Positron bunch and energy compressor for the Pre-Injector-Complex of FCC-ee

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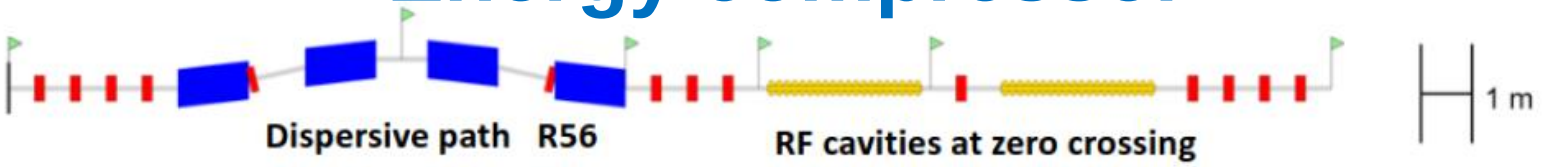
FCC Week 2024

11/06/2024

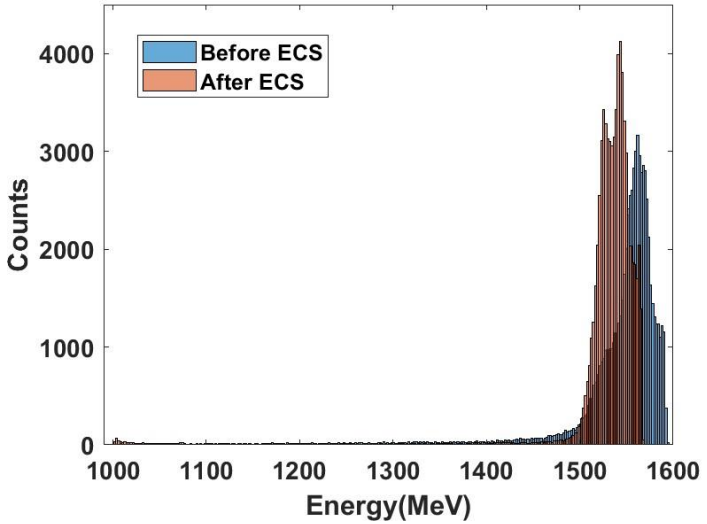
Energy compressor



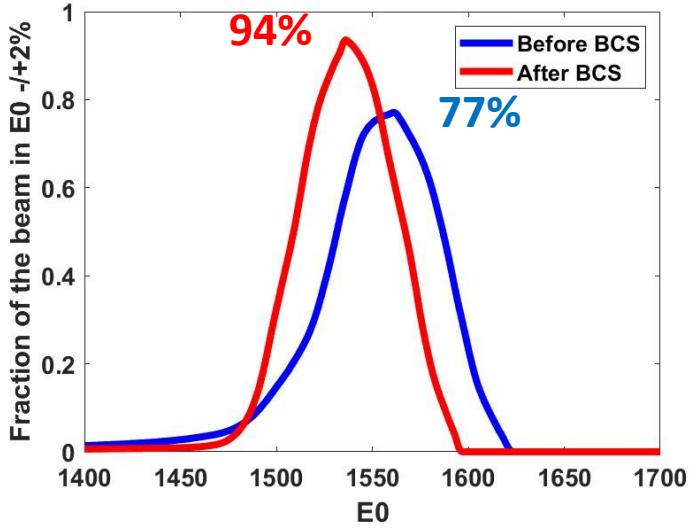
- The aim of the energy compressor is to maximize the number of particles accepted in energy by the DR (1.54 -/+ 2%)
- A four-bending C-shape chicane. Dispersion and second order dispersion closed by symmetry.
- Two cavities of the type used for the positron LINAC **(LINAC 2022) THPOJO08)**
- Distribution at the end of the pLINAC provided by M. Schaer. Simulations of ECS system with ELEGANT

Parameter	Value	Unit
Bending angle	0.2256 (12.9)	Rad (deg)
Dipole magnetic length	1.385	m
Dipole magnetic field	0.8298	T
Distance between magnets	1.03	m
R56	0.205	m
Max dispersion	0.56	m
Number of cavity	2	
RF frequency	2	GHz
Accelerating voltage	99	MV

Energy distribution

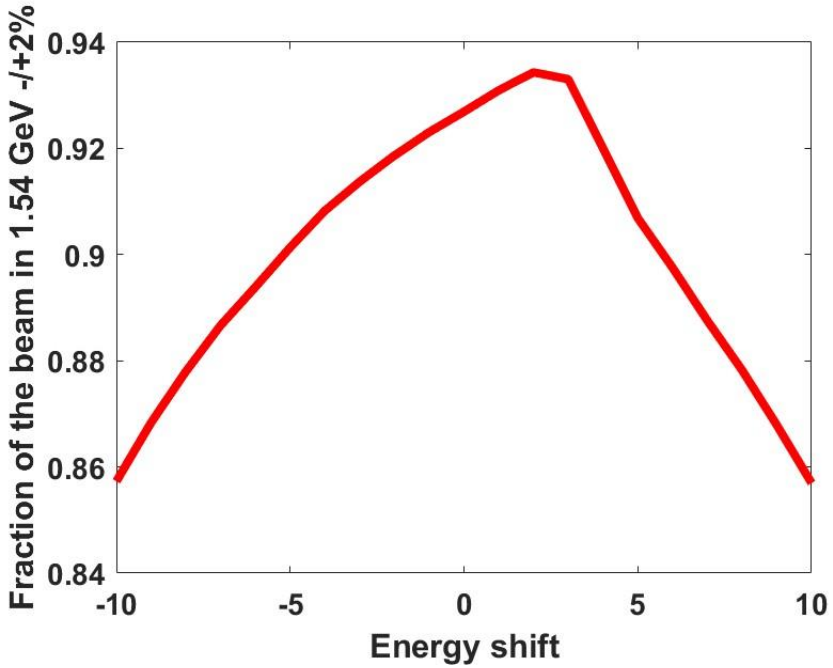


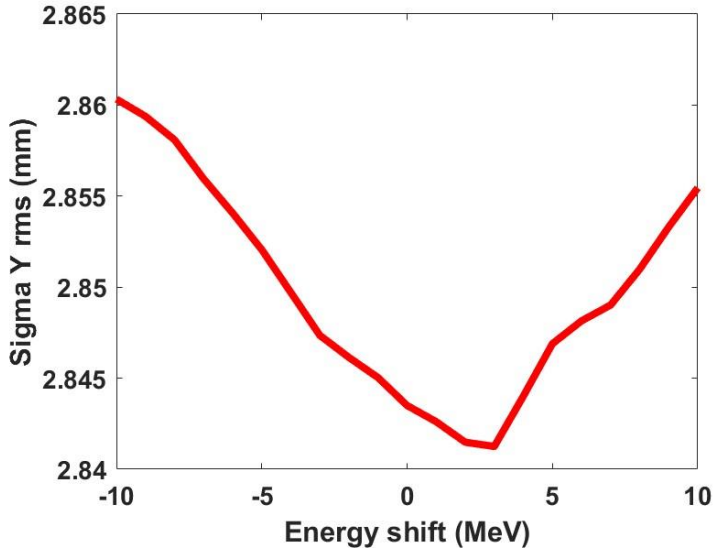
Beam fraction in E0-/+2%

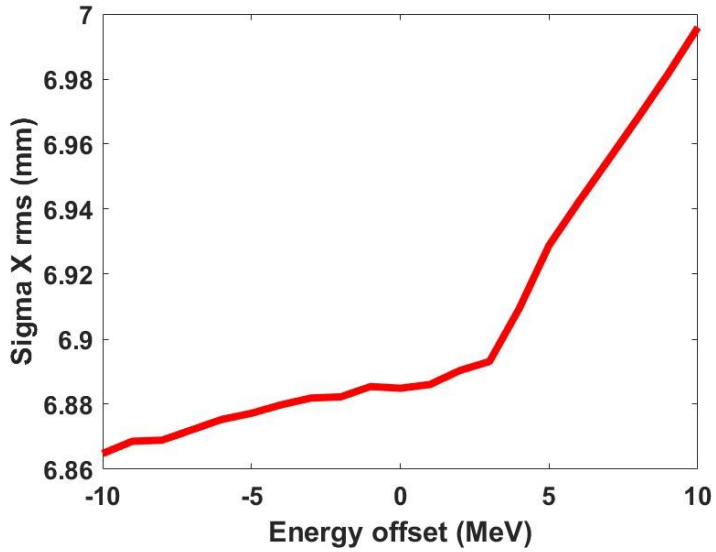


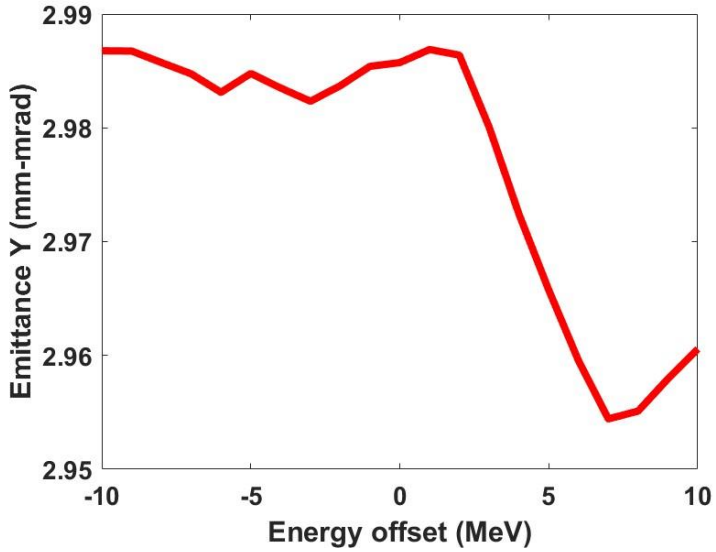
Tolerance on E0

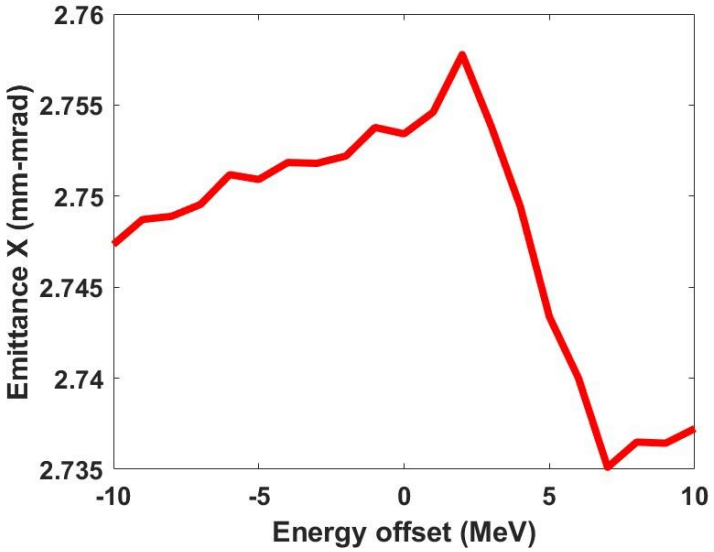
- Distribution at the end of the pLINAC provided by M. Schaer
- Rigid shift applied



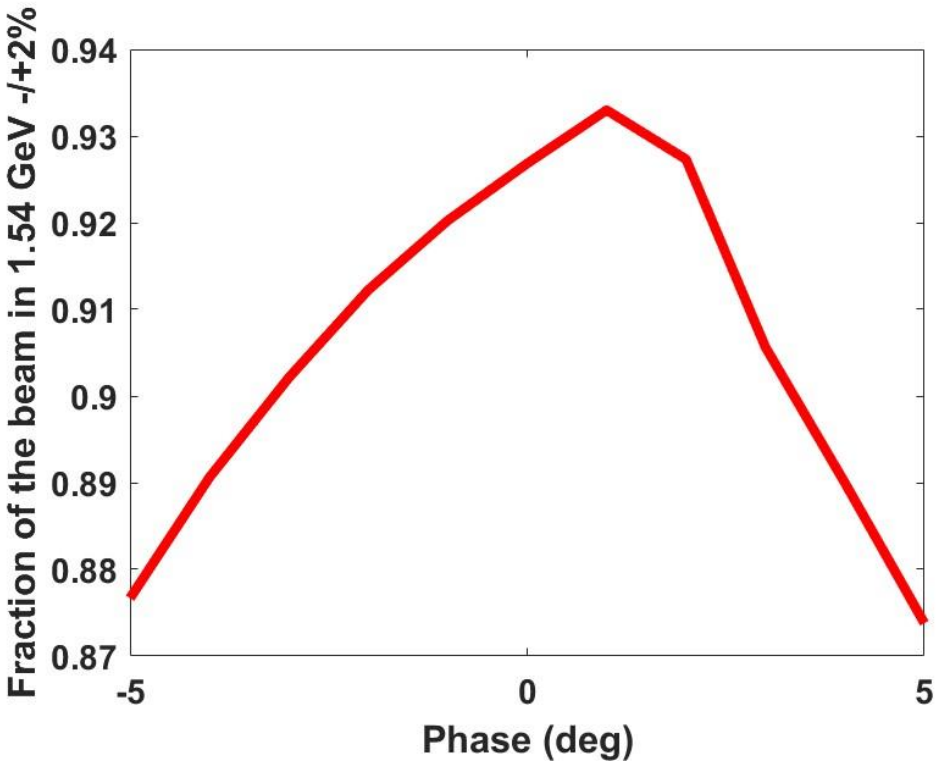


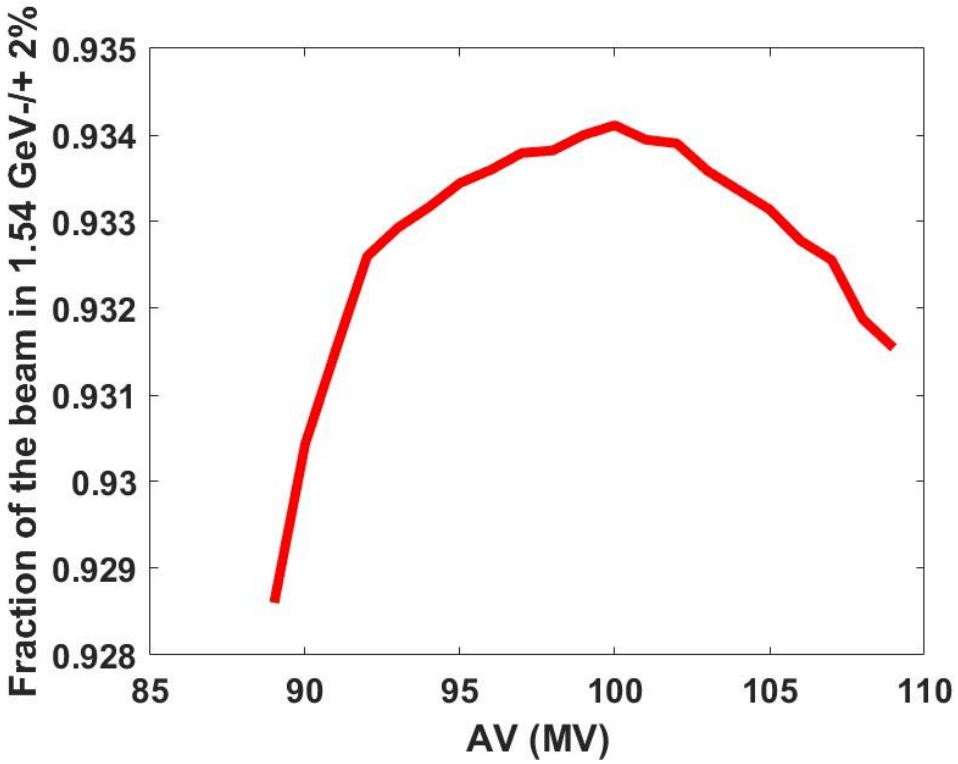






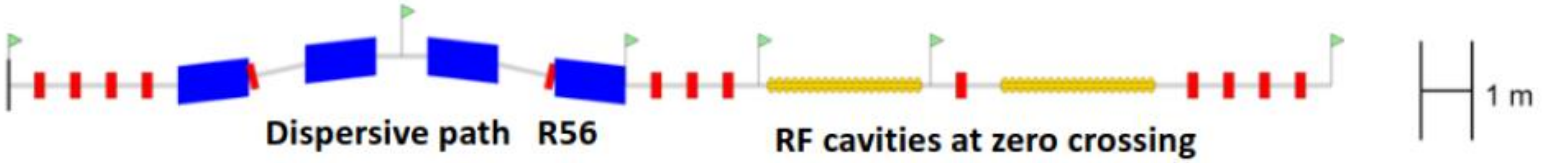
Tolerance on RF





- **Tolerance of Amplitude and phase variation are relaxed**

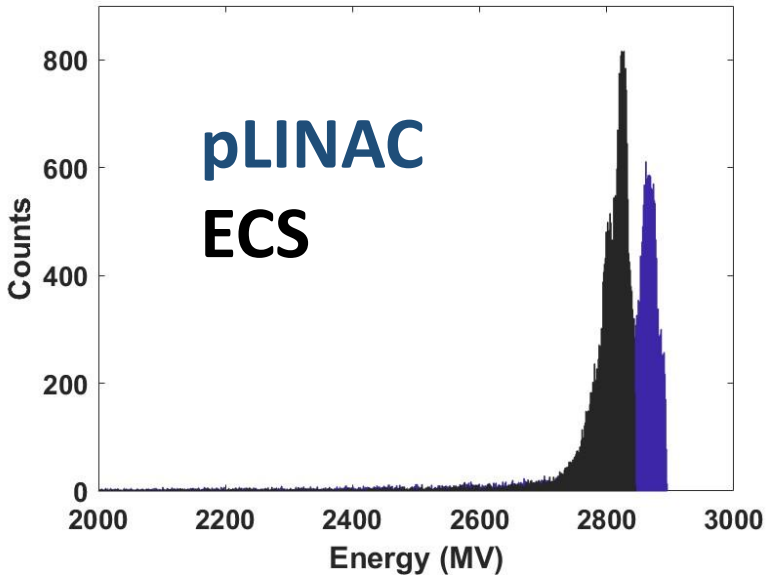
Energy compressor at 2.86 GeV



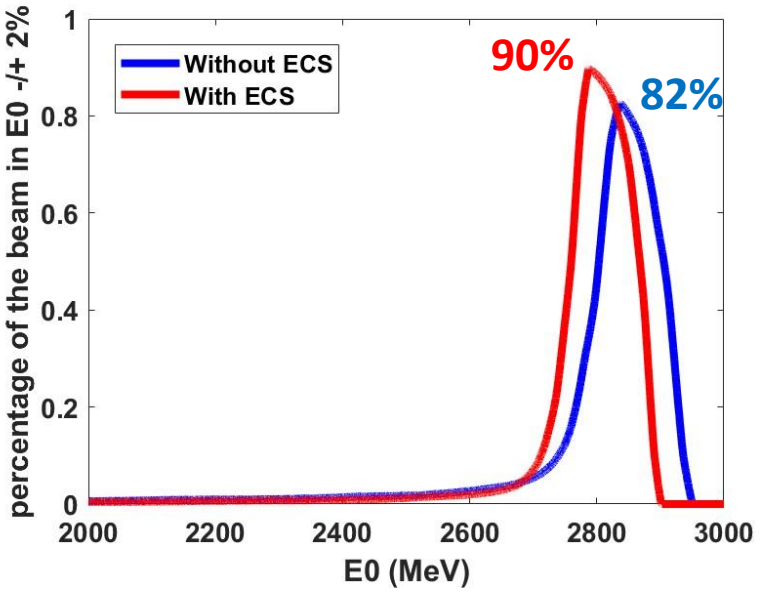
- Distribution at the end of the pLINAC provided by Yongke Zhao
- Thaking the same design requires increasing the accelerating voltage to 120MV and the magnetic field to 1.54T
- Longer dipoles or two chicanes to reduce the magnetic field required and increase R56

Parameter	Value	Unit
Bending angle	0.2256 (12.9)	Rad (deg)
Dipole magnetic length	1.385	m
Dipole magnetic field	1.54	T
Distance between magnets	1.03	m
R56	0.205	m
Max dispersion	0.56	m
Number of cavity	2	
RF frequency	2	GHz
Accelerating voltage	120	MV

Energy distribution



Beam fraction in E0-/+2%



BC purposes and constrains

Beam distribution after the damping

- Equilibrium zero current bunch length 2.9mm (4MV)
- **Expected bunch length <5mm**
- Equilibrium zero current bunch energy spread 0.07%
- **Expected Bunch energy spread ≈0.1%**

Beam distribution at the common LINAC

- Bunch length ≈1mm
- Relative bunch energy spread < 0.65% at 1541MeV

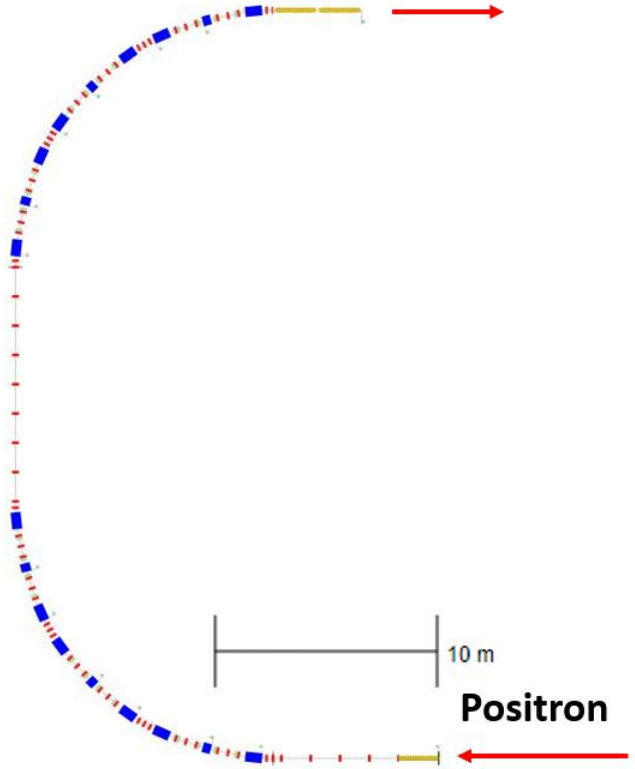
Bunch compressor requirements

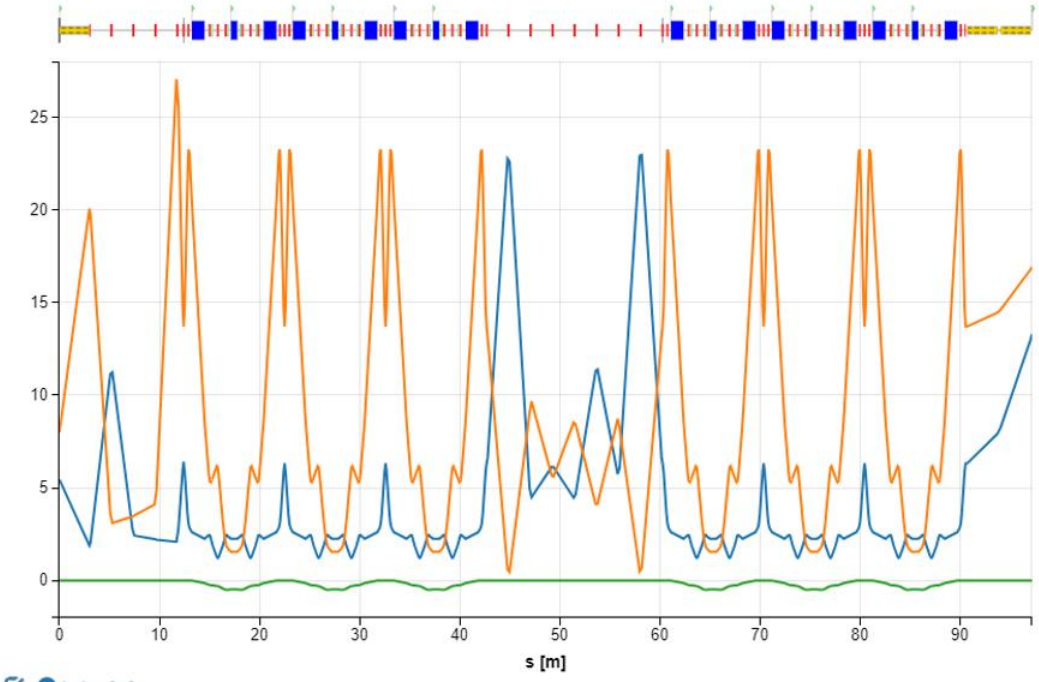
- Compressor factor 1-5 variable
- Final relative at energy spread after bunch compressor at 1541MeV <0.65%
- **Preserve transverse emittance.**

Positron bunch compressor

- Six cells
- Total R56 =0.40m
- π horizontal phase advance between cell 3 and 4, small H in the cells
- Sextupoles in the cells: second order disersion compensation and phase space linearization. Sextupole geometric strength K2=-12.647 m^{-3}
- One cavity to chirp the beam. Accelerating voltage 54 MV
- Two cavities to remove part of the chirp. Accelerating voltage 110 MV

π phase advance (x)

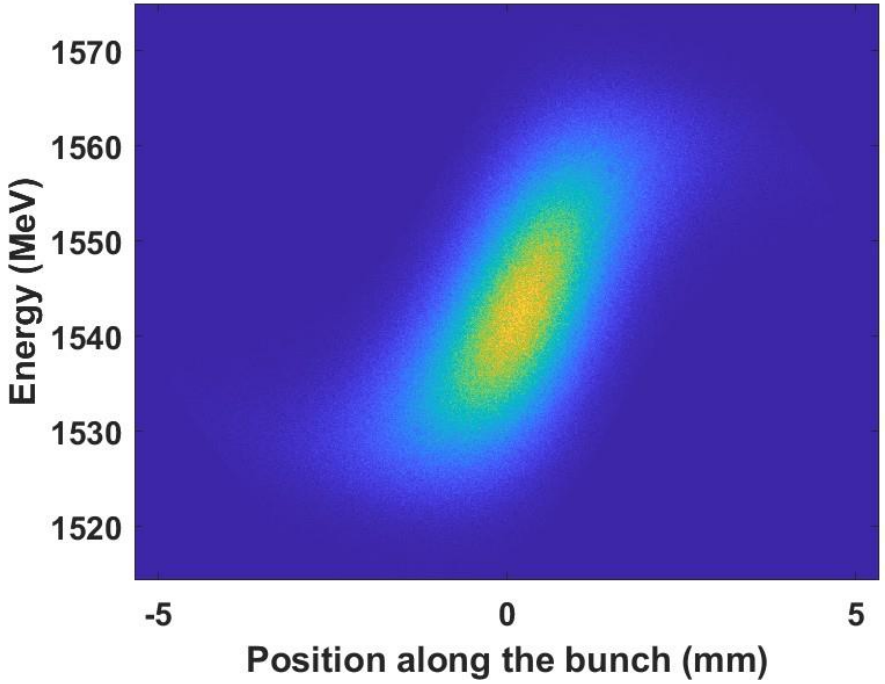




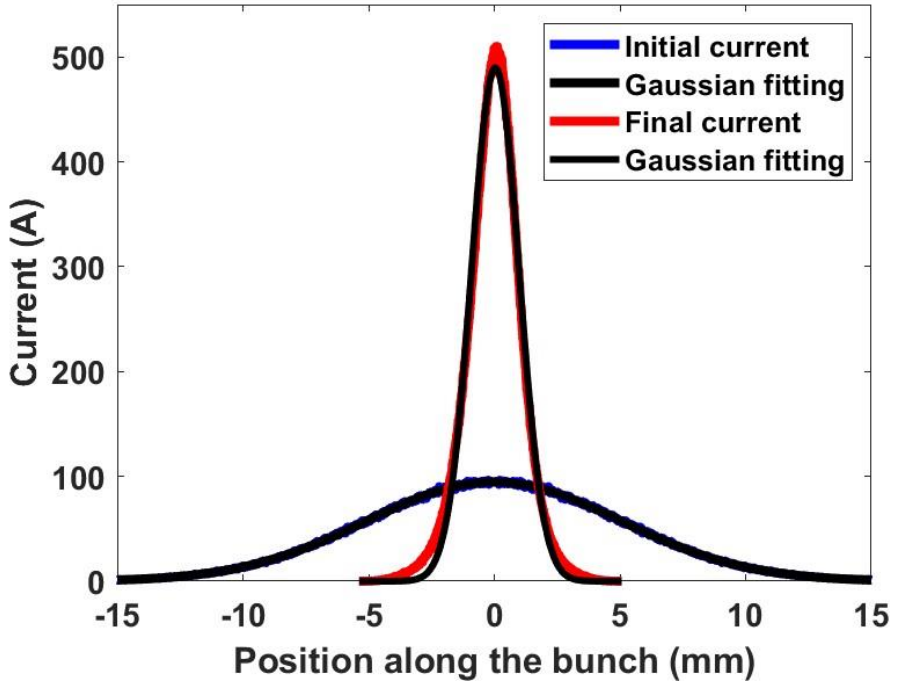
Bunch compressor performances

- Bunch compressor performance evaluated with simulation with the code elegant. 1D CSR module, 4M macroparticle.
- The compression preserves with good approximation the Gaussian current profile
- Phase space dominated by the linear chirp and uncorrelated energy spread
- Final rms bunch length ≈ 1.0 mm Compression factor≈5
- energy spread 6.5*10^- 3.
- Emittance dilution <4% horizontal and <3% vertical

Phase space

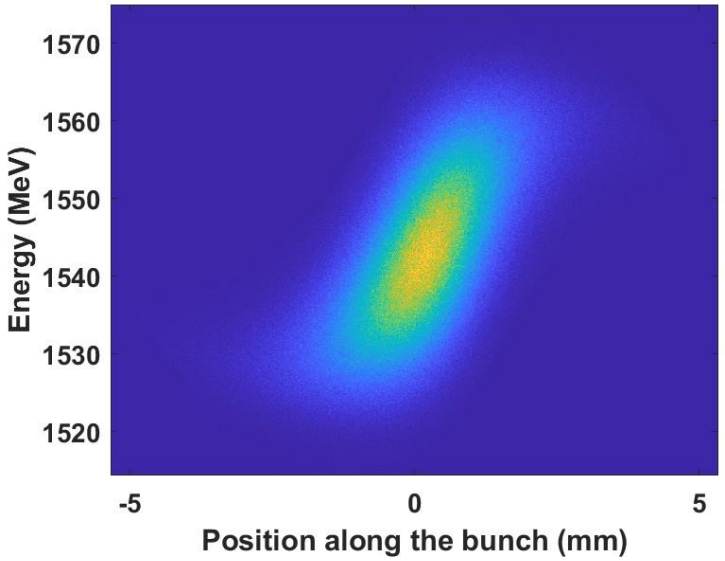


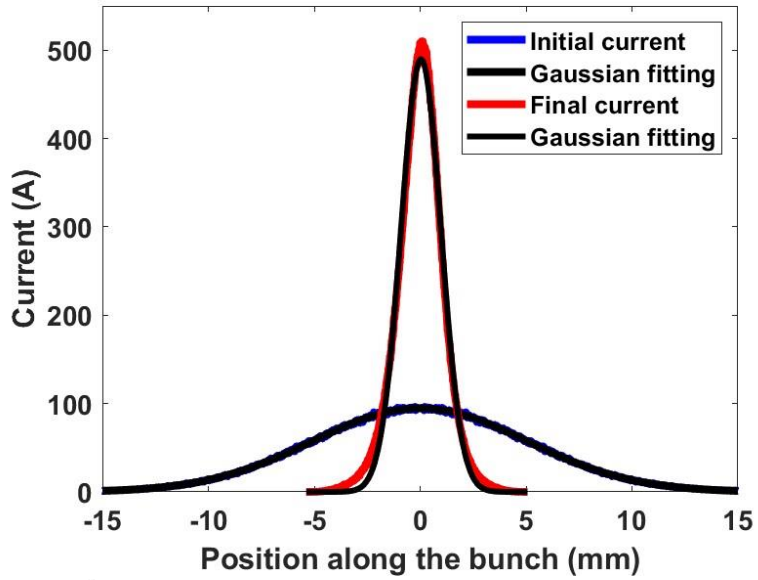
Current profile



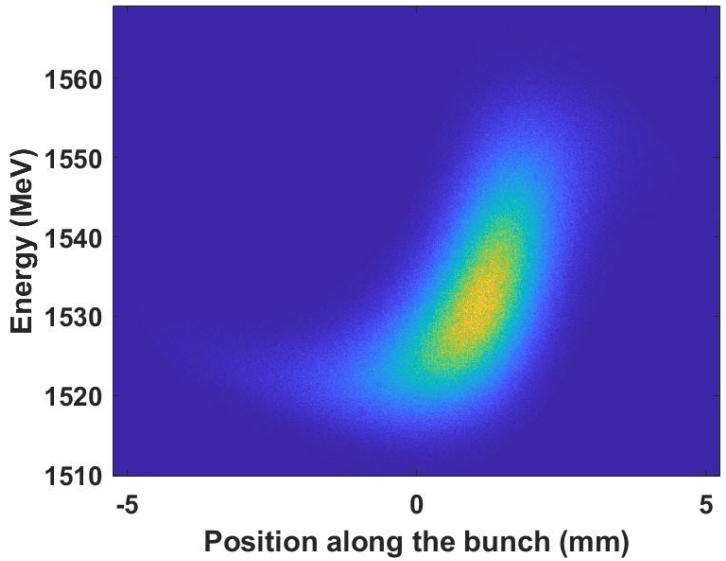
Linearization with sextupoles

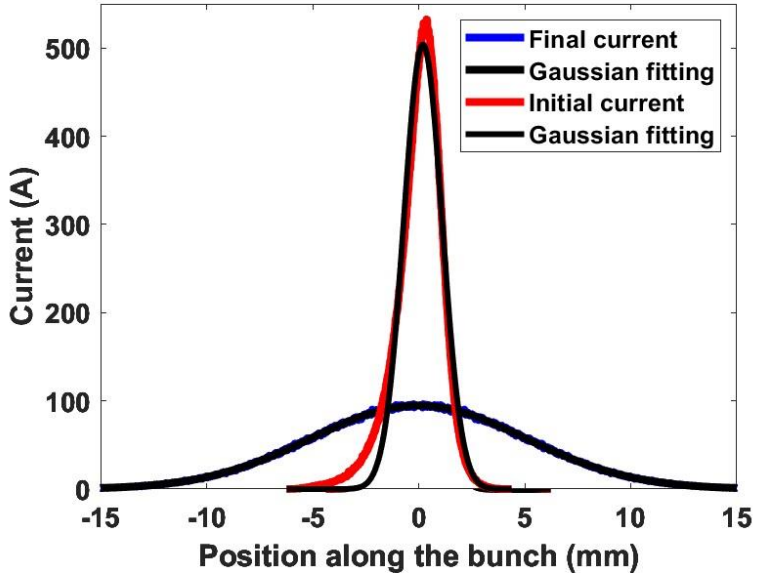
Sextupoles optimized to cancel second-order dispersion



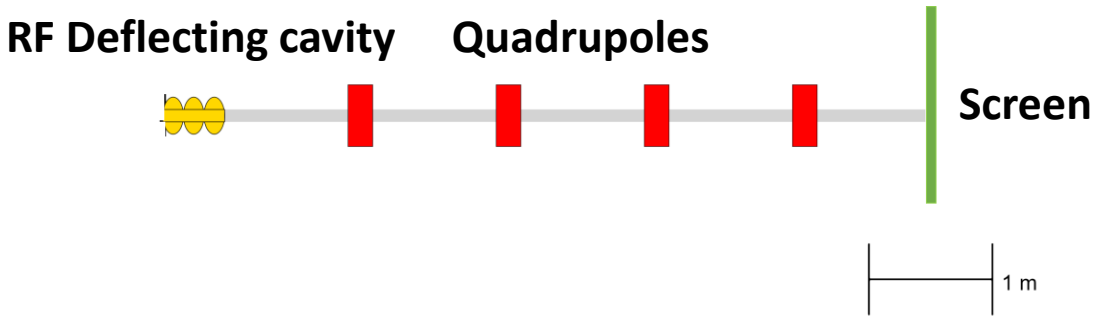


Sextupoles at zero

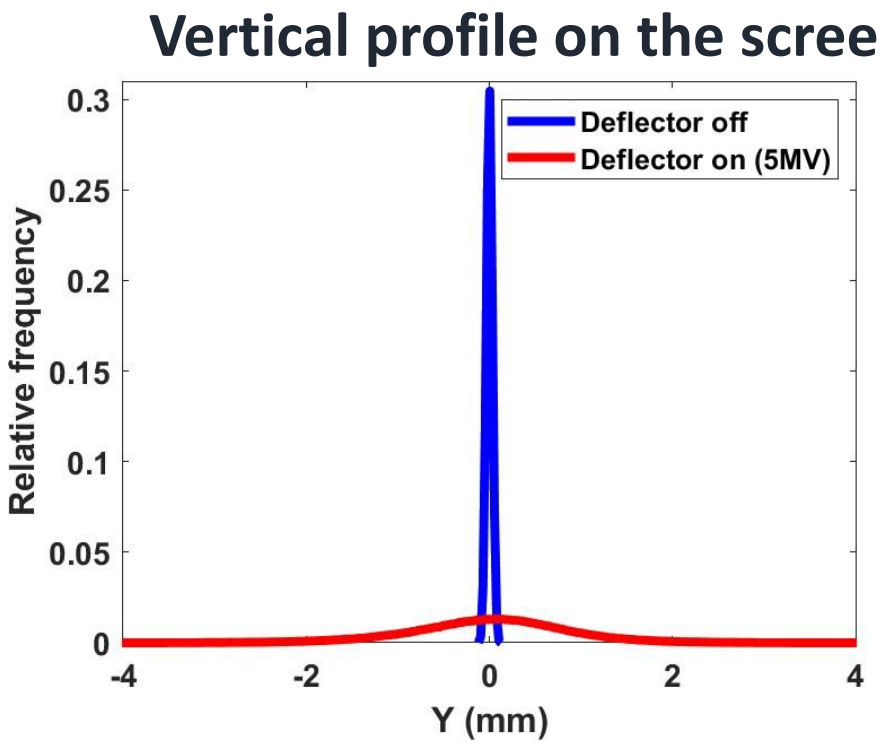


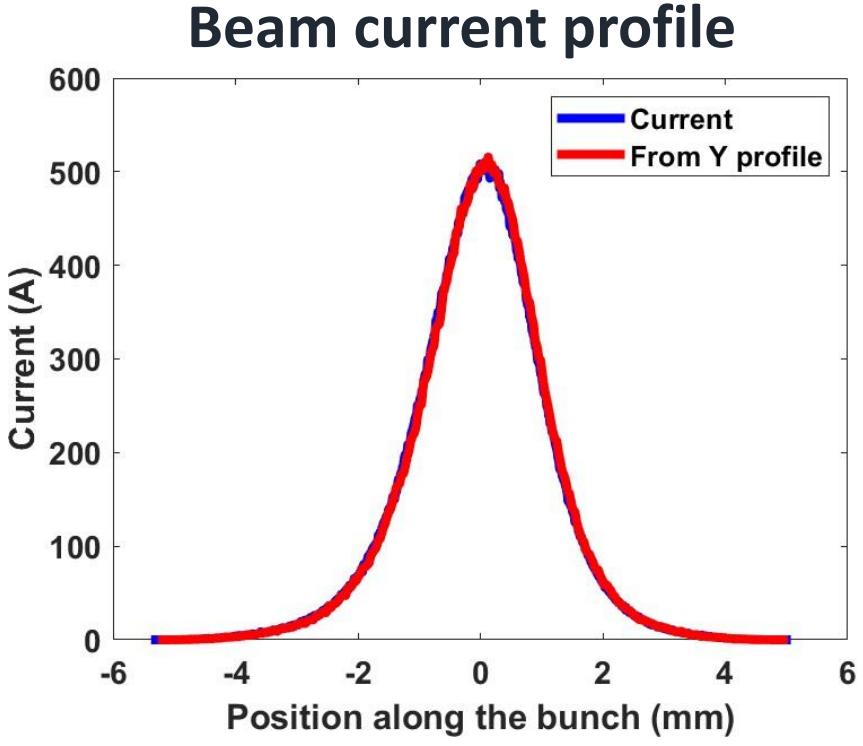


Longitudinal Beam Diagnostics



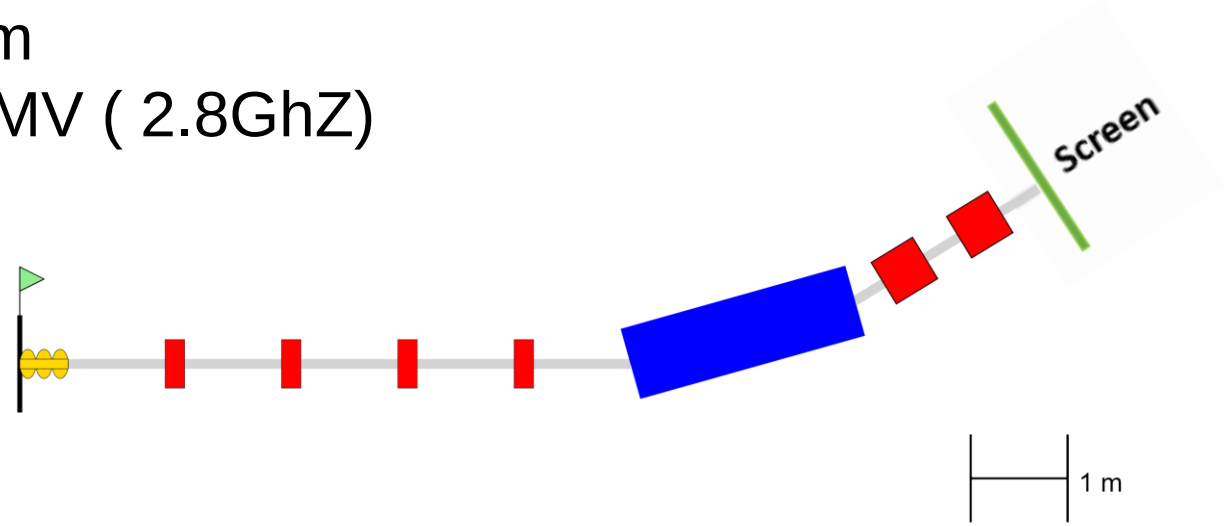
- Deflector length 0.5m
- Deflecting voltage 5MV (2.8GhZ)
- Non-deflected beam Sigma y= 31 μm
- Deflected beam sigma y= 877 μm
- Rms bunch length reconstructed from y profile 1.07 mm instead of 1.08 mm (0.94 mm from gaussian fit)



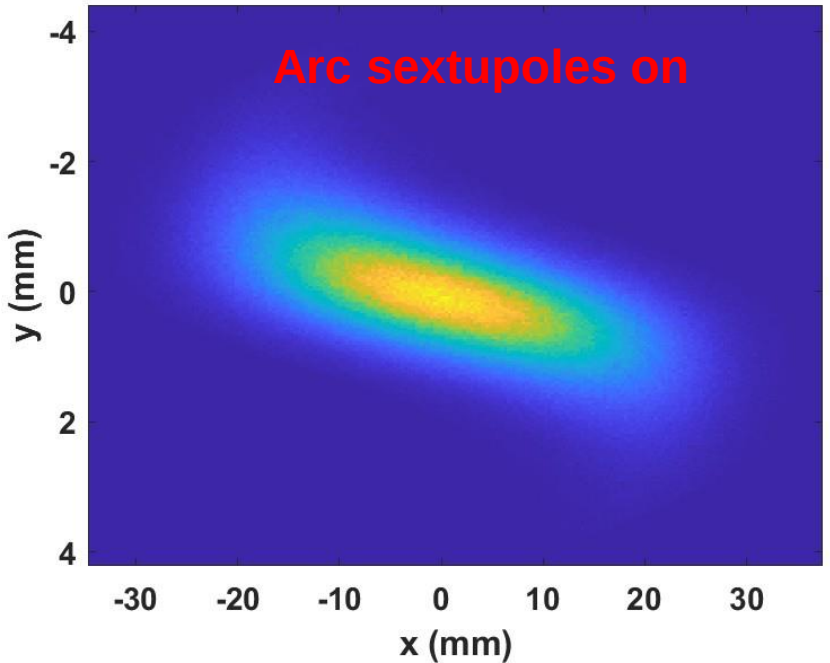


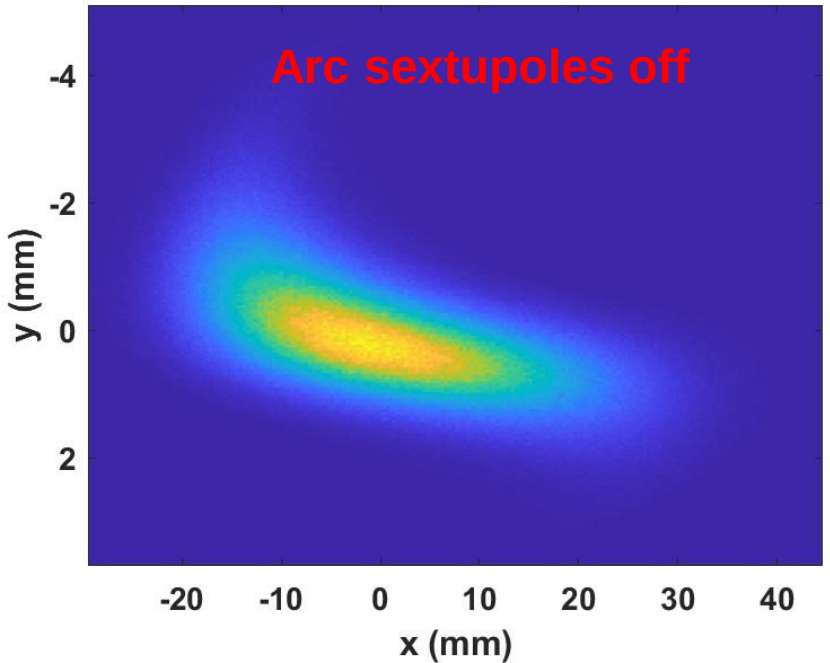
Phase space Beam diagnostics in the DBD

- Deflector length 0.5m
- Deflecting voltage 5MV (2.8GhZ)
- Bending angle 30˚



Transverse distribution on screen∝ Phase space

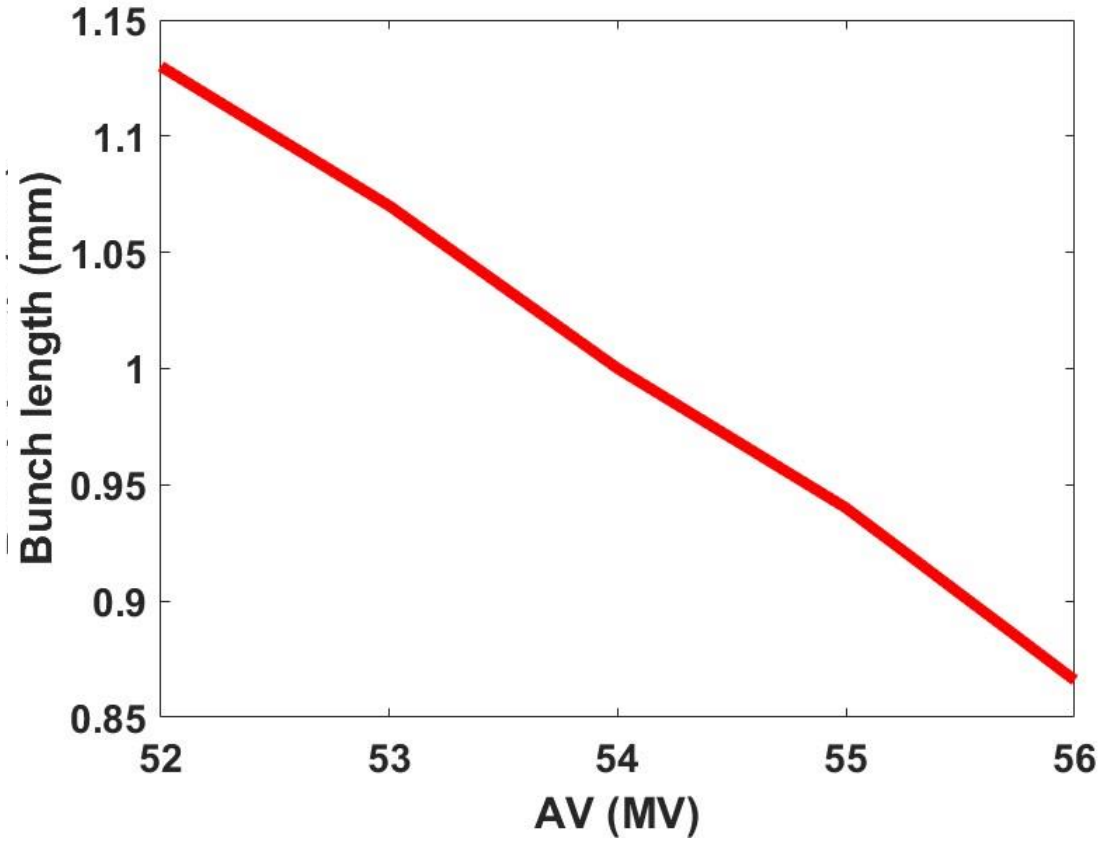


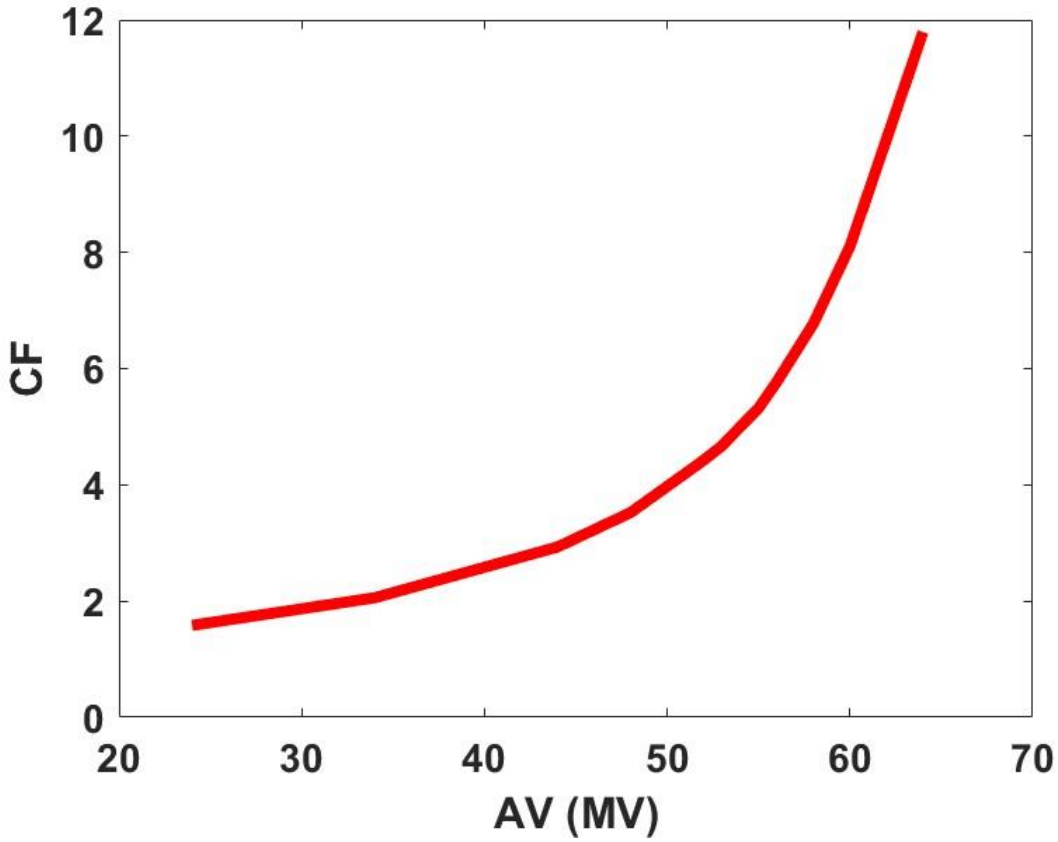


Compression vs RF

Compression vs RF Amplitude

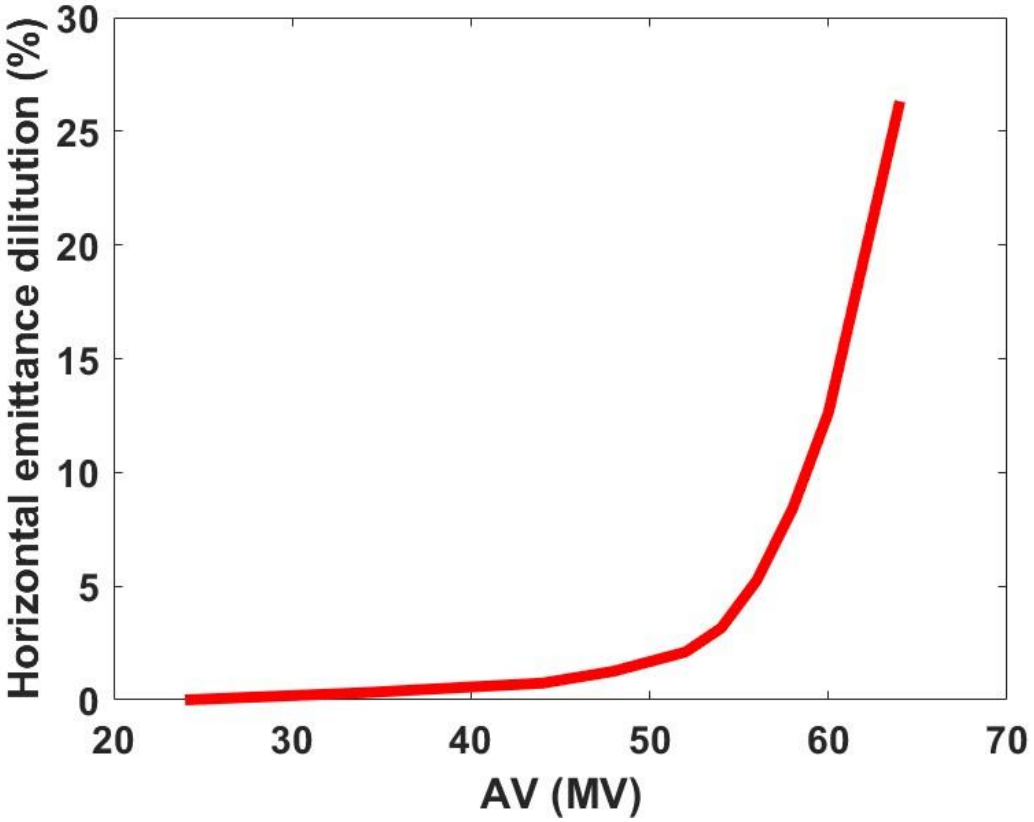
- Initial bunch duration 5mm, 5 nC, 100 K macroparticle to speed up calculation
- Nominal compression factor 3
- -/+ 1.55 MV (-/+3%) produces a +/-10% variation in the nominal bunch length

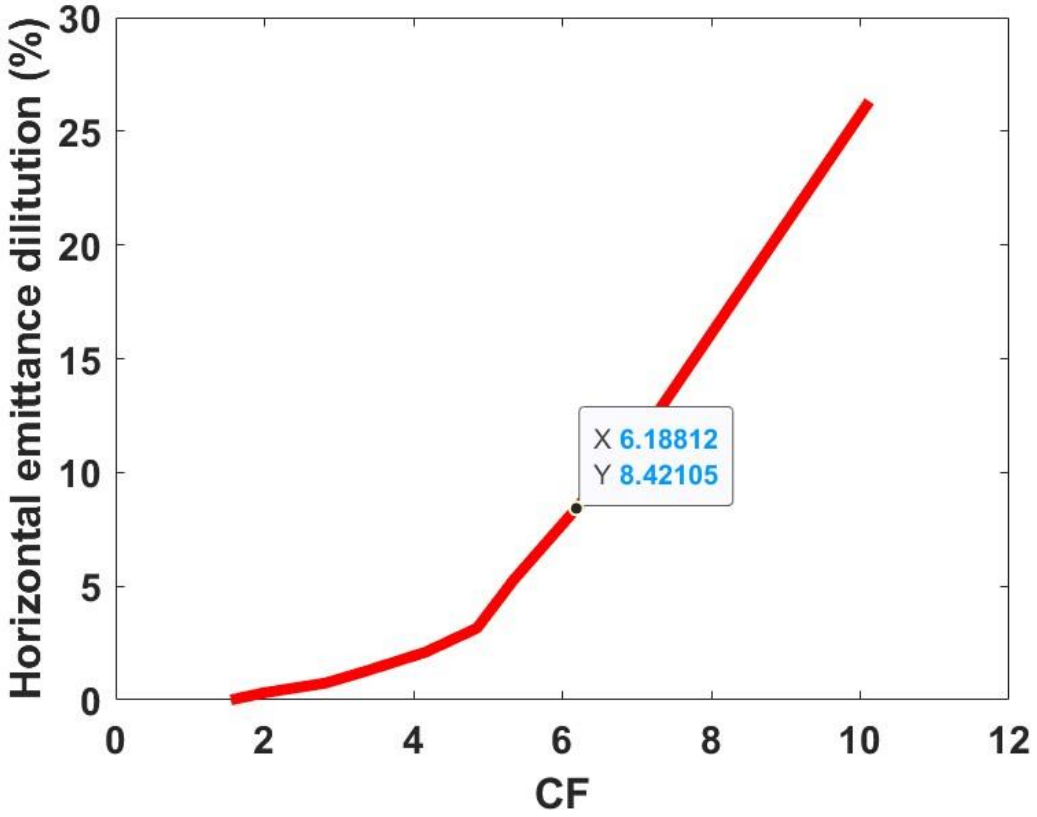




Emittance dilution vs Compression

- Initial bunch duration 5mm,5 nC, 100 K macroparticle to speed up calculation
- The emittance dilution is below the 10% for a compression factor up to ≈6

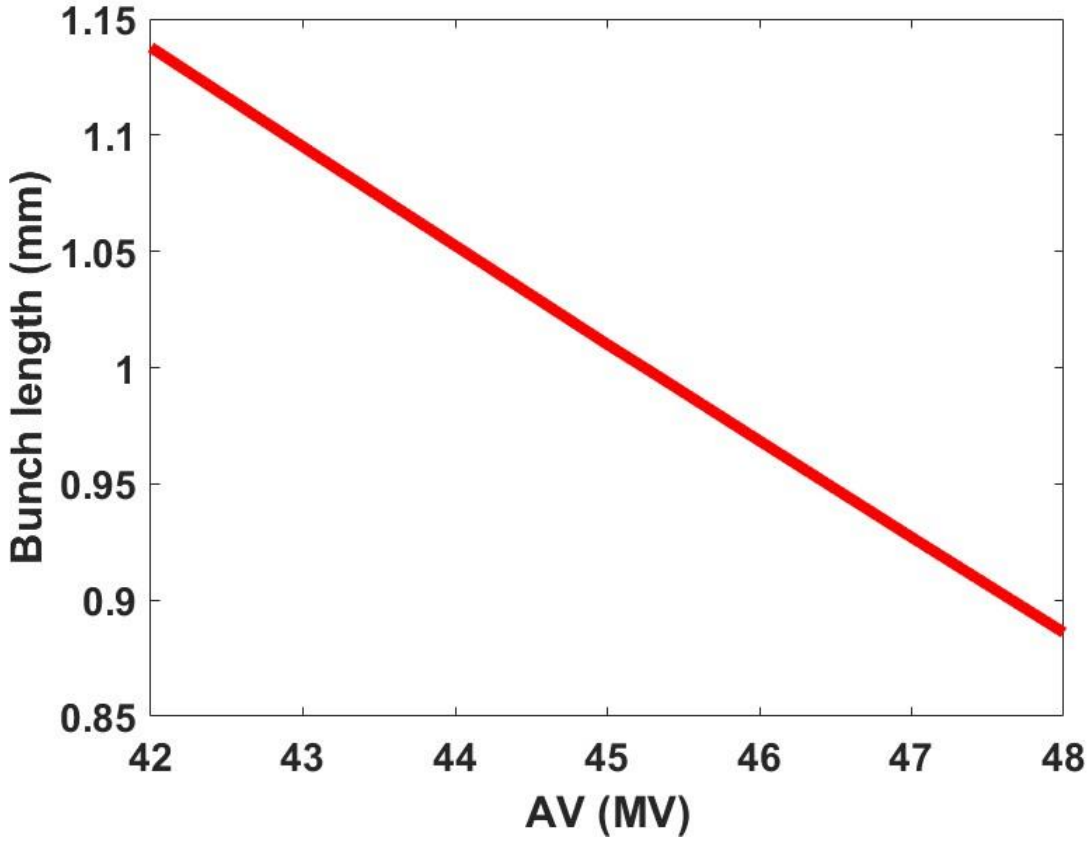


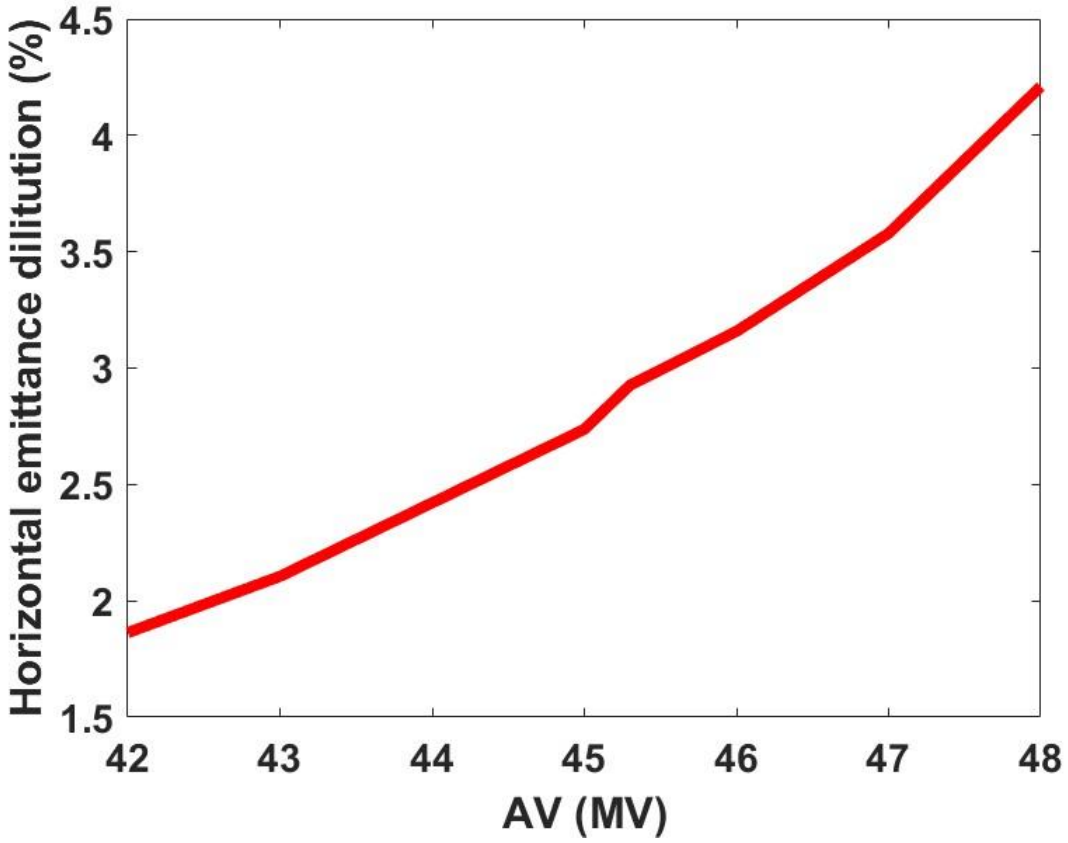


Compression vs RF

Compression vs RF Amplitude

- Initial bunch duration 3mm, 5 nC, 100 K macroparticle to speed up calculation
- Nominal compression factor 3
- -/+ 2.1 MV (-/+5%) produces a +/-10% variation in the nominal bunch length

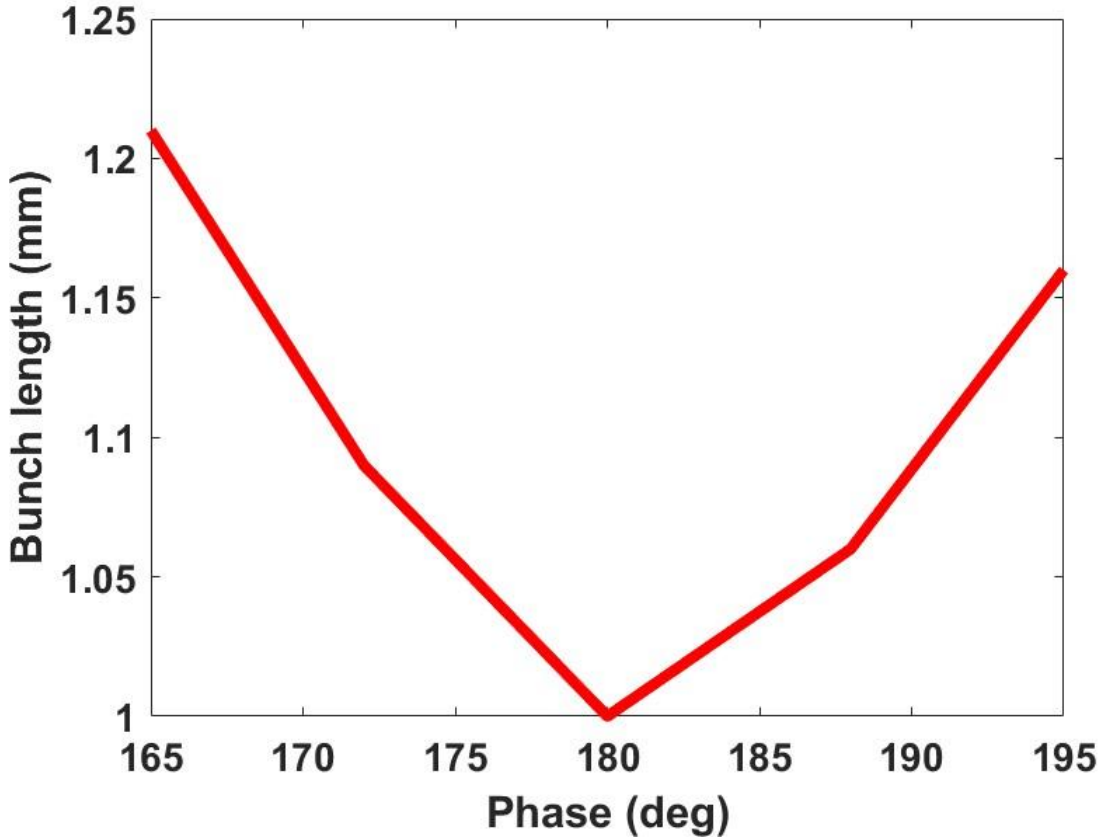


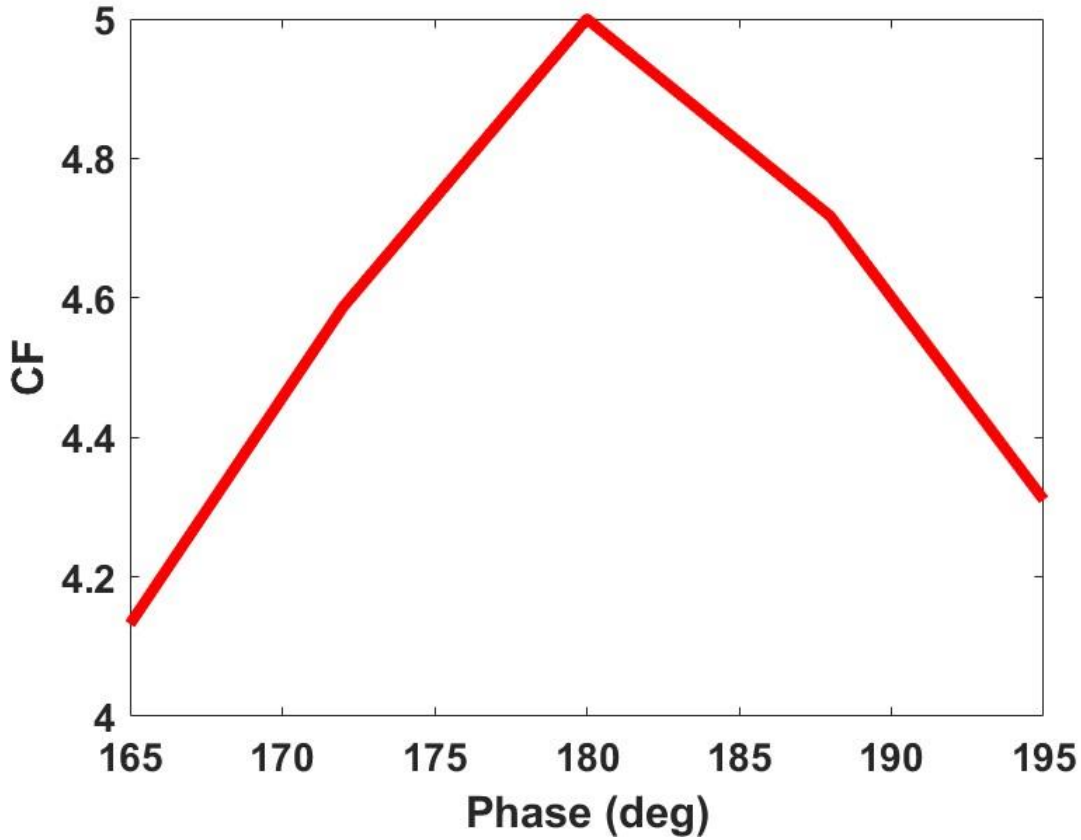


Compression vs RF

Compression vs RF Phase

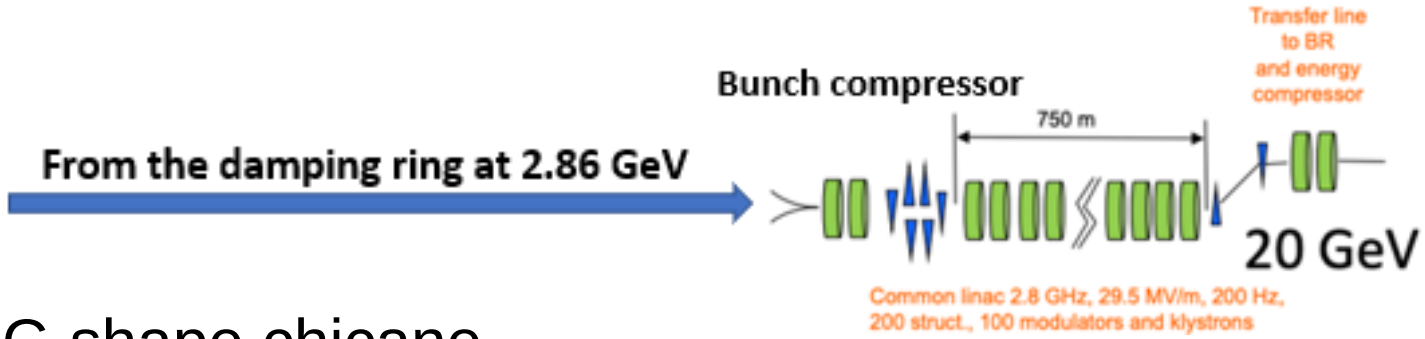
- Initial bunch duration 5mm, 5nC,100 K macroparticle to speed up calculation
- Nominal compression factor 5
- A phase variation of -/+8 deg produces a 10% variation in the nominal bunch length





Bunch compressor at 2.86 GeV

Preliminary design of a bunch compressor at 2.86 GeV



- Four-bending C-shape chicane
- Angle=0.2147 (12.3deg). Magnetic field 1.1T
- Magnetic length of the dipole 1.85m.
- Distance between 1(3) and 2.(4) 2.9m
- R56=-0.39m. Max Disp= 1m
- Two cavities to chirp the beam. Total accelerating voltage 105 MV
- Four cavities to remove part of the chirp. Total accelerating voltage 270 MV

Simulations with ELEGANT

- Energy spread 6.5*10^- 3.
- Compression factor 5. 5mm ⟶ 1mm
- Emittance dilution ≈13% horizontal and <1% vertical

Acknowledgment

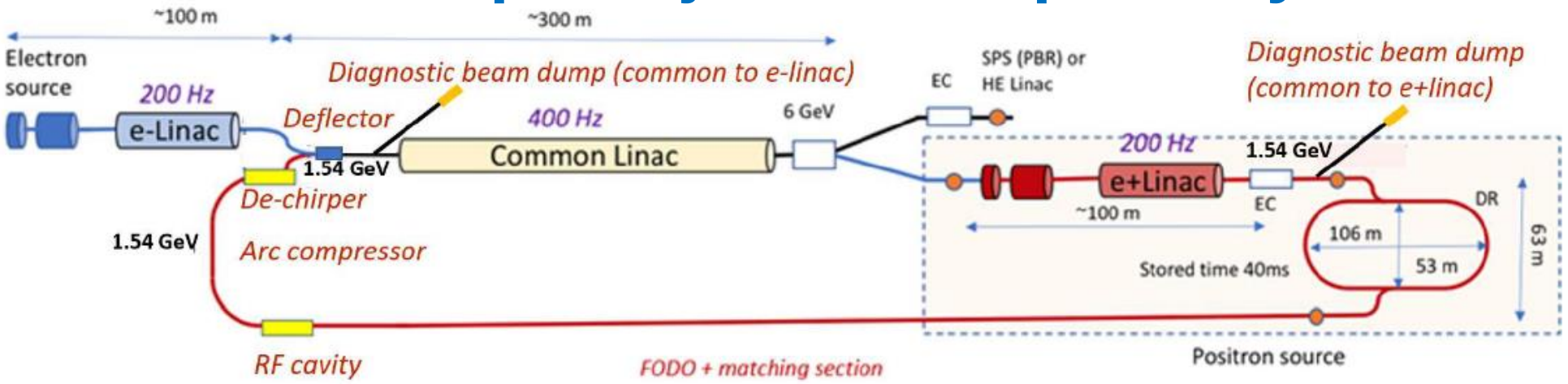
Many thanks to all the Colleagues of the FCC-ee pre-Injector Collaboration

This work was done under the auspices of CHART (Swiss Accelerator Research and Technology) Collaboration, https://chart.ch

FCCIS: 'This project has received funding from the European Union's Horizon 2020 research and innovation program under the European Union's Horizon 2020 research and innovation program under grant agreement No 951754.'

THE END

FCC-ee pre-Injector complex layout



This version of the layout has been used as a reference for project feasibility evaluation and cost estimation in the midterm review report

Alternative designs are considered to damp the emittance of both beams and operate the damping ring at higher energy (2.86 GeV)

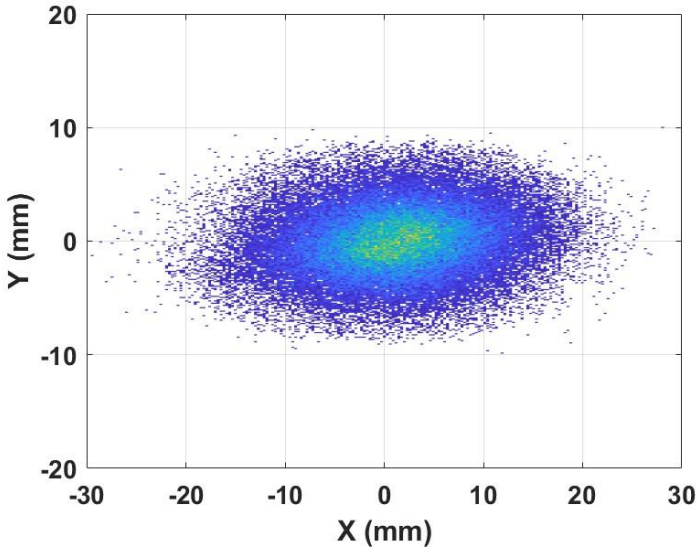
Project structure:

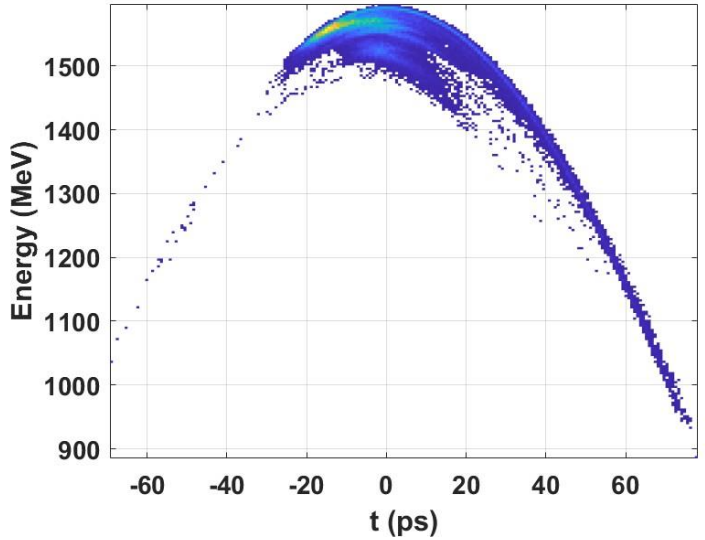
- **WP1/2**: Electron Source, Electron and Positron Linacs
- **WP3:** Positron Source: Target and Capture System
- **WP4:** Damping Ring and Transfer Lines
- **WP6:** PSI Positron Production (P3) Project

Positron damping ring system (WP4) purposes

Positron beam at the positron linac exit (1.54Gev)

Parameter	Value
Geometric Emittance(rms,x,y)	≈3mm·mrad
Energy spread rms	≈5%
Bunch length (rms)	≈4.5mm
Bunch duration	≈15ps

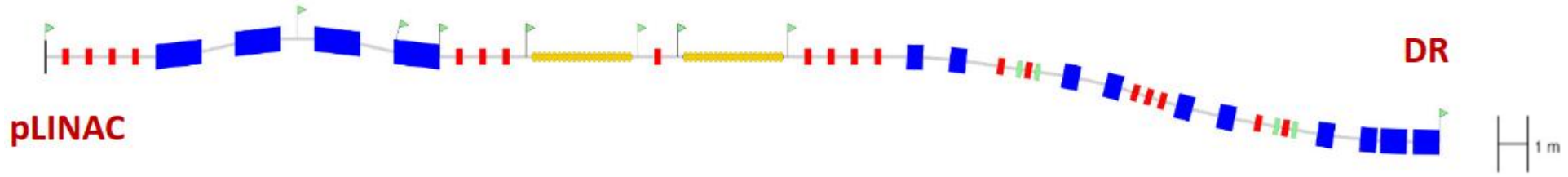


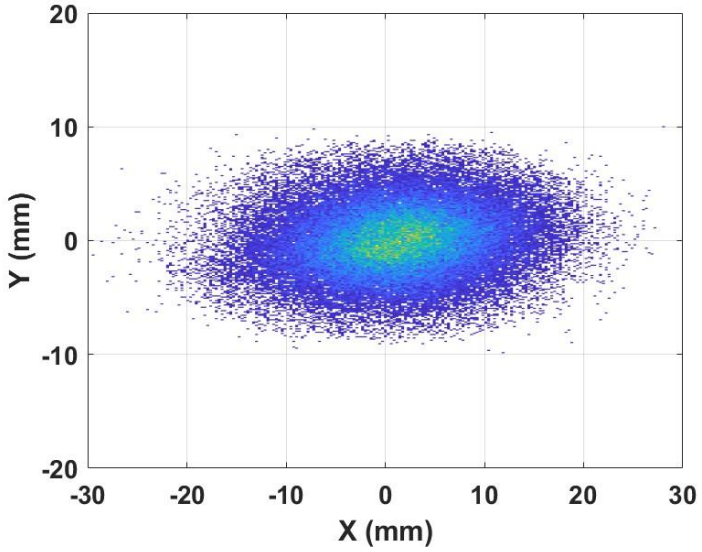


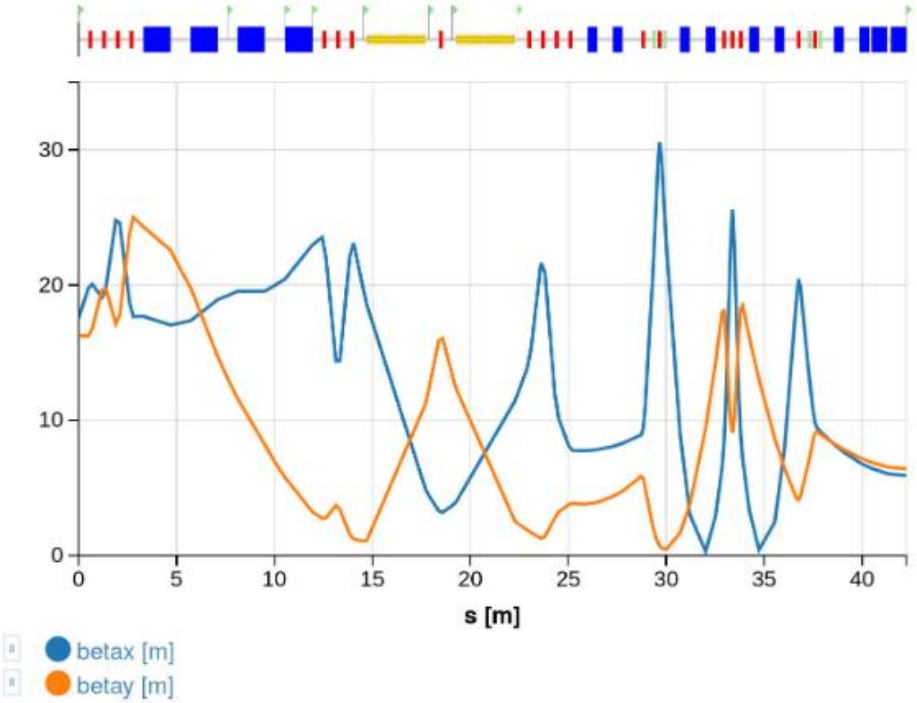
Nominal parameters at the entrance of the common linac (1.54Gev)

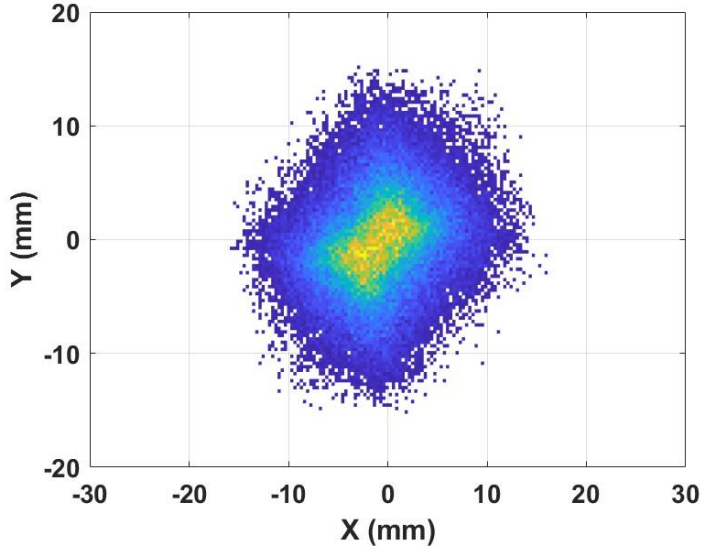
	Parameter	Value
Damping ring	Geometric Emittance(rms,x,y)	≈1.9nm·rad
Damping ring	Energy spread rms	≈0.7%
Bunch compressor	Bunch length (rms)	≈1mm
Bunch compressor	Bunch duration	≈3.3ps

Transfer lines pLINAC - DR





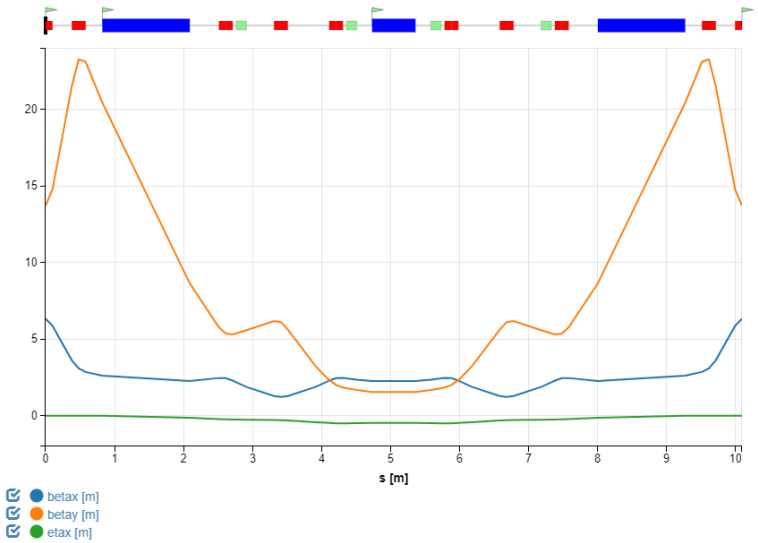




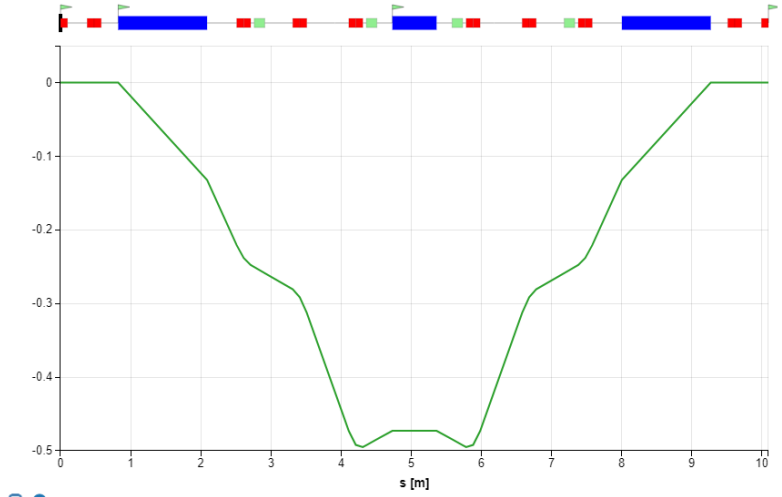
- Transverse emittance is preserved in both planes
- Horizontal geometrical emittance 2.78 mm*mrad
- Vertical geometrical emittance 3 mm*mrad

One cell

TWISS PARAMETERS



DISPERSION



CELL PARAMETERS

Parameter	Value	Unit
Bending angle (1&3)	0. 2094396 (12)	Rad (deg)
Bending length (1&3)	1.2676	m
Bending angle (2)	0.1047198 (6)	Rad (deg)
Bending length (2)	0.63	m
Cel total length	10.09	m
Sextupoles K2	-12.65	m^{-3}
R56	0.06748	m
Max dispersion (abs. value)	0.5	m
H	0.1	m