Status of the POLARIS laser system

Marco Hornung, S. Keppler, H. Liebetrau, A. Kessler, A. Seidel, M. Hellwing, F. Schorcht, J. Körner, A. Sävert, J. Polz, G. Becker, A.K. Arunachalam, D. Klöpfel, J. Hein, and M. C. Kaluza

HI Jena
Helmholtz Institute Jena

Helmholtz Institute Jena, Germany

IOQ Jena

Institute of Optics and Quantum Electronics, FSU Jena, Germany

8th workshop on High-Energy-Class Diode-Pumped Solid-State Lasers, Oxford, 26th March 2014

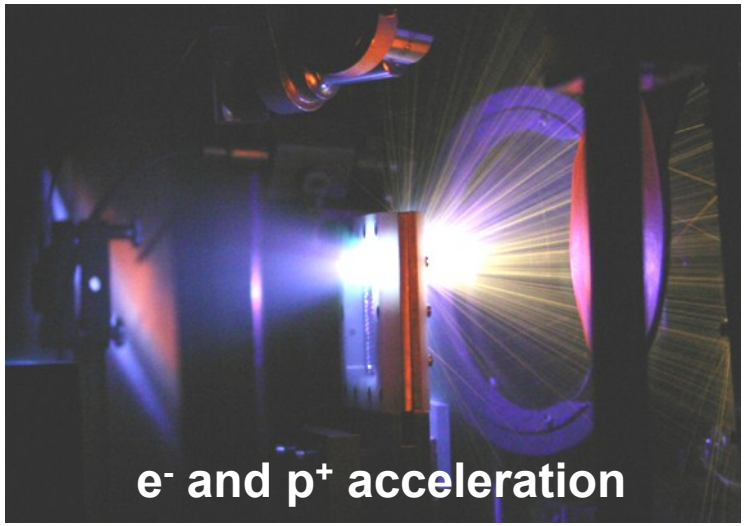
Outline

- POLARIS overview
- High energy pulse amplification
- High contrast frontend
- Pulse characterization & results
- Conclusion

POLARIS

Petawatt **O**ptical **L**aser **A**mplifier for **R**adiation **I**ntensive Experiment**S**

fully diode-pumped
λ_c = 1030 nm
pulse energy = 6.5 J (16.6 J) / 4 J on target
pulse duration = 145 fs
peak intensity = 3.5×10^{20} W/cm^2
temporal contrast for ASE > 5×10^{12}
1 shot every 40 s



Operation and Experience for Experiments

More than 17000 high energy shots in laser matter experiments !

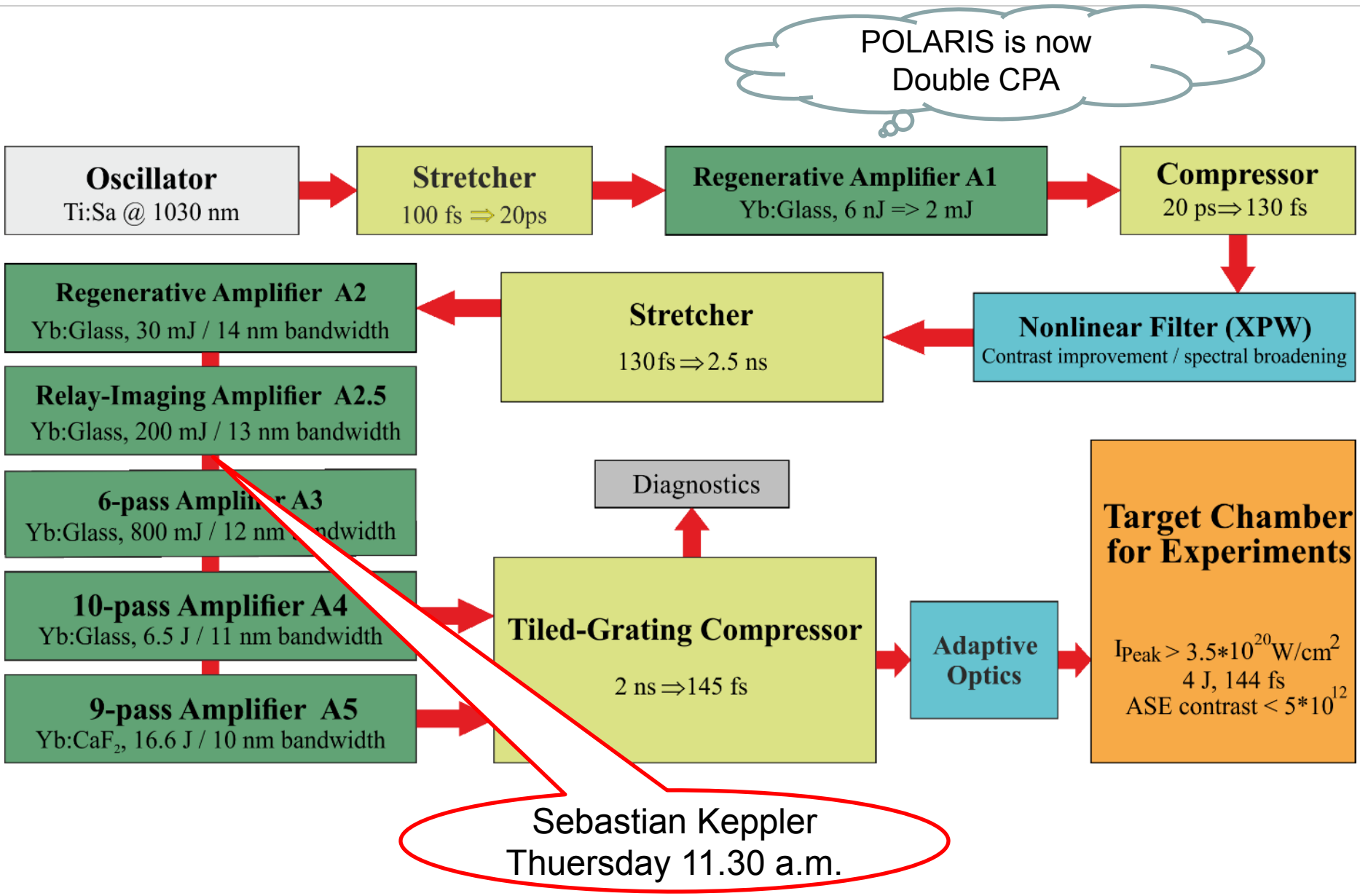
Used targets:

- **thin foils (down to 100 nm thickness)**
- **water droplets (20 µm)**
- **sandwich foils**
- **gas-jet**
- **hydrogen droplets (cryo-cooled, 6-7 µm) (currently used target)**

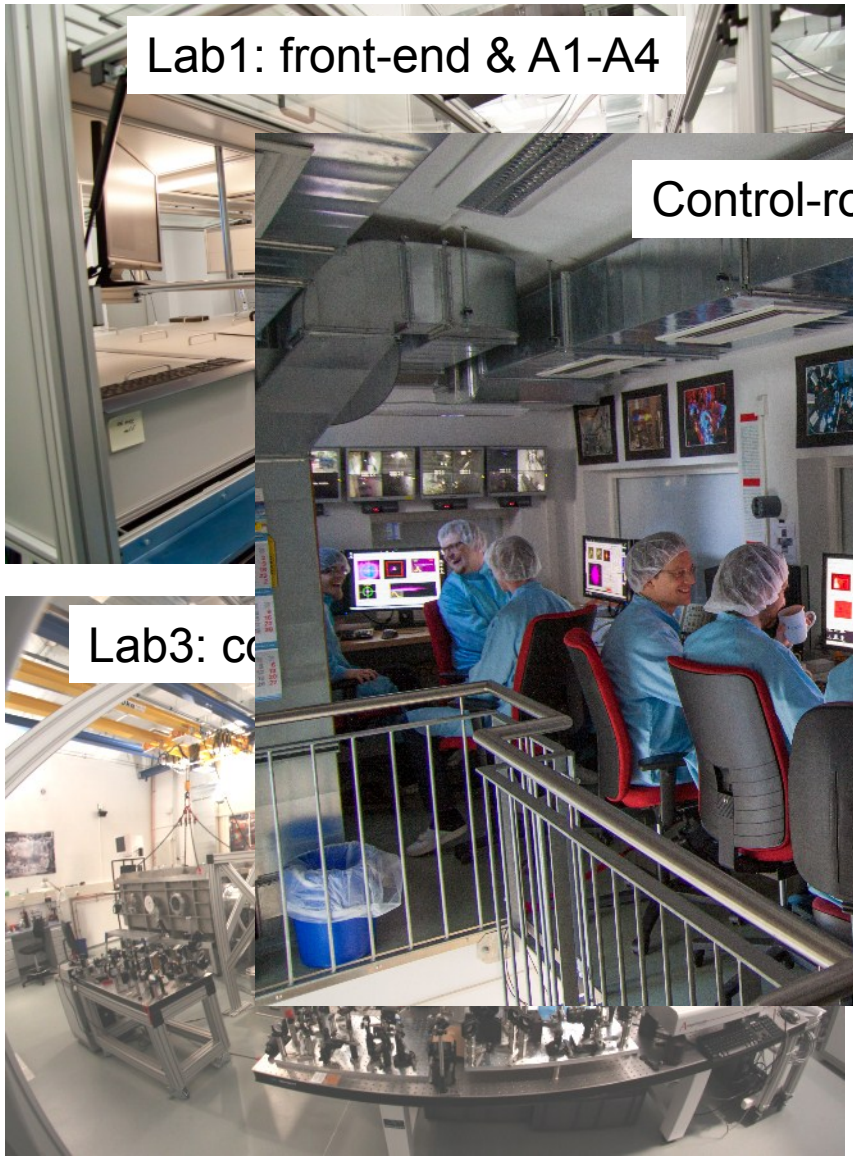
Diagnostics:

- **Multi-channel plate (online, energy, ions)**
- **Scintillation screen & gateable, fast CCD (online, spatial & energy distribution, ions)**
- **CR-39 Stack (energy, spatial distribution, ions)**
- **In-vaccum, soft X-ray camera & bent crystal (spectral & spatial resolution)**
- **2ω or 3ω online focal spot diagnostics**
- **target back-side deformation (Nomarski-Interferometer)**
- **Synchronized side-view (532 nm, 1 ns)**
- **e^- spectrometer**
- **150 fs low-energy probe pulse unit,**
- **variable pre-pulse unit**
- **backreflection diagnostic for safe laser operation**

System Layout



Overview: photography's



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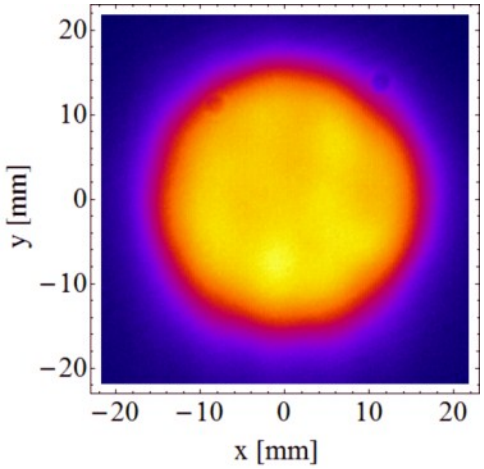
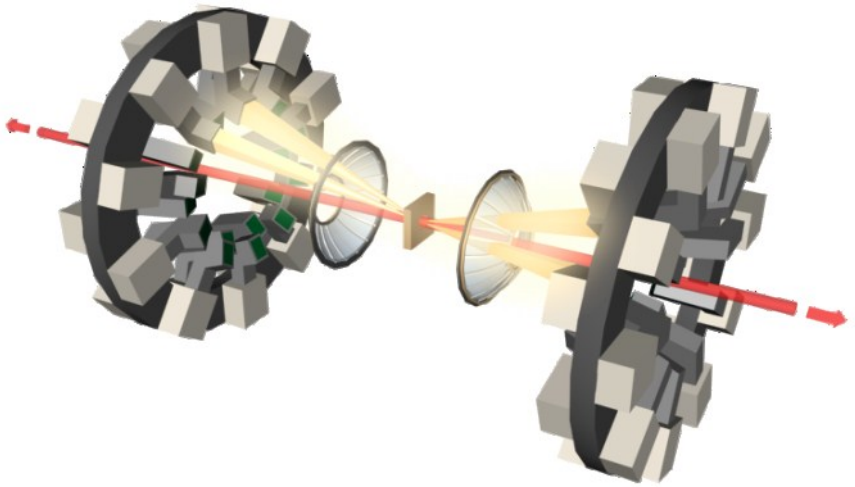
A4 – multipass amplifier

Output: 8 J @ 0.025

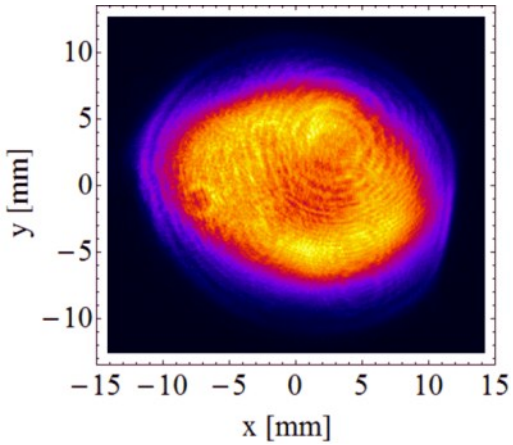
Pump profile:

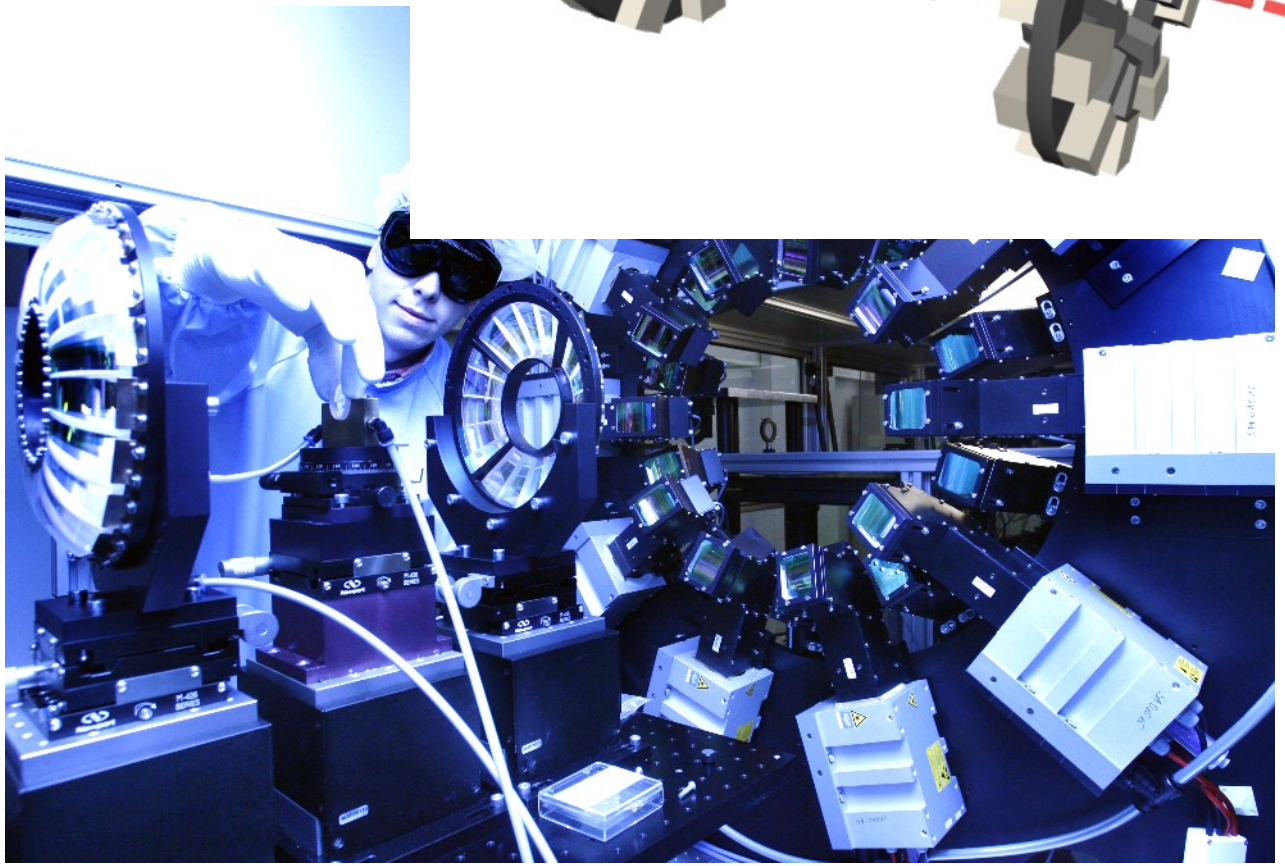


240 J pump energy



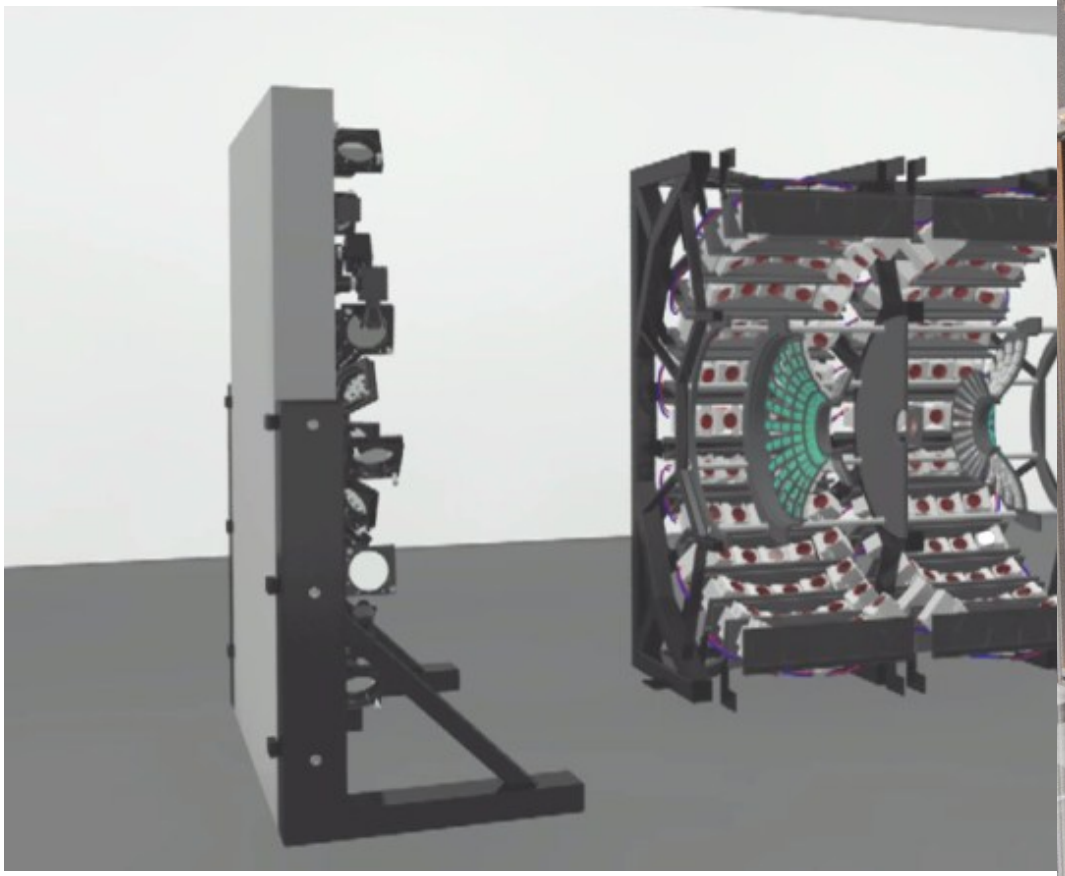
Beam profile:





A5 setup

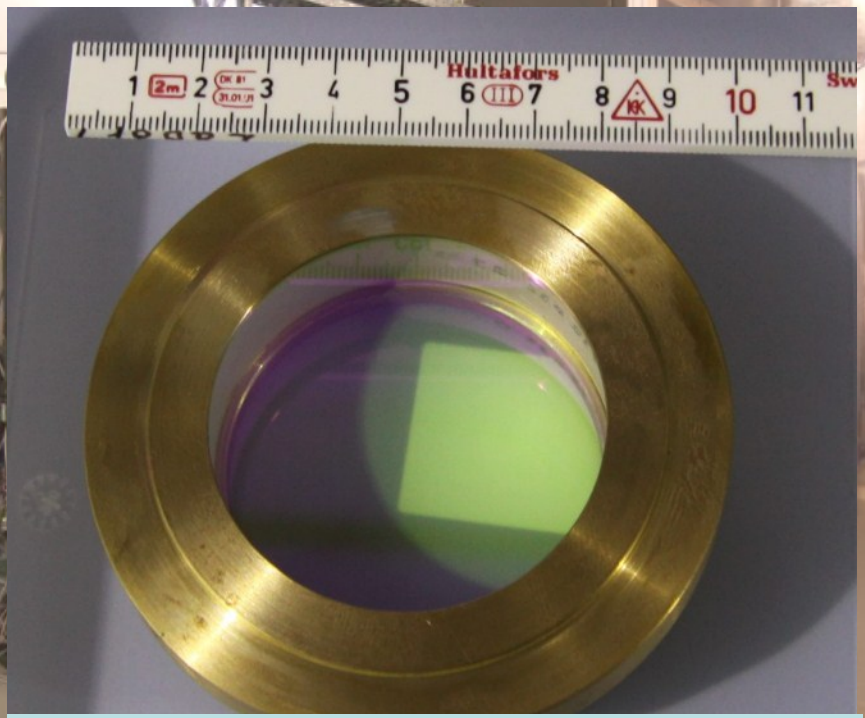
- Currently 120 laser diode stacks λ = 940 nm, P=2.5kW
- Upgrade to 240 stacks is possible
- Yb^{3+} doped CaF_2 crystal or FP20-Glass with 35 mm p



Size: 6 m x 3 m x 3 m

A5 photography

- Active material:
  - Yb:CaF_2 (1.7 at.%)
  - 65 mm diameter
  - 30 mm thickness
- beam diameter approx. 35 mm (FWHM)
- 9-pass configuration

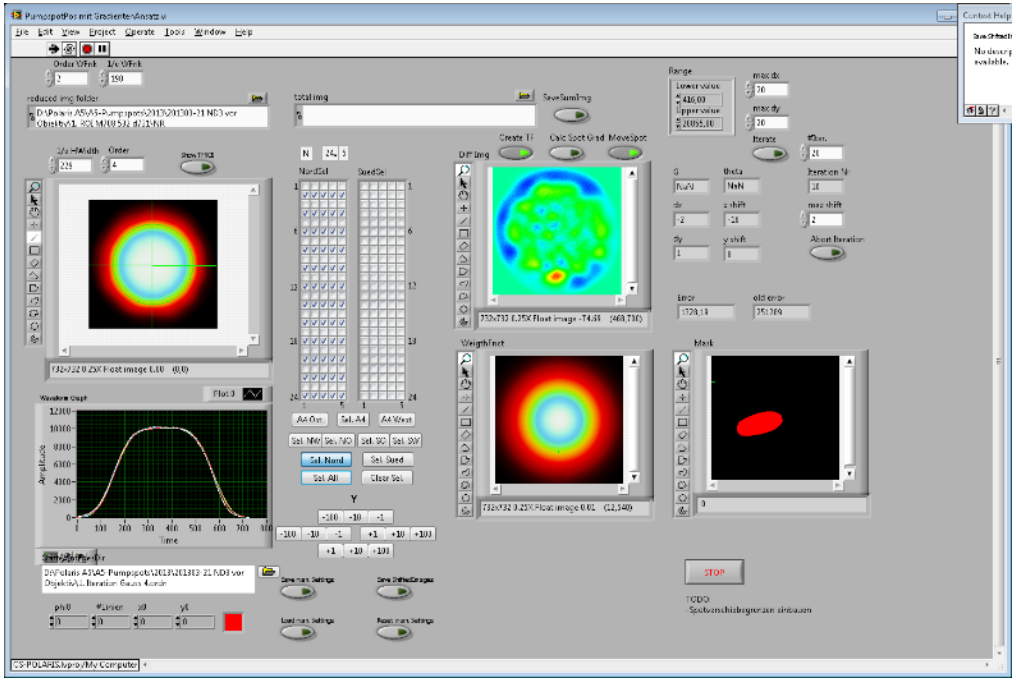


Yb:CaF_2 made by HellmaMaterials / Jena

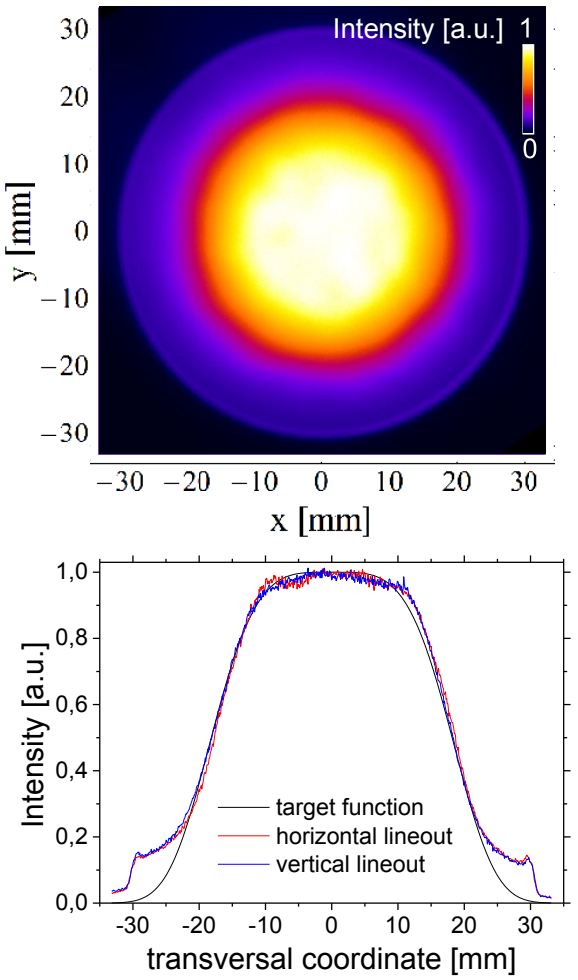
A5 pump profile homogenization

Main challenges:

- Homogenize pump profile with 120 Stacks (LabII adaptive strategy [1])
- Automatisation



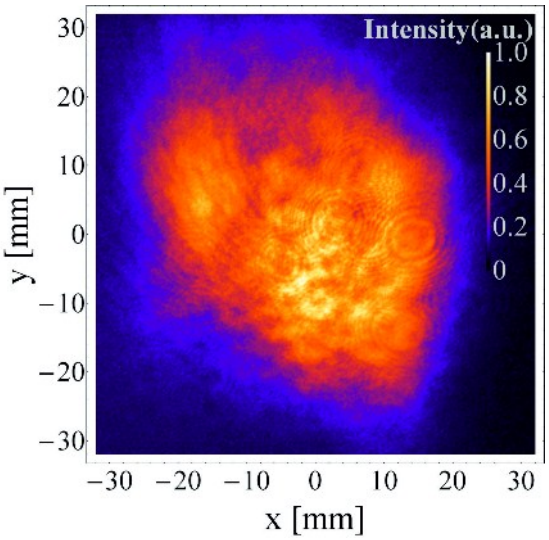
Measured pump profile with 780 J pump energy



[1] B. Schmidt, M. Hacker, G. Stobrawa, T. Feurer; LAB2-A virtual femtosecond laser lab, http://www.lab2.de

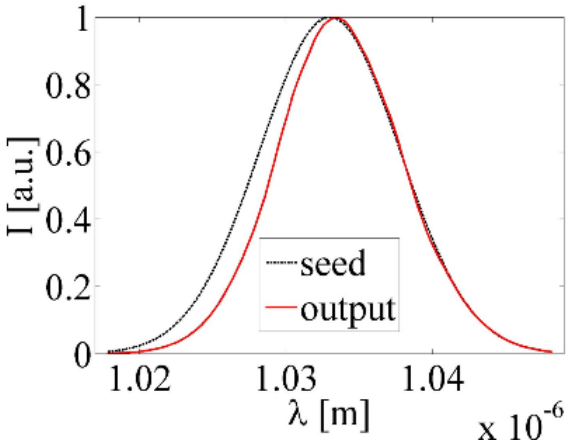
A5 output characteristic

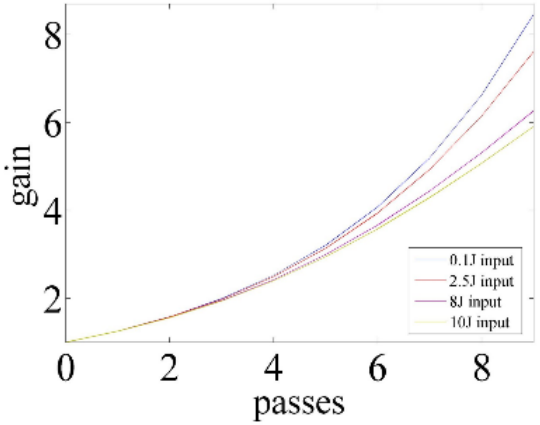
Near-field profile:



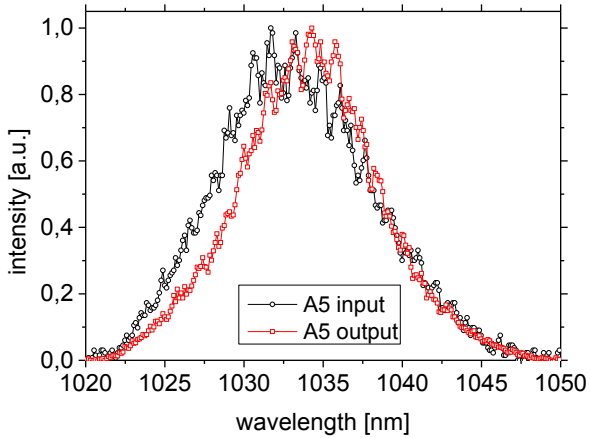
16.6 J pulse energy with 10 nm FWHM-bandwidth

Simulation:





Spectral intensity:

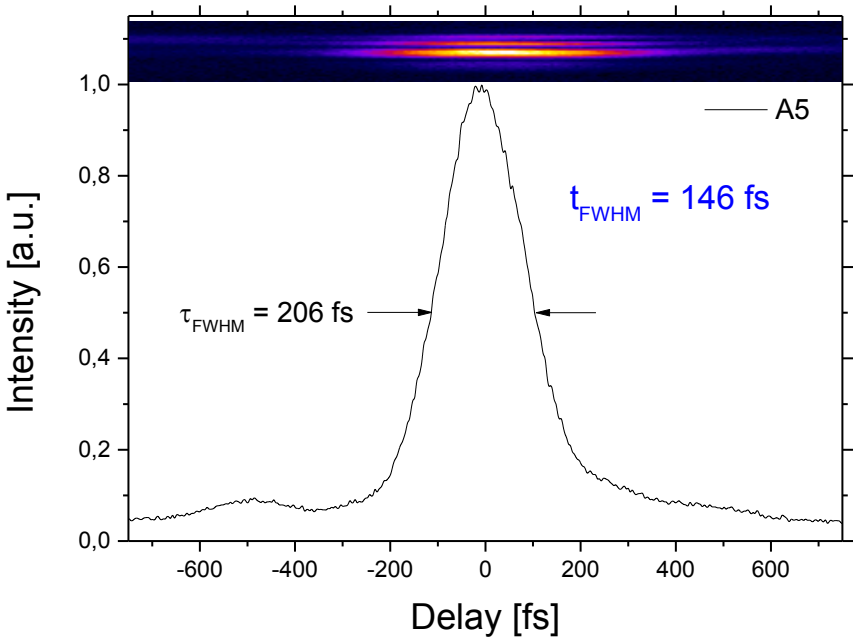


- Seed-energy = 2.7 J (g = 6.1)
- Energy measured by with *Coherent J-50 MB YAG1535* (verified online with 8%-reflection and another J-50 MB)
- Currently limited by fluence on crystal 2 J/cm^2 (coating-LIDT @ 3.5 J/cm^2)

A. Kessler et al., "16.6 J chirped femtosecond laser pulses from a diode-pumped Yb:CaF_2 amplifier", Optics Letters 2014

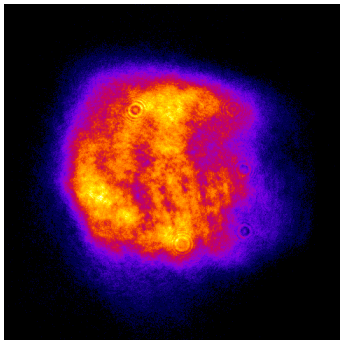
A5 low energy (2 Joule) compression & focusing

Pulse duration measurement in the far-field:

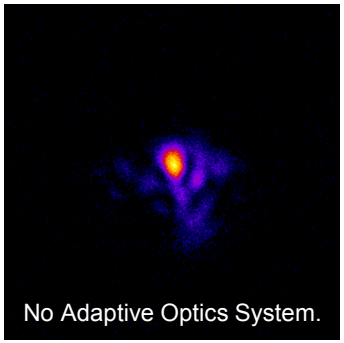


Transport beamline & telescope to compressor:

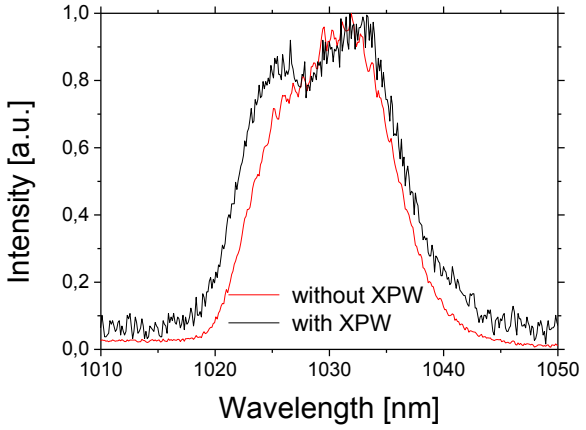
Near-field profile:



Far-field profile:



Spectral intensity:



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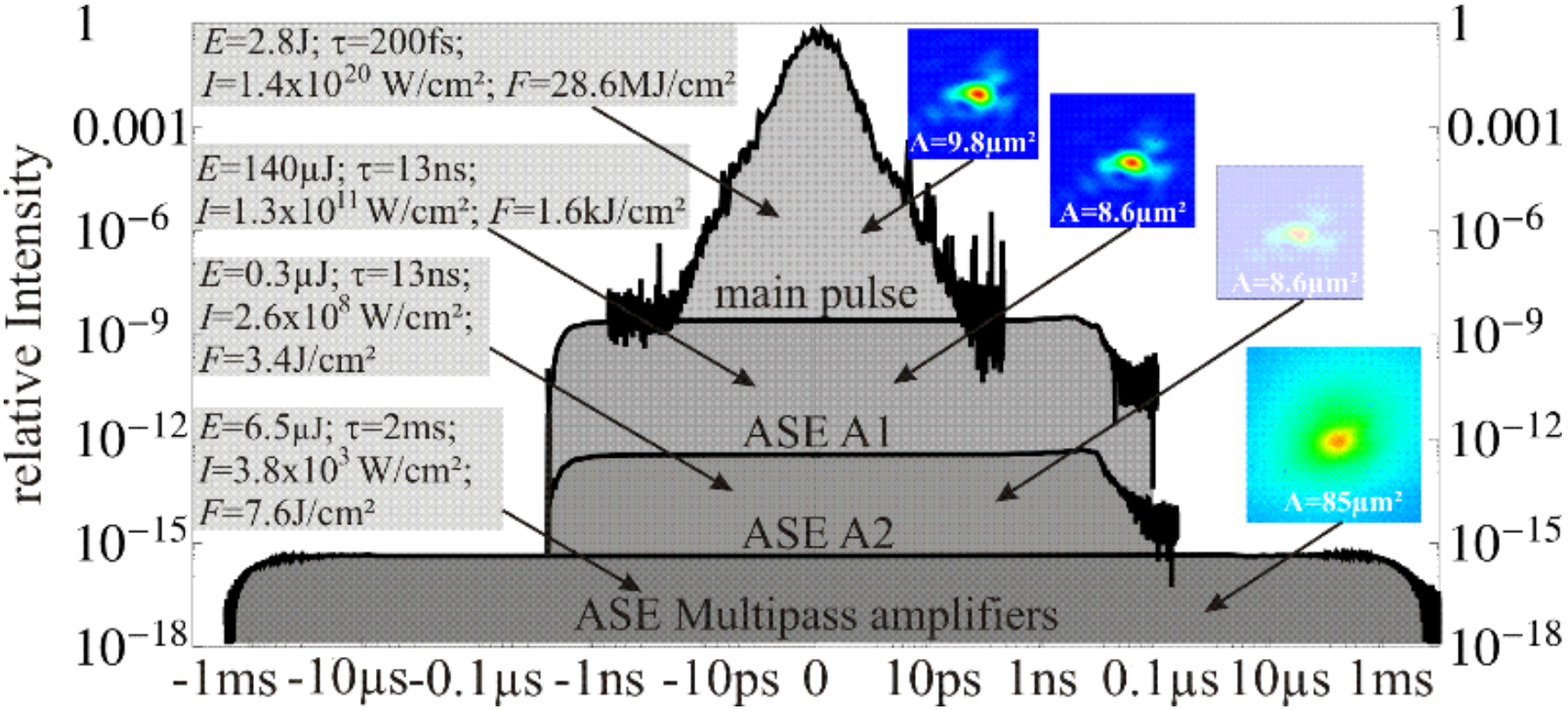
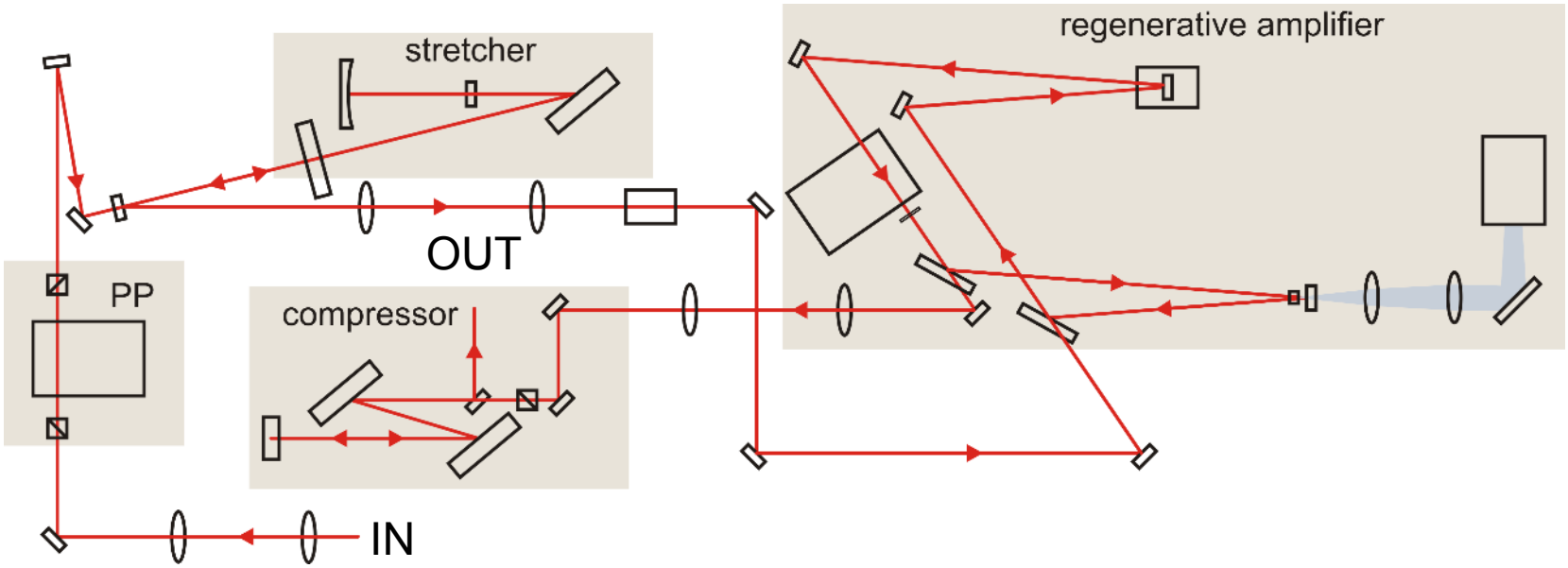
Motivation: ”old“ ASE Characteristics of POLARIS



Measurement of energy, pulse duration and focal spot size.

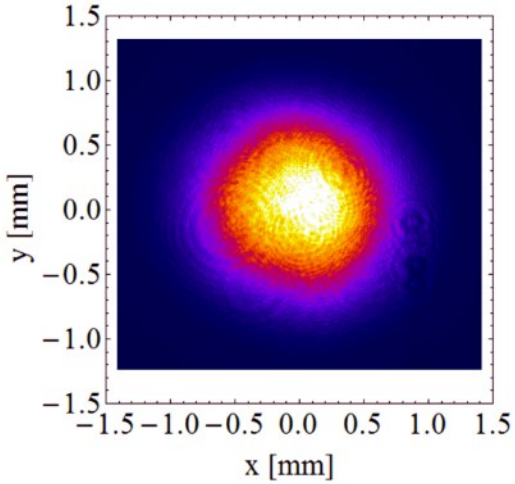
Double-CPA frontend for nonlinear filtering (XPW)



2 mJ pulse energy in a 130 fs laser pulse.

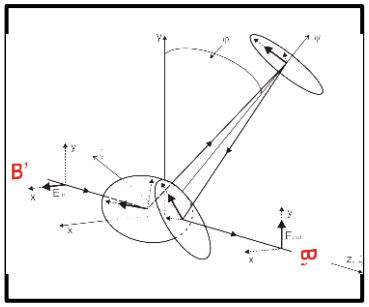
A1 & A2 – regenerative amplifiers

Beam profile:

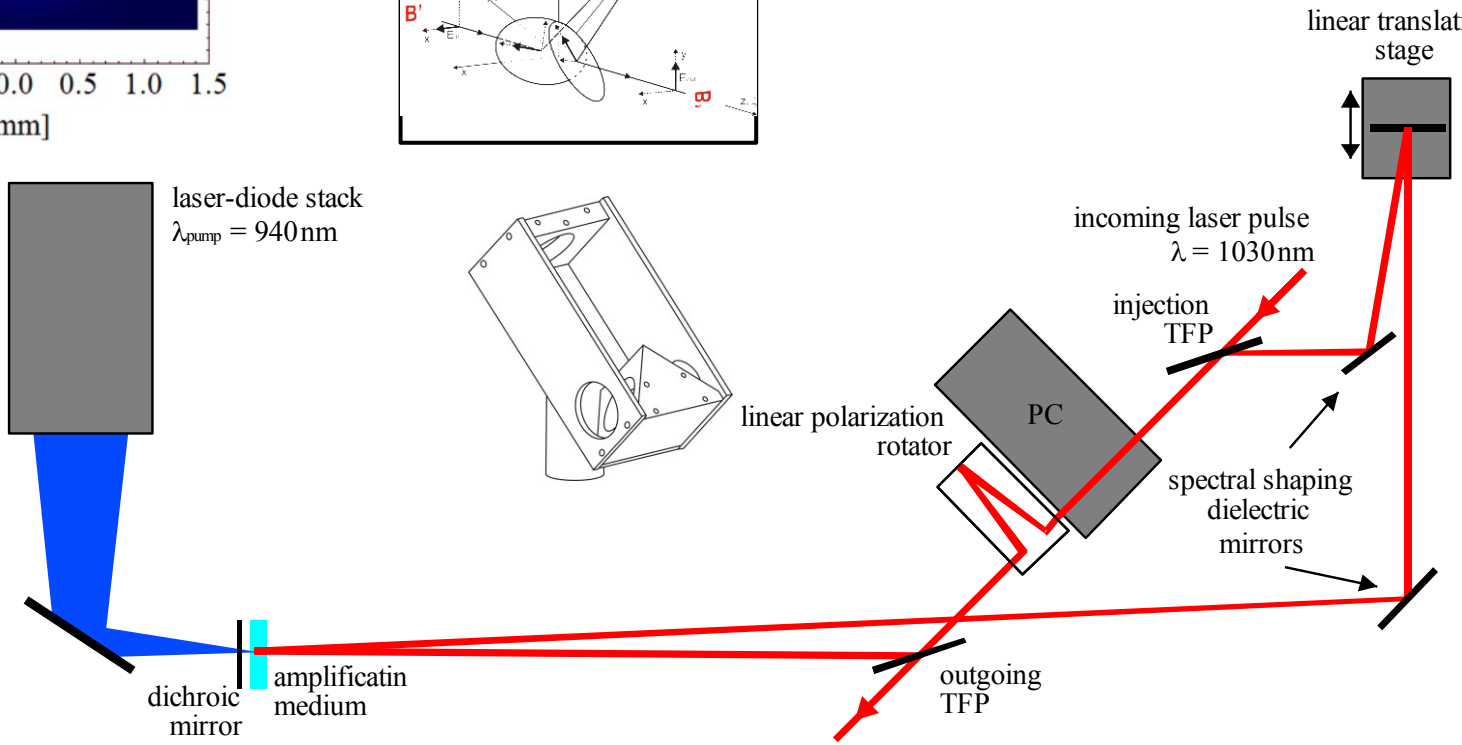


A2 output: 50 mJ @ 1 Hz (15 nm FWHM-bandwidth)

Reflective polarisation rotator



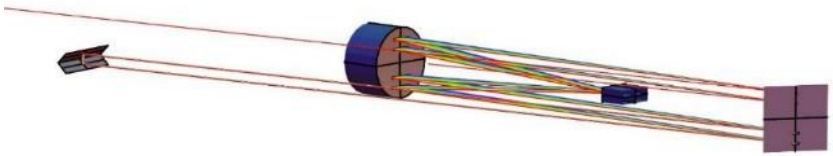
- 25 round-trips
- TEM_{00}-mode
- spectral shaping mirrors

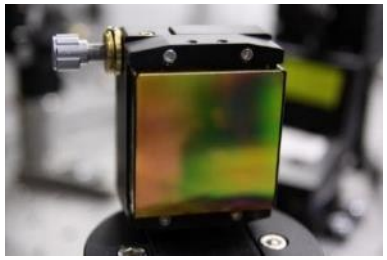


Stretcher & Compressor for Double-CPA

Öffner stretcher

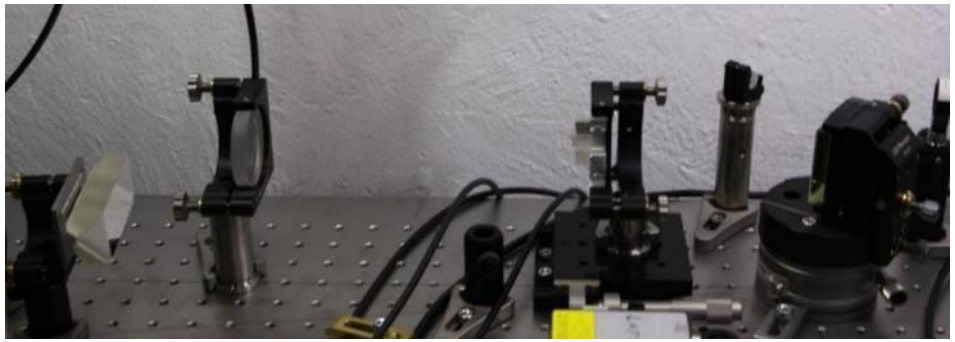
- pulses stretched from 90 fs to 20 ps
- hardclip: 45 nm, efficiency 65%





50x50 mm^2 gold grating, 1200 lines/mm

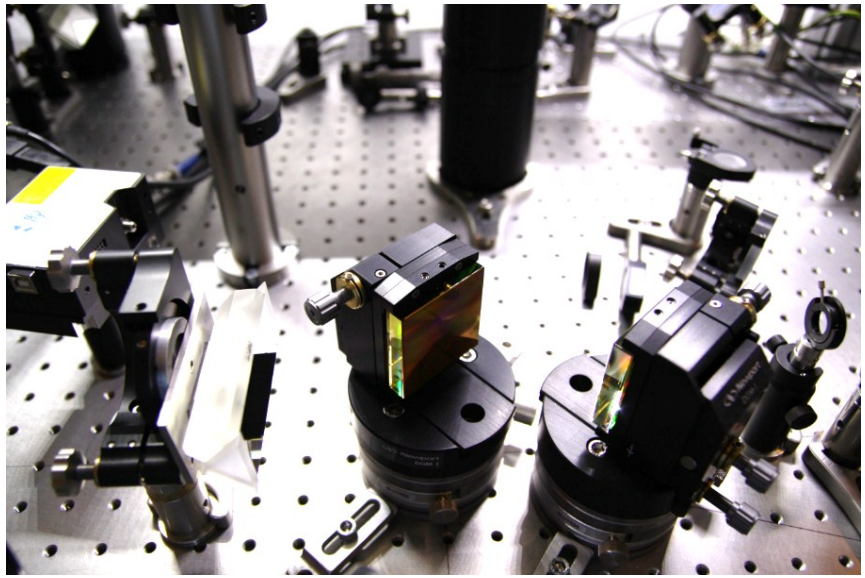
small footprint: 40x20 cm^2



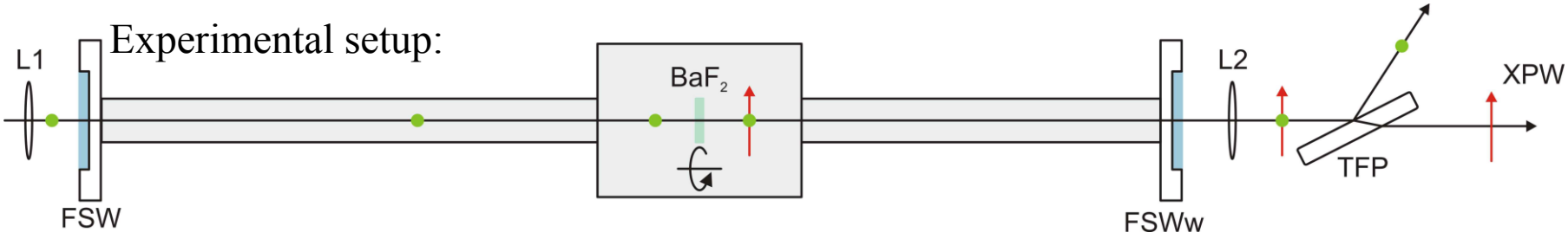
Treacy compressor

- 50x50 mm^2 gold gratings separated by ≈ 9 cm
- transmission 75%
- small footprint 20x20 cm^2

- pulses are compressed to Fourier-limit (Gaussian pulse) of 130 fs
- 2 mJ pulse energy after compression

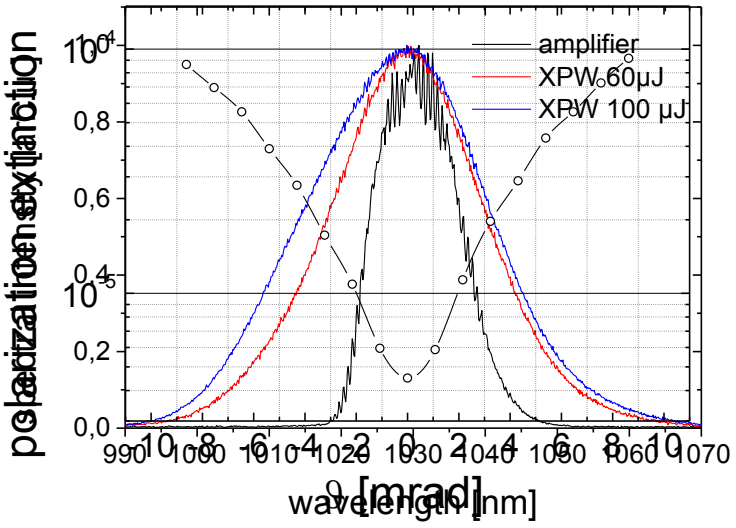


Experimental setup:

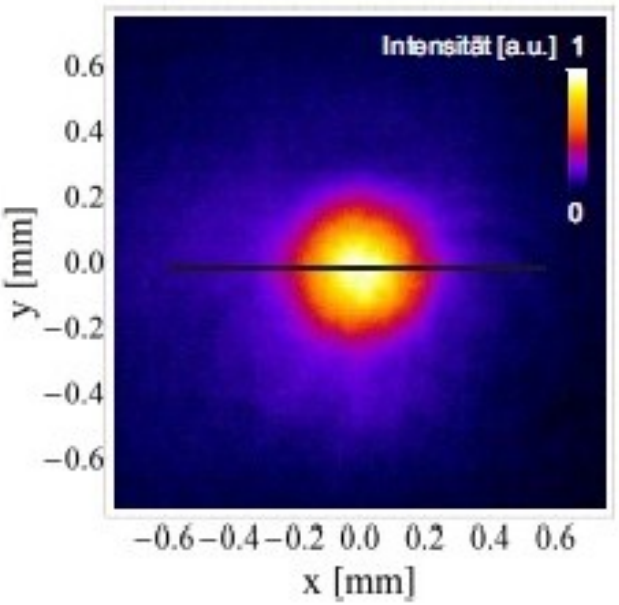


- crossed polarizers with high extinction ratio $R=2\cdot10^{-6}$
- 1 m focusing and collimating lenses
- 2 mm BaF_2-crystal
- vacuum-housing due to high intensities

Up to 200 µJ pulse energy!



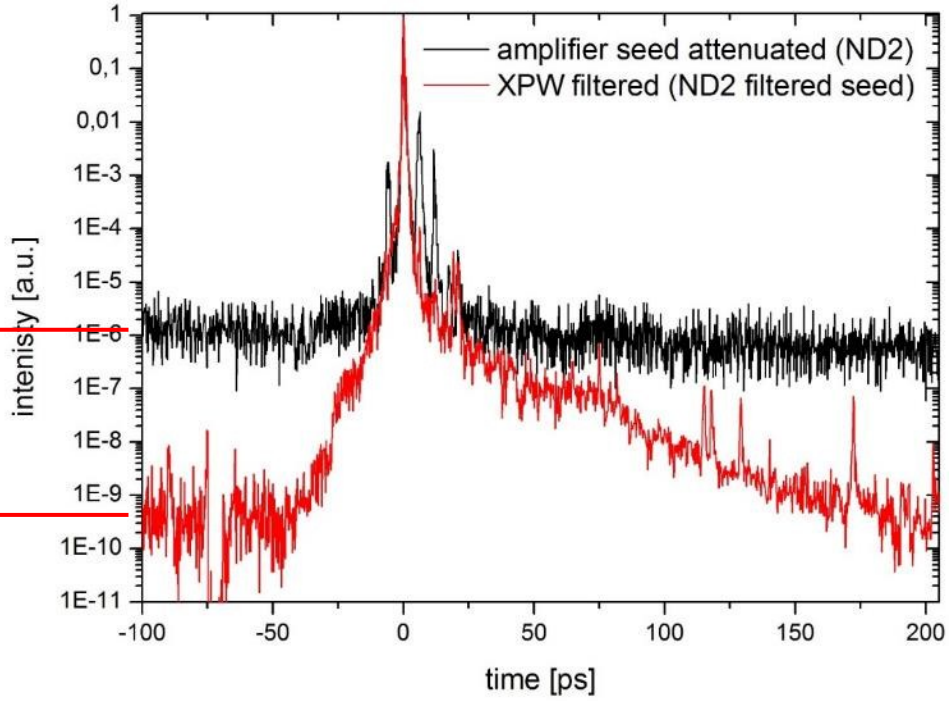
Near-field profile:



Contrast improvement measurement

- intentionally decreased the ASE contrast by decreasing seed of amplifier !

ASE decreased by 4 orders of magnitude!!!!



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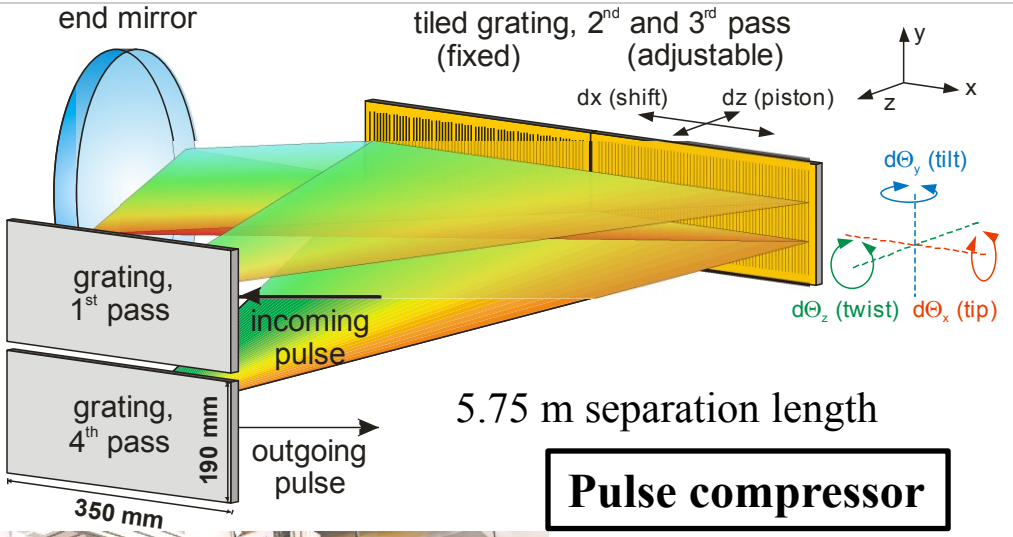
Tiled-Grating Compressor

Stretcher:

- 1480 lines/mm
- 85 fs => 2.6 ns

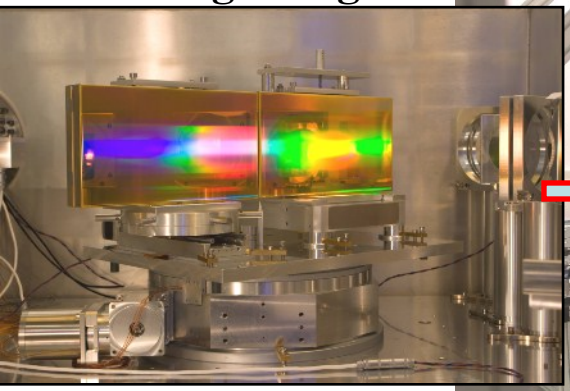
- GDD = $8.28*10^7$ fs^2
- TOD = $-3.71*10^8$ fs^3
- FOD = $2.71*10^9$ fs^4

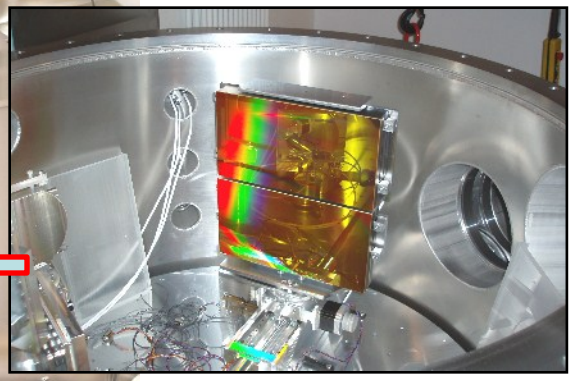


5.75 m separation length

Pulse compressor

Tiled-grating:





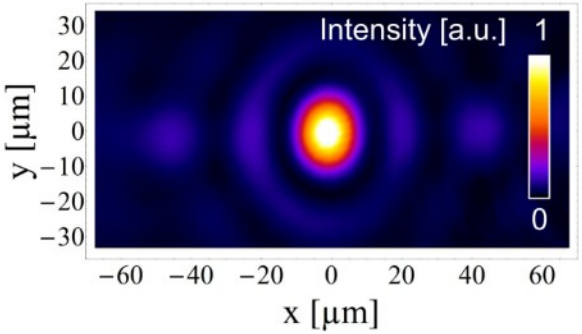
140 mm beam diameter

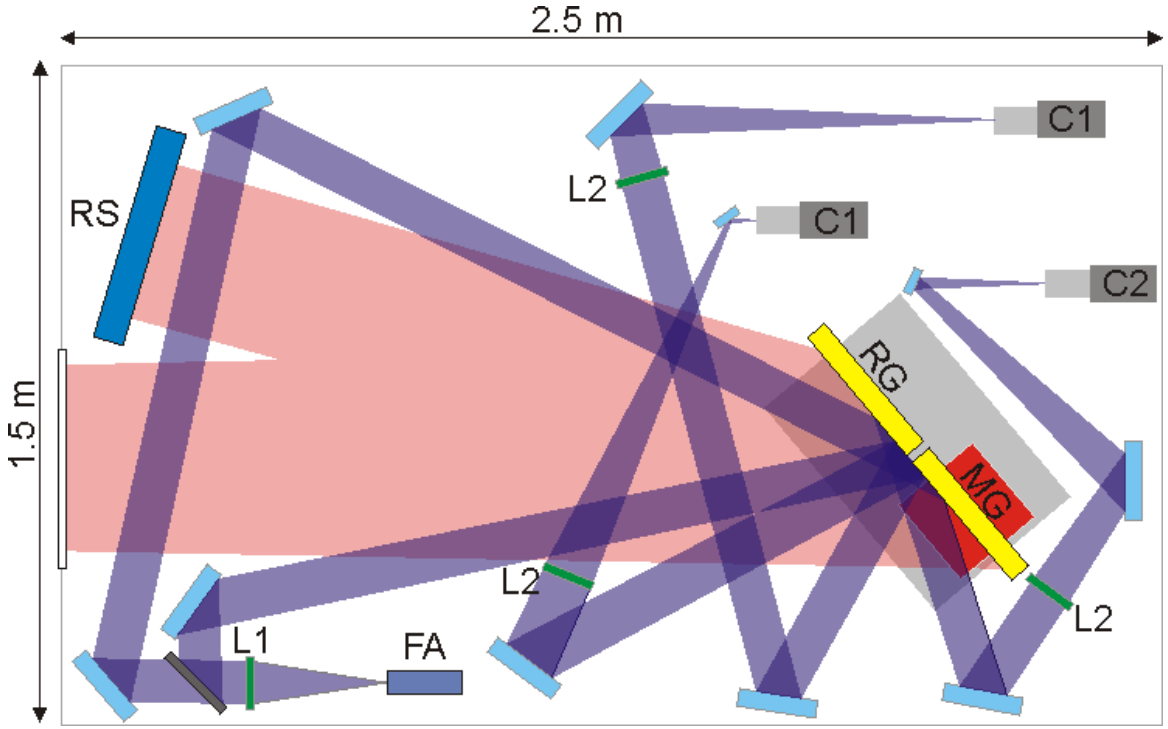
M. Hornung et al., Appl Phys B, 101: 93–102, (2010).

Far-field Analysis for tiled-grating alignment

- 2 x specular reflection
- 1 x -1st diffraction order

ideal far field:

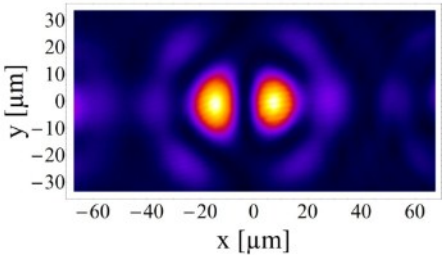


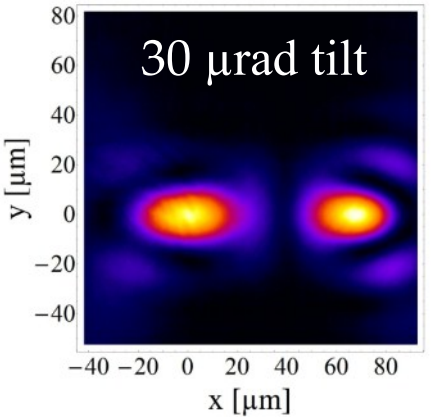


Achieved experimental errors:
rotational: < 0.2 µrad
translational: < 20 nm

➔ Enough to ensure more than 90 % of the peak intensity for a 140 mm diameter, f/2-focussed, 150-fs-pulse (compared to a monolithic grating).

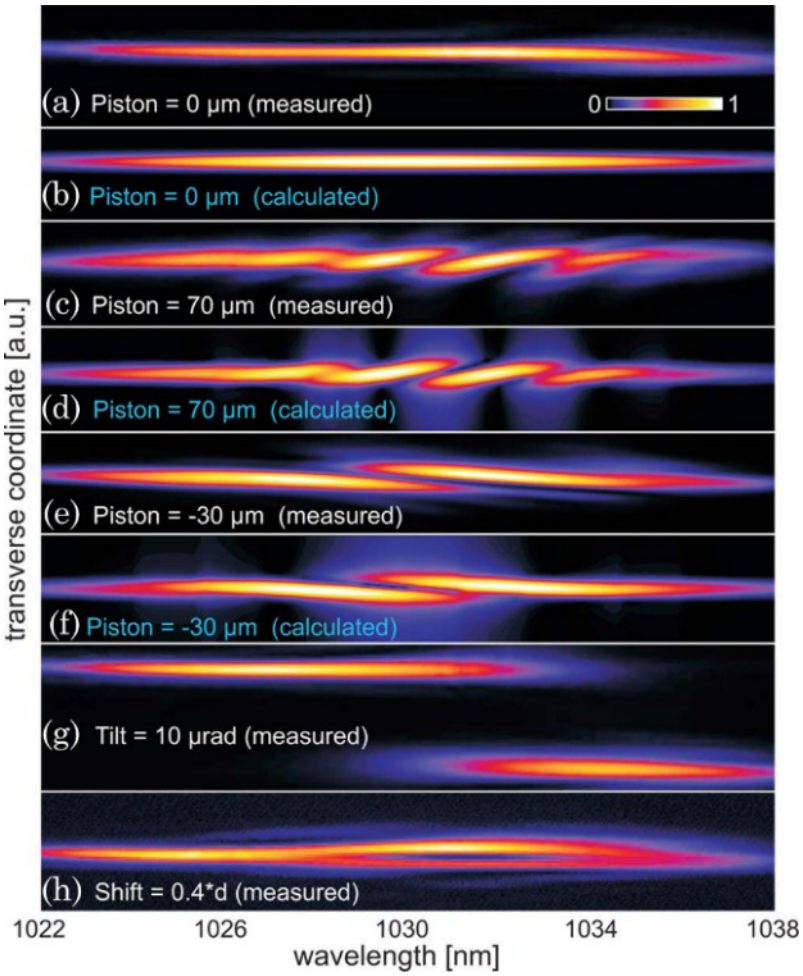
Piston π:





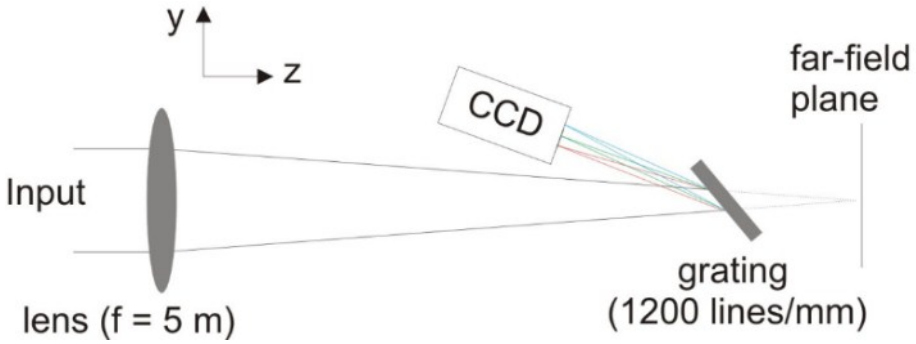
Tiled-grating alignment & shortest pulses

Spectrally resolved far-field measurements:

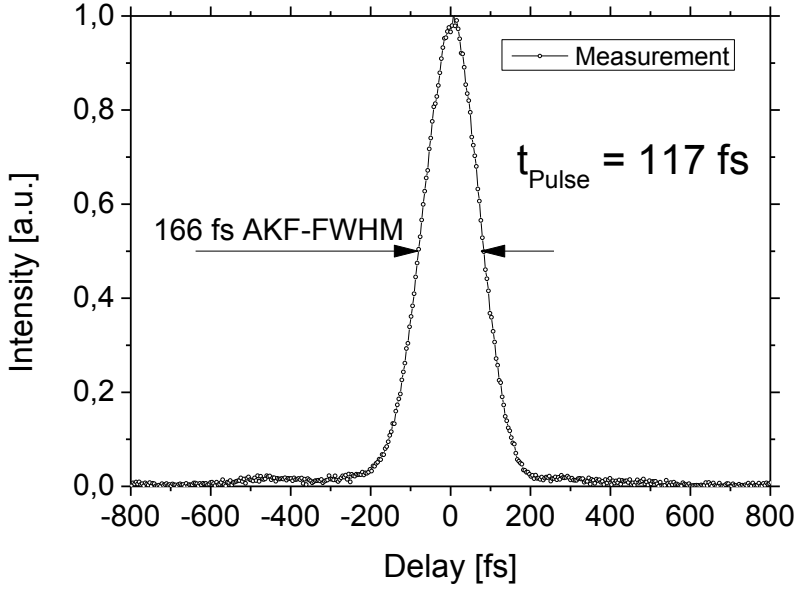


M. Hornung *et al.*, Opt. Lett., **35** 2073, (2010).

SRFF measurement setup:

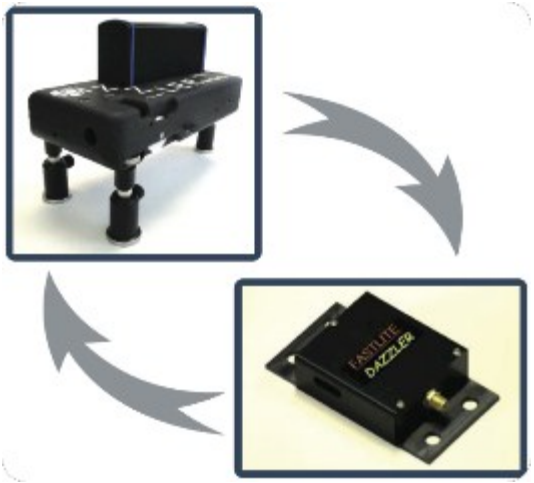


Pulse duration measurement:

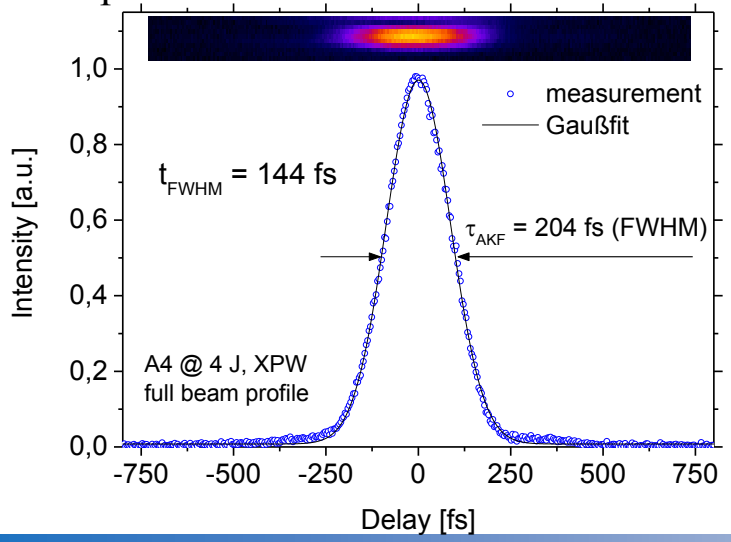


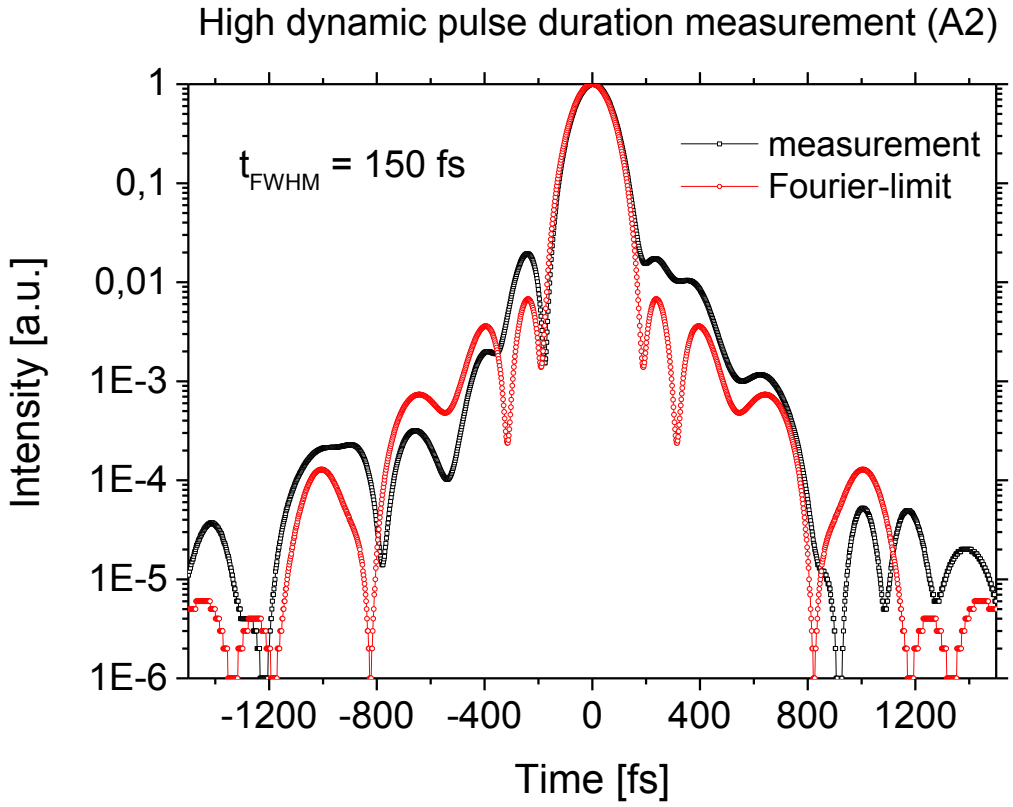
High-dynamic pulse duration measurements

Installation of a Wizzler & Dazzler loop:



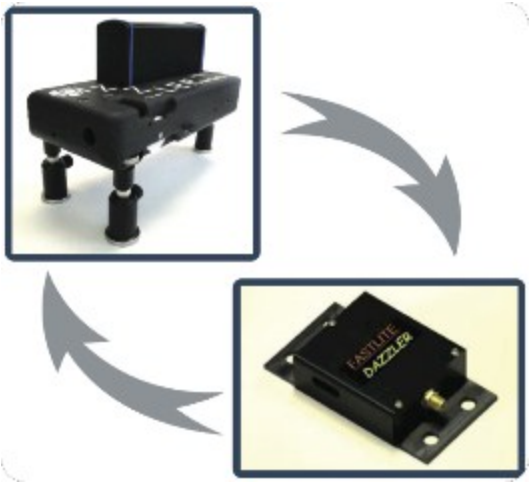
A4 pulse duration:



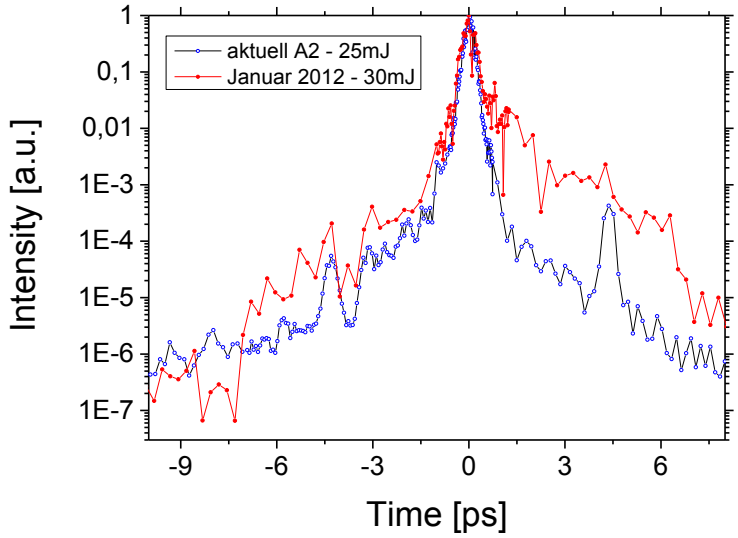


Problem: 10 year old roof-mirror

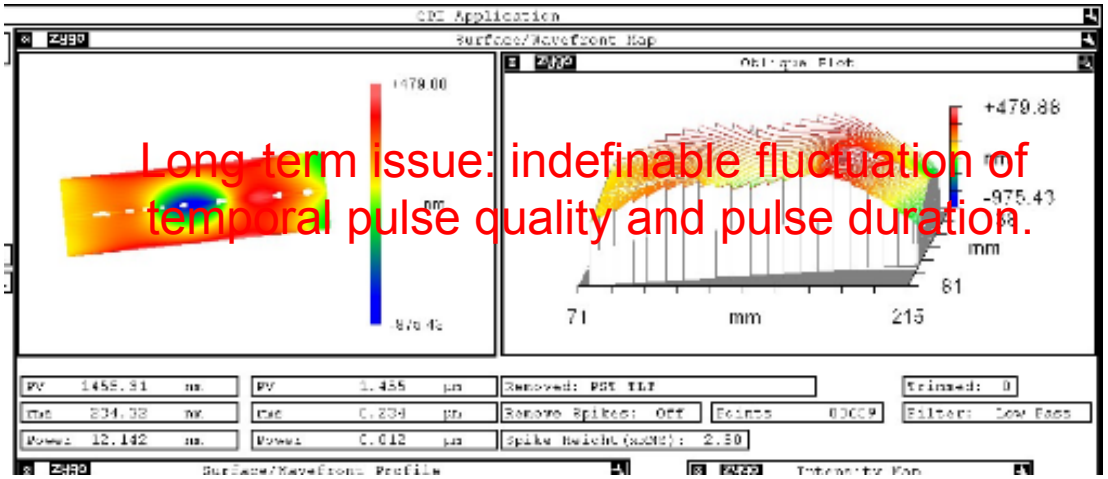
Installation of a Wizzler & Dazzler loop

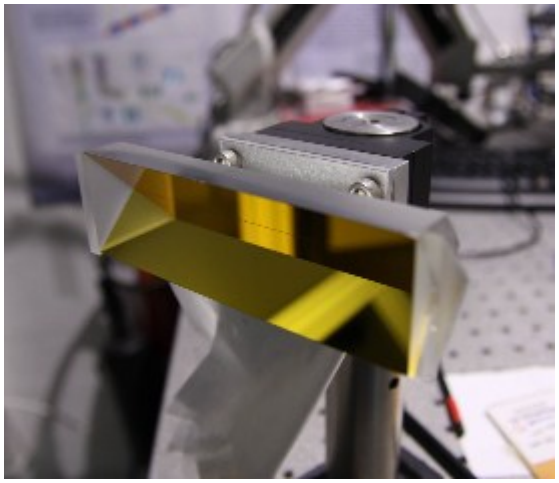


Improved ps-contrast:



Degraded 10 year old roof-mirror:

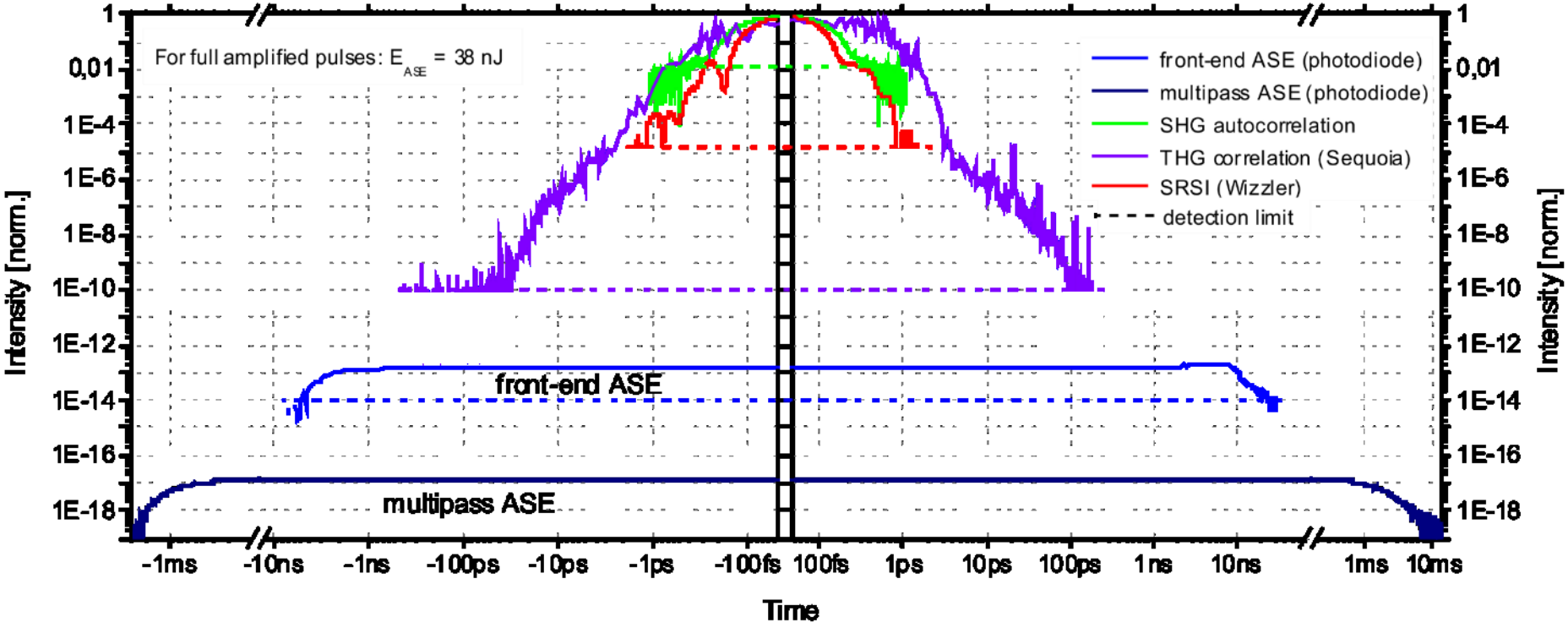




Further contrast improvement: SHG of the laser pulses!

Experiment aimed in autumn with 160 mm diameter KDP-crystal.

$I_{Peak} = 3.5 \times 10^{20}$ W/cm^2



ASE at 2×10^{-13} relative intensity (38nJ) with XPW frontend.

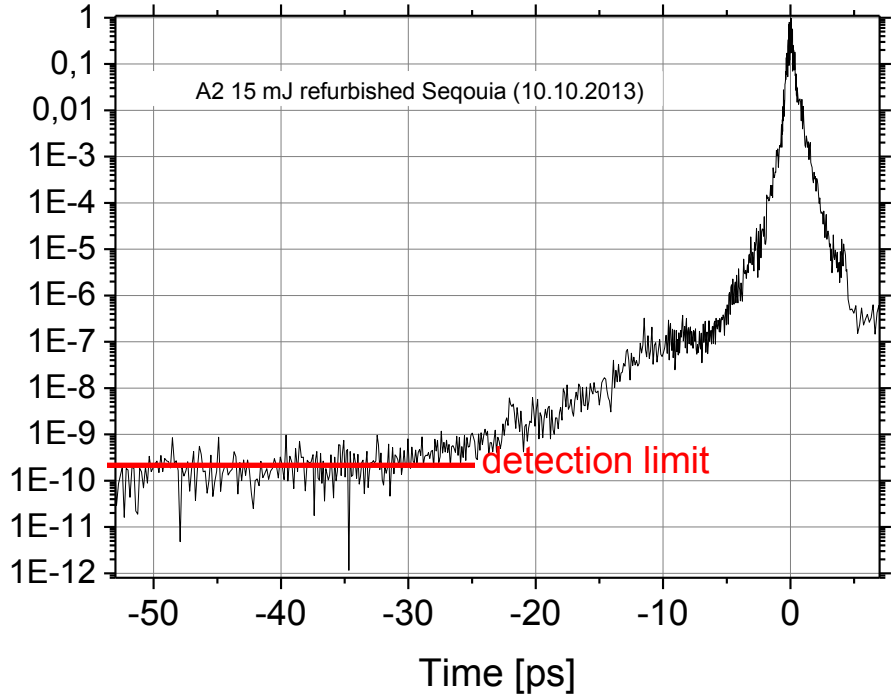
Picosecond Contrast Measurements

For 150 fs-Pulses:

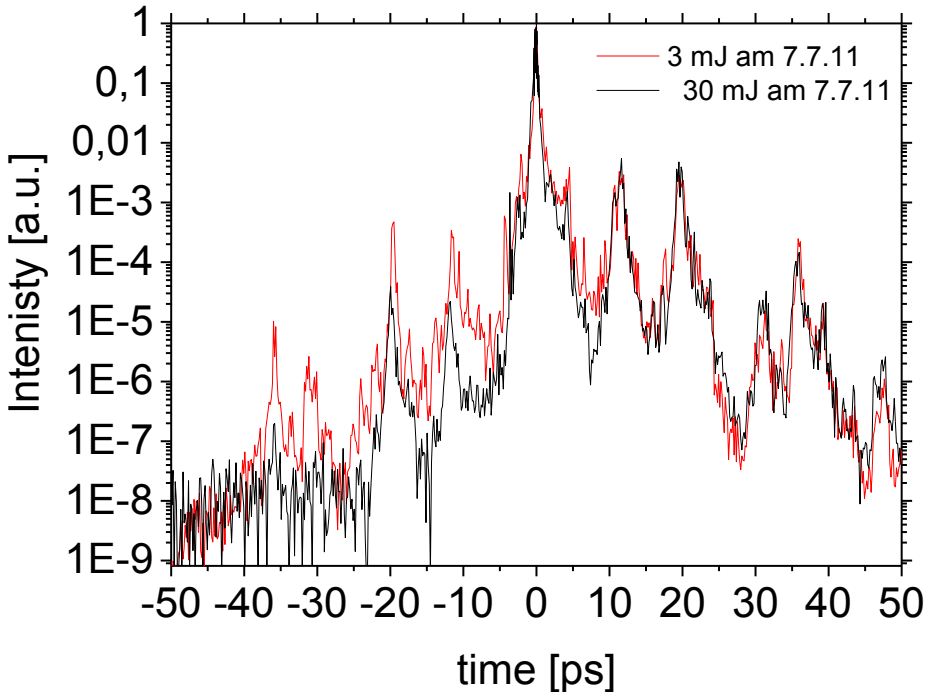
2×10^{-13} @ -200 ps (ASE)

1×10^{-9} @ -25 ps

1×10^{-6} @ -5 ps



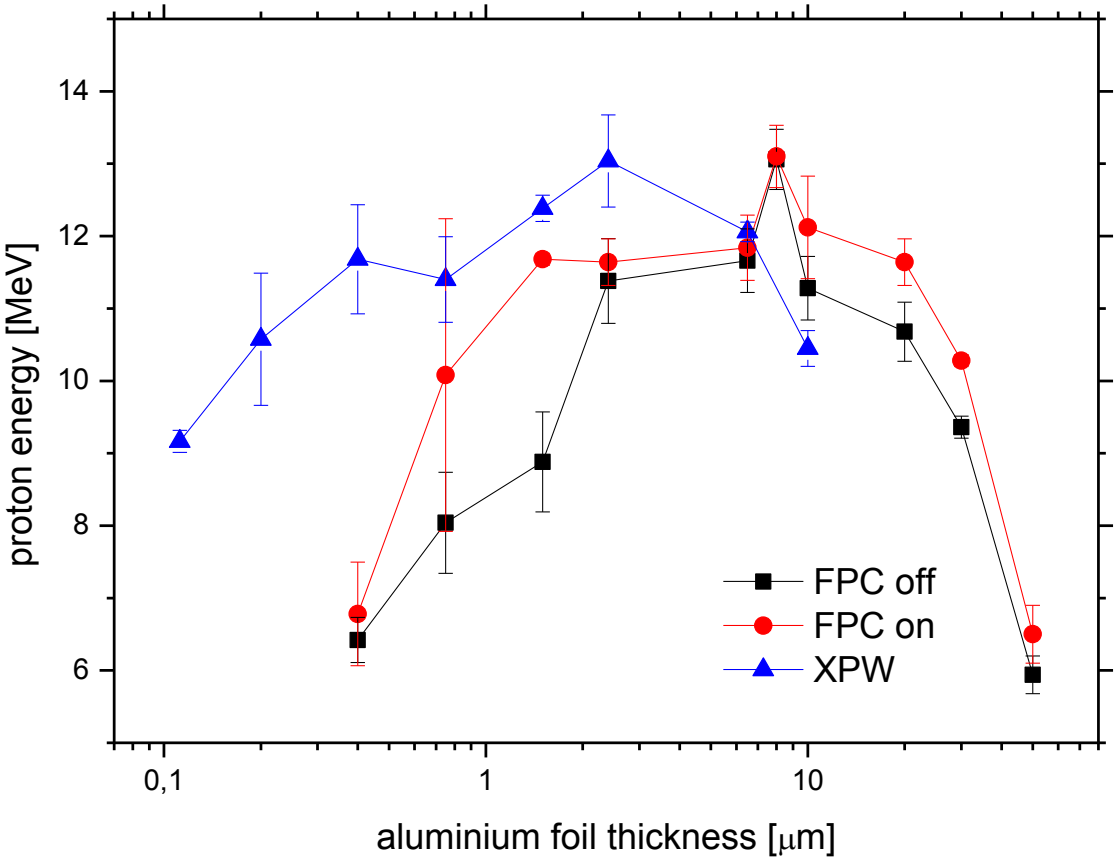
Old measurement:



To do:

Some post/pre-pulses (e.g. @ -130 ps, 10^{-7}) has to be eliminated in the future!

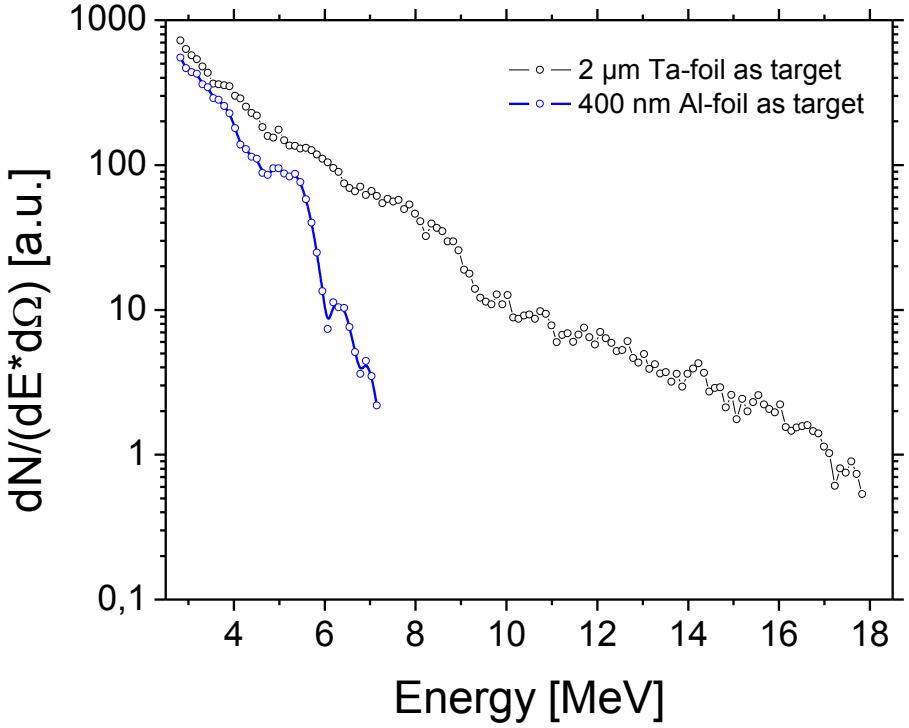
TNSA p^+-acceleration: target thickness scan

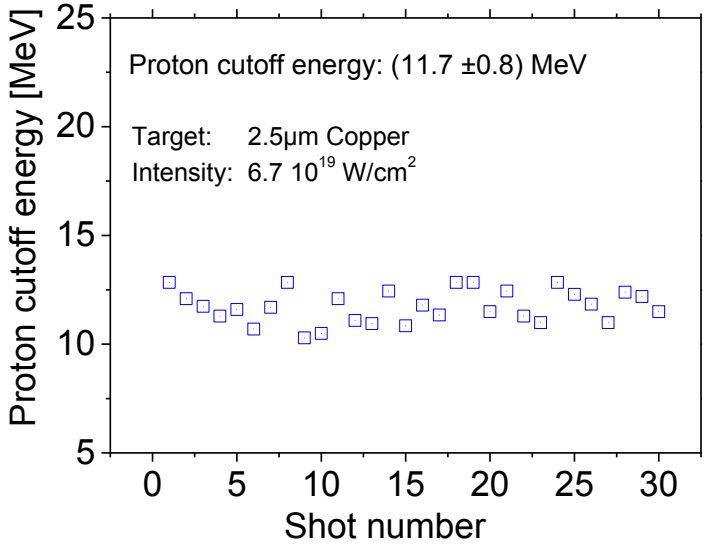


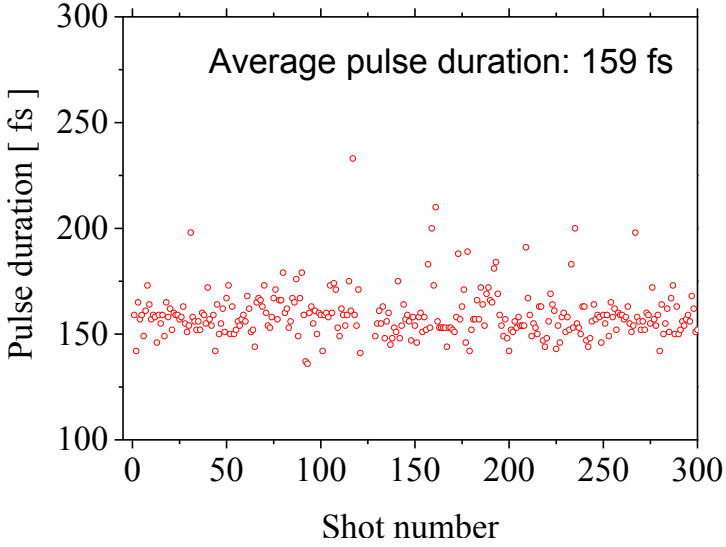
Target thickness for highest p^+-energy decreases with improved contrast!

Experimental Performance - TNSA

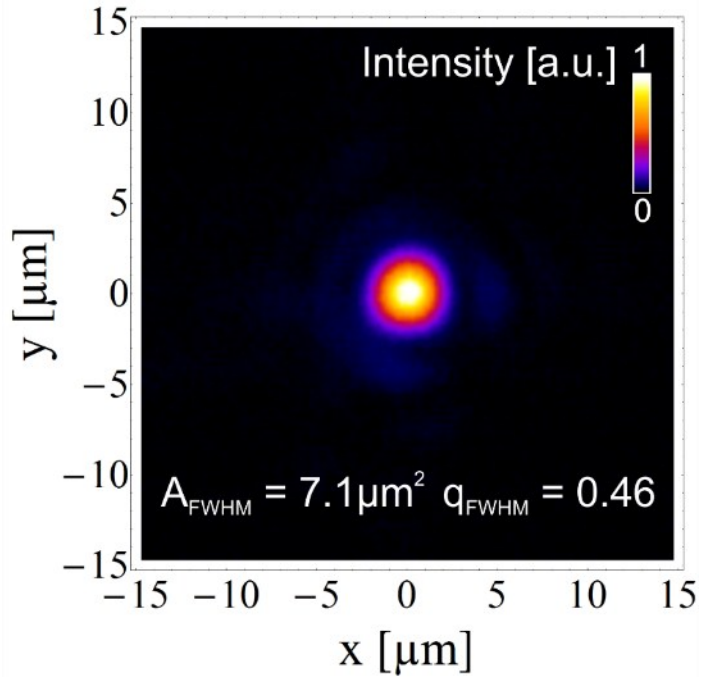
Maximum proton cut-off energy of 17.7 MeV with 2.3 J of laser energy and a 2 µm Ta-foil.







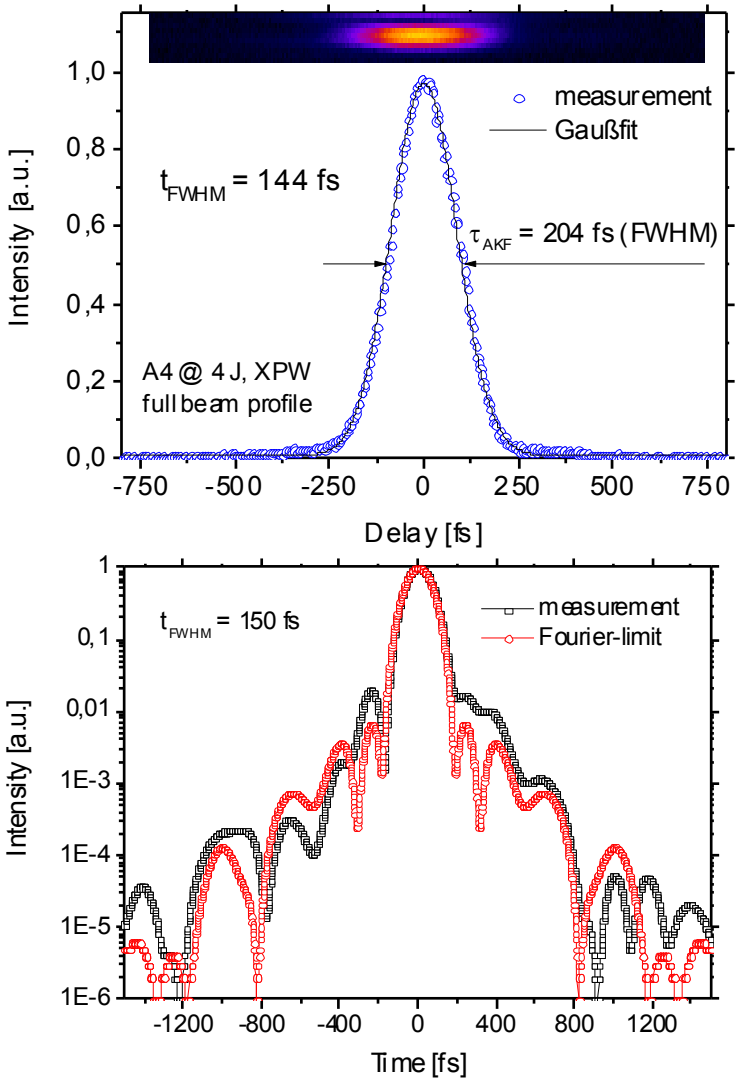
Focal Spot in Targetarea with adaptive optics:



t_{FWHM} = 145 fs
q = 0.46
A_{FWHM} = 7.1 µm²
E_{pulse} = 6.5 Joule
$\eta_{Compressor}$ = 0.63

$I_{Peak} = 3.5 \times 10^{20}$ W/cm²

Pulse duration:



Conclusion

POLARIS as a fully diode-pumped laser is in experimental operation.

(more than 17000 high intensity experiment-shots)

Improvements in terms of temporal contrast and pulse energy was done.

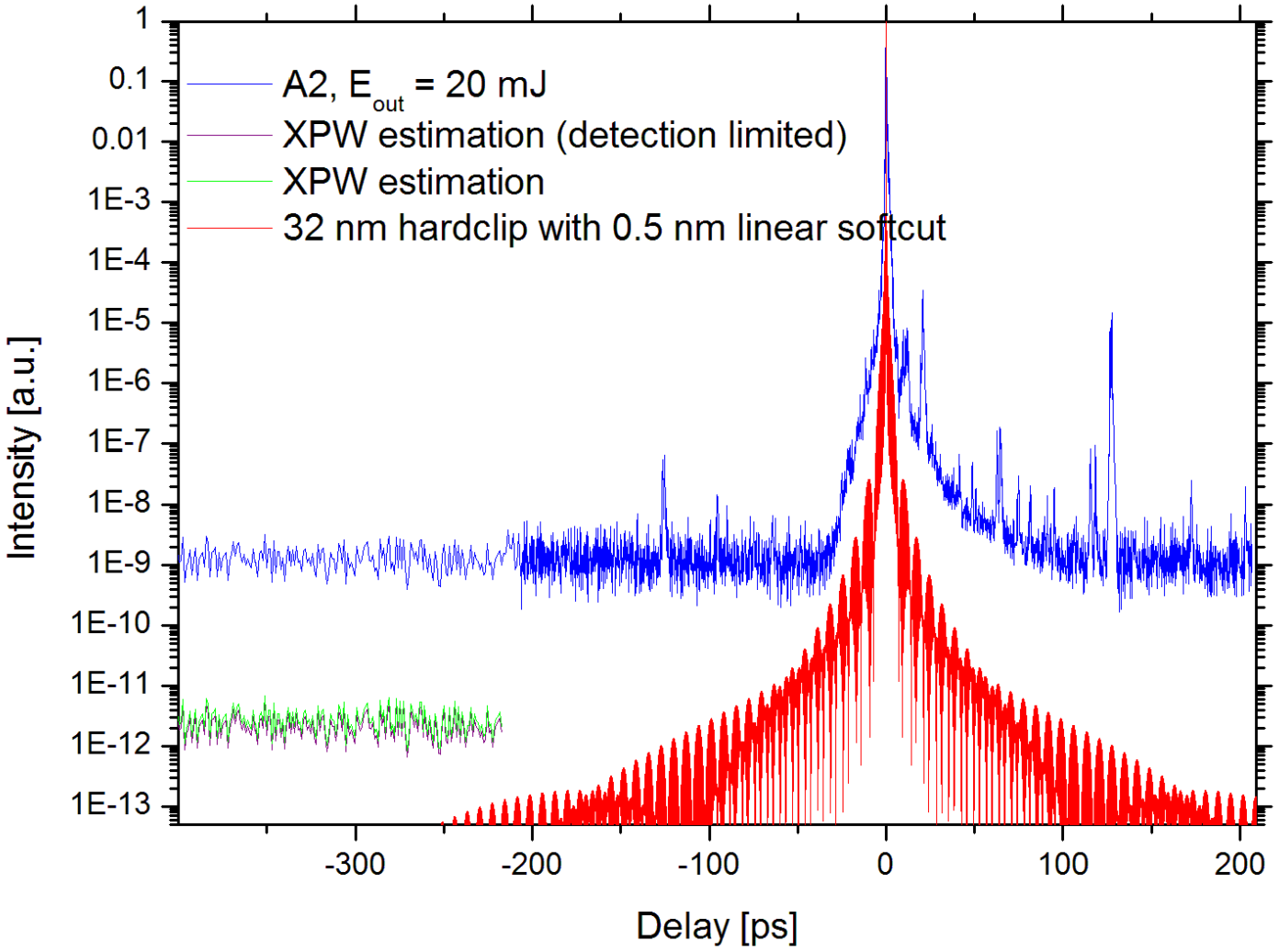
Pulse parameters:

- 3.5×10^{20} W/cm^2 peak intensity
- 4 J on target pulse energy (16 J out of A5 soon available)
- 145 fs pulse duration

- Relative temporal contrast of 2×10^{-13} for ASE and 10^{-8} for (some residual) pre-pulses.

M. Hornung et al., "High intensity, high contrast laser pulses generated from the fully diode-pumped Yb:glass laser system POLARIS", Optics Letters 2013.
A. Kessler et al., "16.6 J chirped femtosecond laser pulses from a diode-pumped Yb:CaF2 amplifier", Optics Letters 2014

Thank You!


A2, E_out = 20 mJ
XPW estimation (detection limited)
XPW estimation
32 nm hardclip with 0.5 nm linear softcut
Intensity [a.u.]
1
0.1
0.01
1E-3
1E-4
1E-5
1E-6
1E-7
1E-8
1E-9
1E-10
1E-11
1E-12
1E-13
-300
-200
-100
0
100
200
Delay [ps]