# R&D for the next long baseline neutrino oscillation experiment


Marco Zito

For the Irfu T2K group


Saclay
June 17, 2013

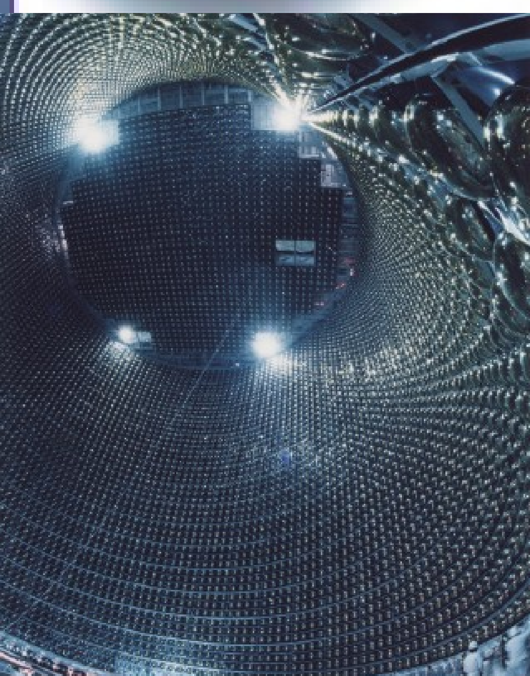
# The T2K group

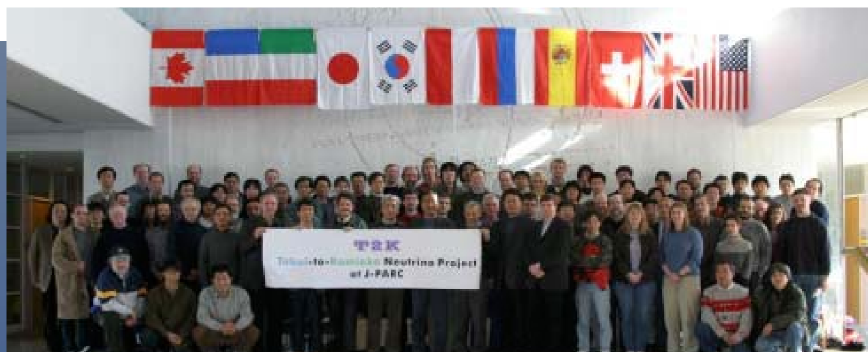
- Alain Delbart – Denis Calvet
- Olivier Bésida (→ R&D solar energy+startup)
- Sandrine Emery
- Chiraz Ferchichi (->thesis defense Jan. 2014)
- Vyacheslav Galymov (->until April 2014)
- Edoardo Mazzucato
- Georges Vasseur (->adjoint chef de service SPP)
- Marco Zito
- + a new staff physicist (fall 2013)

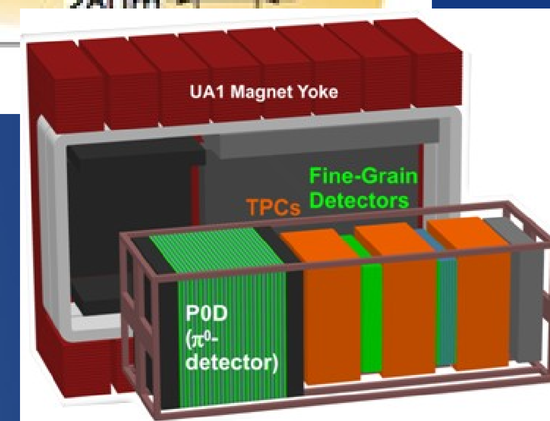
**SEDI**

**SPP**

# The T2K experiment

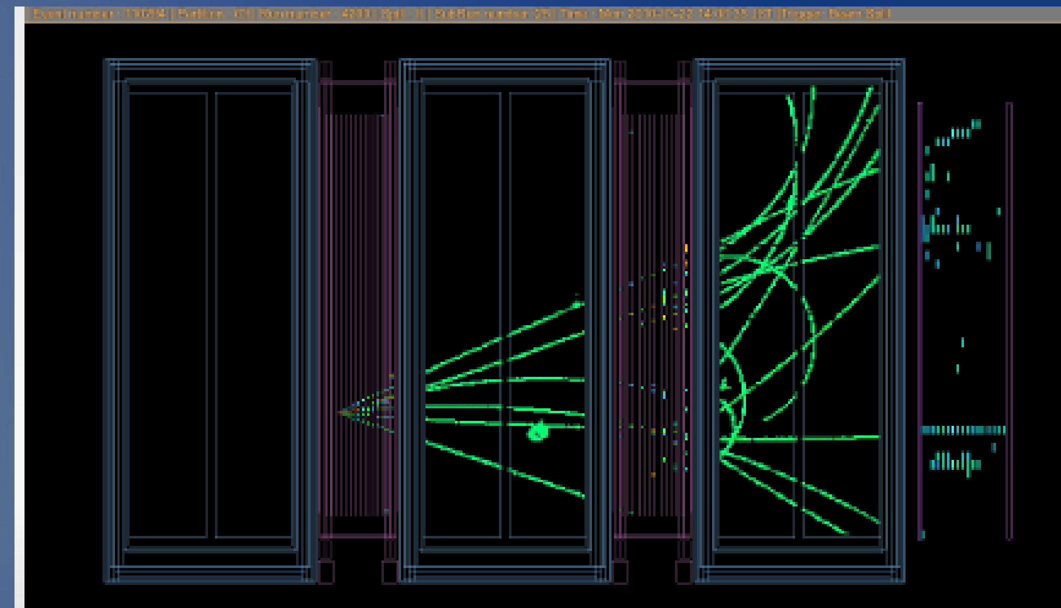





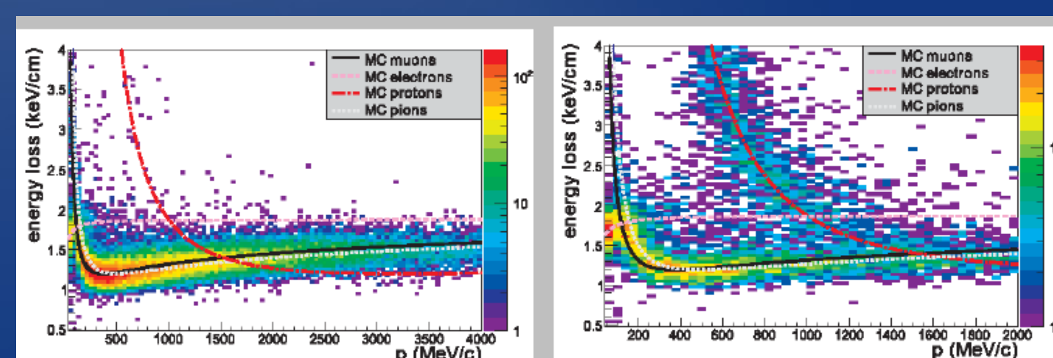



- **Tokai to Kamioka : T2K long baseline (295 km) neutrino oscillation experiment**
- **Japan-EU-USA-Canada collaboration: ~500 physicists**
- **IRFU: near detector and a contribution to the secondary beam-line (quench protection system)**

# T2K: the first large Micromegas TPC



Three large TPC built for the T2K near detector
First large TPC with MPGD
~9m**2 instrumented with MicroMegas
Saclay built also full FE electronics
A key detector for the study of neutrino oscillations

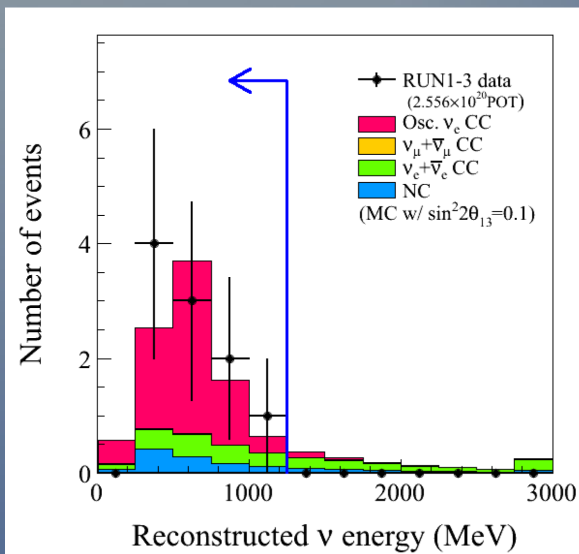


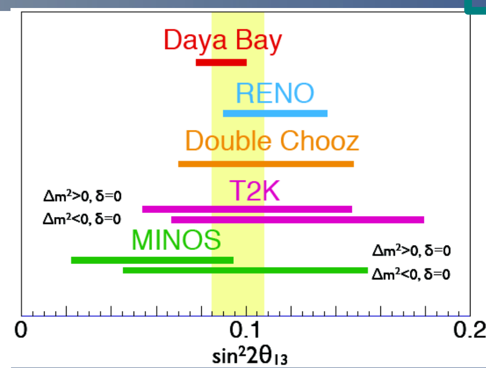

Negative tracks: $\mu^-$, $e^-$        Positive tracks: p, $\pi^+$, $e^+$

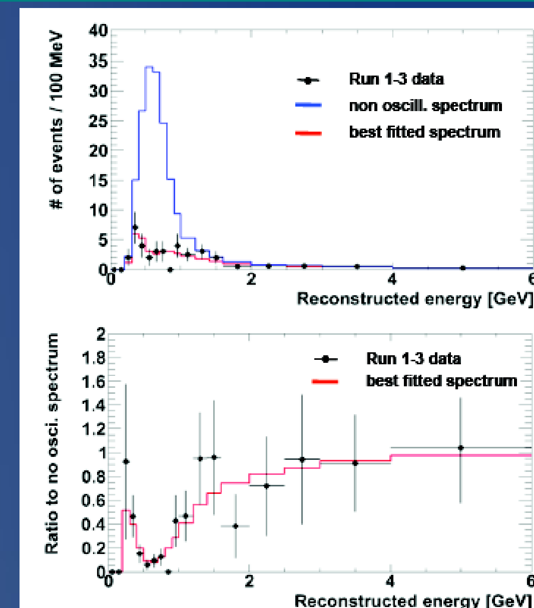
# T2K : neutrino oscillation results

$\nu_\mu \rightarrow \nu_e$ : main channel for CPV exploration

$\text{Prob}(\nu_\mu \rightarrow \nu_\mu) = 1 - \sin^2(2\theta_{23}) \sin^2(\Delta m^2 L/4p)$

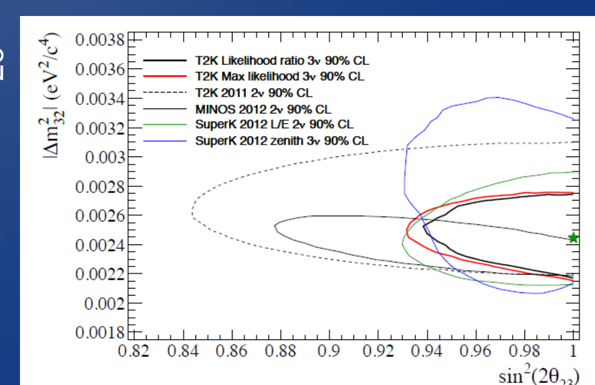



- July 2011: First indication at 2.5 σ of large $\theta_{13}$
- PRL107, 041801 (2011) (> 400 citations, Prix La Recherche)
- Top 40 paper in 2012 (inspire)
- 8% of total POT. Physics program until 2020, first hint of CP violation ?

$\sin^2(2\theta_{23})$




$\Delta m^2$

# Beyond the Standard Model with neutrinos

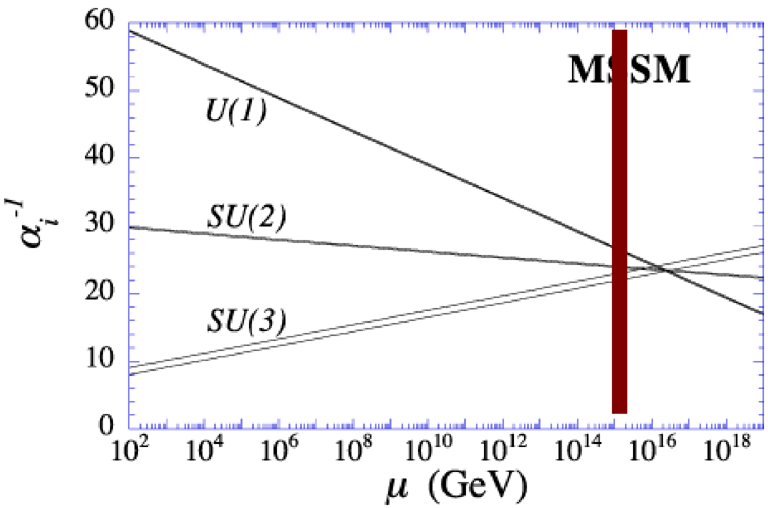
- Standard Model = Gauge symmetry group+Lorentz+renormalizability
- Give up the renormalizability
- Physics beyond the SM as effective operators
- Can be classified systematically (Weinberg)

$$\mathcal{L} = \mathcal{L}_{\rm SM} + \frac{1}{\Lambda}\mathcal{L}_5 + \frac{1}{\Lambda^2}\mathcal{L}_6 + \cdots$$

Lowest order effect of physics at short distances !

$$\mathcal{L}_5 = (LH)(LH) \rightarrow \frac{1}{\Lambda}(L\langle H\rangle)(L\langle H\rangle) = m_\nu \nu\nu$$

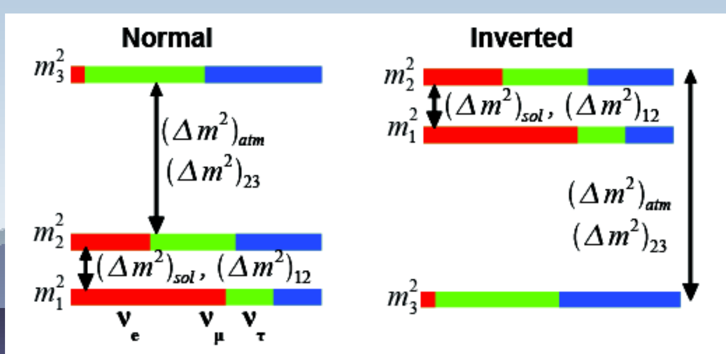
Neutrinos might be our best window on GUT physics

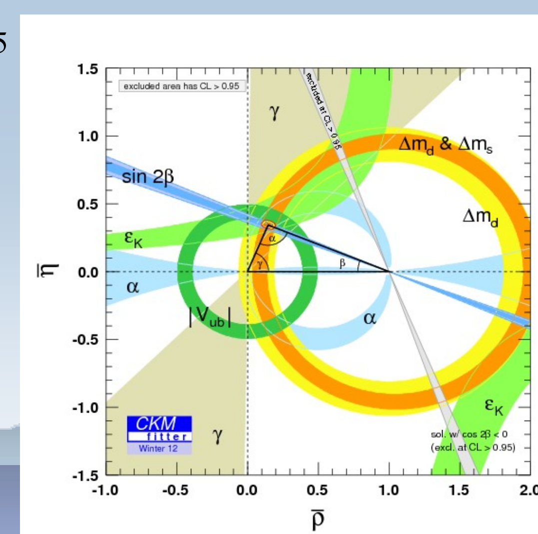


# *The mixing matrix PMNS*

$$U=\begin{pmatrix} U_{e1} & U_{e2} & U_{e3} \\ U_{\mu 1} & U_{\mu 2} & U_{\mu 3} \\ U_{\tau 1} & U_{\tau 2} & U_{\tau 3} \end{pmatrix}=\begin{pmatrix} 1 & 0 & 0 \\ 0 & c_{23} & s_{23} \\ 0 & -s_{23} & c_{23} \end{pmatrix}\begin{pmatrix} c_{13} & 0 & s_{23}e^{-i\delta} \\ 0 & 1 & 0 \\ -s_{23}e^{i\delta} & 0 & c_{13} \end{pmatrix}\begin{pmatrix} c_{12} & s_{12} & 0 \\ -s_{12} & c_{12} & 0 \\ 0 & 0 & 1 \end{pmatrix}$$

- The next step: discovery of the CP violation phase **δ** and mass hierarchy, precise measurement of $\theta_{23}$
- In the end, we would like to explore PMNS to the same level of accuracy as CKM
- This calls for a complete set of precision measurements
- NB: Jarlskog invariant : J(PMNS) = 0.29 sin δ vs J(CKM) = $3\ 10^{-5}$



# $\nu_\mu \to \nu_e$ : beyond the leading term

$$P(\nu_\mu \to \nu_e) \approx \sin^2\theta_{23} \frac{\sin^2 2\theta_{13}}{(\hat{A}-1)^2} \sin^2((\hat{A}-1)\Delta)$$

"Atmospheric" term

$$+\alpha \frac{8 J_{CP}}{\hat{A}(1-\hat{A})} \sin(\Delta) \sin(\hat{A}\Delta) \sin((1-\hat{A})\Delta)$$

CP violating term

$$+\alpha \frac{8 I_{CP}}{\hat{A}(1-\hat{A})} \cos(\Delta) \sin(\hat{A}\Delta) \sin((1-\hat{A})\Delta)$$

$$+\alpha^2 \frac{\cos^2\theta_{23} \sin^2\theta_{12}}{\hat{A}^2} \sin^2(\hat{A}\Delta)$$

"Solar" term

$$J_{CP} = 1/8 \sin\delta_{CP} \cos\theta_{13} \sin 2\theta_{12} \sin 2\theta_{13} \sin 2\theta_{23}$$

Jarlskog invariant

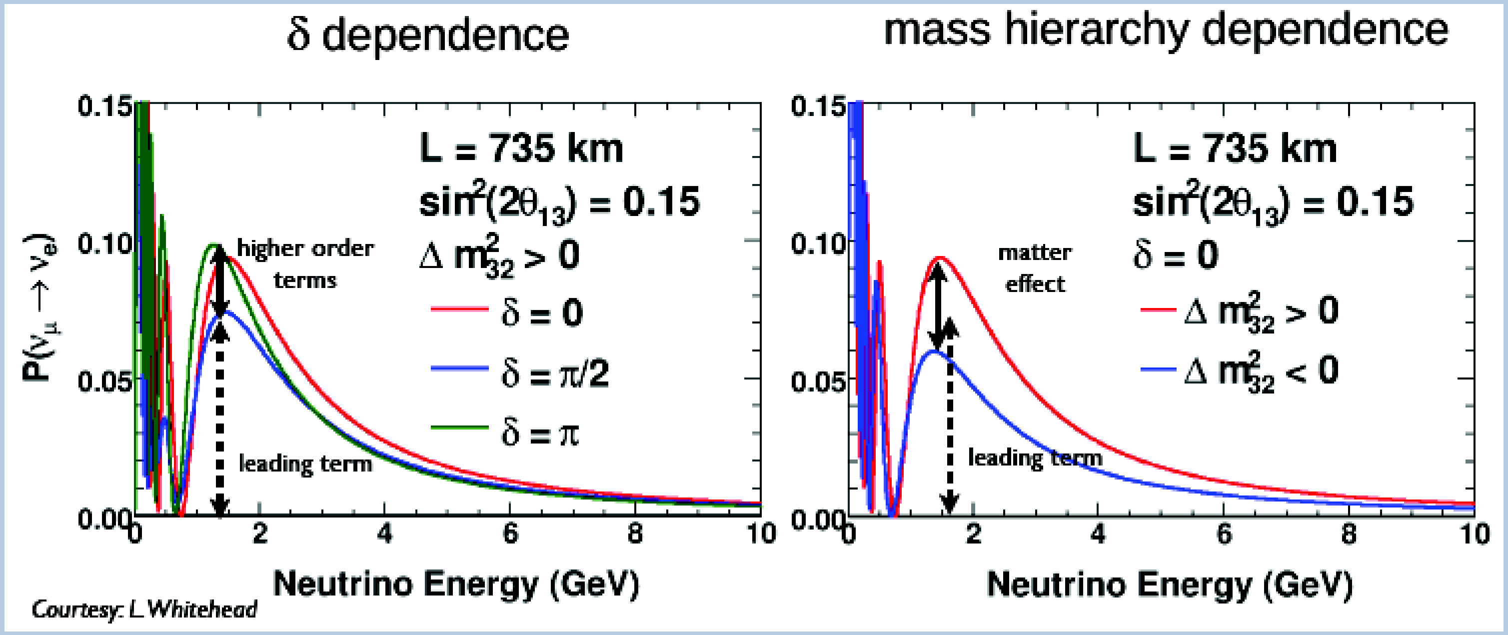
$$I_{CP} = 1/8 \cos\delta_{CP} \cos\theta_{13} \sin 2\theta_{12} \sin 2\theta_{13} \sin 2\theta_{23}$$

$$\alpha = \Delta m^2_{21} / \Delta m^2_{31}, \Delta = \Delta m^2_{31} L / 4E$$

$$\hat{A} = 2VE / \Delta m^2_{31} \approx (E_\nu / GeV)/11$$

Approximate formula with matter effect:
M. Freund hep-ph/0103300

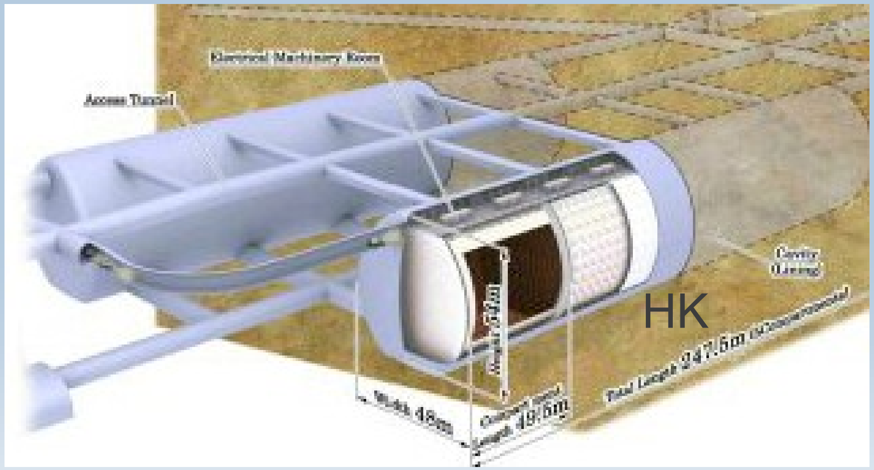
# *Interplay of CP and Matter Effects*

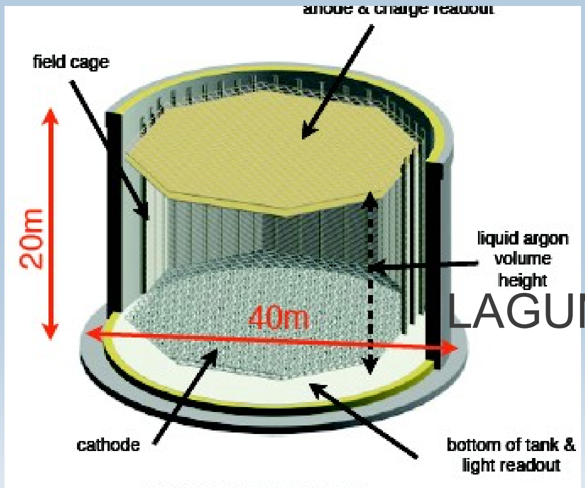



- The simple study of the CP asymmetry is obscured (or enriched) by matter effects (interaction of ν with e in the traversed matter) that mimic a CP effect
- This complication can be seen as a challenge or an opportunity : clean measurement of mass hierarchy

# *The two strategies towards CP violation*

- Short baseline (~100-300 km), lower energy (<1 GeV), narrow beam, large Water Cherenkov (~500 kT). Concentrates on $\nu/\bar{\nu}$ asymmetry, “counting” experiment.
- Longer baseline (>1000 km), higher energy (>1 GeV), wide beam, Liquid Argon TPC. All final states accessible, E/L oscillation pattern and second maximum

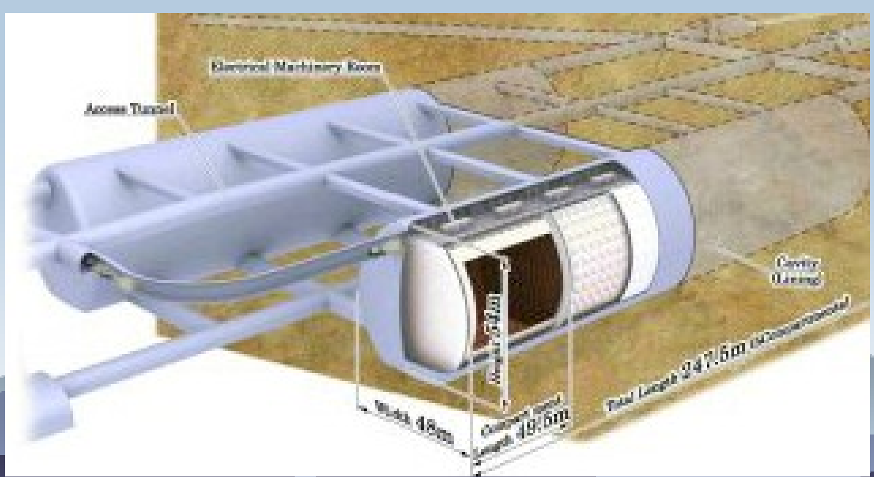


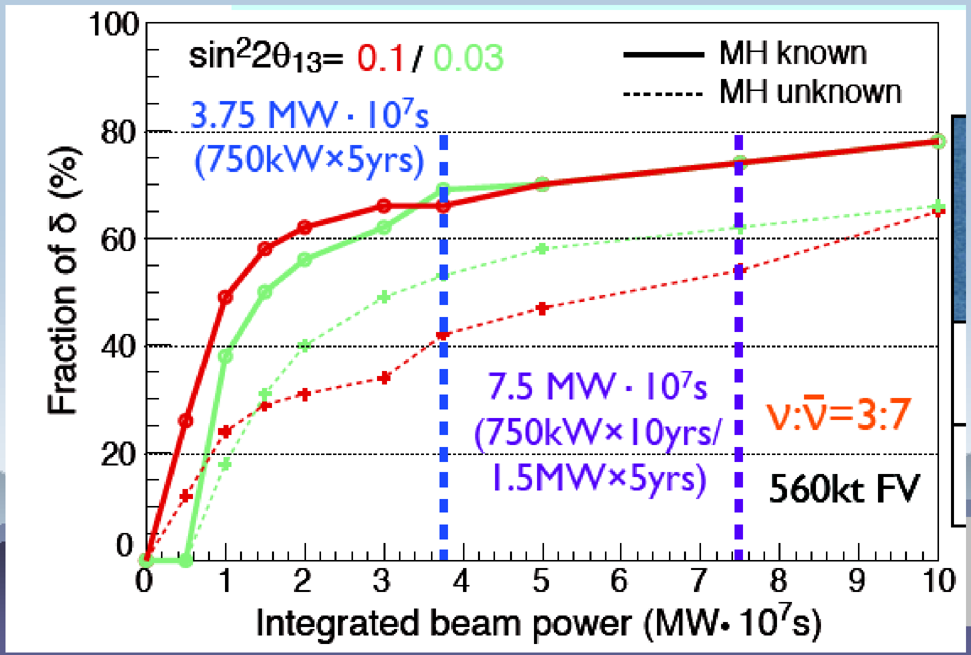




LAGUNA

# *HyperKamiokande: Long baseline project in Japan*

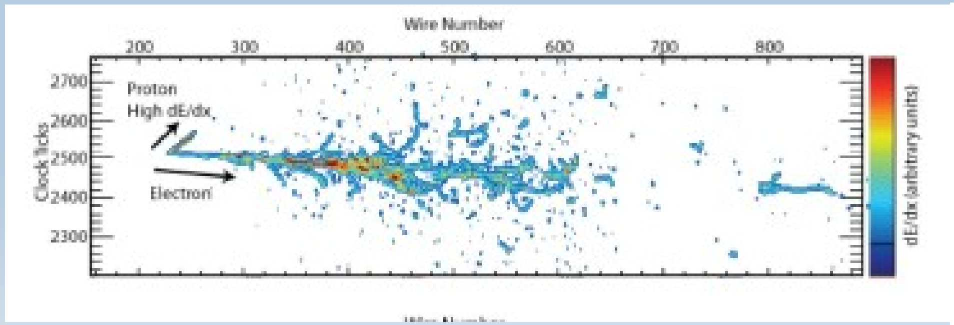
- T2HK :Very large Water Cherenkov with fiducial mass 0.56 Mton (25xSK)
- Two caverns (248x54x48 m$^3$, 99 000 20" PMT)
- 750 kW beam from JPARC : 295 km baseline
- 74% (55%) CP coverage (3σ) if MH known (unknown)

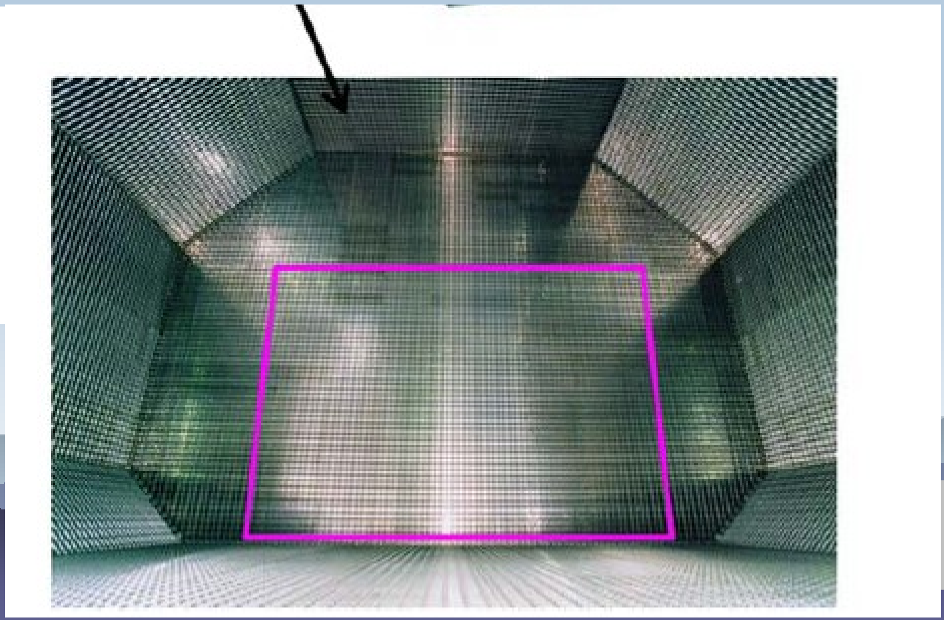




# LBNE : the US long baseline project

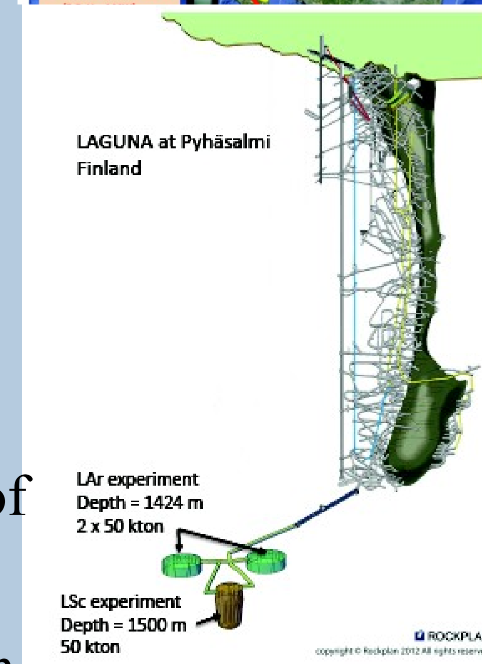
- New 700 kW beam line from Fermilab to Homestake (1300 km) with a 10 kt Liquid Argon detector (on surface, and without Near Detector unless additional funds)
- The project underwent recently a reconfiguration phase
- The further stages include a Near Detector, an underground Far Detector (up to 35 kt) and a 2.3 MW beam (Project X)



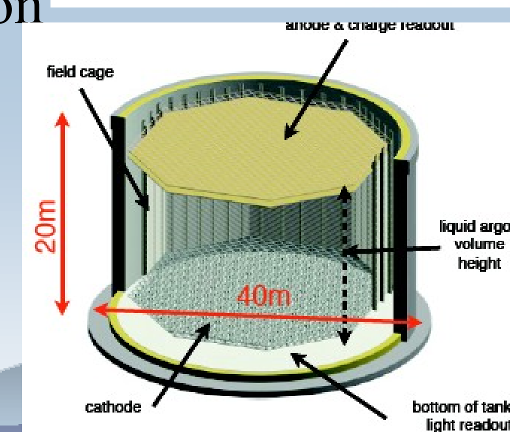



# *LAGUNA-LBNO*


- The LAGUNA-LBNO consortium proposes to create a new European underground laboratory at Pyhäsalmi (Finland) at 2300 km from CERN. <u>Negative feedback from Finland. New configurations under study.</u>




- The choice is based on scientific, technological and practical advantages of the site
- The laboratory can host a 50+50 kT liquid Argon detector combined with a 50 kT magnetized Fe detector for the detection of beam ν
- The first phase of the incremental program would be the operation of a new ν beam based on SPS (500 kW)
- <u>The project has a rich astroparticle physics program</u>
- Recently submitted EOI to SPSC (230 authors, 51 labs)

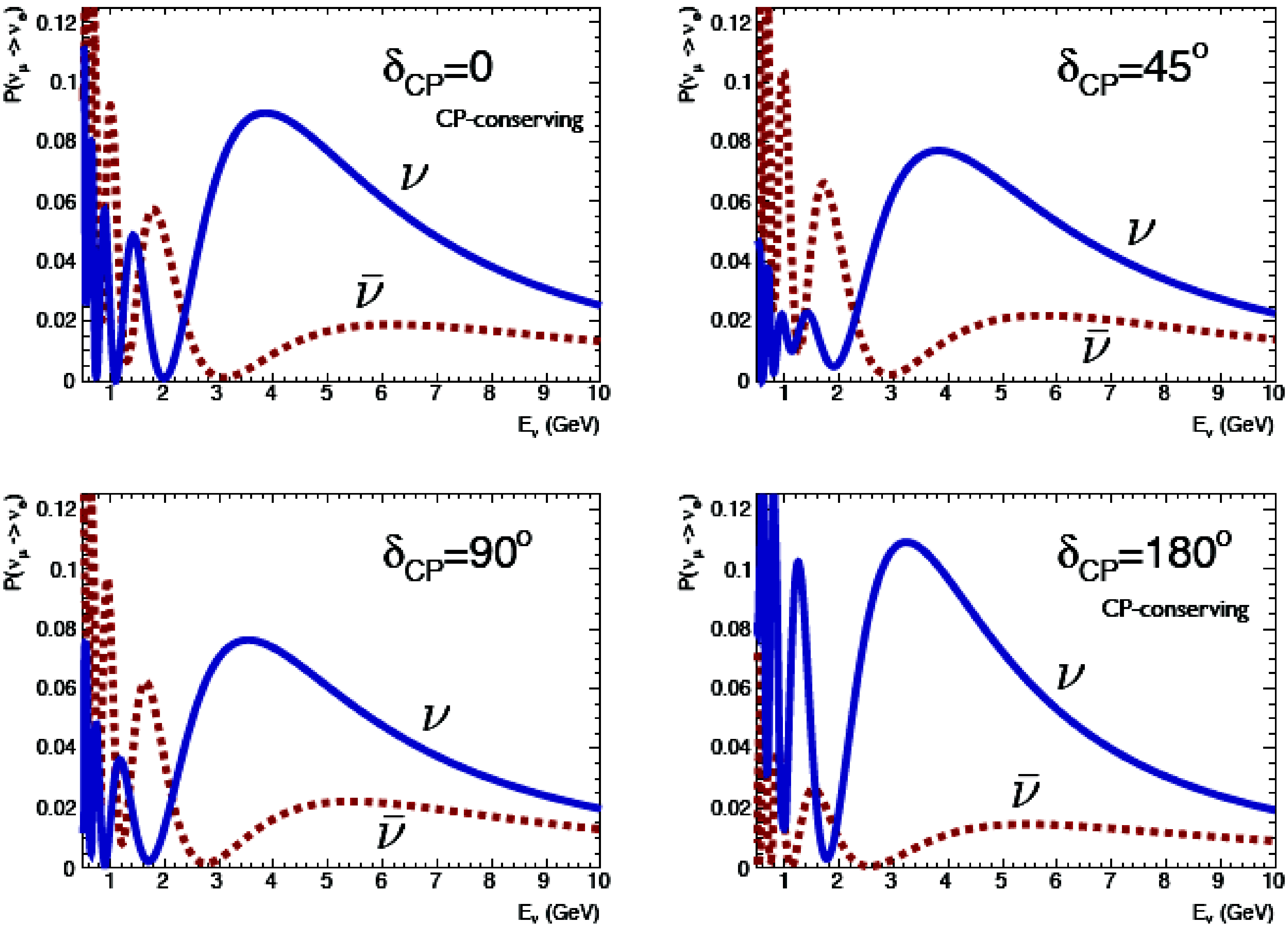


# CERN-Pyhäsalmi: oscillations

★Normal mass hierarchy

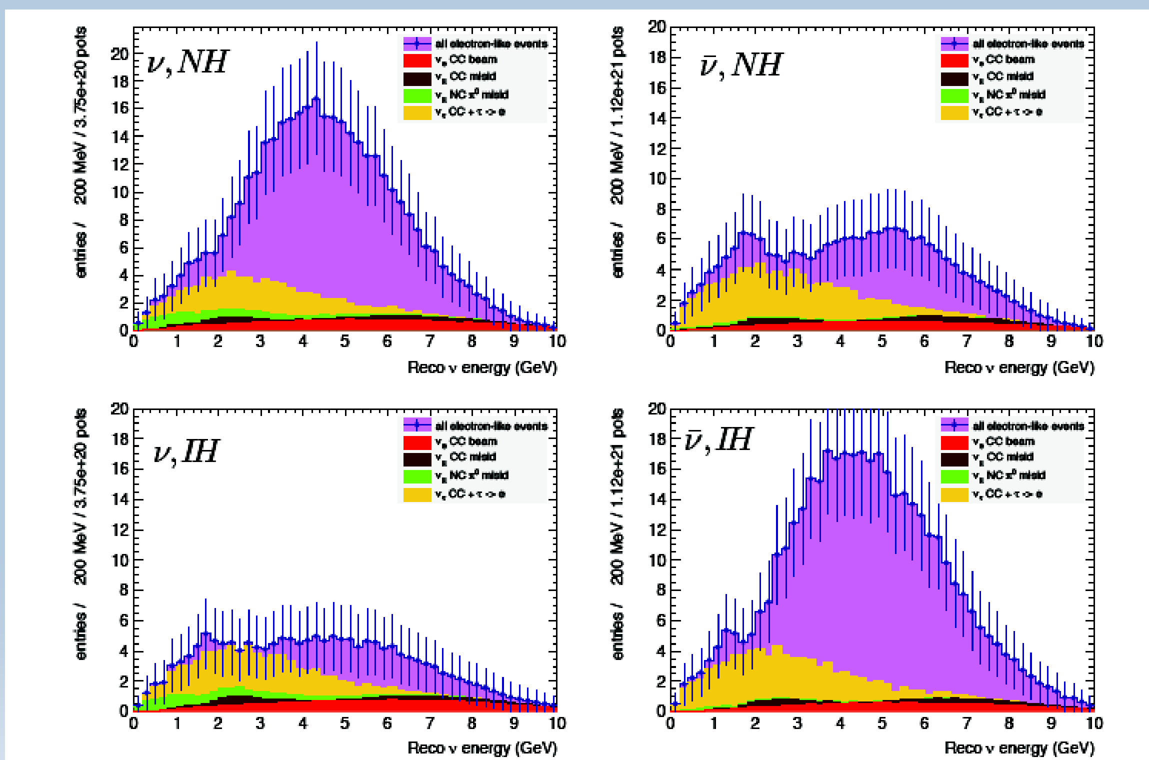
L=2300 km

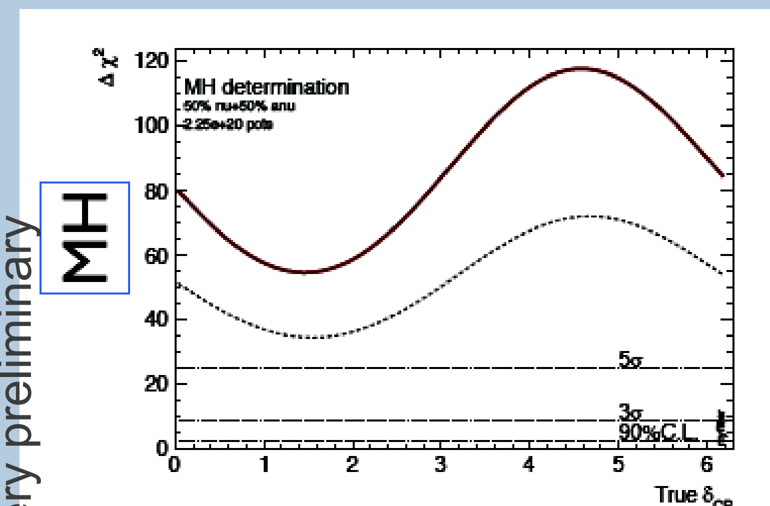
$\sin^2(2\theta_{13}) = 0.09$

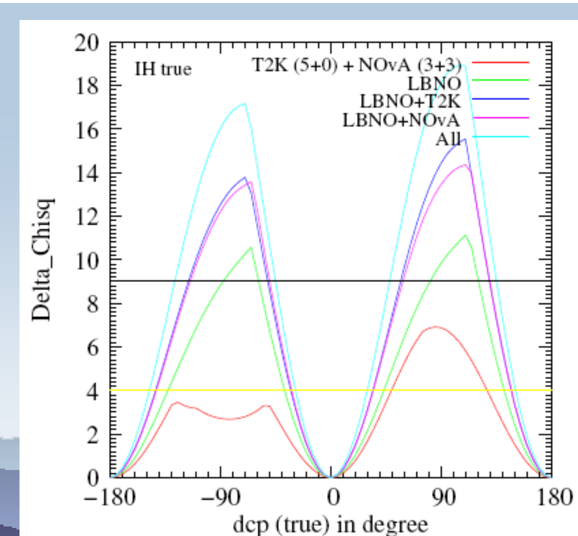


# *LAGUNA-LBNO : physics reach*

- Mass hierarchy : 100 % coverage at 5 σ in a few years
- CPV: 71 (44) % coverage at 90% (3σ)in 10 years




S. Agarwalla, A. Rubbia Very preliminary

# LAGUNA-LBNO

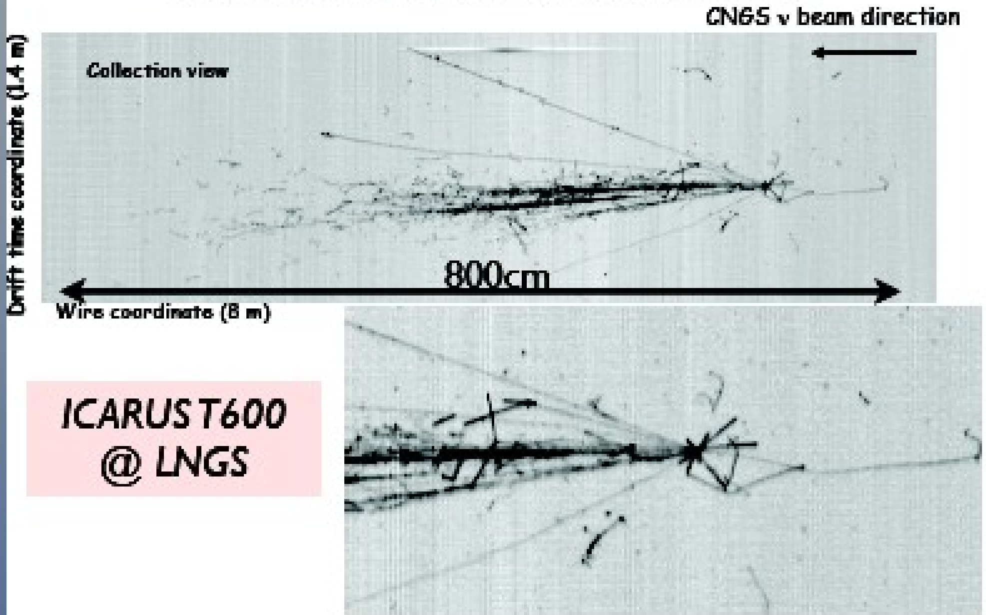
- Strategy statement: "CERN should develop a neutrino programme to pave the way for a substantial European role in future long-baseline experiments. Europe should explore the possibility of major participation in leading neutrino projects in the US and Japan."
- Decision to open discussion with LBNE towards a merger of the two projects: Liquid Argon technology, optimization of the physics programme, ~500 physicists
- Proposal to build a large Liquid Argon TPC prototype at CERN $\rightarrow$ this talk

# A possible timeline

- 2013 European Strategy + Snowmass
- 2014 A unified (EU+USA) Liquid Argon based proposal
- 2016 Critical decision
- 2017-2020 Excavation
- 2021-2024 Detector construction
- 2024 (?) Start of physics data taking

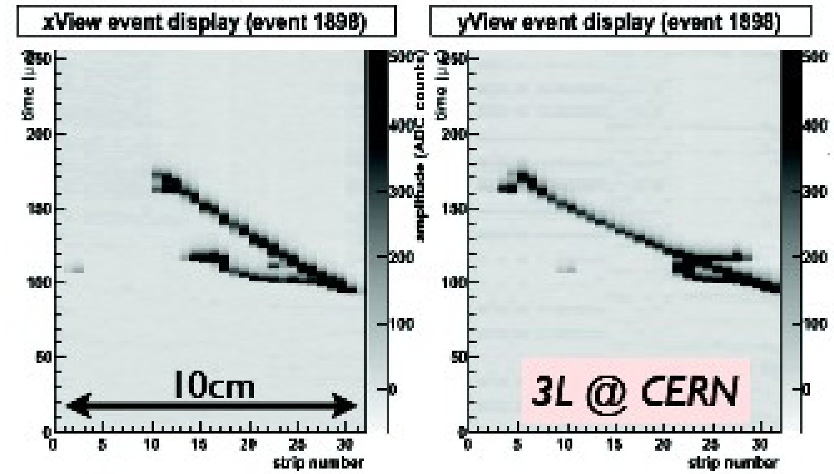
# Liquid Argon Detectors (LArTPC)

*"electronic bubble chambers"*

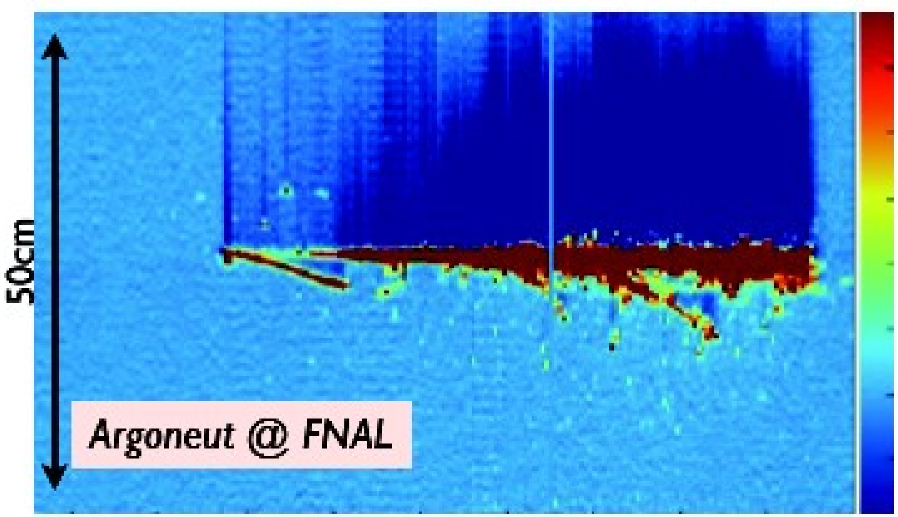



ICARUS T600
@ LNGS

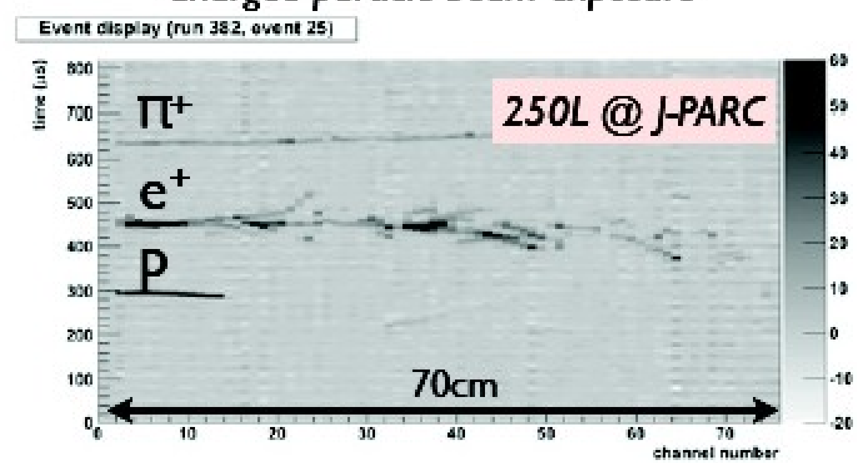
*Cosmic track in double phase 3L LAr-LEM TPC with adjustable gain @ CERN*




**Much improved S/N (>100) compared to single-phase LAr operation (≈15)**




*Charged particle beam exposure*

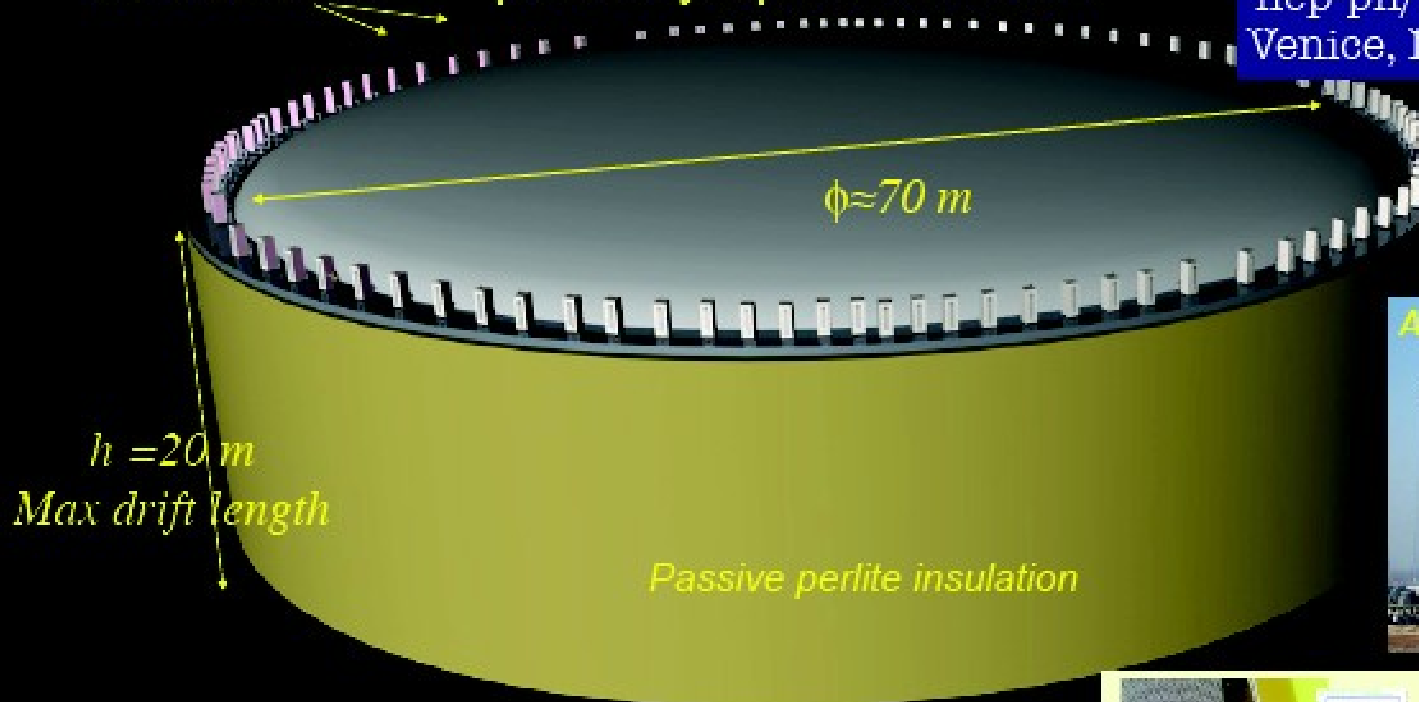


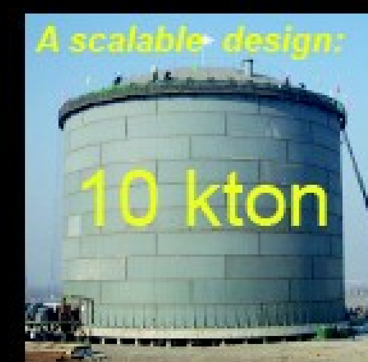
# GLACIER: scalable (“non-ModuLAr”) design

Giant Liquid Argon Charge Imaging ExpeRiment

possibly up to 100 kton

hep-ph/0402110
Venice, Nov 2003

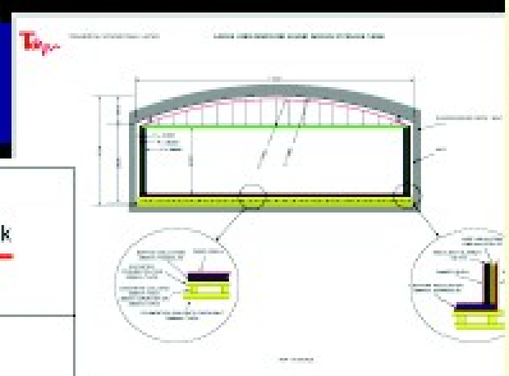


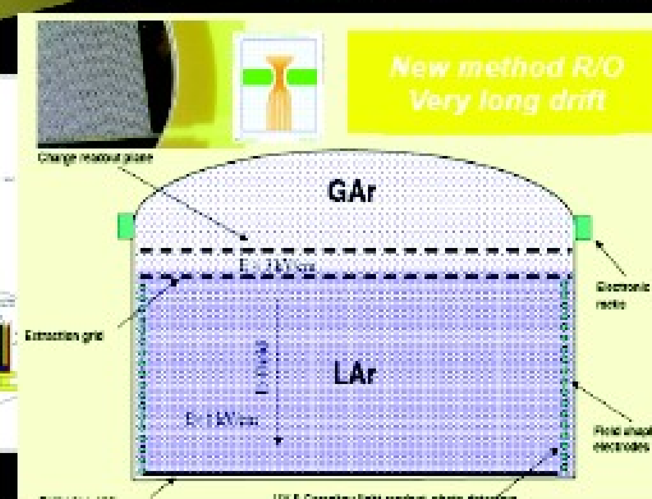




Single module cryo-tanker based on industrial LNG technology

Project: Large Underground Argon Storage Tank

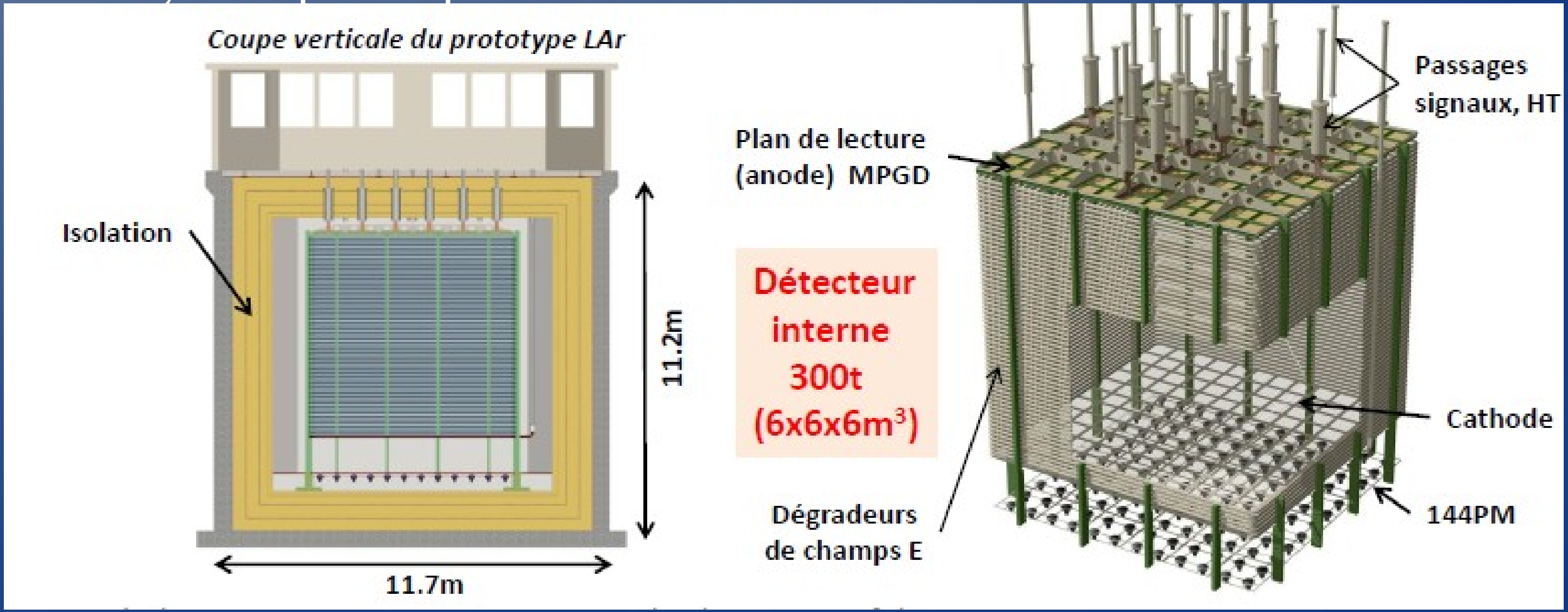
**A feasibility study mandated to Technodyne Ltd (UK): Feb-Dec 2004**



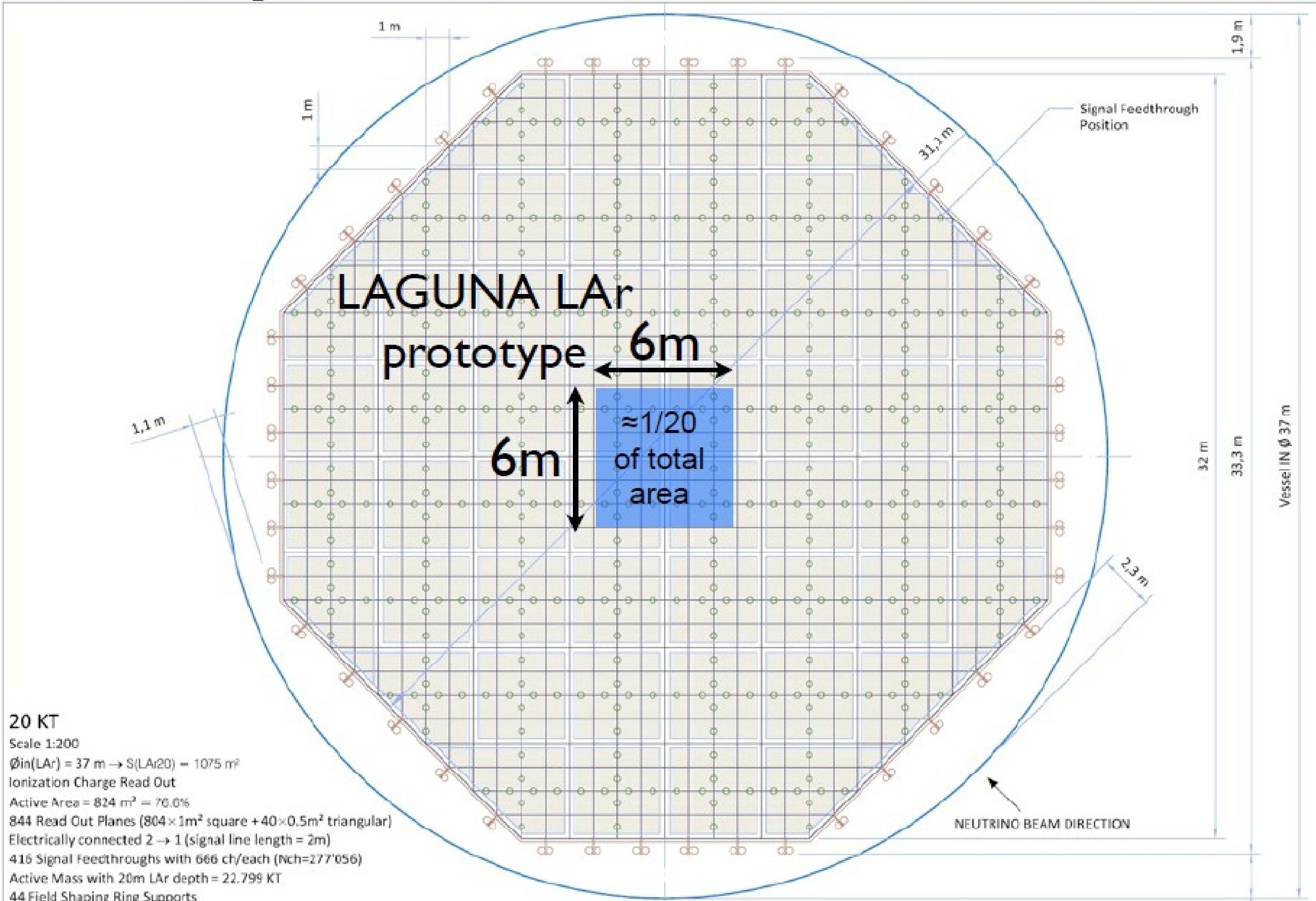


# Proposal for a large Liquid Argon TPC prototype (2014-2017) at CERN

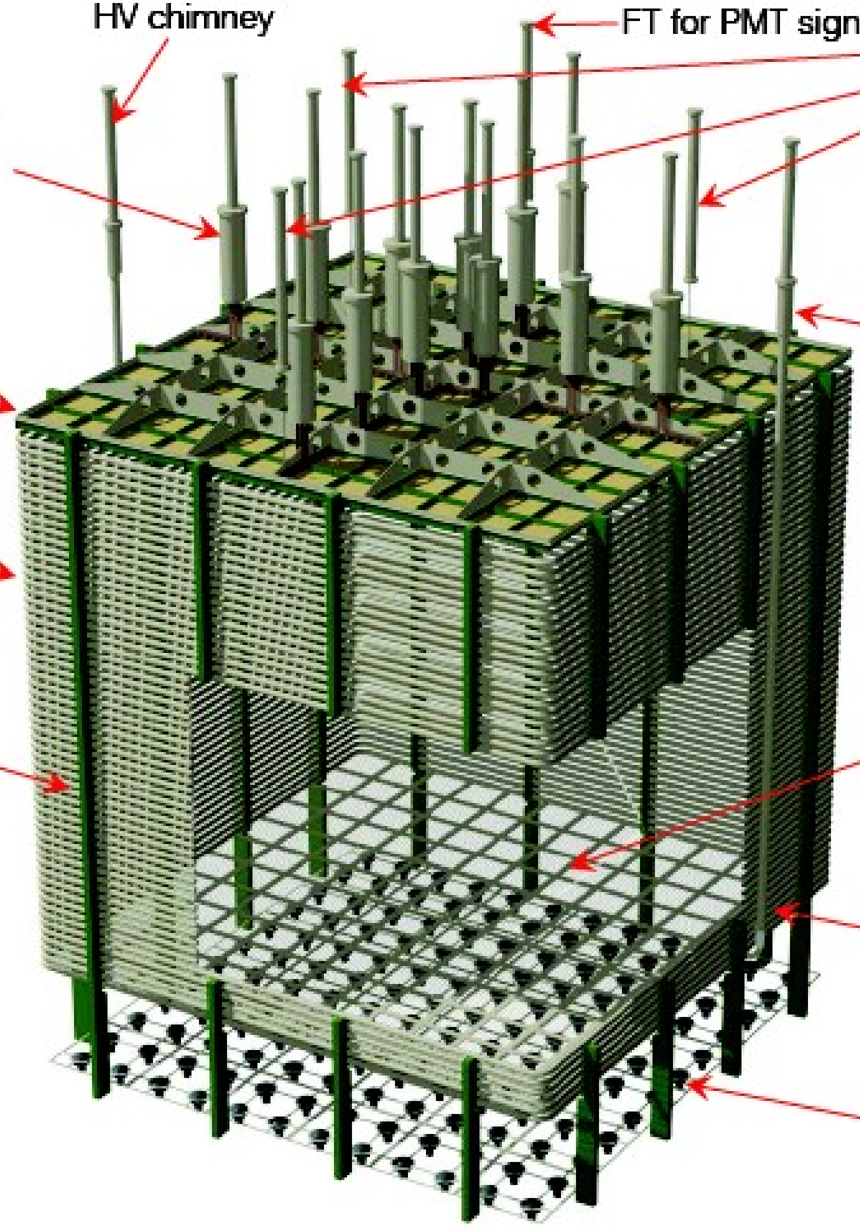
- A large Liquid Argon TPC prototype (6x6x6m$^3$, 300 t) to validate the technology and to test the calorimetry with a charged particle beam from SPS
- Proposal to be submitted to CERN SPSC in June 2013
- Possible location: extension of EHN1 hall int CERN North Area
- French, Swiss and UK collaboration
- Areas to be tested : argon purity, high voltage drift (600kV), large area MPGD, cold preamplifiers



# Compared to GLACIER 20 kton



# LAGUNA LAr prototype

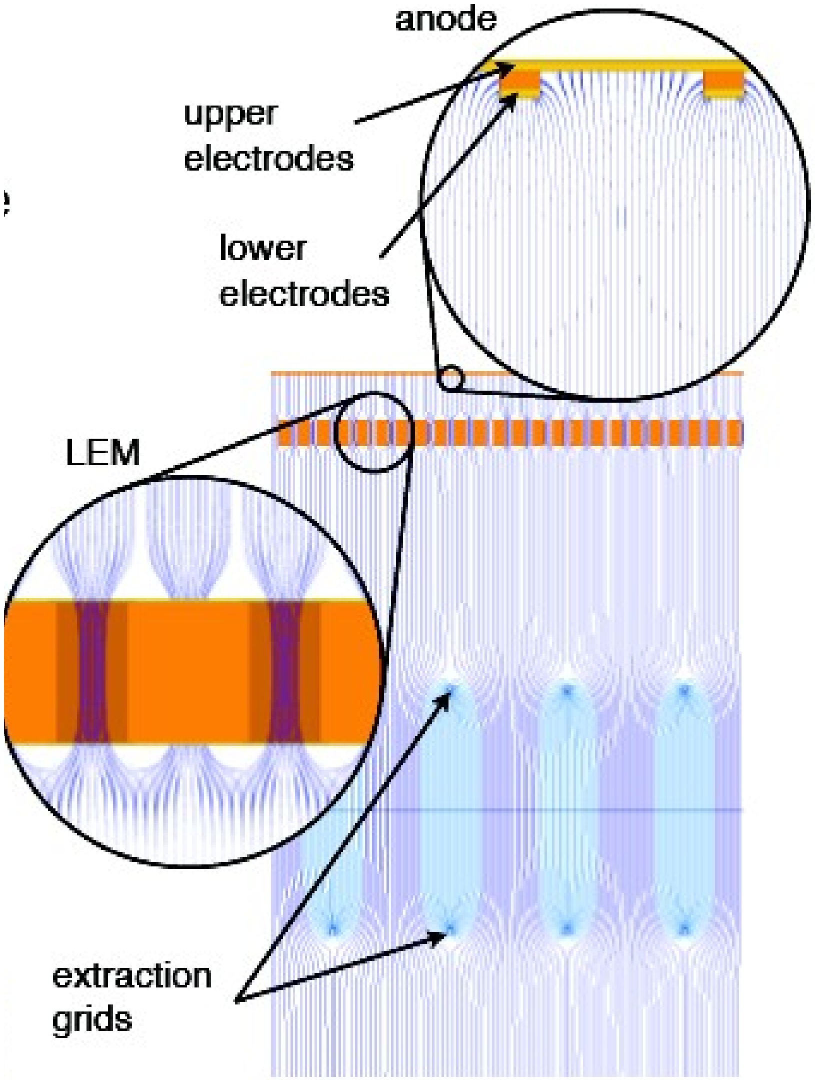



ETH
Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology

# Overview of parameters

| | | |
|---|---|---|
| Liquid argon density at 1.2 bar | [T/m³] | 1.38346 |
| Liquid argon volume height | [m] | 7.6 |
| Active liquid argon height | [m] | 5.992 |
| Pressure on the bottom due to LAr | [T/m²] | 1.05 (≡ 0.1 MPa ≡ 1.031 bar) |
| Inner vessel size (W x L x H) | [m x m x m] | 8.288 x 8.288 x 8.108 |
| Inner vessel base surface | [m²] | 67.6 |
| Total liquid argon volume | [m³] | 509.6 |
| Total liquid argon mass | [T] | 705.0 |
| Active LAr area (percentage) | [m²] | 36 (53.3%) |
| Active (instrumented) mass | [T] | 298.2 |
| Charge readout square panels (0.5m×0.5m) | | 144 |
| Number of signal feedthroughs (640 channels/FT) | | 12 |
| Number of readout channels | | 7680 |
| Number of PMT (area for 1 PMT) | | 144 (0.5m×0.5m) |

# Charge readout




Charge Collection

Gain needed: ~20 to recover attenuation in the drift.
NB: 20 000 e/3mm in Liquid Argon

Charge Amplification

Gaseous Argon

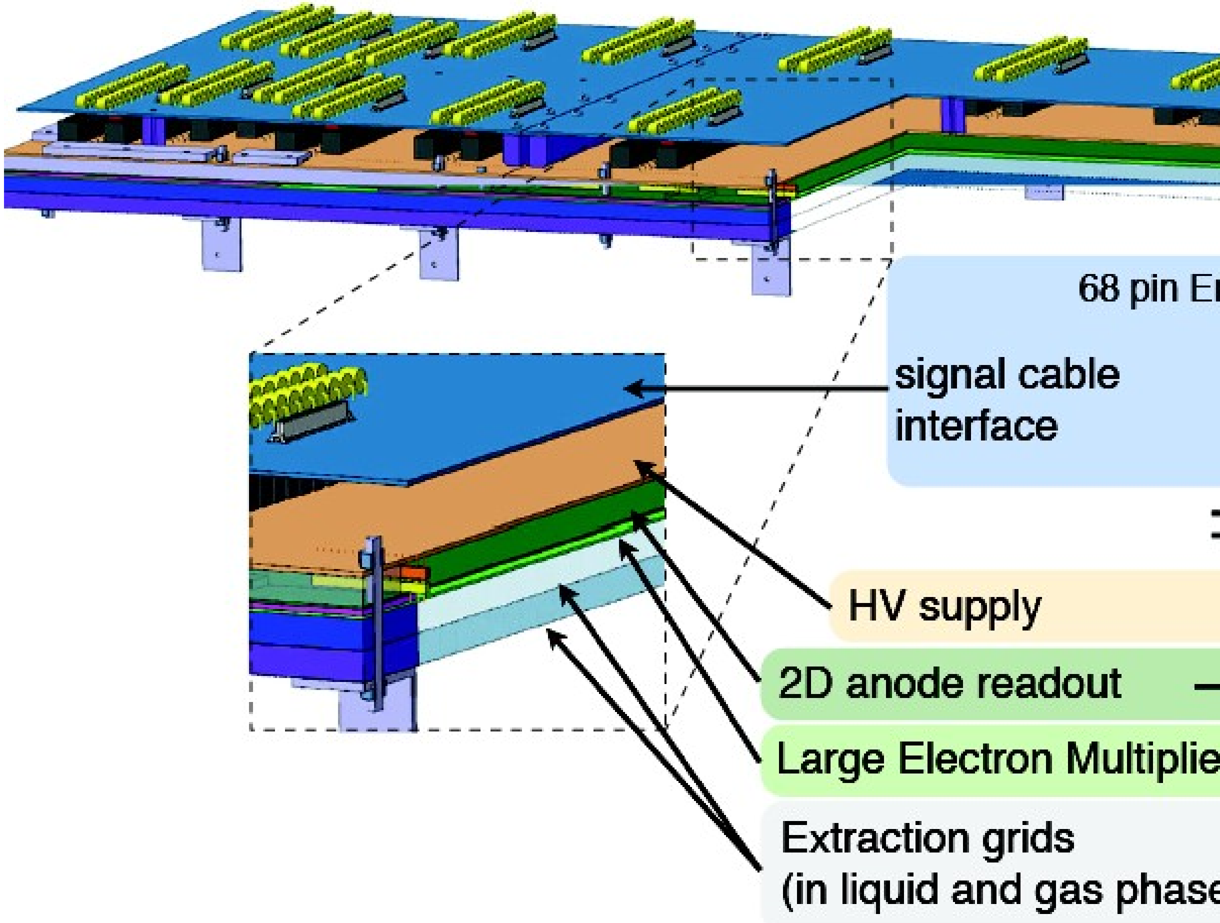
Extraction grids (2.5 kV/cm)

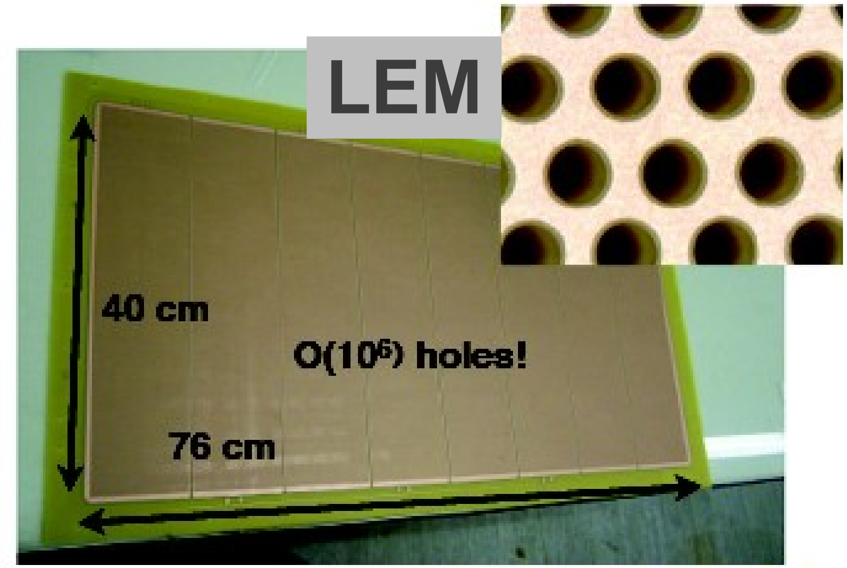
Liquid Argon (1 kV/cm)

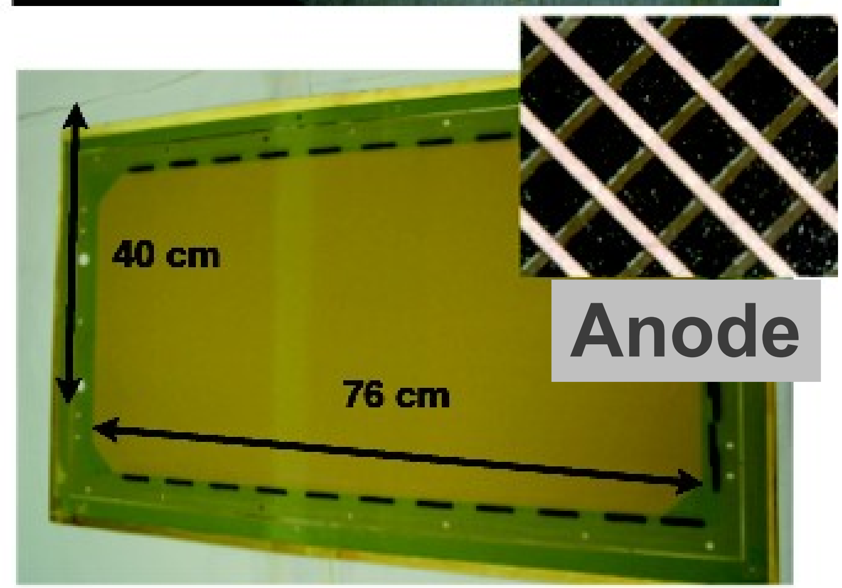


Charge Amplification can be performed with LEM (~thick GEM) or Micromegas

# Charge Readout Panel (LEM)

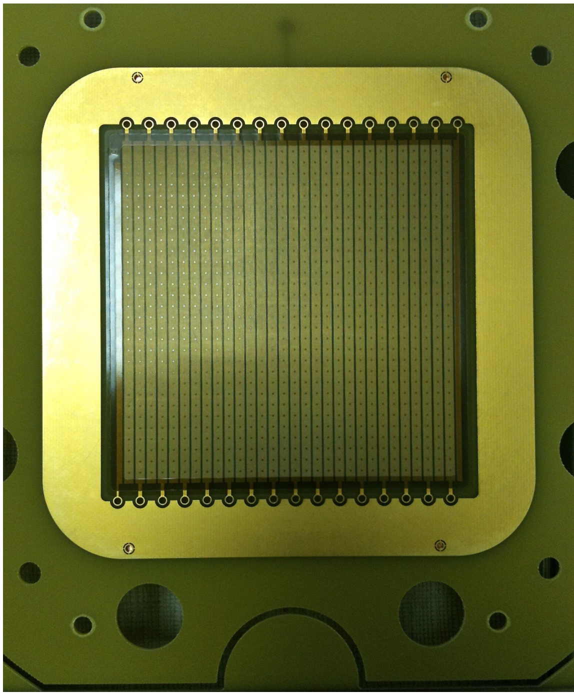


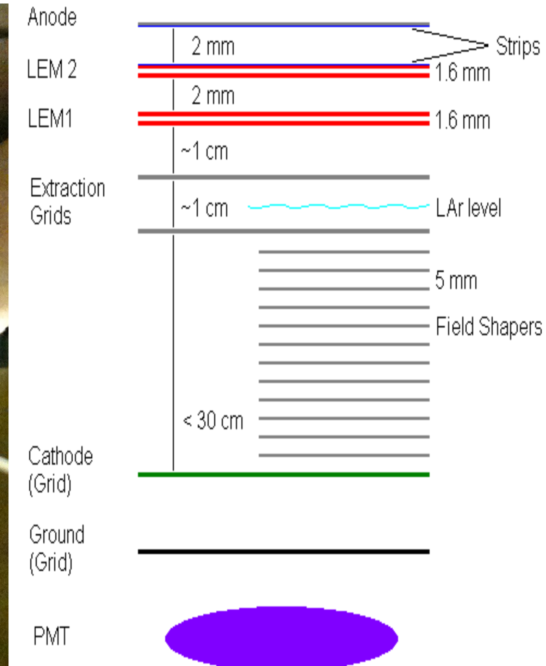



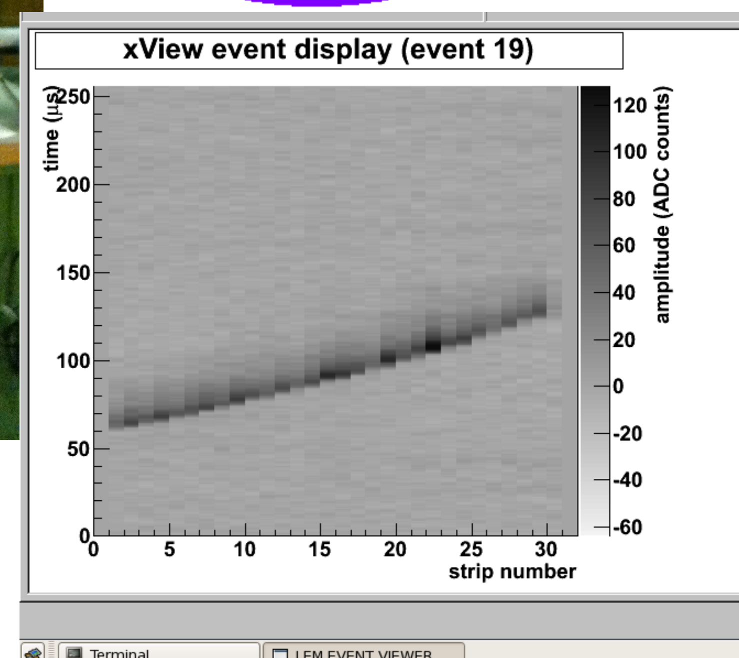




Current baseline solution studied by ETHZ
Gain = 90

# Micromegas for a Liquid Argon TPC



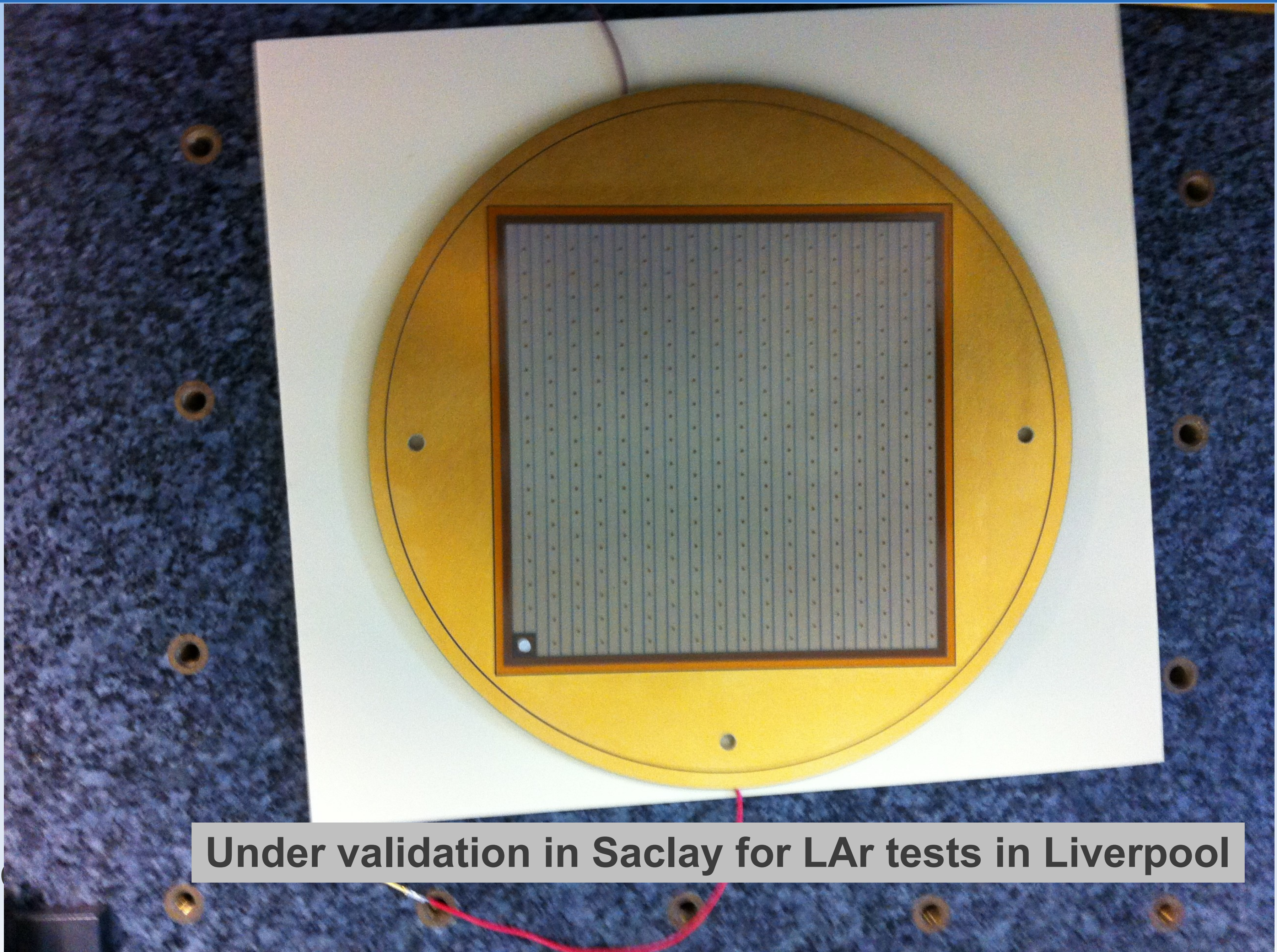



A T2K-like bulk Micromegas was tested in collaboration with ETHZ

- ✔ Argon purity
- ✔ Cryogenic MM operation
- ✔ Cosmic rays observed
- ✔ Gain up to ~5

# MM for amplification gap test



Under validation in Saclay for LAr tests in Liverpool

# The charge readout project

We propose to collaborate with ETHZ on:

1) Understanding the gas amplification phenomena in ultra pure Argon (in conjunction with the RD 51 collaboration).

2) Optimization of the MPGD, including the choice of the device and its parameters.

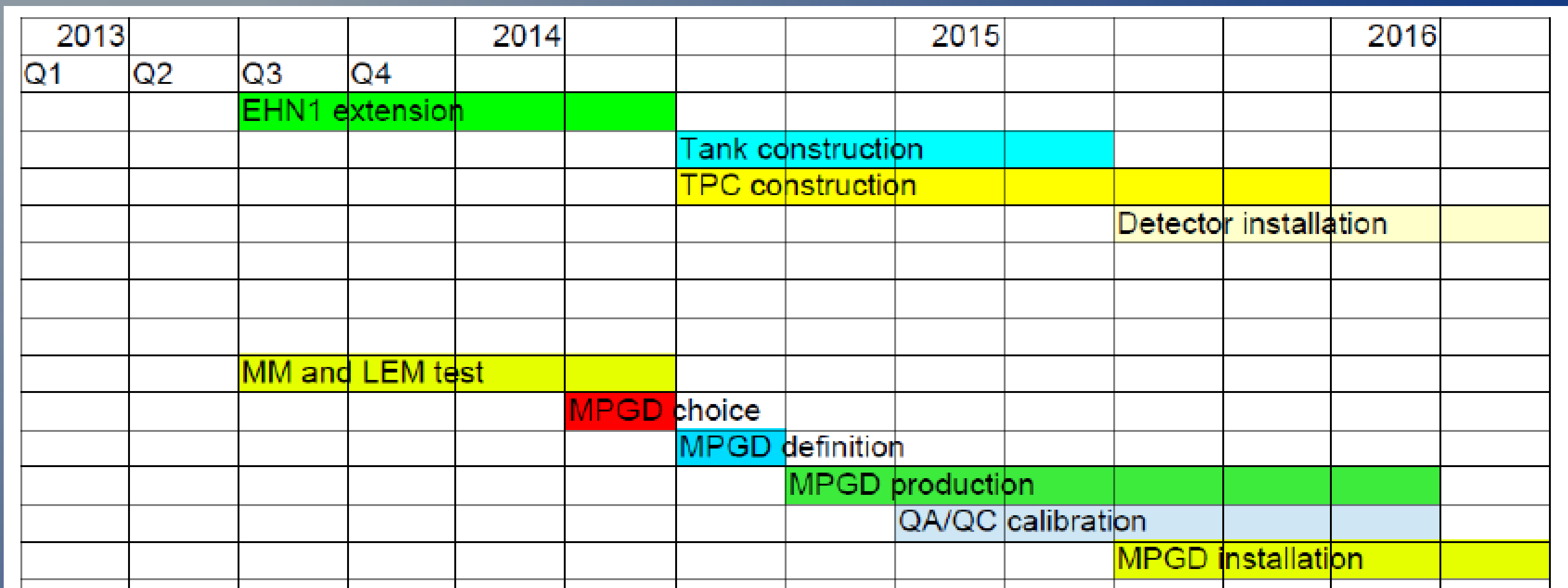
3) Definition (cahier de charge) of the MPGD for external production.

4) Quality Assurance/Quality Control (QA/QC) procedure for the production.

5) Characterization and calibration of the modules after the production, prior to the installation.

6) Task 4 and 5 will profit of the “antenne” infrastructure at CERN

# Preliminary timeline and resources




| | |
|---|---|
| **Investissement** | |
| **Tests** | **20** |
| **Prod. Line** | **30** |
| **MPGD 18m**2** | **270** |
| **Total** | **320 k€** |
| **Person-year (SPP)** | **8** |
| **Person-year (SEDI)** | **12** |
| **Missions** | **45 k€** |

# Participation française

- 6 labos et ~30 physiciens ont signé l'EOI pour LBNO
- Répartition des tâches pour le prototype:
  - APC et LAPP: électronique PMT (PMM2 De La Taille)
  - IPNL : électronique froide, setup de test MM, LEM
  - LPNHE: HV
- Demande au Conseil Scientifique IN2P3 de juin (documentation disponible pour les rapporteurs)

# Conclusions

- T2K: frontier neutrino physics until ~2020. The group is strongly committed to this physics program
- LAGUNA: a technological breakthrough towards future discoveries. European contribution to the world long baseline oscillation program
- Detector prototyping at CERN: best opportunity to prepare the next experimental phase