Stato studi acceleratore Muon Collider

Manuela Boscolo (LNF-INFN)

for the team

RD_FA Collaboration Meeting, Bologna, 3 luglio 2017

Outline

- e^+ ring with target
- Multi-turn simulations
- Conclusion and Perspectives

Preliminary scheme for low emittance μ beam production

Goal:

@T ≈ 10^{11} μ/s

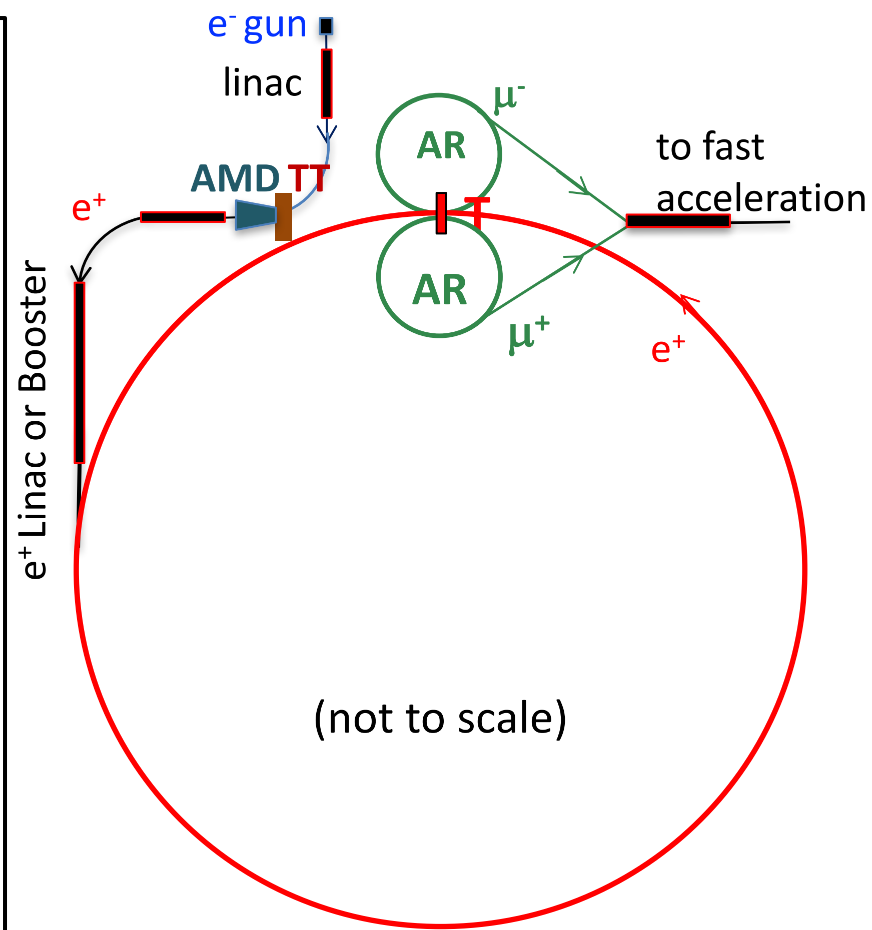
Efficiency ≈ 10^{-7} (with Be 3mm)→

10^{18} e^+/s needed @T →

e^+ stored beam with T

need the largest possible lifetime to minimize positron source rate

LHeC like e+ source required rate with lifetime(e+) ≈ 250 turns [i.e. 25% momentum aperture] → n(μ)/n(e^+ source) ≈ 10^{-5}



Preliminary scheme for low emittance μ beam production

from e^+ SOURCE to RING:

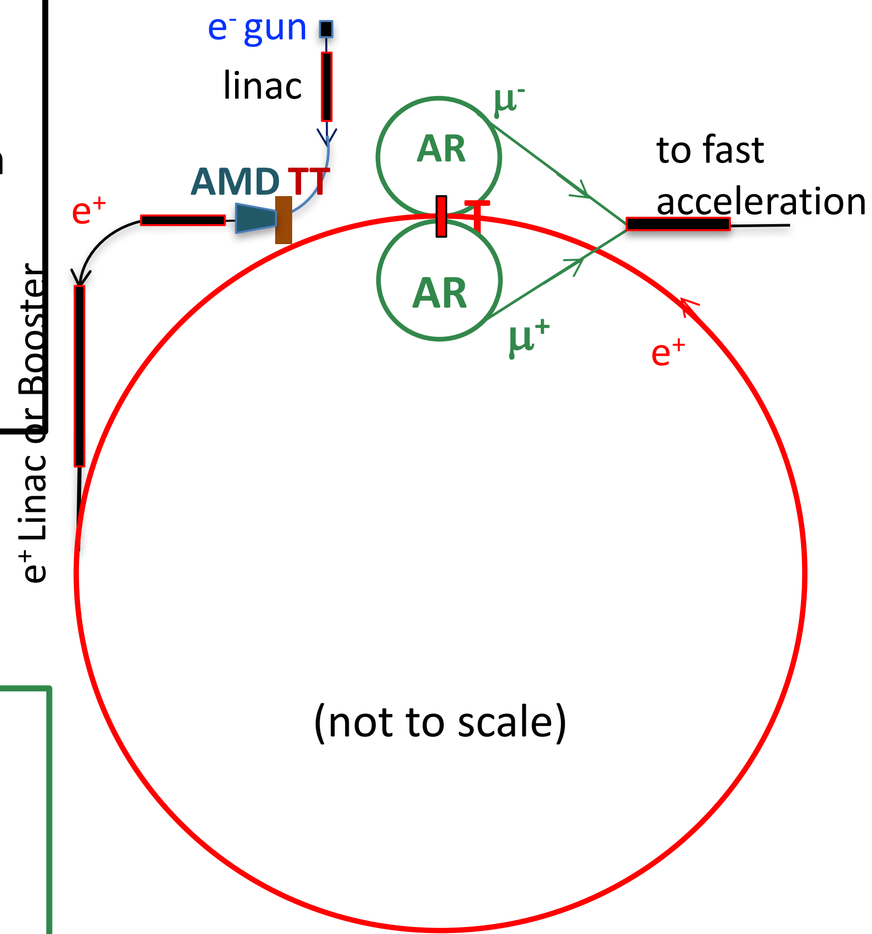
- **e^-** on conventional Heavy Thick Target (**TT**) for e^+e^- pairs production.
- possibly with γ produced by e^+ stored beam on **T**→
- Adiabatic Matching Device (**AMD**) for **e^+** collection →
- acceleration (linac / booster) , injection →

e^+ RING:

- **6.3 km 45 GeV** storage ring with target **T** for muon production

from $\mu^+ \mu^-$ production to collider

- produced by the **e^+** beam on target **T** with **E(μ) ≈ 22 GeV**, $\gamma(\mu) \approx 200 \rightarrow \tau_{lab}(\mu) \approx 500\mu s$
- **AR**: **60 m** isochronous and high mom. acceptance rings will recombine μ bunches for ~ 1 $\tau_\mu^{lab} \approx 2500$ turns
- fast acceleration
- muon collider



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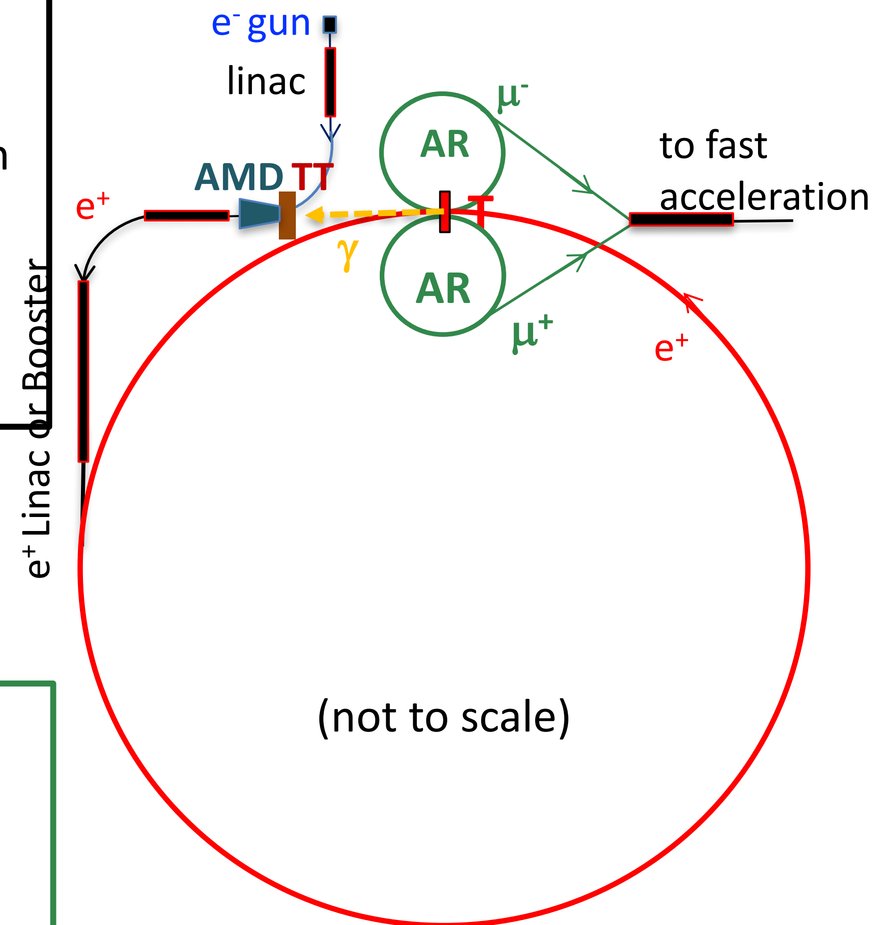
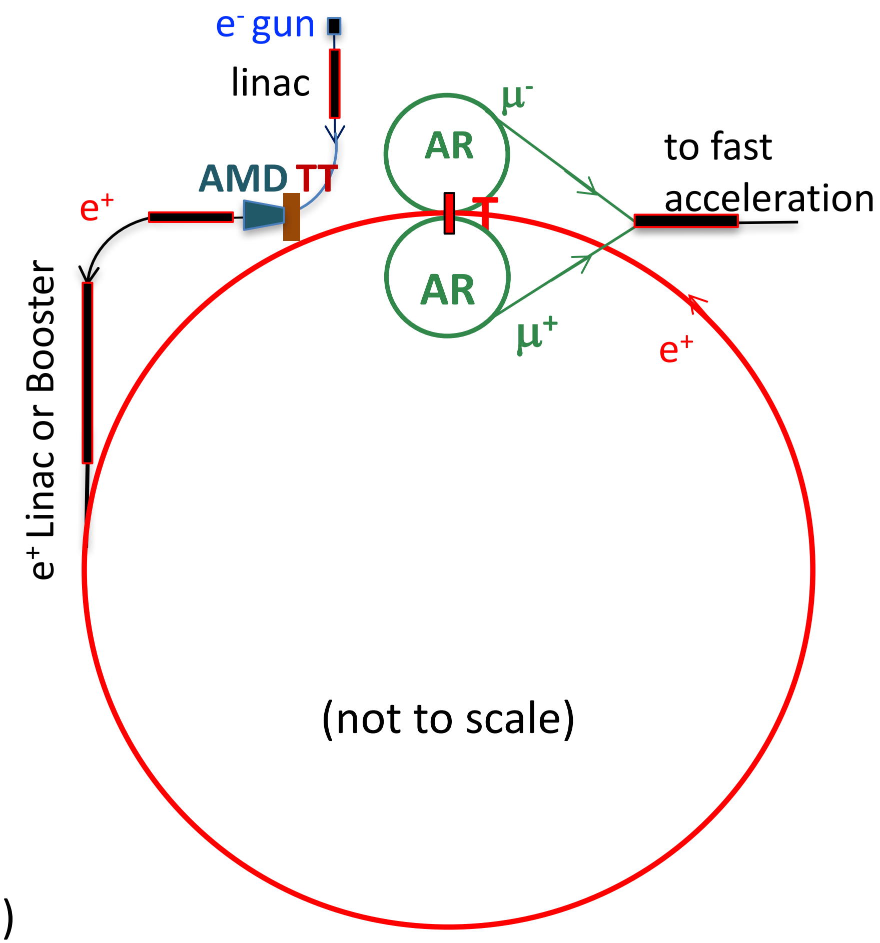


Preliminary scheme for low emittance μ beam production

e+ ring parameter	unit	
Circumference	km	6.3
Energy	GeV	45
bunches	#	100
e^+ bunch spacing = T_{rev} (AR)	ns	200
Beam current	mA	240
$N(e^+)$/bunch	#	$3 \cdot 10^{11}$
U_0	GeV	0.51
SR power	MW	120

(also 28 km foreseen to be studied as an option)

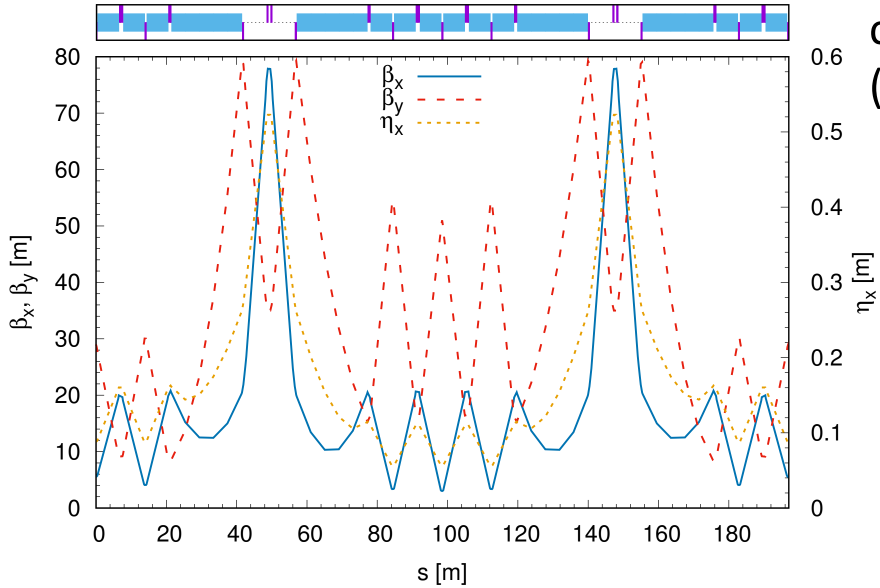


Key topics for this scheme

- **Low emittance and high momentum acceptance 45 GeV e^+ ring**
- **O(100 kW) class target in the e^+ ring for $\mu^+ \mu^-$ production**
- **High rate positron source**
- **High momentum acceptance muon accumulator rings**

Low emittance 45 GeV positron ring

cell

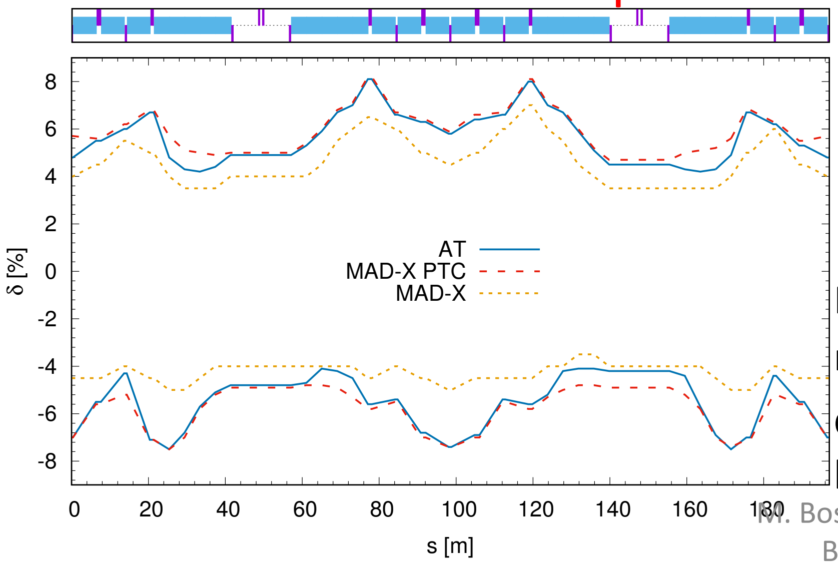


circumference 6.3 km: 197 m x 32 cells
(no injection section yet)

Table e+ ring parameters

Parameter	Units	
Energy	GeV	45
Circumference	m	6300
Coupling(full current)	%	1
Emittance x	m	5.73×10^{-9}
Emittance y	m	5.73×10^{-11}
Bunch length	mm	3
Beam current	mA	240
RF frequency	MHz	500
RF voltage	GV	1.15
Harmonic number	#	10508
Number of bunches	#	100
N. particles/bunch	#	3.15×10^{11}
Synchrotron tune		0.068
Transverse damping time	turns	175
Longitudinal damping time	turns	87.5
Energy loss/turn	GeV	0.511
Momentum compaction		1.1×10^{-4}
RF acceptance	%	± 7.2
Energy spread	dE/E	1×10^{-3}
SR power	MW	120

momentum acceptance



Physical aperture=5 cm constant

no errors

Good agreement between MADX PTC / Accelerator Toolbox, both used for particle tracking in our studies

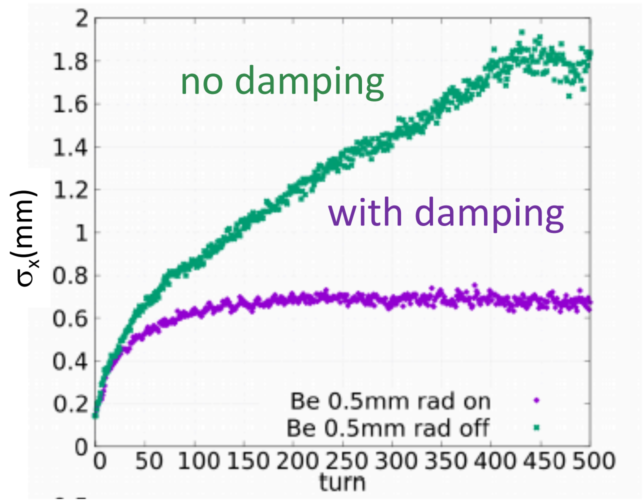
Multi-turn simulations

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

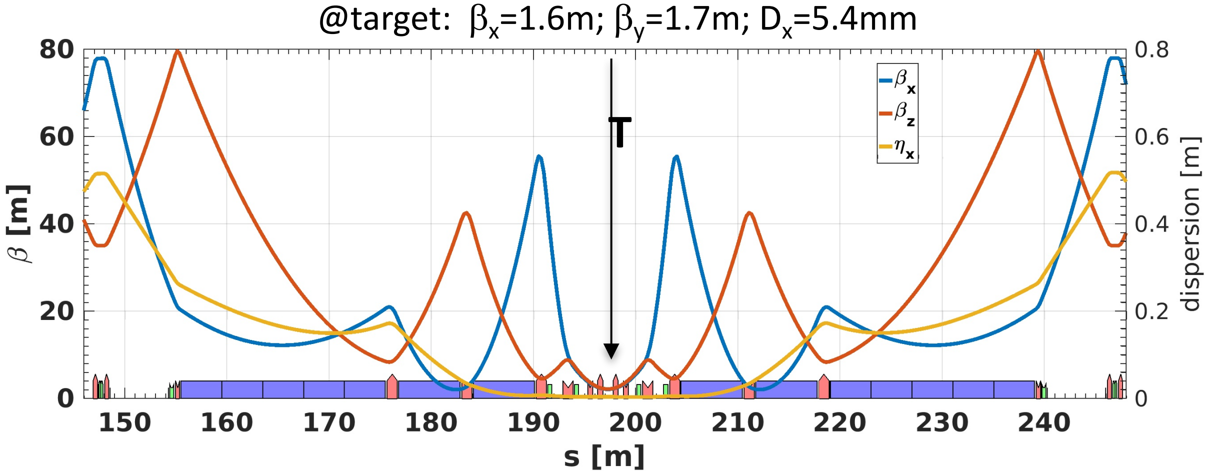
At each pass through the muon target the e+ beam

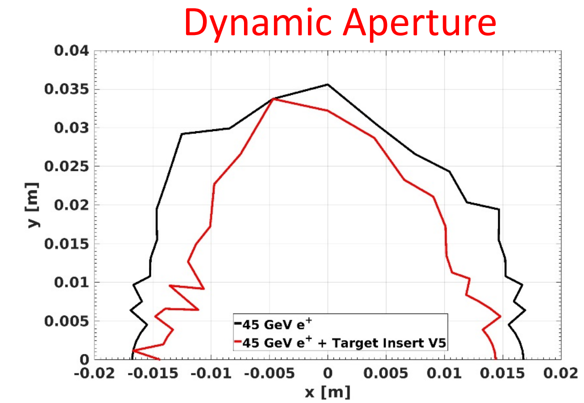
- gets an angular kick due to the **multiple Coulomb scattering**, so at each pass changes e^+ beam divergence and size, resulting in an emittance increase.
- undergoes **bremsstrahlung energy loss**: to minimize the beam degradation due to this effect, D_x=0 at target

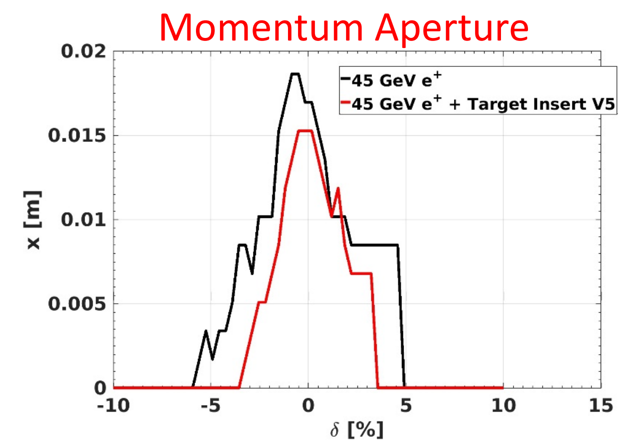
- in addition there is natural radiation **damping** **(**it prevents an indefinite beam growth)



Preliminary low-β IR for muon target insertion

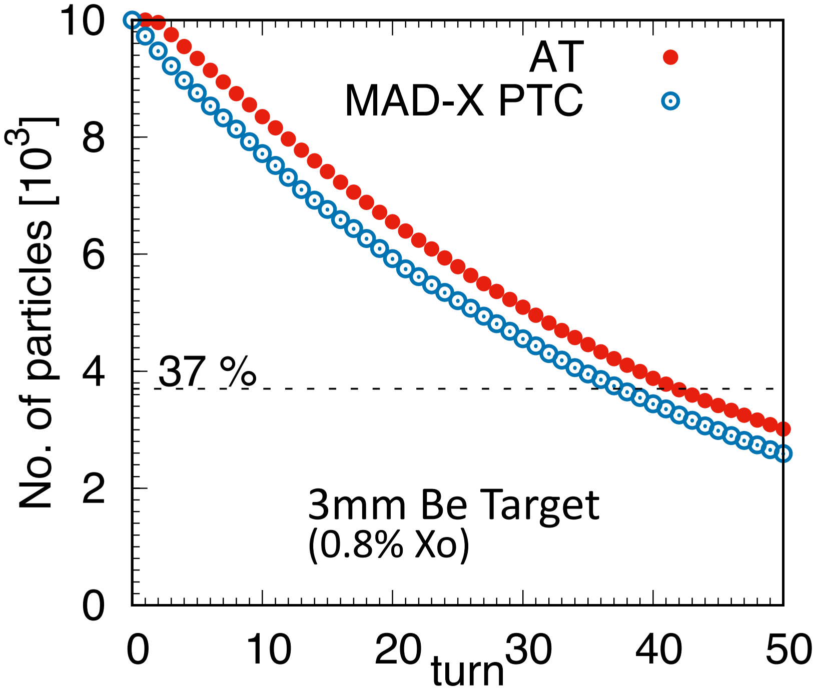


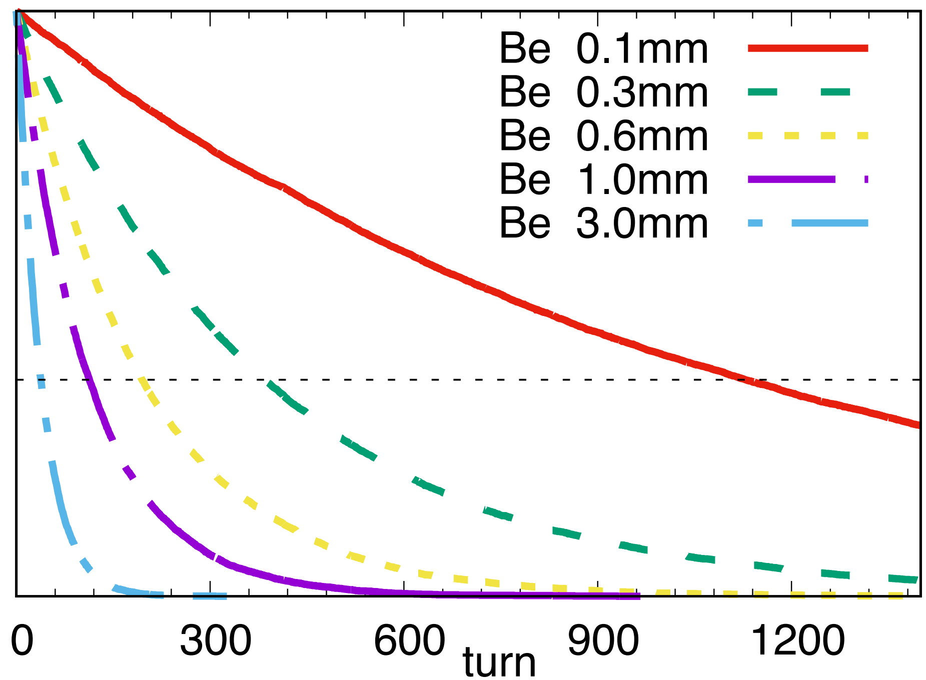




- **@target location:**
  - **$D_x \approx 0$**
  - **low-β**
- Further optimizations are underway:
  - match the transverse minimum beam size with constraints of target thermo-mechanical stress
  - match with other contributions to muon emittance (production, accumulation)
  - dynamic and momentum aperture can be optimized

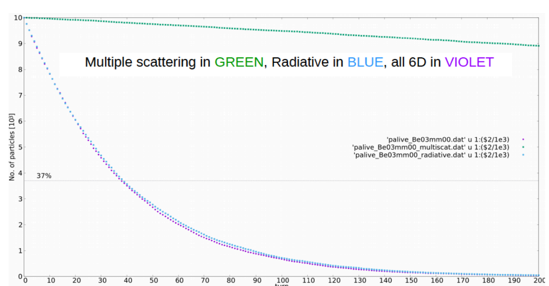
e+ lifetime with Be target



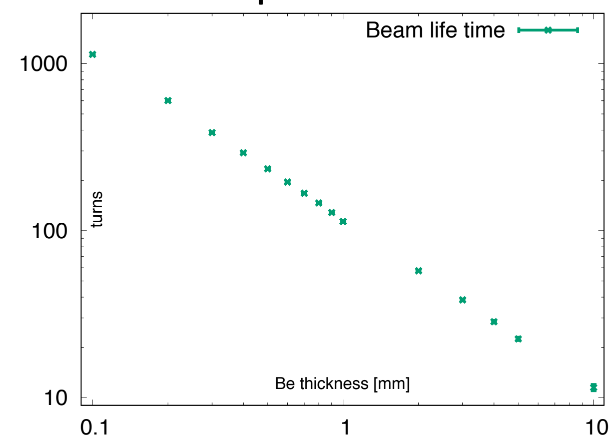


determined by **bremsstrahlung and momentum acceptance**

Lifetime with ~ 40 turns agreement within 10%

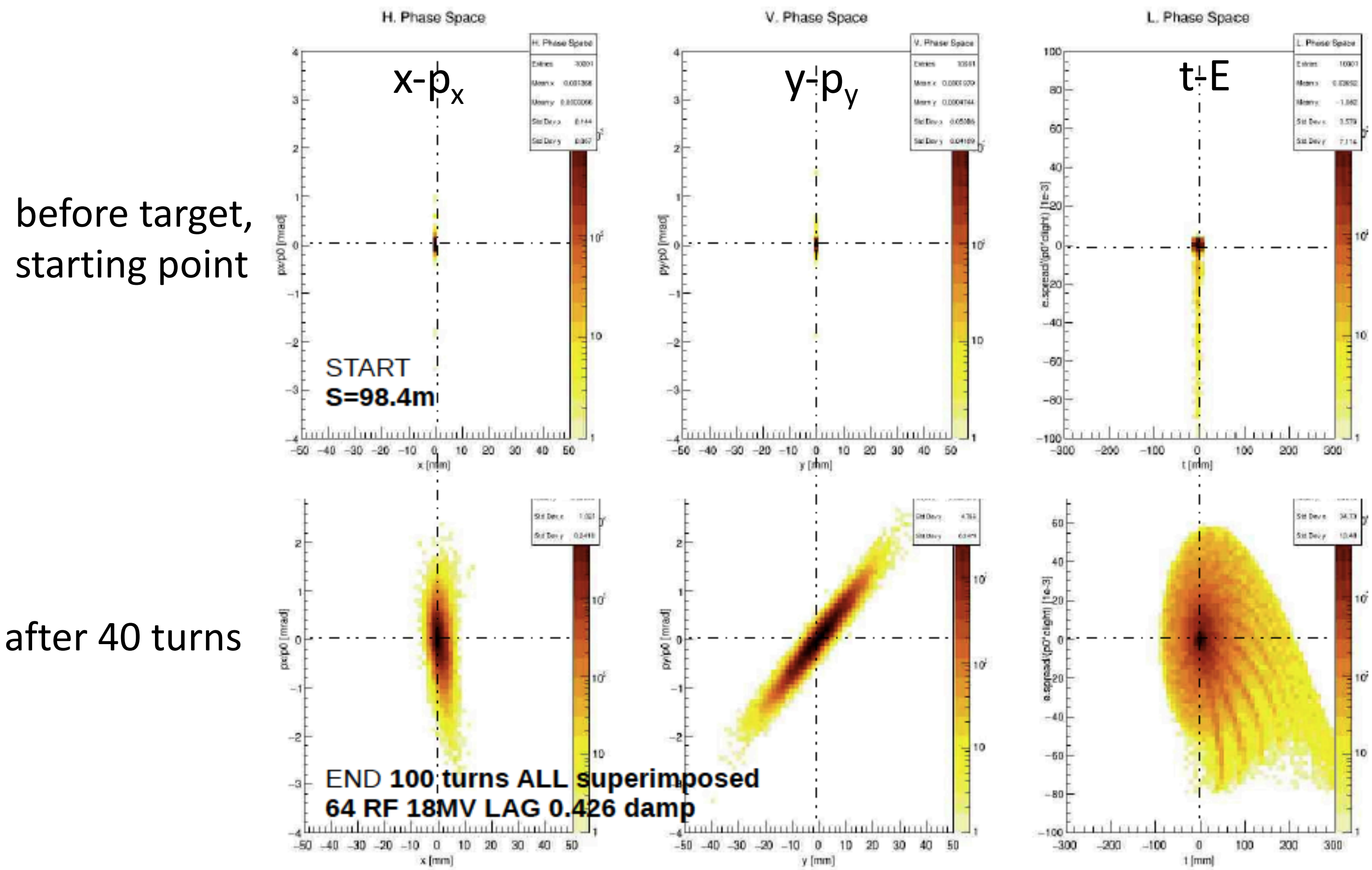


Lifetime ∝ 1/thickness as expected



2-3% e+ losses happen in the first turn

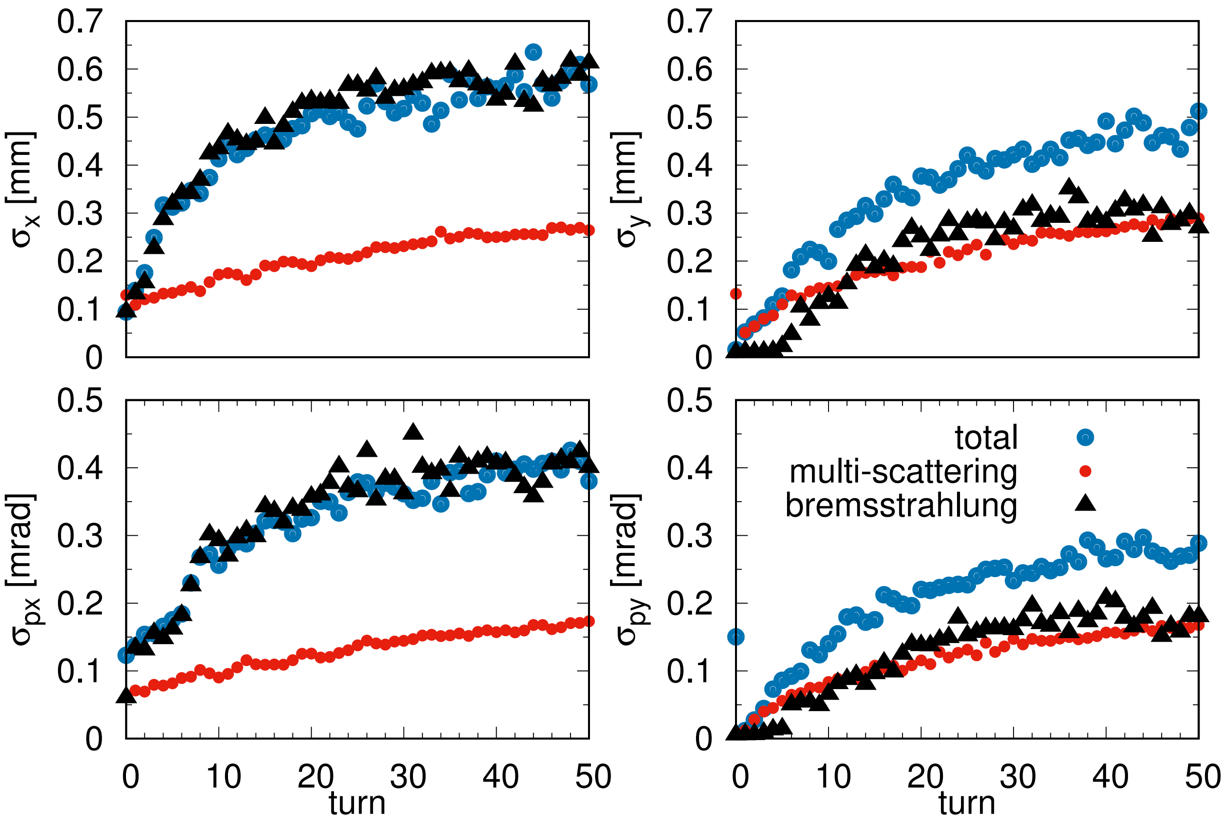
e+ ring with target: beam evolution in the 6D phase space



MAD-X PTC & GEANT4 6-D tracking simulation of e+ beam with 3 mm Be target along the ring (not at IR center in this example)

Evolution of e+ beam size and divergence

3mm Be Target (0.8% Xo) at center of IR



bremsstrahlung and multiple scattering artificially separated by considering alternatively effects in longitudinal (dominated by **bremsstrahlung**) and transverse (dominated by **multiple scattering**) phase space due to target; in **blue** the combination of both effects (realistic target)

Some bremsstrahlung contribution due to residual dispersion at target

multiple scattering contribution in line with expectation: $\sigma_{MS} = \frac{1}{2}\sqrt{n_D}\,\sigma'_{MS}\,\beta$

one pass contribution due to the target: $\sigma'_{MS} = 25\ \mu rad$

n_D number of damping turns

Muon emittance

$$\varepsilon(\mu) = \varepsilon(e^+) \oplus \varepsilon(MS) \oplus \varepsilon(rad) \oplus \varepsilon(prod) \oplus \varepsilon(AR)$$

$\varepsilon(e^+)$ = e^+ emittance
$\varepsilon(MS)$ = multiple scattering contribution
$\varepsilon(rad)$ = energy loss (brem.) contribution
$\varepsilon(prod)$ = muon production contribution
$\varepsilon(AR)$ = accumulator ring contribution

would like all contributions of same size

knobs:

- $\beta_x\ \beta_y$ @target & target material
- $\beta_x\ \beta_y\ D_x$ @target & target material
- $E(e^+)$ & target thickness
- AR optics & target

with constraints from target survival

now: $\varepsilon(\mu)$ dominated by $\varepsilon(MS) \oplus \varepsilon(rad)$ -> lower dispersion & lower β-functions at target with beam spot at the limit of the target survival

also test different material

- crystals in channeling better: $\varepsilon(MS)$, $\varepsilon(rad)$, $\varepsilon(prod)$ (also gain in lifetime)
- light liquid jet target better: $\varepsilon(MS)$, $\varepsilon(rad)$
  (also gain in lifetime & target thermo-mechanical characteristics)

Preliminary consideration on e+ production

[L.Rinolfi *et al.* NIM B **309** (2013)50-55]

The target represented on the figure is a conventional one.

It would be also possible to have an *hybrid positron source* using a crystal providing channeling radiation and an amorphous converter for photon conversion into e+e- pairs

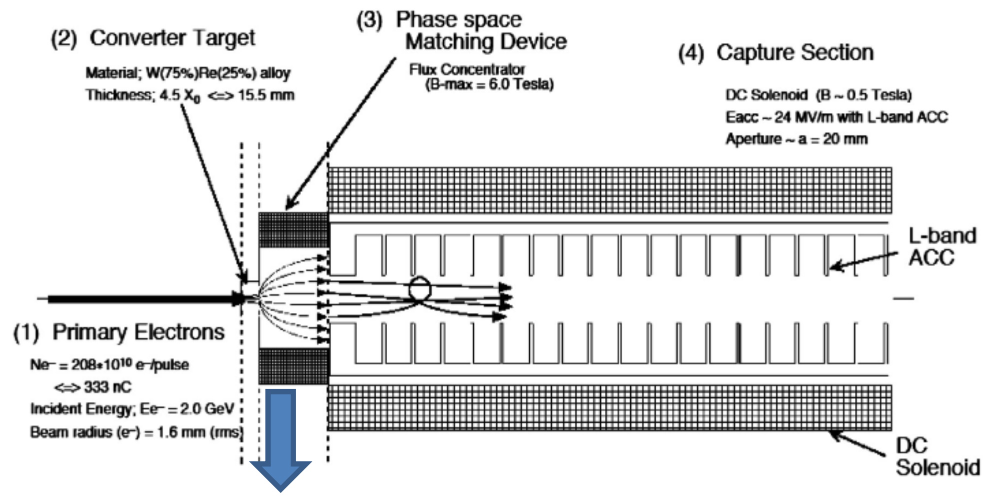
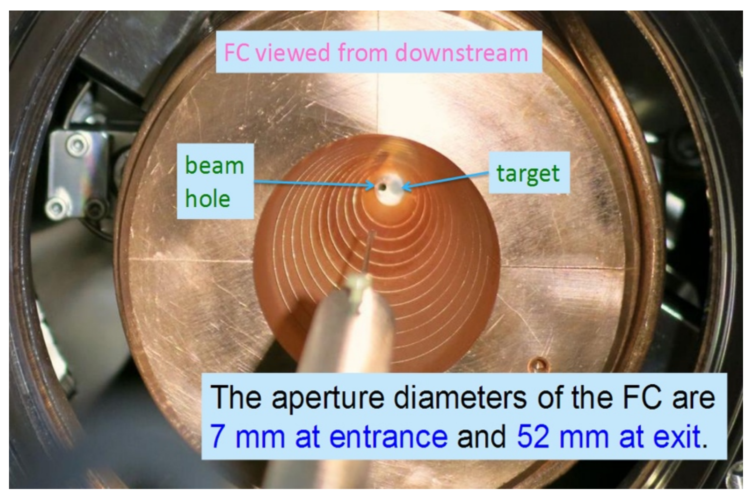
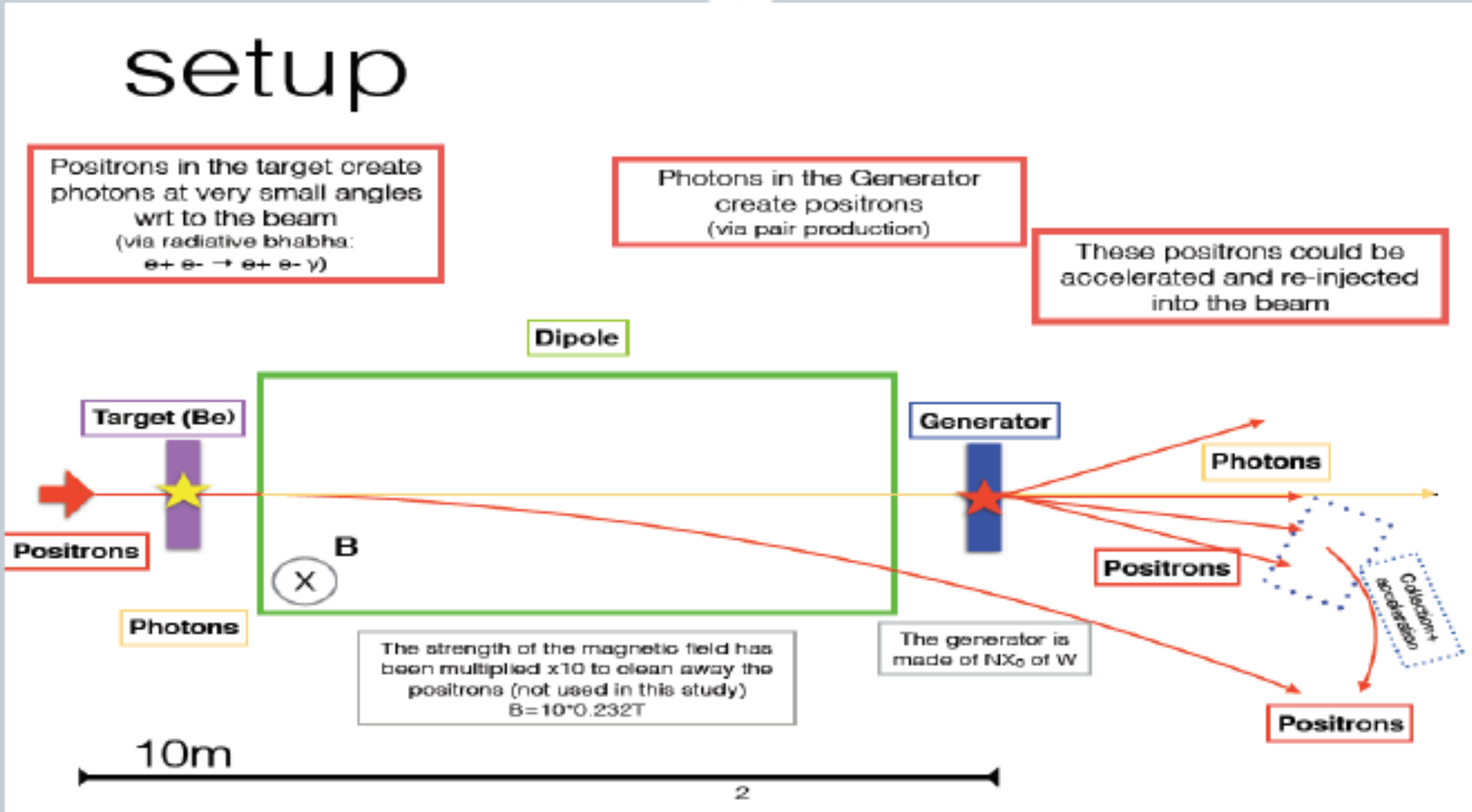


Fig. 2. Layout of the CLIC e⁺ source with a single target.



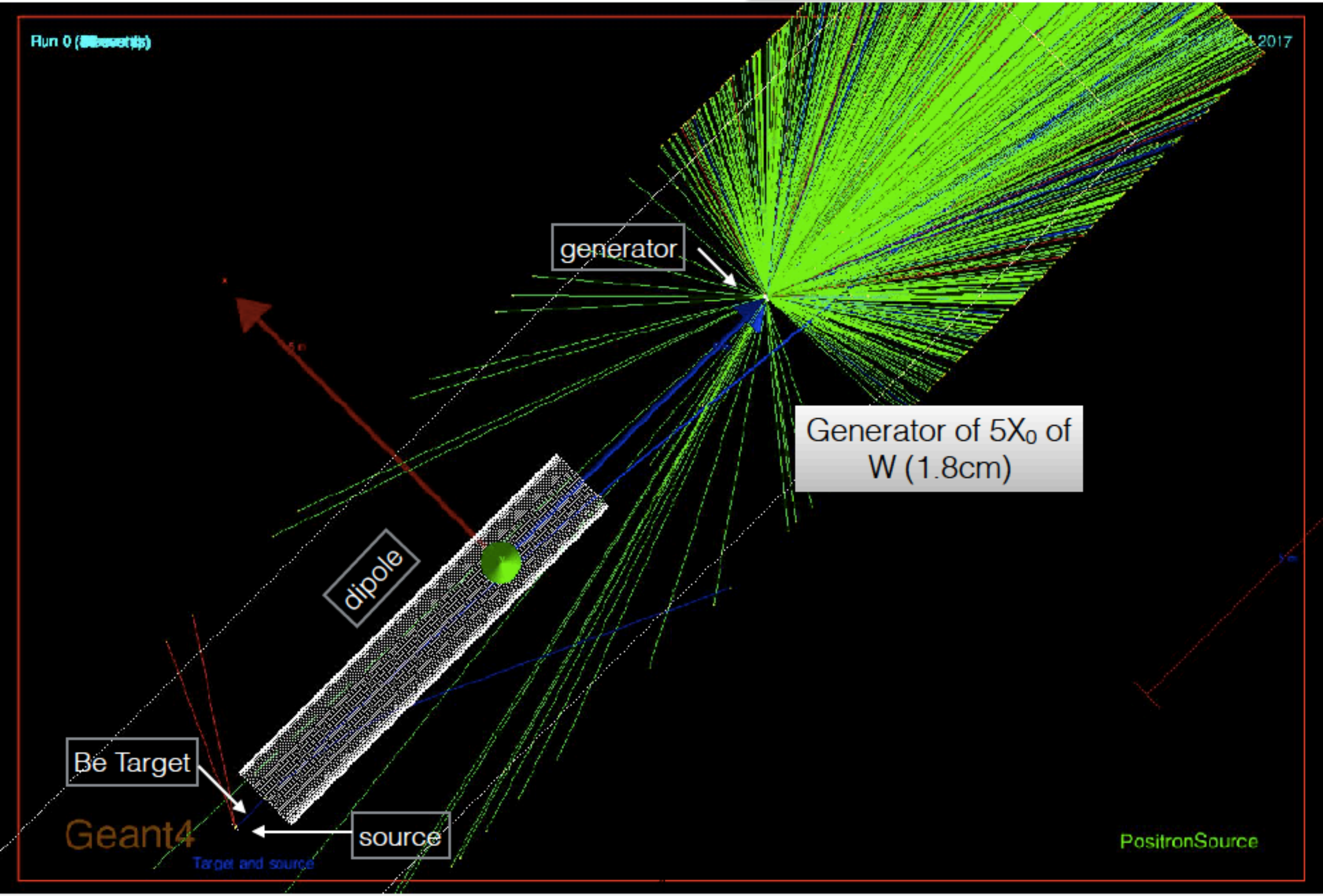
Flux concentrated used for the Adiabatic Matching Device
(from T.Kamitani, LCWS-2014,Belgrade)

FOCUSING SYSTEMS FOR POSITRON SOURCES



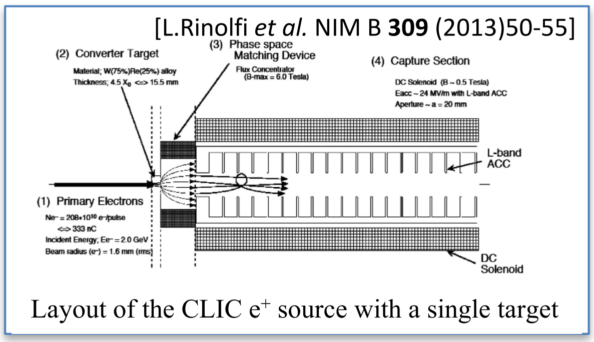
Geant4 simulation

Total flux



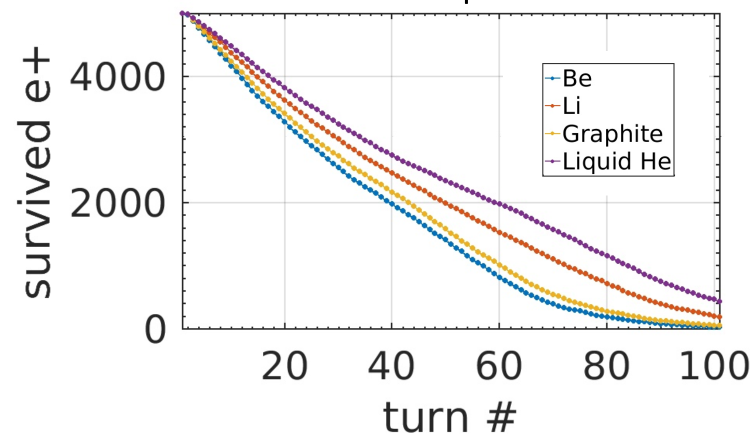
Conclusion and Perspectives

- **First design of low emittance e^+ ring with preliminary studies of beam dynamics**
- Optimization requires other issues to be preliminary addressed:
  - **target material & characteristics**
  - **e^+ accelerator complex**



Layout of the CLIC e^+ source with a single target

thickness according constant muons production



  - **muon accumulator rings design**

Preliminary studies for a low emittance muon source are promising

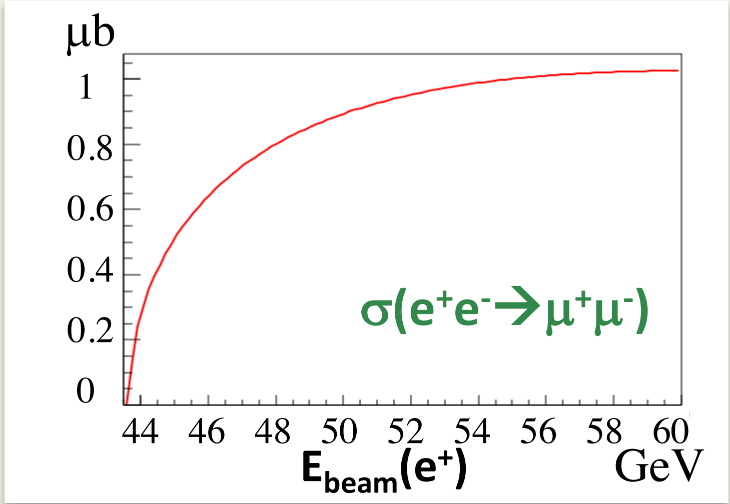
We will continue to optimize all the parameters, lattices, targets, etc. in order to assess the ultimate performances of a muon collider based on this concept

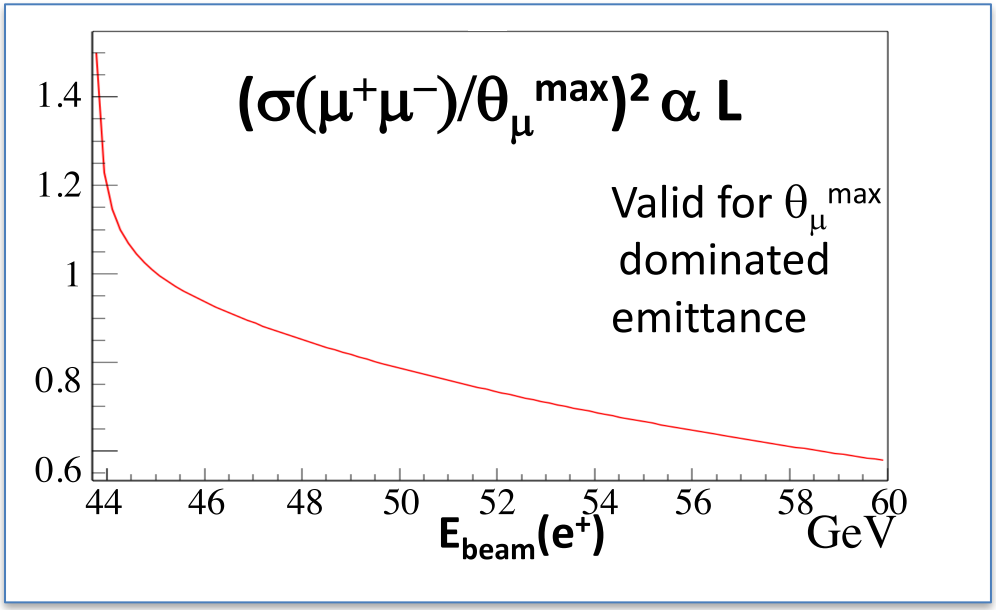
Back-up

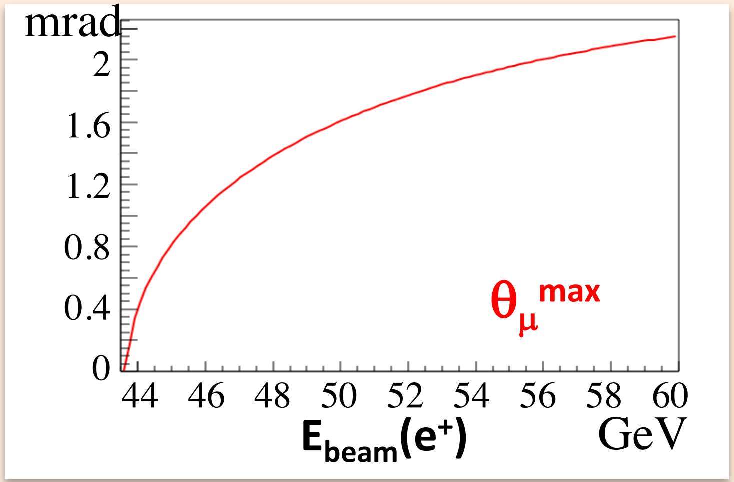
Luminosity of $\mu^+\mu^-$ Collider vs e^+ beam energy

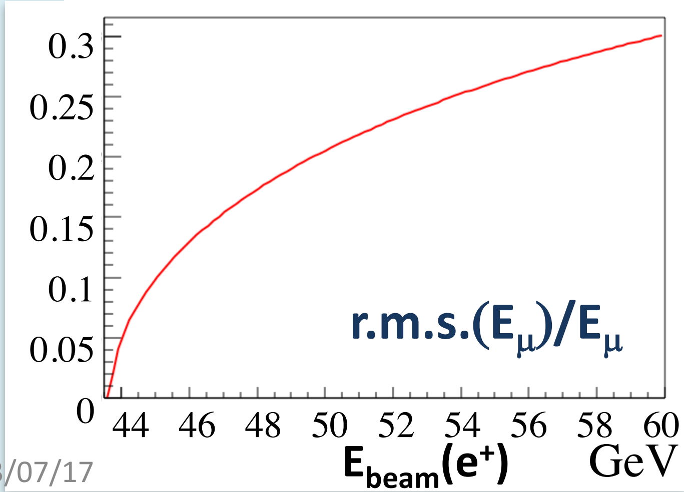
Parametric behaviours

Is there an optimal value for the positron beam energy?







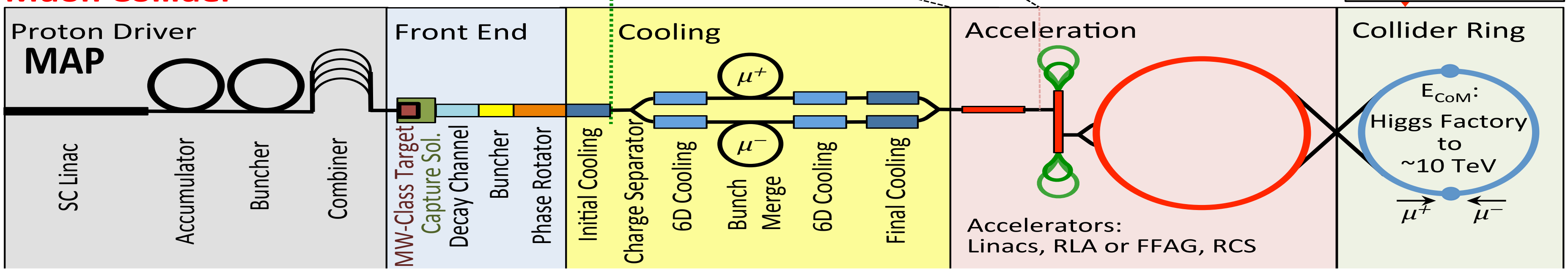


Key R&D

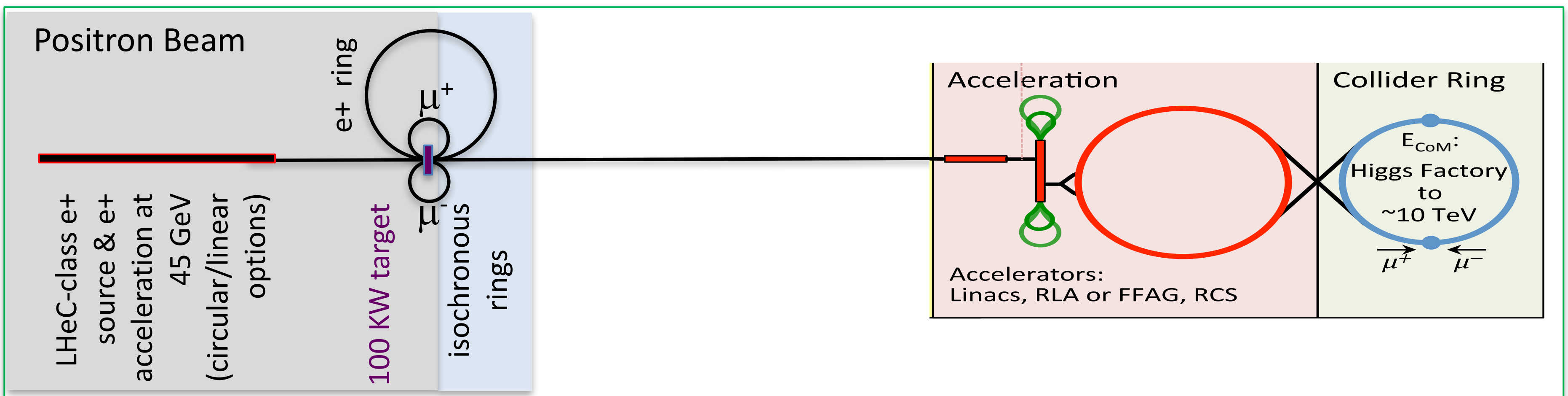
Key Challenges

MW proton driver MW class target NCRF in magnetic field	Ionization cooling High field solenoids (30T) High Temp Superconductor	Cost eff. low RF SC Fast pulsed magnet (1kHz)	Detector/ machine interface
~10^{13}-10^{14} μ / sec Tertiary particle $p \to \pi \to \mu$:	Fast cooling (τ=2μs) by 10^6 (6D)	Fast acceleration mitigating μ decay	Background by μ decay

Muon Collider



share the same complex



Key Challenges

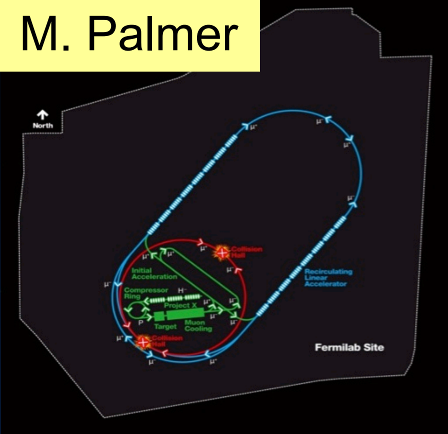
~10^{11} μ / sec from $e+e- \to \mu+\mu-$

Key R&D

10^{15} e+/sec, 100 kW class target, NON distructive process in e+ ring

EASIER AND CHEAPER DESIGN, IF FEASIBLE

M. Palmer



Muon Collider Parameters

Muon Collider Parameters					
		Higgs	**Multi-TeV**		
Parameter	***Units***	*Production Operation*			*Accounts for Site Radiation Mitigation*
CoM Energy	TeV	**0.126**	**1.5**	**3.0**	**6.0**
Avg. Luminosity	$10^{34}cm^{-2}s^{-1}$	0.008	1.25	4.4	12
Beam Energy Spread	%	0.004	0.1	0.1	0.1
Higgs Production/10^7sec		13,500	37,500	200,000	820,000
Circumference	km	0.3	2.5	4.5	6
No. of IPs		1	2	2	2
Repetition Rate	Hz	15	15	12	6
β^*	cm	1.7	1 (0.5-2)	0.5 (0.3-3)	0.25
No. muons/bunch	10^{12}	4	2	2	2
Norm. Trans. Emittance, ε_{TN}	π mm-rad	0.2	0.025	0.025	0.025
Norm. Long. Emittance, ε_{LN}	π mm-rad	1.5	70	70	70
Bunch Length, σ_s	cm	6.3	1	0.5	0.2
Proton Driver Power	MW	4	4	4	1.6
Wall Plug Power	MW	200	216	230	270

Exquisite Energy Resolution Allows Direct Measurement of Higgs Width

Success of advanced cooling concepts
⇨ several × 10^{32} [Rubbia proposal: 5×10^{32}]

Fermilab