The SXL project: Towards a sub-fs soft X-ray FEL at MAX IV

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and the SXL simulations team

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Outlook

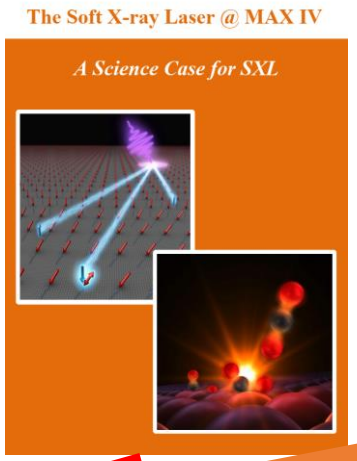
- The SXL project in general
- Baseline operations
- Advanced schemes and challenges
  - Chirped beam
  - Echo
  - Overcompression
  - …

The SXL project

A SWEDISH USERS INITIATIVE

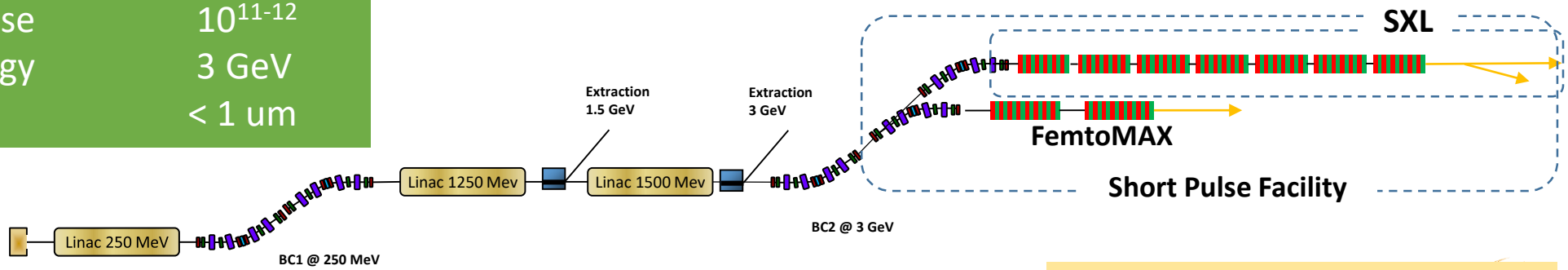
Knut and Alice Wallenberg fundation

- *The baseline design of the SXL will deliver coherent, ultrashort, soft X-ray pulses with full polarization control.*
- *A broad range of pump-possibilities for pump-probe experiments is schedu*
- *Two-pulse and two-color options will be developed at an early stage.*
- *Seeding schemes and attosecond pulses are envisioned at a second stage.*
- *The existing MAX IV linac is well prepared to serve the SXL, and space is a*



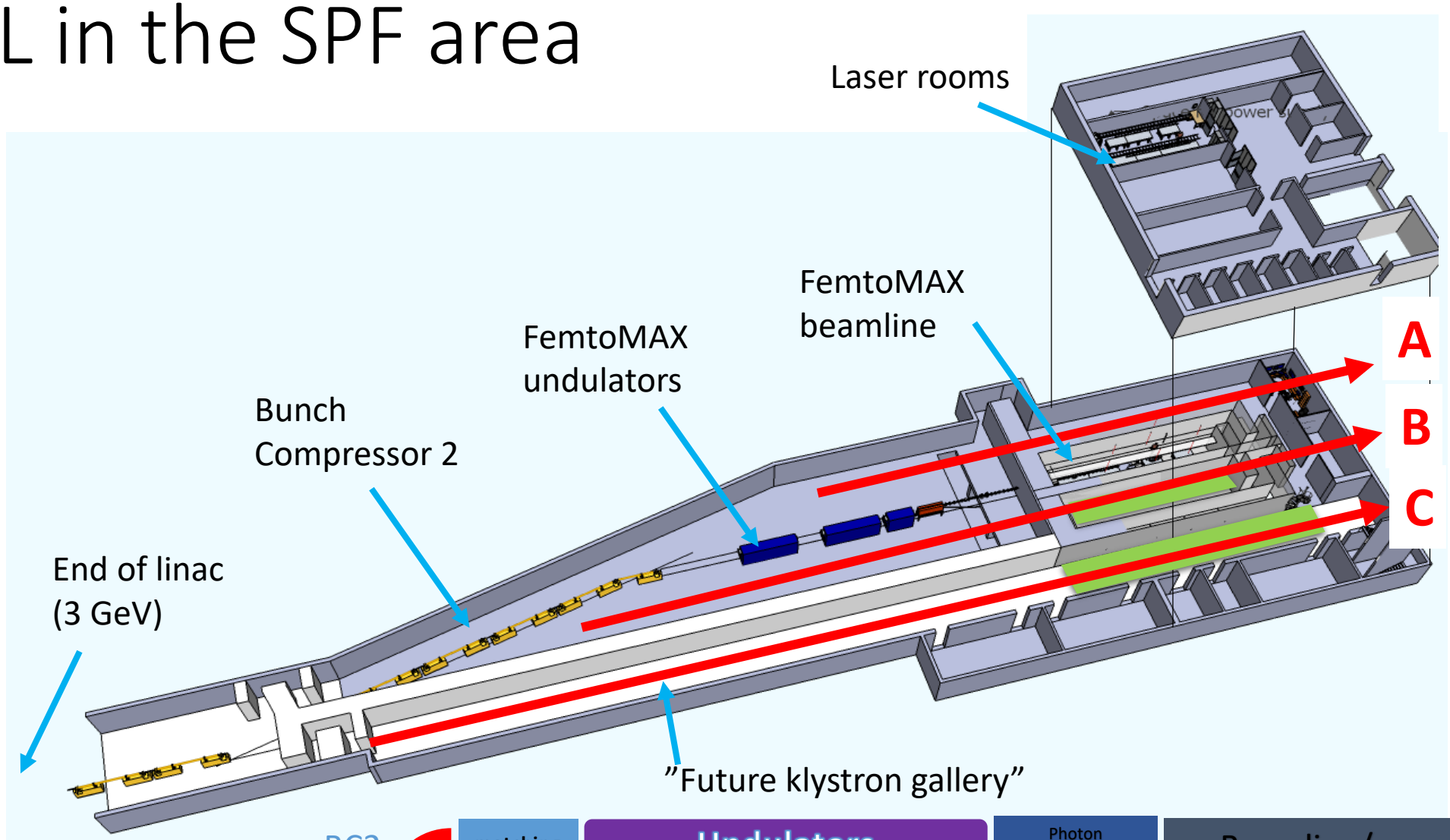
Wavelength	**1—5 nm**
Photon energy	**~0.25—1 keV**
Pulse length	10-100 fs
Repetition rate	100 Hz
Power (peak)	~ 1 GW
Ph/pulse	$10^{11\text{-}12}$
e-energy	3 GeV
ε_N	< 1 um

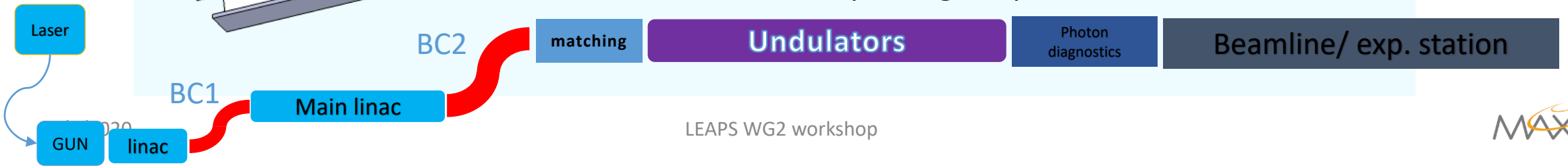
AMO | Cond Mat | Chem | Life Science



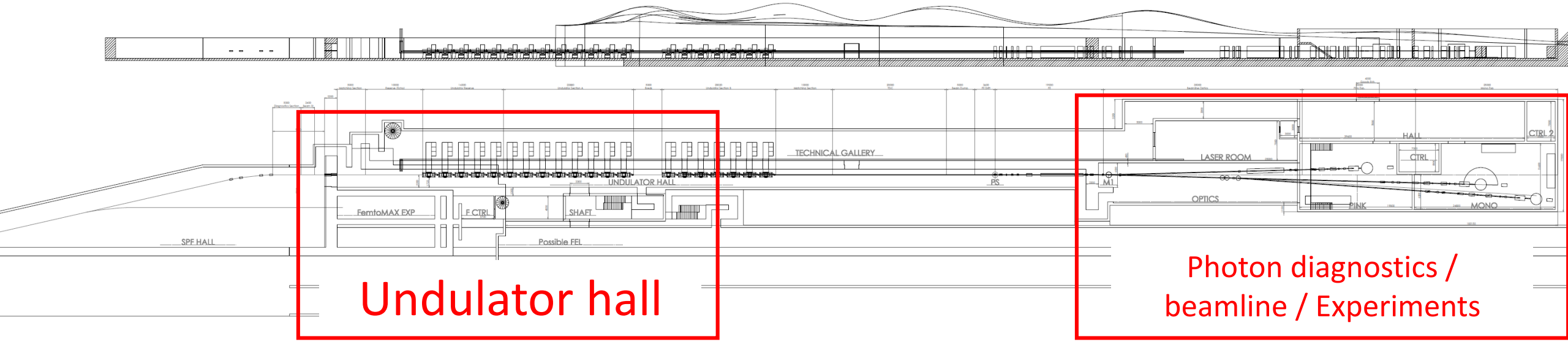
Status of the Soft X-Ray Laser (SXL) Project at MAX IV Laboratory
Proceedings of FEL2019, Hamburg, Germany, THP084

SXL in the SPF area



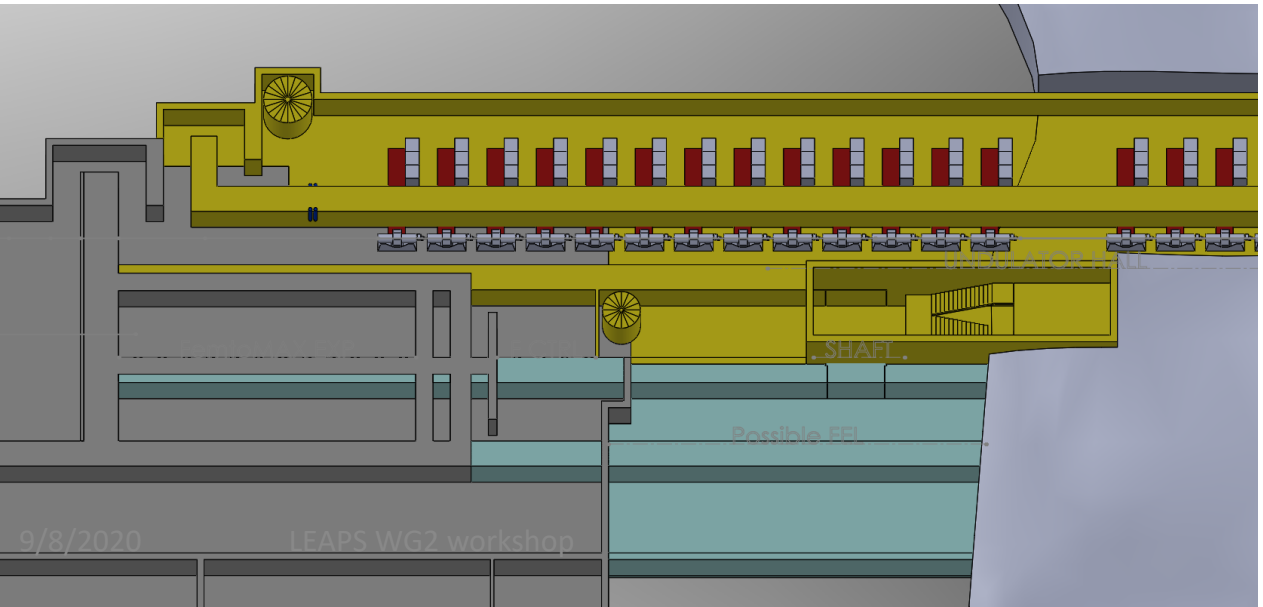


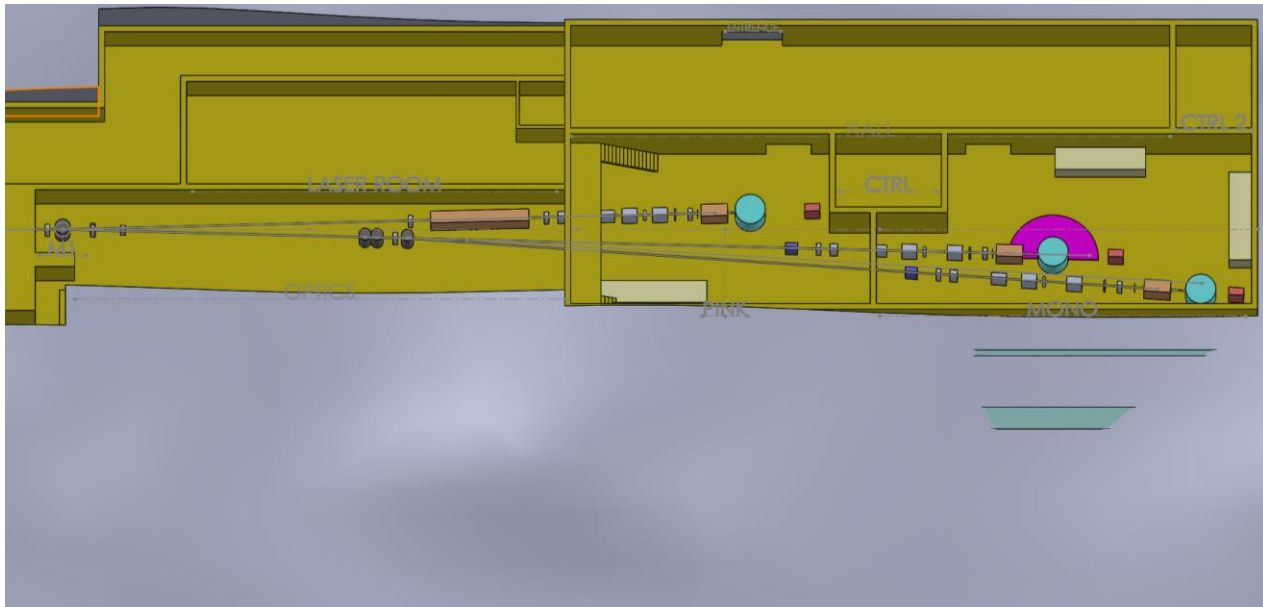
Extension of the buildings



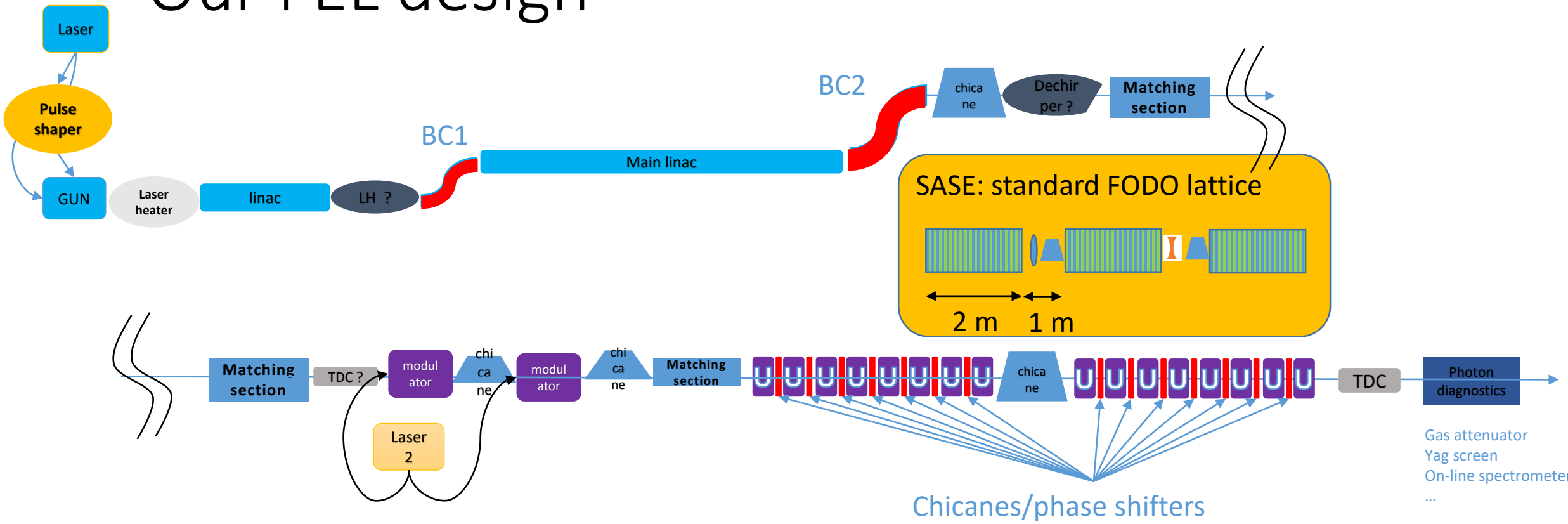
Undulator hall

Photon diagnostics / beamline / Experiments

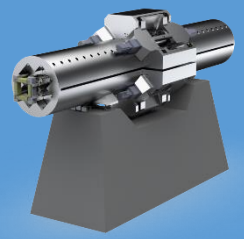




Our FEL design



UNDULATORS
Hamed Tarawneh

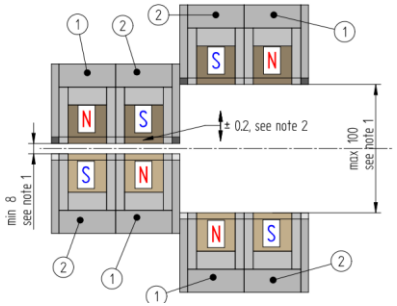


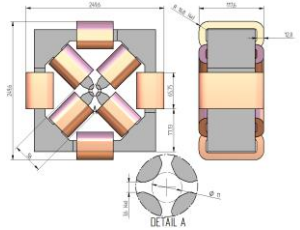
$\lambda_u = 40\ mm$

Magnetic Length= 2 m

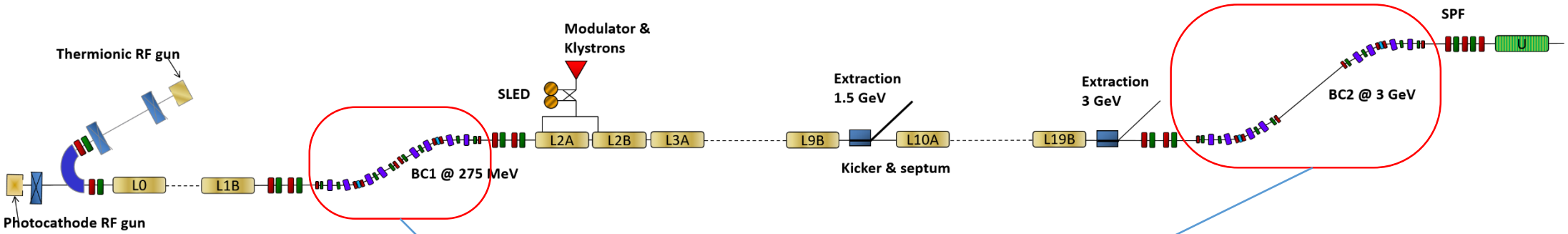
Compact APPLE X type:

1) Full polarization control in helical mode only (inclined polarization is possible too).
2) Possibility to create gradient as extra feature.

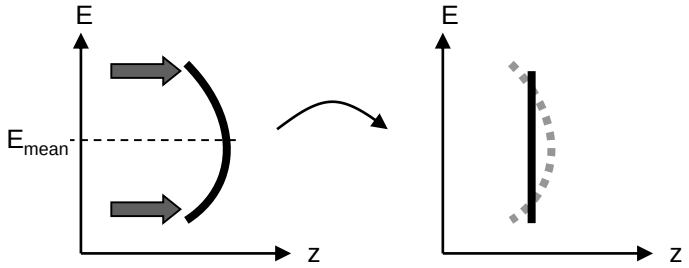




Double achromat BUNCH COMPRESSORS



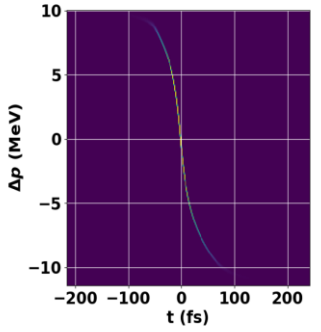
Compression
Self-linearization

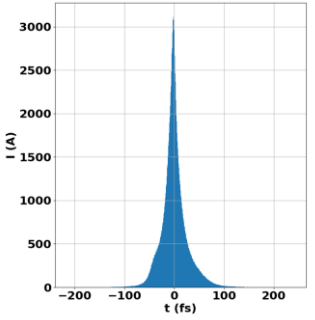


$$\Delta z = R_{56}\left(\frac{\Delta E}{E}\right) + T_{566}\left(\frac{\Delta E}{E}\right)^2$$

R56 > 0
T566 > 0

Chirped beam
Not-flat current profile



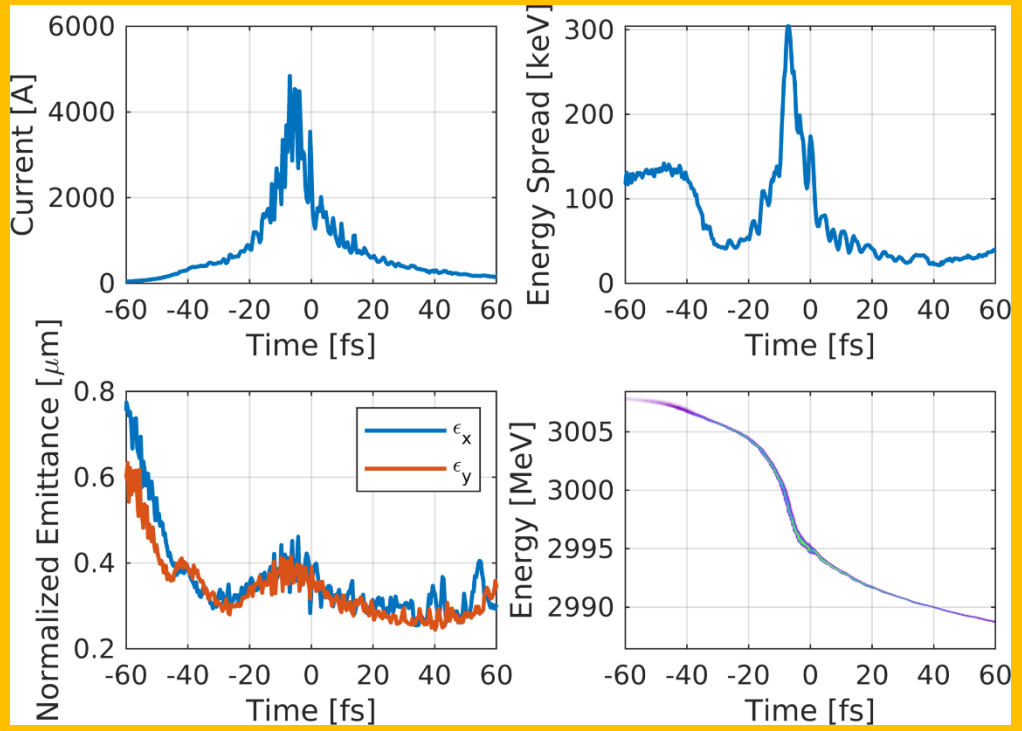


Simulations by Billy Kyle

The standard operation for SXL

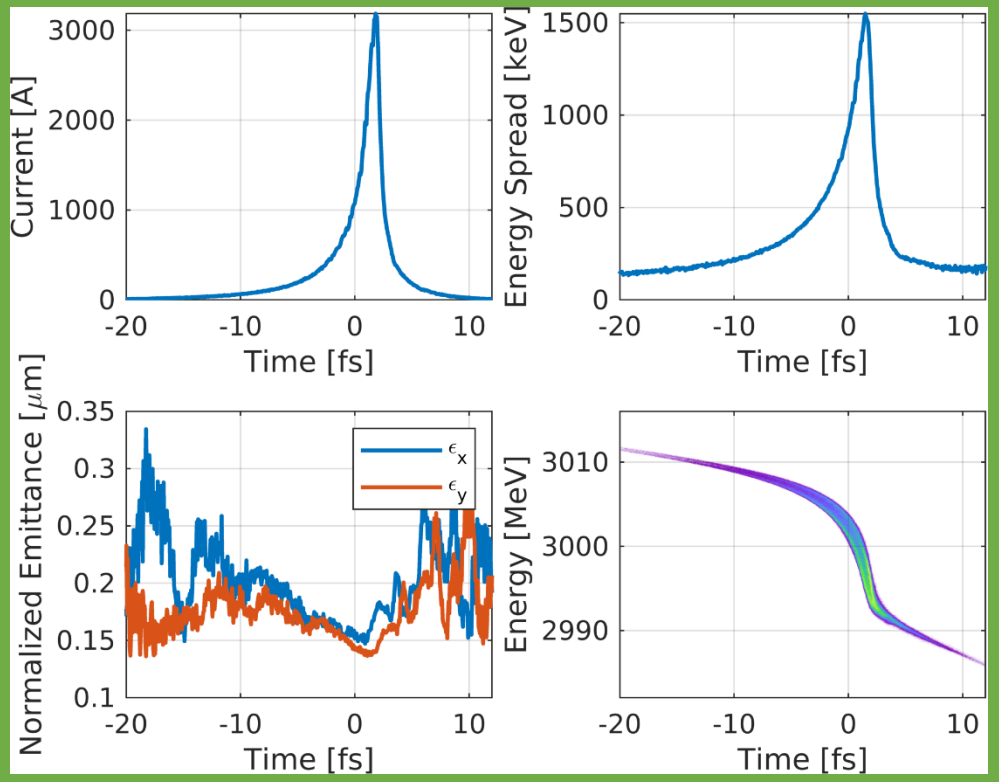
1A long pulse, 100 pC ~10 fs

Peak current (kA)	4.5
Energy chirp (MeV/fs)	0.4
Slice norm Emitt RMS x/y (mm mrad)	0.37/0.38
Slice e-spread RMS (MeV)	0.3



1B short pulse, 10 pC ~1.5 fs

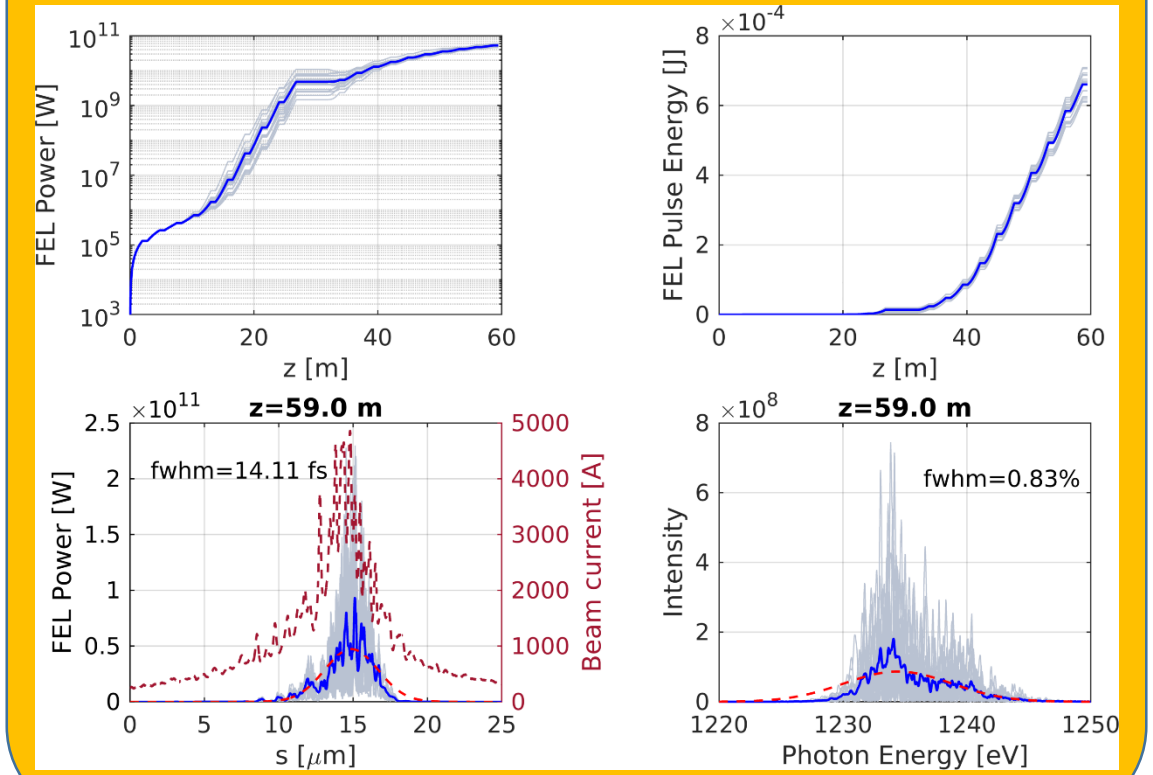
Peak current (kA)	3.1
Energy chirp (MeV/fs)	2
Slice norm. Emitt RMS x/y (mm mrad)	0.17/0.14
Slice e-spread RMS (MeV)	1.5



The performance of the FEL at 1 nm

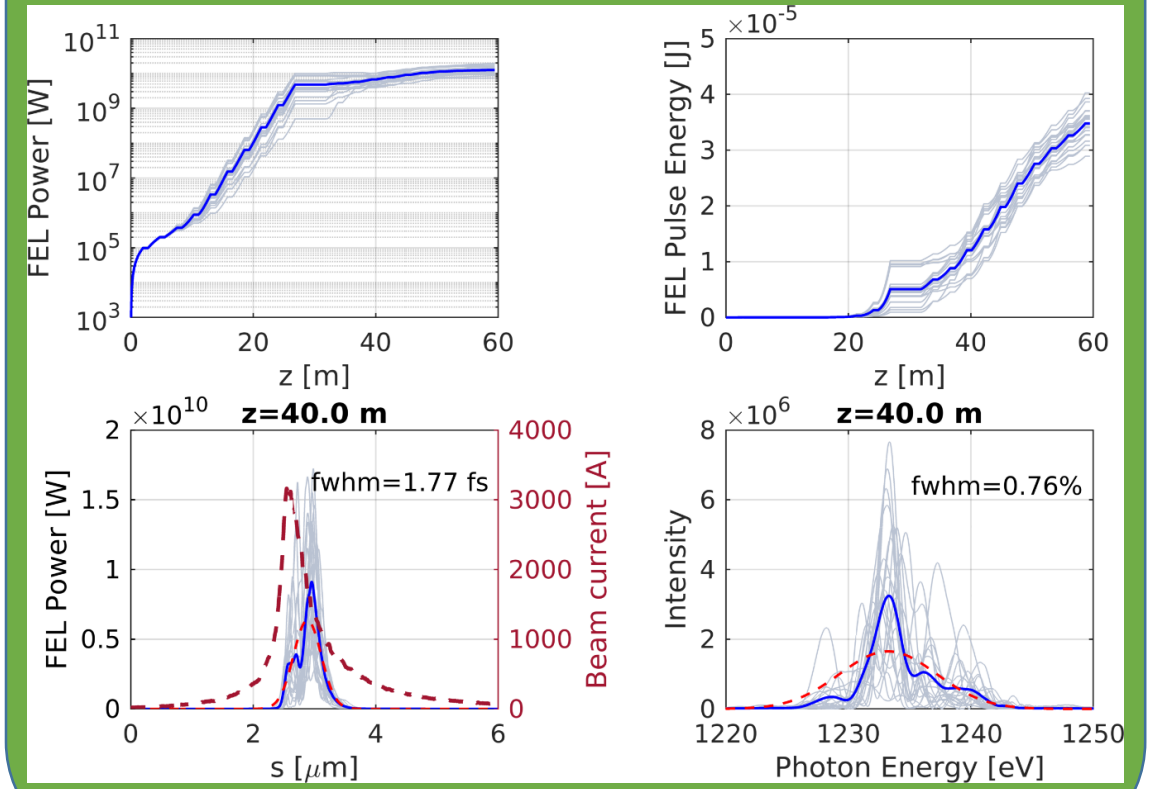
Long pulse, 100 pC

Pulse energy = 660 µJ
Power = 50 GW
Ph./pulse = 3.3E+12



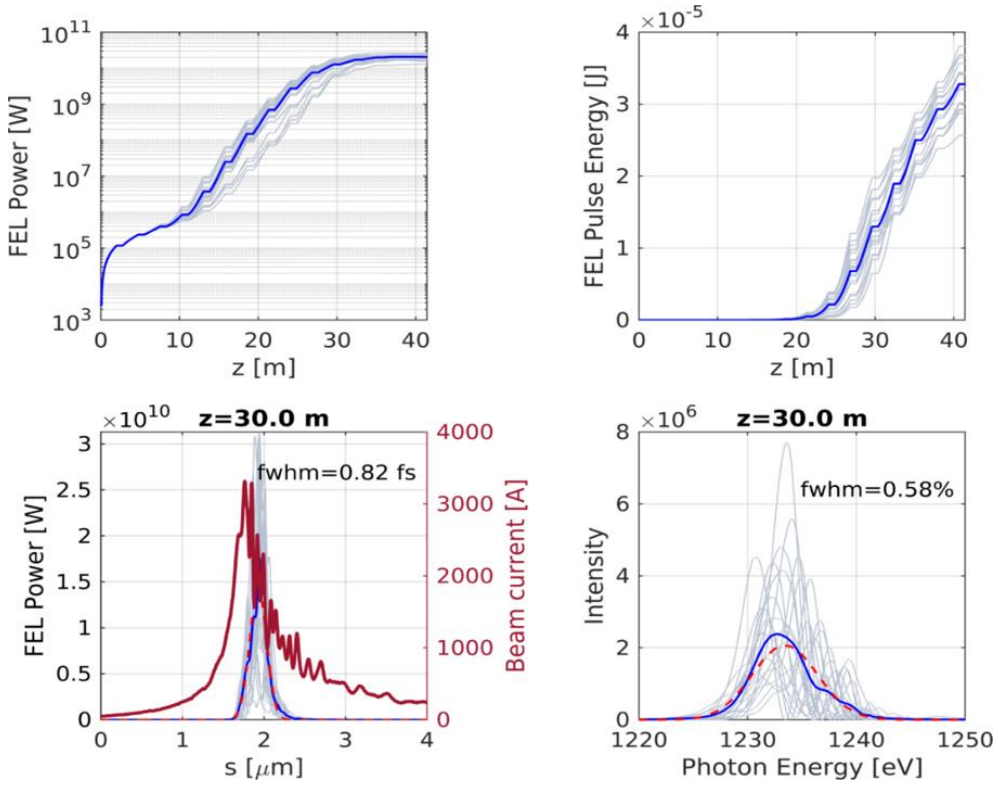
Short pulse, 10 pC

Pulse energy ~12 µJ
Power ~ 6.5 GW (fit)
Ph./pulse ~ .E+10—E+11



Special features for SXL

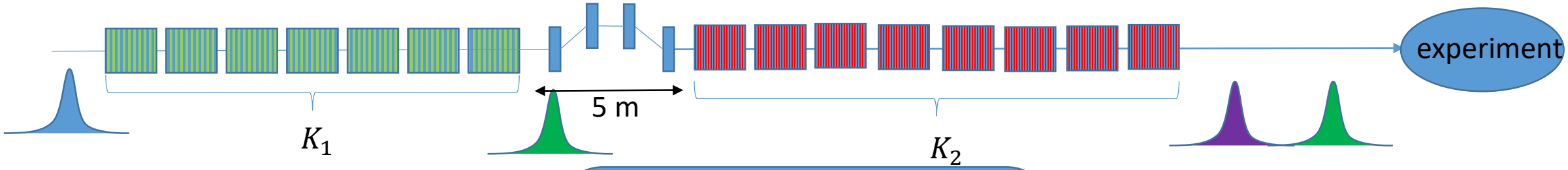
- Sub-fs pulses
- 2 pulse 2 color operations
- Chirp removal
  - Overcompression
- Seeding (Echo) with chirp



Challenges in Short pulses

- Production
- Trasport & diagnostics along the linac
- High peak current, wakefields, …
- High stability required (rf, power supplies, …)
- Compression scheme chosen
- …
- Transport & diagnostics of Photon pulses

2 color with split undulator

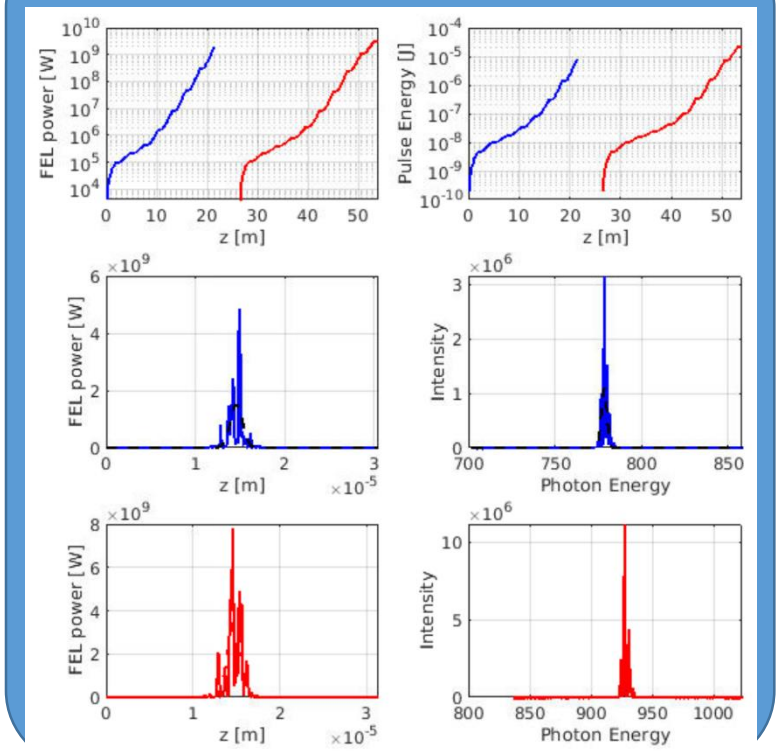


K-edges: C+O (285—535) eV
C+N (285—400) eV
N+O (400—535) eV

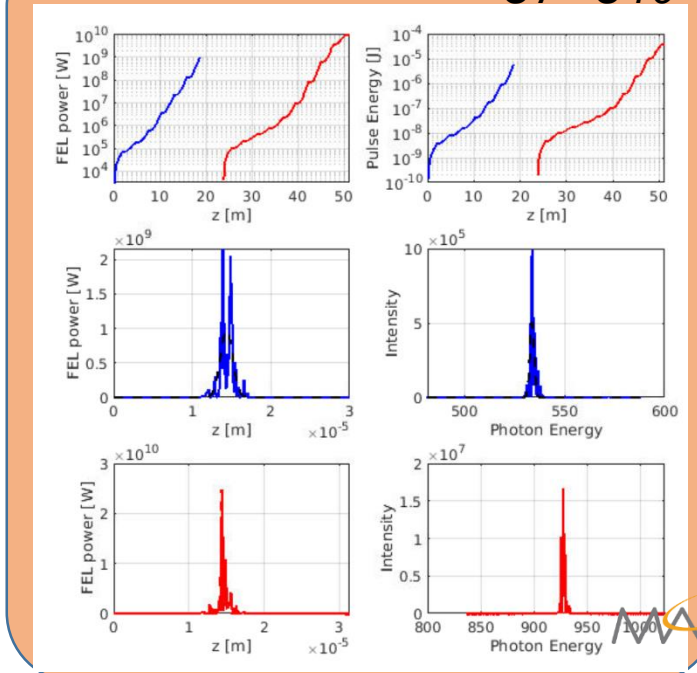
L-edges: O+Mn (535--640)eV
O+Cu (535--930)eV
O+Co (535--780) eV
Co+ Cu (780—930) eV

Some tunability in energy and pulse length

Co+Cu: 780+930 eV *U8+U10*



O+Cu: 535+930 eV *U7+U10*

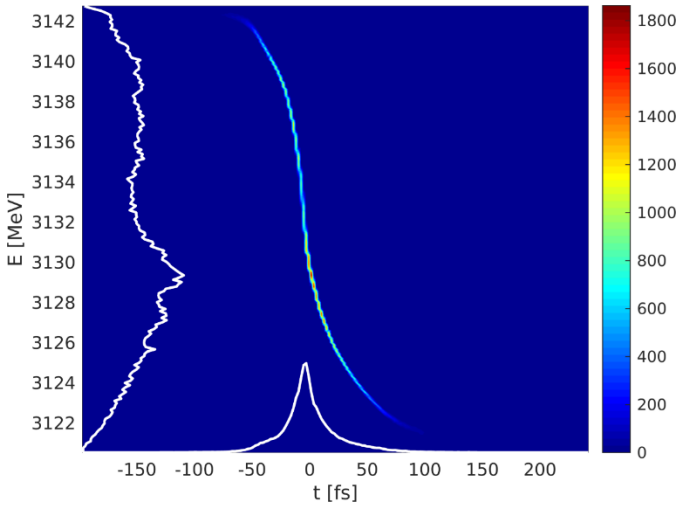


De-chirping->overcompression

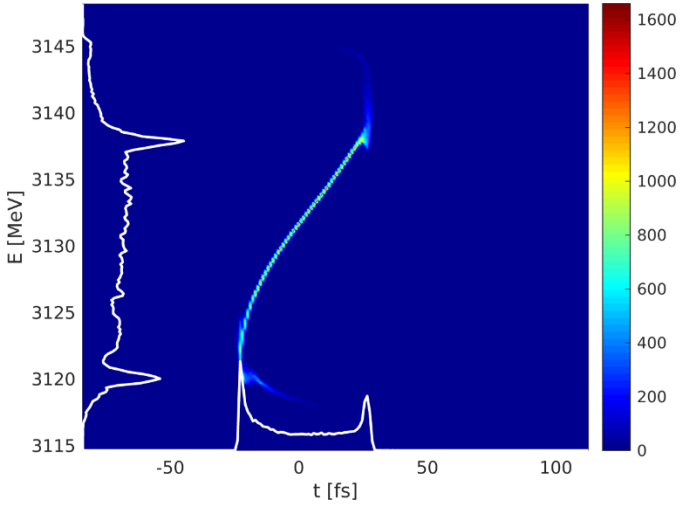
- BC2 overcompression + dechirper

Elegant simulations Weilun Qin

L2 = 0 deg

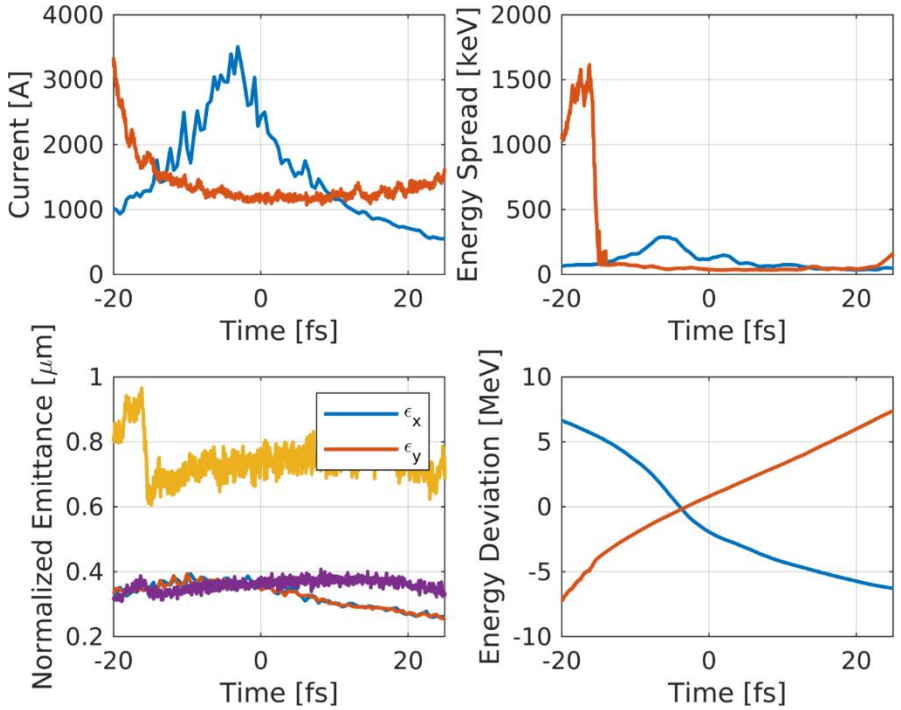


L2 = 9 deg



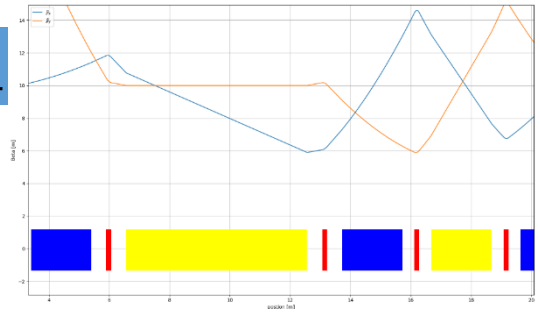
- About 1kA, relatively flat current
- Chirp reversed

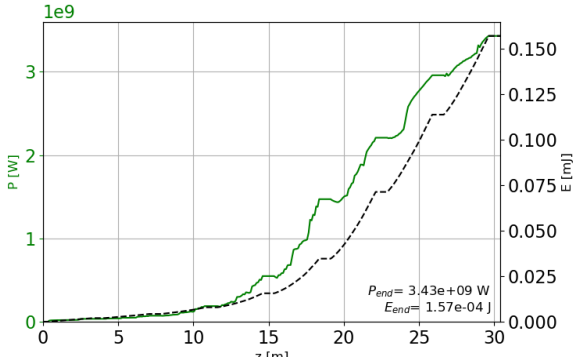
Comparison: normal compression/overcompression

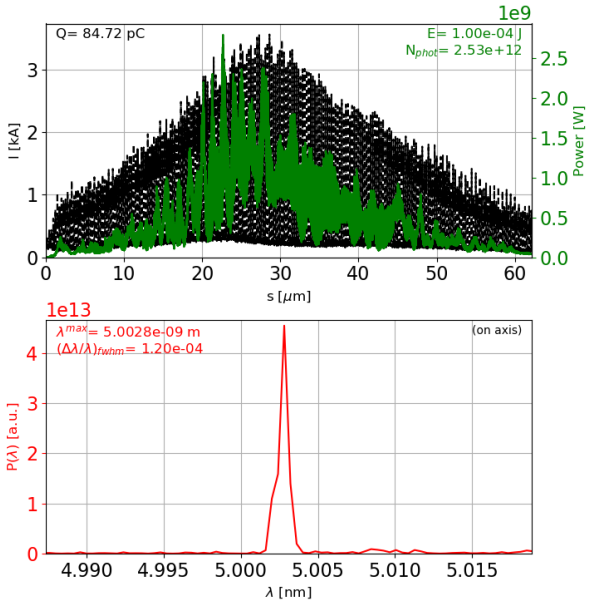


ECHO- 2 options

1- After BC2







2- a modulator in the space between achromat 1 and achromat 2 of BC2
After BC2 a second modulator and a small chicane

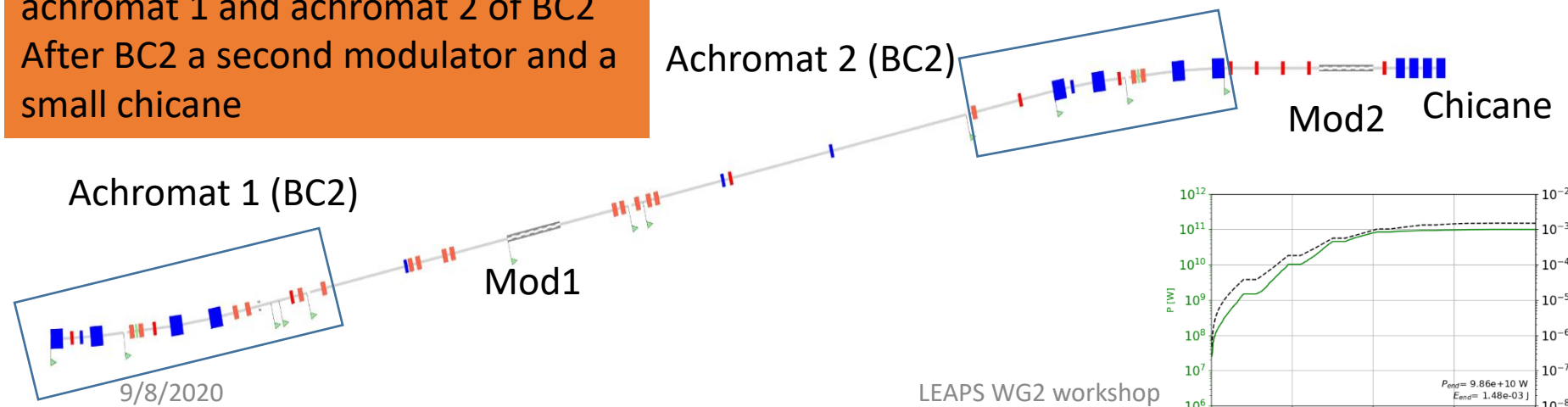
Achromat 2 (BC2)

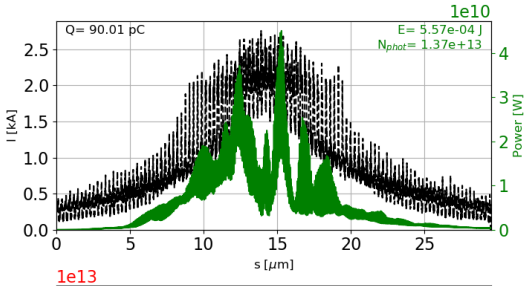
Mod2

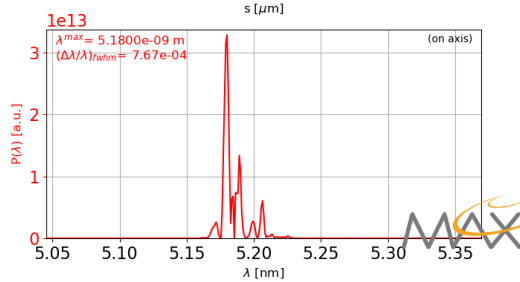
Chicane

Achromat 1 (BC2)

Mod1







Summary

- SXL baseline: 10 fs and 1 fs pulses in 1—5nm range
- Ultrashort pulses < 1fs possible (extra diagnostics!)
- 2 pulse 2 color with split undulator
- Interested in developing ECHO and other advanced seeding schemes w/wo chirp
- Needs of development for
  - Chirp removal and/or achieving flat current profile
  - Ultrashort pulses (sub-fs)
  - Operations with chirped beam