Comparison of different matching device field profiles for the FCC-ee positron source

Y. Zhao[1,3], B. Auchmann[5], I. Chaikovska[4], R. Chehab[4], P. Craievich[5], S. Doebert[3], J. Kosse[5], A. Latina[3], L. Ma[1], P. Martyshkin[2], R. Zennaro[5]

[1] Shandong University. [2] BINP. [3] CERN. [4] IJCLab. [5] PSI.

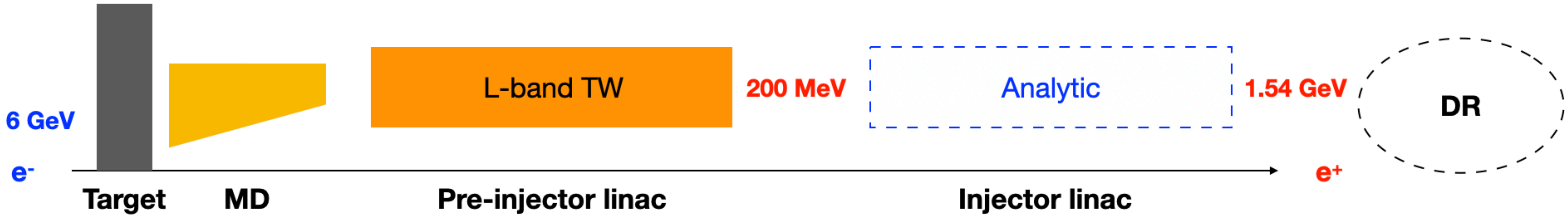
Abstract

In this report, we compared different matching device field profiles for the FCC-ee positron source. The matching device is used to capture positrons with magnetic field. A flux concentrator was designed with a conical inner chamber. A smaller aperture and a larger aperture were studied. An analytic field profile was also studied using an adiabatic formula. The peak field of the analytic profile as well as beam and target parameters was optimised to achieve a maximum positron yield. A safe energy deposition in the target was guaranteed by requiring a constraint on the deposited power and peak energy deposition density.

Introduction

- **FCC-ee positron source layout**
  - Primary e$^-$, **Target**, Matching Device (**MD**), **Pre-injector** linac, **Injector** linac
- **Simulation tools**
  - Geant4, Fot, RF-Track, etc.
- **Figures of merit**
  - **Positron yield** accepted by DR: the higher the better (e$^-$ energy was fixed)
  - Peak energy deposition density (**PEDD**) in target < 35 J/g
  - **Deposited power** in target: the lower the safer (reference limit: ~15 kW)

$$\text{yield}_{e^+} = \frac{n_{e^+}^{\text{DR accepted}}}{n_{e^-}^{\text{primary}}}$$



Target

- **Hybrid scheme** (Fig. 1)
  - Lower e⁺ yield (Fig. 2)
  - Potentially safer radiation and thermal load
  - Alternative scheme with radiation & thermal studies still in progress
- **Conventional scheme** (Fig. 3)
  - Higher e⁺ yield
  - Adopted in this study

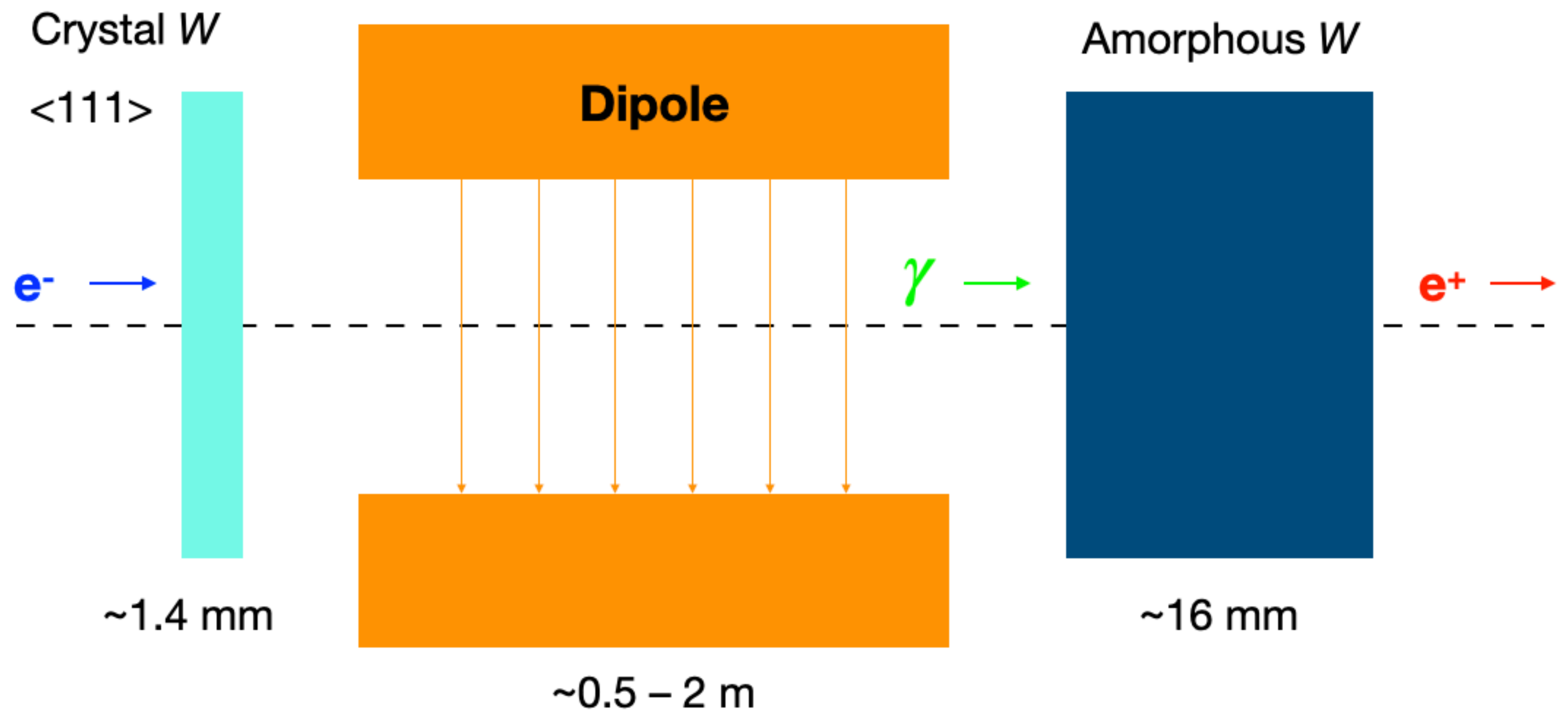


Fig. 1: Hybrid target scheme

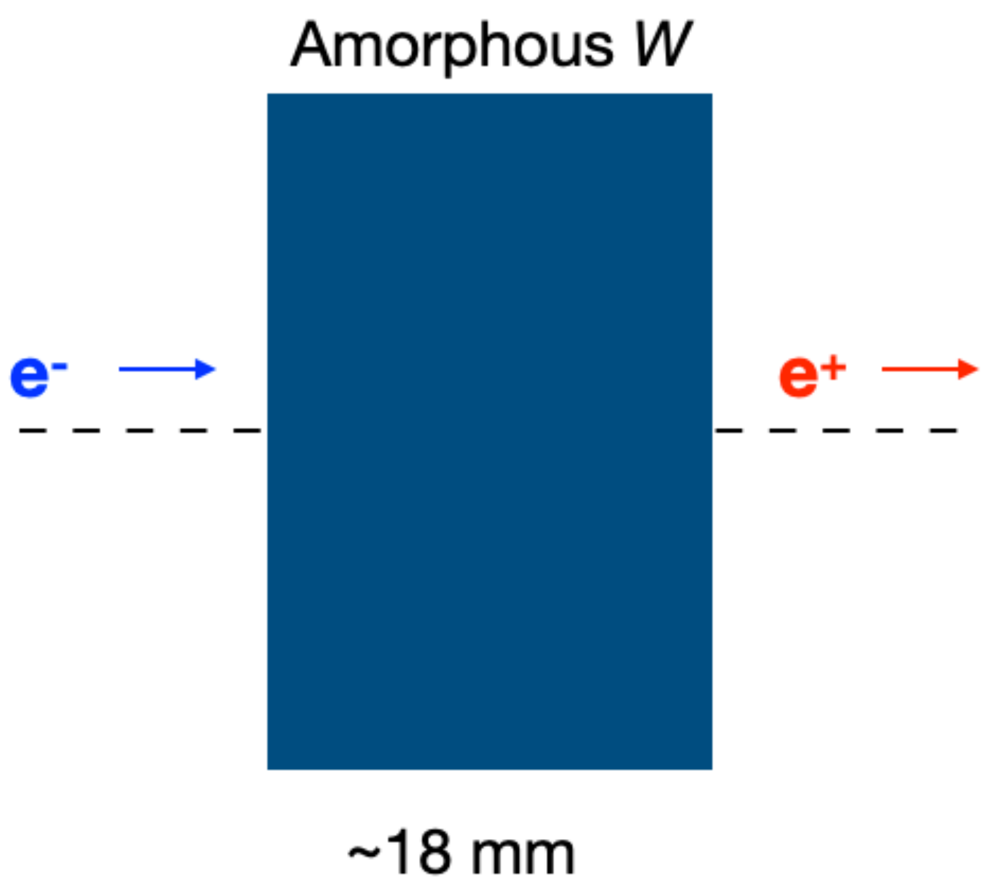


Fig. 3: Conventional target scheme

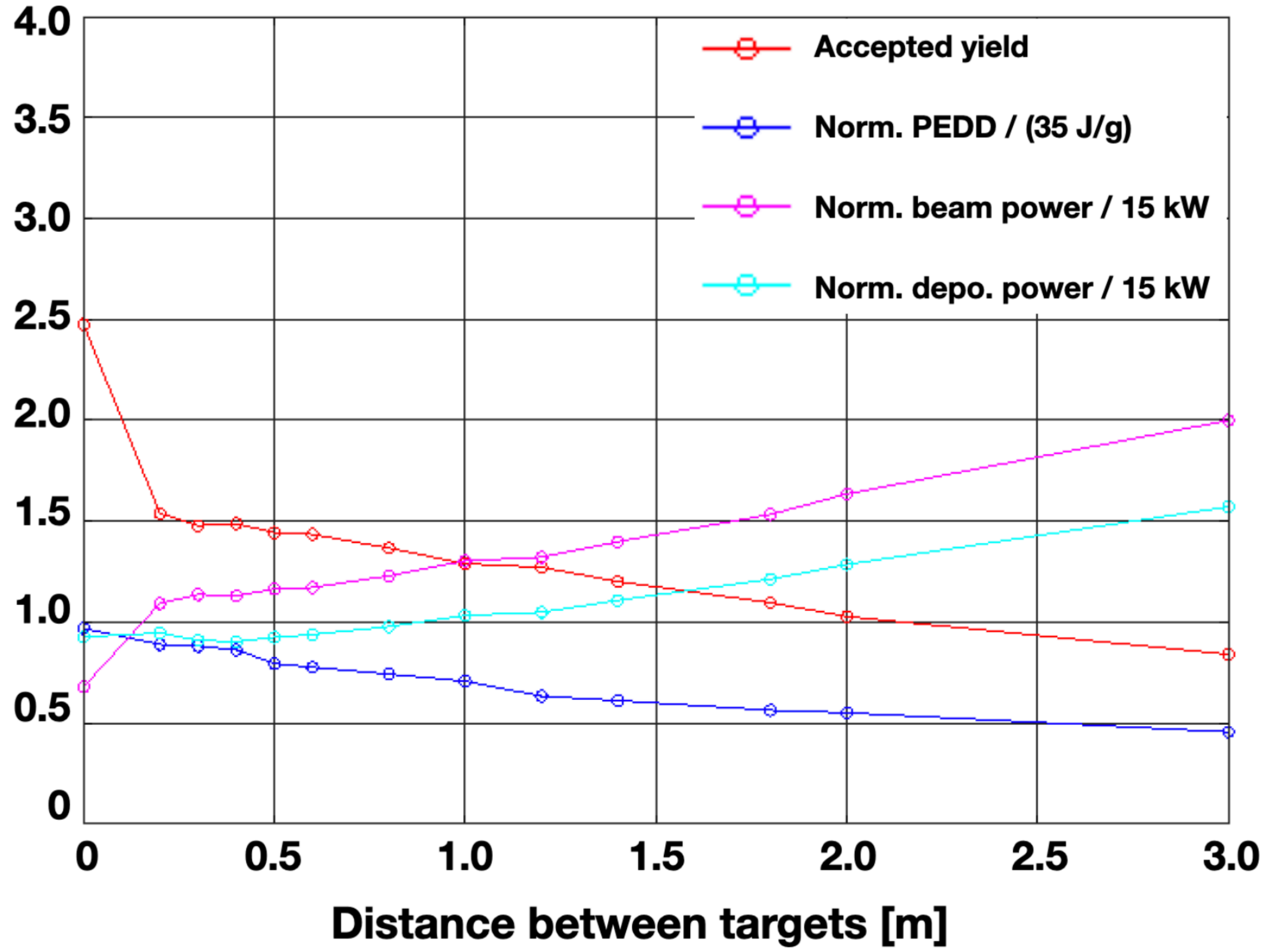


Fig. 2: scan of distance between hybrid targets

- **In reality target material is W_{75}-Re_{25} alloy**

Matching device (MD)

- **Pulsed FC design** (Fig. 1)
  - Smaller aperture
    - Higher peak field (7 T)
    - Aperture diameter: 8-44 mm
    - Target-FC gap: 2 mm
  - Larger aperture
    - Lower peak field (5 T)
    - Aperture diameter: 16-63 mm
    - Target-FC gap: 5 mm
  - NC solenoid field: 0.5 T
- **Analytic profile**
  - Analytic formula for on-axis field

    $B_z = B_0/(1+\mu z), \quad \mu = 50\,\mathrm{m}^{-1}$
  - Aperture diameter assumed: 40 mm

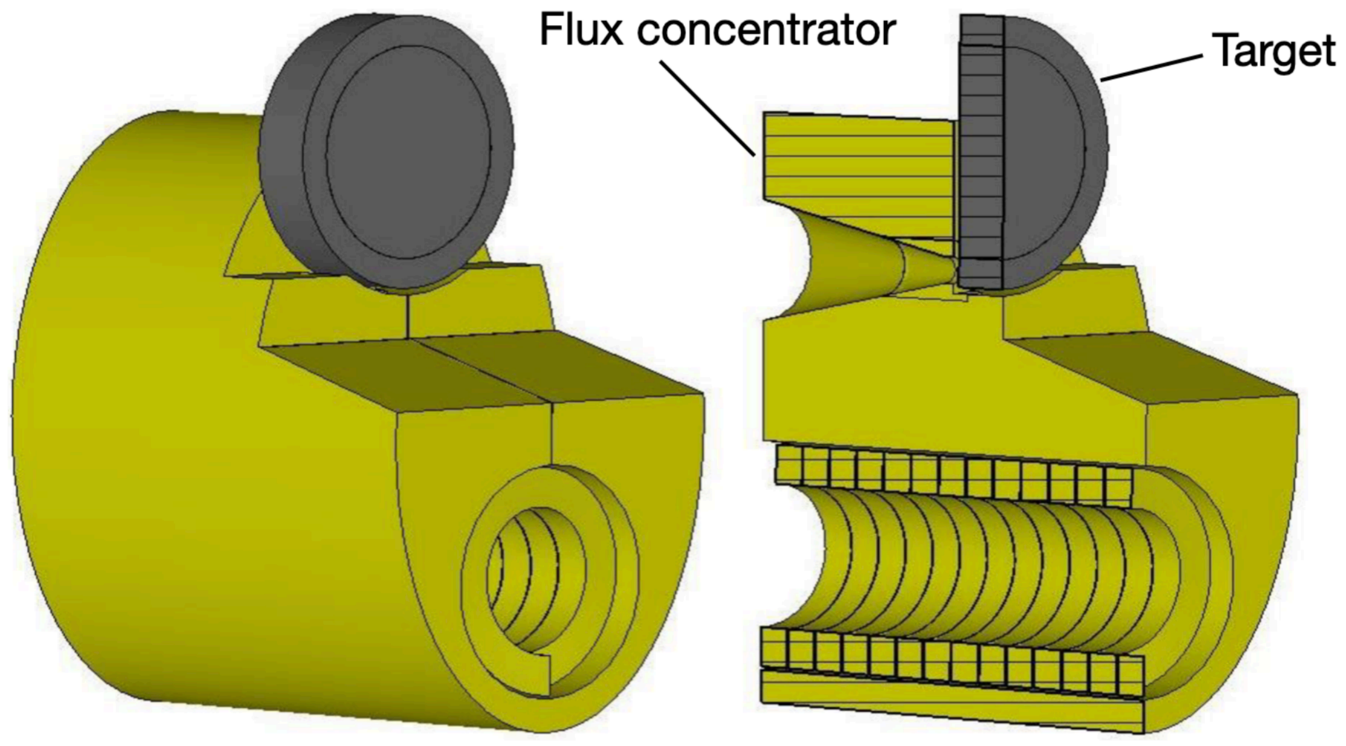
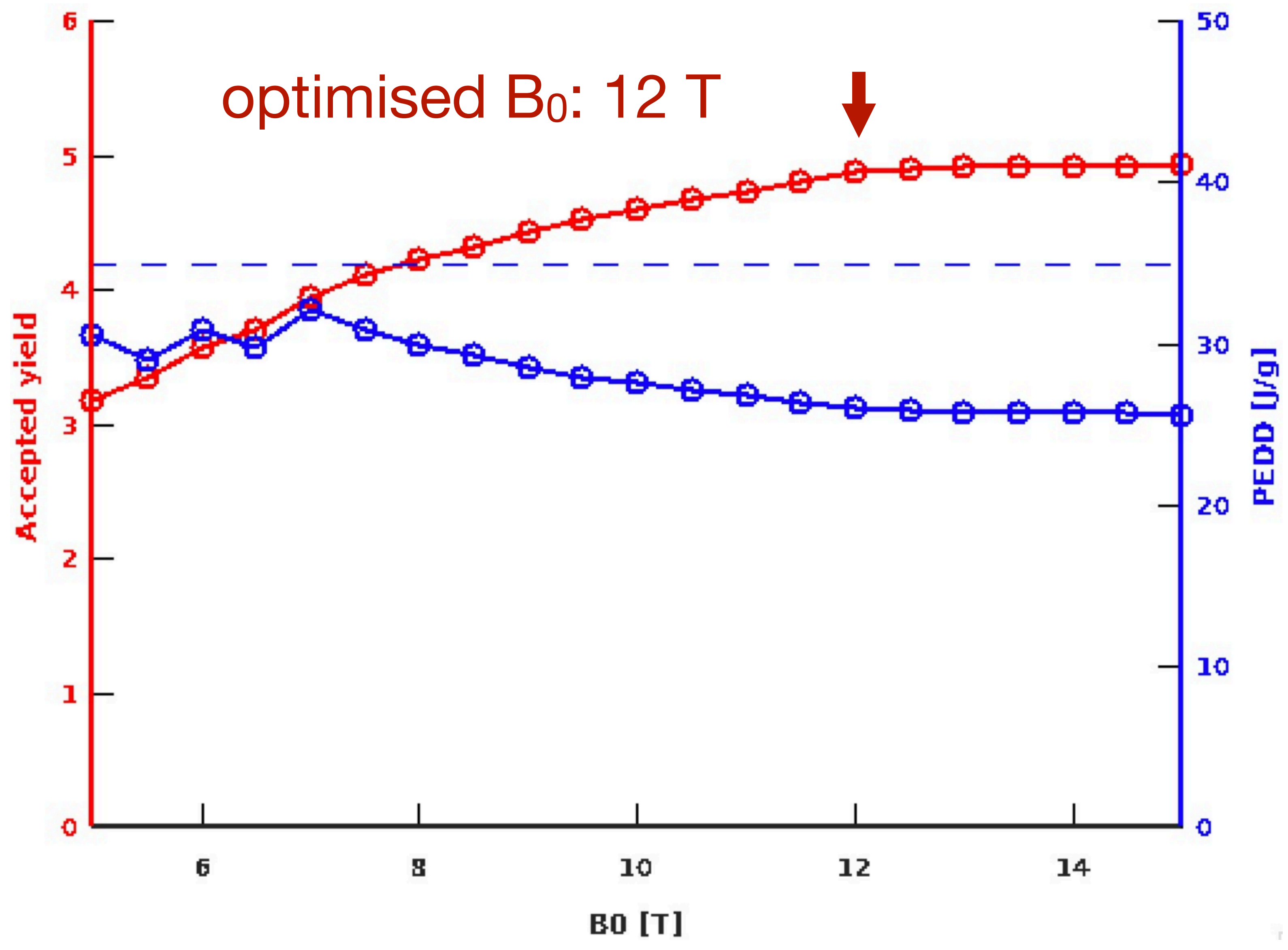
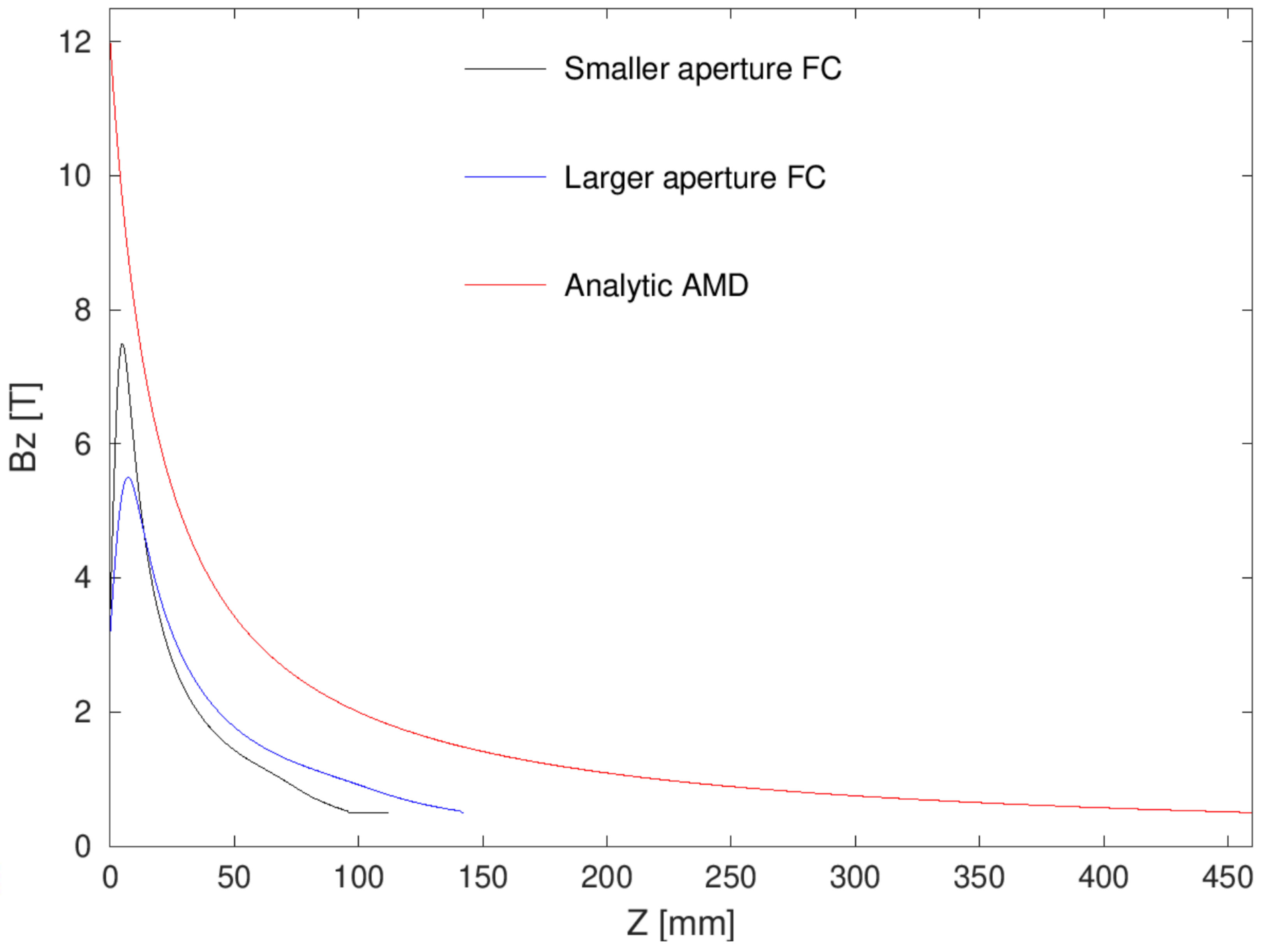


Fig. 1: FC sketch

- **Scan of analytic B_0**



- **On-axis field comparison**



- Primary spot size also optimised:

B0 [T]	< 6	< 7	≥ 7
Spot size [mm]	1.2	1.1	1.0

- PEDD is much more sensitive than positron yield for spot size below 1.0

Pre-injector linac

- L-band TW, 2π/3 mode, 2 GHz
- Aperture diameter: 40 mm
- No. of RF structures: 1 dec. + 10 acc.
- NC solenoid: 0.5 T

Injector linac

- Analytic formula used

$$\Delta E = (1.54\,\mathrm{GeV} - E_{\mathrm{ref}}) \cdot \cos[\omega \cdot (t - t_{\mathrm{ref}})]$$

- Reference particle with energy around 200 MeV
- S-band frequency: 2.856 GHz

Beam parameters

- **e^- parameters**

Parameters	Values	Units
Beam energy	6	GeV
Energy spread (RMS)	0.1	%
Divergence (RMS)	0.01	mrad
Bunch length (RMS)	1	mm
Number of bunches per pulse	25	
Repetition rate	100	Hz

- **e^+ parameters required at the entrance of DR**

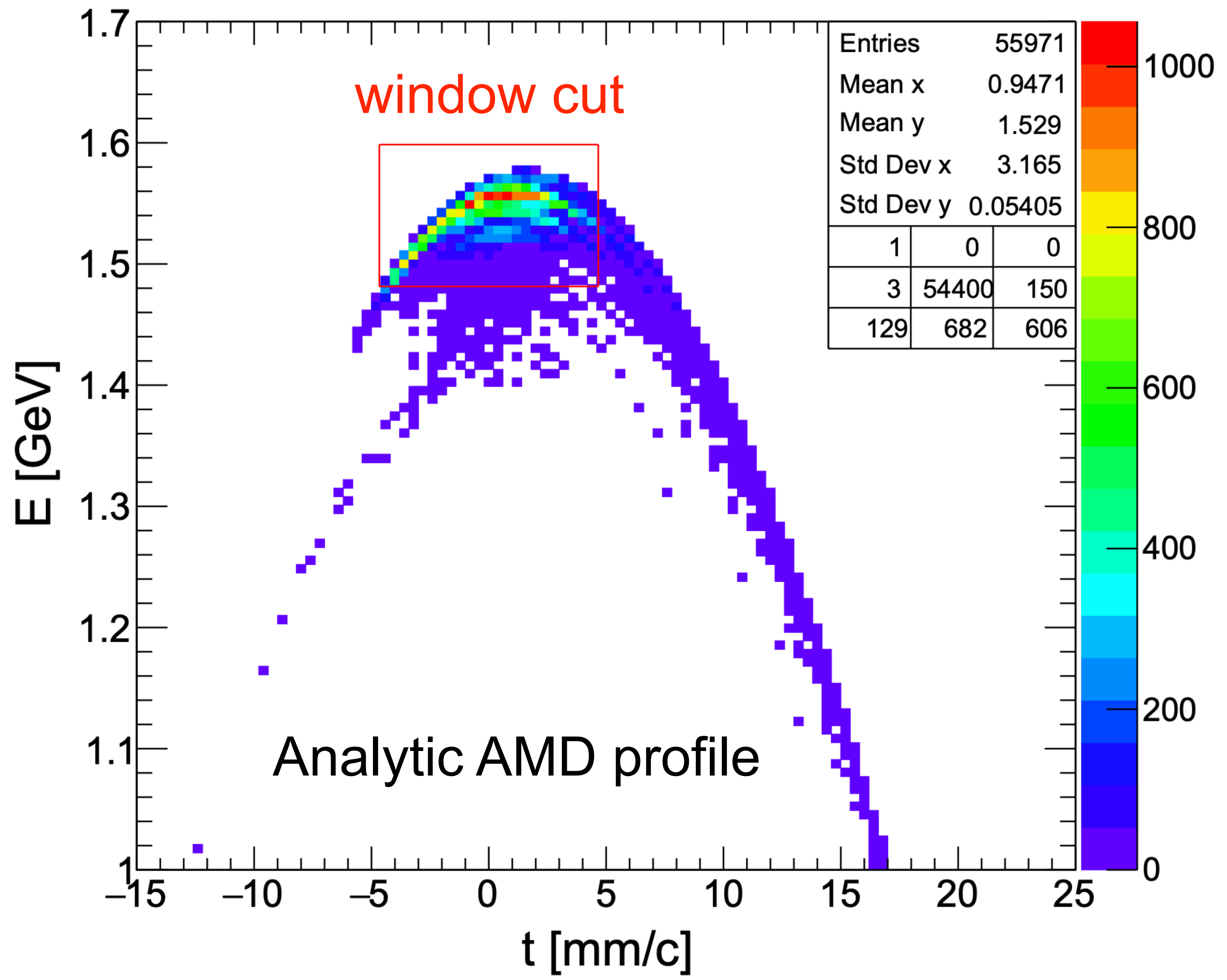
Parameters	Values	Units
Energy acceptance (±)	3.8	%
Time window (total)	9.33	mm/c
Bunch charge	2.1×10^{10}	e^+
Bunch charge safety factor	2	

Final results

- **Normalised results**
  - 8 mm FC refers to the FC with a smaller aperture that the entrance aperture diameter is 8 mm. Similarly, 16 mm FC refers to the FC with a larger aperture

Results	8 mm FC	16 mm FC	Analytic AMD	Units
Spot size	1.5	1.4	1.0	mm
Beam power	42.2	42.3	20.7	kW
Deposited power	10.2	10.2	5.03	kW
PEDD	29.7	31.9	26.0	J/g
Positron yield	2.39	2.38	4.88	

- **e^+ phase space at the entrance of DR**



Summary

- Different matching device field profiles compared for the FCC-ee positron source, with beam and target parameters optimised
- FC with smaller and larger apertures give comparable results
- High positron yield achieved with analytic AMD profile assuming a constant large aperture and a high peak field, which indicates a very promising improvement by using superconducting solenoid