Proposal for Using DAΦNE as Linac Pulse Stretcher for the Positron Beam

S. Guiducci

ICFA Mini-Workshop on
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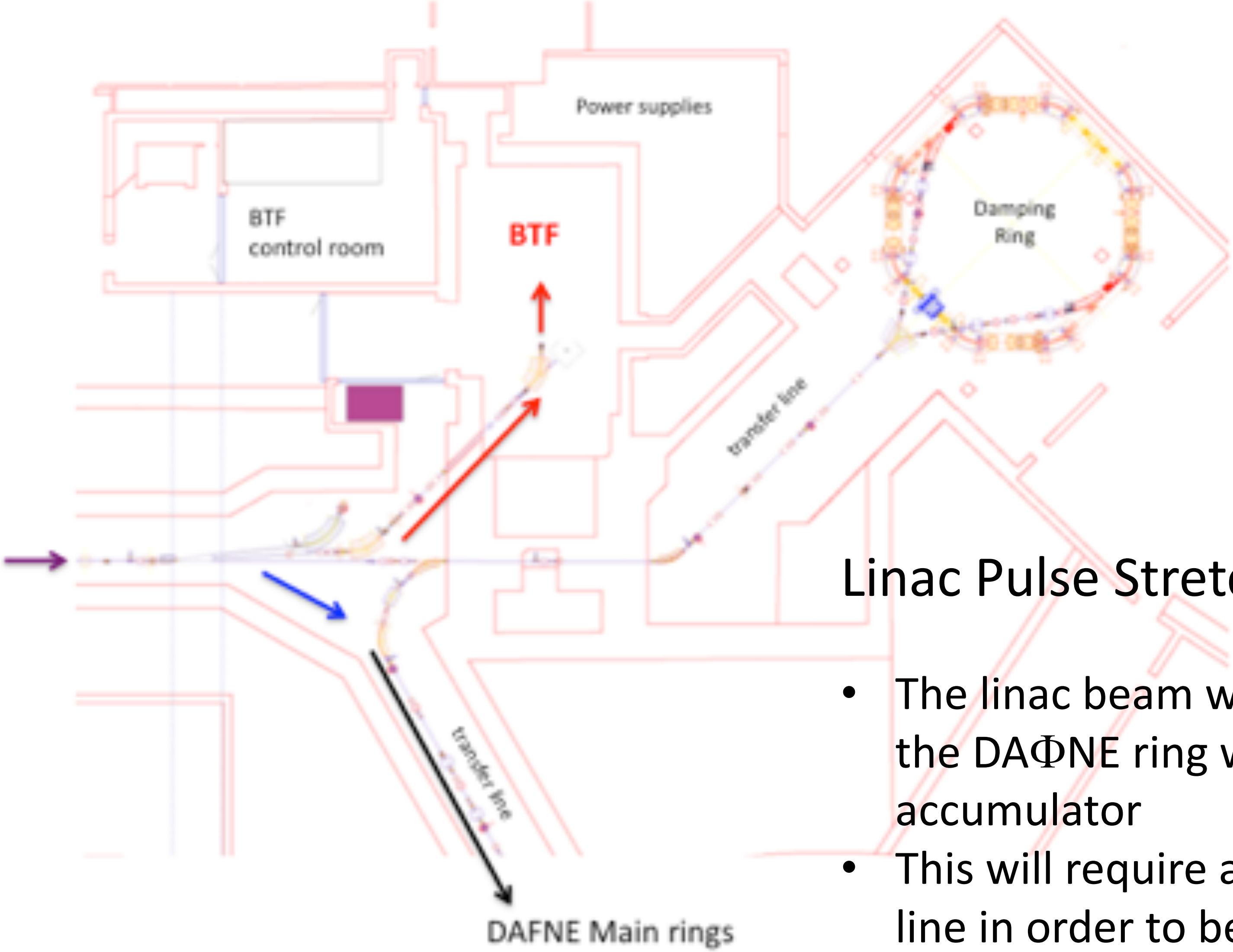
A positron beam for Dark sector experiments

- An application of the DAΦNE test-beam facility for Dark sector experiments, using the positron ring as a Linac Pulse Stretcher (LPS) to distribute the positrons of a single linac pulse in a much longer pulse, is proposed
- The PADME experiment is at present taking data at the **BTF** beam-line searching for the dark photon (A') in the $e^+ e^- \rightarrow A'\gamma$ process in a positron-on-target experiment
- The DAΦNE linac can provide a number of positrons **as high as** 10^{10}/pulse in a 200 ns long pulse
- In order to keep the pile-up probability in the calorimeter at an acceptable level, the number of positrons for PADME is limited **below** 10^5/pulse
- The low duty-factor (10^{-5} = 200ns/20ms) is a major limitation for the PADME experiment at BTF
- However, by injecting the beam in the **DAΦNE positron ring** and by spilling it with a ***slow resonant extraction*** the duty factor can be increased by 3 orders of magnitude (~1% = 0.2ms/20 ms)
- All the following considerations are based on the work done at LNF for the ALFA proposal:

S. Guiducci, G. Martinelli, M. Preger, LNF-78/22(R), 22 maggio 1978

and IEEE Trans. On Nucl. Sci., Vol. NS-26, No.3, June 1979

Layout of the DAΦNE injection system

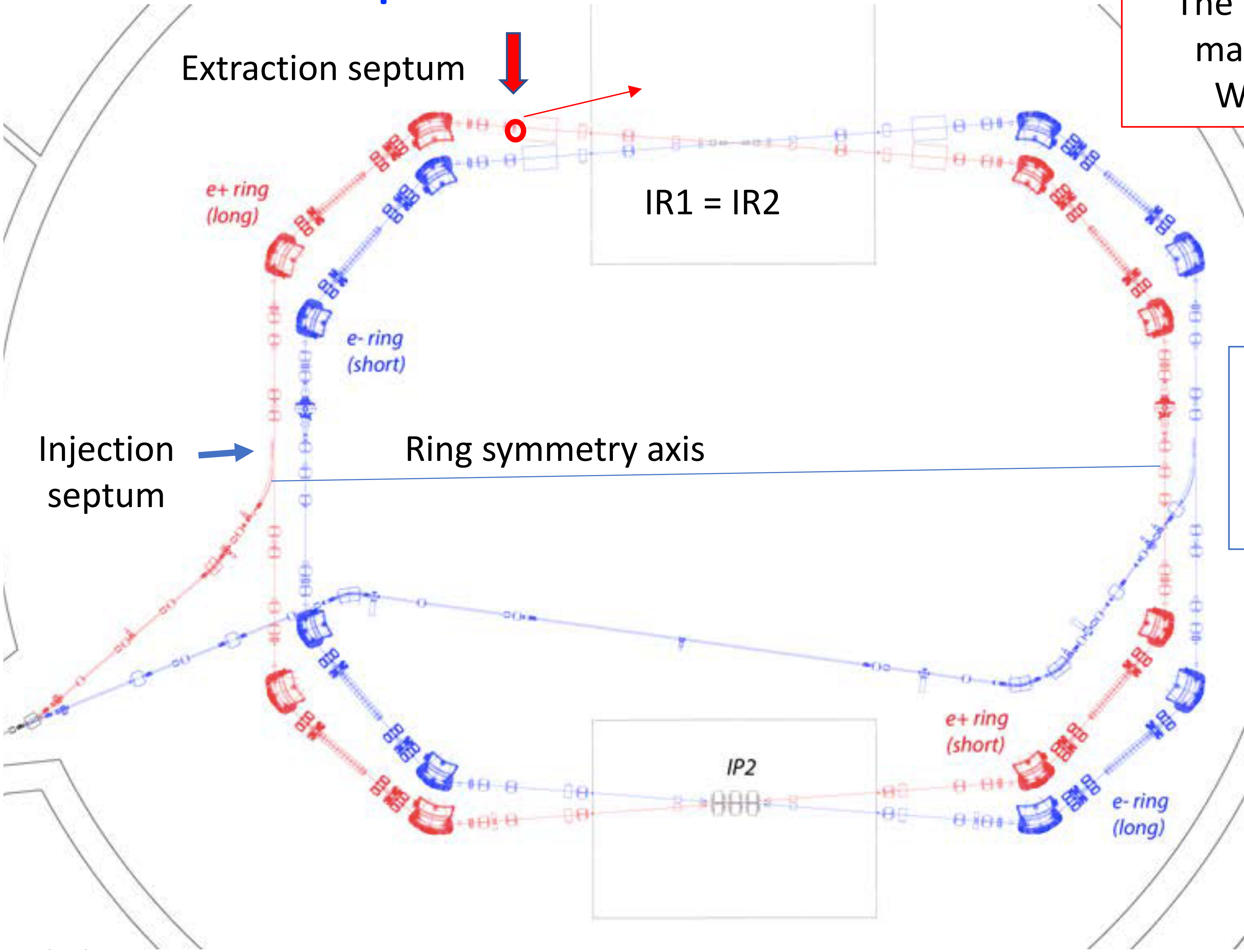


Linac Pulse Stretcher (LPS) configuration

- The linac beam will be injected directly into the DAΦNE ring without passing through the accumulator
- This will require a modification of the transfer line in order to bend the beam directly in the DAΦNE hall (as it was done for ADONE)

DAΦNE LPS layout with the positron injection and extraction septa

The positron ring is made symmetric With IR1 = IR2

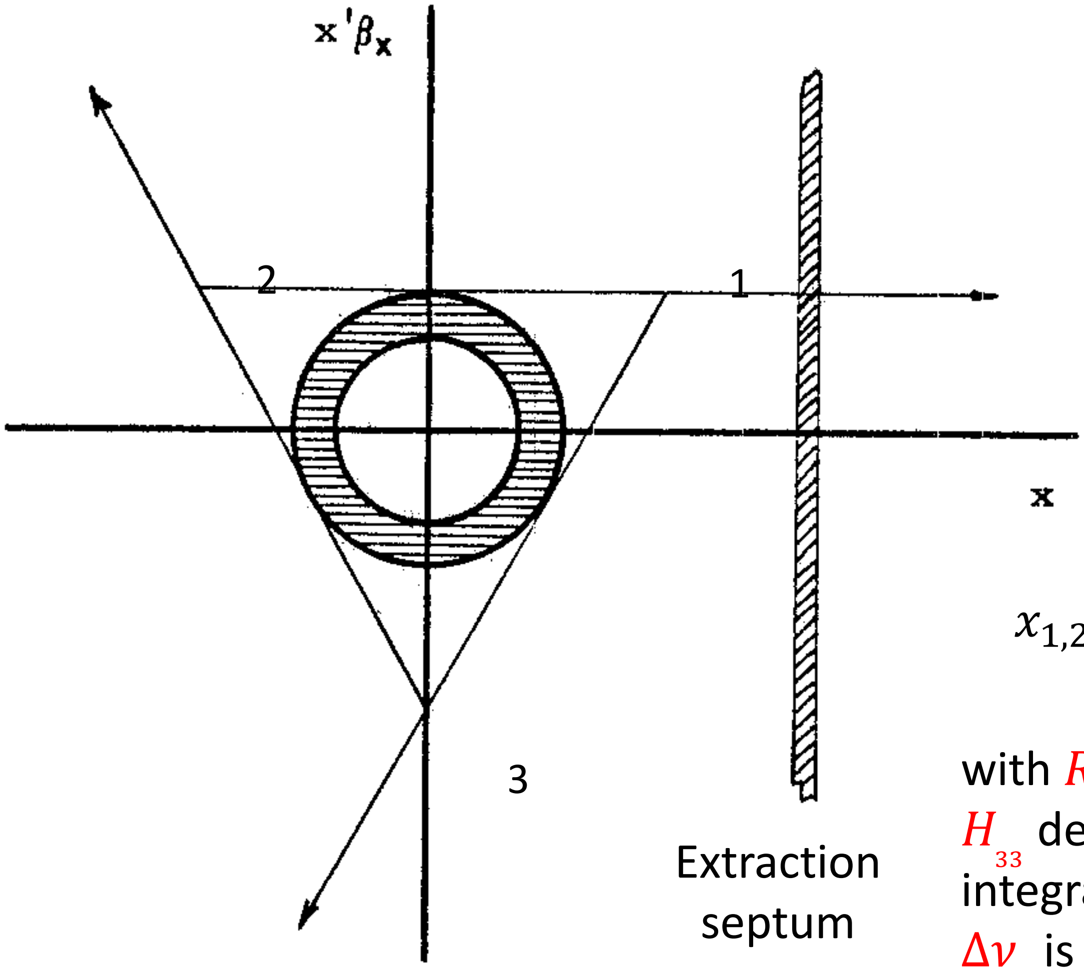


The preferred position for the extraction septum is in IR1

Resonant Extraction in a nutshell

- With a value of the betatron tune near to the 1/3rd resonance and a proper setup of sextupoles the stability region in the horizontal phase space (x, x') is delimited by a triangle
- Particles outside the borders of the triangle become unstable and move outward along three lines, which are the continuation of the triangle's sides
- After injecting the beam inside the triangle it is possible, by moving the betatron tune toward the resonance, to extract all particles at a given time reducing the size of the triangle
- We will adopt a monochromatic extraction: the chromaticity will be adjusted in such a way that as far as the particles lose energy by synchrotron radiation their tune gets closer to the resonance and they are extracted

Schematic layout of the beam horizontal phase space at the extraction septum



- The injected beam has a hollow shape
- Particles outside the stability triangle start moving on the extraction directions and the jump Δx between two successive passages increases going outward
- The coordinates of the triangle's upper vertices are:

$$x_{1,2} = \pm\rho\sqrt{\frac{\beta_x^{ext}}{R}\frac{\Delta\nu_x}{2\sqrt{3}H_{33}}} \quad ; \quad x'_{1,2} = \rho\sqrt{\frac{1}{\beta_x^{ext}R}\frac{\Delta\nu_x}{6H_{33}}}$$

with R = ring radius and ρ = average bending radius, H_{33} depends on the betatron phases and on the integrated strengths of the sextupoles along the ring, $\Delta\nu_x$ is the betatron tune distance from the resonance

Some Comments

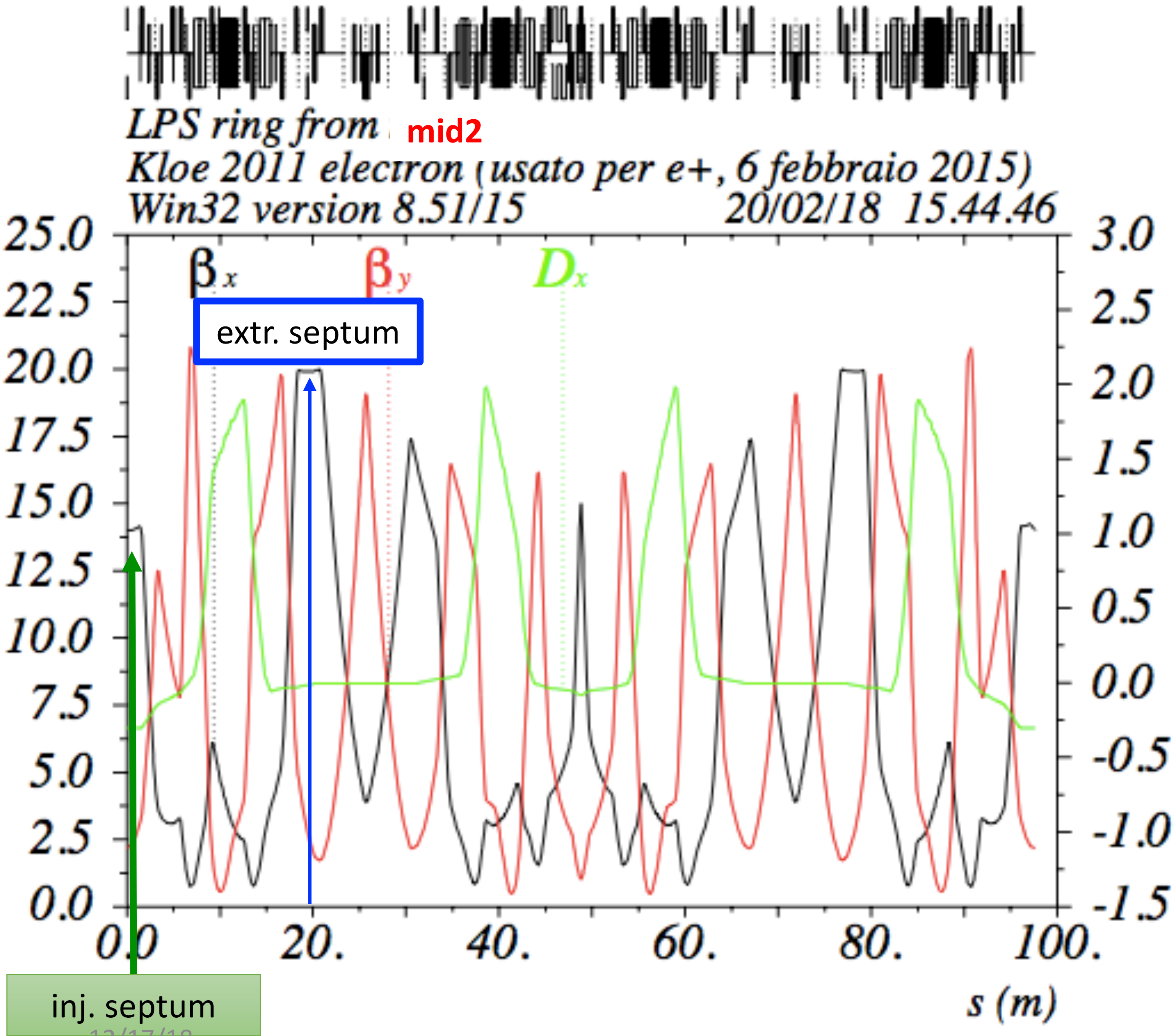
- Analytic expressions to evaluate the extraction time and the extracted beam parameters (emittance and energy spread) are reported in LNF-78/22(R)
- These formulae, valid for a symmetric lattice with the extraction septum placed in the symmetry point, assume that *m/3* is the only resonant term driving the particle trajectories
- They have been used to give a preliminary estimate of the extraction parameters
- To achieve a more precise estimate on the extracted beam parameters a study based on particle tracking is needed

- K. R. Symon, Extraction at a third integral resonance, Reports FN 130, FN 134, FN 140, FN 144, Fermilab (1968).
- G. Gendreau, J. L. Laclare and G. Leleux, Dynamics of chromatic particles in the resonant extraction, SOC/ALIS 22, Saclay (1969).

DAΦNE Lattice modifications

- The machine is made symmetric with respect to the centers of the LONG and SHORT straight sections: the 2 IRs are both equal to IR2, with non intersecting beams
- Sextupoles are kept in the present positions
- The injection septum is kept in the present position
- The extraction septum is in the IR1 straight section, on the outside of the ring, where there is space for the extraction line
- β_x at the extraction septum has to be the ring maximum, the function α_x and the dispersion function D_x need to be zero to minimize the extracted beam emittance
- The horizontal tune is near to the 1/3 resonance

Optical functions in half ring



TUNES

$Q_x = 4.30$, $Q_y = 4.27$

At extraction septum

$\beta_x = 20$ m

$\alpha_x = 0.0$

$D_x = 0.0$

At injection septum

$\beta_x = 14$ m

$\alpha_x = 0.0$

$D_x = 0.25$ m

Chromaticity

$C_x = -6.7$, $C_y = -10.5$

(SXT OFF)

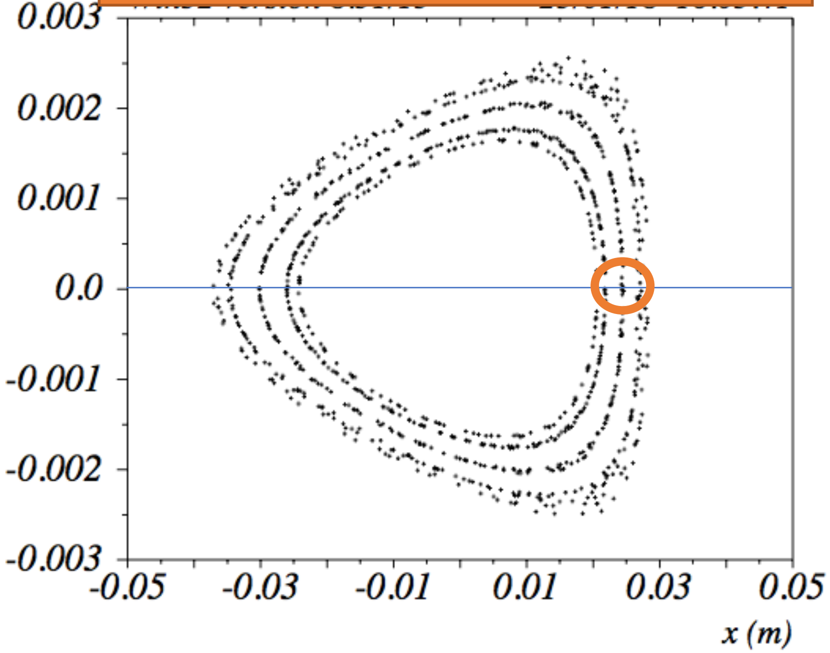
$C_x = -3.3$, $C_y = -6.26$

(k2.sf = 13.8 ; k2.sd = -8.6)

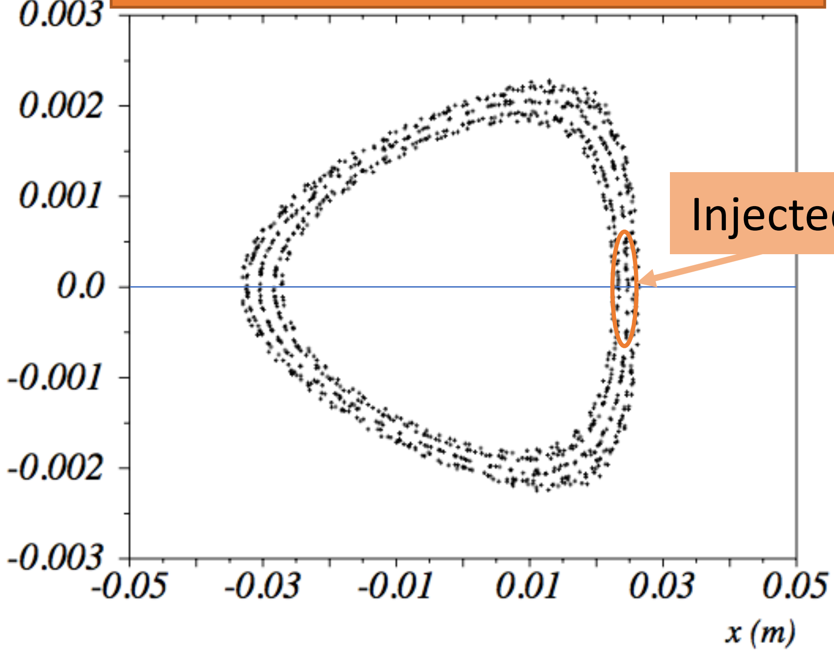
Tracking at the injection septum

Selection of the optimum beta at the end of the transfer line

Transfer line $\beta_x = 14$ m



Transfer line $\beta_x = 3.5$ m



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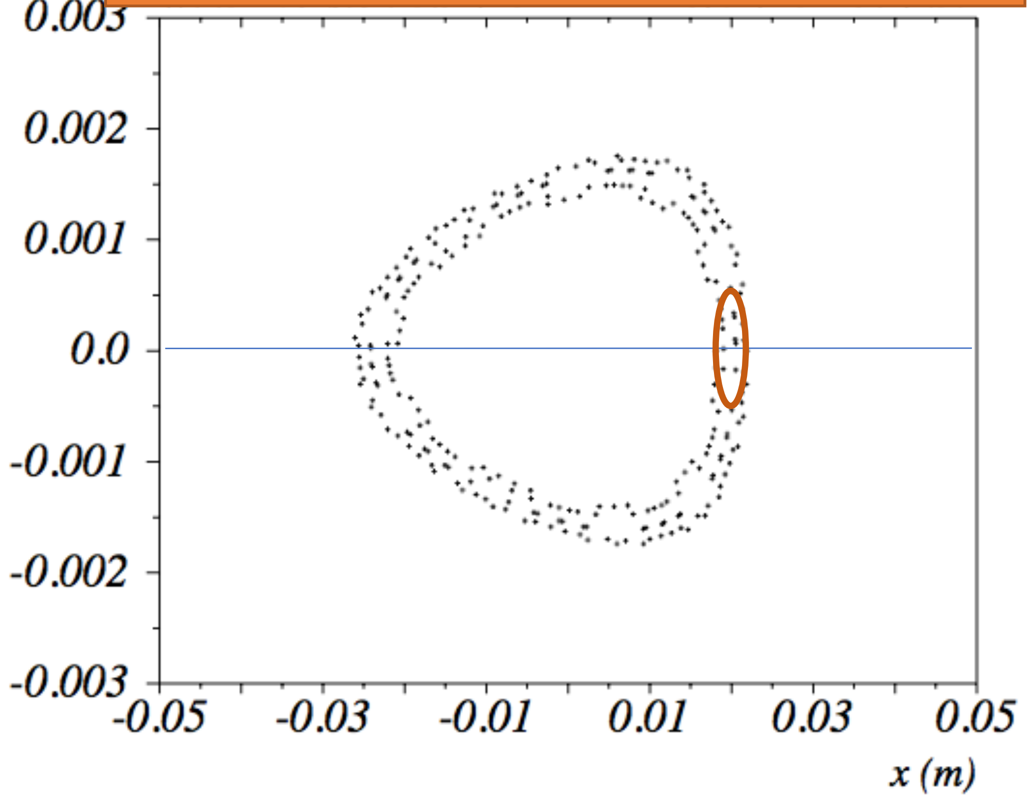
Injected beam

Injection septum
$\beta_x = 14$ m

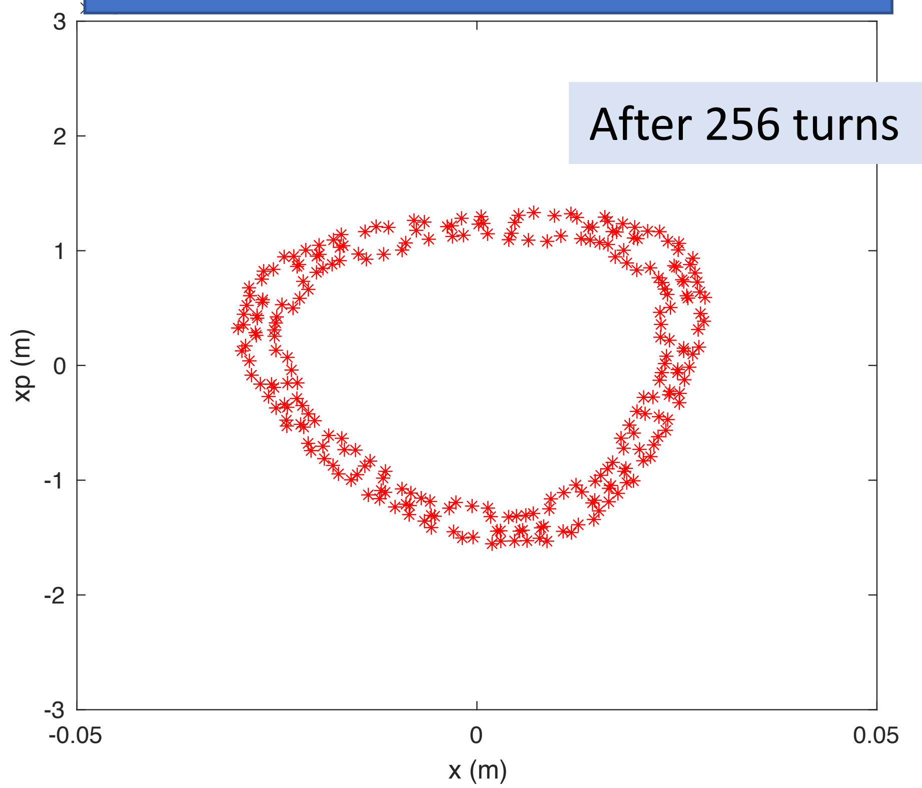
Center of injected beam ellipse $x_0 = 2.45$ cm

Tracking at fixed energy, no SR losses, no RF

Injection septum
$\Delta P/P = 0$

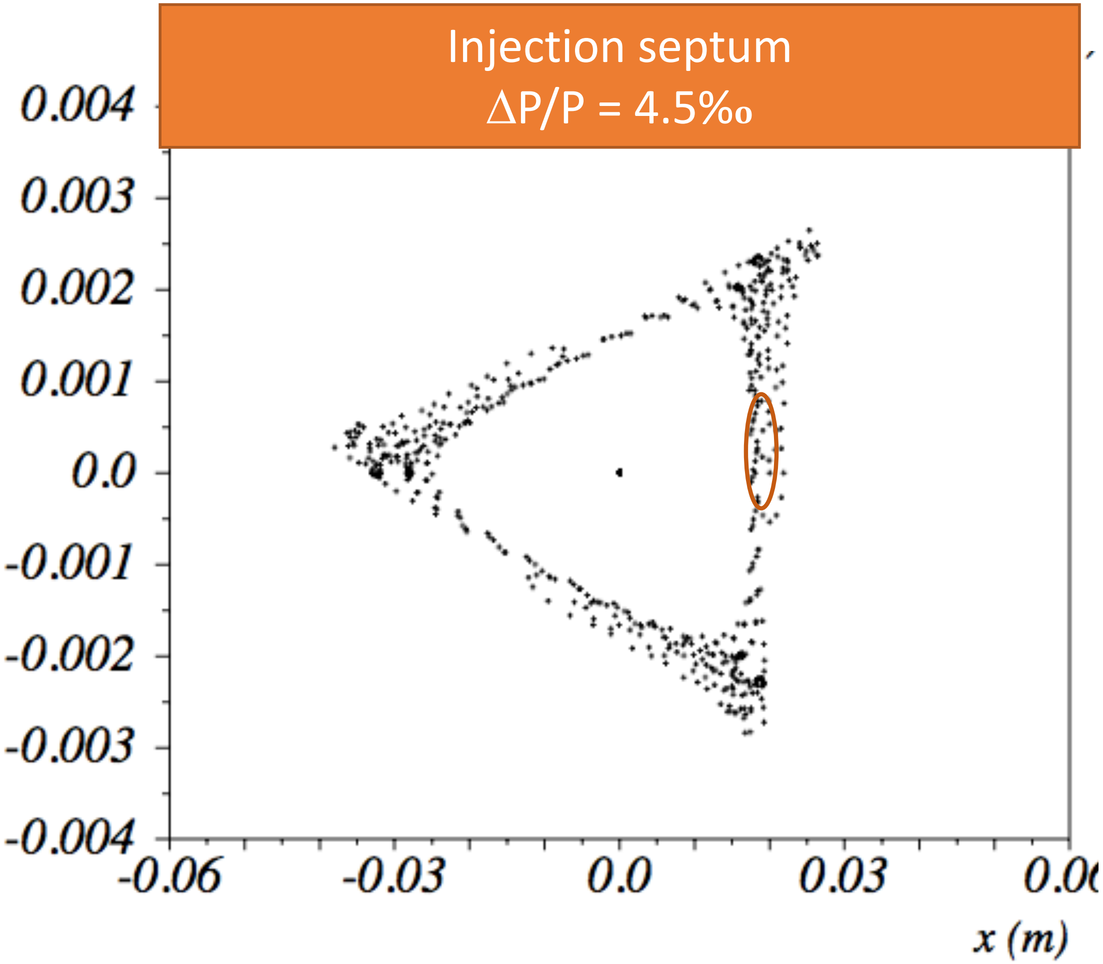


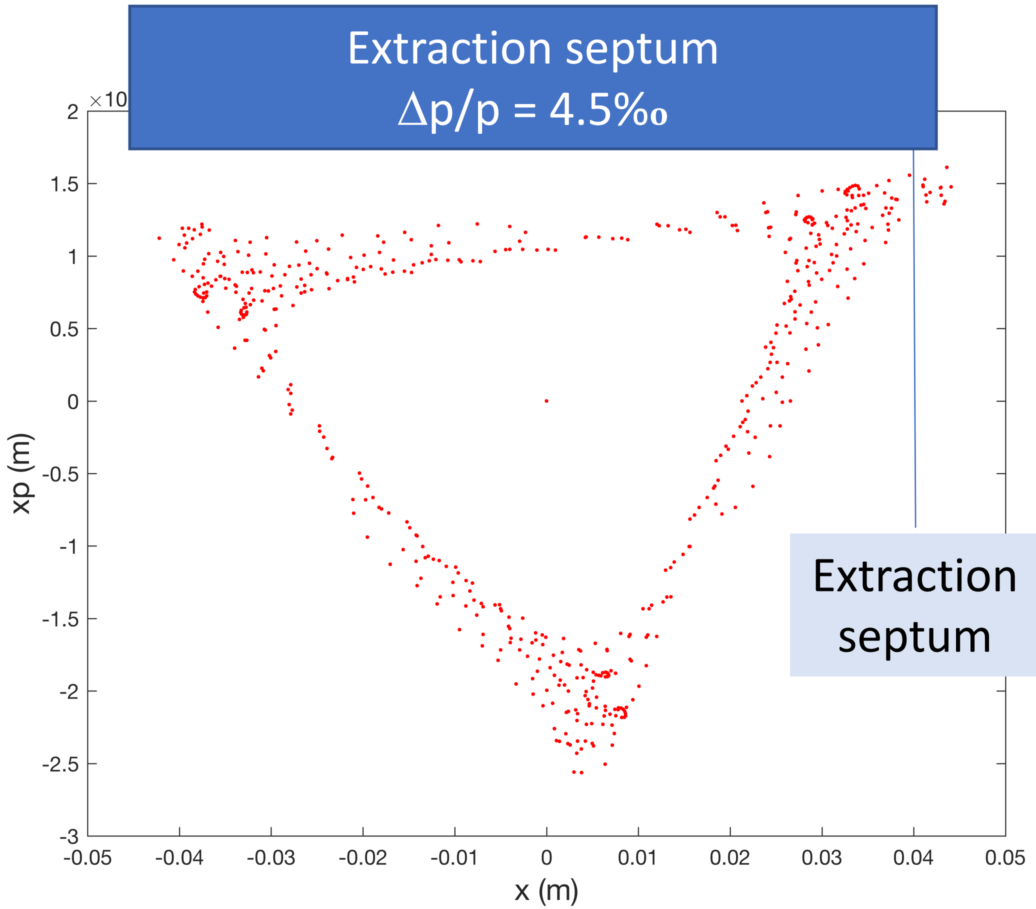
Extraction septum
$\Delta p/p = 0$



Transfer line β_x = 3.5 m
Extraction septum β_x = 20 m
Injection septum β_x = 14 m
Center of injected beam ellipse x_0 = 2 cm

Tracking near the extraction energy, SR losses, no RF





Mad8 tracking with initial energy $\Delta P/P = -0.0045$, average radiation energy loss (no fluctuations), RF off, collimators included

All the particles are extracted within 90 turns

Extraction septum x = 4 cm
Collimators x = 4.5 cm

Extracted beam parameters

- All particles with initial $\Delta p/p = -0.0045$ are extracted at the septum within 90 turns

- Total area of the extracted beam in the phase space is:

$$W_r = 8\cdot 10^{-7}\ \text{m}\cdot\text{rad}$$

- Total extracted relative momentum spread is:

$$\Delta p/p_{\,ext} = 1.4\text{x}10^{-3}$$

- If injected beam has a momentum spread $+.0055 > \Delta p/p > -0.0045$ the extraction time (time needed for particles with $\Delta p/p$=+0.0055 to lose energy down to -0.0045) is: 570 turns + 90 turns

$$T_{ext} = 660\ \text{turns} = 0.2\ \text{ms}$$

- Time between injections: 20 ms → **duty factor is 1%**

Needed hardware modifications

1. Remove the low-β insertion from IR1
2. Magnetic extraction septum (can be equal to the injection one)
3. Electrostatic extraction septum

   ~ 50KV/cm, thickness ~100 μm, length ~ 1m
4. Modification of the transfer line to inject directly from the linac to the ring
5. Insert a collimation system on the transfer line to control emittance and energy spread of the injected beam
6. Installation of additional shielding (to be evaluated)

Conclusions

- A proposal to explore the possibility to use the DAΦNE positron ring as a Linac pulse stretcher for the PADME experiment was presented
- The ring can be operated with RF cavity and wigglers OFF saving power consumption
- A preliminary estimate gives a duty factor of a factor 1000 larger than the one with the BTF beam, with an emittance below 1 mm·mrad and a momentum spread of a few per mil
- To give a more precise estimate of the extracted beam parameters detailed studies of all the error sources and of the required beam diagnostics are needed