PROCEEDINGS OF SCIENCE

Baseline scenario for the Super Beam Proton Driver: challenges and synergies with other programs

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In this contribution the Super Beam, a key project for the future neutrino oscillation facility, is presented. After a brief review of the concept and the various projects considered, we will discuss some issues related to the specifications of the parameters. In particular the energy of the beam plays a crucial role: recent data from hadroproduction experiments like HARP needs to be carefully studied and incorporated in beam simulations. The Euronu design study, where one work package is devoted to SuperBeam studies, will address many of these open questions.

10th International Workshop on Neutrino Factories, Super beams and Beta beams
June 30 - July 5 2008
Valencia, Spain

PoS(Nufact08)071

1. The Super Beam Concept

The Super Beam (SB) concept consists of the following components: a multi-MW proton beam, the target, the focussing system, and the decay volume. The main advantage of this scheme is that, once an intense proton beam is available, a Super Beam facility can be built with a moderate effort. This explains why several SB concepts are considered by the major laboratories around the world. It is also interesting to notice that the neutrino oscillation experiments currently taking data (MINOS, OPERA) or that will do so in the near future (T2K), use this technique.

The main features of the SB with respect to other neutrino sources like the Beta Beam or the Neutrino Factory can be summarized in the following way. The advantages are: a "conventional" technology, moderate investment, shorter construction schedule, and the possibility of a SB as an intermediate stage towards the ultimate facility. The main disadvantage is the limited physics reach for very low value of θ_{13} ($\sin^2 2\theta_{13} < 10^{-3}$) as shown in Fig.1 from Ref.[1]. Therefore, the first indications on the value of θ_{13} (by T2K around 2010-2011) are eagerly expected and will be a major element for the decision of the next neutrino oscillation facility.

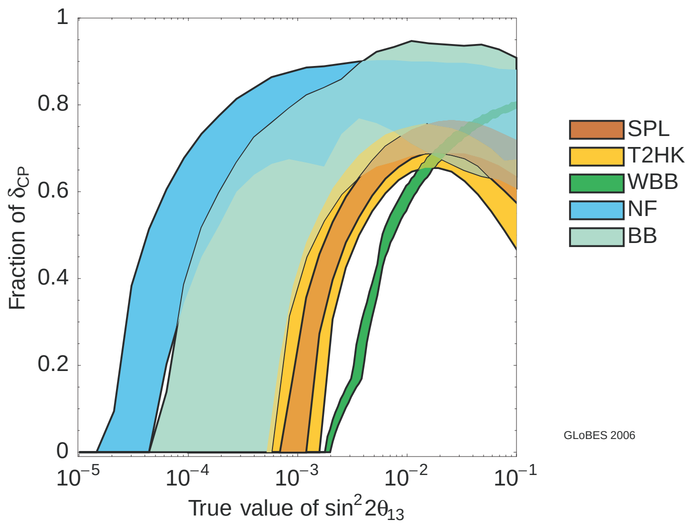

Figure 1: The CP violation discovery reaches of various proposed facilities [1]. The figure shows the fraction of all possible values of δ for which CP violation can be discovered as a function of the simulated $\sin^2 2\theta_{13}$. The right-hand edges of the bands correspond to conservative setups while the left-hand edges correspond to optimized setups.

2. Super Beam projects

All major laboratories consider SB projects in their plans for the next decade. At Fermilab, an intense activity has been devoted to Project X, a 8 GeV superconducting proton linac based on the ILC accelerating structure. Coupled with a Main Injector, this complex would provide a power of 2.3 MW for proton energy in the range between 50 and 120 GeV [2]. A Wide Band Beam, aimed at DUSEL in Homestake and with a baseline of 1300 km, is one of the favored physics strategies.

In Japan, KEK roadmap includes an upgrade of JPARC to deliver a power of 1.7 MW. Various options are considered for the far detector, either at Kamioka (Hyperkamiokande), in Korea (T2KK) or in between.

At CERN, an essential part of the proposed luminosity upgrade plan is the replacement of the PS and its injectors by a 50 GeV proton synchrotron (PS2) and a 4 GeV superconducting linac (SPL). The design of the SPL has recently been updated and the optimization of its high-energy part will continue until 2010. For the foreseen luminosity upgrade of the LHC a low-power version of the SPL (LP-SPL) is under study, which can be upgraded to a multi-megawatt machine providing beam to high-power proton users such as neutrino facilities. The SPL parameters (Table 1 from Ref. [3]) has been designed from the start to comply with the Neutrino Factory specifications.

It has also to be noticed that the SB concept covers a wide range of different physics strategies. For instance, MEMPHYS, based on the SPL, foresees a short baseline and a MegaTon Water Cherenkov detector with a neutrino beam energy in the region where quasi-elastic scattering is dominant. T2HK features an off-axis beam. The Wide Band Beam concept, on the other hand, considers a higher energy beam in order to measure in the same detector the first and second oscillation maximum.

Table 1: Parameters of the nominal SPL and of the low-power LP-SPL [3]

Parameters	unit	SPL	LP-SPL
Energy	[GeV]	5.0	4.0
Beam power (for ν factory)	[MW]	4.0	0.192
Repetition rate	[Hz]	50	2
Average pulse current	[mA]	40	20
Peak pulse current	[mA]	64	32
Chopping ratio	[%]	62	62
Beam Pulse length	[ms]	0.6	1.2
Protons per pulse for PS2	[10^{14}]	1.5	1.5
Beam duty cycle	[%]	2.0	0.24
Number of klystrons (LEP)		14	14
Number of klystrons (704 MHz)		57	28
Peak RF power	[MW]	219	100
Average power consumption	[MW]	38.5	4.5
Cryogenics av. power consumption	[MW]	4.5	1.5
Cryogenic temperature	[K]	2.0	2.0
Length	[m]	534	459

3. SB challenges and synergies : parameters

It has been realized from the start that a SB project has great synergies with the Neutrino Factory. In order to maximize these synergies, the SB parameters must comply with the basic requirements for a NF, established by the ISS working group (Table 2 from Ref.[4]). Partial synergies are related to the target system. In the following we will discuss mainly the requirement about the proton beam energy.

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The most challenging component of the SB is represented by the target. Indeed, no fully proven solution is available and this item certainly needs special attention in the design of a SB. Main difficulties related to the target are: the power dissipation, the thermal stress and the radiation damage. Considering these difficulties, it is natural to adjust the beam parameters in order to alleviate the problem encountered in the target. For instance it has been shown for a solid target that the energy deposited in a target has a minimum for a beam energy around 8 GeV [5].

Taking into account these considerations, among the beam parameters reported in Table 2, it appears that the beam energy is a crucial parameter. Its optimization depends on several requirements: maximizing the pion production and capture efficiency, alleviating the target difficulties, optimizing the physics reach. We notice here that the central parameter value and range for the proton beam energy ($E_b = 10 \pm 5$ GeV) was determined with a Monte Carlo simulation based on the MARS program. Recently, the HARP experiment at CERN has reported a very complete set of measurements [6] of hadroproduction cross-section in these energy region. The yield divided by the proton kinetic energy is shown in Fig.2 for proton Tantalum interactions. These data suggest that the optimum energy may be lower than 10 GeV. Clearly, many questions concerning this apparent data-MC disagreement need to be answered and a detailed study of this data is needed in order to correctly perform the optimization of the beam energy.

Table 2: Proton driver requirements from the ISS Accelerator Working Group Report [4]

Parameter	Value
Average beam power	(MW) 4
Pulse repetition frequency (Hz)	50
Proton energy (GeV)	10 ± 5
Proton rms bunch length (ns)	2 ± 1
No. of proton bunches	3 or 5
Sequential extraction delay (μs)	≥ 17
Pulse duration, liquid-Hg target (μs)	≤ 40
Pulse duration, solid target (ms)	≥ 20

The Euronu design study, recently approved by the EU in the FP7 program, plans to to provide solutions to many of these open questions. In particular the SB workpackage plans to develop conceptual designs for the target, the collector, and the integration, and specifically to address the SB parameter optimization. The aim of Euronu is to produce a Conceptual Design Report by 2012.

4. Conclusion

The SB concept has a very promising physics potential if θ_{13} is not too low. It offers the advantage of a moderate investment and a competitive schedule. The optimization of the SB parameters is still an open question in view of the technical difficulties related to the target for a 4 MW beam. In addition, recent data from the hadroproduction experiment HARP favor a lower energy with respect previous studies. The Euronu design study will address many of these open questions with the aim of delivering a CDR for the SB by 2012.

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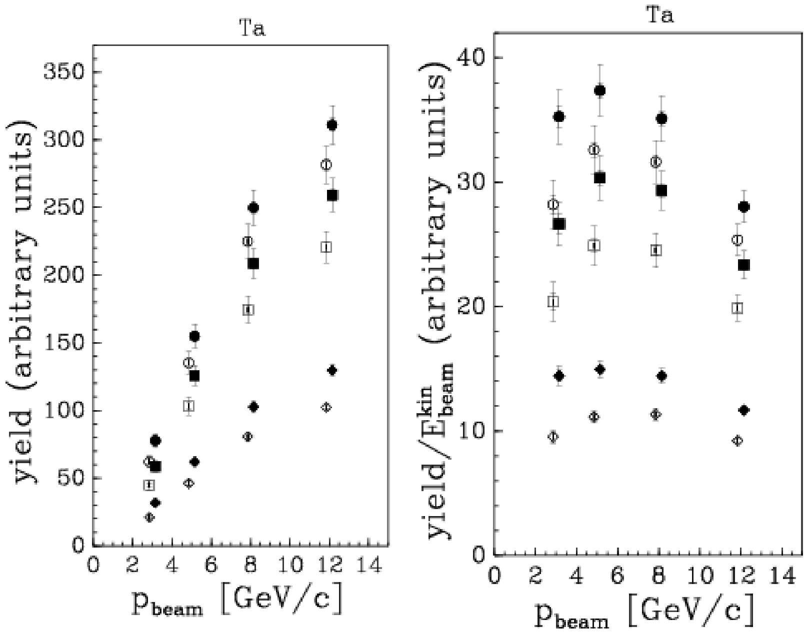

Figure 2: Predictions of the π^+ (closed symbols) and π^- (open symbols) yields for different design of the NF focussing stage from the HARP experiment [6]. Integrated yields (left) and the integrated yields normalized to the kinetic energy of the proton (right) for p Ta interactions. The circles indicate the integral over the full HARP acceptance (100 MeV/c $<$ p $<$ 700 MeV/c and 0.35 rad $< \theta <$ 1.55 rad), the squares are integrated over 0.35 rad $< \theta <$ 0.95 rad, while the diamonds are calculated for the smaller angular range and 250 MeV/c $<$ p $<$ 500 MeV/c.

Acknowledgments

I wish to warmly thank the organizers for inviting me to this conference in the wonderful settings of Valencia. Many thanks to Malika Meddahi for her help in the preparation of this talk.

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