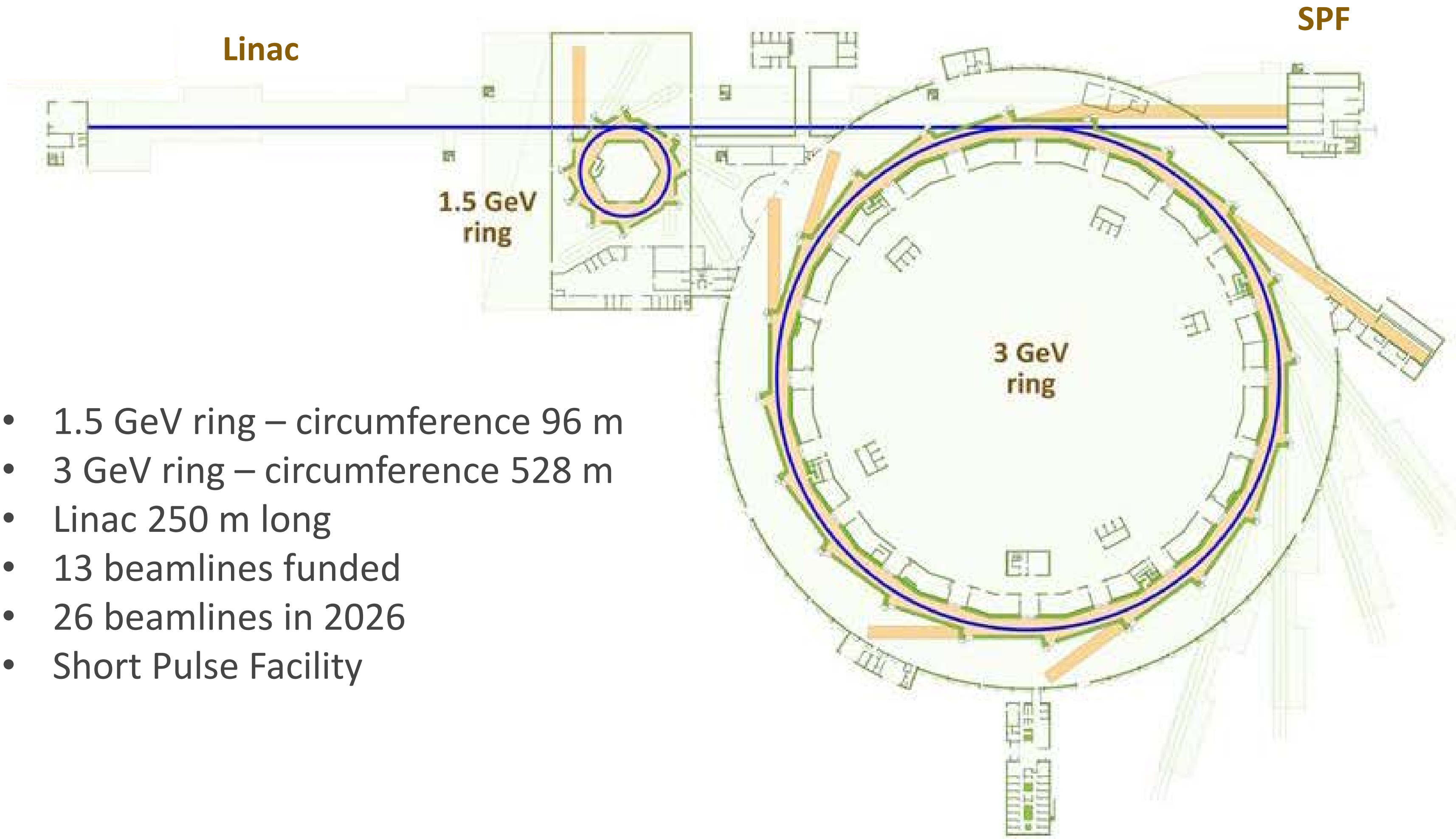
The MAX IV linac

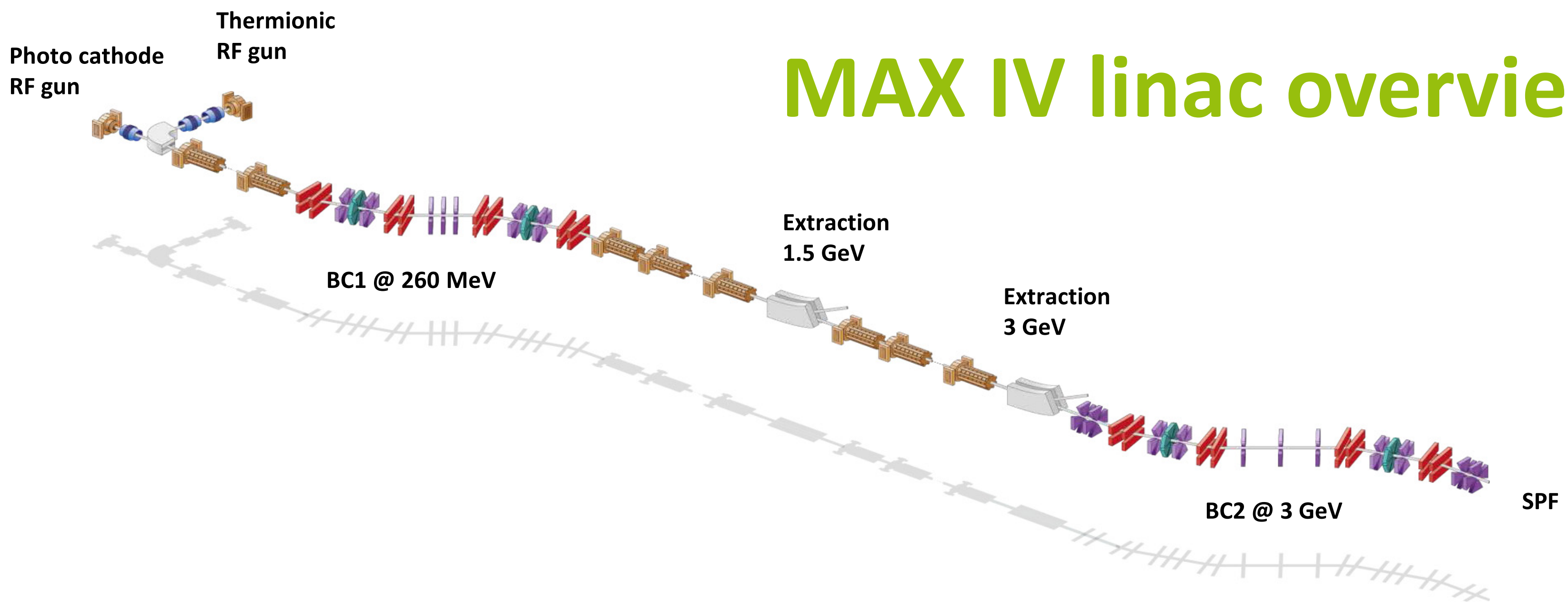
Sara Thorin, on behalf of the
MAX IV linac team

MAX IV



- 1.5 GeV ring – circumference 96 m
- 3 GeV ring – circumference 528 m
- Linac 250 m long
- 13 beamlines funded
- 26 beamlines in 2026
- Short Pulse Facility

MAX IV linac overview

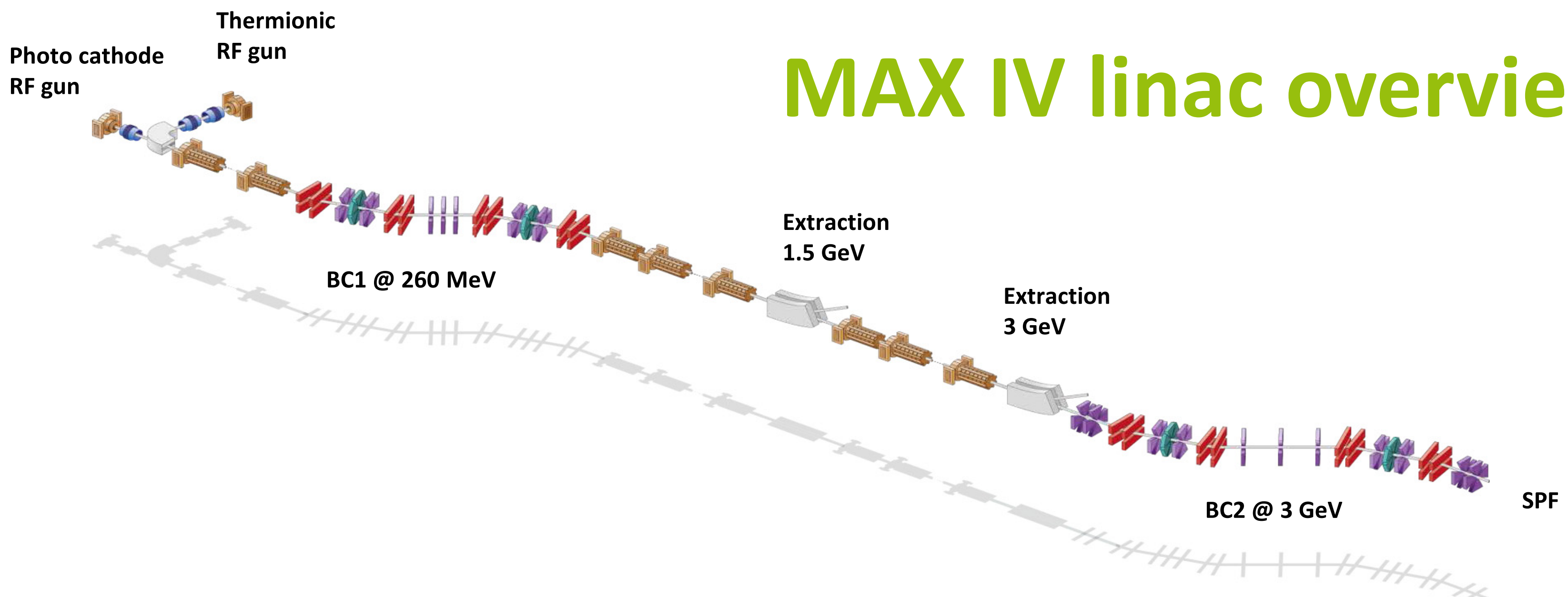


Full energy injection and top up operation for the two storage rings

Energy	1.5 GeV/ 3GeV
Injection frequency	10 Hz
Charge	0.6-1 nC/shot
Emittance	10 mm mrad
Energy spread	<0.2%

MAX IV

MAX IV linac overview



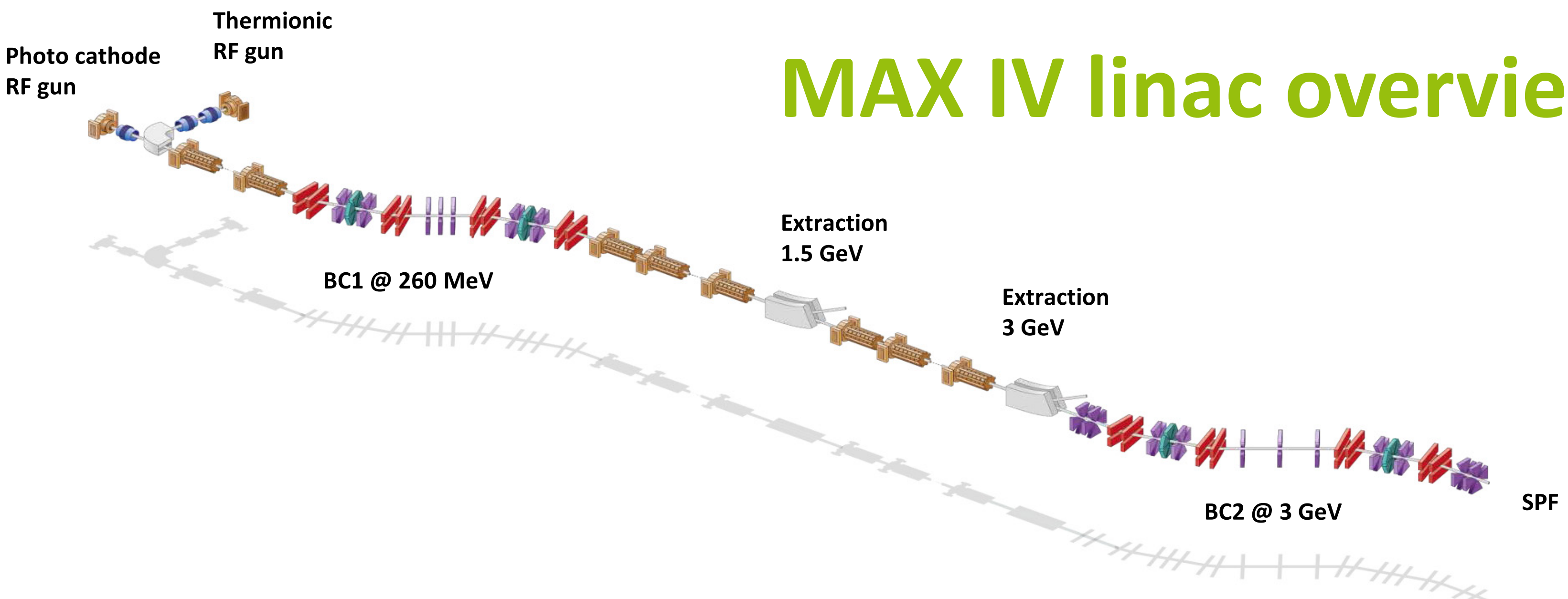
Full energy injection and top up operation for the two storage rings

Energy	1.5 GeV/ 3GeV
Injection frequency	10 Hz
Charge	0.6-1 nC/shot
Emittance	10 mm mrad
Energy spread	<0.2%

High brightness driver for the Short Pulse Facility

Energy	3GeV
Injection frequency	100 Hz
Charge	100 pC
Bunch length	100 fs
Emittance	1 mm mrad
Energy spread	<0.4%

MAX IV linac overview



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

Energy	1.5 GeV/ 3GeV
Injection frequency	10 Hz
Charge	0.6-1 nC/shot
Emittance	10 mm mrad
Energy spread	<0.2%

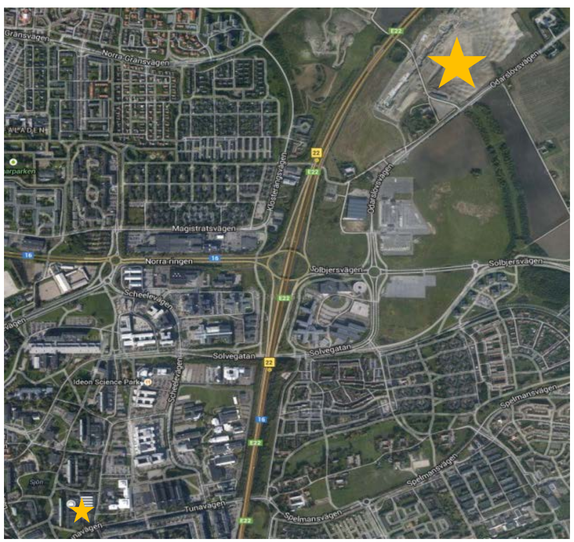
High brightness driver for the Short Pulse Facility

Energy	3GeV
Injection frequency	100 Hz
Charge	100 pC
Bunch length	100 fs
Emittance	1 mm mrad
Energy spread	<0.4%

Possible future Free Electron Laser

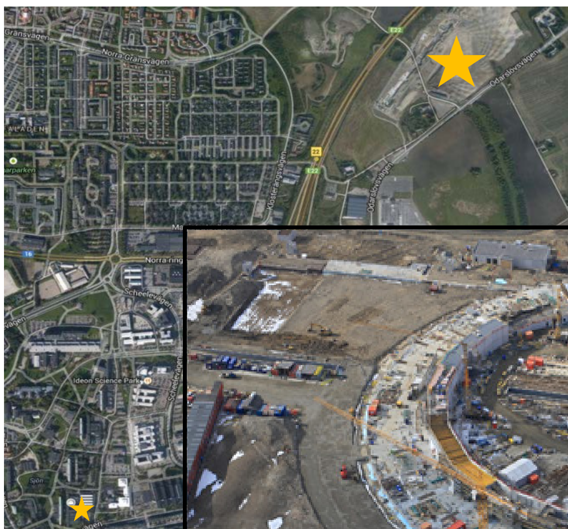
MAX IV linac timeline

	2010	2011	2012	2013	2014	2015	2016
Linac building							
Linac installation							
Linac commissioning							
Linac operation							



MAX IV linac timeline

	2010	2011	2012	2013	2014	2015	2016
Linac building	→	→	→	→			
Linac installation				→	→		
Linac commissioning					→	→	
Linac operation						- - →	- - →



MAX IV linac timeline

	2010	2011	2012	2013	2014	2015	2016
Linac building	———	———	———	——→			
Linac installation				———	——→		
Linac commissioning					———	——→	
Linac operation						- - -	- - -→

MAX IV linac timeline

	2010	2011	2012	2013	2014	2015	2016
Linac building	———	———	———	——→			
Linac installation				———	——→		
Linac commissioning					———	——→	
Linac operation						- - -	- - →

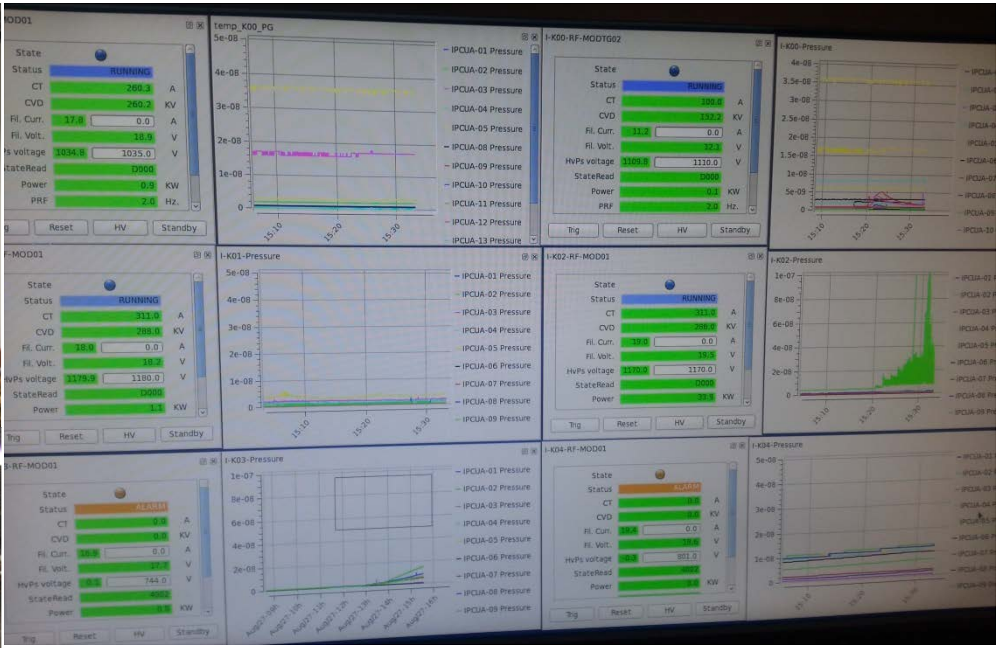
MAX IV linac timeline

	2010	2011	2012	2013	2014	2015	2016
Linac building	→	→	→	→			
Linac installation				→	→		
Linac commissioning					→	→	
Linac operation						- - →	- - →

MAX IV linac timeline

	2010	2011	2012	2013	2014	2015	2016
Linac building							
Linac installation							
Linac commissioning							
Linac operation							

Conditioning

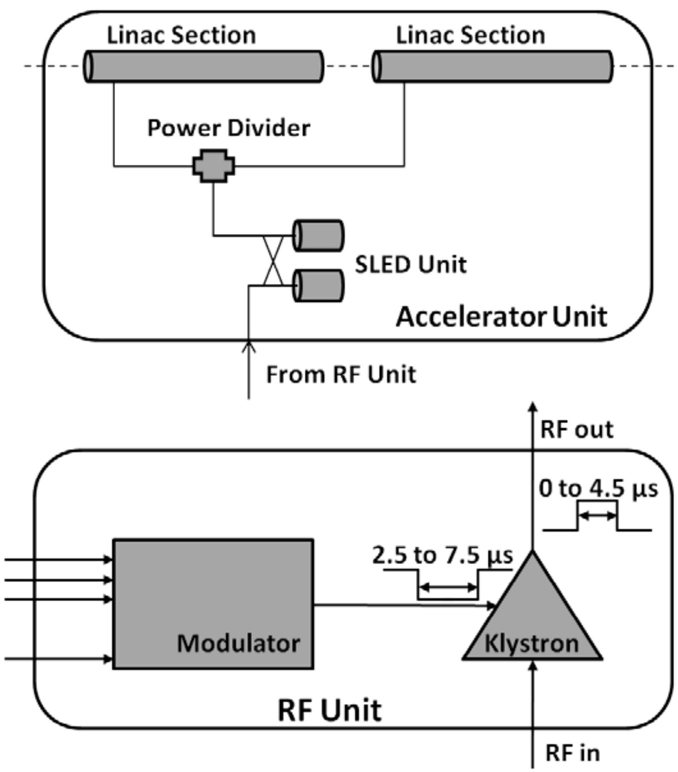


- Linac and SLED pre-conditioned
- Short waveguides
- Good vacuum

→ assumed short conditioning time

- Baking
- Hybrid mode

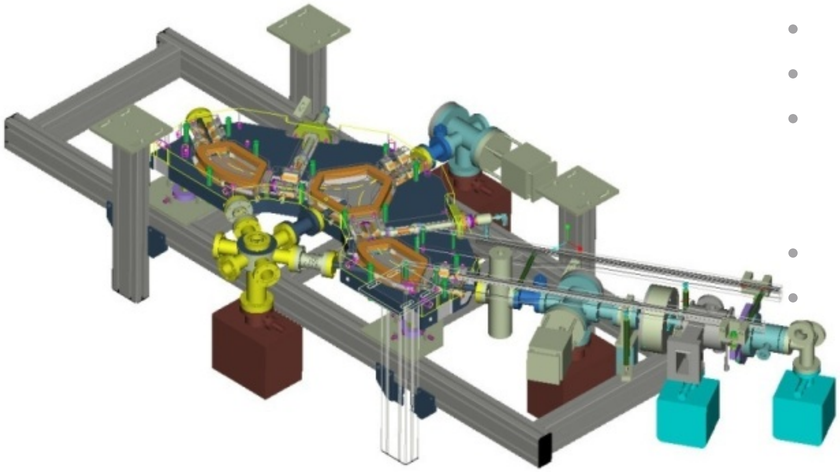
MAX IV linac



- 39 warm s-band linac structures + SLED
- 18 units
- 3 GHz
- 5.3 m/linac
- 20 MV/m gradient
- 3 + 0.6 GeV

- 18 modulators + klystrons
- 37 MW peak power
- 4.5 ms
- 100 Hz
- Thermionic gun: 8 MW 10 Hz RF unit

Thermionic gun

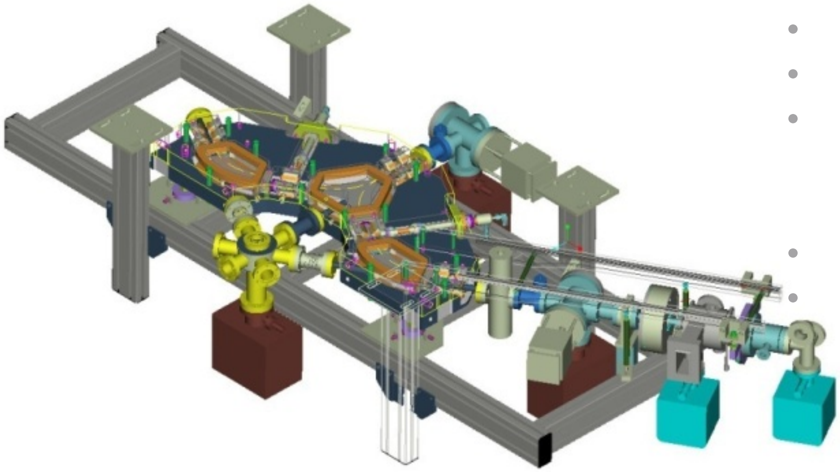


- RF gun
- BaO cathode
- Exported to SOLARIS and Canadian light source
- 270 degree energy filter
- In operation at MAX-lab

Design parameters of the MAX IV thermionic pre-injector	
Beam kinetic energy	2–2.5 MeV
Bunch frequency before chopper, f_{gun}	2.9985 GHz
Bunch train frequency, f_{ring}	99.931±0.5 MHz
Number of bunches per bunch train	3
Number of bunch trains per LINAC shot	1 or 10
LINAC shot repetition frequency	10 Hz
Total injected charge per top-up injection	9.0 nC

MAX IV

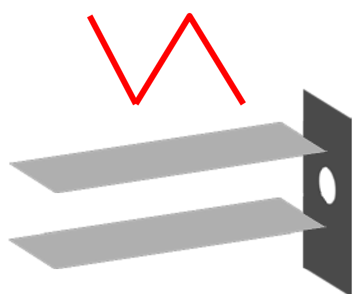
Thermionic gun

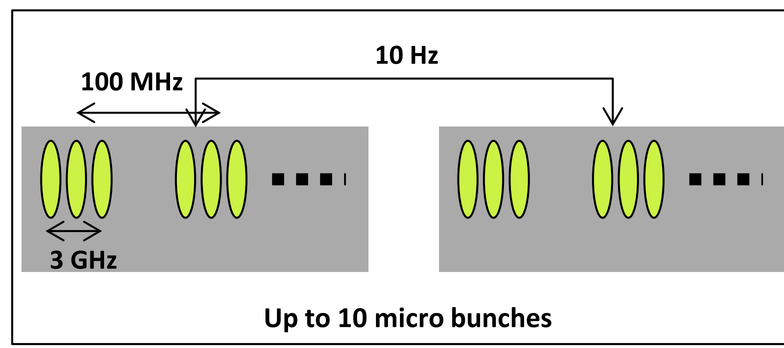


- RF gun
- BaO cathode
- Exported to SOLARIS and Canadian light source
- 270 degree energy filter
- In operation at MAX-lab

Design parameters of the MAX IV thermionic pre-injector	
Beam kinetic energy	2–2.5 MeV
Bunch frequency before chopper, f_{gun}	2.9985 GHz
Bunch train frequency, f_{ring}	99.931±0.5 MHz
Number of bunches per bunch train	3
Number of bunch trains per LINAC shot	1 or 10
LINAC shot repetition frequency	10 Hz
Total injected charge per top-up injection	9.0 nC

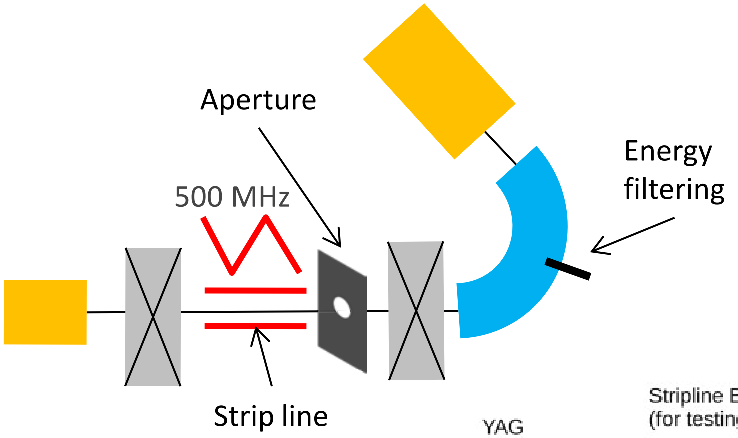
+ Chopper system*

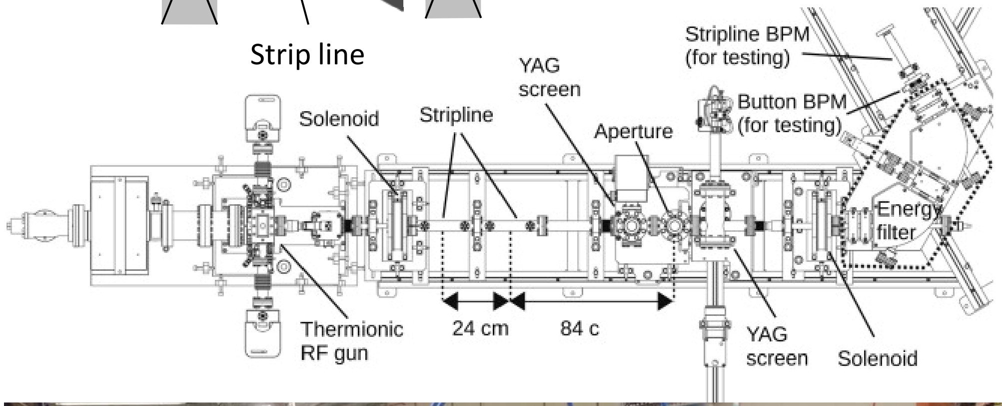


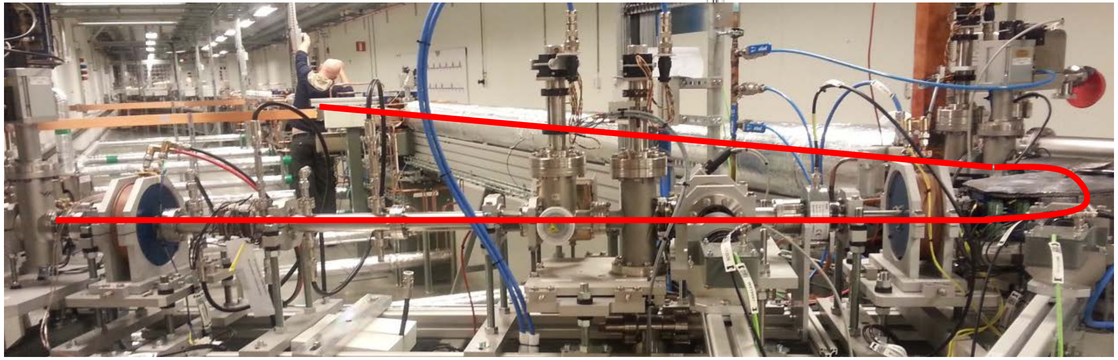


* D. Olsson et al, *A chopper system for the MAX IV thermionic pre-injector,* Nuclear Instruments and Methods in Physics Research, Volume 759, 21 September 2014, Pages 29–35

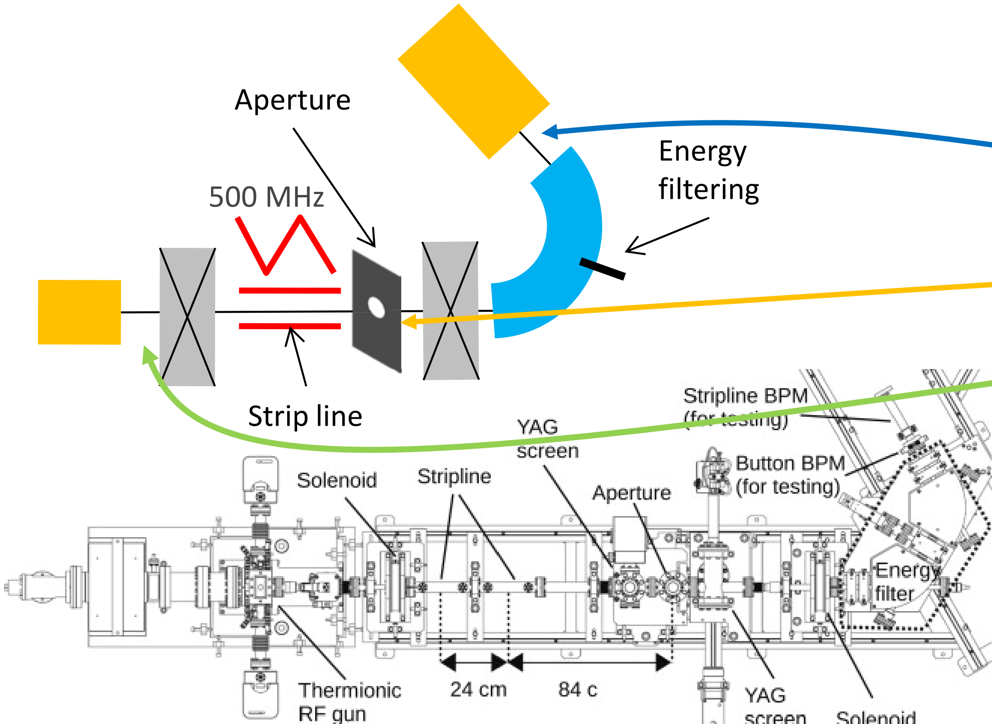
Thermionic gun + chopper

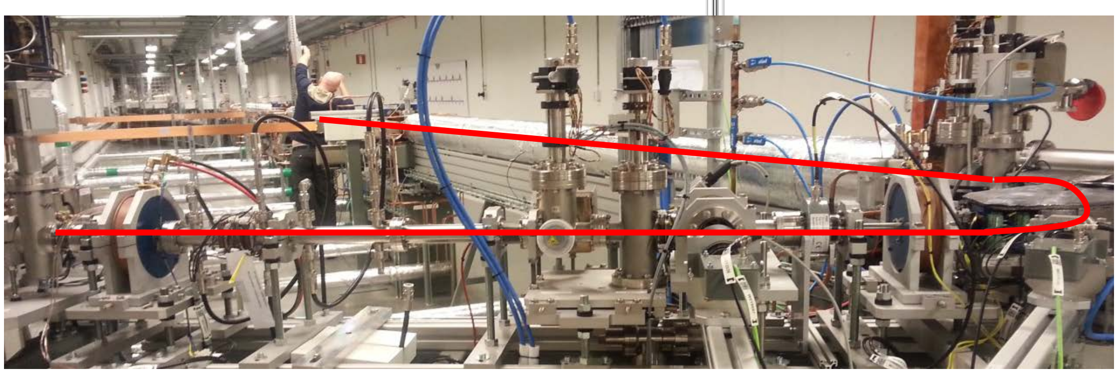






Thermionic gun commissioning

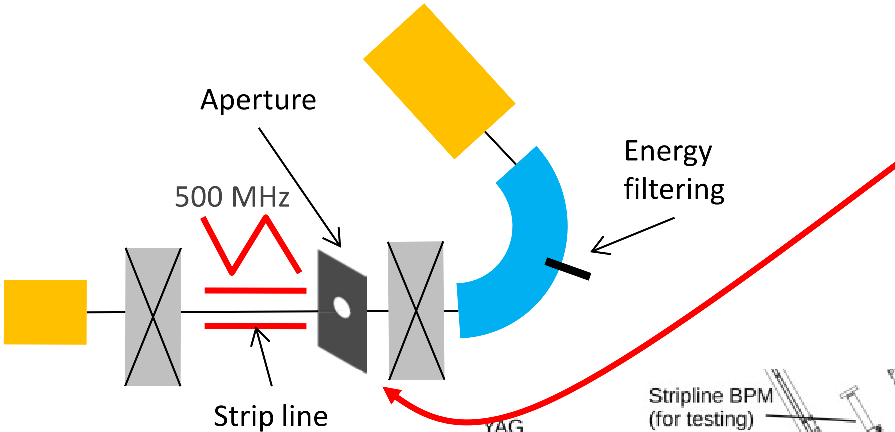




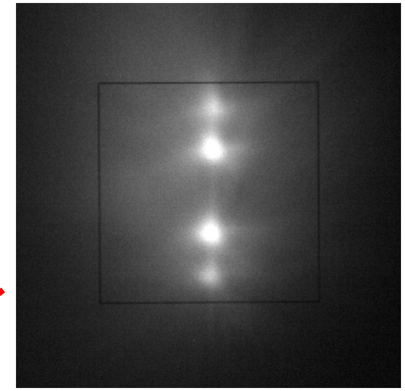
Commissioning parameters	
Charge	0.75 nC/shot
Rep rate	2 Hz
Chopper f	500 MHz

MAX IV

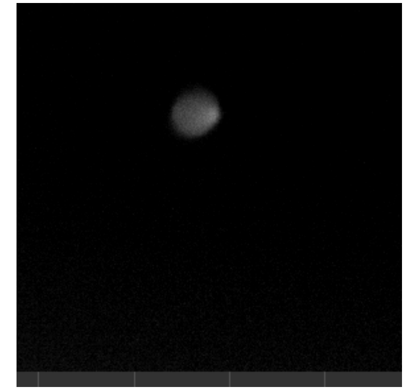
Thermionic gun commissioning

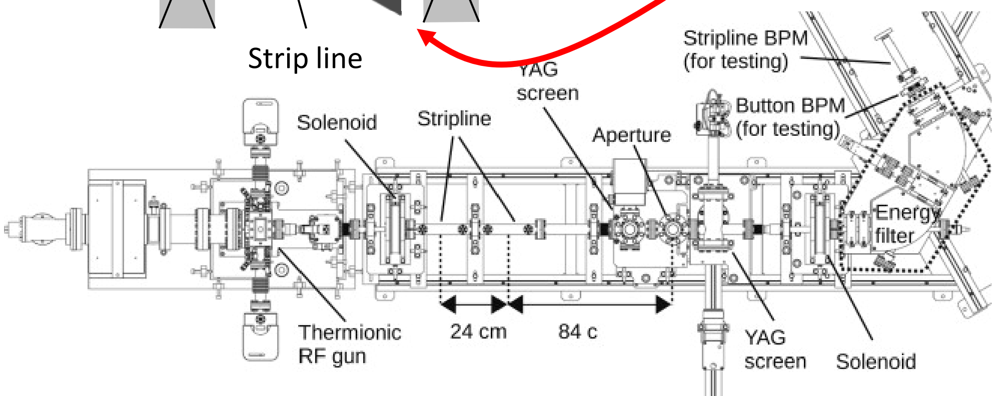


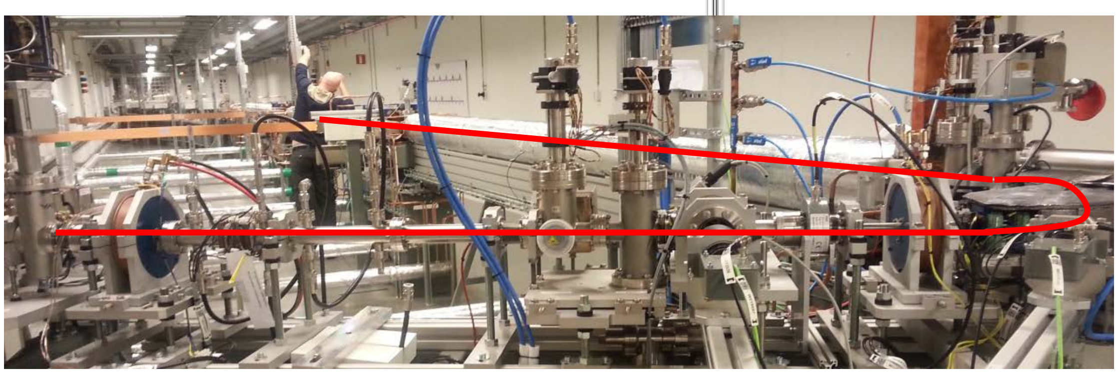
No aperture



With aperture

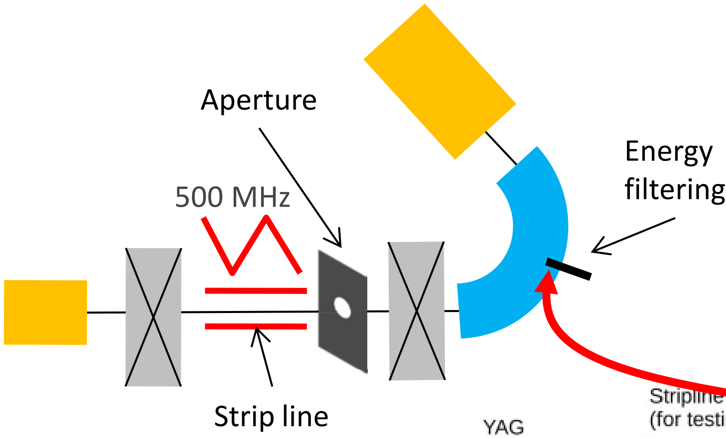


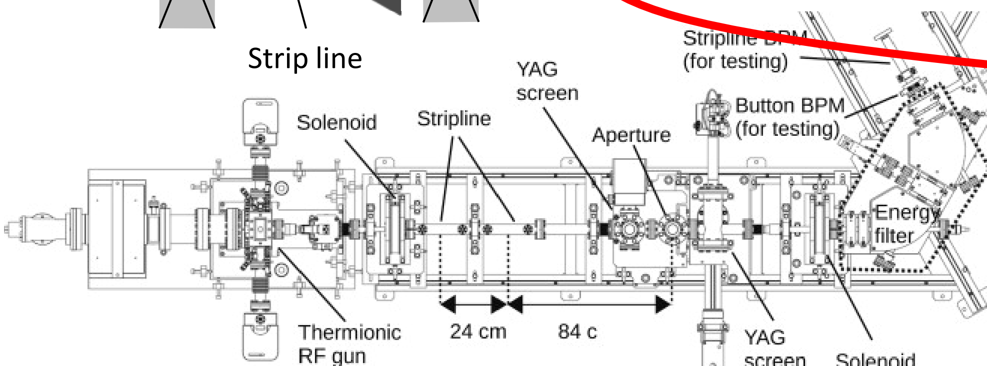




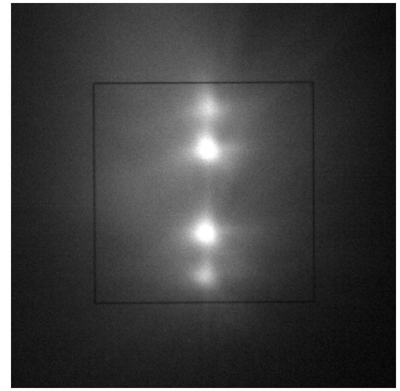
MAX IV

Thermionic gun commissioning

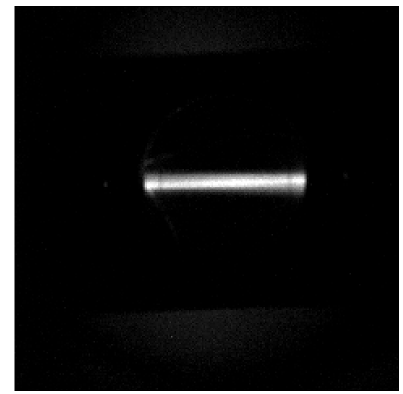


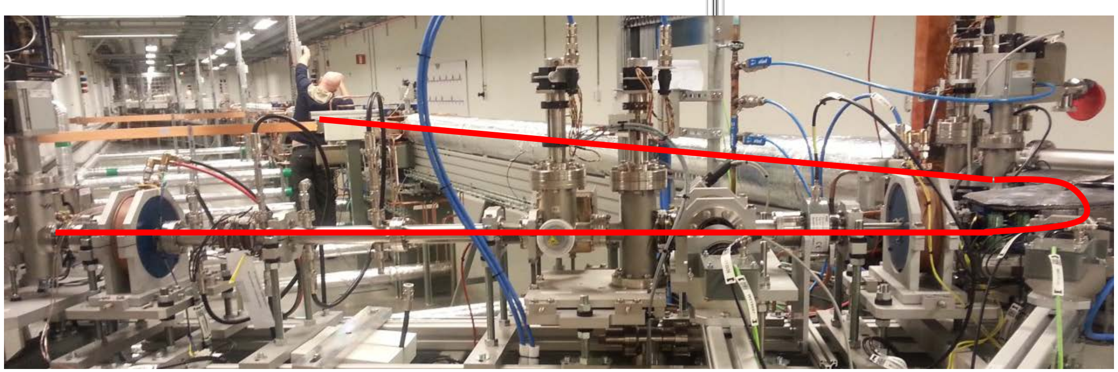


No aperture

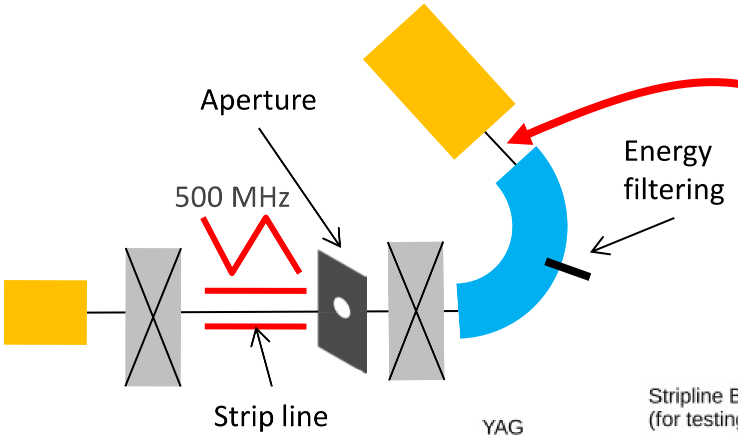


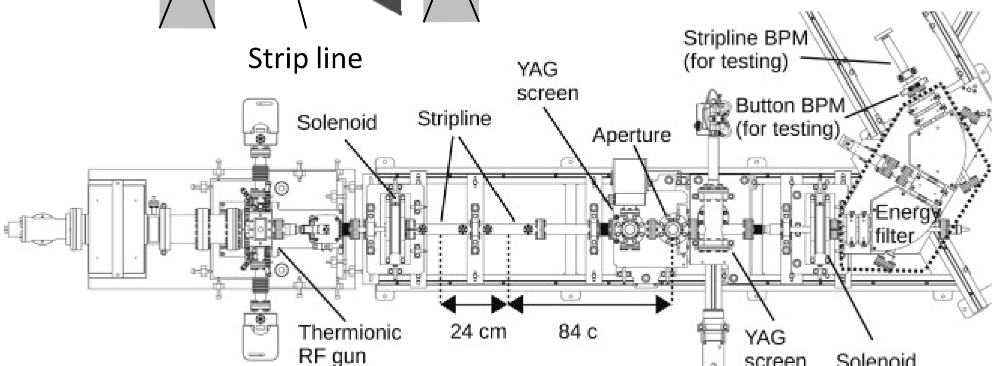
With aperture

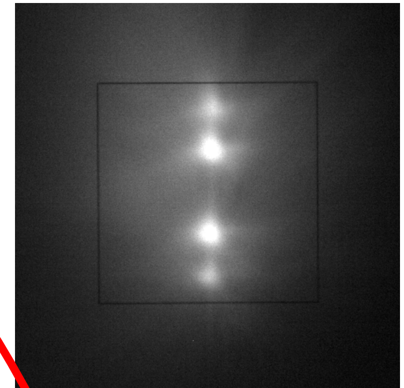




Thermionic gun commissioning

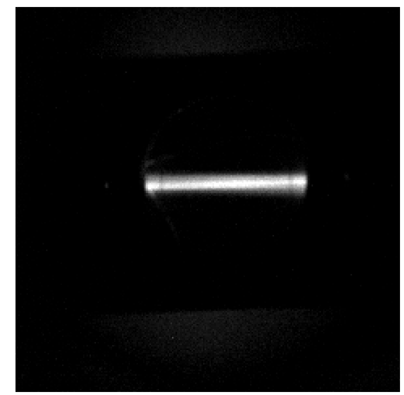


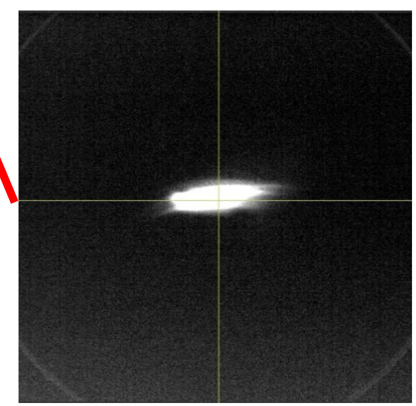


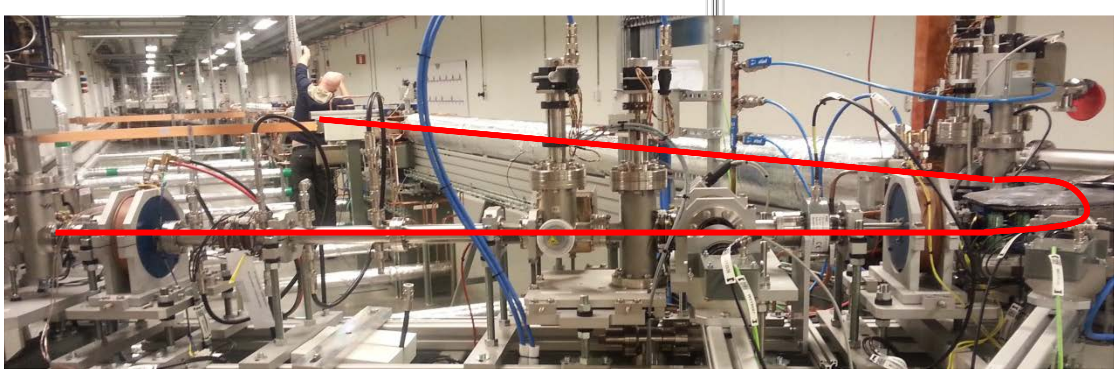


No aperture

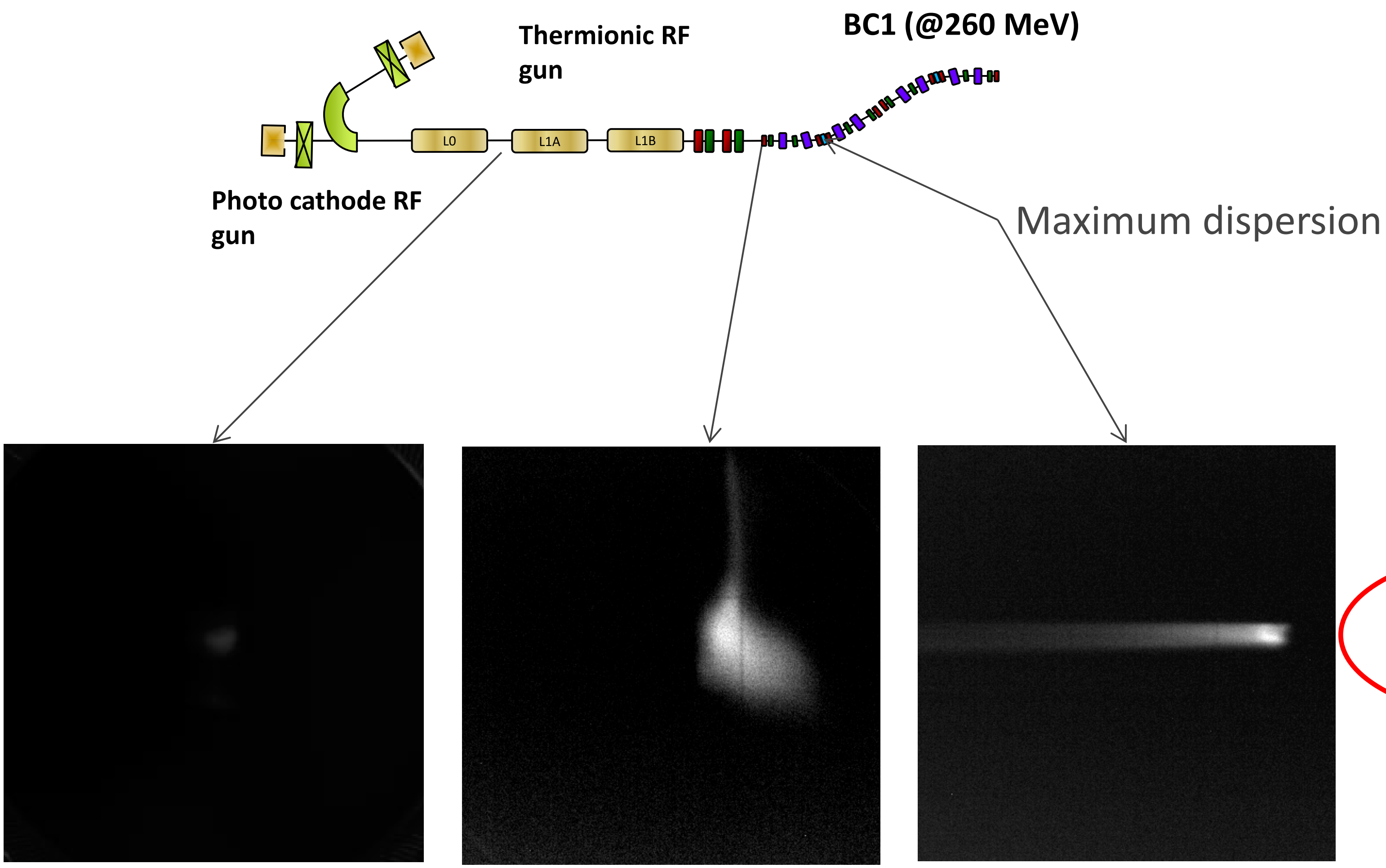
With aperture







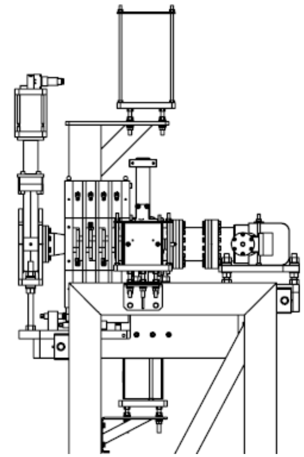
Commissioning

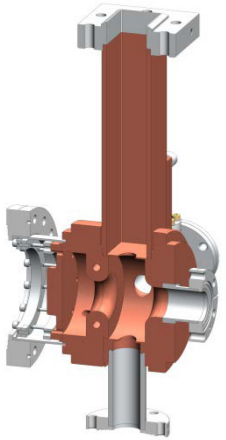


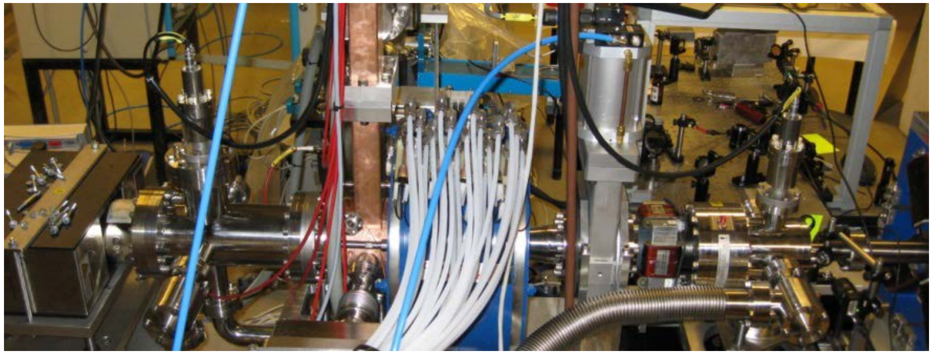
Beam energy 280 MeV

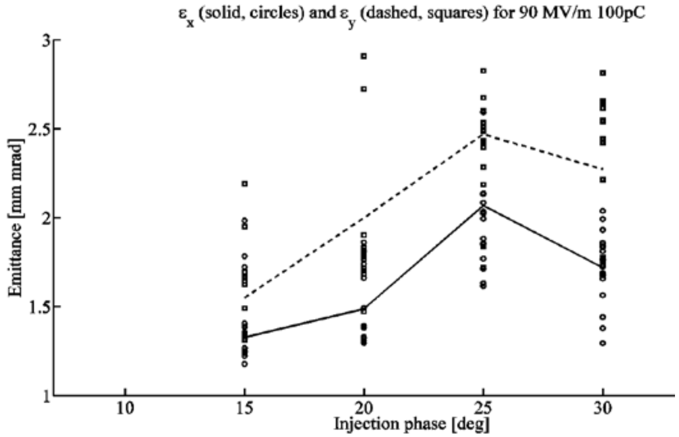
High brightness gun

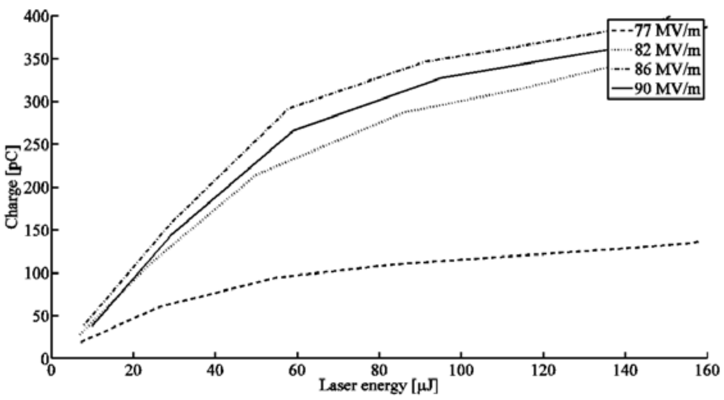
- 1.6 cell UCLA-type RF gun
- Copper cathode
- 10 Hz/100Hz
- SLED
- Ti-sapphire laser, 263 nm
- Commissioned and tested at MAX-lab
    - < 1.5 mm mrad @ 100 pC
    - 4.2 MeV @ 90 MeV/m cathode field
    - Quantum efficiency $2 \cdot 10^{-5}$
- Installed at the MAX IV linac
- Commissioning late 2014





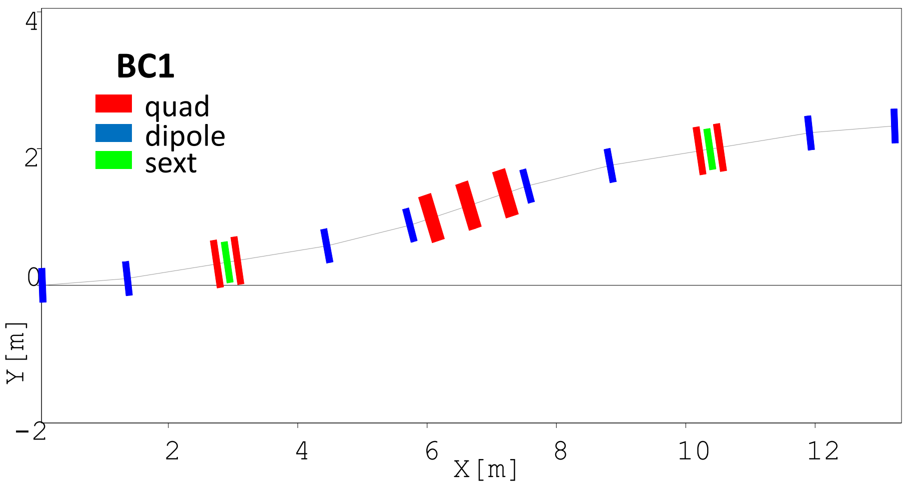


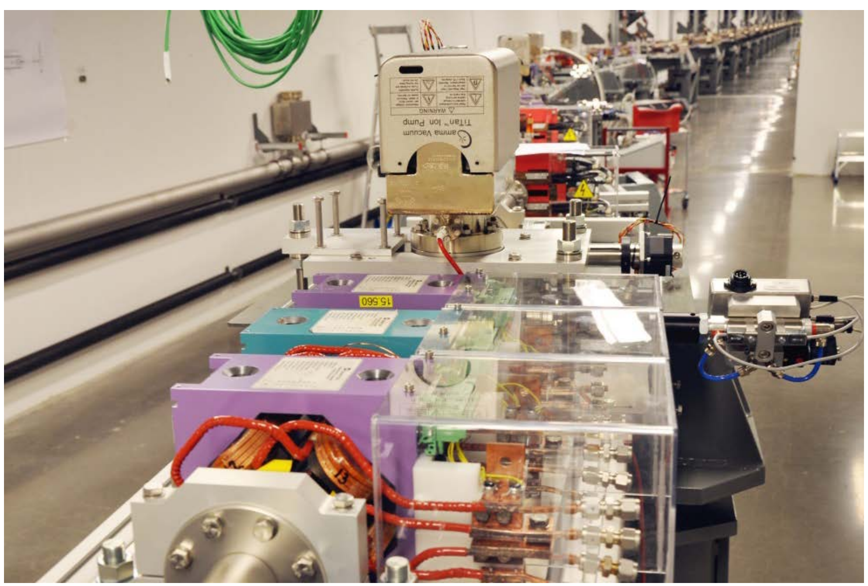


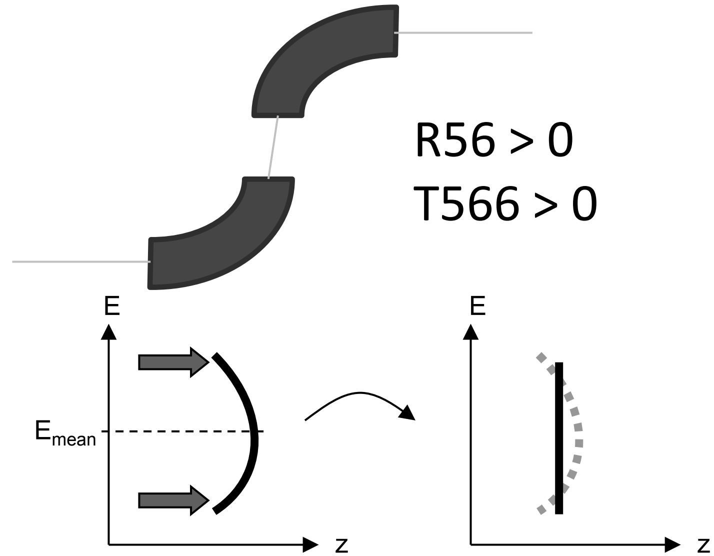


MAX IV

Bunch compressors – double achromats



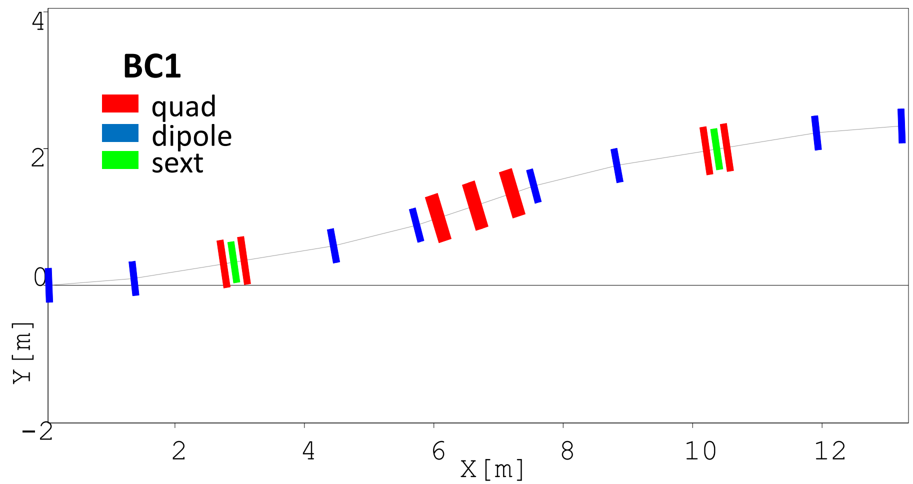




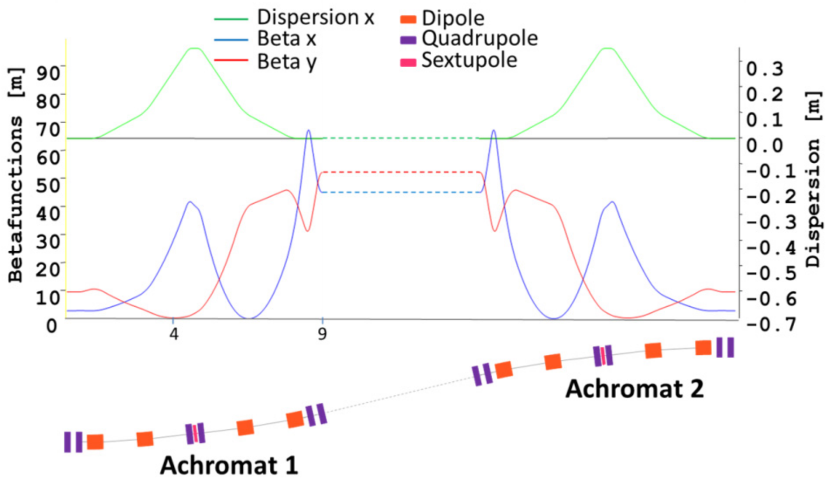
$$\Delta z = R_{56}\left(\frac{\Delta E}{E}\right) + T_{566}\left(\frac{\Delta E}{E}\right)^2$$

	BC1	BC2
R56	2.23 cm	2.89 mm
T566	8.05 cm	6.76µm

Bunch compressors



Bunch Compressor 2

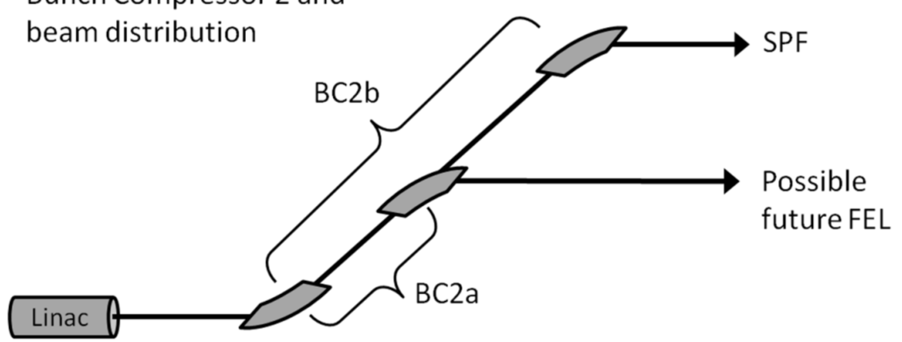


Why self linearising compression?

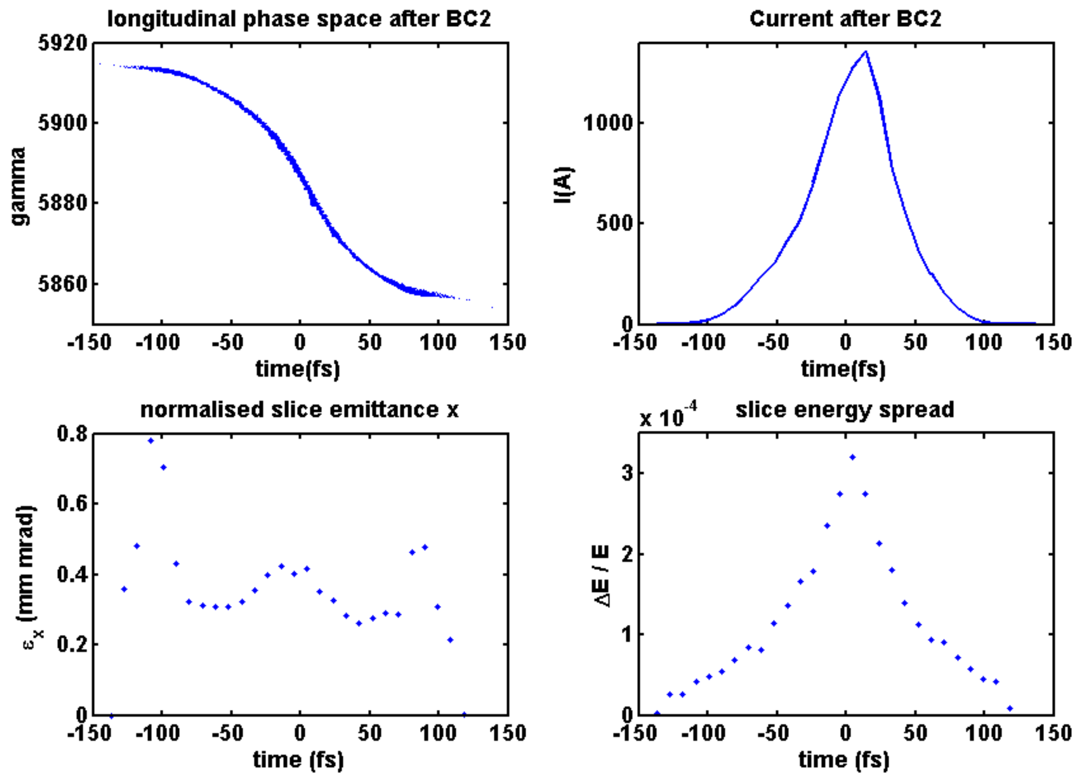
- economy
- reliability
- simplicity

Why compression in double achromats?

- positive R56 (fixed)
- positive T566 for linearisation
- "weak" sextupoles for tuning
- symmetry → small energy depending matrix elements
- beam spreader



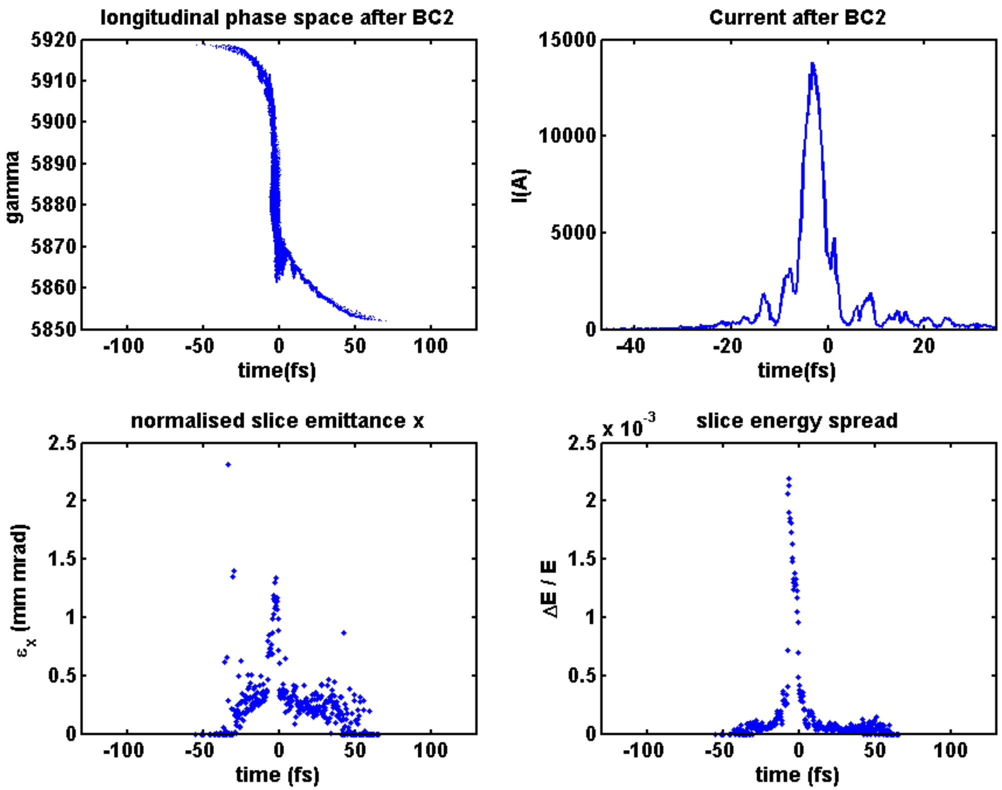
Simulation results - SPF-pulse



Gun – 1st linac: ASTRA
Linac + compressors: ELEGANT

Charge	100 pC
Δt fwhm	100 fs
Peak current	1.5 kA
Compression factor	50
Slice εN	0.42 mm mrad
Proj εN	0.55 mm mrad
Emittance increase	5 %
Slice ΔE/E	0.035 %

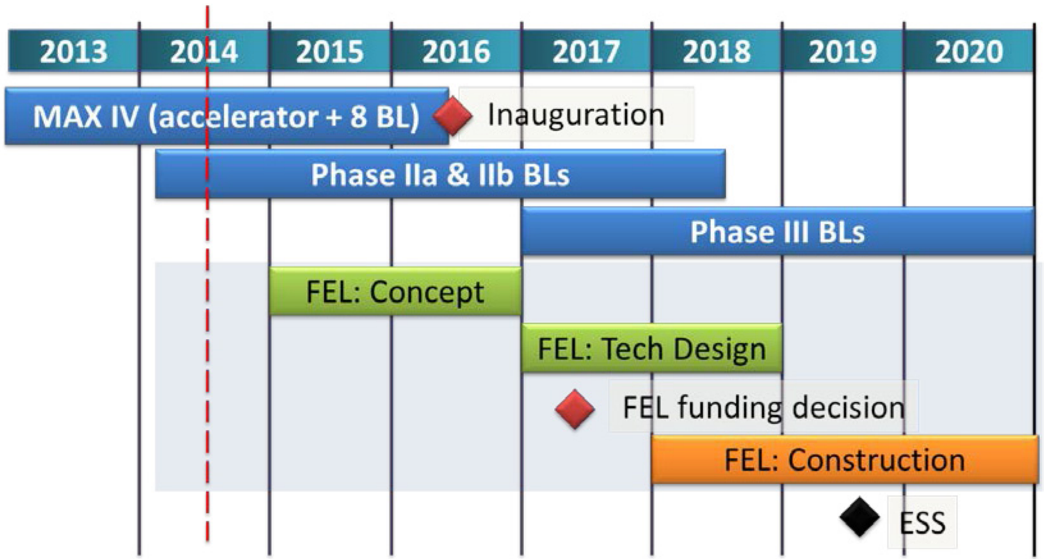
Simulation results - full compression



Gun – 1st linac: ASTRA
Linac + compressors: ELEGANT

Charge	100 pC
Δt fwhm	10 fs
Peak current	14 kA
Compression factor	500
Slice εN	1.5 mm mrad
Proj εN	2.4 mm mrad
Emittance increase (slice)	375 %
Slice ΔE/E	0.25 %

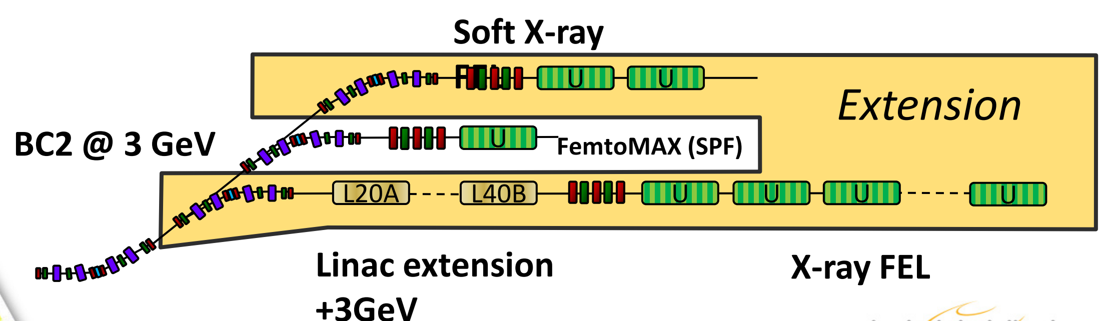
Future plans – X-ray FEL



	FEL 1	FEL 2
Accelerator		
Energy	≈ 6 GeV	2-3 GeV
Rep rate	100 Hz	100 Hz
Linac	S-band	S-band
Bunch compressors	0.250/3 GeV	0.25 GeV
Electron beam		
Peak current	2-3 kA	
Charge	20-150 pC	
Beta function	7.5 m	
Emittance, norm	0.25-0.4 mmRad	
Pulse length	10/100 fs	10/100 fs
FEL undulator		
Undulator period	18 mm	22.5
Undulator K	1.8-2.1	2.1
Type	In-vacuum	In-vacuum
FEL performance		
Wavelength	1.3-10 Å	10-50 Å
Energy	1.2-9 KeV	0.2-1.2 KeV
Flux	10^{12} ph/pulse	

The science case for Swedish X-ray Lasers

- Collaboration between MAX IV Laboratory, the Lund Laser Centre, the Stockholm-Uppsala FEL Centre, and Uppsala University
- More than 40 proposals for science case
- http://www.llc.lu.se/sxlf



MAX IV

MAX IV