FCC-ee Positron Source

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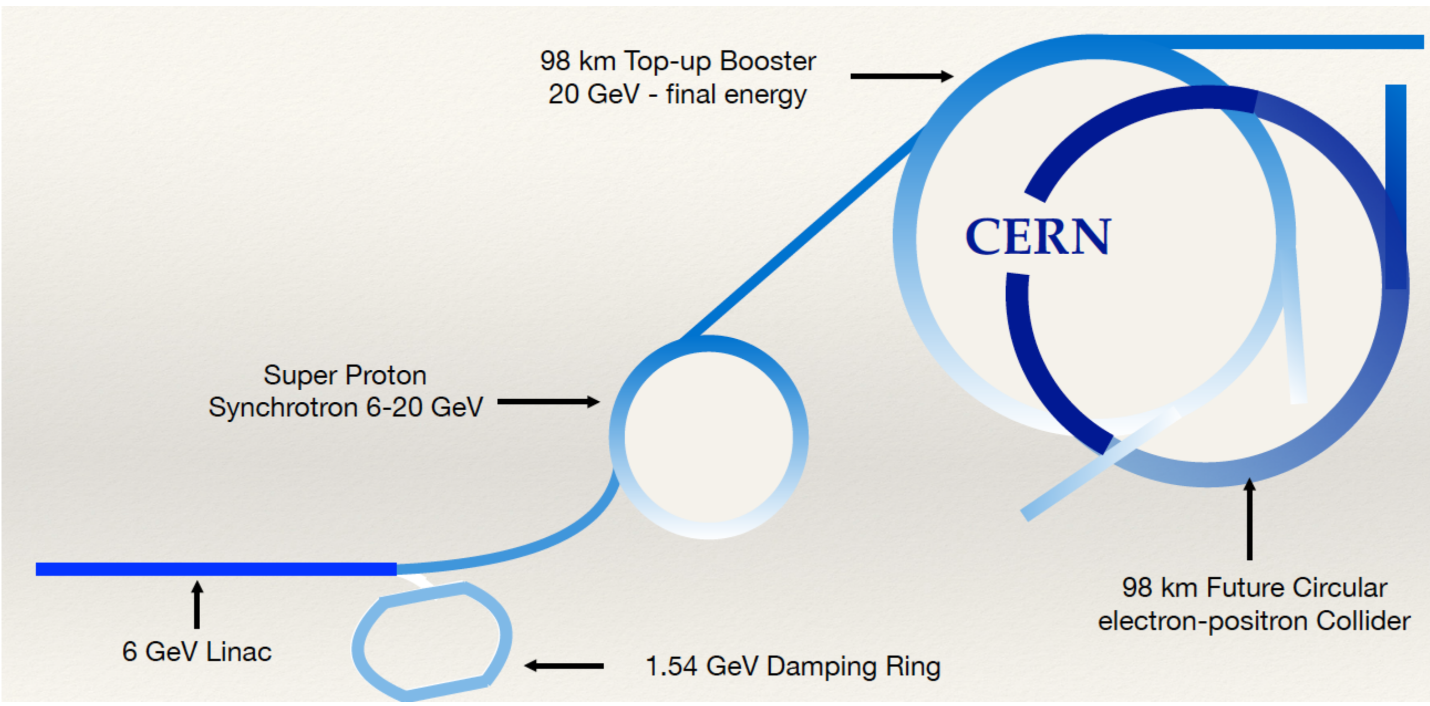
FCC-ee Injector Complex



- RF-gun / thermionic gun
- e-/e+ linac up to 6 GeV
- 1.54 GeV Damping Ring
- SPS as a Pre-Booster Damping Ring (6 - 20GeV)
- Booster Ring (20 - 45.6 GeV)

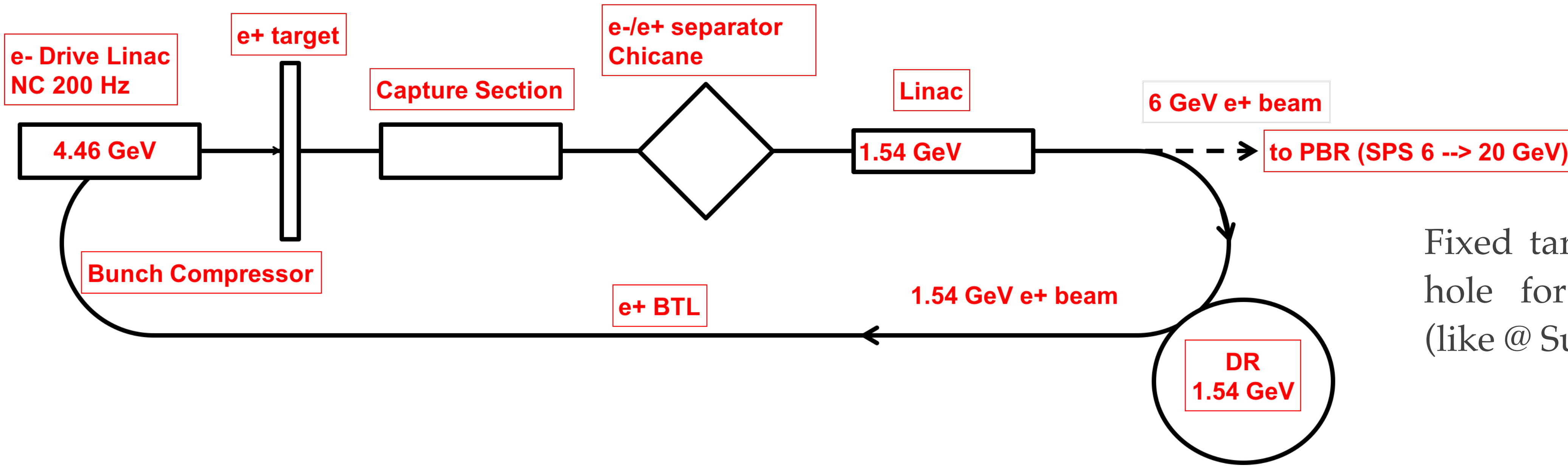
☞ As an alternative option for the FCC-ee injector, a 20 GeV linac is proposed to provide the direct injection into the booster ring.

The main 6(20) GeV linac hosts the e+ source. The positrons are produced with 4.46(18.46) GeV e- beam.

The FCC-ee positron injector has to be designed to produce the positron beam with the requested parameters accepted by the DR.

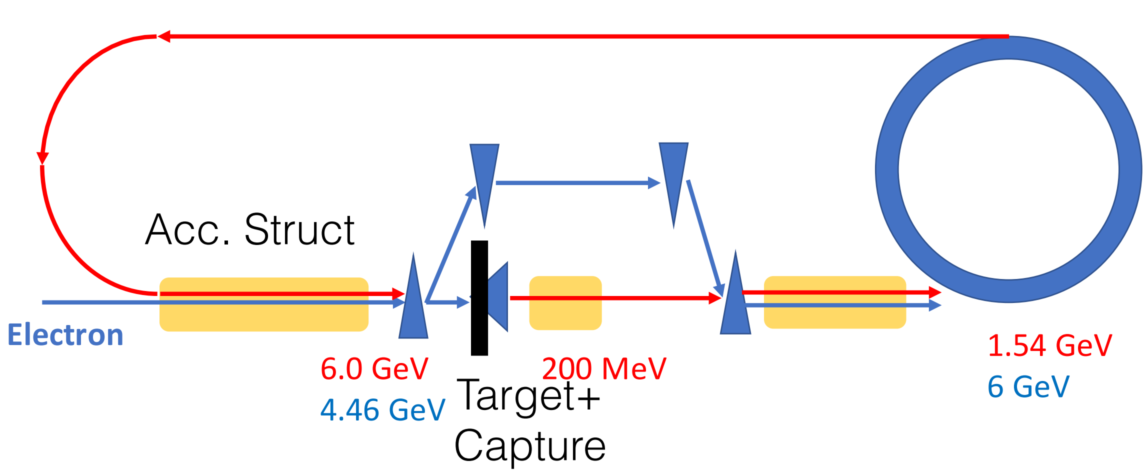
FCC-ee Positron Injector options

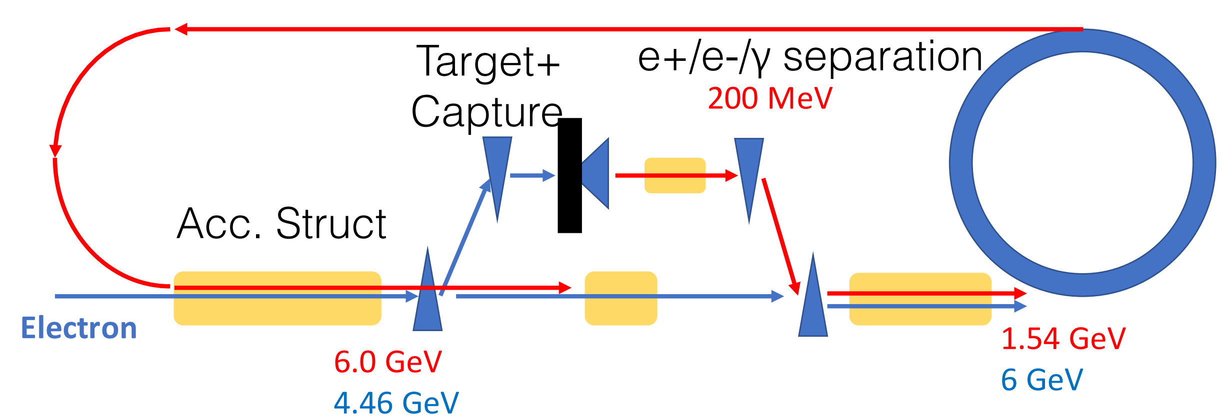
Current scheme



Fixed target-converter has a hole for e- beam passage (like @ SuperKEKB)

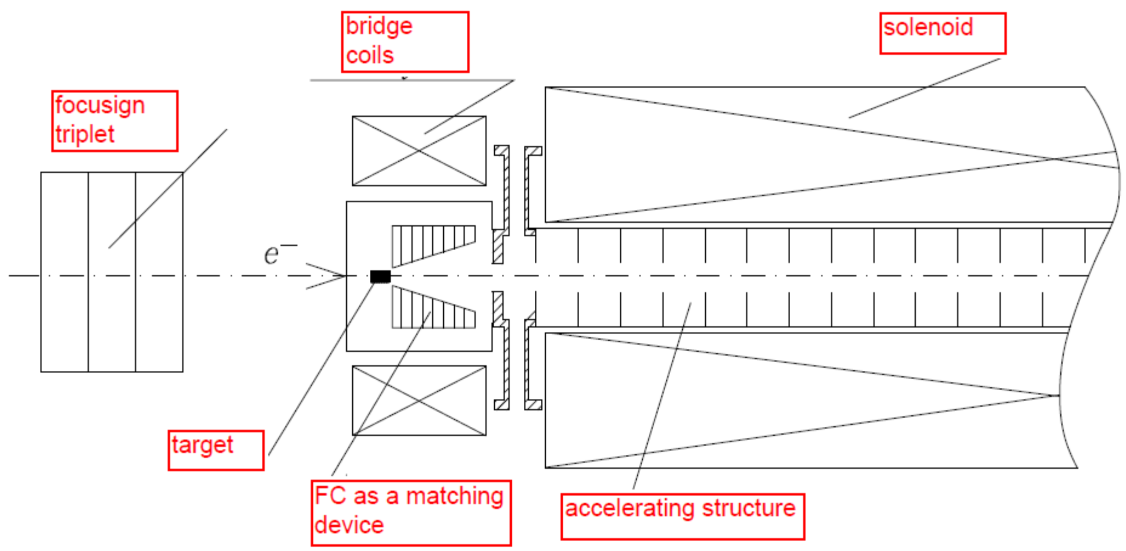
Schemes with the bypass under consideration (very preliminary)



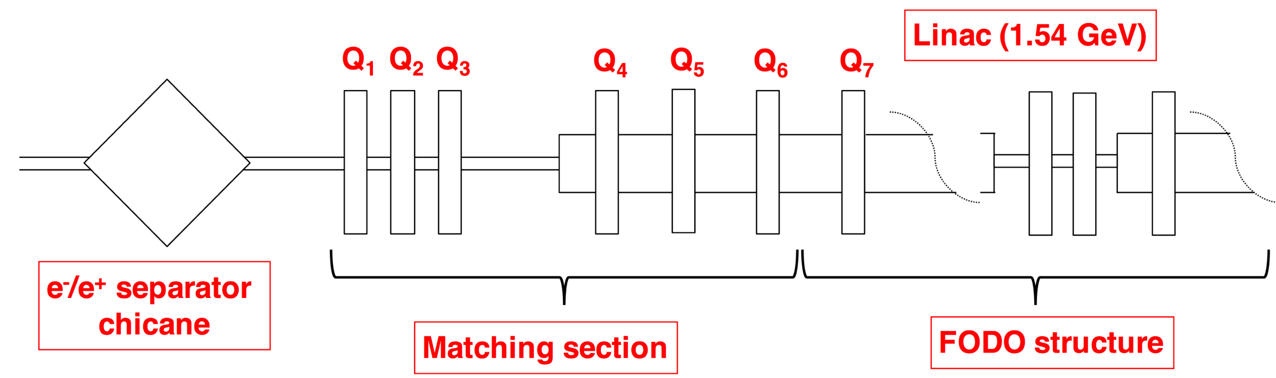


FCC-ee Positron Source and parameters

e+ production and capture section



e+ acceleration up to 1.54 GeV



<u>Primary e- beam</u>

4.46 GeV

3×10^{10} e^-/bunch ~ 5 nC
(main e- beam)

4.2×10^{10} e^-/bunch ~ 7 nC
(for e+ production)

2 bunches/pulse spaced by ~60 ns

The complete filling for Z running (most demanding) => requires a linac bunch intensity of 2.1×10^{10} particles for both species

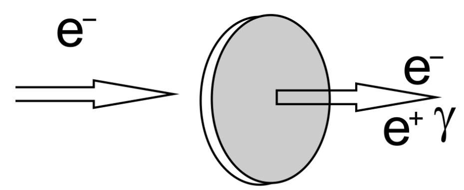
Requirement @ DR:
2.1×10^{10} e^+/bunch (4.3 nC)
~0.5 e+/e- without safety factor

Positron source performances

	SLC	LEP (LIL)	KEKB/SKEKB	FCC-ee*
Incident e- beam energy	33 GeV	200 MeV	4.3/3.5 GeV	4.46 GeV
e-/bunch [10^{10}]	3-5	0.5 - 30 (20 ns)	6.25/6.25	4.2
Bunch/pulse	1	1	2/2	2
Rep. rate	120 Hz	100 Hz	50 Hz/50 Hz	200 Hz
Incident Beam power	~20 kW	1 kW (max)	4.3 kW/3.3 kW	12 kW
Beam size @ target	0.6 - 0.8 mm	< 2 mm	/>0.7 mm	
Target thickness	$6X_0$	$2X_0$	$/4X_0$	
Target size	70 mm	5 mm	14 mm	
Target	Moving	Fixed	Fixed/Fixed	
Deposited power	4.4 kW		/0.6 kW	
Capture system	AMD	λ/4 transformer	/AMD	AMD
Magnetic field	6.8T->0.5T	1 T->0.3T	/4.5T->0.4T	
Aperture of 1st cavity	18 mm	25mm/18 mm	/30 mm	
Gradient of 1st cavity	30-40 MV/m	~10 MV/m	/10 MV/m	
Linac frequency	2855.98 MHz	2998.55 MHz	2855.98 MHz	
e+ yield @ CS exit	~4 e+/e-	~3 $\times 10^{-3}$ e^+/e- (linac	~0.1/~0.5 e+/e-	
Positron yield @ DR	~1.2 e+/e-		NO/0.4 e+/e-	
DR energy acceptance	+/- 2.5 %	+/- 1 % (EPA)	+/- 1.5 % (1 σ)	+/- 8 %
Energy of the DR	1.15 GeV	500 MeV	NO/1.1 GeV	1.54 GeV

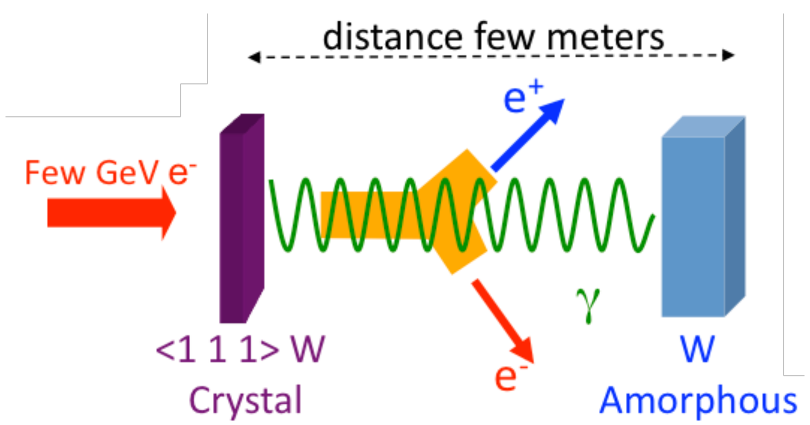
*FCC-ee under study

Two schemes of e+ production



1) <u>Conventional positron target:</u> bremsstrahlung and pair conversion

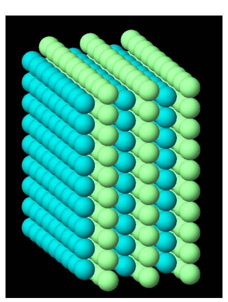
- Classical e+ source.
- It was employed to produce e+ beam at the existing machines (ACO, DCI, SLC, LEP, KEKB…).



2) <u>Hybrid positron target:</u> Two-stage process to generate positron beam. Channeling (crystal target) and pair conversion (amorphous target)

- Use the intense radiation emitted by high energy (some GeV) electrons channeled along a crystal axis => *channeling radiation*.
- Charged particles are swept off after the crystal target => the deposited power and PEDD (Peak Energy Deposition Density) are strongly reduced.
- Granular target can provide better heat dissipation associated with the ratio Surface/Volume of the spheres and the better resistance to the shocks.

Recent idea: to replace the bulk target-converter by a **granular** one made of **small spheres**.

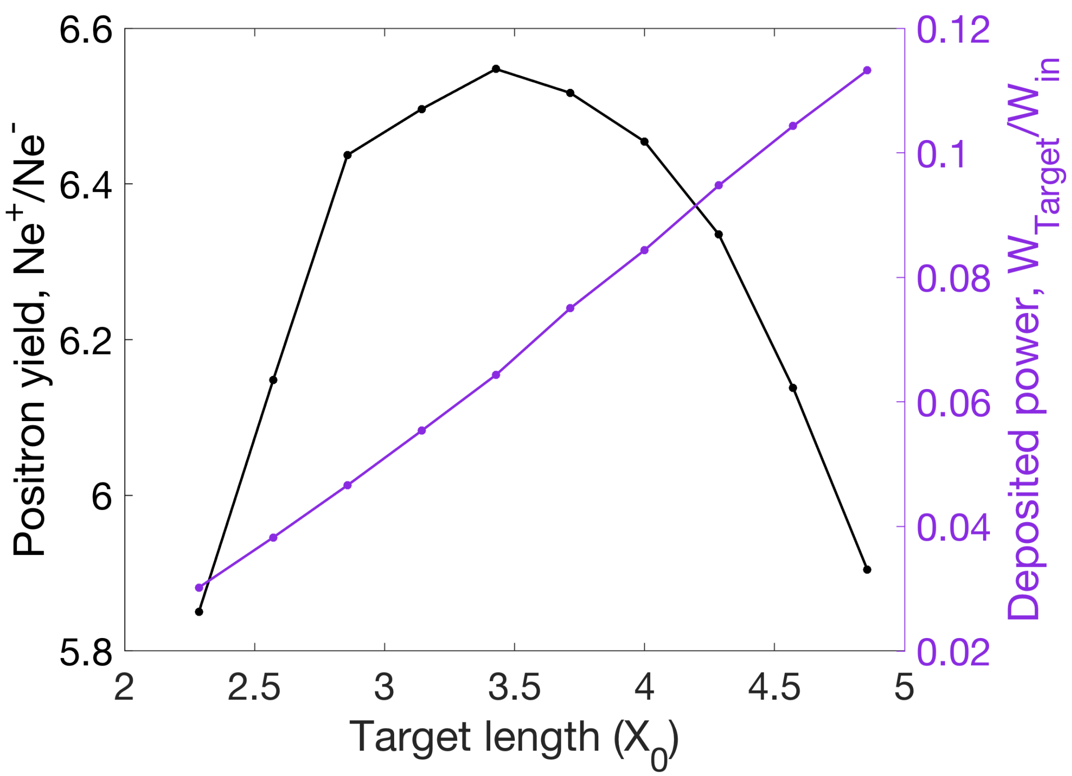


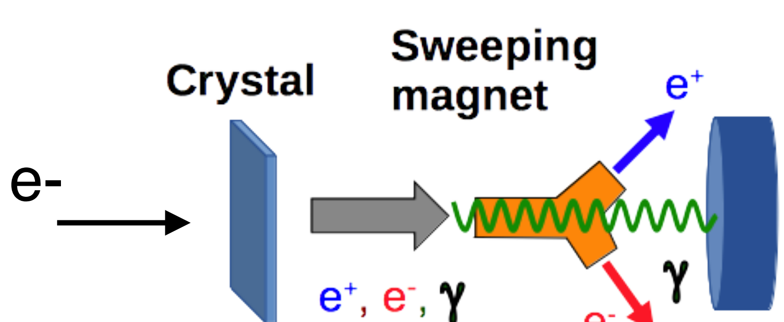
Granular target-converter

Several experiments had been conducted to study the hybrid e+ source (proof-of-principle experiment in Orsay, experiment @ SLAC, experiment WA 103 @ CERN and experiments @ KEK).

Production Target

Hybrid scheme (target-converter)



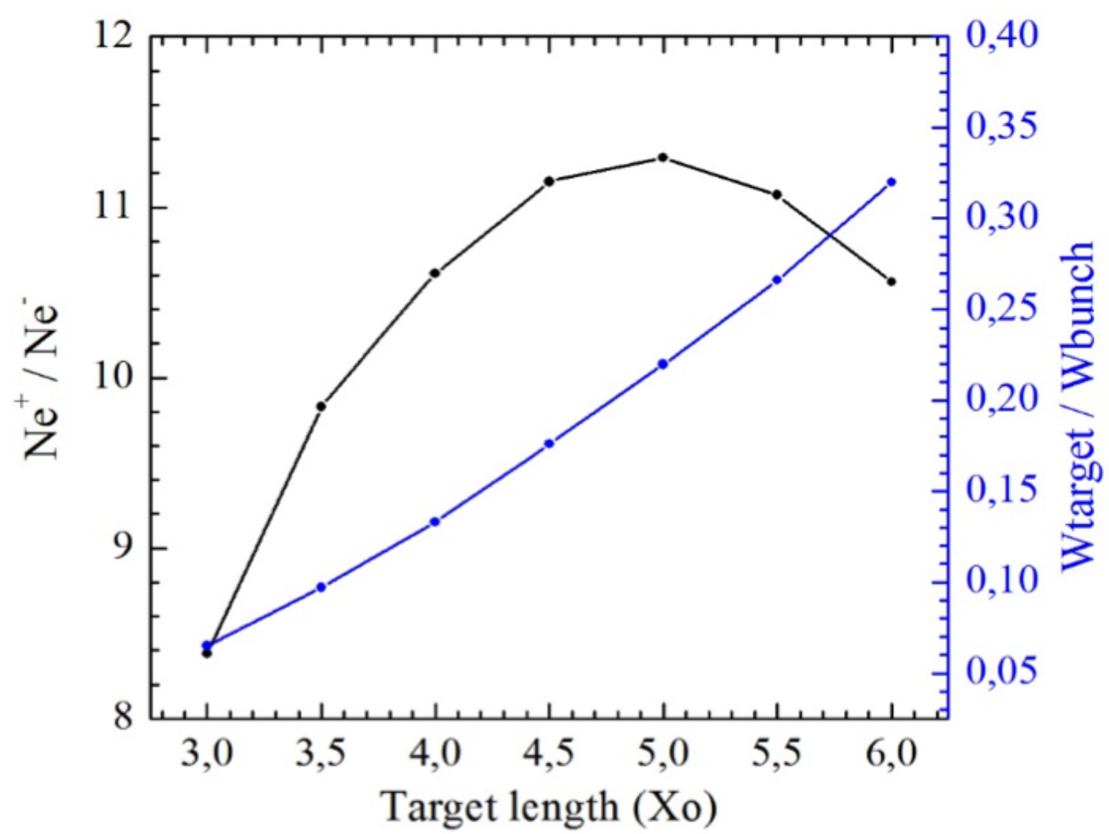


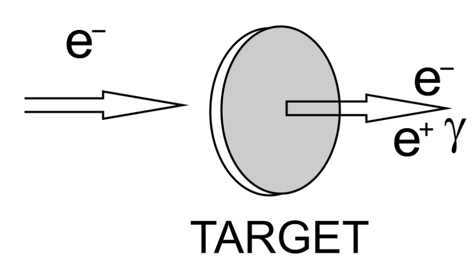
1.4 mm

1.5 m

$3.4X_0$ (12 mm)

Conventional scheme





$4.5X_0$ (16 mm)

Tungsten radiation length X_0 is 0.35 cm.

Production Target

Primary e⁻ beam for e⁺ production	
Beam energy	4.46 GeV
Bunch charge	4.2×10^{10}
Bunch length (rms)	**1**-2 mm
Bunch transv. size (rms)	**0.5** - 2.5 mm
Bunch separation	60 ns
Nb of bunches per pulse	2
Repetition rate	100-**200** Hz
Beam power	12 kW

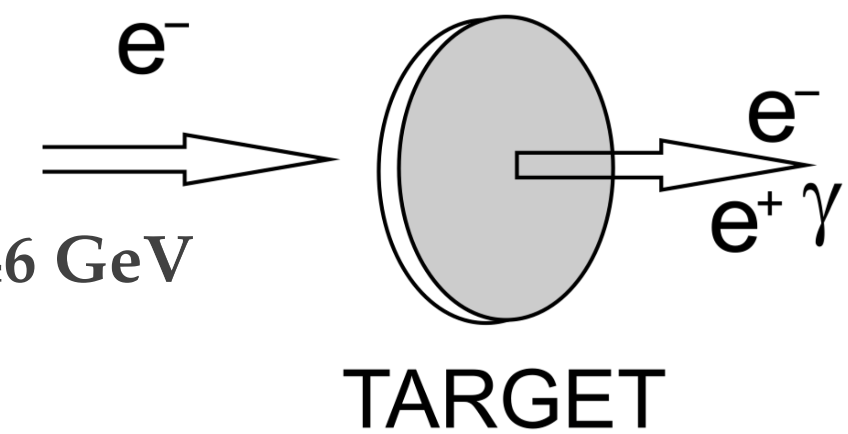
Beam Parameter	Conventional	Hybrid
Target thickness	$4.5X_0$	$0.4\ X_0/\ 3.4X_0$
e+ yield @ Target	~11 e+/e-	~7 e+/e-
PEDD	17 J/g	3 J/g
Deposited power	18 % (2.1 kW)	7 % (0.8 kW)

- PEDD (Peak Energy Deposition Density, [GeV/cm^3/e$^-$] or [J/g]) ~ beam and target parameters (beam energy, spot size and target thickness) => thermo-mechanical stresses.
- According to SLC experience, $W_{74}Re_{26}$ material has a PEDD limit of **35 J/g** (safe value to avoid target failure).

Positron Production (alternative options)

20 GeV linac as the FCC-ee injector:

- The higher-energy incident beam for positron production (18.46 GeV instead of 4.46 GeV)
- A real advantage as *the positron yield is increasing with the incident energy.*



18.46 GeV

d=23 mm

Thickness is chosen to maximize the positron production

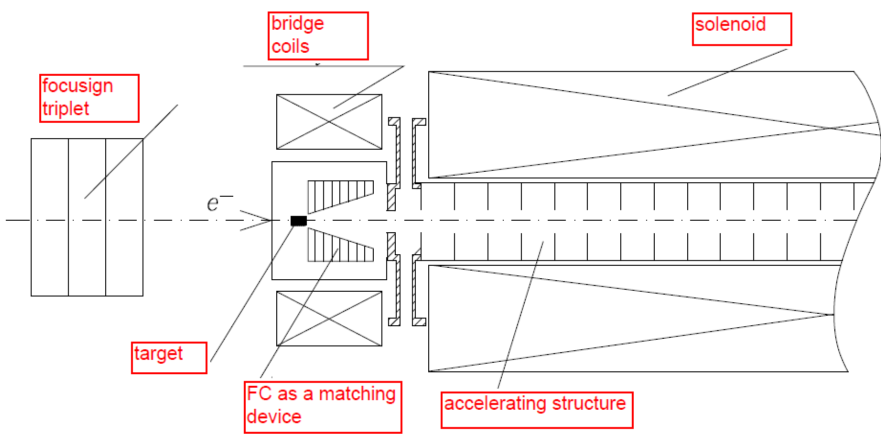
The total positron yield after the target is **39 N_{e+}/N_{e-}** compared to **11 N_{e+}/N_{e-}** obtained with the 4.46 GeV incident beam energy.

☞ The full optimization of the production should be performed including the deposited power in the target, PEDD and *the captured positron yield*.

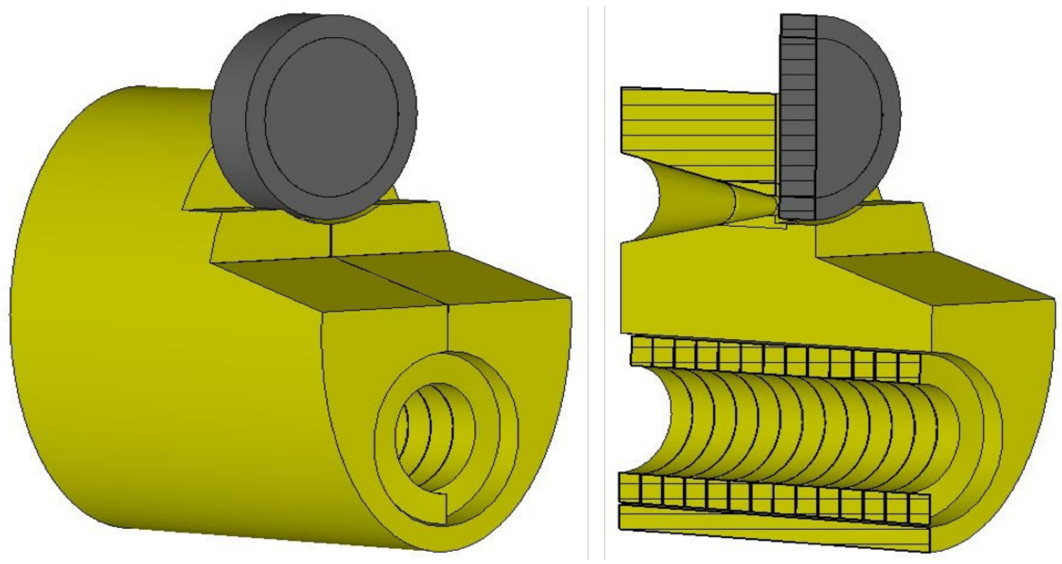
Capture and Primary Acceleration

The capture section design for both schemes is based on an Adiabatic Matching Device (AMD).

☞ *Flux Concentrator (FC) to form* adiabatically decreasing magnetic field

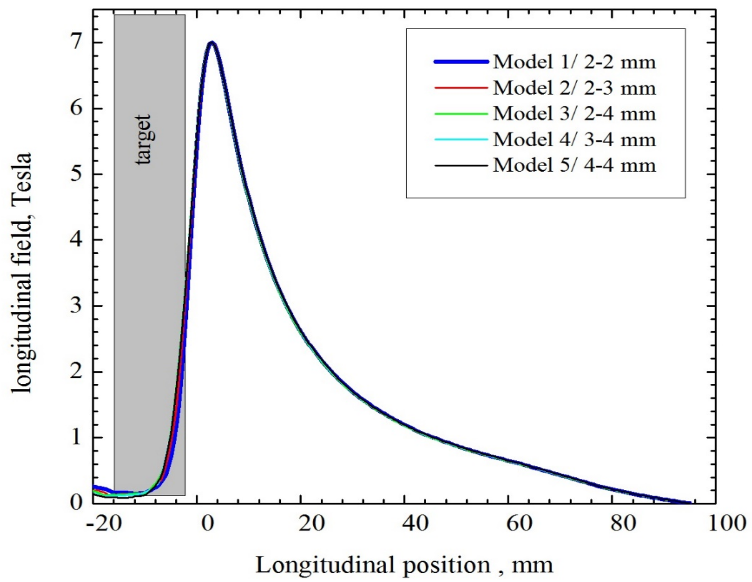


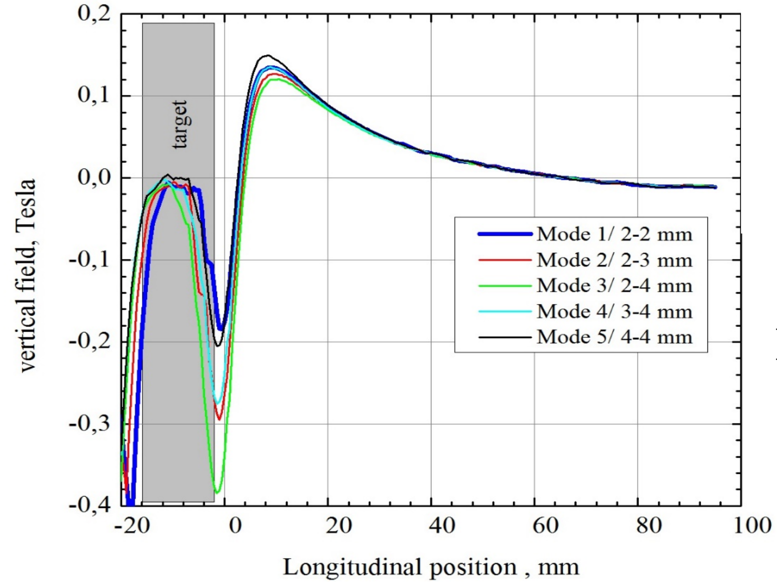
Matching the e+ beam (with very large transverse divergence) to the acceptance of the pre-injector linac.



Parameter [unit]	Value
Target diameter [mm]	90
Target thickness [mm]	15.8
Gap between target and FC [mm]	2
Grooving gap between target side face and FC body [mm]	2
Elliptical cylinder size [mm]	120×180
Total length [mm]	140
Conical part length [mm]	70
Min cone diameter [mm]	8
Maximm cone diameter [mm]	44
Cone angle [deg.]	25
Cylindrical hole diameter [mm]	70
Coil turns [-]	13
Current profile pulse length [μs]	25
Peak field [T]	7
Peak transverse field [mT]	135–157
Gap between coil turns [mm]	0.4
Gap between coil and FC body [mm]	1
Turns size	9.6×14 mm

Flux Concentrator field profile





Full 3D magnetic field map is used in the simulations.

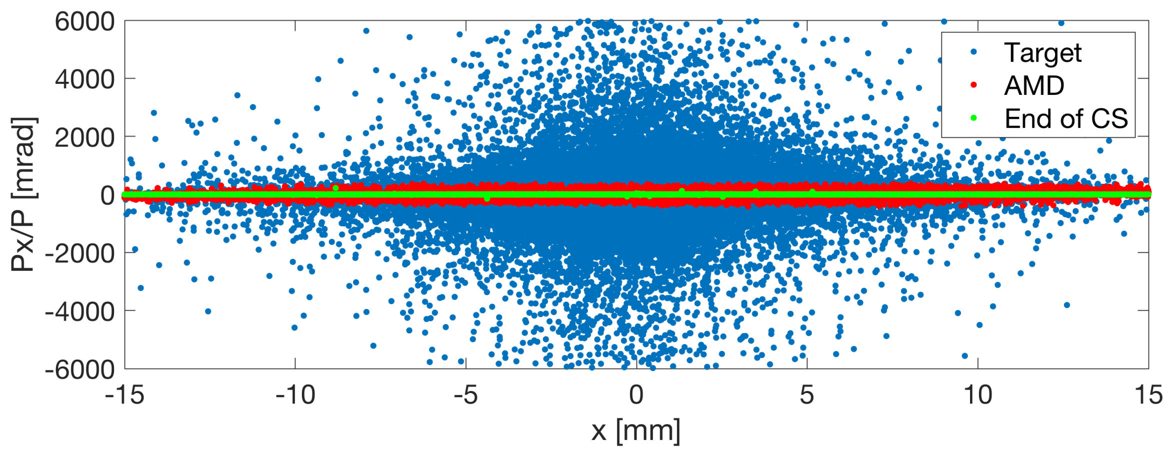
Capture and Primary Acceleration

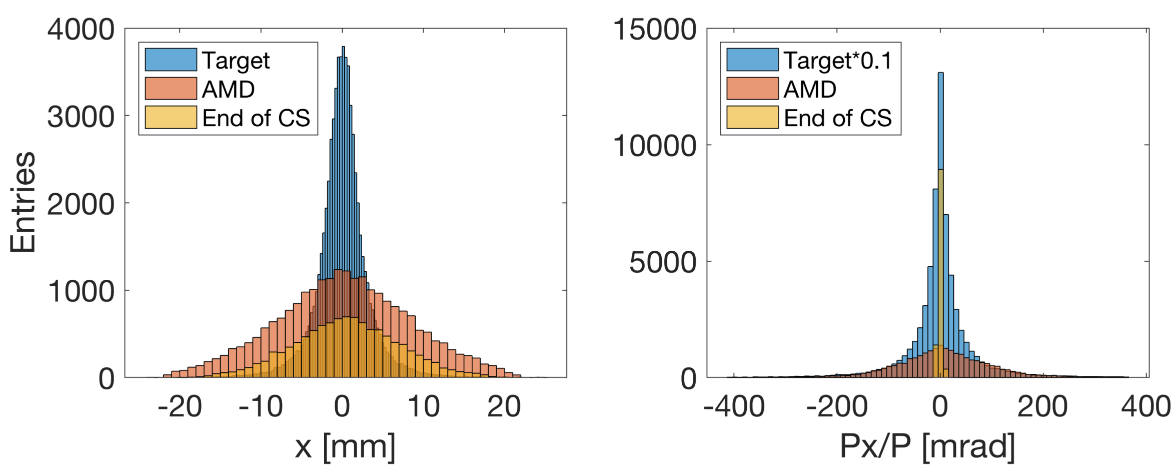
The capture linac is encapsulated inside a solenoid with the axial magnetic field of 0.5-0.7 T.

☞ **Hybrid scheme:** 1.5 meter long 17 MV/m 2 GHz L-band structures.

☞ **Conventional scheme:** 3 meter long 20 MV/m 2856 MHz large aperture S-band structures.

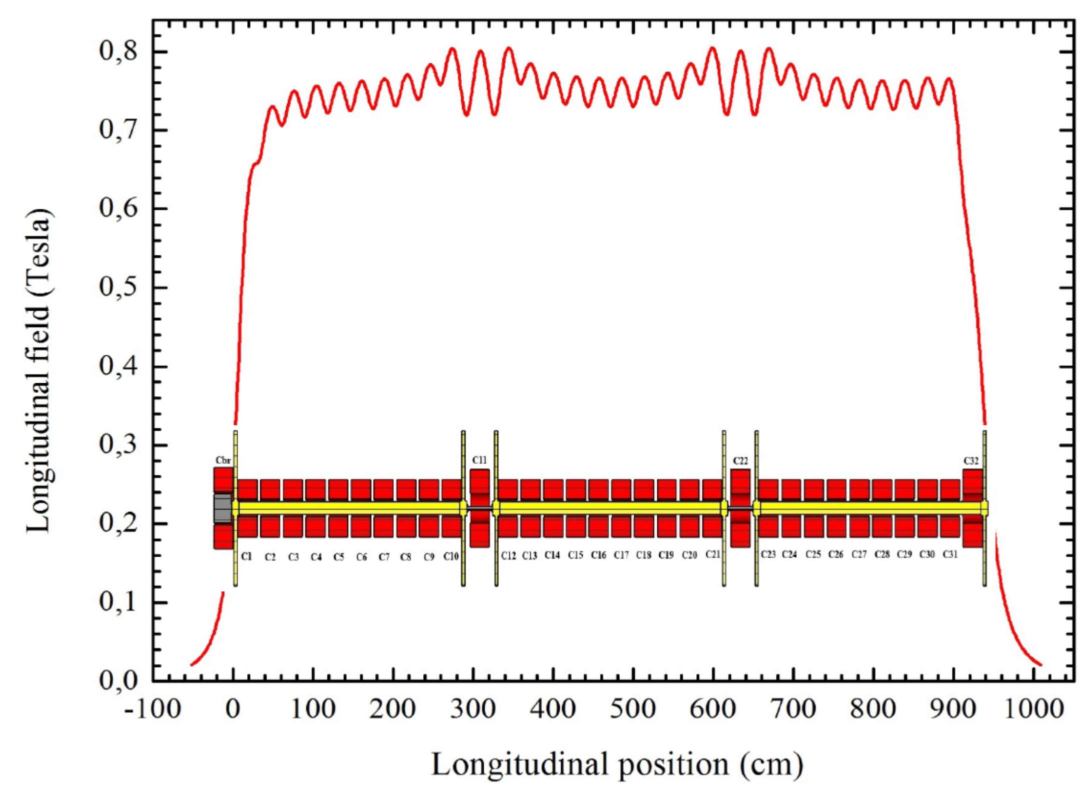
Positron emittance at the exit of the target, the AMD and the capture section at 200 MeV (uniform DC solenoid field)





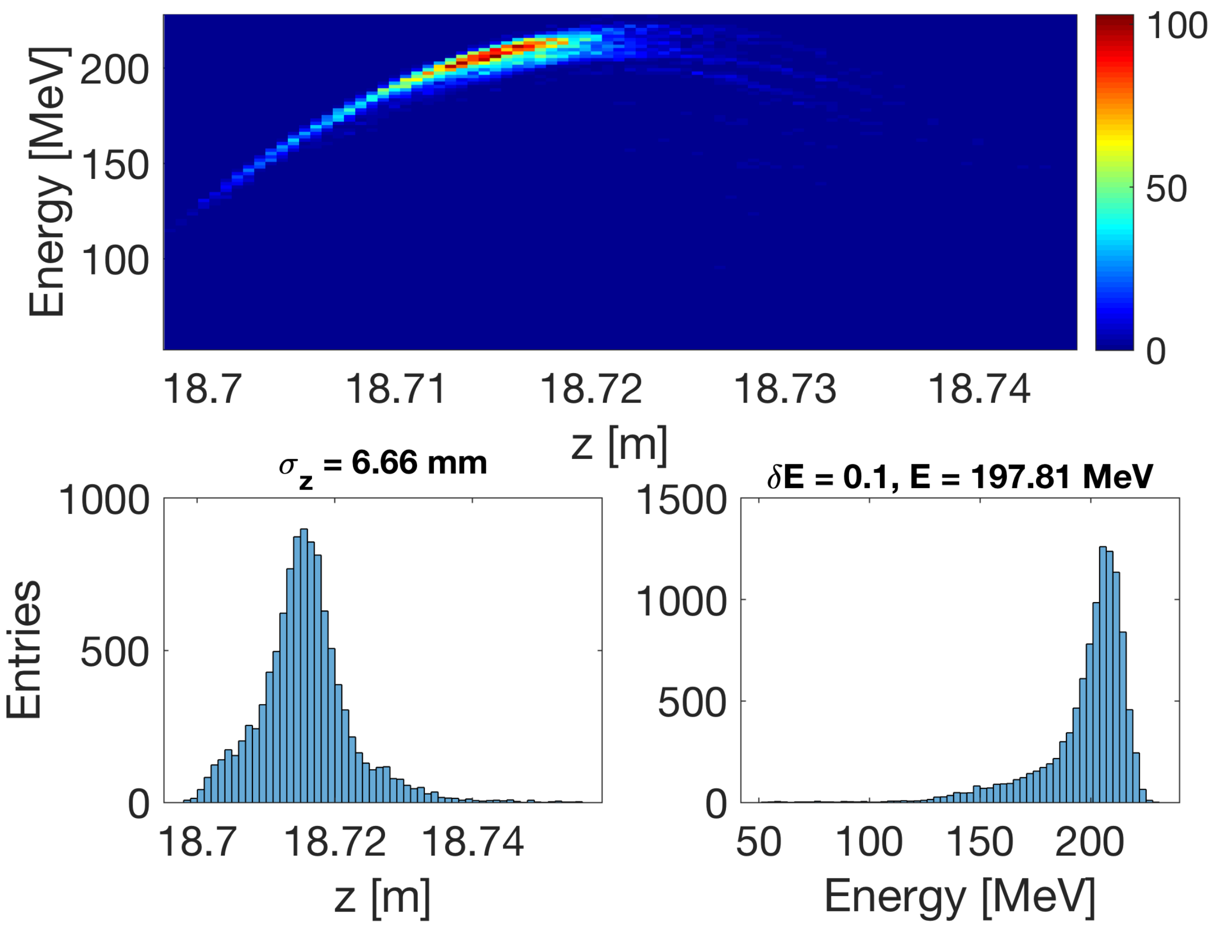
Next step: include the realistic solenoid field distribution along the capture section

Preliminary

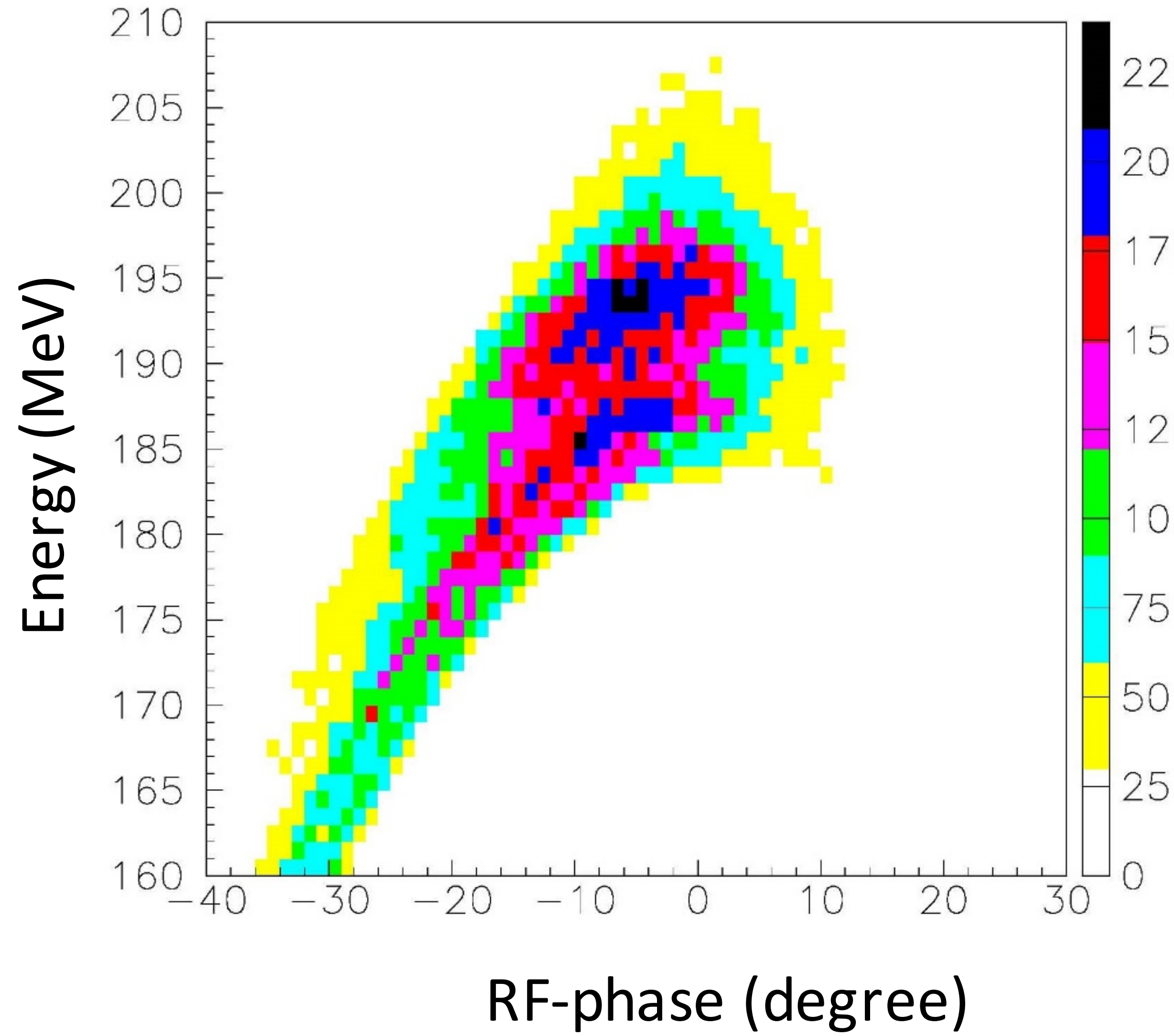


FCC-ee Positron Source (@ 200 MeV)

Longitudinal phase space of the positrons at the end of the capture linac for the hybrid scheme



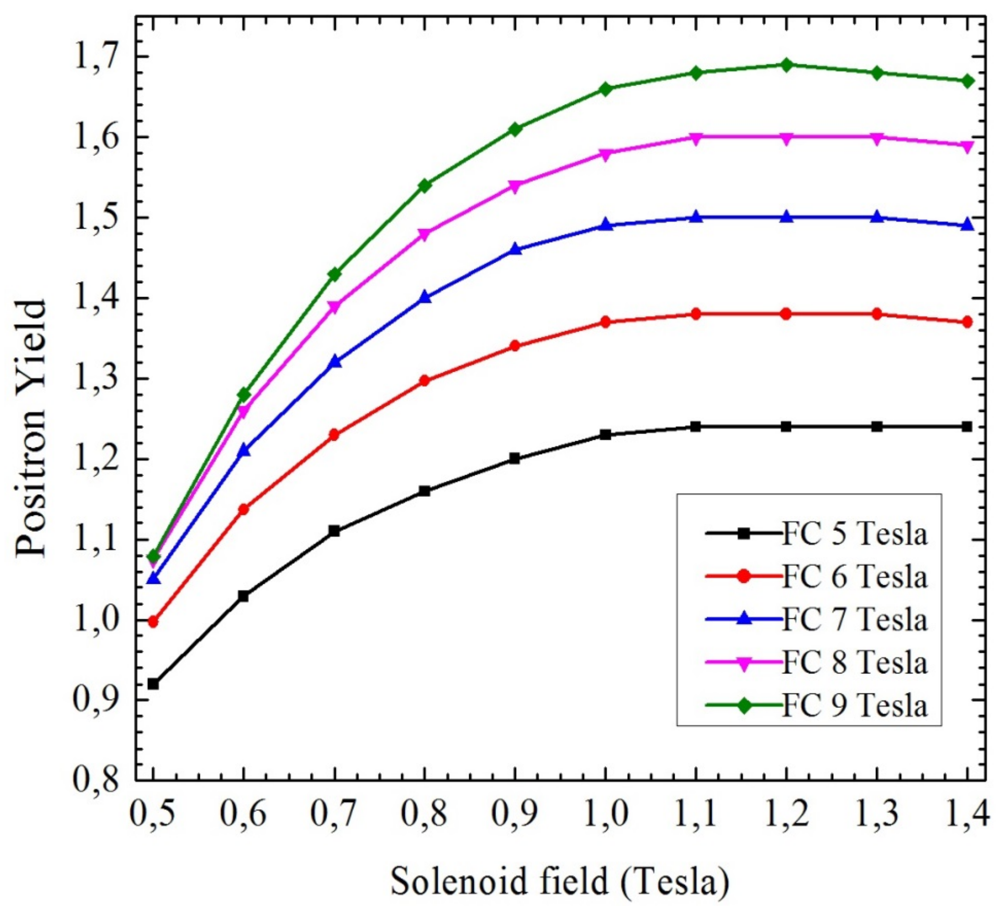
Longitudinal phase space of the positrons at the end of the capture linac for the conventional scheme



An energy-longitudinal position cut around the highest density of positrons made within the DR acceptance allows defining the accepted positron yield.

Capture and Primary Acceleration

Accepted positron yield as a function of the DC solenoid field for different values of the FC peak magnetic field



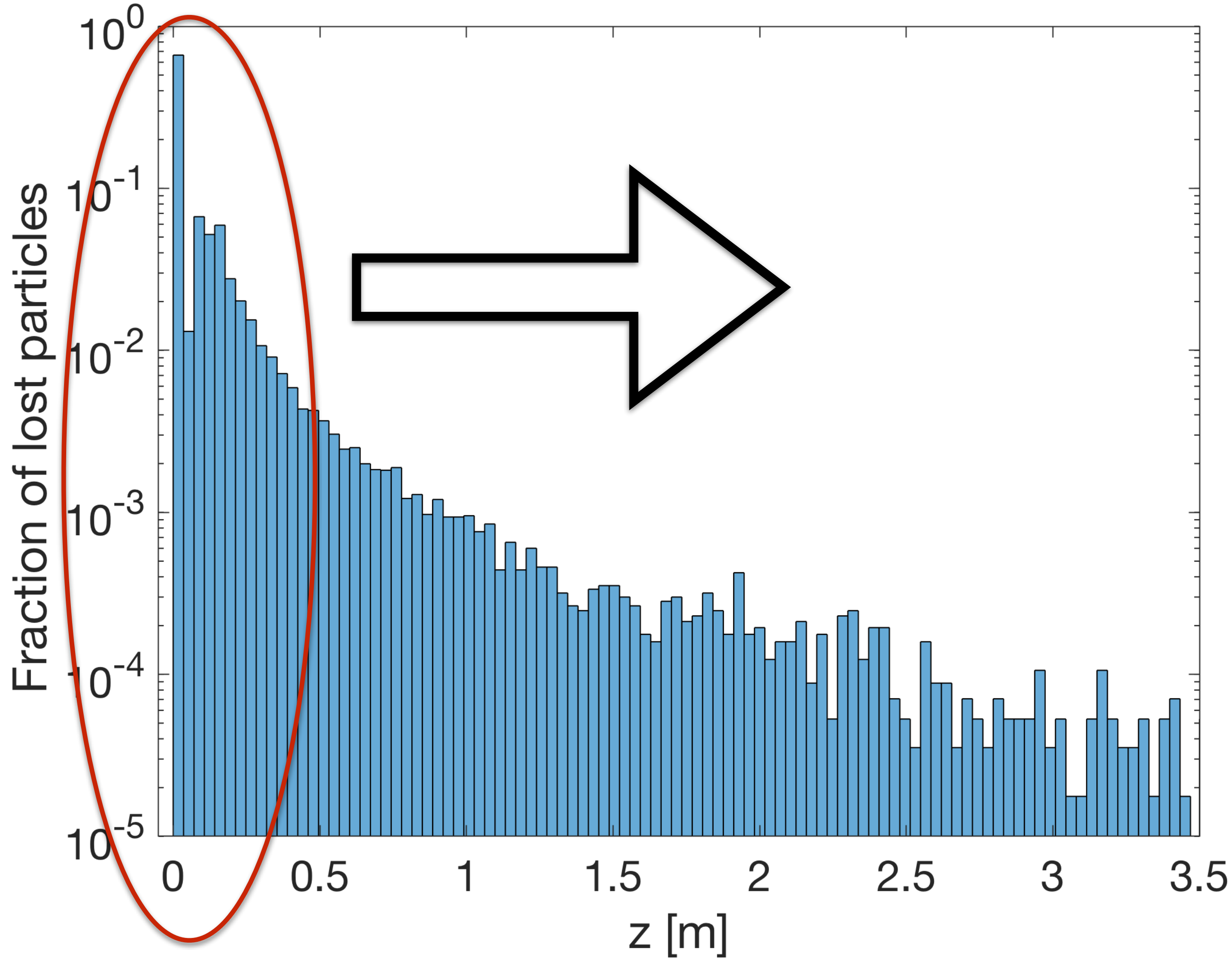
B_{DC} up to 0.7 - 0.8 T and FC B_{max} ~ 7-8 T

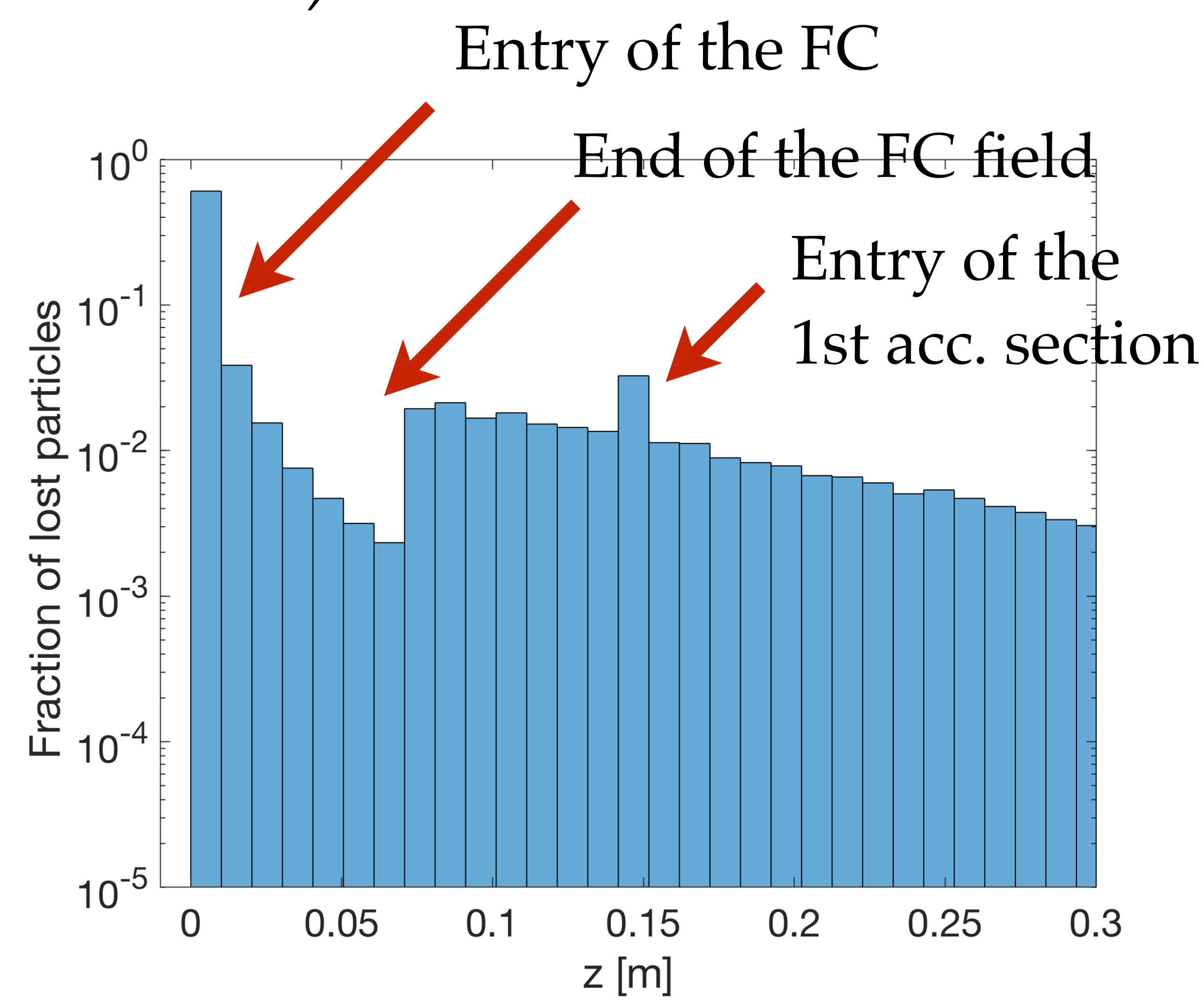
Beam Parameter	Conventional	Hybrid
B_{max} = 5 T, B_{DC} = 0.5 T		
Mean Energy	190 MeV	197 MeV
Accepted yield	1.1 N_{e+}/N_{e-}	0.9 N_{e+}/N_{e-}
Emittance hor./vert.	17 μm (1σ)	14 μm (2σ)
Energy Spread	3.5 %	11 %
Bunch Length	4 mm	7 mm
B_{max} = 7 T, B_{DC} = 0.7 T		
Mean Energy	190 MeV	198 MeV
Accepted yield	1.3 N_{e+}/N_{e-}	1.1 N_{e+}/N_{e-}
Emittance hor./vert.	21μm (1σ)	16 μm (2σ)
Energy Spread	3.9 %	10 %
Bunch Length	4 mm	7 mm

Assuming [transport until 1.54 GeV x DR injection efficiency] ~ 0.7 - 0.8 => e+ yield Ne+/Ne- ≳ 0.5 but the realistic simulations are needed + safety factor.

Capture and Primary Acceleration

Positron loss map along the beamline (hybrid scheme)





- The big part of the positrons are lost at the Flux Concentrator front aperture (∅ 8mm). The next losses occur at the exit of the FC and on the aperture of the first accelerating structure (∅ 40mm).
- Next step: design of bigger aperture Flux Concentrator (∅ 16mm) and simulation to evaluate the positron capture efficiency.

Target Thermal Load

Beam Parameter	Conventional	Hybrid
Target thickness	$4.5X_0$	$0.4\ X_0/\ 3.4X_0$
e+ yield @ Target	~11 e+/e-	~7 e+/e-
PEDD	17 J/g	3 J/g
Deposited power	18 % (2.1 kW)	7 % (0.8 kW)

$W_{74}Re_{26}$ material has a PEDD limit of **35 J/g** (safe value to avoid target failure).

- The target life time will suffer from the cyclic thermal loads and stresses from the beam pulses. Also the evacuation of the average power from the target at 200 Hz can be difficult.
- A stationary target will not be sufficiently robust => rotating/trolling target.
- The effects of eddy currents and the additional power, injected by the pulsed Flux Concentrator into the target, should be investigated.
- **Evaluation of the thermal load in the target (peak stress and fatigue limit) and design of the cooling system to be addressed => reliability of the target.**

Summary

- FCC-ee can employ the conventional/hybrid positron source. *No showstopper identified* => studies ongoing.
- Current studies: both schemes provide *the comparable positron yield (~1 N_{e+}/N_{e-})* accepted by the DR.
- As far as reliability of the target is concerned, *the hybrid scheme is more attractive* allowing *lower deposited power and PEDD* in the production target.
- Evaluation of the thermal load in the target => target design and cooling system.
- Start-to-end simulations to the DR and full optimisation are underway => *investigation of the bypass line for e+ generation/capture*.
- ***Operation experience and R&D of the SuperKEKB positron source is of great importance for the FCC-ee.***