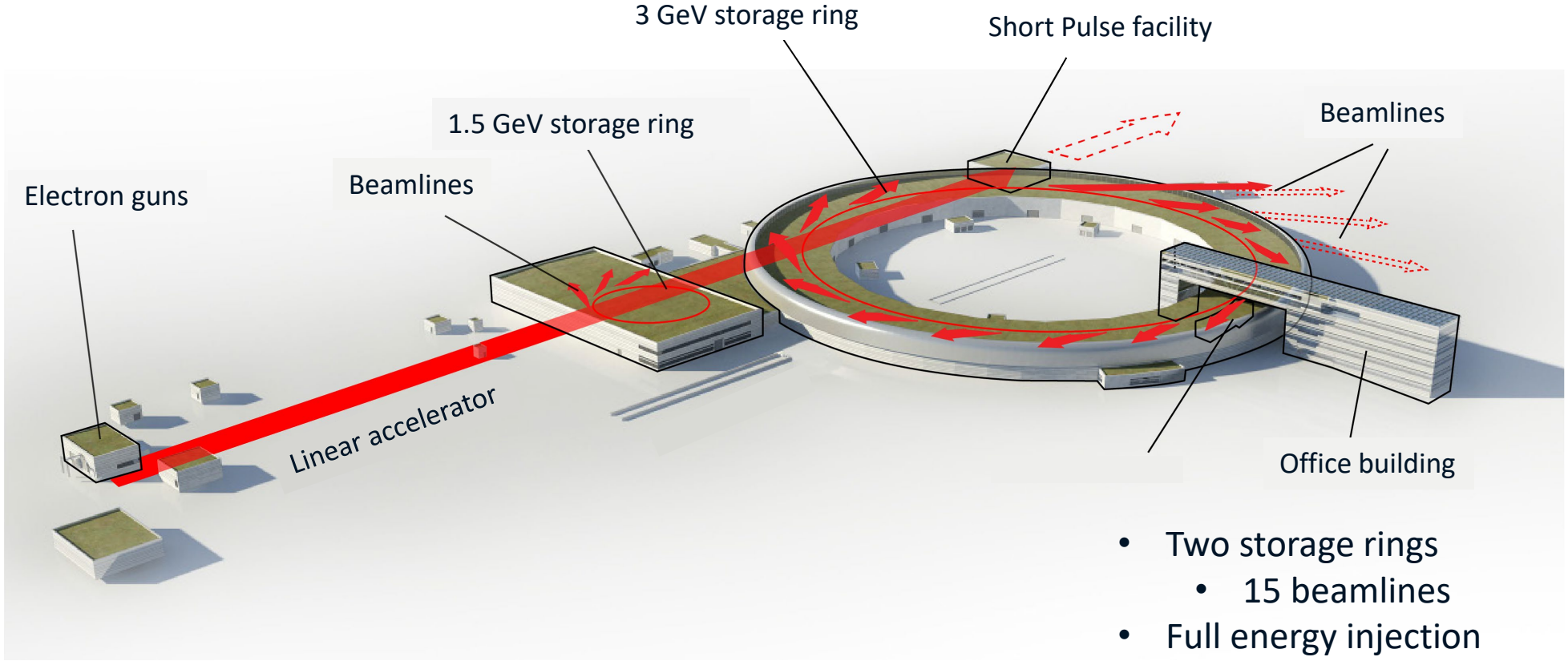
Experience with magnetic linearization, longitudinal jitter and outlook to FEL

LEDS workshop Frascati Oct 2023

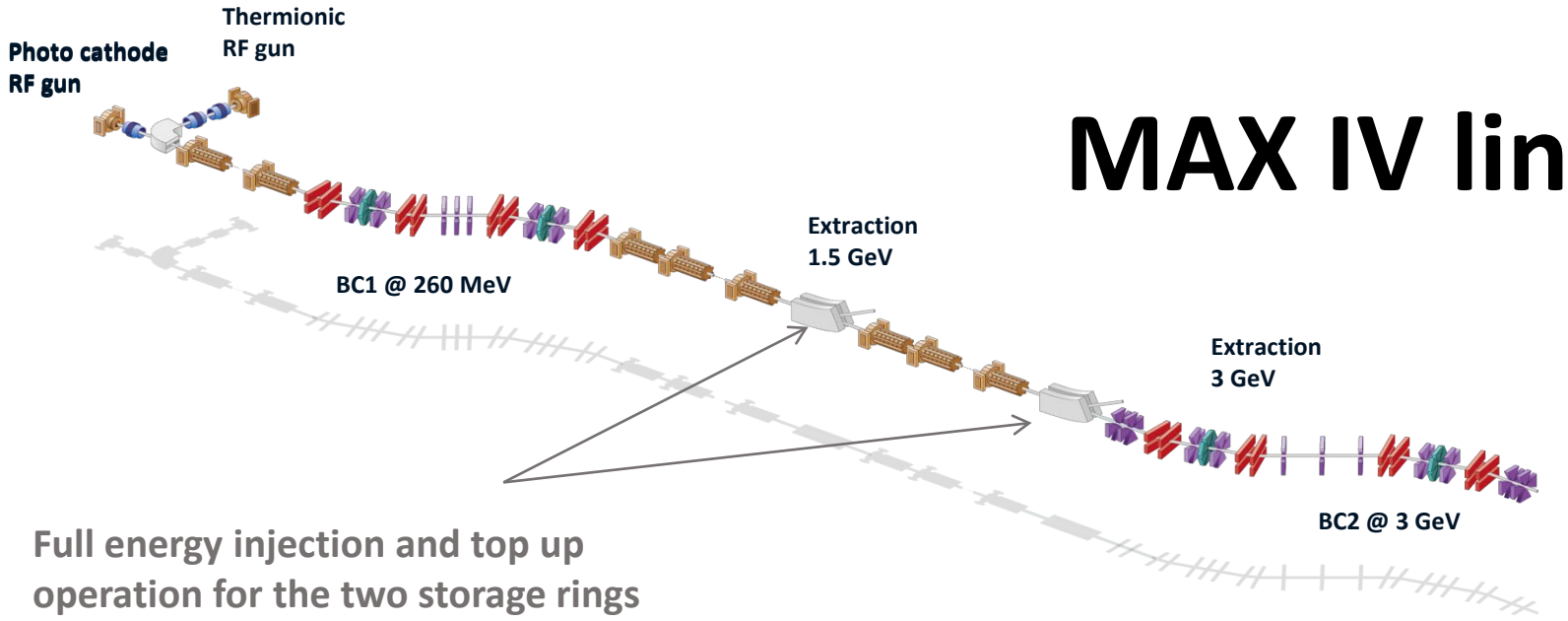
Sara Thorin

Introduction – MAX IV facility



- Two storage rings
  - 15 beamlines
- Full energy injection
- Top-up
- Short Pulse Facility
  - Femtomax beamline

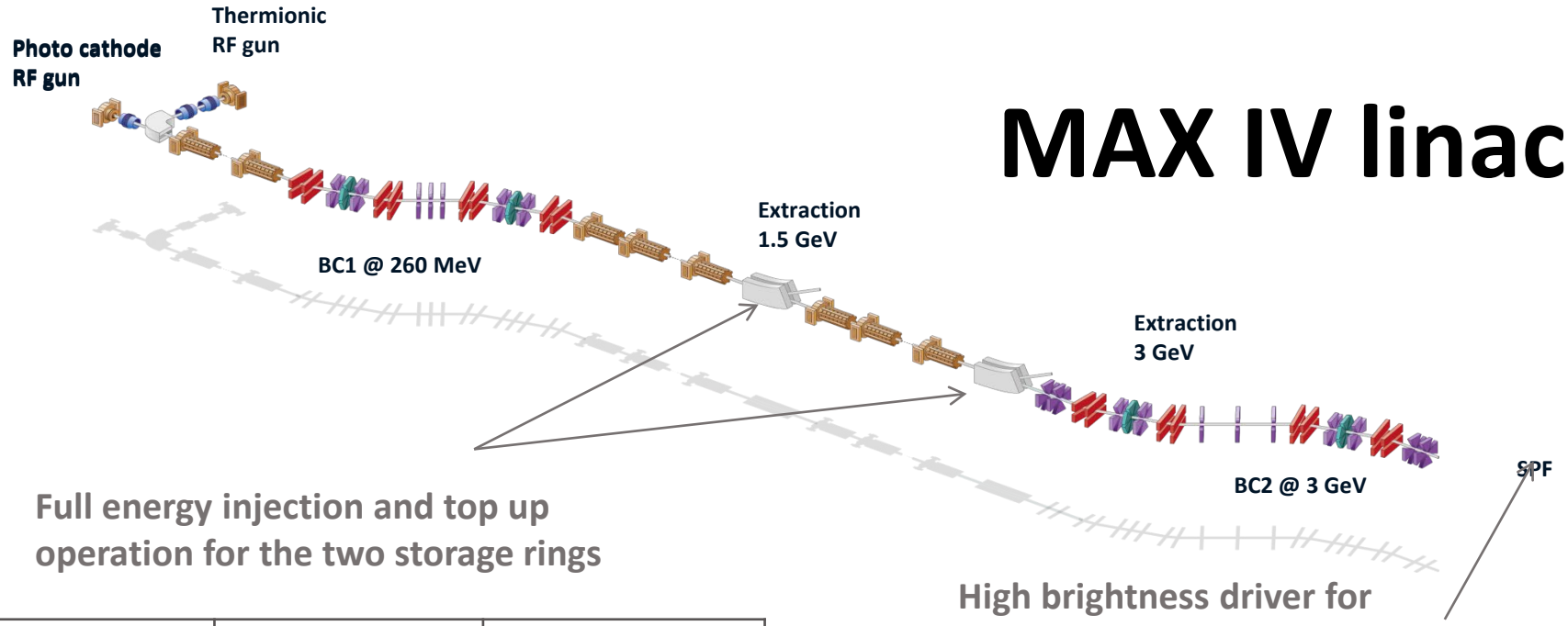
MAX IV linac overview



Full energy injection and top up operation for the two storage rings

	Design	Currently
Energy	1.5 GeV/ 3GeV	1.5 GeV/ 3GeV
Repetition rate	10 Hz	10 Hz
Charge	0.6-1 nC/shot	0.3 nC/shot
Emittance	10 mm mrad	5 mm mrad
Energy spread	<0.2%	<0.25 %

MAX IV linac overview



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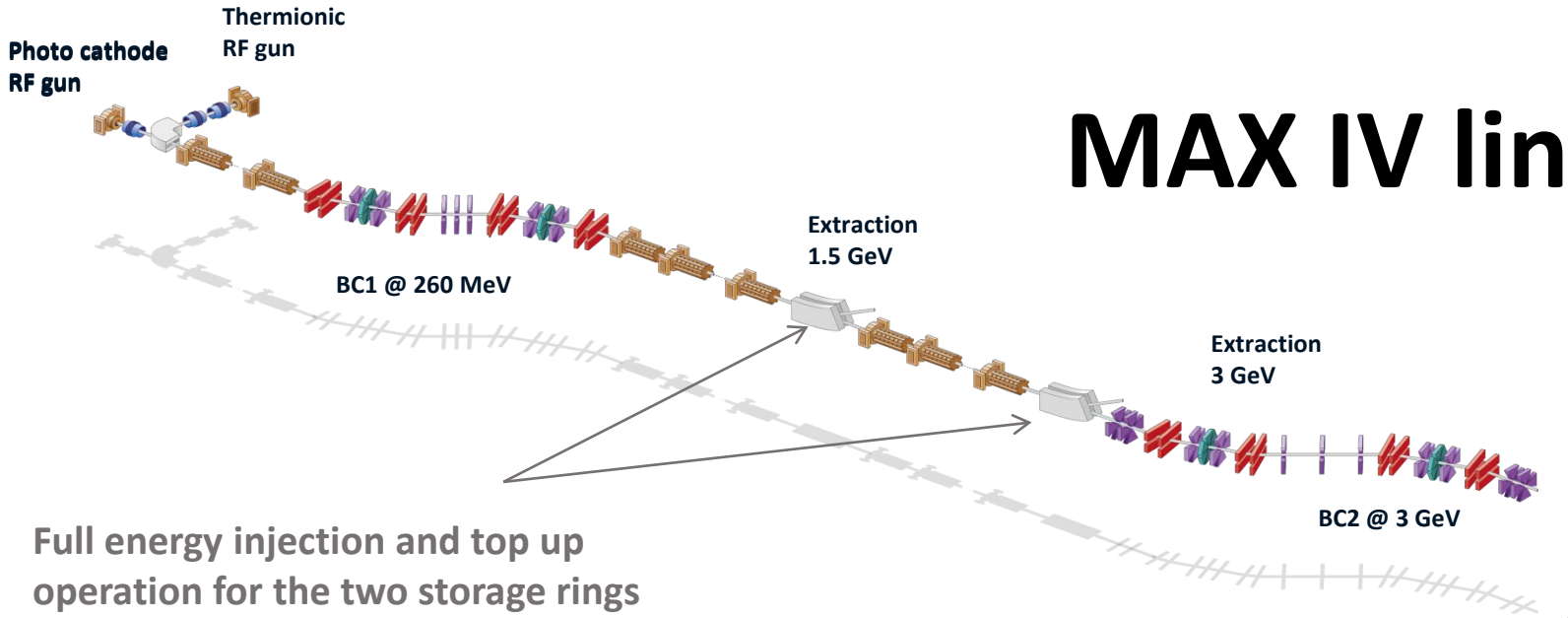
High brightness driver for the Short Pulse Facility

	Design	Currently
Energy	3GeV	3 GeV
Repetition rate	100 Hz	10 Hz
Charge	100 pC	20-200 pC
Bunch length (rms)	100 fs	3 ps – 30 fs
Emittance	1 mm mrad	2-3 mm mrad
Energy spread	<0.4%	0.3-0.7%

MAX IV linac overview



Full energy injection and top up operation for the two storage rings

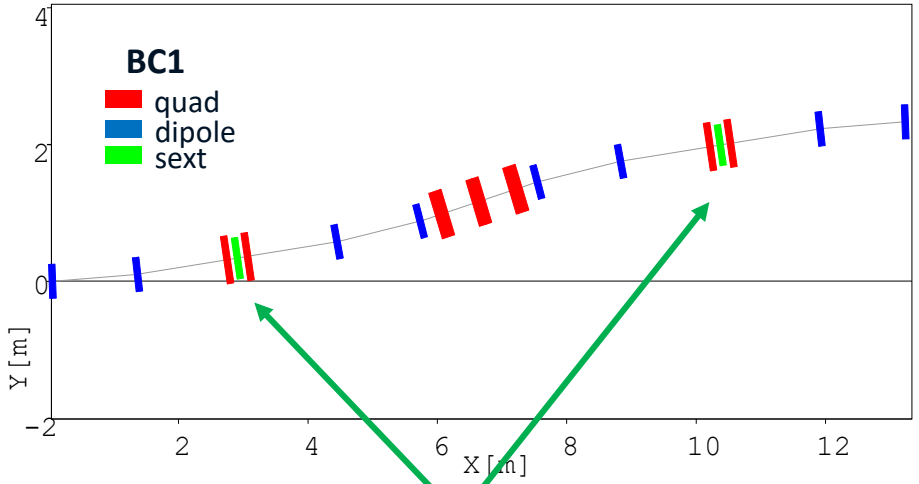
High brightness driver for the Short Pulse Facility

Possible future Free Electron Laser

Rings	**Design**	**Currently**
Energy	1.5 GeV/ 3GeV	1.5 GeV/ 3GeV
Repetition rate	10 Hz	10 Hz
Charge	0.6-1 nC/shot	0.3 nC/shot
Emittance	10 mm mrad	5 mm mrad
Energy spread	<0.2%	<0.25 %

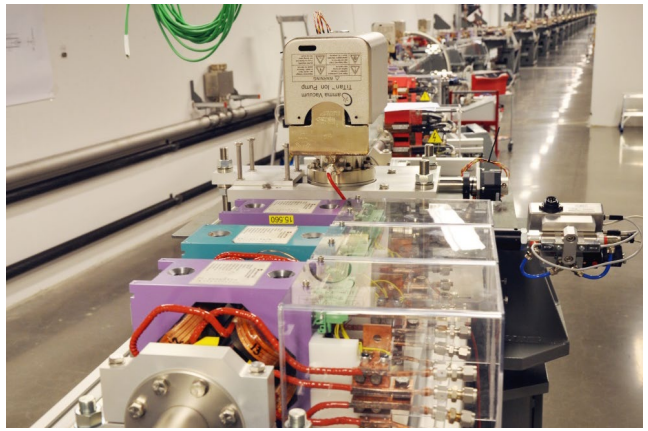
SPF	**Design**	**Currently**
Energy	3GeV	3 GeV
Repetition rate	100 Hz	10 Hz
Charge	100 pC	20-200 pC
Bunch length (rms)	100 fs	3 ps – 30 fs
Emittance	1 mm mrad	2-3 mm mrad
Energy spread	<0.4%	0.3-0.7%

MAX IV bunch compressors – double achromats with magnetic linearisation

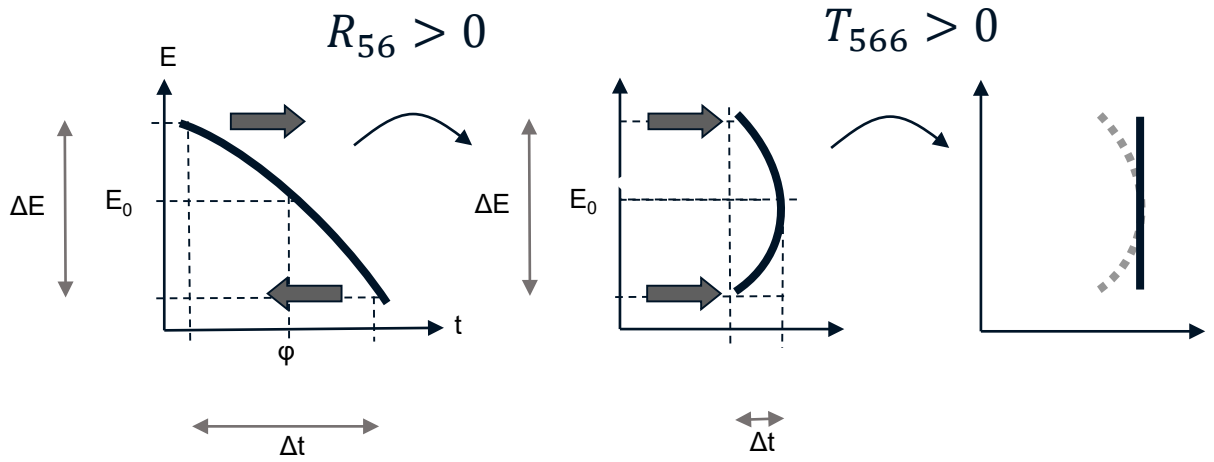


Sextupoles used for both tuning T566 (=linearization) and to close second order dispersion.

$$\Delta z = R_{56}\left(\frac{\Delta E}{E}\right) + T_{566}\left(\frac{\Delta E}{E}\right)^2$$



	BC1	BC2
R56	3.2 cm	2.6 cm
T566	6.6 cm	4.3 cm



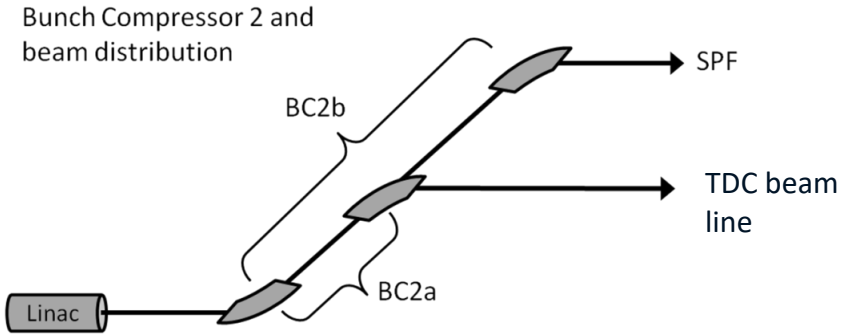
MAX IV bunch compressors – double achromats with magnetic linearisation

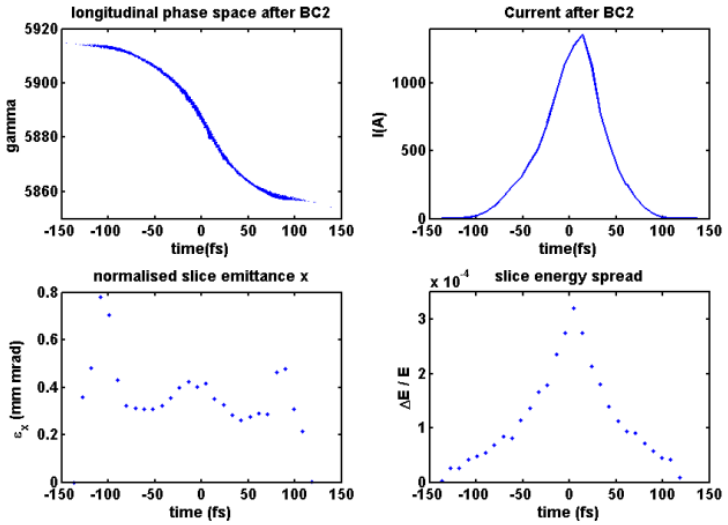
Why magnetic linarisation?

- No need for a harmonic cavity lineariser =
  - Economy
  - Reliability
  - Simplicity
- BC can work as beam spreader

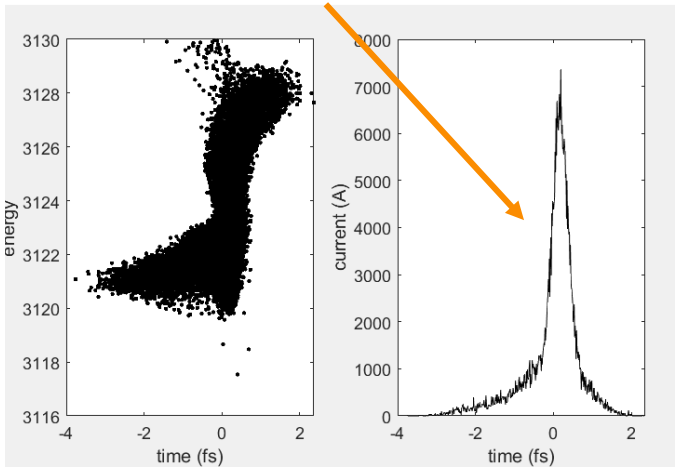
…

- No church-towers, the current peak is in the center. -> **High peak current, short pulses.**
- Magic angle -> Reduce RF amplitude induced timing jitter to zero.
- More in Peter Williams talk after this…

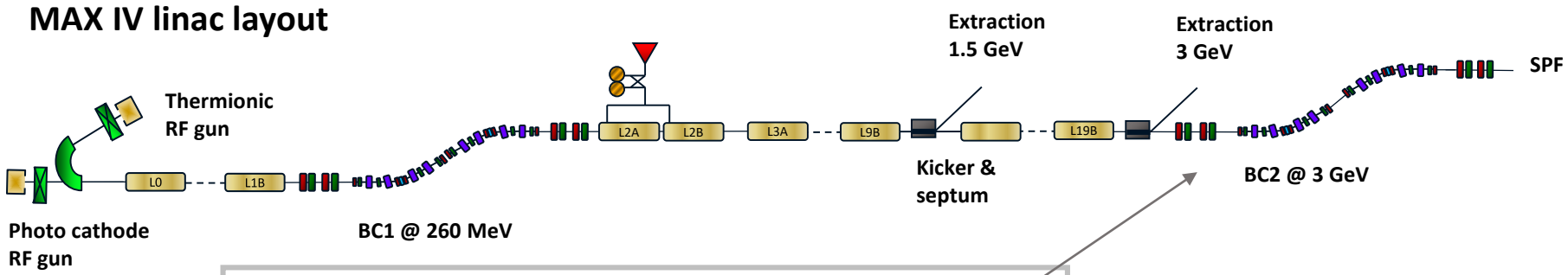


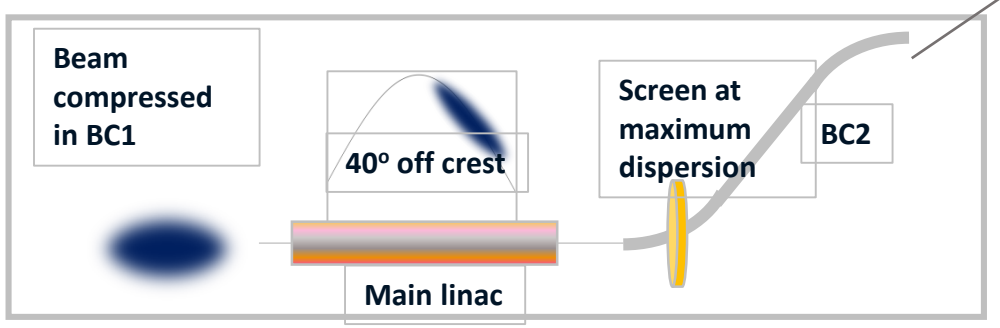


500 as fwhm

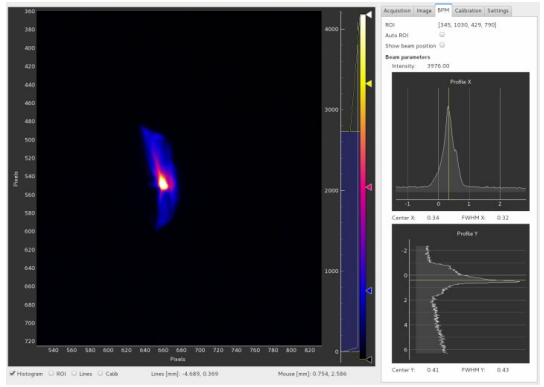


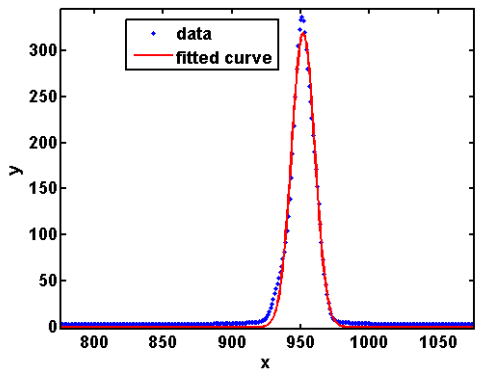
Early compression characterisation – streaking the beam in BC2

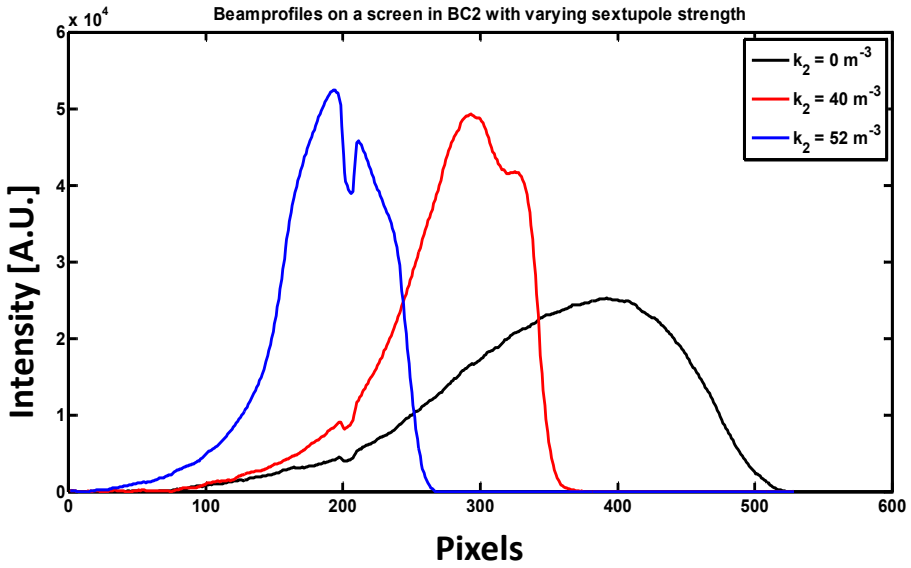




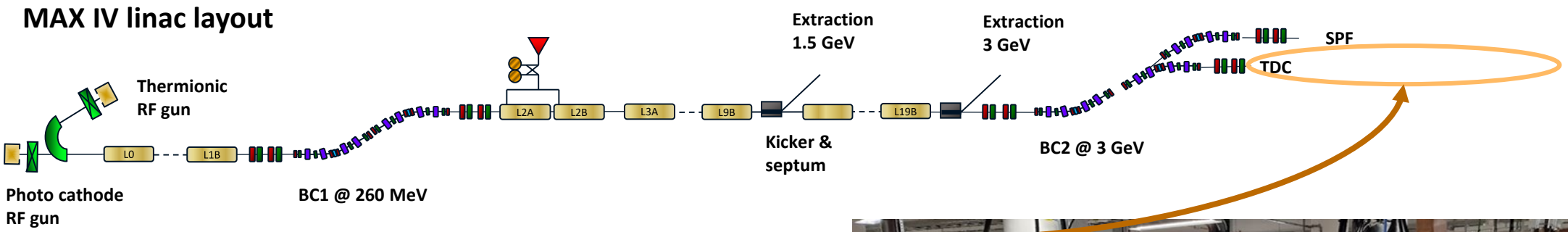
- Resolution around 30 fs
- Could only measure bunch length after BC1

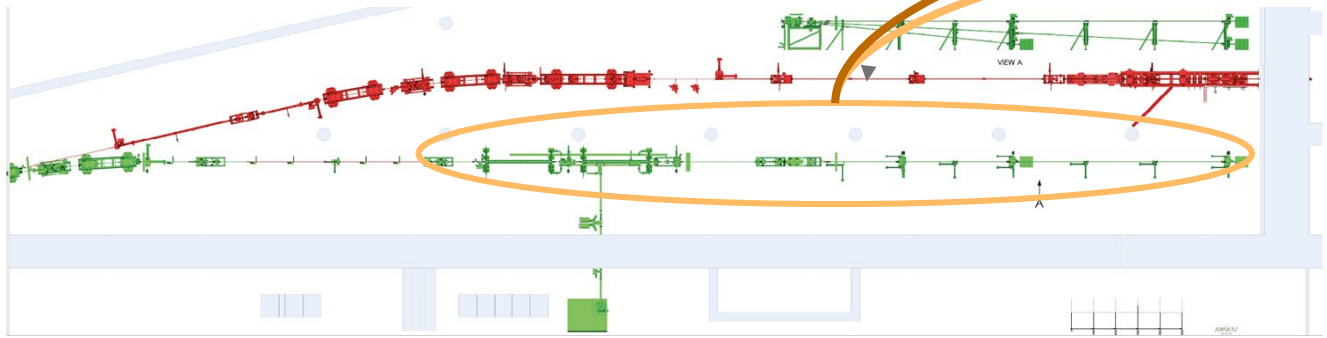




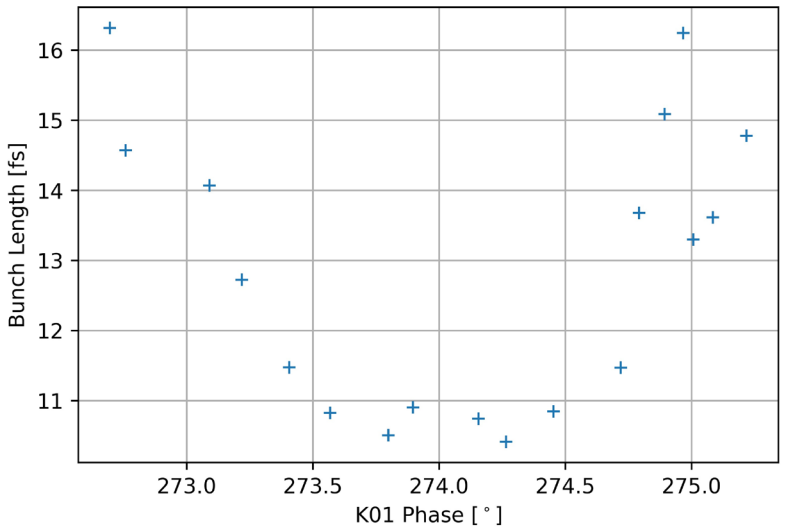


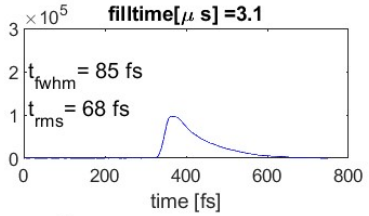
Transverse deflecting cavity!!!

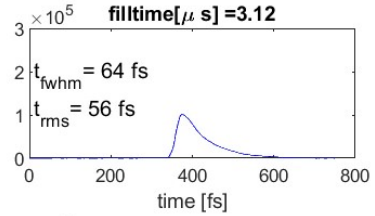


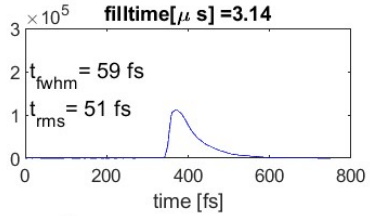


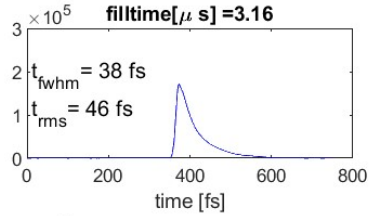
Compression scan – changing the phase before BC1

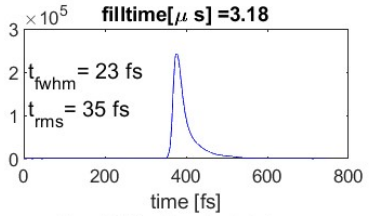


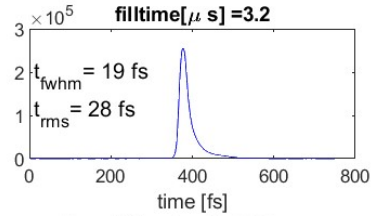


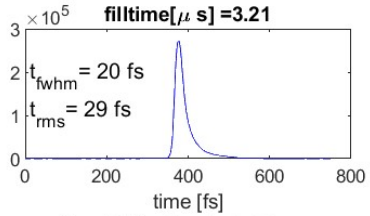


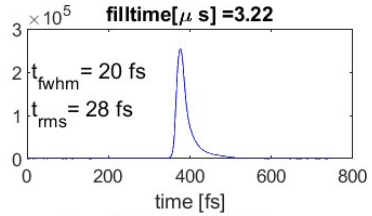


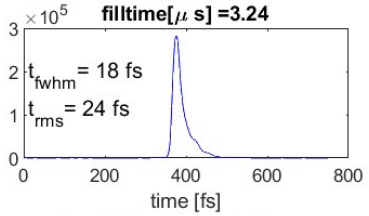


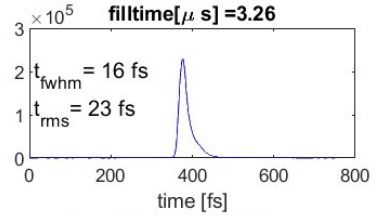


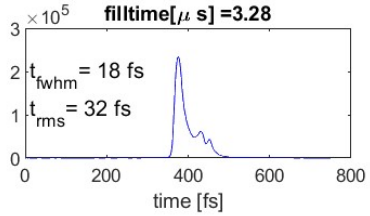


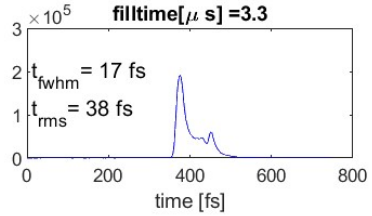


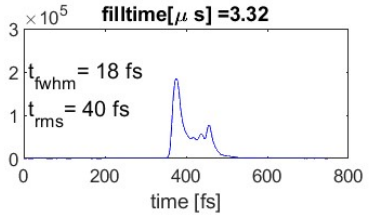


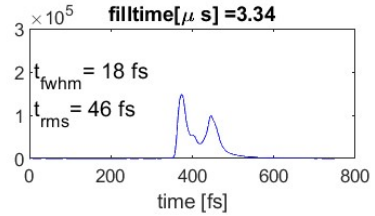




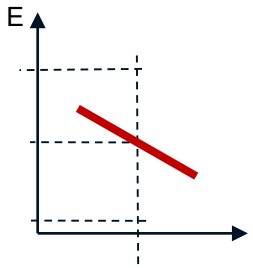


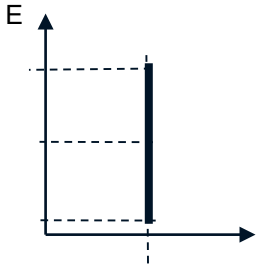


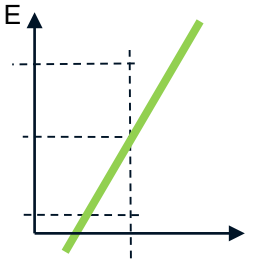


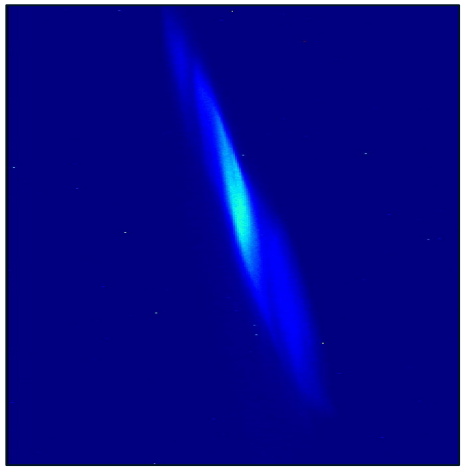


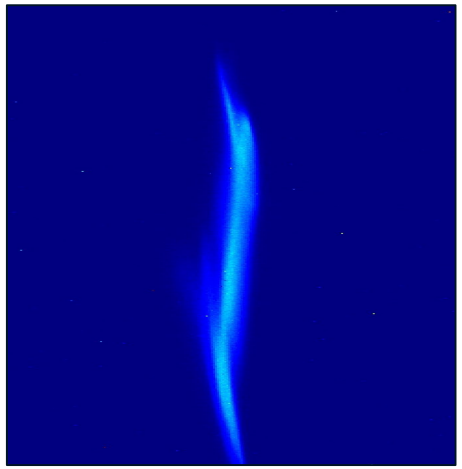
Compression scan – longitudinal phase space

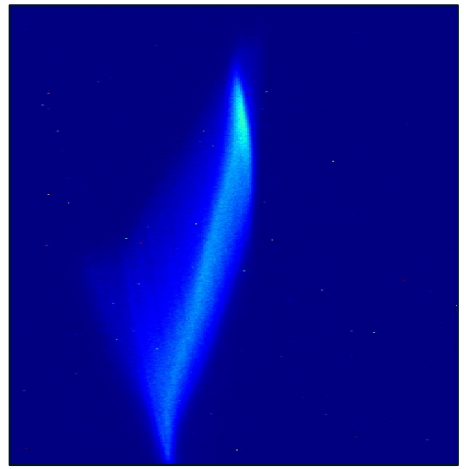






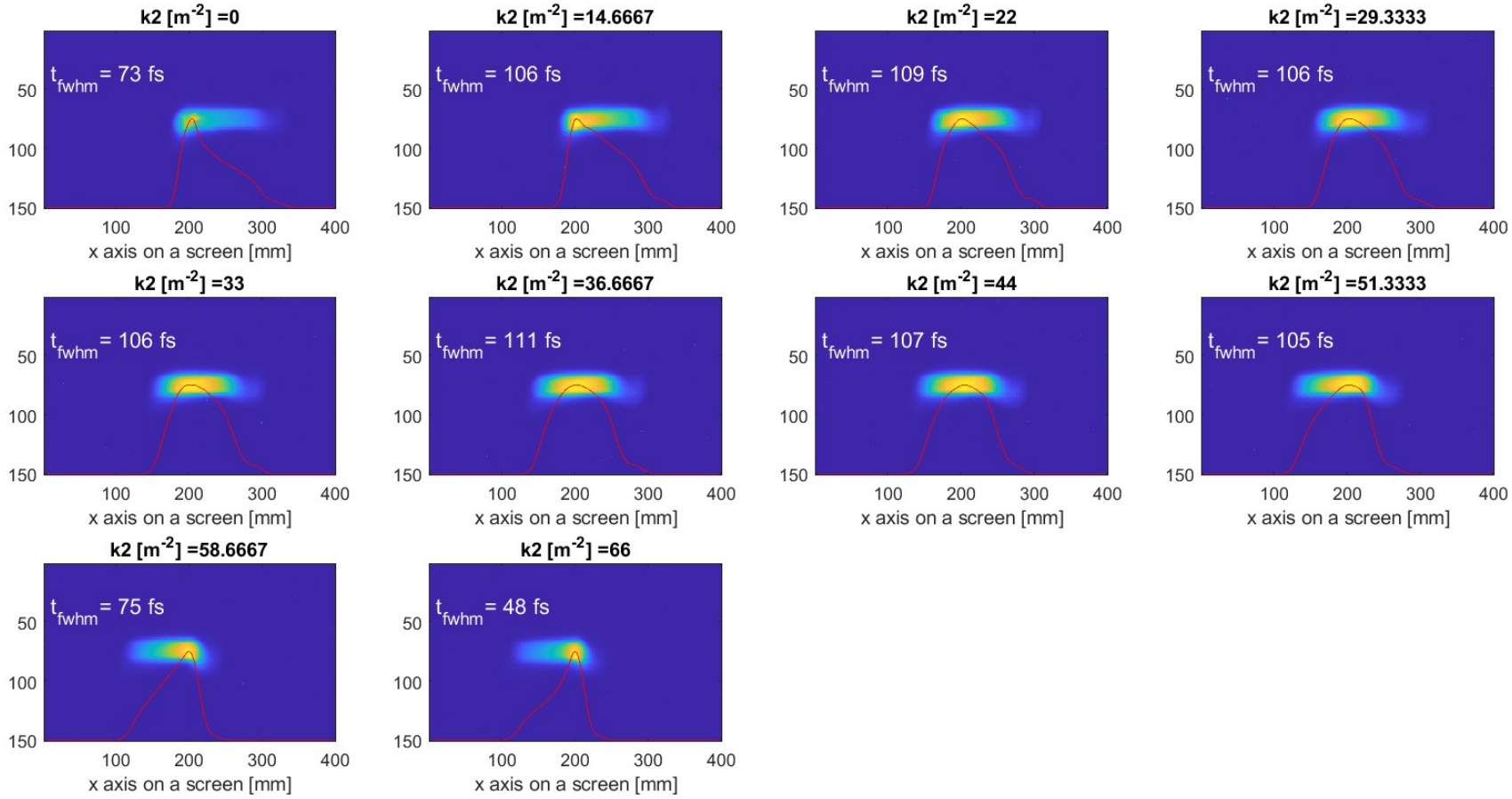




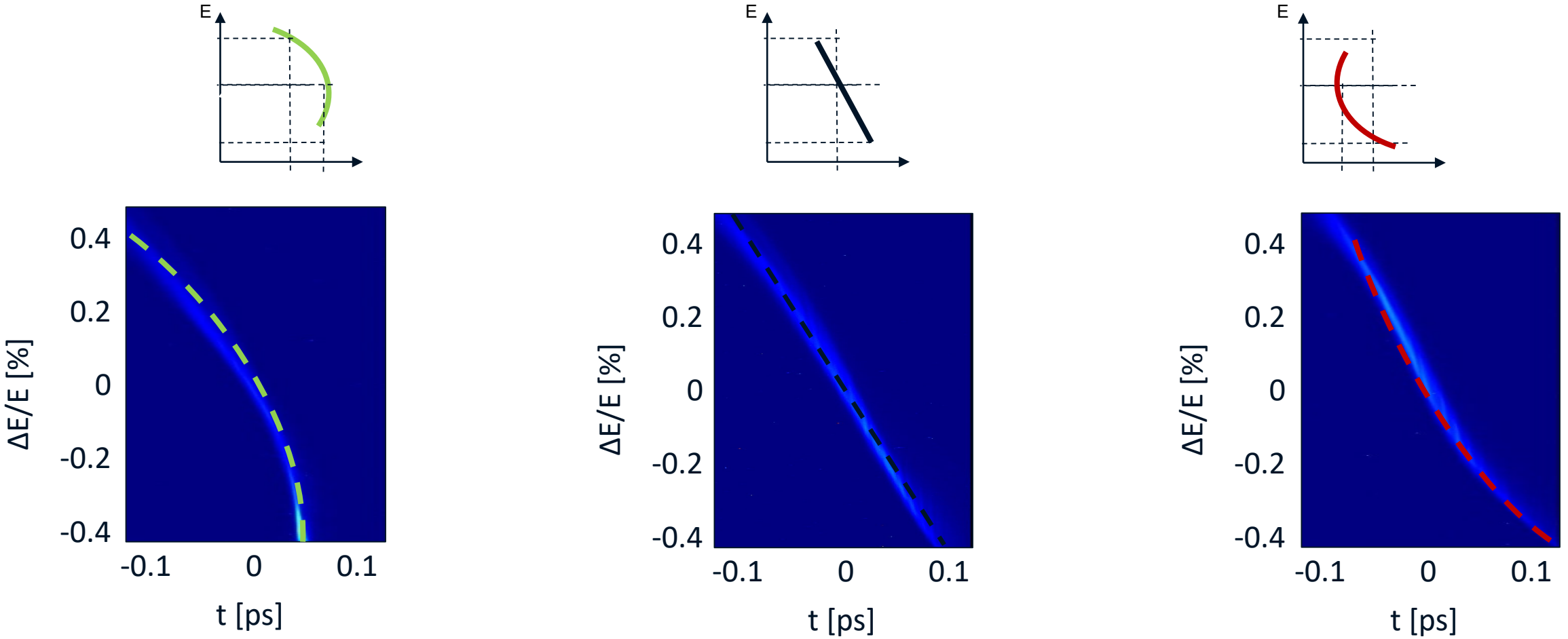


Slide from Erik Mansten, Johan Lundqvist

T566 scan, changing the sextupoles in BC1



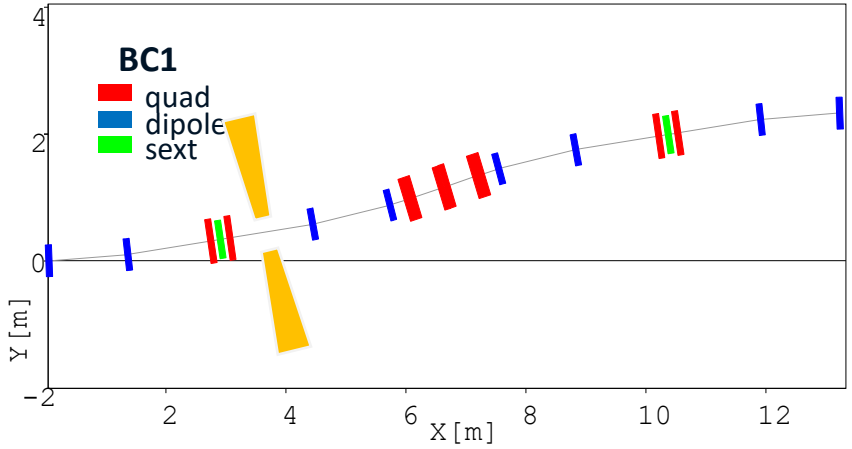
Linearization scan – Longitudinal phase space

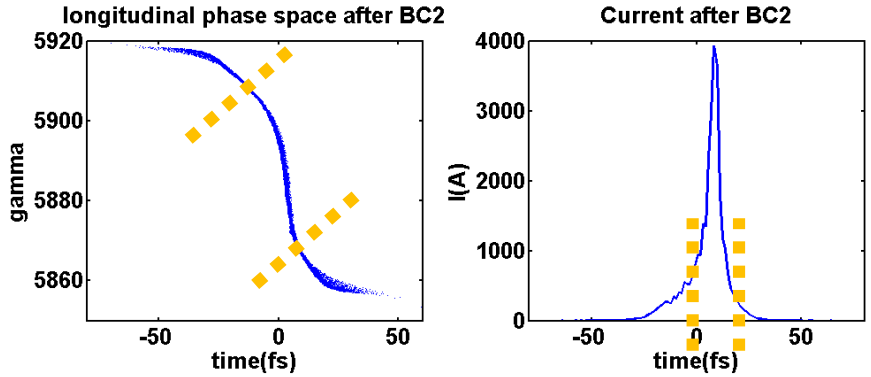


Slide from Erik Mansten, Johan Lundqvist

Shortest bunch measured

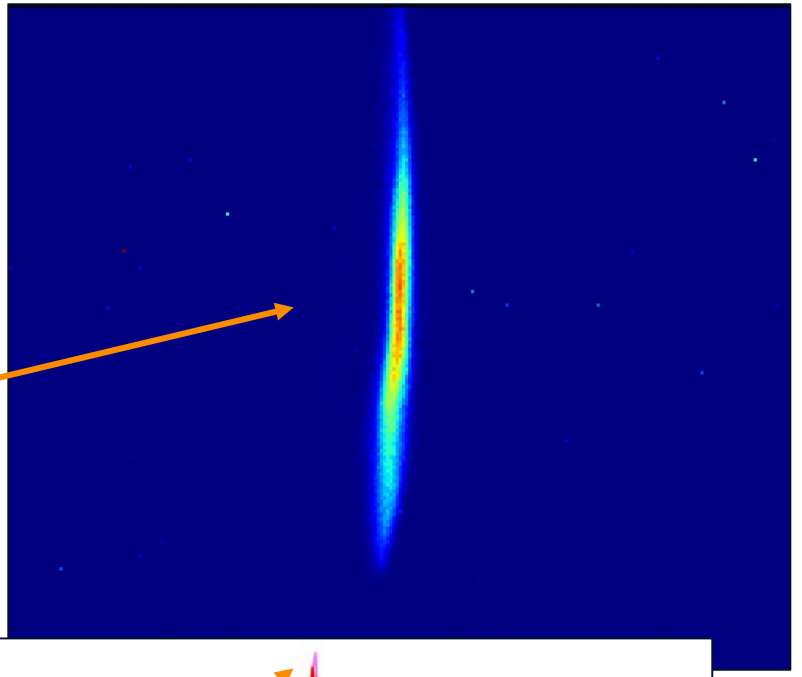
Scrapers used in BC1 high dispersion

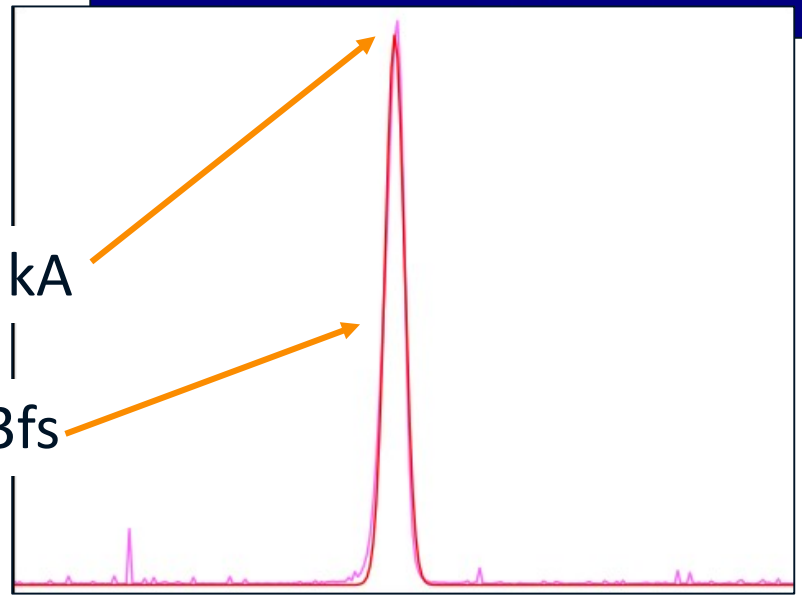




LPS measured with TDC

Initial charge: 100 pC
Charge left: 20 pC

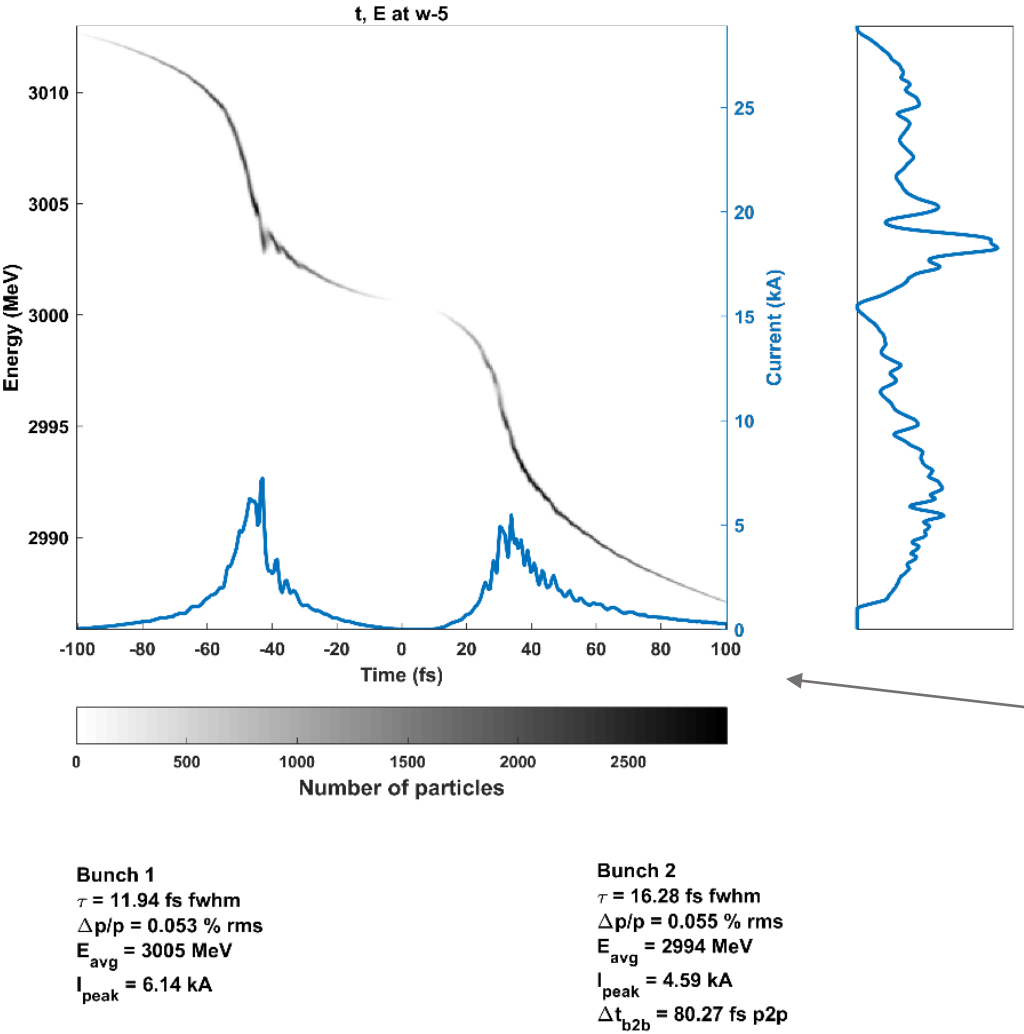




I_{peak} = 6.7 kA

Δt_{fwhm} = 3fs

First attempt at double bunches



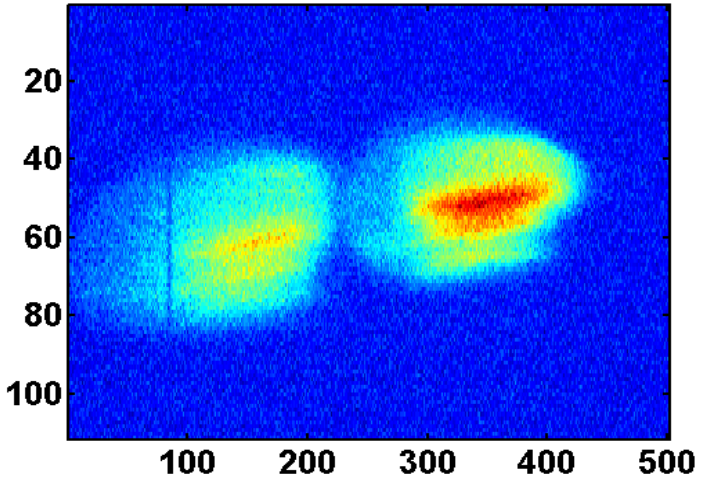
Bunch 1
τ = 11.94 fs fwhm
Δp/p = 0.053 % rms
E_{avg} = 3005 MeV
I_{peak} = 6.14 kA

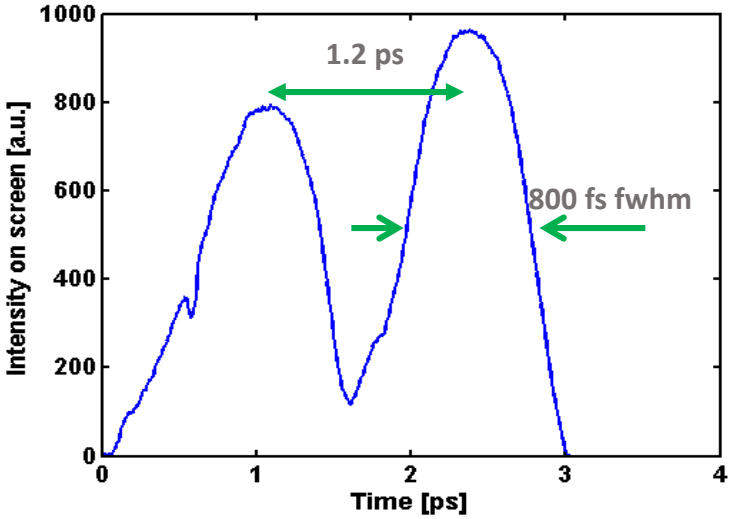
Bunch 2
τ = 16.28 fs fwhm
Δp/p = 0.055 % rms
E_{avg} = 2994 MeV
I_{peak} = 4.59 kA
Δt_{b2b} = 80.27 fs p2p

- Compressed only in BC1
- Measured with BC2 streak
- Two electron bunches within one RF-bucket
- First attempt, used only the crystals in the laser pulse stretcher to achieve two laser pulses.
- Only lightly compressed

Simulation

Experiment



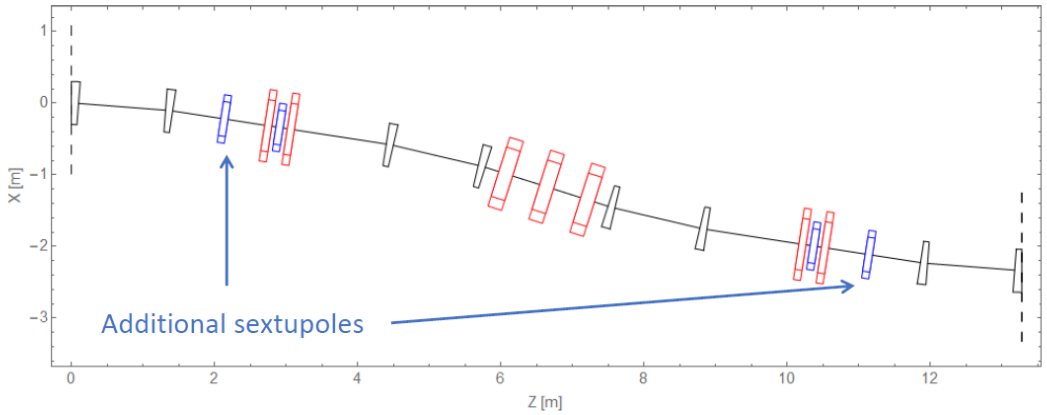


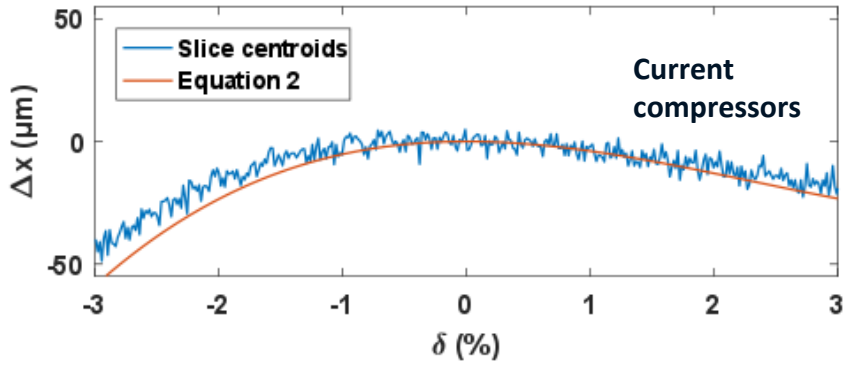
Drawbacks of our achromat compressors

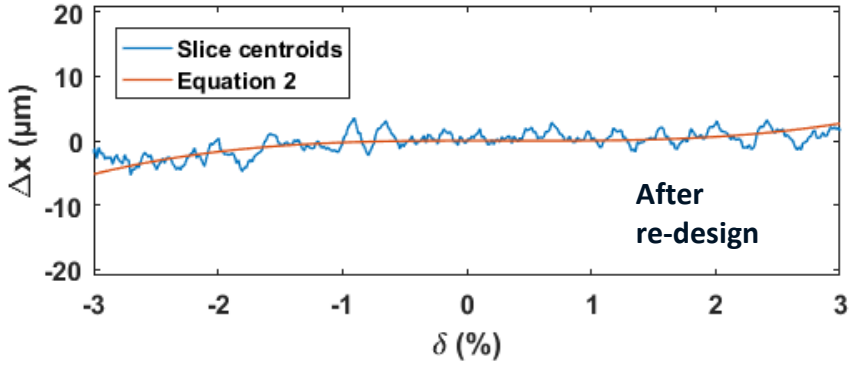
- Normal operation and delivery to the Short Pulse Facility – no issues caused by compressors
- For future FEL:
  - Chromaticity – need to separate linearization and second order dispersion. Twiss and centroid vary along the bunch longitudinaly.

Future BC upgrade – closing chromatic effects to third order

- Adding quads, sextupoles and possibly octupoles to compressors
- Keep longitudinal slice alpha, beta and centroid flat throughout the pulse
- Compensate for CSR-kick
- Keep longitudinal centroid slice offset low



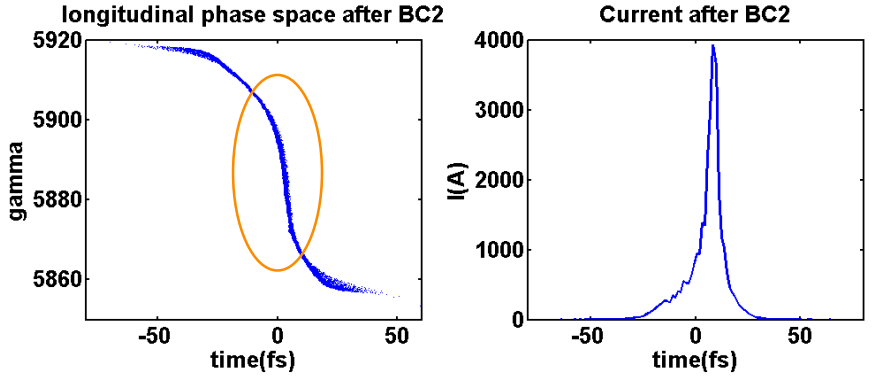




Svensson, J. B., Charles, T. K., Lundh, O., & Thorin, S. (2019). Third-order double-achromat bunch compressors for broadband beams. *Physical Review Accelerators and Beams*, *22*(10), 104401.

Drawbacks of our achromat compressors

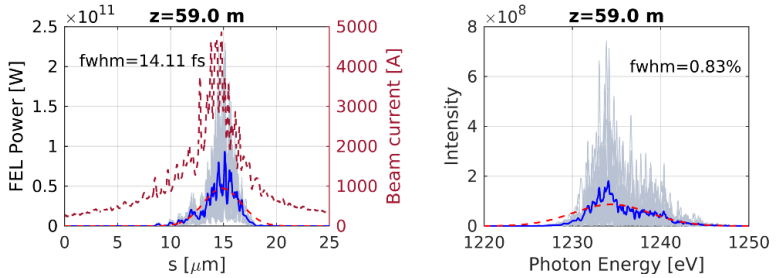
- Normal operation and delivery to the Short Pulse Facility – no issues caused by compressors
- For future FEL:
  - Chromaticity – need to separate linearization and second order dispersion. Twiss and centroid vary along the bunch longitudinally.
  - **Residual energy chirp –** the wakes in the linac work towards larger chirp, not to reduce it as for chicane compressors.



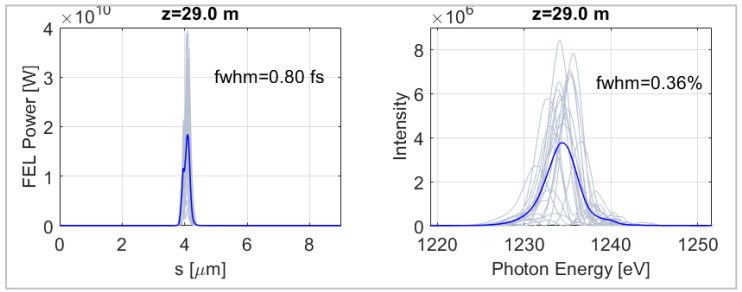
For SASE – it doesn't matter - S2E simulations

S.A.S.E.

"long" pulse -- 1 A



short pulse - - 1 B



For seeding – the chirp is an issue

Francesca Curbis FEL chapter of SXL CDR https://www.maxiv.lu.se/beamlines-accelerators/accelerators/soft-x-ray-laser/

Variable R56 bunch compressors

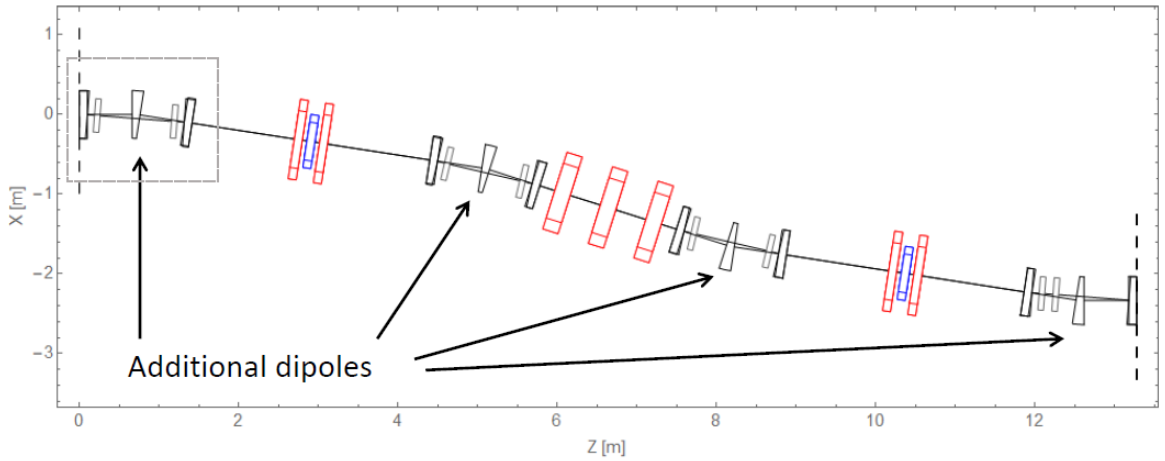
Tunable R56, even to negative R56 – chicane like compression -> Wakes in the linac will de-chirp the beam. Tunable R56 also allows us to operate at exactly the magic angle and reduce arrival time jitter!

Gustavo Perez Segurana, Lancaster University & Cockcroft Institute,

Peter Williams, STFC Daresbury Laboratory & Cockcroft Institute

Williams, Peter H., et al. "Arclike variable bunch compressors." *Physical Review Accelerators and Beams* 23.10 (2020): 100701.

Adam Dixon, Tessa Charles, Liverpool University



More on this in Peters talk in 5 minutes