Energy spread optimisation in the CLIC main linac at 380 GeV

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in collaboration with
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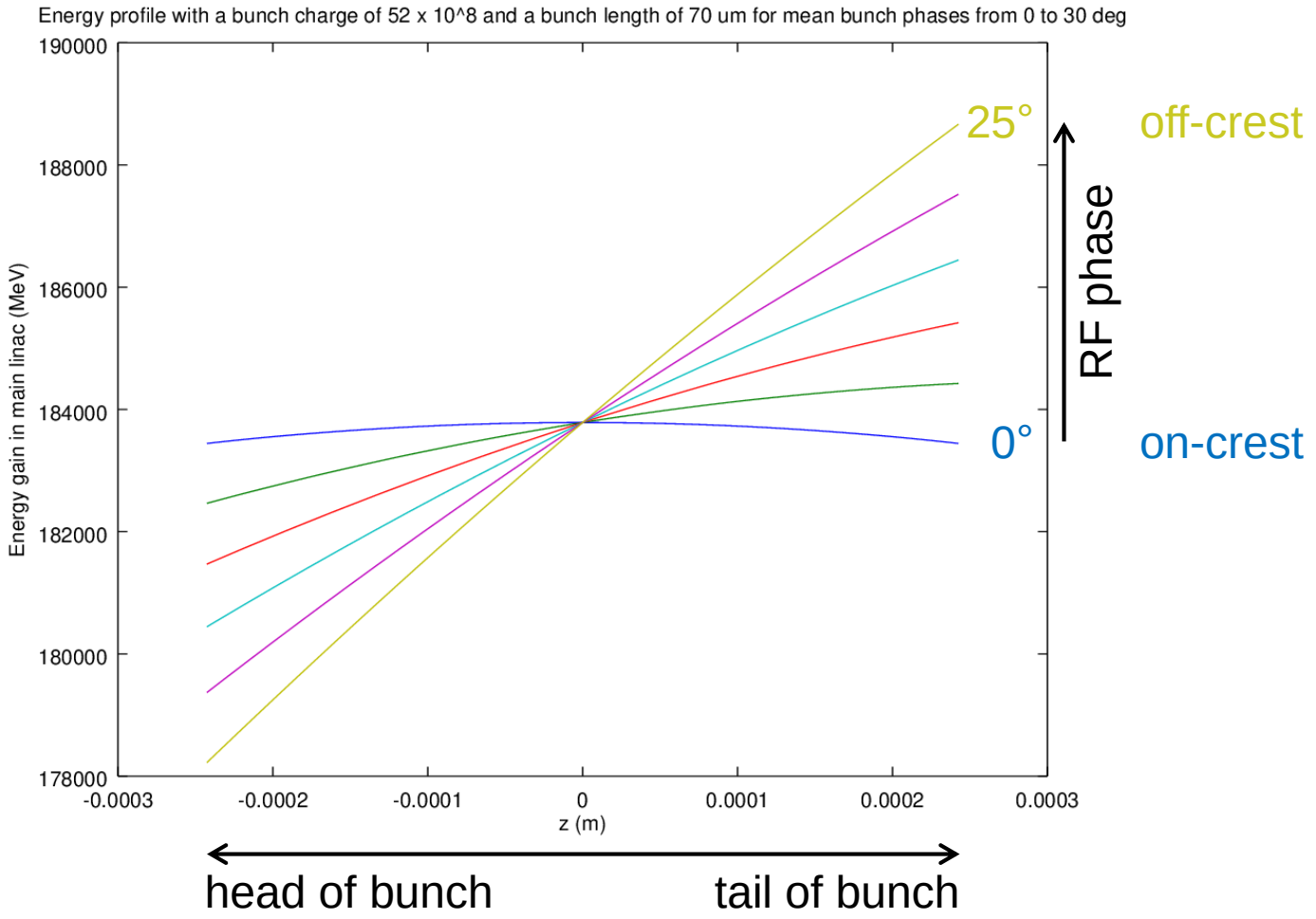
Contents

- Energy spread from RF & wakefields
- Mitigating emittance growth
- Bunch energy profiles for 380 GeV CLIC
- Optimum linac RF phase combination

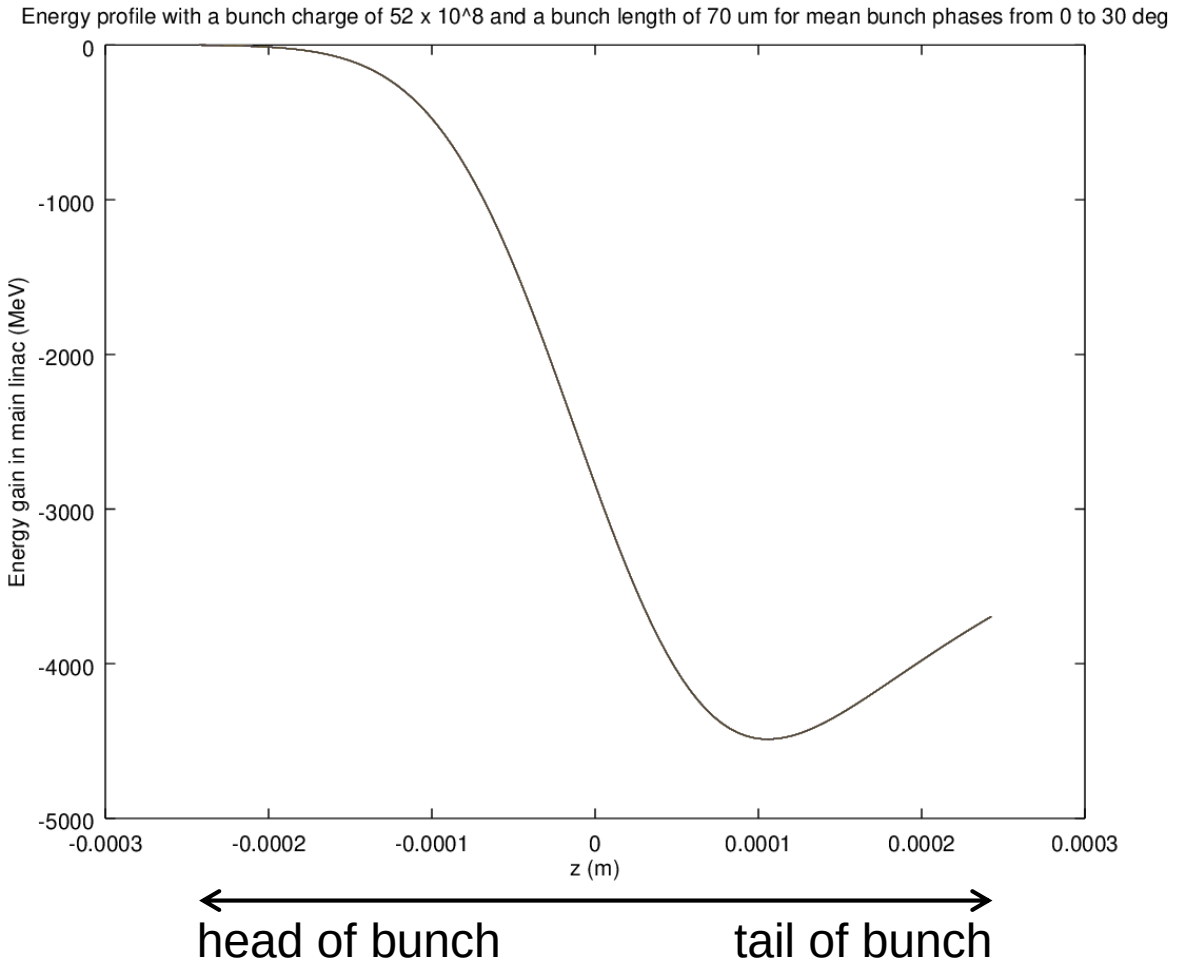
Energy spread

- Energy spread develops in the bunch from
  - RF time-varying profile
  - Bunch wakefield effect

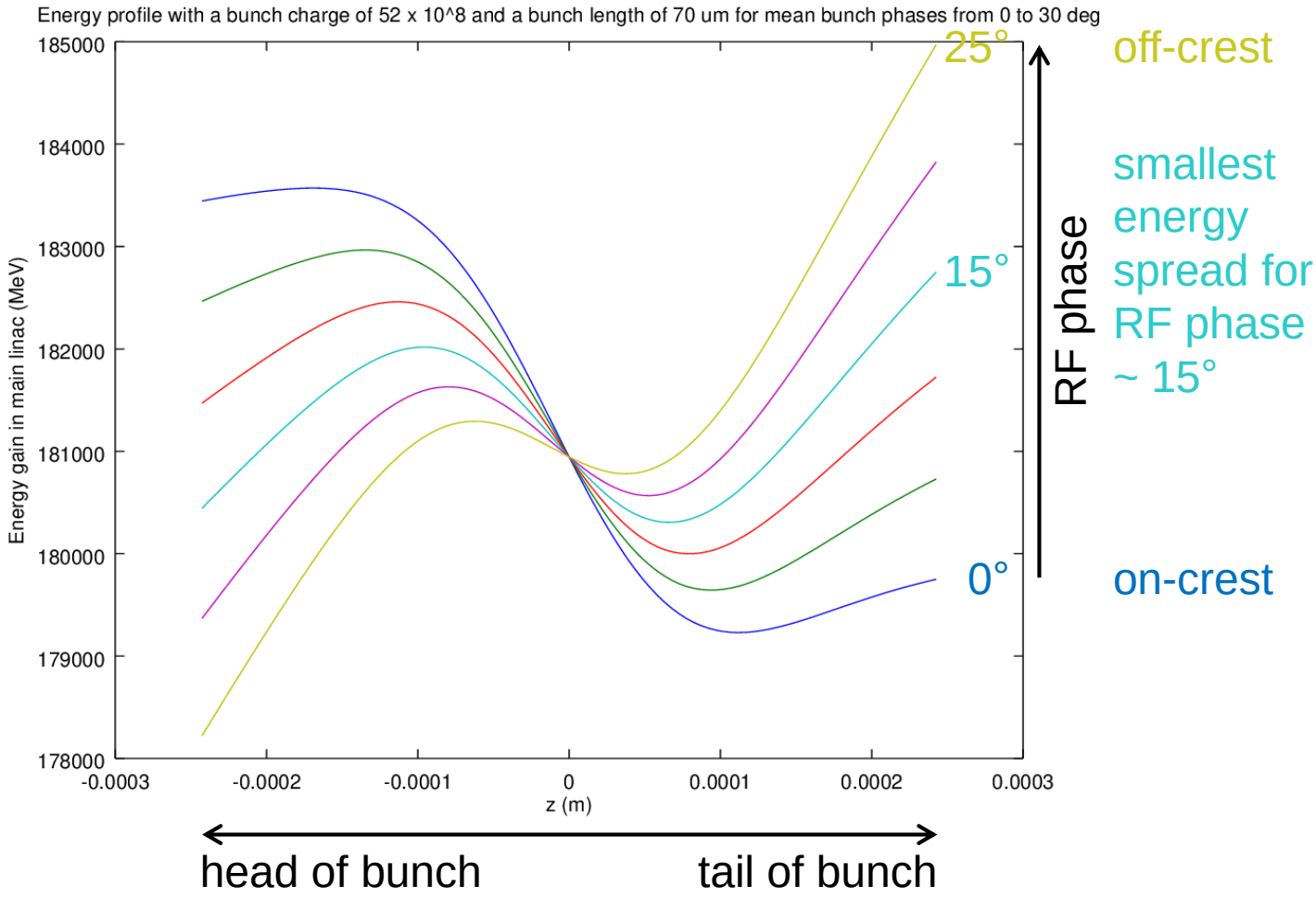
RF contribution



Wakefield contribution



Combined contribution



Emittance growth

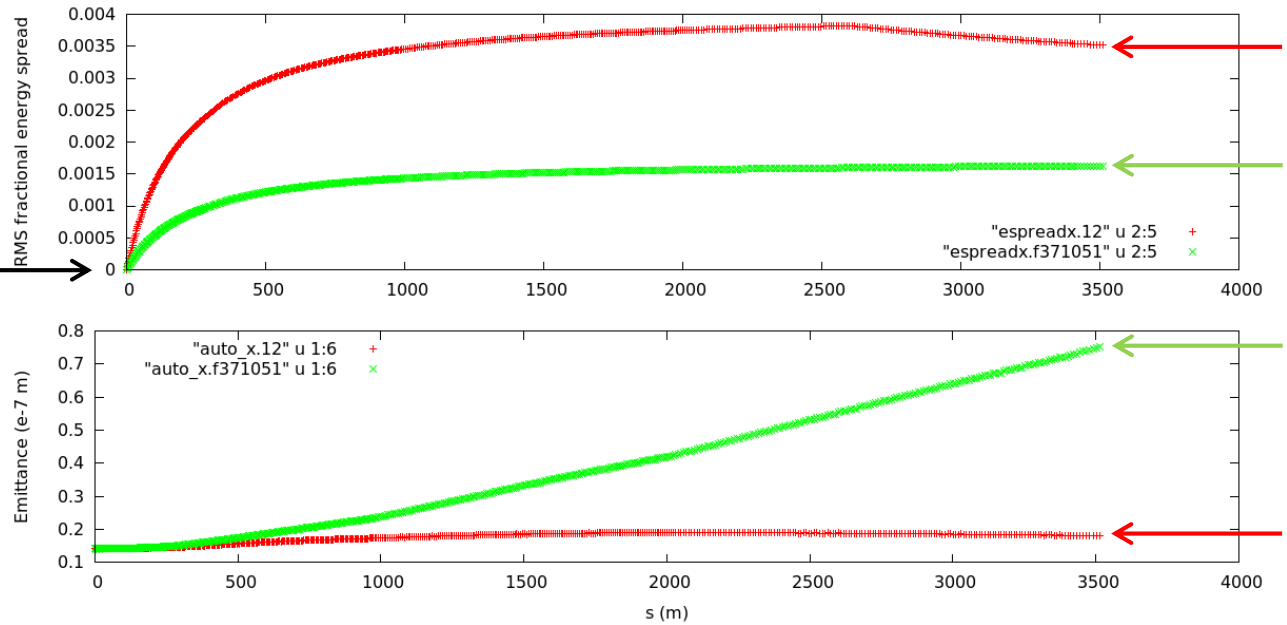
- Bunch tail experiences a defocusing force due to transverse wakefields, leading to emittance growth and ultimately beam break-up
- Mitigate emittance growth by using BNS damping (Balakin, Novokhatsky and Smirnov, HEACC 1983)

BNS damping

- Introduce energy spread along the bunch so that tail has a lower energy than head
- Thus, quadrupole focusing (stronger for bunch tail due to lower energy) balances transverse wakefield's defocusing force
- Lower energy tail can be achieved by accelerating on-crest at start of linac
- Subsequently remove this energy spread by accelerating off-crest at end of linac

Poor BNS damping

assume no incoming energy spread



original

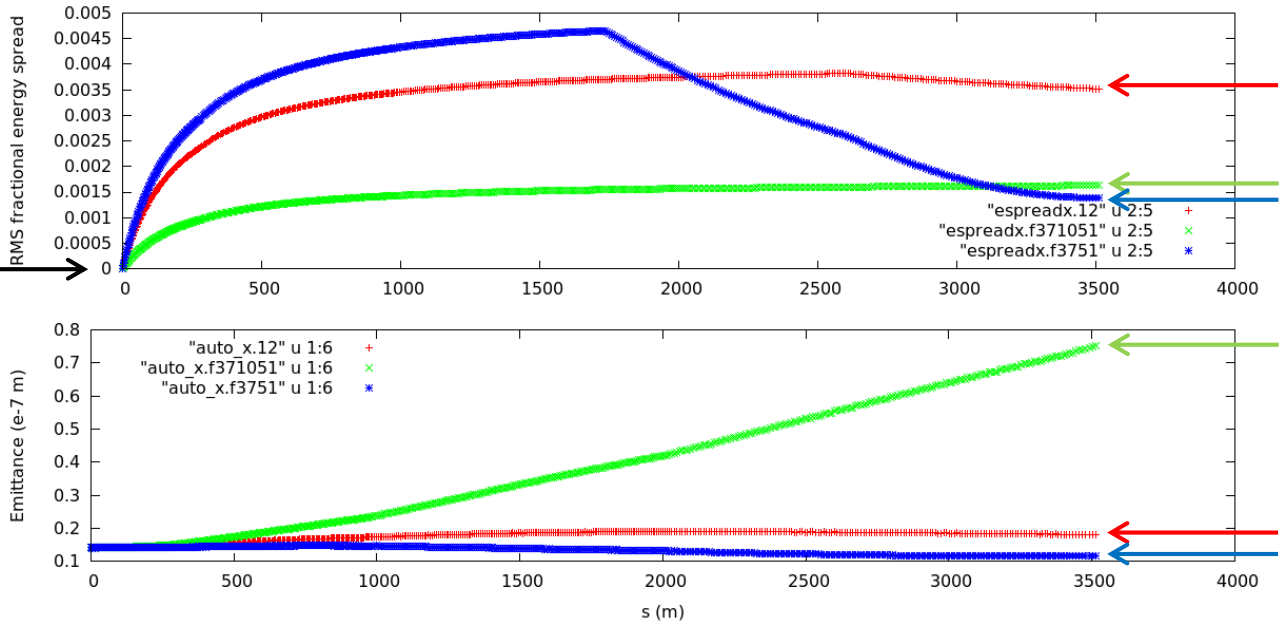
low energy spread

huge emittance!

original

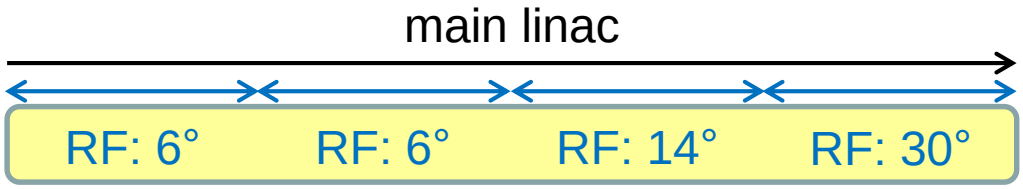
Good BNS damping

assume no incoming energy spread



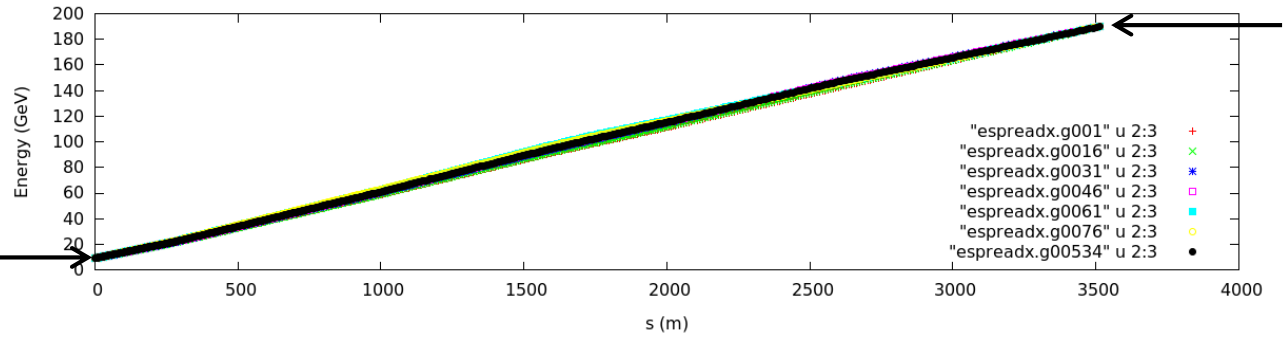
380 GeV design

- Baseline 380 GeV design simulated with:
  - Nominal bunch charge: 5.2 x 10^9 particles
  - Nominal bunch length: 70 um
- Energy spread optimised at 0.35% (std) at the end of the linac by D. Schulte et al.
- Latest RF phases selected by C. Gohil for low emittance & 0.35% std energy spread:



RF phase combinations

linac injection at 9 GeV



190 GeV

RF: 0°	RF: 0°	RF: 0°	RF: 0°
RF: 0°	RF: 0°	RF: 0°	RF: 15°
RF: 0°	RF: 0°	RF: 0°	RF: 30°
RF: 0°	RF: 0°	RF: 15°	RF: 30°
RF: 0°	RF: 0°	RF: 30°	RF: 30°
RF: 0°	RF: 15°	RF: 30°	RF: 30°
RF: 6°	RF: 6°	RF: 14°	RF: 30°

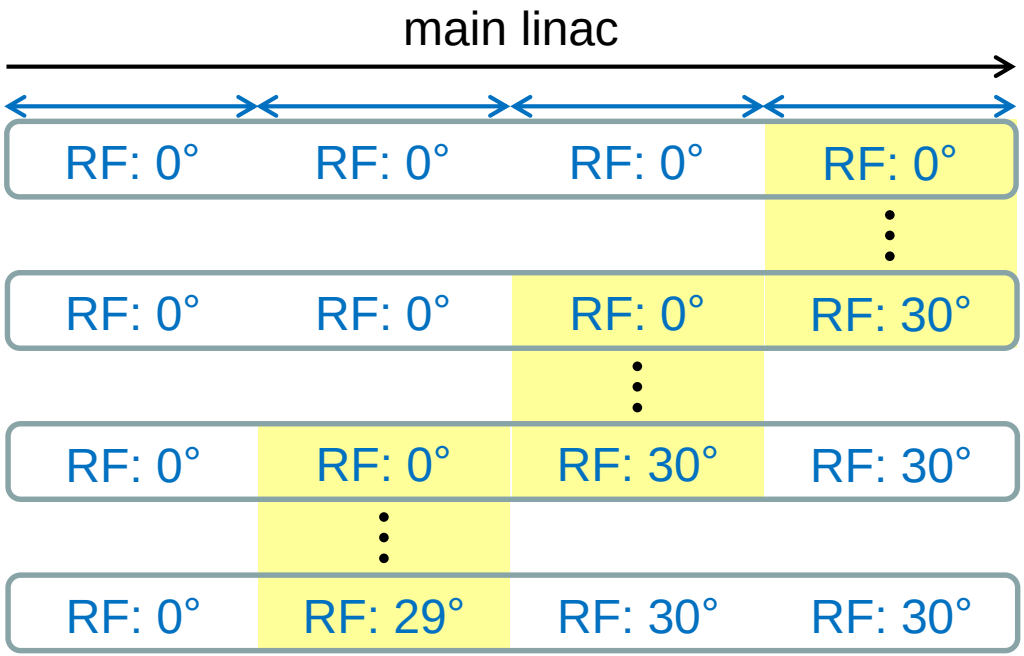
optimum

Simulation

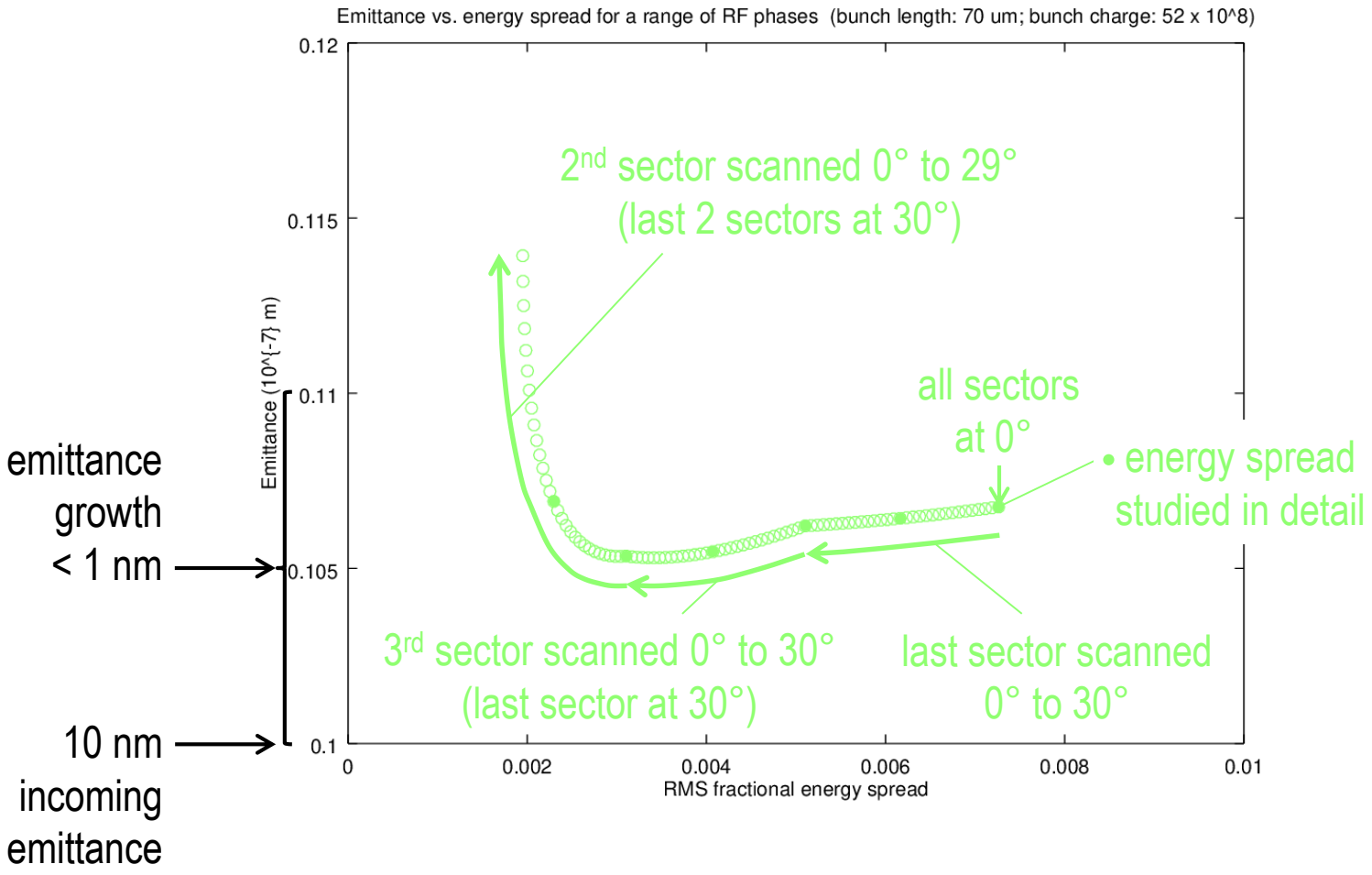
- 200 slices, 2000 macroparticles/slice
- Emittance calculated relative to bunch axis
- No incoming beam offset
- Incoming RMS energy spread: 1.6%
- RMS vertical quad position error: 10 nm
- Incoming horizontal emittance: 920 nm
- Incoming vertical emittance: 10 nm
- RF accelerating gradient: ≤ 72 MV/m

RF phase scan

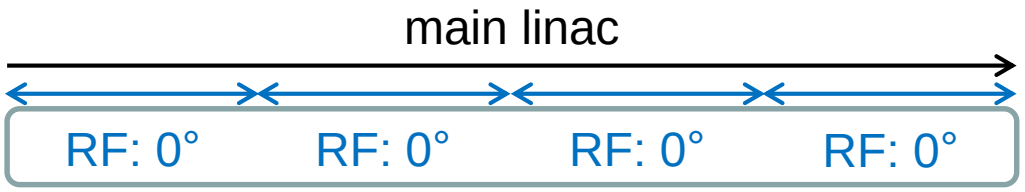
- Scan sequentially fourth, third and second sectors' RF phases from 0° to 30°

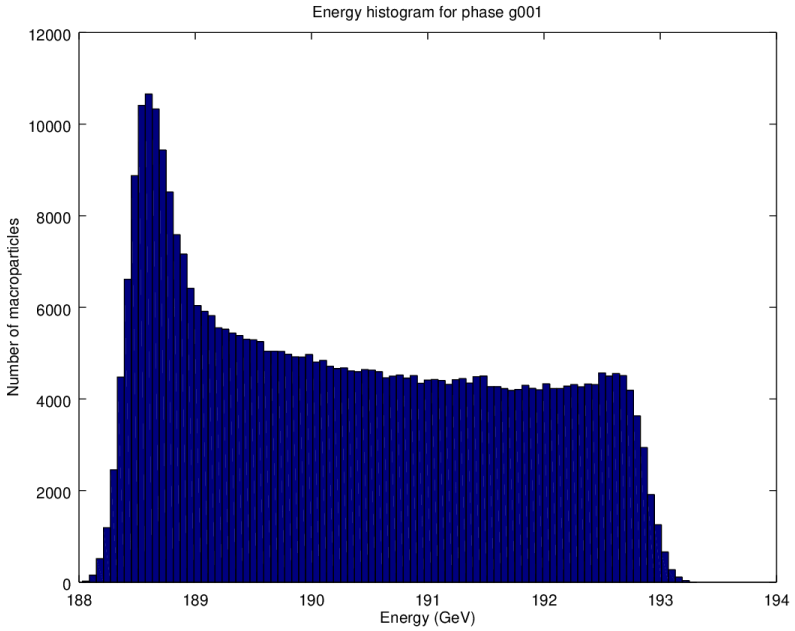


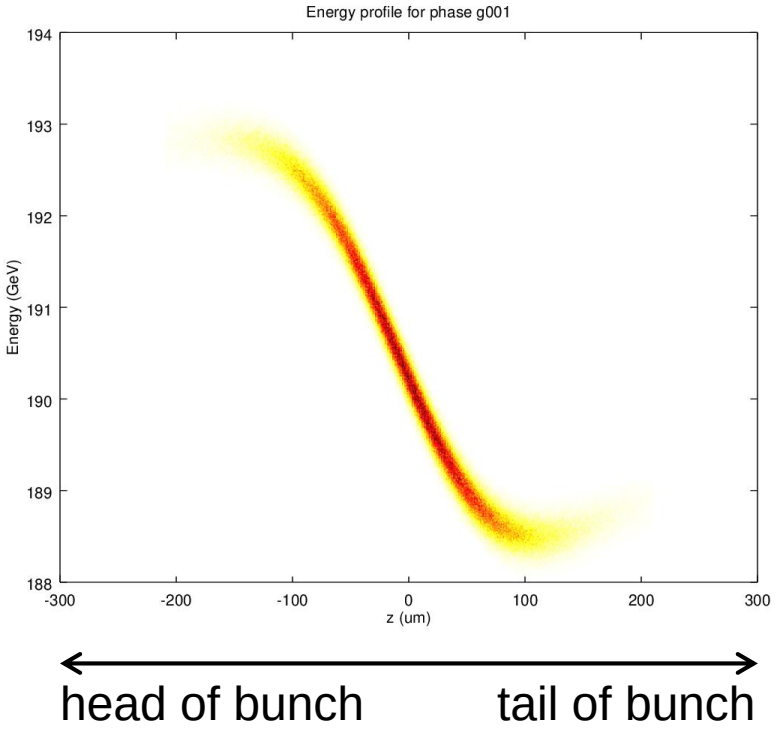
RF phase scan



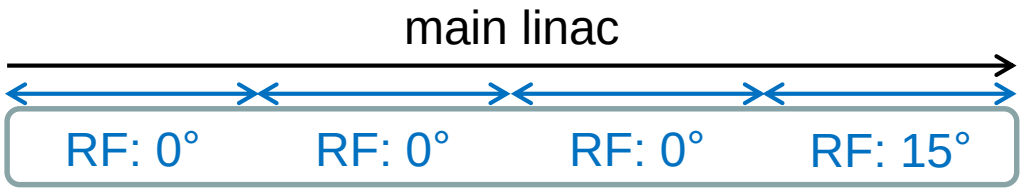
Energy profile

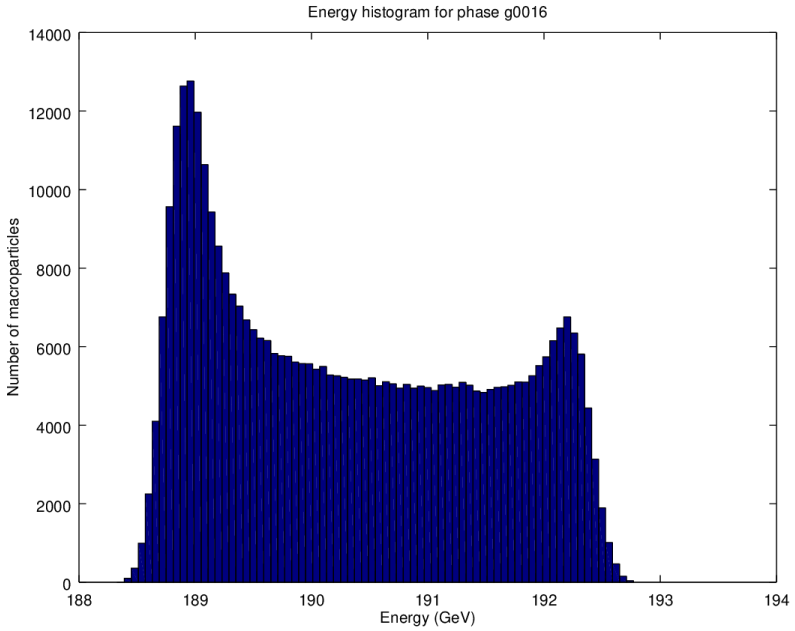


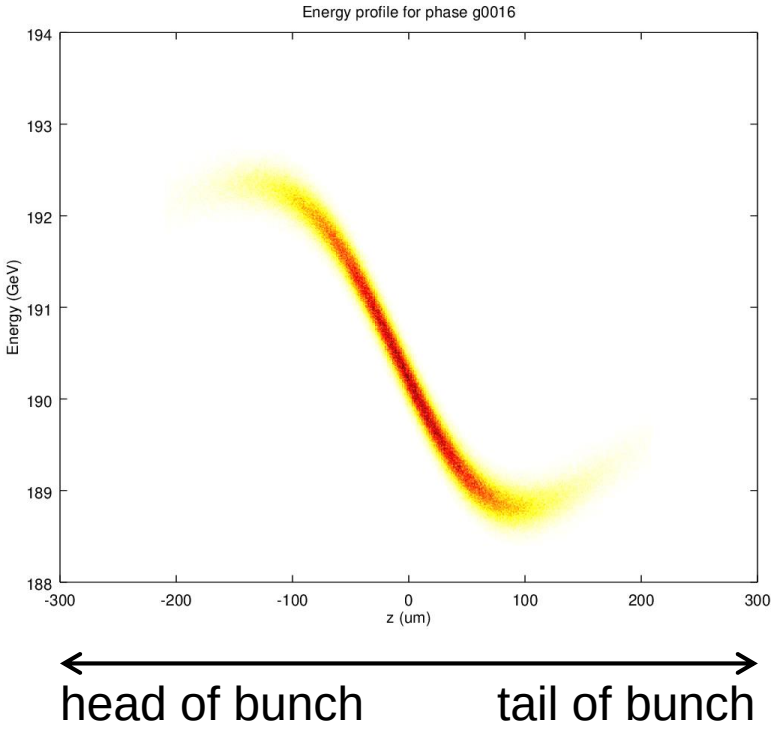




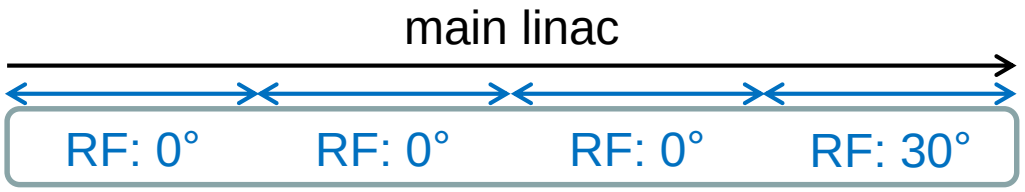
Energy profile

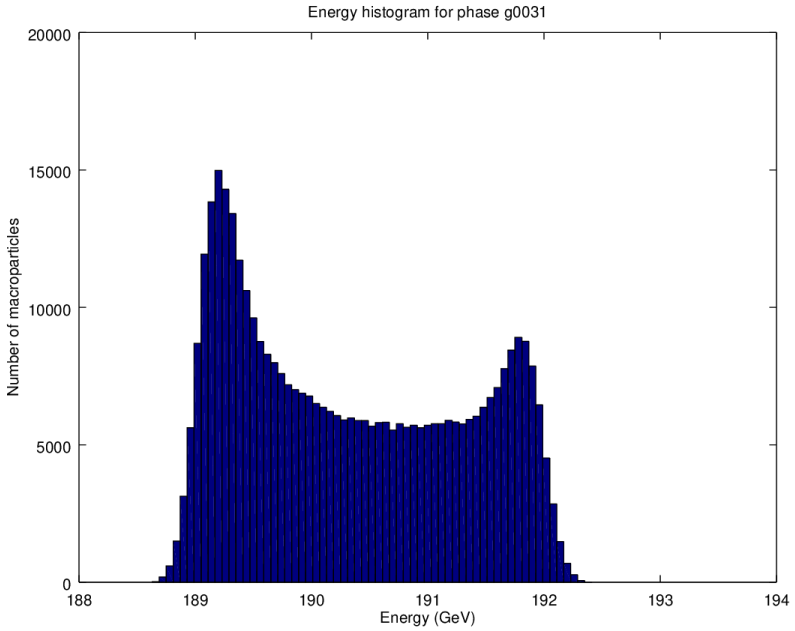


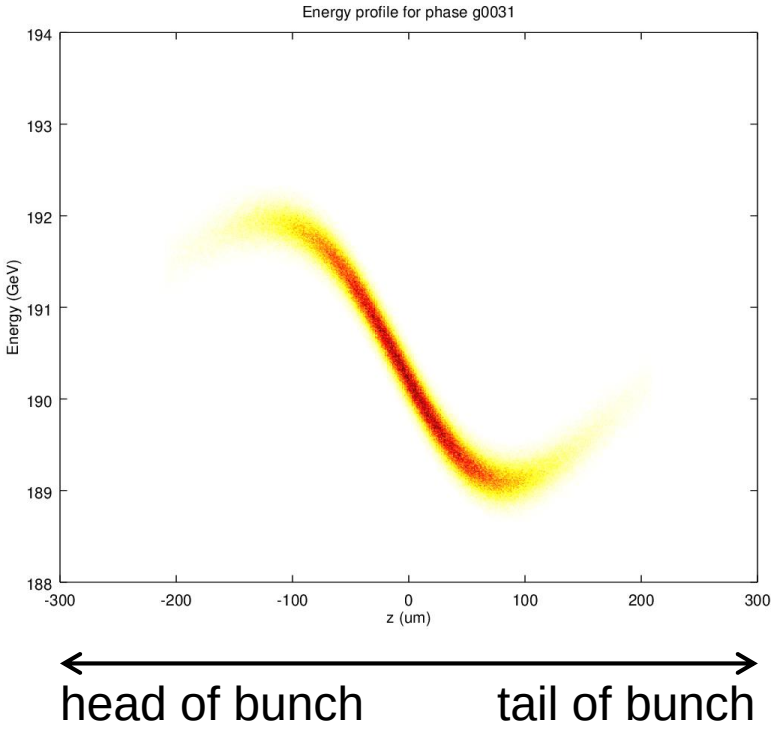




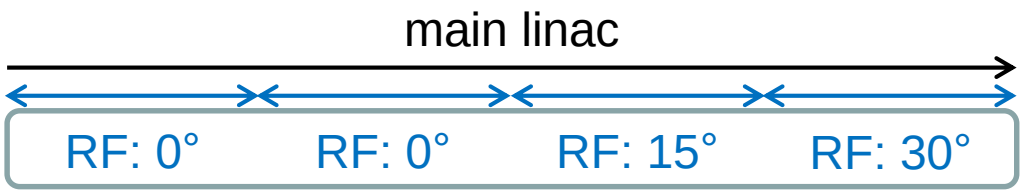
Energy profile

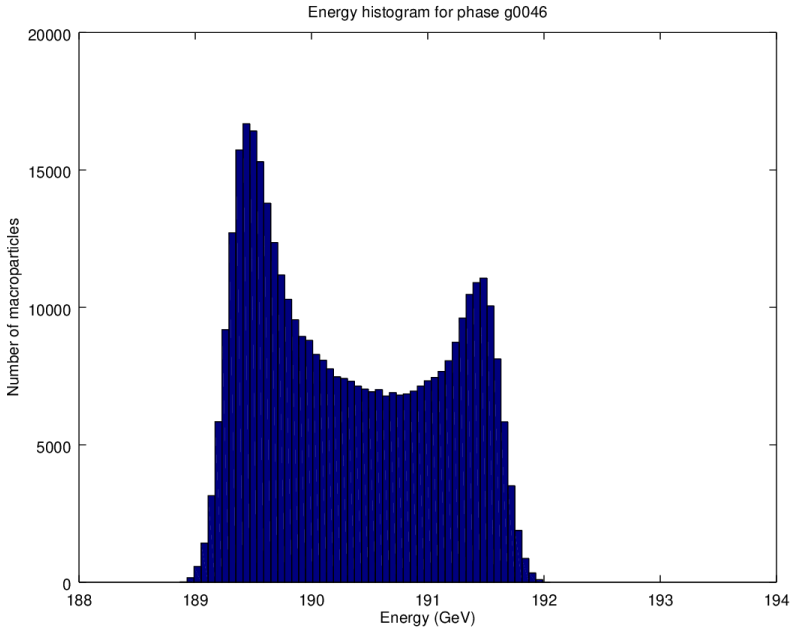


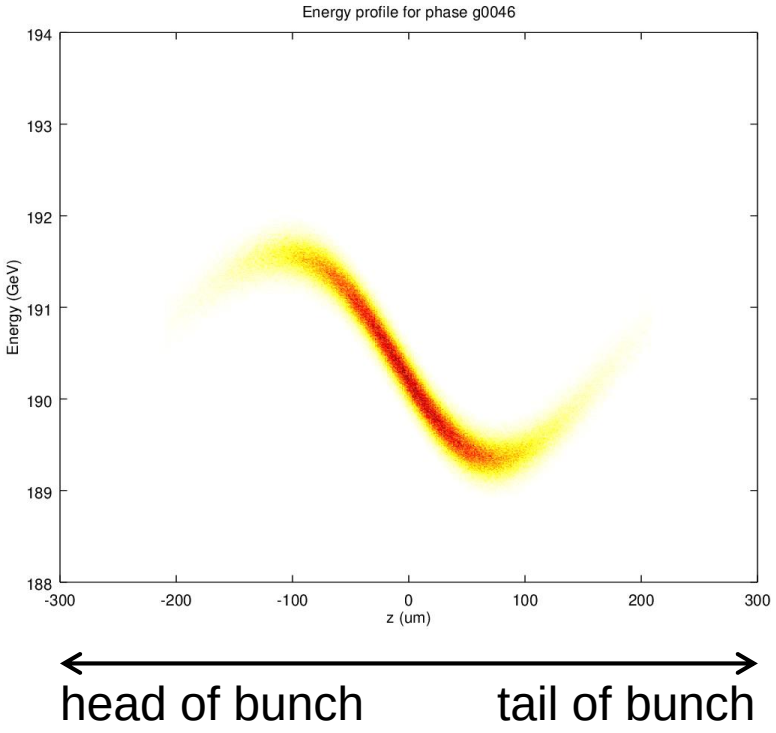




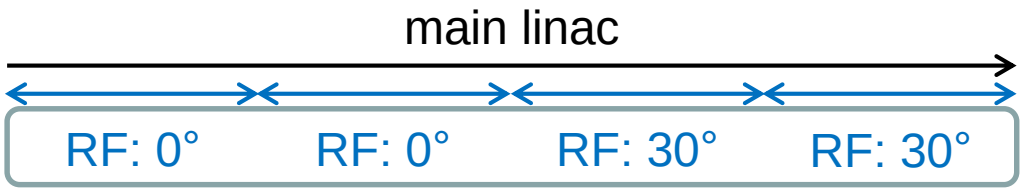
Energy profile

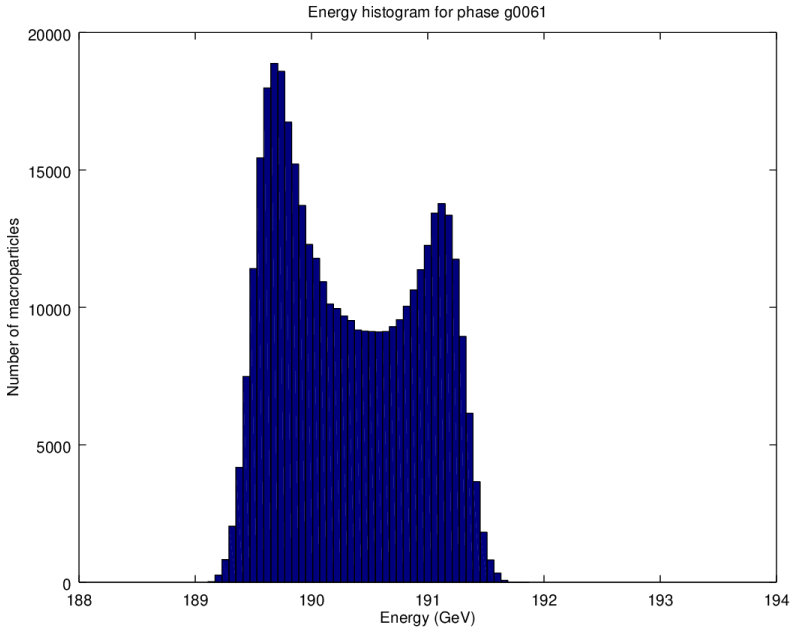


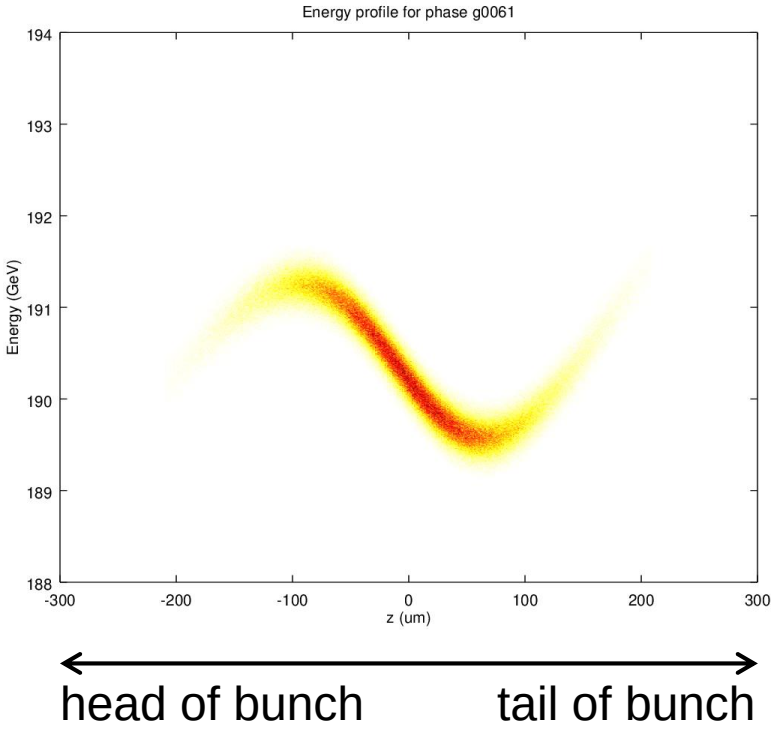




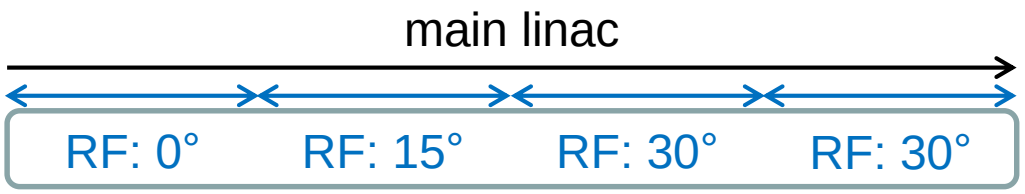
Energy profile

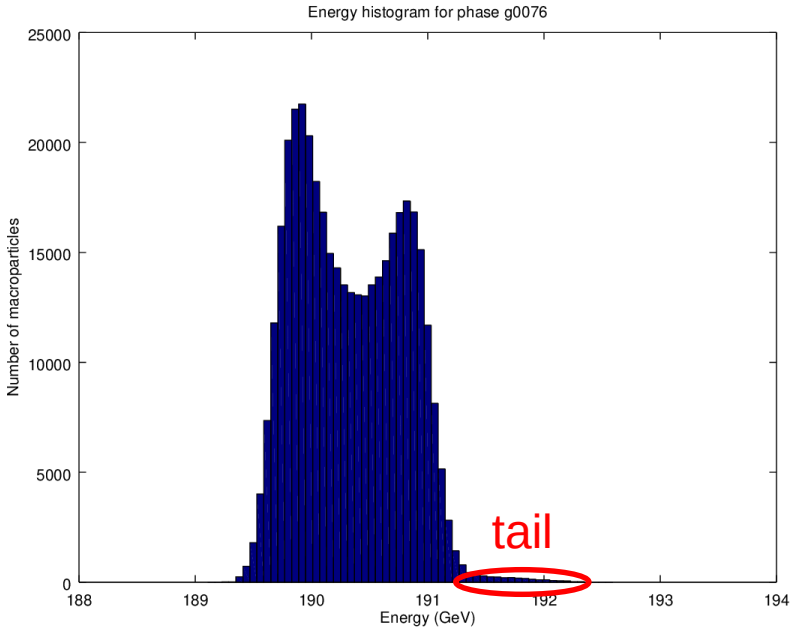


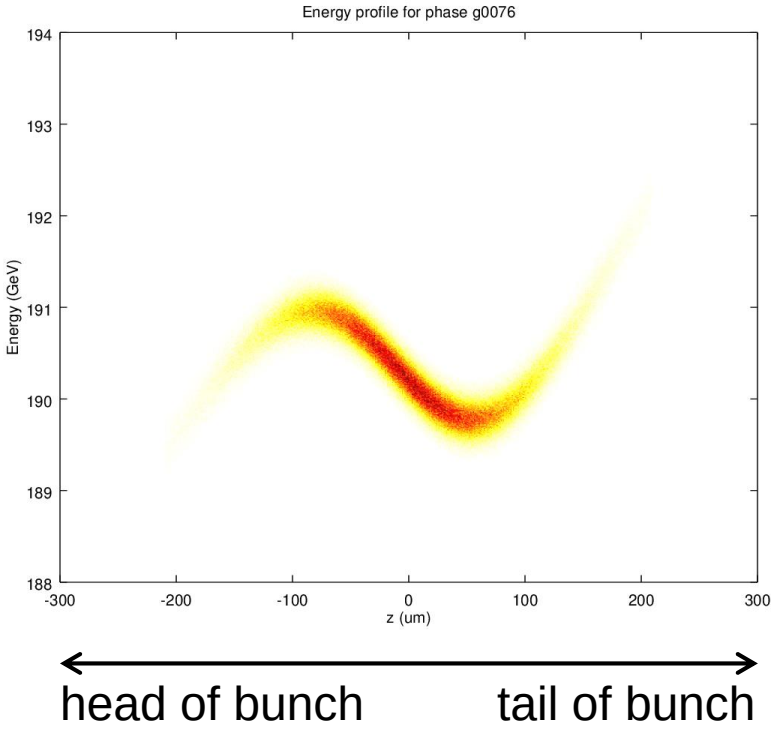




Energy profile



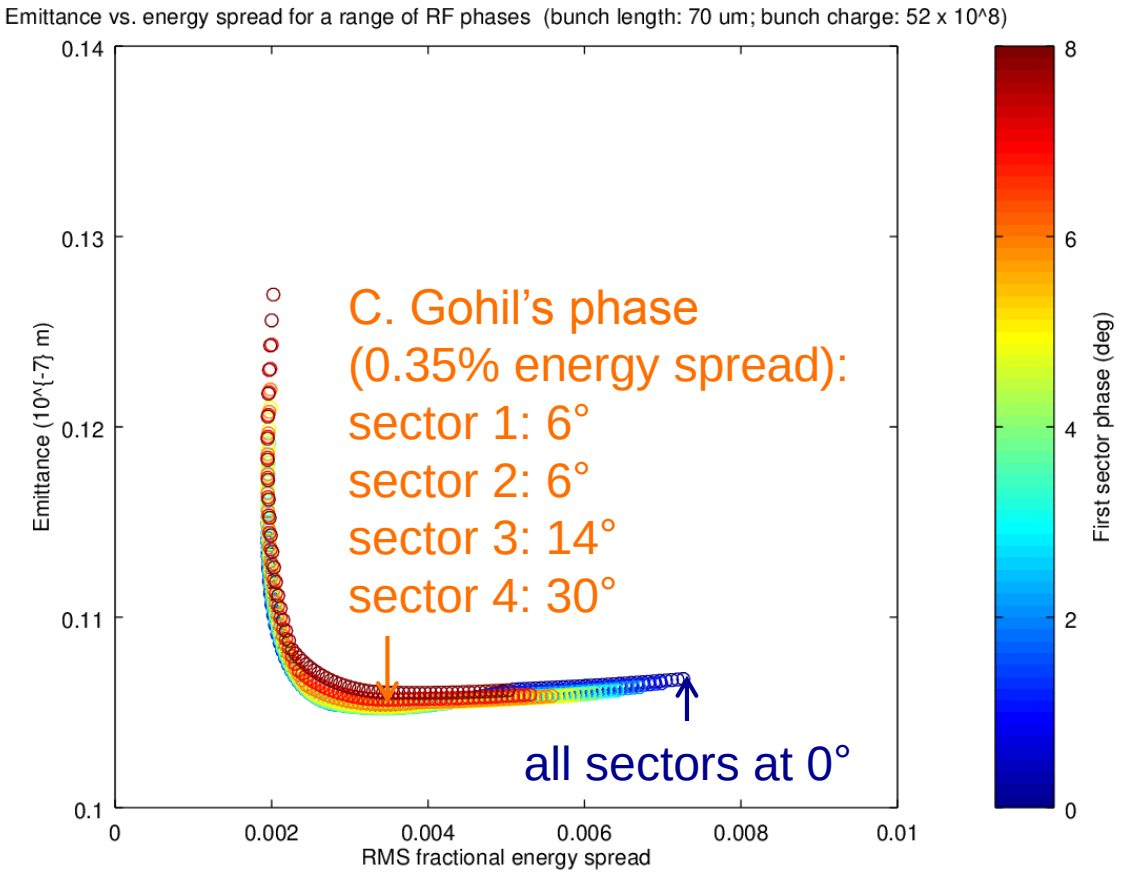




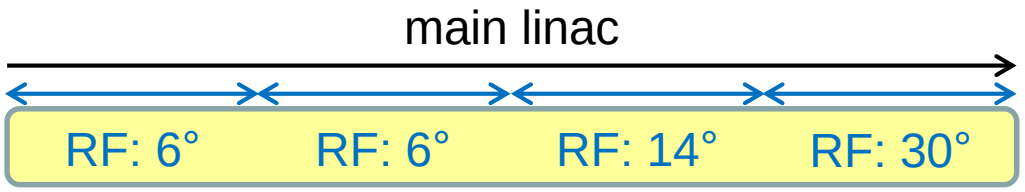
Further RF phase scan

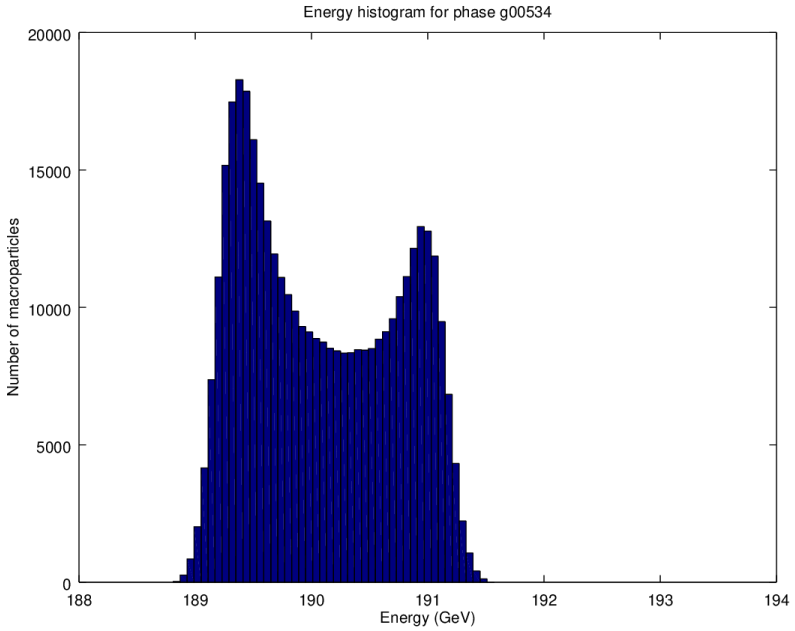
- Using first sector phases > 0°
- RF phases of all 4 linac sectors scanned together from 0° to 30°
- For each phase, sequentially increase:
  - Last sector's phase up to 30°
  - Preceding sectors' phases up to 30°

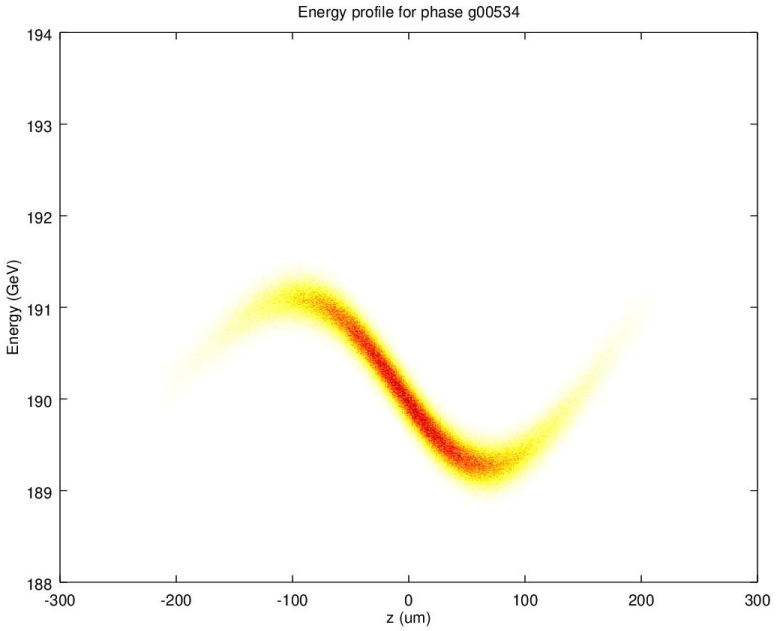
Further RF phase scan



Optimum RF phase combination

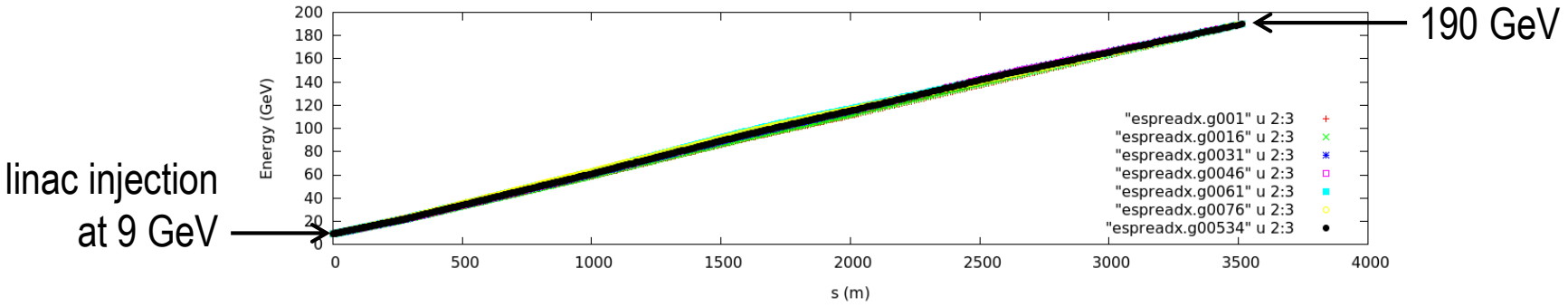






head of bunch — tail of bunch

Comparison


linac injection
at 9 GeV
190 GeV
Energy (GeV)
s (m)
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"espreadx.g0031" u 2:3
"espreadx.g0046" u 2:3
"espreadx.g0061" u 2:3
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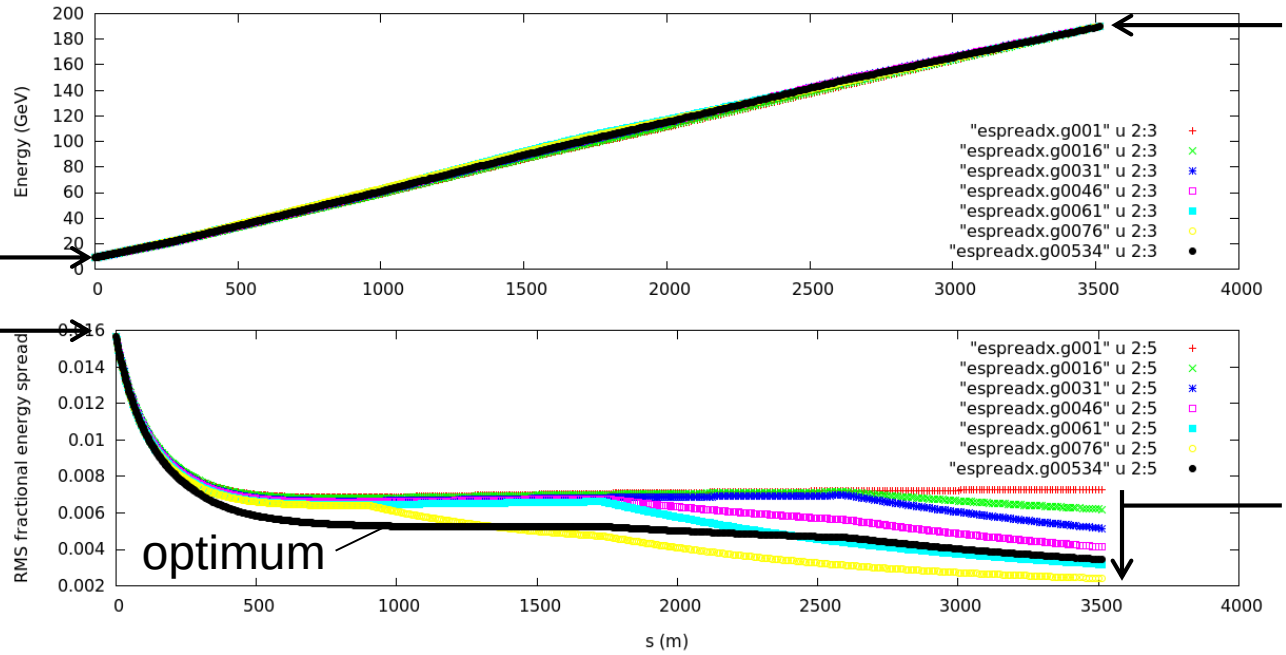
"espreadx.g00534" u 2:3

Comparison



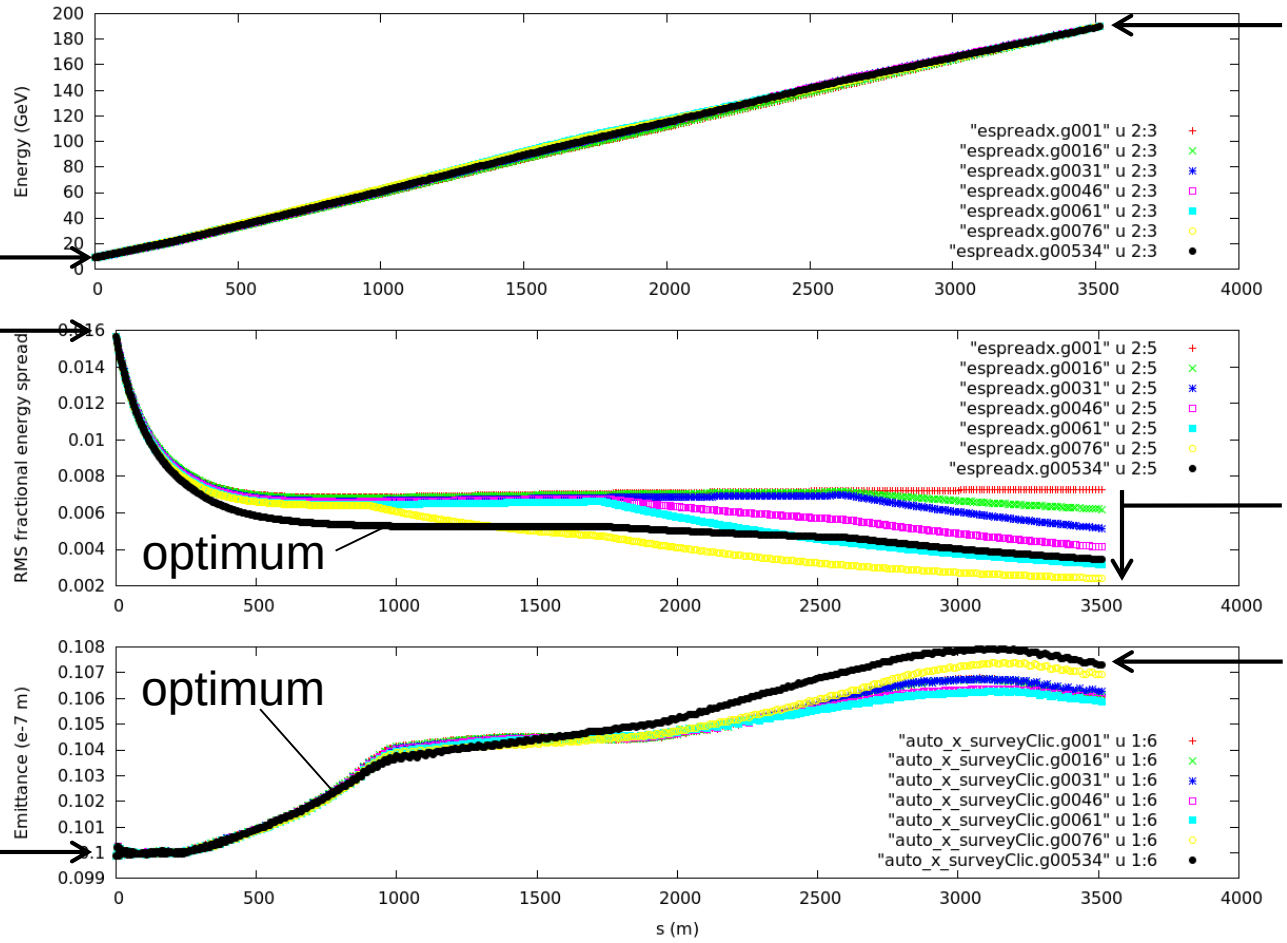
linac injection at 9 GeV

1.6% energy spread from RTML

190 GeV

reduction in final energy spread by increasing final RF phase at end of main linac

Comparison



linac injection at 9 GeV

1.6% energy spread from RTML

10 nm incoming emittance

190 GeV

reduction in final energy spread by increasing final RF phase at end of main linac

Final emittance < 11 nm

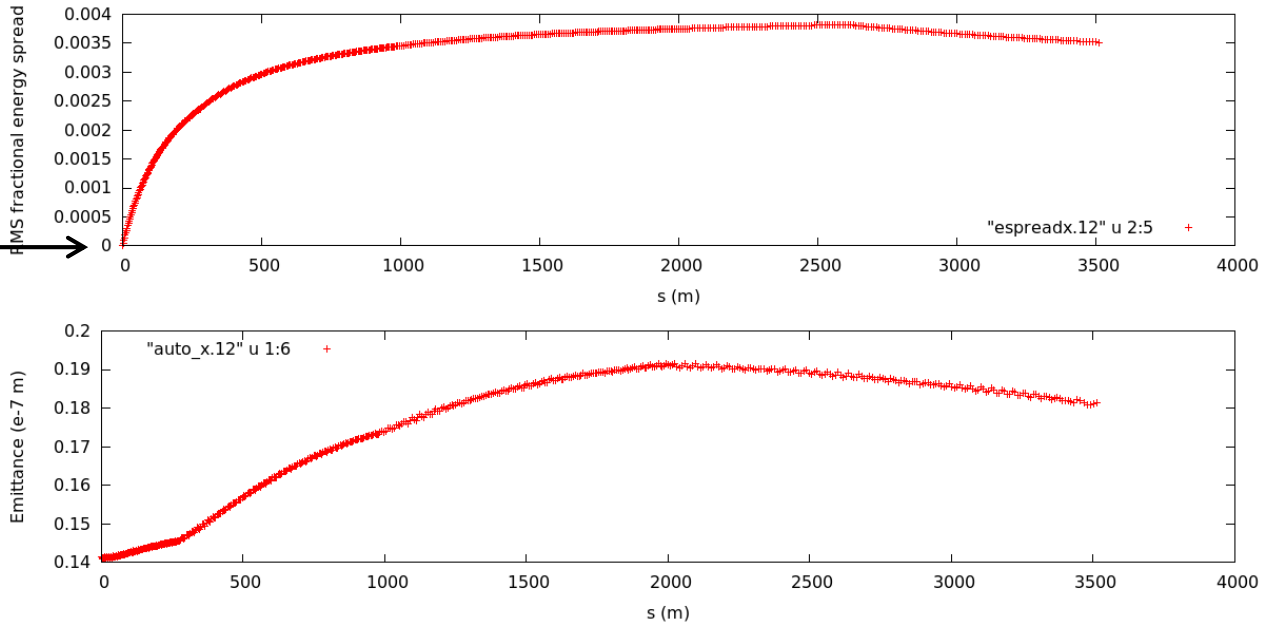
Conclusions

- A range of energy profiles can be obtained by varying the RF phases along the linac
- A target energy spread of 0.35% (std) can be achieved at the end of the main linac with only a small emittance growth

Thank you for your attention!

380 GeV baseline design

incoming energy spread to be added →



Emittance growth

Table 1: Key alignment specifications for the Main-Linac components and the resulting emittance growth. The values after simple steering (1-2-1), dispersion free steering (DFS) and realignment of the accelerating structures using the wakefield monitors are shown (RF).

			$\Delta\epsilon_y$ [nm]		
Imperfection	With respect to	Value	1-2-1	DFS	RF
Girder end point	Wire reference	12 μm	13.78	13.67	0.07
Girder end point	Articulation point	5 μm	1.34	1.33	0.02
Quadrupole roll	Longitudinal axis	100 μrad	0.05	0.05	0.05
BPM offset	Wire reference	14 μm	188.63	6.40	0.10
Cavity offset	Girder axis	14 μm	5.24	5.20	0.07
Cavity tilt	Girder axis	141 μrad	0.16	0.43	0.29
BPM resolution		0.1 μm	0.05	0.67	0.07
Wake monitor	Structure centre	3.5 μm	0.05	0.05	0.29
All			222.73	29.52	0.96