Design and Modelling of the Baseline Layout for the Soft X-Ray Laser (SXL) at MAX IV Laboratory

Francesca Curbis

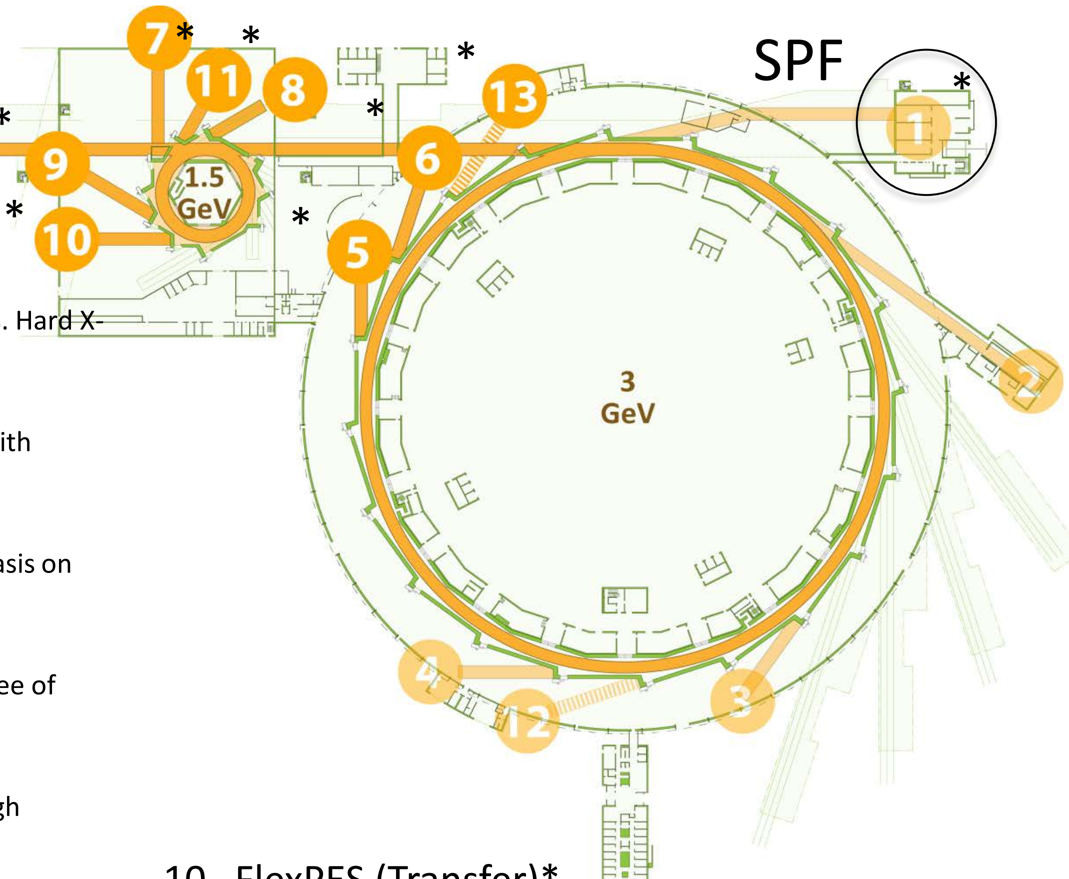
Lund University, MAX IV laboratory

MAX IV

Outline

- SXL@MAX IV: idea and project status
- User initiative, workshop
- Pump-probe and other requirements
- Linac, special features, output
- Building, on ground
- Design considerations
- Coherence enhancement
- Pitch point for the simulations

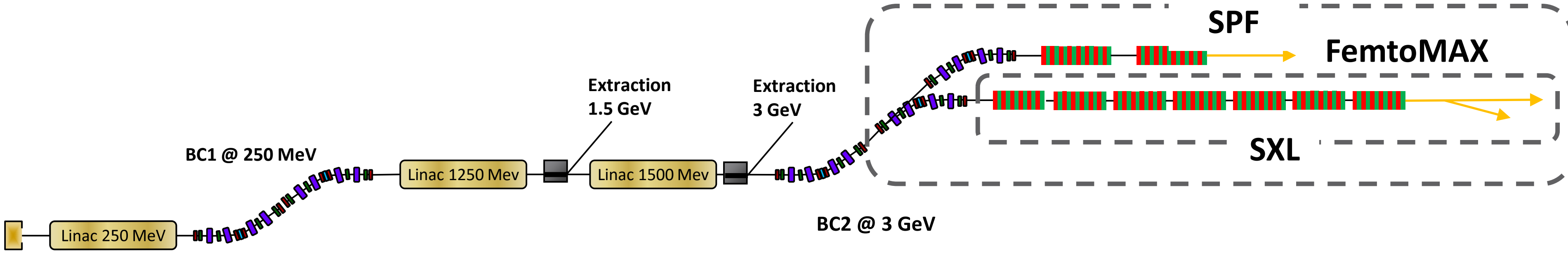
MAX IV laboratory



1. FemtoMAX*
   Studies of ultra-fast processes in materials, 100 fs. Hard X-rays, diffraction and X-ray scattering
2. NanoMAX
   Imaging, spectroscopic & scattering techniques with nanometer resolution
3. BALDER
   (Hard) X-ray absorption spectroscopy with emphasis on *in-situ* and time resolved studies.
4. BioMAX
   Macromolecular crystallography with a high degree of automation and remote access
5. VERITAS*
   RIXS combining a unique resolving power with high spatial resolution.
6. HIPPIE*
   High-pressure photoelectron spectroscopy
7. ARPES
   Angle resolved photoelectron spectroscopy for detailed studies of the electronic structure.
8. FinEstBeaMS*
   Estonian-Finnish Beamline for low density matter
9. SPECIES (Transfer)*
   High-pressure photoelectron spectroscopy and RIXS
10. FlexPES (Transfer)*
    Photoelectron Spectroscopy and NEXAFS
11. MAXPeem (Transfer)*
12. CoSAXS
13. SoftiMAX*
    Coherent Soft X-Ray Scattering, STXM…
14. DanMAX
    Danish beamline for imaging and powder diffraction

MAX IV

SXL- the Soft X-ray Laser @ MAX IV

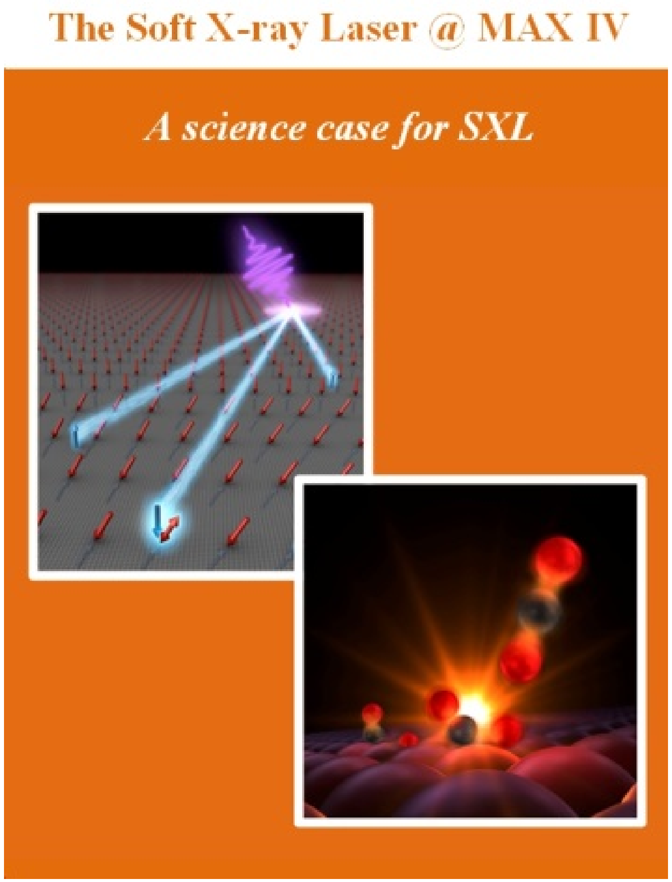


Project status

Conceptual Design Study Proposal

- Two year study of feasibility and detail planning for a soft x-ray laser beamline
- 50 % Funding from
  - Stockholm-Uppsala FEL center (funding from SU and UU)
  - KTH
  - Lund University
  - MAXIV
- Proposal submitted to KAW for the other 50%
- Report planned for 2019-2020 time frame when design and construction would be ready for initiation (start depends on funding and strategic plan)
- Main PI Pedro Fernandes Tavares at MAXIV

A truly User initiative



https://indico.maxiv.lu.se/event/141/material/paper/0.pdf

Initiative from Stockholm University (A. Nilsson) and supported by Stockholm-Uppsala center for Free Electron Laser research, SU, KTH, Uppsala University, Gothenburg University, Lund University, Lund Laser Center

In March 2016 workshop for the Science case with about 100 Swedish scientists

Some possible features of the SXL were discussed:

- *Two colour, two pulses*
- *Synchronization*
- *Multiple Pump-probe sources*
- *Ultra short pulses*
- *Seeding development*

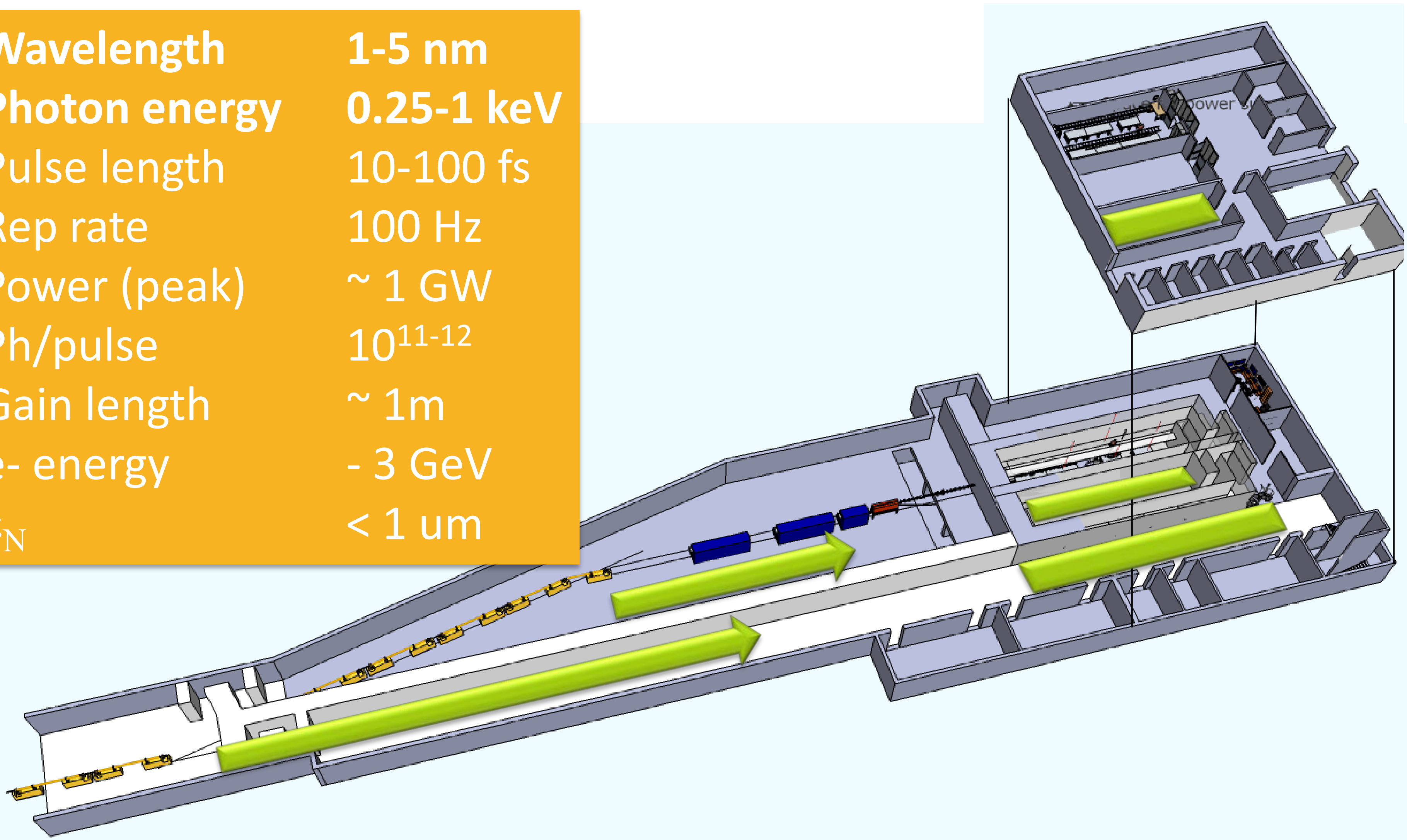
Examples from the science case

- **AMO (Atomic, molecular, and optical physics)**
  - ultrafast charge and structural dynamics
  - Stimulated emission spectroscopy
  - Fundamental non-linear processes involving core shells leading to new spectroscopies
- **Chemistry**
  - Heterogeneous catalysis
  - Probing transition states in surface reactions
  - Electrochemistry
  - Competing pathways in the photodissociation
  - Following the spatial evolution of electronic excitations
  - Stmospheric chemistry
  - Fundamental aspects of light harvesting
- **Condensed matter**
  - Magnetism
  - The role of nanoscale phse separation
  - Superconductors
  - Multiferroics
  - THz pump-probe in water: XAS/resonant scattering
  - Stimulated X-ray emission in Water
- **Life science**
  - Coherent diffractive imaging (live cell imaging, structrure of organelles and viruses)
  - Fluctuation based X-ray scattering

Imaging for LIFE and COND
Coherent diffractive imaging
Holography
Ptychography
Synergies with SoftiMAX

SXL in the short pulse facility (SPF) area

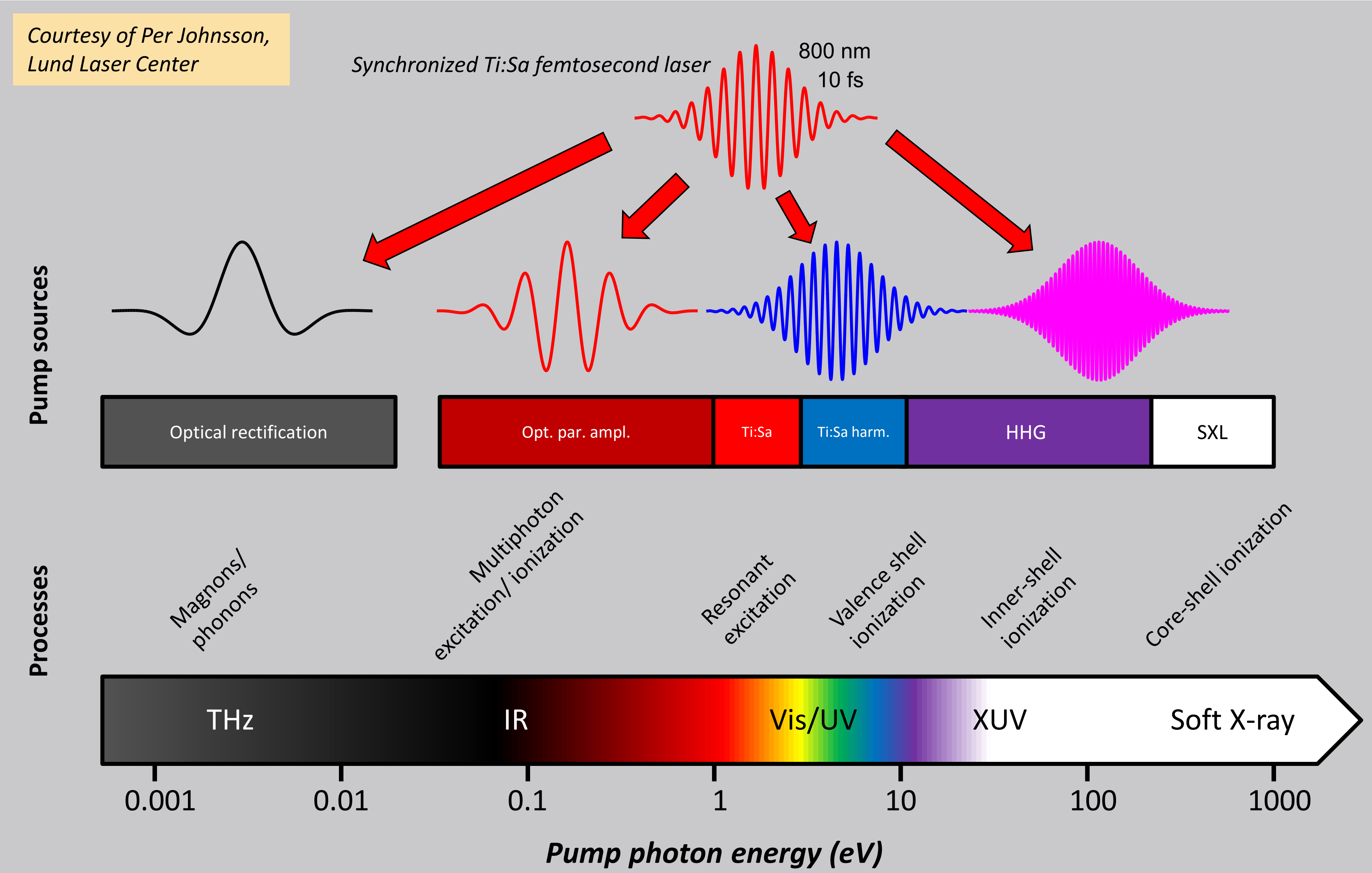
Wavelength	**1-5 nm**
Photon energy	**0.25-1 keV**
Pulse length	10-100 fs
Rep rate	100 Hz
Power (peak)	~ 1 GW
Ph/pulse	$10^{11\text{-}12}$
Gain length	~ 1m
e- energy	- 3 GeV
ε_N	< 1 um



SXL early development

Sketch of before the workshop	Workshop feedback	Phase 1	Phase 2
1-5 nm	1-5 nm	1-5 nm	
SASE	SASE	SASE	
Self seeding	Not 1st prio. External seeding		External seeding
	Two colour	(Two colour)	Two colour
	Two pulses	(Two pulses)	Two pulses
	Ultra short pulses	10 fs	Single fs
Planar in-vacuum undulator	Variable polarisation, APPLE III?	Helical undulators	
18 mm period	Consider 35-40 mm -> no e- energy tuning		
	Multiple pump sources (THz, UV, Soft X)	THz foil, UV laser	HHG laser, THz undulator

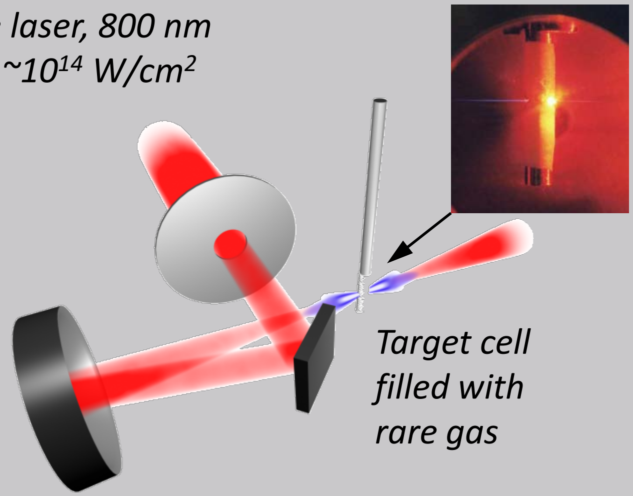
Bridging the spectral gap – a broadband sub-fs pump facility



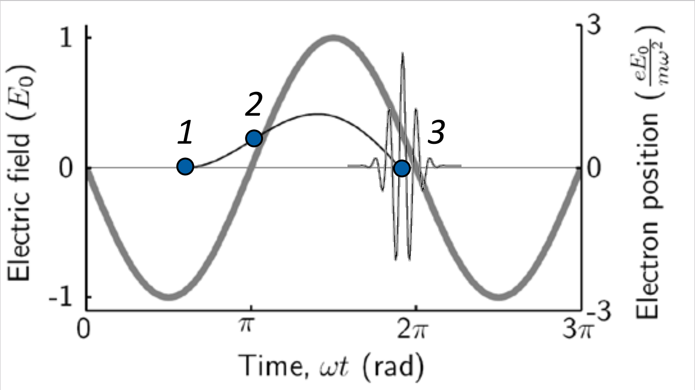
High-Order Harmonic Generation and Attosecond Pulses ...

Experimental Setup

Ti:Sapphire laser, 800 nm
Focused to ~10^{14} W/cm^2



Temporal picture

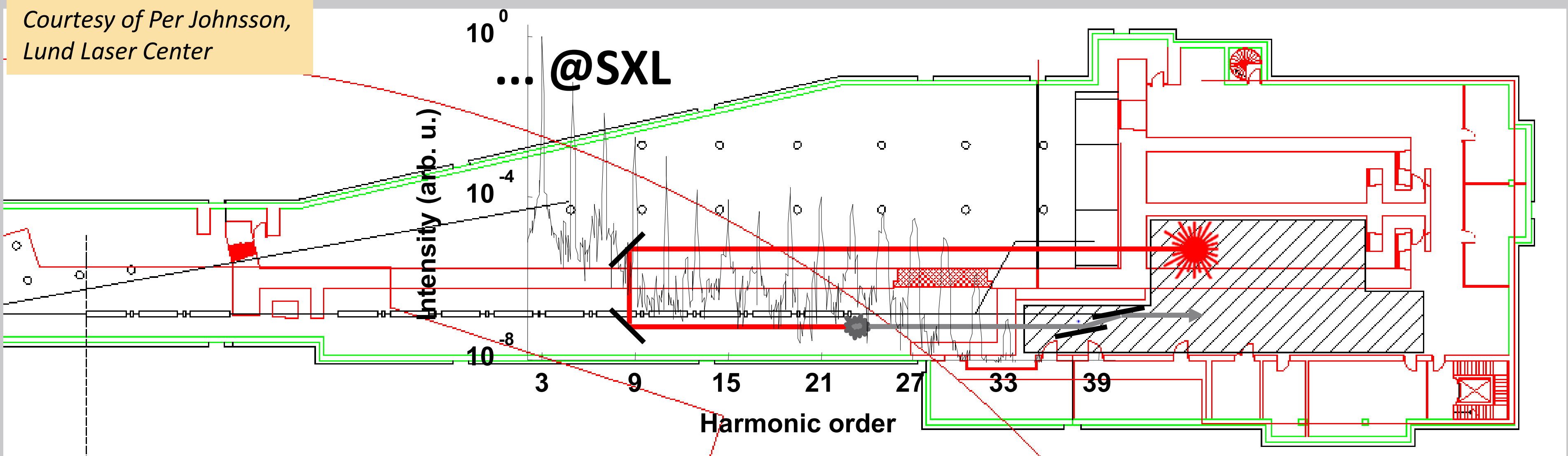


1. Ionization

2. Acceleration

3. Recombination

Courtesy of Per Johnsson, Lund Laser Center



THz radiation sources @ SXL

1 Laser-based

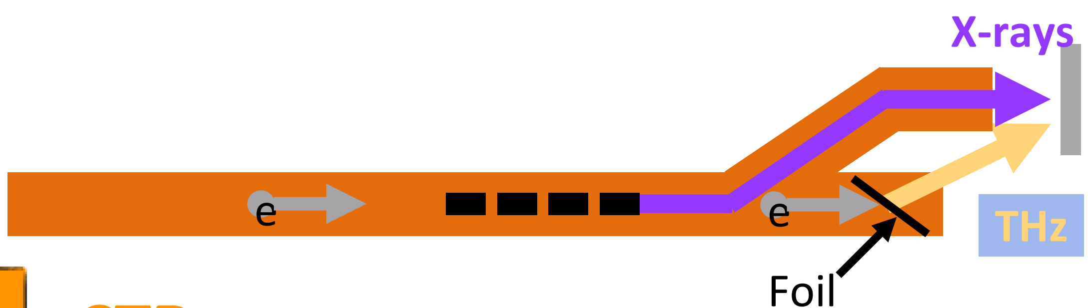
Broad band (single-cycle) 0.1—4 THz with laser based and organic crystals or lithium niobate.

Full polarization control

Fields> 100 MV/m

Narrowband 4—18 THz with non-linear optics

2 CTR



Broadband up to 10-20 THz,
field~1GV/m,
perfect synchronization,

radial polarization

3 THz FEL

Single or multi-cycle (broadband vs narrowband),
fields 1GV/m
1—20 THz

Courtesy of Anders Nilsson, Stockholm U

Workshop summary (23.03)

- **Stability**: ex: condensed matter wants better than 100%
  - photon energy/pulse intensity/in a small band or broad band? →different techniques (Self-seeding or SASE)

- **Pump-probe: THz and VUV**
  - Synchronization is critical but similar to synchronization for the photocathode laser and RF power stations
  - THz: undulator* (narrow bandwidth, pulse, synchronization is not an issue), foil (shorter pulse length, synchronization OK), optical rectification (problem of synchronization), multi-foil
    *it could be a separate source

- **2 color with 2 bunches** in 2 buckets: usually the delay is too long (300ps)→need of split undulator (easier at longer wavelengths)

- Pulse trains: possible to develop but the use has to be defended!

- **Coherent control** seems to be a demand
  - **we could foresee a machine bridging Fermi and SwissFEL:**
  - **single spike for 1nm and external seeded for 5 nm**

Design objectives

- Flexible
- Tuned to user needs
- Exploring the MAX IV linac
- Cost and space efficient
- Allowing a hard X-ray expansion
- Complementarity and co-use with MAX IV rings beamlines

APPLE II undulators: optimization of period length

Helical → extract more energy

Longer period length: 1--5nm @ ~3GeV

- Coherence enhancement (bandwidth)
- Pulse length (control and sub fs options)
- Multiple pulses, multi colour
- Pump-probe

Attosecond pulses?

THz radiation (foil, undulator, bending magnet?)

Connecting

Accelerator features

- 1-3 GeV
- 100 Hz
- (3)-10-100 fs
- Double pulses

- Self linearizing BCs/ reversed E chirp
- BC 2 @ full energy / natural E chirp

FEL

User ideas and demands

- 1-5 nm
  0.25-1.25 keV
- Multiple pump-probe
- External seeding
- Start in SASE mode
- Multi colour
- Multi pulse
- as pulses

Enhancing coherence @ 1-5 nm

Self seeding	Possible later option	Does not satisfy users (intensity fluctuations)
HB-SASE/Mode coupling	Start option	Less intensity fluctuations but wavelength fluctuations
HHG seeding	When available	Preferred by users in a longer perspective

Addressing flexibility…

- HB-SASE/Mode coupling
- Naturally chirped pulses
- Two colour
- Sub-fs pulses

Apple II
Period 0.036 m
Cost will be critical

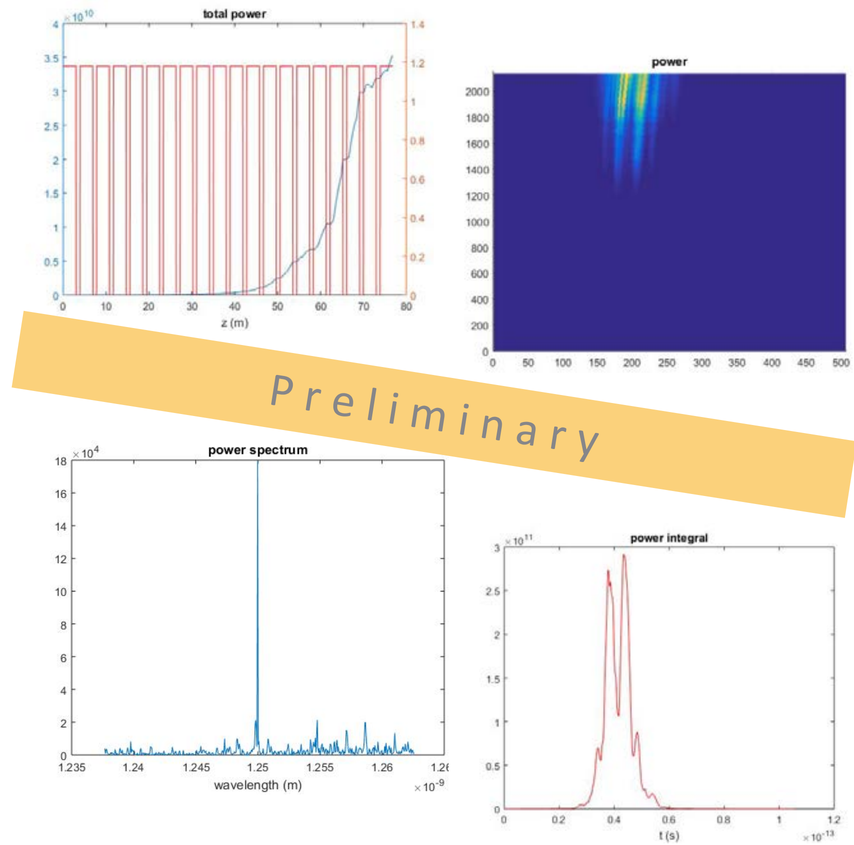
N. Thompson and B. McNeil, PRL 100, 203901 (2008)
N. Thompsson et al, PRL 110, 134802 (2013)
E. Prat et al, J. Synchr. Rad. (2016) 23, 861-868

Pitch point for the simulations

1.5 -3 GeV
100 pC
10 fs

1-5 nm (0.25-1.25 keV)

APPLE II
0.036 m
FUDU lattice
Phase shifting chicanes



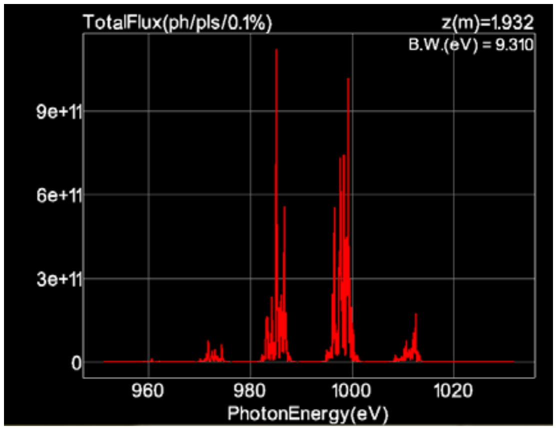
Compact simplified undulator designs

First simulations of mode coupling

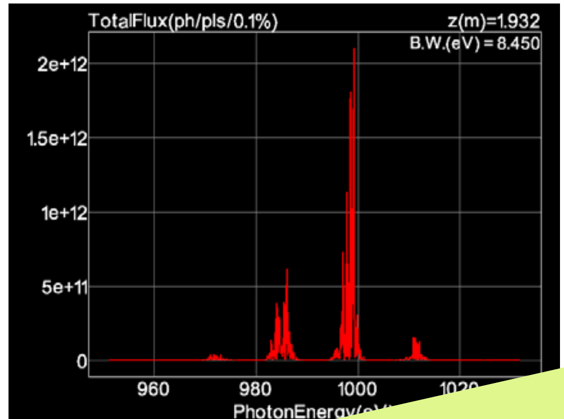
Sverker Werin

Preliminary simulations

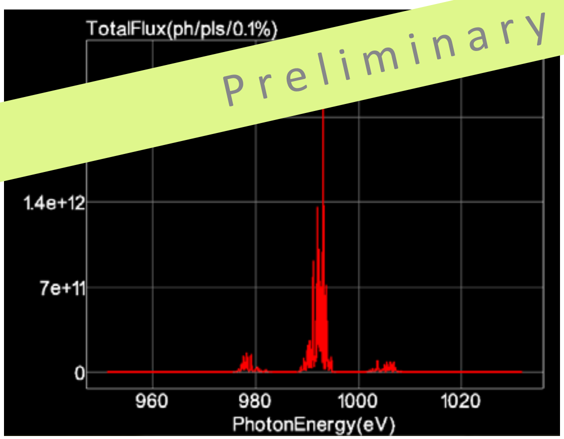
Run-1

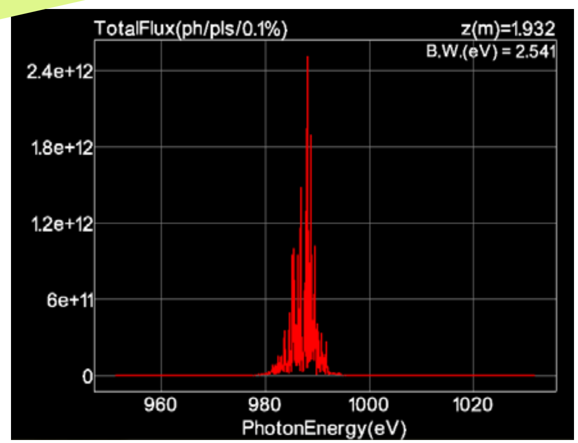


Run-2



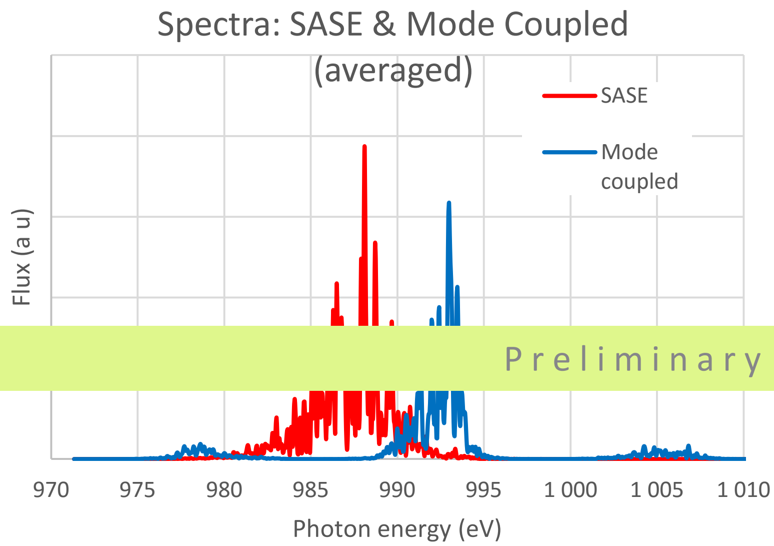
Run-3

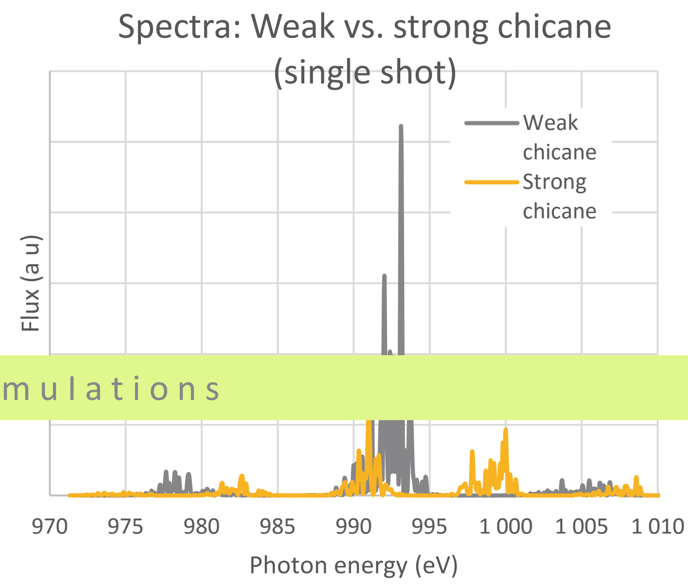




SASE vs. mode coupling

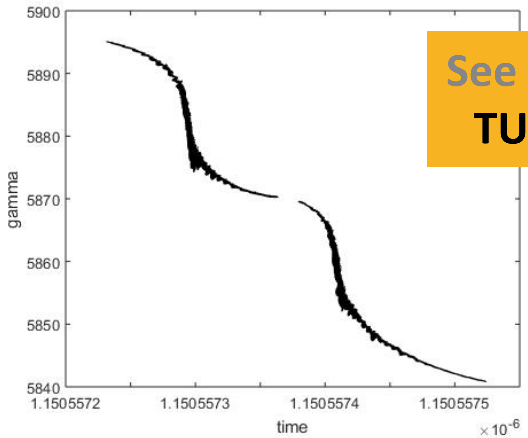
Sverker Werin





Preliminary simulations

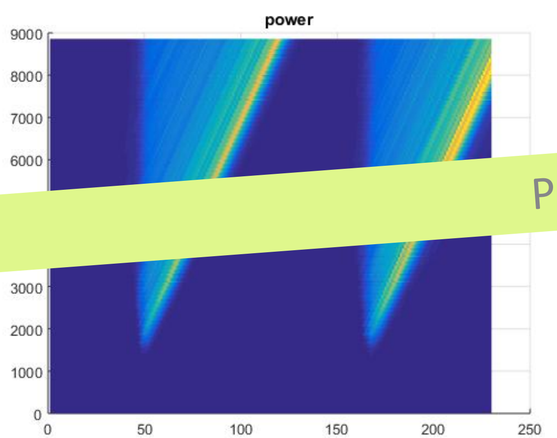
2 color 2 pulses: preliminary results

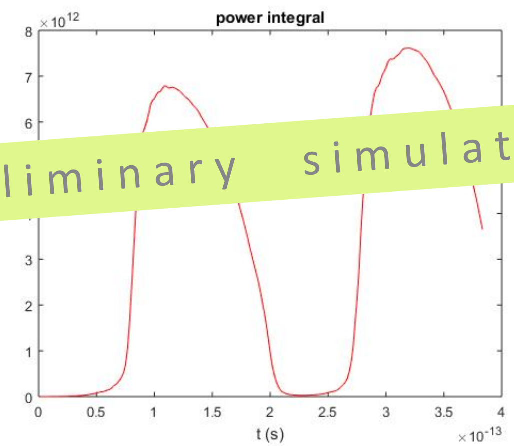


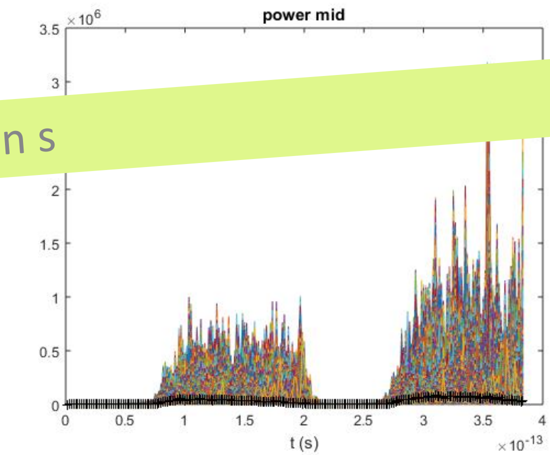
See poster TUP010

2 bunches produced in the photocathode gun are accelerated and compressed
Run through a chain of 3m undulators with 3.6 cm period, for 5 nm target wavelength…

→ **driver/witness bunches in LWPA**







Preliminary simulations

Conclusions

- The MAX IV linac is prepared to drive the SXL
- Going to start a 2-year CDR period soon
- **Single spike for 1nm and external seeded for 5 nm**
- Focus on:
  - intensity stability →different techniques (Self-seeding or SASE)
  - Pump-probe: THz and VUV
  - 2 color FEL with 2 bunches: work on the delay
  - Coherence control
- Flexibility and future expansions

Acknowledgements

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  - Anders Nilsson
  - Per Johnsson
  - Stefano Bonetti
  - Sara Thorin and Jonas Bjorklund Svensson

Thank you for your attention!