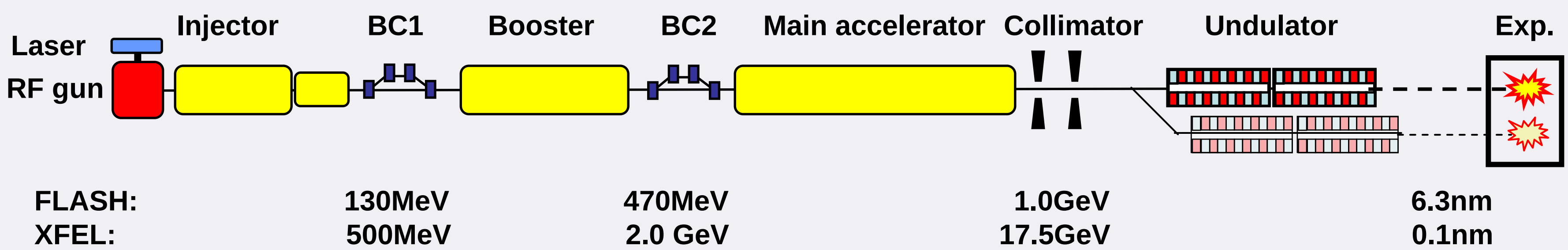
FLASH Upgraded
- Preparing for the European XFEL -

(**F**ree-Electron **LAS**er in **H**amburg)

H. Schlarb, for the TTF/FLASH and the XFEL Project Group

FLASH/European XFEL technology

FLASH and European XFEL are on the fundamental level very similar machines



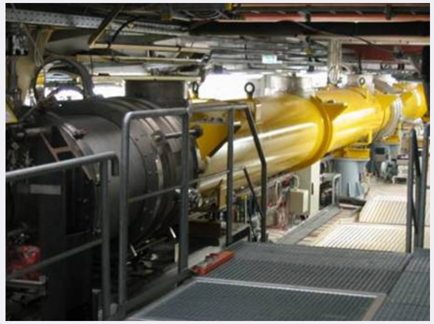
Based on same SRF technology
Only small differences in beam parameter (except E)

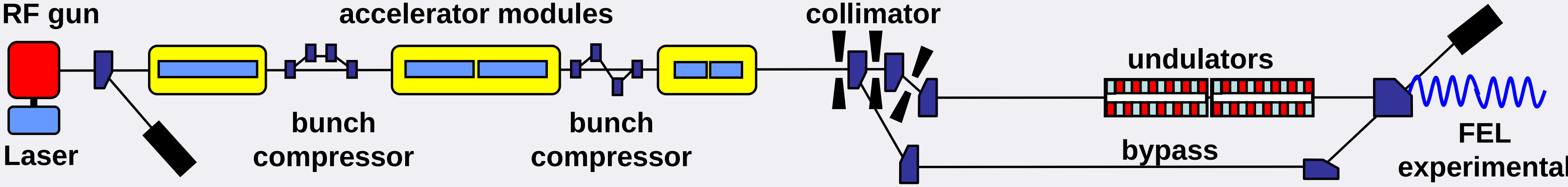
- ⇒ High level RF & RF controls
- ⇒ Beam dynamics issue
- ⇒ Diagnostics development
- ⇒ Test of utility systems

Can almost all be carried out at FLASH!

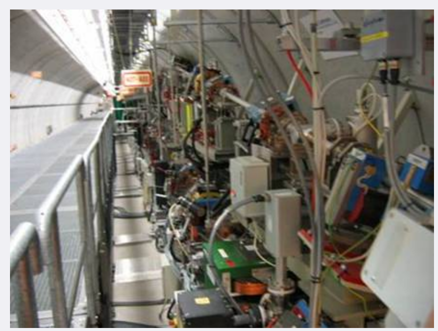
Para.	FLASH	XFEL
$\varepsilon_{x,y}$	2 μm	1.4 μm
I_{peak}	2.5 kA	5 kA
f_{rep}	1 (9)MHz	5 MHz
Q	1 nC	1 nC
E	1 GeV	17.5 GeV
RF	1.3/3.9GHz	1.3/3.9GHz
Δt	800μs	650μs
Δx/Δy	5μm	3μm

FLASH Layout 2006








250 m

FLASH - Progress 2006/07 -

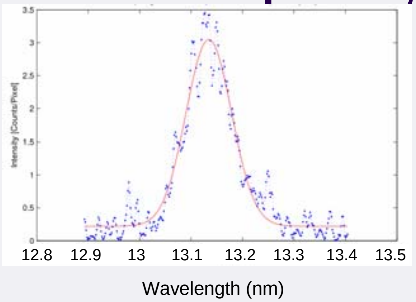
26-Apr-2006: First SASE at 13 nm achieved

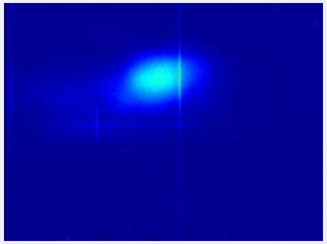
About 4 hours after starting the SASE search shift

Beam energy 693 MeV, SASE wavelength 13.1 nm

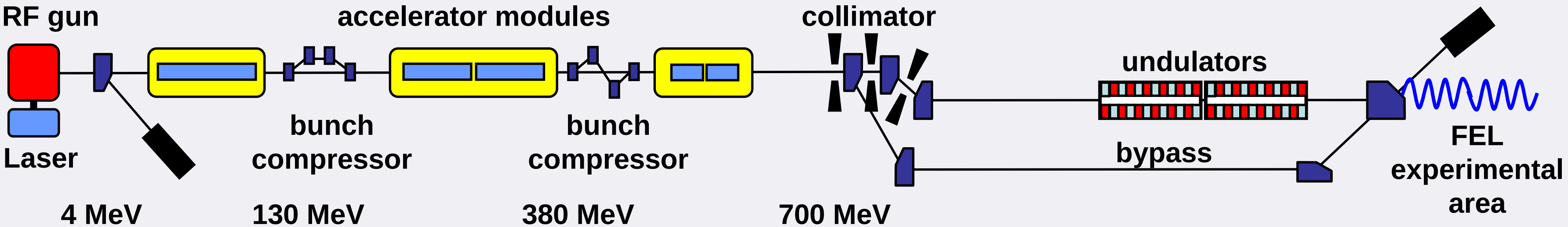
20-Aug-2006: Saturation at 13 nm observed

April 26, 2006

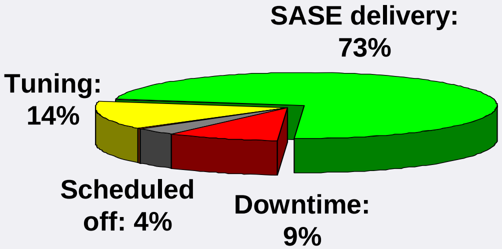


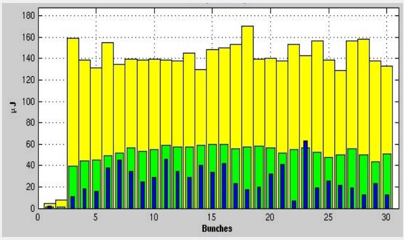


<E> = 5 µJ

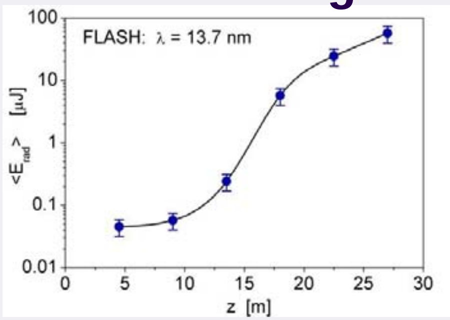


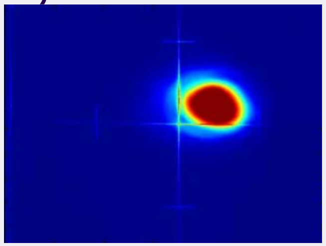
Availability, stability and Av. photon Flux





August 20, 2006





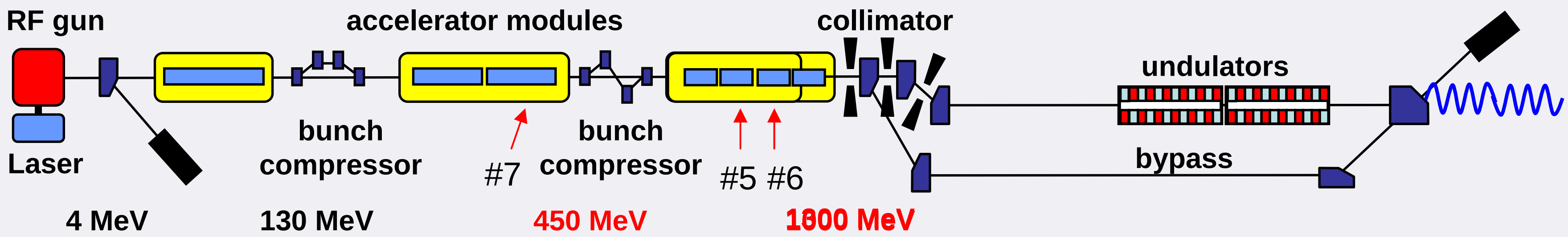
<E> = 70 µJ

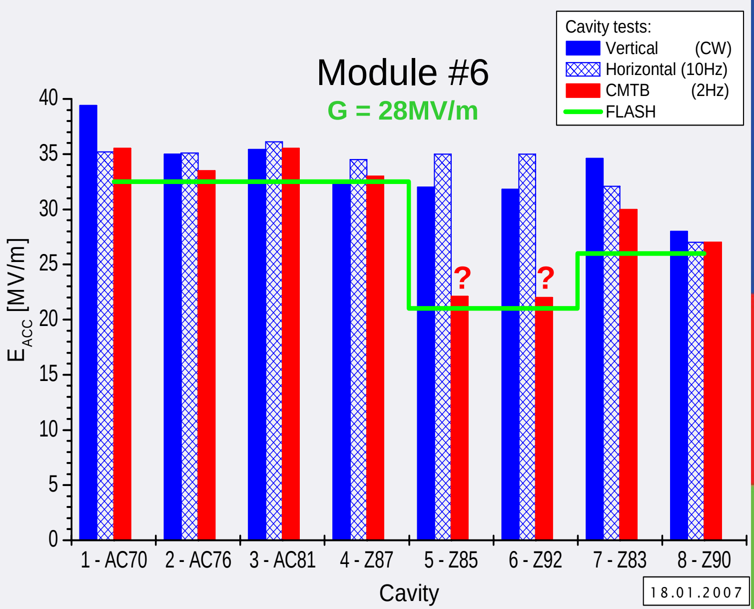
⇒ S. Schreiber, THAAU02, *"Operational Experience of FLASH"*

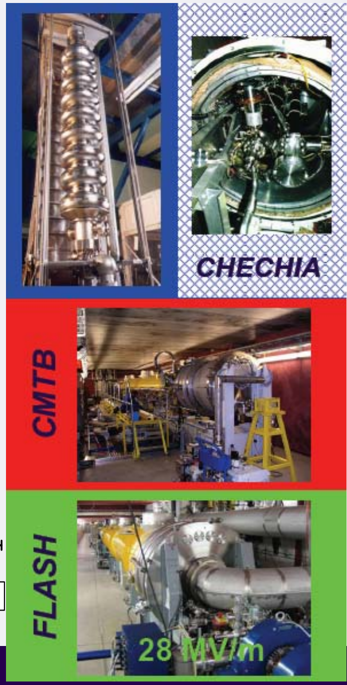
⇒ Rolf Treusch, THBAU01, *"Research Highlights from FLASH"*

FLASH – Energy upgrade –

Shutdown Apr.-Aug. 2007 → Wavelength reach 6.3 nm (design)







Energy upgrade to 1.2-1.3 GeV planned 2009

⇒ Installation of 7th acc. module

⇒ Reach of water window (<4.3 nm) in first harmonic

- Assembly of module #8 at DESY by industry (supervised)
- Almost XFEL design
- XFEL-like waveguide structure
- RF regulation for 4 acceleration modules
- Bench mark of dark current transport

RF gun development @ PITZ

Emittance results October 2006

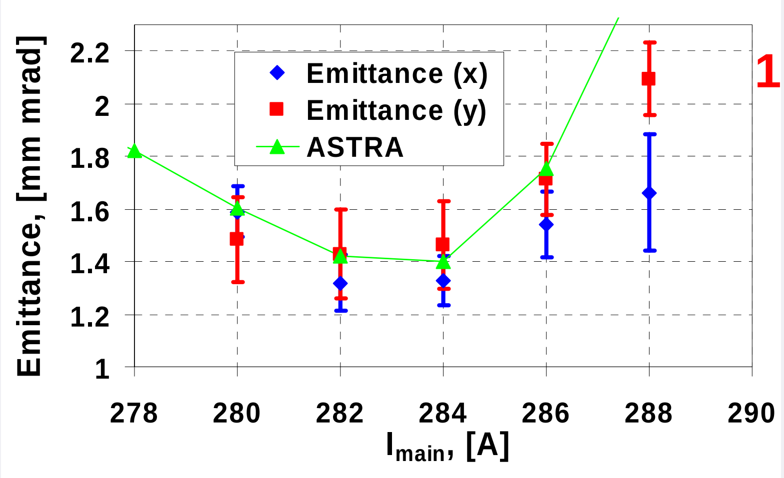
Gun gradient: **~ 43 MV/m**
Total beam momentum: 12.8 MeV/c

= ±

= ±

@1nC

for 100 % RMS emittance !



1nC

Courtesy: F. Stephan

Emittance results summer 2007

Gun gradient: **~ 60 MV/m**
Total beam momentum: 14.5 MeV/c

➔

= ±

= ±

@1nC

for 100 % RMS emittance !

➔ emittance minimum in good agreement with ASTRA prediction

Experimental study and simulation show: if **5-6%** of beam charge is cut (tails) then projected emittance reduces by ~ 37 % ➔

≈

95%

⇒ See talk WEBAU02 and poster MOPPH055

Third harmonic cavity (3.9 GHz)

3rd harmonic cavity will be used for linearization of long. phase space

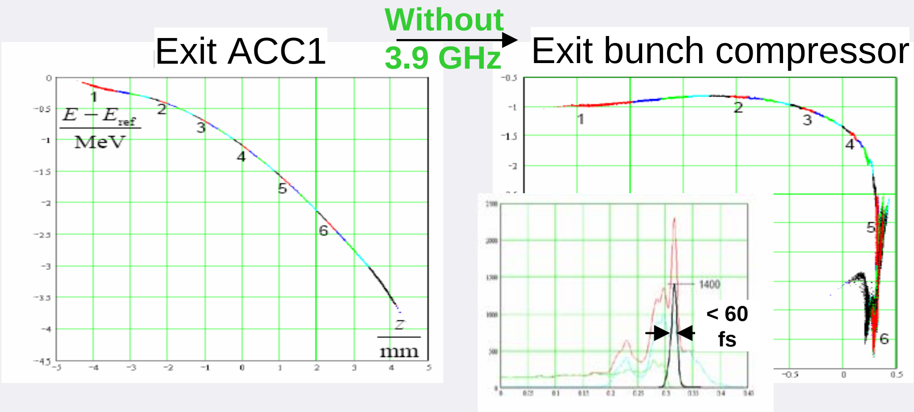
⇒ Achieve homogenous compression of bunch

⇒ High peak current (2.5kA) with long bunches (σ_z=50μm)

⇒ Significant increases of photon flux (x 10)

FLASH:

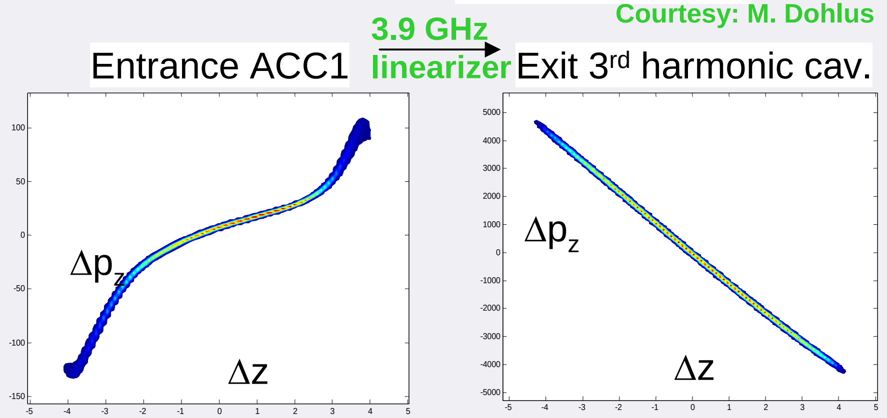
- 4 x cavities with 15MV/m gradient
- 1 x 80kW klystrons at 3.9GHz
- Cryostat attached to ACC1 (E=120MeV)
- Alignment of cavities ~ 0.5mm



Courtesy: M. Dohlus

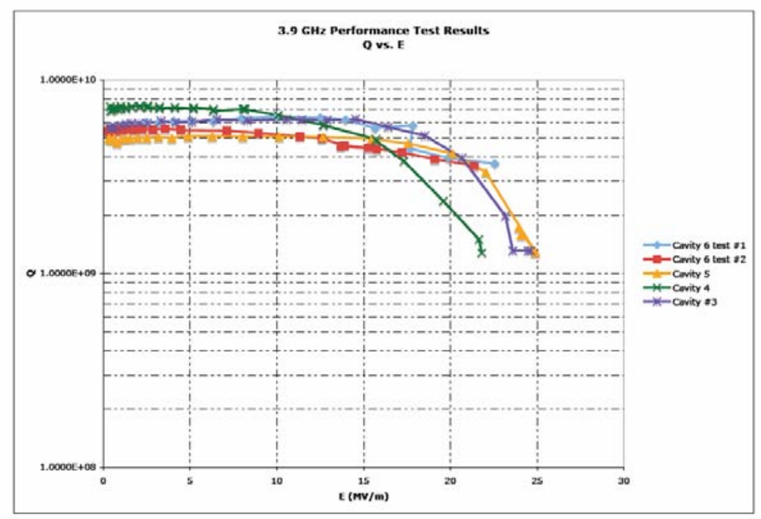
XFEL:

- 24 x cavities, total 108MV ⇒ 13.5MV/m
- 3 x klystrons
- Booster linac (E=500MeV)
- Coupler kick and alignment tolerance under investigation



Courtesy: M. Krasilnikov

Third harmonic cavity (3.9 GHz)



Complete cryomodule delivered by FNAL

FNAL: H. Edwards, E. Harms, et al.

DESY: W.D. Möller, E. Vogel, et al.

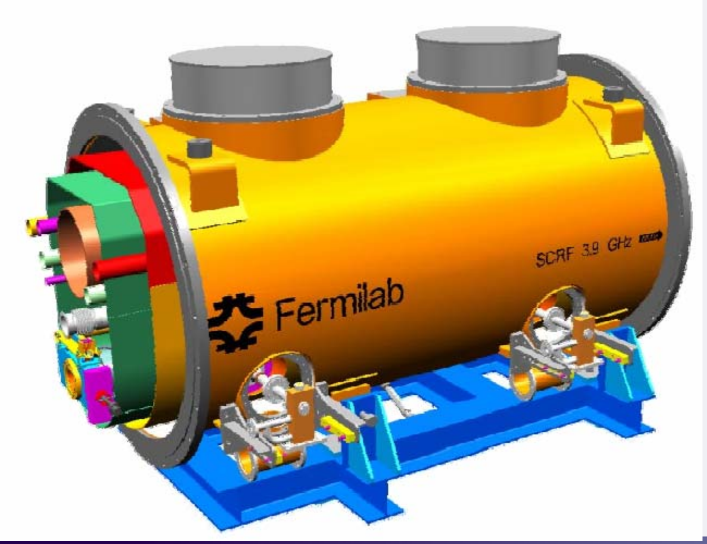
Status:

- Initial problems with HOM coupler solved
- 5 cavities succeeded in vertical test stand
- Cryomodule delivery to DESY spring 2008
- Testing of 3.9 GHz acceleration structure at “Cryo Module Test Bench” at DESY in preparation (2008)

Additional:

- HOM based beam position measurement planned

Installation at FLASH scheduled for 2009



Test of pulsed cables

Kl
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⇒
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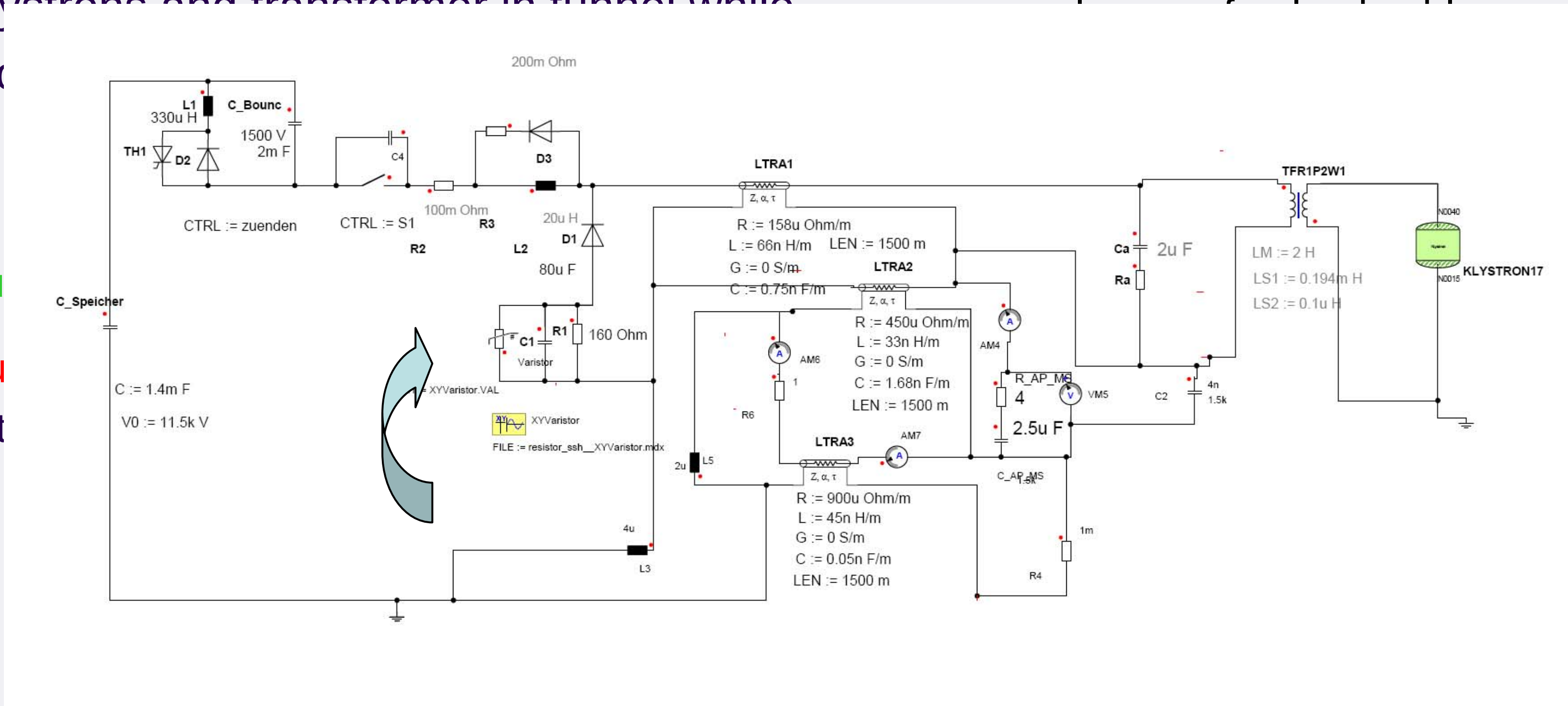
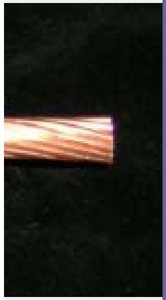
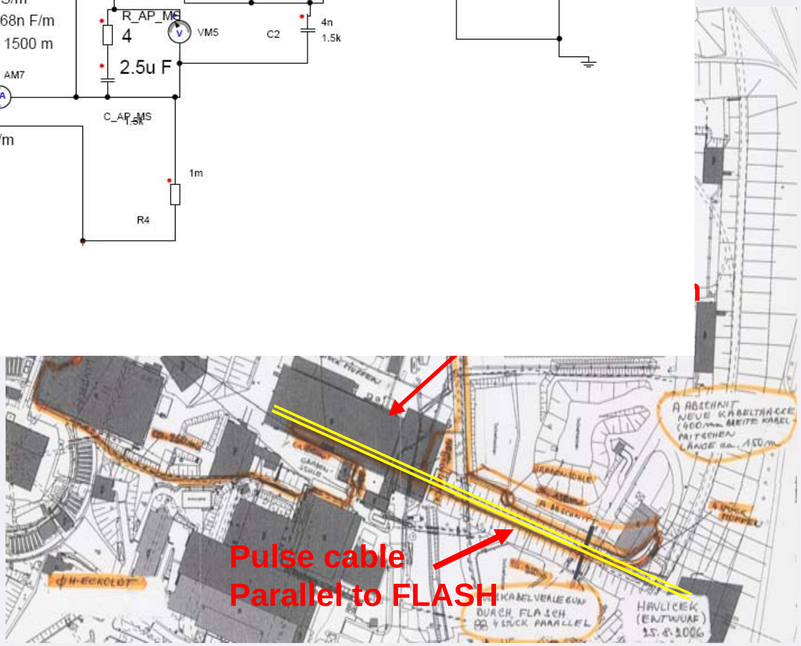
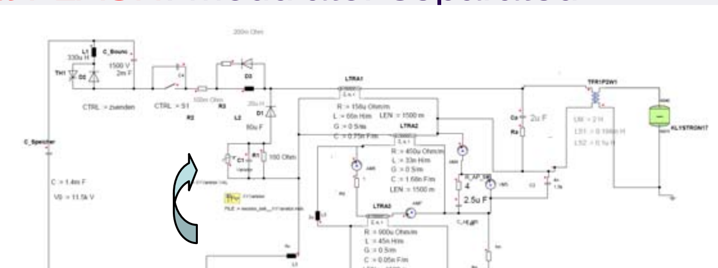
⇒







⇒ Special care taken XFEL grounding scheme
⇒ New test at FLASH: modulator separated from transf.

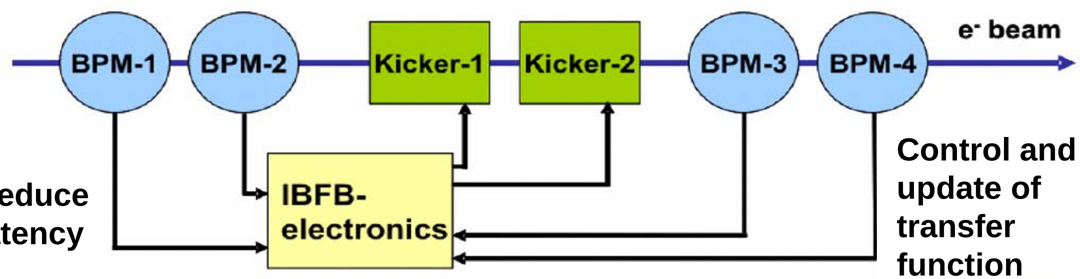


Courtesy: J. Eckoldt, N. Nagad

Transverse intra-train bunch feedback system (IBTB)

- Complete system developed by PSI (V. Schlott et al.)

Topology of E-XFEL Intra Bunch Train Feedback System



Reduce latency

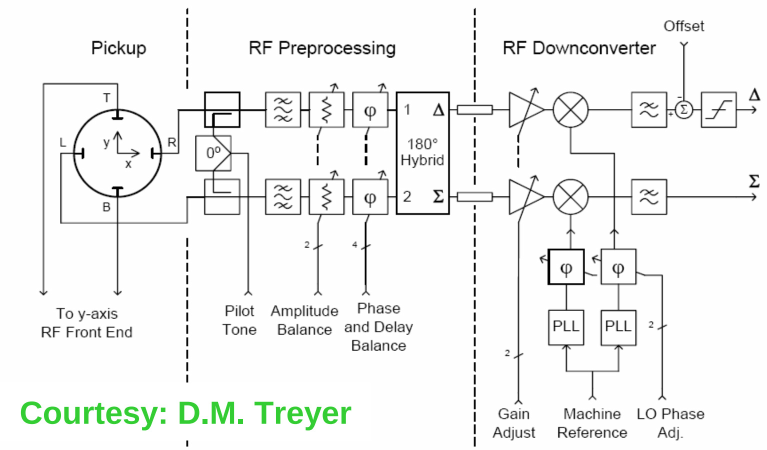
Control and update of transfer function

Courtesy: V. Schlott et al.

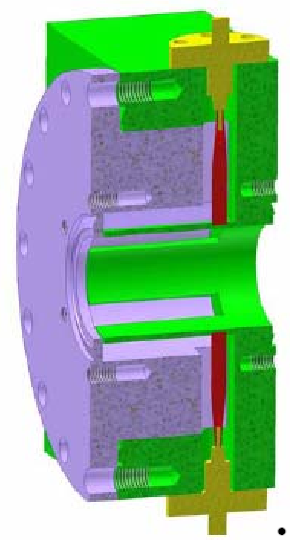
Resonant Stripline Pickup

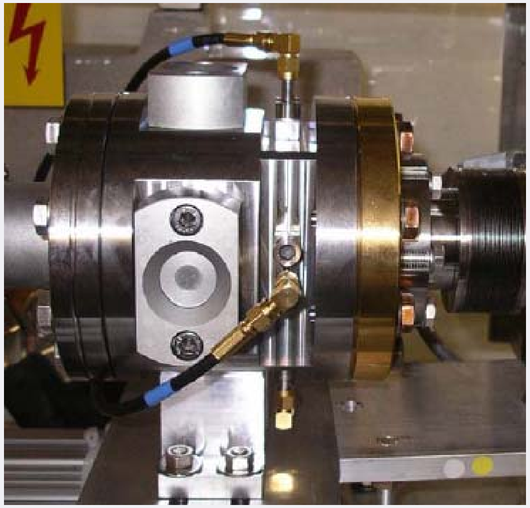
E-XFEL IBFB-System:
$Q_L \approx 32$, $B_{3dB} \approx 50$ MHz
$f_M = 1625$ MHz, $f_D = 1650$ MHz
Sensitivity 2 dB/mm in 34 mm beam pipe

BPM Electronics for 1.6 GHz Resonant Stripline



Courtesy: D.M. Treyer



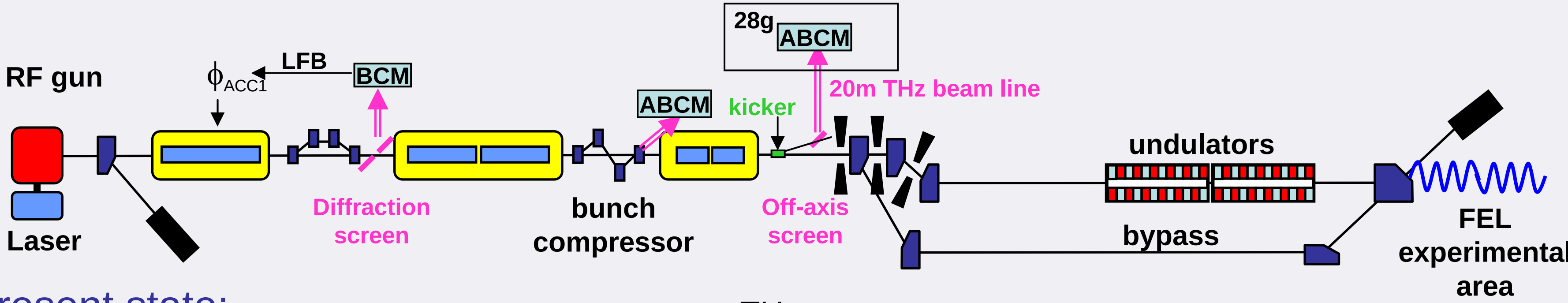


- Transversal resolution: ~1 µm
- Transversal meas. range: ~ ±1 mm
- Latency: ~20 ns
- Bunch charge: 0.1 to 5 nC

- Test of the IBFB at FLASH: end 2008

Diagnostics developments –frequency domain-

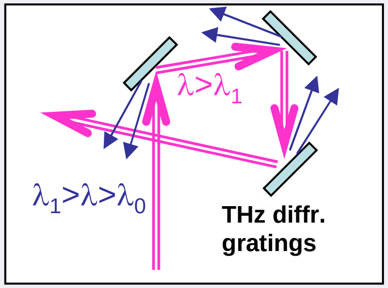
Coherent radiation: bunch compression monitoring (BCM) and long. FB!

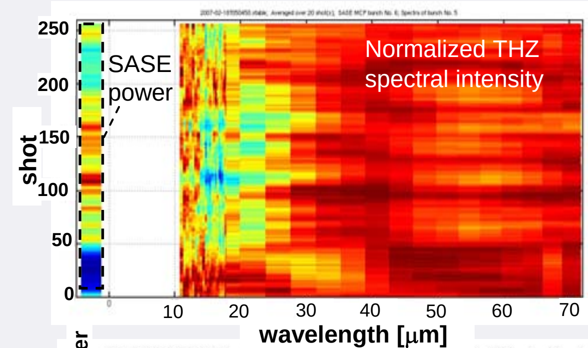


Present state:

- Integrated THz signal (>λ_0) used to stabilize ACC1 phase
- Development of single shot spectrometer (ABCM)
- Reveals importance of spectral information for FEL operation

THz spectrometer

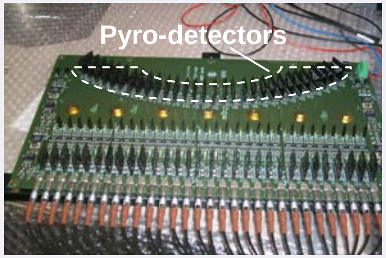


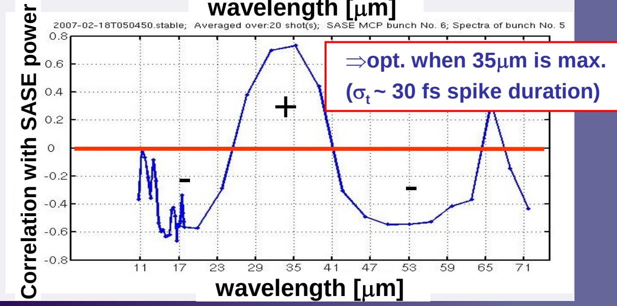


Next steps:

- Investigation of online, suited for macro-pulse operation using CSR
- Compact THz spectrometer (next generation)
- Electronics allowing for readout + processing > 1 MHz for long. feedback systems

Readout system





Courtesy: H. Delsim-Hashemi, B. Schmidt

Diagnostics developments – time domain –

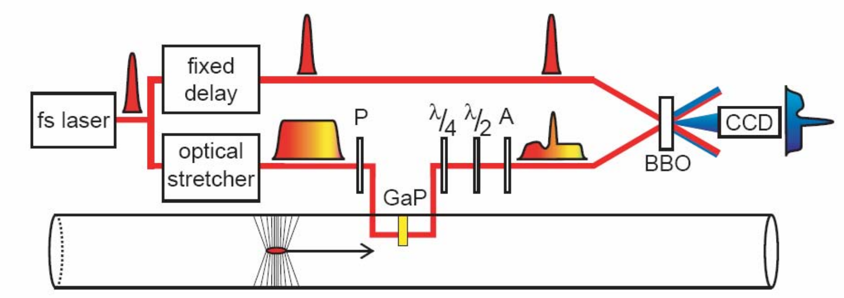
Time domain longitudinal bunch profiling:

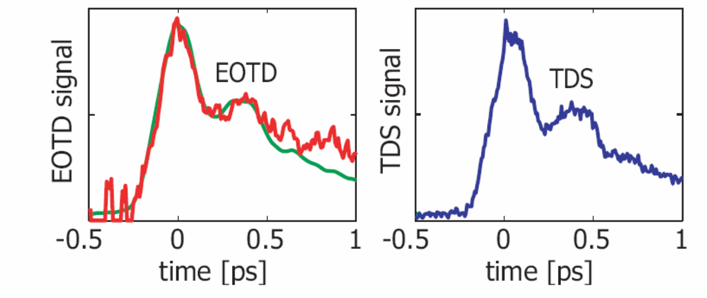
- Electro-optical technique (birefringence crystal)
- Time domain approach with stretched laser pulse + cross-correlation in BBO for encoding (EOTD)
- Bench marked with transverse deflecting structure

⇒ Good agreement with expectation

⇒ Resolution 55fs rms (65 μm GaP crystal)

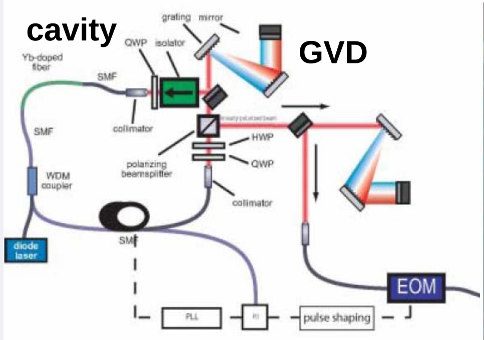
Collaboration: Abertey & Dundee Uni., Daresbury Lab., FELIX / FOM and DESY (See talk WEBAU04)





Next development steps:

- Robust source: mode-locked Yb-fiber laser Δt_{FWHM}<100fs (30fs has been achieved)
- Suitable for operation in acc. tunnel
- Packaging of laser: IRUVX-FP7 proposal in collaboration with BESSY (T. Quast)
- Fast line camera readout (1030nm, >1MHz)
- Technique: EO spectral or spatial

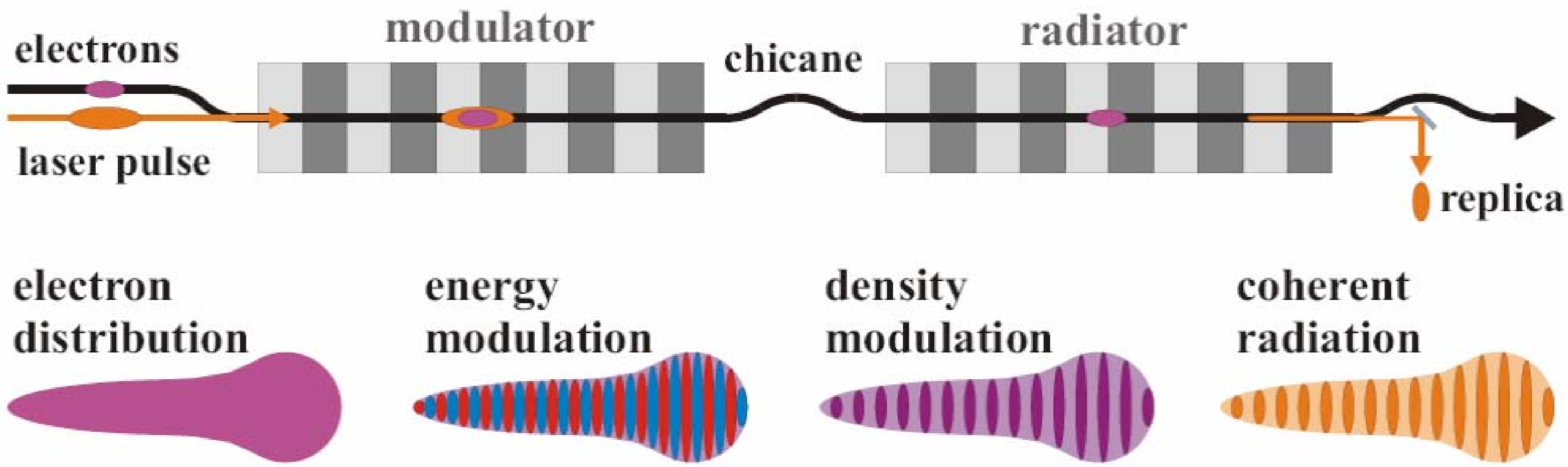


Courtesy: A. Winter, DESY
Ö. Ilday, Bilkent Uni. Ankara
DIPAC07:WEPB03

Diagnostics developments – time domain –

Optical replica synthesizer

SSY: Nucl. Inst. and Methods A 539 (2005) 499.

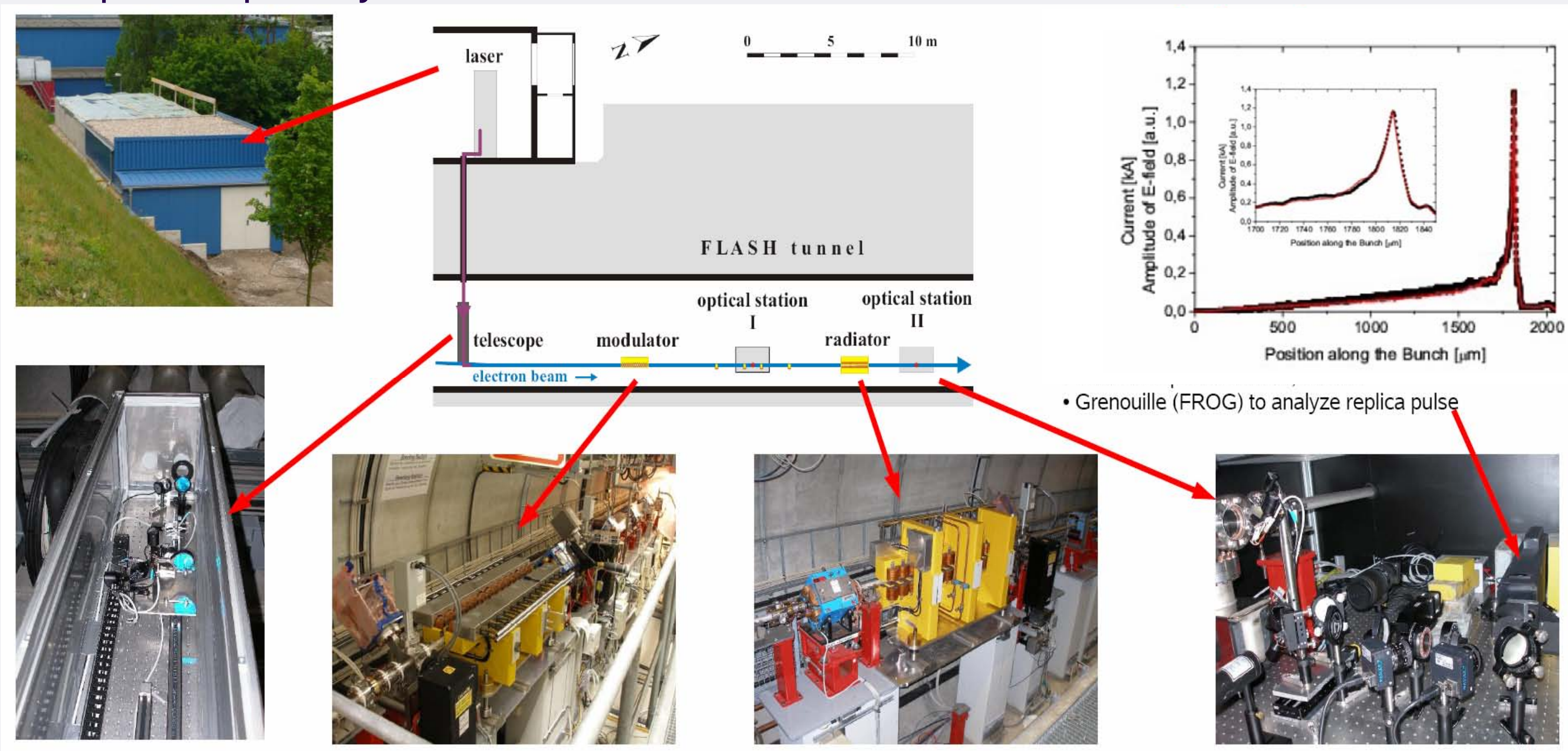


→ Parasitic, high resolution (10fs), single shot, longitudinal bunch profiling
→ Valuable experience for laser heater design

G. Angelova, V. Ziemann, — Uppsala Uni.,
M. Hamberg, P. Salén, P. van der Meulen, M. Larsson, — Stockholm Uni.
S. Khan, J. Bödewadt, A. Winter, — Uni. Hamburg
A. Meseck, — BESSY
E. Saldin, H. Schlarb, B. Schmidt, E. Schneidmiller, M. Yurkov, — @DESY

Diagnostics developments – time domain –

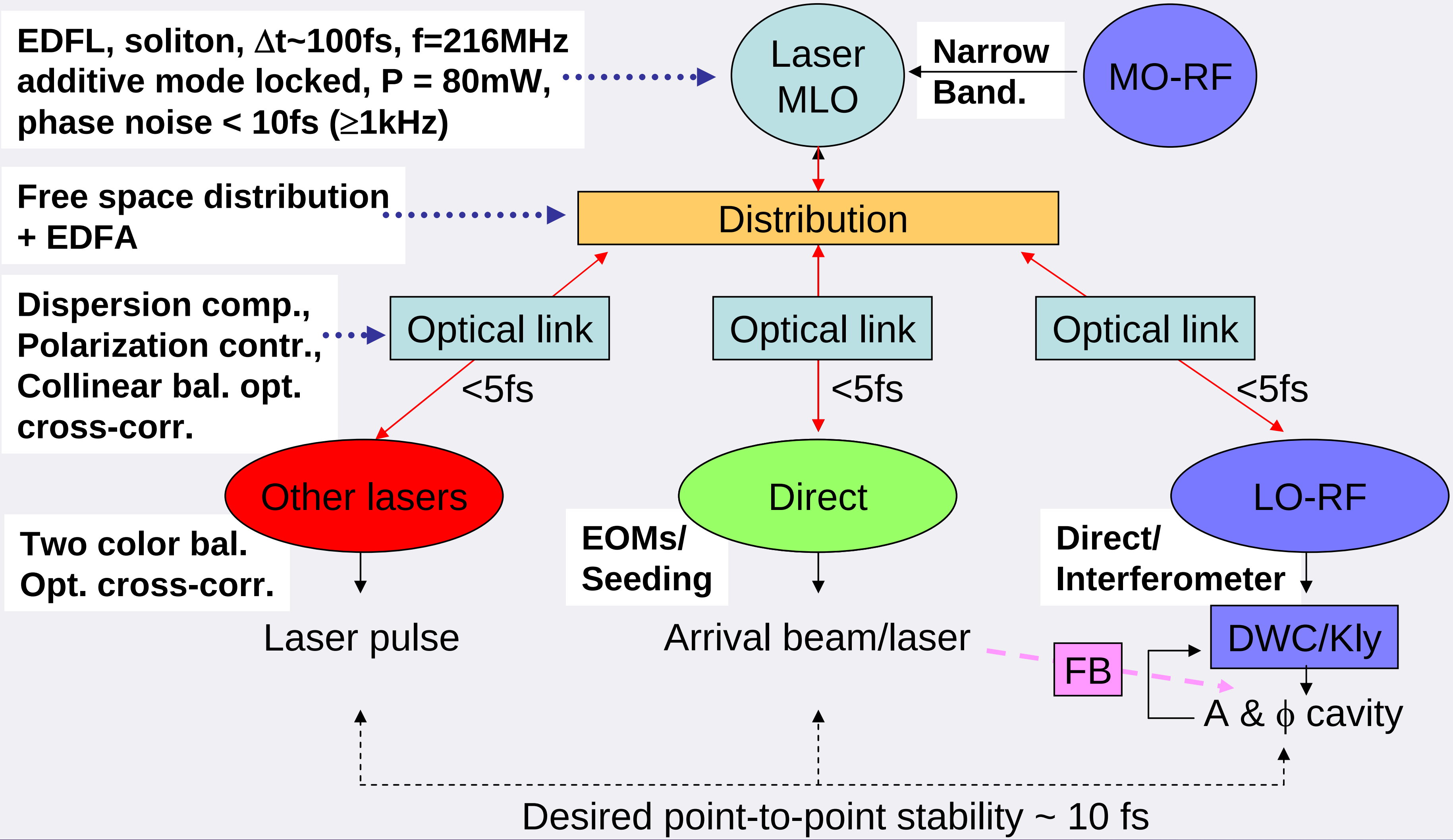
Optical replica synthesizer



Hardware commissioning is scheduled for Sep/Oct 2007

(see Poster: WEPPH039)

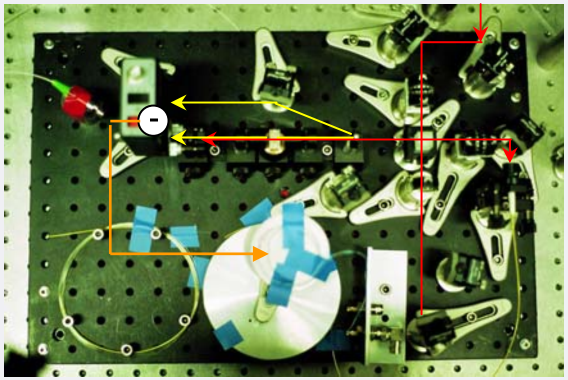
Synchronization system – general layout –



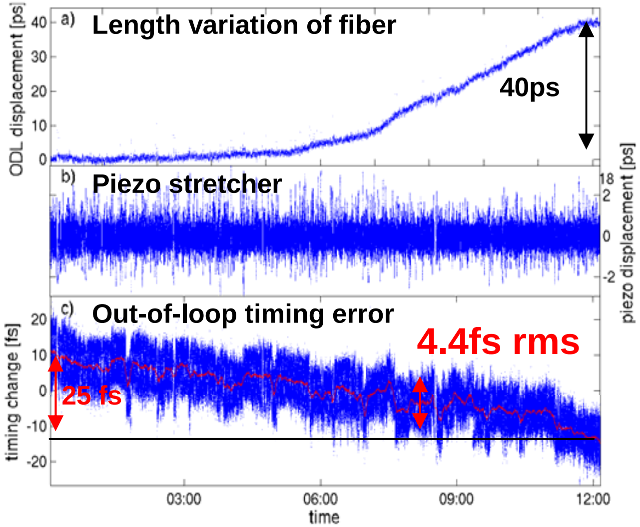
Synchronization system – recent results –

Fiber link stabilization

Balanced cross-correlator



400m link in accelerator hall

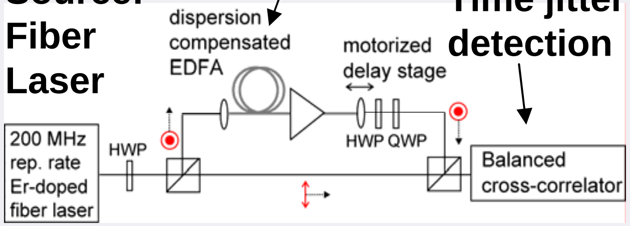


Opt. components test

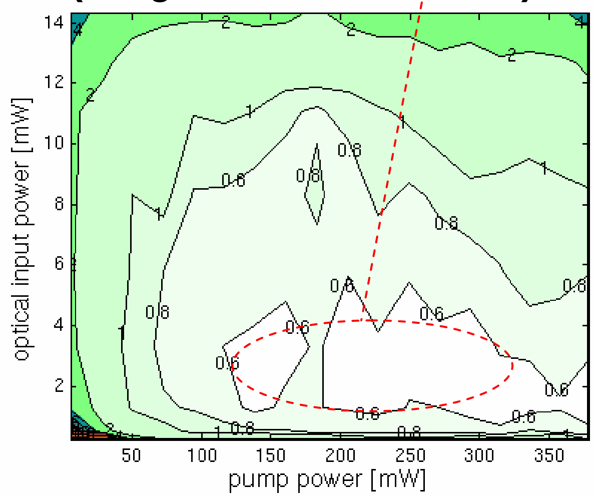
DUT e.g. Erbium doped fiber ampl.

Source: Fiber Laser

Time jitter detection

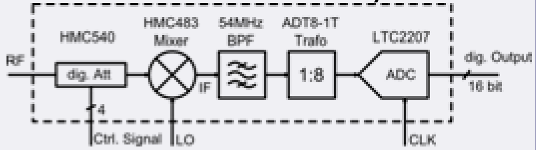


Added timing jitter: 500as (integrated 500Hz-4.5MHz)

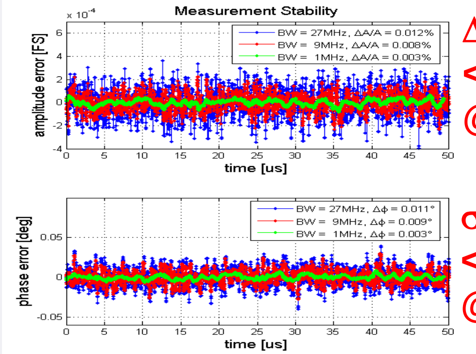


RF down converter

Scheme: IF=54MHz, DBM



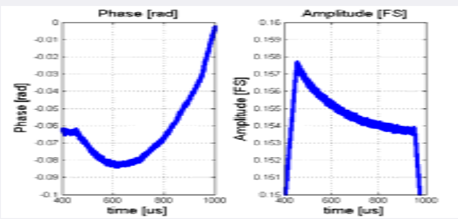
Lab measurements:



ΔA/A <3e-5 @1MHz

σ_ϕ <0.003° @1MHz

Meas. at module test stand



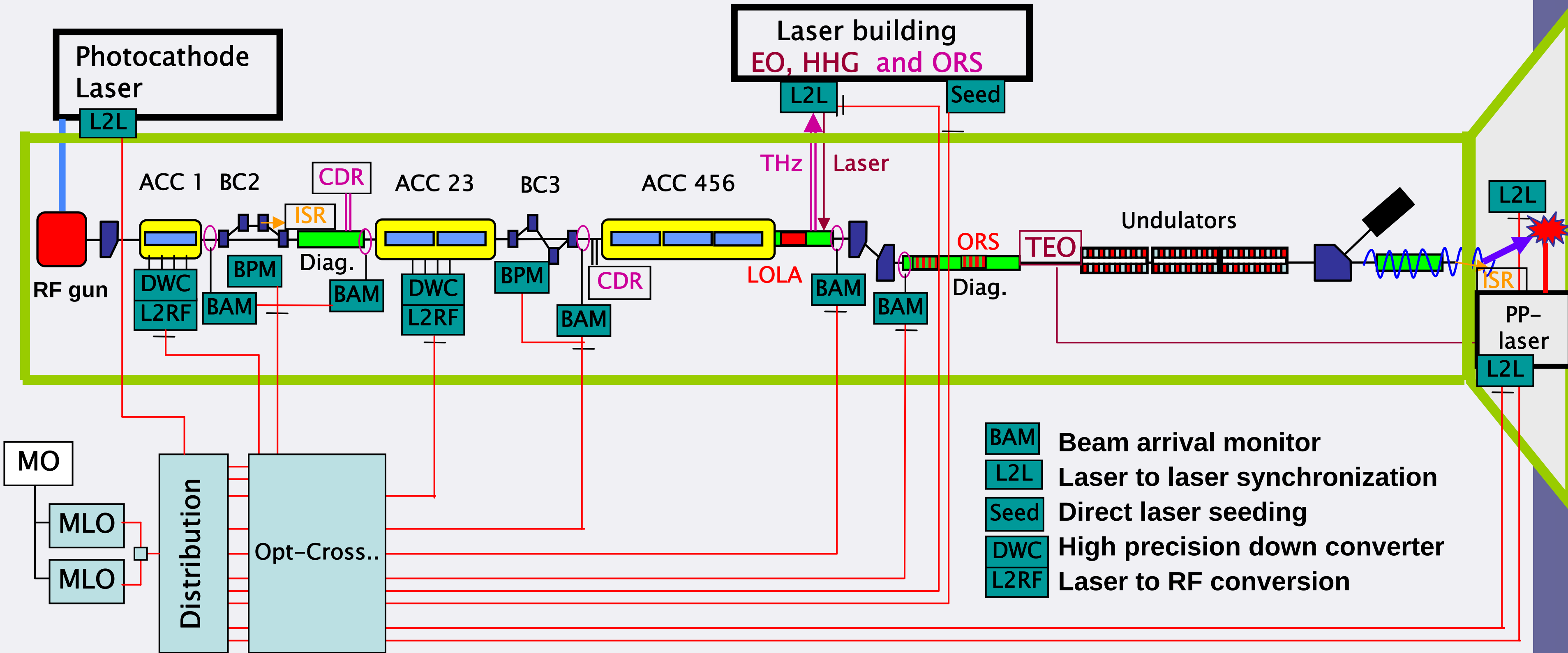
Courtesy: F. Löhl

Courtesy: F. Löhl, J. Müller

Courtesy: F.Ludwig,M. Hoffmann M. Felber

Synchronization system – FLASH –

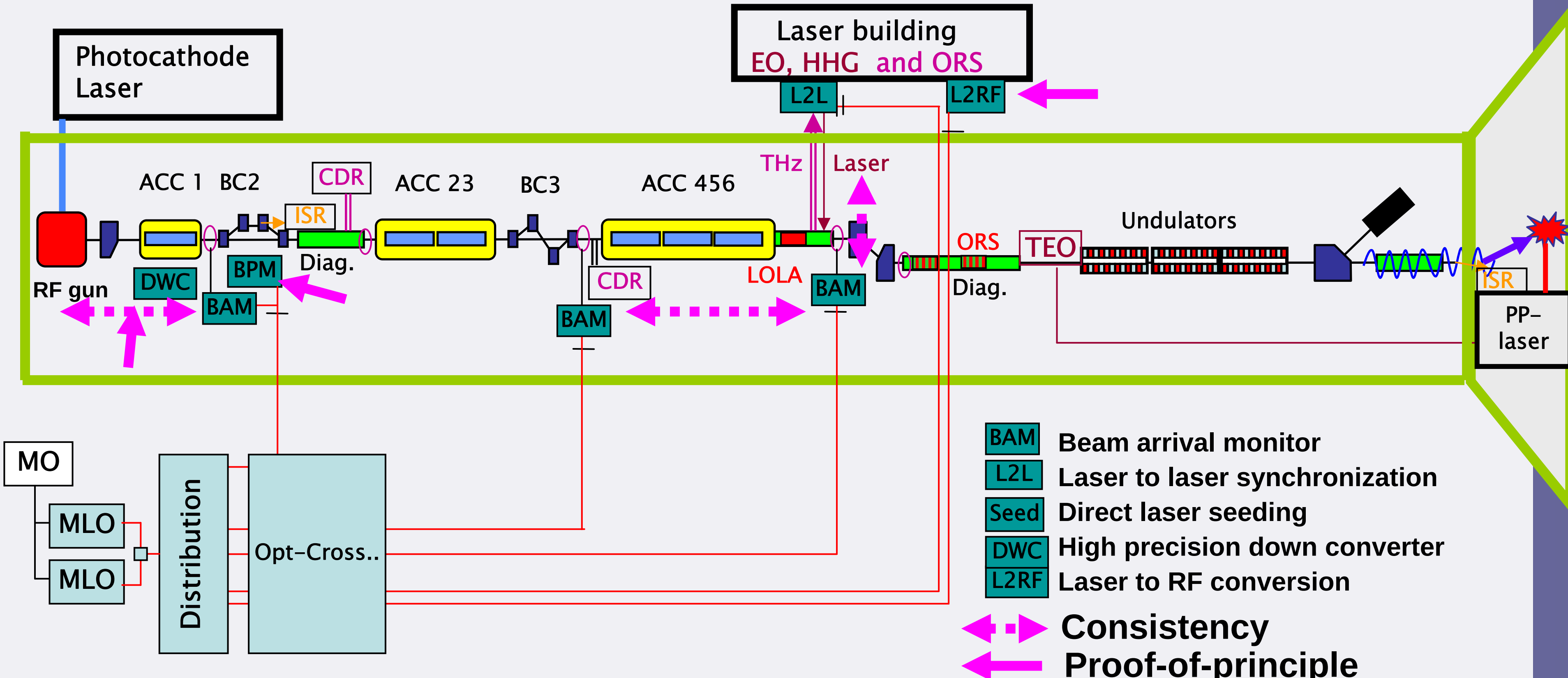
Implementation of complete system 2008/2009



- Synchronization of all timing critical devices (~ 12 points)
- Point-to-point synchronization ~ 10fs rms
- Permanent operation and long term stability /availability investigation

Synchronization system – near future –

2007: consistency checks, opto-mechanical layout, first permanent end-station



- 2 links + BAM at ACC3&ACC7 < 30fs rms
- Chicane BPMs
- Next generation of DWC
- Beam-based feedback around ACC1 dA/A < 0.01%,
- Ti:Sa system locked via opt. cross + BAM/EO timing meas.

High Harmonic Laser Seeding at 30nm (sFLASH)

User operation at FLASH is currently realized using SASE:

+ most robust scheme and fewest technical challenges!
- energy fluct., long. coherence, synchronization, long undulator section

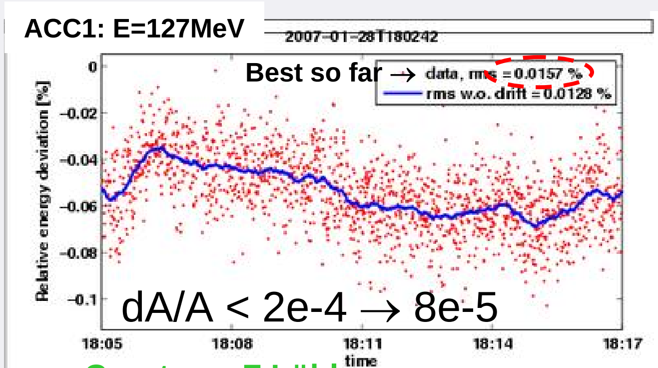
External seeding using higher harmonics of a laser in e.g. gas jet

+ adjustable pulse duration, long. coherence., lower energy fluct. and femtosecond synchronization (timing carrier is the laser)
- considerably technically more challenging: ***temporal*** *and spatial overlap*

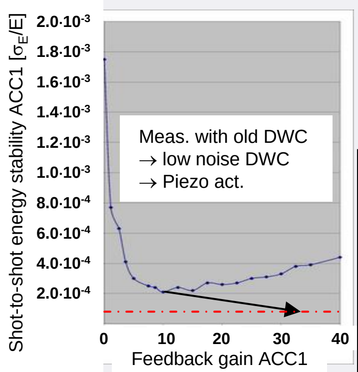
Timing jitter of beam:
~150 fs rms → < 40 fs

$$\Sigma_t^2 \approx \left(\frac{R_{56}}{c_0}\frac{\sigma_A}{A}\right)^2 + \left(\frac{C-1}{C}\right)^2\left(\frac{\sigma_\phi}{c_0 k_{rf}}\right)^2 + \left(\frac{1}{C}\right)^2 \Sigma_{i,t}^2$$

FLASH: 5.5ps/% | 2 ps/deg | 0.05 ps/ps



Courtesy: F.Löhl



Courtesy: E. Vogel

- Laser based synchronization + beam FB
- 2009: 3.9 GHz cav. σ_t=20fs → 160fs rms

⇒ Pre-requisites for HH-Seeding fullf.
⇒ Proposal of technical feasibility study submit to BMBF
⇒ Has been approved (Aug 08) seeded-FLASH (sFLASH)

High Harmonic Laser Seeding at 30nm (sFLASH)

- Simulation with Genesis:

Comb structure of HH pulse used

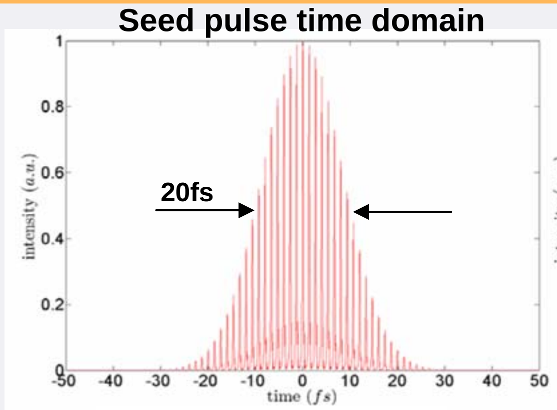
λ= 30 nm, E= 1 nJ, Δt_{FWHM} = 20 fs

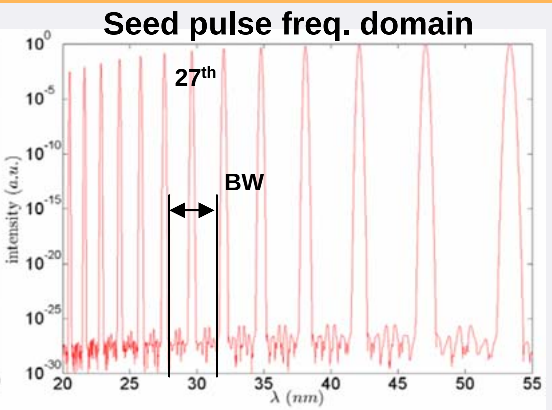
I_{peak} =1.5 kA, ε^n = 2 μm, σ_z= 80 μm

K_{rms}=1.38, λ_u=29mm

$\Rightarrow$ **6 m undulator saturation with 1GW**

$\Rightarrow$ **Longer undulator causes SASE background**



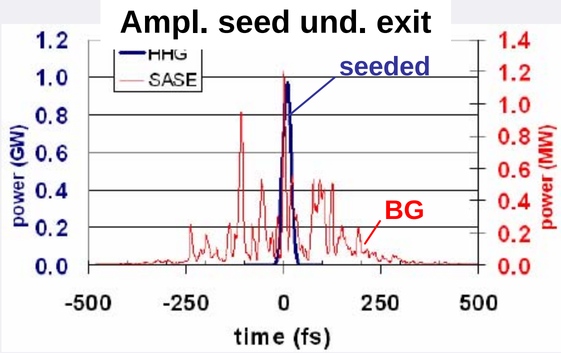


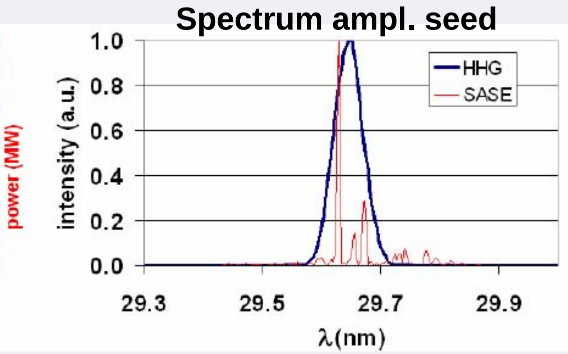
- Tunable gap undulator (PETRA)

Choice: λ_u ~ 32mm, K=1:..2.3, g=18…10mm

$\Rightarrow$ Wide range independent of beam energy

$\Rightarrow$ **λ=12-50nm but initially λ~30nm**





- Laser system:

Optically synchronized TiSa osc.

Regenerative ampl., multi-pass ampl.

E=15mJ, Δt_{FWHM}=35fs, 10 Hz

Courtesy: V.Miltchev

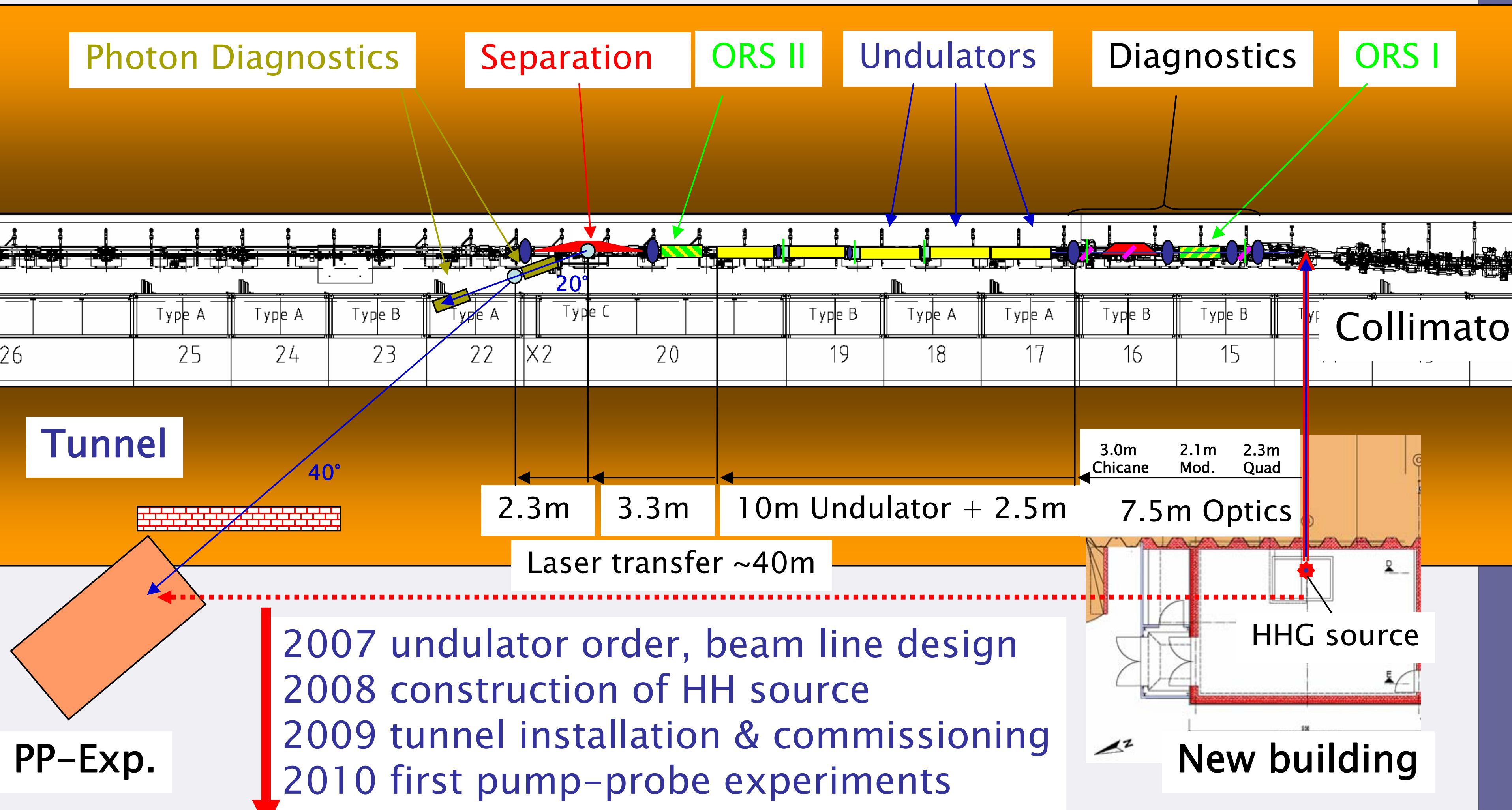
- Out-coupling:

Mirror located near undulator exit (Δz~3m, 6nJ, 2GW, <damage threshold 60mJ/cm^2)

$\Rightarrow$Allows for **laser switching scheme** by using small chicane!

$\Rightarrow$No laser-> SASE background <1MW, with laser ~ 1GW

High Harmonic Laser Seeding at 30nm (sFLASH)



- 2007 undulator order, beam line design
- 2008 construction of HH source
- 2009 tunnel installation & commissioning
- 2010 first pump-probe experiments

Photon switching mirror @2Hz

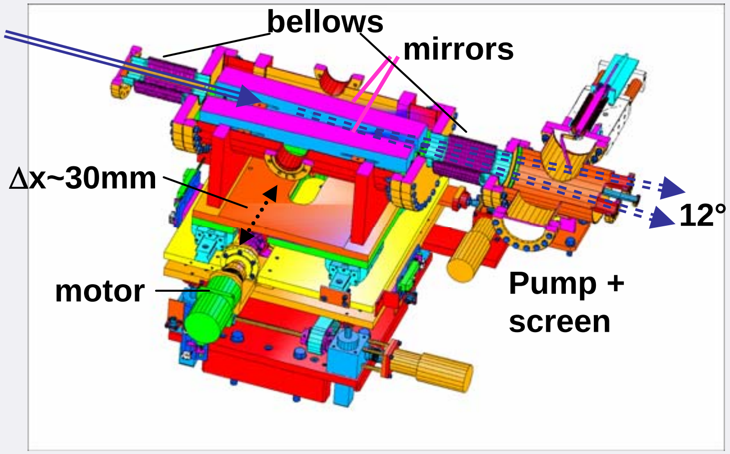
How to increase facility capacity?

switching of photon beam line

- Large beam diameter ~ 10mm (50cm long mirrors)
- Envisioned switching rate ~ 2Hz

Feasibility study for rapidly switching mirror

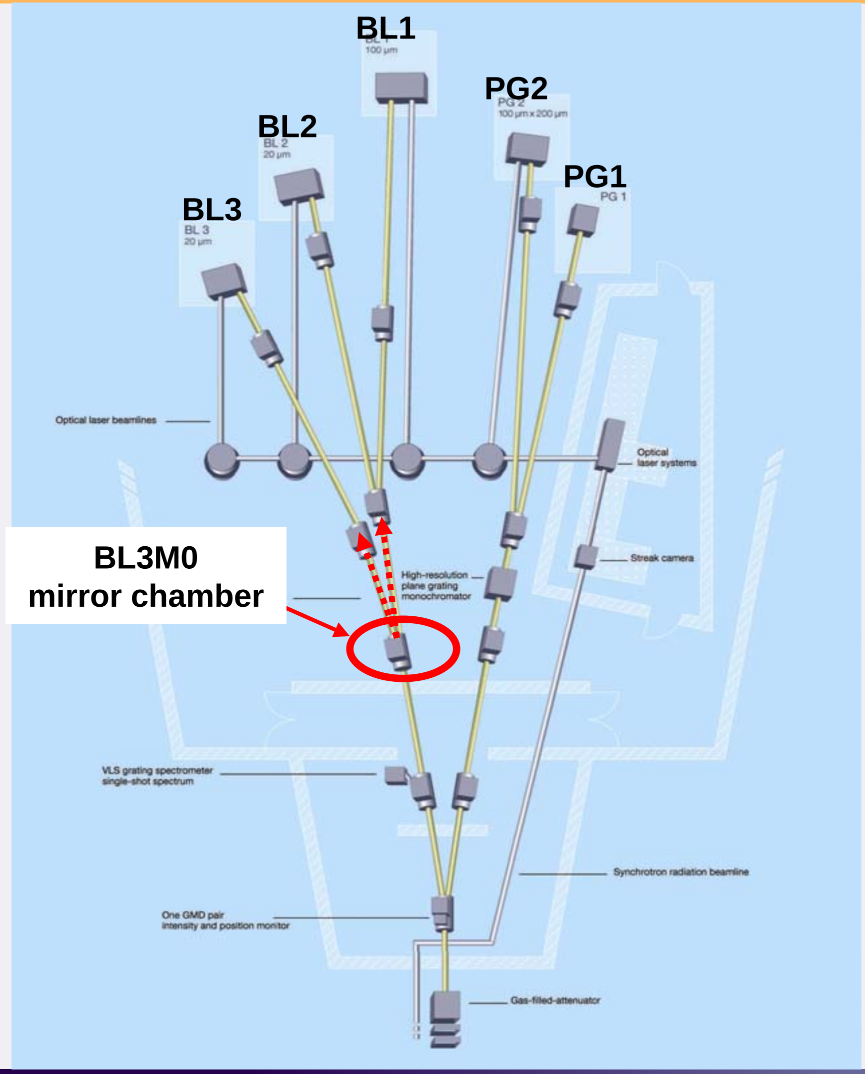
BL1&2 ↔ BL3 2007



First prototype test 2007/8 (built in Zeuthen)

Installation 2008/9

Courtesy: K. Tiedtke, U. Gensch, U. Hahn, M. Sachwitz, H. Thom



Summary

Preparing for the European XFEL important future FLASH upgrades are

- Acceleration structure development:
  - Normal conducting gun development
  - SRF 1.3 GHz modules production in industry
  - Operation of the 3.9 GHz system for phase space linearization
- Diagnostics developments
  - THz/EO/ORS
- Infrastructure and utility systems
  - Transverse Feedback
  - Pulse cable test
  - Laser based synchronization system
- Technical feasibility study of a seed FEL at 30 nm for user operation
- Improvement availability, maintainability and stability!!!!