LEMMA muon source
Letter of Interest
Snowmass 2021

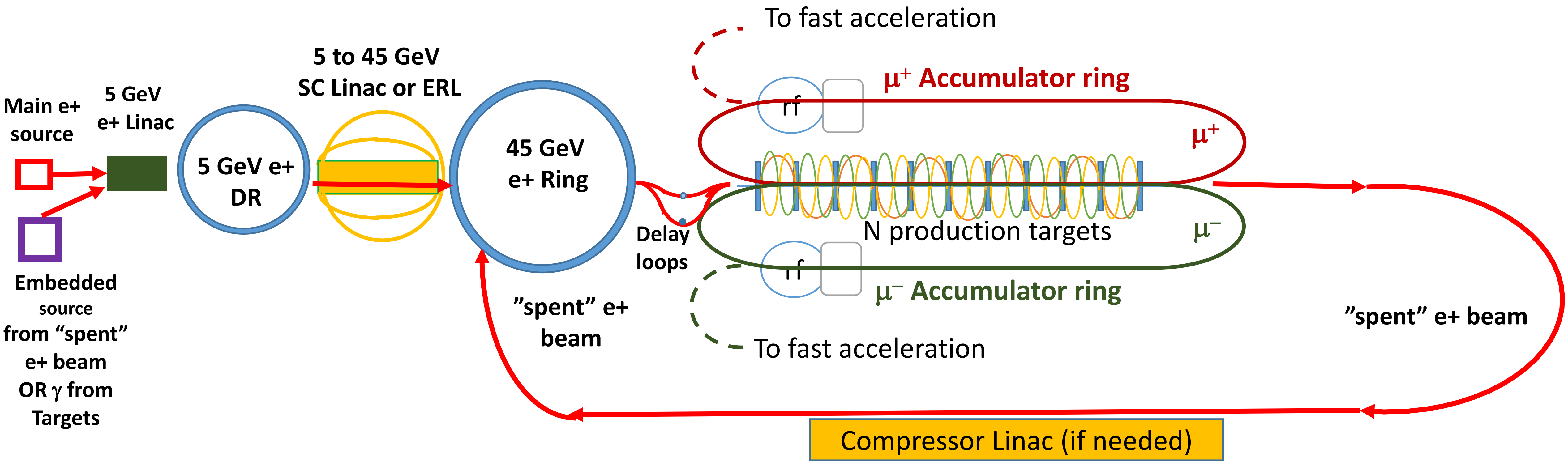
INFN, Italy

LEMMA

- The Low Emittance Muon Accelerator (LEMMA) is based on muons production 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 enough transverse emittance for a high energy collider
- This should provide a muon pair boost for post-production capture and emittance minimization, drastically reducing the source transverse emittance and, coupled with a collider nano-beam scheme, should allow reaching for the luminosity with a lower bunch intensity
- In the scheme under study the positron bunches are extracted to impinge on multiple targets in a dedicated straight section. Muons are then collected in two Accumulation Rings (AR) and stored until the muon bunch has a suitable number of particles. This scheme aims at releasing the impact of the average power on the targets and also reducing the number of positron needed from the source

LEMMA new scheme in brief

- Positron for first fill produced by Main e^+ source (MPS) and accelerated to 5 GeV for damping in a 5 GeV Damping Ring (DR)
- Acceleration to 45 GeV in a SC Linac or ERL and storage of 1000 e^+ bunches in a Positron Ring (PR)
- Extraction of e^+ bunches to one or more muon production lines, while produced muons are accumulated in two AR and a muon bunch is “built” by several passages through the targets, to be then delivered to the fast acceleration chain
- Re-injection and damping in the PR @45 GeV of the spent e^+ beam to save on the number of needed e^+, the MPS and a possible γ-embedded source will provide the refilling of lost e^+



LEMMA R&D: TARGETS

- Targets are a common topic for both the positron production and the muon production
- Most important parameter to increase the muon bunch population is the possibility to produce the maximum number of muon pairs in a single positron bunch passage, up to the limit of its energy and energy spread deterioration that fix the limit to the use of a “fresh” bunch. The need to maintain a low PEDD (Peak Energy Density Deposition), average energy deposition, and temperature, to ensure target durability and efficiency, as well as to maximise the number of produced particles, is a key R&D topic
- The determination of the damage and fusion thresholds, thermo-mechanical stresses, and the evaluation of technical designs for heating evacuation and PEDD remedies need material studies and experimental test. A prototype of a rotational target, both a single thick target or an ensemble of close thin targets, with an amorphous and a granular amorphous material should be built and tested
- Hydrogen targets would improve the integrated thickness reducing the number of passages and so increasing the ration of “fresh” bunches/passage. This would have a linear dependence on the muon per bunch number, and so a quadratic increase of the final luminosity. Taking into account a simple scaling with Z we can expect a factor 15 in increase of the luminosity with H targets (pellet). However, besides the technical challenges of under vacuum H targets, a different Interaction Region (IR), with the low β-function needed for low emittance muon production, should be designed, since at least 1 meter will be needed to host such a target
- Crystal targets should be also considered as a solution for muons recombination and post-production cooling
- A test of the DAΦNE (INFN Frascati National Labs) e^+ beam impinging on a target would allow for benchmarking the simulations of target materials and released power with a real case. Beam lifetime measurements, high currents and beam dynamics studies would help to identify issues and finalise the design. Vacuum tests of different target materials would be also possible

LEMMA R&D: Positron source

- One of the main limit in the source repetition frequency is the physical constraint imposed by the positron source given by the required positron flux, the required cooling and the thermo-mechanical stress on the target
- In this framework a very interesting development is represented by the use of rotating target as already conceived for the ILC. Different schemes at a f_{rep} of 50-100 Hz should be implemented in case that high technology targets and high efficiency positron source should deliver a positron rate higher than 10^{16} e^{+}/sec
- This has to take into account also the possibility to develop immersed large acceptance positron capture systems at 1 GHz, with very high peak B Field in the AMD (20 T in the MAPS scheme) and in the capture solenoid
- A very large energy spread of the damping ring will also increase the efficiency of the positron source also if this has to be carefully harmonized with the damping time. An increase in the efficiency of the positron source, and so of the repetition rate of a factor 5-10, will have a linear dependence on the luminosity
- This work is presently carried out in collaboration with Dr. Iryna Chaikovska’s group at IJC, France

LEMMA R&D: Other topics

- RF cavities
  - High gradient SCRF cavities able to cope with a high average train current (order of 100 mA)
- High field magnets
  - Need to focus 45 GeV positrons and 22.5 GeV muons together in a short low β-function IR calls for high gradient, large aperture and compact quadrupoles
  - Design of the multi-targets muon production line will require also an efficient 3-beams separation design, aiming at minimising particle losses, with high field, large aperture dipoles
- Muon Cooling
  - LEMMA scheme, in spite of the low production cross section, introduces two main advantages in the source: a reduced emittance at the production and a higher production energy resulting in a longer muon lifetime. So, also if the former suggests the possibility to avoid a cooling phase, the second allows for enough time to introduce also 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 revaluation of these mechanisms associated to high energy, low emittance and bunch current needs to be done, targeting an emittance reduction of 1-2 order of magnitude that will linearly impact the final peak luminosity
- Muon Recombination for higher luminosity
  - Due to the quadratic dependence of the Luminosity on the bunch population, testing muon bunches recombination techniques, that can increase the number of particle per bunch without been drastically affected by the consequent emittance increase, could be envisaged. For LEMMA a new hypothesis can be studied: the possible recombination of different muon bunches by injection in a curved crystal. Combining the channeling angle with the volume reflection it should be possible to merge two different bunches with a relative emittance increase, mainly in the distribution tail. The efficiency of this process should be optimized by an extensive R&D program