MEMPHYS SIMULATION
N. Vassilopoulos / APC
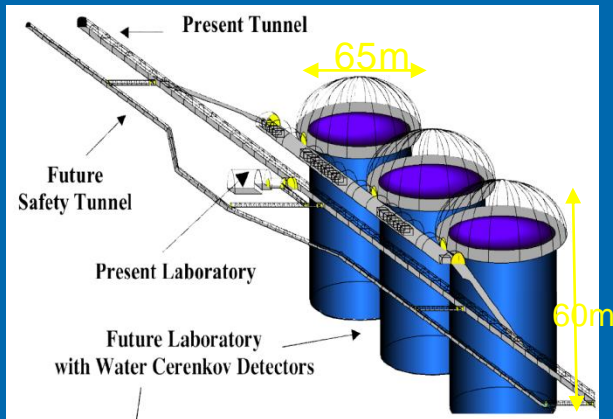
each shaft ≈ 4 x SK = 215 Kton H_2O
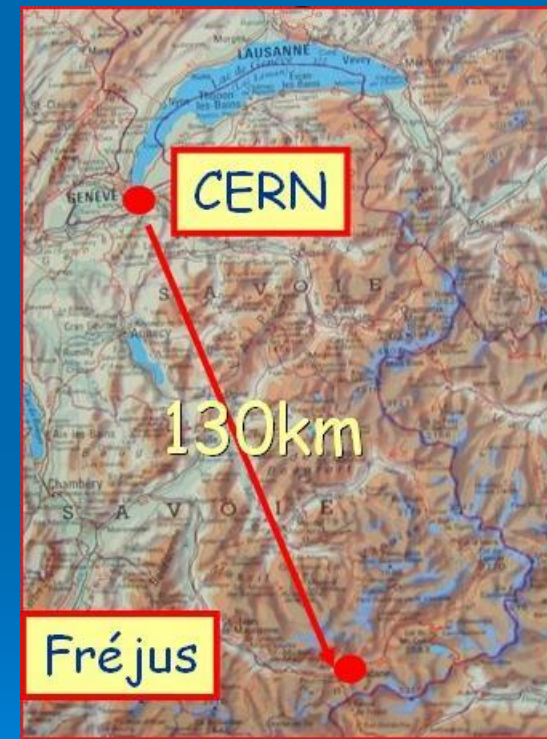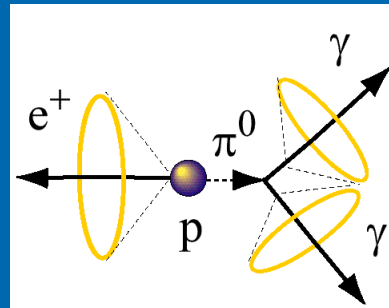
emphasis: software developments

MEMPHYS: Underground Laboratory and Detector

➤ underground water Cherenkov at Fréjus (Alps), Modane, France
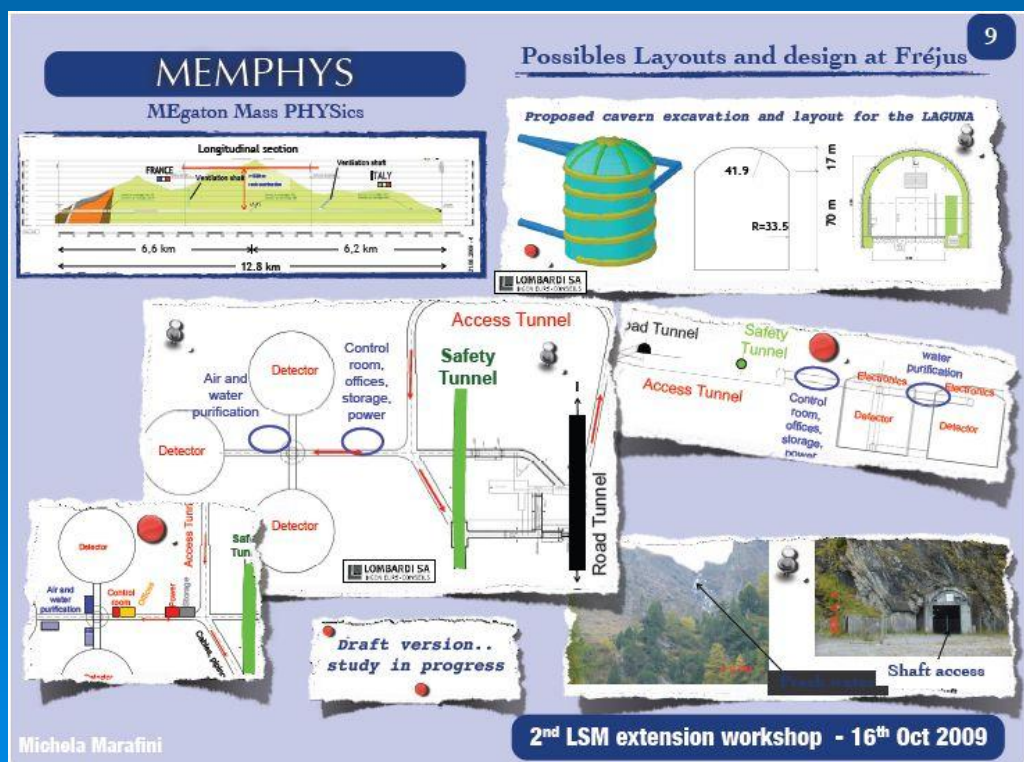
➤ total fiducial mass: up to 400 kton: 3 x 60mX65 modules
  - size limited by light attenuation length (λ~80m) and pressure on PMTs
  - readout : ~3 x 81k 12″ PMTs, 30% cover (# PEs = 40%cover with 20″ PMTs)
➤ PMT R&D + detailed study on excavation existing & ongoing

Modane, France

Fréjus Tunnel

Bardonecchia, Italy

Laboratoire Souterrain de Modane

MEMPHYS
MEgaton Mass PHYSics

Possibles Layouts and design at Fréjus

2nd LSM extension workshop - 16th Oct 2009

Michela Marafini

MEMPHYS physics goals

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

- and, of course... NEUTRINO BEAMS ! *(watch next talk from Andrea Longhin)*

R&D towards MEMPHYS : PMm2
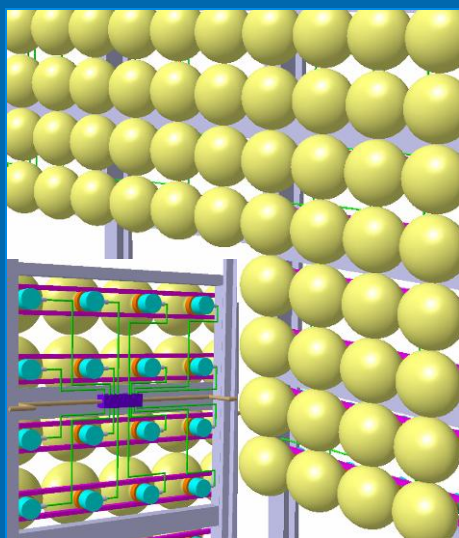
"*Innovative electronics for array of photodetectors used in High Energy Physics and Astroparticles*".

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

<u>Basic concept</u>: 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
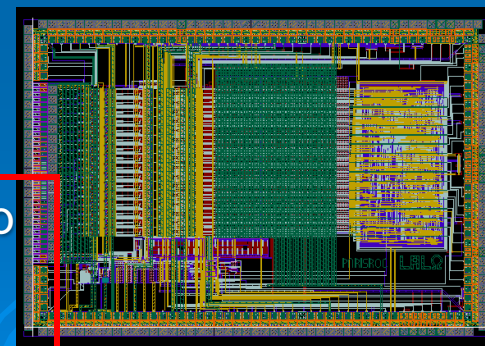- Only one wire out (DATA + VCC)

Latest News & detailed description of the R&D: read J.E Campagne's Talk at NNN09

I. studies on 12" 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

R&D towards MEMPHYS: MEMPHYNO

Goals:

- ➤ full test of electronics and acquisition chain with actual physics events
- ➤ trigger threshold studies
- ➤ self-trigger mode
- ➤ track reconstruction performances
- ➤ Gd doping: feasibility and performance (if studies still needed...)

Test bench for photodetection solutions for large detectors

-> *latest news on MEMPHYNO prototype read M. Marafini's talk from the 2nd LSM-EXTENSION WORKSHOP*

2x2x2m³

Geant4
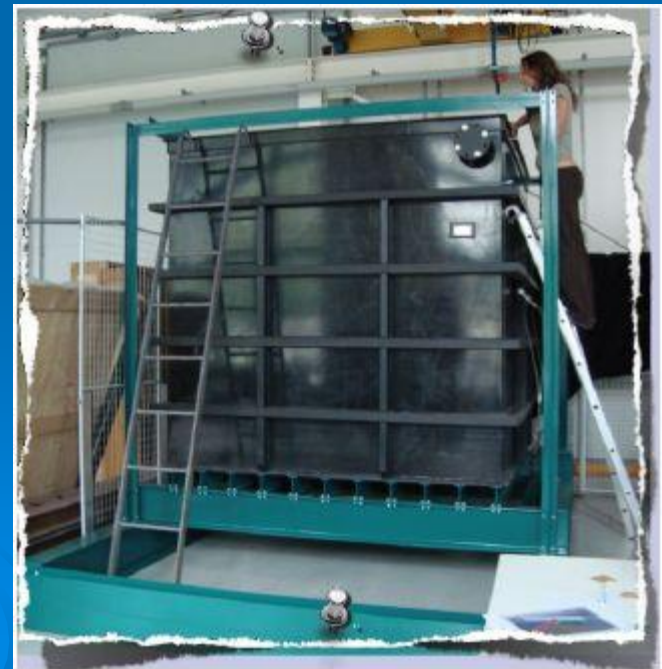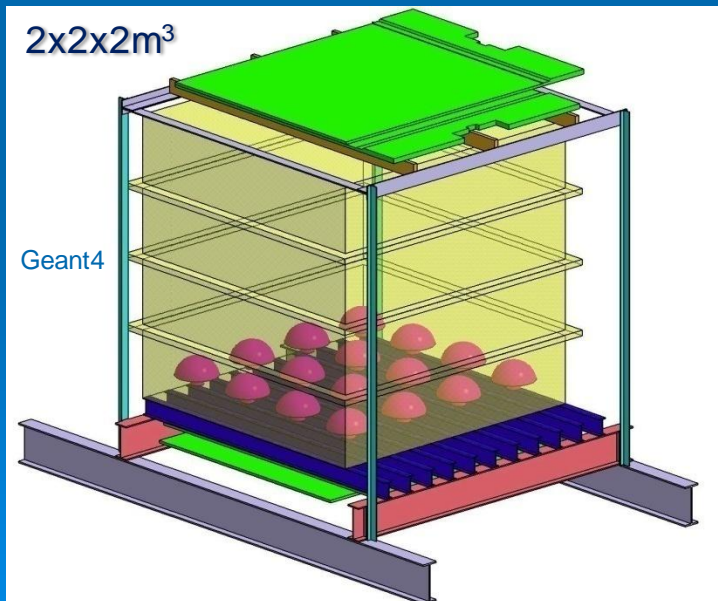
MEMPHYS: MC Present Status

- ➢ 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) provided using distribution kits including 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 + non-Optical photons track infos, track selection, modular detector geometry, etc. ntuples' storage
  - e.g. hits: each PM maintain a list of arrival time of optical photons detected

- ➢ Analyses
  - ROOT- cint
  - Solo C++ with ROOT, AIDA libraries

$$\nu_{\mu} \longrightarrow \mu^{-} \longrightarrow e^{-}$$

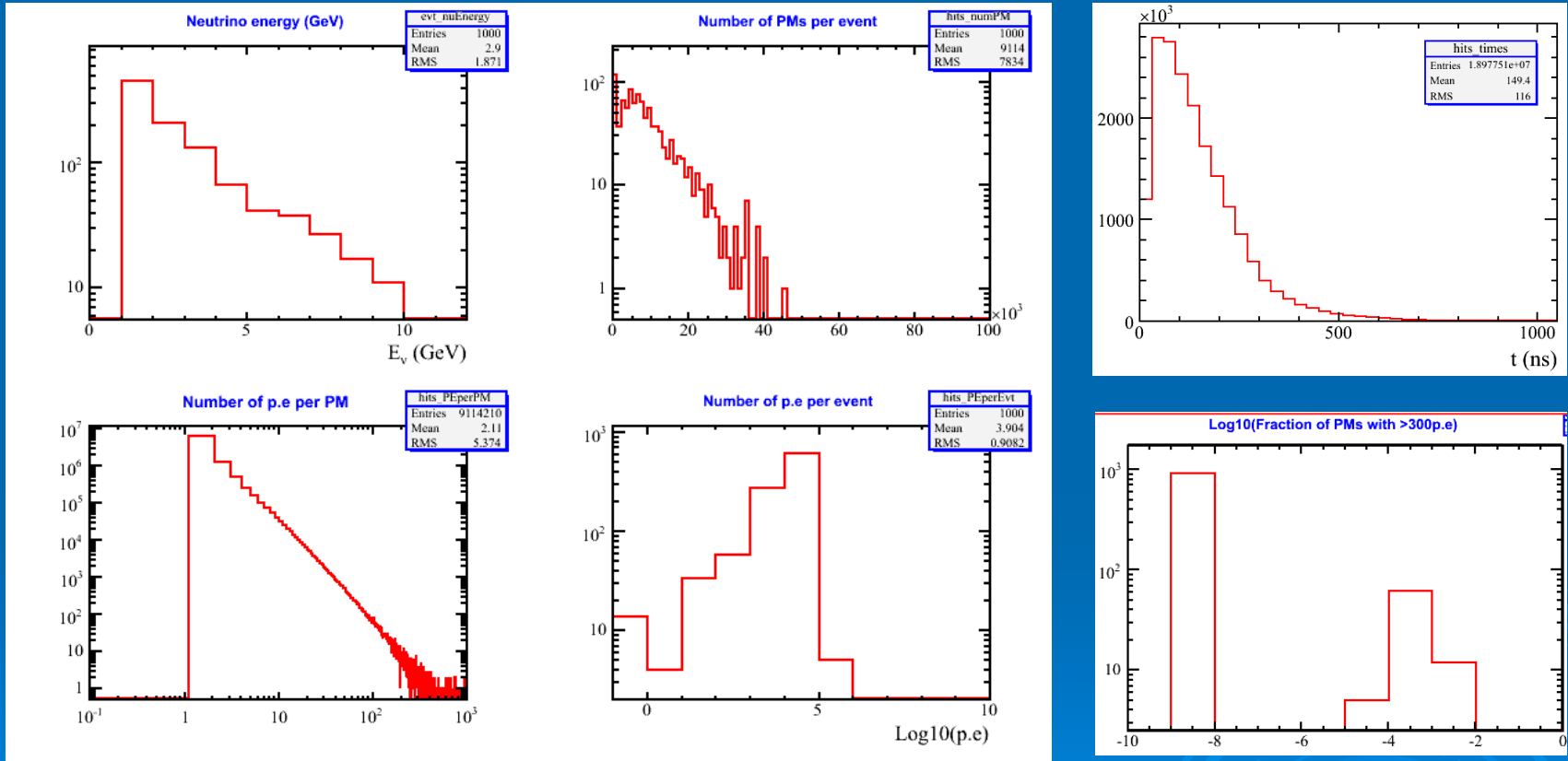Only detected op. photons

HtTime_time
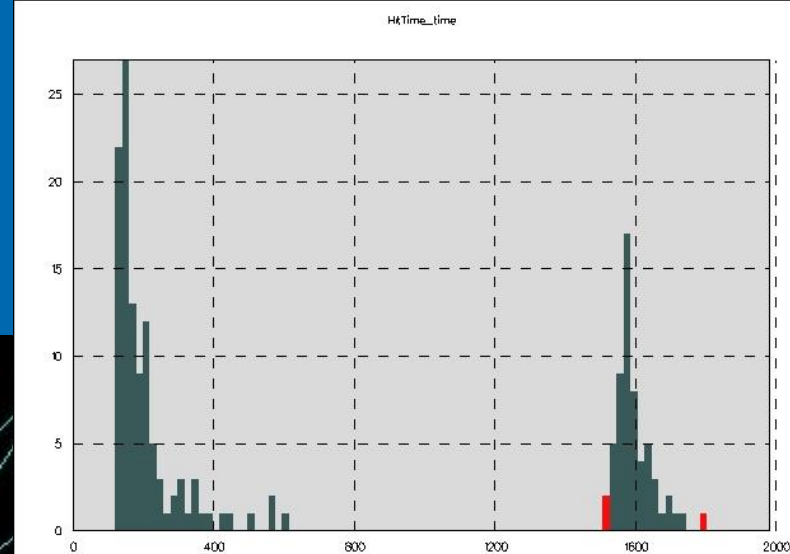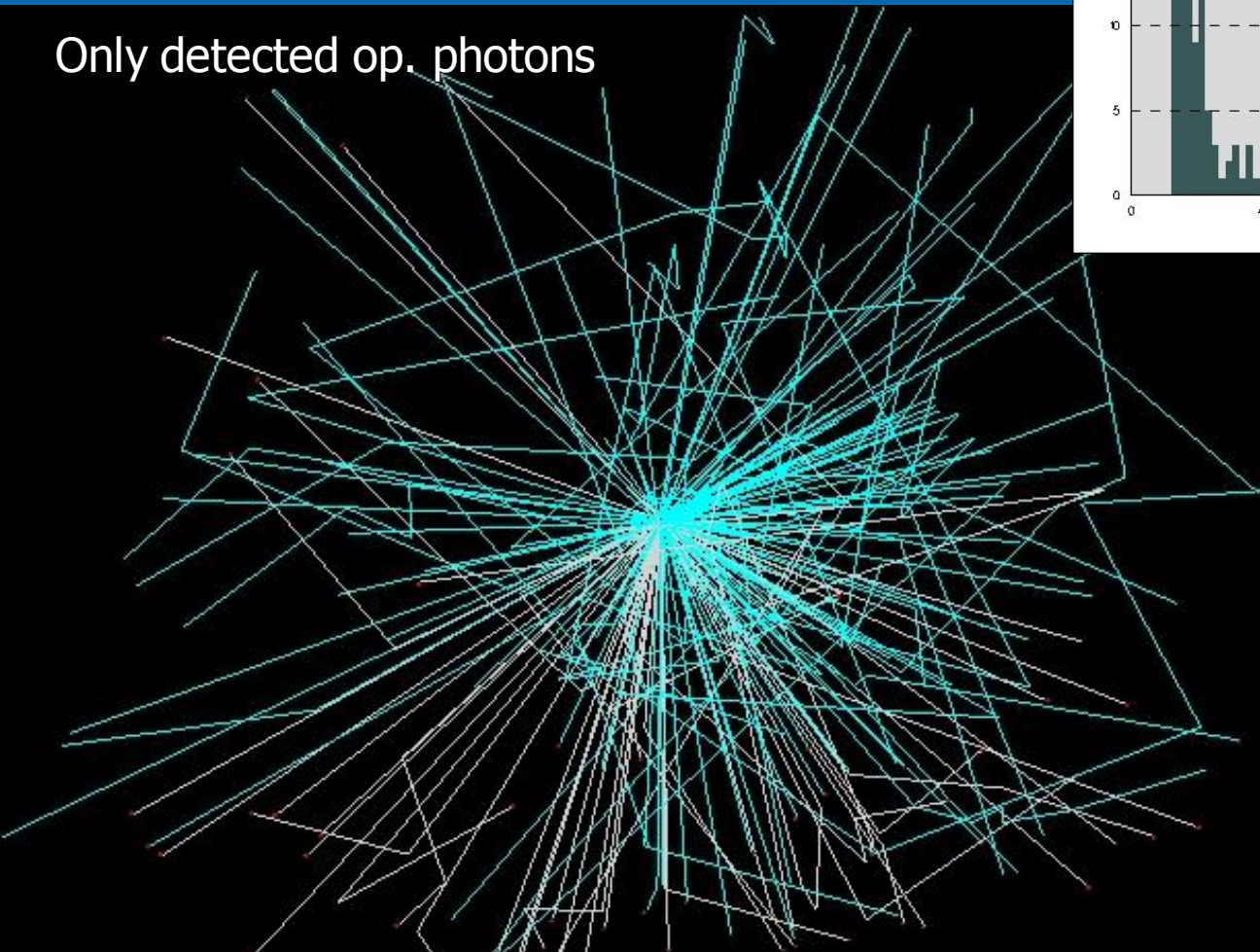
1600ns

Interactive histogram to identify the e Michel optical photons...
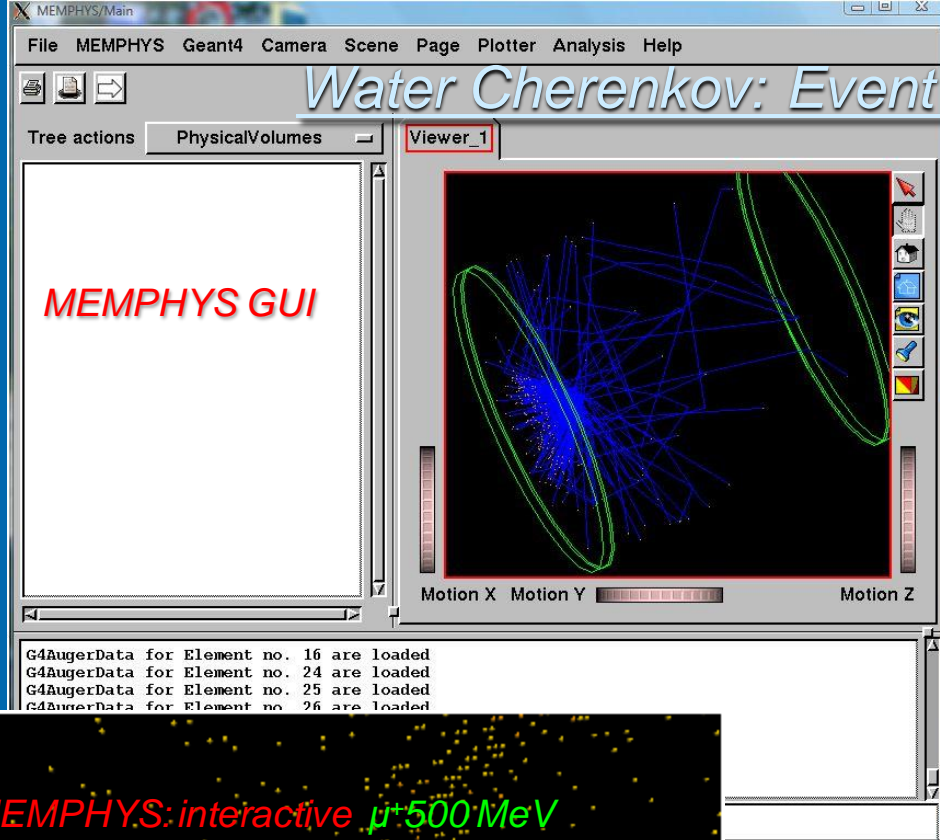
transparency by J. E. Campagne

MEMPHYS v7

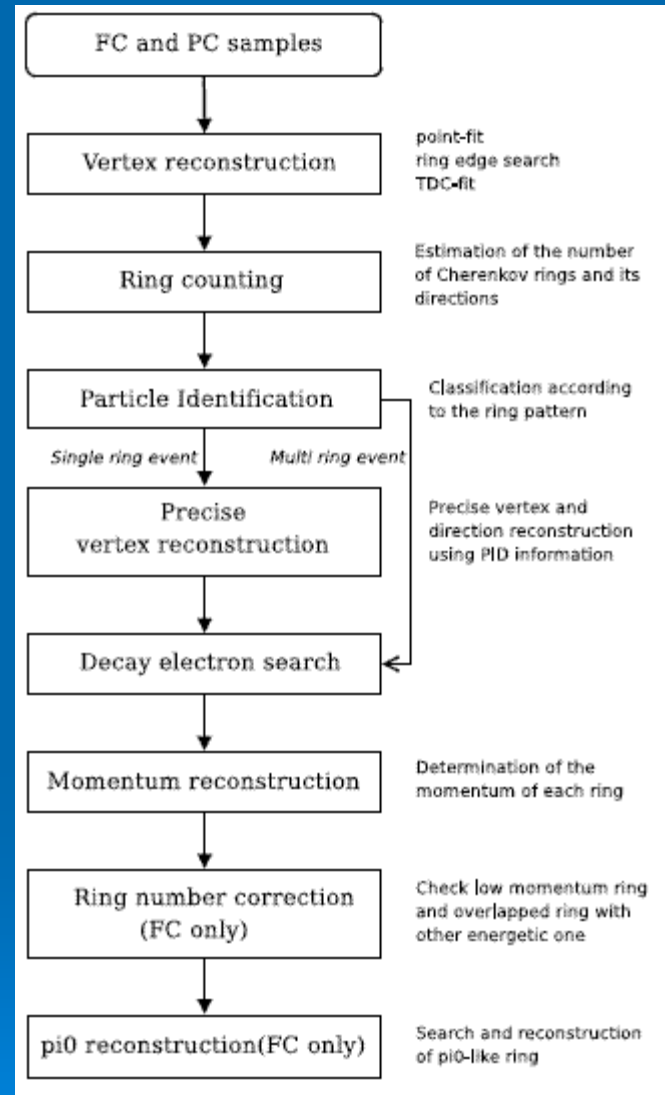# ν atmospheric (1-10GeV)

transparency by J. E. Campagne

MEMPHYS v7

MEMPHYS GUI

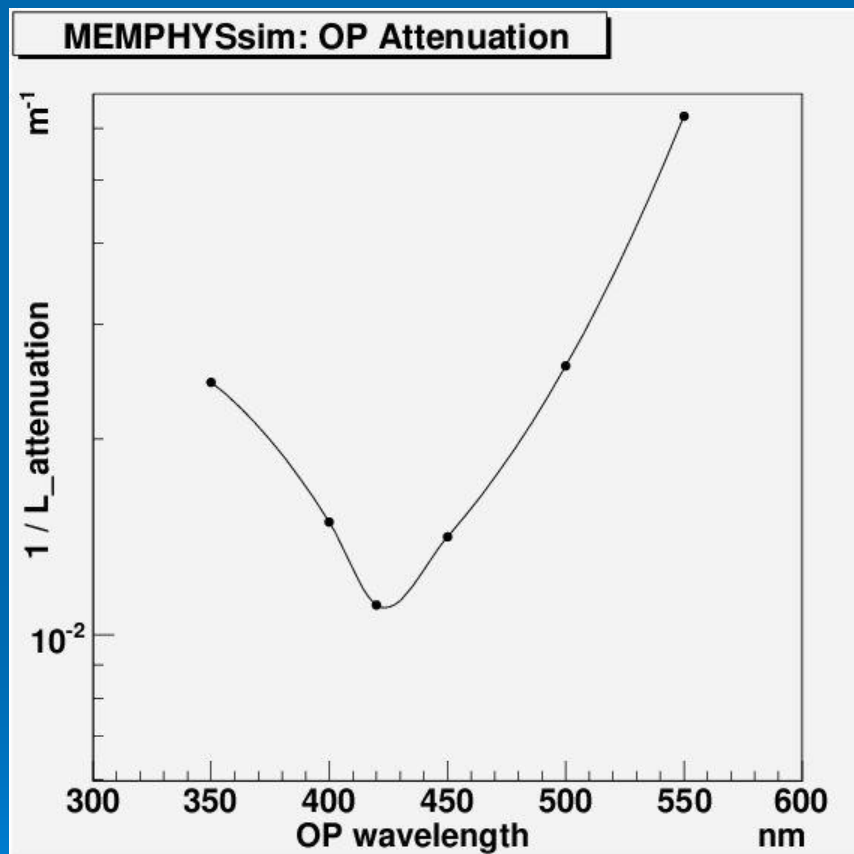*MEMPHYS: interactive μ⁺ 500 MeV*

Step	Description
FC and PC samples	
Vertex reconstruction	point-fit ring edge search TDC-fit
Ring counting	Estimation of the number of Cherenkov rings and its directions
Particle Identification	Classification according to the ring pattern
Single ring event *Multi ring event*	
Precise vertex reconstruction	Precise vertex and direction reconstruction using PID information
Decay electron search	
Momentum reconstruction	Determination of the momentum of each ring
Ring number correction (FC only)	Check low momentum ring and overlapped ring with other energetic one
pi0 reconstruction(FC only)	Search and reconstruction of pi0-like ring

Attenuation length studies

➤ correct modelling of light propagation

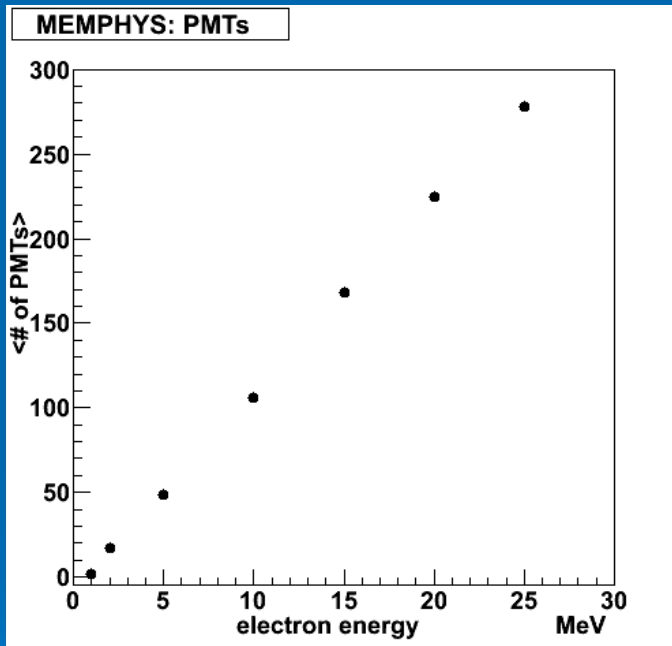**MEMPHYSsim: OP Attenuation**

attenuation length in water as a function of the wavelength in the Gean4 simulation
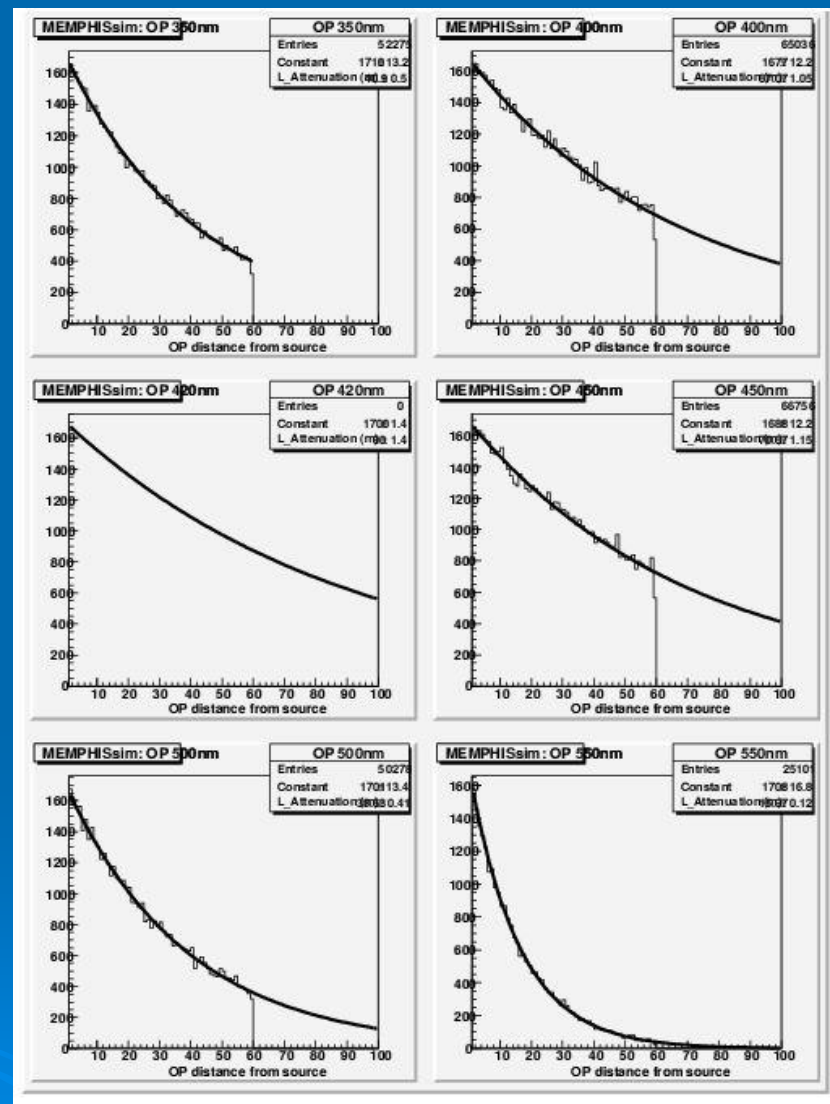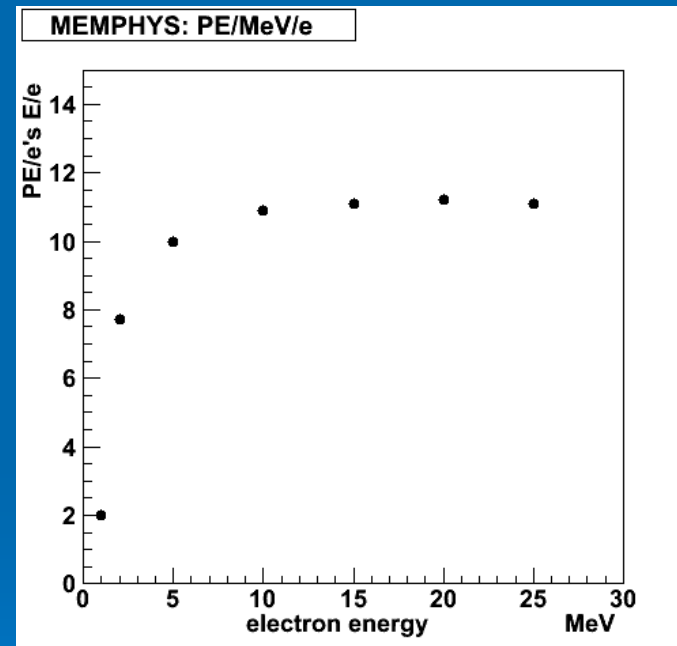

✓ looks comparable to SK data

MEMPHYS Single ring studies, electrons

➤ single e- events from 1 to 25 MeV: PMTs and PE infos

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

Single rings: electrons primary vertex fit

- pick up a 400 MeV electron, 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 to find the true vertex of electron :
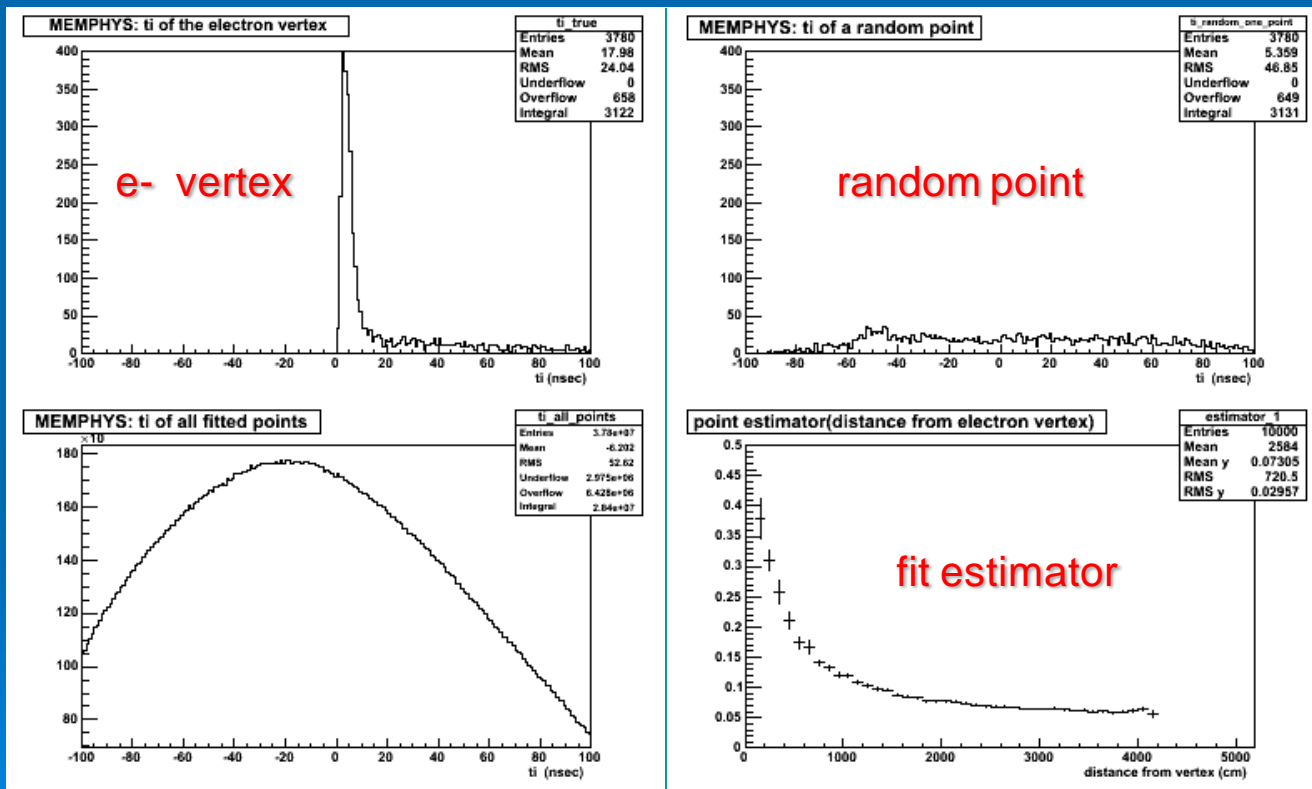
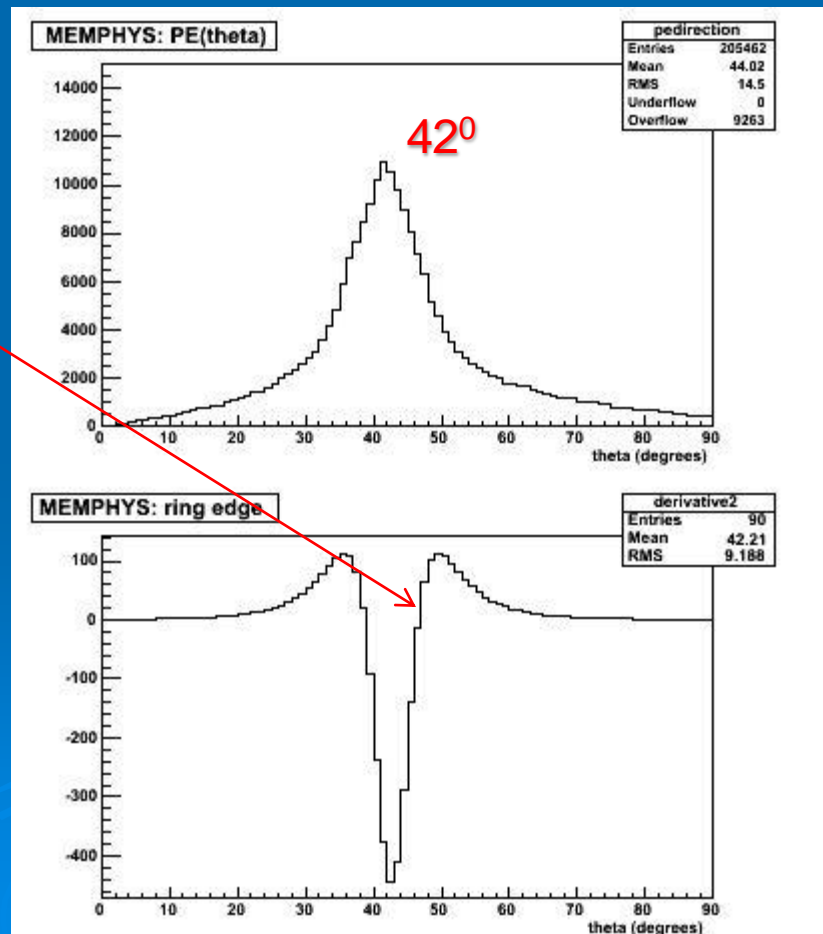# *single rings: particle direction, outer ring edge*

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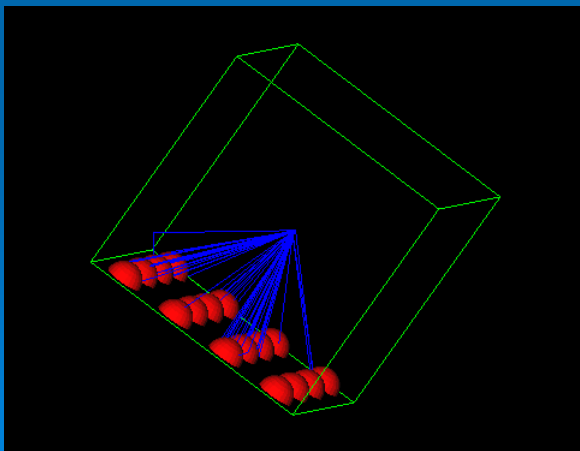 - $d^2PE(\theta) / d^2(\theta) = 0$

MEMPHYS: Simulation Studies for the small scale Prototype MEMPHYNO

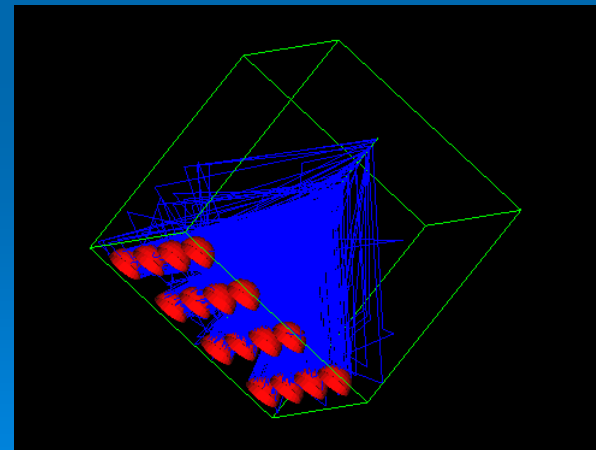*Alessandra Tonazzo, Nikos Vassilopoulos / APC-PARIS*

- ➢ tests with radioactive sources (monoenergetic, point-like) and cosmic muons (direction selected with hodoscope) on surface
- ➢ measure background level @ underground site
- ➢ MEMPHYS simulation & visualization code
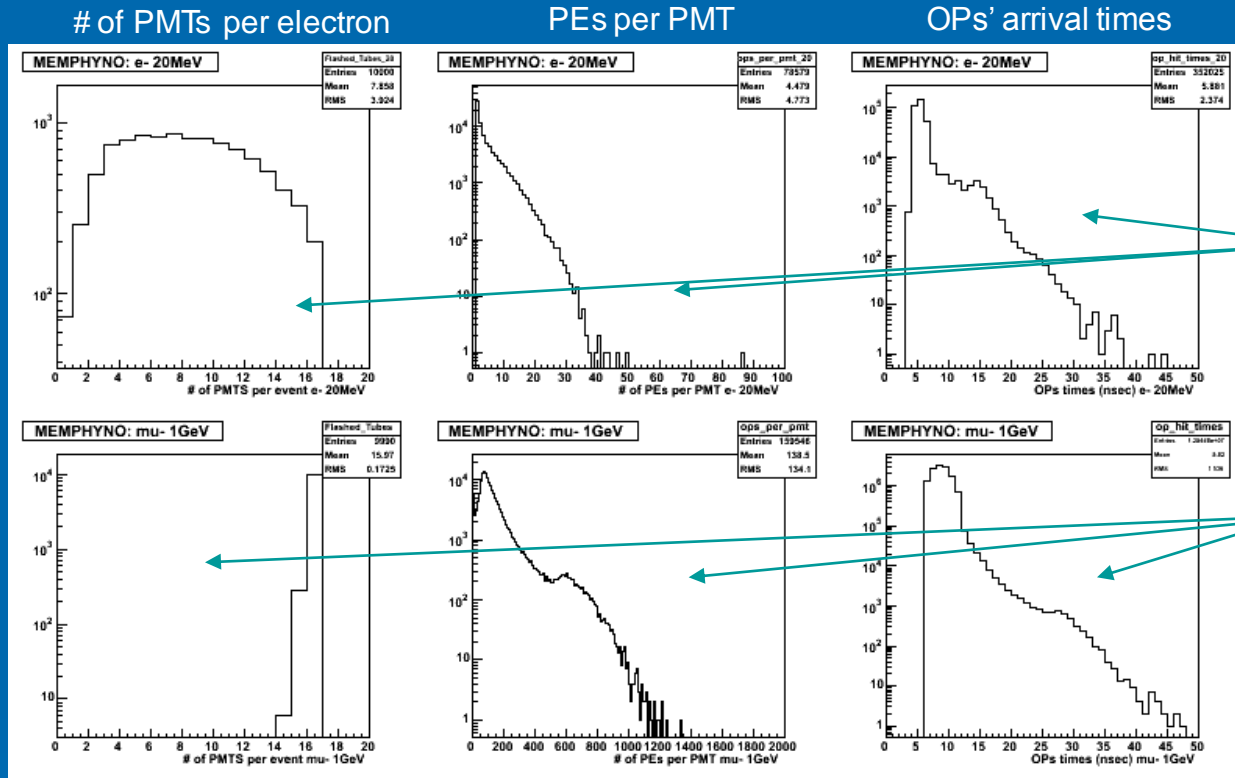- ➢ 4x4 12in PMTs = ~35% coverage (for one side)

MEMPHYS GUI for MEMPHYNO and detected optical photons

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

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

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

| 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

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 :

estimator for all grid points vs distance from true vertex

electrons generated at the detector's centre
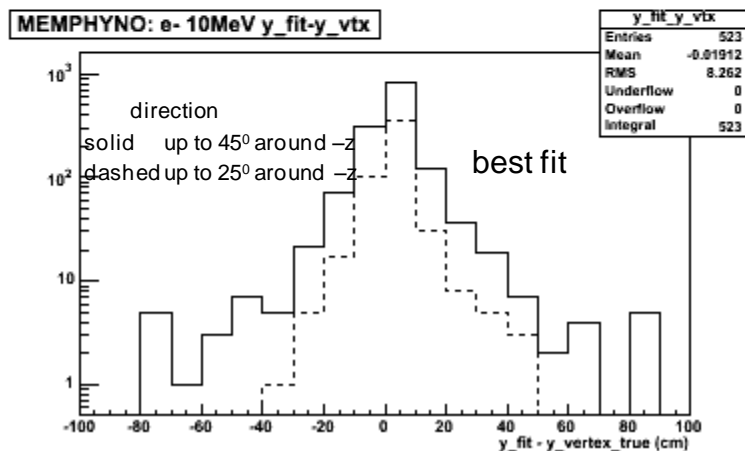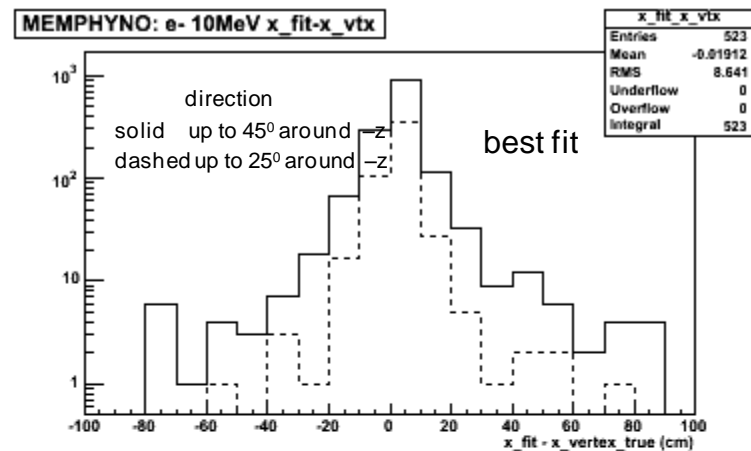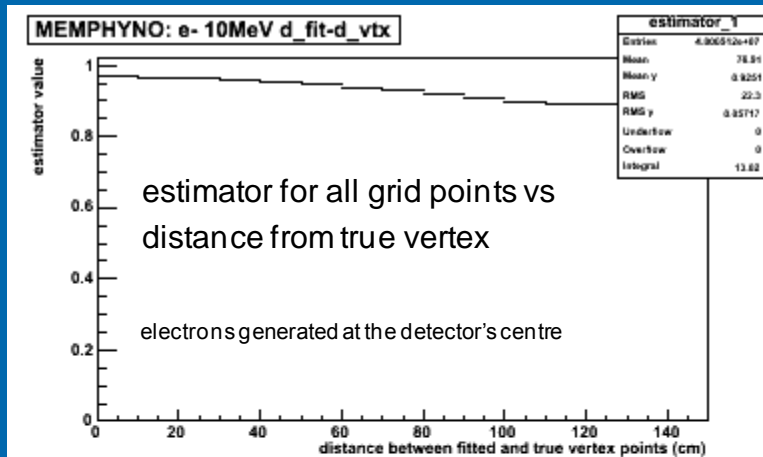
for the primary fit :

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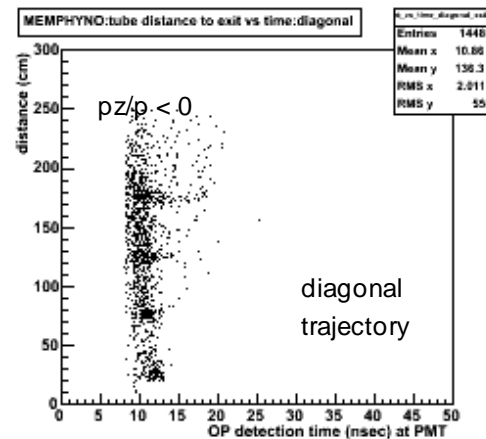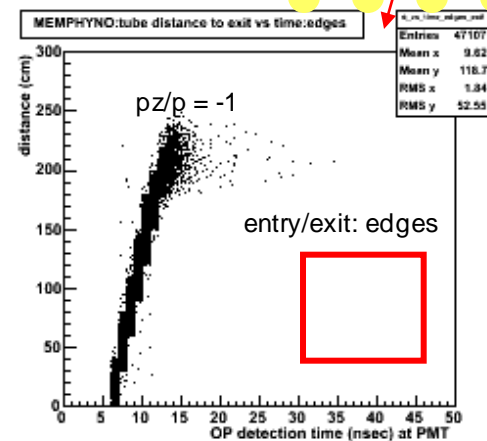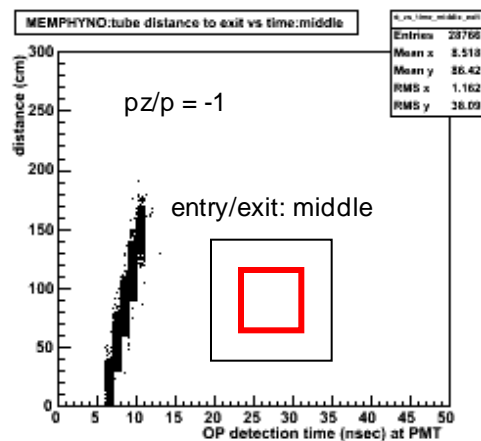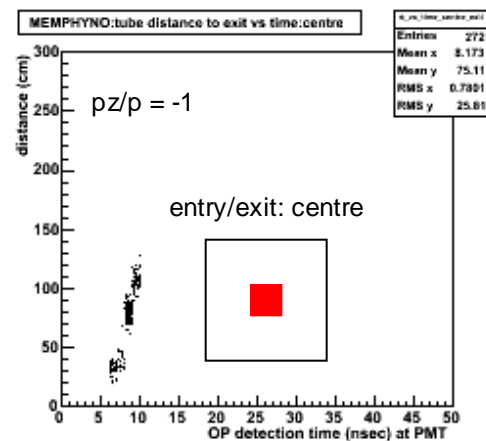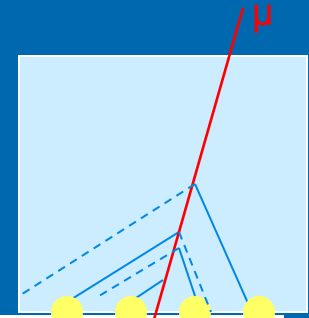
➢ pz/p = -1 : later produced OPs are detected first
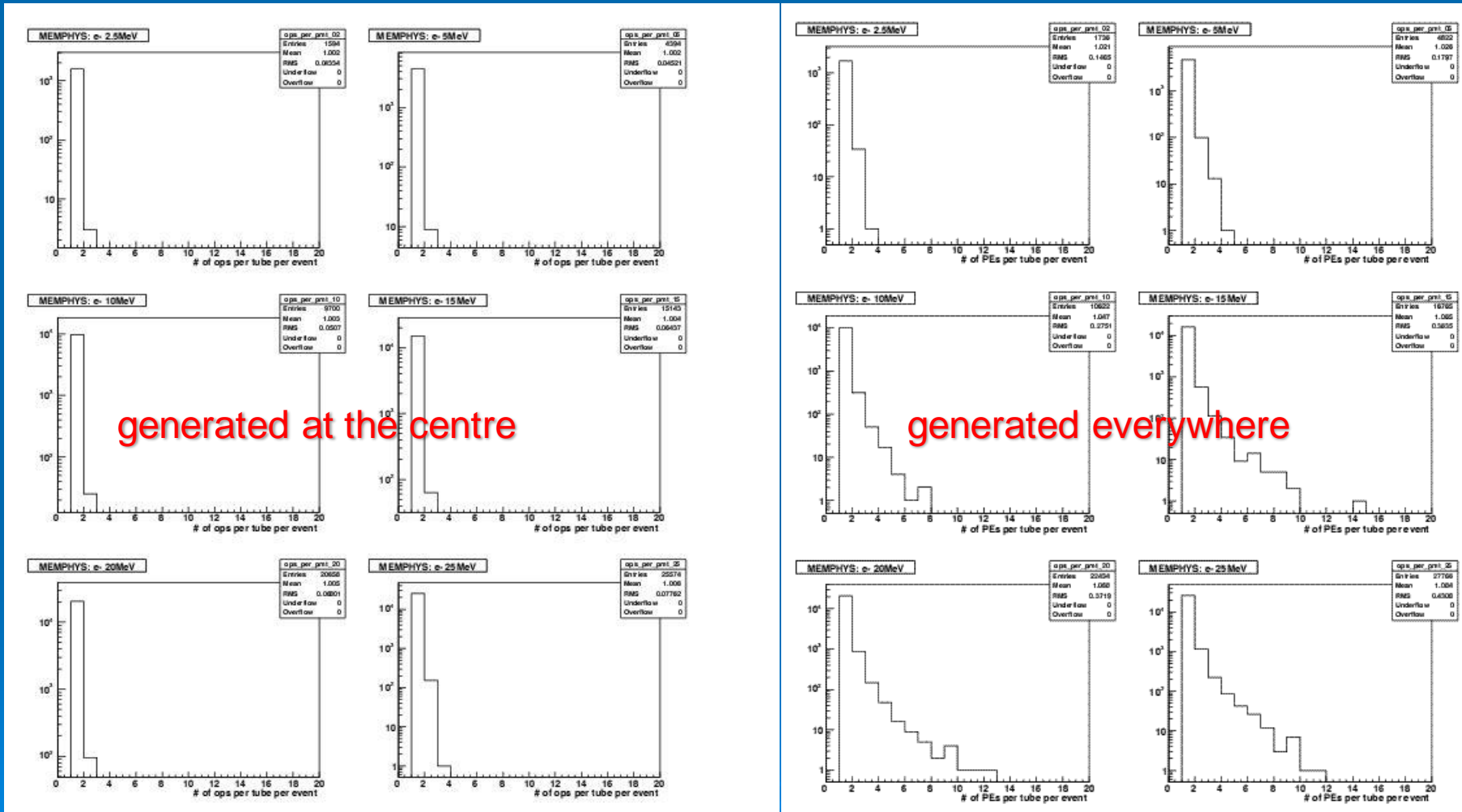➢ pz/p < 0 : relation not clean

MEMPHYS Simulation

> Always on going

next steps:

> vertex fit considering the track's length

> ring separation
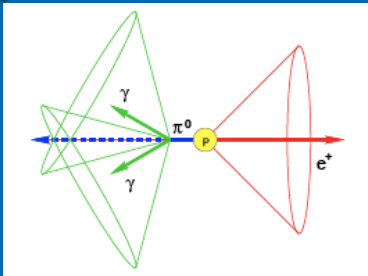
> particle identification

THANKS

➢ single e- events from 1 to 25 MeV: PEs per PMT

generated at the centre

generated everywhere

Distribution of the number of PEs in each PMT for electrons

MEMPHYS: Proton Decay, $p \rightarrow e^+ \pi^0$

➢ search for $p \rightarrow e^+ \pi^0$ (3 showering event), efficiency ~ 43%

➢ predictions: $\tau_p \sim 10^{34}$-10^{36} yrs
➢ bdg: $\mathrm{atm}\text{-}\bar{\nu}_e + N \rightarrow e^+ + N' + \pi^0$
➢ $\tau_p > 1.6 \times 10^{33}$yrs by SK
➢ $\tau_p > 1.6 \times 10^{35}$yrs at 90% CL for 5Mt.yr by MEMPHYS

MEMPHYS coverage 30% with 12"PMTs is equivalent to coverage 40% with 20"PMTs in terms of #PE.
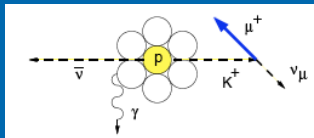MEMPHYS relies on the study by UNO, adapting the results
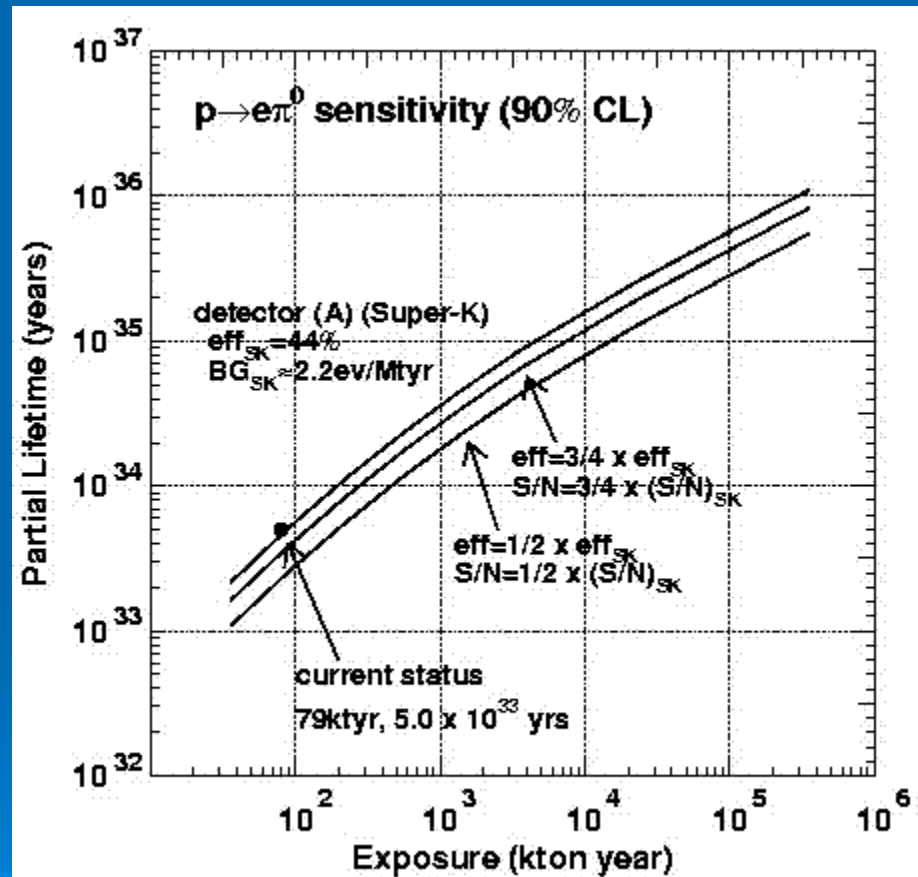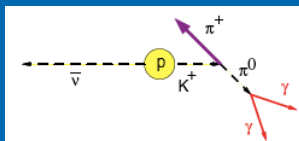

H_2O is best for this channel

MEMPHYS: Proton Decay, $p \to K\bar{\nu}$

- ➢ search for $p \to K\bar{\nu}$ *(K+ below cherenkov threshold so the channel is detected via the decay products of K+)*
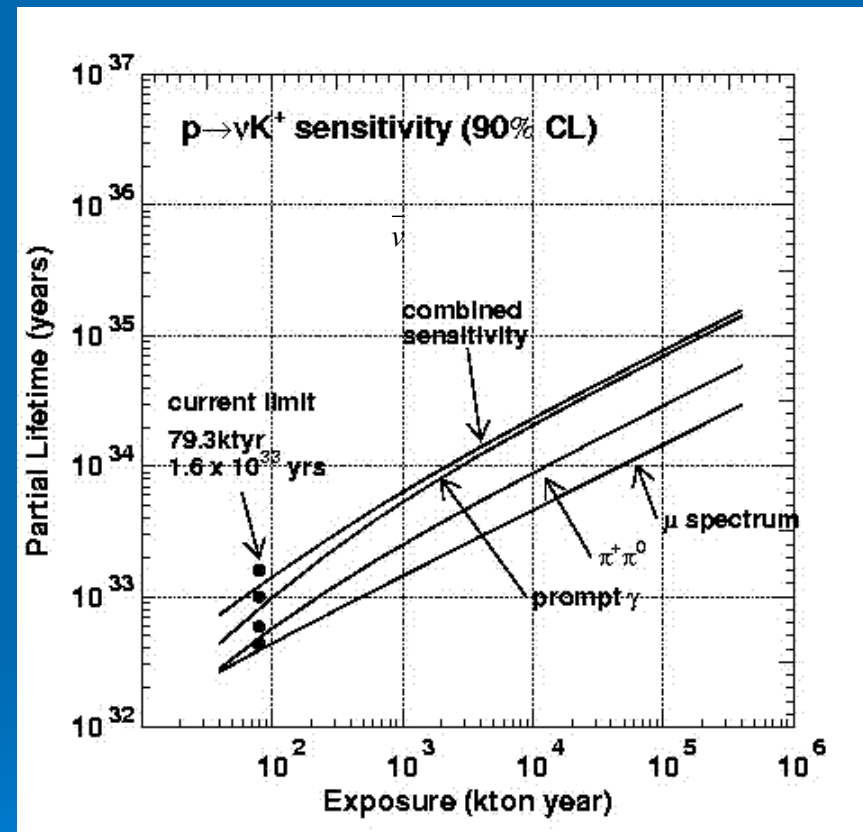
  - · $K \to \mu\nu$, monoenergetic μ + 6.3 MeV prompt-γ from capture

  - · $K \to \pi^+\pi^0$ with $\pi^0 \to \gamma\gamma$

- ➢ predictions: $\tau_p \sim 3\times10^{33}\text{-}3\times10^{34}$ yrs
- ➢ $\tau_p > 2.3\times10^{33}$yrs by SK
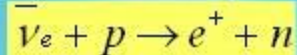- ➢ $\tau_p \sim 2\times10^{34}$yrs for 5Mt.yr by MEMPHYS

H_2O not as good as LAr, Lsint

Detection of SN neutrinos
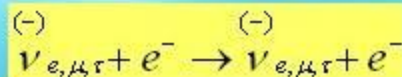
- Inverse-beta (89%)

$$\bar{\nu}_e + p \rightarrow e^+ + n$$

  - Large statistics in detectors with lots of free p
  - Good determination of ν time and energy
  - Option: add Gd to tag neutron from delayed-γ [see talk by Vagins]
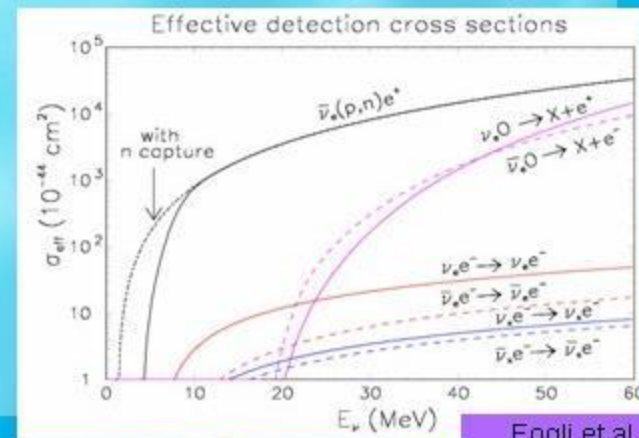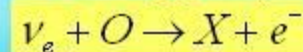
- Elastic scattering (~3%)

$$\overset{(-)}{\nu}_{e,\mu\tau} + e^- \rightarrow \overset{(-)}{\nu}_{e,\mu\tau} + e^-$$

  - Pointing $\sigma \sim 25^0/\sqrt{N}$

- NC on Oxygen (8%)

$$\nu_e + O \rightarrow X + e^-$$

Effective detection cross sections

σ_{eff} (10^{-44} cm^2) vs E_ν (MeV)

$\bar{\nu}_e(p,n)e^+$
with n capture
$\nu_x O \rightarrow X + e^-$
$\bar{\nu}_x O \rightarrow X + e^-$
$\nu_x e^- \rightarrow \nu_x e^-$
$\bar{\nu}_x e^- \rightarrow \bar{\nu}_x e^-$
$\nu_x e^- \rightarrow \nu_x e^-$
$\bar{\nu}_x e^- \rightarrow \bar{\nu}_x e^-$

Fogli et al., hep-ph/0412046

NOW06 15/09/06   A.Tonazzo - MEMPHYS: non-oscillation physics

SN neutrinos

[see talk by Cardall]

- Neutronization burst $\Rightarrow \nu_e$
  - E~10^{51} erg   t~25 ms
- Accretion + K-H cooling $\Rightarrow \nu_{e,\mu,\tau}, \bar{\nu}_{e,\mu,\tau}$
  - E~10^{53} erg   t~10 s
  - 99% of total explosion energy
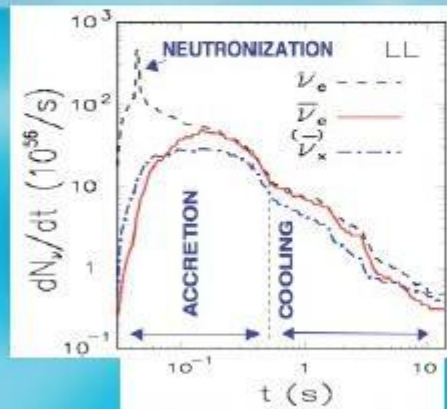
Propagation to Earth:
- Matter effects $P_{ee}(\theta_{12})$
- Level-crossing probability $P_H(E, V(x,t), \Delta m^2, \theta_{13})$
- Survival prob. p= $P_{ee} * P_H$

Scenario	Hierarchy	$\sin^2 \vartheta_{13}$	ν_e p	$\bar{\nu}_e$ $\bar{p}$
A	Normal	$\gtrsim 10^{-3}$	0	$\cos^2 \vartheta_\odot$
B	Inverted	$\gtrsim 10^{-3}$	$\sin^2 \vartheta_\odot$	0
C	Any	$\lesssim 10^{-5}$	$\sin^2 \vartheta_\odot$	$\cos^2 \vartheta_\odot$

"Sensitivity to θ_{13} one order of magnitude better than planned terrrestrial experiments" [see for ex. Lunardini-Smirnov hep-ph/0302033]

Hierarchy of interaction strength $\Rightarrow$

$E_0(\nu_e) \approx 10-12$ MeV
$E_0(\bar{\nu}_e) \approx 13-16$ MeV
$E_0(\nu_x) \approx 15-25$ MeV

Fogli et al., hep-ph/0412046
Raffelt et al., astro-ph/0303226

NOW06 15/09/06   A.Tonazzo - MEMPHYS: non-oscillation physics   5

SN spectral analyses (4)
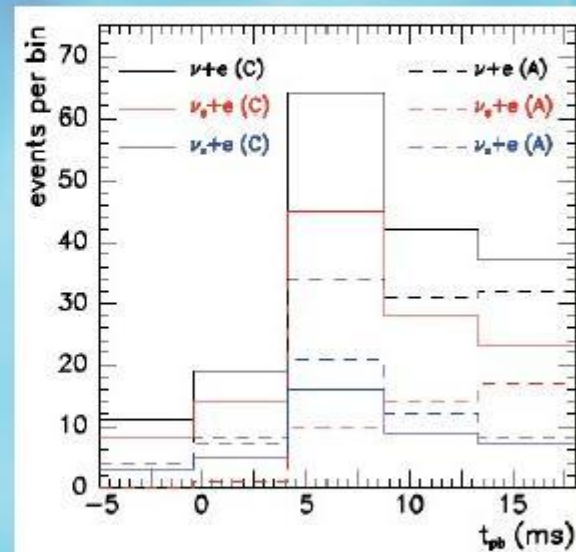
⊙ **Neutronization burst**

Signal: $\nu_e + e^- \rightarrow \nu_e + e^-$

Bkg:
•mainly $\bar{\nu}_e + p \rightarrow e^+ + n$
rejected by angle and E cuts + Gd n-tag
•ES of other ν flavours

Kachelrieβ et al.,
astro-ph/0412082

Observation of time peak
depends on oscillation scenario

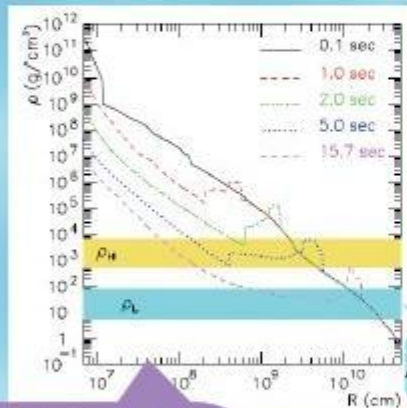| Scenario	Hierarchy	$\sin^2 \vartheta_{13}$	p	$\bar{p}$
A	Normal	$\gtrsim 10^{-3}$	0	$\cos^2 \vartheta_\odot$
B	Inverted	$\gtrsim 10^{-3}$	$\sin^2 \vartheta_\odot$	0
C	Any	$\lesssim 10^{-5}$	$\sin^2 \vartheta_\odot$	$\cos^2 \vartheta_\odot$

• Burst / no-burst ⇒ break degeneracy A/C if θ$_{13}$ unknown

• Measurement of SN distance D~1/N$^{1/2}$ @10kpc within 5%

NOW06 15/09/06   A.Tonazzo - MEMPHYS: non-oscillation physics   6

MEMPHYS: SN shockwave information

2km WC Geometry

10% de γ Č   **1% de γ Č**   **0.1% de γ Č**

$\pi^0 \rightarrow 2\gamma$

γ

μ^-

p

ν_μ(2GeV)

transparency by J. E. Campagne