LEMMA: a positron driven muon source for a muon collider

M.E. Biagini (*), O. Blanco-Garcia, M. Boscolo, A. Ciarma, A. Giribono, S. Guiducci, C. Vaccarezza (INFN, Frascati National Laboratories, Italy), F. Anulli, M. Bauce, G. Cesarini, F. Collamati, R. Li Voti, A. Variola (Roma La Sapienza University, Italy), I. Chaikovska, R. Chehab (IJCLab, Orsay, France), A. Bacci, I. Drebot (INFN, Milan, Italy), S. Liuzzo, P. Raimondi (ESRF, Grenoble, France), D. Lucchesi (INFN, Padova, Italy), N. Pastrone (INFN, Torino, Italy)
and for the International Muon Collider Collaboration

The interest in a future very high energy Muon Collider has sparked again in the last couple of years. An International Muon Collider Collaboration is being set up with CERN and other partners worldwide, to allow for an exchange of competences and to build a test facility for the muons production. The MAP project in US [1] has developed a detailed muon source design from proton beams.

The Low EMittance Muon Accelerator (LEMMA) source is a new concept aiming at producing muon pairs from a 45 GeV positron beam annihilating with the electrons of a target, close to threshold for pair creation, thus generating muon beams with low transverse emittance for a high energy muon collider. The first idea developed at the INFN Frascati Laboratories [2,3,4,5] had the muon production target installed in a positron ring, in order to allow for multiple interactions of the e^+ with the e^- at rest in the target. However, this layout has encountered several limiting difficulties. An alternative design is presently under study [6,7] to identify the challenges within reach of the existing technology, and those requiring further innovation. In the new scheme e^+ bunches are extracted to impinge on multiple targets in a dedicated straight section. This scheme could release the impact of the average power on the targets and also reduce the number of e^+ needed from the source. An example of one of the possible layouts is shown in Fig. 1. The e^+ are produced by a Main e+ source (MPS) and accelerated and injected in a 5 GeV Damping Ring (DR). After storing and damping, they are accelerated to 45 GeV in a SC Linac (or ERL) in order to fill with 1000 e^+ bunches a Positron Ring (PR) with very large energy acceptance. The e^+ bunches are then extracted and driven to one or more muon production lines, while produced μ are accumulated in two Accumulator Rings and a μ bunch is "built" by several passages through the targets, to be then delivered to the fast acceleration chain. To save on the number of needed e^+ from the MPS, the re-injection and damping in the PR @45 GeV of the "spent" e^+ beam, after compression, and/or a γ-embedded e^+ source, will provide the refilling of lost e^+. In case the quality and efficiency of the recuperation of the "spent" beam is not good enough, another option foresees to send the e^+ back to the DR (through a decelerating ERL) for damping and top-up at 5 GeV. This is a work in progress and still no decisions on the more efficient layout have been taken.

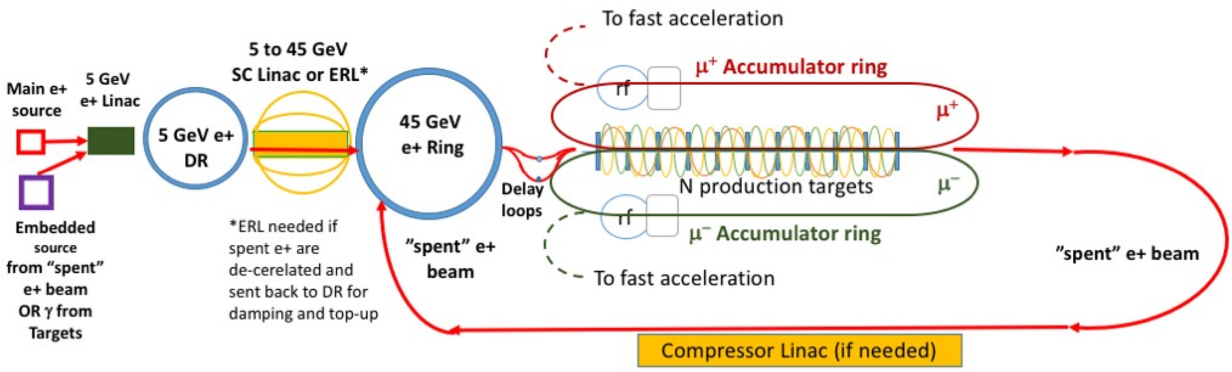

Figure 1: Possible layout of the LEMMA muon source

LEMMA future R&D

In the following is a very concise list of the R&D needed in order to prove the feasibility of the LEMMA scheme. All of them are synergic with the AF1 and AF7 Snowmass Working Groups. This work will be pursued within the newly formed International Muon Collider Collaboration.

- Beam physics studies are needed for the design of the e^+ and $\mu^\pm$ rings, with a very high energy acceptance, and the design of the Interaction Region (IR) and Separation Region (SR) for the 3 beams (e^+, μ^+, μ^-).
- Targets are a common topic for both the e^+ and $\mu^\pm$ sources. Material studies and experimental tests have to be done and several options should be explored for the muon source. For example, a prototype of a rotational target (single thick target or ensemble of close thin targets) with an amorphous and a granular amorphous material would be needed. Also Hydrogen target (pellet) studies could solve some of the thermal problems. Crystal targets studies for muons recombination and post-production cooling are also envisaged (see below). A specific LoI will be presented by Roma La Sapienza University [8].
- A very high production rate e^+ source is needed. Also in this case the quality and material of the target need to be studied, as well as the most efficient layout to increase the number of captured e^+. This is synergic with the future e^+e^- colliders, such as FCCee and CLIC. A specific LoI will be presented by the IJCLab (France) [9].
- High gradient SCRF cavities will be needed to cope with a high average train current (order of 100 mA) in this design. Up to now, no studies have been carried out for this project.
- Special magnets are needed to focus 45 GeV e^+ and 22.5 GeV $\mu^\pm$ together in a short low β-function IR. In particular, high gradient, large aperture, and compact quadrupoles have to be developed. Also, the design of the multi-targets $\mu^\pm$ production line requires an efficient 3-beams SR design, aiming at minimising the particle losses, with high field and large aperture dipoles. INFN has a long standing tradition at designing special magnets.

Two other interesting topics have not been studied yet, that would increase the performances of a Muon Collider in terms of emittance and number of muons in the final muon beams. These are:

- Muon cooling: the LEMMA longer $\mu^\pm$ lifetime at production would allow for introducing a moderate cooling mechanism to further reduce the production emittance. Different evaluations were done in the past for the cooling efficiency given by stochastic cooling, optical stochastic cooling, crystal cooling. A full re-evaluation of these mechanisms associated to high energy, low emittance and bunch current needs to be done.
- Muon recombination: tests of muon bunches recombination techniques, that can increase the number of particle per bunch without been drastically affected by the consequent emittance increase, could greatly improve the collider luminosity. A new hypothesis is a possible recombination of different muon bunches by their injection in a curved crystal. Combining the channelling angle with the volume reflection it should be possible to merge two different bunches with a limited emittance increase, mainly in the distribution tail. The efficiency of this process should be optimized for luminosity increase.

(*) marica.biagini@lnf.infn.it

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