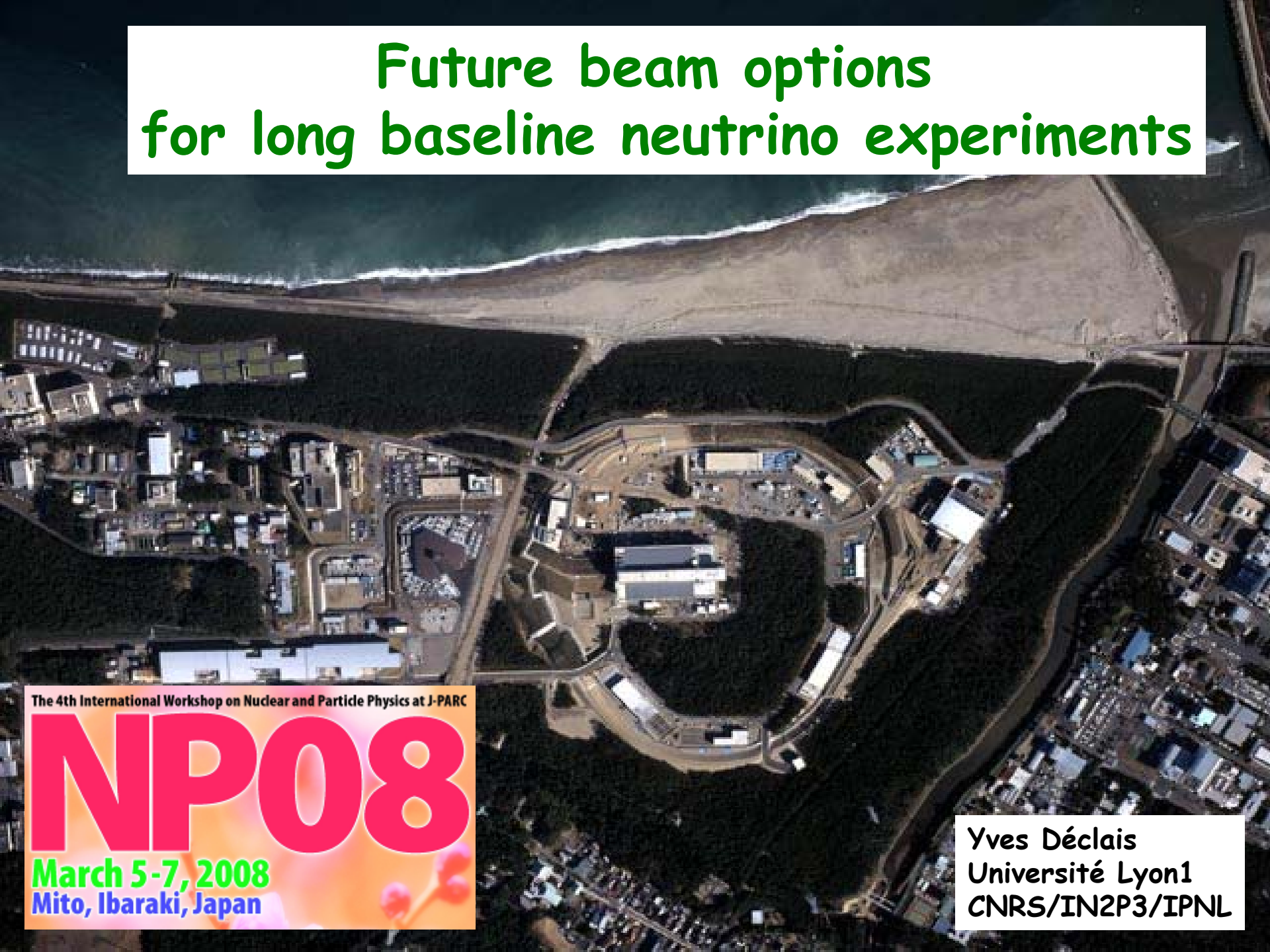
Future beam options for long baseline neutrino experiments



Yves Déclais
Université Lyon1
CNRS/IN2P3/IPNL

Outline

1. On the road to the study of the last piece of the neutrino mixing matrix: experimental status
2. Expected performance of T2K phase 1
3. Landscape of the neutrino program at the end of T2K phase 1
4. Which strategy for T2K phase 2 to exploit fully the result of T2K phase 1
5. Conclusions

Caveat

I am considering myself as a candid in this workshop,
Apologies if raising obvious questions and any possible misunderstanding

The missing piece of the neutrino mixing matrix

$$\begin{pmatrix} \nu_e \\ \nu_\mu \\ \nu_\tau \end{pmatrix} = \begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} \begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix} \begin{pmatrix} \nu_1 \\ \nu_2 \\ \nu_3 \end{pmatrix}$$

θ_{atm} θ_{13}, δ θ_{sol}

Atmospheric sector
Ongoing studies:

- MINOS : $\sin^2 2\theta_{23}$, Δm_{23}
- OPERA : τ appearance

Where is the Graal :
- Mixing angle
- CP phase
- mass hierarchy

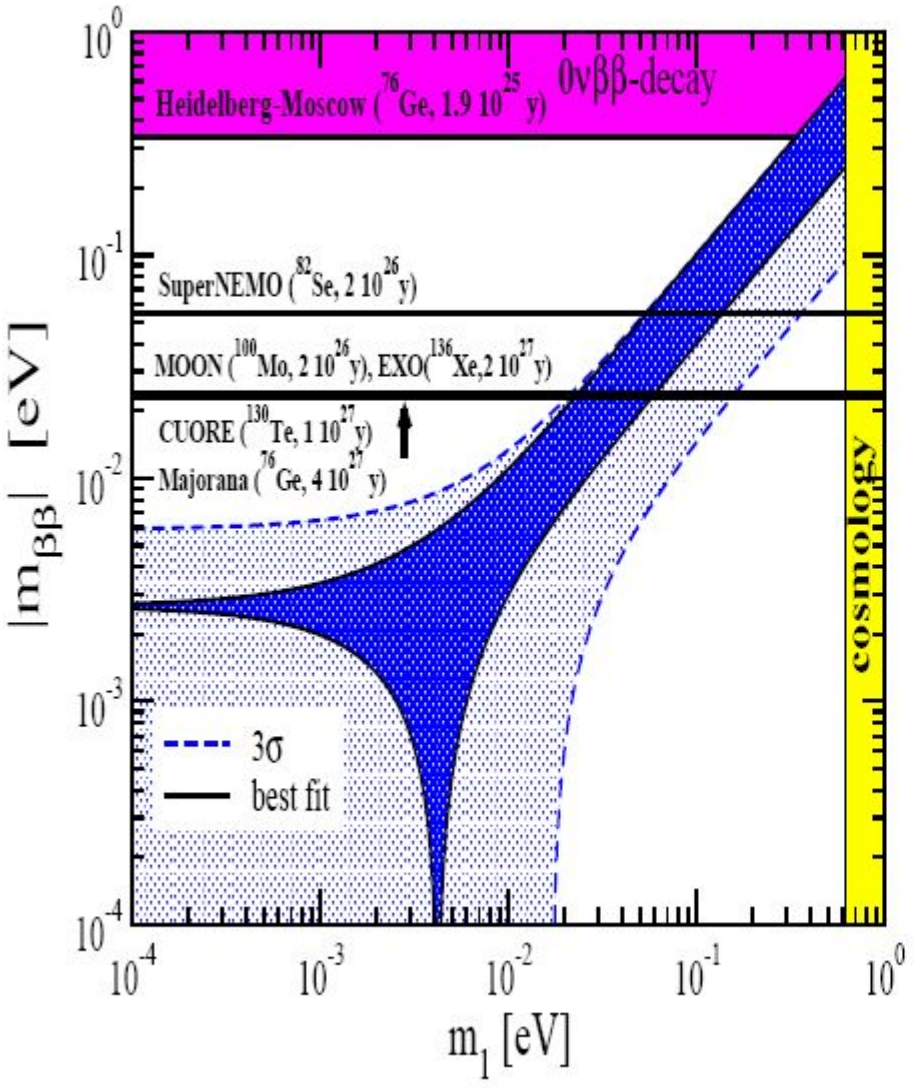
Solar sector
Ongoing studies:

- KamLAND
- BOREXINO

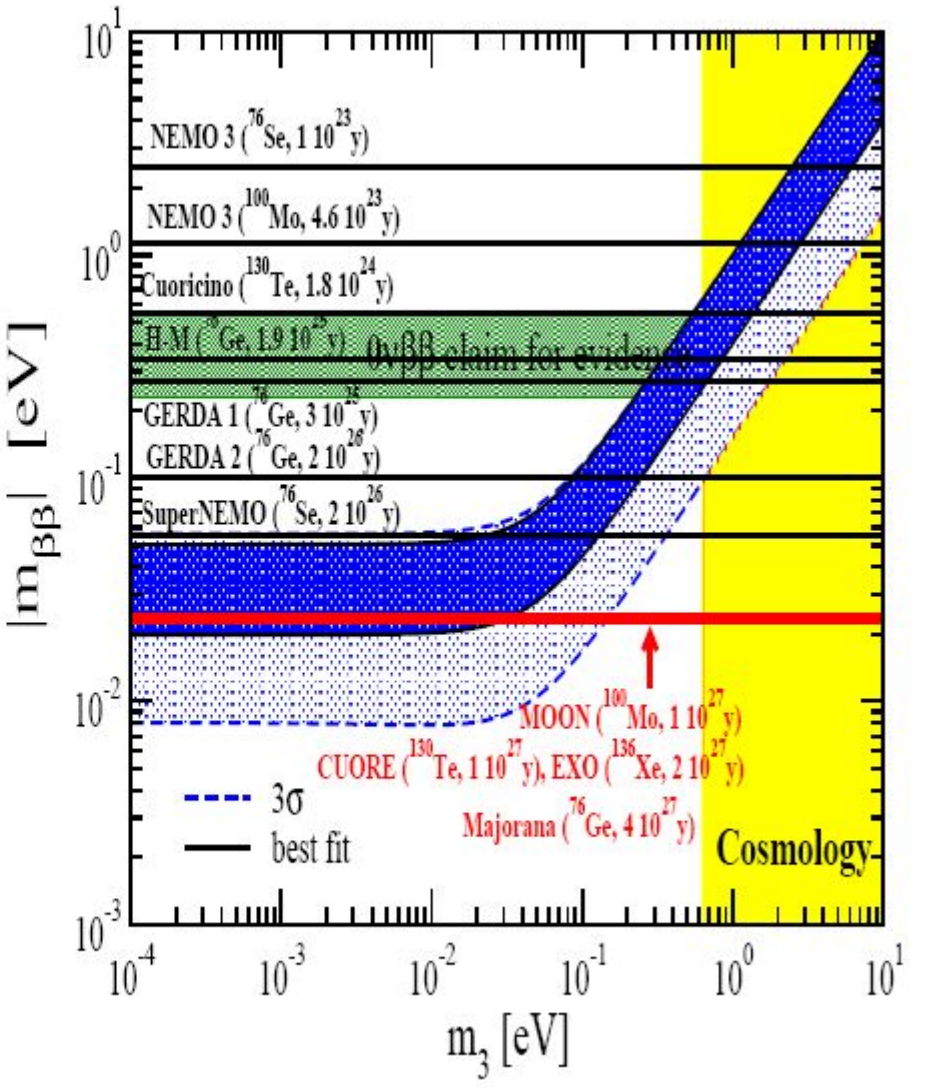
ν_e sector

- Bound from the CHOOZ experiment: $\sin^2 2\theta_{13} < 0.1$
- studied also by MINOS & OPERA ➔ limited sensitivity
- next steps ➔ claim for factor 10 improvement :
  - T2K : appearance experiment
  - reactor experiments : disappearance experiment
- huge brainstorming for futur programs

Mass hierarchy and ββ decay



Normal neutrino mass spectrum



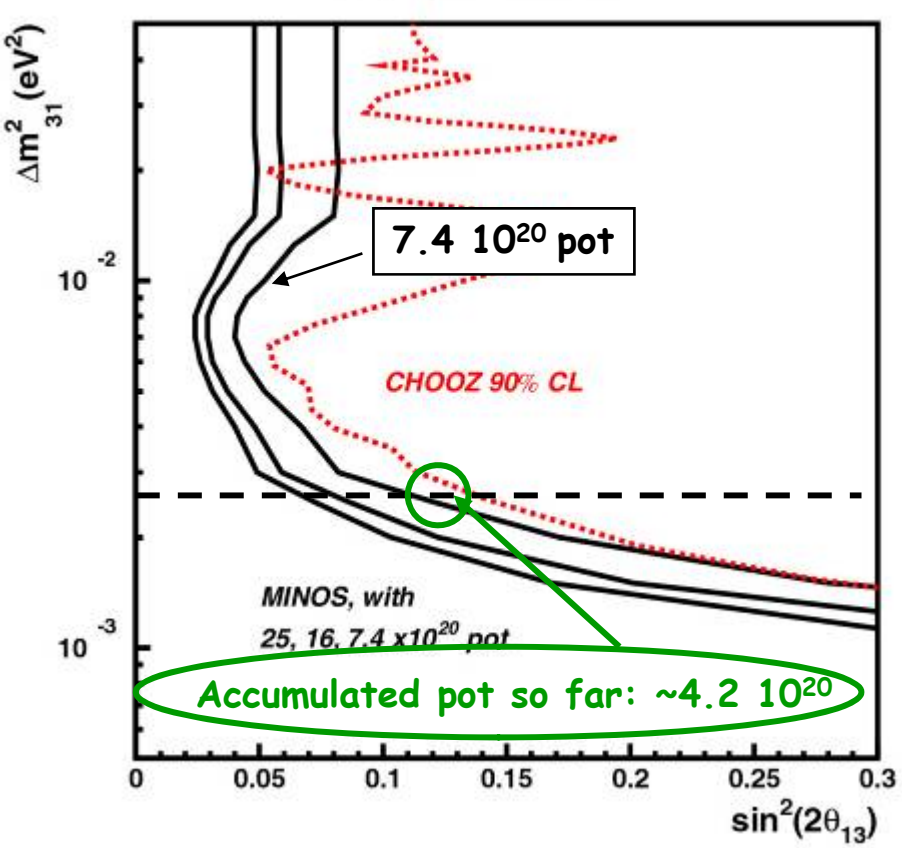
Inverted neutrino mass spectrum

MINOS & OPERA sensitivity

MINOS

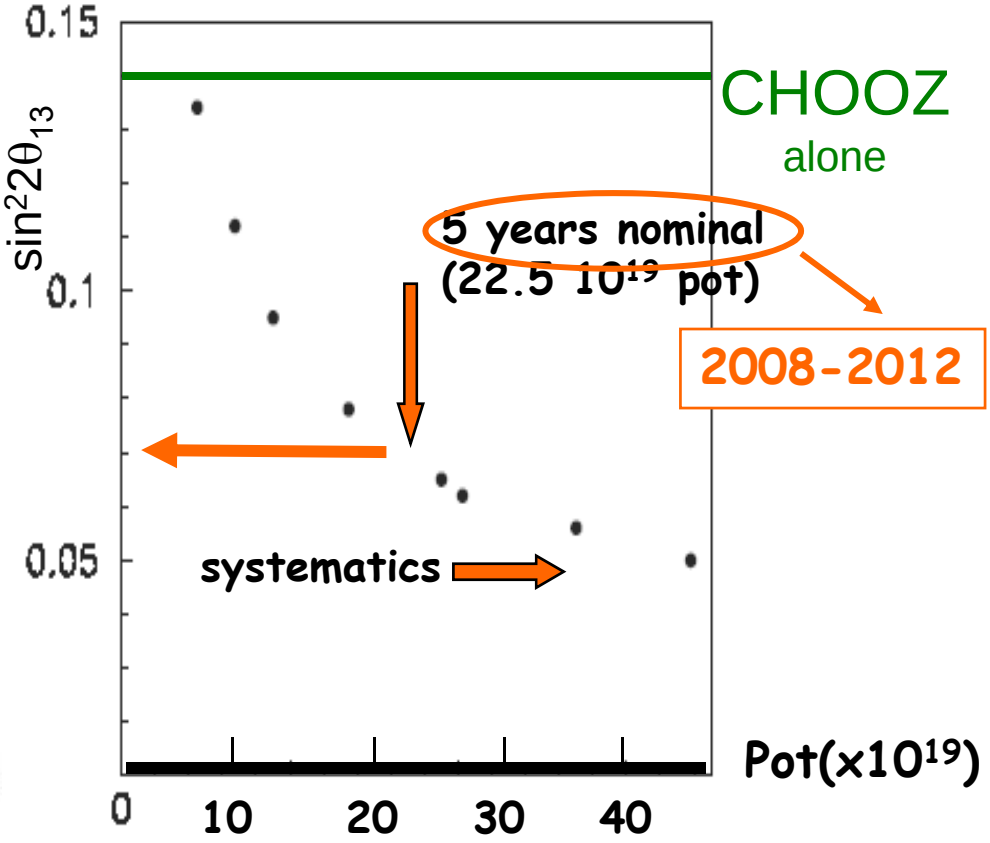
First results coming soon
Analysis is improving

3 σ Contours



OPERA

Reduced sensitivity
due to the 25% reduction
of the target mass

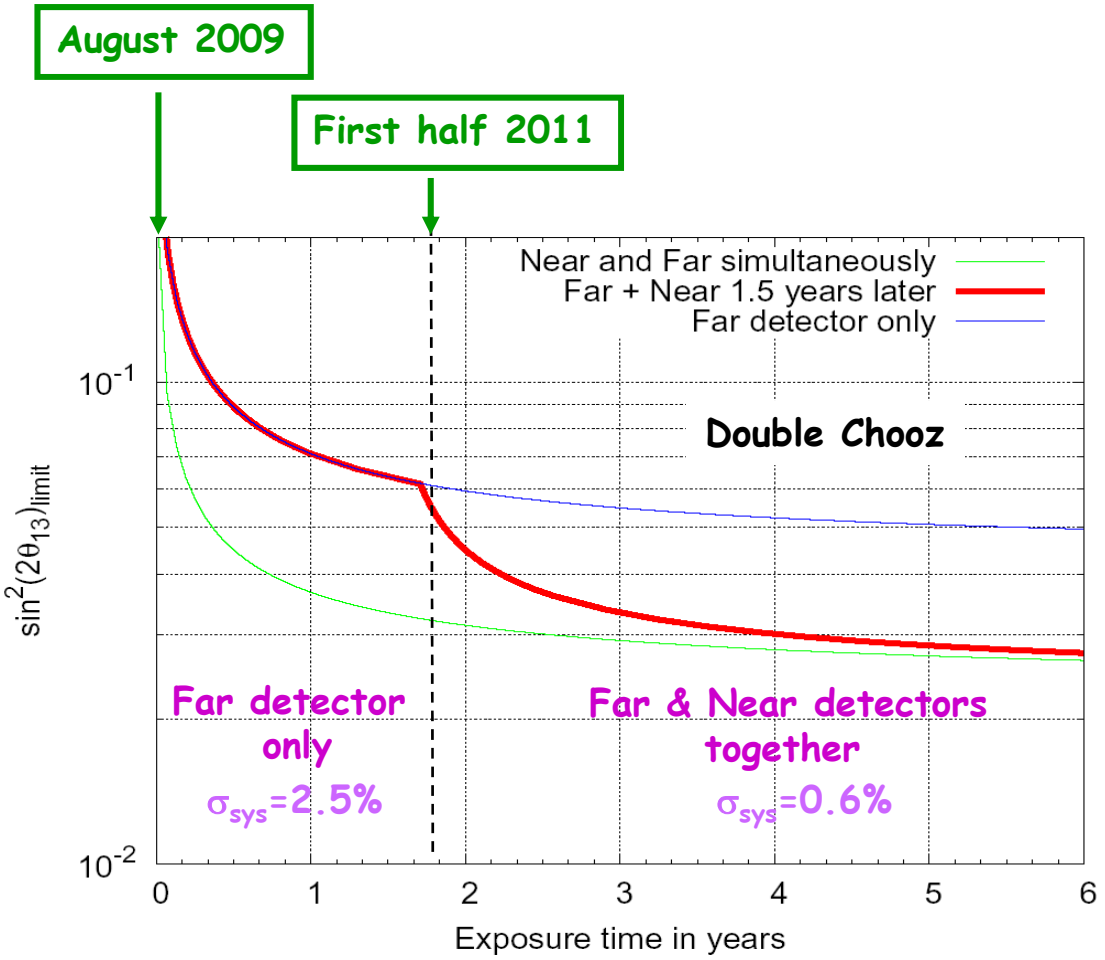


Reactor experiments

Double Chooz:
(far detector construction started)

- Efficiencies included
- Systematics:
  - σ_{abs} = 2.0%
  - σ_{rel} = 0.6%
  - σ_{scl} = 0.5%
  - σ_{shp} = 2.0%
  - $\sigma_{\Delta m^2}$ = 20%
- 1% background subtraction error

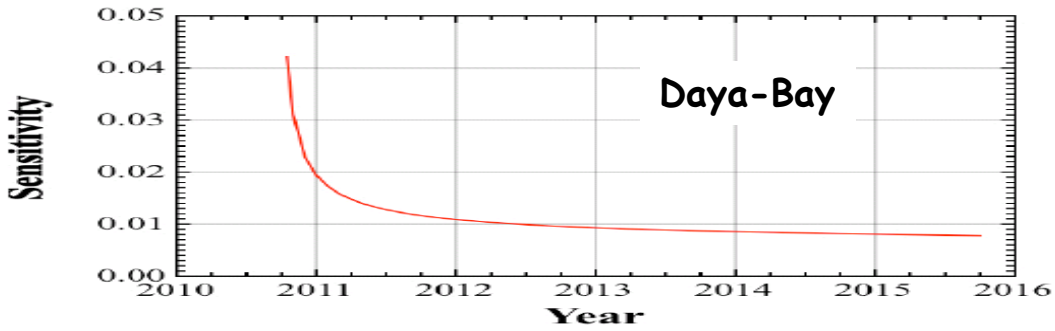
Assuming indirect measurements and a model for the background



Daya-Bay:
(excavation work starting)

- 0.2% background subtraction error

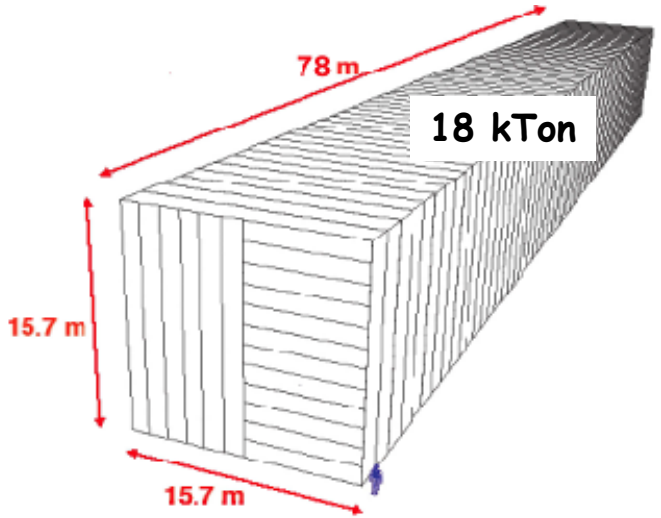
Assuming indirect measurements to prove the background negligible



Fermi Lab : NUMI upgrade

NOνA (beam + detectors :260 M$)

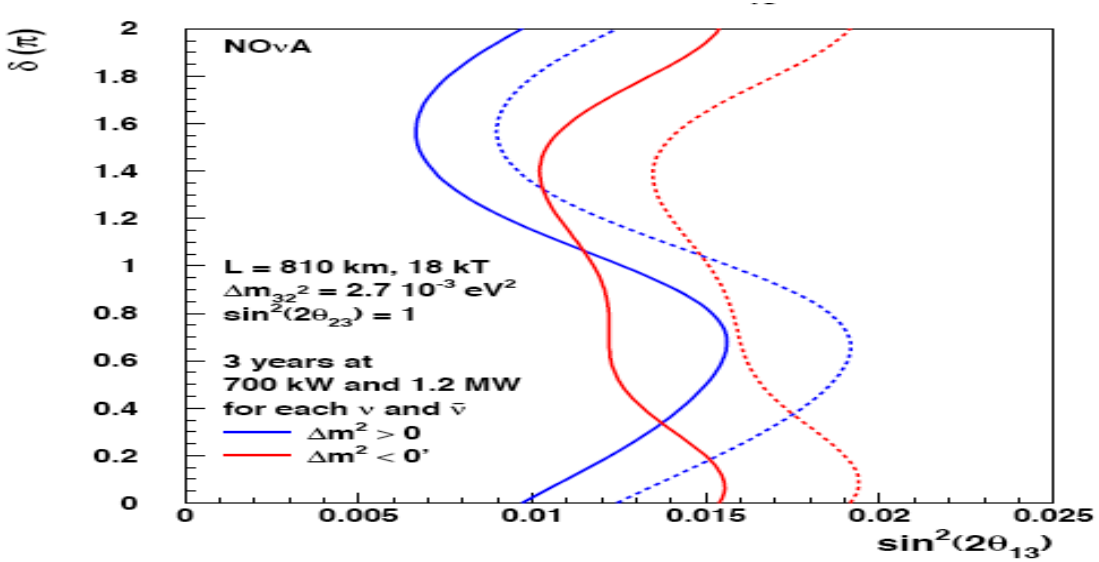
- detectors : Totally active Lscint
- 14 mrad off axis
- NUMI beam line 320 kw → 700kw
- construction starting in 2010 ?
  - ➔ critical budget in Fermi Lab: funding frozen for 1 year
- data taking in 2013 ?

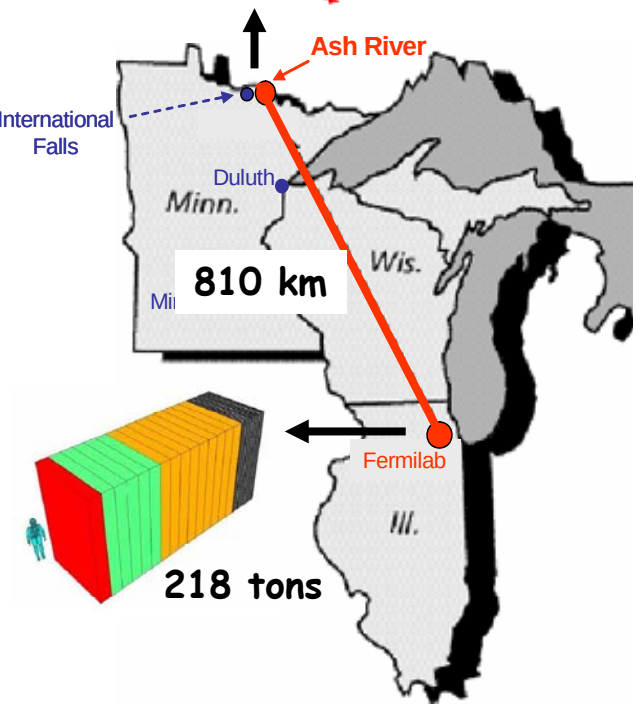


➔ Focusing on Mass hierarchy measurement

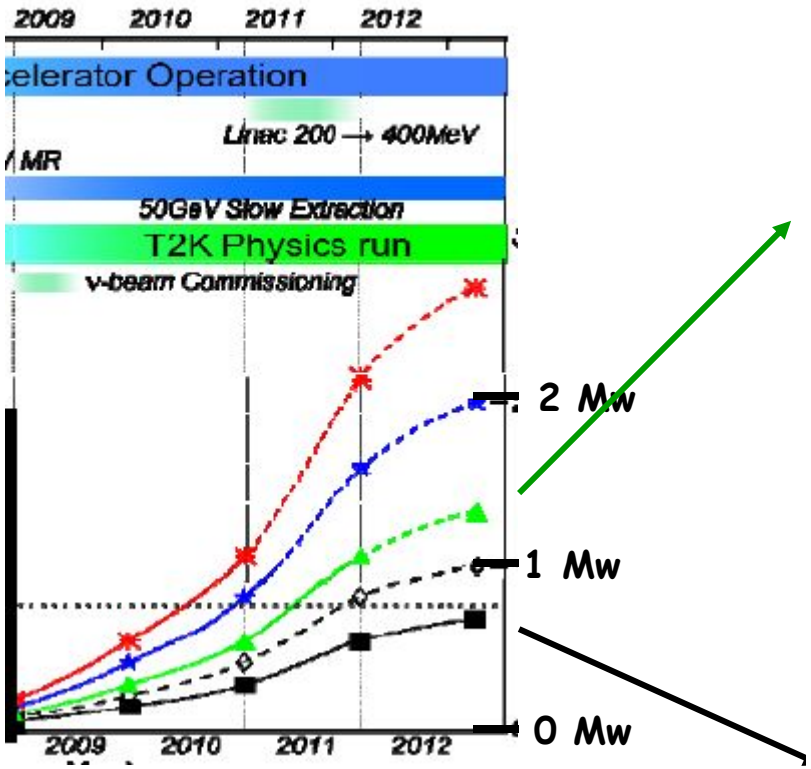
➔ Strong complementarities with T2K

if some signal appears in the data

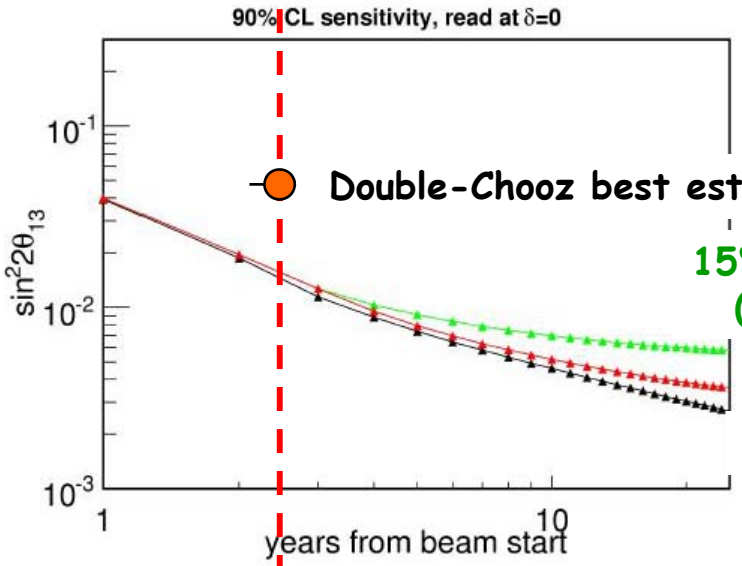




T2K Phase 1 sensitivity



First half 2011

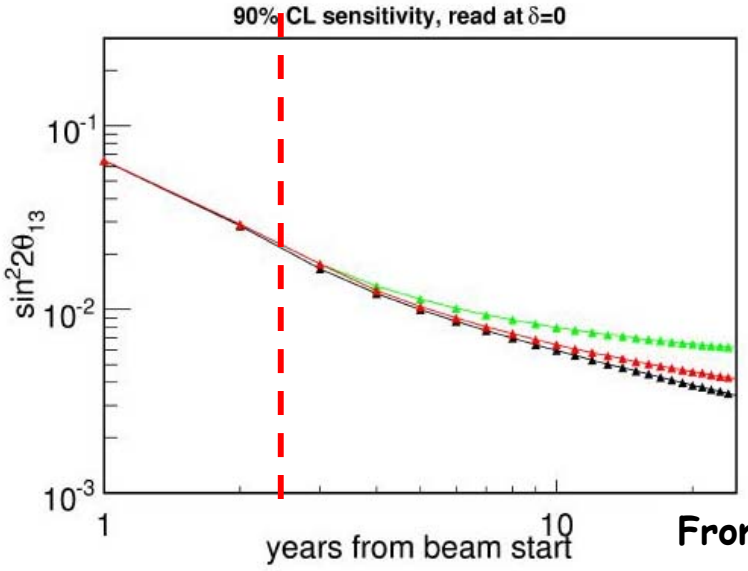


Double-Chooz best estimate

15% systematics (pessimistic)

No systematics

$\delta_{CP} = 0$



Down to 10^{-2}
the sensitivity of T2K
is mostly driven by statistics:
➔Only driven by the integrated flux delivered to SuperK

From M. Fechner

Conclusions on T2K phase 1

By the end of 2011
T2K can reach a sensitivity of 1-2 10^{-2}
for the $\nu_\mu \rightarrow \nu_e$ transition in the atmospheric sector.

The integrated intensity delivered to the T2K program should be maximum during the first 3 years in order to accumulate the needed statistics and to guarantee the T2K discovery potential

Assuming a positive signal is observed then the next step is to determine the value of:

- θ_{13} angle
- the imaginary part : CPV
- the mass hierarchy

- ❑ increased statistics & anti-neutrino running
  - ➢ beam power
  - ➢ larger & improved detectors
- ❑ optimized baseline
- ❑ reducing the systematics

Landscape for neutrino experiments after 2011

Country driven programs:

- European situation
- Fermi Lab road map
- T2K phase 2

International Scoping Studies for dedicated neutrino machines

- Beta beam
- Neutrino factory

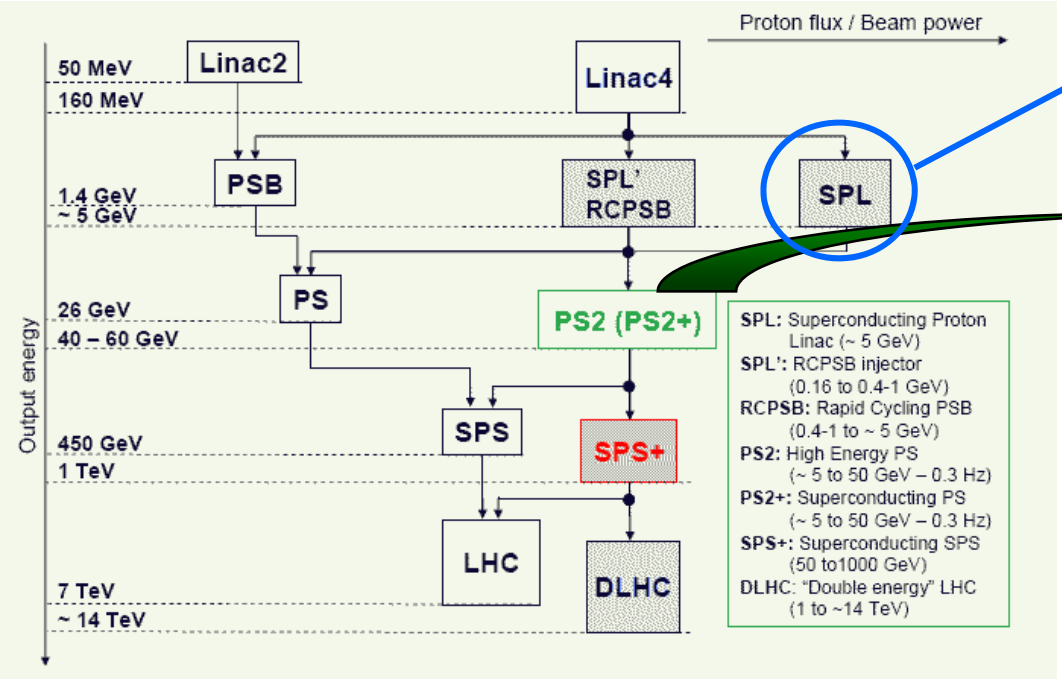
far beyond the scope of this talk
(if we assume an effect observed in T2K phase 1)

European Studies: a)SPS intensity increase

Not yet decided @CERN

Main motivation: LHC upgrade
➔ horizon > 2015

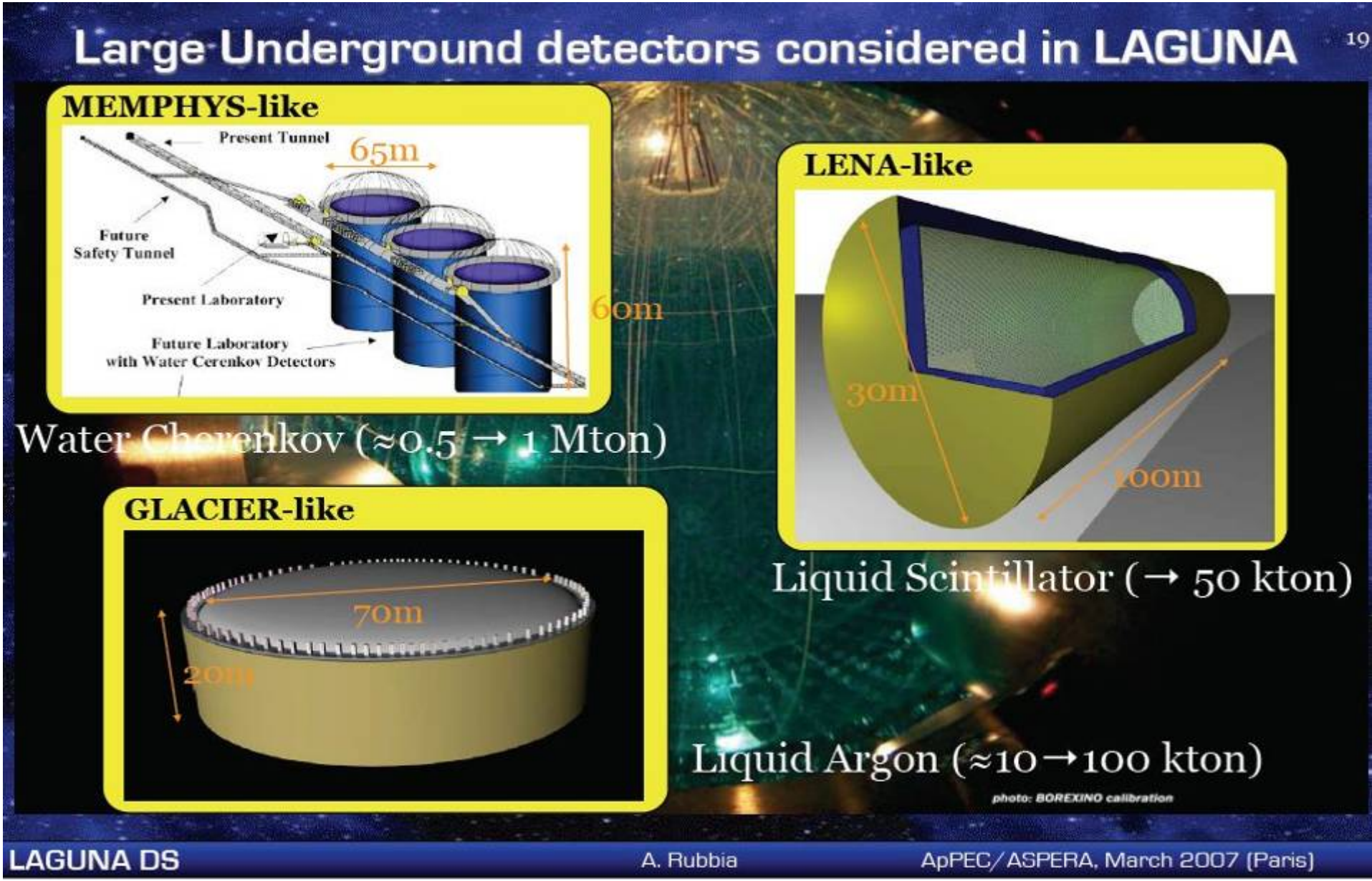
- injector for EURISOL ➔ β beam
- Super Beam to Fréjus
- injector for νfact



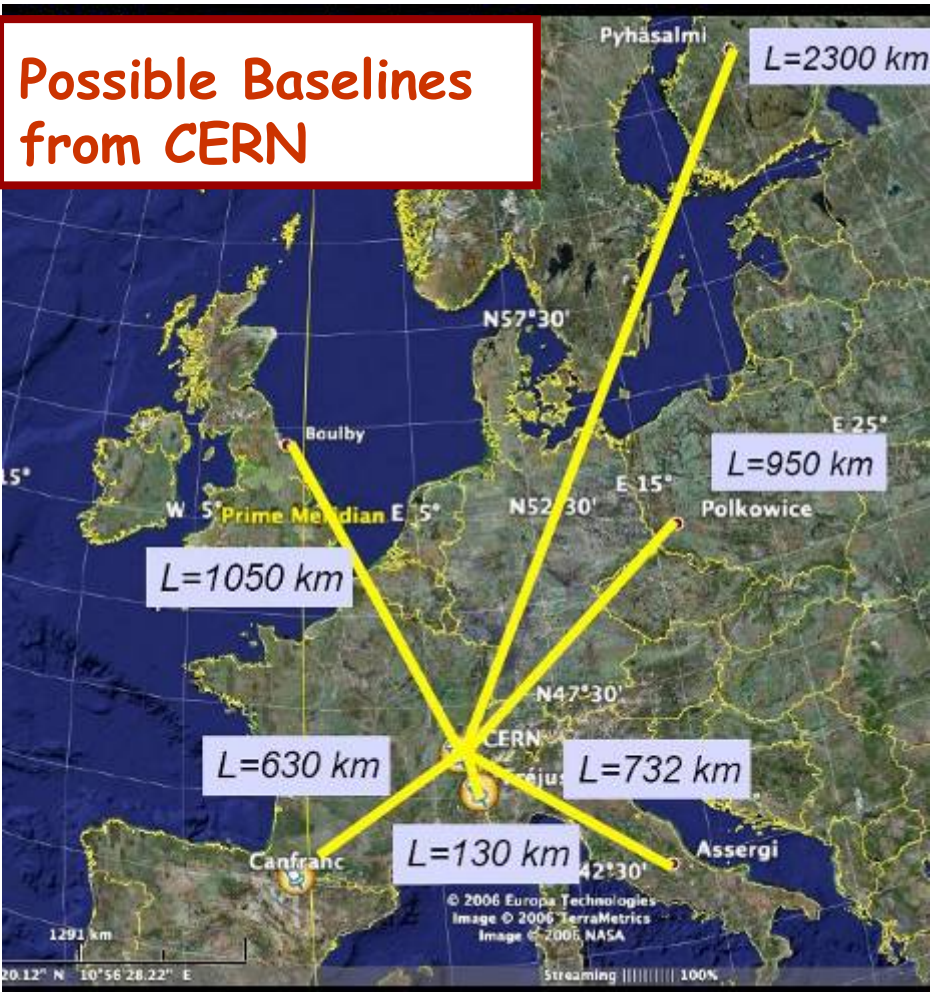
	CERN SpS			
	CNGS	+ [13]	1 [20]	2 [20]
Proton energy E_p	400 GeV			
$ppp(\times 10^{13})$	4.8	14	4.8	15
T_c (s)	6	6	6	6
Efficiency	0.55	0.83	0.8	0.8
Running (d/y)	220	220	240	280
N_{pot} / yr $(\times 10^{19})$	7.6	33	12	43.3
Beam power (MW)	0.5	1.5	0.5	1.6
$E_p \times N_{pot}$ $(\times 10^{22}$ GeV·pot/yr)	3	13.2	4.7	17.3
Relative increase		×4	×1.5	×6
Timescale	> 2008	>2016 ?		

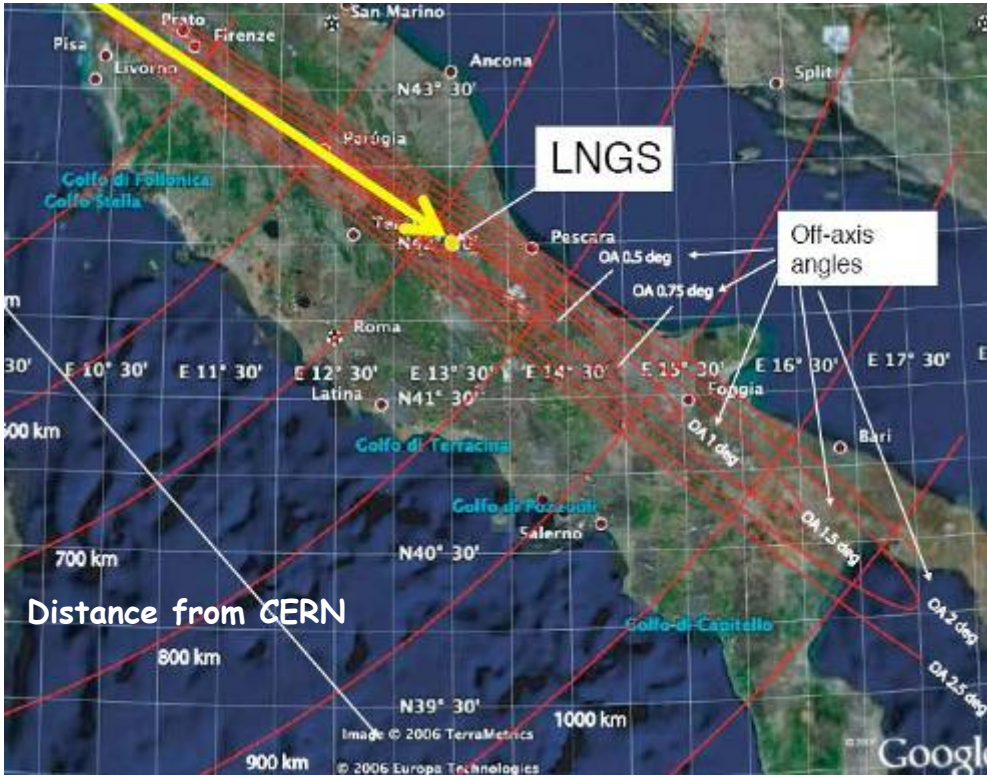
[13] GLACIER : 100 Ktons LAr
[20] MODULAR : 30 Ktons LAr

b) R&D for massive detectors funded by European Community

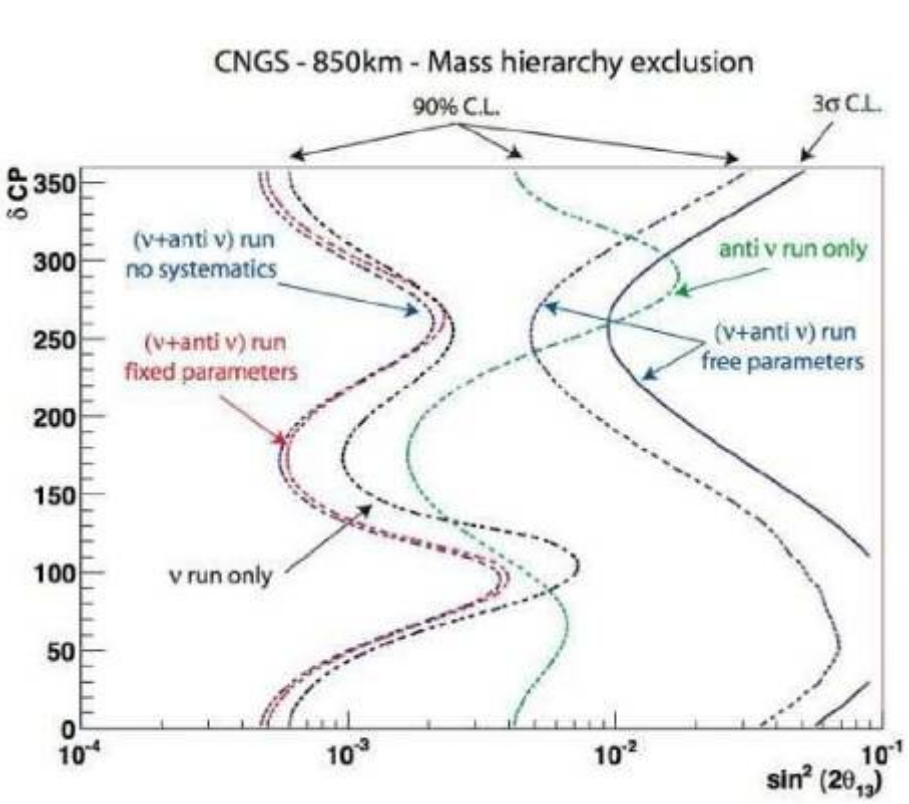


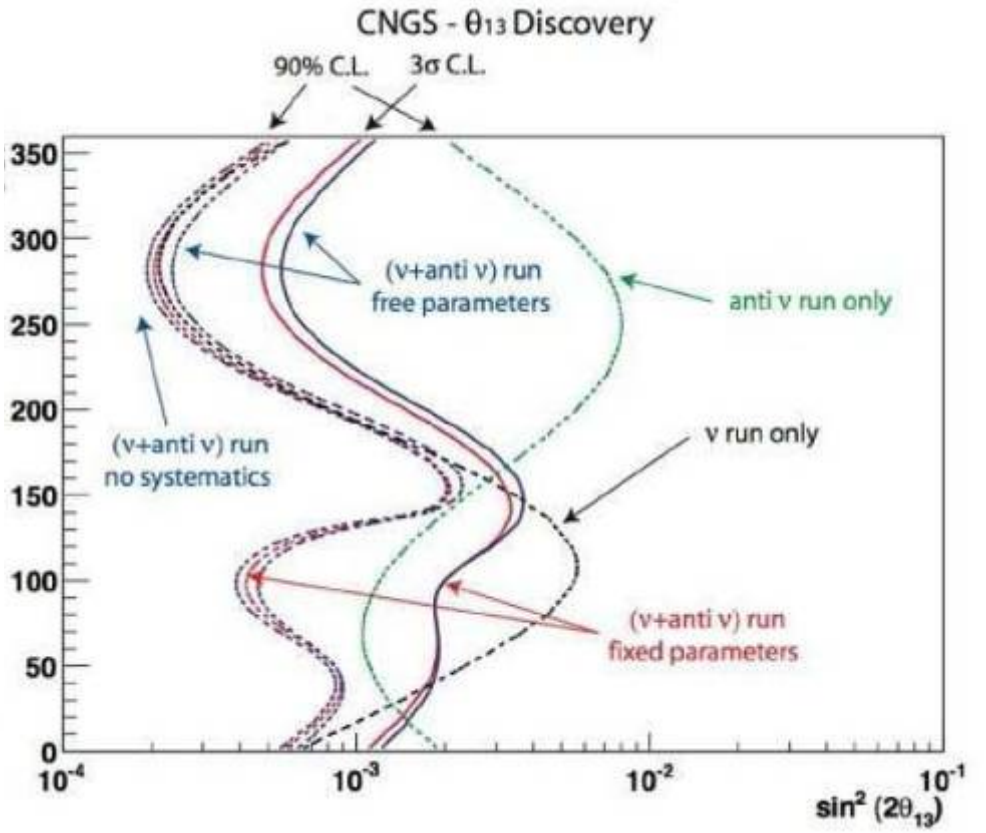
Possible Baselines from CERN





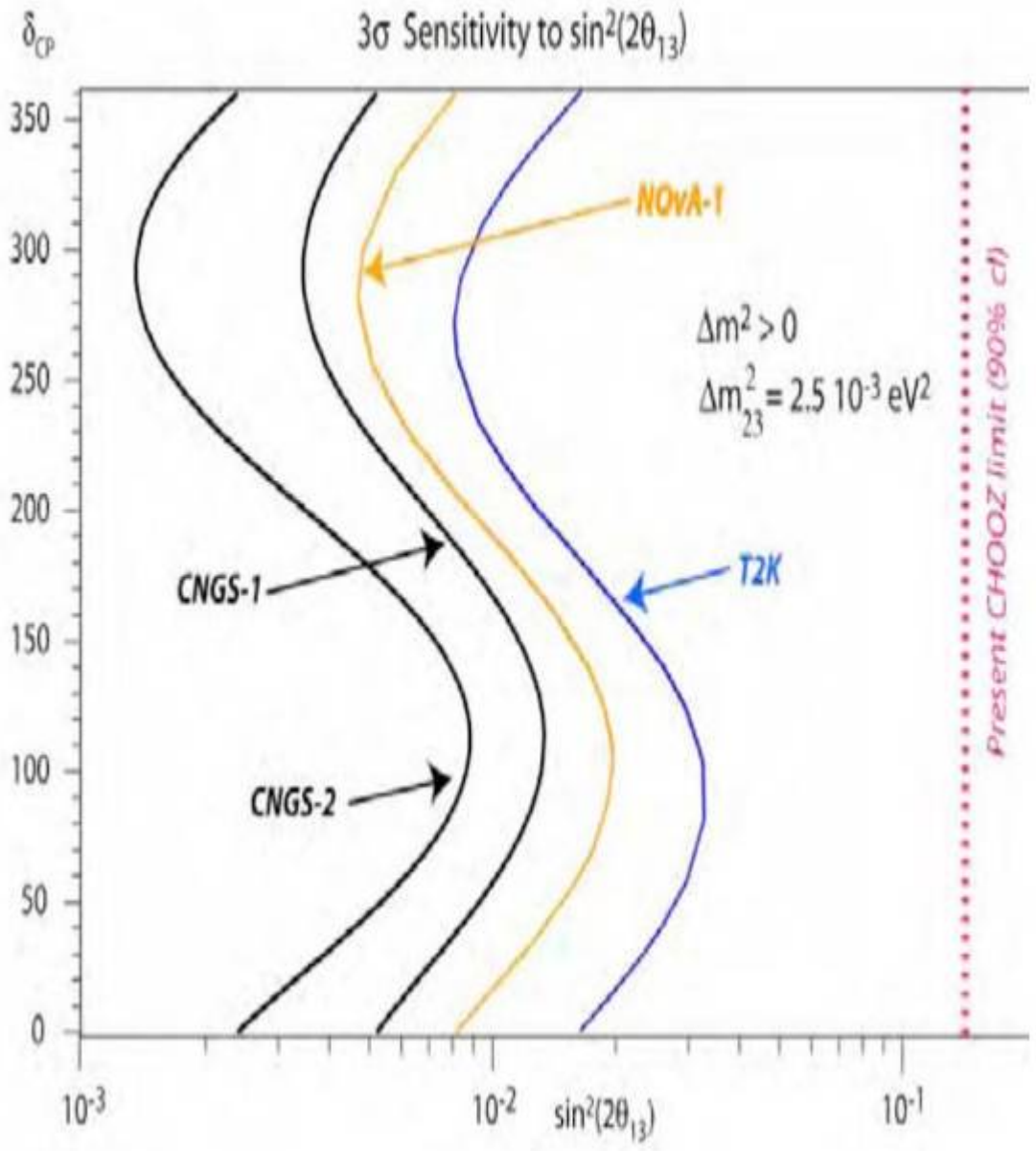
GLACIER @ LNGS



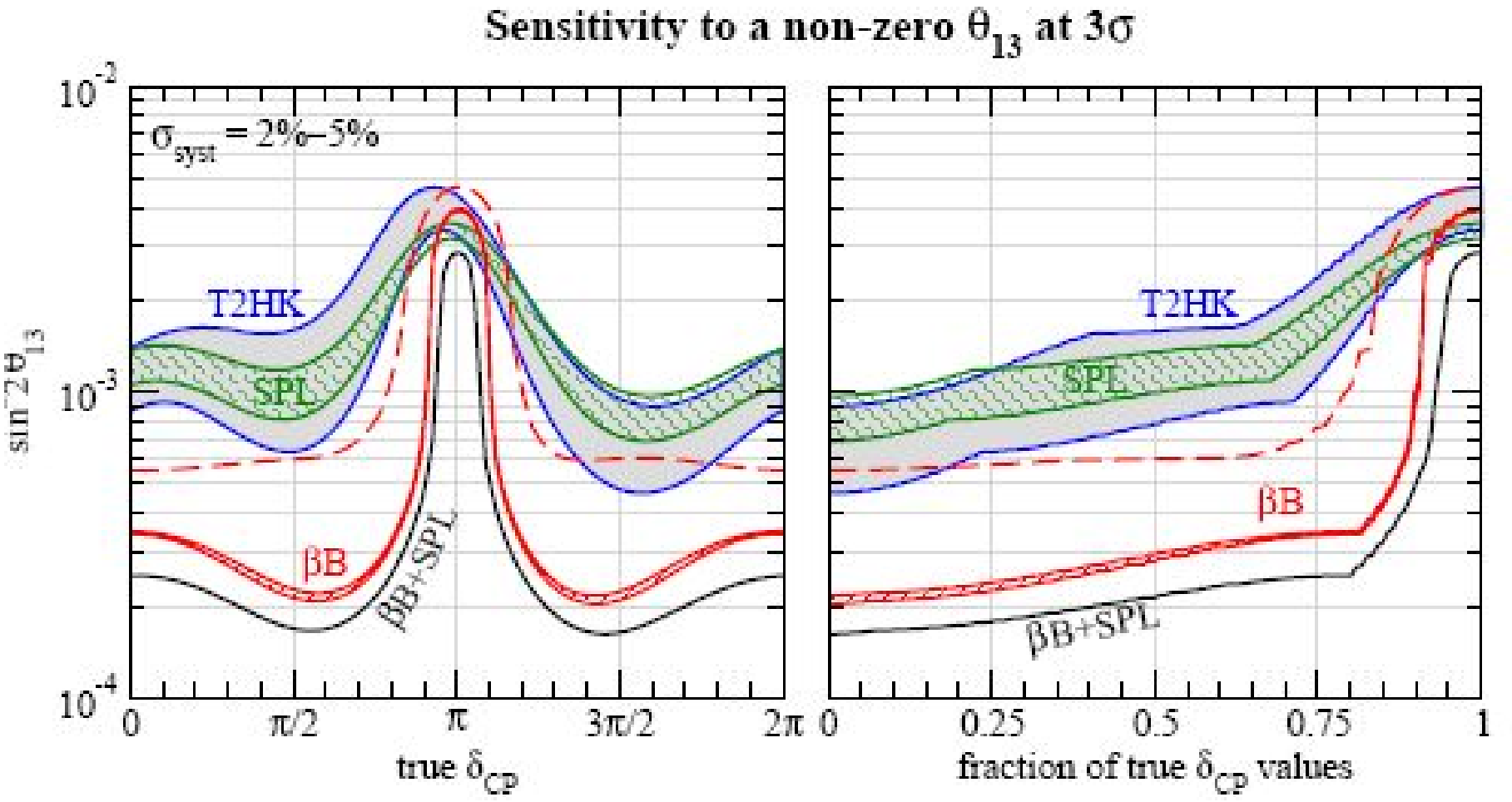


MODULAR @LNGS

T600 in the HallB @LNGS
Should take data
before the end of the year
with the CNGS beam



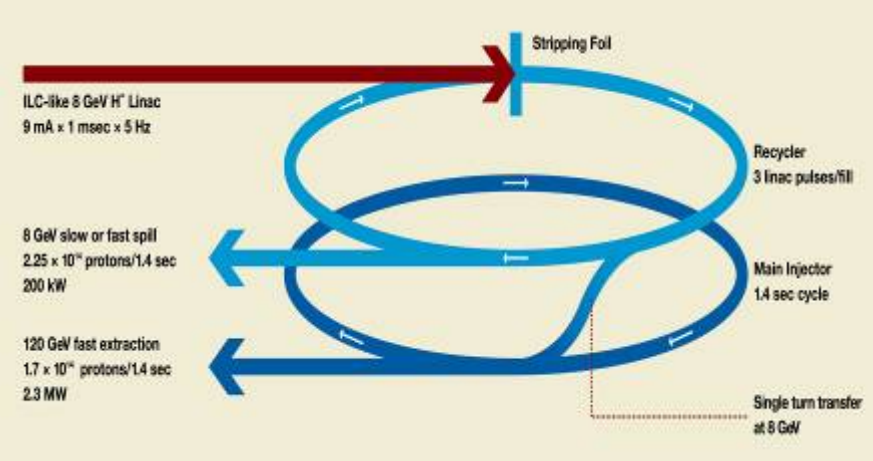
MEMPHYS : megaton water cerenkov @ Frejus

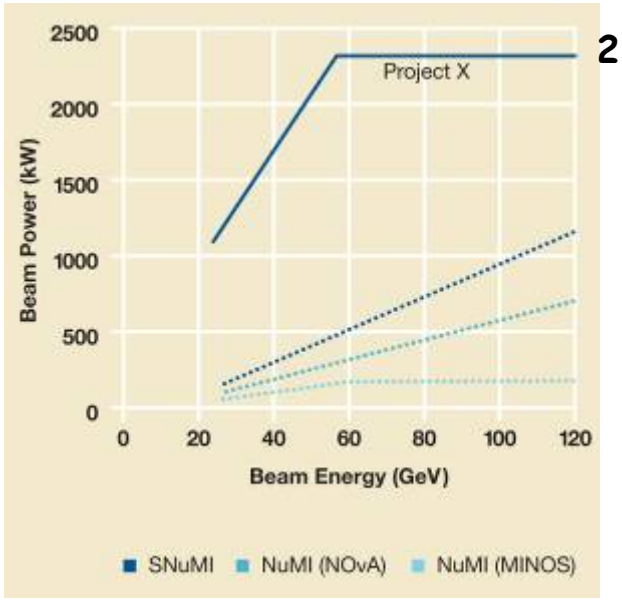


US strategy for neutrino physics : Project X

P. Odone
P5 presentation
January 31th, 2008

1) Breaking the intensity frontier
➔ multi Mw source for intense muon beam

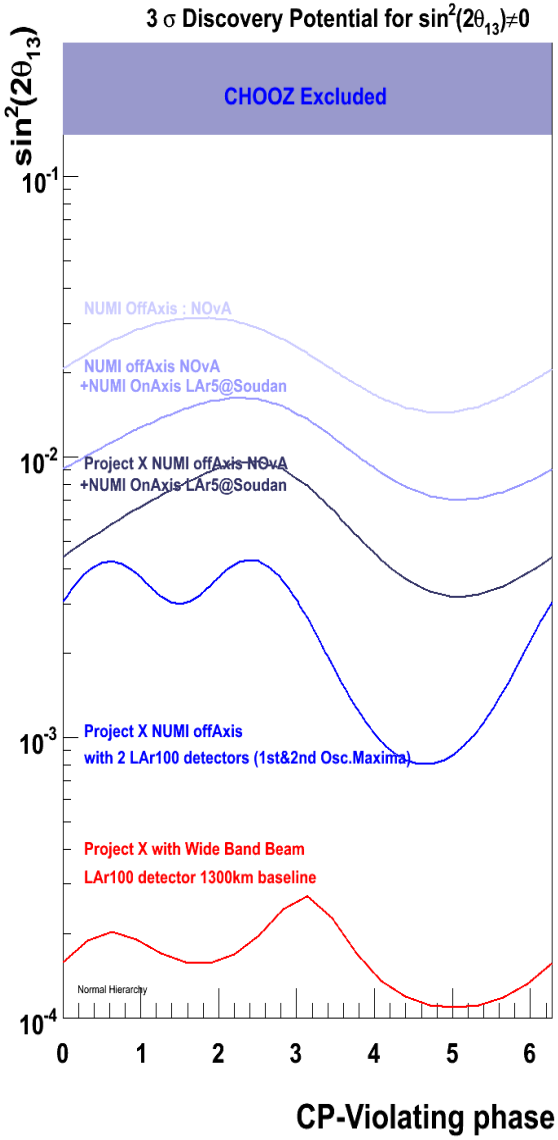


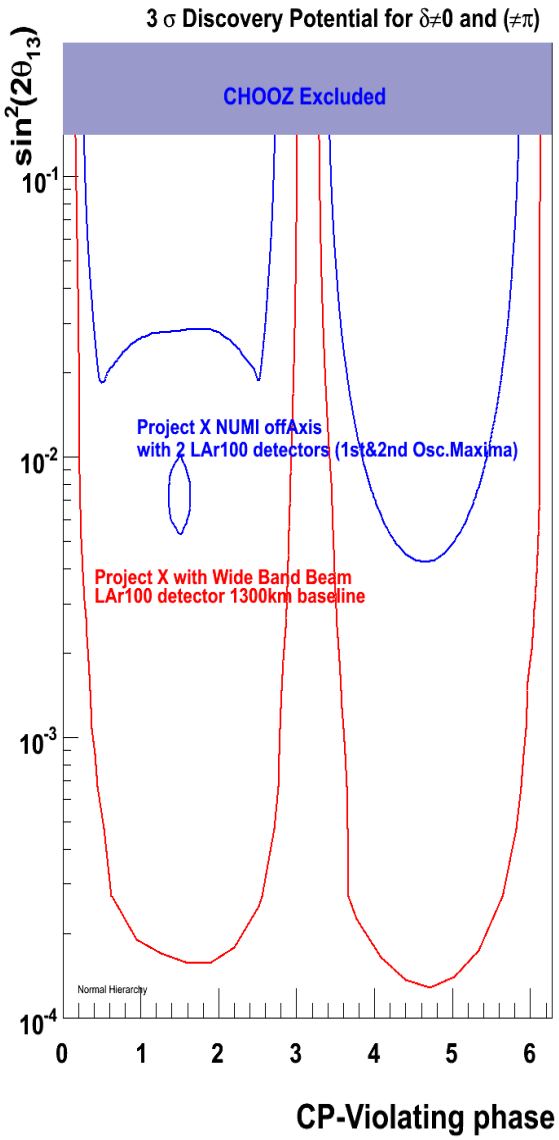


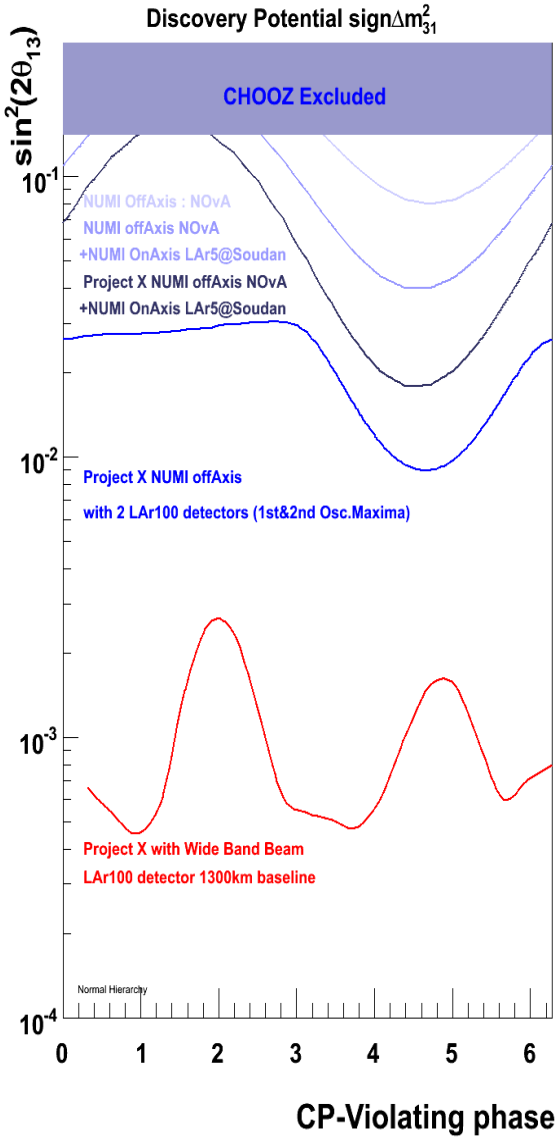
2.3 Mw

2) Build NOνA
3) Replace MINOS by 5kTon LAr "on axis" → complementary to NOνA
4) Develop caverns/detectors for DUSEL
with new beam-line from Project X it is the ultimate super-beam experiment (water or LAr)
5) If neutrino factory is needed – Project X is the ideal source
as an example : hep-ph-0709.3889 (A. Bross, M. Ellis, S. Geer) :
A neutrino factory for both Large and Small θ_{13}

Project X : sensitivity





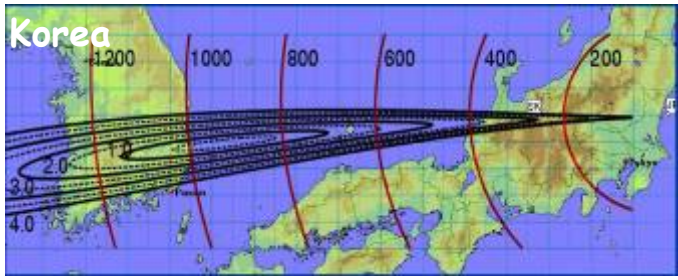


Going to T2K phase 2

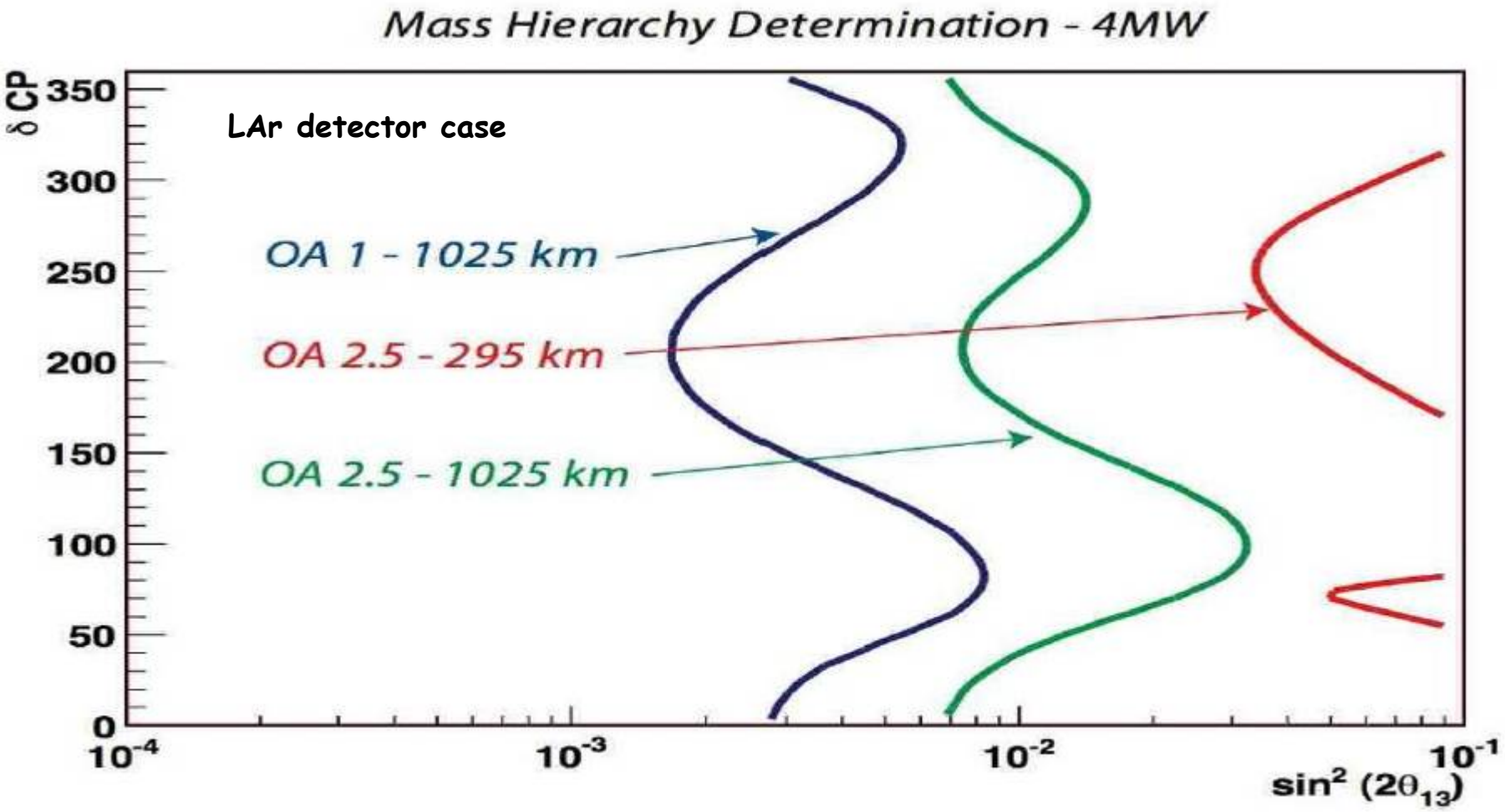
The goal of this workshop is to define the R&D needed for optimizing the strategy and be ready for a proposal in 2012

1) **Intensity upgrade to 4Mw (~200 okuYen):**
   - doubling the number of accelerated protons
   - repetition rate x2.5
   - proton energy : 40 GeV → 50 GeV

2) Optimizing the baseline



- going to the second maximum (T2KK)
  - ✓ More robust signal in the very far detector
  - ✓ Allows mass hierarchy sensitivity



2) Optimizing the Off Axis angle:

- **Reducing the Off Axis angle**
  - ✓ Wider energy distribution for the beam
  - ✓ Spectral information improve mass hierarchy sensitivity
  - ✓ Improve CPV sensitivity

Location	$\sin^2(2\theta_{13})$ = 0.002	neutrino run: ν_μCC + $\bar{\nu}_\mu$CC no osc.	ν_eCC + $\bar{\nu}_e$CC δ=0	90°	270°	180°	beam
J-PARC - 40 GeV/c protons - T2K optics - 4MW							
295 km 2.5 deg (0-5 GeV)	Matter (n.h.)	210970	274	39	393	158	4035 $\sqrt{B}$ = 64
1025 km ~ 1 deg (0-5 GeV)	Matter (n.h.)	85900	226	138	389	300	776 $\sqrt{B}$ = 28
1025 km 2.5 deg (0-5 GeV)	Matter (n.h.)	17475	94	60	126	92	334 $\sqrt{B}$ = 18

Example with 100 KTon LAr

S/√B for δ=0

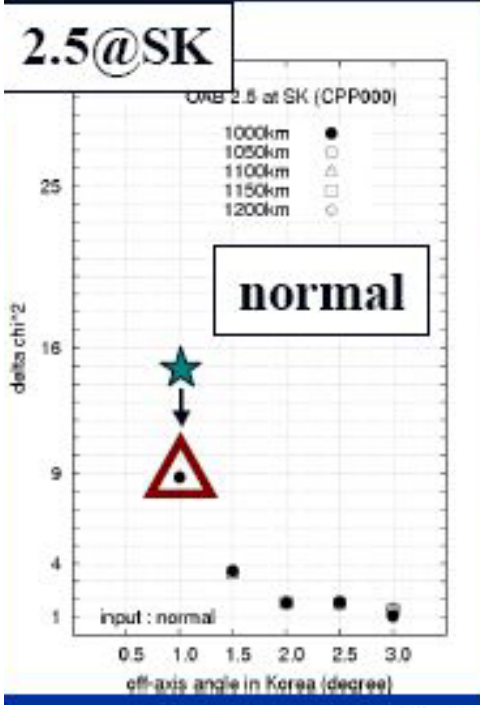
4.3

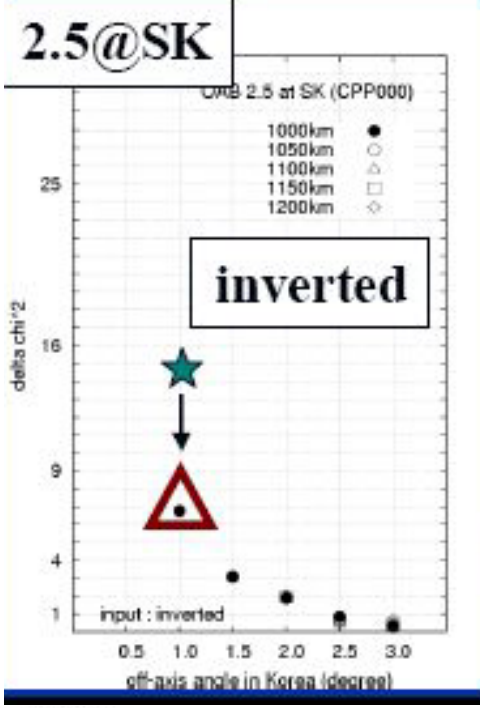
8.1

5.2

Sensitivity

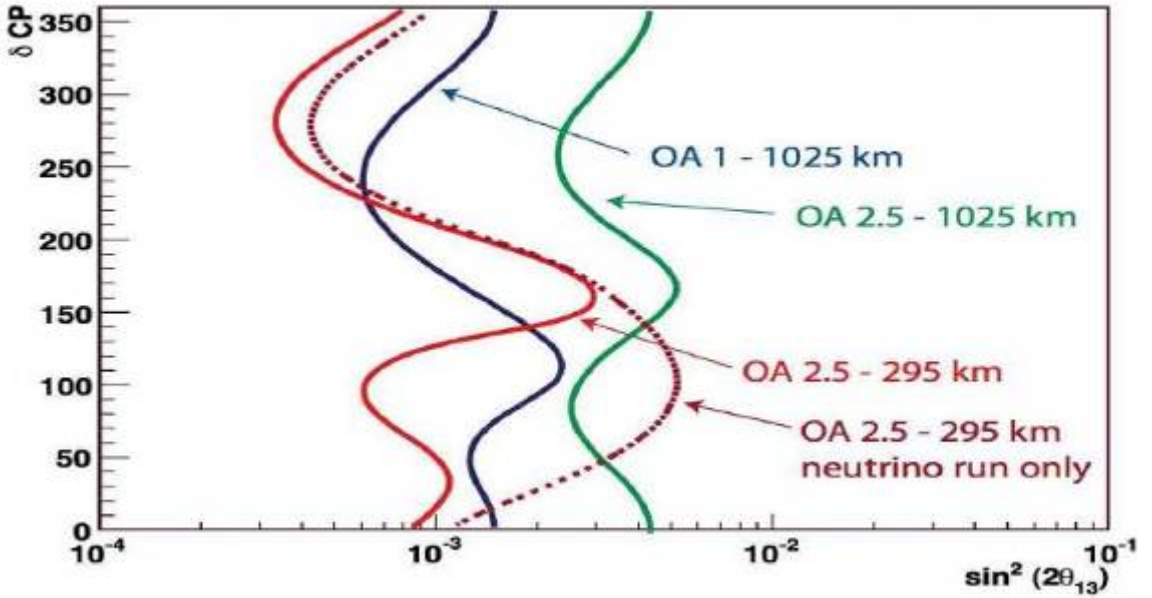
Water Cerenkov detector





LAr detector

θ_{13} Sensitivity - 4MW



4) Detector optimization

Not included in the topics of this talk

Water Cerenkov extrapolation from 50 Ktons ➔ 1000 Ktons

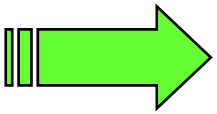
LAr TPC extrapolation from .3 Ktons ➔ 200 Ktons

Technical Difficulties

- Efficiencies
- NC Background rejection
- energy resolution
- accessing other physics fields like proton decay

To be weighted by

Physics Performances



Do not forget systematics studies (beam & detector) with a near detector seeing the neutrino source as a point

Conclusions

T2K phase1 is able to set quickly the scale
for the study of the unknown part of the neutrino mixing matrix
Unique discovery potential

In parallel with the running of T2K phase 1
a vigorous & coherent R&D is mandatory
for building a proposal for the detailed study of the effect
(to be ready in 2012!)

This proposal should be strongly appealing
in order to collect the largest worldwide neutrino community
gathering so the needed resource