FLASH Injector Laser

FLASH.
Free-Electron Laser
in Hamburg

Laser 1

Laser 2

Next steps

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FLASH Meeting
DESY
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MAX-BORN-INSTITUT

HELMHOLTZ GEMEINSCHAFT

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General Design Issues of the Laser

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> L-band RF gun + requirement on e- bunches → determines transverse and longitudinal shape of laser, synchronization

> Photocathode: work function, QE → determines wavelength, energy

> Superconducting accelerator → long bunch trains

			Actual specs
synchronization	<<1 dg of RF cycle	<<2 ps @1.3 GHz	< 1 ps rms
longitudinal and transverse size	~5 dg RF → ~10 ps	field uniformity → ~mm	length 20 ps, Ø = 3 mm
charge ~1 nC per bunch	Cs_2Te cathode QE ~ 1…10% (UV)	~1 µJ/pulse@UV	factor of ~10 overhead
long trains of pulses with low rep rate	trains 800 µs long with up to 7200 pulses (9 MHz) @ 10 Hz		

→ Laser average power in the Watt range

> Suitable type of laser → mode-locked solid-state system (MOPA: synchronized oscillator + amplifiers + frequency converter to UV)

Laser 1 System Overview

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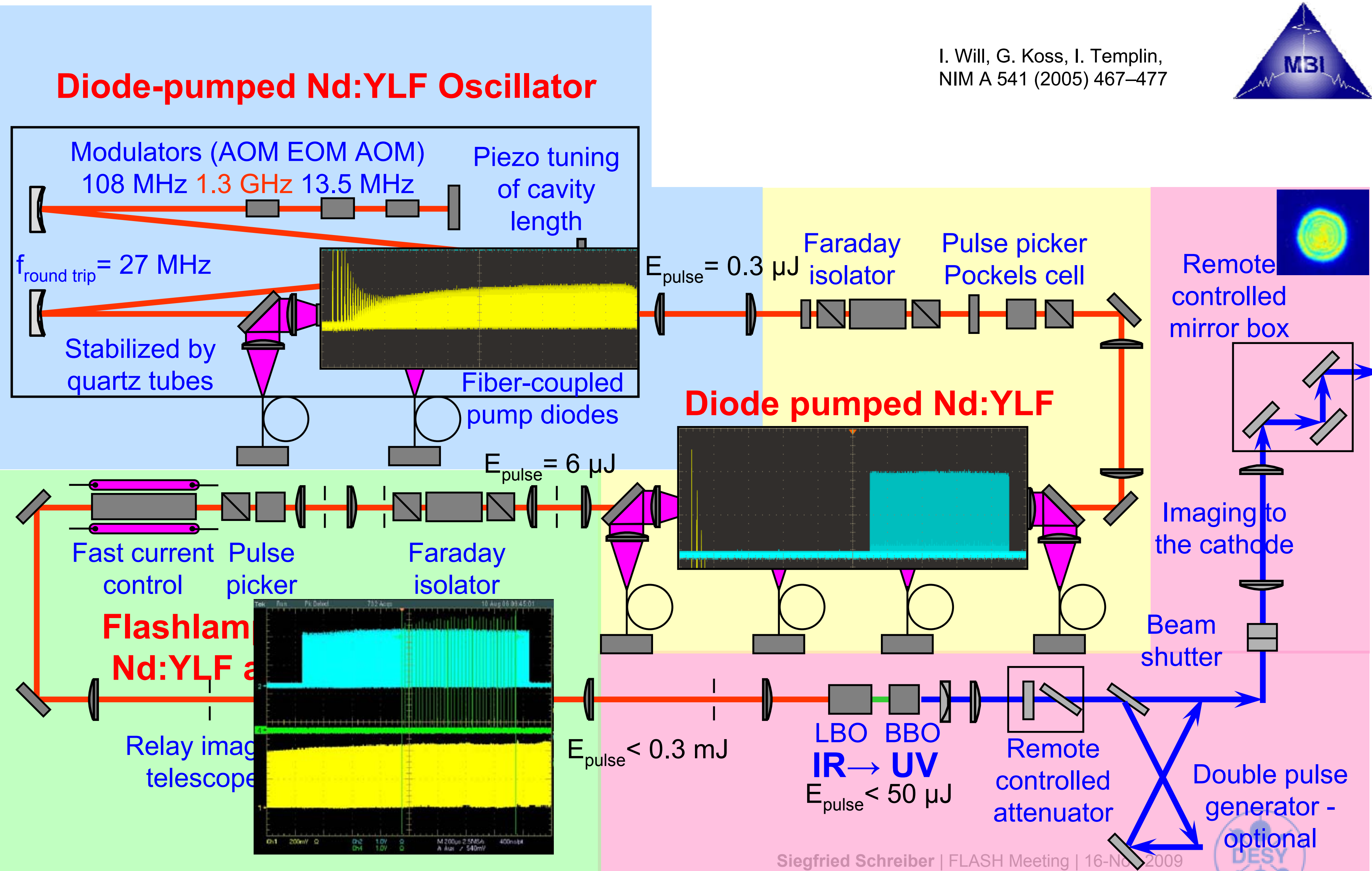
I. Will, G. Koss, I. Templin,
NIM A 541 (2005) 467–477



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Pulse Train Oscillator (PTO) – same for both lasers

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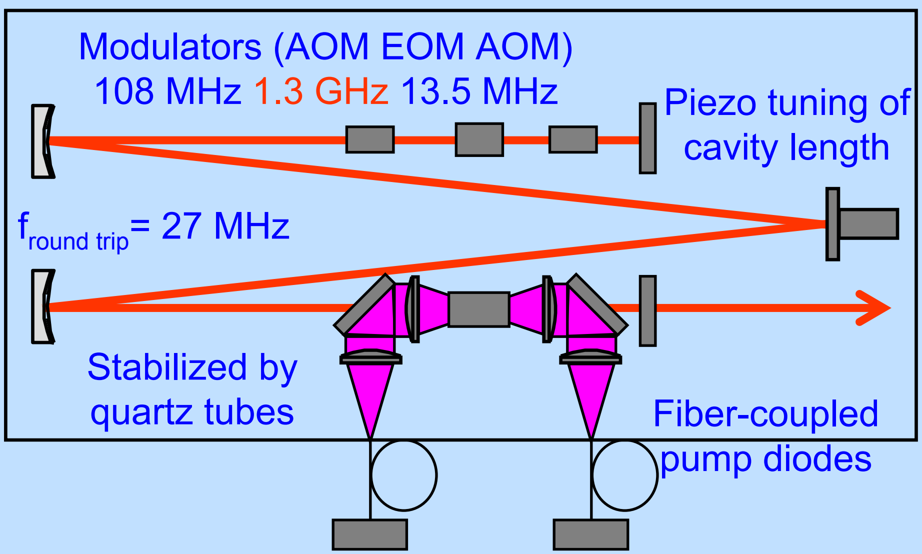
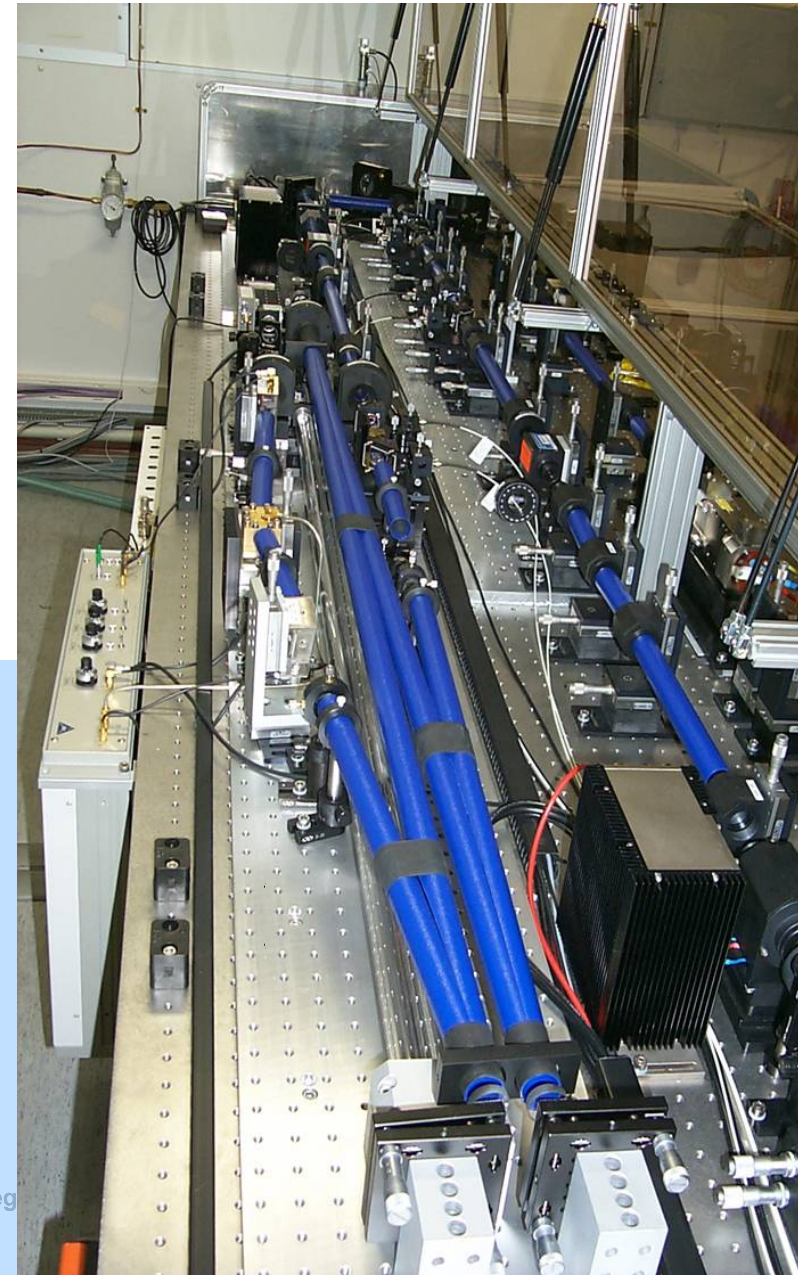
> Mode-locked pulsed oscillator
  - Diode pumped (32 W)

> Synchronized to 1.3 GHz master oscillator
  - 1.3 GHz EO modulator with 2 AOMs (108 + 13.5 MHz)
  - Phase stability < 200 fs rms
  - Pulse length 12 ps (fwhh) IR -> 10 ps UV

> Stabilized with quartz rods
  - Thermal expansion coefficient
    fused quartz = 0.59 ppm/K (Al = 24 ppm/K)

> 27 MHz pulse train
  - Train length 2.5 ms, pulsed power 7 W





Laser 1: Chain of Linear Amplifiers

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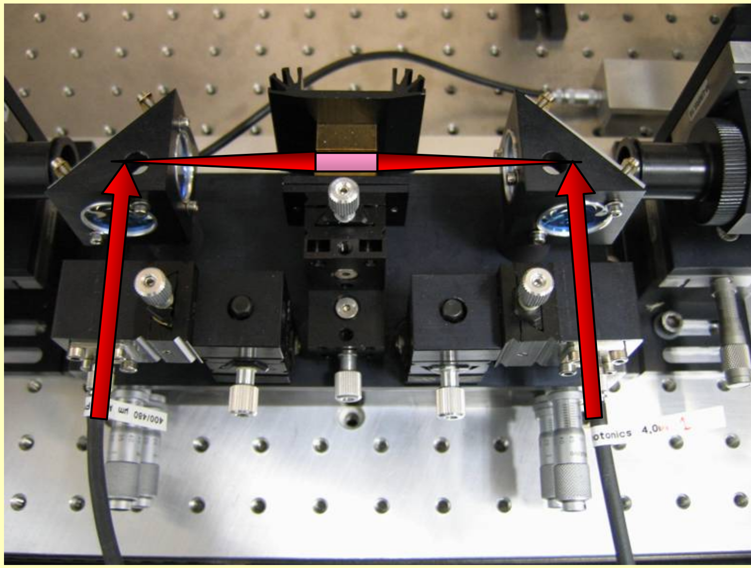
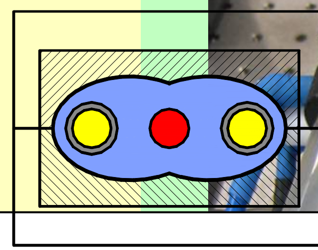
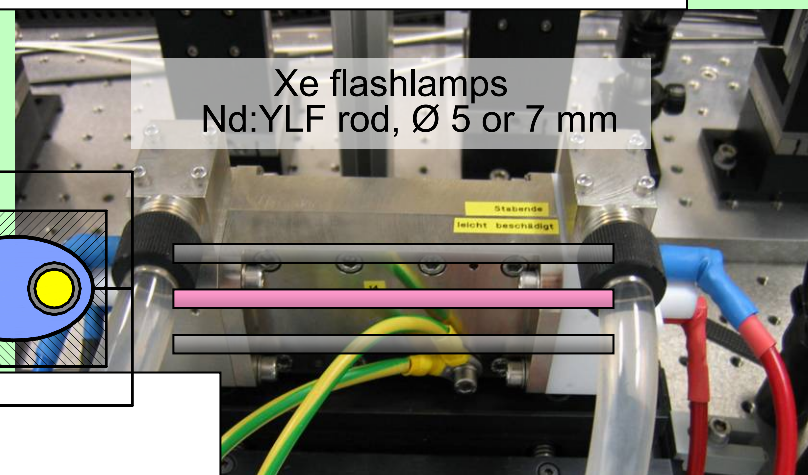
> 2 diode pumped and 2 flashlamp pumped single pass amplifiers

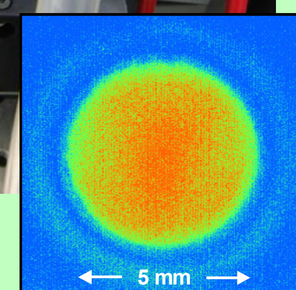


> Laser diodes:
→ 32 W pulsed, 805 nm, laser 2: 100 W diodes
→ end pumped through fibers
→ energy from 0.3 µJ to 6 µJ/pulse





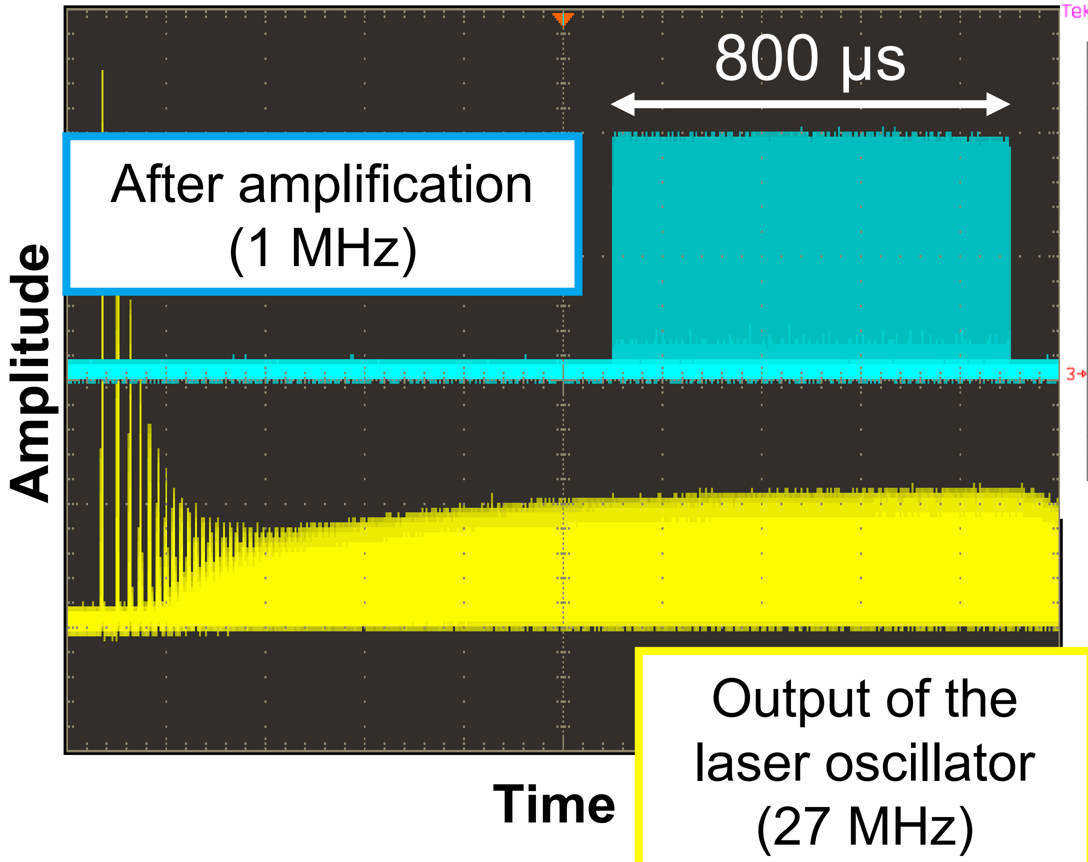
> Flashlamps pumped heads:
→ cheap, powerful (pulsed, 50 kW electrical/head)
→ current control with high power IGPT switches
→ allows flat pulse trains
→ energy up to 300 µJ (1 MHz), 140 µJ (3 MHz)
→ small-signal gain = 20
→ extractable peak power 1.2 kW, duty cycle 2%

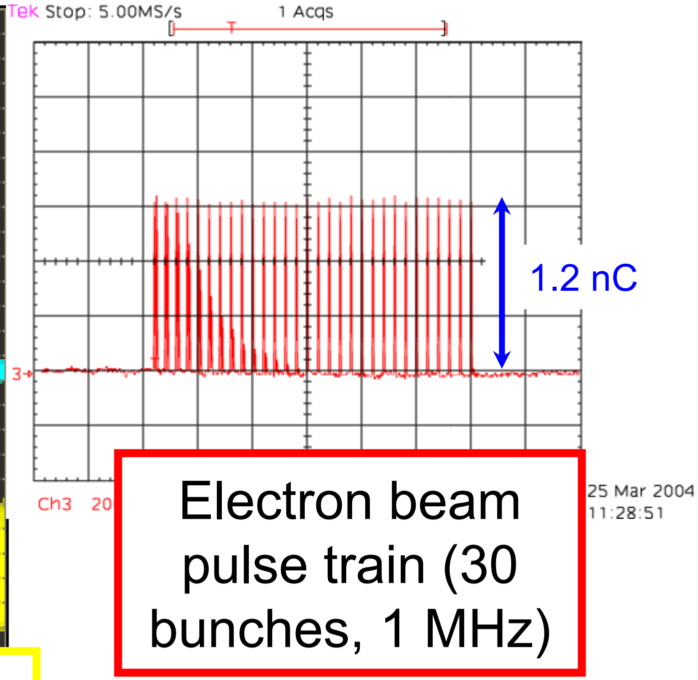


Fluorescence profile

Pulse Trains

> 2 Pulse pickers, based on Pockels cell + polarizer → 1 MHz
> Pre-amplification (diodes) of 1.2 ms long train
> Power amplification with variable bunch pattern





FLASH design goals reached in 2007

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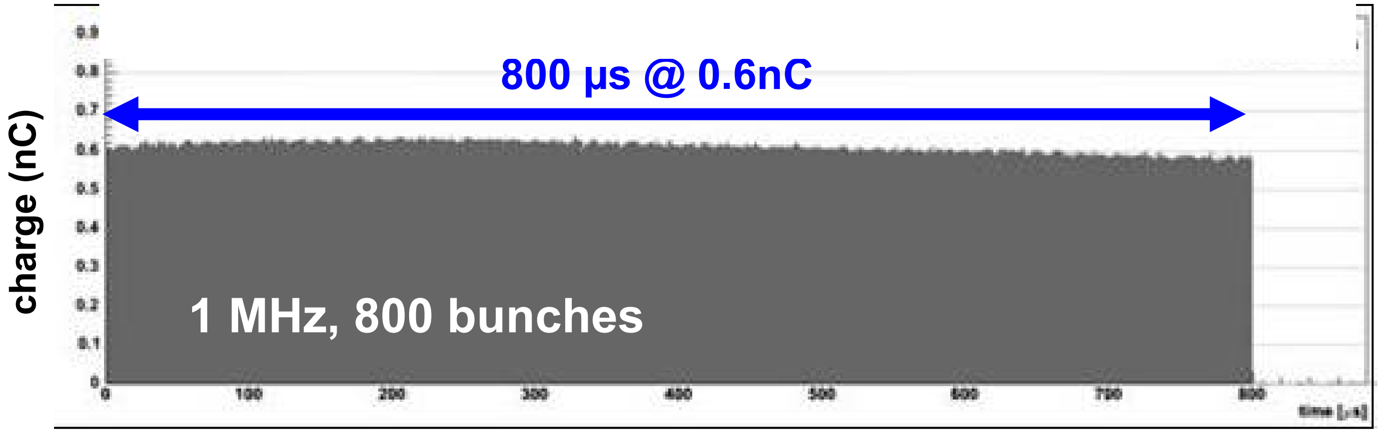
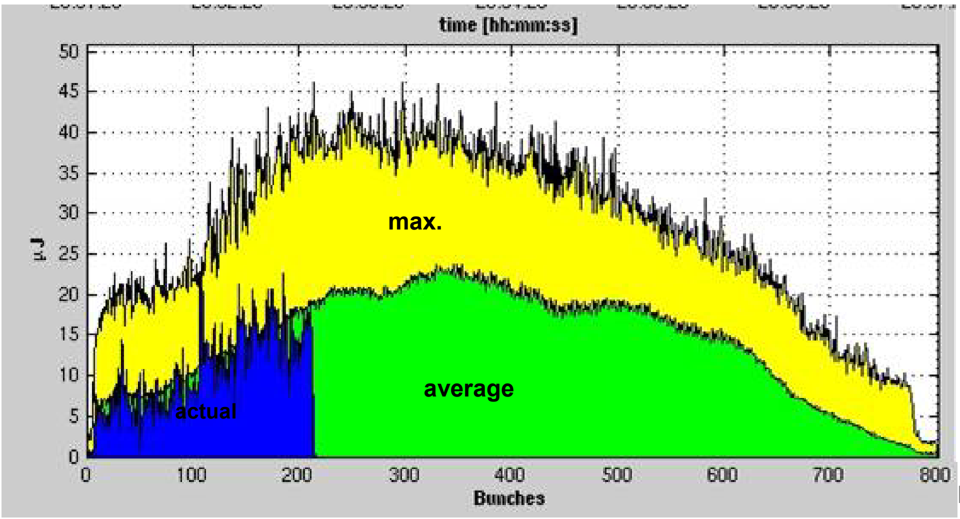
Lasing with a complete bunch train of 800 bunches at 13.4 nm



GMD - gas monitor detector - signal



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Bunch Pattern and MPS

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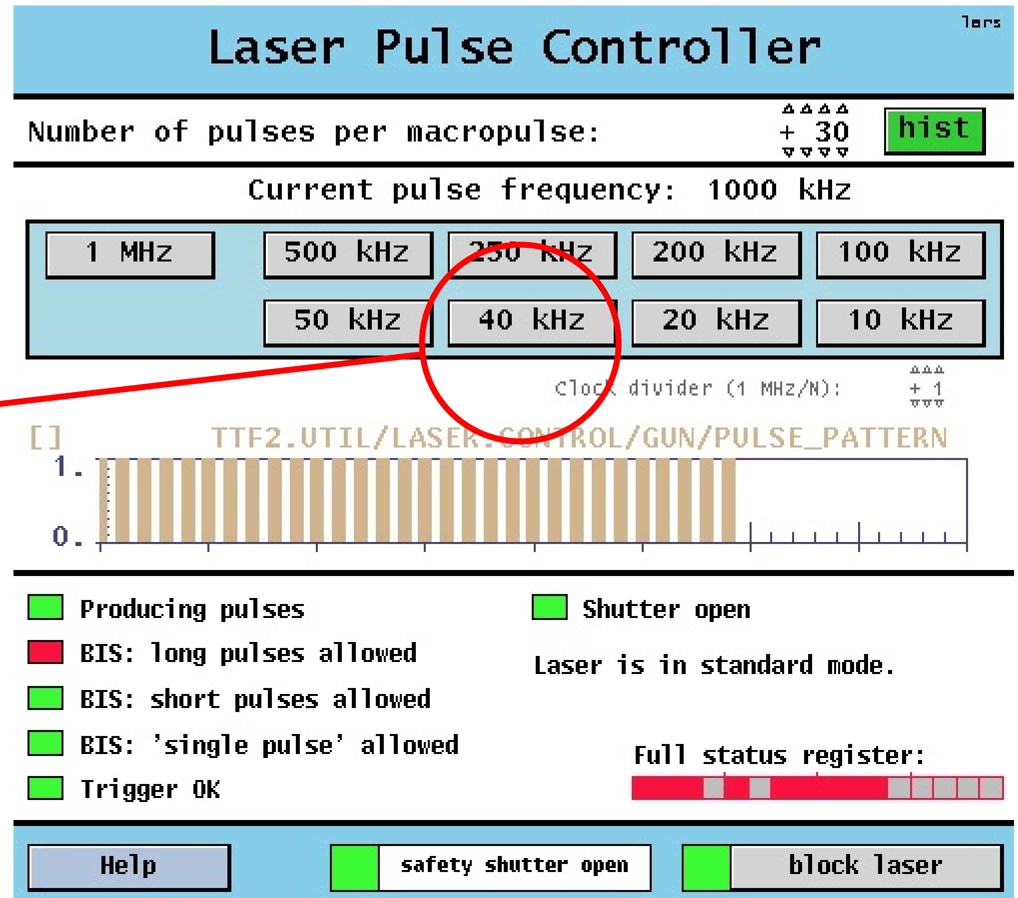
> Change bunch pattern on user request

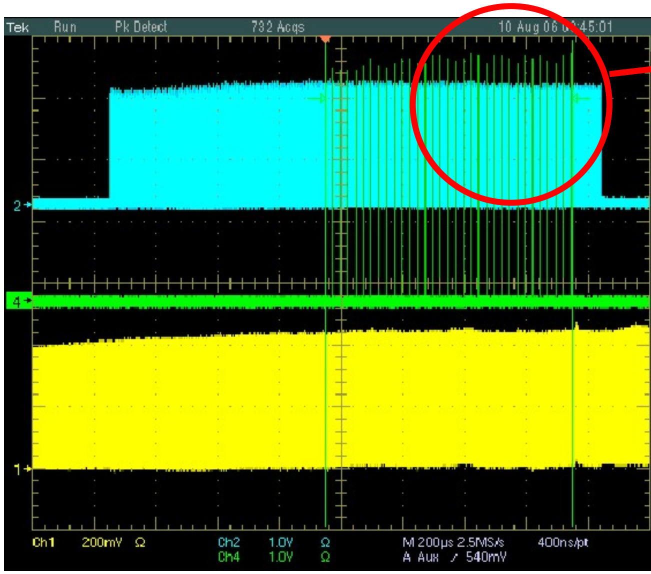
- Number of bunches
- Different bunch frequencies: 1 MHz, 500 kHz, 250 kHz, 100 kHz and others

> Realized with an FPGA based controller producing the appropriate trigger for the Pockels cell

> New card for laser 2 (T. Schulz)

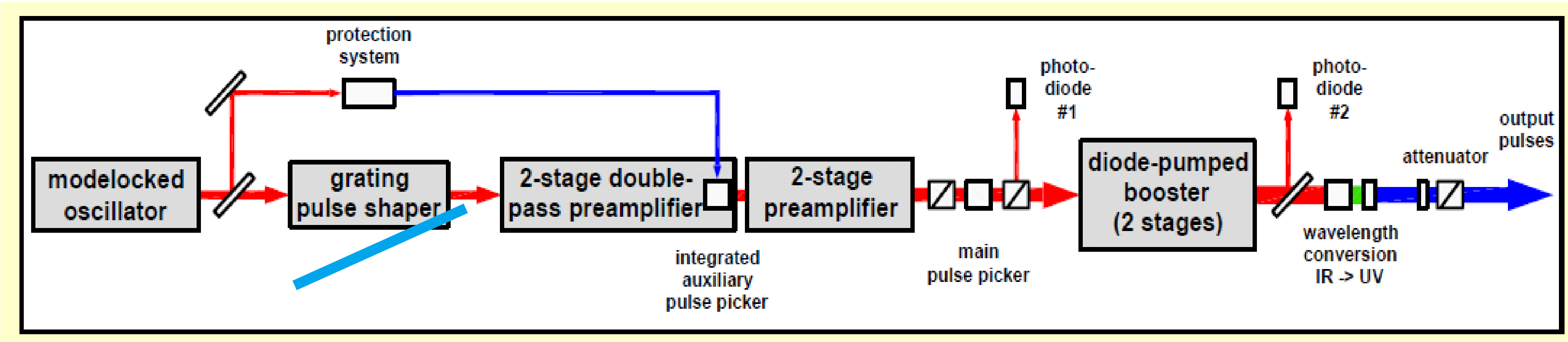
> The controller is also the interface of the machine protection system to the laser

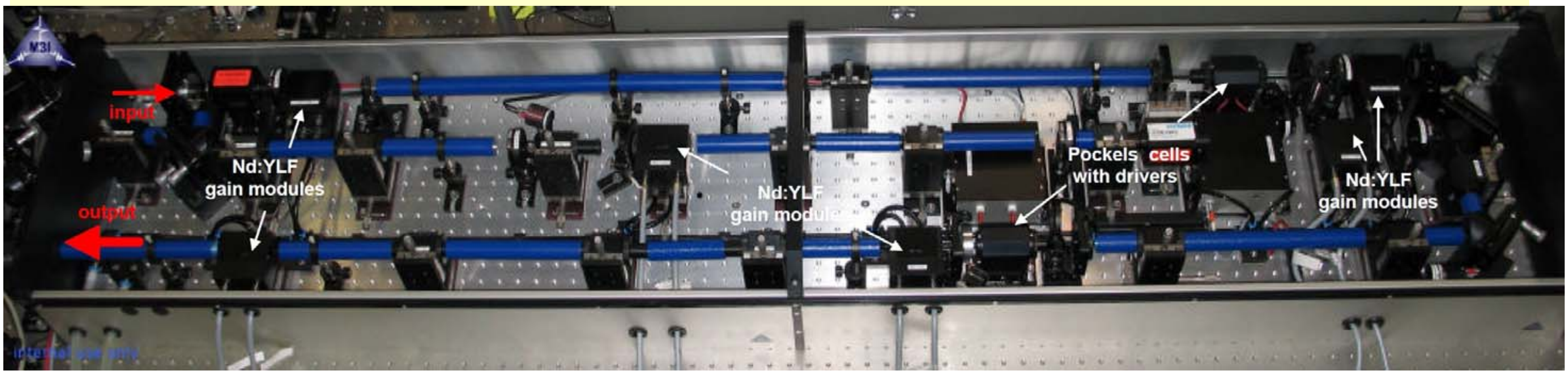




Laser 2 – fully diode pumped

- Has been extensively operated at PITZ
- FLASH version without pulse shaper, but with 3 MHz option (5 Hz only)





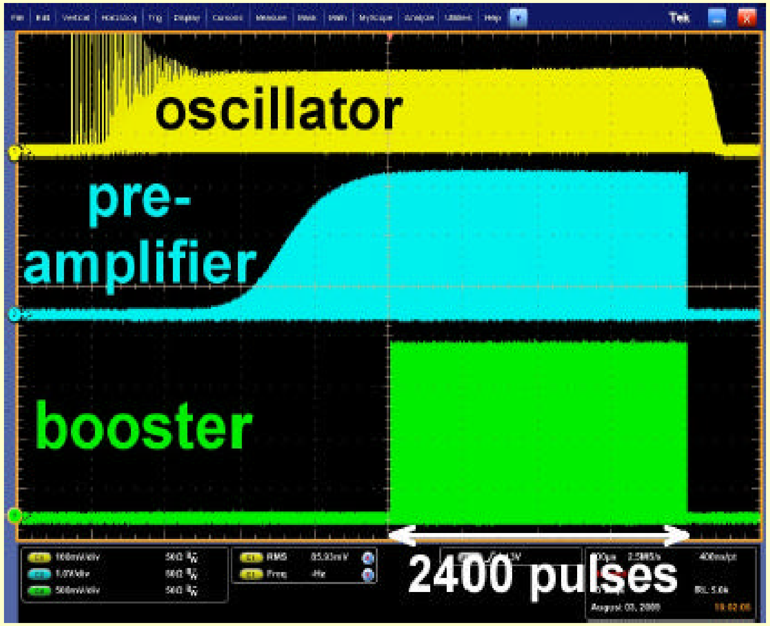
- 6 stage amplification including one double pass
- Power amplifiers pumped with 100 W laser diodes

Diode-pumped Nd:YLF laser at FLASH was upgraded to 3 MHz repetition rate

- New: **Reliable 3 MHz pulse selectors** driven by high-voltage power MOSFETs

- Average power of the laser was increased by:
  - Optimization of the optical layout of the amplifier chain
  - Two optimized protection systems allow operating the laser at higher intensity

- Results
  - **Improved stability and reliability**
  - **Simplified maintenance**:
    Fully diode-pumped system,
    No exchange of flashlamps required.



- Limit of the current laser:
  - 3 MHz / 5 Hz or
  - 1 MHz / 10 Hz
- XFEL mode (5 MHz / 10 Hz) needs:
  - Redesign of the laser heads and of the optical layout of the laser
  - Stronger pump diodes
  - Improved Pockels cell drivers

3 MHz Pockels cell drivers

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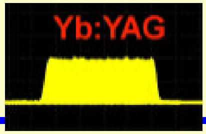
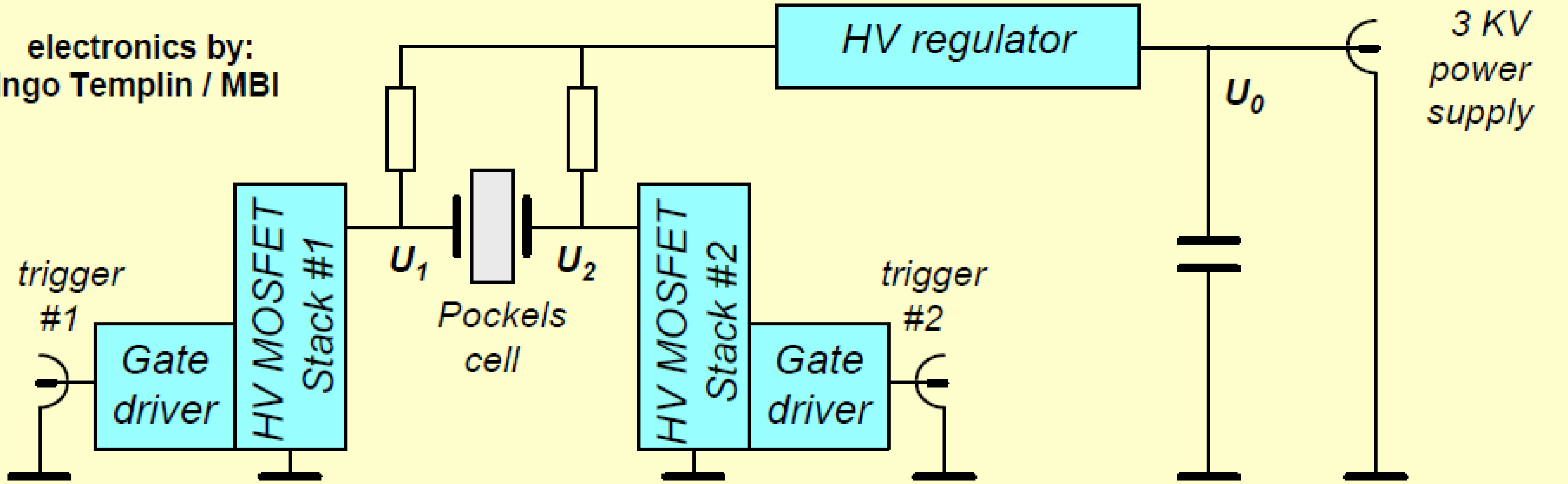
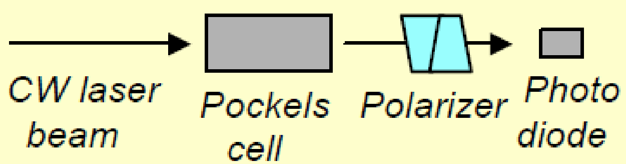
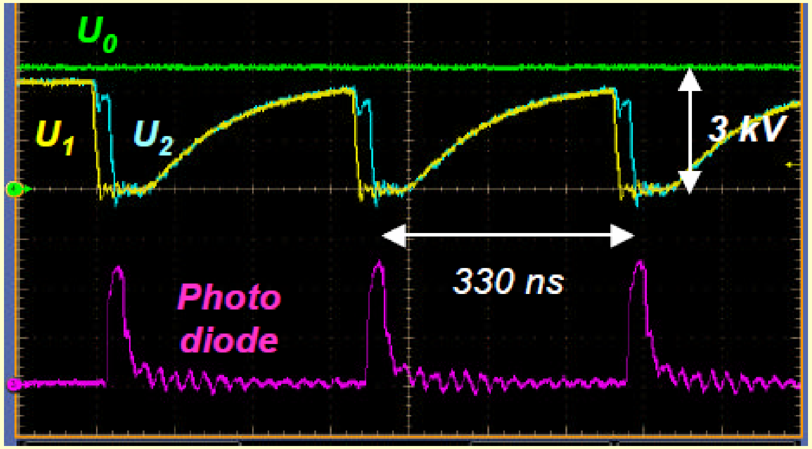
Key element:
3 MHz pulse selector



electronics by:
Ingo Templin / MBI





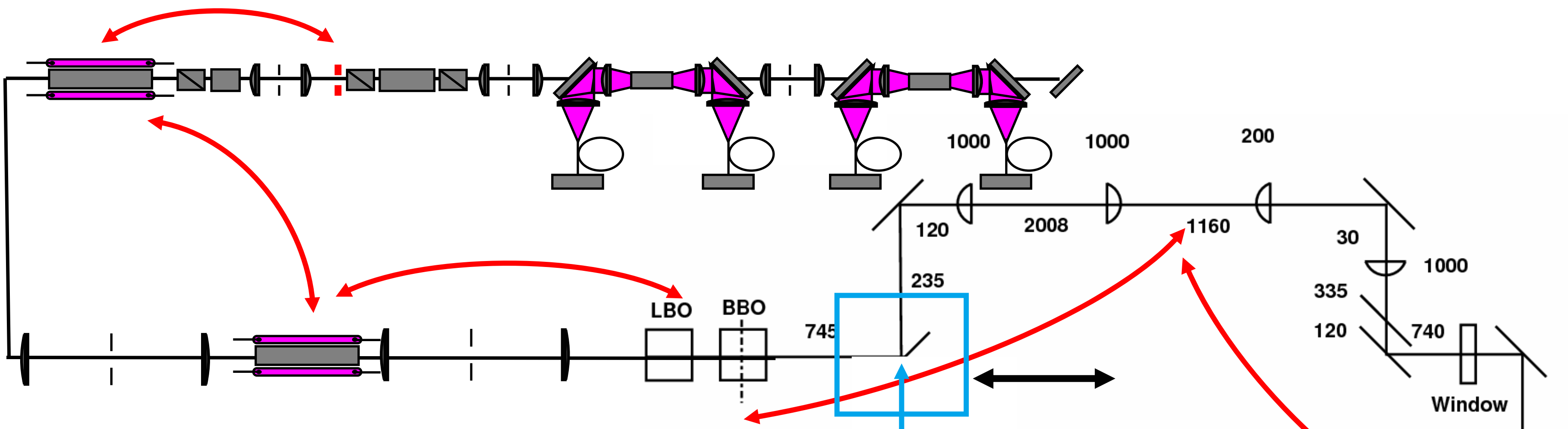


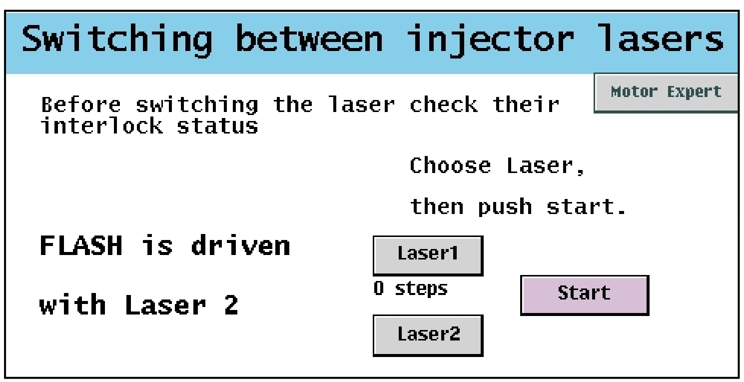
Status

- Stable operation at the following rep. rates:
  - **3 MHz** at 5 Hz rep. rate of the laser
  - **1 MHz** at 10 Hz rep. rate of the laser

Laser Beamline

> Relay imaging with spatial filtering
> Hard edge aperture after diode pumped amplifiers
> Aperture imaged to → amplifier heads → doubling crystals → cathode



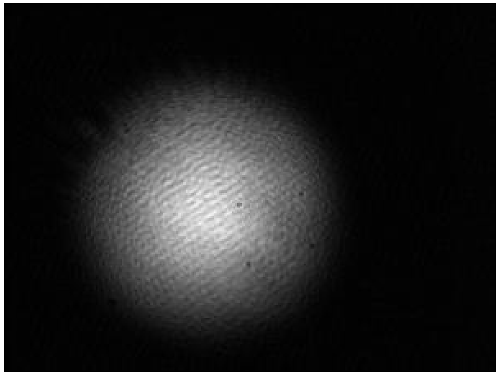


Transverse Shape

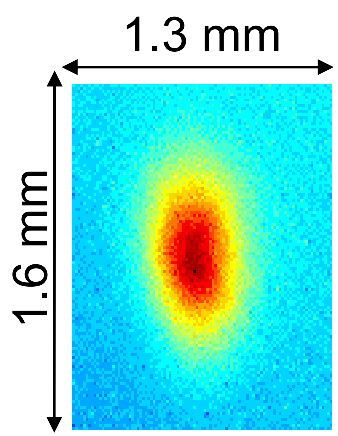
> Shape depends on quality of doubling process

> Irregular shape at laser 1, hard edge iris always required

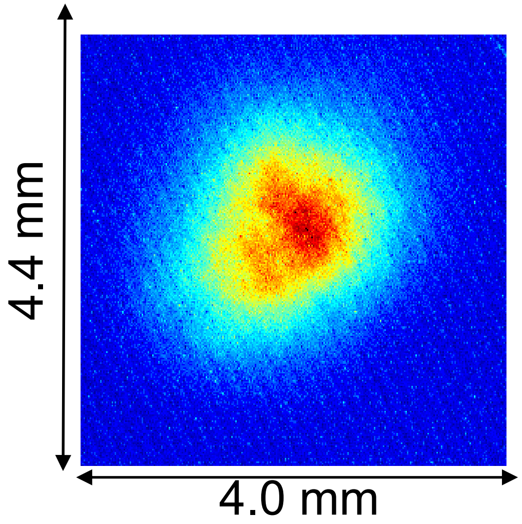
> BBO already exchanged twice, new crystals ordered



exit amplifiers (IR)



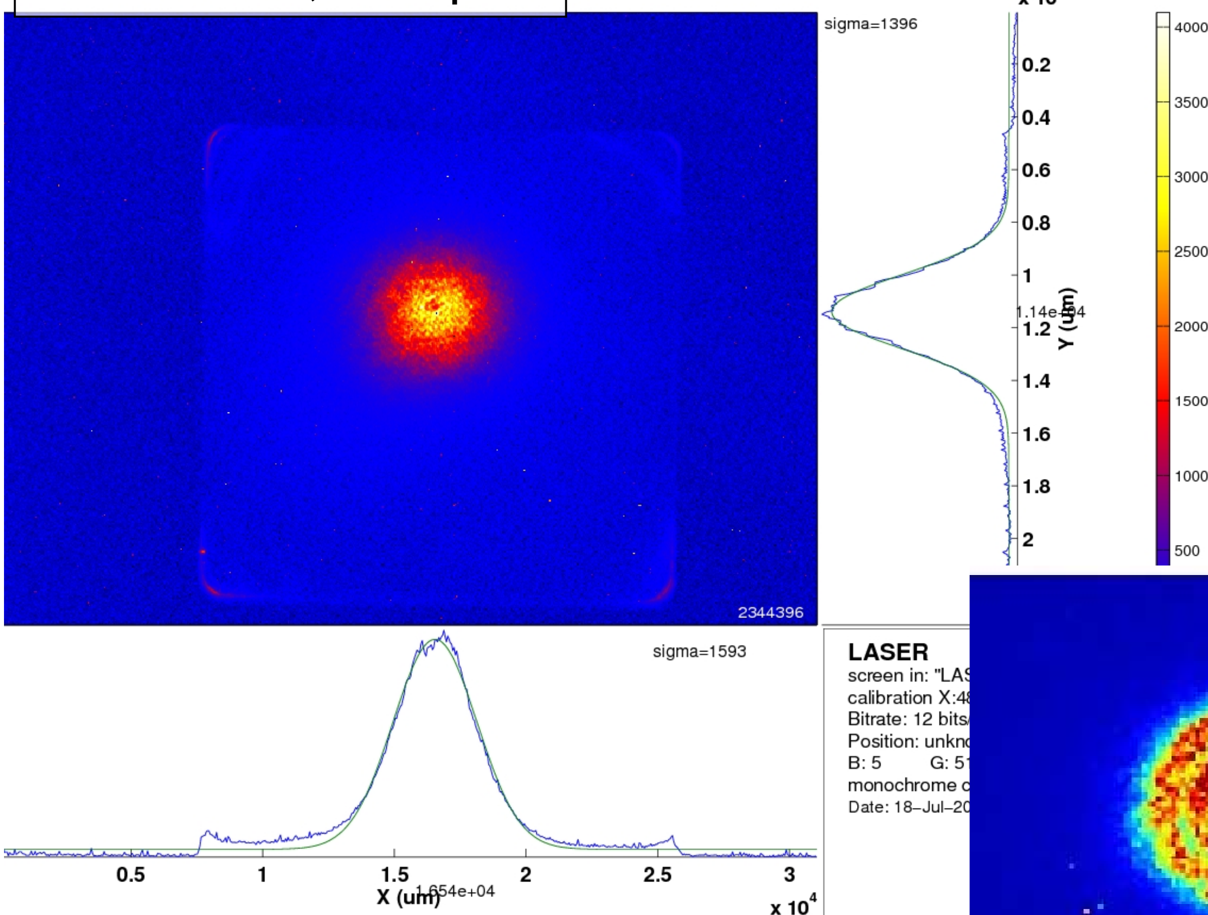
exit BBO (UV)



on cathode

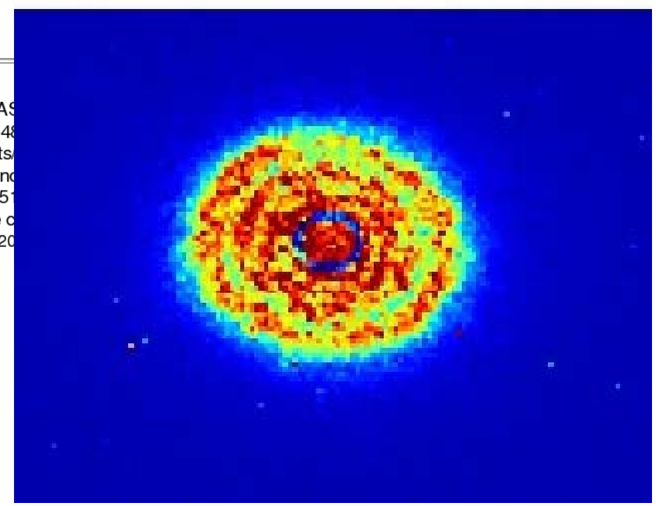
Laser 2 transverse shape

on cathode, iris open



- Laser 2 has a nice and smooth transverse shape

With iris 4 mm diam.



With iris in front of vacuum window

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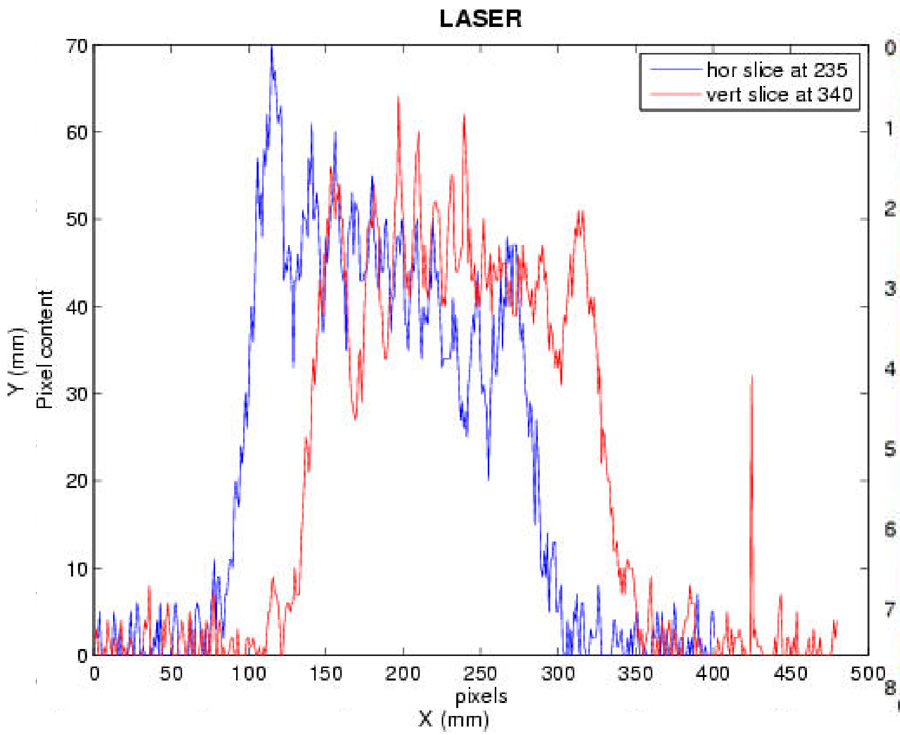
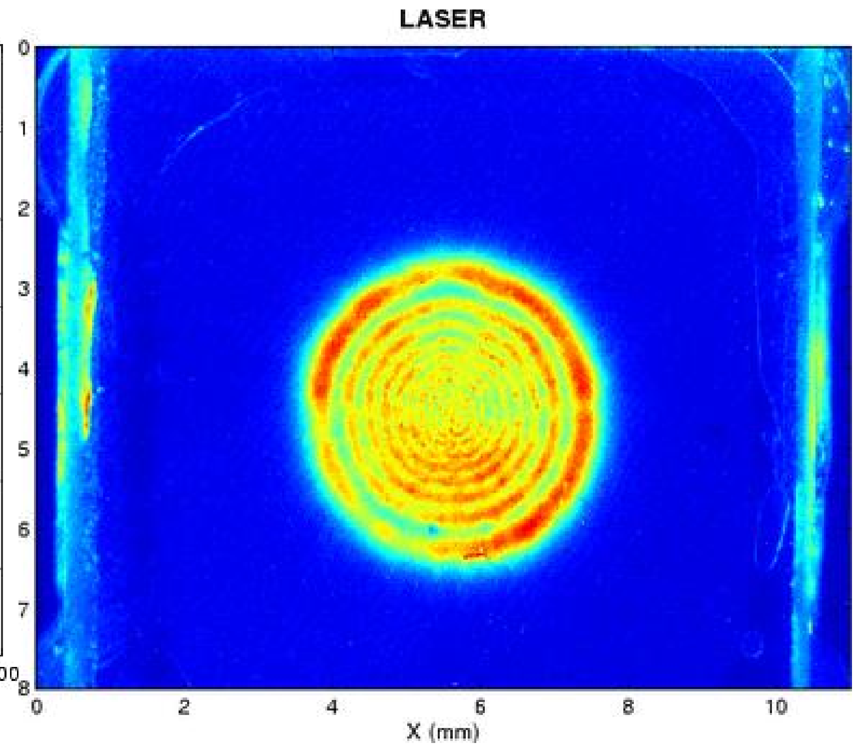
- With additional magnification by 2 (total ~10)
- Very good pointing stability, paid with fringes (~20% modulation)



Large iris (open)
Slices



Nominal iris 2.5 mm diameter

Table Iris on cathode

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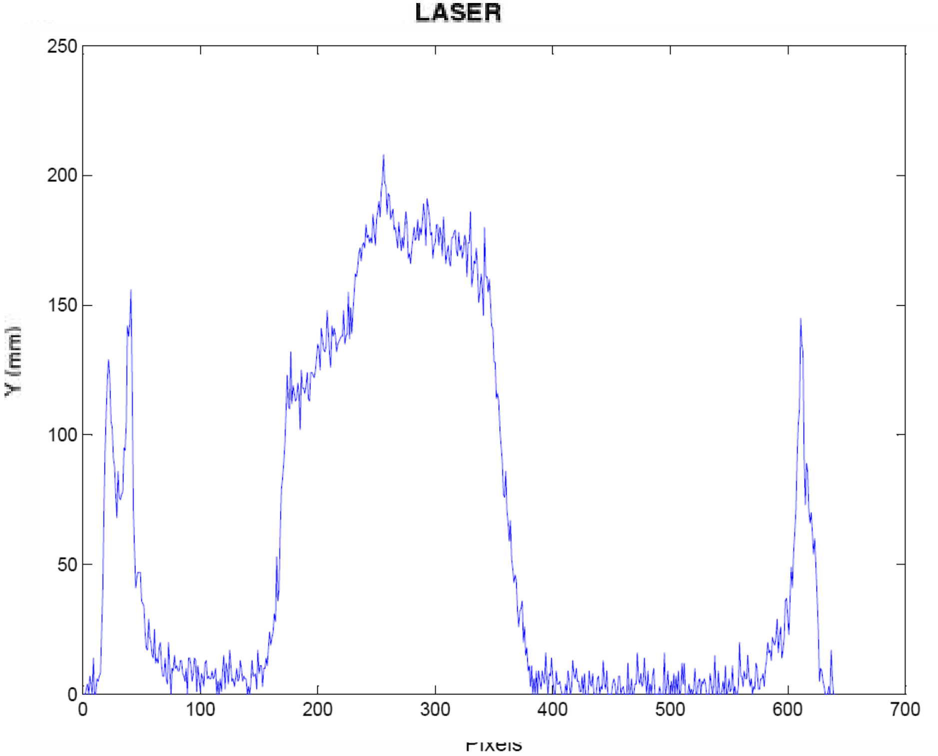
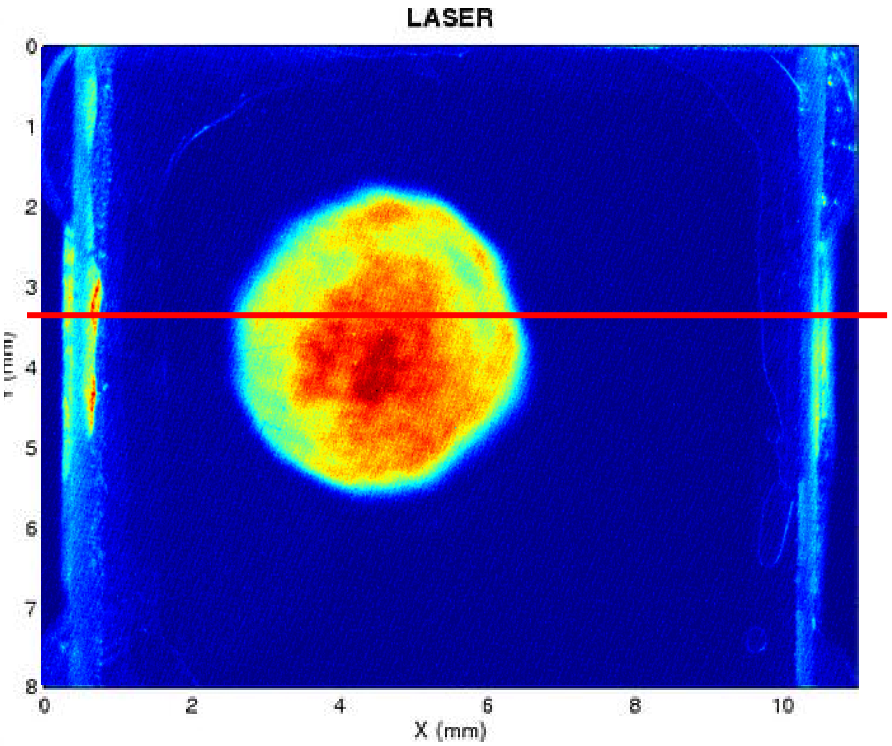
> Imaging the overfilled iris on laser table
> Problem: larger pointing jitter than iris in front of vacuum window
> Jitter about 0.5 of diameter min/max



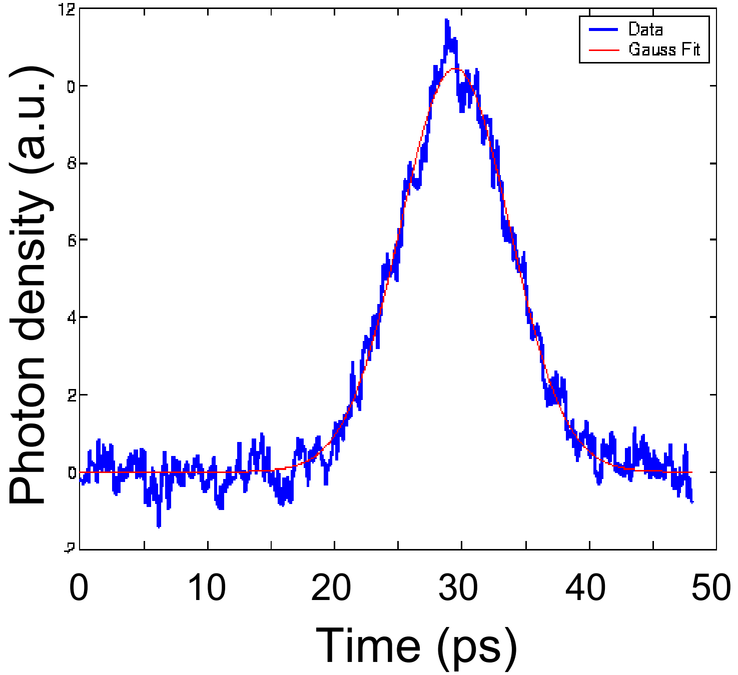
Distance iris – telescope wrong by ~1 cm



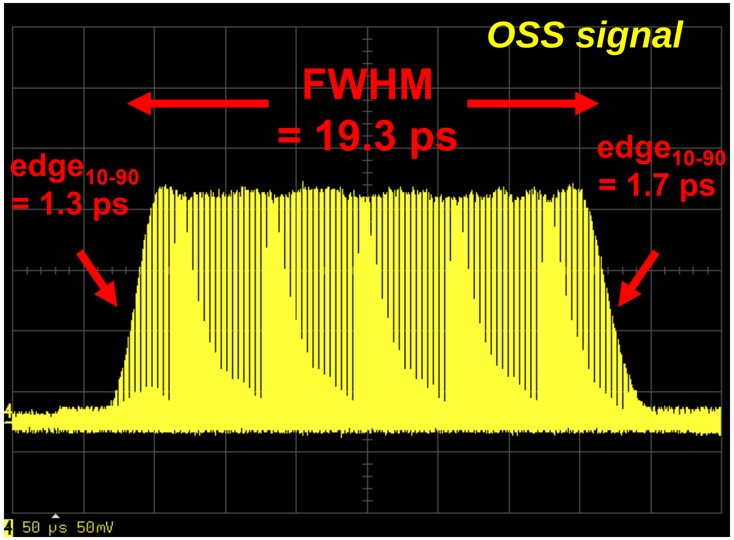
Distance iris – telescope correct

Laser Pulse Length and Shape

- Both lasers have the same longitudinal gaussian shape
- Laser 1: Measurement with a streak camera (FESCA 200)
  $\sigma_L = 4.4 \pm 0.1$ ps (at 262 nm)

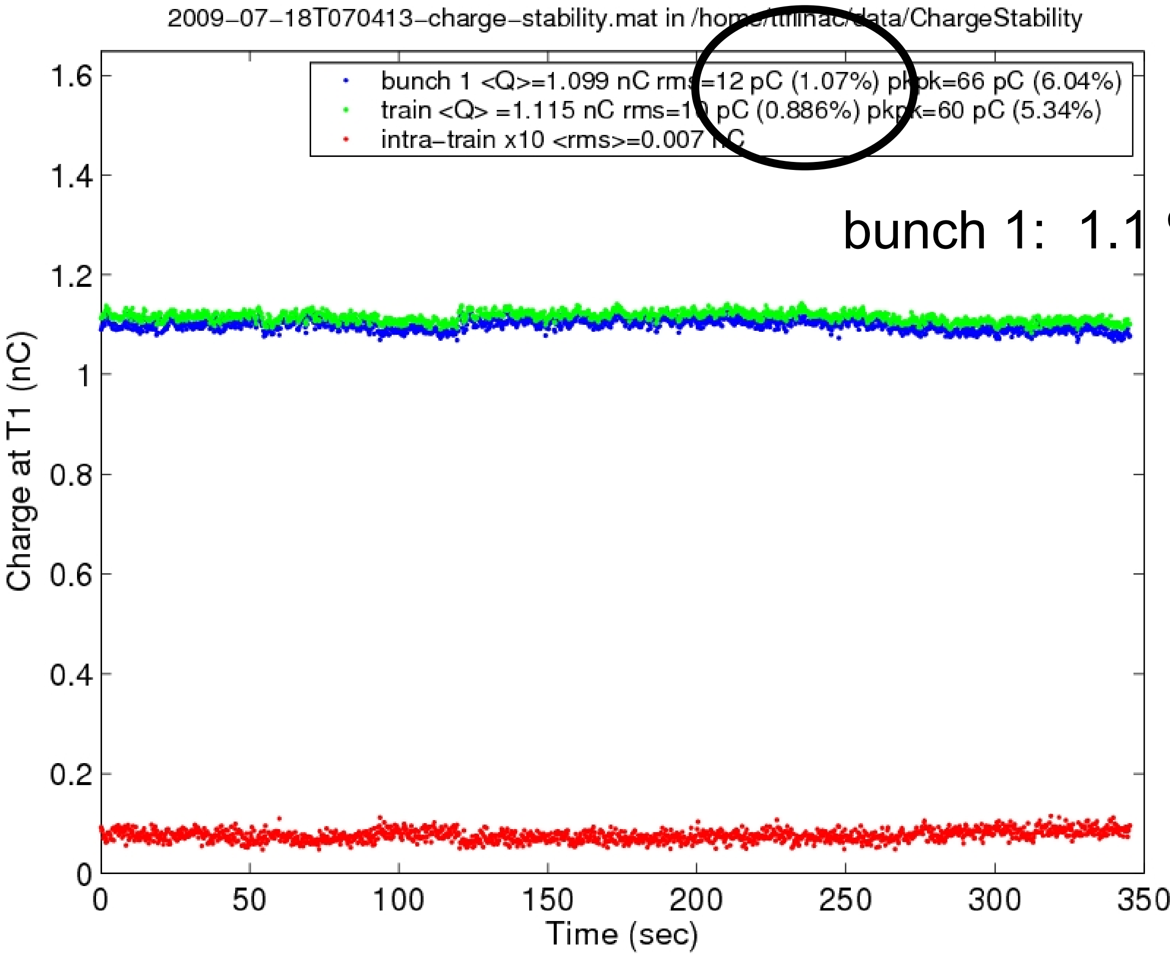


- R&D laser at PITZ:
  Longitudinal flat-hat shape
- Works fine in 'lab environment', not mature yet for a user facility
- To some extend flexible pulse shapes
  - Pulse can be made shorter, even gaussian
  - With Lyot filters smoothening of edges and flat-top



Laser 1: Charge Stability

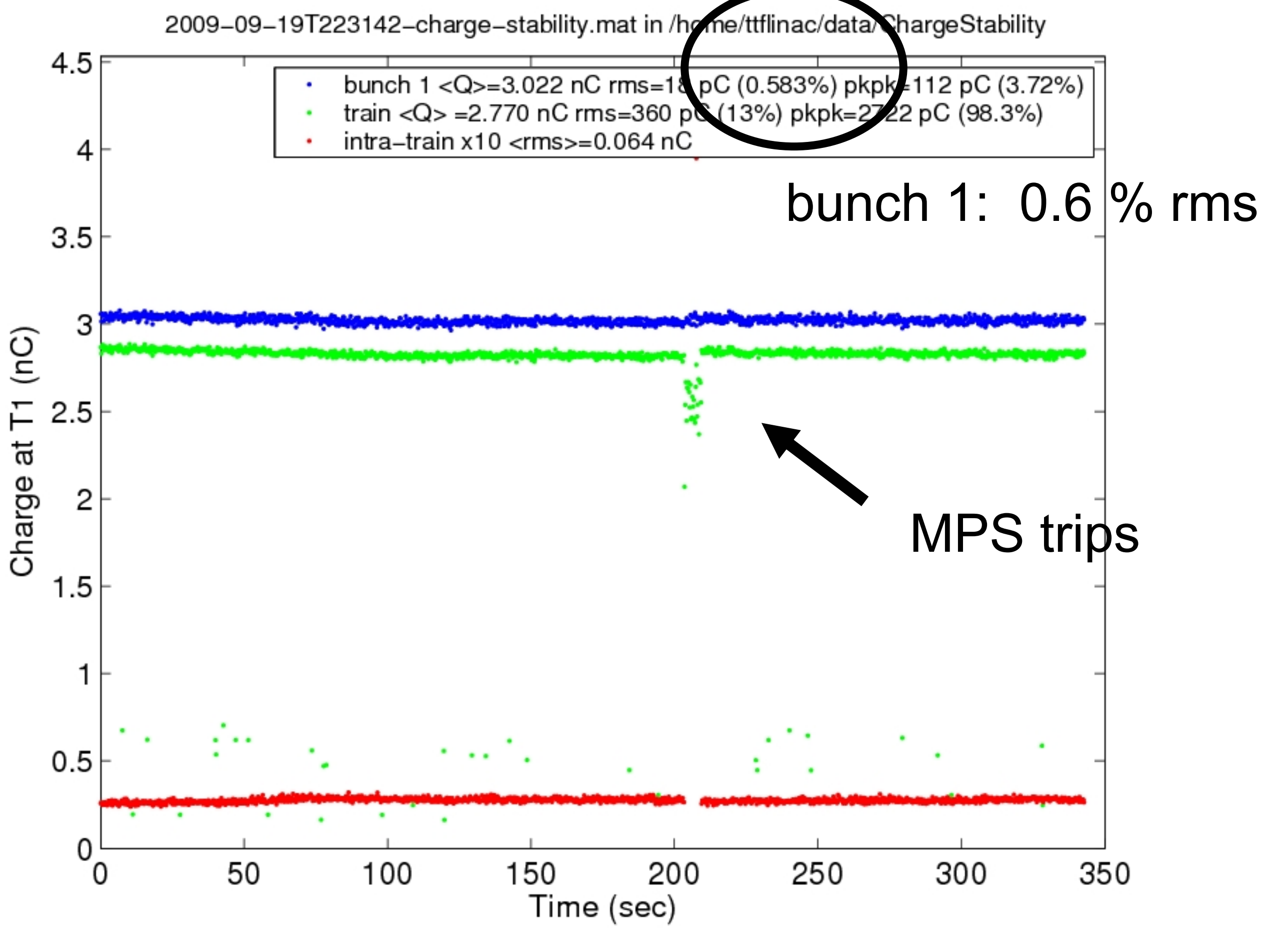
> Laser 1 charge stability 1 % rms



bunch 1: 1.1 % rms

Laser 2: Charge Stability

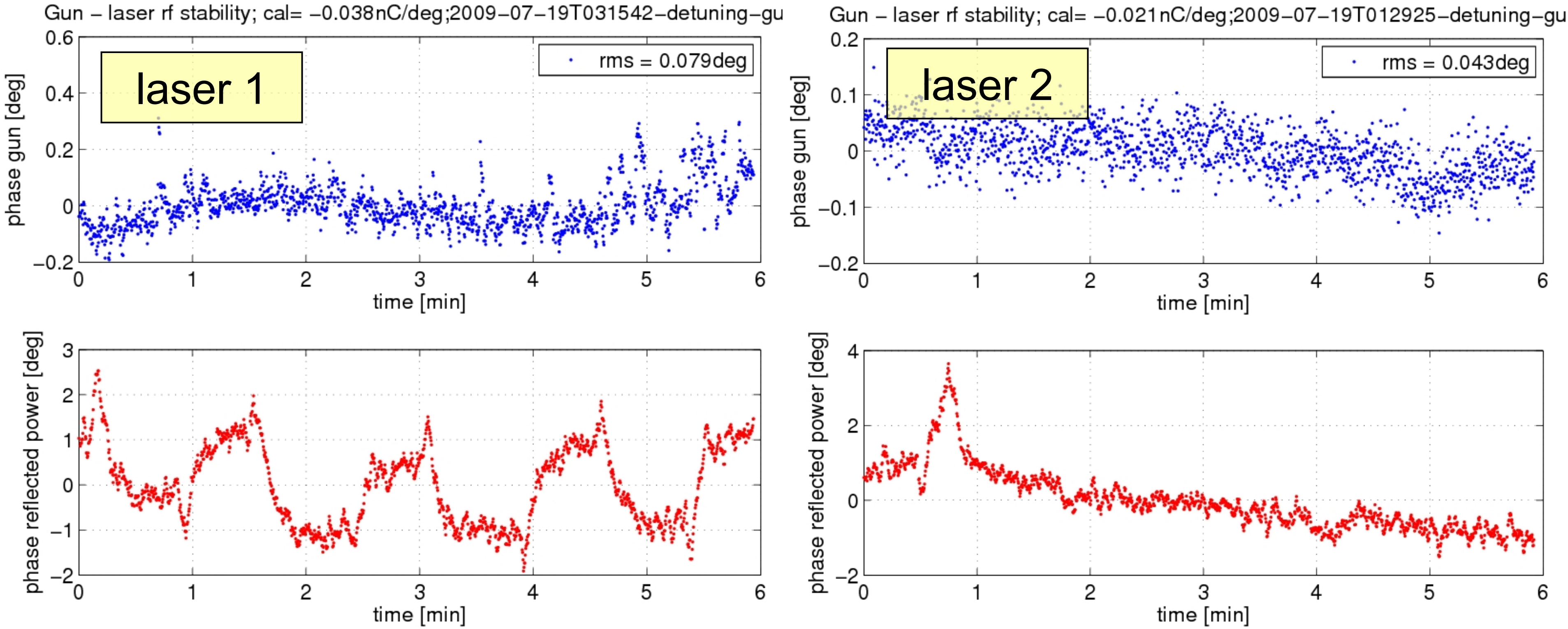
> Laser 2 charge stability better than 1 % rms



Phase Stability

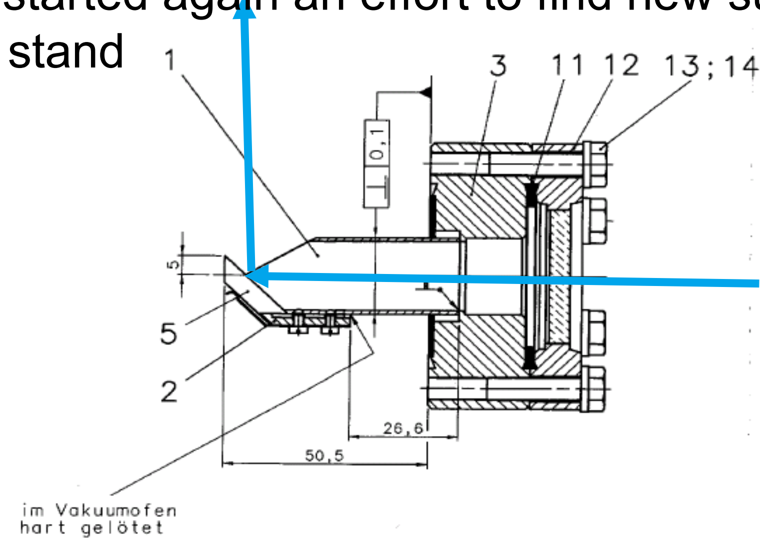
> Phase stability measured with improved rf gun calibration
> Stability laser 1: 0.08 dg (170 fs) – laser 2: 0.04 dg (84 fs)
> no pattern in reflected power measured
> both measurement within 1.5 h
> Remote diagnostics and control of phases is being installed (R. Jonas)
> Integration into synchronization system in preparation

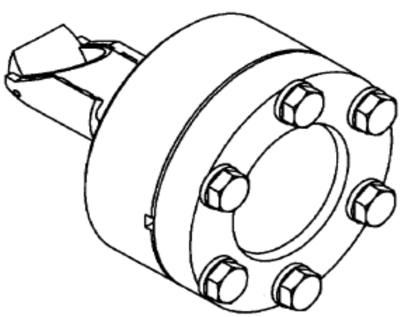
1 dg of 1.3 GHz = 2.1 ps

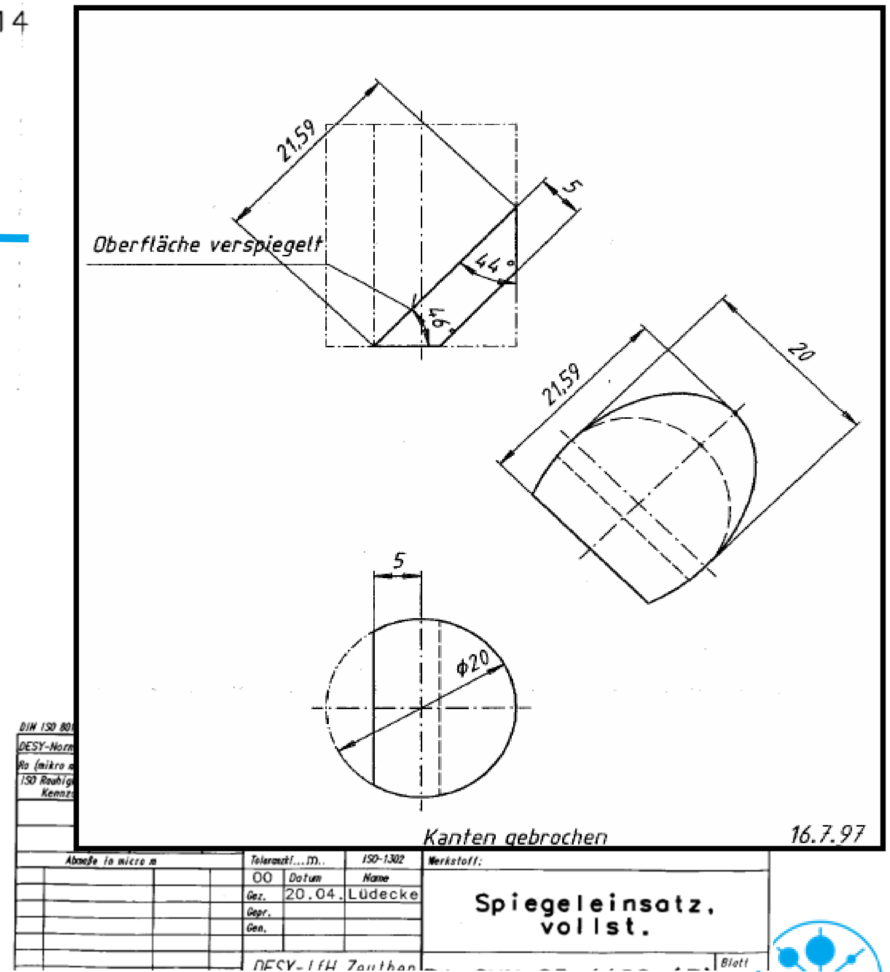


Laser Mirror Quality

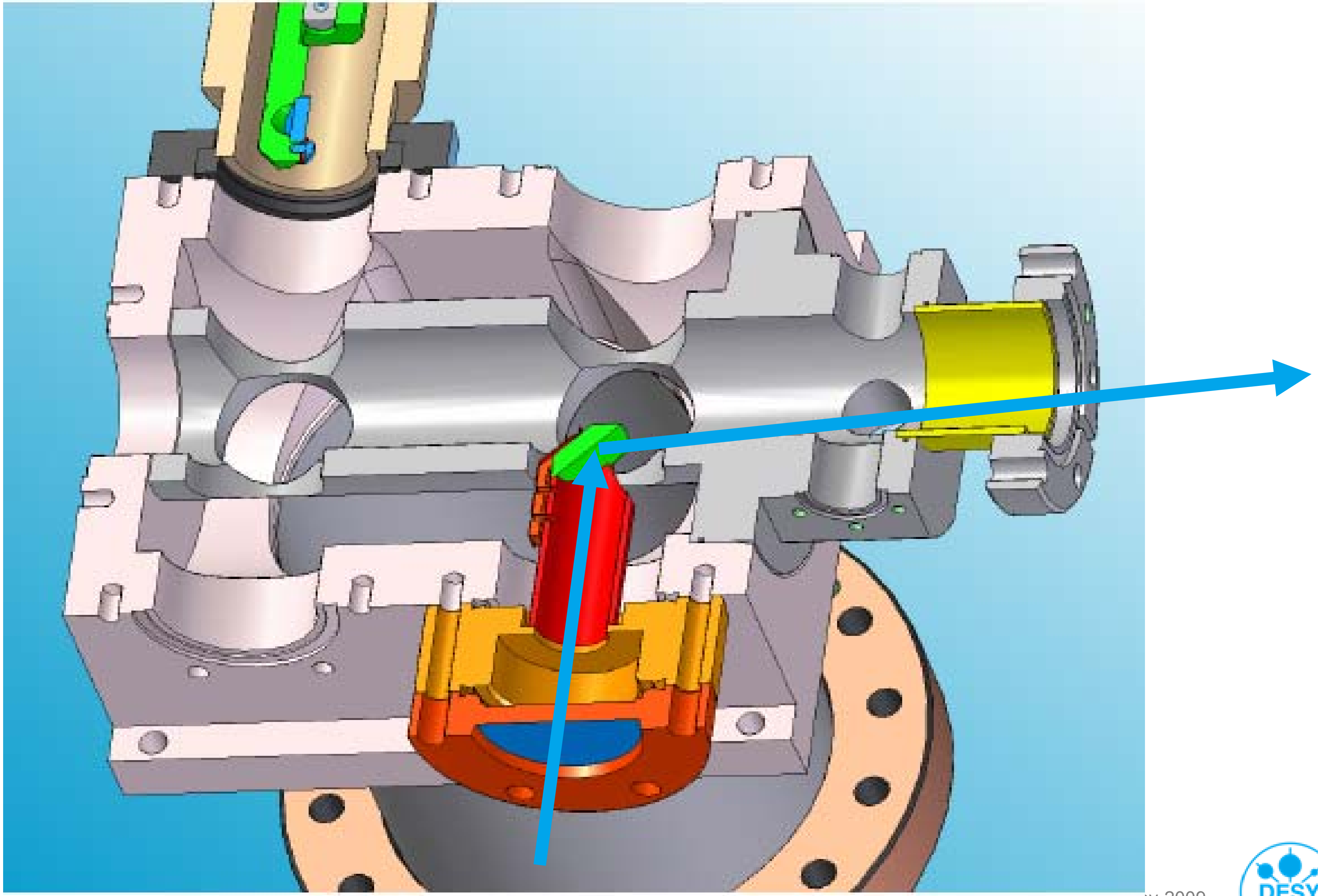
- Issue with halo creation and profile quality observed at PITZ for some mirrors
- We started again an effort to find new suppliers and to set-up a quality control test stand







Laser Mirror in the Diagnostics Cross



Upgrades/Plans

> Next upgrade will be to install the diode pumped amplifiers of the previous PITZ laser to replace the flashlamp pump heads of laser 1

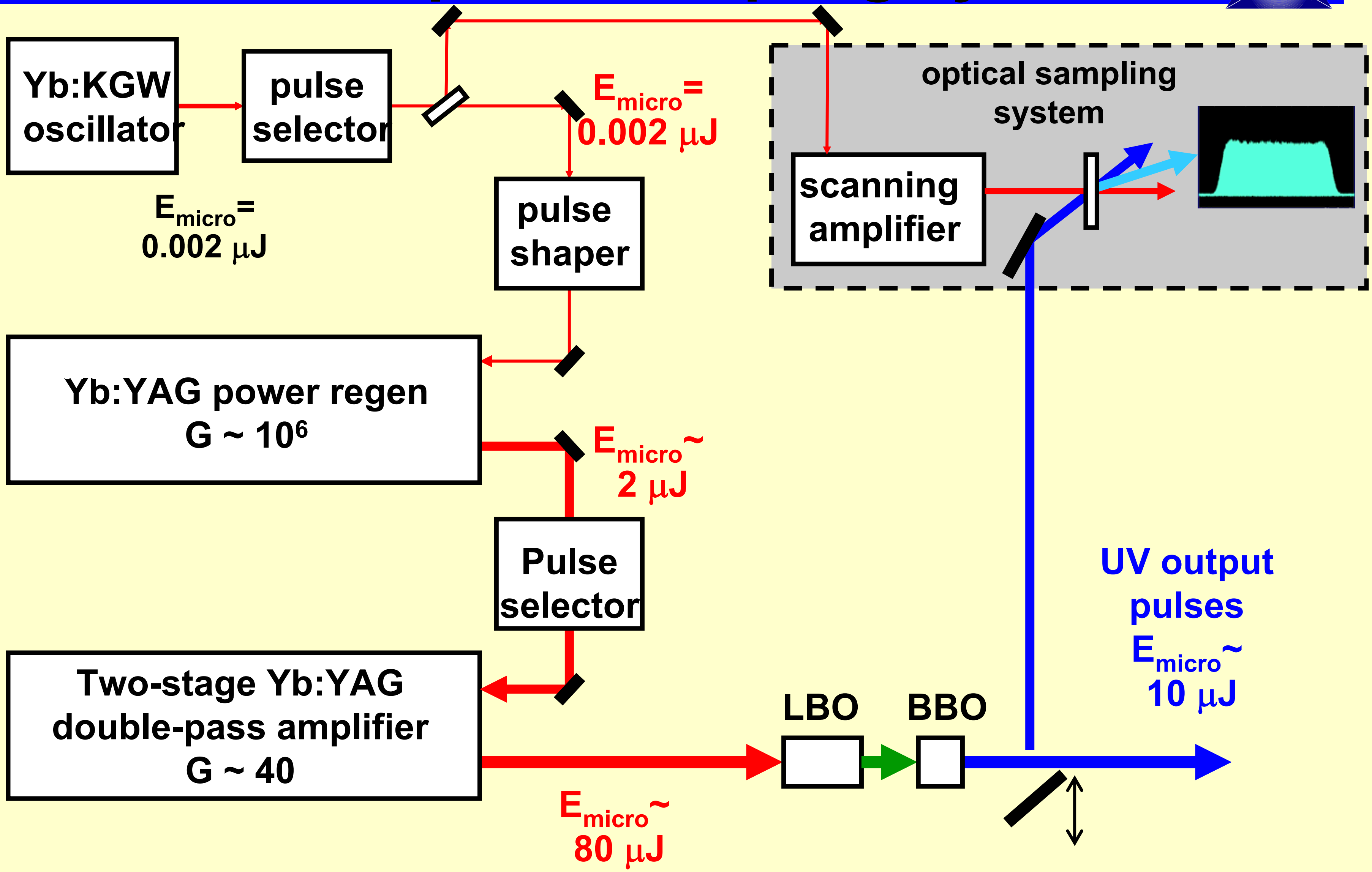
> Once a flat-hat laser has been extensively tested at PITZ, we will install a flat-hat version at FLASH

> MoU with Max-Born-Institute on the development of the XFEL injector laser and upgrades for PITZ and FLASH

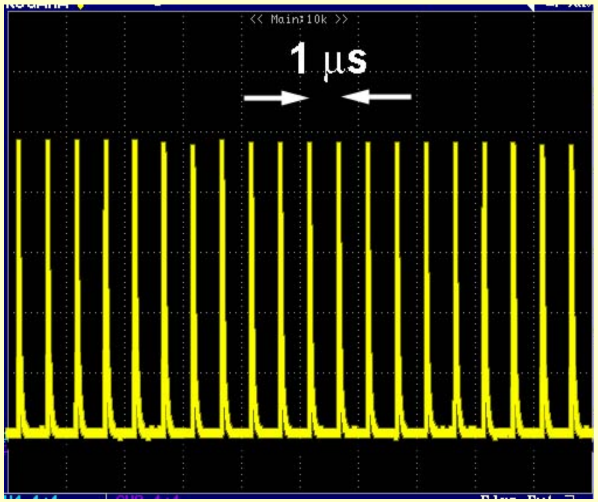
> Goal is to have a working system meeting the XFEL specs in 2012

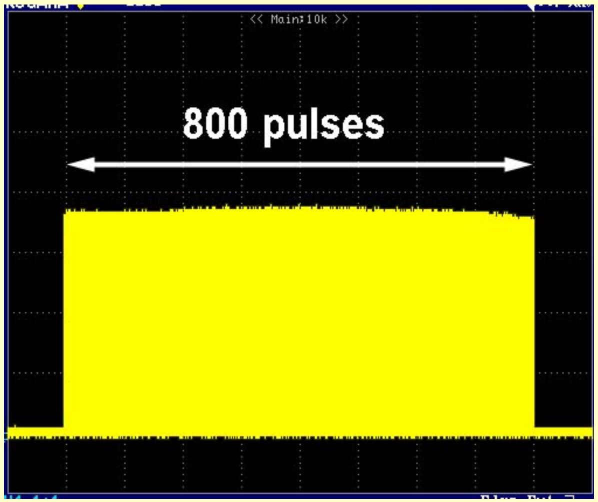
> Main issue now is to combine the flat-hat shape feature with a 5 MHz intra-bunch repetition rate

Present scheme of the Yb:YAG laser with and the optical sampling system



UV output pulses of the laser





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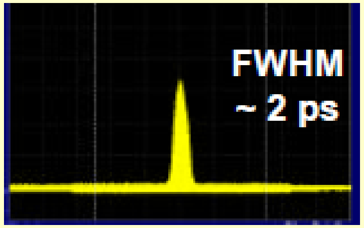
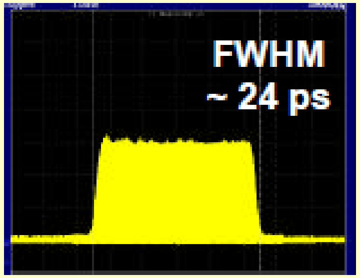
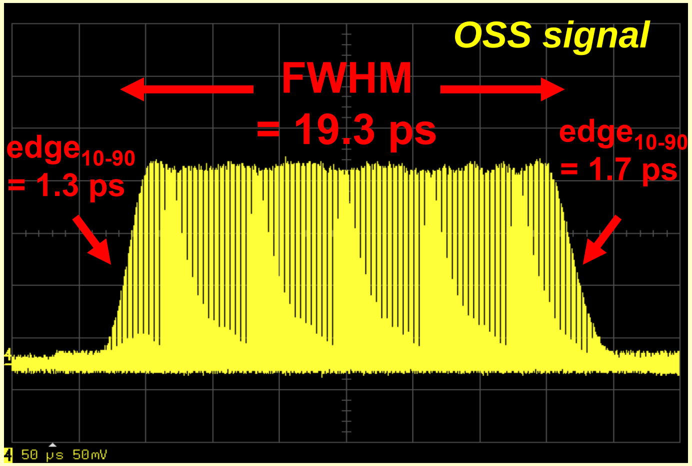
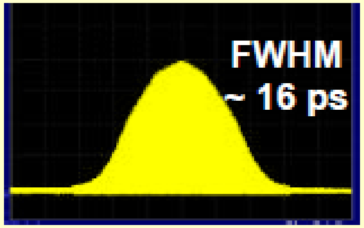
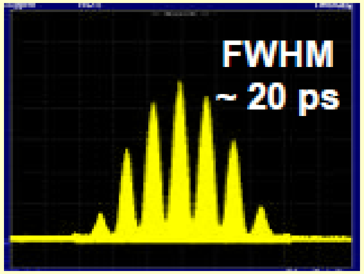






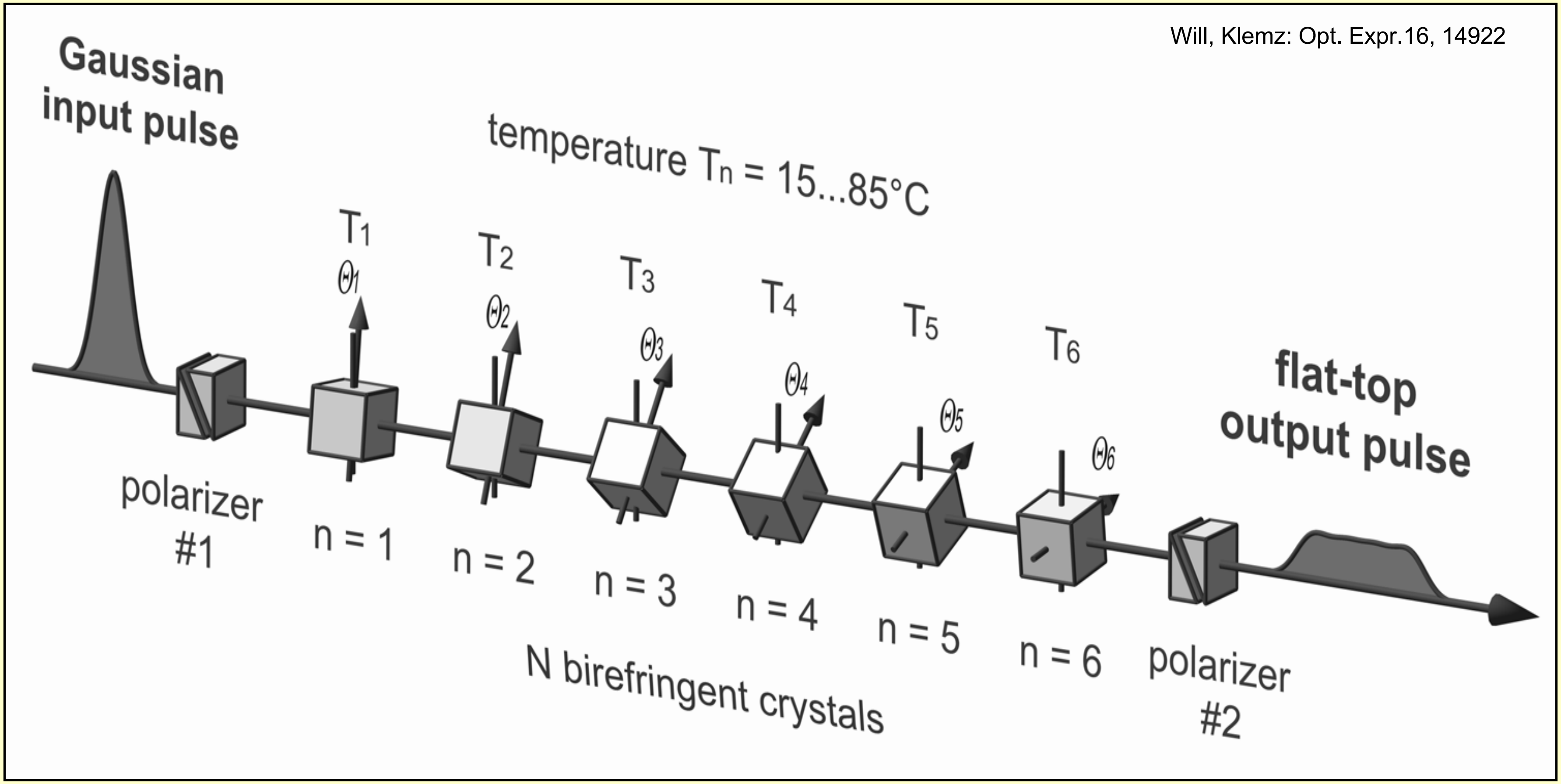
Shape of the micropulses measured wit
optical sampli
system





Generating flat-top laser pulses by means of a multi crystal birefringent pulse shaper

Optical setup



Installed at PITZ: N = 13 crystals