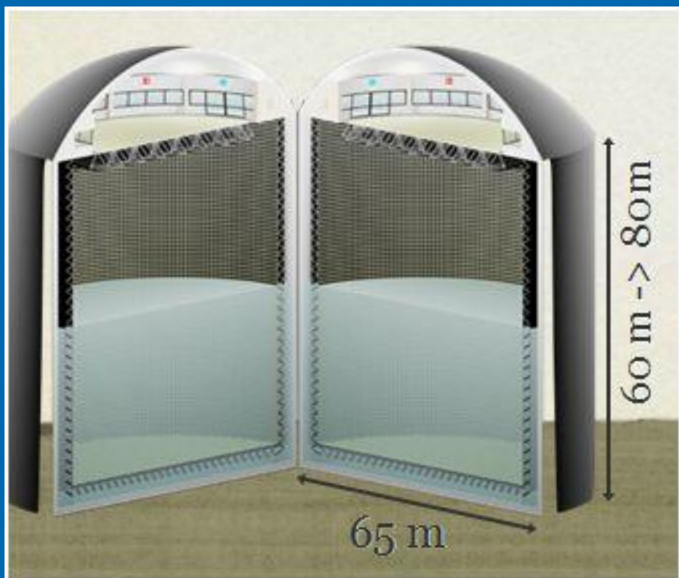
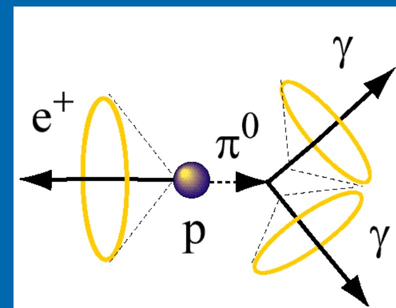
MEMPHYS Simulation & Performance

N. Vassilopoulos / APC for MEMPHYS





ASTROPARTICULE ET COSMOLOGIE

MEMPHYS: Underground Laboratory and Detector

- underground water Cherenkov at Laboratoire Souterrain de Modane Fréjus at 4800 m.w.e.
- total fiducial mass: up to 400 kton: 3 x 65mX60 modules could be designed up to 572kton: 3 x 65mX80m
  - size, shape limited by light attenuation length (λ~80m) and pressure on PMTs
  - readout : ~3 x 81k 12″ PMTs, 30% cover (# PEs = 40%cover with 20″ PMTs)
- PMT R&D + detailed study on excavation existing & ongoing + prototype Cherenkov detector MEMPHYNO

one possible design at LSM
(by Lombardi SA Inagenieurs – Conseils)

MEMPHYS physics goals

- Proton decay sensitivity:
  - up to 10^{35}yrs in 10y from the "golden" channel: $p \rightarrow e^+ \pi^0$
  - up to $2x10^{34}$yrs in 10y from $p \rightarrow K^+$ + anti-ν

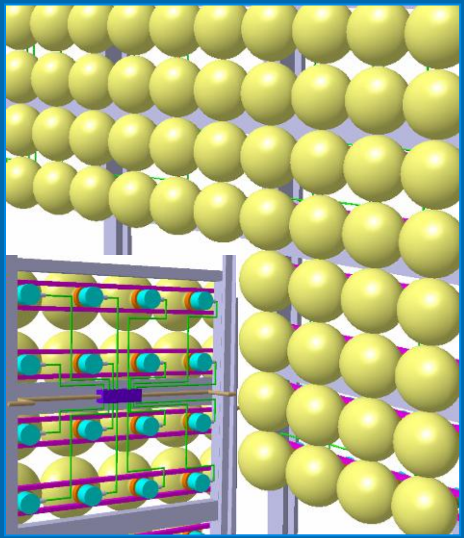
- SuperNova core collapse:
  - huge statistics from galactic SN => spectral analysis in E,t, flavour -> access SN collapse mechanism / neutrino oscillation parameters
  - sensitivity up to ~1 Mpc
  - possibility of early SN trigger (from event coincidence) up to ~5 Mpc

- SuperNova relic neutrinos:
  - observable in few years with significant statistics, according to most of existing models
  - direct measurement of ν emission parameters possible

TOPIC	MEMPHYS (440 ktons)	(~ 572 ktons)
Proton decay:	in 10 years	in 10 years
$e^+\pi^0$	$< 1.0 \times 10^{35}$ [y] 90% CL	$\lesssim 1.4 \times 10^{35}$ [y] 90% CL
$\bar{\nu}K^+$	$< 2 \times 10^{34}$ [y] 90% CL	$\lesssim 2.6 \times 10^{34}$ [y] 90% CL
SN ν (10 kpc):		
CC	2.0×10^5 ($\bar{\nu}_e$)	$\sim 2.6 \times 10^5$ ($\bar{\nu}_e$)
ES	1.0×10^3 (e)	$\sim 1.3 \times 10^3$ (e)
DSN ν (S/B 5 y)	$(43-109)/47$ ($\star$)	$(56-142)/61$ ($\star$)
Solar ν		
^8B ES	1.1×10^6 per y	$\sim 1.3 \times 10^6$ per y
Atm. ν (per y)	4.0×10^4	$\sim 5.2 \times 10^4$
Geo ν	need 2 MeV thr.	need 2 MeV thr.
Reactor ν (per y)	6.0×10^4 ($\star$)	$\sim 7.8 \times 10^4$ ($\star$)

- and, of course... NEUTRINO BEAMS *(see Euronu WP2, WP4)*

R&D towards MEMPHYS : PMm2



latest News & detailed description of the R&D: read J.E Campagne's Talk at NNN09, pmm2.in2p3.fr

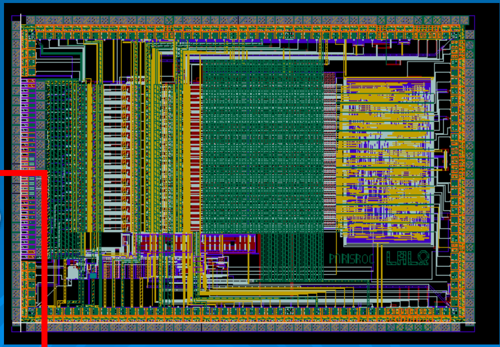
"Innovative electronics for array of photodetectors used in High Energy Physics and Astroparticles".

R&D program funded by French national agency for research (LAL, IPNO, LAPP and ~~Photonis~~) (2007-2010)

Basic concept: very large photodetection surface → macropixels of PMTs connected to an autonomous front-end electronics.

Replace large PMTs (20") by groups of 16 smaller ones (~~12"~~, 8") with central ASIC :

- Independent channels
- charge and time measurement
- water-tight, common High Voltage
- Only one wire out (DATA + VCC)



I. studies on ~~12"~~ 8" PMTs design
- parameter correlation
- potting
- pressure resistance

(collaboration with BNL since NNN07)

II. PArISROC readout chip
- complete front-end chip with 16 channels
- testboard now in layout, soon available

MEMPHYNO

PMTS AND LIGHT SENSORS

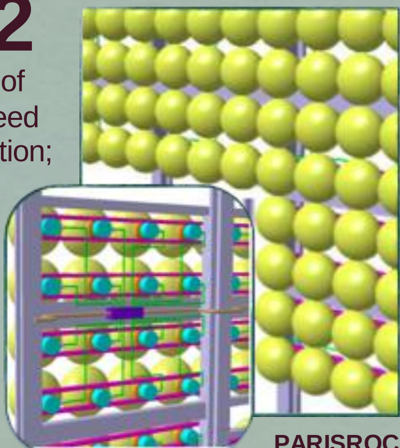
Red

http://pmm2.in2p3.fr

PMm2

- Height number of **light sensor**: need grouped acquisition;

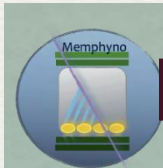
- Common HV
- Common readout
- Common signal digitization

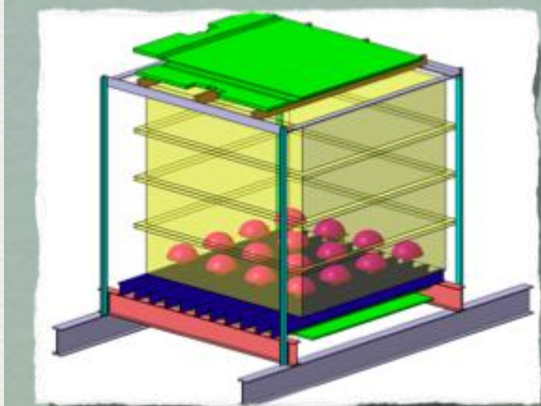


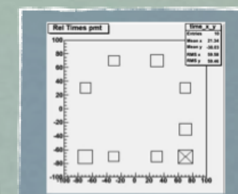
Demonstrator:

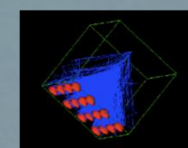
PARISROC

Memphyno







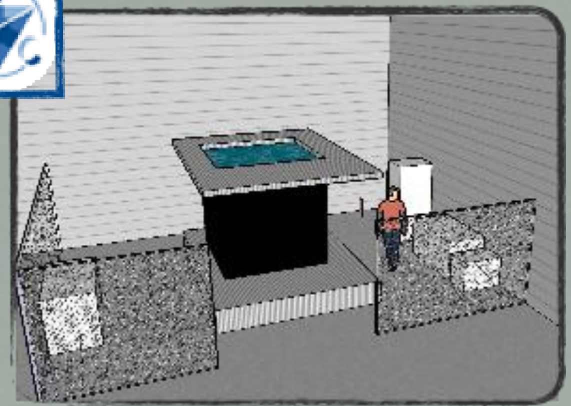


Memphys' Prototype

M. Marafini - APC -Paris

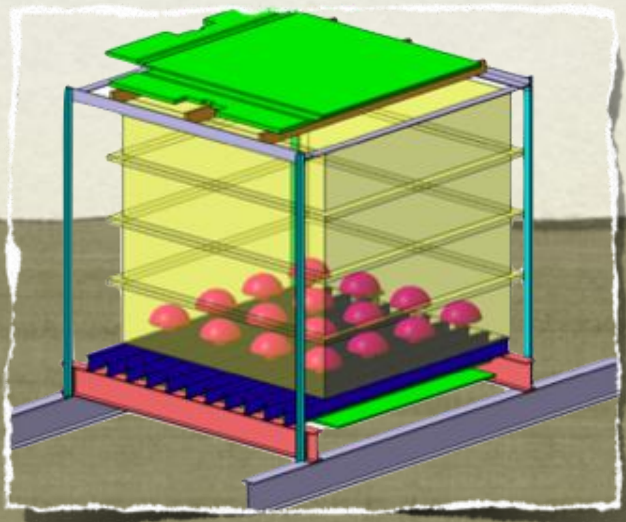
MEMPHYNO

TEST BENCH for photodetection and electronic solutions for LARGE detectors



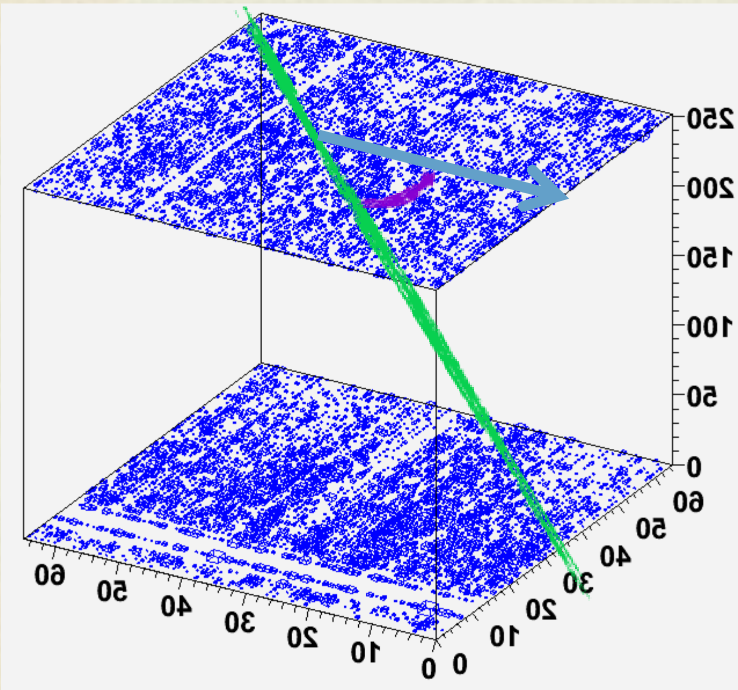
- **~8t of water** (+Gd?)
- 2x2x2m^3 HDPE tank
- Matrix of 16 PMTs and/or other photodetectors (e.g.: X-HPX)
- **Muon hodoscope:**
- 2+2 planes of OPERA-like scintillator bars
- 4 Pmt(ino) multi anodes (64 channels)

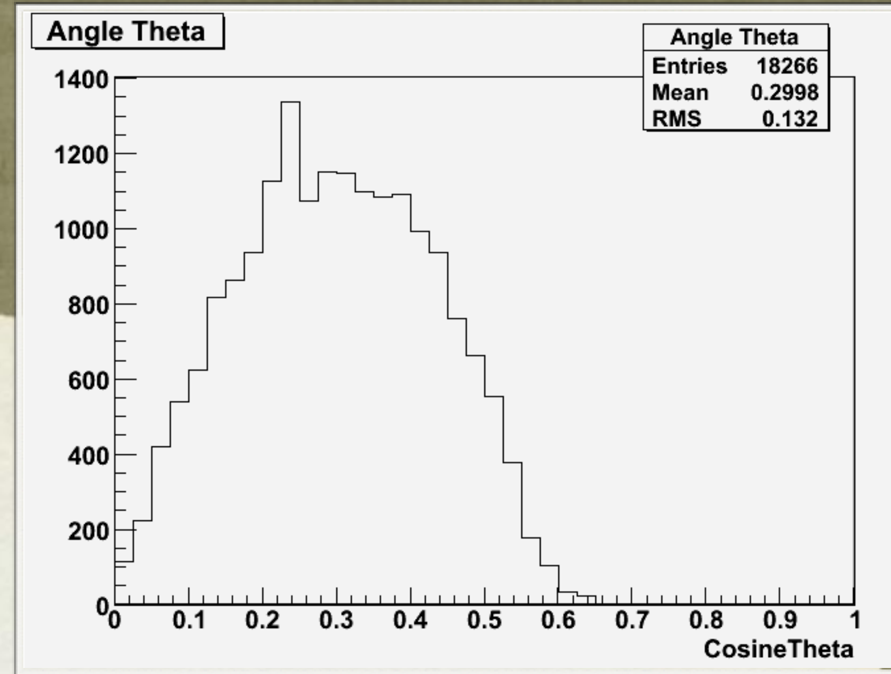
- **Full test of NEW "electronic and acquisition" chain;**
- **Trigger threshold study**
- **Self-trigger mode**
- **Track reconstruction performances;**
- **Gd doping: flexibility and performance.**



MEMPHYNO +μ hodoscopes

Acquisition with 4 planes



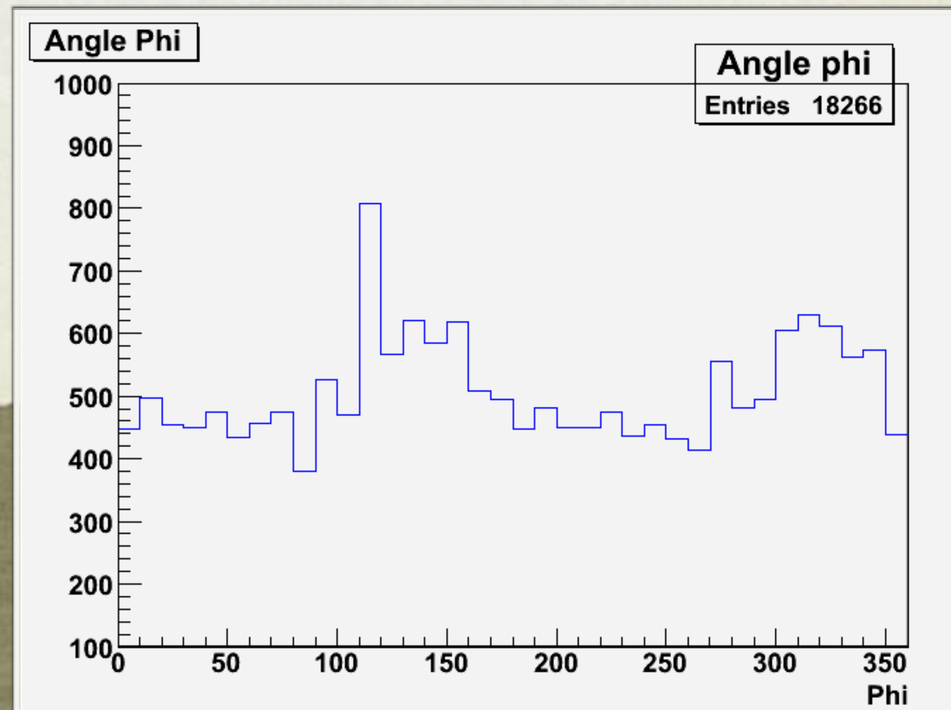


Plane 0 (Right)- Pmt 0 - maroc 17

Plane 1 (Left)- Pmt 1 - maroc 18

Plane 2 (Right)- Pmt 2 - maroc 19

Plane 3 (Left)- Pmt 3 - maroc 20

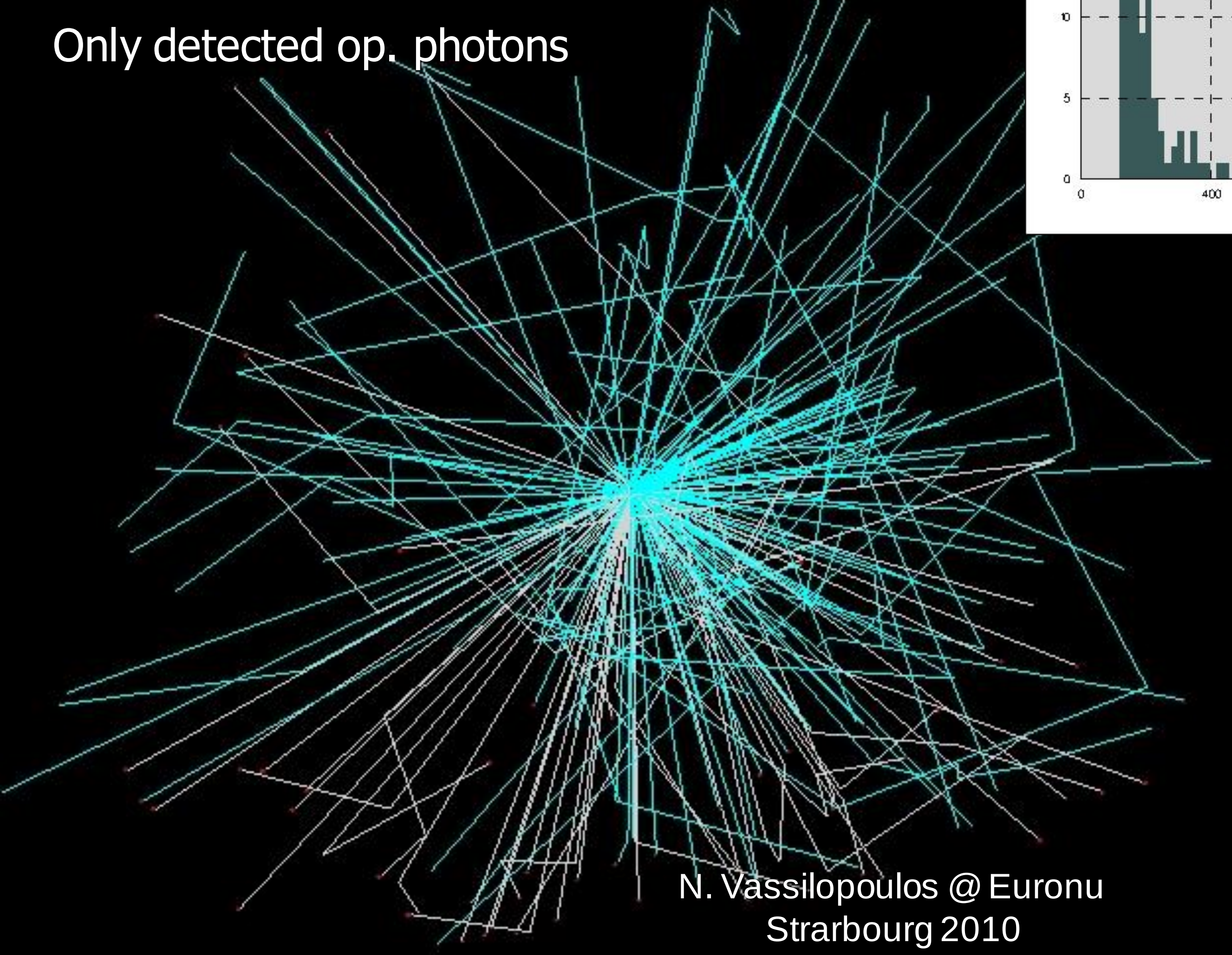


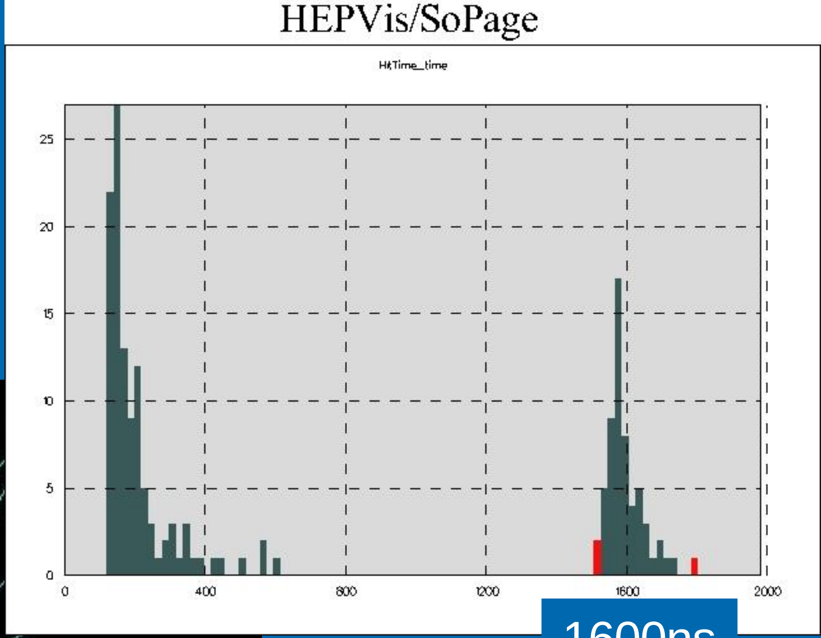
MEMPHYS: MC Present Status

- Event Generator:
  - NUANCE for ν beam, ν Atmospheric & Proton Decay
- MEMPHYS Simulation (M. Fechner , J.E. Campagne, N. Vassilopoulos) :
  - Interface with the OpenScientist v16r0 framework (G. Barrand/LAL) using distribution kits as Geant4 & CLHEP & AIDA-IO implementation to Rio (also HDF5, XML)
  - 3 modes of running in the same framework:
    - Interactive Viewing, Batch processing, AIDA_ROOT analysis
  - event info from MC: primary + secondary + Optical Photon info, track + process selection a la Geant4, modular detector geometry, ntuples' storage, etc...
- MEMPHYS Event Reconstruction, Analyses (N. Vassilopoulos, A. Tonazzo, M. Marafini):
  - interactive ROOT- cint
  - Solo C++ for complex/high stats using ROOT + AIDA libraries

$\nu_\mu \to \mu^- \to e^-$

Only detected op. photons





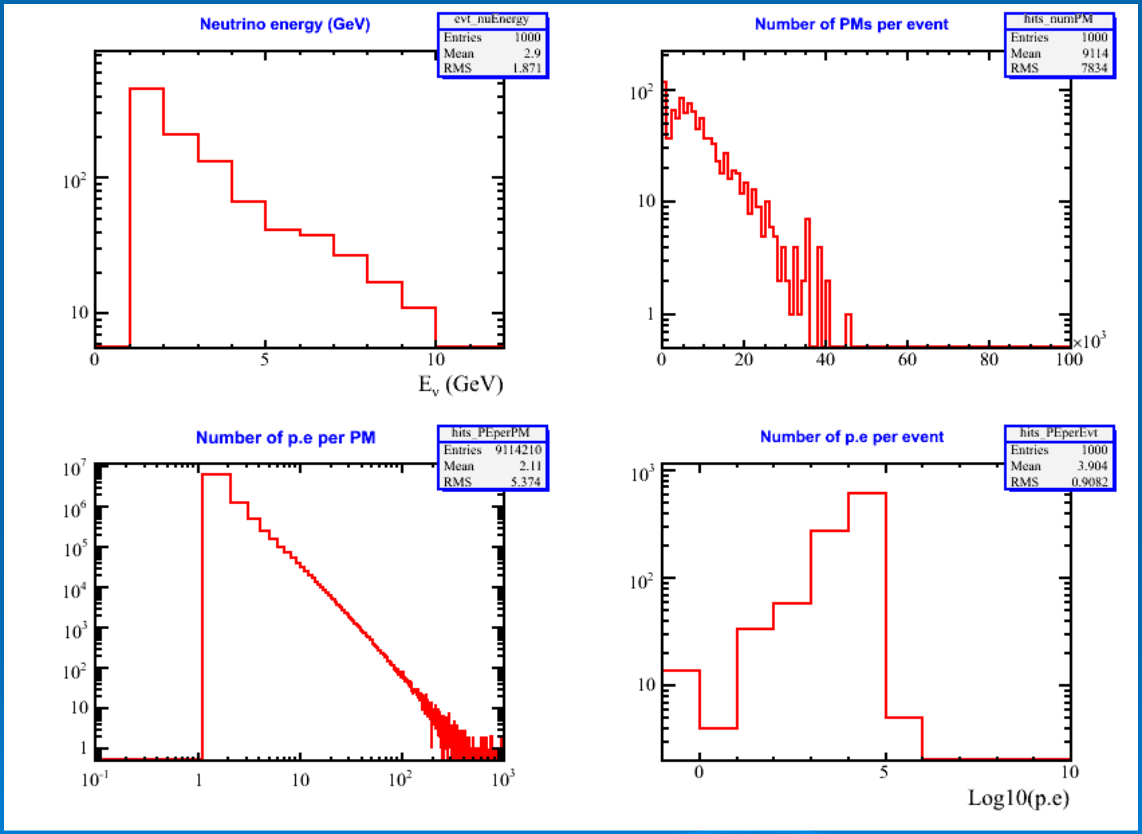
1600ns

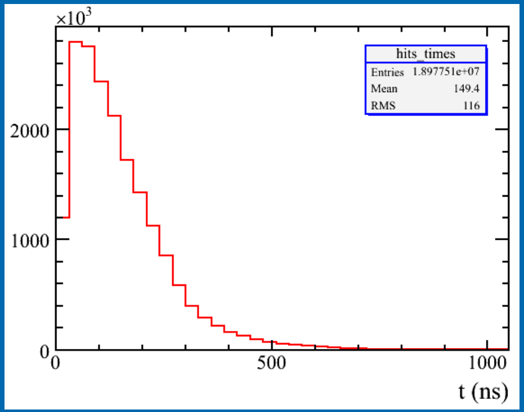
Interactive histogram to identify the e Michel optical photons…

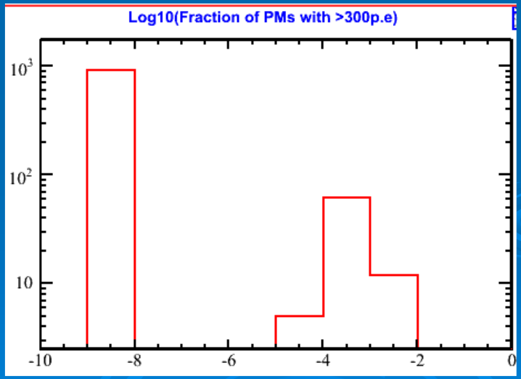
transparency by J. E. Campagne

MEMPHYS v7

ν atmospheric (1-10GeV)

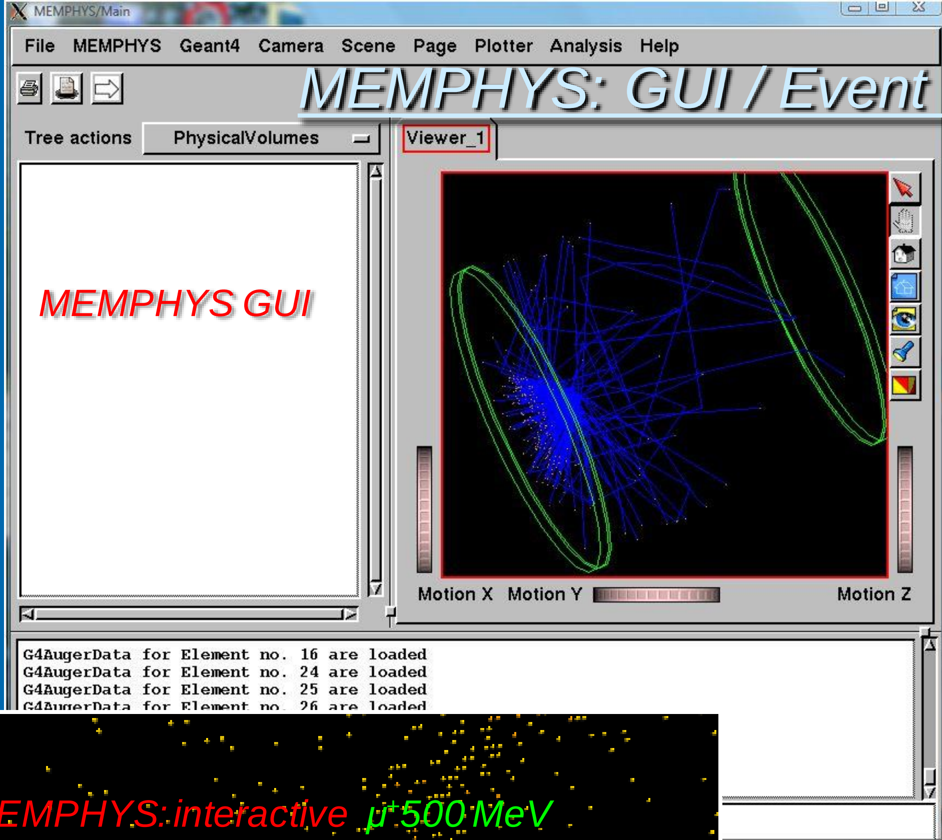


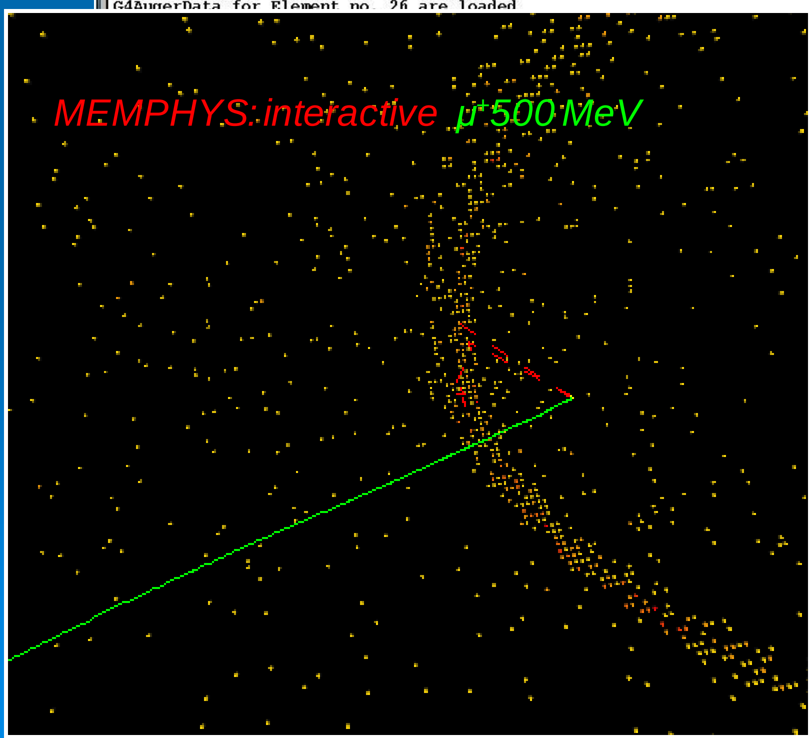


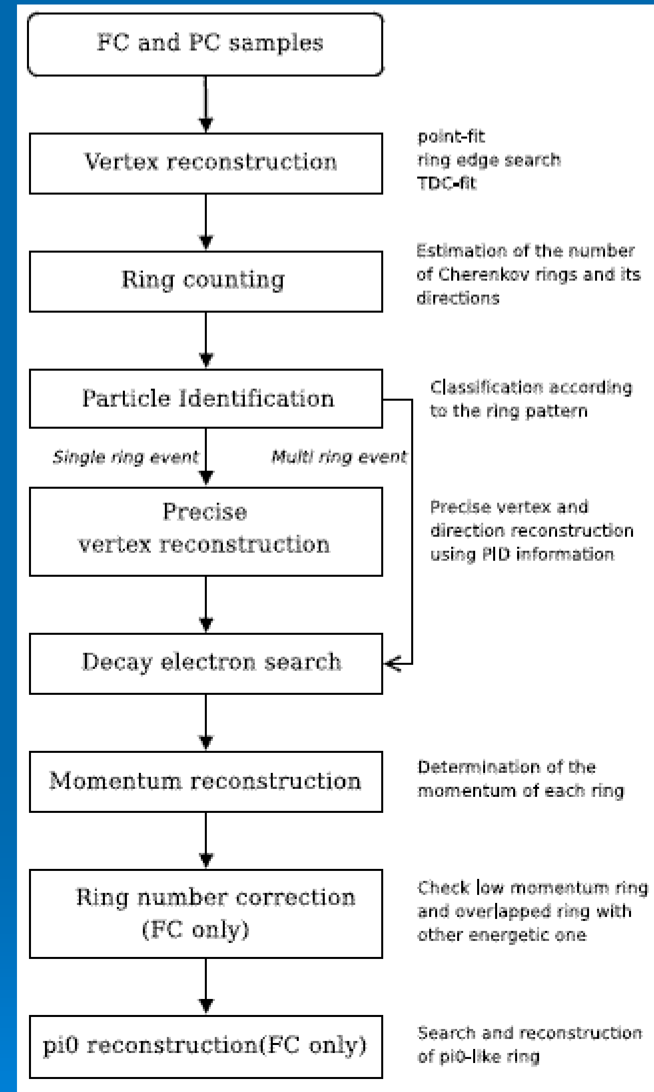


transparency by J. E. Campagne

MEMPHYS: GUI / Event Reconstruction

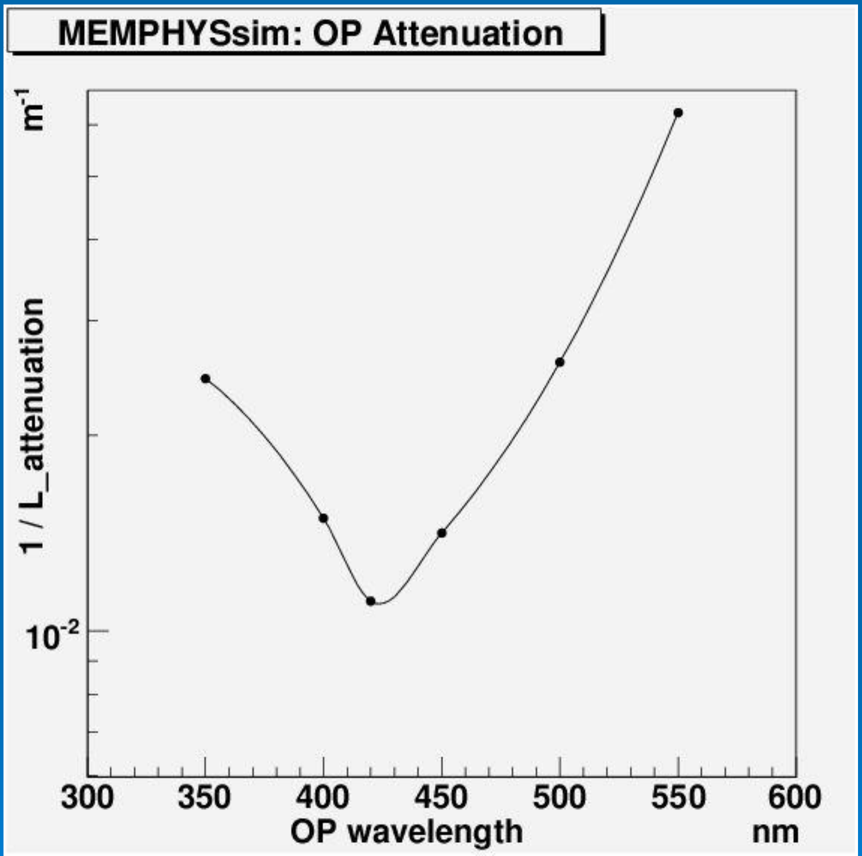




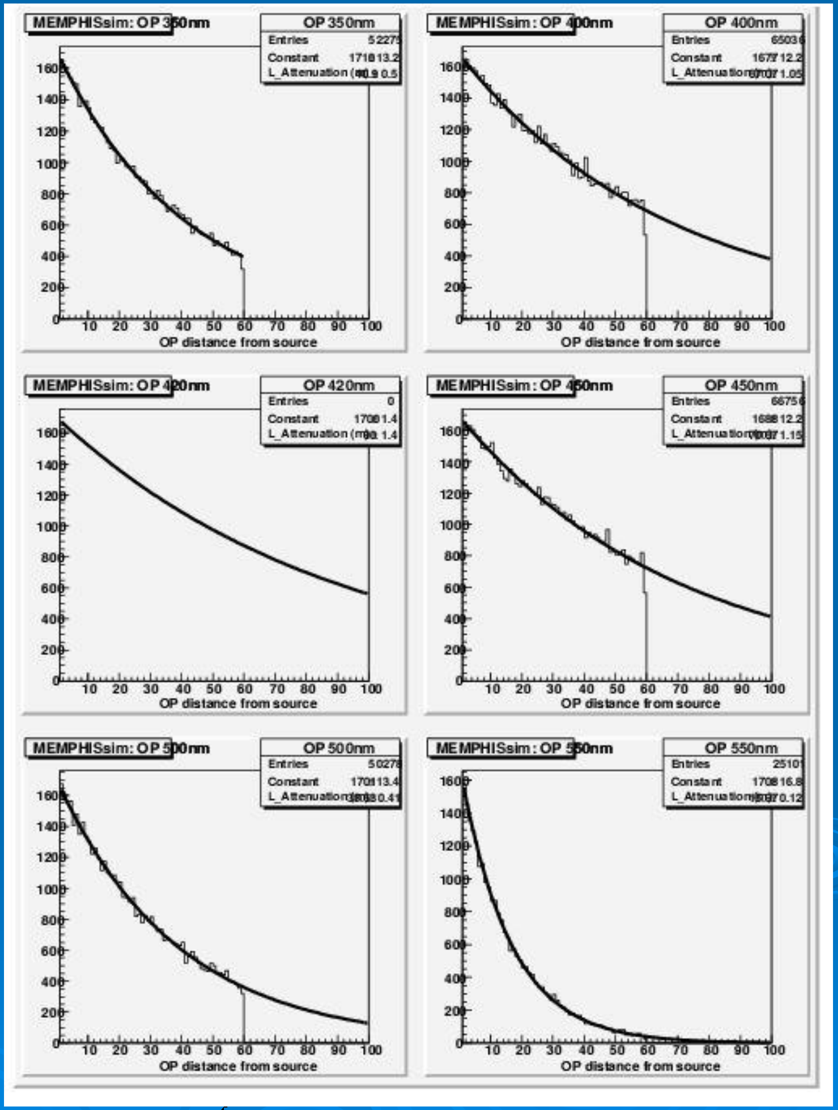


Attenuation length studies

- correct modelling of light propagation



attenuation length in water as a function of the wavelength in MEMPHYS simulation

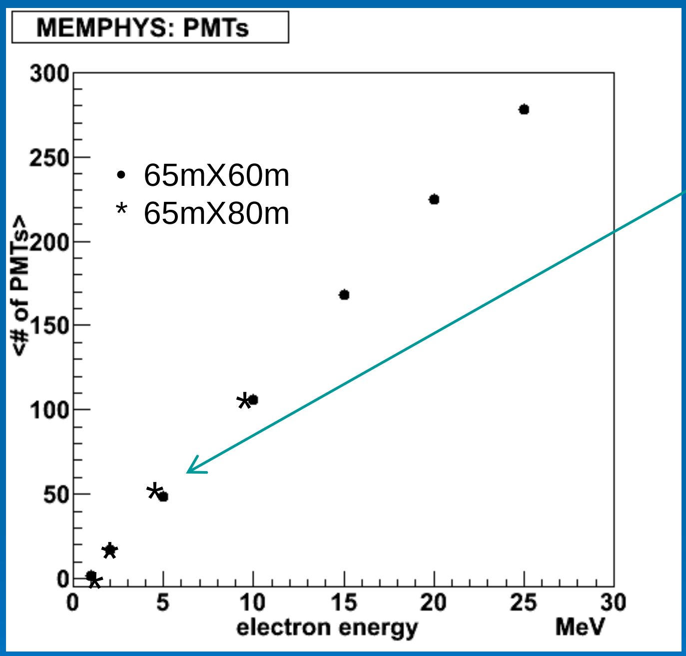


✓ looks comparable to SK data

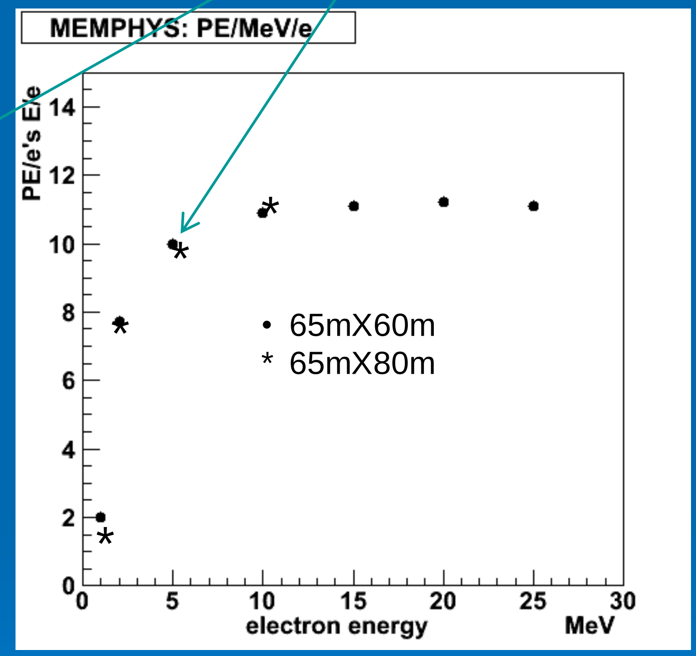
MEMPHYS Single ring studies, electrons

- single *e-* events from 1 to 25 MeV (FC): PMTs and PE infos

27% more FV without light reduction



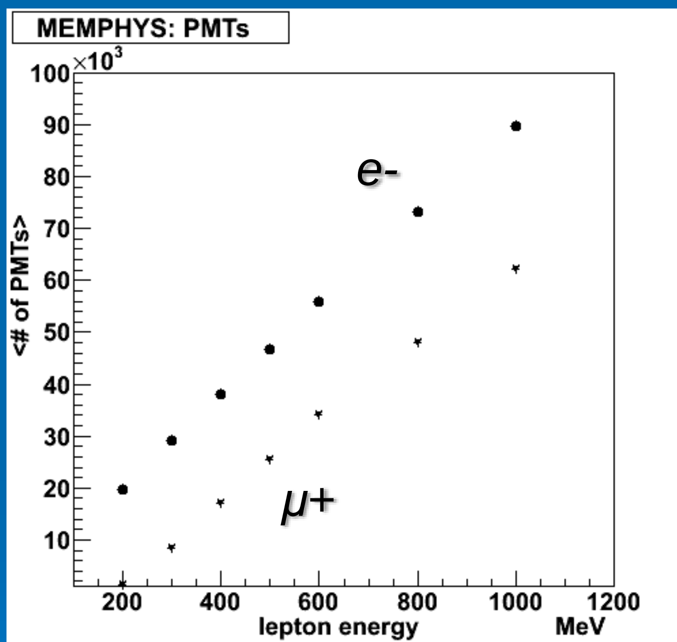
Number of PMTs with at least one photoelectron as a function of electron energy



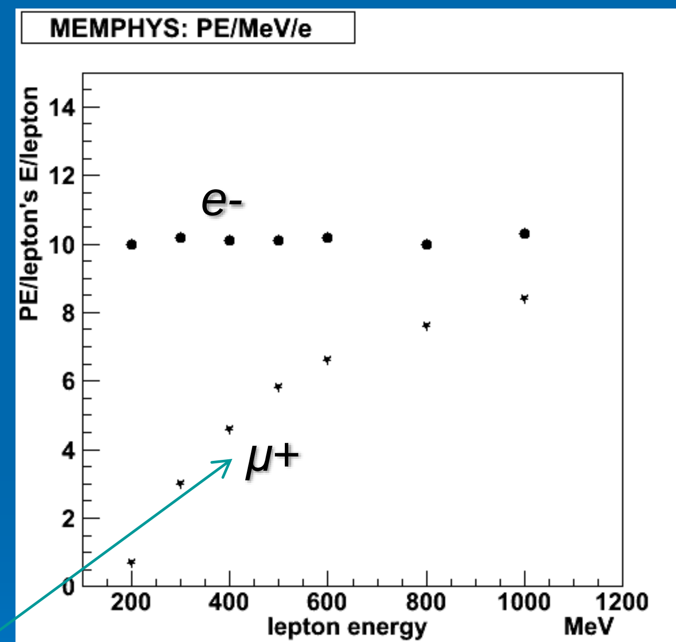
Number of detected photoelectrons per MeV as a function of electron energy

MEMPHYS Single ring studies electrons, muons

- single e- , μ+ (no decays) events from 200 to 1000 MeV: PMTs and PE infos



Number of PMTs with at least one photoelectron as a function of lepton energy



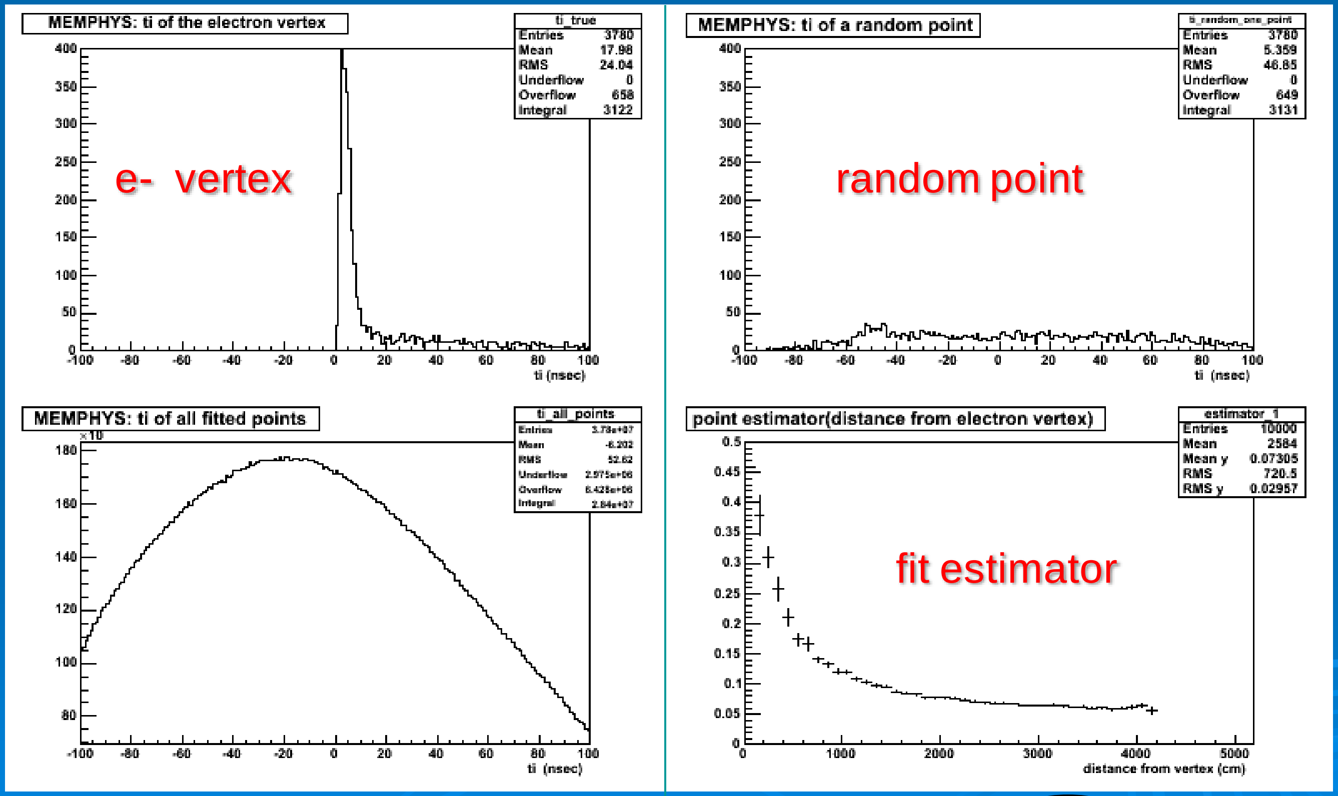
Number of detected photoelectrons per MeV as a function of lepton energy

$$\frac{dN}{dx} = 2\pi z^2 \alpha \sin^2\theta_C \int_{\lambda_1}^{\lambda_2} \frac{d\lambda}{\lambda^2} = 475 z^2 \sin^2\theta_C \text{ photons/cm}$$

$$\cos\theta_C = \frac{1}{\beta n(\omega)}$$

Single rings: electrons primary vertex fit

- pick up a 400 MeV electron (FC), assume point like track length
- primary vertex fit based only on each PMT's timing info: $t_{i\ PMT} = t_i + TOF_i \Rightarrow t_i = t_{i\ PMT} - TOF_i$, where $TOF_i = (n / c) \times D$, D = distance between each PMT and grid's coordinates
- maximize estimator E a la SK $G_p = \frac{1}{N}\sum_i \exp\left(-\frac{(t_i - t_0)^2}{2(1.5\times\sigma)^2}\right)$ to find the true vertex of electron :

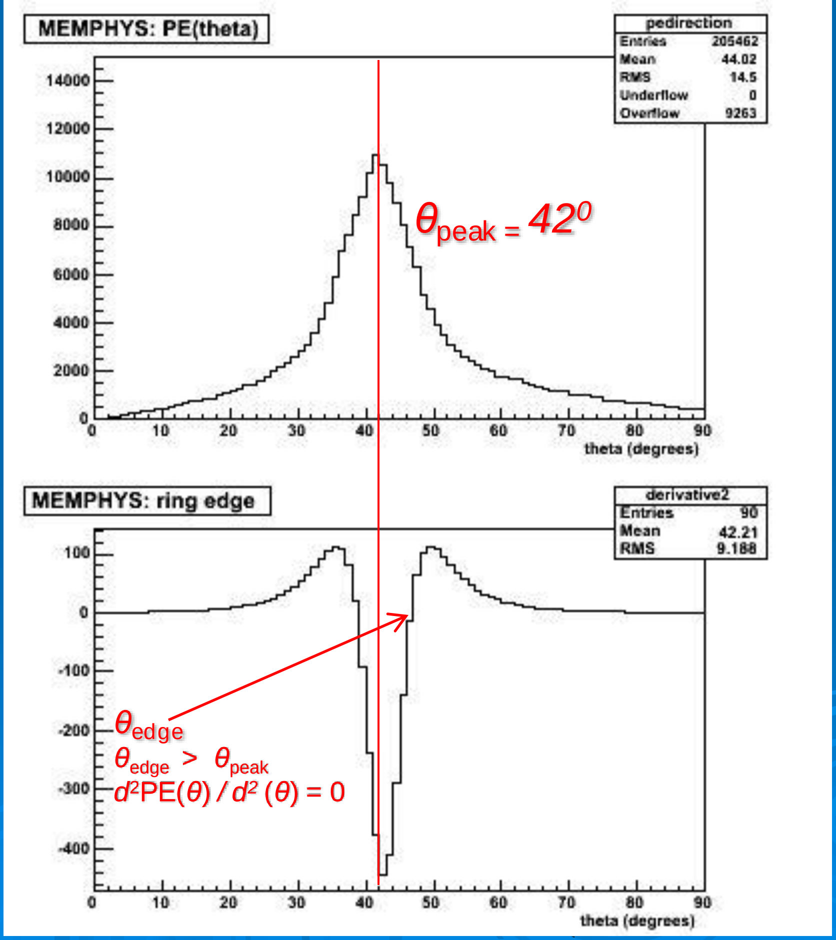


Single rings: particle direction, outer ring edge

- keep the 400 MeV *e-*
- calculate roughly the direction:

$$\vec{d}_0 = \sum_i q_i \times \frac{\vec{P}_i - \vec{O}_0}{|\vec{P}_i - \vec{O}_0|}$$

- θ_{edge}
  - $\theta_{edge} > \theta_{peak}$
  - $d^2PE(\theta) / d^2(\theta) = 0$

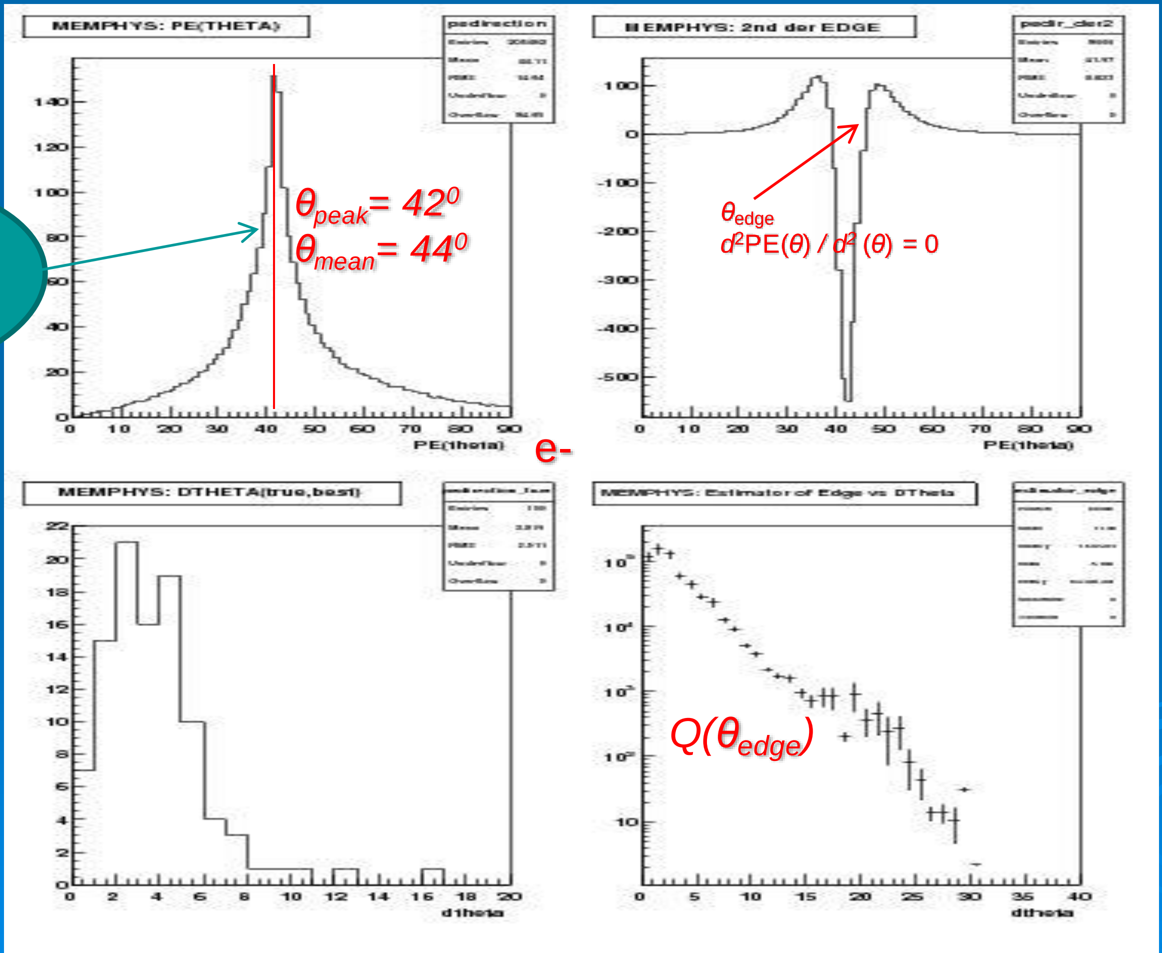


Single rings: e- 400MeV best direction

- cut on $t_{i\ PMT}$ for reflections
- find the best direction maximizing :

$$Q(\theta_{\rm edge}) = \frac{\int_0^{\theta_{\rm edge}} {\rm PE}(\theta) d\theta}{\sin\theta_{\rm edge}} \times \left(\frac{d{\rm PE}(\theta)}{d\theta}\Big|_{\theta=\theta_{\rm edge}} \right)^2 \times \exp\left(- \frac{(\theta_{\rm edge} - \theta_{\rm exp})^2}{2\sigma_\theta^2} \right)$$

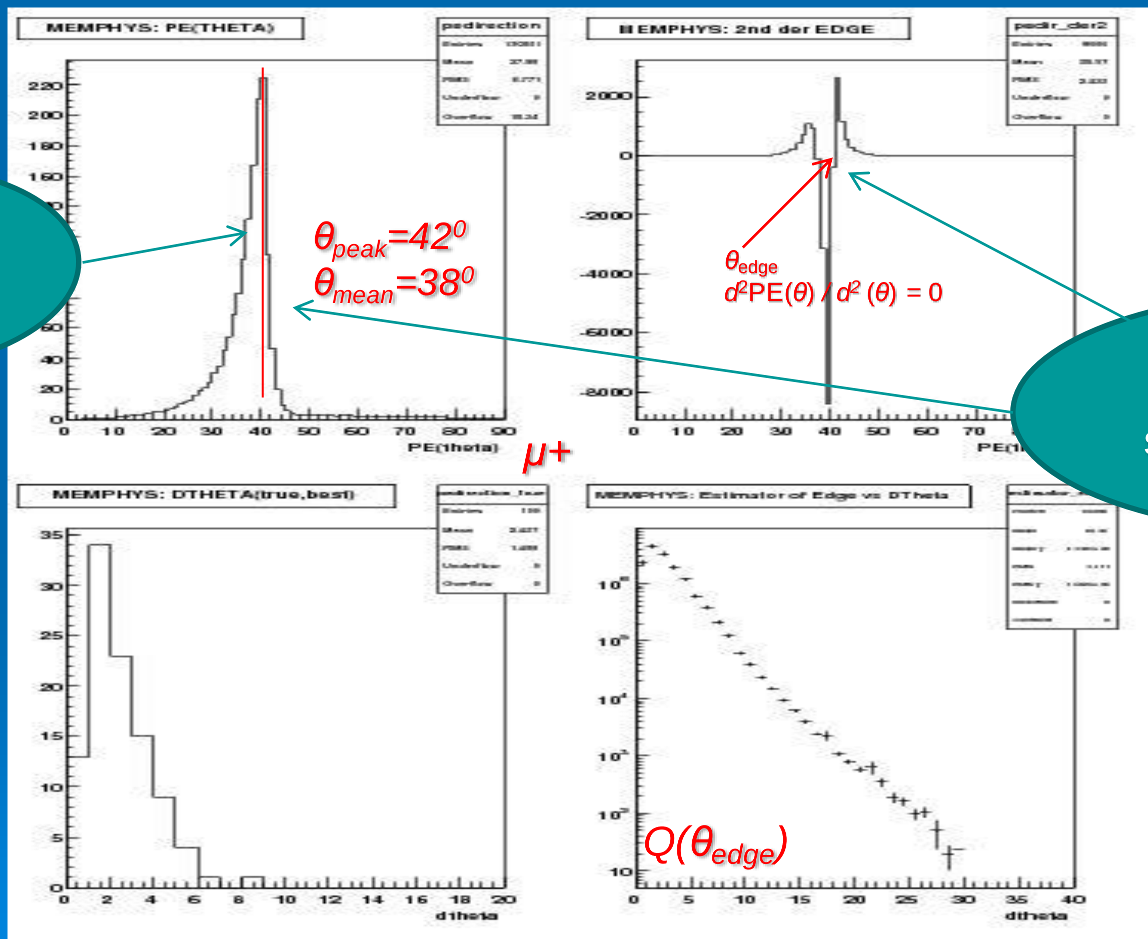
PEs angular distribution seen at best vertex and with respect to true direction



Single rings: μ+ 500MeV best direction

- find the best direction maximizing :

$$Q(\theta_{\rm edge}) = \frac{\int_0^{\theta_{\rm edge}} {\rm PE}(\theta)d\theta}{\sin\theta_{\rm edge}} \times \left(\frac{d{\rm PE}(\theta)}{d\theta}\bigg|_{\theta=\theta_{\rm edge}}\right)^2 \times \exp\left(-\frac{(\theta_{\rm edge}-\theta_{\rm exp})^2}{2\sigma_\theta^2}\right)$$



PEs angular distribution seen at best vertex and with respect to true direction

clearly different shape than e- ring

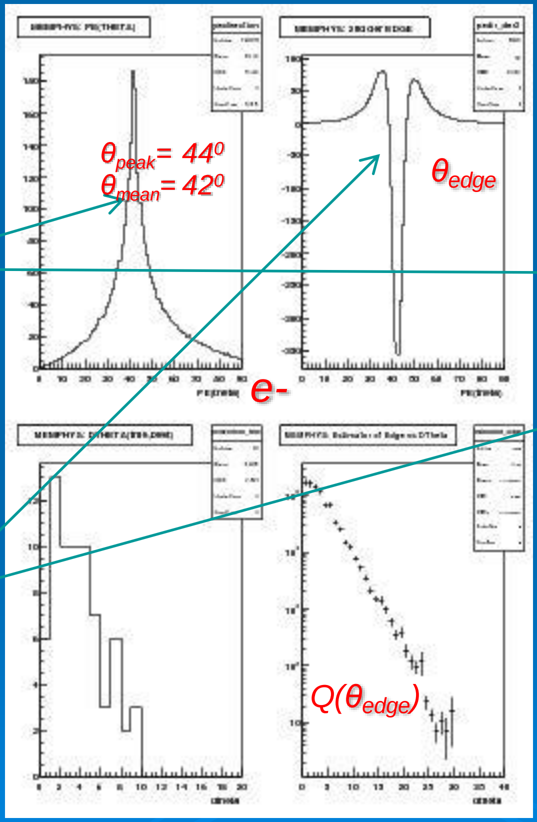
Single rings (FC): e-, μ+ 200MeV to 1000MeV ring direction

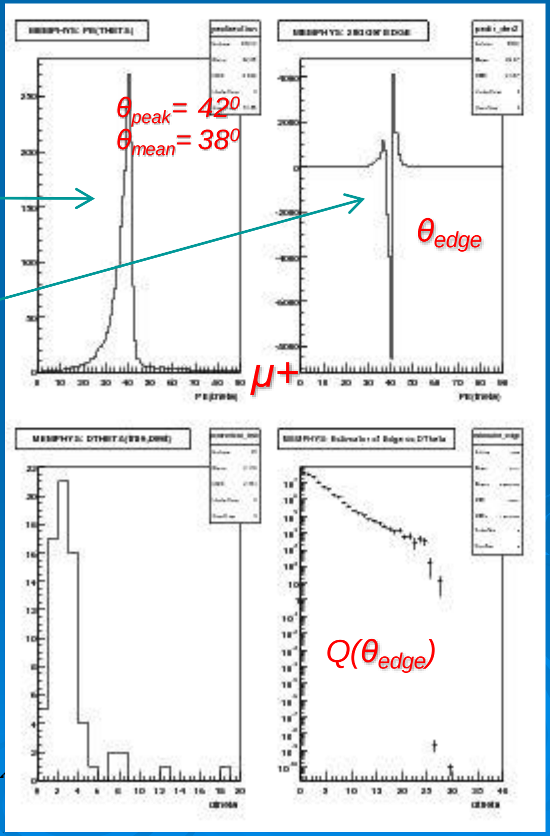
- find the best direction maximizing :

$$Q(\theta_{\rm edge}) = \frac{\int_0^{\theta_{\rm edge}} {\rm PE}(\theta)d\theta}{\sin\theta_{\rm edge}} \times \left(\frac{d{\rm PE}(\theta)}{d\theta}\bigg|_{\theta=\theta_{\rm edge}} \right)^2 \times \exp\left(-\frac{(\theta_{\rm edge}-\theta_{\rm exp})^2}{2\sigma_\theta^2} \right)$$

PEs angular distribution seen at best vertex and with respect to true direction. Different shapes

spread e' s rings sharper μ' s rings





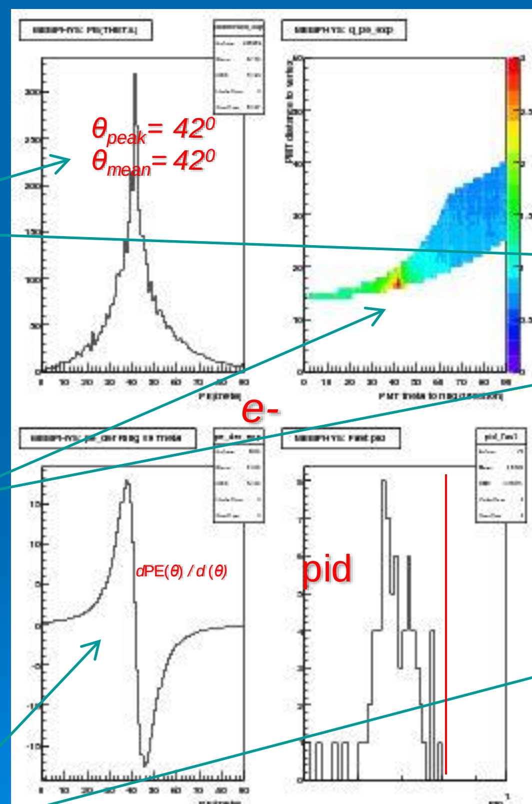
Single rings: e-, μ+ 200MeV to 1000MeV pid

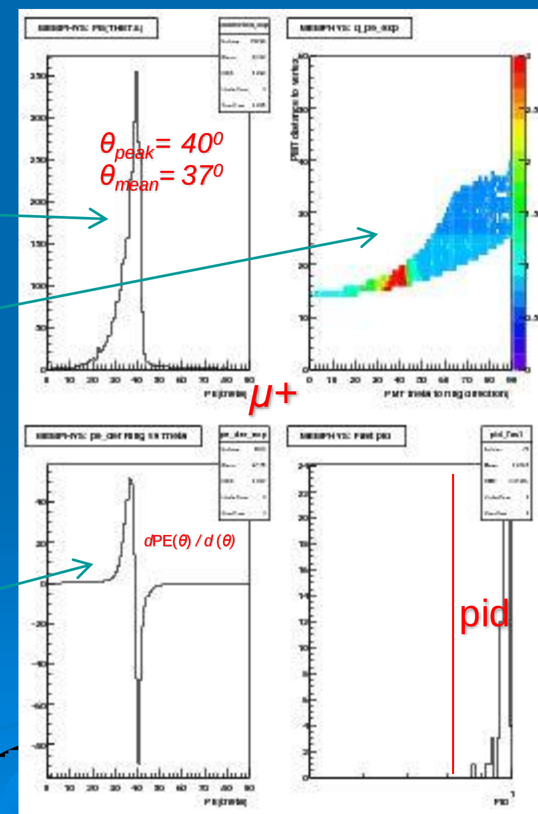
- use PEs (PMT) angular distribution from best reconstructed vertex and true direction as fast pid variable
- examine the case of transparent detector: no Rayleigh or absorption & no-reflection from the plastic cover of ID yet

PEs angular distribution seen at best vertex and with respect to true direction. Different shapes

number of PEs as a function of the PMT distance to the true vertex and with respect to true direction

spread e' s rings sharper μ' s rings





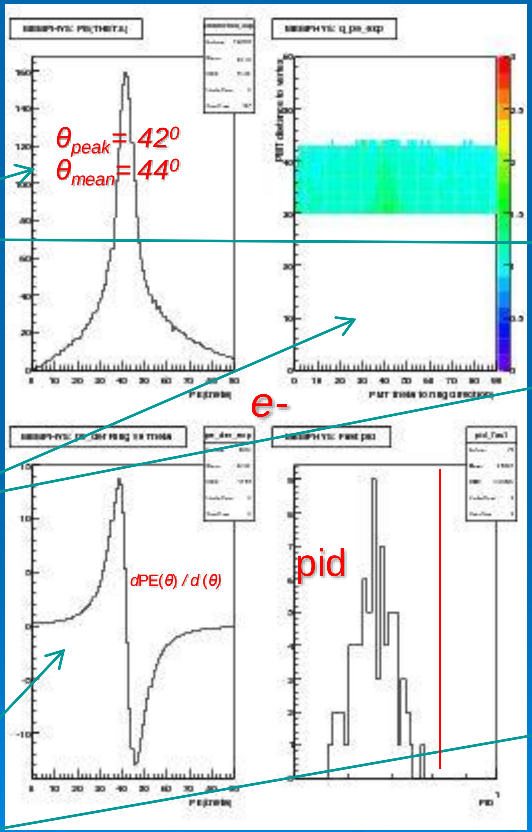
Single rings: e-, μ+ 200MeV to 1000MeV pid

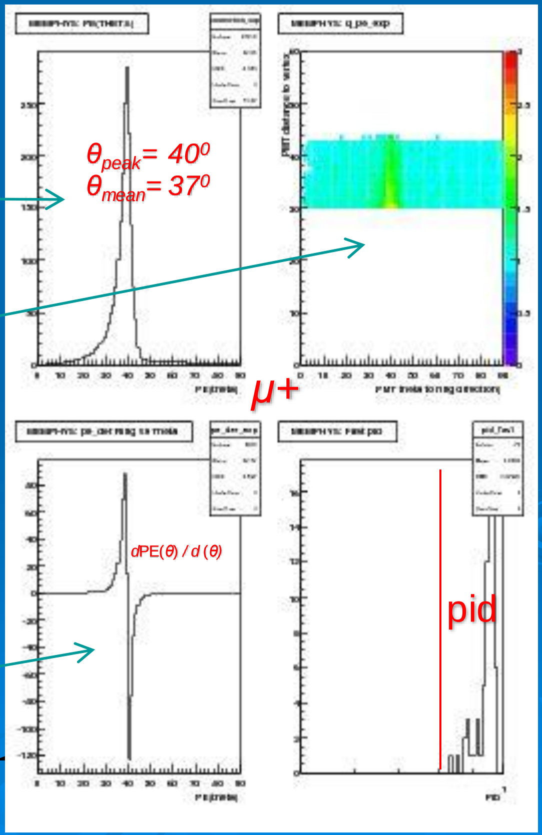
- use PEs (PMT) angular distribution from best reconstructed vertex and best direction as fast pid variable
- full detector simulation

PEs angular distribution seen at best vertex and with respect to best direction. Different shapes

number of PEs as a function of the PMT distance to the best vertex and with respect to best direction

spread e' s rings sharper μ' s rings





conclusions, next steps

conclusions so far:

MEMPHYS MC: accurate

- vertex reconstruction
- ring direction
- single-ring identification as *e or μ* : 200Mev->1GeV almost 100% (low stats)
- initial studies show almost no light reduction when moving from 60mx65m to 60mx85m detector: similar results are expected in event reconstruction.

albeit with no full electronics class in use

next steps:

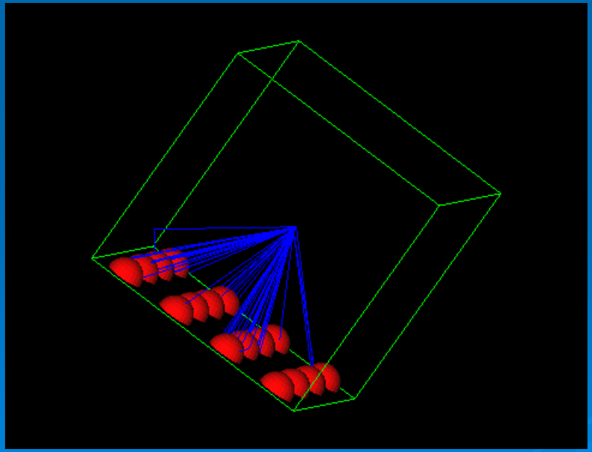
- *QE* (ν_e, ν_μ) efficiency: ring counting: one-ring events, reconstruct momentum
- *NC:* π^0 reconstruction: discrimination from *e,* single charged *π* from *μ*
- volume vs. performance studies: more detailed
- run MEMPHYS MC as SK then correlate the results

THANKS

MEMPHYS: Simulation Studies for the small scale Prototype MEMPHYNO

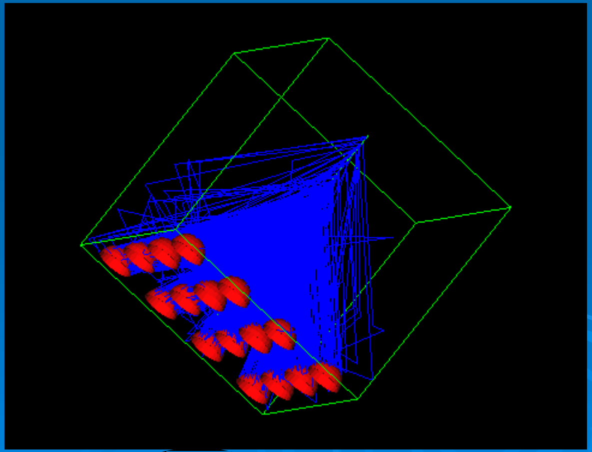
Alessandra Tonazzo, Nikos Vassilopoulos / APC-PARIS

- tests with radioactive sources (monoenergetic, point-like) and cosmic muons
- MEMPHYS simulation & visualization code
- 4x4 12in PMTs = ~35% coverage (for one side)



electron 10 MeV, pz / p = -1, vtx : centre

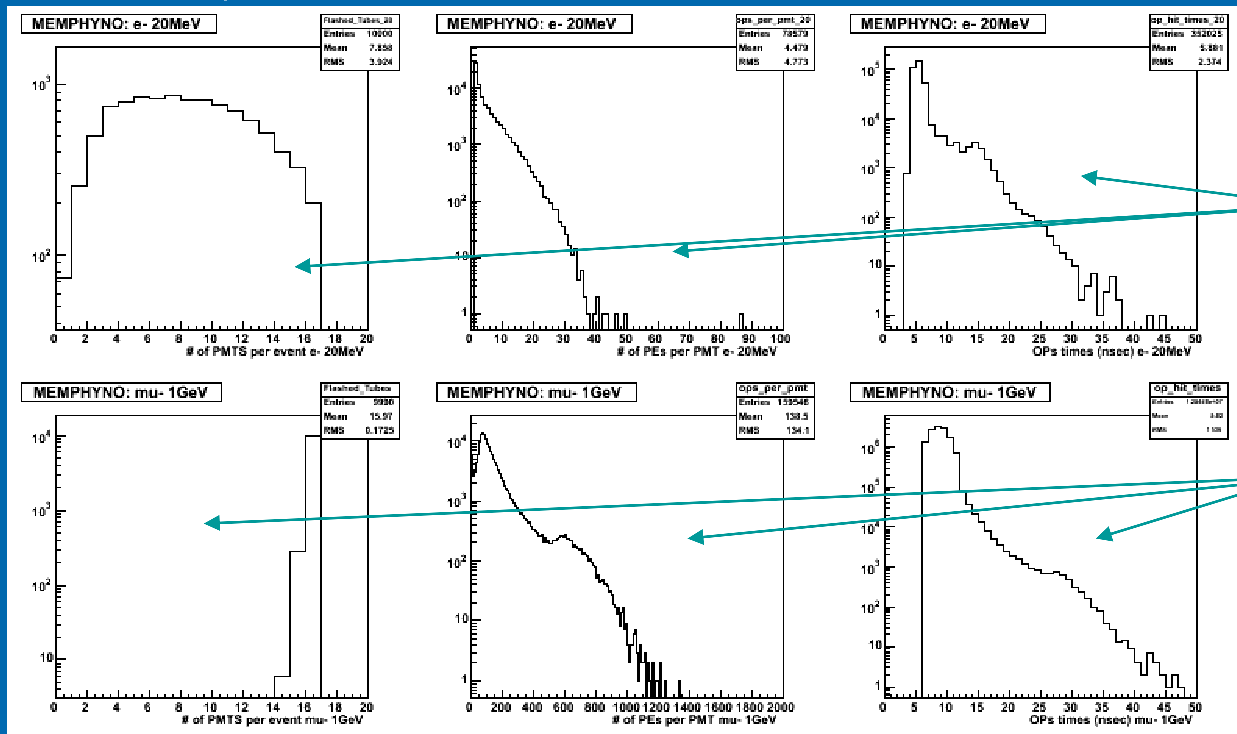
MEMPHYS GUI for MEMPHYNO and detected optical photons



muon 1 GeV, pz / p = -1, vtx : top centre

MEMPHYS: MEMPHYNO e-, μ- studies

of PMTs per electron | PEs per PMT | OPs' arrival times



e- 20MeV

μ- 1GeV

muons generated over the detector's surface with pz / p = -1

e- E (MeV)	1	2.5	5	10	15	20	25
PEs / MeV / el	0.2	1.1	1.5	1.7	1.8	1.8	1.8
X 6 (sides)	1.2	6.6	9	10.2	10.8	10.8	10.8
MEMPHYS	2	7.7	10	10.9	11.1	11.2	11.1

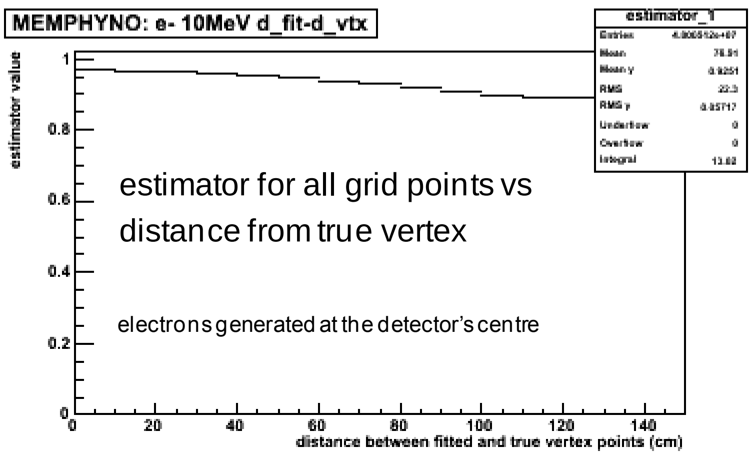
Table: MEMPHYNO's PEs per MeV per electron

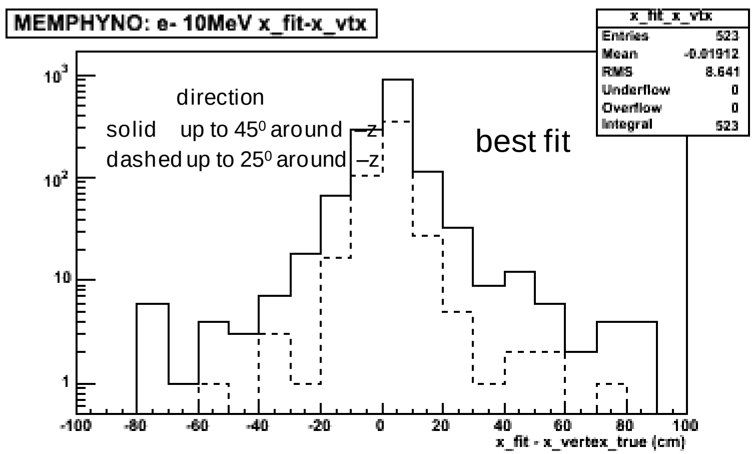
10k per energy electrons generated at the detector's centre with random direction

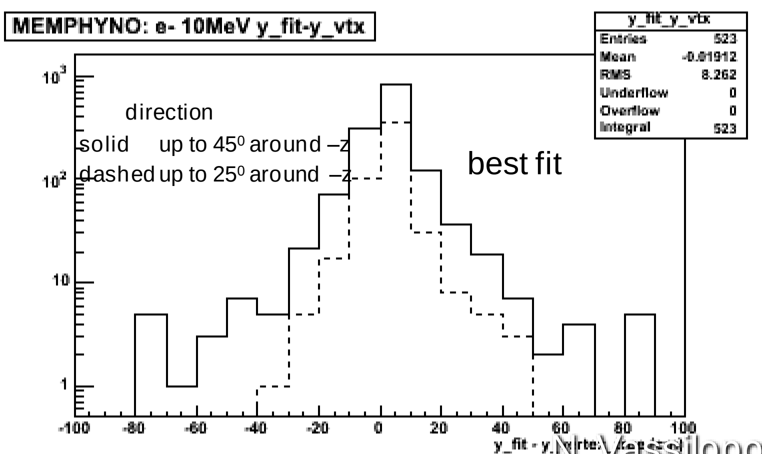
MEMPHYNO

electrons 10 MeV : vertex finding

- primary vertex fit based only on each PMT's timing info: $t_{i\ PMT} = t_i + TOF_i \Rightarrow t_i = t_{i\ PMT} - TOF_i$, where $TOF_i = (n / c) \times D$, D = distance between each PMT and grid's coordinates
- maximize estimator E a la SK to find the true vertex of electron :





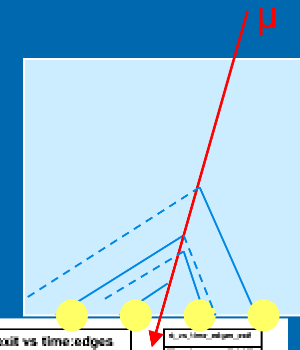


for the primary fit :

1. grid analysis (5cm spacing) in MEMPHYNO
2. good resolution for downwards electrons in x-y plane where is the PMTs' module (shown)
3. resolution becomes worse as pz/p increases due to one PMTs' module : best for perpendicular electrons

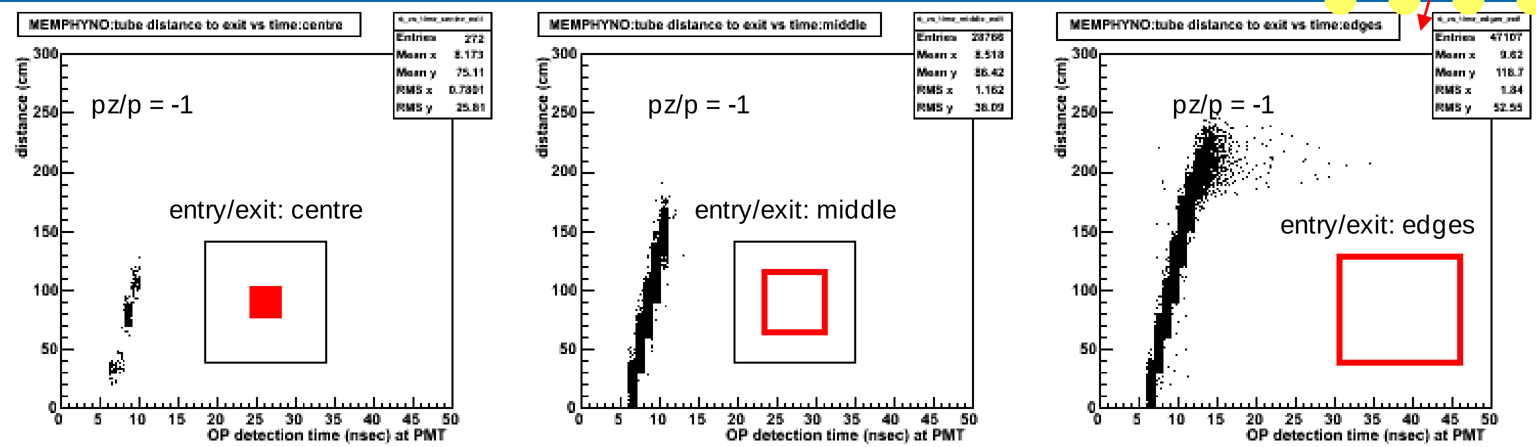
MEMPHYNO

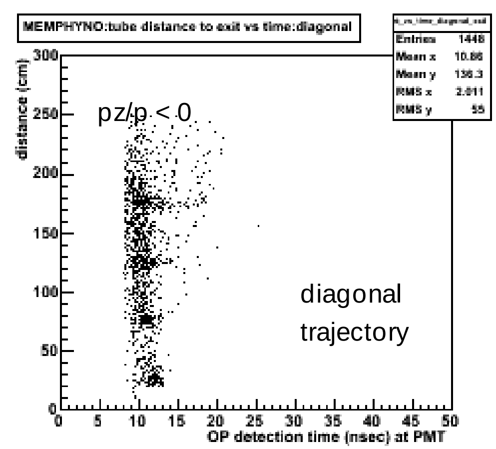
muons 1 GeV



light propagation effect of OPs :

- check correlation of PMT time with distance between muon's exit point and detection PMT's coordinates





- pz/p = -1 : later produced OPs are detected first
- pz/p < 0 : relation not clean

MEMPHYS Simulation

- always on going

next steps:

- vertex fit considering the track's length
- ring separation
- particle identification

THANKS