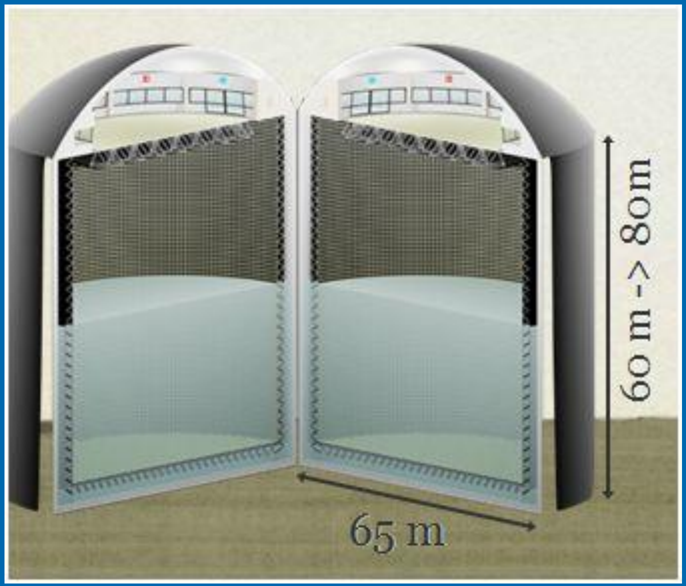
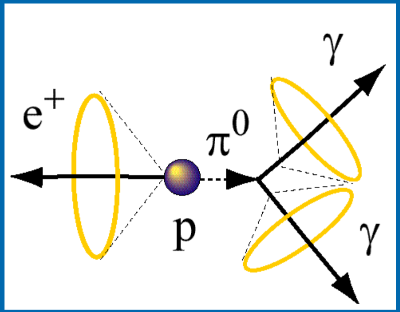
MEMPHYS Simulation & Performance

N. Vassilopoulos, A. Tonazzo / APC for MEMPHYS*

** now at IPHC, Strasbourg*





ASTROPARTICULE ET COSMOLOGIE

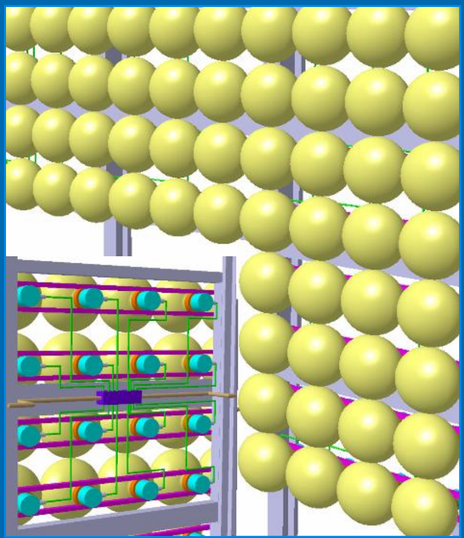
MEMPHYS: Underground Laboratory and Detector

- underground water Cherenkov at Laboratoire Souterrain de Modane Fréjus at 4800 m.w.e.
- total fiducial volume: 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″ (alternatively 8″, 10″) PMTs, 30% cover
- PMT R&D + detailed study on excavation existing & ongoing + prototype Cherenkov detector MEMPHYNO

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

R&D towards MEMPHYS : PMm2

*breaking news: it is already installated **at APC, Paris***



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

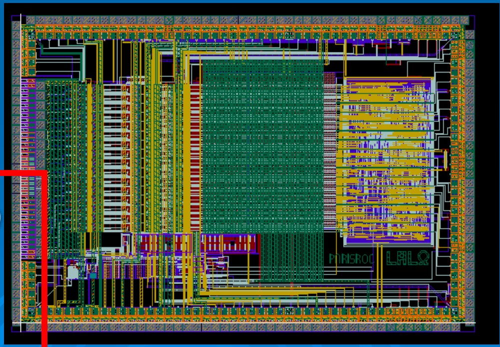
R&D program funded by French national agency for research (LAL, IPNO, LAPP and ~~Photonis~~) (2007-2010)

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

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)



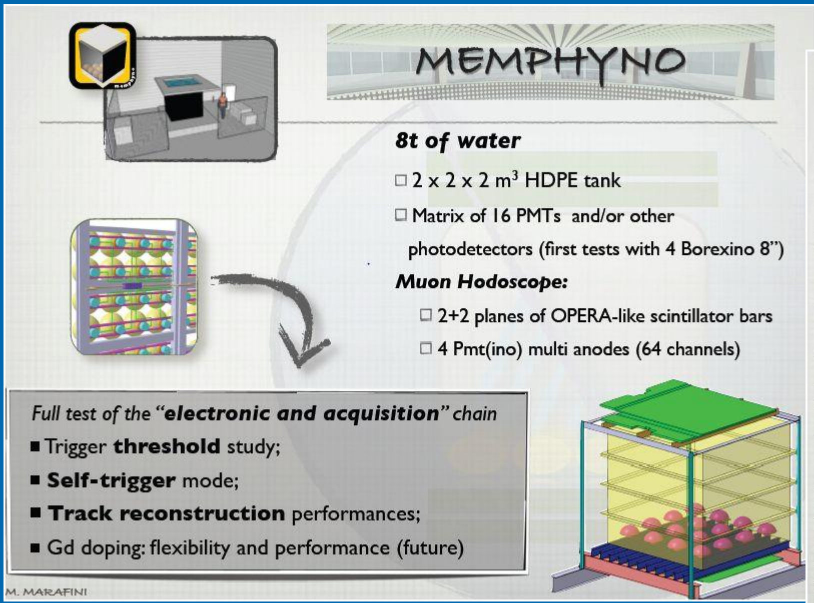
I. studies on ~~12"~~ 8" PMTs design
- parameter correlation
- potting
- pressure resistance

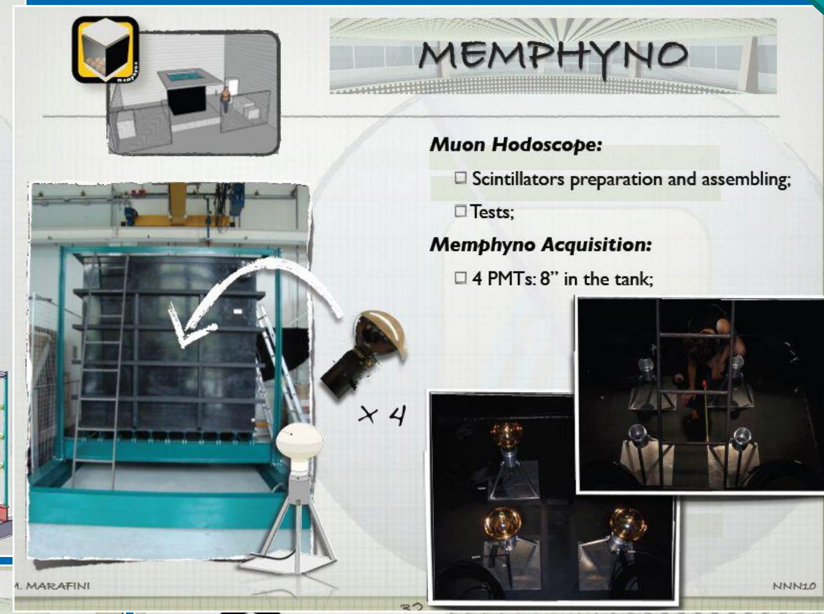
(collaboration with BNL since NNN07)

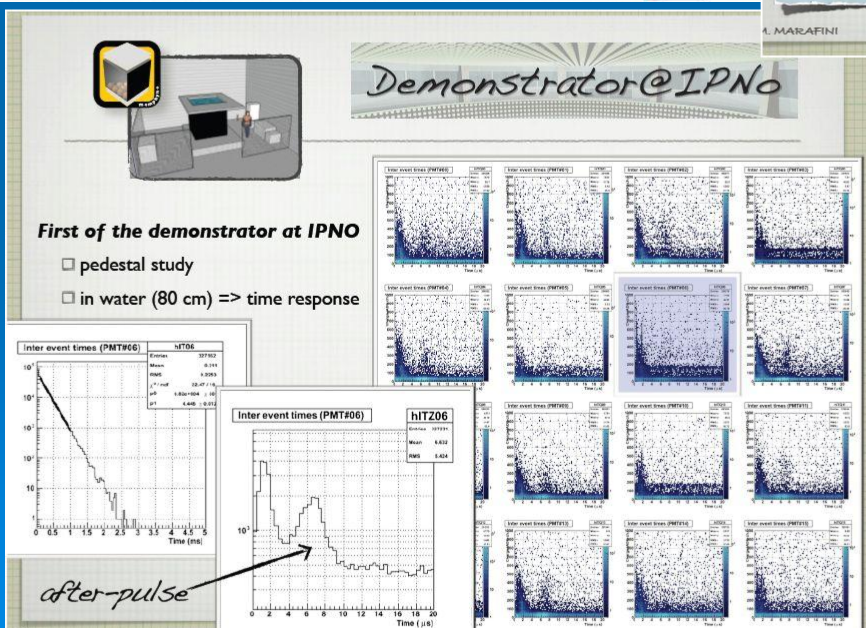
II. PArISROC readout chip
- complete front-end chip with 16 channels
- testboard now in layout, soon available

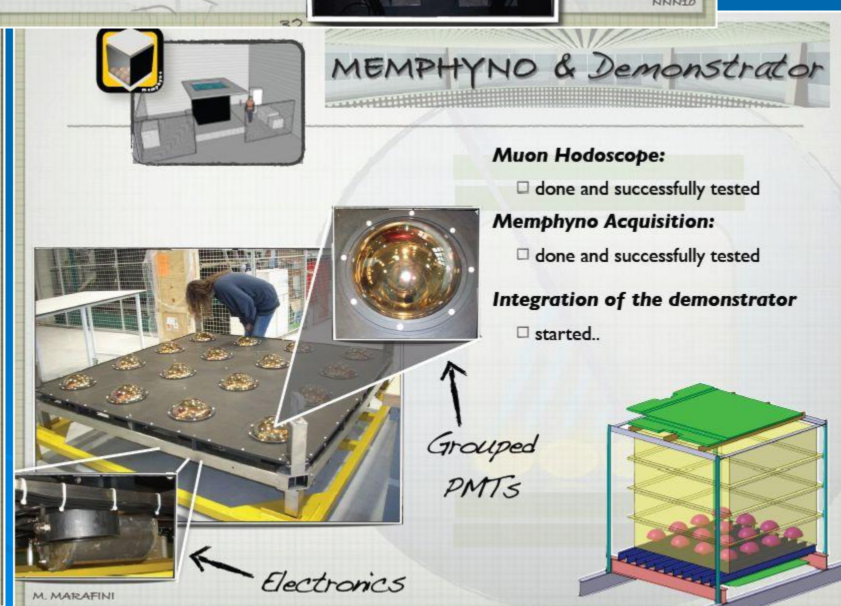
MEMPHYNO at APC & Demonstrator

M. Marafini's talk at NNN10





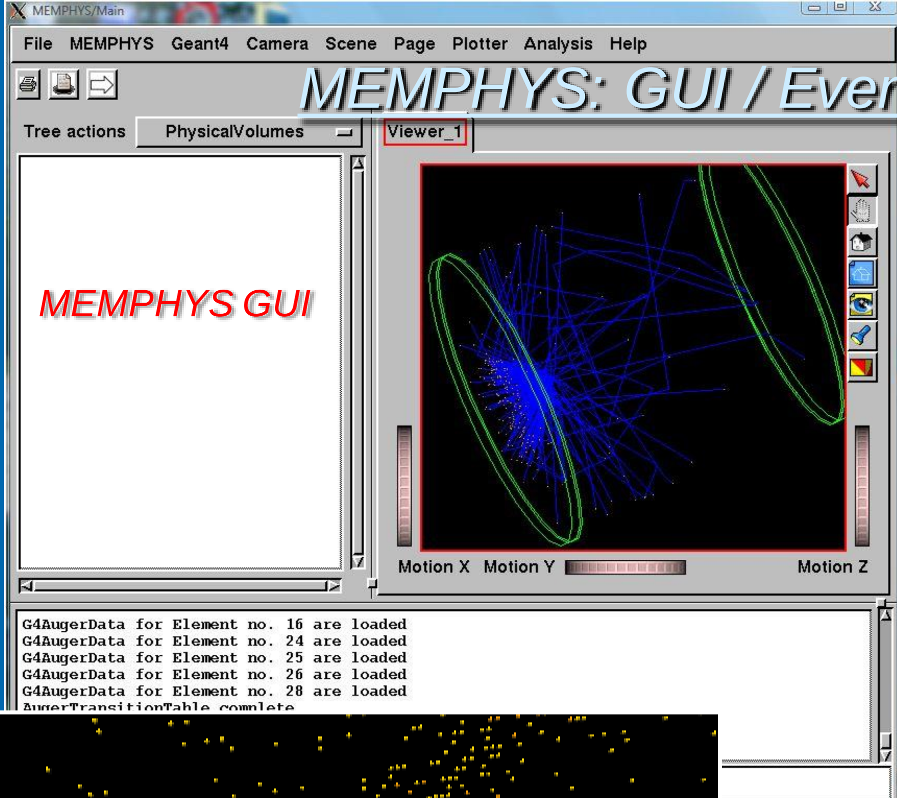


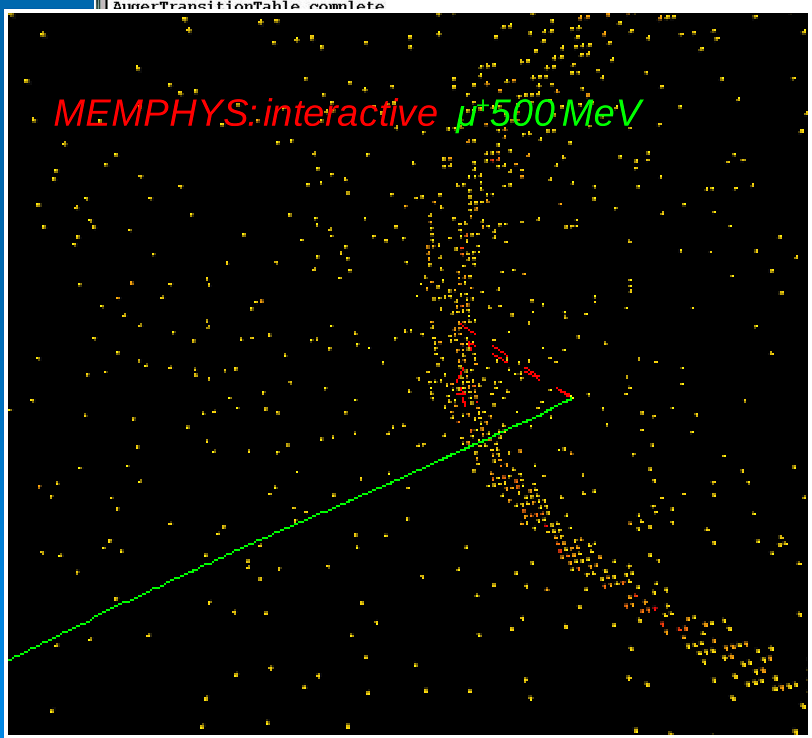


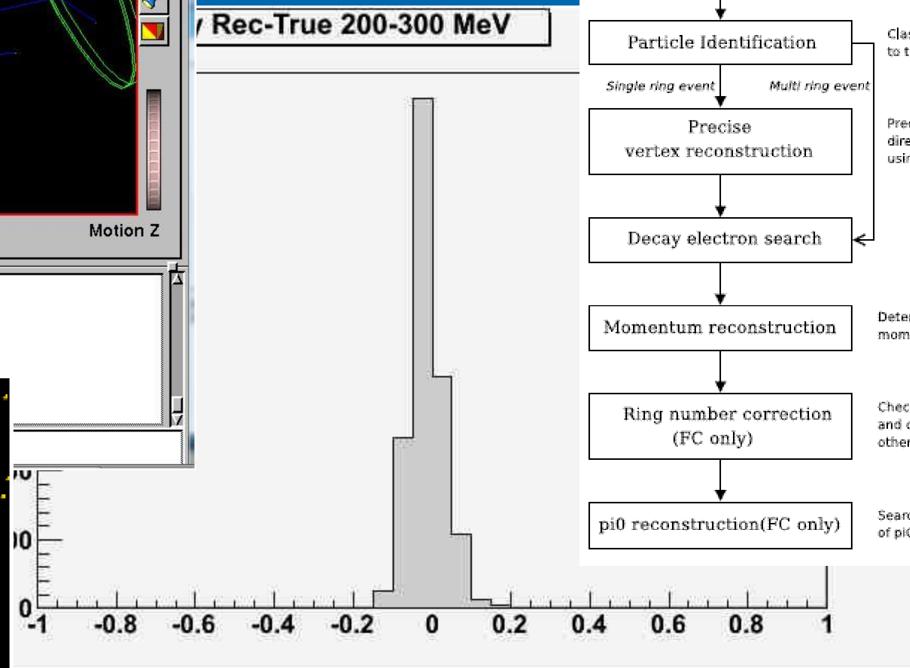
MEMPHYS: Full Simulation Present Status

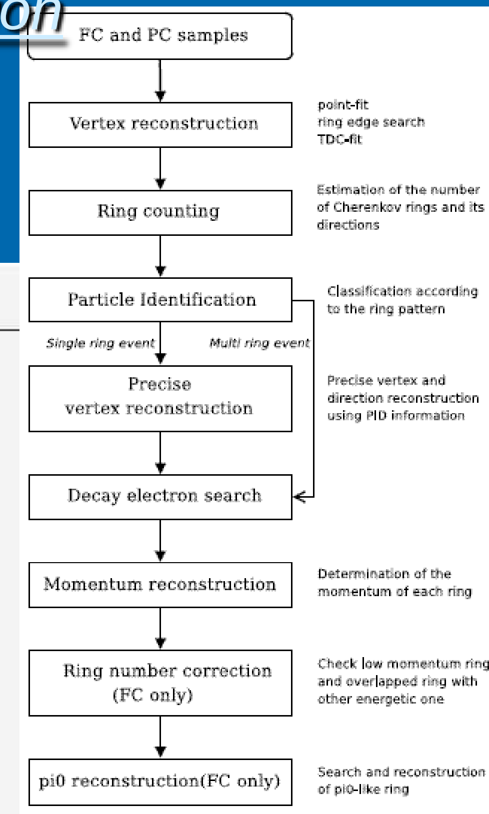
- Event Generator:
  - GENIE for ν beam *new*
- MEMPHYS Full Simulation (M. Fechner , J.E. Campagne, N. Vassilopoulos) :
  - Interface with the OpenScientist v16r0 framework (G. Barrand/LAL) using distribution kits as Geant4 & CLHEP & AIDA-IO implementation to Rio (also HDF5, XML)
  - 3 modes of running in the same framework:
    - Interactive Viewing, Batch processing, AIDA_ROOT analysis
  - primary + secondary + Optical Photon info, 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

MEMPHYS: GUI / Event Reconstruction









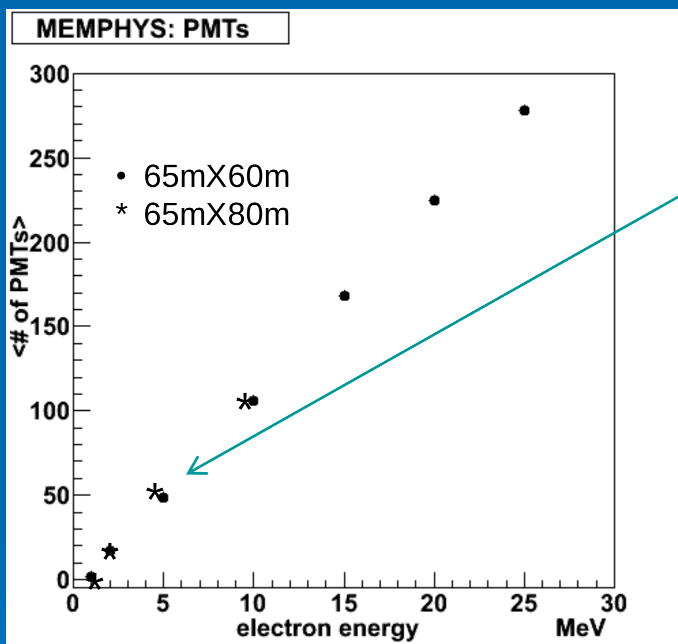
- main task using all the available tools
  - ✓evaluate detector performance
  - ✓extract energy resolutions and lepton efficiencies ⟶ migration matrices

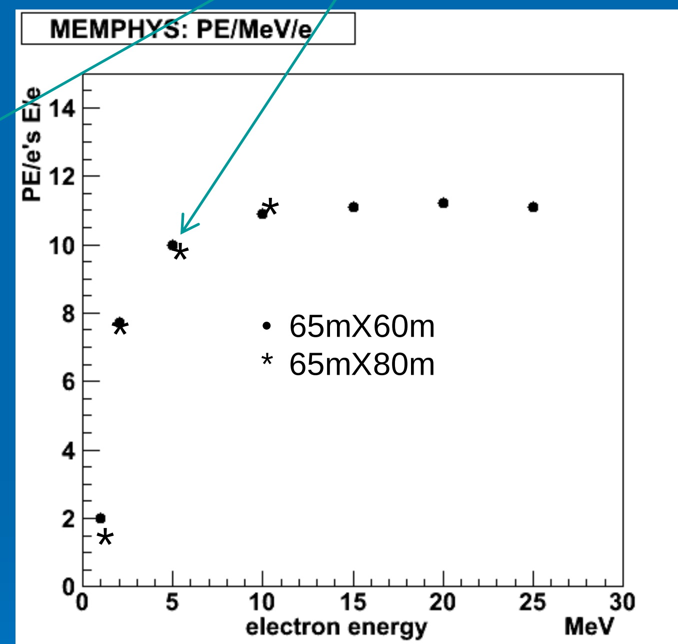
N. Vassilopoulos @ WP5
EUROnu RAL 2011

MEMPHYS Single ring studies, electrons

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

27% more FV without light reduction

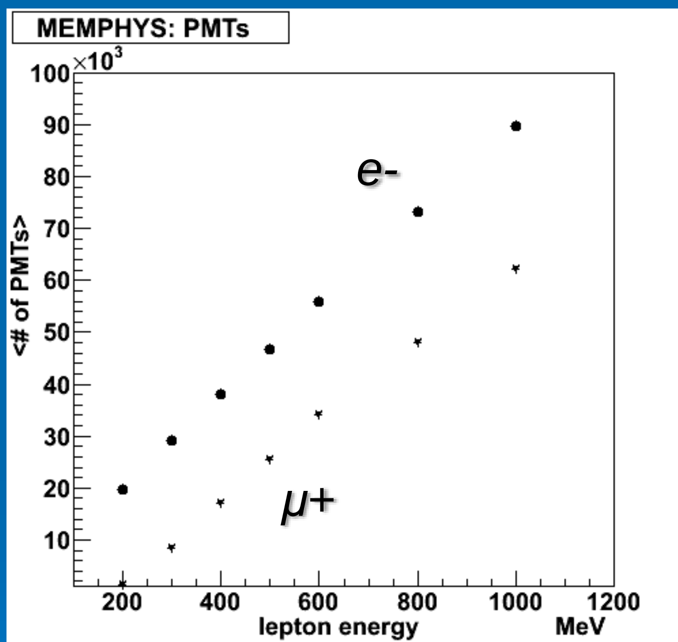




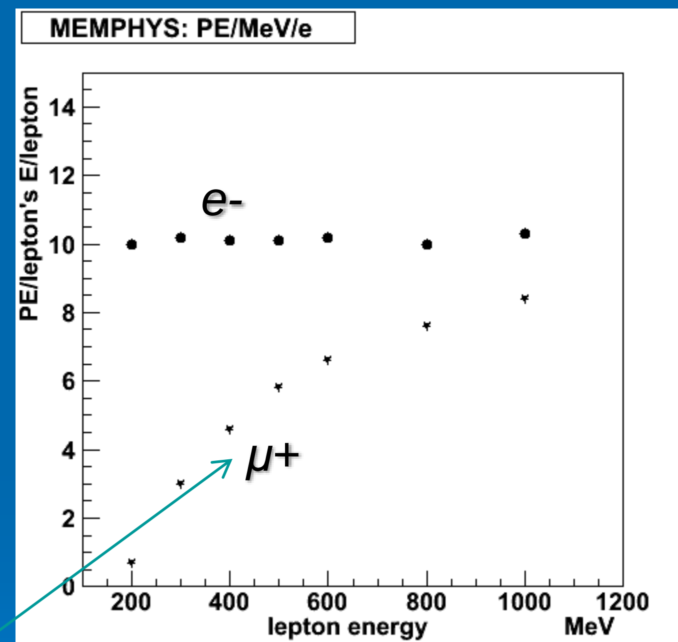
Number of PMTs with at least one photoelectron as a function of electron energy

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



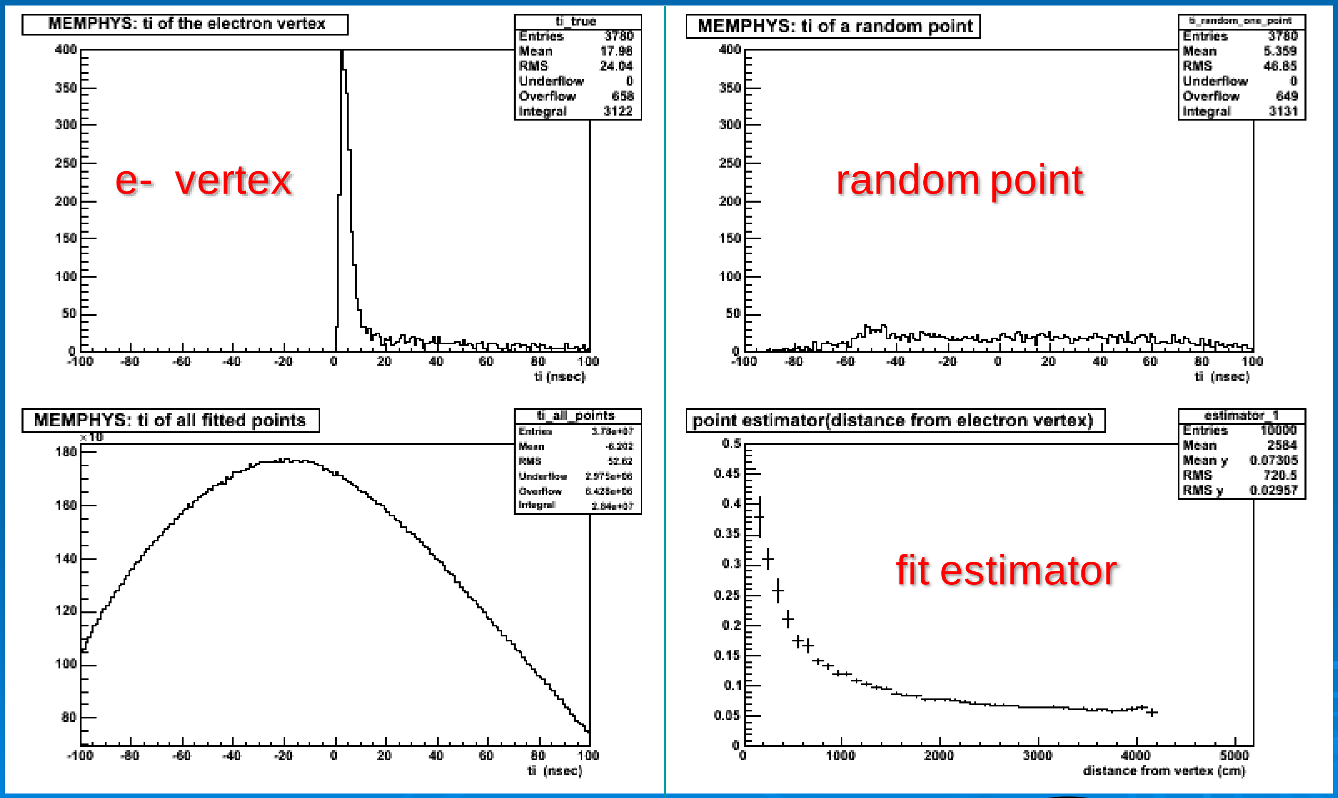
Number of detected photoelectrons per MeV as a function of lepton energy

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

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

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 :



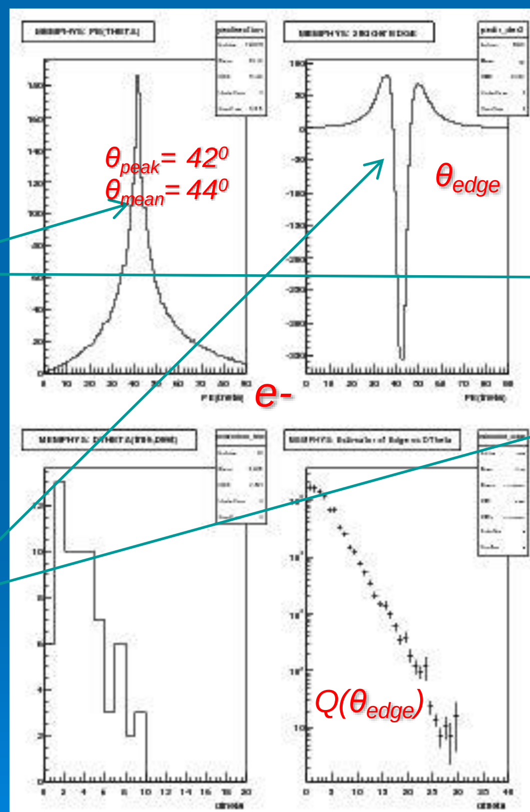
Single rings (FC): e-, μ+ 200MeV to 1000MeV ring direction

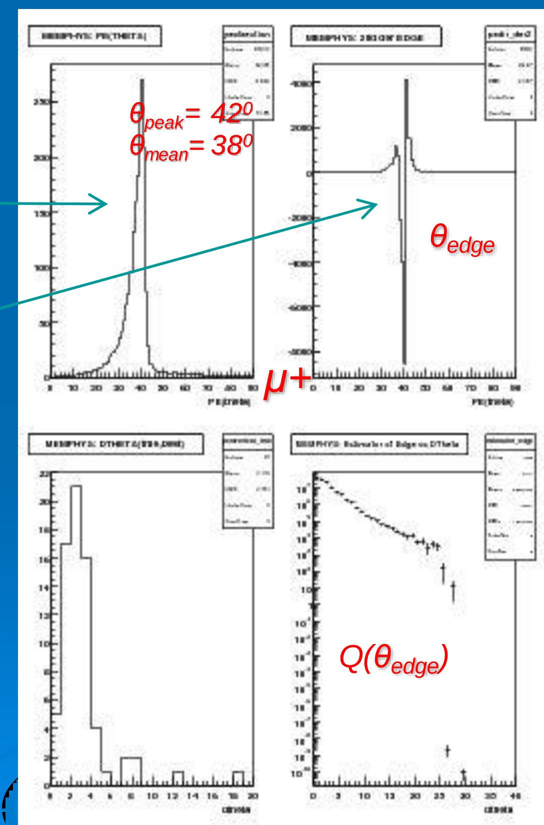
- find the best direction maximizing :

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

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

spread e' s rings
sharper μ' s rings





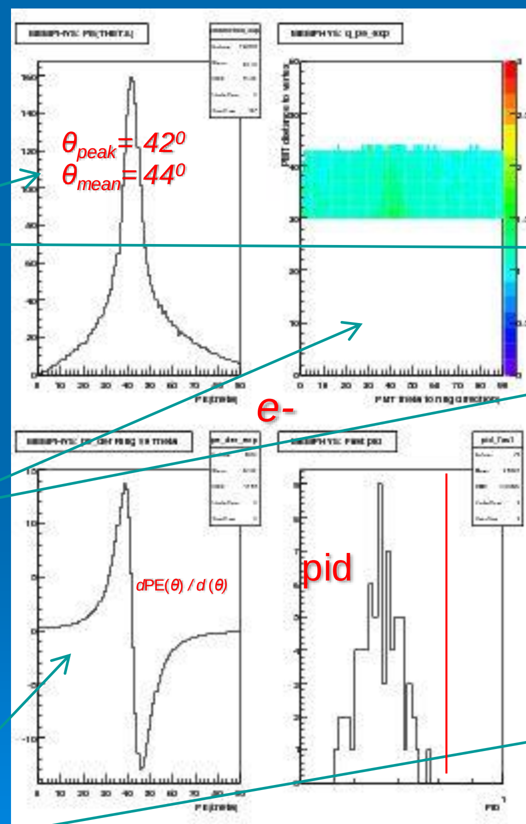
Single rings: e-, μ+ 200MeV to 1000MeV pid

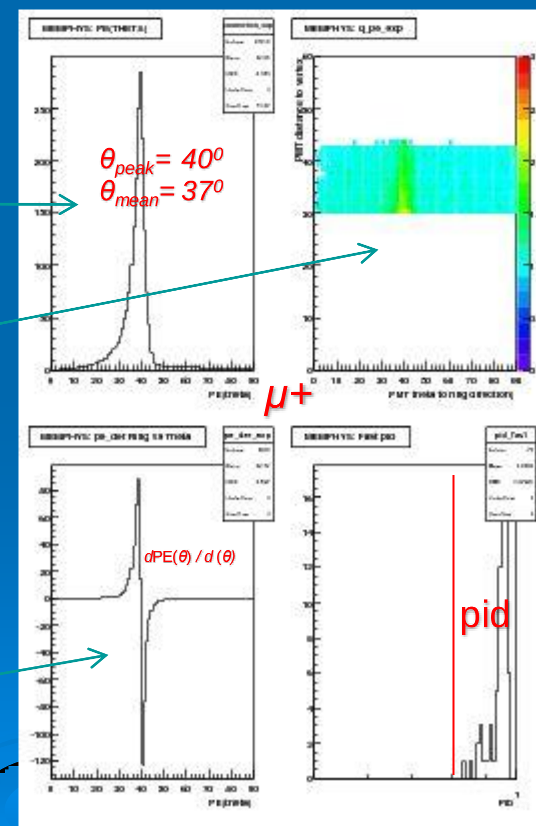
- use PEs (PMT) angular distribution from best reconstructed vertex and best direction as fast pid variable
- full detector simulation

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

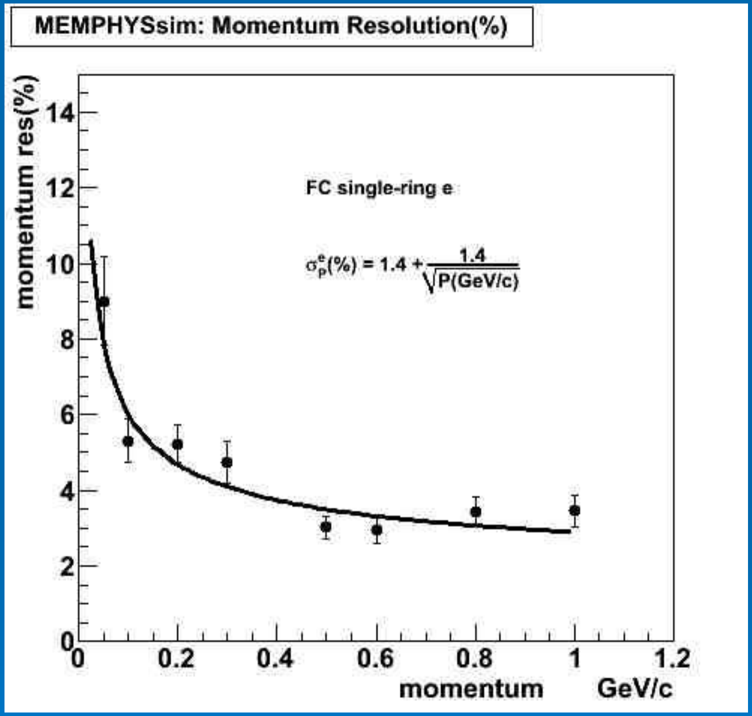
spread e' s rings
sharper μ' s rings

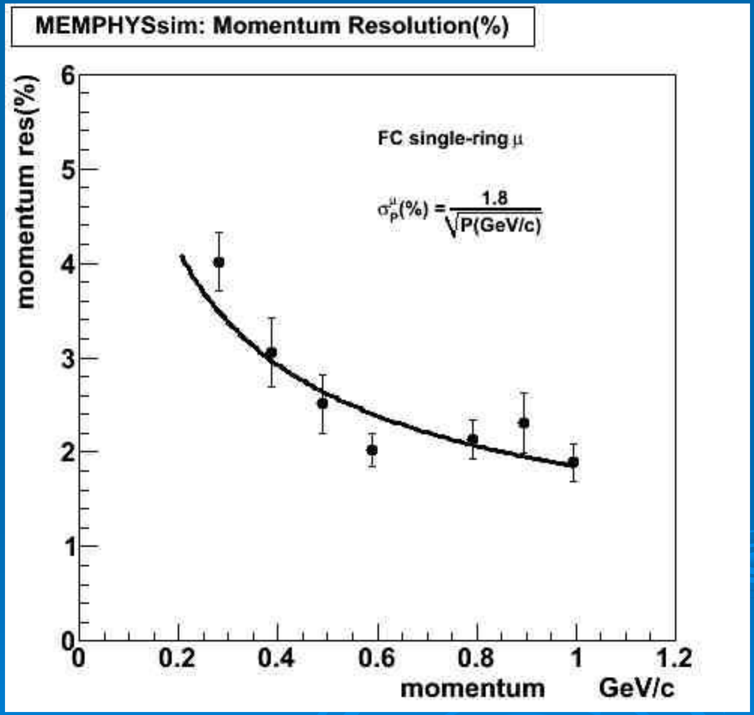




Single rings: e-, μ+ up to 1 GeV/c momentum resolution (magnitude)

- R_{tot} , to correlate momentum with measured charged
- full detector simulation but low statistics

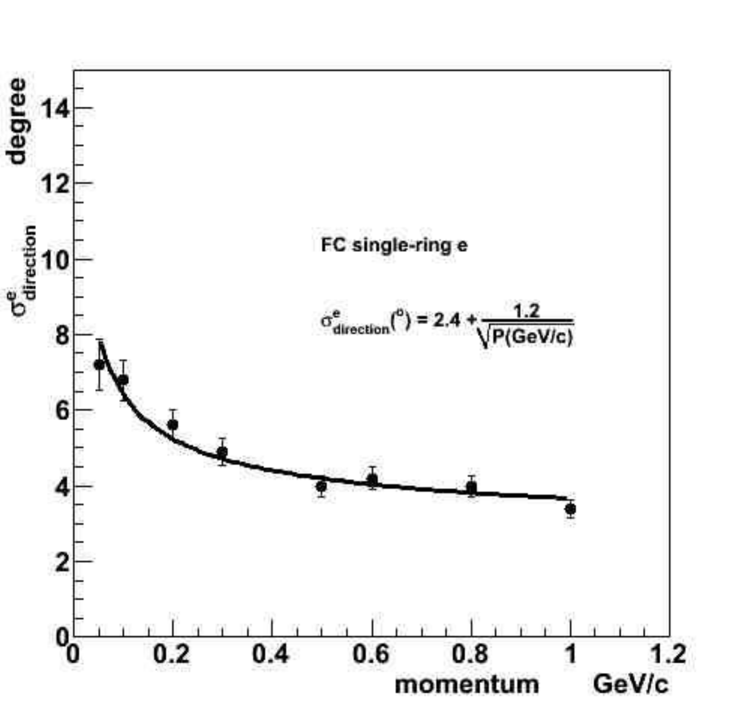


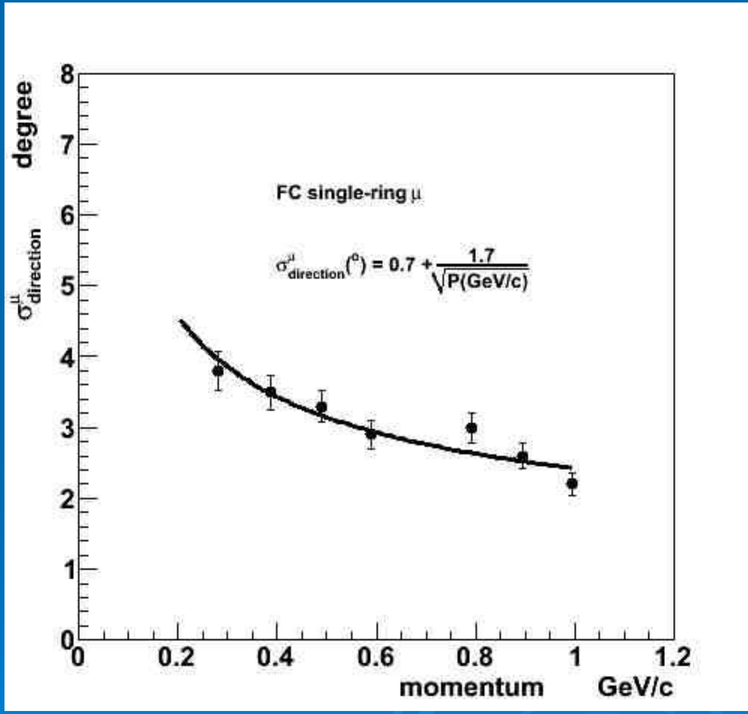


resolutions in between to SK-I, SK-II:
higher energies higher statistics of collected charge
lower energies small degradation due to detector size

Single rings: e-, μ+ up to 1 GeV/c momentum resolution (direction)

- make the difference of true and reconstructed: resolution in degrees at 68% of events
- full detector simulation but low statistics

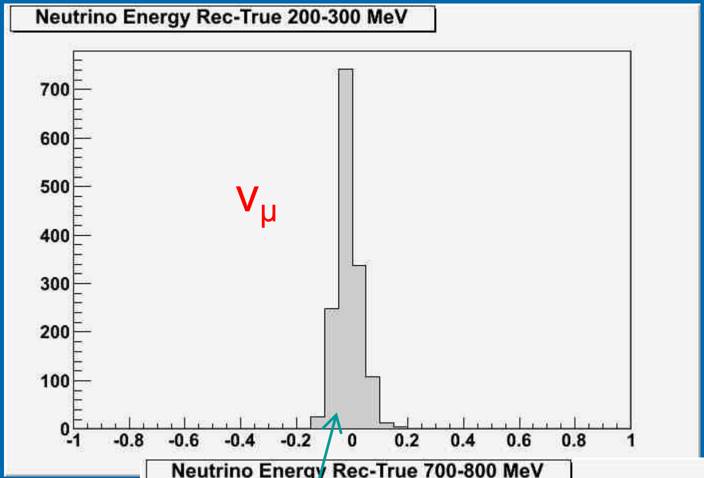


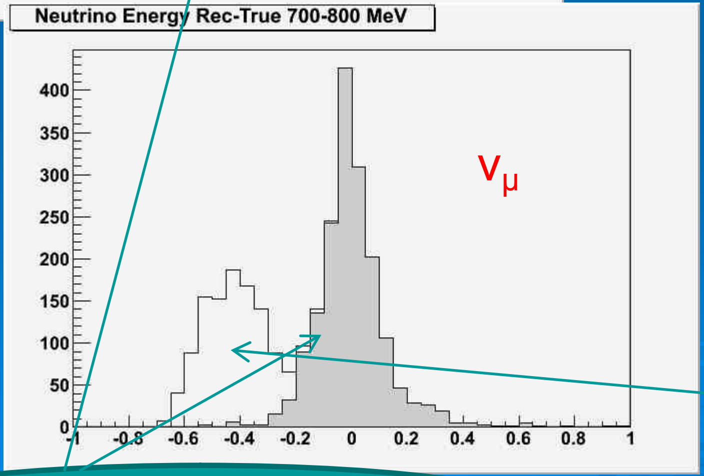


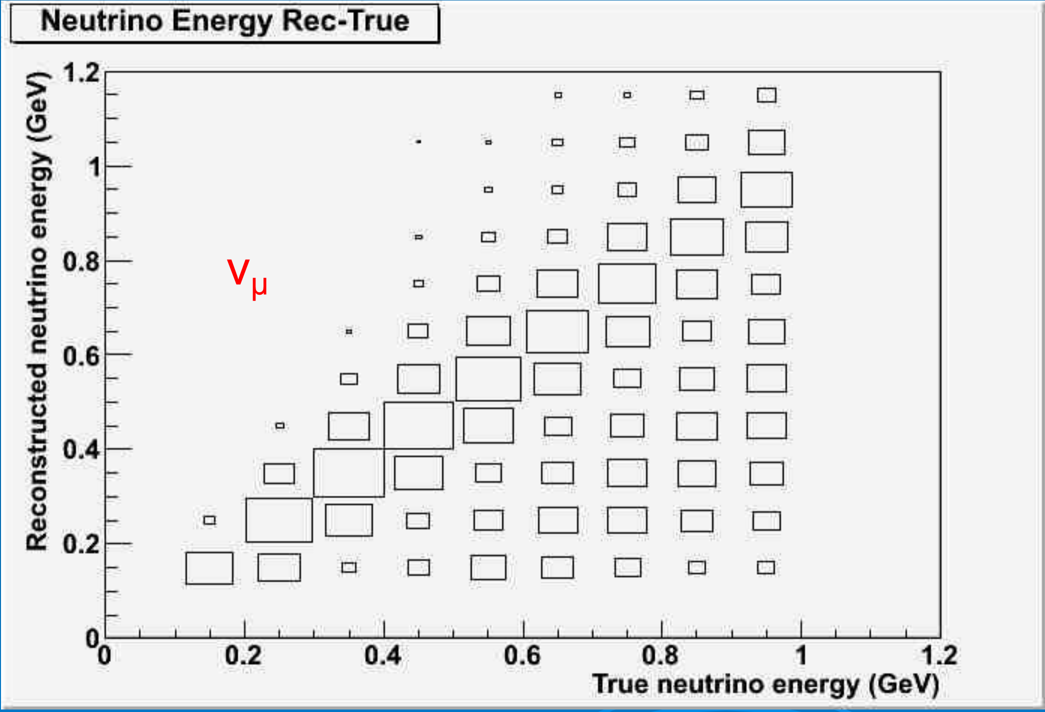
comparable to SK

MEMPHYS energy reconstruction

- momentum resolution could be be applied to any beam design to derive efficiencies, bdg. contamination and migration matrices
- e.g. true versus reconstructed
- uniform neutrino, antinuetrino samples up to 1 GeV, interactions in water simulated with GENIE







tail due to no-QE events, increasing with ν 's energy

gaussian peak due to QE's smearing of Fermi motion and experimental resolution

conclusions, next steps

conclusions so far:

MEMPHYS full simulation:

- primary vertex reconstruction, ring direction
- excellent single-ring identification as *e or μ* (low stats)
- single-ring momentum and direction resolution: energy reconstruction
- detector optimisation: no light reduction when moving from 60mx65m to 60mx85m detector (+27% FV): similar results are expected in event reconstruction.

next steps:

- optimisation of vertex reconstruction, ring counting
- π^0 reconstruction for SB and single π^{+-} for βB background rejection
- volume vs. performance studies: more detailed
- high statistical samples to extract migration matrices (in progress)

THANKS

MEMPHYS physics goals

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

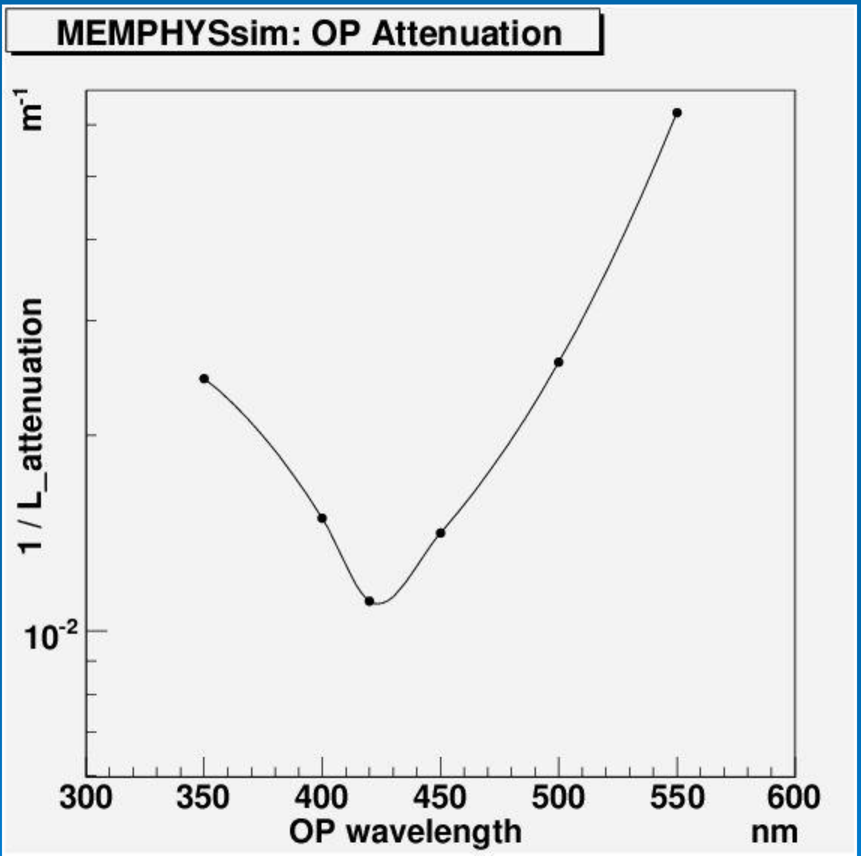
- SuperNova relic neutrinos:
  - observable in few years with significant statistics, according to most of existing models
  - direct measurement of ν emission parameters possible

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

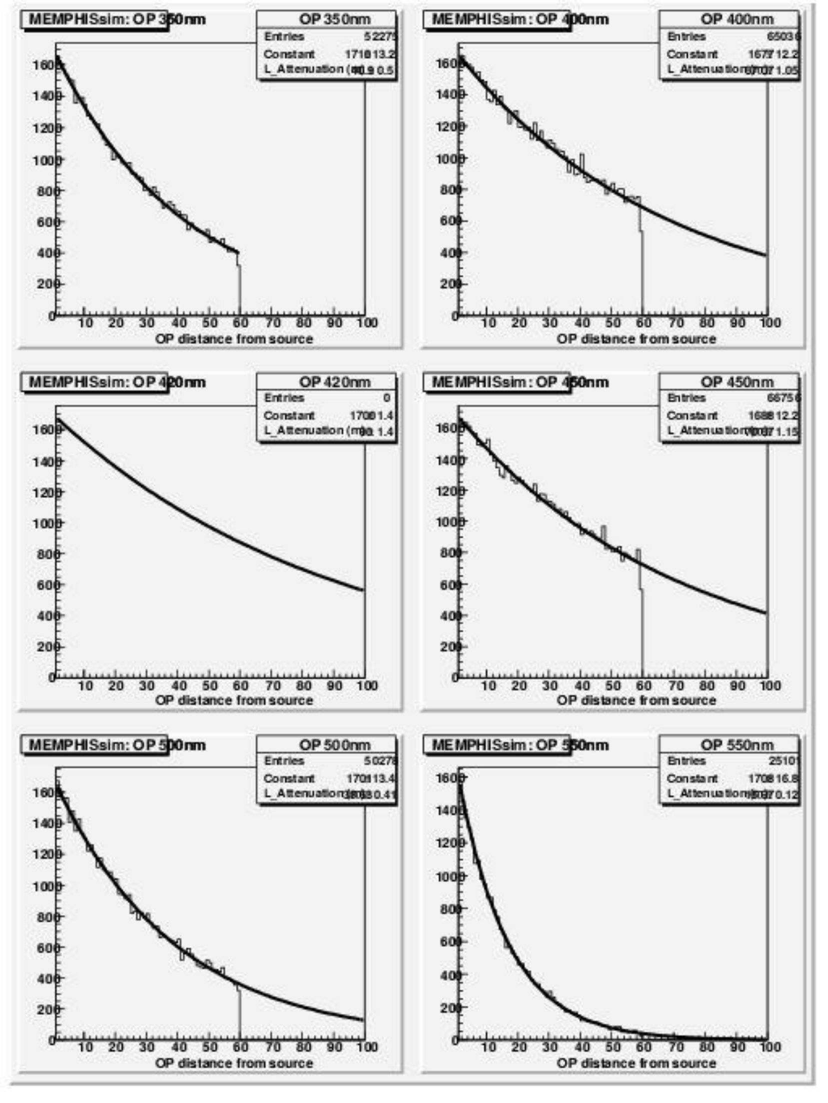
- and, of course... NEUTRINO BEAMS *(see Euronu WP2, WP4)*

Attenuation length studies

- correct modelling of light propagation



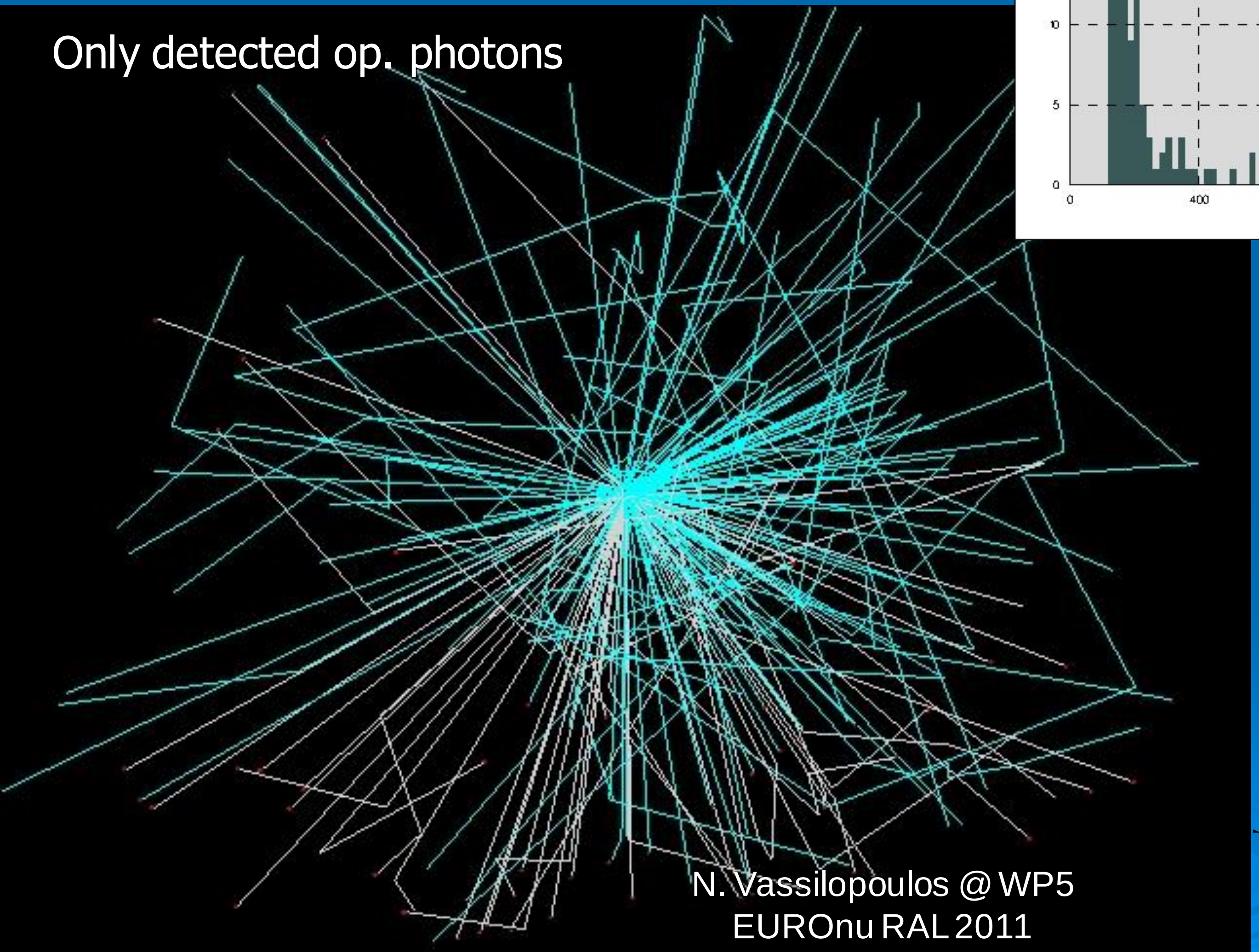
attenuation length in water as a function of the wavelength in MEMPHYS simulation

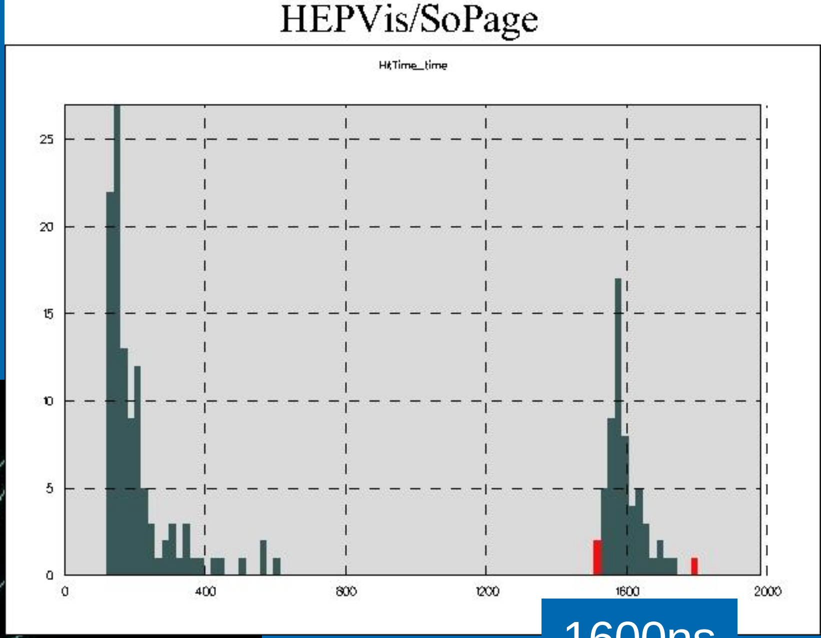


✓ looks comparable to SK data

$\nu_\mu \rightarrow \mu^- \rightarrow e^-$

Only detected op. photons





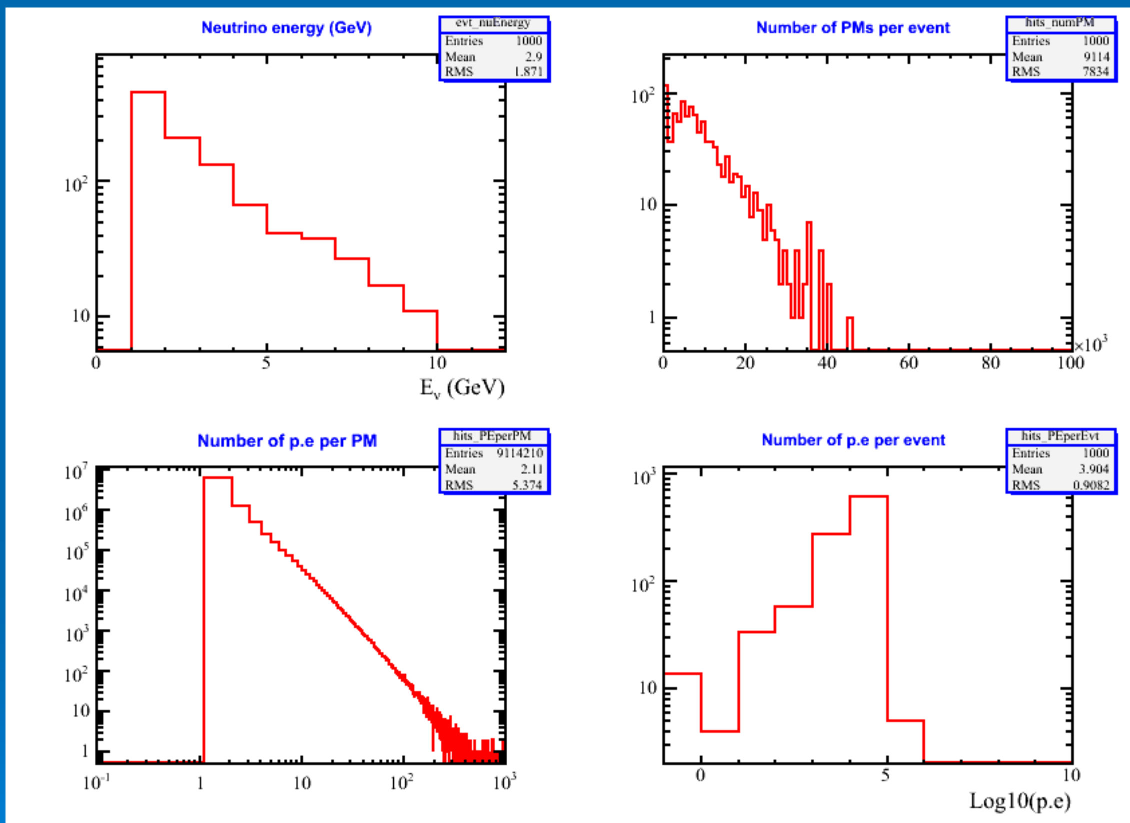
1600ns

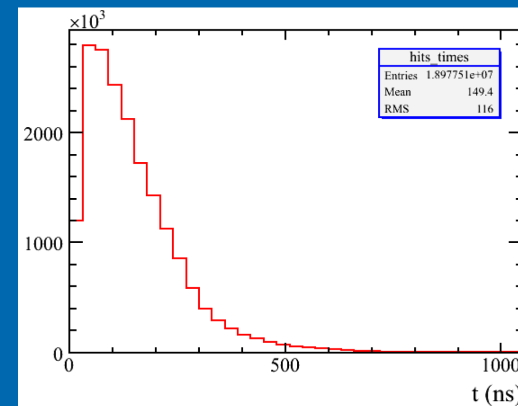
Interactive histogram to identify the e Michel optical photons…

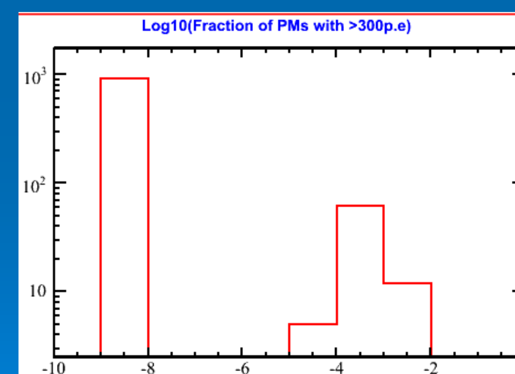
transparency by J. E. Campagne

MEMPHYS v7

ν atmospheric (1-10GeV)







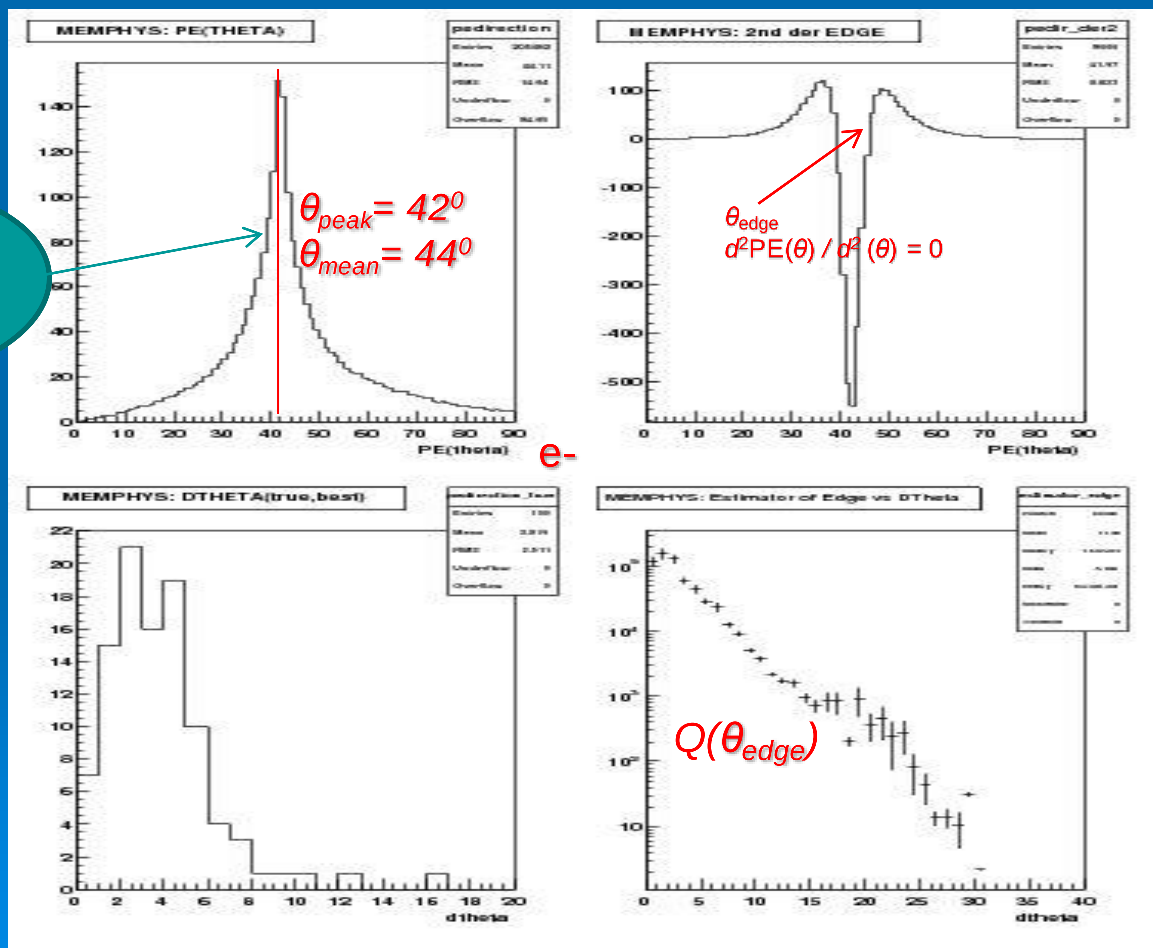
transparency by J. E. Campagne

Single rings: e- 400MeV best direction

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

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

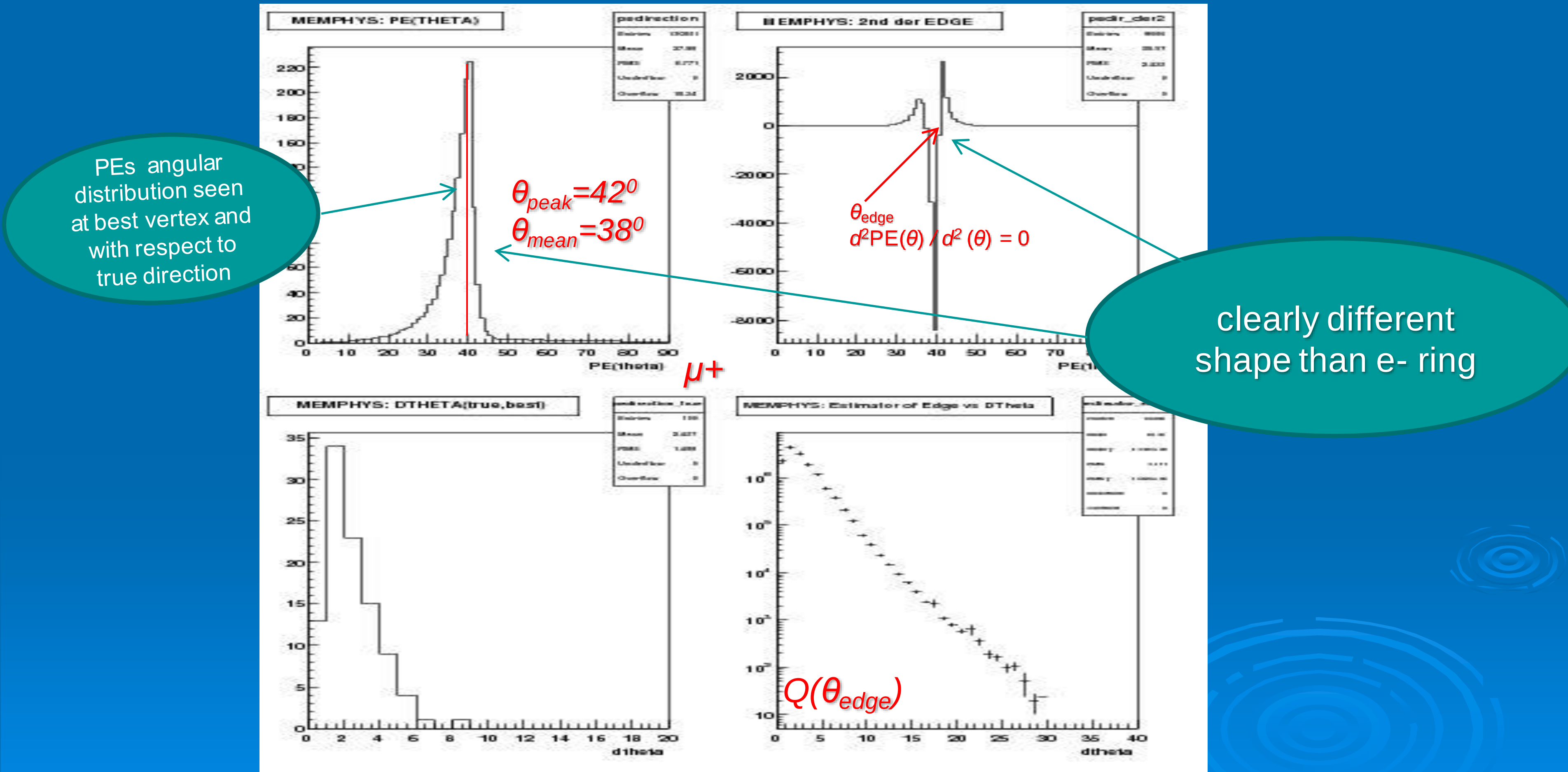
PEs angular distribution seen at best vertex and with respect to true direction



Single rings: μ+ 500MeV best direction

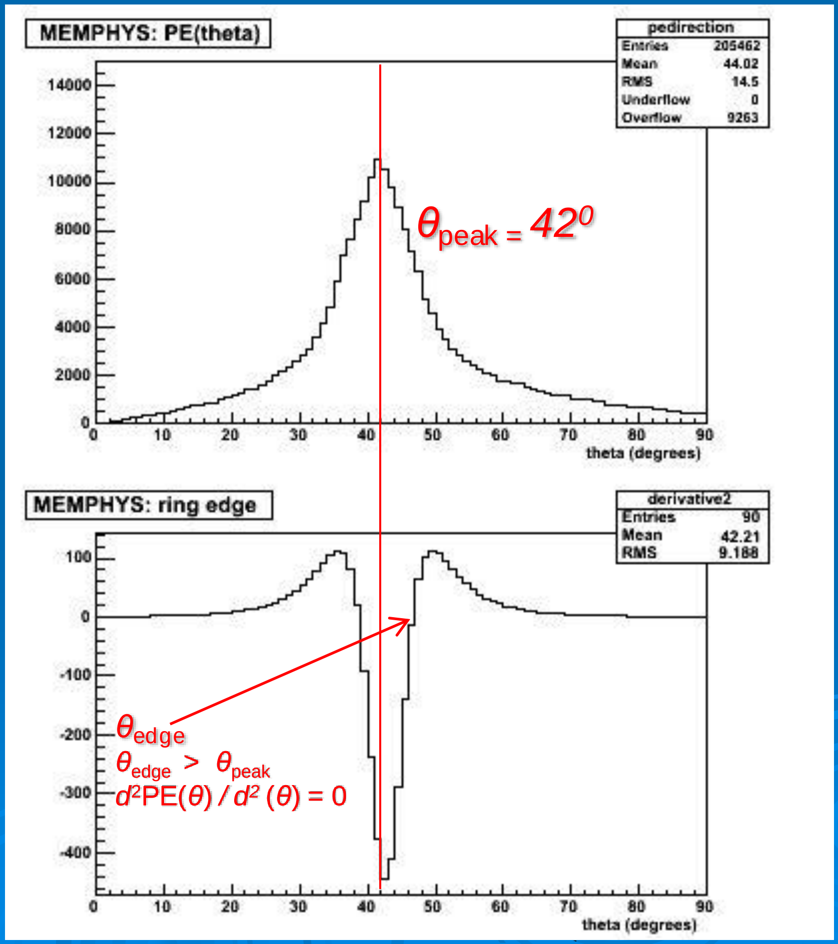
- find the best direction maximizing :

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



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



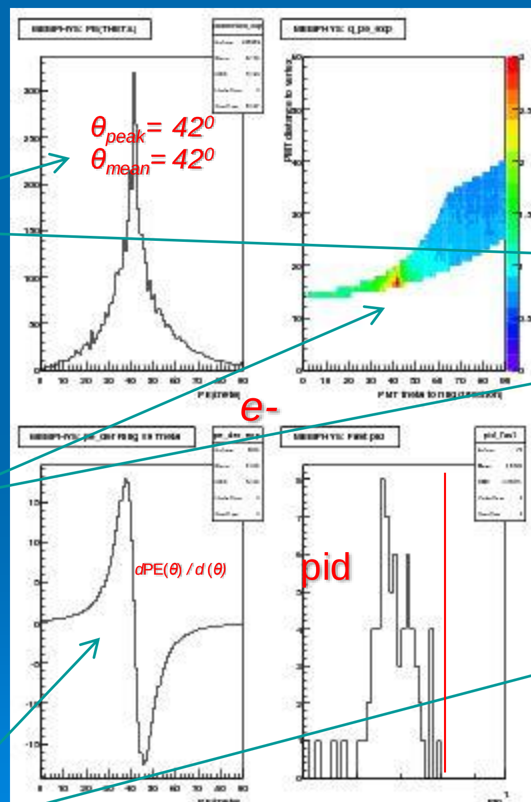
Single rings: e-, μ+ 200MeV to 1000MeV pid

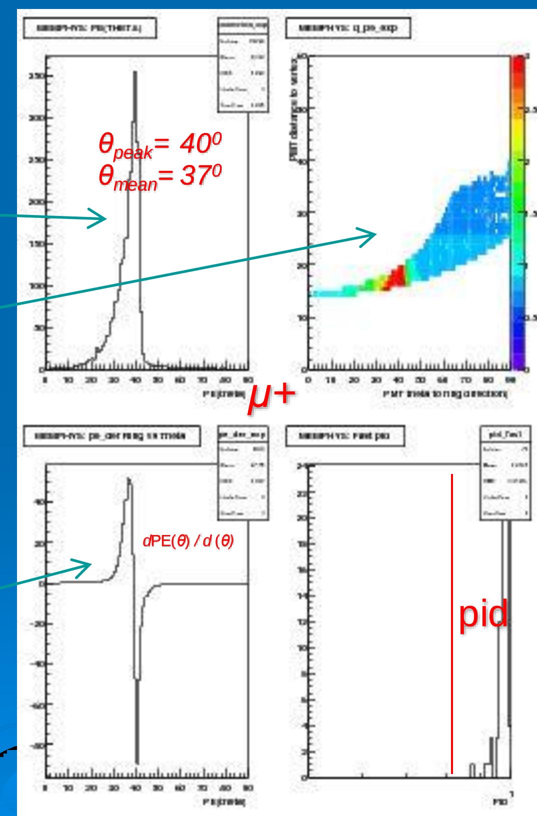
- use PEs (PMT) angular distribution from best reconstructed vertex and true direction as fast pid variable
- examine the case of transparent detector: no Rayleigh or absorption & no-reflection from the plastic cover of ID yet

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

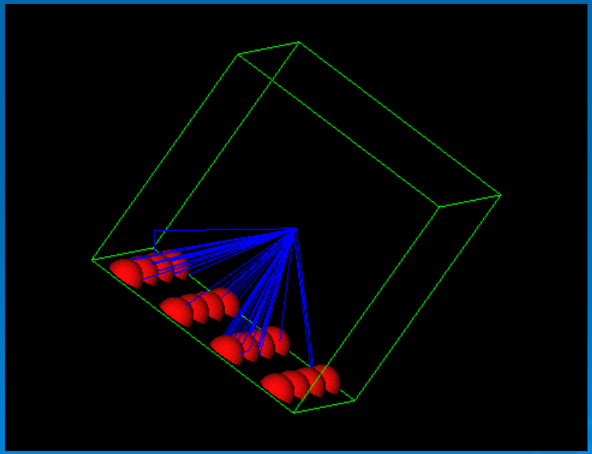




MEMPHYS: Simulation Studies for the small scale Prototype MEMPHYNO

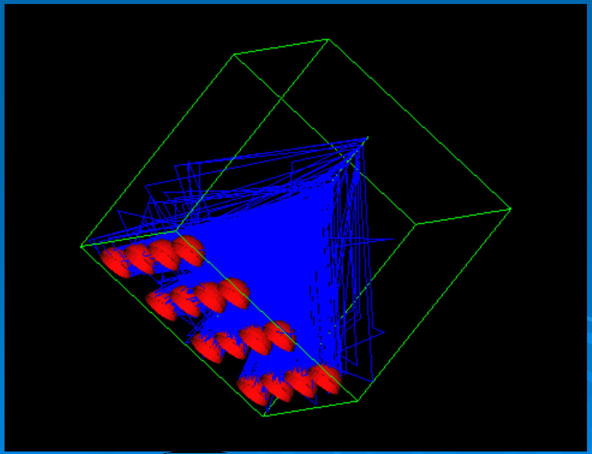
Alessandra Tonazzo, Nikos Vassilopoulos / APC-PARIS

- 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

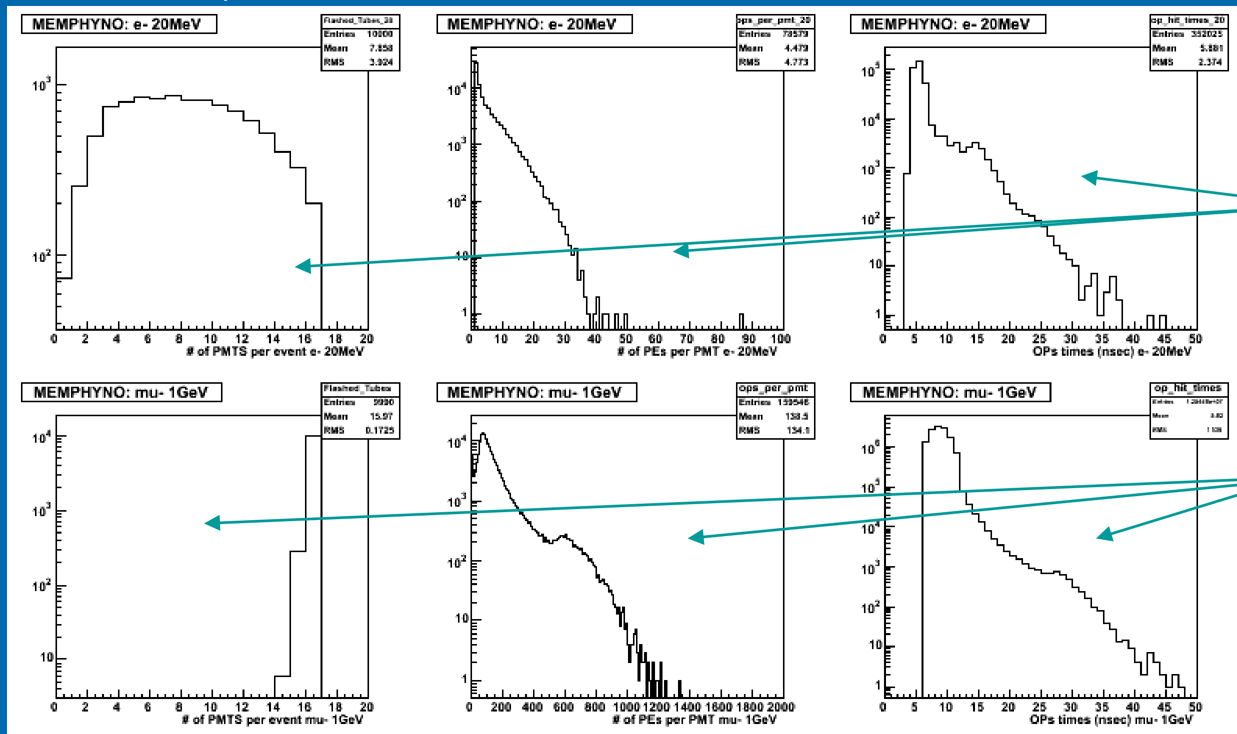
MEMPHYS GUI for MEMPHYNO and detected optical photons



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

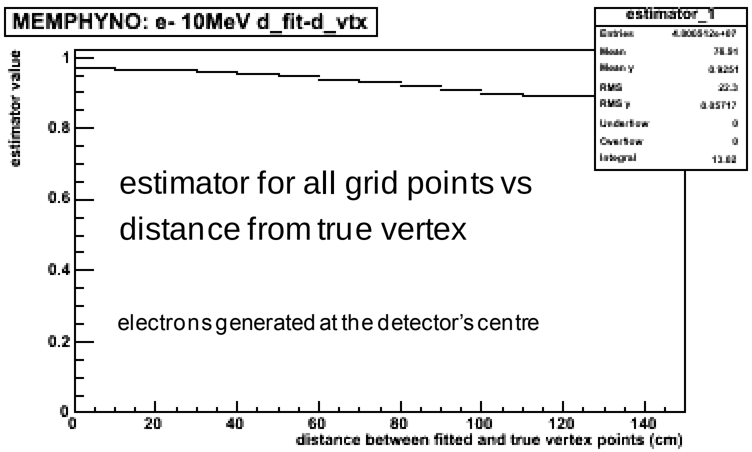
10k per energy electrons generated at the detector's centre with random direction

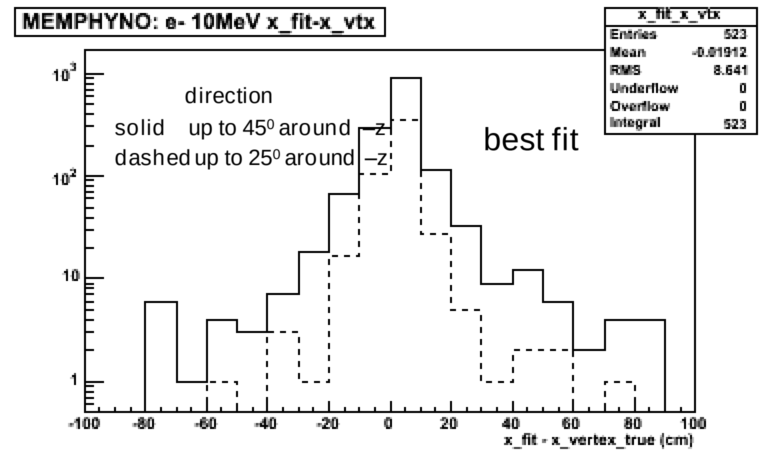
Table: MEMPHYNO's PEs per MeV per electron

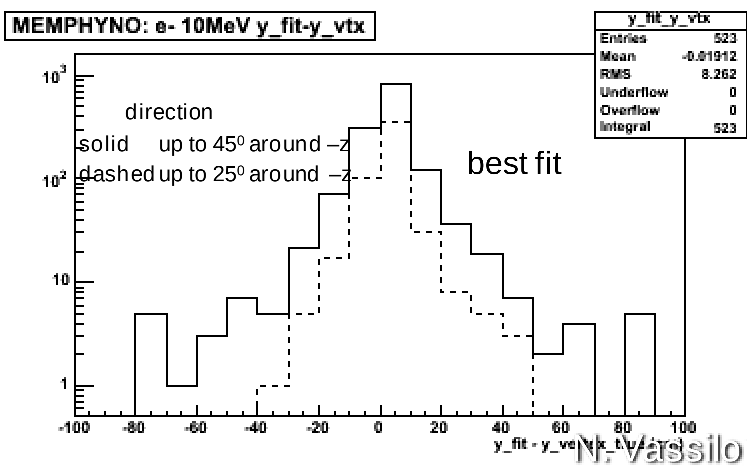
MEMPHYNO

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 :





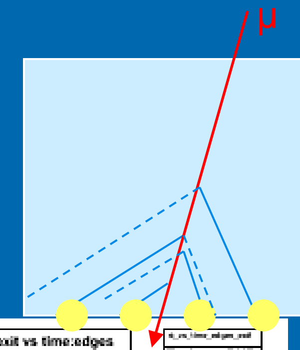


for the primary fit :

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

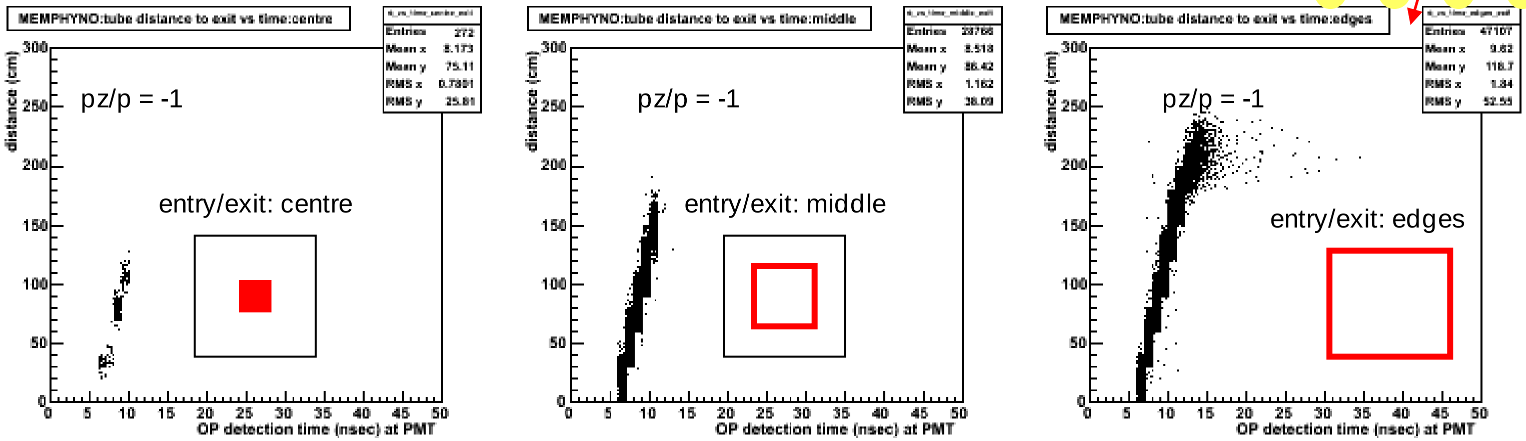
MEMPHYNO

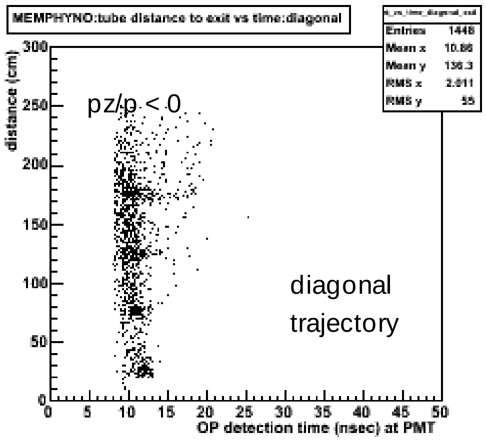
muons 1 GeV



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