Relative bunch length measurements at MAX IV linac

Francesca Curbis

On behalf of the MAX IV linac team /
Sara Thorin, Erik Mansten, David Olsson

Outline

- MAX IV: where and what is about
- The MAX IV linac
  - Injector
  - Bunch compressors
- Relative bunch length measurements
  - Experimental setup
  - Simulations
  - Measurements
- Outlook

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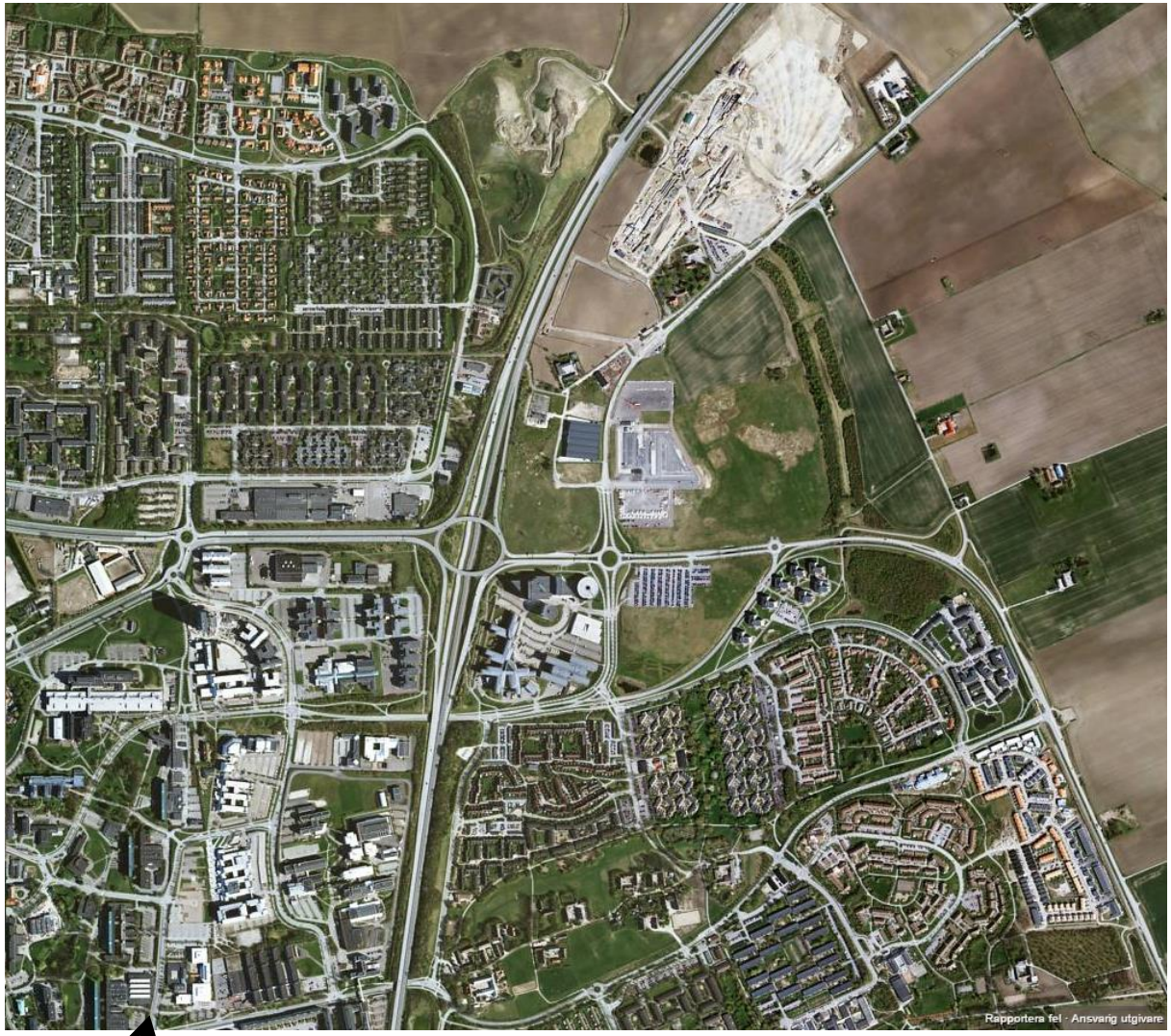

MAX-lab

MAX IV

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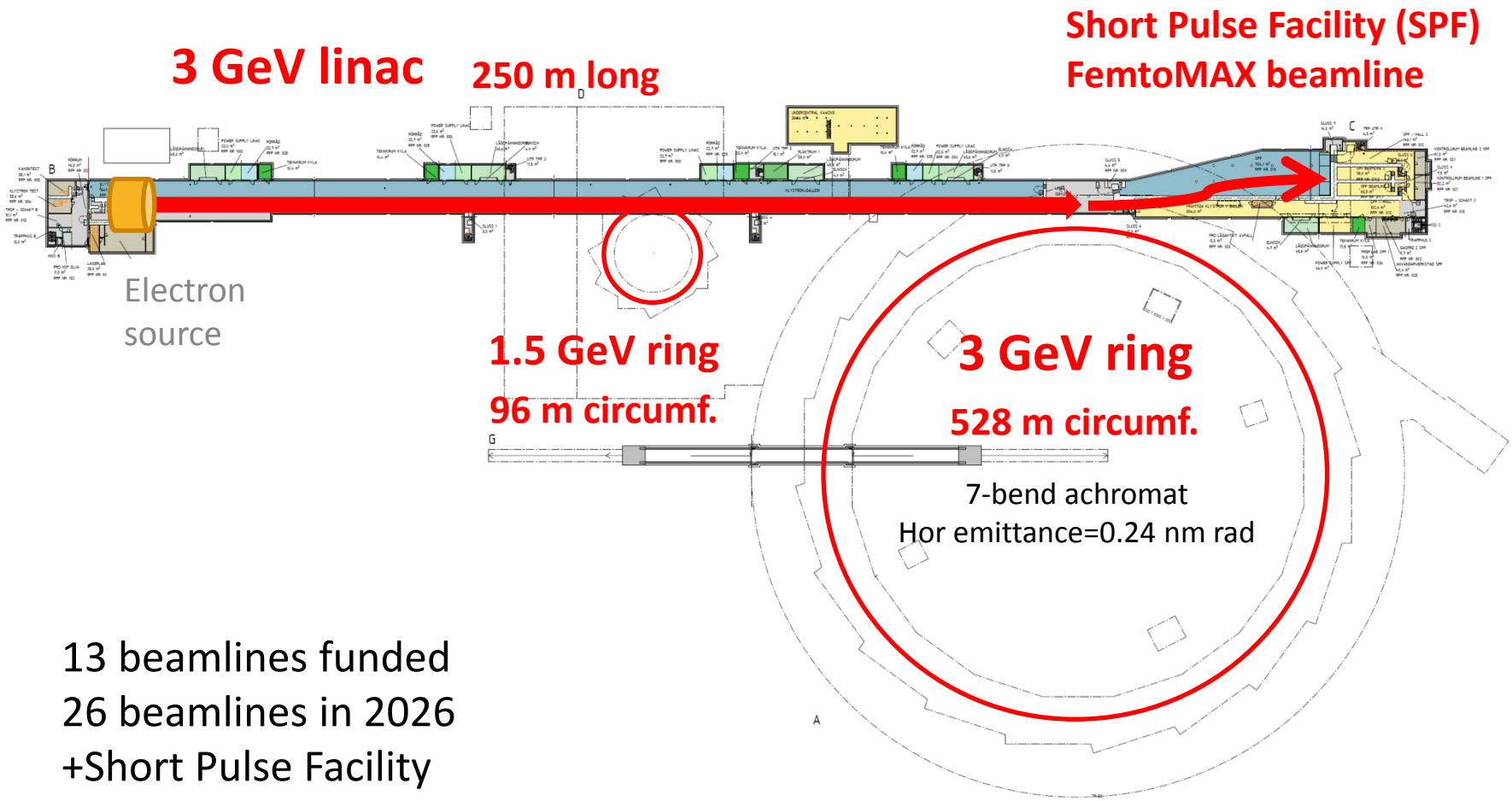
The MAX IV project



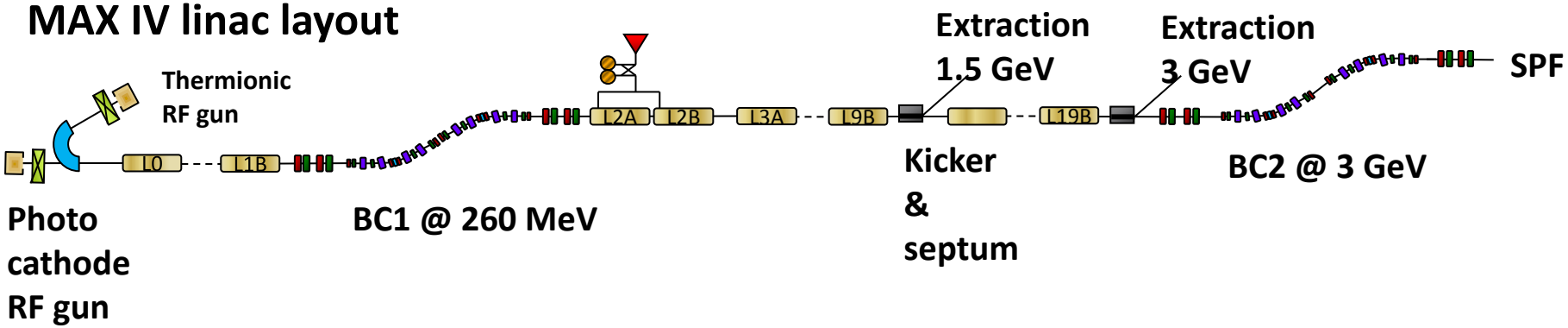
13 beamlines funded
26 beamlines in 2026
+Short Pulse Facility

More details in:

TUP014 S. Thorin | **TUP036 J. Andersson**

Full energy injector

MAX IV linac layout



Ring injection and top up (thermionic gun)

- Energy 3 GeV
- Repetition rate 10 Hz
- Charge 0.6-1 nC
- Emittance 10 mm mrad
- Energy spread <0.2%

High brightness mode for SPF (Short Pulse Facility)

- Energy 3 GeV
- Repetition rate 100 Hz
- Charge 100 pC
- Bunch length 100 fs
- Emittance 1 mm mrad
- Energy spread <0.4%

Milestones (linac)

- 2010-2013:
  - buildings

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- 2013-2014:
  - installation

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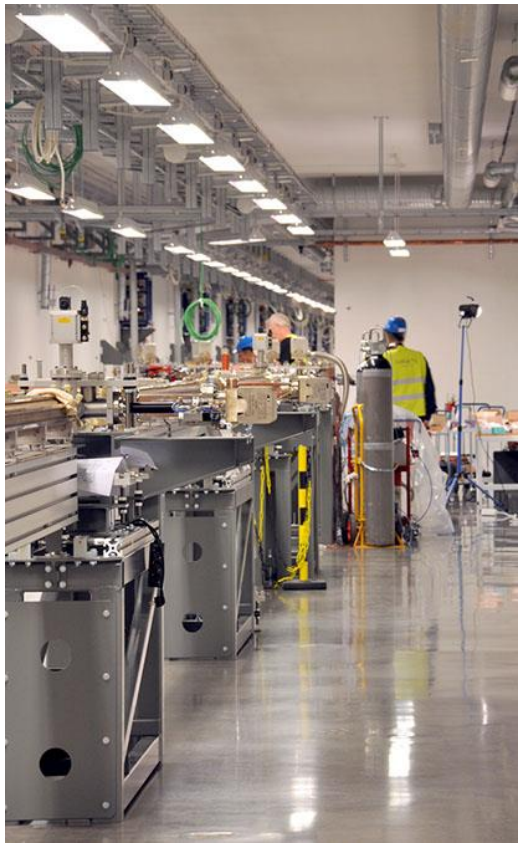
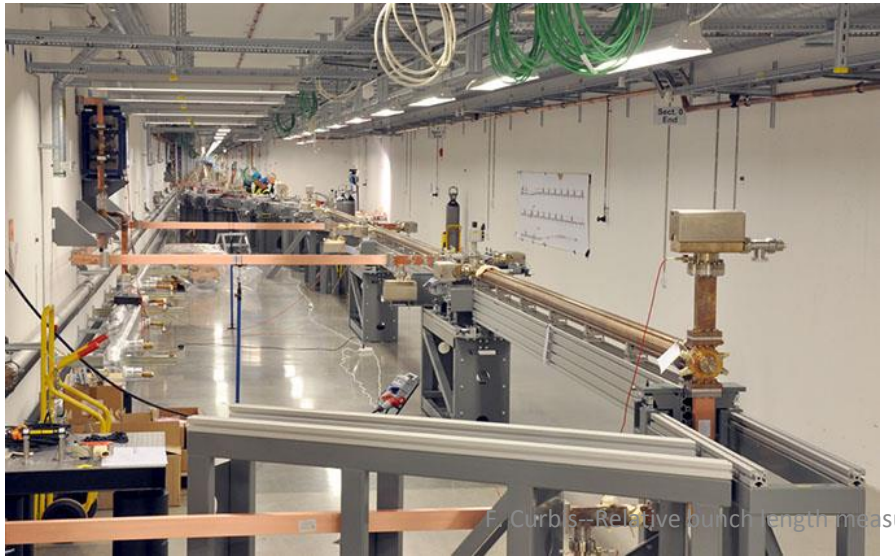
- 2010-2013:
  - buildings
- 2013-2014:
  - installation
- 2014-2015:
  - commissioning
- 2015→ operation

Inside the linac

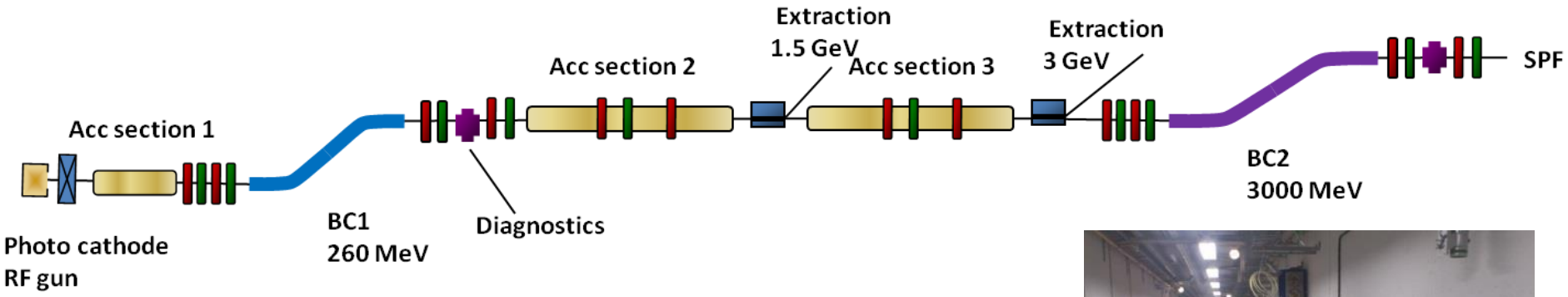


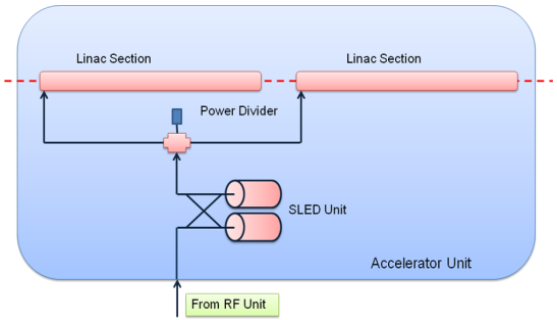


More details in:

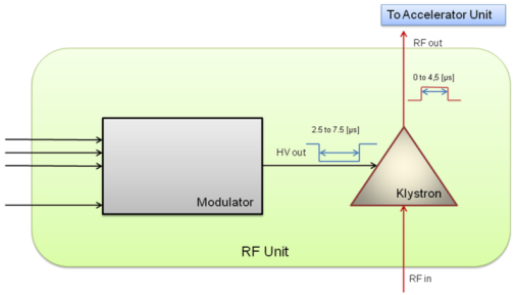
TUP014
S. Thorin

MAX IV linac





39 warm S-band (3 GHz) structures (5.3 m/linac)
20 MV/m gradient→3+0.6 GeV (max on-crest energy)
SLED cavities



18 RF units (solid state modulators + klystrons)
35 MW klystron (peak power) [25MW]
4.5 ms
100 Hz
Thermionic gun: 8 MW, 10 Hz RF unit

MAX IV

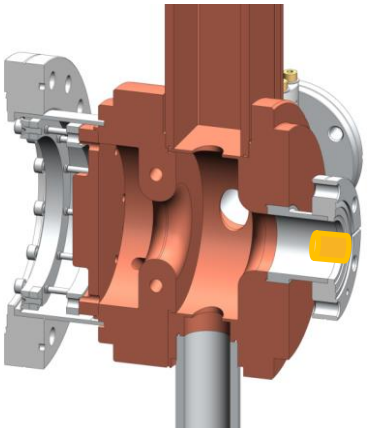
More details in:

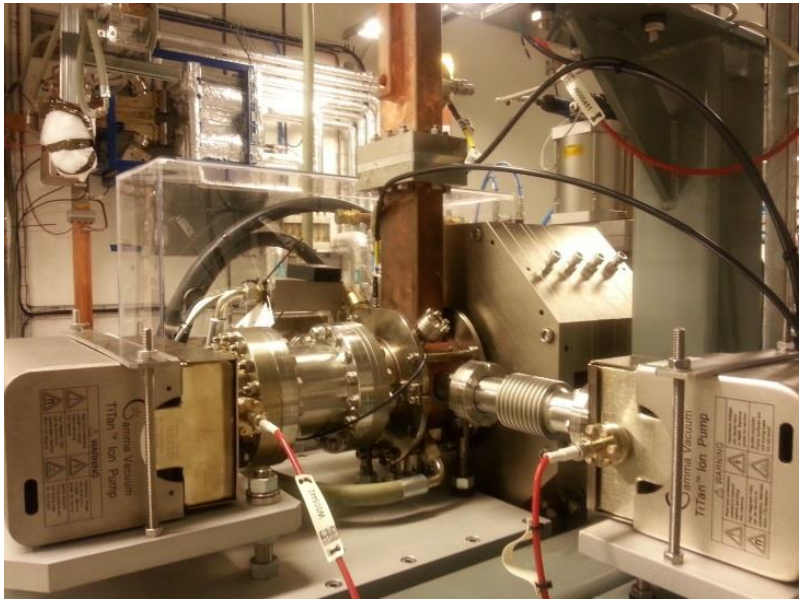
TUP036
J. Andersson

Photocathode gun

- 1.6 cell UCLA-type
- Copper cathode
- 10 Hz→100 Hz
- SLED
- Ti:Sa laser, 263 nm

  KMLabs dual stage Wyvern-1000
  - Pulse energy: 8 mJ at 800 nm (~3 mJ at 400 nm)
  - Pulse duration: 1 ps (FWHM)
  - Repetition rate: 1 kHz
  - Pulse-pulse energy fluctuation: 1% RMS
  - First stage regenerative amplifier
  - Second stage multi-pass
  - Cryo-cooled amplifier crystals
- Commissioned at MAX-lab:
  - <1.5 mm mrad @ 100 pC
  - 4.2 MeV @90 MV/m cathode field
  - QE $2 \cdot 10^{-5}$
- Installed at MAX IV and commissioned late 2014



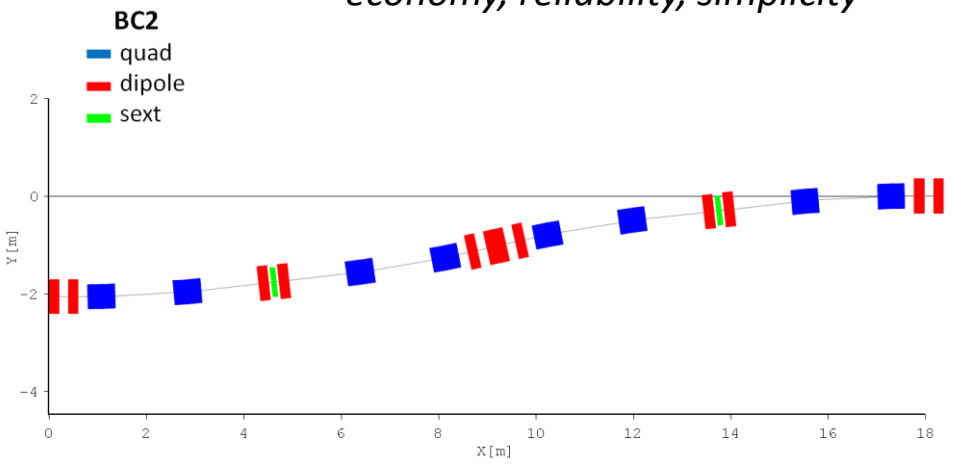


Compression and linearization

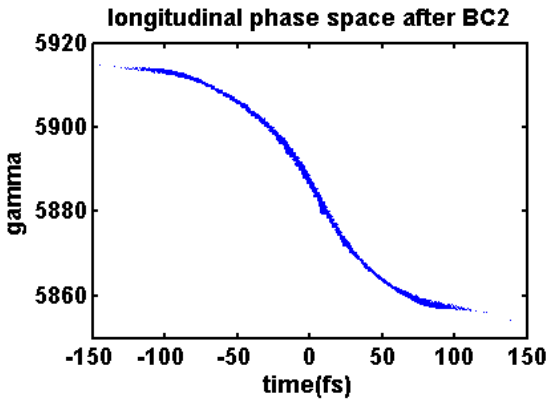
Double achromat Bunch compressors (”self linearising” with T566+ sextupoles for tuning)

- positive fixed R56 (energy chirp from falling RF slope!)
- compression varied with RF phase
- natural T566 used for linearisation
- “weak” sextupoles in the center of each achromat for tuning linearisation
- beam spreader

economy, reliability, simplicity



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



BC1

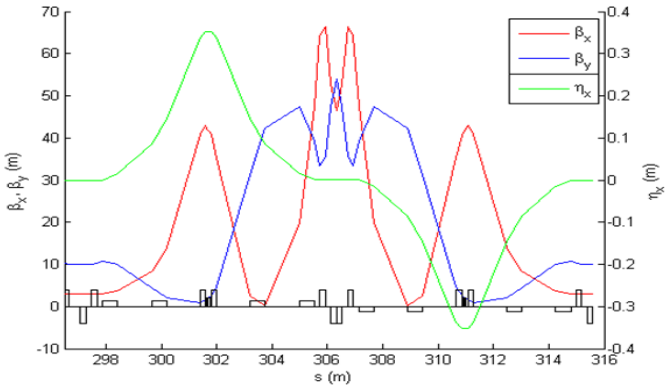
$R_{56} = 2.23\ cm$

$T_{566} = 8.05\ cm$

BC2

$R_{56} = 2.89\ cm$

$T_{566} = 6.76\mu m$



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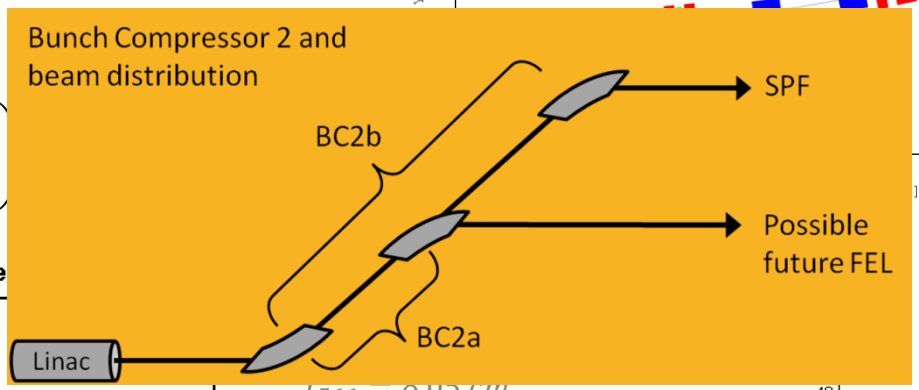

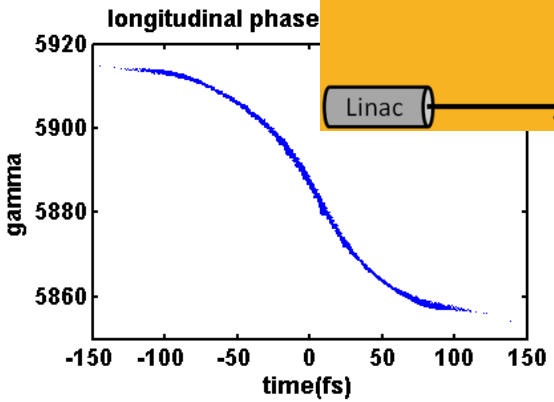

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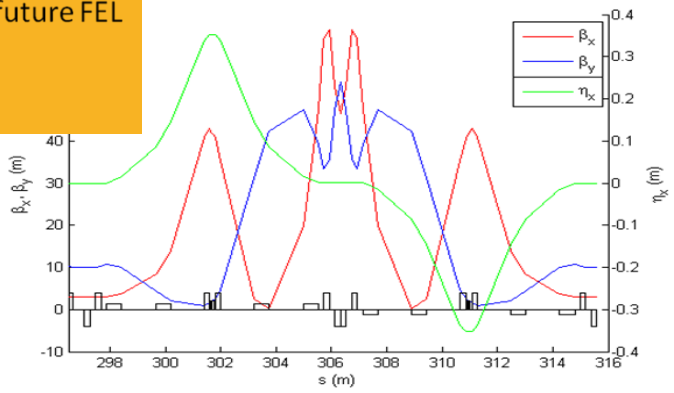
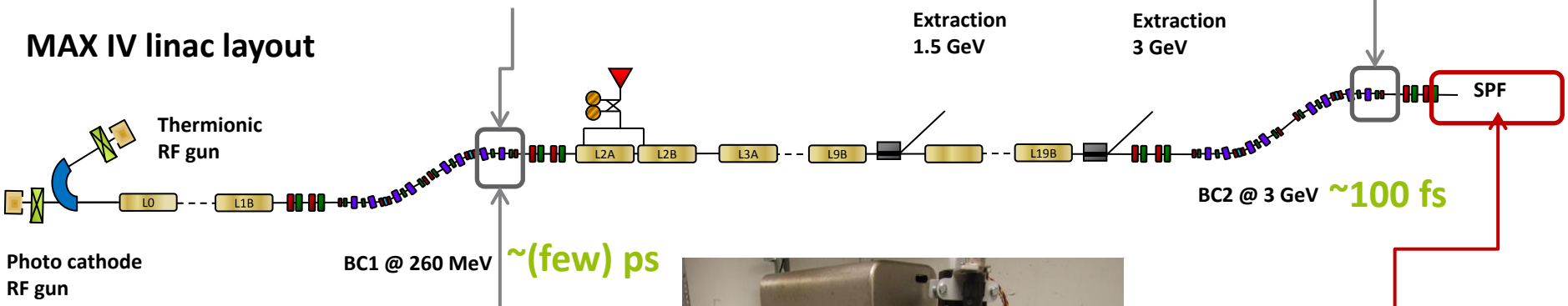
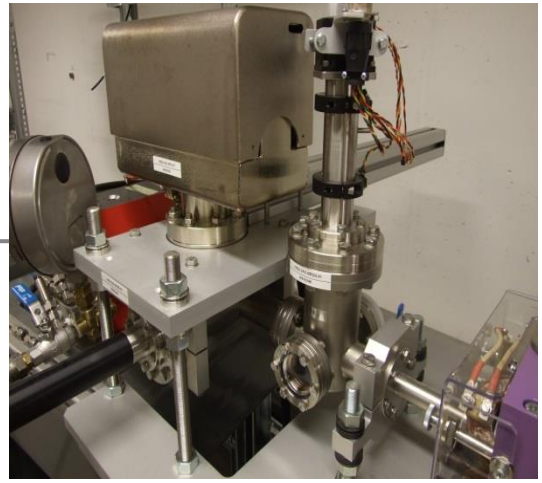


MAXIV longitudinal diagnostics

Prepared for relative measurements





Timing and absolute bunch length

Relative bunch length measurements-our strategy

- Linac not equipped yet with dedicated diagnostics for absolute bunch measurements
- Need of a non-destructive and online tool for feedback

Coherent radiation from dipole in bunch compressor

???

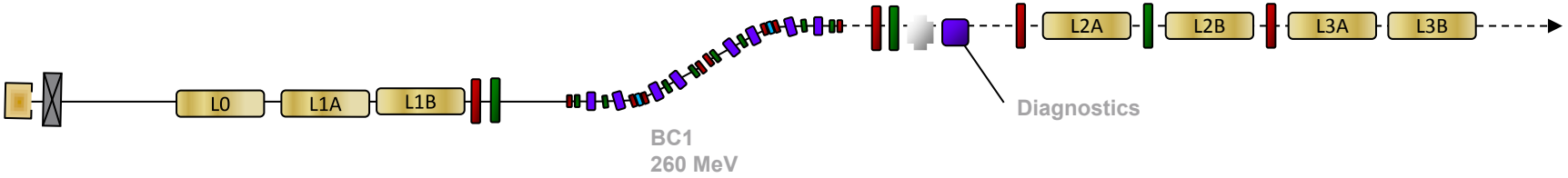
Coherent radiation from ceramic gap

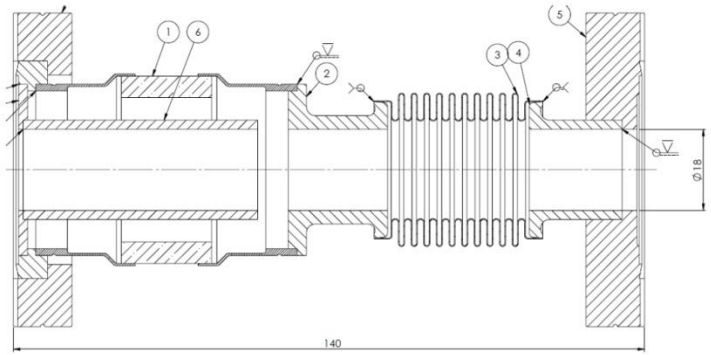
Signal $\propto \sqrt{energy\ \ radiated}$

~30 GHz for 2 ps long bunch

- Relative measurement using transition radiation emitted by the bunch when crossing a ceramic gap discontinuity
- Signal picked up by horn antennas and directed to diodes sensitive to different frequencies

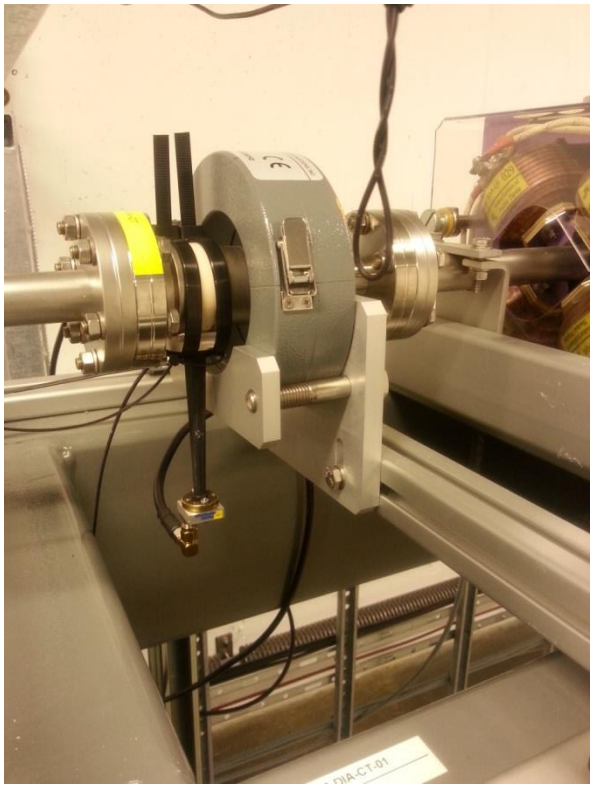
Experimental setup in BC1



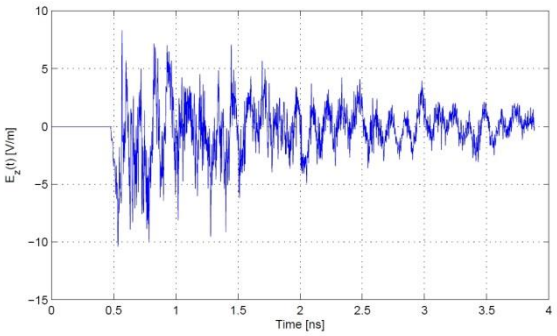


Al_2O_3 ceramic gap

Diodes: 30 GHz and 140 GHz
Conical horn antennas



Simulations (by David Olsson)



- Reproduced a benchmark model of FERMI gap (GdfidL and CST PS)
- Time domain simulations (GdfidL)
  - $\sigma_z = 0.5mm, Q = 1pC, \lambda = 1m$
  - bunch lengths: 0.5,2,5 ps @100pC

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  - trapped TEM modes at 1.5, 3.998, 5.88, 7.981 GHz

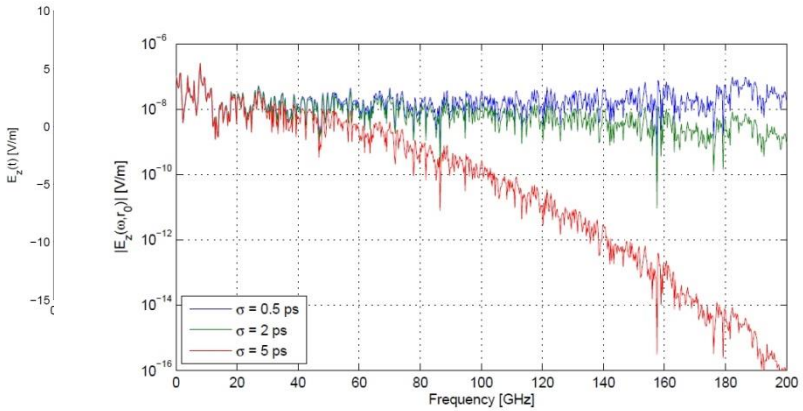

Figure 8: $|E_z(\omega, r_0)|$ for three different bunches with $\sigma_z = 0.5, 2$ and 5 ps. $Q_{\text{tot}} = 100$ pC.

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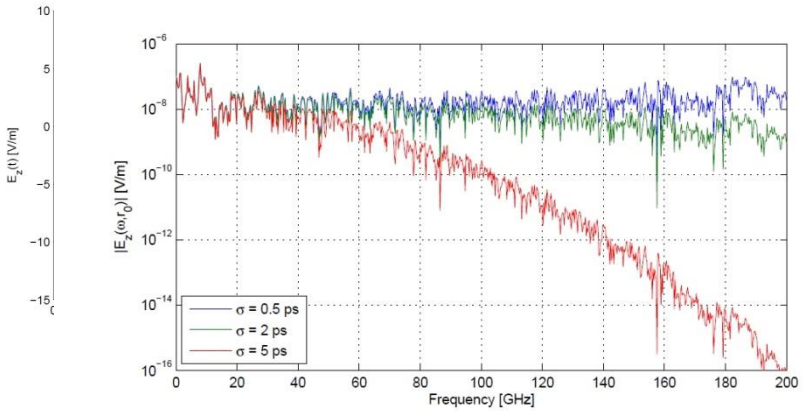

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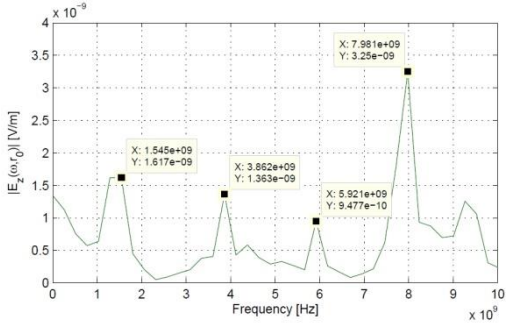

Figure 9: $E_z(\omega, r_0)$ up to 10 GHz obtained with the simulation bunch. The markers are located at peaks caused by trapped eigenmodes.

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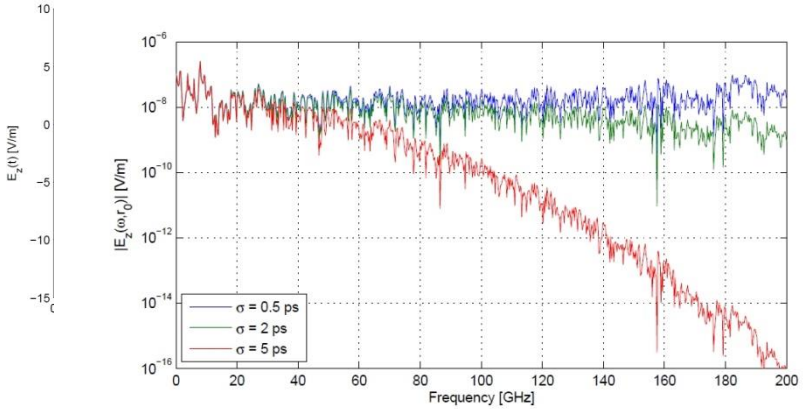

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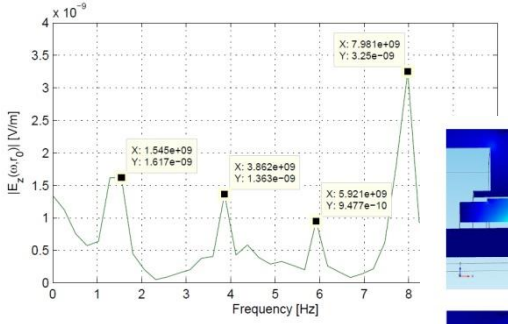

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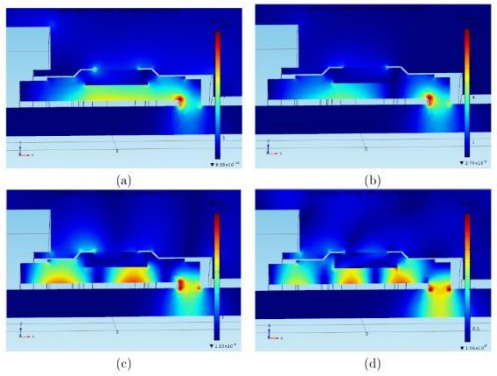
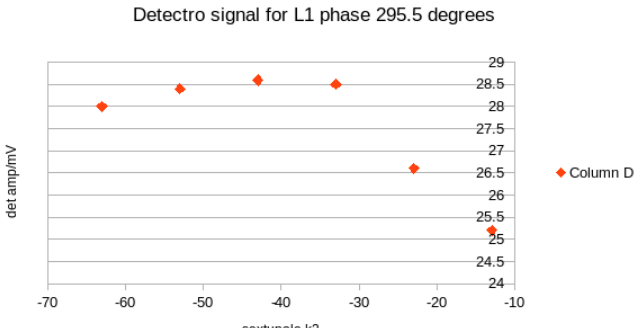
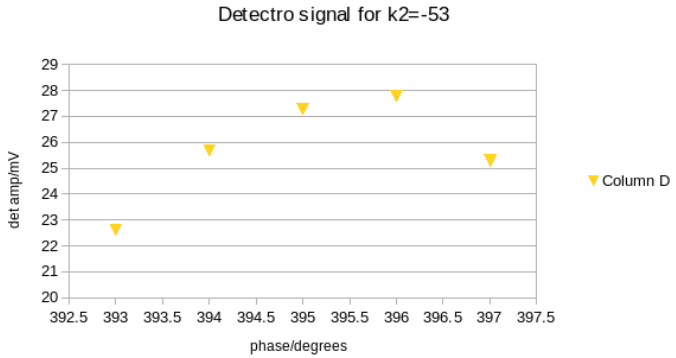


Figure 10: $|\boldsymbol{E}(\mathbf{r})|$ of the eigenmodes found at (a) 1.502 GHz, (b) 3.998 GHz, (c) 5.880 GHz, and (d) 7.981 GHz,. Note that the geometry has been rotated in the coordinate system by mistake....

Measurements in BC1

- Detector signal increases when changing settings from an uncompressed to a compressed beam.
- Influence of beam size and beam position relative to the detector
- Changed horn antennas position (vertical/horizontal, two from the side, one below)





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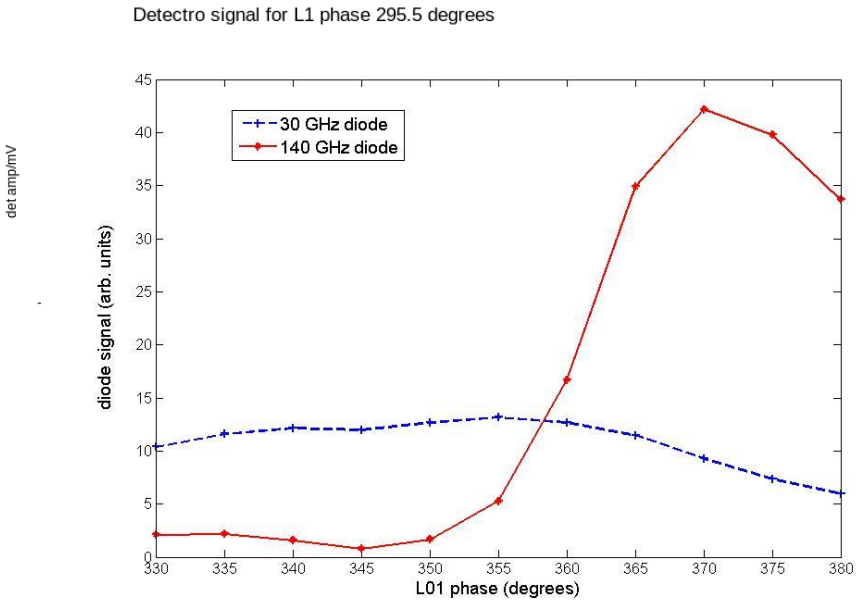
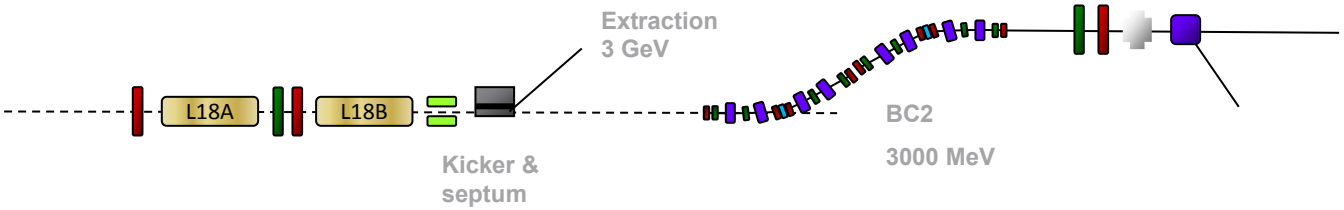


Crest at 340 degrees
Electron energy kept constant in BC1 by varying the SLED filling time and phase

Indication of maximum compression at 370 degrees

Summary/Outlook

- Preliminary measurements of bunch length after BC1
  - Influence of changing compression on the diode signal
- Plan to perform same measurements in BC2
  - New diodes ordered (Shorter bunches →higher frequency detectors)
  - Intensity drops as frequency increases
- Using this measurement as feedback for the linac phase
- Benchmarking with SPF pulse measurements
- Long term plan:
  - Add a transverse deflecting cavity at the end of the linac



Acknowledgements

- Marco Veronese (Elettra Sincrotrone Trieste)
- Roberto Appio (MAX IV laboratory)

Thank you for your attention!