European XFEL
Overview technical layout

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Introduction

Proposal Oct. 2002 – X-ray FEL user facility with 20 GeV superconducting linear accelerator in TESLA technology

Approval by German government Feb. 2003 as European Project

Commitment for 50% of funding + expected max.10% by Hamburg & Schleswig-Holstein, at least 40% European & international partners

Introduction cont'd

- Project preparation phase: get ready to start construction of the facility before end 2006
  - Finalize overall layout and technical design
  - Detailed planning for the new site near DESY
  - Industrialization of major technical components
  - Update of project construction and operation cost estimate
  - Project organization at the European/International level

Project Preparation Group @ DESY

- **XFEL Project Leader at DESY**
  - **Project Office**
  - **01 Linac**
    - 01 RF System
    - 02 Low Level RF
    - 03 Acc. Modules
    - 04 SC Cavities
    - 05 Power Coupler
    - 06 HOM Coupler
    - 07 Freq. Tuner
    - 08 Cold Vacuum
    - 09 Strings
    - 11 Cold Magnets
  - **02 Accelerator SubSystems**
    - 12 Warm Magnets
    - 14 Injector
    - 15 Bunch Compressor
    - 16 Lattice
    - 17 Stand. Beam Diagnostic
    - 18 Special Beam Diagnostic
    - 19 Warm Vacuum
    - 20 Beam Dump
  - **03 Photon Beam Line**
    - 21 Undulators
    - 22 Hard Photons
    - 23 Medium Photons
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    - 36 General Safety
    - 38 Personnel Interlock
    - 39 Electromagn. Interference
  - **05 Infrastructure**
    - 10 Module Test Facility
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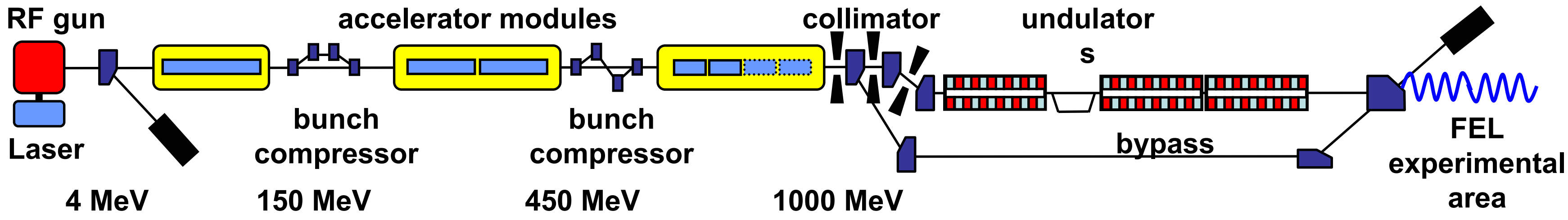
    - 34 Utilities
  - **06 Site & Buildings**
    - 31 Site and Civil Construction
    - 37 Plan Approval Procedure

38 Work Packages
each WP coordinated by a WP Leader

Introduction cont'd

TESLA Test Facility and the VUV-FEL:



→ Pilot facility regarding practically all aspects (accelerator technology, beam physics, FEL process, user operation) of the XFEL

→Test bed for technical developments specifically required for the XFEL

→ **PITZ facility (DESY-Zeuthen) for injector development**

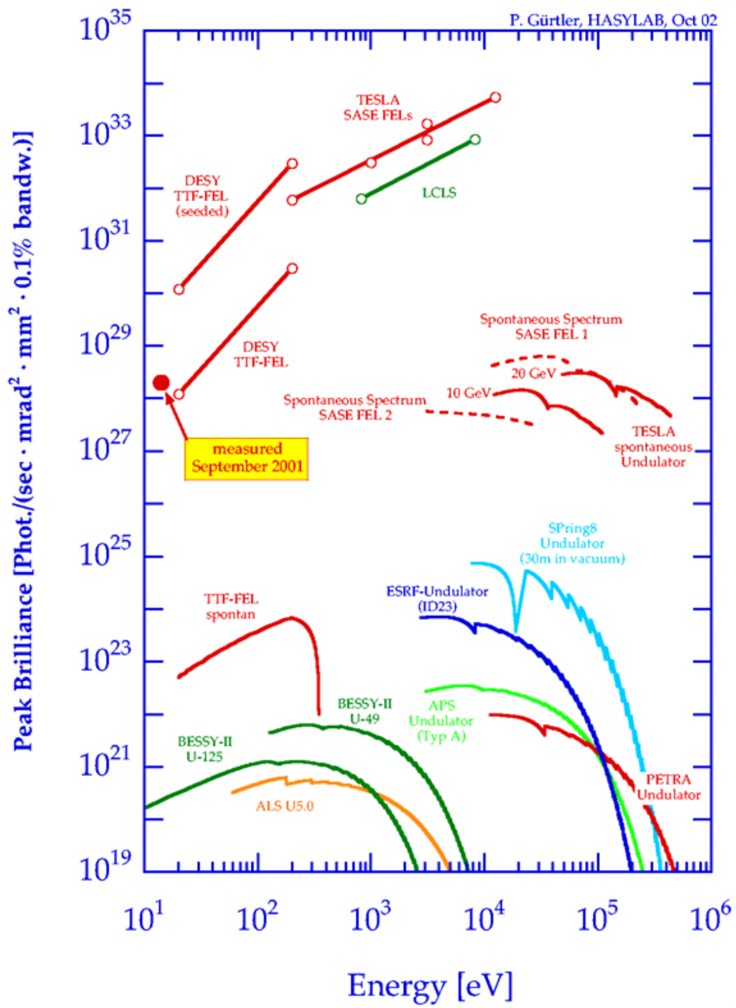
Properties of XFEL radiation

X-ray FEL radiation (0.2 - 14.4 keV)

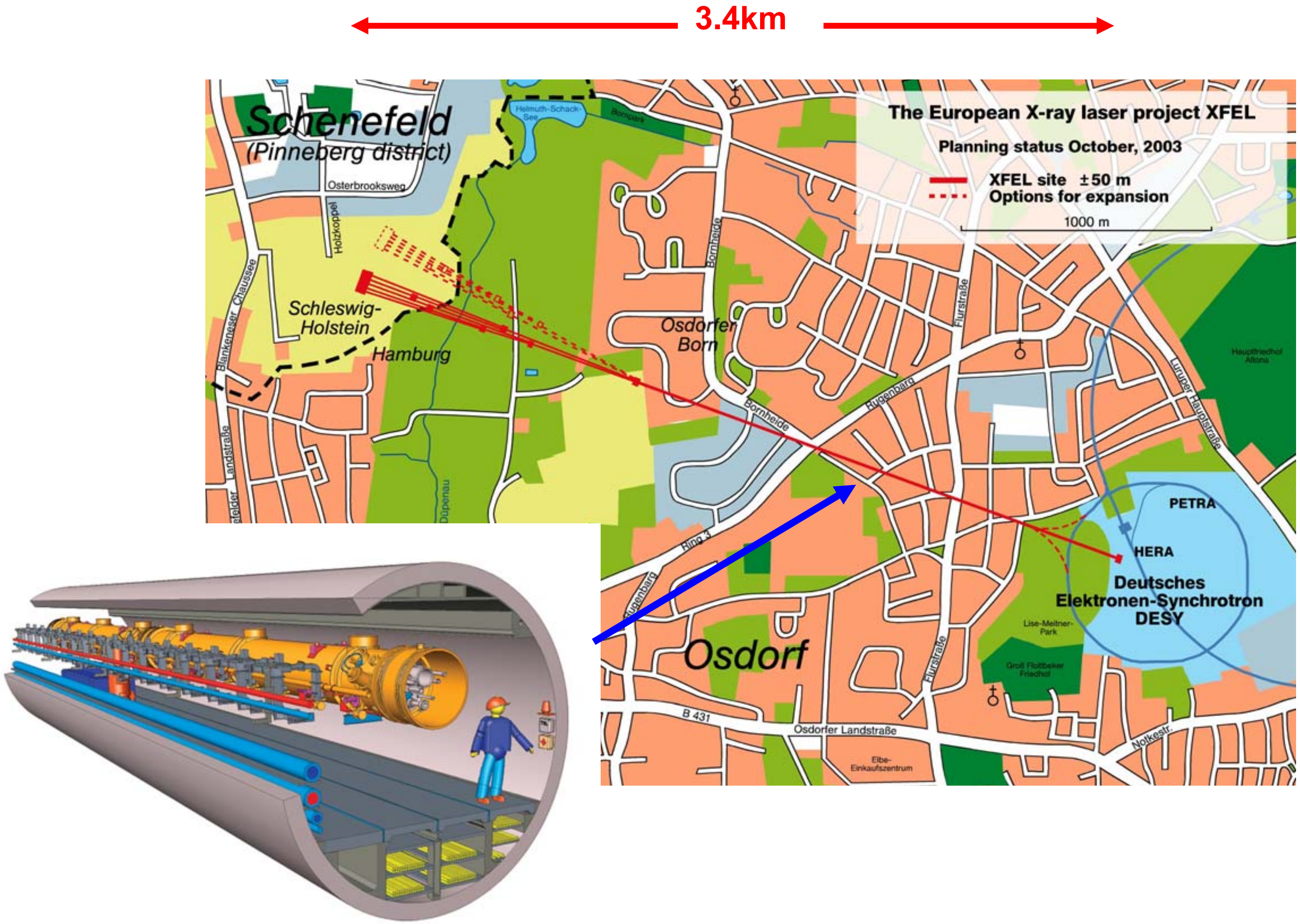
- – ultrashort pulse duration <100 fs (rms)
- – extreme pulse intensities 10^{12}-10^{14} ph
- – coherent radiation x10^9
- – average brilliance x10^4

Spontaneous radiation (20-200 keV)

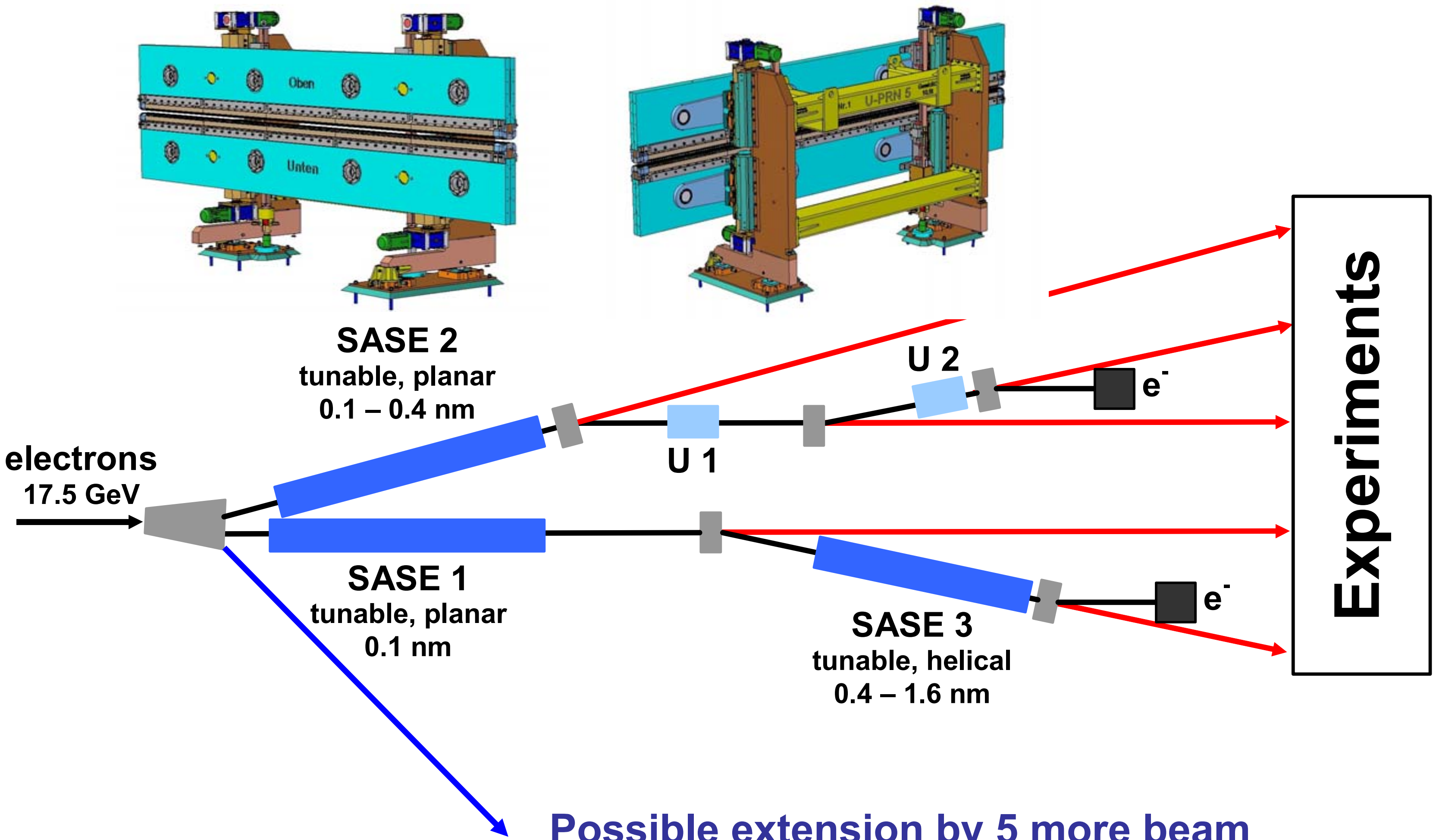
- – ultrashort pulse duration <100 fs (rms)
- – high brilliance



Overall layout and site



Beam lines

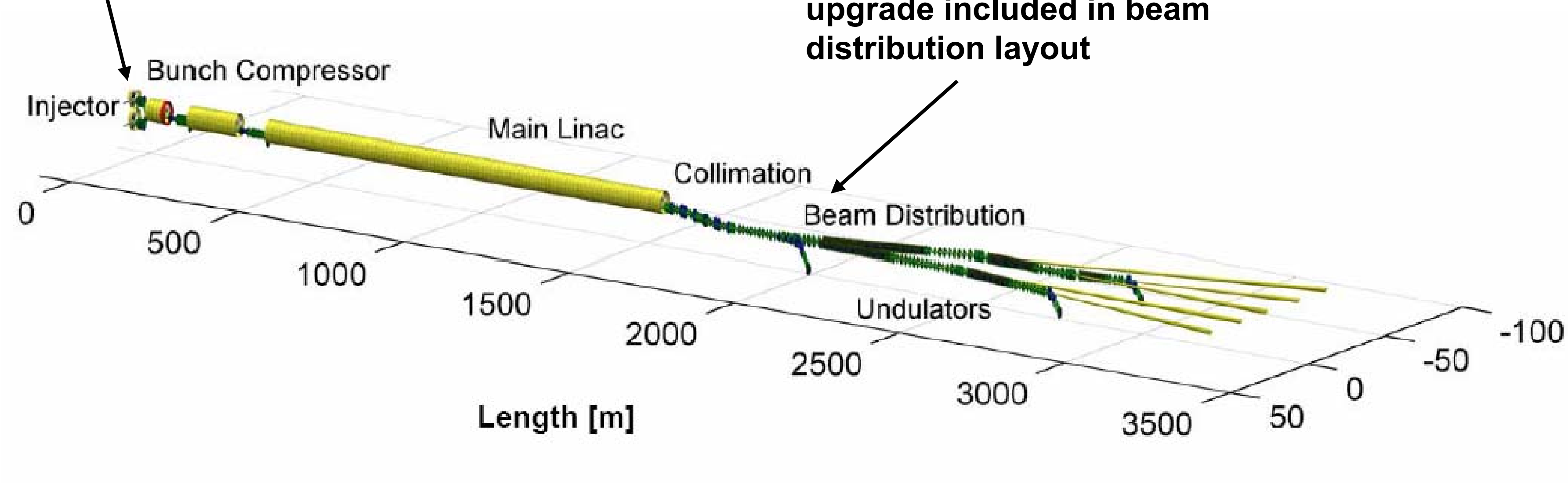


Possible extension by 5 more beam lines/10 experimental stations

Accelerator layout and parameters

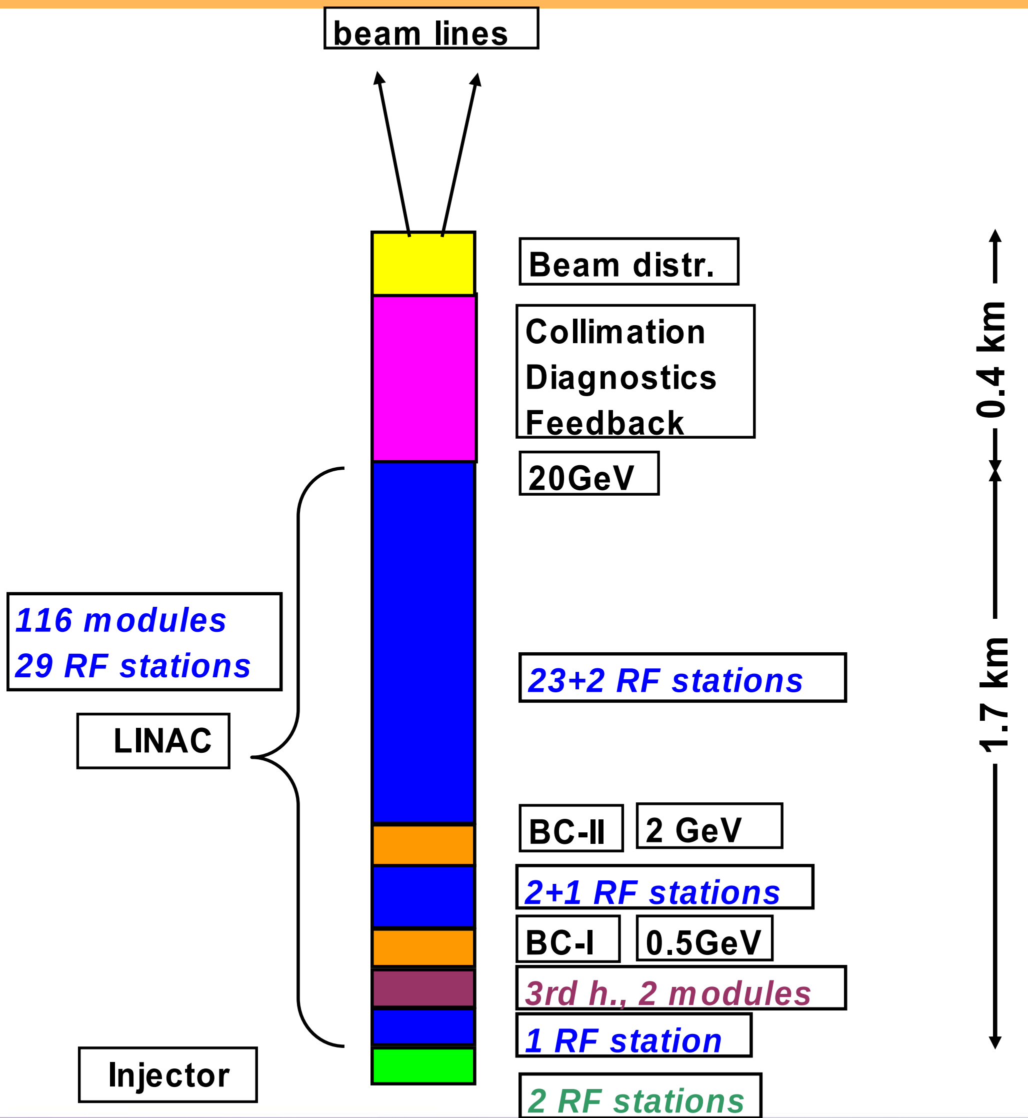
One injector initially installed

Connection to 2nd stage upgrade included in beam distribution layout



Acc. layout & parm's cont'd

Accelerator schematic: functional units



Acc. layout & parm's cont'd

Energy for 0.1nm wavelength *(max. design energy)*	17.5 GeV *(20 GeV)*
# of installed accelerator modules	116
# of cavities	928
Acc. Gradient (104 active modules) at 20 GeV	23.6 MV/m
# of installed RF stations	29
Klystron peak power (26 active stations)	5.2 MW
Loaded quality factor Q_{ext}	$4.6 \cdot 10^{6}$
RF pulse length	1.4 ms
Beam pulse length	0.65ms
Repetition rate	10 Hz
Max. average Beam power	600 kW
Unloaded cavity quality factor Q_0	10^{10}
2K cryogenic load (including transfer line losses)	1.7 kW
Max. # of bunches per pulse *(at 20 GeV)*	3,250 *(3,000)* [1)]
Min. bunch spacing	200 ns
Bunch charge	1 nC
Bunch peak current	5 kA
Emittance (slice) at undulator	1.4 mm*mrad
Energy spread (slice) at undulator	1 MeV

1) The limitation to 3,000 bunches at 20 GeV beam energy is related to a maximum load of 300 kW on each of the beam dumps in the initially installed two electron beam lines.

Operational flexibility & upgrade options

Energy variation:

change acc gradient only in main linac (keep low energy section up to 2nd BC unchanged)

post-linac beam lines are designed for ±1.5% dynamic acceptance → wavelength scan within a pulse train possible

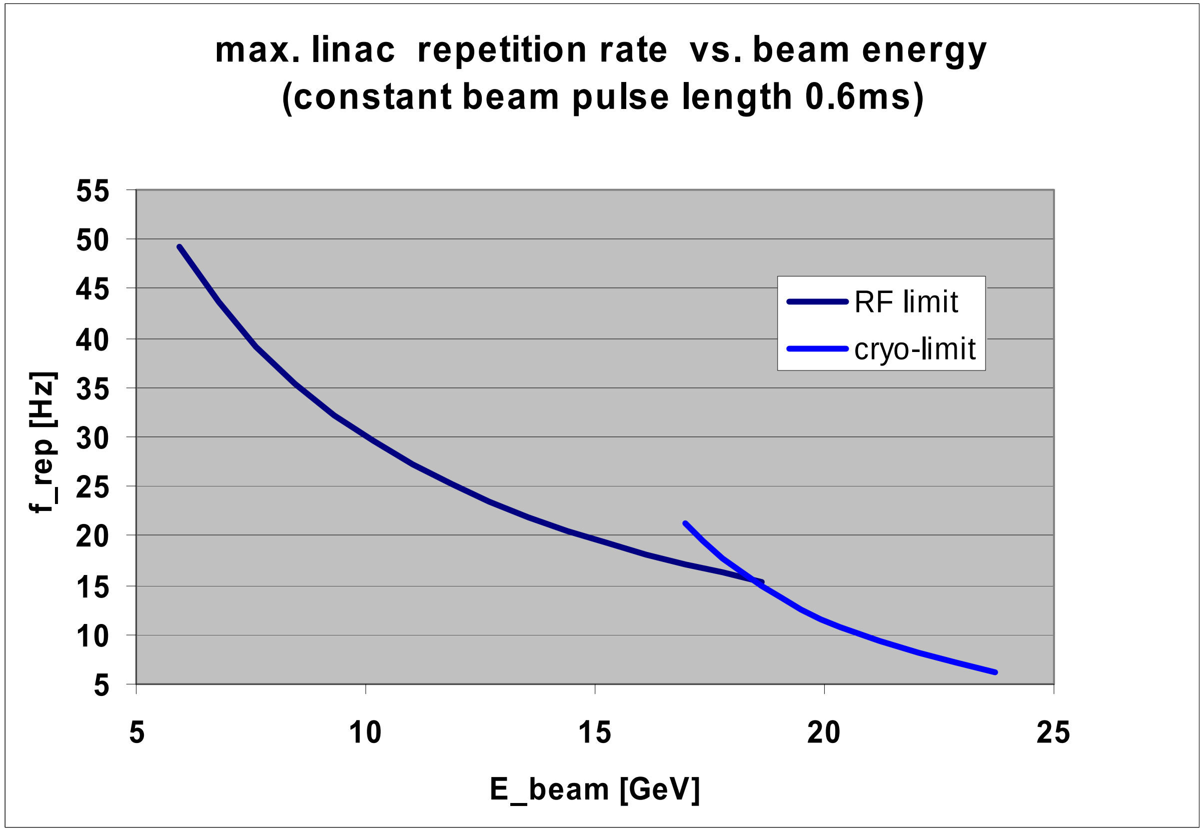
Expect performance of electropolished s.c. cavities better than baseline design specs → potential for higher energy/shorter wavelength

RF and cryogenic systems can support linac operation up to ~ 24GeV (28MV/m), post-linac beam lines laid out for up to 25GeV

Op. flexibility & options cont'd

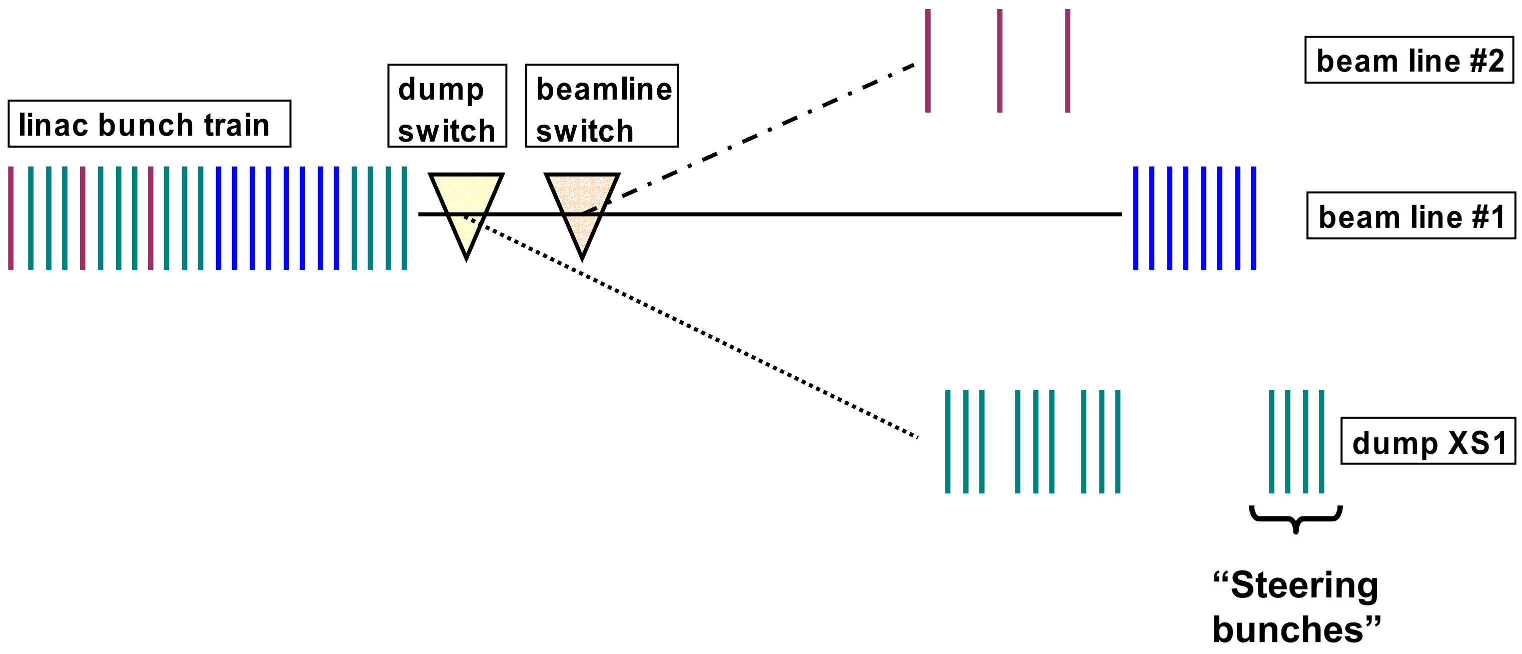
Overhead designed into tech sub-systems also permits higher duty cycle/rep rate of the linac (***if*** injector can support that) – depending on beam energy:

Assumption: RF and cryogenic systems operated at 80% of design limit



Op. flexibility & options cont'd

Different beam time structure to different experiments – concept using kicker devices permits large flexibility without having to change the (preferably homogenous) bunch train structure in the linac



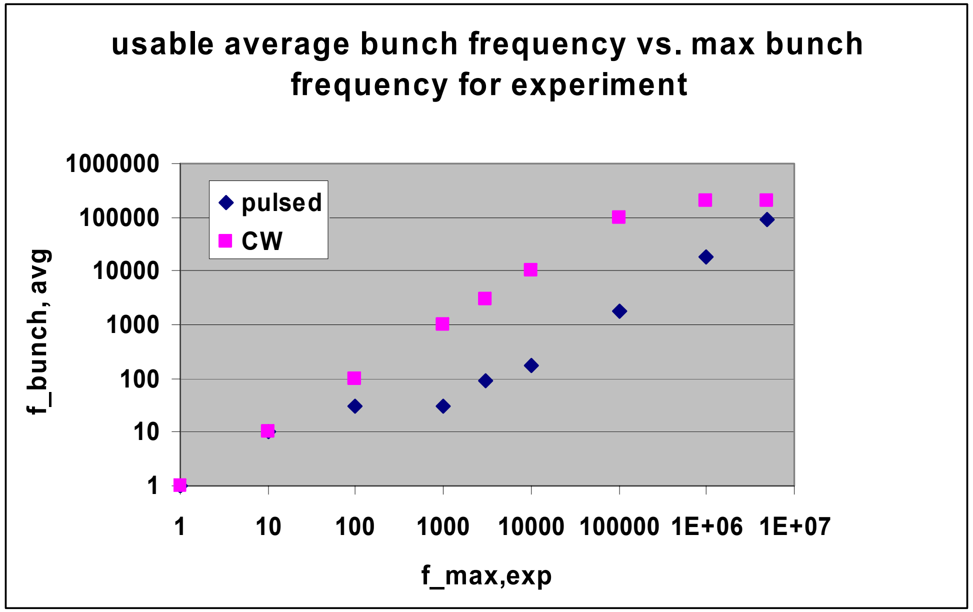
Op. flexibility & options cont'd

CW operation, only possible at lower beam energy, can become a future option if:

high duty cycle at longer wavelength is desirable

improved beam quality + different undulators permit 0.1nm wavelength FEL at lower beam energy

CW beam time structure attractive for experiments which require high average intensity but can not operate with the high bunch frequency (max 5MHz) of the pulsed machine



Op. flexibility & options cont'd

- No detailed design yet, but certain aspects to facilitate CW option:
  - Space & infrastructure for 2nd injector
  - Lower acc gradient in first section of acc (up to 2nd BC)
  - Space in tunnel for additional CW RF system
  - Tunable RF coupling to cavities
  - ERL mode not excluded (cavity spacing, module length)
- Sketch of possible parameters:

Beam energy	7 GeV
Accelerating Gradient	7.5 MV/m
# of CW RF stations	116
RF power per accelerator module	≈20 kW
Beam current	0.18 mA
Loaded quality factor Q_{ext}	$2 \cdot 10^{7}$
Bunch frequency	180 kHz
Unloaded quality factor Q_0	$2 \cdot 10^{10}$
2K cryogenic load	≈3.5 kW

Accelerator technology - collaborative effort

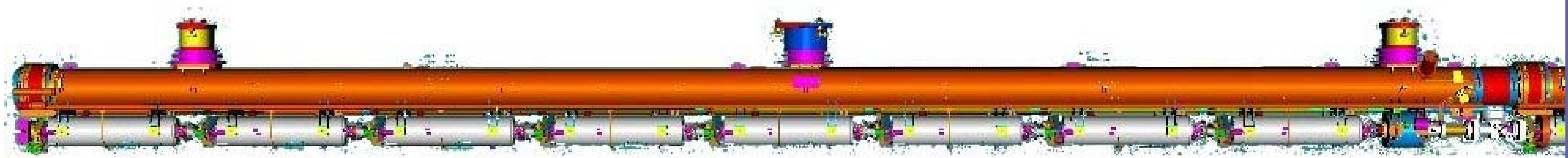
Industrial study module assembly (M6)

2 more cryostats (TTF3/INFN) ordered

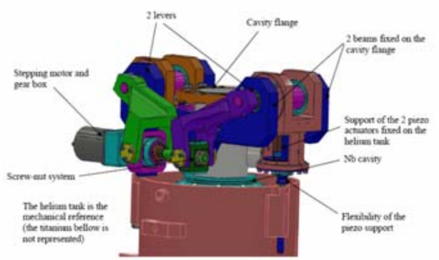
Superferric magnet (CIEMAT)

BPM (Saclay)

Integrated HOM absorber

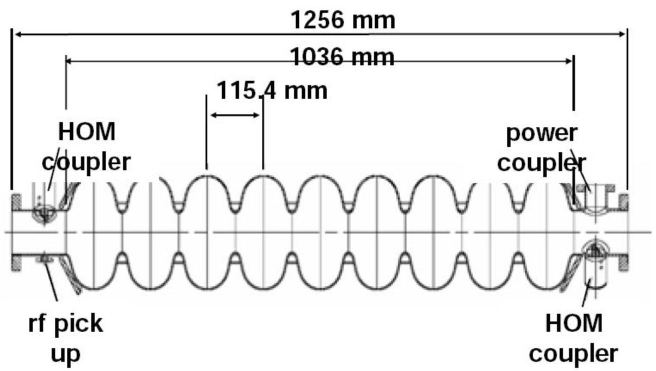


Length quantized n·λ/2 (possibility of ERL)

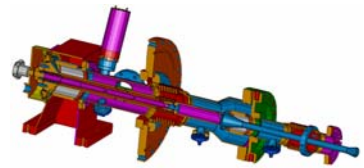


Tuner w/piezo (Saclay)

Industrialization in preparation



LLRF development (collab. Warsaw/Lodz)



TTF3-type coupler

Industrialization launched (Orsay)

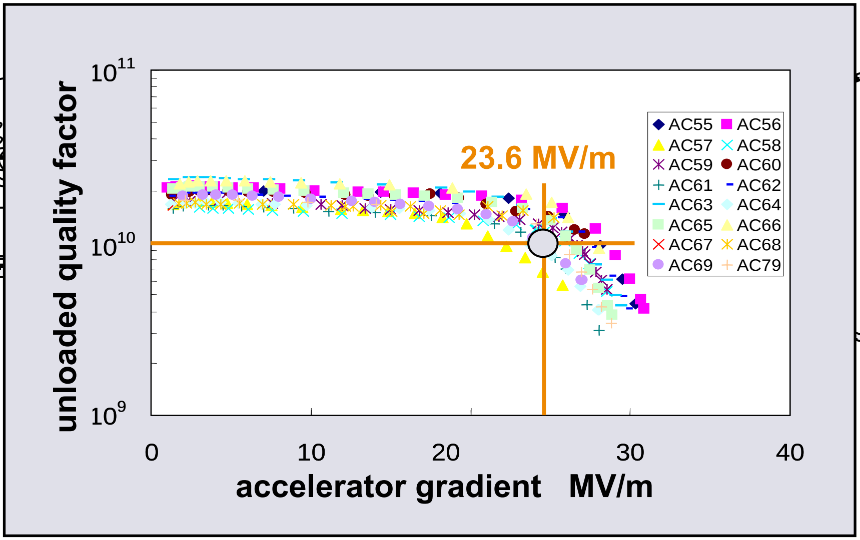
More on acc. collaboration (not exhaustive):

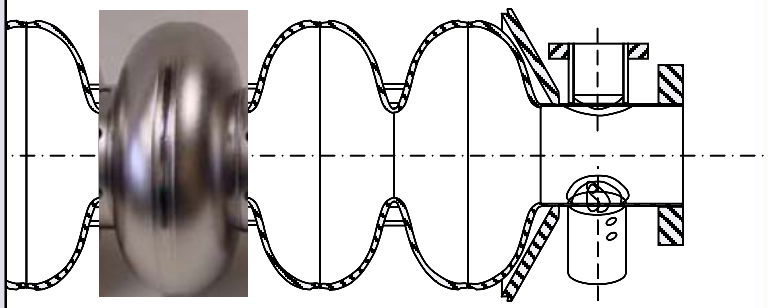
- Within XFEL preparation: PSI on beam stabilization system (2nd workshop March 2006), Swedish Univ. on special diagnostics (started), magnets and vac chamber surface (in prep.)
- EUROFEL: CW, modules, injector, synchronization,…
- PITZ collaboration (DESY-Zeuthen)

- Relation to ILC: clearly organizationally separated projects (different communities, different time-line for realization), but:
  - **Keeping in mind (on both sides) the possible synergies and making the best out of this can be at least as beneficial as keeping the projects strictly separate**

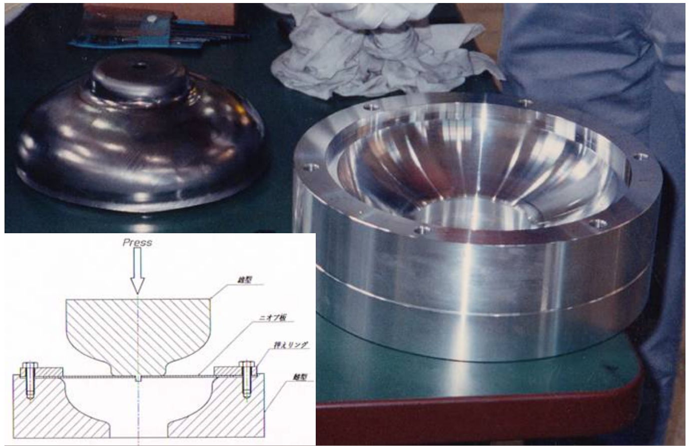
XFEL s.c. Cavities

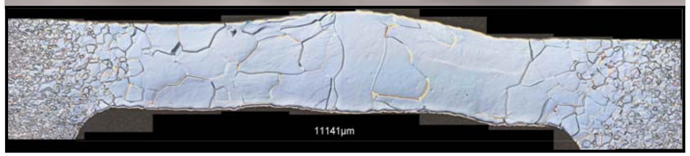
cavity material		RRR 300 niobium
type of accelerating structure		standing wave
accelerating mode		TM010, π-mode
fundamental frequency	f_{RF} [MHz]	1,300
active length	L [m]	1.038
nominal gradient	E_{acc} [MV/m]	23.6
quality factor	Q_0	$>10^{10}$
cell-to-cell coupling	K_{cc} [%]	1.87
iris diameter	[mm]	70





Cavity Fabrication



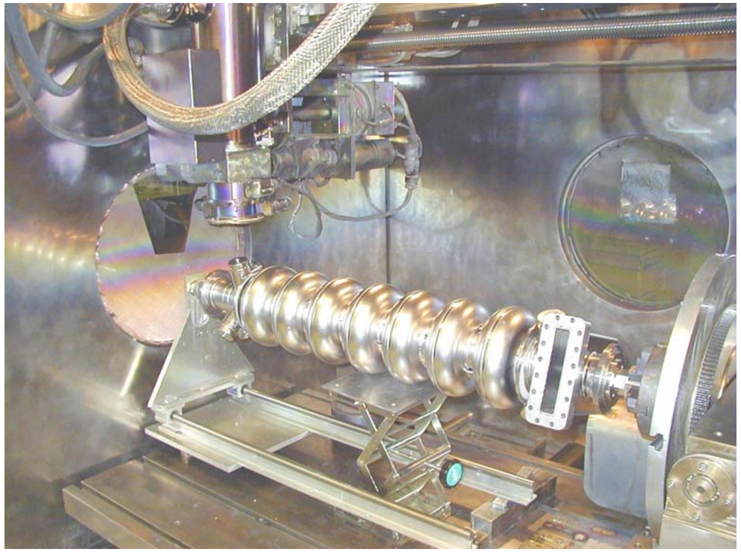


Half cells are produced by deep drawing.

Annealing is next to achieve complete re-crystalisation.

Dumb bells are formed by electron beam welding.

RF measurements support visual inspection.



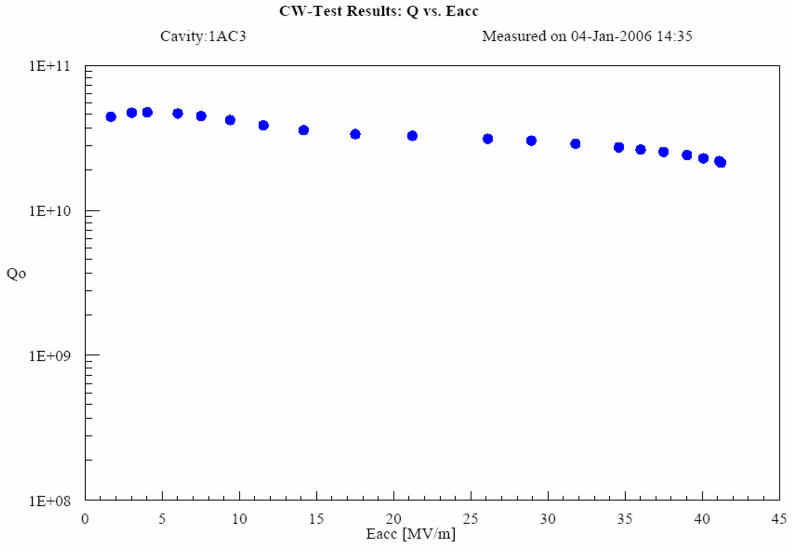
After proper cleaning eight dumb bells and two end group sections are assembled in a precise fixture.

All equator welds can be done in one production step.

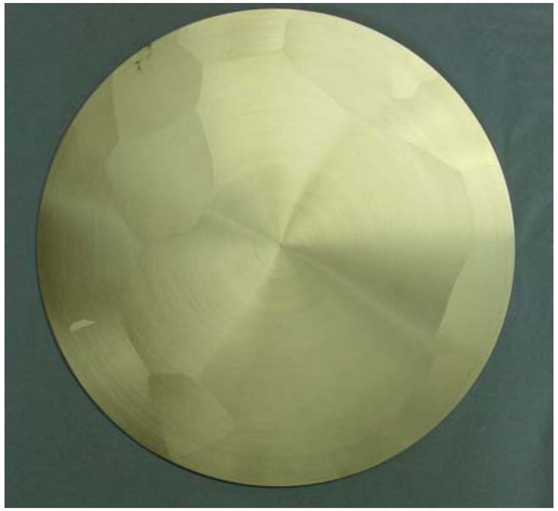
Engineering Data Management Systems (EDMS) is used for the documentation of the cavity fabrication process.

Large-grain cavity R&D

- possible alternative fabrication method: cut Nb sheets directly from ingot (pioneered by P. Kneisel, Jlab)
- Promising initial results for single cells
- 9-cells in preparation
- Need decision by ~ beginning 2007



41 MV/m, Q_0=2x10^{10} at 1.8K

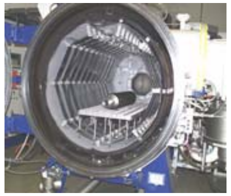


Cavity Prep. (XFEL Industrial Production)

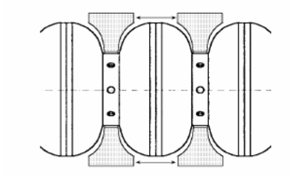
EP 150 µm (inside)

4 bar rinse

BCP 20 µm (outside)



UHV 800°C annealing

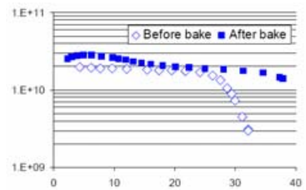


freq./ field flatness tuning

EP 30 µm (inside)

100 bar HPR

inst. pick-up / HOM

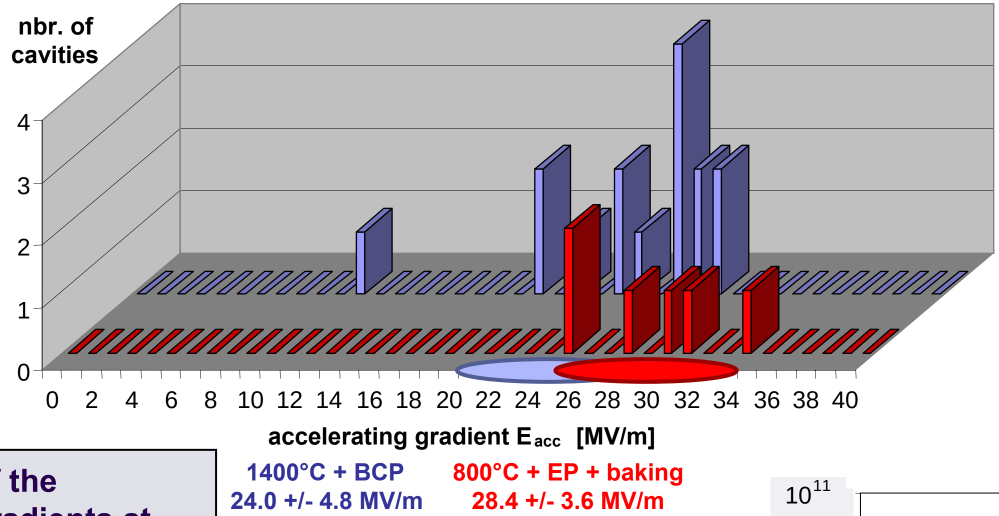


UHV 120°C baking

100 bar HPR (6 ×)

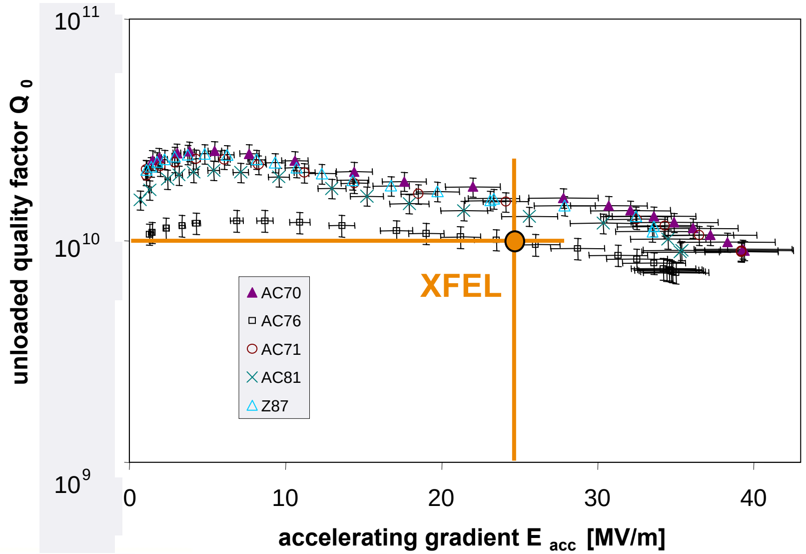
1. electro-chemical removal of a thick niobium layer (so-called damage layer) of about 150 µm from the inner surface
2. a rinse with particle free / ultra-pure water to remove residues form the electro-chemical treatment
3. outside etching of the cavities of about 20 µm
4. ultrahigh vacuum annealing at 800°C
5. tuning of the cavity frequency and field profile
6. removal of a thin and final layer of about 30 µm
7. rinsing with particle free / ultra pure water at high pressure (100 bar) to remove surface contaminants
8. assembly of auxiliaries (pick-up probe and HOM pick-up)
9. baking at 120°C in ultra high vacuum
10. additional six times rinse with high pressure ultra-pure water (100 bar)

Results From Acceptance Tests



Comparison of the accelerating gradients at $Q=10^{10}$ in the first performance test after the full preparation sequences using etching with post-purification at 1400°C (blue) and electro-polishing with 800°C annealing (red).

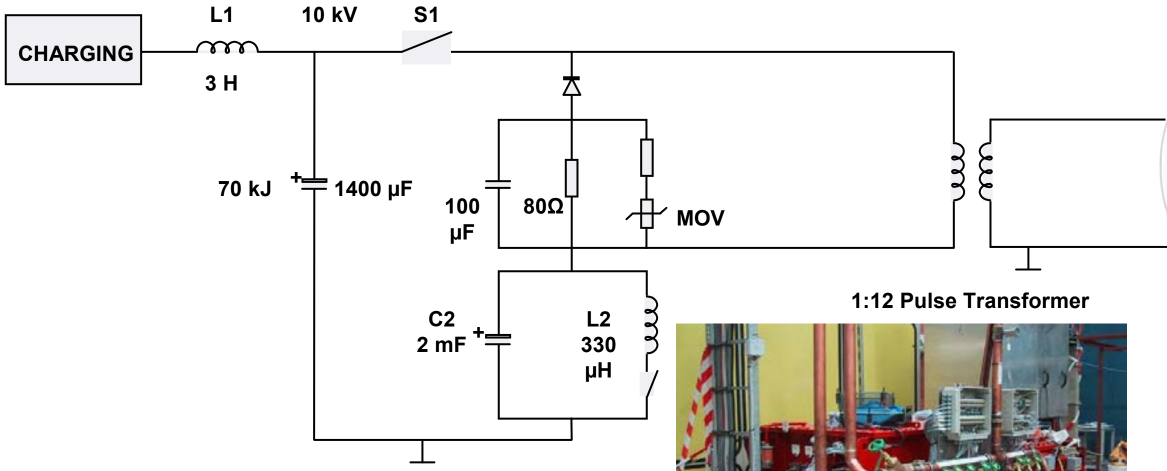
'Excitation curves' of the best cavities treated with 800°C furnace treatment and electro-polishing. The XFEL baseline gradient of 23.6 MV/m is exceeded by a significant margin.

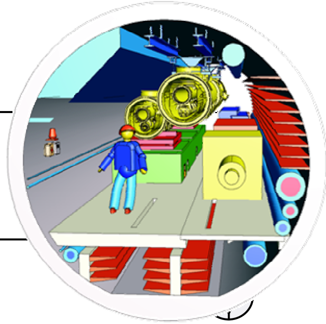


Single Module-Testbench

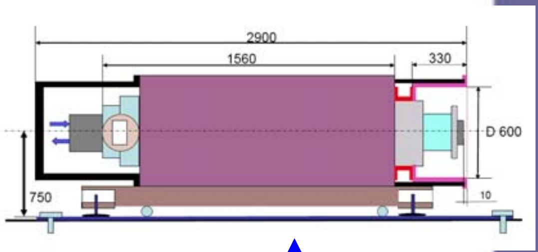
- Necessary for accelerator module prototype & pre-series tests on the way to series production without interfering with FLASH (VUV-FEL) operations
- Commissioning June 2006, module #6 (→ FLASH autumn 2006) will be first tested
- Larger test facility (cavities, modules and RF components) foreseen for XFEL series production

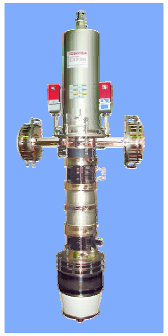
High Power RF System
(Modulator, Pulse Cable, Pulse Transformer, Klystron)





1:12 Pulse Transformer

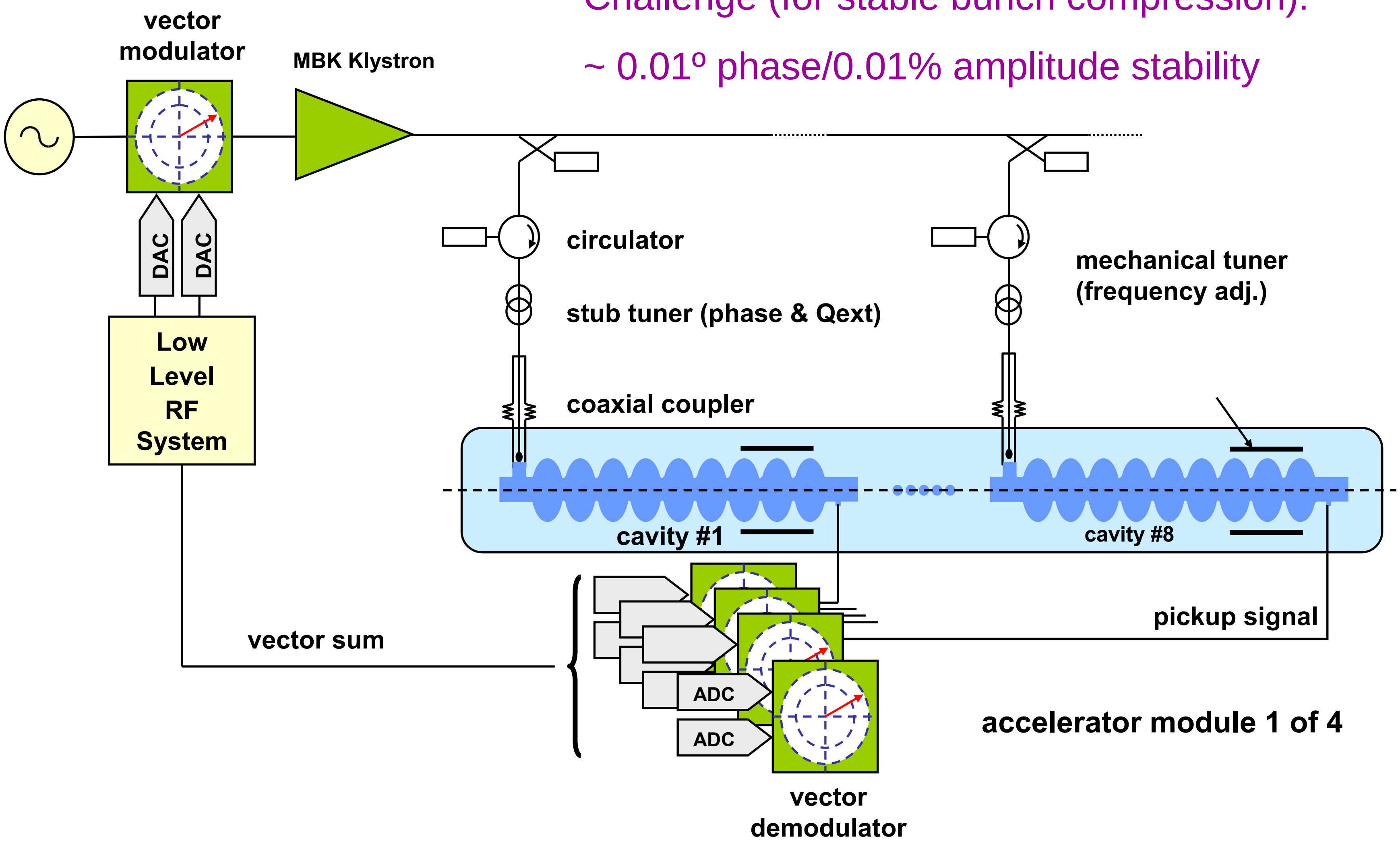




Low Level RF Control

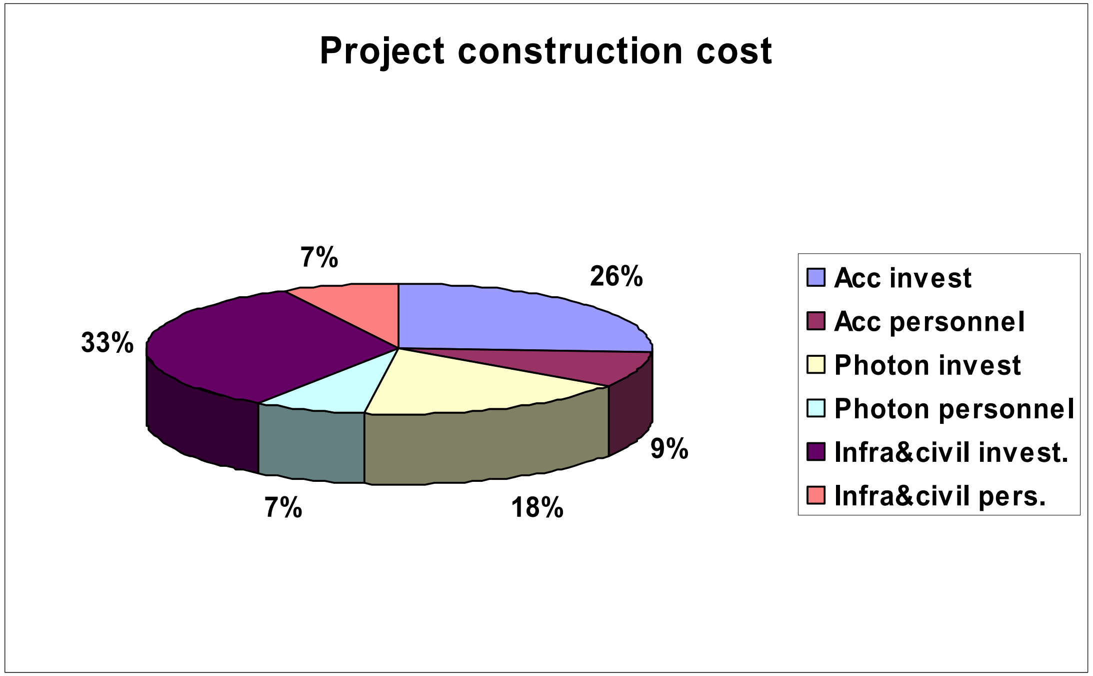
Challenge (for stable bunch compression):

~ 0.01º phase/0.01% amplitude stability



Project cost & schedule

A re-evaluation of construction cost started in 2005. For the accelerator, infrastructure & civil construction it was completed in Jan. 2006 and reviewed (STI-committee) in March 06 (review of photon part May 22/23 2006). The resulting (status March 2006) project construction cost for the facility in its configuration as described in the TDR draft amounts to **974 M€,** 750 M€ for capital investment and 224 M€ for personnel.

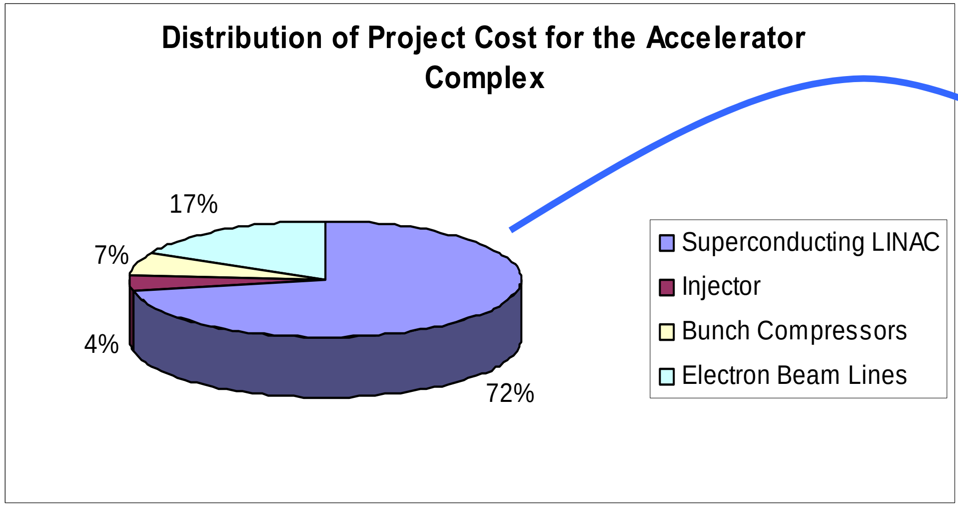


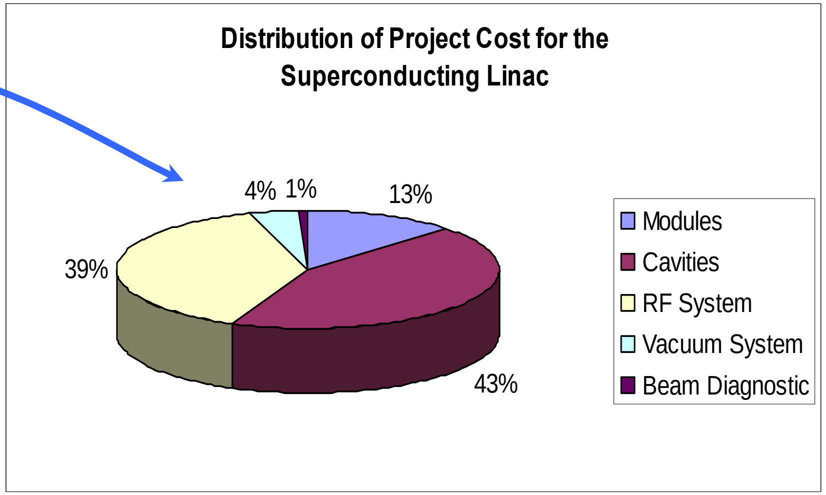
Cost & schedule cont'd

Cost distribution accelerator complex:

261 M€ cap invest

85 M€ personnel

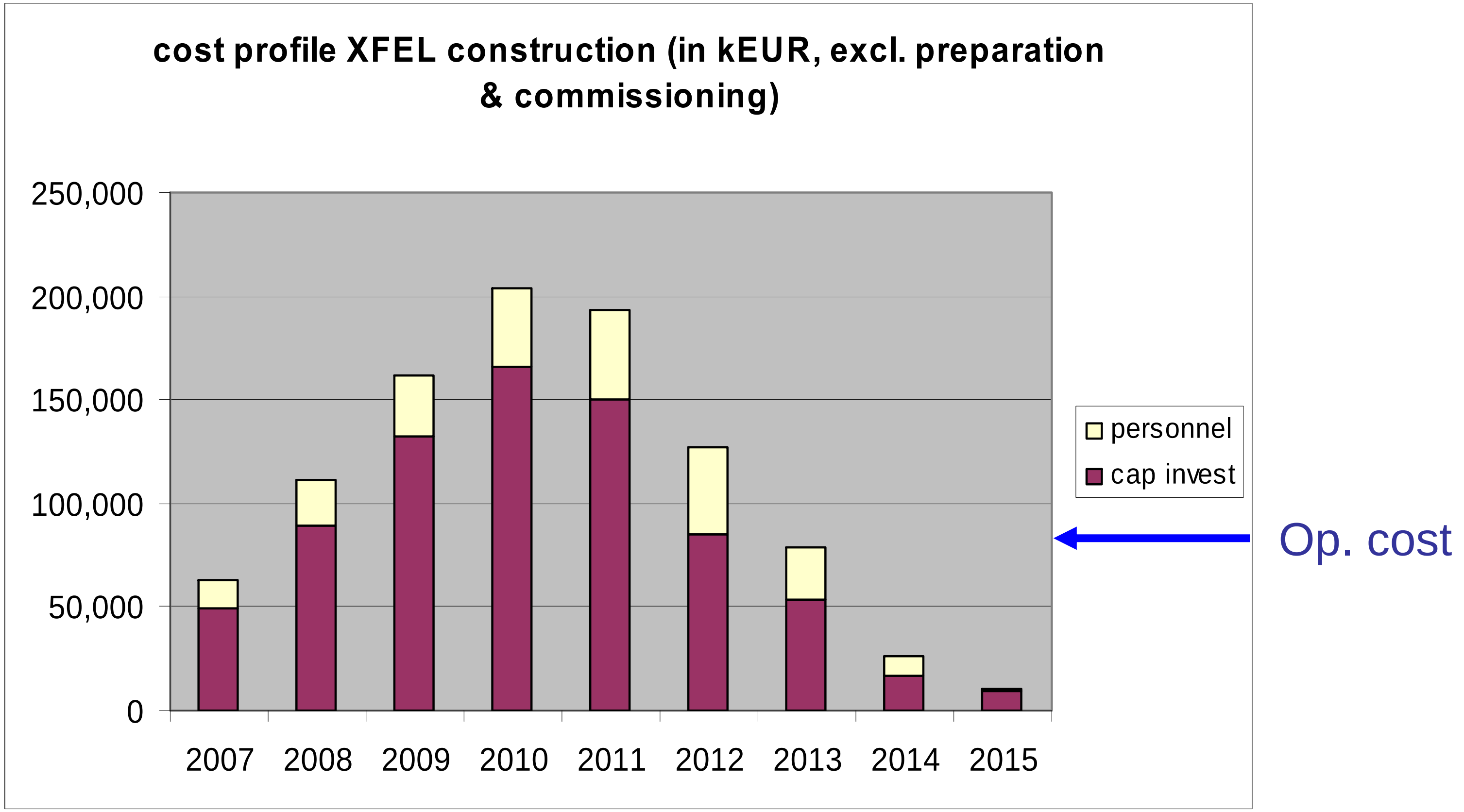




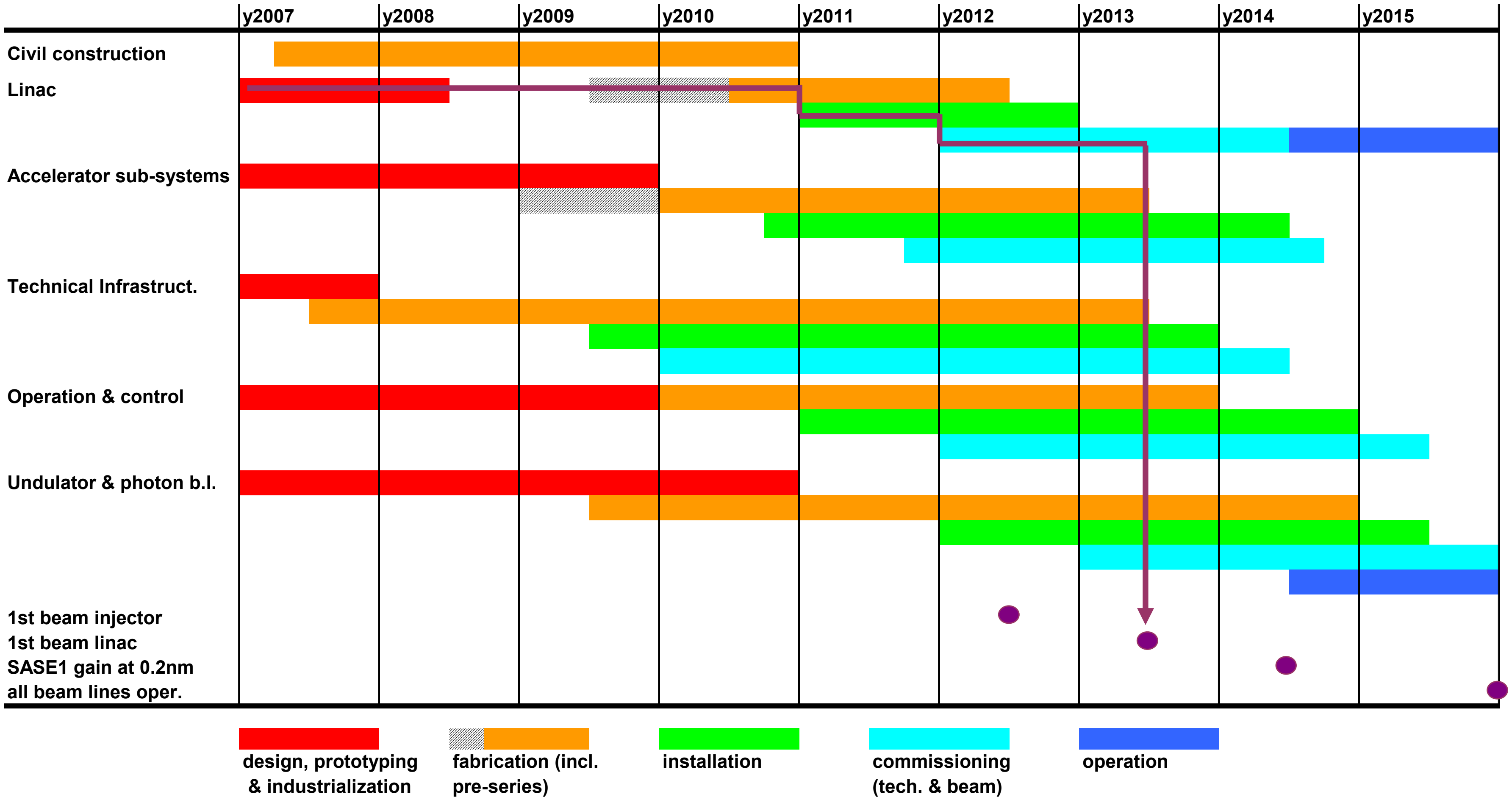
Cost & schedule cont'd

Budget profile for construction (y2005 basis, preliminary)

Overlapping commissioning & operation budget will start mid-2013



Cost & schedule cont'd



Cost & schedule cont'd