Summary of the detectors session

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The detector session aimed at discussing the state of the art of detectors technologies for future neutrino experiments: how these technologies are matched to the possible physics measurements and their possible synergies with non accelerator physics; what has still to be done in order to prove their feasibility and assess/contain the construction costs. The goal of the session was also to outline a possible R&D programme to be carried out in Europe and at CERN.

The session was organised in four review talks on the main detector technologies: Water Cerenkov (WC), Liquid Argon (LAr), Magnetised Iron Calorimeters (MIND) and Totally Active Scintillator Detectors (TASD). For an extensive description of these technologies we refer the reader to the respective papers included in these proceedings. We will mainly discuss in this paper the critical points, as reflected by the outcome of the session. Three additional talks covered common aspects like photo-detection, electronics and the availability of underground sites. Several points/questions to be addressed by the talks were identified beforehand:

1. Detector phenomenology: energy range for each technology, matching to various kinds of beams, oscillation channels, etc... Non-oscillation physics at near detectors.
2. Technological aspects: scintillators, photodetectors, electronics, magnetisation, tanks for water, scintillator and LAr, etc ..
3. Feasibility and cost drivers. R&D towards cost reduction.
4. Time scale and intermediate steps towards full scale detectors.
5. R&D and expertise in Europe
6. What can be learnt from existing detectors?
7. Test-beams to be done at CERN and in other laboratories.
8. Interplay between programs in different regions. The role of Europe in a hypothetic world wide collaboration.
9. Synergy with non accelerator physics
10. Sites within Europe and outside Europe

The session was completed by a round table discussion divided in three parts:

a) **Discussion on the physics performance:** points affecting the sensitivity which have still to be clarified. Possible roles of the various techniques on the future physics scenarios. Synergies with non-accelerator physics.
b) **Discussion on the costs/feasibility:** Identification for each technique of the cost/feasibility drivers and the key R&D points needed in order to assess or improve the feasibility/costs.
c) **R&D roadmap:** planning of the R&D items over the next years, possible intermediate steps in detectors applications, and which could be the role of CERN in participating to the R&D and test-beam activities.

We just list below the main questions raised during the round table discussion. Later on in the text, when summarising the outcome of the session and the round table, will comment on the answers and the overall result of the discussion. The questions raised during the physics performance session of the round table were:

1) Which is the ultimate limit for the muon (and charge) identification threshold in MIND ?
2) The complementarities and possible synergies among TASD and MIND
3) Performance of the electron charge measurement in TASD
4) Possibility of performing tau appearance in TASD
5) Which is the LAr performance at a neutrino factory (for what concerns the golden, silver and platinum channels)?
6) Which is the WC performance at high energy (LBL)?
7) Efficiency and background for electron identification
8) Synergies with astro-particle physics

During the discussion on the feasibility/costs drivers, questions were raised on the plans to establish the cost estimates for each detector, the future availability of wavelength shifting fibres and the projected costs for electronics and photo-detectors. The last part of the discussion on the R&D roadmap was focused on the required test-beam measurements still needed to understand the detector performance and on the possible intermediate steps towards the full size detectors. A review of the test-beam facilities was presented and a possible organisation of the R&D activities based on the past successful structure of the R&D projects for LHC was evocated.

The outcomes of the session and of the round table were summarised in a talk given at the end of the workshop: we report below the conclusions on the state of the art and the still open points concerning each one of the four technologies.

Magnetised Iron Calorimeters (MIND): this is the baseline detector for the conventional Neutrino Factory (0-25 GeV neutrinos), with proven performance both with real data (MINOS) and simulations. One of the main issues is the relatively high neutrino energy threshold (~4GeV), which is mainly due to the requirement of a low muon charge mis-identification. A level of charge mis-identification around 10^{-4} seems feasible on the basis of the MINOS experience and current MIND simulations; however a test-beam programme is needed in order to directly check this figure and also to study the hadron shower profiles and the subsequent hadron angular resolution. MIND, as neutrino factory detector, should try to improve MINOS performance, mainly by reducing the muon reconstruction threshold (at a reasonable background level) from about 4 GeV to 2 GeV. This translates in trying to achieve a better longitudinal segmentation (2.5cm iron plates in MINOS) and increasing the magnetic field (this seems feasible at the level of 20%) to reduce charge mis-identification at low energies. The shape of the scintillator strips (triangular enhancing the space resolution vs rectangular enhancing light yield) should be optimised as well. The cost drivers for this detector are the scintillators, the photodetectors and the electronics. The extrapolated cost is around 230 M$ for a 100 Kton detector (20 times MINOS). It has been agreed that no intermediate steps in the detector construction are needed.

Totally Active Scintillator Detector (TASD): this detector is mainly motivated by its application at low energy neutrino factories, showing an extraordinary performance in muon neutrino appearance searches, with a threshold of about 0.5 GeV. A perfect prototype is represented by the NOνA detector currently under construction. The future detector would have a mass of 20 Kton (1.33 times NOνA) and 6.7 millions of channels (20 times NOνA). Its capabilities would be further boosted if electron neutrino appearance is also possible (NOνA has 35% efficiency for 0.1% NC background), but this relies on a charge mis-identification for electrons at a reasonable level. This particular point needs to be understood with both simulations and test-beams. Furthermore, a tau appearance measurement (at higher energies) on statistical basis seems possible (NOMAD, Super-Kamiokande), but needs to be understood. The cost of such a detector is around 850 M$ (about 6 times the one of NOνA). The cost is driven by scintillators, photodetectors and electronics. The current design assumes solid scintillator, although liquid scintillator (as in NOνA) appears cheaper (3$/Kg against 6-10$/Kg). From the point of view of the feasibility assessment an R&D on the magnet is needed, however an intermediate size detector other than NOνA does not seem necessary. The synergy with non accelerator programs is limited by the detector mass; however this point needs to be further studied.

Liquid Argon TPC; this technique, born in Europe, constitutes a very attractive and challenging option, which also has important synergies with non accelerator physics. The workshop highlighted considerable parallel R&D efforts in Europe, Japan and USA. Although important achievements were obtained on the charge readout (double phase), electronics, integration of a magnetic field and liquid argon purity, critical R&D items for future large scale applications are still represented by the storage tanks, the liquid argon purity, the drift over long distances and the possibility of adding a magnetic field for neutrino factory applications. From the point of view of physics performance it was mentioned that it will be needed to complete the Monte Carlo studies for neutrino factories. Test-beam activities in order to complete the understanding of the detector performance with hadrons, electrons, neutral pions, etc, are needed and will be proposed at CERN in 2010 for a 6 m^3 detector. A detector of the Glacier size (100 KTon) would represent an extrapolation by a factor 150 of the existing ICARUS T600 detector. It is clearly agreed that on the path for building such a large size detector at least one intermediate step will be needed; a detector of the order of 1 Kton (with sufficiently large drift: 12m diameter and 10 m height is one of the proposals) seems to be a reasonable compromise between timescale/cost and the minimisation in the extrapolation.

Water Cerenkov detectors: this is a well established technique, which has proven synergies with non accelerator physics. Detectors have been proposed in Europe, Japan and USA, representing in all cases an extrapolation of a factor 10-20 with respect to Super-Kamiokande. The detector looks feasible with the present state of the art knowledge and many R&D items are ongoing on the cavern excavation, the liner, the support structure for the photodetectors, the water purification, etc. The cost quoted for Hyper-Kamiokande is about 700 M$ including the cavern, being photodetectors the cost driver (about 65% of the instrumentation cost). In this respect important developments are taking place for the HAPD option, which should be ready by 2013. In principle, no intermediate steps are needed for this detector; however if HAPDs are finally chosen, it will be needed to acquire experience with them on large scale. From the point of view of the physics performance the response to high energy showers should be clarified.

Regarding the R&D program for all four technologies, studies on the detector design and performance based on Monte Carlo simulations are already organised in the context of EUROnu (EU FP7 project) for the near detectors, MIND and the WC detectors. However, the technical detector R&D has to be developed in Europe, with the exception of LAr detectors, which were born in here. Prototyping is still missing for MIND and TASD, and new prototypes will be needed for LAr. An important issue to be addressed as soon as possible is the lack of dedicated test-beam activities for all options. It was highlighted the key role that CERN could naturally play both in the technical detector R&D and in the test-beam activities. This could also be the occasion to have a better and more coordinated organisation of all these efforts with a coherent follow-up. The organisation of the past LHC R&D programme was mentioned during the discussions and the round table as a clear positive example.