# Concept of a polarized positron source at CEBAF

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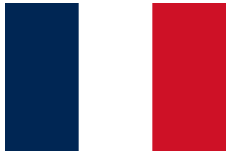
# Plan

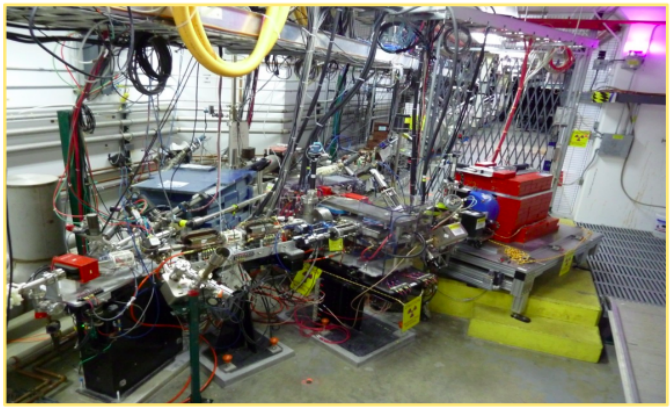
# Background

- **2016** Bachelor degree : Fondamental physics.
- **2018** Master degree : Theroretical physics.
  - Quantum field theory.
  - General relativity.
- **2020** Master degree : Particle accelerator.
  - Beam dynamics.
- **2020-2023** PHD : IJCLab / JLAB.



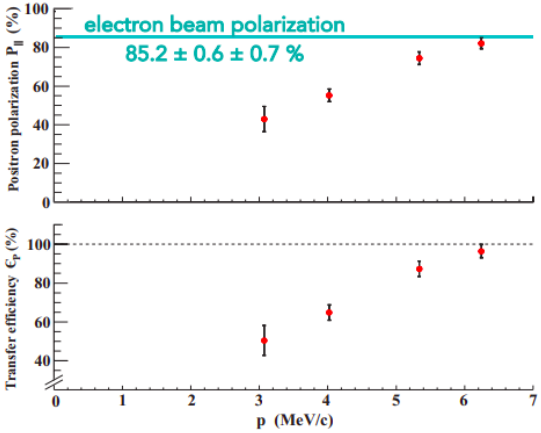
# My Thesis

- **Why positrons?**
  - JLab Users want beams of polarized (and unpolarized) positrons.
  - JLab have a unique polarized source demonstrating the polarization transfer : **PEPPo**



J. Grames, E. Voutier et al. JLab Experiment E12-11-105 (2011)

(PEPPo Collaboration) D. Abbott *et al.* Phys. Rev. Lett. 116 (2016) 214801




- **My tasks**
  - Choosing of the target thickness.
  - High duty cycle positron production.
  - Positron Capture system
  - Design the positron injector
- **How?**
  - Theory and Calcultions.
  - Simulation sofrware
  - Analysis and coding

# Plan

# Positron injector Concept

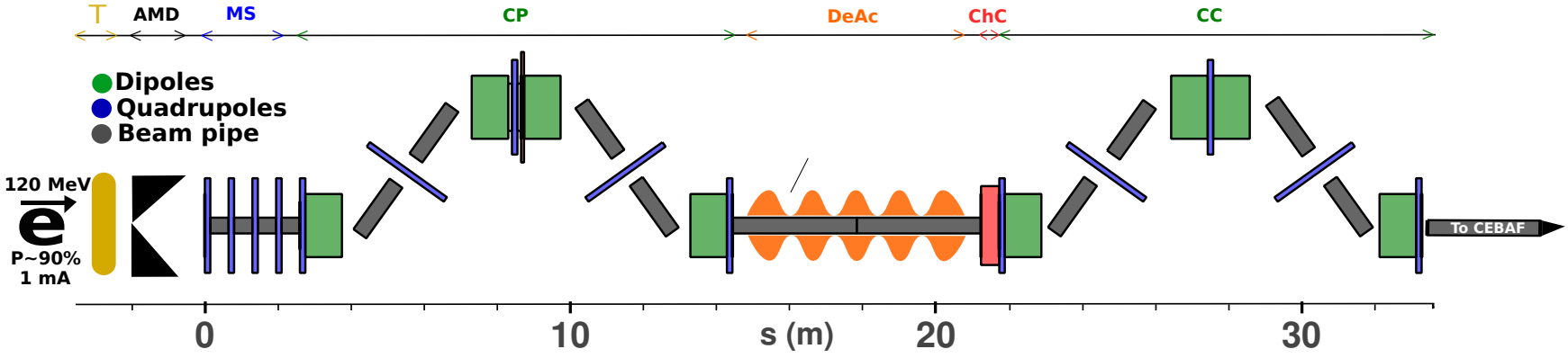



Figure: Conceptual layout of the positron injector for CEBAF.

T : Tungsten target

AMD : Adiabatic Matching Device

MS : Matching Section

CP : Magnetic Chicane

DeAc : Decelerating/Accelerating cavity

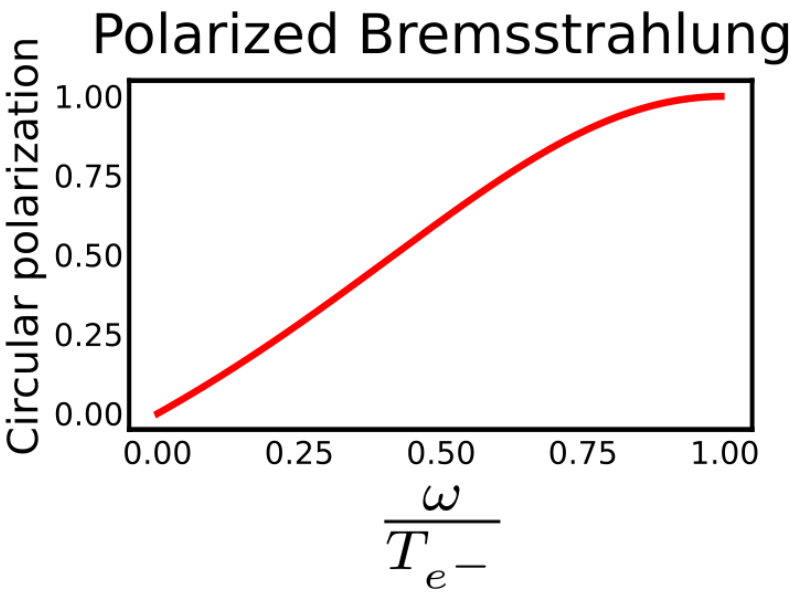
ChC : Chirping cavity

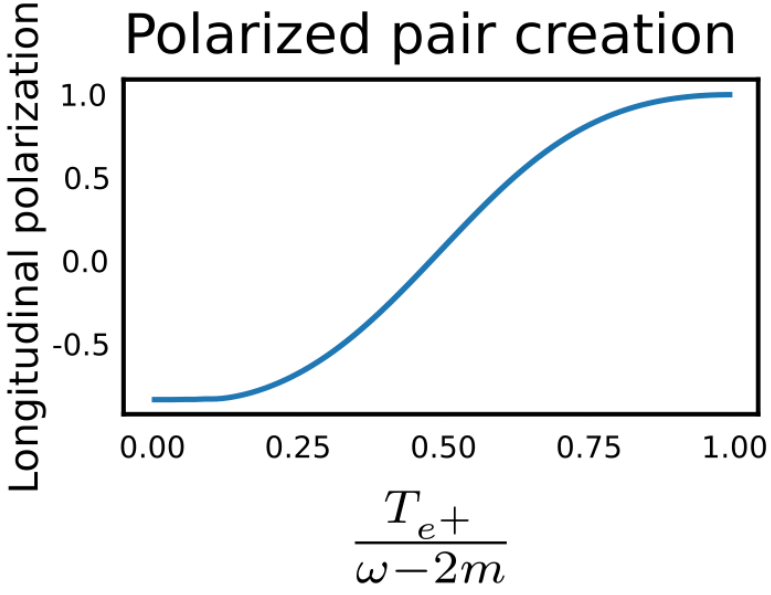
CC : Compression Chicane

# Polarization transfer

- How we get polarized positrons ?

$$e^- \implies \gamma \implies e^+$$



# Positron characteristics

- Efficiency : $\epsilon = \frac{N_{e^+}}{N_{e^-}} \longrightarrow$ **Unpolarized mode**.
- Figure-of-Merit FoM$=\epsilon P_{e^+}^2 \longrightarrow$ **Polarized mode**.

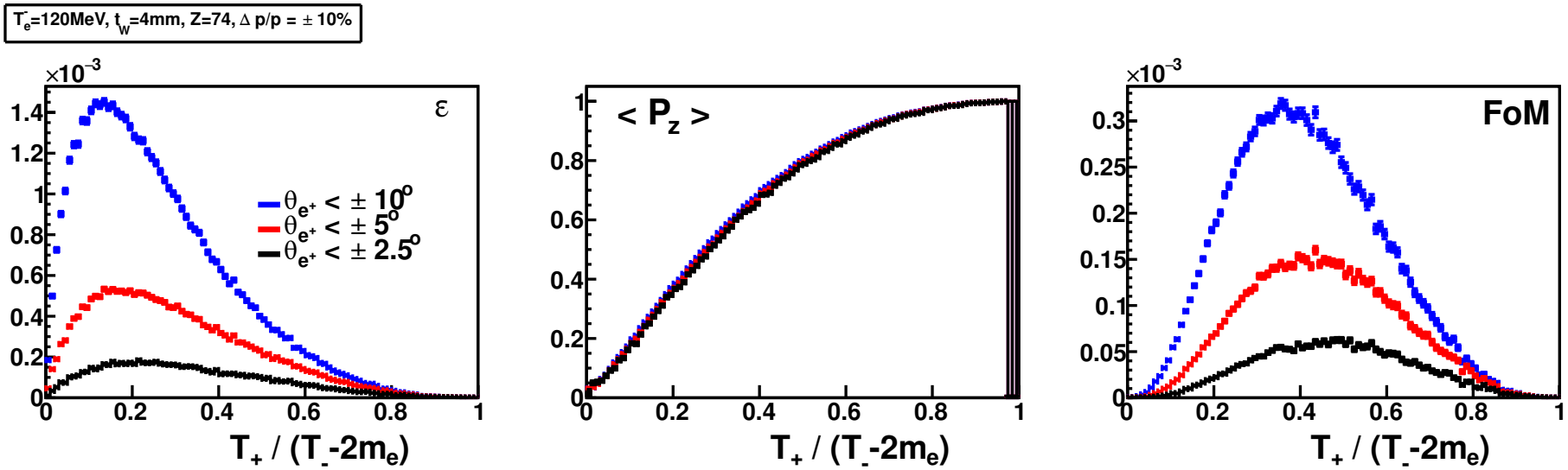
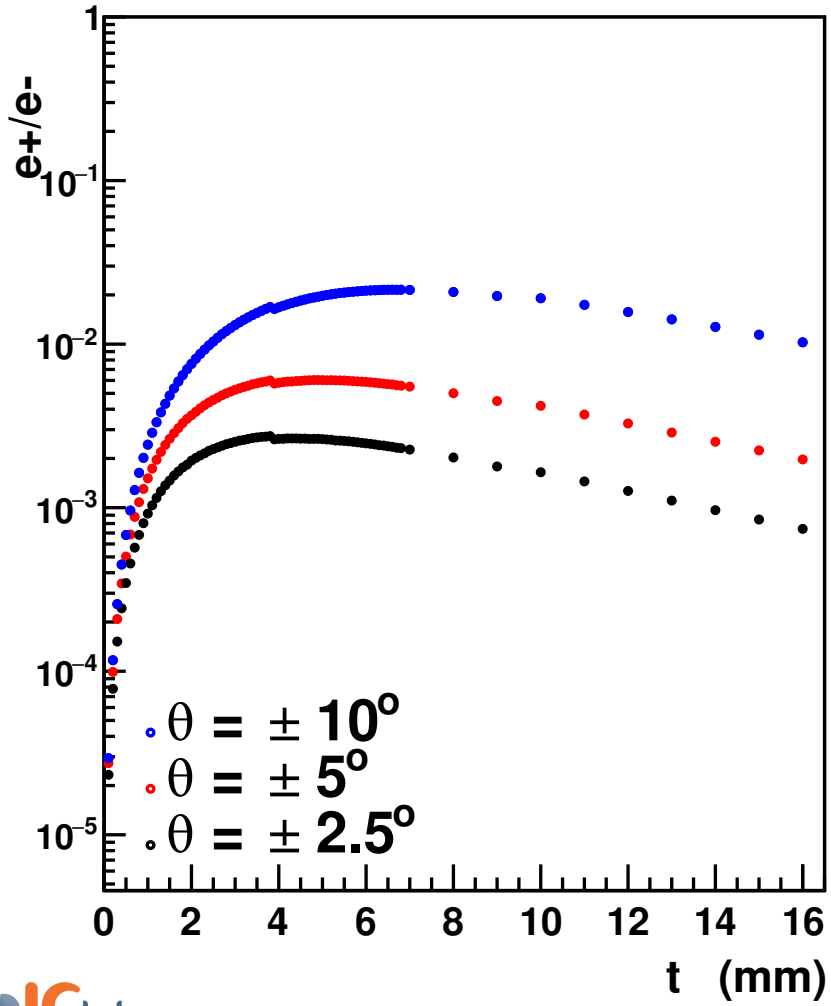
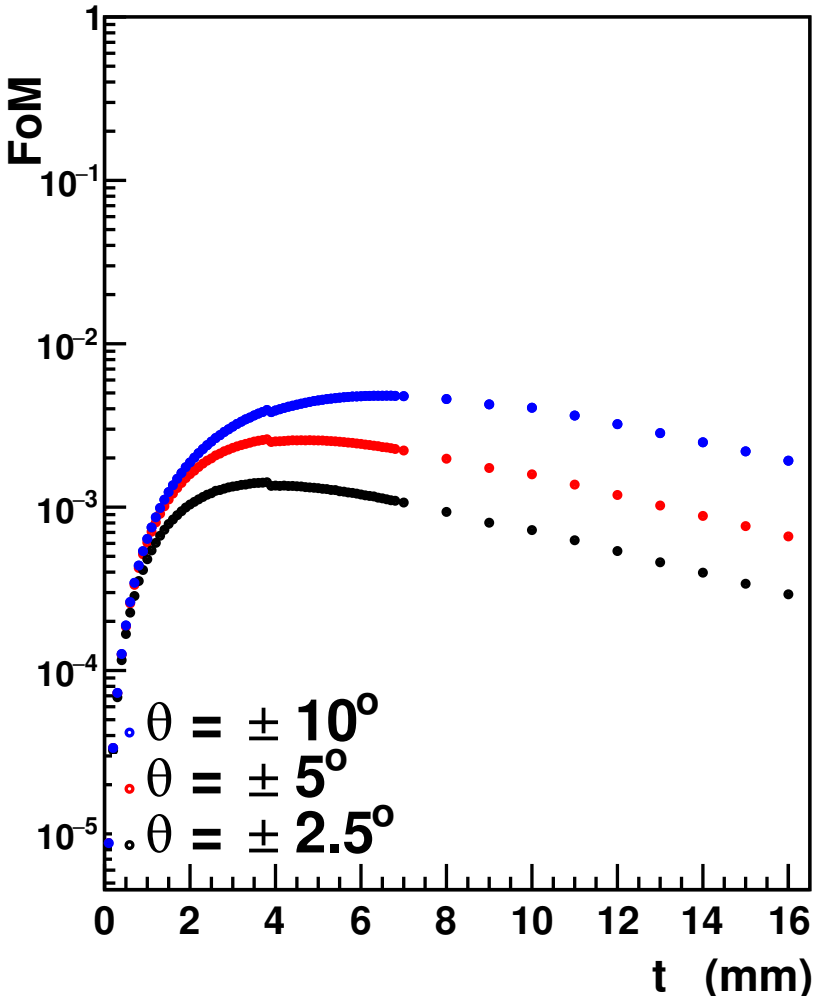



Figure: Positron production characteristics

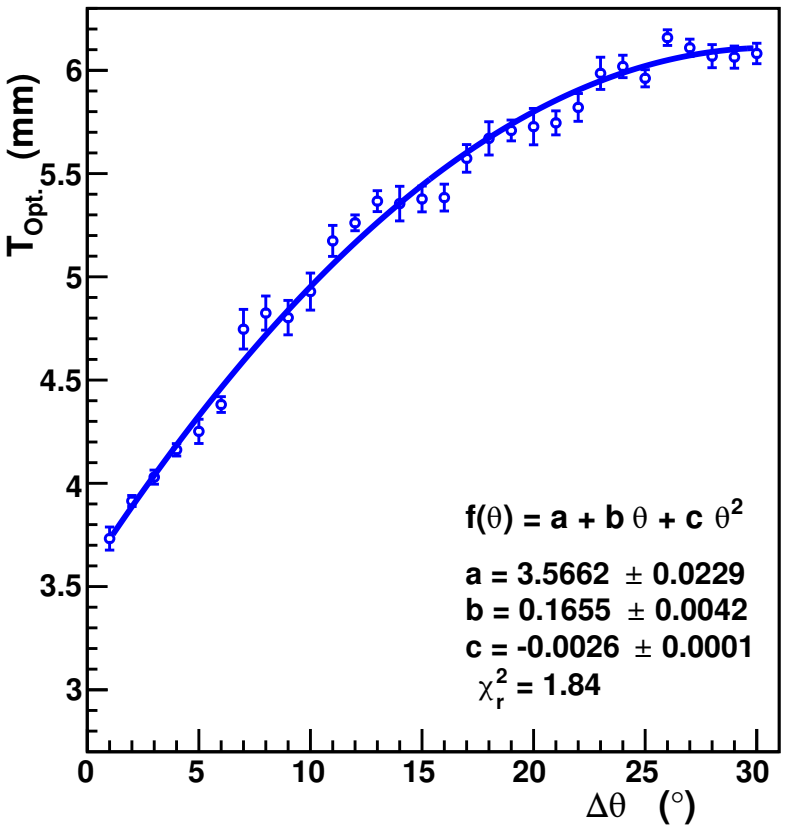
# Target thickness optimization

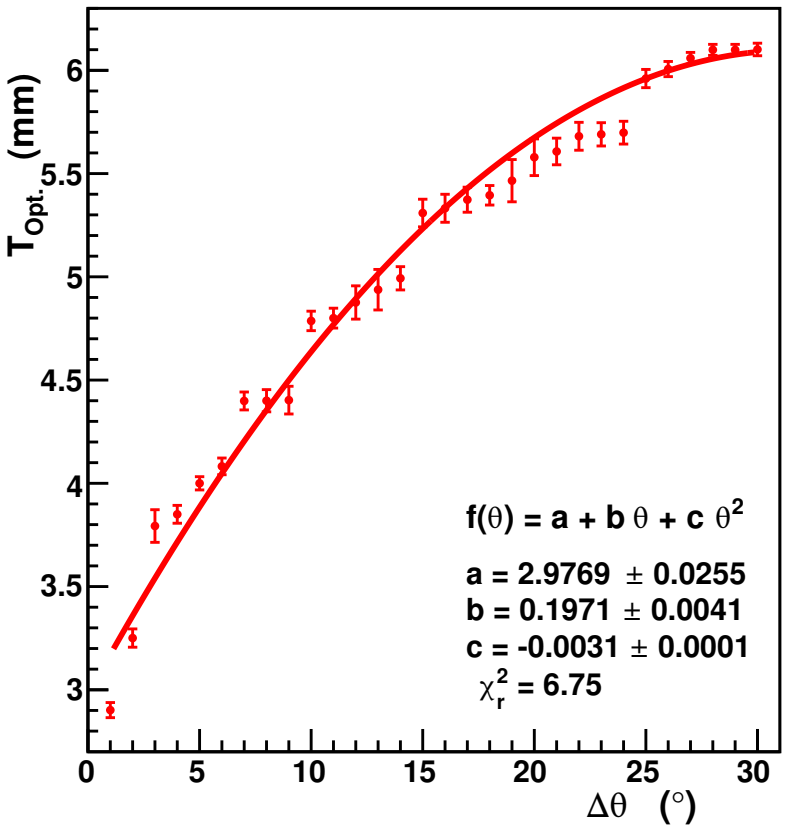
$T_e^-$=120MeV, $\Delta P/P = \pm 10\%$, Z=74



# Optimum thickness VS Collection system aperture

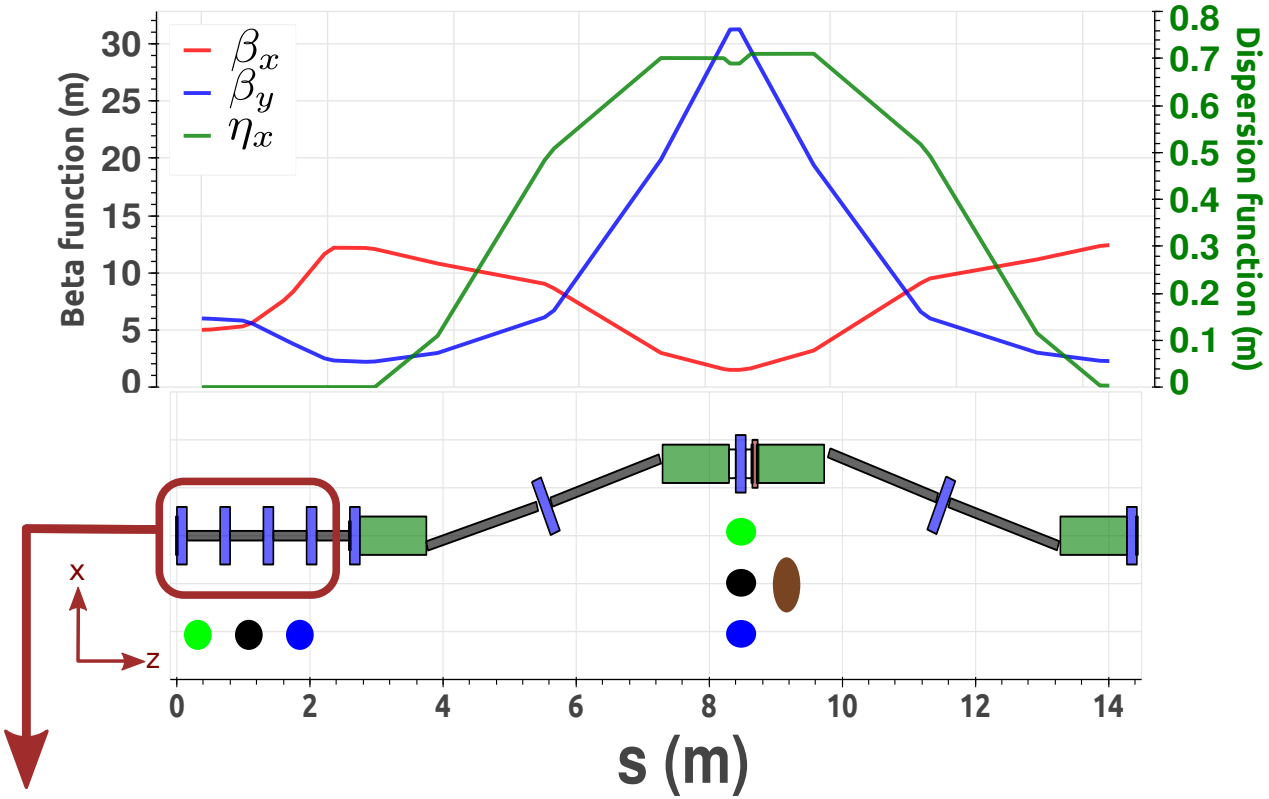


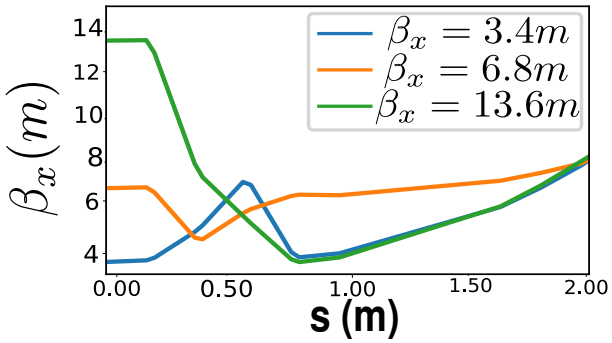

- The optimum thickness of the $e^+$ production target is strongly sensitive to the angular acceptance of the collection system and depends on the operational mode of the source.

# Plan

# Beam size optimization




Matching section



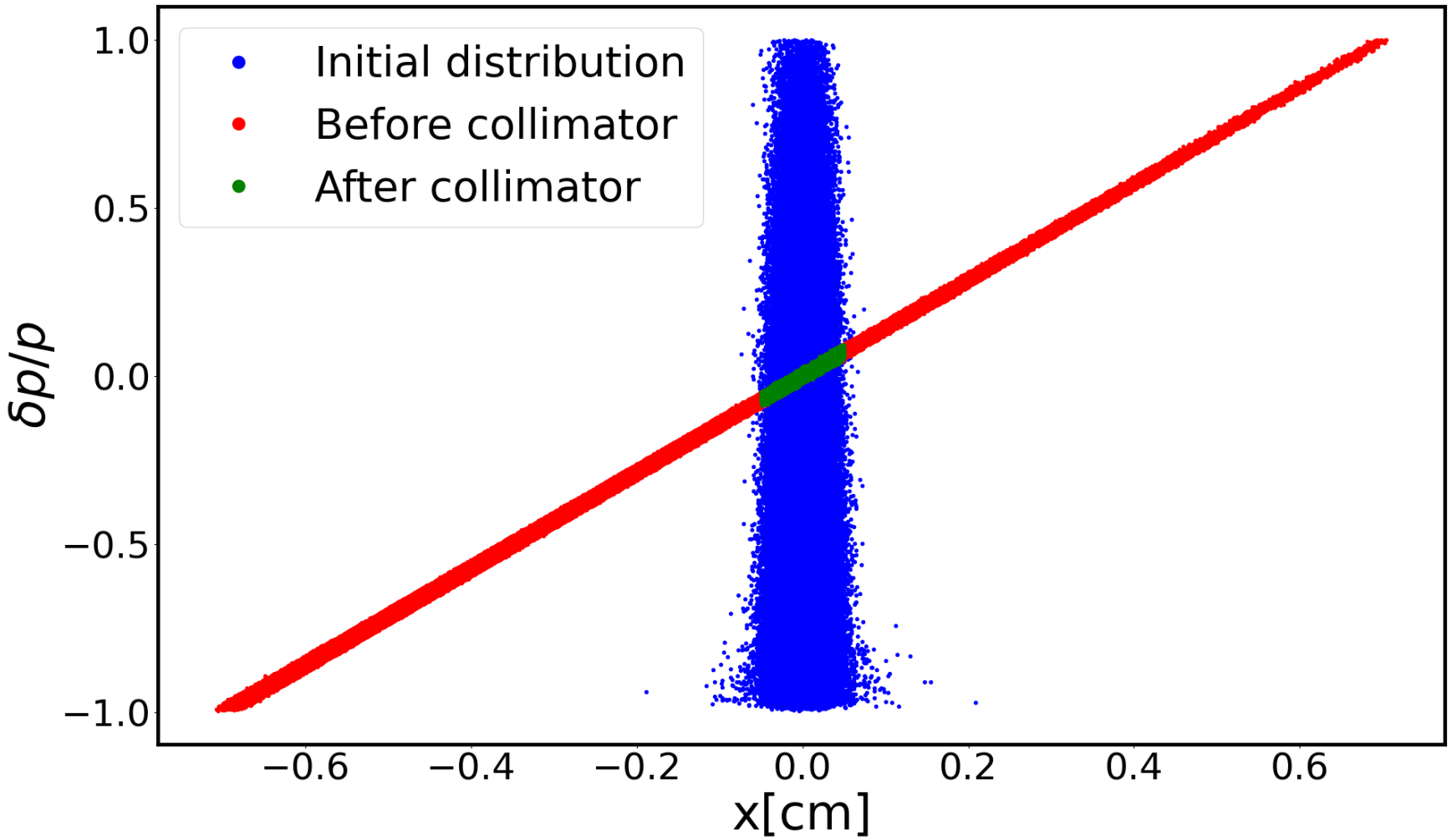

- **Periodic Twiss :**

$$\beta_{x,y_{in}} = \beta_{x,y_{out}}$$

- **Minimum beam size condition:**

$$\beta_x = \beta_{x_{MIN}} \longrightarrow \alpha_x = 0$$

# Positron momentum collimation



# Plan

# Longitudinal bunchlength

- Free dispersion chicane.
- Achromaticity condition.

$$M_{Exit\ \ chicane} = \begin{bmatrix} 1 & R_{12} & R_{13} & R_{14} & R_{15} & 0 \\ R_{21} & 1 & R_{23} & R_{24} & R_{25} & 0 \\ R_{31} & R_{32} & 1 & R_{24} & R_{25} & 0 \\ R_{41} & R_{42} & R_{43} & 1 & R_{25} & 0 \\ 0 & 0 & 0 & 0 & 1 & R_{56} \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} x_0 \\ x_0^{'} \\ y_0 \\ y_0^{'} \\ z_0 \\ \delta_0 \end{bmatrix}$$

$$z_{Exit\,chicane} = R_{55} z_0 + R_{56} \delta_0$$

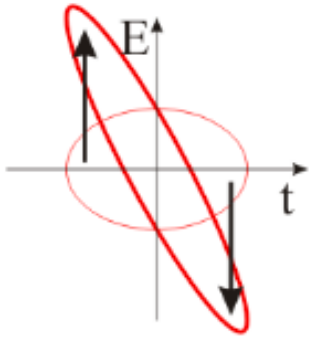
$$\Delta z = R_{56} \delta_0$$

# Longitudinal beam chirp

- **Compression factor** $= \frac{Bunchlength_{z0}}{Bunchlength_{zf}}$

$$C = \frac{1}{1 + [R_{56} \times \kappa]}$$

- **Using z & $\frac{\delta P}{P}$ space, we have:**

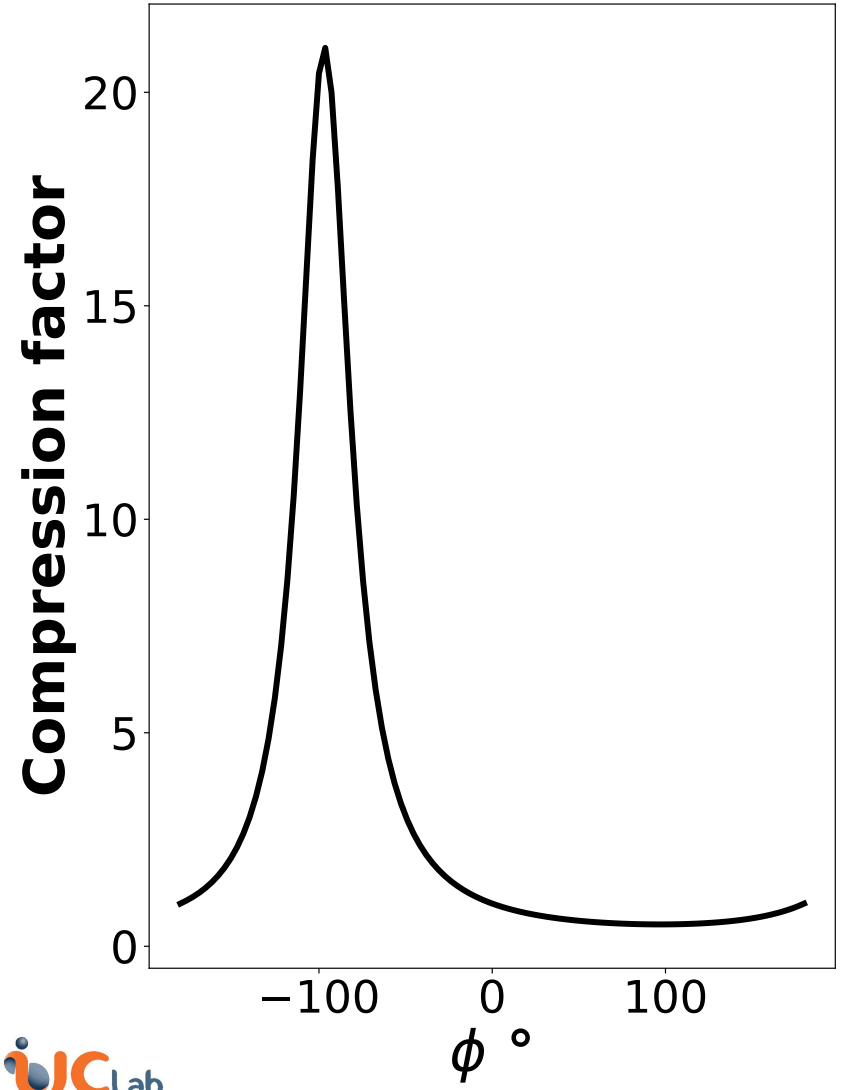



$$\kappa = \frac{d\delta_p}{dz} = \frac{-keV_0}{E0 + eV0\cos\phi}\sin\phi$$

- $k = 2\pi\frac{f}{c}$ $[m^{-1}]$
- $f$ is the cavity frequency
- $eV_0$ Cavity acceleration [MeV]
- $E_0$ Central energy [MeV]
- $\phi$ Cavity phase advance.

$$\longrightarrow \quad C = \frac{1}{1+\left[R_{56}\times\frac{-keV_0}{E0+eV0\cos\phi}\sin\phi\right]}$$

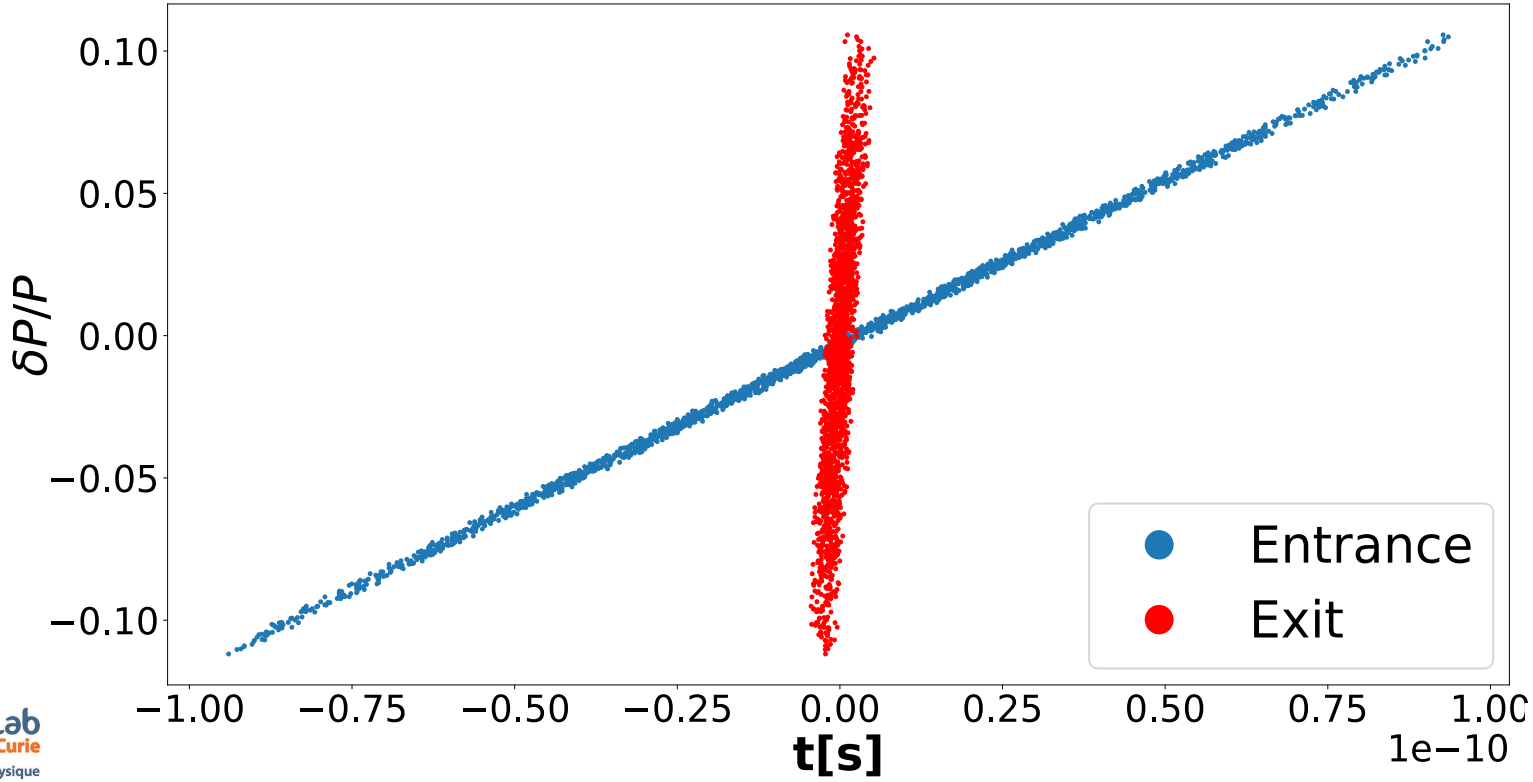
# Compression factor




- $R_{56} = -0.25$ m
- Optimal chirp @ $\kappa = 3.81\ m^{-1}$
- Optimal cavity phase advance $\phi_0 = -96.6°$
- Cavity frequency $f = 1500\ Mhz$

# Longitudinal compression

- $R_{56} = -25\ cm$
- Chirp : $\kappa = 3.81\ m^{-1}$
- Full compresion factor : $C = \frac{1}{1+\kappa \times R_{56}} = 23.3$



# Plan

# Next challenges

- A new injector is under study for possible assembly at the LERF.
- The latest positron injector layout is going to evolve (Collection system, RF cavities...).
- Among potential options to consider for future studies is the possibility of further compressing the beam using the CEBAF arcs together with an appropriate chirp in the linacs.
- Mathematic calculations helps a lot for the software optimization.
- To be continued ...

# Plan

# Beam size along the chicane

- How to reduce the beam size along the chicane?
- **Answer : FODO**
- **Motivation:** $\frac{\Delta P}{P_0} = \pm 10\%$
- **Focusing quadrupole =** $\begin{bmatrix} \cos\sqrt{K}L_q & \frac{1}{\sqrt{K}}\sin\sqrt{K}L_q \\ -\sqrt{K}\sin\sqrt{K}L_q & \cos\sqrt{K}L_q \end{bmatrix}$
- **Defocusing quadrupole =** $\begin{bmatrix} \cosh\sqrt{K}L_q & \frac{1}{\sqrt{K}}\sinh\sqrt{K}L_q \\ -\sqrt{K}\sinh\sqrt{K}L_q & \cosh\sqrt{K}L_q \end{bmatrix}$

# Linear beam optics

- **Initial FODO parameters**
  - Focusing Quadrupole strength $K_{QF} = 0.6\ m^{-2}$
  - Quadrupole length $L_Q = 0.2\ m$
  - Defocusing quadrupole strength $K_{QDF} =?$
- **Drift parameter:**
  - Drift length $L_{drift} = 5.6m$
- **Motivation** Apply the periodicity condition on the FODO lattice to get : $\begin{bmatrix} \beta_{exit} \\ \alpha_{exit} \\ \gamma_{exit} \end{bmatrix} = \begin{bmatrix} \beta_{entrance} \\ \alpha_{entrance} \\ \gamma_{entrance} \end{bmatrix}$
  - $\beta$ $\alpha$ and $\gamma$ are the twiss parameters of the beam wich describes the behaviour of the optics along the lattice.
  - In periodic system, for stability of the equation of the motion we have :

$$|trace(M)| < 2$$

# Linear beam optics

- If the FODO matrix is given by :

$$M(s_1 s_2) = \begin{bmatrix} C & S \\ C' & S' \end{bmatrix}$$

- The transformation matrix from point $s_1$ to $s_2$ in the lattice is given by :

$$\begin{bmatrix} \beta_{s2} \\ \alpha_{s2} \\ \gamma_{s2} \end{bmatrix} = \begin{bmatrix} C^2 & -2SC & S^2 \\ -CC' & SC' + S'C & -SS' \\ C'^2 & -2S'C' & S'^2 \end{bmatrix} \begin{bmatrix} \beta_{s1} \\ \alpha_{s1} \\ \gamma_{s1} \end{bmatrix}$$

- From the stability condition:

$$|trace\ M(s_1 s_2)| = C + S' < 2$$

We get :

$$K_{QDF} = -1.096\ m^{-2}$$

t the begining of the FODO : $\alpha = 0$, then we have $\beta = \beta r$

enter of the focusing quadrupole.

# Linear beam optics

- The FODO matrix become :

$$M_{FODO} = \begin{bmatrix} 0.95 & 6.59 \\ -0.014 & 0.95 \end{bmatrix}$$

- With $\alpha = 0$ then we have $\beta = \beta_0$ and $\gamma = \frac{1}{\beta_0}$, then Using the transformation matrix:

$$\beta_0 = 13.6\ m$$

- We define the phase advance matrix per cell:

$$\begin{bmatrix} \cos\phi + \alpha\sin\phi & \beta\sin\phi \\ -\gamma\sin\phi & \cos\phi - \alpha\sin\phi \end{bmatrix}$$

- We can immediately get the phase advance :

$$\begin{aligned} \cos\phi &= 0.95 \\ \phi &= \arccos 0.95 \end{aligned} \tag{1}$$