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Baseline Scenario(s) for Muon Collider Proton Driver[1]

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This paper gives an overview of the various muon collider scenarios and the requirements they put on the Proton Driver. The required proton power is about 4-6MW in all the scenarios, but the bunch repetition rate varies between 12 and 65Hz. Since none of the muon collider scenarios have been simulated end-to-end, it would be advisable to plan for an upgrade path to around 10MW. Although the proton driver energy is flexible, cost arguments seems to favour a relatively low energy. In particular, at Fermilab 8GeV seems most attractive, partly due to the possibility of reusing the three existing fixed energy storage rings for bunch manipulations.

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1. Muon collider scenarios

There are currently three main muon collider parameter sets, which are generally refered to as the low emittance, medium emittance and high emittance scenarios. All three scenarios share similar traits, in that they start with a proton driver, followed in sequence by a target immersed in a pion/muon capture solenoid, a bunching and phase rotation section, a 6D ionization cooling section, a transverse cooling section, acceleration (e.g. in recirculating linacs) and a collider ring. As the names suggest, a core difference between the three scenarios is in the assumption about what cooling factor is practically achievable. With more effective cooling, fewer muons are required to achieve a given luminosity. The main parameters for the three scenarios are given in Table 1.

	Low ε	Med ε	High ε	
CM Energy	1.5	1.5	1.5	TeV
Luminosity	2.7	1	1	10^{34} cm^2/s
N_μ/bunch	0.1	1	2	10^{12}
No. bunches	10	1	1	
Ring circumf.	2.3	3	3	km
$\beta^* = \sigma_z$	5	10	10	mm
Dp/p (rms)	1	0.1	0.1	%
Ring depth	35	13	13	M
Mu survival	30	4	7	%
ε_T	2.1	12	25	π μm
ε_L	370,000	72,000	72,000	π μm
PD Rep rate	65	24	12	Hz
The PD Power	≈4	≈6	≈4	MW

Table 1. The three main Muon Collider Parameter sets, as of summer 2008.

1.1 High emittance scenario

The high emittance scenario[1] is the only one where all the individual sections (but not the transitions between them) have been simulated, albeit not including any collective effects. This scenario uses so-called Guggenheim rings, consisting of interleaved solenoids, (vacuum) RF cavities and liquid hydrogen wedge absorbers, for 6D cooling, and liquid hydrogen absorbers immersed in 50T solenoids for the final transverse cooling. To maximize the luminosity per muon, the repetition rate is low and all muons are merged into a single bunch in the 6D cooling section. This leads to a relatively high bunch charge, which may also lead to space charge issues that have yet to be fully quantified. The muon survival rate from production target to collisions is less than 10%. About half of this is due to decays in the relatively long cooling channel.

1.2 Low emittance scenario

The low emittance scenario[2], on the other hand, asssumes a larger cooling factor and a higher muon survival rate. The higher survival rate, which is estimated based on muon decay alone, stems from the use of a Helical Cooling Channel (HCC) for the 6D cooling channel. The HCC is more compact than the Guggenheim channel, but by the same token also more difficult to realize in practice. The higher cooling factor in the low emittance scenario can be mostly attributed to the assumed use of Parametric Ionization Cooling, which is a promising idea that has yet to be successfully demonstrated in simulation. To reduce collective effects, in the low emittance scenario muons are assumed to be divided into 10 bunches, which reduces the luminosity per muon. The bunch repetition rate of 65Hz in the low emittance scenario is matched to the muon lifetime in the collider ring.

1.3 Medium emittance scenario

The medium emittance scenario[3] can be seens as an effort to arrive at a compromise parameter set, and may well be the most realistic. It assumes a slightly better cooling than the high emittance scenario, due to the addition of an extra section of 6D cooling channel. This is offset by a smaller muon intensity per bunch, at a somewhat higher rep rate compared to the high emittance scenario. The medium emittance scenario estimates a lower muon survival than the high emittance scenario, since initial studies have shown a rather poor transimission in the extra piece of cooling channel. This causes the medium emittance scenario to require a somewhat higher proton power than the other scenarios.

2. Proton driver requirements for a Muon Collider

Despite the differences in parameters, it turns out the required proton driver power is similar in all three cases. Thus, without making a choice between the collider scenarios, it can be concluded that the proton driver power should be approximately 4-6MW. However, since the parameter sets are still evolving, and none of the scenarios have been simulated end-to-end, it would be wise to plan for a significant performance contingency. A recent excercise at Fermilab to provide input to the Project X requirements[4] suggested an upgrade path to ~10MW would be advisable.

The production yield of muons for a given proton power has been studied and found to be only weakly dependent on energy in the range 5-60GeV. Therefore, the exact energy of the proton driver can be flexible. The higher the energy, the lower the intensity needed to achieve a given target power. However, in practice the low end of the energy range is favored, since achieving sustained bunch repetition rates of 12-65Hz at high energies would require a costly high energy storage ring. Also, to maximize the muon collection efficiency, the proton bunches should be less than 3ns long. This may require yet another ring to act as bunch compressor before the target.

3. Synergies with Neutrino Factory

The international Neutrino Factory scoping study has produced consensus numbers for the Neutrino Factory proton driver parameters. They are similar to the Muon Collider number (4MW at 5-15GeV with a 50Hz cycle rate). The main difference is that in the Neutrino Factory case, bunches are expected to come in short bursts of 3-5 bunches separated by a few microseconds, whereas for the muon collider they are equally spaced at 12-65Hz.

In general, it seems that the requirements for a muon collider are somewhat more stringent than for a Neutrino Factory. It may be argued that any Proton Driver capable of serving a Muon Collider also could serve a Neutrino Factory. However, the inverse may not be true. Therefore, to maintain synergy it would seem reasonable to optimize the proton driver for the muon collider parameters, which should also be adequate for the neutrino factory.

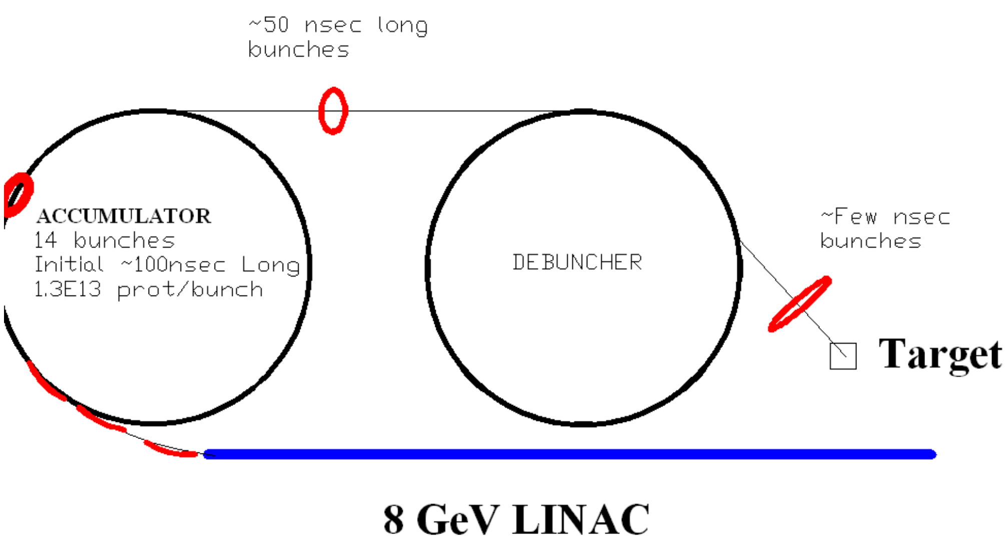

Figure2. Possible proton driver scenario utilizing the existing accumularot and debuncher.

4. Proton driver scenarios based on Project X

A number of Muon Collider scenarios based on Project X, or variants thereof, have been considered. One scenario[5] based on the original Project X linac accelerates the protons to 56GeV in the Main Injector. This is the highest energy that can be reached in 0.6 seconds, which corresponds to three 5MHz linac pulses. The acceleration yields a 2MW power without a linac upgrade, however at least one new 56GeV storage ring would be needed.

Flexibility in the bunch repetition rate could be obtained by utilizing the various 8GeV fixed energy rings available at Fermilab. An attractive scenario (see Fig. 2) would have an upgraded ~4MW Project X linac inject directly into the accumulator[6]. Protons would then be bunched at a suitable harmonic number, and sent one-by-one to the debuncher ring, where the bunches would be compressed before being sent to the production target.

5. Conclusions

The general proton driver requirements for a Muon Collider is about 4-6MW beam power, (upgradable to about 10MW), more or less independent on the details of the collider scenario. The scenarios considered here are for 1.5TeV center-of-mass energy, but scaling arguments suggest that the required proton power is not a strong function of the collision energy[4]. The bunches must be short (less than 3ns), with a bunch repetition frequency of 12-65Hz. The spread in bunch repetition frequency favors a flexible design. To maintain synergy with the Neutrino Factory, the Muon Collider parameters, in particular for bunch repetition rate, should be considered in the Neutrino Factory Proton Driver deisgn, as these parameters are more demanding.

References

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