WP3 Joint Meeting

Task 3.1 Physics design of the positron target and capture system

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13 May 2024

Requirements for design studies

The complete filling for Z running => Requirement ~2.75 × 10^{10} e^+/bunch (4.4 nC) at the linac end or 5.4 nC accepted in the DR

50% losses for injection in the DR (assumed) + 20% additional losses from target up to the end of the e+ linac (assumed)

$$N_{e-}/\text{bunch} \times \eta^{e+}_{Accepted} \geq 5.4\ \text{nC/bunch} \times 2.5$$

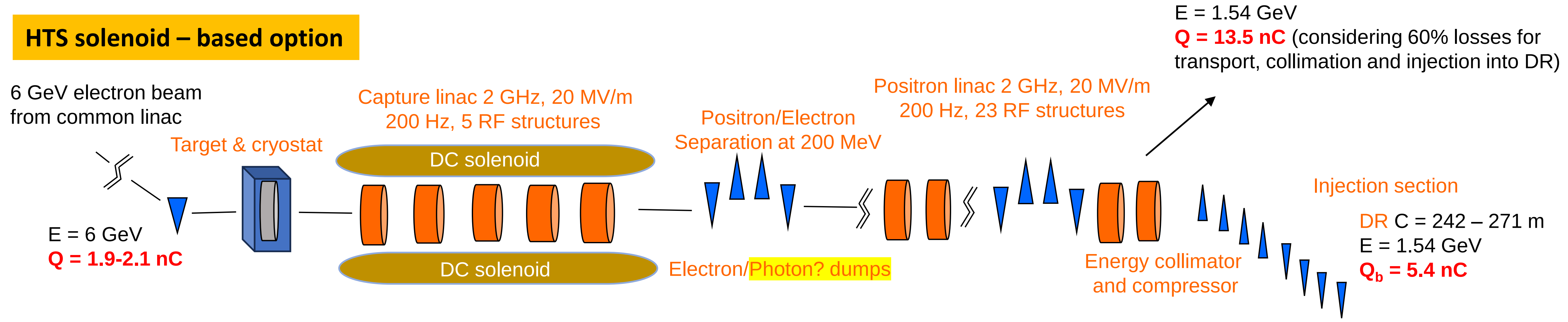
$$\eta^{e^+}_{\text{Accepted}} = \frac{N^{e^+}_{\text{DR accepted}}}{N^{e^-}_{\text{Primary}}}$$

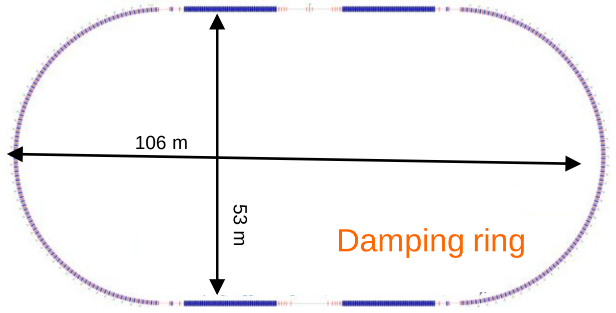
A safety margin of 2.5 is currently applied for the whole studies (60% losses for transport, collimation and injection into the DR).

- 20% additional losses from target up to the end of the e+ linac
  - e+ linac simulations (including chicane) will provide more realistic estimation of the accepted yield
  - Include the ESC in the linac start-to-end simulations
  - Still a reasonable safety margin
- 50% losses for injection in the DR
  - To be discussed/fixed with the WP4 (studies including ESC from 2023 => DR acceptance ~ 80%)

Organize a joint meeting with WP1/WP4 to discuss the acceptance of the DR (including the ESC) and the way how to implement it in our studies.

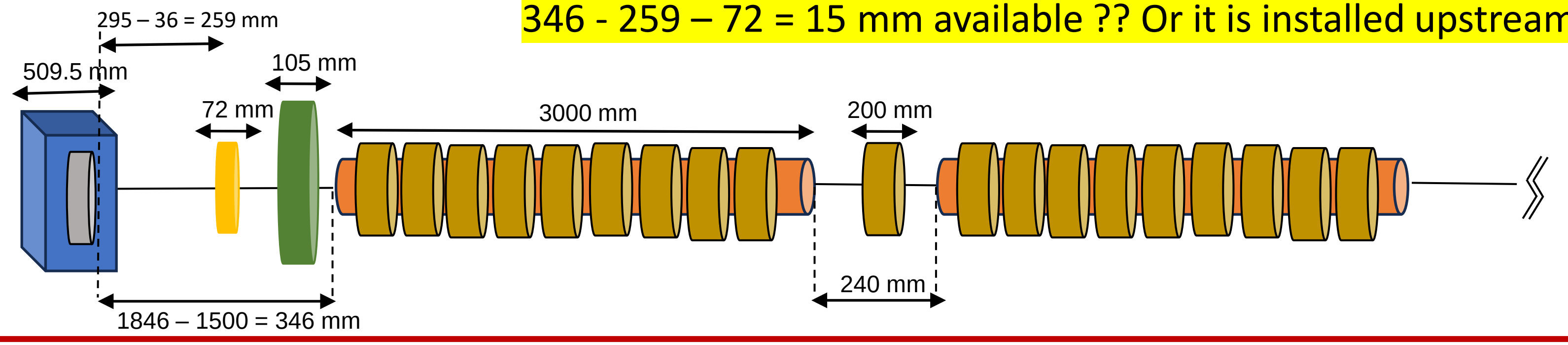
Positron source physics design (current baseline)





Capture system -version 1

Does FLUKA model include short "tuning" solenoid?
346 - 259 – 72 = 15 mm available ?? Or it is installed upstream?



Positron production: conventional scheme (e- beam size on target = 1 mm rms). Target exit located at 40 mm w.r.t. peak field.

Matching Device is based on the SC solenoid (5 HTS coils, 72 mm bore including shielding)

Capture Linac is based on the L-band TW RF structures (2 GHz, 60 mm, 3-m long)

NC long solenoid B = 0.5 T (realistic conventional design based on the short coils B = 0.31 T) + short "tuning" solenoid B = 0.124 T before the 1st RF structure

Shielding made of W before the 1st RF structure (position tbc)

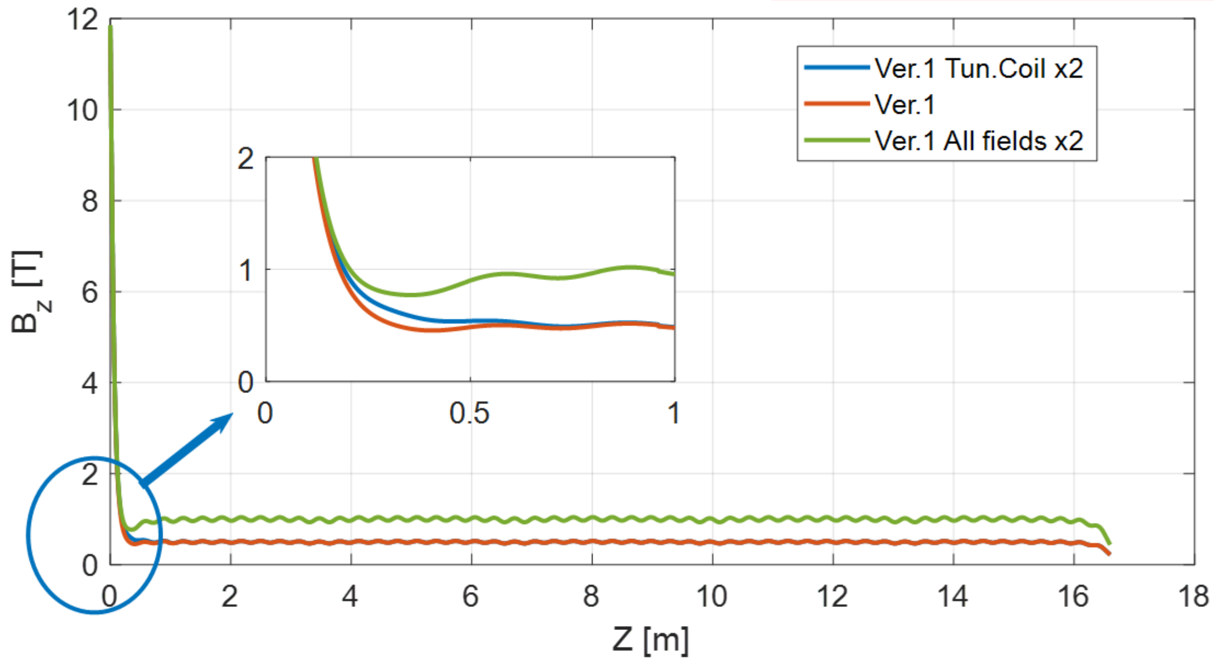
Simulation results

See Viktor's update

HTS solenoid – based option

- The realistic field of the short "tuning" and regular solenoids is used now (instead of the uniform profile). Accepted e+ yield @ DR is ~ 7 e+/e-
- Increasing the field of the "tuning" solenoid by factor of 2 (still compatible with the current design) improves the yield *(CS layout to be updated).*
- Assuming the SC solenoid after the cryostat (~1T) and decreasing the aperture of the RF structures (Ø40 mm) can provide the similar positron yield.

<u>Do we continue the studies in this direction?</u>



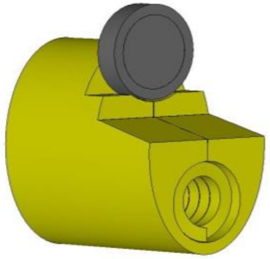
Capture system -version 1

Accepted e^+ yield @ DR	6.5
Norm. emittance [mm*rad]	13.7
Energy spread (RMS) [%]	1.4
Bunch length (RMS) [mm]	2.9

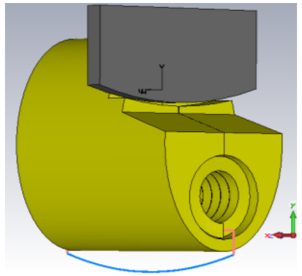
*Uniform solenoid field profile (Bz = 0.5 T) is assumed for the CS

See Yongke's update on positron linac studies

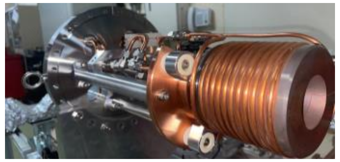
Positron capture: Flux Concentrator (FC) as a matching device



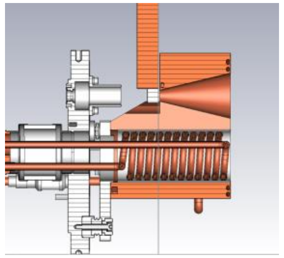
Originally designed by BINP for the FCC-ee (P. Martyshkin)
=> FC:FCC-BINP
Dropped as no info and further studies available



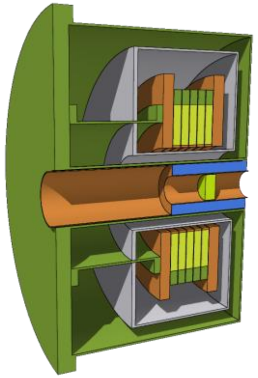
Originally designed by BINP for the ILC (P. Martyshkin) => FC:ILC-BINP
Dropped as no info and further studies available



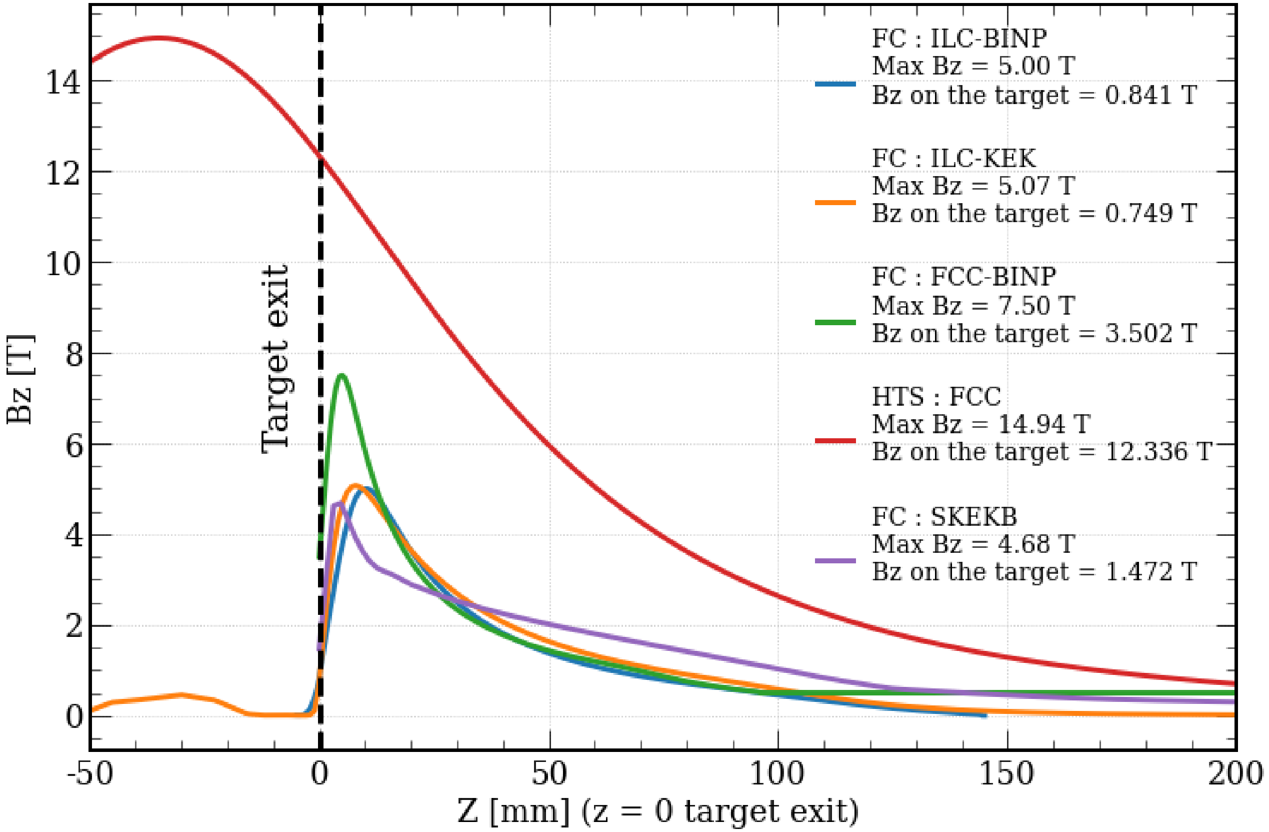
Originally designed by KEK for the SuperKEKB => FC:SKEKB-KEK
Under consideration for the FCC-ee : with and w/o BC



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



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



Simulation parameters (work in progress)

See Yuting's updates

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

SKEKB-FC (with BC)
Target thus assumed fixed

This option is now under investigation by CERN-STI group

SKEKB-FC (without BC) **Possibility to employ the moving target**

Flux Concentrator SKEKB w/o BC (2a=7-52mm)			
Beam energy, GeV	6		
Number of bunches	**2**	**4**	***8***
e+ bunch charge, e+	8,4E+10	8,4E+10	*8,4E+10*
Bunch charge, e-	5,0E+10	5,0E+10	*5,0E+10*
Bunch charge, [nC]	**7,94**	**7,94**	***7,94***
Bunch transv. size (rms), mm	1	1	*1*
Repetition rate (max), Hz	**200**	**100**	***50***
Beam power, kW	**19,0**	**19,0**	***19,0***
Production rate [Ne+/Ne-]	14,1	14,1	*14,1*
Positron yield @CS [Ne+/Ne-]	1,96	1,96	*1,96*
Positron yield @DR [Ne+/Ne-]	1,7	1,7	*1,7*
PEDD (target), J/g	**11,87**	**23,74**	***47,48***
Deposited power (target), [kW]	**4,42**	**4,42**	***4,42***

Current positron capture simulations show

- More sophisticated target design should be considered
- Thermionic e- gun will be needed to provide the requested bunch charge of the e- drive beam
- FC operation at 200 Hz is very difficult (4 bunches scheme @100 Hz?)
- Linac simulation for high-charge e- beam will be needed

Summary Table (DR @2.86 GeV)

Parameter	Unit	V0	V1		CLIC-PDR	
Primary energy	GeV	6			2.86	
Beam size x/y	mm	0.5	1		0.5	1
Target thickness	mm	17.5			15	
Positron yield @ Target		14.1	14.2		7.1	7.2
Positron yield @ CS		8.5	8		4.3	4.1
Positron yield @ DR		7	6.5		2.9	2.7
e- bunch charge	nC	1.93	2.1		4.66	5
Target deposited power	kW	1.13	1.2		1.19	1.28
PEDD	J/g	7.7	3.1		9.3	3.9
Normalized emmitance (rms)	mm.rad	12	13.7		11.3	13
Energy spread (rms)	%	1.6	1.4		0.6	0.6
Bunch length (rms)	mm	3.1	2.9		2.2	2.3
e+ bunch charge	nC			13.5		

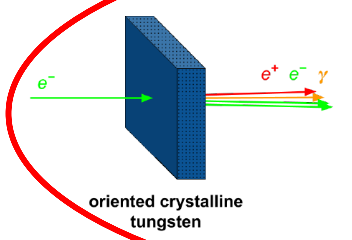
CLIC –PDR :
E = +/- 1.2%
t = 20mm/c

*Uniform solenoid field profile (Bz = 0.5 T) is assumed for the CS

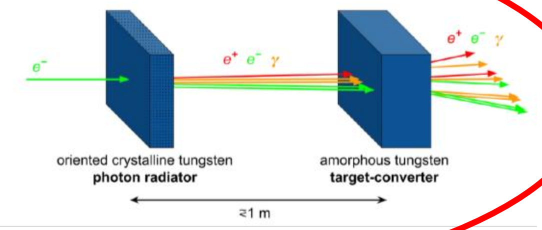
Crystal-based positron source

towards conceptual design

1)

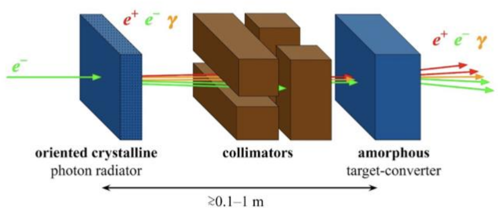


2)



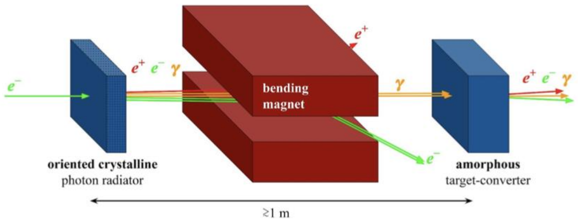
3)

…with **collimator**



4)

…with **magnet**



13.5nC at DR

Case	Thickness [mm]	Target				AMD	Capture Linac	Positron Linac	e- beam	Target	
		Rate	σx [mm]	Edep [GeV/e-]	PEDD $[\frac{MeV}{mm^3}/e^-]$	Yield (AMD) R = 30mm	**Yield**	**Accept Yield**	Drive beam charge [nC]	PEDD [J/g]	Power Deposited [kW]
Conventional	17.5	14.4	0.85	1.46	38.3	13.1	8.6	7.0	1.93	7.67	1.12
Thick W crystal	9	13.7	0.67	0.6	35.35	13.3	7.8	6.6	2.05	7.53	0.5
	10	14.5	0.71	0.8	36.45	14.1	8.5	7.2	1.88	7.12	0.6
	11	15.1	0.72	0.93	36.73	14.7	8.9	7.5	1.8	6.87	0.67
	12	15.4	0.73	1.1	38.15	15	9.2	7.7	1.75	6.9	0.77
	13	15.6	0.77	1.3	36.36	15.1	8.4	7.9	1.7	6.4	0.88

One thick crystal option provides good results. Integration and operation of the crystal within the HTS magnet (control of the crystal alignment) is under investigation.

Positron source design studies

- FCC week (10-14 June 2024): "**Positron source and capture system (HTS-solenoid vs FC options)" and "Developments of P-cubed and FCC-ee positron source targets at CERN"**
    - Should we show/discuss the positron production @2.86 GeV ?

We should fix the e+ source parameters (layouts) to be shown at the FCC week.

- HTS solenoid option: capture system –v1 (update of the magnetic field profile, check shielding in the FLUKA model, necessity of the photon dump at the chicane, feasibility of the SC solenoid around the capture linac and interest of decreasing the RF structure aperture, revise the DR acceptance)
- FC option: simulations are in progress (first results are available). Waiting for the feedback from CERN-STI group regarding the SuperKEKB FC simulations for the next steps.

Difference in Geant4 simulations @6GeV: e+ production rate 13.9 (mesh off) vs. 14.1 (mesh on).
RF-track update: difference in accepted e+ yield (under investigation by Yongke)

Version 0	Version 1
Positron production: conventional scheme (e- beam size on target = 0.5 mm rms). Target exit located at 35 mm w.r.t. peak field Matching Device is based on the SC solenoid (5 HTS coils, 72 mm bore including shielding) Capture Linac is based on the L-band TW RF structures (2 GHz, 60 mm, 3-m long) NC long solenoid B = 0.5 T (realistic conventional design based on the short coils) + short “tuning” solenoid before the 1st RF structure (before uniform profile 0.5 T)	Positron production: conventional scheme (e- beam size on target = 1 mm rms). Target exit located at 40 mm w.r.t. peak field. Matching Device is based on the SC solenoid (5 HTS coils, 72 mm bore including shielding) Capture Linac is based on the L-band TW RF structures (2 GHz, 60 mm, 3-m long) NC long solenoid B = 0.5 T (realistic conventional design based on the short coils) + short “tuning” solenoid before the 1st RF structure
Accepted yield 7.0 for the uniform 0.5 T NC and the simulation was actually up to 200 MeV. After 200 MeV, the analytic formula was used. Accepted yield now: Last week, the DR accepted yield was 6.4 (Geant4 mesh off 13.9 e+/e-) or 6.6 (Geant4 mesh on 14.2 e+/e-, which was used to benchmark Mattia's result). After an update of RF-Track, the yield is reduced to 6.0 (Geant4 mesh off 13.9 e+/e-) or 6.4 (Geant4 mesh on 14.2 e+/e-).	Accepted yield 6.5 was obtained with uniform NC field and the analytic formula. Accepted yield (from e+ linac simulations): 5.8 e+/e- with G4 production rate of 13.9 e+/e- The yield from the full simulation was 5.7 (mesh off) or 5.9 (mesh on) last week Now it's 5.3 (mesh off) or 5.8 (mesh on) The Geant4 production rate is 13.9 (mesh off) or 14.1 (mesh on), independent on RF-Track versions