FCC positron source: PSI HTS solenoid as AMD

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On behalf of the team

Configuration for the studies

Table 1: Main parameters of the primary electron beam.

Parameters	Values	Units
Beam energy	6	GeV
Energy spread (RMS)	0.1	%
Divergence (RMS)	0.01	mrad
Bunch length (RMS)	1	mm
Number of bunches per pulse	25	
Repetition rate	100	Hz

The positron bunch population was required to be 2.1×10^{10} (~3.4 nC bunch charge). An additional safety factor of 2 was considered.

PRE-INJECTOR LINAC

The same pre-injector linac with the CLIC [9,10] positron source was used in this study. The pre-injector linac is composed of 11 L-band travelling wave (TW) structures working in the $2\pi/3$ mode with a frequency of 2 GHz and an aperture of 20 mm radius. Each TW structure is 1.5 m long, composed of 30 cells. The first structure was supposed to capture positrons with deceleration, while the others accelerate positrons to 200 MeV. The distance between the FC and the first TW structure is 40 mm. The distance between the structures is 20 cm. The TW structures are surrounded by a NC solenoid with a constant magnetic field of 0.5 T. The average gradient for the TW structures is 16 MV/m.

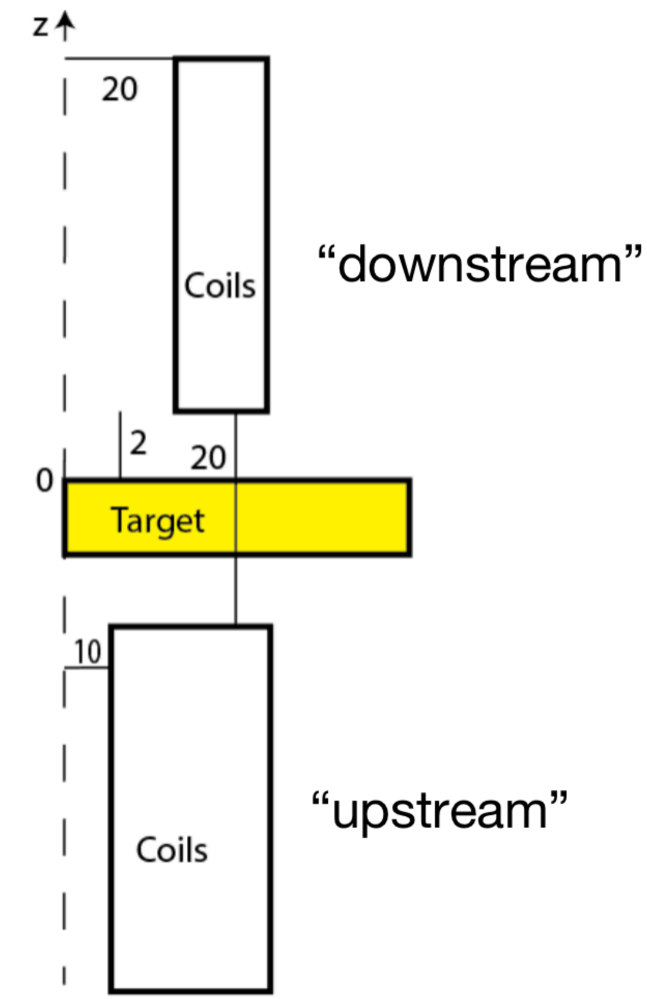
INJECTOR LINAC

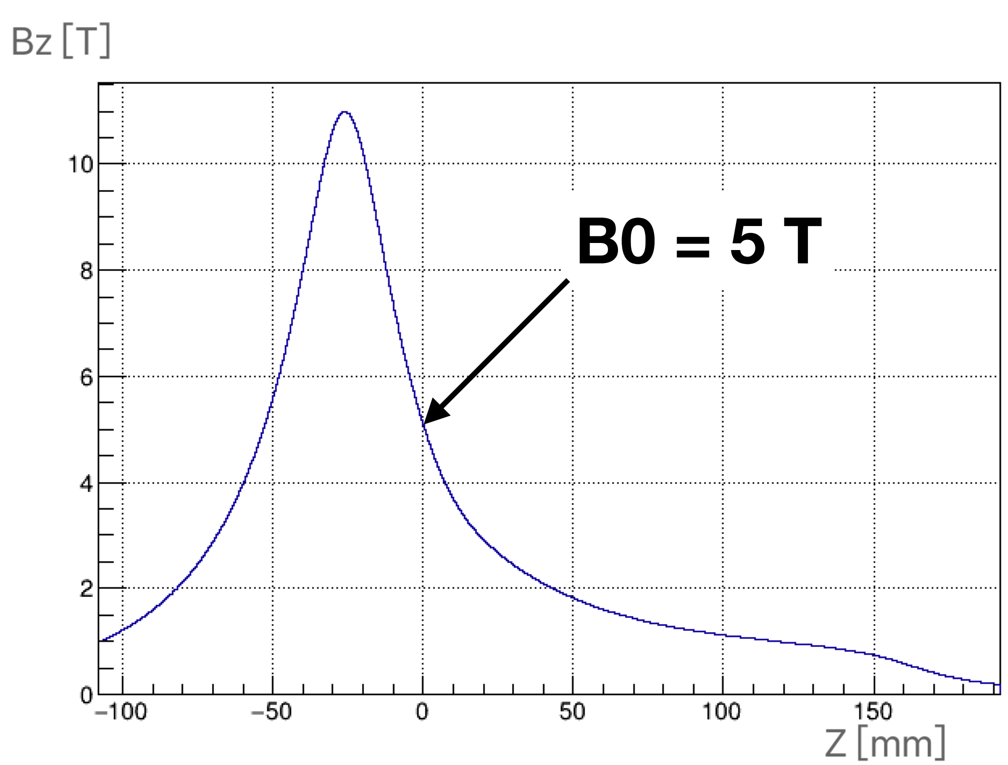
The acceleration of positrons in the injector linac up to 1.54 GeV was simplified in the simulation with an analytic calculation: $\Delta E = \Delta E_0 \cdot \cos(2\pi f \cdot \Delta t)$. In the formula, $\Delta E_0 = 1.54\,\text{GeV} - E_{\text{ref}}$ is the maximum energy gain for the reference particle, $f = 2.856\,\text{GHz}$ is the RF frequency assumed for S-band structures and $\Delta t = t - t_{\text{ref}}$ is the time difference from the reference particle. The reference particle with an energy around 200 MeV was defined such that the mean energy of positrons accepted by the DR was exactly 1.54 GeV and the accepted positron yield was maximised.

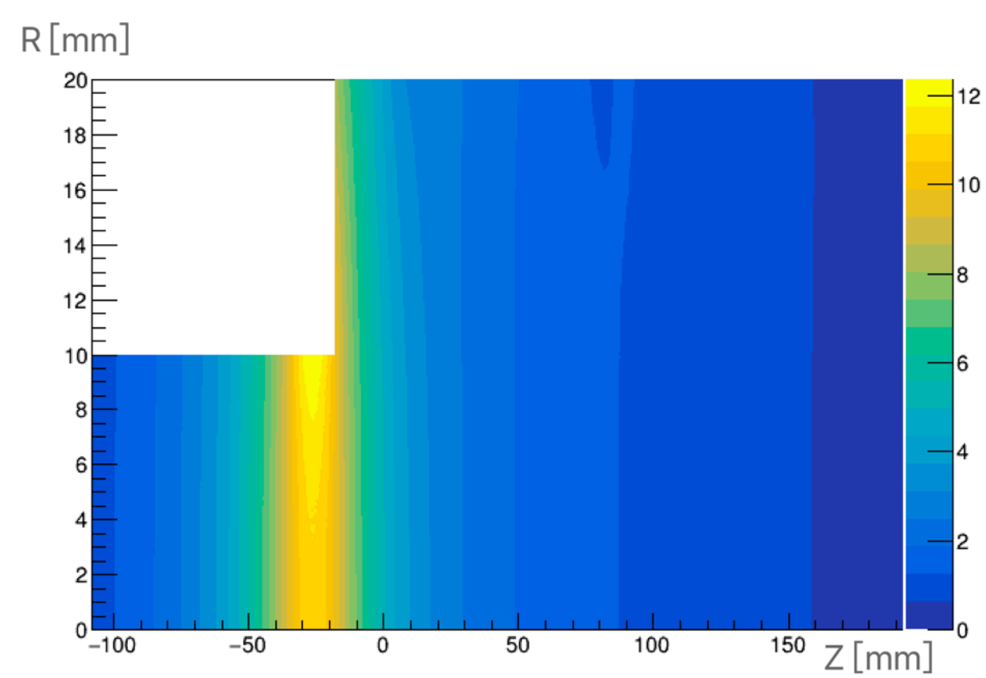
The acceptance of DR was considered by applying a window cut on the energy and time of positrons arriving at the injector linac exit. The energy acceptance is within ±3.8% of the desired energy, 1.54 GeV, while the total size of time window is 9.33 mm/c corresponding to a RF phase window of 32°. The longitudinal phase space of the positrons at the end of the injector linac for the analytic AMD profile is presented in Fig. 5, with the energy and time window displayed by a red rectangle on the plot.

Review of previous studies

- Layout of PSI HTS solenoid includes two coil sections
  - Upstream coils: small aperture for high peak field
  - Downstream coils: large aperture for high e+ collection efficiency
- Two field profiles have been tested
  - Effective peak field (at target exit), B0 = 5 T or 7 T
  - Higher field → higher e+ yield
- The fringe field before B0 was found to have negligible effect on e+ yield







Review of previous studies

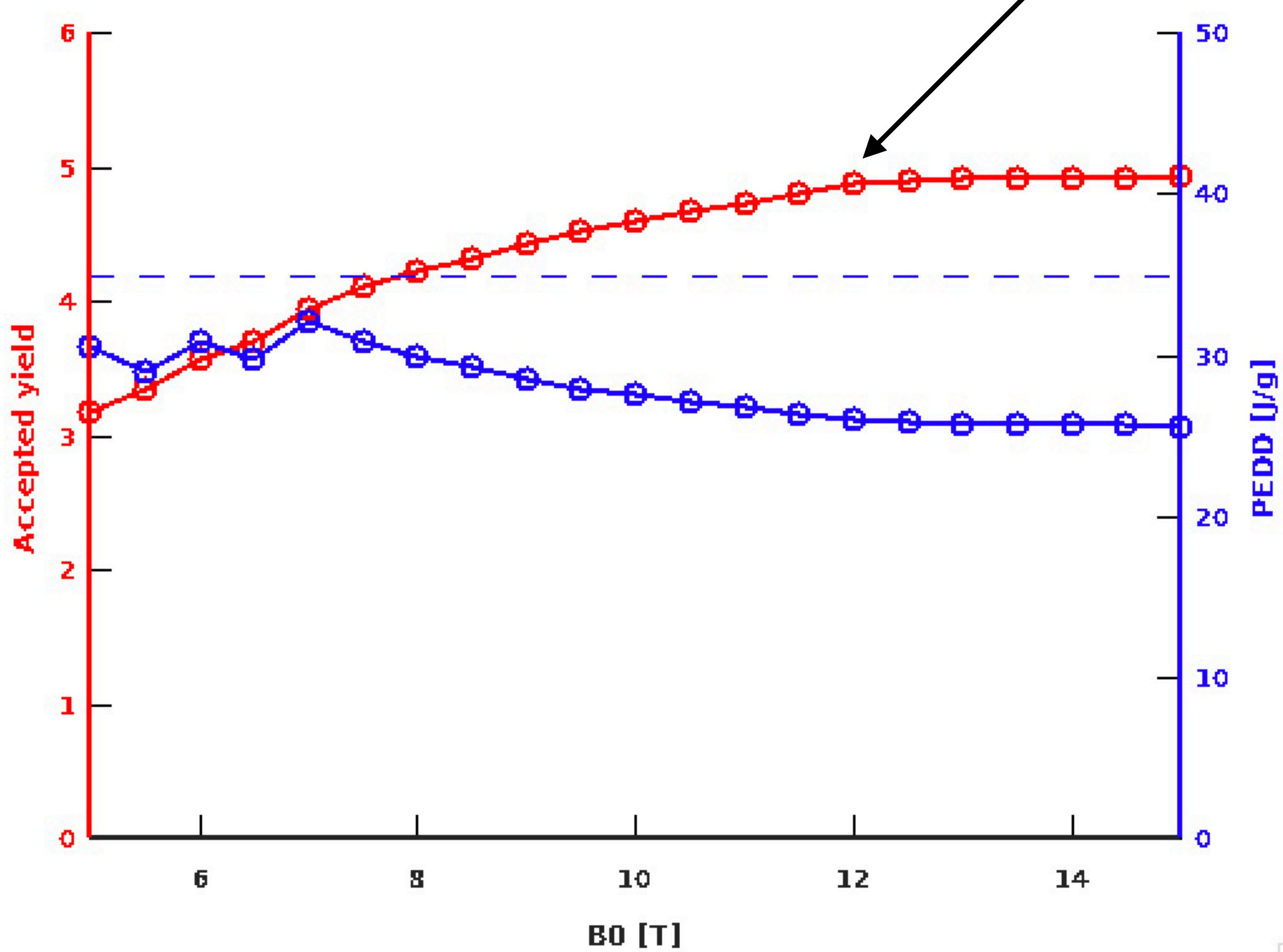
- A study performed to optimize B0 using analytic field profile

$$B_z = B_0/(1 + \mu z)$$

u = 50 m^{-1}

Optimized B0: 12 T

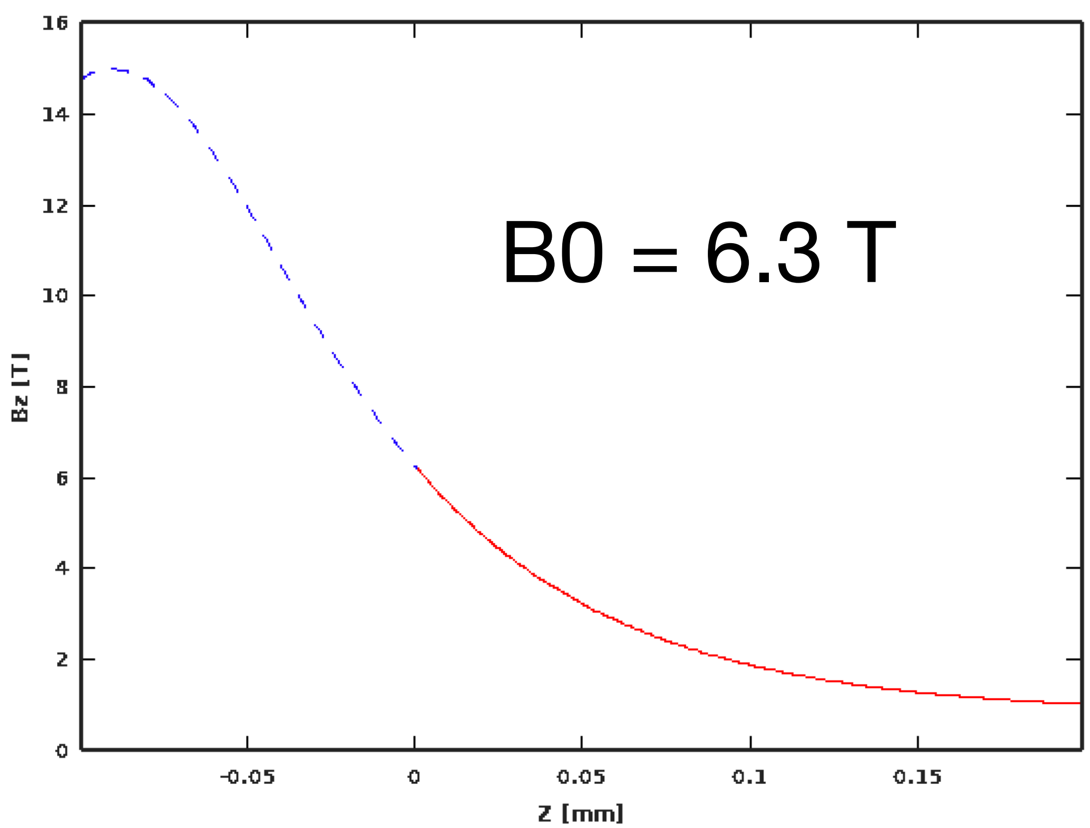
(e- spot size: 1.0 mm)



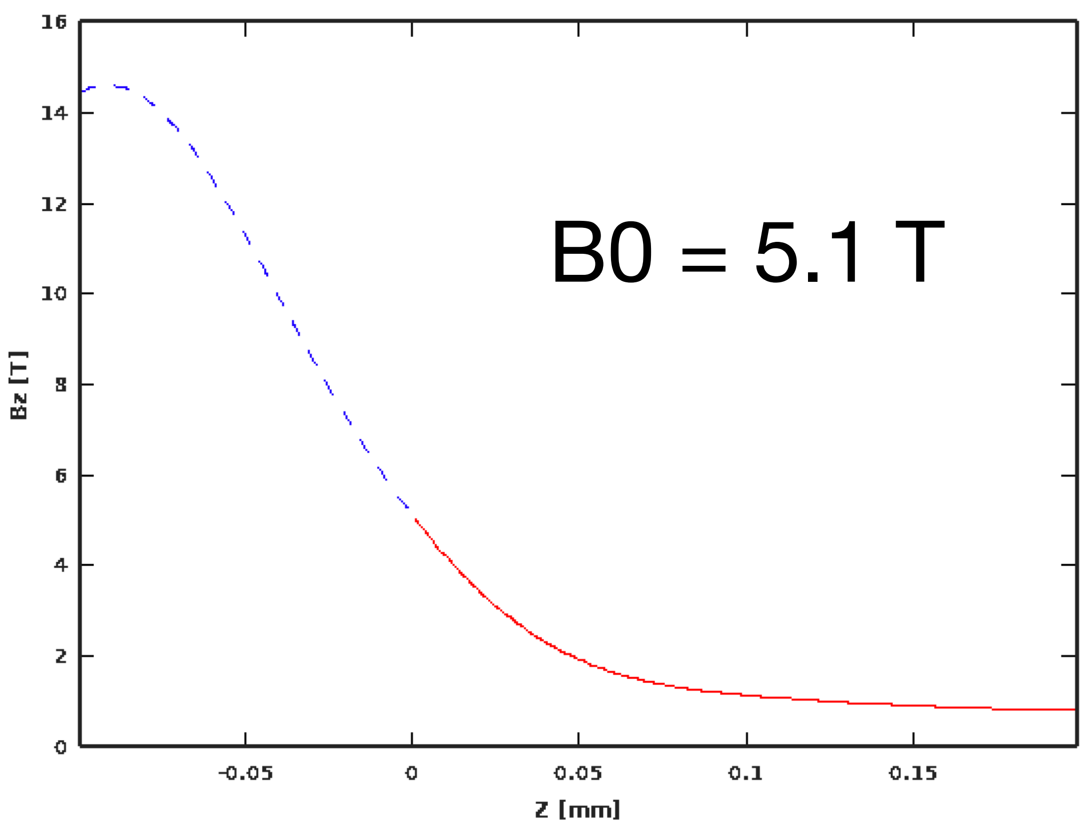
- Best yield: 4.9
- Much higher than using FC: 2.4
- More in IPAC'21 paper: WEPAB015

Latest field profiles

- Upstream only



- Upstream + downstream



Field maps provided by Jaap on 03/07/2021

- Upstream only profile has a higher effective peak field

Simulation results

- Accepted e+ yield comparison

AMD options	AMD profiles	B0 @ target exit [T]	Opt. spot size [mm]	Acc. yield	PEDD [J/g]
BINP FC (Pavel)	a = 8 mm	7	1.5	2.39	29.7
	a = 16 mm	5	1.4	2.38	31.9
Analytic SC	Optional	5	1.2	3.18	30.6
		6	1.1	3.57	30.9
		7	1.0	3.95	32.1
		8	1.0	4.24	29.9
		9	1.0	4.44	28.6
		10	1.0	4.60	27.6
		11	1.0	4.73	26.8
	Optimised	**12**	**1.0**	**4.88**	**26.0**
		13	1.0	4.92	25.8
PSI HTS (Jaap)	Up & Down streams	5.1	1.2	3.10	31.4
	Up stream only	6.3	1.1	3.27	33.8

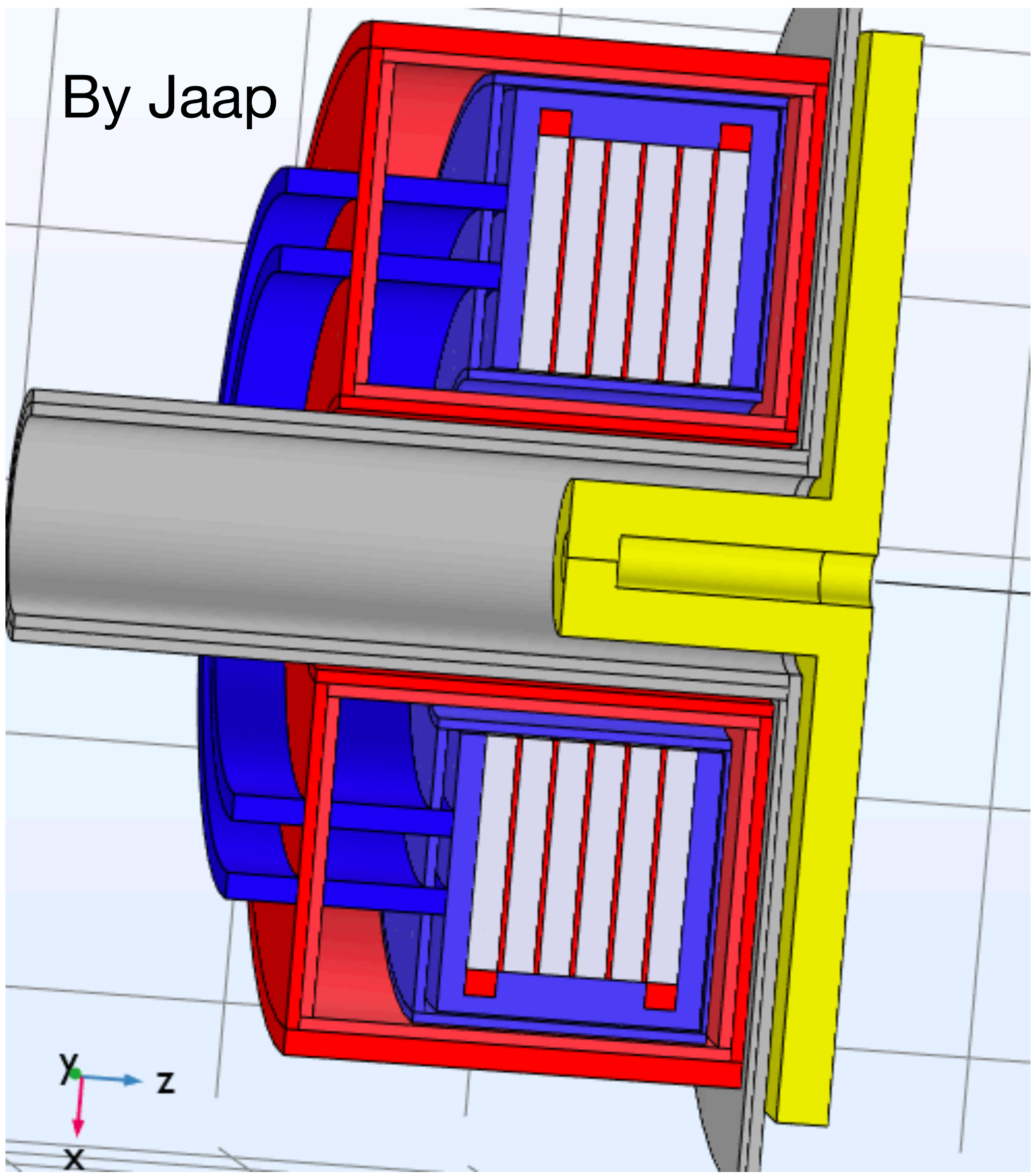
Config:
Electron energy: 6 G
Target profile: conventional, 5 X0
Capture linac: CLIC L-band TW, 0.5 T
E&time acceptance: ±3.8%, 9.33 mm (32° @ 2.856 GHz)

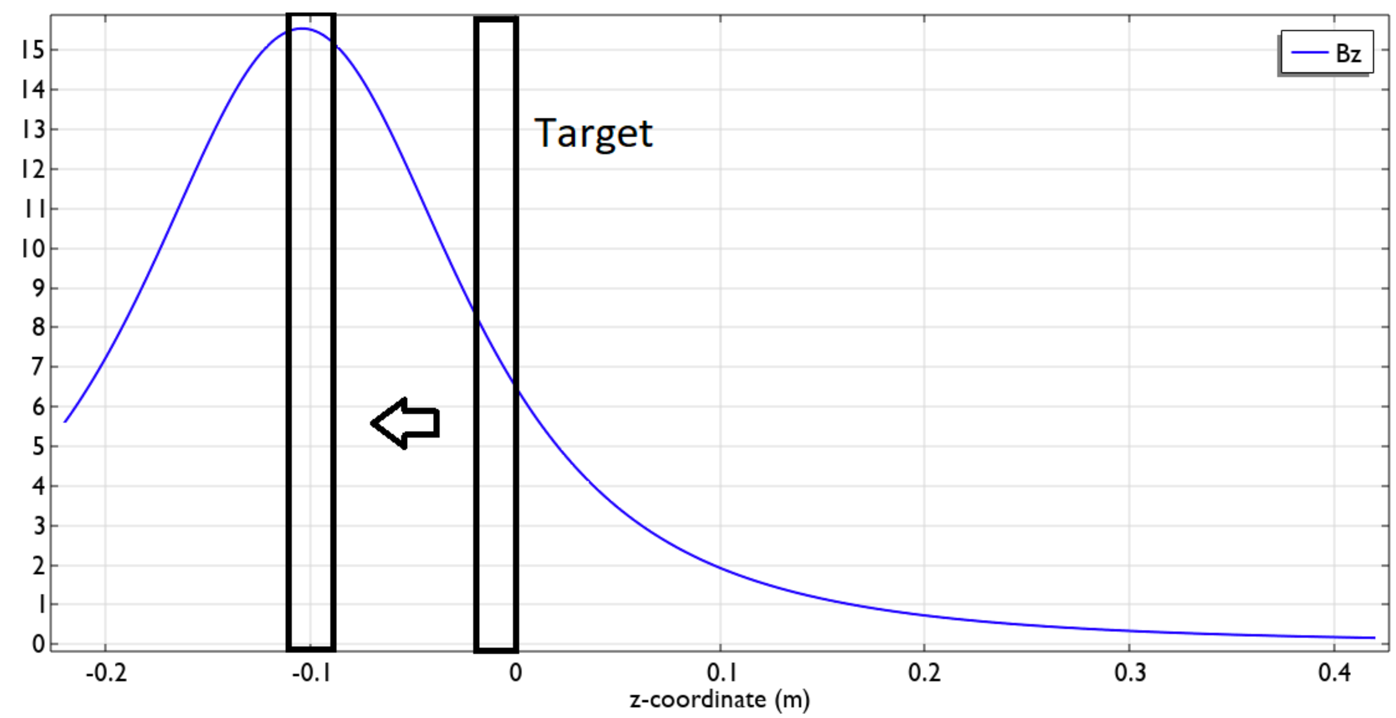
- Analytic and simulated results are comparable. Higher yield is achievable with high B0

Study based on field maps provided by Jaap on 03/07/2021

New ideas

- Jaap proposed to put target inside the upstream coils
  - to increase the effective peak field (B0)





Field maps provided by Jaap on 14/09/2021

(Small improvement w.r.t 03/07/2021)

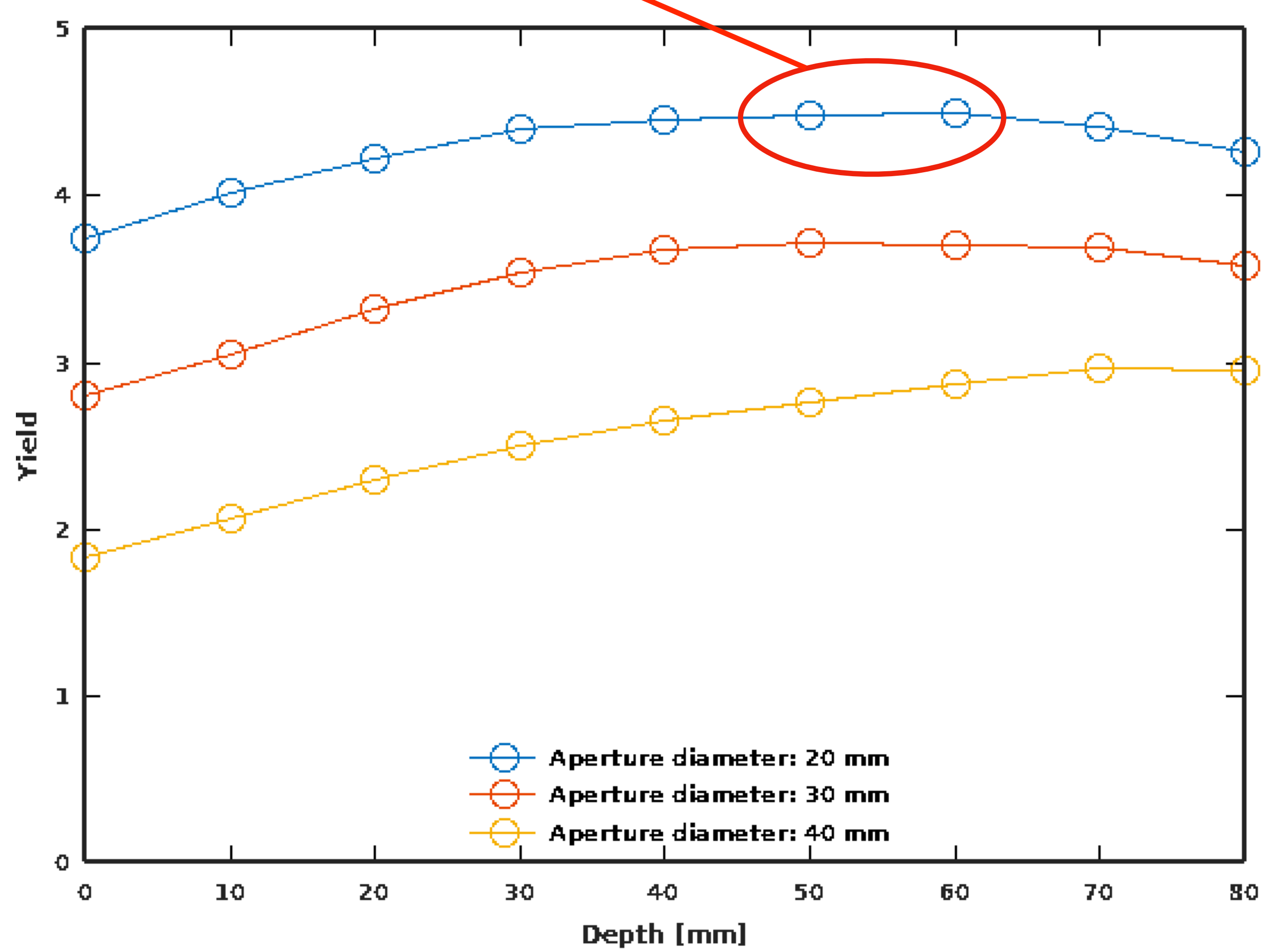
New ideas

- However, optimization is needed to achieve a compromise between:
  - Depth of target (exit face) in coils: the deeper the higher B0 is. Maximum B0 at 72 mm depth (Z = -90 mm in field map coordinate, since target thickness is 18 mm)
  - Aperture of coils: the larger the higher e+ collection efficiency is, but also B0 will be lower. Currently aperture is 20 mm diameter
- A quick scan was performed
  - Depth scan range: 0 - 80 mm (for scan over 80 mm, more completed field map is needed, but 80 mm depth already includes the peak field)
  - Aperture (diameter) scan range: 20 - 40 mm (to avoid boundary uncertainties, aperture can not be too small)
    - Field floated with aperture: $B_0 \propto 1/R^2$
    - e^- spot size fixed to 1.1 mm (spot size ↑, Yield ↓, PEDD ↓)
    - $\mathrm{PEDD} \propto 1/\mathrm{Yield}$ (for fixed e^- spot size)

Study based on field maps provided by Jaap on 03/07/2021

New ideas

- Optimized results:
  - Depth of target (exit face) in coils: 50-60 mm
  - Aperture of coils: 20 mm diameter (not changed)
  - B0 (at target exit): ~14-15 T
  - e^+ Yield: 4.5
  - e^- spot size: 1.1 mm
  - PEDD: 25 J/g

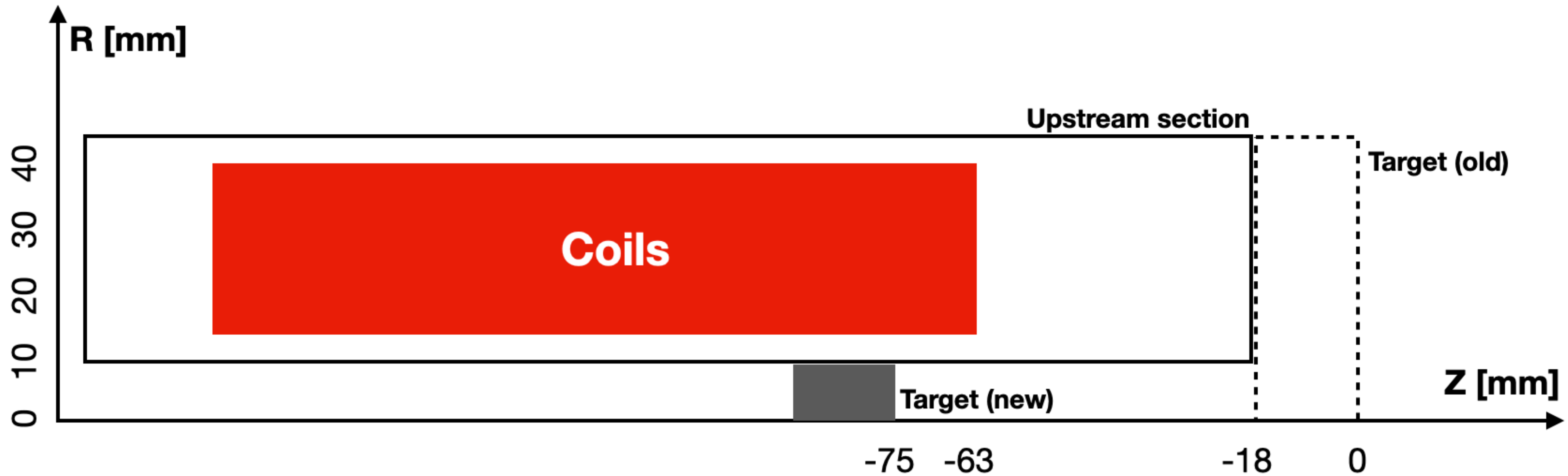


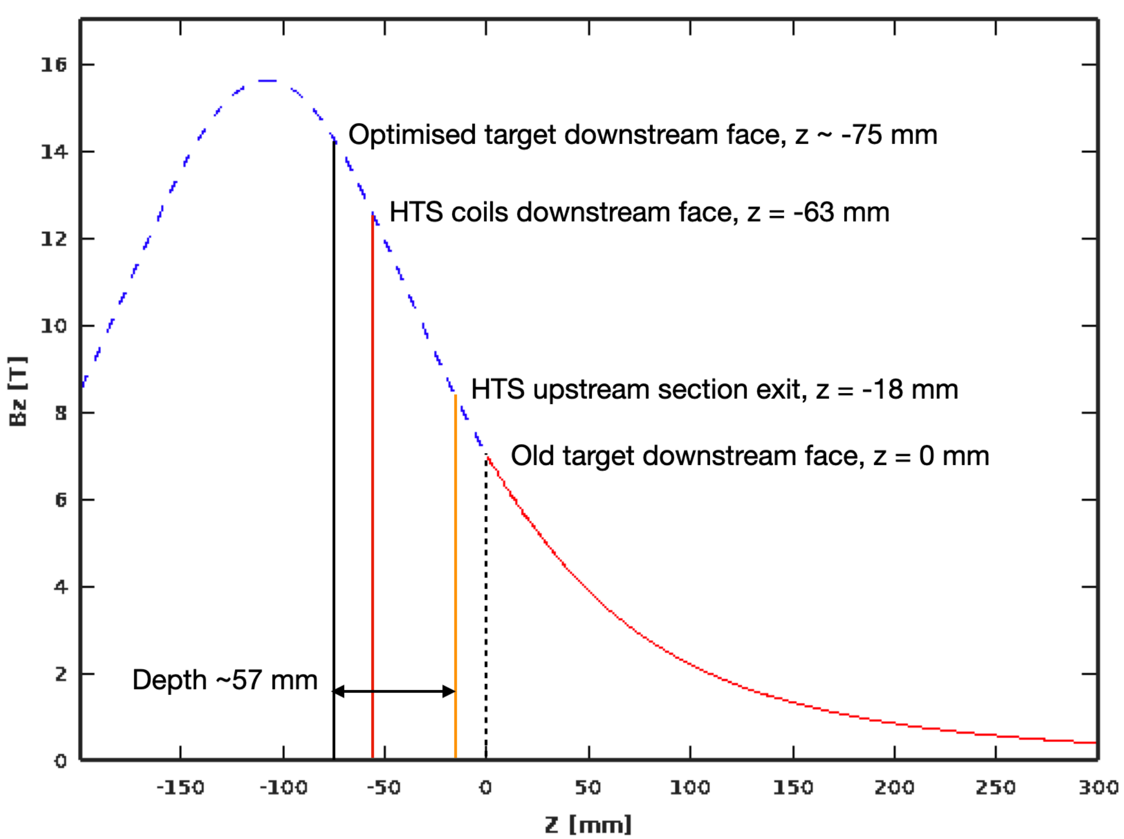
- NB: B0 is already at the plateau of the B0 scan with a maximum yield, so no need to go to smaller apertures

Study based on field maps provided by Jaap on 03/07/2021

New ideas

- Optimised HTS & target layout sketch



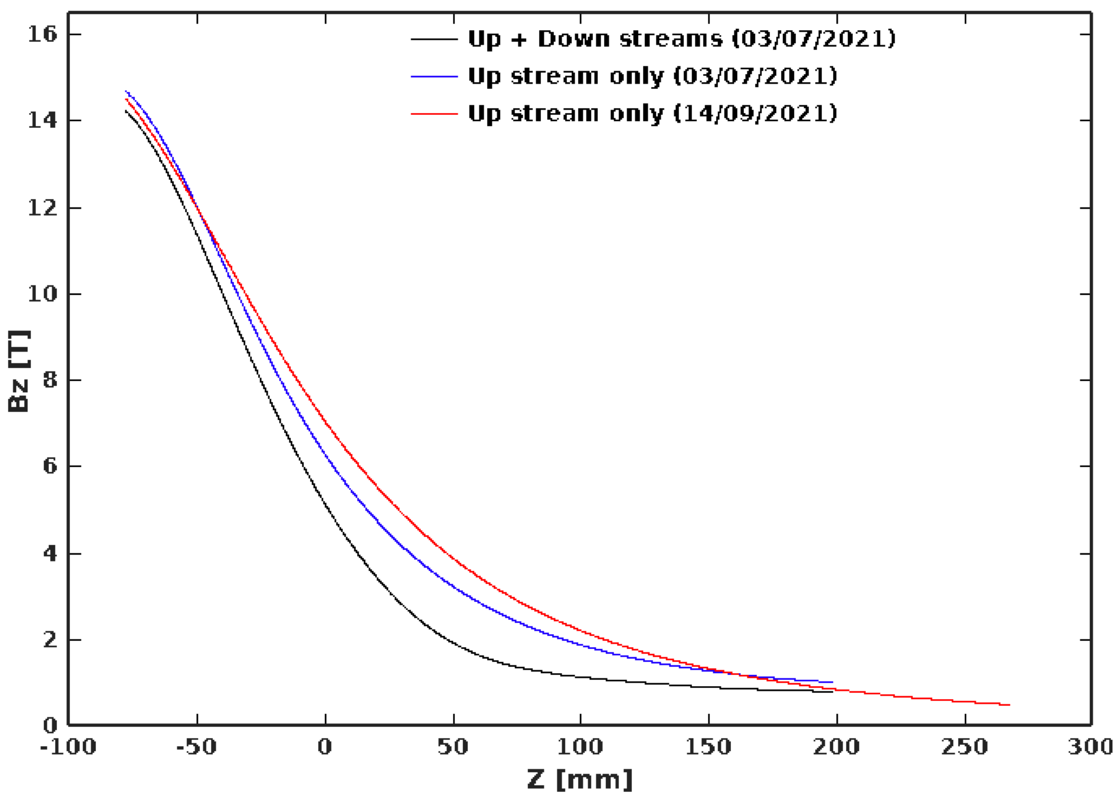


- **More details of the placement of target to be considered**

(Using latest field map provided on 14/09/2021)

Difference in yield due to field map update

- Field maps used in the simulation



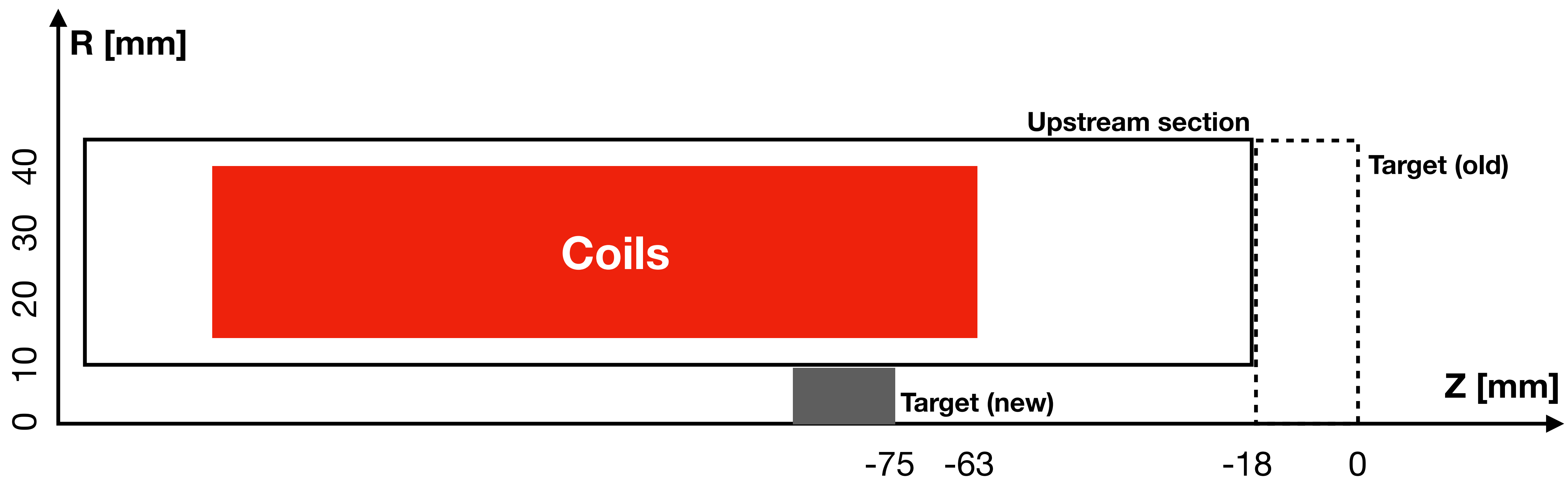
- **Difference in yield:**
  - Target depth 60 mm

Field map used	Bz_end	Z_start	Z_end	Yield
Up + Down (03/07/2021)	0.8 T	-78 mm	199 mm	4.5
Up only (03/07/2021)	1.0 T		199 mm	**4.5**
Up only (14/09/2021)	1.0 T		182 mm	4.1
	0.8 T		208 mm	4.1
	0.5 T		268 mm	**3.8**

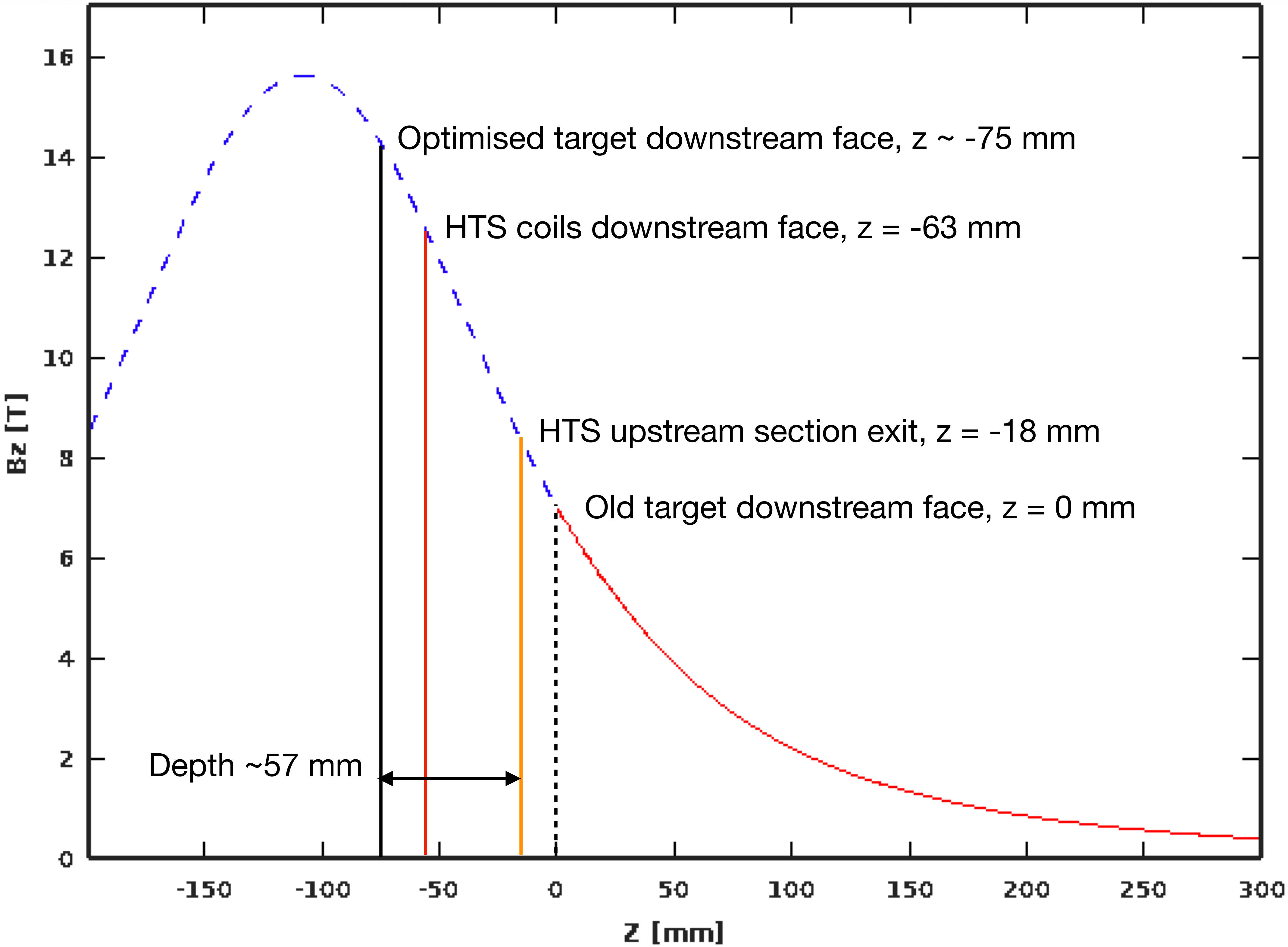
- **Field is improved, but yield is lower. To be investigated**

BACKUP

Plot draft


R [mm]
0 10 20 30 40
Upstream section
Coils
Target (old)
Target (new)
Z [mm]
-75 -63 -18 0

Plot draft



Optimised target downstream face, z ~ -75 mm
HTS coils downstream face, z = -63 mm
HTS upstream section exit, z = -18 mm
Old target downstream face, z = 0 mm
Depth ~57 mm
16
14
12
10
8
6
4
2
0
Bz [T]
-150
-100
-50
0
50
100
150
200
250
300
z [mm]