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Status of the PSI X-Ray Free Electron Laser "SwissFEL"

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for the PSI SwissFEL Team

32nd International Free Electron Laser Conference,
Malmö, August 23rd, 2010.

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SwissFEL, the next Large Research Facility at PSI

SwissFEL key parameters

Wavelength range	1 Å - 70 Å
Pulse duration	1 fs - 20 fs
e^- Energy	5.8 GeV
e^- Bunch charge	10-200 pC
Repetition rate	100 Hz

Site constraints

Power consumption < 5 MW

Overall length < 900m

We would like to build 1st phase of SwissFEL 2012-2015

SwissFEL Rational

The research capabilities of an X-ray FEL would be an ideal complement to PSI's existing synchrotron light source and spallation neutron source research facilities.

SwissFEL is to be built as a national facility in a "small" country.

Total cost must fit within a reasonable financial boundary.

$$\lambda = \frac{\lambda_U}{2\gamma^2}\left(1+\frac{K^2}{2}\right)$$

$$\varepsilon_N \approx \gamma \frac{\lambda}{4\pi}$$

$$\varepsilon_N \approx 1\,\mu\mathrm{m}\sqrt{q_B[\mathrm{nC}]}$$

$$Cost \propto \gamma$$

- Lowest beam energy technically possible
- Small period undulators with low K values
- Low q_B charge
- Normal conducting linac technology

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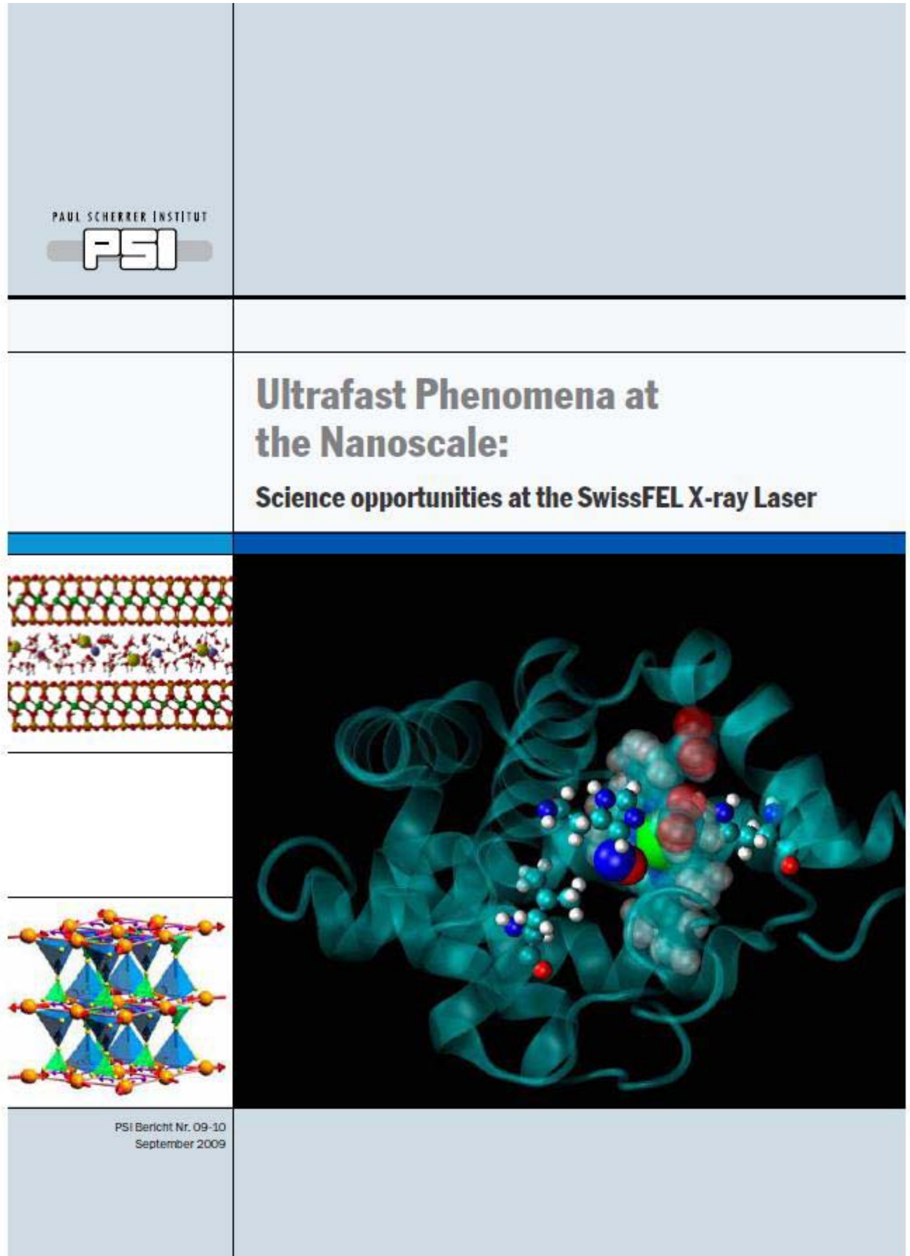
SwissFEL Science Case

PDF of science report at
http://fel.web.psi.ch/

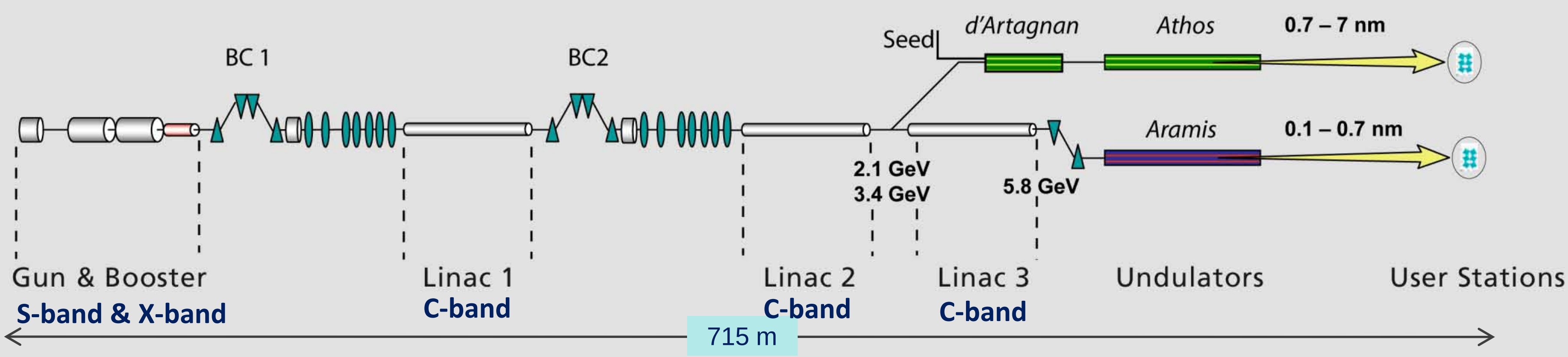


SwissFEL Baseline

To keep the tight schedule for SwissFEL the baseline design has to use state of the art technical solutions for all key components. These solution consist of:

- An injector based on a 3 GHz RF gun with laser driven Cu-photocathode and 3 GHz booster.
- Normal conducting 5.8 GeV linear accelerator with 5.7 GHz frequency, 26 MV/m accelerating gradient, SLED pulse compression and solid state klystron modulator technology.
- Two magnetic bunch compressors with 12 GHz harmonic cavity on BC1 to reach fs scale bunch length.
- Undulator design for ARAMIS hard x-ray FEL (1-7 Å) uses planar, in-vacuum, room temperature, permanent magnet arrays with variable gap, 15 mm period length and nominal *K* value of 1.2 .
- Undulator design for ATHOS soft x-ray FEL (7-70 Å) uses permanent magnet APPLE II undulators with 40 mm period, allowing full control of photon beam polarization.
- A high field / short pulse THz pump source in the experimental area driven by a small dedicated electron accelerator.

SwissFEL layout

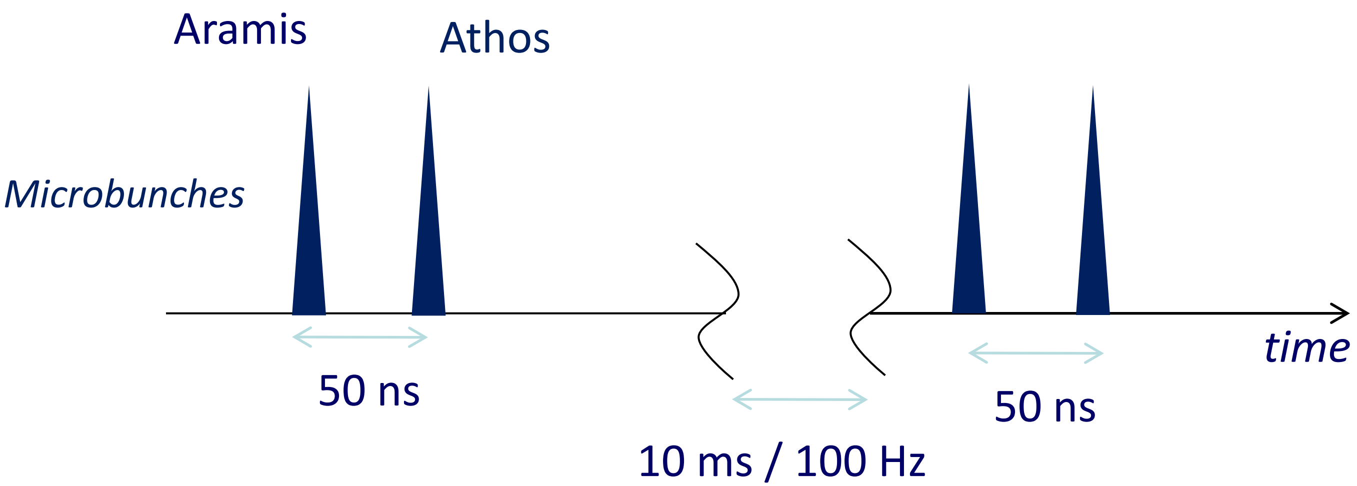


Aramis: 1-7 Å hard X-ray SASE FEL,
In-vacuum , planar undulators with variable gap.

Athos: 7-70 Å soft X-ray FEL for SASE & Seeded operation .
APPLE II undulators with variable gap and full polarization control.

D'Artagnan: FEL for wavelengths above Athos, seeded with an HHG source. Besides covering the longer wavelength range, the FEL is used as the initial stage of a High Gain Harmonic Generation (HGHG) with **Athos** as the final radiator.

Time structure



- Fast extraction at 3.4 GeV allows to serve 2 undulator lines simultaneously at full repetition rate

SwissFEL e^- beam parameters

Design Parameters	nominal operation modes	
	long pulse	short pulse
single bunch charge (pC)	200	10
beam energy for 1 Å (GeV)	5.8	5.8
core slice emittance (mm.mrad)	0.43	0.18
projected emittance (mm.mrad)	0.65	0.25
rms slice energy spread (keV)	350	250
Relative energy spread (%)	0.006	0.004
peak current at undulator (kA)	2.7	0.7
bunch length rms (fs)	30	6
bunch compression factor	125	240
repetition rate (Hz)	100	100
number of bunches / pulse	2	2
bunch spacing (ns)	50	50

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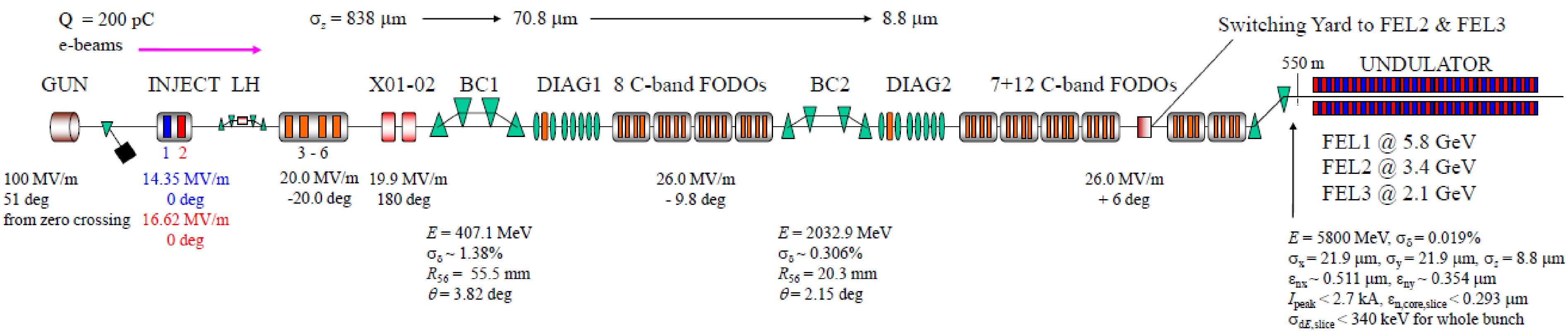
SwissFEL photon beam parameters

FEL parameters ARAMIS (for 5.8GeV operation)	nominal operation mode	
	long pulse	short pulse
undulator Period (mm)	15	15
undulator Parameter	1.2	1.2
energy Spread (keV)	350	250
laser Wavelength (Å)	1	1
maximum saturation length (m)	50	50
saturation Pulse Energy (µJ)	60	3
effective Saturation Power (GW)	2	0.6
rms photon pulse length at 1 Å (fs)	13	2.1
number of photon at 1 Å (×109)	31	1.7
bandwidth (%)	0.03	0.04
peak brightness (# photons·mm^{-2}·mrad^{-2}·s^{-1}/0.1% bandwidth)	$3\cdot10^{32}$	$1\cdot10^{32}$
average brightness (# photons·mm^{-2}·mrad^{-2}·s^{-1}/0.1% bandwidth)	$1\cdot10^{21}$	$5.7\cdot10^{18}$

Start2End simulation with ASTRA & ELEGANT



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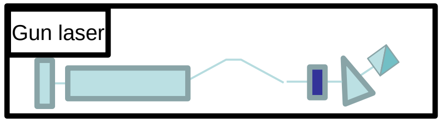
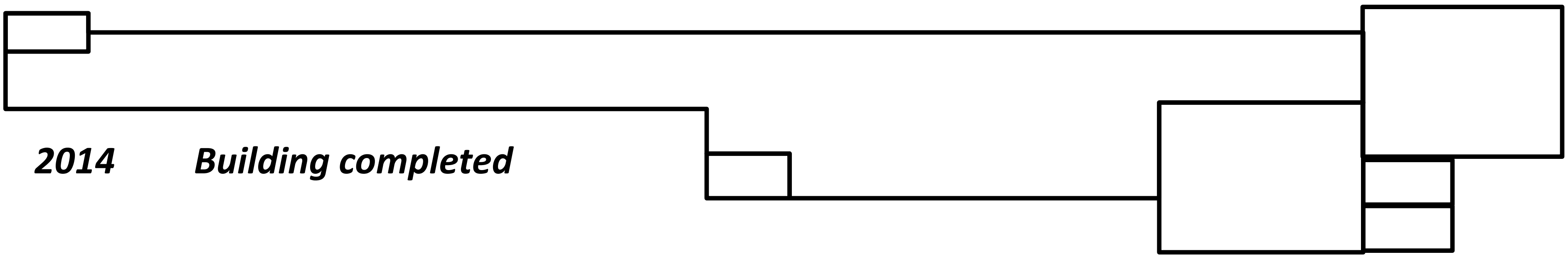
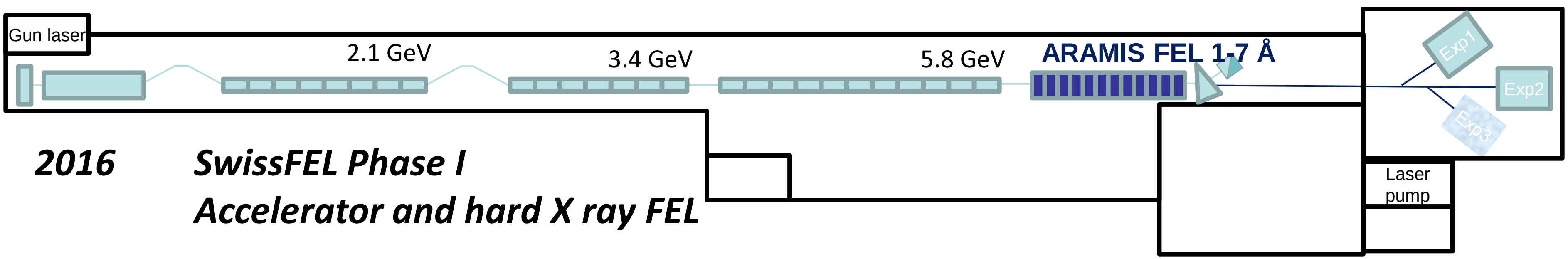
SwissFEL Milestones



2010 250 MeV Injector facility

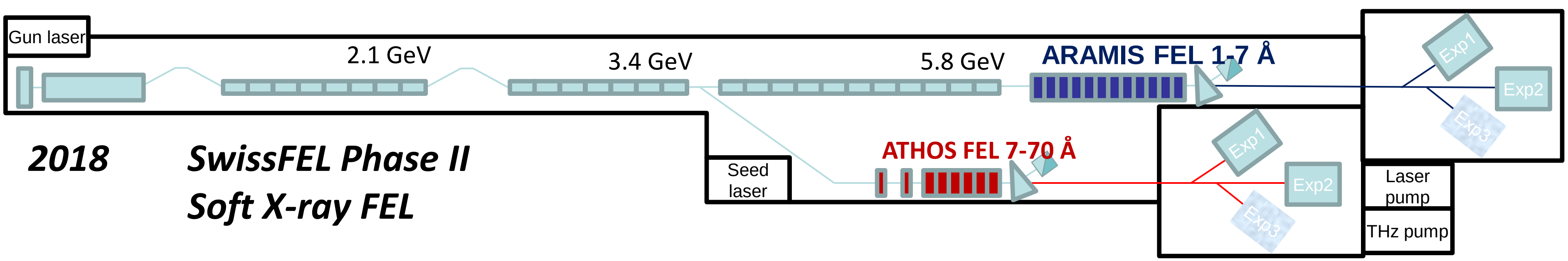


2014 Building completed



2016 SwissFEL Phase I

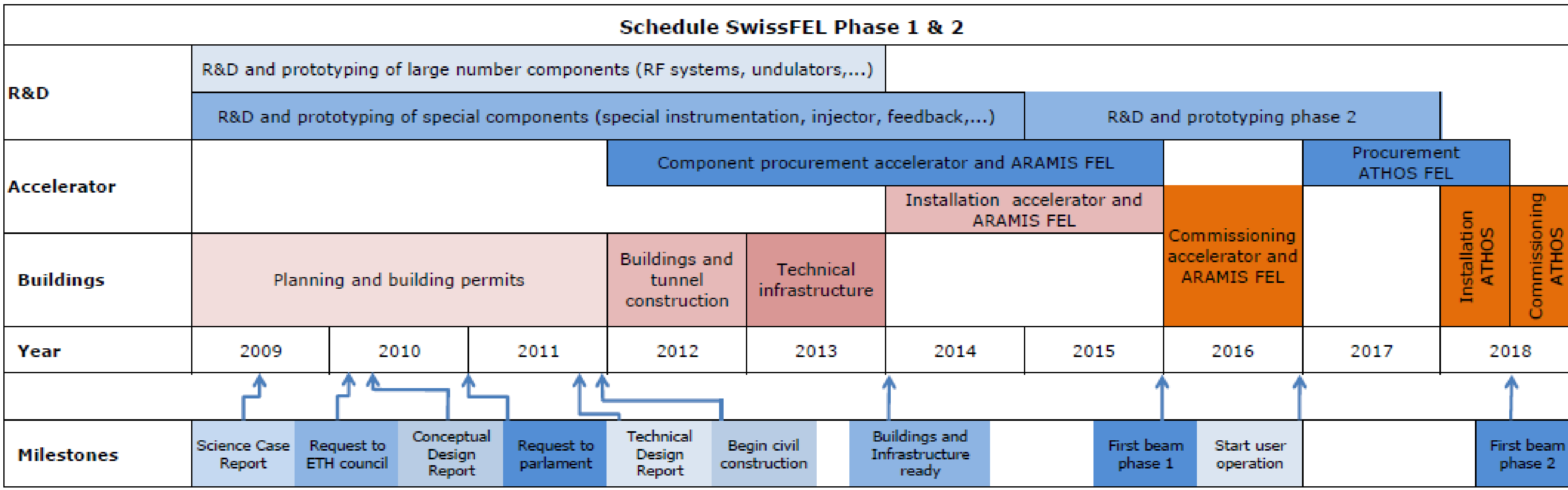
Accelerator and hard X ray FEL



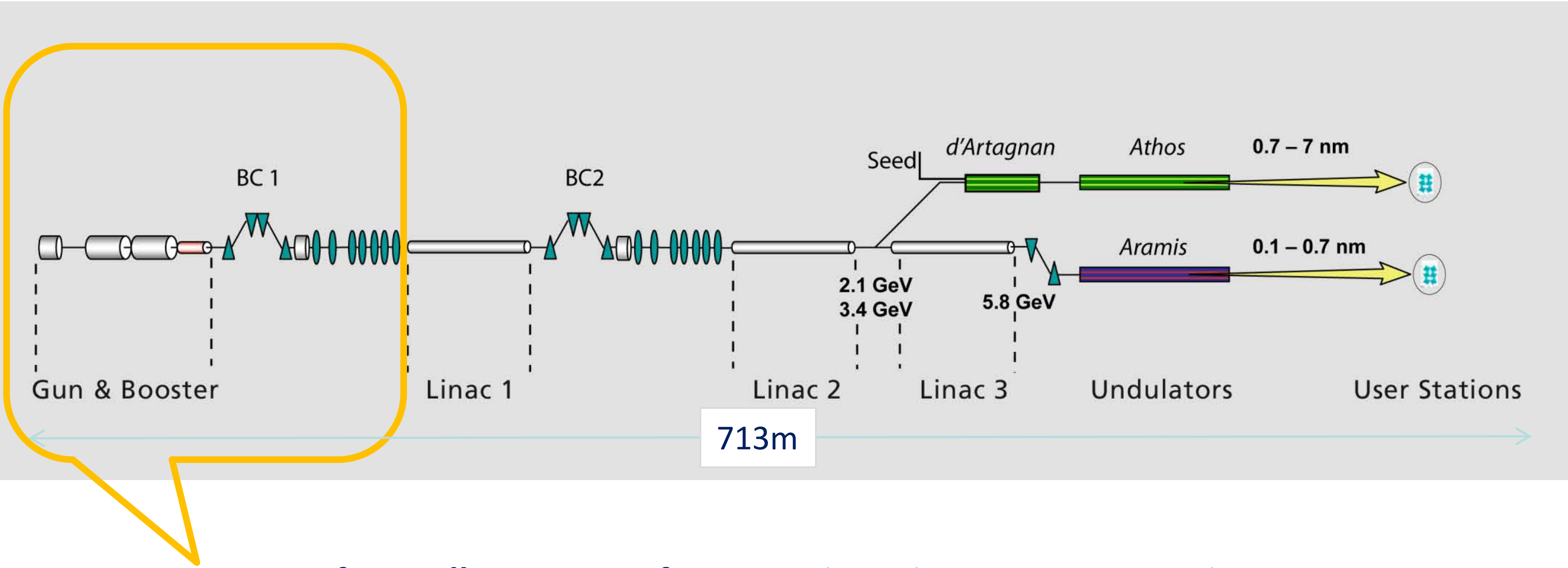
2018 SwissFEL Phase II

Soft X-ray FEL

SwissFEL Schedule

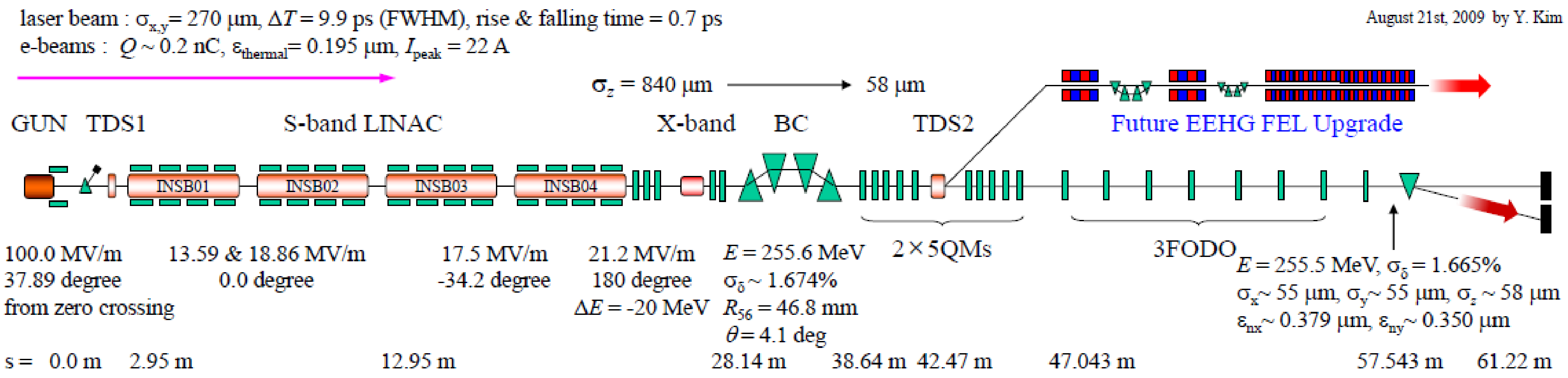


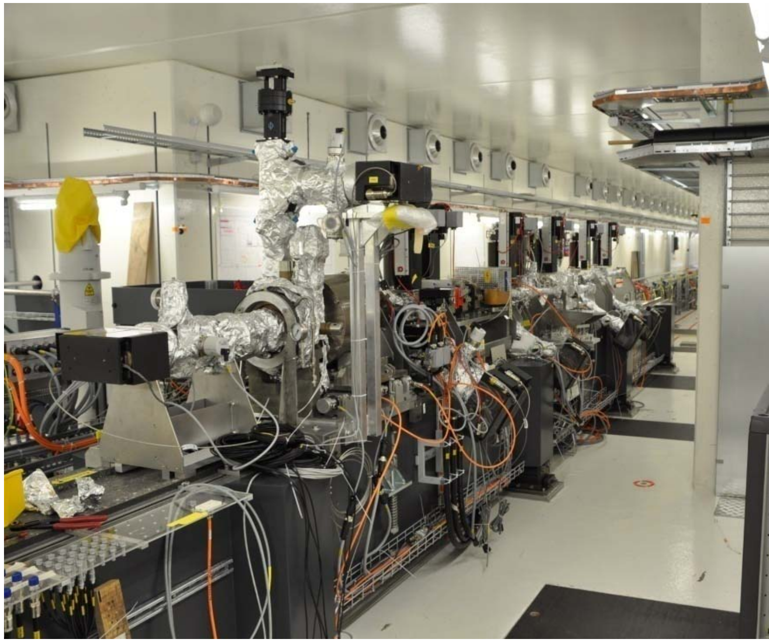
SwissFEL preparatory R&D, I



Test of overall system performance in SwissFEL 250 MeV Injector

SwissFEL 250 MeV Injector Test Facility

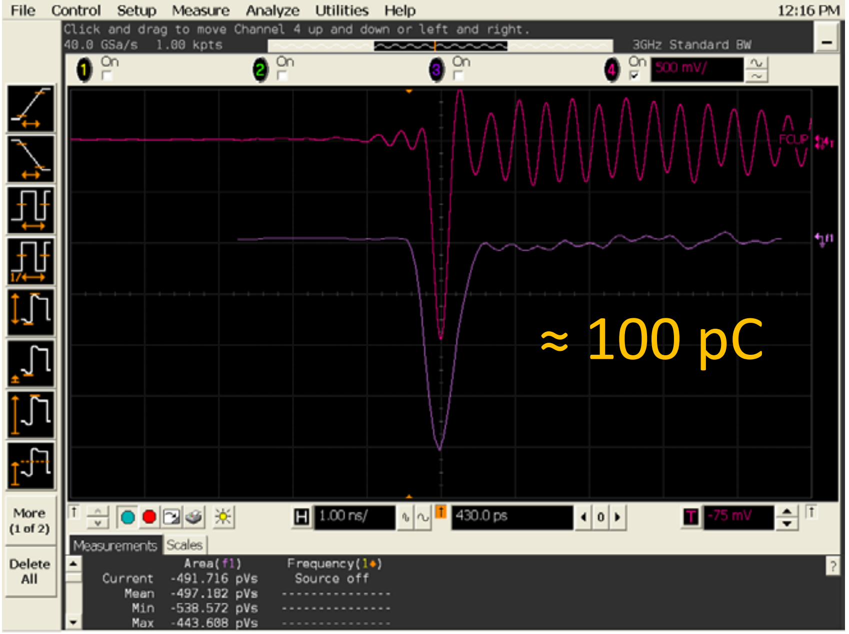




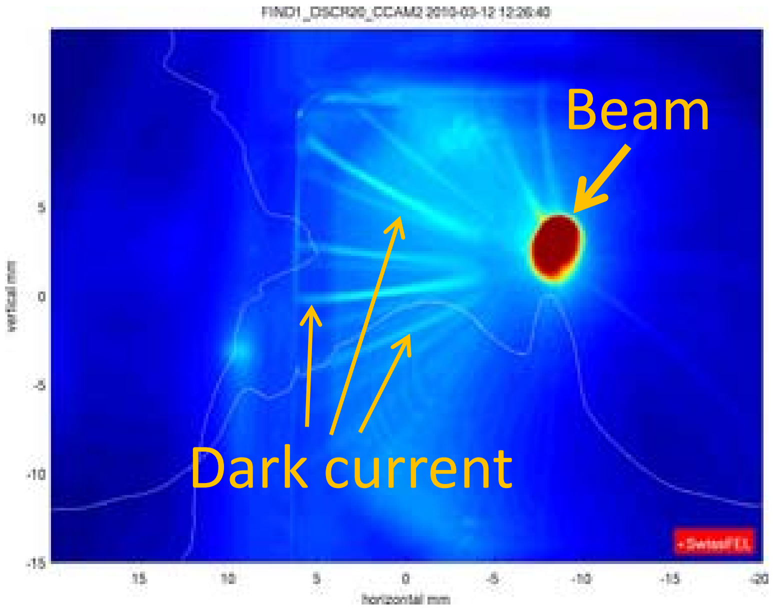
First Beam from RF Gun SwissFEL Injector

March 12, 2010, ~12h10

Faraday cup signal



YAG screen image



Commissioning phases

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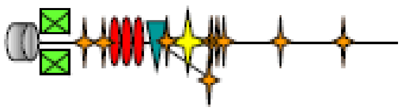
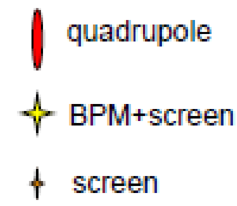
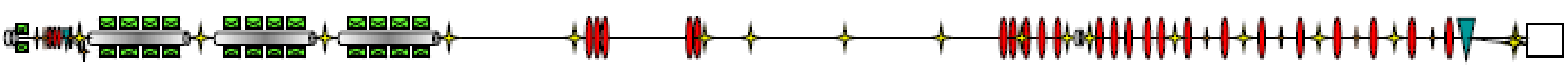
- **Phase 1: Electron source and diagnostics**





  - March 2010 to May 2010
  - Characterization of the electron source
  - Installation of remaining machine behind shielding wall

- **Phase 2: Phase 1 + (some) S-band acceleration**

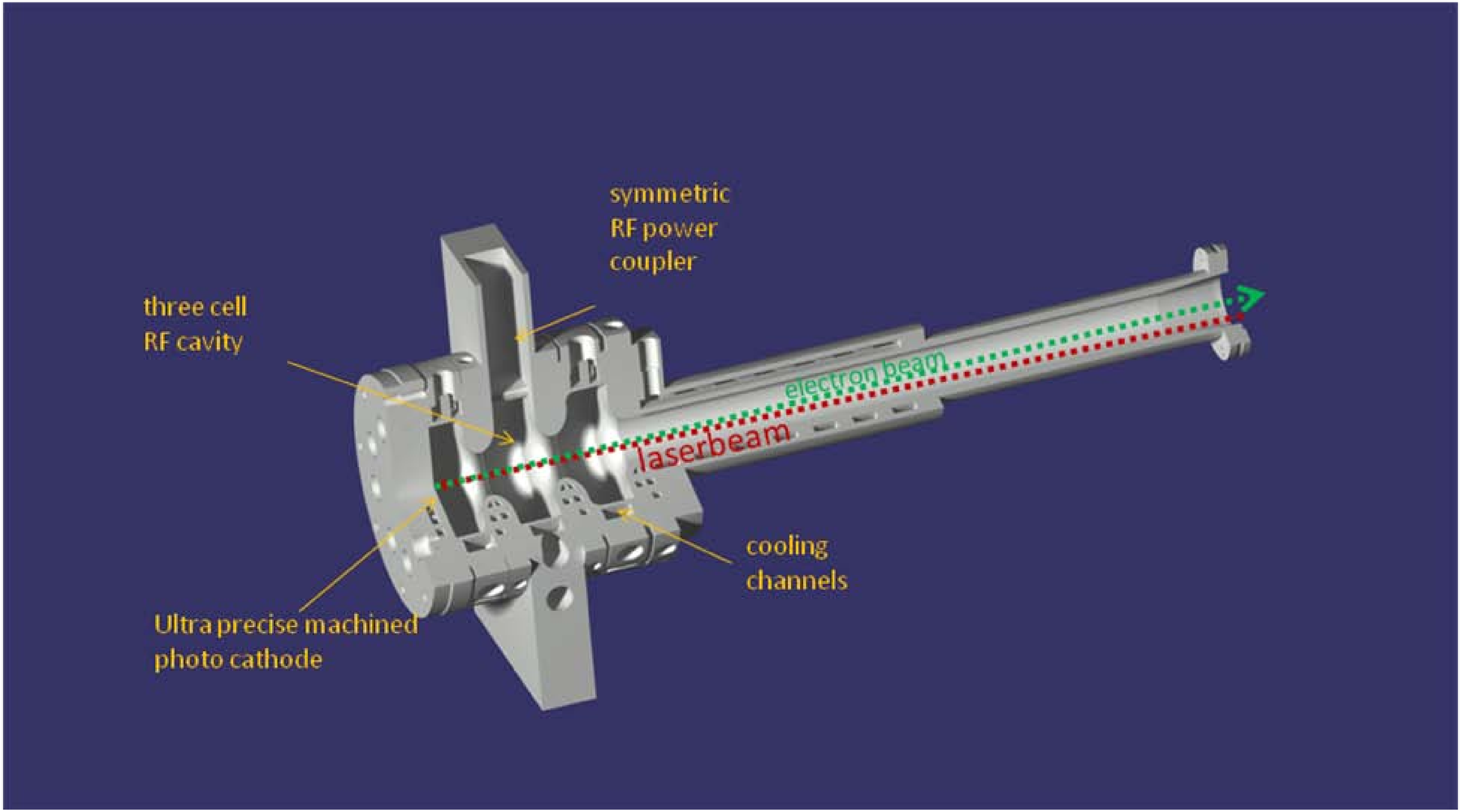


  - August 2010 to December 2010 (official injector inauguration 24 August)
  - Emittance damping in S-band booster (invariant envelope)
  - Jaguar (Nd:YLF) laser

- **Phase 3: The full machine**

  - End of 2010 / early 2011 (installation bunch compressor and X-band cavity)
  - Pulsar (Ti:Sapph) laser

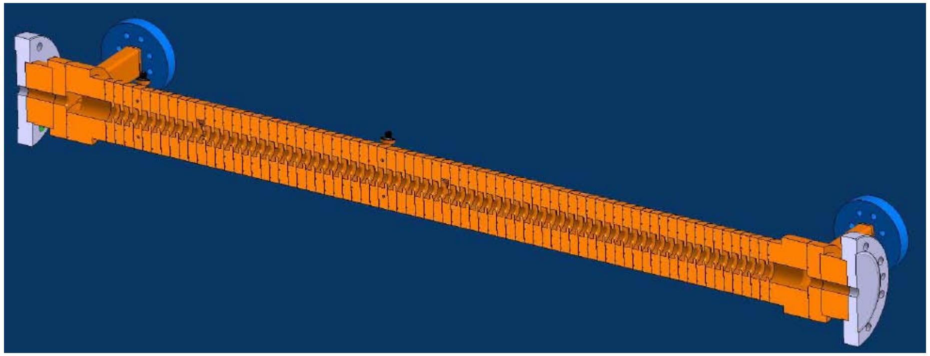
New SwissFEL gun for test in 250 MeV injector 2012



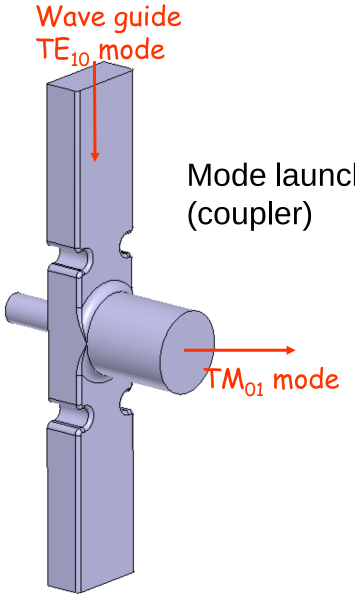
X-band harmonic cavity

Collaboration between PSI - CERN - FERMI @ ELETTRA
Klystron from SLAC

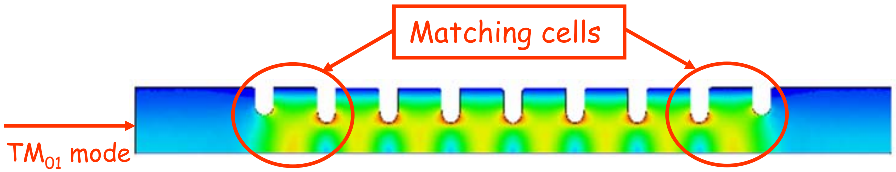
Frequency (MHz)	11991.65
Number of cells	72
Cell phase advance	$5/6\pi$
Iris aperture range (mm)	4.993 - 4.107
Active length (m)	0.75
Nominal decelerating voltage (MV)	29



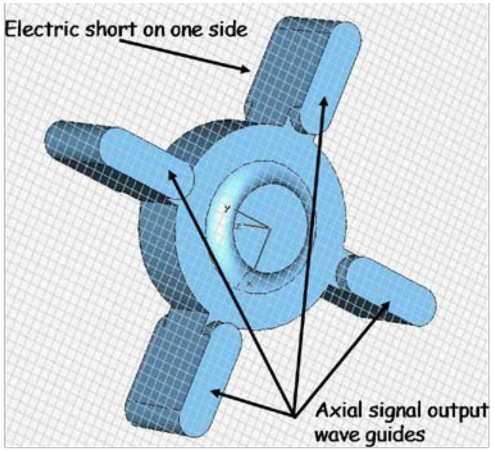
PSI: Cell procurements
CERN: Assembly brazing
ELETTRA: Wake analysis & support
All: tuning & RF LLE analysis



Mode launcher (coupler)

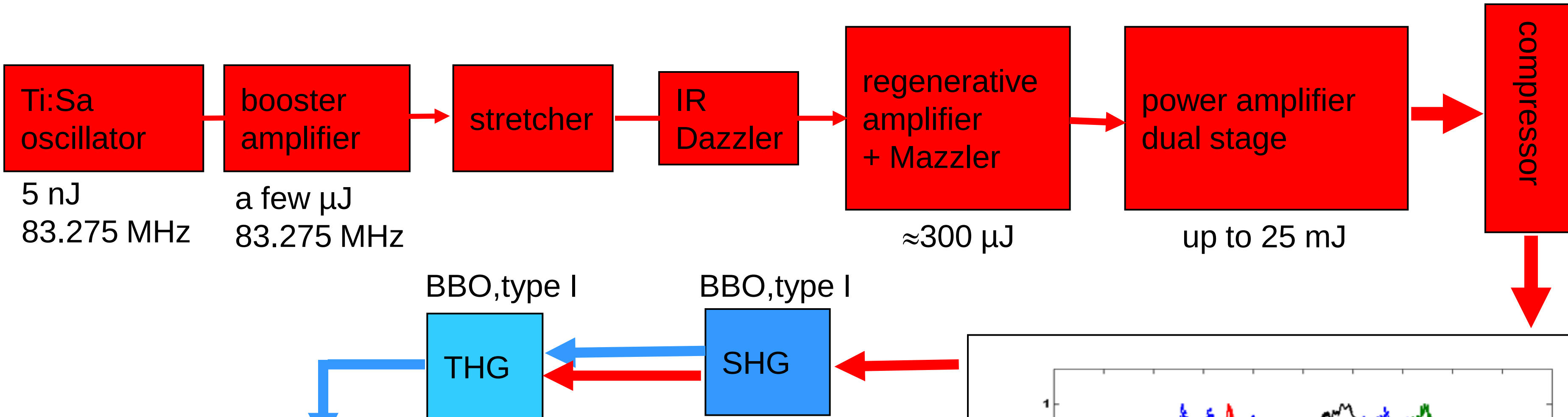


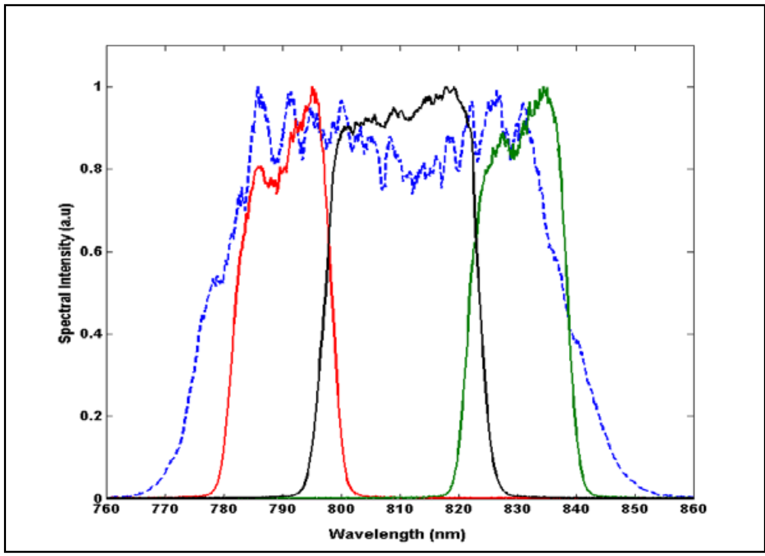
HFFS simulated fields



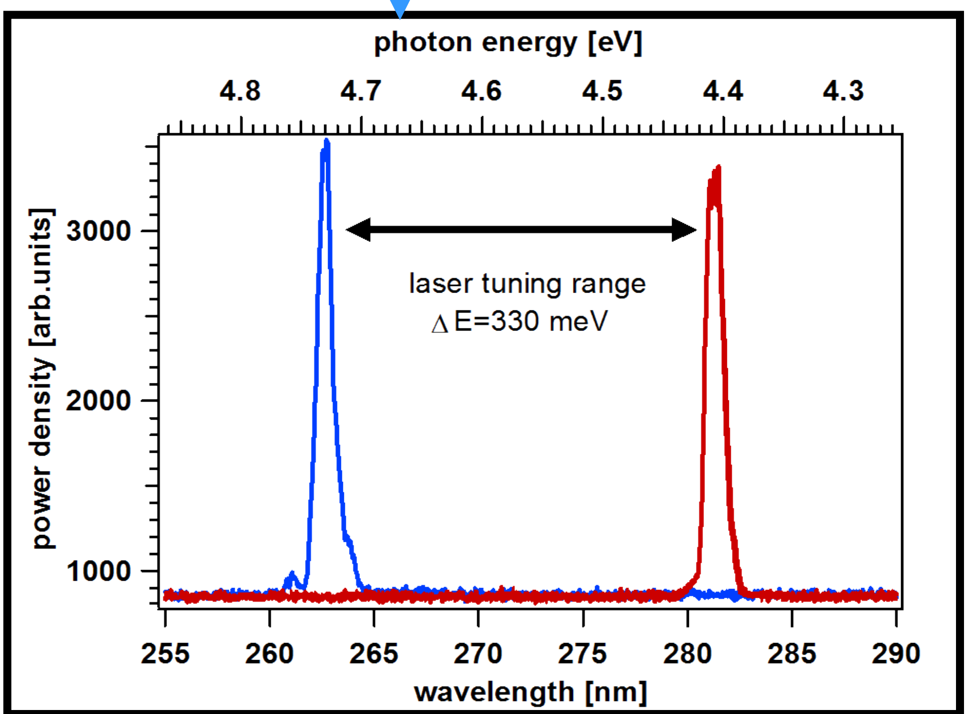
Cell 36 and 63 equipped with WG couplers for dipole mode monitoring

Wavelength tunable gun laser system (see WEPB14)



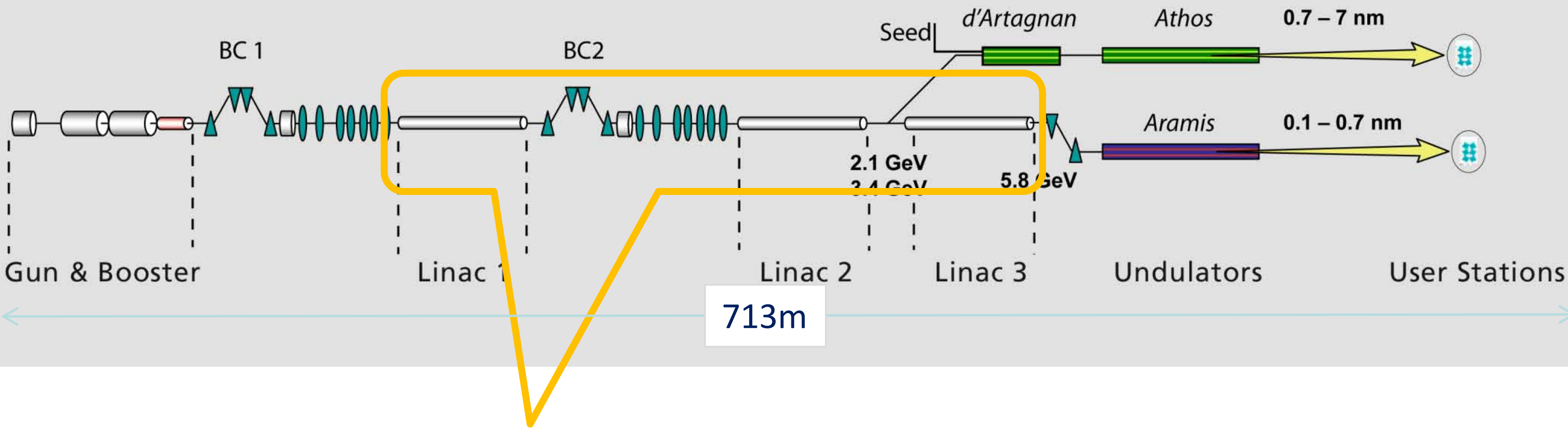


770 – 840 nm, up to 17 mJ
20-100 fs, ≥0.37% rms



262 – 283 nm, up to 900 µJ
100 fs, ≥ 0.7% rms

SwissFEL preparatory R&D, II



Linear accelerator

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Linear space requirements

Active length S-band acceleration	24 m	
Active length C-band acceleration	208 m	(1/4 of building length)
ARAMIS string of undulators	60 m	
Other beam line elements	273 m	
Photon beam transport	100 m	
Experiment halls	50 m	
Total facility length	**715 m**	

⇒ ***No strong motivation for very high gradients***

⇒ ***C-band instead of S-band is motivated by power consumption and number of RF stations !***

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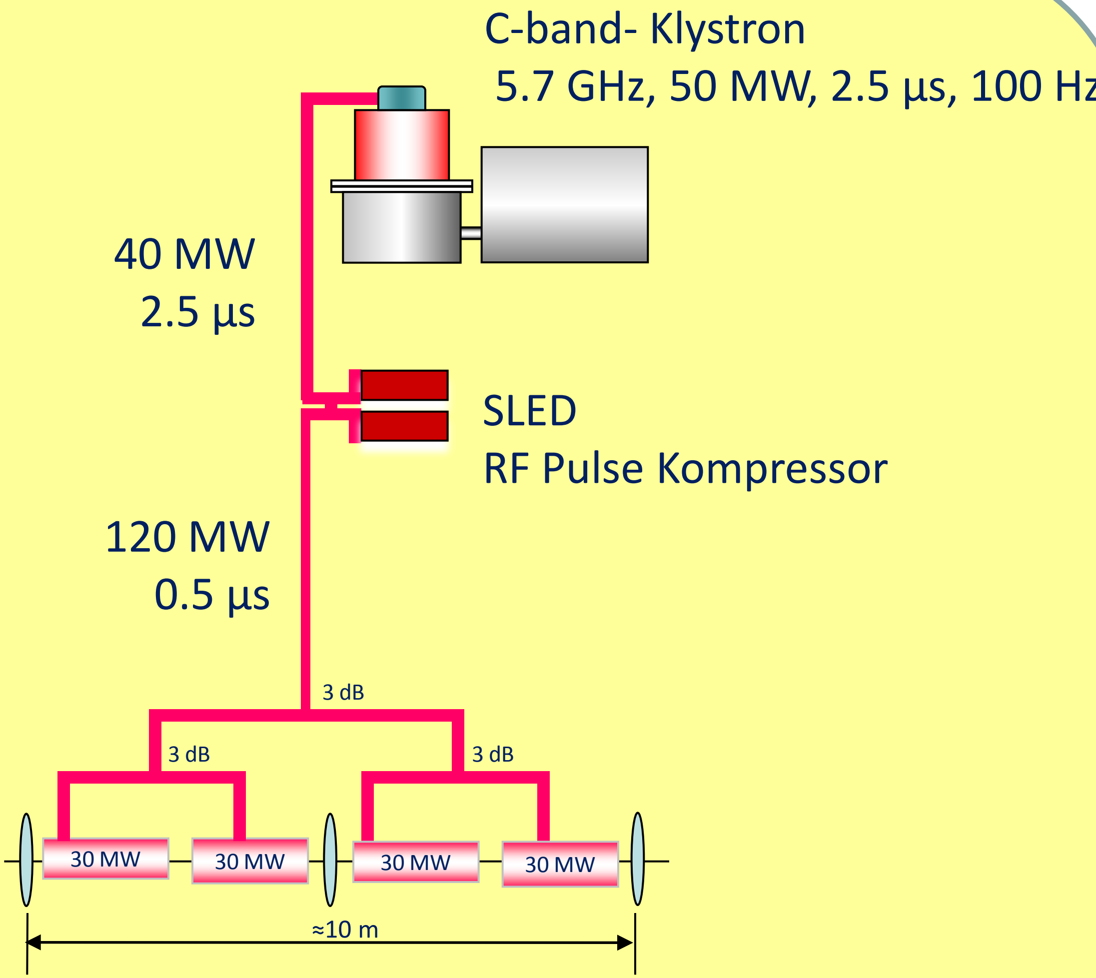
SwissFEL Linac Module

New high power test stand for linac module in prepration. Procurement of C-band klystron in progress

27 x



For RF strucutres, 2 m each (5712 MHZ, 26 MV/m)
Energy gain per module: 208 MeV

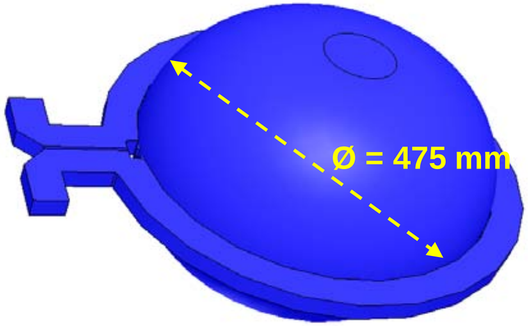
C-band pulse compression with BOC

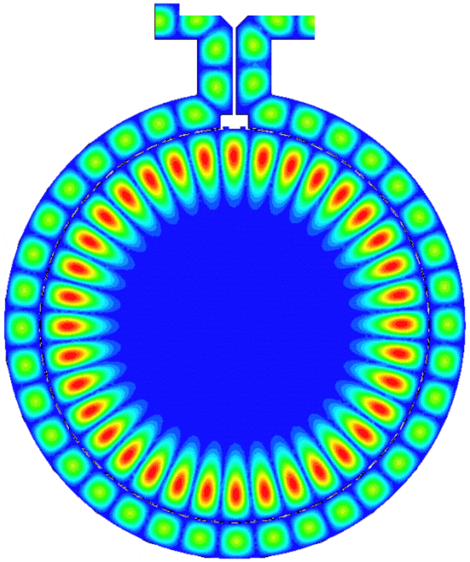
BOC=Barrel Open Cavity

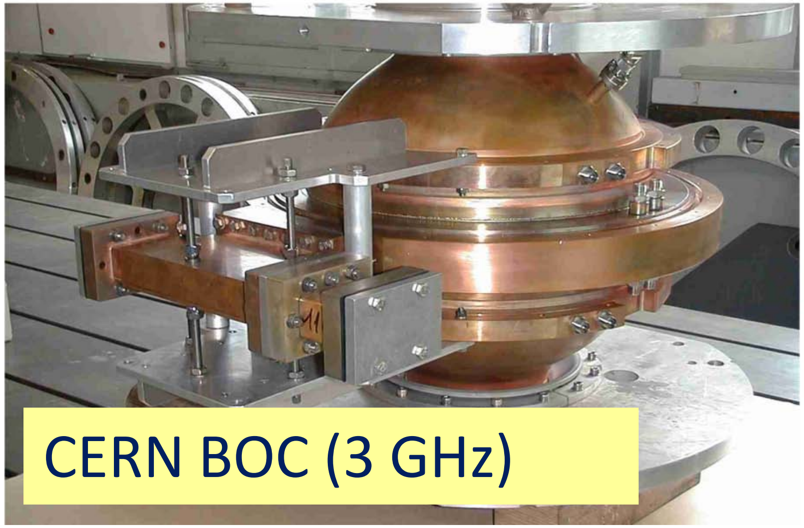
Operating mode: $E_{18,1,1}$

Q: 220000

Coupling: 11







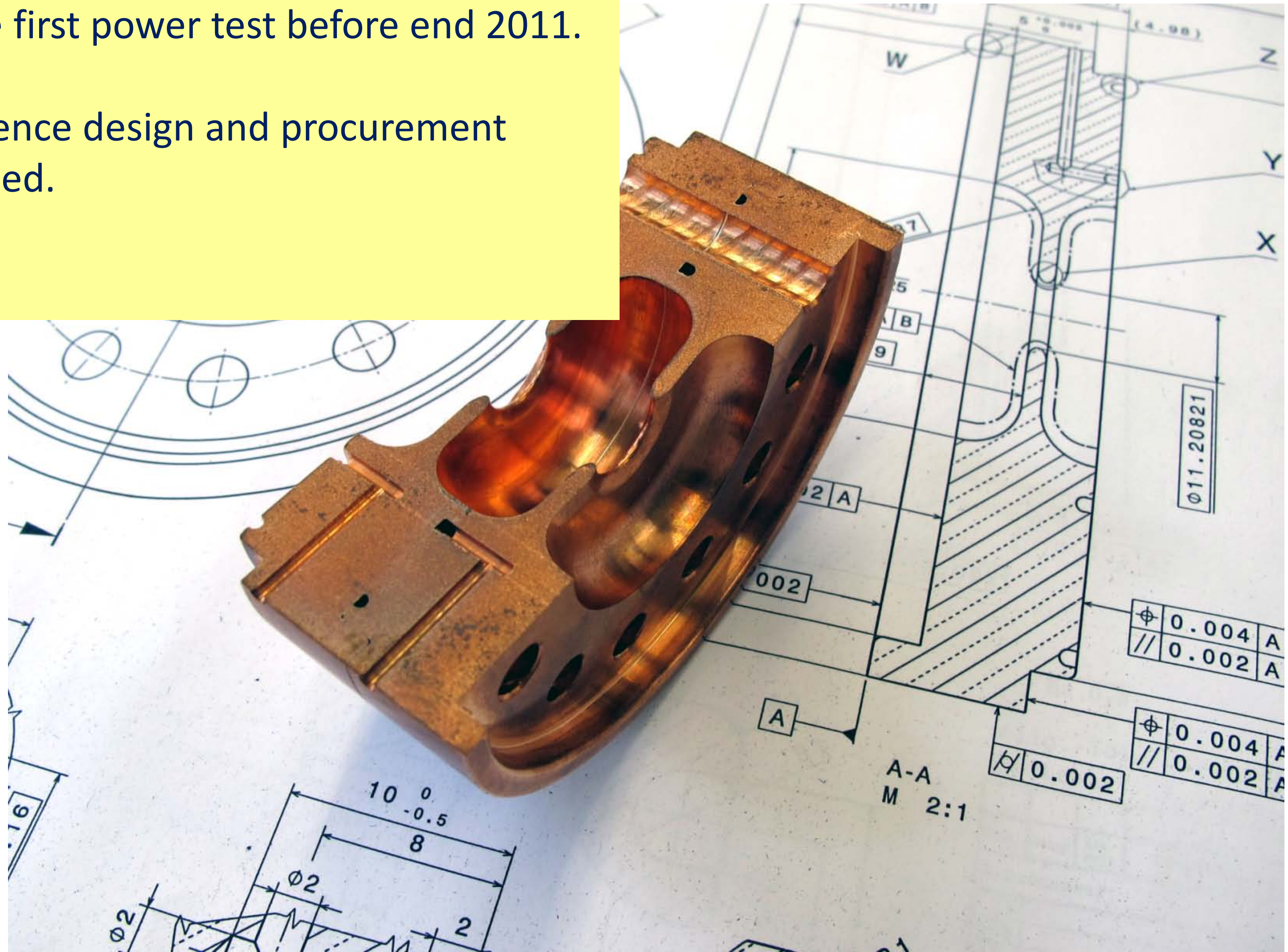
CERN BOC (3 GHz)

Main linac C-band RF structures

Different cell geometries being studied.

PSI will design, will build and test 80 cm prototypes.
Milestone: Complete first power test before end 2011.

Based on this experience design and procurement strategy will be defined.



PAUL SCHERRER INSTITUT PSI

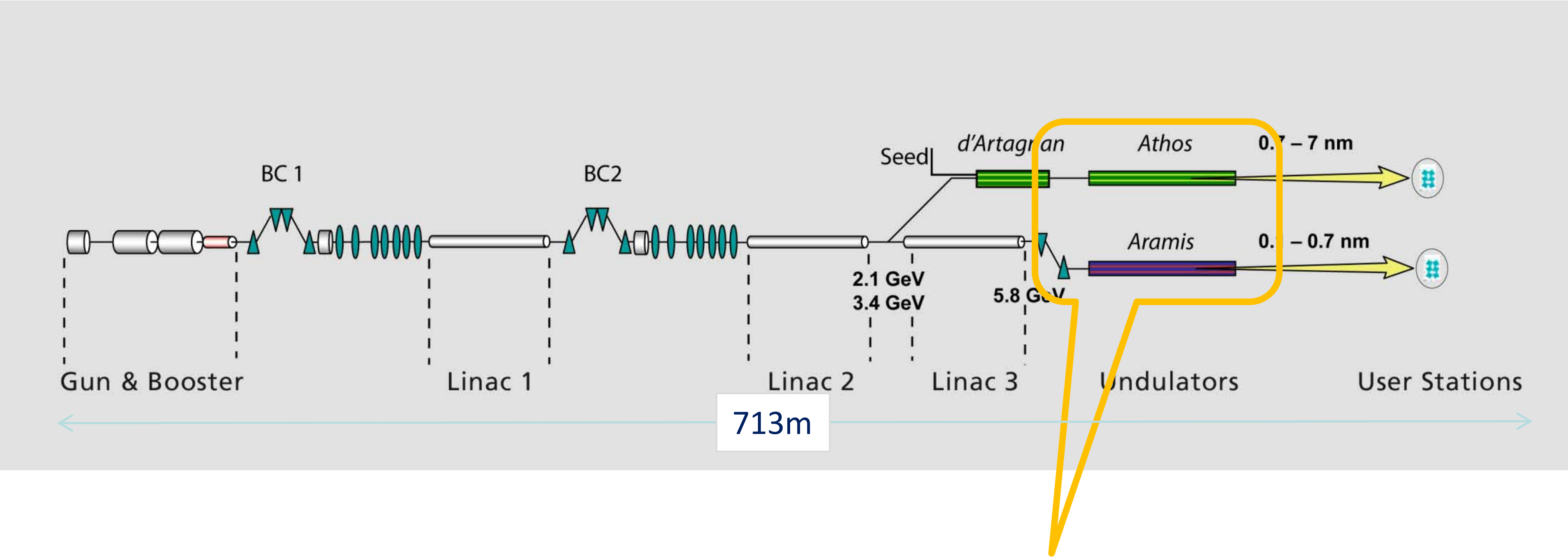
SwissFEL Frequencies in MHz

SwissFEL frequencies

		„European“	„American „	f_b=142.8
Injector	S-Band	2997.912 most parts already delivered	2856	2998.8 (21xf_b)
	X-Band (4 x S-band)	11991.648 most parts on order, could still be changed	11424	11995.2 (84xf_b)
Main linac	C-Band (2 x S-band ?)	5998.524 requires development of klystron with PSI presently the only customer	5712 klystron available almost “off the shelf” Spring8, KEK, LNF are already customers	5712 (40xf_b)

Common sub-harmonic 142.8MHz, minimum bunch spacing 7 ns

SwissFEL preparatoy R&D, III



Undulator

Undulator Strategy

SPring-8

hard x-ray:

small period
small gap
in-vacuum undulators
high harmonics

soft x-ray:

variable polarization
circular and inclined
APPLE II
standard, fixed gap

BESSY

Continuous development from SLS ID's

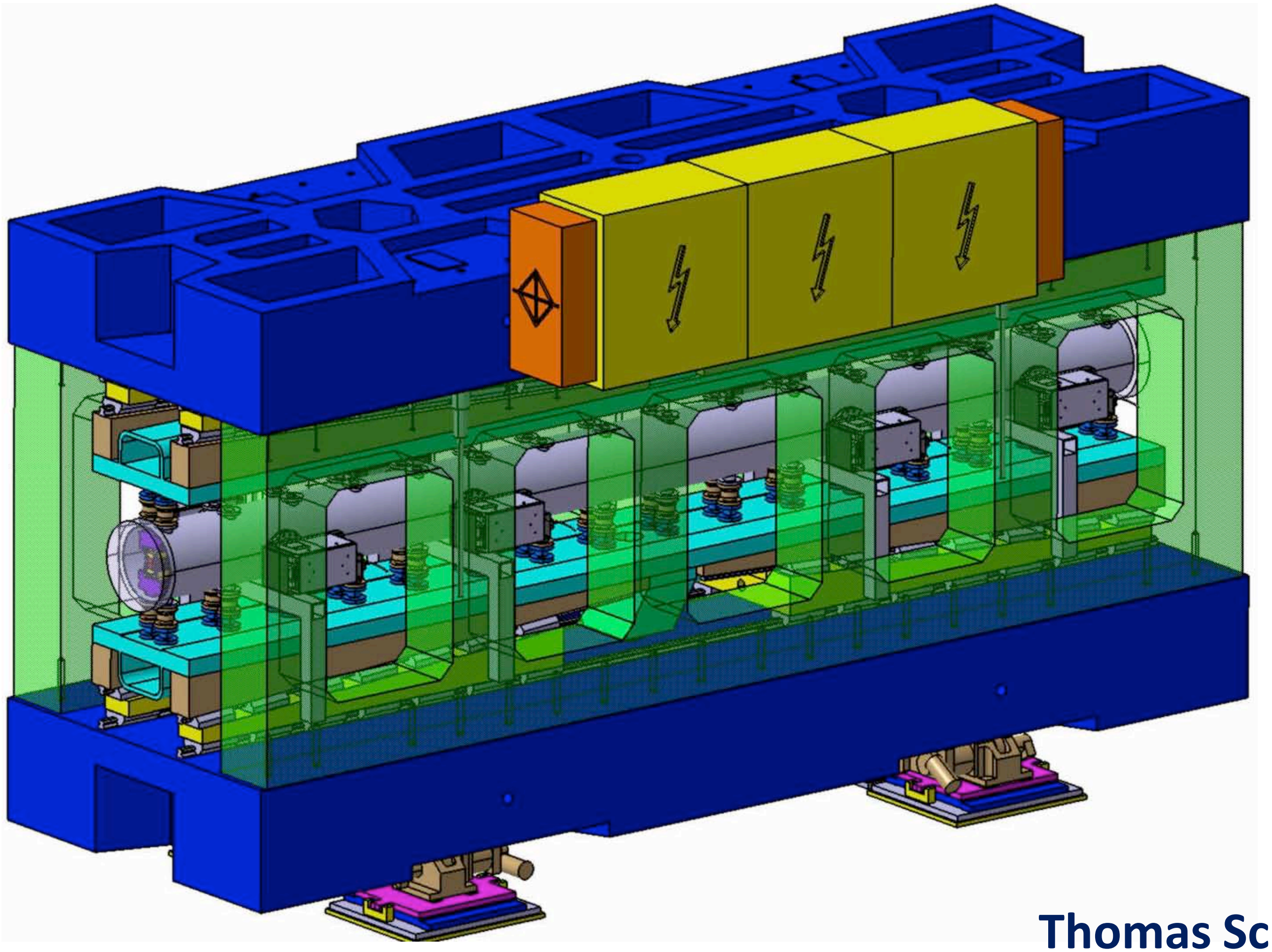
U15, gap > 4mm, length 4m

UE40, gap 6.5mm, length 4m

Undulator Strategy for SwissFEL

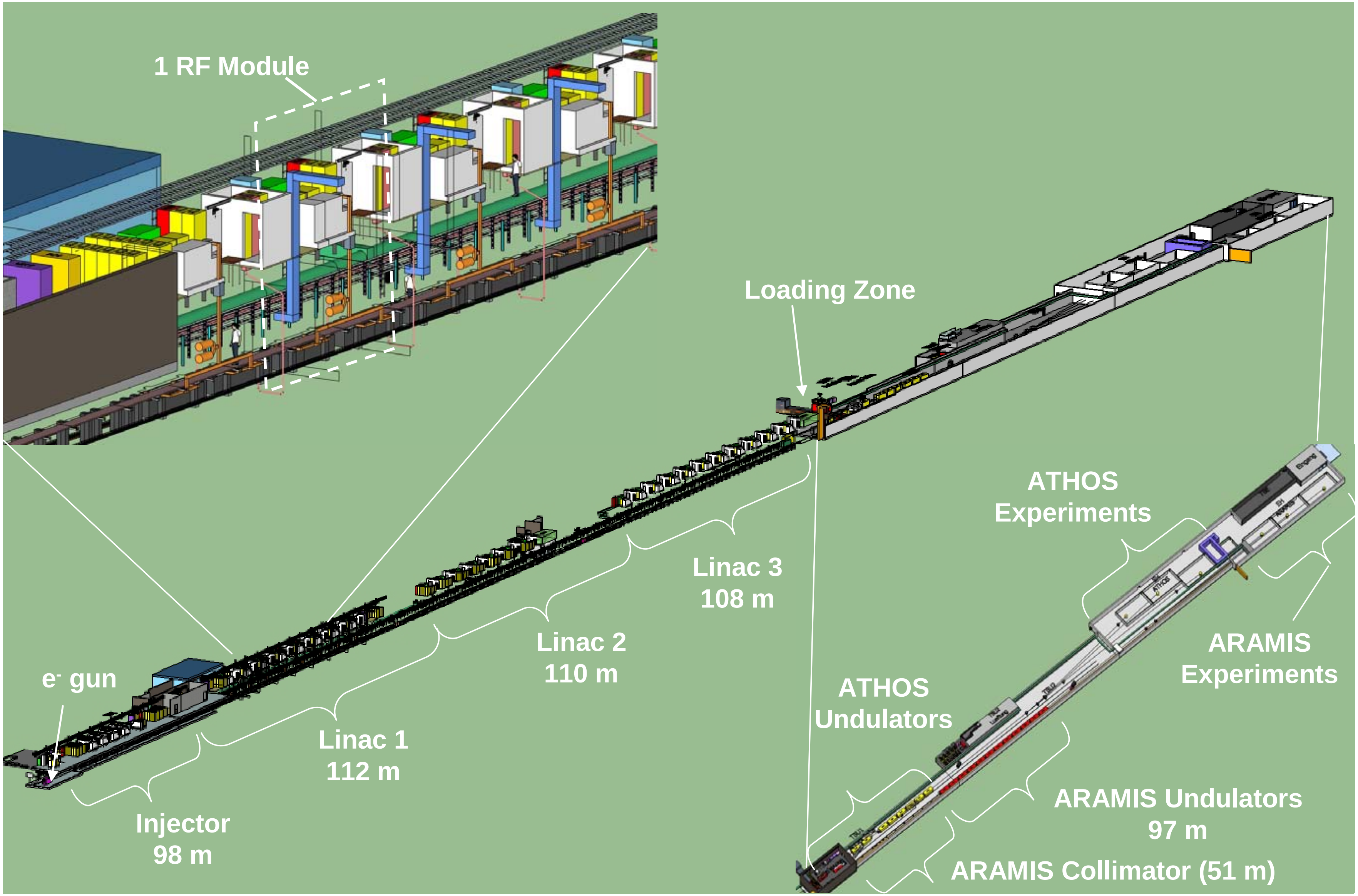
Undulator Development

Mechanical design of frame, choice of materials etc… all presently under study.

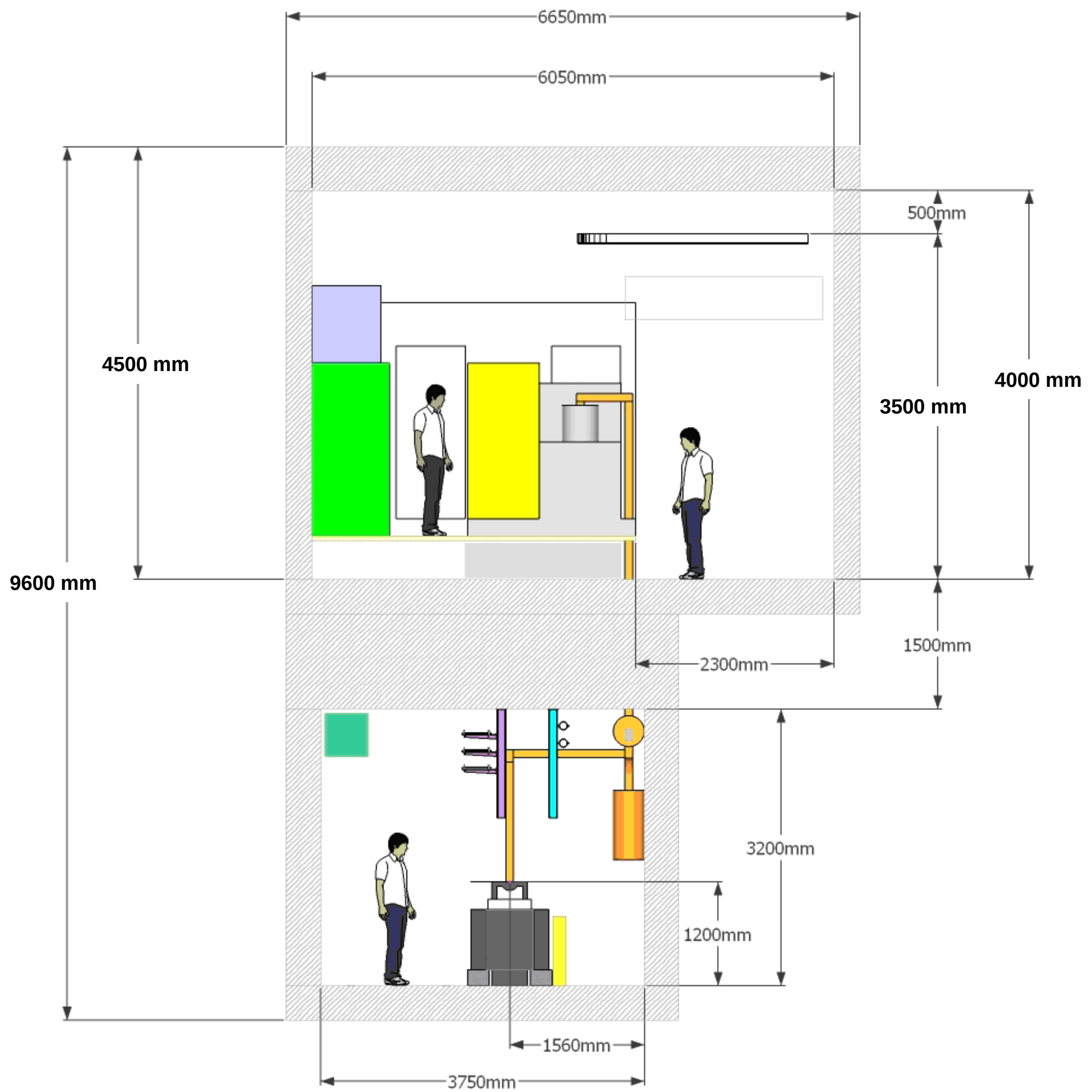


Thomas Schmidt

Building lay-out

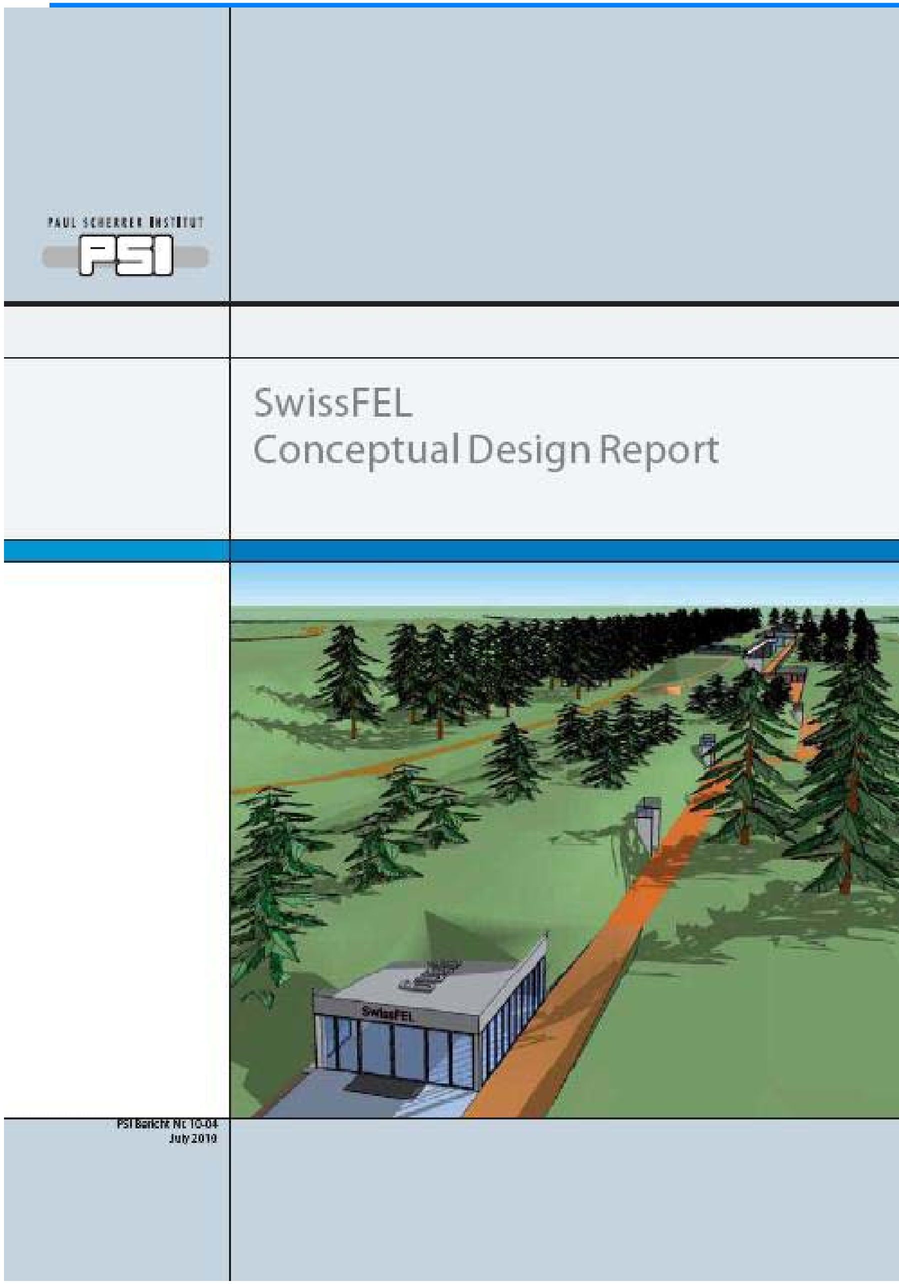


Linac cross section



SwissFEL buildings

SwissFEL CDR



Official publication 24th August 2010
for Inauguration ceremony of 250 MeV Injector

SwissFEL posters at this conference

- S. Reiche - Coherence properties MOPC20
- C. Vicario - Photocathode drive laser WEPB14
- B. Keil – Injector BPM commisioning WEPB15
- N. Milas - The Switchyard WEPB16
- B. Beutner – Tolerance studies WEPB17
- M. Aiba – Orbit correction scheme THPA08

Thank you for your attention !