LEMMA UPDATE

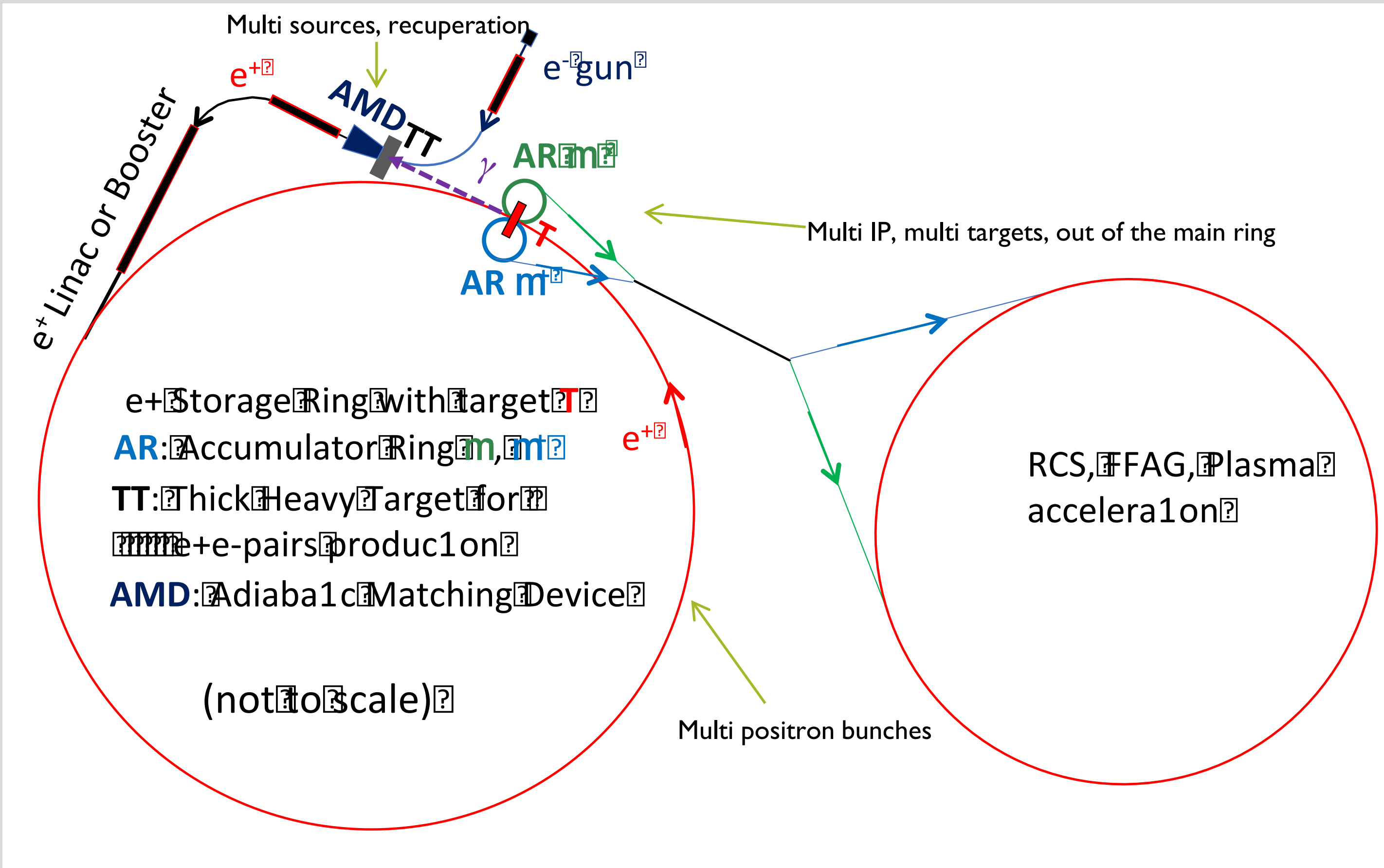
A.VARIOLA, INFN ROMA1
MUON COLLIDER WORKSHOP

LEMMA

“Positron driven muon source for a muon collider“

https://arxiv.org/abs/1905.05747

BASIC PRINCIPLE AND FIRST SCHEME



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

From last meeting: A long way

- LEMMA is not ready for a CDR since there is not magic solution for high luminosity…need a 'pre CDR' document in order to:
  - fix the baseline and the alternative schemes,
  - simulate in detail the subsystems,
  - PROPOSE AND CHOOSE innovative design solutions to increase the luminosity
  - set the list of the R&D needed in this framework
  - harmonize in a global design (positron based collider, subsystems are correlated)

Definition of the needs for a Pre CDR

Project: LEMMA -A muon source for the muon collider project.
Pre-design and feasibility study. Tasks and needed resources definition.
Delivered to the INFN Executive Board

Pre CDR Scope

- The document will provide:
- - The baseline and the alternative configuration of the muon source complex for the muon collider project.
- - The energy extended analysis to have a preliminary value of the final luminosity.
- - The associated parameters tables for all the subsystems.
- - The conceptual design, based on simulations, of the main subsystems.
- - The start to end simulations of the different beams of the LEMMA scheme
- -The parametric definition and eventually the conceptual design of elements which characteristic are supposed to be critical, in respect to the state of the art
- - The list of the necessary R&D to perform to reach a TDR maturity
- - The complete definition of the argument to be treated in the CDR.

Resources

- E (expert) – Highly experienced physicist or engineer capable not only to coordinate the activity related the tasks but also, and especially, to propose and evaluate innovative solutions in the domain taking into account the global constraints of the facility design.
- S (senior) – Well experienced physicist or engineer providing all the skills to realize the simulations the analytical analysis and the tests necessary to finalize the tasks. He/She will be able to coordinate the work of less experienced staff in its task domain.
- J (junior) – PhD student or first experience post doc position researcher or engineer. He/She will demonstrate the capability to acquire and apply the technicality to perform all the activities required in the framework of his attributions.

Document Elaboration Example : Positron source

- ***Positron Source Tasks*** **- WBS1002 / HIGH**
- Montecarlo simulations of the positron production in the target with three different type of drive beams, electrons (classical source), positrons and photons (embedded sources). Definition of the produced positrons 6D phase space. Generation of the particle showers in the target and evaluation of the deposited energy. Optimization of the target thickness and material (even hybrid configuration) vs the energy of the drive beams. Input for task A.5.
- Evaluation of the thermo-mechanical efforts on the targets for both classical and embedded sources. Determination of the damage and fusion thresholds. Evaluation of technical designs for heating evacuation and PEDD remedies.
- Design of the possible configuration for the magnetic capture line, AMD or QWT for both classical and embedded sources. Input for task A.5.
- Design of the capture section accelerating structures, optimization for L Band or S band with large iris for both classical and embedded sources. Input for task A.5.
- Simulation of the capture line and optimization of the magnetic and RF parameters, evaluation of the captured beam emittance
- and global capture efficiency for both classical and embedded sources. Input for task B.1.

Task	A.1	A.2	A.3	A.4	A.5
Resource	1S, 1J	1E, 1J	1S	1S, 1J	1E, 1J

	RF Engineer	SC RF Engineer	Mechanical Engineer	Magnet Engineer	Vacuum Engineer	Electronic Engineer	Accelerator physicist, LINAC	Accelerator physicist, RING	Accelerator physicist, Instabilities	Accelerator physicist, Impedances	Physicist, cooling	Physicist, sources, MC
A.1												1S, 1J
A.2			1E, 1J									
A.3				1S								
A.4	1S, 1J											
A.5							1E, 1J					
B.1							1E, 1S, 2J					
B.2	1S, 1J	1E, 1J										
B.3									1S, 1J			
C.1								1E, 1S, 1J				
C.2									1E, 1J	1S, 1J		
C.3				1E, 1S, 1J								
C.4		1E										
C.5					1E, 1S							
C.6						1E						
D.1								1E, 1S, 1J				
D.2									1E, 1J	1S, 1J		
D.3				1E, 1S, 1J								
D.4		1E										
D.5												
D.6												
E.1								2E, 1S, 2J				
E.2									1S	1S		
E.3				1E, 1S, 1J								
E.4		1E										
E.5					1E							
E.6			1E, 1S									
E.7												1S, 1J
F.1							1S, 1J					
F.2	1S, 1J	1E, 1J										
G.1								1S				
H.1	ALL	ALL	ALL	ALL	ALL	ALL	ALL	ALL	ALL	ALL	ALL	ALL
I.1											3E	
J.1												
J.2								1E, 1S				1E, 1S
J.3												1E, 1S
	3S, 3J	5E, 2J	2E, 1S, 1J	3E, 4S, 3J	3E, 2S	2E	2E, 2S, 4J	5E, 5S, 3J	2E, 2S, 3J	3S, 2J	3E	2E, 4S, 2J

Total profiles required
29 E, 26 S, 23 J

Each topic has been inserted in a WBS

PBS code	WBS code	System	Sub System or System Item	Tasks (Study)	Durata	Responsible	Ressources	Requirements	Required Expertise	Deliverables
	1001	Global layout				Nome Cognome				
	1001.01		Baseline scheme			Nome Cognome			Project leader	Definition of the baseline scheme for the LEMMA muon source
	1001.02		Alternative schemes			Nome Cognome			Project leader	Definition of the alternative schemes for the LEMMA muon source
	1001.03		Parameters tables			Nome Cognome			Project leader	Facilities parameters tables for the baseline and alternatives schemes

1002	1002	Positron source (classical and embedded)			Nome Cognome			
1002.01	1002.01		Magnetic AMD or QWT (both)		Nome Cognome			Optimized magnetic desig of the capture magnetic systems
	1002.01.01			Magnetic design		Nome Risorse	Magnetic Design	
	1002.01.02			Capture efficicency optimization		Nome Risorse	Particle tracking	
1002.02	1002.02		Capture Section (both)		Nome Cognome			Optimized RF and magnetic design of the capture sections
	1002.03			RF accelerating sections		Nome Risorse	RF engineering	
	1002.04			Solenoids		Nome Risorse	Magnetic engineering	
				Transmission			Parametric codes and particle tracking	
1002.03	1002.03		Target (both)		Nome Cognome			Choice of the baseline and alternatives targets.
	1002.03.01			Positron production		Nome Risorse	Particle sources, channeling	
	1002.03.02			Thermal and mechanical stresses		Nome Risorse	Thermal engineering	
	1002.03.03			Vacuum evaluation		Nome Risorse	Vacuum design	
	1002.03.04			Configuration engineering		Nome Risorse	Mechanical engineering	
1002.04	1002.04		Embedded source			Nome Risorse		Optimization of the embedded soucre integration in the baseline and alternative schemes
	1002.04.01			Photon production		Nome Risorse	Physics, Montecarlo	
	1002.04.02			Reuse of the spent positron		Nome Risorse	Parametric codes and particle tracking	
	1002.04.03			Layout optimization		Nome Risorse	Parametric codes and particle tracking	

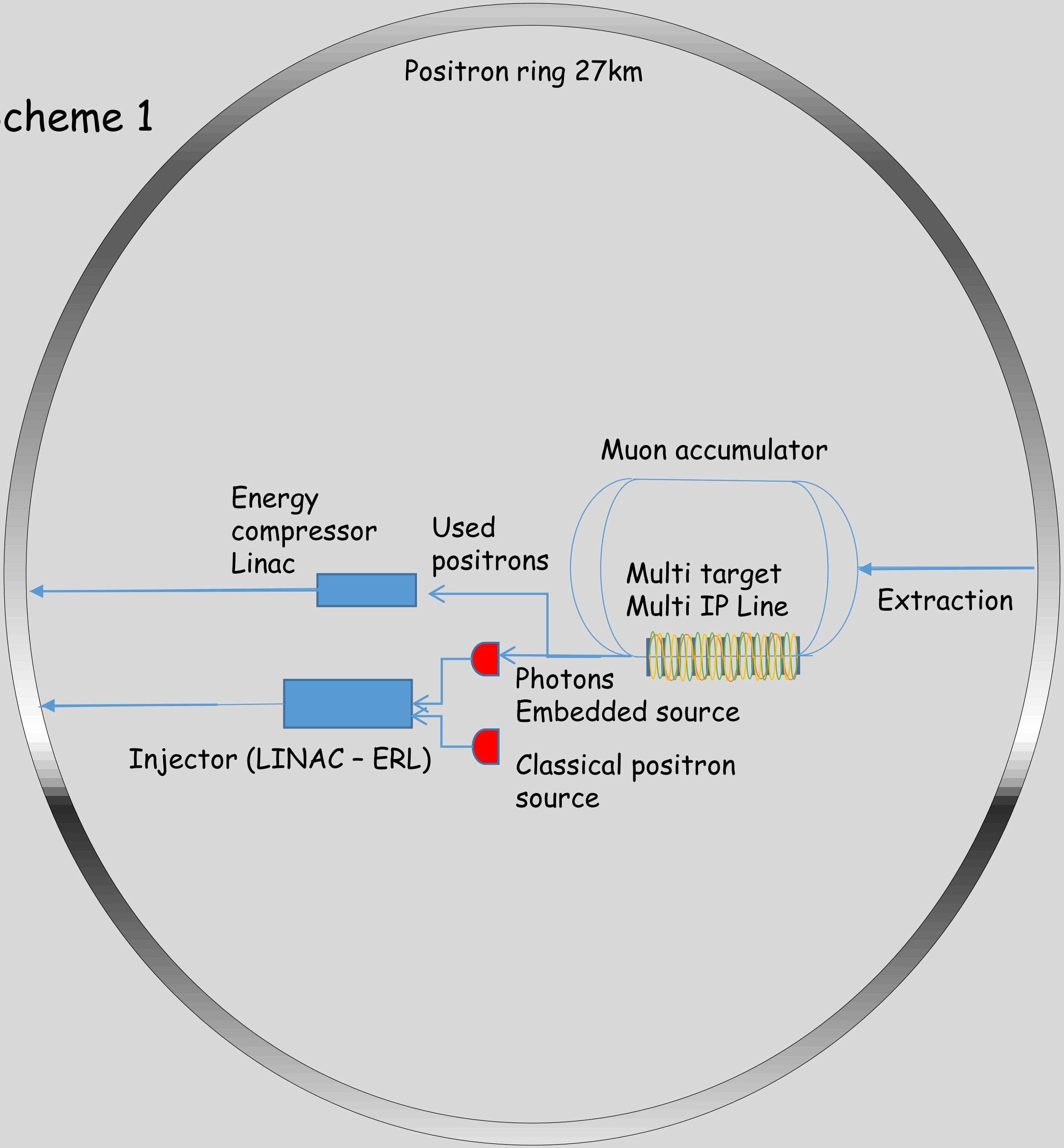
On the basis of this document also an OBS has been produced

Schemes

We proposed different schemes to take into account all the problems correlated with the proposal. The goal is to find a baseline configuration that should represent the reference for the 'upgrade studies' and the proposed R&D.

Detailed studies dedicated to the coherence of the different systems:
1) Positron source
2) Damping Ring
3) Post Acceleration Linac
4) Positron ring
5) Muon accumulation ring and production line
6) Target

EXAMPLE . Scheme 1



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

We decide to proceed to a preliminary study of the third scheme, to have a published proposal.

Scheme 3 ->

1) does not suffer of the high current Linac system

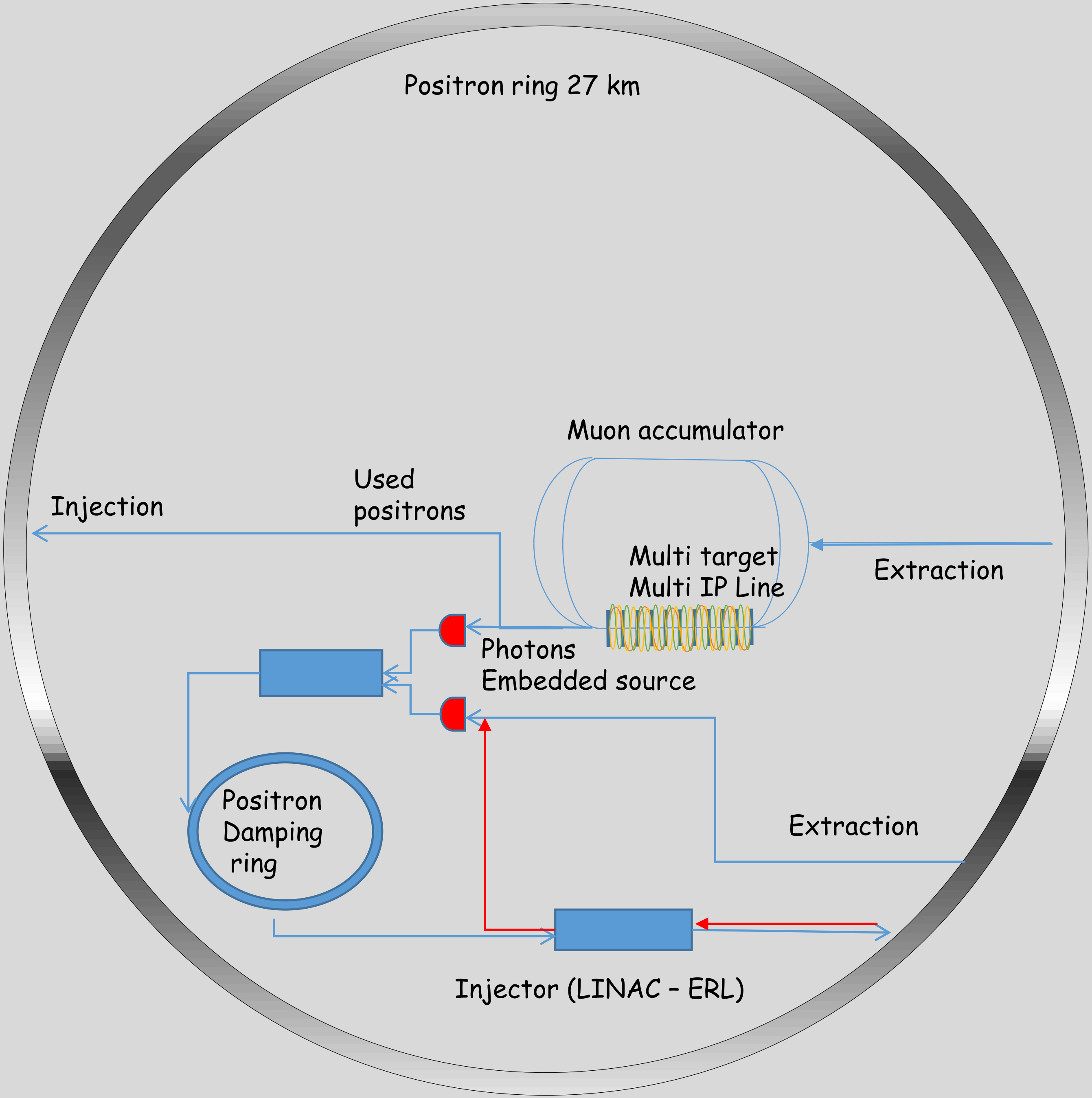
2) Good schemes for positron reuse

3) Parallel positron production from the natural source

1) Higher synchrotron power

2) Depends on injection efficiency and usually on positron source delivery rate

GOAL -> Produce a first coherent parameters table


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 ring

- - By the end of 2019 -> 150 m accumulator ring designed by P. Raimondi, optimized to get about ±10% energy acceptance, with a beta* of 2 m and a very small momentum compaction factor to preserve the longitudinal emittance.

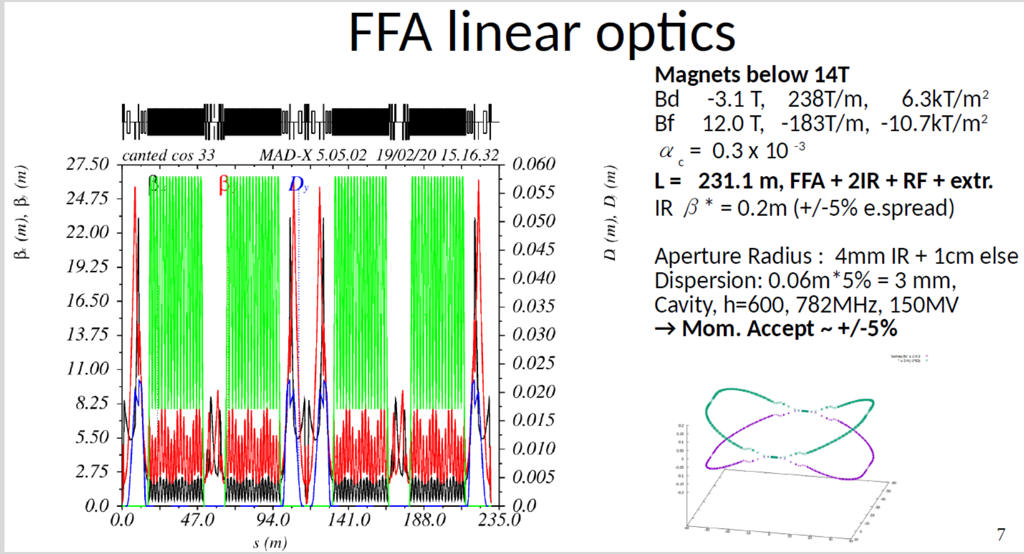
  - in parallel study of the possible use of an FFA ring. Very small circumference of 100 m and more than ±20% energy acceptance with a similar value of beta* (2 m), however with a very large momentum compaction factor.
- Benchmarking and simulation of the FFA muon production line with MUFASA (MADX + Montecarlo code). Optimization ongoing for the working point (and energy)

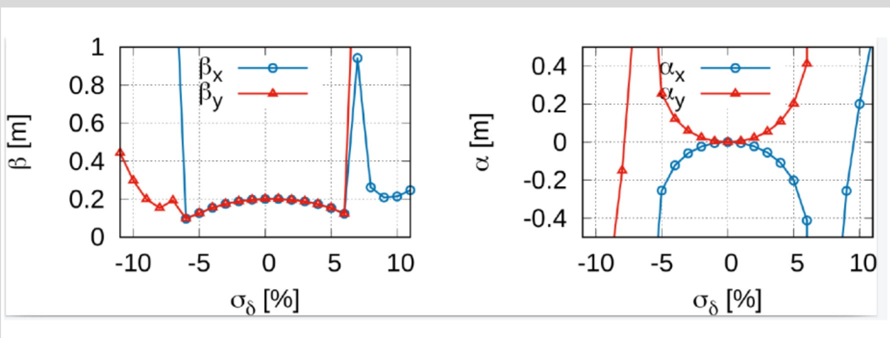
  - recently -> focus on in reducing the momentum compaction factor and beta*. Obtained a 230m ring with 2 IPs done with a combination of FFA arcs and strong focusing elements below 14 T, achieving a small momentum compaction factor of the order of 3×10^{-4}, energy acceptance of ±5%, and beta * of 20cm.

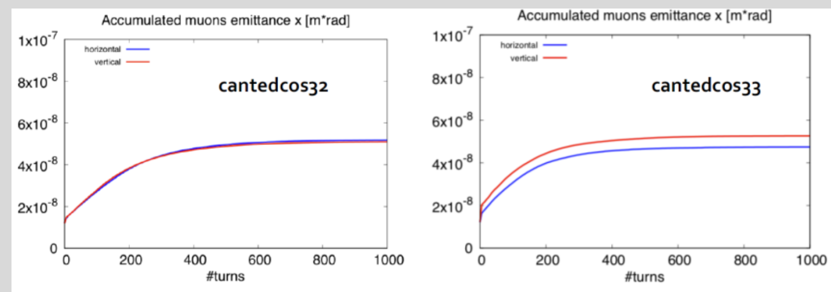
  1) The result of the accumulation simulation shows that population is limited by the energy acceptance and that emittance increases due to multiple scattering with the target(s) in few hundred turns.

  2) The current work is focused on gaining back the energy acceptance. For that we need to reduce dispersion in the arcs by one order of magnitude, have a very low chromaticity so that sextupoles don't have to run too high because of the reduction of dispersion, reduce first and second order momentum compaction factor so that the stable region in the longitudinal phase space grows, while keeping the arcs as short as possible with magnets under 16/20 T.

  3) In the long term need to further reduce the beta* by a factor 20, i.e. achieve a beta* of 1 cm that could mitigate multiple scattering over a thousand turns.





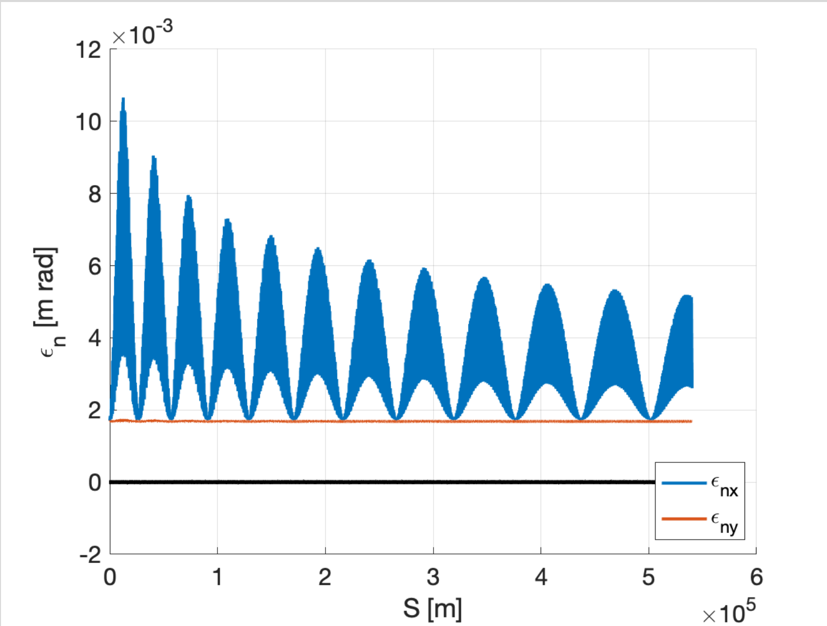


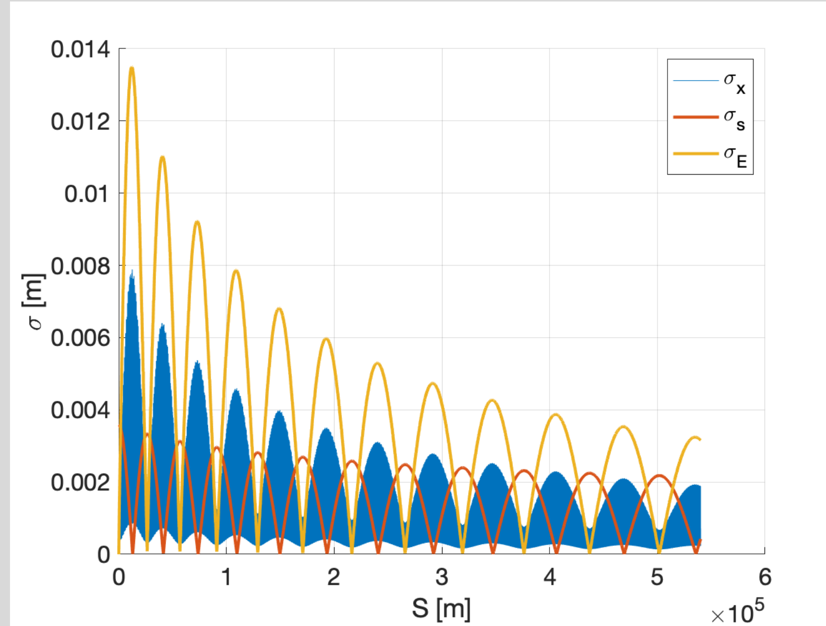
O.Blanco, A.Ciarma, P.Raimondi, S.Liuzzo, M.Boscolo, M.Antonelli

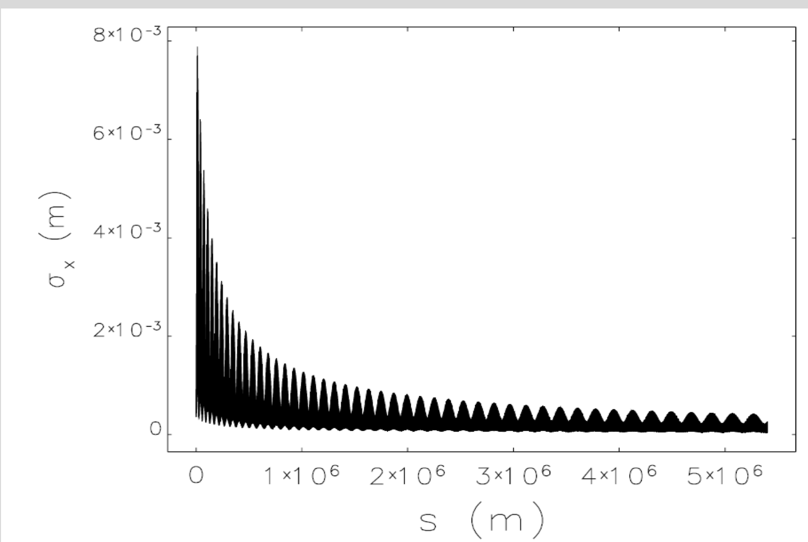
Positron injection studies in the PR

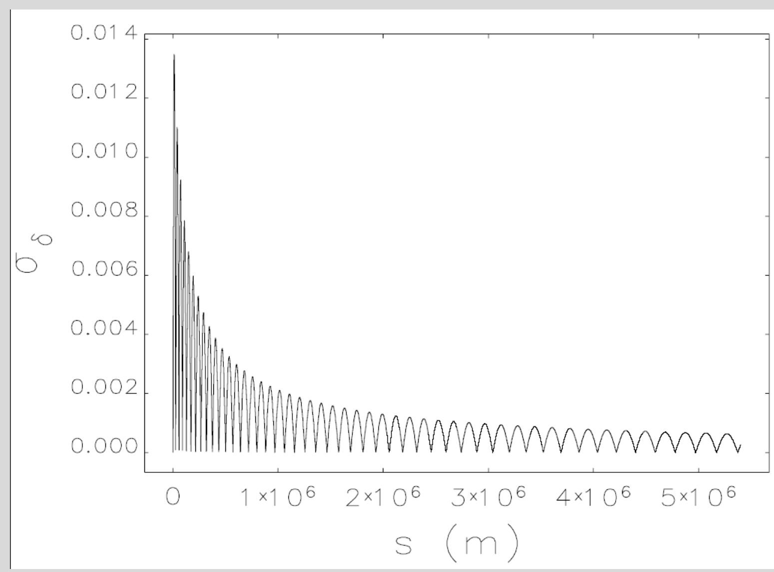
- Aim: study the possibility to re-inject the “spent” positron beam after muon production back to the 45 GeV ring, to decrease the number of positrons needed by the main positron source
- This beam can be then decelerated and sent back to the DR for damping or to an embedded positron source
- Due to the long tails and energy spread of the e+ beam distribution after the muon production, only a fraction of this beam will be accepted into the PR acceptance. A 70% efficiency for this process could be envisaged
- Injection simulations are being performed to check the fraction of spent beam actually accepted into the PR which are not lost
- Both the original 45 GeV beam after the muon production targets than the beam compressed by a compressor system are being considered

Tracking in Elegant for 20 and 200 turns, cut at 80%



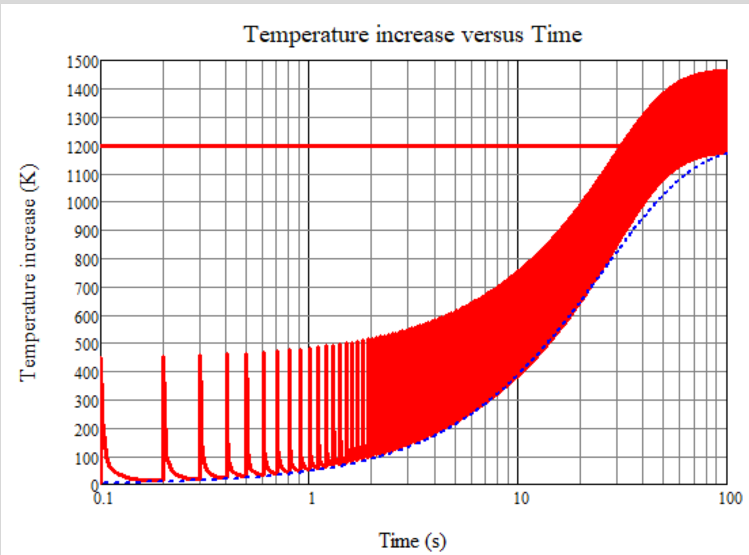


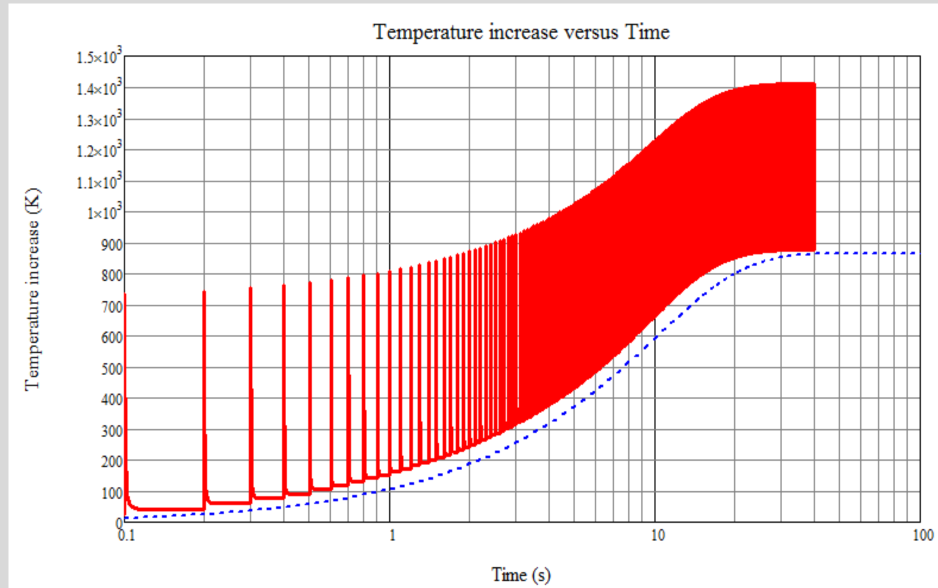


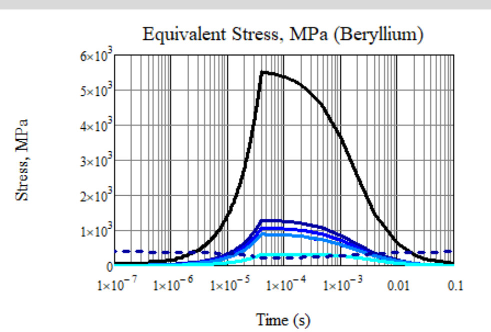


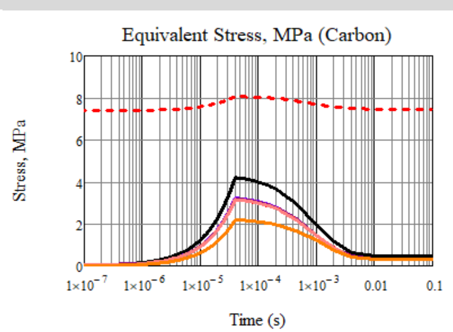
I.Drebot, M.Biagini, S.Guiducci, S.Liuzzo

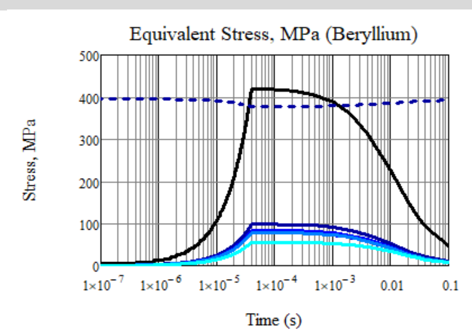
Targets, Static regime for average temperature and PEDD (R.Li Voti Talk)

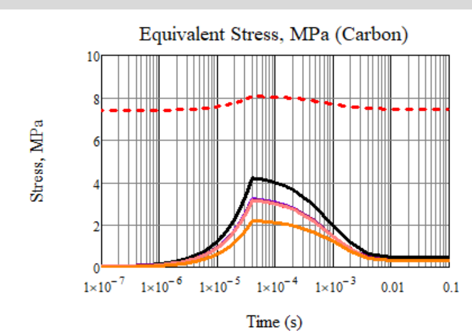












(R.Li Voti, G Cesarini, M.Antonelli)

Positron Sources (I Chaikovska Talk)

A lot of R&D are needed!

Based on the present schemes

=> Flux of **10^{15} - 10^{16} e+/s** is needed (experience from ILC/CLIC + R&D program on new targets).

Initial injection: the e+ source has to provide trains of 1000 bunches with **5×10^{11} e+/bunch** to inject in the DR at 5 GeV.

But the e+ source needed to replace the e+ lost in the muon production process is a real challenge (very short time available ~ 50 ms).

☞ A positron recovery system based on the use of positrons (or photons produced in the muon targets) to compensate the positron losses in the main ring is under study. This system can be eventually integrated in the main positron injector complex.

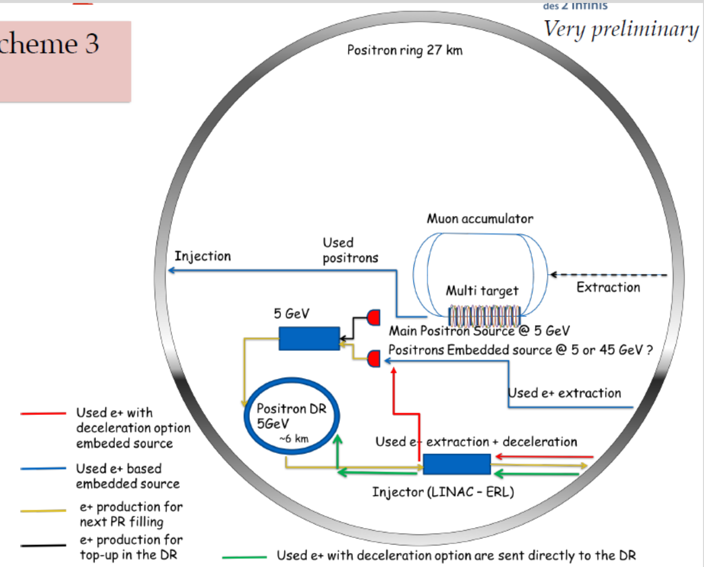
Main challenges: provide high intensity in a short time, target design, high field capture section…

Next cycle (after muon production) for scheme 3
arXiv:1905.05747 (2019)

- Injection of used e+ back in the PR
- Slow extraction of used e+ with possible deceleration to 5 GeV
- Embedded source as an option: e+ production using e+ drive beam @ 5 GeV or 45 GeV
- Top-up in the DR with the Main Positron Source
- Direct injection in the DR as an option.

☞ Work in progress to study all the scenarios

Very preliminary



- Simulations and optimization for 5 and 45 GeV extracted beams.
- High field magnets.
- Primary beams obtained by taking into account the characteristics after extraction form PR
- Secondary beams produced with GEANT
- Genetic Algorithm for parameters optimization (GIOTTO)
- Measurements of the global source efficiency
- To be transported to the DR and injected in high energy acceptance system

How to proceed…. nothing changed

- As you see LEMMA is far from a baseline definition.
- We need to perform a huge work…
- Many dedicated people in a coherent scenario
- Fix a baseline
- Study all the solutions
- Understand how to implement them in the baseline
- Feedbacks and loops.
- Get a final baseline
- Define the R&D and prototyping needed.
- Only way to go is to build this community…if does not happens no true feasibility study should be possible

- .

To be explored

- Positron source and targets : 10^{15}/s class sources. High peak field AMD or QWT and high B field RF capture. Targets for both Natural and Embedded sources (Hybrid, Granular, Rotating….). Longitudinal capture in 'proton' RF frequencies, drive beam sweeps
- Muon Targets : Liquid hydrogen pellets, Light targets (Be, C,…), Shock wave impedance matching (new materials).
- RF : High current RF SC cavities (hundreds mA in short macropulses)
- Design : High energy acceptance ring, Injection, Emittance exchange with post compression Linac. Multibunch instabilities. Synchrotron power management. Lower energy positron ring and post acceleration
- Recombination : MAP style, Longitudinal (D.Schulte), Crystal
- Post cooling : LEMMA has 10^9 particles