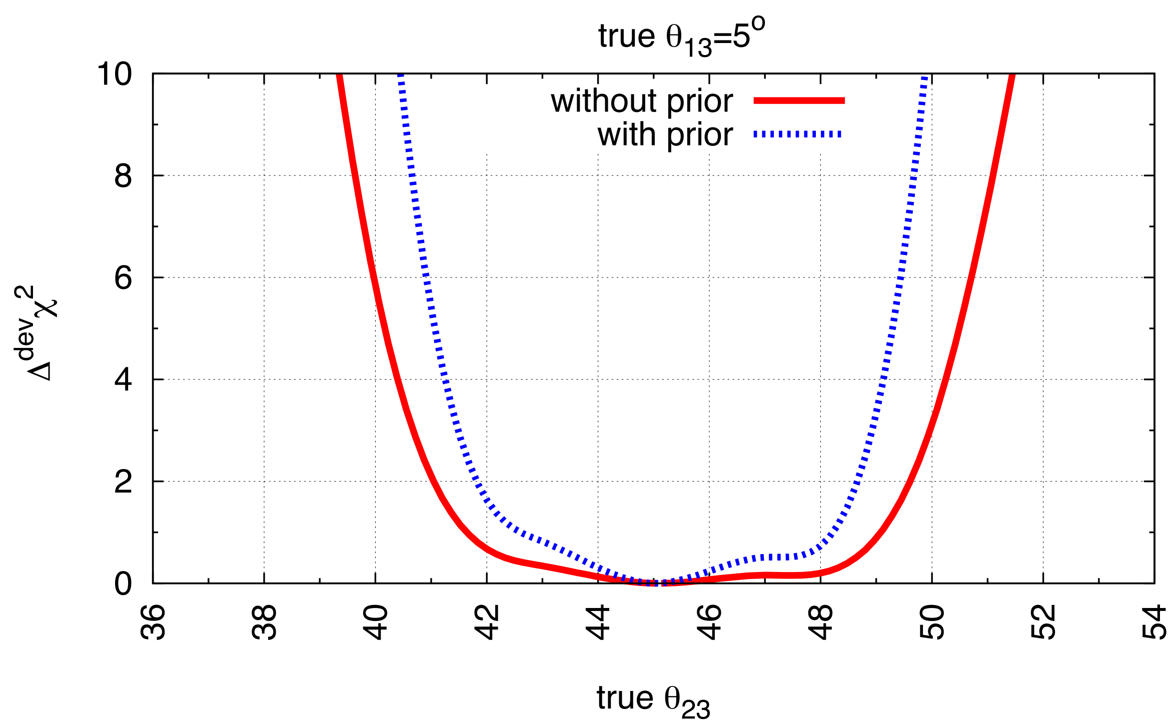
Sensitivity independent of CP angle. Assumes maximal 2-3 mixing. Non-maximal case in progress. Results shown are for NH. Sensitivities will be less for IH. Will improve with addition of LBL data.

RG, Ghoshal, Goswami, Mehta, Sankar and Shalgar, arXiv 0707.1723, Samanta, arXiv 0907.3540, Indumathi and Murthy, hep-ph 0407336

ICAL........Major Physics goals... Octant Sensitivity

Use sensitivity to matter effects to determine if θ_{23} is maximal





Samanta and Smirnov, arXiv 1012.0360; Choubey and Roy, hep-ph 0509197

2 sigma sensitivity to octant at 1 Mt-yr at 40/50 deg; 3 sigma sensitivity to deviation of 5 deg around maximal.

A maximal value of θ_{23} would signal the presence of an under-lying symmetry.

Similarly, its deviation $\delta_{23} \equiv 45^\circ - \theta_{23}$ would provide a measure of its breaking.

ICAL........Other Important Physics goals.......

ICAL atmospheric data can provide strong bounds on CPT violation.

Datta, RG, Mehta, Sankar, hep-ph 0312027

Functioning as a large pair-meter, ICAL will provide VHE muon detection at energies significantly beyond those presently accessible, (5-1000 TeV surface energy)

RG and Panda, JCAP 0607:011, 2006

Atmospheric down-going muon neutrino signal provides a probe of sterile (eV^2 scale) oscillations separately for particles and anti-particles. This is also testable if ICAL is used as an LBL detector with a near-magic baseline.

RG and Ghoshal, arXiv 1108.4360, (atmospheric); Dighe and Ray, arXiv 0709.0383 (LBL)

NSI parameters can be probed in ICAL when used as an end detector for a beam at ~7000 km. Coloma, Donini, Lopez-Pavon and Minakata, arXiv 1105.5936; Adhikari, Agarwalla, Raychaudhuri hep-ph 0608034.

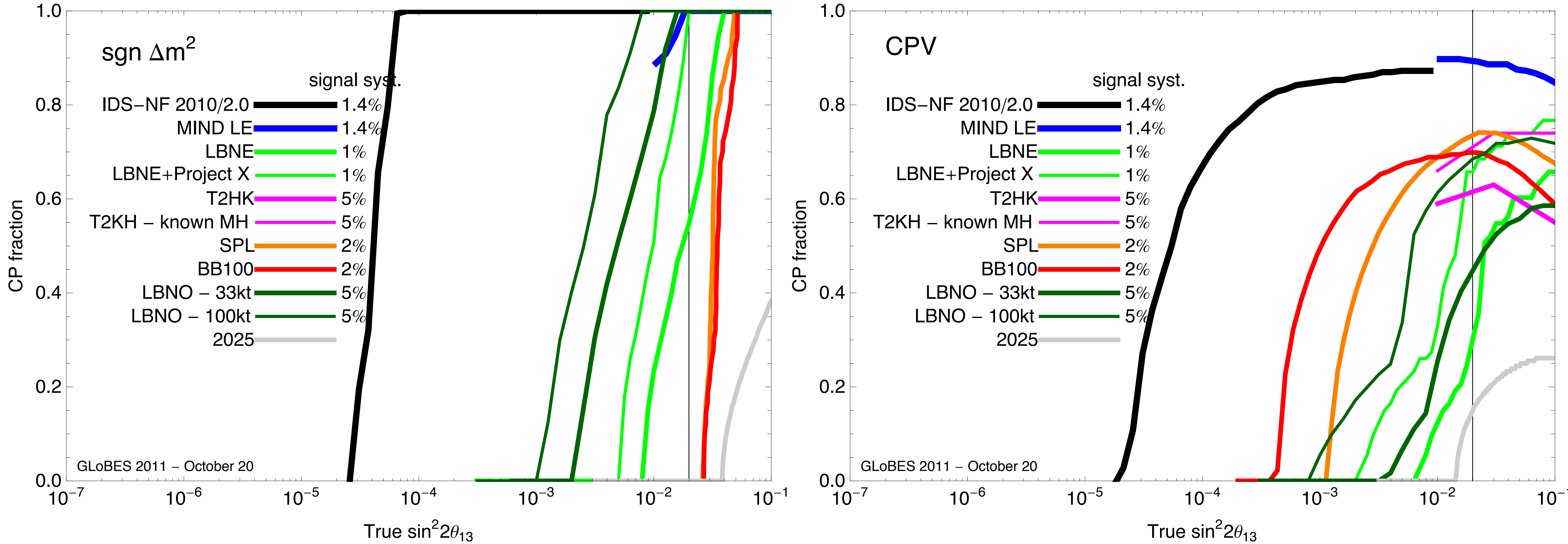
ICAL atmospheric signal can probe long-range forces.

Joshipura and Mohanty, hep-ph 0310210; Samanta, arXiv 1001.5344

Indirect detection of DM, Agarwalla, Blennow, Martinez, Mena arXiv1105.4077

Superluminal neutrinos at long baselines.......(?!)

ICAL..Potential as part of future International LBL program for MH and CPV



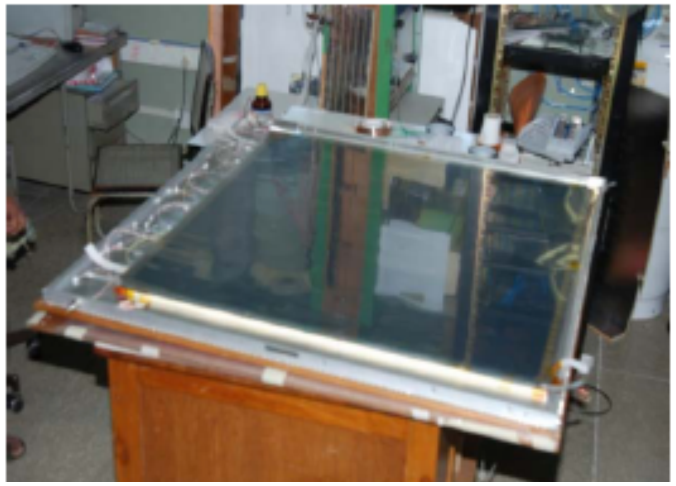
from P. Huber, talk at FNAL pre-meeting of Intensity Frontier Neutrino group, Oct 2011 and refs therein

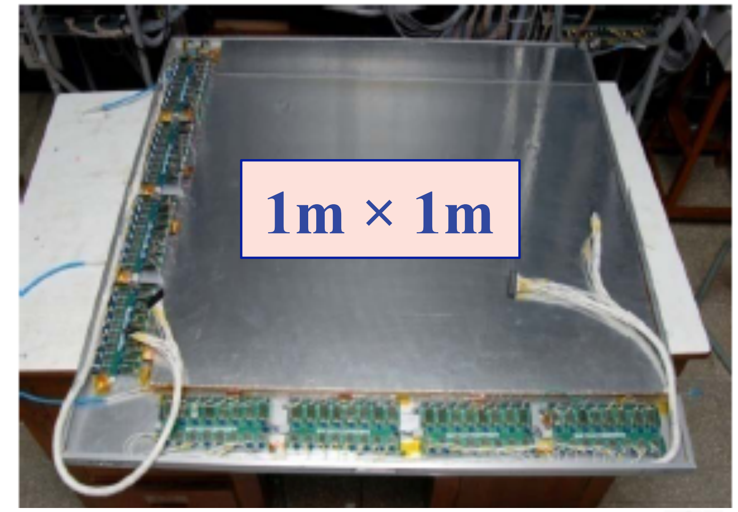
A co-ordinated International effort may be essential to the realization of major neutrino physics goals.

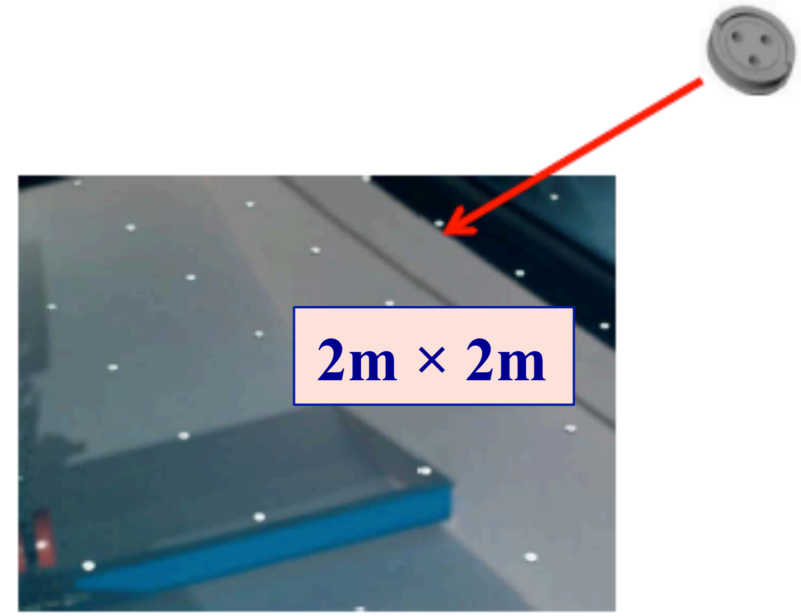
The IDS-NF offers the most signifiant sensitivities, using 100 kT and 50 kT magnetized iron detectors at 4000 km and 7500 km resply.

ICAL satisfies the distance, detector type and mass criteria for the far detector

ICAL.......Status of Detector R&D.......Glass RPC





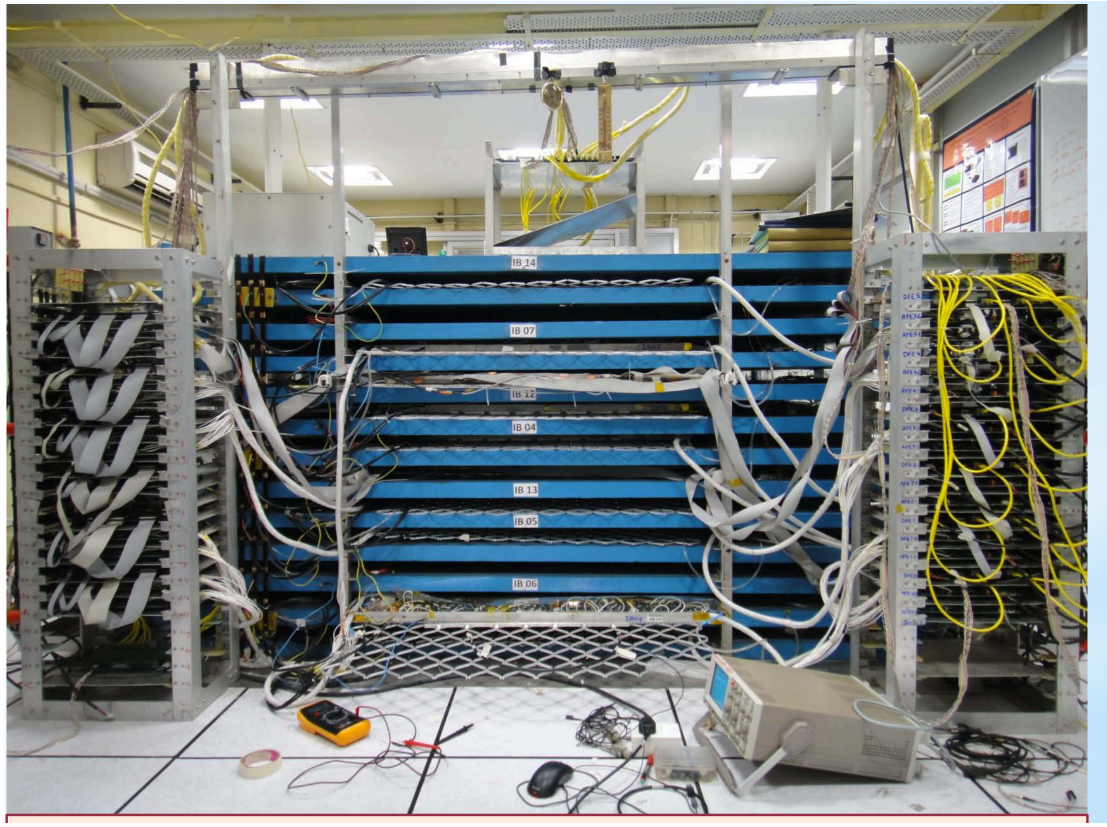


After extensive lab tests on both 1 m x 1 m and 2 m x 2 m glass RPCs, industrial production of the latter has started.

ICAL........Status of Detector R&D........

The first batch of ASIC front-end electronics, designed by the INO electronics team and manufactured by Euro practice IC Services is being tested in the lab using RPC pulses

The ICAL 50 t prototype detector, with 13 layers of soft iron, 12 layers of 1 m x 1 m RPC, 1.6 tesla field, constructed and running at VECC/ SINP, Kolkata



ICAL........ Status...

An INO graduate student training program has been underway for the past 3 years to provide man-power.

All forest and environmental clearances have been obtained.

Project has been strongly supported and pushed by the funding agencies (Departments of Atomic Energy and Science and Technology), and is one step away from full financial approval at the highest (PMO and Cabinet) level

About 4 weeks ago the State Government formally allotted the required land for the project to the Collaboration.

Land for the supporting National Center for HEP at Madurai is under process for acquisition.

Work on a Physics and Simulation White paper on in full ernest

ICAL....... Conclusions.....

As its major physics goal, with 1 Mt-yr exposure to atmospheric neutrinos, ICAL offers an opportunity using its charge-id capability to probe the crucial mass hierarchy issue in a mode (muon neutrino survival) free of degeneracies induced by the CPV angle. Its sensitivity will be heightened by synergistic combination with LBL data

ICAL will provide complementary measurements of atmospheric oscillation parameters.

It will be sensitive to the deviation from maximality for the 2-3 mixing angle.

It will have a broad "other physics" program, including bounds on CPT violation. NSI, VHE muon charge ratio, UHE muon detection as a large pair-meter, indirect DM detection.....

ICAL....... Conclusions.....

ICAL/INO hopes to not just do interesting stand-alone physics, but to be an integral part of a co-ordinated international program in combination with future LBL facilities.

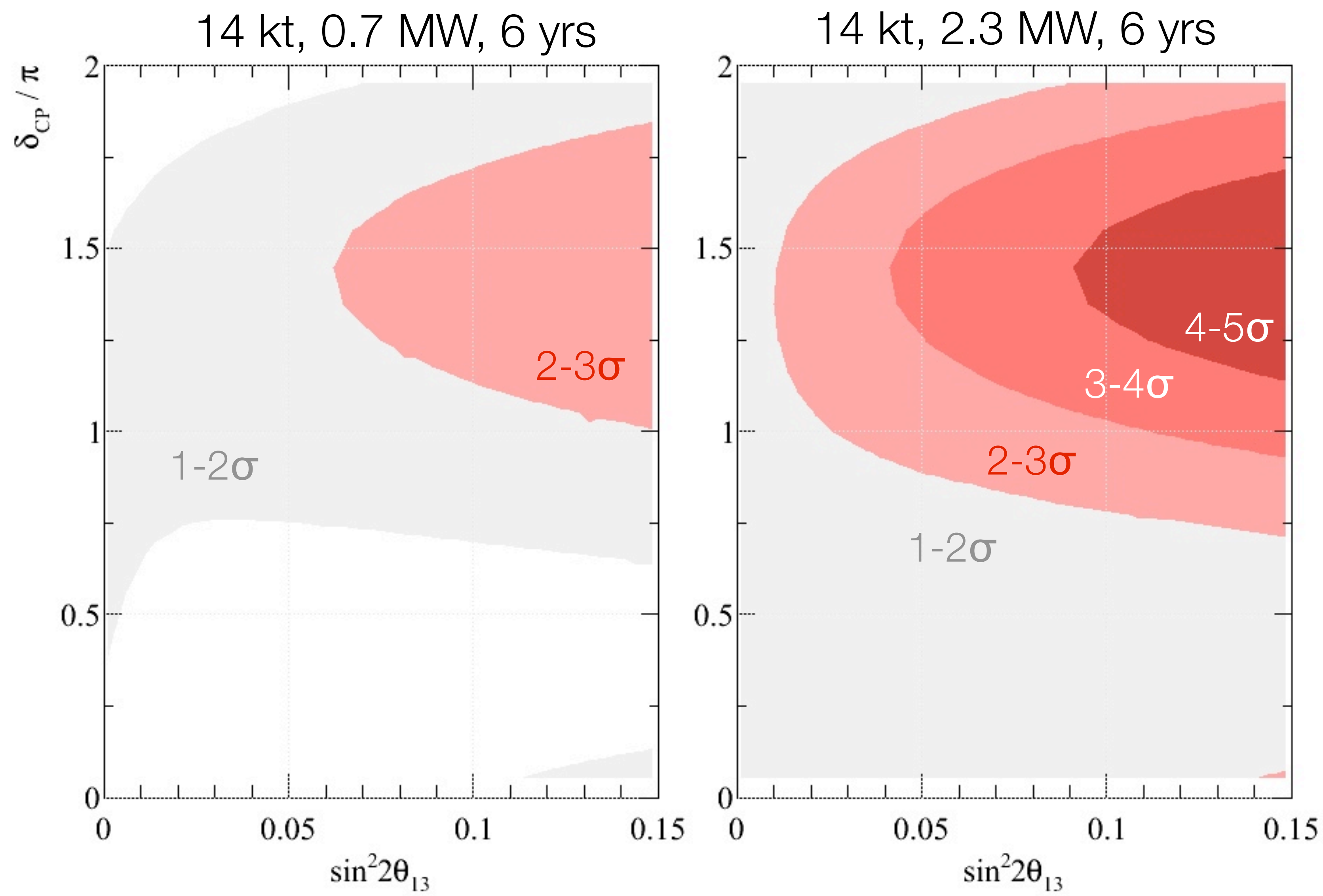
In particular, as a 50-100 kT magnetized iron calorimeter situated at near "magic" distances from Japanese and European accelerator facilities, it offers an opportunity to be an important part of a precision neutrino parameter measurement effort.

Its detector R&D program is on track, work is actively ongoing on a physics and simulation white paper, the graduate training program is in place, land and all approvals and clearances (except final stage financial approval --expected very soon) have been obtained. Current timescale for start of data-taking is 2017.

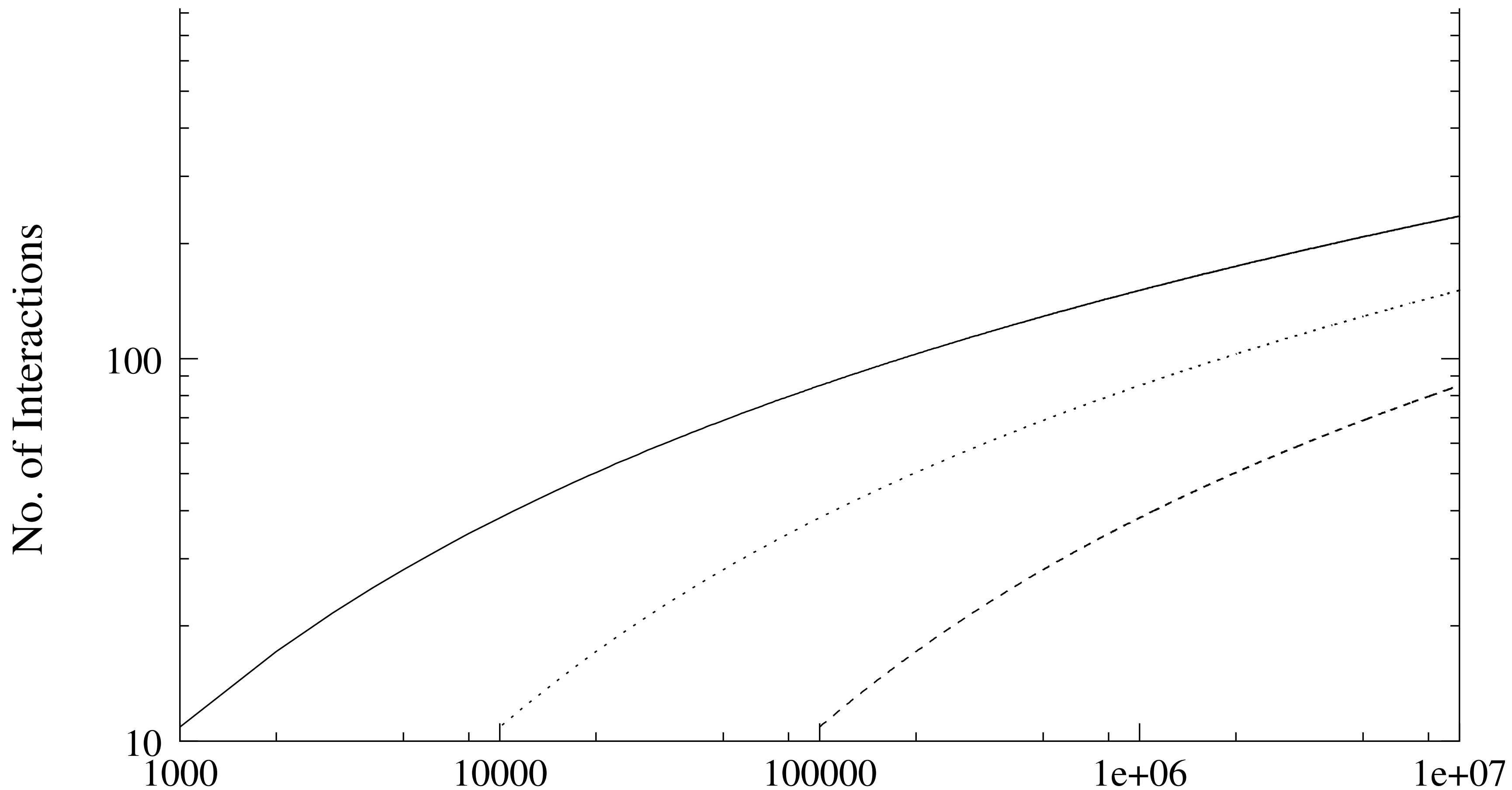
Thank you for your attention...........!

Back-up Slides (more to be added....)

NoVA........ Mass Hierarchy...



Stand-alone Physics.......UHE Muons from Cosmic Rays



RG and Panda
JCAP 0607:011,2006.

Average number of pair cascades produced by an energetic muon above a threshold E_0 vs. muon energy for E_0 = 1 GeV (solid line), 10 GeV (dotted) and 100 GeV (dashed).
ICAL mass of 50 Kt assumed

Stand-alone Physics.......Long Range Forces

- The SM has several global flavour symmetries which can, in principle, be gauged in an anomaly free way. (L_e - L_mu, L_e-L_tau).
- If the gauge bosons corresponding to these are massless or very light, long-range forces may arise.
- Due to the flavour dependance, these may alter oscillation probabilities at a measurable level, which can be detected in an atmospheric neutrino detector.
- SK data has been used to set such bounds, which can be complemented or improved by ICAL.

Joshipura and Mohanty,
Physlett. B, 2004.01.057

Physics in conjunction with LBL experiments......

- Due to these reasons, determinations of $\Delta m2$ (which depend on L/E) in atmospheric detectors are usually not as accurate as those possible in LBL setups.
- Similarly, the precision likely to be achieved by experments like T2K and NOvA for sin^2 2θ23 may be higher than what may be possible in future atmospheric detectors.
- Results of LBL experiments, while providing precision, must confront the existence of several types of parameter degeneracies.

Physics in conjunction with LBL experiments……

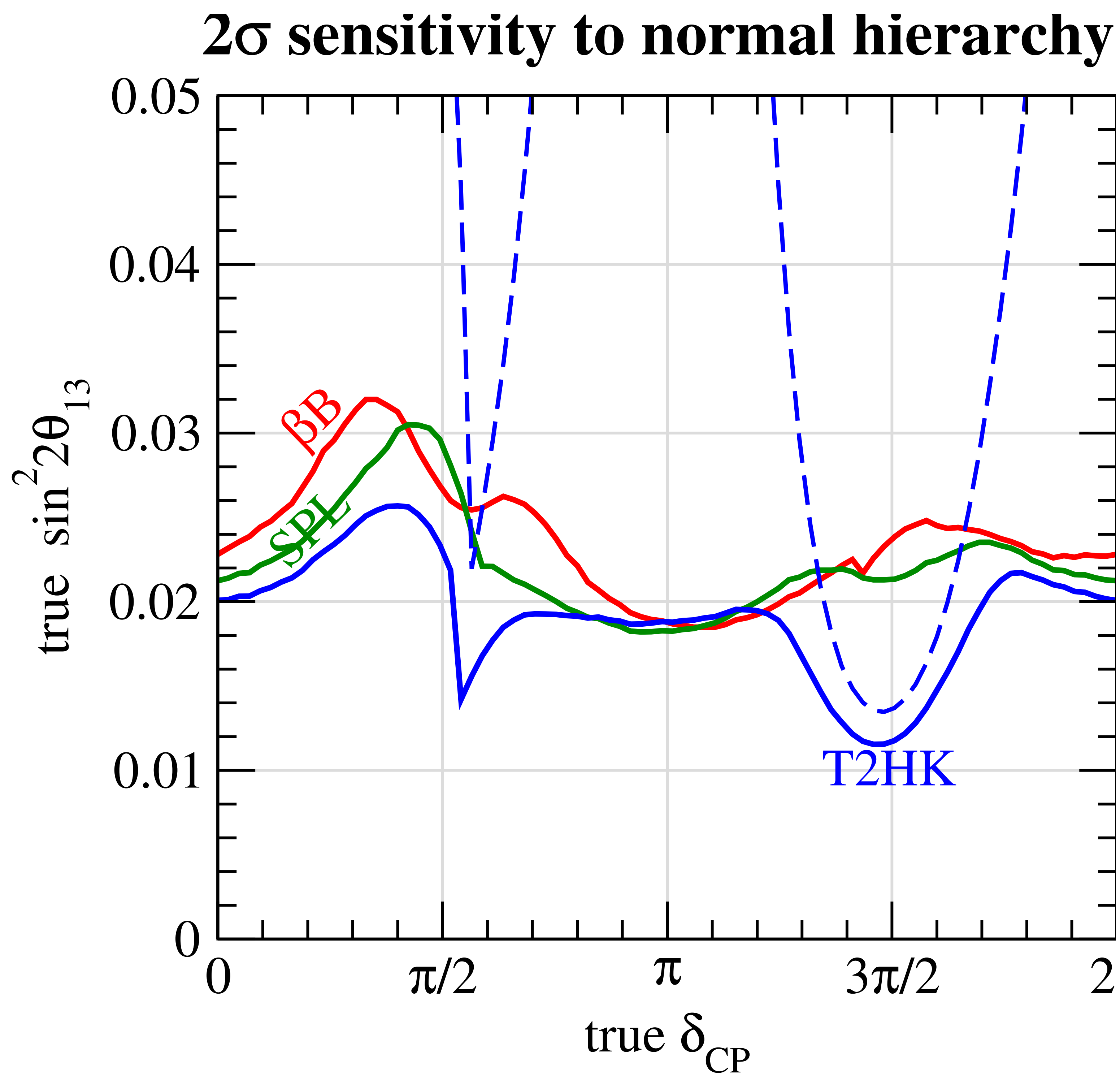
- The intrinsic, or {δ,θ13} degeneracy, which arises when different pairs of values of the parameters δ and θ13 give the same neutrino and anti-neutrino oscillation probabilities, assuming other parameters to be known and fixed.

$$P(\delta, \theta) = P(\delta', \theta') \quad \text{(neutrinos)}$$
$$\bar{P}(\delta, \theta) = \bar{P}(\delta', \theta') \quad \text{(anti-neutrinos)}$$

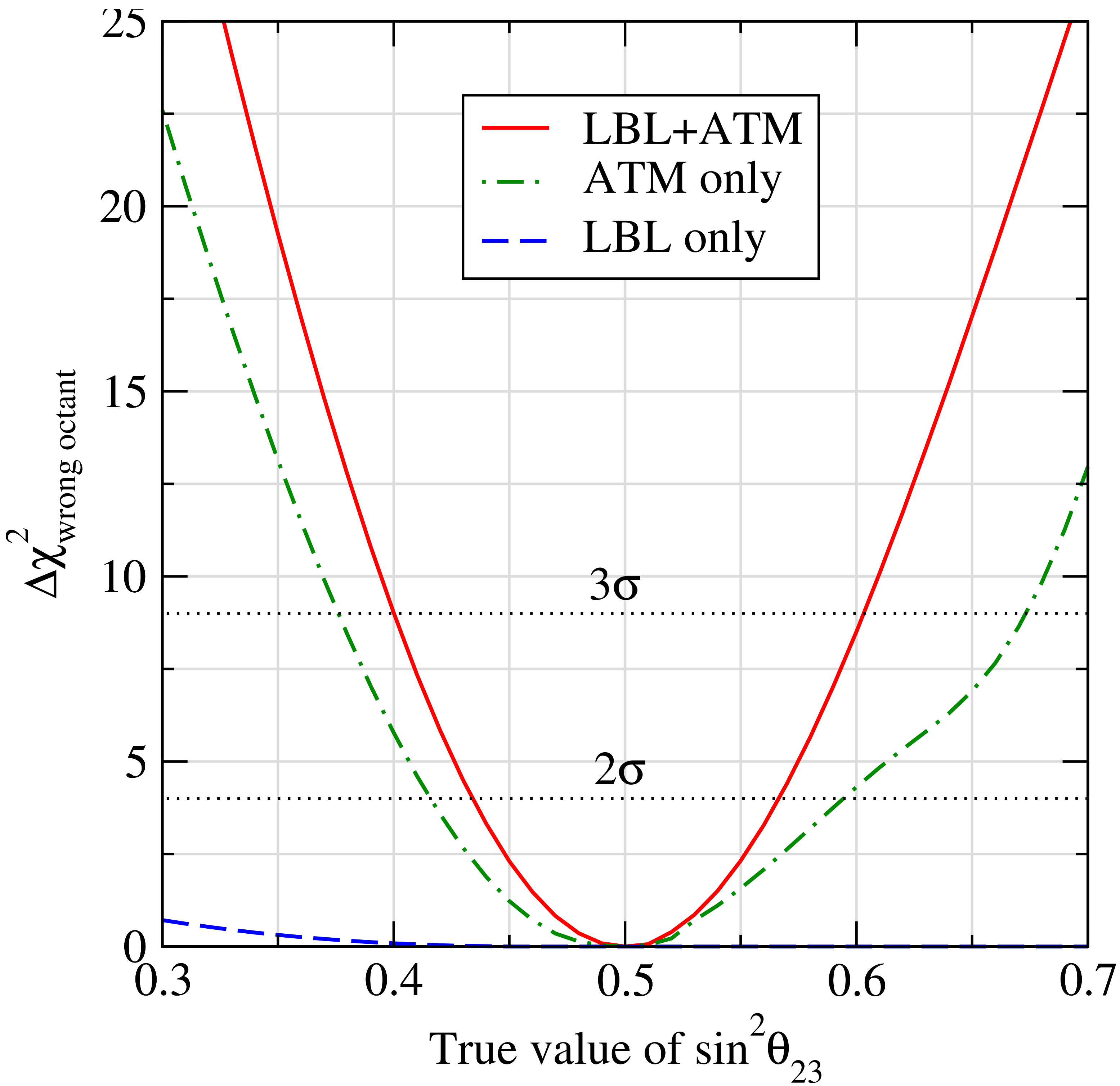
The octant degeneracy. LBL experiments being mainly sensitive to sin^2 2θ_23, one obtains two solutions of equal statistical significance, but associated with different pairs of values of (δCP, θ13).

Physics in conjunction with LBL experiments......

- Similarly, the mass hierarchy degeneracy occurs due to identical solutions for P and P̄ for different pairs of δ_CP and θ_13 with opposite signs of Δ_31 (fixing other parameters).
- Consequently, while providing high precision measurements of |Δm^2 31| and sin2 2θ_23, LBL experiments of the (near) future will not be able to provide definitive information on the mass hierarchy, the CP phase or the octant in which θ_23 lies.
- However, combining the precision measurements of upcoming LBL experiments with the wide-band (in L and E) capabilities of data gathered by a large mass atmospheric experiment like ICAL can lead to a resolution of these problems, as we illustrate by a couple of examples.



Hierarchy sensitivity of CERN-MEMPHYS LBL on its own (dashed curves) and when combined with atmospheric data (solid curves).



Huber, Maltoni & Schwetz

Phys. Rev. D 71, 053006 (2005)

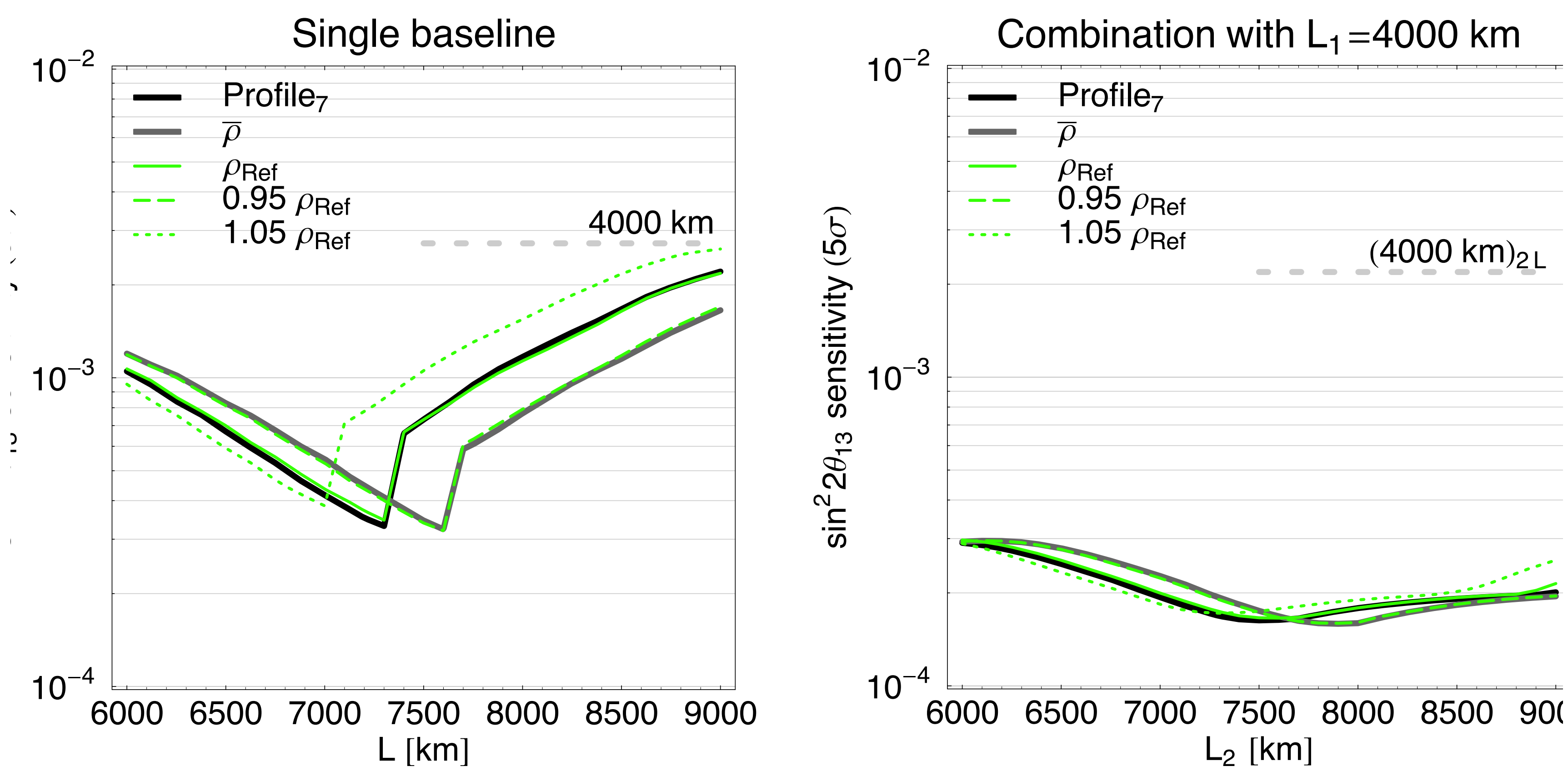
Octant discrimination capabilities of LBL and atmospheric detectors, both individually and when combined.

Physics in conjunction with Neutrino factories and Beta beams........the Magic Baseline

ˆ

At a baseline length of about 7000-7500 km, terms which contain a CP dependence drop out of the probability. This lifts the degeneracies which afflict the precision measurements of oscillation parameters.

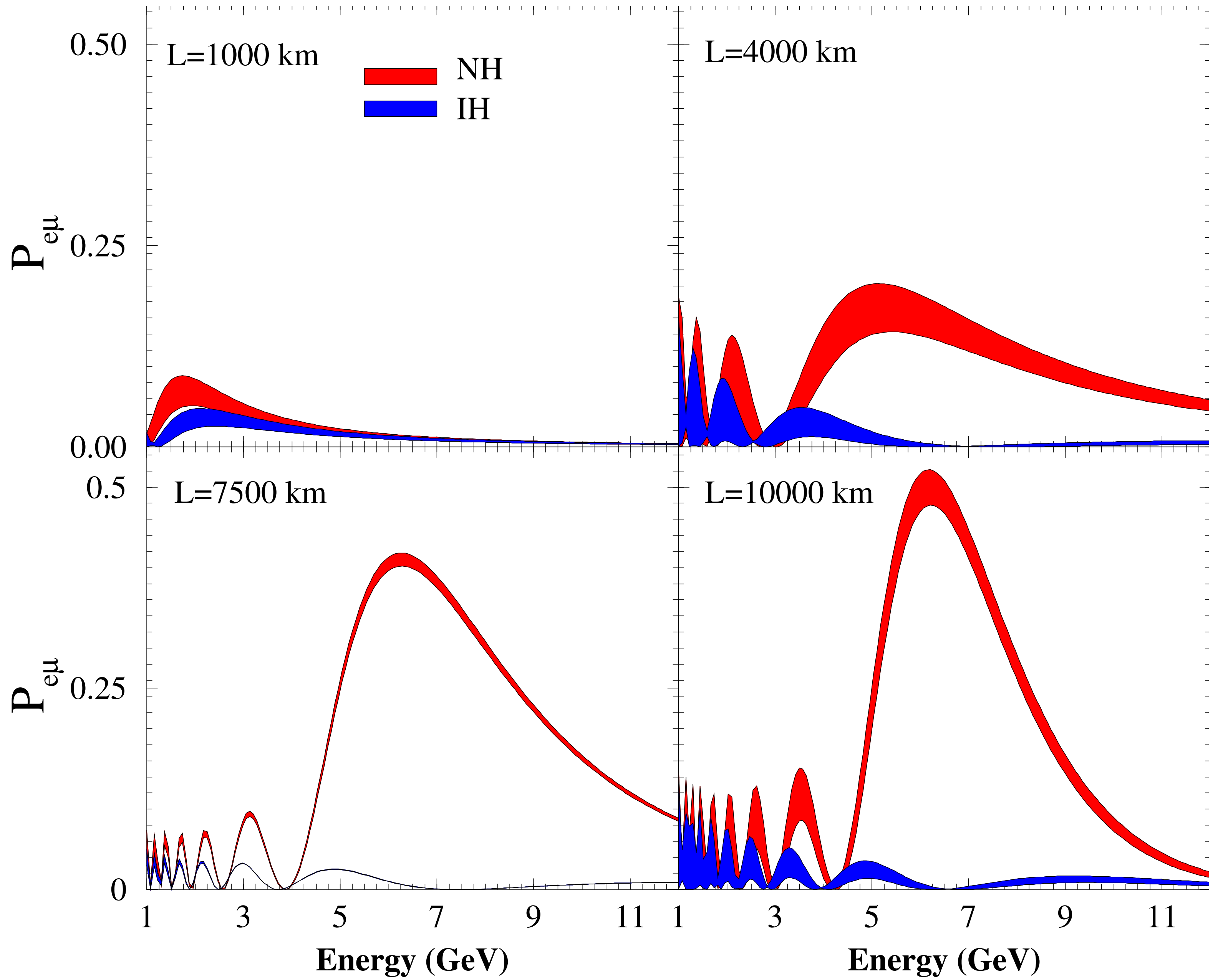
The CERN-ICAL distance is close to the magic baseline, as is the UK (RAL) - ICAL distance. This provides very attractive possibilities for factories and beta beams which may use ICAL as an end detector.



The sin2 2θ13 sensitivity as function of L including systematics, correlations, and degeneracies at the 5σ confidence level.

Gandhi and Winter

Phys.Rev.D75:053002,2007.



Agarwalla, Choubey and Raychaudhuri,
PoS NUFACT08:034,2008.

The energy dependance of the e-mu oscillation probability, at four different baselines, with bands showing the spread due to the CP parameter.