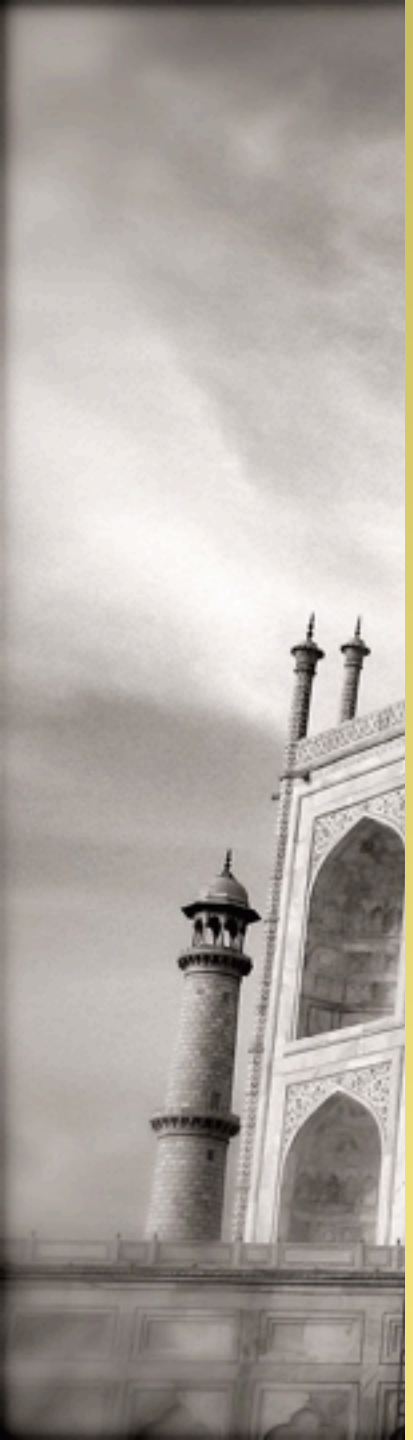


Detector R&D for future neutrino oscillation facilities

Anselmo Cervera Villanueva
IFIC (UV-CSIC), Valencia

- Introduction
- Future Neutrino Oscillation facilities
- Detectors
- R&D program
- Conclusions

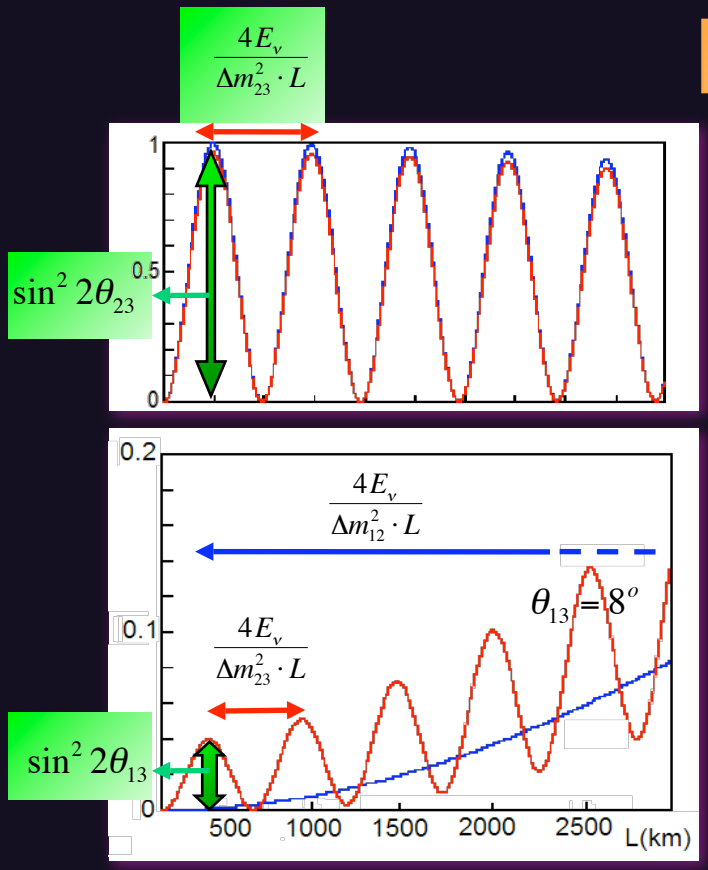
RETENU, UB, Barcelona, 19/10/2007

Three-family mixing

atmospheric **solar** **interference**

$$P(\text{no } \nu_e) \simeq cos^2 2\theta_{13} \cdot P_{atm}(\theta_{23}, \Delta m^2_{23})$$

$$P(\nu_e) \simeq sin^2 2\theta_{13} \cdot P_{atm}(\theta_{23}, \Delta m^2_{23}) + P_{sol}(\theta_{12}, \Delta m^2_{12}) \pm sin 2\theta_{13} \cdot P_{atm} \cdot P_{solar} \cdot P(\delta_{cp})$$



oscillations without ν_e

$\nu_\mu \rightarrow \nu_\tau$ | current → Conventional beams, Super-beams

$\nu_\mu \rightarrow \nu_x$ | future → Neutrino factories

θ_{23}=45^0 ?
θ_{23} octant

$\nu_\tau \rightarrow \nu_\mu$ science fiction

oscillations with ν_e

$\nu_\mu \rightarrow \nu_e$ | current → Conventional beams, Super-beams

future → Neutrino factories

$\nu_e \rightarrow \nu_\mu$ | future → Beta-beams, Neutrino factories

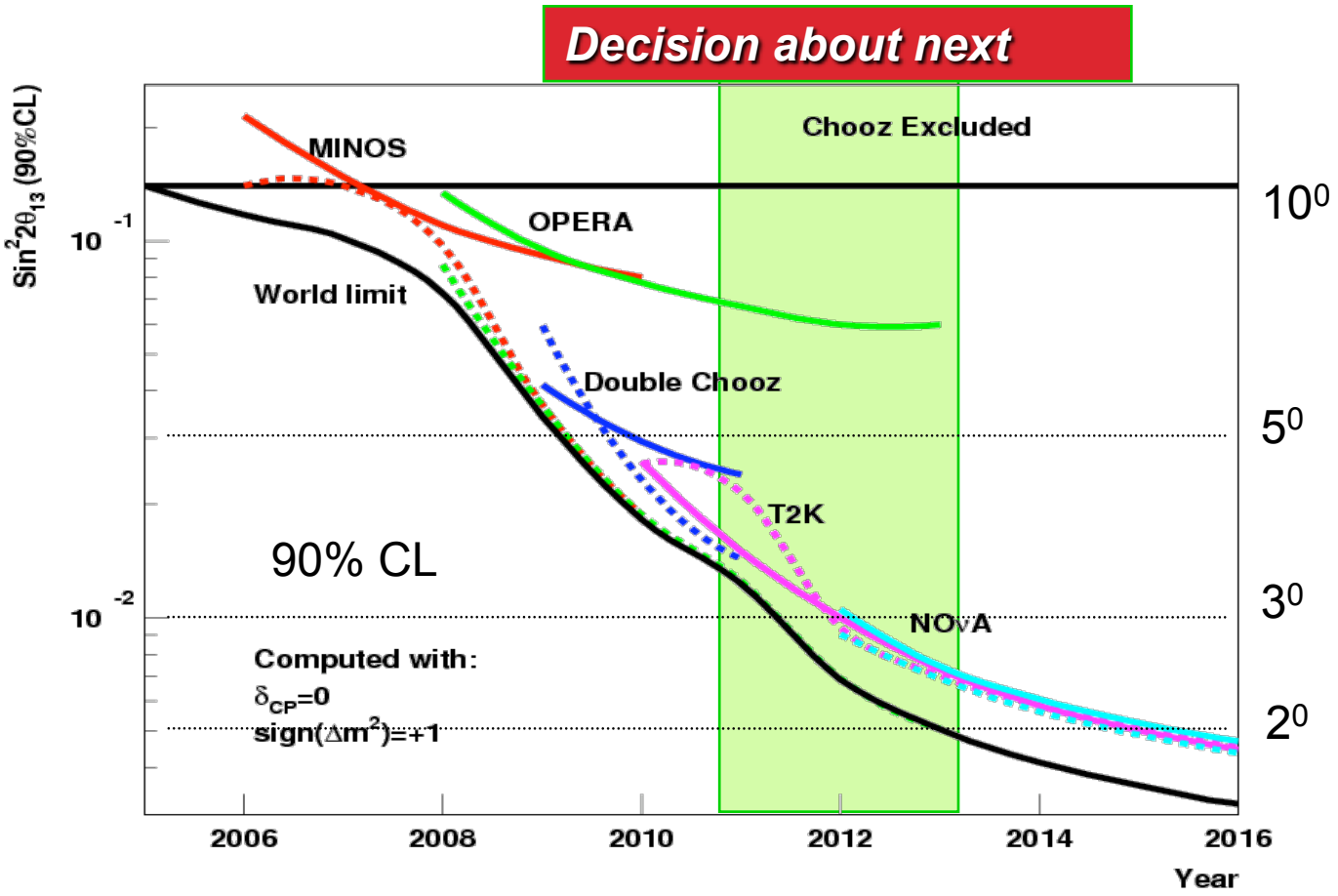
$\nu_e \rightarrow \nu_\tau$ |

θ_{13}
δ_{cp}
sign(Δm^2_{23})

$\nu_e \rightarrow \nu_x$ reactors

$\nu_\tau \rightarrow \nu_e$ science fiction

The θ_{13} quest



- If θ_{13} is not measured by 2011, the probability to measure it with ongoing experiments would be very small
- Building new facilities will take more than 5 years

The roadmap (... surprises ...?)

1st step: transition era

Ongoing: 2005-2010

- Improve the precision on the atmospheric parameters looking at ν_μ disappearance
- Confirm (atm. osc)=($\nu_\mu \rightarrow \nu_\tau$) and first look at $\nu_\mu \rightarrow \nu_e$

Conventional beams
- MINOS
- OPERA

---

2 nd step: θ_{13} era

Under construction: 2008-2015

- Demonstrate visibility of sub-leading transitions: $\nu_\mu \rightarrow \nu_e$, $\nu_e \rightarrow \nu_e$
- Explore θ_{13} down to 2^0 (today $<10^0$)

Reactors
- D-Chooz
- DayaBay
- ...

Super-beams
- T2K
- NOvA

---

3 rd step: precision era

To be prepared: 2015-2030

$\theta_{13} > 3^0$ — Known by 2011 — $\theta_{13} < 3^0$

- Existing facilities could reach it
- … but with very small sensitivity to δ_{CP} and mass hierarchy

- No access for ongoing experiments at that time

Super-beams II
Beta-beams
Neutrino Factory

Cleaner and more intense beams + bigger detectors

Current limitations

- Low energy beams:
  - Low neutrino cross section
  - Uncertainties in neutrino cross sections
  - Influence of Fermi motion
    - poor energy resolution
- Beam from pion/kaon decay. In a ν_μ beam:
  - Intrinsic ν_e contamination
    - Depends on pion/kaon ratio: not very well known
  - Intrinsic $\overline{\nu}_\mu$ contamination
    - Depends on pi+/pi- ratio
  - The ν_μ energy spectrum is not well know either
    - Depends on differential pion production x-section

What should we improve ?

- The sensitivity to the oscillation parameters depends on
  - The signal to noise ratio (S/N)

$$\frac{S}{N} = \frac{N_{sig}}{\sqrt{N_{sig} + N_{bkg} + systematics}}$$

  - and the neutrino energy resolution:
    - Helps in measuring the oscillation pattern

beam	power	More neutrinos	S↑ N↑
	purity	Less undesired neutrinos	N↓
	energy	• Higher x-section • Lower uncertainty in x-sections • Lower uncertainty in detector efficiency • No Fermi motion: better energy resolution	S↑ N↑ N↓ N↓ δE/E↓
detector	mass	More interacting neutrinos	S↑ N↑
	granularity + resolution	• Better energy resolution • Better detection efficiency • Better background rejection	δE/E↓ S↑ N↓

Future facilities

- Super beams II: Off-axis ν_μ beam from pion/kaon decay
  - Increase mass and power by an order of magnitude
    - Systematic errors unchanged (ν_e contamination, x-sections, ...)
    - Not elegant, but effective
- Beta beam: beta decay of stored radioactive ions
  - pure ν_e beam: no intrinsic beam background
    - Very well know flux
  - Statistics unchanged for baseline option: similar flux and detectors

$$^6_2He \rightarrow ^6_3 Li^{+++} \; \overline{\nu}_e \; e^-$$

- Neutrino factory: Neutrinos from muon decay in a storage ring
  - Two neutrino flavours: ν_e and ν_μ
    - Reacher physics program: more oscillation channels
  - Higher energy and flux
  - Very well known flux

$$\mu^+ \rightarrow e^+ \; \overline{\nu}_\mu \; \nu_e$$

Strategy for Detectors

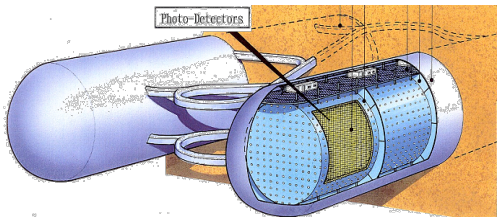
- Aim is to write a CDR by 2012
- Strategy is simpler for super-beams and beta-beams:
  - Less flavours, less detector options: basically water cerenkov
  - Synergies with supernova neutrinos and proton decay
- For Nufact a complete strategy is not yet designed but we are not far. Guidelines:
  - Best possible measurement of all osc. parameters
  - But, don't forget other physics
    - Using the neutrino beam
    - Using other particle sources and the Nufact detectors

Water Cerenkov

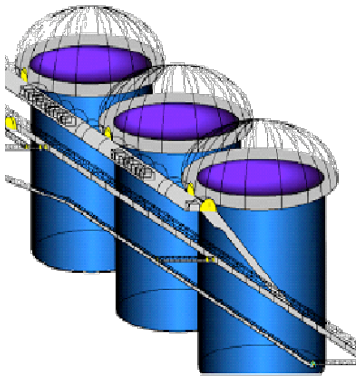
- Baseline detector for Super-beams and low-E beta-beams

- This is a mature technology, however new issues related to the size of the projects have appeared:
  - Engineering and cost of excavation at different sites
  - Engineering studies of mechanics
  - R&D on water container (vessels versus multi-liners).
  - R&D on photo-detectors: large area HPDs or standard PMTs

Hyper-Kamikande (Japan)

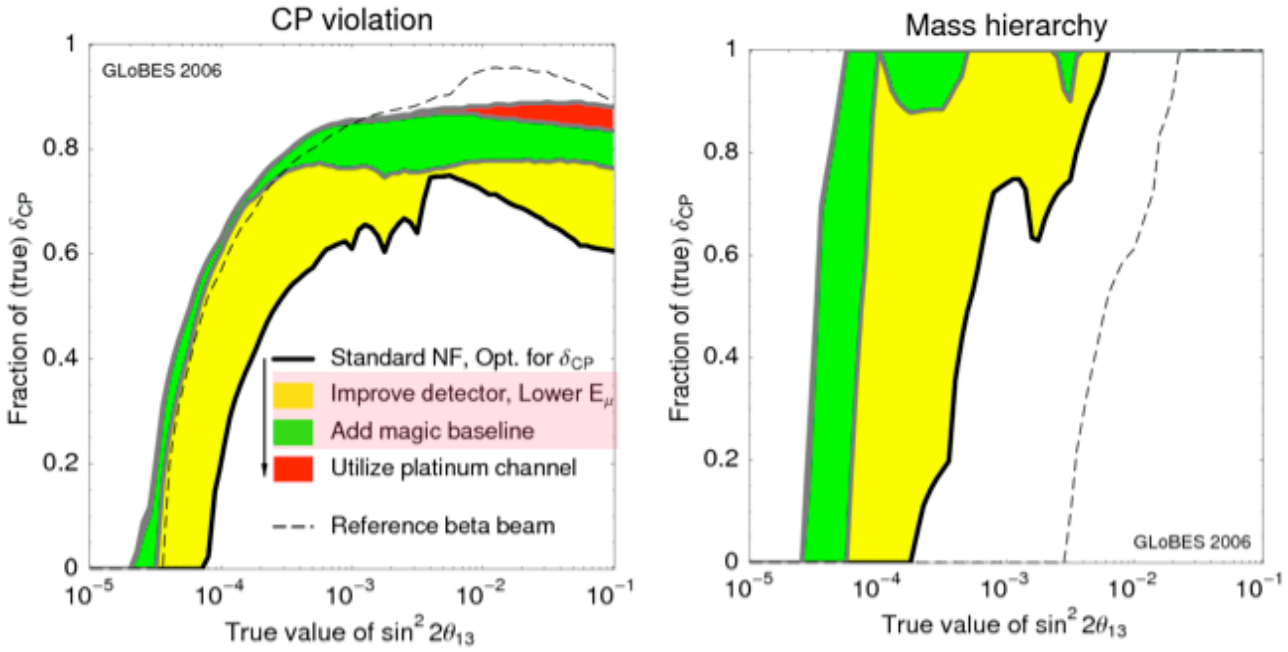


Memphys (Frejus)



Nufact Comparisons

- Default option: A single MINOS-like detector at ~4000 km with energy threshold at 10 GeV (obsolete)
  - reduce threshold to 3 GeV. Demonstrated !!!
  - A second detector at ~7500 km
  - Introduce platinum channel $\nu_\mu \rightarrow \nu_e$



(from: Huber, Lindner, Rolinec, Winter, 2006)

- Baselines
- Channels
- # detectors
- Detector types
- beam energy
- off-axis angle

Requirements

1. Golden $\nu_e \rightarrow \nu_\mu$: High statistics and high purity ($<10^{-4}$ bkg)
   - This is the basic channel for all measurements
   - Good muon and muon charge identification
2. Energy threshold:Good efficiency and purity for low E
   - Useful to solve degeneracies, second osc. maximum
   - Low density and/or higher B field
3. Silver $\nu_e \rightarrow \nu_\tau$: Detector able to detect taus and their sign
   - Useful to solve degeneracies, atmospheric channel
   - Use nuclear emulsions
4. Platinum $\nu_\mu \rightarrow \nu_e$: Detect electrons and their sign
   - Degeneracies, T and CPT violation, ν_e disappearance
   - Low density and/or very good spatial resolution

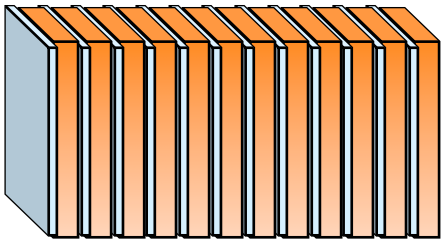
Nufact far detectors

MIND

25xMINOS

Magnetised Iron Neutrino detector

100 Kton

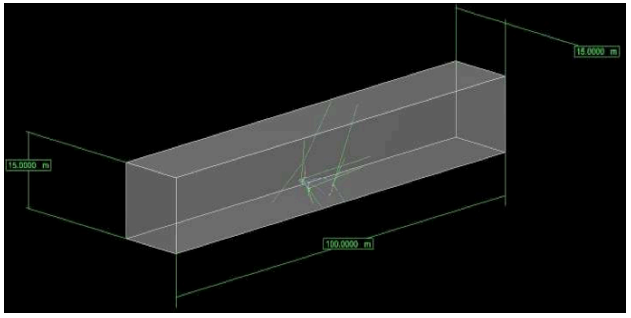


TASD

NOvA + B

Totally active Scintillating Detector

25 Kton



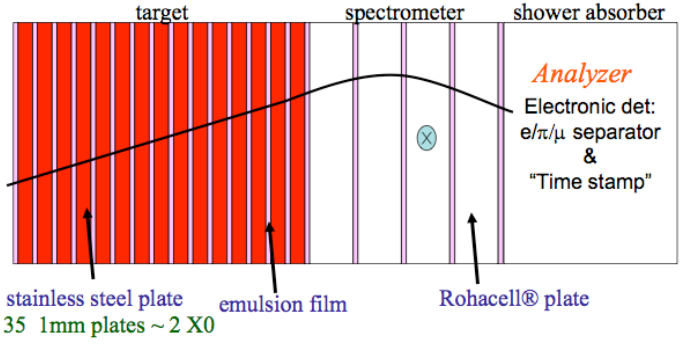
(M)ECC

(2-7)xOPERA (+ B)

(Magnetised) Emulsion Cloud Chamber

4-15 Kton

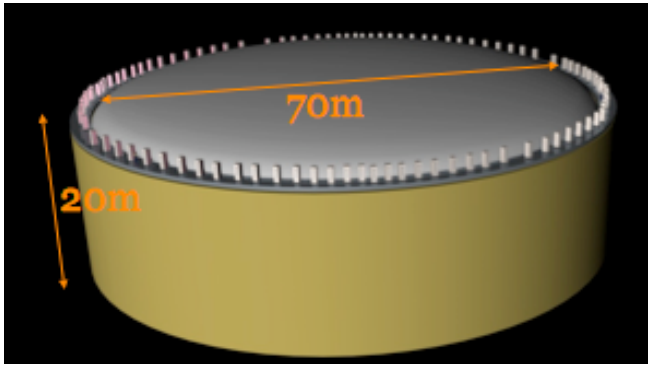
MECC cell



GLACIER

Giant Liquid Argon Charge Imaging ExpeRiment

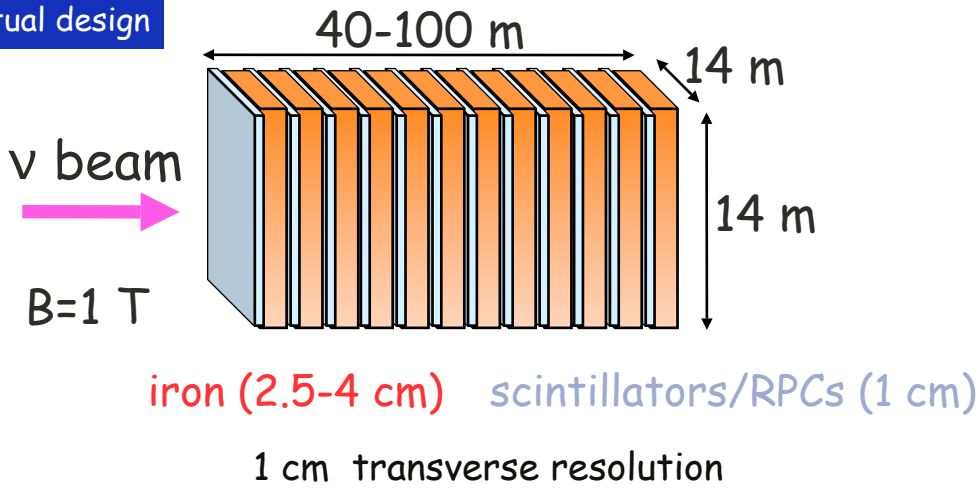
100 Kton



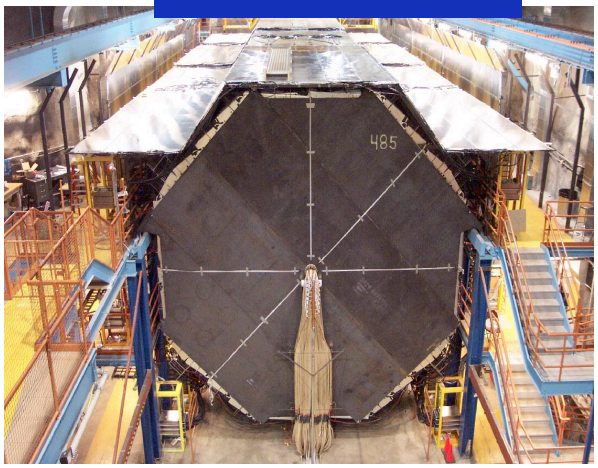
baseline detector: MIND

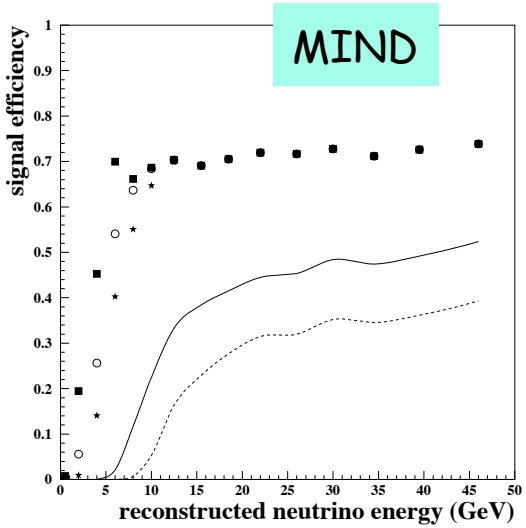
Mangetised **I**ron **N**eutrino **D**etector

conceptual design



10-20xMINOS

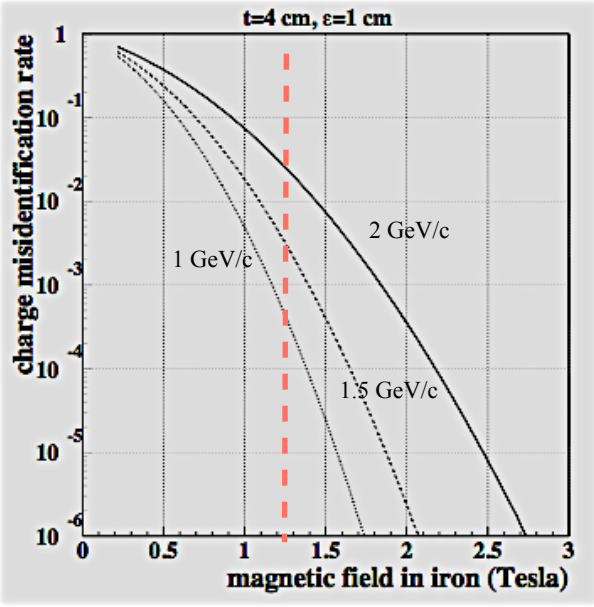




- Able to identify the muon and the muon charge down to ~5 GeV neutrino energy, with high purity (<10^{-3})
- Known technology
- "Cheap": ~300-400 M€ for 100 kton

MIND issues

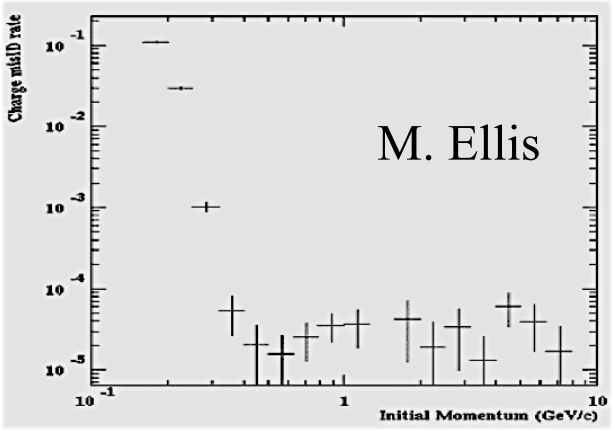
- Technology
  - Active layer: scintillators or RPCs (cheaper)
- Neutrino energy threshold should be reduced
  - Plateau at 2-5 GeV. Exact value is important !!!
  - Pattern recognition at low muon momentum “should be” the main issue
    - Muon and muon-charge mis-identification due to hit mismatching
  - Improvements
    - Optimise segmentation
    - Increase magnetic field: 1.25→1.8 Tesla not a problem
  - Intrinsic limitation due to iron should be around 2 GeV --> Sufficient

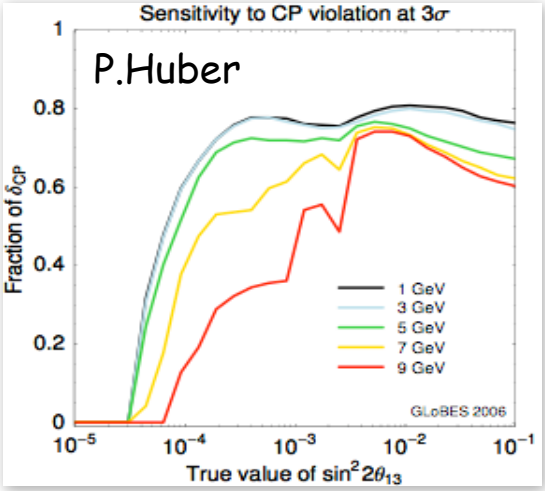


- This detector cannot measure electrons nor taus
- Is the golden channel sufficient ?

Lowering E_ν threshold

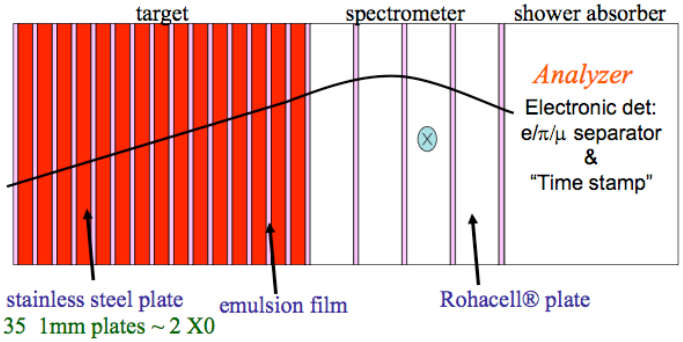
- MIND has poor performance below 5 GeV due to charge mis-id of low momentum muons
- A Totally Active Scintillating Detector (TASD), like NOvA, could make it
  - Large purity and efficiency above 0.4 GeV
- Main issue is hadron decay background
  - π→μ decay before showering. Can we control it kinematically ?
- R&D: This is however a challenging option:
  - Need of big air-core magnet
  - Very large cost due mainly to the number of electronic channels (5 x MIND)
  - R&D for cost reduction is mandatory
- This effort is not worth if it cannot detect electrons since sensitivity saturates at 3 GeV





Detecting taus

- Emulsion Cloud Chamber (as OPERA): tau decay vertex
- Performance: Main issue is statistics (0.01 x golden). Solutions:
  - More mass
    - Scanning load is not the limiting factor
    - The problem is the cost. Possible solution is hybridisation.
  - Magnetising the emulsion part:
    - Improves the visible BR (x 3): $\tau \to h$, $\tau \to e$
    - Allows platinum: e-charge misid < 0.5 %



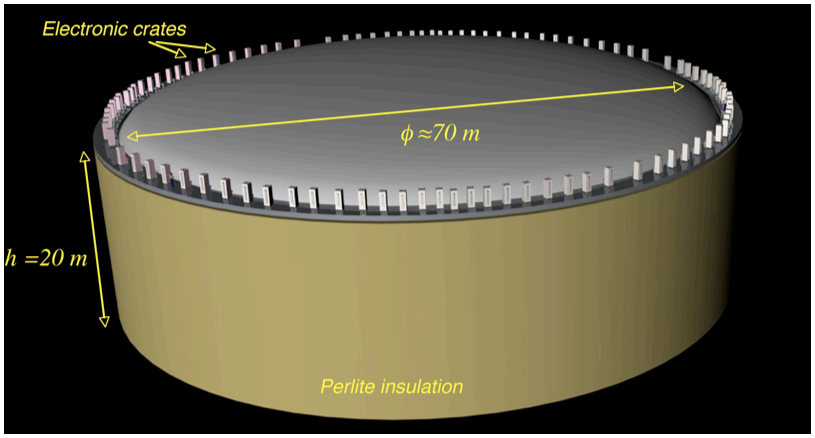
- Technology
  - Not an issue for non magnetic version. Basically scaled OPERA
  - No studies for magnet: probably similar to TASD

- Cost
  - This is the limiting factor (Lead/emulsion bricks is o.o.m. 10 M€/Kton)
  - Missing cost estimate for the magnet (in the case of MECC)

Detecting electrons

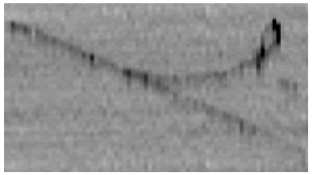
- The electron charge must be measured before it showers
- The baseline IRON detector cannot make it
- Three options:
  - Liquid Argon TPC: baseline option (GLACIER)
    - Very challenging concept
    - R&D program underway
  - TASD: To be demonstrated
  - MECC:
    - Few points with very good resolution (~ μm)

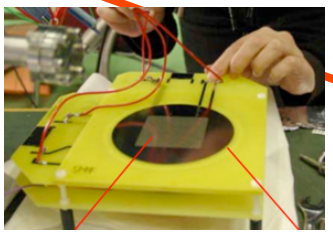
GLACIER conceptual design

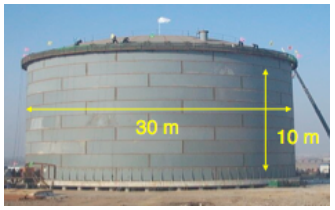


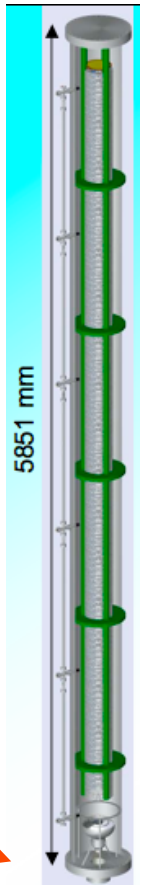
GLACIER issues

- Limiting factor is today's feasibility and probably cost
- Performance: Missing for Neutrino Factory
- Technology: Ongoing ambitious R&D program
  - Underground lab: Logistics, infrastructure, safety, shallowness ...
  - Large container, production, purification, safety
  - Long drift distances
  - Charge collection: LEMs
  - Magnet for Nufact
- Cost
  - Missing









Hybrid detectors

- The final Nufact detector will be most likely a hybrid
  - Maximises the ratio $\frac{\#\ \text{osc. channels}}{\text{cost}}$
  - All three channels at the same distance (3000-4500 Km)

- The baseline combination is

ECC

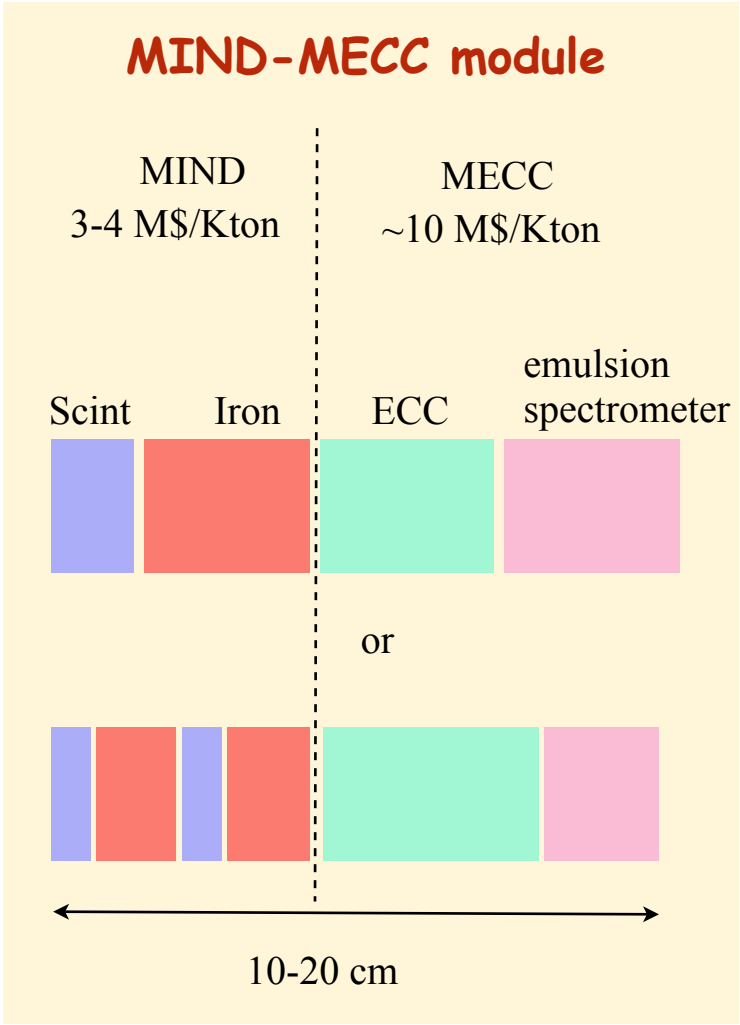
MIND

- Silver
  - ECC as an scaled version of OPERA (x2-7)
- Golden
  - MIND (100 Kt)

~2 o.o.m difference in statistics between ECC and MIND

Science: Scintillator Iron Emulsion Neutrino Charge Experiment

- Lets consider the same mass of ECC blocks and iron
  - Average cost is ~7M$/Kton --> 700 M$ for 100 Kton (o.o.m)
- 100 Kton for golden
  - MECC helps MIND in identifying the muon and measuring its charge
  - Lower threshold
- 50 Kton for silver
  - ECC modules for ν_τ target and tau selection
  - Emulsion spectrometer to increase visible BR
  - MIND as TT and time stamp
- 25-50 Kton for platinum
  - e-charge in emulsion spectrometer
  - e/NC pre-separation in MIND
  - final e/NC separation in ECC

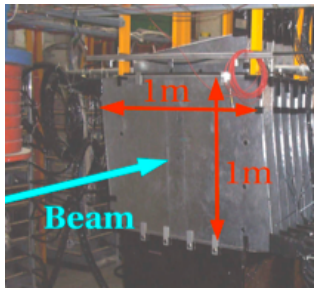


Summary of R&D items

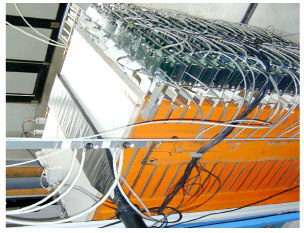
- Simulations
  - Full simulation of MIND: pattern recognition and charge ID
  - pion decay bkg and electron charge ID in TASD
  - Full performance study of GLACIER at Nufact
  - Test Science idea
- Performance evaluation with prototypes
  - Demonstrate charge mis-id rejection in MIND
  - Study energy threshold in MIND
  - Demonstrate electron charge ID in TASD
  - Performance of a hybrid Science prototype
- Hardware R&D
  - Cost reduction of photo-detectors and electronics
  - Large magnetic volumes: preferred option is STL
  - Continue with LAr R&D

Past prototypes

- MINOS CalDet
  - Response to hadrons
    - resolutions and showering profiles



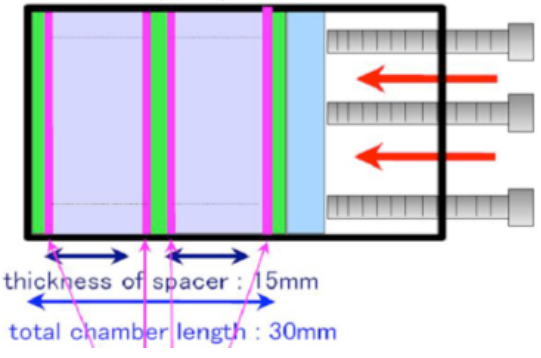
- Monolith prototype
  - Response to hadrons
  - RPCs performance



Iron (5cm)
+
RPC (2cm)

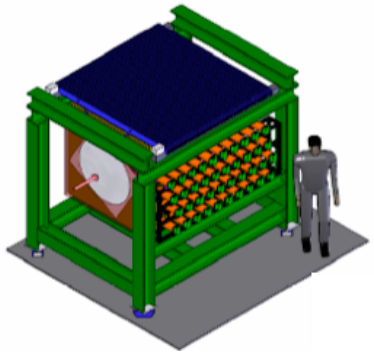
- MINOS (exposed to a neutrino beam)
  - patter recognition efficiency/purity (muon selection)
  - charge identification in neutrino interactions

- MECC prototype
  - 3 emulsion films and 2 spacers was exposed to a pion beam at KEK
  - 14% momentum resolution



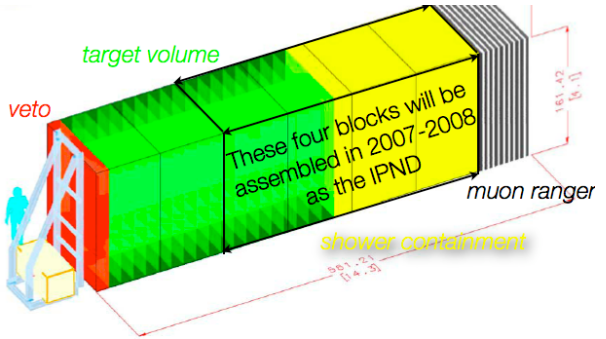
Forthcoming prototypes

- MINERvA prototype
  - 40 planes, 1x1 m^2, no B field
  - Removable Fe and Scint planes
  - MTEST, Fermilab, 2008



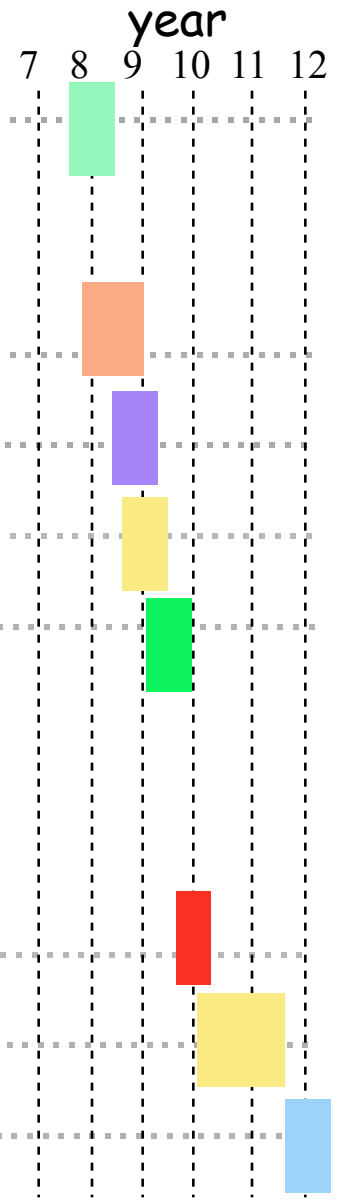
- INO prototype
  - 2.5x2.3x1.5 m^3
  - 1.5 T dipole field
  - VECC, Kolkata, 2008

- NOvA prototype
  - 3 prototypes in 2008
    - Full scale assembly prototype
    - Full height engineering prototype
    - Integration prototype near detector



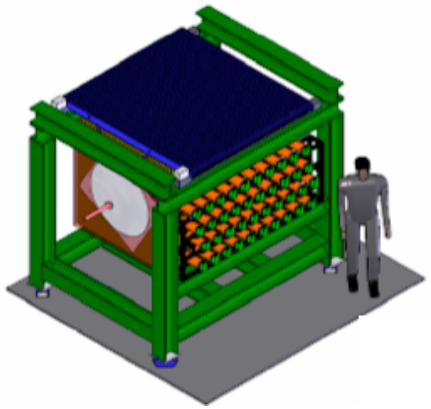
Strategy for detectors

1. Understand the performance of existing detectors
   - MINOS→MIND, OPERA→(M)ECC
   - MINERvA→TASD, T600+protos→GLACIER
2. Introduce this info into full simulations
3. Improve design (segmentation, B fields, hybrids, etc)
4. Identify issues
5. Use info from forthcoming prototypes:
   - MIND: INO and MINERvA prototypes
   - TASD: NOvA and MINERvA prototypes
   - (M)ECC: OPERA detector + (M)ECC prototype (?)
   - GLACIER: argontube (2008), EPiLAr (?), ...
6. Update simulations. Identify missing info
7. Build dedicated prototypes if necessary
8. Results + CDR



IFIC involvement

- Long tradition in simulation and phenomenological studies in close contact with UAM since 1999
- Organisers of Golden07 and Nufact08 workshops
- Strong involvement in ISS and IDS (International Scoping/ Design study)
- EUROnu and NEUDET FP7 proposals
  - Leading roles detector and physics working packages
- Close contact with MINERvA and INO groups for participating in the test beams next year



Golden workshops

- A Valencian Initiative
- The Golden07 workshop has been a major milestone for the understanding of the Nufact detectors and physics, and designing a well balanced strategy
  - Input from INO, NOvA, MINOS and MINERvA
  - Status of simulations and hardware R&D
  - Non standard physics at a Nufact and synergies with other fields
  - Detector prototyping
- It has been accepted as annual review for the IDS detector and physics

http://ific.uv.es/golden07

Golden 08
2nd International Workshop on Physics and Detectors at a Neutrino Factory

Golden 08	**Golden 09**
May 2008, Glasgow	early 2009, India

Nufact08

10th International Workshop on
Neutrino Factories,
Super beams and
Beta beams

Valencia
Spain

June 30 - July 4 2008

Local Organising Committee

J. Bernabeu
A. Cervera (chair)
A. Donini
J.J. Gómez (co-chair)
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S. Parke
C. Prior
L. Roberts
A. Rubbia
A. de Rújula
M. Sakuda
F.J.P. Soler
P. Strolin
M. Zisman

Working groups

WG1: neutrino oscillation
Sandhya Choubey
Pilar Hernández
Chris Walter

WG2: neutrino scattering
Steven Boyd
Yoshinari Hayato
Kevin McFarland

WG3: accelerator physics
Roland Garobi
Derun Li
Malika Meddahi
Tom Uesugi

WG4: muon physics
Flavio Gatti
Jim Miller
Akira Sato

European FP7 proposals

- EURONU
  - Approved (4 M€, 80% of the request). Starts on February 1st
  - Spain
    - 1 postdoc for physics studies (UAM, Madrid)
    - 1 postdoc for detector simulation studies (IFIC, Valencia)
- NEUDET: Integrated Infrastructures for Neutrino Detectors
  - To be submitted by February 15th
  - Items:
    - test beam area, test magnet, common use electronics and detectors
    - possibly a near detector test station on CNGS?
    - common tools for simulations (beams, detectors, neutrino interactions etc..)
    - other infrastructure relevant for the development and construction of neutrino detectors, perhaps in conjunction with underground labs

Conclusions I

- The European Strategy Group for Particle Physics has given high priority to future neutrino oscillation facilities
- We are talking about far future, ~15 years, which could be >30 if we don't do something now
- And remember that this is something real: 4 M€ from UE for 3 years

Conclusions II

- A preliminary detector strategy has being defined. Detector R&D program should start next year
- For Nufact aim is to write a CDR by 2012 based on information from existing detectors, forthcoming prototypes, full simulations and dedicated prototypes
  - The status will be revised at Golden08 and later at Nufact08
- WC should pursue studies on excavation, container and PDs
- A FP7 proposal for detector R&D will be submitted by February 2008
- Spanish collaborators are welcomed