TRIUMF THz/IR source proposal

Victor Verzilov

TRIUMF

Canada's national laboratory
for particle and nuclear physics
and accelerator-based science

"Be or not to be"

Operating THZ/IR Facilities

UCSB, THz/IR FEL, USA
FELIX, Nijemegen, Netherland
NovoFEL, Novosibirsk, Russia
CLIO, Orsay, France
ELBE, Dresden, Germany
IR FEL, Fritz Haber Institute, Berlin, Germany
FLASH THz beamline, DESY, Hamburg, Germany
THz CUR Beijing University, China
CAEP THz FEL, China
FEL-SUT IR FEL, Tokyo (Japan)
LUCX R&D THz facility, KEK, Japan
ELPH, CUR, Tohoku University, Japan
ISIR-FEL, Osaka, Japan
THz KU- FEL, Kyoto University, Japan
HGHG FEL, ATF NSLS, USA
ENEA Compact FEL, Frascati, Italy
Tel Aviv University FEL, Israel

Proposed/Under development

PITZ IR/THz SASE FEL, Germany
FREIA, Uppsala, Sweden
Shangai Institute of Applied Physics, China
FELiChEM, Hefei, China
THZ FEL KAERI, Korea
TARLA IR FEL, Ankara, Turkey

There is an enormous interest to THz/IR accelerator based photon sources in Europe and Asia. "Baby boom" has been happening over the last decade.

THz/IR research presently opens a unique opportunity for small, low energy linear electron accelerators.

TRIUMF electron linac suits very well as a driver for a high power THz/IR source. RF power capacity is enough to serve both RIB production and light source.

But this is also an excellent opportunity for the Canadian THz/IR user community to obtain a world-class photon source in just few years and join international FEL network.

TRIUMF Planning Committee: "This may be an interesting future direction, but this new user community needs to be engaged(e.g. in a dedicated workshop) prior to investing TRIUMF resources."

TRIUMF

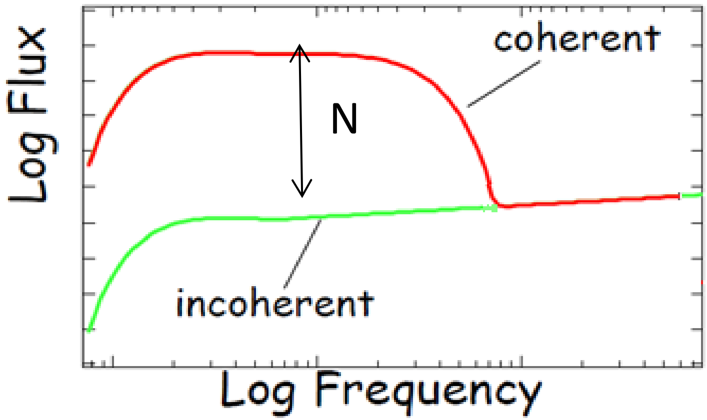
Coherent action what counts

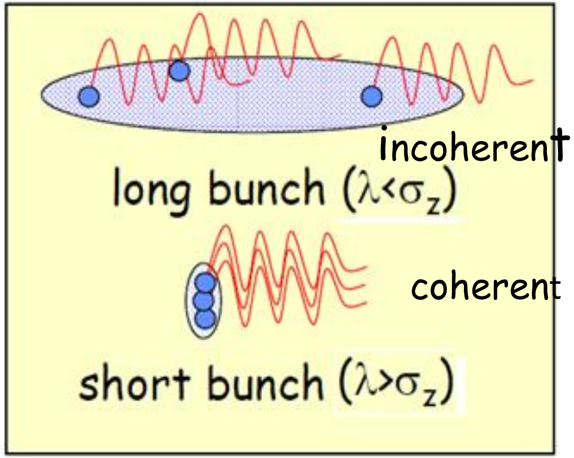
From very basic principles and valid for any electromagnetic radiation by an ensemble of charged particles !

$$I_{tot}(\omega) = I_e(\omega)\left(N + N(N-1)f(\omega)\right)$$

Incoherent — Coherent

$$f(\omega) = \left| \int_{-\infty}^{\infty} dz S(z) e^{i(\omega/c)z} \right|^2$$





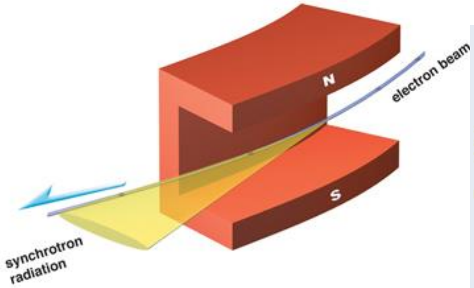
Form factor is the frequency spectrum of the bunch charge distribution.

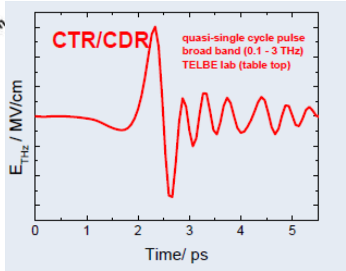
A short ~0.1λ bunch is required for a full coherence.

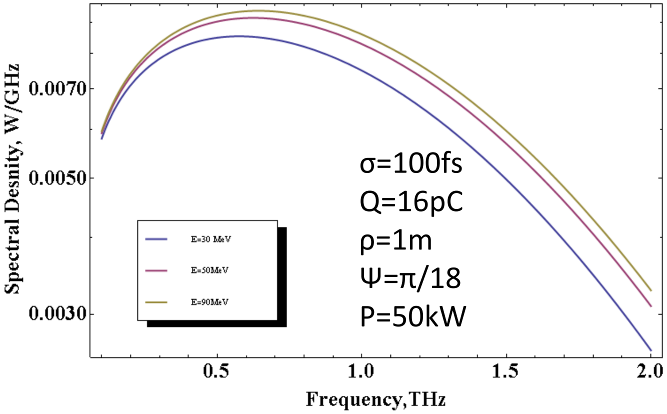
E-linac
16 pC bunch contains ~10^8 electrons!

Producing Coherent Radiation

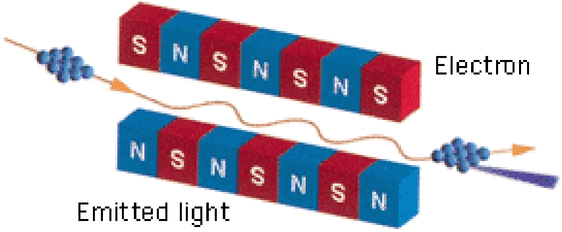
Coherent Synchrotron Radiation

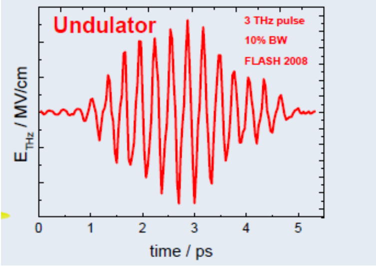




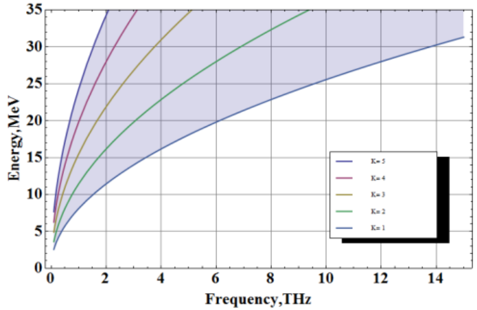


Coherent Undulator Radiation

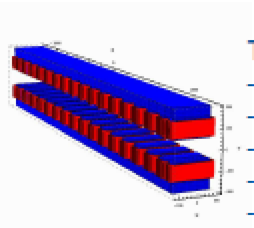




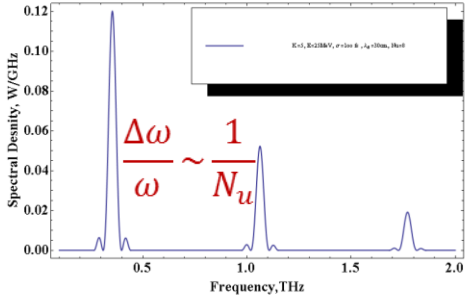
$$\lambda_\ell = \frac{\lambda_u}{2\gamma^2}\left(1 + \frac{K^2}{2}\right)$$



TELBE undulator

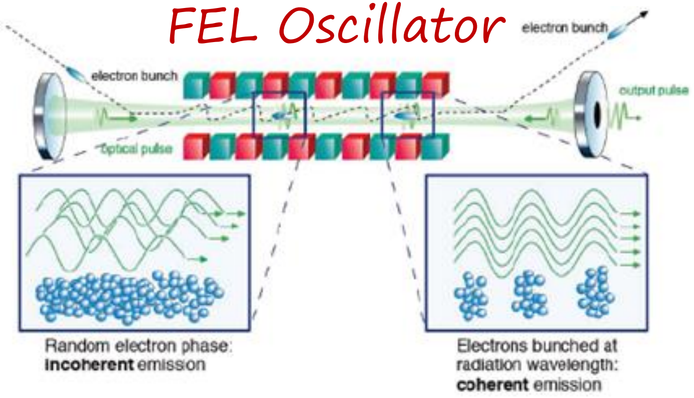


THz Undulator:
- Electromagnetic
- 8 periods
- Peak field on-axis: 0.4 T
- max. K parameter: 8
- period length: 300 mm



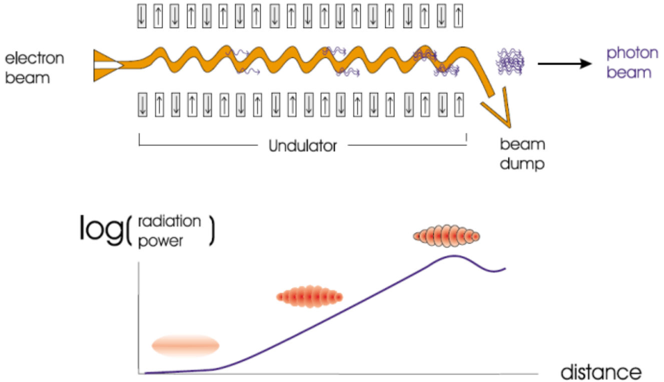
Coherent action can be assisted

FEL Oscillator

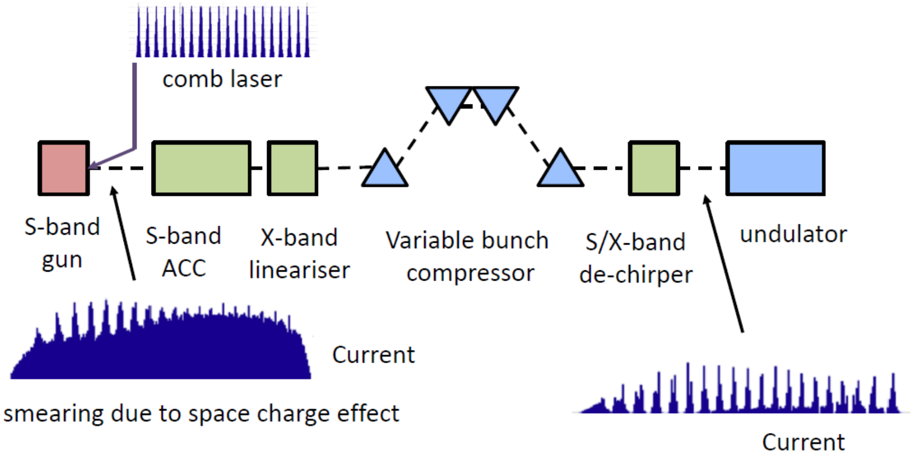


The bunch can be stimulated to emit coherently through FEL process. Interaction with electromagnetic field in an undulator may lead to microbunching at the radiation wavelength and following coherent emission.

SASE FEL amplifier



Pre-bunched SASE FEL



Spontaneous coherent radiation vs FEL

Thus, photon source can be based on
- spontaneous incoherent radiation
- spontaneous coherent radiation
- stimulated (coherent) radiation

It is the last two that make accelerated based photon sources competitive!

	SCR	FEL
Bunch length	~ 0.1λ	> λ N
Energy Spread	few %	< 0.5%
Bun Rep. Rate	any	Match cavity round trip
		any for SASE and PB SASE
Radiation phase	determined	ND for SASE
		pulse to pulse in FELO
		determined in PB SASE
Bandwidth	wide	narrow
Power	similar	similar
Complexity/cost	Simpler	More costly

Spontaneous coherent radiation can be a good choice above 200μm, pump-probe and high field applications.

TRIUMF

What kind of beam do we need for a photon source

Generally: high bunch charge and small size !

Due to space charge forces that scale as E^{-2}
the receipt is to accelerate the beam as fast as possible.
The electron source (the gun) is of paramount importance.

Laser driven electron source are most popular

Offers full control over the bunch parameters
and possibility of synchronization to external source

DC guns

Better developed
CW and pulse operation
Beam energy to ~500 keV
Bunch charge < 200pC
Require HV source
Less expensive

RF guns

Less developed
CW mostly with SRF
Beam energy to ~ 3-4 MeV
Bunch charge < few nC
Require RF source
More expensive

Present TRIUMF thermionic electron source delivers 16pC bunches ~120ps long with 300keV of energy at 650 MHz.

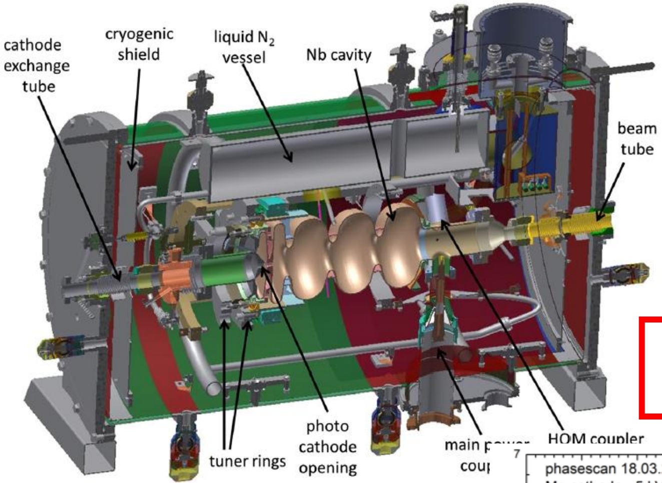
-The charge is too low.
-Bunch is too long
-Frequency is too high.

Electron source upgrade is required!

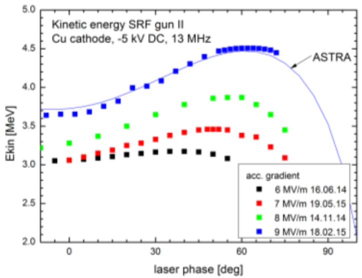
A dc gun could be a short to mid term solution with an SRF gun being a long term goal.

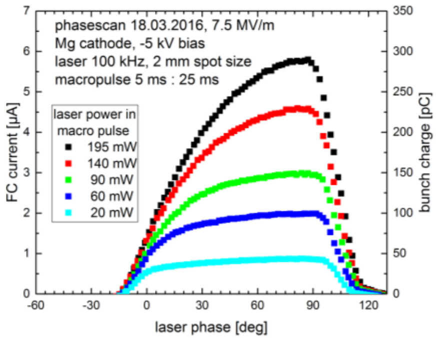
SRF guns examples

HZDR ELBE gun



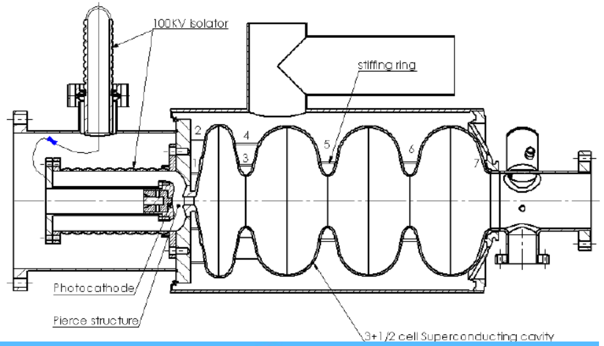
Mg photocathode
QE = 0.1 – 0.2 %

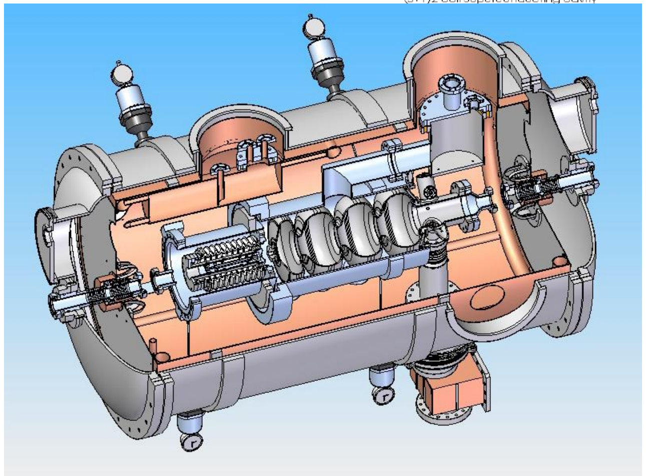




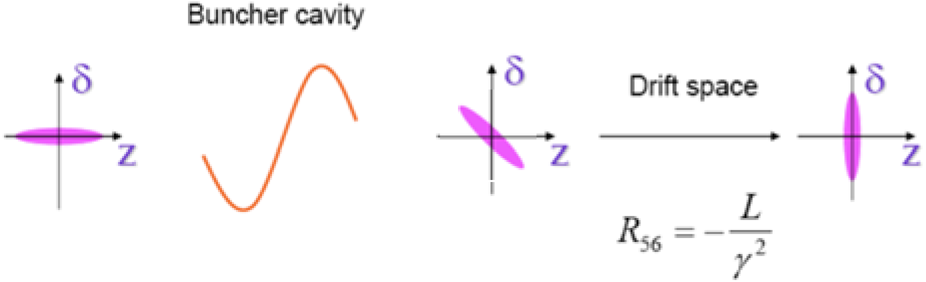
Mg cathode in gun since March 3rd, 2016, 270 h beam time, no QE decrease

Beijing DC-SRF gun



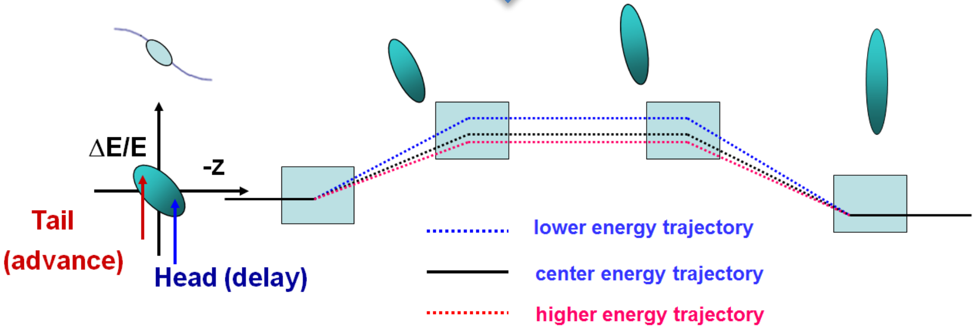


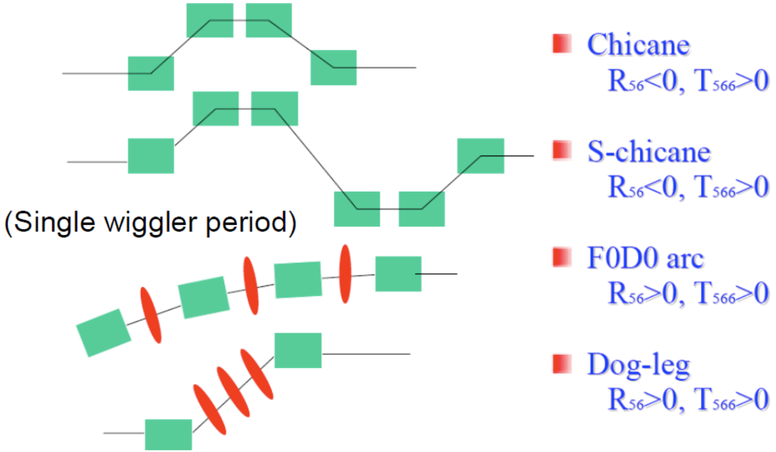
Bunch manipulation after the gun



Ballistic (velocity) Compression V < C

Magnetic compression V ~ C





Project staging

Staged approach to the construction of the photon source is a path for a gradual evolution of the facility that enables conducting required developments of accelerator and (possibly) user areas at earlier times.

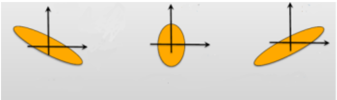
Essential preparation steps are

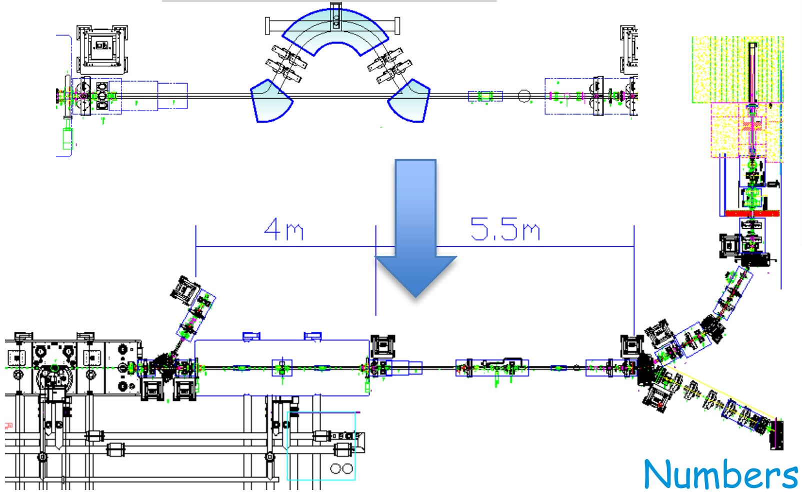
- Define the design parameters for both the electron beam and THz/IR radiation in collaboration with the user community
- Conduct design studies and required R&D (new electron source)
- Select appropriate technologies.
- Produce the conceptual design report.
- Engage the user community in design the end stations and user labs

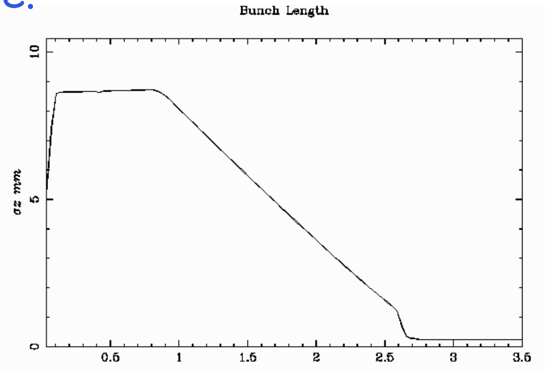
1. Produce first THz radiation with the present beam as a demonstration experiment
2. Through smaller grants develop/construct a new electron source and, possibly, procure an undulator/FEL. This will enable first pilot experiments
3. Depending on available funds full scale facility is implemented including FEL(s) and SRF gun, user areas

Stage 1

According to ASTRA simulations 16 pC bunch can be compressed from 120ps to ~ 800fs due to ballistic bunching.
Further bunch length reduction can be done with magnetic compressor. Bunch length in the range 300fs -100fs is eventually possible.





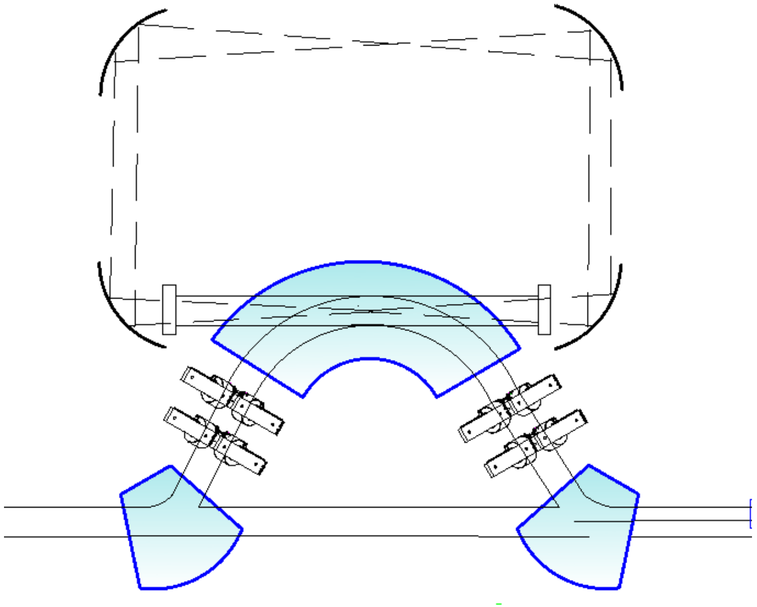


CSR, comes at essentially no cost.
It can be used to study the bunch compression and, possibly, conduct first THz experiment.

Type	Spectral Density @1THz, W/GHz	Average power in 0.1GHz-2THz range, W	Energy per bunch, nJ
CSR	0.007	12	110

Numbers in the table are optimistic estimates obtainable with 30MeV 50kW beam consisting of 16pC bunches compressed to 100fs.

Stage 1.5



ELSEVIER

Nuclear Instruments and Methods in Physics Research B 145 (1998) 49–53

NIM B
Beam Interactions with Materials & Atoms

Prebunched free electron laser with a broadband spectrum

Yukio Shibata [a], Kimihiro Ishi [a], Shuichi Ono [a], Yuta Inoue [a], Satoshi Sasaki [a], Mikihiko Ikezawa [a,*], Toshiharu Takahashi [b], Tomochika Matsuyama [b], Katsuhei Kobayashi [b], Yoshiaki Fujita [b], Evgueni G. Bessonov [c]

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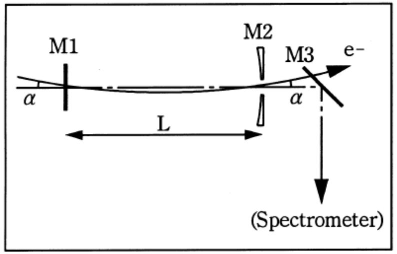
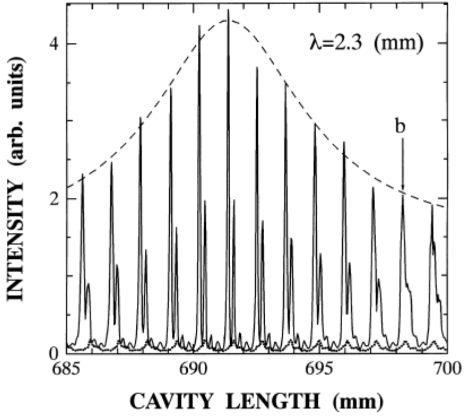
Received 2 December 1997; received in revised form 2 February 1998

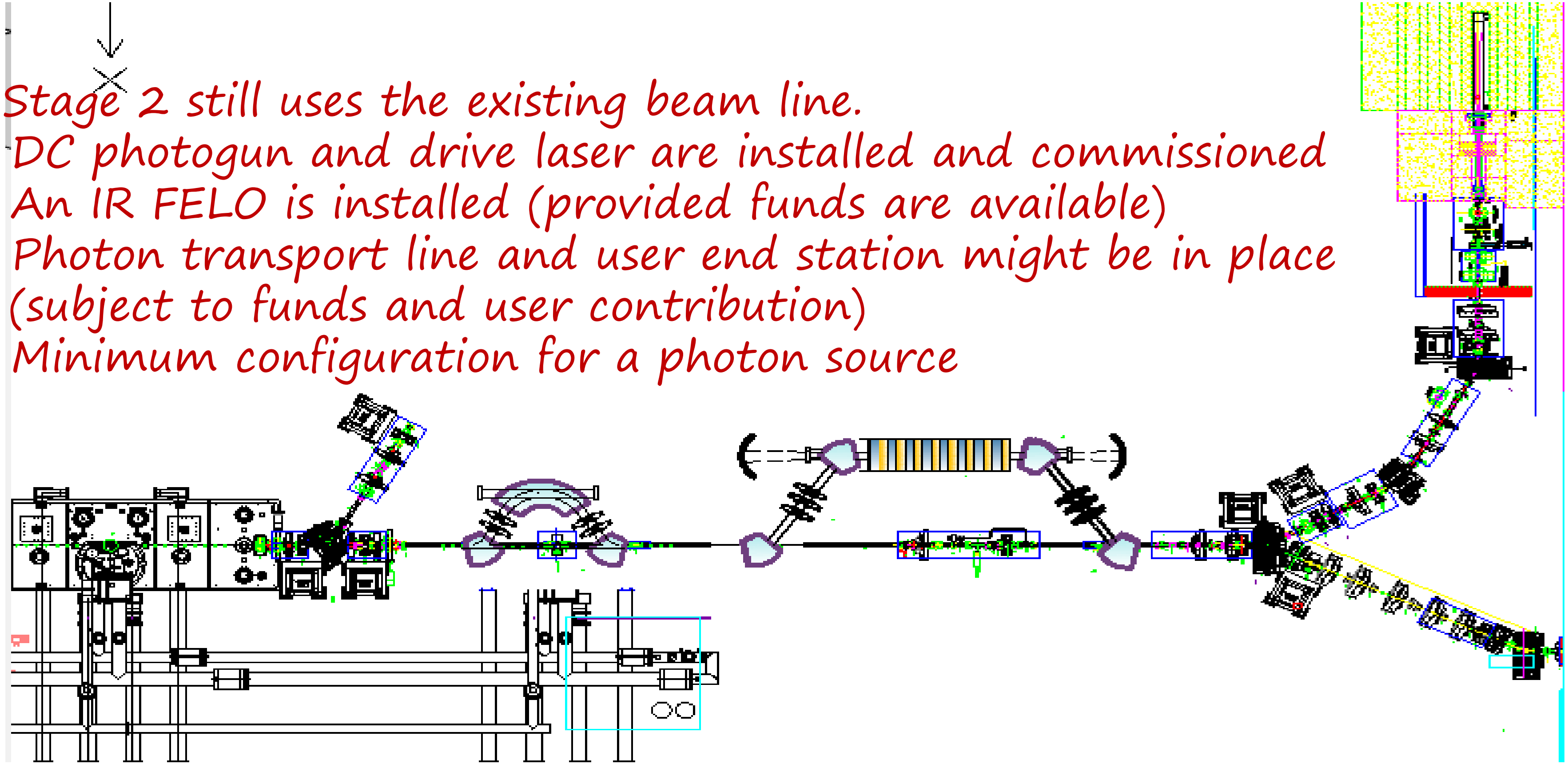




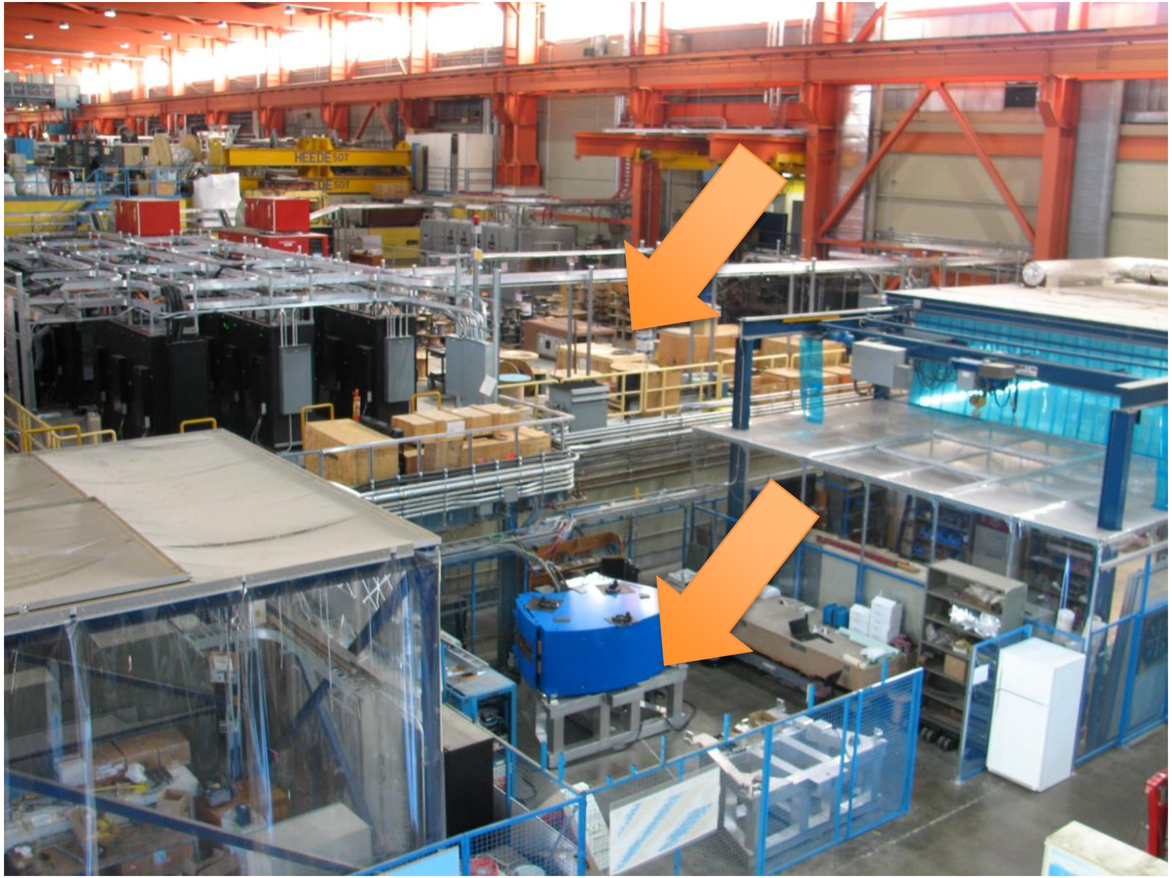
Enhancement of one – two orders of magnitude can be obtained. Pulse energy of ~ few μJ is about what one can get from an FEL

Stage 2

- Stage 2 still uses the existing beam line.
- DC photogun and drive laser are installed and commissioned
- An IR FELO is installed (provided funds are available)
- Photon transport line and user end station might be in place (subject to funds and user contribution)
- Minimum configuration for a photon source



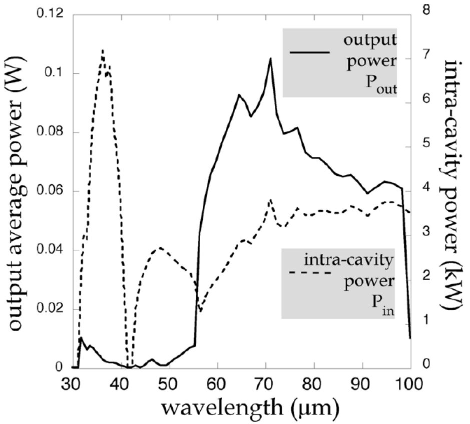
User areas



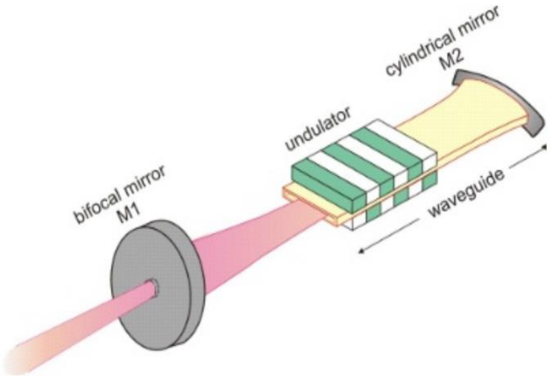
Waveguide FEL

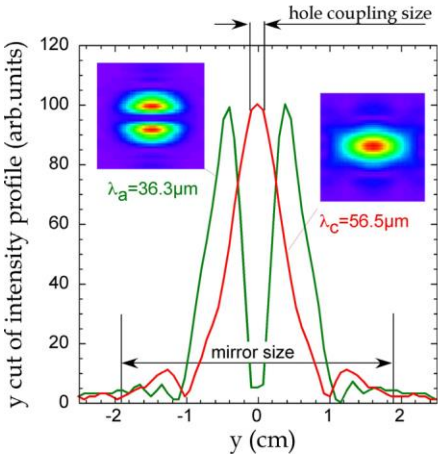
The diffraction of the light in the resonator increases the photon beam radius and reduces the overlap with the electron beam for longer wavelengths and, thus, the FEL gain.

A waveguide is typically required above 40µm-50µm



The waveguide strongly modifies the free-space laser mode, introduces dispersion and higher-order modes.

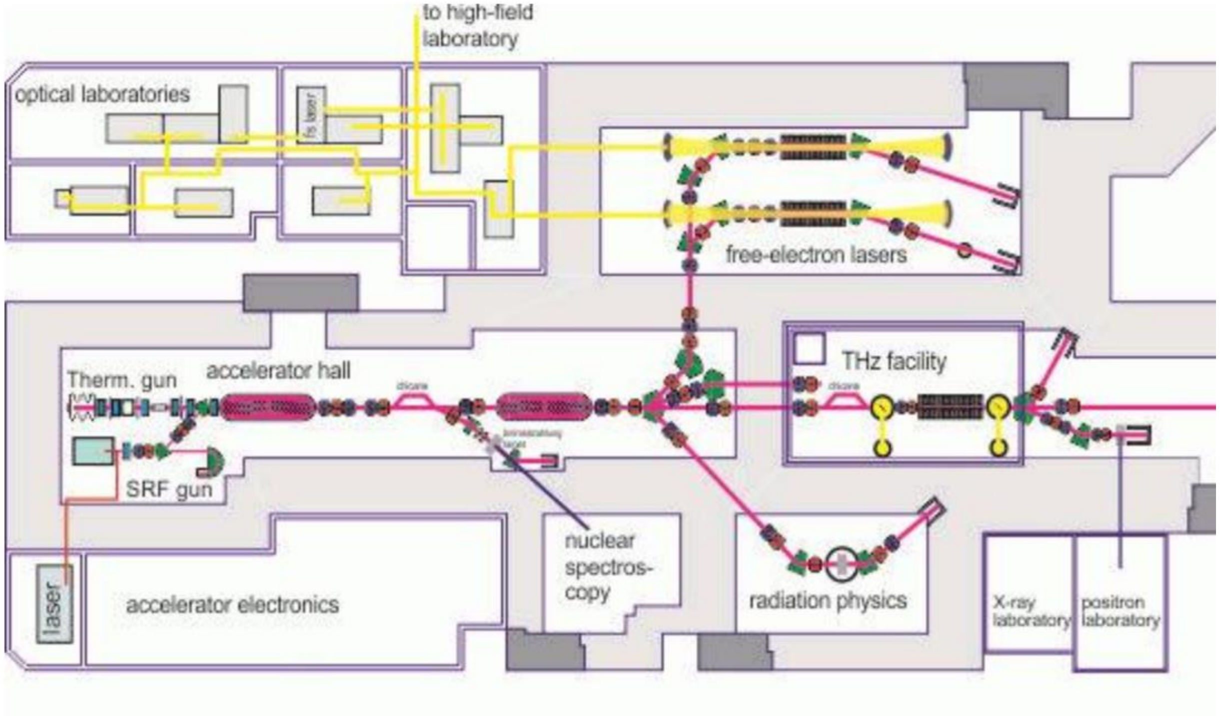




It is likely not possible to cover the whole IR range with a single FEL configuration.

Elbe facility

ELBE Layout



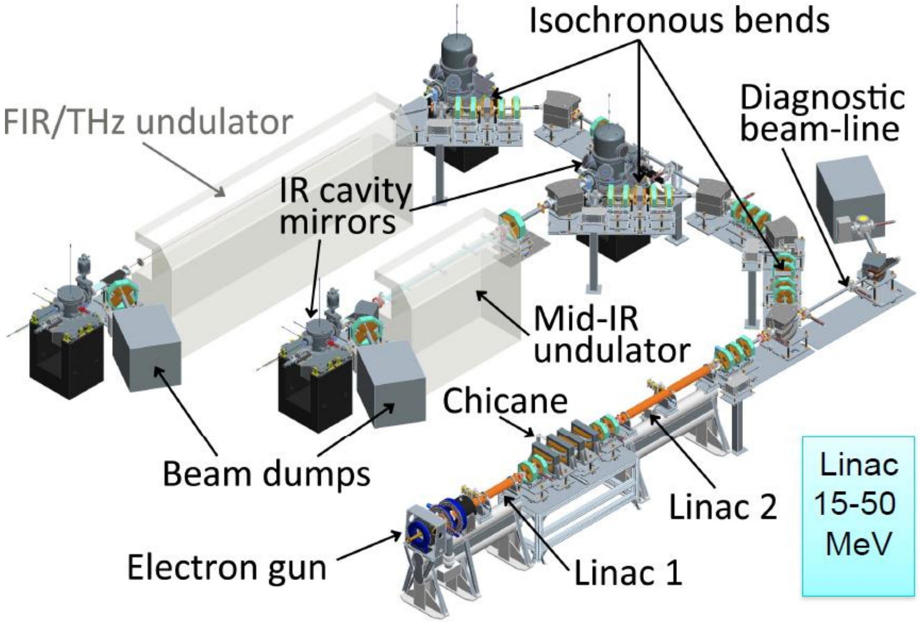
Electron beam

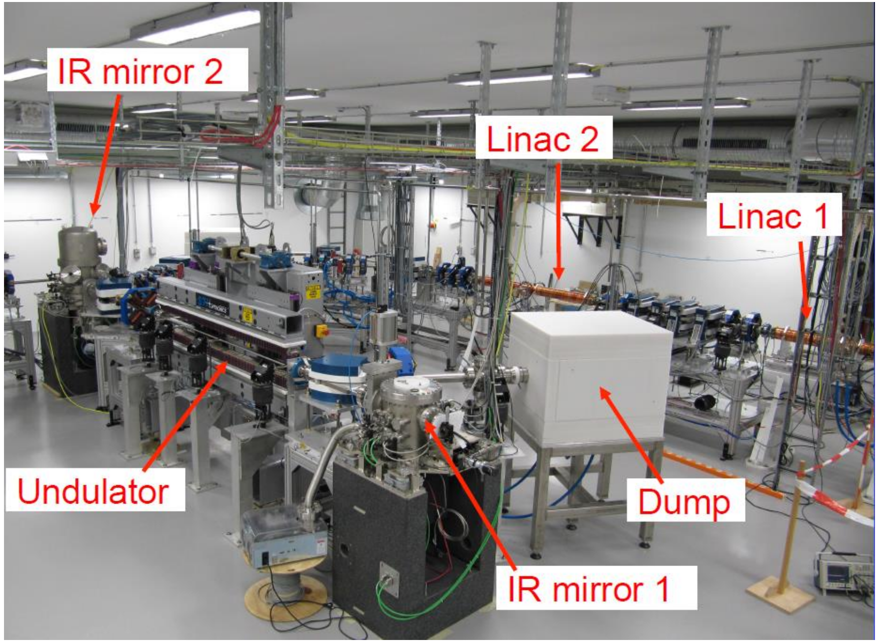
Kinetic energy [MeV]	12 - 34
Bunch charge [pC]	77
Bunch repetition rate [MHz]	13
Average beam current [mA]	1
Long. beam emittance [keV*ps]	50
Transverse beam emittance [mm*mrad]	13

Radiation

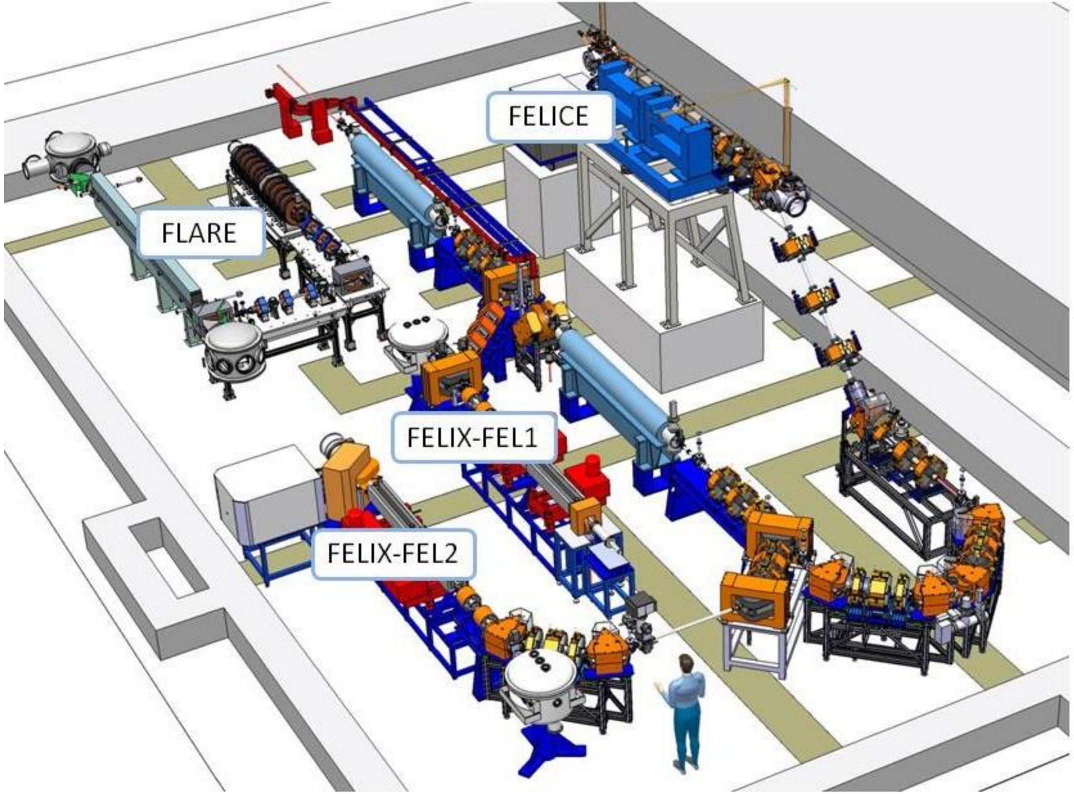
Undulator	U27	U100	
Wavelength [µm]	4 - 22	18 - 250	details
Average output power [W]	0.1 - 40	0.1 - 40	details
Pulse energy [µJ]	0.01 - 3	0.01 -3	

Fritz Habert Institute Berlin



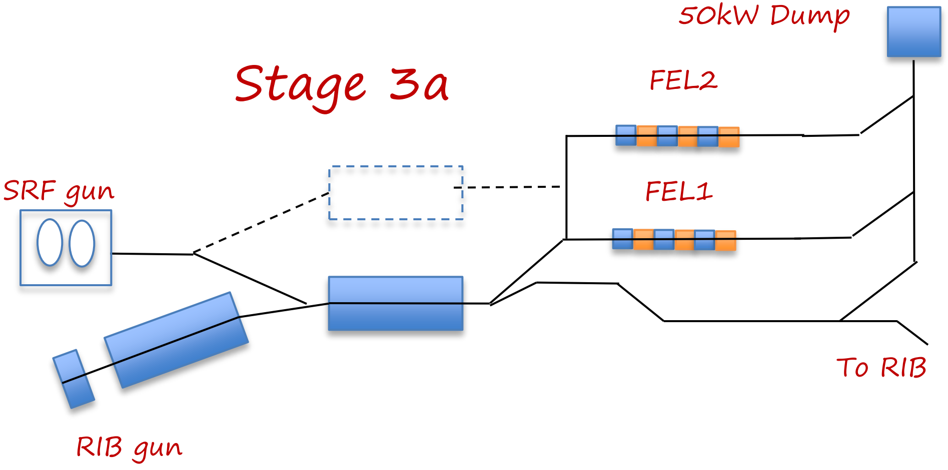


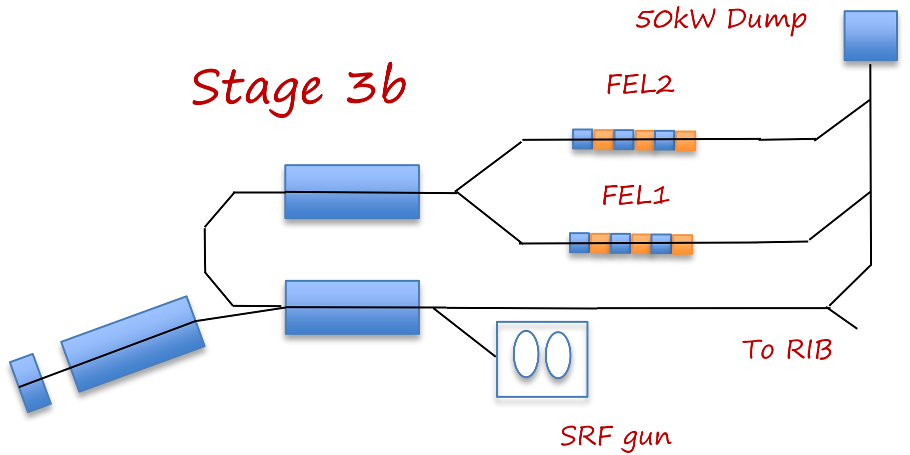
FELIX Facility



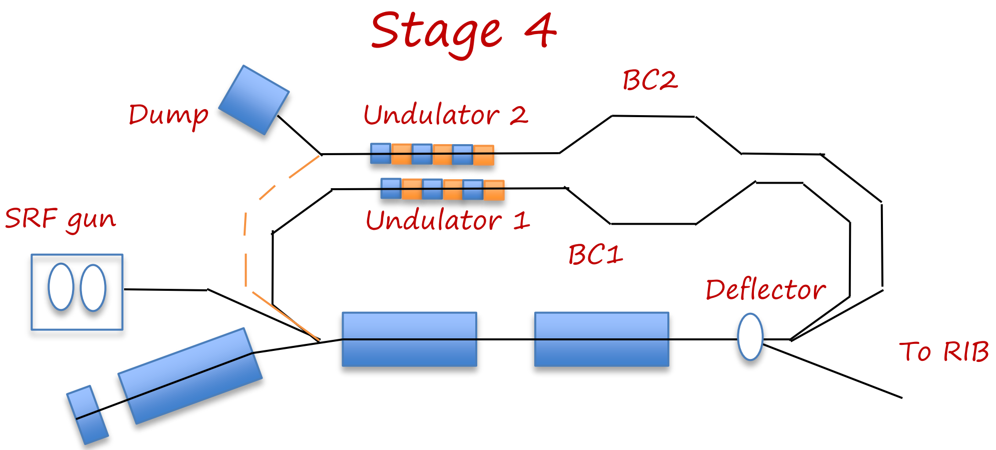
	FELIX	FLARE	FELICE
spectral range	2.7 – 150 μm 3600 – 66 cm-1 120 – 2 THz 450 – 8 meV	100 – 1500 μm 100 – 6 cm^{-1} 3 – 0.25 THz 12 – 0.75 meV	5 – 100 μm 2000 – 100 cm-1 60 – 3 THz 250 – 12 meV
micropulse energy	1 – 20 μJ	5 μJ	1 mJ
macropulse energy	100 mJ @ 1 GHz	100 mJ @ 3 GHz	5 J @ 1 GHz
peak power	100 MW	10 MW	5 GW
polarisation	linear	linear	linear
spectral bandwidth (FWHM) *	0.2 – 5%	≈ 1%	0.4 – 3%
corresponding pulse length*	250 fs - 6 ps @ 10 μm	70 ps @ 500 μm	400 fs - 3 ps @ 10 μm

Stage 3 and beyond





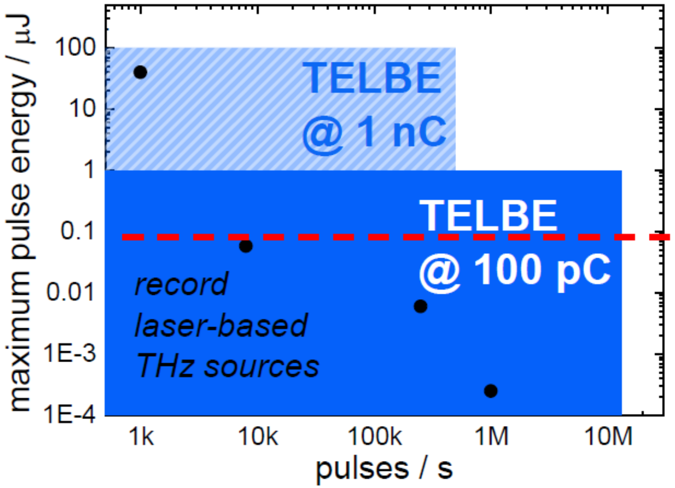
Stage 3 includes several FEL and coherent sources. Covers wide range of wavelengths and fully developed user area. Simultaneous Operation RIB and FEL highly desirable.



Stage 4 targets ERL/RLA operation and requires much more thoughts. Reward is a very high power and efficiency.

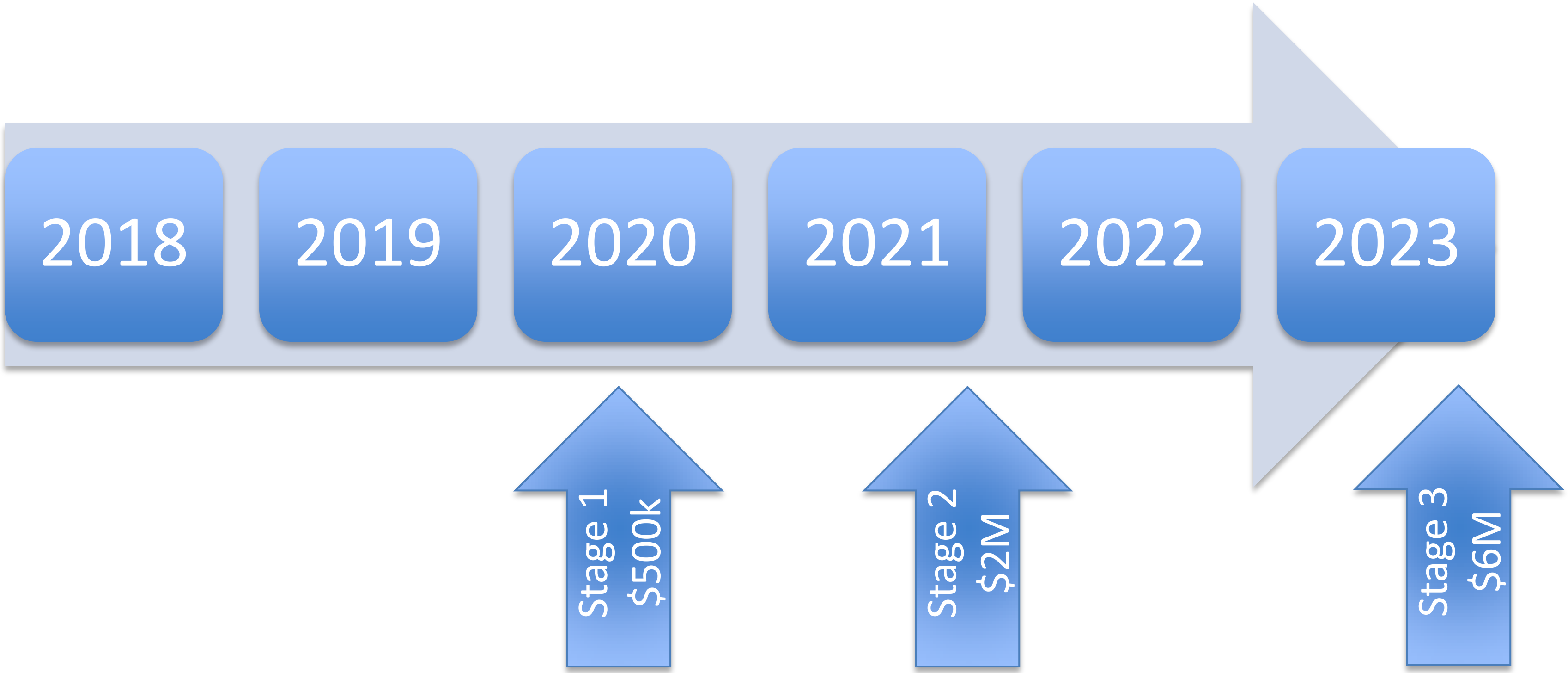
Projected performance

Bunch Charge	Radiation pulse energy
100pC	few μJ
200pC	few 10s of μJ
1nC	few 100s of μJ or few mJ intra-cavity



200pC @ ~30MHz , pulsed, should be a lowest bar to clear

Timeline and budget



User end stations excluded

TRIUMF

Canada’s national laboratory
for particle and nuclear physics
and accelerator-based science

Thank you!
Merci!

TRIUMF: Alberta | British Columbia | Calgary | Carleton | Guelph | Manitoba | McGill | McMaster | Montréal | Northern British Columbia | Queen’s | Regina | Saint Mary’s | Simon Fraser | Toronto | Victoria | Western | Winnipeg | York

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