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“ Detector parameters ”

More open questions than answers.

- What kind of optimization.
- Choice of muon momentum.
- Magnetic detectors. The 5 GeV cut. The combination of baselines.
- The silver channel.
- Liquid Argon
- Conclusions

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What purpose will the Neutrino Factory serve?

As pointed out by P. Huber, M. Lindner, M. Rolinec and W. Winter, hep-ph/0506237 Nufact cannot be simultaneously optimized for all its purposes. A choice must be done. Furthermore the present absence of information about θ_{13} prevents a parameter optimization.

My personal ranking of Nufact objectives is

1. Discover leptonic CP violation (LCPV).
2. Decide $\mathrm{sign}(\Delta m^2)$
3. Discover θ_{13} or measure it

Muon momentum: 20 vs. 50 GeV

In favor of 50 GeV

- About 6 times more oscillated and detected events at a given baseline (computed with Globes)
- Better match with the 5 GeV cut (see later)

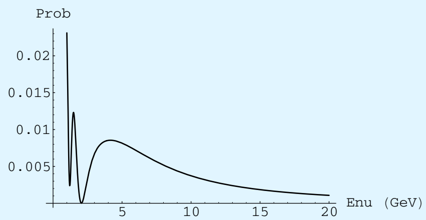
In favor of 20 GeV

- Save 1 G$
- Better match with the oscillation probability.

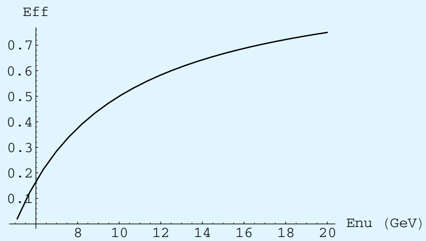
- Nufact feasibility study 2: 20 GeV.
- Literature (to my knowledge): no detailed study of Nufact performances at 20 GeV. Most of the papers are for 50 GeV muons.

20 GeV

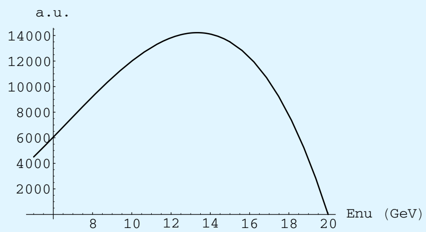
Oscillation Prob.



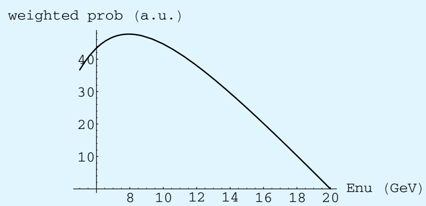
Efficiency (cut at $p_\mu > 5$ GeV)



$\overline{\nu}_e$spectrum (a.u.)

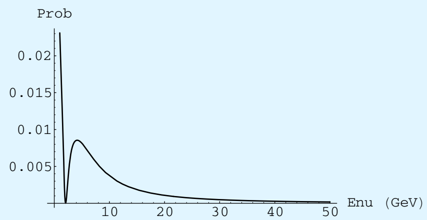


weighted prob. (a.u.)

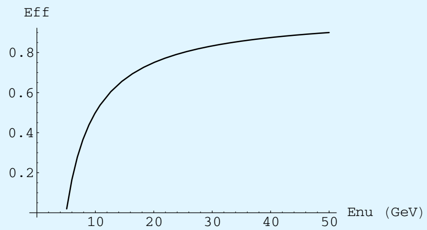


50 GeV

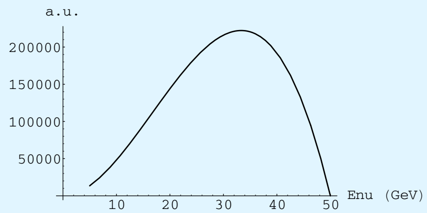
Oscillation Prob.



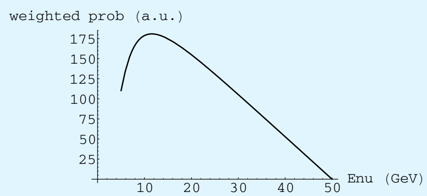
Efficiency (cut at $p_\mu > 5$ GeV)



$\overline{\nu}_e$spectrum (a.u.)

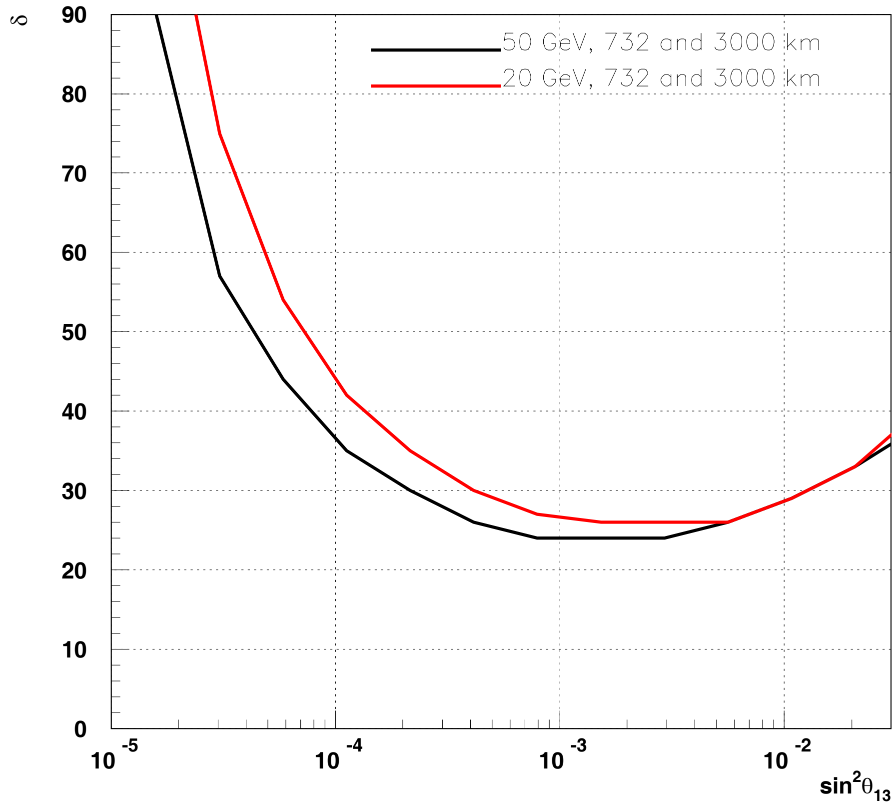


weighted prob. (a.u.)



Concerning δ discovery potential, the difference is not that big

- Computed with Globes, using the magnetic detector parametrization of Huber, Lindner and Winter, hep-ph/0204352.
- $\mathrm{sign}(\Delta m^2)$ and octant degeneracies not included. Everything else is included.



Detector technology

At present, three candidates:

- **Iron magnetized detector (LMD)**: studied in A. Cervera, F. Dydak and J. Gomez Cadenas, Nucl. Instrum. Meth. A **451**, 123 (2000). Most informations derived by the Minos proposal. The detector parametrized by Huber, Lindner and Winter, hep-ph/0204352 is very similar with a notable difference: more aggressive energy binning.
- **Liquid Argon**: studied in A. Bueno, M. Campanelli and A. Rubbia, "Physics potential at a neutrino factory: Can we benefit from more than just detecting muons?," Nucl. Phys. B **589** (2000) 577 [hep-ph/0005007]. It could be complemented by a downstream spectrometer or embedded in a gigantic open air magnet.
- **Emulsions**: as studied in D. Autiero *et al.*, Eur. Phys. J. C **33** (2004) 243 [hep-ph/0305185].

	Iron	LAr + spectr.	LAr +magnet	Emulsions
ν_μ disappearance	X	X	X	
$\overline{\nu}_\mu$ appearance (golden)	X	X	X	
$\overline{\nu}_e$ disappearance			X	
ν_e appearance			X	
ν_τ appearance		?	?	
$\overline{\nu}_\tau$ appearance (silver)		X	X	X

Detector technology (II)

- A comparison/optimization of the different options is not present in literature
- It is impossible (to me) to compare the capabilities of the different choices with the information available in the published papers.
- It would be highly desirable to have a fair parametrization of the detector inside Globes and then compare different options on an equal foot.
- Obvious: without a reasonable cost estimate it's impossible to have a fair comparison.

The magnetic detector

A. Cervera, F. Dydak and J. Gomez Cadenas, Nucl. Instrum. Meth. A **451**, 123 (2000).

Parametrized from Minos:

$$\delta E_{\rm had} = 0.03 + \frac{0.76}{\sqrt{E}} \qquad \delta\theta_{\rm had} = \frac{17}{\sqrt{E}} + \frac{12}{E}$$

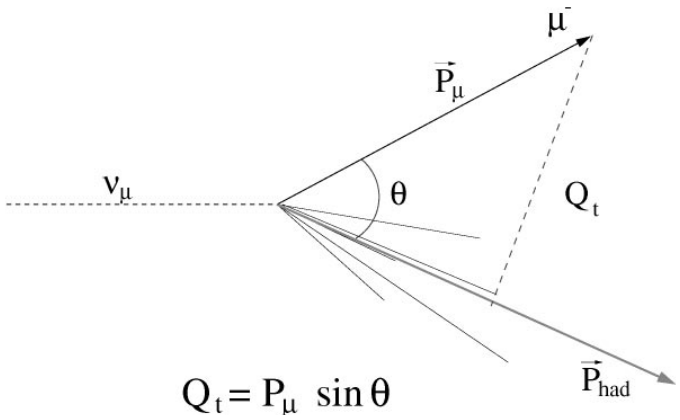
Backgrounds for the wrong-sign muon analysis:

- $D^- \to \mu^-$ decays in $\overline{\nu}_\mu$CC events where the primary μ goes undetected (NC-like).
- π^- decays in NC and NC-like events.
- Charge mis-ID of primary μ^+ (not studied in the paper).

To cut backgrounds:

$$p_\mu > 5 \text{ GeV/c} \qquad q_t > 0.5\text{GeV/c}$$

rejection power: 10^{-7} against $\overline{\nu}_\mu$CC and 10^{-6} against NC.



The magnetic detector (II)

Some remarks:

- It is misleading to believe that the magnetic detector task is to measure the charge and momentum of the muon: **to reject backgrounds it must measure the full momentum of the hadronic system. Hadronic energy must be measured to extract E_ν too**.
- For the given rejection powers a gaussian parametrization of $\delta\theta_{\mathrm{had}}$ is inadequate. Also a full MC reconstruction of the events would probably be inadequate.
- Hadronic jet momentum reconstruction is probably the main source of systematic error for Nufact computation, never taken into account.

My conclusion: background rate at Nufact is not precisely known.

According with (some of) the authors, the 1999 paper should be revised.

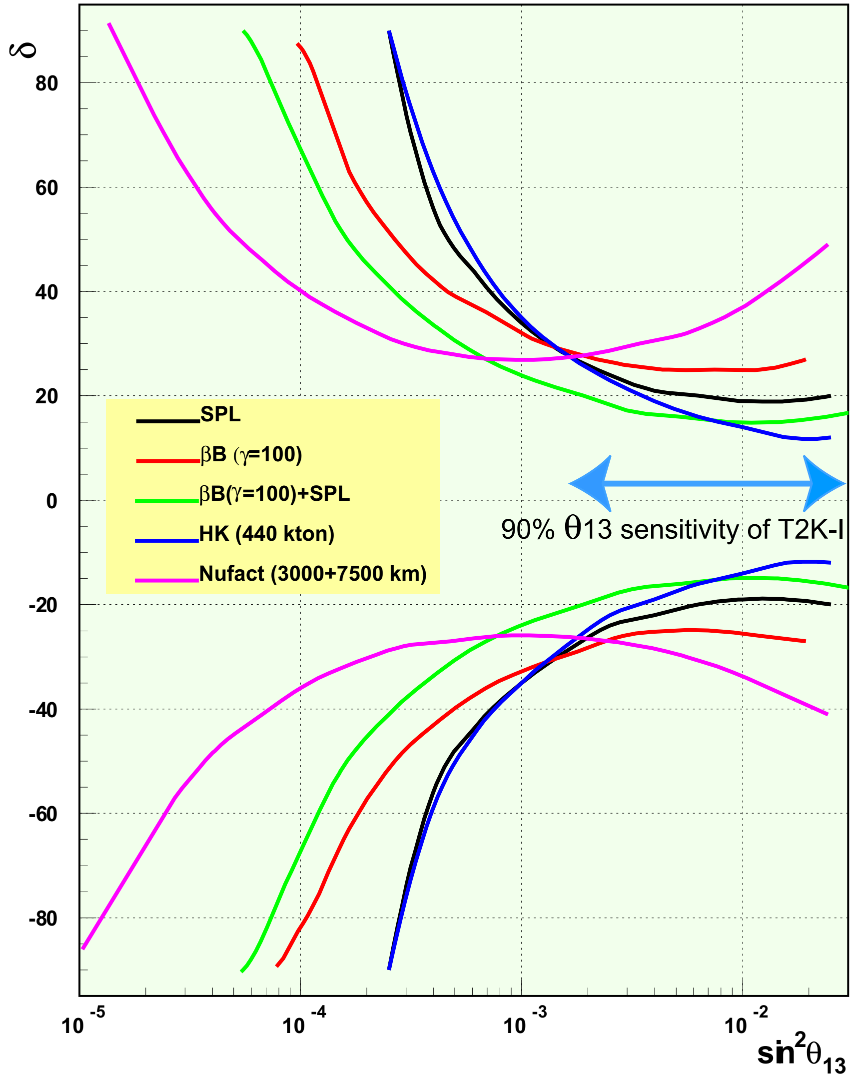
The 5 GeV cut

- Nufact detector at 3000 km is off-peak.
- Oscillation maximum is at low energy.
- The 5 GeV cut removes these events.
- Could this threshold lowered at the price of more backgrounds?
- The answer requires new simulations.

Anyway regarding LCPV:

- Nufact performances for $\theta_{13} > 2-3^\circ$ are compromised by the uncertainty of local matter density.
- Nufact outperforms any other facility at small θ_{13} just because its backgrounds are so small.

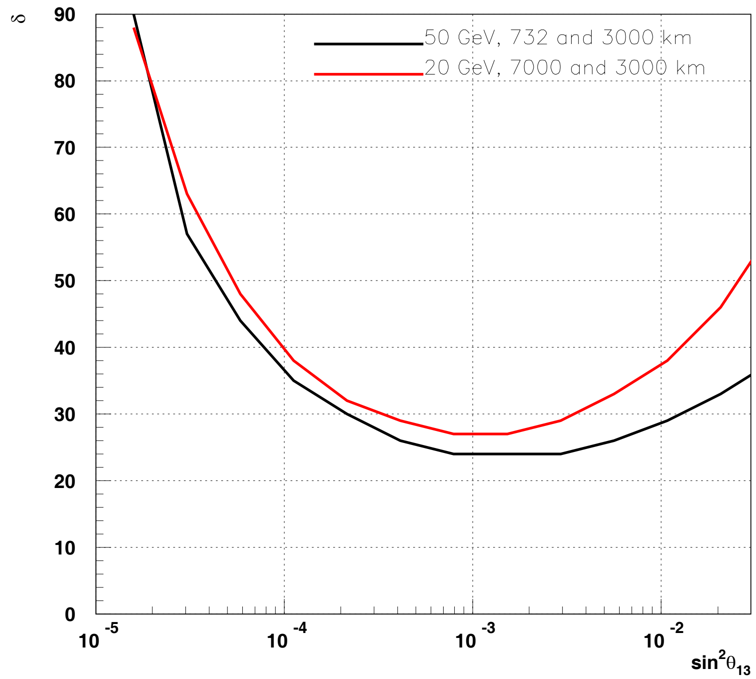
A reduction of the 5 GeV threshold could only deteriorate Nufact performances both on θ_{13} and LCPV.



The combination of baselines

A magnetic iron detector at 3000 km cannot remove the $\delta - \theta_{13}$ degeneracy.

It should be complemented by an identical detector at a different baseline. 732 and 7000 km have been studied. I find better performances for the 3000-732 combination, as far as concerns LCPV.



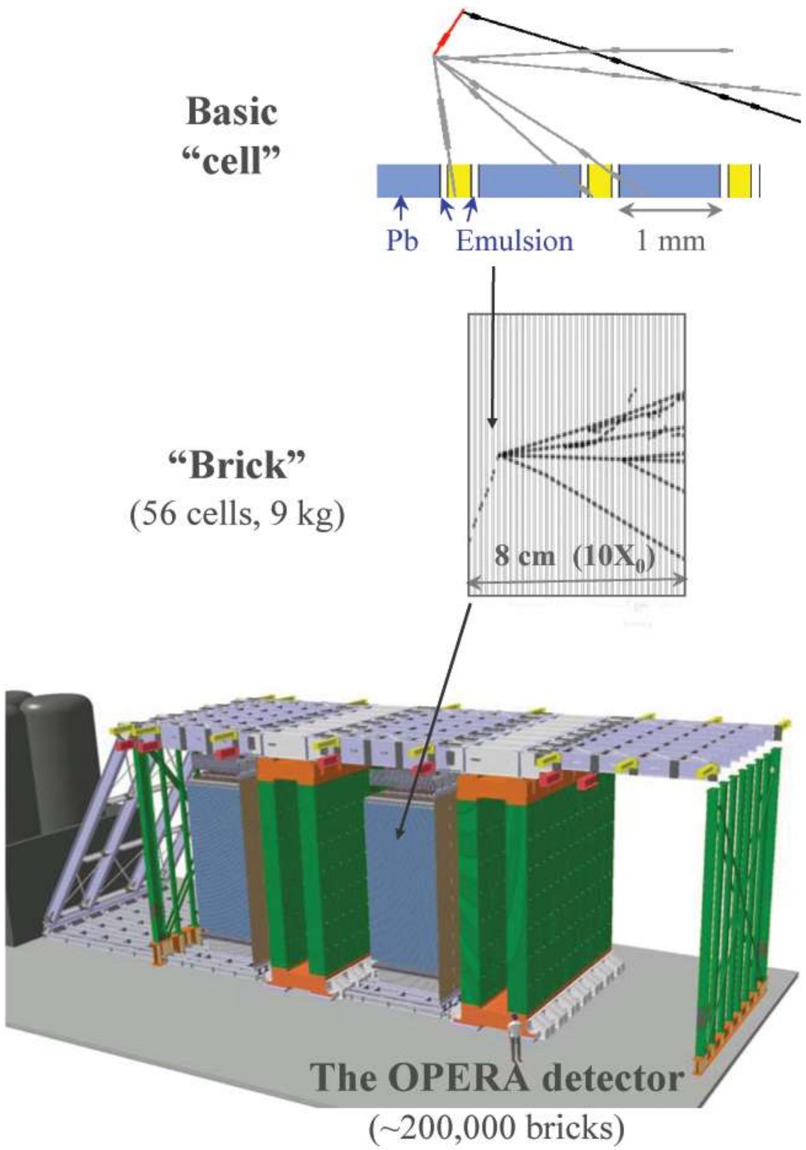
The combination of baselines (II)

Anyway I don't find very attractive this combination of two magnetic detectors:

- Of the 6 open oscillation channels, only 2 are exploited and the different L/E feature of the second experiment is used to solve the degenerate solution of the first one (3000 km).
- The second experiment is as difficult as the first one, but it doesn't see any oscillation signal. Not exciting.

The Emulsion Cloud Chamber (ECC) for $\nu_e \rightarrow \nu_\tau$ appearance at ν Factories

- $\nu_e \rightarrow \nu_\mu$ (golden events) and $\nu_e \rightarrow \nu_\tau$ (silver events) to reduce θ_{13} - δ ambiguities
- Pb as passive material, emulsion as sub-μm precision tracker: unique to observe τ production and decay
- 1.8 kton OPERA target mass $\rightarrow$ ~ 4 kton at ν Factory
- Search for τ-decay only in events with a "wrong sign" muon: x 2 increase of scanning power required
- Hybrid experiment: emulsion + electronic detectors
- OPERA as a "milestone" for the technique

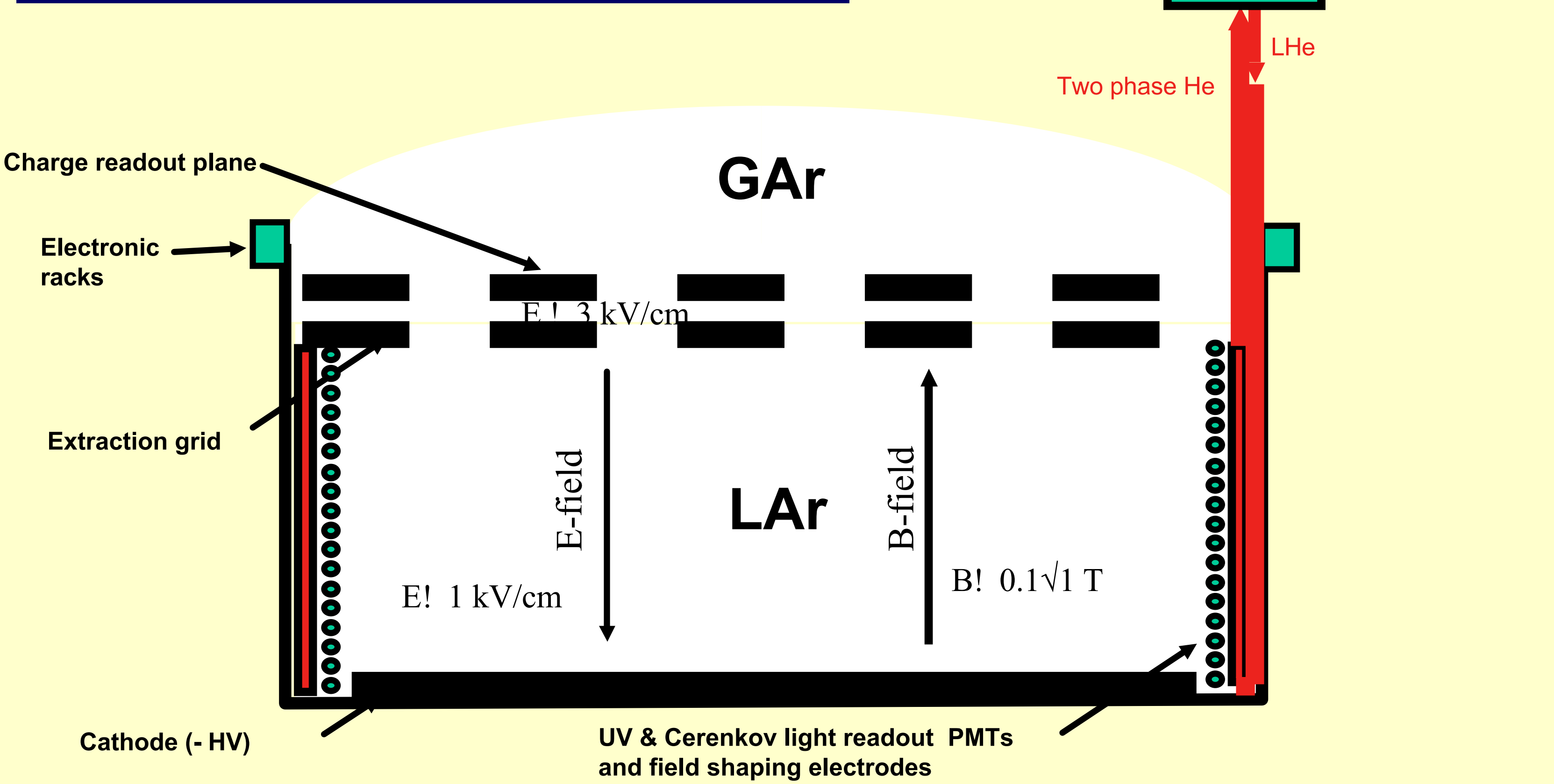


The silver channel (II)

- I still don’t understand if golden+silver is more or less powerful of golden+golden.
- It would be highly desirable to have a public Globes AEDL file for the emulsion detector.
- An emulsion detector needs a spectrometer, it is naturally complemented by a LMD detector.
- At CNGS Opera needs 20 microscopes to scan the changeable sheets plus 50 microscopes to scan the bricks. A single microscope costs 110 kEuro and must run 7/7 and 365/365.
- Also the on-line emulsion development appears to be close to its reasonable limit.

Tentative layout of a large magnetized GLACIER

Magnet: solenoidal superconducting coil



LHe Cooling: Thermosiphon principle + thermal shield=LAr

The Liquid Argon (II)

- The concept of measuring all the oscillation channels in a single detector overconstraining the oscillation parameters should be energetically developed.
- Once again the liquid argon technology appears as the most powerful.
- Once again the question is about the timescale and the costs of a several 10 ktons liquid argon detector possibly immersed in a 1 Tesla magnetic field.
- The operation of the T600 detector (whose technology cannot be used for Glacier), will be the first milestone for this long R&D program.

Conclusions

The Neutrino Factory physics potential studies now require more informations about detectors.

Iron magnetized detectors The only paper is 6 years old. It needs to be revised. Top priorities: background rejection, systematic errors, cost estimates.

Emulsions Thanks to Opera we have a detailed simulation of such detectors. Opera operation will be a crucial milestone. More studies could clarify the optimal combination of an emulsion detector with a LMD detector.

Liquid Argon The far future dream.

Other technologies, i.e. liquid scintillator + downstream spectrometer could be explored, but the real breakthrough would be the measure of the electron charge