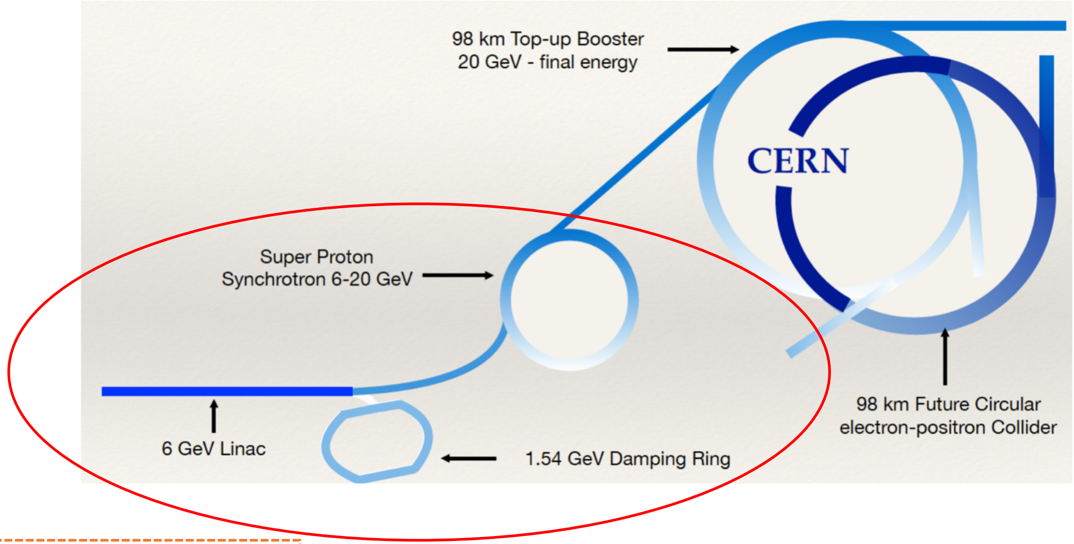
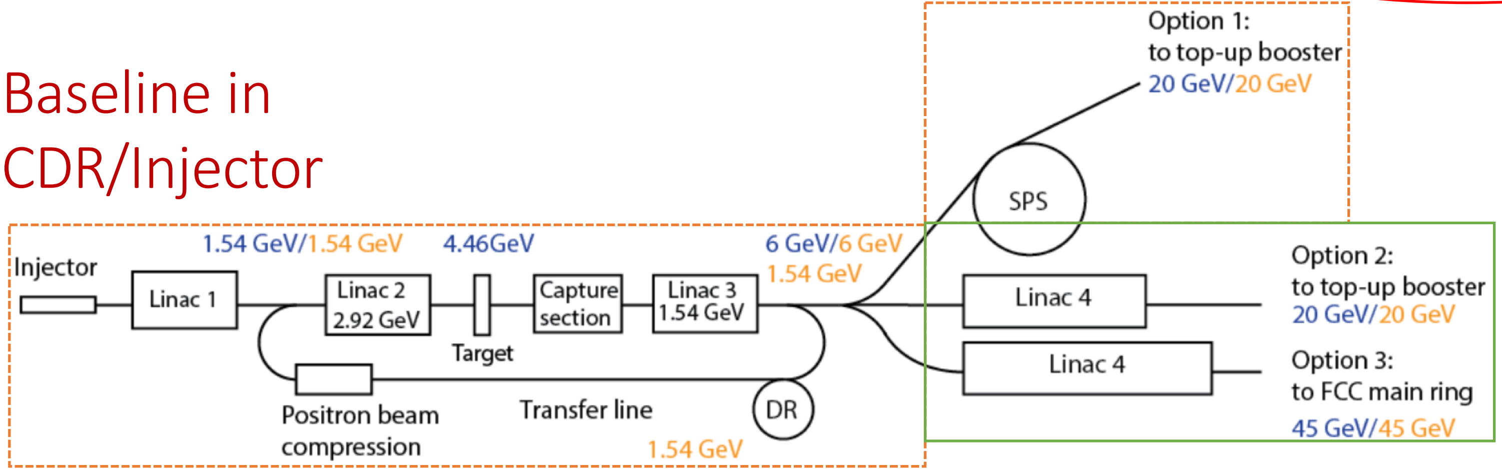
Status of the FCC-ee positron source

Iryna Chaikovska, IJCLab/IN2P3/CNRS
on behalf of the WP3 team, the FCC-ee Injector update studies

- e-/e+ linac up to 6 GeV, 1.54 GeV Damping Ring
- Pre-Booster Ring (SPS or new ring) (6 - 20GeV)
- Booster Ring (20 → 45 GeV)
- The main 6 GeV linac hosts the positron source. The positrons are produced with 4.46 GeV e- beam



Baseline in CDR/Injector



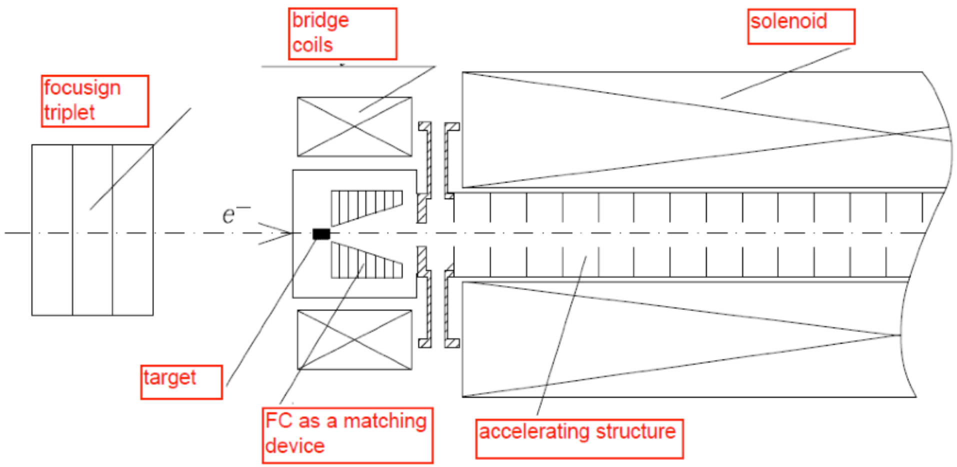
As alternative options for the FCC-ee Injector, a 20 GeV or a 40 GeV linacs are proposed to provide the direct injection into the main booster or main ring

The complete filling for Z running => **Requirement @ DR ~2.1 × 10^{10} e+/bunch (3.5 nC)**

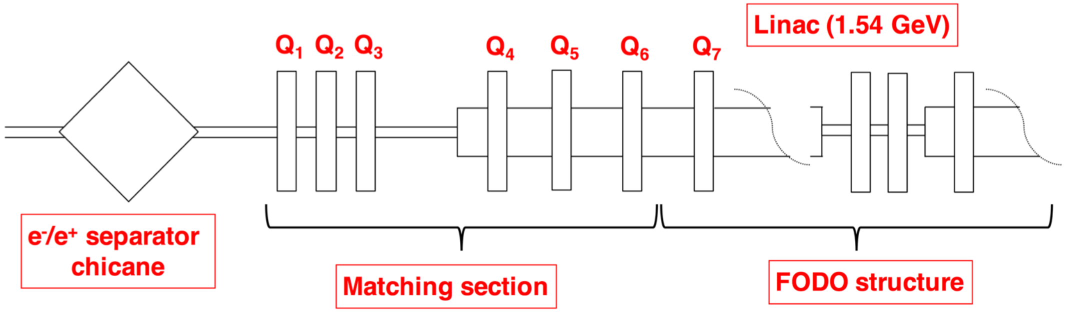
$$N_{e-}/\text{bunch} \times Y_{e+/e-} \geq 3.5\ \text{nC/bunch} \times 2$$

**A safety margin of 2 is currently applied for the whole studies.*

e+ production and capture section

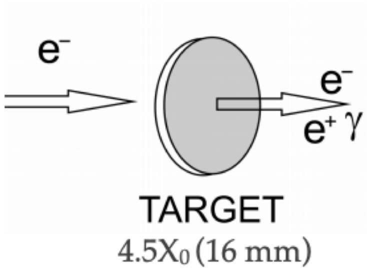


e+ acceleration up to DR energy (1.54 GeV)

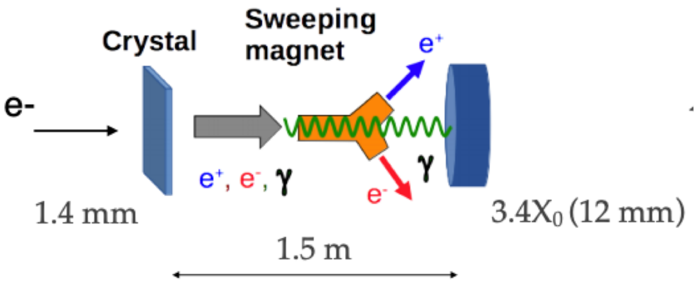


Production scheme:

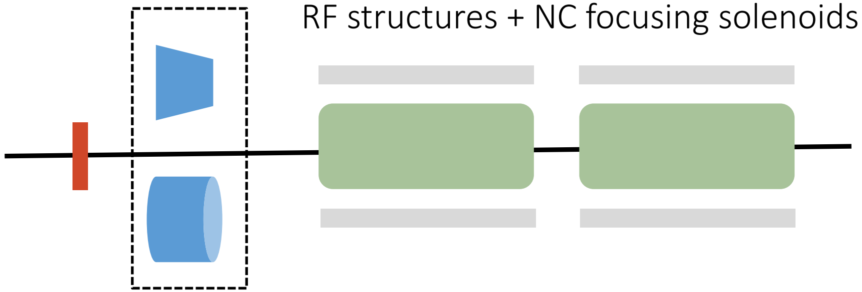
1) Conventional target



2) Hybrid target



Capture system:



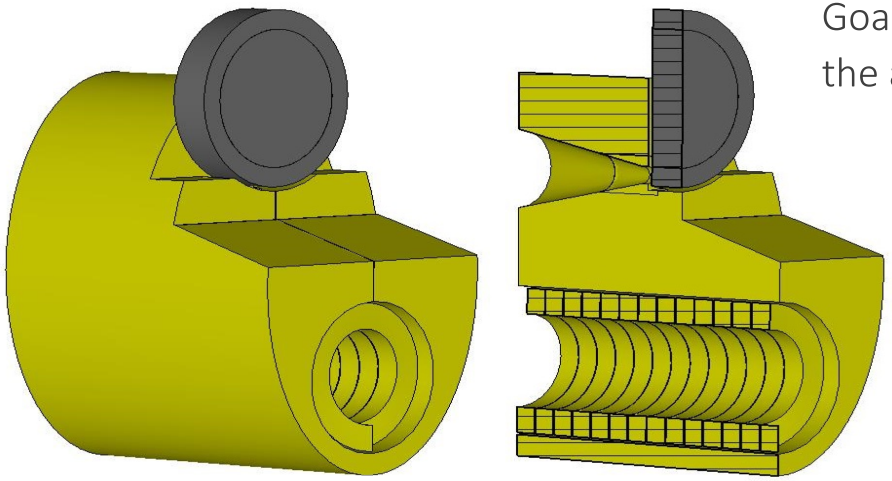
2 options to be considered for the Adiabatic Matching Device (AMD):

a. Flux concentrator (pulsed magnet)

b. Superconducting solenoid (new solution)

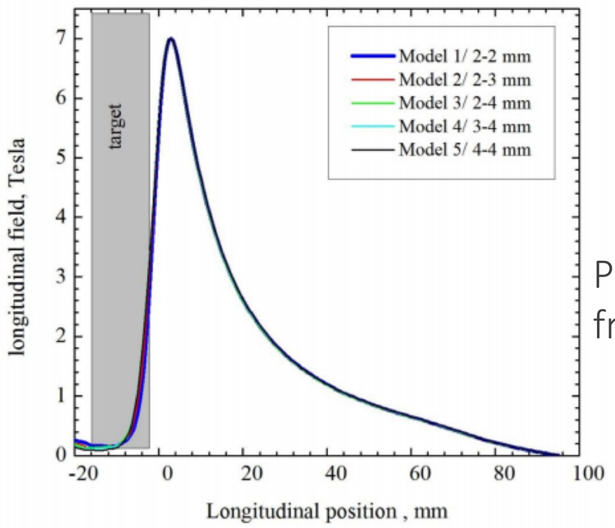
The capture linac is encapsulated inside the NC solenoid with the axial magnetic field of 0.5-0.8 T.
Options to be considered for the RF structures:
L-band (2 GHz) and large aperture S-band structures.

Flux Concetrator – FCC-ee Design (presently)



Goal: matching the e+ beam (with very large transverse divergence) to the acceptance of the capture 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



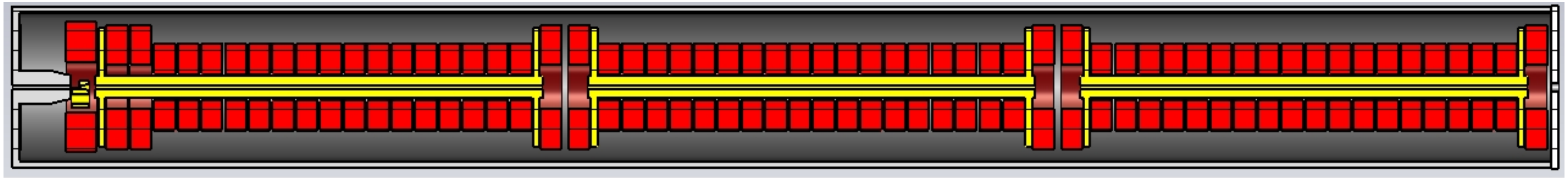
Peak of the magnetic field is at 5 mm from the target => field on target: ~3 T

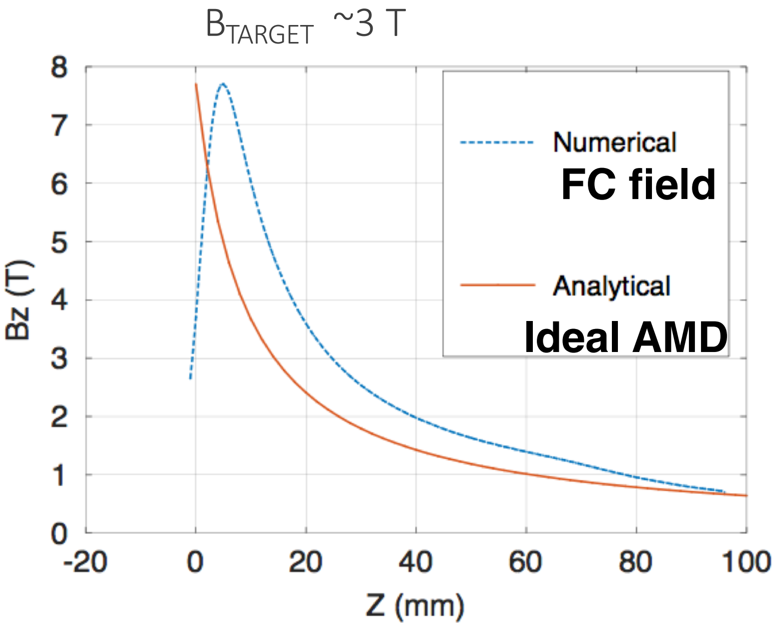
Full 3D magnetic field map is used in the simulations

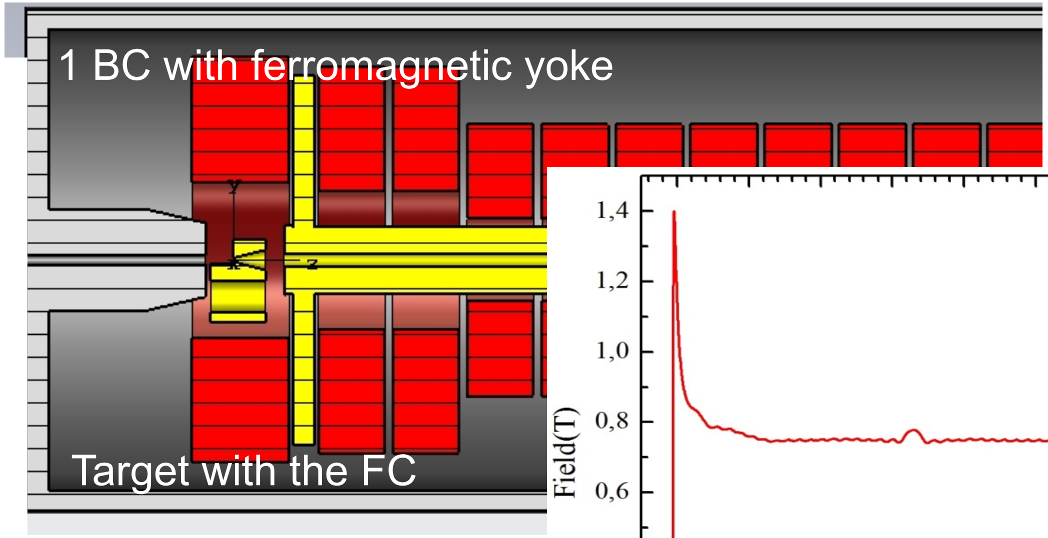
Courtesy of P. Martyshkin (BINP)

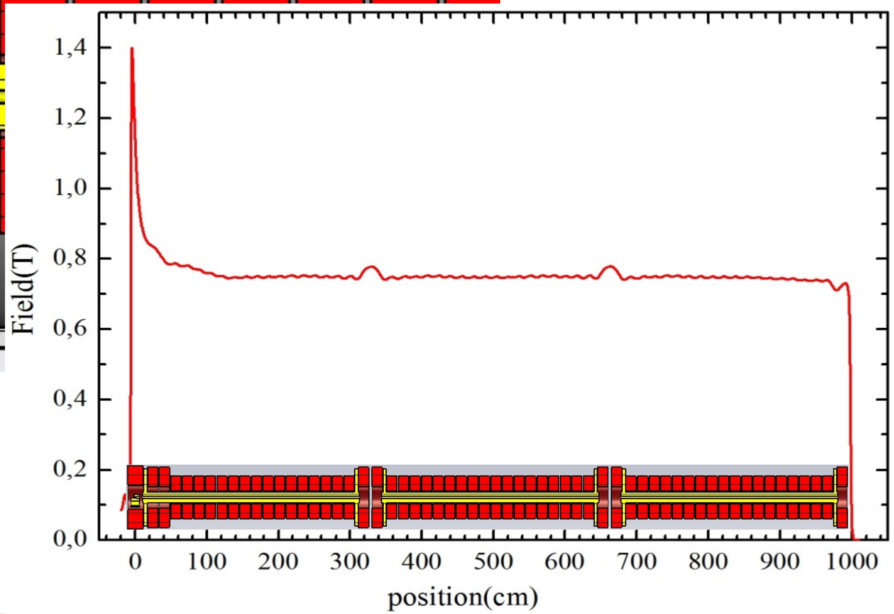
Positron Capture Section Design (work in progress)

Courtesy of P. Martyshkin (BINP)









Peak of the magnetic field is at 5 mm from the target => ~40 % drop in capture efficiency

SC Solenoid as the AMD for the FCC-ee

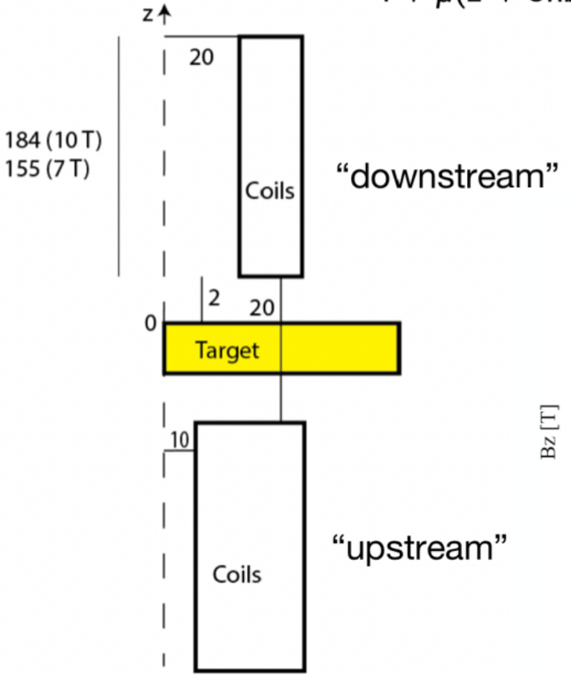
Advantages => higher field value on the target, DC operation
Promising results of the first tests at KEK (next slide)

HTS solenoid

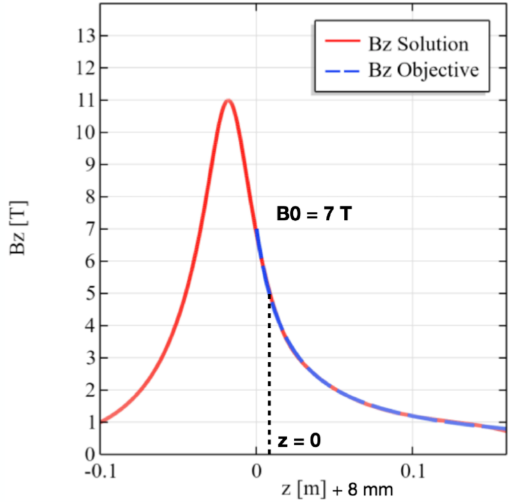
Courtesy of J. Kosse and B. Auchmann (PSI)

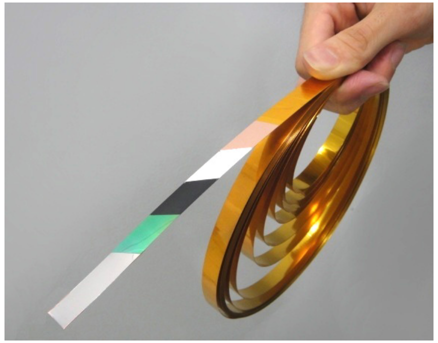
Design studies started @PSI

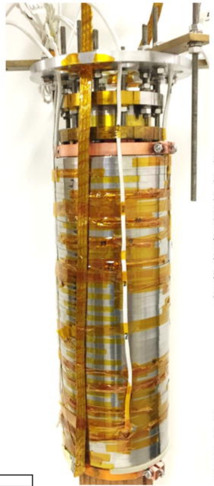
$$B_z(z) = \frac{B_0}{1 + \mu(z + 8mm)}$$

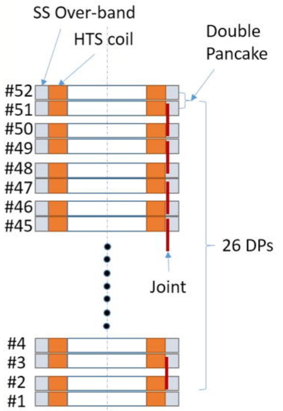


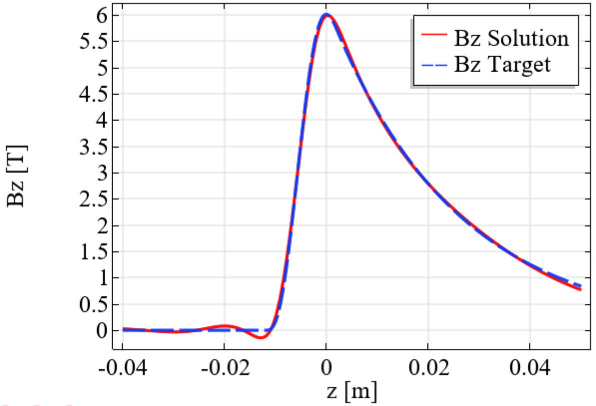
Field profile (Peak Bz ~11 T and Bz @Target exit ~5 T)

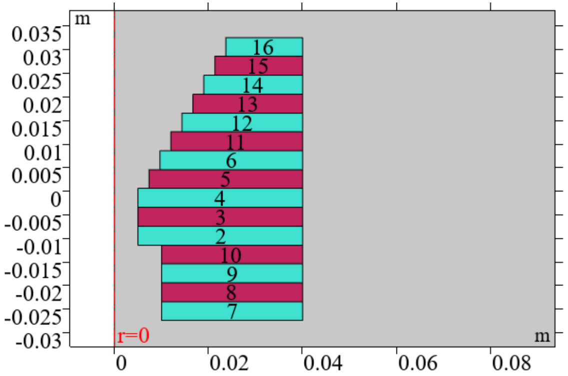








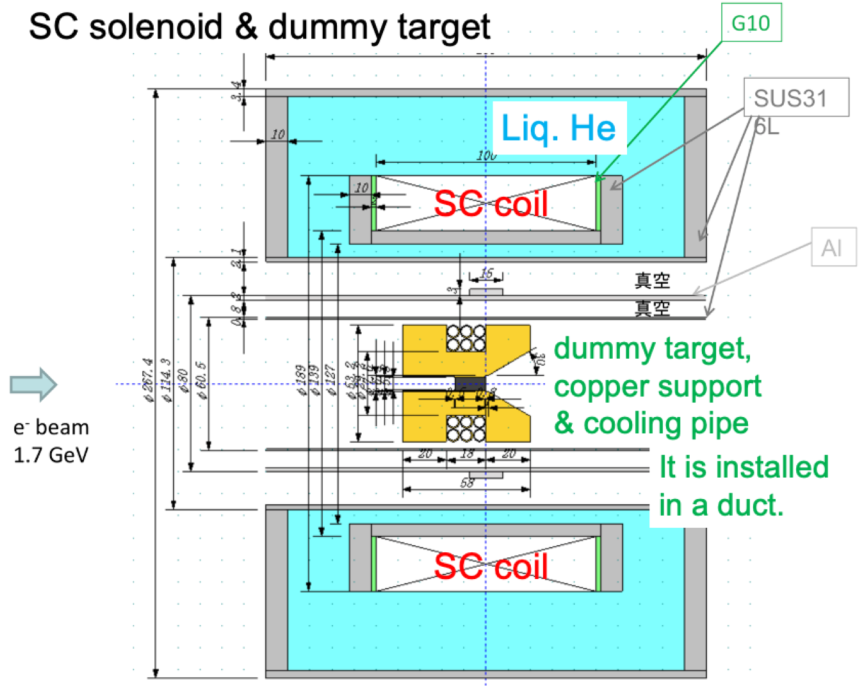




Next step: simulation of the radiation environment in target vicinity

SC solenoid as the AMD: SuperKEKB Positron Source Design Studies

Courtesy of T. Kamitani (KEK)



Beam tests in the KEKB linac (2009 - 2011):

- beam irradiation experiment directly into a superconducting solenoid to investigate a quench limit
- beam irradiation experiment of a dummy target installed inside a beam pipe which penetrate a cryostat of a SC solenoid at the beam dump at 1.7 GeV. The solenoid survived at least for 10 minutes at 3.2 T field level with an irradiation of 7nC x 2 bunch 1.7 GeV beam at 49 Hz. Max field obtained 4.7 T

Studies on the Positron Production (work in progress)

Electron beam energy 4.46 GeV (FCC-ee Injector CDR baseline)

Beam Parameter	CLIC-like Hybrid	Absorber Hybrid	Conventional	18.5 GeV	SuperCon.
Target thickness	**0.4 X_0/ 3.4X_0**	**0.4X_0/ 3.4X_0**	**4.5X_0**	**6.3X_0**	**4.5X_0**
e+ yield @ Target	6.5 e+/e-	6.5 e+/e-	10.5 e+/e-	38.6 e+/e-	10.5 e+/e-
PEDD (Target)	2.1 J/g	2 J/g	24 J/g	80 J/g	24 J/g
Power deposited (Target)	1.5 kW	1.5 kW	2.6 kW	13.2 kW	2.6 kW
AMD Field	7 T	7 T	7 T	7 T	8 T
AMD length	7.4 cm	7.4 cm	7.4 cm	7.4 cm	-
AMD aperture ⌀	8/44 mm	8/44 mm	8/44 mm	8/44 mm	-
e+ yield @ AMD	2.4 e+/e-	~2.4 e+/e-	5.6 e+/e-	21 e+/e-	10.2
DC Solenoid Field	0.7 T	0.7 T	0.7 T	0.7 T	0.8 T
RF frequency	2 GHz	2 GHz	2 GHz	2 GHz	2.856 GHz
AS length (TW)	1.5 m	1.6 m	1.6 m	1.6 m	3.2 m
Axial E-field	16 MV/m	16 MV/m	16 MV/m	16 MV/m	20 MV/m
Aperture	40 mm	40 mm	40 mm	40 mm	30 mm
e+ yield @ 200 MeV	1.30 e+/e-	1.4 e+/e-	3 e+/e-	11.5 e+/e-	4.6 e+/e-
Accepted e+ yield @ 200 MeV	0.74 e+/e-	0.67 e+/e-	1.4 e+/e-	8.2 e+/e-	1.8 e+/e-

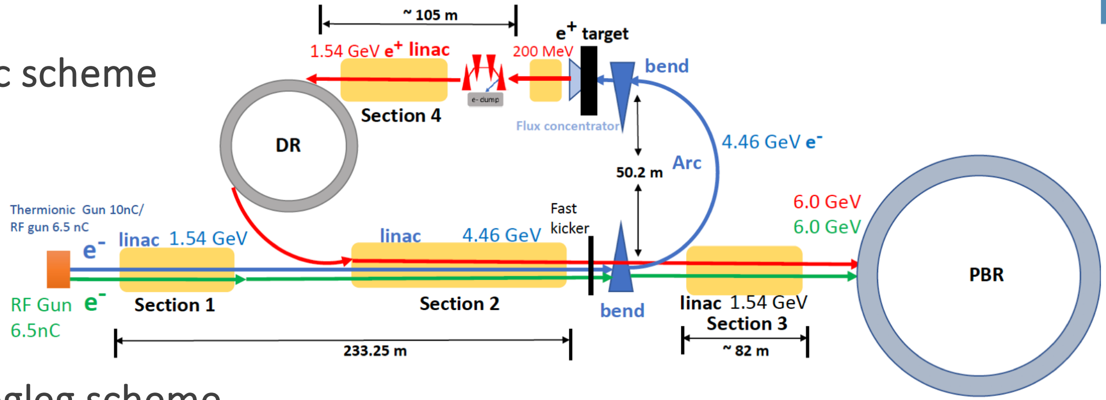
FC

SC-solenoid (fringe field)

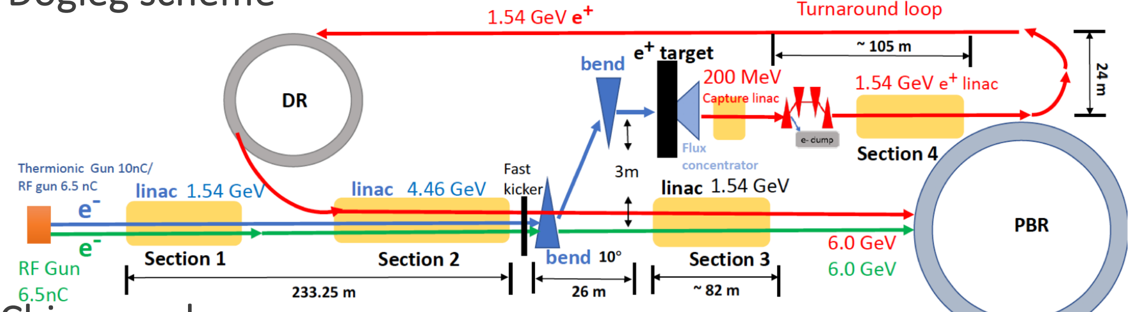
FCC-ee Positron Injector (CDR): Bypass for Positron Production

Courtesy of B.Bai (IJCLab/IHEP)

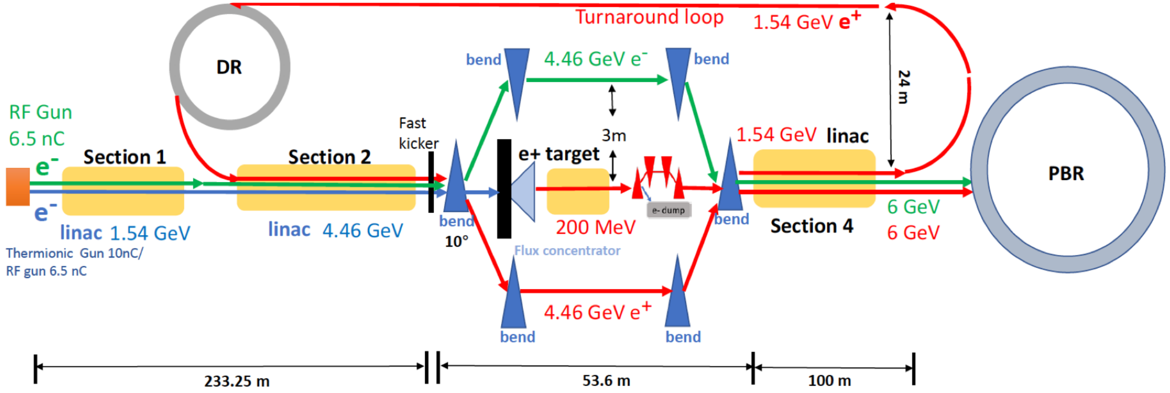
Arc scheme



Dogleg scheme



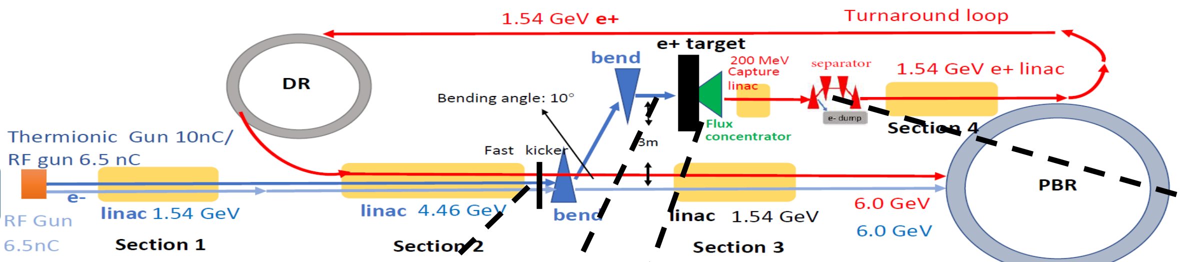
Chicane scheme

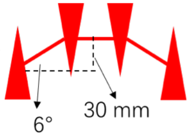


- CDR: FCC-ee Injector complex is based on the SuperKEKB scheme with fixed target (has a hole for e- beam passage)
- Positrons from the target share the same linac with electrons
- Additional degradation of the positron yield
- 3 bypass schemes are proposed to achieve a better performance and increase flexibility
- All can meet the requirement of the Z running of the FCC-ee (e+ yield is ~1.2 e+/e-)

1. Dogleg scheme

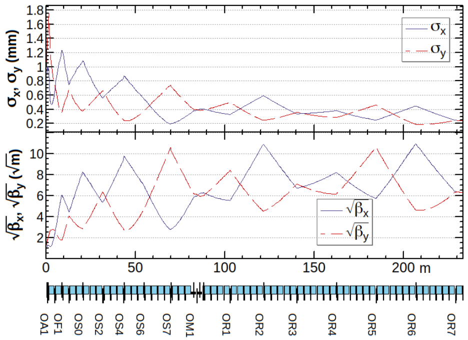
Courtesy of B.Bai

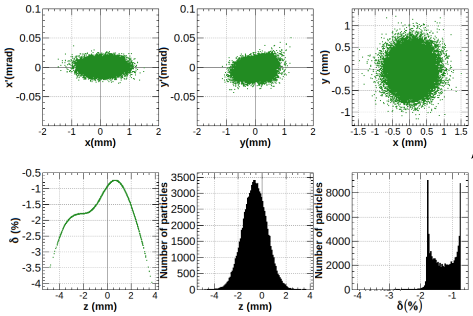




Code: SAD

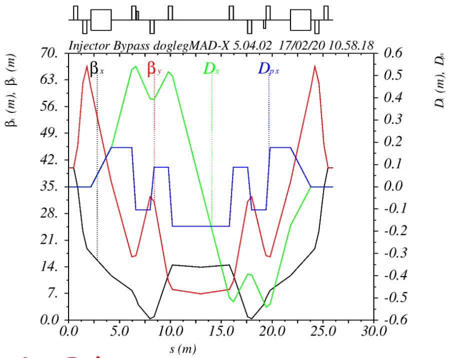
1.1) 4.46GeV e- linac

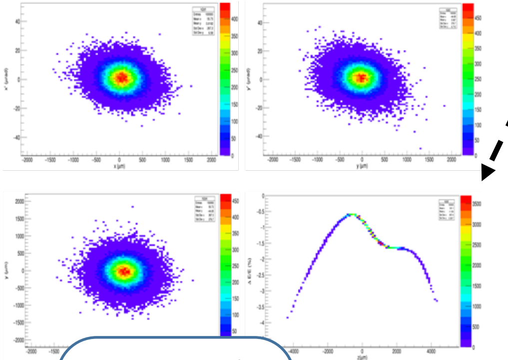




1.2) dogleg bypass

Code: MADX + PLACET



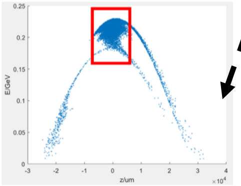


1.3) e+ generation

Results from Dr. Yanliang Han

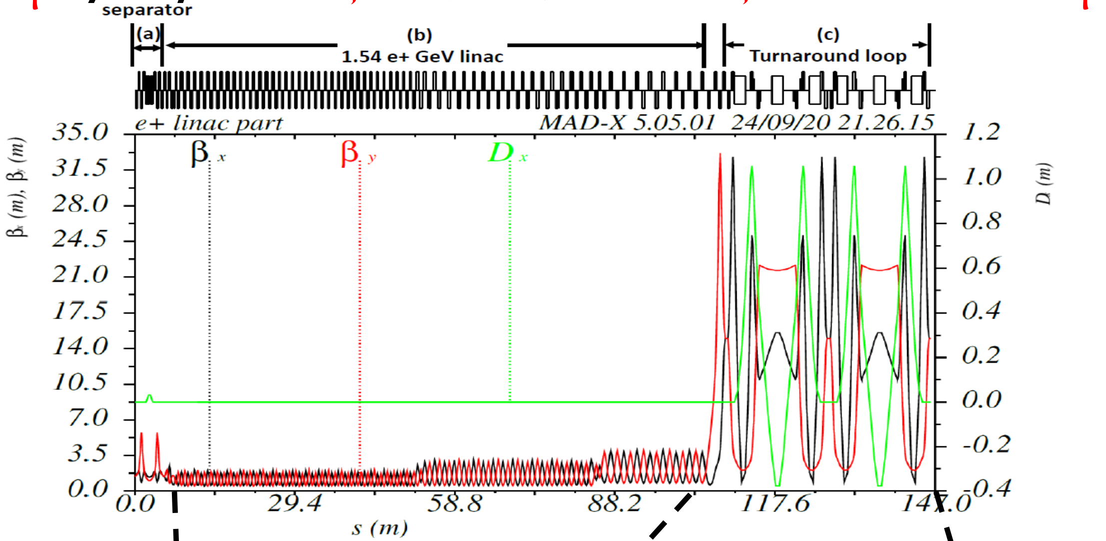
Accelerating mode /decelerating mode + Conventional target /hybrid target

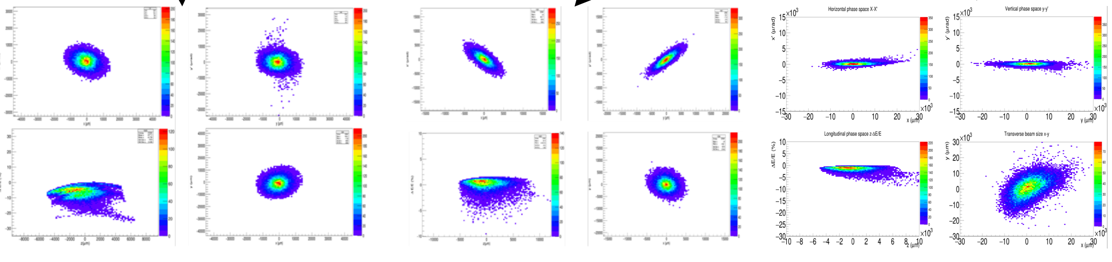
Conventional target + deaccelerating mode
Positron yield: **2.3**



1.4) After e+ capture section:

separator, chicane, 1.54 GeV e+ linac, turnaround loop





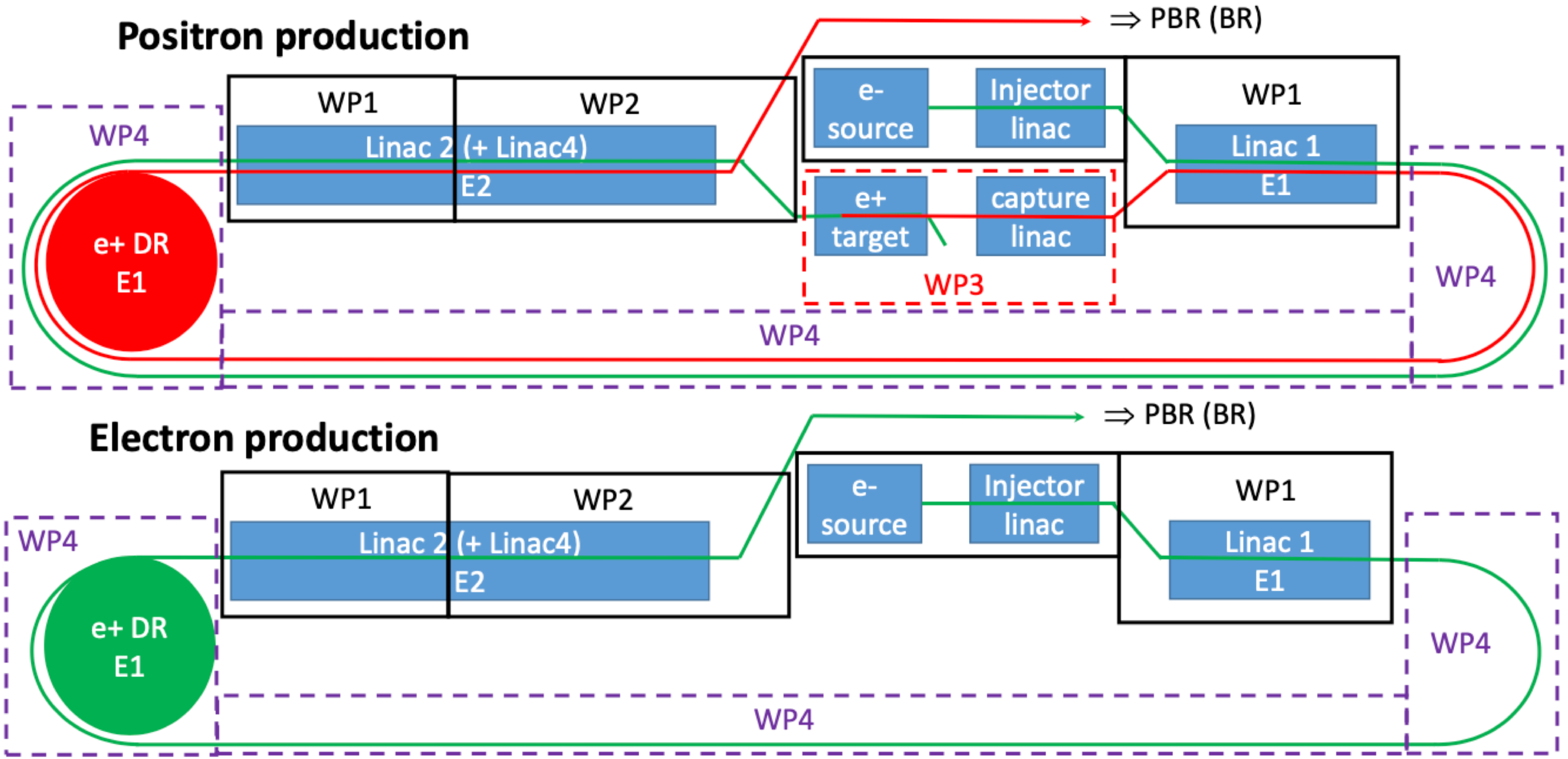
FCC-ee Injector Update Studies and Proof of Principle Experiment

– Recently the *Swiss Accelerator Research and Technology* (CHART II) collaboration approved to finance the FCC-ee Injector update studies and a proof of principle for a positron source at PSI/SwissFEL facility

- Collaboration between PSI and CERN with several external partners (IJCLab, INFN-LNF, INFN-Ferrara, BINP, KEK…)
- Duration 4 years (from September 2020) + to be considered 1 year extension
- FCC-ee injector studies: 7 WP (Coordination, e+/e- 6 GeV injector linacs, e-/e+ linac extension study, **Positron Source: target and capture system**, DR and TL, CDR+, **Proof of principle capture in SwissFEL**)
- Goals:
  - ➢ review of the actual CDR/Injector and write a CDR+/Injector with cost estimate
  - ➢ Proof of principle of the positron source at PSI/SwissFEL

New Layout of the FCC-ee Injector 6 GeV (20 GeV)

Outcome from WP0.2 meetings leading by A. Grudiev



A full injector energy (6 or 20 GeV) can be used for the positron production

FCC-ee injector: Overall Parameter Optimization (work in progress)

Outcome from WP3

Positron Source: target and capture system

Goal: provide 2.1 × 10^{10} e+/bunch × 2 = **4.2 × 10^{10} e+/bunch** accepted by the DR

e- drive beam

	DR acceptance 3.8%		DR acceptance 7.8%		
Beam energy	**6**	**20**	**6**	**20**	GeV
e+ bunch charge @200 MeV	4,20E+10	4,20E+10	4,20E+10	4,20E+10	e+
Bunch charge	3,26E+10	1,11E+10	2,82E+10	9,23E+09	e-
Bunch length (rms)	1	1	1	1	mm
Bunch transv. size (rms)	1,8	1,9	1,9	1,9	mm
Bunch separation	wakefiled limit	wakefiled limit	wakefiled limit	wakefiled limit	ns
Nb of bunches per pulse (max)	25	25	30	30	
Repetition rate (max)	100	100	100	100	Hz
Beam power	78,24	88,8	81,216	88,608	kW
Beam energy	782,4	888	812,16	886,08	J
Emittance (normalsed max)	<1	< 1	<1	< 1	mm.rad
Energy spread	< 1	< 1	< 1	< 1	%
PEDD (target)	32.8	31	31.2	31	J/g
Deposited power (target)	14.6	16.8	15.2	16.8	[kW/pulse]

e+ beam @200 MeV

Drive beam energy	**6 GeV**			**20 GeV**			
	FULL	**±3.8% @2MV**	**±7.8% @4MV**	**FULL**	**±3.8% @2MV**	**±7.8% @4MV**	
Total e+ yield	2,64	—	—	8,1	—	—	Ne+/Ne-
Accepted e+ yield	—	1.46 ($\sigma_{x/y}$ = 1.5mm)	1.94 ($\sigma_{x/y}$ = 1.2mm)	—	4.46 ($\sigma_{x/y}$ =1.5mm)	5.93 ($\sigma_{x/y}$ =1.2mm)	Ne+/Ne-
Bunch length (rms)	—	2,2	2,7	—	2,2	2,7	mm
Emittance geometrical (rms)	23,7	17,2	18				µm
Energy spread (rms)	—	6,0	8,3	—	6,0	8,3	%

Simulations with the conventional scheme + FC + S-band acc. structures

HTS solenoid as the AMD

Courtesy of Y. Zhao (CERN/SDU)

Results								
Peak Bz	11 T				20 T			
Bz @ target exit	**5 T**				**7 T**			
TW solenoid field	**0.7 T**							
DR acceptance	**3,8 %**		**7,8 %**		**3,8 %**		**7,8 %**	
Primary energy [GeV]	6		6		6		6	
Gradient dec. [MV/m]	22				22			
Gradient acc. [MV/m]	16				16,5			
Accepted **yield**	2,75		2,81		3,20		3,18	
E_mean @ TW exit	200		200		200		201	
PEDD [J/g]	18,2		19,7		15,3		17,1	
Beam **power** [kW]	36,7		43,0		31,5		38,1	
Deposited power [kW]	7,24		8,49		6,27		7,52	

- Goal: 4.2 × 10^{10} e+/bunch (7 nC) accepted in the DR
- The e- drive beam parameters are kept the following:

  6 GeV, beam spot size 1.8-1.9 mm, bunch length 1 mm*, 25-30 bunches per pulse, 100 Hz rep. rate.

* zero bunch length was used in the presented simulations.

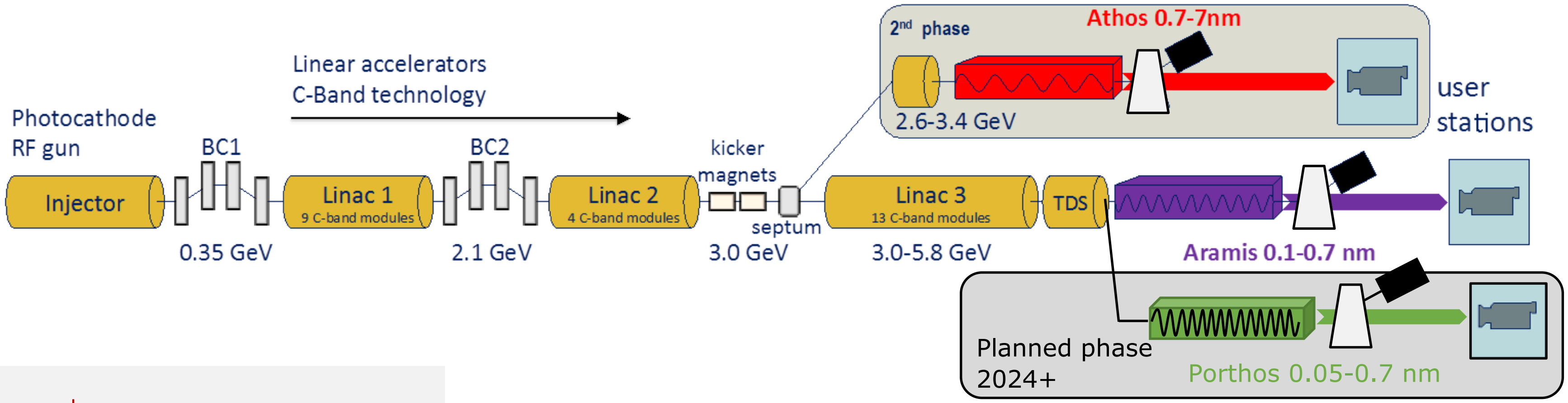
Results obtained with the FC 7 T, B_TW = 0.7 T, DR acceptance 3.8% *(ceteris paribus)*

E: 6 GeV, Spot size: 1.8 mm Amor. thickness: 17.5 mm (5 X0)	**Conventional scheme**
Accepted yield	**2,22**
Normalised PEDD [J/g]	23,2
Normalised beam power [kW]	45,4
Normalised deposited power [kW]	11,0

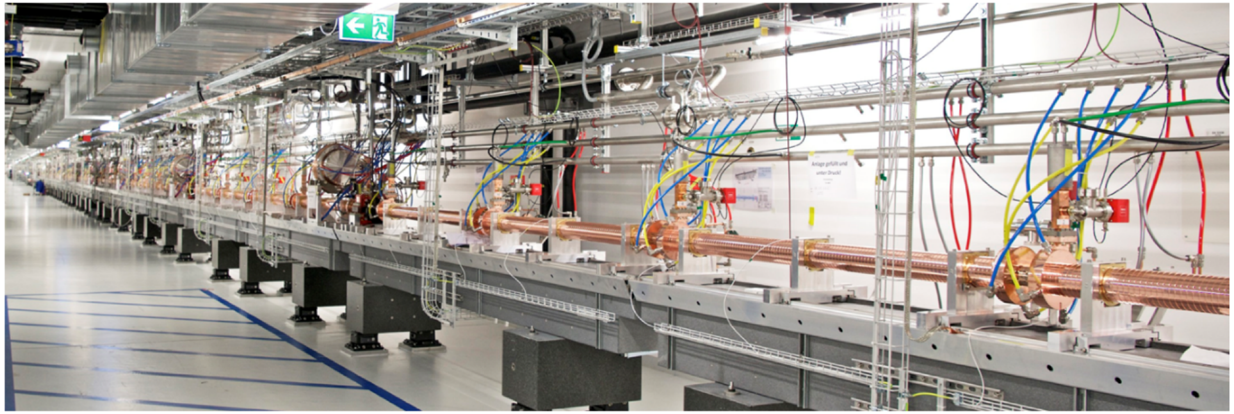
Talk by Y. Zhao – Tuesday A2: Sources

Introduction to the PSI/ SwissFEL

Courtesy of P. Craievich (PSI)



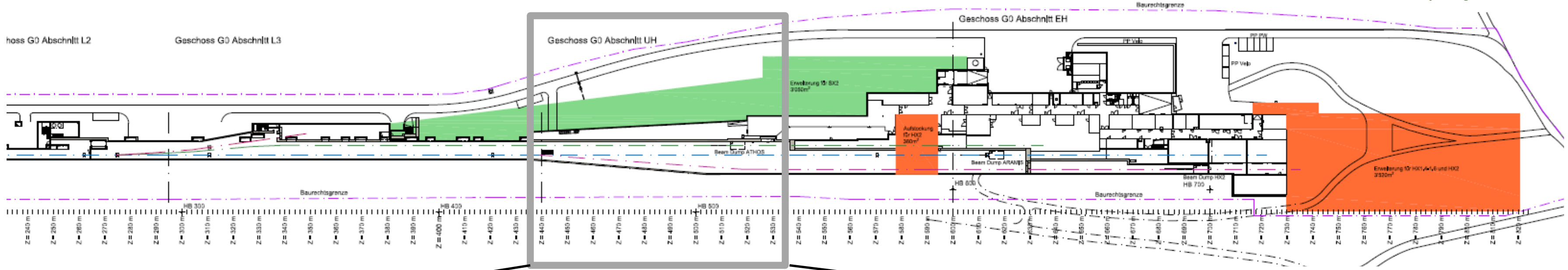
Main parameters	
Beam energy	6.2 GeV
Bunch charge	10-200 pC
Repetition rate	up to 100 Hz
Pulse duration	<1 fs – 3 ps (rms)
Norm. emittance	400 nm
Overall length	740 m

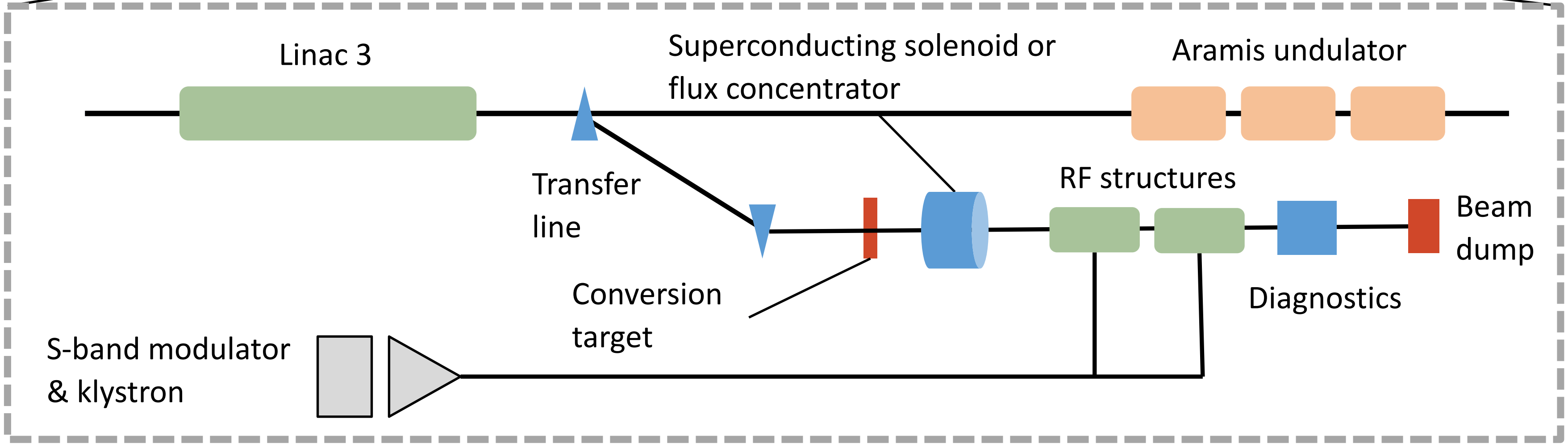


Positron source in PSI/ SwissFEL: Proof of Principle Experiment (WP6)

Courtesy of P. Craievich (PSI)

SwissFEL transfer lines





Thank you for the attention!