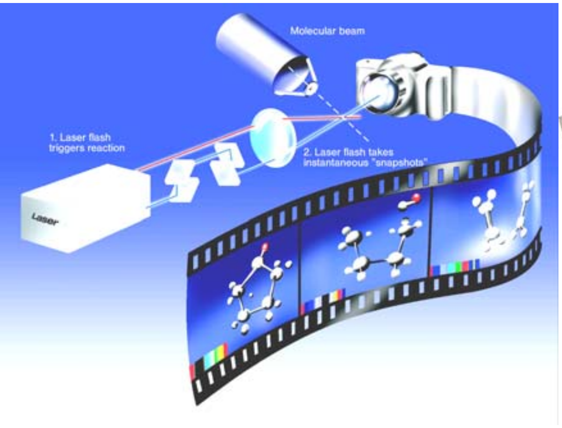
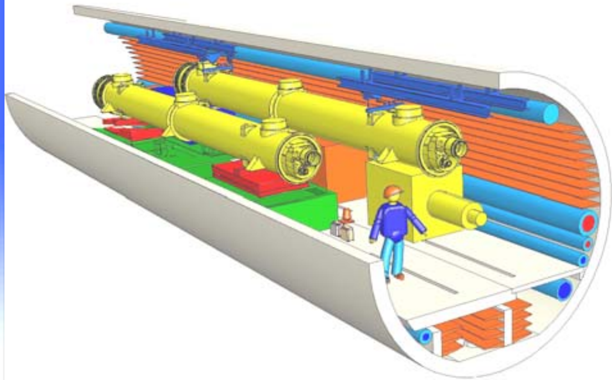
The European XFEL Project

R. Brinkmann, DESY

for the XFEL team





HELMHOLTZ
GEMEINSCHAFT
DESY

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 + 10% by Hamburg & Schleswig-Holstein, 40% European & international partners

TESLA

TESLA XFEL

First Stage of the X-Ray Laser Laboratory

Technical Design Report

Supplement

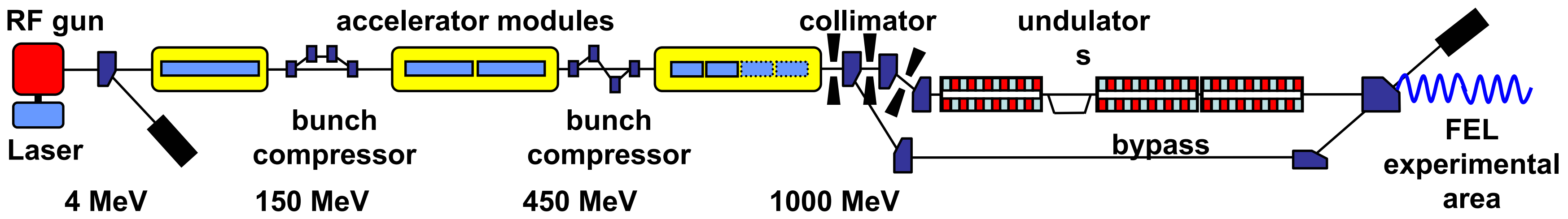
October 2002

Introduction cont'd

- Project preparation phase: get ready to start construction by beginning of 2007
  - 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

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

International Project Organization

XFEL Steering Committee ISC (Chair: H. Schunck, Germany)

- Representatives of all countries intending to contribute to the XFEL facility
- ***13 countries have signed MoU (project preparation phase)***

CH	CN	DE	DK	ES	FR	GB	GR	HU	IT	PL	RU	SE

- ***Nomination of European Project Team (Leader: Massimo Altarelli)***

WG on Scientific and Technical issues STI (chair: F. Sette, ESRF)

WG on Administrative and Funding issues AFI (chair: H.F. Wagner, Germany)

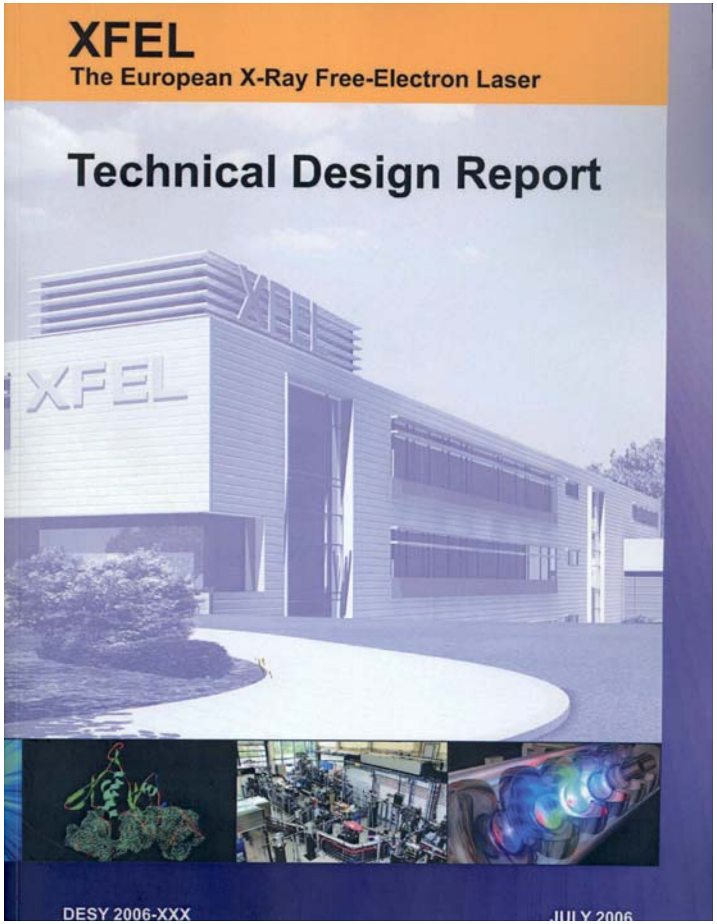
Bi-lateral negotiations between Germany and signature countries on funding contributions are ongoing

Completion of documents

Technical Design Report

- March 2006: Review of Accelerator & Infrastructure parts by STI + international experts
- May 2006: Review of Photon Beam Line & Experiments parts by STI + international experts
- July 2006: Complete TDR → ISC
  approved July 25 at ISC meeting

- Administrative documents essentially completed and delivered to ISC



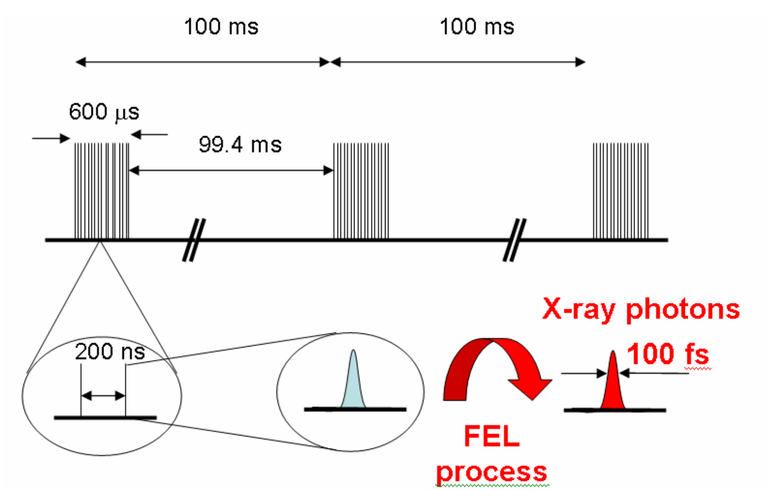
Properties of XFEL radiation

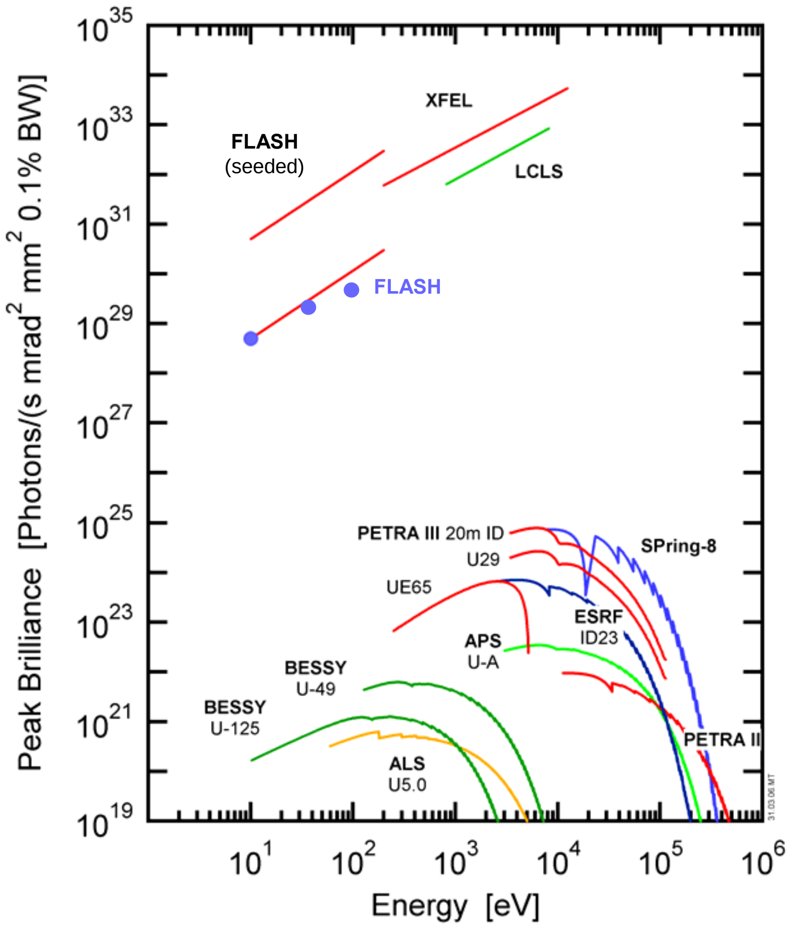
X-ray FEL radiation (0.2 - 14.4 keV)

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

Spontaneous radiation (20-100 keV)

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

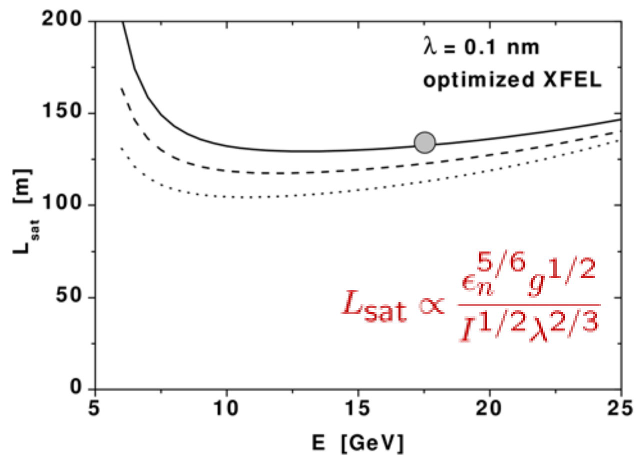


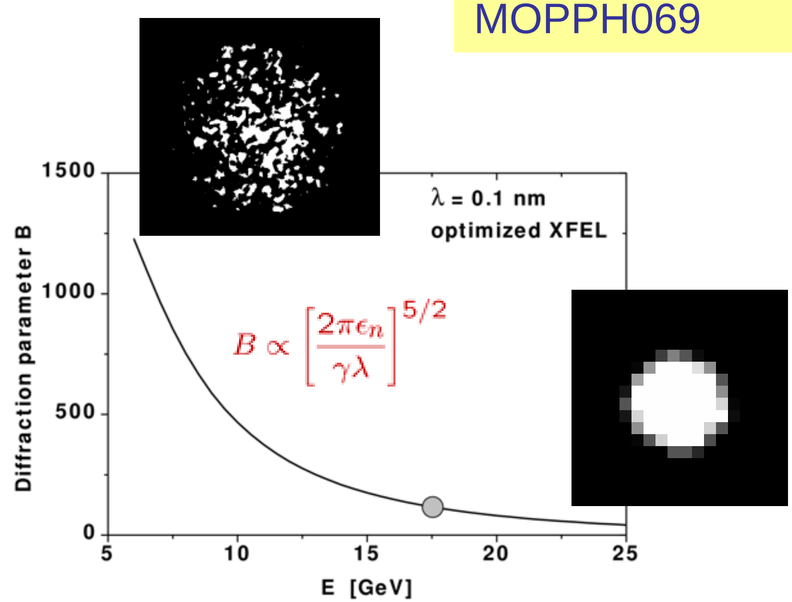


Choice of beam energy: 17.5 GeV for 0.1nm wavelength

E. Saldin et al.,
MOPPH069

gap = 6 mm, 8mm, and 10 mm





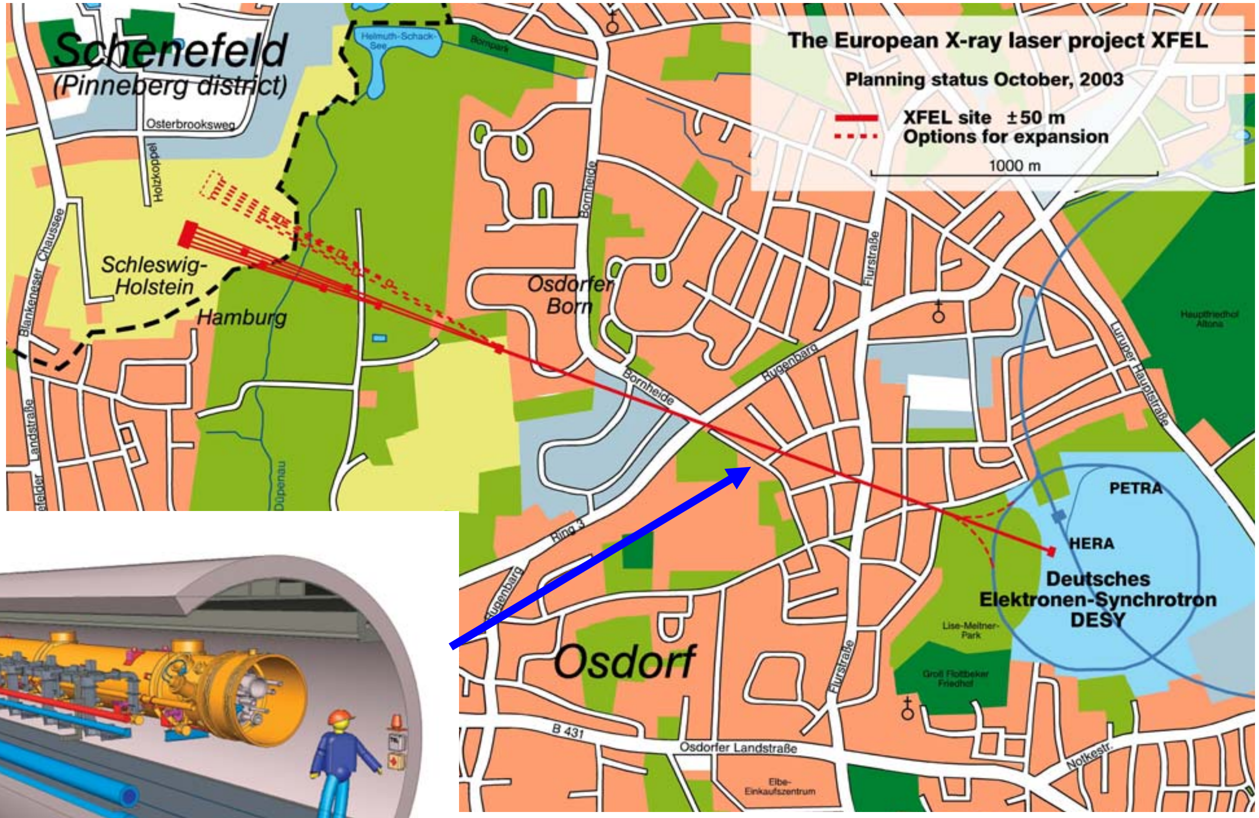
Diffraction parameter : $B = 2\Gamma\sigma^2\omega/c$

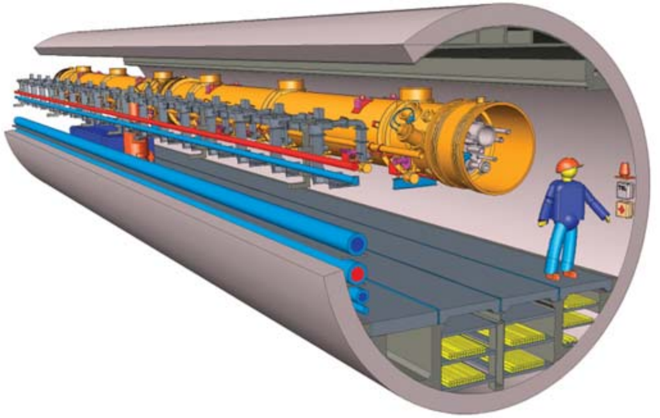
$$\Gamma = \left[I\omega^2\theta_s^2 A_{JJ}^2/(I_A c^2\gamma_z^2\gamma)\right]^{1/2} ,$$

$$\gamma_z^2 = \gamma^2/(1+K^2) , \quad \theta_s = K/\gamma$$

Overall layout and site

3.4km





Schenefeld Site

Schenefeld Site

Plan approval procedure – construction permission

May/June 2005: documents for PFV open to public; time to submit objections/complaints

Oct. 25/26 2005: Hearing

July 2006: Plan approval announced by authority in charge
(LBEG Clausthal-Zellerfeld)

→

<u>Bekanntmachung</u>

**zum
Planfeststellungsbeschluss
für den Bau und Betrieb des Röntgenlasers XFEL einschließlich der für seinen Betrieb notwendigen Anlagen und Gebäude
des Deutschen Elektronen-Synchrotron (DESY), Hamburg**

Der von der Stiftung Deutsches Elektronen-Synchrotron (DESY), Notkestraße 85, 22607 Hamburg, mit Datum vom 27.04.2005 vorgelegte Antrag zur Durchführung des Planfeststellungsverfahren für die Errichtung und den Betrieb des Freien-Elektronen-Lasers (Röntgenlaser oder XFEL) wurde festgestellt. Das Vorhaben ist damit genehmigt.

Der festgestellte Plan umfasst die im Antrag und seinen Planunterlagen dargestellte Errichtung und den Betrieb der Forschungsanlage. Sie setzt sich zusammen aus einem nordwestlich in rund 6 bis 38 Meter Tiefe verlaufenden ca. 3,4 km langen Tunnelbauwerk vom DESY-Betriebsgelände in Hamburg Bahrenfeld zum vorgesehenen XFEL Forschungsgelände, im Süden der Stadt Schenefeld im Kreis Pinneberg, Schleswig-Holstein sowie den zugehörigen Haupt- und Nebengebäuden.

Die Errichtung und der Betrieb der Forschungsanlage sind entsprechend dem festgestellten Plan sowie den in diesem Beschluss festgelegten Nebenbestimmungen auszuführen.

Eine Ausfertigung des Planfeststellungsbeschlusses und eine Ausfertigung des festgestellten Planes liegen zur Einsichtnahme für die Dauer von zwei Wochen zu jedermanns Einsicht bei folgenden Behörden öffentlich aus:

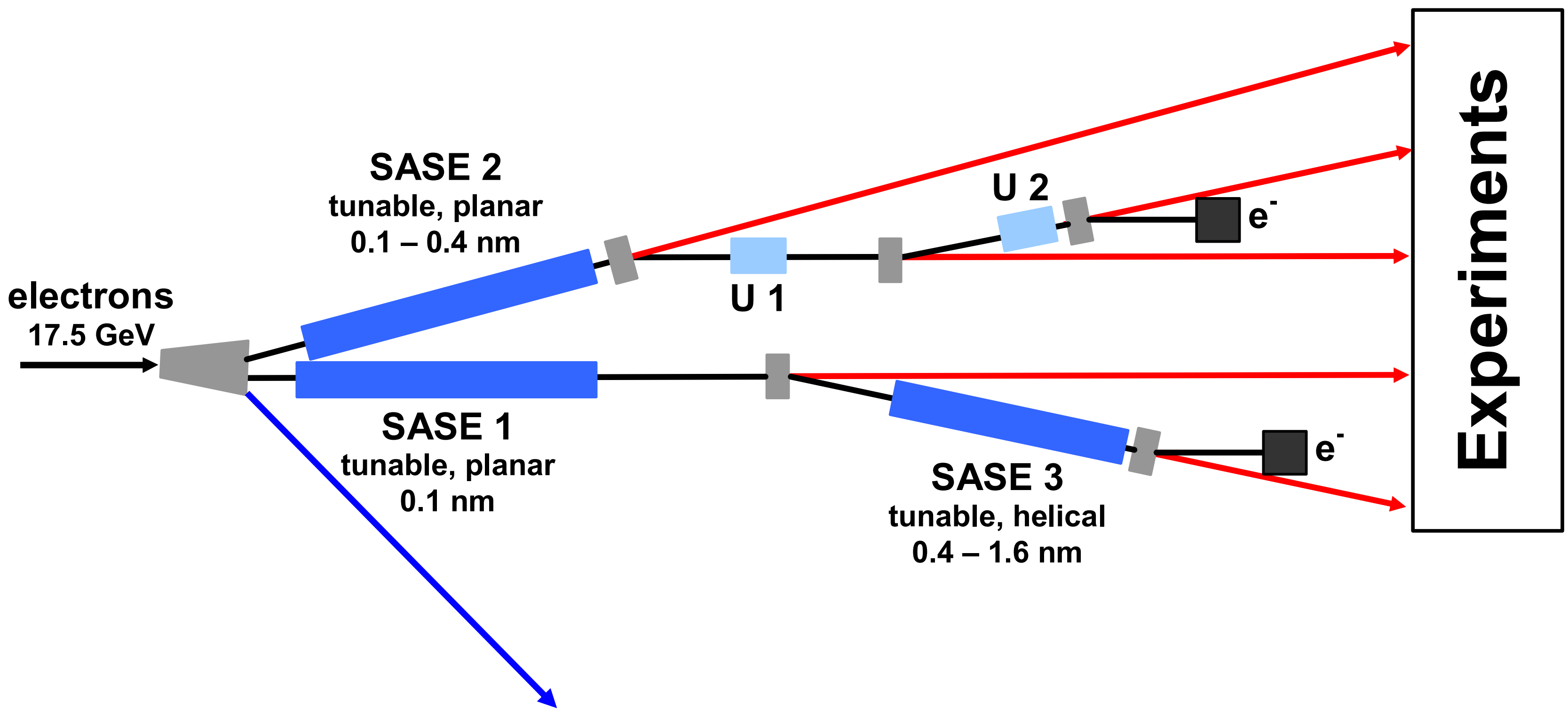
1. beim Bezirksamt Altona

   im Bauamt
   Stadtplanungsabteilung, Zimmer 342
   Platz der Republik 1,
   22767 Hamburg,

Montag bis Donnerstag	09.00 Uhr bis 16.00 Uhr
Freitag	09.00 Uhr bis 15.30 Uhr

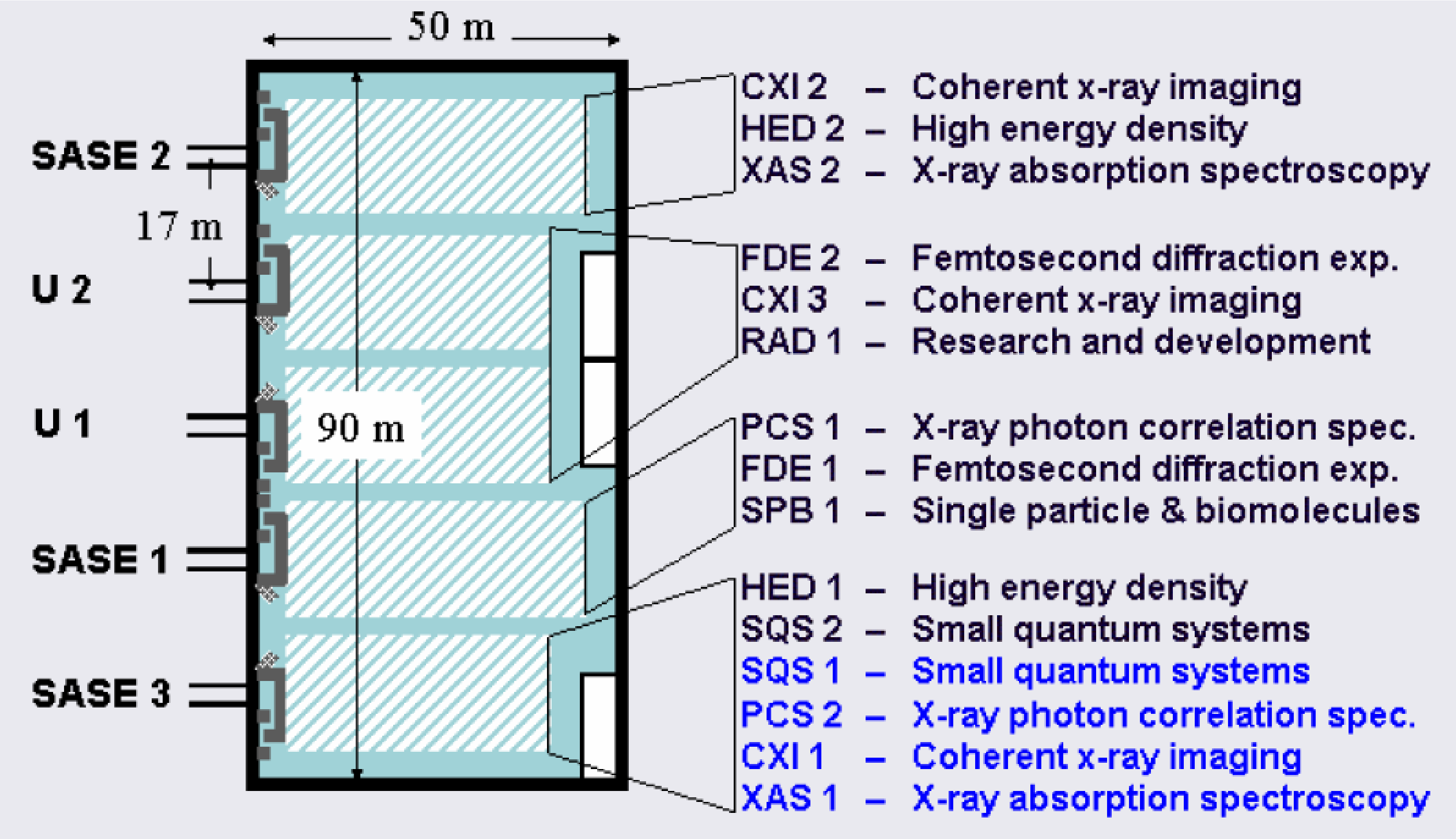
(andere Zeiten sind erforderlichenfalls unter Tel. Nr.: 040/428111402 abzusprechen)

Beam lines



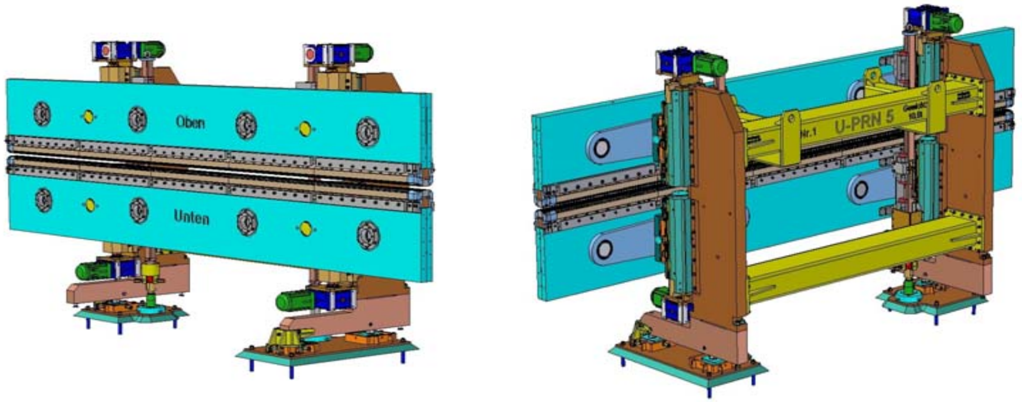
Possible extension by 5 more beam lines/10 experimental stations

Scientific instruments

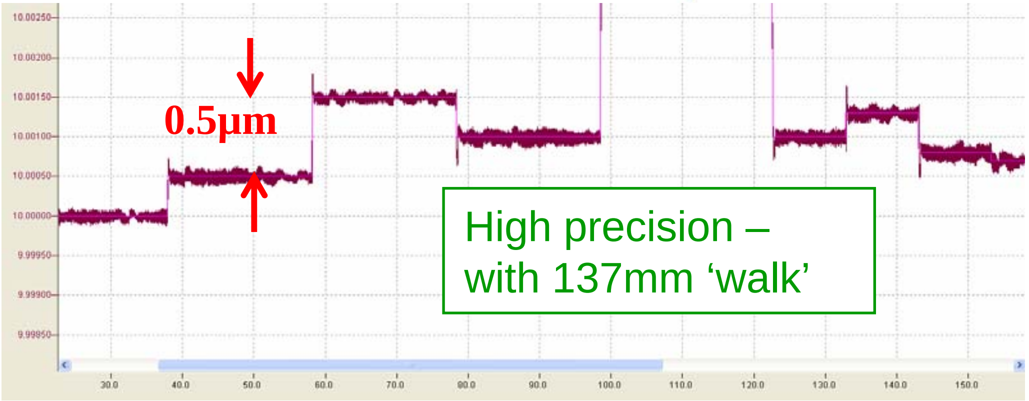


Undulator sections

Prototyping of variable gap undulators started



First tests of high precision mechanics



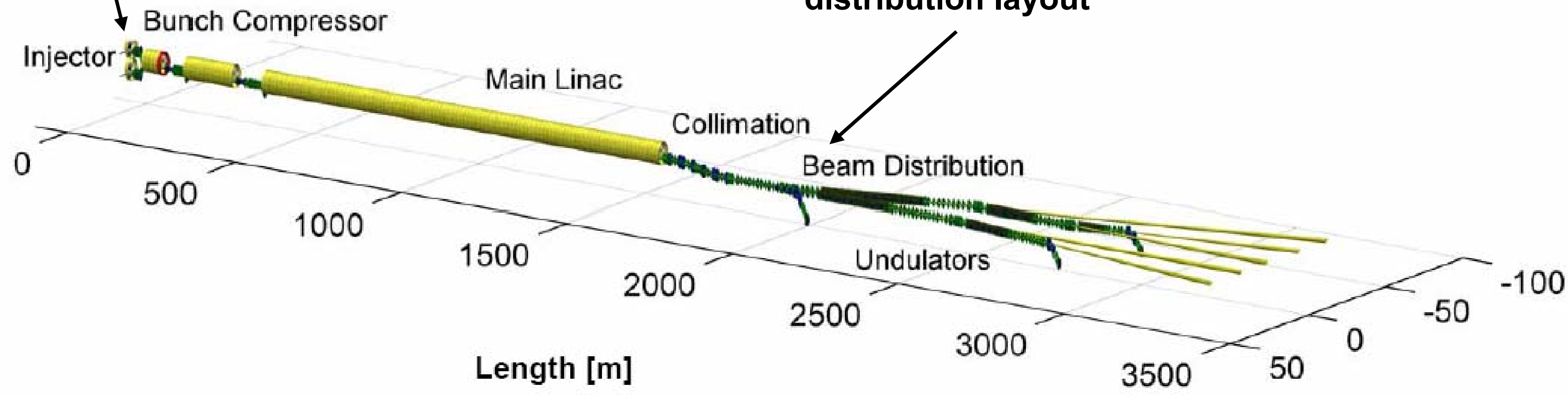
Studies of wakefields/gap tapering & gap tolerances (few µm)

I. Zagorodnov et al., EPAC2006, MOPCH015

Accelerator layout and parameters

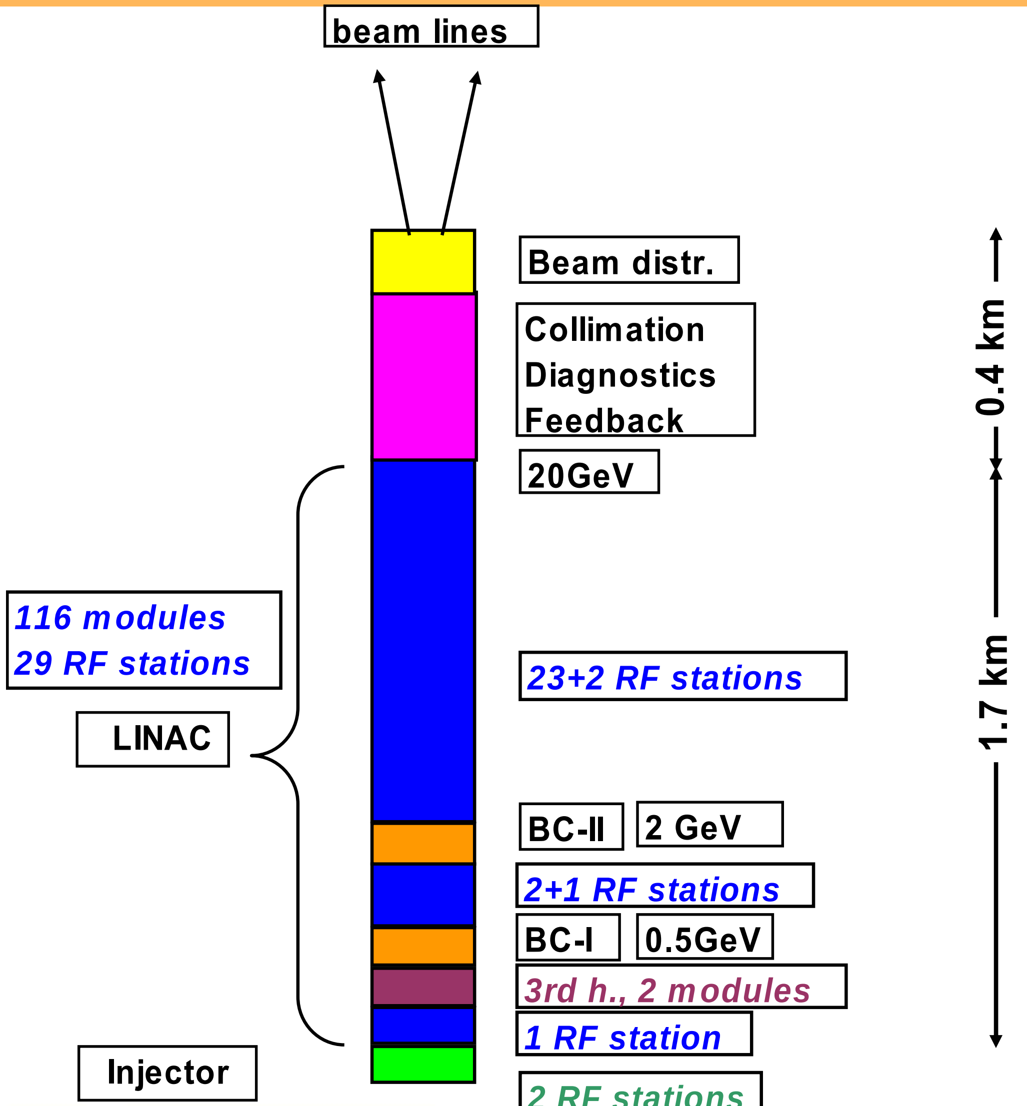
One injector initially installed

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 2^{nd} BC unchanged)

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

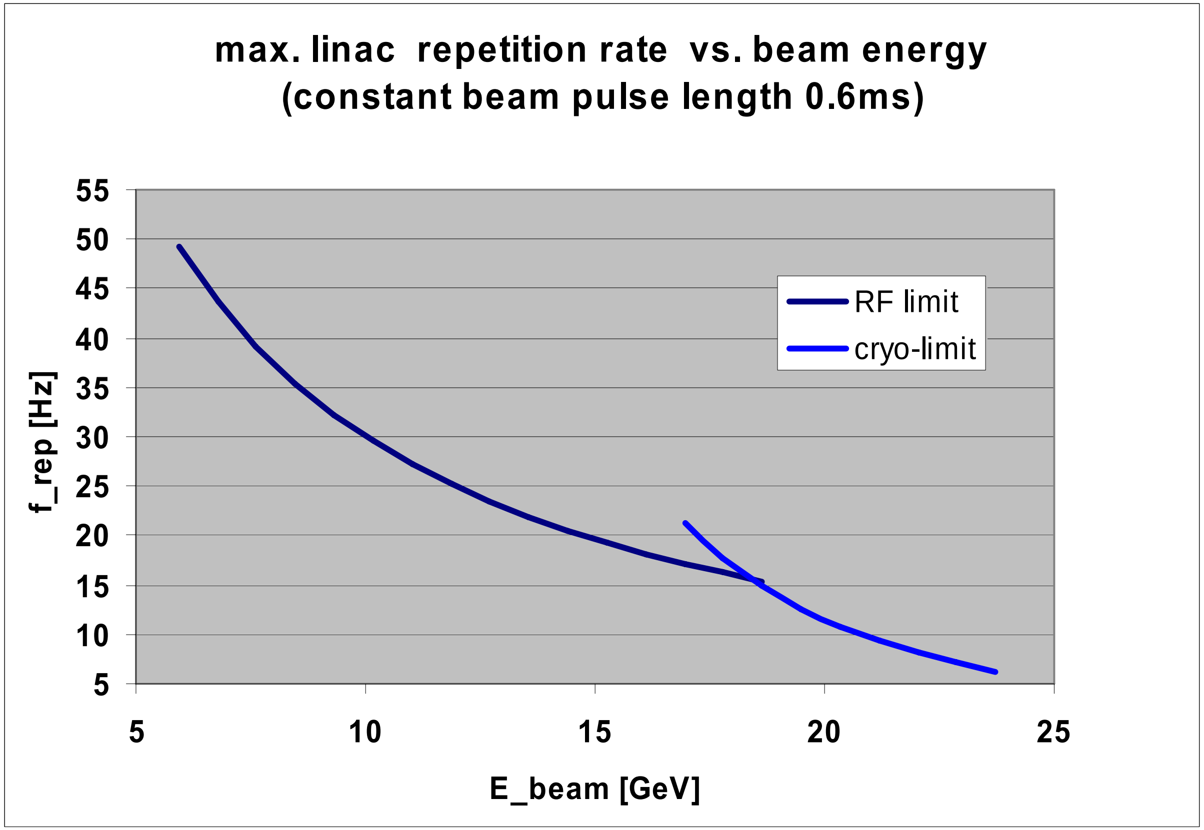
Expect performance of electropolished s.c. cavities better than baseline design specs → potential for higher energy/shorter wavelength

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

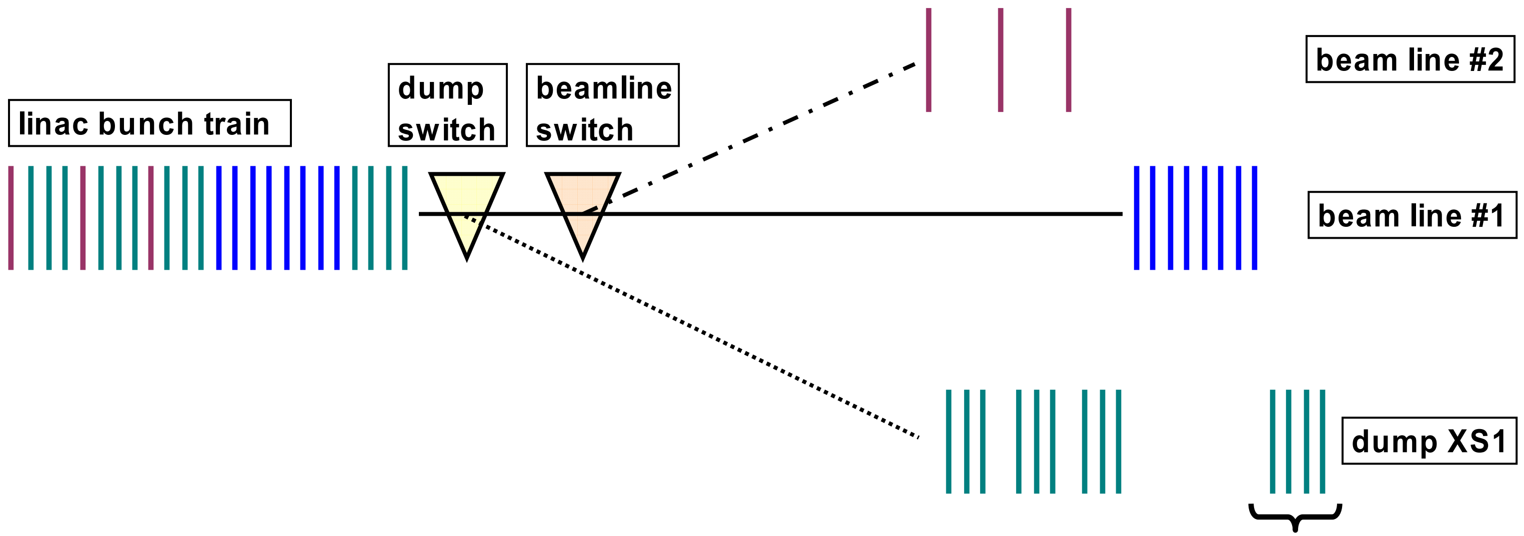
Overhead designed into tech sub-systems also permits higher duty cycle/rep rate of the linac (***if*** injector can support that) – depending on beam energy:

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



Fast intra-bunch train feedback system → "Steering bunches"

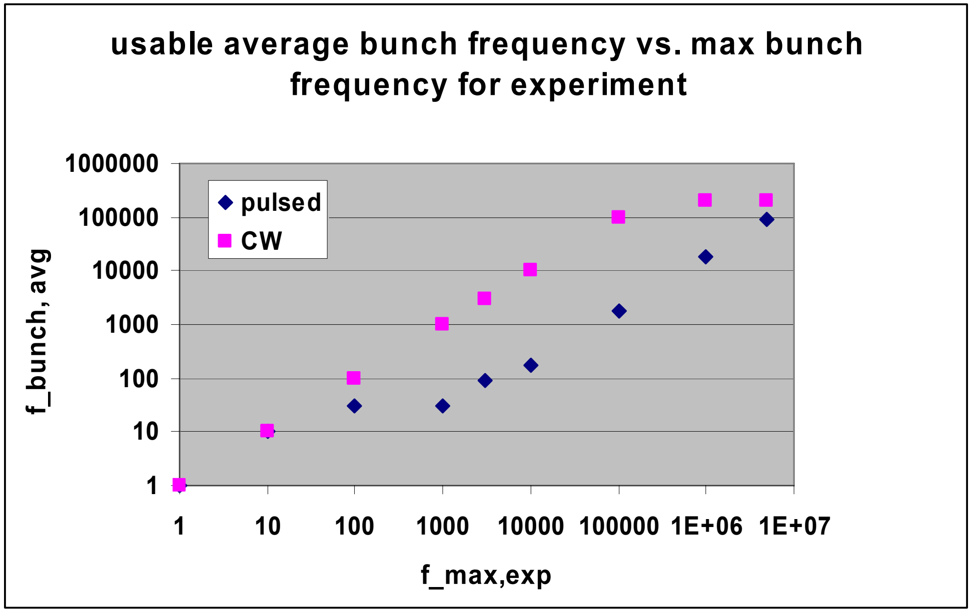
V. Schlott et al.,
EPAC2006, THPCH096

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}	$2\cdot10^{7}$
Bunch frequency	180 kHz
Unloaded quality factor Q_0	$2\cdot10^{10}$
2K cryogenic load	≈3.5 kW

Accelerator technology - collaborative effort

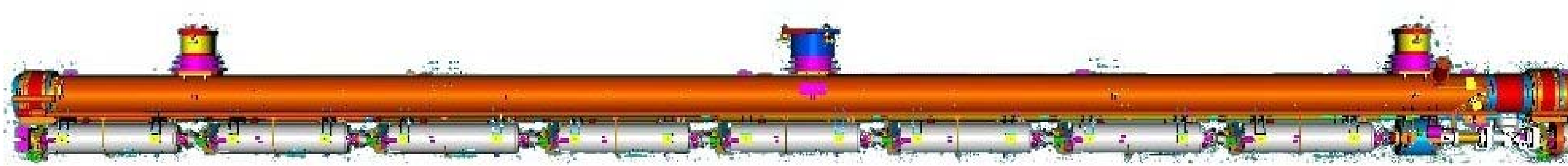
Industrial study module assembly (M6)

2 more cryostats (TTF3/INFN) ordered

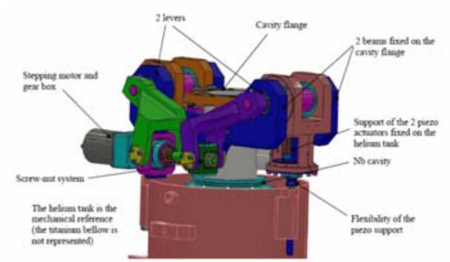
Superferric magnet (CIEMAT)

BPM (Saclay)

Integrated HOM absorber

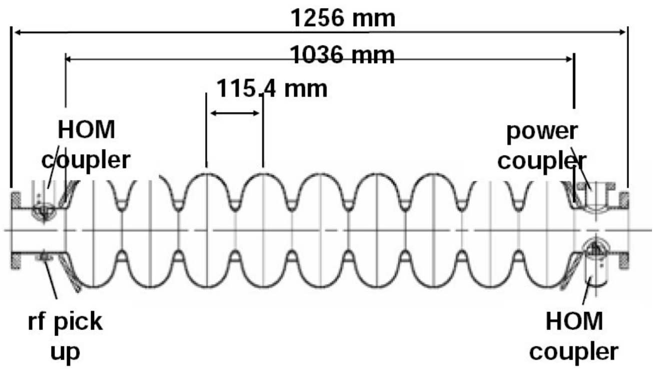


Length quantized n·λ/2 (possibility of ERL)

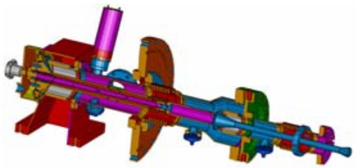


Tuner w/piezo (Saclay)

Industrialization in preparation



LLRF development (collab. Warsaw/Lodz)



TTF3-type coupler

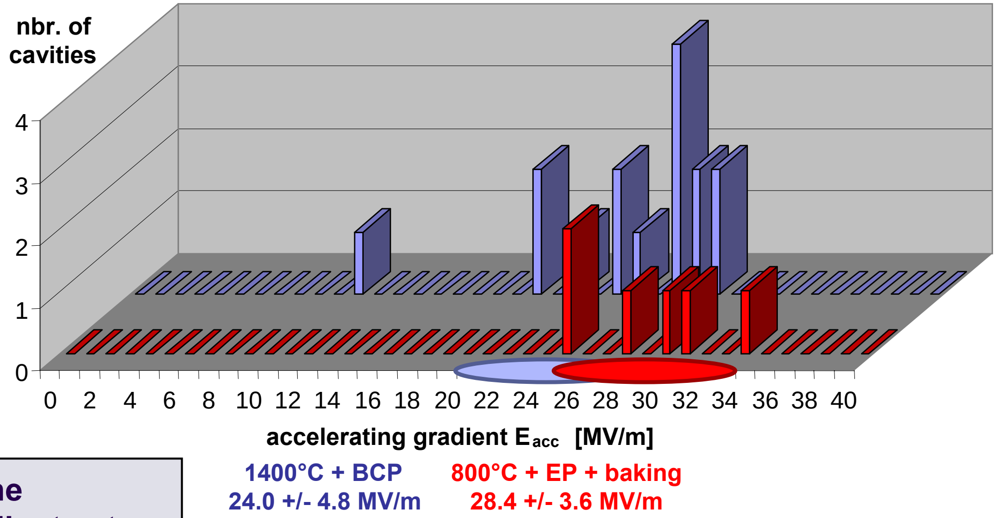
Industrialization launched (Orsay)

More on acc. collaboration (not exhaustive):

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

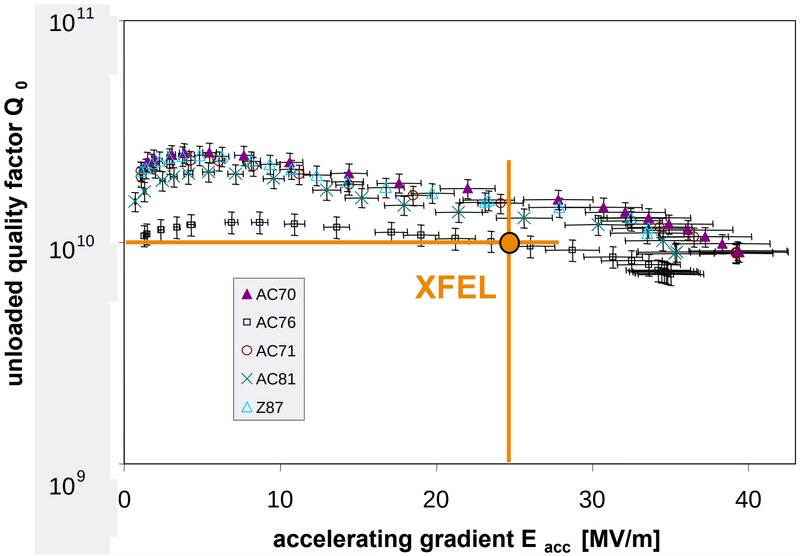
- Relation to ILC: clearly organizationally separated projects (different communities, different time-line for realization), but:
  - **Keeping in mind (on both sides) the possible synergies and making the best out of this can be at least as beneficial as keeping the projects strictly separate**

Results From Cavity Acceptance Tests



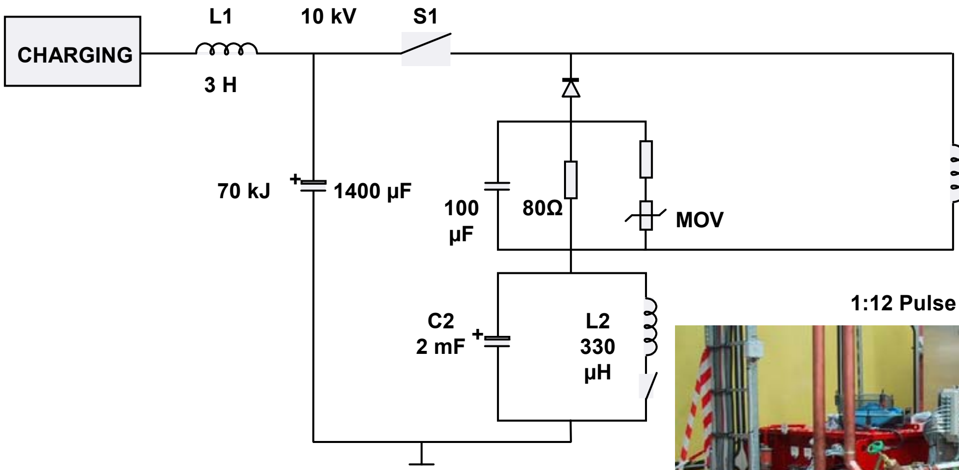
Comparison of the accelerating gradients at $Q=10^{10}$ in the first performance test after the full preparation sequences using etching with post-purification at 1400°C (blue) and electro-polishing with 800°C annealing (red).

'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.

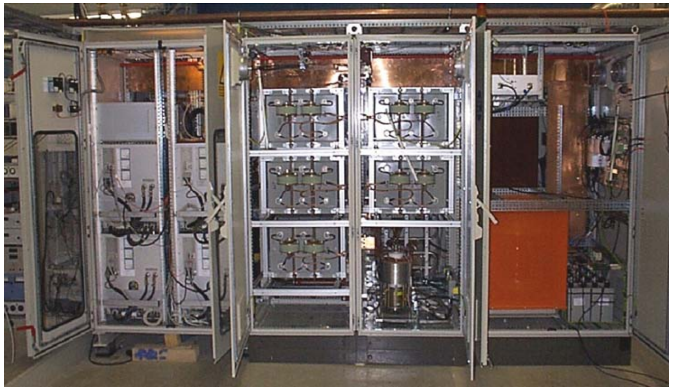


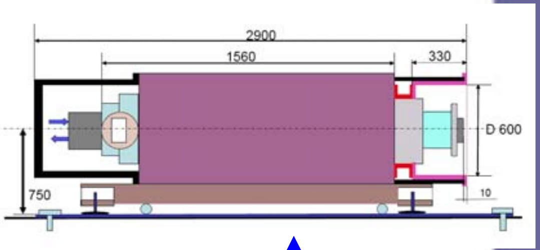
EPAC2006 prize: → Lutz Lilje, DESY

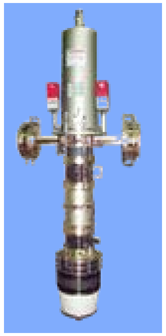
High Power RF System
(Modulator, Pulse Cable, Pulse Transformer, Klystron)



1:12 Pulse Transformer



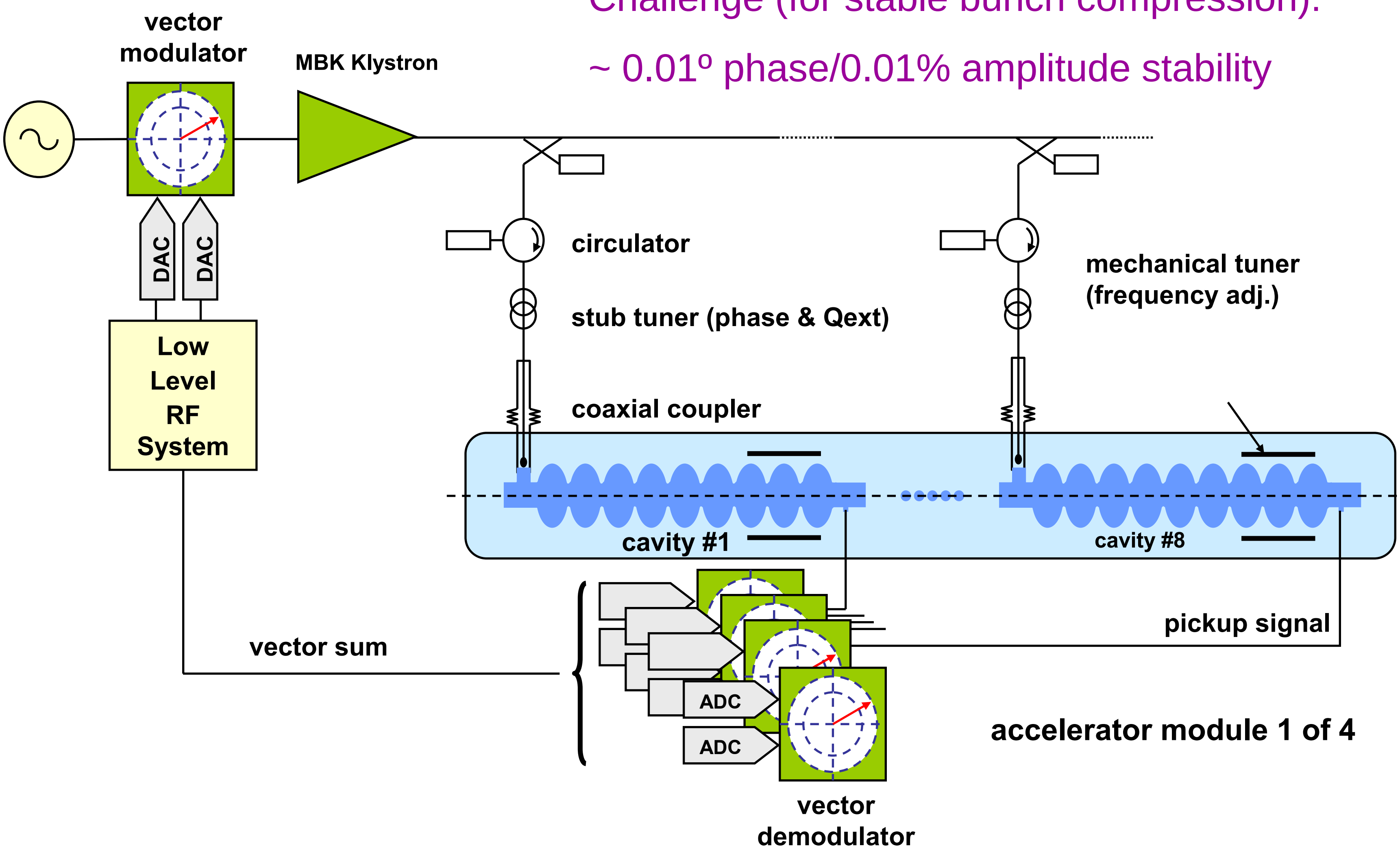




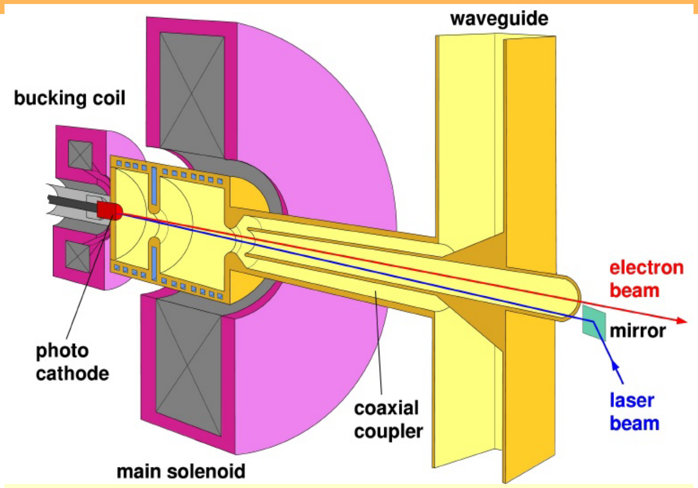
Low Level RF Control

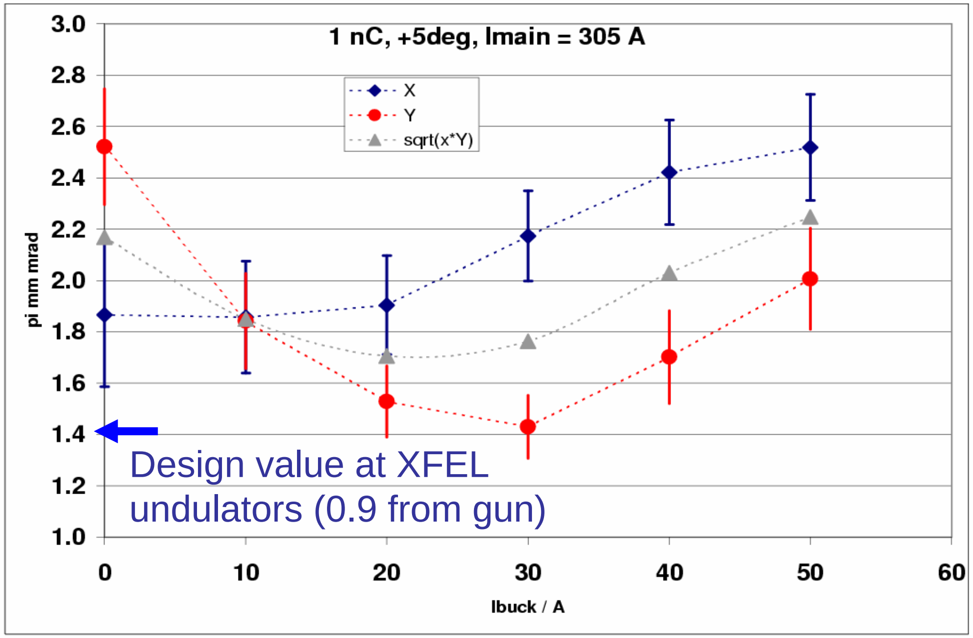
Challenge (for stable bunch compression):

~ 0.01º phase/0.01% amplitude stability



Injector development (DESY Zeuthen & FLASH)



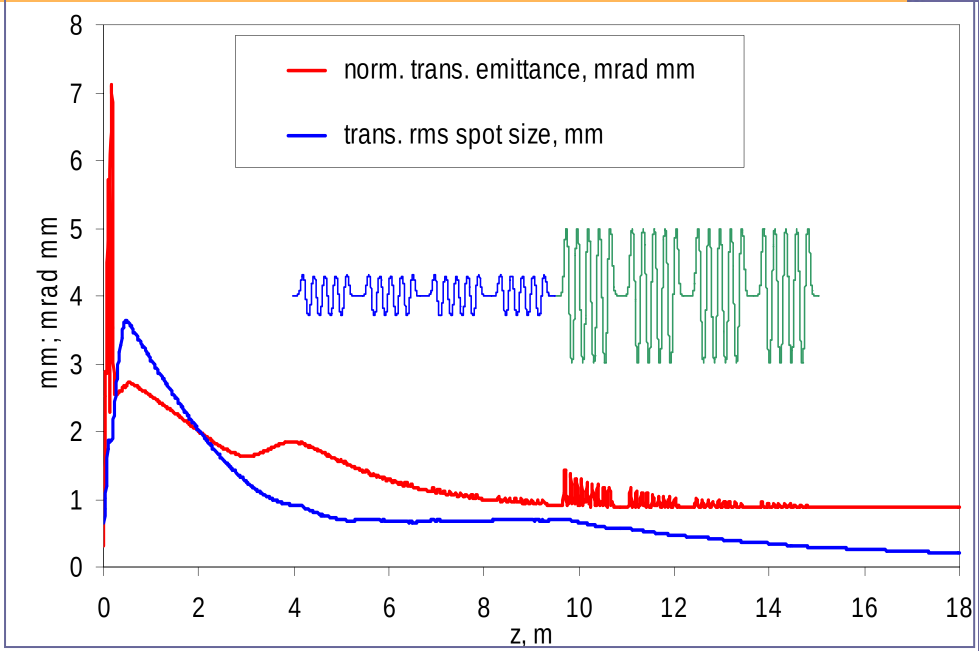


On-going programme:

- **increase the gradient on the cathode from 40 MV/m to 60 MV/m**
- **further improve the transverse and longitudinal laser profile (collab. Max-Born Institute, Berlin)**
- **PITZ gun now part of FLASH injector**

Injector – Emittance Simulations

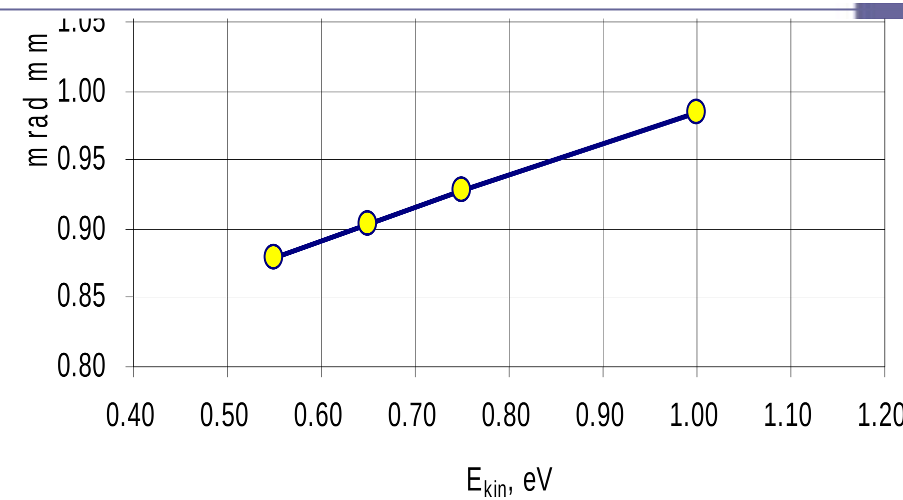
Charge	nC	1
Laser Pulse length (total)	ps	20
Laser Pulse rise/fall time	ps	2
Laser spot radius	mm	1.1
Peak electric field on the cathode	MV/m	60
Solenoid centre position (w.r.t. cathode)	m	0.41
Solenoid peak field	T	0.19
Accelerator module: -Gradient Cavities 1 - 4 -Gradient Cavities 5 - 8	MV/m MV/m	7.5 25



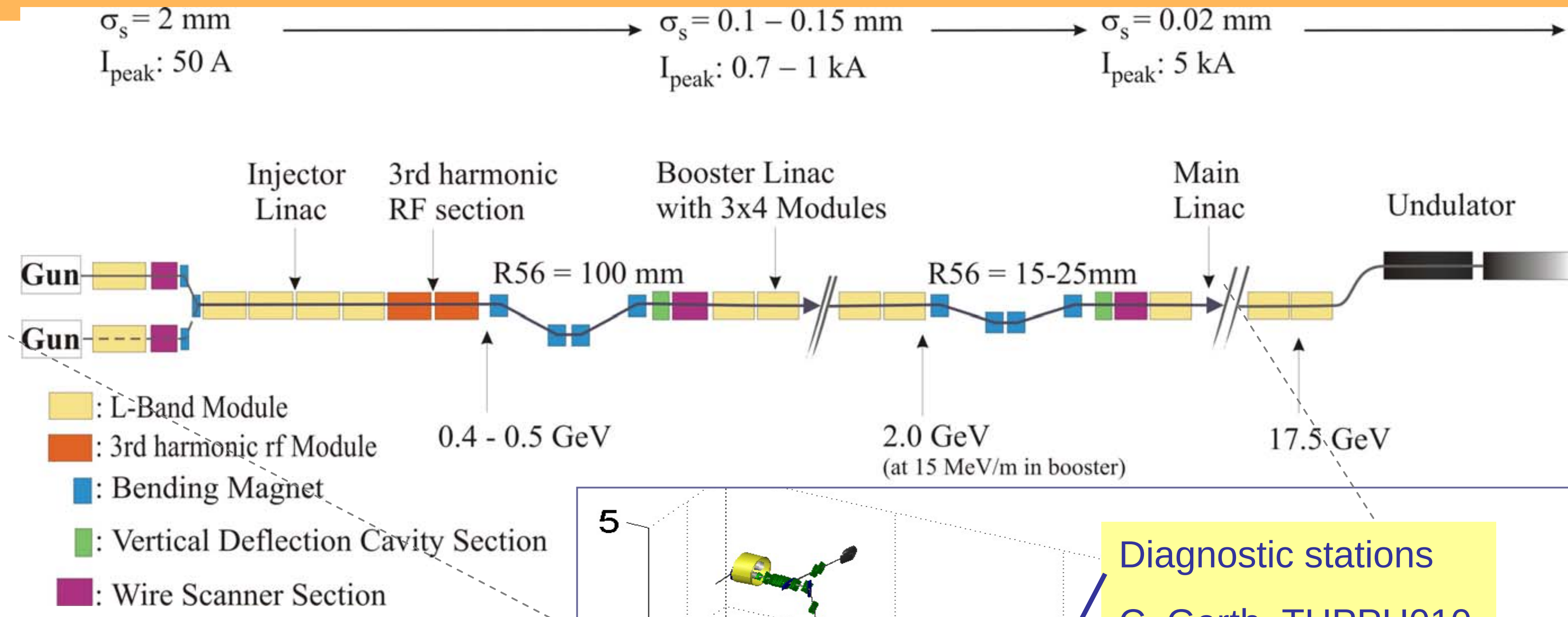
Posters:

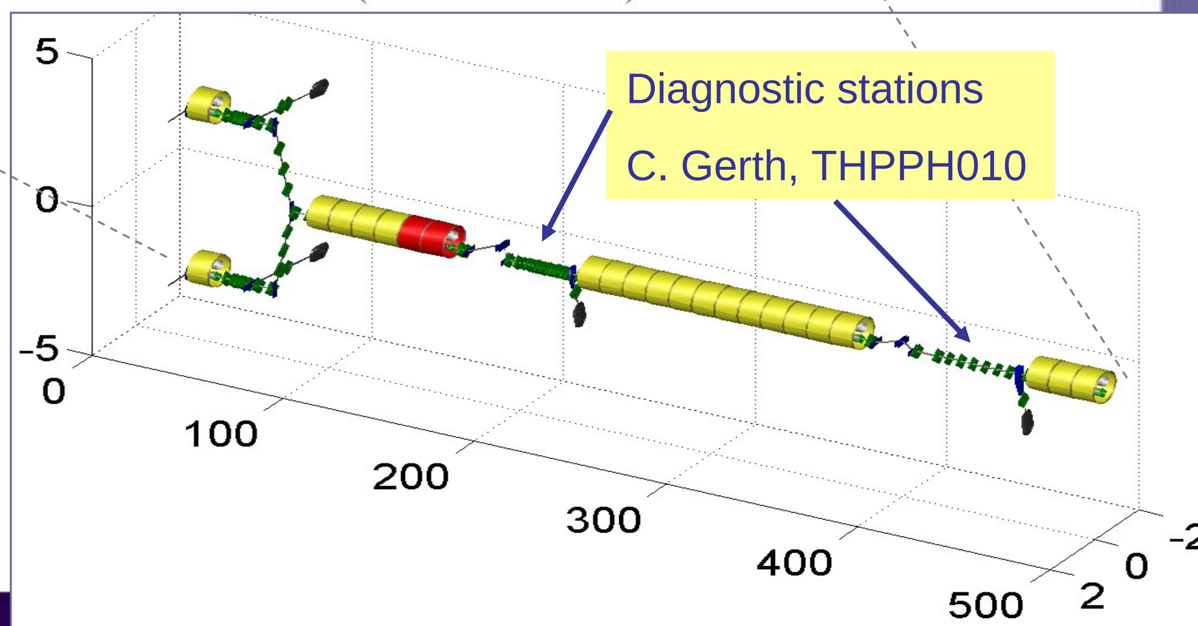
THPPH012,
THPPH013,THPPH017,
THPPH019,
THPPH020,THPPH021,
THPPH022,THPPH023,
THPPH024

Final emittance versus thermal emittance (after optimization)



Bunch Compression

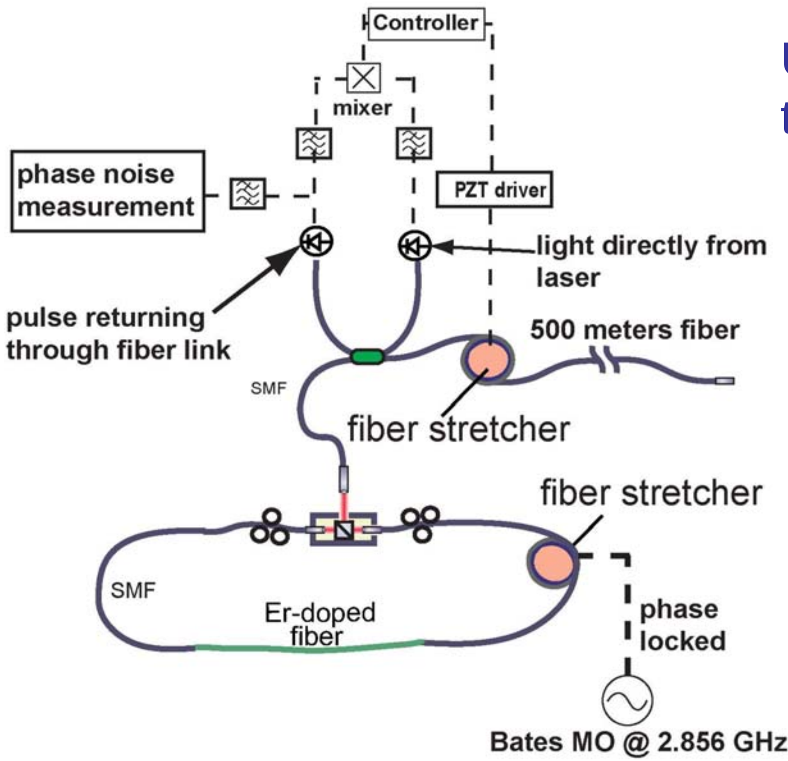




Simulation codes:

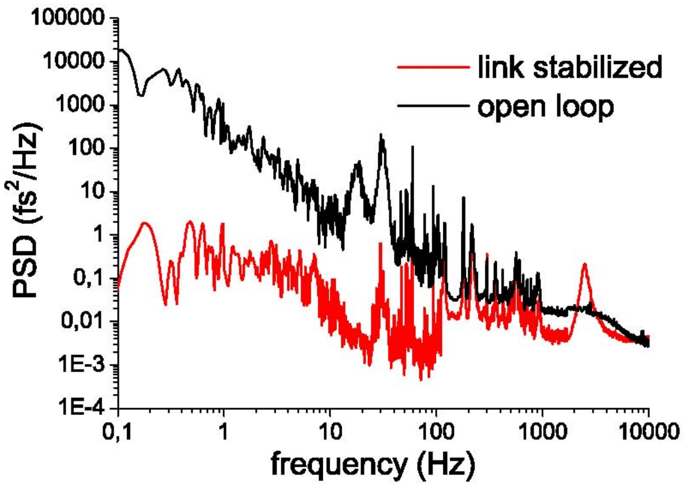
M. Dohlus,
EPAC2006, WEYFI01

Diagnostics, timing & synchronization in fs regime



Uni HH/DESY & MIT: 500m fiber link tested with 12fs noise level

EPAC2006 student prize → A. Winter, Uni HH



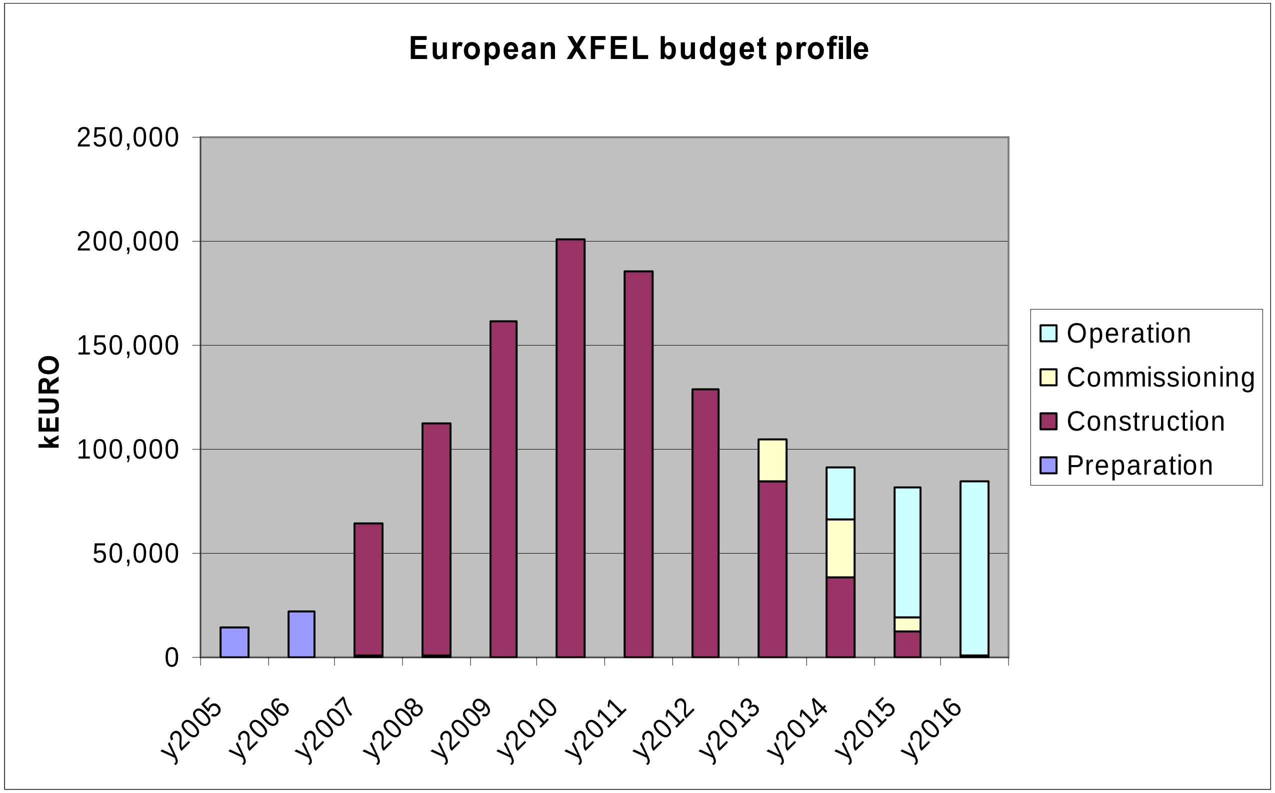
→Talk by J.-W. Kim, TUBAU02

Large amount of diagnostics development ongoing at FLASH (deflecting mode cav./slice diagn., EOS methods, arrival time detector,…) → talk B. Schmidt, THCAU01

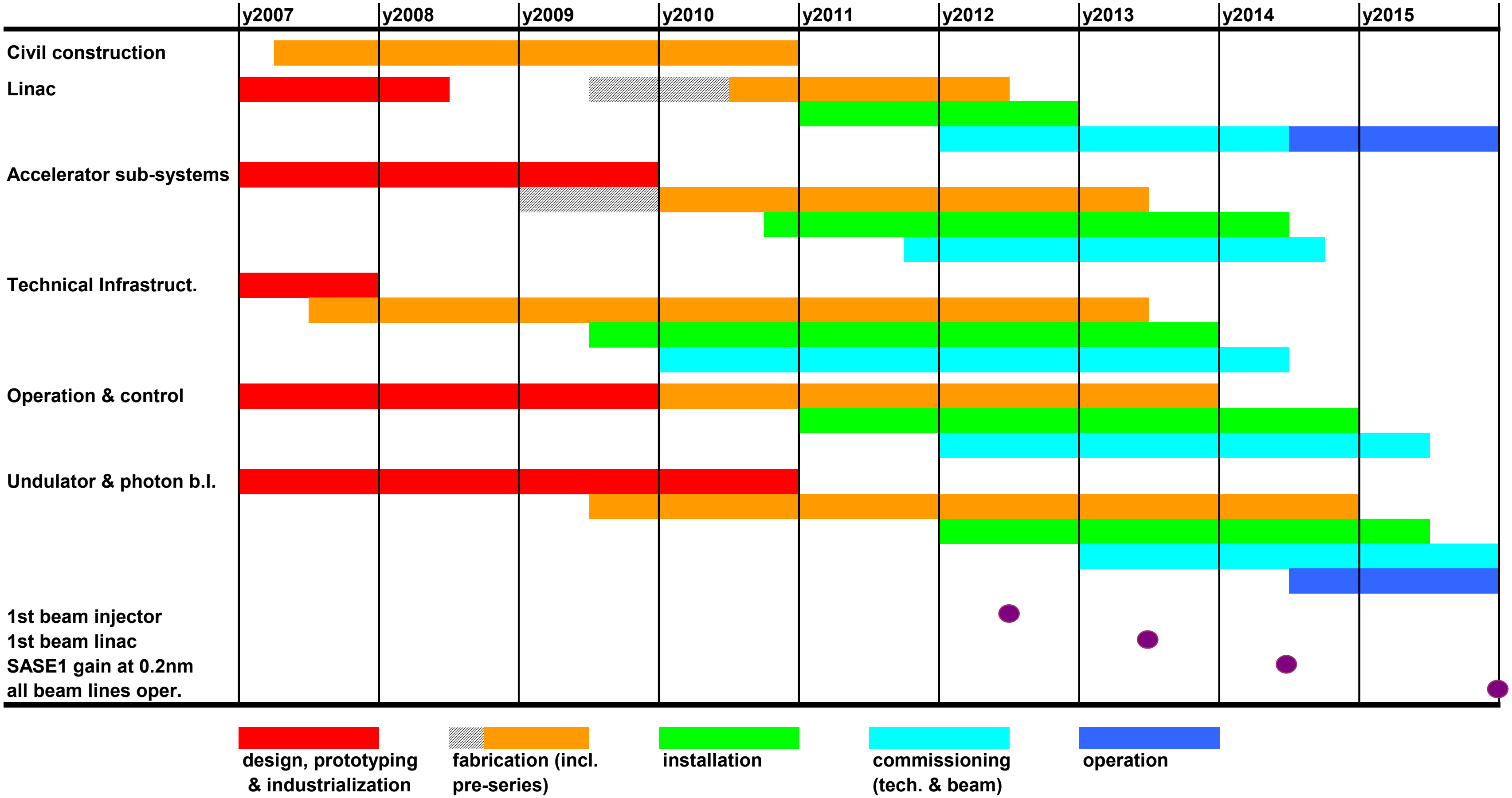
Project cost & schedule

Construction cost in year 2005 prices: **986 M€** (736 M€ capital investment, 250 M€ personnel incl. overhead)

Yearly operation cost: **83 M€** (incl. e.g. user support)

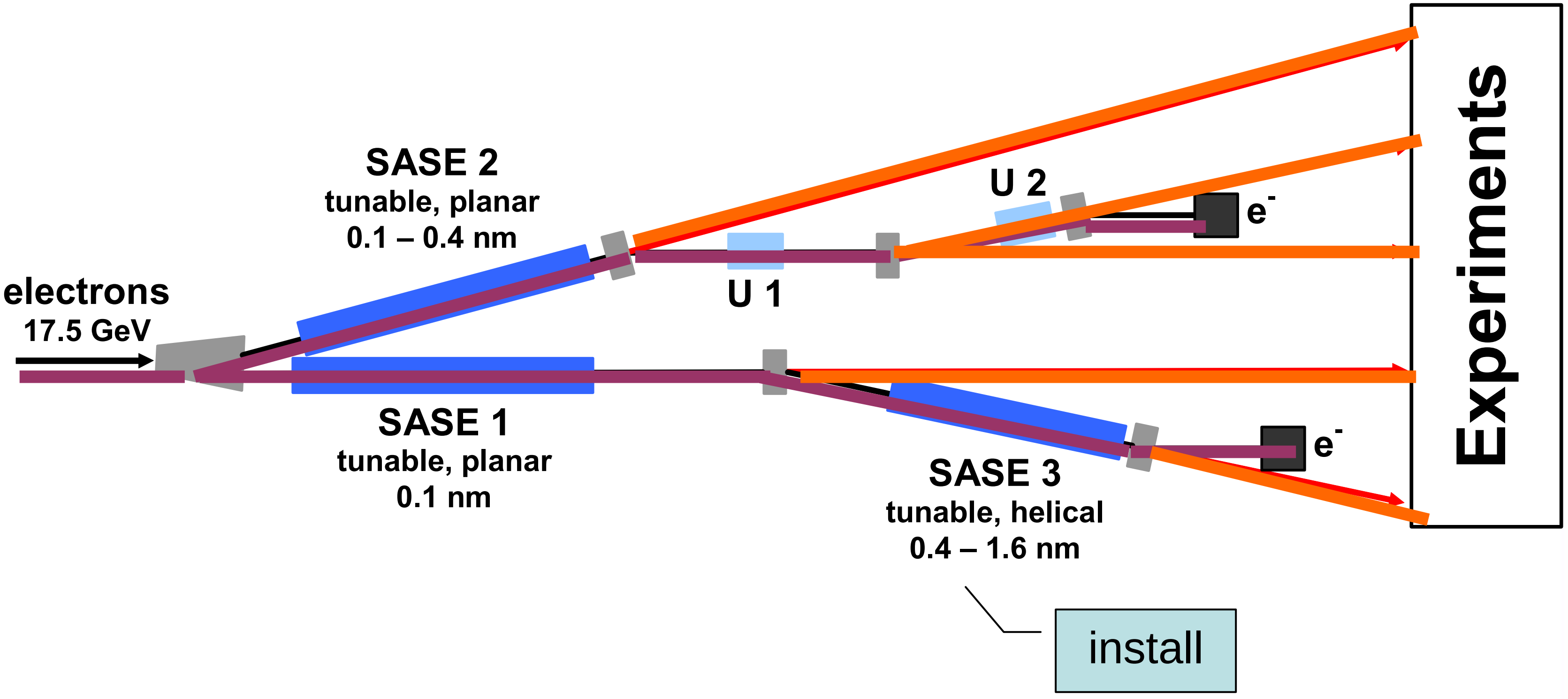


Project cost & schedule cont'd



Beam line commissioning (2013 – 2015)

Sequence of beam line commissioning



The end