

Towards spin-polarised electron beams from a laser-plasma accelerator

Felix Stehr^[1, 2], Simon Bohlen^[2], Jennifer Popp^[1, 2], Jenny List^[2],
Gudrid Moortgat-Pick^[1, 2], Jens Osterhoff^[2] and Kristjan Pöder^[2]

DPG Spring Meeting, 23.03.2023

[1] Deutsches Elektronen-Synchrotron (DESY)

[2] Universität Hamburg

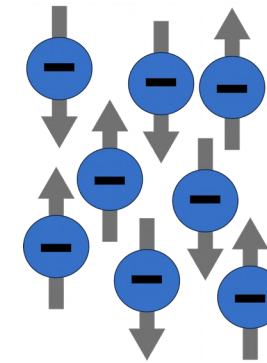
HELMHOLTZ



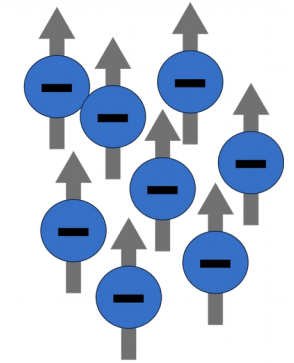
Polarisation of an electron beam

What makes it of special interest?

- Polarised particle beams are indispensable for many research fields where spin dependent processes are to be studied
 - Particle physics
 - Nuclear physics
 - Atomic physics
 - Material Science
- Polarised electron beams can generate polarised photon and positron beams
- Longitudinal spin of main interest in high energy physics
- Polarisation also important in fusion [1,2]



unpolarised



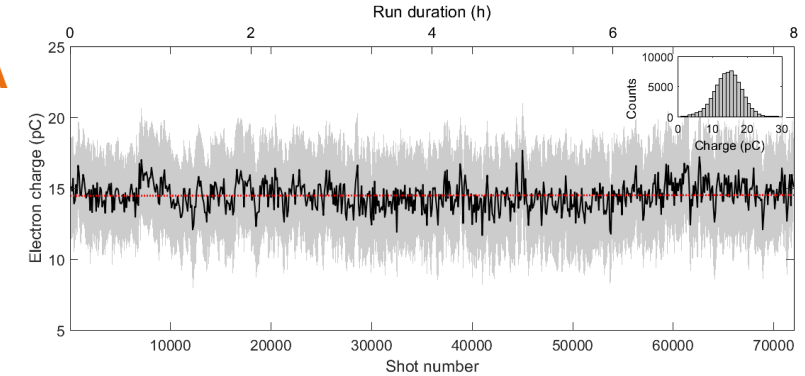
polarised

$$P = \frac{N_{\uparrow} - N_{\downarrow}}{N_{\uparrow} + N_{\downarrow}}$$

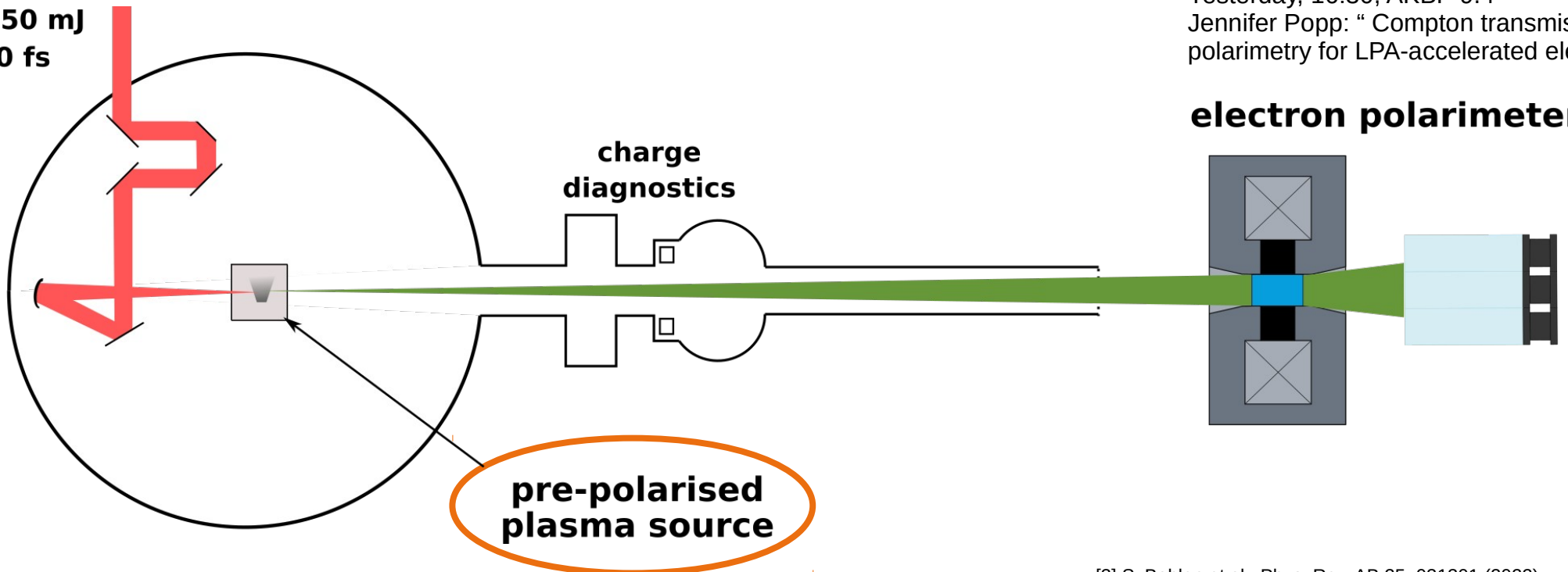
LEAP project at DESY

A proof of principle experiment for spin-polarised electrons from a LPA

- Using our existing **high-stability plasma accelerator** [3]
- Polarisation will be introduced via a **pre-polarised plasma target** [4]
- The later polarisation measurement will be based on **Compton transmission Polarimetry**



$E \sim 550 \text{ mJ}$
 $t \sim 30 \text{ fs}$

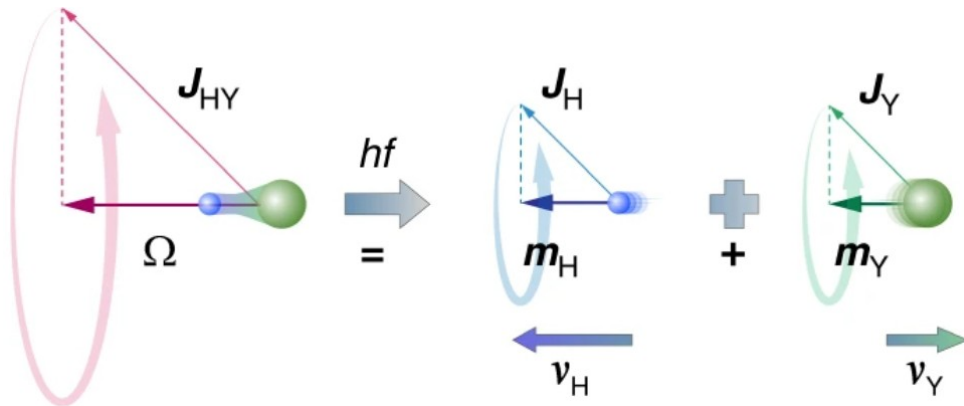
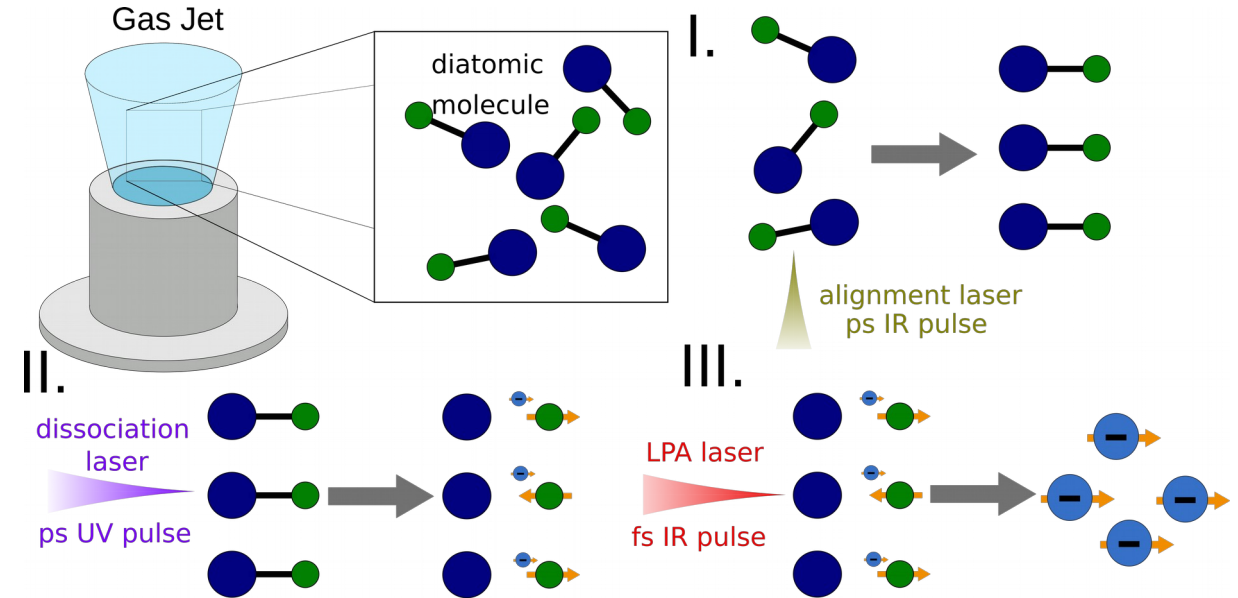


Yesterday, 16:30, AKBP 9.4
Jennifer Popp: “Compton transmission
polarimetry for LPA-accelerated electron beams”

Concept of the pre-polarized plasma source

A three step recipe

- I. Align bonds of diatomic molecules with a linear polarised IR pulse
- II. Photodissociate the molecules with a circular polarised UV pulse
- III. Ionisation and acceleration through LPA driver pulse



A. Spiliotis et al., Light Sci. Appl. 10, no 35 (2021)

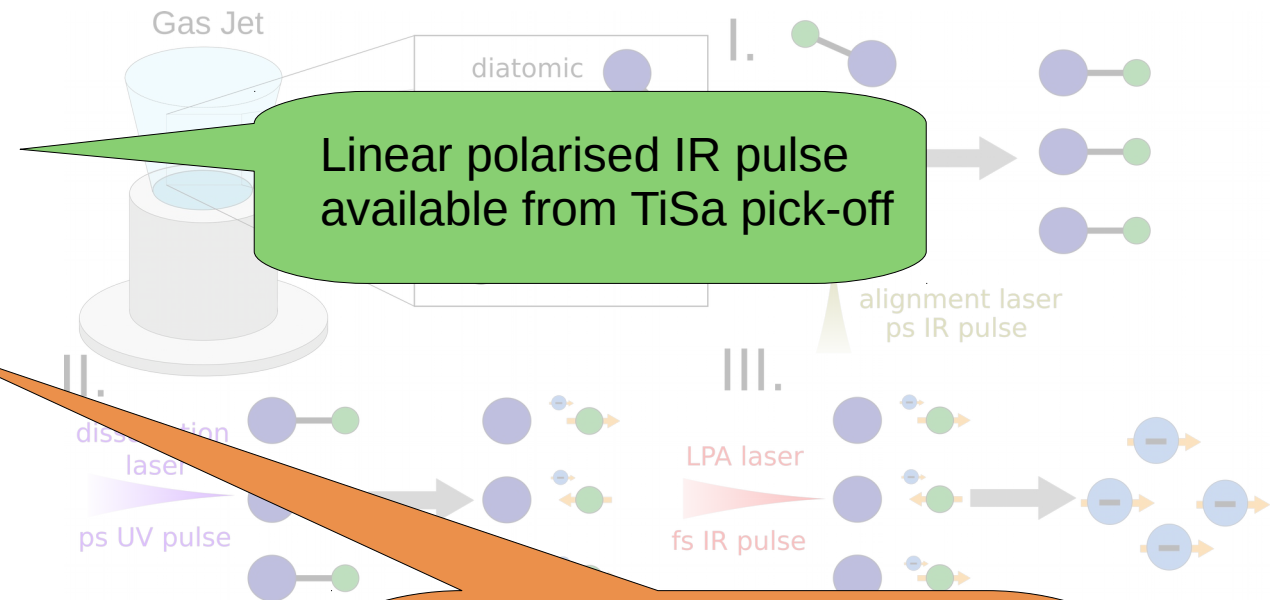
- The dissociation preserves the total angular momentum projection quantum number
 - Valence electrons will be polarised
- The spin-polarisation will be transferred between the electrons and the nuclei on a timescale of 350 ps for H atoms

Concept of the pre-polarized plasma source

A three step recipe

- I. Align bonds of diatomic molecules with a linear polarised IR pulse
- II. Photodissociate the molecules with a circular polarised UV pulse**
- III. Ionisation and acceleration through LPA driver pulse

Planned to use **colliding pulse injection:**
Paper in preparation
(reference)



Key challenge for the preparation of the pre-polarised momentum plasma source
→ **this Talk**

- The dissociation projection of the molecules
- Valence electrons will be polarised
- The spin-polarisation will be transferred between the electrons and the nuclei on a timescale of 350 ps for H atoms

Key Challenge: The dissociation

Choice of Gas

- Has been shown for hydrogen halides @ ~ **210nm** [5]
- Hydrogen halides contain many easily ionisable unpolarised electrons

Gas	Pol. e-	Unpol. e- for $a_0 < 2$	Absorption crosssection @ 210 nm
HF	2	7	
HCL	2	15	6e-21 cm ²
HBr	2	23	7e-19 cm ²
HI	2	25	8e-19 cm ²

- Unpolarised electrons delute the overall polarisation
- HCl best choice for now (P~10%)
- Future option H₂ (P~100%)

[5] Sofikitis, D. et al., Phys. Rev. Lett. 121, 083001 (2018)

Key Challenge: The dissociation

The dissociation laser

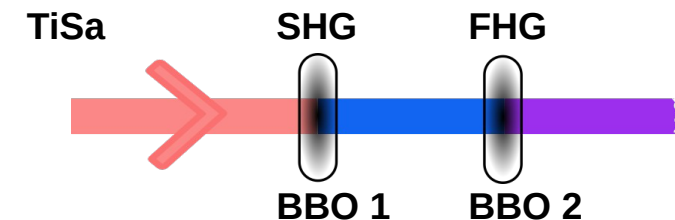
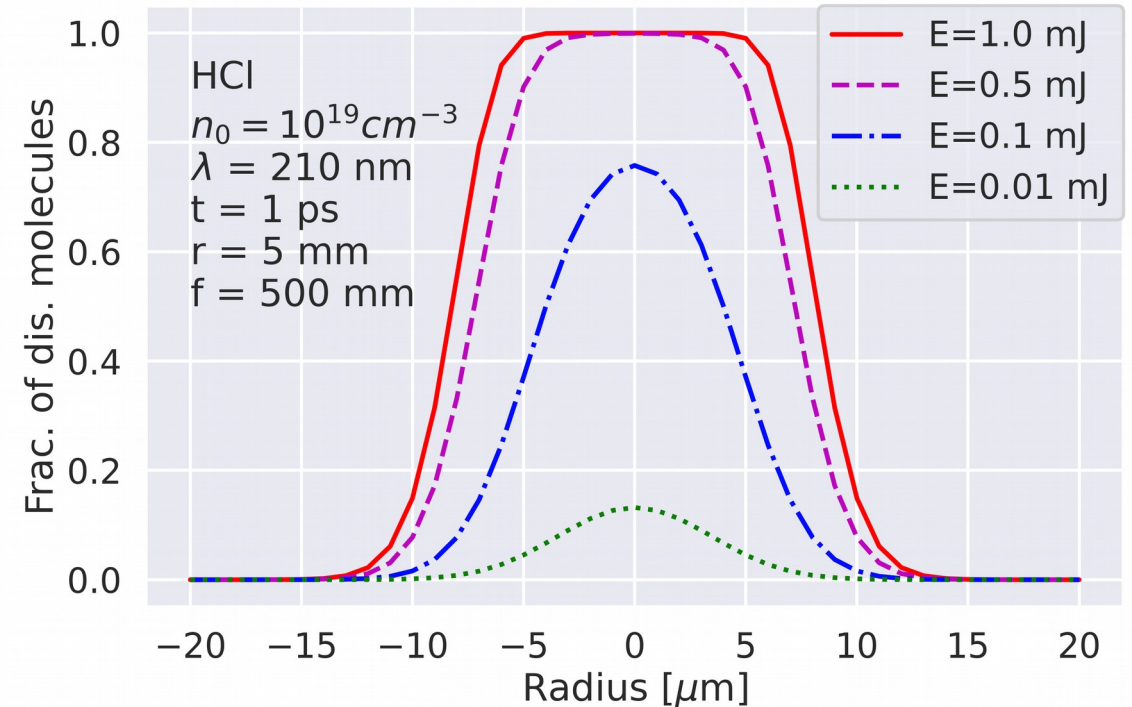
Requirements

- Wavelength ~ **210 nm**
- **Synchronisation** with the LPA driver pulse
- ~ **1 ps** pulse duration
- ~ **0.5 mJ** energy to fully dissociate a gas volume the size of the plasma bubble (~ 10 μm)

At **LEAP** the UV pulse will be generated from **TiSa** by cascading **SHG** using two **BBO** crystals

- Need to stretch the generated UV pulse
- Maximising the FHG conversion efficiency (~ 1 %)

Absorption model



FHG simulations

Estimating the achievable conversion for a small scale setup

- Simulating the SHG and FHG in the wavelength range we are aiming for
- Here up to 60 % for SHG and **3 % for FHG** are shown

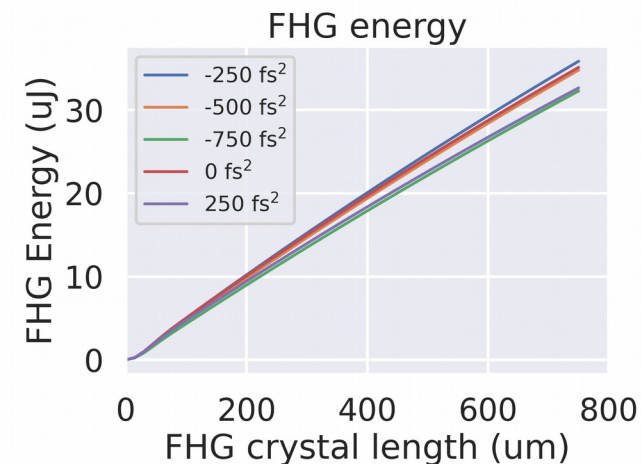
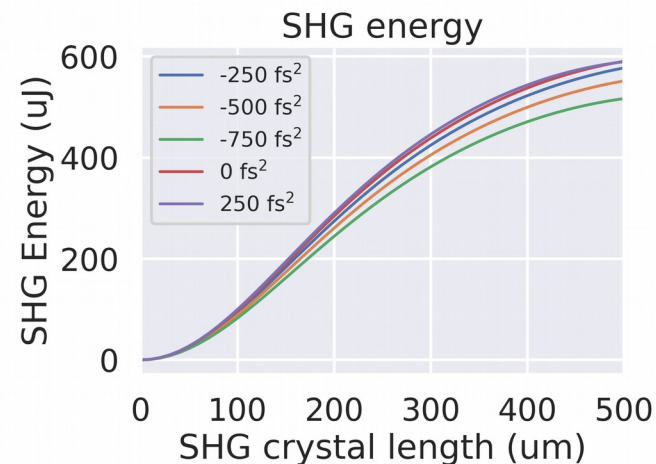
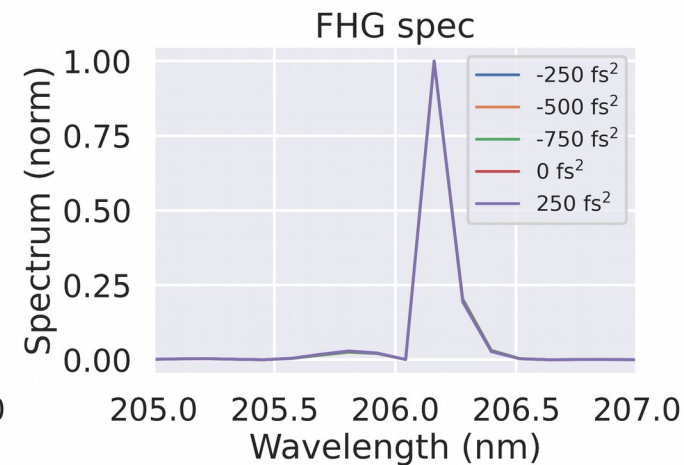
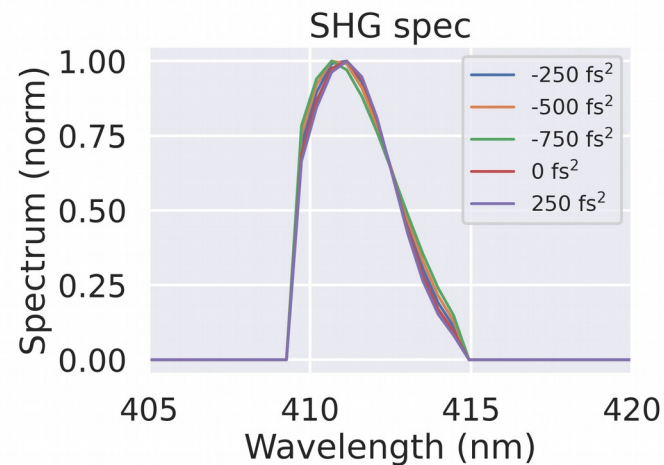
➤ Measure efficiencies in the laboratory

Simulation parameter

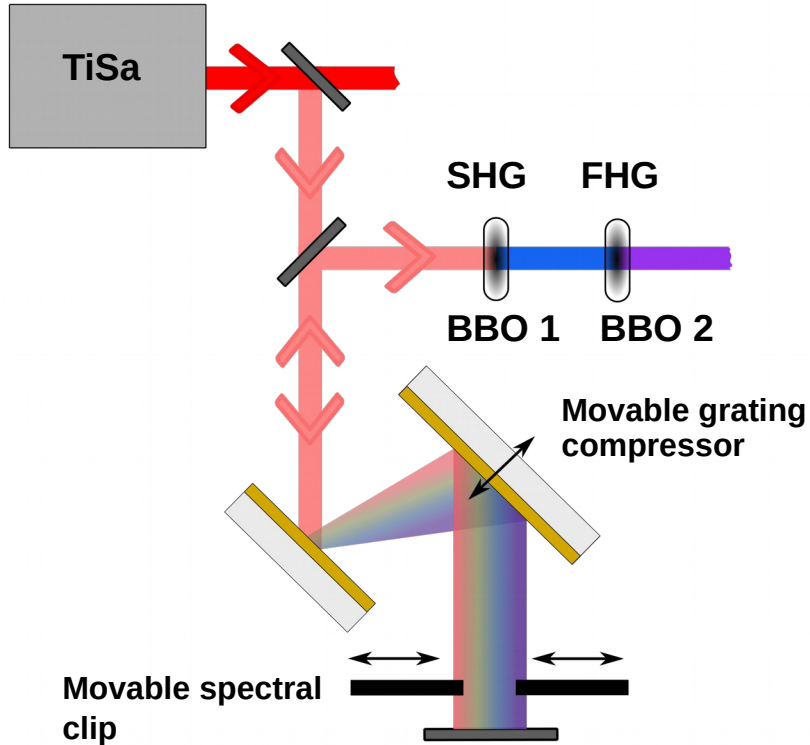
$E = 1 \text{ mJ}$, $r = 2.5 \text{ mm}$

$\theta_{\text{SHG}} = 28.36^\circ$, $L_{\text{SHG}} = 0.5 \text{ mm}$

$\theta_{\text{FHG}} = 82.56^\circ$, $L_{\text{FHG}} = 0.75 \text{ mm}$



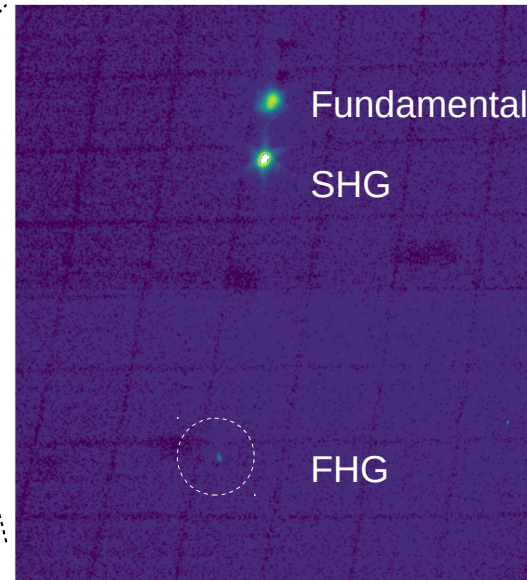
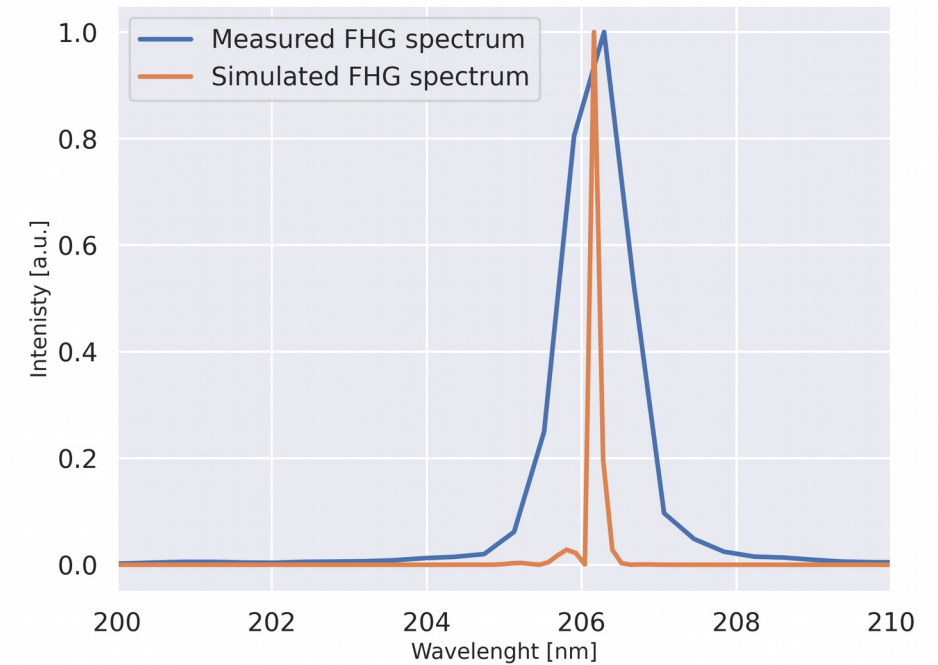
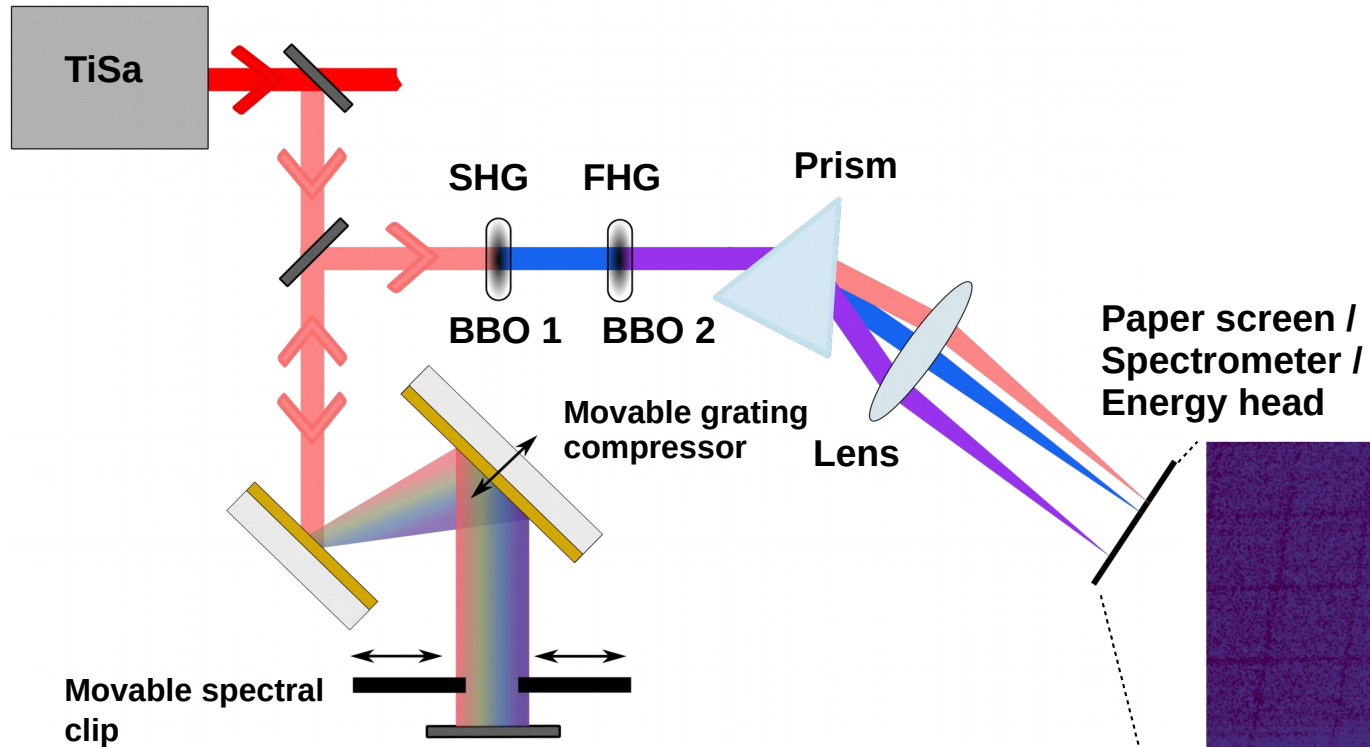
Test setup in the laser lab



Tasks:

First detection of the FHG signal

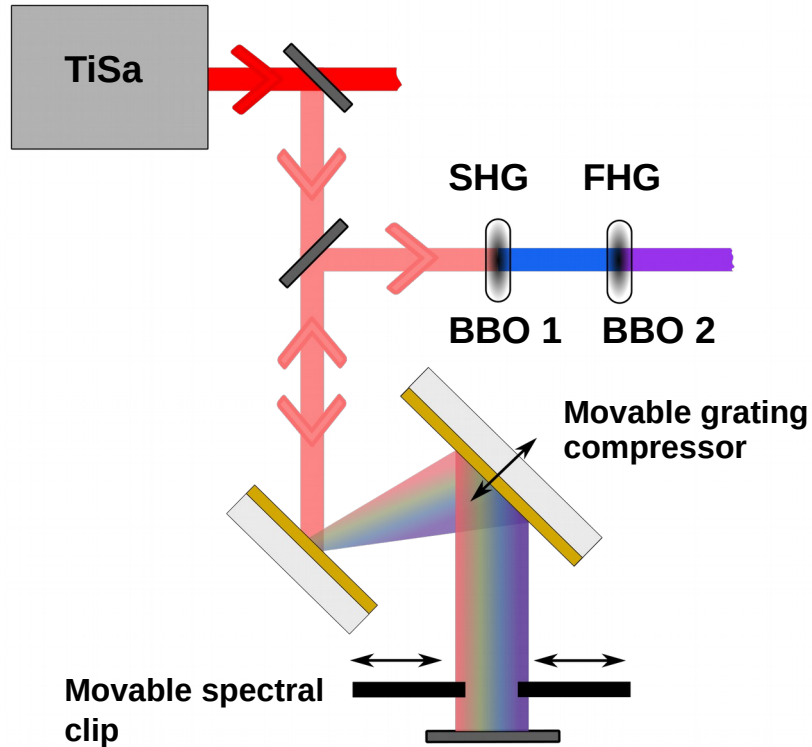
Separation with fused silica prism



- FHG visible through fluorescence on a paper screen
- $E_{\text{Fundamental}} \sim 400 \mu\text{J}$
- $E_{\text{FHG}} \sim 300 \text{ nJ}$
- Conversion $\sim 0.1\%$

Next steps

Toward the pre-polarised plasma source

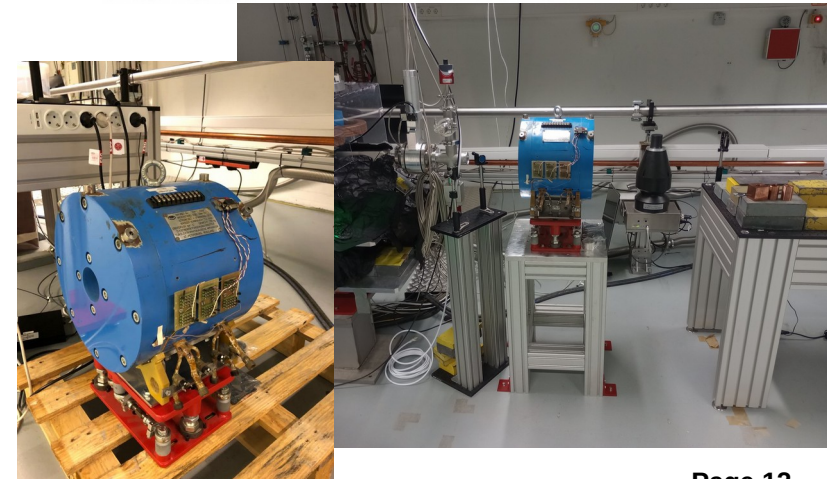
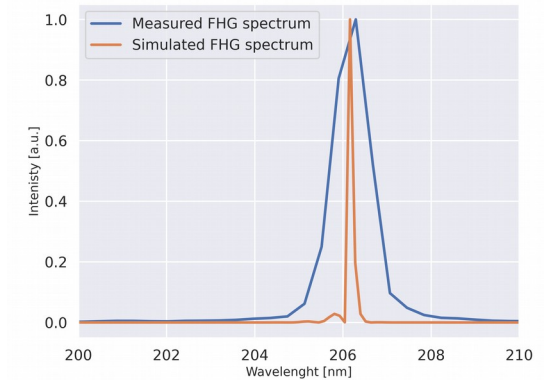
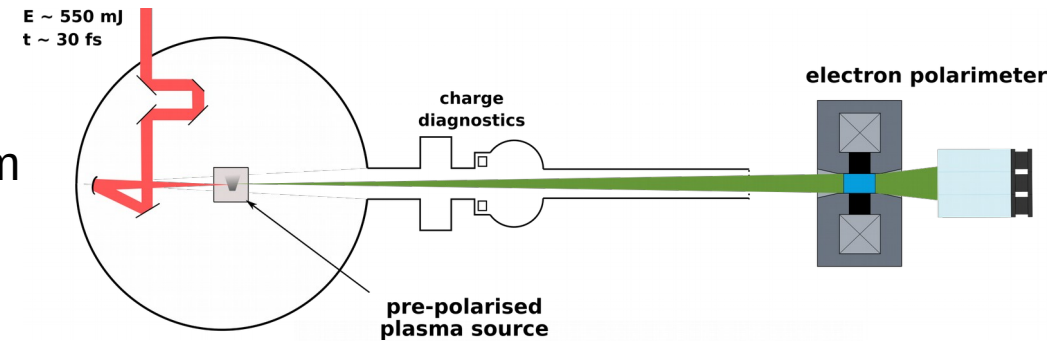


- ☒ Detecting the FHG signal
 - ☐ Optimising the conversion efficiency for FHG
 - ☐ Demonstrating the dissociation of HCl with TiSa-driven UV source
- Stretching the generated UV pulse to ps length to avoid ionisation
- Measuring the dissociation [5]

[5] Sofikitis, D. et al., Phys. Rev. Lett. 121, 083001 (2018)

Summary and status of the LEAP project

- LEAP: demonstrate the production of a polarised electron beam from LPA
- Using existing high-stability plasma accelerator for unpolarised beams
- Polarised beams through a prepolarised plasma source
 - Key challenge: The dissociation of HCl molecules
 - Ongoing work to generate the needed 210 nm UV pulse by cascading SHG using two BBO crystals
 - Colliding pulse injection promising injection technique
- Compton transmission polarimeter for the polarization measurement
 - Under construction
 - Commissioning of the polarimeter is planned end of April (zero polarisation measurement)



Thank you

Contact

Deutsches Elektronen-
Synchrotron DESY

www.desy.de

Felix Stehr

FTX

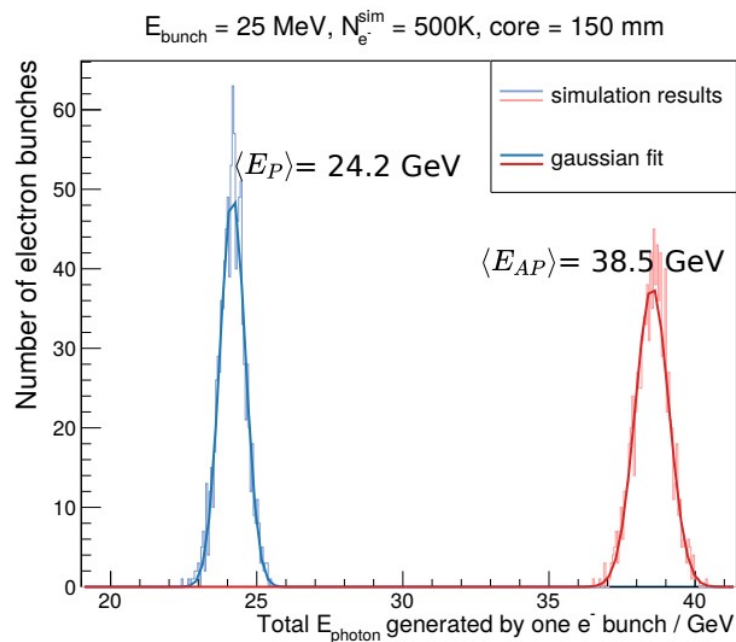
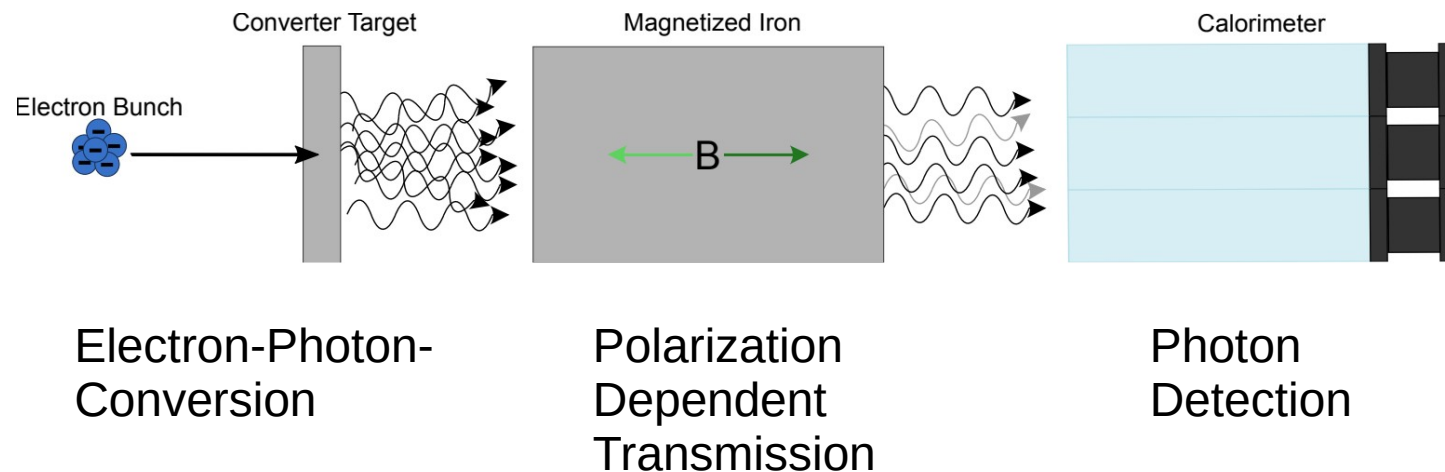
Felix.paul.georg.stehr@desy.de

+49 40 8998 5343

Polarimeter for LEAP

Compton transmission polarimetry

- The magnitude of the asymmetry with respect to the magnetization direction is proportional to the photon polarization.
- The value we have to measure in the experiment is the photon energy sum



$$\delta = \frac{\bar{E}_{AP} - \bar{E}_P}{\bar{E}_{AP} + \bar{E}_P}$$

$$P = \frac{\delta}{\text{analyzing power}}$$

Laboratory

Lab Overview

Laser lab:

- Amplitude laser system
- 25 TW Ti:Sa Laser
- 25 fs, 10 Hz

Experimental lab:

- LPA setup to test diagnostics and concepts

