PROCEEDINGS OF SCIENCE

Accelerator Working Group -WG3- summary

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The accelerator working group addressed the worldwide R&D activities performed on future neutrino facilities. These studies cover Super Beam, Beta Beam and muon cooling for Neutrino Factory facilities. Muon Colliders present numerous synergies with Neutrino Factories, especially in sections such as the proton driver and the much more demanding muon cooling for muon collider. The first muon collider design studies were as well followed with great interest. Beta Beam activities reported the excellent progress made, together with the research activity scheduled to take place in the coming years. Discussion sessions were also organised together with the other working groups in order to define common grounds for the optimisation of a future neutrino facility. The lessons learnt from already operating neutrino facilities are providing key elements for the design of any future neutrino facilities. Radiation damages, remote handling for equipment maintenance and exchange, primary proton beam stability and monitoring, were amongst the crucial subjects presented and discussed.
Status reports for each of the facility sections were presented: proton drivers, capture systems, front-end systems, targets and acceleration systems. Emphasise was given during each of the working group session to discussions. Prior to the conference, each speaker received a list of questions to be addressed during the presentation. The preferred scenario for each of the possible future facilities was presented, together with the challenges and remaining issues. The baseline specification for the Neutrino Factory was reviewed and updated when required. This report will emphasize new results / ideas and discuss possible changes in the baseline scenario of the facilities. A list of possible future steps will be proposed and could be followed-up at the NuFact09.

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1. Introduction

The accelerator working group addressed the worldwide R&D activities performed on future neutrino facilities. These studies cover Super Beam, Beta Beam and muon cooling for Neutrino Factory facilities. Muon Colliders present numerous synergies with Neutrino Factories, especially in sections such as the proton driver or the much more demanding muon cooling for the collider. The first muon collider design studies were as well followed with great interest. Beta Beam activities reported the excellent progress made, together with the research activity scheduled to take place in the coming years. Discussion sessions were also organised together with the other working groups in order to define common grounds for the optimisation of a future neutrino facility. The lessons learnt from already operating neutrino facilities are providing key elements for the design of any future neutrino facilities. Radiation damages, remote control and handling for equipment maintenance and exchange, primary proton beam stability and monitoring, were amongst the crucial subjects presented and discussed.

Status reports for each of the facility sections were presented: proton drivers, capture systems, front-end systems, targets, muon cooling and acceleration systems. Emphasize was given during each of the working group session to have more discussions. Prior to the conference, each speaker was invited (only) and received a list of questions to be addressed during the presentation. The preferred scenario for each of the possible future facilities was presented, together with the challenges and remaining issues. The baseline specification for the Neutrino Factory was reviewed and updated when required. This report will emphasize new results / ideas and discuss possible changes in the baseline scenario of the facilities. A list of possible future steps is proposed and could be followed-up at the NuFact09.

2. Proton Drivers

Since the final produced neutrinos represent a tertiary beam and since at each of the decay stage the fraction of usable particle is small, the proton driver is required to generate high beam power on target. Therefore, future neutrino facilities assumed a challenging primary proton beam power of 4 MW, which in turns leads to a bunch peak current of 2500 A in the 10 GeV one-bunch operating scenario –1 ns r.m.s. Each of the section of the proton driver requires pushing the technology to its limit or developing new techniques. For instance, amongst the many critical subjects presented –beam chopper, halo control / preparation for injection, injection, compression- the injection issues were in particular discussed. Apart from the charge exchange injection foils, with beam painting to reduce the foil heating, laser stripping shows very promising results at SNS and may be a solution for the future.

Possible changes in the baseline scenario parameter:

- Pulse duration at the liquid mercury target: disruption development measured at MERIT showed that the pulse duration could be relaxed to 150 μs within a solenoid field of 15 T. Consequences of such change on each system are to be assessed together with end-to-end simulation.

- Proton beam energy: better understanding of the low energy behavior around 5 GeV is to be performed making use of the recent HARP results.

The following baseline parameters for the Neutrino Factory proton driver scenario were endorsed:

Mean beam power	4 MW
Pulse repetition rate	50 Hz
Proton kinetic energy	5-10-15 GeV
Bunch duration at target	1-3 ns r.m.s.
Number of bunch extracted per pulse	1-3
Separated bunch extraction delay	≥ 17 µs
Pulse duration	≤ 40 µs for liquid mercury target → ≤ 150 µs ? ≥ 70 µs for solid metal target

Due to the early stage of the muon collider design, the specifications are still being assessed and design flexibility is therefore highly desirable. Needs are much more demanding than for Neutrino Factory, especially in the cooling systems.

Follow-up at NuFact09:

- Beam chopper, halo control / preparation for injection, injection (laser stripping results), compression issues
- Pulse duration at target: consequences of using 150 µs on each system, including end-to-end simulations
- Proton kinetic energy: better understanding of the lower energy behavior around 5 GeV, using cross section results from HARP

3. Targets

The target on which the proton beam impinges is a very challenging aspect of the neutrino facilities. Both solid and liquid mercury jet targets are studied with consideration given to effective pion production and the negative aspects of heating and thermal shock. At somewhat lower beam power (1-2 MW) solid targets are good candidates, but at higher beam powers, the target would need to be moving. This led the International Scoping Study to identify liquid mercury jet for the baseline target choice for Neutrino Factory.

The recently HARP cross section data are of great importance to cross-check the simulation performed in the design of neutrino facilities and re-visit the estimation made in the past, especially in the lower energy part where HARP results seem to indicate a lower optimum energy. An optimum design is to be found, and detailed analysis of the particle production around 5 GeV is to be clarified for the Neutrino Factory scenario.

Concerning solid targets, an important R&D work is being done, being on static or moving solid targets, and experiences from operating facilities are to be taken into account (CNGS, NuMI, T2K, PSI, LANL). Failure test with beam must be performed for solid targets and engineering and laboratory studies must continue.

Concerning free liquid jet targets, MERIT has validated the Neutrino Factory, Muon Collider target concept of a free liquid jet for 4 MW operation at 50 Hz. More R&D is to be performed on improving the jet quality and understanding of system design issues.

It was decided to keep the liquid jet target as baseline for the Neutrino factories and Muon colliders. For super beams which will be limited in beam power, static targets continue to be appealing.

Follow-up at NuFact09:

- Take advantage of the HARP data and revisit the estimates made in the past. This is essential for the design of any new neutrino facility
- Radiation damage: safety issues have to be taken as input from the beginning in the target design. Propose first maintenance / replacement scenario
- Liquid targets: results on R&D on improving the jet quality - engineering progress on the system design issues
- Solid targets: results of failure test with beam – progress on engineering and laboratory studies

4. Capture system

In order to maximize the secondary pion collection efficiency, the target needs to be surrounded by a large acceptance pion collection and focusing system. In the solenoid option, the equipment lifetime is limited by the radiation damage. R&D on radiation damage of insulator up to 10 MGy has started and must be pursued and closely followed-up. For the horn option case, the lifetime is limited by the mechanical fatigue of the equipment, which need to overcome ~ 10^9 pulses / year at 50 Hz. There again, engineering R&D is mandatory.

Finally the beam dump remains an issue as there is no way to extract protons off the solenoid, and therefore all the beam energy is dumped in the solenoid, which lead to the already mentioned solenoid radiation resistance issue. The radiation dose in the target station is also a concern as 70% of beam power is deposited in target cell. Finally, a maintenance scenario is to be proposed. There, experiences of operating facilities are crucial inputs to take into account as early as possible in the design phase.

Concerning the Neutrino Factory, it was decided to keep the solenoid as baseline (both signs can be provided simultaneously). As far as Super Beams are concerned, the horn is probably the best option.

Follow-up at NuFact09:

- Solenoids: R&D on radiation damage of insulator up to 10 MGy
- Horns: Can we overcome ~10^9 pulses / year at 50 Hz?
- Beam dump design: the energy not dissipated in the target has to be dissipated a few meters from the target. How to get all these MW out of the main channel?
- Radiation resistance of the target cell
- Maintenance / exchange scenario

5. End-to End Simulation

Simulation codes being ready, a campaign of end-to-end simulation is able to start. The codes must have an input-output compatibility, and few codes should be used for the same accelerator section to compare results. The start point is located right after the target and the end point at the decay ring. The simulation will be performed in sections with a re-generation of the beam distribution done at each stage. Matching regions in between each sections are to be done.

Follow-up at NuFact09:

End-to-end simulations: first results, including on matching regions between sections

6. Muon Cooling

Pros and cons of existing cooling schemes are presented，compared and discussed. Muon ionization cooling is considered to be one of the most promising schemes in practice so far. Theoretical and hardware development for muon ionization cooling channels are actively pursed under the US NFMCC (Neutrino Factory and Muon Collider Collaboration). The international MICE (Muon Ionization Cooling Experiment) collaboration continues making progress on the muon cooling demonstration experiment at RAL (Rutherford Appleton Laboratory), UK.

MICE cooling channels consist of three liquid hydrogen absorbers, eight 201-MHz normal conducting RF cavities that are surrounded by superconducting focusing and coupling coil magnets, respectively. MICE will measure ~ 10% of emittance reduction of muons at ~ 200-MeV/c energies. The cooling experiment is expected to begin in 2010.

However, challenges still remain in designing, building and operating the muon ionization cooling channel. Operating a high gradient normal conducting RF cavity in strong magnetic field is in particular very difficult, and more experimental studies are under way. Previous experiments conducted at MTA (Muon Test Area) of Fermilab using an 805-MHz cavity show that achievable RF gradients degrade with the increase of external magnetic fields. The experimental program is turned to more fundamental study of RF breakdown in strong magnetic fields. More tests are conducted using an RF button with different materials and coatings to study the RF breakdown affected by peak electric field and its relationship with external magnetic fields. Data analysis is ongoing. Theoretical models have been developed, and numerical simulations have been carried out to understand cavity surface damage due to RF breakdown and the accelerating gradient limit due to external magnetic fields. A 201-MHz normal conducting cavity, also as a prototype for MICE RF cavities, has been built and tested at MTA with stray magnetic fields from Lab-G magnet at MTA. A superconducting coupling coil is being designed and fabricated now at HIT (Harbin Institute of Technology), China. The magnet will be used for the RF breakdown studies using the 201-MHz cavity at MTA. The magnet should be ready one year from now.

Follow-up at NuFact09:

- Optimization of muon ionization cooling and other cooling schemes
- The international MICE experiment

- Experimental studies on RF breakdown and accelerating gradient limits in strong magnetic fields
- Physics model and numerical simulation study on the RF breakdown in strong magnetic fields

7. Beta-Beams

The concept of using beta-beam to produce high intensity neutrino beams for neutrino oscillation physics was first proposed by Zucchelli in 2002. The intense neutrino beams is created through beta decay of completely ionized radioactive ions. These ions must be produced, collected, accelerated and stored in a ring. Most of the Beta-beam R&D progresses presented have been conducted in Europe. Progress is reported on the production of radioactive ions by neutron converters with low energy deuteron drivers (20 ~ 40-MeV) that can produce ^{6}He and ^{8}Li. Other R&D areas include bunching and ionization of the ions. Significant progress has been made on acceleration scheme by RCS and decay ring. Collimation remains a challenge in the decay ring. Dealing with the radioactive beams and red-hard machine enviroment, concepts of using remote controled robots for machine design and mantainance is suggested to be considered during the design study phase. Automatic protection controls, reliable (redundant) hardware with spares, such as vacuum windows, BPM, monitors, and etc. are necessary and essential.

Follow-up at NuFact09:

- New studies on production and ionization
- Magnet protection (collimation)
- Progress on decay ring design with RF and collimation system

8. Acceleration: IDS Baseline

The goal for the acceleration is to achieve large acceptance and accelerate the beam up to 25-GeV with beam ‘shaping’. Pros and cons of acceleration schemes have been presented and discussed. The IDS acceleration scenario is to optimize the accelerator at each stage (see below) and take maximum advantage of appropriate acceleration scheme at a given stage. The various acceleration stages are as follows:

- Linear pre-accelerator from 244-MeV to 900-MeV
- RLA-I for 4.5 passes with 0.6-GeV/pass from energy of 900-MeV to 3.6-GeV
- RLA-II for 4.5 passes with 2-GeV/pass from 3.6-GeV to 12.6-GeV
- Non scaling FFAG acceleration from 12.6-GeV to 25-GeV

Follow-up at NuFact09:

- End-to-end tracking simulations
- Machine acceptance

9. FFAG Acceleration

FFAG R&D activities have been presented and discussed. Active scaling FFAG research programs in Japan have been reported, the programs include:

- PRISM at Osaka University for phase rotation for muon physics;
- p-FFAG at Kyusyu University: 150-MeV proton FFAG developed at KEK for versatile applications;
- e-FFAG at NHV corp.: 500-keV and 10-mA e-FFAG for industrial applications;
- ADSR study at Kyoto Univ. RRI: p- FFAGs cascade + Nuclear Critical Assembly
- Neutron source at Kyoto Univ. RRI: ERIT (emittance/energy recovery internal target) with FFAG

Beam test results are reported on FFAG-ERIT, the beam lifetime is reported up to 1000 turns! Other progresses reported are: two-beam scaling FFAG with uni-directional for μ^+ and μ^-. Technical challenges include large aperture magnet (B = 2.9-T), large aperture RF cavity and how to increase the number of turns in FFAG.

Follow-up at NuFact09:

- Beam tests on Japanese FFAGs
- Small dispersion and long straight section in (semi-) scaling FFAG?

10. Aknowledgements

The authors would like to thank all chairpersons, speakers, discussion leaders and participants of the accelerator working group. This report summarizes the presentations made during the various sessions and references to each of these talks can be found in the same conference proceedings.

References

These proceedings and presentations at NuFact-2008 at: http://ific.uv.es/nufact08/