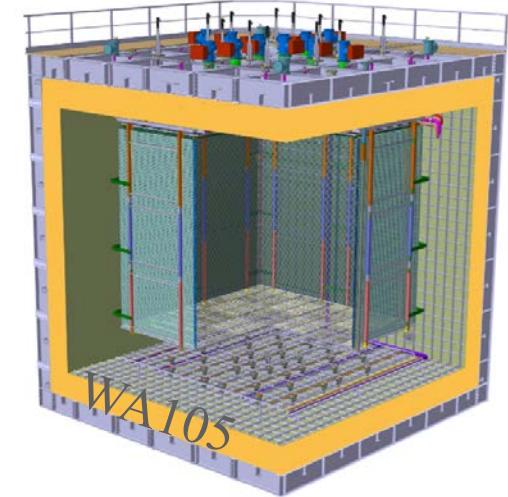
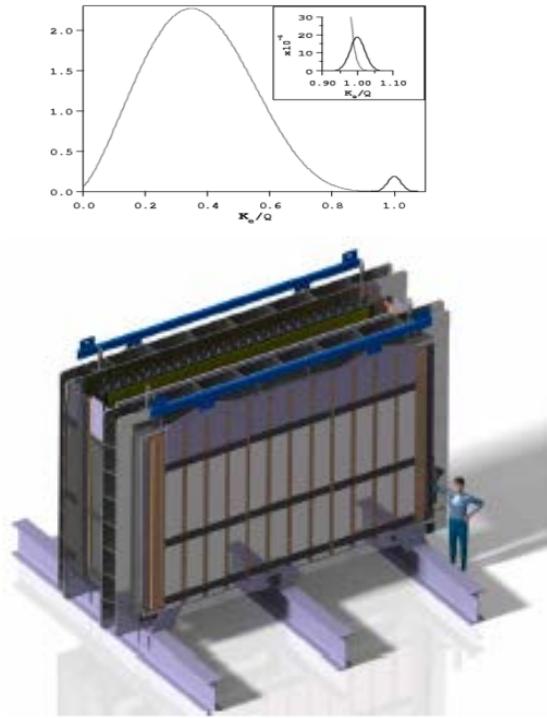
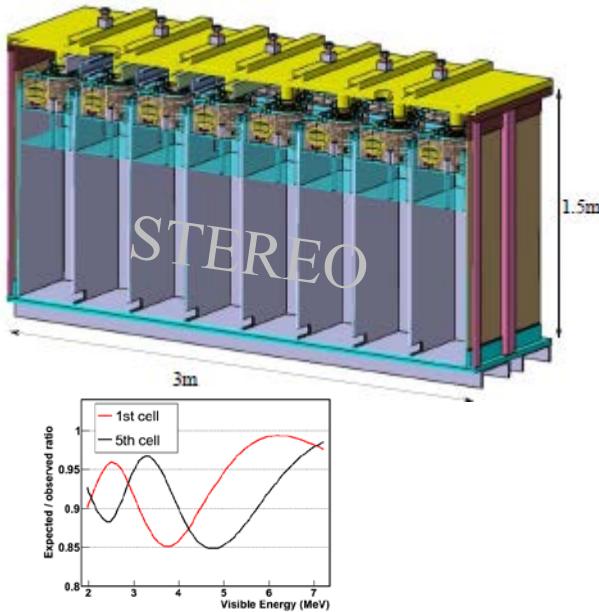


# Neutrino physics

D.Duchesneau

- Neutrino activities since 2013
- Scientific program for 2018-2028



SuperNEMO

# Neutrinos:

The neutrino properties are less well tested than for quarks and charged leptons and several unknown still exist.

still several fundamental questions to answer:

- what is the absolute mass scale?
  - fundamental for cosmology and unification scheme of interactions
- are neutrinos their own antiparticles (Majorana) or not (Dirac) ?
  - if Majorana  $\Rightarrow$  leptonic number violation, theoretical consequence (leptogenesis, GUT)
- Are there more than 3 mass eigenstates?
  - Some experimental data prefer sterile neutrino(s) with mass close to  $1 \text{ eV}/c^2$



- Which is the mass hierarchy?
  - Essential for CP violation quest
- Is CP symmetry violated in the leptonic sector?

Challenging experimental program: Enigmass is a major actor

## Neutrino Pole in ENIGMASS

The scientific program covers several of the present fundamental research topics in neutrino physics

The neutrino project proposed within ENIGMASS is based on the successful development of the activity in this field among the different experimental laboratory (LAPP, LPSC ad LSM)

=> rich neutrino physics program covering three of the key subjects with scientific output guaranteed in a medium term and the preparation of the future with longer-term project

**This program is in adequacy with the national and international roadmaps.  
It is performed using close infrastructures : CERN, ILL, LSM**

# Experimental activities in this framework:

## STEREO project (2013-2019)

(ANR ‘programme blanc’ grant)

- Radioactive source calibration system
- Shieldings: mechanics, realisation
- Acquisition electronics +  $\mu$  veto
- Installation and commissioning at ILL reactor in 2016
- Running and data analysis (start end of 2016)



## SuperNEMO demonstrator (2013-2019)

- development of the double beta source foils
- development of the detector ‘Slow control’
- Chemical Se purification (with JINR Dubna)
- Installation and commissioning at LSM in 2017
- Running and data analysis (expected to start in 2018)



## WA105 / ProtoDUNE-DP (2014-2020)

- Scintillation light readout electronic
- Mechanical structure and automated control of the charge readout plane
- Simulation
- Running and data analysis (expected to start in 2018)



+ ....

## Neutrino Human Resources

Neutrino activities (LPSC+LAPP+LSM): 11 permanents  
+ 4 postdocs => 3 Enigmass  
+ 5 PhD => 1 Enigmass  
+ 3 Invited professors

### STEREO

- 1 postdoc: V. Hélaine (2013-2016)

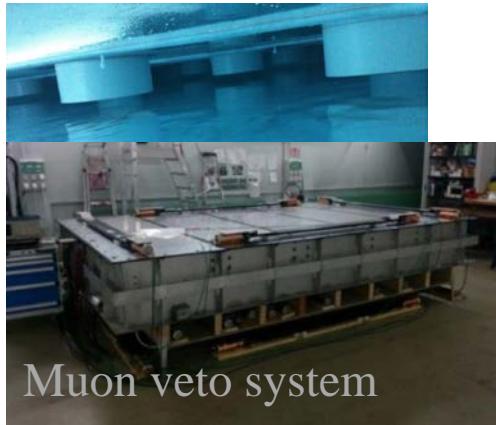
### SuperNEMO

- 1 postdoc: A. Remoto (2013-2017)
- 2 Invited professors: K. Lang (2014-2015) from UT Austin and R. Saakyan from UCL (2016-2017)
- 2 visitors from ITEP (S. Konovalov (29 days), A. Barabash (9 days))

### WA105/DUNE

- 1 postdoc: L. Zambelli (2016-2019)
- 1 PhD: A. Chappuis (2015-2018)
- 1 Invited professor: J. Yu (2015-2016) from UT Arlington

# STEREO activity status in 2016



August 2016 : Assembly of the shielding and the detector complete

September 2016 : Detector moved to its data-taking position

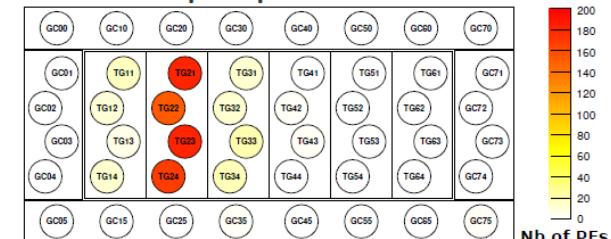
Installation of the source calibration system



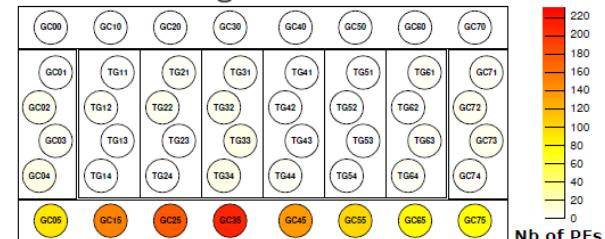
Filling of the detector  
in November 2016



Event of prompt neutrino candidate :



Event of background in Gamma-catcher :

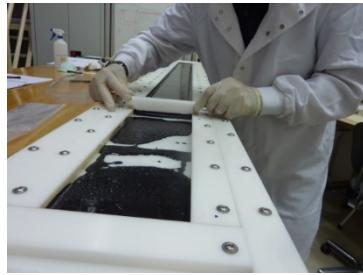


⇒ 1.5 reactor cycle already taken; detector maintenance under way

⇒ Next step: reinstall detector by September and restart data acquisition in Oct 2017<sup>6</sup>

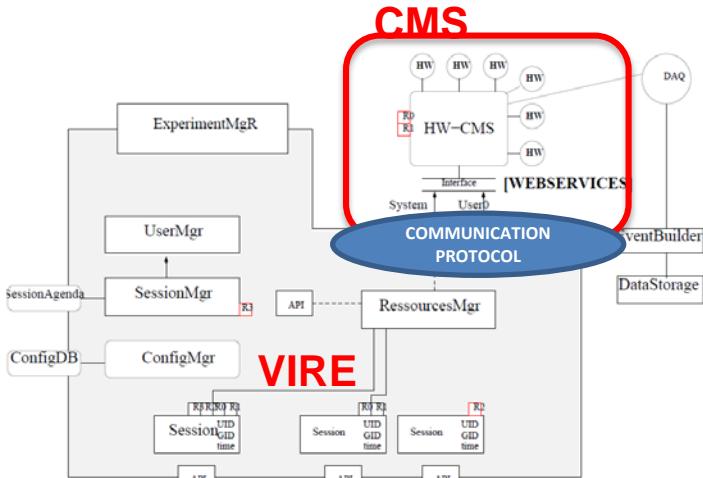
# SuperNEMO activity status

Realization of full size foils with enriched  $^{82}\text{Se}$



Production ending: 16 foils prepared with the LAPP method and 15 with ITEP

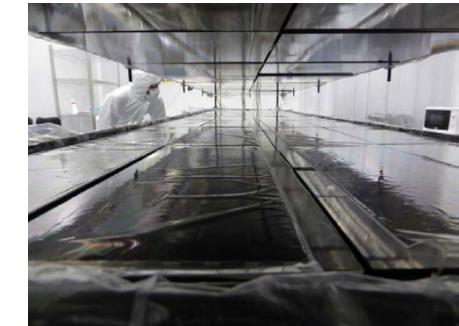
Control & Monitoring System development



- CMS integration and commissioning with  $\frac{1}{2}$  detector
- Interface control definition for each sub system

Source radiopurity measurement in Canfanc

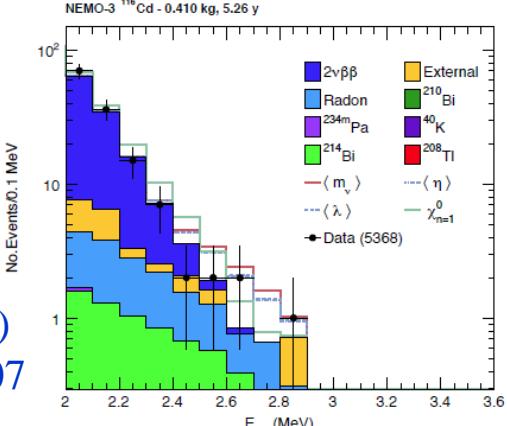
Measure  $^{214}\text{Bi}$  et  $^{208}\text{Tl}$



$^{116}\text{Cd}$  analysis with NEMO-3

$$T^{2\nu}_{1/2} = [2.74 \pm 0.04(\text{stat.}) \pm 0.18(\text{syst.})] \times 10^{19} \text{ y}$$

$$T^0\nu_{1/2} \geq 1.0 \times 10^{23} \text{ y} @ 90\% \text{ C.L. } \langle m_\nu \rangle \leq 1.4 - 2.5 \text{ eV}$$



Phys.Rev.  
D95 (2017)  
no.1 012007



## Detector installation at LSM

Construction and assembly of parts in 2016 and 2017



- 2 calorimeters ready
- 1 half tracker ready,
- Second half is being integrated
- Source foil installation in autumn
- Shielding, magnetic coil, anti-radon system and electronics to be installed in the autumn



Commissioning and  
detector run by the end of  
2017

The world experimental neutrino physics program for the coming 10 years (until 2027) will focus mostly on a few main subjects:

- Sterile neutrino searches using short baseline accelerator and reactor experiments
- Mass hierarchy determination with reactor, accelerator and deep-sea detector
- Understanding the CP violation in the lepton sector and its CP phase measurement on accelerator long baseline experiments (running and in preparation)
- The nature of the neutrino will continue to be investigated through neutrinoless double beta decay experiments where running projects should see upgrades to higher masses in order to improve the actual limits on the half-life of isotopes and the effective neutrino mass

This list is not exhaustive but gives the main topics

The scientific goals of the proposed neutrino project for the coming 10 years are 3 folds:

- A. To pursue the present activities in order to complete the different running experiments developed within the labex framework since 2013, which are STEREO at ILL and the SuperNEMO demonstrator at LSM
- B. To develop the participation to the future long baseline project called DUNE aiming at discovering the CP violation in the lepton sector and measuring the CP phase. This long-term project should become the main activity beyond 2020 for ENIGMASS after STEREO and SuperNEMO have finalised their results.
- C. To develop eventually low energy neutrino experiment at LSM and prospect for ideas to upgrade SuperNEMO double beta source foils with different isotopes (like  $^{150}\text{Nd}$ )

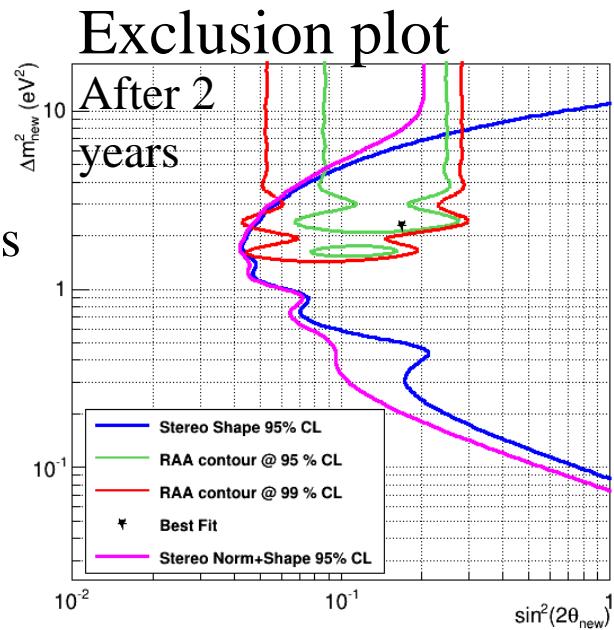
## A) Continue the actual projects (2018-2021)

### STEREO running and analysis

#### Schedule and goals:

2018: run the experiment during 3 reactor cycles. This will be added to 3 cycles in 2017 and 0.5 in 2016

2019: Analyse and get results on sterile search



### SuperNEMO demonstrator running and analysis

#### Schedule and goals:

2018: commission and run the full demonstrator during 2.5 years with 7kg of  $^{82}\text{Se}$   
 $\Rightarrow$  study all background channels in detail

2020: End of run

2021: Analyse and get results on half life of  $^{82}\text{Se}$  and full background estimate

Background level  $\sim 10^{-4}$  cts./(keV kg y)

- Background free at high energy
- Sensitivity:

$$T_{1/2} > 6.6 \cdot 10^{24} \text{ y}$$

$$\langle mv \rangle \sim 0.20 - 0.40 \text{ eV}$$

$\sim 1.5$  better than NEMO-3

## B) Develop participation to Long Baseline (2018-2028)

### ProtoDUNE-DP / WA105 (2018-2020)

#### Schedule and goals:

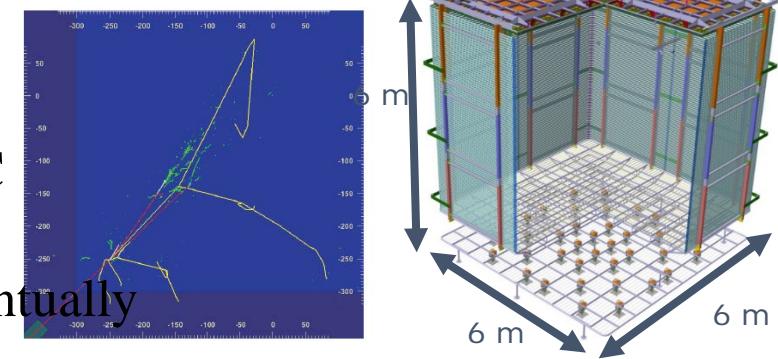
**2018:** Finish the construction and installation of the Dual Phase TPC in the cryostat.

Commission and prepare the experiment to take beam data before CERN accelerator stop in Oct

Run with cosmics data

**2019:** Analyse and get results to validate the TPC technology for DUNE far detector TDR

**2019-2021:** long run with cosmics and beam eventually



### DUNE LBL physics studies and Far detector design/construction

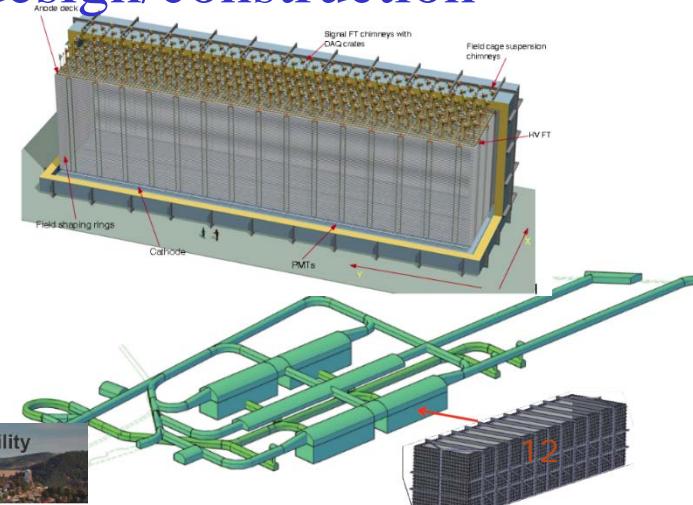
#### Schedule and goals:

**2020-2021:** Design of the Far detector Lar TPC

**2022:** start installation in underground cavern

**2026:** Detector commissioning and first beams

- Prepare the analysis and develop detector simulation and reconstruction software



## C) Develop low energy neutrino experiments at LSM. Possibility of R&D but program has to be better setup

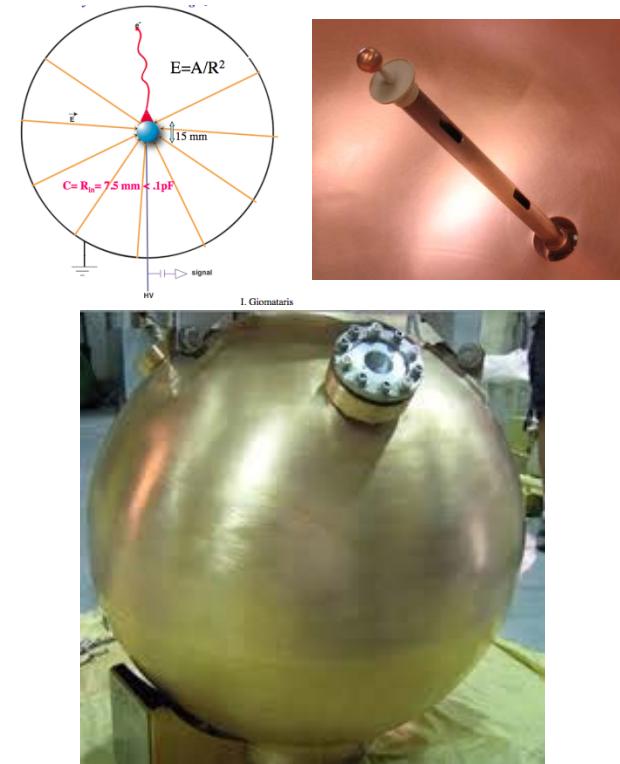
### Spherical Proportional Counter R&D

Develop a large scale Radial TPC with spherical proportional counter read-out

With SPC filled with Xenon:

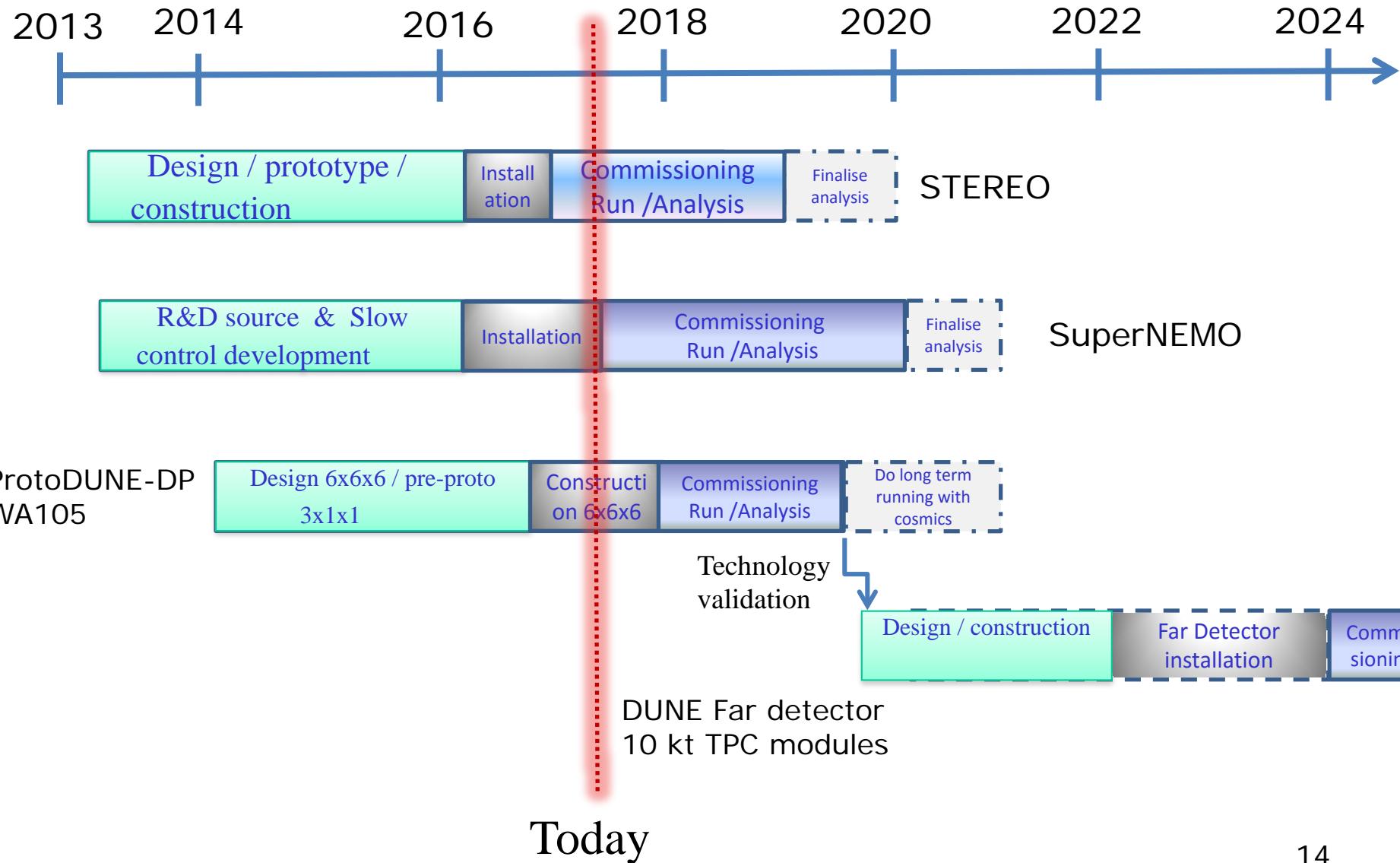
- Double beta decay experiment
- Low energy neutrino coherent scattering
- Supernovae neutrino detector

To be discussed among groups



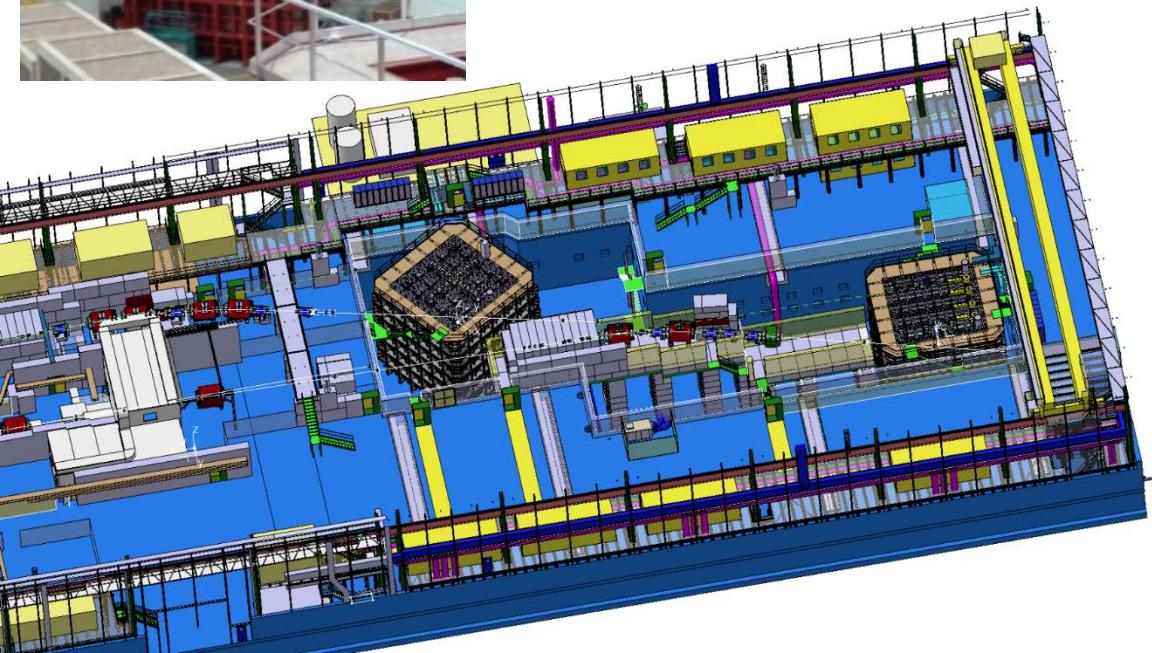
Example: Sedine at LSM

# Neutrino activity Timeline for items A and B





# Thank you



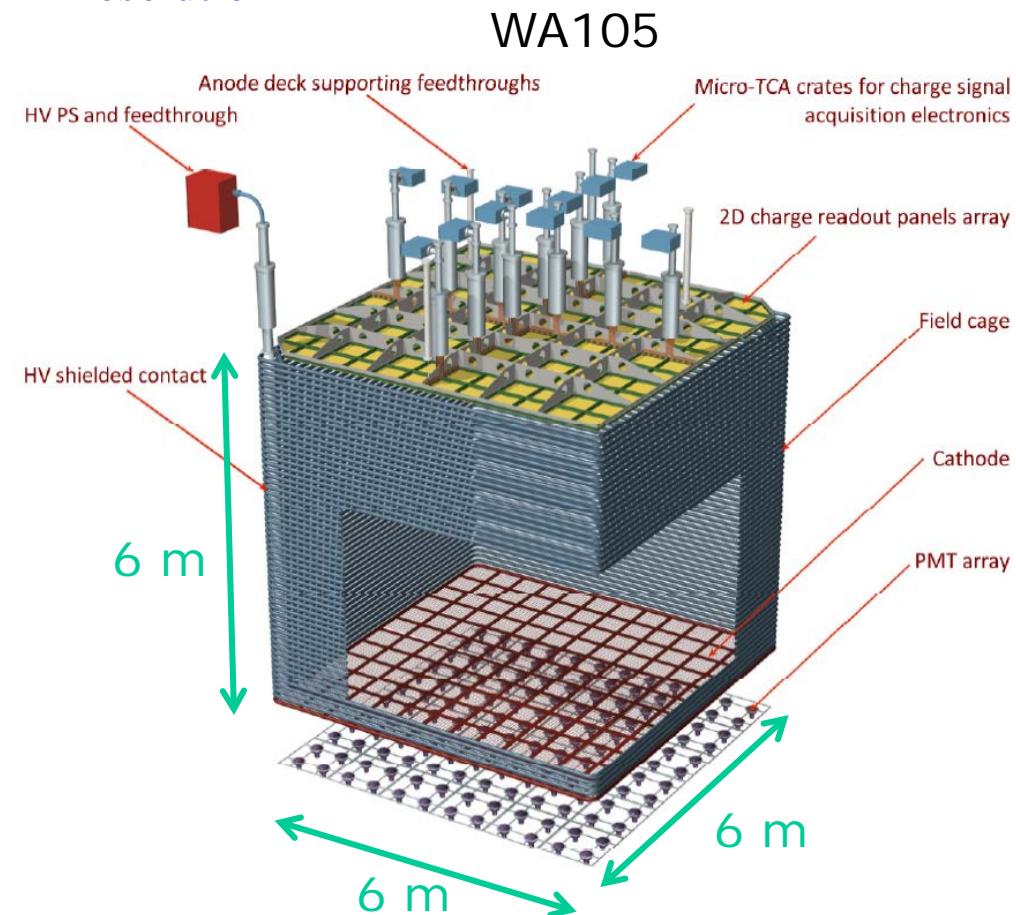
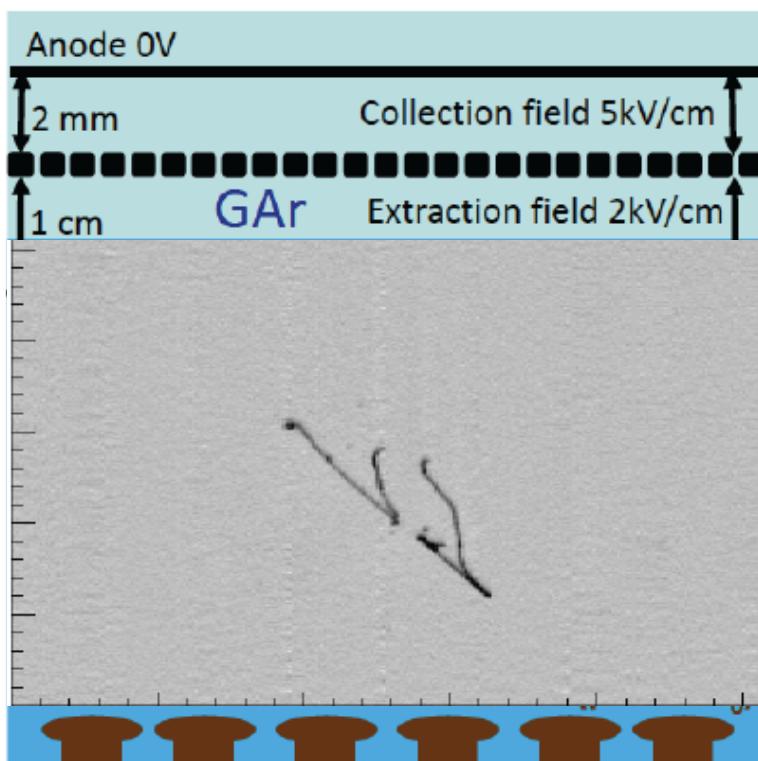
# WA105:

## Liquid Argon TPC

Principle: 3D imaging in a large volume Liquid Argon TPC

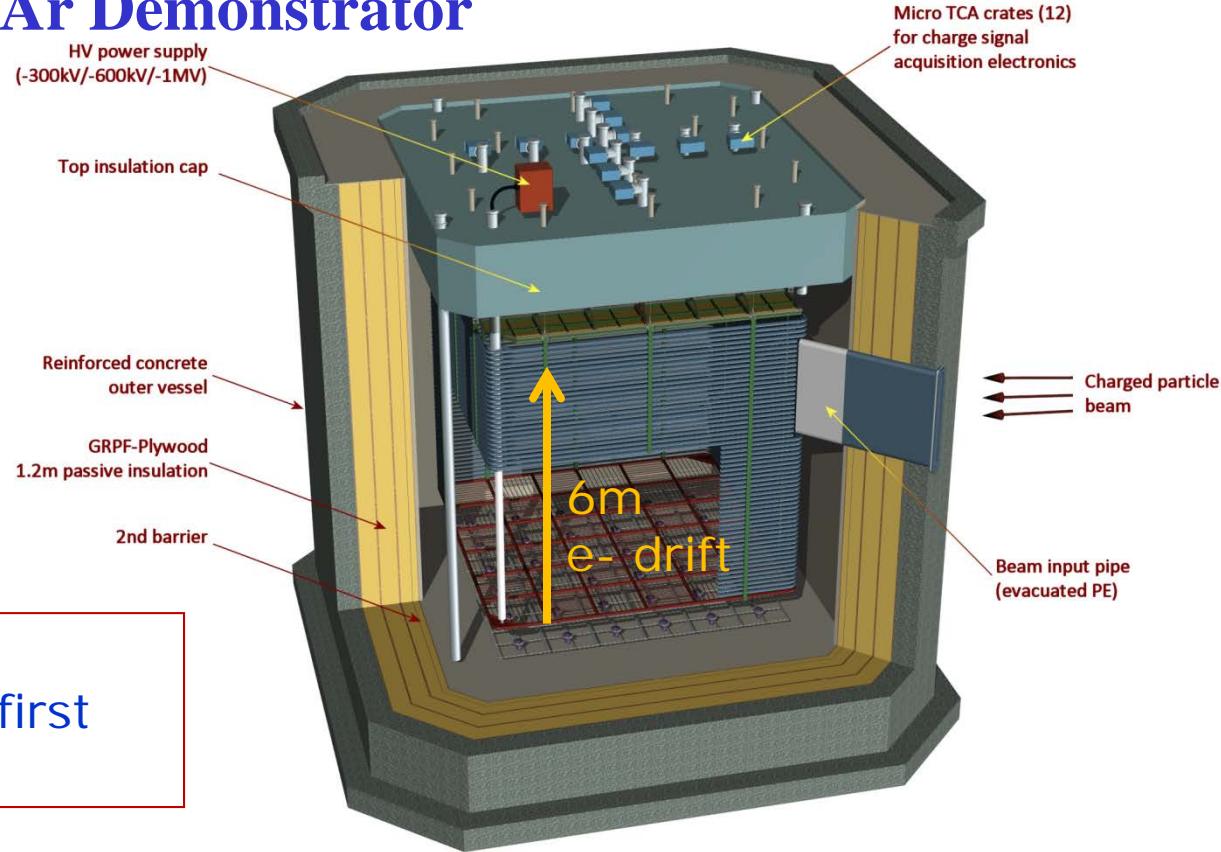
- very pure LAr (<0.1 ppb) → electrons can drift over large distances (>1.5 m)
- UV scintillation light (5000 photons/mm @ 128 nm) for  $t_0$
- Primary ionization in LAr: 1 m.i.p ~ 20000 e- on 3 mm
  - 3D reconstruction with ~1 mm resolution

Concept of double-phase LAr TPC (Not to scale)



# WA105 Double Phase LAr Demonstrator

At CERN to test technical solutions and study the detector physics performance with charged particle beams



Validation of number of technical aspects with the first  $3 \times 1 \times 1 \text{ m}^3$  prototype

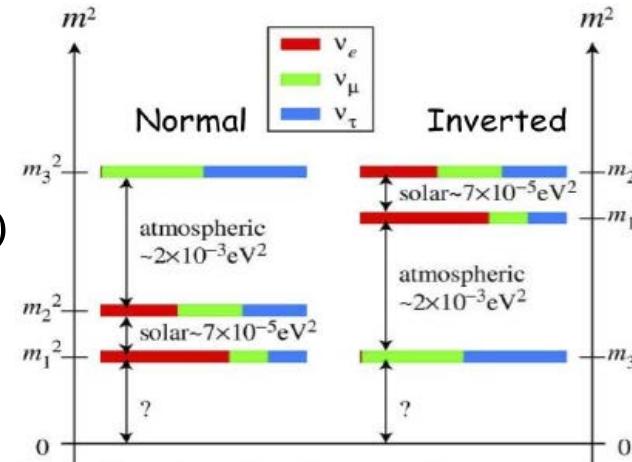
Several technical items have to be validated with a large scale prototype

- LNG tank construction technique
- Purity in non evacuated membrane tank
- Long electron drift distance
- High voltage system for the cage field 300-600 KV
- Double phase readout
- Cold front end electronic
- Interaction reconstruction in the TPC

# Hiérarchie de masse des $\nu$ et violation CP

## Hiérarchie de masse: avec des nouveaux projets

- atmosphériques (ex: Pingu, **Orca**, INO, HyperK)
- Réacteurs (**JUNO**, RENO-50 (20kton LSc, 60 km))
- Faisceau Long baseline  $\nu$  ( $> 1000$  km)
  - US => **DUNE** avec TPC Argon Liquide



$$U_{PMNS} = U_{\theta_{23}} \begin{pmatrix} c_{13} & 0 & s_{13}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{13}e^{i\delta} & 0 & c_{13} \end{pmatrix} U_{\theta_{12}}$$

## Violation CP:

quête en cours (T2K et NOvA) mais nécessite des nouveaux projets

- Faisceaux  $\nu$  Long baseline ( $>100$  km)
  - US => DUNE / TPC argon liquide / 1300 km
  - Japon => Water Cerenkov / 295 km (**T2K** => HyperK)

Ces 2 questions peuvent être abordées avec faisceaux conventionnels en étudiant les oscillations  $\nu_\mu \rightarrow \nu_e$  et  $\bar{\nu}_\mu \rightarrow \bar{\nu}_e$

## Hiérarchie de masse des $\nu$ et violation CP

Perspective d'ici 2026:

Nova (USA) et T2K (Japon): sur faisceaux

Premières indications d'une potentielle violation de CP mais la signification restera marginale et ne pourra pas dépasser 2-3 sigmas en 2026

Orca (Europe) et JUNO (Chine):

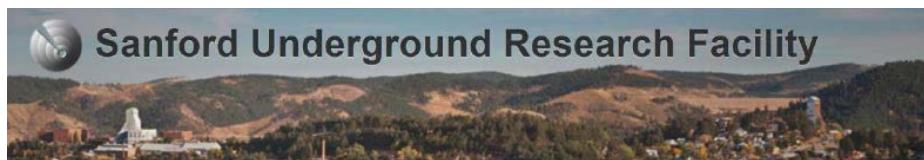
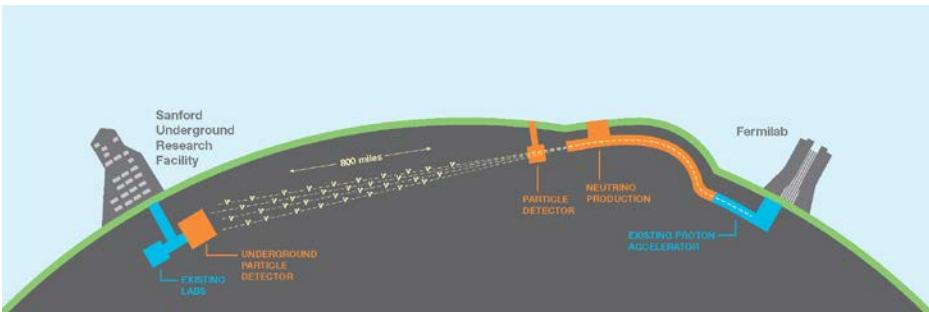
Chercheront à déterminer la hiérarchie de masse avec des atmosphériques dans la mer (Orca) et avec des neutrinos de réacteurs (JUNO);

=> Pourraient déterminer à 3-4 sigmas la hiérarchie d'ici 2026

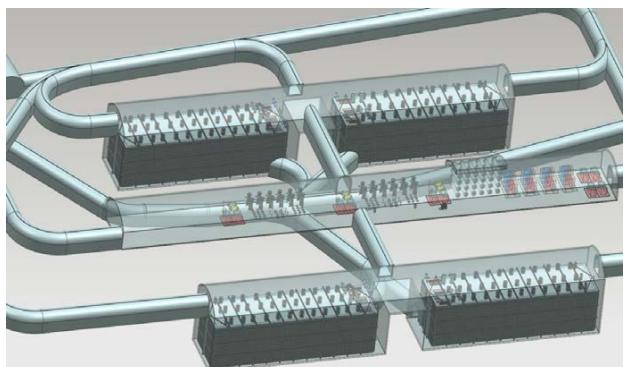
# Futurs projets de faisceau neutrino (>2026):

## USA : DUNE/LBNF

TPC Argon Liquide 4x10 kton  
à SURF (Mine de Homestake) ~2400mwe  
Faisceau de Fermilab (1.2-2.4MW)  
baseline=1300 km  $\langle E \rangle$  ~3 GeV



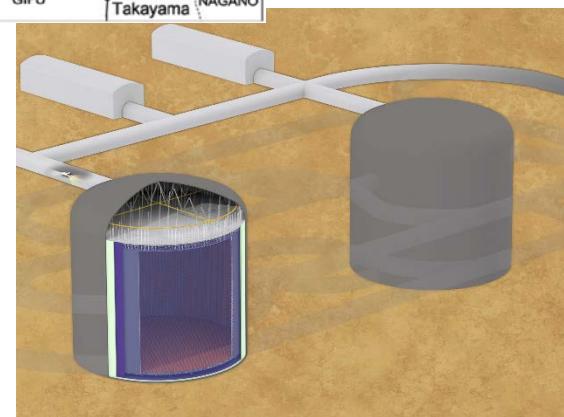
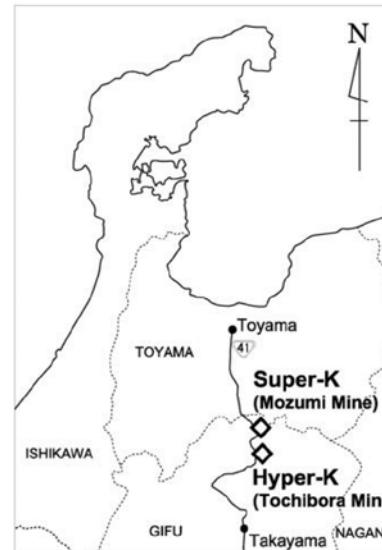
Ancienne mine d'or désaffectée:



niveau = -1.5 km

## Japon : Hyper-K

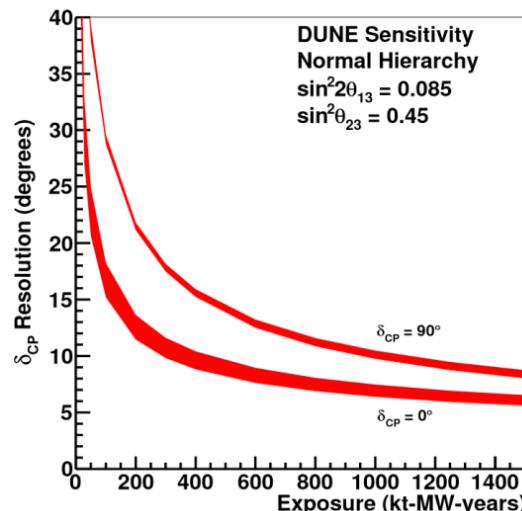
Cherenkov à eau 520 kton  
à Tochibora près de Kamioka, ~ 1750 mwe  
Faisceau Off axis de JPARC (1.3MW)  
baseline=295 km  $\langle E \rangle$  ~0.7 GeV



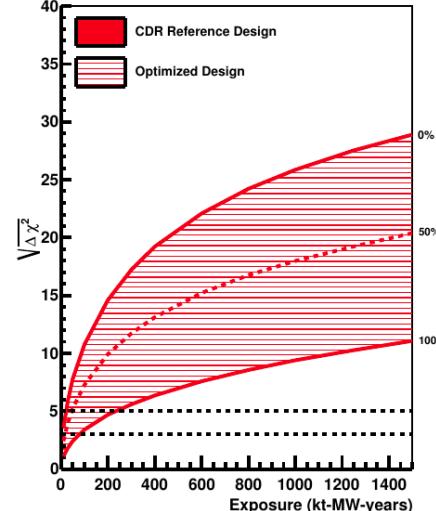
# DUNE physics performance

Physics milestone	Exposure kt · MW · year (optimized beam)	
1° $\theta_{23}$ resolution ( $\theta_{23} = 42^\circ$ )	45	1 year
CPV at $3\sigma$ ( $\delta_{\text{CP}} = +\pi/2$ )	60	
CPV at $3\sigma$ ( $\delta_{\text{CP}} = -\pi/2$ )	100	2 years
CPV at $5\sigma$ ( $\delta_{\text{CP}} = +\pi/2$ )	210	
MH at $5\sigma$ (worst point)	230	5 years
10° resolution ( $\delta_{\text{CP}} = 0$ )	290	
CPV at $5\sigma$ ( $\delta_{\text{CP}} = -\pi/2$ )	320	7 years
CPV at $5\sigma$ 50% of $\delta_{\text{CP}}$	550	
Reactor $\theta_{13}$ resolution ( $\sin^2 2\theta_{13} = 0.084 \pm 0.003$ )	850	
CPV at $3\sigma$ 75% of $\delta_{\text{CP}}$	850	

$\delta_{\text{CP}}$  Resolution

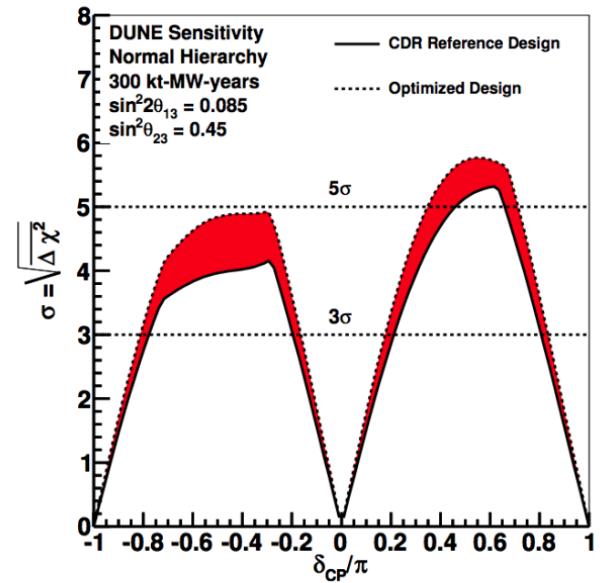


CDR, arXiv: 1512.06148

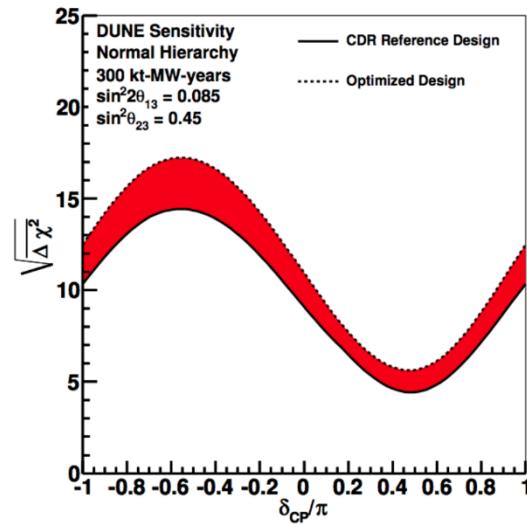


300 kt-MW-yrs = 3.5+3.5 years x  
40kt @ 1.08 MW, 80GeV protons

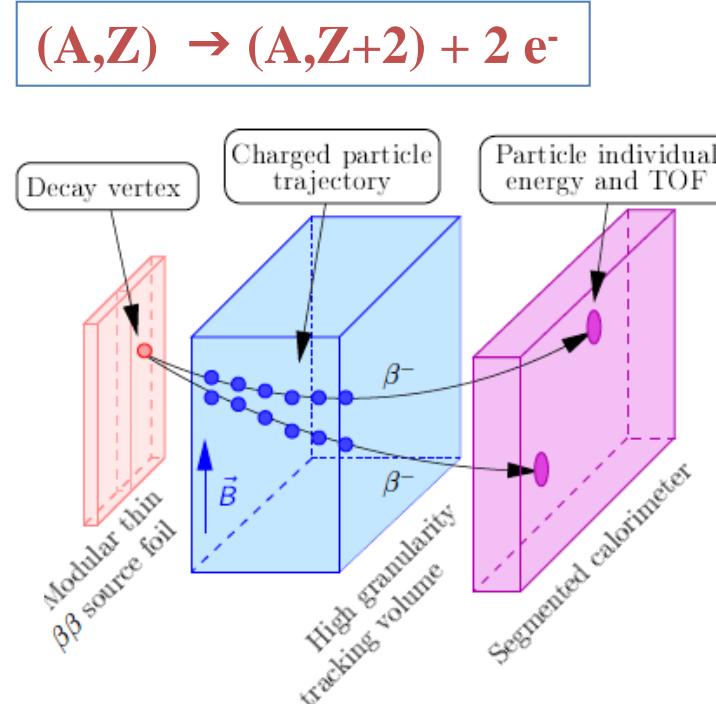
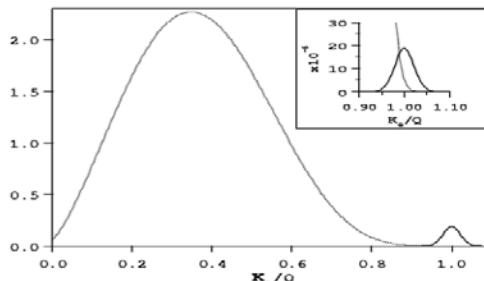
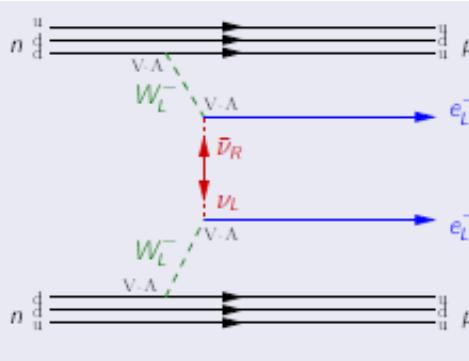
CP Violation Sensitivity



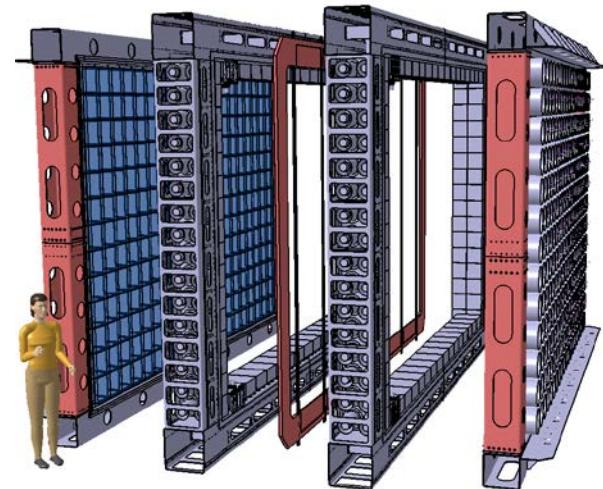
Mass Hierarchy Sensitivity



# SuperNEMO: $0\nu$ double beta decay experiment



Detector composed of a tracking chamber and a calorimeter + source foils of the  $2\beta$  isotope



Observables: electron energies, angular distributions

**Goal:** to reach the background level for 100 kg

↔ to perform a no background experiment with 7 kg isotope of  $^{82}\text{Se}$  in 2 yr

Sensitivity after 2 years :  $T_{1/2} > 6.6 \cdot 10^{24} \text{ y}$  and  $\langle m_\nu \rangle < 0.2 - 0.4 \text{ eV}$