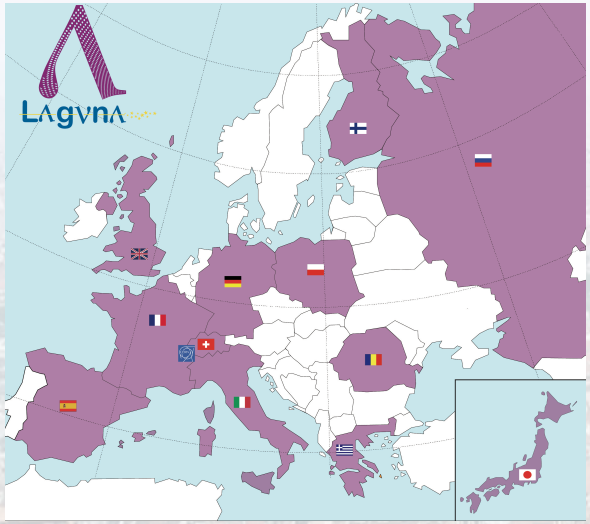
New technical studies for the MEMPHYS detector

M. Buizza Avanzini for the MEMPHYS Collaboration
APC Paris

GDR Neutrino **IPNL, Nov 13th 2013**

OUTLINE

- THE LAGUNA-LBNO PROJECT
- THE MEMPHYS OPTION
- ENGENEER AND TECNICAL CHALLENGES
- WATER SYSTEM PROJECTS
- DETECTOR OPTIMIZATION STUDIES (PMT INSTRUMENTATION)
- PMT ENCAPSULATION AND MATRIX DESIGN

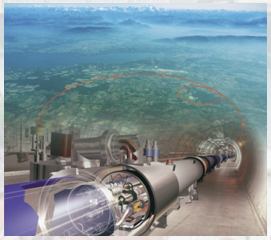


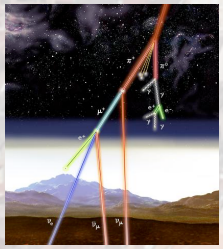
LAGUNA-LBNO: Large Apparatus for Grand Unification and Neutrino Astrophysics and Long Baseline Neutrino Oscillations

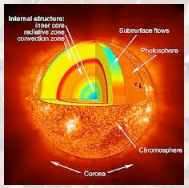
LAGUNA-LBNO consortium = 13 countries, 45 institutions, ~300 members

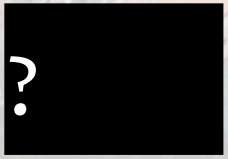
FP7 DS: 2011 - 2014; 4.9 M€

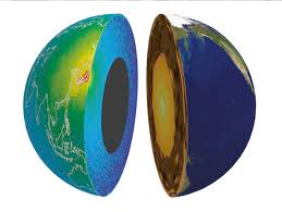
LAGUNA-LBNO Physics:











1. Accelerator based:

- **Mass Hierarchy**
- **δ_{CP}**
- PMNS precision
- 3 ν or 3+n ?

large θ_{13}

2. Non-Accelerator based:

- Proton decay

3. Neutrino Astronomy:

- Supernova neutrinos
- Diffuse Supernova Neutrinos
- Solar Neutrinos
- Atmospheric Neutrinos

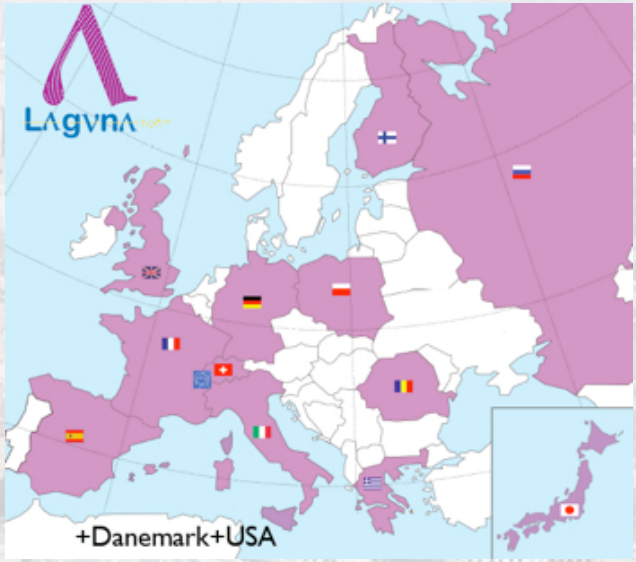
4. Geo neutrinos

5. Dark Matter

LAGUNA-LBNO consortium

Large Apparatus for Grand Unification and Neutrino Astrophysics
and
Long Baseline Neutrino Oscillations

- **LAGUNA DS** (FP7 Design Study 2008-2011)
  - ~ 100 members; 10 countries
  - 3 detector technologies ⊗ 7 sites, different baselines (130 → 2300km)
- **LAGUNA-LBNO DS** (FP7 **DS Long Baseline Neutrino Oscillations**, 2011-2014)
  - ~300 members; 14 countries + CERN
  - Down selection of sites & detectors
- **LBNO** (**CERN SPSC EoI for a very long baseline neutrino oscillation experiment**, June 2012)
  - An incremental approach, based on the findings of LAGUNA
  - ~230 authors; 51 institutions
  - CERN-SPSC-2012-021 ; SPSC-EOI-007, under review



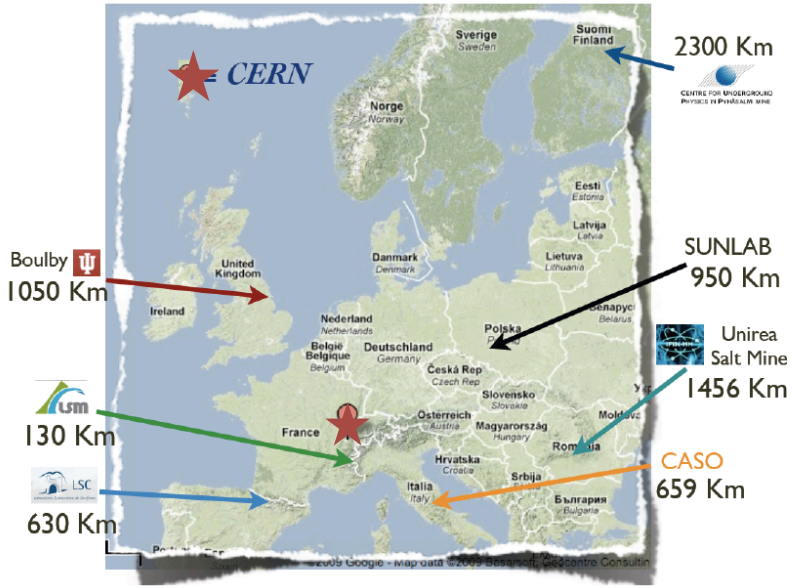
Steering group:

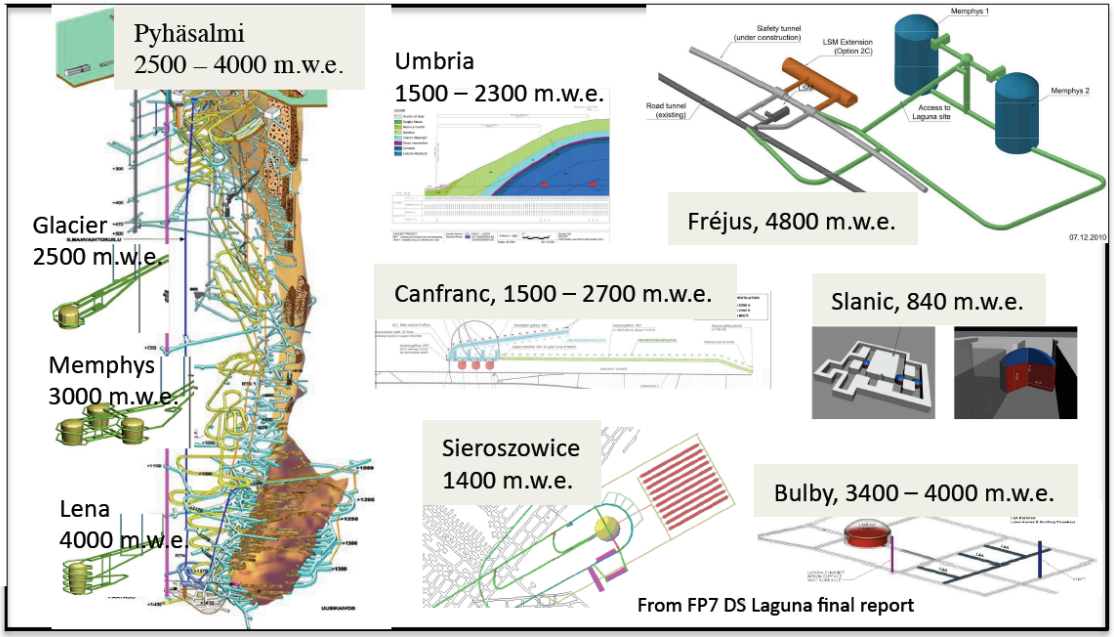
Alain Blondel (UniGe),
Ilias Efthymiopoulos (CERN)
Takuya Hasegawa (KEK)
Yuri Kudenko (INR)
Guido Nuijten (Rockplan, Helsinki)
Lothar Oberauer (TUM)
Thomas Patzak (APC, Paris)
Silvia Pascoli (Durham)
Federico Petrolo (ETH Zürich)
André Rubbia (ETH Zürich)
Chris Thompson (Alan Auld Engineering)
Wladyslaw Trzaska (Jyväskyla)
Alfons Weber (Oxford)
Marco Zito (CEA)

LAGUNA (2008 - 2011):

~ 100 members; EU funding 1,7 M€

- ✓ LAGUNA => very comprehensive evaluation of all sites, construction and costs
- ✓ LAGUNA => baselines from 130 km to 2300 km available in Europe = advantage
- ✓ LAGUNA => allowed to form a strong community in Europe (> 100 physicists and Ing.)
- ✓ LAGUNA => showed the need to evaluate constraints and costs for the detector options





New program: LAGUNA-LBNO, Start September 2011 – End September 2014

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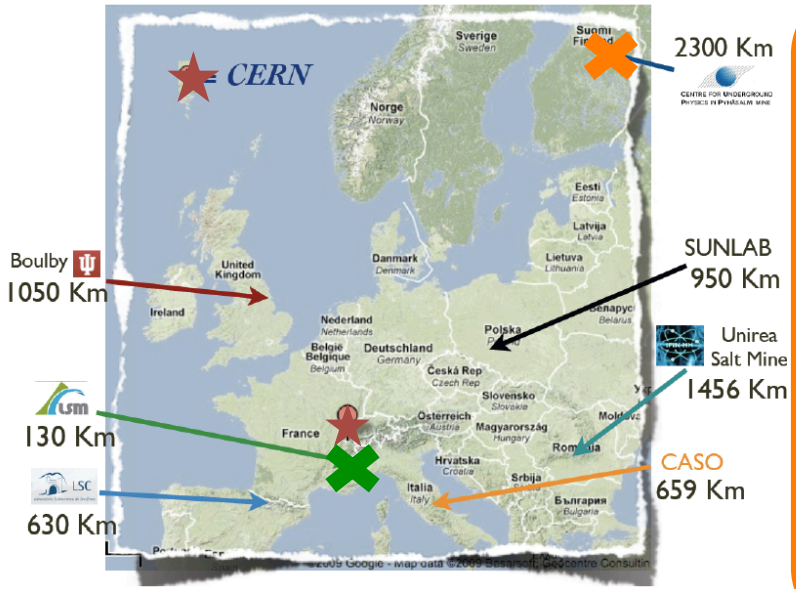
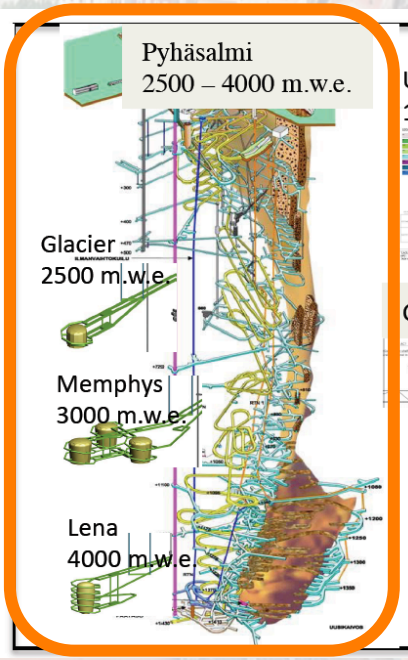
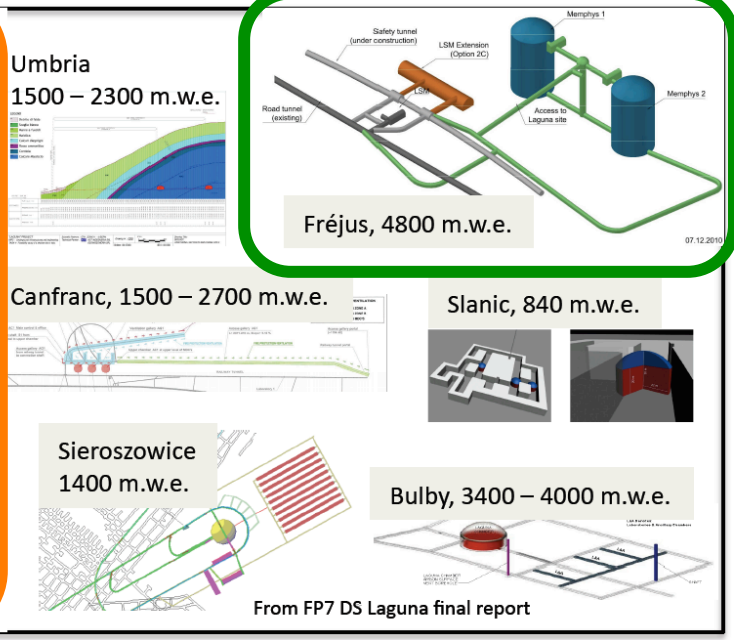






New program: LAGUNA-LBNO, Start September 2011 – End September 2014

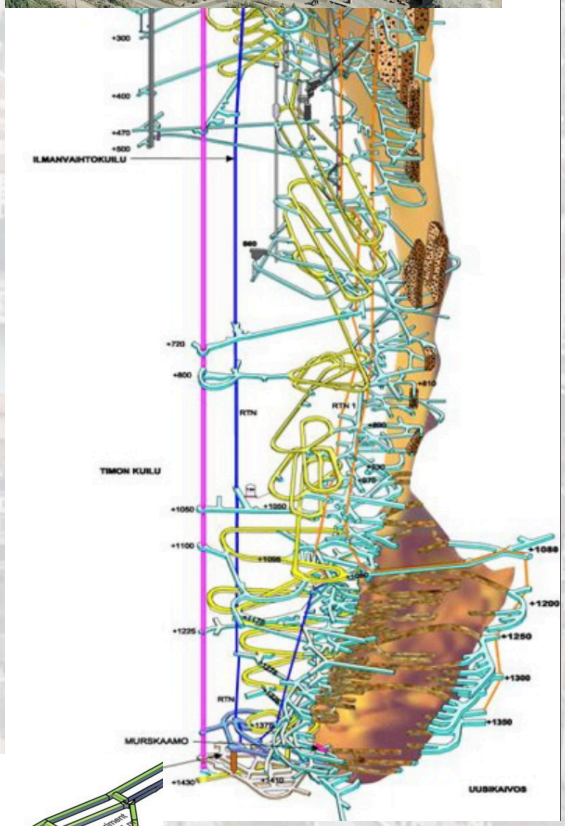
LAGUNA-LBNO (2011 - 2014)

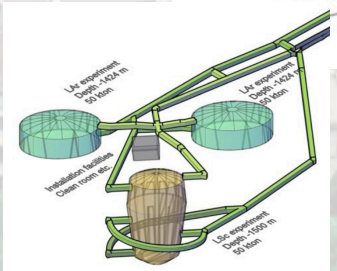
EOI for a very long baseline neutrino oscillation experiment

CERN-SPSC-2012-021; SPSC-EOI-007

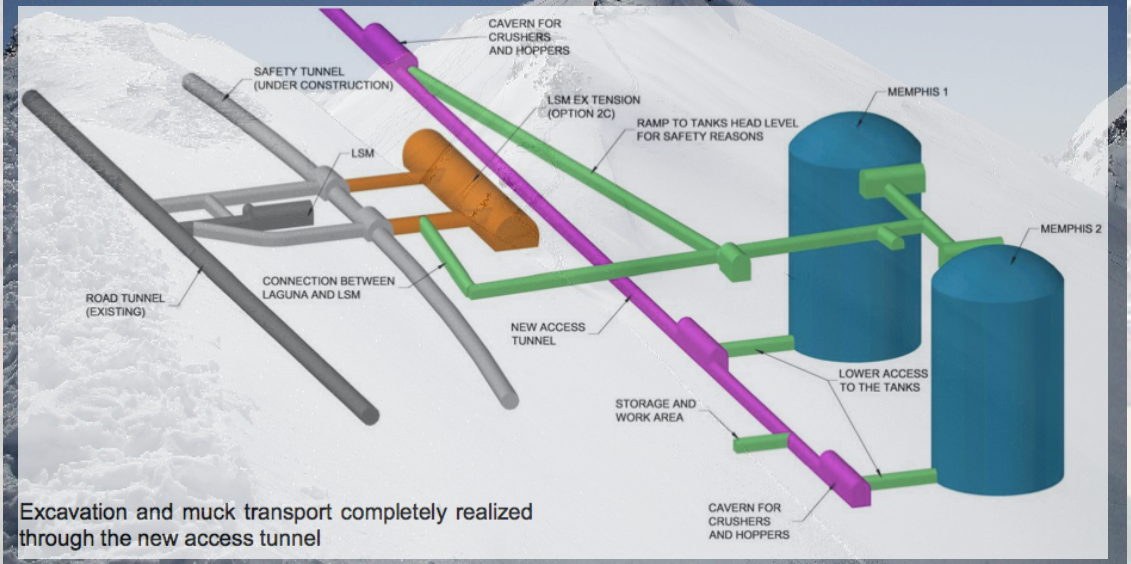
1. **Longest baseline (2300 km)**, CERN -> Pyhäsalmi: matter effect; mass hierarchy, LCPV
2. Shortest baseline (130 km), CERN -> Fréjus: no matter effects; clean measurement of LCPV

1st option: LAGUNA-LBNO at Pyhäsalmi (Finland)





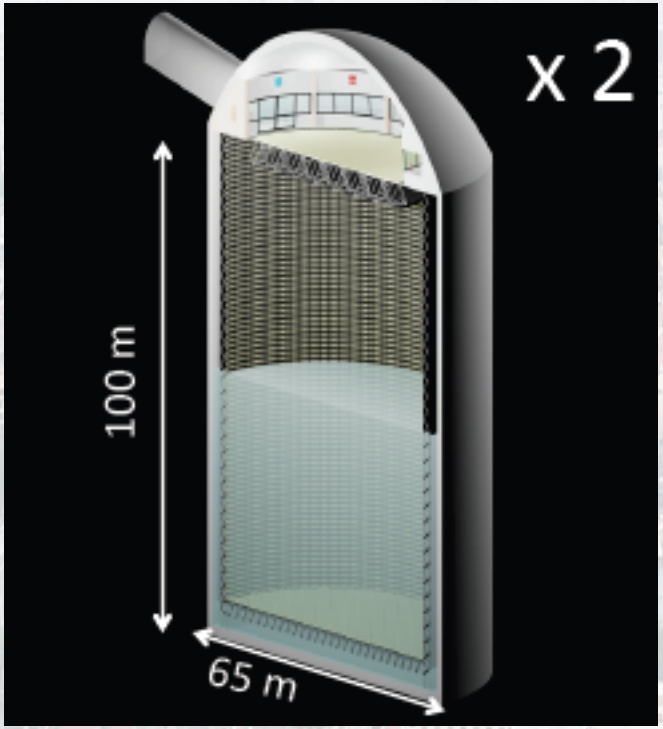
2nd option: LAGUNA-LBNO at Fréjus (France)



Excavation and muck transport completely realized through the new access tunnel

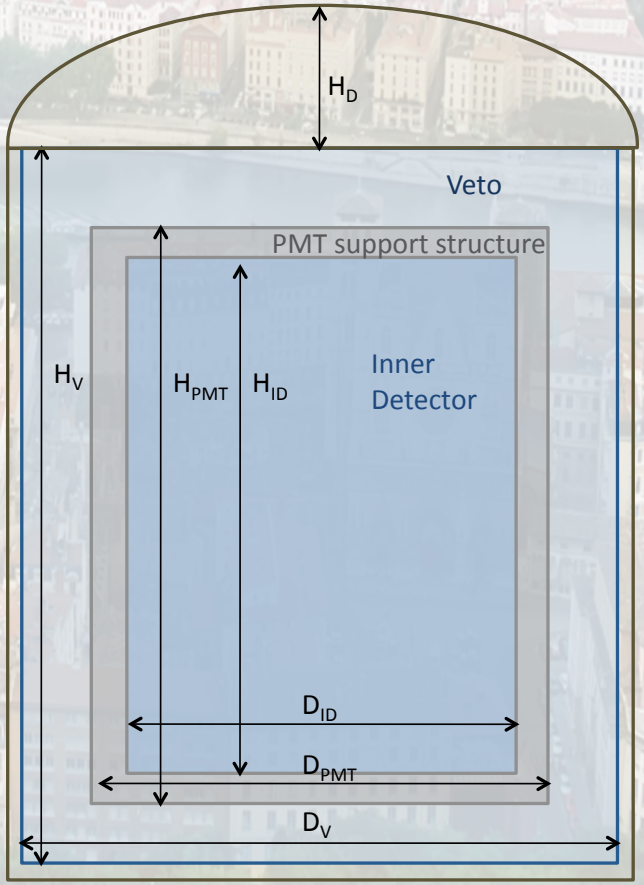
THE MEMPHYS OPTION

MEMPHYS (MEgaton Mass PHYSics)



Detector design:

- 2 cylindrical modules **65m x 100m**
- Size limited by light attenuation length (λ~80m)
- Total fiducial mass: **540 kt**
- Readout: 130000, 12" PMTs, 20% geom. coverage



H_D	17 m
H_V	100 m
H_{PMT}	96 m
H_{ID}	94 m
D_V	65 m
D_{PMT}	61 m
D_{ID}	60 m

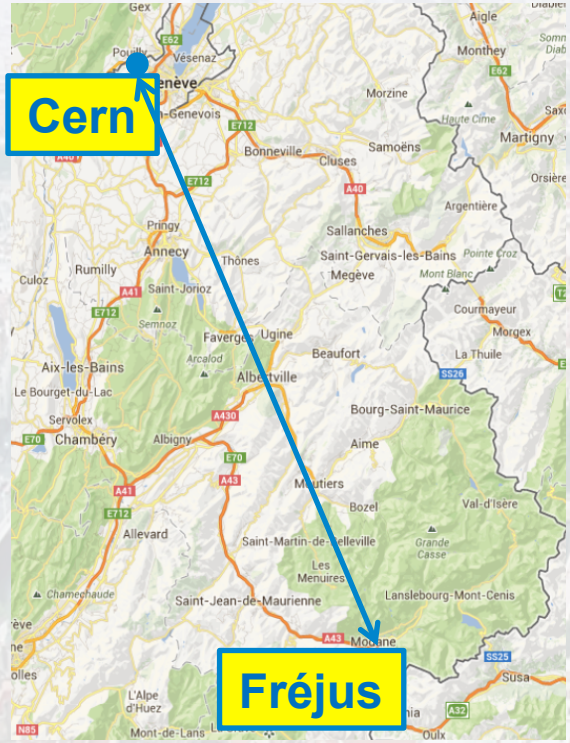
Water Cherenkov techniques is well proven technology

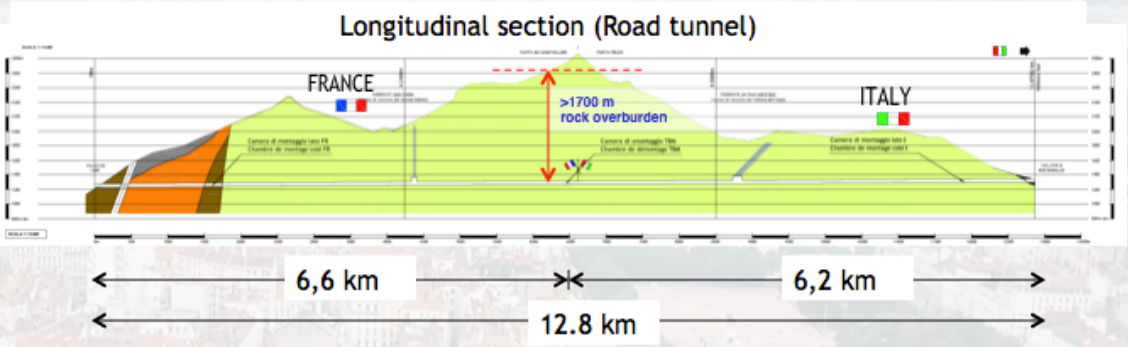
Laboratoire Souterrain de Modane - Frejus

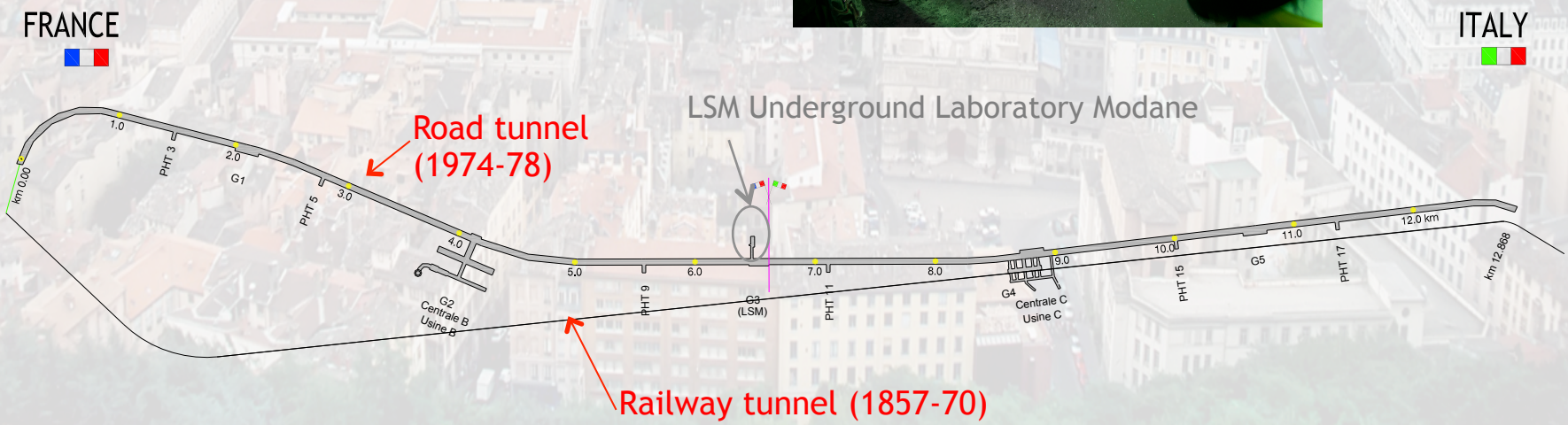
ENGENEERING AND TECHNICAL CHALLENGES

Lombardi

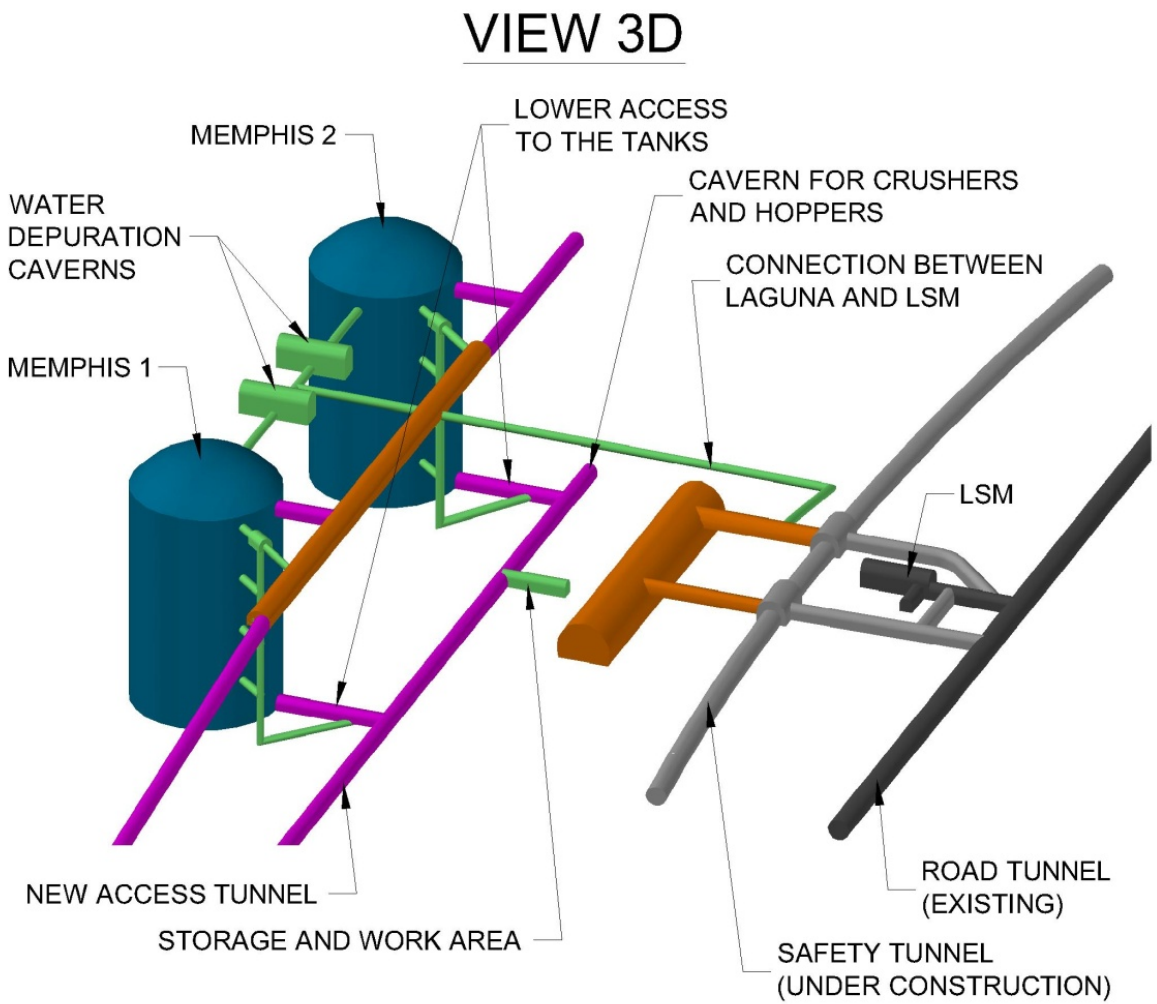
The Fréjus Tunnel







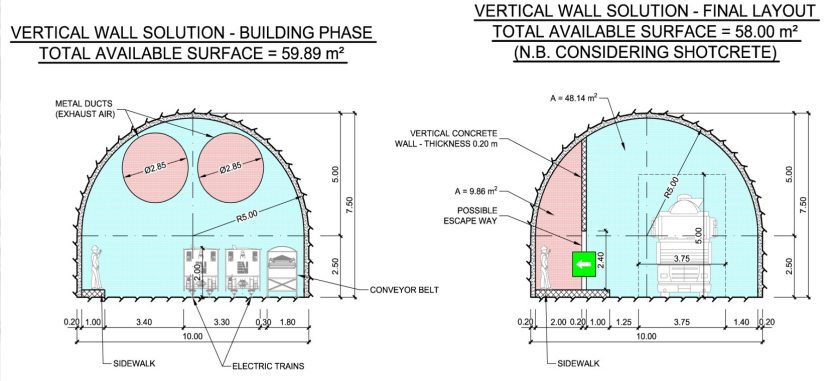
Global layout in the caverns area



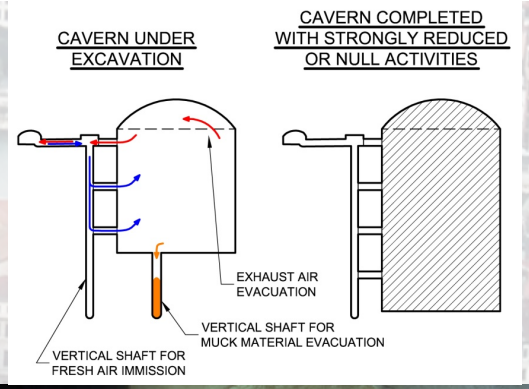
Thanks to Lombardi

ESCAVATION

- ACCESS TUNNEL LAYOUT



- HANDLING AND STORAGE SOLUTIONS

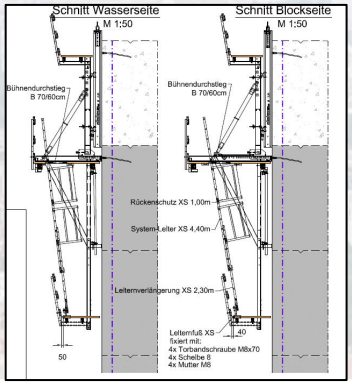


- APPLICATION OF SPRAYED WATERPROOFING MEMBRANE (WHITE)

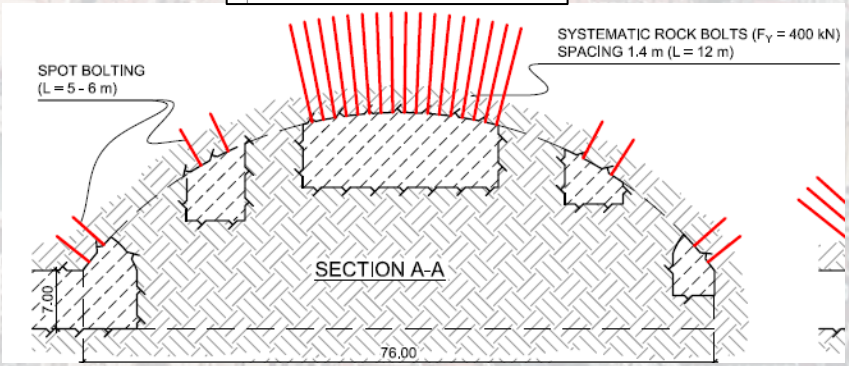
Thanks to Lombardi

COSTRUCTION

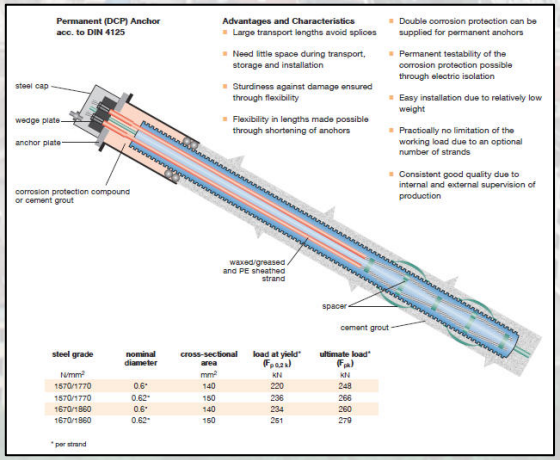
- LINING SYSTEM AGAINST DEFORMATIONS



- DOME SUPPORT STUDIES



- ROCK BOLTING SOLUTIONS

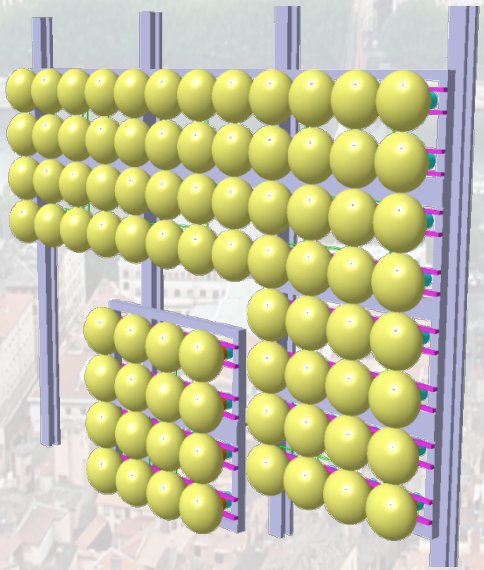


Thanks to Lombardi

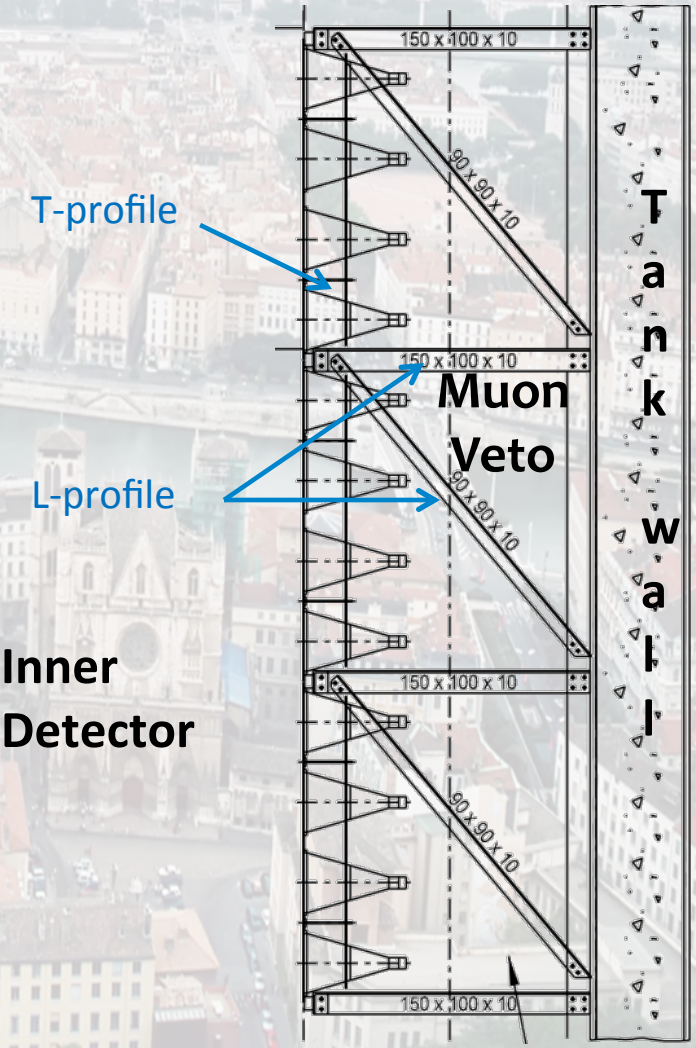
Fastening of PMT Panels

Photomultipliers organized in 4x4 matrices (see moreover)

Support structure:



Yann Colaitis – APC Laboratory



Technodyne International Ltd.

Thanks to Lombardi

THE CONTENT: THE WATER

Sofregaz

VEOLIA WATER

Solutions & Technologies

ORIGIN OF WATER

Water will come from Acquedotto di Susa system.

THE PROJECT

Fire water pipeline in the future Italy to France Frejus tunnel

- Diameter of 250mm
- only gravity
- 0.5% slope
= 250 m³/h

➔ **6 months for the global filling**

WATER ANALYSIS @ LSM

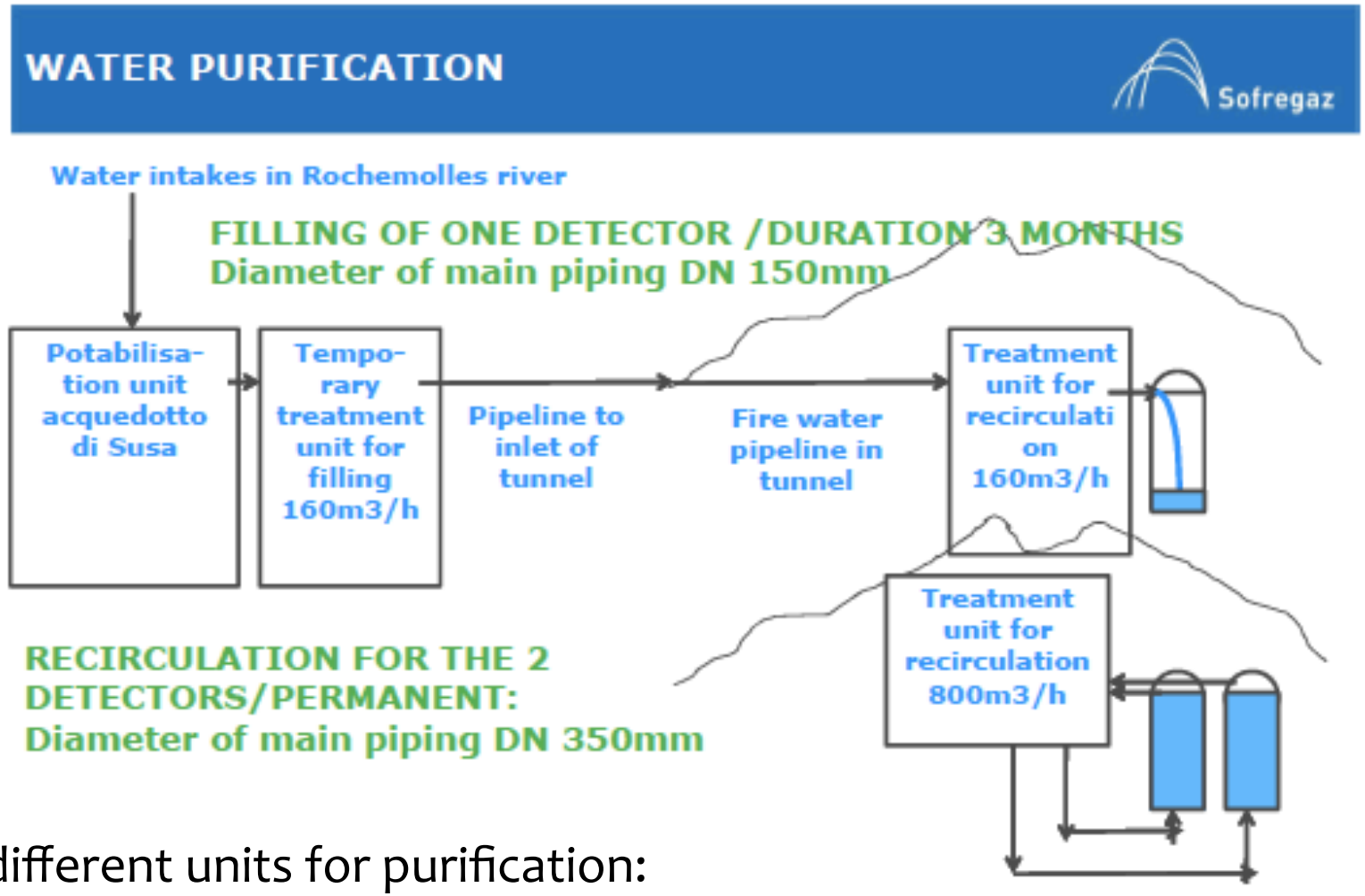
5L Susa Water	activity in mBq/m3		
^{210}Pb	1,48E+04	±	9,44E+02
^{234}Th	4,62E+03	±	6,39E+02
^{228}Ra	**1,27E+03**	**±**	**3,11E+02**
^{40}K	1,27E+04	±	1,47E+03
^{214}Pb	0,00E+00		0,00E+00

Water Requirements for MEMPHYS

Temperature	13° C
ΔT	1° C
Attenuation length	> 100 m @ 400 nm
Resistivity	18 MΩcm
Rn contamination	< 1 mBq/m^3
Oxigen	0.06 mg/l

Rock temperature ~ 29°

➔ **Purification and cooling are needed**



Two different units for purification:

1. **for filling up of tanks**: this unit takes water after flocculation, sand filtration from Aquedotto di Susa Bardonecchia potabilization plant and removes solid particles, dissolved salts, organic components.
2. **to purify the re-circulated water from the filled up tank:** it will remove Bacteria, TOC, Radon and Oxygen.

Cavern Temperature Control in Operation

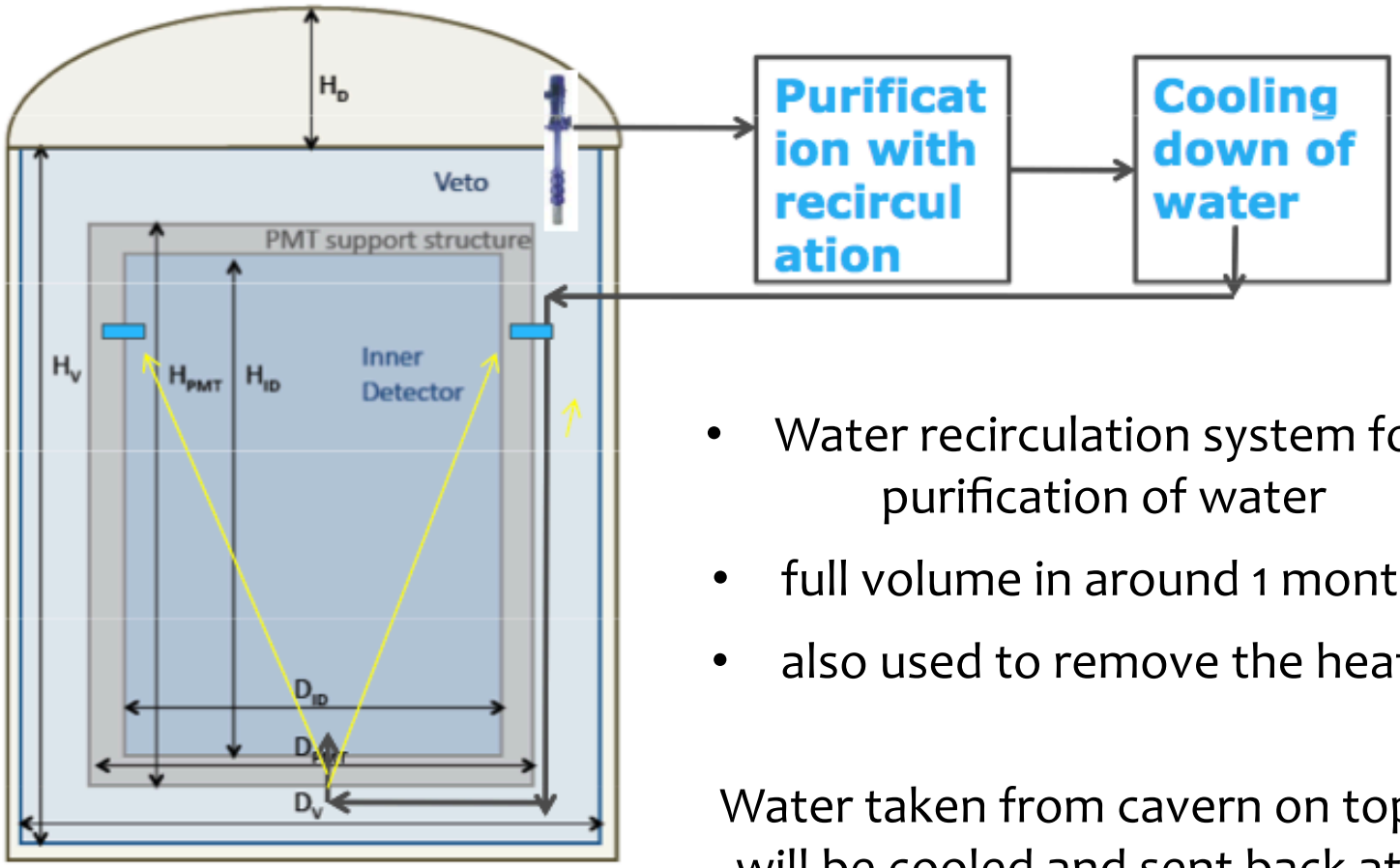


Figure 1: Layout of the MEMPHYS tank and cavern.

- Water recirculation system for purification of water
- full volume in around 1 month
- also used to remove the heat.

Water taken from cavern on top will be cooled and sent back at lower temperature at bottom of cavern

PURIFICATION DURING FILLING OF TANK

Sofregaz

VEOLIA WATER
Solutions & Technologies

VEOLIA WATER STI

Aquamove

UF Mobile Unit		
RO Mobile unit		

Memphys

37

Project for the purification unit was prepared with VEOLIA water Solution and Technologies

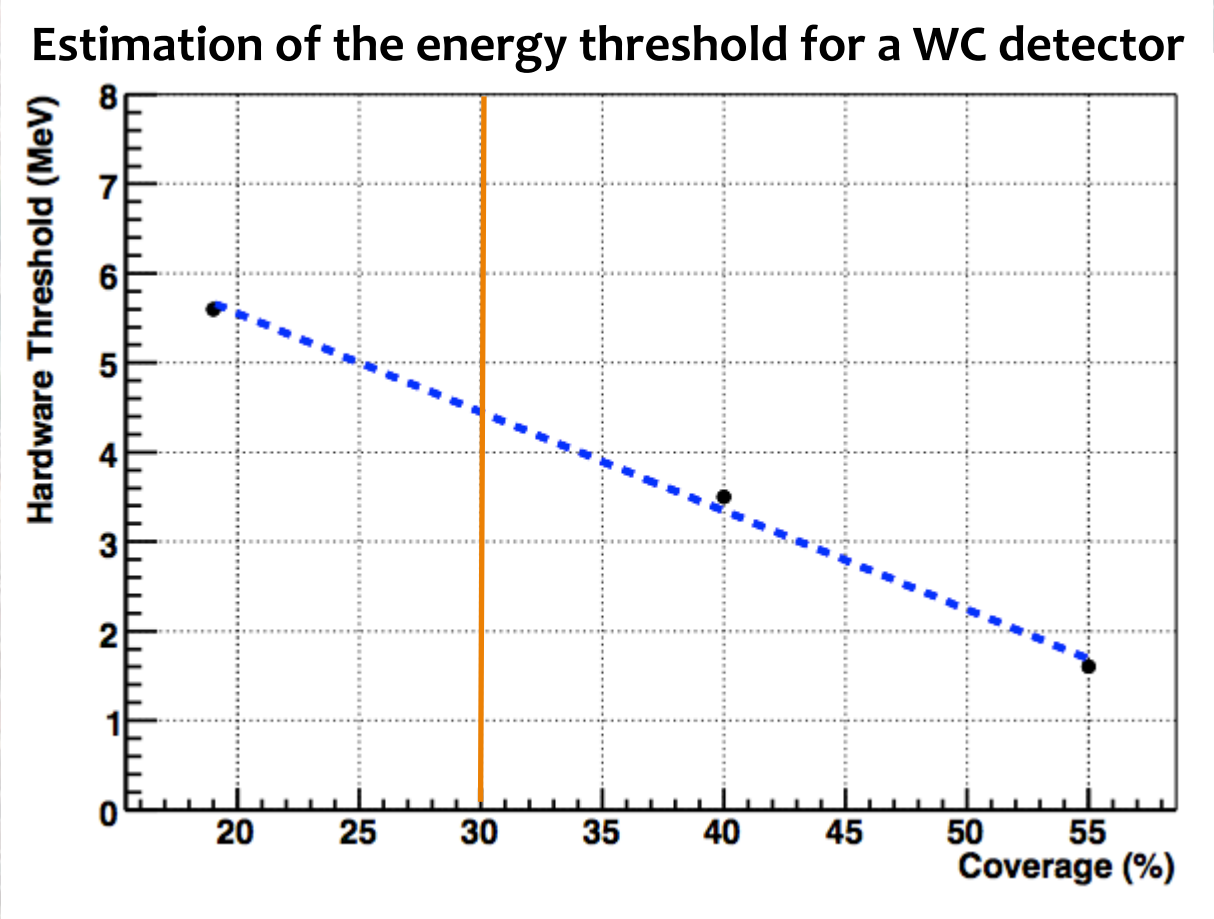
Constraints: the flow

Starting point: plants in Super Kamiokande and projects for Hyper Kamiokande and LBNE.

ABOUT PHOTODETECTION

MEMPHYS Optical Coverage

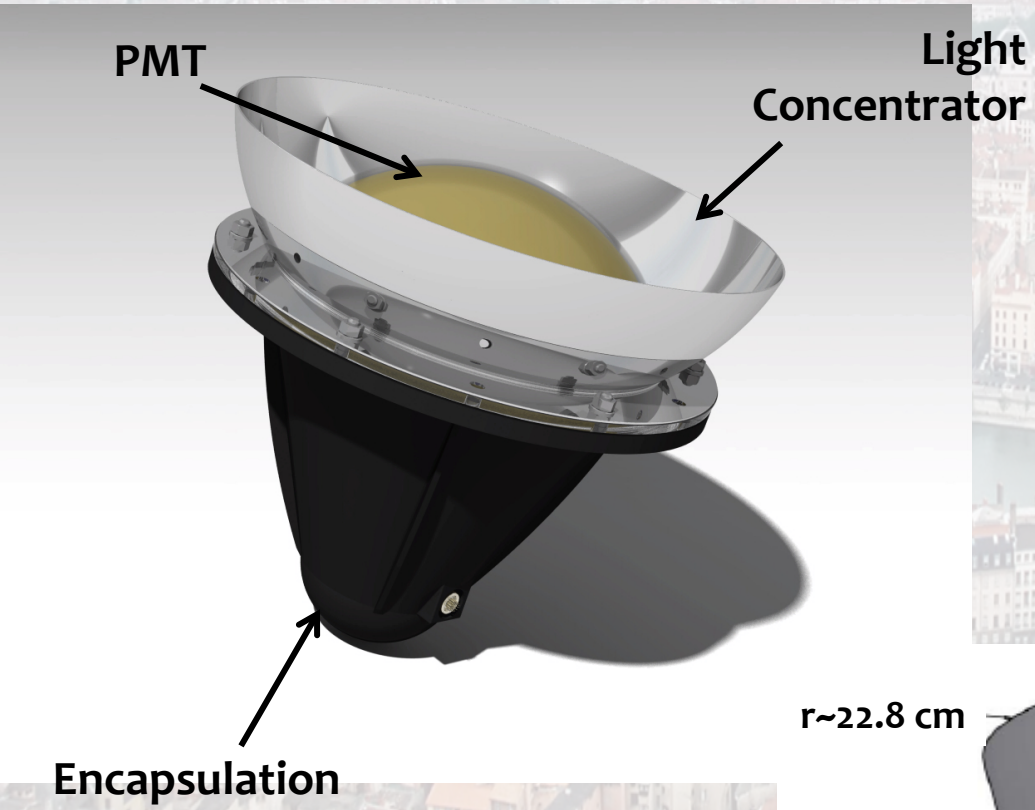
Starting point: 30% coverage (scaled by SuperKamiokande and SNO)



arXiv:1204.2295v

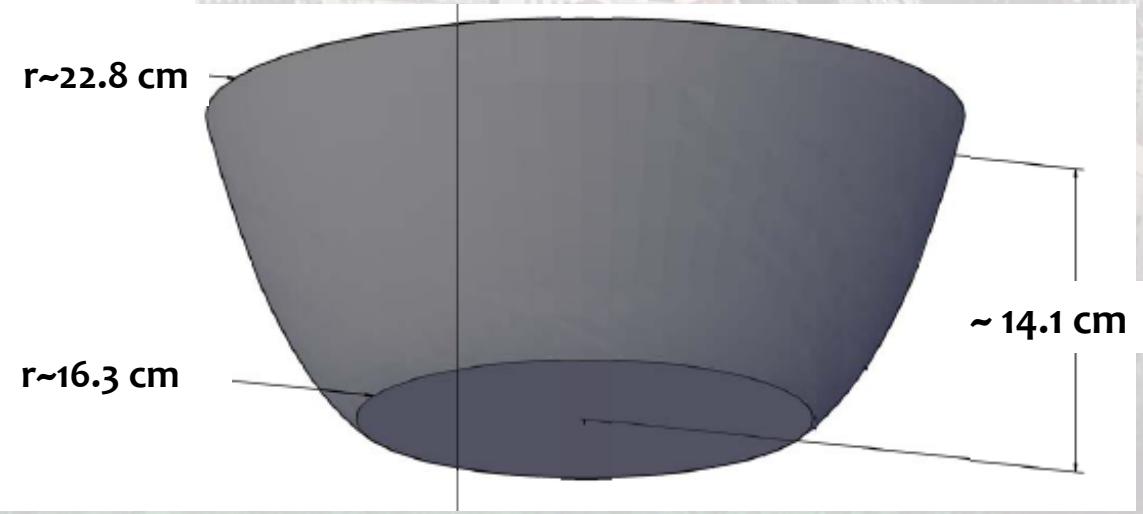
How To Reduce the Number of PMTs

Basing on experience from other experiments (Borexino, SNO) and the LBNE project



Expected gain of about **50%**

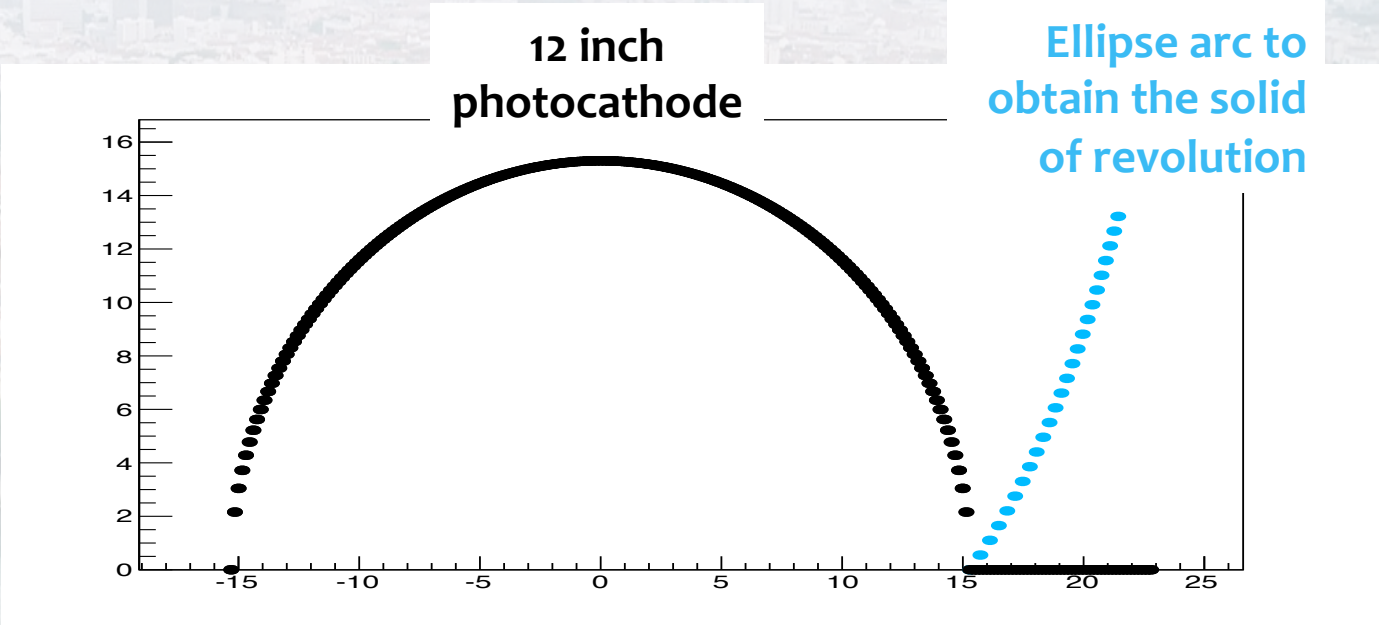
➔ Possibility to reduce the geometrical coverage



Simulating Light Concentrators (LC)…

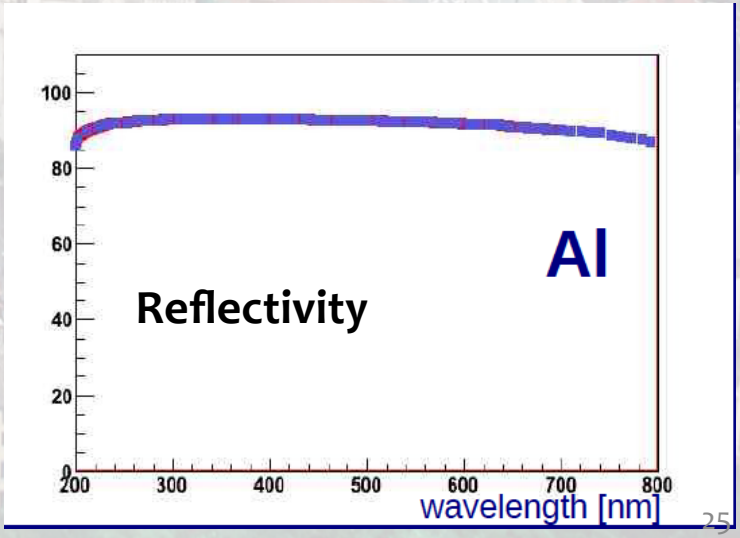
The choosen shape is an **ellipsoidal cone** (as suggested by LBNE studies)

Light concentrators located at the equator of the photocathode. 60° opening angle

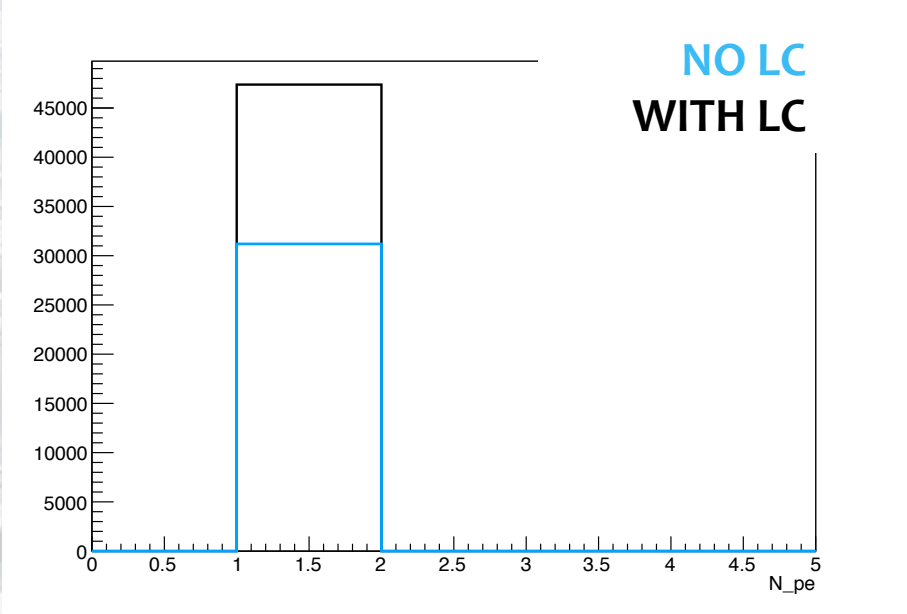


Ellipsoidal Cone Structure: plastic (acrylic) cone + metal coating
Metals for coating: Al, Ag

Ag compatible: already used for many years in Borexino – CTF
Al not compatible: need of additional protective coating



Possible coverage configurations



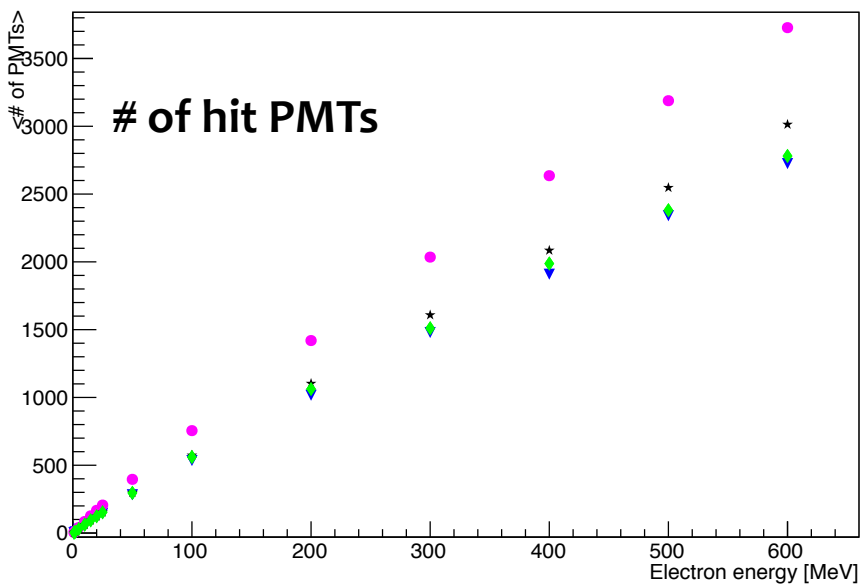
Optical photons of 3 eV

Gain: $Npe_{LC}/Npe_{noLC} = 1.5$

In principle, 30% effective coverage is reachable by:

- 30% geometrical coverage (~ 100k PMTs per tank)
- 20% geometrical coverage (~ 66k PMTs per tank) + LC (~ 1.5 gain)
- 15% geometrical coverage (~ 50k PMTs per tank) + LC (~ 1.5 gain) + High Quantum Efficiency (HQE) photocathodes (~ 1.5 gain)

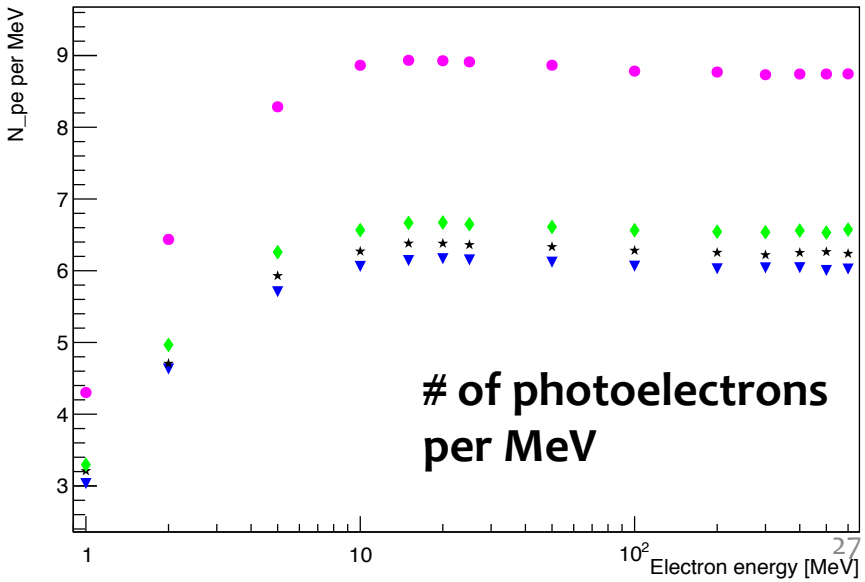
Comparing different configurations



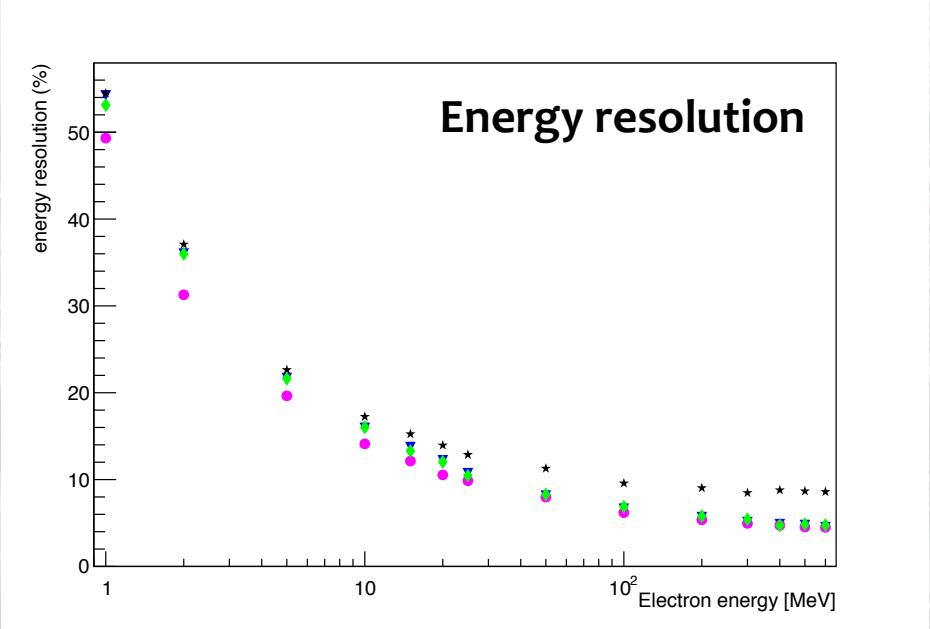
- 30% coverage, normal QE (22% @ peak)
- 20% coverage + LC, normal QE (22% @ peak)
- 20% coverage + LC, high QE (32% @ peak)
- 15% coverage + LC, high QE (32% @ peak)

As expected, 15% geom. coverage + LC + HQE gives same results as 30% geom. coverage with NQE…

but using 50% of PMTs!!



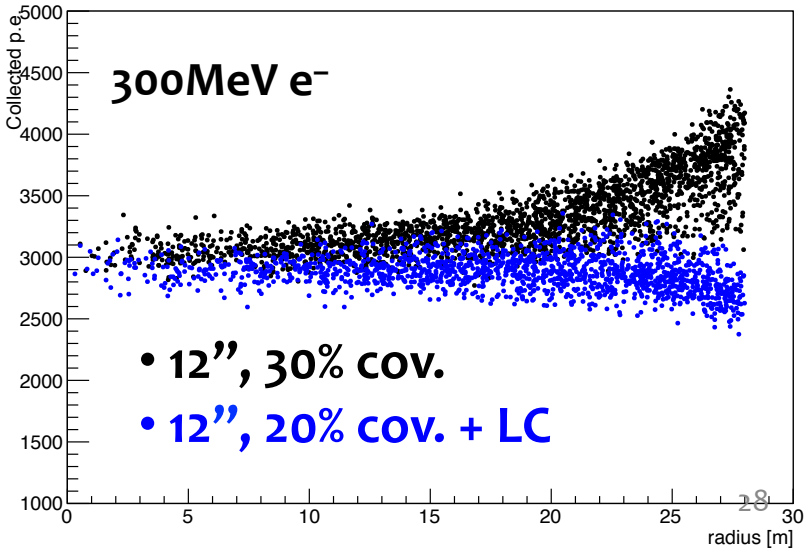
LC: improvement of the energy resolution



- 30% coverage, normal QE (22% @ peak)
- 20% coverage + LC, normal QE (22% @ peak)
- 20% coverage + LC, high QE (32% @ peak)
- 15% coverage + LC, high QE (32% @ peak)

The use of LC improves the energy resolution, as the light collection is no more dependent on the radial position (shielding effect)

Collected p.e. vs radius



Conclusions on PMT instrumentation

- In terms of effective coverage, **30% geometrical coverage** is equivalent to **20% geom. coverage + LC** and **15% geom. coverage + LC + HQE** photocathode
- Vertex reconstruction, direction reconstruction, particle identification (at 680MeV) are not affected by different instrumentation configurations
- The use of LC improves the energy resolution

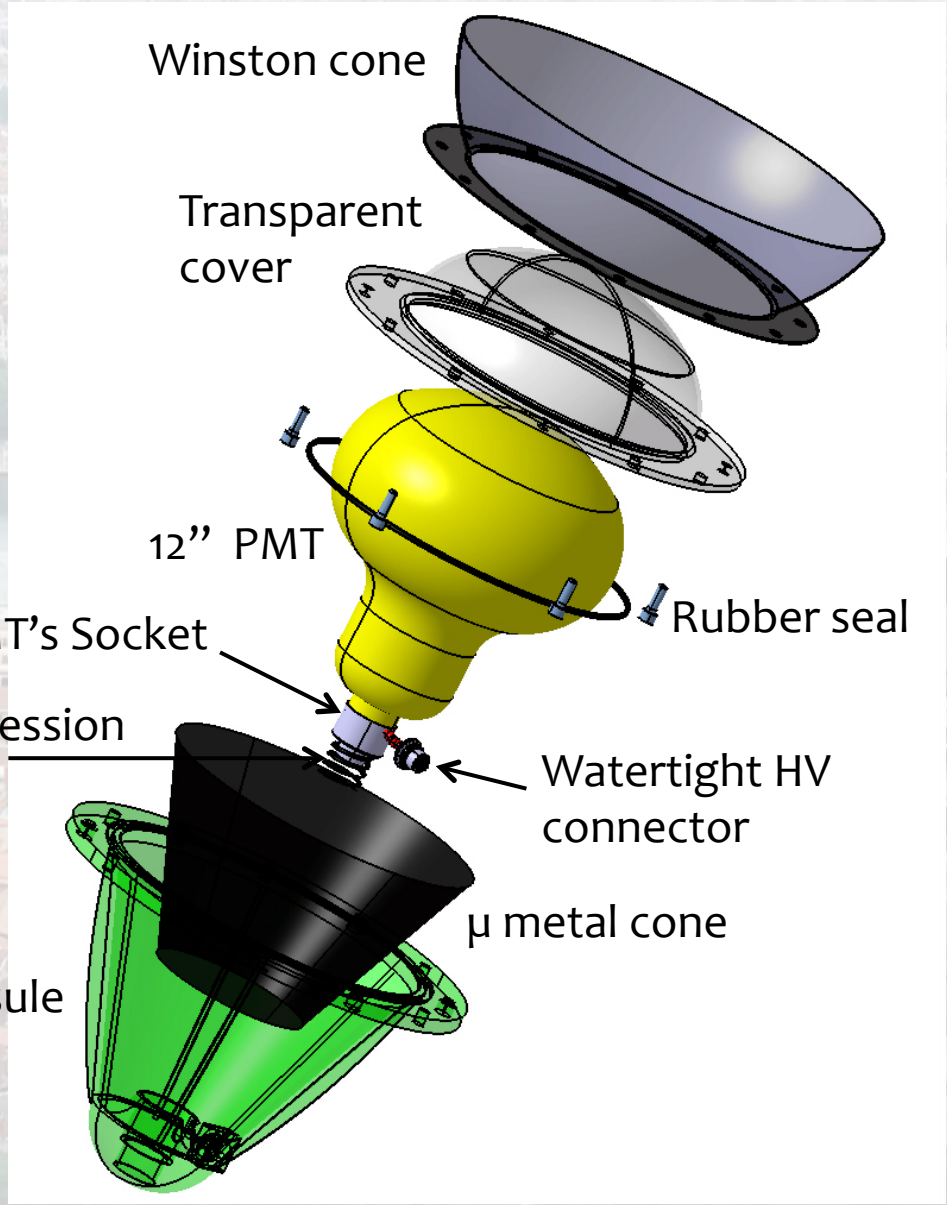
Considering 20% geometrical coverage for 12" Hamamatsu NQE PMTs (R11780)

Hamamatsu	R11780
Diameter	12"
Dark rate (@25° C)	10 kHz
Quantum eff. (@390 nm)	22%
Geometrical coverage	20%
Number (2tanks)	130 k
Production Time	5y
Cost (transportation included)	195 M€

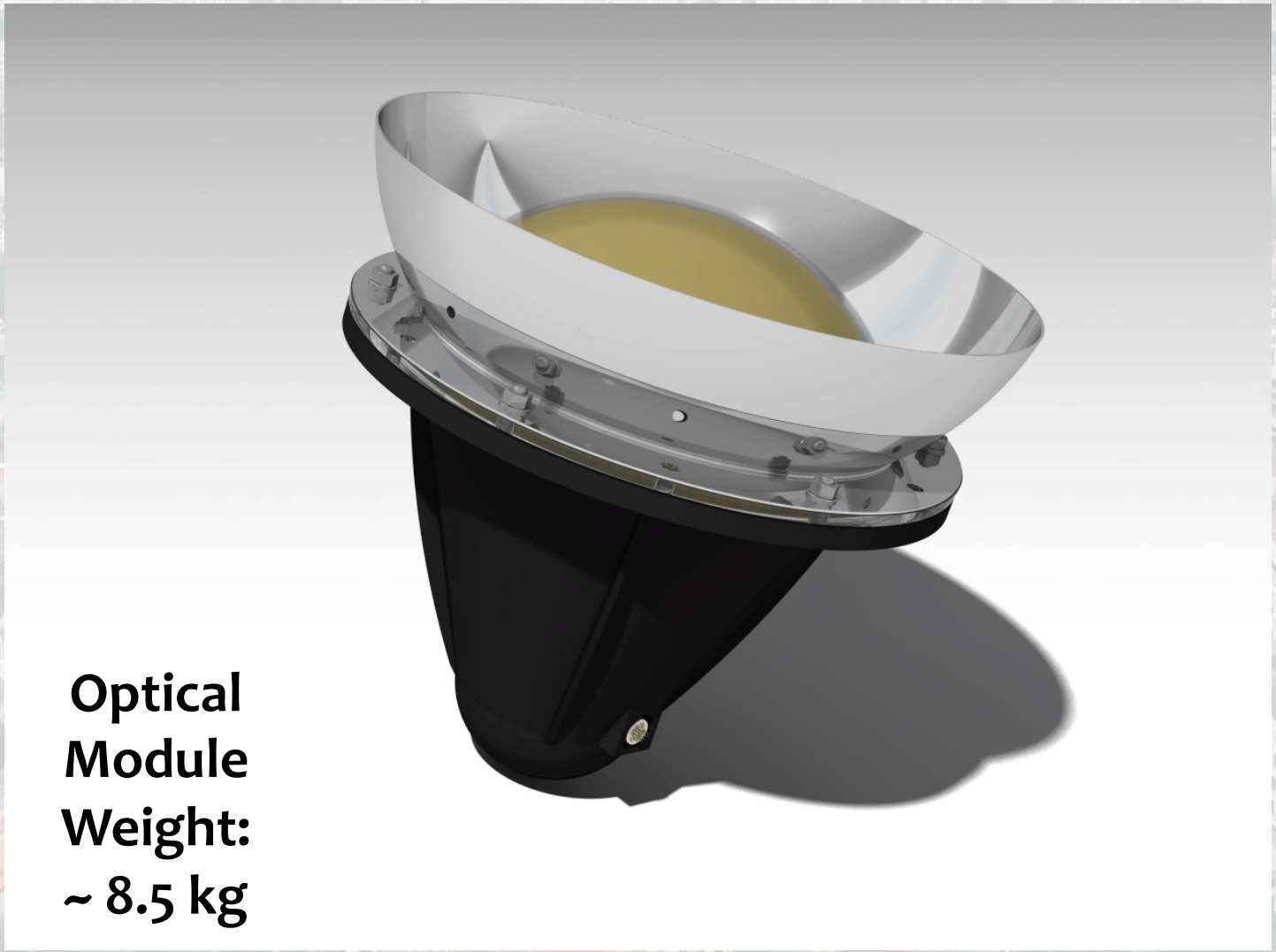
PMT ENCAPSULATION

(thanks Yann Colaitis)

The Optical Module: Components



The Optical Module

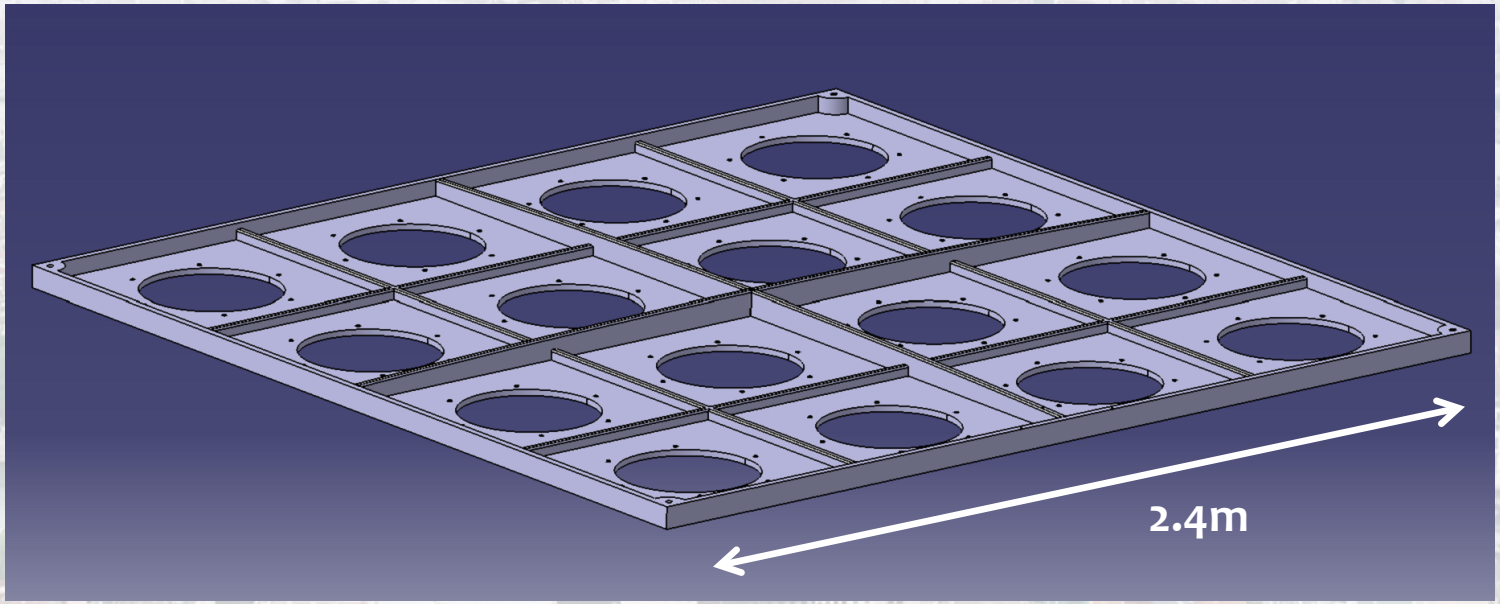


Optical Module Weight: ~ 8.5 kg

PMT MATRIX

(thanks Yann Colaitis)

Matrix design



- **Matter : ABS plastic (Acrylonitrile-butadiene-styrene)**
  available in different colors

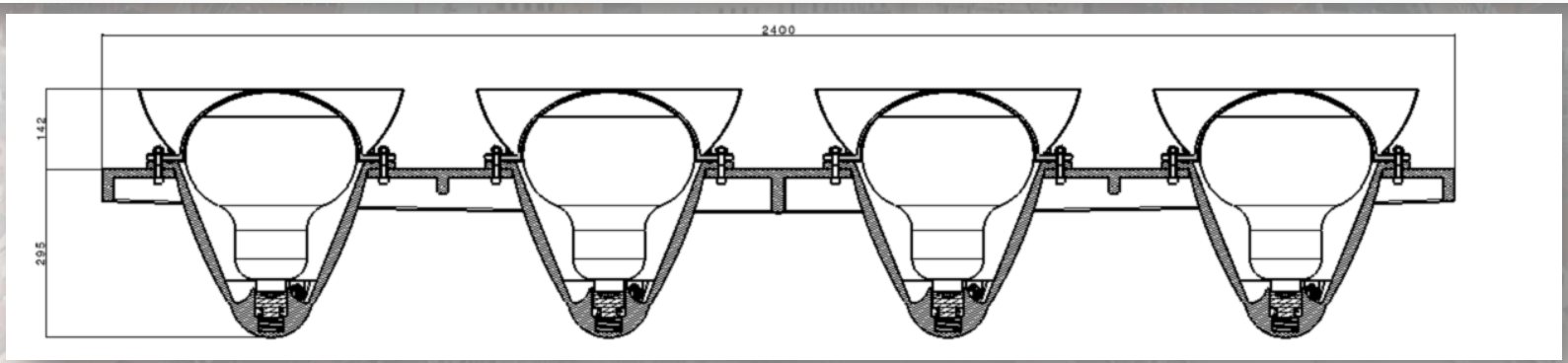
- Weight : 85kg

- Production : compression/ injection molded, water jet cutting (for boltings)

Matrix & Optical Modules

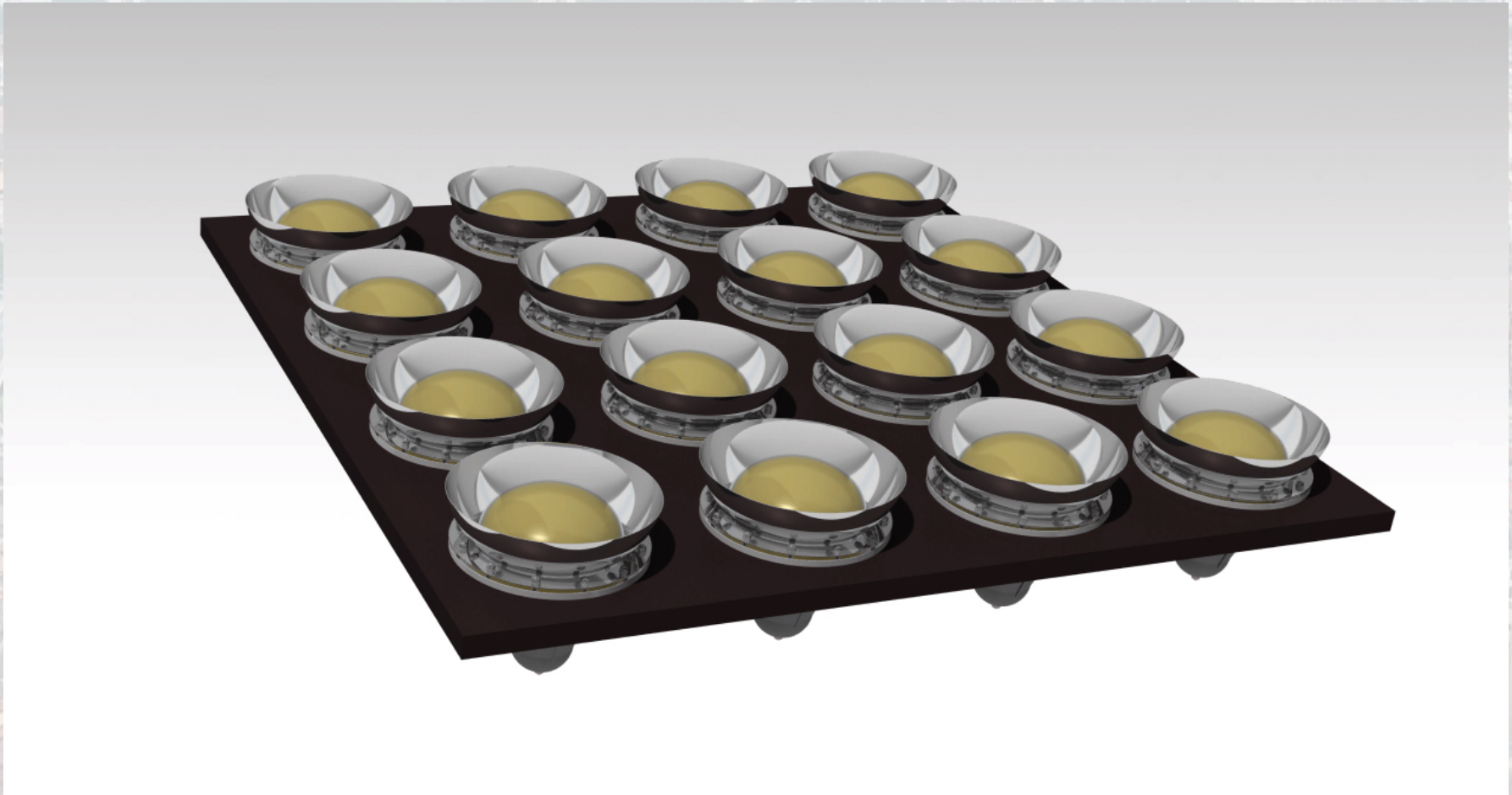
Récapitulatif sur **MYM3001-Assemblage_Matrice_Memphis**
Pièces différentes : 17
Total des pièces : 769

Quantity	Reference	Matter	Weight (kg)
1	MYM3002- Matrice 4x4 PM 2400x2400	UHMWPE (Ultra High Molecular Weight Polyethylene)	76.24
16	MYM0002-PM Memphys 12"		35.2
16	MYM0003-Capsule PM Memphys	ABS (Acrylonitrile butadiene styrene)	38
16	MYM0004-Couvercle_transparent_PM	PMMA (Polymethyl methacrylate)	22.4
16	MYM0005-Cone_de_Winston	ABS (Acrylonitrile butadiene styrene)	7.2
16	MYM0007-Joint_torique_d350xdt6	EPDM (ethylene propylene diene monomer (M-class) rubber)	0.3
16	MYM0008-Cage PM	ABS (Acrylonitrile butadiene styrene)	3.86
16	MYM0009-Cone mu-metal	μ-metal	2.75
16	MYM0010-Socket_PM		
16	MYM0011-Cablage_Connecteur_PM		
16	MYM0012-Connecteur_etanche_SW3DPS-Fischer_DBPE_DBPU_105_A038-130		0.8
16	MYM0013-Rondelle frein denture interieure emile maurin 7200020 2 03	Stainless Steel	0.08
16	MYM0014-Ecrou connecteur SW3DPS-FISCHER HEX M20X1	Stainless Steel	0.11
96	ISO 4762 SCREW M10x30 STEEL HEXAGON SOCKET HEAD CAP	Stainless Steel	2.98
96	ISO 4762 SCREW M10x55 STEEL HEXAGON SOCKET HEAD CAP	Stainless Steel	4.42
192	ISO 4032 NUT M10 STEEL GRADE A HEXAGON	Stainless Steel	2.1
192	ISO 7089 WASHER 10x20 STEEL GRADE A PLAIN NORMAL SERIES	Stainless Steel	0.58
TOTAL			**197.02**



Total Weight: ~ 200 kg

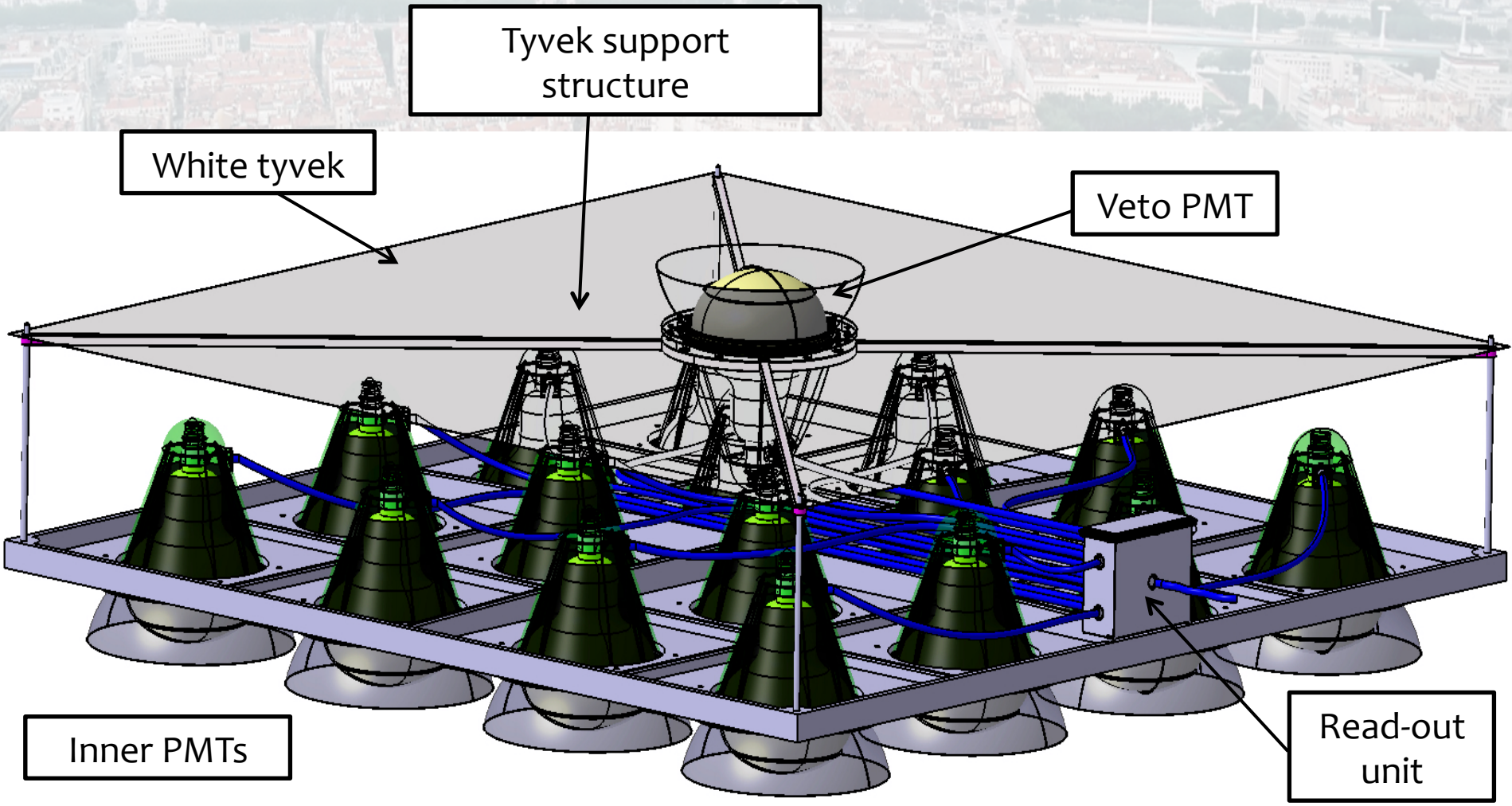
The Inner Face of the Matrix



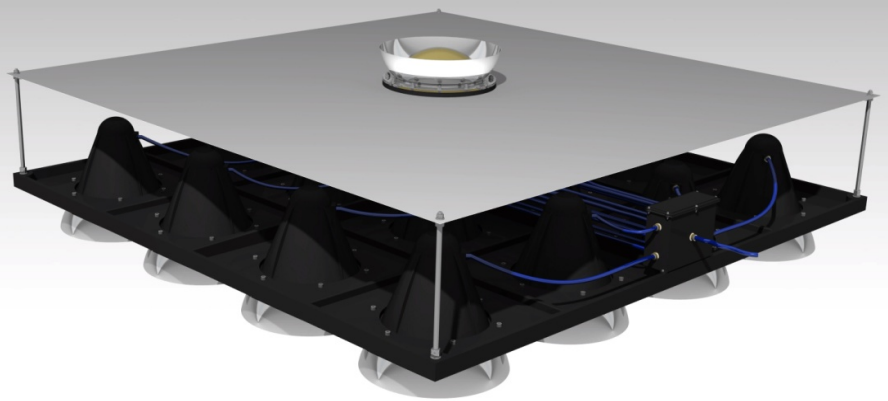
Total Weight: ~ 200 kg

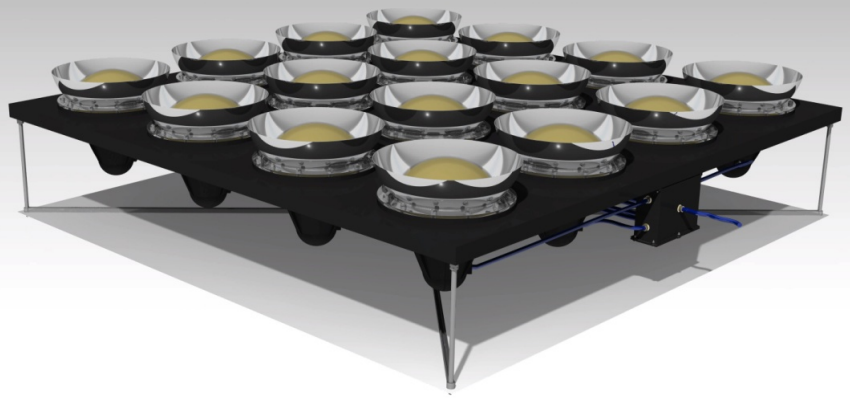
… the outer

… and the Veto PMT



The Matrix: Global Design





Matrix + tyvek veto structure
Total Weight ~260kg

Final deliverables in summer 2014

WATER PURIFICATION

Sofregaz

There is two different units for purification:

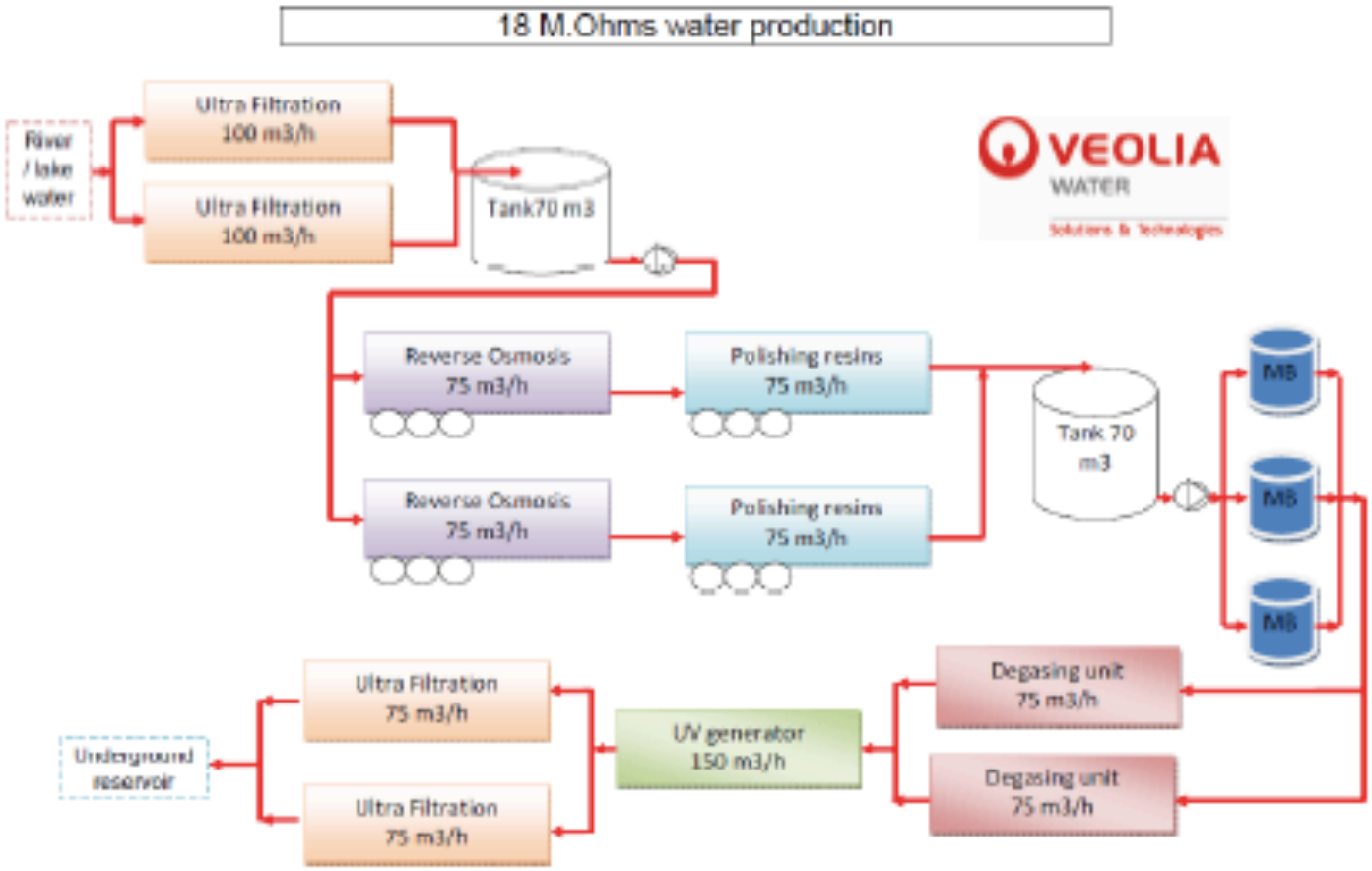
One unit for filling up of tanks

- This unit takes water after flocculation , sand filtration from Aquedotto di Susa Bardonecchia potabilization plant and remove solid particles, dissolved salts , organic components .
- This unit has water rejection, it will be installed outside close to SMAT potabilization plant.
- A polyethylene DN 200 pipeline will be used to transport water to entrance of tunnel with tie in to the DN 250 fire water pipeline of the Itaiy to France tunnel ;
- This unit will be used around 3 months for each cavity will better be a rented unit as standard unit similar to that are used for emergency uses. Only upstream and downstream pumps if necessary will be fix.
- Inlet flow will be 200m3/h and outlet flow 160m3/h

SEVENTH FRAMEWORK PROGRAMME

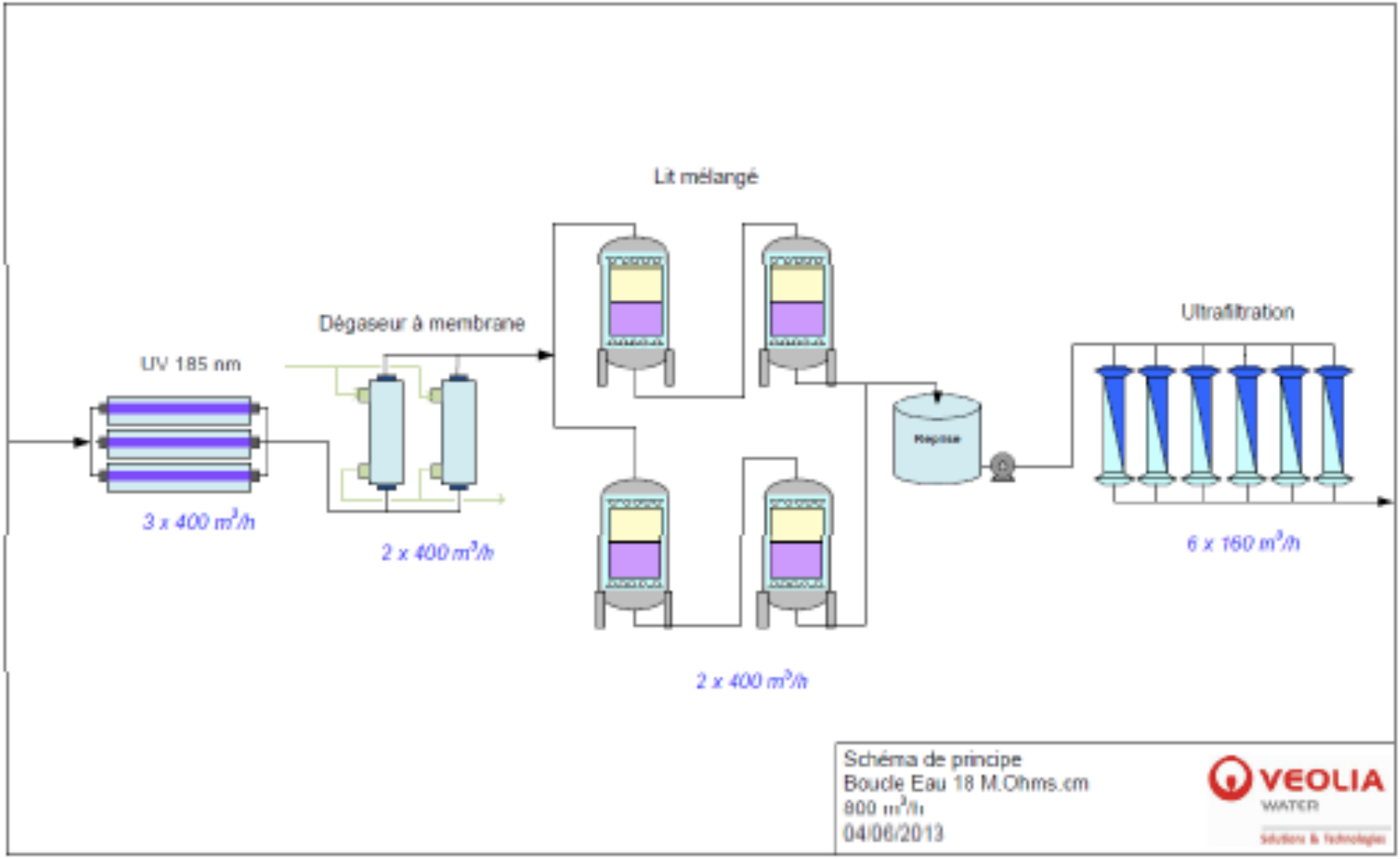
PURIFICATION DURING FILLING OF TANK

Sofregaz



PURIFICATION WITH RECIRCULATION OF WATER DURING OPERATION

Sofregaz



WATER PURIFICATION

Sofregaz

One unit to purify re circulated water from the filled up tank

- What is removed above is not supposed to appear in the cavern so it's not useful to recirculate water in the unit used for filling, for instance if salts are removed and water is at 18Mégohm*cm resistivity.
- Only things to be removed with recirculation during operation are :
  - Bacteria - kill them and then remove them
  - TOC , ionize the TOC particies with short UV then catch the ionized particles in a de ionizer
  - Radon from PMT
  - Oxygen from air ?

  Or as in DUSEL : U, Th with resin
- This unit will be common for the 2 detectors and sized for a 800m3/h flow, 400m3/h per detector.
- Water for filling of detectors with is pretreated outside tunnel at flow 160m3/h will go through this unit before going to detector .

SEVENTH FRAMEWORK PROGRAMME

Considered Photomultipliers for 30% coverage

Hamamatsu	R5912	R7081	R11780
Diameter	8”	10”	12”
Dark rate (@25° C)	4 kHz	7 kHz	10 kHz
Quantum eff. (@390 nm)	25%	25%	22%
Number (2tanks, 30% cov.)	462 k	273 k	206 k
Production Time	18 y	11 y	8 y

In principle, High Quantum Efficiency (HQE, 32% at 400nm) PMTs will be available

Considered Photomultipliers for 30% coverage

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Number (2tanks, 30% cov.)	462 k	273 k	206 k
Production Time	18 y	11 y	8 y

In principle, High Quantum Efficiency (HQE, 32% at 400nm) PMTs will be available

OVERVIEW ON PHYSICS POTENTIAL

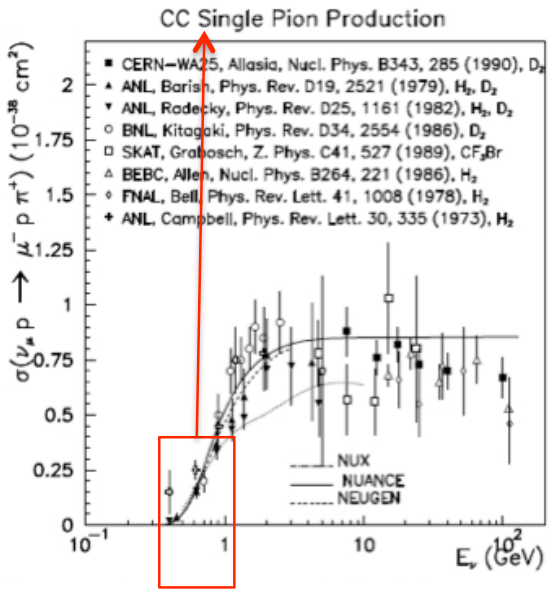
ENERGY RECONSTRUCTION

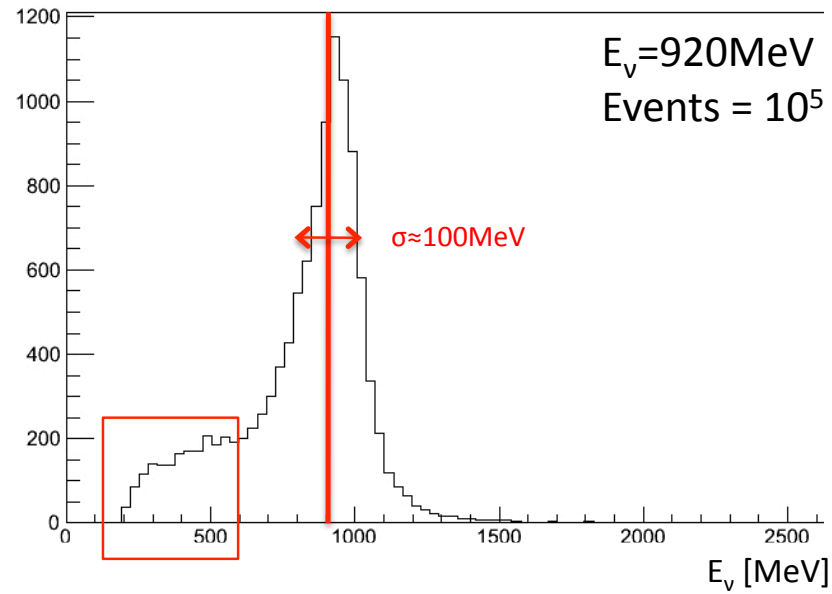
$$E_\nu = \frac{m_n E_\mu - m^2{}_\mu/2}{m_n - E_\mu + p_\mu \cos\theta_\mu}$$

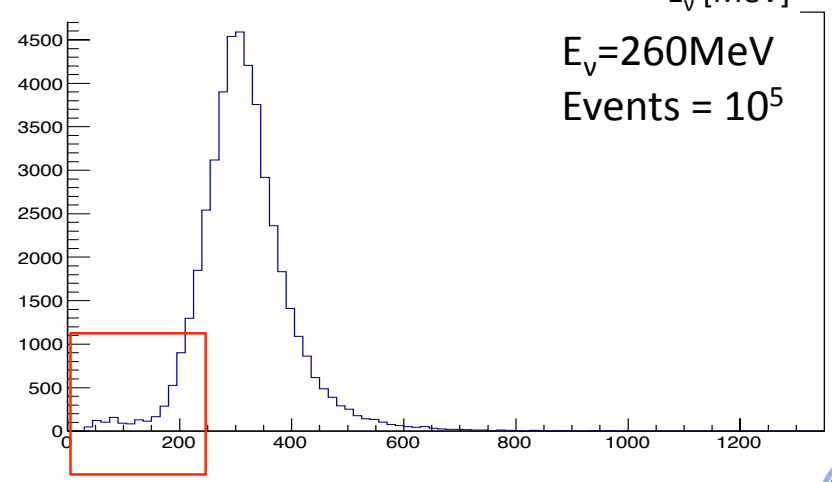
CC Pion production activation over 300 MeV

$$\nu_\mu + p \rightarrow \mu^- + p + \pi^+$$

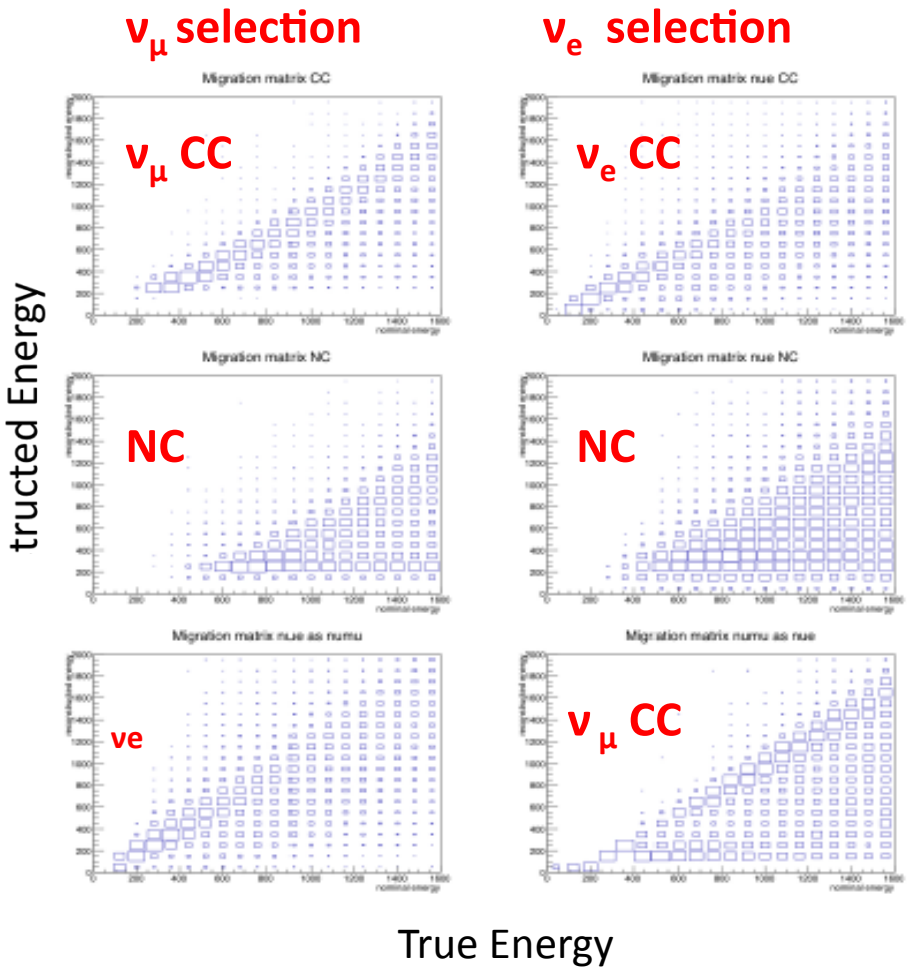
$$\nu_\mu + n \rightarrow \mu^- + n + \pi^+$$







MIGRATION MATRICES

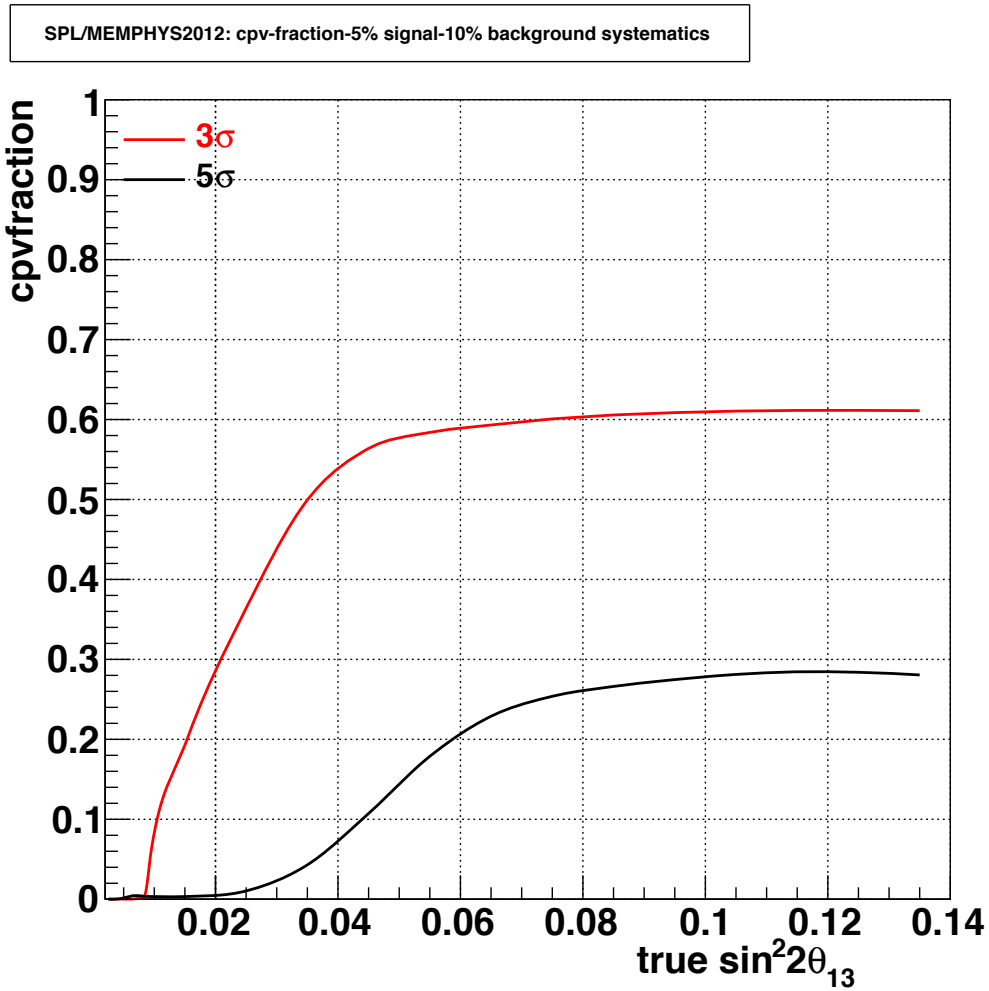


JCAP 1301 (2013) 024

.dat (GLOBES format) files are avalible

patzak@apc.univ-paris7.fr
luca.agostino@apc.univ-paris7.fr
tonazzo@in2p3.fr
buizza@apc.in2p3.fr

PHYSICS POTENTIAL

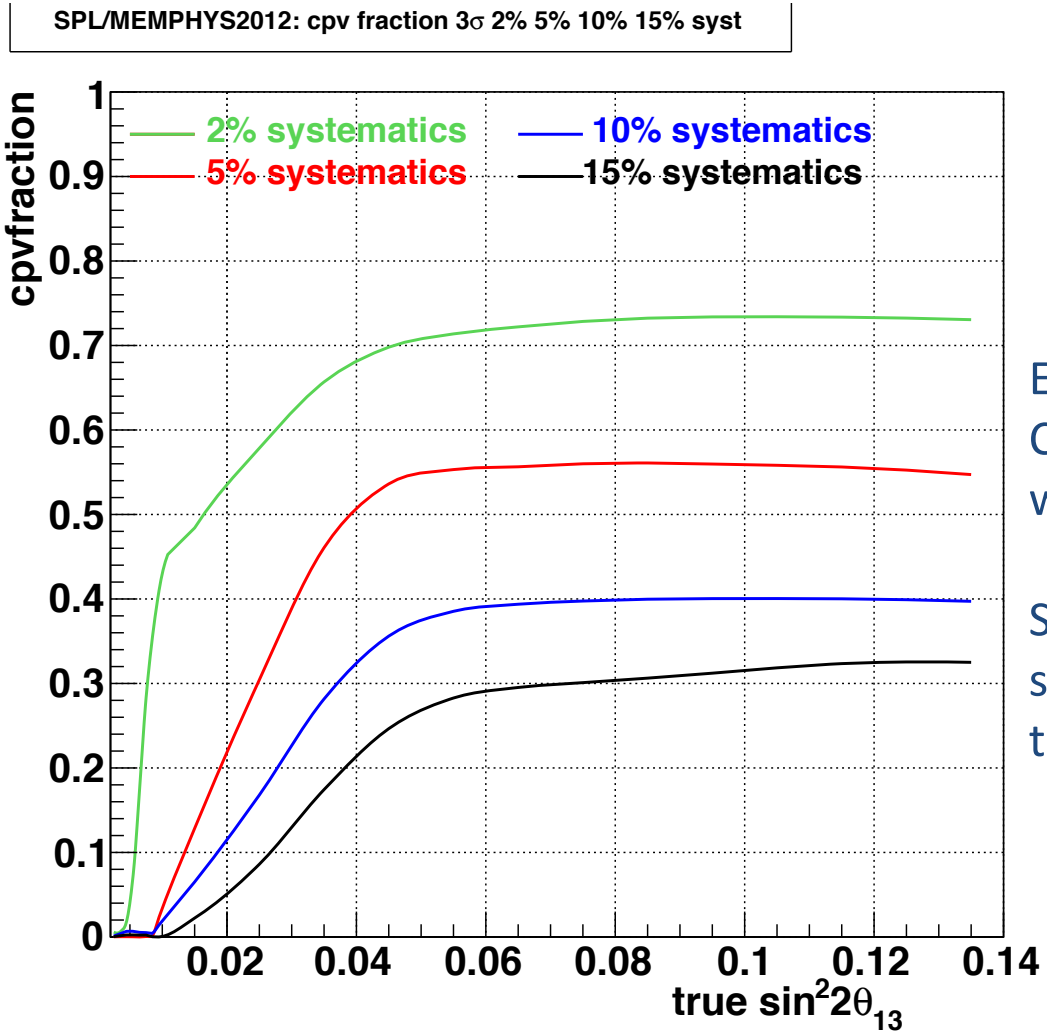


JCAP 1301 (2013) 024

CP fraction coverage with MEMPHYS at 3-5 sigmas

5% signal 10% background systematics

SYSTEMATIC ERRORS STUDIES



CPV fraction at 3σ

Effect of the systematics on the CP fraction coverage power with MEMPHYS.

Signal and Backgrounds systematic errors are set to be the same values

MEMPHYNO: A Test Bench for new readout electronics and DAQ systems

MEMPHYNO CONCEPTION

-2 x 2 x 2 cube meters black box

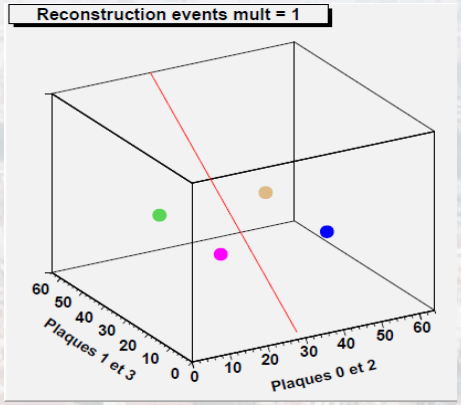
- 16 PMTs matrix

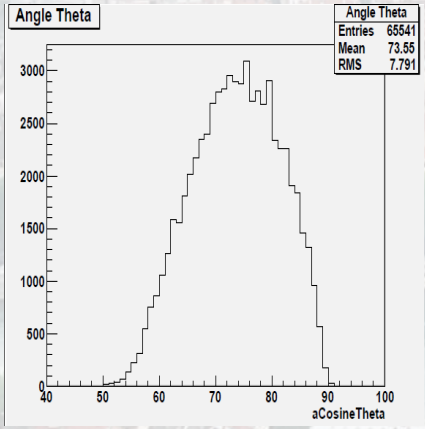
- 4 scintillator strips to sign muons trajectories

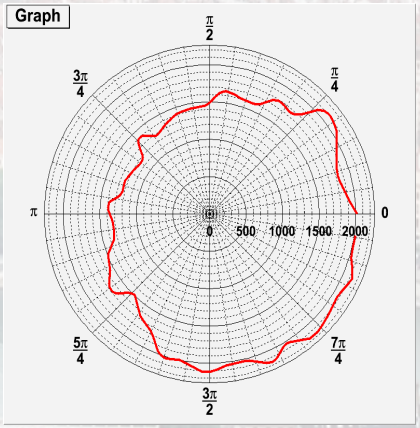
- Automatic reconstruction

MEMPHYNO HODOSCOPE

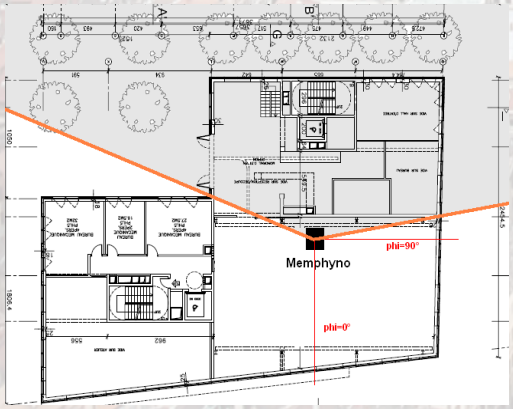
1. Muons tracks reconstruction

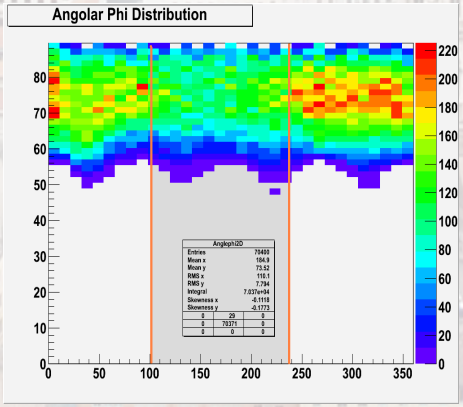






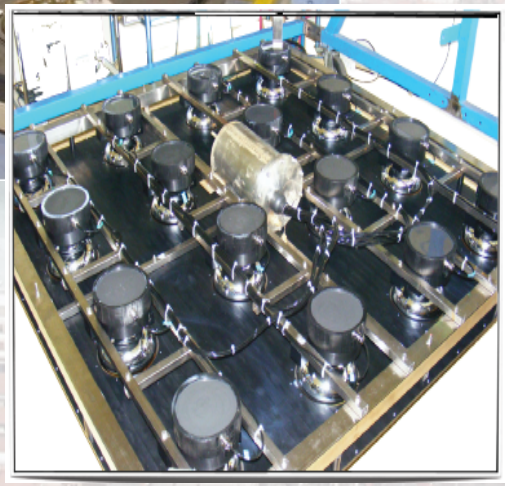
2. Angular distributions



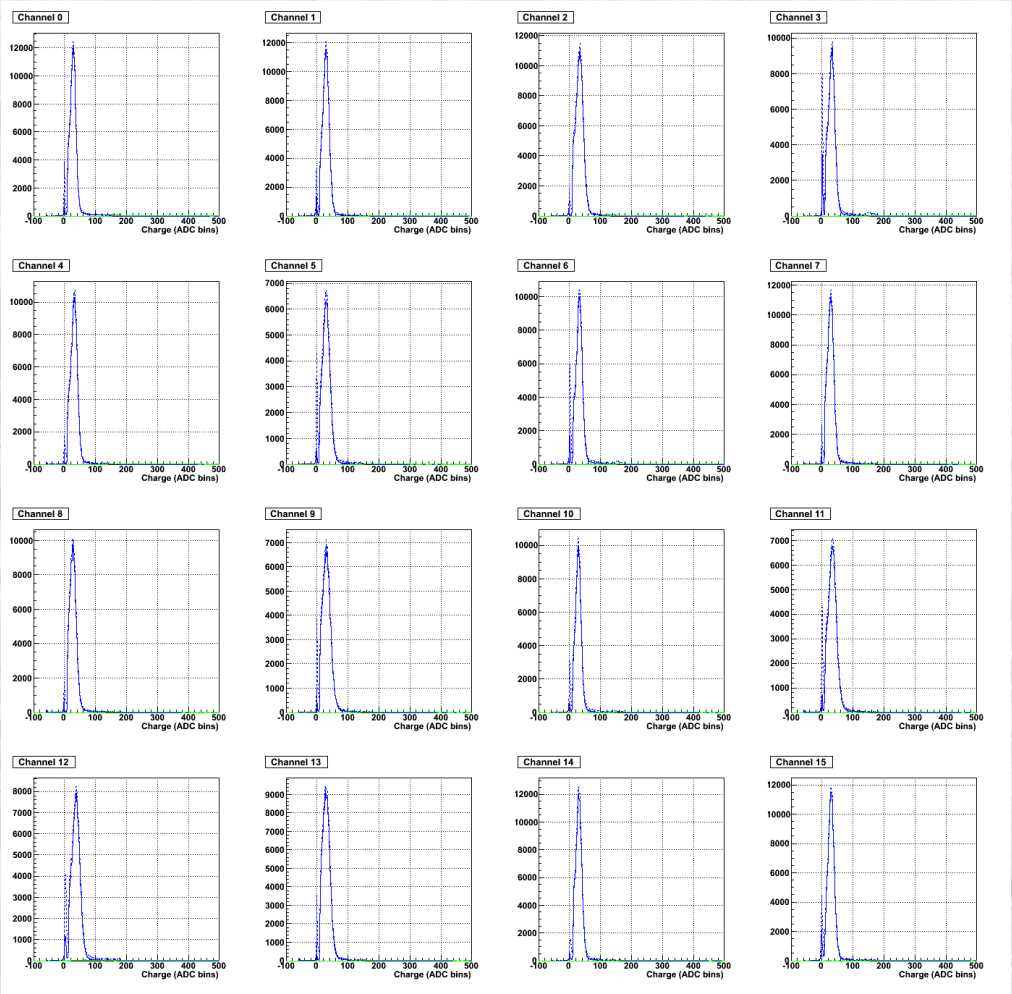


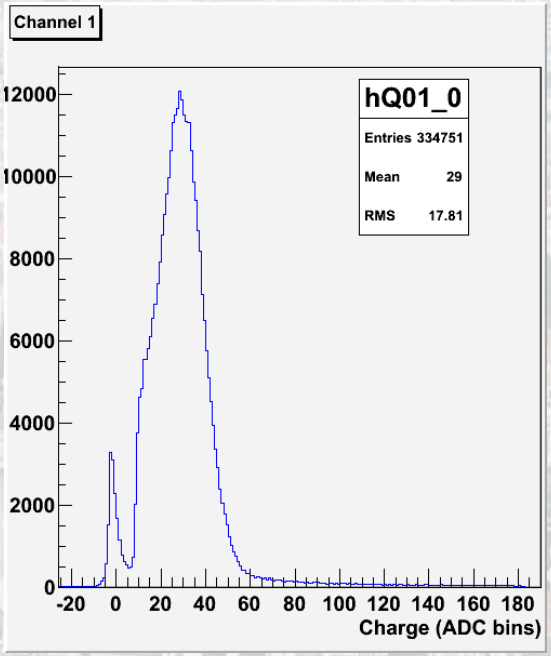
3. Hodoscope as a scanner

THE PMm2 MATRIX



THE PMm2 MATRIX (2)





First Cherenkov Light Signal!

SuperKamiokande energy resolution

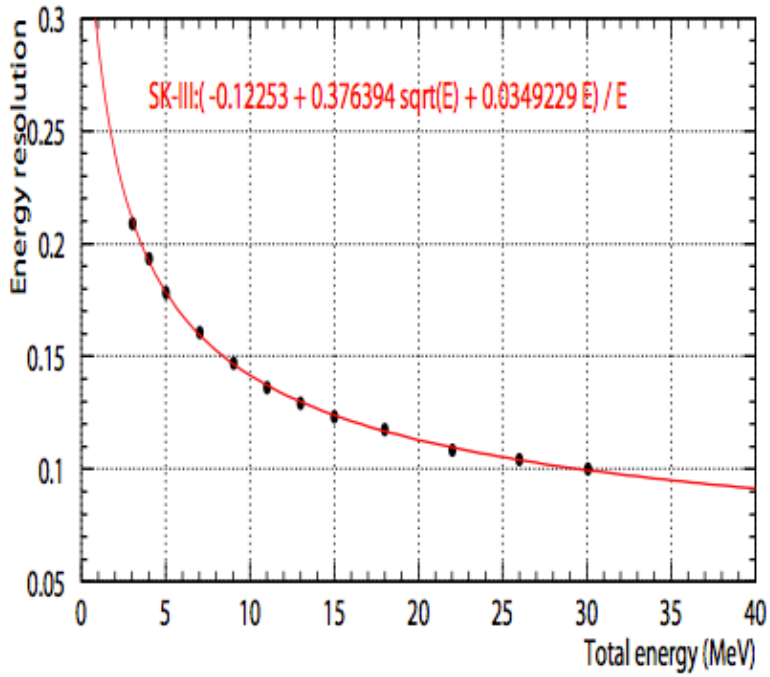


Figure 6.23: Energy resolution function obtained by electron MC simulation . Black points show the one standard deviation of Gaussian fit of MC simulation (see top plot of Figure6.18), while the line shows the fitting by the polynominal function.

SuperKamiokande angular resolution

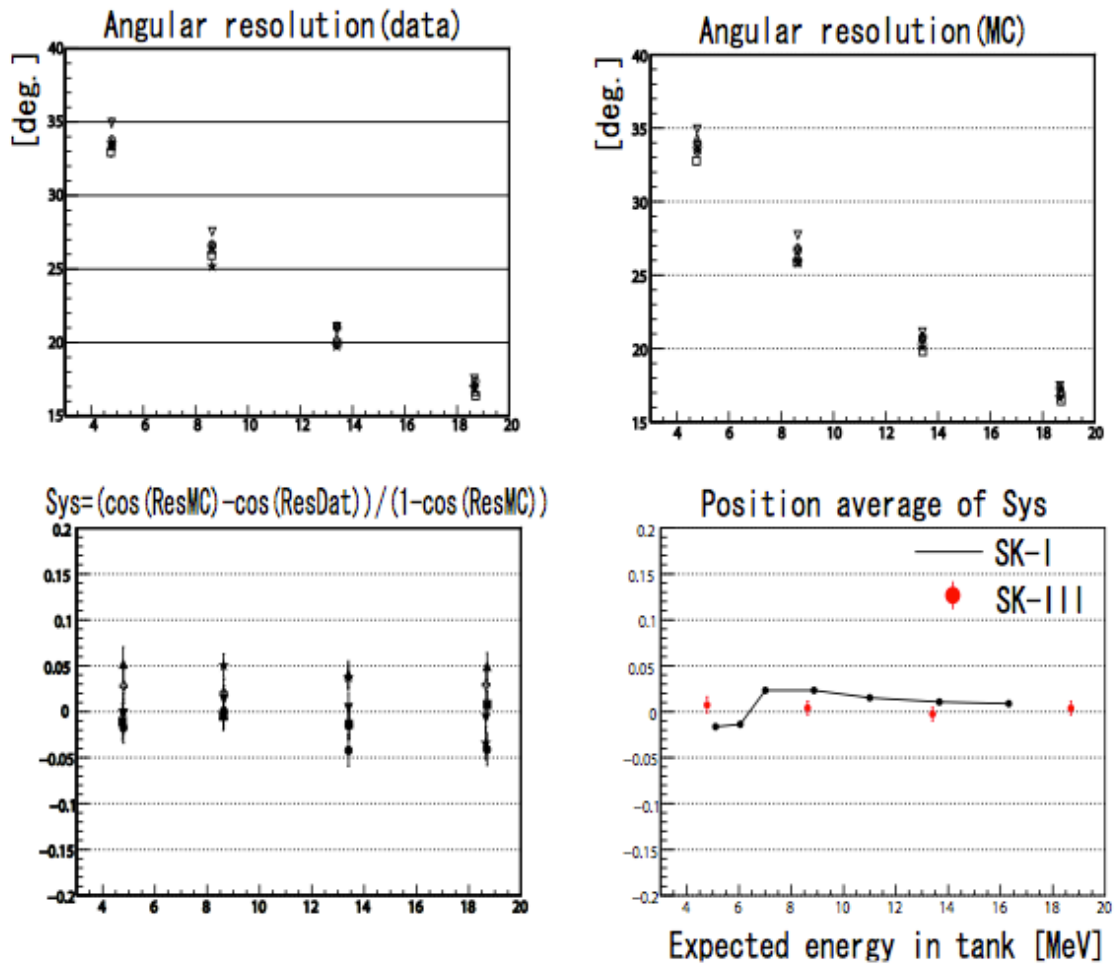


Figure 6.25: Angular resolution of LINAC data and MC simulation

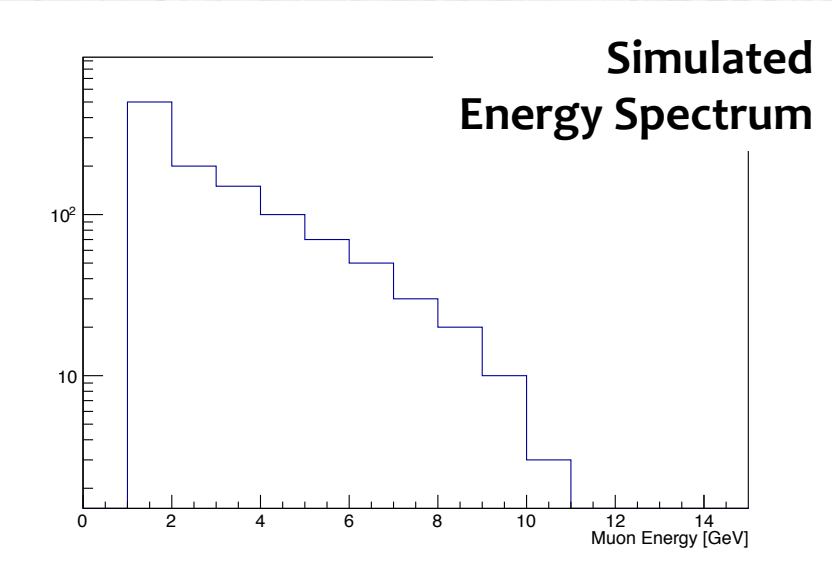
Table I. *Accuracies and resolutions of some important parameters of the Super-Kamiokande detector.*

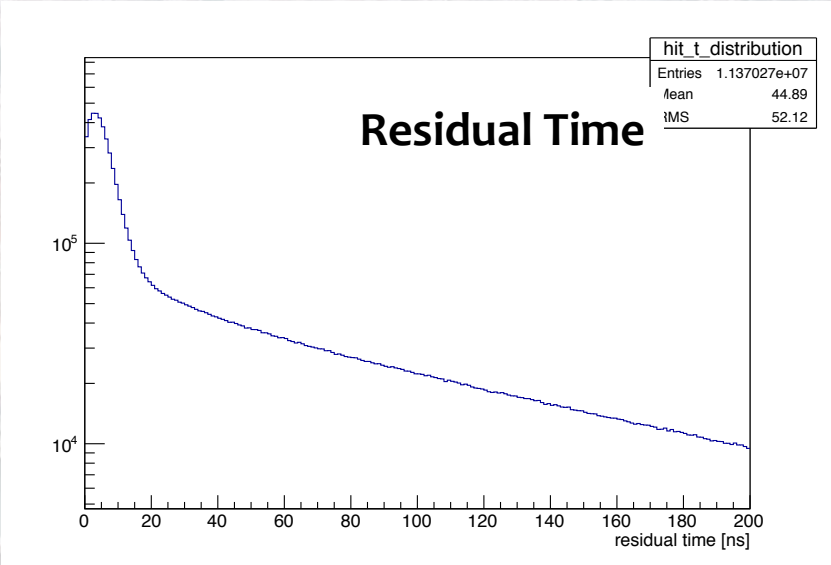
Items	Accuracies, Resolutions	Remarks
energy scale ($5 \sim 20$ MeV)	$\leq 0.9\%$	electrons
energy resolution (10.78 MeV)	14.8 %	electrons[a]
angular resolution (10.78 MeV)	25.3 deg	electrons[a]
position resolution (10.78 MeV)	74.4 cm	electrons[a]
energy scale (≥ 30 MeV)	$\leq 2.5\,\%$	electrons and muons
energy resolution (≥ 100 MeV)	$2.5\,\%/\sqrt{\mathrm{E(GeV)}} + 0.5\,\%$	electrons (estimated)
energy resolution (≥ 200 MeV/c)	$\leq 3\,\%$	muons
angular resolution (~ 500 MeV)	3 ± 1 deg	electrons and muons
position resolution (~ 500 MeV)	30 cm	electrons and muons
light absorption length (420 nm)	101 ± 6 m	as of Nov., 1997
light scattering length[b] (420 nm)	149 ± 2 m	as of Nov., 1997

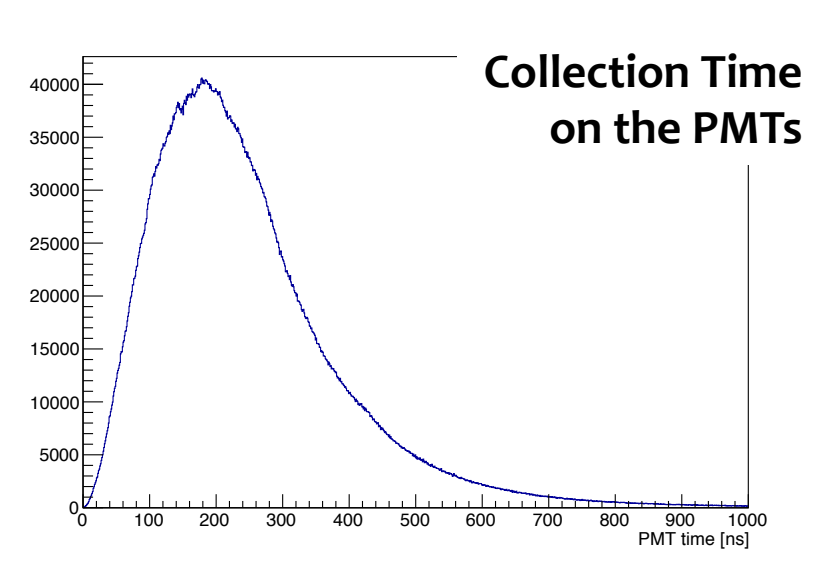
[a] Data taken at the position $(x, y, z) = (-813, -71, 27)$ mm where z is the vertical axis and the detector center is (0, 0, 0). Measurements were also made at other energies.

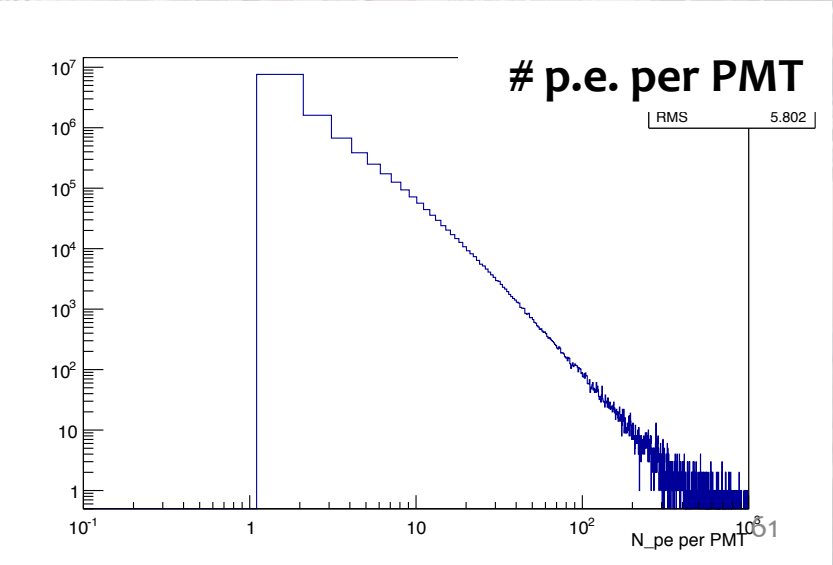
[b] The angular dependence is consistent with the Rayleigh scattering, $1 + \cos^2\theta$.

ATHMOSPHERIC MUONS

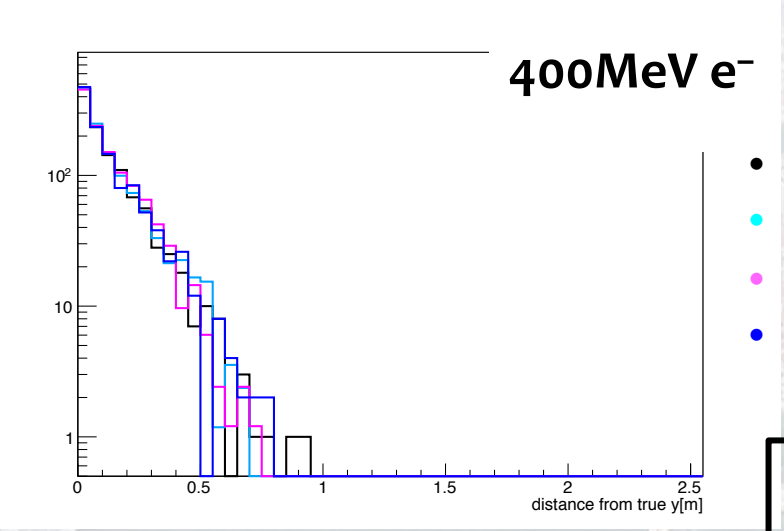




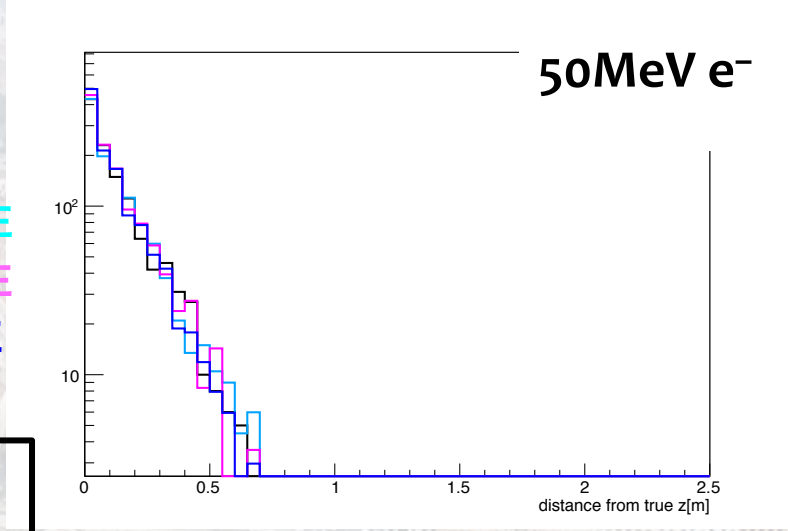




Vertex reconstruction for different configurations

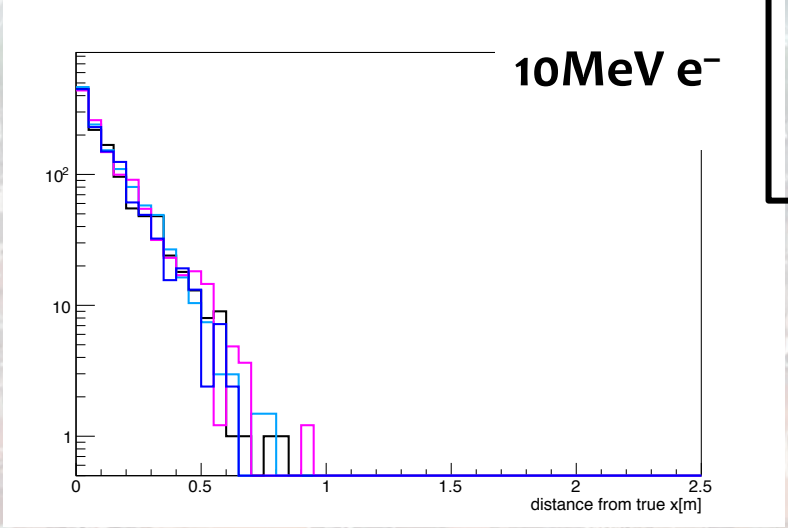


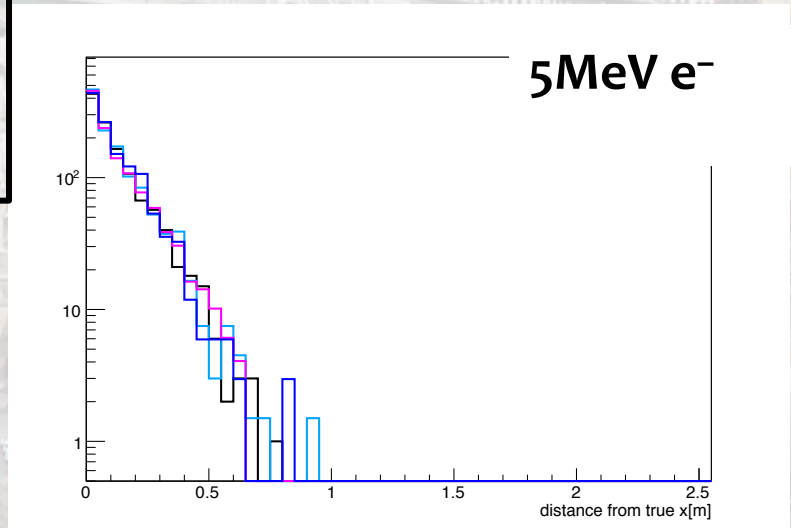
- 30%, NQE
- 20% + LC, NQE
- 20% + LC, HQE
- 15% + LC, HQE



Distance between true and reconstructed coordinates

$|vtx_{true} - vtx_{rec}|$
~ 25 cm





- Not evident dependency on energy
- Not evident dependency on PMT instrumentation