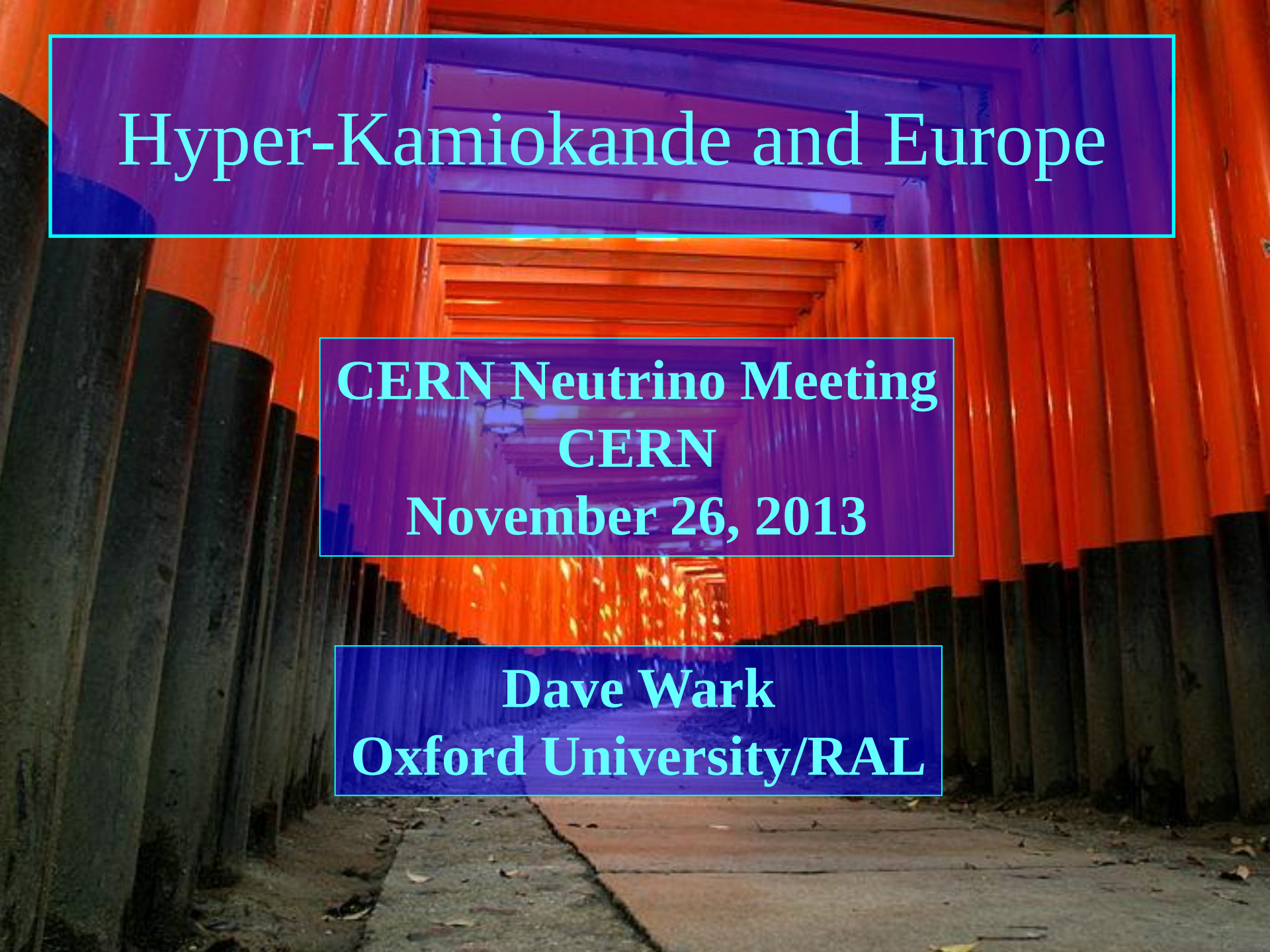
Water detectors?

Nobody ever called me divine,
so I will stick to Hyper Kamiokande

Dave Wark
Oxford U./RAL



Hyper-Kamiokande and Europe

CERN Neutrino Meeting
CERN
November 26, 2013

Dave Wark
Oxford University/RAL

The T2K Collaboration

~500 members, 62 institutes, 12 countries

Canada
TRIUMF
U. Alberta
U. B. Columbia
U. Regina
U. Toronto
U. Victoria
York U.

France
CEA Saclay
IPN Lyon
LLR E. Poly.
LPNHE Paris

Germ
U. Aa

Italy
INFN, U. Roma
INFN, U. Napoli
INFN, U. Padova
INFN, U. Bari

Japan
Hiroshima U.
ICRR Kamioka
ICRR RCCN
KEK
Kobe U.
Kyoto U.
Miyagi U. Edu.
Osaka City U.

Poland
A. Soltan, Warsaw
H.Niewodniczanski, Cracow
T. U. Warsaw
U. Silesia, Katowice
U. Warsaw
U. Wroklaw

Russia
INR

S. Korea
N. U. Chonnam
U. Dongshin

Spain
IFIC, Valencia
U. A. Barcelona

Switzerland
U. Bern
U. Geneva
ETH Zurich

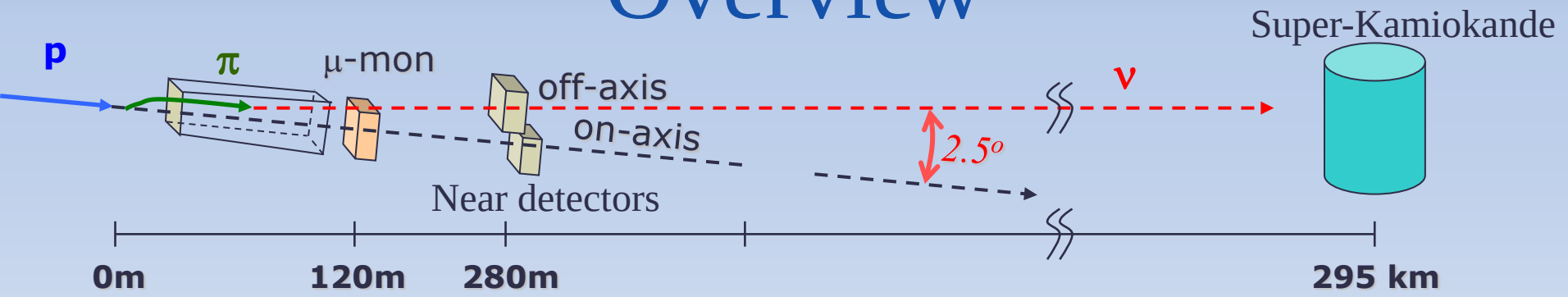
United Kingdom
Imperial C. London
Queen Mary U. L.
Lancaster U.
Liverpool U.
Oxford U.
STFC/RAL
STFC/Daresbury

USA
Boston U.
B.N.L.
Colorado S. U.
Duke U.
Louisiana S. U.
Stony Brook U.
U. C. Irvine
U. Colorado
U. Pittsburgh
U. Rochester

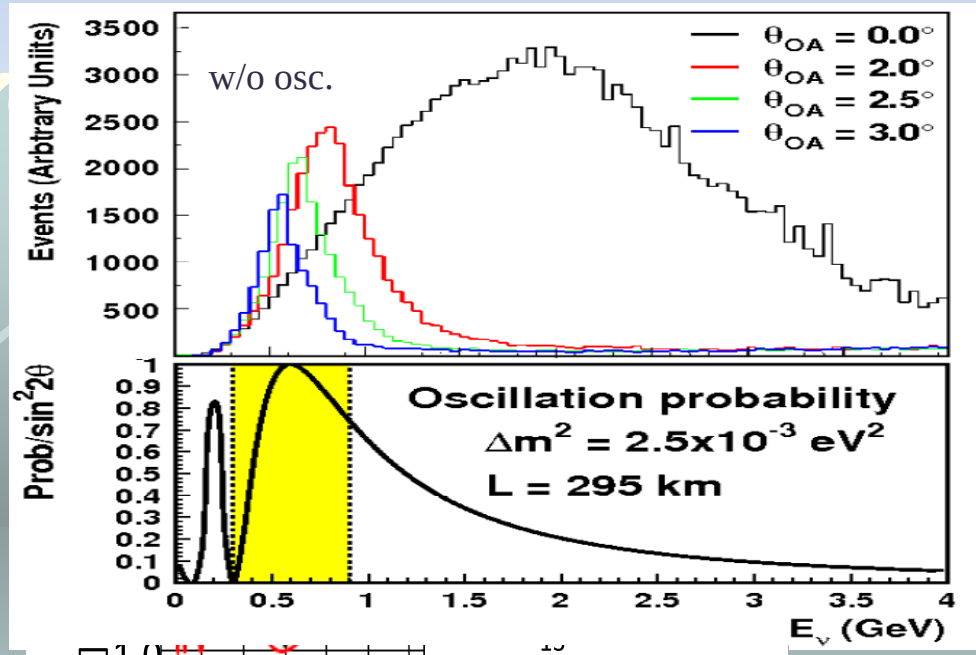
>50% of members are from Europe.

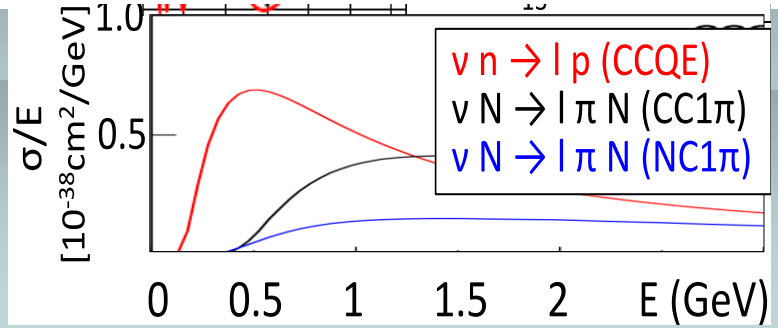
➢Largest (by numbers) neutrino exp. in Europe

Overview



- **30GeV proton beam from J-PARC MR to produce neutrino beam**
- **Beam is 2.5 deg off-axis from far detector direction**
  - **Peak ~0.6GeV @ osc. max**
  - **Small high energy tail**
  - **Dominated by CCQE**
  - **➔ Low background**
- **Muon monitors @ ~120m**
- **Near detector @280m**
  - On-axis detector "INGRID"
  - Off-axis (toward SK direction)
- **Far detector Super-Kamiokande @ 295km**



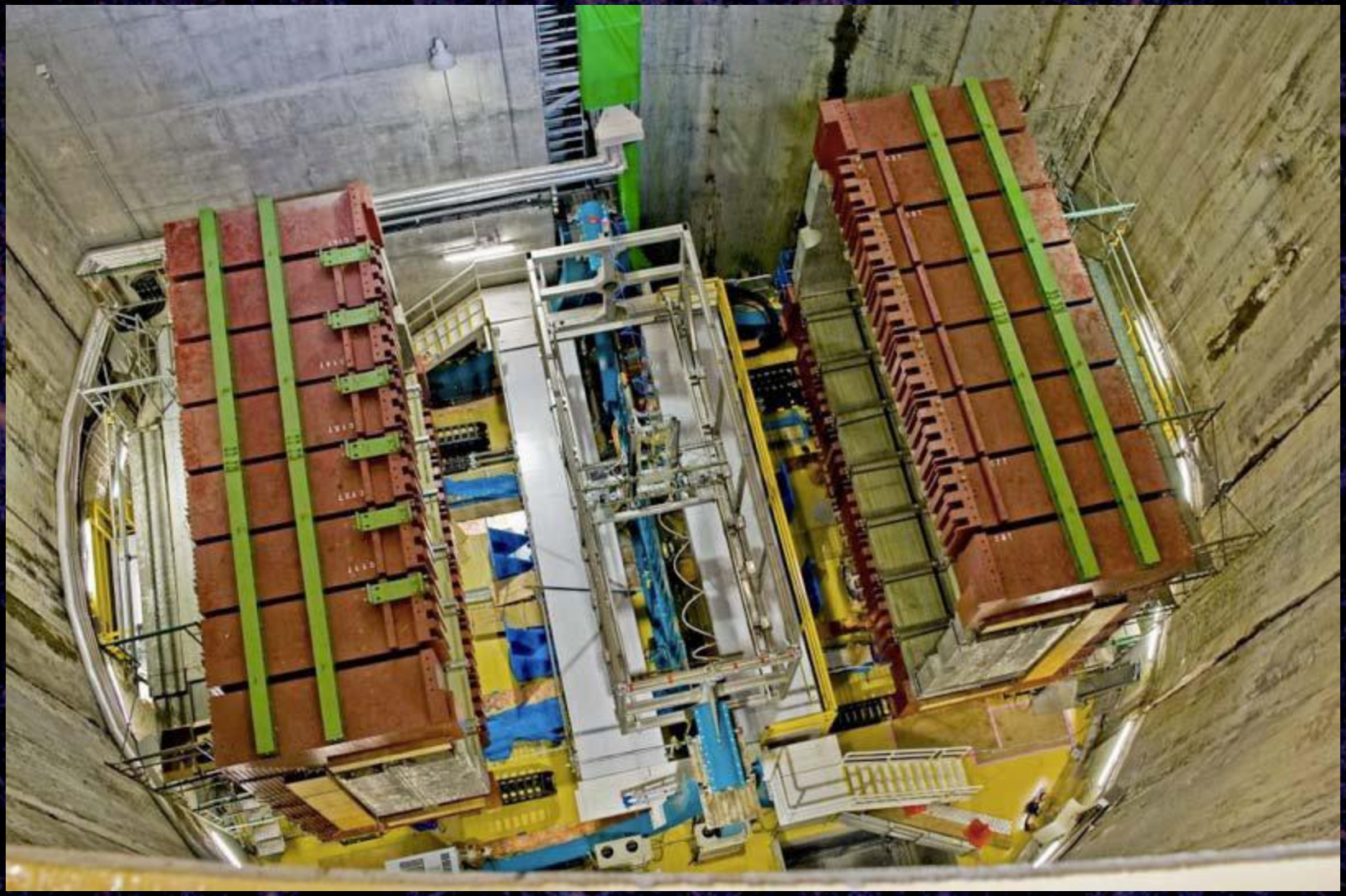


CERN Contributions to T2K

- Donation of the magnet.
- Technical support for the magnet refurbishment.
- Technical support for magnet services.
- Administrative and technical support for the magnet shipment.
- Procurement of the magnet cooling system.
- Maintenance contract for the magnet cooling system.
- Technical support for magnet field mapping system.
- Technical support for the Micromegas design, construction of the MM, support for their testing.
- Testing of other TPC components.
- Test beam access for TPC and ECAL.
- Enormous support for the NA61 experiment, which is a key part of T2K.

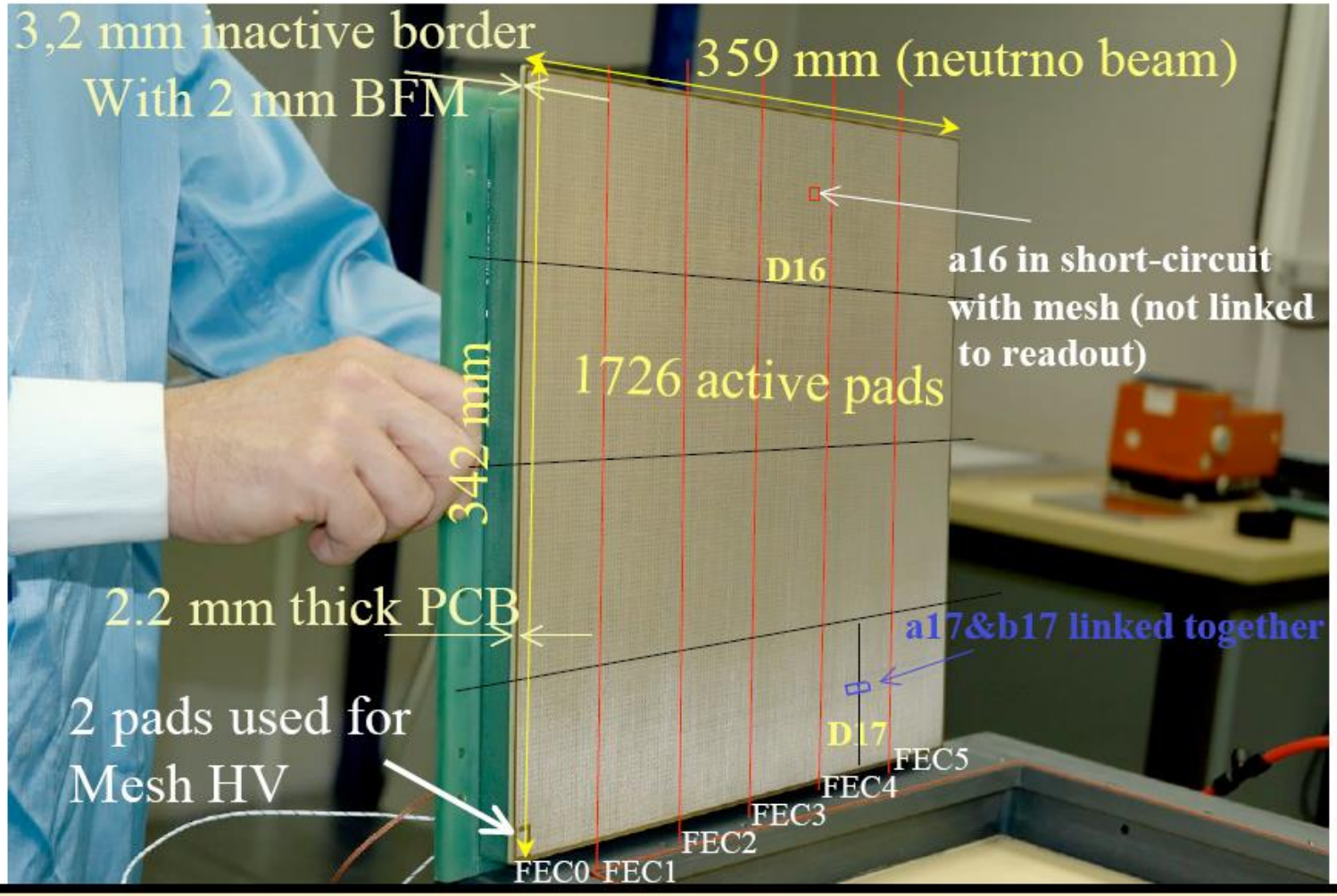
Dave Wark
Imperial College/RAL

CERN REC and T2K



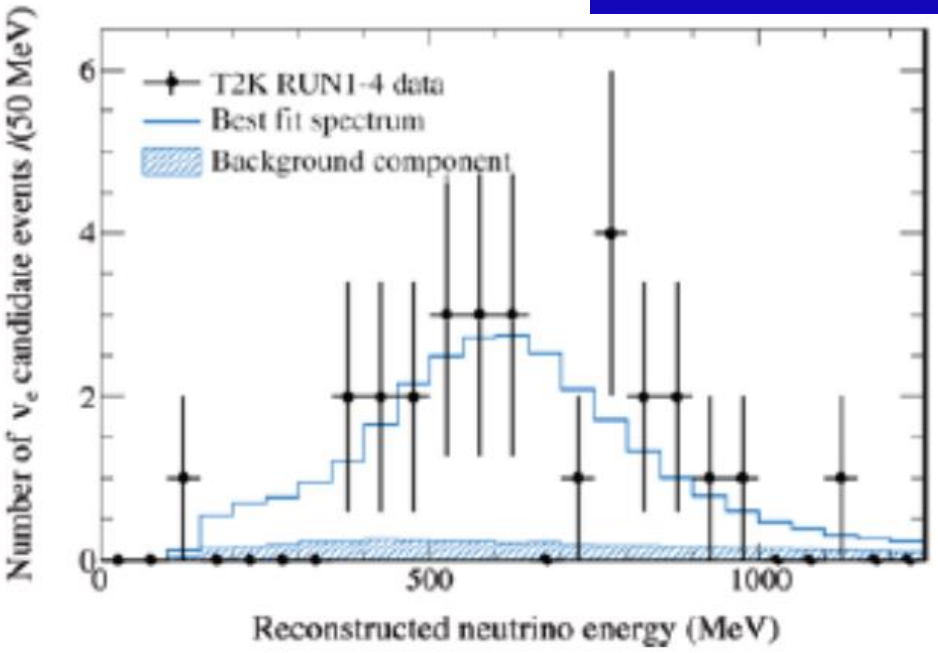
Dave Wark
Imperial College/RAL

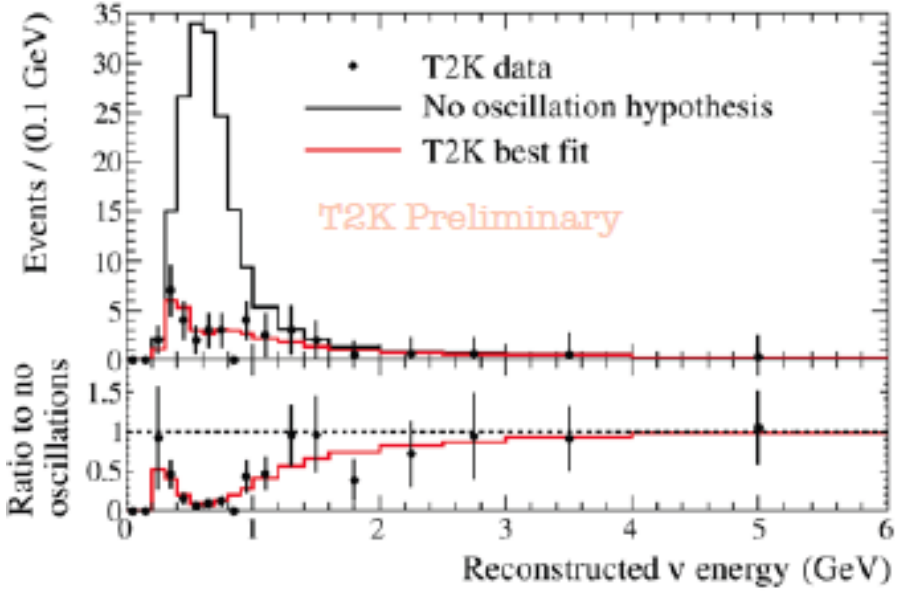
MM1_001 (stiffener V2) (HARp tests 09/19/2007)



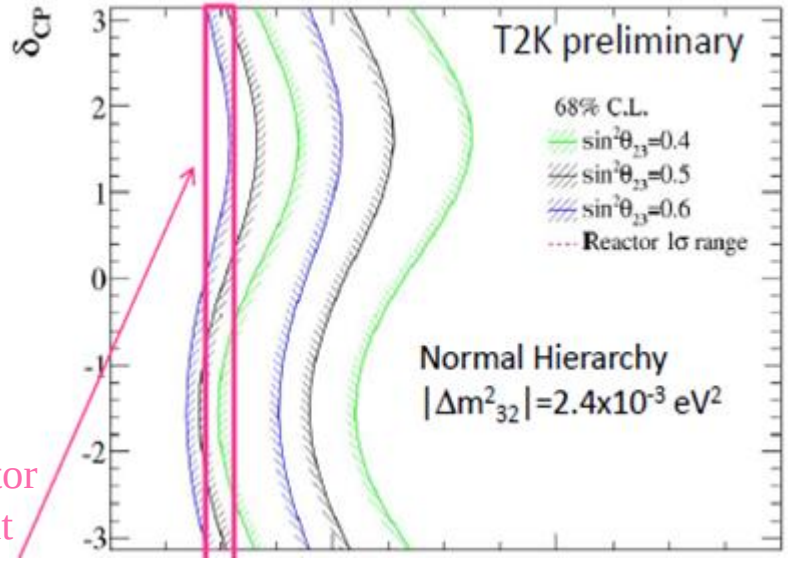
- a 30 μm thick 440 Lpi woven micromesh is embedded between 2 layers of pyralux
- 4 layers PCB with internal shielding layer & 6,9x9,7 mm pads with 7x9,8 mm pitch
- 128 μm amp. gap / 12 x ϕ0,5 mm pillars per pad / « stretched » mesh procedure
- 93% of PCB surface is active area / less than 2 faulty pads per module

T2K Results

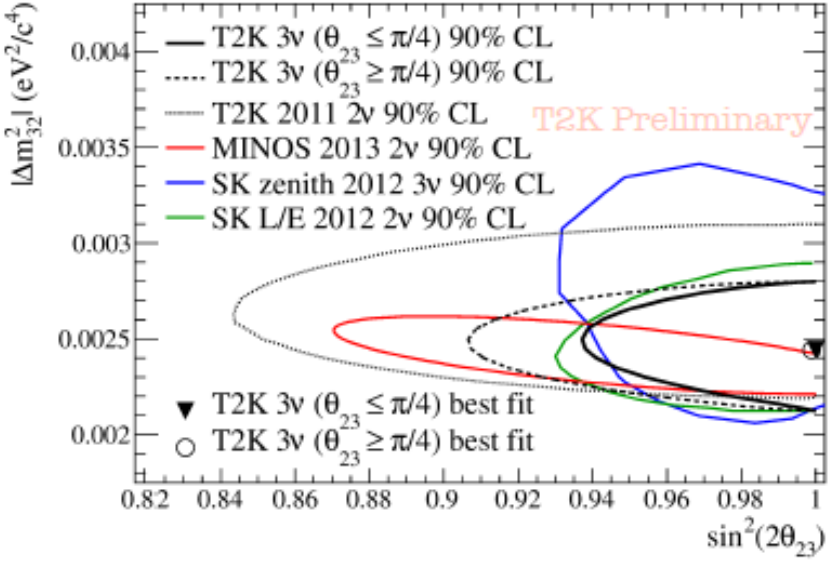




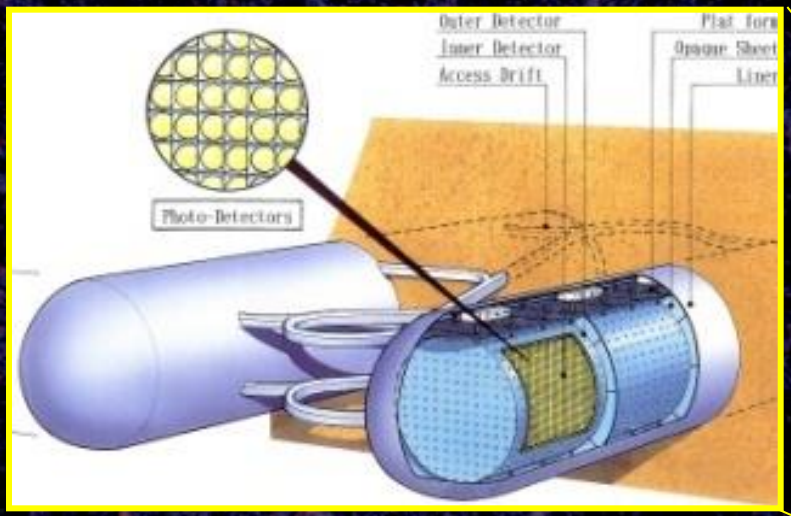
T2K Appearance



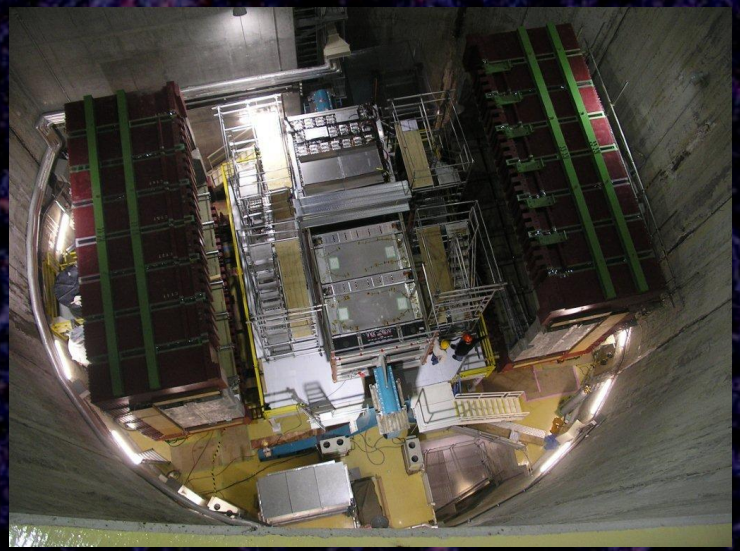
PDG Reactor constraint



The Next Step in Japan



Hyper Kamiokande L=295km OA=2.5deg
Water Cerenkov optimal on this baseline.

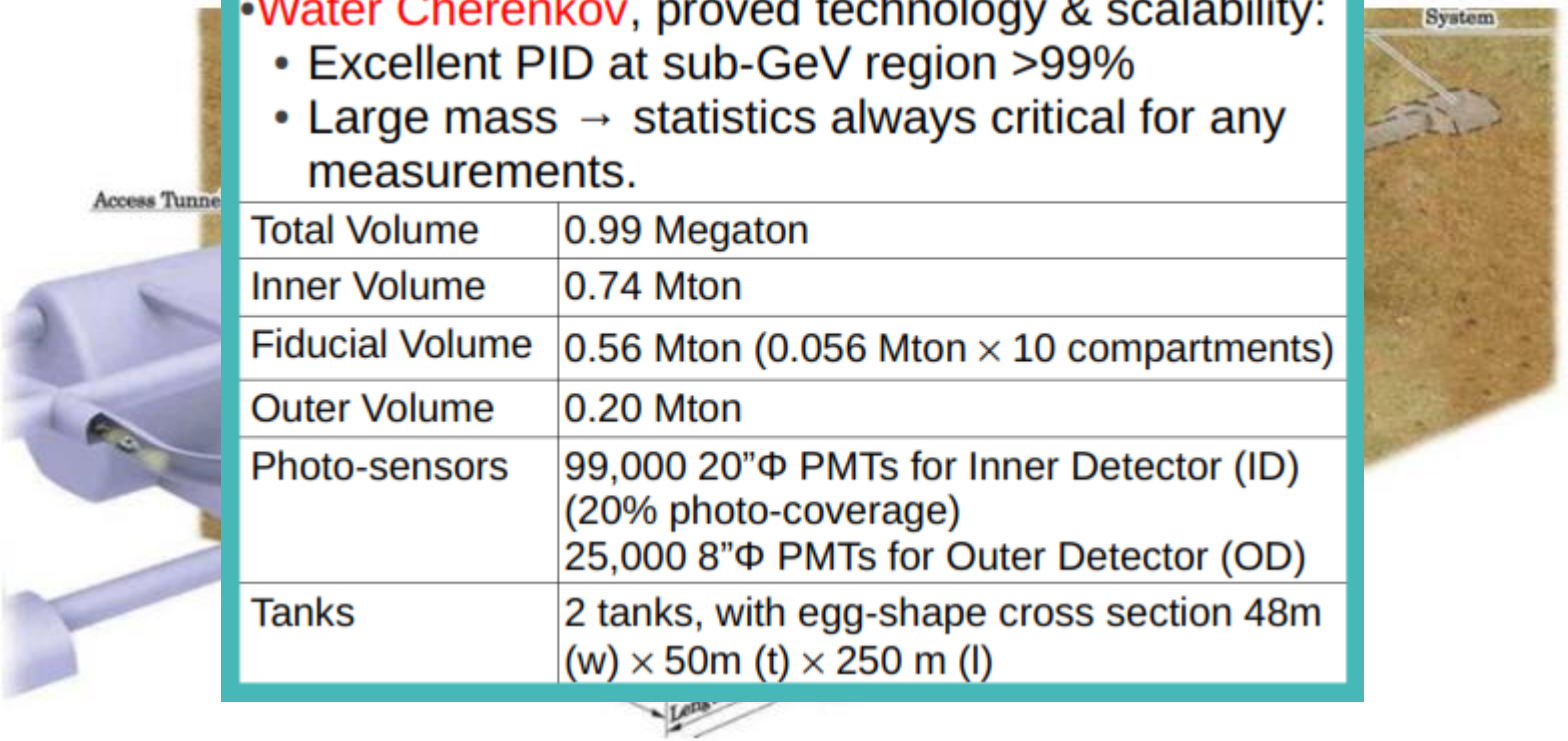


T2K 280m near detectors, will be re-used, but upgraded (?) and maybe enhanced with new near detector(s) at 2km.

J-PARC MR
→~>1.0MW

Interference with ILC in Japan?

Hyper-Kamiokande Overview



- Water Cherenkov, proved technology & scalability:
  - Excellent PID at sub-GeV region >99%
  - Large mass → statistics always critical for any measurements.

Total Volume	0.99 Megaton
Inner Volume	0.74 Mton
Fiducial Volume	0.56 Mton (0.056 Mton × 10 compartments)
Outer Volume	0.20 Mton
Photo-sensors	99,000 20"Φ PMTs for Inner Detector (ID) (20% photo-coverage) 25,000 8"Φ PMTs for Outer Detector (OD)
Tanks	2 tanks, with egg-shape cross section 48m (w) × 50m (t) × 250 m (l)

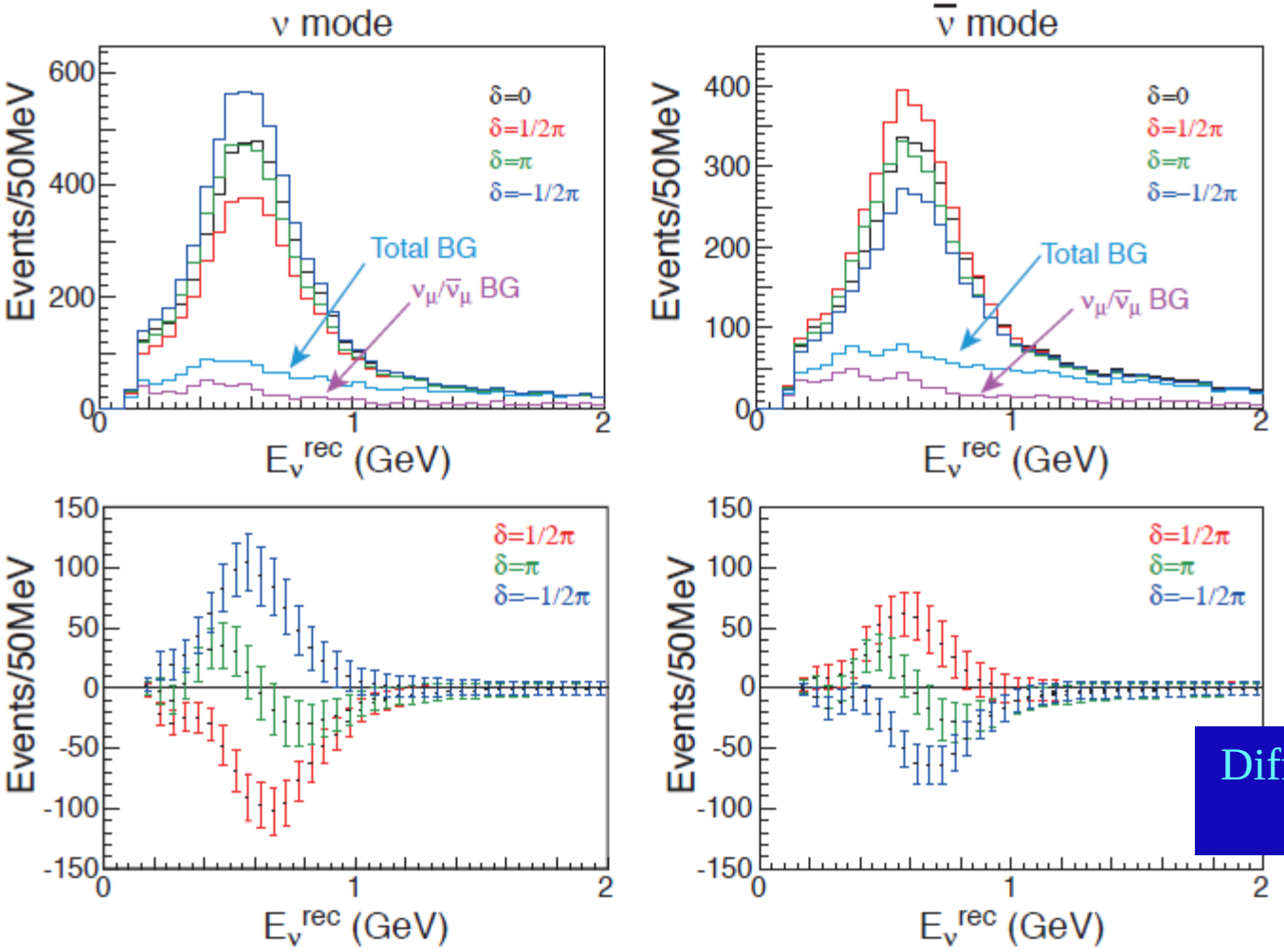
25 x Super-Kamiokande

Most HK slides stolen from Di Lodovico's talk at NNN 13

Dave Wark
Oxford U./RAL

Hyper Kamiokande Appearance Spectra

NB: Normal Hierarchy Assumed!



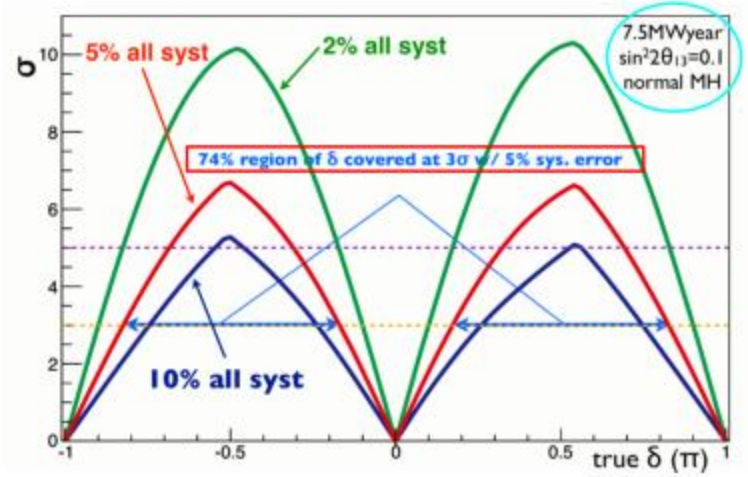
Difference from $\delta = 0$.

10 yrs running (3 ν, 7 anti-ν) @ 750 kW assumed…

Dave Wark
Oxford U./RAL

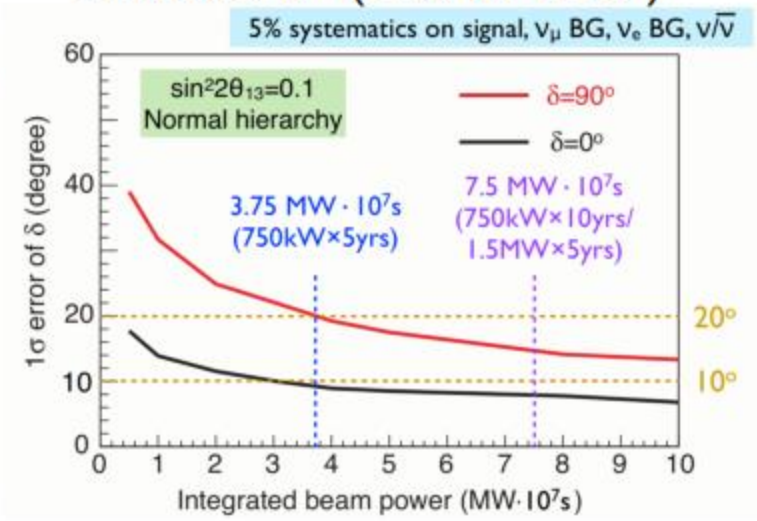
Expected Sensitivity to CP Violation

CPV discovery sensitivity w/ mass hierarchy known.



δ precision:

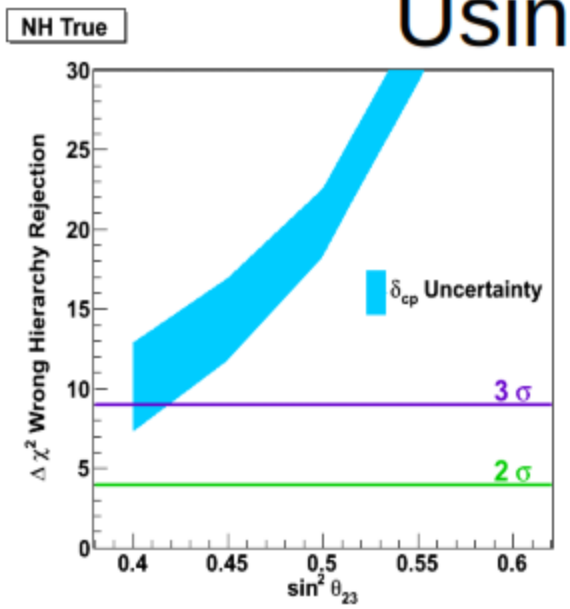
< 10°for δ=0° (< 20°for δ=90°)



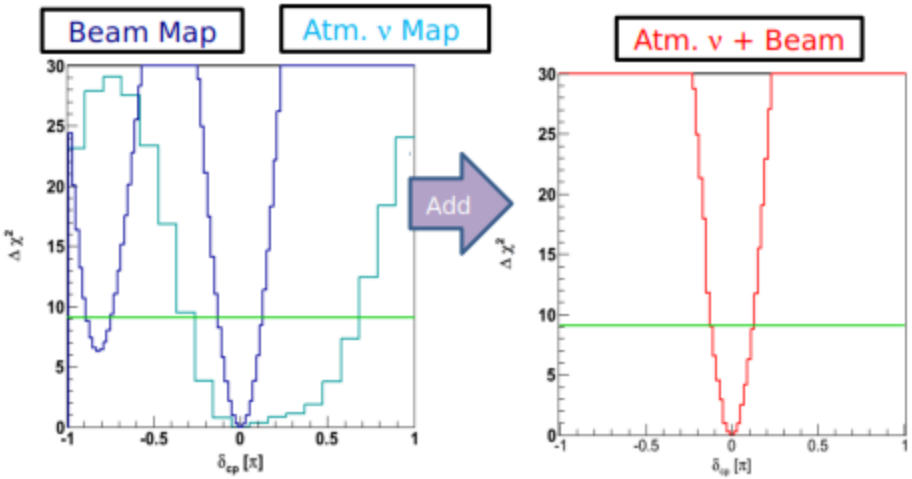
- Assuming 5% nominal systematics and 0.750MW/y (3y ν-beam and 7y $\bar{\nu}$-beam), 74% region of δ can be covered at 3σ.
- It corresponds to a precision of < 10° for δ=0°.

Dave Wark
Oxford U./RAL

Using Atmospherics



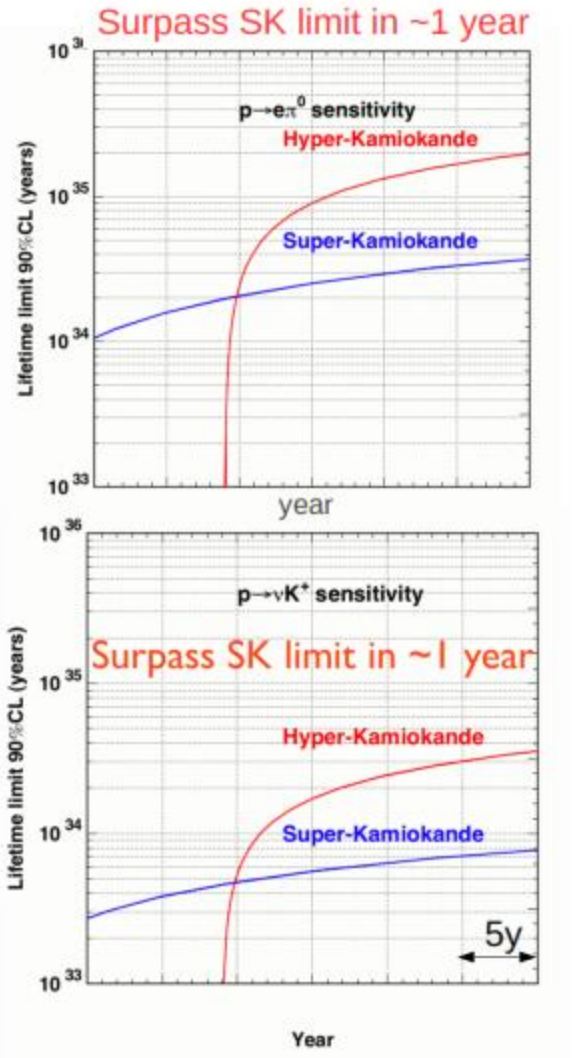
- Sensitivity mainly depends on θ_{23}, δ, and MH.
- 3σ mass hierarchy determination for $\sin^2\theta_{23} >$ 0.42 (0.43) for normal (inverted) hierarchy (10y).
- Caveat: the $\Delta\chi^2$ method to determine σ is used. Ongoing work to use Qian et al., PRD 86 113011 (2012).



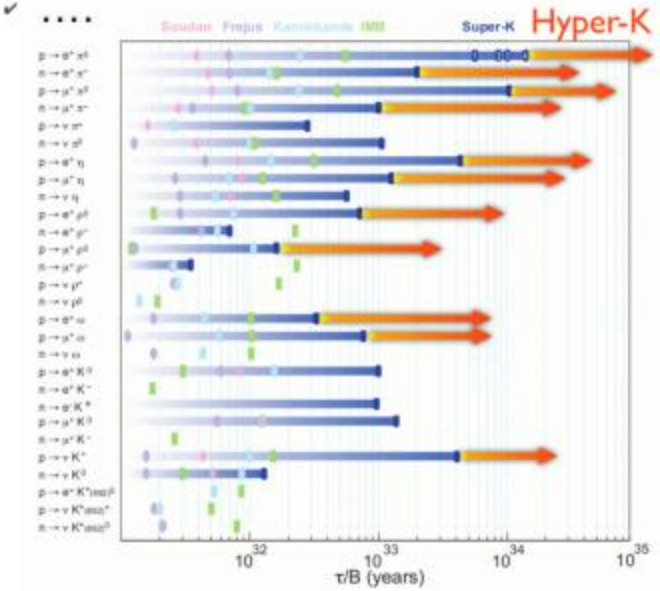
- Hierarchy is unknown, but NH is true.
- True $\delta_{CP} = 0.0$; $\sin^2 2\theta_{13} = 0.10$; $\sin^2 2\theta_{23} = 1.0$
- Degenerate solution exists at 3σ for the beam-only case.

Dave Wark
Oxford U./RAL

Proton Decay Sensitivities

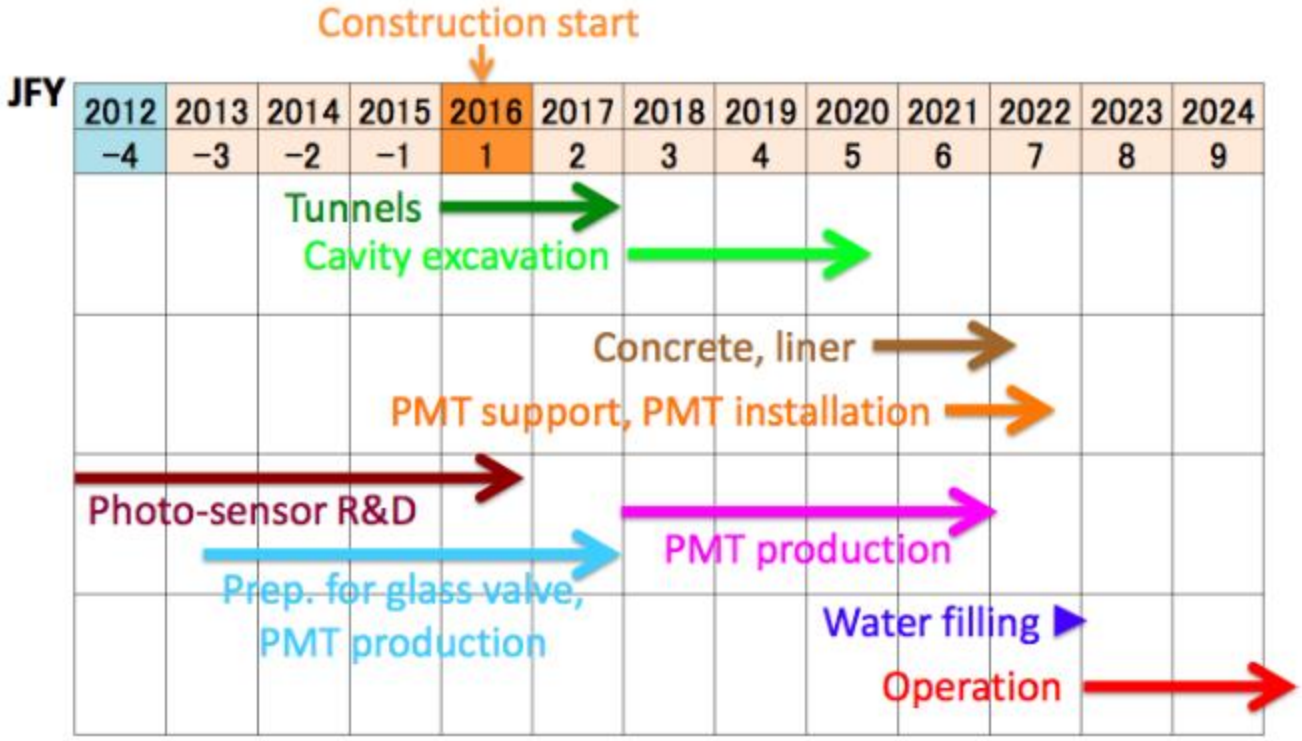


- 10 times better sensitivity than Super-K
- Hyper-K surpasses SK limits in ~1y
  - $p \rightarrow e\pi^0$: 1.3×10^{35} y at 90%CL
  - $p \rightarrow \nu K^+$: 2.5×10^{34} y at 90%CL
  - Many other modes:
    - $(p,n) \rightarrow (e,\mu) + (\pi,\rho,\omega,\eta)$
    - K^0 modes
    - $\nu\pi^0$, $\nu\pi^+$
    - ....



Dave Wark
Oxford U./RAL

Overall Project Schedule



Overall Hyper-K construction: ~7 years

Dave Wark
Oxford U./RAL

European Involvement in HK

- An ongoing involvment in HK will be a natural outgrowth of the large European involvement in T2K, and is warmly welcomed by our Japanese collaborators.
- Europeans are being involved in Hyper Kamiokande from the start, meaning that the separation between T2K and Super Kamiokande will not happen in the new project.
- We are still exploring many different possibilities for our involvement, mostly centred on the near detectors(s). We are likely to build at least one, and perhaps 3, new ones.
- A meeting is scheduled at Queen Mary in London on Dec. 18th to begin planning coordinated European involvement, and ~30 people have signed up so far (that is similar to the number that showed up at the first Euro-JHFnu meeting at CERN, which grew into the ~250 on T2K).
- I think significant European involvement in HK is certain (assuming it is built, of course!).

Dave Wark
Oxford U./RAL

CERN Involvement in HK?

- European collaborators in Hyper Kamiokande will no doubt wish to request help from CERN on many different things, however I don't currently know of anything on the scale of the UA1/NOMAD magnet.
- The most critical thing, in my view, will be NA61 – which will be critical as we move into systematics limited experiments.
- CERN should think carefully about how it can support NA61 or its successors on the time scale of decades.
- A precision measurement of electron (anti-)neutrino cross sections would be extremely useful in establishing the reality of any effect.
- The UK and the US were heavily involved in the neutrino beamline for T2K. CERN involvement in upgrades to the entire accelerator complex could well be extremely useful.
- We are speculating about a beam at the 2nd maximum…
- Does all this compete with other LBNx's? No.

Dave Wark
Oxford U./RAL

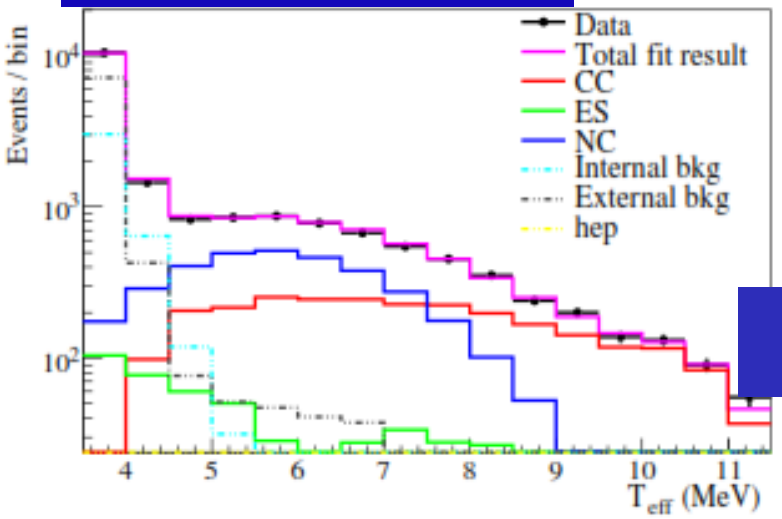
Why do we need multiple experiments?

- The history of our field is littered with wrong results – my first exposure to ν physics was Reines et al. "discovering" neutrino oscillations in the mid-70's, as did Bugey, and about a dozen other experiments, and there was Lubimov's ν mass and the 17 keV neutrino and many, many others – superluminal neutrinos come from a proud tradition of ν anomalies.
- ν experiments are hard – so why do we believe the current measurements of 3ν oscillations?

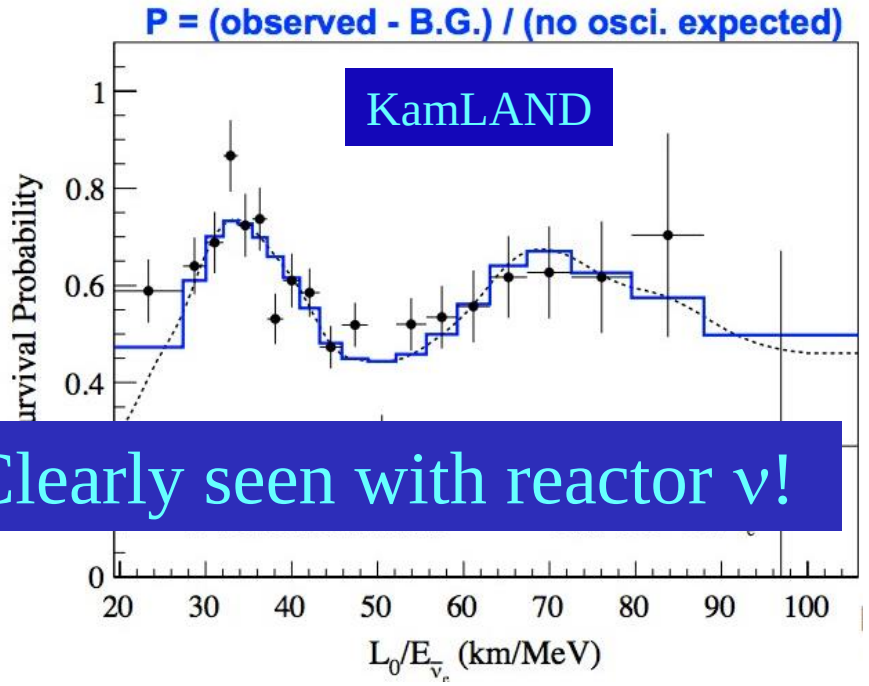
Dave Wark
Oxford U./RAL

How do we know θ_{12}, Δm_{12}?

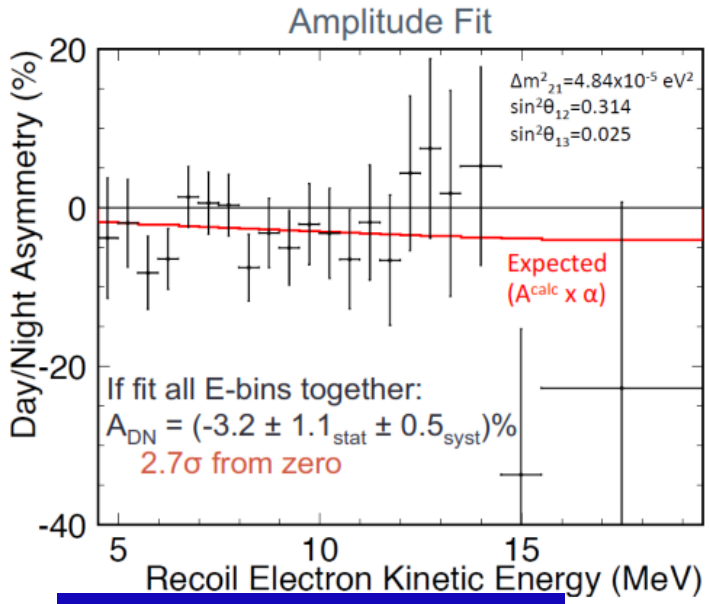
SNO LETA and 3-Phase



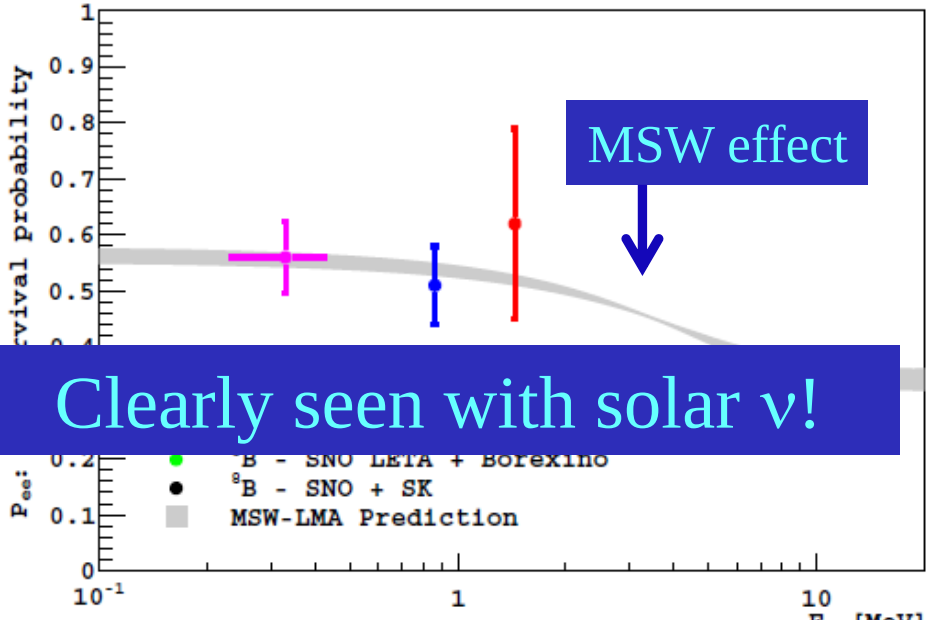
KamLAND



Clearly seen with reactor ν!



Super Kamiokande D/N



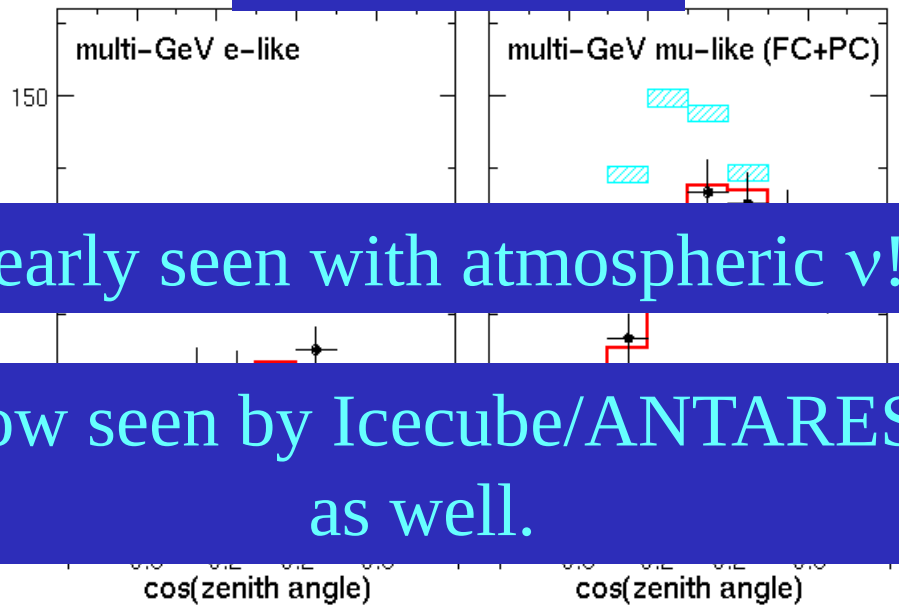
Clearly seen with solar ν!

Raaf, this conference. arXiv:0910.2984v2 [nucl-ex] 9 Jun 2010

Ishidoshiro, this conference. arXiv:1110.3230v1 [hep-ex]

How do we know θ_{23}, Δm_{23}?

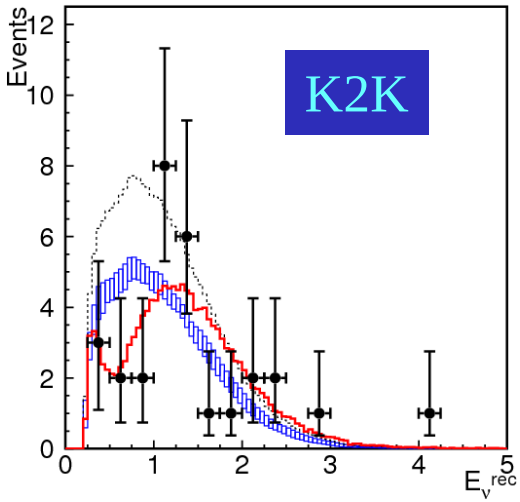
Super Kamiokande



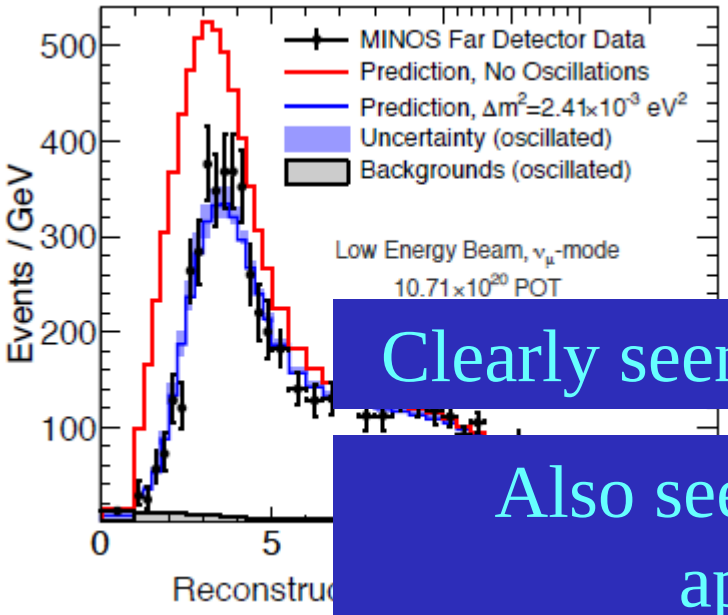
Clearly seen with atmospheric ν!

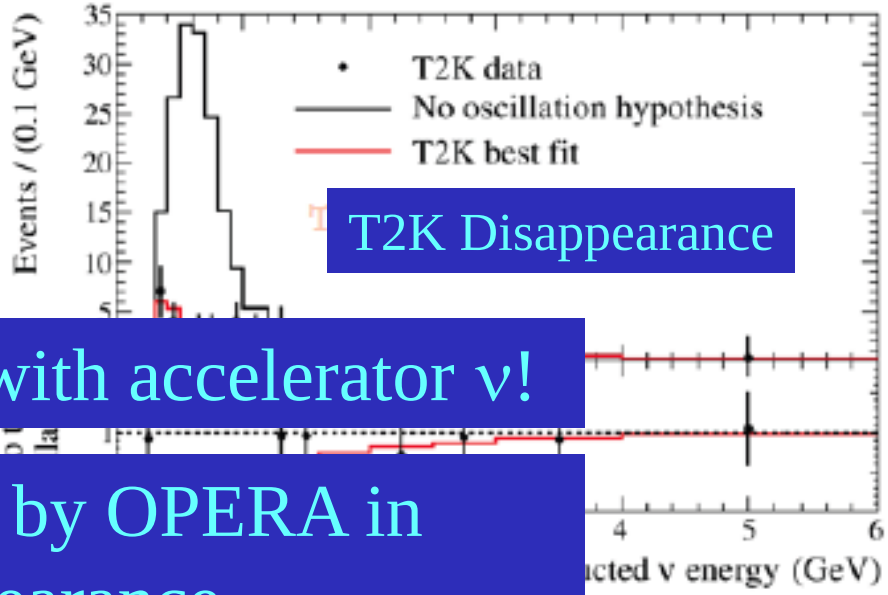
Now seen by Icecube/ANTARES as well.

K2K



MINOS Beam and Atm.





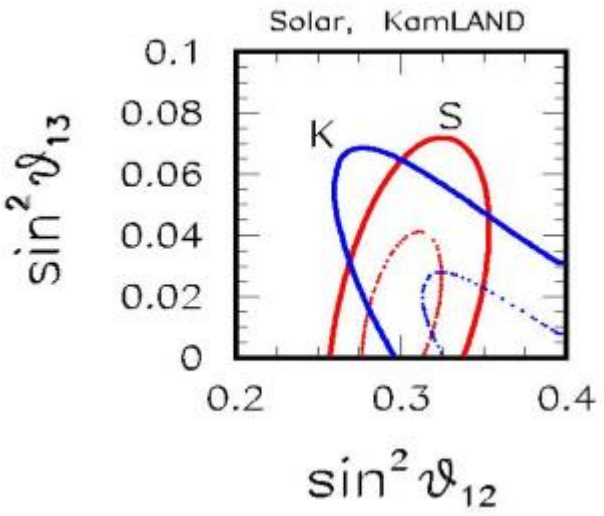
T2K Disappearance

Clearly seen with accelerator ν!

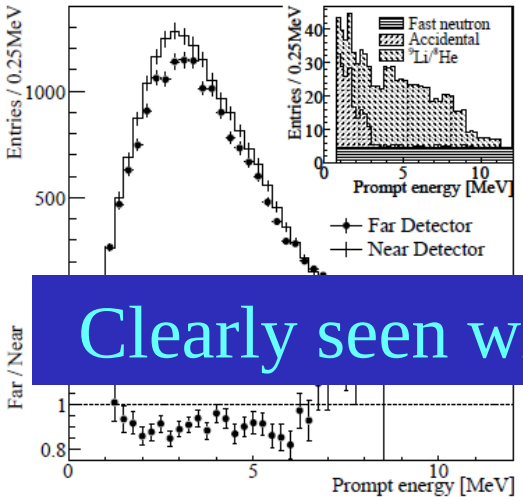
Also seen by OPERA in appearance.

How do we know θ_{13}, Δm_{13}?

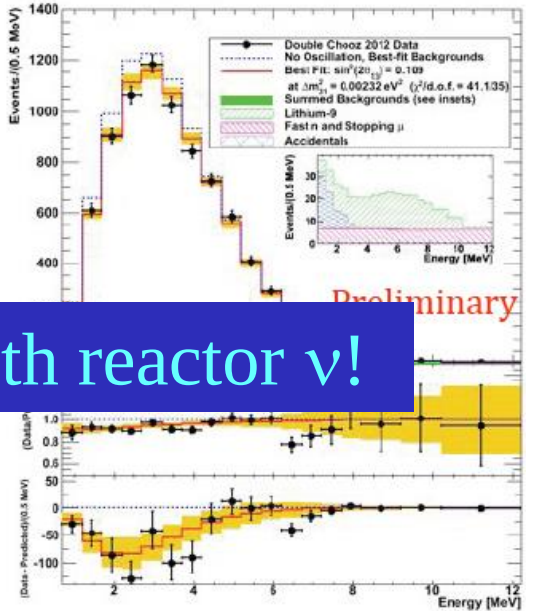
hep-ph/0806.2649



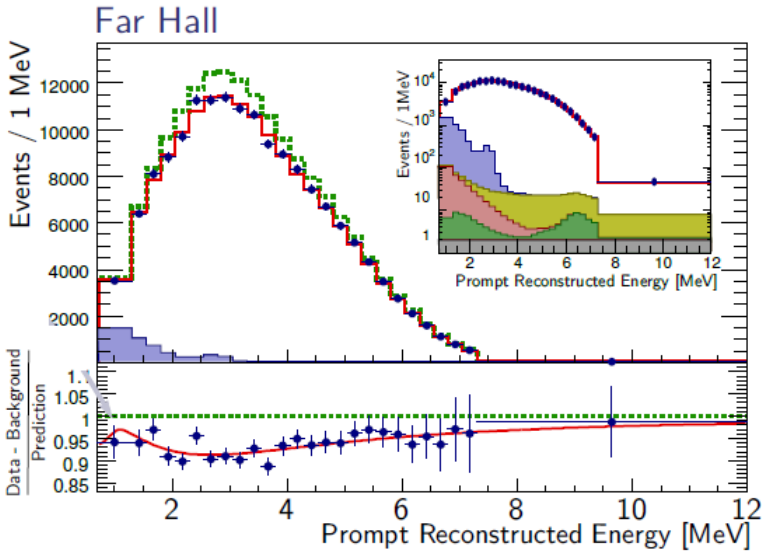
RENO



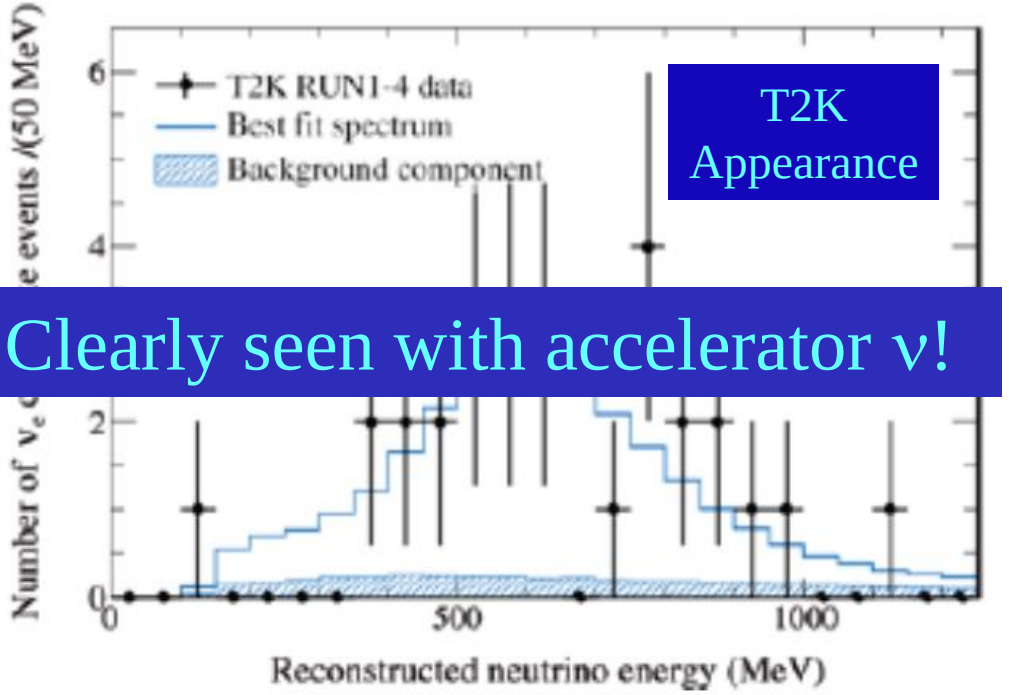
Double Chooz



Clearly seen with reactor ν!



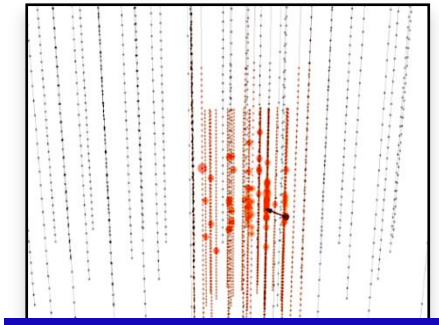
Daya Bay rate plus shape

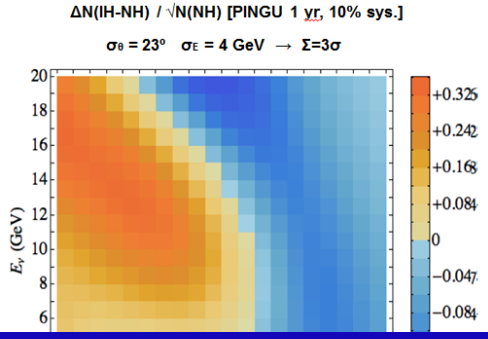


T2K Appearance

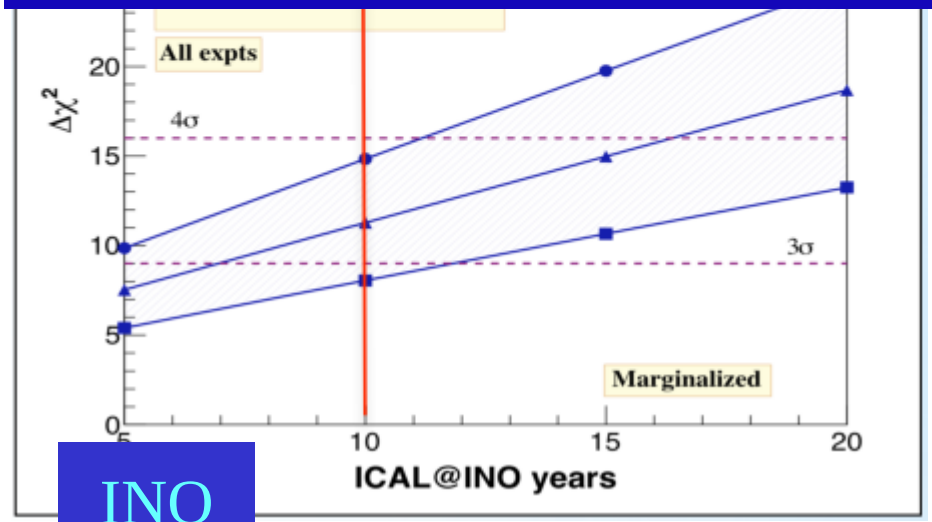
Clearly seen with accelerator ν!

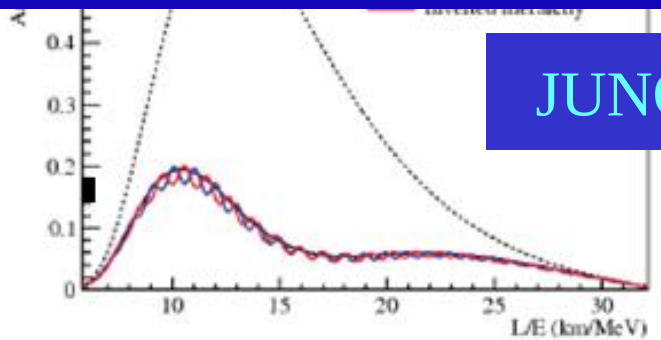
Many are called to measure the MH…





Measuring CP violation, on the other hand, can only currently be done with long-baseline. We therefore need more than one long-baseline experiment (as in the case of colliders)….

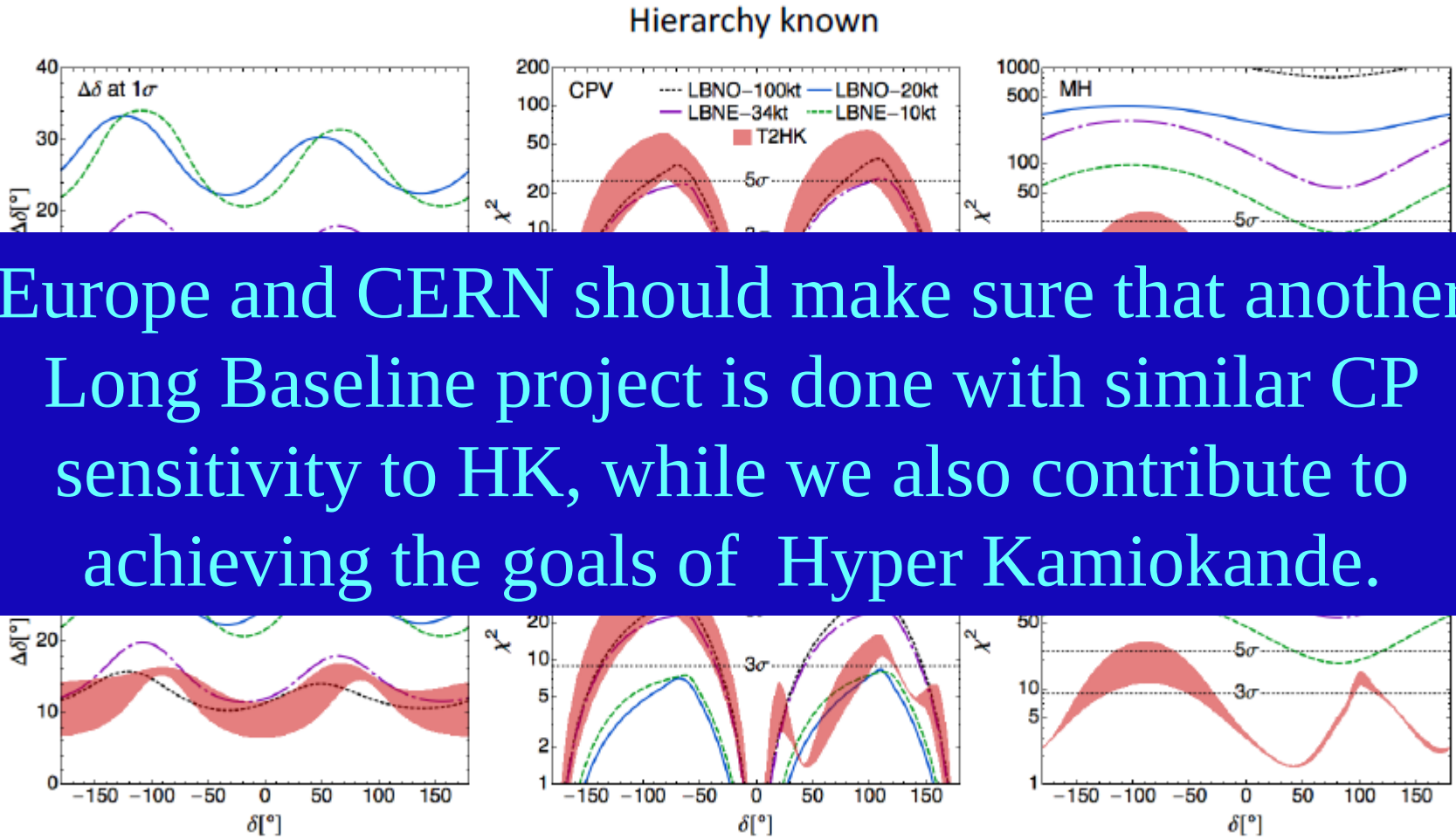




$\sin^2\theta_{12}$ to ~2% from dedicated reactor experiment at optimized L~60km

From Pilar Hernandez's talk in Kracow…

In 20 years from now with conventional beams…



Europe and CERN should make sure that another Long Baseline project is done with similar CP sensitivity to HK, while we also contribute to achieving the goals of Hyper Kamiokande.

Compiled by P. Coloma

Systematics as in Coloma, Huber, Kopp, Winter to appear