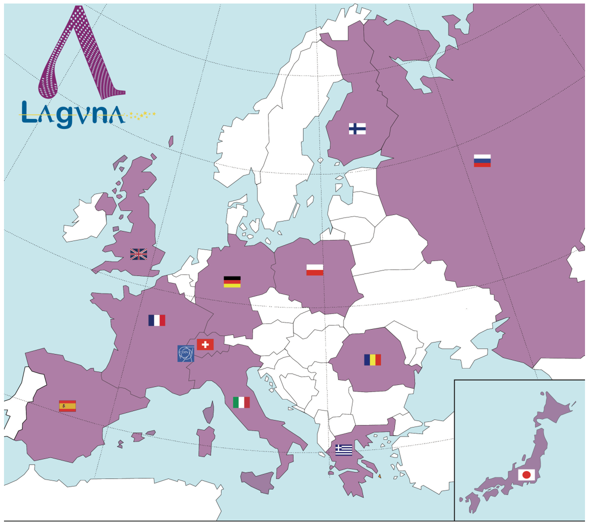
MEMPHYS R&D

L. Agostino on behalf of the MEMPHYS collaboration
APC Paris

NNN13 conference **Kashiwa, Nov 12th 2013**

OUTLINE

- THE LAGUNA LBNO DESIGN STUDY
- THE MEMPHYS OPTION
- ENGINEERING AND TECNICAL CHALLENGES
- DETECTOR OPTIMIZATION AND PMT DESIGN STUDIES
- OVERVIEW ON PHYSICS POTENTIAL
- MEMPHYNO: A Test Bench for new readout electronics and DAQ systems

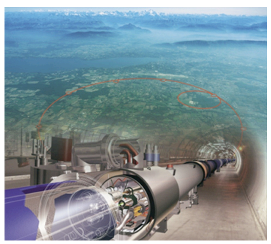


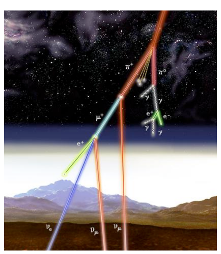
LAGUNA-LBNO: Large Apparatus for Grand Unification and Neutrino Astrophysics and Long Baseline Neutrino Oscillations

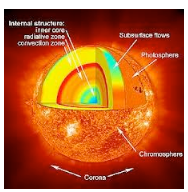
LAGUNA-LBNO consortium = 13 countries, 45 institutions, ~300 members

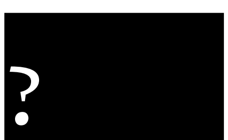
FP7 DS: 2011 - 2014; 4.9 M€

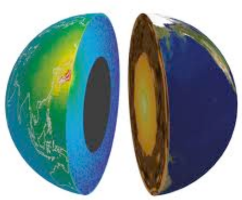
LAGUNA-LBNO Physics:











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

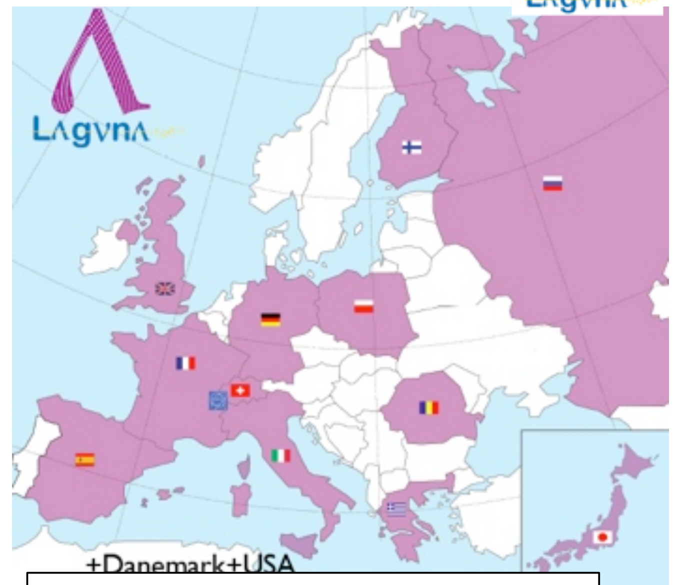
4. **Geo neutrinos**

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



Steering group:

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

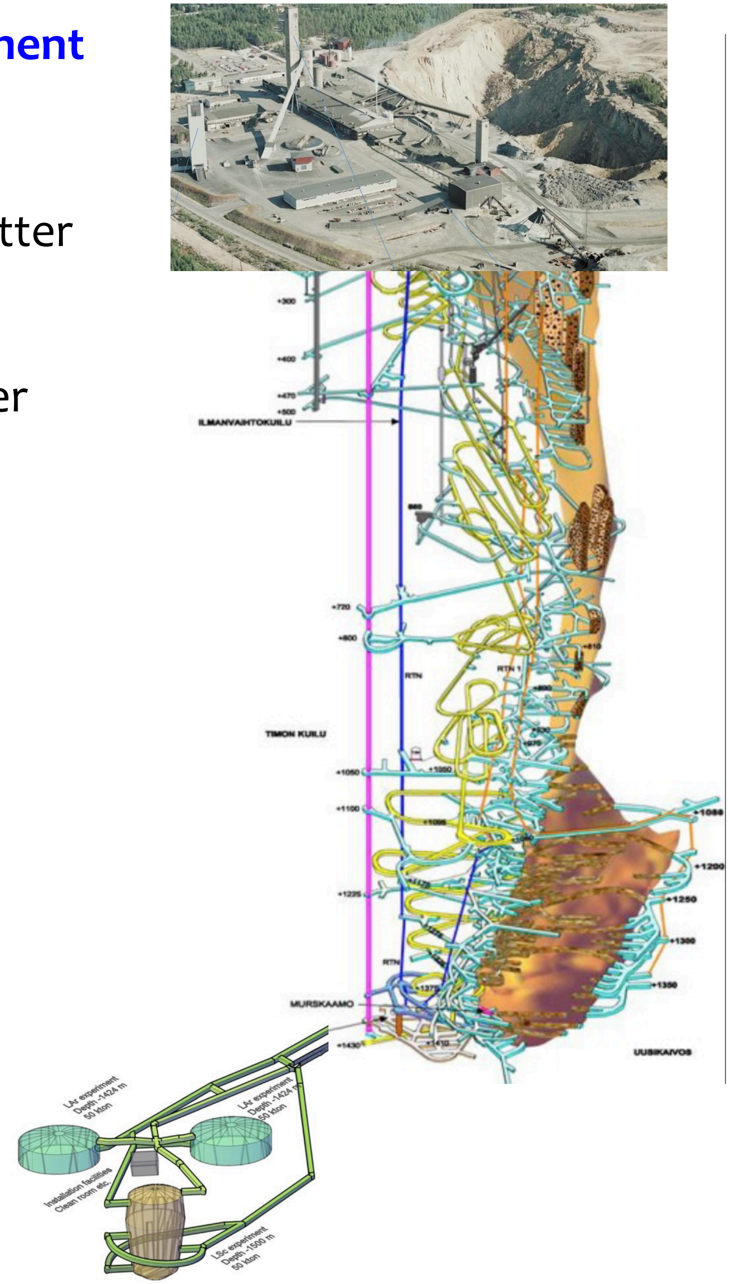
LAGUNA-LBNO (2011 - 2014)

EOI for a very long baseline neutrino oscillation experiment

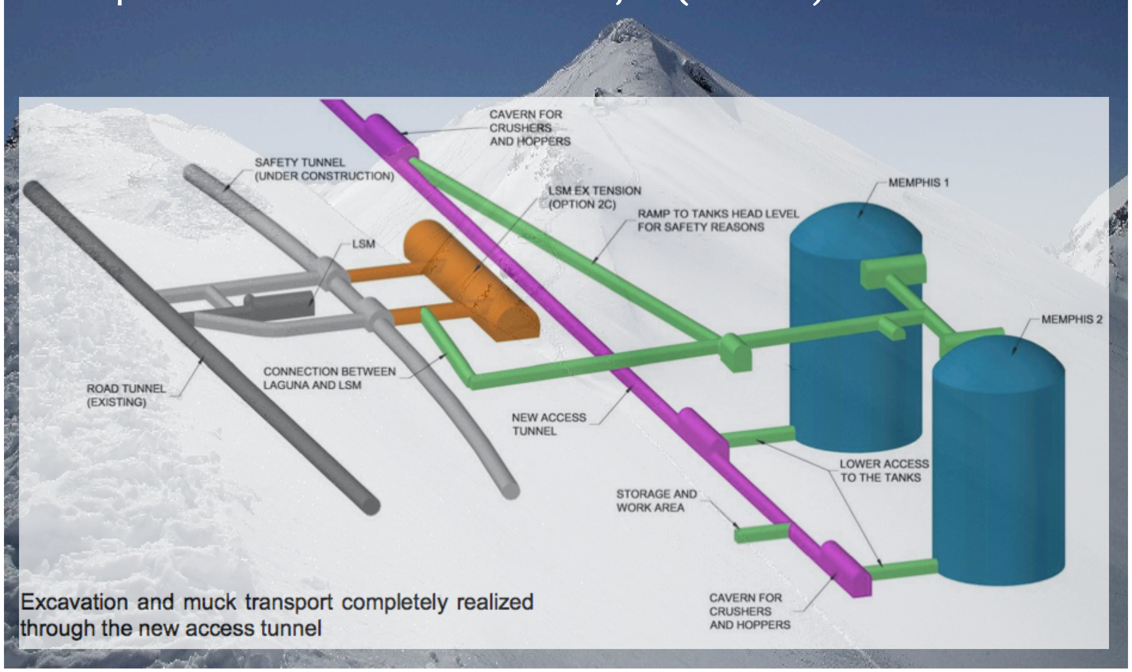
CERN-SPSC-2012-021; SPSC-EOI-007

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)



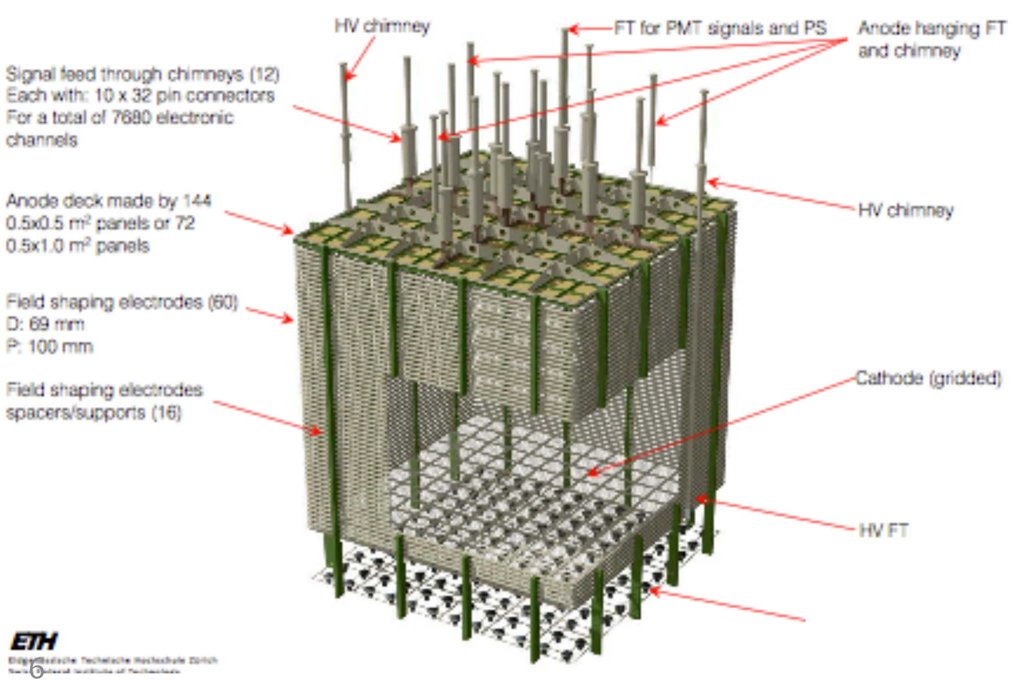
2nd option: LAGUNA-LBNO at Fréjus (France)



LBNO PROTOTYPE WA105 WILL BE BUILT AND OPERATING AT CERN

It will consist of a 6x6x6 m^3 active volume
double phase LAr detector

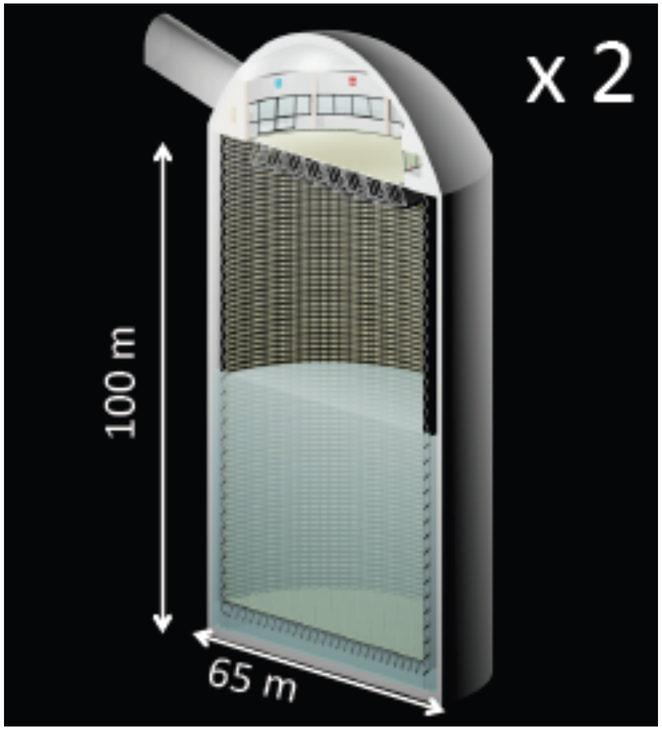
It will collect charged particle datasets, for electromagnetic and hadronic calorimetry and general detector performance(PID, ...) characterisation, simulation and reconstruction improvement and validation.



SEE SEBASTIAN MURPHY'S TALK

THE MEMPHYS OPTION

MEMPHYS (MEgaton Mass PHYSics)

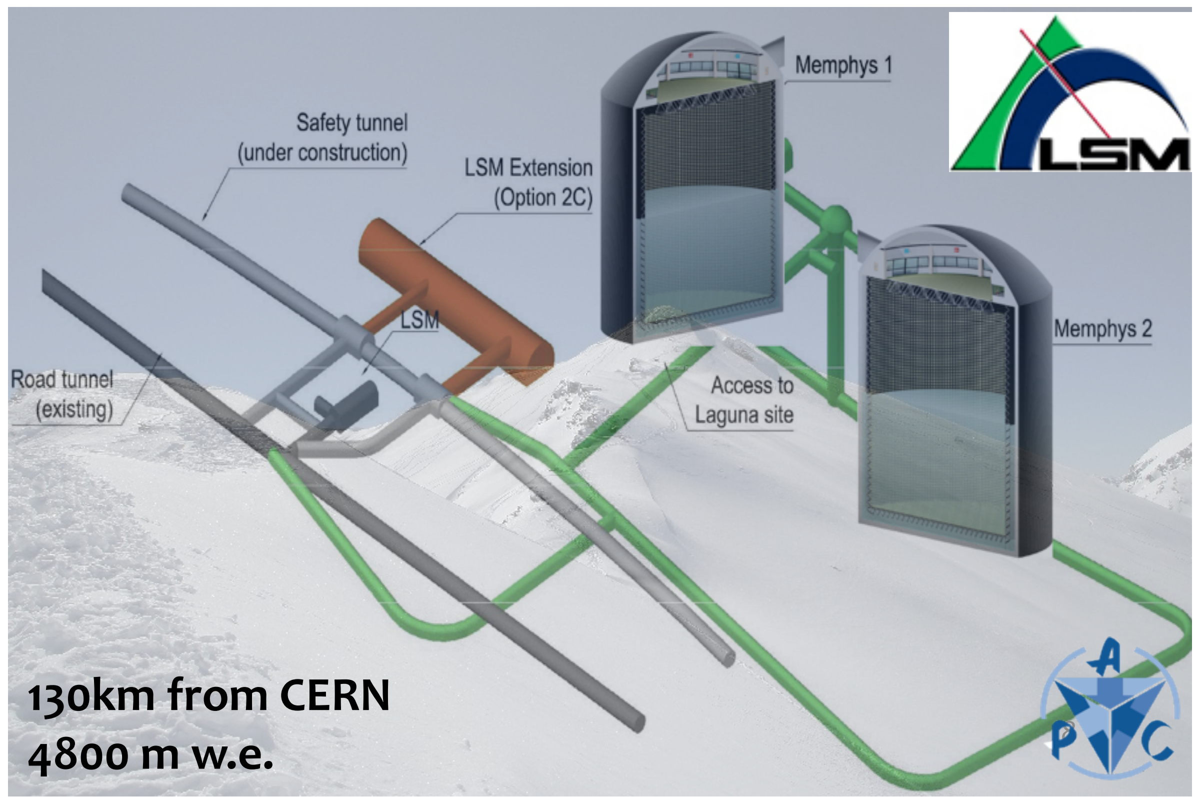


Detector design:

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

Water Cherenkov techniques is well proven technology

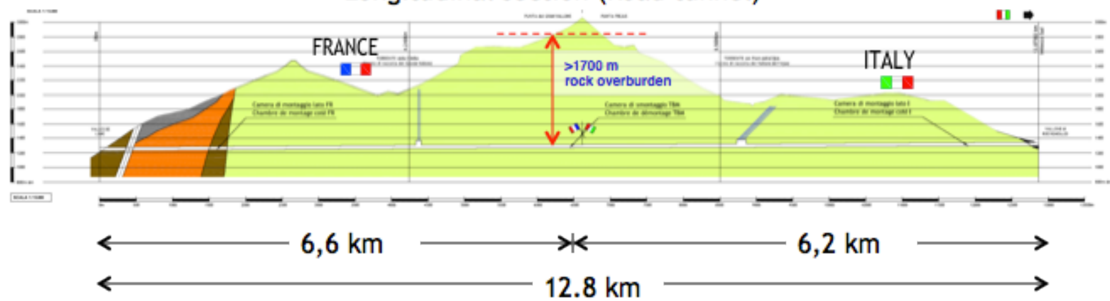
Laboratoire Souterrain de Modane - Frejus

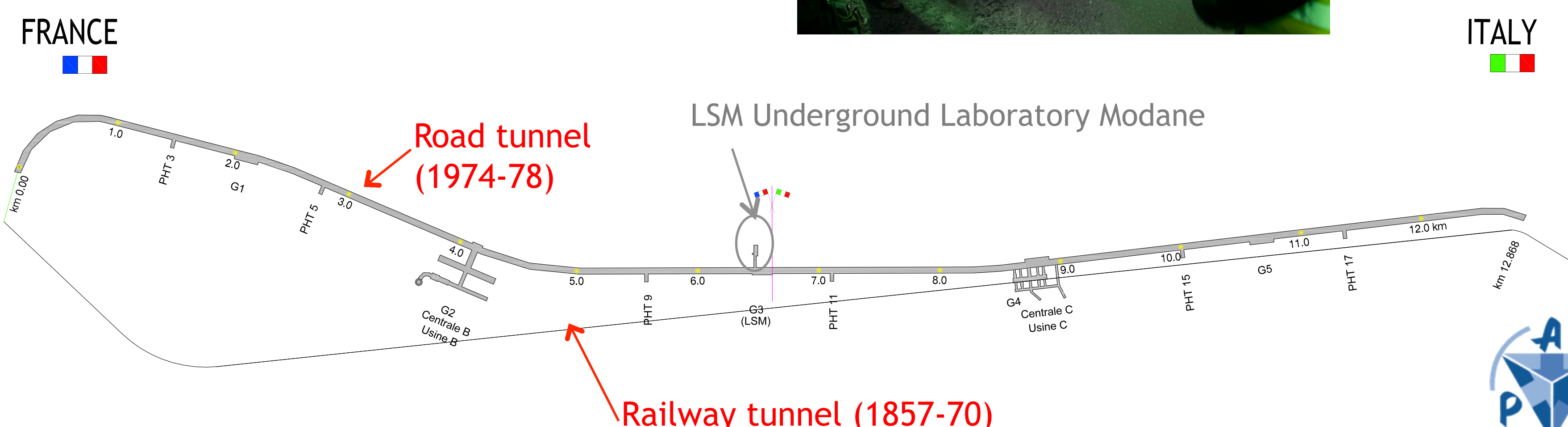


ENGINEERING AND TECHNICAL CHALLENGES

MEMPHYS @ Fréjus

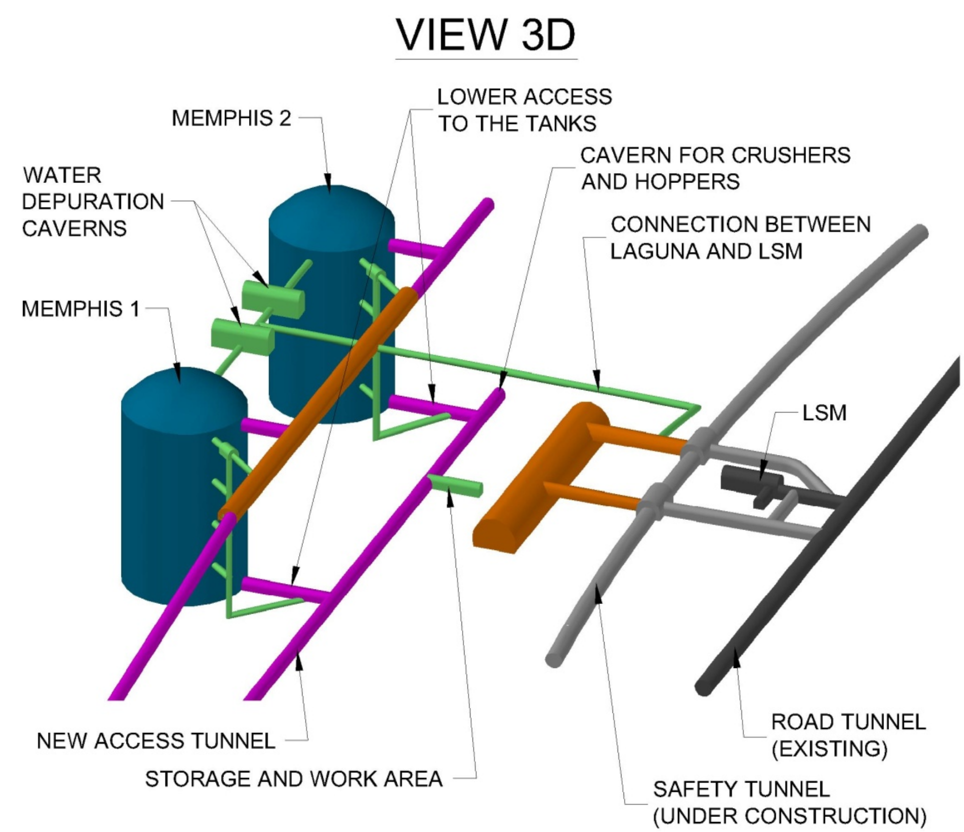
Longitudinal section (Road tunnel)





Global layout in the caverns area

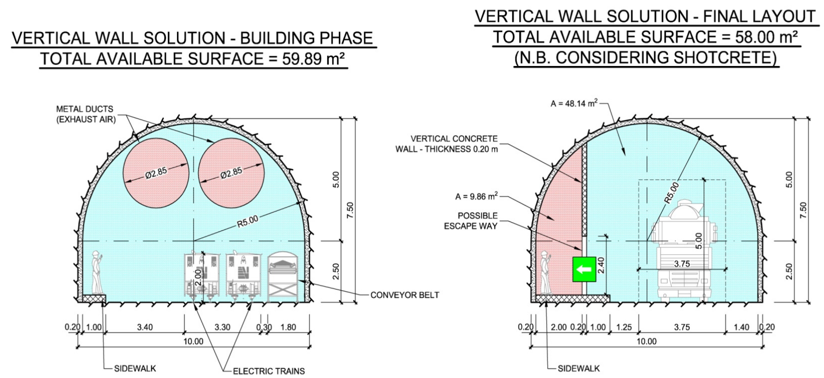
Possible optimizations and solutions:



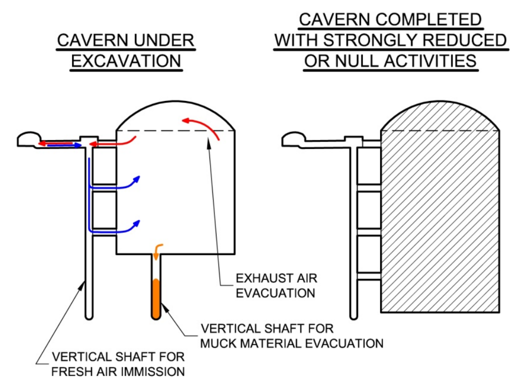
Thanks to Lombardi

MEMPHYS @ Fréjus
ESCAVATION

- ACCESS TUNNEL LAYOUT



- HANDLING AND STORAGE SOLUTIONS

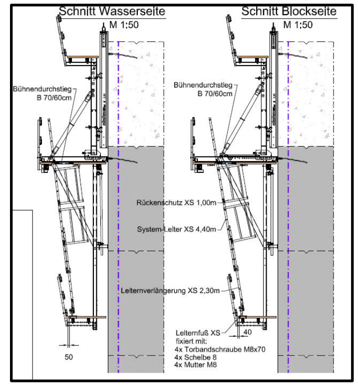


- APPLICATION OF SPRAYED WATERPROOFING
MEMBRANE INSTEAD OF STAINLESS STEEL
INNER LINING

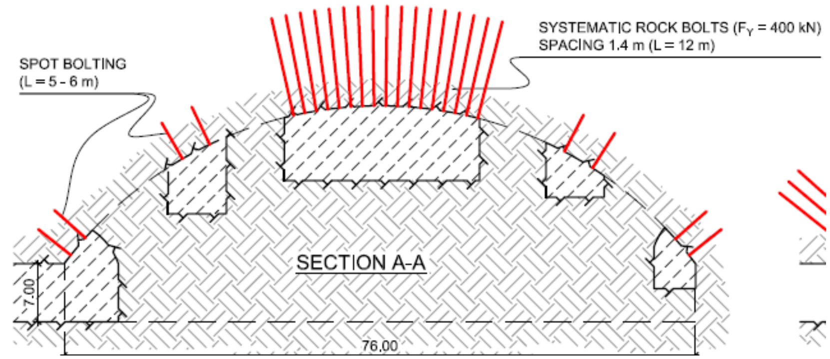
Thanks to Lombardi

MEMPHYS @ Fréjus
COSTRUCTION

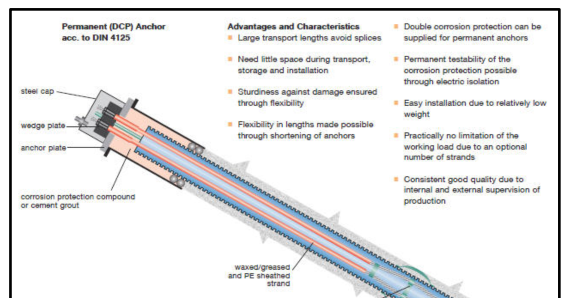
- LINING SYSTEM AGAINST DEFORMATIONS



- DOME SUPPORT STUDIES



- ROCK BOLTING SOLUTIONS



Advantages and Characteristics

- Large transport lengths avoid splices
- Need little space during transport, storage and installation
- Sturdiness against damage ensured through flexibility
- Flexibility in lengths made possible through shortening of anchors
- Double corrosion protection can be supplied for permanent anchors
- Permanent testability of the corrosion protection possible through electric isolation
- Easy installation due to relatively low weight
- Practically no limitation of the working load due to an optional number of strands
- Consistent good quality due to internal and external supervision of production

steel grade	nominal diameter	cross-sectional area	load at yield* ($F_{p\,0,2\,k}$)	ultimate load* (F_{pk})
N/mm²		mm²	kN	kN
1570/1770	0.6"	140	220	248
1570/1770	0.62"	150	236	266
1670/1860	0.6"	140	234	260
1670/1860	0.62"	150	251	279

* per strand

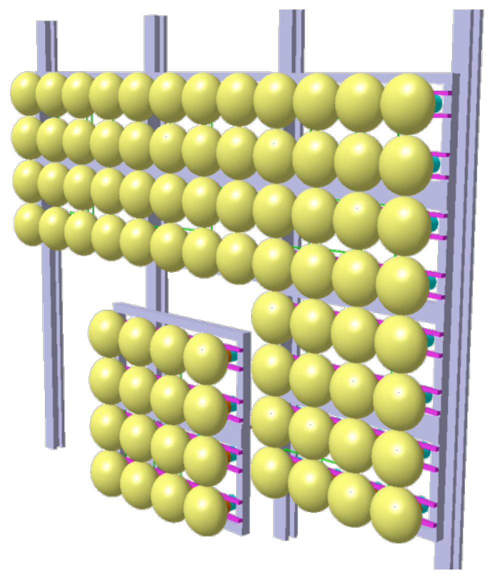
Thanks to Lombardi

MEMPHYS @ Fréjus
FASTENING OF PMT PANELS

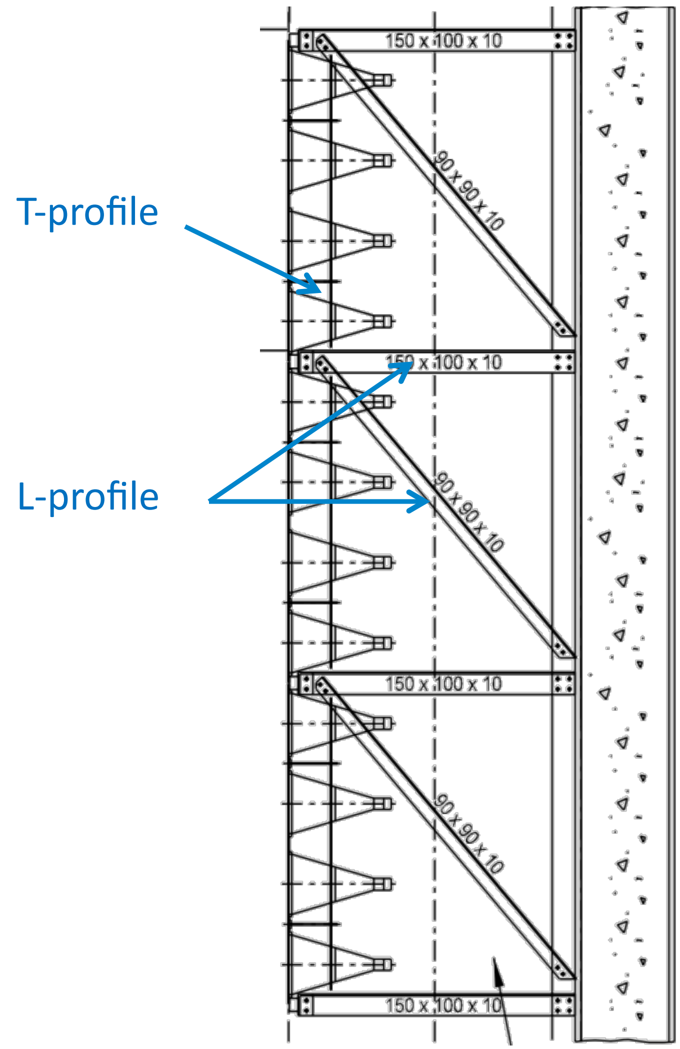
Photomultipliers organized in 4x4 matrices (see moreover)

Problems of fastening

Support structure:

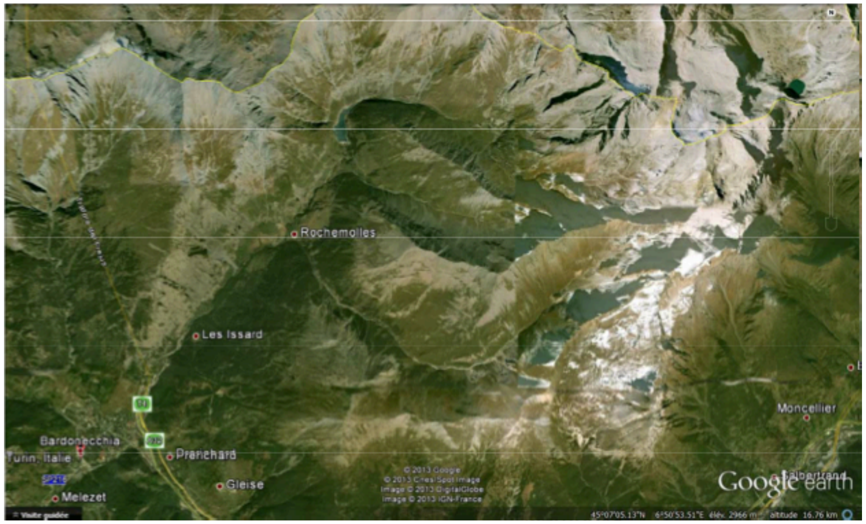


Yann Colaitis – APC Laboratory



Technodyne International Ltd.

MEMPHYS @ Fréjus
WATER FILLING



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 m^3/h

➔ **6 months** for the global filling

MEMPHYS @ Fréjus
WATER ANALYSIS

5L	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
^{228}Th	0,00E+00		0,00E+00
^{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

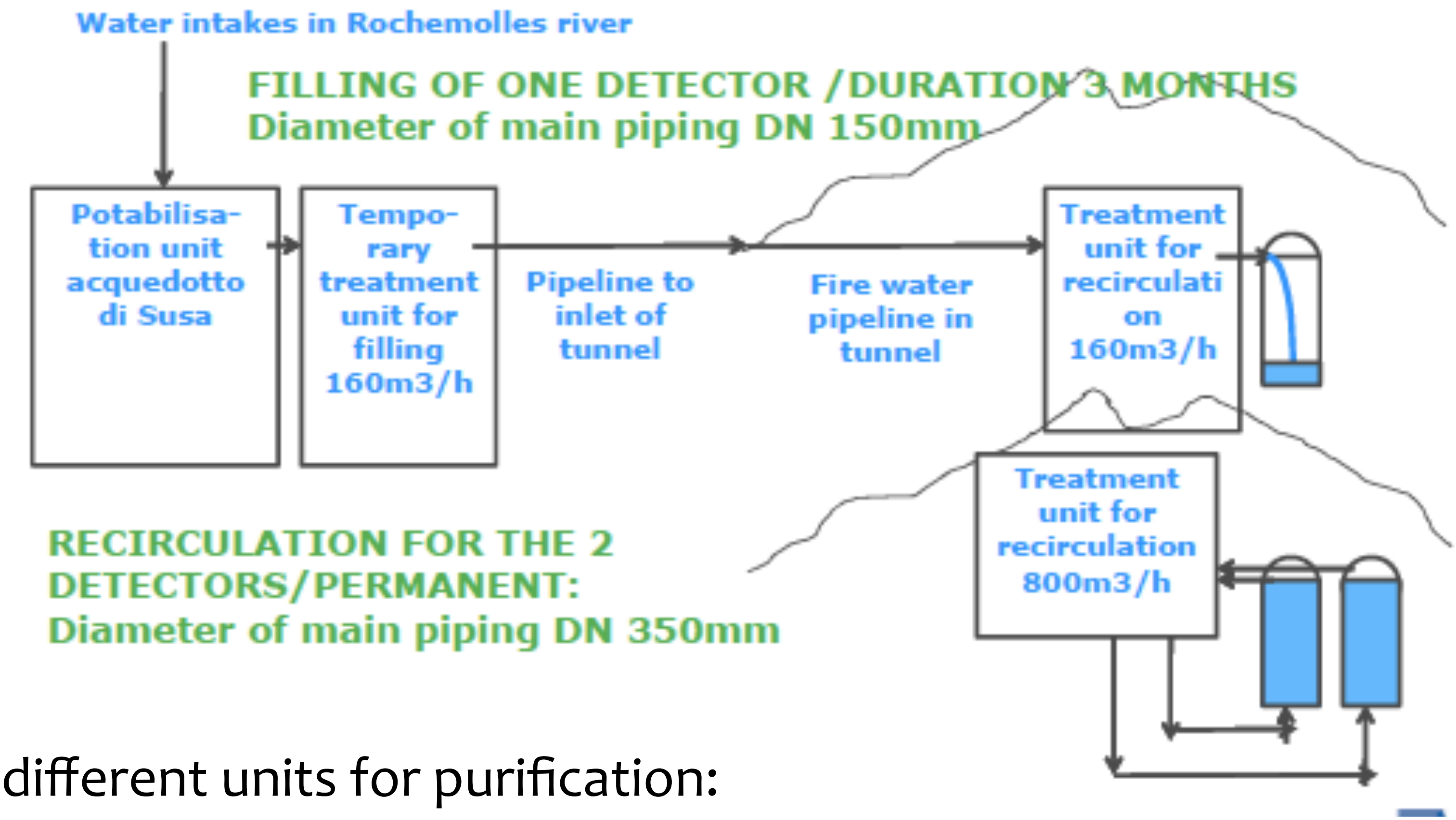
Rock temperature ~ 29°

➔ **Purification and cooling are needed**

Thanks to

Sofregaz

MEMPHYS @ Fréjus
WATER PURIFICATION



Two different units for purification:

1. **for filling up of tanks**: his unit takes water after 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.

Thanks to Sofregaz

MEMPHYS @ Fréjus
TEMPERATURE CONTROL

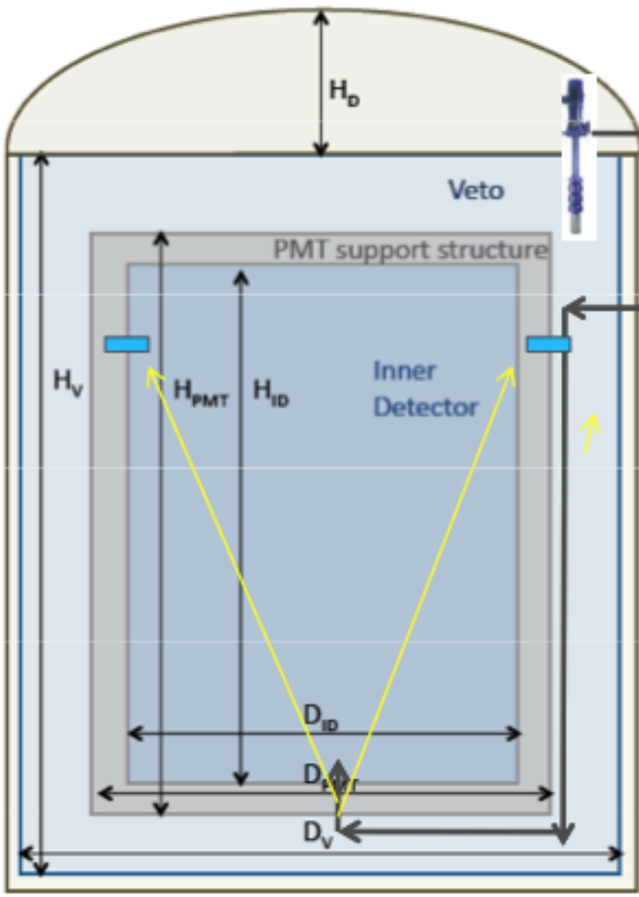


Figure 1: Layout of the MEMPHYS tank and cavern.

Purification with recirculation → **Cooling down of water**

-Water recirculation system for purification

-Full volume in around 1 month

-Also used to remove the heat.

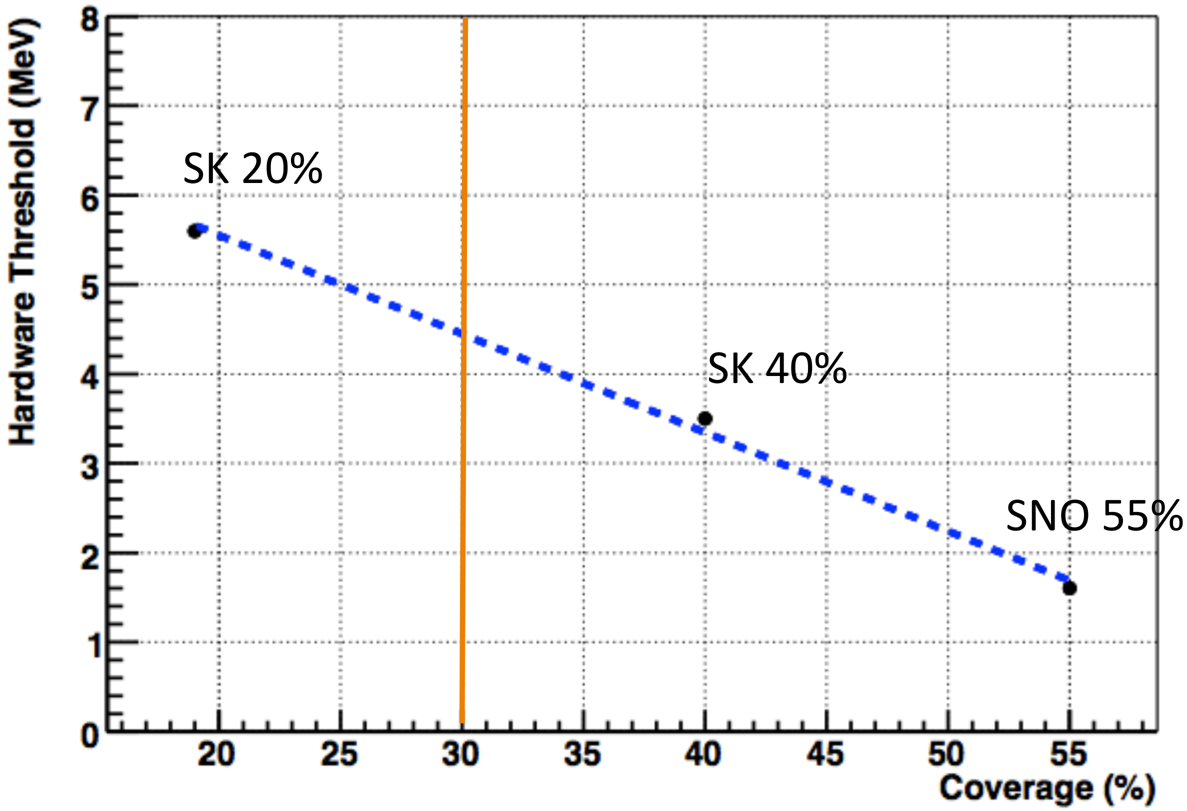
Water taken from cavern on top will be cooled and sent back at lower temperature at the bottom of cavern

DETECTOR OPTIMIZATION AND PMT DESIGN STUDIES

MEMPHYS
Optical Coverage

Starting point: 30% coverage

Estimation of the energy threshold for a WC detector



arXiv:1204.2295v

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

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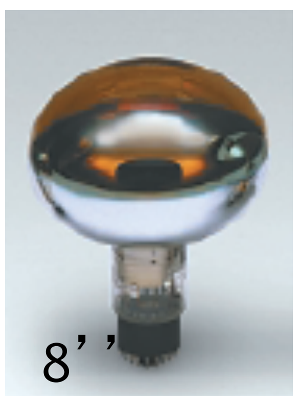
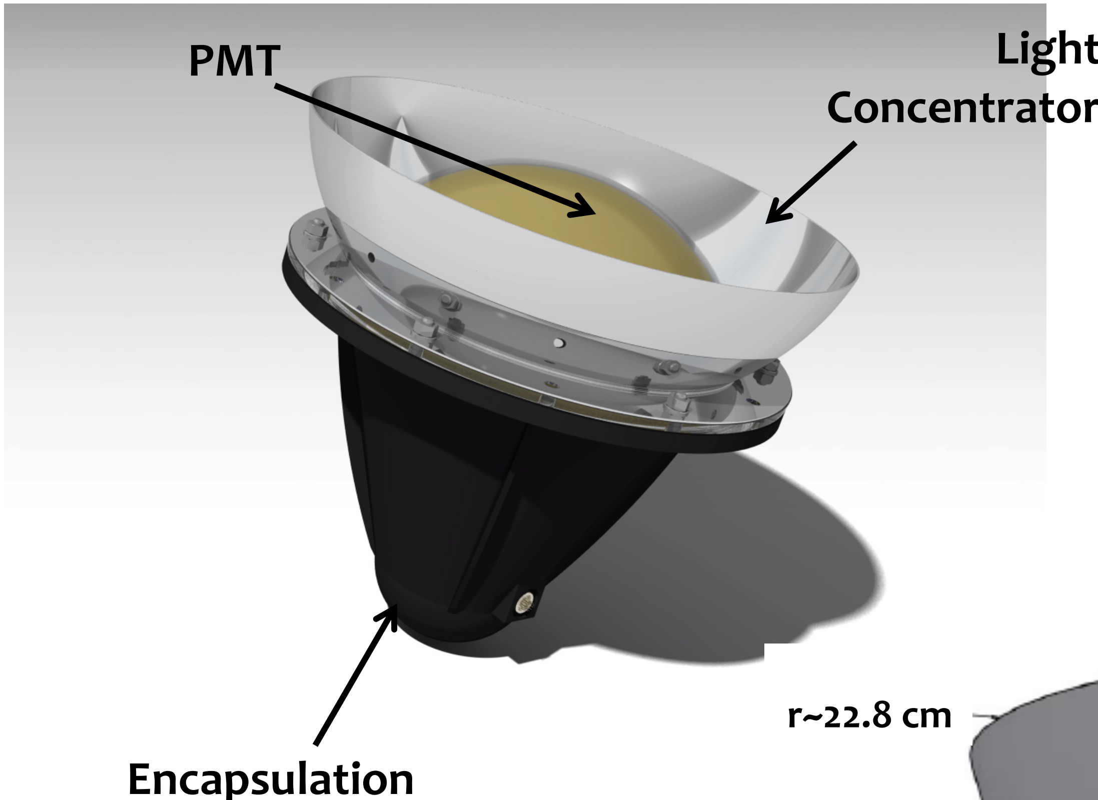
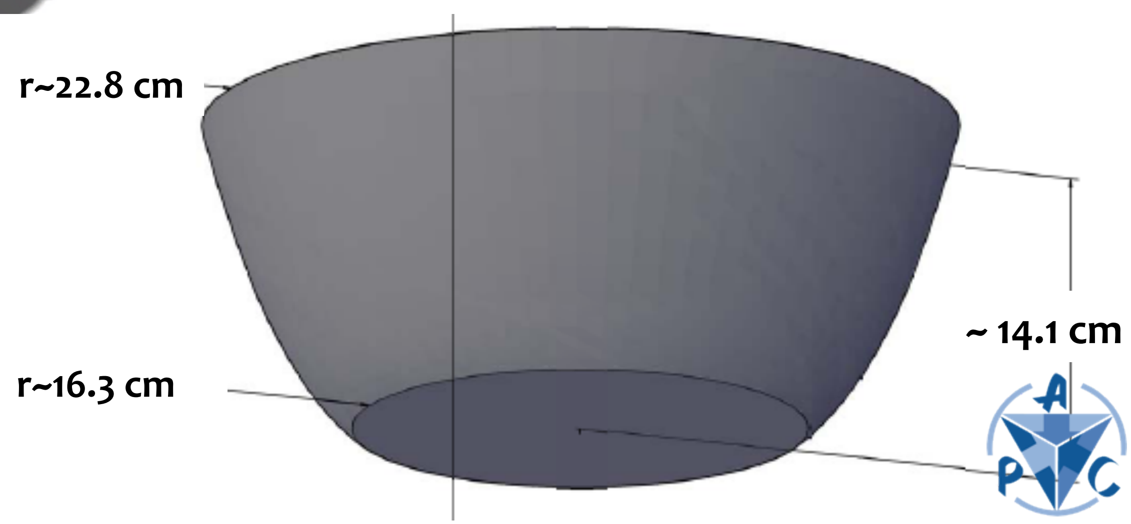


SOLUTIONS TO DECREASE THE # OF PMTs

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



Expected gain of about **50%**
➔ Possibility to reduce the geometrical coverage

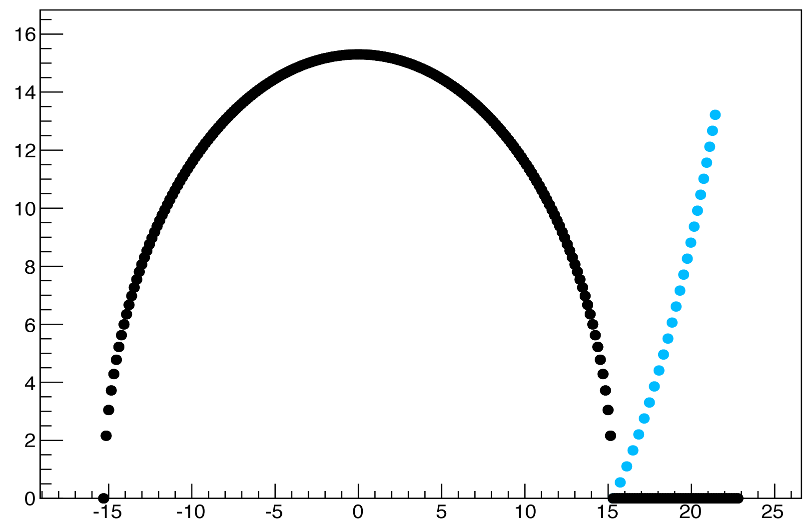


SIMULATION OF LIGHT CONCENTRATORS

The choosen shape is an **ellipsoidal cone**

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

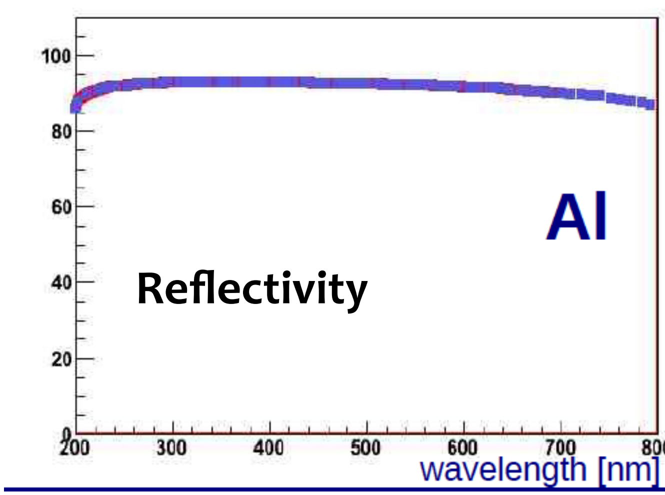
12 inch photocathode



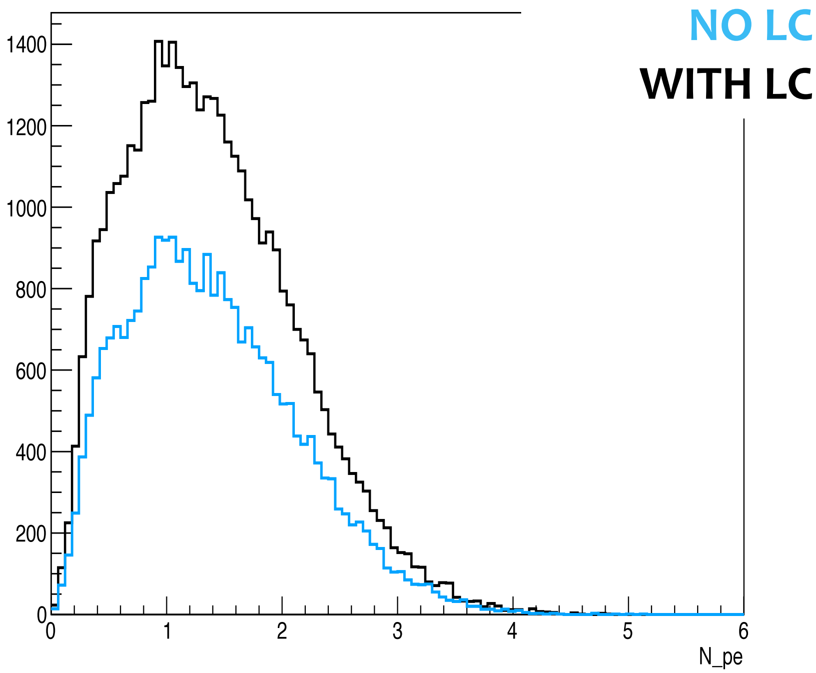
Ellipse arc to obtain the solid of revolution

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



RESULTS



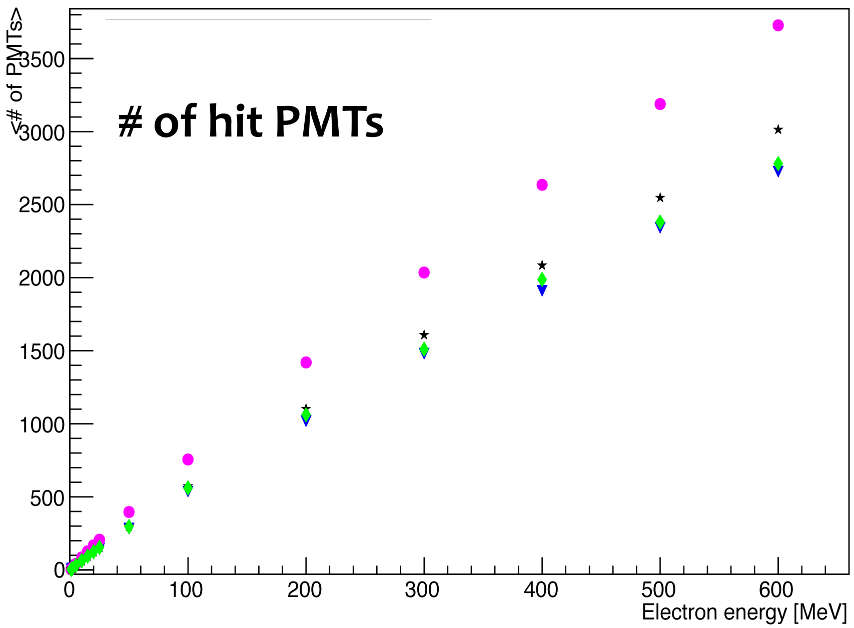
Optical photons of 3 eV

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)

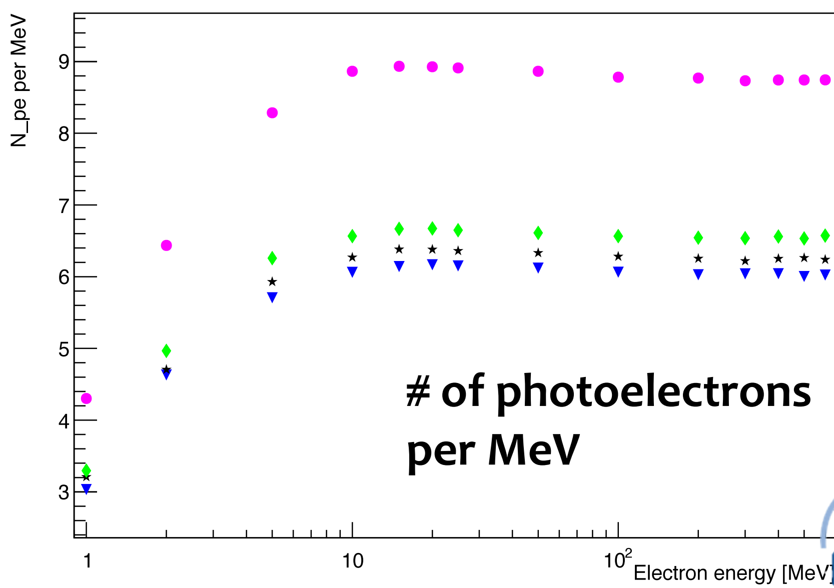
TESTING CONFIGURATIONS (1)



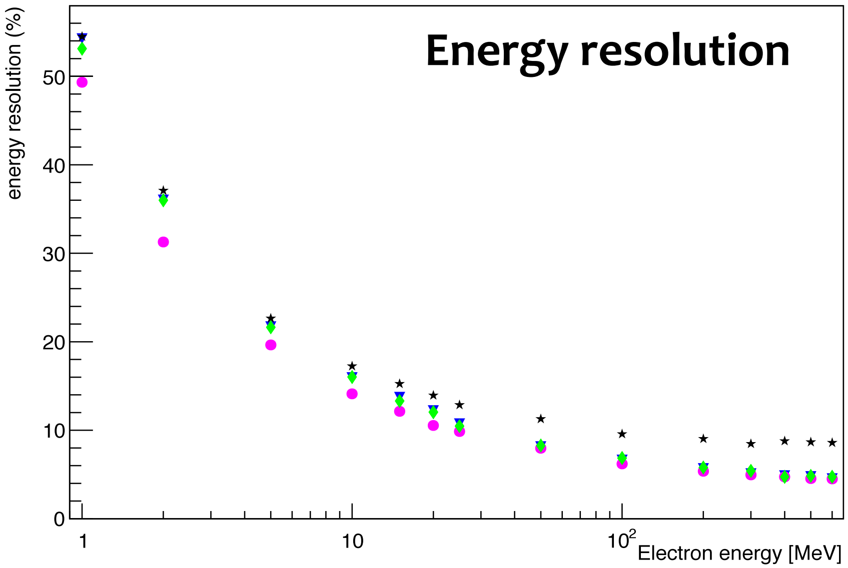
- 30% coverage, normal QE (22% @ peak)
- 20% coverage + LC, normal QE (22% @ peak)
- 20% coverage + LC, high QE (32% @ peak)
- 15% coverage + LC, high QE (32% @ peak)

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

but using 50% of PMTs!!



TESTING CONFIGURATIONS (2)



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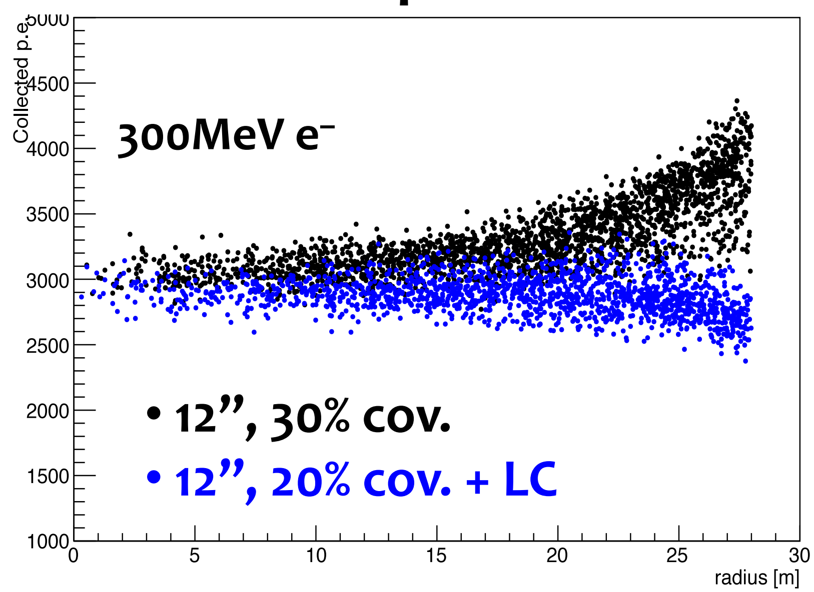
- 15% coverage + LC, high QE (32% @ peak)

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

- 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" NQE PMTs**
- **15% geometrical coverage for 12" HQE PMTs**

Hamamatsu	R11780	R11780
Diameter	12"	12"
Dark rate (@25° C)	10 kHz	10 kHz
Quantum eff. (@390 nm)	22%	32%
Geometrical coverage	20%	15%
Number (2tanks)	130 k	103 k
Production Time	5y	4 y
Cost (transportation included)	195 M€	170 M€

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OVERVIEW ON PHYSICS POTENTIAL

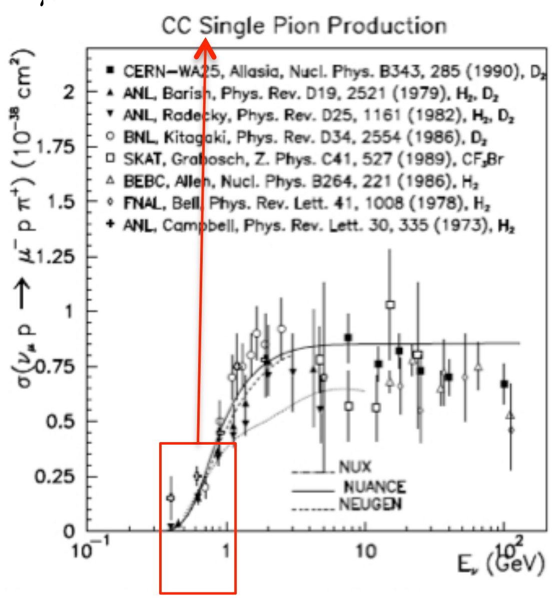
ENERGY RECONSTRUCTION

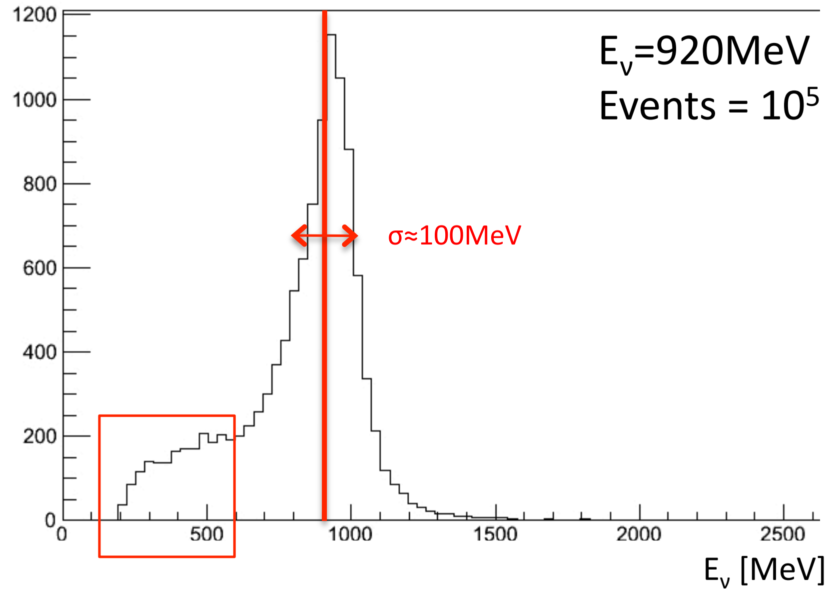
$$E_\nu = \frac{m_n E_\mu - m^2{}_\mu / 2}{m_n - E_\mu + p_\mu \cos\theta_\mu}$$

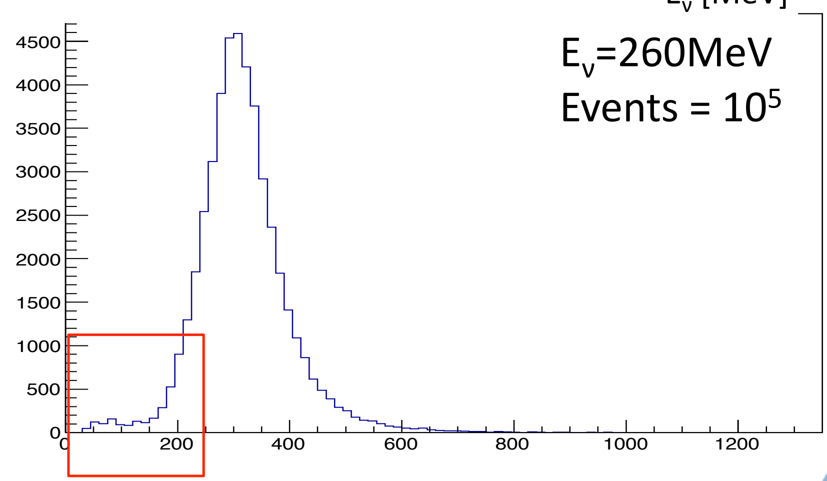
CC Pion production activation over 300 MeV

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

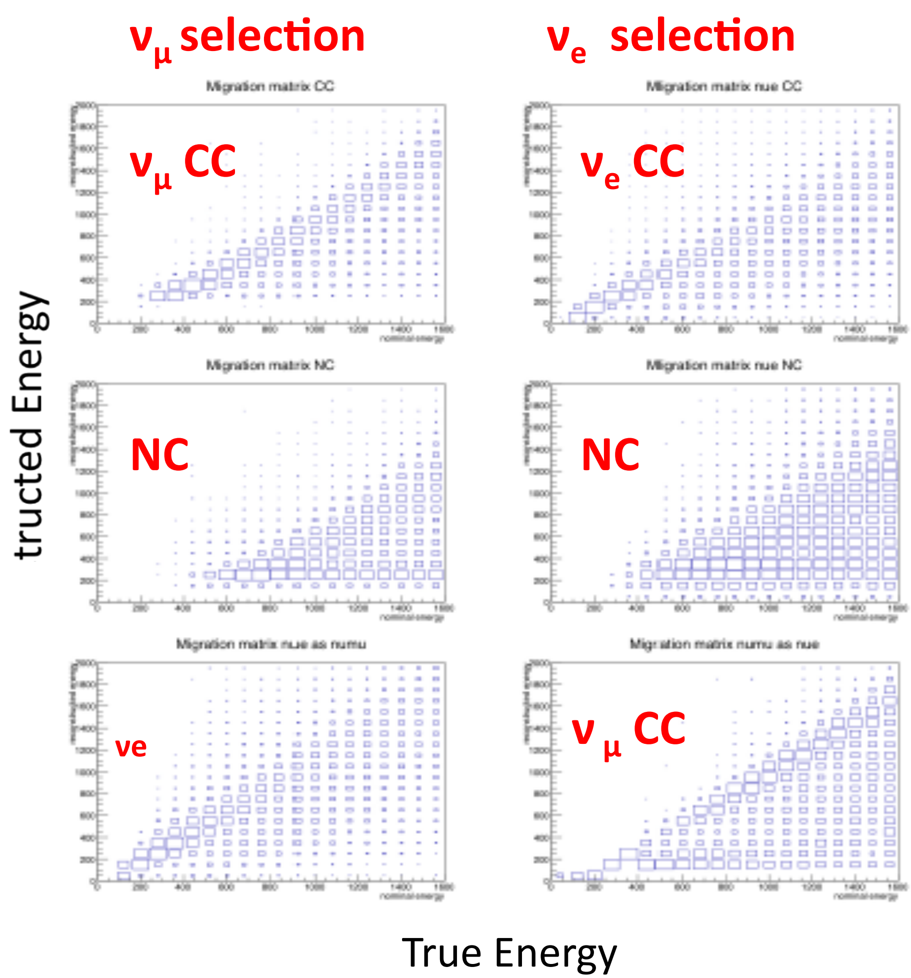
$$\nu_\mu + n \rightarrow \mu^- + n + \pi^+$$







MIGRATION MATRICES



JCAP 1301 (2013) 024

.dat (GLOBES format) files are avalible

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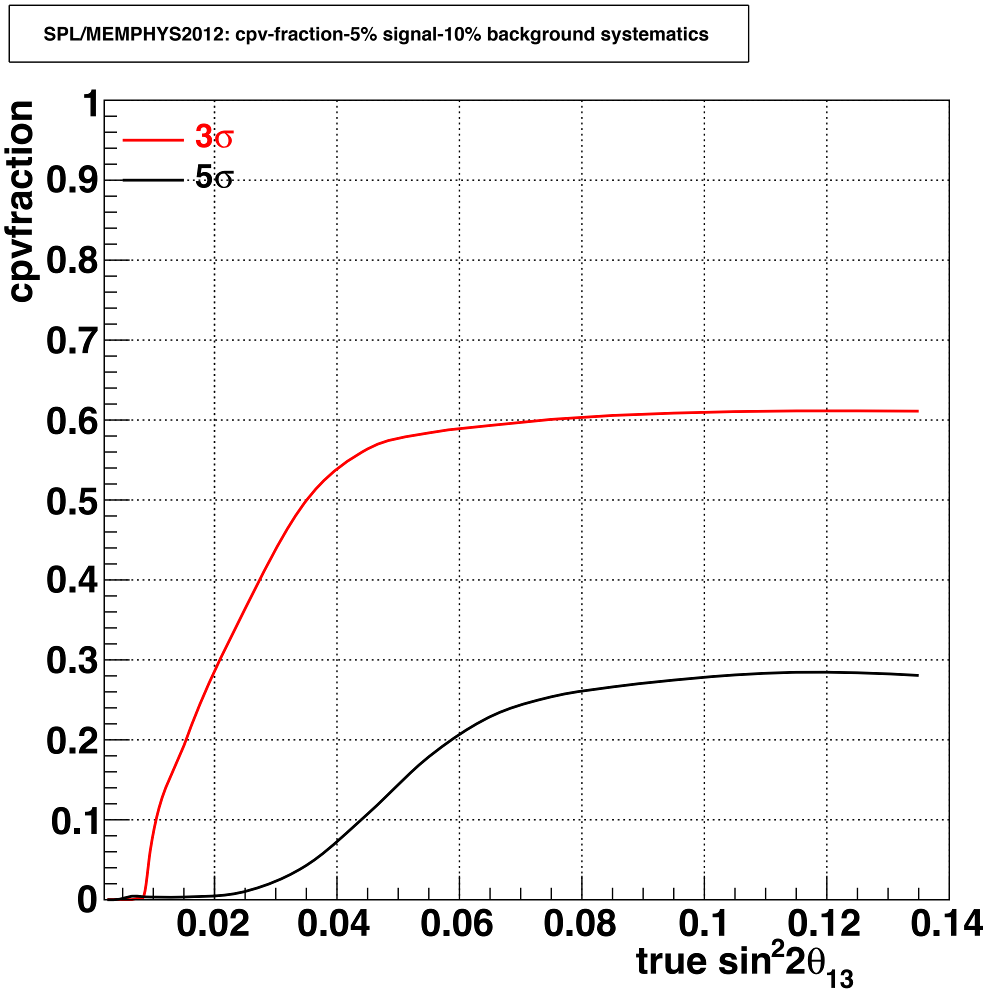
PHYSICS POTENTIAL



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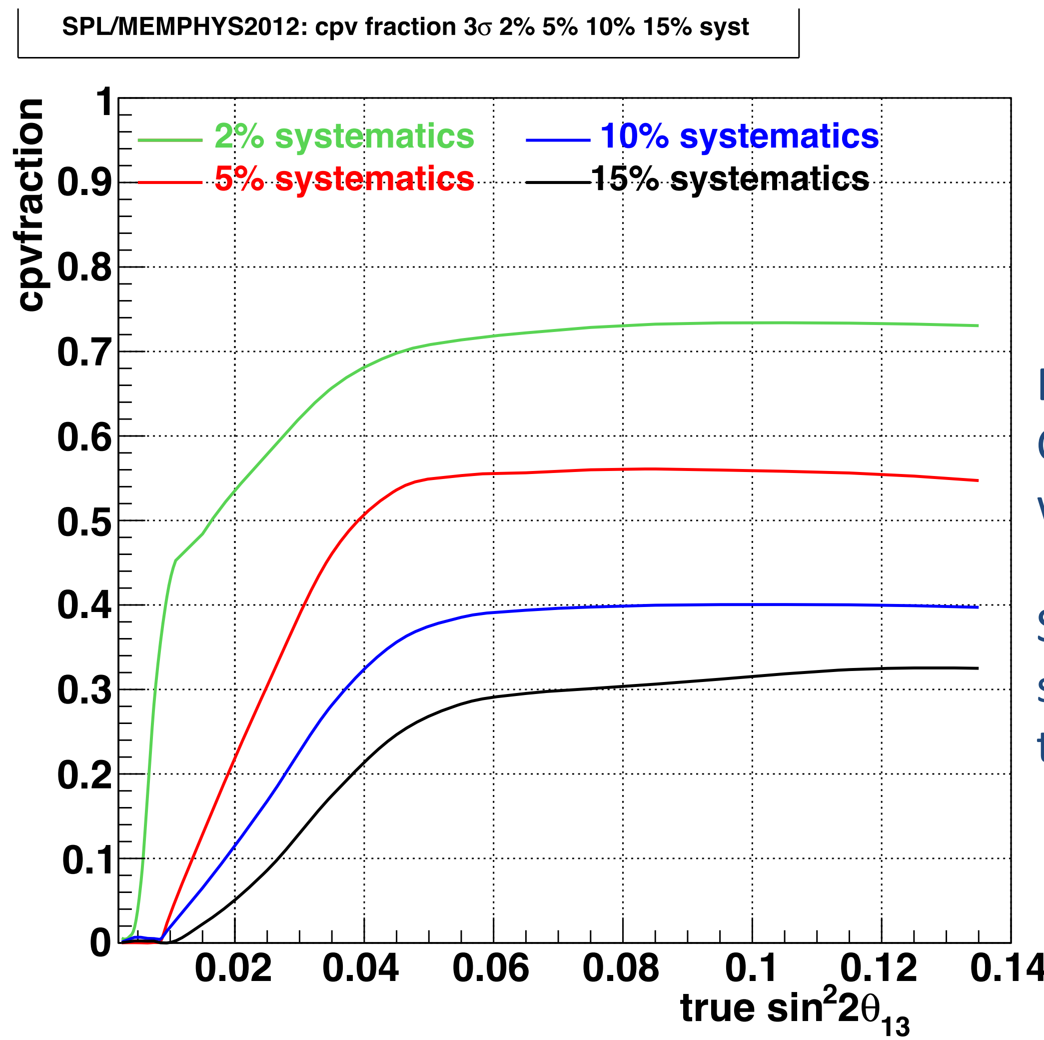
CP fraction coverage with MEMPHYS at 3-5 sigmas

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

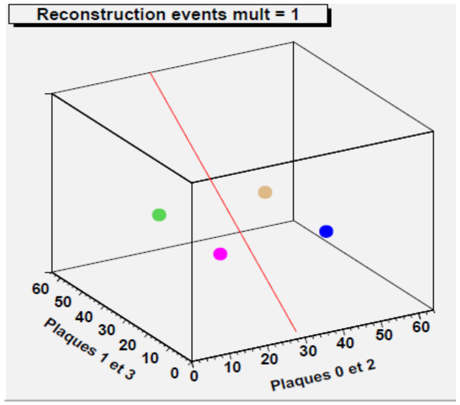
- 16 PMTs matrix

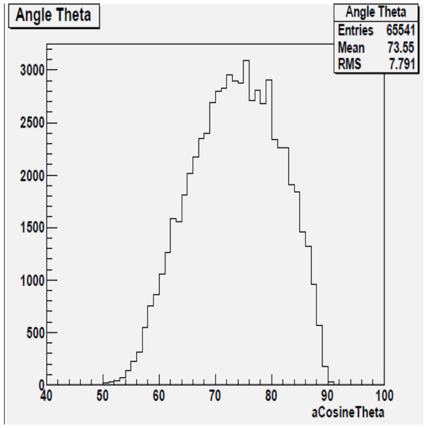
- 4 scintillator strips to sign muons trajectories

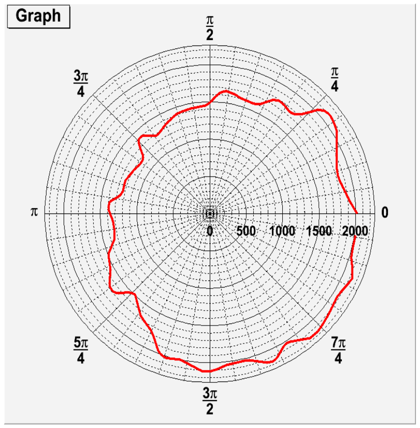
- Automatic reconstruction

MEMPHYNO HODOSCOPE

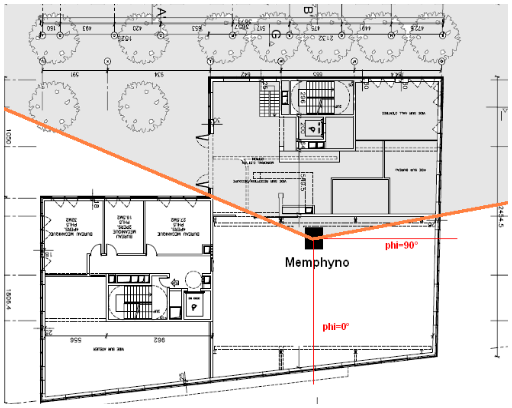
1. Muons tracks reconstruction

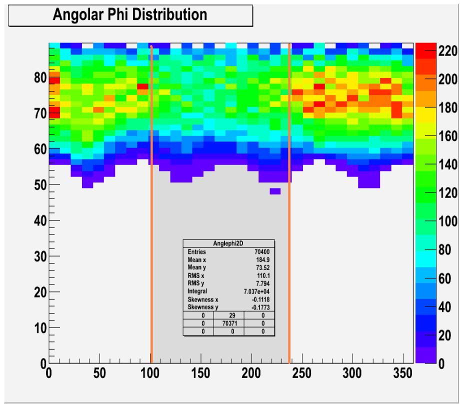






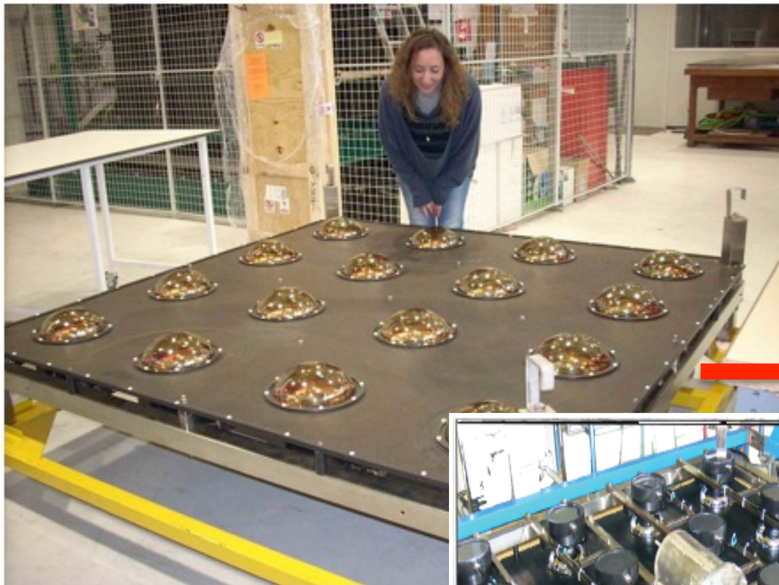
2. Angular distributions

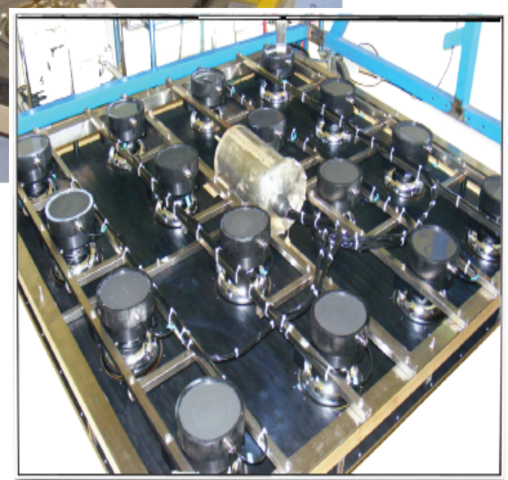




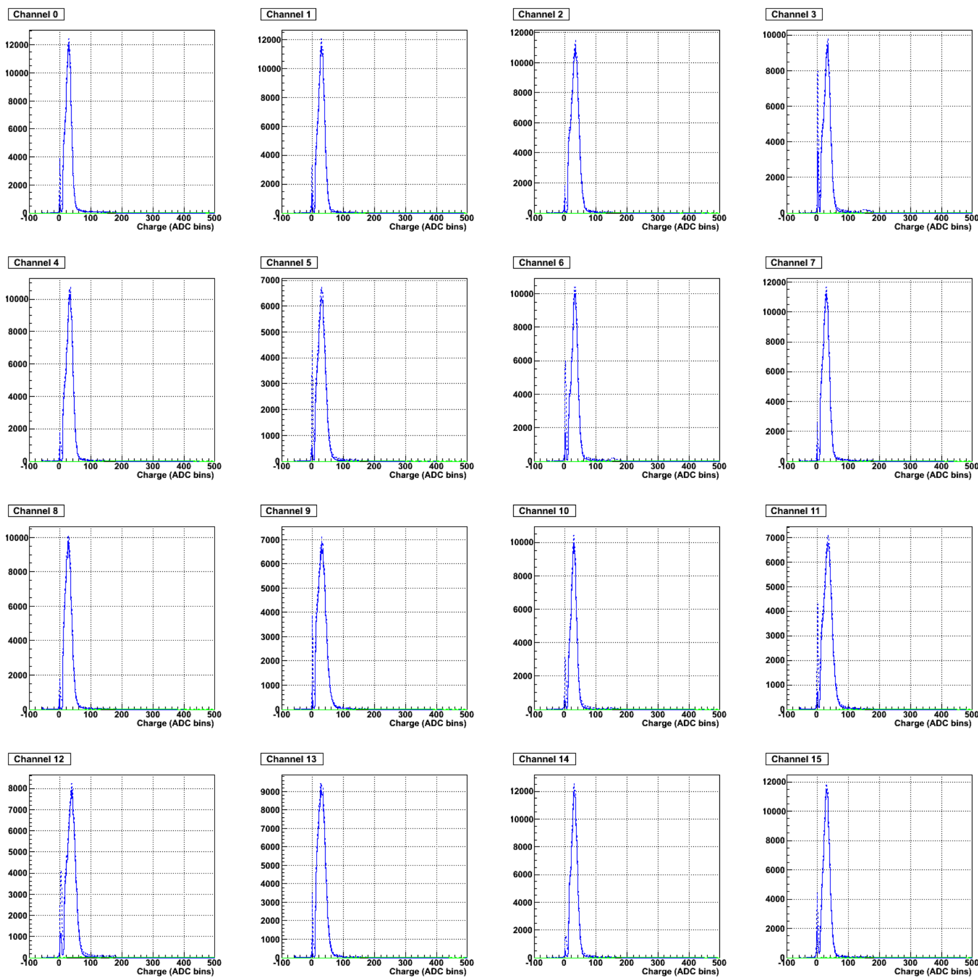
3. Hodoscope as a scanner

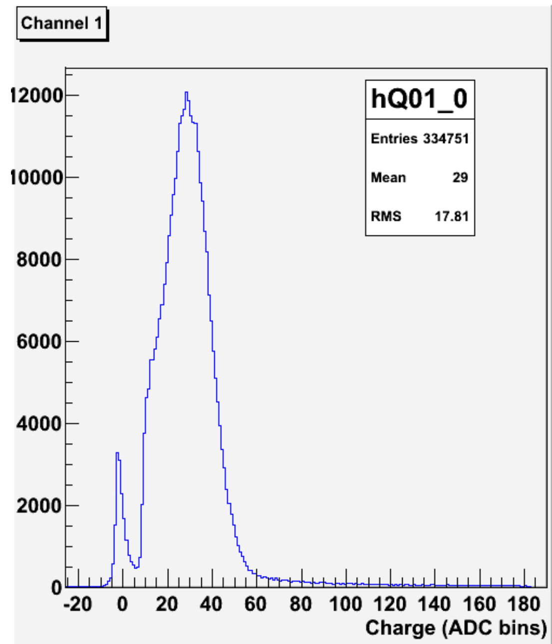
THE PMm2 MATRIX





THE PMm2 MATRIX (2)





First Cherenkov Light Signal!

SUMMARY

- THE MEMPHYS DETECTOR IS UNDER STUDY UNDER THE TECHNICAL AND PHYSICS POTENTIAL POINTS OF VIEW

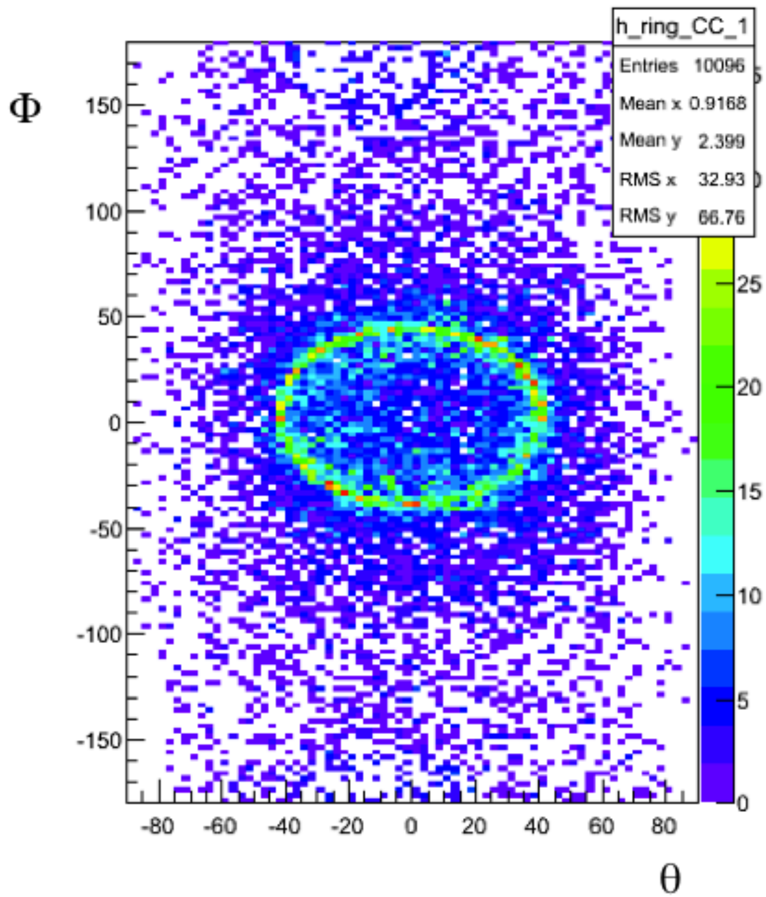
- A TESTBENCH IS OPERATING AT THE APC LABORATORY IN PARIS

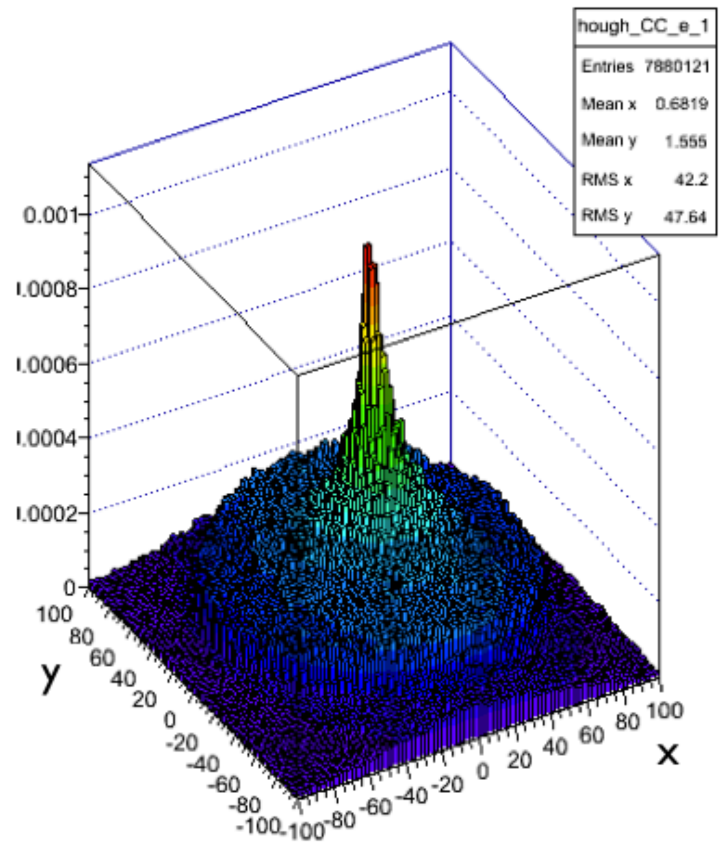
THANK YOU FOR YOUR ATTENTION

ありがとう

BACKUP

ELECTRON FUZZINESS





SuperKamiokande energy resolution

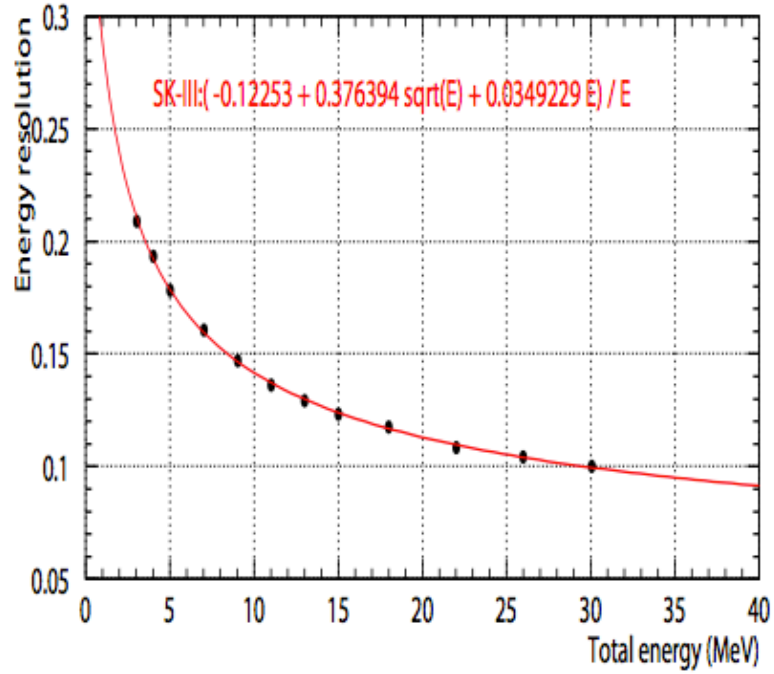


Figure 6.23: Energy resolution function obtained by electron MC simulation . Black points show the one standard deviation of Gaussian fit of MC simulation (see top plot of Figure6.18), while the line shows the fitting by the polynominal function.

SuperKamiokande angular resolution

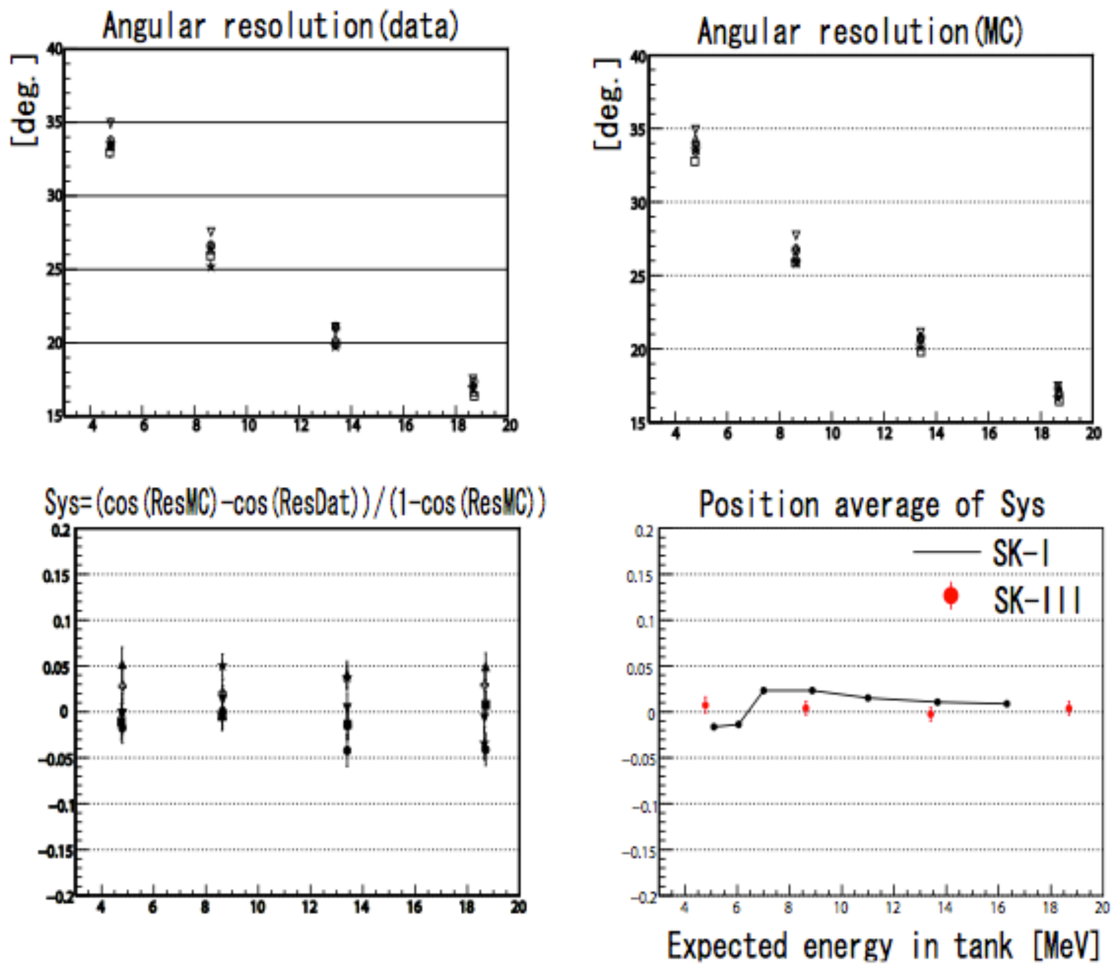
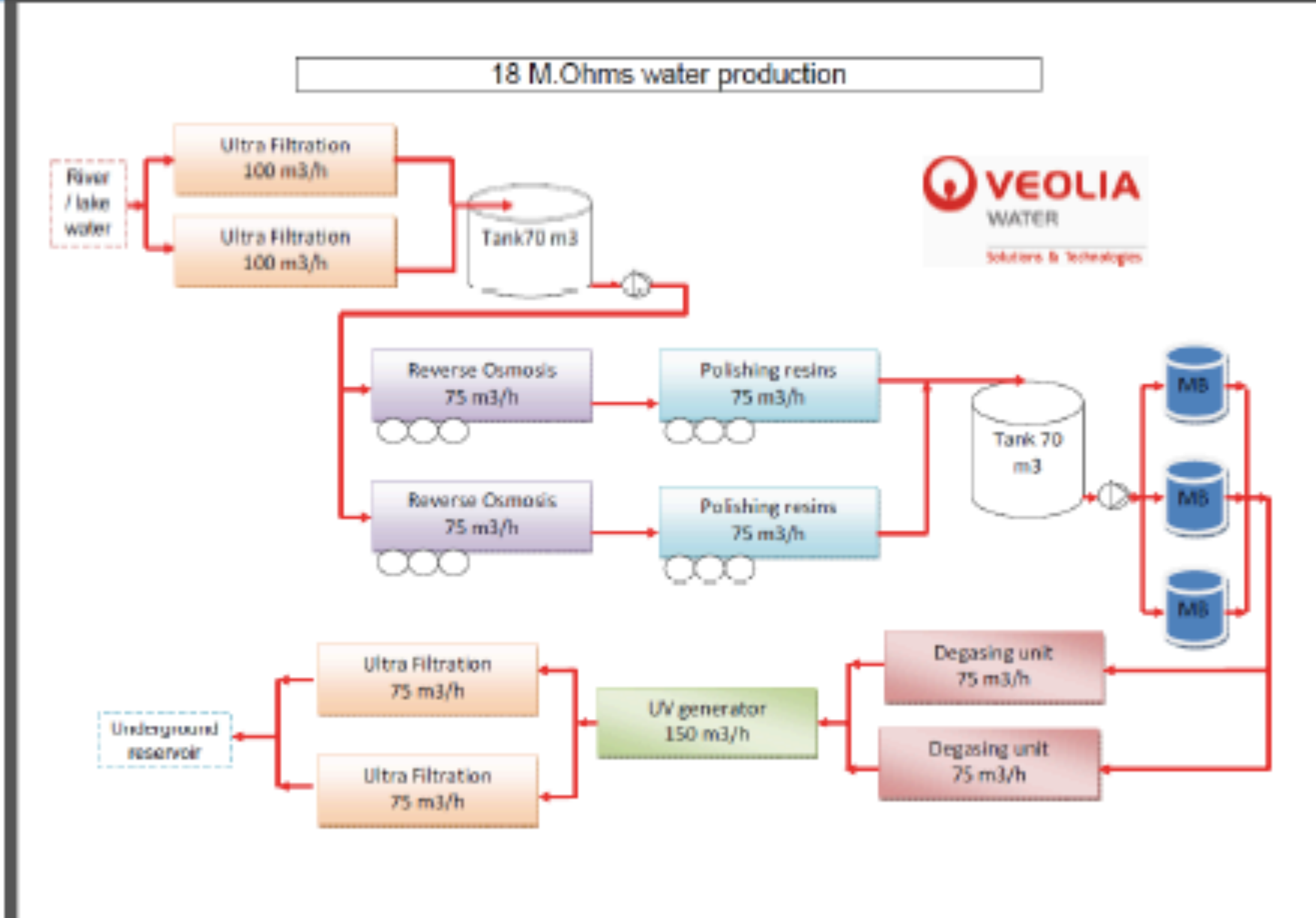


Figure 6.25: Angular resolution of LINAC data and MC simulation

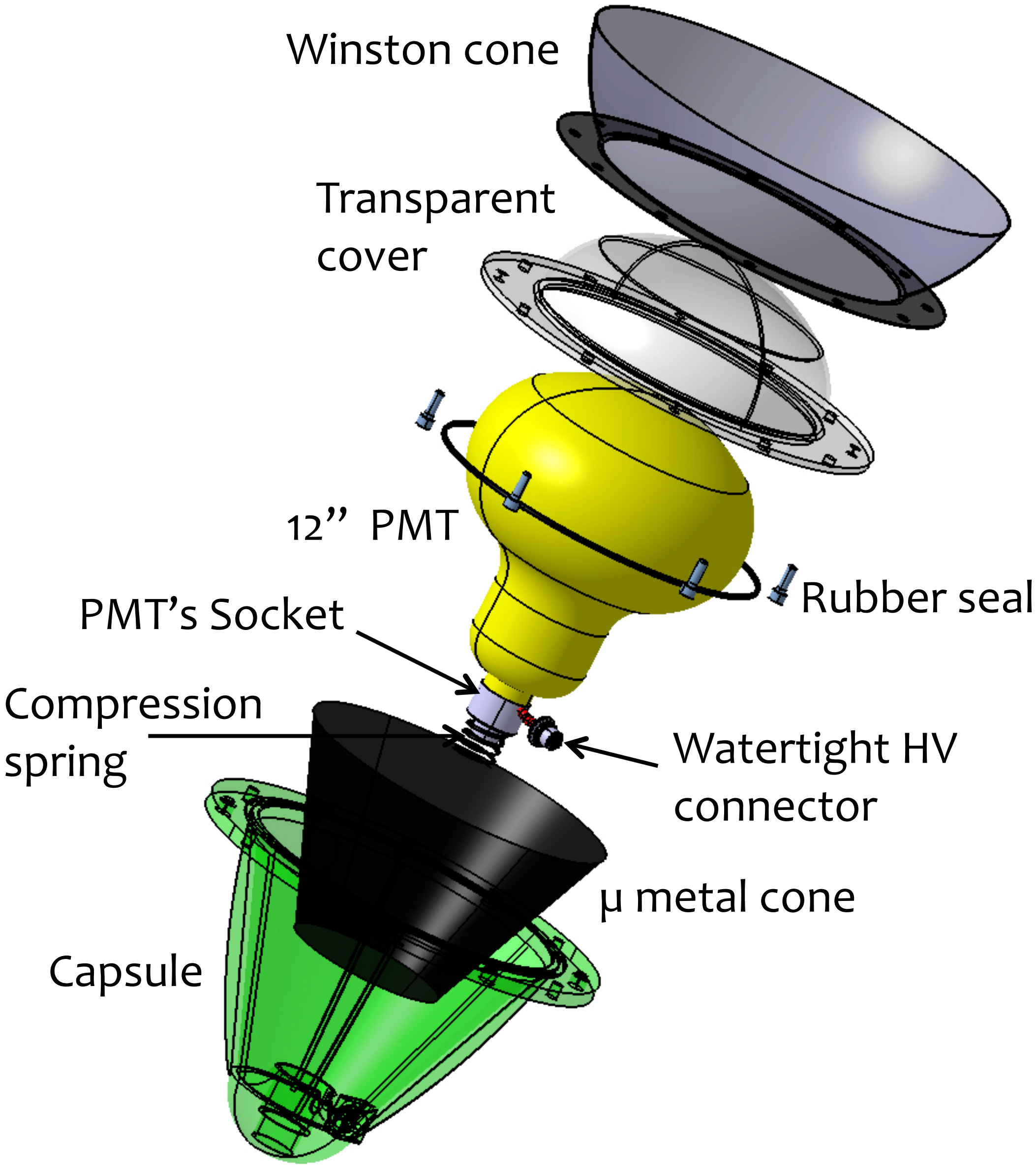
PURIFICATION DURING FILLING OF TANK



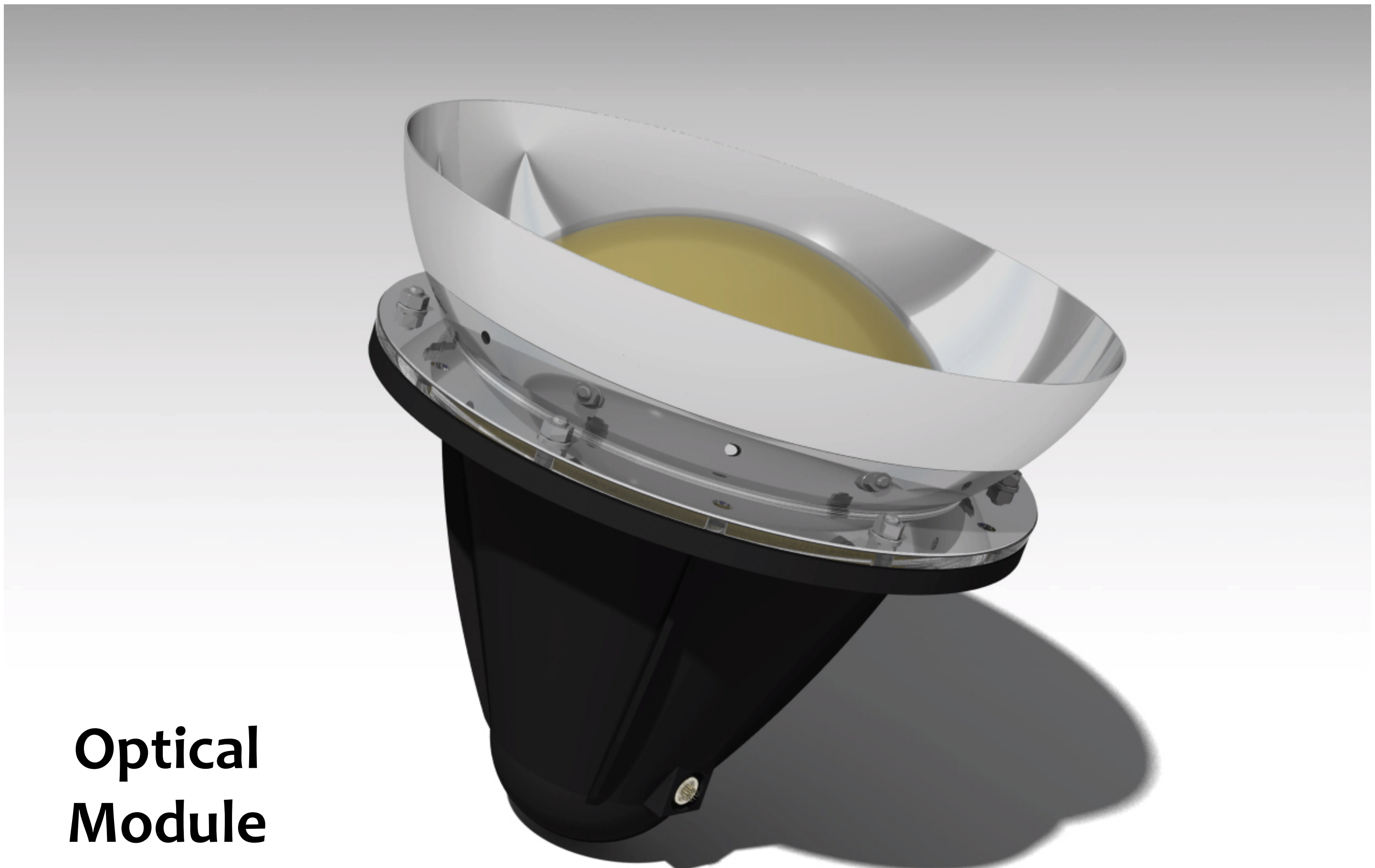
PMT ENCAPSULATION AND MATRIX DESIGN

Thanks to Yann Colaitis – APC Laboratory

DETAILED SCHEME OF PMT INSTALLATION

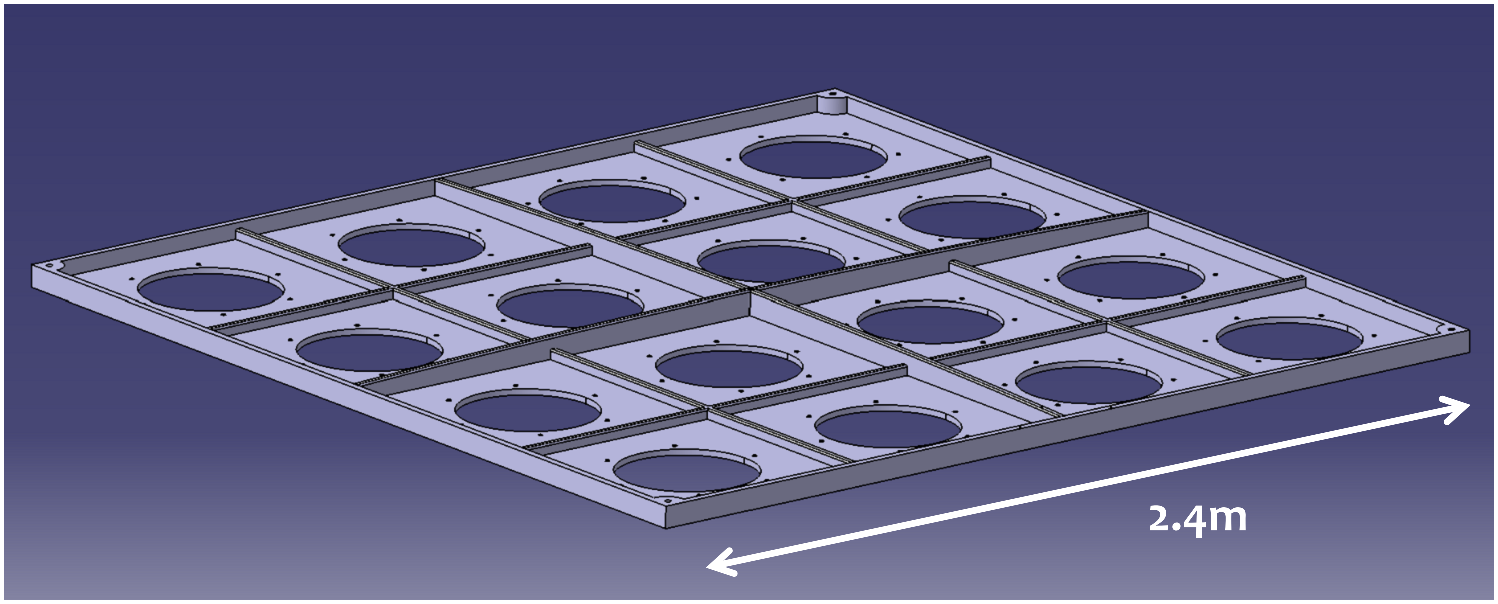


DETAILED SCHEME OF PMT INSTALLATION



Optical Module Weight: ~ 8.5 kg

MATRIX SUPPORT DESIGN



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

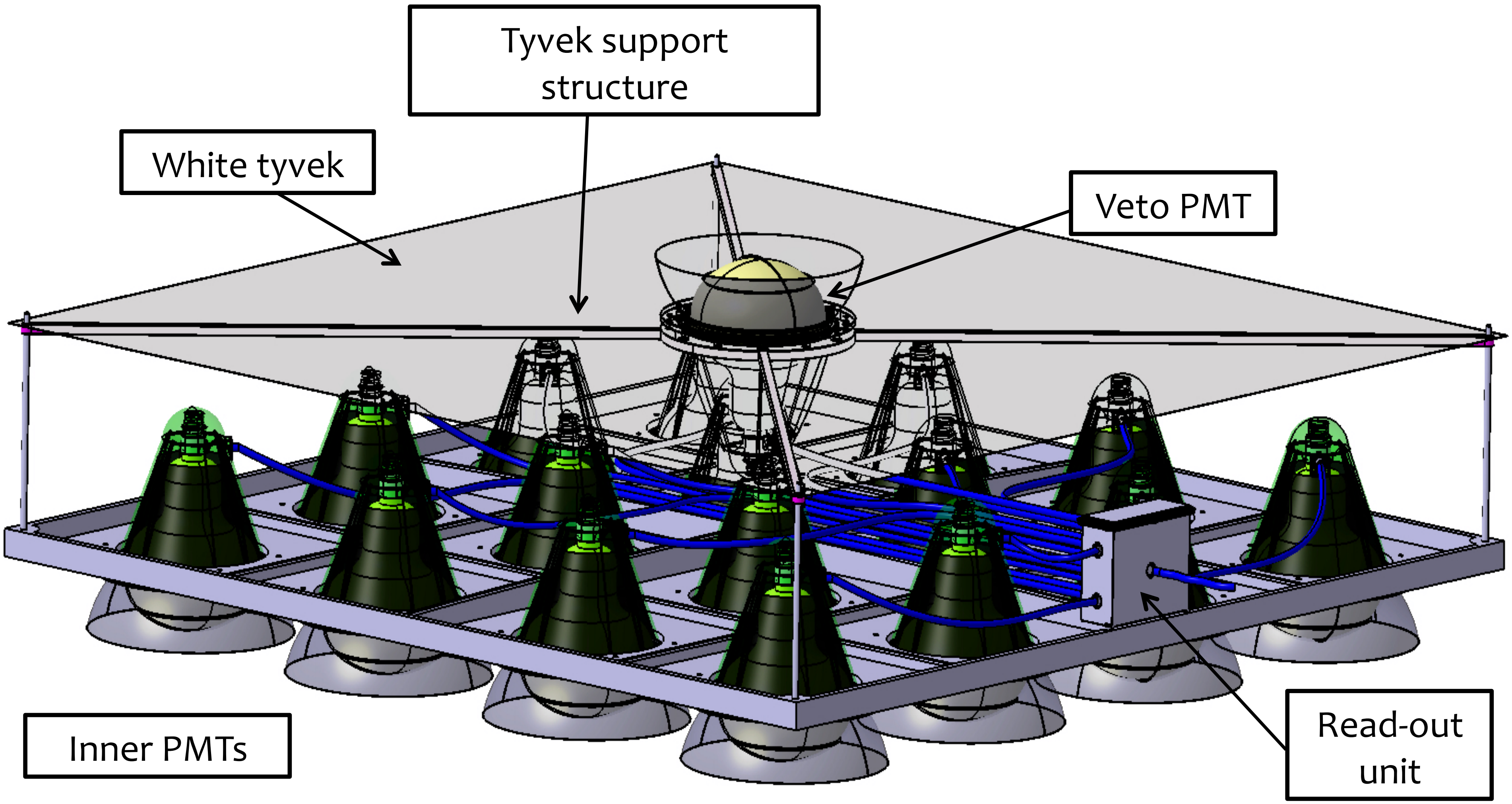
- Weight : 85kg

- Production : compression/ injection molded, water jet cutting (for boltings)
  Request for an estimate in progress

MATRIX SUPPORT DESIGN

Total Weight: ~ 200 kg

MATRIX SUPPORT DESIGN



MIGRATION MATRICES EVALUATION

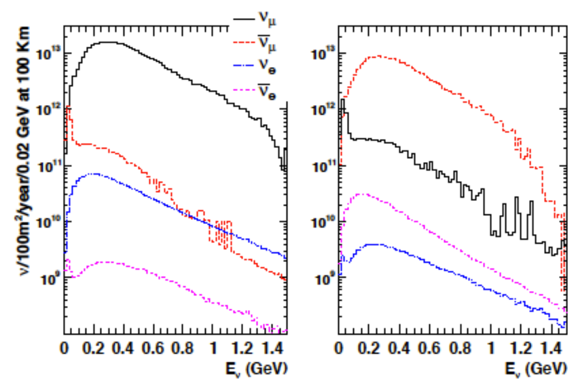
ANALYSIS CUTS FOR A RECONSTRUCTED ELECTRON NEUTRINO EVENT

MEMPHYS

1. Fully Contained Event inside the FidVo
2. Number of pes > 500
3. Only one ring reconstructed
4. Electron-like identified
5. Reconstructed Energy < 2 GeV

GLOBES INPUT : AEDL FILE

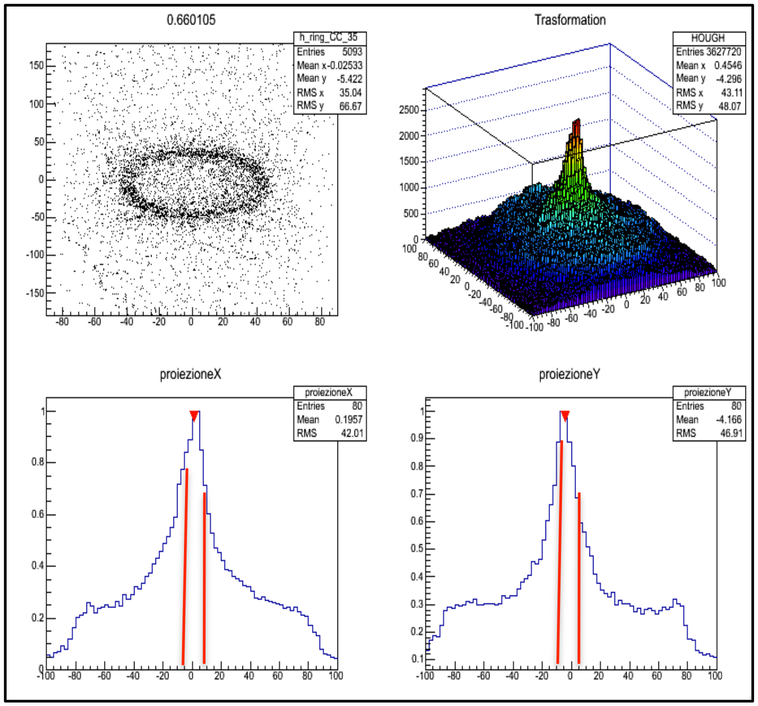
- BEAM FLUX 2-8 years neutrino antineutrinos (SPL by A. Longhin)
  4-4 years neutrino antineutrinos (BetaBeam by Mezzetto)

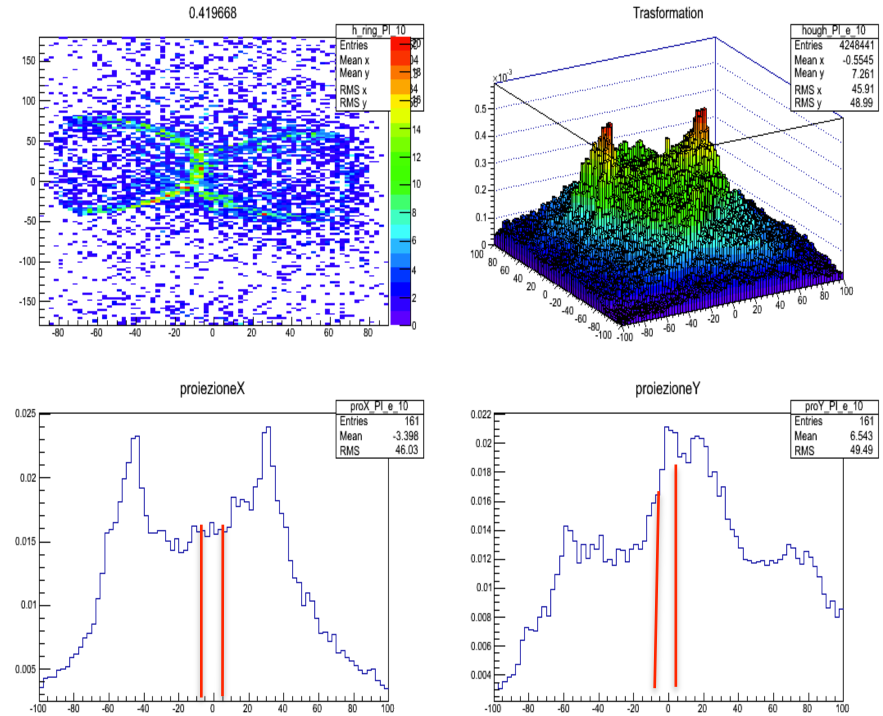


- Base Line 130 km
- Fiducial Volume 500 kt
- Efficiencies and Energy Smearing with new MMs
- Flat efficiency distribution as it is inside the MMs
- Cross Sections by NUANCE (willl be soon updated to GENIE)
- Systematic errors: 5% signal 10% background

4. RING COUNTING (2)

How to count peaks (using projections)





Best estimator:
Area between -5 and +5 bins