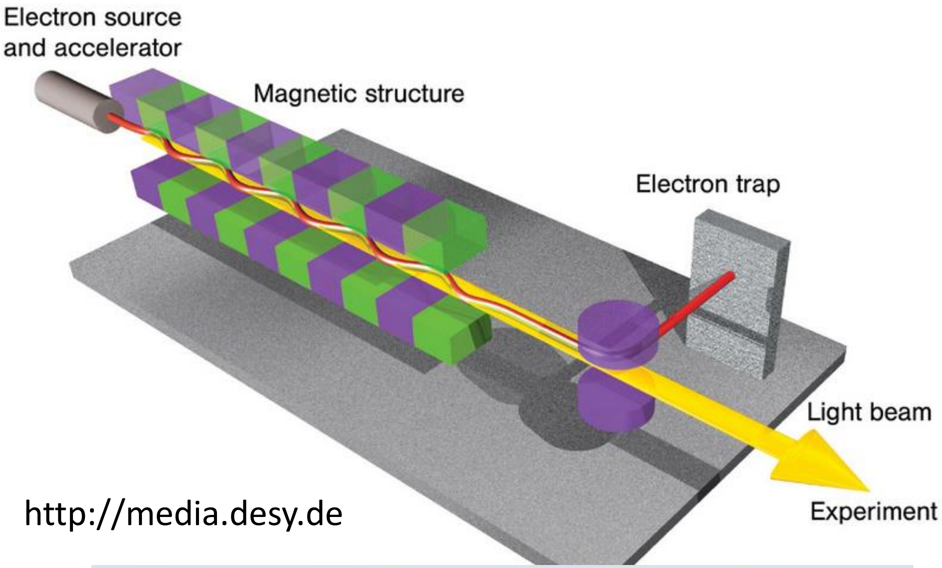
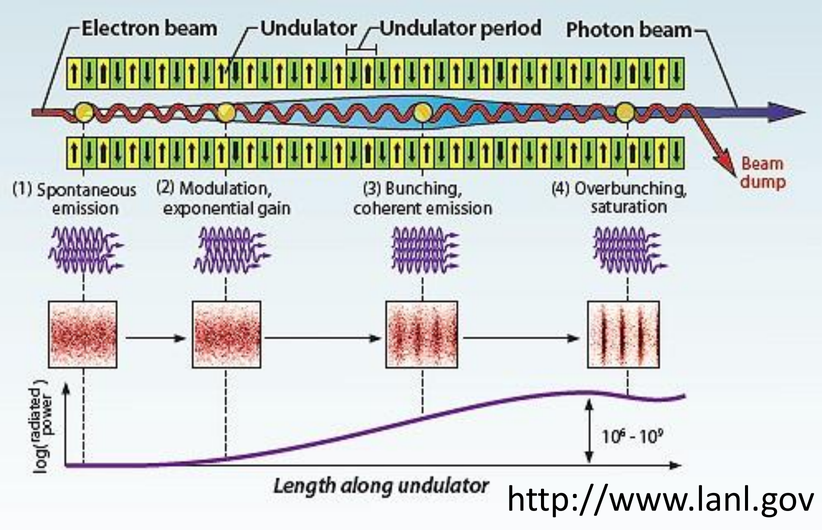
X-band XFEL Proposals

Mark Boland for the X-band FEL and CLIC collaboration

FEL Principle

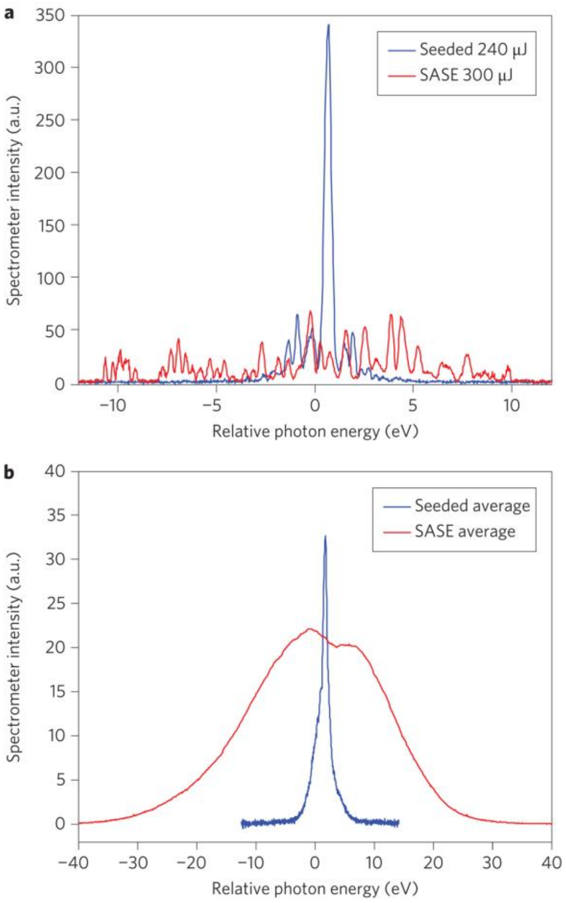


http://media.desy.de



http://www.lanl.gov

Measured X-ray spectra at LCLS

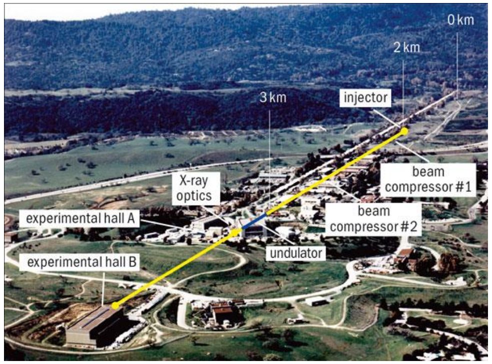


http://www.nature.com/nphoton/journal/v6/n10/fig_tab/nphoton.2012.180_F5.html

Existing XFELs

FLASH (Desy)

FERMI (Elettra)



LCLS (SLAC)

SACLA (SPring-8)

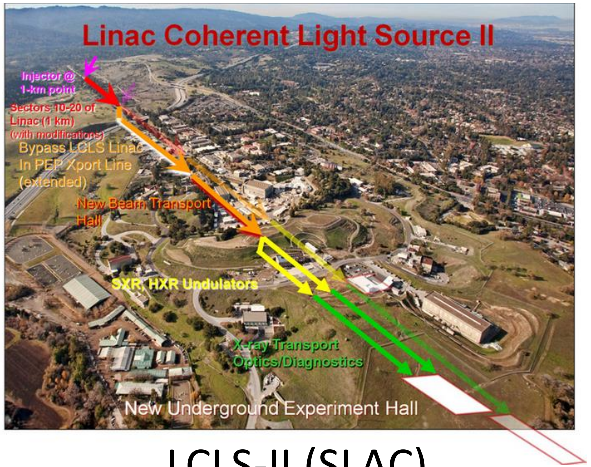
XFELs Under Construction

PAL-XFEL (PAL)

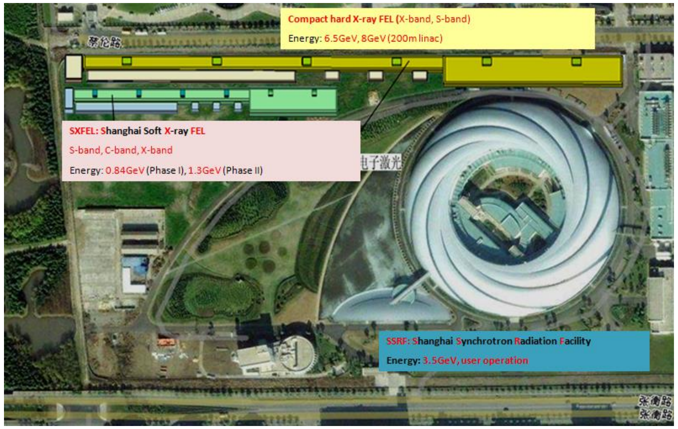
European XFEL (Desy)

SwissFEL (PSI)

XFEL Advanced Stages of Development



LCLS-II (SLAC)



SXFEL (SSRF)

Collaboration Goals

- Individual partner goals
  - Some want to upgrade an existing or future FEL
  - Some have plans to build a new FEL
  - Some have more long-term plans regarding FELs
- Common goals
  - Take advantage of X-band technology development
  - Foster it further to make it available to the FEL community, in particular develop as standardised RF units as possible and promote their industrialisation
  - Take advantage of each others expertise
  - Combine forces in preparation of CDRs for each project
- Dedicated Accelerator Session: X-Band and FEL, Thu 29 Jan 14:00-18:00, Council Chamber, CERN

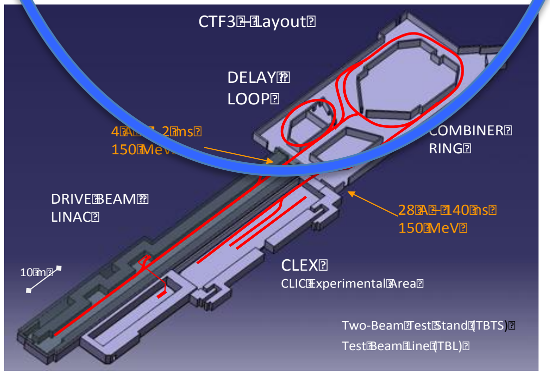
Why X-band for FELs?

- Light sources have spread around the world rapidly
  - Have become locally available in many countries
- Expect FELs to spread in a similar fashion when the technology is mature enough
  - XFEL photon science user community growing similarly to the storage ring user community http://www.lightsources.org/regions
- Normal conducting X-band FELs are a promising technology for this
  - Significantly cheaper than superconducting machines
  - High gradients allow compact machines
  - Repetition rate of kHz interesting for some experiments
  - Technology has matured very much in the past years, a little more to go
  - A good moment to develop the standards together with industry

CLIC Timeline

2012-18 Development Phase

Develop a Project Plan for a staged implementation in agreement with LHC findings; further technical developments with industry, performance studies for accelerator parts and systems, as well as for detectors.



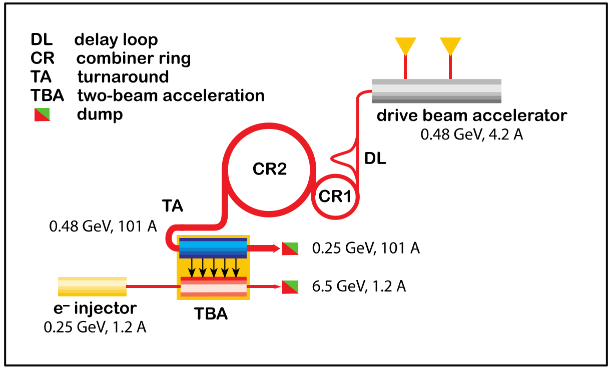
2018 Decisions

On the basis of LHC data and Project Plans (for CLIC and HiE LHC variants in particular), take decisions about next project(s) at the Energy Frontier.

2019-23 Preparation Phase

Finalise implementation parameters, Drive Beam Facility and other system verifications, site authorisation and preparation for industrial procurement.

Prepare detailed Technical Proposals for the detector-systems.



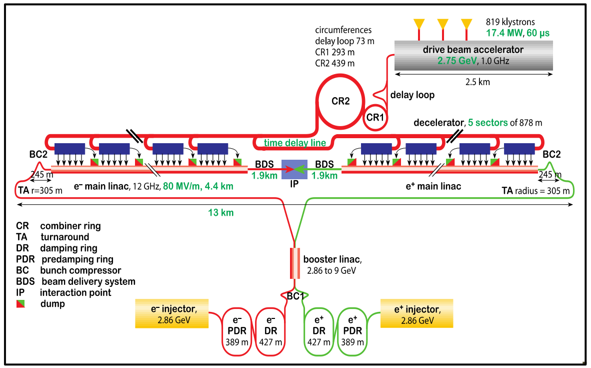
2023-24 Construction Start

Ready for full construction and main tunnel excavation.

2023-2030 Construction Phase

Stage 1 construction of a 500 GeV CLIC, in parallel with detector construction.

Preparation for implementation of further stages.



2030 Commissioning

From 2030, becoming ready for data-taking as the LHC programme reaches completion.

Why Does CLIC Support FELs?

- CERN does not do light sources
  - It is not part of CERN’s mandate
- Use of X-band in FELs in other labs would help CLIC for a number of tasks
  - Further technical developments with industry
    - Will create the industrial basis
  - Performance studies of accelerator parts and systems
    - From components up to large scale main linac system test
- FELs can profit from X-band technology
- Obvious win-win situation
  - In addition, FELs in different institutes can also profit from common development

  $\Rightarrow$ Started a collaboration
    - Submitted an application for an EU co-funded Design Study XbFEL

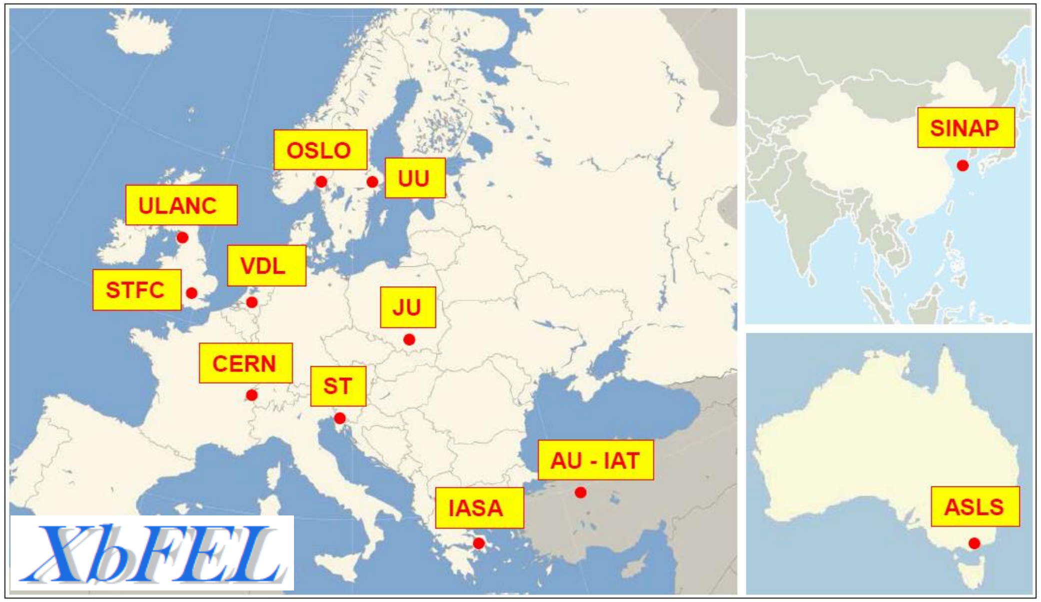
XbFEL

See G. D’Auria
Thursday 9:30

A proposal for an EU co-funded Design Study

A core activity of the FEL collaboration

Submitted September 3



ST	*Elettra - Sincrotrone Trieste, Italy.*
CERN	*CERN Geneva, Switzerland.*
JU	*Jagiellonian University, Krakow, Poland.*
STFC	*Daresbury Laboratory Cockcroft Institute, Daresbury, UK.*
SINAP	*Shangai Institute of Applied Physics, Shanghai, China.*
VDL	*VDL ETG T&D B.V., Eindhoven, Netherlands.*
OSLO	*University of Oslo, Norway.*
IASA	*National Technical University of Athens, Greece.*
UU	*Uppsala University, Uppsala, Sweden.*
ASLS	*Australian Synchrotron, Clayton, Australia.*
UA-IAT	*Institute of Accelerator Technologies, Ankara, Turkey.*
ULANC	*Lancaster University, Lancaster, UK.*

Other Interested Institutes

A more long-term interest in the technology also exists (often with future projects in mind):

- University of Oslo
- University of Uppsala
- National Technical University of Athens
- Jagiellonian University, Krakow
  - Operating synchrotron, X-band injector
- Lancaster University
- Some other institutes are interested but are focusing on construction projects right now (e.g. PSI use X-band in Swiss-FEL injector and considers building ATHOS with X-band,)

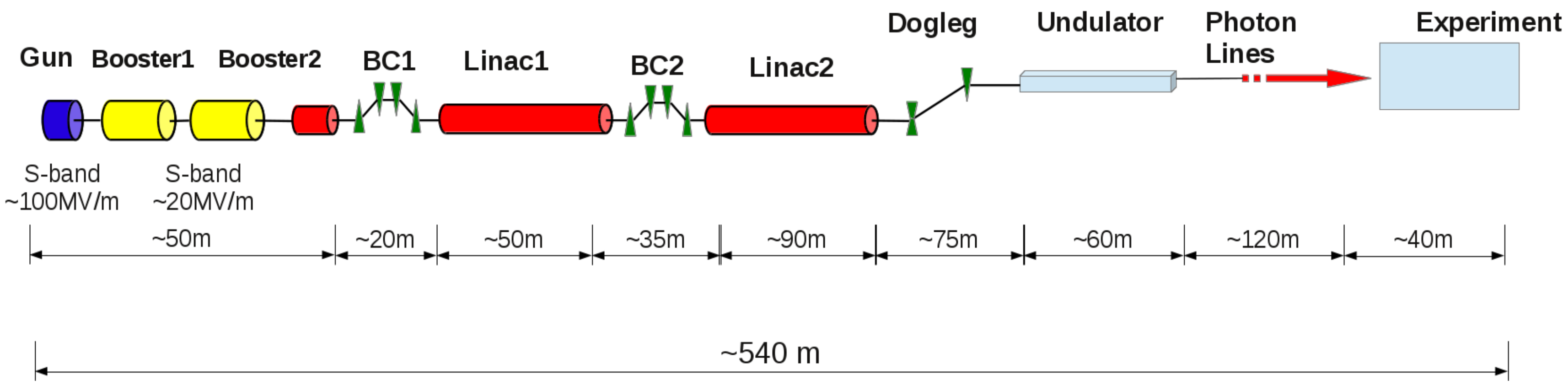
Interest in industry exists

- VDL
  - Interested in the industrial technology development

Work Programme

- Develop FEL designs that serve as examples
  - Upgrade of FERMI
  - Soft X-ray FEL
  - Hard X-ray FEL
- Identify and develop common hardware solutions for the linacs
  - In particular, RF units and structures
- Develop prototypes of these components
- Build them
- Perform power tests
- Outside of the proposal: use the components for a beam
  - Due to limited time not included in the proposal

FEL Example Scheme (TAC)



- 300 MeV injector (standard S-band linac)
- BC1 @ 300 MeV
- 2GeV Linac 1
- BC2 @ ~2GeV
- 6 GeV Linac 2
- Splitting Linac 2 for producing soft x-ray FEL?

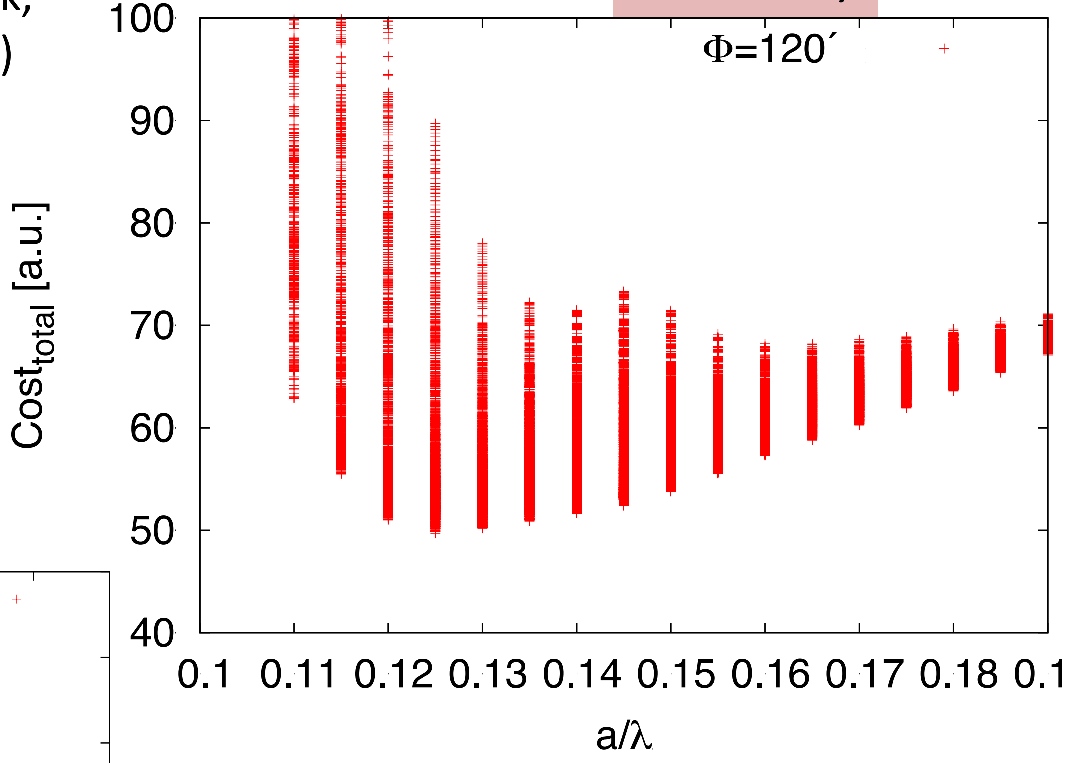
First Iteration on Cost Minimum

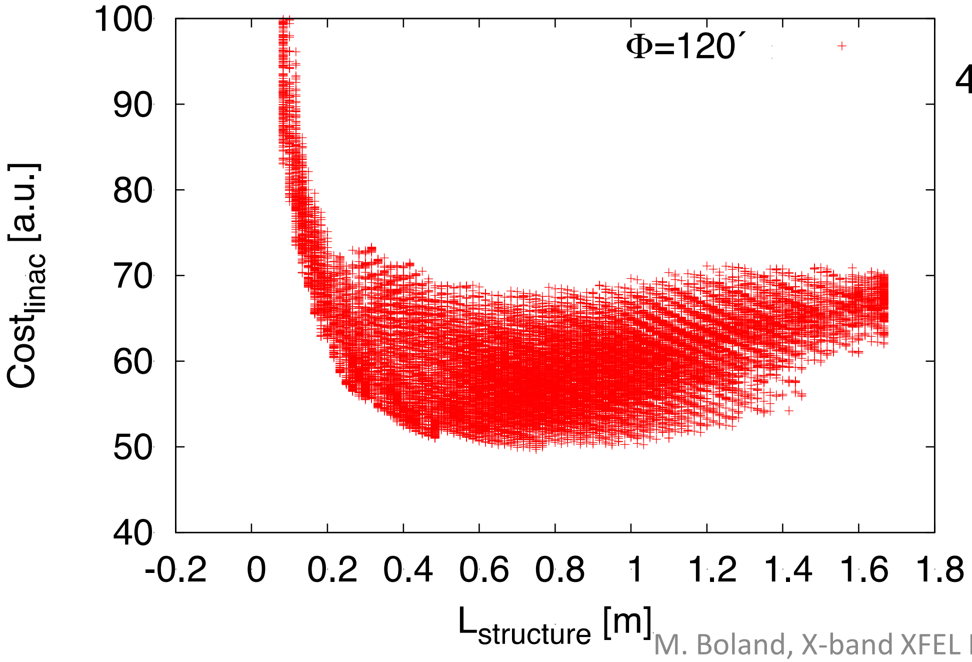
Based on CLIC structure database (K. Sjobak, A. Grudiev), simple cost model (Ph. Lebrun) and beamdynamics constraints

Cheapest structure:
L=0.75m, G=65MV/m,
P_{in}=41.8MW, τ=149.6ns

$a_1/\lambda=0.15$, $a_2/\lambda=0.1$,
d_1/λ=0.9mm, d_2/λ=1.7mm,

Preliminary





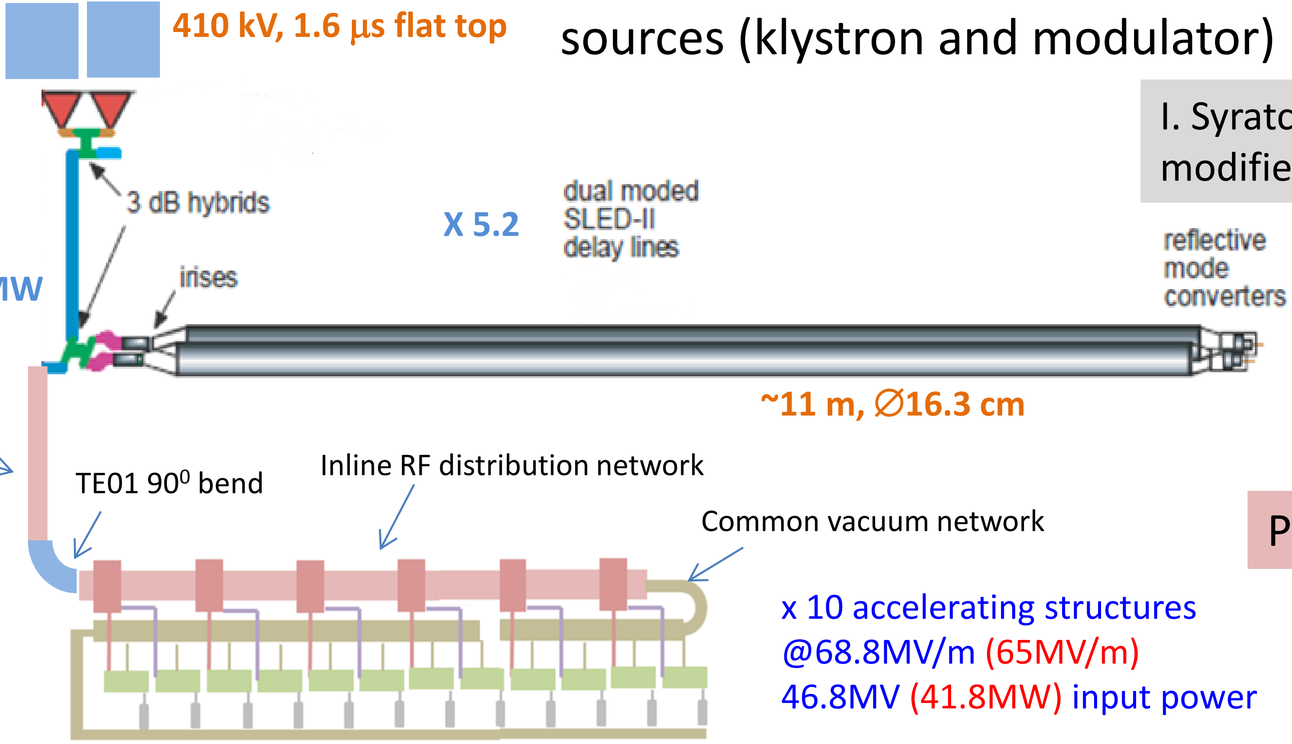
Many solutions with almost the same cost
Can chose most reasonable parameter set

Need to refine cost model design constraints

Electron Linac RF Unit Layout

based on the existing (industrialized) RF sources (klystron and modulator)

I. Syratchev,
modified by D. Schulte



2x ScandiNova solid state modulators

2x CPI klystrons

410 kV, 1.6 μs flat top

50 MW
1.5 μs
(Operated
@45MW)

100 (90) MW
1.5 μs

X 5.2

~11 m, ∅16.3 cm

TE01 transfer line (η_{RF}=0.9)

TE01 90^0 bend

Inline RF distribution network

Common vacuum network

Preliminary

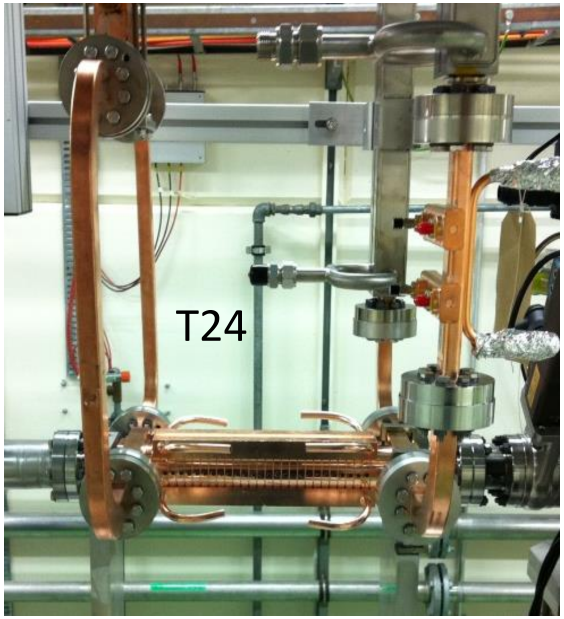
468 MW
(418 MW)
150 ns

x 10 accelerating structures
@68.8MV/m (65MV/m)
46.8MV (41.8MW) input power

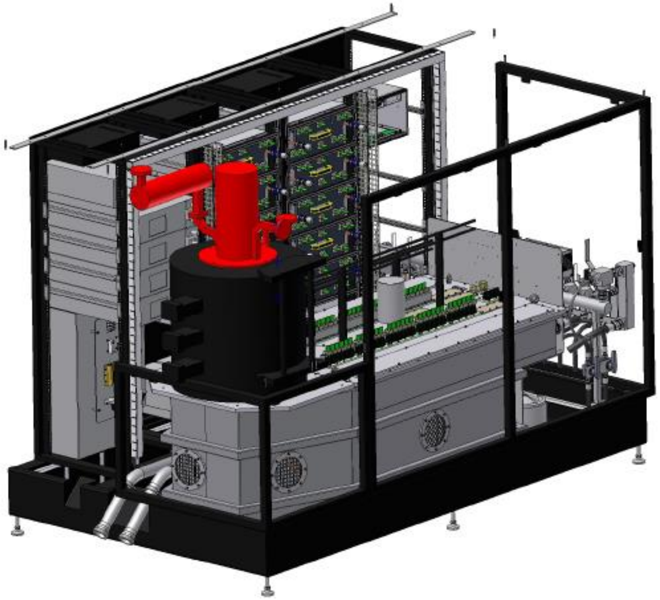
← 10 m, 7.5 active →

This unit should provide ~488 MeV acceleration beam loading.
Need 12 RF units.
Cost 51.7 a.u., 4% more than optimum

Some Components



I. Syratchev



Examples of Basic Parameters

Preliminary

	unit	CLIC_502		Opt.	Swiss
Structures per RF unit		12	16	10	4
Klystrons per RF unit		2	2	2	1
Structure length	m	0.23	0.23	0.75	1.98
<a>/lambda		0.145	0.145	0.125	
Allowed gradient	MV/m	100		80+	
Operating gradient	MV/m	77	67.5	65	27.5
Energy gain per RF unit	MV	213	248	488	203
RF units needed		27	23	12	26
Total klystrons		54	46	24	26
Linac active length	m	74	85	88	206
Cost estimate	a.u.	76.2	71.5	51.7	

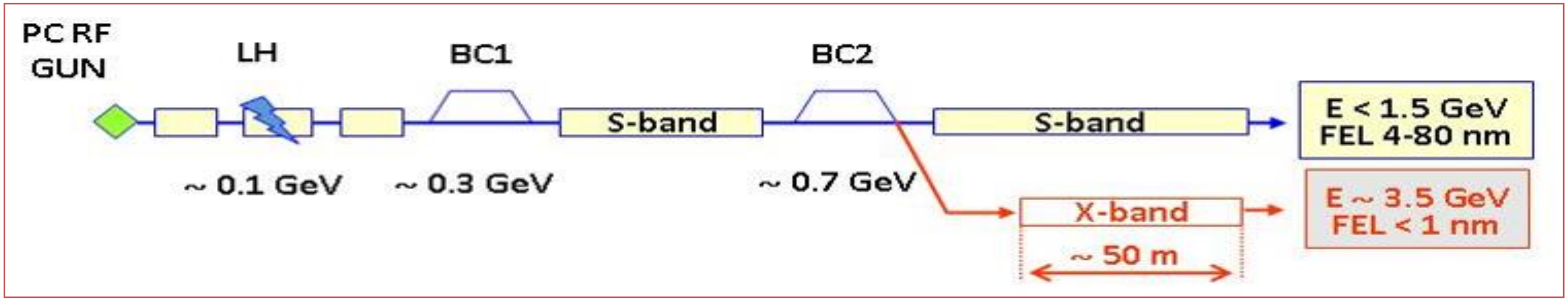
TAC Collaboration

Turkish Accelerator Centre
Infrared FEL TARLA under construction
X-FEL planned

Ankara University (Coordinator)
Gazi University
İstanbul University
Uludağ University
Dumlupınar University
Osmangazi University

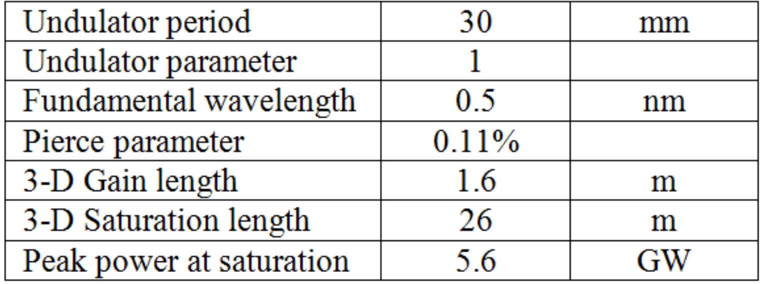
Boğaziçi University
Doğuş University
Erciyes University
Süleyman Demirel University
Niğde University
Gebze Institude of Technology

ELETTRA



- Existing FEL is based on injector for synchrotron (FERMI)
- Upgrade with X-band to increase beam energy for FEL

Table 3. FEL3 expected performance.



Undulator period	30	mm
Undulator parameter	1	
Fundamental wavelength	0.5	nm
Pierce parameter	0.11%	
3-D Gain length	1.6	m
3-D Saturation length	26	m
Peak power at saturation	5.6	GW

UK FEL Aspirations

Jim Clarke

- Two FEL facility proposals in the UK have been generated
  - 4GLS (2006), ERL-based accelerator incorporating single pass, seeded, FEL (8 to 100 eV, 1 kHz)
  - NLS (2010), SC Linac-based accelerator with 3 single pass seeded and upconverted FELs after beam spreader (50 to 1000 eV, 1MHz)

- A third proposal is now being actively discussed
  - Results from LCLS especially seem to have convinced the UK life science community that FELs offer new capabilities
  - Implications are that higher photon energies will be required (250 eV to 15 keV) and so higher electron energies
  - To keep costs manageable this is likely to mean that NC RF will be selected (compromise on repetition rate)
  - Hence our interest in the application of X Band accelerating technology

Shanghai Photon Science Center at SINAP

Compact hard X-ray FEL (X-band, S-band)

Energy: 6.5GeV, 8GeV (200m linac)

SXFEL: Shanghai Soft X-ray FEL

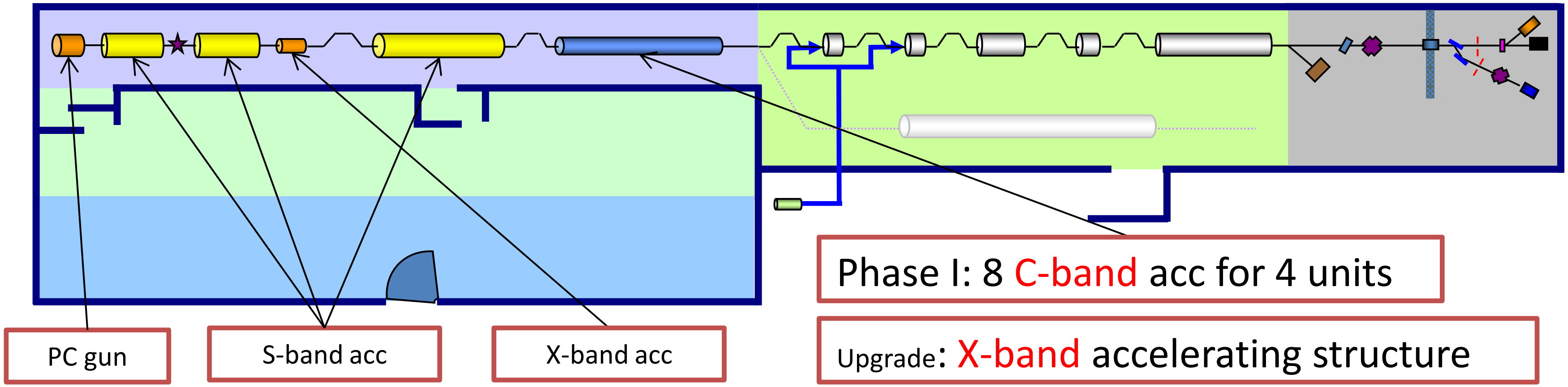
S-band, C-band, X-band

Energy: 0.84GeV (Phase I), 1.3GeV (Phase II)

SSRF: Shanghai Synchrotron Radiation Facility

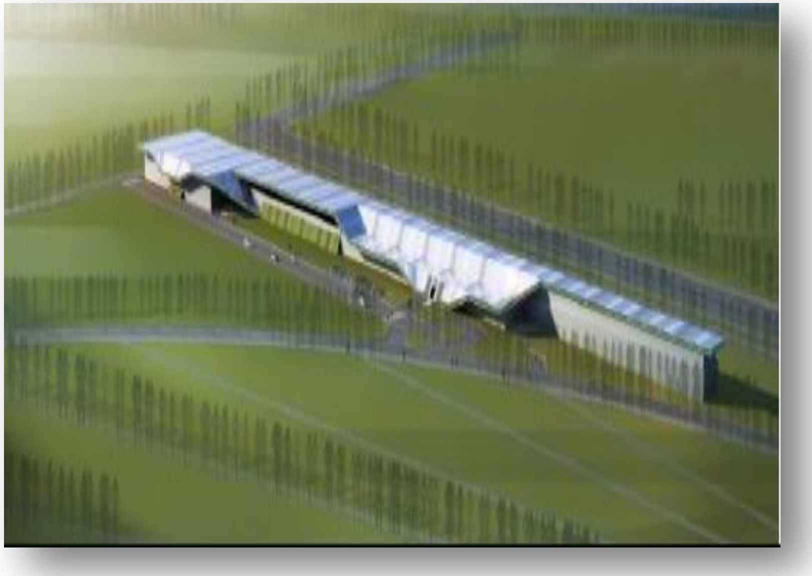
Energy: 3.5GeV, user operation

C-band and X-band plan for soft X-ray FEL (SXFEL started in 2014)



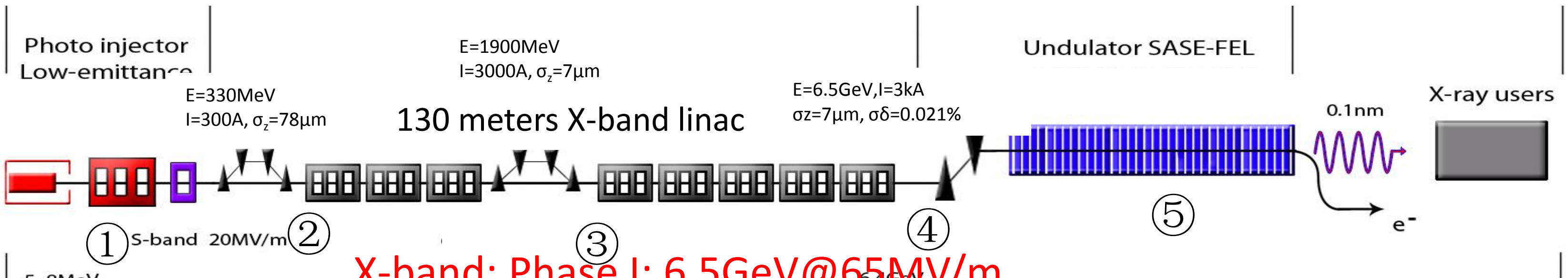
Phase I: 8 C-band acc for 4 units

Upgrade: X-band accelerating structure



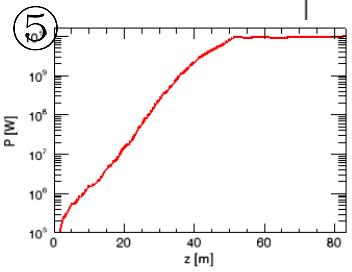
Parameters	Phase I	Upgrade	Unit
Output Wavelength	9	3	nm
Bunch charge	0.5~1	0.5~1	nC
Energy	0.84	1.2~1.3	GeV
Energy spread	0.1~0.15%	0.15%	
Energy spread (sliced)	0.02%	0.03%	
Normalized emittance	2.0~2.5	2.0~2.5	mm.mrad
Pulse length (FWHM)	1.	1	ps
Peak current	~0.5	0.5	kA
Rep. rate	1~10	1~10	Hz

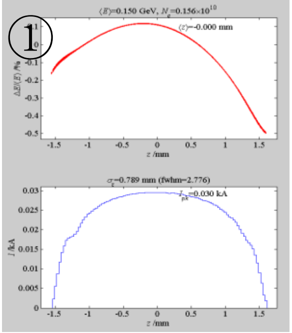
X-band plan for compact hard X-ray FEL (On proposal)

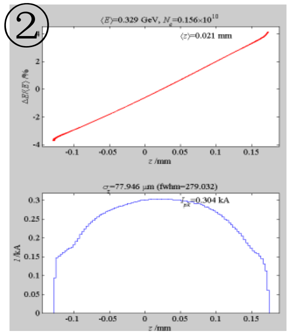


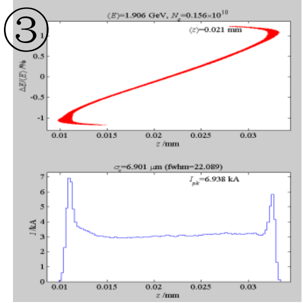
X-band: Phase I: 6.5GeV@65MV/m

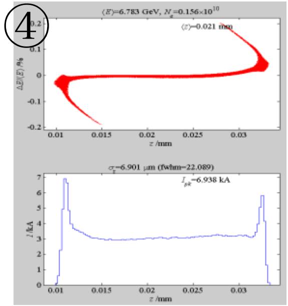
Upgrade: 8GeV@80MV/m



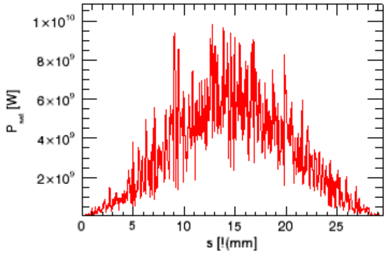


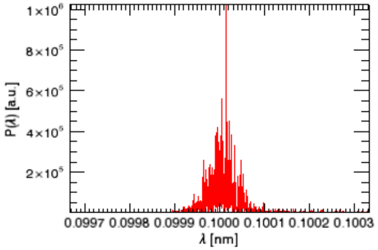






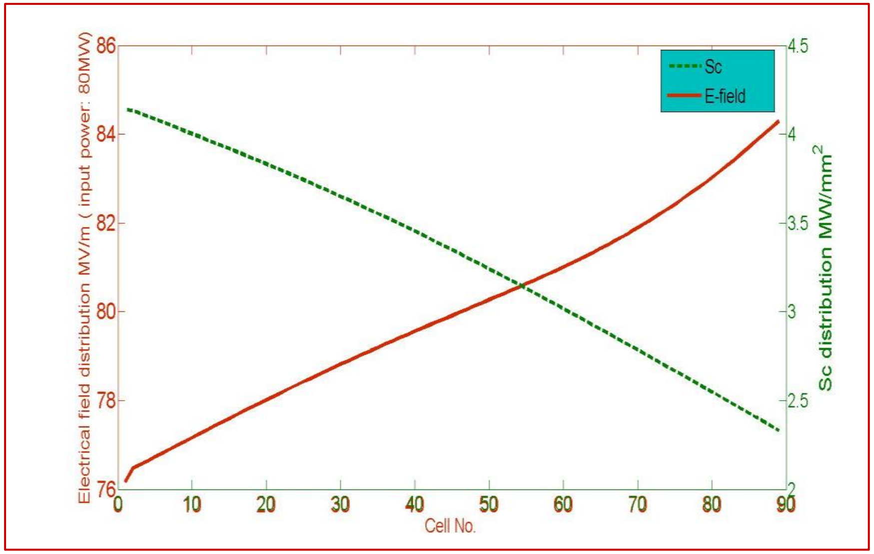
Parameters	Value
Output Wavelength	0.07nm
Bunch charge	250pC
Energy	6.5GeV
Normalized emittance	0.4µm
Energy spread (projected)	0.02%
Pulse length (Full)	40fs
Peak current	3kA
Rep. rate	60Hz
Peak power	10GW
Peak brightness	$2*10^{33}$



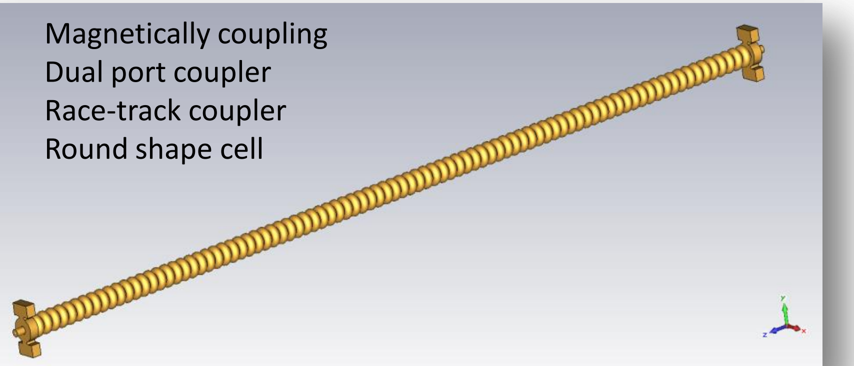


X-band accelerating structure for XFEL

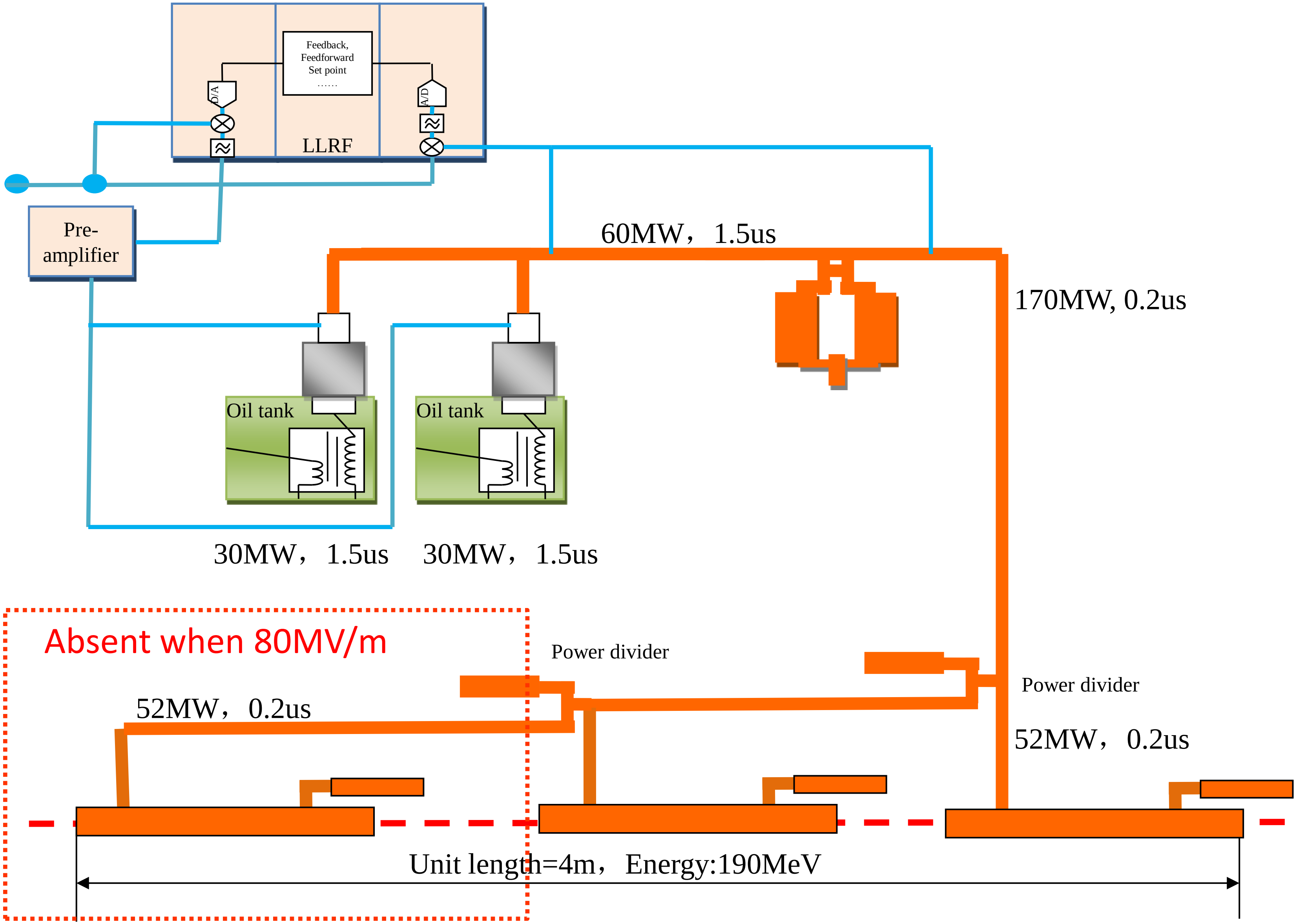
Frequency	11424MHz
Phase advance	4π/5
Cell No.	89+2
Effective length	944.73mm
Cell length, d	10.497mm
Iris thickness, 2a	1.5 mm
Ratio of elliptic radius, b_a	1.8
Aperture, a_r	4.3~3.05.mm
Group velocity, Vg/c	3.45%~1.12%
Shunt impedance, R	86.7~108.7MΩ/m
Attenuation factor, τ	0.61
Filling time, t_f	150 ns
Sc	4.14~2.33 MW/mm^2
Emax/E0	2.68~2.02
Hmax/E0	2.68~2.39 mA/V
Input power, P_{in}	52MW @65MV/m 80MW @80MV/m
Two-Klystrons units	34 @65MV/m 51 @80MV/m



1. Magnetically coupling
2. Dual port coupler
3. Race-track coupler
4. Round shape cell



Layout of X-band acceleration unit of XFEL for 65MV/m, 80MV/m



Feedback,
Feedforward
Set point
……

D/A

A/D

LLRF

Pre-amplifier

60MW，1.5us

170MW, 0.2us

Oil tank

Oil tank

30MW，1.5us

30MW，1.5us

Absent when 80MV/m

52MW，0.2us

Power divider

Power divider

52MW，0.2us

Unit length=4m，Energy:190MeV

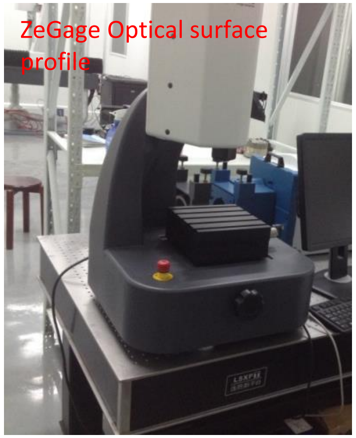
Dedicated workshop for X-band R&D at SINAP


Milling


Tuning


3D measuring machine


3D Vision Measuring Machine


ZeGage Optical surface profile


ZYGO DynaFiz dynamic laser interferometer


Vacuum furnace


Baking


Water treatment for cleaning room

AXXS

- Strong XFEL user base with regular beamtime on LCLS and members of review committees for European XFEL
- Strong government funding, especially in life sciences

CENTRE FOR ADVANCED MOLECULAR IMAGING
AN ARC CENTRE OF EXCELLENCE

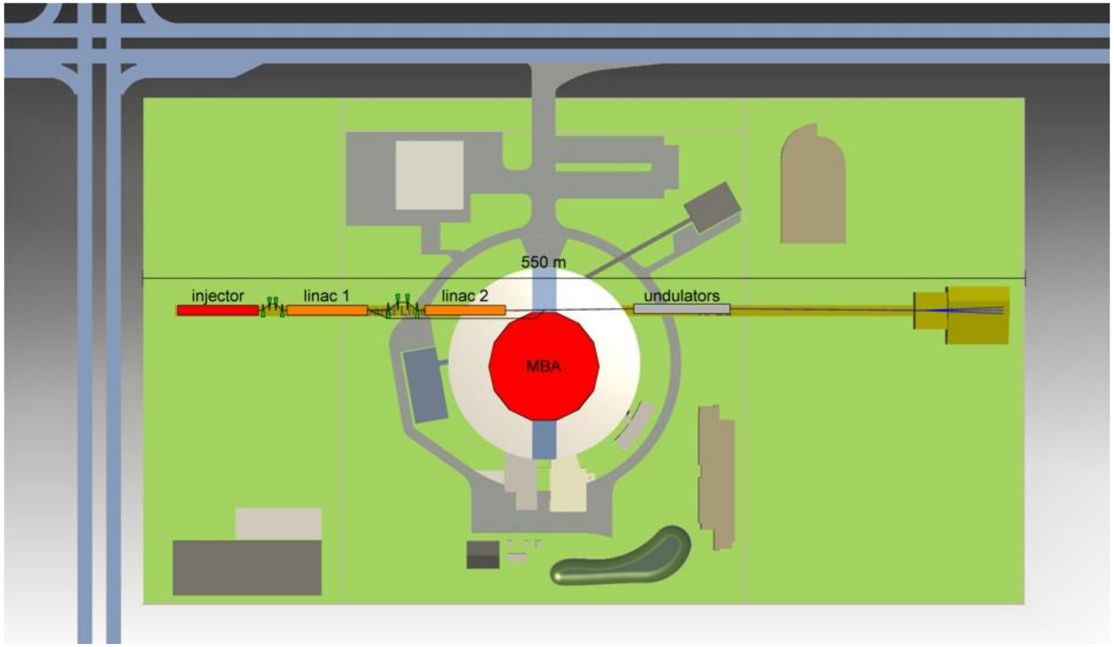
AXXS – Australian X-band X-ray Source

AXXS n. /ˈæksɪs/ *fig.* A central prop, which sustains any system.

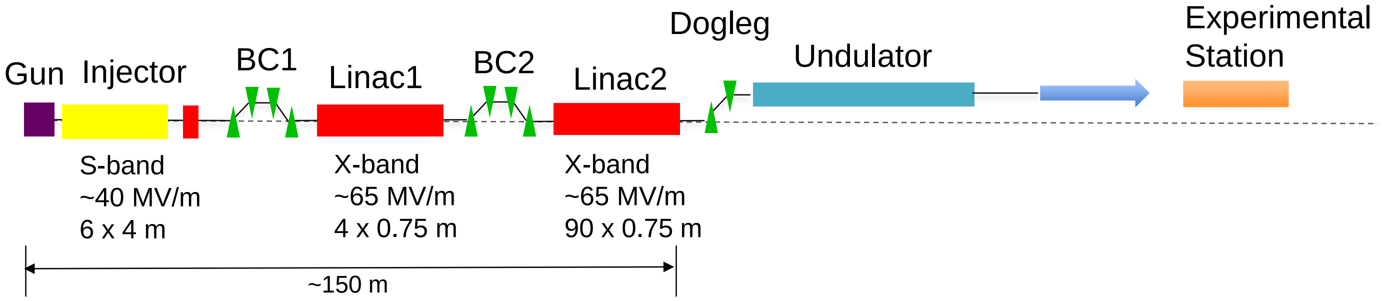
Development plan for the Australian Light Source community:

1. develop the remaining beamlines (space for an additional 6 IDs)
2. upgrade the storage ring lattice to MBA (compact MAX IV magnets)
3. upgrade the injector to a full energy x-band linac (3 GeV)
4. upgrade to additional linac for XFEL

- Site constraint 550 m:
- Same tunnel, energy and source points for storage ring upgrade.
- Time constraints: need to finish building out the remaining beamlines before justifying a new ring or FEL.



1. Base line design: S-band with X-band structure for linearizing before BC1



Gun Injector BC1 Linac1 BC2 Linac2 Dogleg Undulator Experimental Station

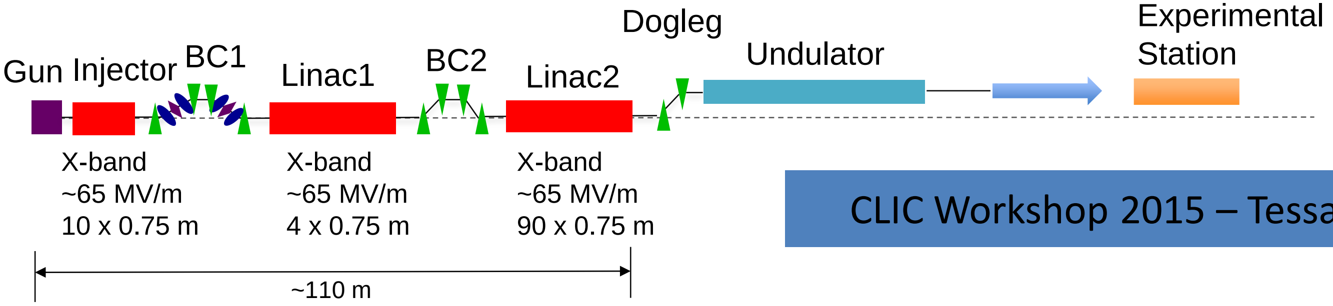
S-band
~40 MV/m
6 x 4 m

X-band
~65 MV/m
4 x 0.75 m

X-band
~65 MV/m
90 x 0.75 m

~150 m

1. Alternative design being considered: X-band the whole way



Gun Injector BC1 Linac1 BC2 Linac2 Dogleg Undulator Experimental Station

X-band
~65 MV/m
10 x 0.75 m

X-band
~65 MV/m
4 x 0.75 m

X-band
~65 MV/m
90 x 0.75 m

~110 m

CLIC Workshop 2015 – Tessa Charles

Planned Oslo work in the XbFEL collaboration

Erik Adli, Jurgen Pfingstner
Department of Physics, University of Oslo, Norway

- There are currently no photon science facilities in Norway.
- Norway is part of a Norwegian-Swiss beam line at ESRF
- The «XbFEL» project has been presented to the Norwegian light source user community (about 100 scientists). Several scientists show a general interest for a national facility.
- Norwegian users have for the moment no experience with XFEL science.
- Interest for a Norwegian XFEL might depend on whether Max IV will be extended with an XFEL and how much Norway will be involved in a Swedish project.

Advanced seeding schemes

- To improve spectrum of created light: seed with one “nice” light wave.
- Problem: There are no lasers with sufficient intensity at these wave lengths.

FEL-Oscillator	**Direct seeding (HHG)**	**High gain harmonic generation (HGHG)**	**Echo-enabled harmonic generation (EEHG)**	**Self seeding**
• Light trapped in an oscillator. • Limitations are mirrors. • > 250 nm.	• Laser ionizes novel gases and creates higher harmonics. • > 40 nm	• First seeding with laser. (modulator) • Then lasing at higher harmonic (radiator). • > 10nm	• Complex three stage scheme similar to HGHG. • > 1nm • Interesting for soft XFEL design.	• Laser creates SASE light in first stage. • Light is filtered. • Second stage for lasing. • No wave-length limitation. • Interesting for soft and hard XFEL design.

Technical work where we plan to participate

- Participate in overall FEL design for a compact FEL (soft x-ray) for "small countries"
- WFM and emittance preservation strategies in FELs
- If EU app: participate in Module Tests
- **Seeding schemes**. Integrated studies with beam line and Genesis for radiation generation (has asked Andrea for a lattice) . We will start with this topic .

Proposed activities

1. SASE seeding

- Compare available simulation codes (widely used is GENESIS).
- Setup simulations with test bunches.
- Interface with the XFEL linac design to check performance with created bunches.

2. Advanced seeding

- Investigate how advanced schemes can be simulated (especially self seeding and maybe EEHG).
- Setup simulations and determine reachable light quality.
- Take into account the user needs and cost issues.
- Also take a look at other schemes (multicolor, …).

XbFEL Summary

- Collaboration has been established to pursue an x-band XFEL design based on CLIC technology for the mutual benefit of HEP and lightsouce communities (12 institutes to date).
- Work packages have been drawn up and design and simulation efforts are underway.
- A funding application has been written and opportunities are being explored to boost the support for the work.
- XFELs seem to be a good field in which to expand the use of x-band.