Characterization and Optimization of Polarized and Unpolarized Positron Production

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Abstract

The electron induced production of positrons is a multi-parameter problem which combines elementary physics processes with complex collection systems. The optimization of this technique for 120 MeV and 1000 MeV electron beam kinetic energies is here discussed considering a tungsten target. A strong correlation between the optimum target thickness and the angular acceptance ($\Delta\theta$) of the collection system is observed, as well as sizeable differences between the optimum unpolarized and polarized operational modes. These also extend to the positron momentum and the positron polarization at the optimum, as well as the benefit of high electron beam energies for a high duty cycle positron source.

1 Introduction

The generation of positrons from the interaction of an electron beam in a high Z target is the method selected for the production of positron beams at CEBAF [1], especially because it allows an efficient transfer of the polarization of the initial electron beam to the secondary positron beam [2] and is particularly suited to high-duty cycle beams. This technique proceeds through two distinct processes which occur in a single or two separate targets: firstly the radiation of photons via the bremsstrahlung of the electron beam, and secondly the creation of e^+e^--pairs from the radiated photons.

The present study reports about the optimization of this two step production for a single target scheme, in the perspective of the generation of polarized and unpolarized positron beams. The next sections revisit the elementary polarized bremsstrahlung and pair creation processes, particularly characterizing their angular distributions. The following section discussed the electron induced pair creation, specifically the effects of thick targets and the parameters characterizing the positron production. The optimization procedure is then discussed and applied for 120 MeV and 1000 MeV electron beam kinetic energies. The last section discusses the sensitivity of this production method to the electron beam energy.

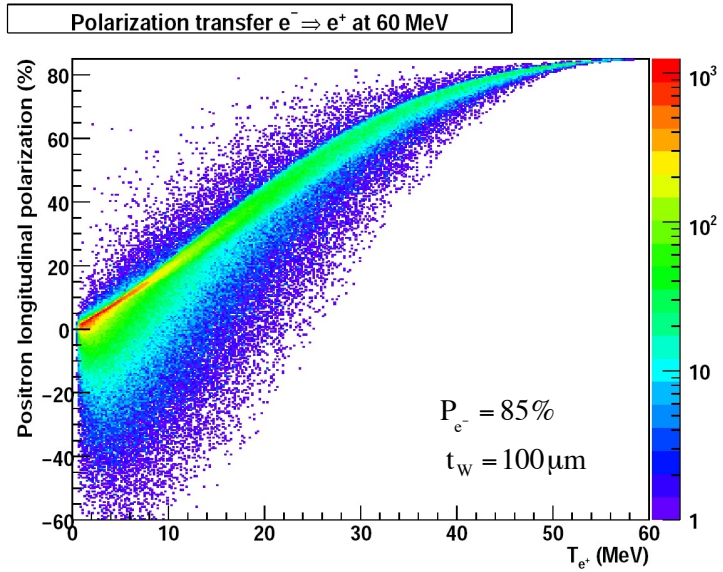
1

Final document about the production of polarized positrons based on calculations and analysis of GEANT4 simulations.

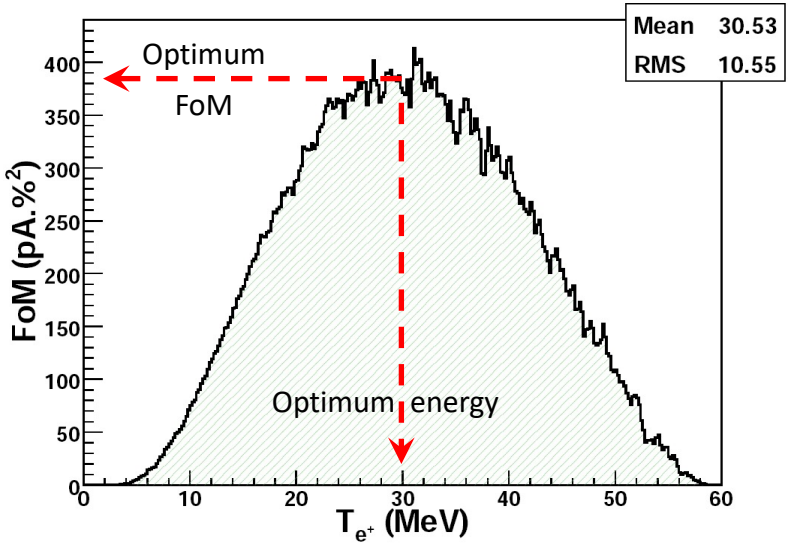
- Characterization of polarized bremmstrahlung
- Characterization of polarized pair-creation
- Characterization of pair creation on thick targets
- Optimization procedure
- Optimized production at 120 MeV
- Optimized production at 1000 MeV
- Electron beam energy dependence

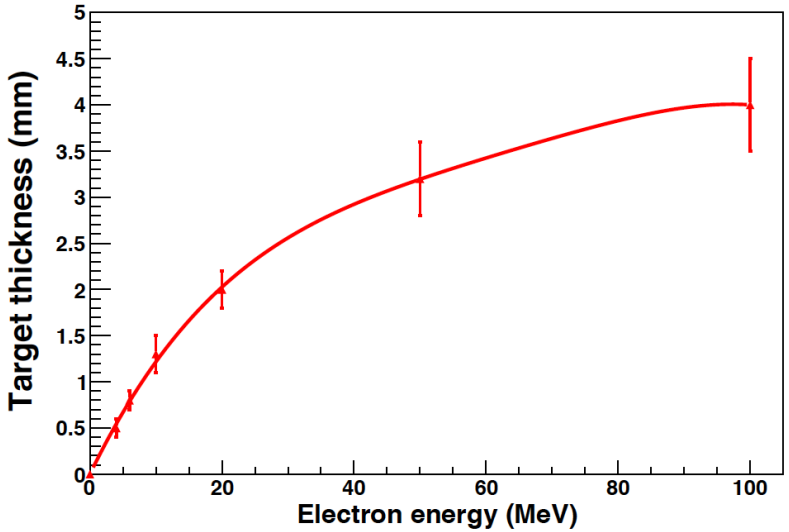
R. Dollan, K. Laihem, A. Schälicke, NIM A 559 (2006) 185 J. Dumas, J. Grames, E. Voutier, JPos09, AIP 1160 (2009) 120 J. Dumas, Doctorate Thesis (2011)

➢ The **polarization distribution** of generated positrons is typical of bremsstrahlung induced pair creation with a production rate dominated by low-energy particles.



$\Delta p/p = 10\%$ $\Delta\Theta = 10°$



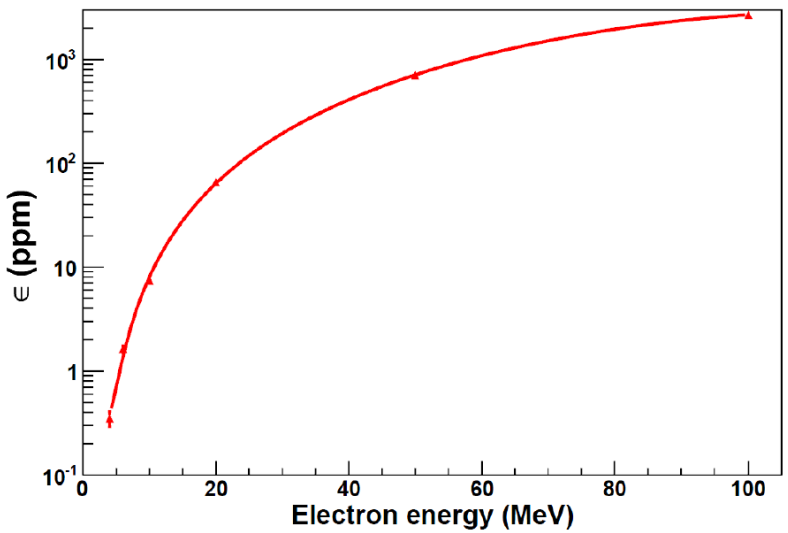


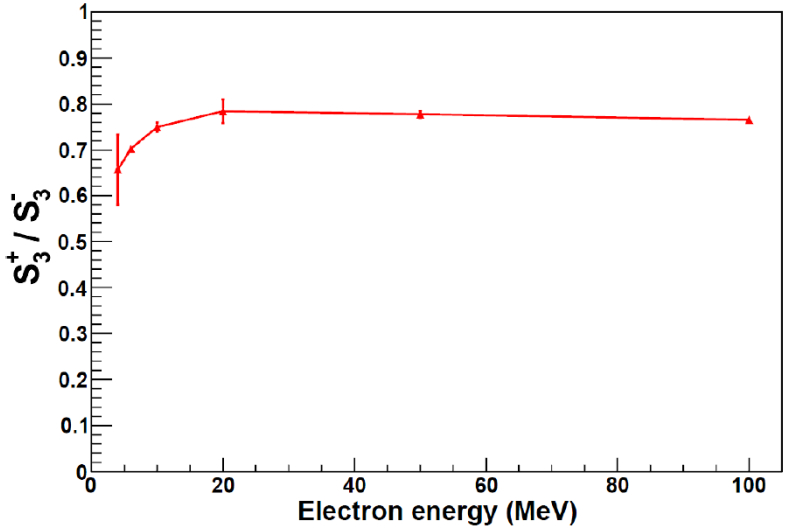
The **positron energy** at optimum FoM is about **half** of the **electron beam energy**.

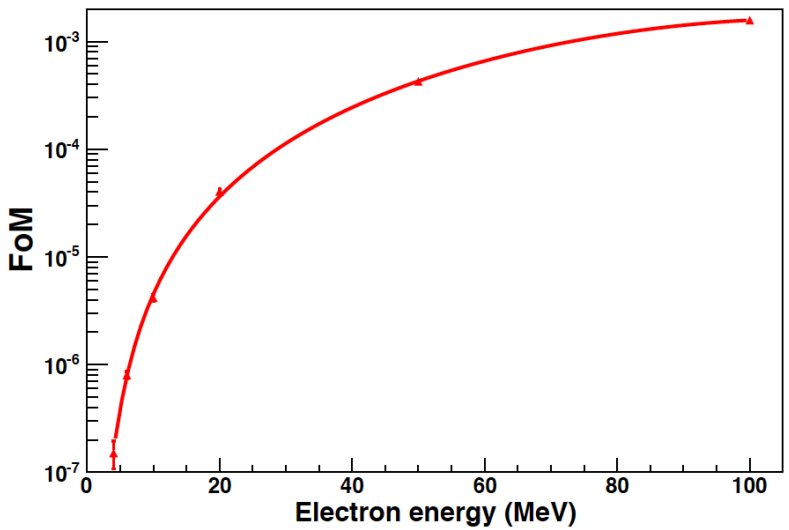
J. Dumas, Doctorate Thesis (2011)

- The **optimized FoM** at each beam energy defines the « **operational conditions** » in terms of the optimum target thickness.
- Simplistic cuts mimic a **capture system** and/or an **accelerator acceptance**, and define the quantitative **source performance**.

$\Delta p/p = 10\%$ $\Delta\Theta = 10°$

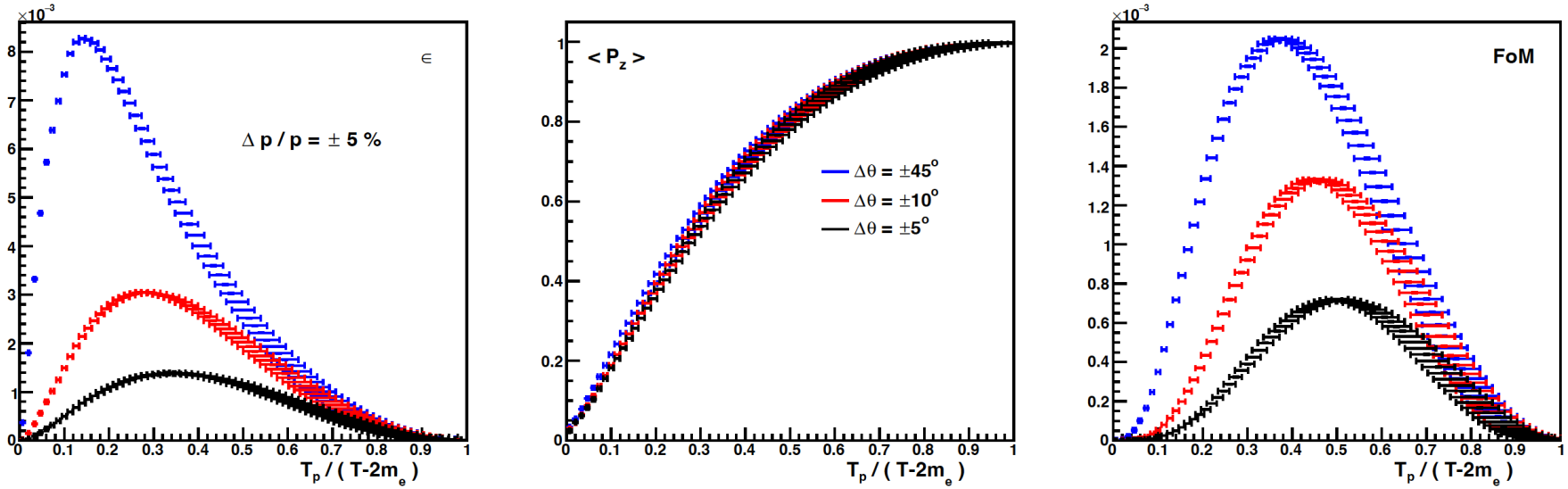






In the 10-100 MeV energy range, one can expect to achieve 75% electron polarization transfer and 10^{-5}-10^{-3} e^+/e^-.

A factor 10 in the e^+ production rate is comfortably obtained for an unpolarized beam.



- ε_{max}, the maximum positron production efficiency;
- FoM_{ε}, the Figure-of-Merit at ε_{max};
- p_{ε}, the positron momentum in MeV/c units at ε_{max};
- P_{ε}, the longitudinal polarization of positrons at ε_{max}.
- FoM_{max}, the maximum Figure-of-Merit;
- ε_{FoM}, the positron production efficiency at FoM_{max};
- p_{FoM}, the positron momentum in MeV/c units at FoM_{max};
- P_{FoM}, the longitudinal polarization of positrons at FoM_{max}.

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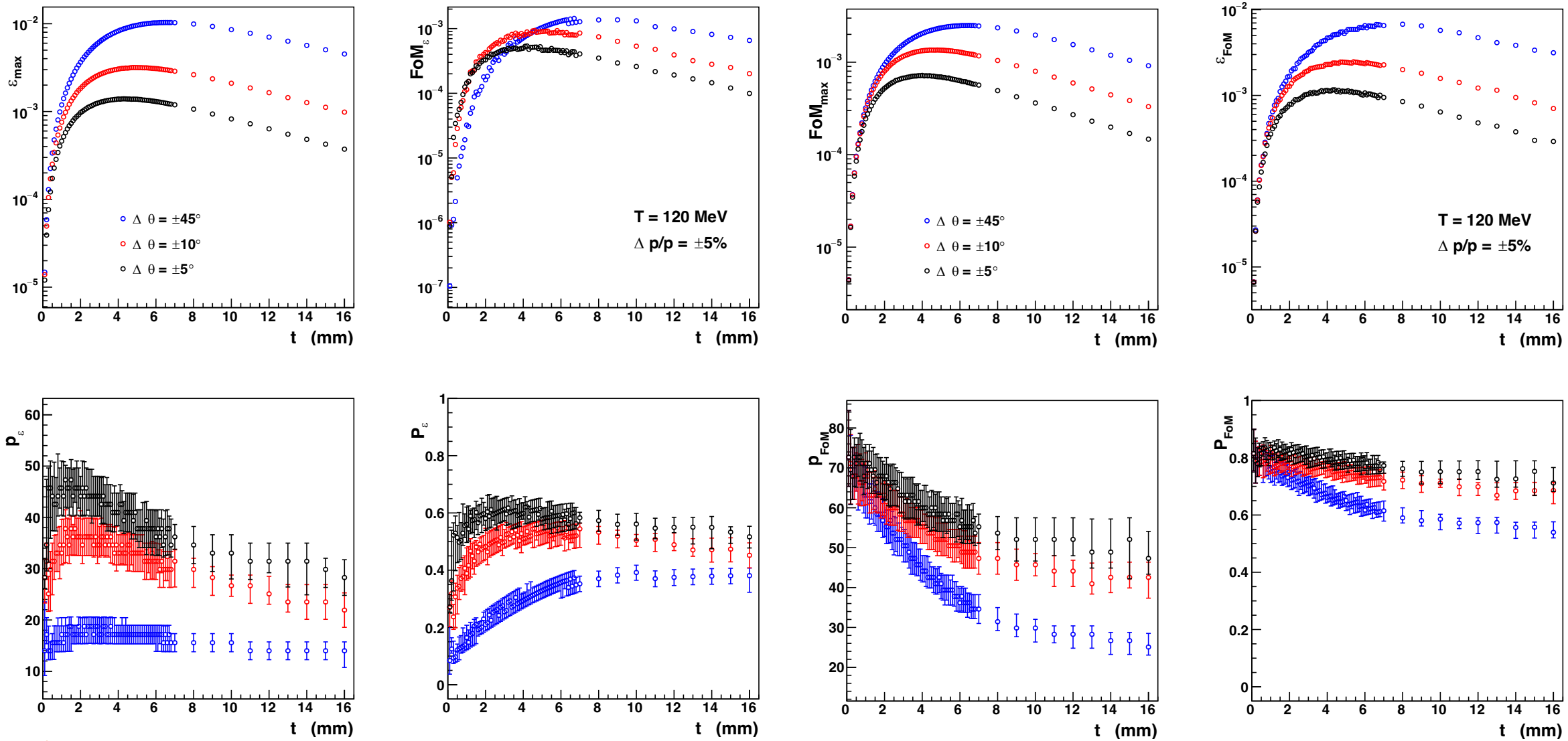
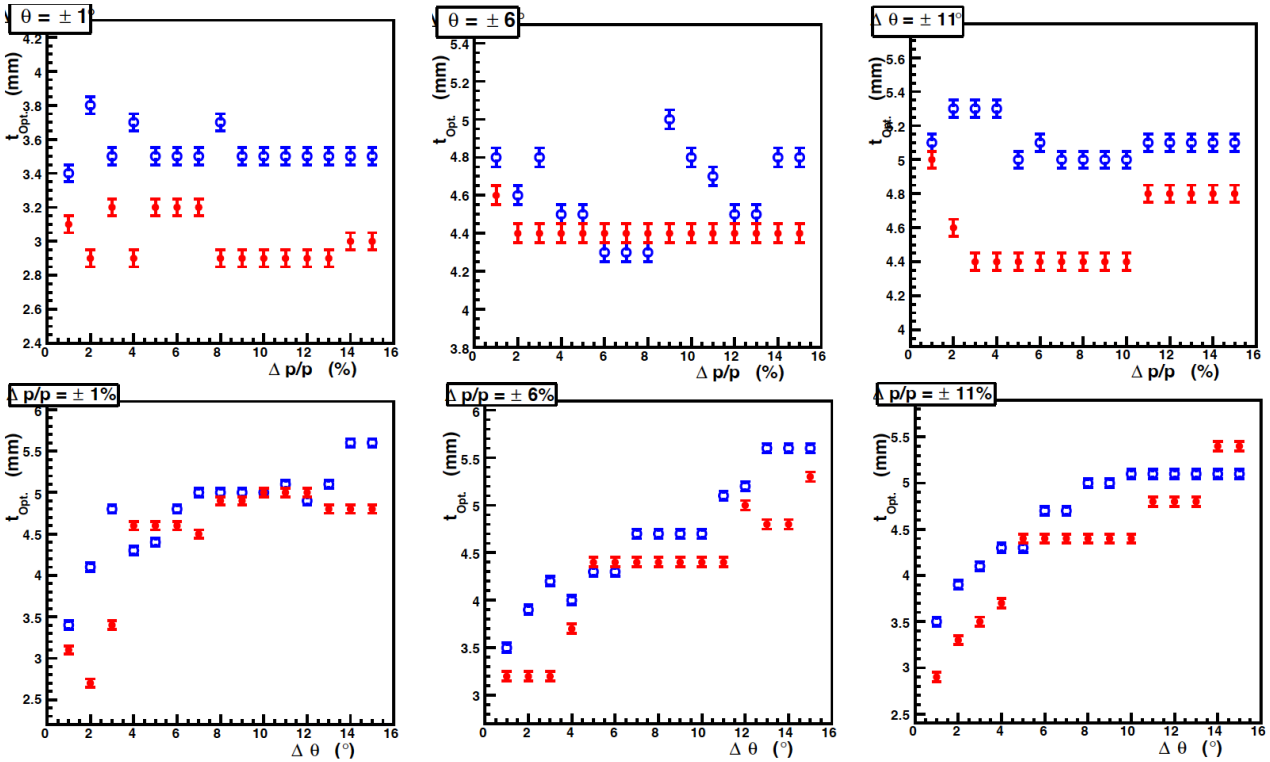
Efficiency optimization

Figure-of-Merit optimization



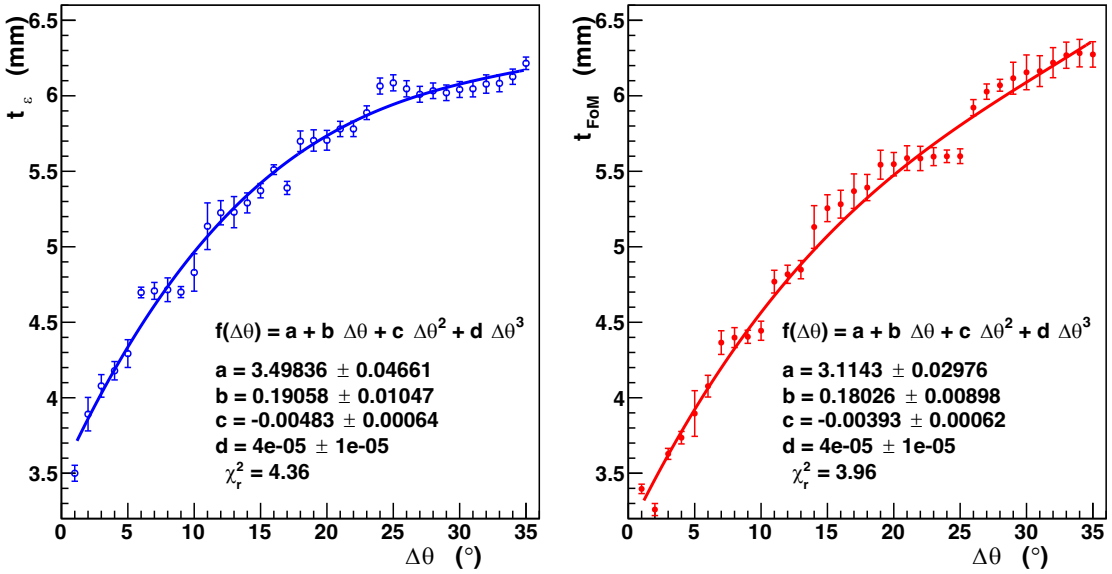
➢ **Operating** conditions of the positron source **strongly depend** on the **angular** and **momentum acceptance** at the source, that is the collection system, and further down the complete beam line till injection into CEBAF.

Δp/p sensitivity at fixed Δθ



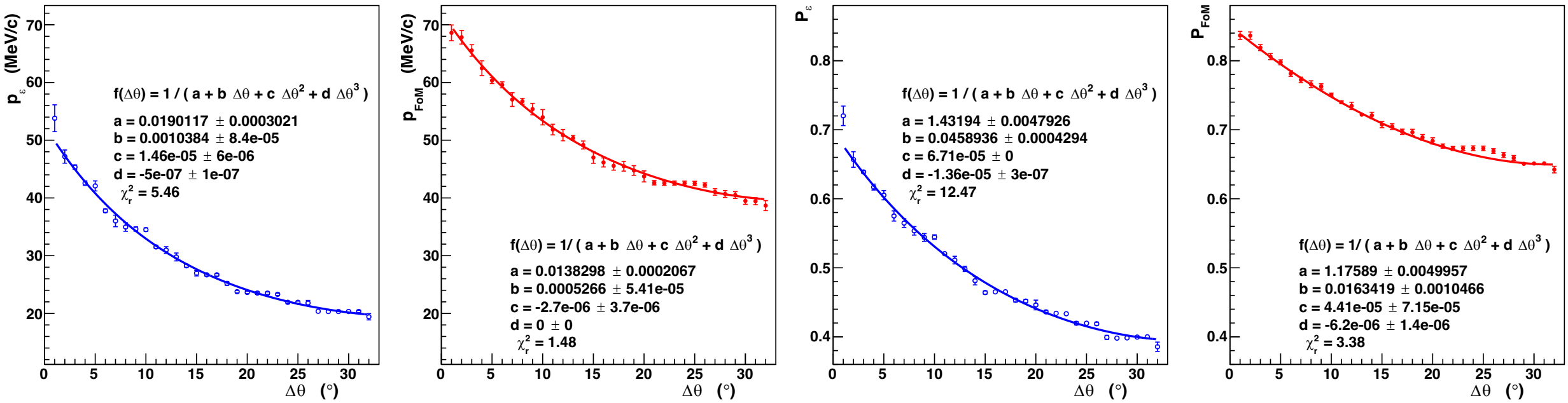
Δθ sensitivity at fixed Δp/p

Optimizing for efficiency or FoM does not provide the same optimum target thickness.



The optimum target thickness is strongly correlated with the effective angular acceptance of the positron source.

- These features naturally extend to the positron momentum and polarization at optimum efficiency or FoM.



The unpolarized mode defined as a maximum efficiency features significant non-zero polarization.

➢ The **comparison** between positron source performances at different **beam energies** **cannot be relevantly achieved independently the full chain of elements that constitute the final positron injector**.

QWT positron collector

$$p_0 = \frac{eB_1L_1}{\pi}$$

$$\frac{\Delta p_0}{p_0} = \frac{4}{\pi}\frac{B_2}{B_1}$$

$$r_0^{QWT} = \frac{B_2}{B_1}R$$

$$\Delta\theta^{QWT} = \frac{\pi}{2}\frac{R}{L_1}$$

Assuming the same collection technology, that is the **same B1** and **B2** magnetic fields, the filtering of high momentum positrons requires a longer high field region.

$$L_1^{1000} = \frac{p_0^{1000}}{p_0^{120}} L_1^{120} \Rightarrow \Delta\theta^{1000} = \frac{p_0^{120}}{p_0^{1000}} \Delta\theta^{120}$$

T (MeV)	$\Delta\theta$ (°)	t_ε (mm)	p_ε (MeV/c)	P_ε (%)	ε_{max} ($\times10^{-3}$)	FoM_ε ($\times10^{-3}$)	$\Delta\theta$ (°)	t_{FoM} (mm)	p_{FoM} (MeV/c)	P_{FoM} (%)	ε_{FoM} ($\times10^{-3}$)	FoM_{max} ($\times10^{-3}$)
					+63%							+48%
1000	1.0	4.9	293.9	53.9	3.97	1.20	1.0	4.6	495.0	78.2	2.99	1.87
120	7.9	4.7	35.82	55.8	2.44	0.72	9.1	4.5	54.34	75.5	2.22	1.26
1000	3.0	6.4	169.3	38.3	12.5	1.76	3.0	6.1	362.2	67.1	7.88	3.61
120	17.5	5.6	25.63	45.8	5.47	1.22	29.3	6.0	37.14	65.1	5.52	2.33
					+129%							+55%

Table 7: Comparison of optimum performances of a PEPPo-like positron source operating at different beam energies, considering the technological constraints of the collection system and a momentum acceptance of $\pm5\%$.

- The angular acceptance at the production target is the most important parameter for reaching high positron beam intensities.
  It calls for small high field region L_1, together with high magnetic field B_1 and moderate B_2 field.

- Small angular acceptances leads to minimal differences between the unpolarized and polarized operational modes, always providing significant longitudinal polarization.

- It is only for large angular acceptances that the unpolarized mode strongly differ from the polarized ones and features minimal longitudinal polarization.