LEMMA

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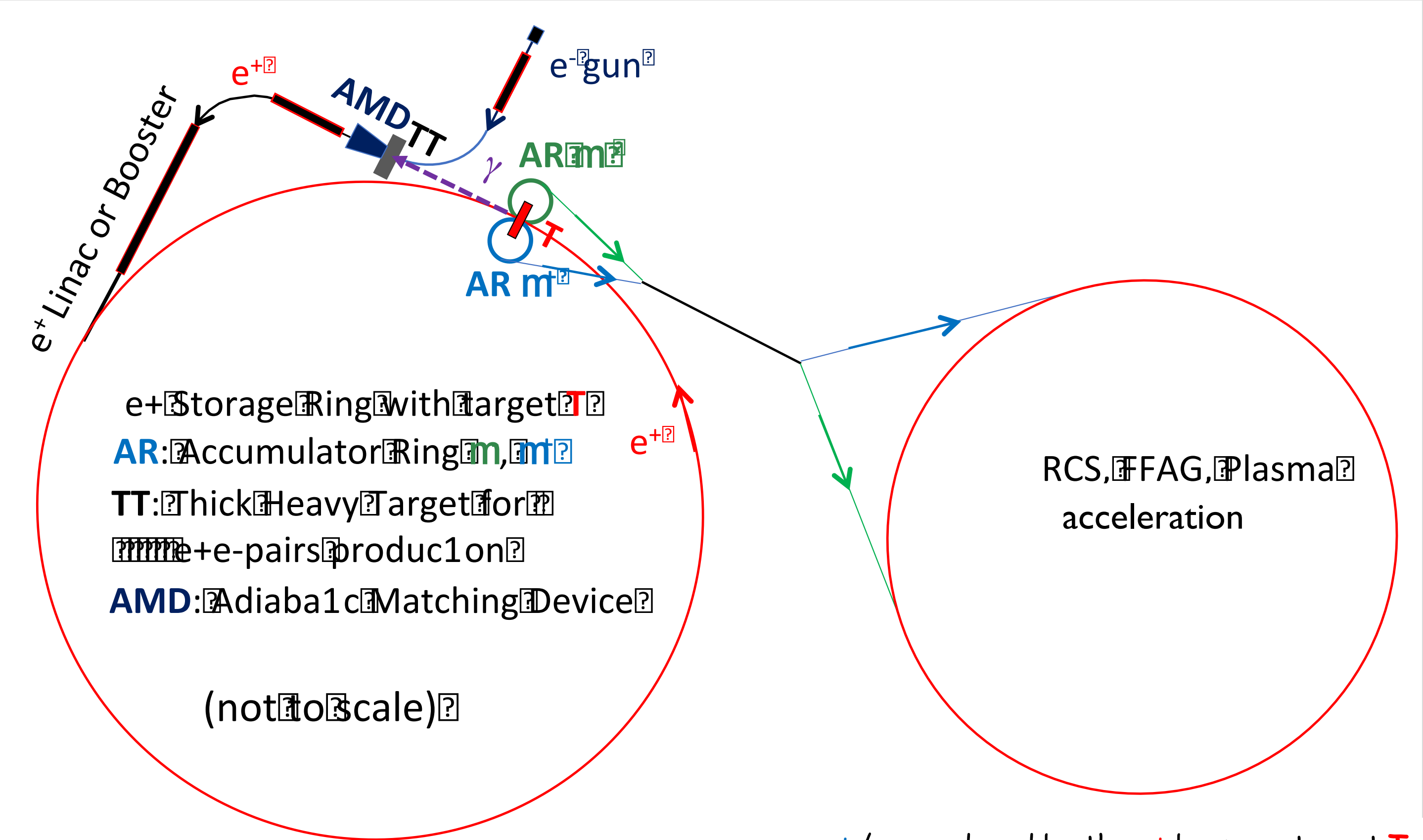
FOR THE LEMMA GROUP

- **Main idea :** muons from **direct m pair production**:

Muons produced from $e^+e^- \rightarrow \mu^+\mu^-$ at √s around the m^+m^- threshold **(√s ≈ 0.212GeV)** in asymmetric collisions (to collect m^+ and m^-)

M. Antonelli and P. Raimondi, Snowmass Report (2013) also INFN-13-22/LNF Note

FIRST LEMMA SCHEME



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

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

NOT FOR FREE

muon production by positron beam impinging on a target.

Why it is difficult….

1) Cross section , not enough (max 1μb)

2) bremsstrahlung, high Z->Z^2

3) multiple scattering in target (Sqrt (X0))

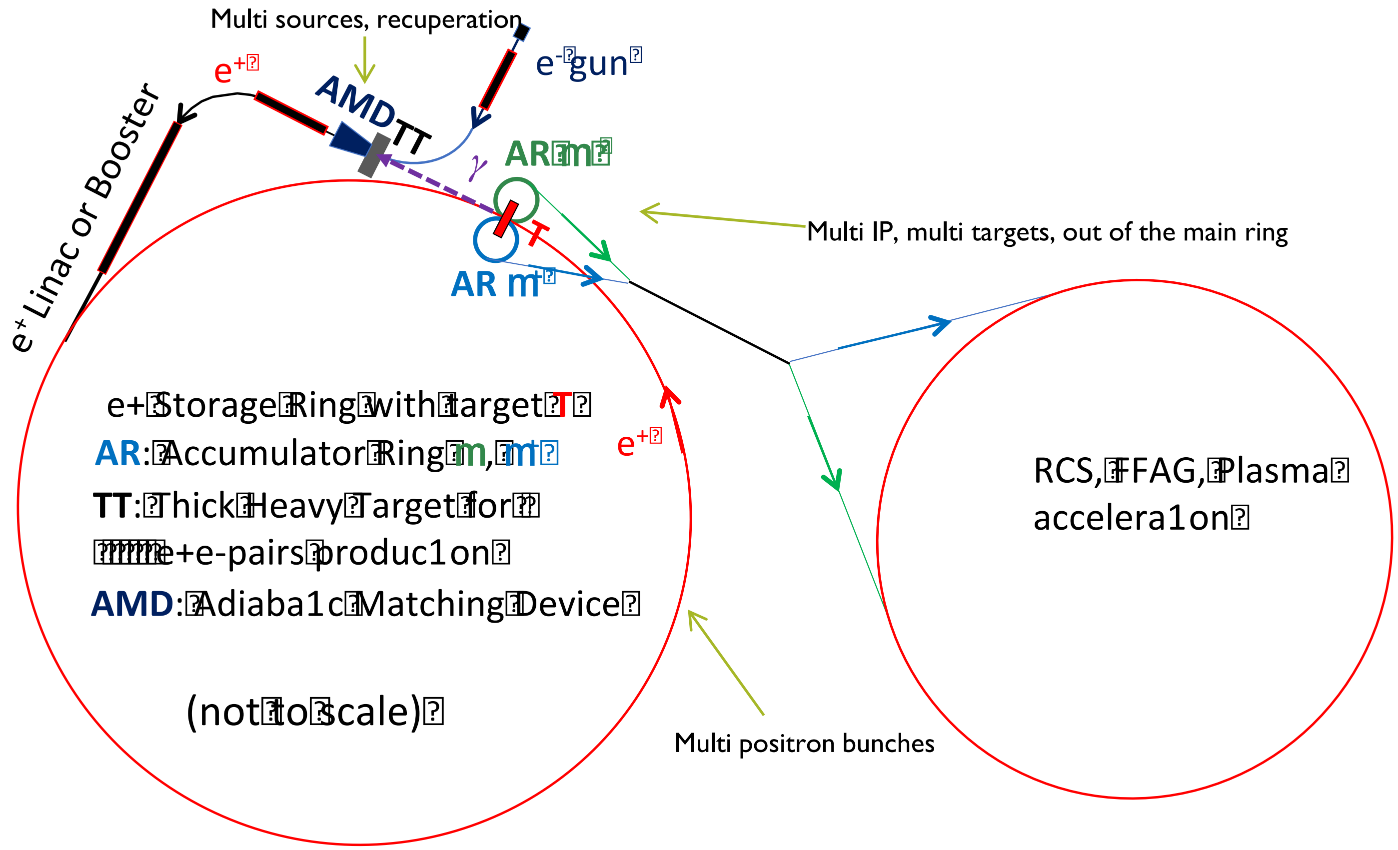
4) PEDD and target heating

5) Available positron sources

6) 45 GeV positrons – Sync Power

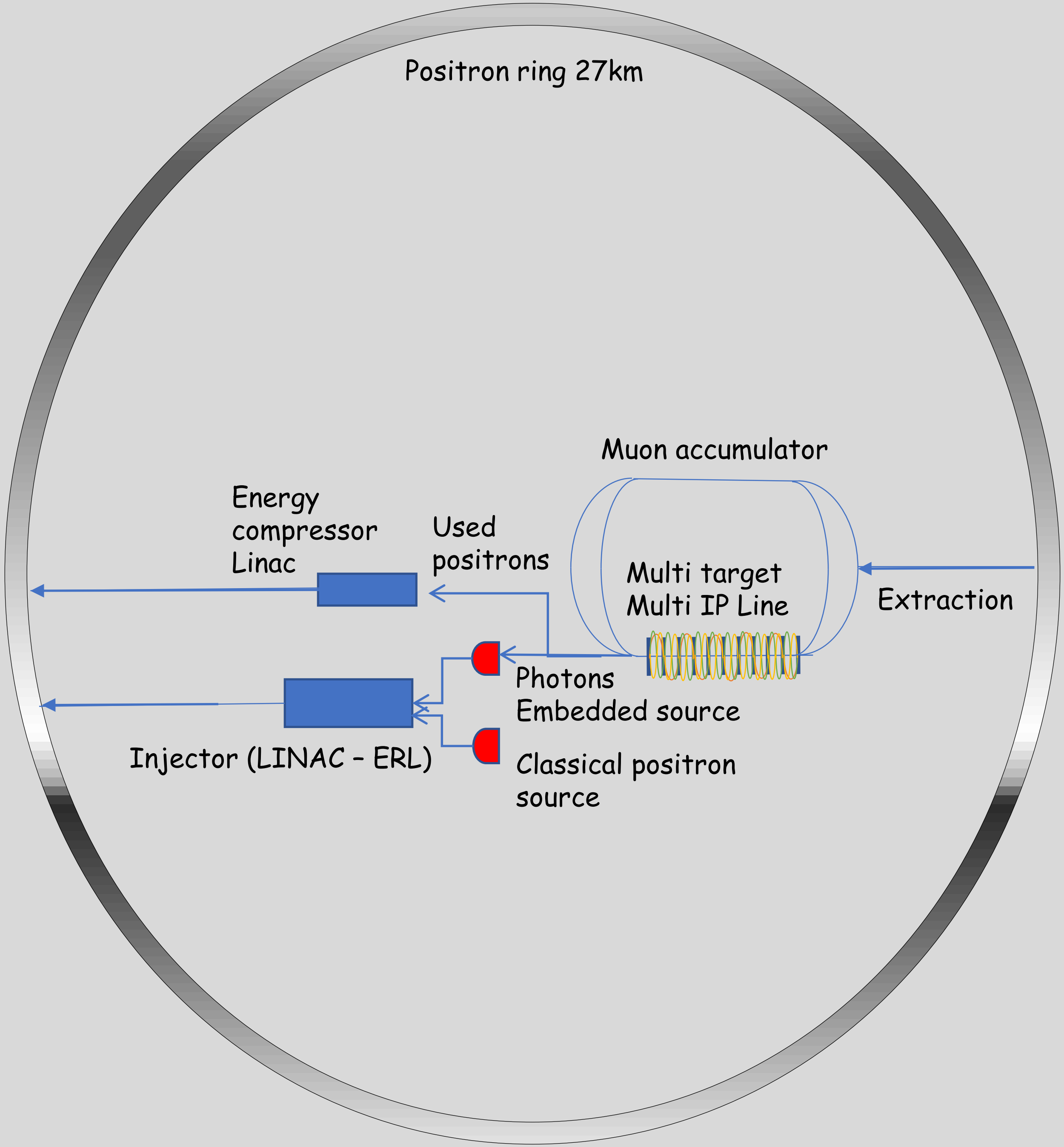
KEY ISSUES

	Challenges	Solutions
μ production	**Target average power** [material, shape, heat matching, average e^+ current on target]	Multiply N of targets to distribute average deposited energy
	Instantaneous PEDD [material, shape, bunch charge, e^+ spot on target]	Increase σ on target (increase ε_m!). Develop solid R&D program
	Integrated PEDD [material and shape, thermo-mechanical wave evacuation and matching, bunch charge and σ on target, time interval between bunches]	Increase σ on target (increase ε_m!). Increase interval between 2 e^+ beam passages (μ lifetime!)
μ beam	**μ emittance** [e^+ emittance and energy on target, target material and thickness (multiple scattering), μ production angle]	Preserve e^+ beam 6D characteristics @ targets. Optimize target thickness and material
	μ bunch intensity [cross section, material, e^+ beam energy and charge, target thickness]	Increase N of μ bunches produced/cycle and/or multiple μ production lines. Multivariable optimization of effect of the target (thickness, material, spacing, number)
	μ beam recombination [recombination scheme, μ lifetime, e^+ beam charge]	
e^+ beam	**Intensity and losses [**interaction with target, ring acceptance, injection, positron source intensity]	Use of "fresh" bunches. Re-use of "spent" bunches. Embedded e^+ source
	Source [target, N of sources, injection cycles for e^+ damping]	Re-use of "spent" bunches. Multiply embedded e^+ source. Damping Ring
	Emittance at the target [interaction with target, storage ring and cooling time]	Minimize N of bunch-target interactions per production cycle before cooling. Use "fresh" bunches
	Ring synchrotron power [very high energy]	Increase ring circumference, reduce beam current or reduce e^+ ring energy



Multi sources, recuperation
e+
e- gun
AMD
TT
e+ Linac or Booster
γ
AR m
AR m
T
Multi IP, multi targets, out of the main ring
e+ Storage Ring with target T
AR: Accumulator Ring m, m
TT: Thick Heavy Target for
e+e-pairs produc1on
AMD: Adiaba1c Matching Device
(not to scale)
e+
Multi positron bunches
RCS, FFAG, Plasma
accelera1on

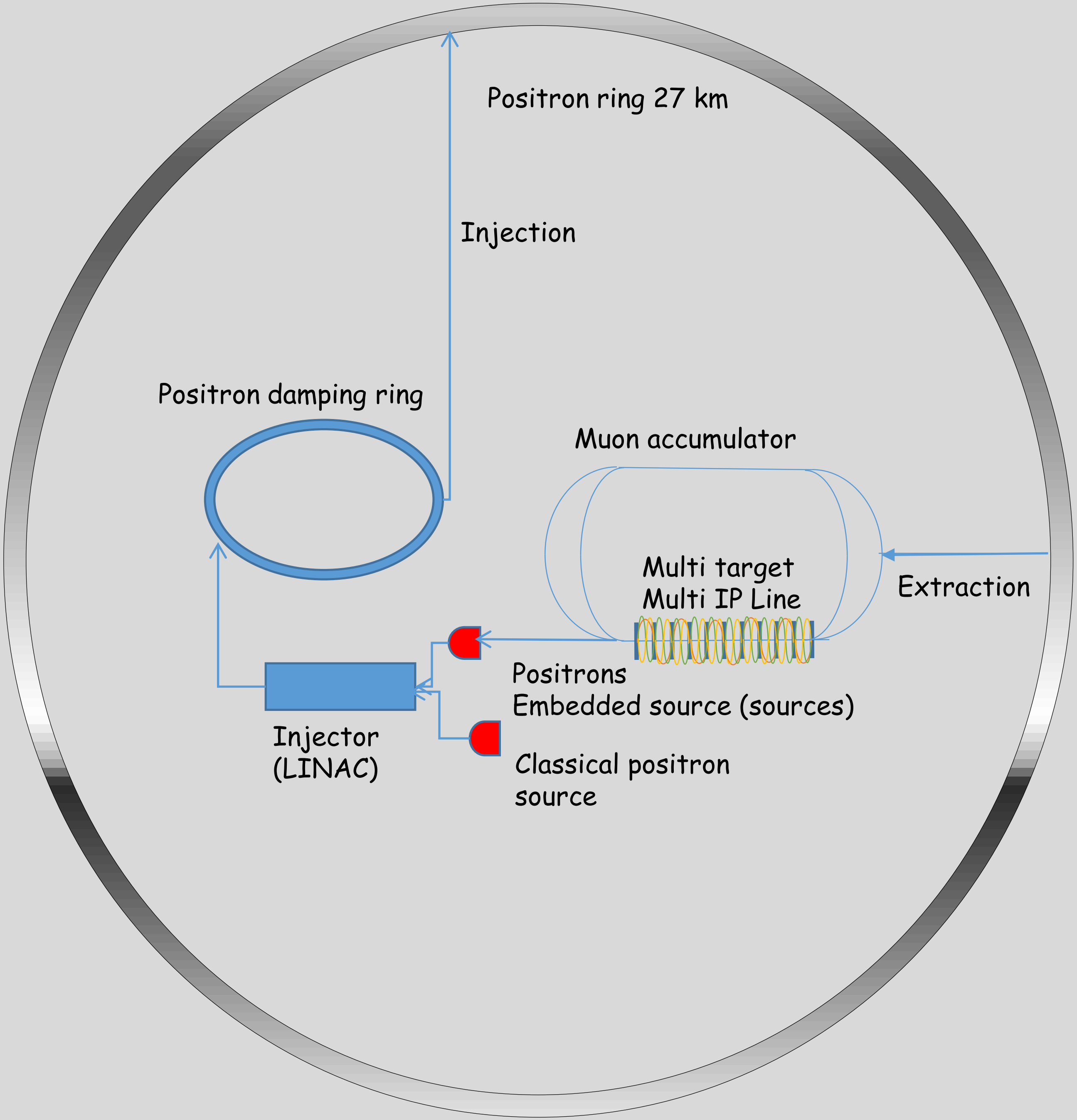
SCHEMES


Positron ring 27km
Muon accumulator
Energy
compressor
Linac
Used
positrons
Multi target
Multi IP Line
Extraction
Photons
Embedded source
Injector (LINAC – ERL)
Classical positron
source

Cycles

		2 damping time 80ms		300 μs		20ms		2 damping time 80ms
Positron source	Stand by		Stand by		Positron generation	1000 bunch, 3 exp 10/bunch, 0,24 mA	Target cooling	
Injection Linac	Stand by		Injection from the embedded source	1000 bunch, 2 exp 10/bunch, 10 mA	Injection from the natural source	1000 bunch, 3 exp 10/bunch, 0,24 mA	Stand by	
Positron ring	Cooling	1000 bunch, 5 exp 11/bunch, 11kHz, 0.88 A	Extraction to the muon production lines		Top up injection	1000 bunch, 4,5 exp 11/bunch,	Cooling	1000 bunch, 5 exp 11/bunch, 11kHz, 0.88 A
Muon accumulator	Stand by		Muon generation	1 bunches mu+/-, 10exp9/bunch,~1MHz, 300mA	Extraction to post acceleration		Target cooling	
Recuperation LINAC	Stand by		Positron beam energy compression	1000 bunch, 4.5 exp 11/bunch, 240 mA	First post acceleration	2 bunches mu+/-, 10exp9/bunch,	Stand by	
Embedded source	Stand by		Positron generation	1000 bunch, 2 exp 10/bunch, 10 mA	Target cooling		Target cooling	

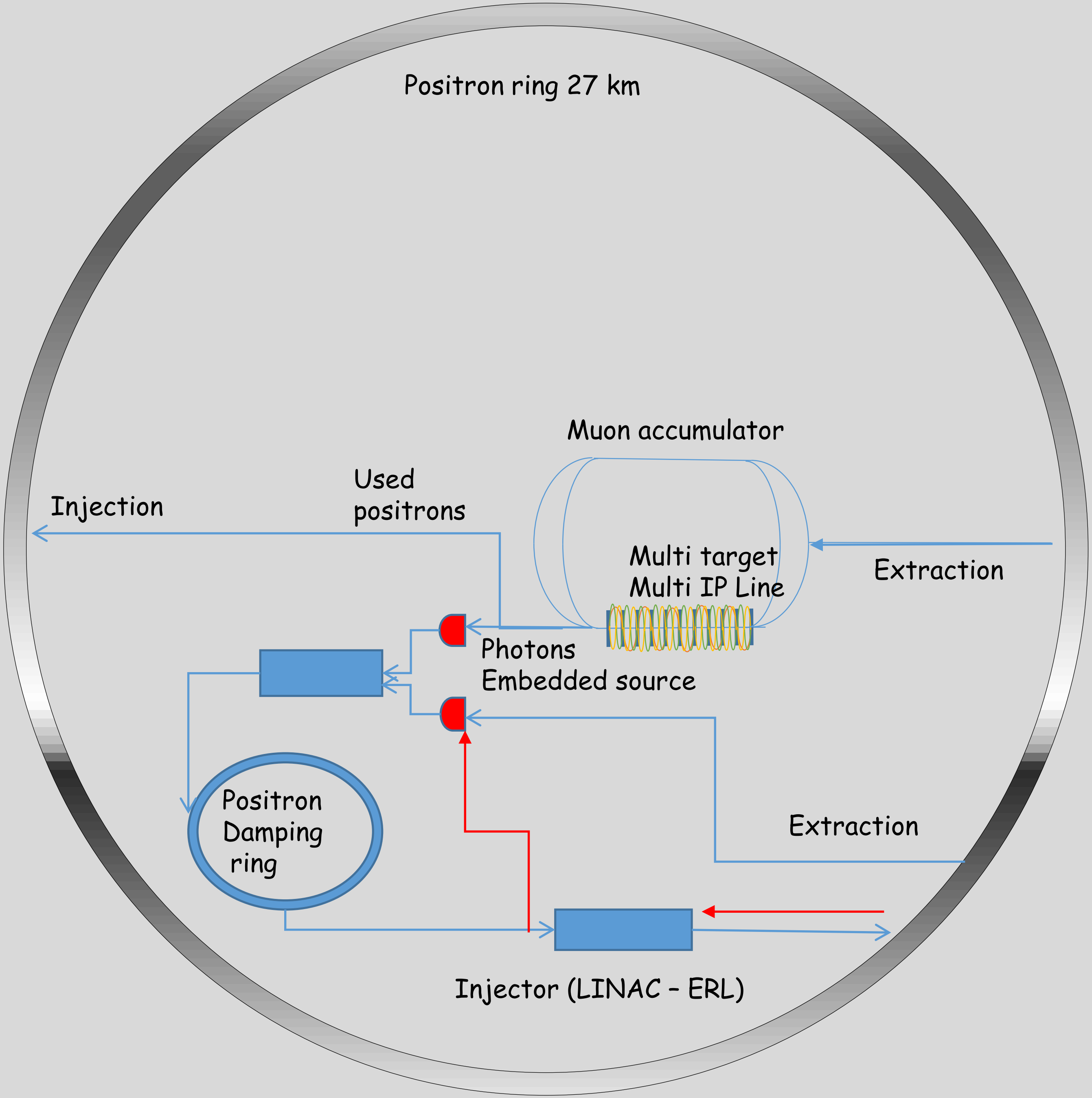
	Positron Ring	1000 bunch, 5 exp 11/bunch, 11kHz, 0.88 A, 90-110 MW@ 2 damping time
	Injection LINAC	5 10exp14/s@45GeV. 80mA - 3,5 MW
AVERAGE	Positron source	3 10exp14/s@300MeV. 48mA - 14,5kW
	Embedded source	2 10exp14/s@300MeV. 32mA - 9,5kW
	Muon Accumulator	2 10exp9/bunch,~3MHz, 1mA x 0,003 = 3mA 22.5 GeV. No damping
	Recuperation LINAC	4.5 exp 15/s, ~720mA@3GeV, 2,15 MW


Positron ring 27 km
Injection
Positron damping ring
Muon accumulator
Multi target
Multi IP Line
Extraction
Positrons
Embedded source (sources)
Injector
(LINAC)
Classical positron
source

Cycles

		90 ms		70 ms	Action	300 µs		30 ms	
Positron source	Stand by				Stand by				
Injection Linac	Stand by				Stand by	1000 bunch, 5 exp 11/bunch, 260 mA @ 5 GeV or Damping ring initial energy (if ramped)			
Positron ring	Injection	1000 bunch, 5 exp 11/bunch, 11kHz, 0.88 A@ initial energy	Ramp up	1000 bunch, 5 exp 11/bunch, 11kHz, 0.88 A @ 45 GeV	Extraction to the muon production lines		ramp down		
Muon accumulator	Stand by		Target cooling		Muon generation	1 bunches mu+/-, 10exp9/bunch,~3MHz,1mA	First post acceleration	2 bunches mu+/-, 10exp9/bunch,	Target cooling
Positron damping ring	Extraction		Rump down (if damping ring ramped)		Injection form the embedded positron source	1000 bunch, 5 exp 11/bunch, 260 mA	Cooling and Rump up (if damping ring ramped)	1000 bunch, 5 exp 11/bunch, 11kW	
Embedded source	Stand by				Positron generation	1000 bunch, 5 exp 11/bunch, 260 mA	Target cooling		Target cooling

	Positron Ring	1000 bunch, 5 exp 11/bunch, 11kHz, 0.88 A, 0,9 MW fascio
	Injection LINAC	5 10exp15/s@5GeV. 800mA - 4 MW
AVERAGE	Positron source	3 10exp14/s@300MeV. 48mA - 14,5kW
	Embedded source	3 10exp15/s@300MeV. 800mA - 240 kW
	Muon Accumulator	2 10exp9/bunch,~1MHz, 1mA x 0,003 =3mA 22.5 GeV. No damping
	Positron Damping Ring	1000 bunch, 5 exp 11/bunch, 16kW


Positron ring 27 km
Muon accumulator
Used
positrons
Injection
Multi target
Multi IP Line
Extraction
Photons
Embedded source
Positron
Damping
ring
Extraction
Injector (LINAC – ERL)

Cycles

		30ms		10 ms		300 µs		10 ms		30 ms
Positron source	Stand by		Top up in the positron ring	N positrons	Stand by		Top up in the positron ring	N positrons	Target cooling	
Injection Linac	Stand by		Top up in the positron ring	N positrons	Stand by		Top up in the positron ring	N positrons + 1000 bunch, 5-N exp 11/bunch, 8mA	Stand By	
Positron ring	Stand by		Injection	1000 bunch, 5 exp 11/bunch, 11kHz, 0.88 A	Extraction to the muon production lines and reinjection in the ring	1000 bunch, 5-n exp 11/bunch, 11kHz, 0.88 A	Extraction to the embedded sources		Stand By	
Muon accumulator	Stand by				Muon generation	1 bunches mu+/-, 10exp9/bunch,~3MHz, 1mA	First post acceleration and target cooling	2 bunches mu+/-, 10exp9/bunch,	Target cooling	
Positron damping ring	Cooling	1000 bunch, 5 exp 11/bunch, 16kW	Extraction and injection form the source		Injection from the source	N positrons	Injection from the embedded sources	1000 bunch, 5 exp 11/bunch, 16kW	Cooling	1000 bunch, 5 exp 11/bunch, 16kW
ERL	Stand By		Injection	1000 bunch, 5 exp 11/bunch, 8mA	Stand By		Stand By		Stand By	
Embedded source	Stand by						Positron generation	1000 bunch, 5-N exp 11/bunch, 8mA < / N sources	Target cooling	

	Positron Ring	1000 bunch, 5 exp 11/bunch, 11kHz, 0.88 A, 22 MW
	Injection LINAC	N positron /s - up to feasible
AVERAGE	Positron source	N positron /s - up to feasible
	Embedded source	10exp16-N/s@300MeV / N source. 20 Sources 5 Exp-14/s @ 300 MeV
	Muon Accumulator	2 10exp9/bunch,~3MHz, 1mA x 0,003 = 3mA 22.5 GeV. No damping
	ERL	10exp16/s , 1.6 mA
	Positron damping ring	1000 bunch, 5 exp 11/bunch, 16kW

MUON PRODUCTION

Work in progress on the single-pass scheme [NIM A 807 (2016) 101-107]

1. **Muon beam production in single-pass scheme vs multi-pass scheme**
2. **Multi-IP and single-IP beamline**
3. **Muon Accumulator rings**
4. **IR optics design: recombination and separation of e^{+}, μ^{+}, μ^{-}**

Software Tools for the muon production and muon transport:

- **GEANT4** for muon prodution and **MDISim** for the interface with MADX and muon transport
- **FLUKA** for muon production, mainly for comparison and benchmark

- Under development
- **MUFASA**: novel 'MC' under development for muon production simulation and interface with MADX/PTC for muon beam transport

Multi-IP Beamline

- Many different **multi-IP beamline optics** (need to split the power on target)
- **Multi-IP beamline optics** is made of regular unit cells where targets are placed at the beginning and at the end of each cell.
- Three beams will pass through this beamline: e^+, μ^+, μ^-

e^+ beam:
$e(e^+)$=5.7 nm, E(e+) = 45 GeV

$\beta^*(e^+)$= 3.8m

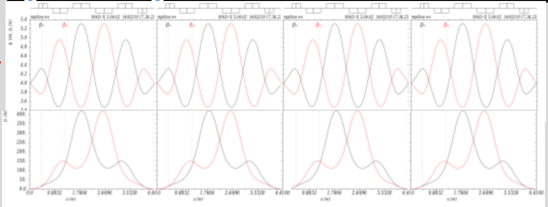
E(e+) = 18 GeV

e^+ →

... → e^+ μ^+ μ^-

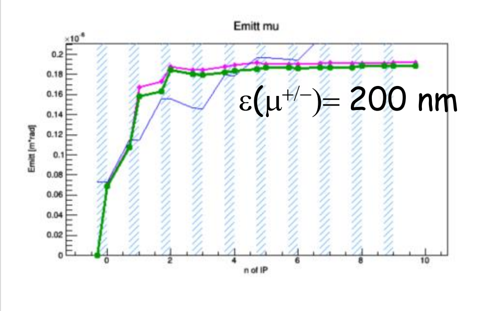
e+

μ^+

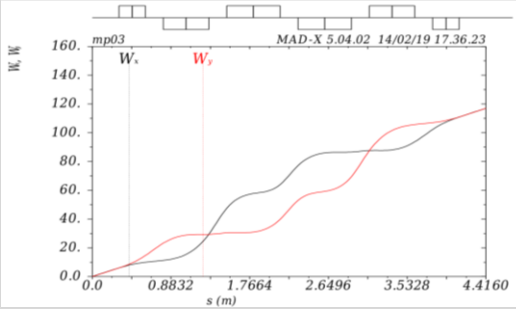


10.5 GeV < **E($\mu^{+/-}$)** < 26.2 GeV

10 targets, 0.3 mm Be targets ->
0.3 X_0(Be) = 10.5 cm (efficiency = 1.3 10^{-6} μ/e^+)



Emittance increase due to chromaticity



- Beamline has to maximize the muon production → constraint @target for e+ spot size and divergence
- Beamline has to preserve the e+ beam (to relax the e+ source requirements) → constraint to the target but also to the energy acceptance of the beamline
- Beamline as short as possible due to the short lifetime of muons

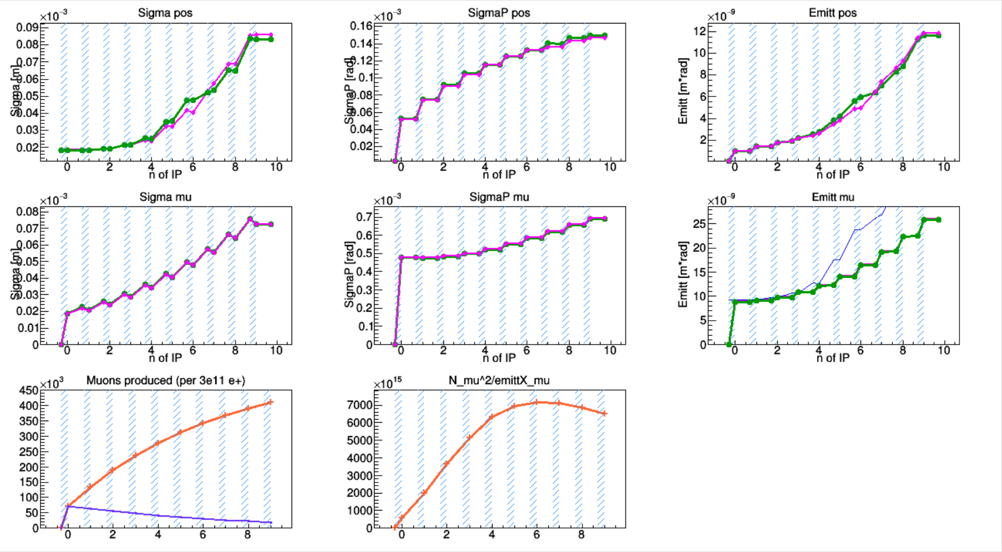
[O.Blanco, P.Raimondi, M Boscolo]

Single IP Beamline

10 targets, 3 mm Beryllium, spaced only by 2 cm drifts (to split the power on target) :

Different cases considered: $\varepsilon(e^+)$=5.7 nm, 70pm, 700 pm for different $\beta^*(e^+)$ and spot sizes:
$\sigma(e^+)$=150μm, 20 μm (minimum sustainable beam spot)
Simulations shows a smaller muon emittance if compared to multi-IP beamline

Drift=6 mm between targets
Total length = 5.4 cm



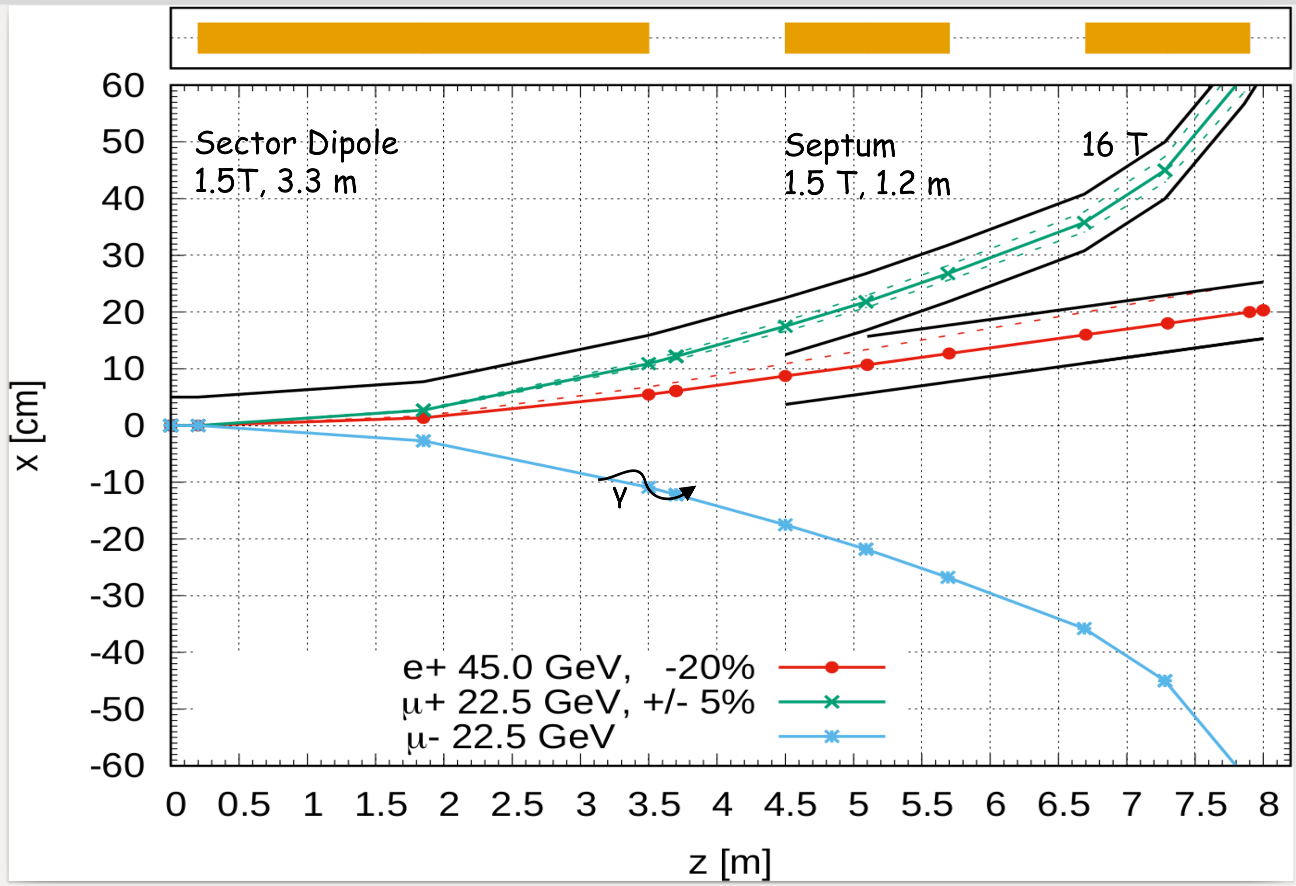
$\varepsilon(e^+)$~factor 2 degradation

$\varepsilon(\mu^{+/-})$=70 nm
E(e+) = 45 GeV

With $\varepsilon(e^+)$=70pm and $\sigma(e^+)$= 20 μm (*) $\rightarrow$ $\varepsilon(\mu^{+/-}) \approx$ 20 nm

[O.Blanco, A.Ciarma, M.Boscolo]

Beam Separation-Combination, Mar/2019



5cm of aperture radius
around μ+ and e+ beam trajectory

<u>μ ± 20% in energy occupy all the aperture when they reach the septum</u>

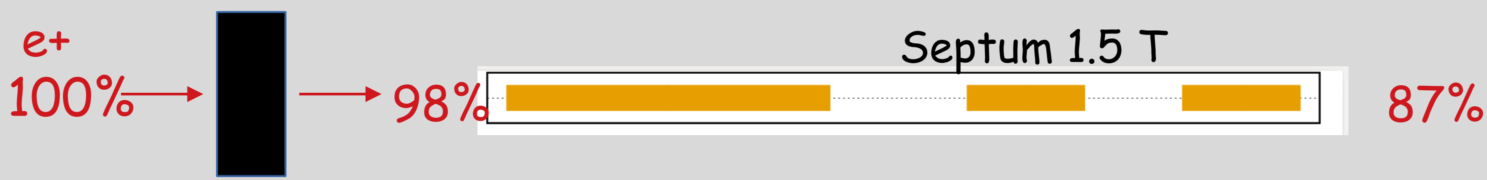
e+ above 36 GeV (-20% Energy) pass through

About 10 cm of separation between beam pipes at the 16 T magnet entrance, to give space to separated magnets.

1.5 T , 3.3 m long dipole

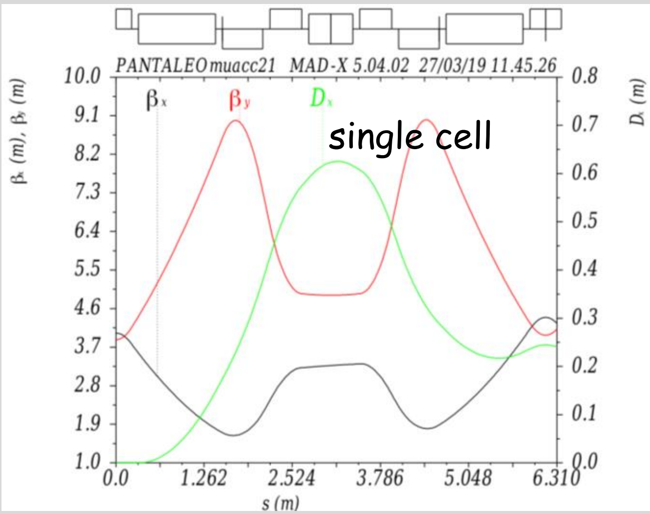
e+ E. Loss = 20 MeV

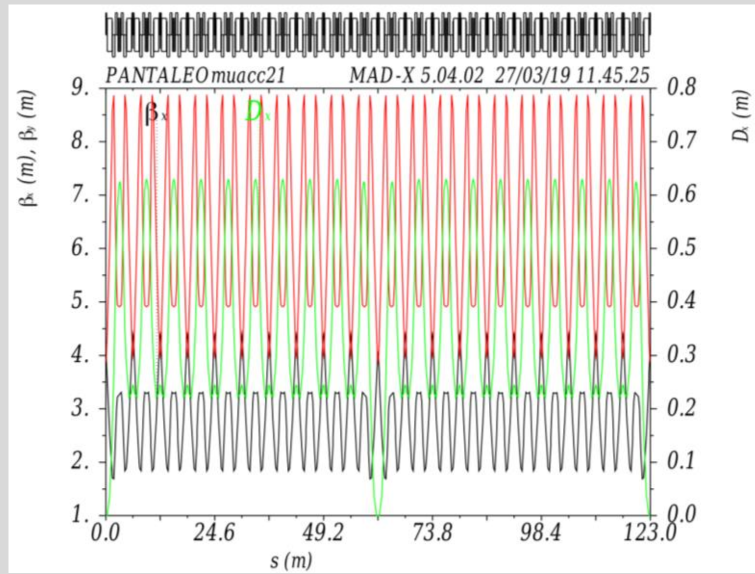
γ E. Crit = 2 MeV



[P.Raimondi, O.Blanco, M.Boscolo]

Preliminary: Muon Accumulator Ring optics





Circumference=123 m
Two section with zero dispersion for the target(s)
Optimized to get small momentum compation factor

DRIFTS : 0.1m long
BENDING MAGNETS : 18.4 T, -24.7 T, 15.9 T
QUAD GRADIENTS :100T/m
SEXTUPOLE GRADIENTS : <300 T/m2

Additional multipoles : 3rd, 4th, 5th order
To cancel momentum compaction factor

[P. Raimondi]

Single-IP: Carbon and Hydrogen vs Beryllium

Hydrogen:

- Additional factor 2 muons produced for the same X_0 with Hydrogen
- reduced multiple scattering
- Issue: target feasibility

Carbon:

- For the same fraction of radiation length, Carbon produces -25% muon pairs
- Increased multiple scattering
  - much suppressed with crystal in channeling
- Easier from target point of view

Ee+	N	L	Ltot		Mat	eff
GeV		mm	mm	X0		10^{-7} μ/e+
45	10	3	30	0,085	Be	5,1
45	5	3,2	16	0,085	C	3,8
45	7	3,2	22,4	0,089	C A412	4,0

POSITRON RINGS

Damping Ring

- The DR should provide fast cooling of the positrons produced by the source. Limiting the total collider cycle.
- A 5 GeV DR, similar to the ILC one, could provide the needed damping time and emittance
- The lattice may be similar to the main Positron Ring
- To provide the needed damping time (12 msec), about 100 wigglers similar to ILC ones have to be installed
- A shorter ring (ex. 6.3 Km) is preferred since a smaller number of damping wigglers is needed

DR parameters table (preliminary) to achieve 12 msec damping time

Parameter	Units		
Beam Energy e+	GeV	5	
e+ mass	GeV	5,11E-04	
Gamma (Lorentz factor)		9784,74	
Circumference	m	6300	
Bending Field	T	0,23	ILC
Average bending radius	m	72	ILC
Magnetic rigidity	T m	17	
Bending Field WIG	T	2,16	ILC
Average bending radius WIG	m	7,72	ILC
Coupling (full current)	%	0,5	
Normalised Emittance x	m	5,61E-05	
Emittance x (eq)	m rad	5,73E-09	
Emittance y (eq)	m rad	2,87E-11	
Emittance ratio		200,0	
Emittance spent beam	m rad	2,00E-08	
Emittance x after 1 taux	m rad	7,66E-09	
Bunch length (zero current)	mm	3	
Beam current	A	3,807	
Bunch current	mA	3,8	
RF frequency	Hz	5,00E+08	
Revolution frequency	Hz	4,76E+04	
Revolution period	s	2,10E-05	
Harmonic number	#	10507	
Number of bunches	#	1000	
Bunch distance (uniform fill)	m	6	
Bunch distance (uniform fill)	sec	2,10E-08	
N. Particle/bunch	#	5,00E+11	
Energy Loss/turn DIP	GeV	7,63E-04	
Energy Loss/turn WIG	GeV	1,68E-02	ILC*2 (108 W)
Total Energy Loss/turn	GeV	1,76E-02	
RF voltage	GV	1,15E+00	
Synchrotron tune	#	6,80E-02	
Energy acceptance	%	±7	
RF acceptance	%	±7,2	
Energy spread DIP		5,03E-04	
Energy spread WIG		9,93E-04	
Total Energy spread		1,11E-03	
Momentum compaction		1,10E-04	
Damping time x,y	msec	12,0	
Damping time L	msec	6,0	
Damping time x,y	turns	569	
Damping time L	turns	285	
SR power	MW	64	
SR power/meter	MW/m	1,02E-02	

[M.Biagini, S.Liuzzo, P. Raimondi]

Positron Ring

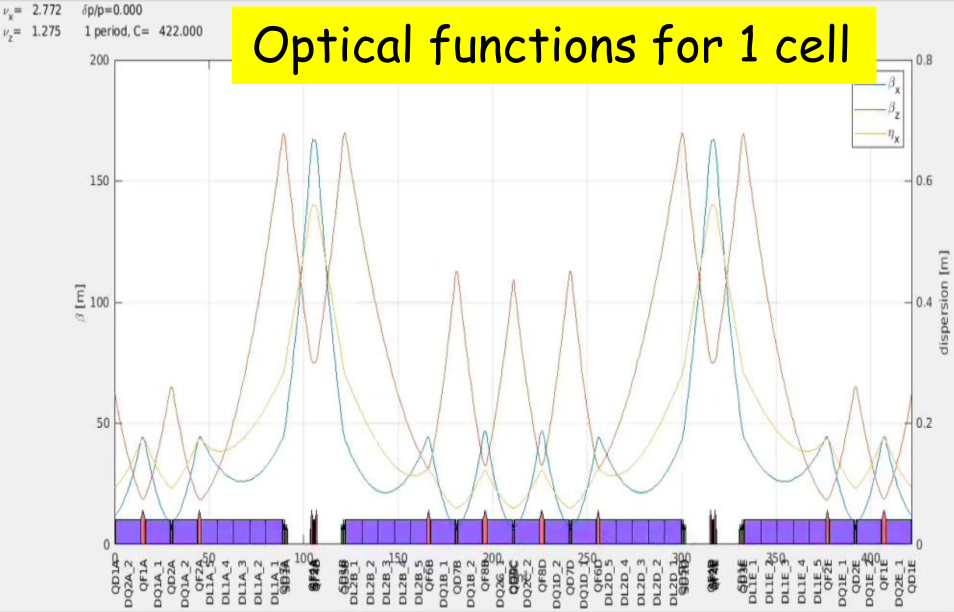
- The 45 GeV positron ring has a small emittance, mostly round beams, and should accommodate the 1000 bunches/5×10^{11} e^+ needed for the muon production
- The present layout is for a 27 Km long ring
- Several lattices have been designed with emittance ranging from 700 pm to 20 nm for a 27 Km ring
- The choice of the final lattice will be based on the larger energy acceptance since it is mandatory that possibly all the “spent” beam from the muon production be successfully re-injected in the PR to be later decelerated and re-injected in the DR for cooling.
- 100 km solution will increase the luminosity of at least a factor 3.5

PR parameters table for 3 different 27 Km ring lattices

Parameter	Units	27Km 64 cells	27Km 32 cells	27Km 32 cells
		700pm	6nm	10 nm
Beam Energy e+	GeV	45	45	45
e+ mass	GeV	5,11E-04	5,11E-04	5,11E-04
Gamma (Lorentz factor)		88062,62	88062,62	88062,62
Circumference	m	27008	26720	27008
Ring average radius	m	4298	4253	4298
Bending Field	T	0,05	0,05	0,08
Average bending radius	m	3050	3000	1900
Magnetic rigidity	T m	150	150	150
Coupling (full current)	%	100	100	100
Normalised Emittance x	m	6,32E-05	5,04E-04	8,24E-04
Emittance x (eq)	m rad	7,18E-10	5,72E-09	9,36E-09
Emittance y (eq)	m rad	7,18E-10	5,72E-09	9,36E-09
Emittance ratio		1,0	1,0	1,0
Emittance spent beam	m rad	2,00E-08	2,00E-08	2,00E-08
Emittance x after 1 taux	m rad	3,33E-09	7,65E-09	1,08E-08
N. Particle/bunch	#	5,00E+11	5,00E+11	5,00E+11
Beam current	A	0,888	0,898	0,888
Bunch current	A	8,88E-04	8,98E-04	8,88E-04
RF frequency	Hz	5,00E+08	5,00E+08	5,00E+08
Revolution frequency	Hz	1,11E+04	1,12E+04	1,11E+04
Revolution period	s	9,00E-05	8,91E-05	9,00E-05
Harmonic number	#	45044,50	44564,16	45044,50
Number of bunches	#	1000	1000	1000
Bunch distance (uniform fill)	m	27	27	27
Bunch distance (uniform fill)	sec	9,00E-08	8,91E-08	9,00E-08
Energy Loss/turn	GeV	0,119	0,121	0,192
Energy Loss/turn (formula)	GeV	0,119	0,121	0,191
RF voltage	GV	4,76E-01	4,84E-01	7,68E-01
SR power	MW	106	109	170
SR power/meter	MW/m	3,91E-03	4,06E-03	6,31E-03
Bunch length (zero current) formula		1,9	3,6	3,8
Bunch length (full current, Z/n=0.1 Ohm)	mm	12,9	12,8	11,0
RF acceptance	%	±5,7	±3,1	±3,7
Energy spread		7,17E-04	7,17E-04	9,10E-04
Momentum compaction		2,90E-05	1,05E-04	1,11E-04
Damping time x,y	msec	68	66	42
Damping time L	msec	34	33	21
Damping time x,y	turns	755	741	467
Damping time L	turns	378	371	233
Damping time x,y (formula)	msec	68,1	66,2	42,2
Damping time L (formula)	msec	34,0	33,1	21,1
Beta at target	m	2,00	0,50	0,50
Spot at target	m	3,79E-05	5,35E-05	6,84E-05

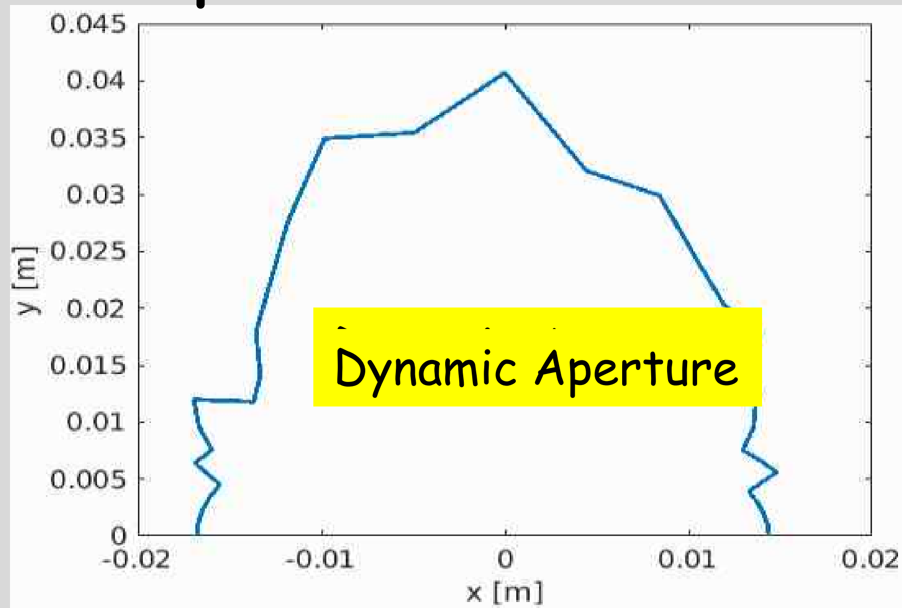
[M.Biagini, S.Liuzzo, P. Raimondi]

Example: lattice for 700 pm emittance

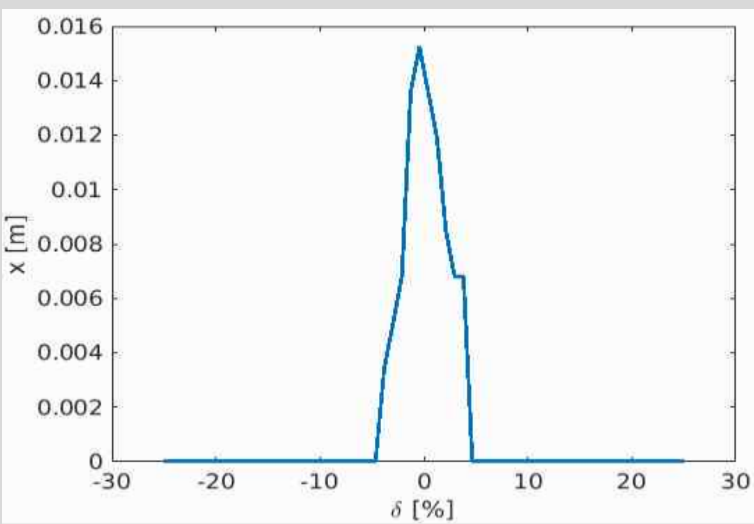


Optical functions for 1 cell

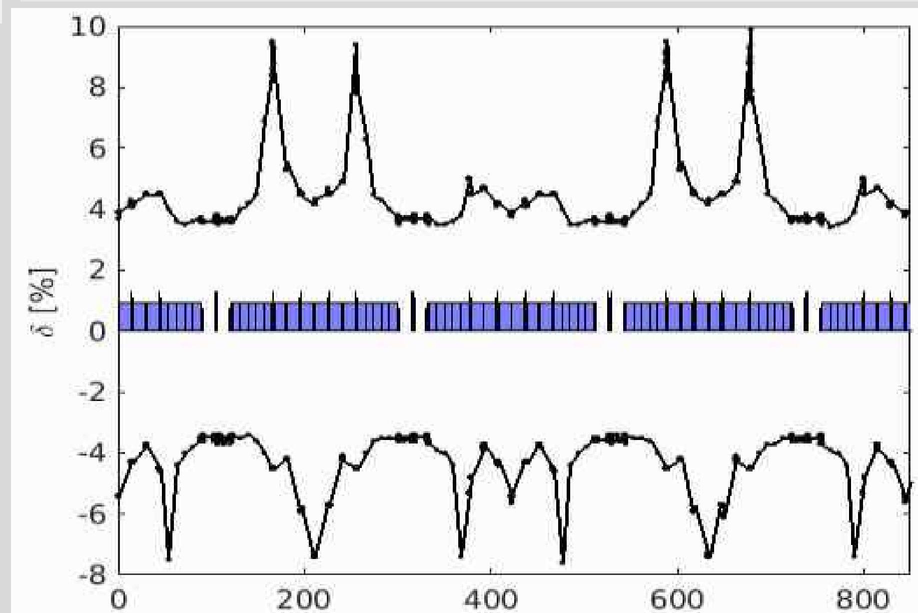
S.Liuzzo, M.Biagini



Dynamic Aperture



Off-momentum Dynamic Aperture



Energy acceptance along 2 cells

COMPRESSOR LINAC

A possible accelerating structure as taken from XFEL TDR

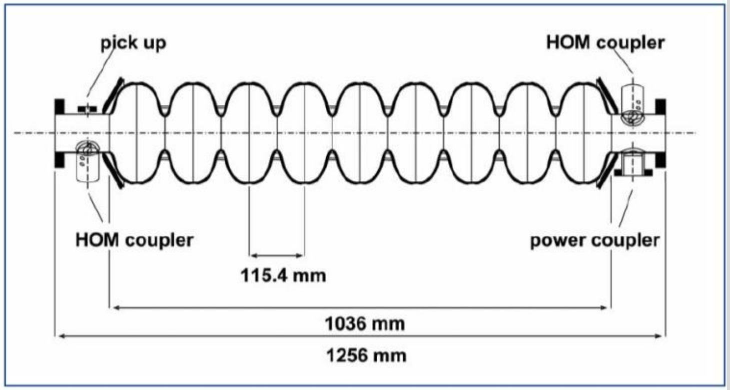
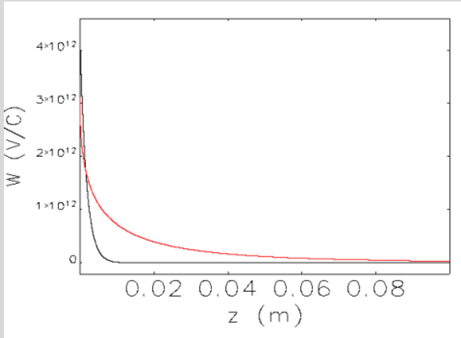


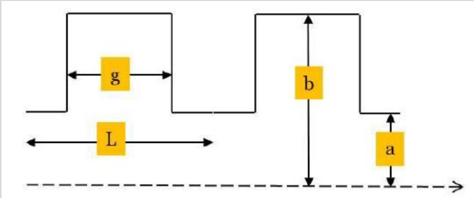
Figure 4.2.1: *Side view of the nine-cell cavity with the main power coupler port (right), the pick up probe (left), and two HOM couplers.*

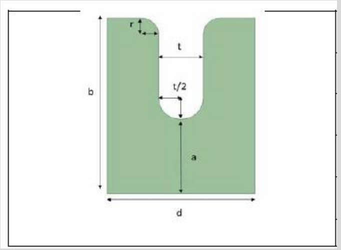
Eacc=20 MV/m
SW short range wf should be ok as TW
1 cavity=9 cells
1 cryomodule= 8 cells

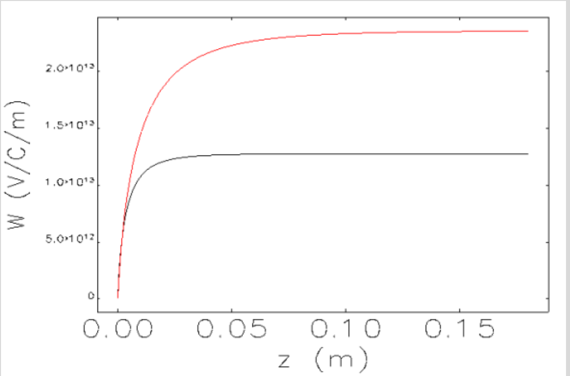
From L3 Xfel.xls= 2cryomod-quad-2cryomod



-- pure pill box
-- Xfel multistructure (2014)







Pill box cavity model considered for the wake feld calculations: a is the iris radius, L is the cell length. The asymptotic values of the longitudinal and transverse wake functions have been calculated according to K. Bane SLAC{PUB{7862 (Revised) November 1998 with a=3.2 mm)

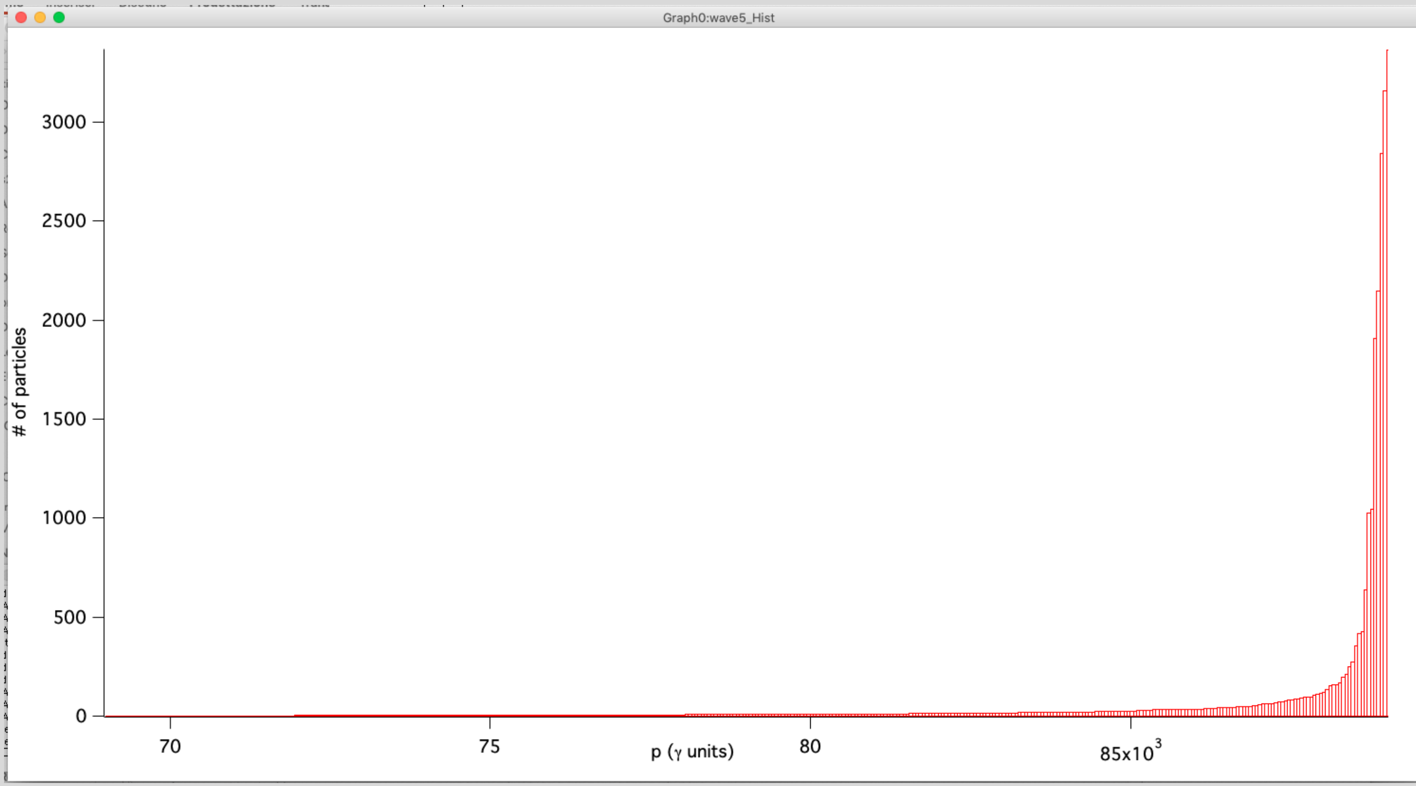
Geometrical paramaters	
a (mm)	35
g (mm)	90
L (mm)	105.4

C.Vaccarezza, D.Alesini

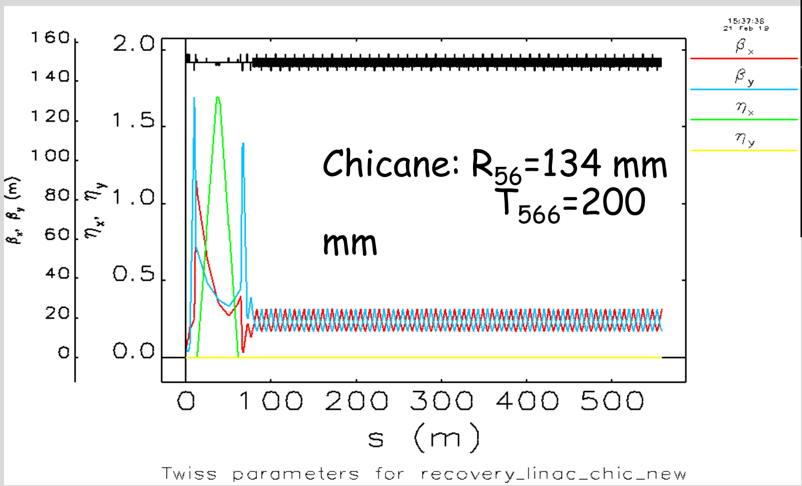
Starting from the 90% the beam after the 10° target -> considered particle distribution

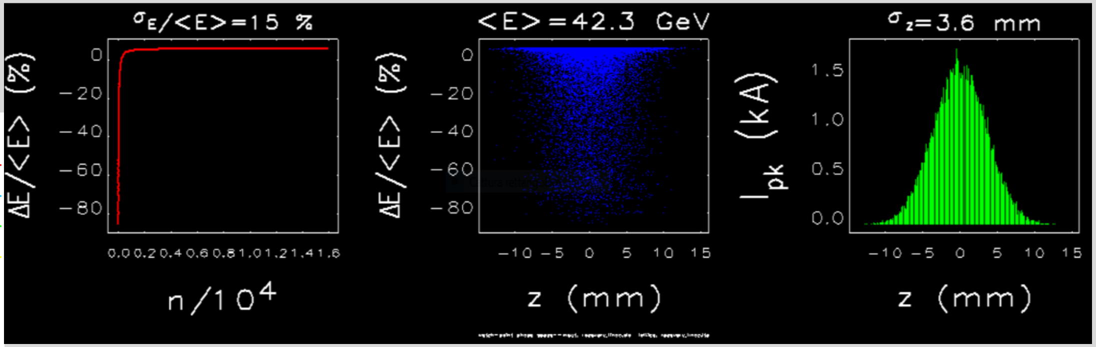
90%= 26398/29398

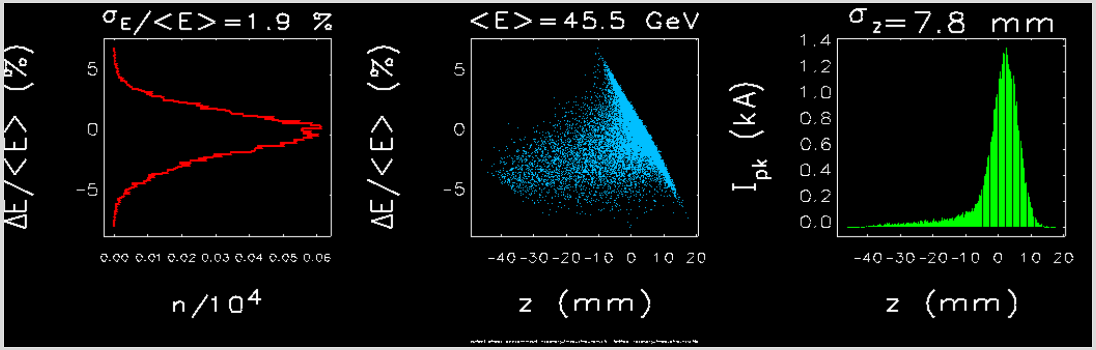
more in detail:
26398/30000= 0.879



One chicane only + L-band linac (not optimized length).
Compression from ~ 30% -> 10% total.
Bunch length σ<1cm







C.Vaccarezza

POSITRON SOURCE

How to produce the required positrons?

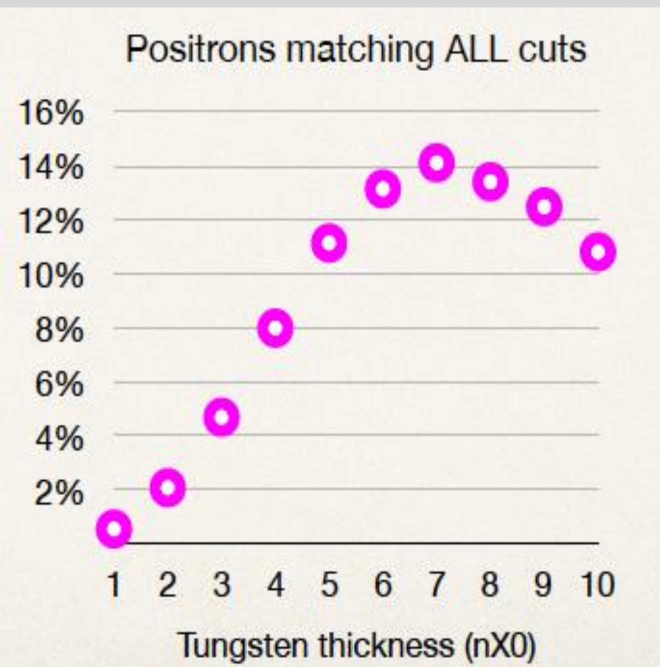
- Repetition frequency 10Hz, t_{cycle} 100 ms, recover or re-use the spent positron beam after the targets
  - We assume that 70% of the positron at the targets exit can be recovered, injected in the main e+ ring, slowly extracted and decelerated and injected in the damping ring.
  - Therefore only 30% of the required e+ need to be produced by the source
  - e+ production rate: 0.3x1000x5e11/0.07 = 2e15 e+/s
- This is our challenge! Other configuration requires more positrons….

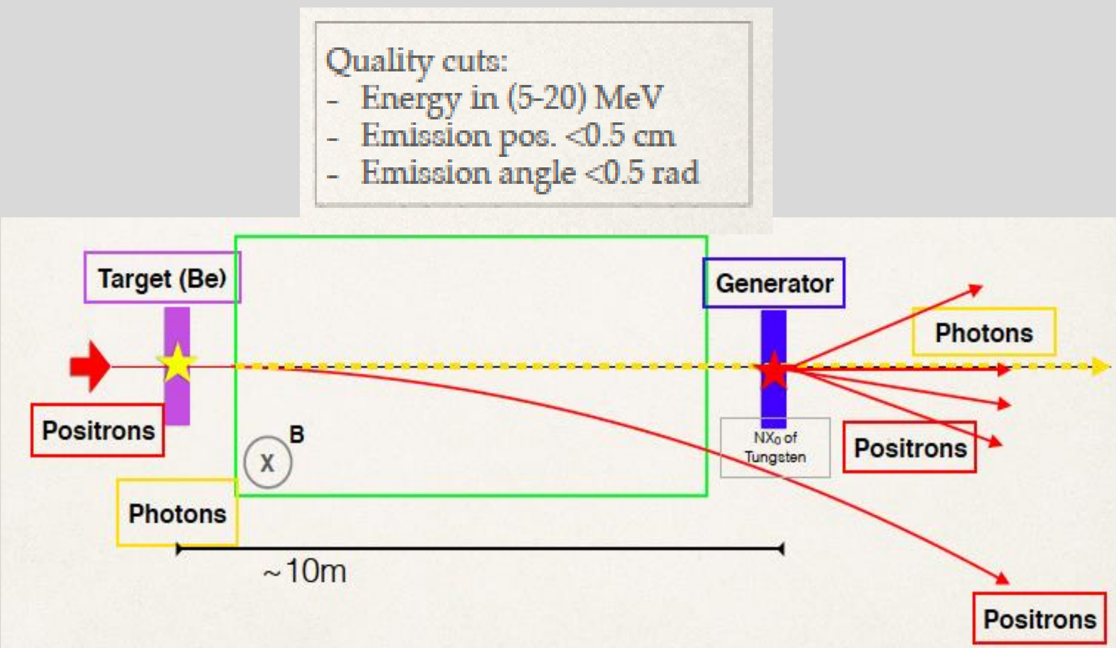
- Apply the techniques developed for ILC and CLIC
  - Hybrid targets (crystal target + tungsten target)
  - Rotating target
- Develop an R&D program on new targets
- Take advantage from the large energy acceptance that is required for the DR (~6% similar to the main ring), which increases the Yield
- Use more than 1 source
- Try to increase the energy acceptance of the main ring to reduce the fraction of lost positrons to be replaced by the source

S.Guiducci

Embedded source

- For each positron on the primary Be target there are:
  - 0.11 photons hitting the tungsten target
  - 0.65 e+ coming out of the 5 X0 tungsten target
- To estimate the number of collected positrons the number of e+ within the following cuts have been evaluated
- For 5 X_0 target thickness 11% of the positrons are within the cuts, corresponding to a yield of 0.07
- Giotto simulation 15%.

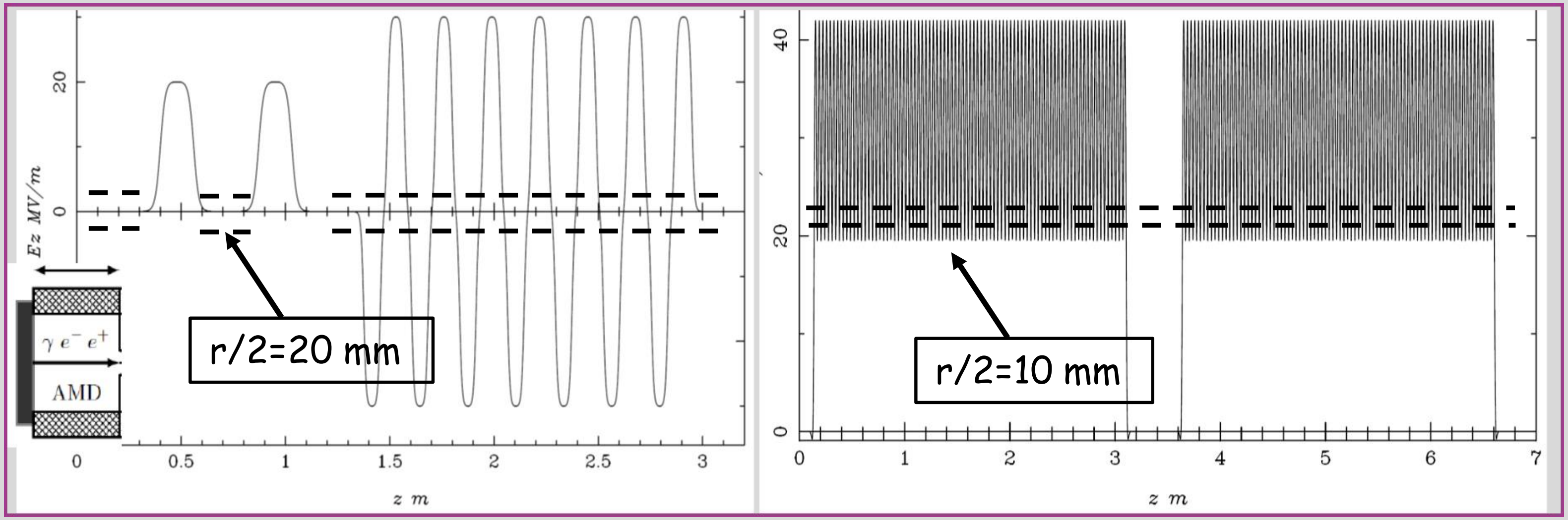




F. Collamati, Posipol 2018
https://indico.cern.ch/event/727621/timetable/#20180905

F.Collamati

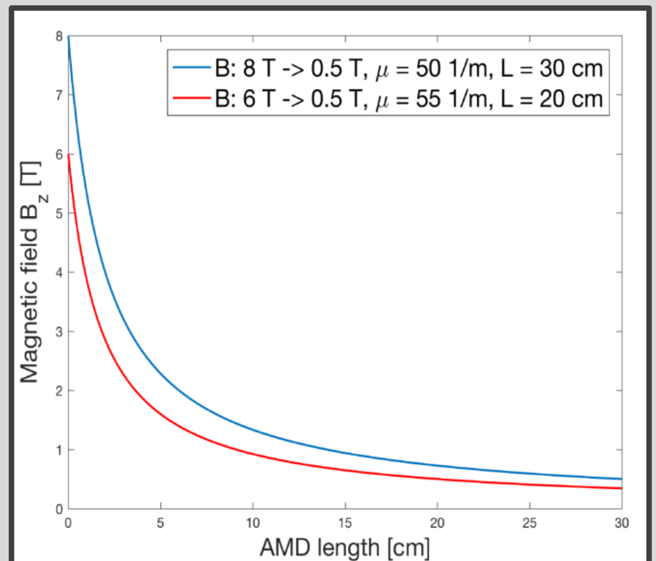
Simulation of the collection efficiency with **ASTRA** Tracking Code



Lattice:
AMD 8T/30 cm, 2 sub_harm (650 MHz)
L cavity PITZ type
3 Sband cavity SLAC type
B_0 (Mag. field around acc. Cavities) = 0.5T

All acc. Cavities work in crest

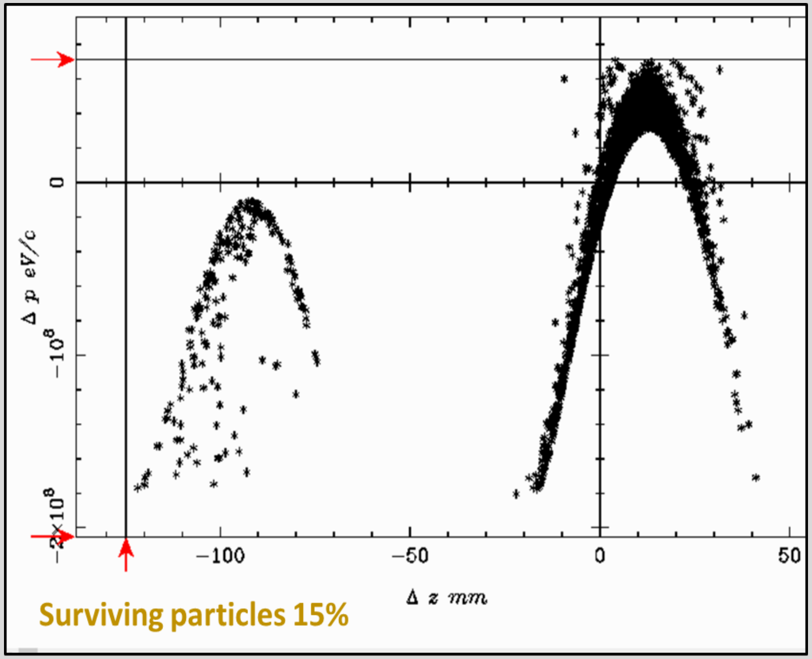
under sampling the original distribution
20k macro particles are used



Adiabatic Matching Device (AMD) profile proposed by I. Chaikovska and R. Chehab

A. Bacci

Embedded source preliminary optimization



For 5 X_0 target thickness 15% of the positrons are collected, corresponding to a yield of 0.1
An optimization of the AMD, capture section and first linac sections will be performed using the genetic algorithm code GIOTTO

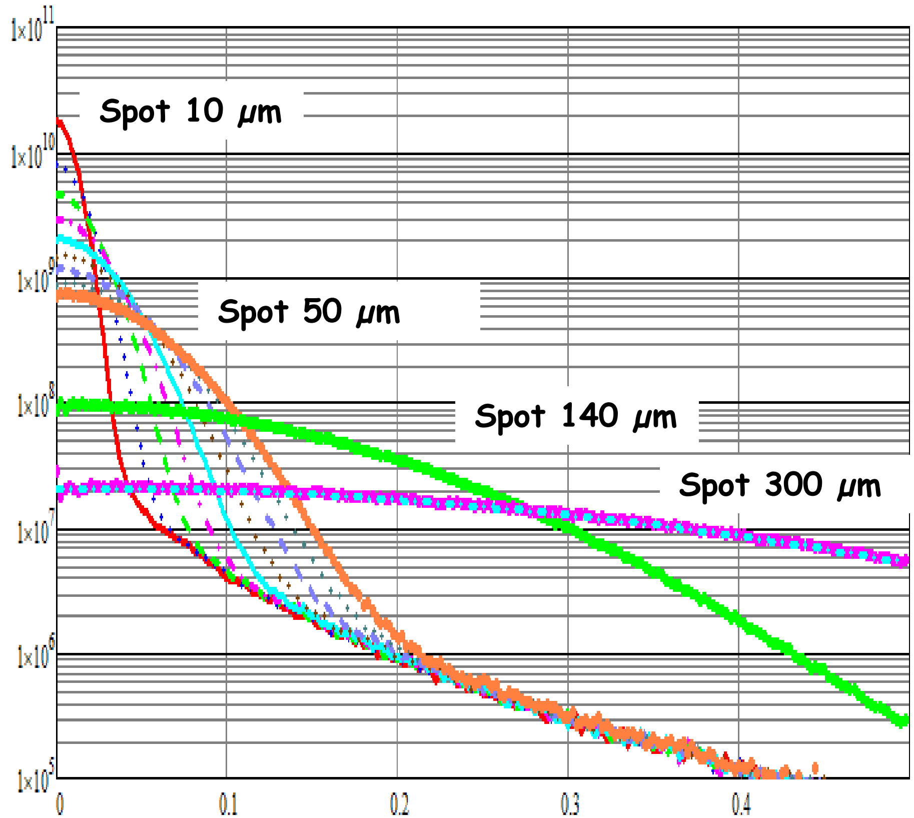
- Due to the high photon energy a thick target is required to increase the positron production
- The main issue for this configuration is the high power deposition in the target

TARGETS

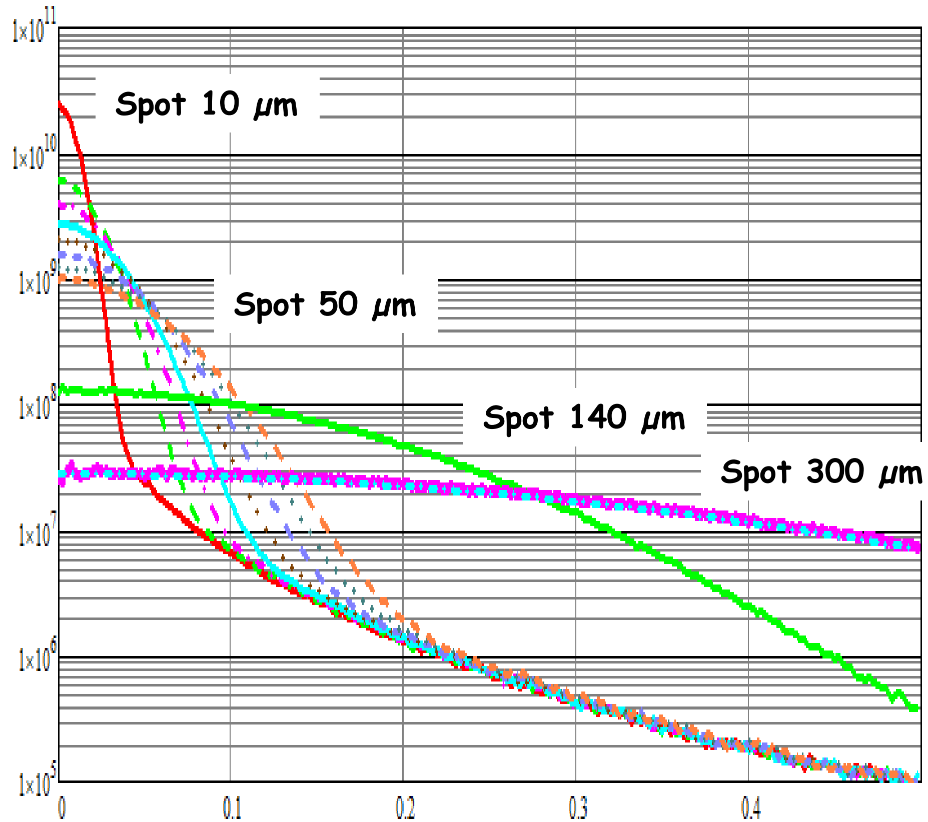
Heat density (single bunch), J/m^3

($N_{Part}=3\cdot 10^{11}$ positrons, simulation of the energy deposited for a single particle obtained from the Fluka code)

Beryllium (3 mm)



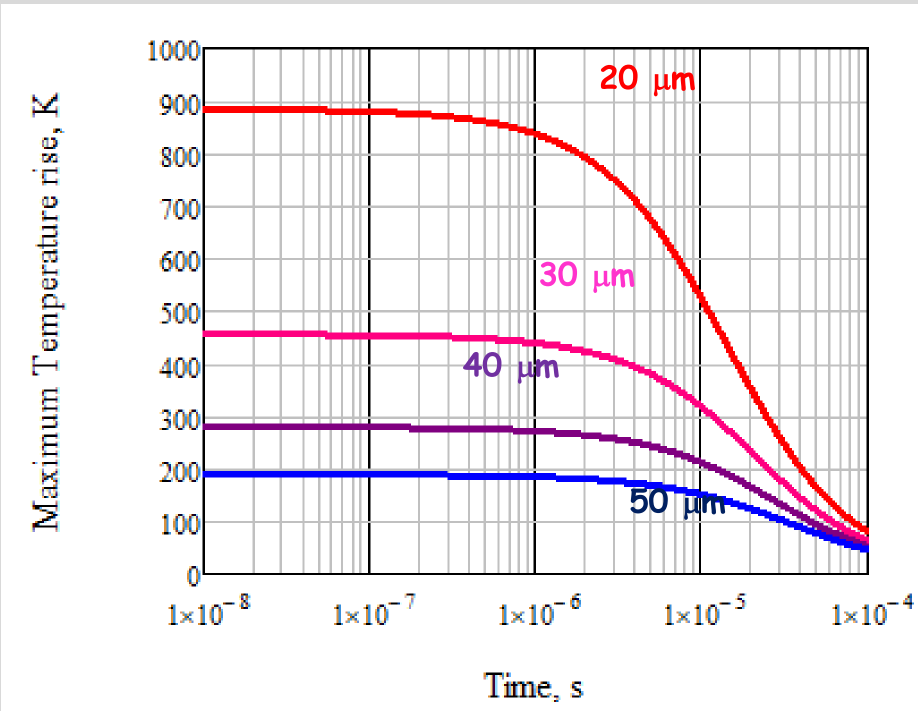
Carbon (1 mm)



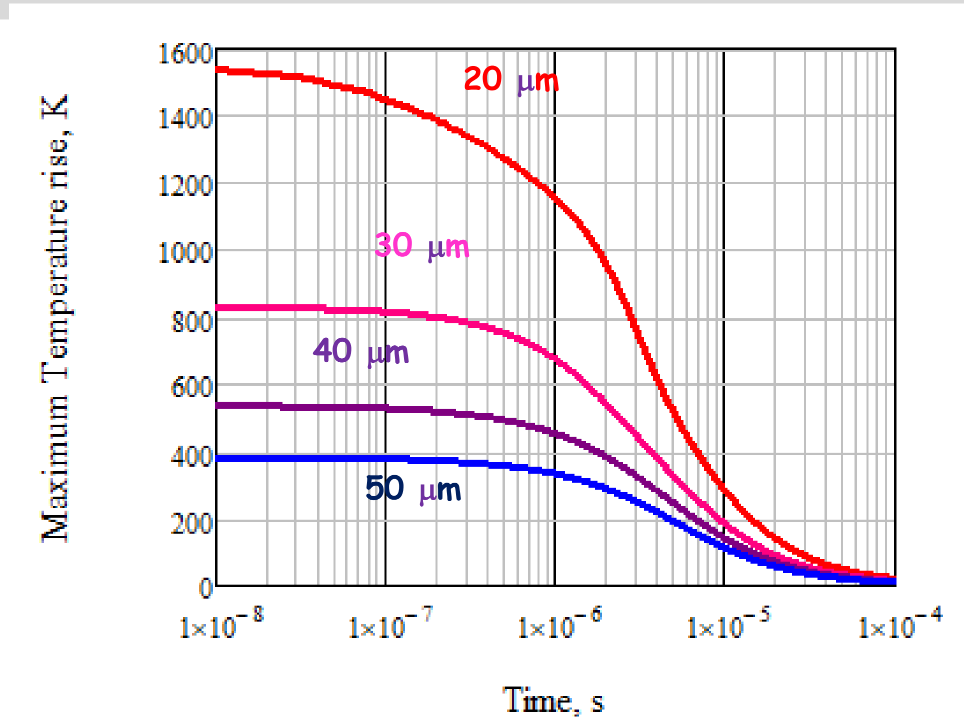
R.Livoti, G Cesarini

Increase in target surface temperature
(varying the spot size of the Gaussian beam)

Beryllium

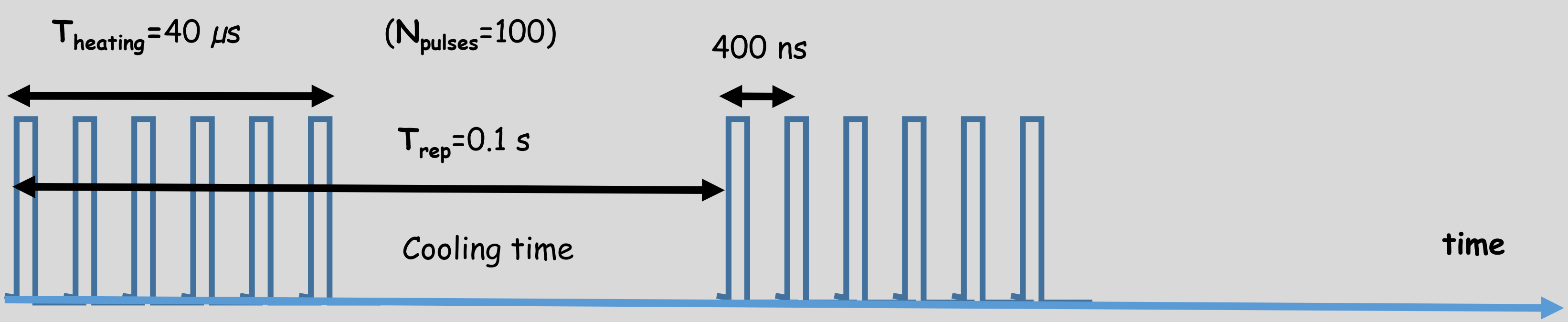


Carbon



For the calculation of the temperature an FDTD code has been implemented in the Mathcad environment and the non-linearity of the thermal parameters with respect to the temperature (specific heat, thermal conductivity) has been taken into account .

Considering the ILC configuration



Steady State Temperature

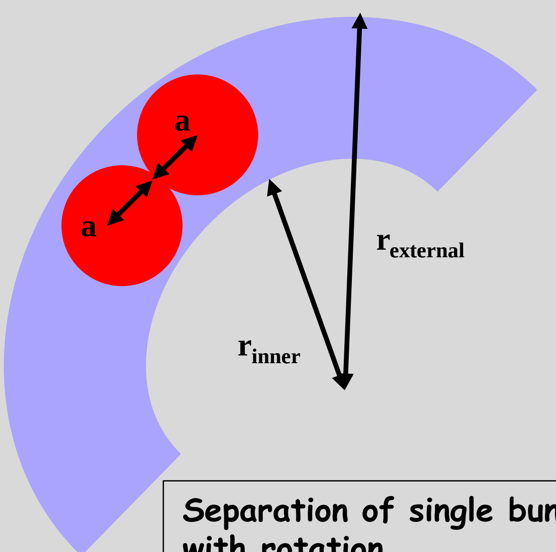
Assuming an external radius of 55 cm and an inner radius of 45 cm, there are increases with respect to the room temperature (298 K) of the equilibrium temperature equal to:

Beryllium (3 mm)

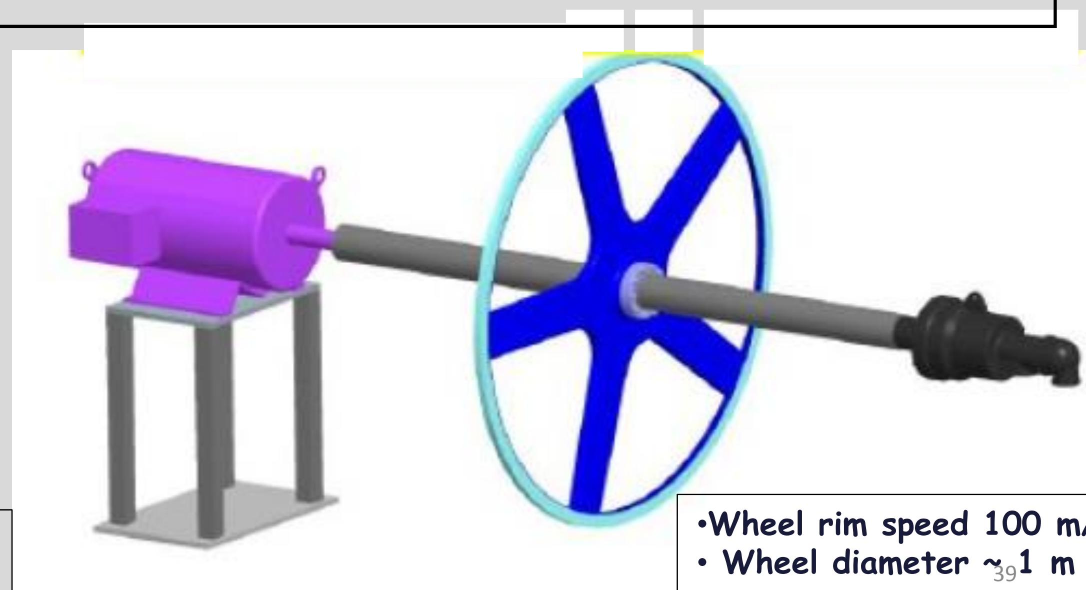
- In the case of 100 bunches ~ 11 K
- In the case of 1000 bunches ~ 78 K

Carbon (1 mm)

- In the case of 100 bunches ~ 4 K
- In the case of 1000 bunches ~ 36 K



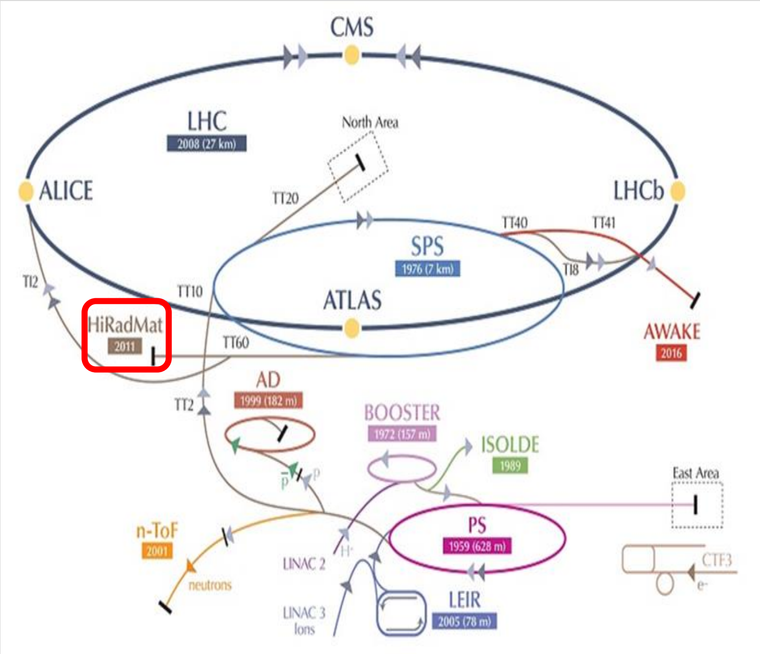
Separation of single bunches with rotation



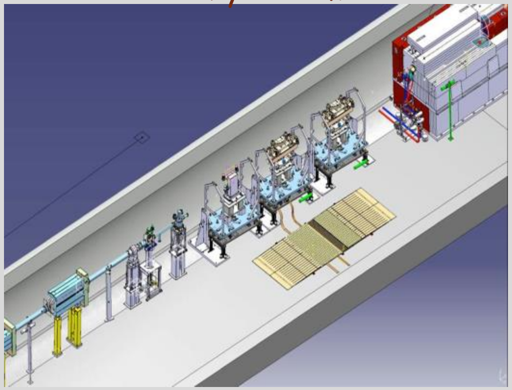
- Wheel rim speed 100 m/s
- Wheel diameter ~ 1 m

M.Antonelli

Reference: CERN experiments with protons HiRadMat Facility



'single-shot' experiments with 10^{16} POT/year limit



Beam Parameters	
Beam energy	440 GeV
Max. bunch intensity	1.7×10^{11}
No. of bunches	1 - 288
Max. pulse intensity	4.9×10^{13} ppp
Pulse length	7.2 µs
Gaussian beam size	1σ: 0.1 – 2 mm

REFERENCE: CERN EXPERIMENTS WITH PROTONS

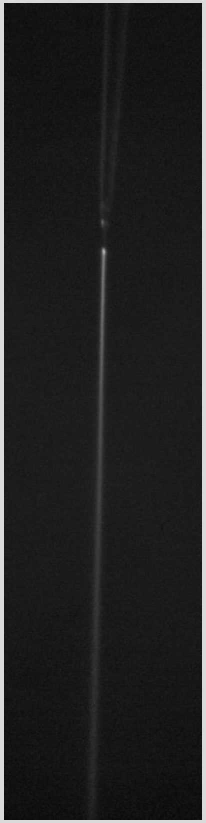
BEAM PULSE INFORMATION				BEAM PARAMETERS					
Pulse Name	Array #	# of bunches	Pulse date/time	Measured pulse intensity (proton)	Avg. bunch intensity (proton)	SPS x emittance (micron)	SPS y emittance (micron)	Calculated σ_x at focal point 2 (mm)	Calculated σ_y at focal point 2 (mm)
Alignment 1	1	12	9/17/2015, 13:52:32	1.440E+12	1.200E+11				
Alignment 2	2.1	12	9/17/2015, 14:18:21	1.399E+12	1.166E+11				
Alignment 3	3	12	9/17/2015, 14:31:14	1.447E+12	1.206E+11				
Alignment 4	4	12	9/17/2015, 14:52:44	1.415E+12	1.179E+11				
Pulse 1	3	24	9/17/2015, 16:03:15	3.196E+12	1.332E+11	3.505	1.924	0.296	0.202
Pulse 2	2.1	36	9/17/2015, 16:37:39	4.722E+12	1.312E+11	2.874	2.163	0.268	0.214
Pulse 3	2.2	72	9/17/2015, 17:06:02	9.508E+12	1.321E+11	3.929	2.518	0.313	0.231
Pulse 4	1	144	9/17/2015, 17:27:32	1.868E+13	1.297E+11	3.224	3.089	0.284	0.256
Pulse 5	3	144	9/17/2015, 17:37:00	1.845E+13	1.281E+11	3.579	4.451	0.299	0.307
Pulse 6	3	144	9/17/2015, 17:43:01	1.822E+13	1.265E+11	3.742	2.713	0.306	0.240
Pulse 7	3	144	9/17/2015, 17:49:02	1.860E+13	1.292E+11	3.679	3.919	0.303	0.288
Pulse 8	3	144	9/17/2015, 17:58:30	1.749E+13	1.215E+11	3.556	3.543	0.298	0.274
Pulse 9	3	144	9/18/2015, 10:12:25	1.930E+13	1.340E+11	3.556	3.543	0.298	0.274
Pulse 10	3	144	9/18/2015, 10:23:36	1.937E+13	1.345E+11	3.556	3.543	0.298	0.274
Pulse11	4	216	9/18/2015, 11:16:55	2.792E+13	1.293E+11	3.556	3.543	0.298	0.274

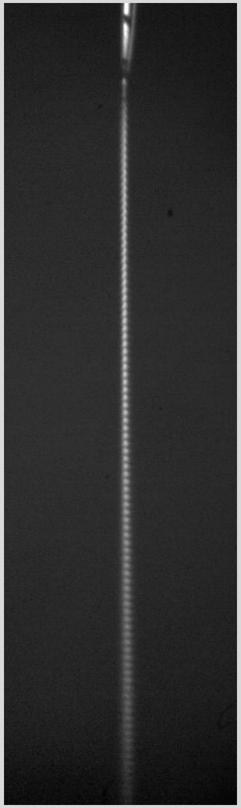
- Average bunch intensity: 1.3×10^{11} ppb
- σ_x : 0.268 – 0.306 mm
- σ_y : 0.202 – 0.307 mm
- Total protons on target: 1.8×10^{14}

No wire scans on Pulses 8 – 11. Emittance estimated by averaging emittances of Pulses 4-7

HYDROGEN TARGET : MICROSCOPIC VIEW CLOSE TO THE NOZZLE

- Nozzle diameter determines stream diameter
  - $2 \times \varnothing_{nozzle} \sim \varnothing_{droplet}$
- Droplet distance given by jet flow velocity and piezo frequency
- Piezo switched off: Spaghettis!





A.Khoucaz

EXTRAPOLATED MUON COLLIDER TABLE

		LHC 8T dipoles	LHC 16T dipoles	FCC 16 T dipoles	LHC 8T dipoles	LHC 16T dipoles
Parameter	Units					
LUMINOSITY/IP	cm^{-2} s^{-1}	5,34E+29	1,30E+30	1,24E+30	5,34E+29	6,49E+30
Beam Energy	TeV	7	17	60	7	17
C.M. Energy	TeV	14	34	120	14	34
Number of IP	#	2	2	2	2	2
Production Emittance	nm rad	100	100	100	0,100	20
Production bunch length	mm	6	6	6	6	6
Production energy spread	%	10	10	10	10	10
Bunch length compression	#	10	10	10	10	10
Lifetime	msec	145,8	354,0	1249,3	145,8	354,0
N turns before decay		1614,5	3921,0	3736,5	1614,5	3921,0
Number of bunches	#	1	1	1	1000	1
N. Particle/bunch	#	1,00E+09	1,00E+09	1,00E+09	1,00E+06	1,00E+09
Circumference	m	27000	27000	100000	27000	27000
Bending Field	T	8	16	16	8	16
Bending radius	m	2917	3542	12500	2917	3542
Magnetic rigidity	T m	23333,33	56666,67	200000,00	23333,33	56666,67
b_x @ IP	mm	0,5	0,5	0,5	0,5	0,5
b_y @ IP	mm	0,5	0,5	0,5	0,5	0,5
b ratio		1	1	1	1	1
Normalized prod. Emittance	m rad	2,08E-05	2,08E-05	2,08E-05	2,08E-08	4,16E-06
Hourglass reduction factor		0,950	0,950	0,950	0,950	0,950
s_x @ IP	micron	0,40	0,254	0,135	0,01	0,114
s_y @ IP	micron	0,40	0,254	0,135	0,01	0,114
$s_{x'}$ @ IP	mrad	7,93E-04	5,09E-04	2,71E-04	2,51E-05	2,28E-04
$s_{y'}$ @ IP	mrad	7,93E-04	5,09E-04	2,71E-04	2,51E-05	2,28E-04
Bunch length (full current)	mm	0,60	0,60	0,60	0,60	0,60
Beam energy spread	%	0,314	0,129	0,037	0,314	0,129
Beam current	mA	0,002	0,002	0,0005	0,002	0,002

FUTURE AND R&D…

- Rotation target / multi an single IP test, target rotation and target cooling feasibility

  Hydrogen - Spaghetti target instead of pellets.

  Curved crystals as recombiner, crystal cooling

  MW class target for positron source

- RF SC cavities high current, section stabilization

  Cryogenic accelerating sections

  High field magnets, low beta multiline, separator

  High acceptance positron capture at 1 GhZ

  High efficiency beam separation system

  Fast ramping magnets for ramped scheme

  Systems radiation hardness

  Positron Ring .

DAΦNE TESTS

Test lifetime , High current variable & stability

AND

Sync power and vacuum systems.

Hydrogen targets vacuum

SUMMARY

- We are working on the present feasibility of the LEMMA scheme to define the final performances and the future R&D to achieve very high luminosity
- First encouraging results also if the required scheme is complex
- To have a net increase in the learning curve we need support from experts in different fields

THANKS TO THE LEMMA GROUP

- P.Raimondi, S.Guiducci, M.Boscolo, M.Biagini, N.Pastrone, A.Giribono, A.Bacci, R.Chehab, I.Chaikovska, F.Collamati, O.Blanco, S.Liuzzo, A.Ciarma, L.Keller, P.Sievers, L.Pellegrino, M.Iafrati, M.Scapin, L.Peroni, R.Cimino, G.Cesarini, D.Alesini, D.Lucchesi, M.Antonelli, D.Schulte, A.Allegrucci, C.Vaccarezza, I.Drebot,

LEMMA E+ SOURCE

First injection in the e+ Damping Ring at 5 GeV

- For the first injection there are no time constraints, we need to inject 1000 bunches with 5e11 e+
- Assuming a positron source, like the CLIC or ILC one, which produces 1e14 e+/s the injection takes 5 seconds
- The source needed to replace the positrons lost in the muon production process is a real challenge, since the time available is very short

HOW MANY E+/S DO WE NEED?

- Repetition frequency 20Hz, t_{cycle} 50 ms

  10ms to produce the e+ and inject into the Damping ring

  30 ms to damp the beam

  10 ms to extract, accelerate and inject the beam in the main e+ ring at 45 GeV

  - e+ production rate: 1000x5e11/0.01 = 5e16 e+/s
  - This is ~500 times the CLIC and ILC rate, too much!

- Repetition frequency 10Hz, t_{cycle} 100 ms
  - The luminosity is a factor 2 lower
  - We assume to inject the bunches as soon as they are extracted, using for the injection also the extraction time

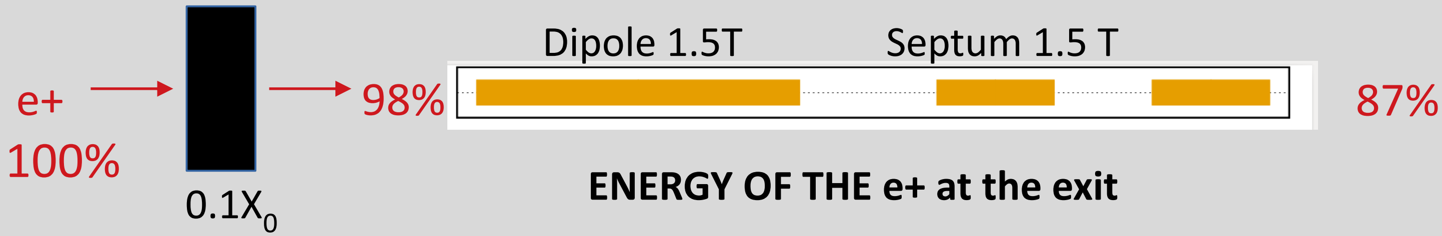
  70ms to produce the e+ and inject into the Damping ring

  30 ms to damp the beam

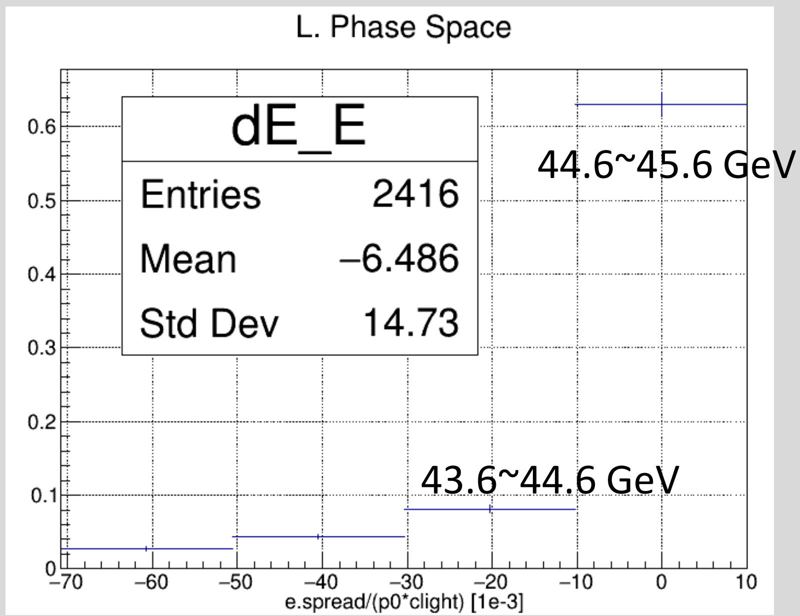
  - e+ production rate: 1000x5e11/0.07 = 7e15 e+/s
  - This is ~70 times the CLIC and ILC rate, still too much

Beam Separation-Combination, Mar/2019

Only part of the initial e+ population survive, the ones with e. spread below 20%.



ENERGY OF THE e+ at the exit



-30 = 43.7 GeV **0 = 45 GeV**

From the remaining 87% of e+,

about 70% is above μ prod. energy threshold at 43.7 GeV,

the remaining 17% is distributed in a tail down to 36 GeV