Muon accumulator ring
(or challenges for a muon acc. ring)

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The LEMMA team

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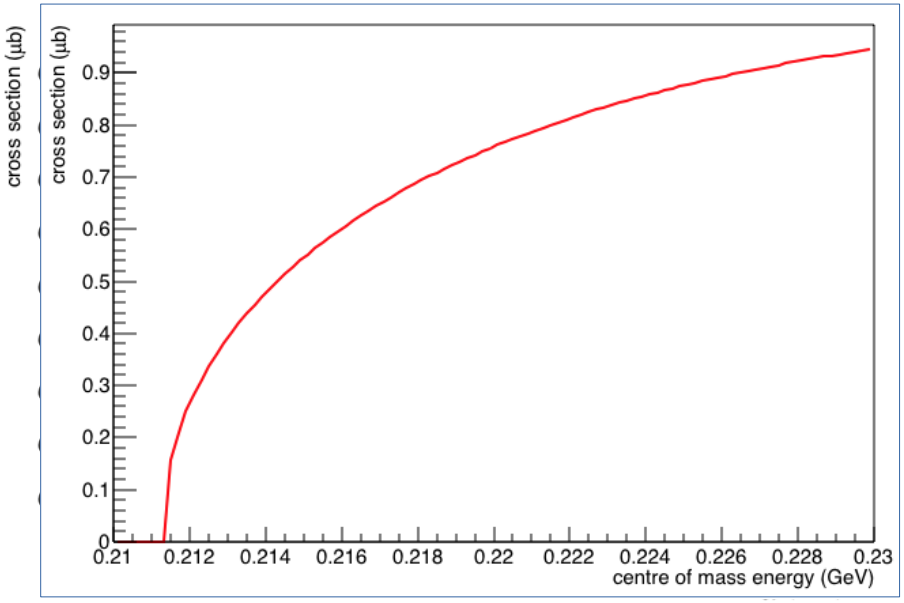
Muon Collider Workshop 2018

Muon production at $\sqrt{s}$ around 0.212 GeV c.o.m.

- Positron beam at 45GeV impinging on a target = ~0.212 GeV c.o.m.
- $e^+e^- \rightarrow \mu^+\mu^-$ cross section: 0.1~1 μbarn



M. Antonelli. Novel proposal for a low emittance muon beam using positron beam on target, NIM-A, Volume 807, 2016, https://doi.org/10.1016/j.nima.2015.10.097

The small cross section forces us to use a high number of positrons.

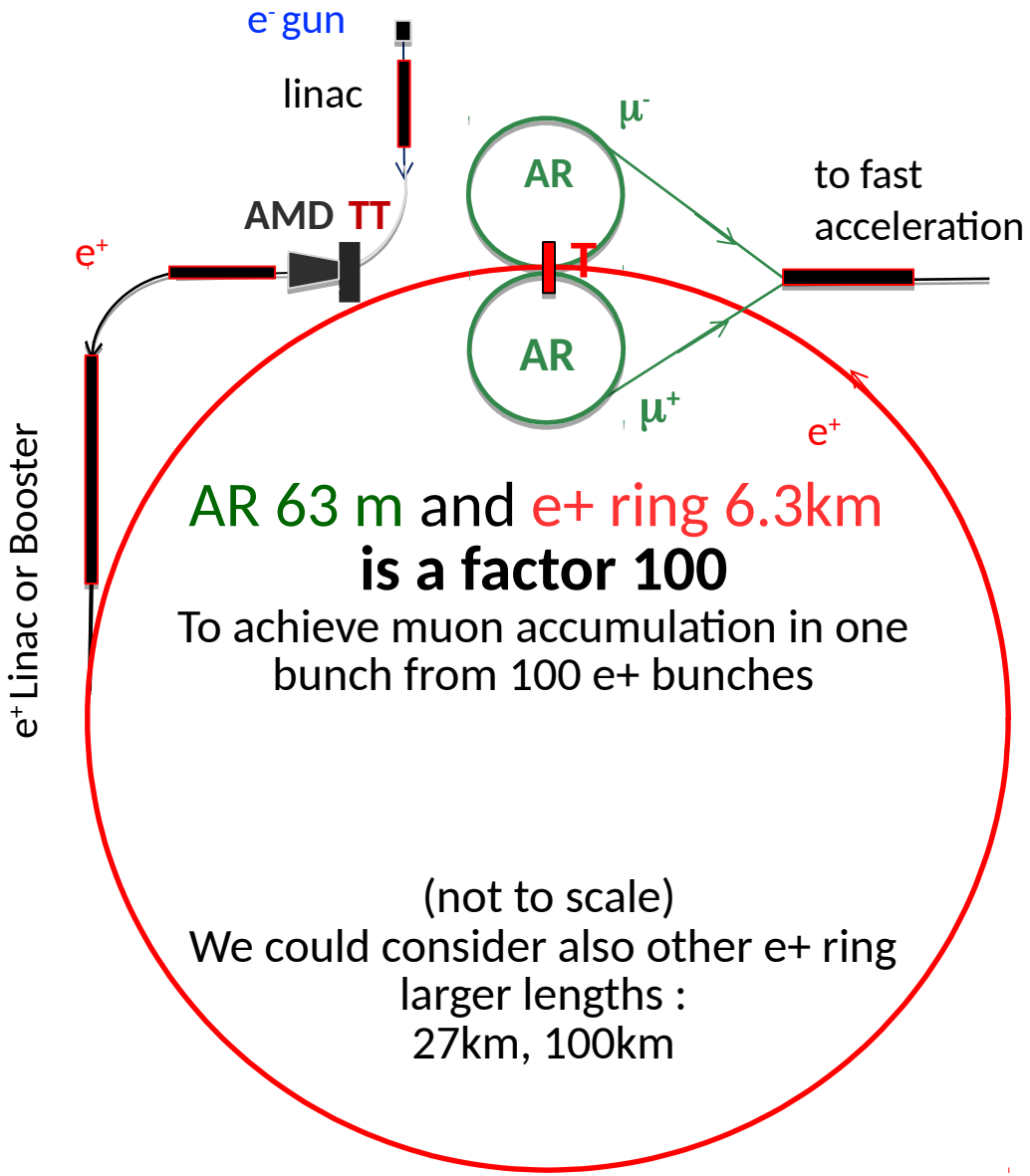
To reduce the demand on the positron source the positron beam is forseen to be recirculated.

The current GOAL ≈ 10^{11} e^+/bunch and 100 bunches over >25 turns
10^{15} e^+→ to get ~$10^{(7\sim8)}$ muons in one bunch

Efficiency is ~10^{-7} (for Be of 3mm in thickness)
theoretically it is possible to do 10^{-5}

SCHEME FOR LOW EMITTANCE MUON BEAM PRODUCTION FROM POSITRONS ON TARGET

M. BOSCOLO. Studies of a scheme for Low EMittance Muon Accelerator with production from positrons on target arXiv:1803.0669



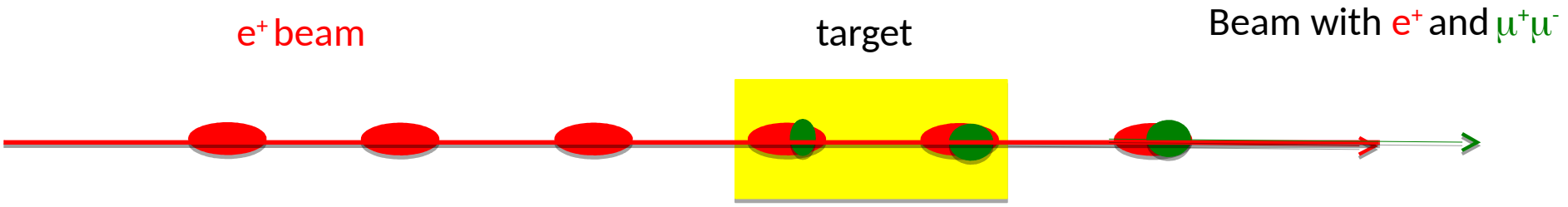
← In this presentation I talk about the ACC. Rings and the Target

Muons cross the target many times over
1 muon lifetime ≈ 0.5ms

We want all muons in 1 bunch in the AR (to have large muon bunch intensity).

Therefore, the distance between bunches in the e+ ring must match the AR circumference.

The low emittance μ beam production idea



Ideally muons will *copy* the positron beam
From simulations we have seen that there are contributions to emittance from bremstrahlung and multiple scattering

<u>The positron energy deposition in the target is one of the biggest concerns</u>,

Even so, in simulations the positron beam emittance growth can be controlled by optics matching the target

Meaning :
low beta regions and dispersion (1st, 2nd, … orders) cancelled
For the e+ ring and the accumulator

Interaction point parameters on the e+ ring and the muon accumulator

β to match the divergence of the produced muon beam

θ_μ mrad	ϵ_{e^+} nm	$\beta^*_{e^+}$ m	σ_{e^+} μm	σ'_{e^+} mrad	σ'_μ mrad	ϵ_{μ^+} nm	β_μ m
1	10	0.01	10	1	1.41	14.1	0.01
1	10	0.49	70	0.14	1.01	70.7	0.07
1	10	1.00	100	0.10	1.0	100	0.10
0.5	10	0.01	10	1	1.12	11.2	0.01
0.5	10	1.00	100	0.1	0.51	51.4	0.20

From e+ at 45GeV

From e+ at 44GeV

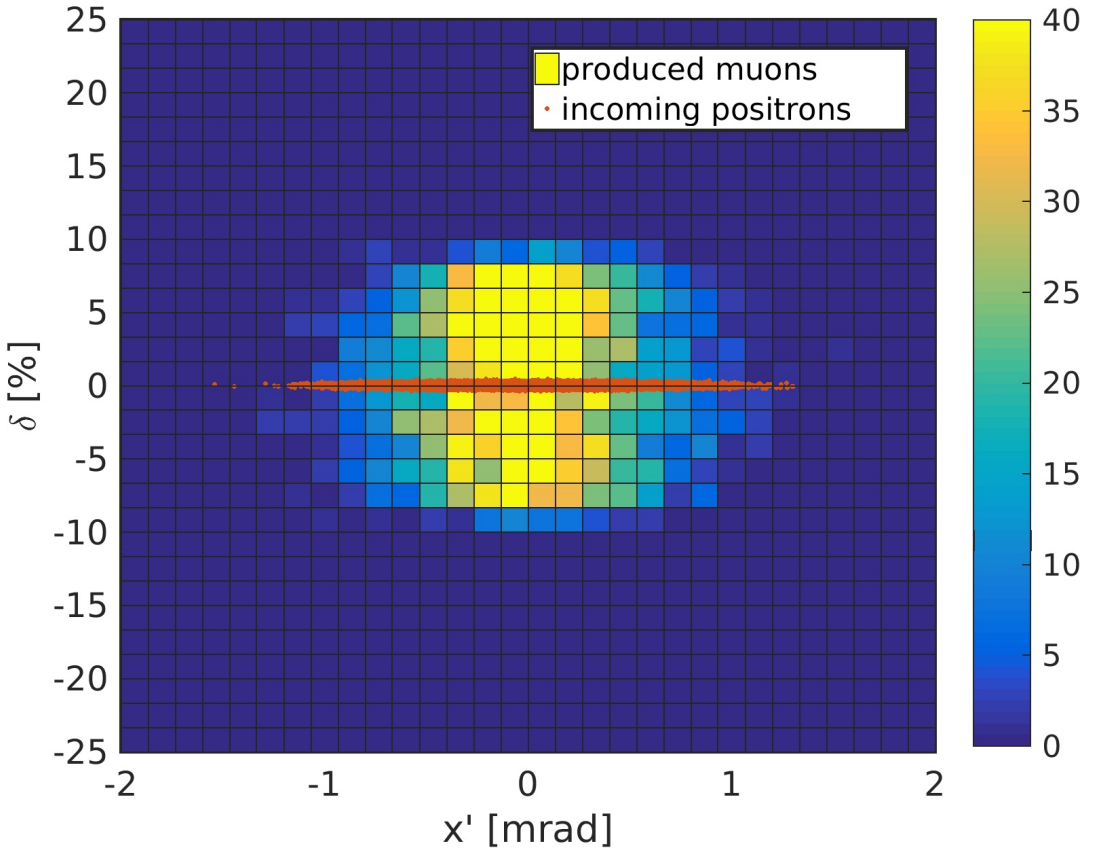
We need beta* of the order of cm in the e+ ring AND in the accumulator

M. Boscolo. Muon Accumulator Ring Requirements for a Low Emittance Muon Collider from Positrons on Target. IPAC2018, MOPMF087

The muon production

Simulations from a 3 mm thick Beryllium target, and a positron beam at 44GeV

The positron beam has been focused, β*(e+) is 0.05m ,
to reduce the muon spread.



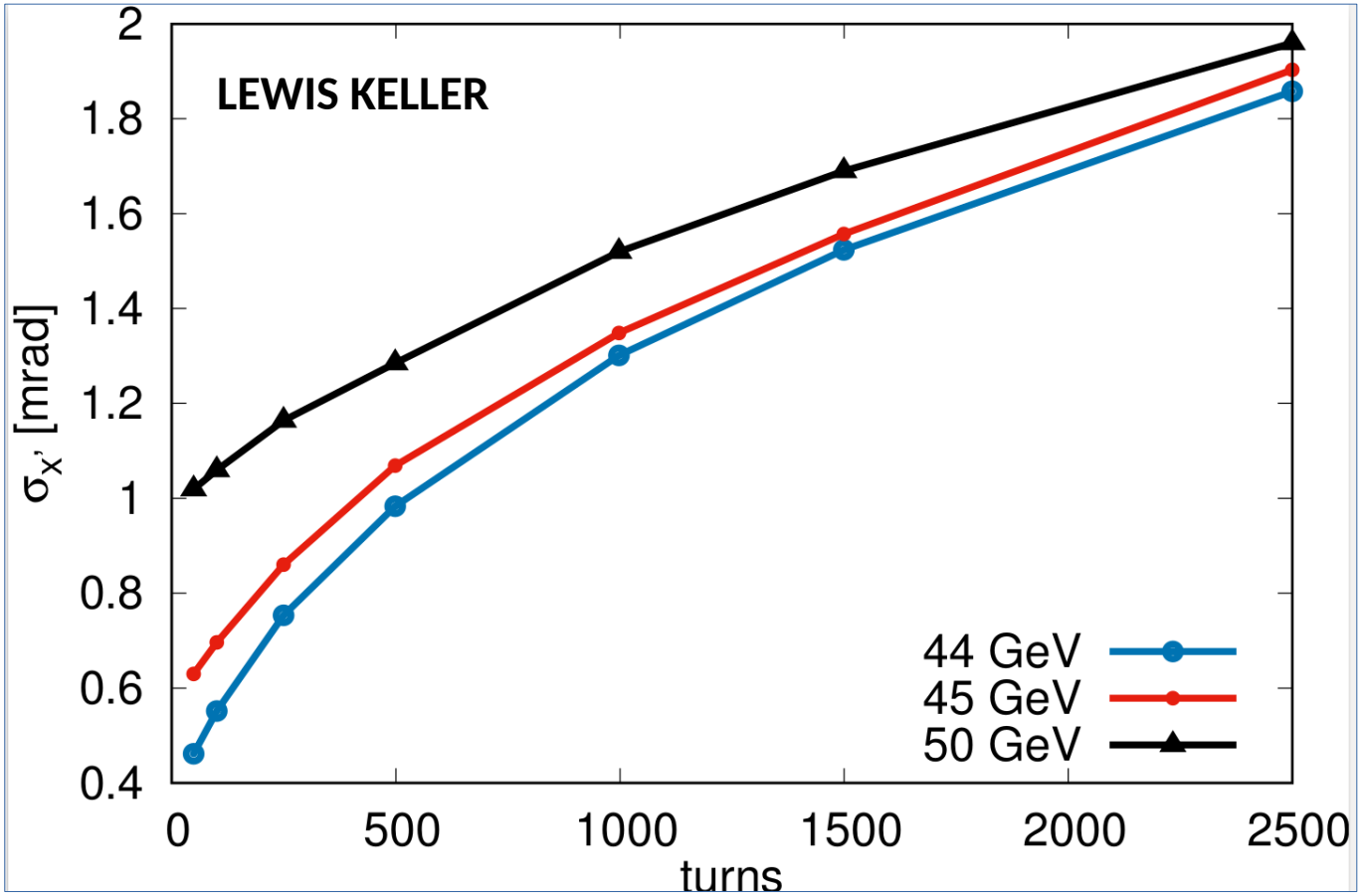
(This figure shows only one of the two species of muons, the other species has similar distribution)

The muon accumulator ring will need an energy acceptance close to 5%, and small momentum compaction factor to avoid bunch lengthening.

M. Boscolo. Muon Accumulator Ring Requirements for a Low Emittance Muon Collider from Positrons on Target. IPAC2018, MOPMF087

The muon accumulation

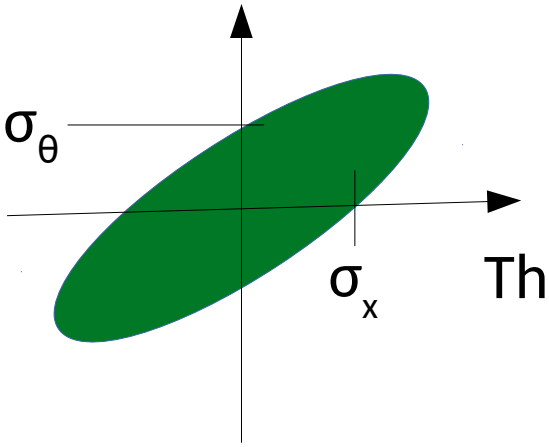
Muon beam divergence as a result of the interaction with the target over several turns in the AR.



Muons almost don't loose energy when crossing the target.
The increase of the muon beam divergence comes from multiple scattering with the target, and therefore muon emittance will increase

The muon emittance growth due to accumulation

Using the RMS divergence produced from one pass through the target, it is possible to analytically estimate the optics functions to match the beam at the target exit and the emittance growth.



$$\sigma_\theta \approx \frac{13.6\mathrm{MeV}\sqrt{L/\lambda}}{E} \qquad \sigma_x \approx \frac{L}{\sqrt{12}}\sigma_\theta$$

The optics functions to match the beam to the target :

$$\beta = \frac{4}{\sqrt{3}}L \qquad \alpha = -\sqrt{3}$$

Thus, the normalized emittance growth is : $\Delta\epsilon = \sigma_\theta^2 \frac{L}{\sqrt{12}} \times \frac{E}{m_\mu c^2}$

For the 3 mm Be target the RMS divergence is ~60 urad,
and the emittance growth AFTER ALL ACCUMULATION is
0.61 um (normalized) = 3 nm

The muon emittance growth due to accumulation

NOTE that muon emittance (from the positron beam) was in the order of tens of nm, now, it has a contribution of nm

3 nm

Seems small but if emittance growth comes from muon scattering in the target :

Is channeling a solution ?
Is accumulation the best option ?

At the end we want high luminosity : $L \propto N^2/\varepsilon$
At some point accumulation does not increase luminosity because of the decay of muons and the emittance growth.

For a Be target, it was initially estimated that 500~1000 turns of accumulation could give the best peak luminosity
Assuming an ideal lattice (transport matrix = I)
Keller. Muon Accumulator issues. 03/Feb/2017 https://agenda.infn.it/conferenceDisplay.py?confId=12809

How do we do the lattice ?

The muon accumulator

For the 22 GeV muon beam, $B\rho = P/e \approx 73$ T.m

An accumulator of 63 m in circumference and 80% dipole occupancy needs 9T dipoles.

Seems possible but very challeging taking into account :

- Low beta* interaction point for the target (~cm)
- Large energy acceptance (better than 5%)
- Large dynamic aperture because of the beam divergence
- Low momentum compaction factor to avoid further lengthening of the beam
- Survival to radiation because of muon decay, and possibly gammas because…
- Target region is shared between three different species of particles at two different energies (e+ at ~45 GeV and mu+,mu- at ~22 GeV)
- extraction point(s)

CONCLUSIONS

LEMMA is studying the low emittance muon production from positrons on a target, an innovative idea that could lead to new accelerators.

The muon production relies in a high rate of positrons, thus, we have considered the recirculation of a 45 GeV beam, where we keep the emittance growth under control.

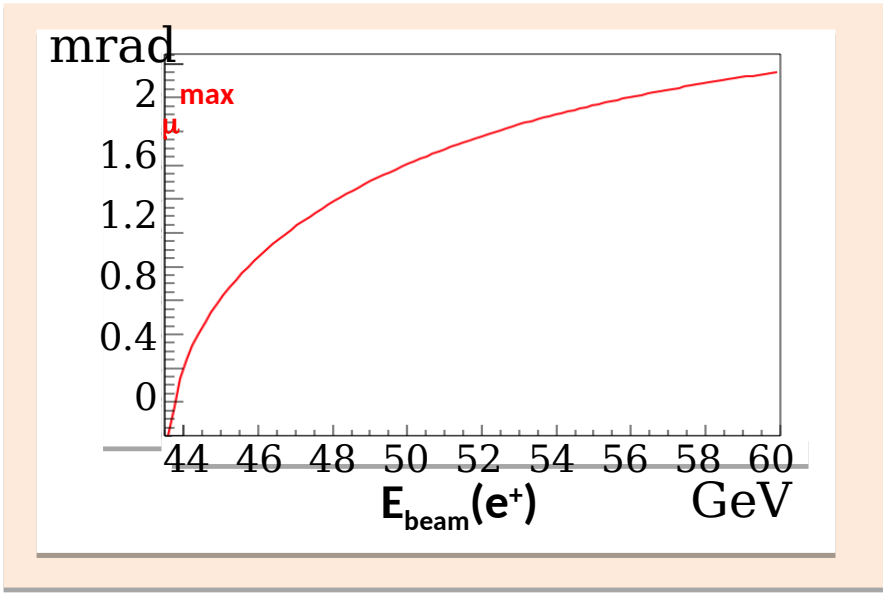
In order to increase the muon current, muons are accumulated for less than 0.5ms (~one lifetime at 22 GeV).

The accumulator design includes very challenging characteristics : low beta regions shared for three beams, large momentum and dynamic apertures, negligible momentum compaction factor, and radiation hardening in an small circumference.

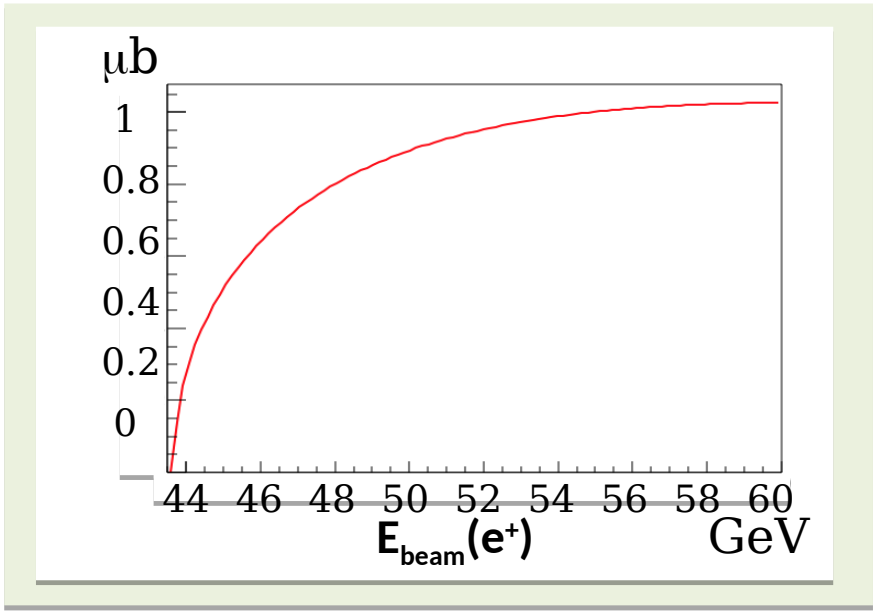
OPEN QUESTIONS :
Emittance growth has been estimated and seems small, but :
Is channeling an option ?
Do we possibly loose luminosity from (long) accumulation ?

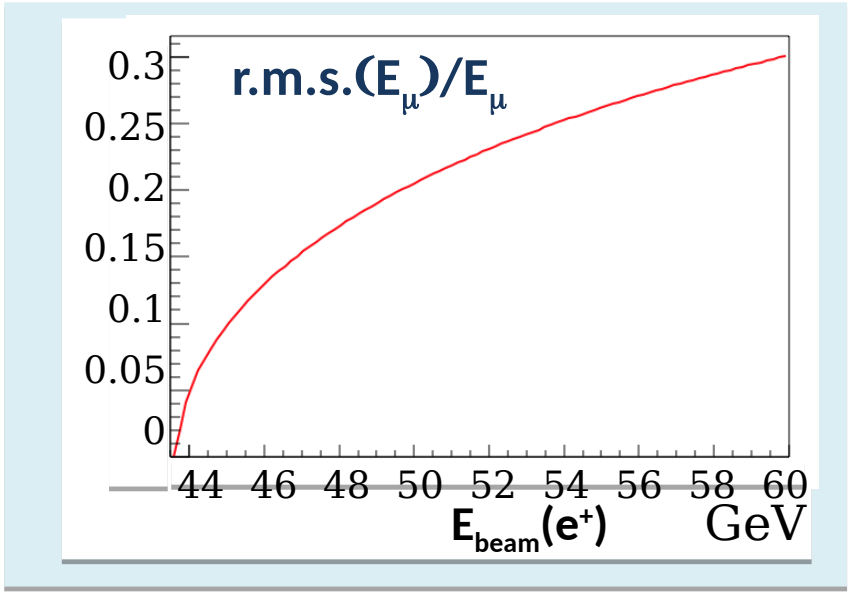
Backup Slides

Parametric behaviours



$\sigma(e^+e^- \to \mu^+\mu^-)$





Low EMittance Muon Accelerator team:

(Italy) **INFN institutions involved: LNF, Roma1, Pd, Pi, Ts, Fe**
Universities: Sapienza, Padova, Insubria
(International) **Contributions from: CERN, ESRF, LAL, SLAC**

This new proposal covers different areas of research:
accelerator physics, high energy, theory, engineering material science, …
Many colleagues are interested to collaborate,
informal contacts with international experts has started
We believe in the potential of this idea, but key challenges need to be demonstrated to prove its feasibility.

I will show the work done up to now <u>on the positron ring for low emittance muon production</u>

Exploring the potential for a Low Emittance Muon Collider

some <u>References:</u>

- M. Boscolo *et al.*, **"***Studies of a scheme for low emittance muon beam production from positrons on target"*, **IPAC17 (2017)**
- M.Antonelli, *"Very Low Emittance Muon Beam using Positron Beam on Target"*, **ICHEP (2016)**
- M.Antonelli *et al.* , *"Very Low Emittance Muon Beam using Positron Beam on Target"*, **IPAC (2016)**
- M. Antonelli, *"Performance estimate of a FCC-ee-based muon collider"*, **FCC-WEEK 2016**
- M. Antonelli, *"Low-emittance muon collider from positrons on target"*, **FCC-WEEK 2016**
- M. Antonelli, M. Boscolo, R. Di Nardo, P. Raimondi, *"Novel proposal for a low emittance muon beam using positron beam on target"*, **NIM A 807 101-107 (2016)**
- 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, **Presentation Snowmass 2013**, Minneapolis (USA) July 2013, [M. Antonelli and P. Raimondi, Snowmass Report (2013) also INFN-13-22/LNF Note

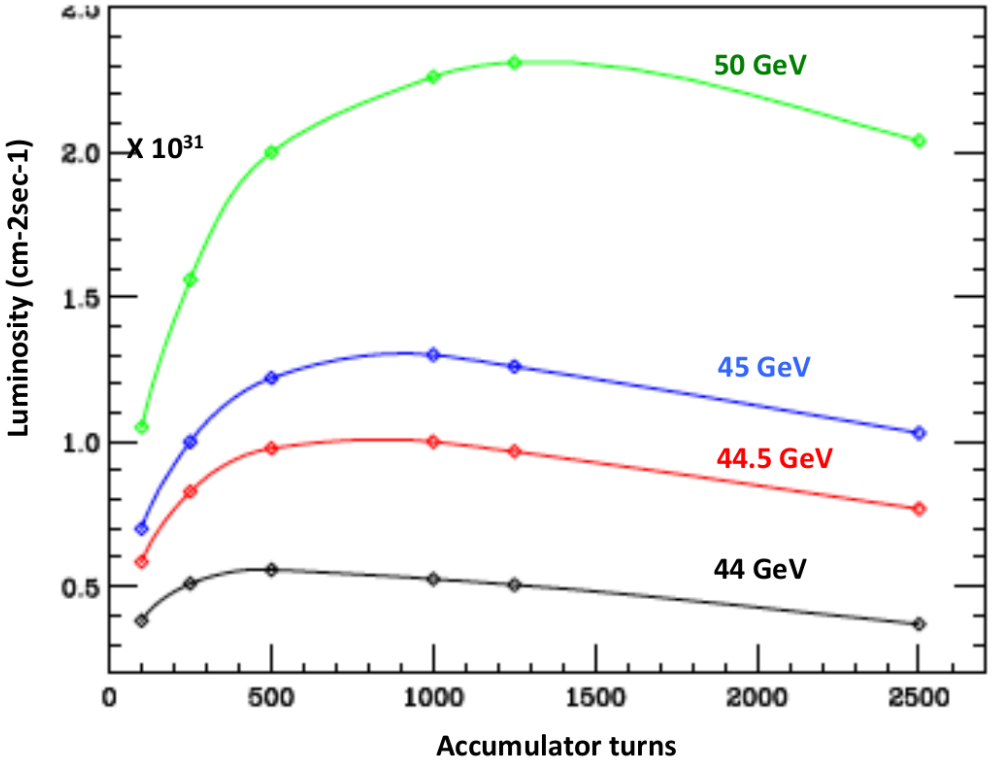
Also investigated by SLAC team:

L. Keller, J. P. Delahaye, T. Markiewicz, U. Wienands:

- *"Luminosity Estimate in a Multi-TeV Muon Collider using $e^+e^- \rightarrow \mu^+\mu^-$ as the Muon Source"*, MAP 2014 Spring workshop, Fermilab (USA) May '14
- Advanced Accelerator Concepts Workshop, San Jose (USA), July '14

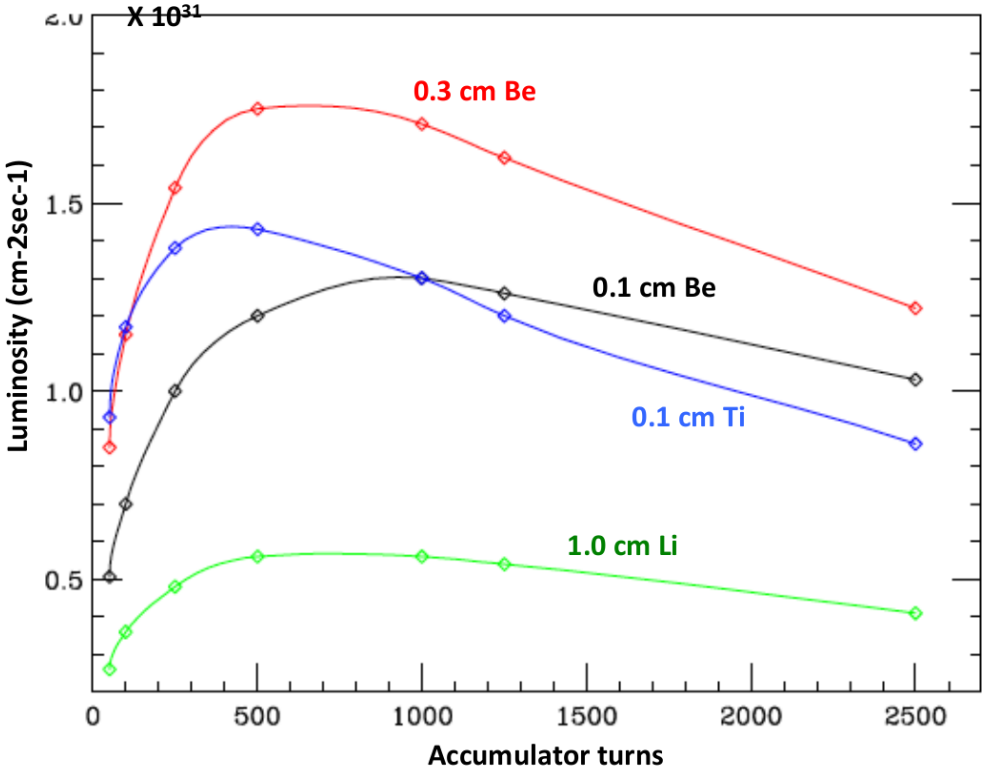
Luminosity in 6 TeV CM Muon Collider for Different Positron Energies

Production Target 0.1 cm Be



Luminosity in 6 TeV CM Muon Collider for Different Production Targets

Positron energy = 45 GeV



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