EUROnu Annual Meeting, CERN March 24-25 2009
WP5 Session

LAGUNA detectors:
Water Cherenkov, Liquid Argon

Alessandra Tonazzo, Nikolaos Vassilopoulos
(APC Paris)

WP5 task for Water Cherenkov

"Define performance of water Cherenkov detectors for Super-Beam and Beta Beams, including efficiency as a function of threshold and background evaluation."

In addition, it would be nice to include the other front-runner detectors for neutrinos at super-beams and beta-beams:

Liquid Argon and Liquid Scintillator

The three types of detectors (MEMPHYS, GLACIER, LENA) are already participating in the LAGUNA FP7-DS, focused on underground sites.

Contact: Alessandra Tonazzo, APC Paris

Other participants: Thomas Patzak, Nikolaos Vassilopoulos [EUROnu postdoc], APC

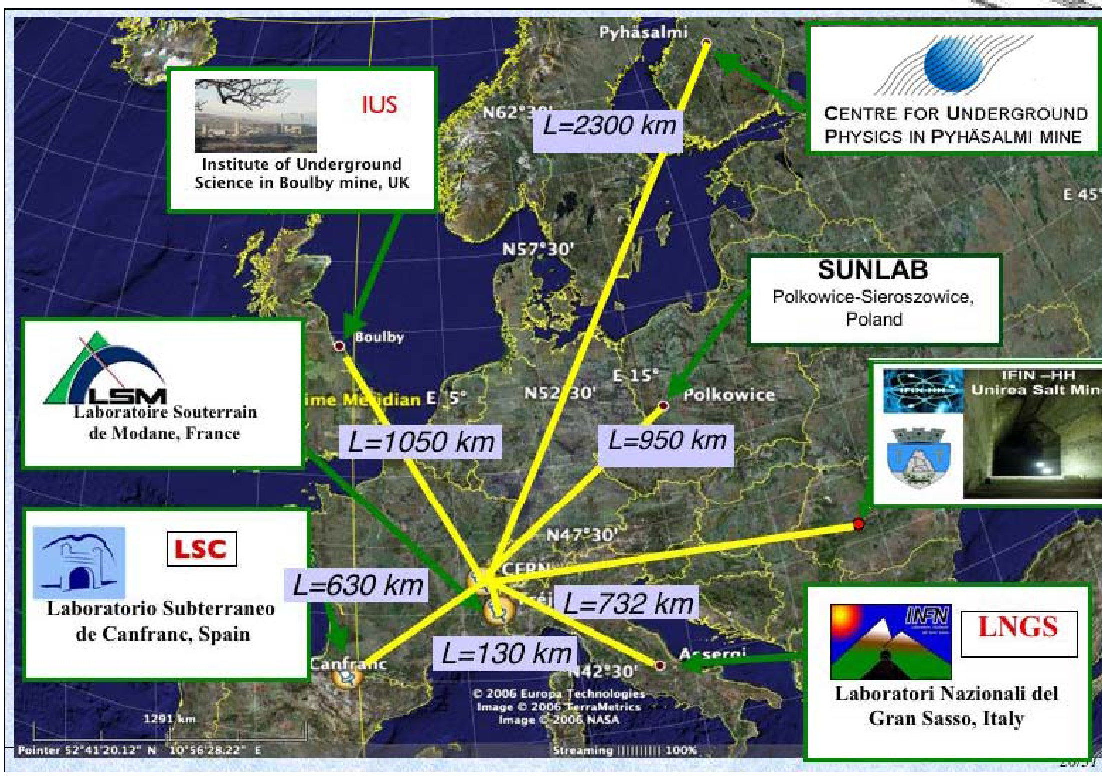
Michela Marafini [PhD student], APC

interest from LAPTH-Annecy (A.Zghiche), LAL-Orsay (J.E.Campagne)

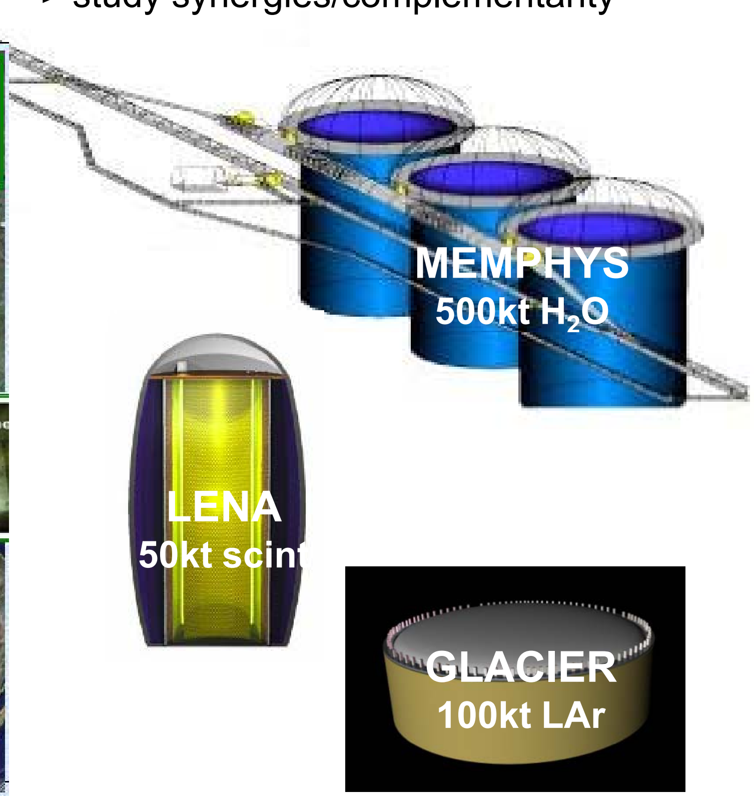
Reminder on LAGUNA

Large **A**pparatus for **G**rand **U**nification and **N**eutrino **A**strophysics
EU-FP7 2008-2010 - Contact: A.Rubbia

7 possible underground sites:
-> test feasibility, choose optimum



3 possible detector technologies
-> study synergies/complementarity



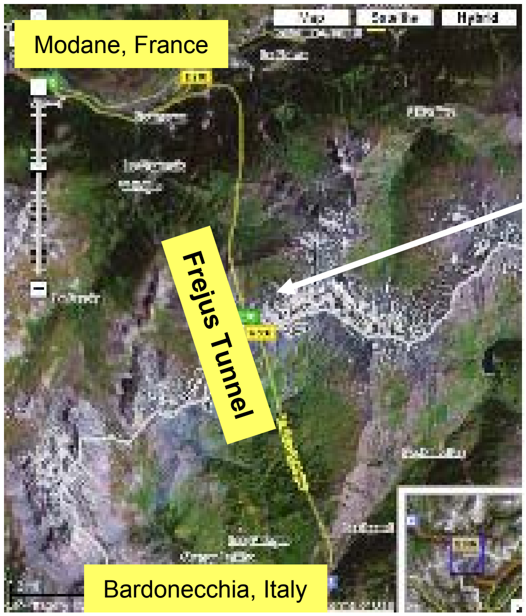
Physics discovery potential within MEMPHYS, LENA, GLACIER: proton decay and astrophysics

JCAP 0711:011,2007
(ArXiv 0705.0116)

	Water Cerenkov	Liquid Argon TPC	Liquid Scintillator
Total mass	500 kton	100 kton	50 kton
$p \rightarrow e\,\pi^0$ in 10 years	1.2×10^{35} years ε = 17%, ≈ 1 BG event	0.5×10^{35} years ε = 45%, <1 BG event	~10^{32} years in 1year ε = 12%, BG under study
$p \rightarrow \nu\, K$ in 10 years	0.15×10^{35} years ε = 8.6%, ≈ 30 BG events	1.1×10^{35} years ε = 97%, <1 BG event	0.4×10^{35} years ε = 65%, <1 BG event
SN cool off @ 10 kpc	194000 (mostly $\nu_e p \rightarrow e^+ n$)	38500 (all flavors) (64000 if NH-L mixing)	20000 (all flavors)
SN in Andromeda	40 events	7 (12 if NH-L mixing)	4 events
SN burst @ 10 kpc	≈250 ν-e elastic scattering	380 ν_e CC (flavor sensitive)	≈30 events
SN relic	250(2500 when Gd-loaded)	50	20-40
Atmospheric neutrinos	56000 events/year	≈11000 events/year	5600/year
Solar neutrinos	91250000/year	324000 events/year	?
Geoneutrinos	0	0	≈3000 events/year

Clear complementarity between techniques !

The MEMPHYS detector



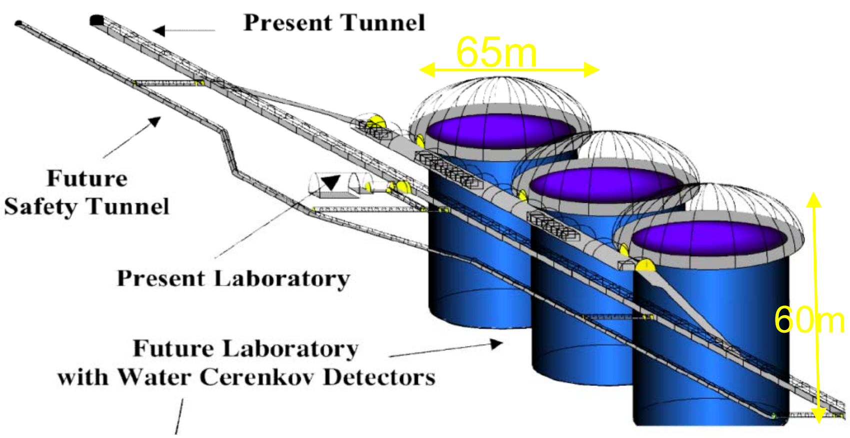
Laboratoire Souterrain de Modane

4800 m.w.e.

Megaton Mass PHYSics @Fréjus

- Water Cherenkov ("cheap and stable")
- Total fiducial mass: 440 kt
- Baseline:

  3 Cylindrical modules 65x65 m
  - Size limited by light attenuation length (λ~80m) and pressure on PMTs
  - Readout: 12" PMTs, 30% geom. cover (#PEs =40%cov. with 20" PMTs)
- PMT R&D + detailed study on excavation existing & ongoing

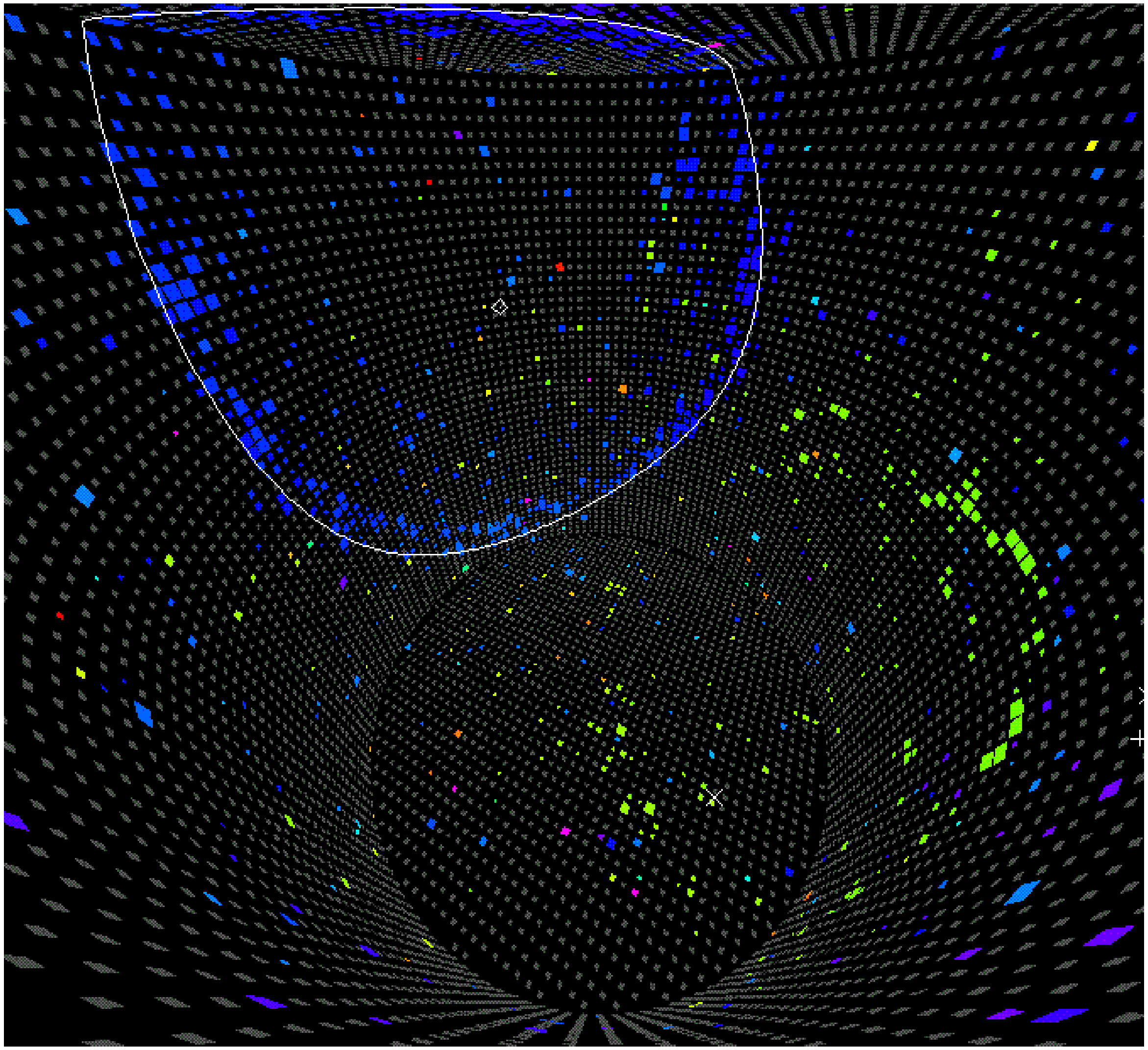


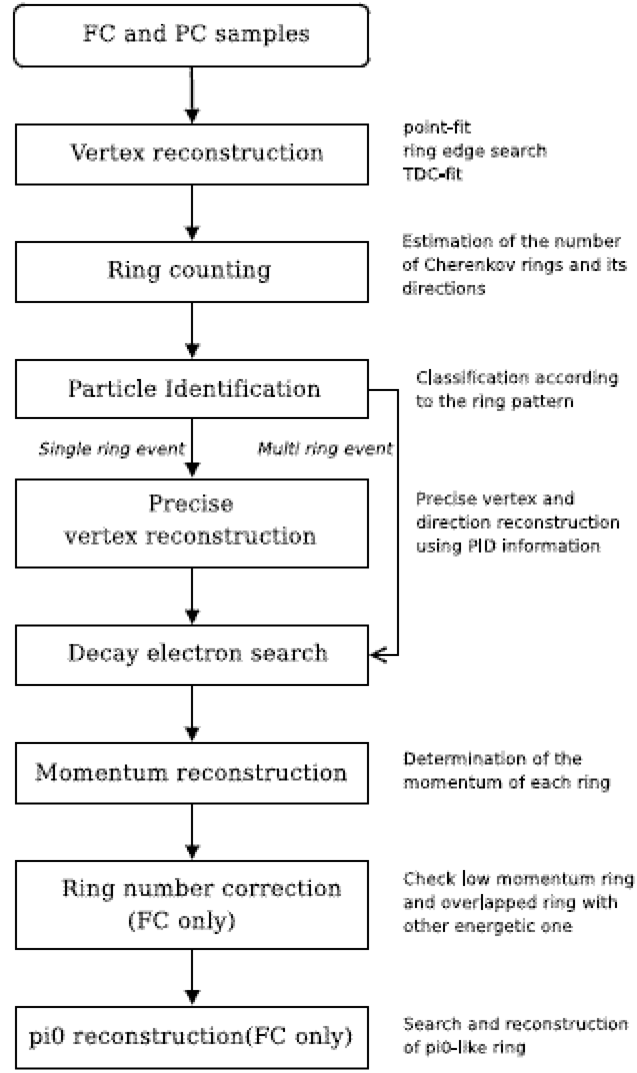
http://www.apc.univ-paris7.fr/APC_CS/Experiences/MEMPHYS/

arXiv: hep-ex/0607026

Contact: Th. Patzak (APC)

Water Cherenkov: Event Reconstruction





Super-Kamiokande:
481 MeV muon neutrino (MC) produces 394 MeV muon which later decays at rest into 52 MeV electron.

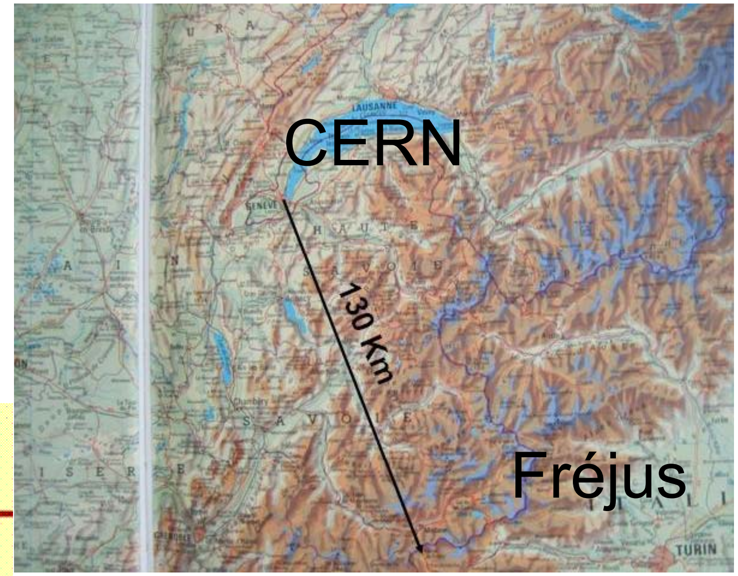
MEMPHYS physics goals

- 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 !

CERN-MEMPHYS: Oscillation measurements with ν beams

Campagne, Maltoni, Mezzeto, Schwertz
hep-ph/0603172

- θ_{13} discovery reach and sensitivity to CP Violation



Three options for future LBL exps

	βB	SPL	T2HK
Baseline:	130 km (CERN-Frejus)		295 km (Tokai-Kamioka)
WC Detector:	MEMPHYS (440 kt)		Hyper-K (440 kt)
$\langle E_\nu \rangle$:	400 MeV	300 MeV	760 MeV
Channel:	$\overset{(-)}{\nu}_e \to \overset{(-)}{\nu}_\mu$	$\overset{(-)}{\nu}_\mu \to \overset{(-)}{\nu}_e$	
Time $(\nu + \bar{\nu})$:	(5+5) y	(2+8) y	
Beam:	$\gamma = 100$	$E_p = 3.6$ GeV	$E_p = 50$ GeV
	$\frac{5.8}{2.2}\, 10^{18}\, \frac{\mathrm{He}}{\mathrm{Ne}}$ dcy/y	4 MW	
Systematics:	2%–5% uncertainty on signal & background		

T. Schwetz, NOW2006, Otranto, 15 September 2006 – p.3

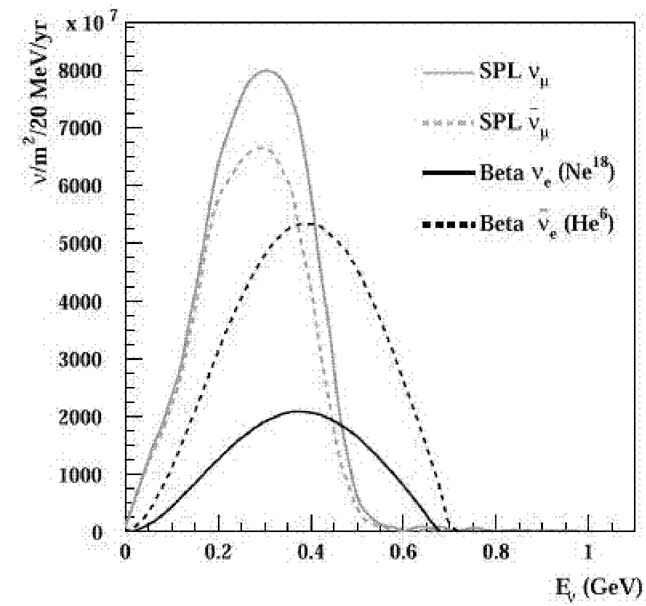
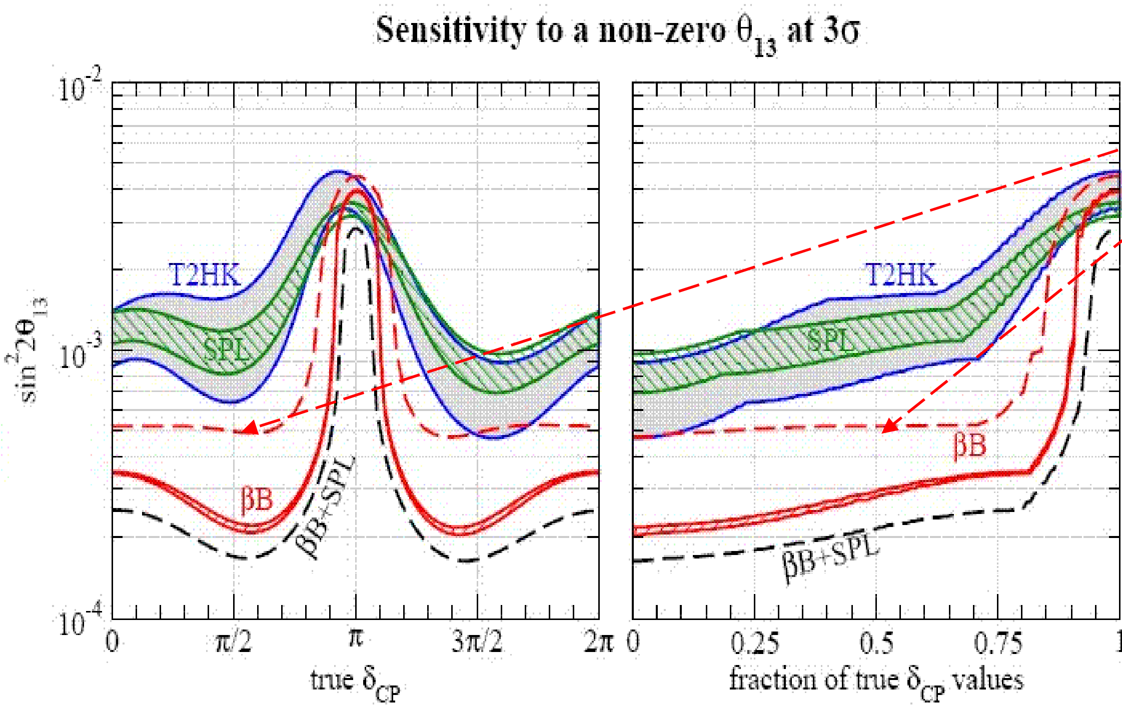
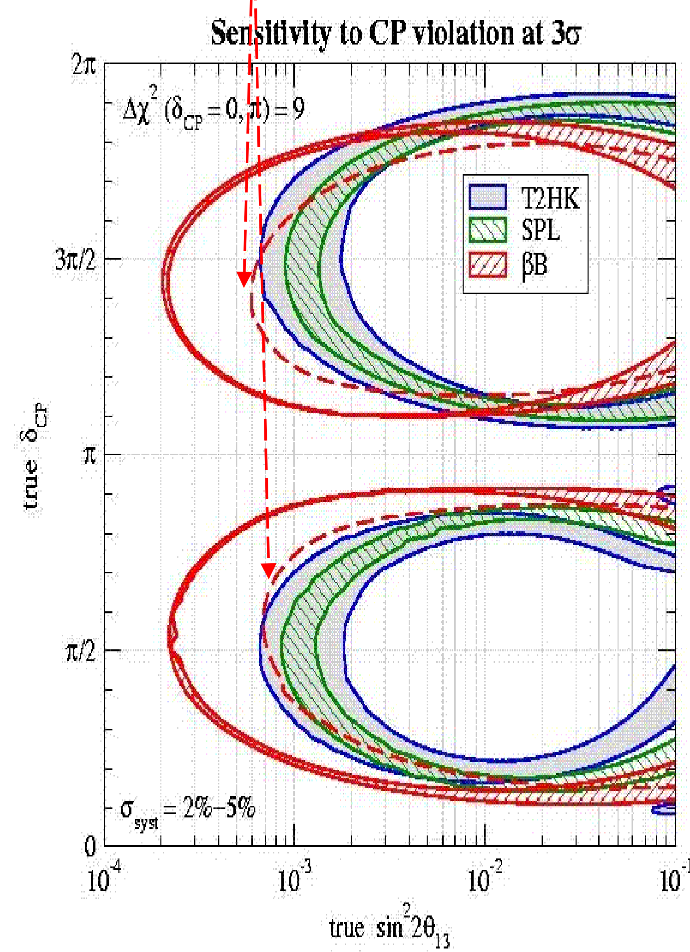


Figure 4: Comparison of the fluxes from SPL and βB.

CERN-MEMPHYS:
Oscillation measurements with ν beams main results

βB beam’s ions/year reduced by 2: performance is strongly depended on ion production

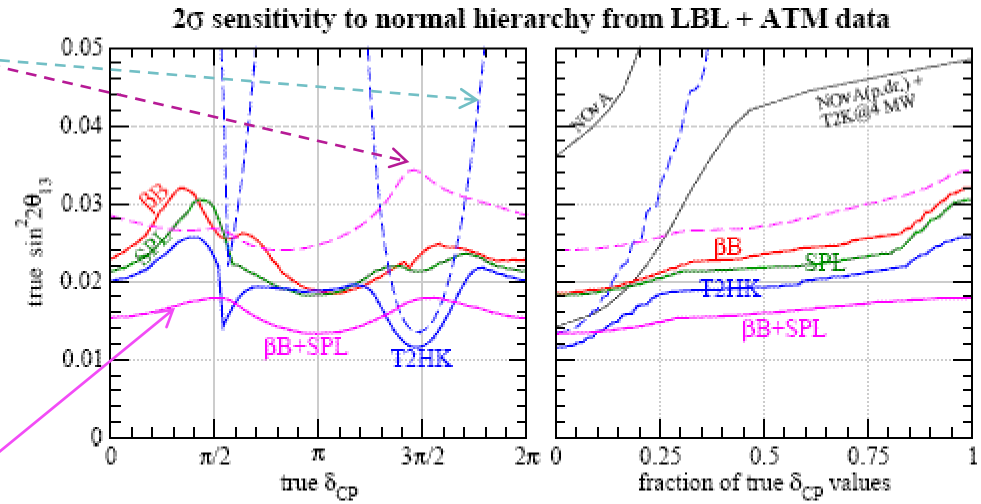




- ➢ good sensitivity of θ_{13} and δ_{CP} for super- beams ($\nu_\mu \rightarrow \nu_e$) & beta-beams ($\nu_e \rightarrow \nu_\mu$)
- ➢ improved performance with the 2 beams combined

CERN-MEMPHYS: mass hierarchy and degeneracies

without ATM data



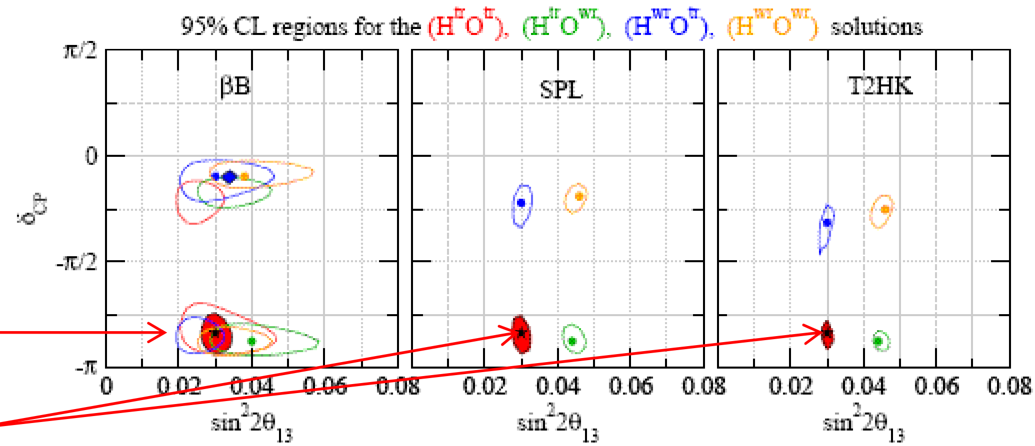
for large sin $^{2}2\theta_{13}$ degeneracies and mass hierarchy is possible to be resolved

- addition of ATM data leads to a sensitivity to the neutrino mass hierarchy at 2σ CL for sin $^{2}2\theta_{13} \geq 0.025$ for βB and SPL

- the optimal hierarchy sensitivity is obtained from combining βB + SPL + atmospheric data

- beta beam + ATM can not solve degeneracies (no ν_μ and insufficient spectral info)

- super beam + ATM: degeneracies lifted



MEMPHYS for nu-factory ?

P.Huber and Th.Schwetz, ArXiv:0805:2019

Neutrino Factory: need to distinguish wrong-sign from right-sign muons in the detector to separate the appearance signal $\bar{\nu}_e \to \bar{\nu}_\mu$ from the disappearance signal $\nu_\mu \to \nu_\mu$
Common solution: magnetised detector (MIND, TASD)

T.S.@NNN08

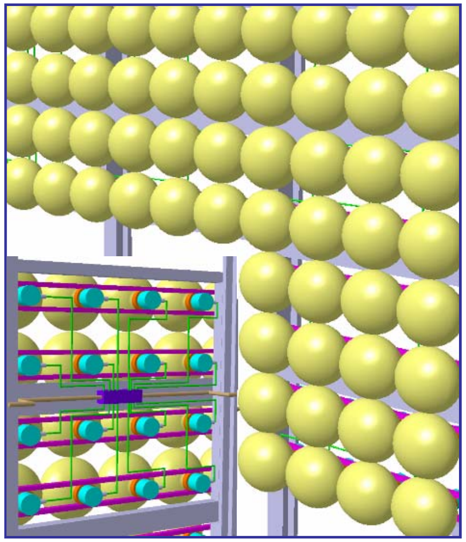
A large non-magnetized detector IS interesting also in the context of a (low-energy) Neutrino Factory

- Oscillation provides a right sign muon suppression of $1:10$ down to $1:100$, depending on energy resolution
- Statistical $\nu/\bar{\nu}$ separation:
  muon lifetime, $\cos\theta$ distribution, nucleon tagging
- separation efficiencies and purities of 50%-90% allow to use NNN detectors for $\sin^2 2\theta_{13} \gtrsim 0.004$

A task for WP5

All of this requires detailed simulations and a precise understanding of nuclear effects, detector effects...!

R&D towards MEMPHYS : PMm2



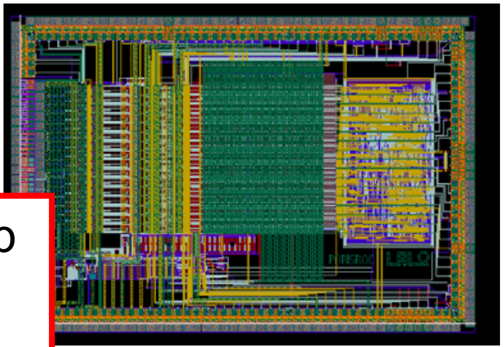
"*Innovative electronics for array of photodetectors used in High Energy Physics and Astroparticles*".

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

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") with central ASIC :

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



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

(collaboration with BNL since NNN07)

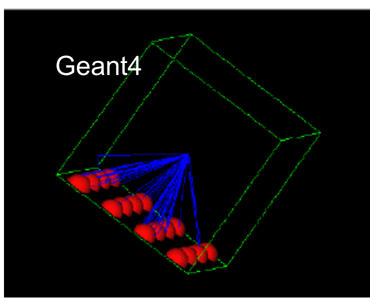
II. PArISROC readout chip
- complete front-end chip with 16 channels
- testboard now in layout, soon available

R&D towards MEMPHYS: MEMPHYNO

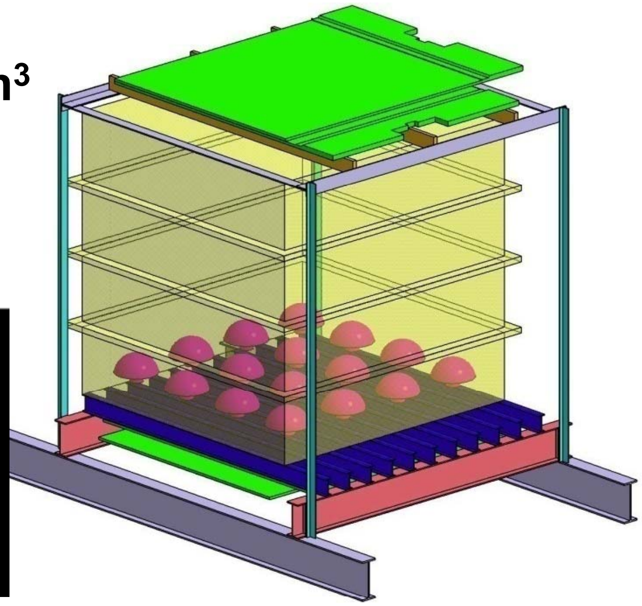
Goals:

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

Test bench for photodetection solutions for large detectors



$2x2x2m^3$



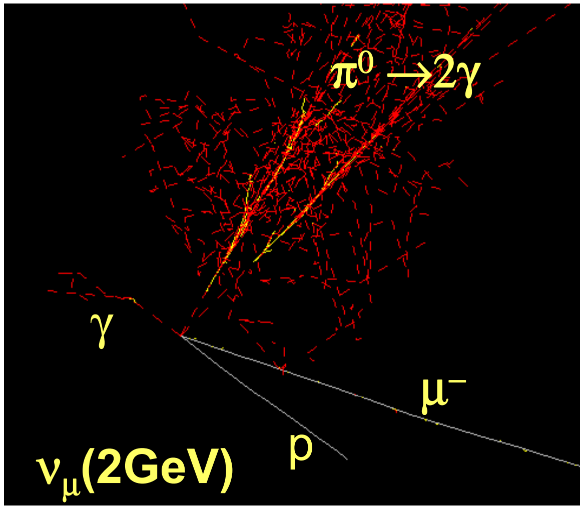
being installed at APC

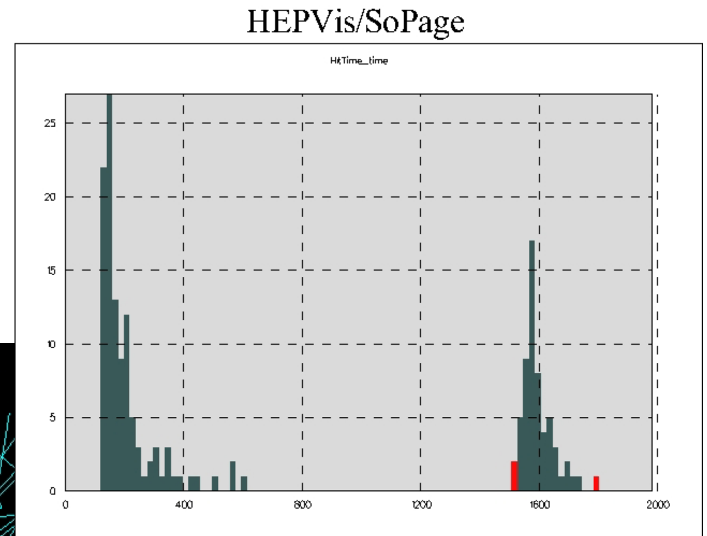
MEMPHYS simulations

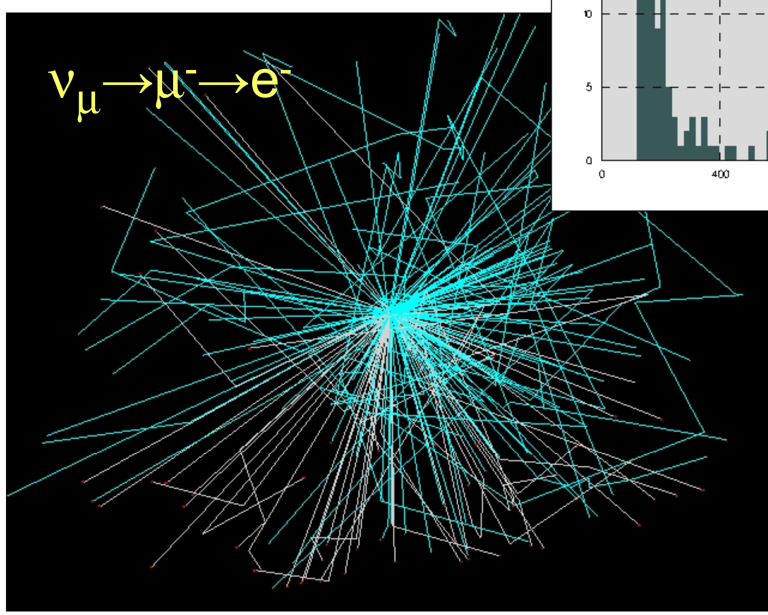
- Event Generator:
  - **NUANCE** for ν beam, ν Atmospheric & Proton Decay
- Simulation:
  - Version 0:
    - adapted by J.E.Campagne from **Geant 4** code used by M. Fechner et al. for T2K-WC-2km. The simulation was x-checked using SK & K2K data.

      includes Water & PMT & wall reflectivity optical parameters
  - Current version 7:
    - Interface with the OpenScientist v16r0 framework (G. Barrand@LAL)
    - 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
    - Hits: each PM maintain a list of arrival time of optical photons detected (i.e photo-cathod efficiency)
- Future developments: (work in progress at APC, LAL, LAPP)
  - Code review to improve the geometry implementation, clean up the patches used to adapt the code from T2K-WC to MEMPHYS use case, improve flexibility
  - Implement the electronics simulation
  - Implement a Data Model to be able to do “replay” event-display

MEMPHYS simulations



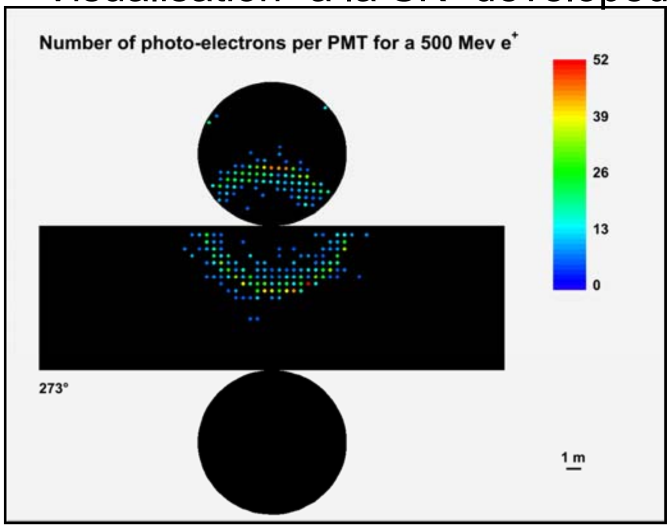




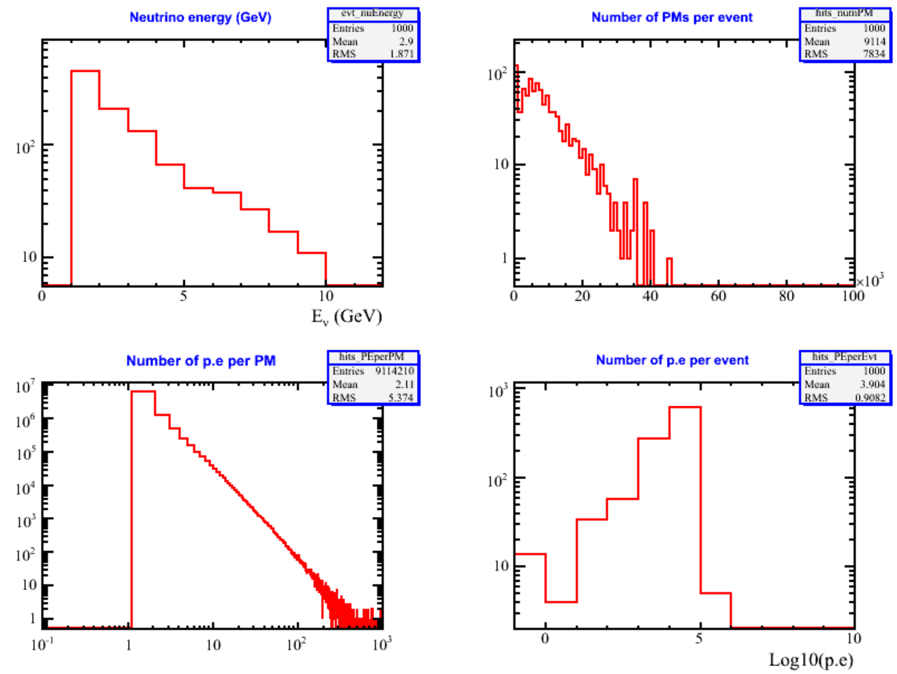
Interactive histogram to identify the e Michel optical photons...

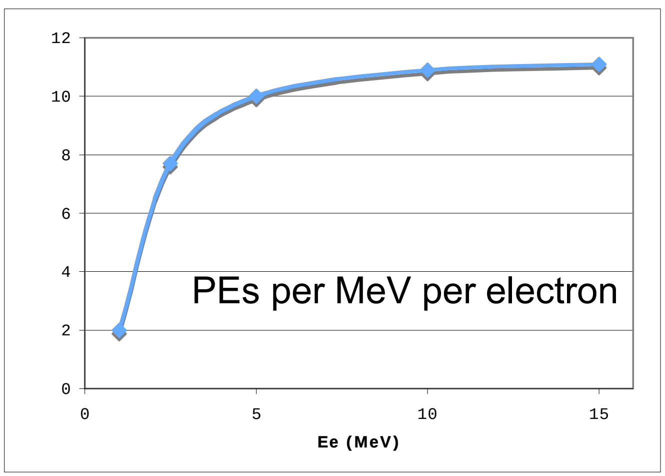
MEMPHYS simulations

» Visualisation "à la SK" developed



Atmospheric nu studies

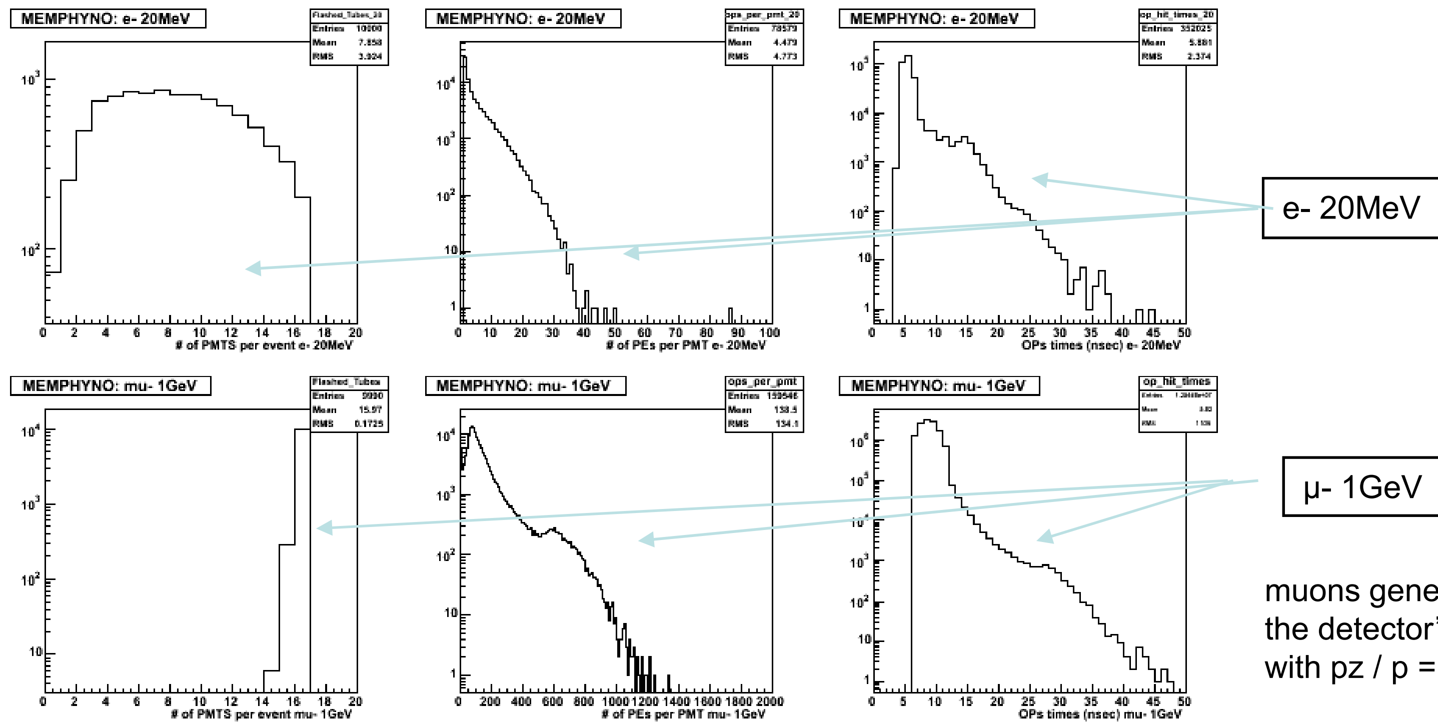




Vertex reco algorithm developed
Next step: Particle-ID

MEMPHYS: MEMPHYNO e-, μ- studies

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



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

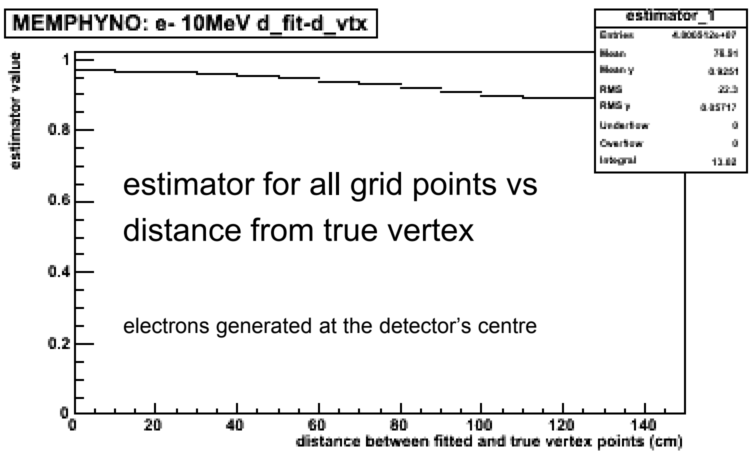
e- E (MeV)	1	2.5	5	10	15	20	25
PEs / MeV / el	0.2	1.1	1.5	1.7	1.8	1.8	1.8
X 6 (sides)	1.2	6.6	9	10.2	10.8	10.8	10.8
MEMPHYS	2	7.7	10	10.9	11.1	11.2	11.1

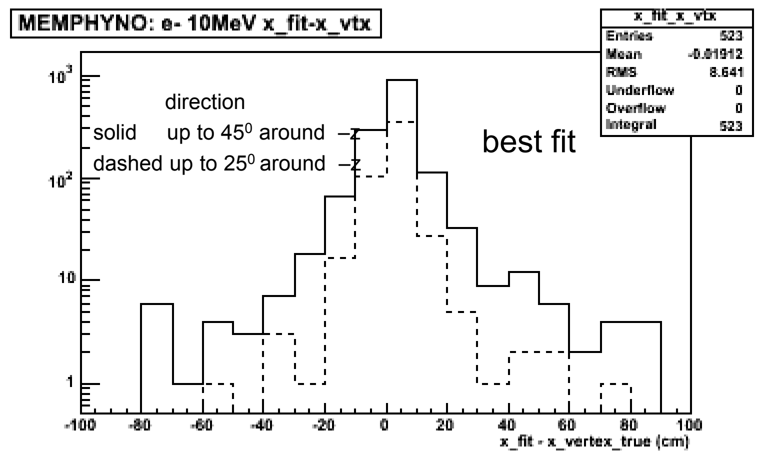
Table: MEMPHYNO's PEs per MeV per electron

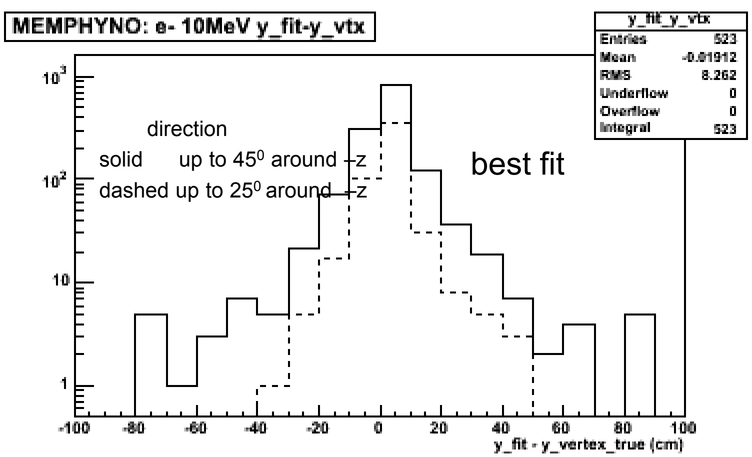
10k electrons per energy generated at the detector's centre with random direction

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 :



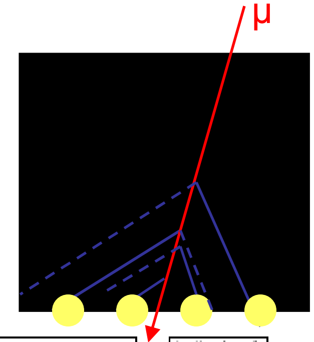




for the primary fit :

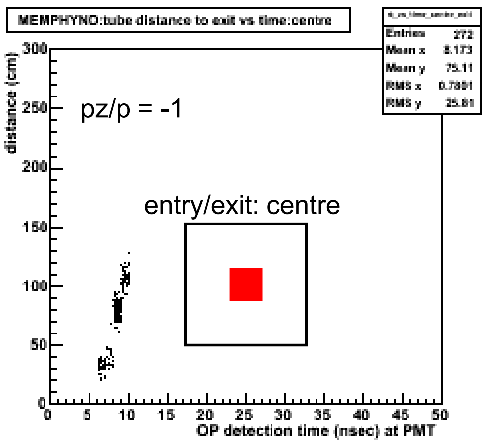
1. grid analysis (5cm spacing) in MEMPHYNO
2. good resolution for downwards electrons in x-y plane where is the PMTs' module (shown)
3. resolution becomes worse as pz/p increases due to one PMTs' module : best for perpendicular electrons

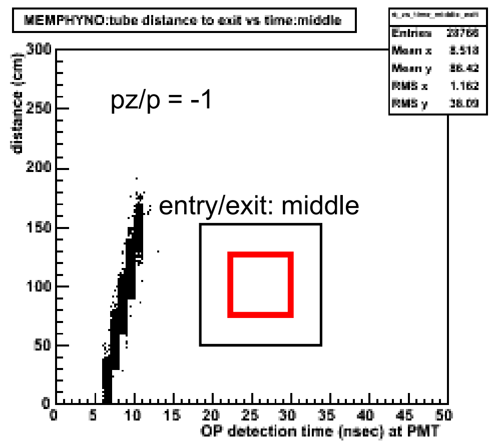
MEMPHYNO: muons 1 GeV

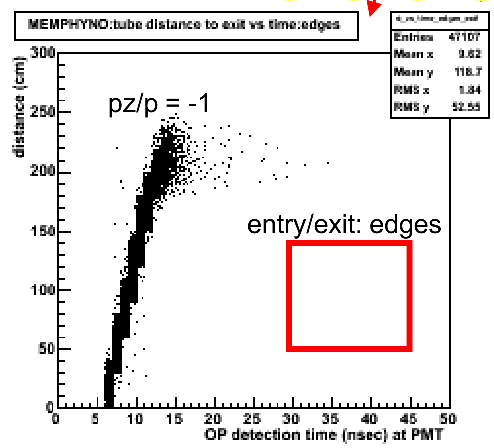


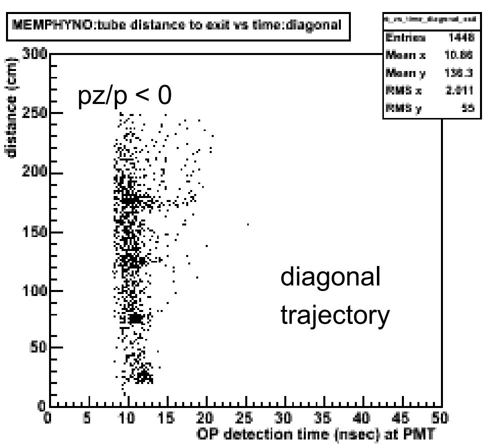
light propagation effect of OPs :

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





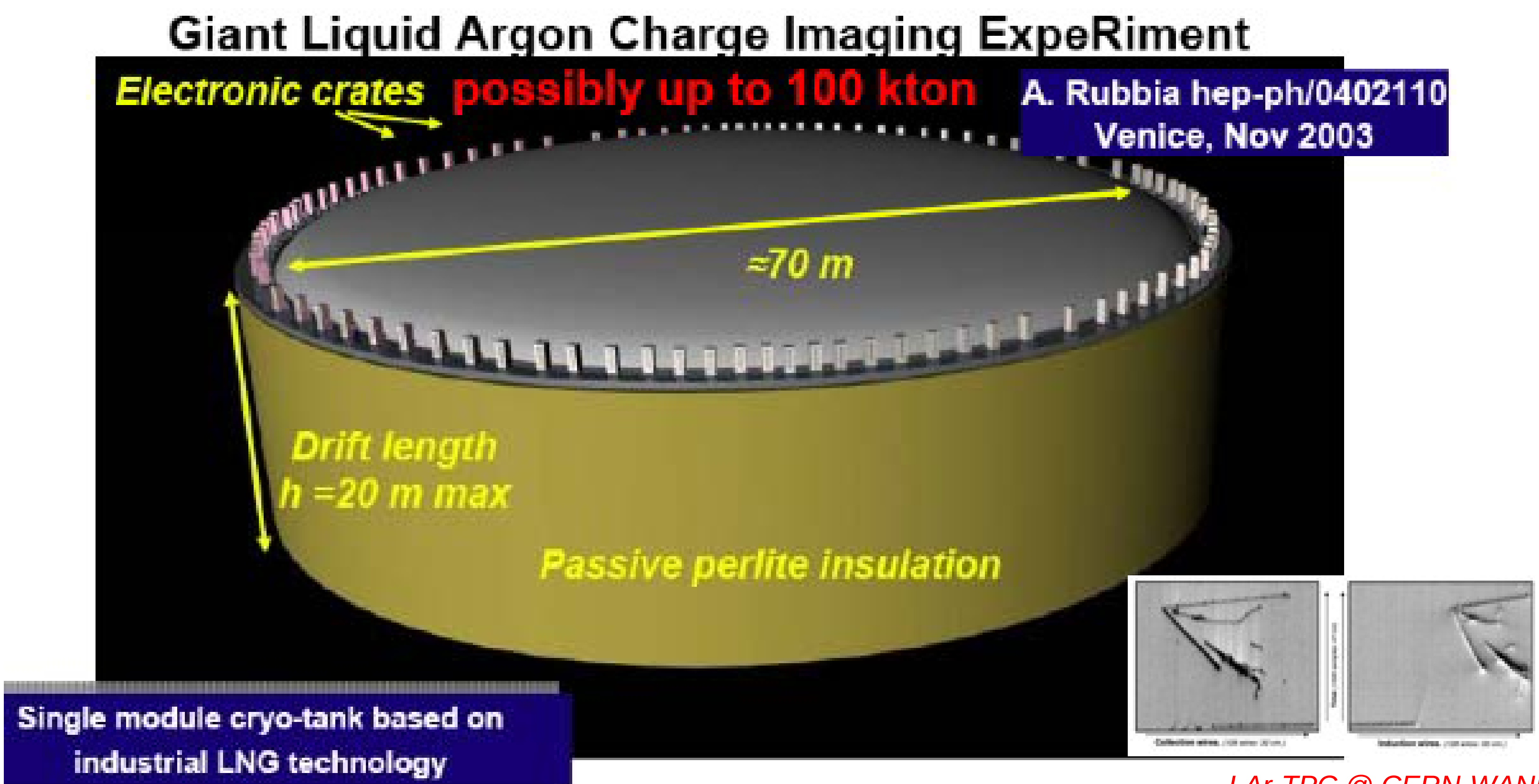




- pz/p = -1 : later produced OPs are detected first
- pz/p < 0 : relation not clean

LAr: GLACIER

A scalable detector with a non-evacuable dewar and ionization charge detection with amplification



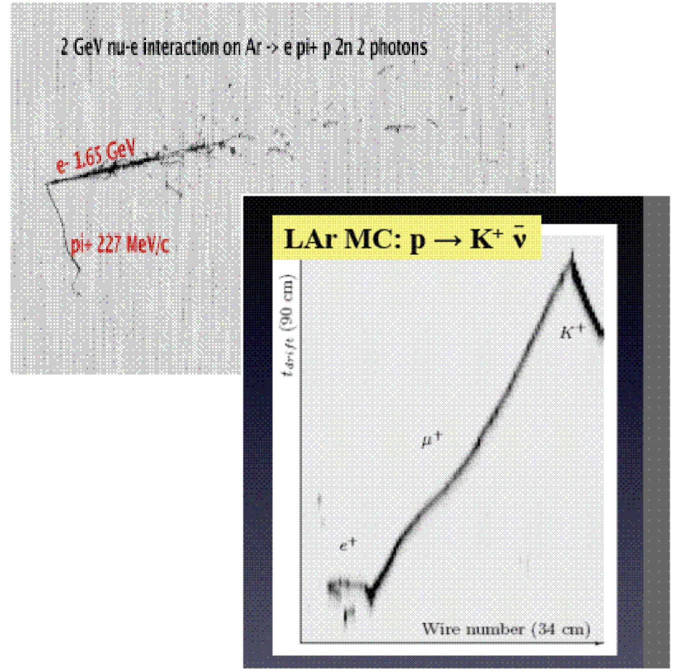
LAr-TPC @ CERN-WANF
Phys. Rev. D 74, 112001 (2006)

- LAr allows lower threshold than water Cherenkov for most particles
- Comparable performance for low energy electrons

LAr: Electronic Bubble Chamber

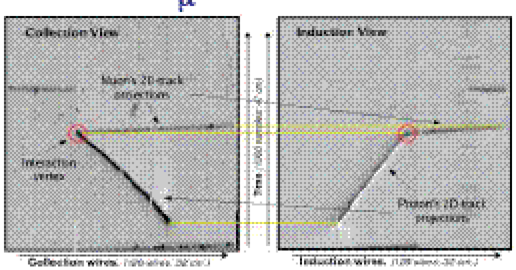
excellent tracking and calorimetric resolution to constrain the final state kinematics and suppress atmospheric neutrino background

- provides high efficiency for ν_e charged current interactions
- high rejection against ν_μ NC and CC backgrounds
- ideal for branching mode identification in p decays
- embedded in a magnetic field provides the possibility to measure both wrong sign muons and wrong sign electrons samples in a neutrino factory beam
- unlike WC detectors, detection and reconstruction efficiency does not depend on volume of detector

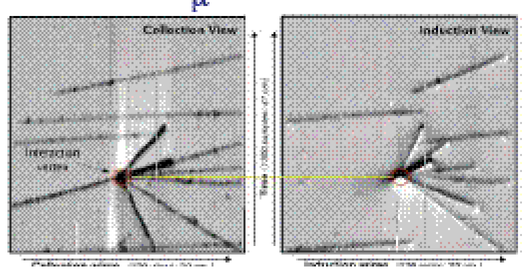


LAr-TPC @ CERN-WANF *Phys. Rev. D 74, 112001 (2006)*

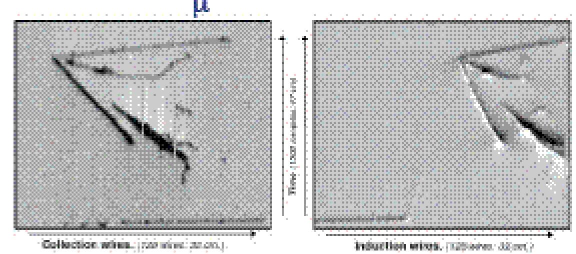
ν_μ CC-QE



ν_μ CC DIS



ν_μ CC-RES

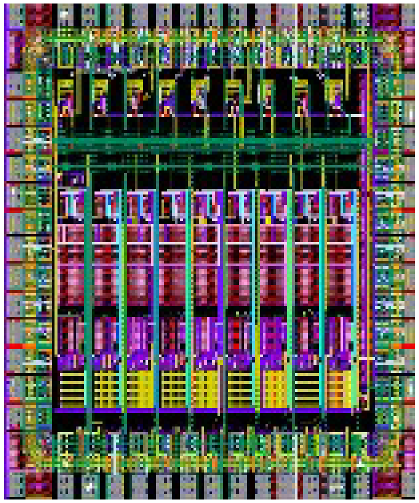


GLACIER R&D

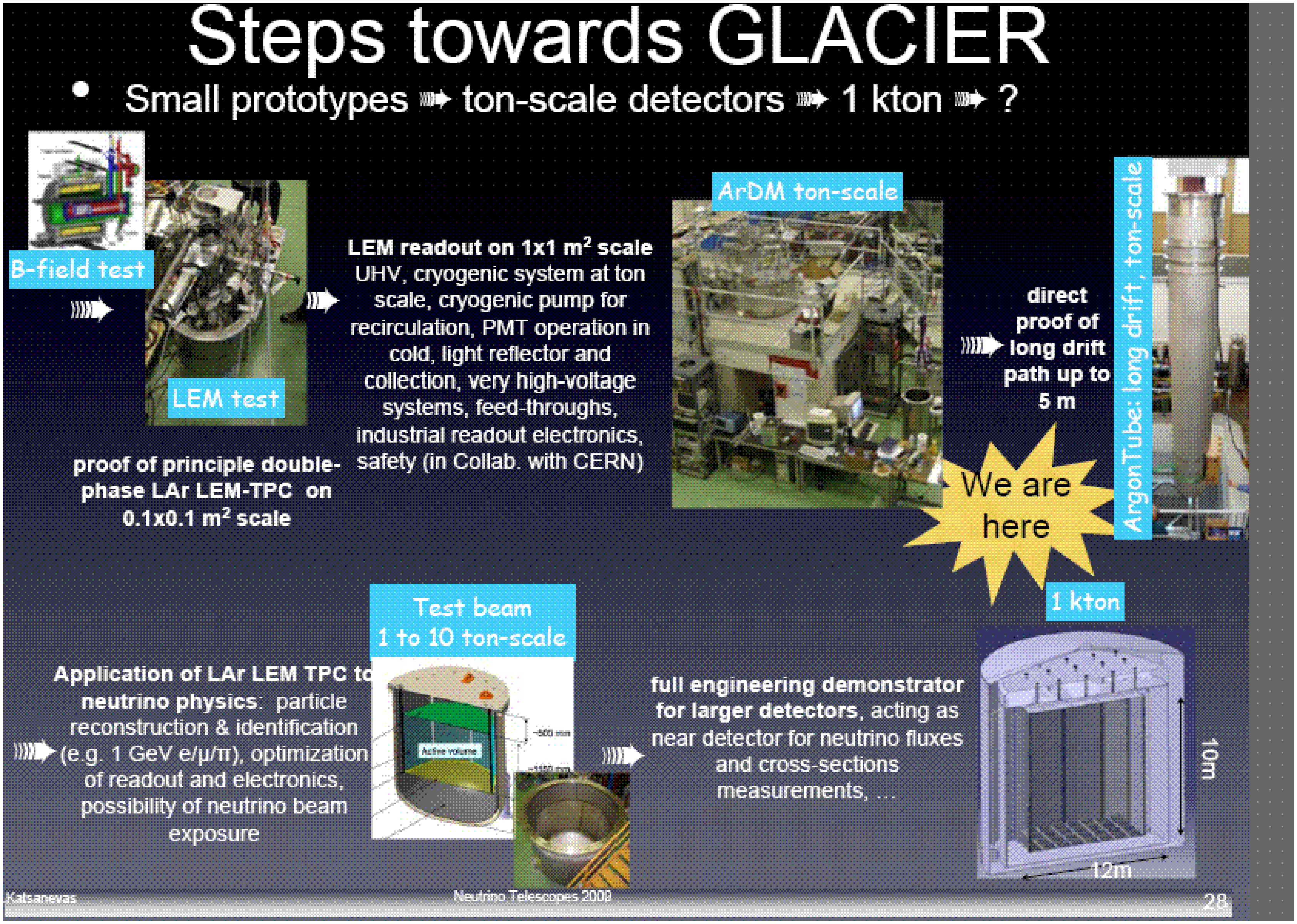
A.Marchionni @NNNN08

Critical issues for construction ➲ R&D items:

- Drift over long distances in Ar: Ok if high purity ➲ purification system
- Dewar ➲ (non evacuable?) R&D with Technodyne in LAGUNA
- HV system
- ReadOut system ➲ Novel techniques, other than wires, possibly with charge multiplications (double-phase with Large Electron Multiplier)
- Electronics ➲ Aggressive R&D on warm/cold solutions (IPNL+ETHZ)
  - analog ASIC amplifier working at cryo temperature
  - Gygabit Ethernet readout chain + network time distribution PTP
- Detector engineering

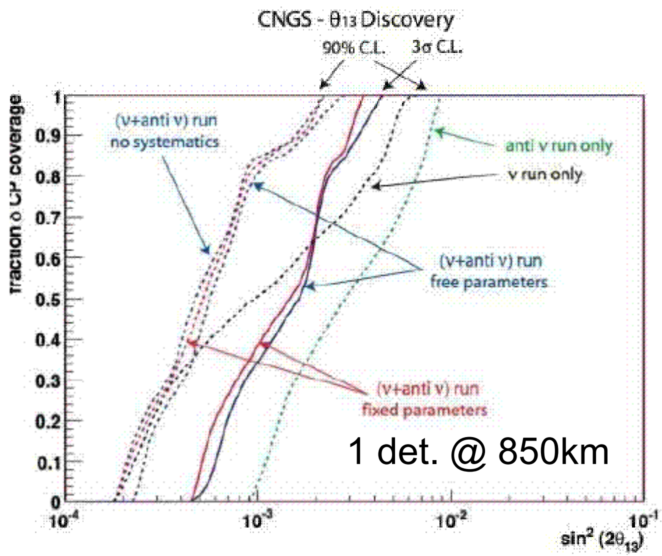


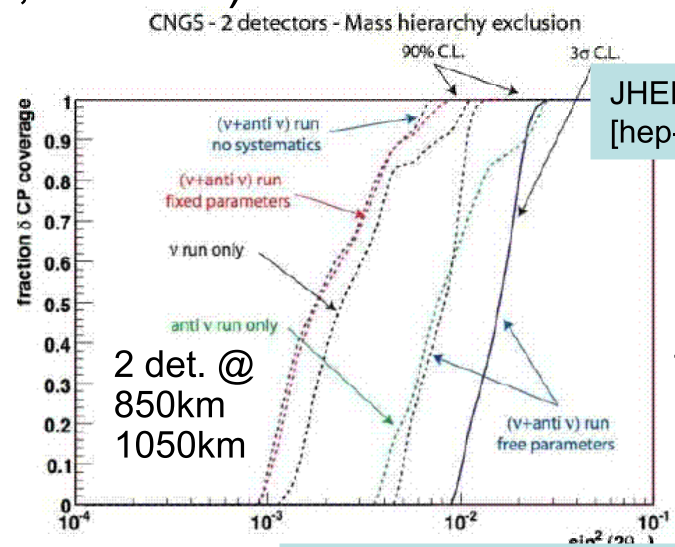
Prototyping: ArDM [ton-scale], ArTube [long drift]


Steps towards GLACIER
Small prototypes ➠ ton-scale detectors ➠ 1 kton ➠ ?
B-field test
LEM test
proof of principle double-phase LAr LEM-TPC on 0.1x0.1 m² scale
LEM readout on 1x1 m² scale
UHV, cryogenic system at ton scale, cryogenic pump for recirculation, PMT operation in cold, light reflector and collection, very high-voltage systems, feed-throughs, industrial readout electronics, safety (in Collab. with CERN)
ArDM ton-scale
direct proof of long drift path up to 5 m
ArgonTube: long drift, ton-scale
We are here
1 kton
10m
12m
Test beam
1 to 10 ton-scale
Application of LAr LEM TPC to neutrino physics: particle reconstruction & identification (e.g. 1 GeV e/μ/π), optimization of readout and electronics, possibility of neutrino beam exposure
full engineering demonstrator for larger detectors, acting as near detector for neutrino fluxes and cross-sections measurements, …
Katsanevas
Neutrino Telescopes 2009
28

GLACIER physics reach @ ν-beams

- Upgraded CNGS (PS+ 50 GeV/c, 200 kW) + GLACIER off-axis



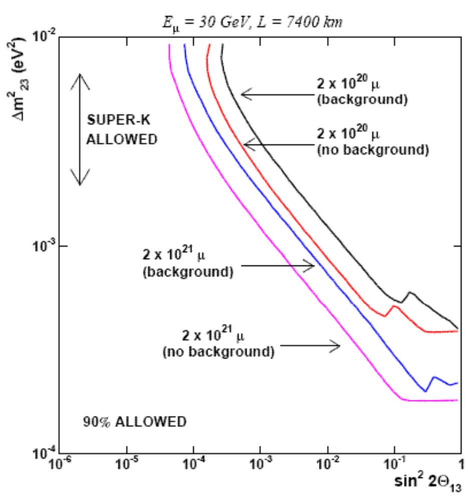


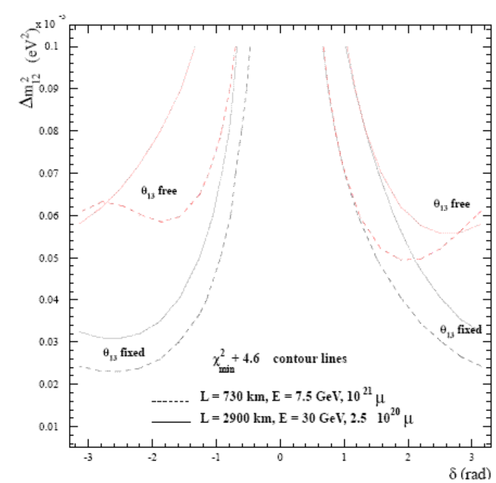
JHEP11(2006)032
[hep-ph/0609106]

=> Similar sensitivity to T2KK

- Neutrino Factory + magnetized GLACIER

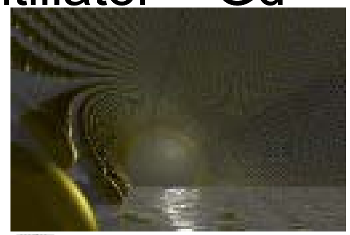
Nucl. Phys. B 589 577 [hep-ph/0005007]
Nucl. Phys. B 631 239 [hep-ph/0112297]

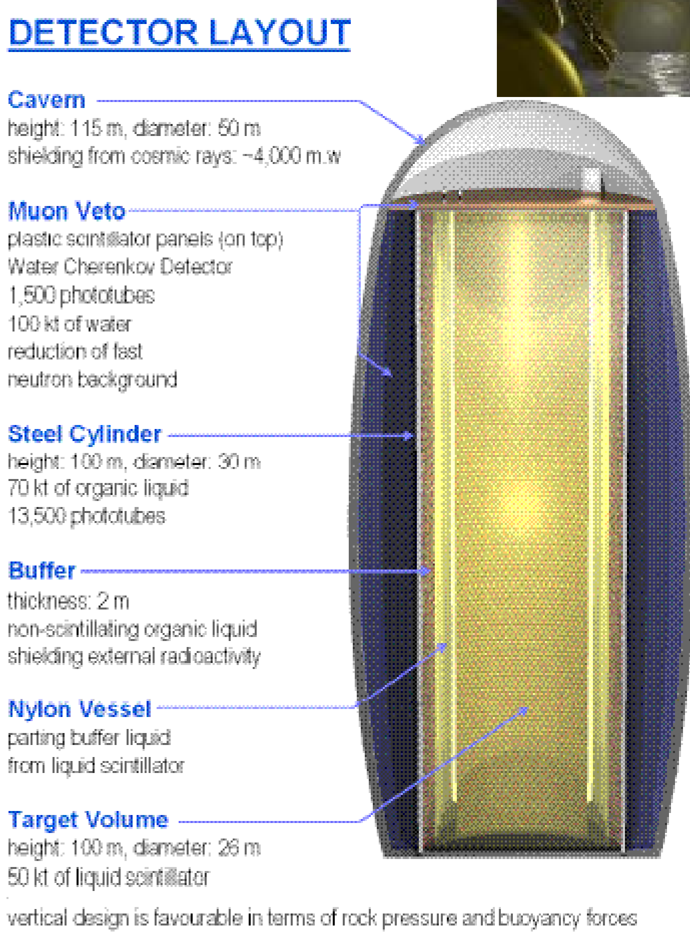




LENA

- 50 kt Liquid Scintillator + Gd





Physics reach:

Can be used for low-energy beta-beams

- e/μ separation based on track length and scattering, μ decays
  => 90% eff. on μ with 1% e bkg

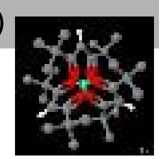
Advantage: good energy reconstruction

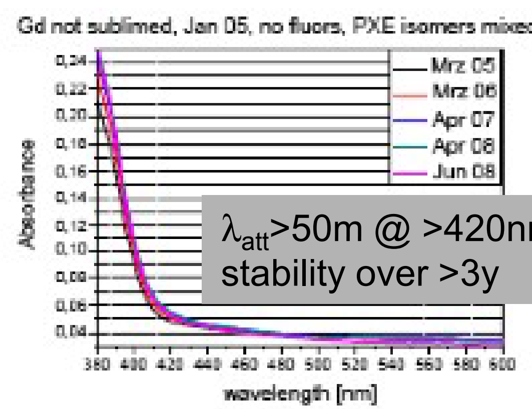
R&D towards LENA:

- Gd-doped scintillator:
  timing, stability

cfr results already achieved in Double Chooz
Scaling to very large scale not trivial

carboxylates (LNGS)
beta-dikitonates (MPIK)





λ_{att}>50m @ >420nm
stability over >3y

A 1st draft of our workplan (1)

Physics reach:

- Continue developing Water-Cherenkov simulation, including particle-ID algorithm to make realistic evaluations of efficiencies and background vs threshold

- New input beams for WC, LAr
  - optimize SPL target, optics
  - higher proton energy ?

  (cfr WP2 - thanks to M.Zito, M.Mezzetto)

- Water-Cherenkov at a Neutrino Factory ? [Huber-Schwetz]

- Possible physics reach at other European underground sites [LAGUNA]

- Possibility of smaller modules at different locations (Europe, USA, Japan)

A 1st draft of our workplan (2)

Cost estimate:

- excavation --> LAGUNA
- infrastructure
- tank
- liquids
- purification
- cooling/refrigeration
- photon detectors (for WC, LS)
- readout electronics
- .....

PHOTONIS will stop PMT production in July 2009:
- dramatic impact on costs and timescales for PMTs
- more urgent need for alternative photodetection solutions

Need to collaborate with LAGUNA Design Study