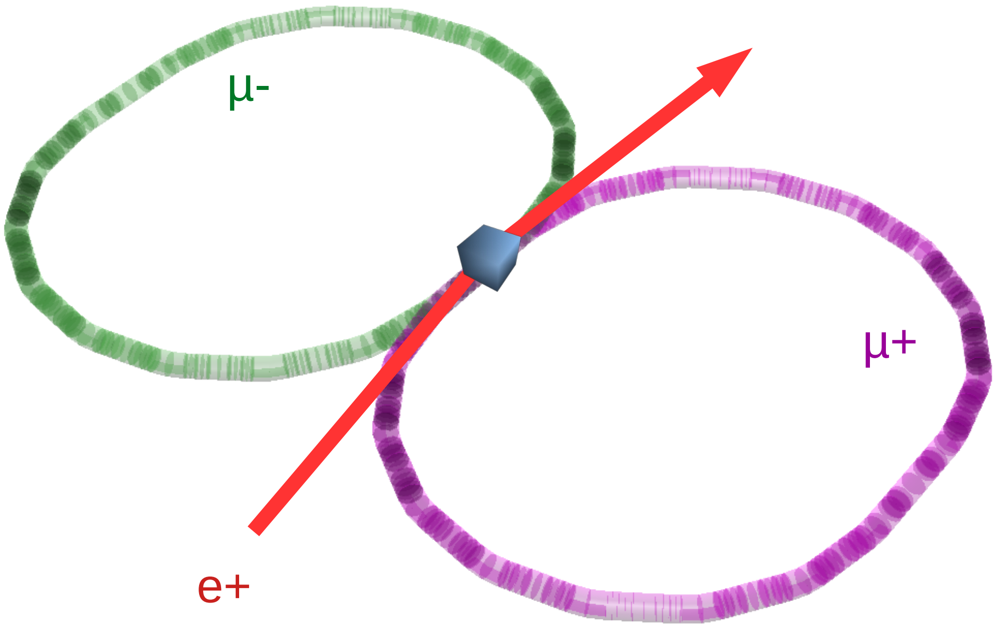
Muon Accumulator Optics for a Muon Beam produced from positron-electron annihilations



Oscar BLANCO
M. ANTONELLI,
M. BOSCOLO,
A. CIARMA,
P. RAIMONDI

International Workshop on Fixed Field Alternating Gradient Accelerators
PSI, 19-22/NOV/2019

LEMMA (Low Emittance Muon Accelerator)
It is a low emittance muon source, no cooling needed

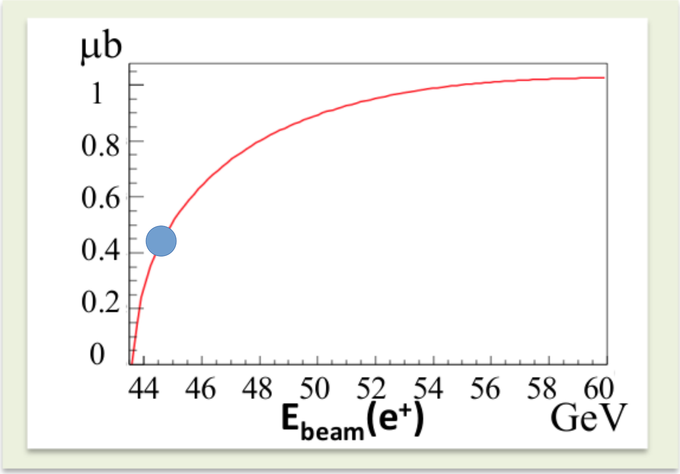
from **direct μ pair production**:

Muons produced from $\mathbf{e^+e^- \to \mu^+\mu^-}$ at $\sqrt{s}$ around the $\mu^+\mu^-$ threshold **($\sqrt{s} \approx$ 0.212GeV)** in asymmetric collisions (to collect μ^+ and μ^-)

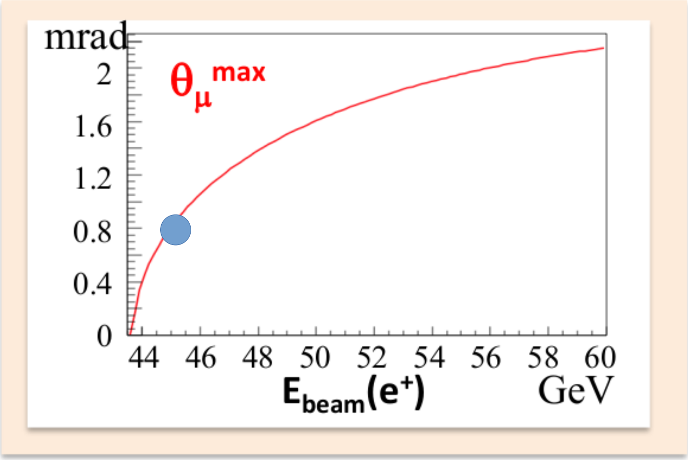
- **Need Positrons of $\approx$ 45 GeV**
- $\gamma(\mu)\approx 200$ and μ laboratory lifetime of about 500 μs

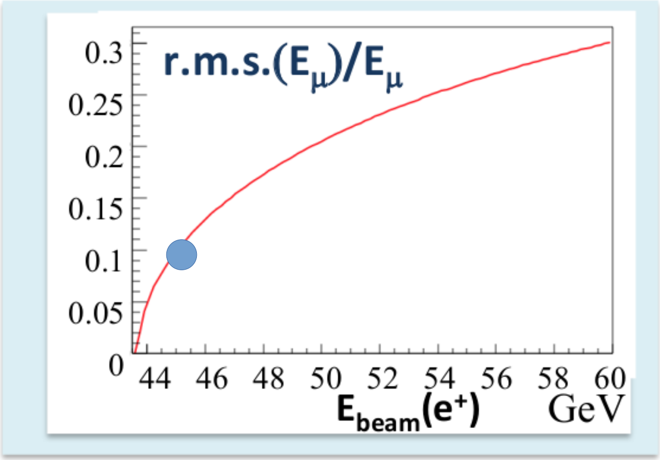
Muon transverse and longitudinal emittance depend on the e+ beam energy and size

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



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 energy spread



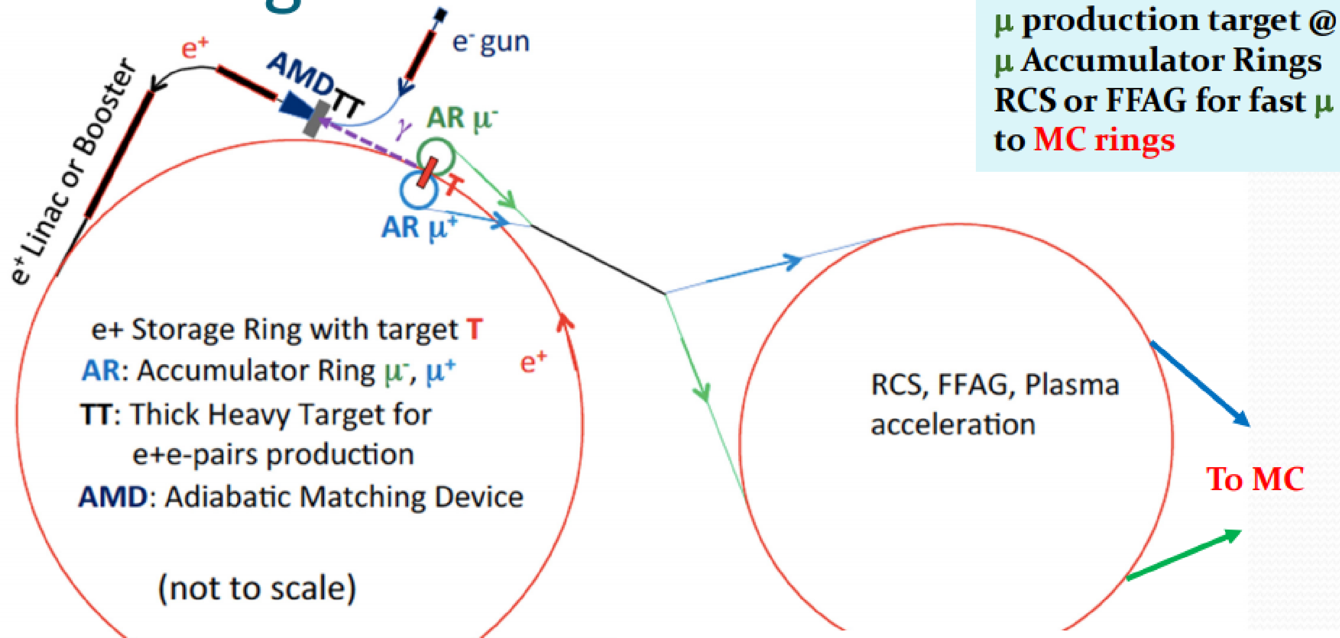


M. Antonelli. et al. Novel proposal for a low emittance muon beam using positron beam on target. NIM A 807 (2016) 101

M. Biagini,et al. IPAC19.

LEMMA original scheme

- e^+ high intensity source
- e^+ acceleration to 45 GeV
- e^+ storage ring @ 45 GeV
- μ production target @ 22 GeV
- μ Accumulator Rings
- RCS or FFAG for fast μ acceleration to MC rings



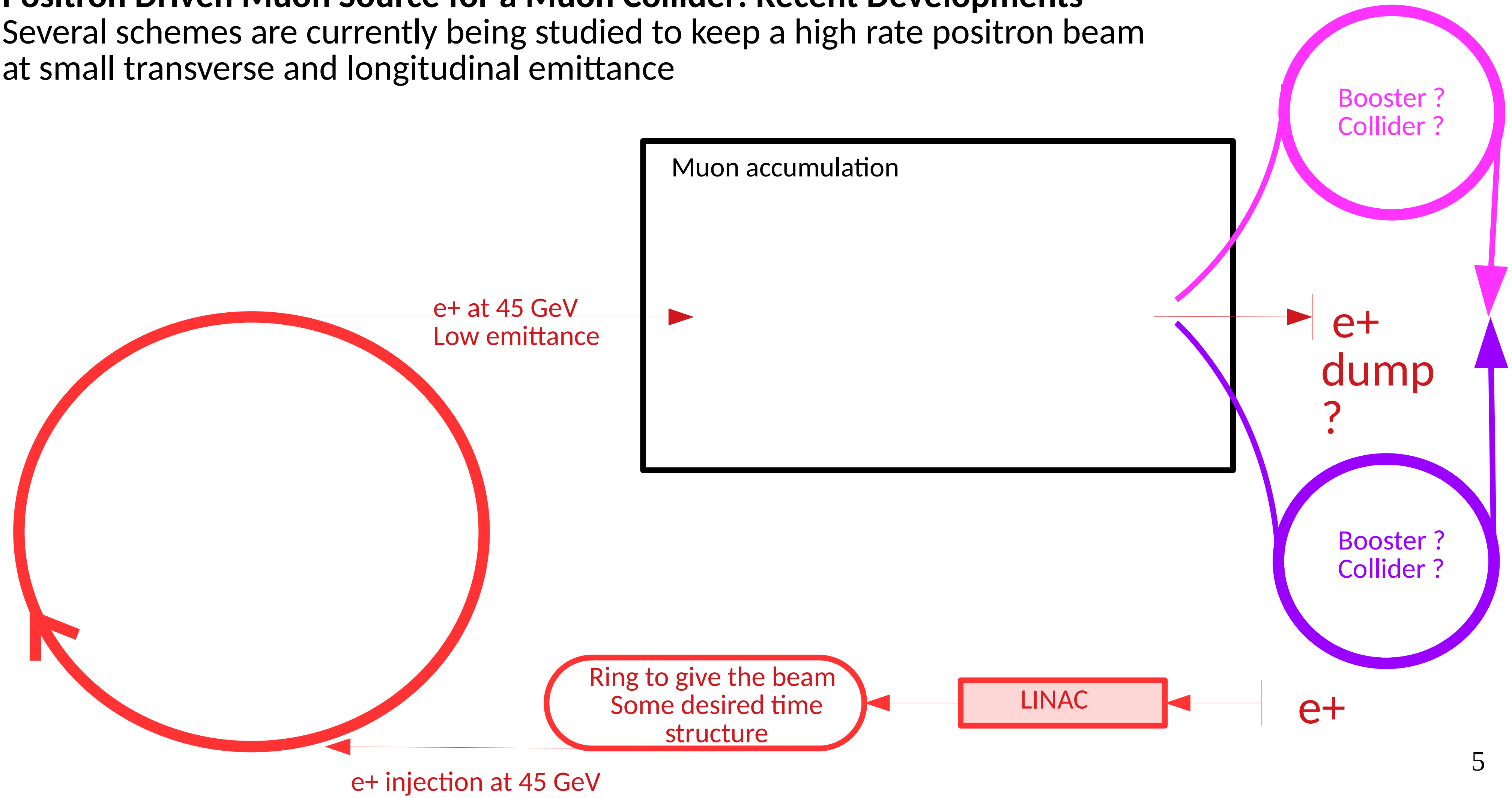
Goal: $\approx 10^{11}$ μ/s produced at target with target efficiency $\approx 10^{-7}$ (Be, 3mm)

Request: 10^{18} e^+/s impinging on target → 45 GeV e^+ storage ring with target insertion

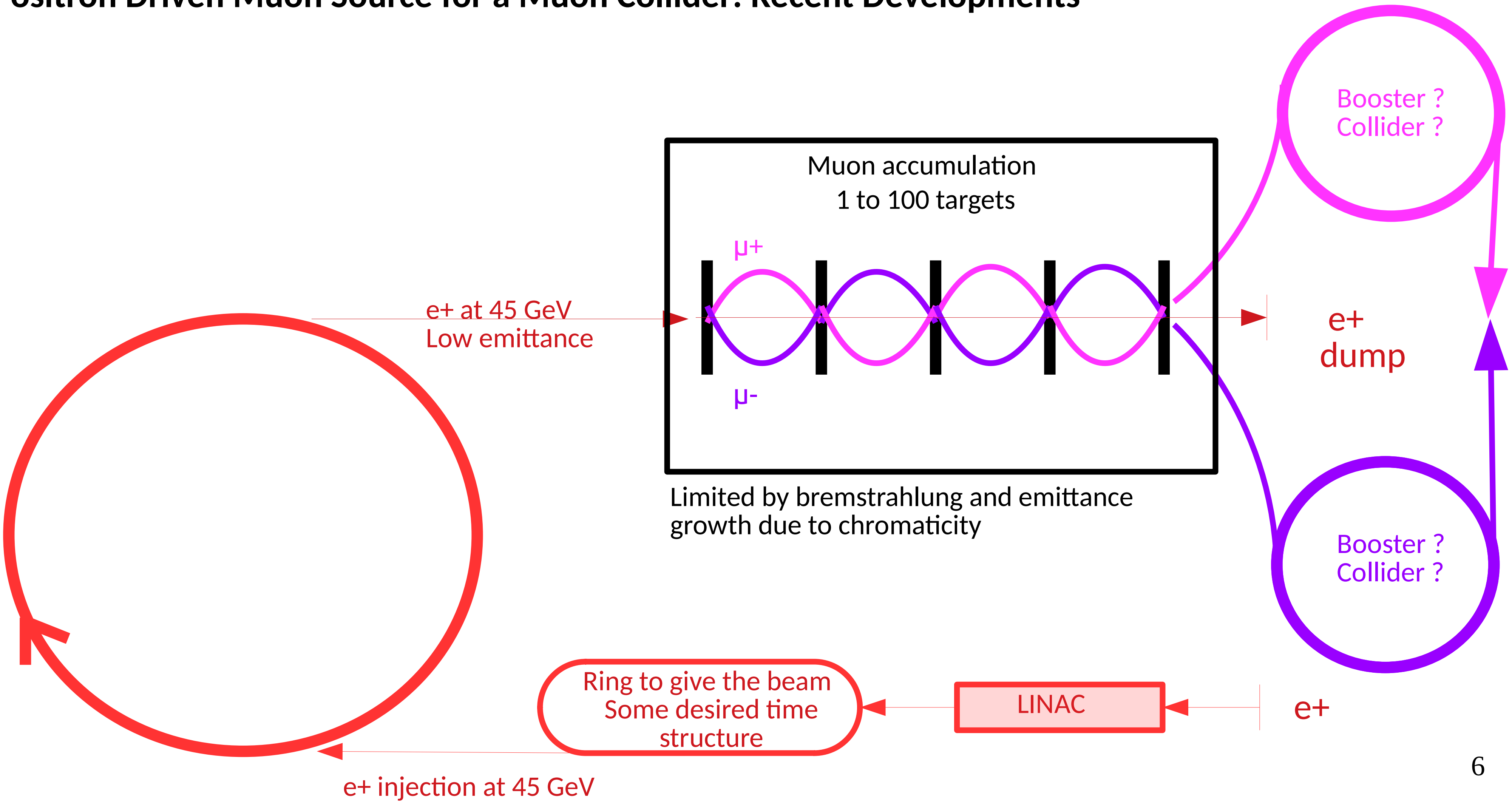
$\mu^\pm$ produced by e^+ beam on target T @ ~ 22 GeV → $\tau_{lab}(\mu) \approx 500\mu s$ ($\gamma(\mu) \approx 200$)

Muon Accumulator Rings (MA) isochronous with high momentum acceptance, recombine $\mu^\pm$ bunches for ~ 1 $\tau_\mu^{lab} \approx 2500$ turns

M. Biagini,et al. IPAC19. MOZZPLS2,
Positron Driven Muon Source for a Muon Collider: Recent Developments
Several schemes are currently being studied to keep a high rate positron beam at small transverse and longitudinal emittance



M. Biagini,et al. IPAC19. MOZZPLS2, Positron Driven Muon Source for a Muon Collider: Recent Developments



M. Biagini,et al. IPAC19. MOZZPLS2,
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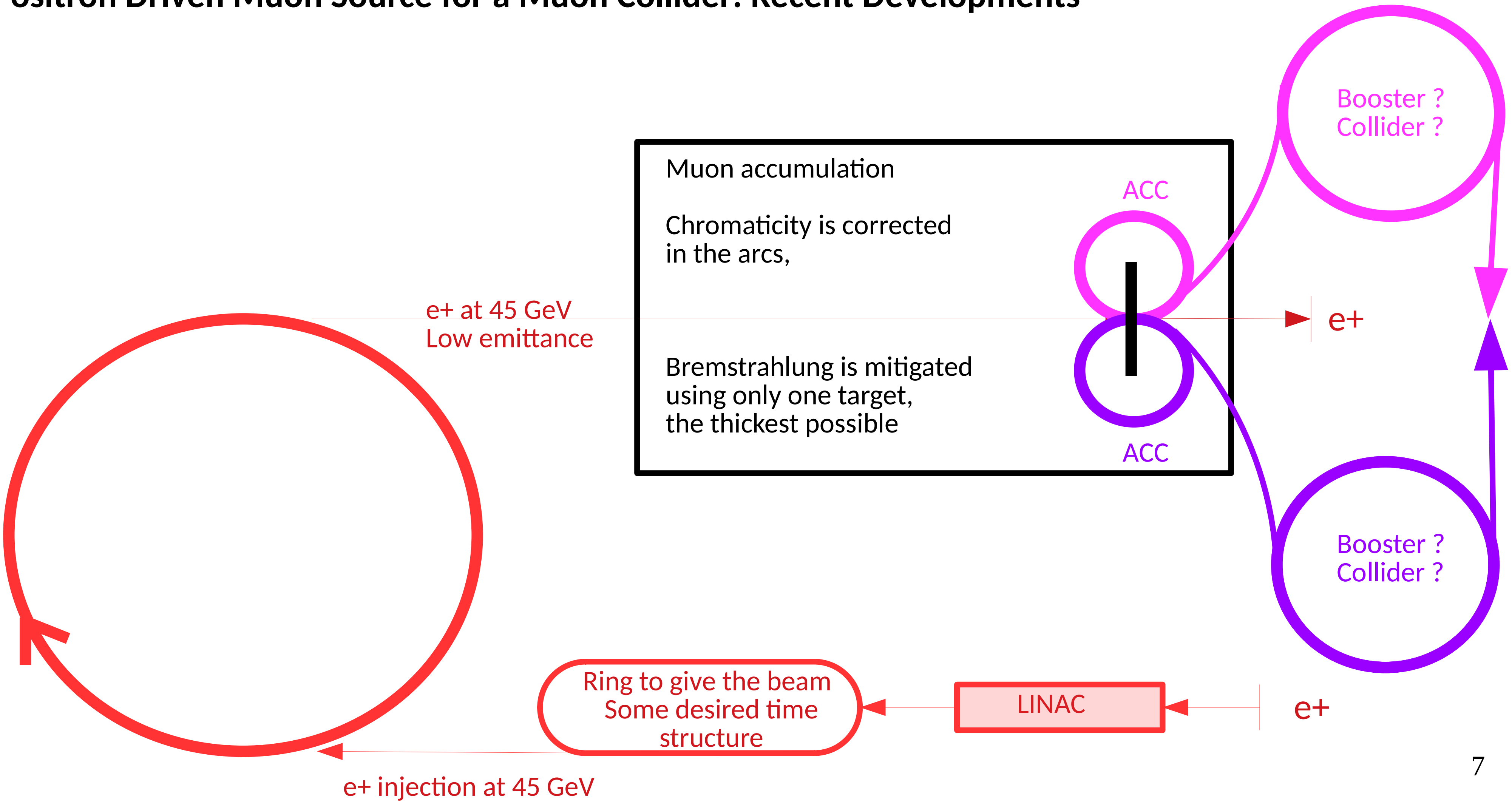
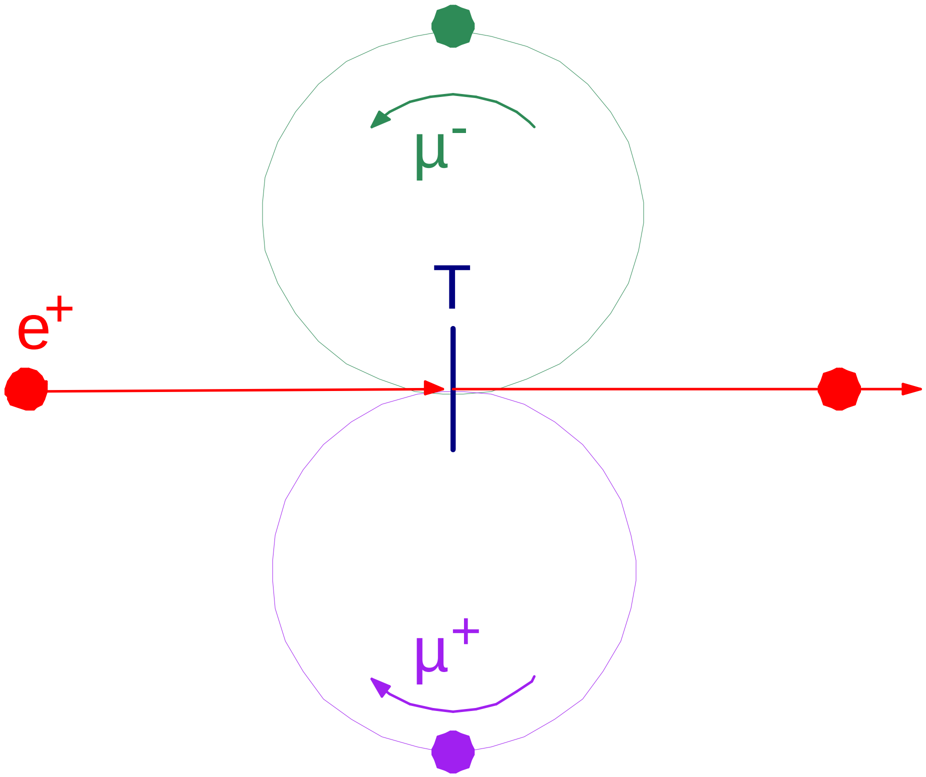


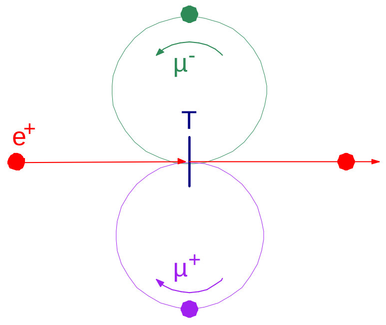
Muon Accumulator Rings

The muon accumulator rings collect and recirculate the muons produced on every positron bunch passage, increasing the muon bunch intensity



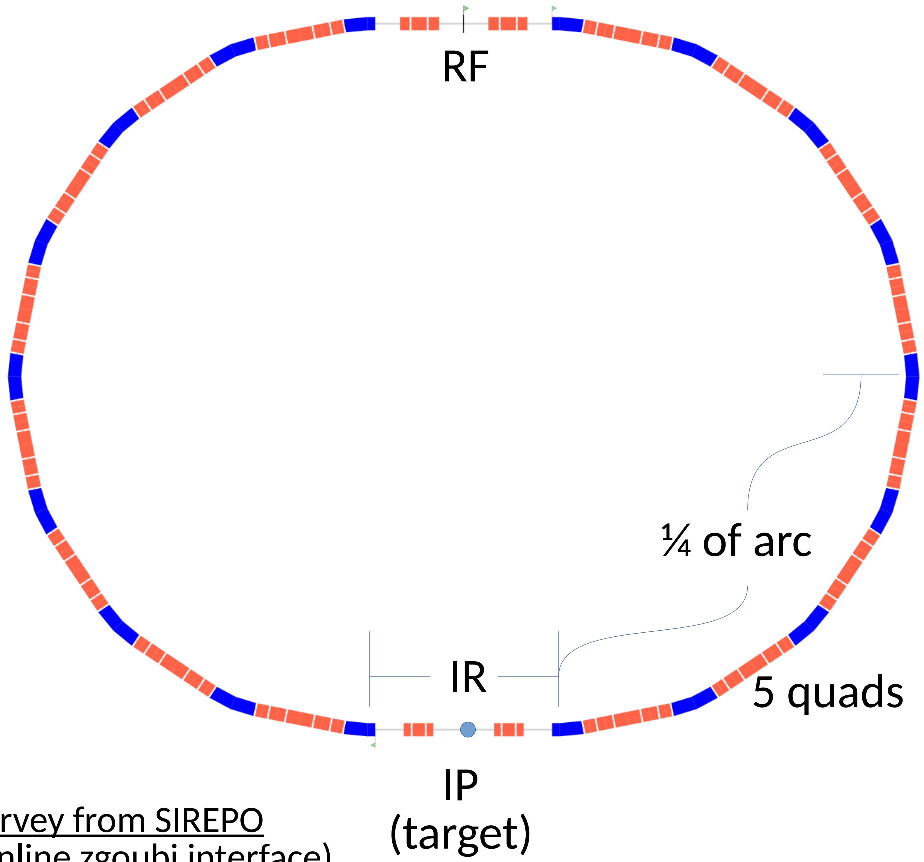
Requirements 2018 and status 2019

	Required 2018	**Optics Design Status**	
Small Length	60 m	150 m (x2.5)	To mitigate muon decay
Large Dynamic Ap.	±20%	±10%	Production efficiency and energy spread are proportional
Low ß*	According to target length	1.3 m	To avoid emittance growth from multiple scattering
Time of accumulation	1000 turns	-to be checked with the targets	To get ~10^9 muons in one bunch in less than 0.4 ms



Layout (One Ring)

By Pantaleo Raimondi

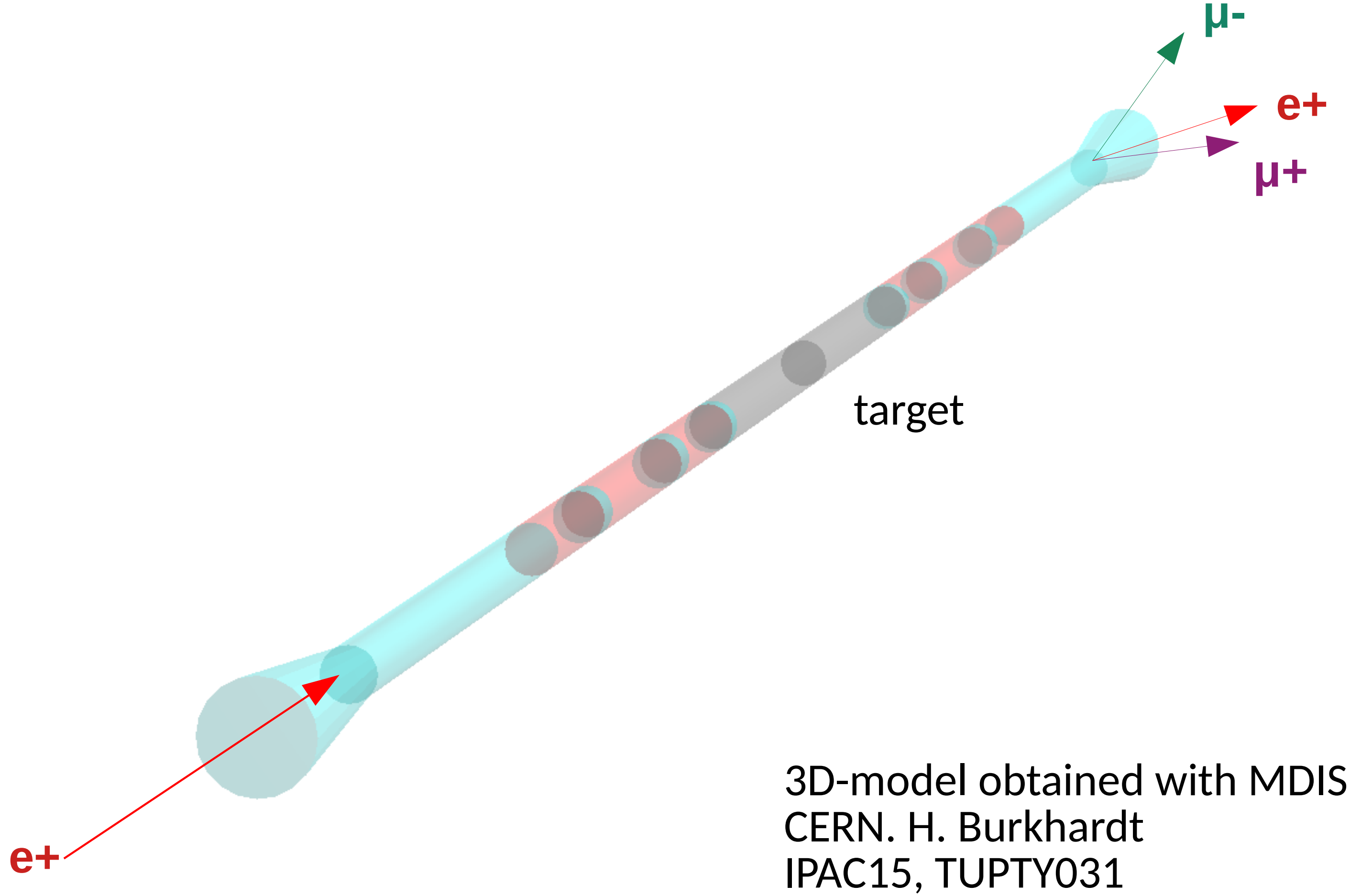


survey from SIREPO
(online zgoubi interface)

- The IR region is shared among three beams :
  μ+, μ- at 22.5 GeV, and e+ at 45 GeV
  Two triplets focus the beam around the IP (target location)
- Each ¼ of arc, is composed by 4 units of
  two halves of a sector bend dipole, and 5 quadrupoles.
  Zero-length multipoles (2nd, 3rd, and 4th order) are located inbetween quadrupoles.
- L* is long to make space for a H_2 target of $0.3X_0$ in total
- The lattice is matched to cancel α_c
  Sextupoles cancel chrom., 2nd order disp.
  Oct, Dec, Doc opt. to cancel α_c at higher orders

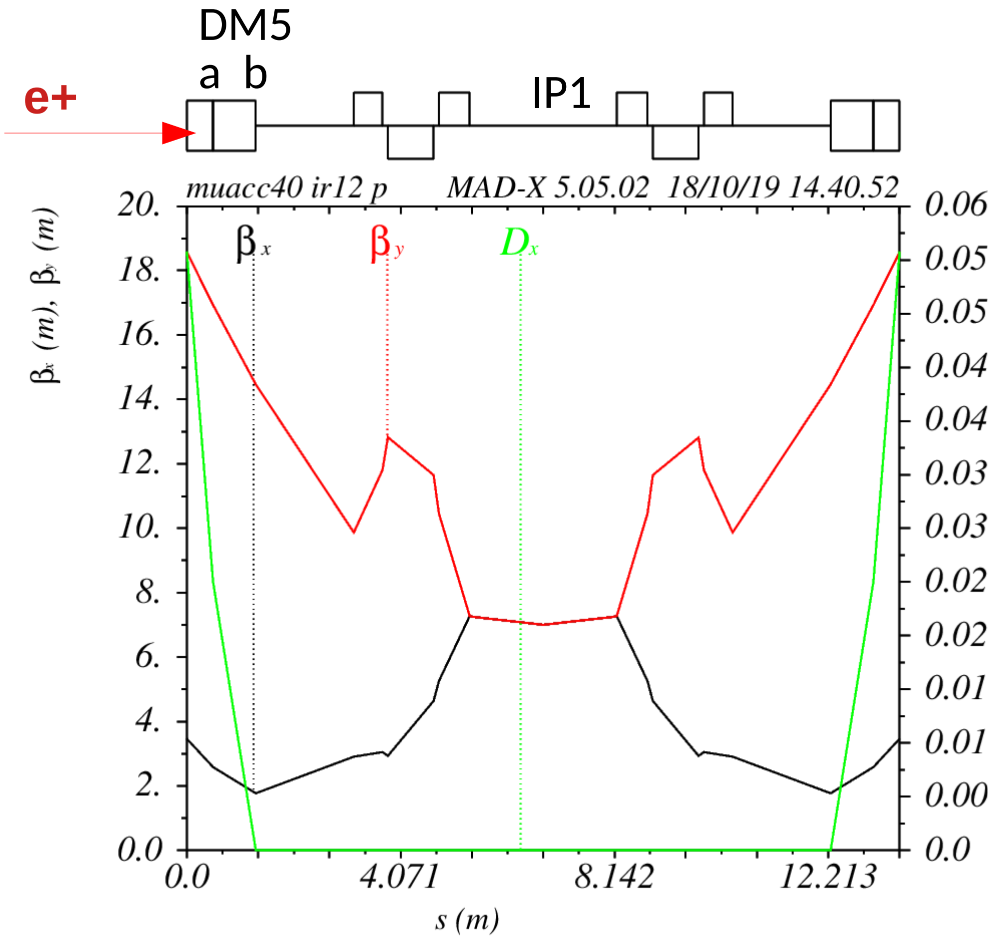
Length	147 m
Energy Acceptance	±10 %
Max. Dipole field	12 T
Quad field gradient	<151 T/m
ß*	1.3 m
Target space (2 x L*)	2 x 1.4 m
RF Freq	1.2 GHz
RF Voltage	100 MV

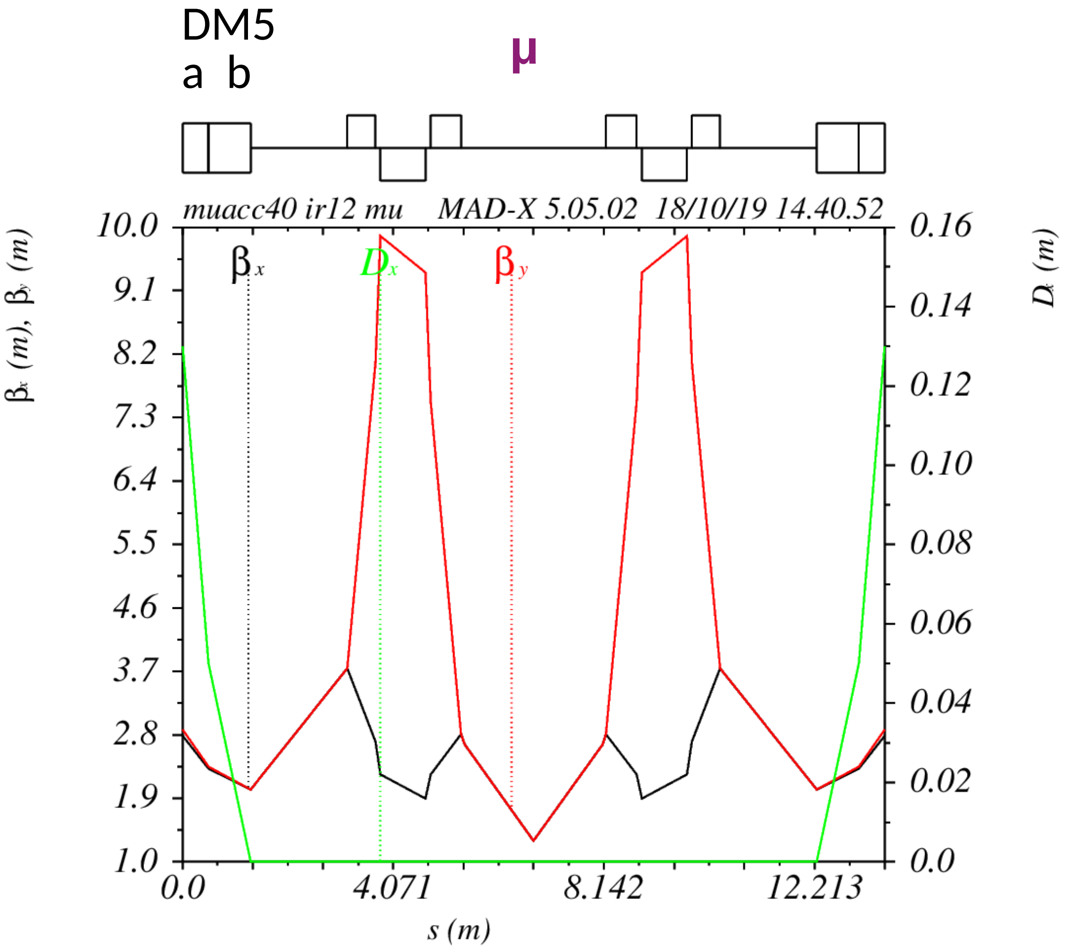
MUACC Interaction Region12



3D-model obtained with MDISim
CERN. H. Burkhardt
IPAC15, TUPTY031

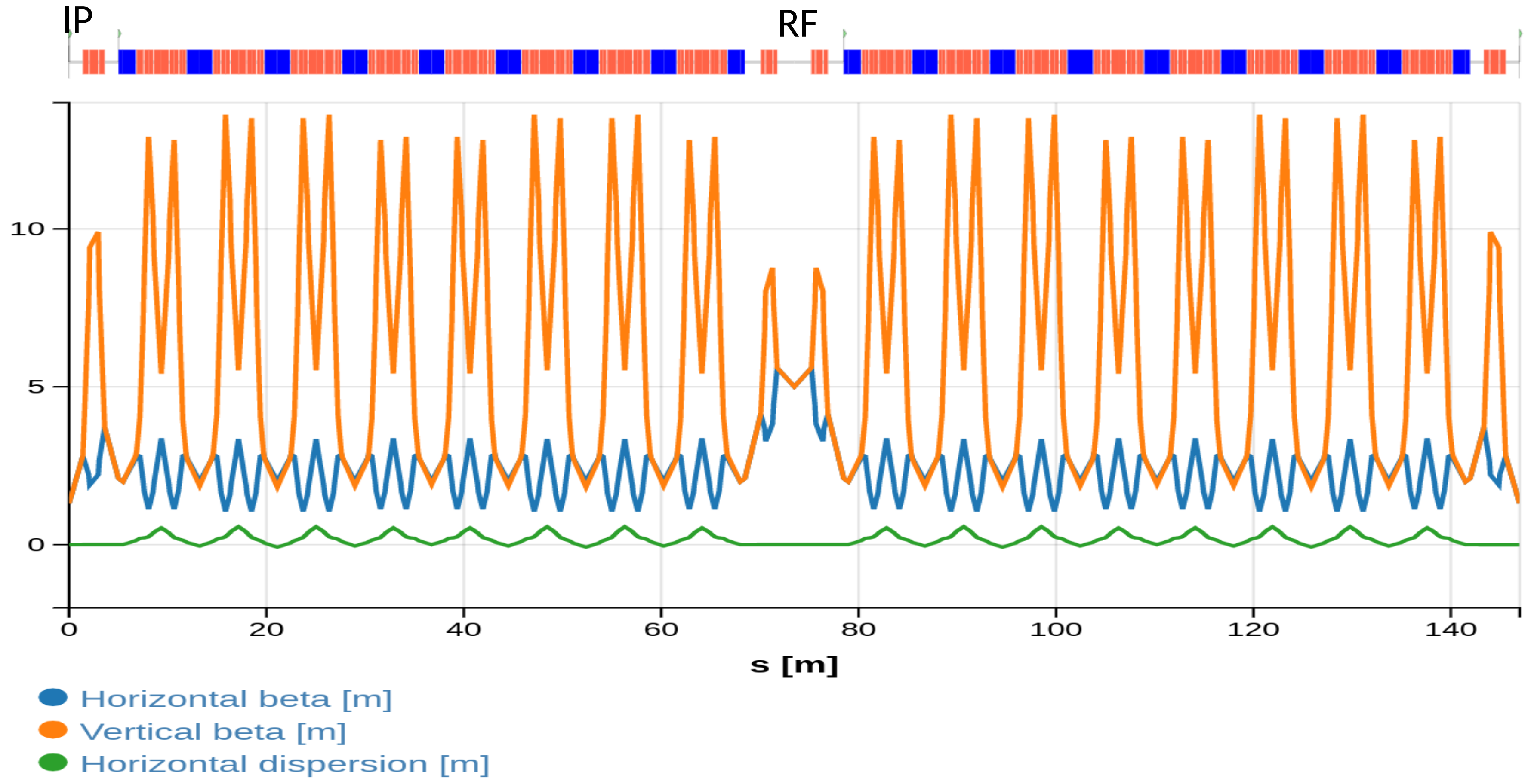
MUACC40 IR12 e+ and μ optics





Linear Optics

First order optics agreement among MAD, MAD-X, MAD-X PTC and ZGOUBI



Chromaticity

- Natural chromaticity agrees among simulation codes

MAD (Qx’,Qy’)	**MAD-X** (DQ1,DQ2)	**MADX PTC** (DQ1,DQ2)	**ZGOUBI** (DQ1,DQ2)
-9.37	-	-9.41	-9.37
-19.69	-	-19.47	-19.69

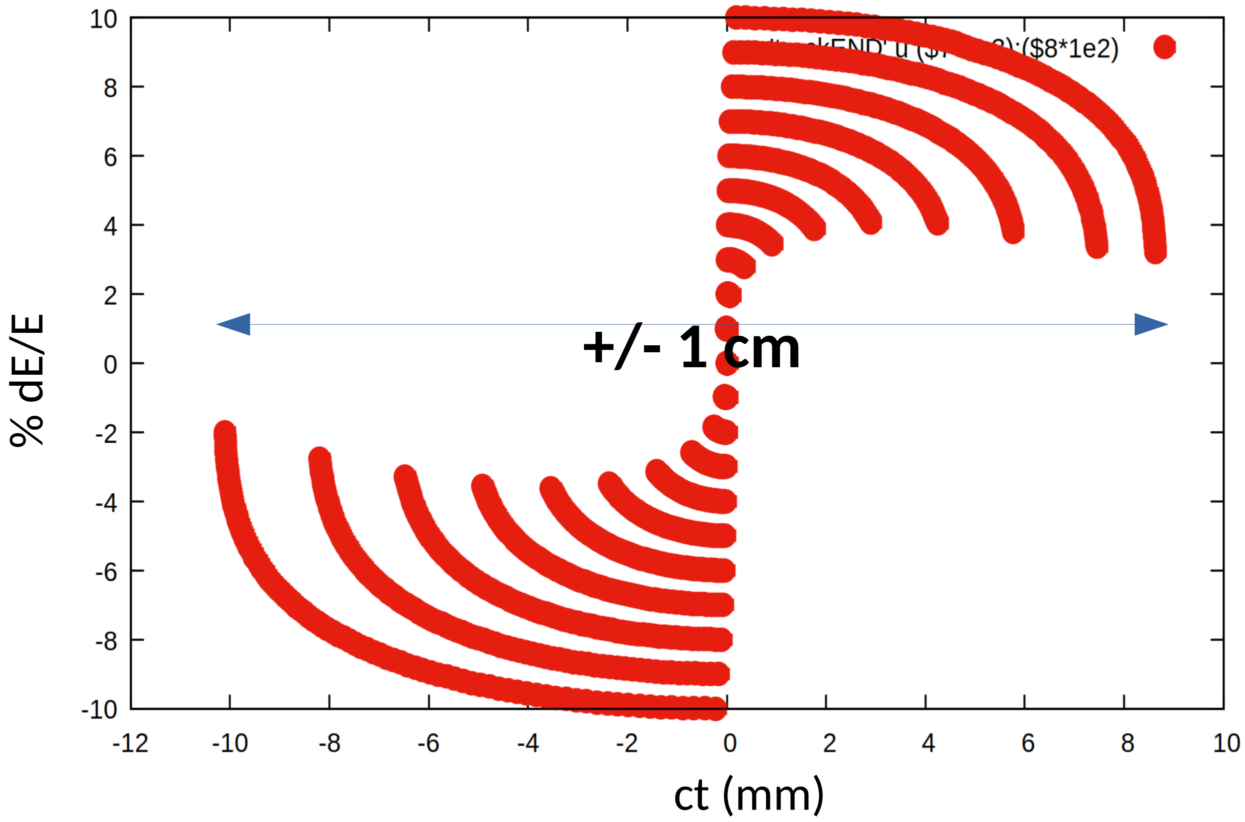
- The multipole optimization done by Pantaleo in MAD does not automatically work in PTC, therefore, a new multipole optimization has been carried out after the translation from MAD to MAD-X.

The differences in the optimization change the dynamics

MAD (Qx’,Qy’)	**MAD-X** (DQ1,DQ2)	**MADX PTC** (DQ1,DQ2)	**ZGOUBI** (DQ1,DQ2)
-0.08	-	-0.03	-0.08
0.06	-	0.00	0.05

Longitudinal Phase Space

100 turns, No Energy loss, PTC model



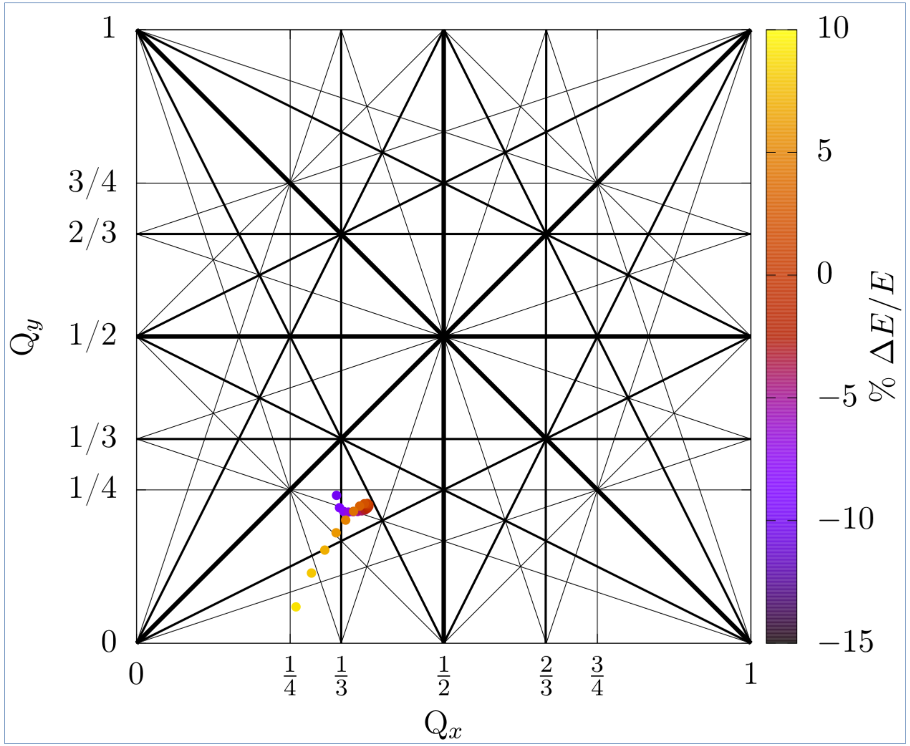
IF MUONS DO NOT RADIATE AND α_c IS ZERO , WHY DO WE NEED A CAVITY ?

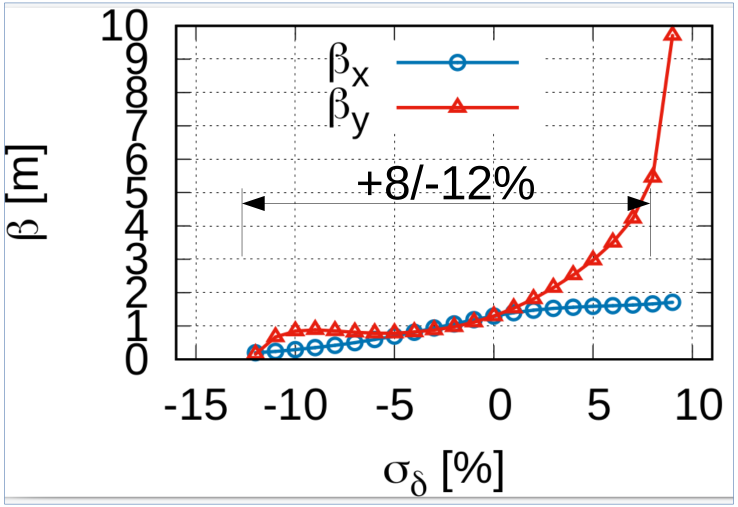
We expect to have approximately 0.1~0.2% energy loss per passage through the target due to bremstrahlung.

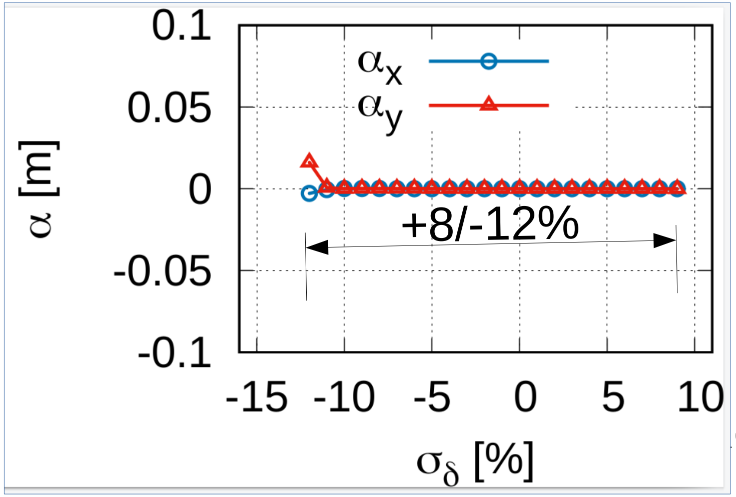
The cavity is tuned to recover the energy loss, which along all accumulation period of 1000 turns is 1~2 times the initial 22 GeV

Tune and optics functions at the IP

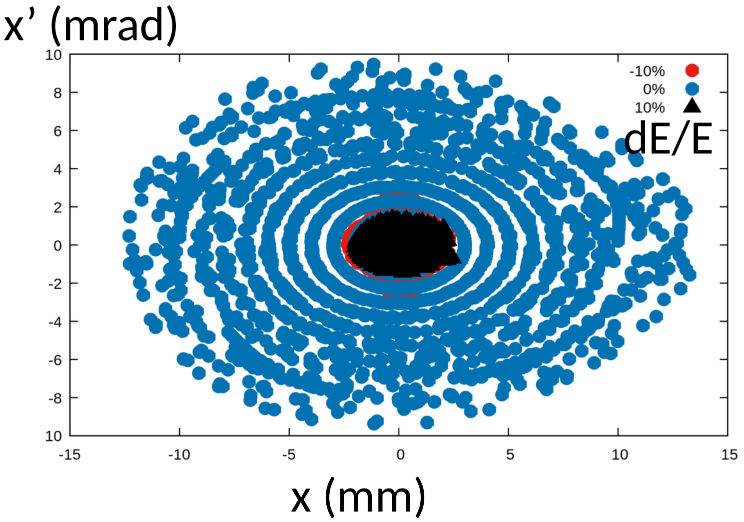
Using the PTC model we achieved +8/-12% energy acceptance, although, tune footprint crosses 3rd and 4th order resonances pointing to possible particle losses in a lattice with errors.

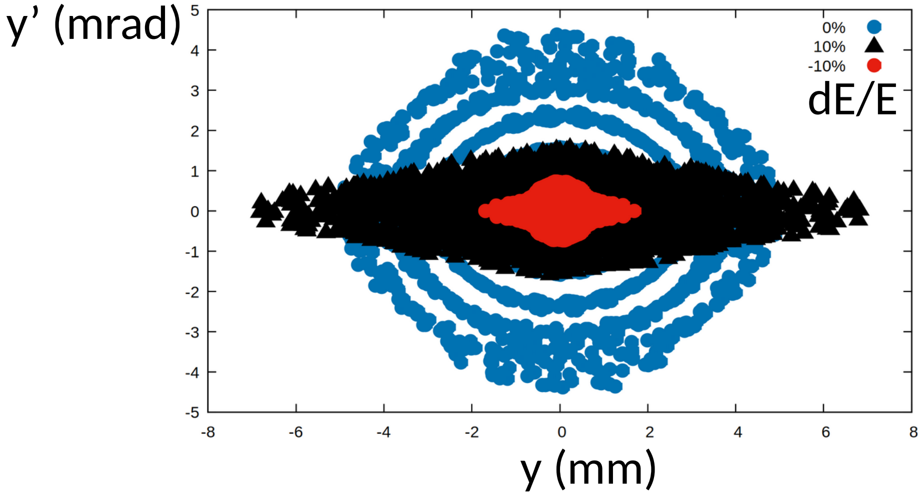






Admittance (100 turns)





- From multiturn tracking, we have estimated an admittance of 1~10 μm.rad.
- This is expected to be far larger than needed as the typical muon beam emittance is much less than 1μm.rad

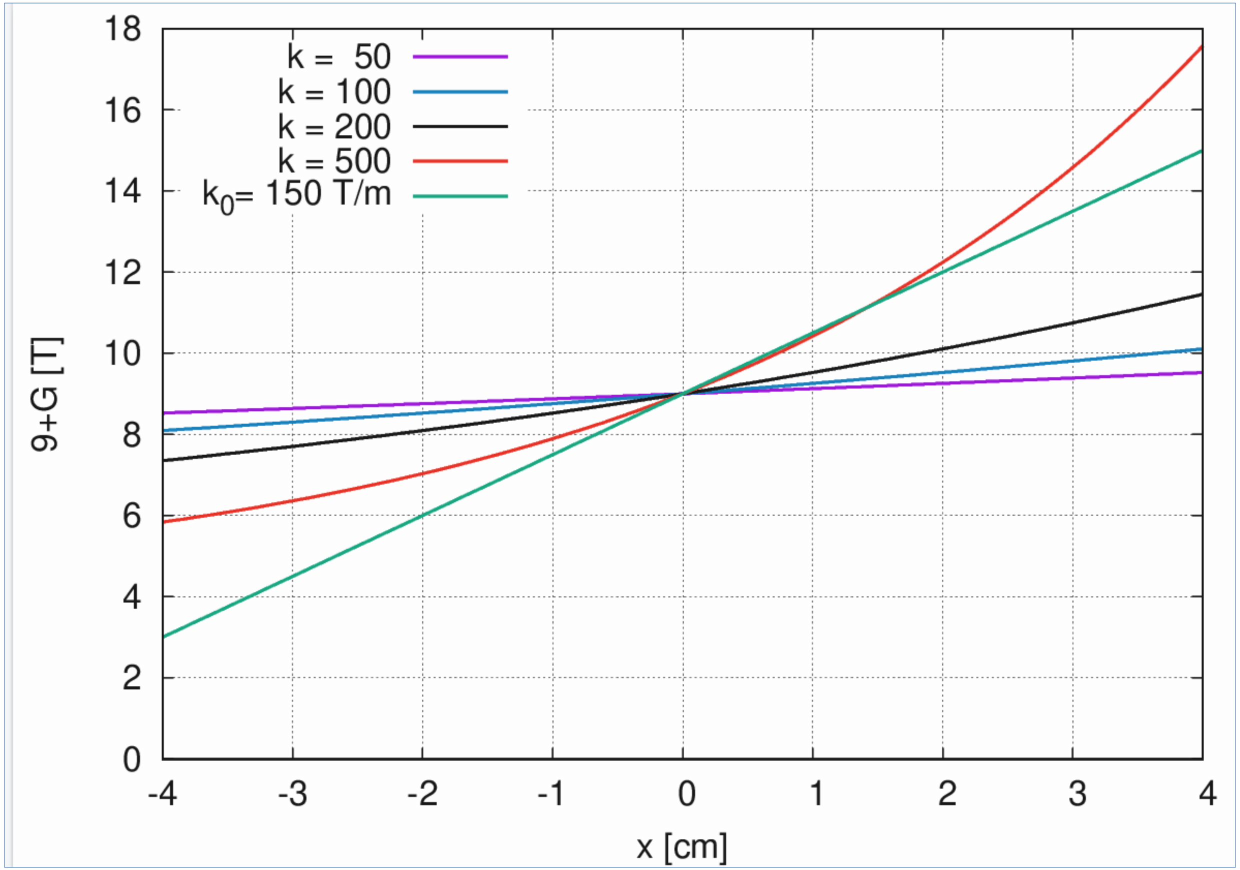
Open Questions on Optics

- Radiation from positron beam crossing strong magnets in the accumulator,
- Further optimization of the lattice : length reduction, increment energy acceptance, considerations on multipoles,

10% energy aceptance in the model is already a great achievement and this lattice could be used for initial studies with target.

- **HOW MUCH COULD WE GAIN WITH A FFA LATTICE ?**
- **Energy acceptance, smaller circumference, ...**

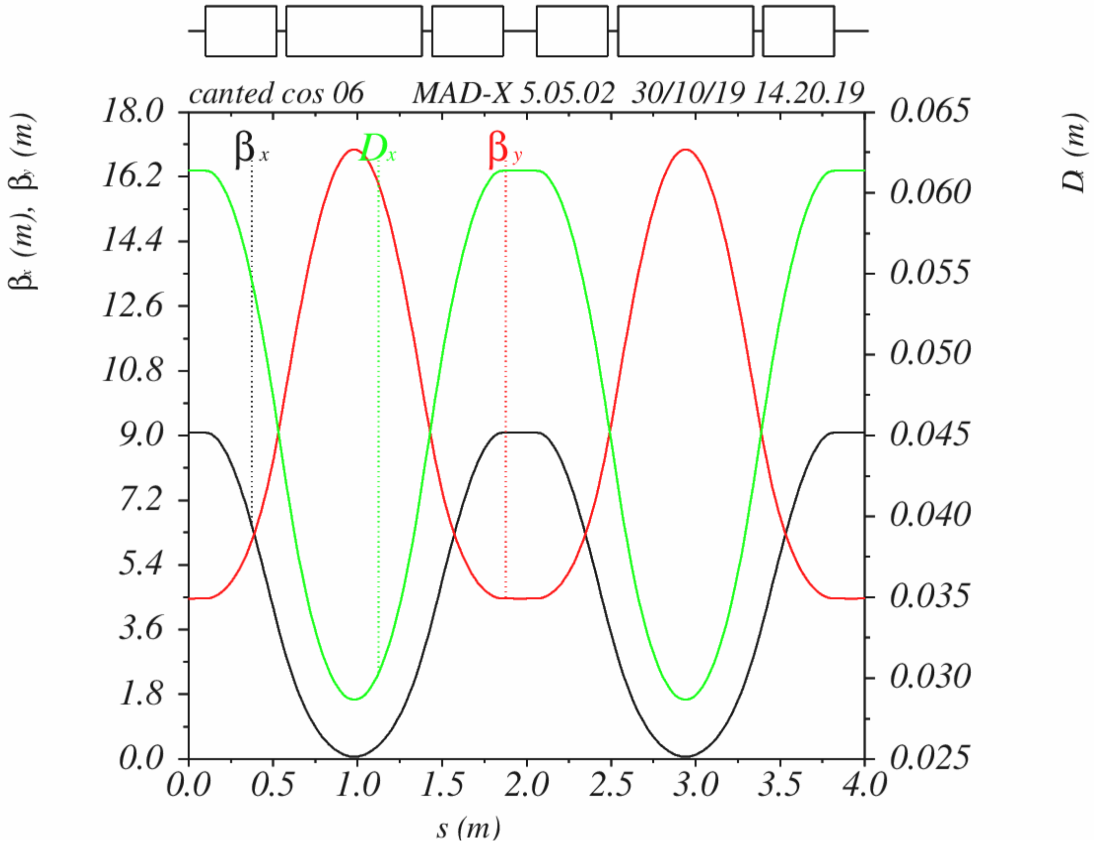
FFA design



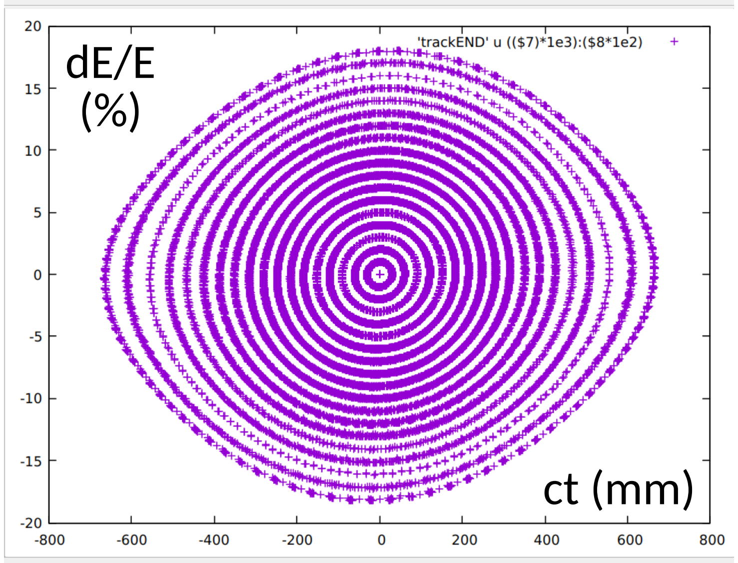
I will assume a magnet with B0=9T and gradient of 150 T/m can be built.

It restricts the aperture to 3 cm, maybe 4 cm

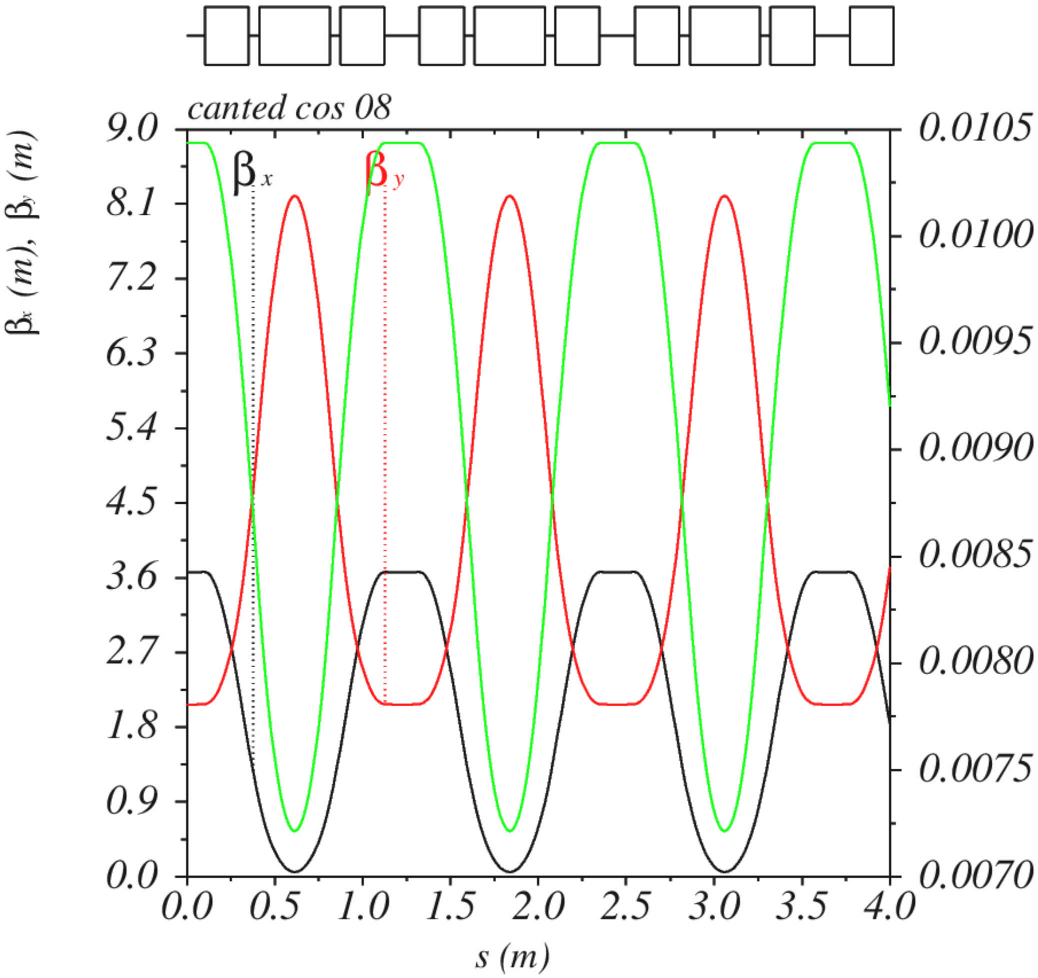
Smallest circumference ~100m



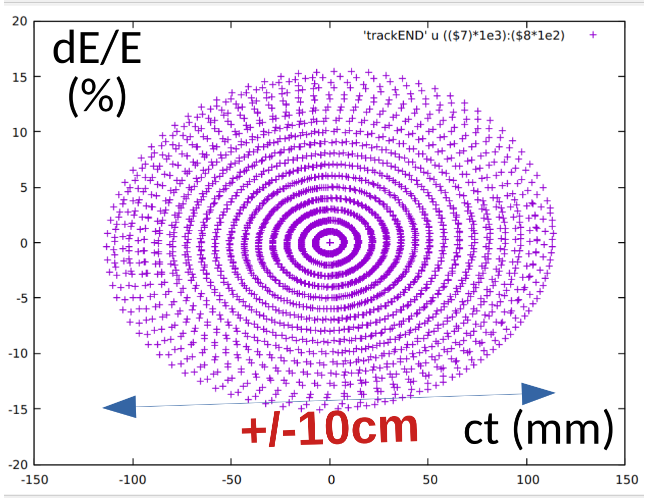
B0 approx 6 T
Grad < 320 T/m
Alfa c = 2.8e-3
L = 98 m
Nat dq1=-91,dq2=-49
Dispersion is large
0.06m*20% = 1.2 cm,
Cavity 150MHz, 200MV
→May be a possible FFA



Reducing alfa_c by brute force



Bf 5.6T, 900T/m, 89kT/m2
Bd -1.2T, -700T/m, -92kT/m2
Alfa c = 2.6e-4
L = 245 m
Nat dq1=-233,dq2=-157
Aperture Diameter of 5mm
Dispersion is reasonable
0.01m*20% = 0.2 cm,
Cavity 306MHz, 400MV
→May be a possible FFA



Cancelling alfa_c in a more effective way

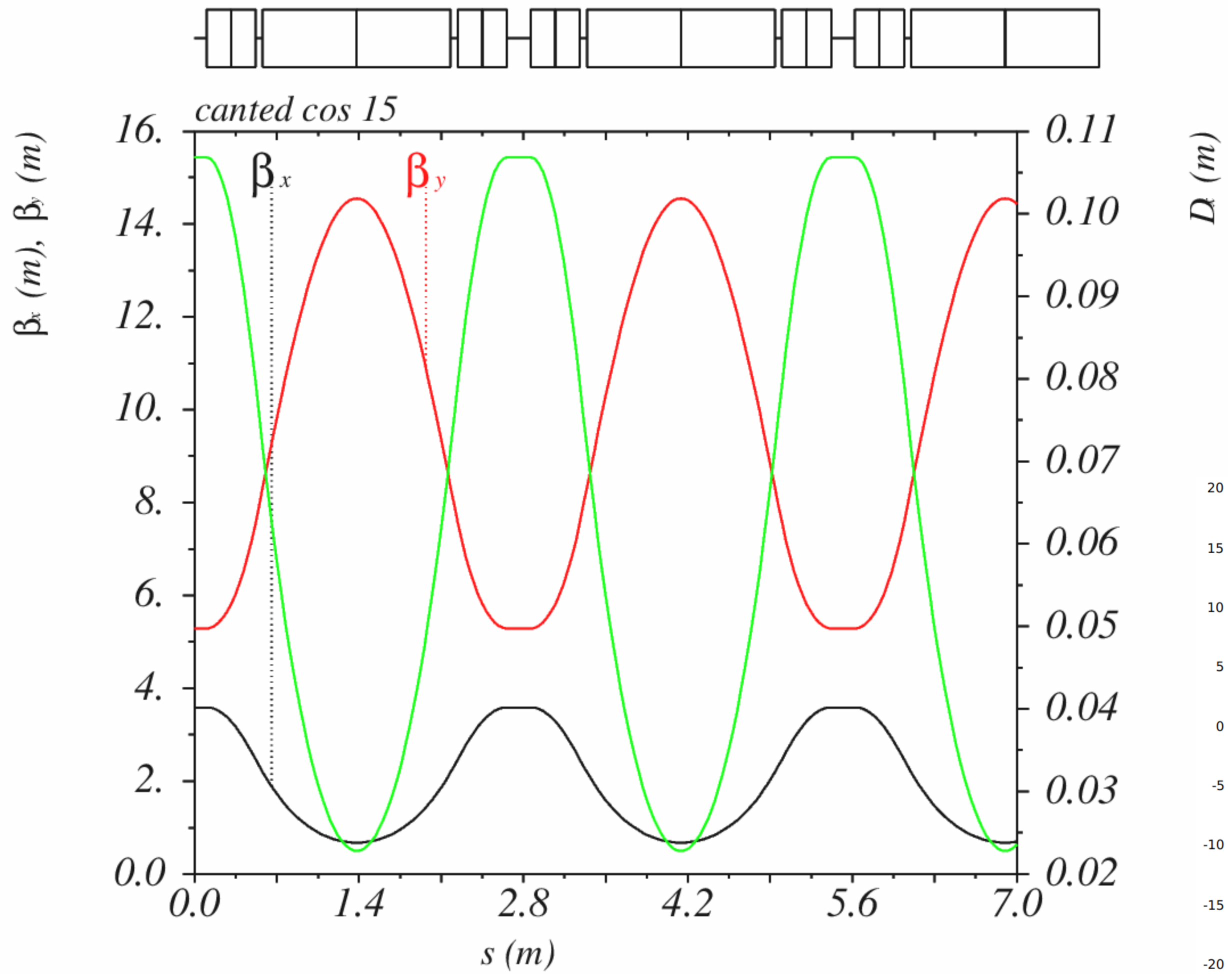
- I will explore two possible combinations :
  DFD, or FDF.
  Chech which one reduces the natural chromaticity and dispersion.

- To close the circumference with n cells, the angles must add up to 2π
  $n * (\Sigma \theta_i) = 2\pi$

- Alfa_c is cancelled if the products of dispersion by bending angle add up to zero.
  $n * (\Sigma \theta_i * \eta) = 0$

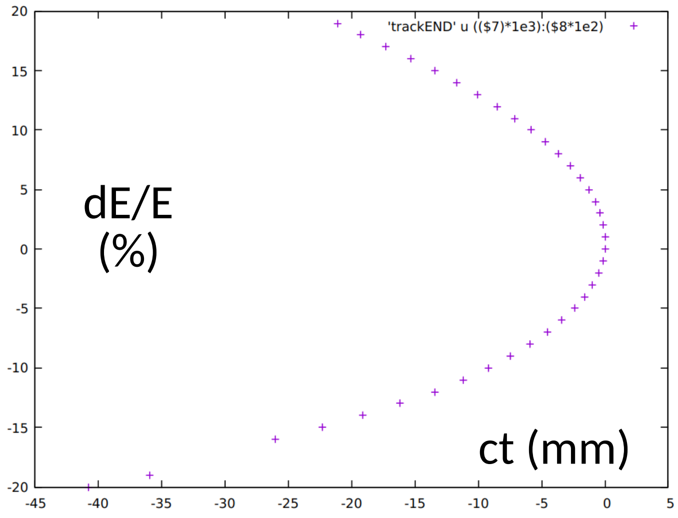
  There are two ways here:
  produced negative dispersion, but, the design becomes similar to the linear optics,
  or, use antibends and enlarge the circumference.

Alfa_c is as small as needed, but alfa_c1 is visibly large



Bf -7.1 T, 159T/m, 1786T/m^2
Bd 9.6 T, -60T/m, -1764T/m^2
alfa c = 0.6e-4
L = 138 m
Nat. dq1=-13, dq2=-14
Aperture Diameter of +/- 3cm

Dispersion: 0.1m*20% = 2 cm,
~~Cavity 61MHz, 400MV~~
~~→**May be a possible FFA**~~



Cancelling alfa_c1…

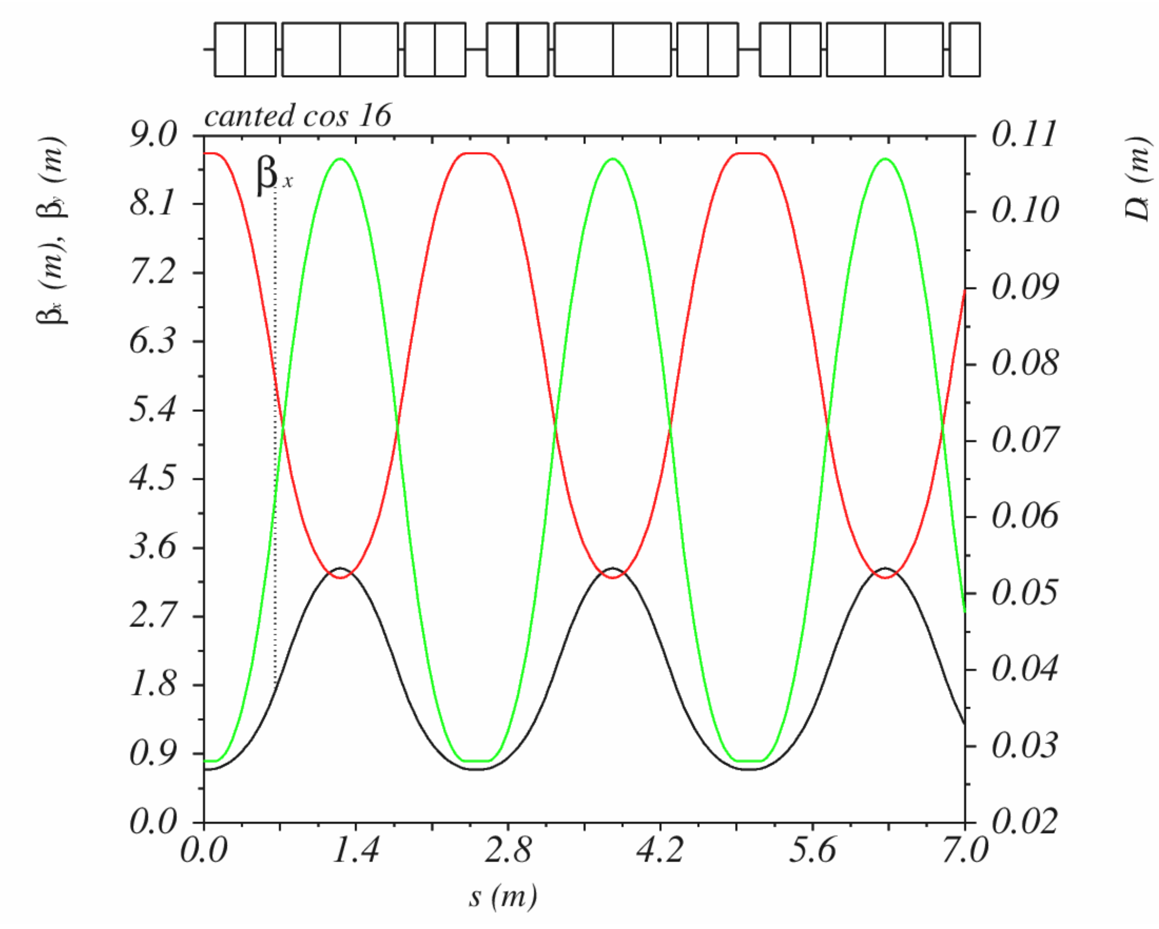
- I will explore two possible combinations :
  DFD, or FDF.
  Chech which one reduces the natural chromaticity and dispersion.

- To close the circumference with n cells, the angles must add up to 2π
  $n * (\Sigma \theta_i) = 2\pi$

- Alfa_c is cancelled if the products of dispersion by bending angle add up to zero.
  $n * (\Sigma \theta_i * \eta_i) = 0$

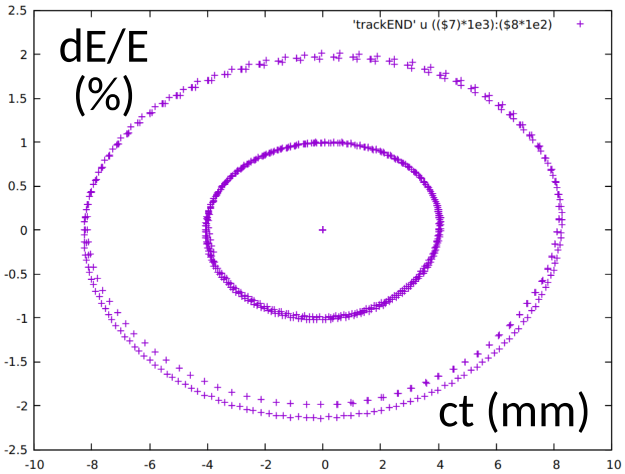
- Alfa_c1 is approximately cancelled if the product of the second order dispersion by the bending angle adds up to zero
  $n * (\Sigma \theta_i * DDX_i) = 0$

Alfa_c and alfa_c1 are zero by adding sextupoles, but, magnets are not longer scaling



Bd 13.7 T, -95T/m, -11.2kT/m^2
Bf -5.5 T, 133T/m, 3.2kT/m^2
alfa c = 2.6e-4
L = 126 m
Nat. dq1=-14, dq2=-14
Aperture Radius > +/- 3cm

Dispersion: 0.1m*20% = 2 cm,
Cavity 2GHz, 100MV



CONCLUSIONS

Not a happy ending design yet, but, the road is worth trying.

The goal for LEMMA is the production of a large lifetime and small emittance muon beam from positrons impinging on a target.

LEMMA design foresees to increase the muon bunch intensity by recirculating muons on an accumulator over a fraction of the muon lifetime.

I have presented the lattice by P. Raimondi of the accumulator ring: circumference of ~150 m and ±10% of energy acceptance.

The plan is to continue with optimizations to reach ±20% energy acceptance. Meanwhile we started to look on FFA possibilities.

FFAs could be also interesting in accelerating stages downstream.