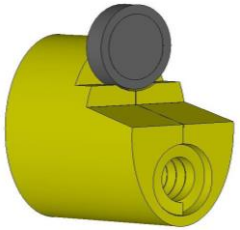
FCC-ee Flux Concentrator

Points to be discussed:

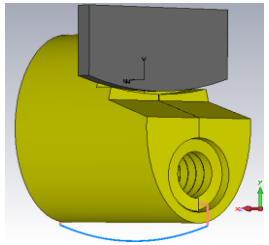
- current status
- first simulation results
- parameter table –v0 for the assessment of the target design and integration

10/04/2024

Positron capture: Flux Concentrator (FC) as a matching device



Originally designed by BINP for the FCC-ee (P. Martyshkin)
=> FC:FCC-BINP
Dropped as no info and further studies available



Originally designed by BINP for the ILC (P. Martyshkin) => FC:ILC-BINP
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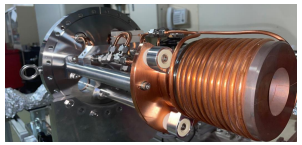
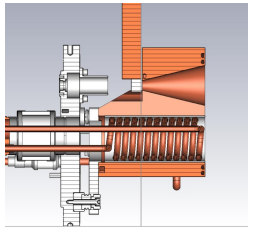
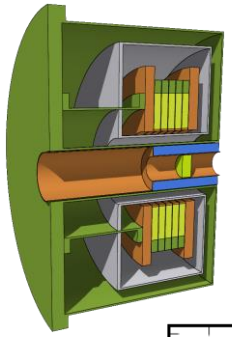


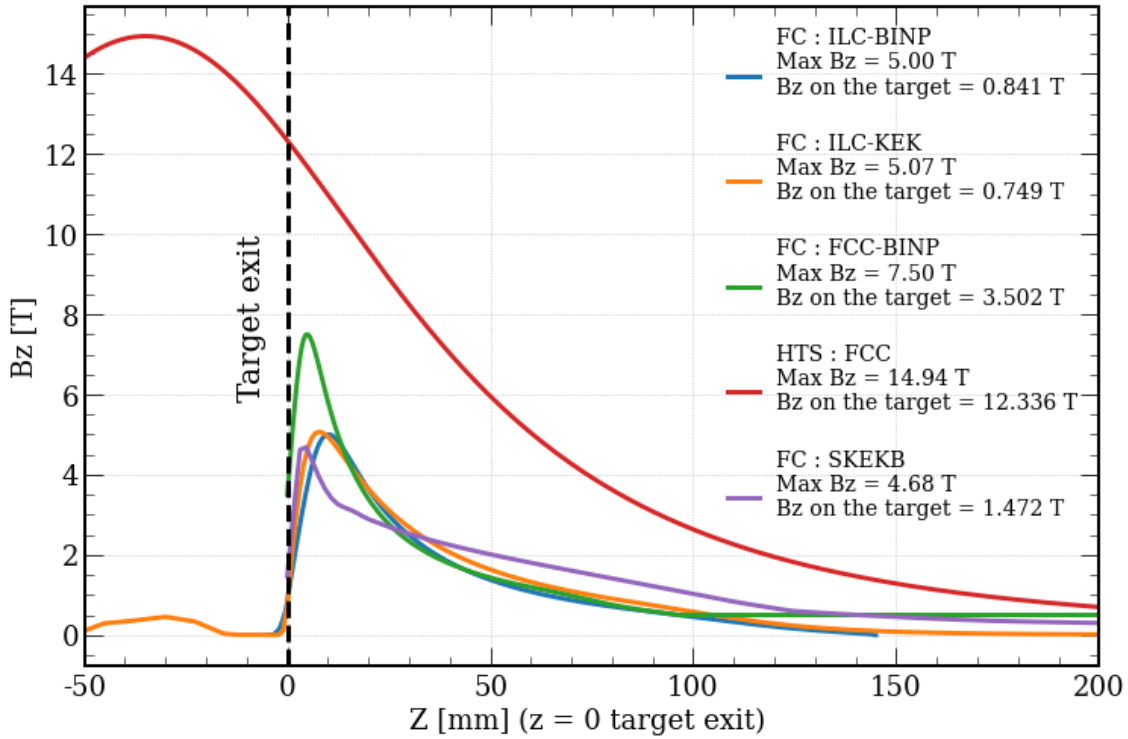
Originally designed by KEK for the SuperKEKB => FC:SKEKB-KEK
Under consideration



Designed by KEK for the ILC (Y. Enomoto) => FC:ILC-KEK
Assumed for the FCC-ee



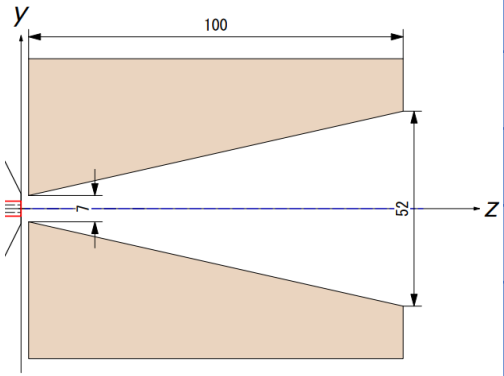
High-Temperature Superconducting (HTS) solenoid designed by PSI => HTS:FCC (submitted to mid-term review)



SuperKEKB FC designed by KEK in application to FCC-ee

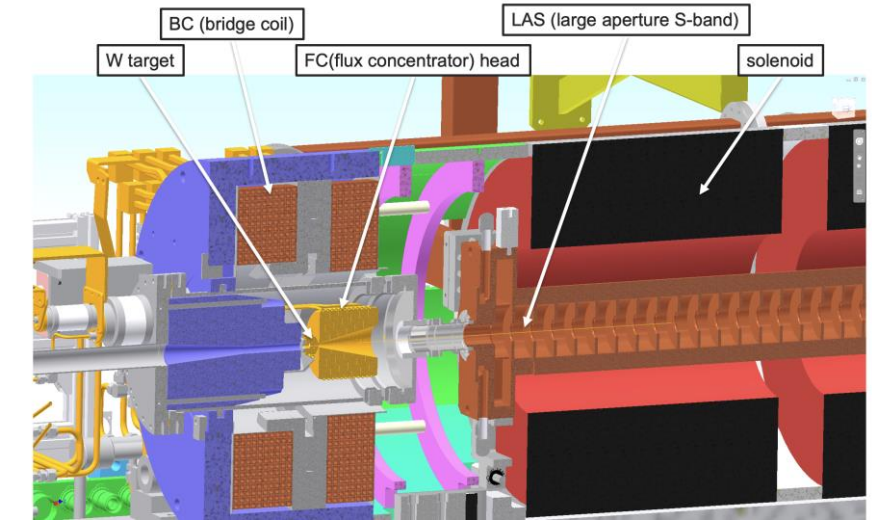
AMD consists of : Flux concentrator (FC) + Bridge Coils (BC)

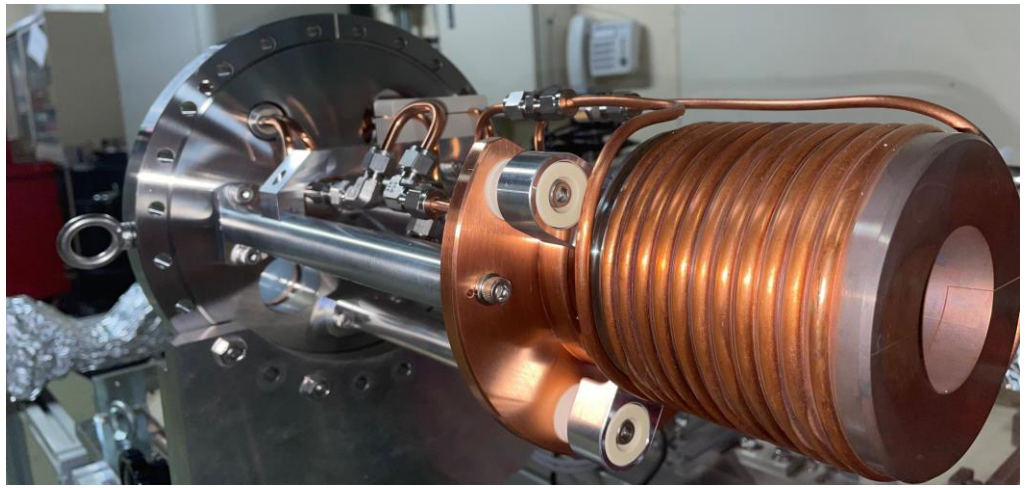
- FC field : 3.5T at 12.5kA **(Pulsed, 50 Hz)**



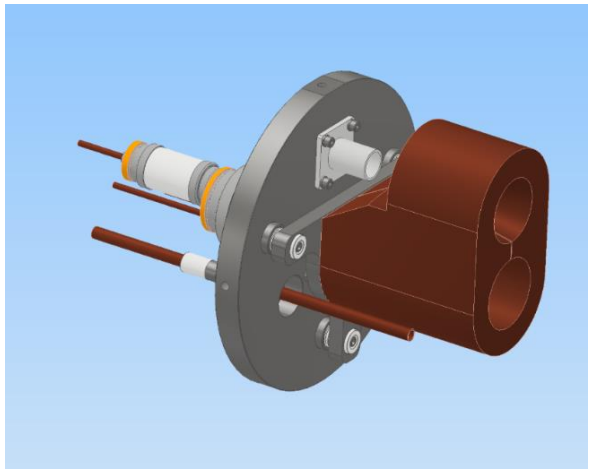
SKEKB FC	
Peak field (FC+BC)	4.68 T
2Ri	7mm
2Ro	52mm
Length	100mm
Field on the target (FC+BC)	1.47 T (with BC)

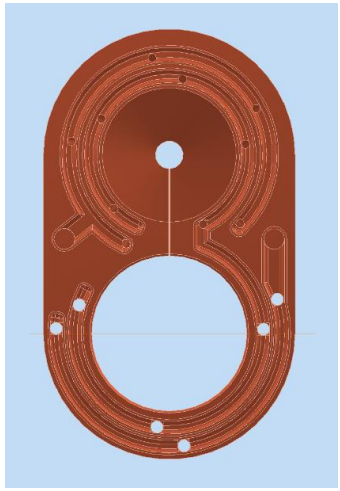
FC head + BC + target = FC assembly

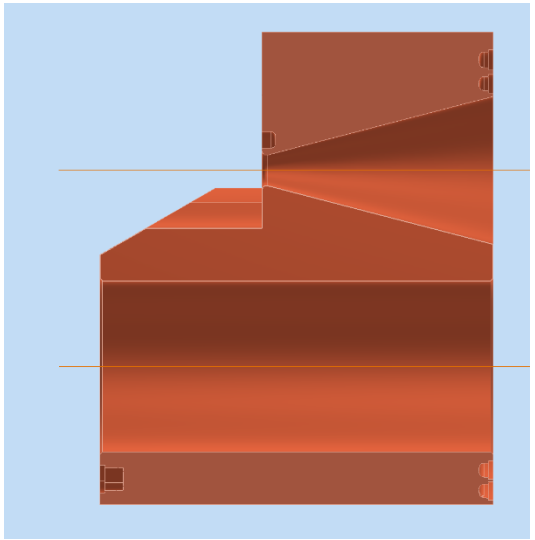


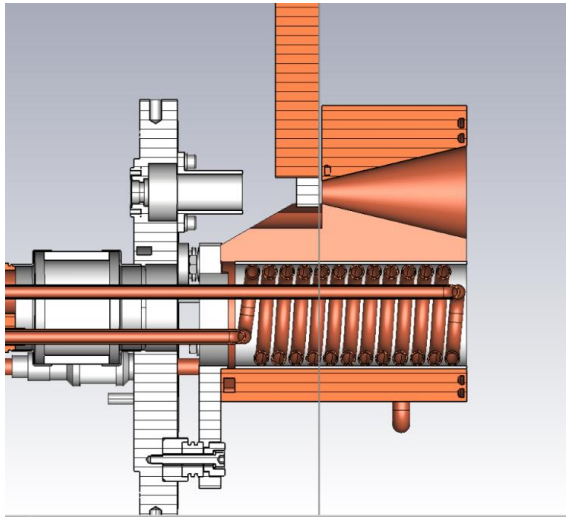


ILC FC designed by KEK in application to FCC-ee









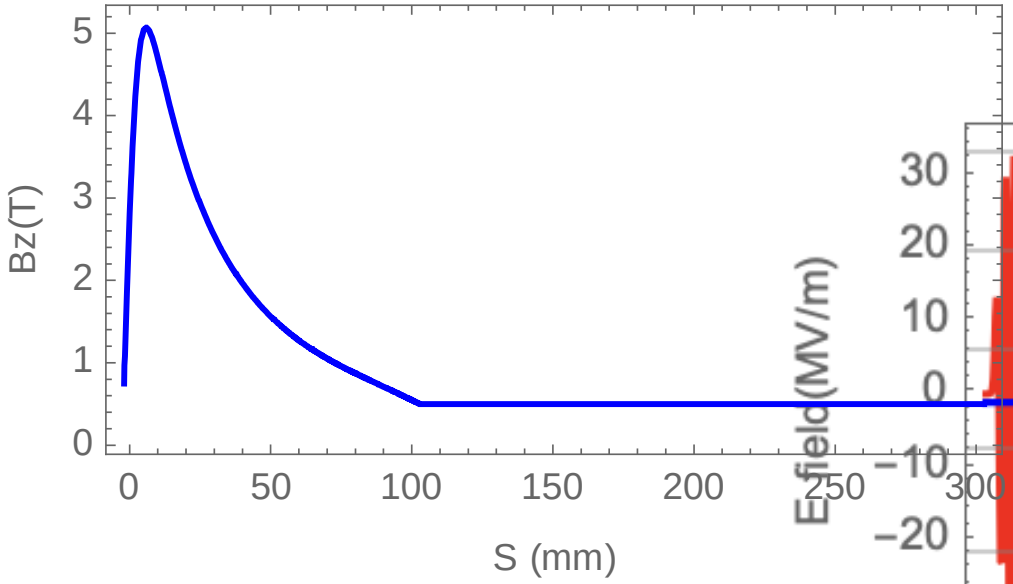
No Bridge Coils (BC) by design

- FC is under construction now at KEK **(Pulsed, ~100 Hz)**

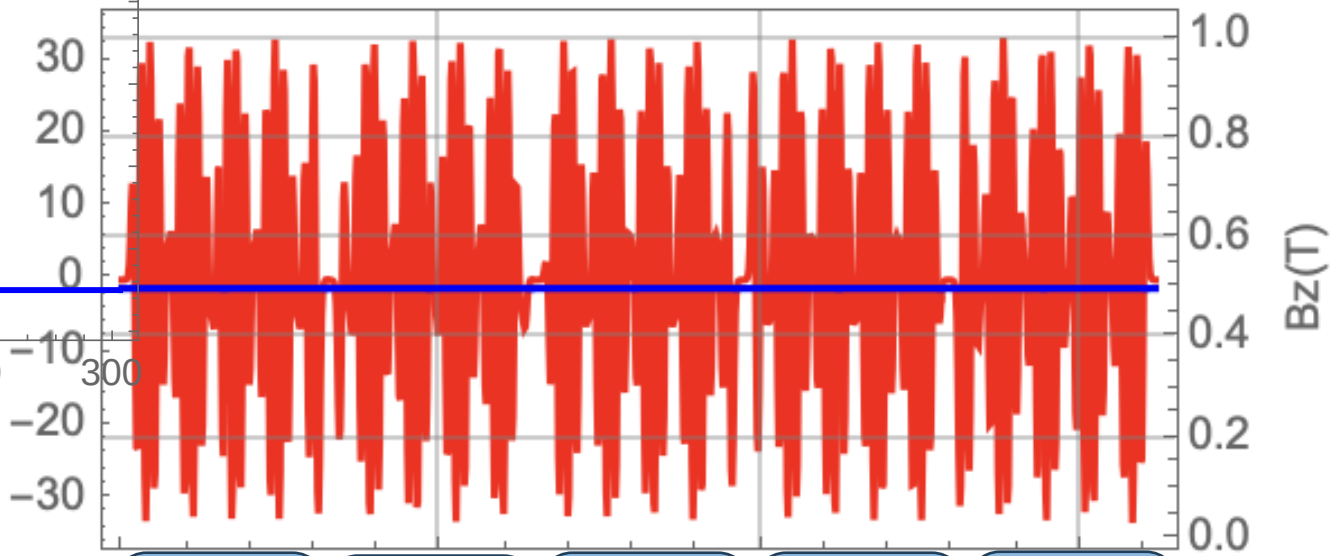
ILC FC	
Peak field	5 T
2Ri	12mm
2Ro	64mm
Length	100mm
Field on the target FC	0.75T

Curtesy of Enomoto-san (KEK)

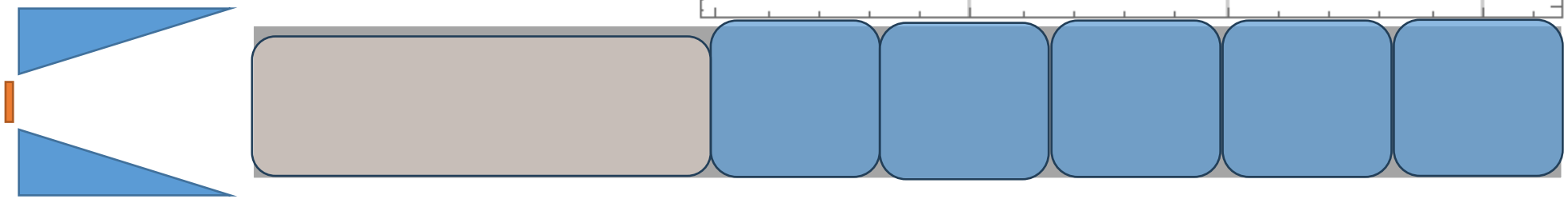
Simulation results: FC-based layout –v0



ILC FC designed by KEK



Front gap: 2 mm



FC
Ri: 6 mm Ro: 32 mm
Length: 100 mm

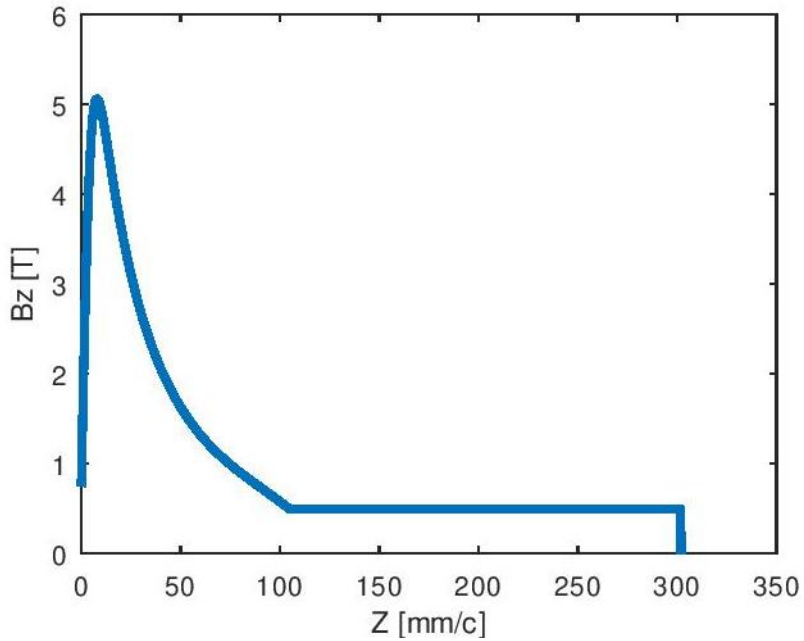
End gap
R: 30 mm
Length:(0mm - 200mm)

RF structures: 5
Length: 3240 mm with two drift of ~120 mm
Autophase

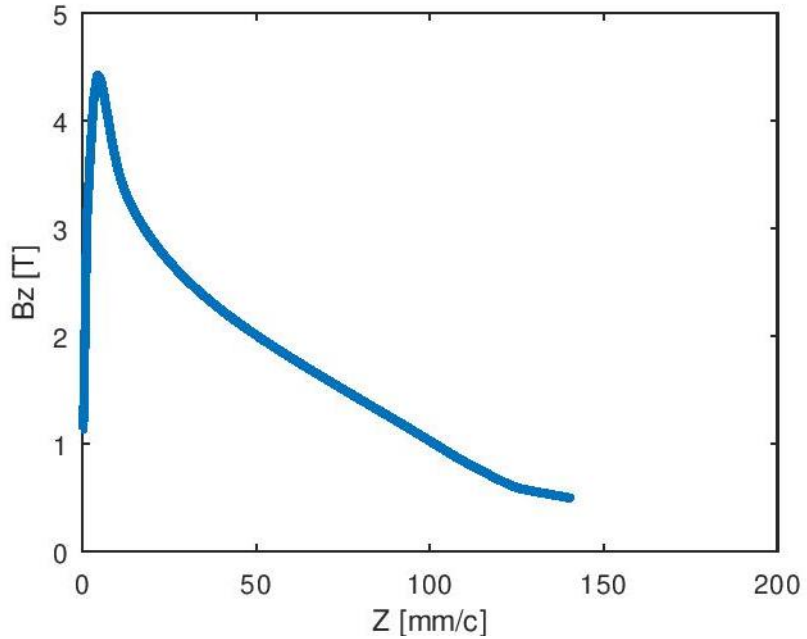
Solenoid
R: 30 mm
Strength: 0.5 T

Beam tracking scenarios

1) **ILC-FC + 0.5 T (when the FC field drops to 0.5 T) => FC-based layout –v0**
2) **SKEKB-FC : Field map is cut when FC + BC drops to 0.5 T**



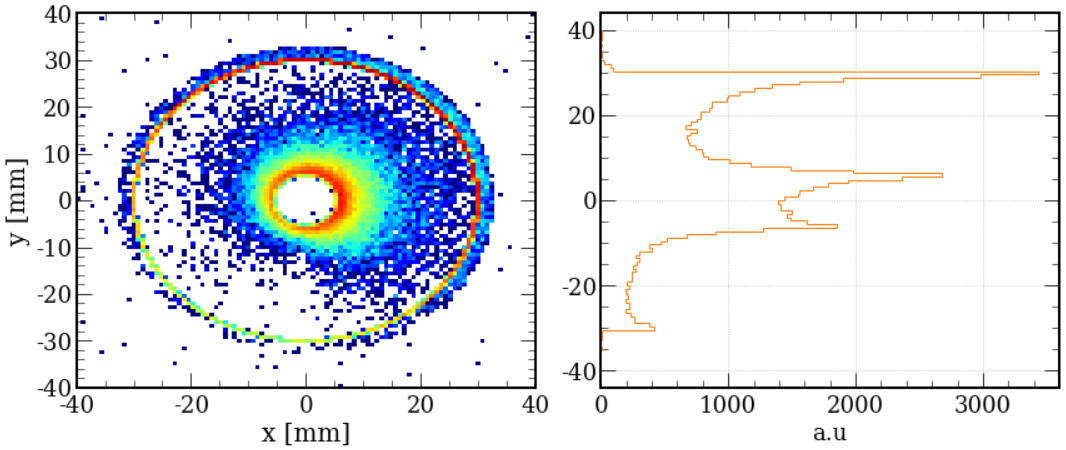
ILC-FC + 0.5 T

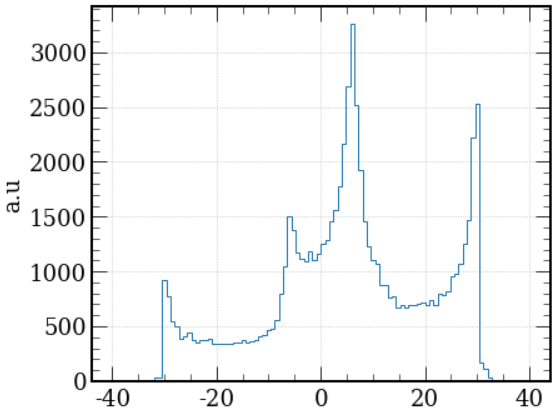


SKEKB-FC + BC + 0.5 T

Simulation results: loss map from target to RF structure entrance

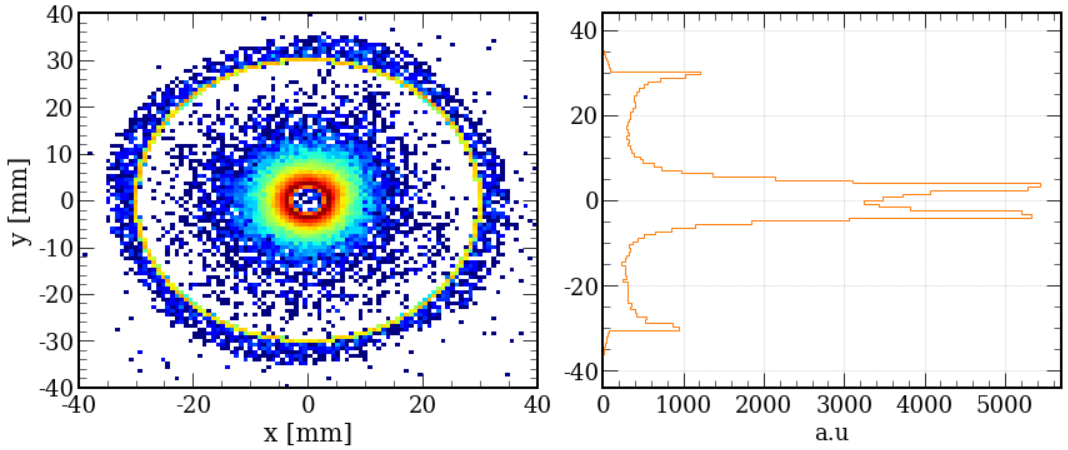
ILC-FC + 0.5 T

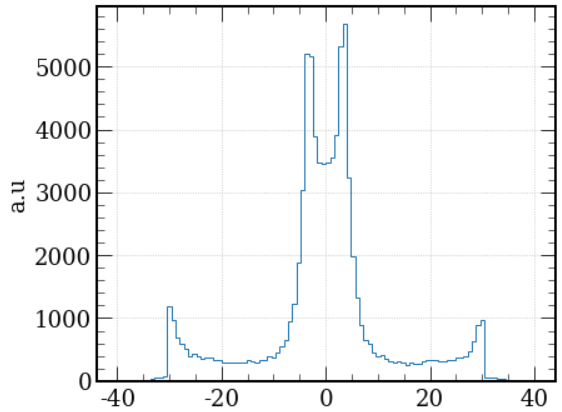




End gap
R: 30 mm
Length: 200mm

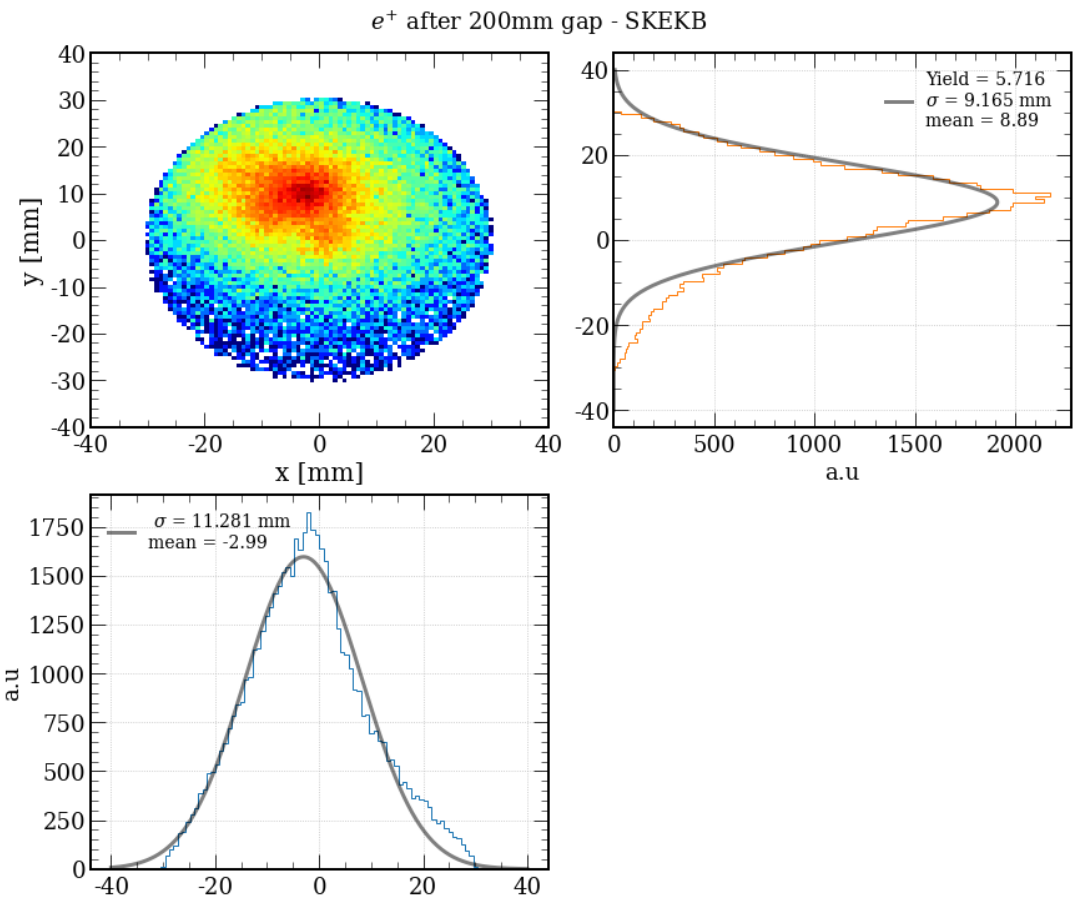
SKEKB-FC + BC + 0.5 T



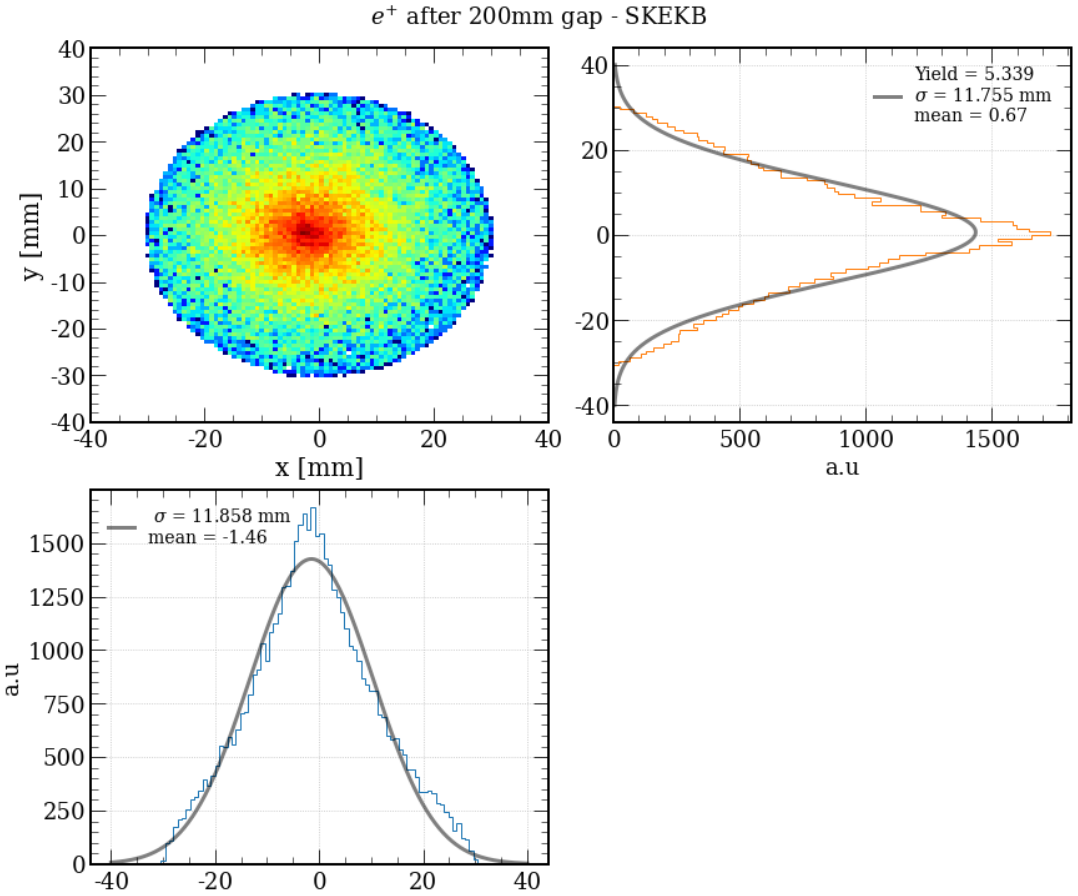


Simulation results: survived positrons at the RF structure entrance

ILC-FC + 0.5 T



SKEKB-FC + BC + 0.5 T

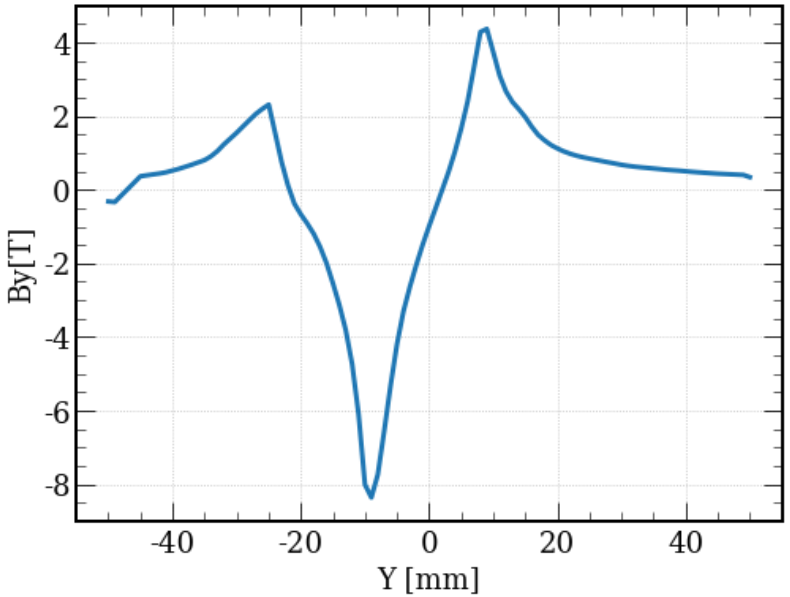


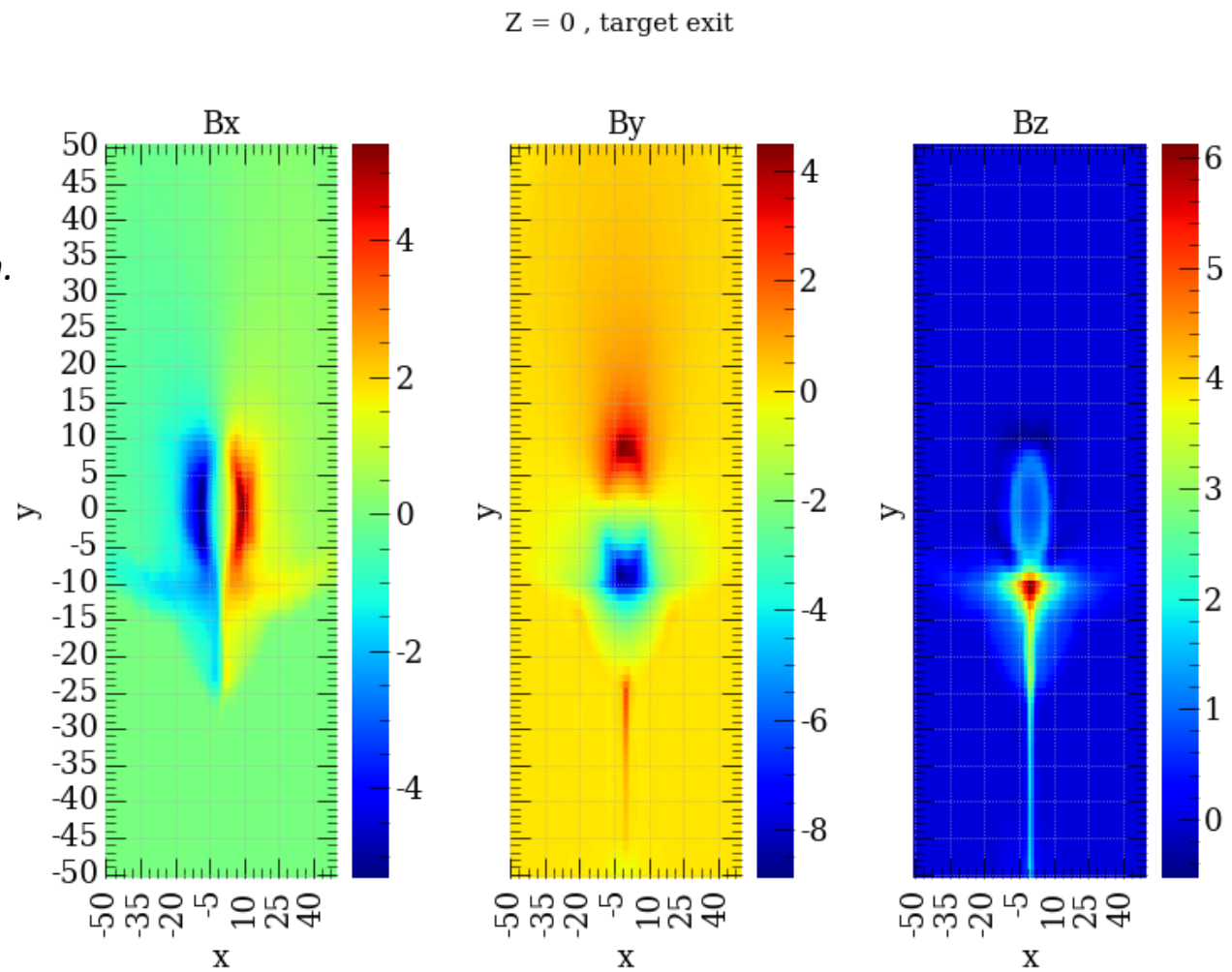
ILC-FC magnetic field map

Asymmetry in By field (caused by the slit)

- result: transverse offset of the e+ beam

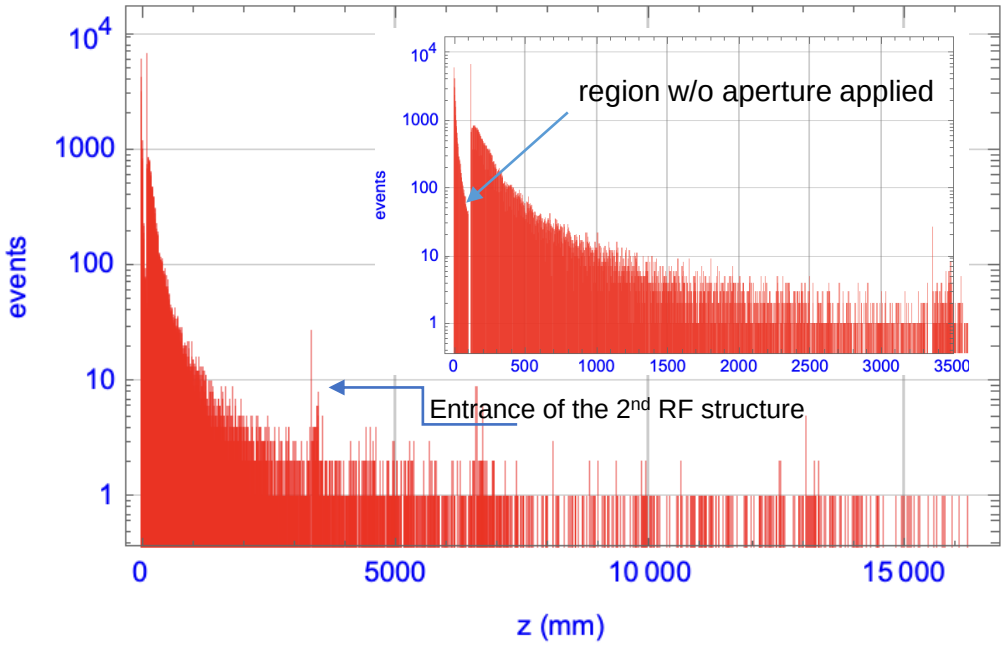
This effect is "known" and confirmed by Enomoto-san.



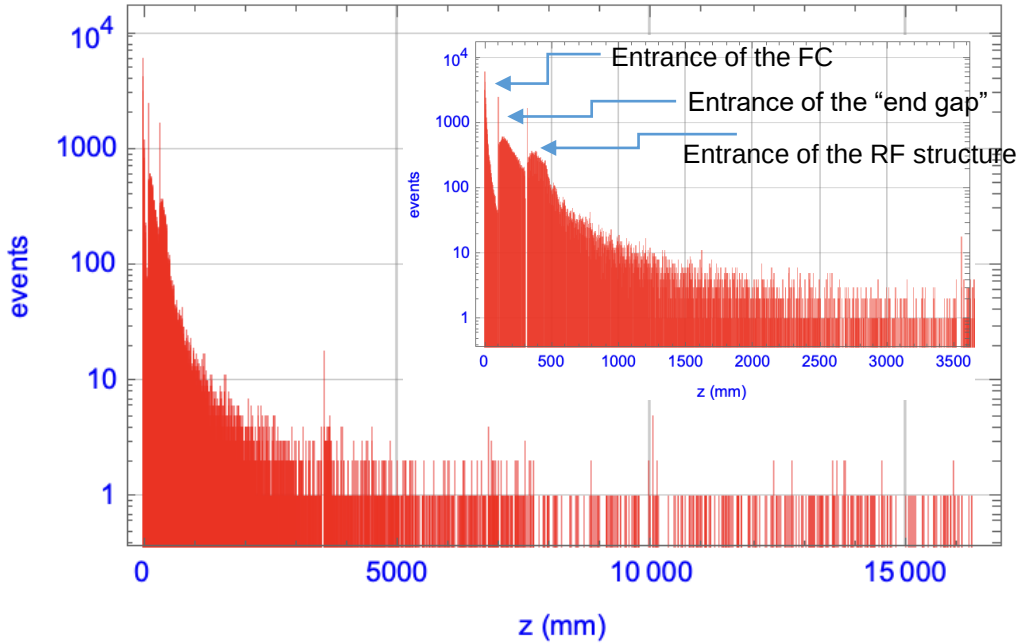


Simulation results: loss map for the capture section

6 GeV electron beam with beam size of 1 mm (RMS)



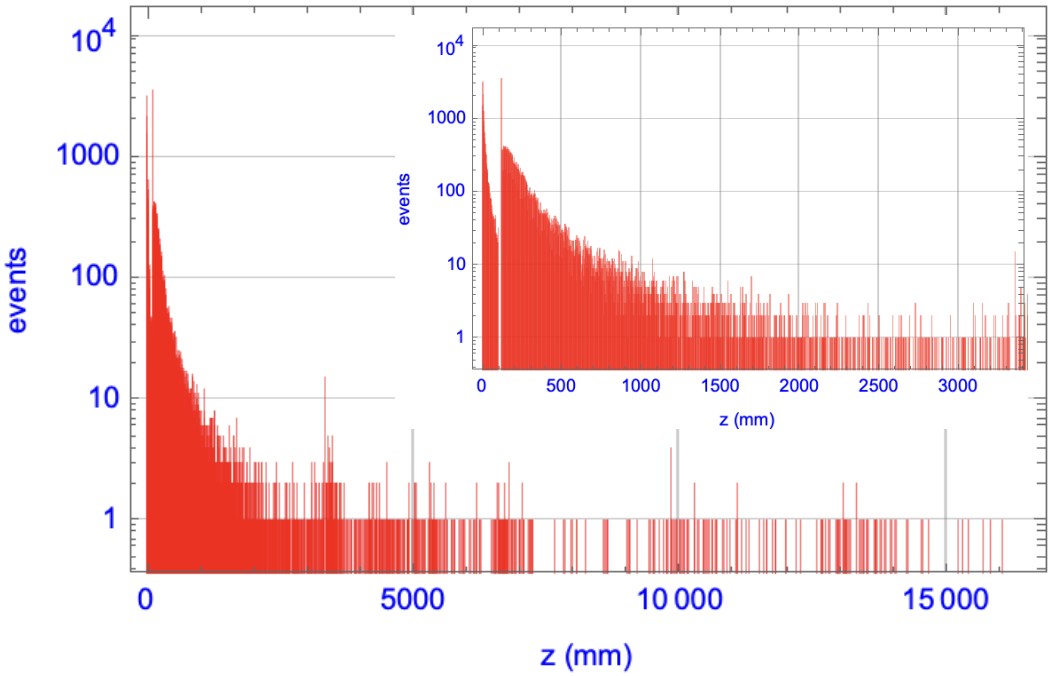
End gap: 0mm



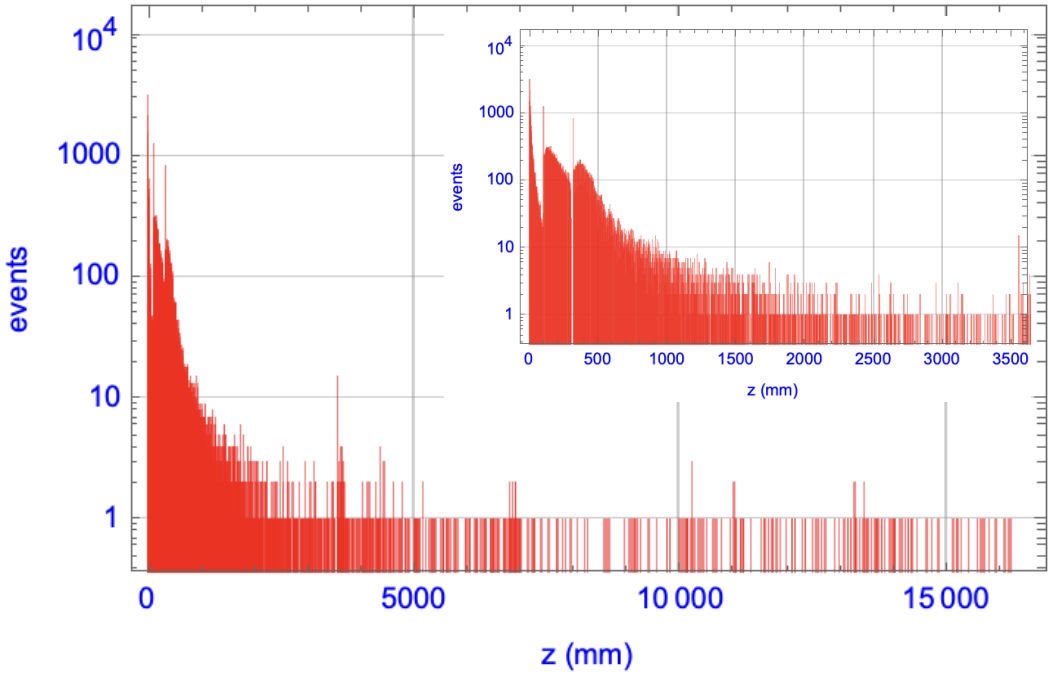
End gap: 200 mm

Simulation results: loss map for the capture section

2.86 GeV electron beam with beam size of 1 mm (RMS)

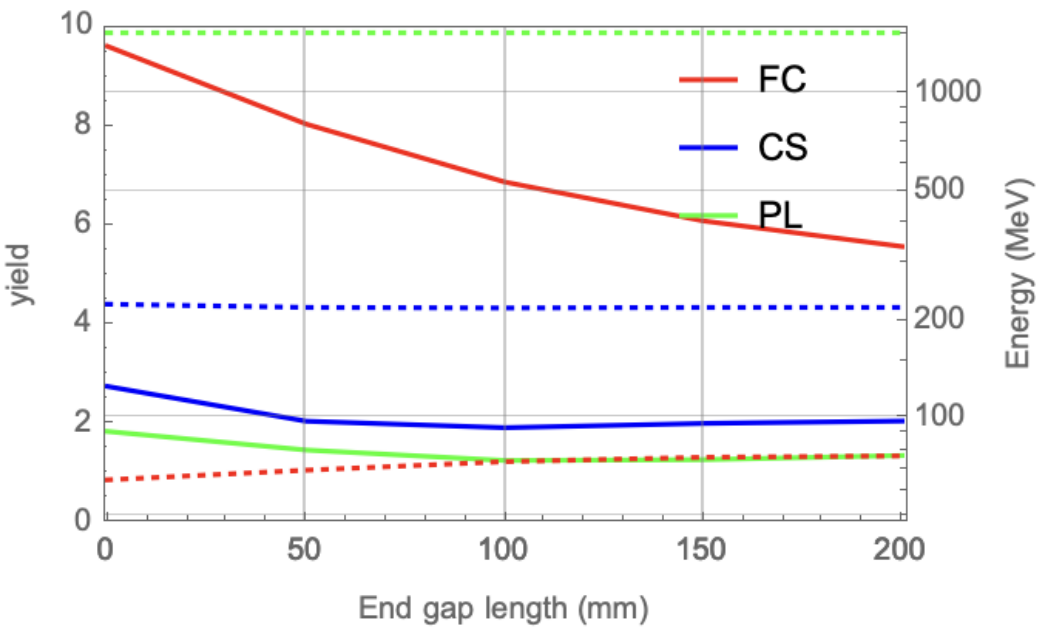


End gap: 0mm



End gap: 200 mm

Simulation results: next steps



Dashed line : Energy Line: Yield

FC: end of Flux concentrator

CS: end of Capture section

PL: end of positron linac

6 GeV electron beam with beam size of 1 mm (RMS)

- With current configuration of the magnetic field (uniform of 0.5 T), the effect of the distance between the FC and the first RF structure is small.
- Next steps: implementation of the realistic solenoid field in the gap and optimization of the gap length.
- Optimization of the capture linac (phases, gradients)
- We are ready to provide the loss particles phase space for FLUKA simulations

Simulation parameters (work in progress)

Conventional target		DR acceptance 3.8%		Requirement	5.4 nC accepted in the DR 13,5 nC		*Safety margin
Capture Section -v1					50% losses for injection in the DR		
		Target: 5X0 (17.5 mm)		15 mm	20% additional losses from target up to the end of the e+ linac		
HTS							
Beam energy, GeV	**6**			**2,86**			
Number of bunches	**2**	**4**	***8***	**2**	**4**	***8***
e+ bunch charge, e+	8,4E+10	8,4E+10	*8,4E+10*	8,4E+10	8,4E+10	*8,4E+10*
Bunch charge, e-	1,3E+10	1,3E+10	*1,3E+10*	2,6E+10	2,6E+10	*2,6E+10*
Bunch charge, [nC]	**2,08**	**2,08**	***2,08***	**4,09**	**4,09**	***4,09***
Bunch transv. size (rms), mm	1	1	*1*	1	1	*1*
Repetition rate (max), Hz	**200**	**100**	***50***	**200**	**100**	***50***
Beam power, kW	**5,0**	**5,0**	***5,0***	**4,7**	**4,7**	***4,7***
Production rate [Ne+/Ne-]	14,2	14,2	*14,2*	7,2	7,2	*7,2*
Positron yield @CS [Ne+/Ne-]	8	8	*8*	4,1	4,1	*4,1*
Positron yield @DR [Ne+/Ne-]	6,5	6,5	*6,5*	3,3	3,3	*3,3*
PEDD (target), J/g	**3,1**	**6,2**	***12,4***	**3,21**	**6,42**	***12,84***
Deposited power (target), [kW/pulse]	**1,2**	**1,2**	***1,2***	**1,05**	**1,05**	***1,05***

Starting point?

Flux Concentrator KEK (2a=12-64 mm)						
Beam energy, GeV	**6**			**2,86**		
Number of bunches	**2**	**4**	***8***	**2**	**4**	***8***
e+ bunch charge, e+	8,4E+10	8,4E+10	*8,4E+10*	8,4E+10	8,4E+10	*8,4E+10*
Bunch charge, e-	5,3E+10	5,3E+10	*5,3E+10*	1,1E+11	1,1E+11	*1,1E+11*
Bunch charge, [nC]	**8,44**	**8,44**	***8,44***	**16,88**	**16,88**	***16,88***
Bunch transv. size (rms), mm	1	1	*1*	1	1	*1*
Repetition rate (max), Hz	**200**	**100**	***50***	**200**	**100**	***50***
Beam power, kW	**20,2**	**20,2**	***20,2***	**19,3**	**19,3**	***19,3***
Production rate [Ne+/Ne-]	14,2	14,2	*14,2*	7,2	7,2	*7,2*
Positron yield @CS [Ne+/Ne-]	2,1	2,1	*2,1*	1	1	*1*
Positron yield @DR [Ne+/Ne-]	1,6	1,6	*1,6*	0,8	0,8	*0,8*
PEDD (target), J/g	**12,5**	**25**	***50***	**12,9**	**25,8**	***51,6***
Deposited power (target), [kW/pulse]	**4,6**	**4,6**	***4,6***	**4,2**	**4,2**	***4,2***

***2.86 GeV DR acceptance parameters are the same as 1.56 GeV version**

***Beam size of 1 mm is chosen as for now (mainly to PEDD)**

ILC-FC => FC-based layout –v0

Thermionic e- gun will be needed to provide the requested bunch charge

Simulation parameters (work in progress)

Flux Concentrator KEK (2a=12-64 mm)						
Beam energy, GeV	**6**			**2,86**		
Number of bunches	**2**	**4**	***8***	**2**	**4**	***8***
e+ bunch charge, e+	8,4E+10	8,4E+10	*8,4E+10*	8,4E+10	8,4E+10	*8,4E+10*
Bunch charge, e-	5,3E+10	5,3E+10	*5,3E+10*	1,1E+11	1,1E+11	*1,1E+11*
Bunch charge, [nC]	**8,44**	**8,44**	***8,44***	**16,88**	**16,88**	***16,88***
Bunch transv. size (rms), mm	1	1	*1*	1	1	*1*
Repetition rate (max), Hz	**200**	**100**	***50***	**200**	**100**	***50***
Beam power, kW	**20,2**	**20,2**	***20,2***	**19,3**	**19,3**	***19,3***
Production rate [Ne+/Ne-]	14,2	14,2	*14,2*	7,2	7,2	*7,2*
Positron yield @CS [Ne+/Ne-]	2,1	2,1	*2,1*	1	1	*1*
Positron yield @DR [Ne+/Ne-]	1,6	1,6	*1,6*	0,8	0,8	*0,8*
PEDD (target), J/g	**12,5**	**25**	***50***	**12,9**	**25,8**	***51,6***
Deposited power (target), [kW/pulse]	**4,6**	**4,6**	***4,6***	**4,2**	**4,2**	***4,2***

Flux Concentrator SKEKB (2a=7-52mm)						
Beam energy, GeV	**6**			**2,86**		
Number of bunches	**2**	**4**	***8***	**2**	**4**	***8***
e+ bunch charge, e+	8,4E+10	8,4E+10	*8,4E+10*	8,4E+10	8,4E+10	*8,4E+10*
Bunch charge, e-	3,0E+10	3,0E+10	*3,0E+10*	6,0E+10	6,0E+10	*6,0E+10*
Bunch charge, [nC]	**4,82**	**4,82**	***4,82***	**9,64**	**9,64**	***9,64***
Bunch transv. size (rms), mm	1	1	*1*	1	1	*1*
Repetition rate (max), Hz	**200**	**100**	***50***	**200**	**100**	***50***
Beam power, kW	**11,6**	**11,6**	***11,6***	**11,0**	**11,0**	***11,0***
Production rate [Ne+/Ne-]	14,1	14,1	*14,1*	7,2	7,2	*7,2*
Positron yield @CS [Ne+/Ne-]	3,1	3,1	*3,1*	1,6	1,6	*1,6*
Positron yield @DR [Ne+/Ne-]	2,8	2,8	*2,8*	1,4	1,4	*1,4*
PEDD (target), J/g	**7,3**	**14,6**	***29,2***	**7,5**	**15**	***30***
Deposited power (target), [kW/pulse]	**2,7**	**2,7**	***2,7***	**2,45**	**2,45**	***2,45***

ILC-FC => FC-based layout –v0

SKEKB-FC (with BC, target thus assumed fixed)

For 2.86 GeV option, the SKEKB layout seems applicable (cf. beam time structure)

Discussion and next steps

- Sharing the CAD model of the ILC-KEK FC. Assumption for the target design ?

https://cernbox.cern.ch/files/link/public/LP4rKwbzOUmtl4C/task3.2?items-per-page=100&view-mode=resource-table&tiles-size=1

- FLUKA model and simulations
- Target design and integration
  - Possibility to put the Bridge Coils (in case of moving target will be difficult). BC are currently assumed for the SuperKEKB layout. Should be iterated with CERN-STI group.
- Continuation of the beam dynamics simulations for the FC-based option (optimized parameters and layout). Should be iterated with CERN-STI group.

- Considerations on the FC power source (high-power sources engineer). The new layout allowing operation at 100 Hz seems very attractive in this context. Operation at 200 Hz seems difficult.

Summary of the simulation results (6 GeV production scheme)

Drive beam parameters	FC-based capture system		Capture system –v1
Matching device	*BINP FCC FC*	**KEK ILC FC –v0**	**HTS solenoid**
Matching device aperture	*2a=8-44mm*	**2a=12-64mm**	**$2a_{min}$=30 mm (bore 72mm)**
Matching device peak magnetic field (@Target) [T]	*7.5 (3.5)*	**5 (0.8)**	**15 (12)**
e- beam bunch charge [nC] / e- beam power [kW]	***3.1 / 7.4***	**8.4 / 20.2**	**2.1 / 5**
Target deposited power [kW] / PEDD [J/g]	*1.7 / 11.1*	**4.6/12.5**	**1.2 / 3.1**
Positron yield @CS [Ne^+/Ne^-]	*4.9*	**2.1**	**8**
Positron yield @DR [Ne^+/Ne^-]	***4.4***	**1.6**	**6.5**
Normalized emittance (rms) [mm.rad]	*12.2*	**12.3**	**13.7**
Energy spread (rms) [%]	*1.2*	**1.5**	**1.4**
Bunch length (rms) [mm]	*2.9*	**3.3**	**2.9**
e+ beam bunch charge [nC]		**13.5**	