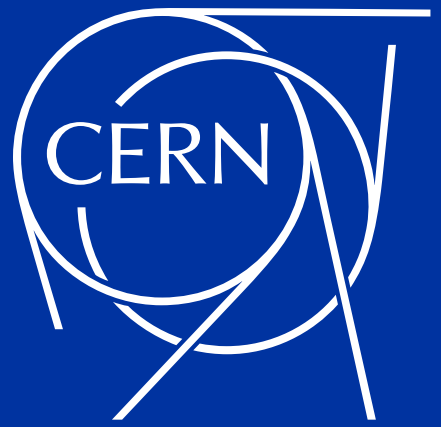


Electron gun studies

Zdenek Vostrel, Steffen Doebert

20 April 2023

Overview

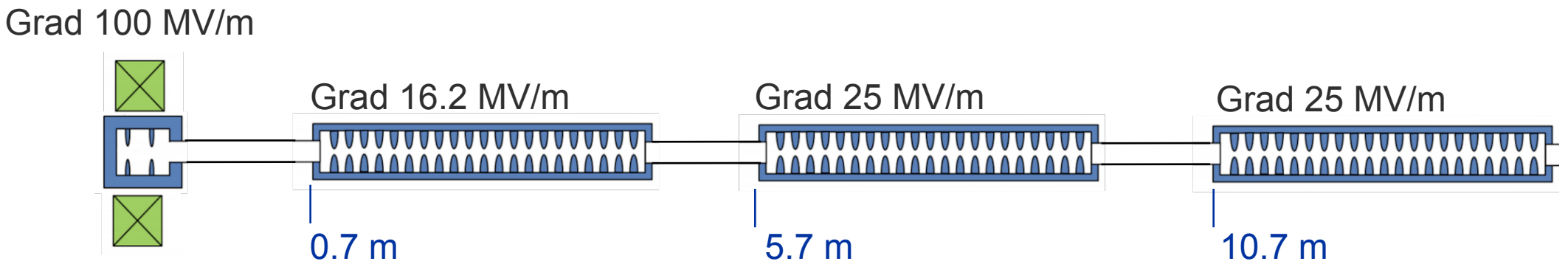
- Overall status
- Top-up injection scheme
- Latest optimisation
  - Optimising for shorter bunches
  - Switch to 2.8 GHz structures
  - RF structures lengths

Electron source overview

- RF Gun
- Focusing solenoid
- 3 TWS
- Total length: 15 m
- Target energy: 200 MeV
- RF structures based on SwissFEL

Structure	Number of cells	Gradient [MV/m]	Operating frequency [GHz]	Length [m]
RF Gun	2.5	100	3	0.17
1st TWS	120	16.2	3	4
2nd TWS	120	25	3	4
3rd TWS	120	25	3	4

* We are also testing 84 cells structures and 2.8 GHz frequency



The gun should provide

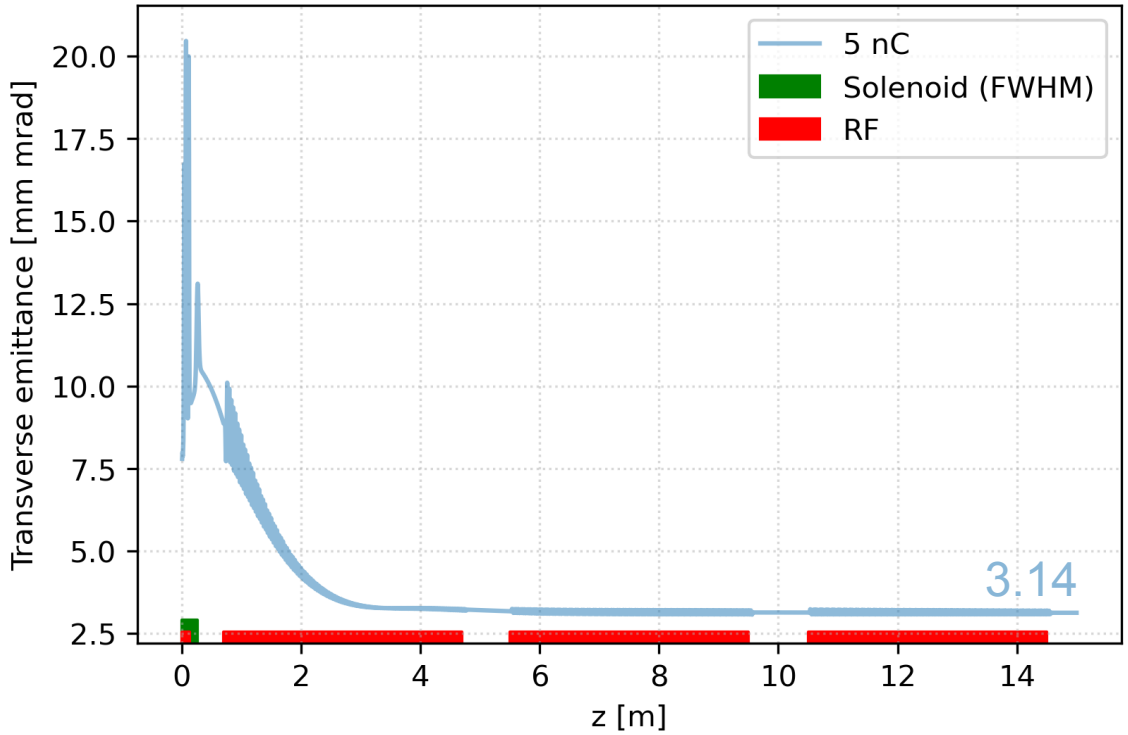
Bunch property	Target
Transverse emittance	< 4 mm mrad
Bunch length	~ 1 mm (or shorter)
Energy	~ 200 MeV
Energy spread	0.5 %
Frequency	200 Hz
Peak charge	5 nC

- Top-up injection → charge variation
- High stability and reliability → we are being rather conservative

What we can provide

Bunch property	Simulation	Target	
Transverse emittance	3.14 mm mrad (rms)	< 4 mm mrad	✓
Bunch length	0.96 mm (rms)	~ 1 mm (or shorter)	✓
Energy	204.94 MeV	~ 200 MeV	✓
Energy spread	390 keV (0.2 %)	< 0.5 %	✓
Peak charge	5 nC	5 nC	✓

- Target properties reached
- Simulations done in ASTRA
- We have quite large margin (in emittance)



Emittance development along the trajectory for 5 nC charge.

Optimised parameters

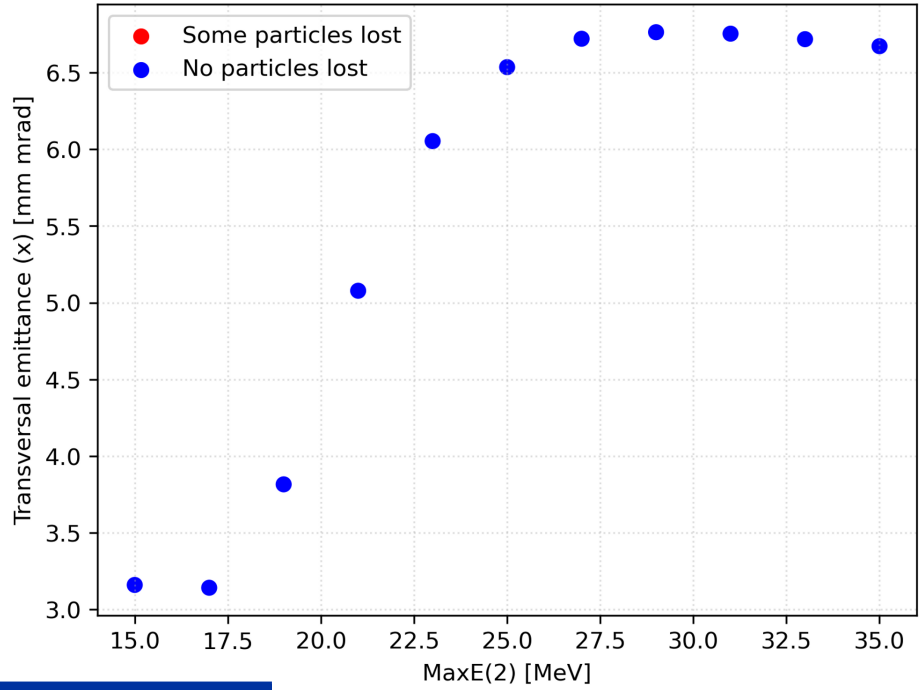
Structure	Number of cells	Gradient [MV/m]	Operating frequency [GHz]	Length [m]
RF Gun	2.5	100	3	0.17
1st TWS	120	16.2	3	4
2nd TWS	120	25	3	4
3rd TWS	120	25	3	4

* RF structures based on SwissFEL

Parameter	Value	Comment
RF gradient	In table above	Gradient of the first structure important for focusing
Position of the first TWS	0.7 m	Important for focusing.
RF frequency	In table above	Can be changed to 2.8 yielding slightly better emittance, I will talk about this later
Transverse initial distr	Radial uniform, d = 2.2 mm	Uniform distribution should be fine.
Longitudinal initial distribution	Plateau, 7 ps emission	We also tested gaussian distribution, which yields significantly worse results.

Focusing

Emittance vs gradient of the first TWS, magnetic field is optimised, **the position is constant**



Gun elements:

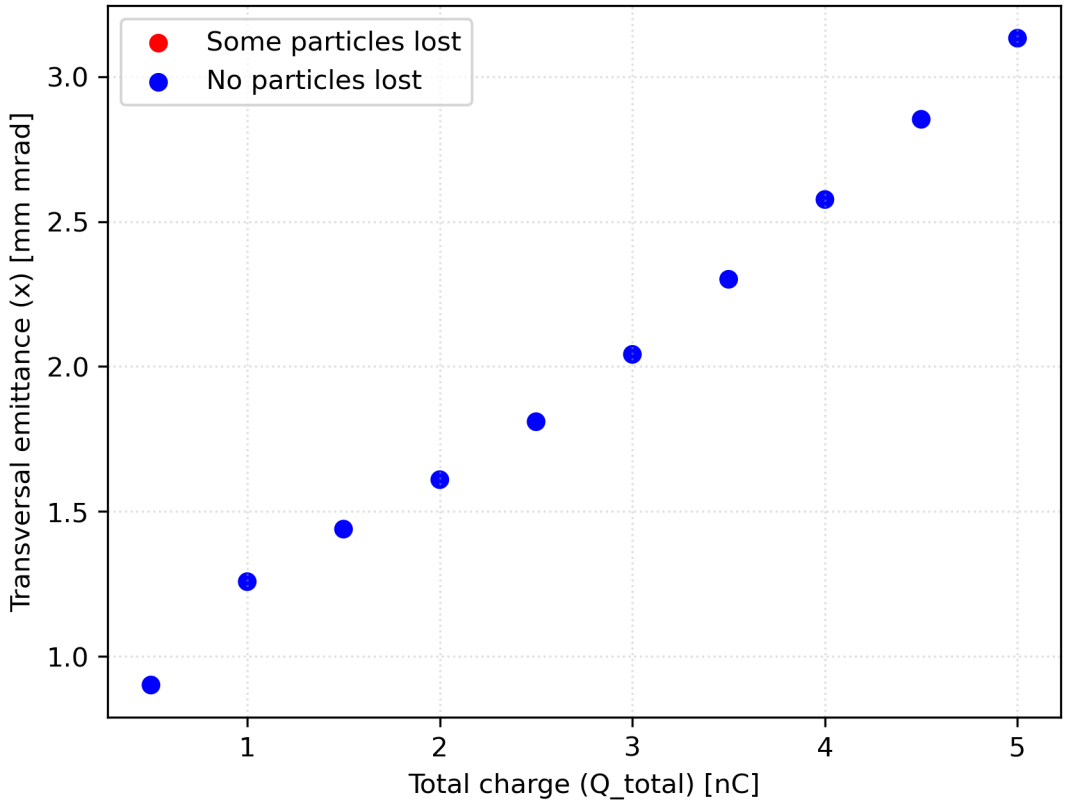
- Solenoid (magnetic field)
- Position of the first TWS
- Gradient of the first TWS

Must be optimised all at once!

Gradient of first TWS [MeV]	Position of first TWS [m]	Focusing magnetic field [T]	Transverse emittance [mm mrad]
15	0.7	0.250	3.19
16	0.7	0.245	3.22
17	0.7	0.245	3.18
18	0.9	0.255	3.25
19	0.9	0.255	3.28
20	0.9	0.250	3.23

Top up injection

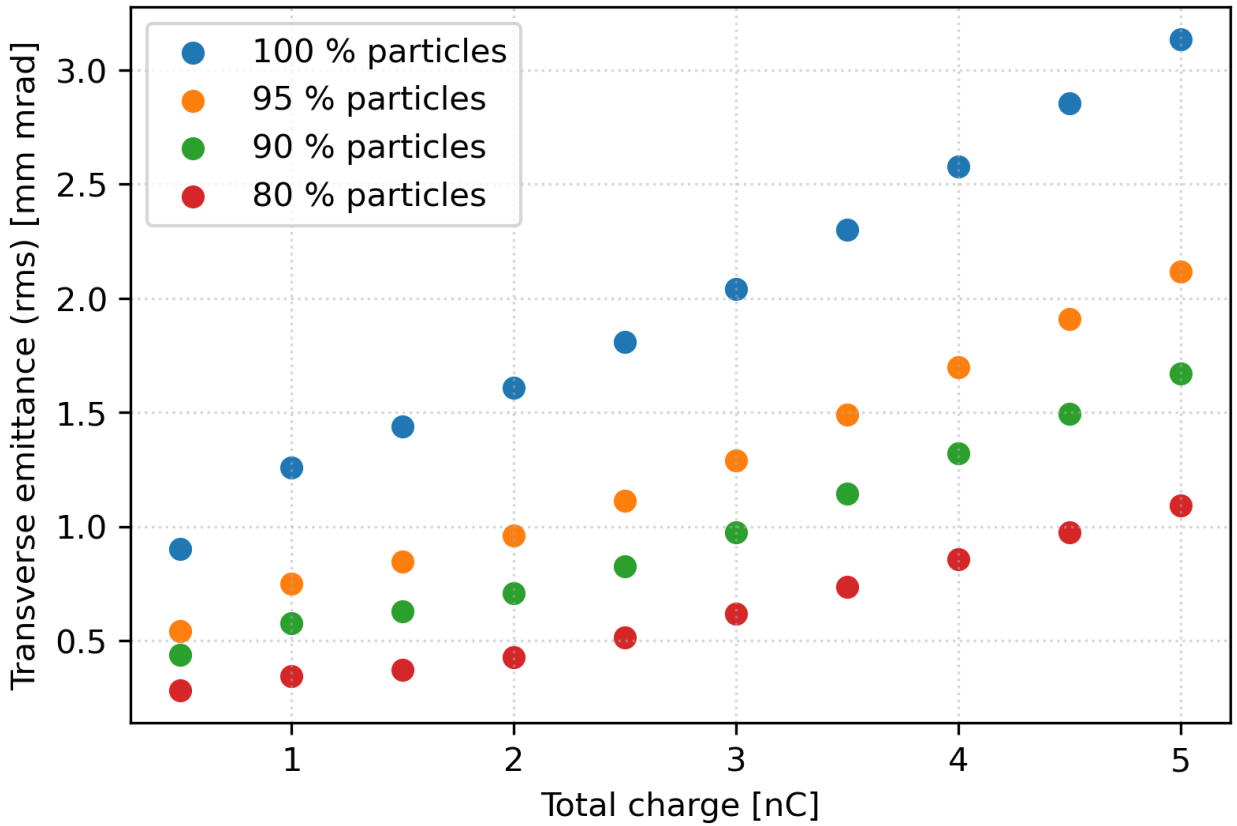
- We have to be able to **vary the charge in range 10-100 % at the frequency of 200 Hz**
- We propose:
  - Use special mirrors that cut the outer parts of the laser inducing the photoemission
  - The mirrors are able to change at the frequency of 200 Hz
  - Space charge density remains constant
- Other gun settings would remain constant



Emittance dependance on the total charge in the proposed top up injection scheme

Top up injection – core emittance

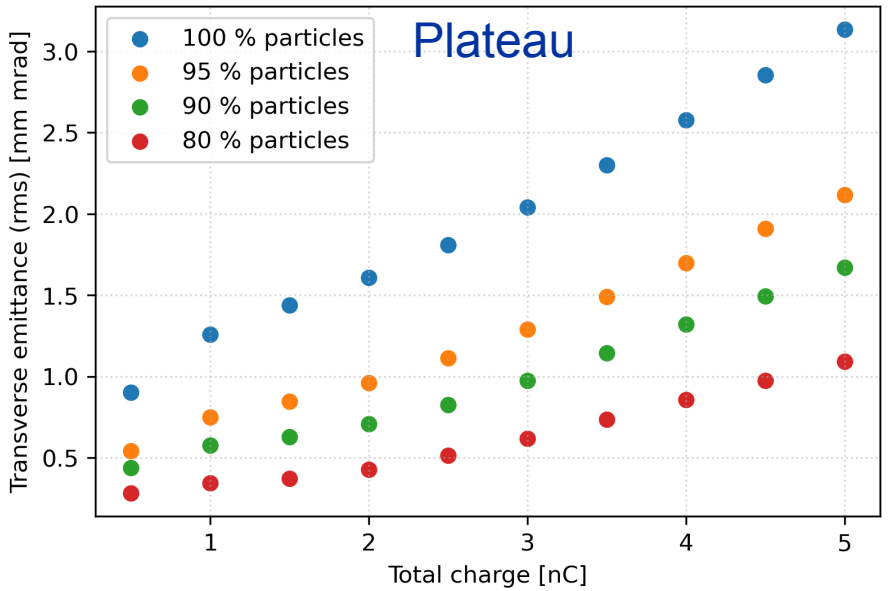
- Looking at the core emittance, outer particles contribute a lot

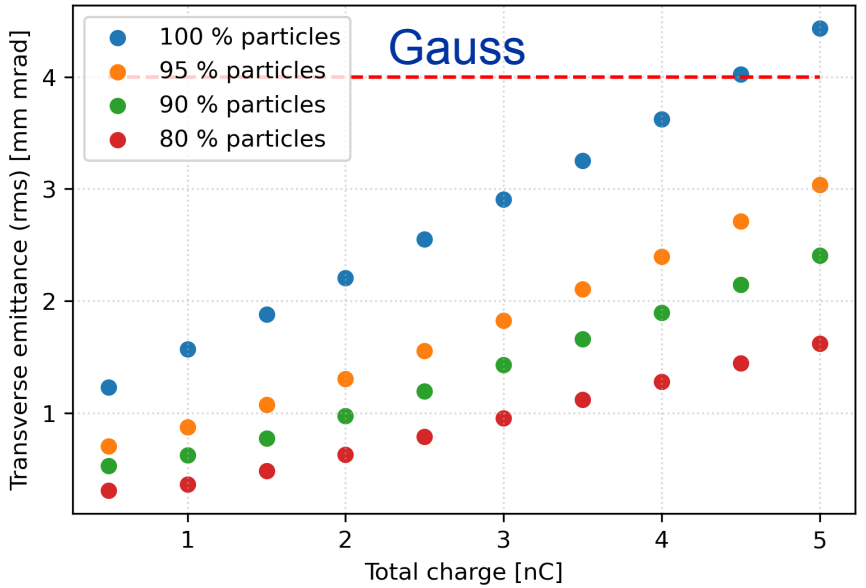


Emittance dependance on the total charge in the proposed top up injection scheme, **core emittance** distinguished by color

Initial longitudinal distribution

- I model the plateau initial longitudinal distribution
  - We have margin in terms of the emittance limit
- We may in fact get gaussian longitudinal distribution
  - We no longer fit into the emittance limit
  - But the core emittance is within the limit
- **We prefer to get as uniform longitudinal distribution as possible**

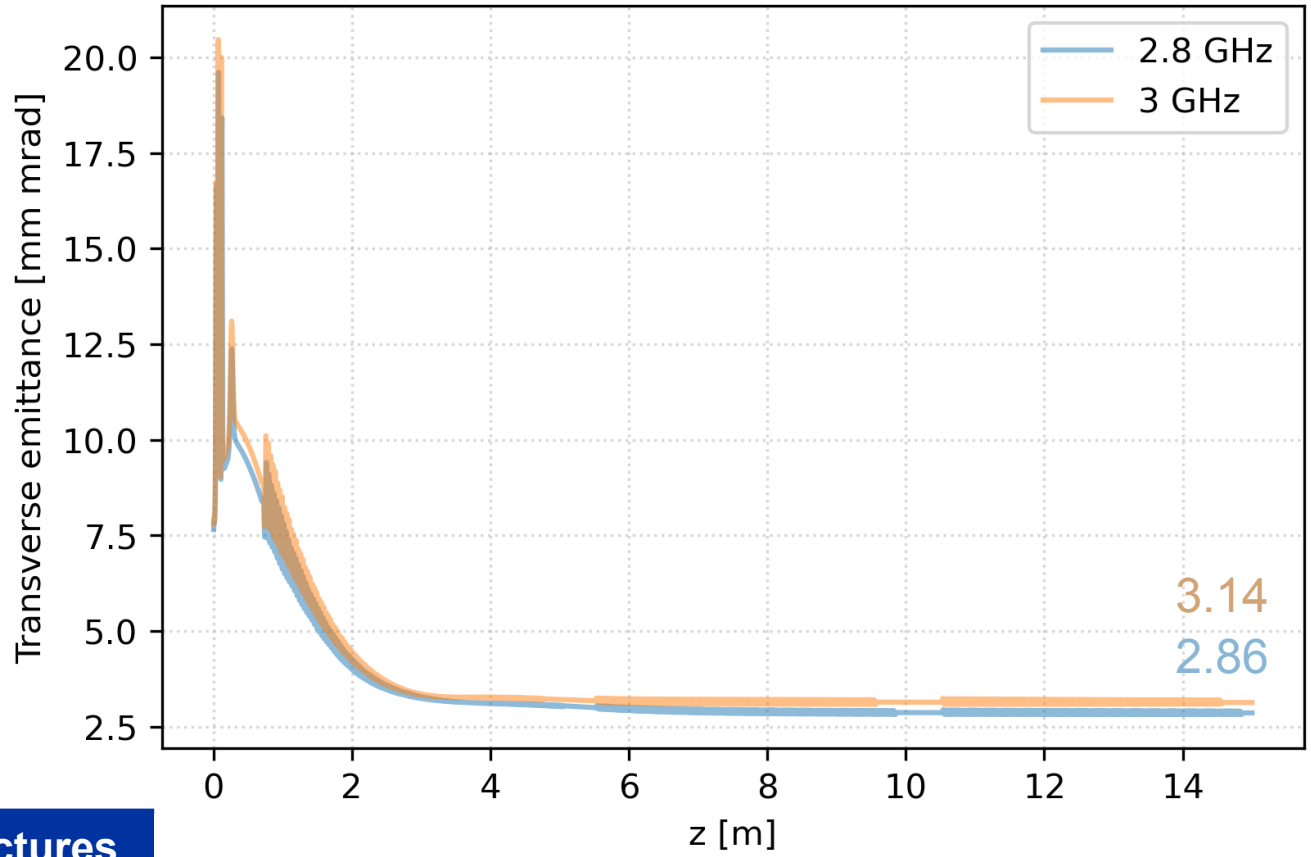




Emittance dependance on the total charge in the proposed top up injection scheme, **core emittance** distinguished by color

2.8 GHz structures

- **In simulations presented up to now: 3 GHz RF structures**
- We may want to use 2.8 GHz structures
  - We don‘t have them yet → I rescalled the existing 3 GHz structures
- **We slightly better results**

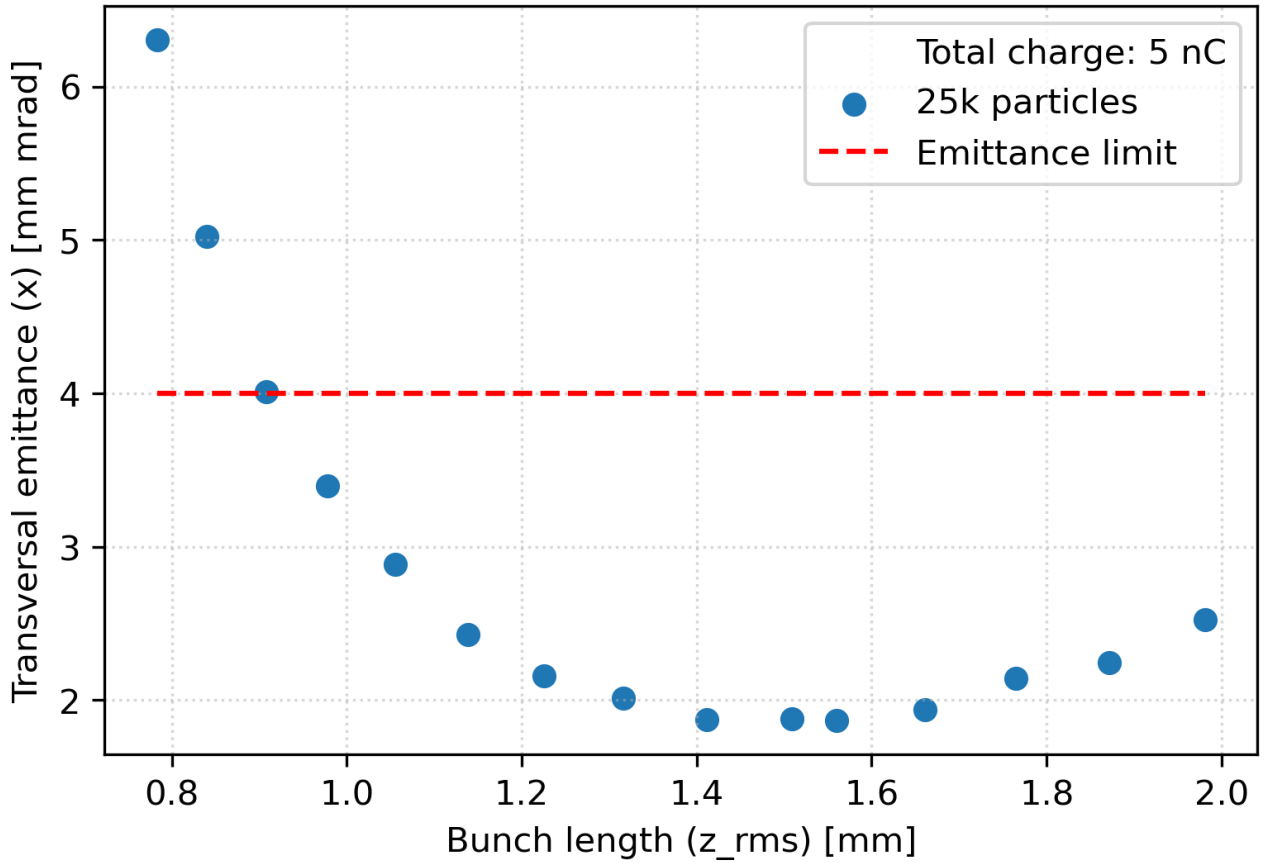


Emittance development along the trajectory for 5 nC charge.

Bunch property	3 GHz structures	2.8 GHz structures
Transverse emittance	**3.14** mm mrad (rms)	**2.86** mm mrad (rms)
Bunch length	0.96 mm (rms)	0.95 mm (rms)
Energy	204.94 MeV	219.45 MeV
Energy spread	390 keV (0.2 %)	385 keV (0.2 %)
Peak charge	5 nC	5 nC

Optimising for shorter bunches

- **We are limited both in the emittance and the bunch length**
  - Emittance < 4 mm mrad
  - Bunch length < 1 mm
- **We can decrease the emittance significantly by increasing the bunch length**
- Shorter bunches would be favourable for the following acceleration phases
- **I could not fit into the emittance limit for shorter bunches (0.5 mm)**

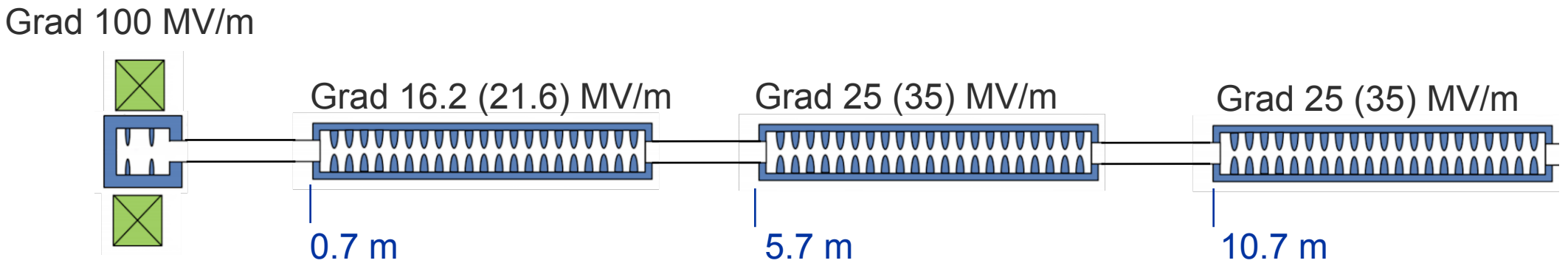


Emittance dependance on the bunch length (changed by the emission length), focusing magnetic field was optimised for all cases.

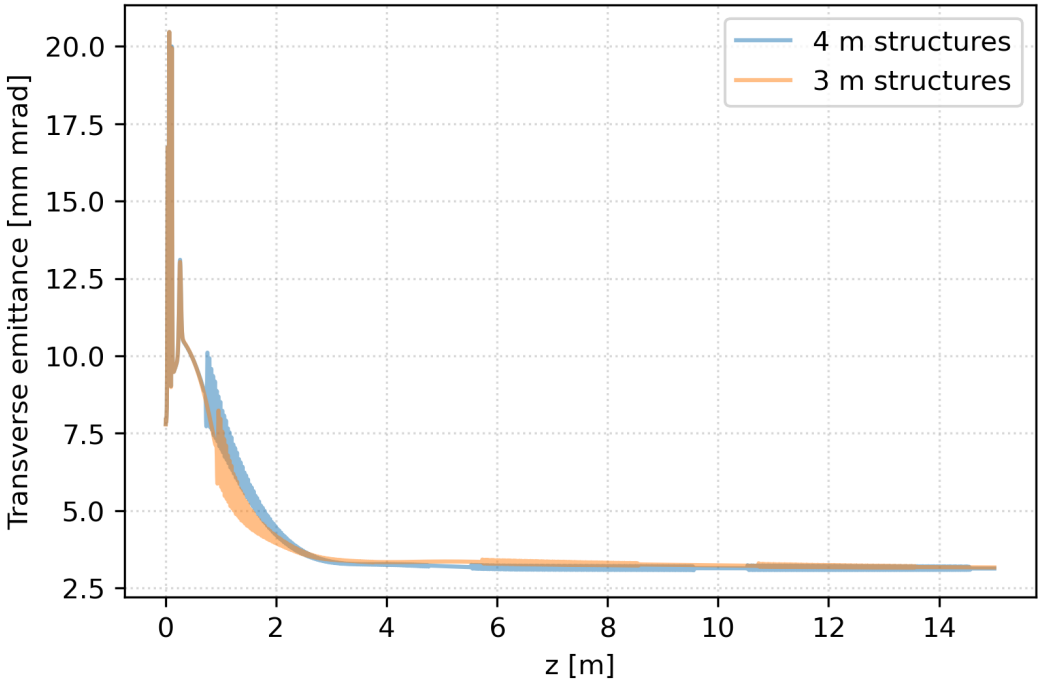
RF lengths

- First TWS must be optimised for focusing

Structure	Number of cells	Gradient [MV/m]	Operating frequency [GHz]	Length [m]
RF Gun	2.5	100	3	0.17
1st TWS	120 (84)	16.2 (21.6)	3	4 (3)
2nd TWS	120 (84)	25 (35)	3	4 (3)
3rd TWS	120 (84)	25 (35)	3	4 (3)



RF lengths



Emittance development along the trajectory for 5 nC charge.

Bunch property	4 m structures	3 m structures
Transverse emittance	3.14 mm mrad (rms)	3.17 mm mrad (rms)
Bunch length	0.96 mm (rms)	0.97 mm (rms)
Energy	204.94 MeV	199.44 MeV
Energy spread	390 keV (0.2 %)	381 keV (0.2 %)
Peak charge	5 nC	5 nC

We can achieve comparable properties with both 4 and 3 m structures.

Summary

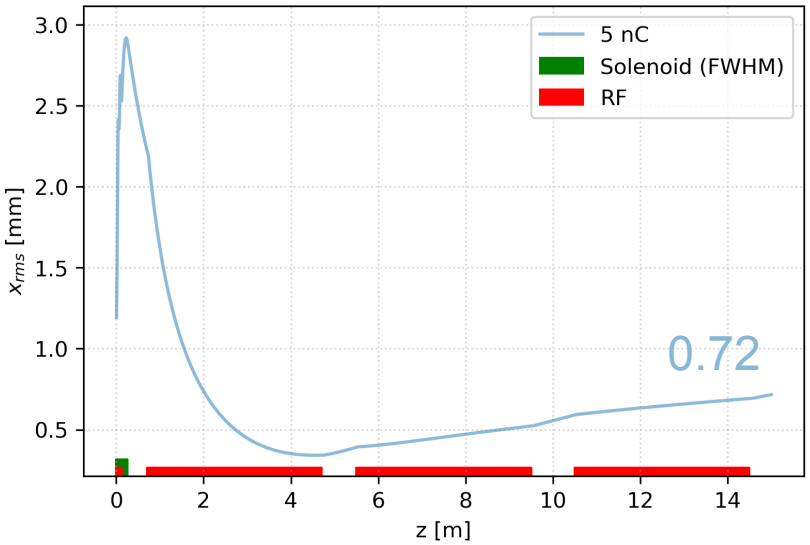
- **Baseline design complete**
  - We fit into the limits
  - We have margin in the emittance **for uniform longitudinal distribution** (→ preferable)
  - Problems with the **gaussian longitudinal distribution** (high emittance)
- **We can vary the charge for the top-up injection** at the desired frequency

- Emittance grows rapidly for shorter bunches, we should stay around 1 mm (rms)
- No problems with 2.8 GHz structures
- No problems shortening the RF structures
  - We could possibly only use 2?

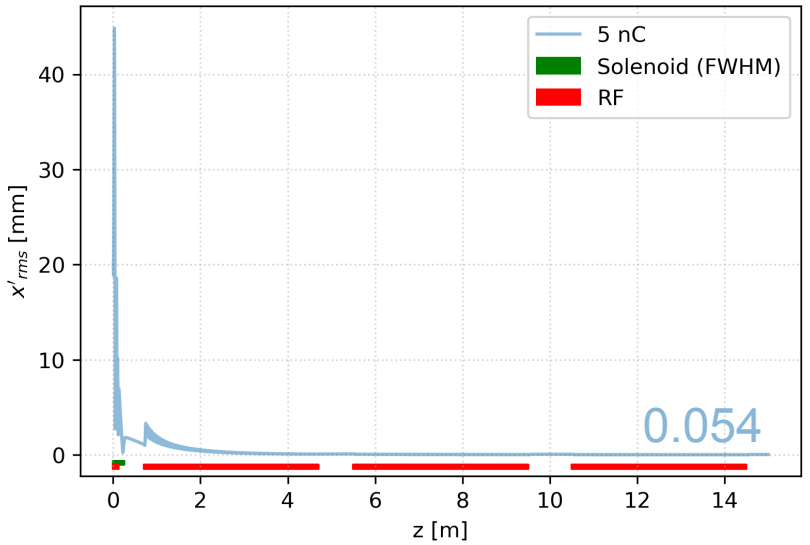
Backup slides

Most optimised bunch

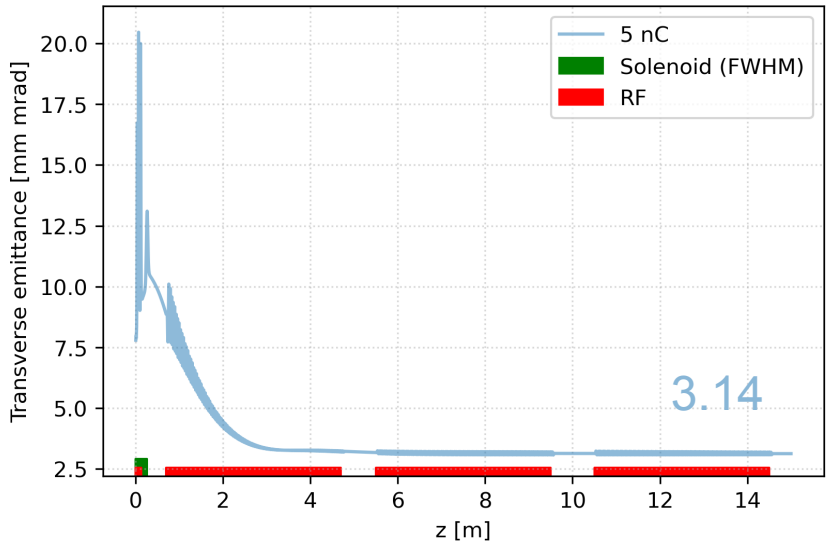
3 GHz RF structures, 4 m long (120 cells)



Bunch transverse size development along the trajectory for 5 nC charge.



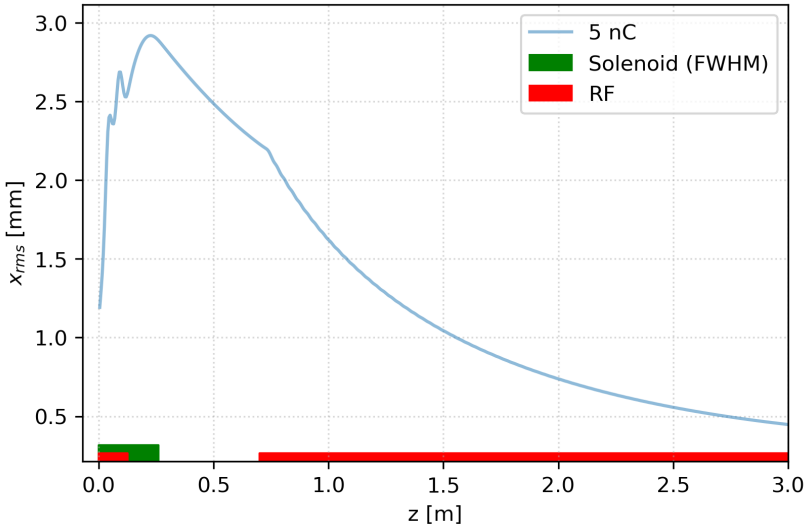
Bunch divergence development along the trajectory for 5 nC charge.



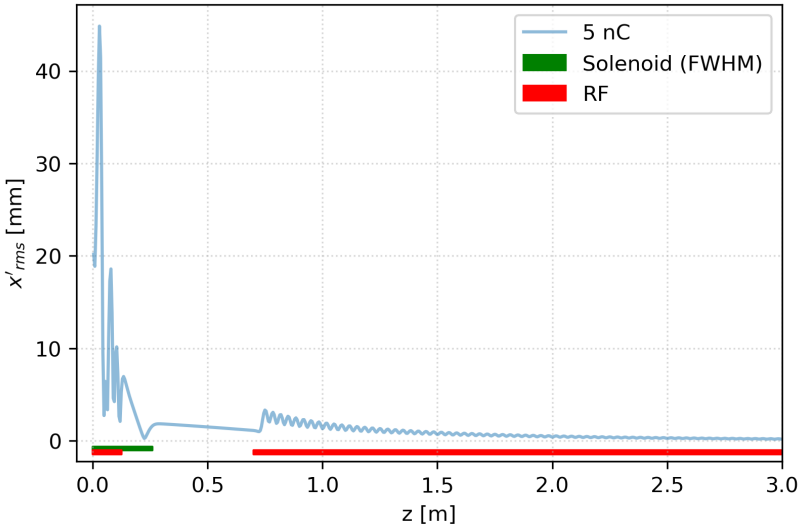
Emittance development along the trajectory for 5 nC charge.

Most optimised bunch – detail

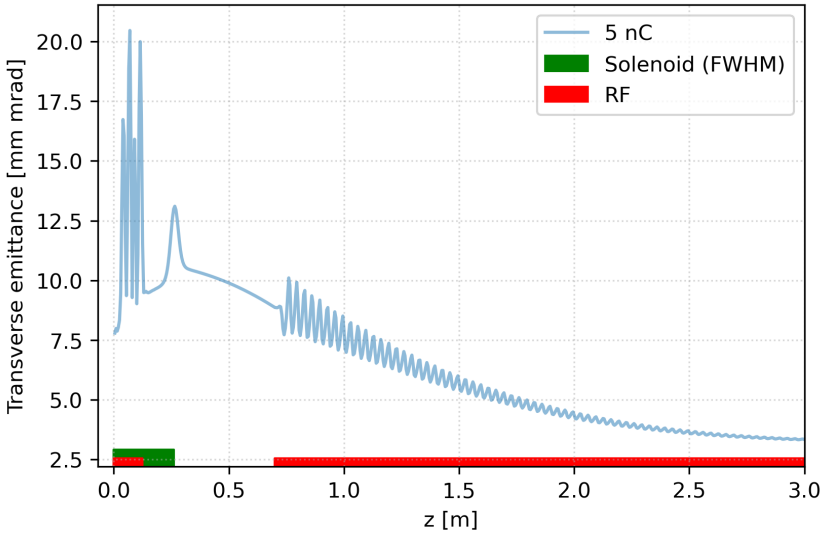
3 GHz RF structures, 4 m long (120 cells)



Bunch transverse size development along the trajectory for 5 nC charge.



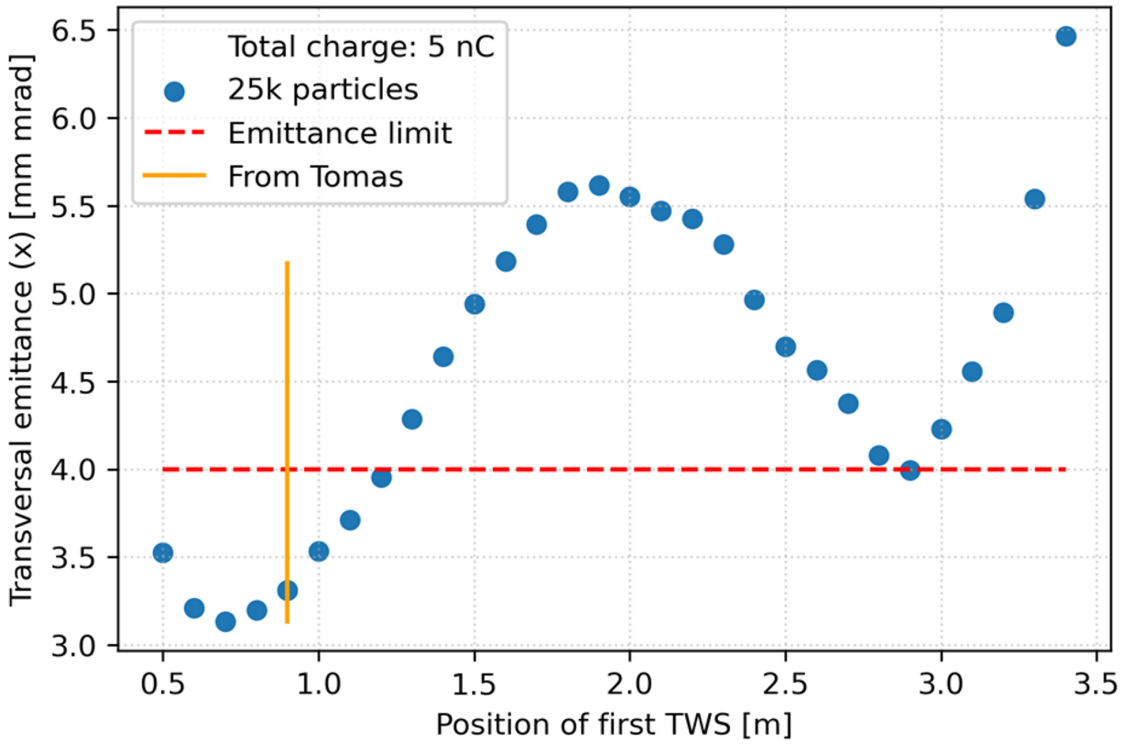
Bunch divergence development along the trajectory for 5 nC charge.



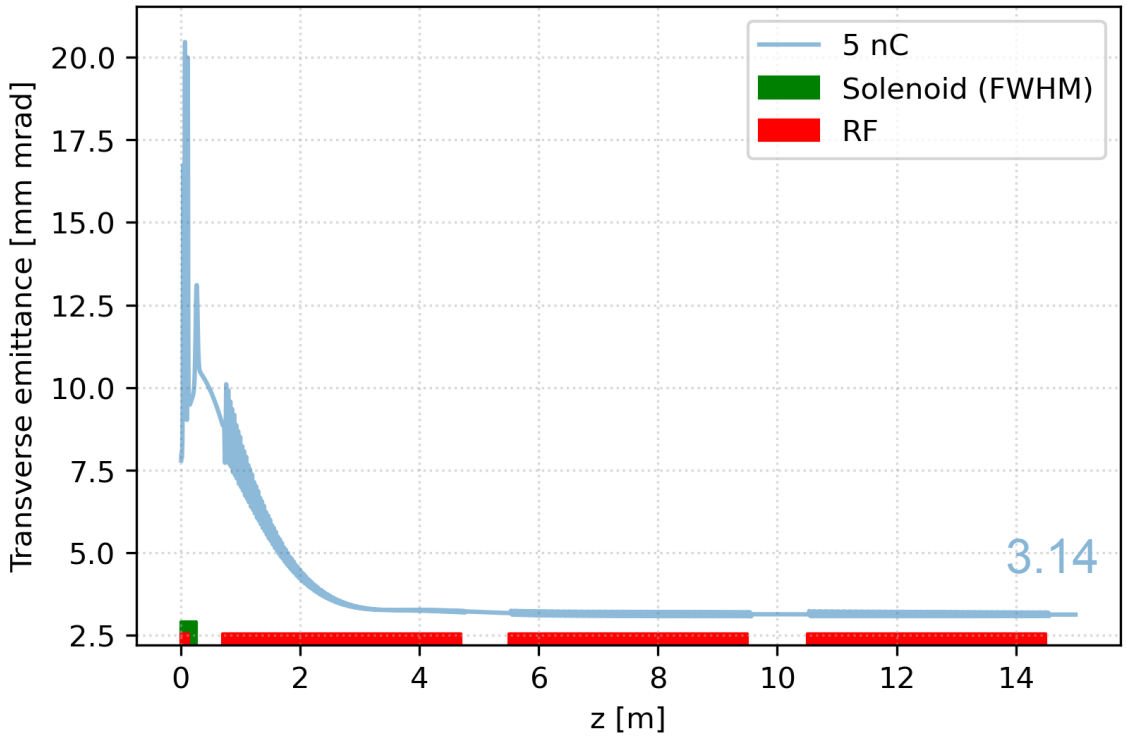
Emittance development along the trajectory for 5 nC charge.

RF position optimisation

For each position of the first TWS, the focusing solenoid magnetic field was optimised

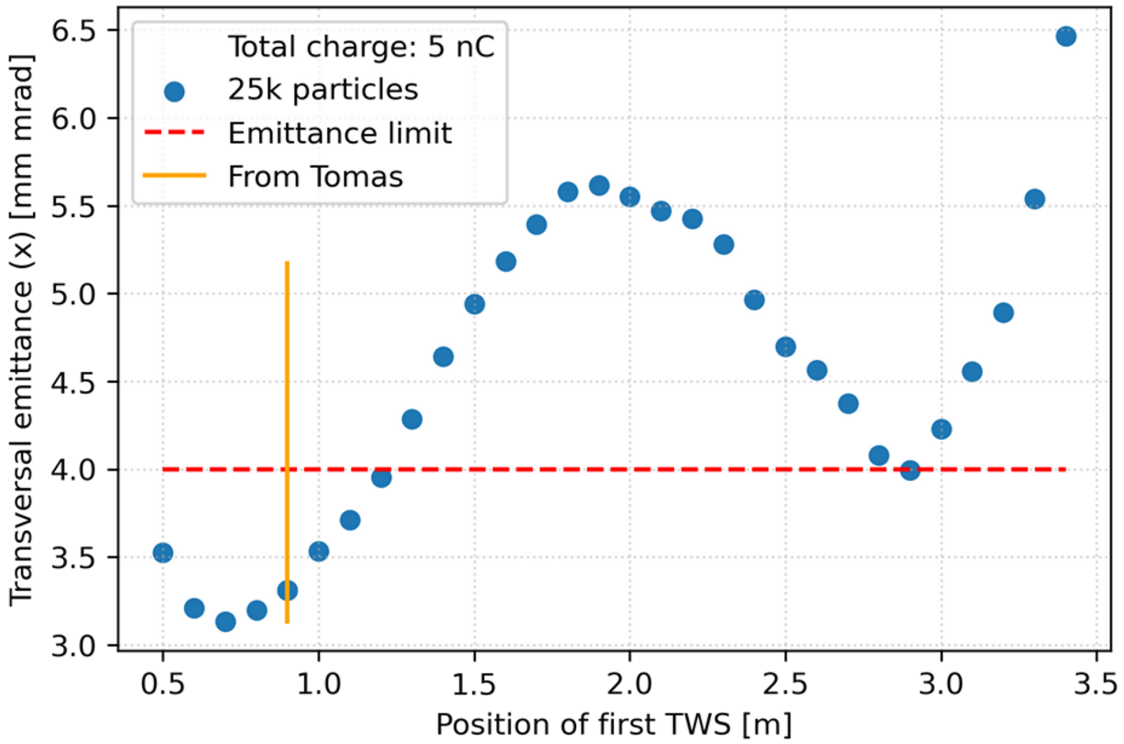


Emittance dependance on the position of the first TWS, focusing magnetic field was optimised.

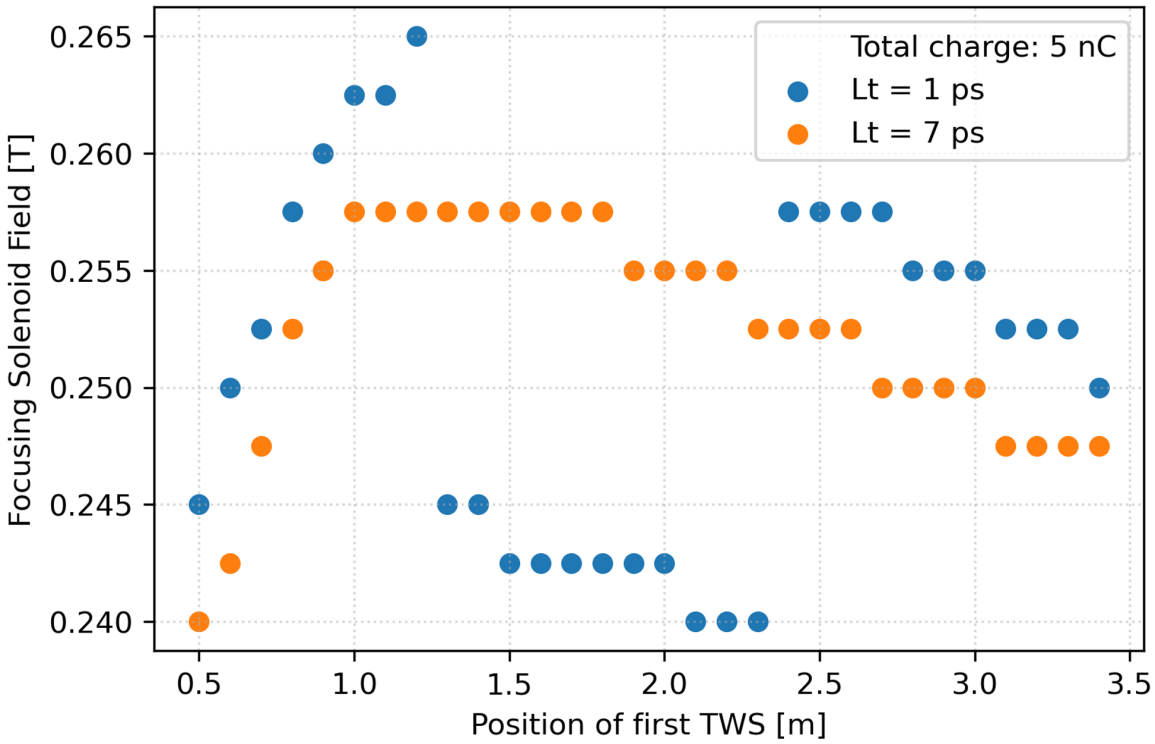


Emittance development along the trajectory achieving the lowest emittance (position of the first TWS = 0.7 m)

RF position optimisation – focusing magnetic field

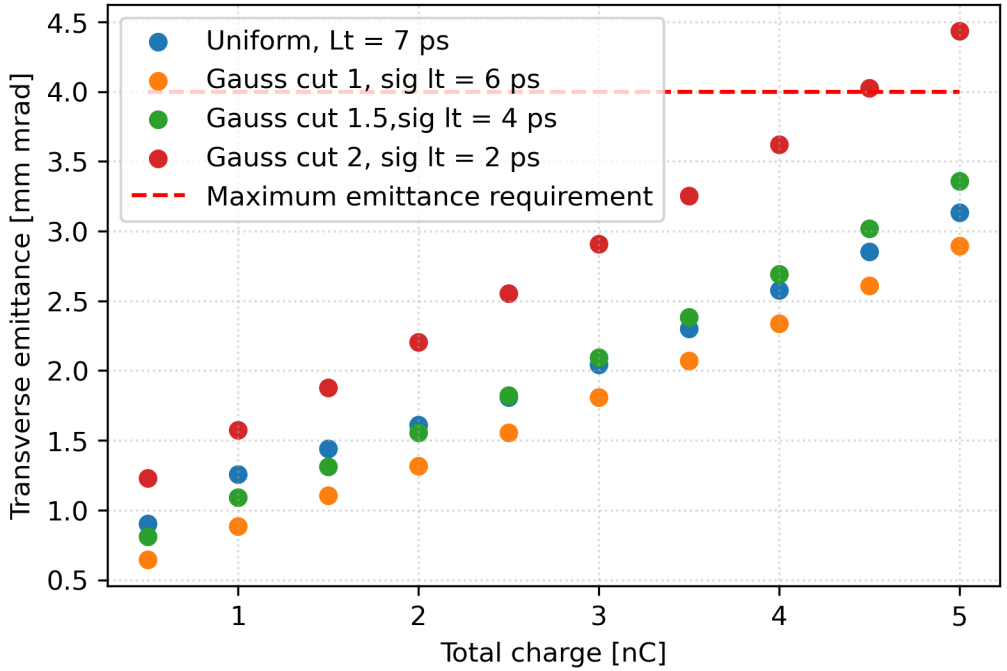


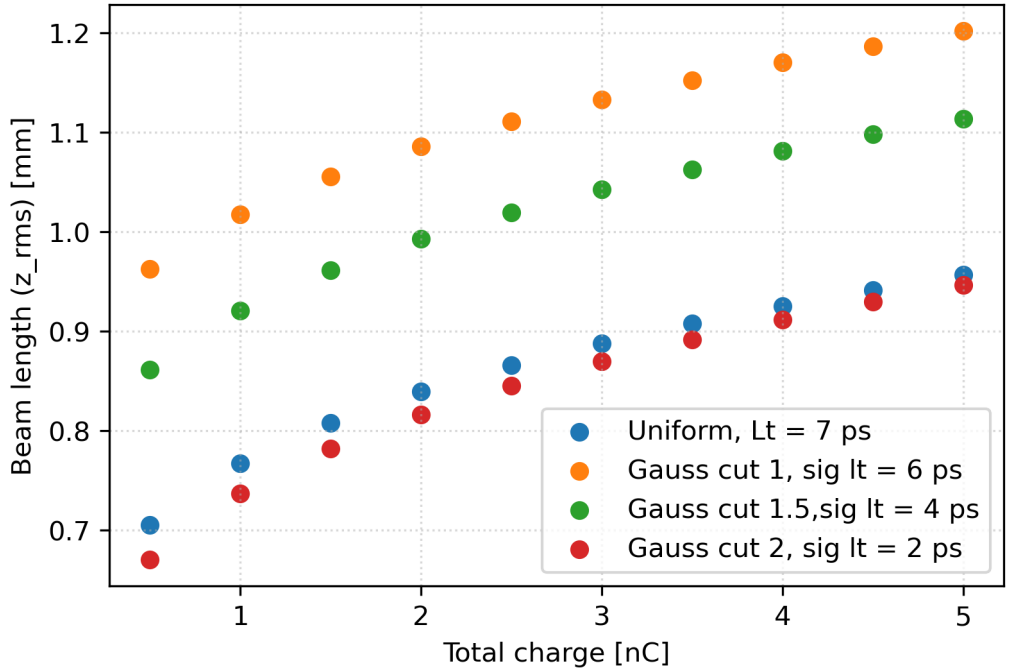
Emittance dependance on the position of the first TWS, focusing magnetic field was optimised.



Emittance development along the trajectory achieving the lowest emittance (position of the first TWS = 0.7 m)

Initial distribution comparison

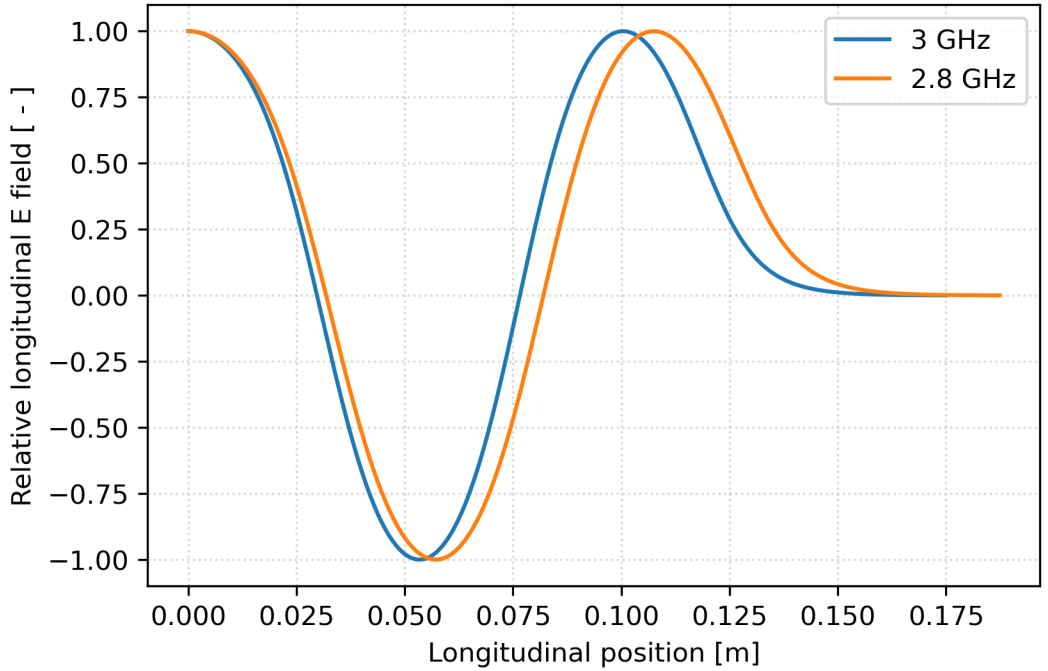




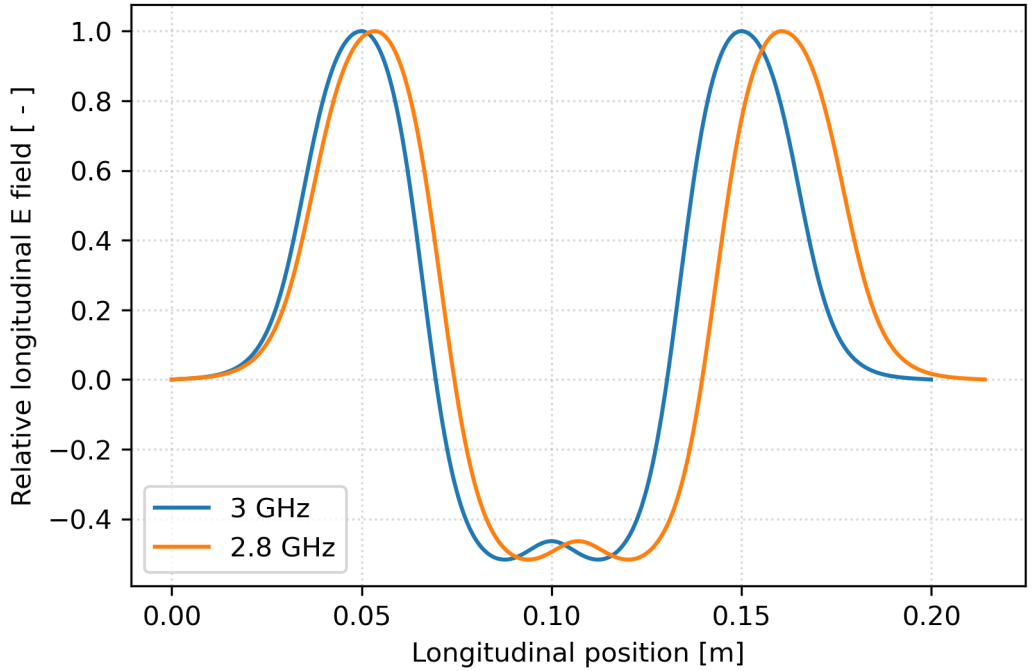
For each of these, focusing magnetic field was optimised

Emittance (left) and rms bunch length (right)dependance on the total charge in the proposed top up injection scheme, different initial distibutions distinguished by color

2.8 vs 3 GHz structures at top-up scheme

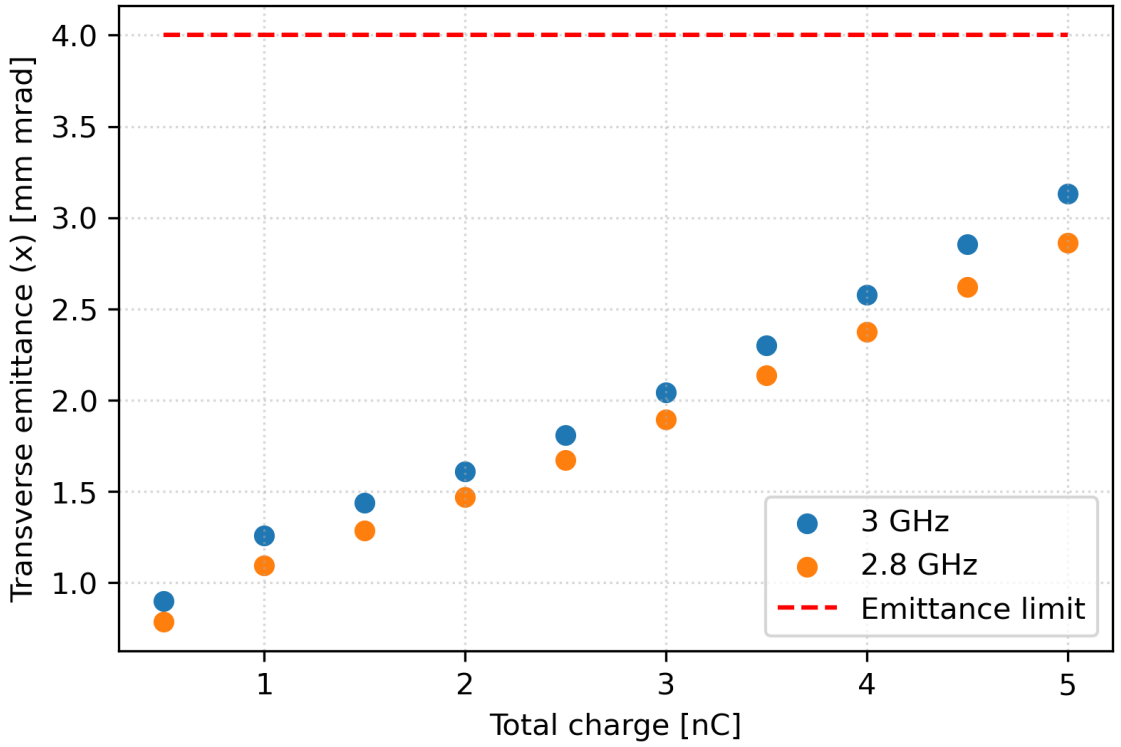


Relative longitudinal electric field dependance of the **gun** (standing wave structure) on the longitudinal position

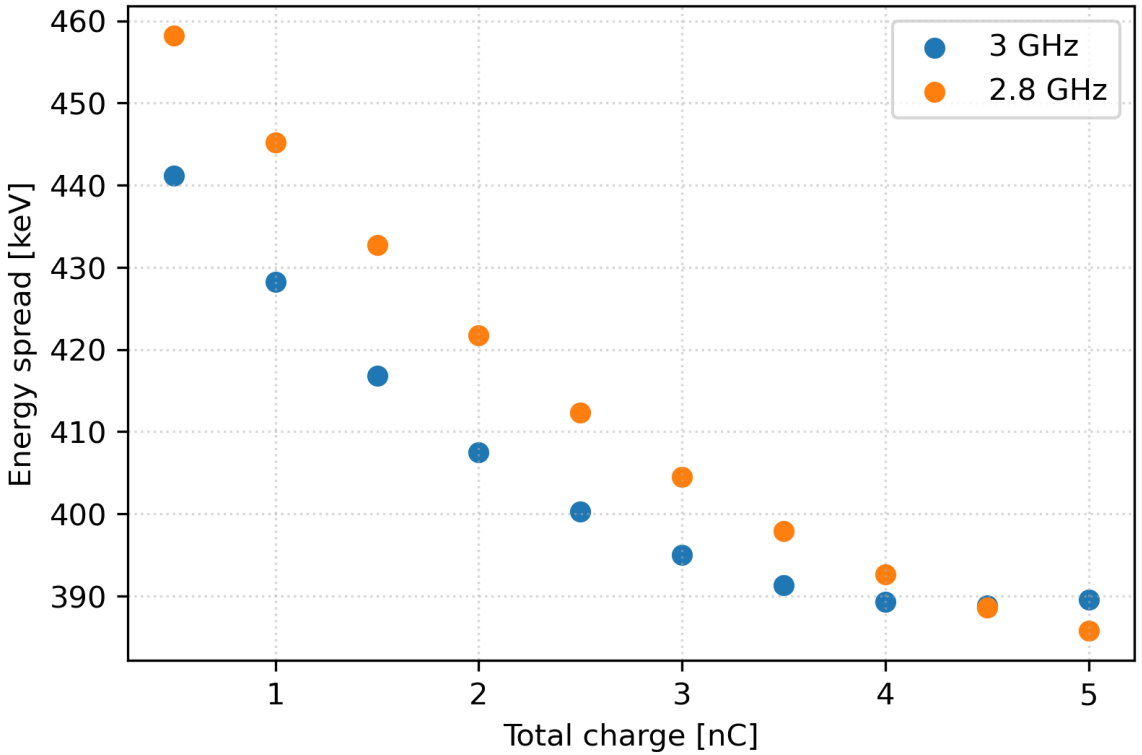


Relative longitudinal electric field dependance of the **TWS** on the longitudinal position

2.8 vs 3 GHz structures at top-up scheme

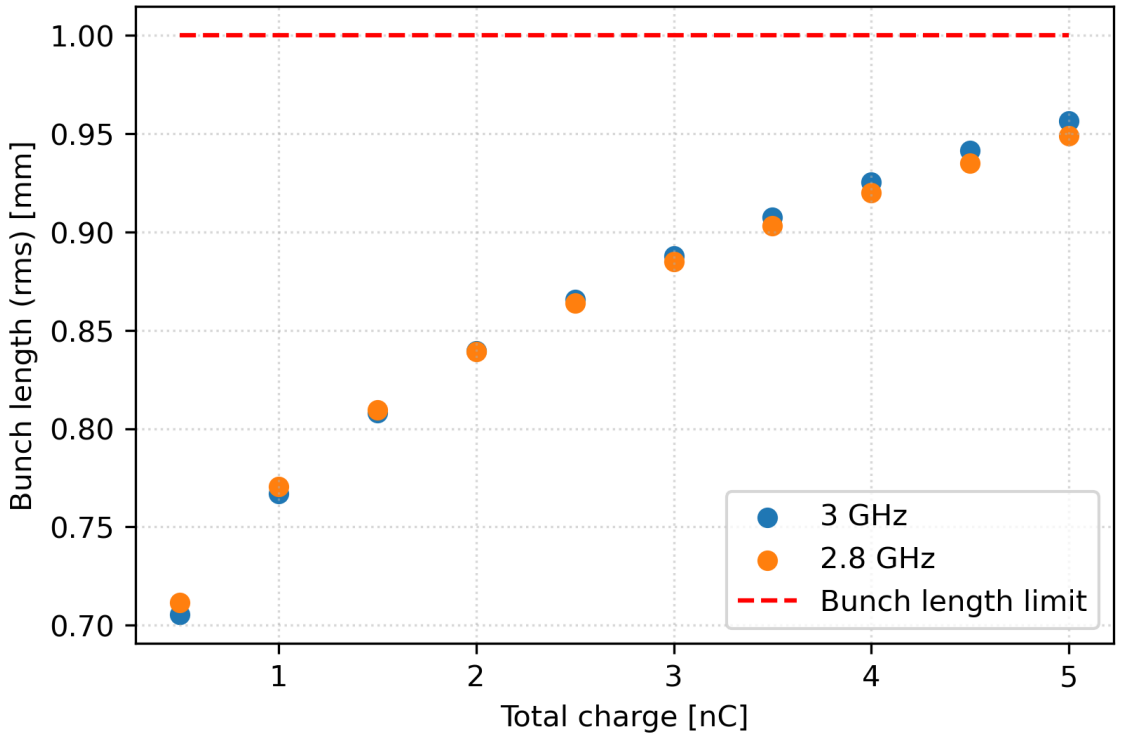


Emittance dependance on the total charge in the proposed top up injection scheme

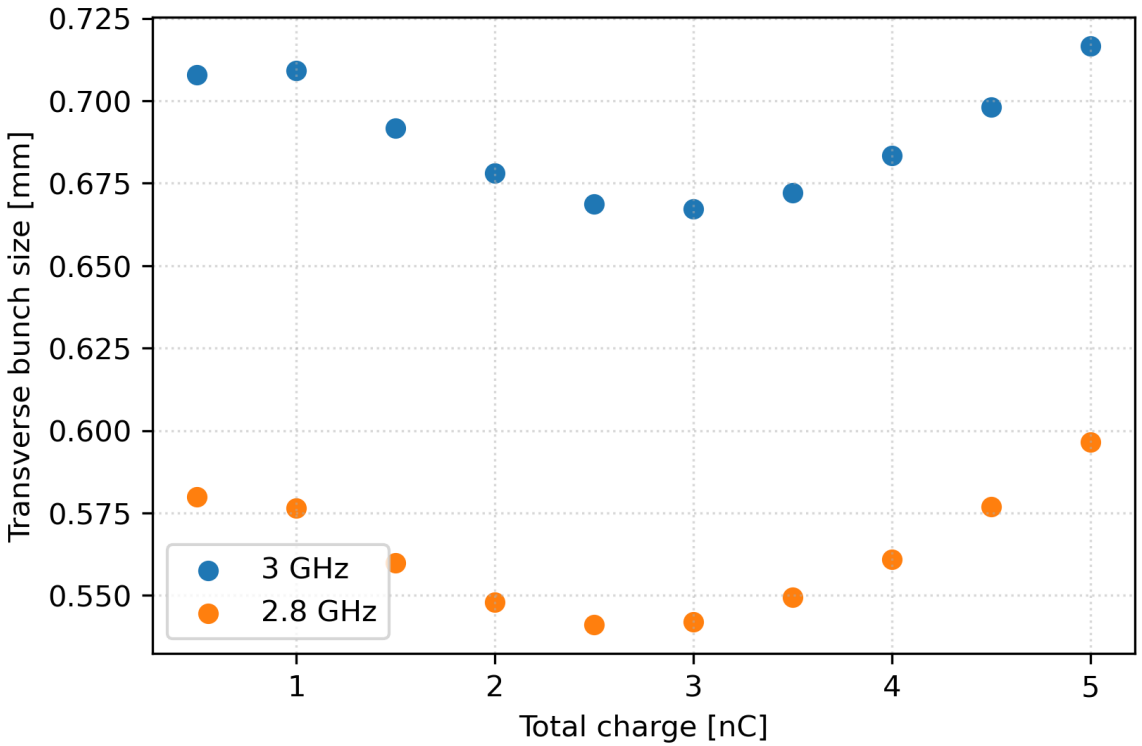


Energy spread dependance on the total charge in the proposed top up injection scheme

2.8 vs 3 GHz structures at top-up scheme

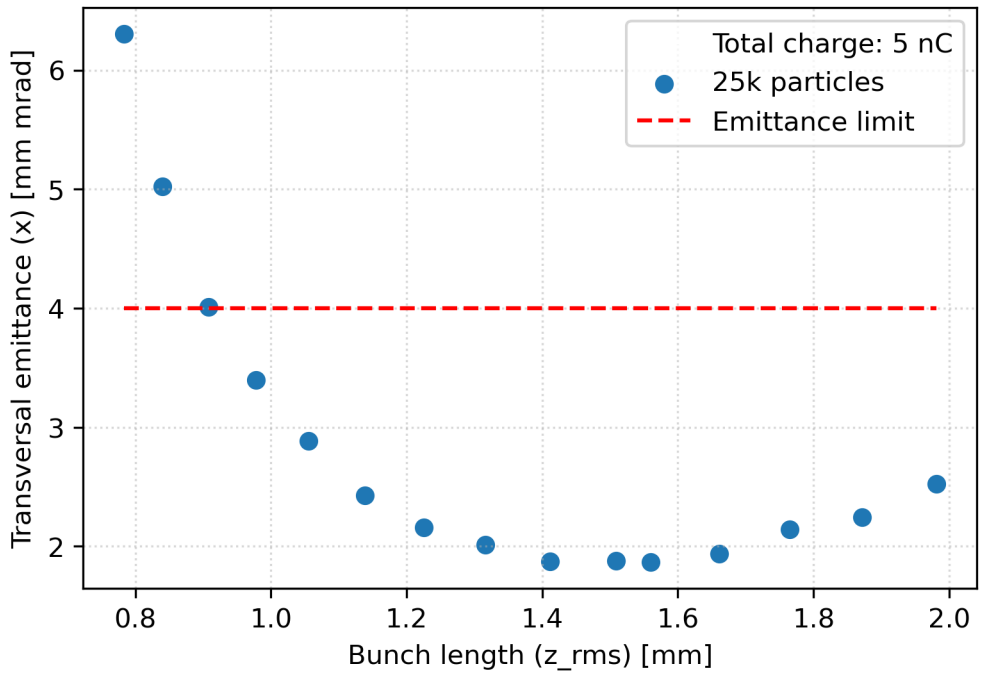


Bunch length dependance on the total charge in the proposed top up injection scheme

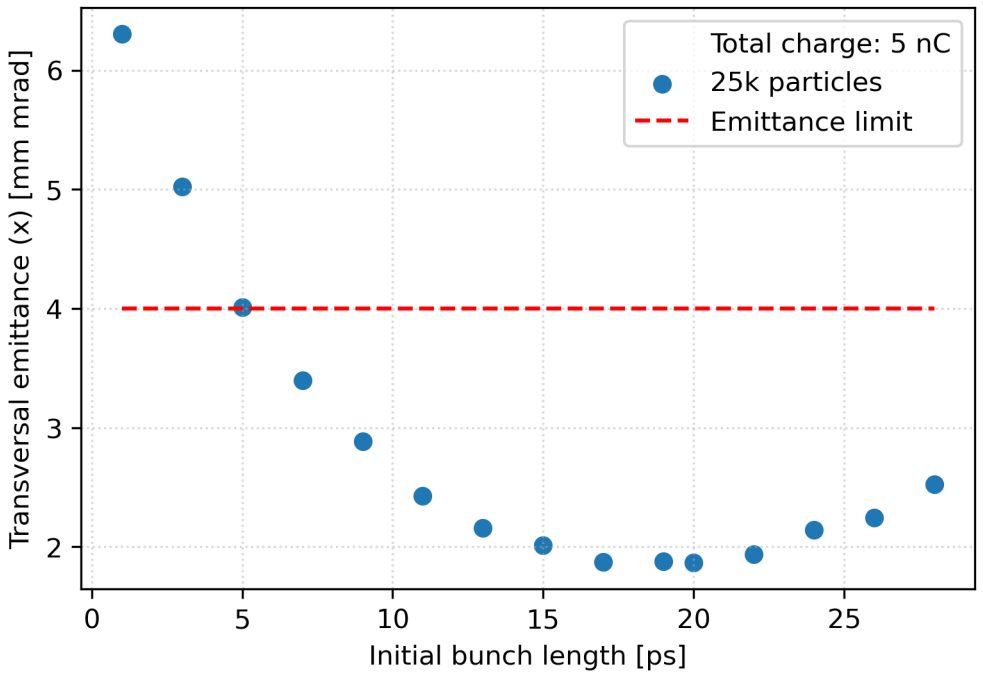


Transverse bunch size dependance on the total charge in the proposed top up injection scheme

Emittance vs bunch length



Emittance dependance **on the bunch length** (changed by the emission length), focusing magnetic field was optimised for all cases.



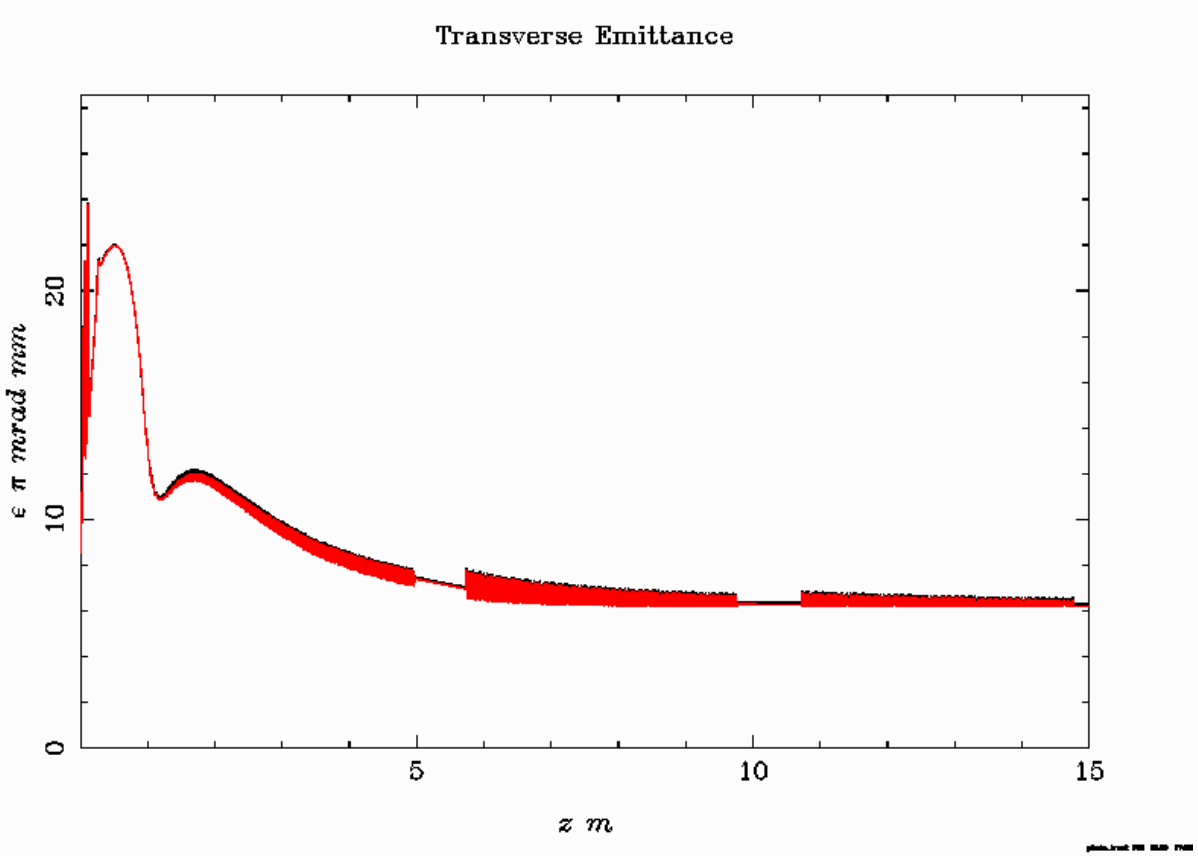
Emittance dependance **on the emission time**, focusing magnetic field was optimised for all cases.

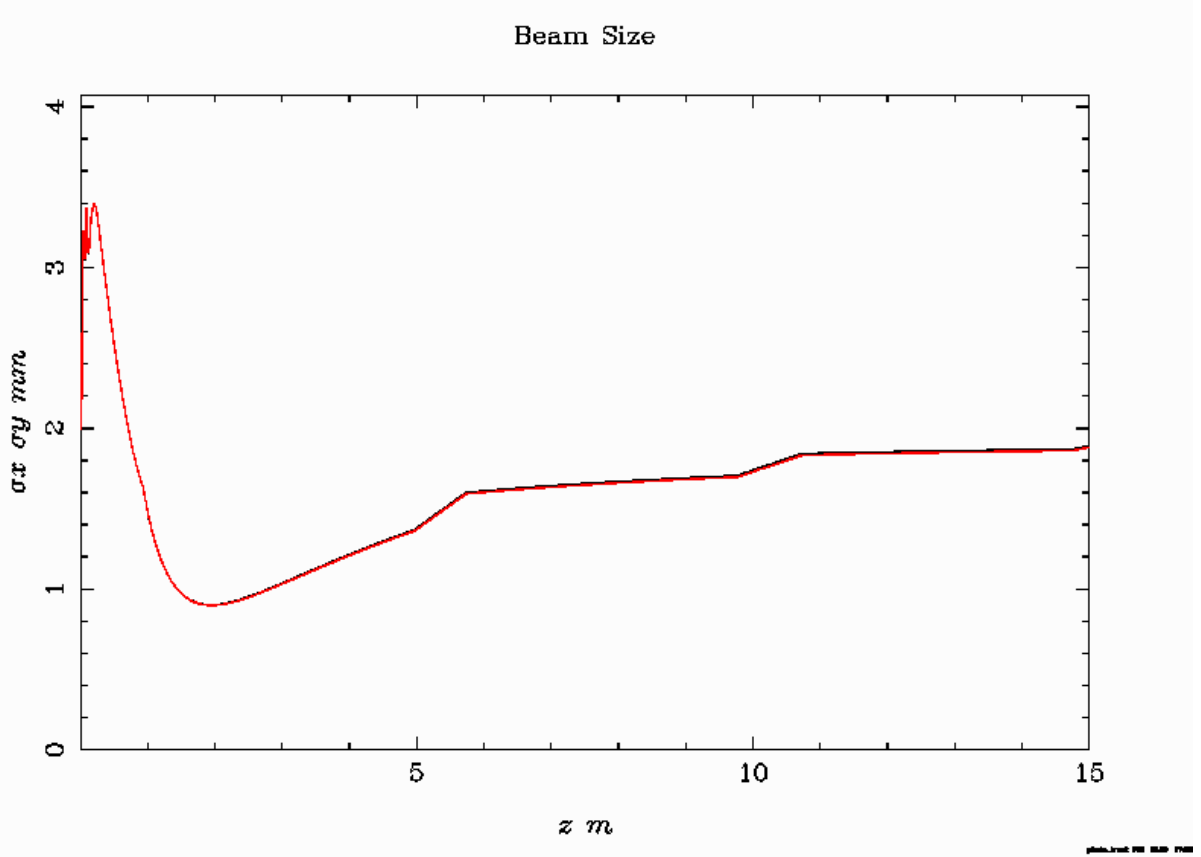
From Steffen:

FCC-ee simulations

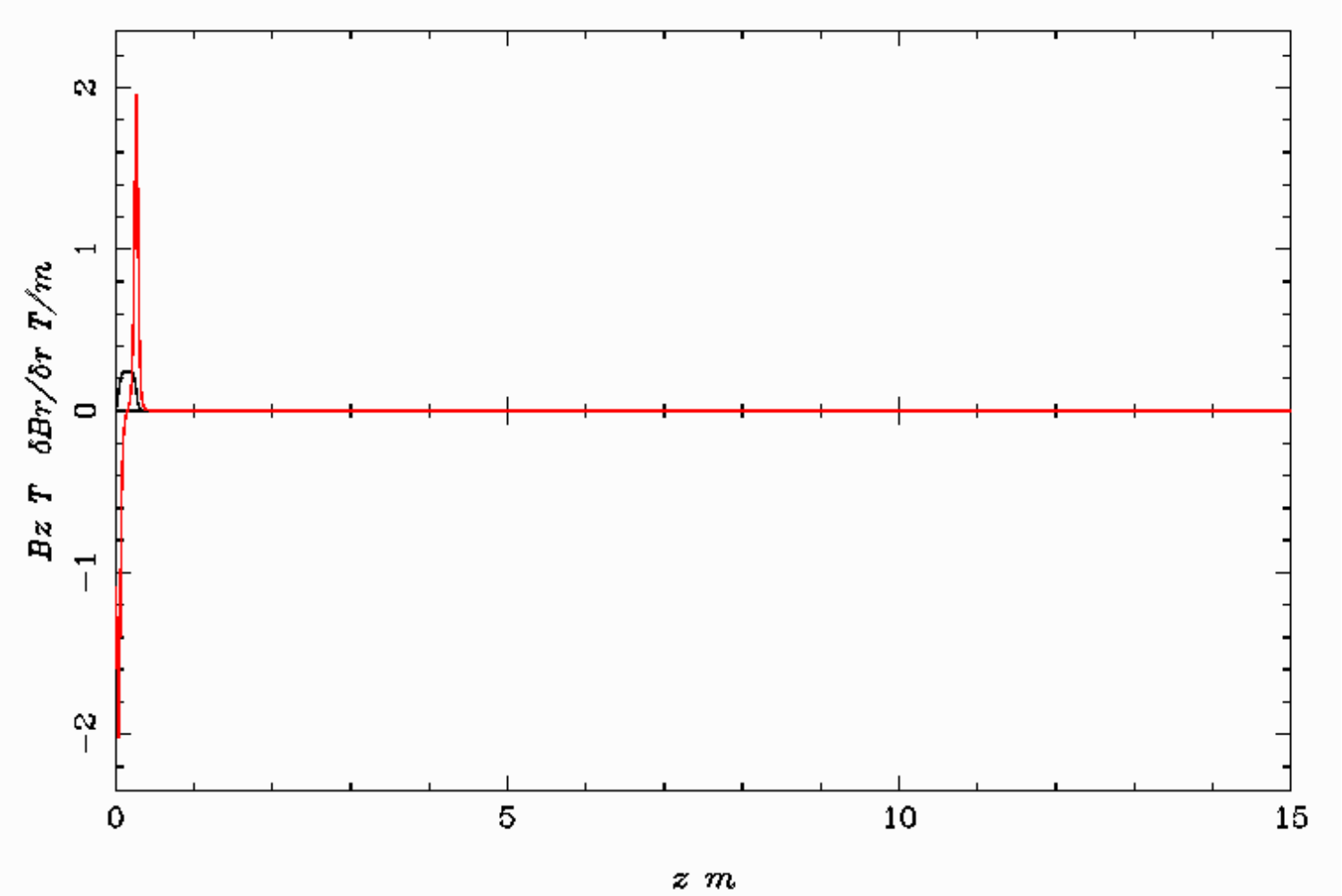
Uniform distribution, 5.0 nC, spot size: 2.0 mm, Bsol:0.243 T, Accdist:0.9 m, pulse length 4 ps

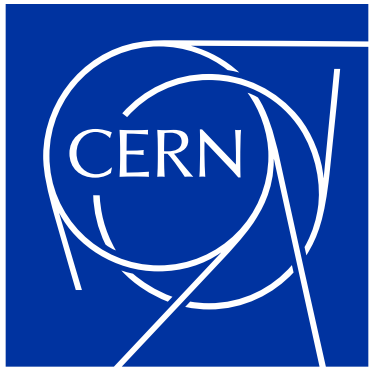
Emittance: 6.1 mm mrad, beam size: 1.9 mm , bunch length: 0.65 mm, deltaE= 0.24 %





Solenoid field





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