Neutrino Physics – Accomplishments and Future Challenges

Joint ECFA-EPS Session
EPS HEPP
Grenoble
July 23 2011

Science & Technology Facilities Council

Dave Wark
Imperial/RAL
(but speaking only for me!)

Imperial College London

Photo by Olivier Fruchart

What will I talk about?

This is not the plenary neutrino talk – that is by Nishikawa-san on Tuesday.

This talk is about the decisions we need to make.

This is an ECFA session, so I will only talk about experiments with an accelerator in them – no solar neutrinos, no double-beta decay, not even very much reactor neutrinos – sorry.....

And I won't talk all that much about accomplishments.

We have more than enough Future Challenges for a 20 minute talk....

Three neutrino mixing.

If neutrinos have mass: $|\nu_l\rangle = \sum U_{li} |\nu_i\rangle$

$$U_{li} = \begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu1} & U_{\mu2} & U_{\mu3} \\ U_{\tau1} & U_{\tau2} & U_{\tau3} \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \cdot \begin{pmatrix} c_{13} & 0 & s_{13}e^{i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{-i\delta} & 0 & c_{13} \end{pmatrix} \cdot \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

$where\ c_{ij} = \cos\theta_{ij},\ and\ s_{ij} = \sin\theta_{ij}$

Remember degeneracies
And covariances!

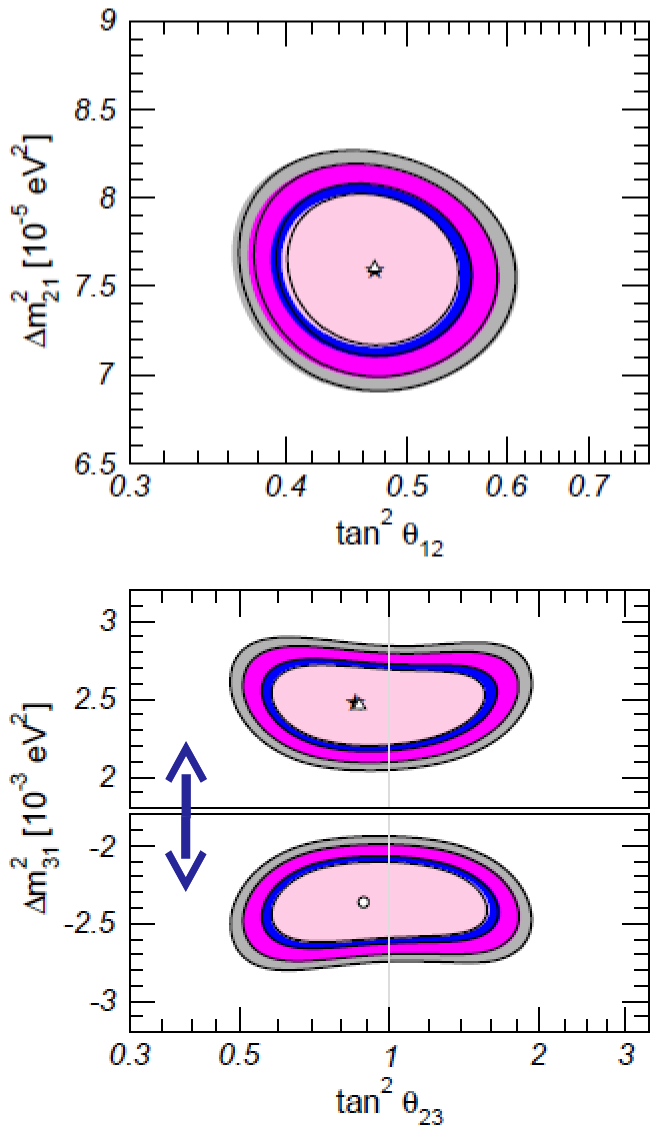
~0.03

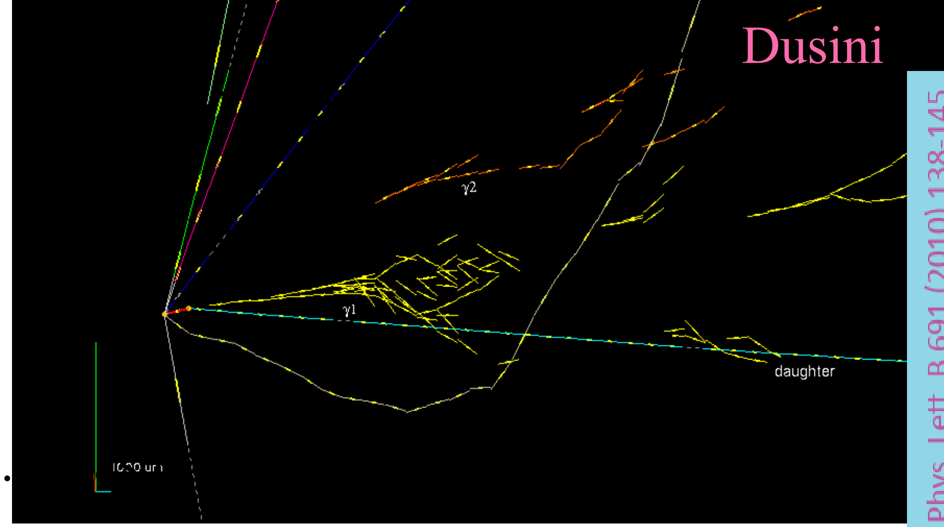
~ π /4

Dave Wark
Imperial College/RAL

How well do we know θ ij?

Gonzalez-Garcia, Maltoni, Salvado



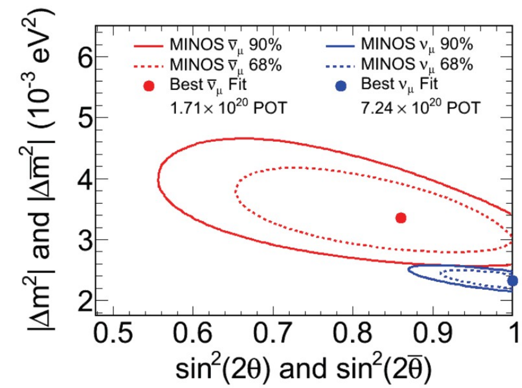


Dusini

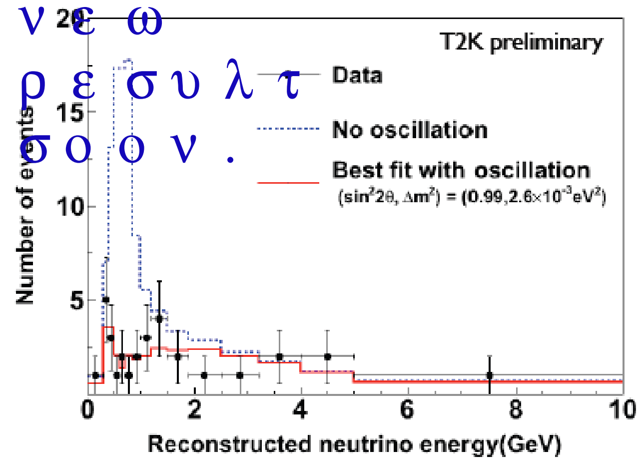
Phys. Lett. B 691 (2010) 138-145

MINOS ν ϖ σ
ν ι ν
μ ι λ δ
τ ε ν σ ι ο ν

Holin



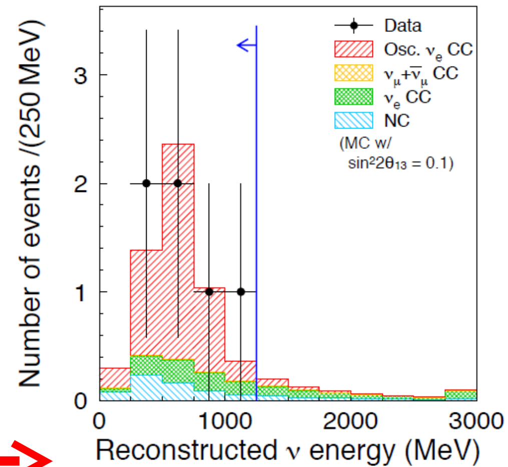
ν ε ω
ρ ε σ υ λ τ
σ ο ο ν .

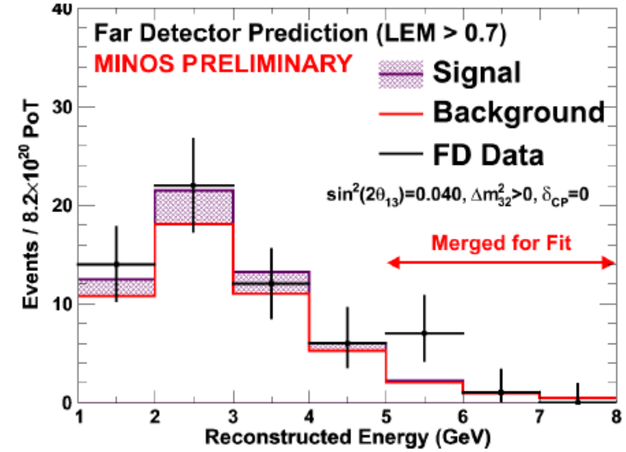


1st T2K
ν μ
disappearance

Giganti

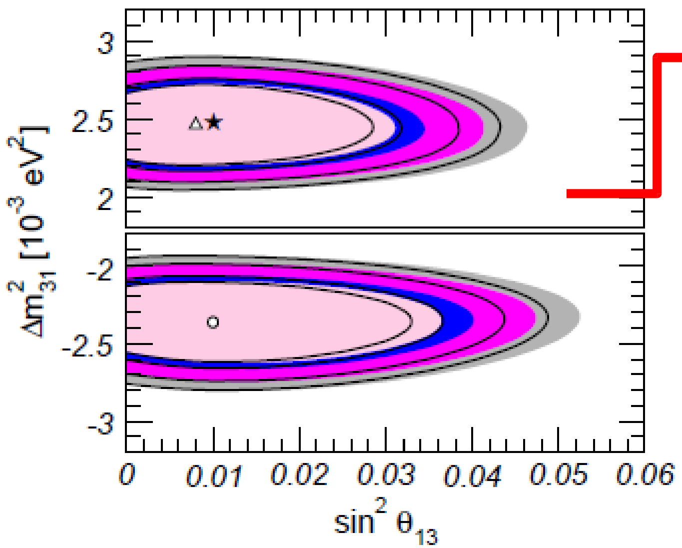
What about θ 13?





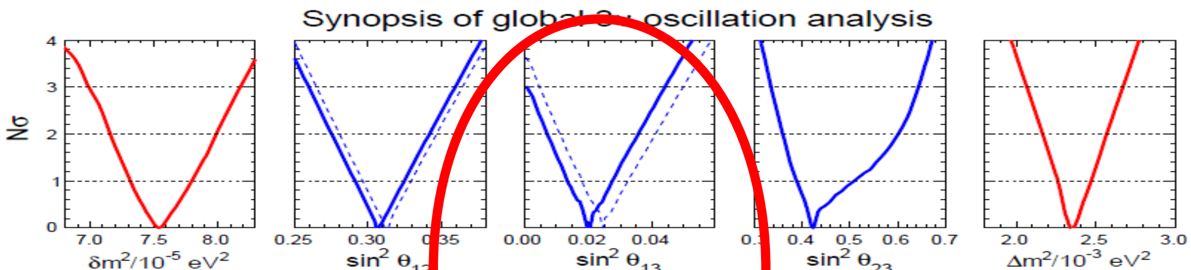
T2K (2.5σ) MINOS (1.7σ)

ν e appearance, θ 13 > 0?



Evidence of $\theta_{13} > 0$ from global neutrino data analysis

G.L. Fogli,[1,2] E. Lisi,[2] A. Marrone,[1,2] A. Palazzo,[3] and A.M. Rotunno[1]



arXiv:1106.6028v1 [hep-ph] 29 Jun 2011

For this talk, assume θ 13 > 0, and T2K and NOvA will prove it!

What then for ν oscillations?

Prove $\theta_{13} > 0$.

Measure all parameters with greater precision (because you need it for the rest of the list, but is there any particular necessary accuracy indicated by theory?).

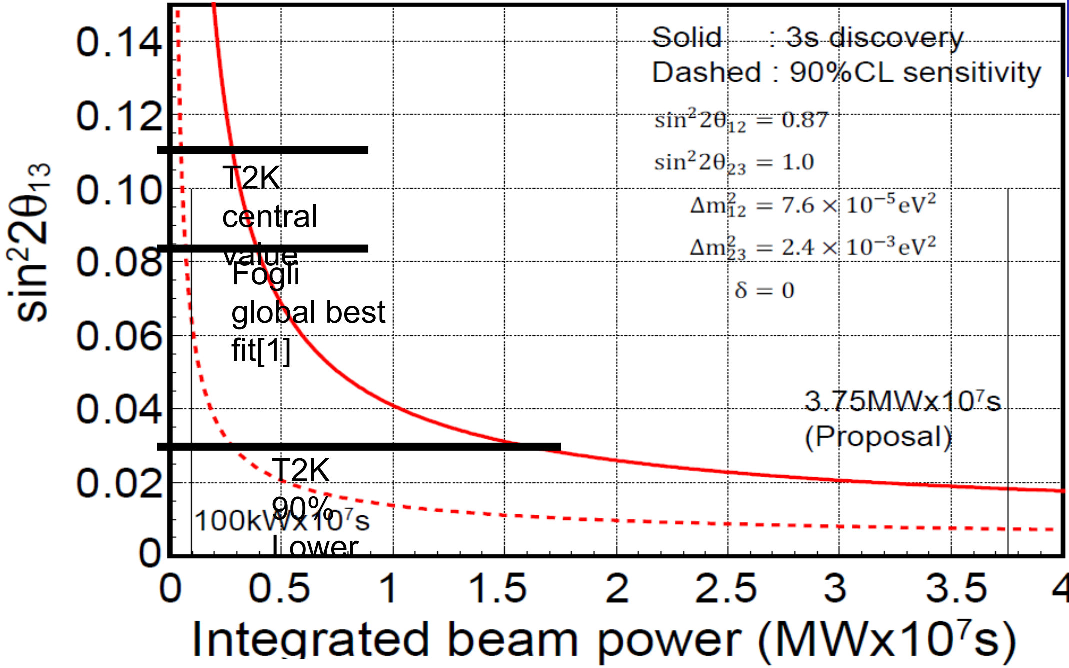
Make the most sensitive possible test of the deviation of θ_{23} from 45º.

Determine the mass hierarchy by observing matter effects → higher energy, longer baseline.

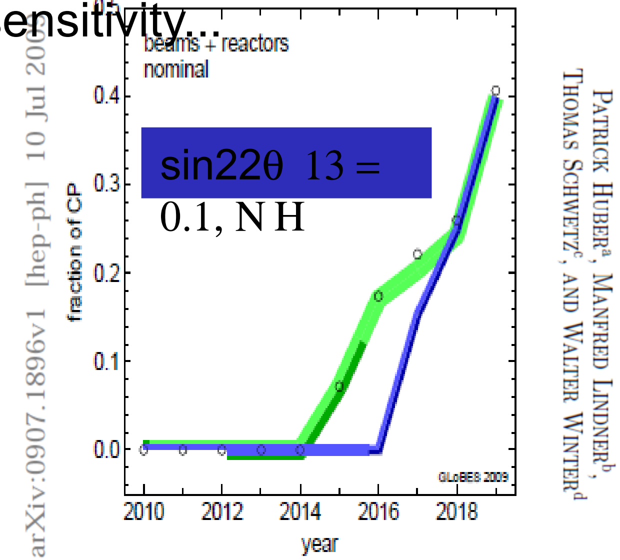
Measure the angle δ !

Are there any surprises?

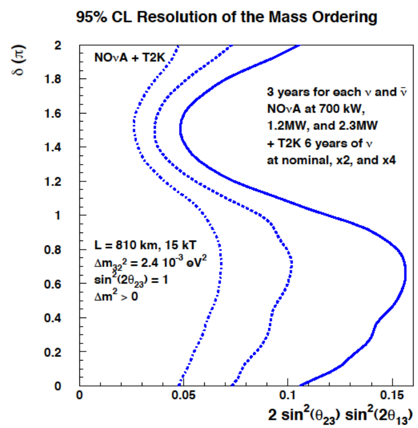
Dave Wark
Imperial College/RAL

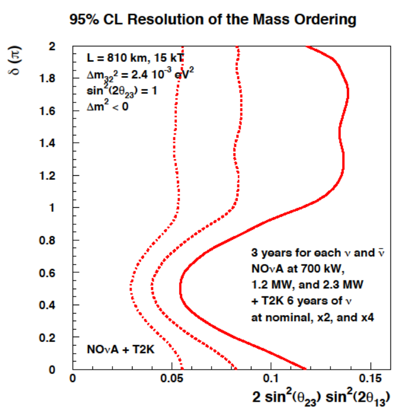


Even some 90% CP violation sensitivity...



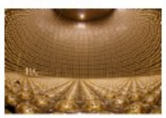
sin22θ 13 = 0.1, N H

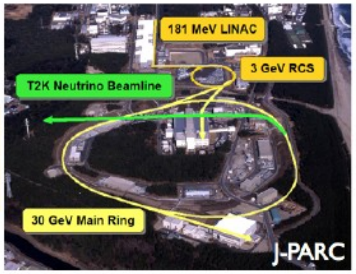




T2K and NOvA

Kamioka





- Ran from Jan 2010 till March 2011
- Presently stopped; restart foreseen in 2012
- Maximum beam power 145 kW
- Muon disappeara[…] conference
- Electron appeara[…] (90%C.L.):
  - $0.03 < \sin^2 2\theta_{13} < 0.28$ (best fit 0.11) normal
  - $0.04 < \sin^2 2\theta_{13} < 0.34$ (best fit 0.14) inverted

→500 kW (2yr)
→ >1 MW (>5yr)

Aim: sensitivity $\sin^2 2\theta_{13} > 0.006$ @ 90%C.L. for $\delta_{CP}=0$

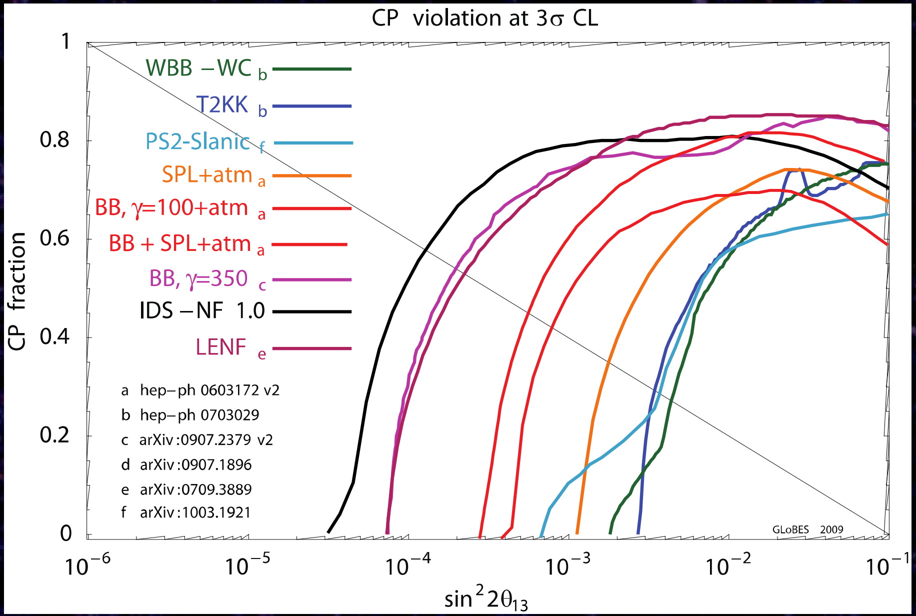
- Far detector under construction
- Start foreseen in fall 2013
- Beam power 750 kW (after upgrade)
- Baseline L=830 km gives some matter effect sensitivity
- Consider neutrino + antineutrino runs

Aim: sensitivity $\sin^2 2\theta_{13} > 0.007$ @ 90%C.L. for $\delta_{CP}=0$

$$P(\nu_\mu \to \nu_e) \approx \sin^2 2\theta_{13} \sin^2\theta_{23} \sin^2\left(\frac{\Delta m^2_{31} L}{4E_\nu}\right) + higher\ order\ f(\delta_{CP}, \theta_{12})$$

OK, then what?

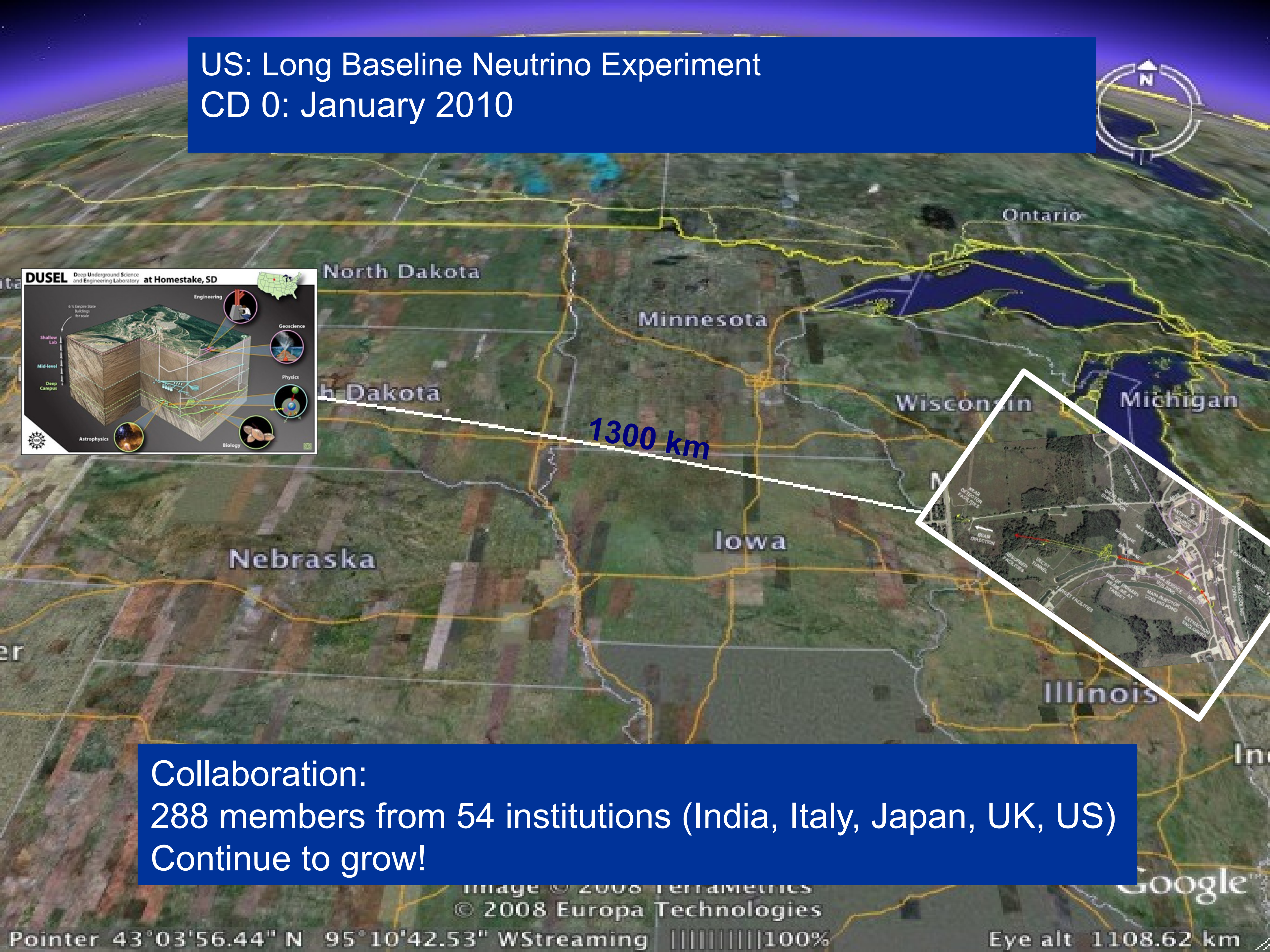
Simon van der Meer, 1925 -



- Three "conventional" beam proposals:
  - An upgrade of T2K based on reaching 1.6 MW beam power and a new far detector.
  - LBNE – a plan to build a new neutrino beam at Fermilab aimed at Homestake, where either a large water Cerenkov detector or a LAr tracking calorimeter would be built.
  - LAGUNA-LBNO – three different options for new long baseline in Europe.

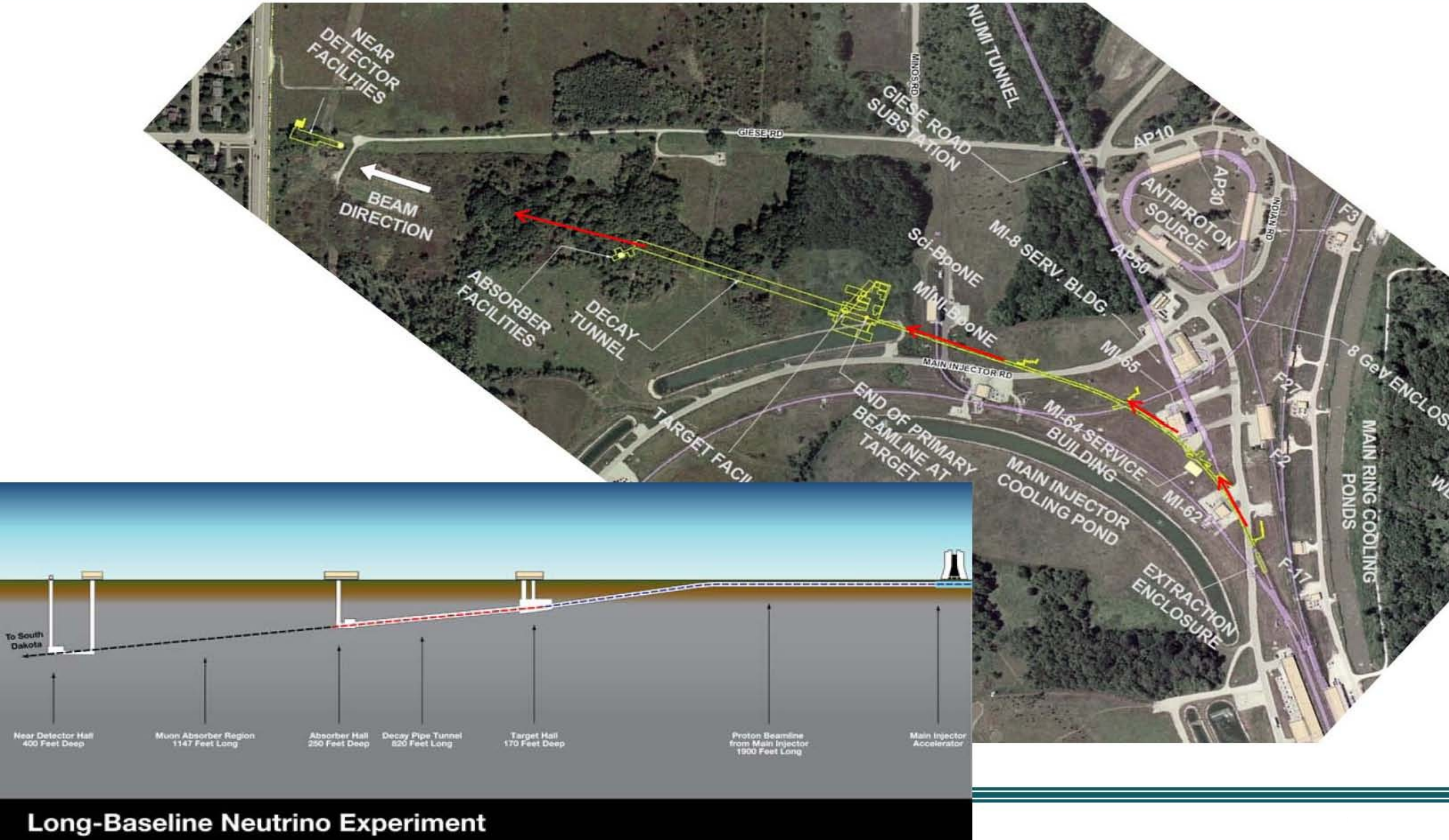
Dave Wark
Imperial College/RAL

US: Long Baseline Neutrino Experiment
CD 0: January 2010

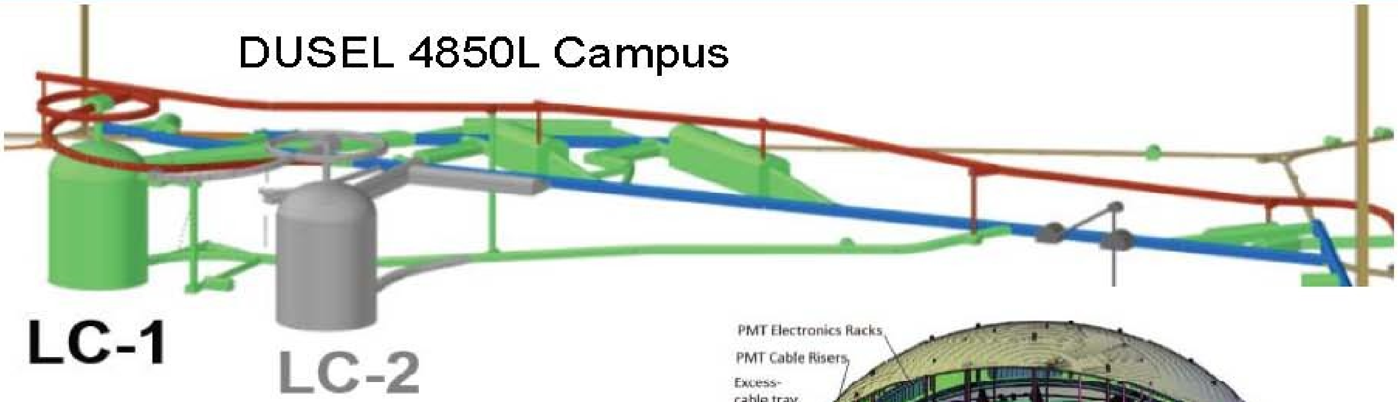


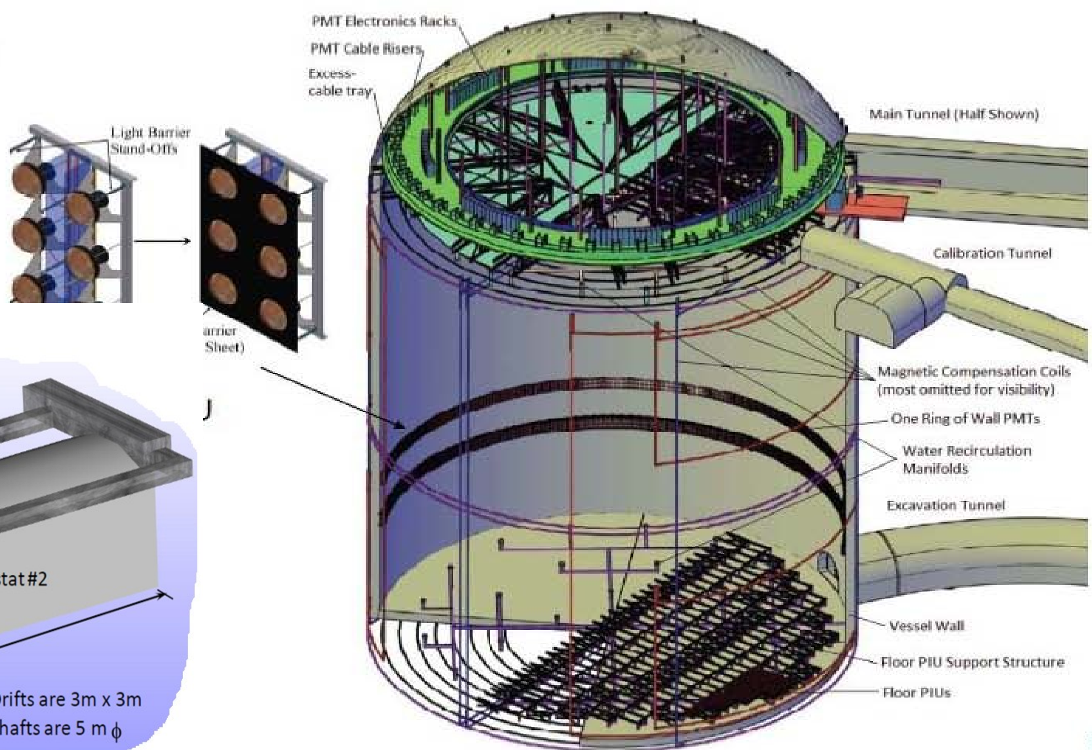
Collaboration:
288 members from 54 institutions (India, Italy, Japan, UK, US)
Continue to grow!

Conceptual Design Overview – Neutrino Beam

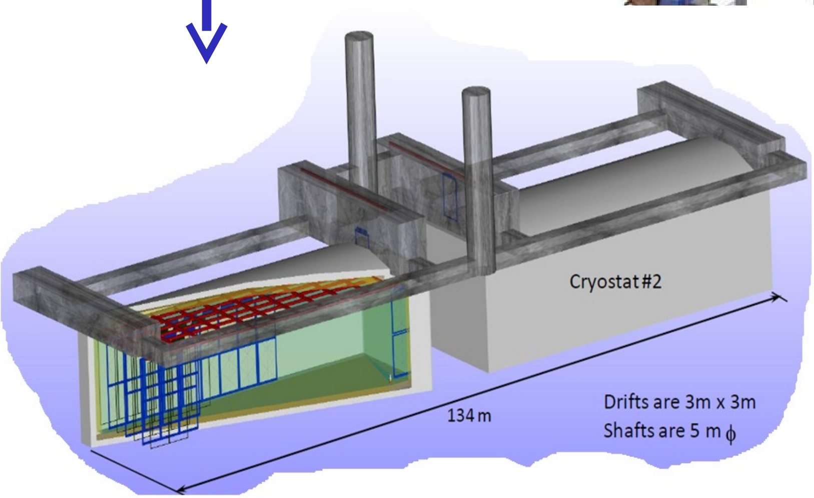


Conceptual Design Overview – Water Cherenkov

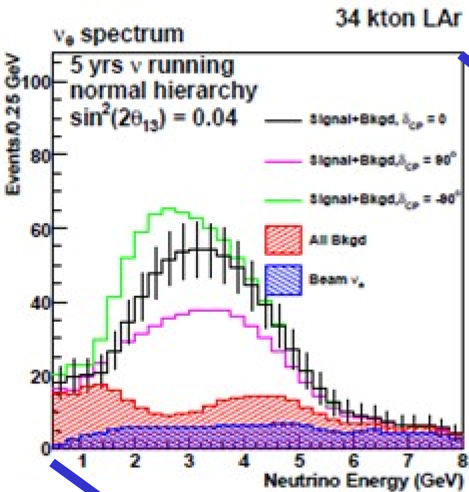


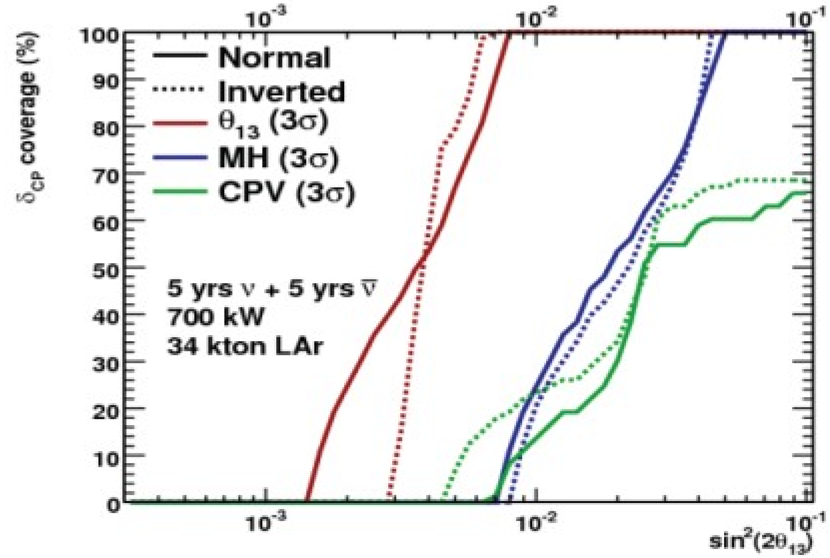


Alternative is 34 kT of LAr

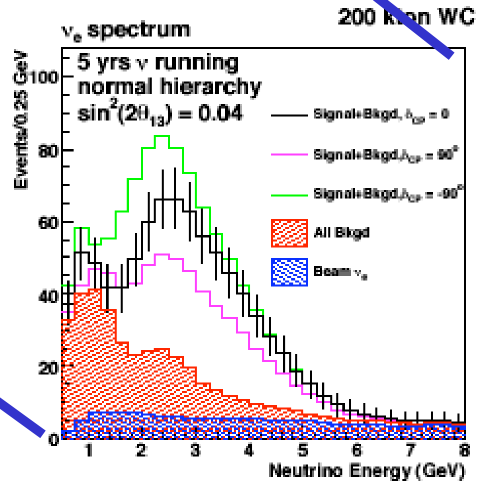


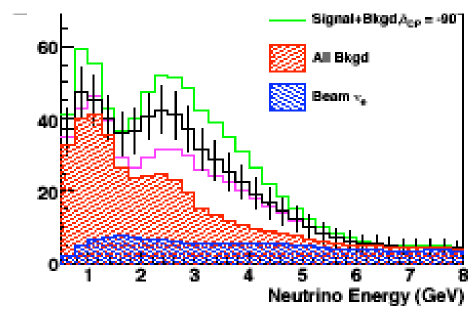
LAr Slight cheaper but riskier – Marx Committee





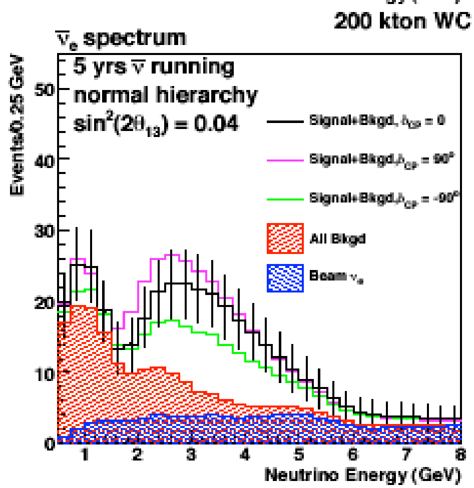
normal

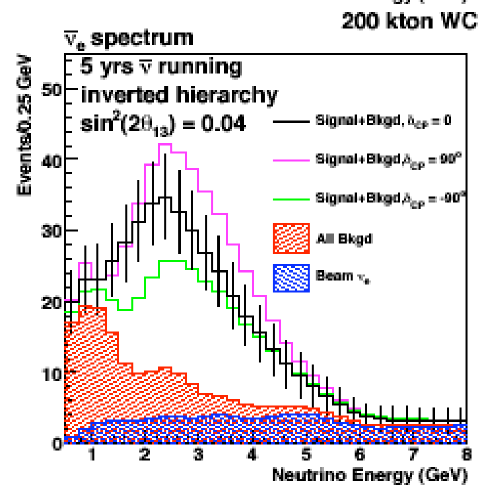




nu

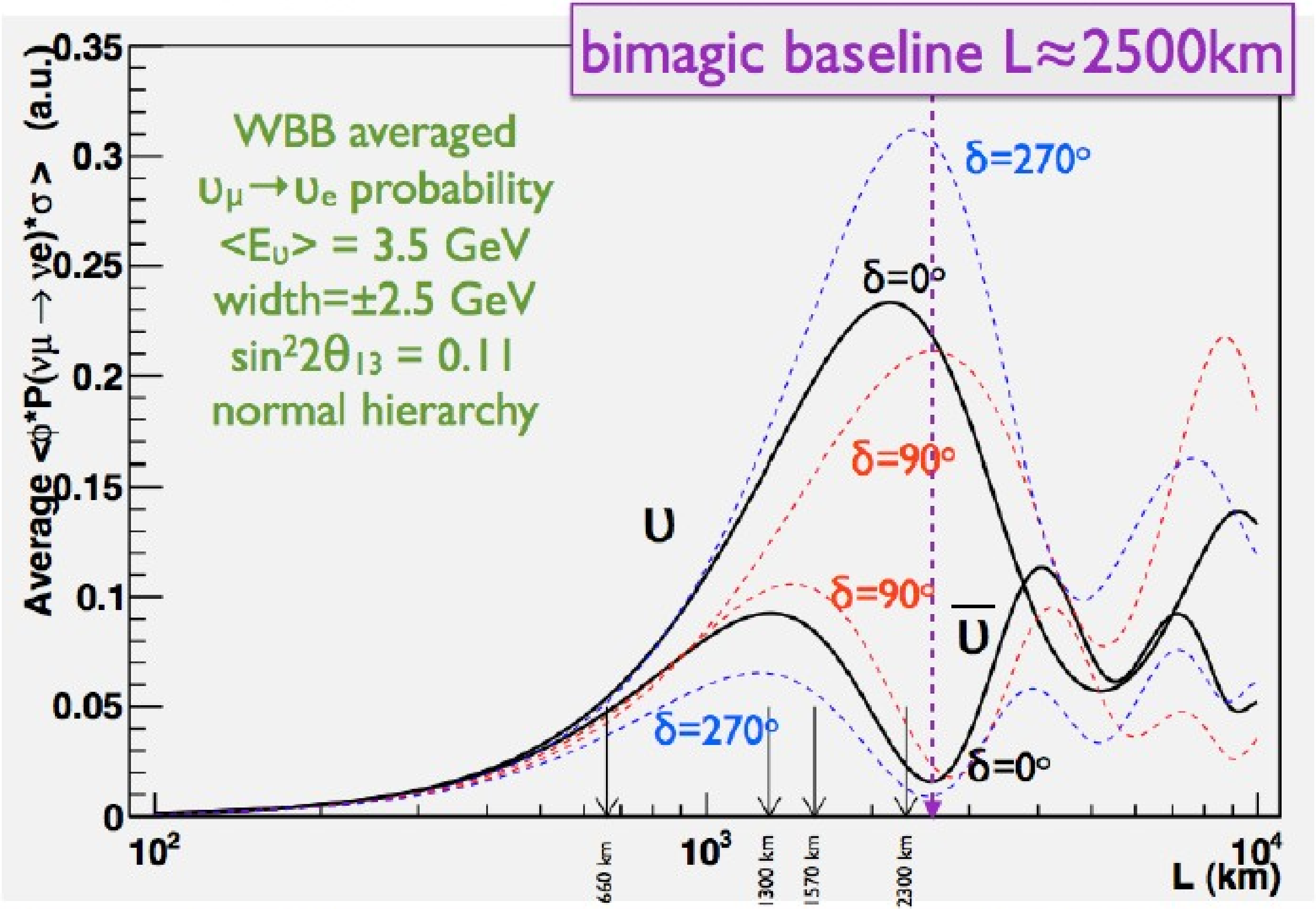
anti-nu





Lisa Whitehead

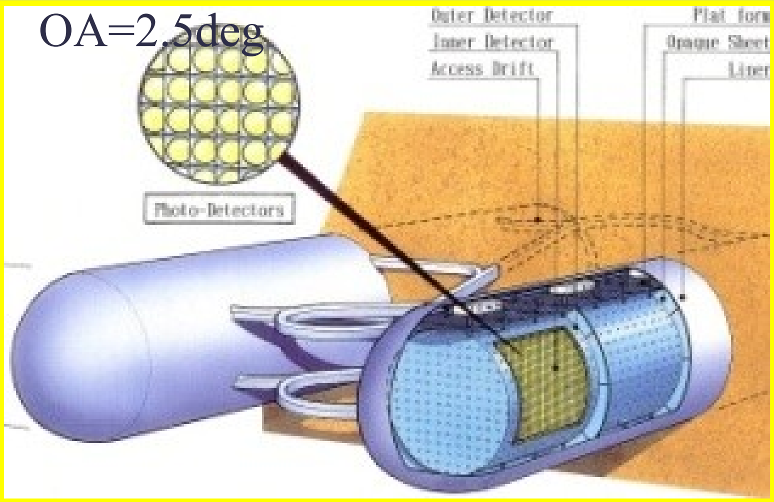
Baseline consideration



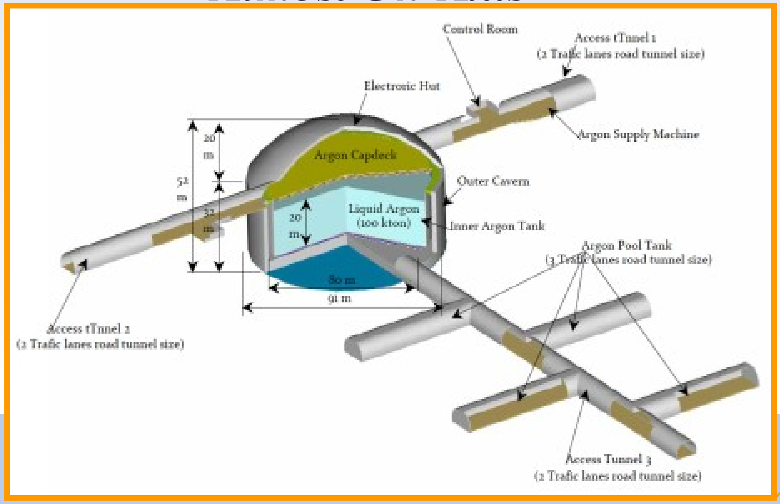
The optimal baselines are in the range 1300-2500 km

Scenarios in Japan

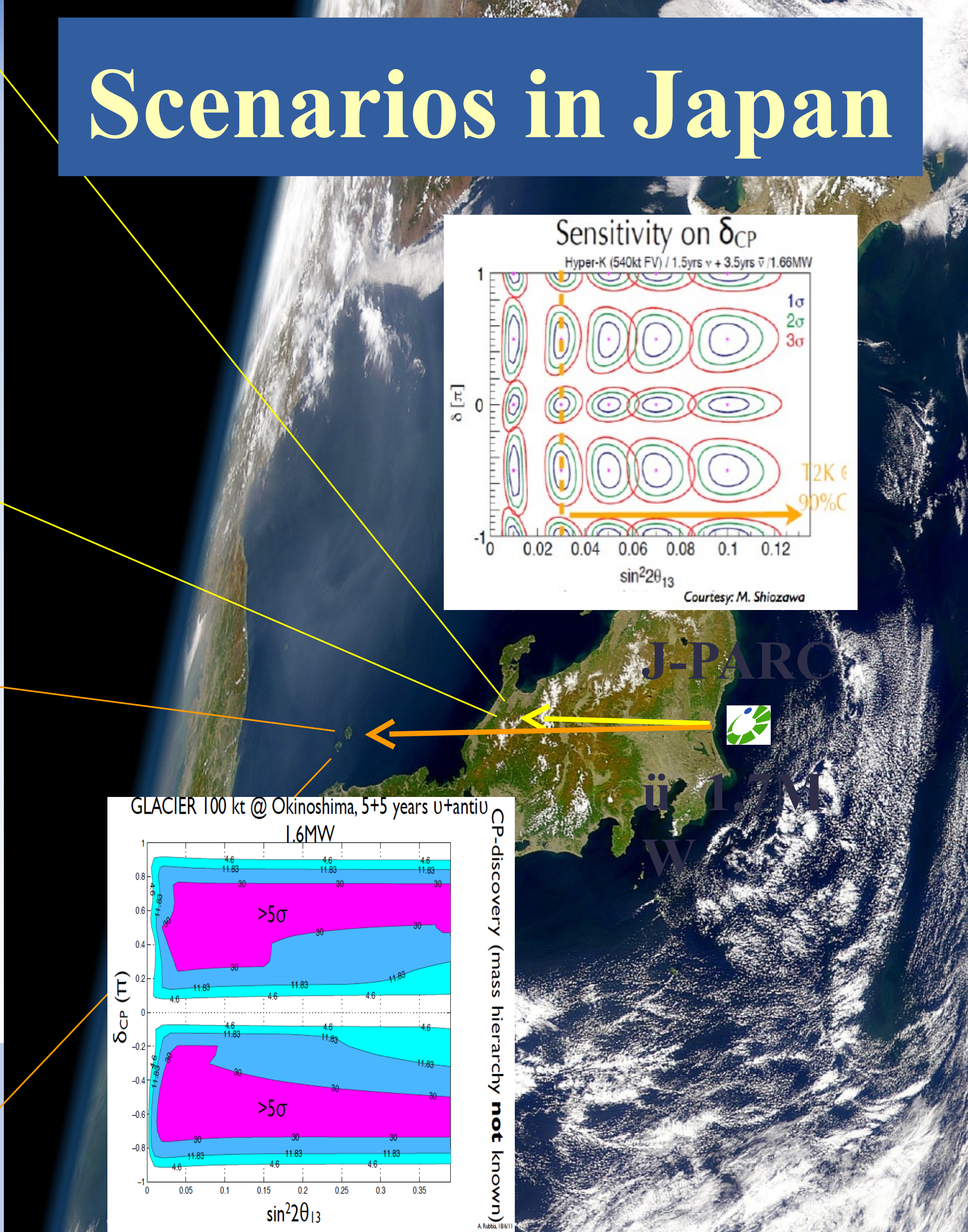
Kamioka L=295km
OA=2.5deg



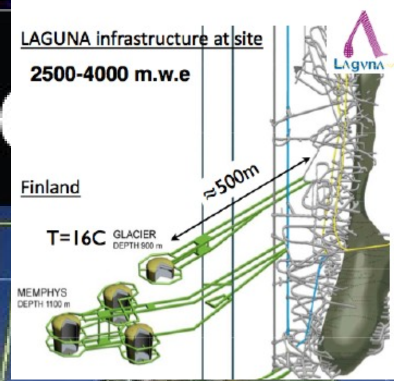
Okinoshima L=658km OA=0.78deg
Almost On-Axis



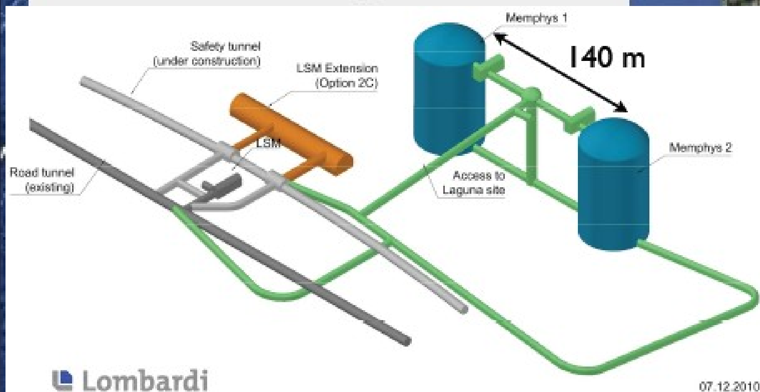
P32 proposal (Lar TPC R&D)
Recommended by J-PARC PAC
(Jan 2010), arXiv:0804.2111



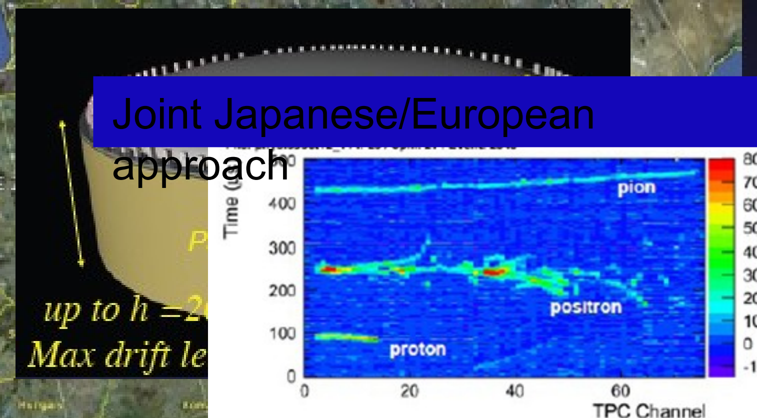
Thre options



3 main options selected for LAGUNA-LBNO



CN2PY
L=2288 km, CERN SPS 400 GeV
+ new beam line 0.75 MW
+ near detector infrastructure
Longer term: 2MW with
LP-SPL+HPPS accelerator



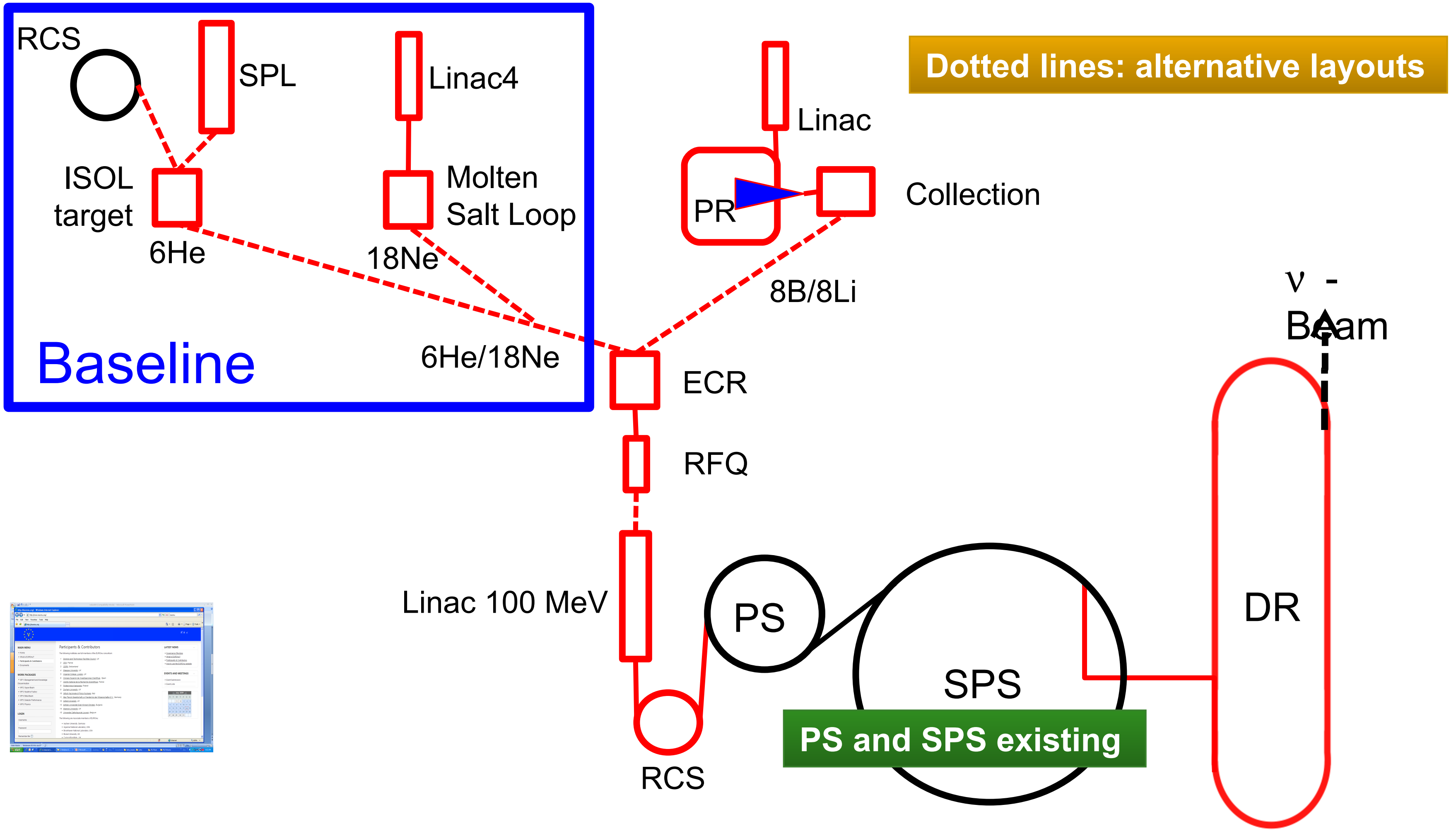
Joint Japanese/European approach

CN2FR
L=130 km,
HP-SPL 5 GeV 4 MW LINAC +
accumulator ring
+ MMW target + horn
+ near detector infrastructure

CNGS-Umbria
L=658 km, 1deg OA
CERN SPS 400 GeV
presently operating 0.3 MW
(0.5 MW max)
no near detector infrastructure

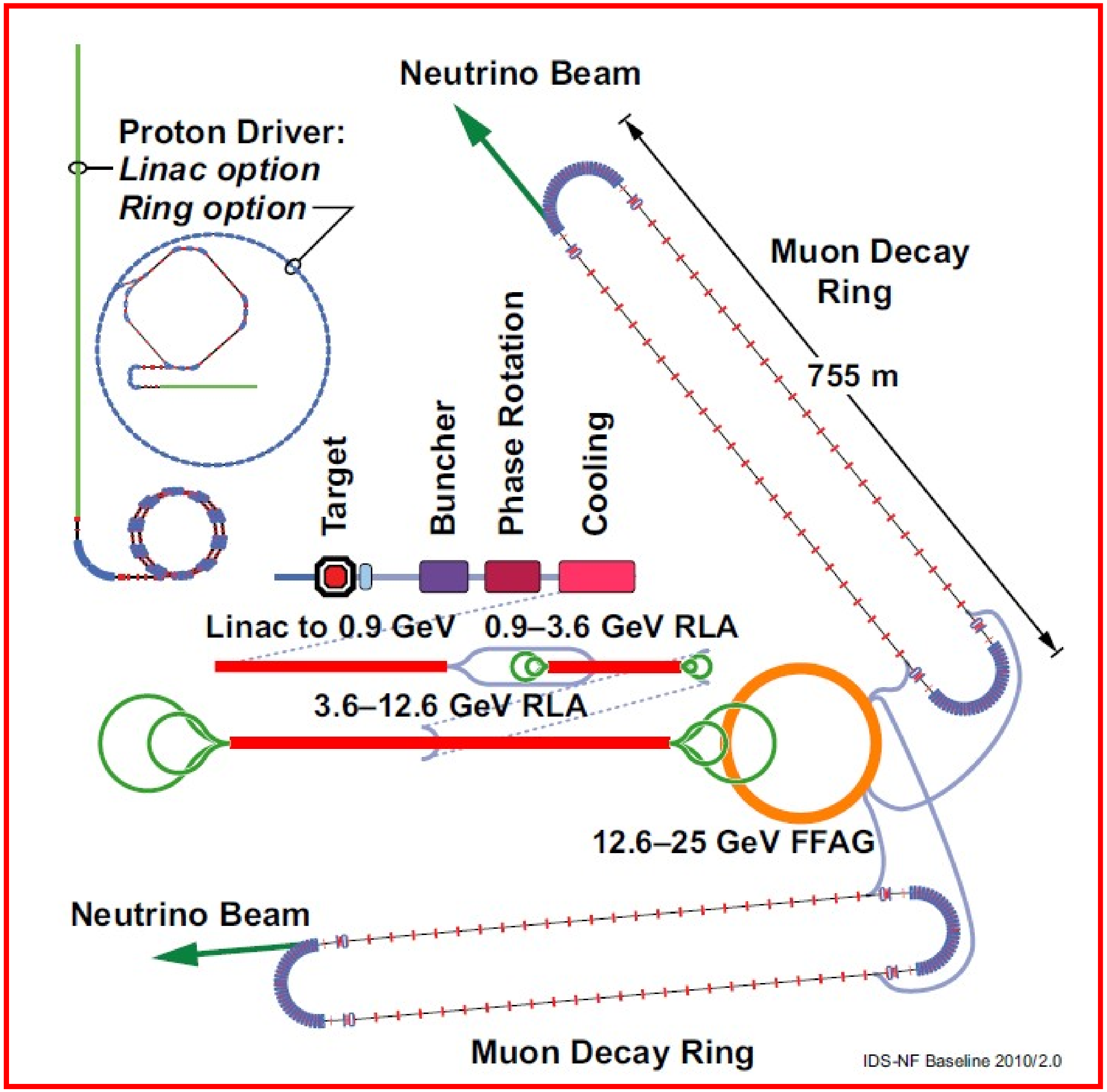
Possible synergy with a β beam

CERN Beta Beams, Synoptic

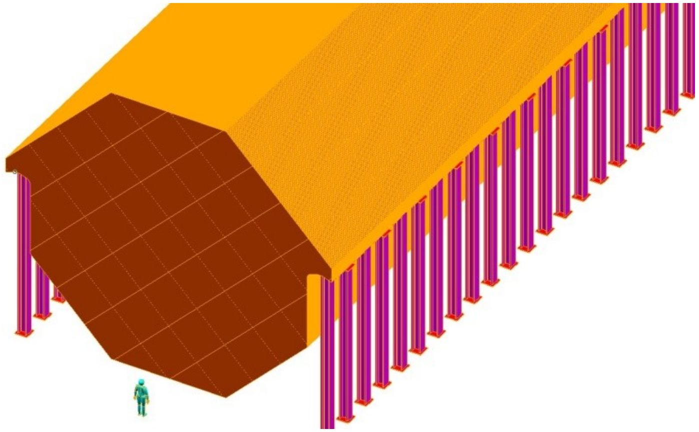


Decay Ring: Bρ ~ 500 Tm, B = ~6 T, C = ~6900 m, Lss= ~2500 m, γ = 100, all ions

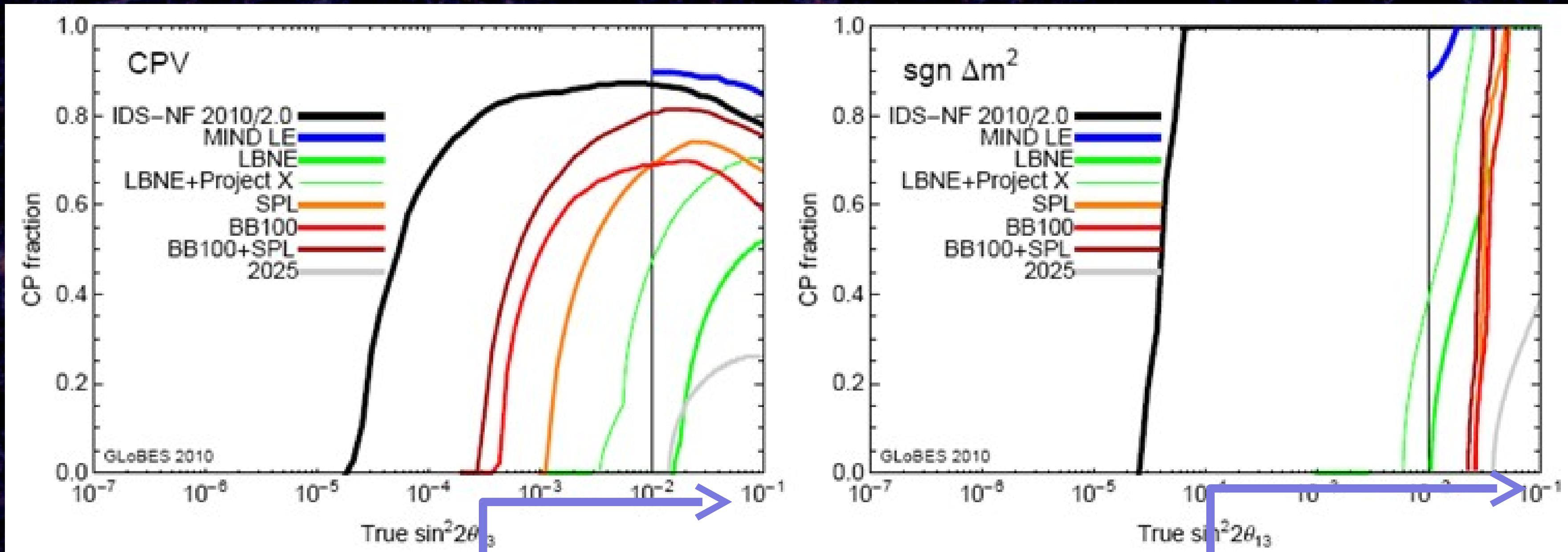
Neutrino Factory Baseline



- Two Magnetised Iron Neutrino Detectors (MIND):
  - 100 kton at 2500-5000 km
  - 50 kton at 7000-8000 km

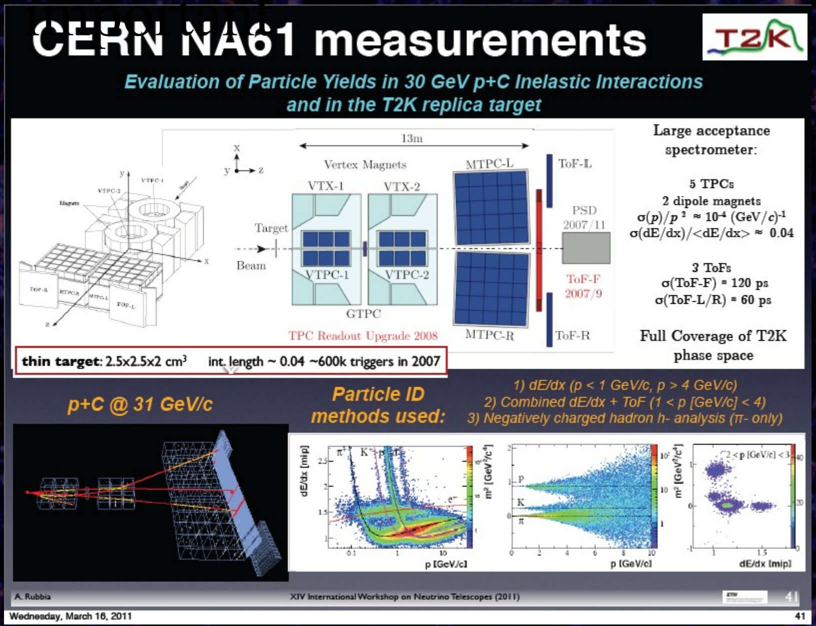


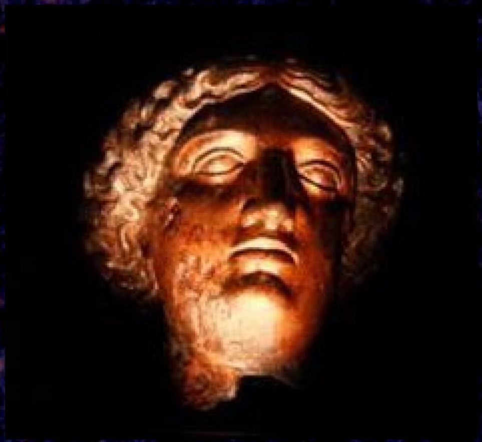
Baseline constantly under review in light of new physics results

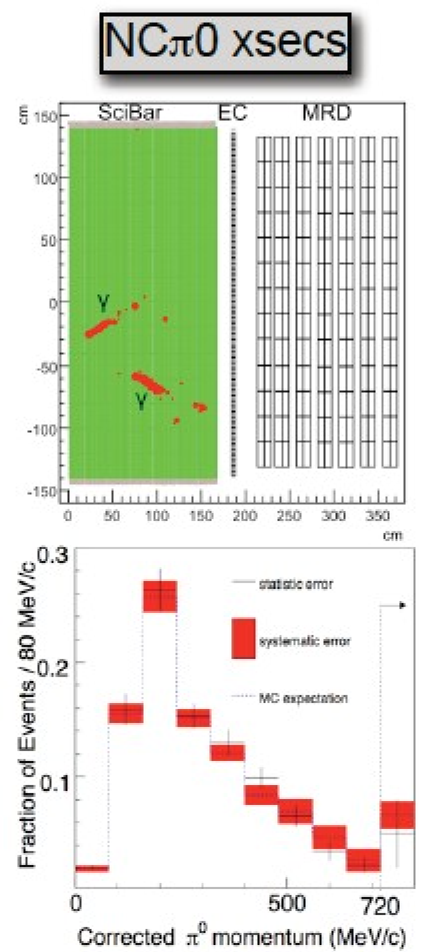

CPV
IDS−NF 2010/2.0
MIND LE
LBNE
LBNE+Project X
SPL
BB100
BB100+SPL
2025
GLoBES 2010
CP fraction
True sin²2θ13
sgn Δm²
1.0
0.8
0.6
0.4
0.2
0.0
10⁻⁷
10⁻⁶
10⁻⁵
10⁻⁴
10⁻³
10⁻²
10⁻¹

In the systematics dominated era support measurements are even more important!

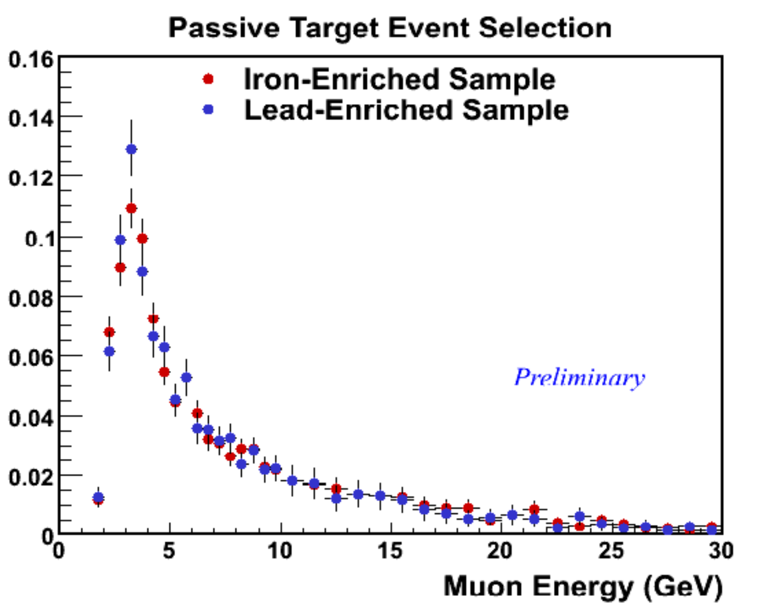
http://www-sciboone.fnal.gov/

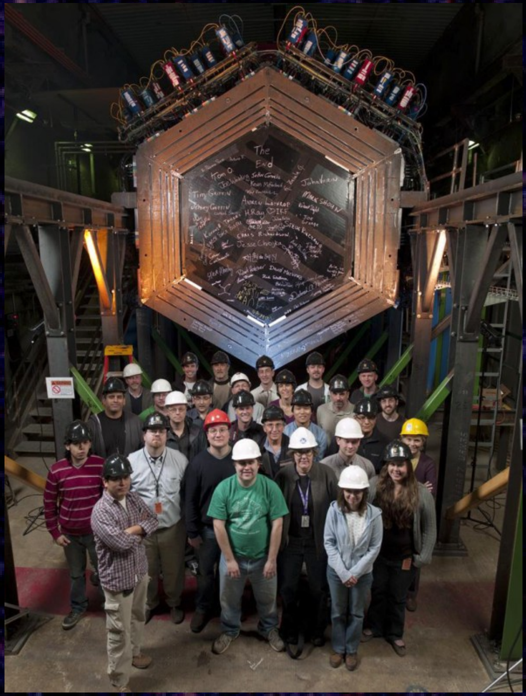






Phys. Rev. D 81, 033004 (2009)
Phys. Rev. D 81, 111102(R) (2009)





Dave Wark
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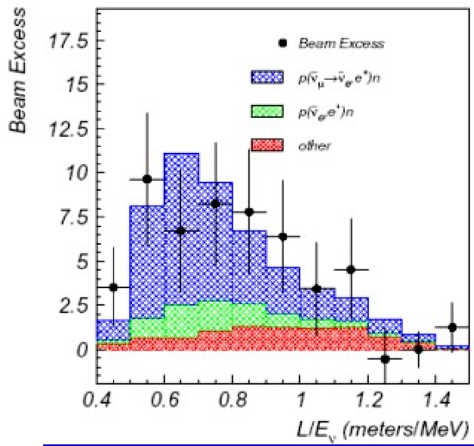
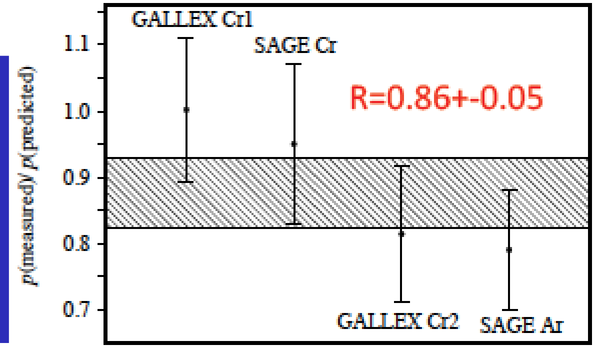
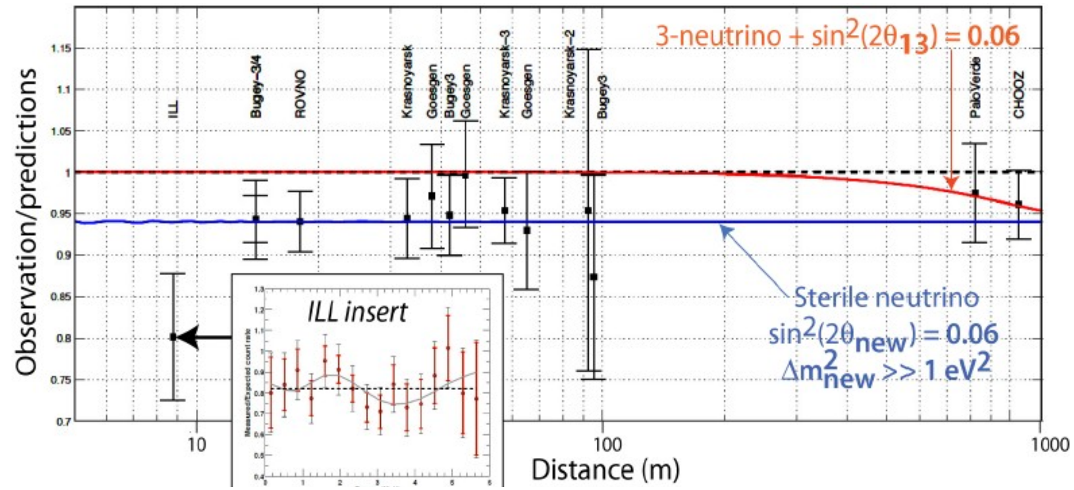
LSND Starts it all...



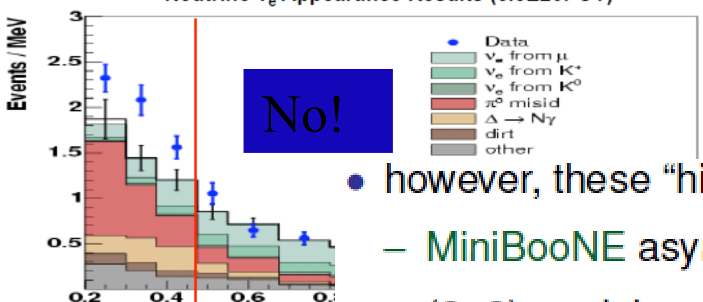
Short baselines (L/E ~ 1) and sterile ν .





MiniBooNE says....

Neutrino ν_e Appearance Results (6.5E20POT)

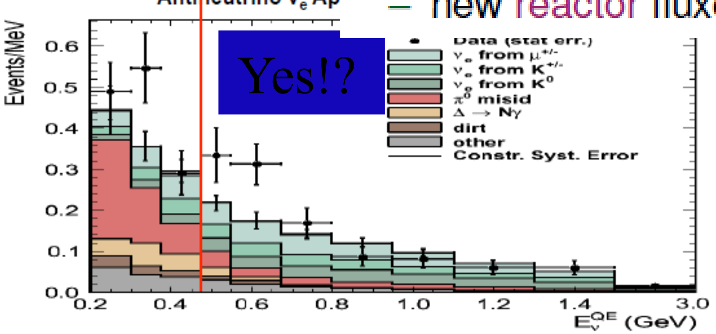


No!

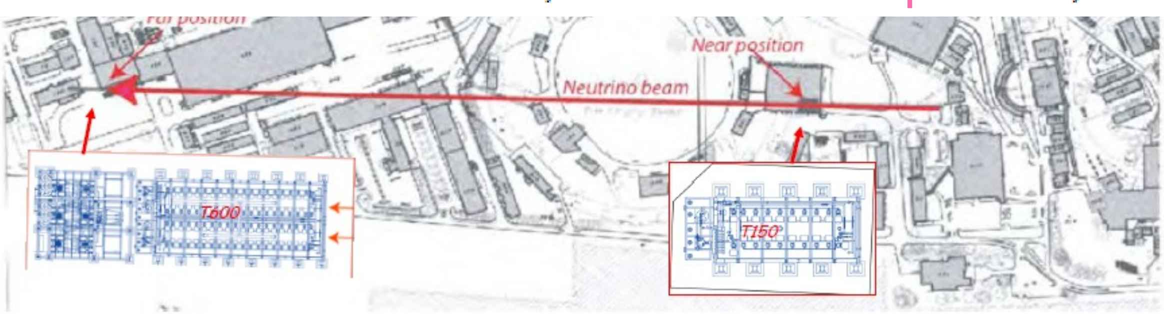
- however, these "hints" for sterile neutrinos are **not** in agreement among them:
  - MiniBooNE asymmetry in $\nu/\bar{\nu}$ requires CP violation, hence at least **two sterile** ν**'s**;
  - (3+2) models reconcile APP data, but DIS ones still show tension;
  - new reactor fluxes reduce tension with DIS data, but **not** for MB low-E excess;

Malton

Antineutrino $\bar{\nu}_e$ Ap



Yes!?



Conclusions (I)

- Neutrino oscillations are the first confirmed physics beyond the SM, and their continued study is essential to extend our knowledge of fundamental interactions.
- Current indications are that $\sin^2 2\theta_{13} \geq \sim 0.01$, which would make further long baseline experiments the most attractive option for first searches for CP violation in the neutrino sector.
- Do not assume we know everything that is going on – redundancy is essential!
- Continued operation of "existing" experiments (T2K, MINOS, NOvA, Double Chooz) is the highest priority.
- There are three proposed next-generation projects. We can probably justify two, but not three, so we need to some international coordination.
- The mine at Pyhäsalmi is potentially an extremely valuable resource for European neutrino physics due to its distance from CERN, but we should move fast if we are going to retain the option of using it in the future. Can we build a 5 kT LAr prototype?

Conclusions (II)

There will be many other opportunities for smaller-scale involvement in cross-section, hadron production, and other critical technological development projects such as the MICE experiment.

Oscillations depend on L/E, not E or L, so other possibilities should be considered – DAEdALUS?

Beyond those facilities we will almost certainly wish to have an even more capable facility, either a Beta Beam or a Neutrino Factory – more work is needed to optimize the sensitivity if θ_{13} is large.

A PS neutrino beam project to look for sterile neutrinos has been suggested for CERN. Here are my very personal views:

- We don't need another 2-3 sigma effect. Any proposed experiment should have clear 5 sigma sensitivity over the entire indicated range.
- It could be an interesting part of a broad suite of European neutrino experiments, but I wouldn't want to see it be CERN's only neutrino experiment.

Neutrino oscillations offers a very wide range of experiments, which must happen, no matter what we do at the energy frontier!

Dave Wark
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