View metadata, citation and similar papers at core.ac.uk

brought to you by CORE

provided by Scientific Open-access Literature Archive and Repository

IL NUOVO CIMENTO Vol. 32 C, N. 3-4 Maggio-Agosto 2009
DOI 10.1393/ncc/i2009-10469-5

Colloquia: IFAE 2009

Future perspectives for neutrino physics at accelerators

M. Bonesini

INFN, Sezione di Milano Bicocca - Milano, Italy

(ricevuto il 19 Settembre 2009; pubblicato online il 23 Novembre 2009)

Summary. — New developments for neutrino physics at accelerators are reviewed, with a special emphasis on the Neutrino Factory option and its related R&D projects.

PACS `14.60.Pq` – Neutrino mass and mixing.

1. – Introduction

The on-going long baseline ν experiments (LBL) will confirm the atmospheric neutrino oscillation claim and establish the oscillation pattern itself. This is the first evidence, together with solar neutrinos, of a result beyond the Standard Model. The next step will be to determine mainly θ_{13} and the CP violating phase δ. In this context a vigorous *R&D* program (Neutrino factories, conventional superbeams and β-beams) is needed.

2. – The Neutrino Factory project

A neutrino factory (νF) is a muon storage ring where decaying muons produce collimated neutrino beams along its straight sections. Several νF designs have been proposed, such as the ones of references [1-3]: the IDS design is shown in fig. 1 (left panel). A high-intensity beam accelerated by a high-power proton driver produces in a thin Hg target, after some accumulation and bunch compression, low-energy pions. After a collection system, muons are cooled before acceleration up to 20–50 GeV/c, depending on the design. Accelerated muons of well-defined charge and momentum are then injected into an accumulator where they circulate until they decay, giving two neutrino beams along the straight sections. The physics program at a neutrino factory is very rich and includes long-baseline ν oscillations, short-baseline ν physics and slow muon physics [4]. For the design of a νF some key points have to be clarified with dedicated R&D experiments. They include targetry, both MC validation and feasibility studies of the target-pion collection complex, μ cooling and accelerator R&D (mainly the development of fixed-field alternating-gradient (FFAG) accelerators).

© Società Italiana di Fisica

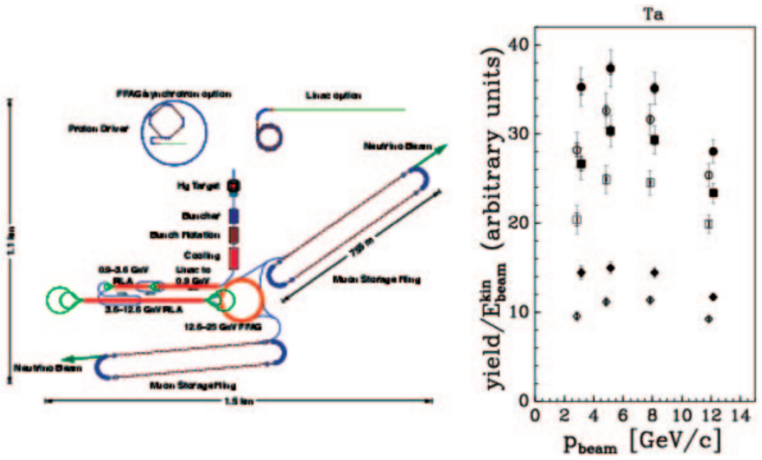

Fig. 1. – Left panel: schematic layout of a Neutrino Factory (IDS baseline). Right panel: π^+ (closed symbols) and π^- (open symbols) yields for different design of the NF focussing stage. The circles indicate the integral over the full HARP acceptance, the squares are integrated over $0.35\,\text{rad} \le \theta \le 0.95\,\text{rad}$, while the diamonds require in addition $250\,\text{MeV}/c \le p \le 500\,\text{MeV}/c$.

The baseline option for a νF target is a Hg jet target with impinging particles at energies $10 \pm 5\,\text{GeV}$. Available data are very scarce and for the tuning of the MC simulations of the νF beamline the HARP hadron production large-angle data on heavy targets, such as Ta or Pb, are of utmost importance [5]. In the kinematics range of interest for a νF, the pion yield increases linearly with momentum and has an optimum between $5\,\text{GeV}/c$ and $8\,\text{GeV}/c$, as shown in fig. 1 (right panel).

In a νF, the produced pions are then collected through a magnetic horn or focussed through a superconducting solenoid (IDS baseline design). The MERIT (MERcury Intense Target) experiment at CERN [6] has studied the feasibility of a mercury-jet target for a 4 MW proton beam with solenoidal pion capture, obtaining positive results.

The cooling of muons (accounting for $\sim 20\%$ of the final costs) increases the performances of a νF up to a factor 10. Due to their short lifetime ($2.2\,\mu$s), novel methods such as the ionization cooling [7] must be used. The cooling of the transverse phase-space coordinates of a muon beam can be accomplished by passing it through an energy-absorbing material and an accelerating structure, both embedded within a focusing magnetic lattice. Both longitudinal and transverse momenta are lost in the absorber while the RF-cavities restore only the longitudinal component.

The MICE experiment [8] at RAL aims at a systematic study of one cell of the US Feasibility Study 2 cooling channel (see fig. 2 for its layout). A secondary muon beam from ISIS (140–240 Mev/c central momentum) enters the cooling channel after a diffuser. Pions from a movable Ti target grazing the primary ISIS beam, during its flat top, are captured by a quadrupole triplet and then momentum selected. Muons from the following pion decays inside a 5 m long, 5 T decay solenoid are momentum selected and directed towards the MICE apparatus. In the upstream section, before the MICE cooling cell, one TOF detector and two threshold Aerogel Cherenkov counters are used for the beam PID (see left panel of fig. 2). The 5.5 m long cooling section cell consists of three low-Z absorbers and eight 201 MHz RF cavities encircled by SC lattice solenoids, providing strong focussing. Particles are measured before and after the cooling section by two

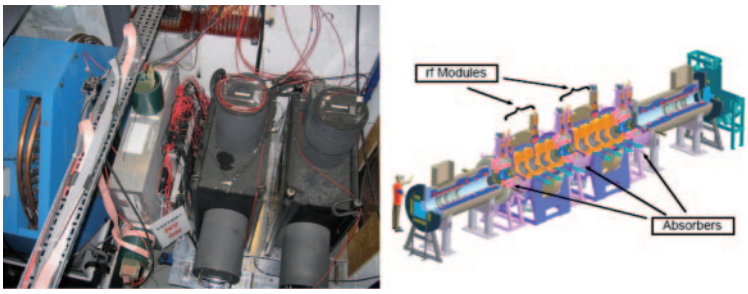

Fig. 2. – Left panel: upstream MICE PID detectors. Right panel: layout of the MICE experiment at RAL. The secondary μ beam from ISIS enters from the lower left.

magnetic spectrometers complemented by TOF detectors (with $\sigma_t \sim 50\,\mathrm{ps}$). For each particle the trackers determine x, y, $x' = p_x/p_z$, $y' = p_y/p_z$ and $t' = E/p_z$ coordinates, while the TOF stations measure the time coordinate t. For an ensemble of N particles, the input and output emittances are thus measured with high precision (0.1%), at a level not within reach of conventional multiparticle methods.

The driving design criteria of the MICE beam instrumentation are robustness, in particular of the tracking detectors, to sustain the severe background conditions nearby the RFs and redundancy in PID in order to keep contaminations (e, π) well below 1%. The MICE experiment will be done in stages and is expected to be finished by 2012.

3. – Conventional superbeams and β-beams

Conventional neutrino superbeams [9] exploit intense proton sources to produce ν's from pion decay. Open problems include targetry (mainly heating and thermal shock in the target) and the development of a multi-MW proton driver. The main limitations of a ν superbeam are connected to the intrinsic ν_e contamination ($\sim 1\%$) in the $\nu_\mu \mapsto \nu_e$ channel, the low energy of the produced neutrinos and the need of gigantic low-density far detectors, to access sub-dominant transitions to study θ_{13}. For neutrino superbeams two different approaches are envisaged: either the upgrade of an existing facility or the construction of a new facility usually as a first step towards a νF. As an example of the first case, in the JHF project the 0.75 MW Jaeri PS will be upgraded to 1.66 MW in a second phase. To increase the flux and reduce the energy spread, the detector will be put off-axis. Instead in the SPL CERN project, a 3.5–5 GeV superconducting H^- linac (SPL2) is designed mainly as a new injector to the LHC complex, with the possibility in mind to feed up a neutrino superbeam or be the first step of a future νF facility.

Many ingredients similar to a νF are incorporated in the β-beam concept. This novel scheme to produce high-intensity, low-energy ν_e beams is based on the decay in flight of accelerated β-emitters [10]. As an example, in the decay of the radioactive ion: $^6\mathrm{He}^{+++} \rightarrow {}^6_3\mathrm{Li}^{+++}e^-\overline{\nu_e}$ the He^6 ion can be accelerated to a Lorentz factor $\gamma = 150$ giving a highly collimated, low energy $\overline{\nu_e}$ beam (divergence $\sim 7\,\mathrm{mrad}$, $\langle E_\nu \rangle \simeq 581\,\mathrm{MeV}$). In the CERN design, β-emitters are produced using the SPL. The produced ions are then accelerated in the PS/SPS complex and stored in a storage ring, where ν's are produced by decay in flight along two straight sections. As the β-beam requires only a small fraction of the SPL protons ($\leq 10\%$), it is possible to run concurrently the β-beam and the superbeam. Both beams produce sub-GeV neutrinos, making feasible to use the

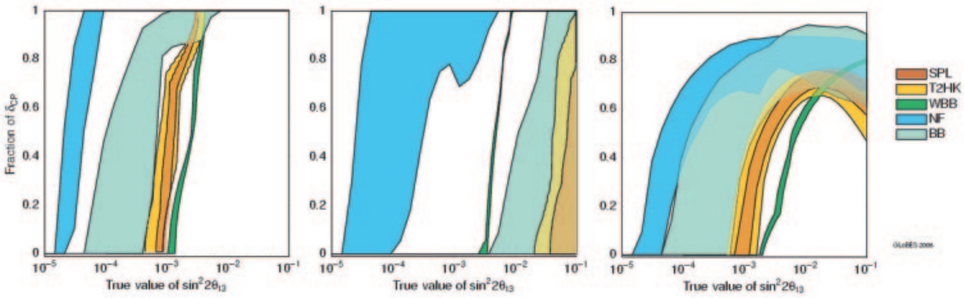

Fig. 3. – Comparison of physics performances for the different facilities proposed, where WBB refers to a wideband superbeam, BB to a β-beam and T2HK to the proposed upgrade of the T2K experiment. The bands show the room for improvements with respect to the baseline option.

same baseline and detector. Figure 3 shows from left to right the sensitivity to a non-zero value of $\sin^2 2\theta_{13}$, the sensitivity to the mass hierarchy (sign of Δm_{32}) and to the leptonic CP violation for the proposed facilities. Discovery limits are shown as fractions of all the possible values of the true values of the CP phase δ and $\sin^2 2\theta_{13}$, see [2] for more details.

4. – Conclusions

Experimental R&D results may soon strengthen the physics case for a νF and/or a superbeam/β-beam facility. Establishing the key techniques by the end of this decade, can pave the way to build a facility in the next one.

REFERENCES

[1] Alsharo'a M. M. *et al.*, *Phys. Rev. ST Accel. Beams*, **6** (2003) 081001.
[2] Bandyopadhia A. *et al.*, arXiv:0710.4947.
[3] Blondel A. *et al.*, CERN-2004-002.
[4] Bonesini M. and Guglielmi A., *Phys. Rep.*, **433** (2006) 65.
[5] Catanesi M. G. *et al.* (HARP Collaboration), *Phys. Rev. C*, **77** (2008) 055207.
[6] Bennet J. *et al.*, MERIT proposal, CERN-INTC-2004-016.
[7] Skrinsky A. N. and Parkhomchuk V. V., *Sov. J. Nucl. Phys.*, **12** (1981) 3.
[8] Blondel A. *et al.*, MICE proposal, RAL (2004); Gregoire G. *et al.*, MICE Technical Report, RAL (2005).
[9] Richter B., SLAC-PUB-8587.
[10] Zucchelli P., *Phys. Lett. B*, **532** (2002) 166.