The Petawatt Field Synthesizer – towards high energy few-cycle pulses

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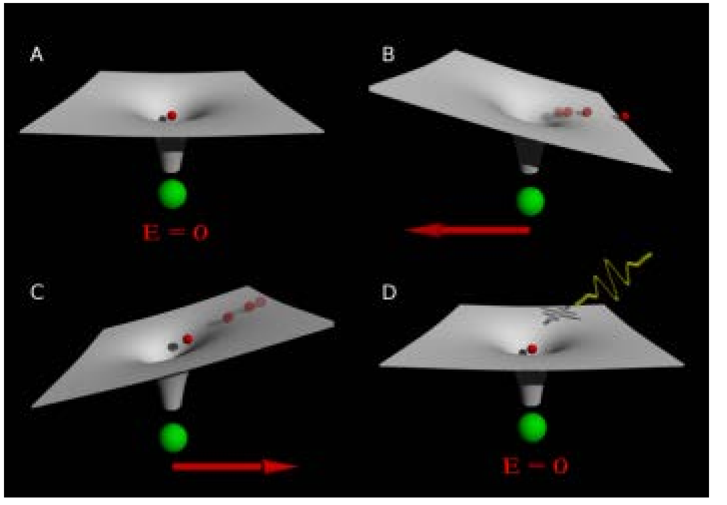
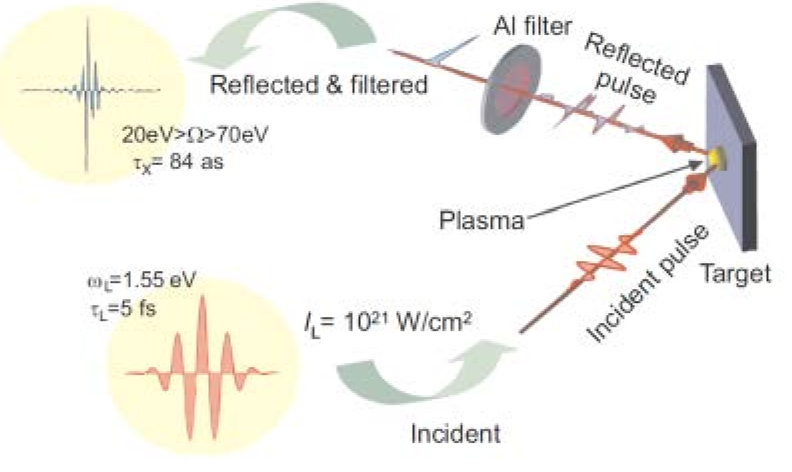
Motivation: Single attosecond pulse generation



HHG in gas:
- Low efficiency
- Not scalable in laser intensity

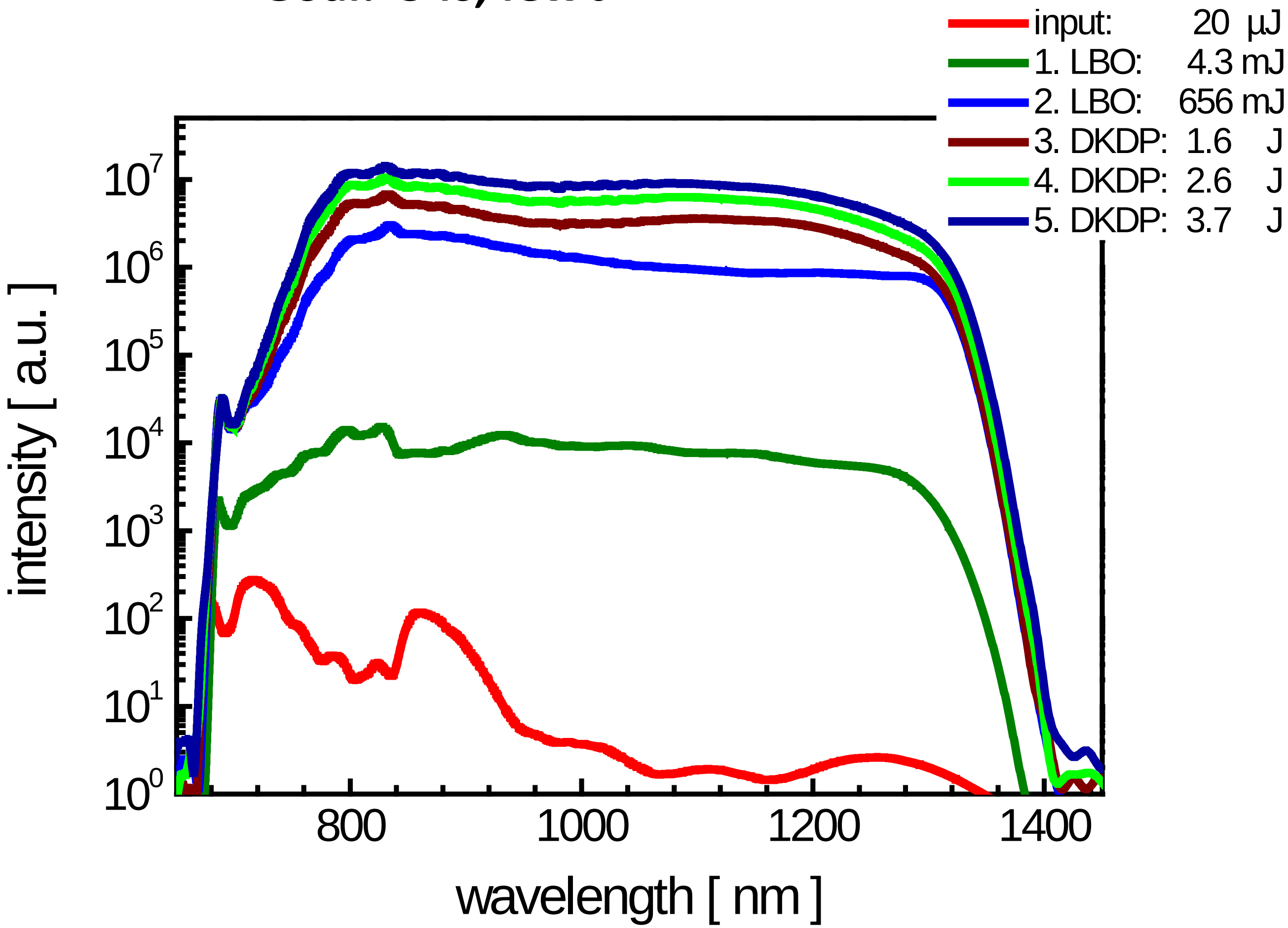


HHG from solid surfaces:
- higher efficiency
- Wavelength and photon flux scales with laser intensity
- **For single attosecond pulse: relativistic, CEP-stable few-cycle pulses needed**

PFS design considerations

Goal: 5 fs, few J

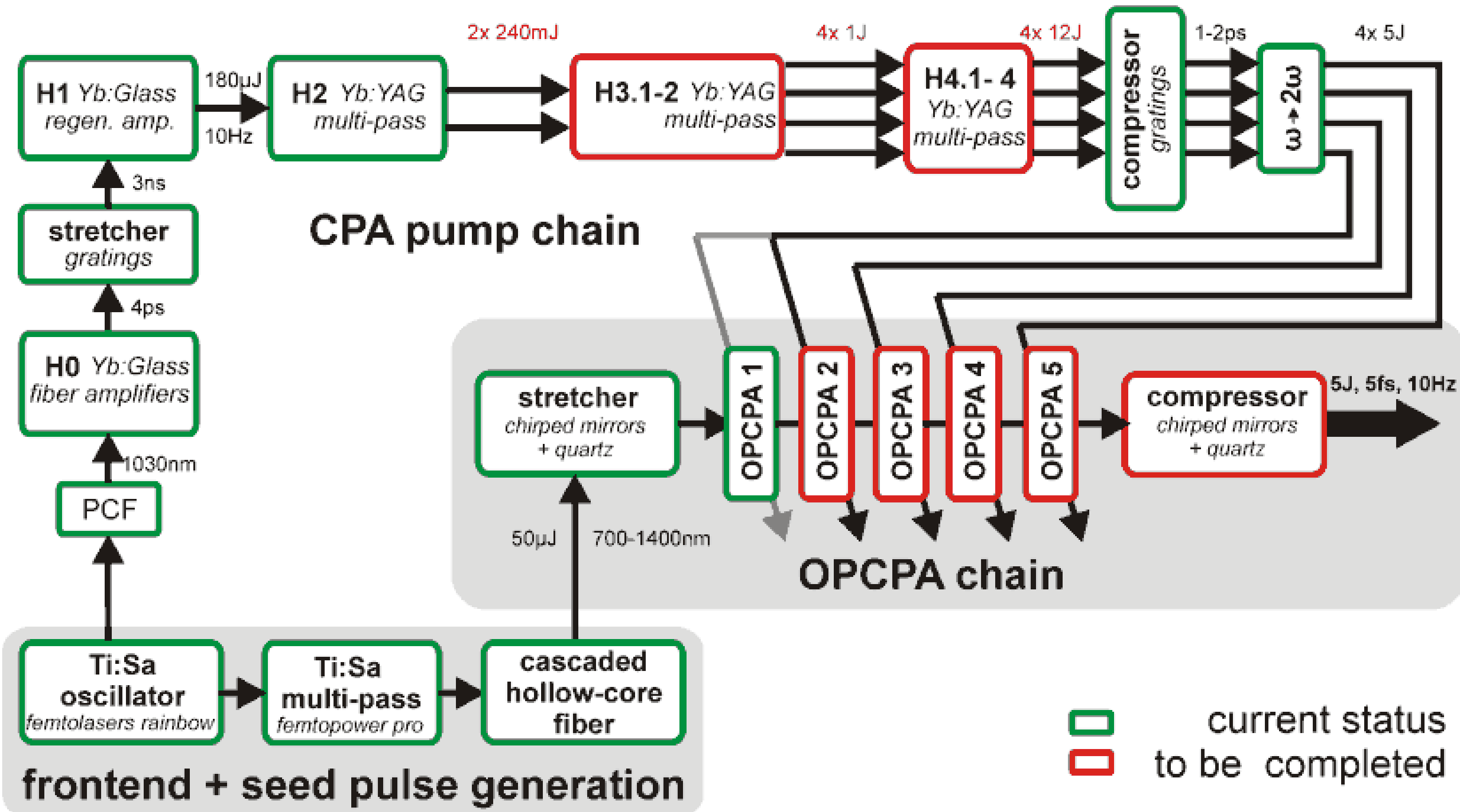
5 fs → broad ban
→ High intensity



The main challenges :

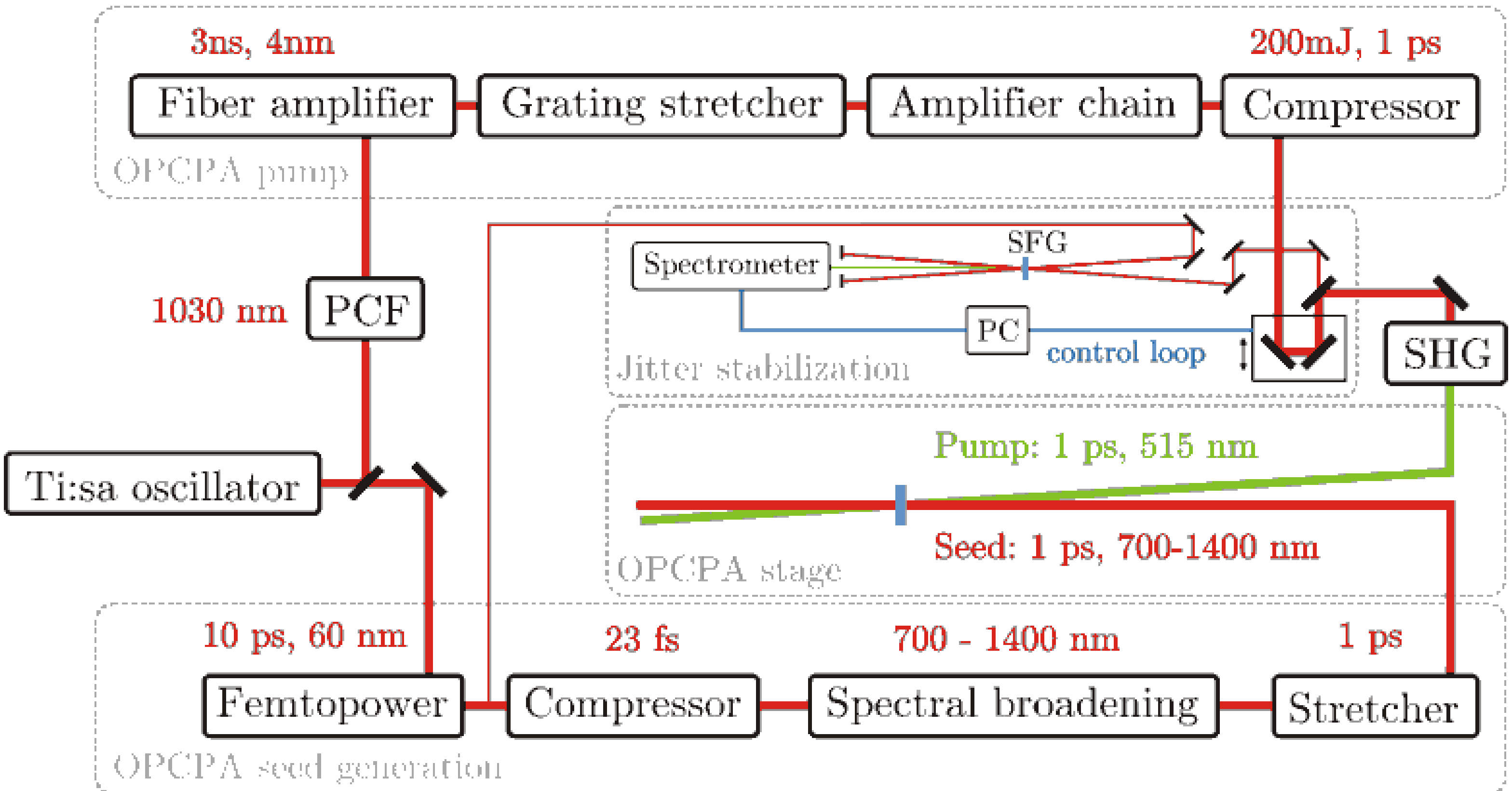
- **seed generation**
- **pump laser development (4x 5J, 1ps @ 515 nm)**
- **Pump-seed synchronization**

PFS Layout



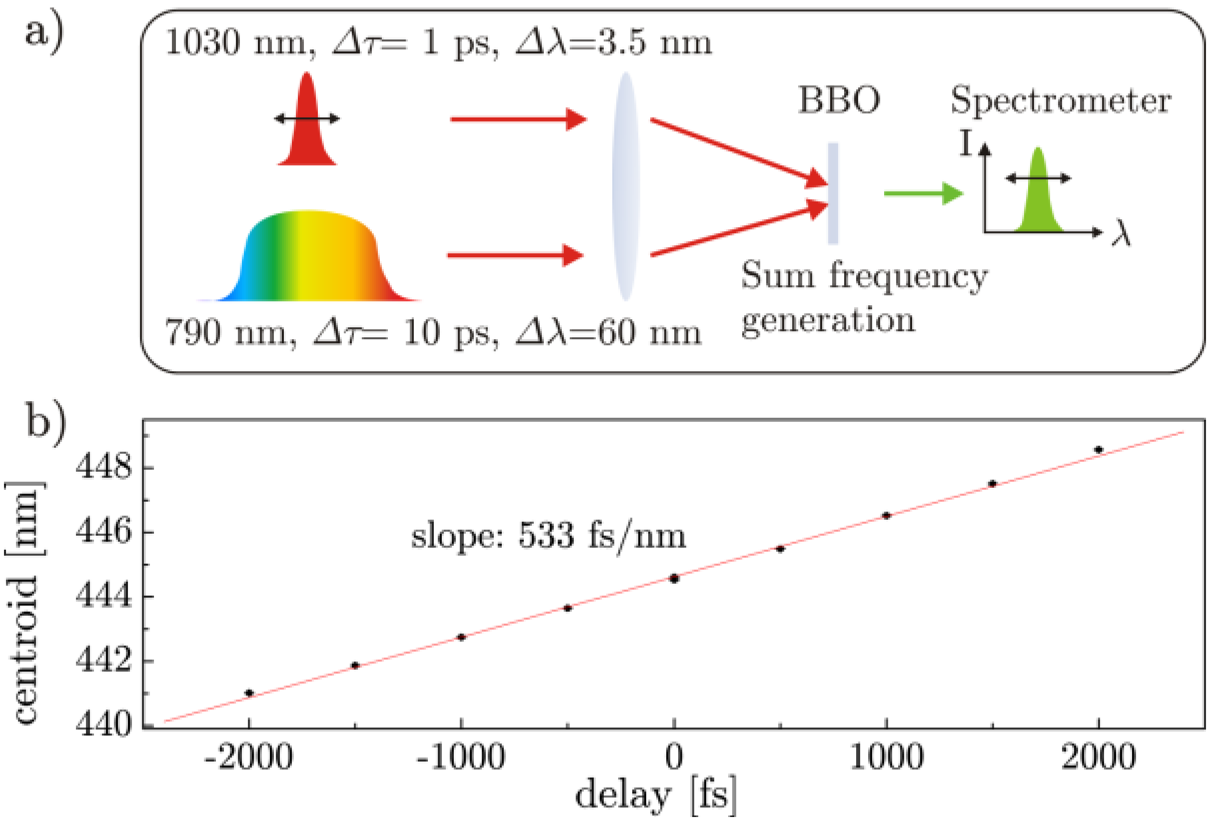
H1 Yb:Glass regen. amp.
180µJ
10Hz
H2 Yb:YAG multi-pass
2x 240mJ
H3.1-2 Yb:YAG multi-pass
4x 1J
H4.1- 4 Yb:YAG multi-pass
4x 12J
compressor gratings
1-2ps
ω→2ω
4x 5J
3ns
stretcher gratings
4ps
CPA pump chain
H0 Yb:Glass fiber amplifiers
1030nm
PCF
stretcher chirped mirrors + quartz
OPCPA 1
OPCPA 2
OPCPA 3
OPCPA 4
OPCPA 5
compressor chirped mirrors + quartz
5J, 5fs, 10Hz
50µJ
700-1400nm
OPCPA chain
Ti:Sa oscillator femtolasers rainbow
Ti:Sa multi-pass femtopower pro
cascaded hollow-core fiber
frontend + seed pulse generation
current status
to be completed

OPCPA + timing jitter

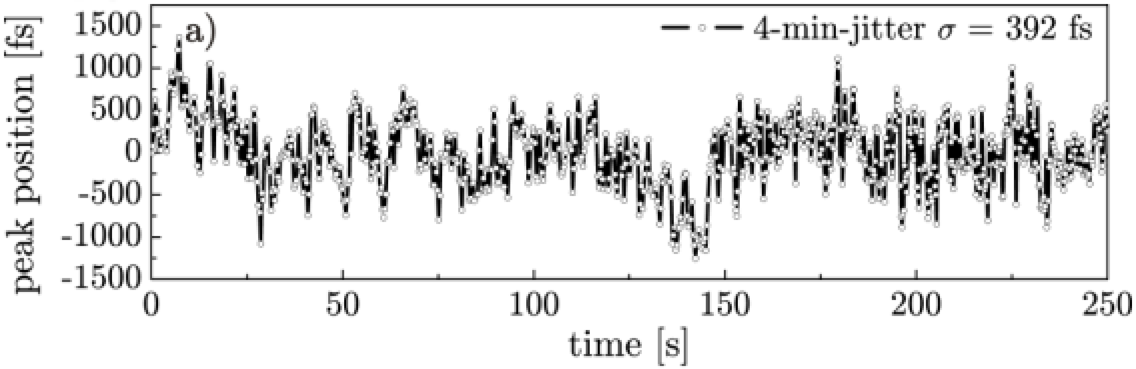


Before first OPCPA- resolve jitter problem!

Jitter measurement



Experimental investigation of timing jitter



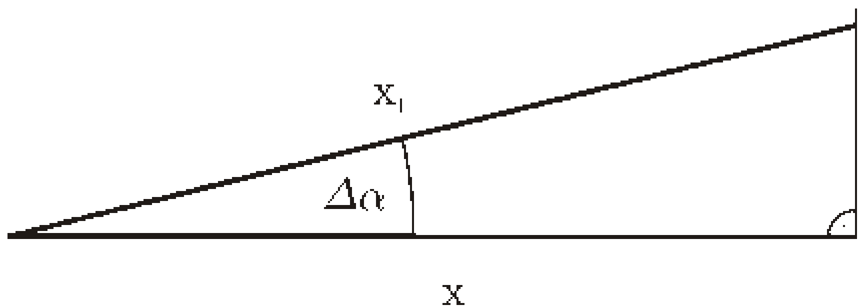
Full pump chain

Optical path inside stretcher/compressor has larger effect on timing jitter compared to free space propagation

Can air fluctuations inside stretcher/compressor cause large timing jitter?
→ Check influence of angle deviations on timing

Timing jitter from angle deviation

Can shot-to-shot pointing fluctuation (few µrad) cause timing jitter?

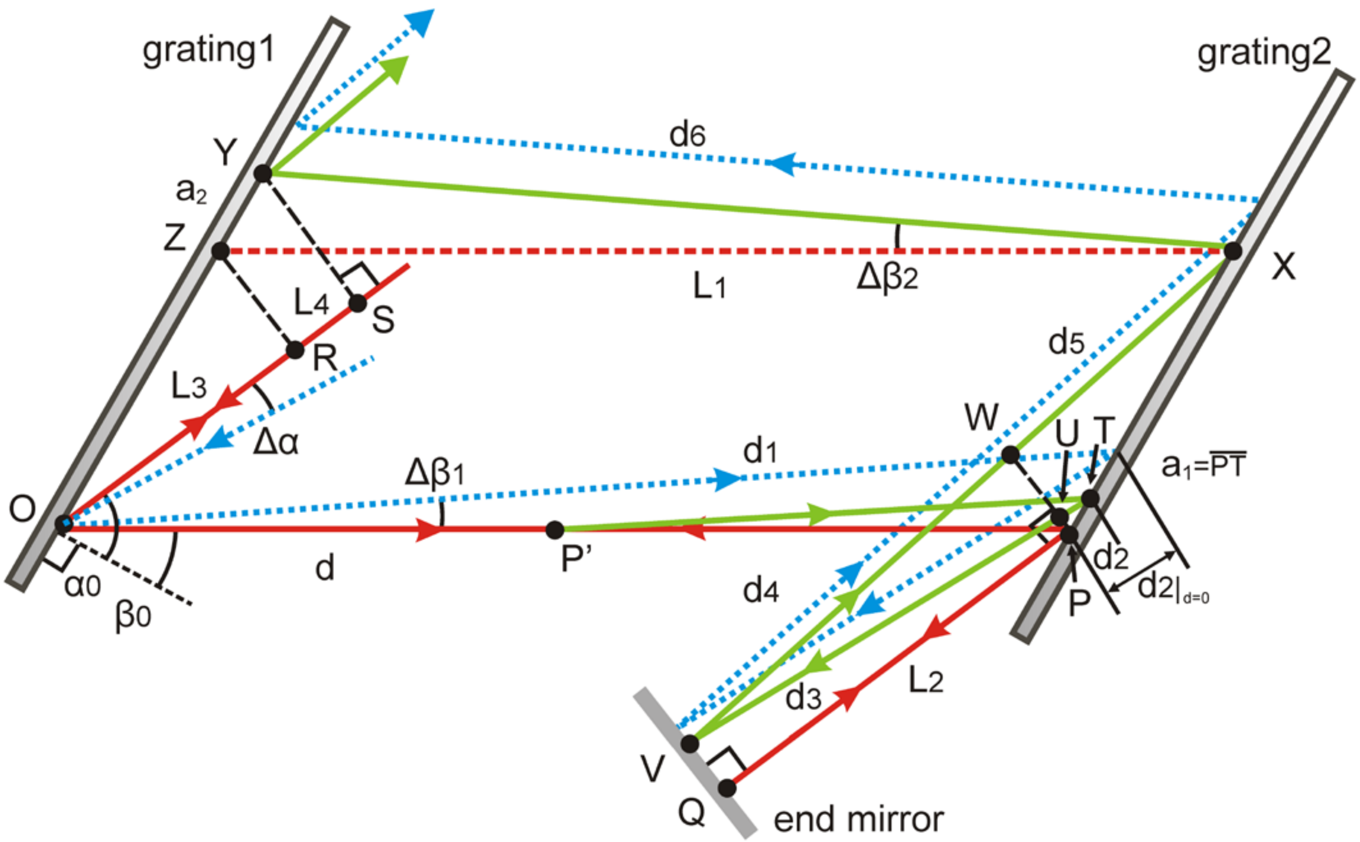


$$x - x_1 = x\left(1 - \frac{1}{cos(\Delta\alpha)}\right) \approx \frac{x \cdot \Delta\alpha^2}{2}$$

Example: x=100m, $\Delta\alpha$=10µrad →Δx= 50nm → $\Delta\tau$ =0.17fs

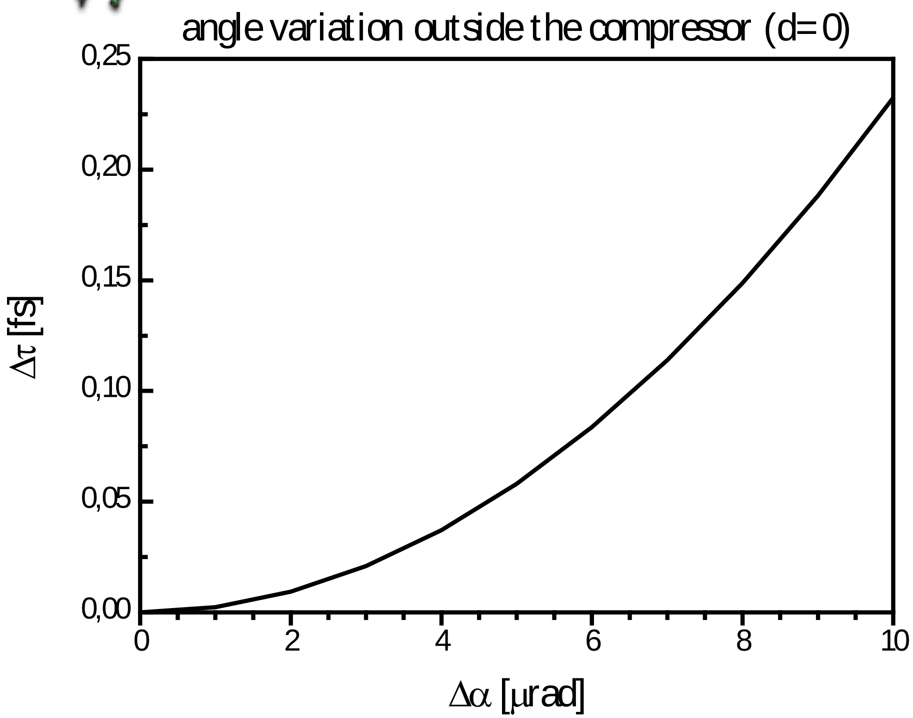
This effect is negligible in most cases!

Timing jitter from angle deviation



$$\Delta\tau = \frac{L_1}{c}\left(\frac{\Delta\beta_2\, N\,\lambda_0}{\cos(\beta_0-\Delta\beta_2)} - \frac{\Delta\beta_1\, N\,\lambda_0}{\cos(\beta_0+\Delta\beta_1)}\right) + \frac{d}{c}\left(\frac{\Delta\beta_1\, N\,\lambda_0}{\cos(\beta_0+\Delta\beta_1)}\right)$$

Angle fluctuation outside compressor (d=0)



$$N = 1740\,\text{lines/mm}$$
$$\lambda_0 = 1030\,\text{nm}$$
$$\alpha_0 = 58.5^\circ$$
$$\beta_0 = 69.97^\circ$$
$$L_1 = 6\,\text{m}$$
$$L_2 = 3\,\text{m}$$

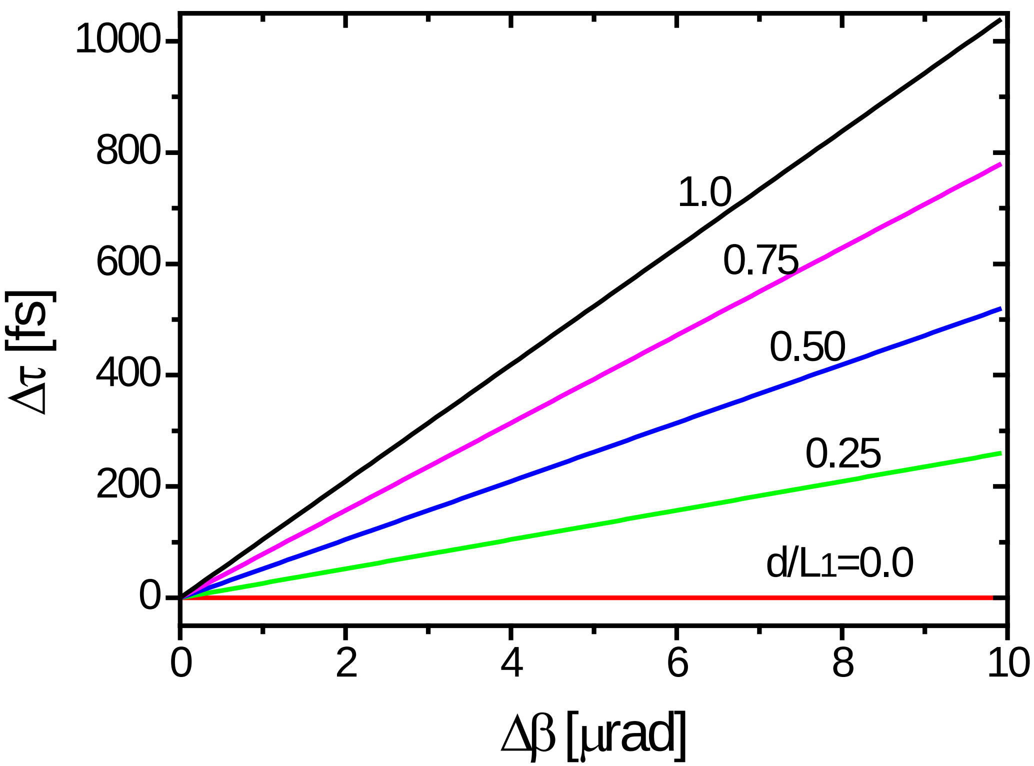
$$\Delta\tau = \frac{L_1}{c}\left(\frac{\Delta\beta_2\,N\,\lambda_0}{\cos(\beta_0 - \Delta\beta_2)} - \frac{\Delta\beta_1\,N\,\lambda_0}{\cos(\beta_0 + \Delta\beta_1)}\right)$$

Pathdifference from path to the endmirror
And back from endmirror cancel out nearly

Angle fluctuation inside the compressor

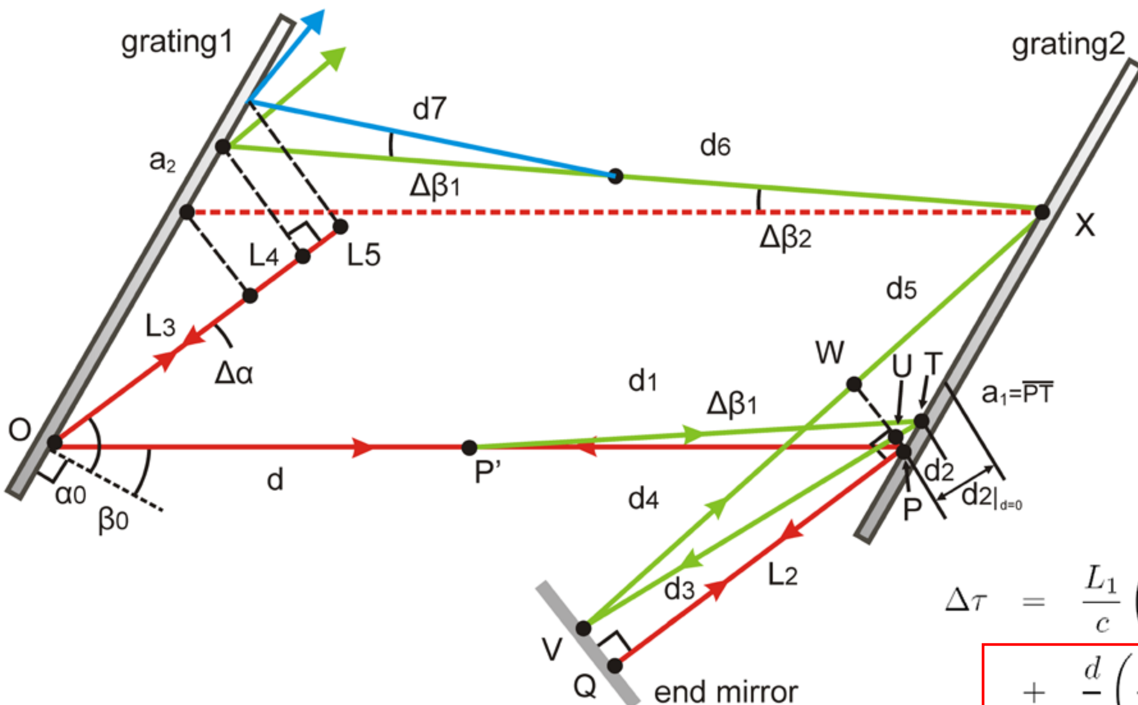
$$\Delta\tau = \frac{L_1}{c}\left(\frac{\Delta\beta_2\, N\,\lambda_0}{\cos(\beta_0 - \Delta\beta_2)} - \frac{\Delta\beta_1\, N\,\lambda_0}{\cos(\beta_0 + \Delta\beta_1)}\right) + \frac{d}{c}\left(\frac{\Delta\beta_1\, N\,\lambda_0}{\cos(\beta_0 + \Delta\beta_1)}\right)$$

→significantly increased timing jitter



Still not the truth!

Perturbance will also be there on the backpropagation:



new terms:

$$d_6 = (L_1 - d)\frac{\cos(\beta_0)}{\cos(\beta_0 - \Delta\beta_2)}$$

$$d_7 = d\frac{\cos(\beta_0 - \Delta\beta_2)}{\cos(\beta_0 - \Delta\beta_1 - \Delta\beta_2)}$$

$$L_5 = d\frac{\sin(\Delta\beta_1)}{\cos(\beta_0 - \Delta\beta_1 - \Delta\beta_2)}\sin(\alpha_0)$$

$$\Delta\tau = \frac{L_1}{c}\left(\frac{\Delta\beta_2\, N\, \lambda_0}{\cos(\beta_0 - \Delta\beta_2)}\right) - \frac{(L_1 - d)}{c}\left(\frac{\Delta\beta_1\, N\, \lambda_0}{\cos(\beta_0 + \Delta\beta_1)}\right) + \frac{d}{c}\left(\frac{\cos(\beta_0)}{\cos(\beta_0 - \Delta\beta_2)} - 1 + \frac{\Delta\beta_1\, N\, \lambda_0}{\cos(\beta_0 - \Delta\beta_1 - \Delta\beta_2)}\right)$$

$$\Delta\tau = \frac{d}{c}\left(\frac{\Delta\beta_1\, N\, \lambda_0}{\cos(\beta_0 + \Delta\beta_1)} + \frac{\cos(\beta_0)}{\cos(\beta_0 - \Delta\beta_2)} - 1 + \frac{\Delta\beta_1\, N\, \lambda_0}{\cos(\beta_0 - \Delta\beta_1 - \Delta\beta_2)}\right)$$

→ approximately doubles jitter

Timing jitter

- From experiment we suspect the stretcher/compressor to cause main timing jitter

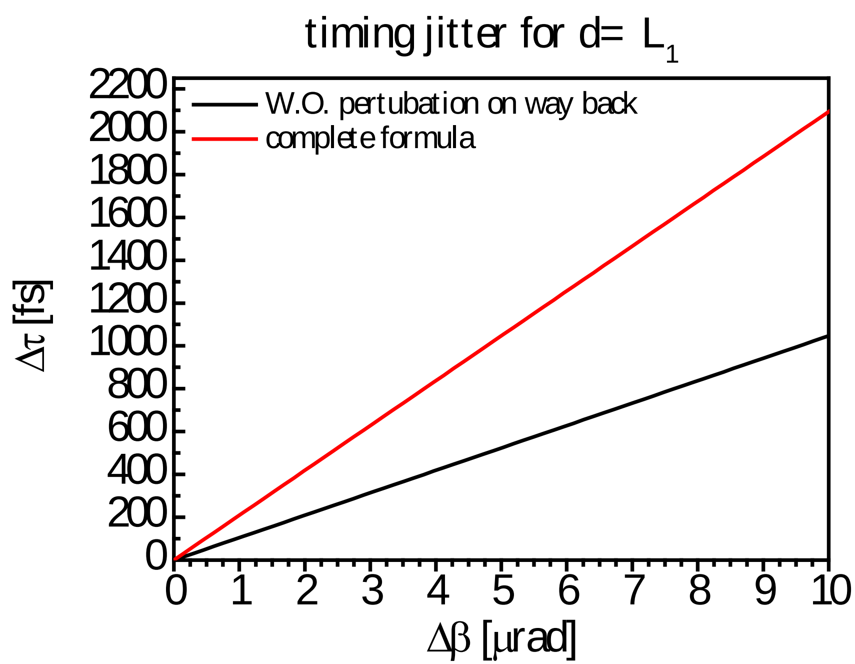
- beam pointing outside the compressor has negligible effect

- beam pointing inside the compressor can introduce significant timing jitter

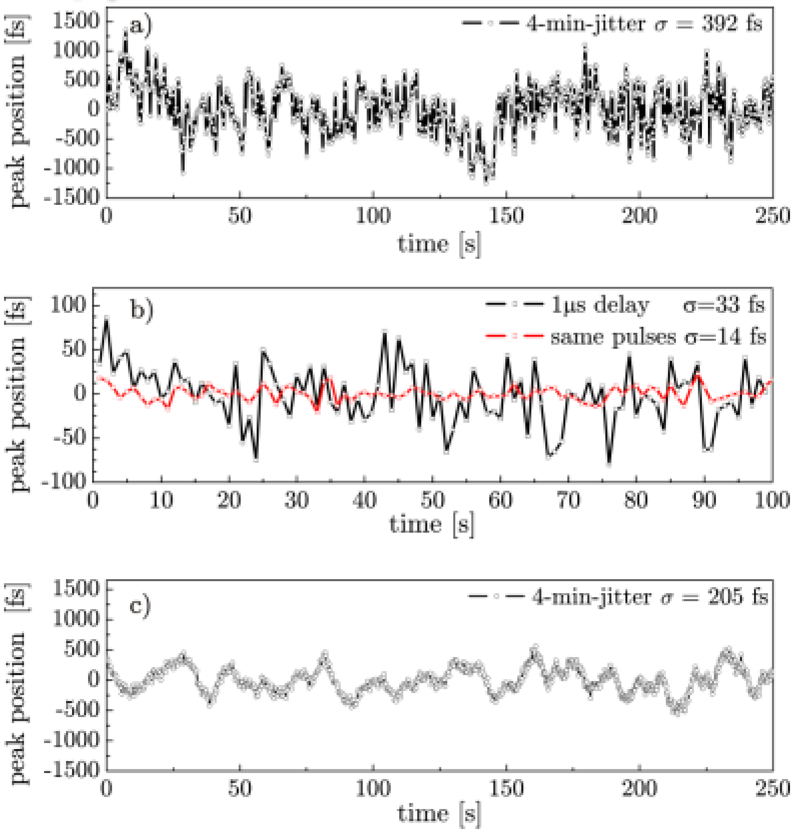
-Angle perturbation could arise from air turbulence or mechanical stability of optical components

- results account also for stretcher

$$\Delta\tau \approx \frac{2\,N\,\lambda_0}{c \cdot \cos(\beta_0)} \Delta\beta_1 \ \mathrm{d}$$



Experimental investigation of timing jitter



Full pump chain

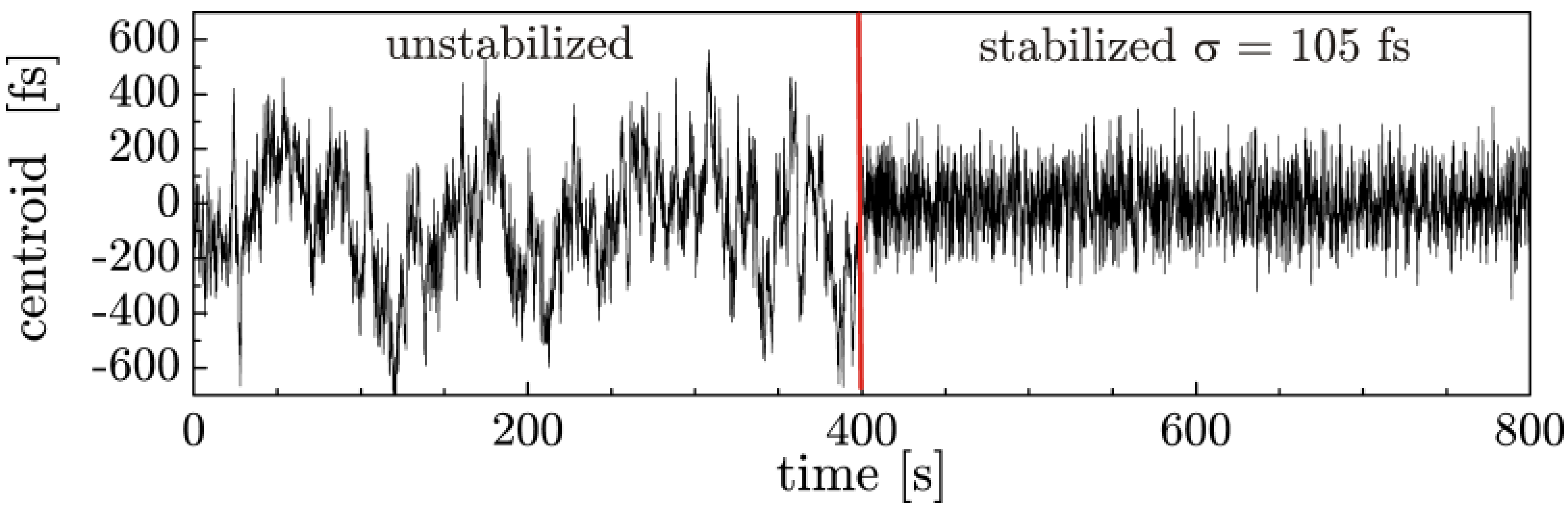
Regen without stretcher/compressor

Full pump chain – reduced air turbulence

Air-tight housing for stretcher and beam tubes in the compressor reduce air turbulence and timing jitter.

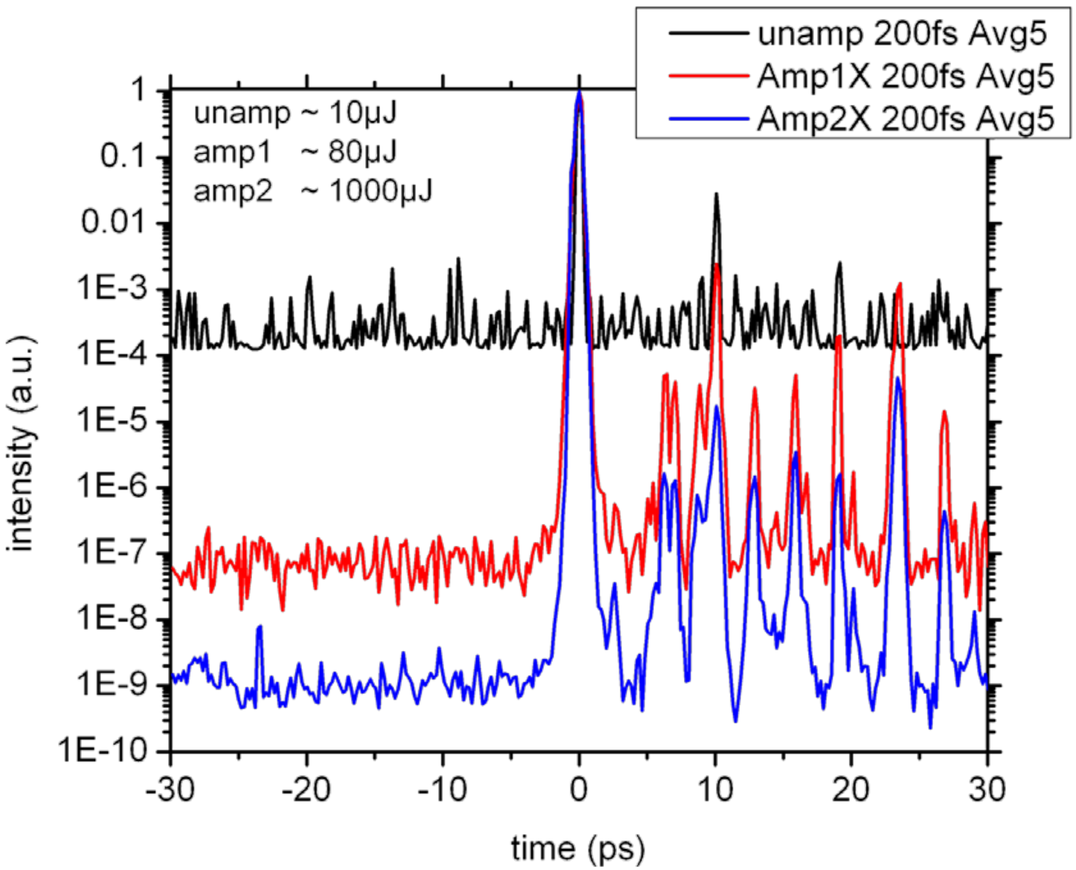
Active stabilization

- Move a delaystage acording to measured jitter
- works with 10 Hz (on every shot)

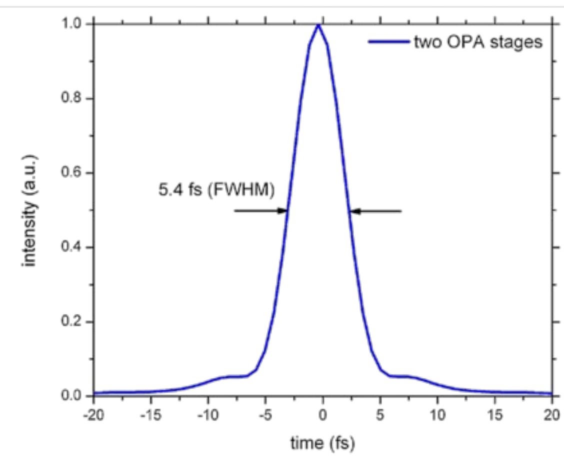


Preliminary OPCPA results

4 mm & 2 mm LBO and a pump energy of 50 mJ, E_{out}= 3mJ

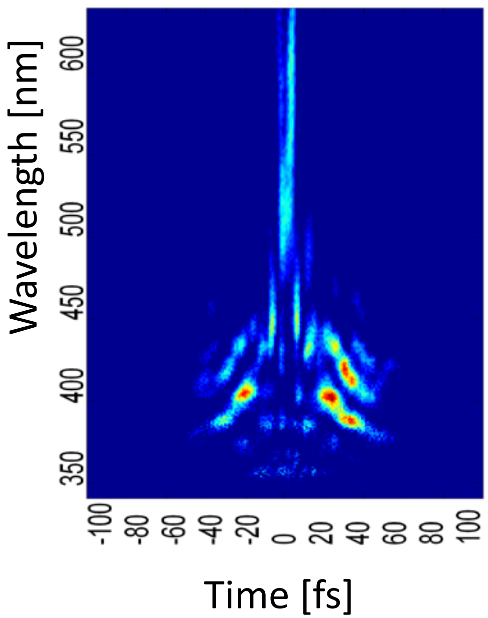


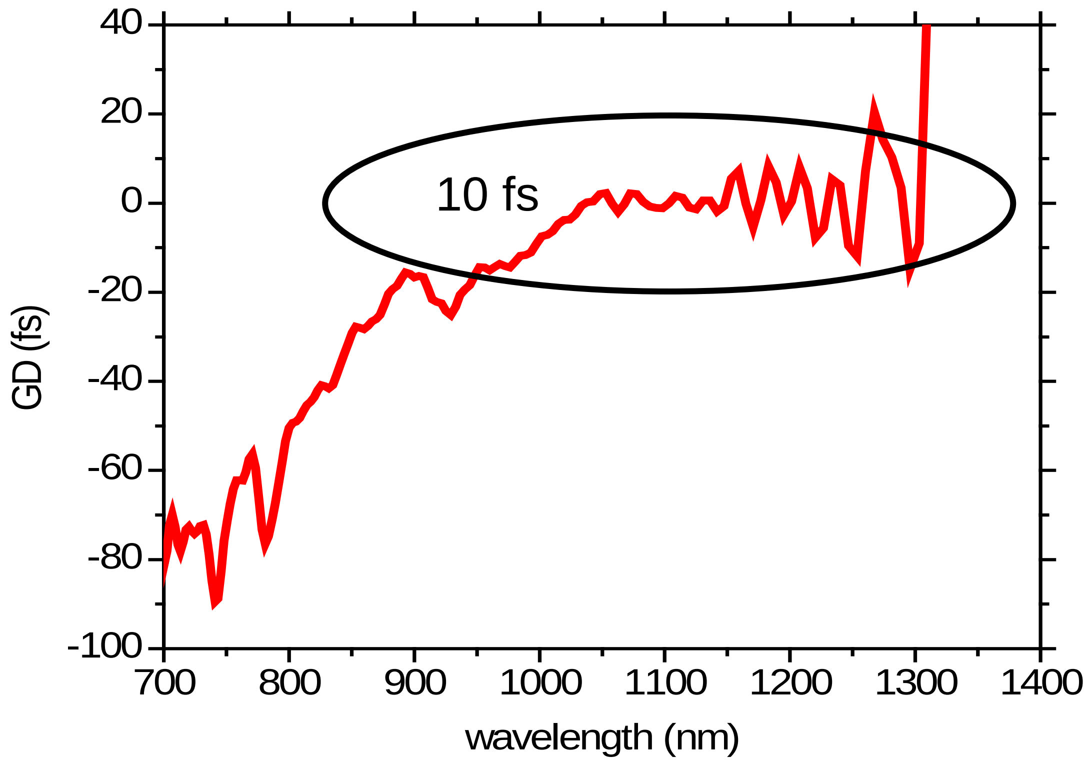
Fourier limit



Preliminary OPCPA results

First compression with CaF + chirped mirrors

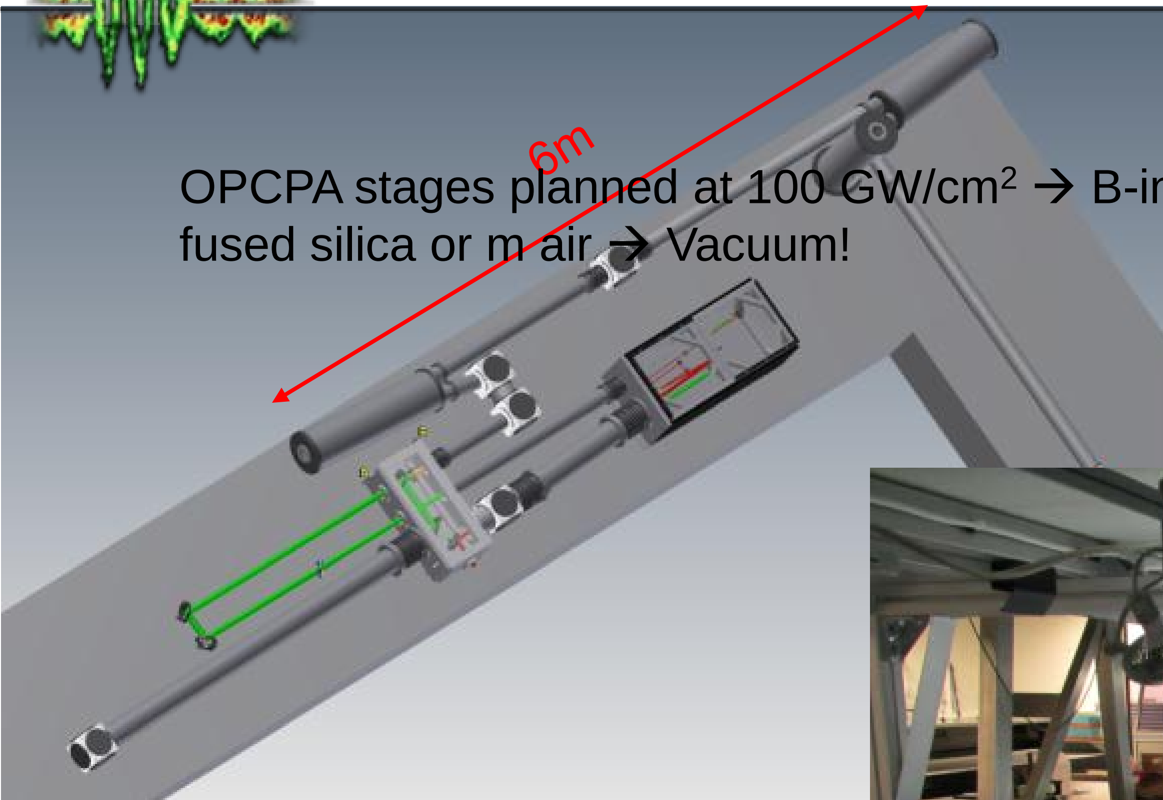




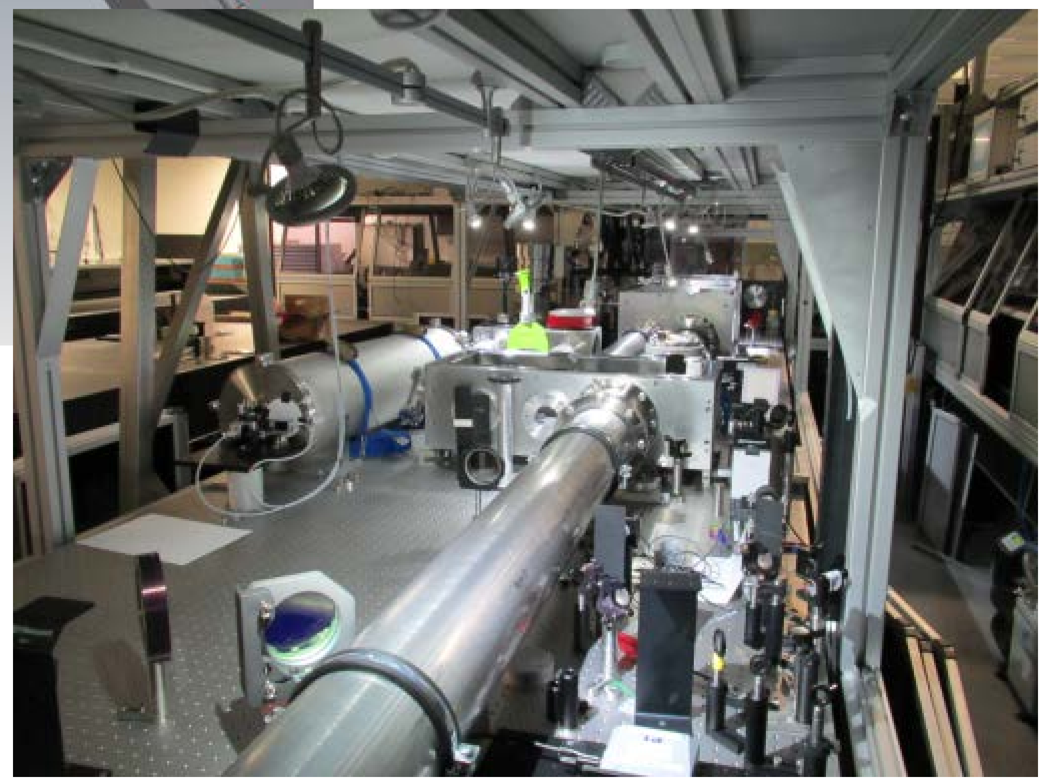
Summary

- Timing jitter between seed and pump is investigated experimentally
- it is shown theoretically, that the main source are angular deviations inside the stretcher/compressor
- The jitter could be reduced to 100 fs std by reduced air turbulences and an active stabilization
- First OPCPA results are promising: bandwidth, contrast & compression

Further steps



OPCPA stages planned at 100 GW/cm^2 → B-integral B=0.36 per mm fused silica or m air → Vacuum!



Can use up to 1J (0.5J) pump beam in 2 OPCPA stages

For 10 J (5J) pump beam: Compressor chamber needed

Further steps

- Implementation of the high energy pump laser stages

→ See Christophs talk on Fiday

Thank you for your attention!