Prospectives IN2P3 – IRFU
Presqu'île de Giens, 2-5 Avril 2012

Les expériences futures pour les oscillations de neutrinos , la désintégration du proton et l'astrophysique

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GT 4 – Neutrino: masses, oscillations. Désintégration du proton.

The physics

cf S.Lavignac

- Neutrino oscillations:
  - mixing angle θ_{13} ← *Since 2011: measurement by T2K, Double Chooz, Daya Bay*
  - mass hierarchy
  - CP violation in lepton sector
  - Precision on oscillation parameters

- Proton decay :
  - Explore models not yet excluded by current limits : push to 10^{34}-10^{35} y

- Astro(+geo)physics with neutrinos:
  - SuperNovae core collapse [cf GT10] → investigate mechanism
  - Diffuse SN neutrinos → measure
  - Solar neutrinos → helioseismology, CNO rate
  - Geoneutrinos [cf GT17] → gain insight on Earth's structure

New for θ_{13}

Daya Bay : $\sin^2 2\theta_{13} = 0.092 \pm 0.016(\text{stat}) \pm 0.005(\text{syst})$ cf S.Lavignac

they will have stat~syst in ~ 1 year

→ <u>Independent measurements are mandatory !</u>

Complementarity of reactor and accelerator measurements must be exploited :

- Reactor: disappearance $P\left(\bar{\nu}_e \rightarrow \bar{\nu}_e\right) = f\left(\theta_{13}, [\Delta m^2_{23}]\right)$
  - → clean measurement of θ_{13}
    - Double Chooz
    - RENO (Korea)
- Accelerator : appearance $P\left(\nu_\mu \rightarrow \nu_e\right) = f\left(\theta_{13}, \delta_{CP}, sign\Delta m^2_{23}\right)$
  - → sensitivity to other parameters
    - T2K
    - NOvA (US) start 2014

Near future for θ_{13}

Double Chooz

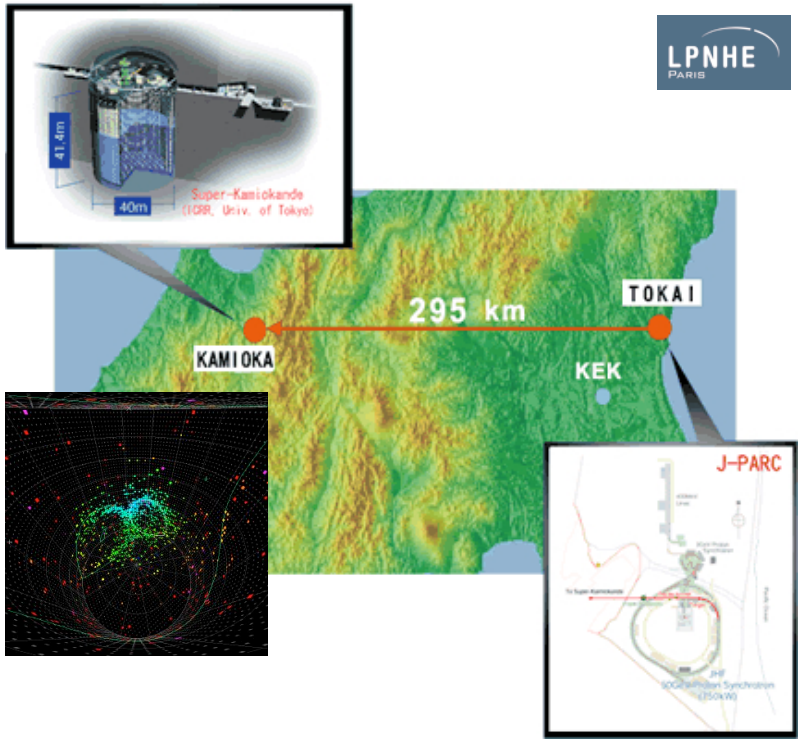
Data taken with far detector only

Near detector in construction, data in 2013

$\sigma(\sin^2 2\theta_{13})$~0.01 [conservative!] in 3 years

- France has a leading role
- Only two reactors: possibility to measure background, easier to control systematics
- Other physics scopes: Δm^2_{23}, ν directionality ...

T2K



$\sigma(\sin^2 2\theta_{13})$~0.02 in 5 years

- Some sensitivity to δ_{CP}, MH
- Precise measurement of θ_{23}, Δm^2_{23}

The physics – today

cf S.Lavignac

- Neutrino oscillations:
  - ~~mixing angle θ_{13}~~
  - mass hierarchy
  - CP violation in lepton sector
  - Precision on oscillation parameters

} given "large" θ_{13}

- Proton decay :
  - Explore models not yet excluded by current limits : push to 10^{34}-10^{35} y

- Astro(+geo)physics with neutrinos:
  - SuperNovae core collapse [cf GT10] → investigate mechanism
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The world context

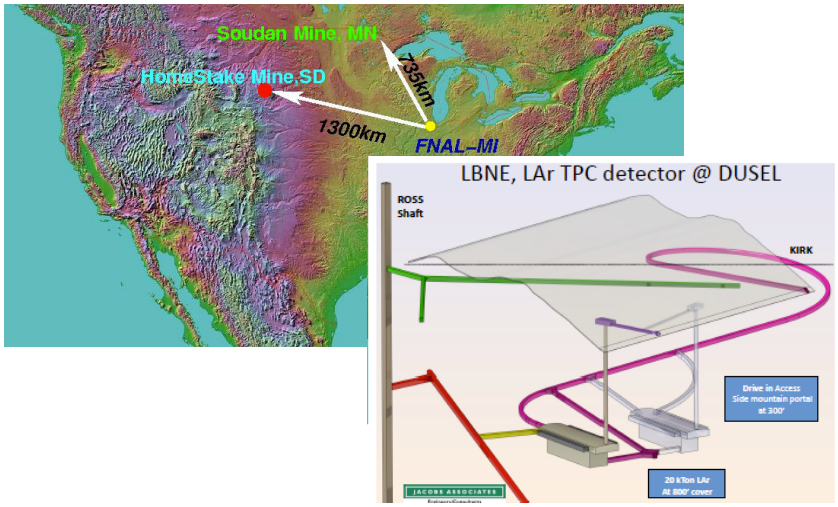
US : LBNE

Liquid Argon TPC 25 kton

at DUSEL (Homestake Mine) ~2400mwe

Beam from Fermilab (0.7-2.5MW)

baseline=1300 km <E>~3 GeV



Recently "downscoped" by DOE

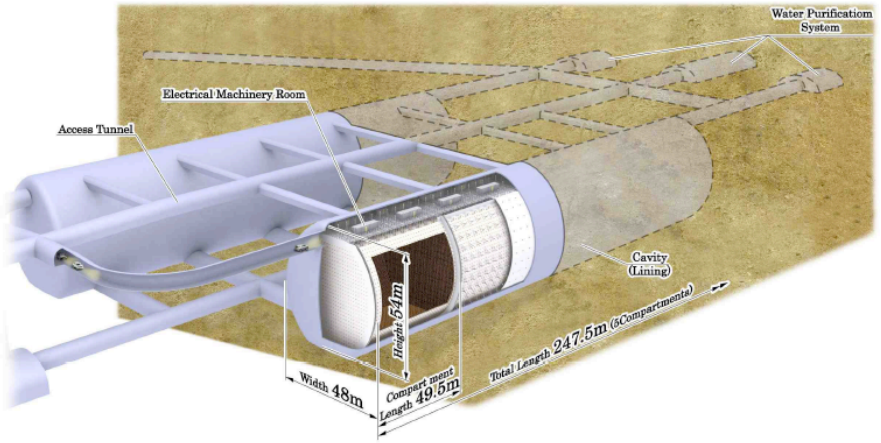
Japan : Hyper-K

Water Cherenkov 560 kton

near Kamioka, 1750 mwe

Beam from JPARC (1.66MW)

baseline=,295 km <E>~0.8 GeV

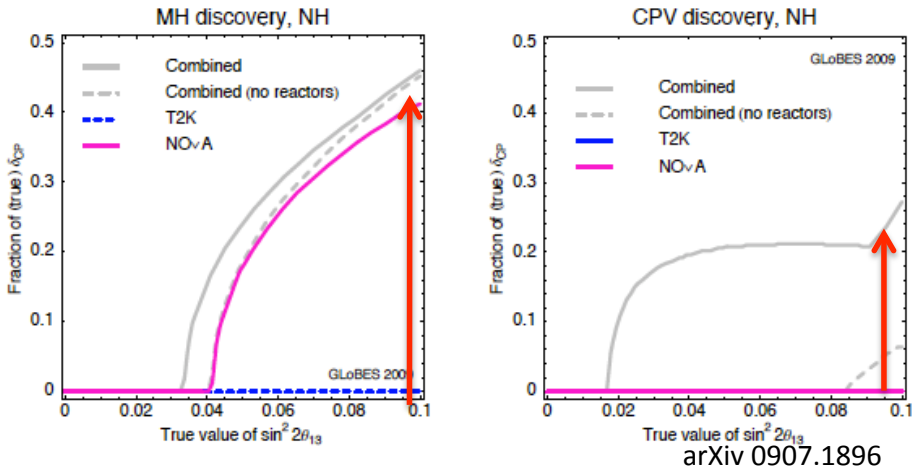


Letter of Intent ArXiv 1109.3262

Neutrino oscillations in EU

Since θ_{13} is large, T2K and NOvA will access at most (@90%CL) in 3-5 years

- MH for <50% of δ_{CP} values
- ~20% of δ_{CP} values.



arXiv 0907.1896

Need for future experiments to go further:

→ new detectors and possibly new beams

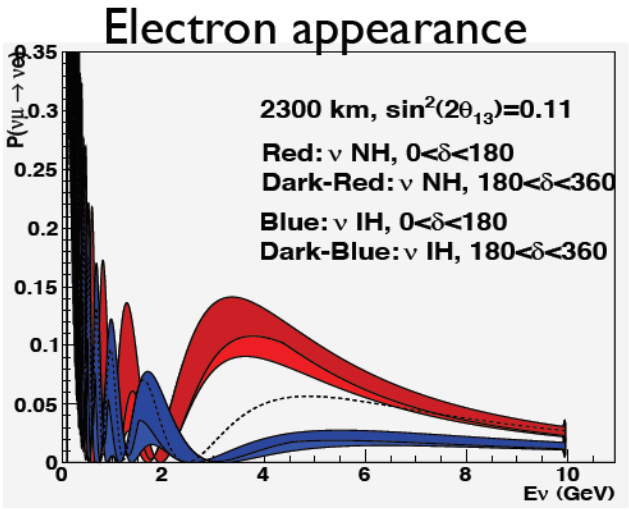
Consensus on a realistic <u>"incremental approach"</u> :

- phase 1. : establish Mass Hierarchy, extend δ_{CP} coverage
  - → detector of 10-20kt, beam based on existing accelerators
- phase 2. : if CP not discovered, extend coverage as much as possible
  - → larger detector and new beam
  - → best option investigated by LAGUNA-LBNO FP7 design study

⇒ **Expression of Interest to CERN/SPSC + input to EU roadmap, CERN May 2012**

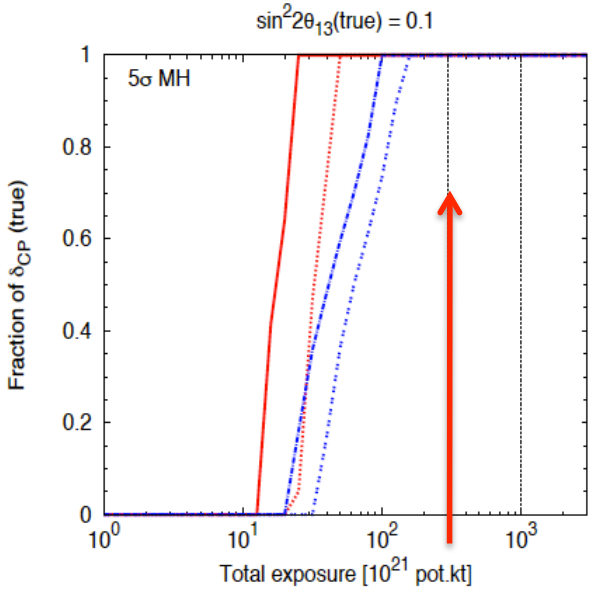
ν oscillations: phase I

- 10-20 kton Liquid-Argon TPC (+ magnetised iron det.)
- located in Pyhäsalmi mine, Finland
- wide-band-beam from CERN, based on SPS
  - baseline = 2290 km, close to "magic" where matter effects for MH disentangle from CP-viol.

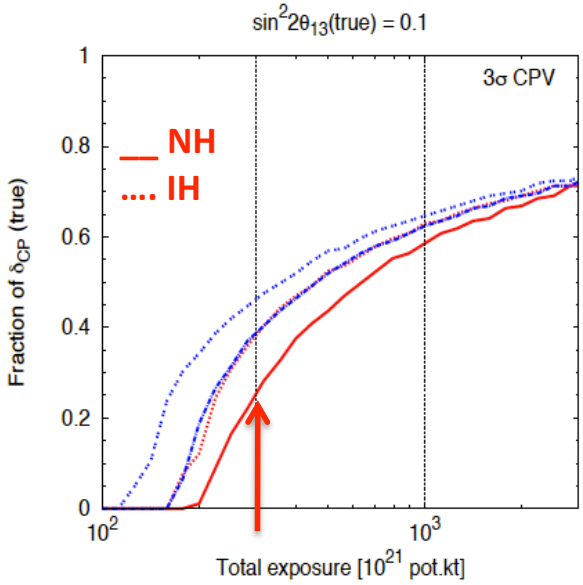


Physics reach :

1) measure **Mass Hierarchy** @3 σ in 3 y with ν only,
@5 σ in 10 y with $\nu + \nu$ bar ; 2) cover 20-30% of δ_{CP} values @3 σ



arXiv 1109.6526



ν oscillations: phase 2 [LAGUNA-LBNO]

EU FP7 Design Studies

LAGUNA (2008-11)
studied 7 underground sites in Europe

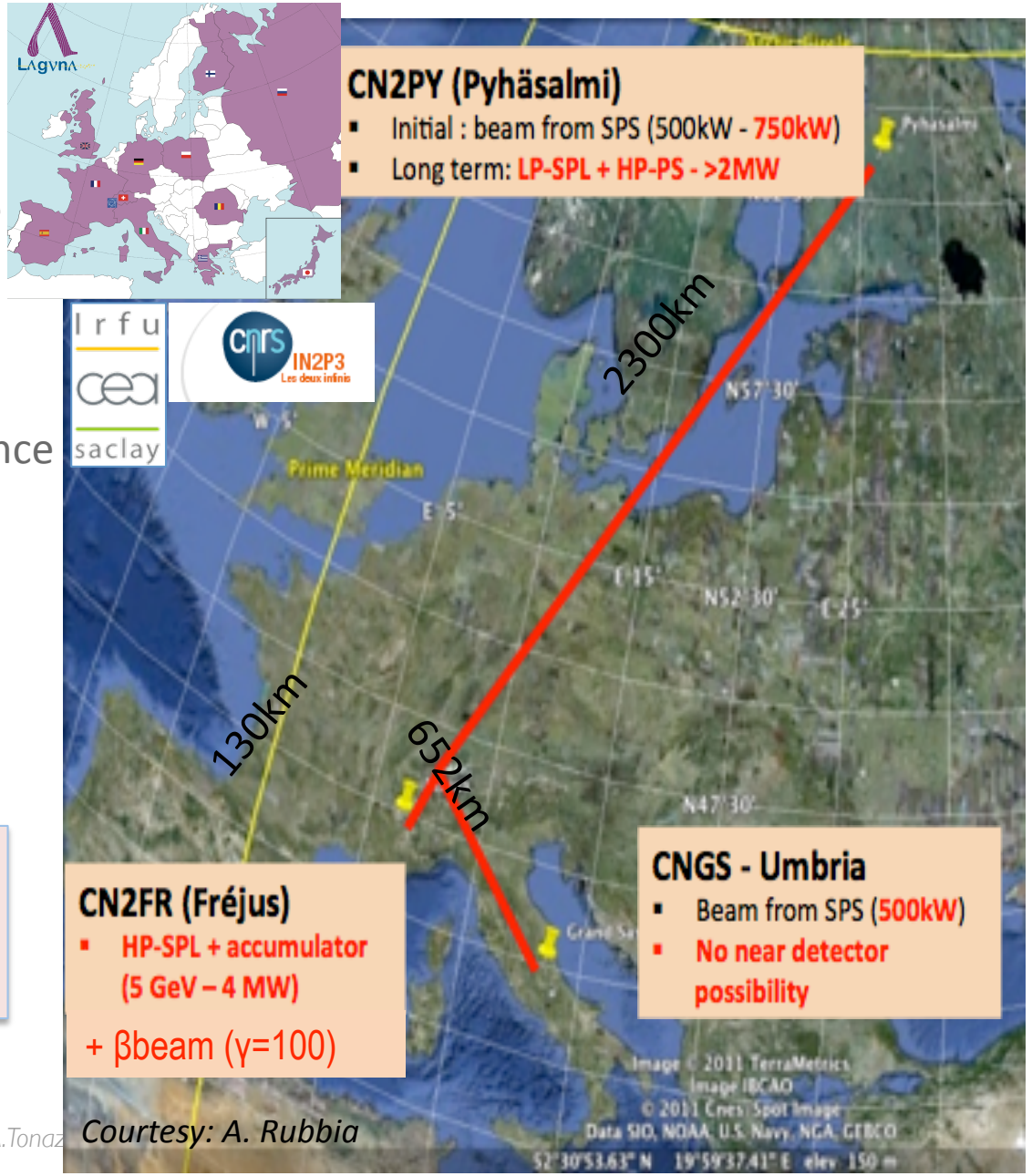
LAGUNA-LBNO (2011-14)

- New conventional ν_μ beams to be considered, based on CNGS experience
- Focus on the 2 baselines specific to Europe:

▶ **CERN-Fréjus** short baseline.
- No Matter effects, pure CP-violation
- Good synergy for enhanced physics reach with β-beam

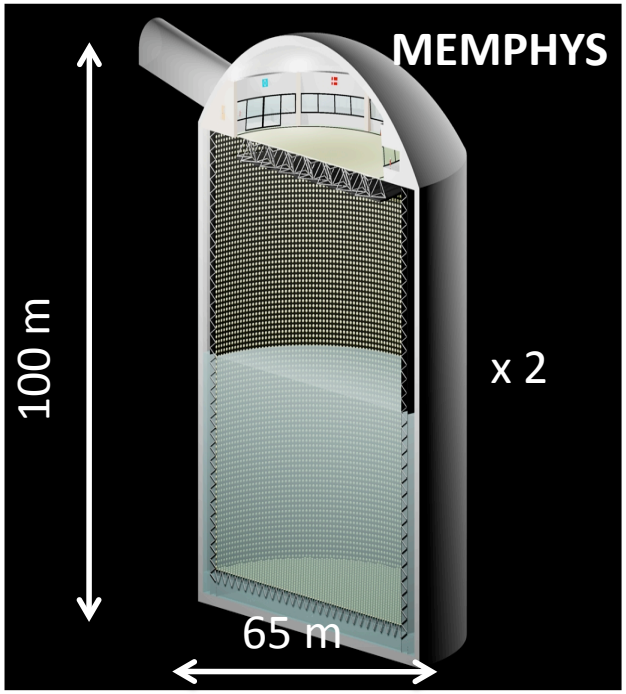
▶ **CERN-Pyhäsalmi** longest baseline.
- Close to "magic baseline"
- Good synergy for enhanced physics reach with a NF

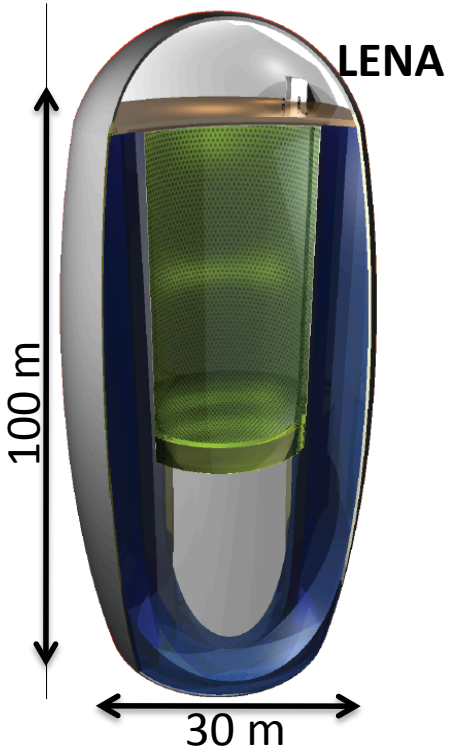
[+CERN-Umbria, with lower priority]

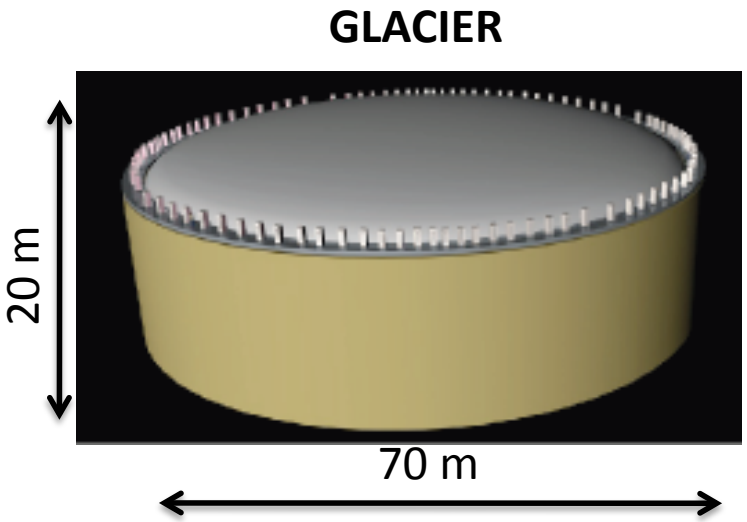


Courtesy: A. Rubbia

The detectors







Water-Cherenkov 2 x 330 kt

Excellent particle-ID and momentum measurement

Liquid scintillator 50 kt

Very low energy threshold
Potential for use with beam under development

Liquid Argon TPC 100 kt

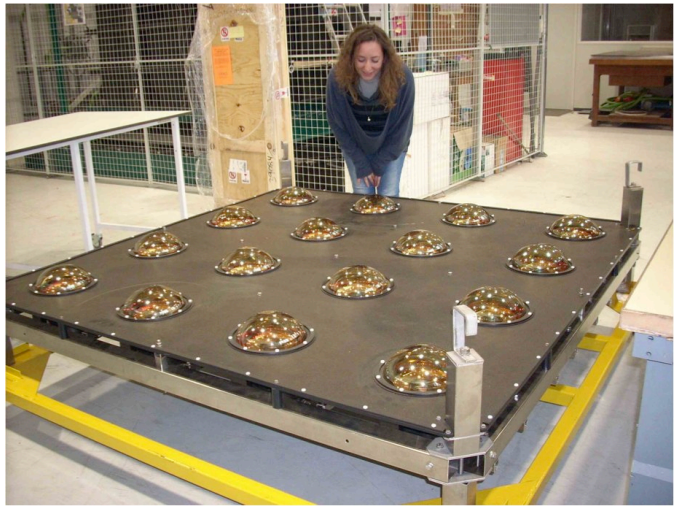
Excellent background rejection
Good efficiency at high energy
Excellent energy resolution

+ Magnetised Iron Detector
MIND

Activities in France : R&D

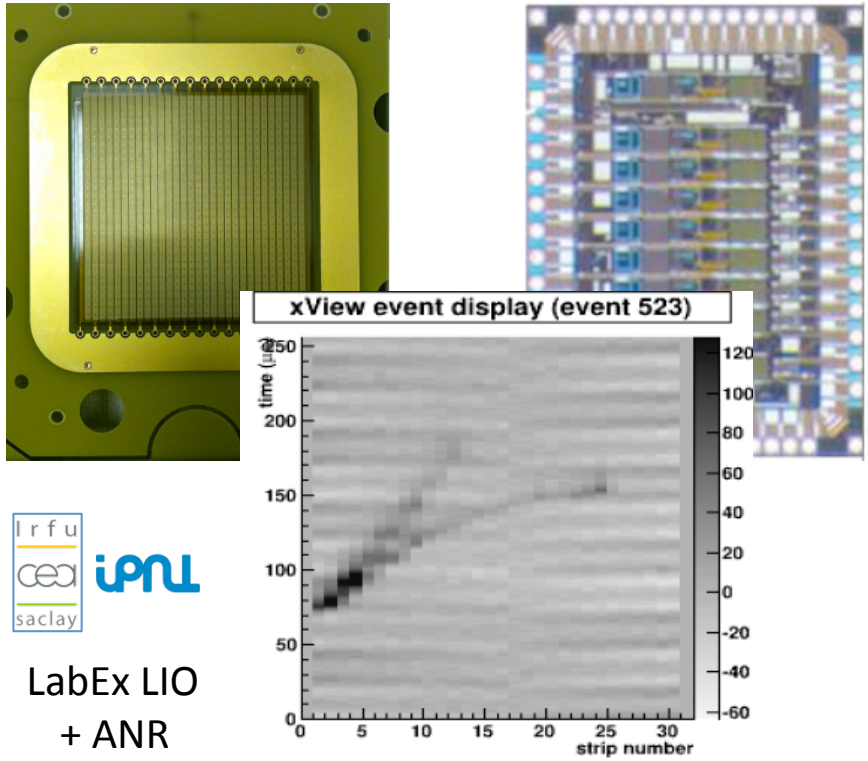
Grouped readout and electronics for PMTs

All LAGUNA detectors have a very large number of PMTs (45000-220000):
need to reduce costs and complexity
→ParisROC card
→MEMPHYNO test bench



MicroMegas + readout electronics for double-phase LAr TPC

(expertise from T2K ND280)
→ Operation in cryogenic environment



LabEx LIO
+ ANR

R&D will have a key role in the upcoming 10 years

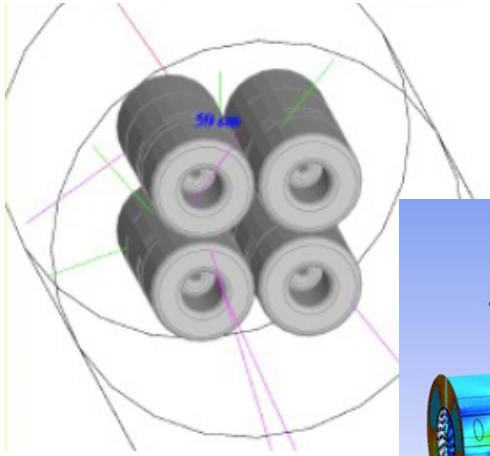
Activities in France : FP7 D.S.

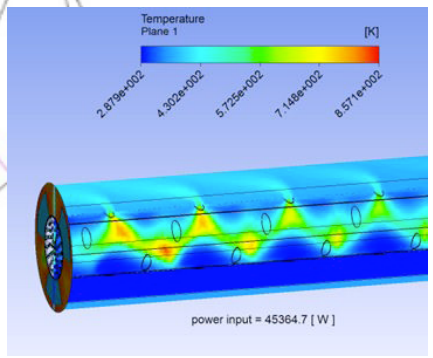
EUROnu (2008-2012)

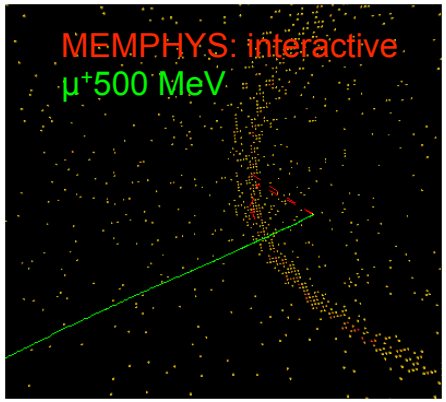
- Design and optimisation of target and horn for super-beam
- Water Cherenkov detector optimisation and simulation
- Study of physics potential

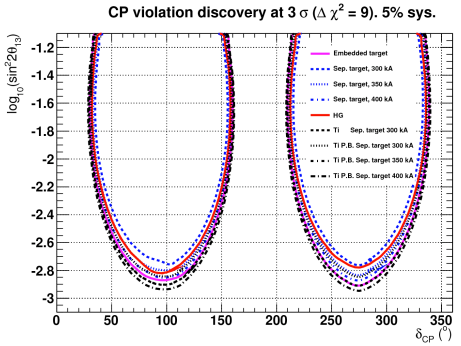
LAGUNA-LBNO (2011-2014)

- Physics coordination
- Detector construction and long-term operation studies
- Underground facilities
- Common simulation and analysis framework
- Detailed physics potential





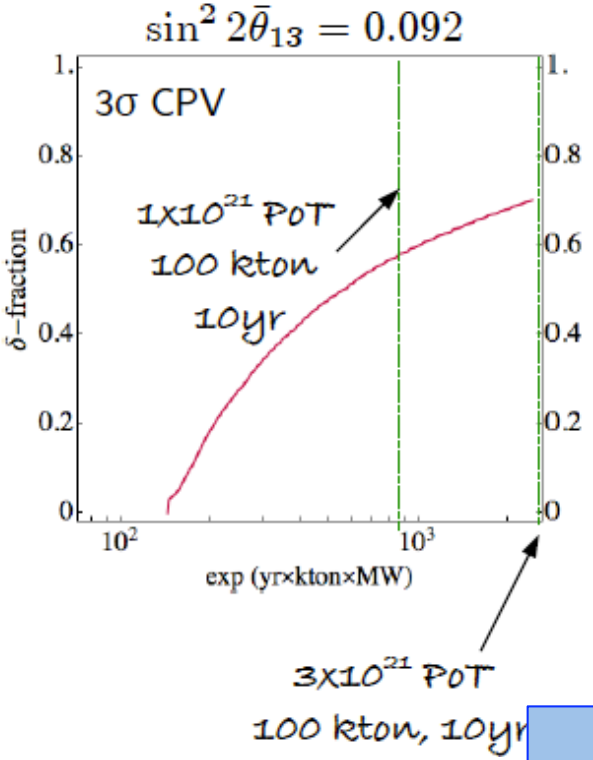


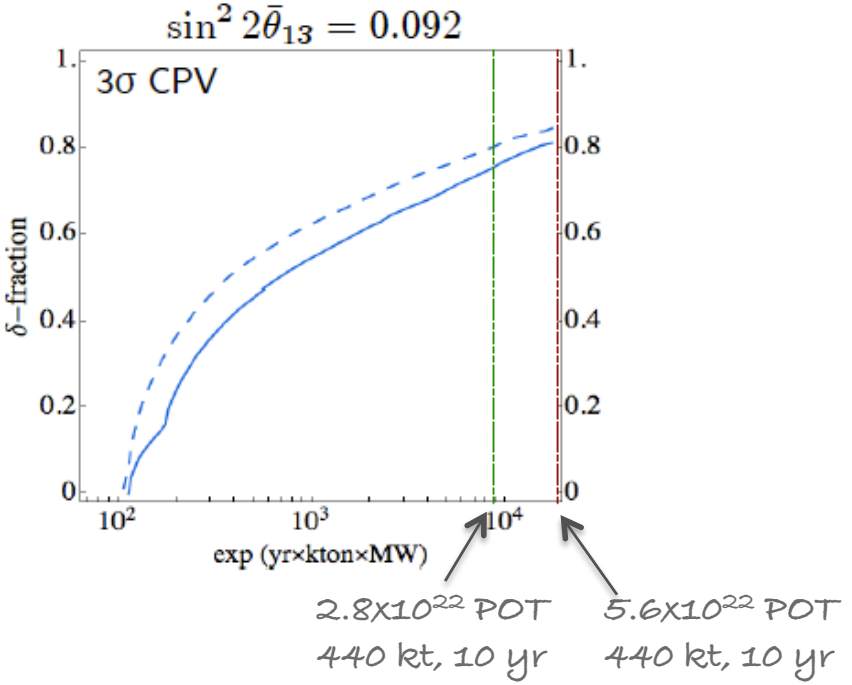


Physics reach – ν oscillations

GLACIER @ Pyhäsalmi:
→ up to 70% of δ_{CP} values (@3 σ)

MEMPHYS @ Fréjus:
→up to 80% of δ_{CP} values (@3 σ)



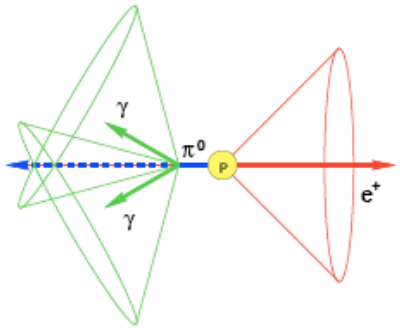


NEW:
tracking in liquid scintillator
=> LENA useful for beam ν s

More detailed studies ongoing in LAGUNA-LBNO

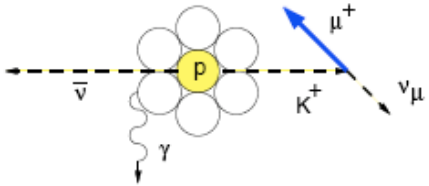
Physics reach – Proton decay

$p \rightarrow \pi^0 e^+$

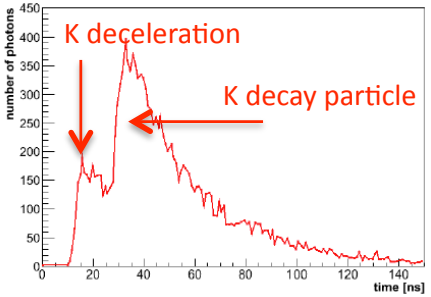


golden channel for Water Cherenkov
ε >40%, bkg from atm. antinue's

$p \rightarrow K^+ \bar{\nu}$



golden channel for Liquid Scintillator using pulse-shape, LAr using dE/dx. Bkg from atm. numu's



	MEMPHYS	LENA	GLACIER
$e^+\pi^0$: ε(%)/bkg(Mton.y) τ_p/B (90%CL 10y)	43 / 2.25 1.0×10^{35}	- -	45 / 1 0.4×10^{35}
$K^+\nu$: ε(%)/bkg(Mton.y) τ_p/B (90%CL 10y)	8.8 / 3 0.2×10^{35}	65 / 2.2 0.4×10^{35}	97/1 0.6×10^{35}

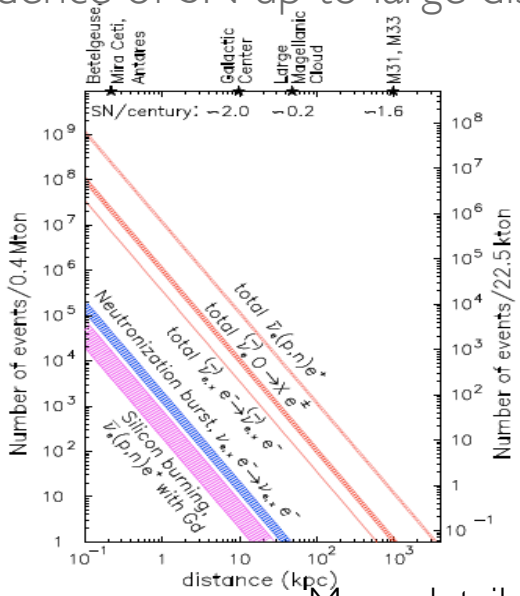
More detailed studies ongoing in LAGUNA-LBNO

Physics reach – ν astrophysics

Supernova Core Collapse

Large statistics of neutrinos, all flavours in different detection channels

1) **spectral analyses** in E,t =>
   - SN explosion mechanism: shock waves, neutronization burst
   - Neutrino production parameters: rate, spectra
   - Neutrino properties
2) Evidence of SN up to large distance



[cf GT10]

Diffuse Supernova Neutrinos

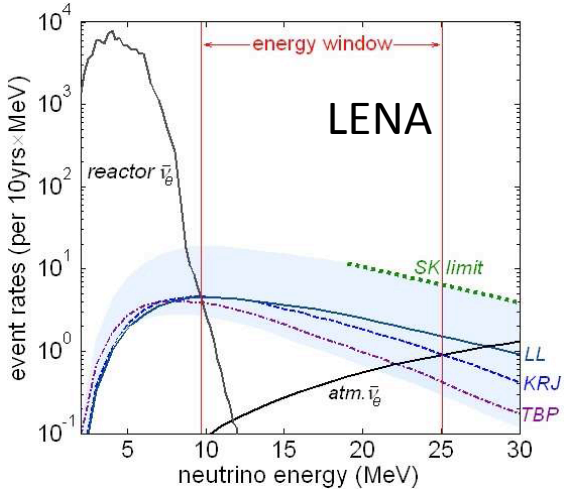
-current upper limit from SK and SNO:

$$\Phi(E_\nu > 19.3MeV) < 1.2cm^{-2}s^{-1}$$
$$@90\%C.L.$$

-Predictions : O(0.01-0.1)cm^{-2}s^{-1}MeV^{-1}

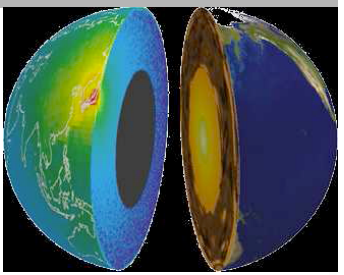
→Few to tens events/year in megaton detectors: **3 σ evidence** in few years

→Measure emission parameters

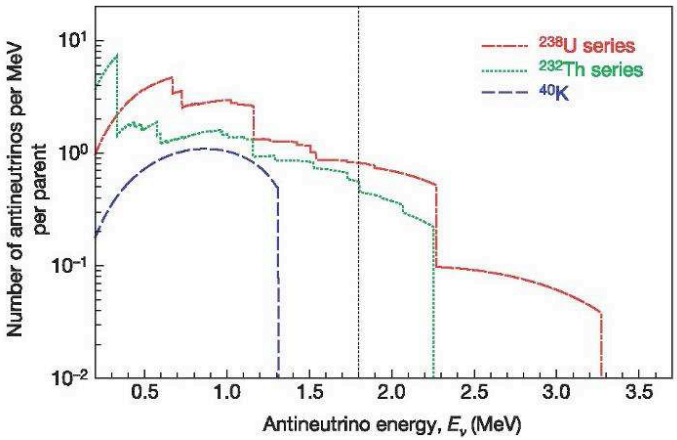


More detailed studies ongoing in LAGUNA-LBNO

Physics reach – Geoneutrinos

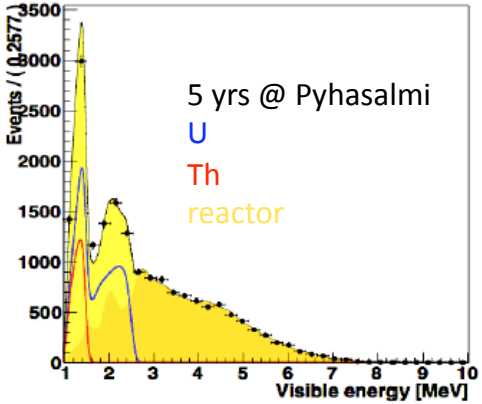


- total heat flux from the Earth ~40TW, radiogenic heat is a large fraction :
  → $\bar{\nu}_e$'s from decay chains of U,Th,K
- ν s provide a unique access to distribution of radiogenic elements in the mantle
- U/Th ratio can discriminate models of Earth's formation



1st evidence: KamLAND 2005
Measurement @3 σ : Borexino+KamLAND 2010

LENA potential: ~1000 evts/y
- overall flux @ few % in 1 year
- U/Th @ 5% in 5y @Pyhasalmi
  @ 11% in 5y @Frejus



[cf GT17]

More detailed studies ongoing in LAGUNA-LBNO

Summary and outlook

- Large θ_{13} will be precisely measured with independent methods by current reactor and beam experiments: **Double Chooz**, **T2K**
- Consensus for a "**staged approach**" to investigate mass hierarchy and CP violation with neutrino oscillations
  - phase 1: 10-20kt LAr @Pyasalmi + beam from CERN with existing accelerators
  - phase 2: "megaton"-scale detector + new beam
- The physics case for a "megaton"-scale detector is strong:
  neutrino oscillations, proton decay, neutrino astro(+geo)physics
- The definition of the best long-term scenario is being addressed by the community within **LAGUNA-LBNO** FP7 DS

Possible scenario in EU