LEMMA Accelerator studies

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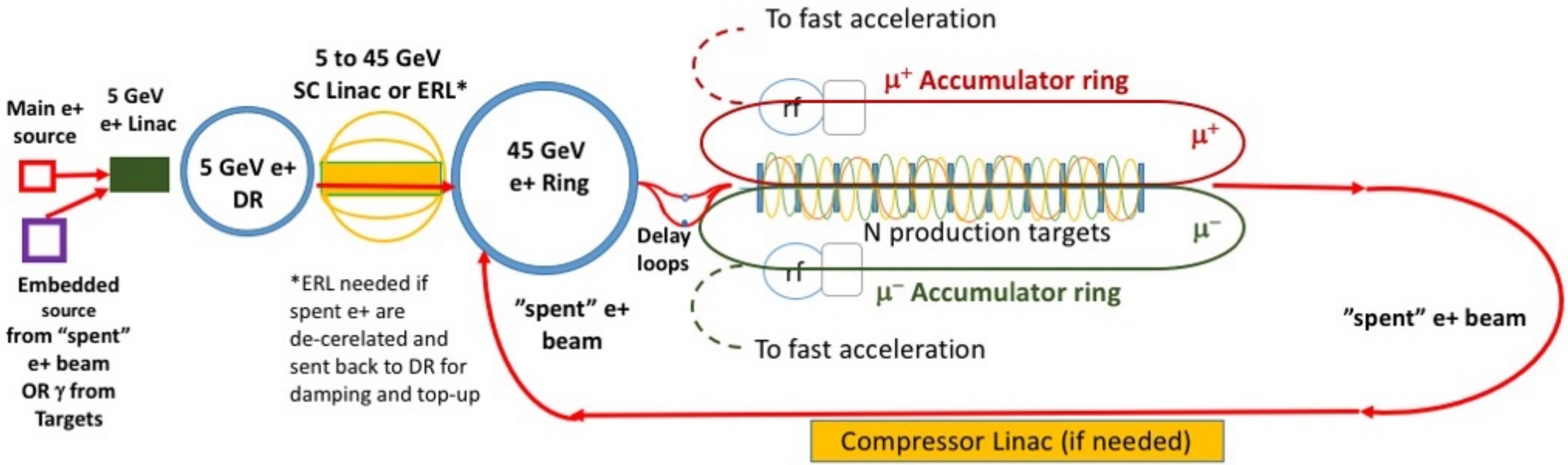
LEMMA muon source, 2019 scheme, A. Variola et al
arXiv:1905.05747v2 [physics.acc-ph]

- LEMMA source: $\mu^{\pm}$ production from a 45 GeV e^+ beam annihilating with e^- of a target close to threshold for pair creation, thus generating muon beams with low transverse emittance for a high energy collider
- e^+ production by Main e^+ source (MPS) and accelerated to 5 GeV for damping in a 5 GeV Damping Ring (DR)
- Acceleration to 45 GeV in a SC Linac or ERL and storage of 1000 e^+ bunches in a Positron Ring (PR)
- Extraction of e^+ bunches to one or more muon production lines, while produced μ are accumulated in two AR and a muon bunch is “built” by several passages through the targets, to be then delivered to the fast acceleration chain
- Re-injection and damping in the PR @45 GeV of the spent e^+ beam to save on the number of needed e^+, the MPS and a possible γ-embedded source will provide the refilling of lost e^+. Other option: send e^+ back to DR (through decelerating ERL) for damping and top-up



Accelerator studies during 2020

- Design for the Damping Ring, 45 GeV e+ ring, and compressor Linac were established last year already
- This year the work has been focused on:
  - Positron source and embedded sorce (IJCLab, Milano, LNF, Roma I)
  - Injection of spent beam (LNF, Milano, Roma I)

  } this talk

  - Accumulator design and targets line (LNF) (Blanco and Ciarma talk)
  - Target studies (Roma I) (Li Voti talk)

LEMMA: positron source requirements

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 **$5x10^{11}$ 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…

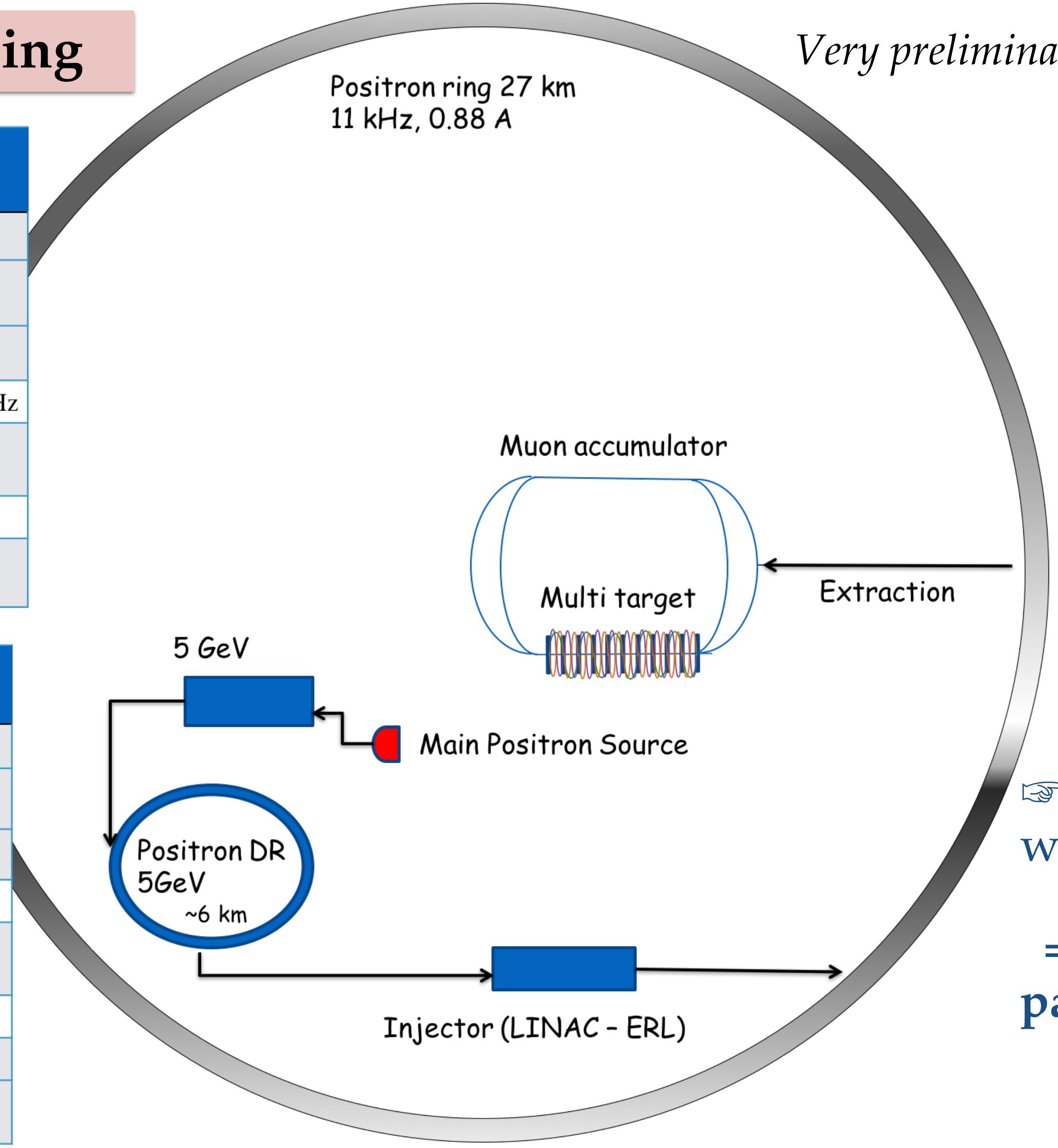
I. Chaikovska, IJCLab

LEMMA: main positron source

First filling

Primary e⁻ beam for e⁺ production (as for now)	
Beam energy	5 GeV
Bunch charge	2 × 10^9
Bunch length (rms)	**1** mm
Bunch separation	20 ns/50 MHz
Nb of bunches per pulse	1000
Repetition rate	10-20 Hz
Beam power	16 (32) kW

Damping Ring (as for now)	
Beam energy	5 GeV
Bunch charge	5 × 10^{11}
Circumference	6 km
Bunch separation	20 ns
Nb of bunches per pulse	1000
Energy acc	±10%
Damping times	~10 ms
Number of inj.	~500



Very preliminary

- Positron beam requirement @ Target for muon production: 5x10^{11} e+/bunch, 1000 bunches/pulse, 10-20 pulses/s => **(0.5-1)x10^{16} e+/s**
- If we use **the same injection scheme as CLIC**, the PEDD for LEMMA is about 90% of PEDD for CLIC.
- With 500 stacking in the DR, the main positron beam intensity can be reached.

☞ CLIC e+ source design seems compatible with the LEMMA main e+ source requirements.

=> optimisation with LEMMA beam parameters is needed.

I. Chaikovska, IJCLab

LEMMA: injector options

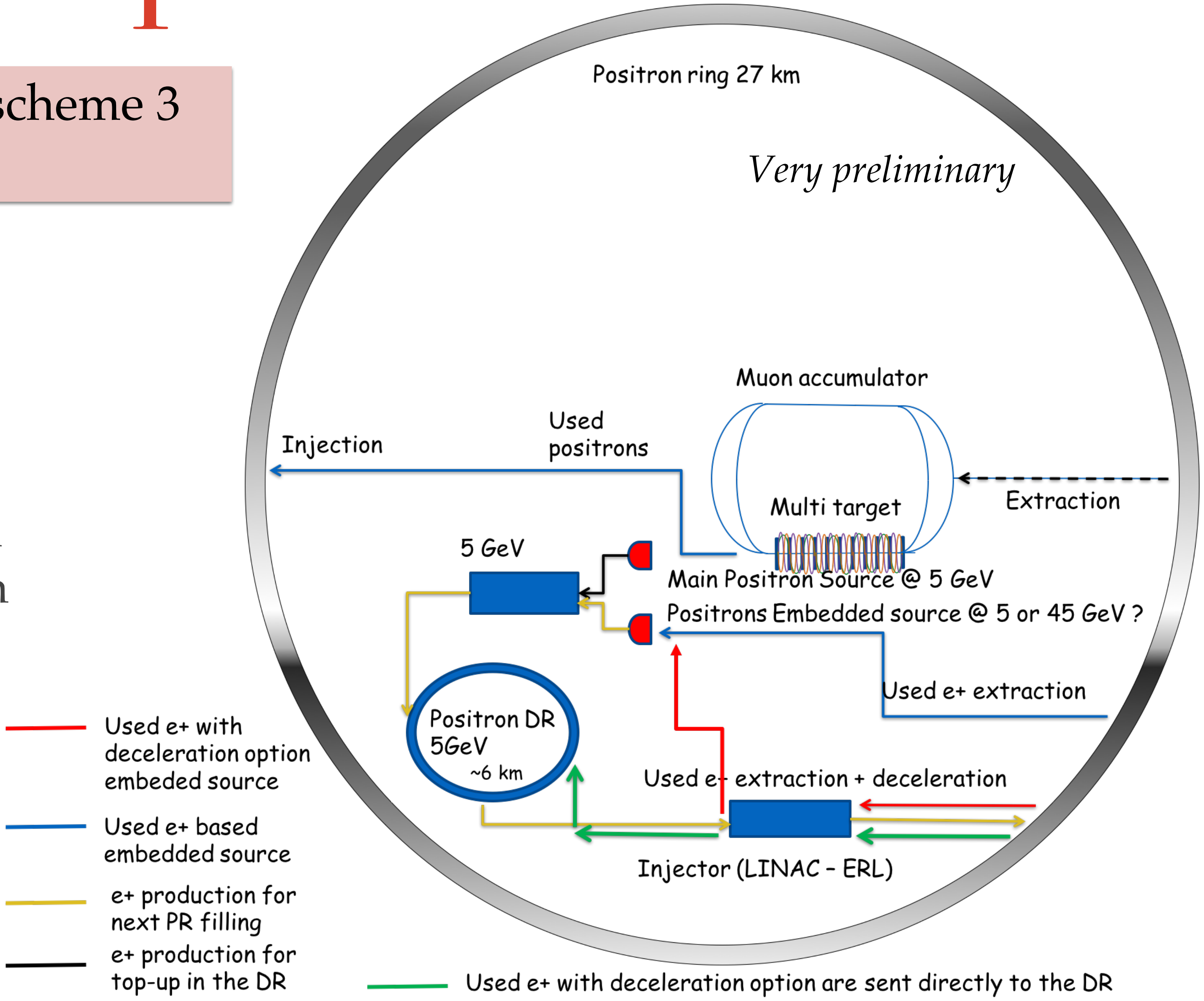
I. Chaikovska, IJCLab

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

Re-injection of used e+ back in the PR =>

- Used e+ decelerated and sent back to the DR for damping
- Embedded source: slow extraction of used e+ and e+ production using e+ drive beam @ 5 GeV (deceleration) or 45 GeV

Top-up in the DR with the Main Positron Source.



☞ Work in progress to study all the scenarios

Muon collider activity in Milano on LEMMA positron source

- 50 GeV e^+ entrapment chain has been studied and simulated with **following main contributes, in other INFN structures and international labs**:
- Geant4 simulations @ Roma 1 – **Francesco Collamati, Matteo Bauce**
- Insights, tips and discussions @ Roma 1 - **Alessandro Variola**
- Insights, tips and discussions @ LNF **– Susanna Guiducci**
- Entrapment layout chain and particle tracking simulations @ Milano - **Alberto Bacci**
- Insights, tips, discussions and comparison with their simulations @ IJCLab, Orsay (Parigi**), Iryna Chaikovska, Robert Chehab and Yanliang Han –** @ IJCLab the group is going ahead with a parallel analysis, with some different approach, very useful for comparison and insights

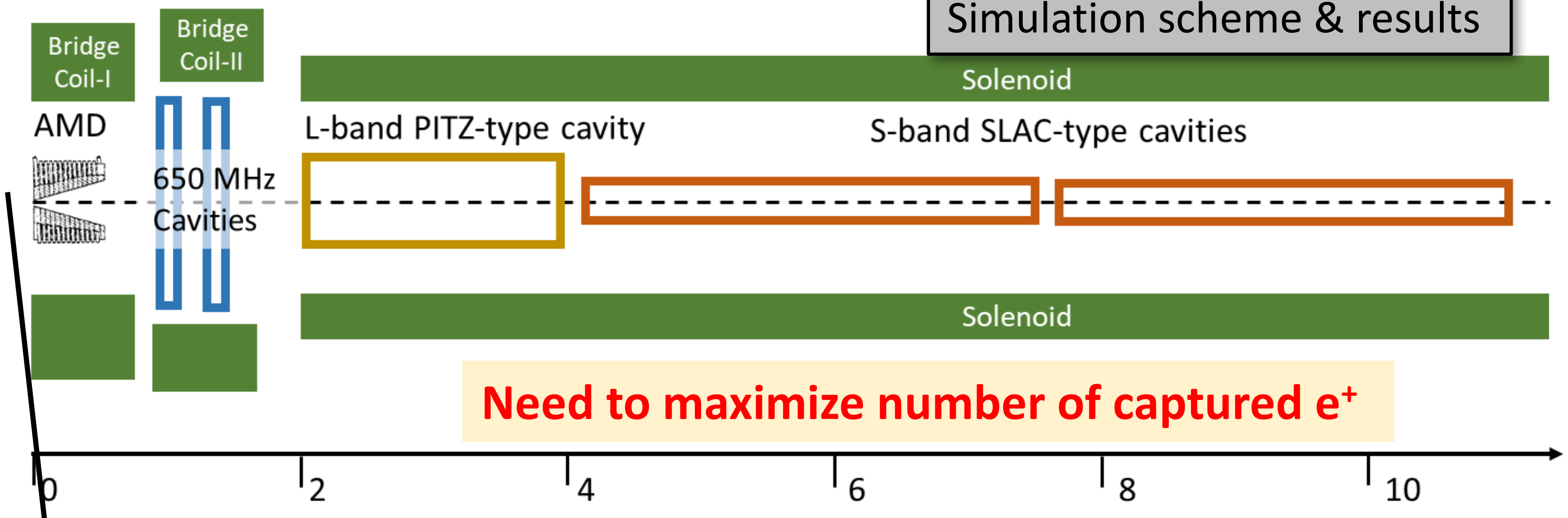
A common test case: INFN and IJCLab:
50GeV e+ bunch @ target

Generation method = G4 (Han), Astra's generator (Alberto)
sigX=sigY=1 mm (Gaussian distrib.)
SigZ= 3 mm (Gaussin distrib)
E_K = 5.GeV, DE/E = 4% MeV (200 MeV)
Emit. X e Y (norm.) di 100 mm-mrad

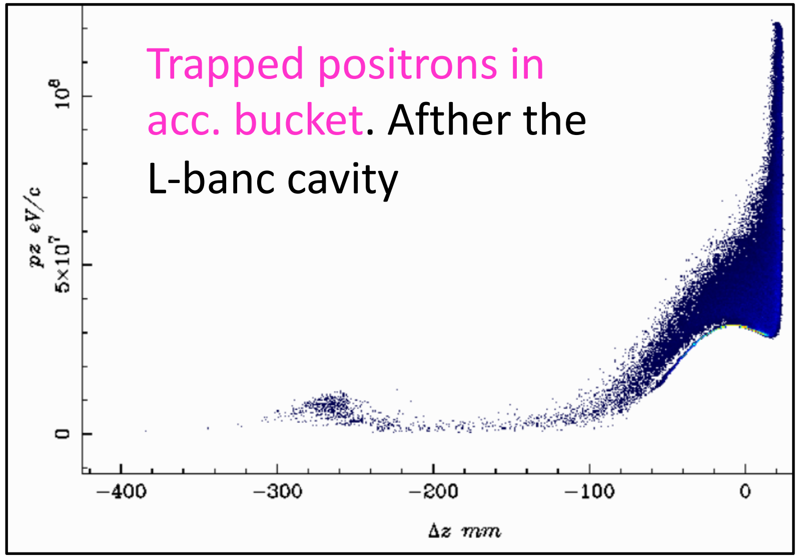
Benchmarking simulations
for 50 GeV "spent" e^+ embedded source

A. Bacci, INFN MI

Simulation scheme & results



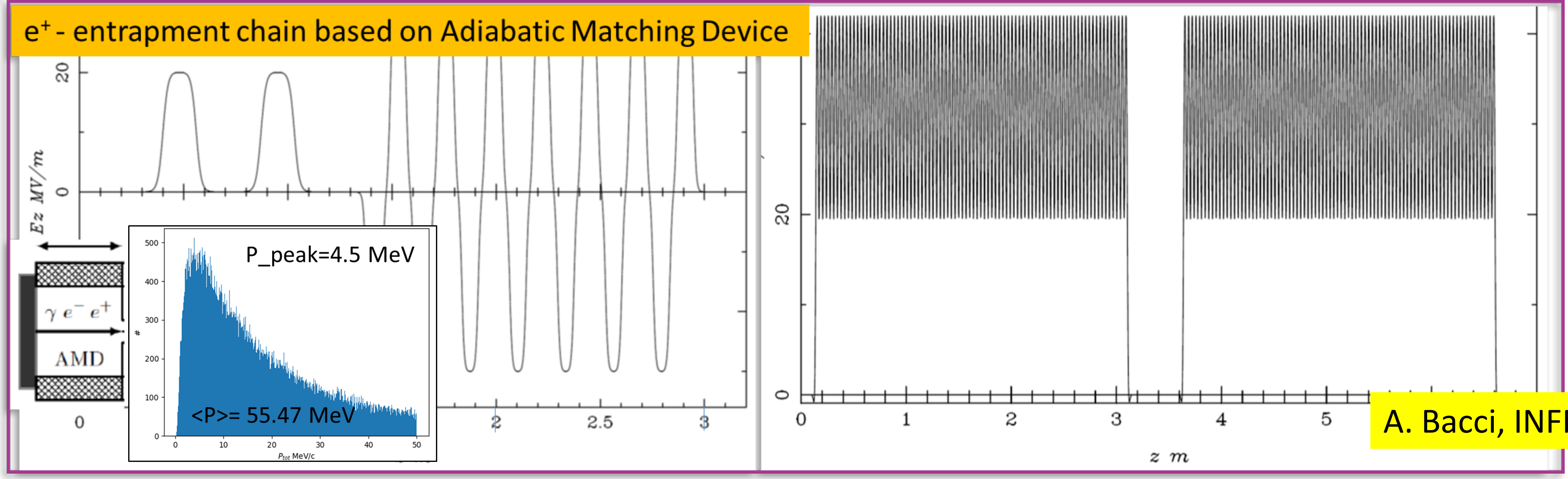
Need to maximize number of captured e^+



The Simulation flow:

Bunch generated by Astra Code → Geant4 e+ target interaction and rigeneration → Astra to capture and accelerate

e^+ - entrapment chain based on Adiabatic Matching Device

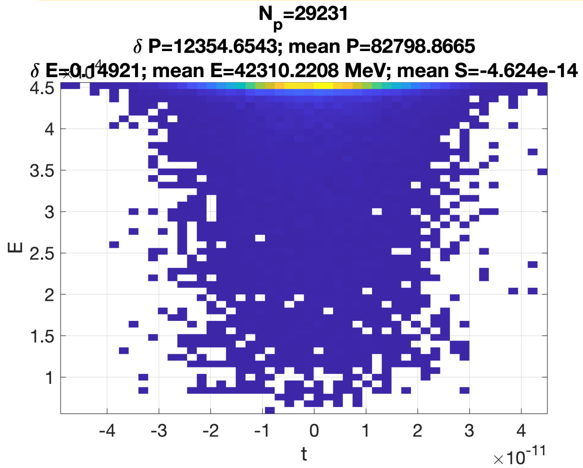


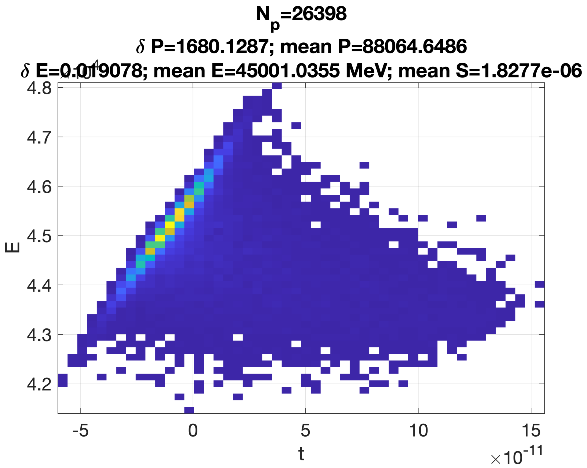
A. Bacci, INFN MI

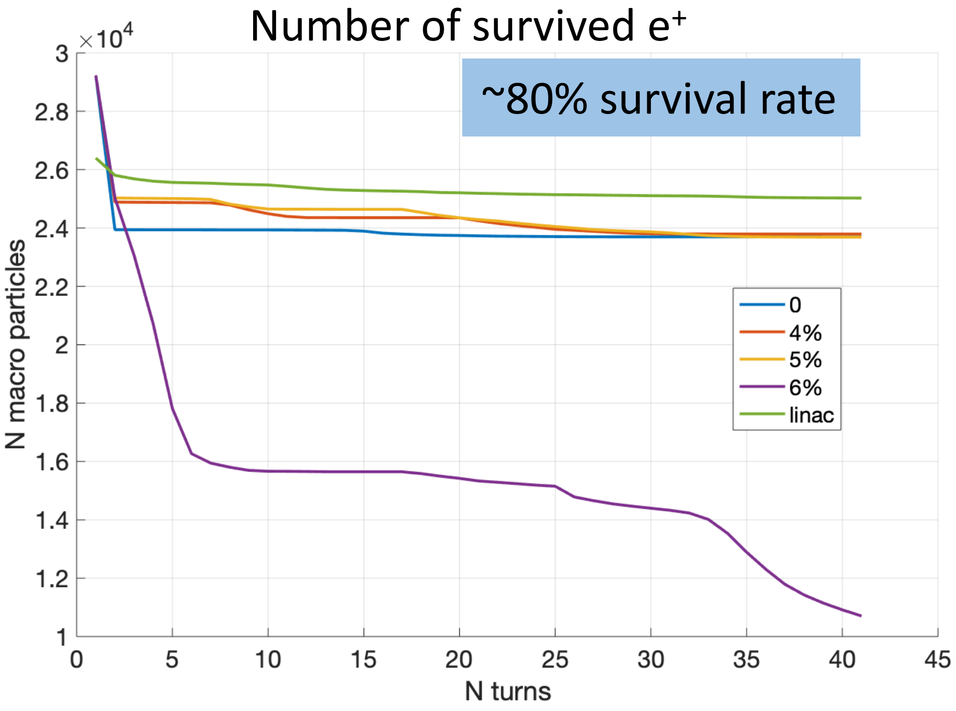
Study of injection of spent positrons in 45 GeV ring: 2 beam options

1) e+ beam after target (O. Blanco)

2) e+ beam after linac compression (C. Vaccarezza)

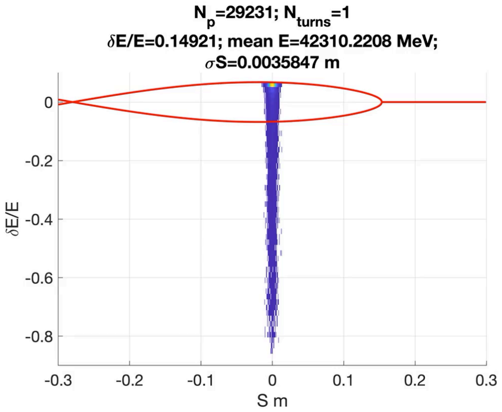




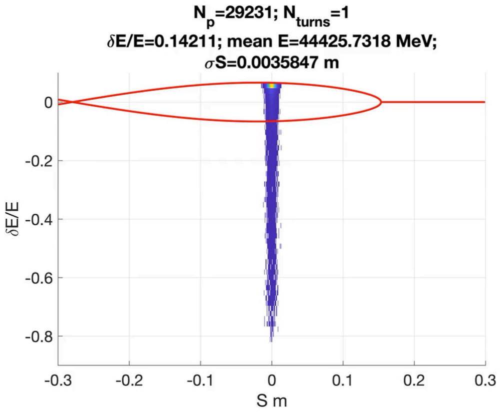


Changing energy offset

0%



5%



Trying to increase the number of survived e^+ by playing with different parameters at injection, like energy offset

Still to do: benchmarking Elegant with AT codes

With a 80-90% efficiency we can refill the 45 GeV beam in the 50 msec available, and release stress on main PS

Illya Drebot, INFN MI

Snowmass Letter of Interest

- 3 LoI LEMMA related were presented:
  - General layout and possible R&D topics
  - Studies on target materials and layout
  - Physics and technologic challenges of generating high intensity e^+ beams

LEMMA: a positron driven muon source for a muon collider

M.E. Biagini (*), O. Blanco-Garcia, M. Boscolo, A. Ciarma, A. Giribono, S. Guiducci, C. Vaccarezza (INFN, Frascati National Laboratories, Italy), F. Anulli, M. Bauce, G. Cesarini, F. Collamati, R. Li Voti, A. Variola (Roma La Sapienza University, Italy), I. Chaikovska, R. Chehab (IJCLab, Orsay, France), A. Bacci, I. Drebot (INFN, Milan, Italy), S. Liuzzo, P. Raimondi (ESRF, Grenoble, France), D. Lucchesi (INFN, Padova, Italy), N. Pastrone (INFN, Torino, Italy)
and for the International Muon Collider Collaboration

LEMMA μ source - LoI Snowmass'21 - AF4 Multi-TeV colliders

- Proposed R&D:
  - **TARGETS** → common to e^+ and $\mu^\pm$ source. Material studies and experimental tests. Prototype of rotational target (single thick target or ensemble of close thin targets) with an amorphous and a granular amorphous material. Hydrogen target (pellet) studies. Crystal targets studies for muons recombination and post-production cooling. **Synergy with AF7, separate LoI will be presented by Roma I (R. Li Voti)**
  - **VERY HIGH PRODUCTION RATE e^+ SOURCE** → **synergy with AF7, separate LoI will be presented by IJCLab (France) (I. Chaikovska)**
  - **RF CAVITIES** → high gradient SCRF cavities able to cope with a high average train current (order of 100 mA). **Synergy with AF7**
  - **HIGH FIELD MAGNETS** → need to focus 45 GeV e^+ and 22.5 GeV $\mu^\pm$ together in a short low β-function IR → high gradient, large aperture and compact quadrupoles. Design of the multi-targets $\mu^\pm$ production line requires efficient 3-beams separation design, aiming at minimising particle losses, with high field, large aperture dipoles. **Synergy with AF1, AF7**
  - **MUON COOLING** → longer $\mu^\pm$ lifetime at production allows for introducing moderate cooling mechanism to further reduce production emittance. Different evaluations were done in the past for the cooling efficiency given by stochastic cooling, optical stochastic cooling, crystal cooling. A full revaluation of these mechanisms associated to high energy, low emittance and bunch current needs to be done. **Synergy with AF1, AF7**
  - **MUON RECOMBINATION** → testing muon bunches recombination techniques, that can increase the number of particle per bunch without been drastically affected by the consequent emittance increase. New hypothesis: possible recombination of different muon bunches by injection in a curved crystal. Combining the channeling angle with the volume reflection it should be possible to merge two different bunches with a relative emittance increase, mainly in the distribution tail. The efficiency of this process should be optimized. **Synergy with AF1, AF7**
  - **BEAM PHYSICS** → design e^+ and $\mu^\pm$ rings with very high energy acceptance, design of Interaction Region and Separation Region for 3 beams (e^+, μ^+, μ^-). **Synergy with AF1**

An International Muon Collider Collaboration is being set up with CERN and other partners worldwide

Studies of target materials and layout for a low emittance muon source (LEMMA)

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Physics and technology challenges in generating high intensity positron beams

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