FCC-ee positron source

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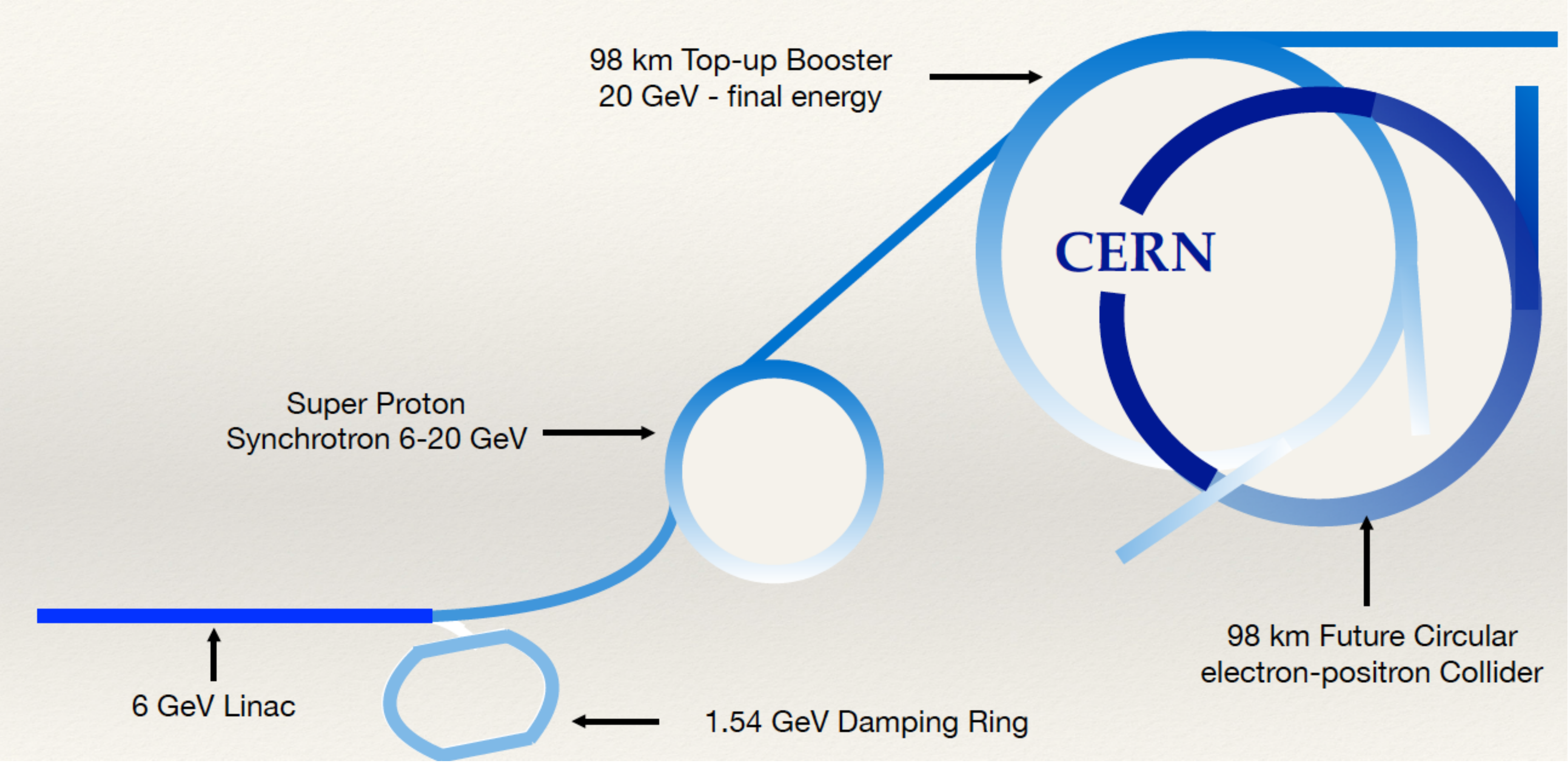
J. Seeman (SLAC), P. Sievers (CERN), F. Zimmermann (CERN)

FCC-ee Injector Complex



- RF-gun
- e-/e+ linac up to 6 GeV
- 1.54 GeV Damping Ring and bunch compressor
- SPS or new Ring as a Pre-Booster Ring (6 - 20GeV)
- Booster Ring (20 - 45.6 GeV)

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

Y. Papaphilippou, FCC-ee injector overview", FCC week 2018

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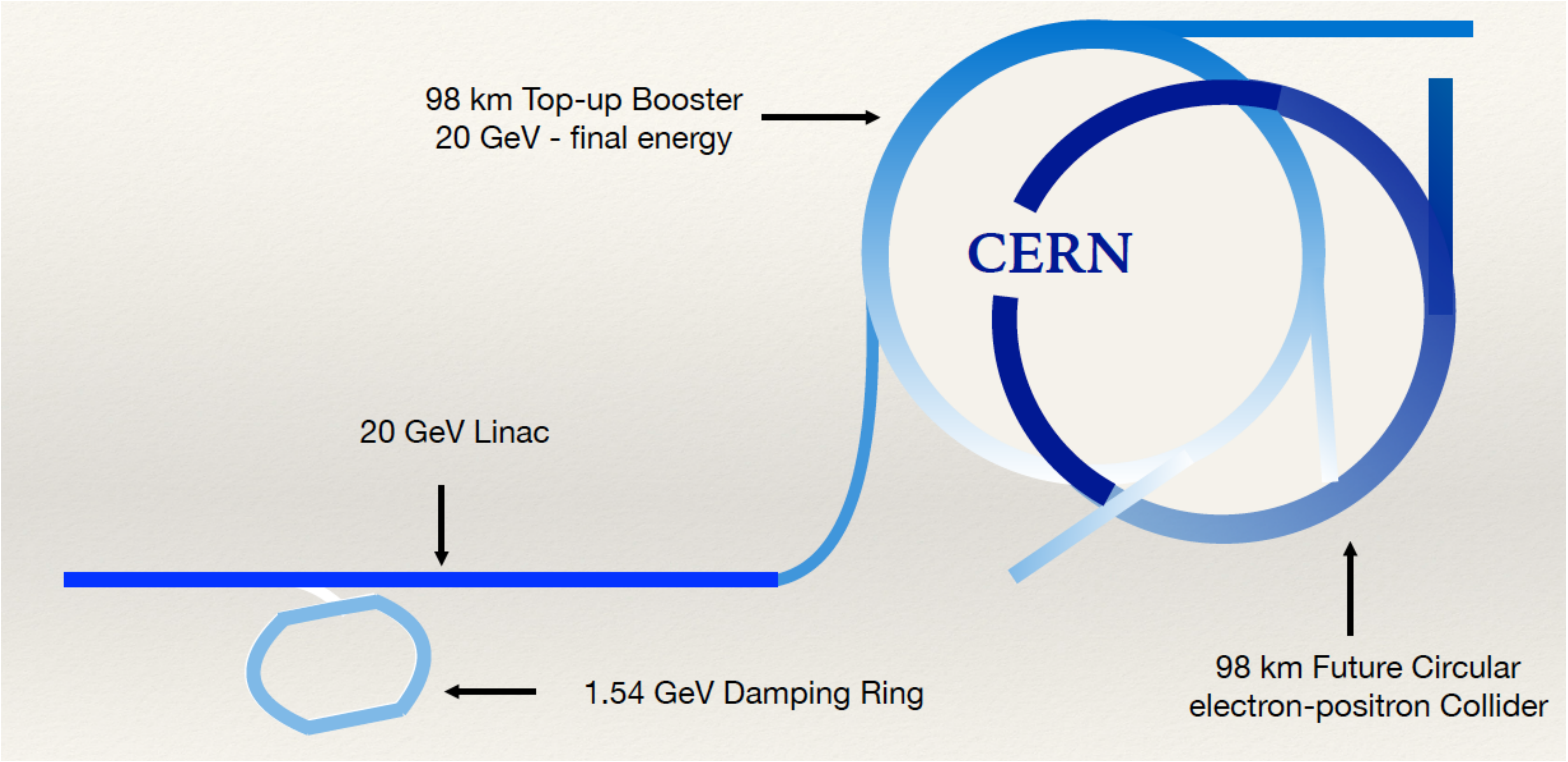

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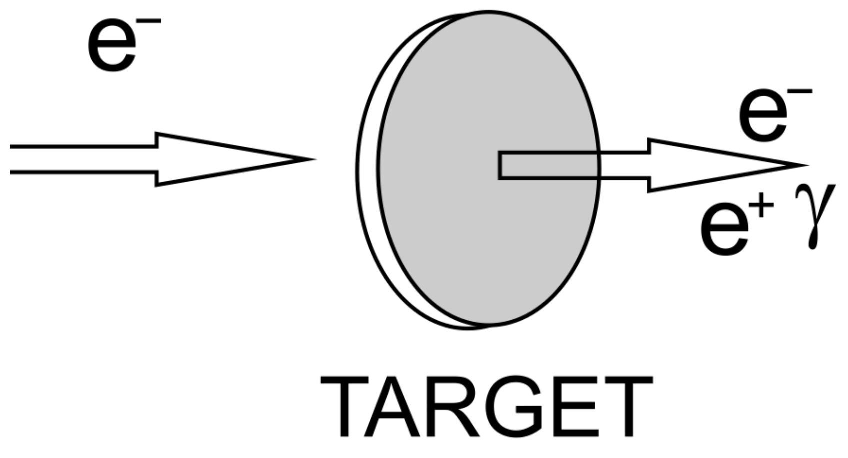
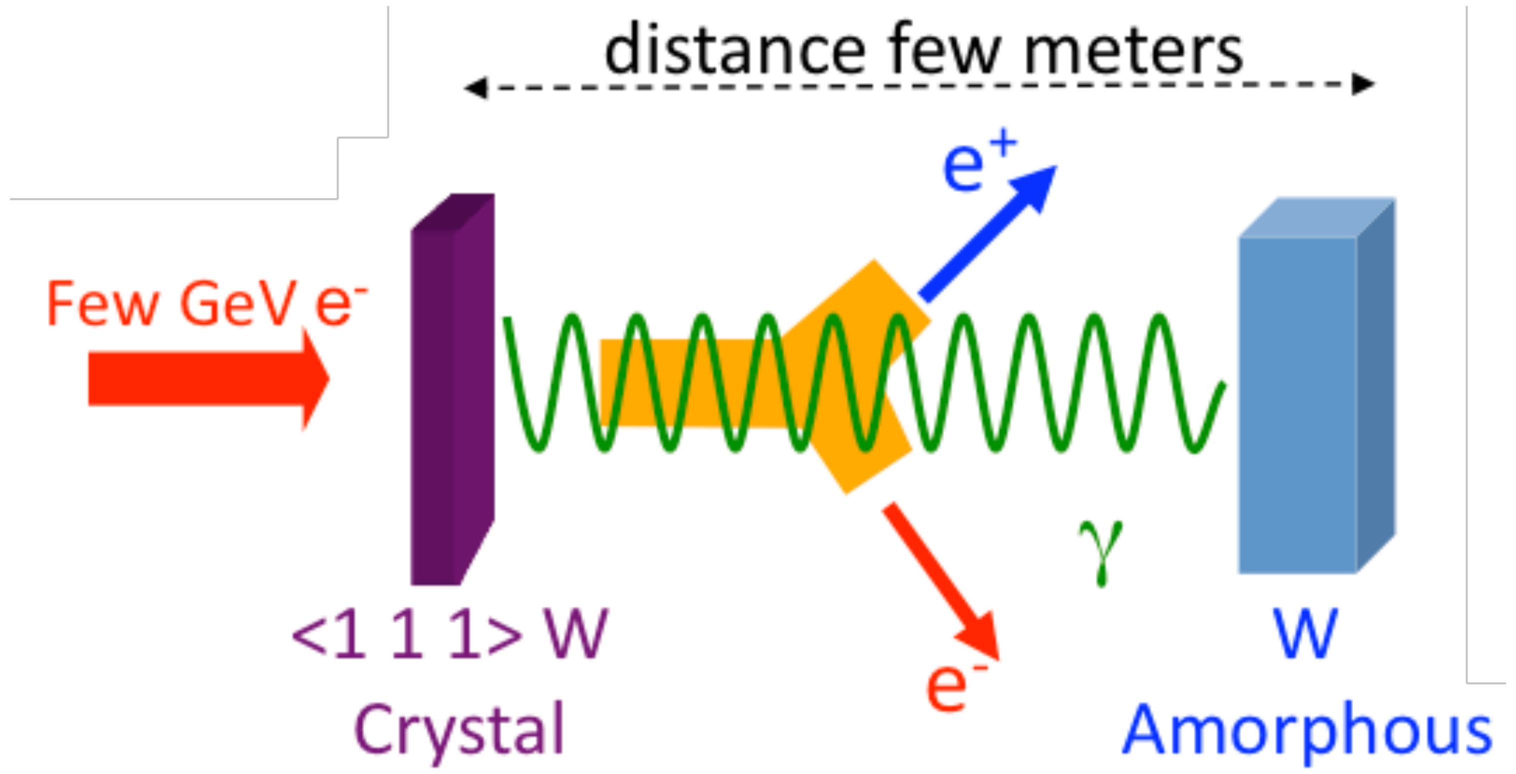
Positron Sources



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

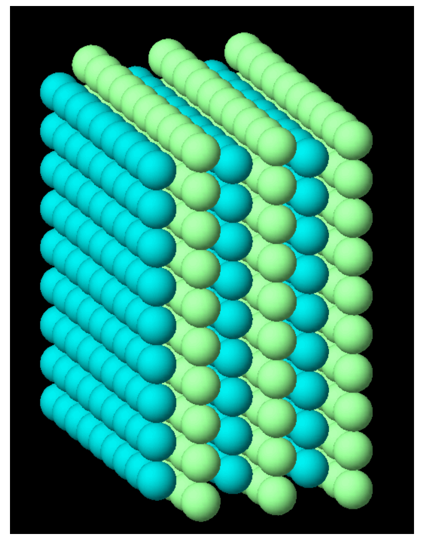
- Classical e+ source.
- It was employed to produce e+ beam at the existing machines (ACO, DCI, SLC, LEP, KEKB…).



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**.



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).

FCC-ee Positron Source

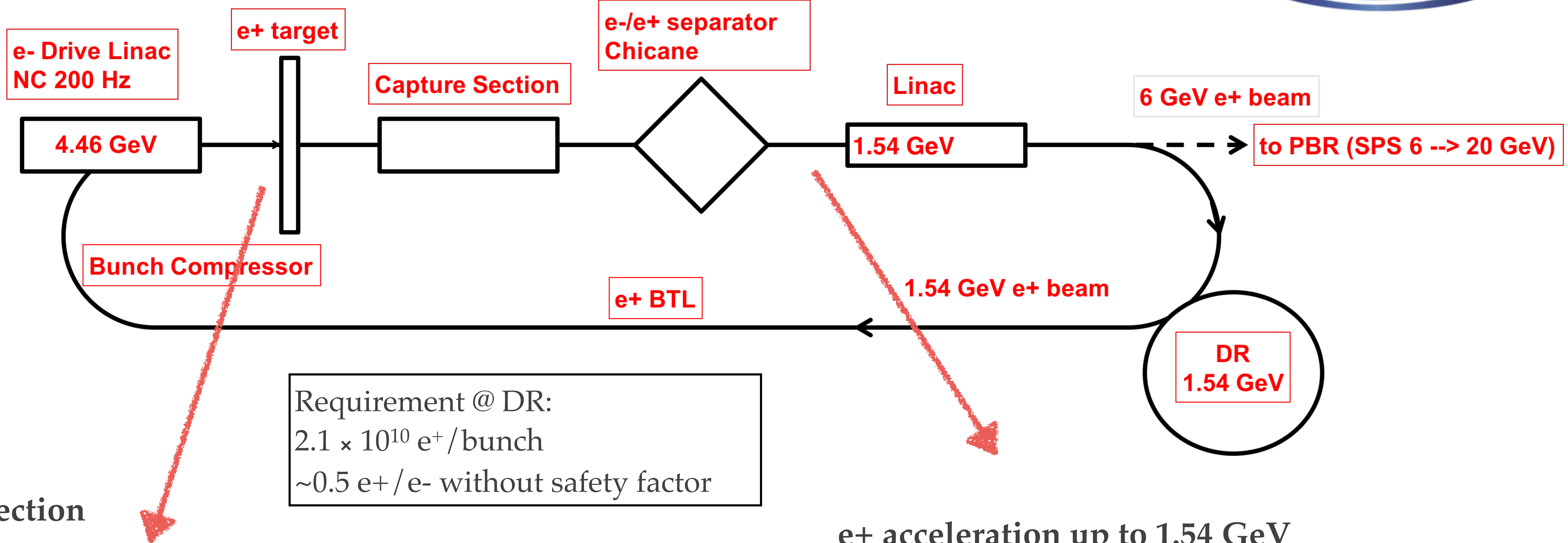
Primary e- beam

4.46 GeV

2.1×10^{10} e-/bunch ~ 3.4 nC (main e- beam)

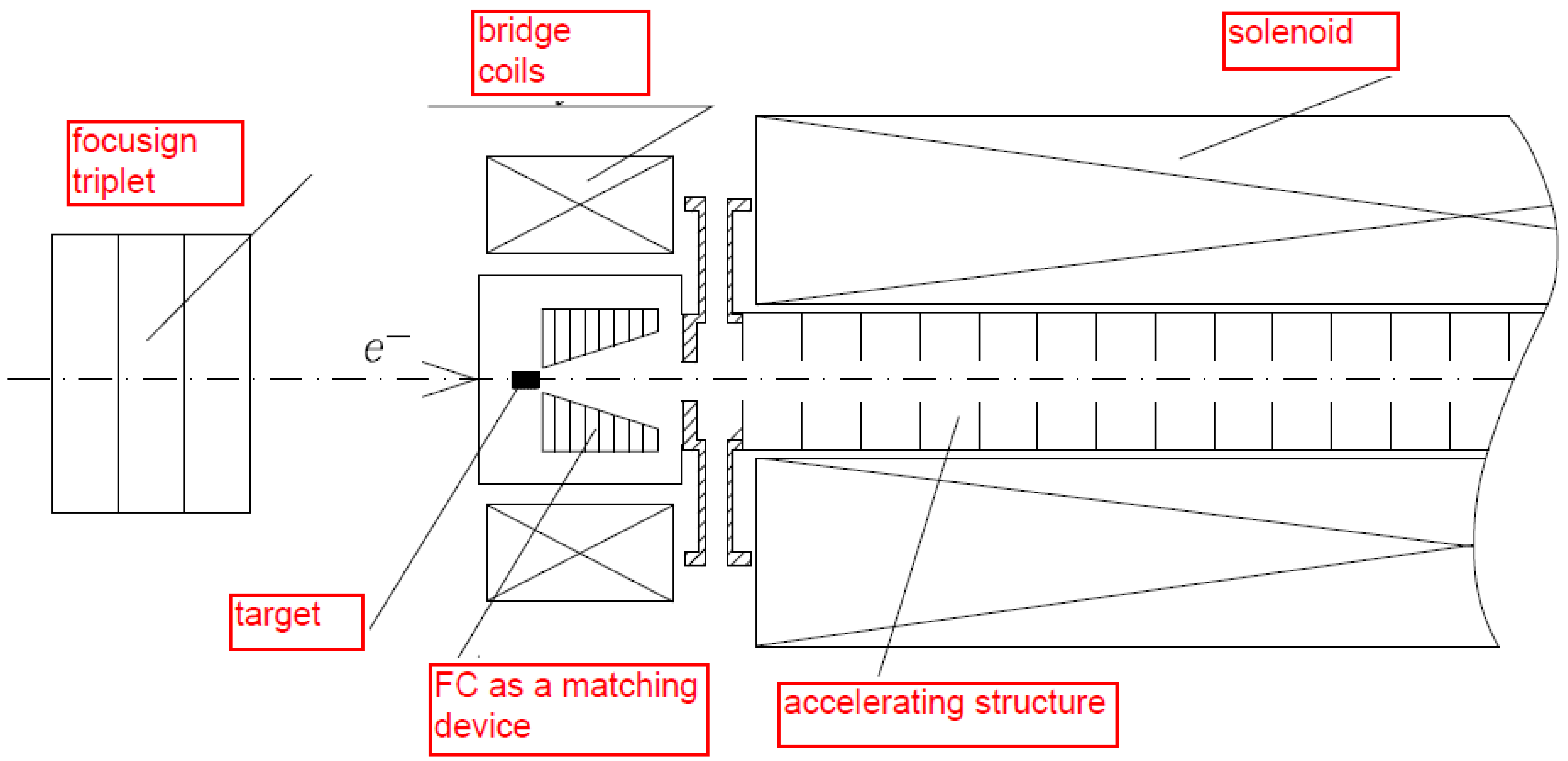
4.2×10^{10} e-/bunch ~ 6.7 nC up to 8.8 nC (for e+ production)

2 bunches/pulse spaced by 60 ns

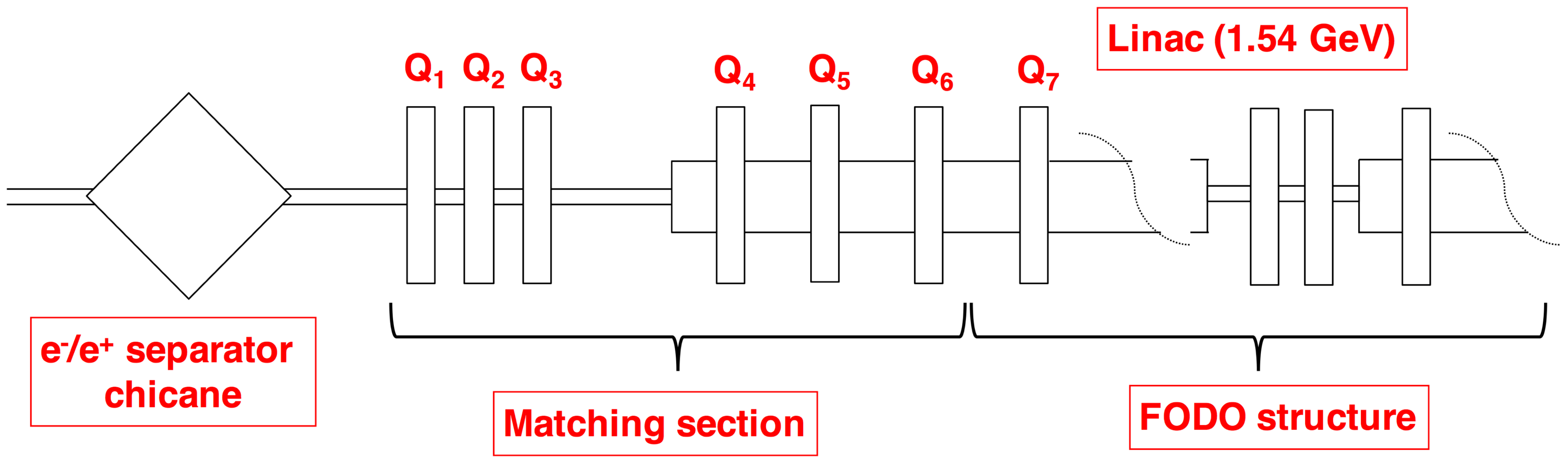


Requirement @ DR:
2.1×10^{10} e+/bunch
~0.5 e+/e- without safety factor

e+ production and capture section

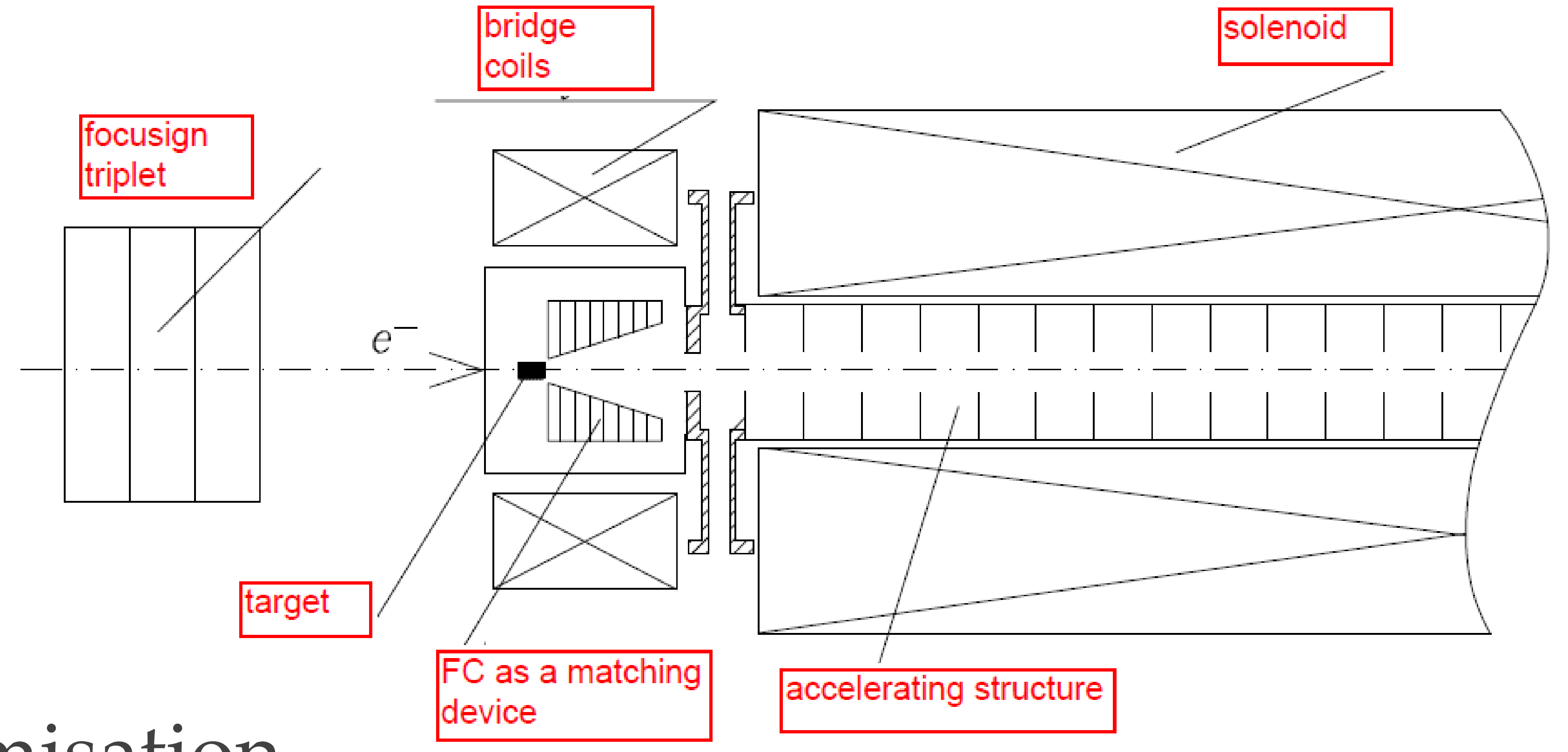


e+ acceleration up to 1.54 GeV



FCC-ee Positron Source (Target)

Conventional scheme

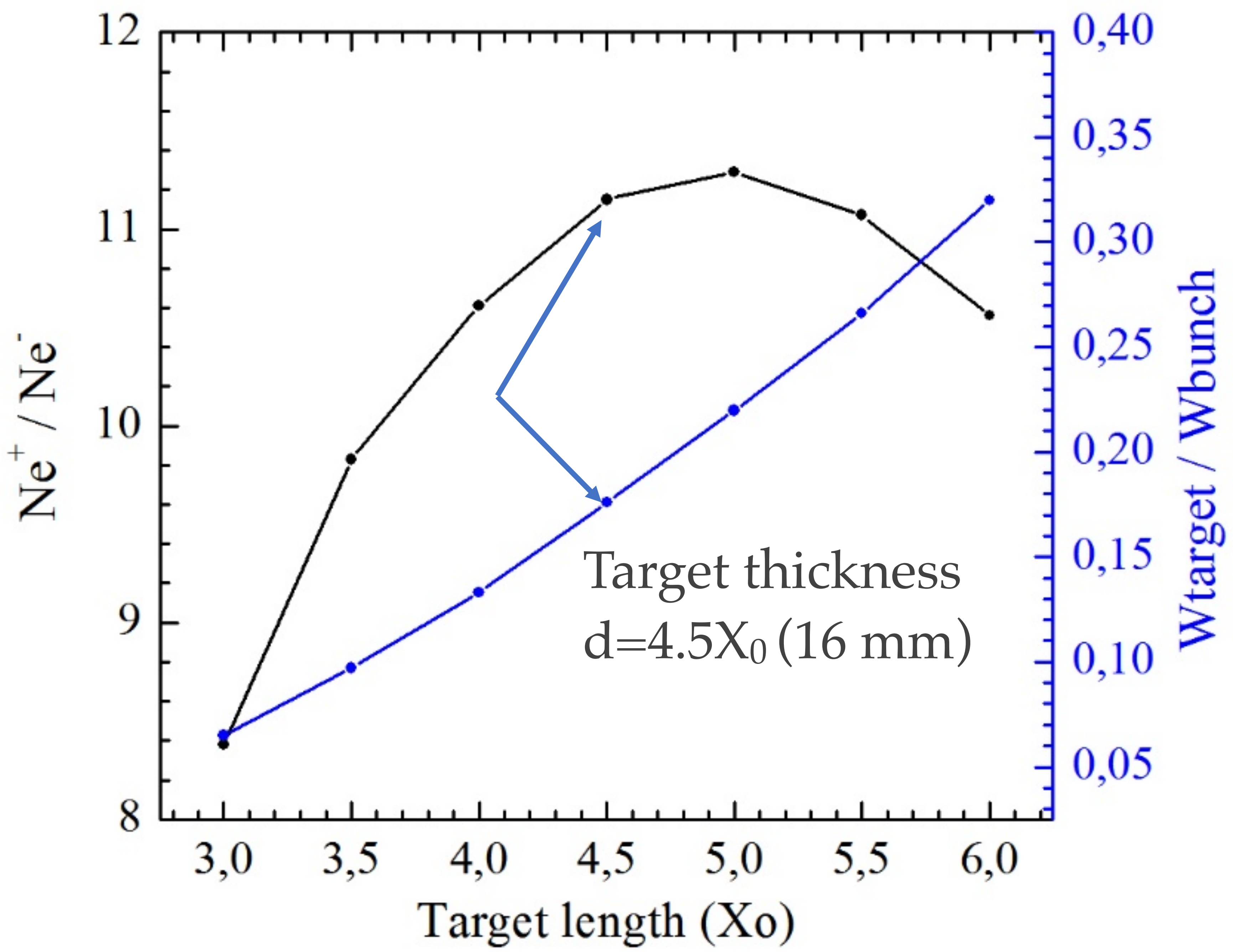


For max e- bunch charge 8.8 nC (5.3×10^{10} e^-/bunch):

- e- beam energy (2 bunches @ 200 Hz) 76 J or average e- beam power on target 15 kW.
- Power deposited in the target ($4.5X_0$) 2.8 kW per pulse.

Mean target power deposition with 50 pps	Mean target power deposition with 200 pps
700 W	2800 W

e+ target ($W_{74}Re_{26}$) optimisation

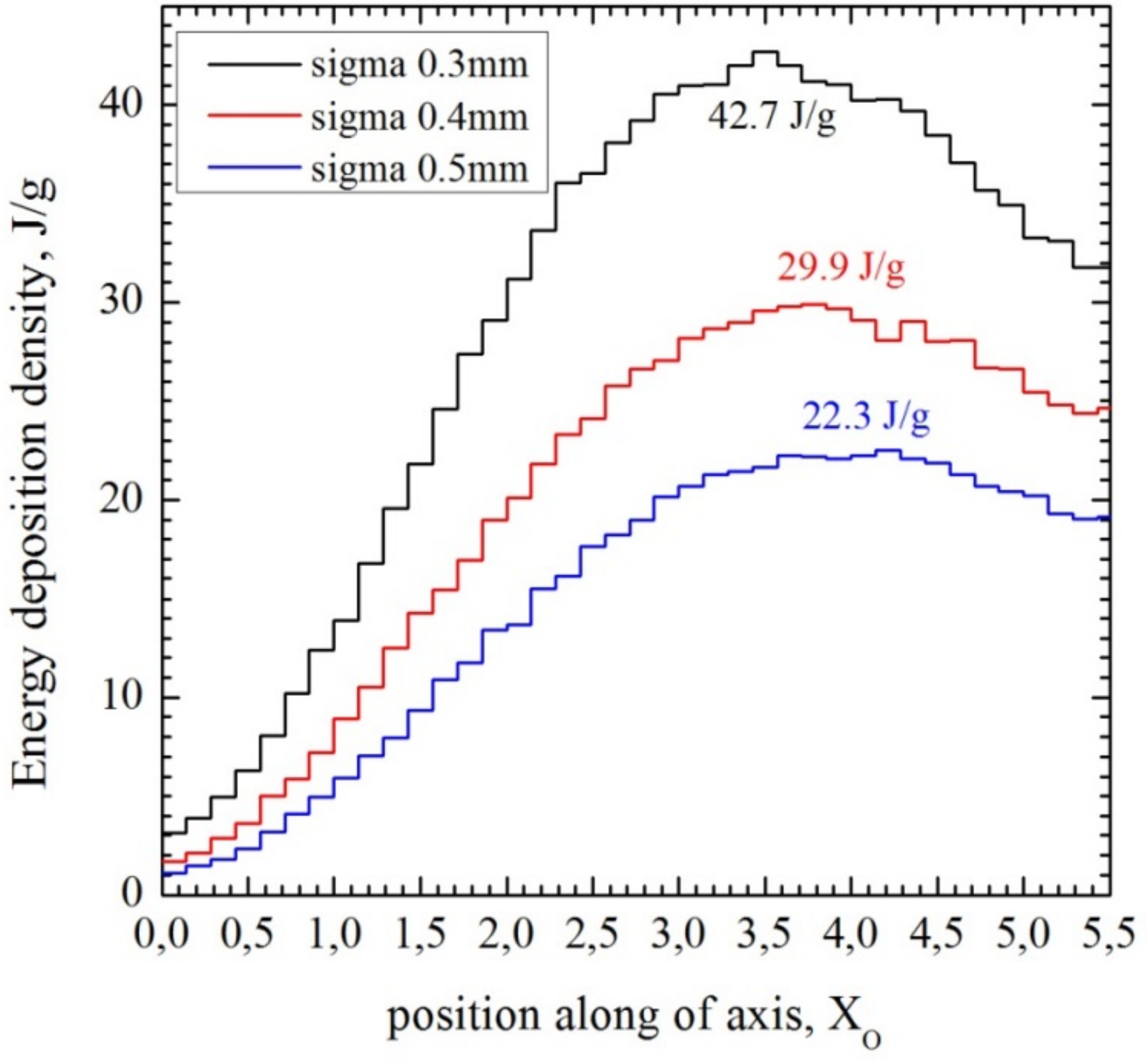


Tungsten radiation length X_0 is 0.35 cm.

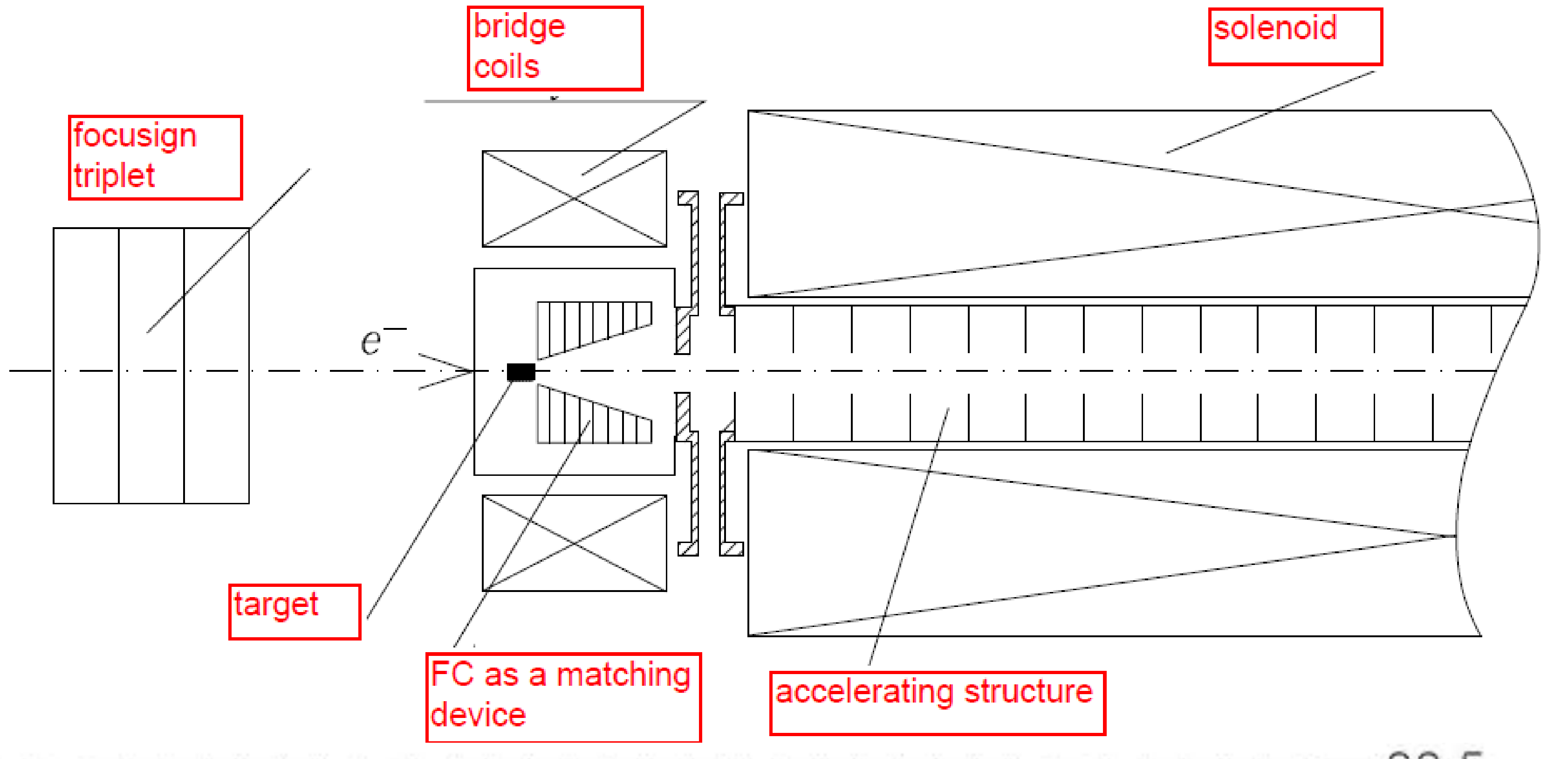
FCC-ee Positron Source (Target)

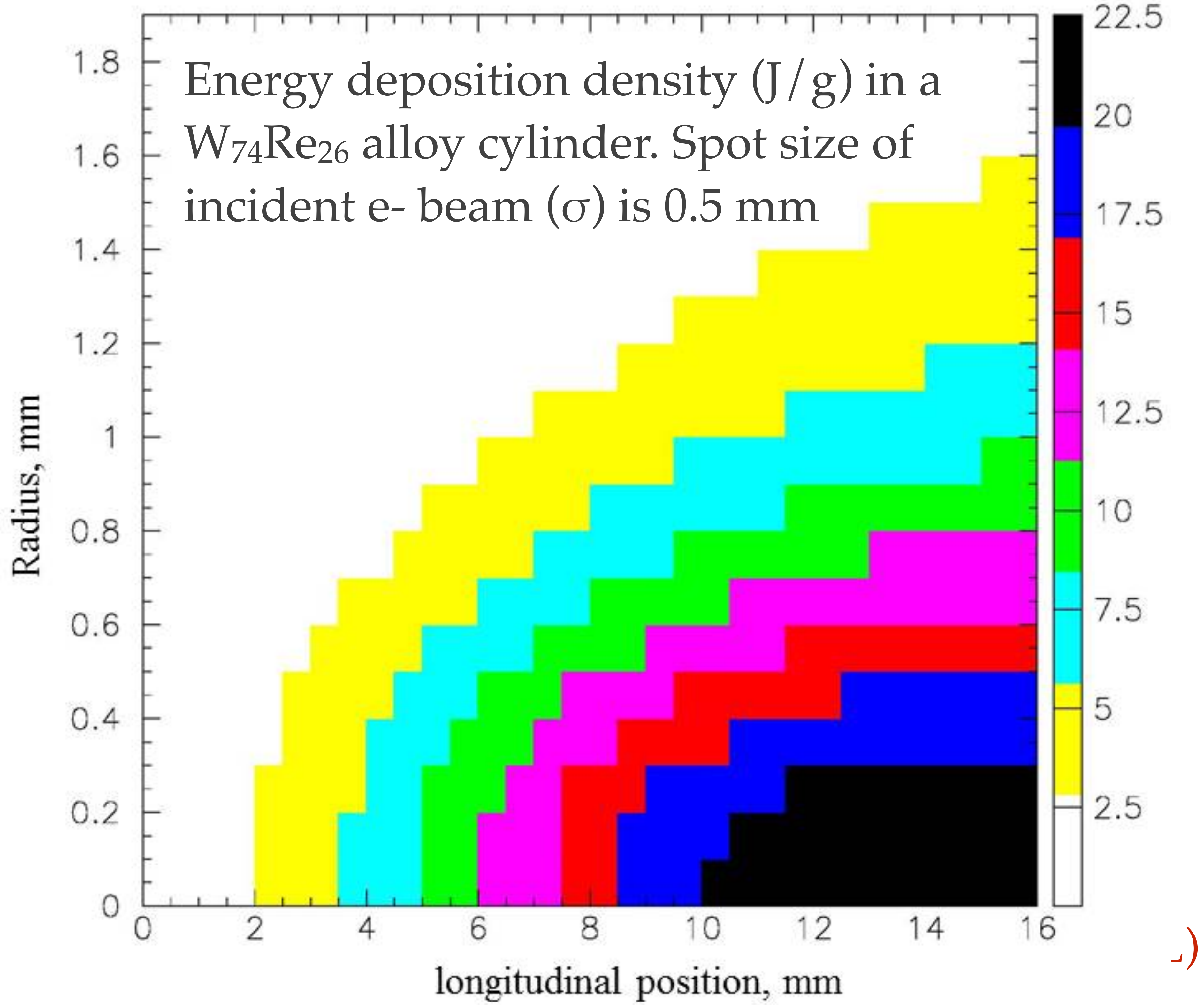
Conventional scheme

Energy deposition density along the target axis for different e-beam spot size



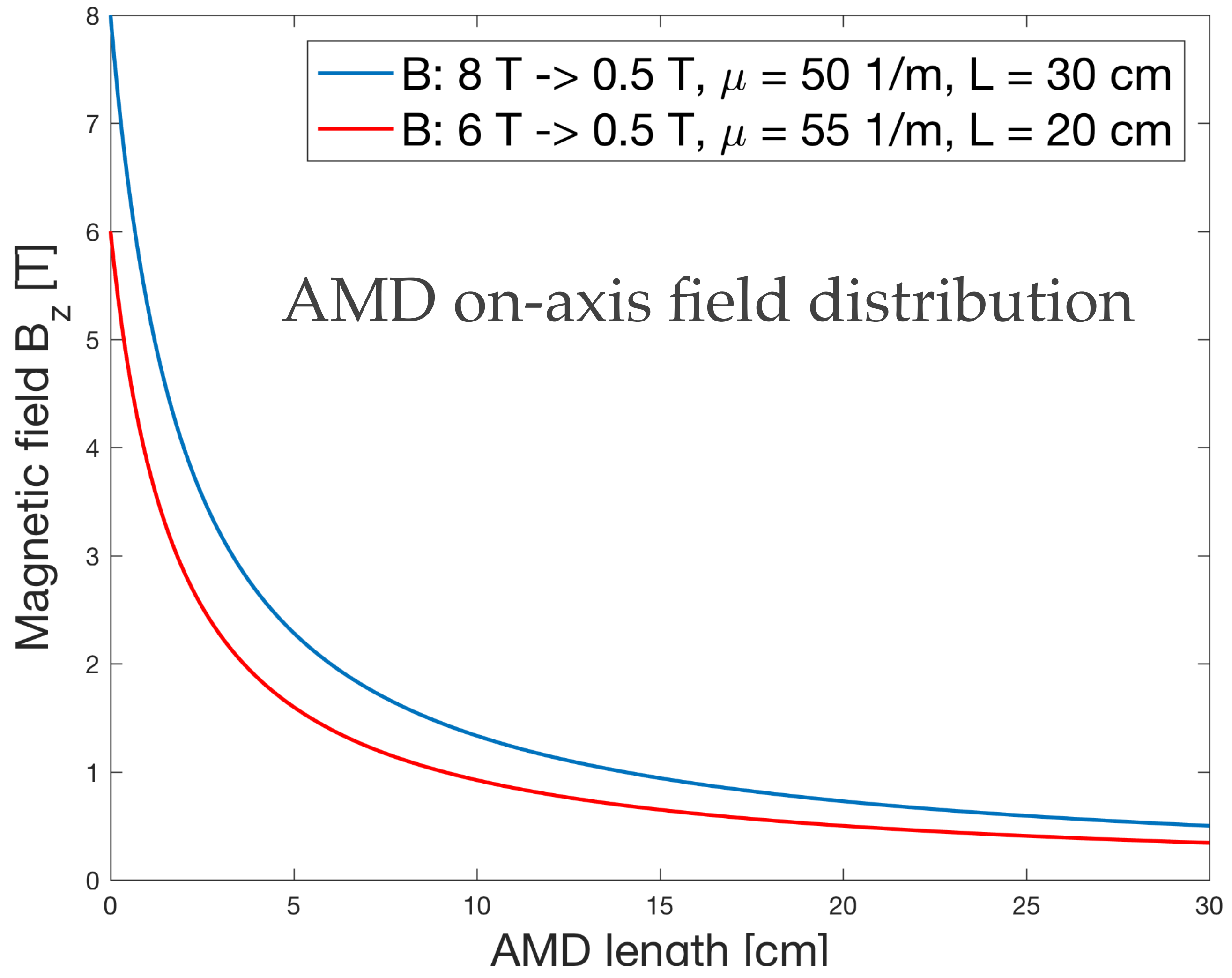
- PEDD ~ beam and target parameters (beam energy, spot size and target thickness) => thermo-mechanical stresses.
- According to SLC experience, $W_{74}Re_{26}$ material has a PEDD limit of 35 J/g (safe value to avoid target failure).

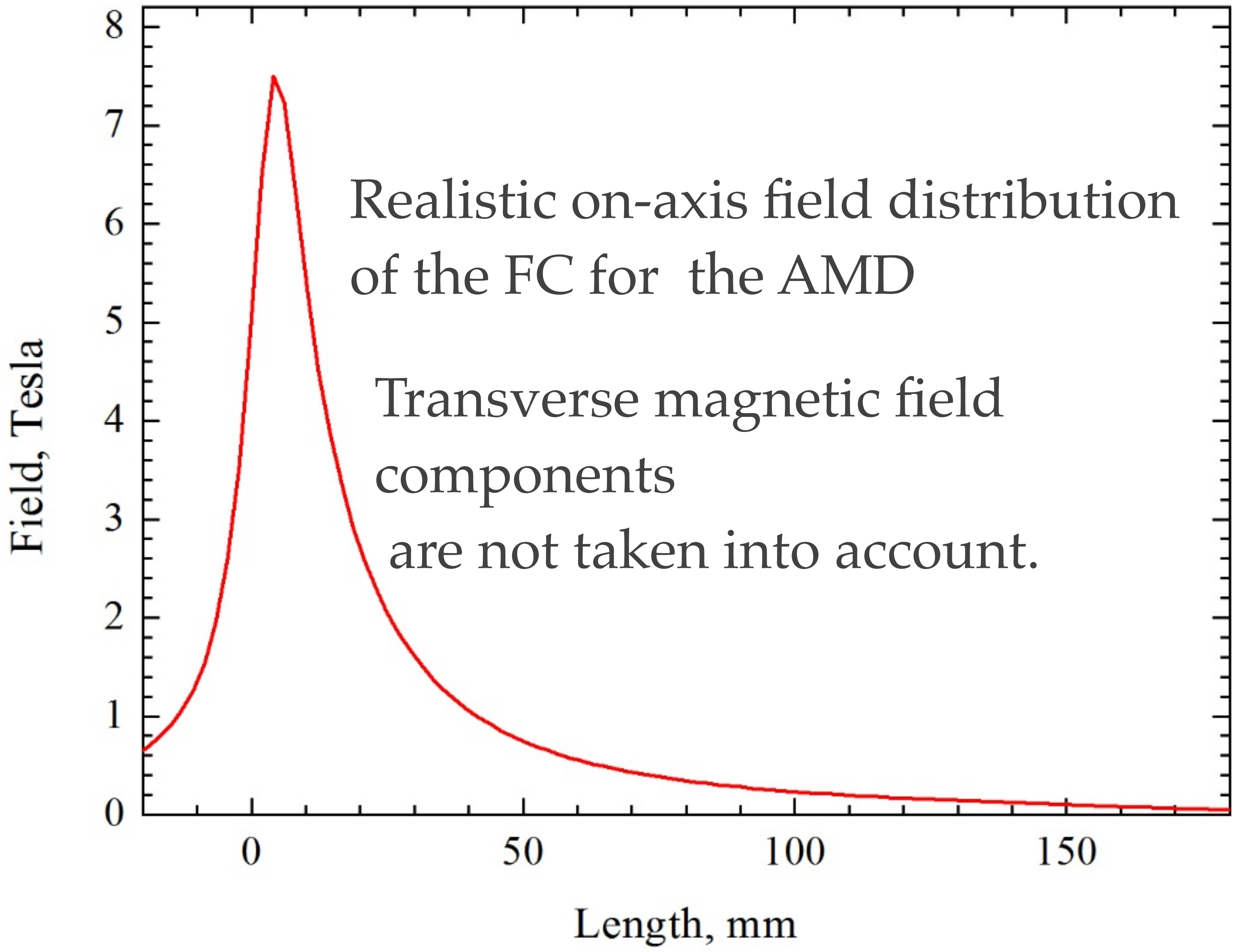


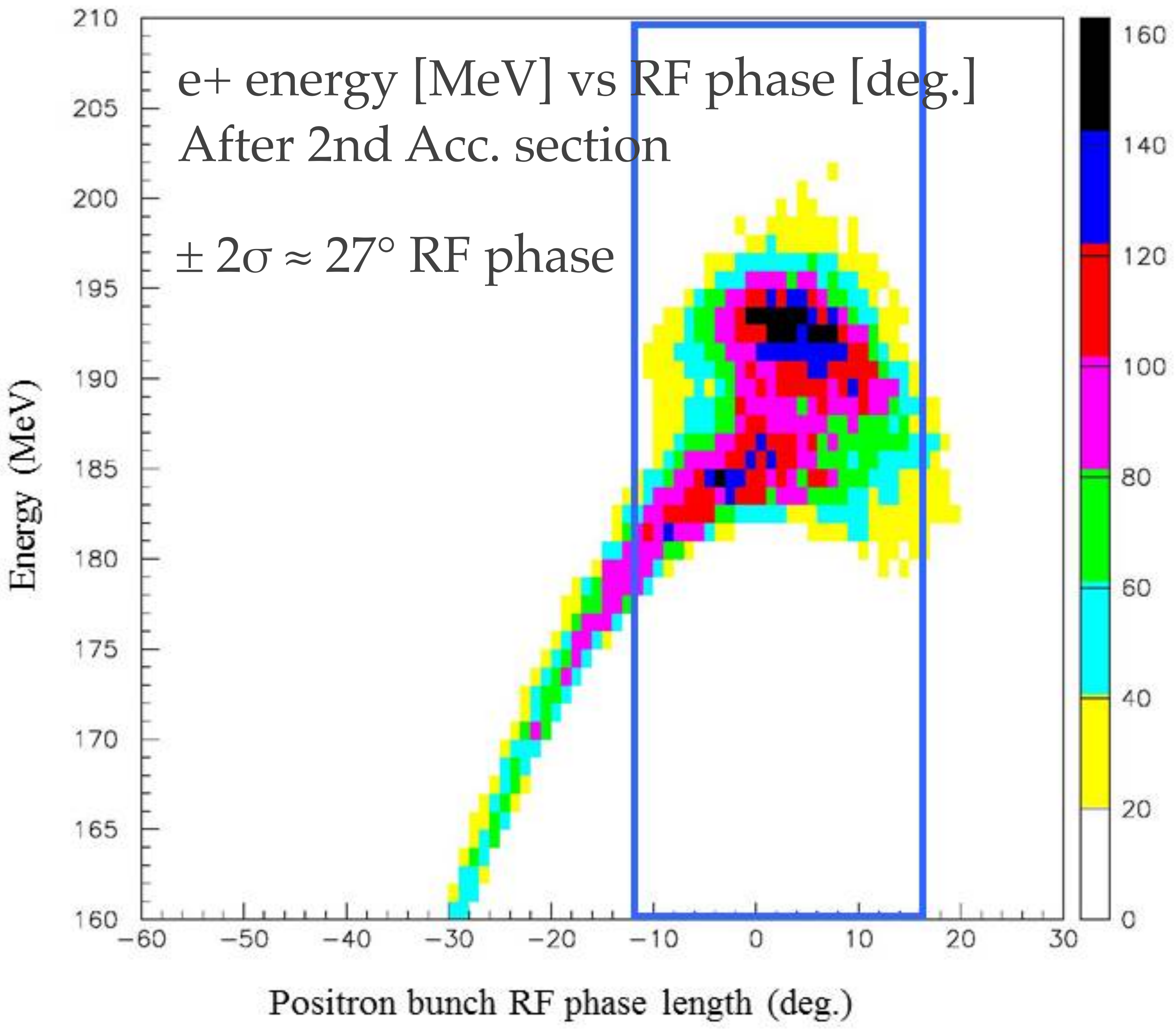


FCC-ee Positron Source (Capture Section)

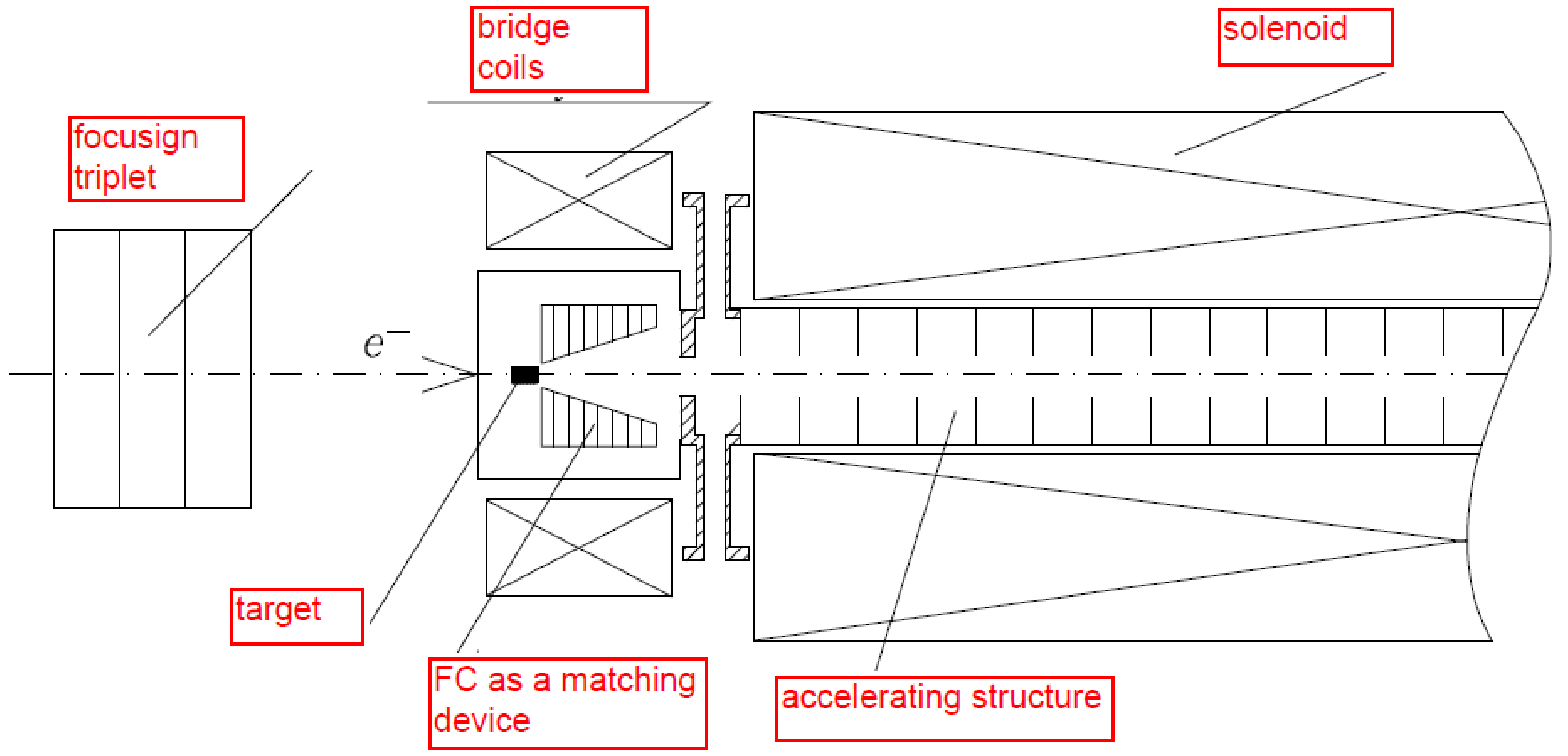
Conventional scheme







Energy acceptance of DR ±6-8% (±92 MeV)

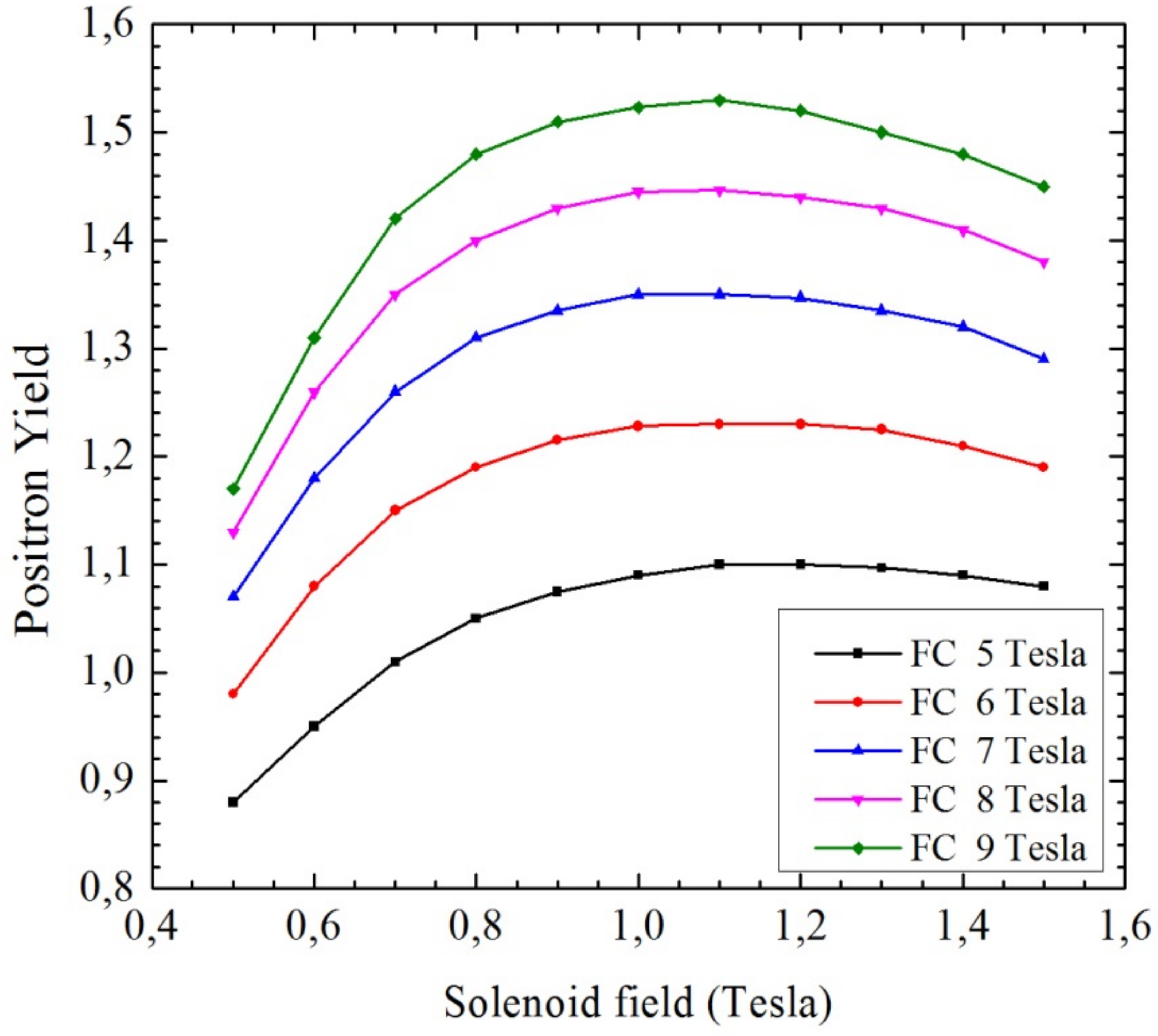


- **Flux Concentrator (FC):** peak field is 7.5 T, DC solenoid field is 0.5 T, length = 15 cm, front/rear aperture is 10/70 mm, offset between target and FC peak field position is 7 mm.
- **Accelerating structures:** S-band, 20 MV/m, length is 3 m, aperture is 30 mm.

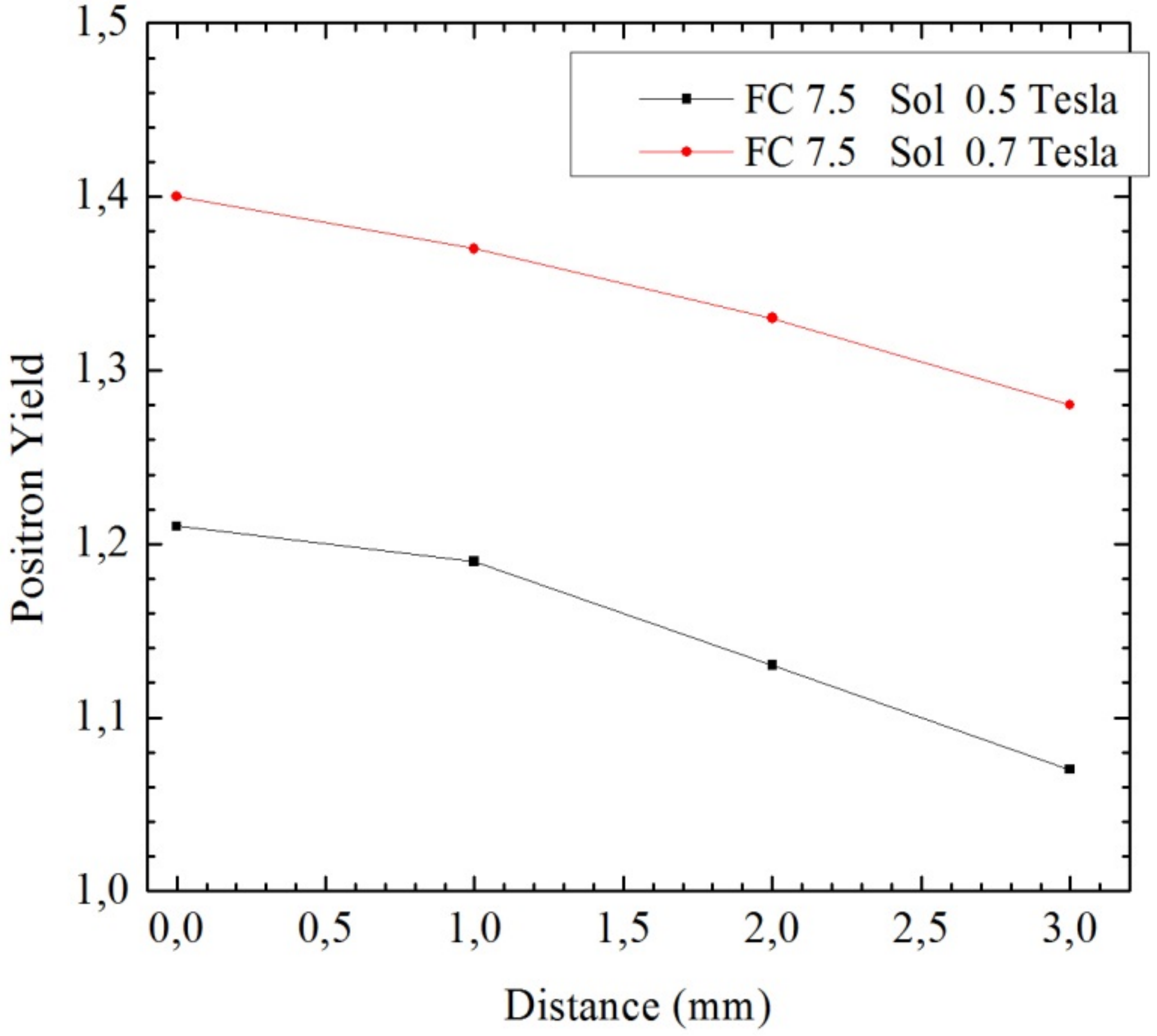
FCC-ee Positron Source (Capture Section)

Conventional scheme

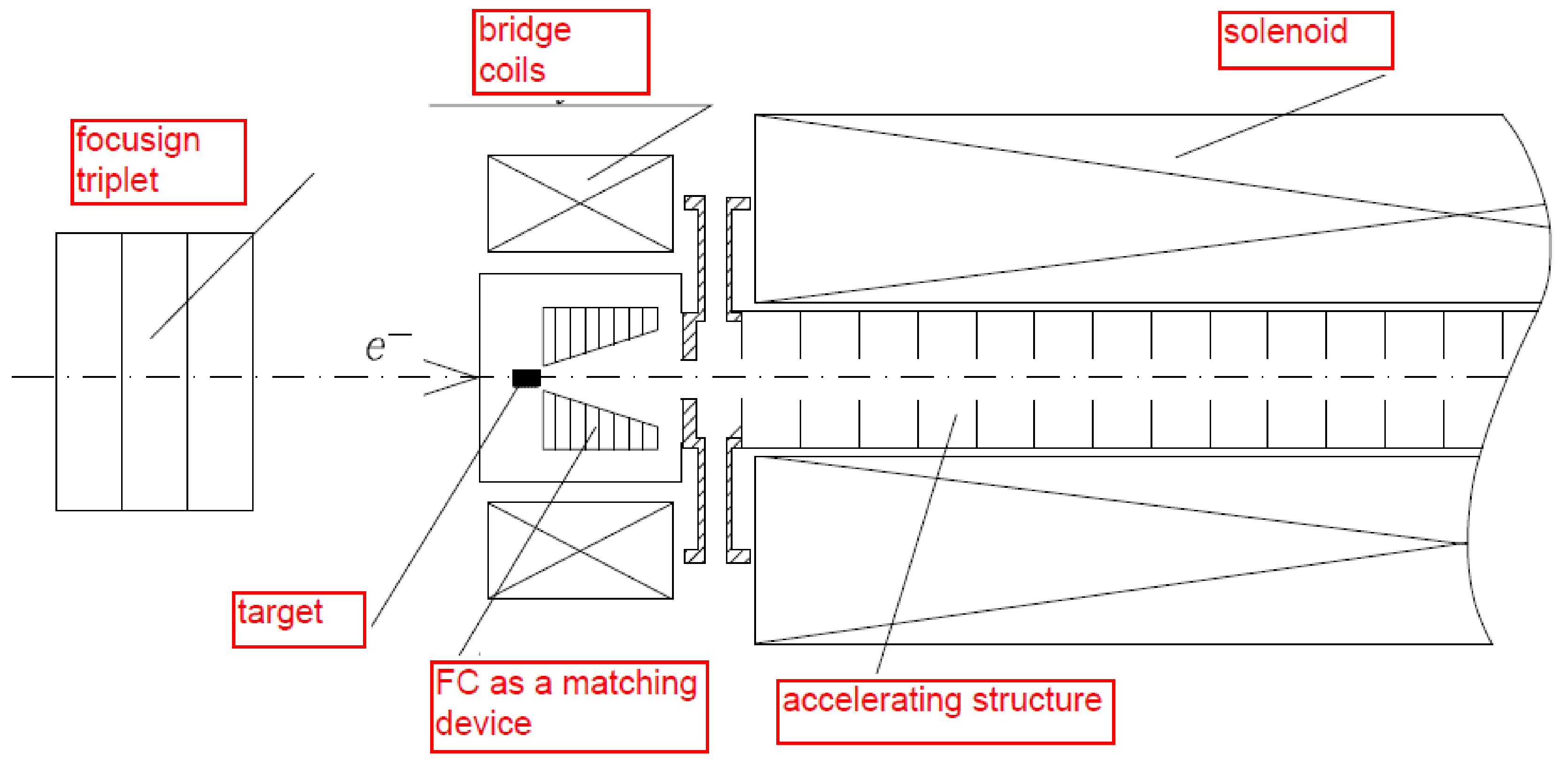
e+ yield @exit of the capture section with variation of FC and solenoid field strength



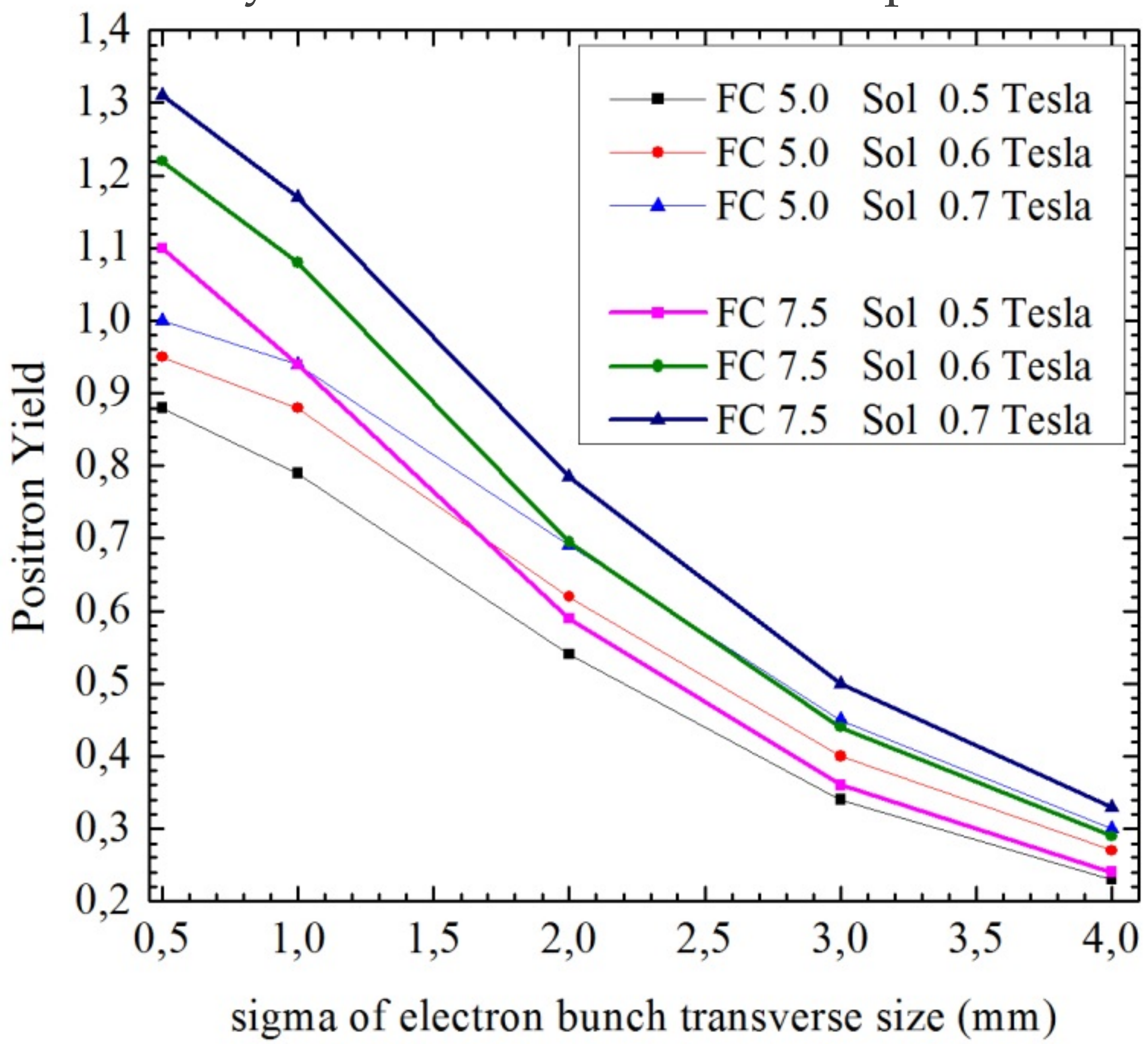
e+ yield vs. distance between target and FC front face



RF frequency	2856 MHz
Diameter of aperture	30 mm
Length	3 m
Accelerating gradient	20 MeV/m



e+ yield vs. incident e- beam spot size



FCC-ee Positron Source (@ 190 MeV)

Conventional scheme

@ 190 MeV, incident e- beam spot size (σ) is 0.5 mm

	FC–Solenoid field, Tesla											
	5-0.5		5-0.6		5-0.7		7.5-0.5		7.5-06		7.5-0.7	
Accelerating. Structure diameter, mm	20	30	20	30	20	30	20	30	20	30	20	30
Positron yield e^+/Ne^-	0.57	0.88	0.67	0.95	0.75	1.0	0.68	1.1	0.8	1.2	0.9	1.3
Emittance, μm	8.2	15.3	9.4	17.1	10.6	18.2	8.2	15.7	9.4	17.4	10.6	18.7

FCC-ee Positron Source (CLIC design)

Hybrid scheme

A baseline design for the CLIC positron source

Target Parameters Crystal		
Material	Tungsten	W
Thickness (radiation length)	0.4	χ_0
Thickness (length)	1.40	mm
Energy deposited	~1	kW

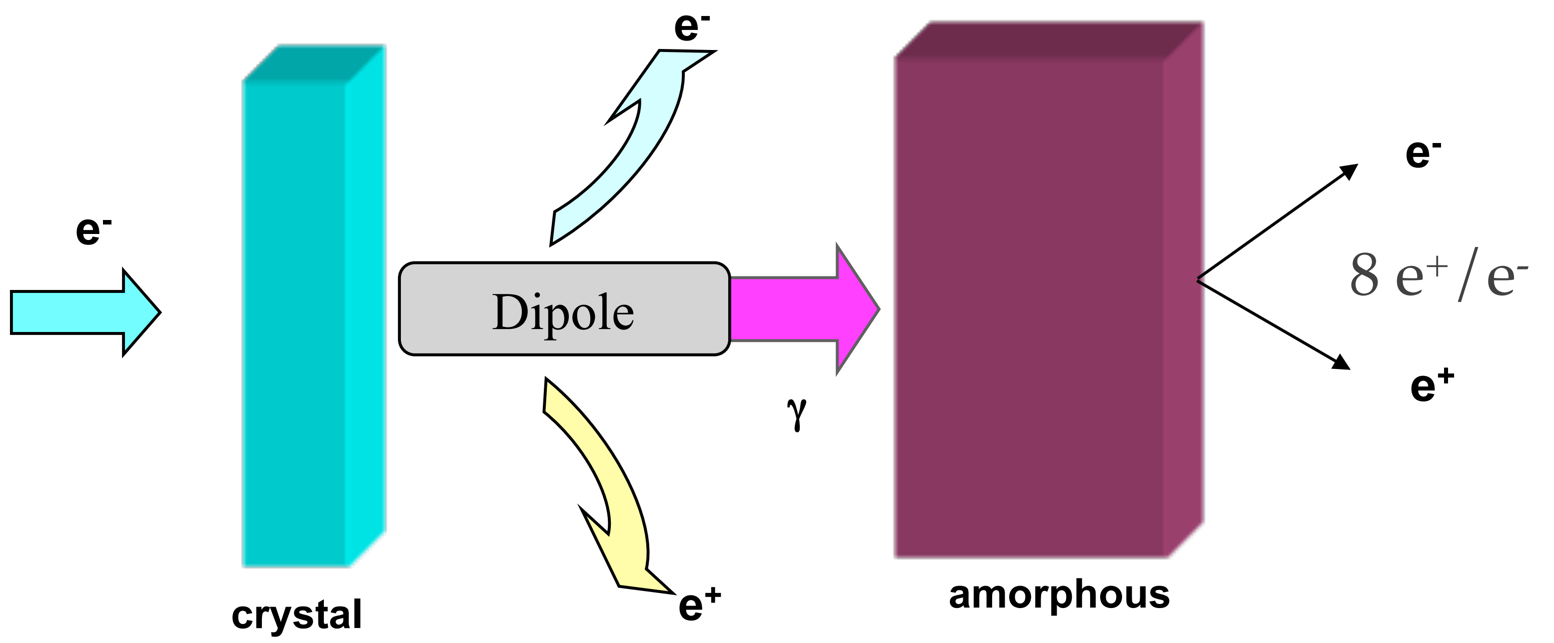
Target Parameters Amorphous		
Material	Tungsten	W
Thickness (Radiation length)	3	χ_0
Thickness (length)	10	mm
PEDD	30	J/g
Distance to the crystal	2	m

Distance (crystal-amorphous) d = 2 m

Primary e- beam
5 GeV
1.1× 10^{10} e^-/bunch

~ 10 kW

< 35 J/g

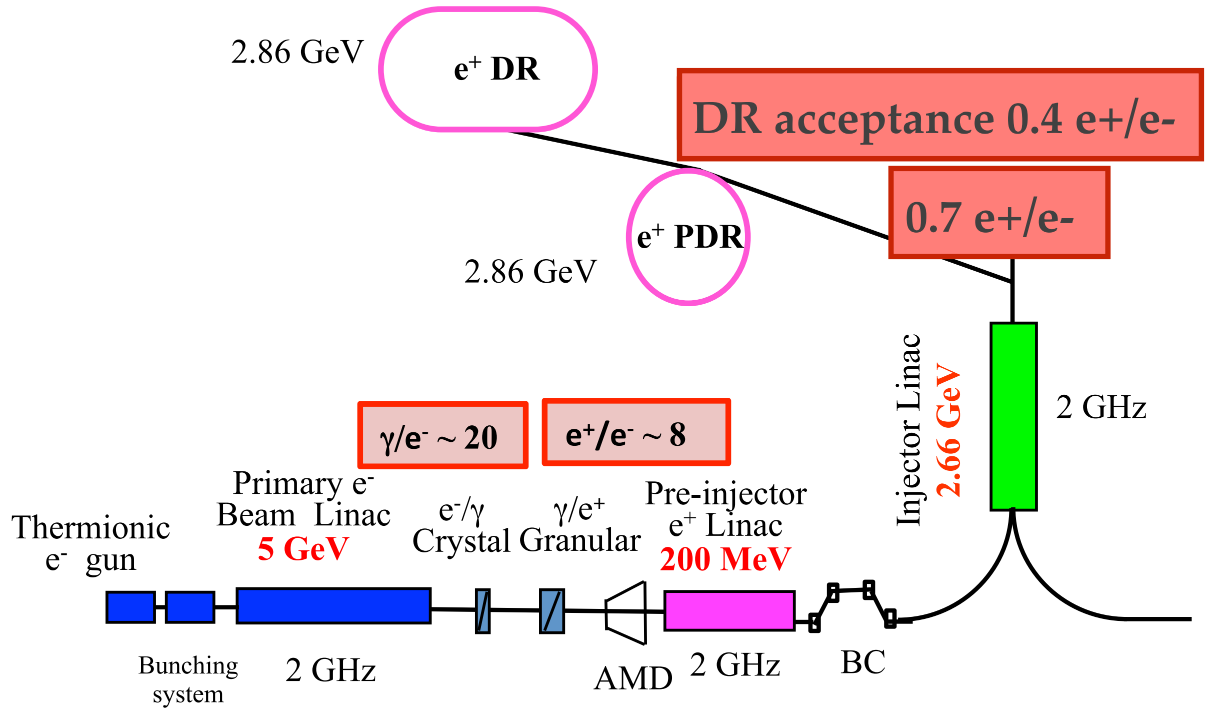


Crystal thickness: 1.4 mm
Oriented along the <111> axis

Amorphous thickness: 10 mm

Required: 4.3 × 10^9 e^+/bunch

unpolarized e^+



Yield: 8 e+/e- (total) => ~ 1 e+/e- @ 200 MeV => CLIC requirements are fulfilled.

- **Flux Concentrator (FC):** peak field is 6 T, DC solenoid field is 0.5 T, length = 20 cm, aperture 40 mm.
- **Accelerating structures:** L-band 2 GHz, 15 MV/m, aperture 30 mm (radius).

	@ 200 MeV	@ 2.86 GeV
e+ yield, Ne+/Ne-	0.9	0.7
Emittance, µm rad	21	1.4

☞ CLIC e+ source design seems compatible with the FCC-ee requirements => optimisation with FCC-ee beam parameters.

Further optimisation: C. Bayar et al. NIM A 869 (2017): 56-62.

Work of Yanliang Han (Cf. talk "CLIC target optimisation")

FCC-ee Positron Source (Target)

FCC-ee can employ the conventional/hybrid positron source. Studies are ongoing.

Comparison between the two options: conventional/hybrid (very preliminary)

General conditions: E = 5 GeV, $\sigma_{x,y}$ = 2.5 mm, C = 8.5 nC, 2 bunches @ 200 Hz.
Incident beam power is 15 kW.

Kind of e+ source	Deposited energy	PEDD
Conventional scheme (4.5 X0):	2.7 kW	2.1 J/g
Hybrid scheme (1.4 mm/10 mm)	1.2 kW	1 J/g
Hybrid scheme with granular converter (6 layers)	0.85 kW	0.6 J/g

FCC-ee Positron Source

Primary e- beam	
Beam energy	4.46 GeV
Bunch charge	2.66 (5.3) × 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	200 Hz
Beam power	15 kW
Beam energy	76 J

Beam Parameter	Conventional	Hybrid (CLIC)
Conversion target		
Target thickness	$4.5X_0$	$0.4\ X_0/\ 3X_0$
e+ yield @ Target	~11 e+/e-	~8 e+/e-
PEDD (Target)	XXX GeV/cm^3/e-	~1.04 GeV/cm^3/e-
PEDD (Target)	22 J/g	XXX J/g
Power deposited (Target)	~18 % 2.7 kW	~8 % 10 kW
Capture section		
AMD Field	7.5 T => 0.5 T/0.7 T	6 T => 0.5 T
AMD length	15 cm	20 cm
AMD aperture ⌀	10/70 mm	40 mm
Accepted e+ yield @ AMD	XXX e+/e-	~2 e+/e-
DC Solenoid Field	0.5 T/0.7 T	0.5 T
RF frequency	2855.98 MHz	1999.2 MHz
AS length	3 m	1.8 m
Max. Axial E-field	20 MV/m	15 MV/m
Aperture ⌀	30 mm	60 mm
Accepted e+ yield @ 200 MeV	~XXX / XXX e+/e-	~1 e+/e-
Booster linac up to 1.54 GeV		
RF frequency	2855.98 MHz	1999.2 MHz
Accepted e+ yield @ 1.54 GeV	1.1/1.3 e+/e-	~0.7 e+/e- @ 2.8 GeV
Accepted e+ yield @ DR	XXX e+/e-	~0.4 e+/e-

Target Thermal Load/Cooling

Present studies show

- Power deposited in the target 2 bunches/pulse @ 200 Hz is 2.7 kW => **average heating.**
- PEDD with σ_x/σ_y ~ 0.5 mm is 22 J/g (can be lowered by increasing the e- spot size) => **thermo-mechanical stress and fatigue**.

- **Target cooling.** Water cooling: 0.223 kW per cm of target width from ILC studies => one need to use a target of about 10 cm wide to evacuate the deposited power by water cooling. A single, stationary target having ~1 cm width is difficult to cool. Granular target ?
- **Mechanical stress and fatigue limit.** Peak stress and fatigue limit resulting from cycling loading should be evaluated. Preliminary: need a large spread of the beam over a wide target, more than 100 cm => moving/rotating target. To spread the pulses over 100 cm, a rotating wheel 30 cm in diameter @ 120 rpm can be considered.
- **Shock waves and thermal dynamics:** In principle should be OK. In our case, target should survive one shock, no pile up between successive shock waves between 5 ms. Enough time for the shock wave to be damped (μs time scale).

Positron source performances

	SLC	LEP (LIL)	KEKB/SUPER KEKB	FCC-ee (conv.)*
Incident e- beam energy	33 GeV	200 MeV	3.3/3.3 GeV	4.46 GeV
e-/bunch [10^{10}]	3-5	0.5 - 30 (20 ns pulse)	6.25/6.25	5.53
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)	3.3 kW	15 kW
Beam size @ target	0.6 - 0.8 mm	< 2 mm	/>0.7 mm	0.5 mm
Target thickness	$6X_0$	$2X_0$	$/4X_0$	$4.5X_0$
Target size	70 mm	5 mm	14 mm	
Target	Moving	Fixed	Fixed/Fixed	
Deposited power	4.4 kW		/0.6 kW	2.7 kW
Capture system	AMD	λ/4 transformer	/AMD	AMD
Magnetic field	6.8T->0.5T	1 T->0.3T	/4.5T->0.4T	7.5T->0.5T
Aperture of 1st cavity	18 mm	25mm/18 mm	/30 mm	30 mm
Gradient of 1st cavity	30-40 MV/m	~10 MV/m	/10 MV/m	20 MV/m
Linac frequency	2855.98 MHz	2998.55 MHz	2855.98 MHz	2855.98 MHz
e+ yield @ CS exit	~1.6 e+/e-	~3 $\times 10^{-3}$ e+/e- (linac exit)	/~0.5 e+/e-	
Positron yield @ DR	~1.1 e+/e-		0.4 e+/e-	~1.1 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

Summary

- FCC-ee can employ the conventional/hybrid positron source. No showstopper identified.
- Conventional scheme: further optimisation and simulation of the beam transport to the DR are under way.
- Hybrid scheme: full optimisation with the FCC-ee beam parameters. CLIC design seems very promising.
- Start to end simulation to the DR.
- Evaluate the thermal load in the target (peak stress and fatigue limit) => reliability of the target. Preliminary conclusion: At ~20 J/g the main problem is the fatigue and so the target lifetime (try to lower the PEDD by increasing the beam spot on the target). Rotating wheel/pendulum. Water cooling of a 10 cm wide target can be engineered.
- As a design criteria ~50% margin/safety factor on the e+ charge accepted by the DR should be provided (realistic field of the AMD, more realistic RF configuration with beam loading…).