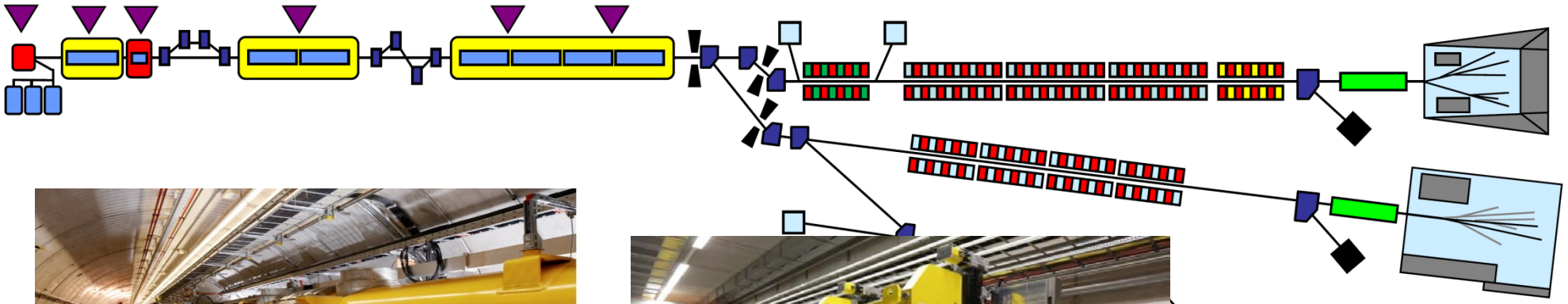
From TTF to FLASH2020+

FLASH: the pioneering XUV and soft X-ray FEL User Facility

Siegfried Schreiber

FLASH2020+
Kick-Off Meeting

3-July-2020



HELMHOLTZ RESEARCH FOR GRAND CHALLENGES

DESY.

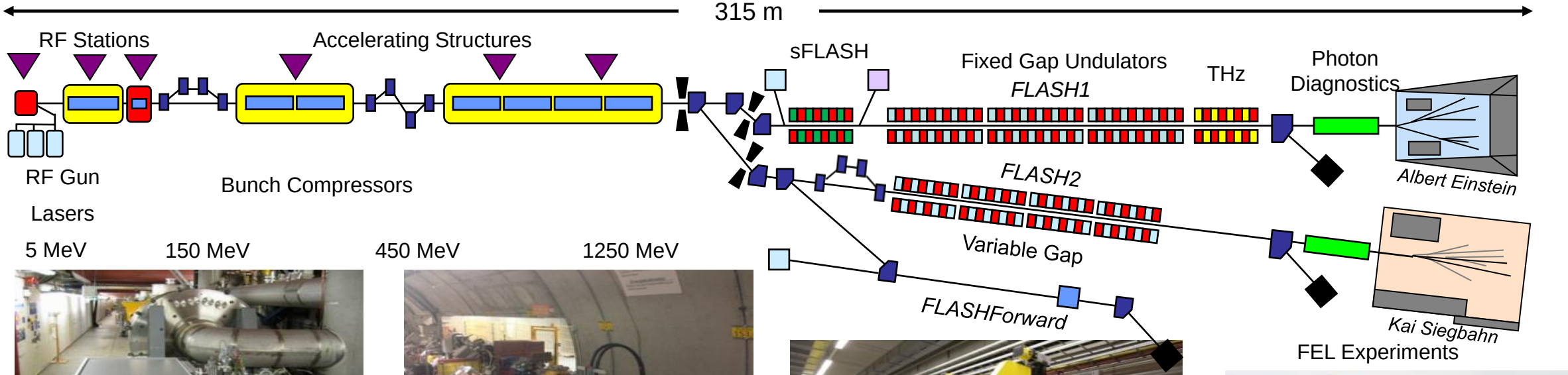
FLASH Facility 2020 – two beamlines act in tandem

3rd harmonic sc module 3.9 GHz

TESLA type superconducting accelerating modules 1.3 GHz

FLASH1 fixed gap undulators

FLASH1 Albert Einstein Hall



Normal conducting 1.3 GHz RF gun
Ce_2Te cathode / 3 injector lasers

Extraction to FLASH2

FLASH2 variable gap undulators

FLASH2 Kai Siegbahn Hall

FLASH delivers >5000 XUV and soft X-ray pulses per second

3rd harmonic sc module 3.9 GHz

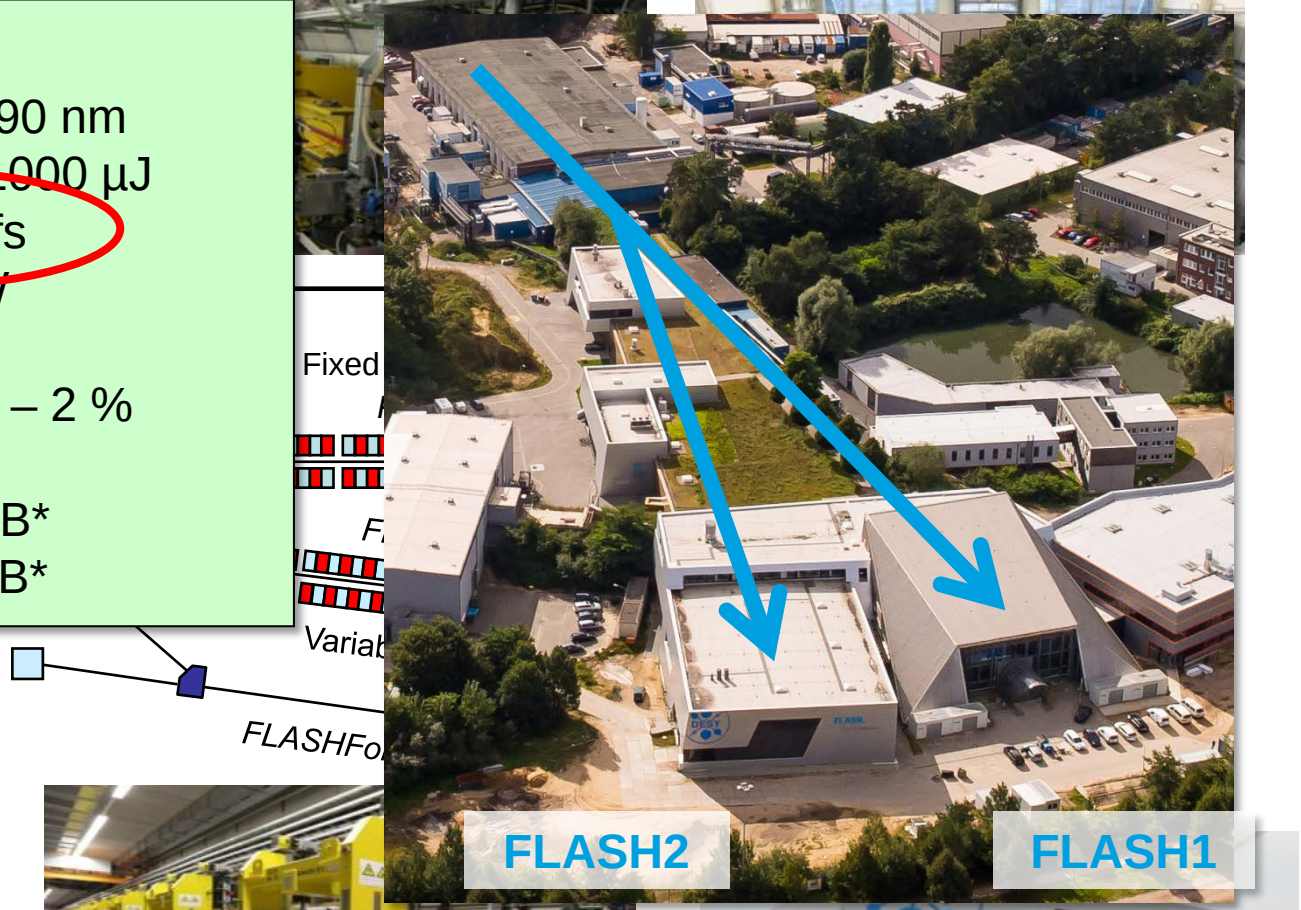
TESLA type superconducting accelerating modules 1.3 GHz

FLASH1 fixed gap undulators

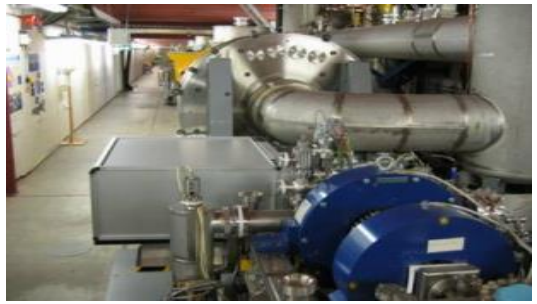
FLASH1 Albert Einstein Hall

FEL Radiation Parameter FL1 / FL2

Wavelength range (fundamental)	4.2 – 51 nm / 4 – 90 nm
Average single pulse energy	1 – 500 µJ / 1 – 1000 µJ
Pulse duration (FWHM)	< 30 – 200 fs
Peak power (from av.)	1 – 5 GW
Pulses per second	10 – 5000
Spectral width (FWHM)	0.7 – 2 % / 0.5 – 2 %
Photons per pulse	10^{11} – 10^{14}
Average Brilliance	10^{17} – 10^{21} B*
Peak Brilliance	10^{28} – 10^{31} B*



5 MeV 150 MeV 450 MeV 1250 MeV



Normal conducting 1.3 GHz RF gun
Ce_2Te cathode / 3 injector lasers

Extraction to FLASH2

FLASH2 variable gap undulators

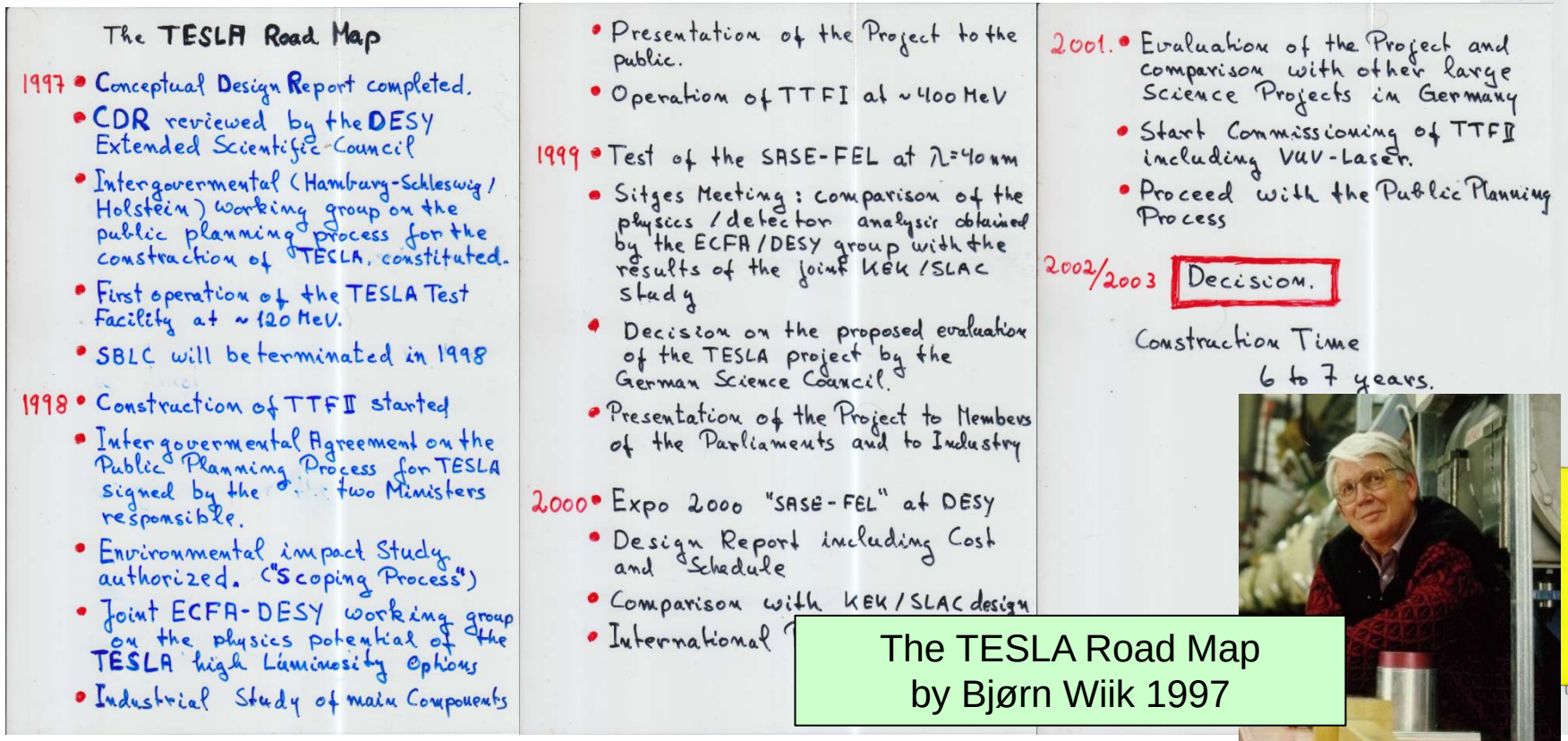
FLASH2 Kai Siegbahn Hall

TESLA Linear Collider Project

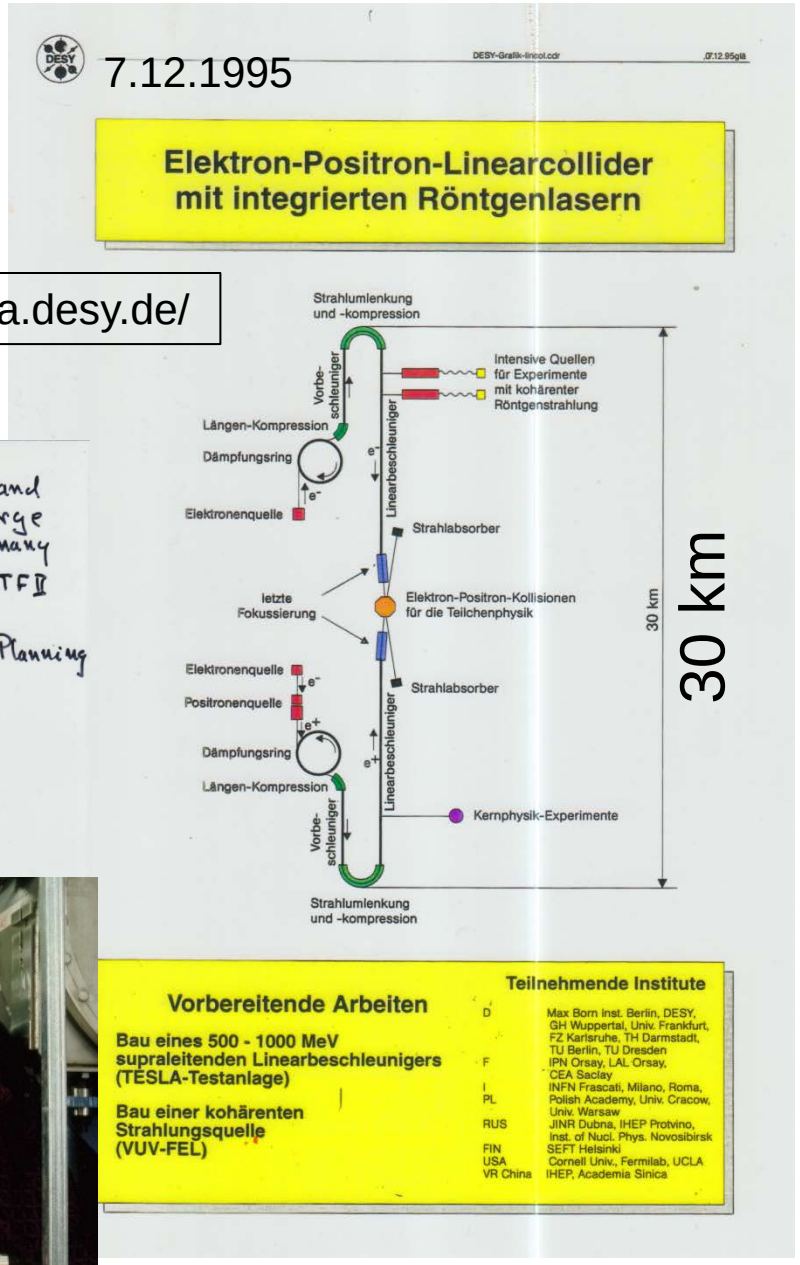
e+ e- Linear Collider with integrated X-ray Free-Electron Laser

- TESLA Test Facility (TTF) was constructed in the mid 1990's at DESY to test the feasibility of superconducting accelerator technology in the framework of the TESLA Linear Collider project

https://tesla.desy.de/



The TESLA Road Map
by Bjørn Wiik 1997



TESLA Linear Collider Project

e+ e- Linear Collider with integrated X-ray Free-Electron Laser

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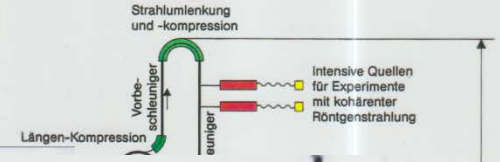
7.12.1995

Elektron-Positron-Linearcollider mit integrierten Röntgenlasern



30 km

1997 •

2000 •

2001. • Evaluation of the Project and comparison with other large Science Projects in Germany

1998

1999 • Te

• Start Commissioning of TTF II including VUV-Laser.

• Environmental impact Study authorized. ("Scoping Process")
• Joint ECFA-DESY working group on the physics potential of the TESLA high Luminosity Options
• Industrial Study of main Components

and "Schedule
• Comparison with KEK / SLAC design
• International Project Organisation

Bjørn Wiik 1997

(TESLA-Testanlage)

Bau einer kohärenten Strahlungsquelle (VUV-FEL)

F	CEA Saclay
I	INFN Frascati, Milano, Roma,
PL	Polish Academy, Univ. Cracow, Univ. Warsaw
RUS	JINR Dubna, IHEP Protvino, Inst. of Nucl. Phys. Novosibirsk
FIN	SEFT Helsinki
USA	Cornell Univ., Fermilab, UCLA
VR China	IHEP, Academia Sinica

TESLA Linear Collider Project

e+ e- Linear Collider with integrated X-ray Free-Electron Laser

- TESLA Test Facility (TTF) was constructed in the mid 1990's at DESY to test the feasibility of superconducting accelerator technology in the framework of the TESLA Linear Collider project

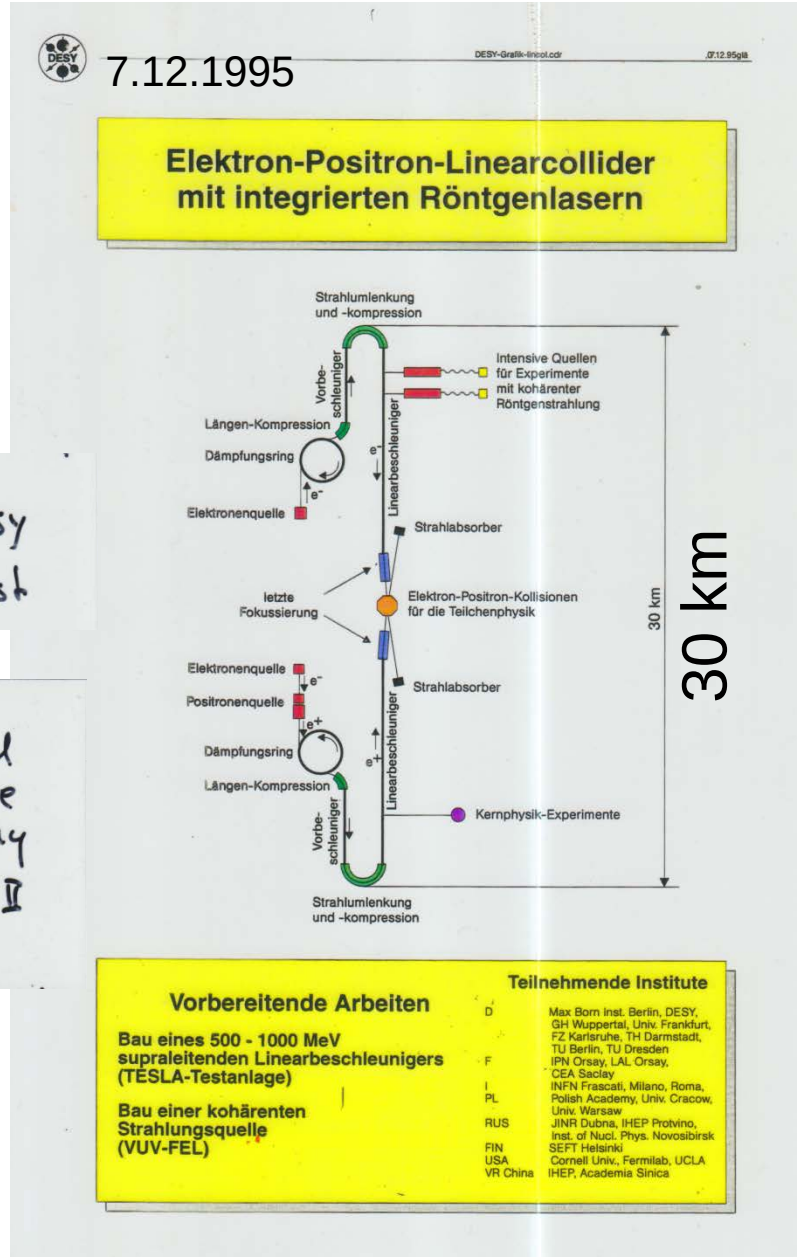
1997 • First operation of the TESLA Test Facility at ~120 MeV.
• SBLC will be terminated in 1998

1998 • Construction of TTF II started
• Presentation of the Project to the public.
• Operation of TTF I at ~400 MeV

1999 • Test of the SASE-FEL at λ=40 nm

2000 • Expo 2000 "SASE-FEL" at DESY
• Design Report including Cost

2001. • Evaluation of the Project and comparison with other large Science Projects in Germany
• Start Commissioning of TTF II including VUV-Laser.



Björn Wiik 1997

TESLA Linear Collider Project

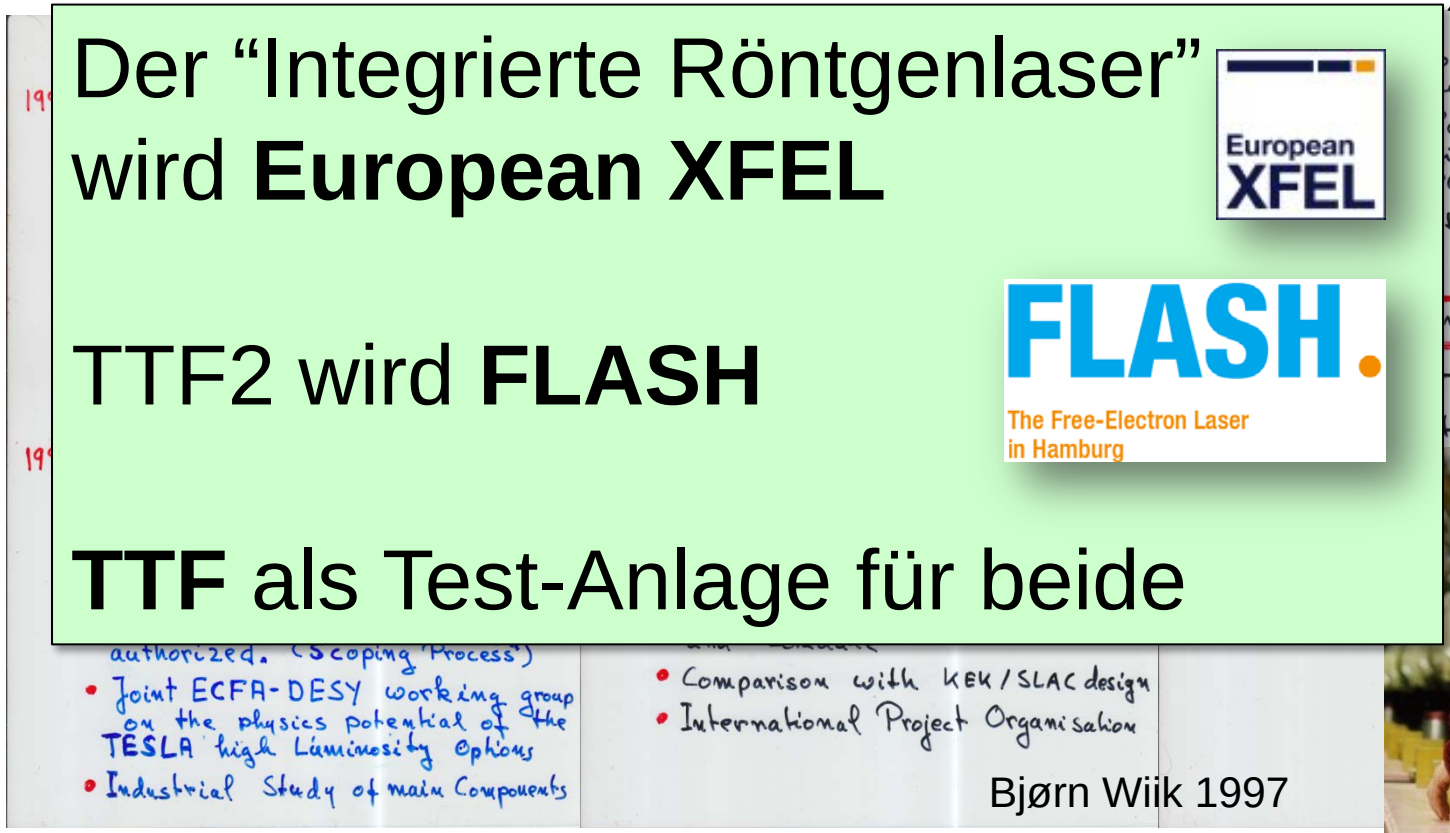
e+ e- Linear Collider with integrated X-ray Free-Electron Laser

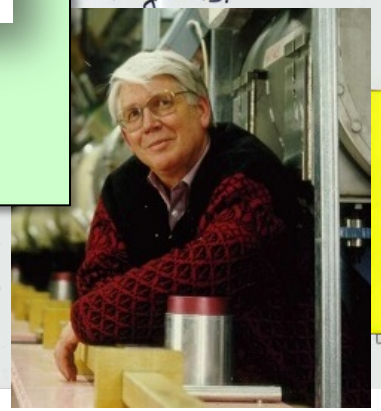
- TESLA Test Facility (TTF) was constructed in the mid 1990's at DESY to test the feasibility of superconducting accelerator technology in the framework of the TESLA Linear Collider project

Der "Integrierte Röntgenlaser" wird **European XFEL**

TTF2 wird **FLASH**

TTF als Test-Anlage für beide



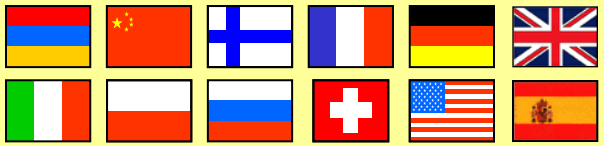


The TESLA Collaboration

Increase cavity gradient from 5 to 25 MV/m - Reduce costs by a comparable factor

Common effort of almost all laboratories using s.c. accelerating cavities, e.g.

- (CERN), Cornell, DESY, INFN, (KEK), Saclay, TJNL
- 53 partners from 12 countries

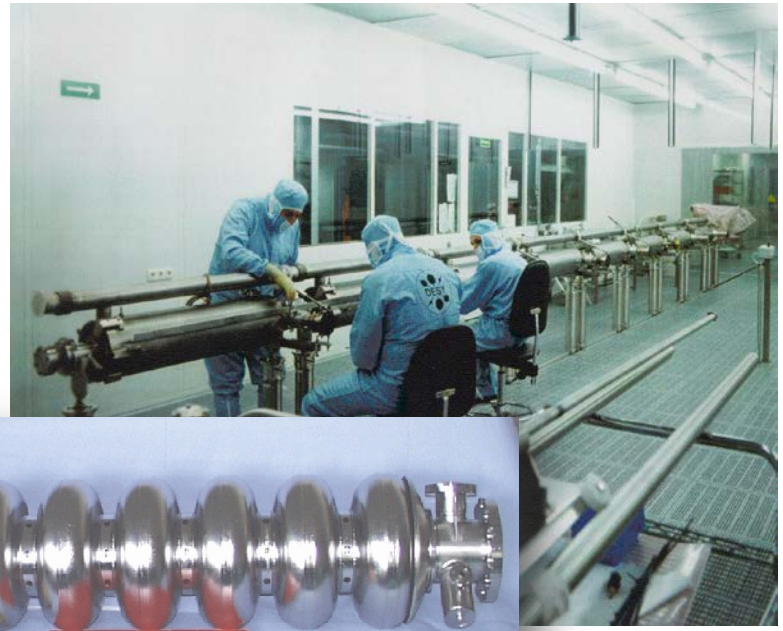


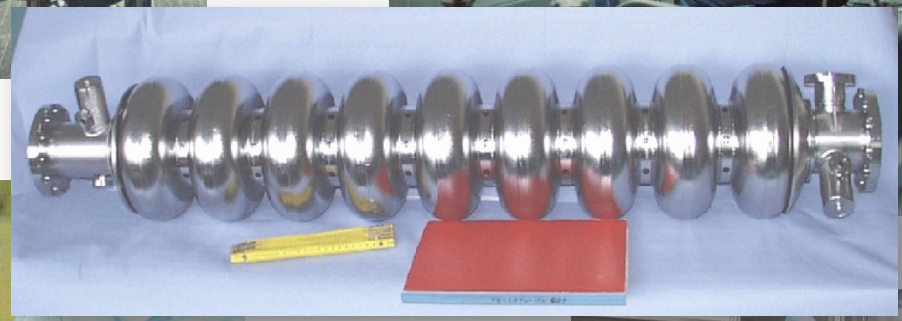
Improved material quality check

New cavity preparation procedures

- 1400 ºC annealing with a titanium getter
- ultra-pure, high pressure water rinsing
- high peak power processing

H. Weise ESFRI XFEL Workshop 30./31.10.2003





TESLA Test Facility

From a conceptual design report to reality

- TTF goes into Hall 3

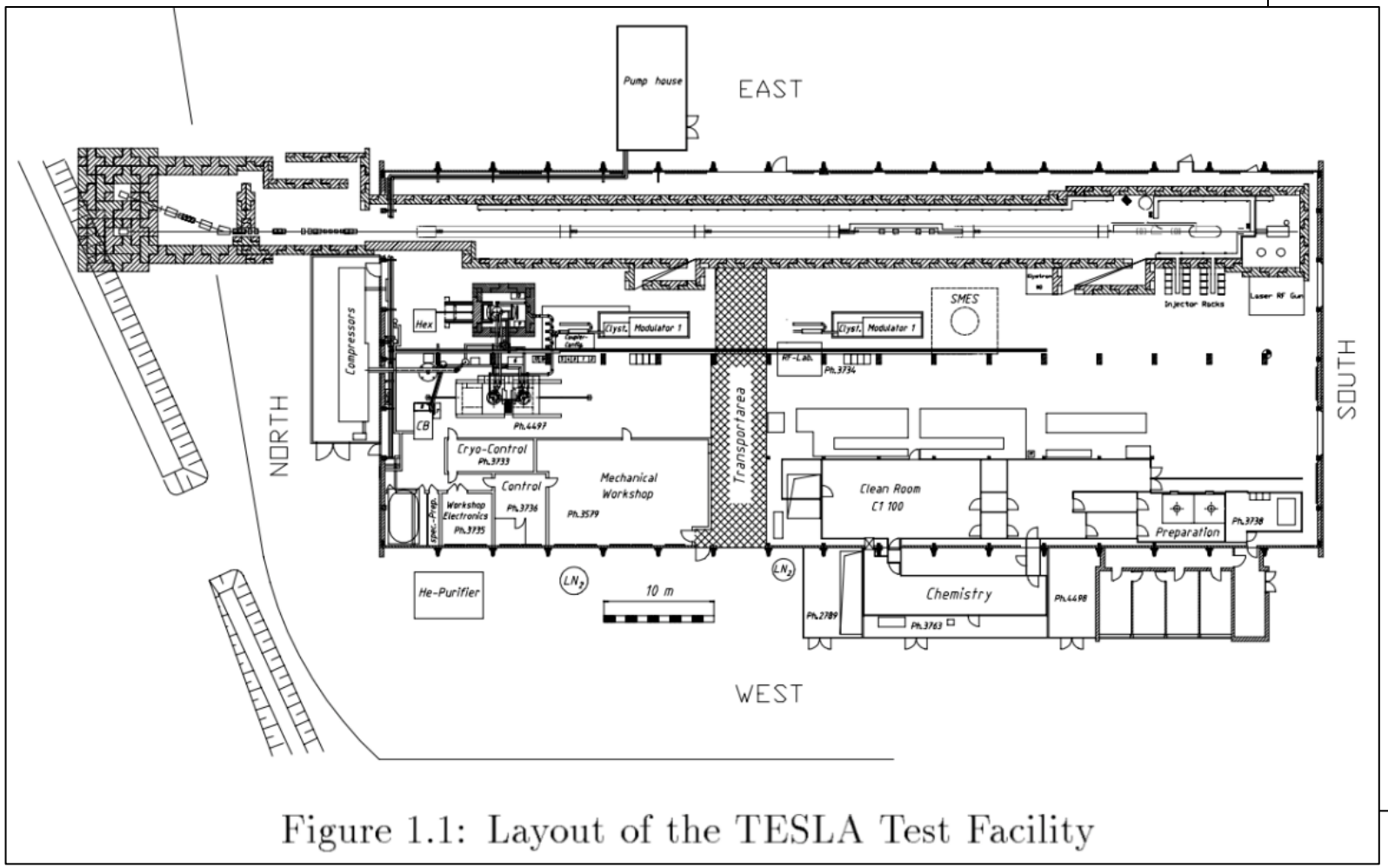


Figure 1.1: Layout of the TESLA Test Facility

TESLA Test Facility Linac Design Report

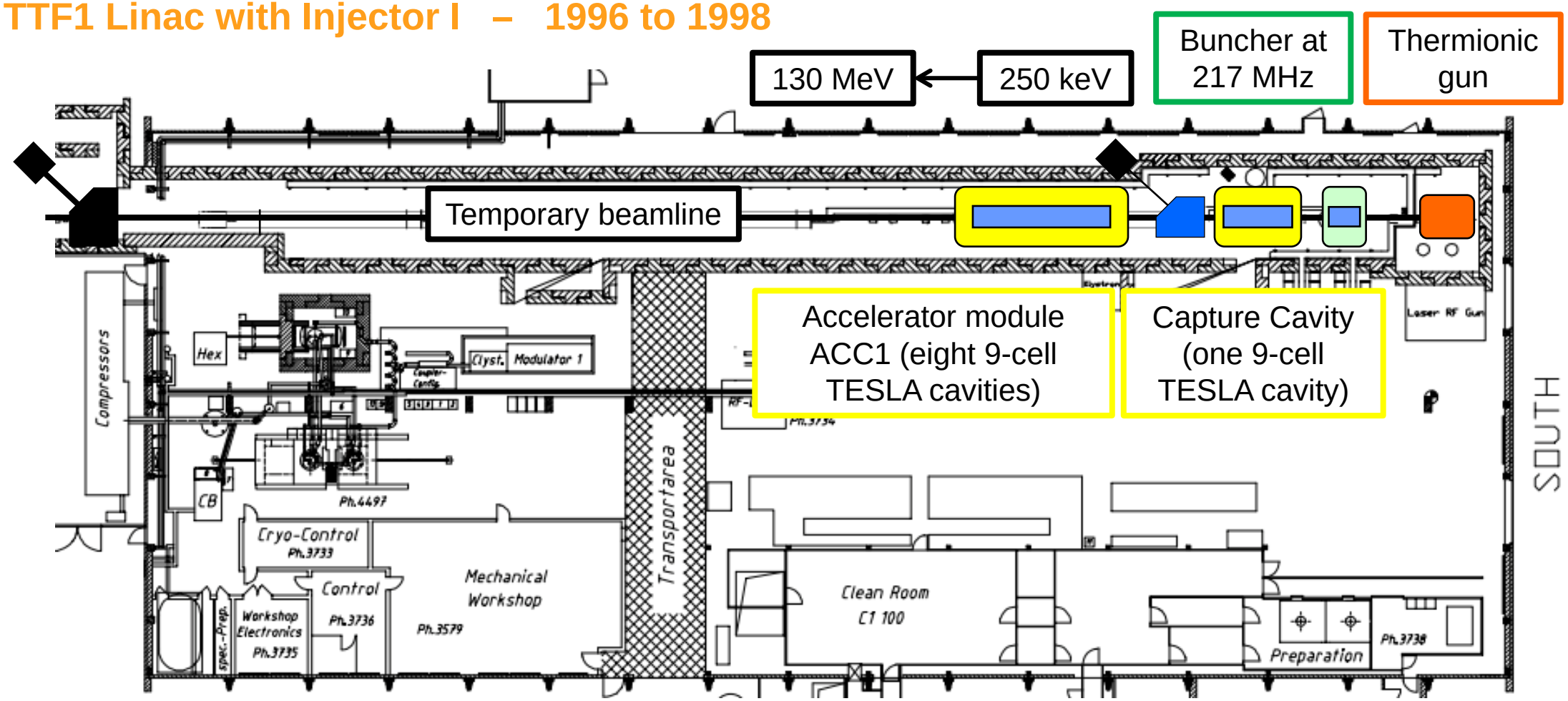
Editor: D. A. Edwards

Version 1.0
1 March 1995

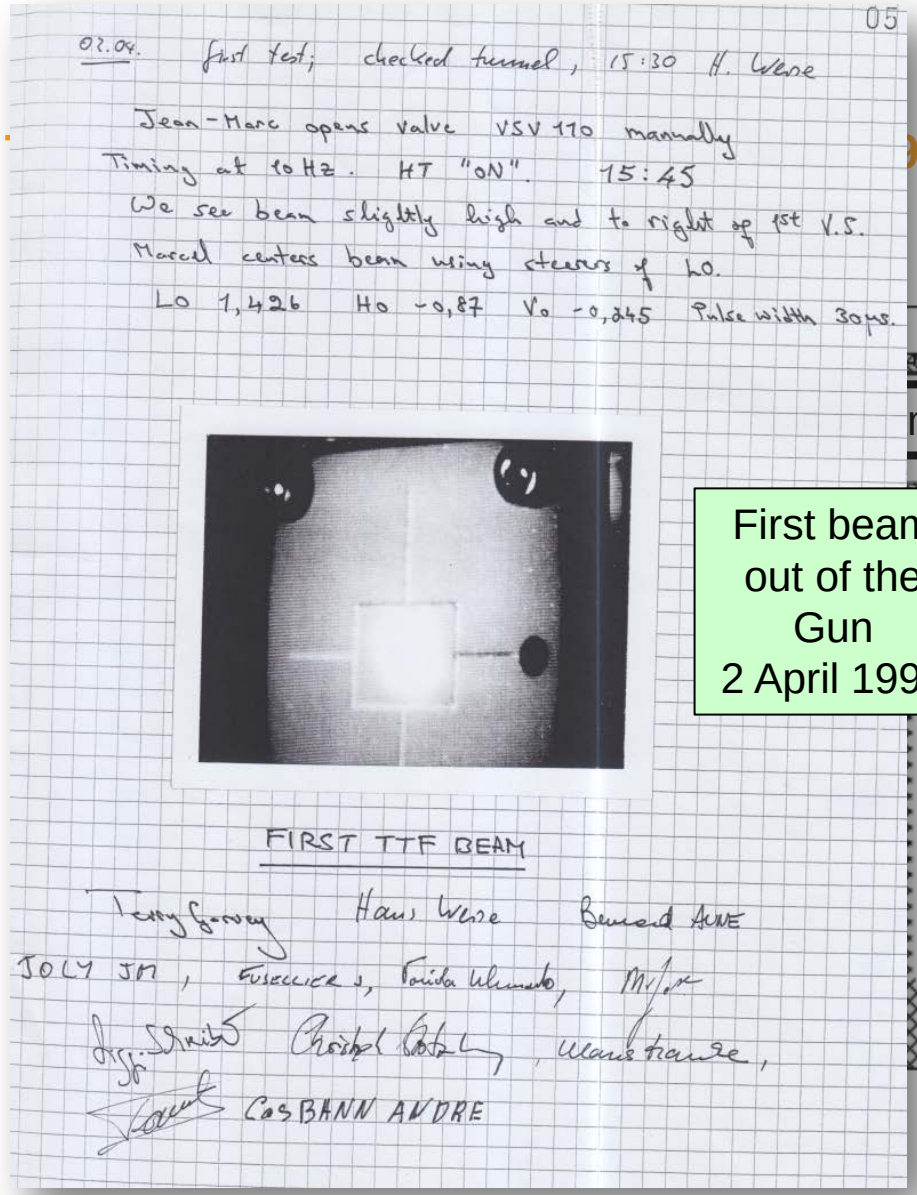
flash.desy.de/ -> Reports -> TESLA Reports 1995

First electron beam accelerated by TESLA type cavities – 8 mA within 800 µs at 10 Hz with 217 MHz beam achieved

TTF1 Linac with Injector I – 1996 to 1998



First electron beam accelerated by TESLA type cavities – with 217 MHz beam achieved



998

130 MeV ← 250 keV

Buncher at 217 MHz

Thermionic gun

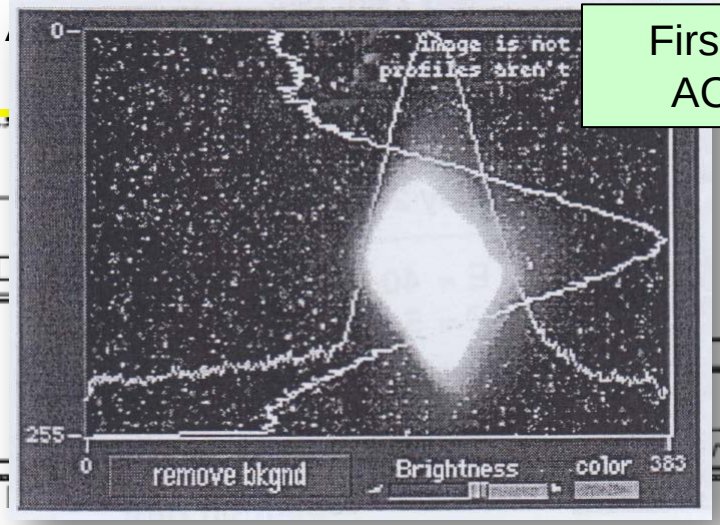
mline

First beam out of the Gun 2 April 1996

Accelerator module

Capture Cavity

First beam through ACC1 May 1997



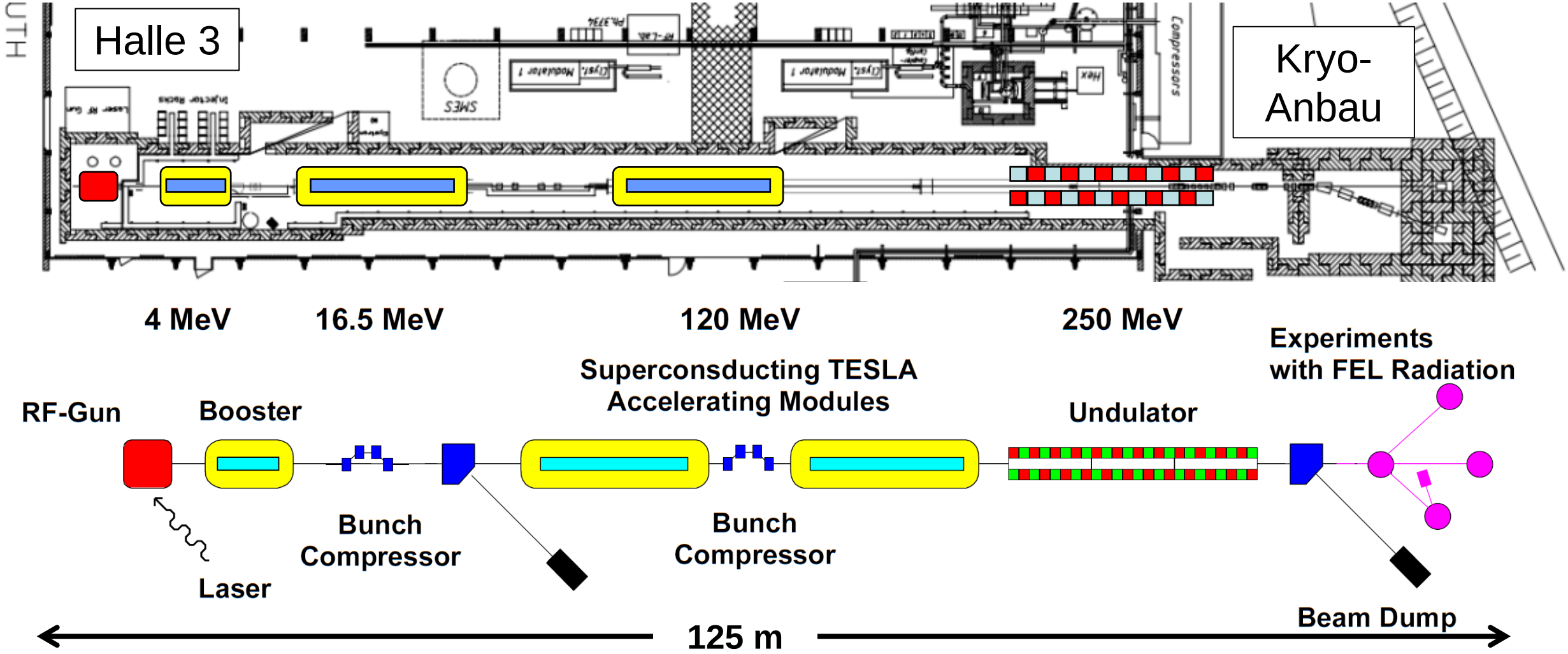
Transportarea

Laser RF Gun

Ph.3738

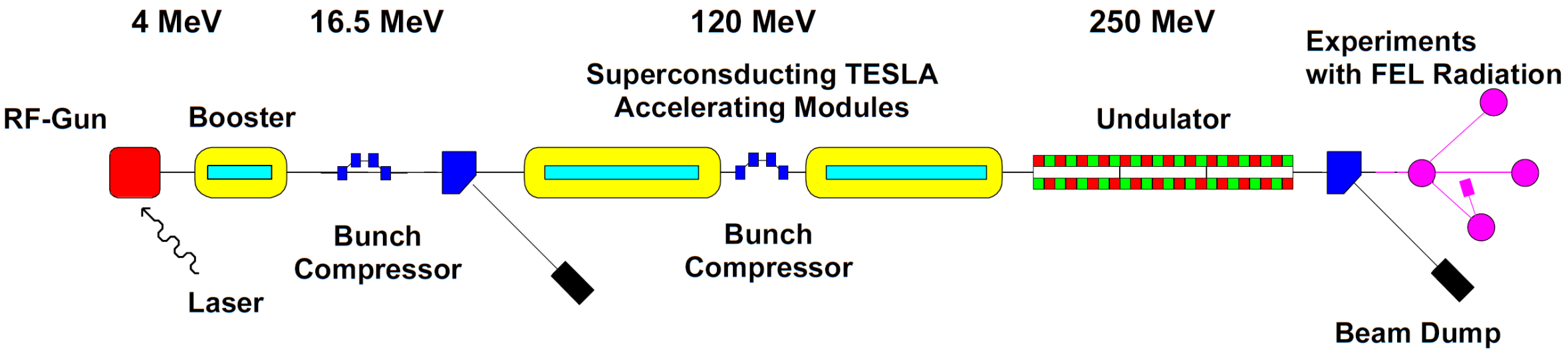
From a Test Bed for TESLA to a VUV Free-Electron Laser

TTF1 VUV-FEL with Injector II – 1998 to 2002



TTF1 VUV-FEL with Injector II – 1998 to 2002

Laser → Cathode → RF-Gun → Capture Cavity → Bunch Compressor BC1 → Module → Bunch Compressor BC2 → Module → Collimator → Undulator → Experiment → Beam Dump



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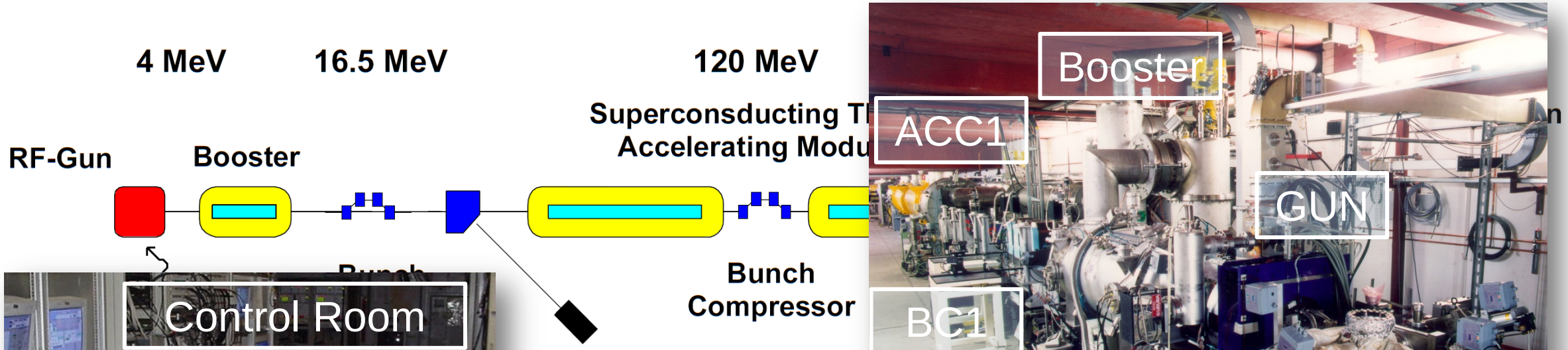

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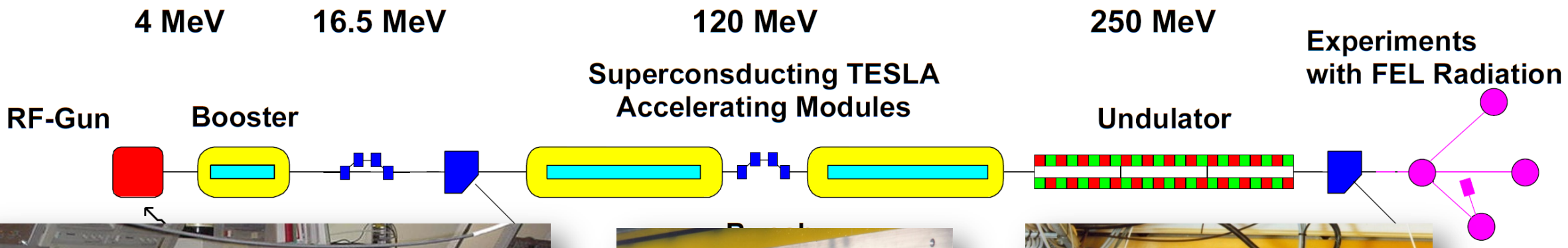
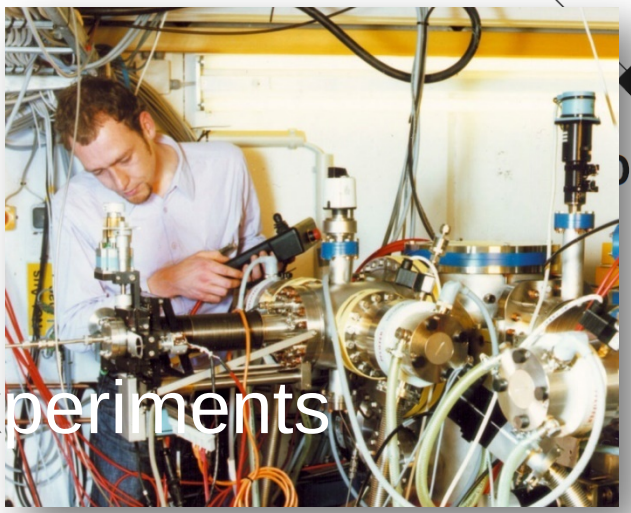
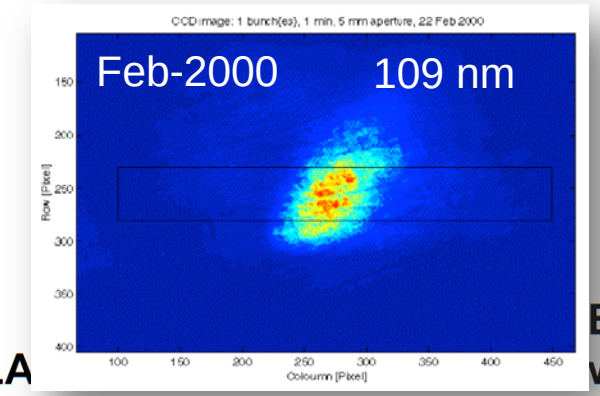


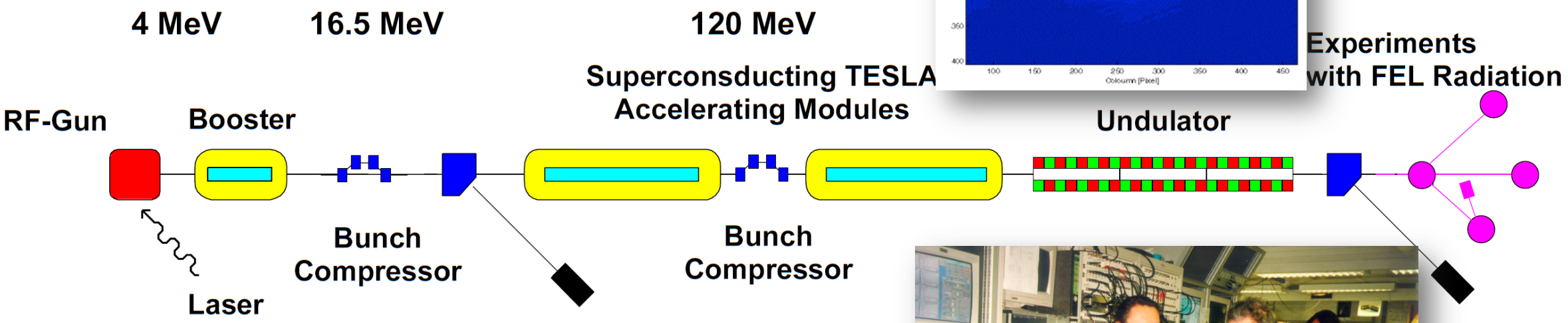


From Electron Beam to Radiation to Experiments

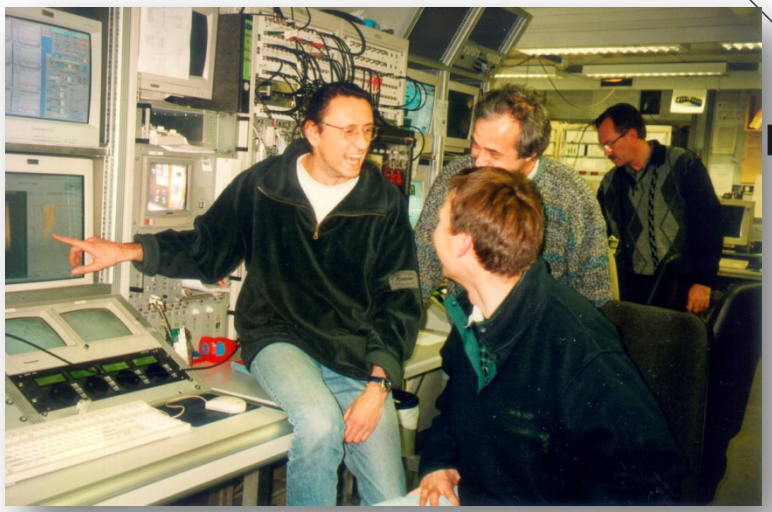
TTF1 VUV-FEL – for the 1st time worldwide SASE in VUV

Form a test bed for the TESLA linear collider to a VUV free-electron laser



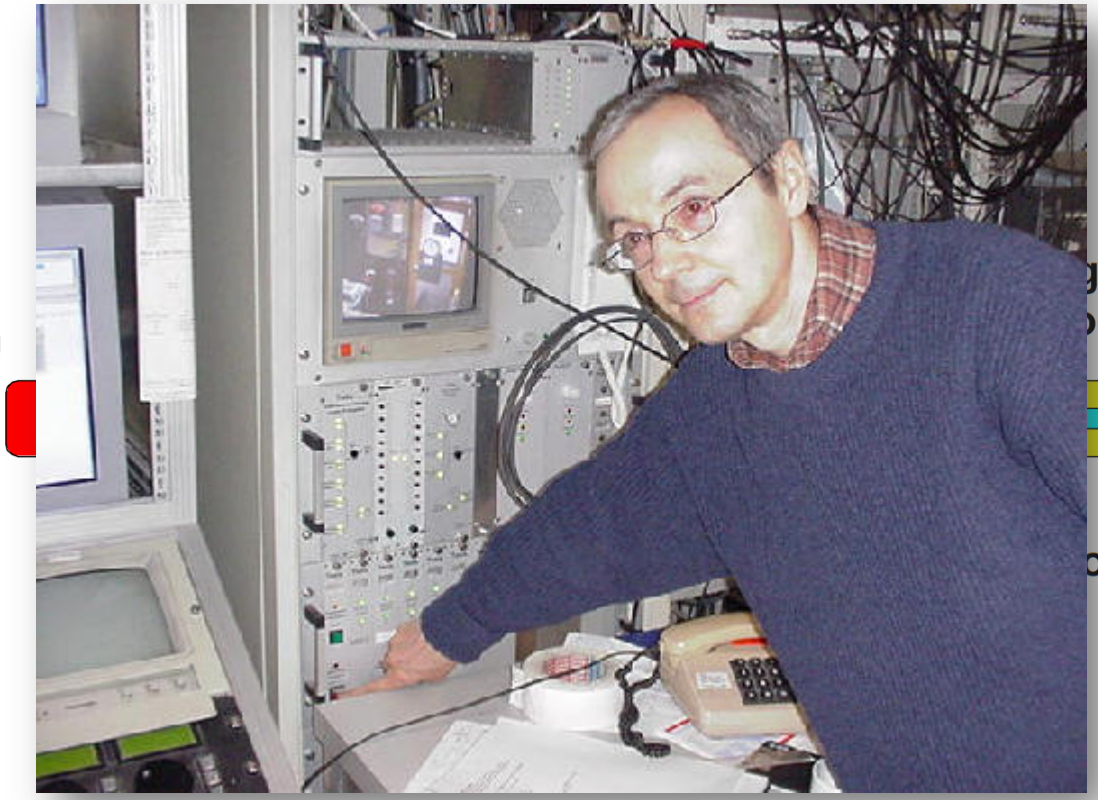


Aug 1999 – Nov 2002
Operated in a wavelength range of 80 nm – 120 nm
to demonstrate the feasibility of SASE FELs
in the VUV range for photon experiments



TTF1 VUV-FEL – ended its operation in Nov 2002

Start of the construction of TTF2 and the VUV-FEL Facility



TTF1 switched off 18-Nov-2002 06:57 h

From TTF1 to TTF2 – from a Test Facility to a User Facility

Extension of the linac to 1 GeV with the goal to produce SASE down to 6 nm for user experiments

ELSEVIER

Nuclear Instruments and Methods in Physics Research A 375 (1996) 269–273

NIMA 375 (1996) 269

NUCLEAR INSTRUMENTS & METHODS IN PHYS RESEAR Section A

A VUV free electron laser at the TESLA test facility at DES

J. Rossbach*

Deutsches Elekronen Synchrotron, Notkestr. 85, D-22603 Hamburg, Germany

for the TESLA FEL Study Group[1]

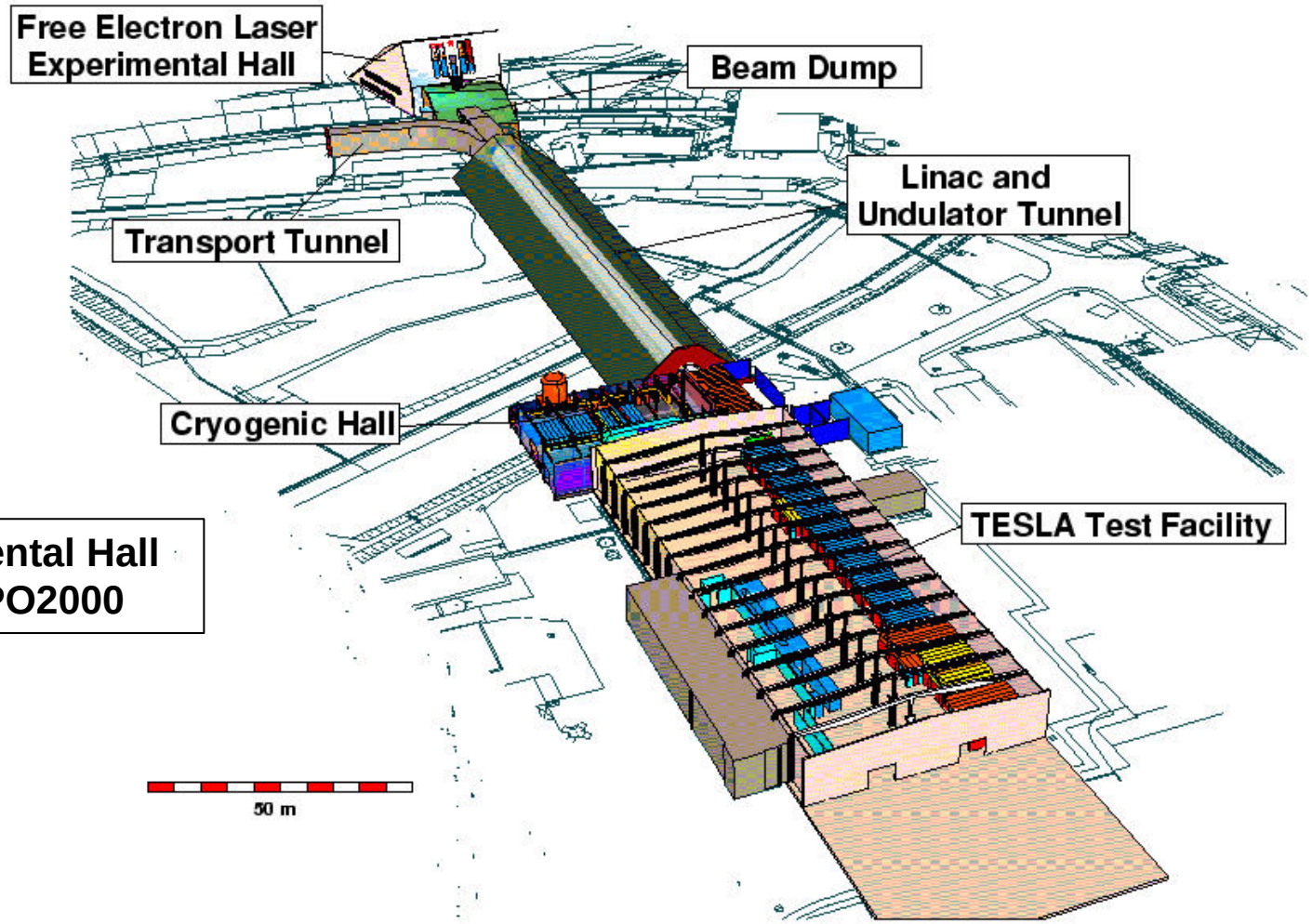
Abstract

We present the layout of a single pass free electron laser (FEL) to be driven by the TESLA Test Facility (TTF) under construction at DESY. The TTF is a test-bed for high-gradient, high efficiency superconducting acceleration for a future linear collider. Due to its unrivaled ability to sustain high beam quality during acceleration, a superconc linac is considered the optimum choice to drive a FEL. We aim at a photon wavelength of $\lambda = 6$ nm utilizing the TT has been extended to 1 GeV beam energy. Due to lack of mirrors and seed-lasers in this wavelength regime, a si FEL and self-amplified spontaneous emission (SASE) is considered. A first test is foreseen at a larger photon wa The overall design as well as both electron and photon beam properties are discussed.

[1] The TESLA FEL Study Group: ASC Samara: E.L. Saldin, E.A. Schneidmiller; CE Saclay: A. Mosnier; DESY: R. Bacher, W. Brefeld, M. Dohlus, B. Dwersteg, H. Edwards, B. Faatz, J. Feldhaus, K. Flöttmann, A. Gamp, P. Gürtler, K. Hanke, L.M. Kiernan, M. Leenen, T. Limberg, G. Materlik, T. Möller, J. Pflüger, D. Proch, J. Rossbach, J. Schneider, S. Schreiber, M. Seidel, J. Sekutowicz, C. Stolzenburg, K. Tesch, D. Trines, N. Walker, R. Wanzenberg, H. Weise, B.-H. Wiik, S.G. Wipf; Fermilab Chicago: E. Colby, T. Nicol; INFN Milano: R. Bonifacio, C. Pagani, P. Pierini, L. Serafini; JINR Dubna: A. Molodozhentsev, N. Petrov, M.V. Yurkov; Lawrence Berkeley Laboratory: W.M. Fawley; Lawrence Livermore Natl. Lab.: T. Scharlemann; Los Alamos Natl. Lab.: J. Goldstein, R.L. Sheffield; Max-Born-Institut Berlin: H. Rottke, W. Sandner, I. Will; Polish Acad. of Sciences Warschau: J. Krzywinski; UCLA, Los Angeles: J. Rosenzweig; Univ. Hamburg: C. Kunz, B. Sonntag, H.J. Voß; Univ. Tomsk, Russia: Y. Nikitina.

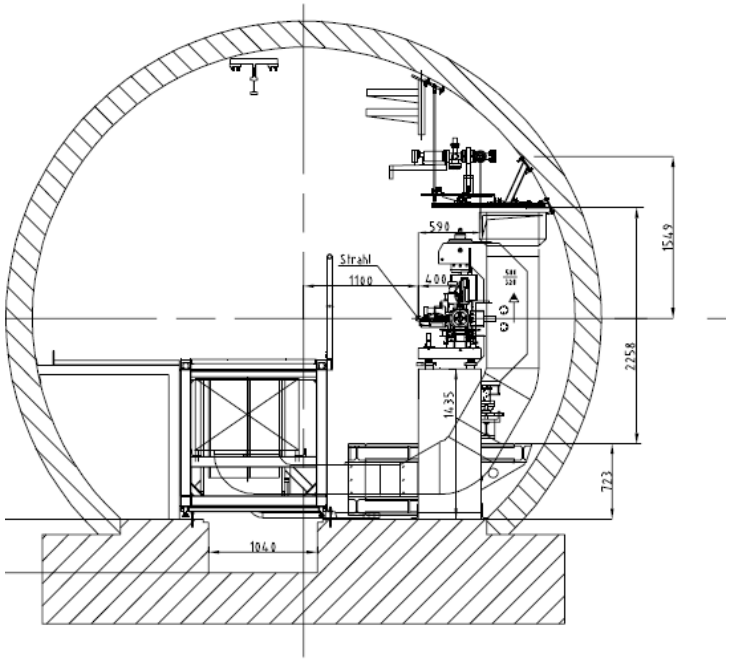
Towards FLASH

From Hall 3 through a TESLA/XFEL Prototype Tunnel to the Experiments – crossing PETRA



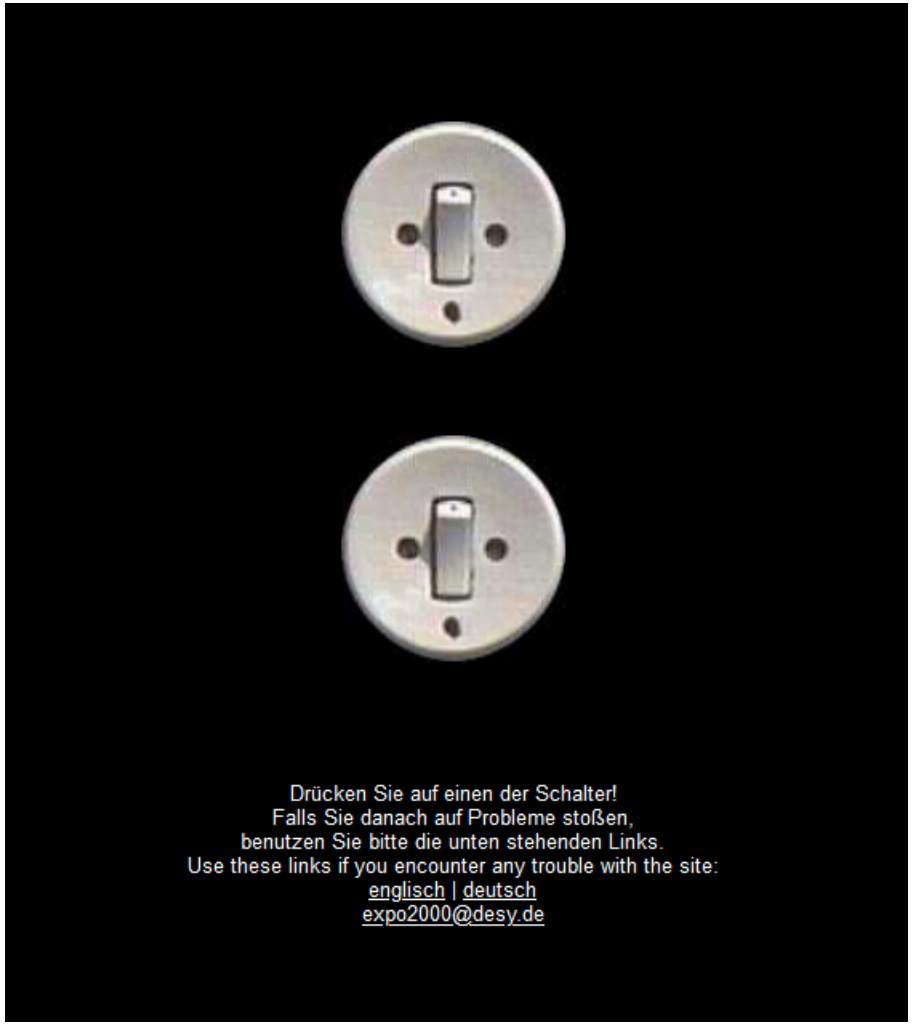
Experimental Hall for EXPO2000

Tunnel as a TESLA/XFEL mock-up



FLASH for World Exhibition 2000 – Switch on the Light

Tunnel and experimental hall for EXPO 2000 with lots of fun



FLASH for World Exhibition EXPO 2000

Experimental hall and tunnel with lots of fun

Construction of TTF2 and the VUV-FEL

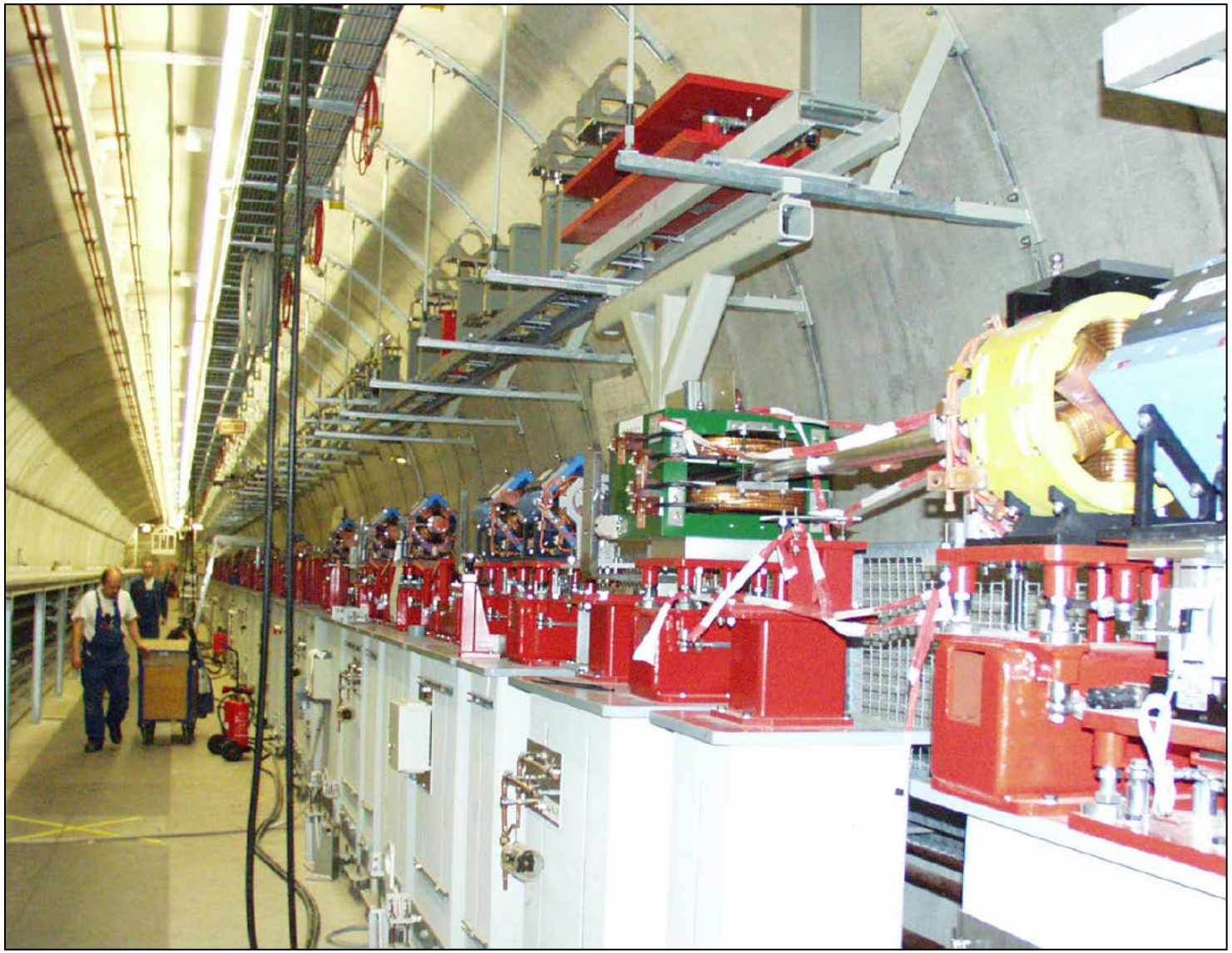
Filling Tunnel

Construction of TTF2 and the VUV-FEL

Filling Tunnel

Construction of TTF2 and the VUV-FEL

Filling Tunnel



Building TTF2 and the VUV-FEL

Flying modules

Construction of TTF2 and the VUV-FEL

Flying modules

Construction of TTF2 and the VUV-FEL

Flying modules

Construction of TTF2 and the VUV-FEL

Flying modules

Construction of TTF2 and the VUV-FEL

Flying modules

Construction of TTF2 and the VUV-FEL

Flying modules through the hall

Construction of TTF2 and the VUV-FEL

Flying modules through the hall

Construction of TTF2 and the VUV-FEL

Flying modules through the hall

Construction of TTF2 and the VUV-FEL

Flying modules through the hall

Construction of TTF2 and the VUV-FEL

Flying modules through the hall

Construction of TTF2 and the VUV-FEL

Flying modules through the hall

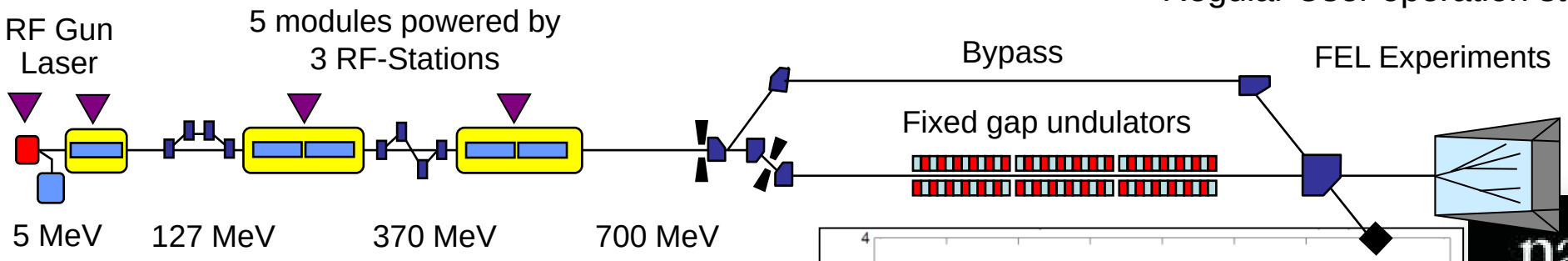
Construction of TTF2 and the VUV-FEL

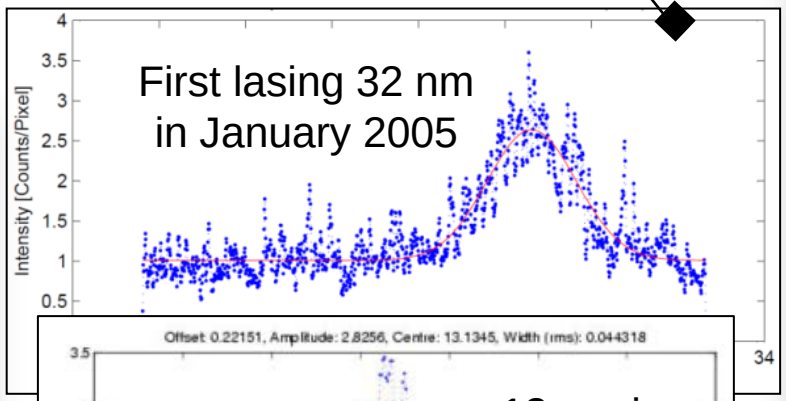
Flying modules through the hall

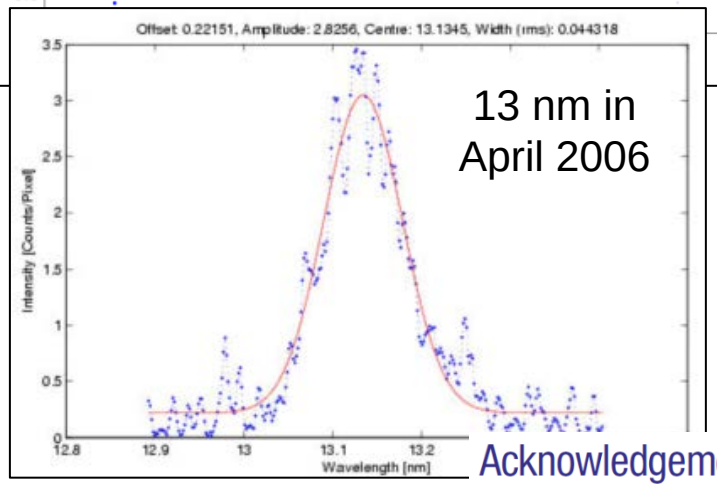
TTF2 VUV-FEL / FLASH – the 1st FEL in the XUV – 2004 to 2013

More modules, new undulators, new experimental hall

- Constructed in 2003-2004
- Regular User operation started summer 2005





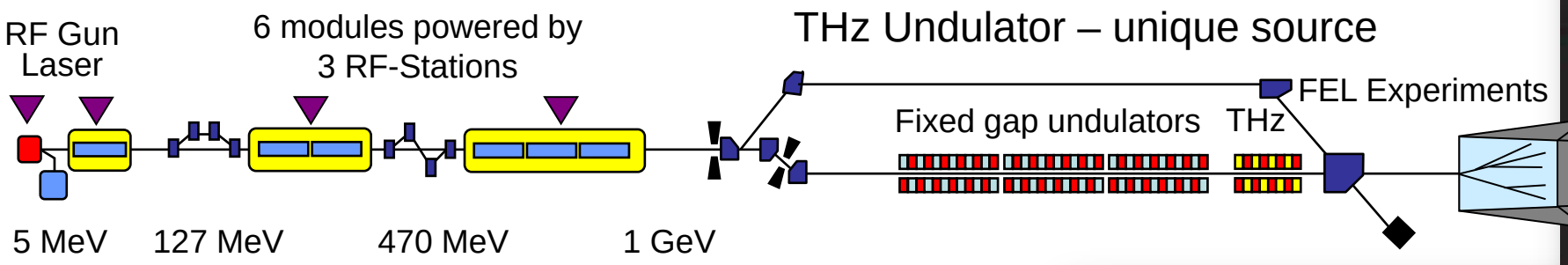


Acknowledgements

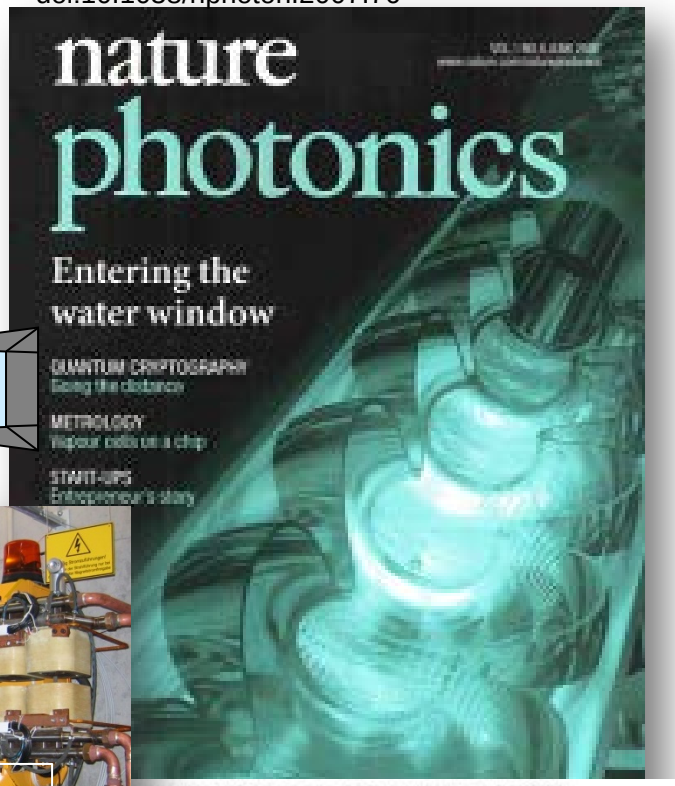
We owe special thanks to the scientific and technical staff of FLASH

FLASH is entering the water window in 2007

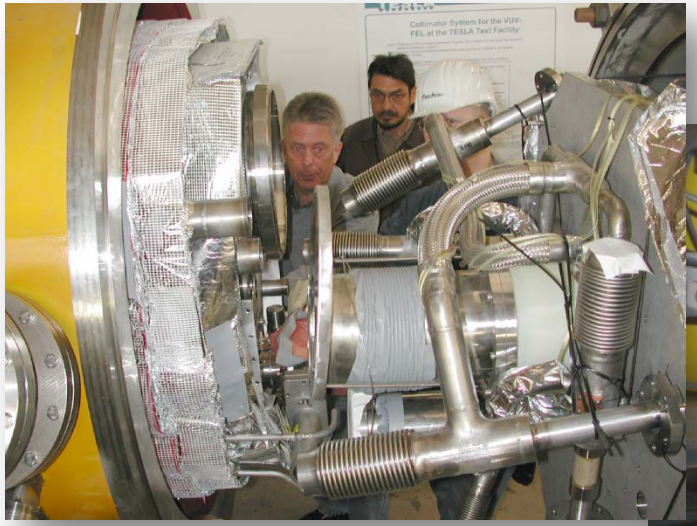
Energy upgrades to achieve smaller photon wavelengths

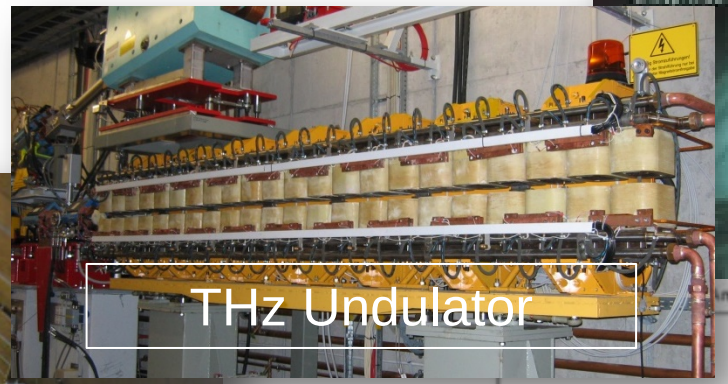


Published online: 1 June 2007;
doi:10.1038/nphoton.2007.76

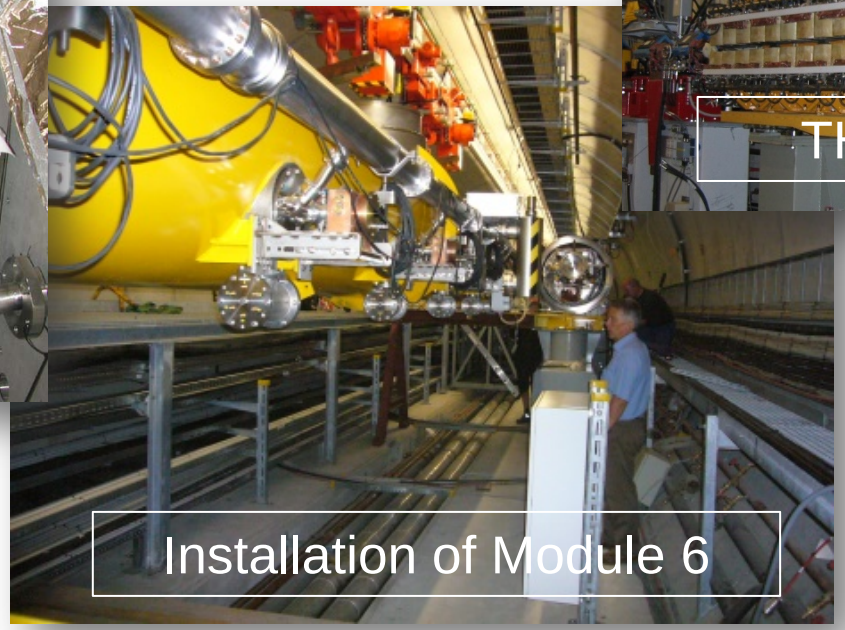


Energy upgrade to 1 GeV



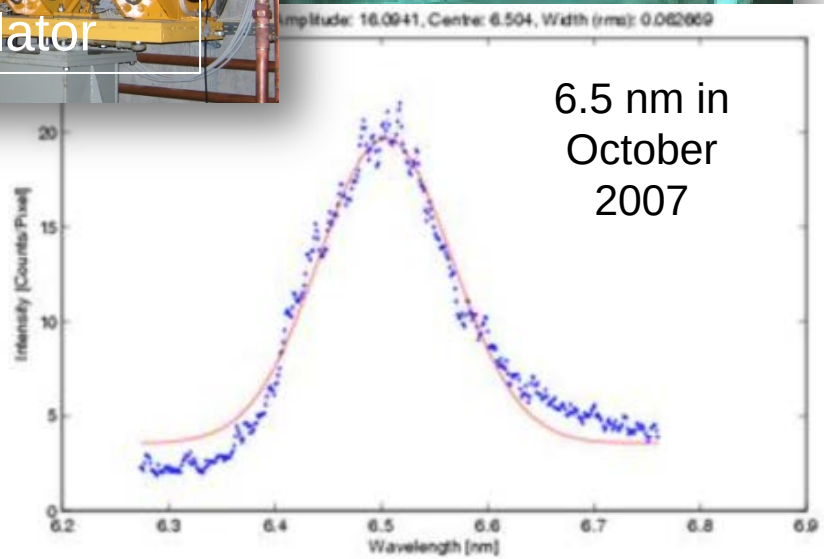


THz Undulator



Installation of Module 6

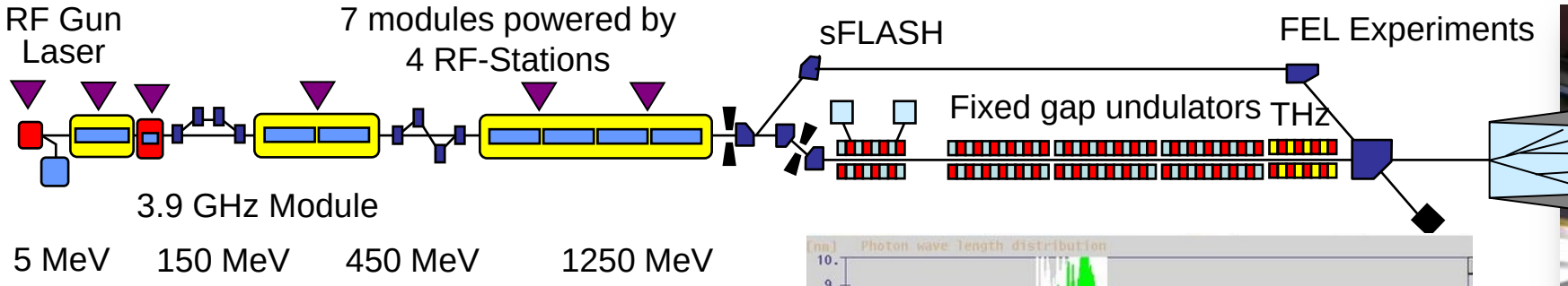
- Exchange 3rd module
- Repair 5th module

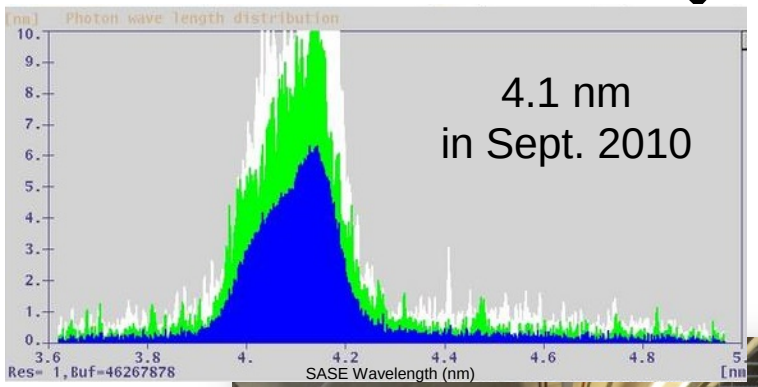


6.5 nm in October 2007

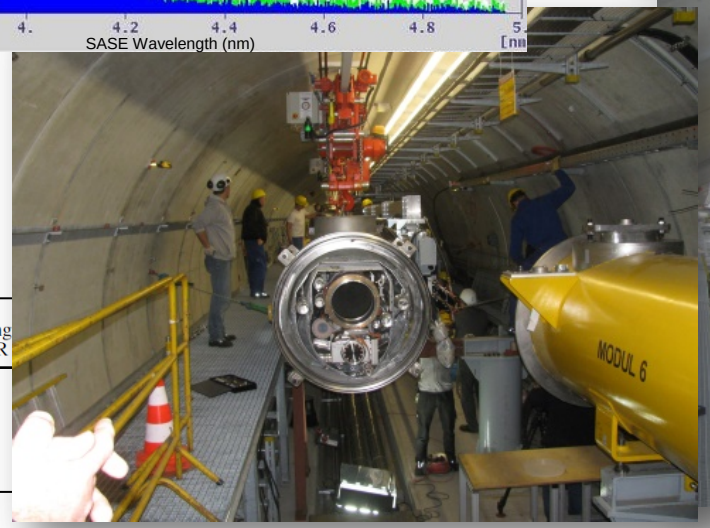
With a 7th Module FLASH achieved 1.25 GeV – 2009/2010

With 3rd harmonic cavities at 3.9 GHz we have been able to tune the FEL pulse length





- Energy upgrade to 1.25 GeV
  - Installation 7th, exchange 1st module
  - Installation 3rd harmonic module
- sFLASH – a seeding test stand
  - 38 nm - the shortest HHG-Seeding wavelength up to today



PRL 111, 114801 (2013) PHYSICAL REVIEW LETTERS week ending 13 SEPTEMBER

Generation of Coherent 19- and 38-nm Radiation at a Free-Electron Laser Directly Seeded at 38 nm

FLASH builds a 2nd Beamline with a 2nd Experimental Hall

The long pulse trains allows to share the between two beamlines simultaneously

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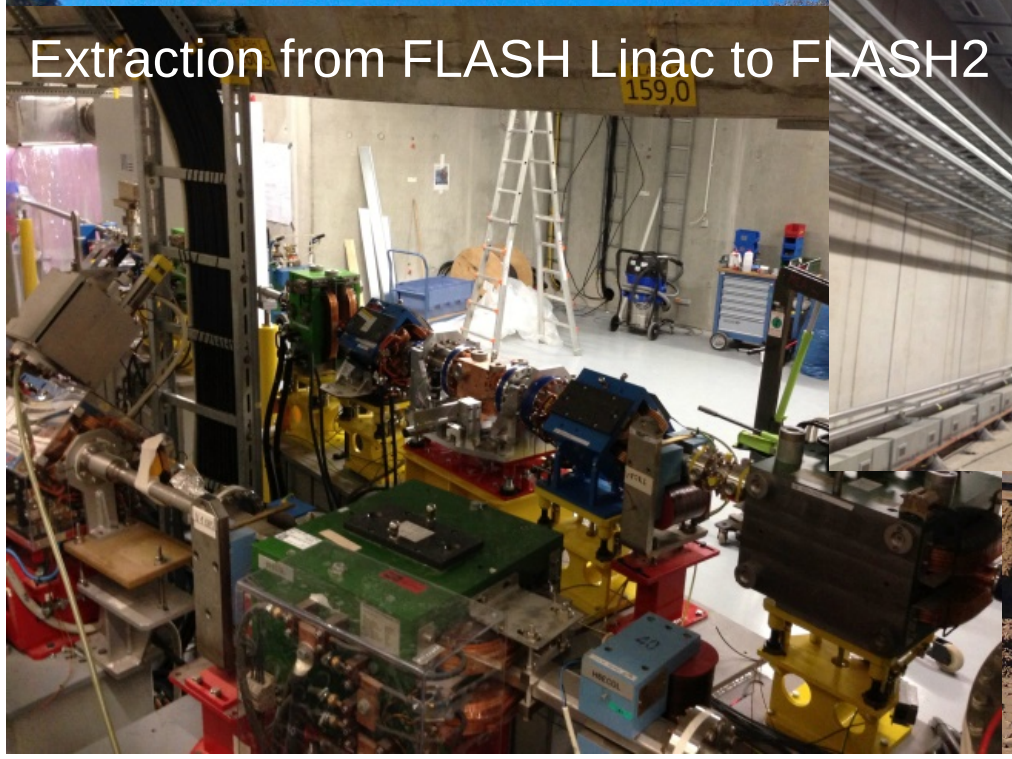
Construction during two shutdown for FLASH1: 3.5 months in 2011, 6 months in 2013

FLASH builds a 2nd Beamline with a 2nd Experimental Hall

The long pulse trains allows to share the between two beamlines simultaneously

Construction during two shutdown for FLASH1: 3.5 months in 2011, 6 months in 2013

Extraction from FLASH Linac to FLASH2



Empty FLASH2 Tunnel

Variable Gap Undulators

Two Beamlines, two experiments – both run with 10 Hz bursts

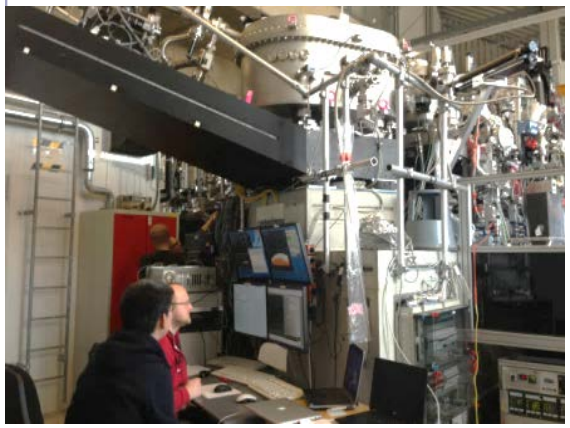
First soft X-ray FEL operating two undulator beamlines simultaneously – and flexible SASE properties

- First lasing of FLASH2 in August 2014 – and – in parallel (!) to FLASH1 SASE operation - sharing the same burst
- FLASH2 user operation started in April 2016

FLASH1. Free-Electron Laser FLASH

Setup, 1h / Dean, 10.2 nm+/- 0.20 nm, 400 bunch(es), 1MHz, >100 fs (uncritical)

SASE Delivery



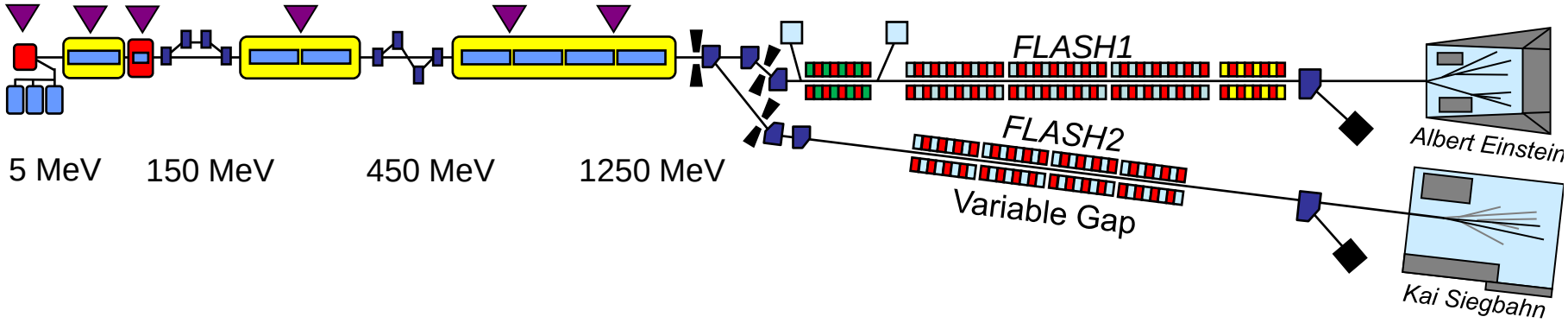
Bunches 400	Beam Energy 774.9 MeV
Charge 0.30 nC	Wavelength 10.2 nm
Rep.Rate 1003 kHz	SASE Energy 95.1 µJ

FLASH2. Free-Electron Laser FLASH

Feldhaus/Toleikis, 13.5 nm+/- 0.10 nm, 30 bunch(es), 1MHz, 100 fs, max µJ, FL24

SASE Delivery

Bunches 10 Hz 11	Beam Energy 790.2 MeV
Charge 0.31 nC	Wavelength 13.2 nm
Rep.Rate 1003 kHz	SASE Energy 137.8 µJ



Erster Nutzerbetrieb bei FLASH2

Seit Freitag, dem 8.April um 12:14 Uhr läuft der Freie-Elektronen-Laser F
Experimente, eines in der Experimentierhalle „Albert Einstein“ (FLASH1)
„Kai Siegbahn“ (FLASH2). Erste FLASH2-Nutzer sind die Forscher um d
Andreas Przystawik, die am Ende der Strahlführung FL24 mit einem Mel
Edelgascluster fokussieren und die Fluoreszenz des so erzeugten Nanop
Clustergröße studieren.

Nach dem erfolgreichen Begi
später, eine erste Bestmarke
FLASH1 lief für das Experime
National Laboratory, New Yor
Pulsen pro Sekunde und bis
während die zweite Lichterze
Pulse pro Sekunde mit je ca.

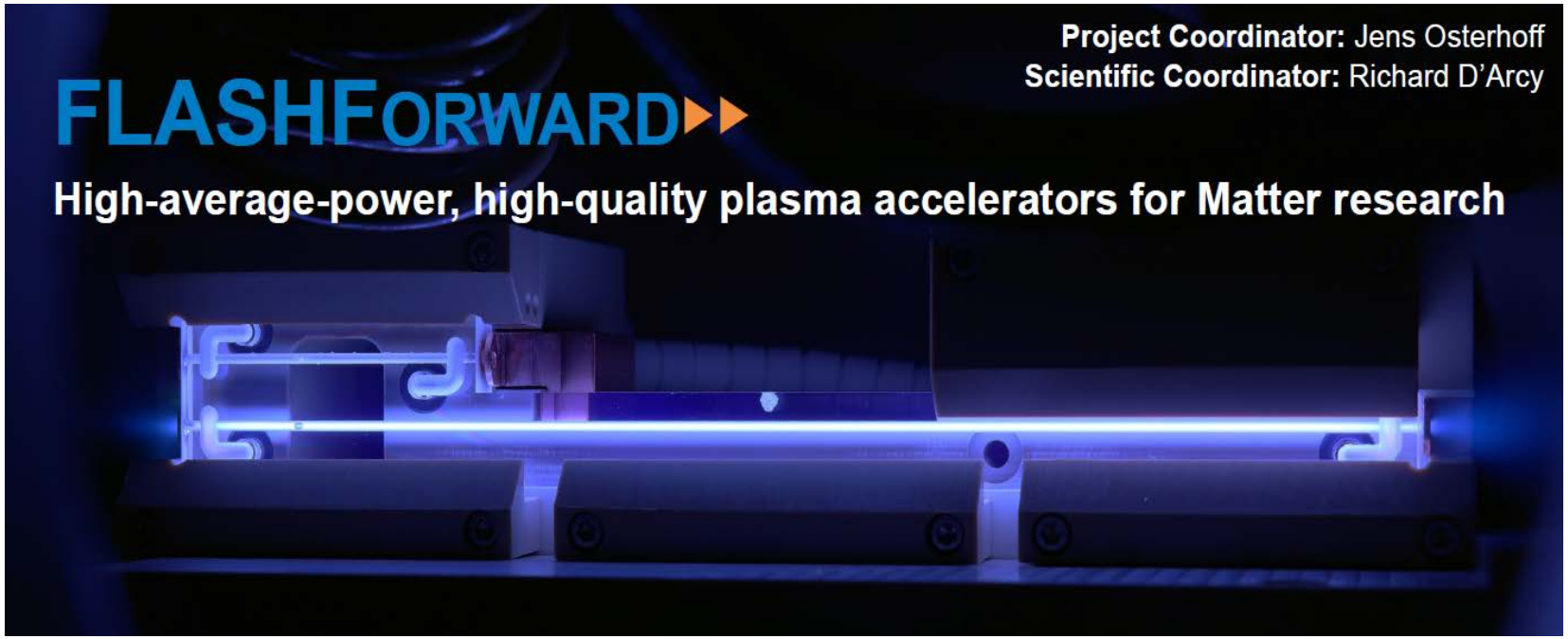
Thanks to all who contributed to TTF and FLASH

First simultaneously multi-beamline operation of a free-electron laser

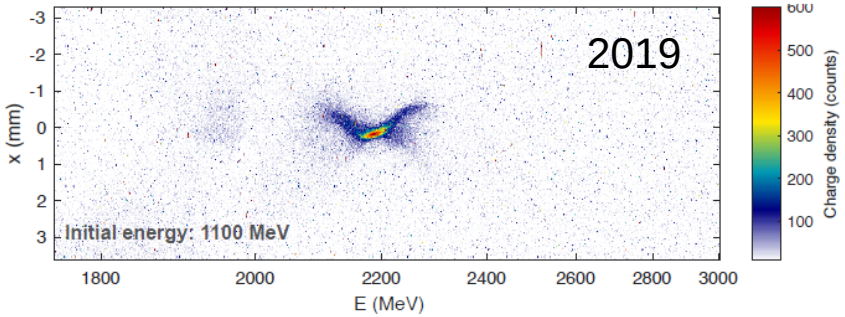
albrecht leuschner, alexander kaukher, alexander petrov, andreas hoppe, andreas noll, andreas liedtke, andreas schoeps, antonio wagner, arik willner, armin brand, arvid hage, axel hauberg, bart faatz, bastian forbeer, bernhard schmidt, bernward krause, bo liu, britta petersen, brunhilde racky, burghard sparr, christel oevermann, christian gruen, christian schmidt, christoph lechner, christopher behrens, christopher gerth, cornelius martens, daniel meissner, detlef sellmann, dieter mross, dirk keese, dirk noelle, edgar weckert, elke ploenjes, erland mueller, evgeny schneidmiller, evgueni saldin, florian gruener, frank-reinhard ullrich, frank brinker, frank marutzky, frank obier, frank schmidt-foehre, franz tavella, gabi weichert, gerhard schlesselmann, hans-joerg eckoldt, hans weise, heinrich muench, helmut remde, henning-christof weddig, holger schlarb, horst-arno bolz, horst-guenter damker, horst schulte-schrepping, igor zagorodnov, iris gehrmann, jan havlicek, jan kuhlmann, jens osterhoff, jianhui chen, joachim spengler, joerg rossbach, joern schaffran, johann zemella, johannes prenting, josef feldhaus, josef gonschior, juergen liebing, juergen schaefer, juliane roensch, jutta bentien, kai tiedtke, karo amyan, karsten klose, katja honkavaara, kay rehlich, kay wittenburg, kirsten petersen, klaus-dieter jansen, lindemar haenisch, lutz lilje, maciej brachmanski, maike pelzer, maike roehling, margit gibau, marion kuhlmann, markus drescher, markus koerfer, markus schloesser, markus tischer, martin staack, mathias hesse, mathias vogt, matthias felber, matthias scholz, matthias steckel, max goerler, max holz, mi schulz, michael boehnert, michael dressel, michael koepke, michael schmitz, mikhail yurkov, nicoleta baboi, nikola stojanovic, nils mildner, nina golubeva, norbert tesch, olaf borkenhagen, olaf hensler, olaf krebs, pedro castro, raimund kammering, ralph boespflug, reinhard neumann, rolf treusch, siegfried schreiber, silke vilcins, stefan duesterer, stefan koch, stephan molnar, svea kreis, sven ackermann, sven lederer, swaantje mette, takanori tanikawa, thomas bruns, thorsten kracht, thorsten vielitz, tim laarmann, tim wilksen, torsten limberg, torsten ramm, torsten wohlenberg, ulf fini.jastrow, ulrich hahn, ulrich schuetz, valeri ayvazyan, velizar miltchev, vladimir balandin, vladimir rybnikov, werner kook, winfried decking, wojciech jalmuzna

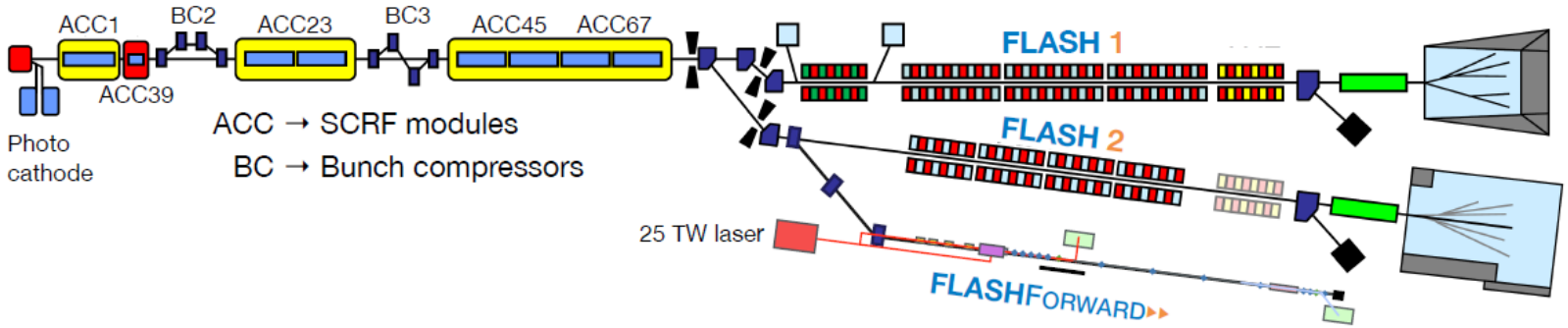
High-Average-power high quality plasma acceleration

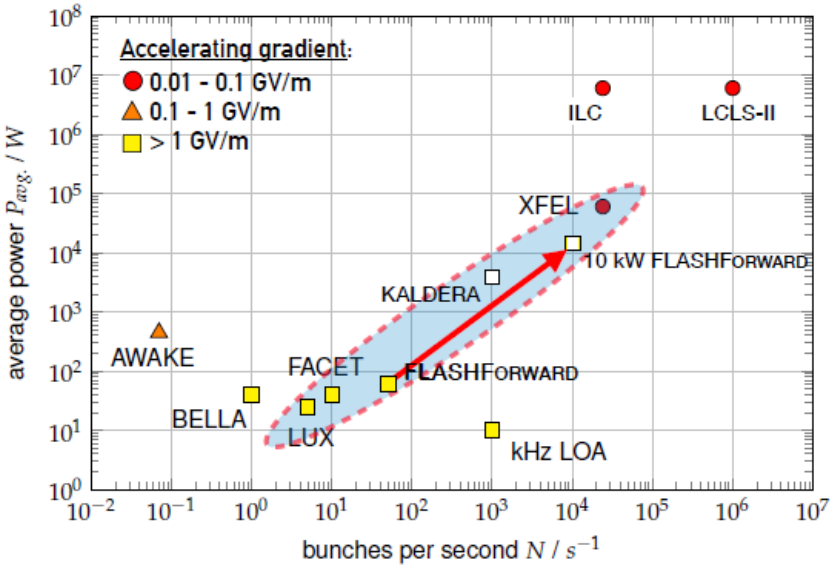
FLASHForward in the 3rd Beamline – highway to future



1.1 GeV → 2.2 GeV



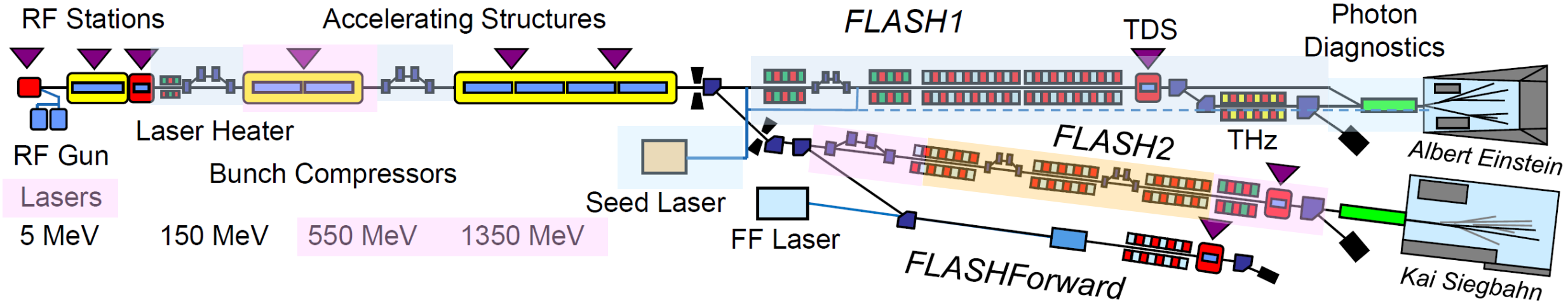




Roadmap from W to kW

FLASH2020+

Towards an extraordinary XUV- and soft X-ray facility



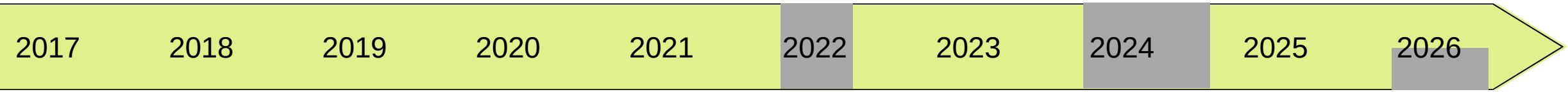
Phase 0
Energy upgrade
3rd BC (FLASH2)
TDS (FLASH2)
Injector Laser
Afterburner FLASH2

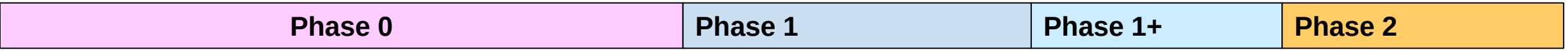
Phase 1
Variable gap undulators (FLASH1)
Pump-probe laser (FLASH1)

Laser heater in 1st BC
New 2nd bunch compressor (BC)

Phase 1+
High rep.rate seeding (FLASH1)
Photon diagnostics (FLASH1)

Phase 2
New variable gap undulators + chicanes
for new lasing concepts (FLASH2)






It is a team work!