Progress in the design of the linacs and electron sources for the FCC-ee injector complex

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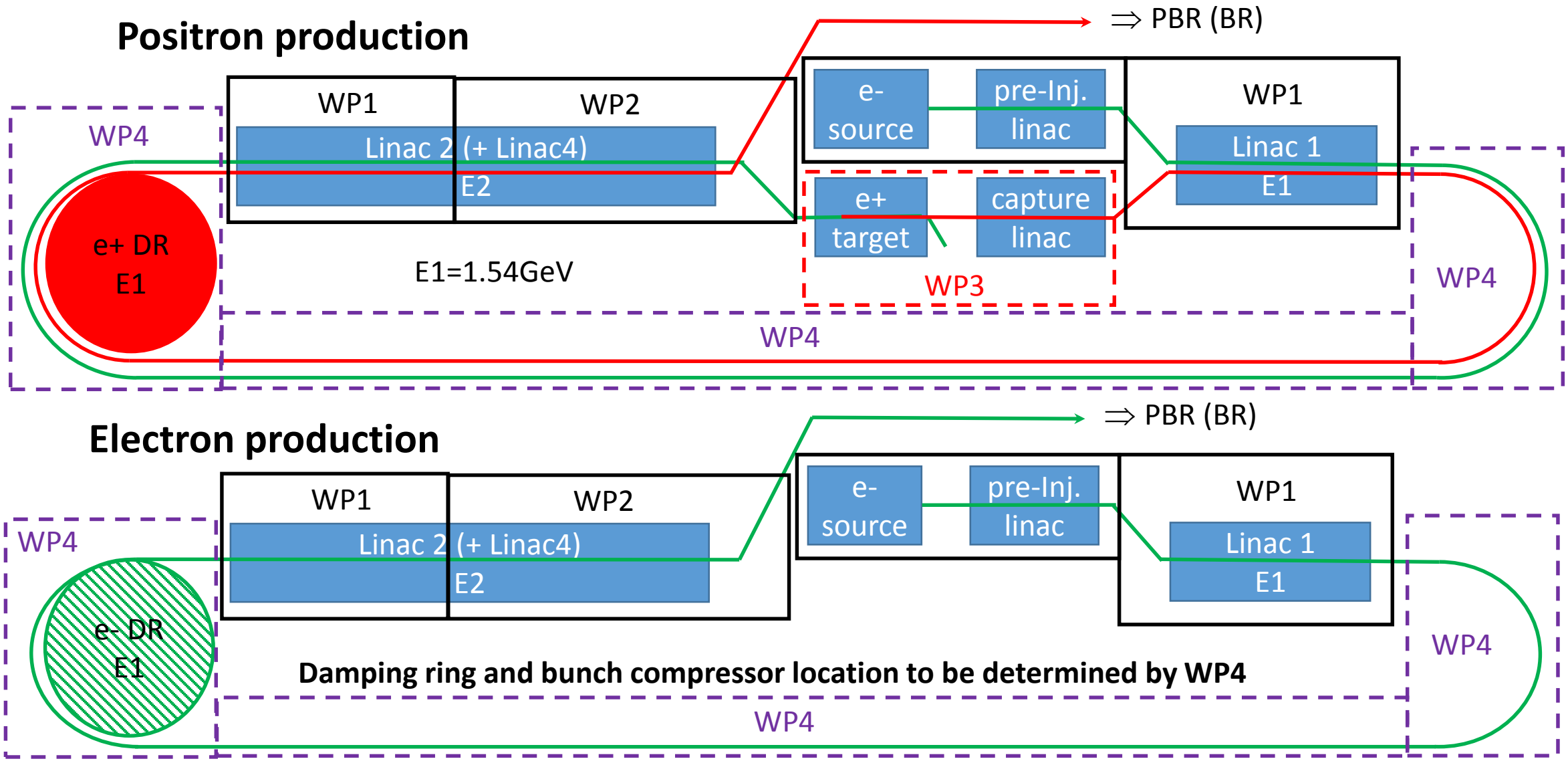
Outline

- Layout
- Parameter specifications
- Electron source and pre-injector
- RF design of the linacs
- Beam dynamics in the linacs
- RF power sources and RF unit
- Next steps
- Summary

Layout of the injector 6(20) GeV and WPs



Specification of the **nominal** beam parameters at injection into the rings: PBR or BR (from rings)

parameter	Baseline	Alternative	Comments
Ring for injection	PBR	BR	Destination
Injection energy [GeV]	6	20	Fixed
Bunch population [1e10]	2.1	2.1	Nominal
Number of bunches	2	2	
Bunch spacing [ns]	15, (17.5, 20)	15, (17.5, 20)	To be defined
Normalized transverse emittances (RMS): γε_x,y [um]	**50, 50**	**50, 8**	**Vertical acceptance of BR**
Bunch length (RMS) [mm]	~1	~1	<10 ring acceptance
Energy spread (RMS) [%]	~0.1	~0.1	

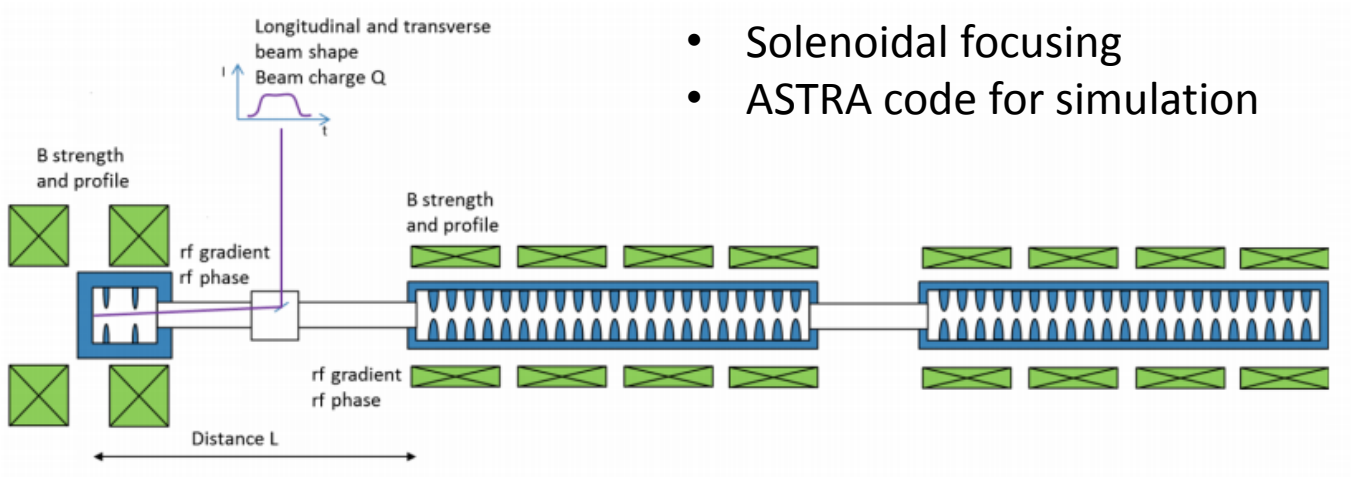
Specification of the **driver** e-beam parameters for the positron production (from WP3, preliminary)

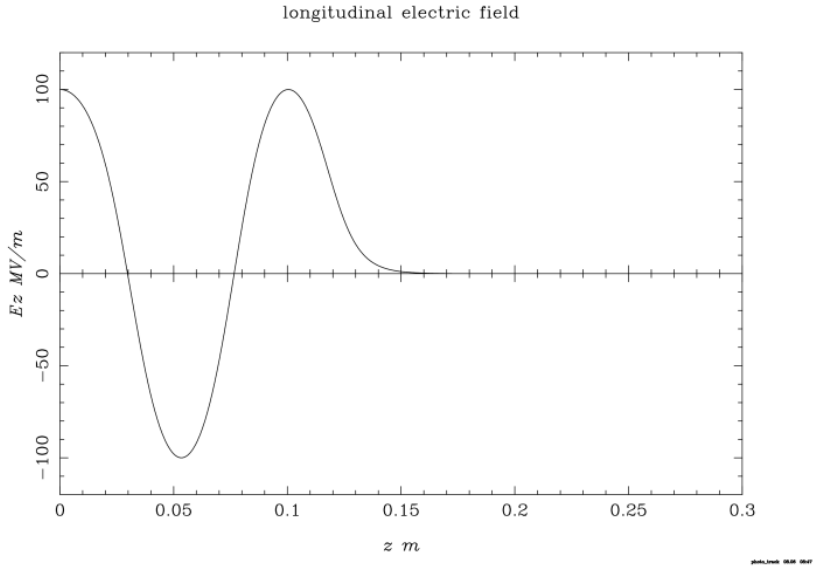
parameter	Baseline	Alternative	Comments
Energy [GeV]	6	20	
Bunch population [1e10]	**~3**	**~1**	
Number of bunches	2	2	
Bunch spacing [ns]	15, (17.5, 20)	15, (17.5, 20)	Same as nominal beams
Normalized transverse emittances (RMS): $\gamma\varepsilon_{x,y}$ [um]	few 100	few 100	< 1000
Bunch length (RMS) [mm]	1-2	1-2	
Energy spread (RMS) [%]	few 0.1	few 0.1	< 1

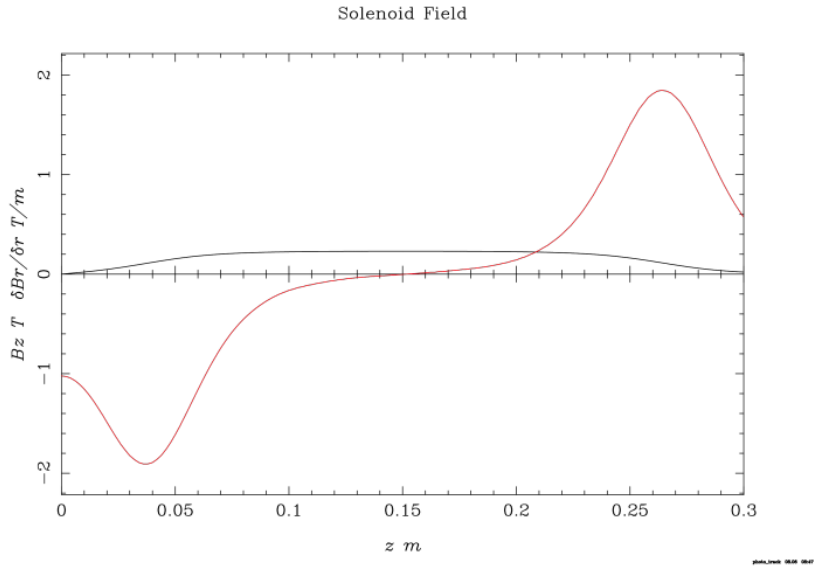
Optimization of electron source and pre-injector

Beam line configuration

- 2.5 cell RF photo gun
- 2 S-band structures
- Solenoidal focusing
- ASTRA code for simulation

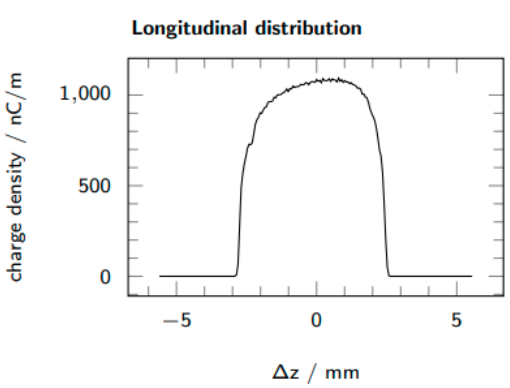


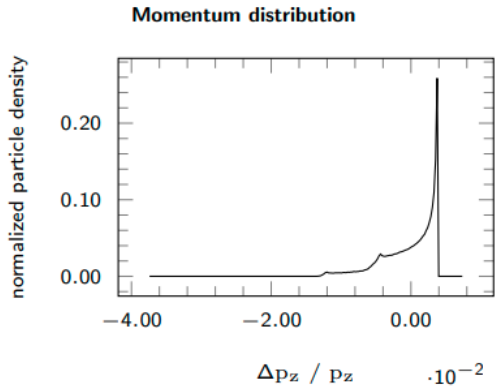


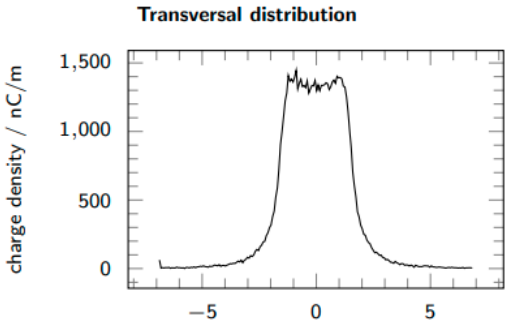


Optimization: 5 nC bunch (work in progress)

- ‘Plateau’ laser spot (optimistic)

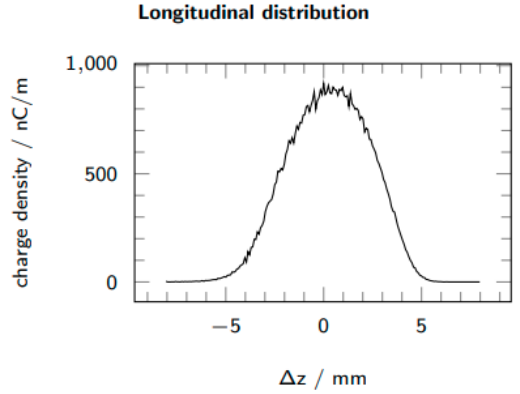


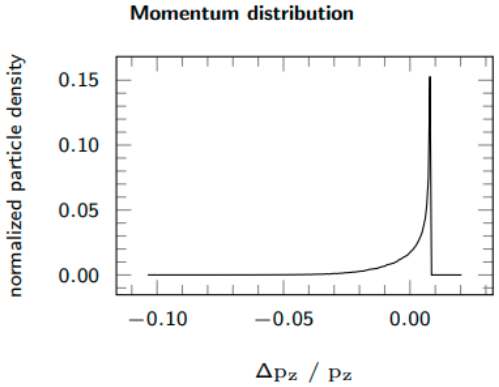


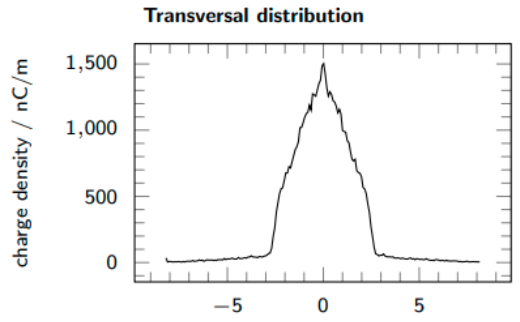


Transversal emittance	2.96 mrad mm
Energy spread	760 keV
Average energy	202 MeV
Beam size	1.38 mm
Bunch length	1.40 mm

- Gaussian laser spot (pessimistic)





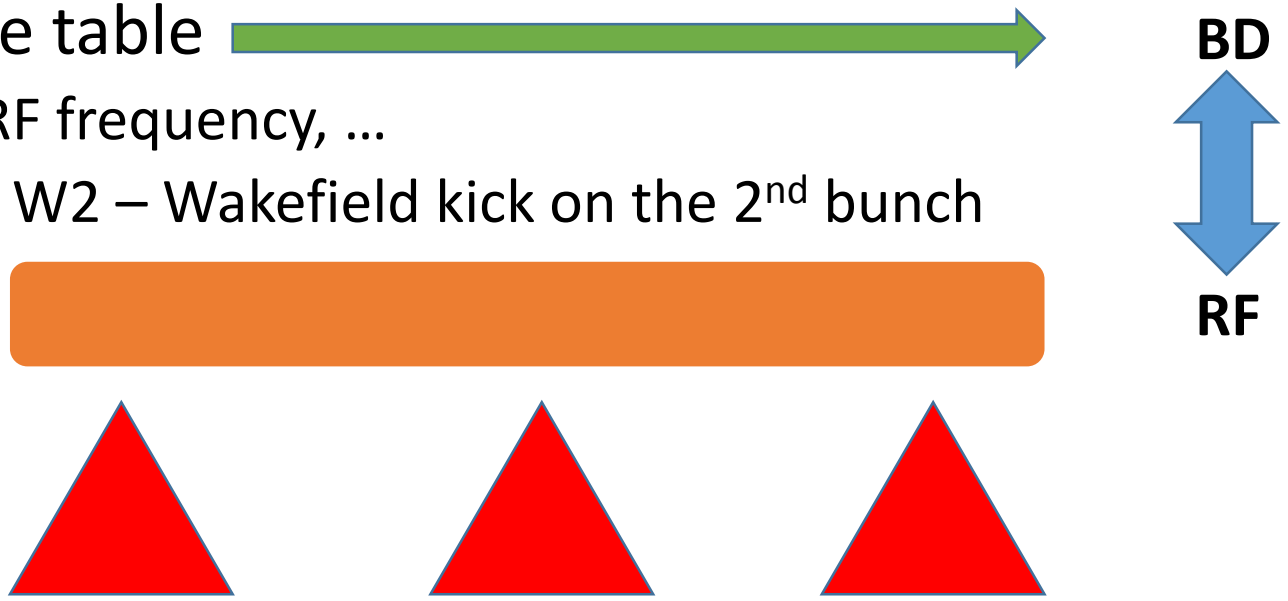


Transversal emittance	12.3 mrad mm
Energy spread	1810 keV
Average energy	186 MeV
Beam size	1.12 mm
Bunch length	1.95 mm

Strong impact of the laser spot shape on the output beam parameters

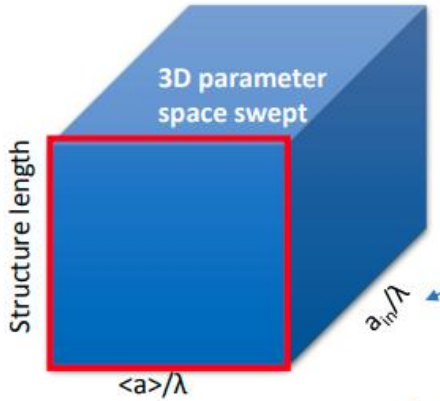
Interface between RF and BD in the linacs

- Beam: parameters from the table
  - <G> - average gradient, f - RF frequency, …
  - => <a> - average iris radius; W2 – Wakefield kick on the 2nd bunch
- Linac: RF design: PC+AS
  - P_kl, t_kl, for given f
- RF power sources

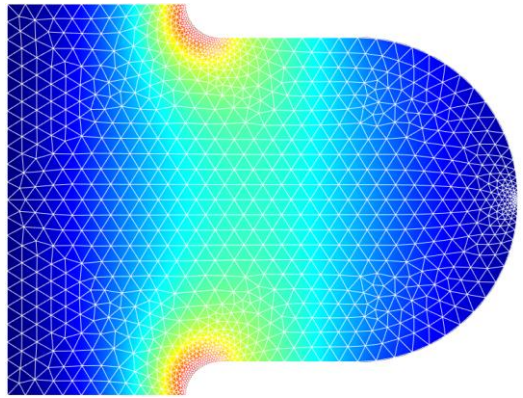


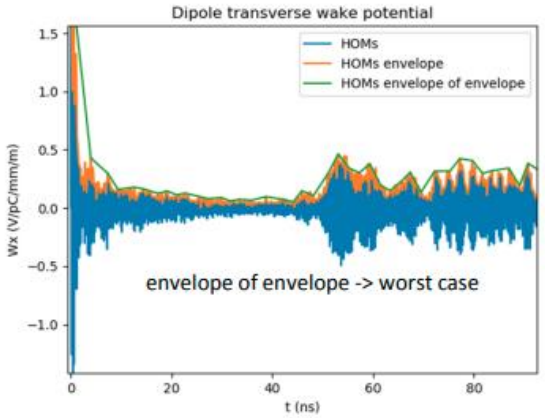
Tools for linacs RF design and optimization

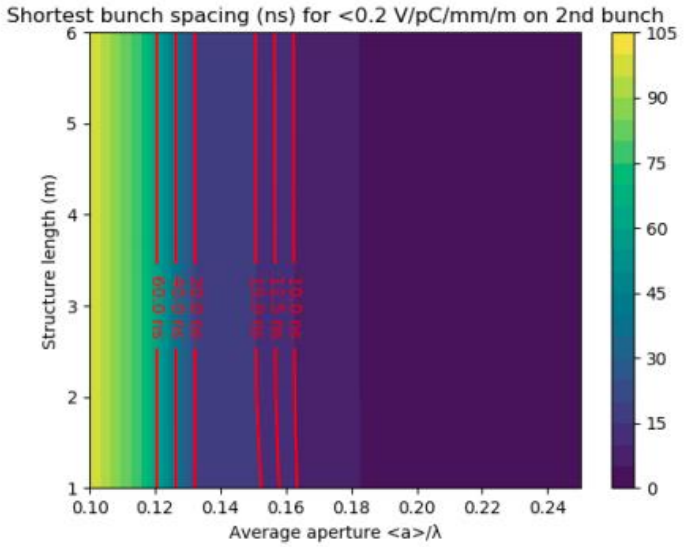
Structures investigated: 3 GHz, <G> = 25 MV/m, ψ = 120°, 150°
Linear tapering defined by 3 parameters: structure length, average aperture <a>, input aperture a_{in} (where $a_{out} = 2\langle a\rangle - a_{in}$, iris thickness constant 3 mm)

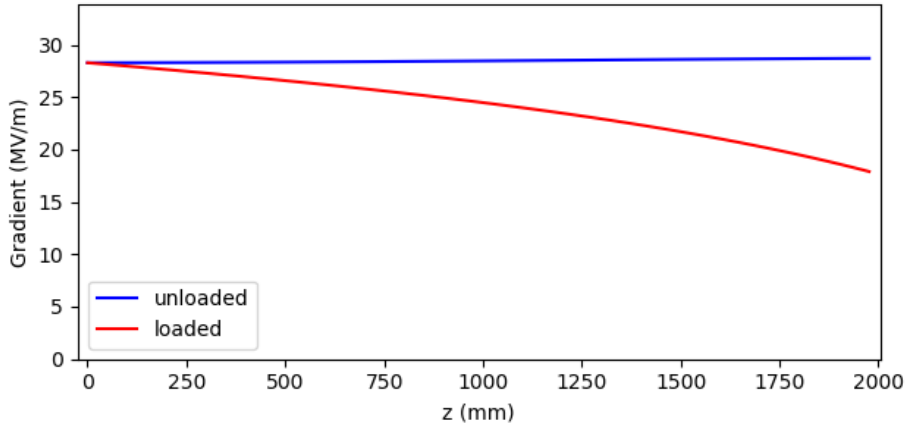


reduce this axis by selecting a_{in} that gives shortest bunch spacing, such that kick on 2nd bunch < 0.2 V/pC/mm/m





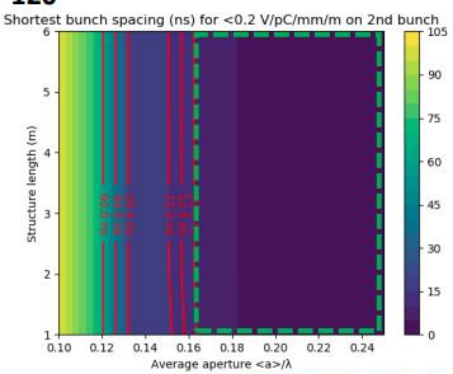


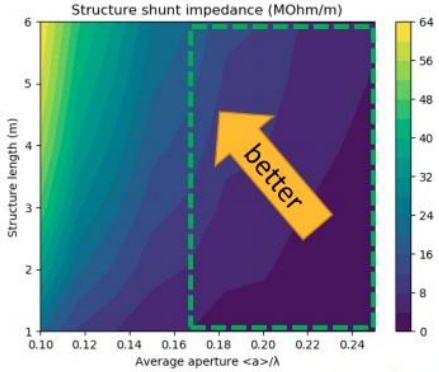


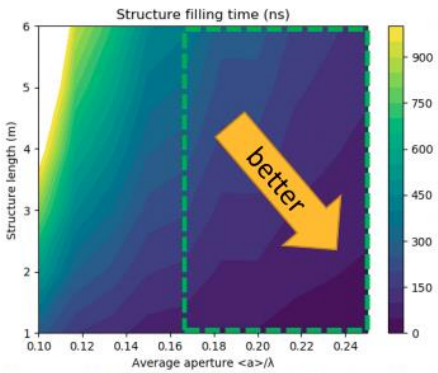
Preliminary RF design studies of Linac 1

120° vs. 150°, trade-offs

120°



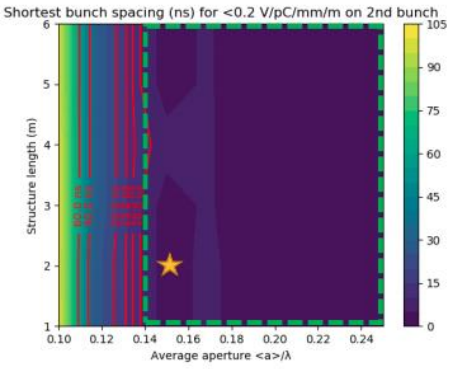


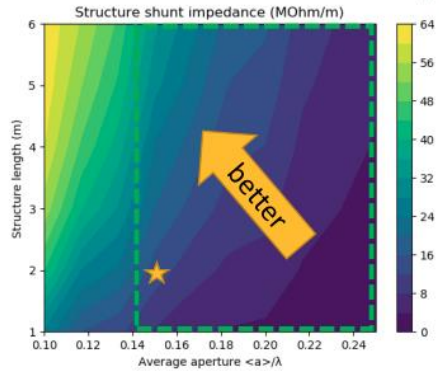


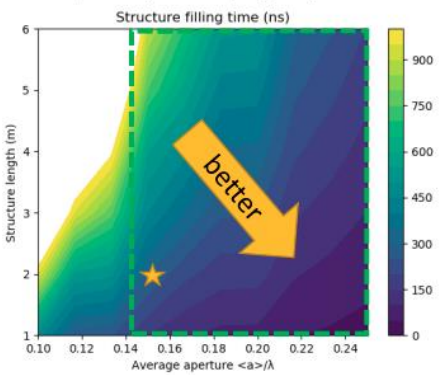
fulfill Wx < 0.2 V/pC/mm/m on 2nd bunch at 10 ns

trade-off between filling time and shunt impedance, optimum to be found w.r.t. pulse-compression system (work in progress)

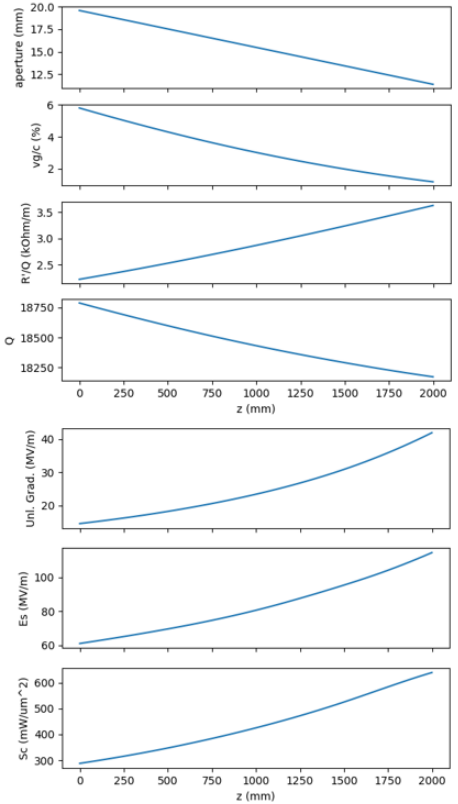
150°



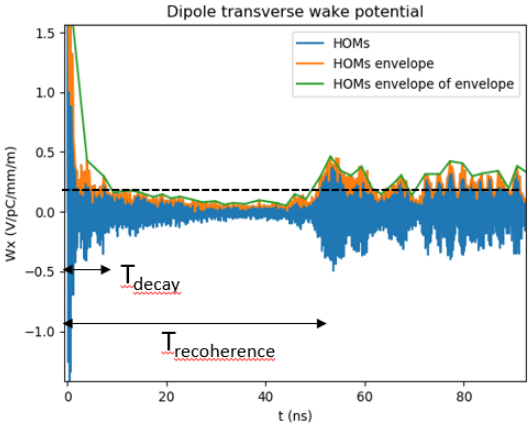




★ 150° Example structure



Frequency	3 GHz
Phase advance	5π/6 = 150°
Length	2 m (60 cells)
Avg. aperture	15 mm (0.15 λ)
Avg. gradient	25 MV/m
Max. Es	115 MV/m
Max. Sc	640 mW/um²
Filling time	300 ns
Input power	88.2 MW (44.1 MW/m)
Shunt impedance (R = G²L/P)	14 MΩ/m



Preliminary BD studies for Linac 1

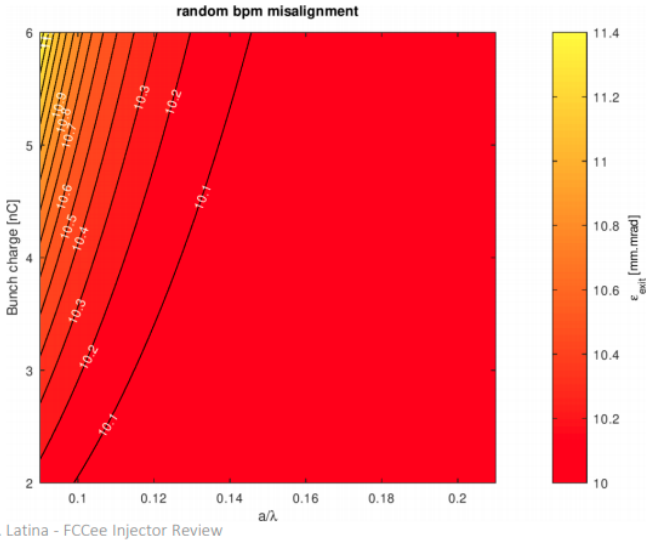
Linac 1: single-bunch

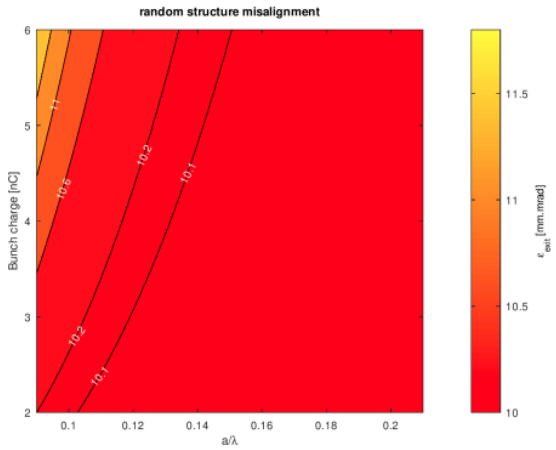
% Bunch
Ei = 200 MeV
Ef = 1.54 GeV
Norm. emitt = 10 um
bunch length = 1 mm

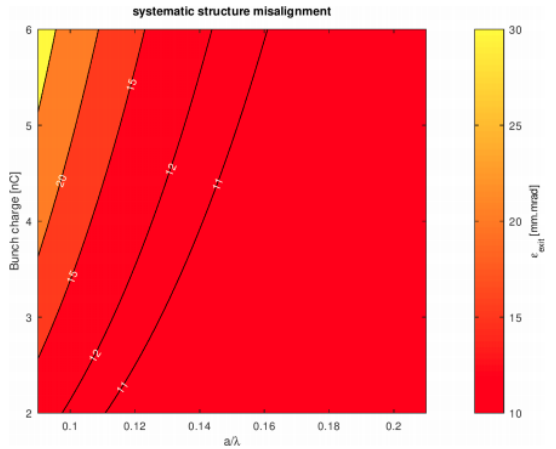
% RF
frequency = 2.9985 GHz
Gradient = 18 MV/m
Lstructure = 1.25 m
a/λ = 0.2 mm

% FODO lattice
Nb of structures between quads = 4
Average beta = 8.3 m
Ph advance = 90 deg

% misalignment
Structures = 100 um rms
Bpms = 30 um rms







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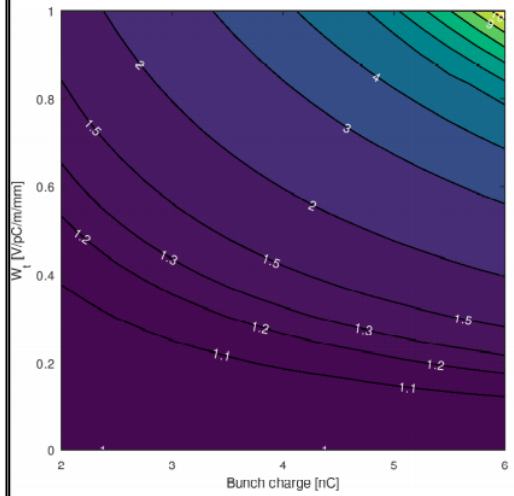
Linac 1: multi-bunch effects

% Bunch
Ei = 200 MeV
Ef = 1.540 GeV
Norm. emitt = 10 um

% RF
frequency = 2.9985 GHz
Gradient = 18 MV/m
Lstructure – 1.25 m

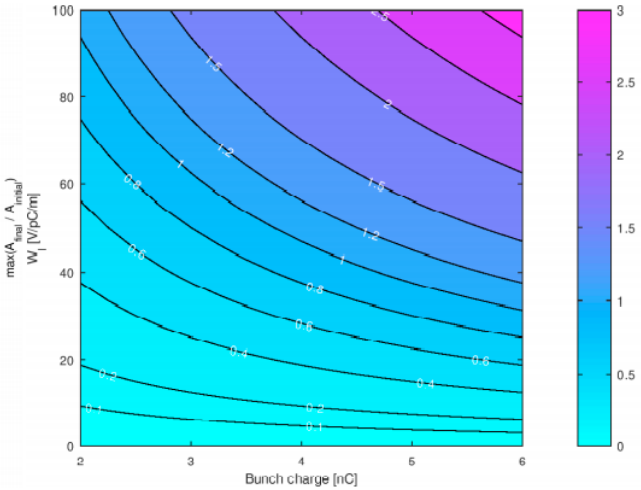
% FODO lattice
Nb of structures between quads = 4
Average beta = 6.6 m
Ph advance – 90 deg

Beam jitter



10% sigma jitter rms

Beam loading



dQ/Q = 1% rms

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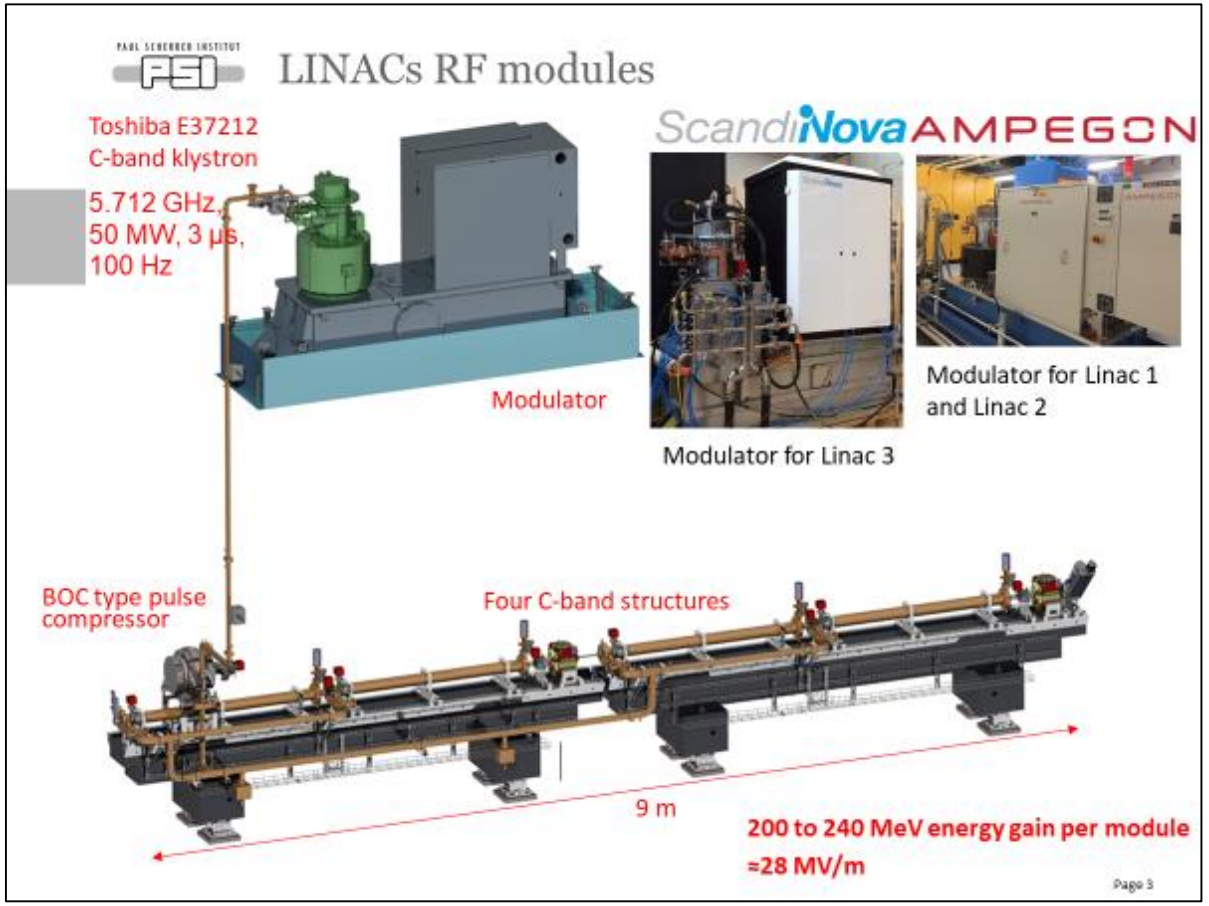
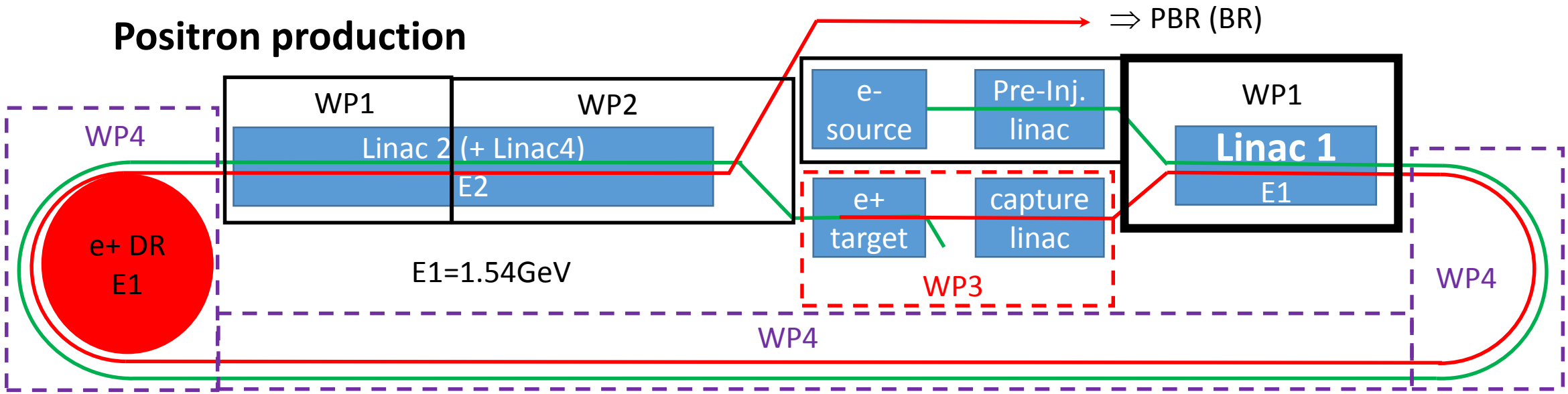
RF power source and RF unit considerations

- Review of possible RF module layouts
- In depth analysis of commercial RF power sources in L-, S- and C-band range for FCCee injector linacs (input for RF design)
- Evaluation of possible cost models for linac optimization

Example of RF unit: SwissFEL RF module



Next steps: Linac 1 design for positrons



- Start with the design of Linac 1 for the case of positron beam
- This is probably most critical linac accelerating large positron beam
- It interfaces two other WPs:
  - WP3. Positron production
  - WP4. Damping ring and Transfer lines

Specification of the positron beam parameters for the design of Linac 1 (from WP3, preliminary)

parameter	L1 input	L2 output	Comments
Energy [GeV]	0.2	1.54	
Bunch population [1e10]	**~4**	**~3**	< 4.2 = 2 x 2.1, depends on the loss location
Number of bunches	2	2	
Bunch spacing [ns]	15, (17.5, 20)	15, (17.5, 20)	tbd
Normalized transverse emittances (RMS): γε_x,y [um]	**~8000**	**~8000**	
Bunch length (RMS) [mm]	**~3**	**~3**	
Energy spread (RMS) [%]	**~8**	**~8**	DR energy acceptance

Summary

- Specification of the preliminary design parameters has been done together with the other WPs
- Adequate tools for RF and BD simulations have been identified and/or developed
- Linac design and optimization work can start now
- Linac 1 has been identified as a starting point for the design and optimization studies, which will begin soon after BD postdoc will join WP1
- Electron source based on photo-cathode RF gun looks promising to meet FCC-ee injector requirements