Positron capture

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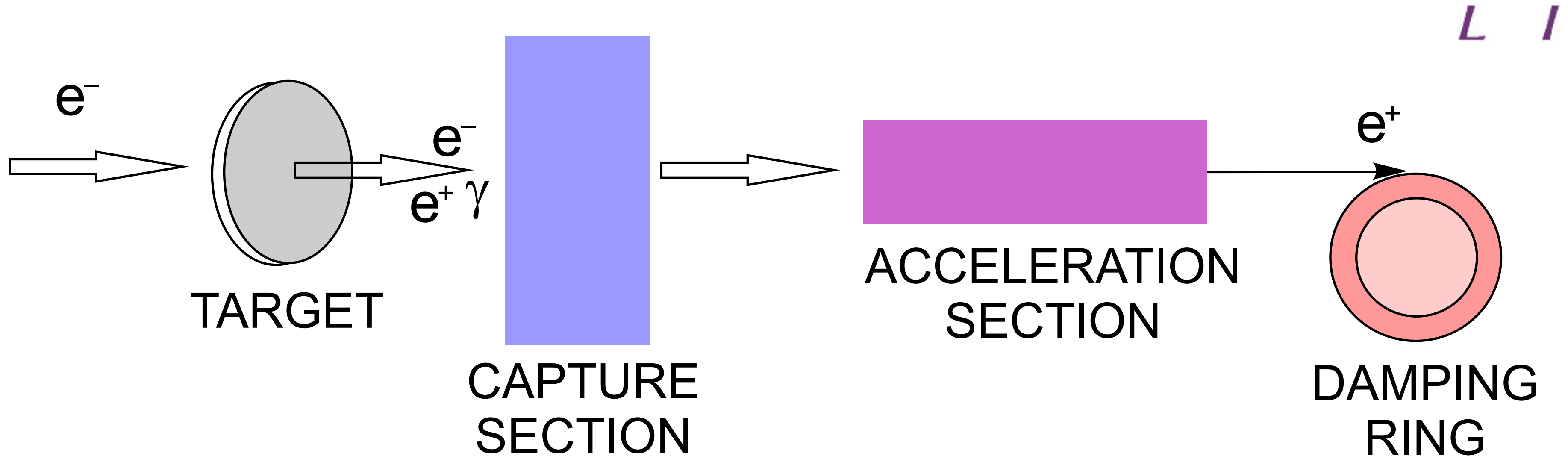
Thanks to: V. Rodin and other collaborators.

Introduction

☞ Conventional Positron Source layout



- e+ are produced within large 6D phase space (e+/e- pairs produced in a target-converter).
- Due to large emission angles (multiple scattering in the target), the e+ must be captured in an efficient matching system before being accelerated in the linac and injected in the Damping Ring.
- Many kinds of matching system have been studied: Quarter Wave Transformer (QWT), Adiabatic Matching Device (AMD), Lithium Lenses, Plasma Lenses…
- One of the most used is the AMD. First studied and installed at SLAC by R. Helm in 60s.

FCC-ee Positron Source

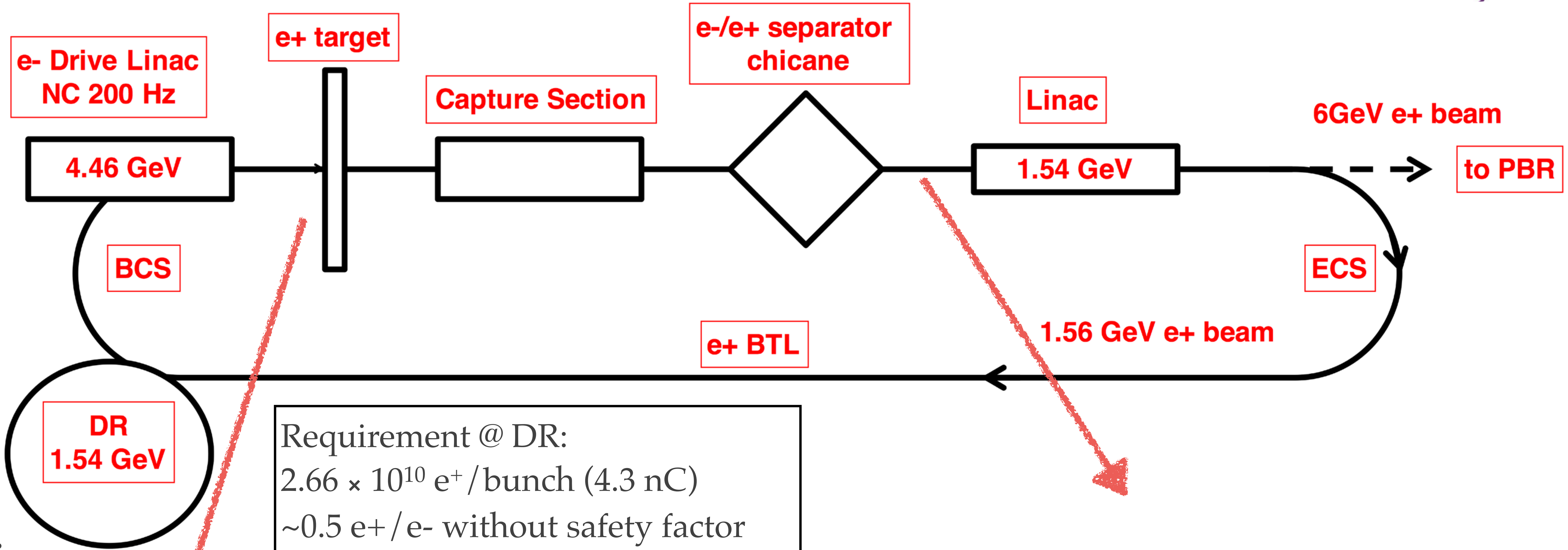
<u>Primary e- beam</u>

4.46 GeV

2.66×10^{10} e^-/bunch ~ 4.3 nC (main e- beam)

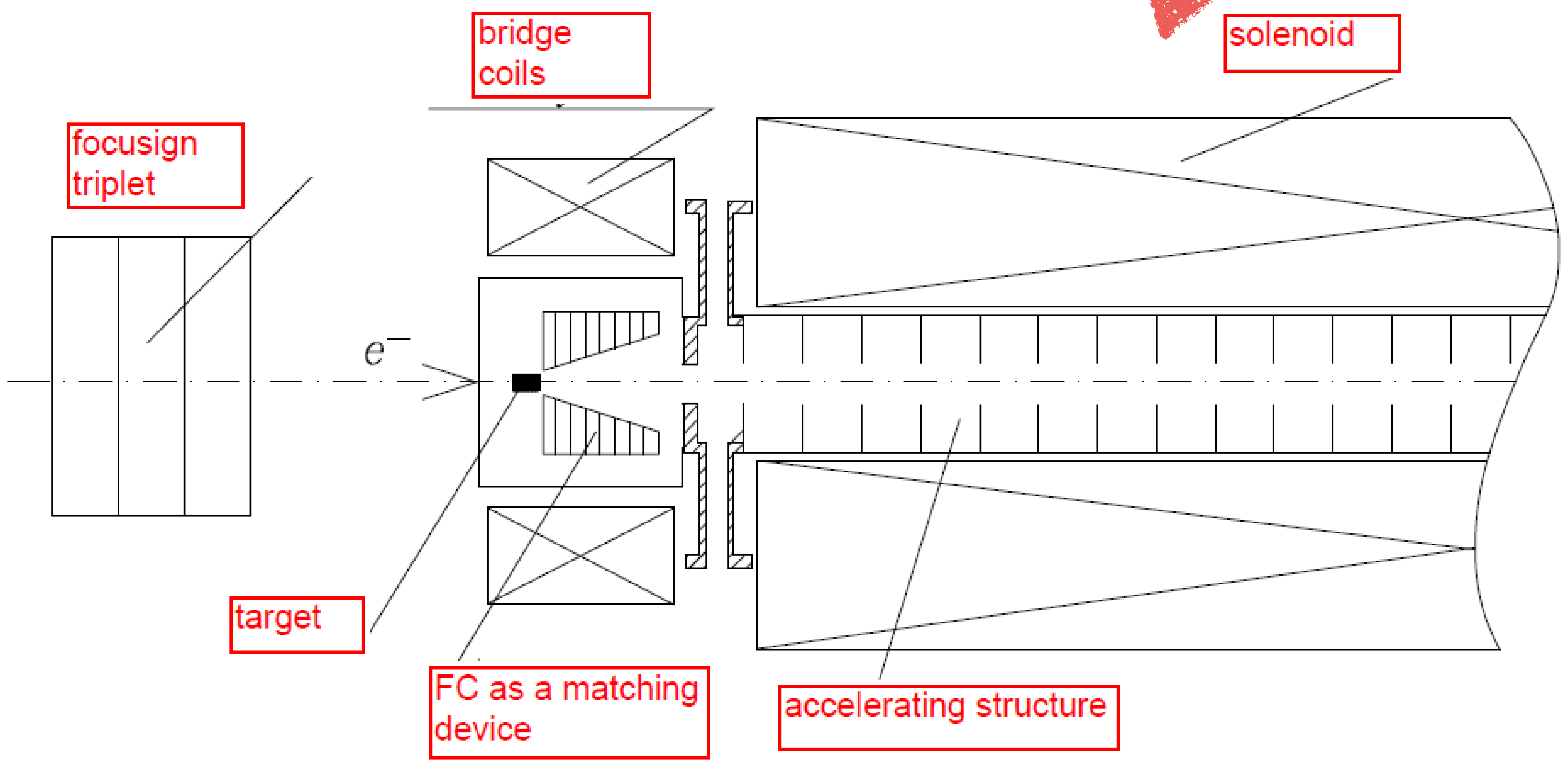
5.3×10^{10} e^-/bunch ~ 8.5 nC (for e+ production)

2 bunches/pulse spaced by 60 ns

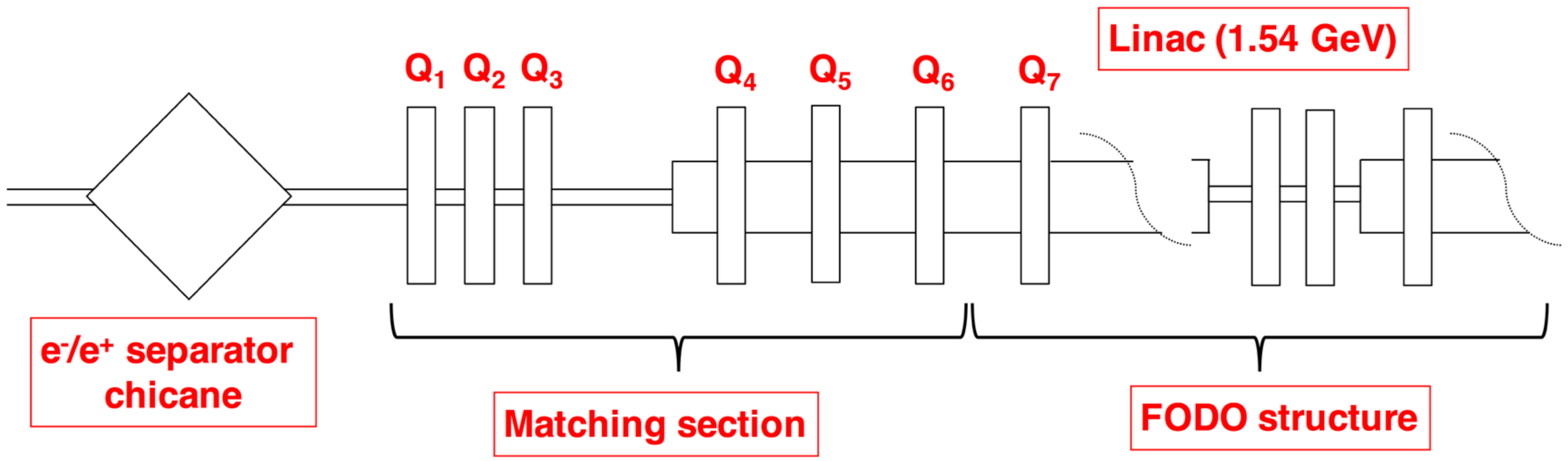


Requirement @ DR:
2.66×10^{10} e^+/bunch (4.3 nC)
~0.5 e+/e- without safety factor

e+ production and capture section



e+ acceleration up to 1.54 GeV

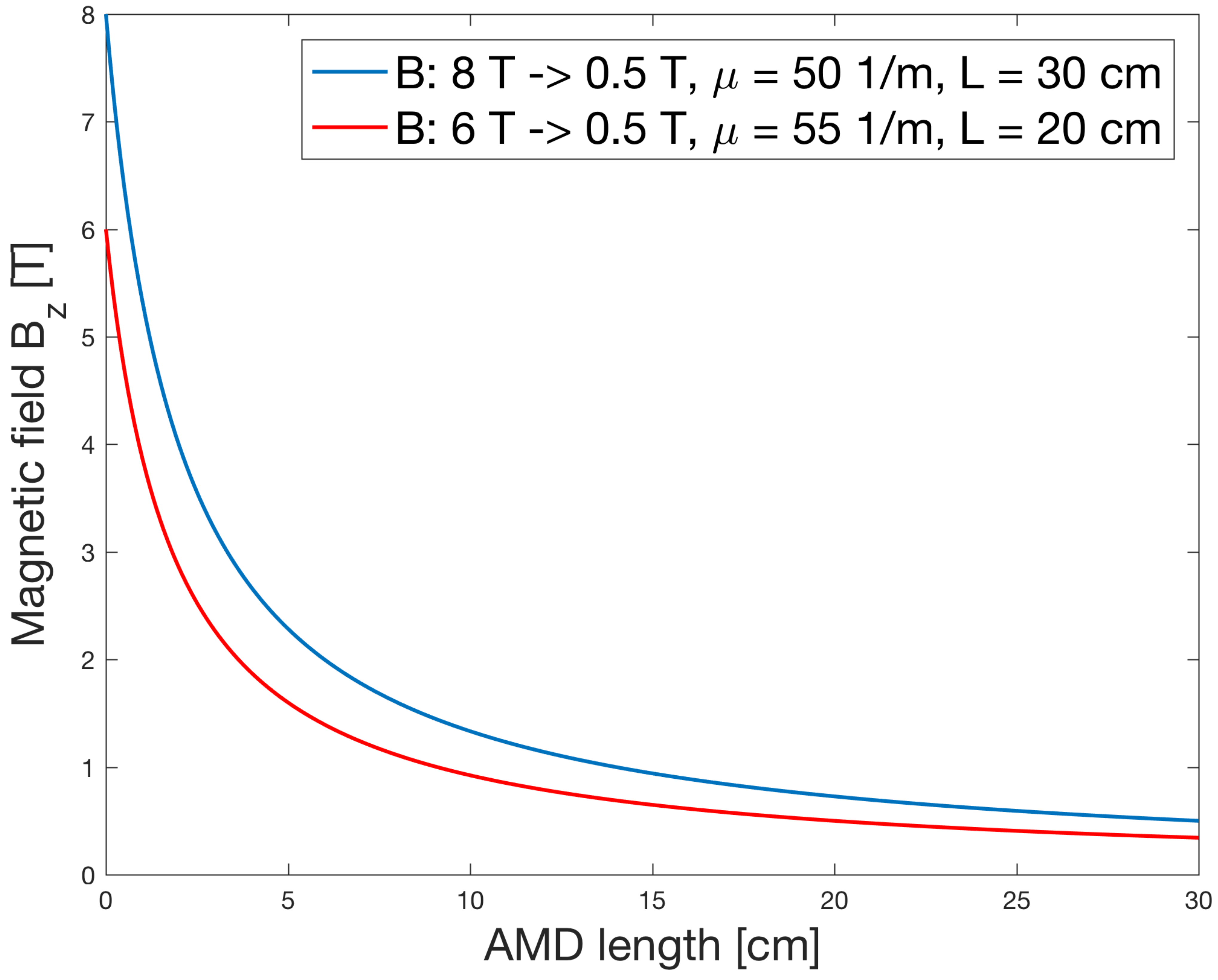


e+ capture in the AMD

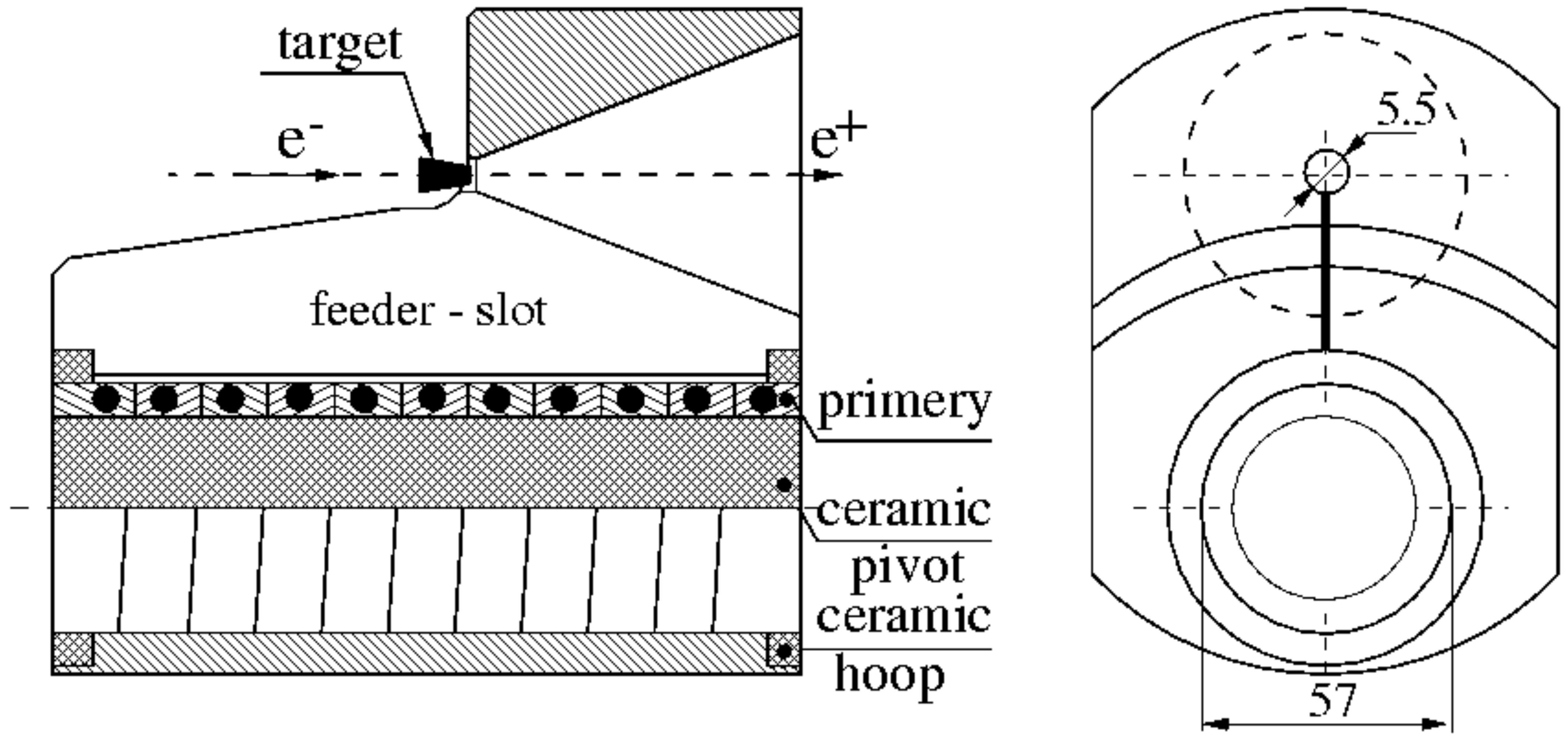
- The AMD uses a slowly varying magnetic field followed by a long solenoidal magnetic field extending over some accelerating sections. Between maximum B_0 and minimum B_s the field tapers adiabatically (the flux of magnetic field though the beam section is conserved).
- The strong tapered solenoidal field, provided by the Flux Concentrator, focuses the positrons emerging from the target.
- The phase space matching is obtained from the FC and the DC magnetic field along the Pre-Injector linac which form the Adiabatic Matching Device (AMD).
- e+ are accelerated with L-band RF structures. Larger iris apertures allow larger transverse acceptances (more than a factor 4 compared to S-band).
- At 200 MeV, e+ pass through the quadrupole focusing system and they are accelerated up to energy needed to be injected into the DR.

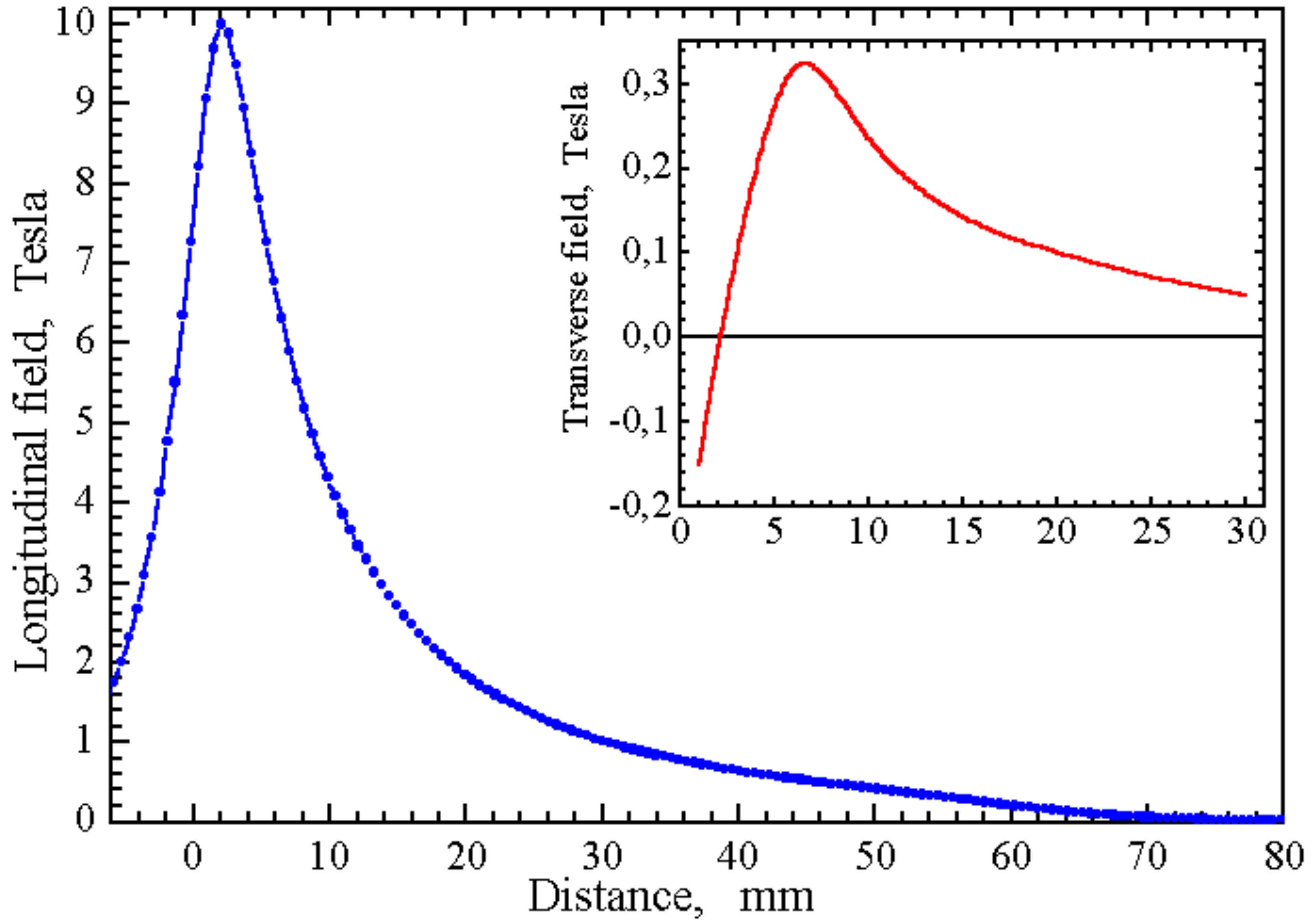
Focusing system: AMD

- The magnetic field law $$B(z) = \frac{B_0}{1 + \mu z}$$
- Field at the target $B_0 = 5 - 8$ T, μ is such $\mu = \varepsilon B_0/P_0$, where P_0 a "central" momentum value and ε smallness parameter: $\varepsilon=(P/eB^2)dB/dz$
- Magnetic length L = 10 - 50 cm
- Magnetic field at the end B(L) = Bs = 0.5 T
- High fields in the adiabatic lens => flux concentrator.



VEPP-5 Flux Concentrator



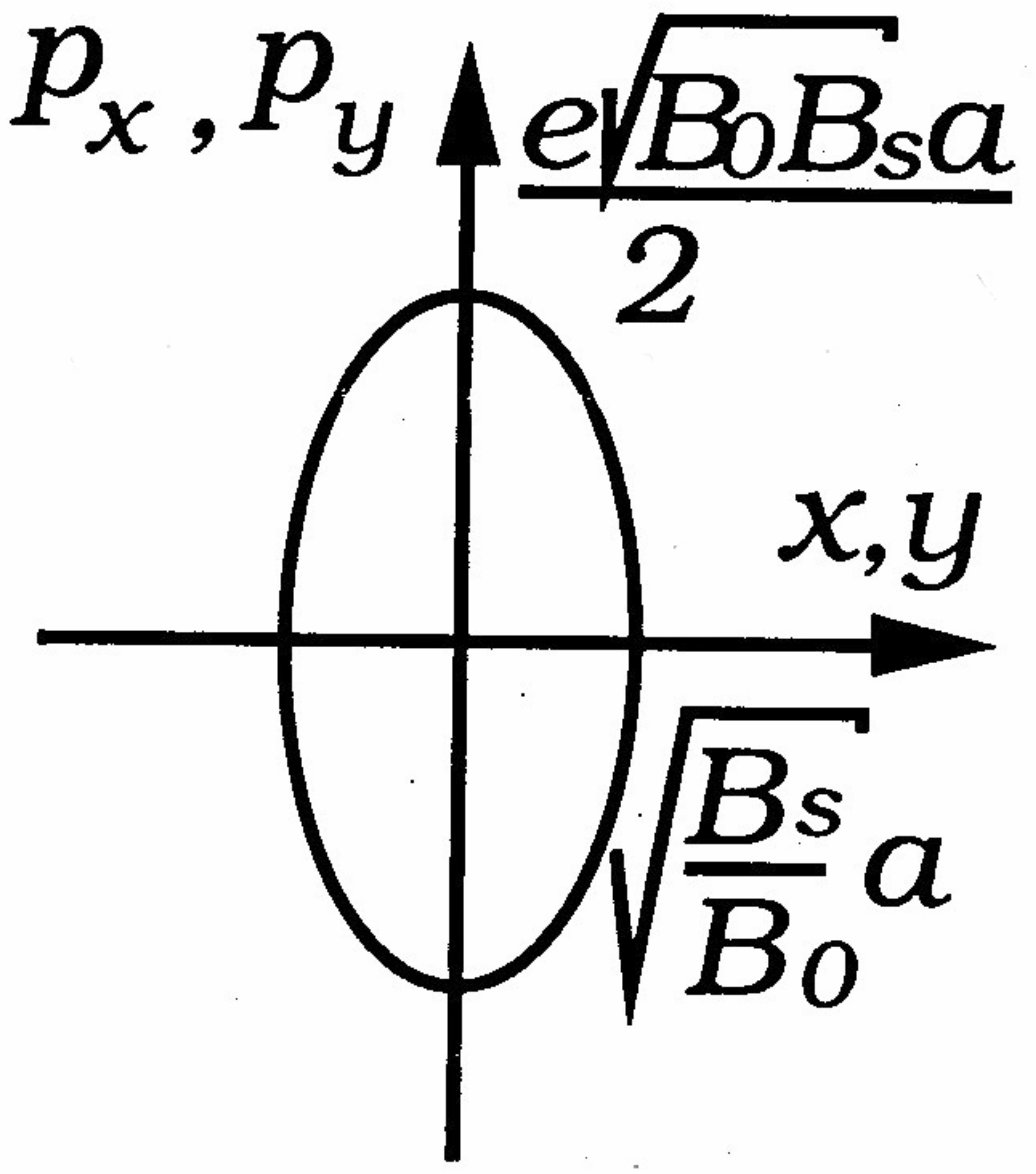


Focusing system: AMD

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Transverse phase space

$$\left[\frac{B_0}{B_s}\right]\left(\frac{r_0}{a}\right)^2+\left(\frac{p^*_{r0}}{\frac{1}{2}e\sqrt{B_0B_s}\,a}\right)^2+\left(\frac{p^*_{\varphi 0}}{\frac{1}{2}eB_sa^2}\right)^2\left[\frac{B_0}{B_s}\cdot\frac{1}{[\frac{r_0}{a}]^2}-1\right]\leq 1$$



- Transverse acceptances at the target exit, with canonically conjugate variables, are represented by upright ellipses:
- Xo, Yo = $[Bs/Bo]^{1/2}a$ {small axes}
- Pxo, Pyo = $e[BoBs]^{1/2}a/2$ {big axes} , a is accelerator radius.
- The transverse momentum acceptance (target inside the solenoid): $P_T = e[BoBs]^{1/2}a$.
- Maximum emittance at solenoid exit: $eBs\, a^2/2$.

Focusing system: AMD

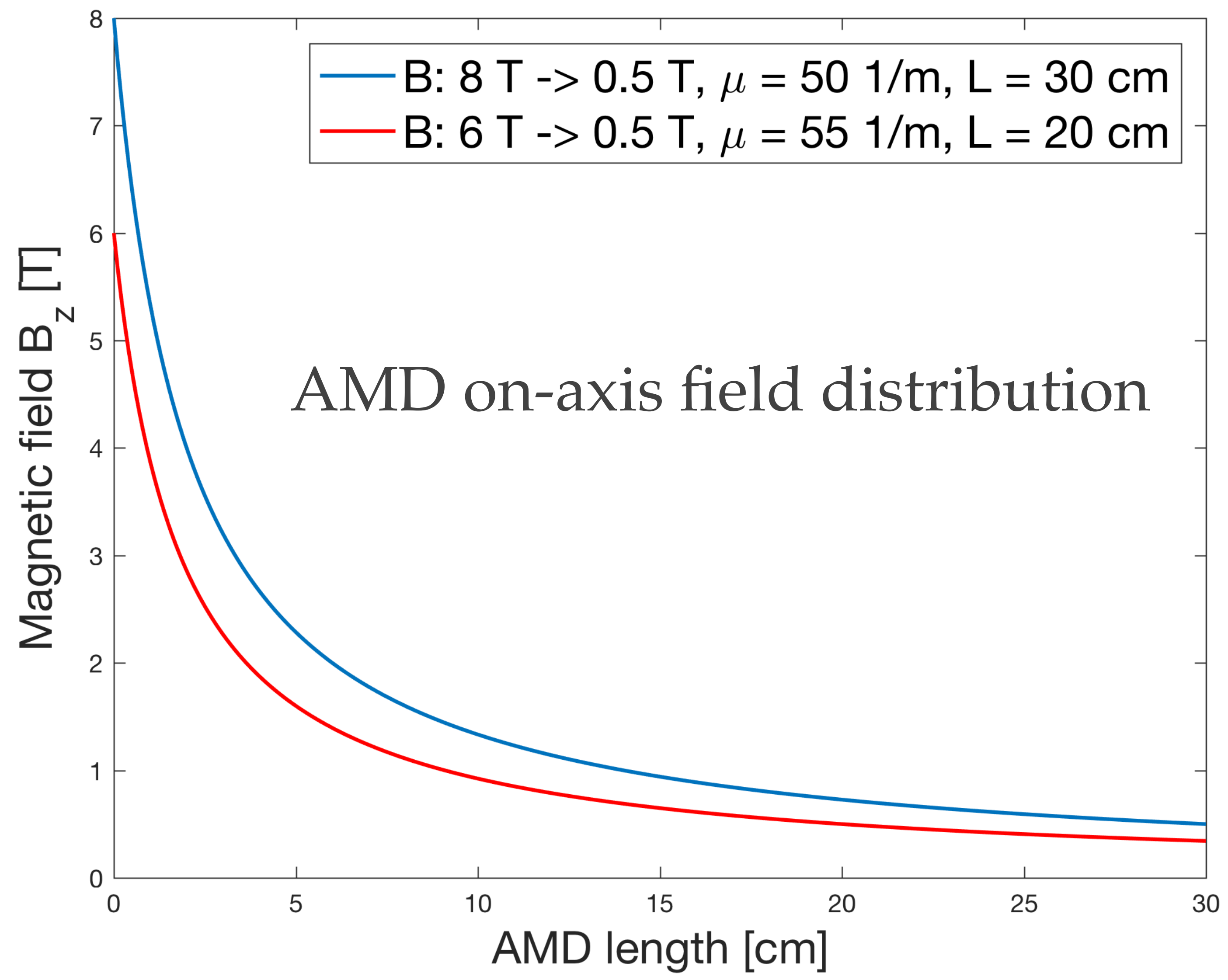
LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

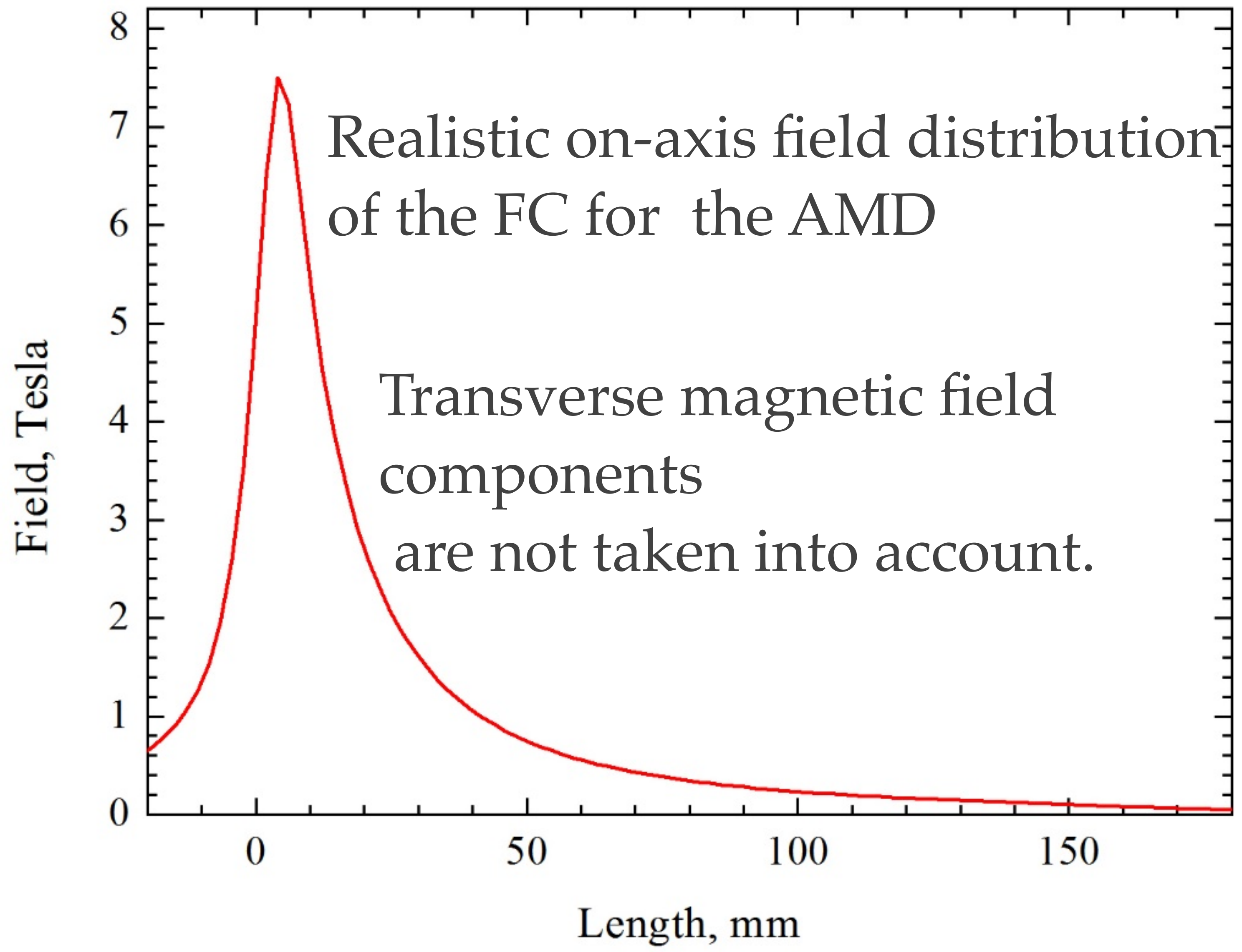
<u>Longitudinal phase space</u>

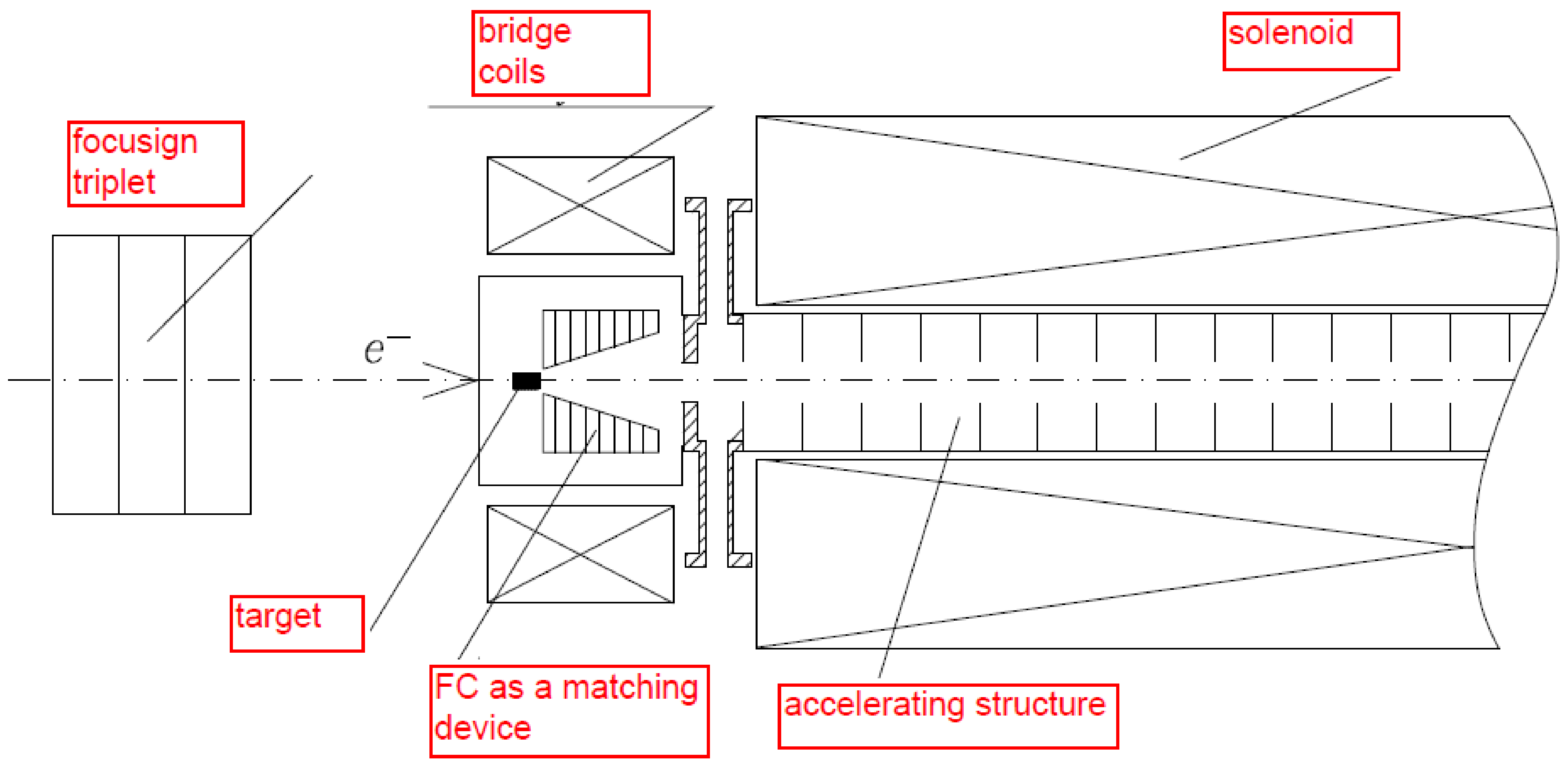
- At the target exit the positrons undergo trajectory lengthening (debunching) due to: velocity dispersion and spiralization of the particles in the solenoidal field.
- Trajectory lengthening induces phase dispersion worsening and momentum dispersion broadening.
- Max momentum is determined by the validity of the adiabatic condition $\varepsilon = \frac{\mu P}{eB_0} \approx \frac{\mu P_z}{eB_0} \leq 0.5$
- The particles which have the momentum higher than the limit are assumed not to be accepted.

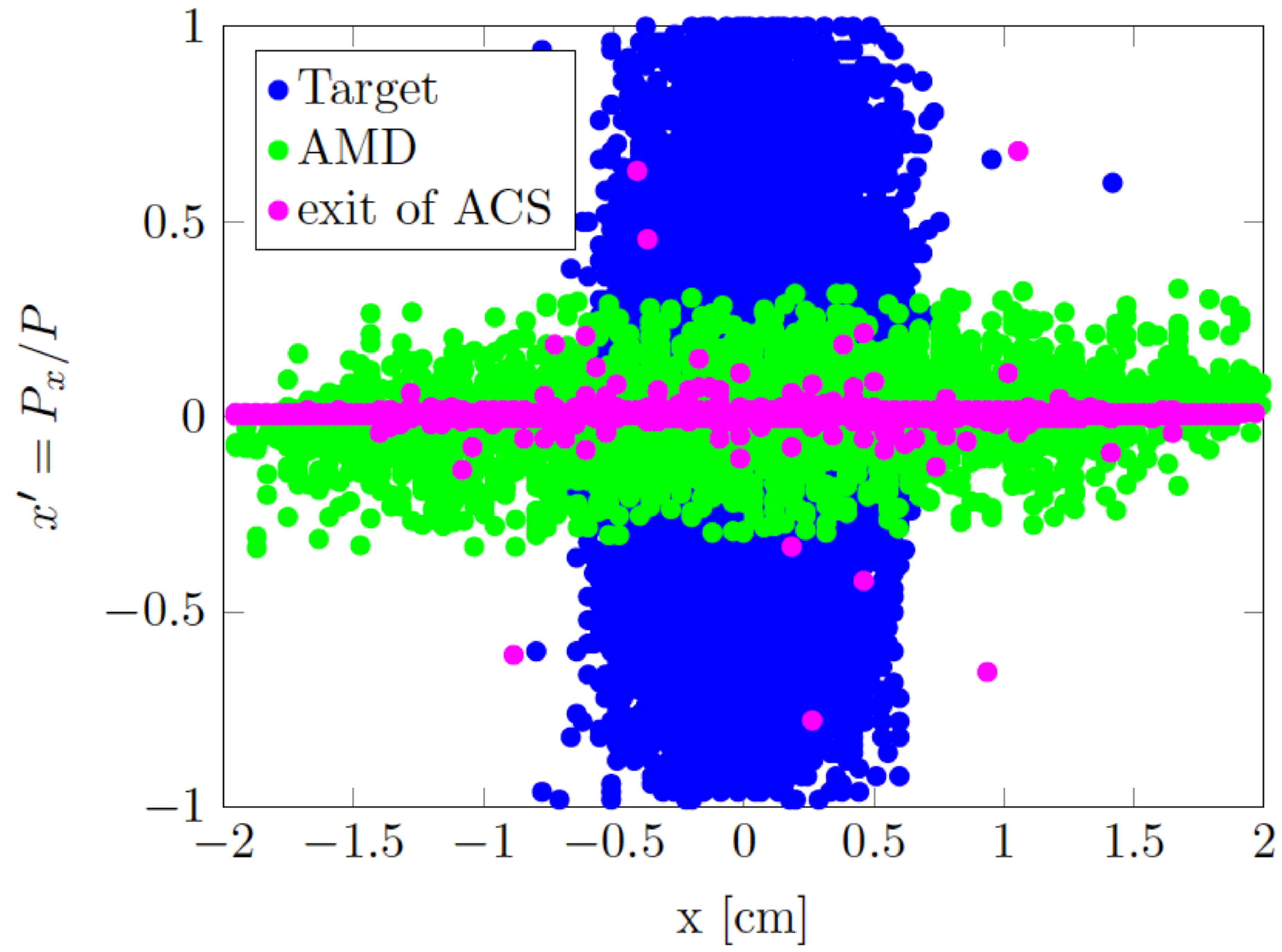
The parameter of smallness ε is usually taken no larger than 0.5 (R.Helm & R.Chehab)

Focusing system: AMD





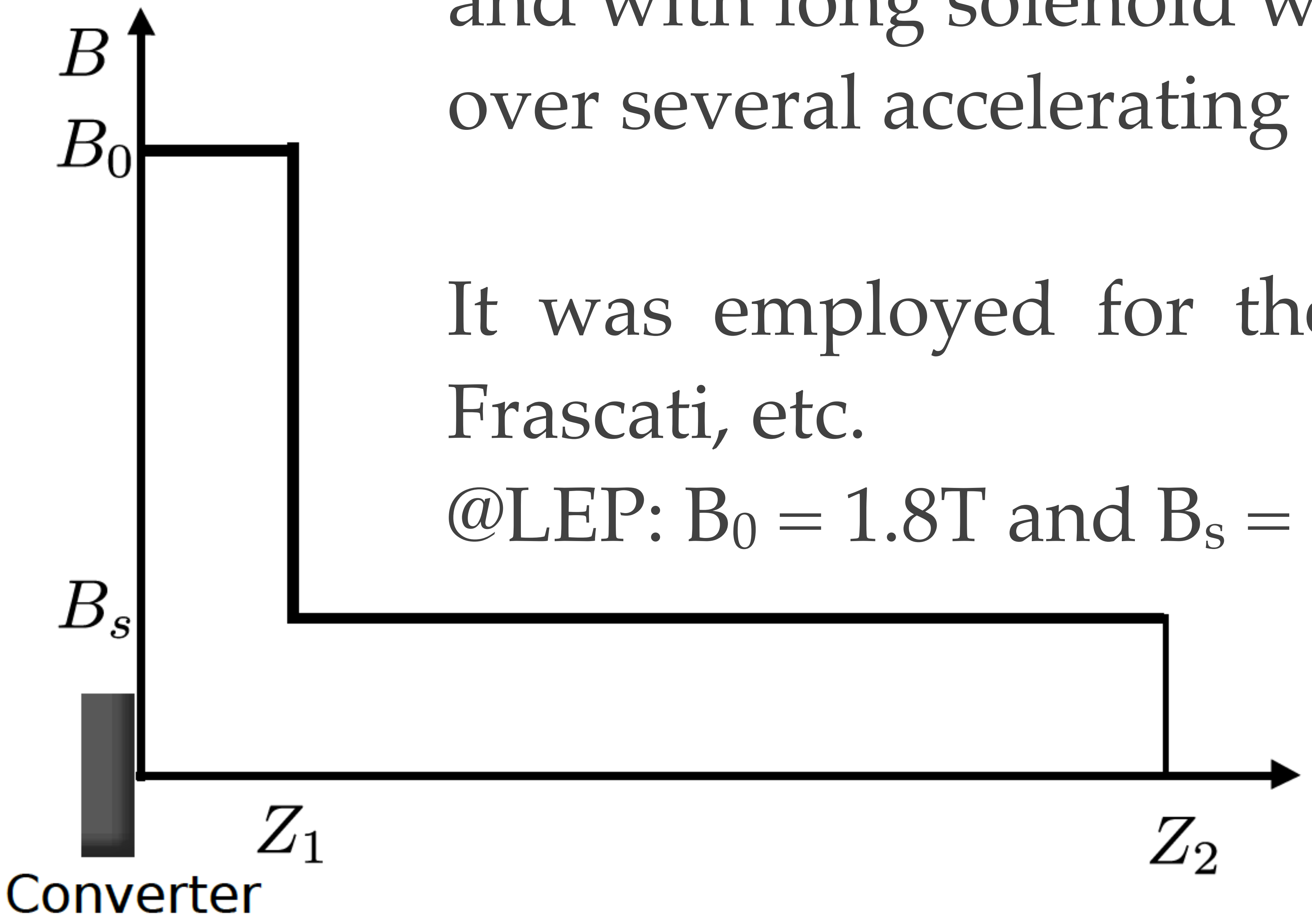




- The AMD is used to match the e+ beam (with very large transverse divergence and energy spread) to the acceptance of the pre-injector linac.
- Advantage: large energy acceptance.
- Drawback: bunch lengthening => increase of the energy spread in the pre-injector linac.

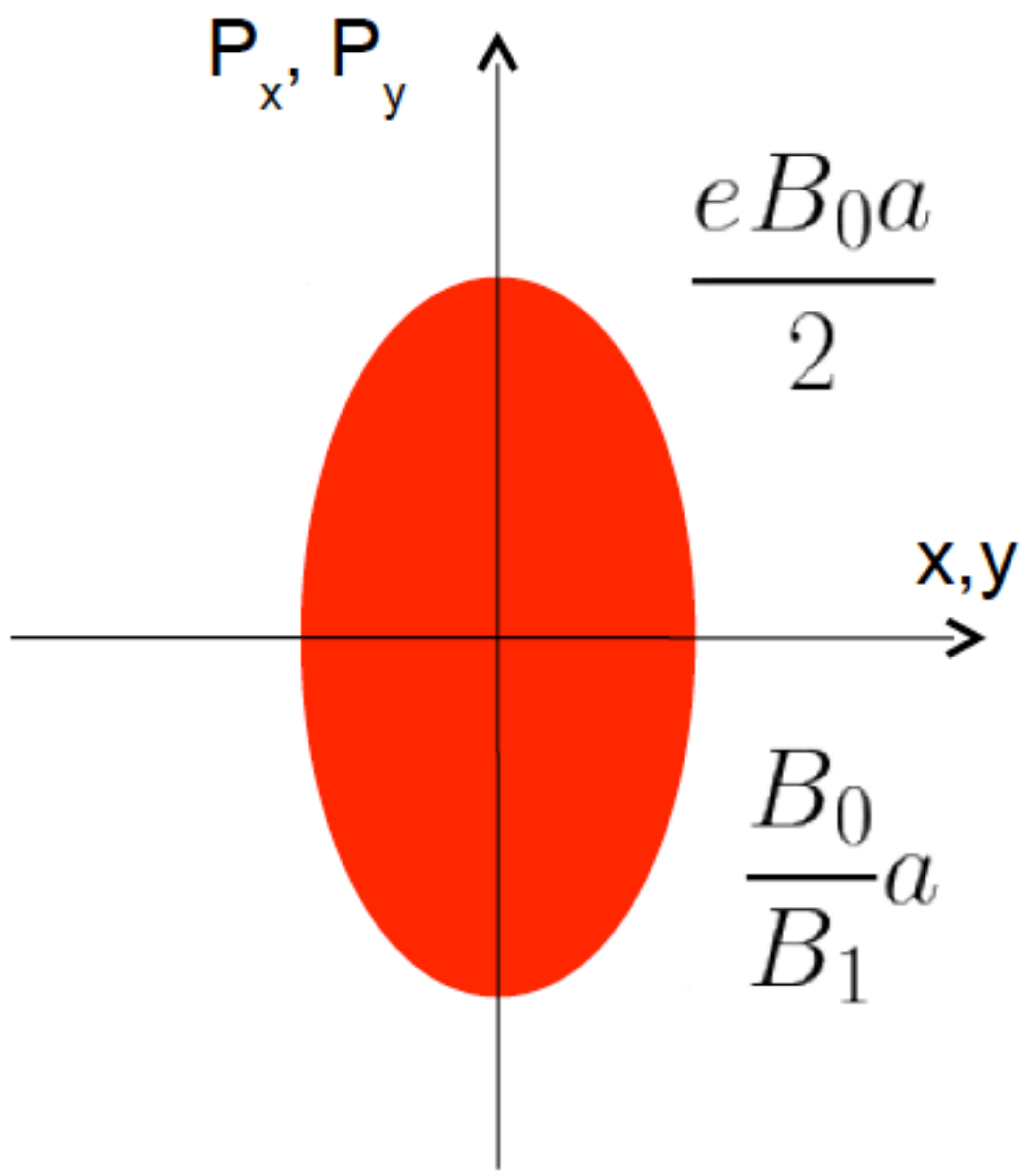
Focusing system: QWT

QWT is made of a short solenoid with high magnetic field and with long solenoid with lower magnetic field extending over several accelerating sections.



It was employed for the positron source at LEP, Orsay, Frascati, etc.

@LEP: B_0 = 1.8T and B_s = 0.3 T.



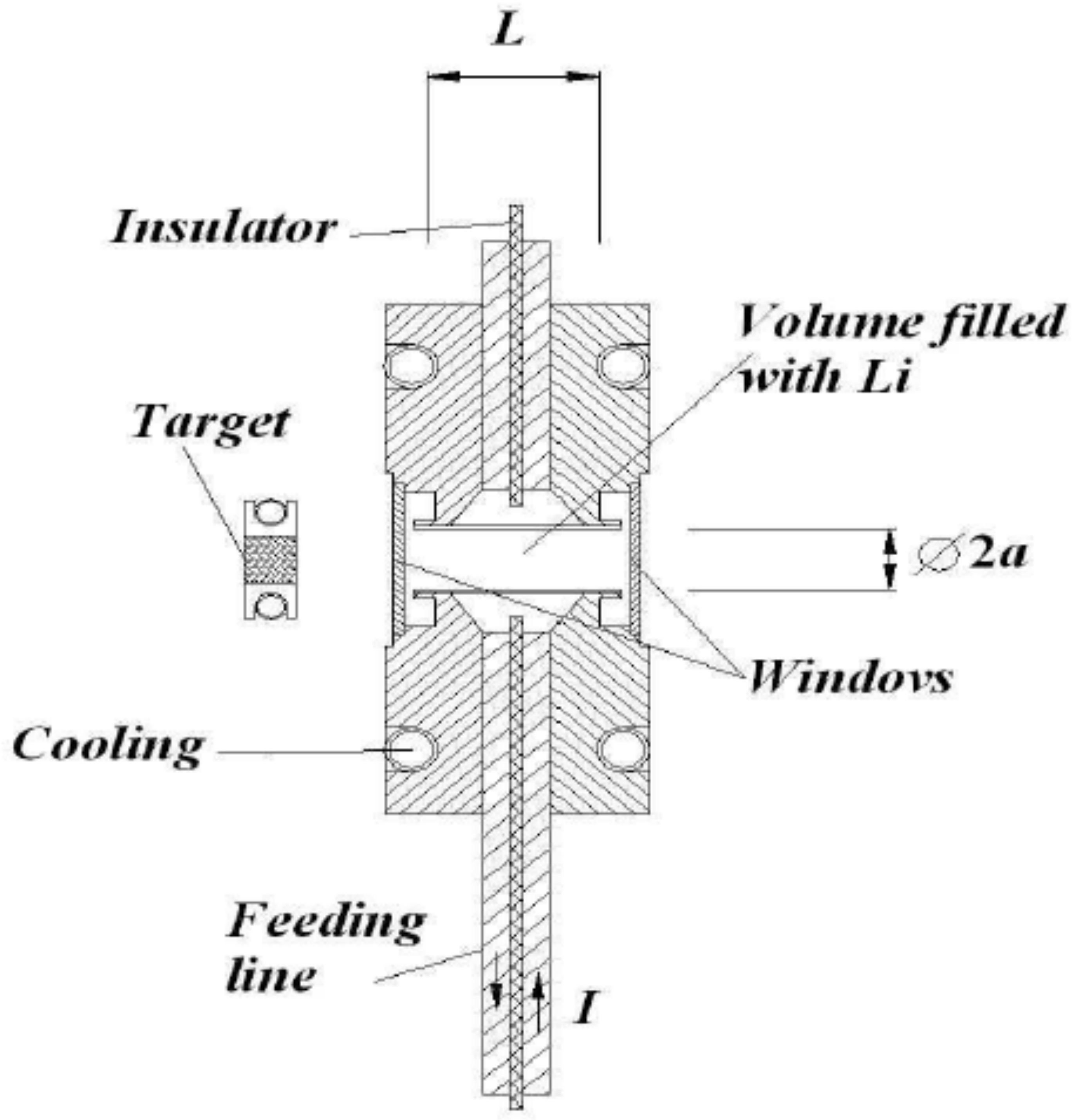
☞ Main disadvantage of the QWT is its rather small energy acceptance.

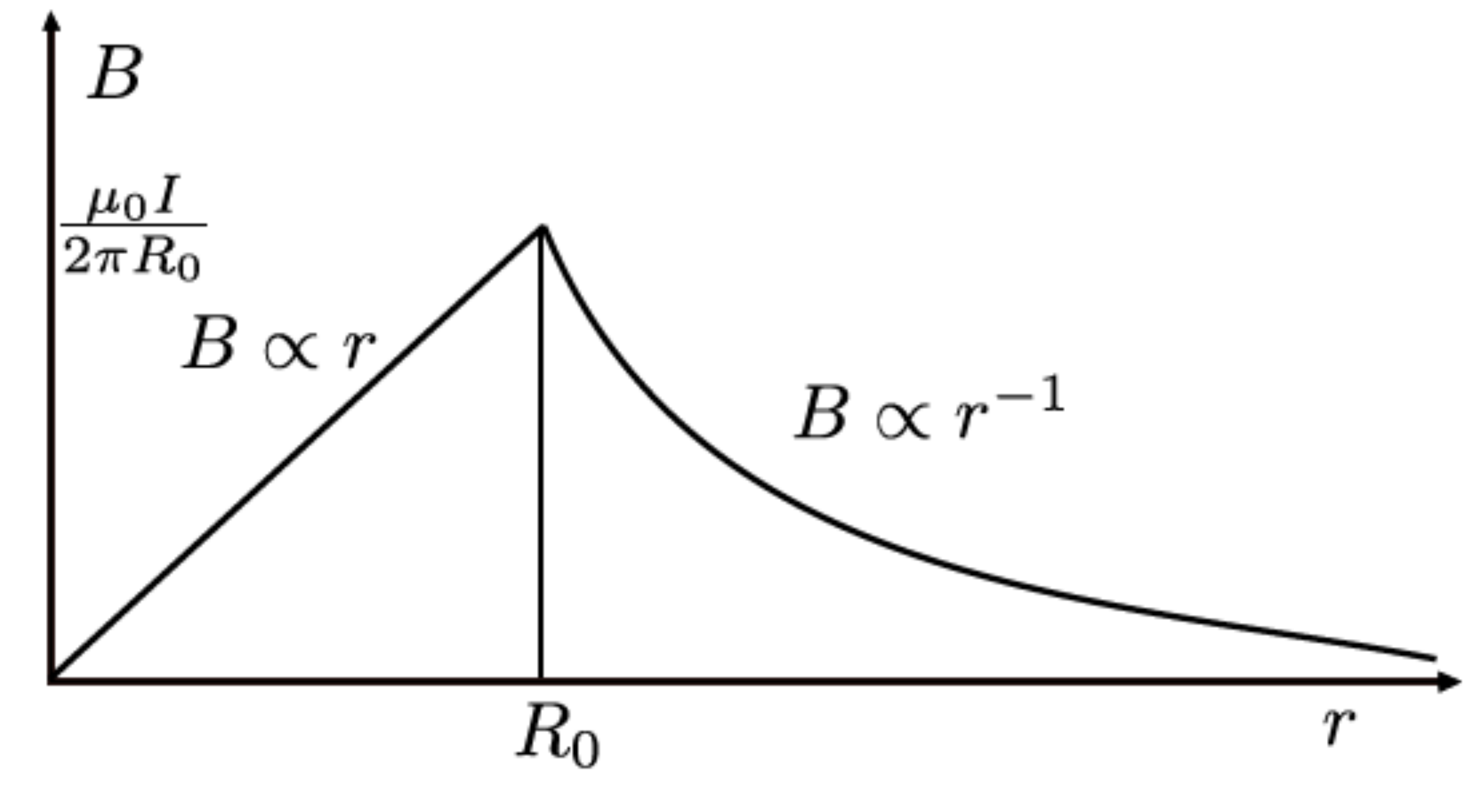
☞ On the hand, due to short solenoid length, the bunch lengthening is restricted.

Lithium and Plasma Lenses

☞ Matching device using the azimuthal magnetic field (focuses one kind of particles e+ and defocuses the other e-).

- Usage of Lithium Lenses for focusing of antiprotons are known (FERMILAB, CERN). Application to the e+ collection was developed in Novosibirsk (only one in operation).
- Particles are focused by field generated by the current running through the body of Lithium cylinder, so the particles are going through the Lithium co-directionally with the current flow.
- Typical dimensions are ~10 mm length and a few mm diameter. Pulsed current may exceed 100kA (produces magnetic field of several Tesla).
- In the Plasma Lenses, a plasma discharge provides a strong current density parallel to the beam. Azimuthal magnetic field rises linearly yielding a strong focusing for axially traversing charged particles. Tested at CERN and GSI.





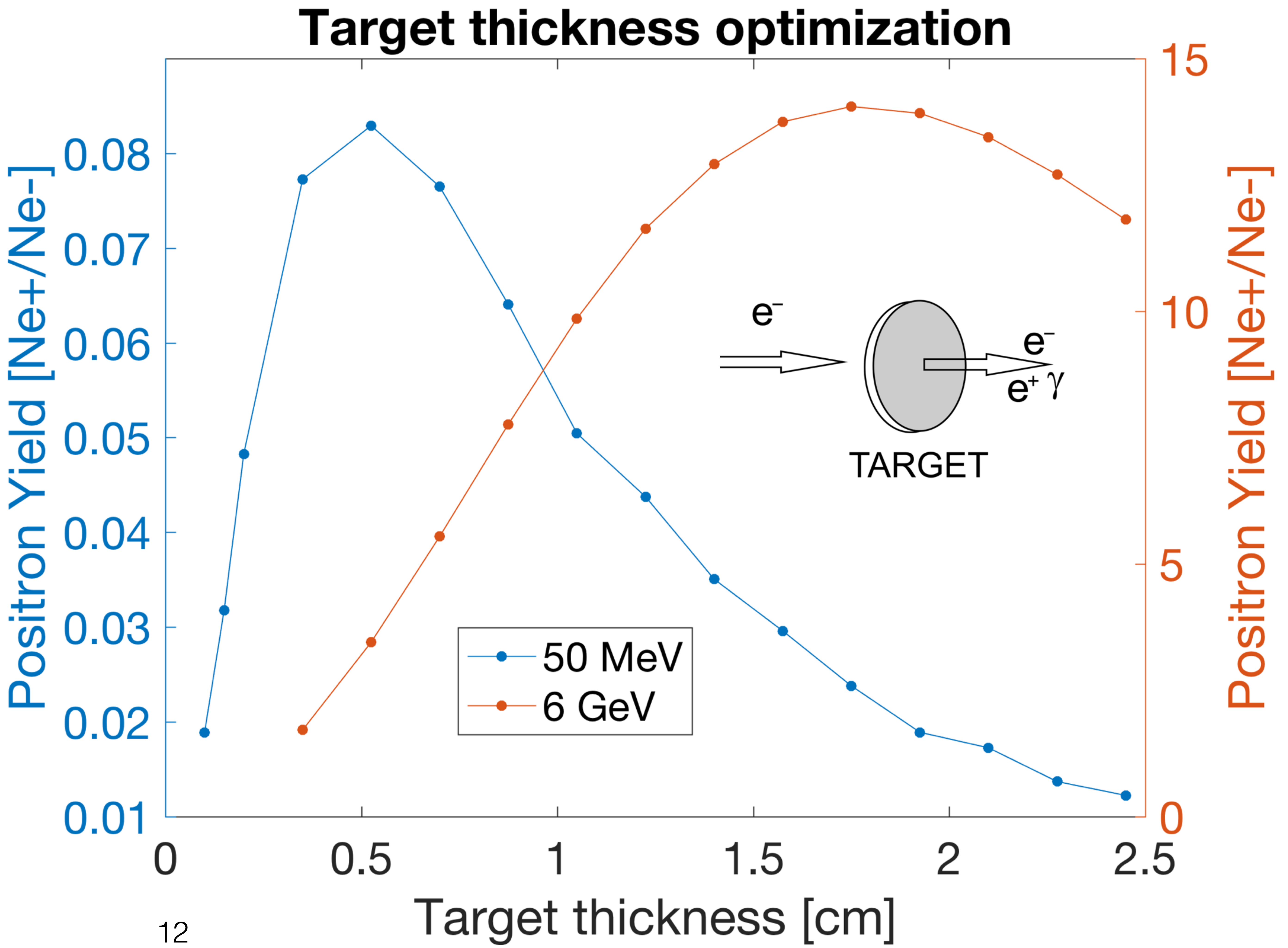
Positron Production

☞ Geant4 simulation of shower development generated by 6 GeV and 50 MeV electrons

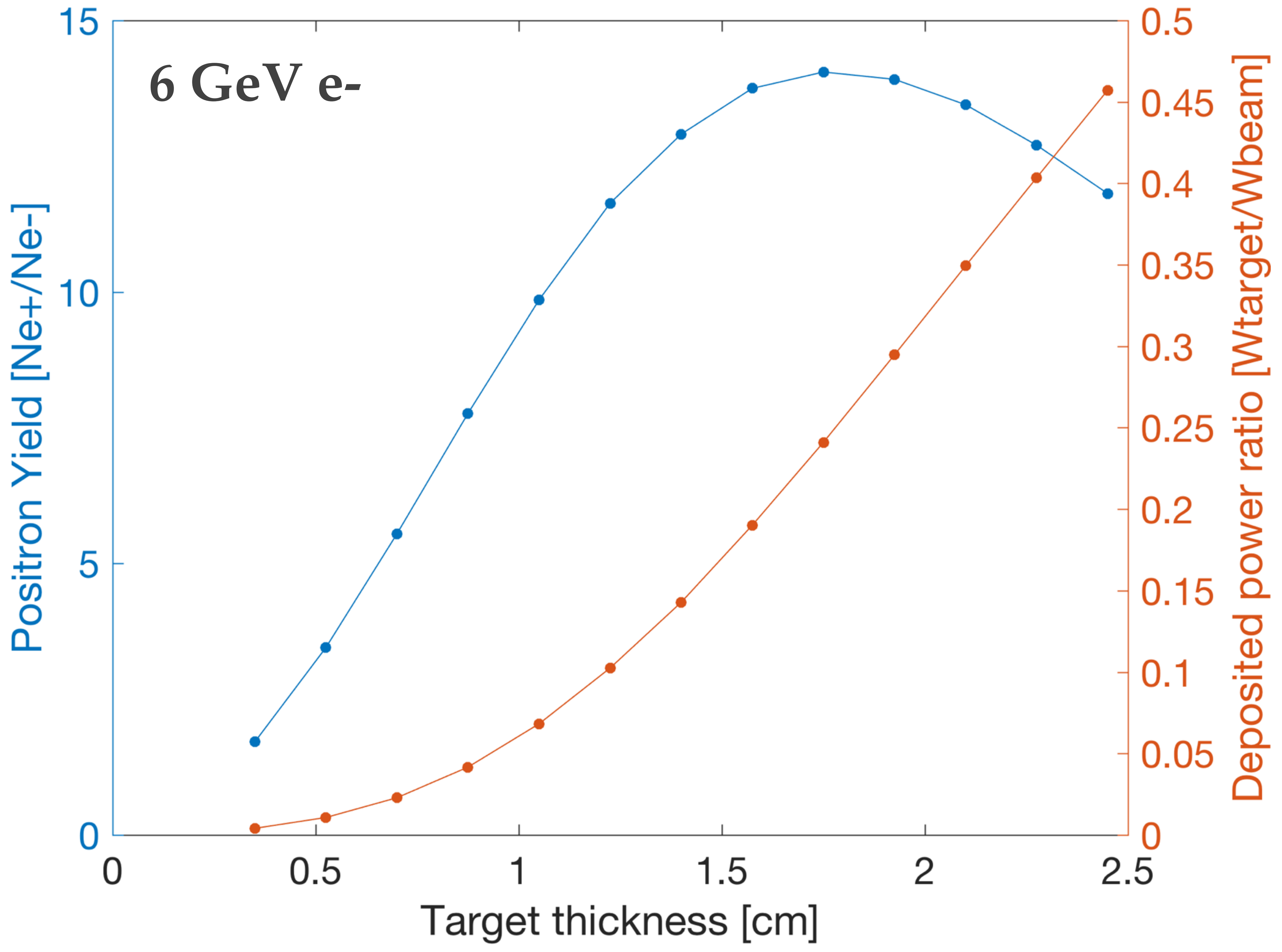
ALTO parameters

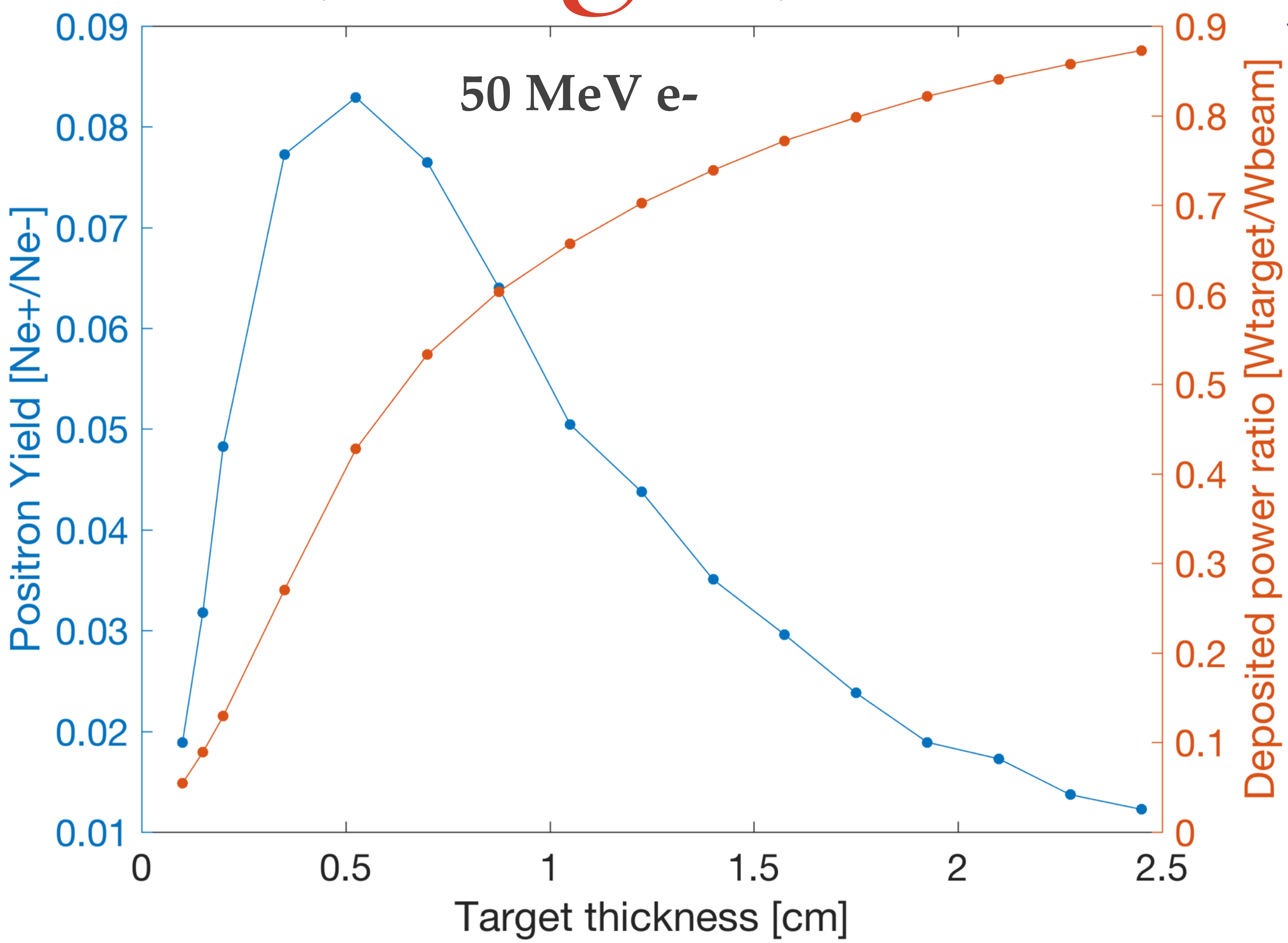
Primary e- beam	
Beam energy	50 Mev
Repetition rate	100 Hz (max)
Beam power	0.5 kW
RF frequency	2998.55 MHz
Average current	<=10 uA
Pulse length	< = 3 us
Pulse charge	100 nC
Nb of bunches per pulse	XXX
Bunch charge	XXX × 10^{10} e-
Bunch separation	333 ns
Emittance @ 50 MeV	0.6 Pi mm mrad
Beam on target (diameter)	10 mm

Tungsten radiation length X_0 is 0.35 cn



Positron Production (Target)





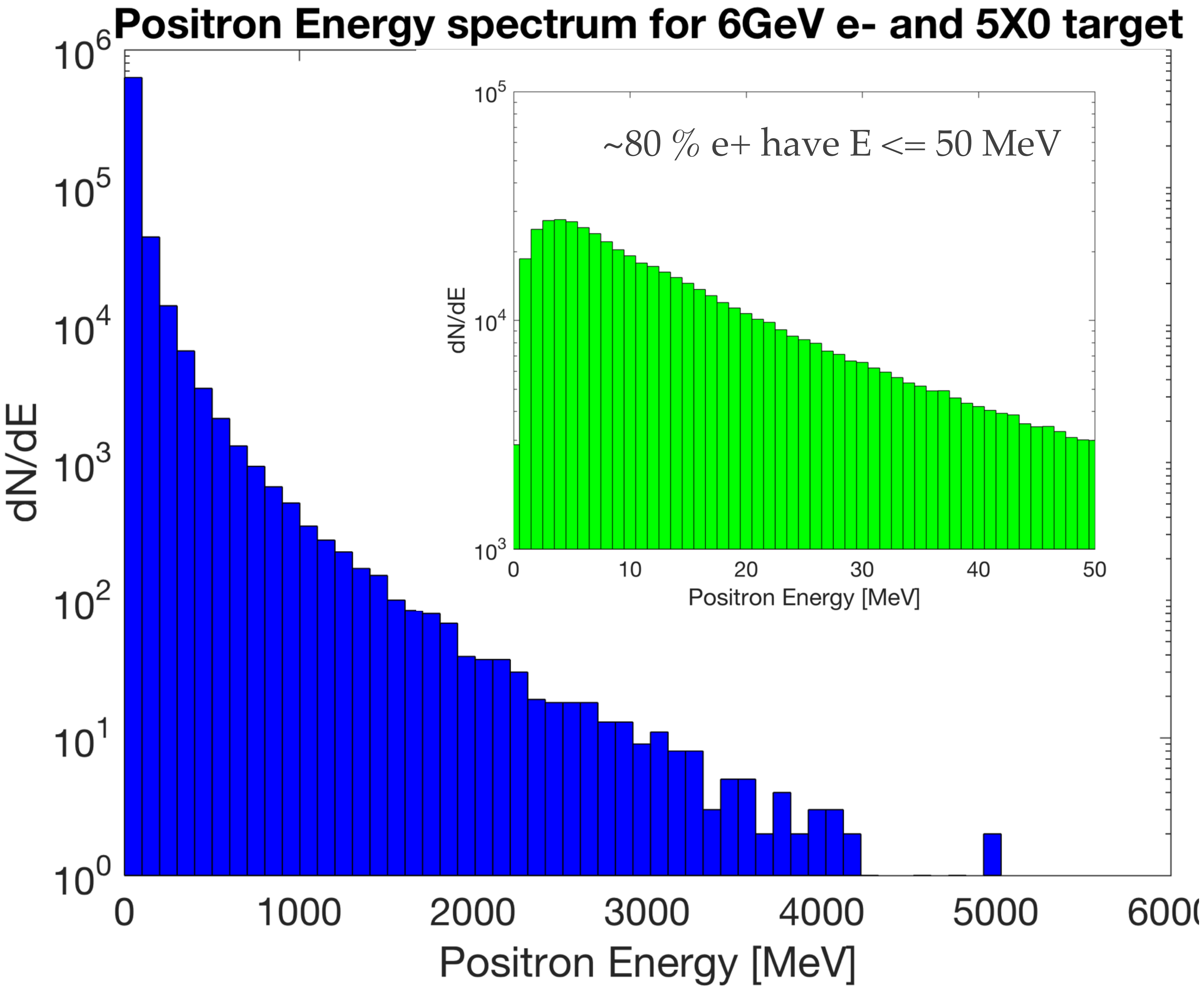
For average e-current 10uA (~100 nC/pulse or 6.24 × 10^{11} e^-/pulse):

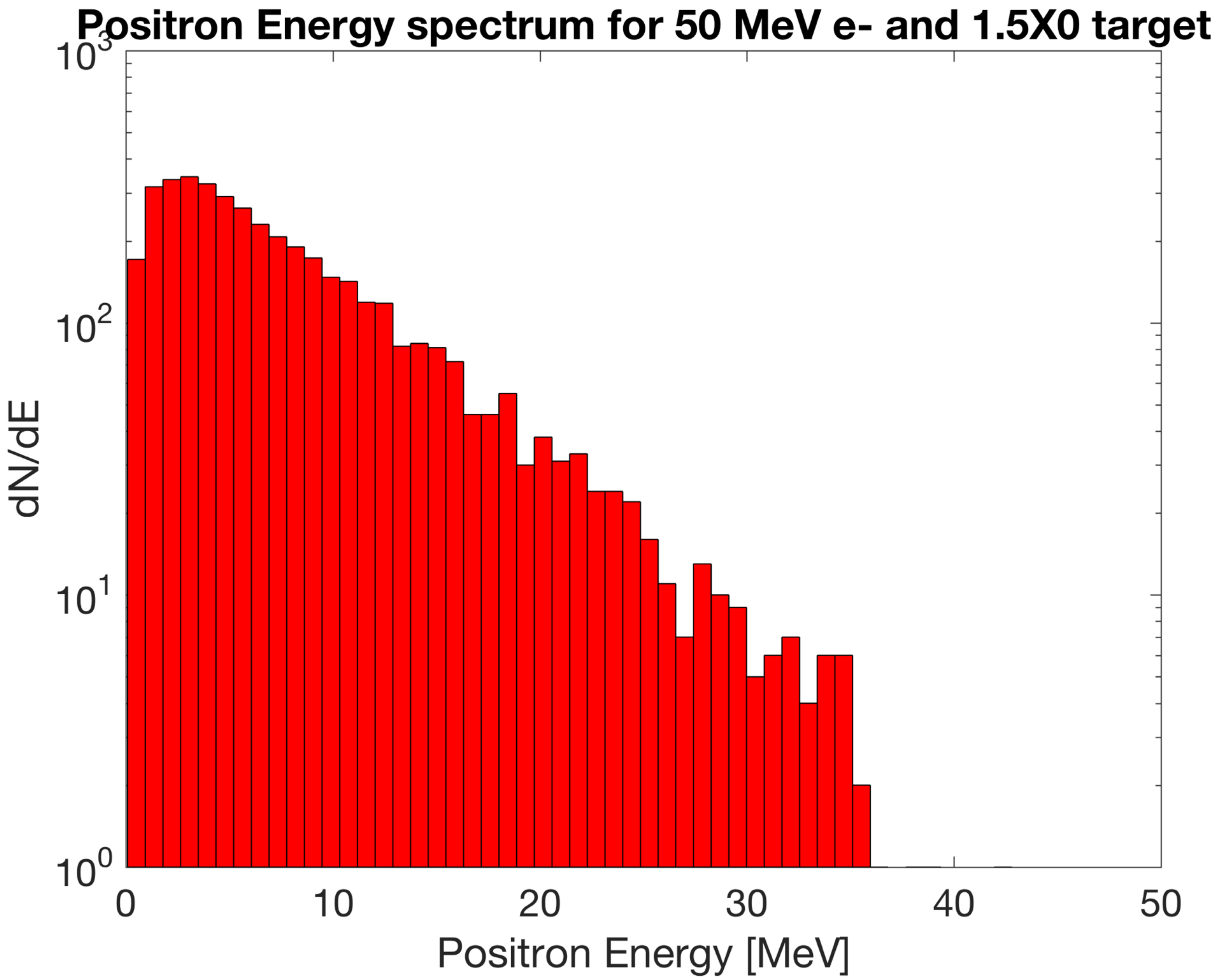
- Incident e- beam energy is 5 J or @ 100 Hz average e- beam power on target 500 W.
- Power deposited in the target (1.5X_0 or ~0.53 cm) is 0.43 * 500 W ~ 200 W per pulse.

PEDD. Peak stress and fatigue limit resulting from cycling loading should be evaluated.

Positron Source (Capture Section)

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

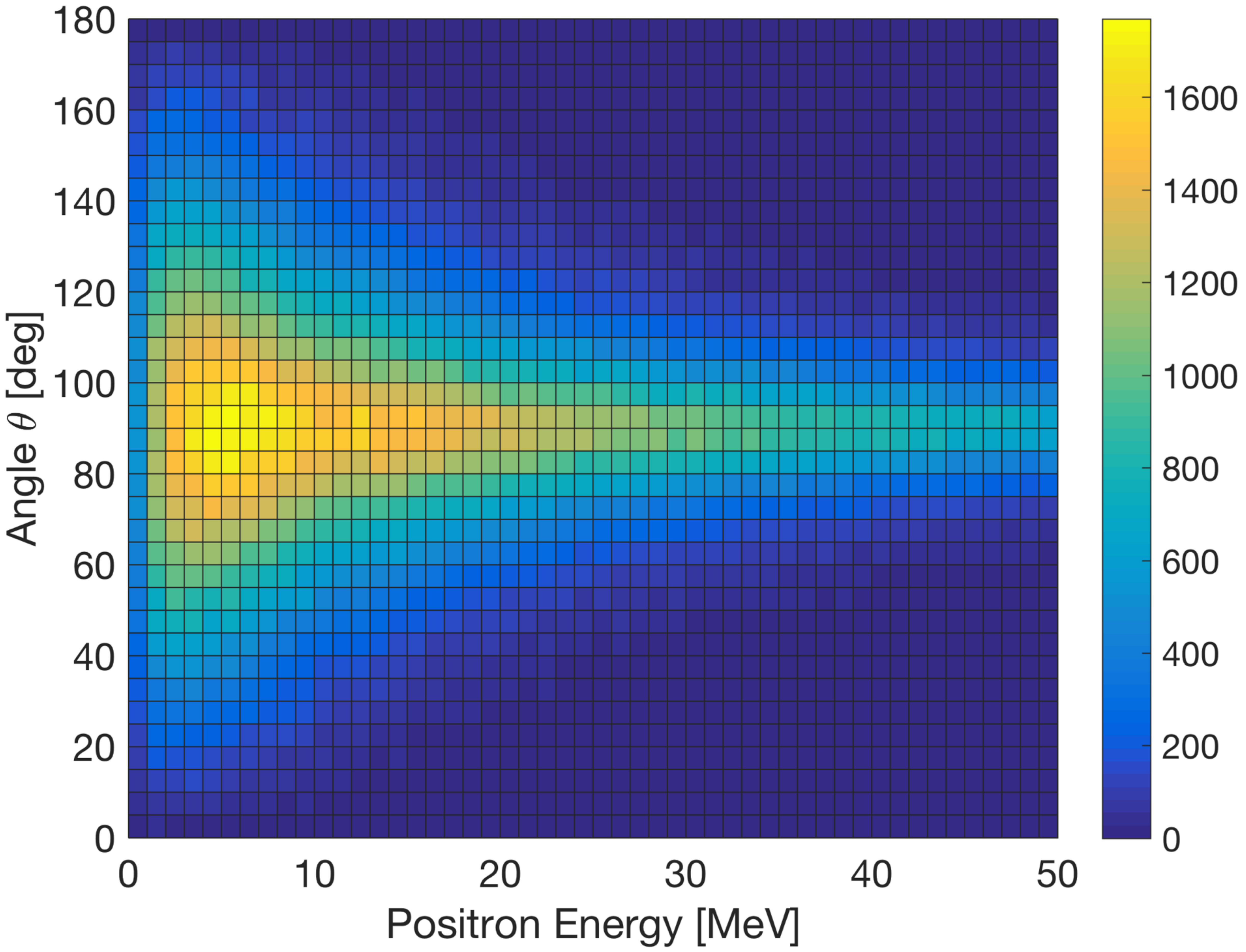




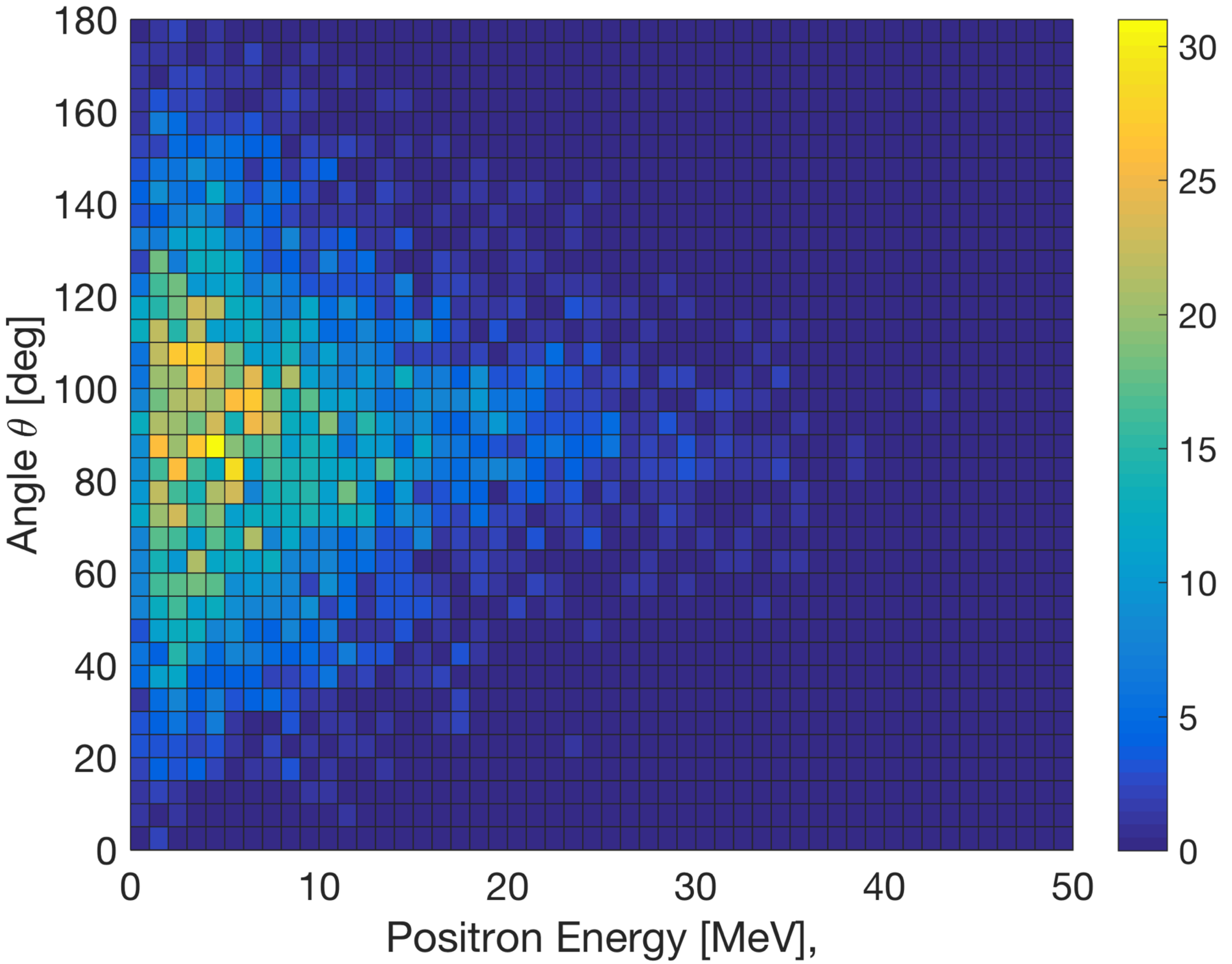
Positron Source (Capture Section)

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

6 GeV e- on the $5X_0$ target



50 MeV e- on the $1.5X_0$ target

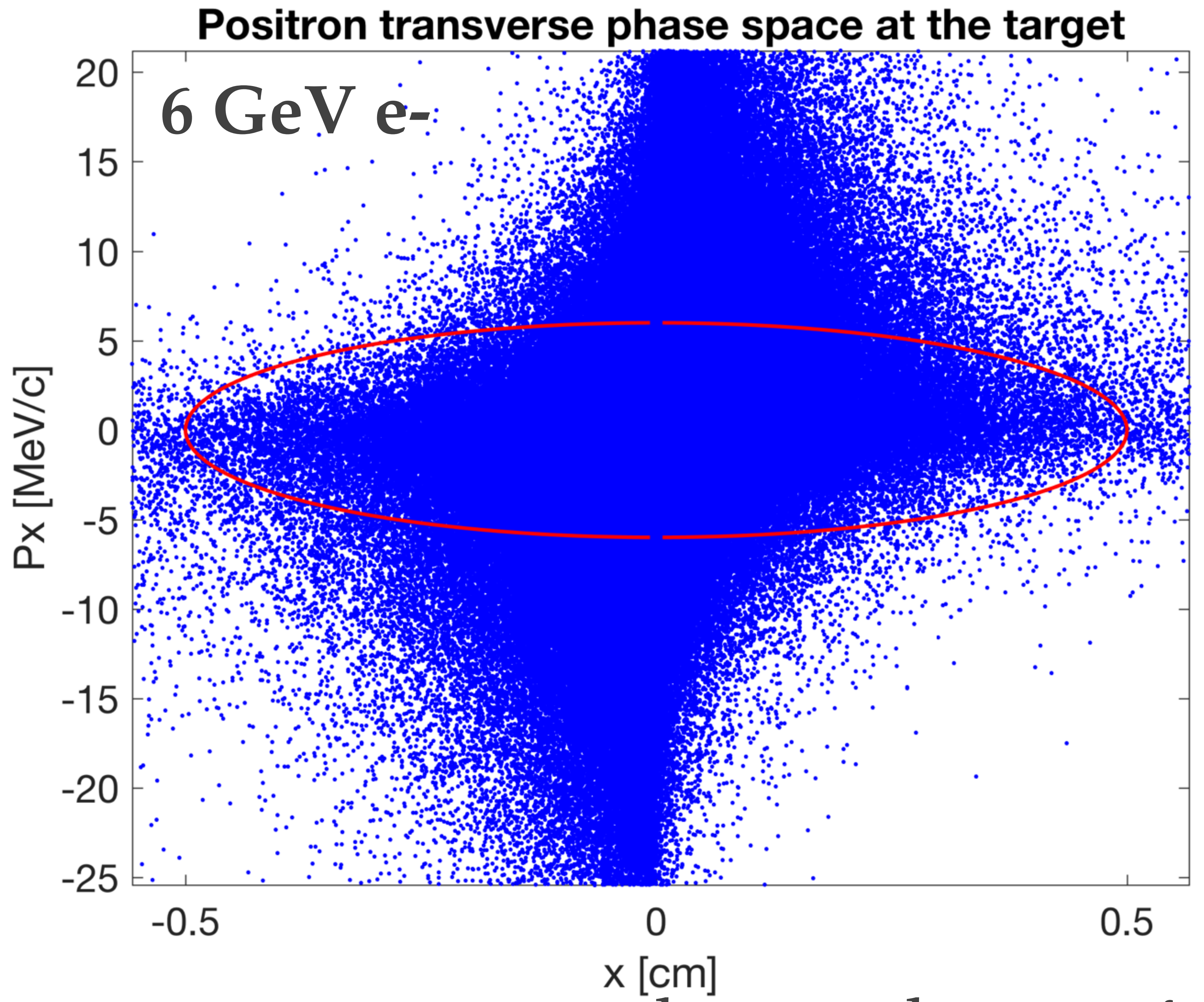


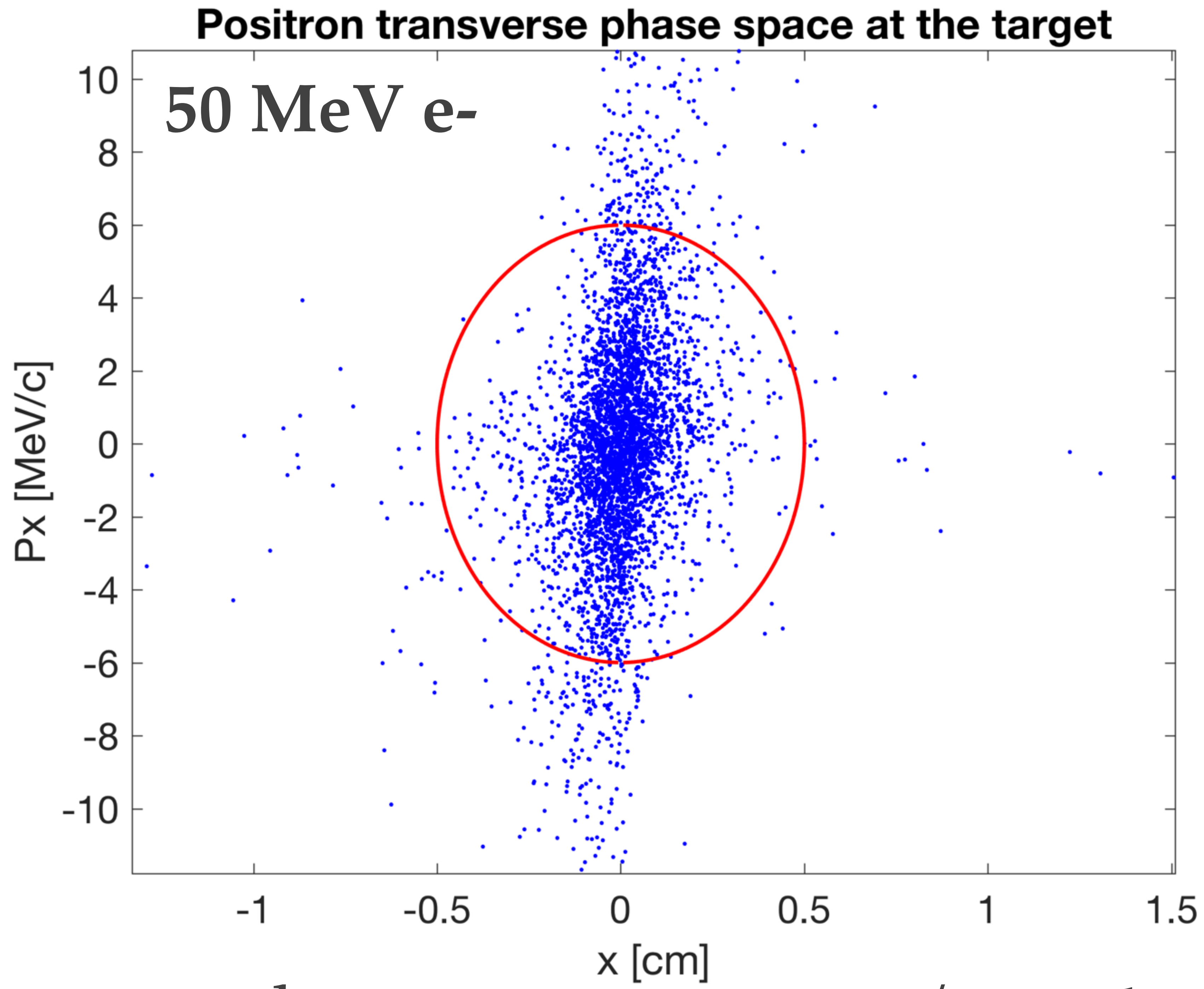
Positron Source (Capture Section)

LABORATOIRE DE L'ACCÉLÉRATEUR LINÉAIRE

Preliminary

Let's assume AMD: $\mu = 50\ m^{-1}$ with $B_0 = 8$ T. We choose an AMD length of 20 cm; that leads to a minimum field value of 0.5 T. AMD aperture a = 20 mm (radius).





- Transverse acceptance: with our choice of the parameters we have: P_T = 12 MeV/c and r_{max} = 5 mm. Accepted yield @ 6 GeV: $N_{e+}^{AMD}/N_{e+}^{Target} \sim 0.2$. Accepted yield @ 50 MeV: $N_{e+}^{AMD}/N_{e+}^{Target} \sim 0.46$
- Longitudinal acceptance: Pz <= 24 MeV/c. Accepted yield @ 6 GeV: $N_{e+}^{AMD}/N_{e+}^{Target} \sim 0.58$. Accepted yield @ 50 MeV: $N_{e+}^{AMD}/N_{e+}^{Target} \sim 0.97$