Low Emittance Muon Collider (LEemma)

M. Boscolo (INFN-LNF)

Thanks to the LEMMA collaboration and in particular to
J. P. Delahaye, L. Keller, M. Palmer, N. Pastrone, P. Raimondi, D. Schulte, ...

gratefully acknowledging input from all contributors
Outline

• Introduction
• Positron driven source
• LEMMA scheme
• Optics & Beam dynamics
• R&D on key topics
• Goal parameter table for Multi-TeV muon collider
• Conclusion
Muon based Colliders

• A $\mu^+\mu^-$ collider offers an ideal technology to extend lepton high energy frontier in the multi-TeV range
  ▪ No synchrotron radiation (limit of $e^+e^-$ circular colliders)
  ▪ No beamstrahlung (limit of $e^+e^-$ linear colliders)
  ▪ but muon lifetime is 2.2 $\mu$s at rest

• Great potentiality if the technology proves its feasibility

• Best performances in terms of luminosity and power consumption
Muon Source

**Tertiary production from protons on target:** \( p + \text{target} \rightarrow \pi/K \rightarrow \mu \)

typically \( P_\mu \approx 100 \text{ MeV/c} \) (\( \pi, K \) rest frame)

whatever is the boost \( P_T \) will stay in Lab frame

\( \rightarrow \) **very high emittance** at production \( \rightarrow \) **cooling needed**

production Rate \( > 10^{13} \mu/\text{sec} \quad N_\mu = 2 \cdot 10^{12}/\text{bunch} \)

**from direct \( \mu \) pair production:**

muons produced from \( e^+e^- \rightarrow \mu^+\mu^- \) at \( \sqrt{s} \) around the \( \mu^+\mu^- \) threshold

\( (\sqrt{s} \approx 0.212 \text{GeV}) \) in asymmetric collisions (to collect \( \mu^+ \) and \( \mu^- \))

\( e^+e^- \) **annihilation:** \( e^+ \) beam on target

\( \rightarrow \) **cooled muon** beam with **low emittance** at production

Goal: production Rate \( \approx 10^{11} \mu/\text{sec} \quad N_\mu \approx 6 \cdot 10^9/\text{bunch} \)

by **Gammas** (\( \gamma \) Nuclei \( \rightarrow \mu^+\mu^- \) Nuclei): **GeV-scale Compton \( \gamma s \)**

also: \( (e^-\text{Nuclei} \rightarrow \mu^+\mu^-e^-\text{Nuclei}) \)

W. Barletta and A. M. Sessler NIM A 350 (1994) 36-44

[V. Yakimenko (SLAC)]

M. Boscolo, NuFact18, 16 August 2018
LEMMMA: Low EMittance Muon Accelerator

Concept based on a positron driven source

- Muons are produced in positron annihilation on $e^-$ at rest
  $\rightarrow e^+$ beam impinging on target
- It is a low emittance muon source

- Low emittance concept overcomes muon cooling
- Low emittance allows operations at very high c.o.m. energy
  opening the perspective to a Multi-TeV Muon Collider (MC)

Summary of LEMMA pro&cons features

Pro LEMMA:

• \( \mu \) beam divergence can be very small close to the \( \mu^+\mu^- \) threshold \( \theta_\mu \) is tunable with \( \sqrt{s} \) in \( e^+e^- \rightarrow \mu^+\mu^- \)
• Reduced losses from decay: high collection efficiency
• Low background: Luminosity at low emittance will allow low background and low neutrino radiation \( \rightarrow \) easier experimental conditions & can go to higher energies
• Energy spread: muon energy spread might be also small at threshold, it gets larger as \( \sqrt{s} \) increases

Cons LEMMA: Low \( \mu \) prod. Rate

much smaller cross section \wrt\ proton-driven-source
\( \sigma(e^+e^-\rightarrow\mu^+\mu^-) \approx 1 \mu b \) at most \wrt \( \sigma(\text{from } p) \approx \text{mb} \)
Cross-section, muons beam divergence and energy spread as a function of the e+ beam energy

\[ \sigma(e^+e^- \rightarrow \mu^+\mu^-) \]

The value of sqrt(s) (i.e. E(e^+) for atomic e^- in target) has to maximize the muons production and minimize the beam angular divergence and the energy spread.

\[ \theta_{\mu}^{\text{max}} \]

\[ \text{r.m.s.}(E_{\mu})/E_{\mu} \]
Radiological hazard due to neutrinos from a MC

- First studies by B.J. King in Proc. EPAC98, p. 841-843 and Proc. 1999 PAC p. 319
  (on neutrino dose equivalent/fluence)
- see also D. Neuffer, MC workshop, Padova. 2-3 July 18

MAP design for a 6 TeV MC (500 m depth)

muon rate:
- p on target option: $3 \times 10^{13} \mu/s$
- $e^+$ on target option: $9 \times 10^{10} \mu/s$

This plot is based on numbers reported in C. Jonhson et al adding Lemma, M.Antonelli

Annual Dose equivalent (mSv)

Dose equivalent due to neutrino radiation at 36 km distance (collider at 100 m depth)
LEMMMA scheme

e^+ Linac or Booster → AMDTT → e^+ gun

AR μ^+, AR μ^-

e^+ Storage Ring with target T

AR: Accumulator Ring μ^-, μ^+

TT: Thick Heavy Target for e^+e^-pairs production

AMD: Adiabatic Matching Device

(not to scale)

Acceleration: Linacs, RLA or FFAG, RCS

μ^+μ^- collider

IP

M. Boscolo, NuFact18, 16 August 2018
Goal: $\approx 10^{11} \mu/s$ produced at Target
with target efficiency $\approx 10^{-7}$ (Be 3mm)

Request: $10^{18} e^+/s$ needed at Target $\rightarrow$
45 GeV $e^+$ storage ring with Target insertion

- **e+ Linac or Booster**
- **e- gun**
- **AMD/TT**
- **e+ Storage Ring with target T**
- **AR**: Accumulator Ring $\mu^-, \mu^+$
- **TT**: Thick Heavy Target for $e^+e^-$ pairs production
- **AMD**: Adiabatic Matching Device

**Acceleration**: Linacs, RLA or FFAG, RCS

$\mu^+\mu^-$ collider

IP

M. Boscolo, NuFact18, 16 August 2018
**LEMMA scheme**

**Goal:** $\approx 10^{11} \mu/s$ produced at Target with target efficiency $\approx 10^{-7}$ (Be 3mm)

**Request:** $10^{18} e^+/s$ needed at Target $\rightarrow$ 45 GeV e+ storage ring with Target insertion

- **e+ Linac or Booster**
- **AMDTT**
- **e+ Storage Ring with target T**
- **AR**: Accumulator Ring $\mu^-$, $\mu^+$
- **TT**: Thick Heavy Target for $e^+$-$e^-$-pairs production
- **AMD**: Adiabatic Matching Device

**Acceleration:** Linacs, RLA or FFAG, RCS

**from $\mu^+$-$\mu^-$ production to collider**
- $\mu^+$/$\mu^-$ produced by the $e^+$ beam on target T at about 22 GeV $\rightarrow \tau_{lab}(\mu) \approx 500 \mu s$ ($\gamma(\mu) \approx 200$)
- Accumulator Rings (AR) isochronous with high momentum acceptance, they recombine $\mu$ bunches for $\approx 1 \tau_{\mu}^{lab} \approx 2500$ turns
- fast acceleration and to collider

**IP**

$\mu^+\mu^-$ collider

M. Boscolo, NuFact18, 16 August 2018
**Neutrino Factory (NuMAX)**

- **Proton Driver**
  - SC Linac
  - Accumulator
  - Buncher

- **Front End**
  - MW-Class Target
  - Capture Channel
  - Buncher
  - Phase Rotator

- **Cooling**
  - Initial 6D Cooling
  - Charge Separator

- **Acceleration**
  - 0.2–1 GeV
  - 1–5 GeV

- **μ Storage Ring**
  - Initial 6D Cooling
  - Charge Separator

- **ν Factory Goal:** $10^{21}$ $\mu^+ \& \mu^-$ per year within the accelerator acceptance

**Muon Collider**

- **Proton Driver**
  - SC Linac
  - Accumulator
  - Buncher
  - Combiner

- **Front End**
  - MW-Class Target
  - Capture Channel
  - Buncher
  - Phase Rotator

- **Cooling**
  - Initial 6D Cooling

- **Acceleration**
  - Bunch Merge
  - 6D Cooling
  - Final Cooling

- **Collider Ring**
  - Higgs Factory: $\sim$10 TeV

- **μ-Collider Goals:**
  - 126 GeV $\Leftrightarrow$ ~14,000 Higgs/yr
  - Multi-TeV $\Leftrightarrow$
  - Lumi $> 10^{34}$ cm$^{-2}$s$^{-1}$

**Low EMittance Muon Accelerator (LEMMA):**

- $10^{11}$ $\mu$ pairs/sec from $e^+e^-$ interactions. The small production emittance allows lower overall charge in the collider rings – hence, lower backgrounds in a collider detector and a higher potential CoM energy due to neutrino radiation.

**Positron Linac**

- Positron Linac
  - Positron Ring
  - 100 KW target
  - Isochronous Rings

- **Acceleration**
  - Accelerators: Linacs, RLA or FFAG, RCS

- **Collider Ring**
  - $E_{\text{CoM}}$: 10s of TeV

**ArXiv:** 1808.01858
Figure of merit: Luminosity per wall plug power

Lepton Colliders Figure of Merit:
Total Luminosity per wall plug power

Lepton Colliders Figure of Merit:
Peak (1%) Luminosity per wall plug power

Circular

Muons

Linear

Muons

10^{31} \text{ cm}^{-2}\cdot\text{s}^{-1}/\text{MW}

C.M. colliding beam energy (TeV)

J.P. Delahaye

ARIES workshop (July 03, 2018)
This value for LEMMA is dominated by the power required for the high rate 45GeV e⁺, it can be reduced by changing muon target, increase circumference and energy acceptance of the e⁺ ring.
LEMMA concept and MC prospects

The LEMMA concept renewed the interest and extended the reach of Multi-TeV Muon Colliders

- Two interesting recent proposals:
  - CERN Muon Collider @14 TeV c.m.e. V. Shiltzev, D. Neuffer, Proc. IPAC18, MOPMF072
  - LHC/FCC based MC F. Zimmermann, Proc. IPAC18, MOPMF065

- In view of the European Strategy Update an international WG has been established last September 2017 to prepare the input on muon colliders.
- Recent updates discussed recently at: ARIES Muon Collider Workshop, Padova 2-3 July 2018 https://indico.cern.ch/event/719240/
On going activity on the LEMMA proposal

- Our goal is to define the potentiality of this concept for a multi-TeV MC:
  - in terms of luminosity and beam power
  - design the optics for the accelerator complex
  - identify and possibly start with the necessary key R&D

- Updates of our studies can be found in Refs.:
  - “Low emittance muon accelerator studies with production from positrons on target”, Phys. Rev. Accel. and Beams 21, 061005 (June 2018)
  - “Muon accumulator ring requirements for a low emittance muon collider from positrons on target”, M. Boscolo et al., in Proc. IPAC18, MOPMF087 (May 2018)
  - “Proposal of an experimental test at DAΦNE for the low emittance muon beam production from positrons on target”, in Proc. IPAC18, MOPMF086 (May 2018)
Key steps of the study for LEMMA

1. High rate $e^+$ source
2. $\mu^+/\mu^-$ production target (high peak energy density deposition (PEDD), power $O(100\ kW)$)
3. $e^+$ ring (low $\varepsilon$ and high momentum acceptance)
4. Muon Accumulator Rings (high momentum acceptance)
5. Fast acceleration
6. Muon Collider

All steps require R&D studies and raise challenges
Optics design positron ring

<table>
<thead>
<tr>
<th>e+ ring parameter</th>
<th>unit</th>
<th>MAP option</th>
<th>LHC tunnel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>GeV</td>
<td>45</td>
<td>45</td>
</tr>
<tr>
<td>Circumference</td>
<td>km</td>
<td>6.3</td>
<td>27</td>
</tr>
<tr>
<td>No.part./bunch</td>
<td>#</td>
<td>3 \cdot 10^{11}</td>
<td></td>
</tr>
<tr>
<td>bunched</td>
<td>#</td>
<td>100</td>
<td></td>
</tr>
<tr>
<td>e^+ bunch spacing = T_{rev} (AR)</td>
<td>ns</td>
<td>200</td>
<td></td>
</tr>
<tr>
<td>Beam current</td>
<td>mA</td>
<td>240</td>
<td></td>
</tr>
<tr>
<td>Emittance</td>
<td>nm</td>
<td>6</td>
<td>0.7</td>
</tr>
<tr>
<td>U_0</td>
<td>GeV</td>
<td>0.51</td>
<td>0.12</td>
</tr>
<tr>
<td>SR power</td>
<td>MW</td>
<td>120</td>
<td>29</td>
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S. Liuzzo, Padova workshop, 2-3 July 2018
**Optics design positron ring**

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<td>bunches</td>
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<td>100</td>
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<td>SR power</td>
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Target Insertion Region

\[ D_x \approx 0 \]

low-$\beta$ ($\beta_{x,y} = 0.5$ m)

S. Liuzzo, Padova workshop, 2-3 July 2018
Multi-turn simulations

1. Initial 6D distribution from the equilibrium emittances
2. 6D e⁺ distribution tracking up to the target (AT and MAD-X PTC)
3. tracking through the target (with Geant4beamline and FLUKA and GEANT4)
4. back to tracking code

At each pass through the muon target the e⁺ beam
• gets an angular kick due to the **multiple Coulomb scattering**, so at each pass changes e⁺ beam divergence and size, resulting in an emittance increase.
• undergoes **bremsstrahlung energy loss**: to minimize the beam degradation due to this effect, $D_x=0$ at target
• in addition there is natural radiation **damping** (it prevents an indefinite beam growth)
Beam dynamics $e^+$ beam in ring-with-target


$e^+$ emittance growth controlled with proper $\beta$ and D values @ target

After 40 turns \( \sigma_{MS} = 25 \, \mu\text{rad} \)

@Target:
linear and non-linear terms of horizontal dispersion $\eta_x = 0$

Multiple scattering

Bremstrahlung
Muon emittance contributions

\[ \varepsilon(\mu) = \varepsilon(e^+) \oplus \varepsilon(\text{MS}) \oplus \varepsilon(\text{rad}) \oplus \varepsilon(\text{prod}) \oplus \varepsilon(\text{AR}) \]

\[ \varepsilon(e^+) \quad = \text{e}^+ \text{ emittance} \]

\[ \varepsilon(\text{MS}) \quad = \text{multiple scattering contribution} \]

\[ \varepsilon(\text{rad}) \quad = \text{energy loss (brem.) contribution} \]

\[ \varepsilon(\text{prod}) = \text{muon production contribution} \]

\[ \varepsilon(\text{AR}) \quad = \text{accumulator ring contribution} \]

All these values need to be matched to minimize emittance growth due to beam filamentation.

\[ \sigma_x \text{ and } \sigma_{x'} \text{ and correlations of } e^+ \text{ and } \mu \text{ beams have to be similar} \]

M. Boscolo, NuFact18, 16 August 2018

Proc. of IPAC18, Vancouver, MOPMF087
R&D for the muon production target

• This is the core topic of LEMMA feasibility.
• Thermo-mechanical stress is the main issue (very high Peak Energy Density Deposition)

• Engineering simulations and experimental tests will be required to find the optimal target material, considering mechanical stress and heat load resistance properties.
• We are considering now:
  ▪ Beryllium seemed optimal from first MADX-/Geant-4 simulations
  ▪ Carbon composites
  ▪ Liquid Lithium
  ▪ Hydrogen pellet
  ▪ Crystals or more exotic targets

M. Boscolo, NuFact18, 16 August 2018
Target: thermo-mechanical stresses considerations

Beam size as small as possible (matching various emittance contributions), but

- constraints for power removal (200 kW) and temperature rise
- to contrast the temperature rise
  move target (for free with liquid jet) and e\(^+\) beam bump every 1 bunch muon accumulation

- **Solid target**: simpler and better wrt temperature rise
  - Be, C

  Be target: @HIRadMat safe operation with extracted beam from SPS, beam size 300 \(\mu\)m, 
  \(N=1.7\times10^{11}\) p/bunch, up to 288 bunches in one shot  [Kavin Ammigan 6\(^{th}\) High Power Targetry Workshop]

- **Liquid target**: better wrt power removal
  - Li, difficult to handle lighter materials, like H, He
    - LLi jets examples from neutron production, Tokamak divertor
      (200 kW beam power removal seems feasible), minimum beam size to be understood
Conventional options for $\mu$ target

- Aim at bunch ($3 \times 10^{11} e^+$) transverse size on the 10 $\mu$m scale: rescaled from test at HiRadMat ($5 \times 10^{13} p$ on 100$\mu$m) with Be-based targets and C-based (HL-LHC) [F. Maciariello et al., IPAC2016]
- No bunch pileup → Fast rotating wheel (20000 rpm)
- Power removal by radiation cooling (see for instance PSI muon beam upgrade project HiMB) [A. Knecht, NuFact17]
- Need detailed simulation of thermo-mechanical stresses dynamics
  - Start using FLUKA + Ansys Autodyrn (collaboration with CERN EN-STI)
- Experimental tests:
  - **DAFNE** available from 2020

Alternative options like H pellet, crystals or more exotic targets are under consideration
R&D on high rate positron source

- R&D on this topic can take advantage of significant synergies with future collider studies as FCC-ee, ILC and CLIC.
- The required intensity for LEMMA is strongly related to the beam lifetime, determined by the momentum acceptance and the target material.
- So, also optics and beam dynamics optimization is necessary.

<table>
<thead>
<tr>
<th></th>
<th>S-KEKB</th>
<th>SLC</th>
<th>CLIC (3 TeV)</th>
<th>ILC (H)</th>
<th>FCC-ee (Z)</th>
<th>LEMMA</th>
</tr>
</thead>
<tbody>
<tr>
<td>$10^{14}$ e$^+$ / s</td>
<td>0.025</td>
<td>0.06</td>
<td>1.1</td>
<td>2</td>
<td>0.05</td>
<td>100</td>
</tr>
</tbody>
</table>

Present: 3 mm Be, 40 turns lifetime, $\Delta N/N=2.5\%$, $\Delta N=2.5E+16$, P= 247 MW
Goal: 3 mm Be, 240 turns lifetime, $\Delta N/N=0.4\%$, $\Delta N=3.8E+15$, P= 39 MW
R&D on Fast Acceleration for LEMMA

- Muon beams must be accelerated to high energy in a very short period of time to account for their short lifetime.
- Synchrotron radiation is not a limiting factor in accelerating muons at the TeV-scale, so multi-pass acceleration is preferred for cost considerations.
- LEMMA scheme utilizes a natural cycle time of 2.2 KHz and cannot be matched to the slower ramp rate of the MAP hybrid Rapid Cycling Synchrotron.
- For LEMMA two acceleration options to study are:
  - the Recirculating Linear Accelerator (RLA)
  - fixed-field alternating gradient (FFAG) machines with large energy acceptance
- Also accelerator technologies developed for the e+e- linear collider could be of benefit.
Muon collider at 6 TeV com energy

Values considered for this table:
• $\mu^+\mu^-$ rate $= 0.9 \times 10^{11}$ Hz
• $\varepsilon_N = 40$ nm (as ultimate goal)
• 3 mm Beryllium target

Comparison with MAP:

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Unit</th>
<th>LEMMA-6 TeV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Beam energy</td>
<td>Tev</td>
<td>3</td>
</tr>
<tr>
<td>Luminosity</td>
<td>cm$^{-2}$s$^{-1}$</td>
<td>$5.1 \times 10^{34}$</td>
</tr>
<tr>
<td>Circumference</td>
<td>km</td>
<td>6</td>
</tr>
<tr>
<td>Bending field</td>
<td>T</td>
<td>15</td>
</tr>
<tr>
<td>N particles/bunch</td>
<td>#</td>
<td>$6 \times 10^9$</td>
</tr>
<tr>
<td>N bunches</td>
<td>#</td>
<td>1</td>
</tr>
<tr>
<td>Beam current</td>
<td>mA</td>
<td>0.048</td>
</tr>
<tr>
<td>Emittance $x,y$ (geo)</td>
<td>m-rad</td>
<td>$1.4 \times 10^{-12}$</td>
</tr>
<tr>
<td>$\beta_{x,y}$ @IP</td>
<td>mm</td>
<td>0.2</td>
</tr>
<tr>
<td>$\sigma_{x,y}$ @IP</td>
<td>m</td>
<td>$1.7 \times 10^{-8}$</td>
</tr>
<tr>
<td>$\sigma_{x',y'}$ @IP</td>
<td>rad</td>
<td>$8.4 \times 10^{-5}$</td>
</tr>
<tr>
<td>Bunch length</td>
<td>mm</td>
<td>0.1</td>
</tr>
<tr>
<td>Turns before decay</td>
<td>#</td>
<td>3114</td>
</tr>
<tr>
<td>Muon lifetime</td>
<td>ms</td>
<td>60</td>
</tr>
</tbody>
</table>

Same L thanks to lower $\beta^*$ (nanobeam scheme)

no lattice for the muon collider yet
Comment on the parameters table

• **Low Emittance**: is the core of LEMMA idea, the greatest benefit of the positron driven source. The ultimate value has to be determined by R&D studies, we know that it will be given by the convolution of different contributions. Our goal is to reduce multiple scattering to a negligible value and have the best possible matching at target [with 3 mm Be target the multiple scattering contributes for a factor 15 in emittance increase]

• **Bunch intensity** $6 \times 10^9$: a muon bunch charge of $4.5 \times 10^7$ is provided by the AR, an enhancement by a factor 120 can be obtained by a combination scheme either in the longitudinal [D. Schulte] or in the transverse [P. Raimondi] plane. Feasibility needs to be studied, also to verify impact on emittance.

• $\beta^* = 0.2$ mm: aim is nano-beam scheme, final focus lattice not designed yet, permanent quads might be used.

M. Boscolo, NuFact18, 16 August 2018
Conclusion

• LEMMA is a novel concept for muon production, that renewed the interest and extended the reach of Multi-TeV Muon Colliders

• Key topics for the LEMMA feasibility validation:
  - Positron ring-with-target: low emittance and high momentum acceptance
  - Muon Accumulator Rings: compact, isochronous and high $(\Delta p/p)_{\text{accept}}$
  - Muon production target: extreme Peak Energy Density Deposition
  - High positron source rate
  - Fast acceleration
  - Final focus at MC

• Preliminary studies pioneered by the INFN-LNF group are promising, progresses require to continue the design study of the accelerator complex

• More details this afternoon in parallel talk in WG3
Back-up
Positron source requirements for LEMMA

<table>
<thead>
<tr>
<th>Ring energy acceptance</th>
<th>Be 3mm</th>
<th>LI 10mm</th>
<th>H2 liquid 35mm</th>
</tr>
</thead>
<tbody>
<tr>
<td>%</td>
<td>e⁺ beam lifetime (turns)</td>
<td>ΔN/sec</td>
<td>P e⁺ drive beam (MW)</td>
</tr>
<tr>
<td>5</td>
<td>35</td>
<td>2.69E+16</td>
<td>277</td>
</tr>
<tr>
<td>10</td>
<td>47</td>
<td>2.01E+16</td>
<td>207</td>
</tr>
<tr>
<td>20</td>
<td>71</td>
<td>1.34E+16</td>
<td>39</td>
</tr>
</tbody>
</table>

To evaluate the number of positrons per second required from the source we assume to have 100 bunches with $3 \times 10^{11}$ e⁺/bunch stored in the ring for one beam lifetime.
The drive beam power is given by the number of positrons accelerated per second up to 45 GeV.
One of the objectives of the studies on the positron ring is to increase the ring energy acceptance in order to reduce the requirements on the positron source.

**Present ring:** $Dp/p = 6\%$, tau = 40 turns, $e⁺/s = 2.4e16$, $P = 250$ MW

**Target:** tau $> 100$ turns, $e⁺/s < 1e16$, $P < 100$ MW

S. Guiducci, “Positron source options”, Muon Collider Workshop, Padova 2 July 2018
References on LEMMA


• M. Antonelli et al., "Very Low Emittance Muon Beam using Positron Beam on Target", in Proc. IPAC16

• M. Boscolo et al., "Studies of a Scheme for Low Emittance Muon Beam Production From Positrons on Target" in Proc. IPAC17

• F. Collamati et al., "Studies of a scheme for low emittance muon beam production from positrons on target", PoS EPS-HEP2017 (2017) 531

• "Preliminary study of the definition of a white paper for a conceptual Design Study of a Low EMittance Muon Accelerator (LEMMA)" pp58, document prepared for the MAC of INFN, not for distribution, October 2017


• M. Boscolo et al., "Muon accumulator ring requirements for a low emittance muon collider from positrons on target", in Proc. IPAC18 after Snowmass2013 also SLAC team investigated the idea:
  L. Keller, J. P. Delahaye, T. Markiewicz, U. Wienands: "Luminosity Estimate in a Multi-TeV Muon Collider using e+e- à µ+µ- as the Muon Source", MAP14 Spring worksh., Fermilab (USA) Advanced Accelerator Concepts Workshop, San Jose (USA), July '14 M. Boscolo, NuFact18, 16 August 2018

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Lepton Colliders Luminosity

Lepton Colliders
Total (100%)
Luminosity

Lepton Colliders
Peak (1%)
Luminosity

C.M. colliding beam energy [TeV]

Linear

Circular

Muons

FCC ee

ILC

CLIC

Muon Collider (MAP)

Muon Collider (LEMMA)

PWFA

10^{24} cm^{-2}s^{-1}

J.P. Delahaye
ARIES workshop (July 03, 2018)
Conferences and Workshops

After first presentation in Snowmass

- P. Raimondi, “Exploring the potential for a Low Emittance Muon Collider”, in Discussion of the scientific potential of muon beams workshop, CERN, Nov. 18th 2015
- M. Antonelli, “Low-emittance muon collider from positrons on target”, FCCWEEK2016
- M. Antonelli et al., “Very Low Emittance Muon Beam using Positron Beam on Target”, IPAC16
- F. Collamati, EPS17
- F. Collamati, Nufact17
- M. Boscolo et al., “Studies of a scheme for low emittance muon beam production from positrons on target”, IPAC17 (2017)
- M. Boscolo, “LEMMA”, INFN MAC, LNGS, Ottobre 2017
- D. Lucchesi, FERMILAB Colloquium, 2018
- P. Raimondi, “Towards a future muon collider”, La Thuile 2018
- L. Sestini, Test beam workshop 2018
- F. Anulli, Muon Collider: LEMMA proposal”, XXIV Cracow EPIPHANY Conference on Advances in Heavy Flavour Physics, 2018
- Workshop on Targetry LNF mini-workshop
- M. Boscolo et al., IPAC18
- M. Boscolo, Invited talk at 1° ARIES annual meeting “The muon collider”, May 2018
- M. Iafrati et al., “Preliminary study of high power density target for the LEMMA proposal”, to be presented at HPTW workshop, 2018
- ARIES Muon Collider workshop, Padova 2-3 July 2018

not exhaustive list
R&D on high rate positron source

Embedded e+ source to relax e+ source requirement

Positron source extending the target complex
Possibility to use the \( \gamma \)'s from the \( \mu \) production target to produce e+

About 0.6 new e\(^+\) produced per e\(^+\) on thin target
Required collection efficiency feasible with standard design
not yet found a system able to transform the temporal structure of the produced positrons to one that is compatible with the requirement of a standard positron injection chain