First plasma acceleration experiments at PITZ

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For the LAOLA collaboration (http://laola.desy.de/)

Matthias Gross

2nd EAAC, Elba

15. September 2015

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PITZ Photo Injector Test Facility Zeuthen

DESY

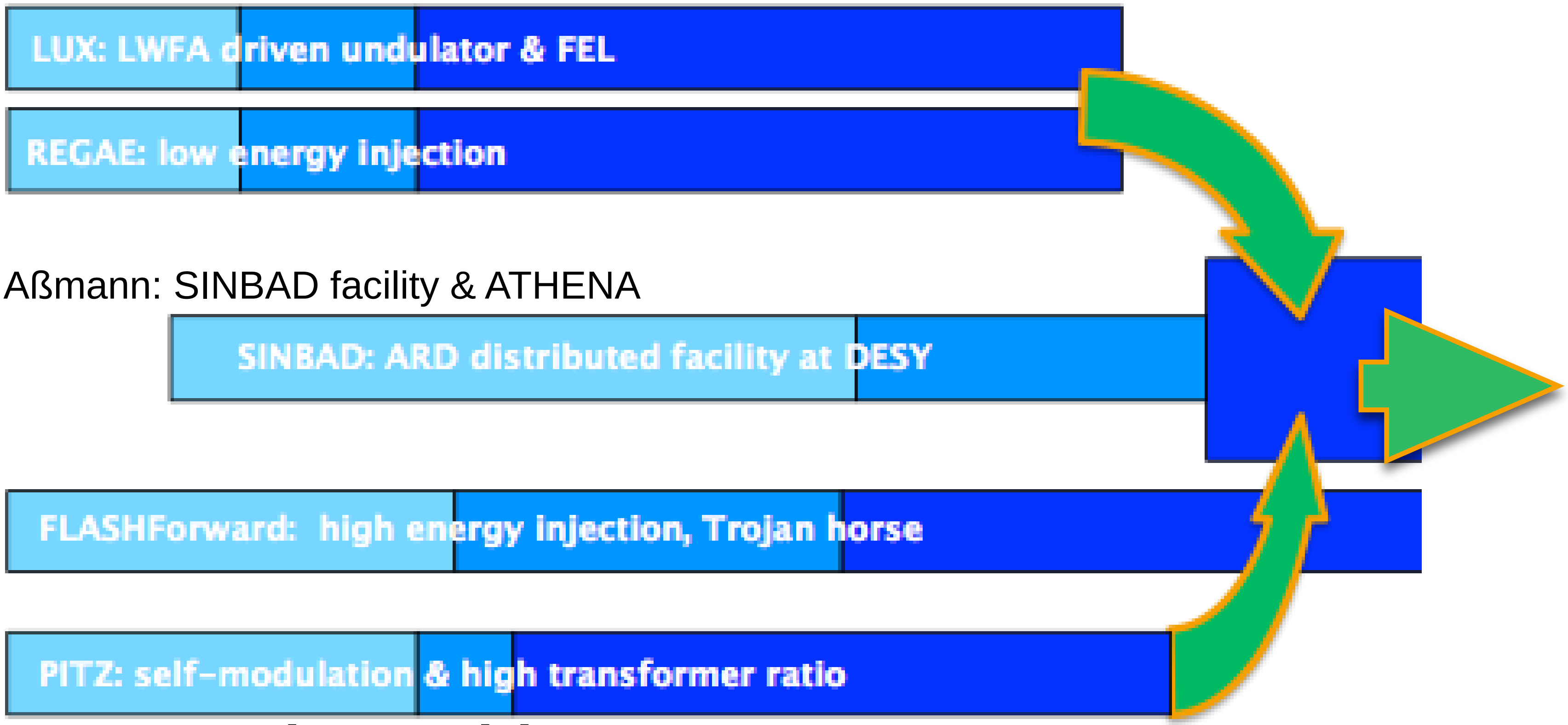
Joint LAOLA Strategy

laser-driven

A. R. Maier: ANGUS laser & LUX beamline

K. Flöttmann: REGAE beamline

Ralph Aßmann: SINBAD facility & ATHENA



beam-driven

J. Osterhoff: FLASHForward

F. Stephan: PITZ

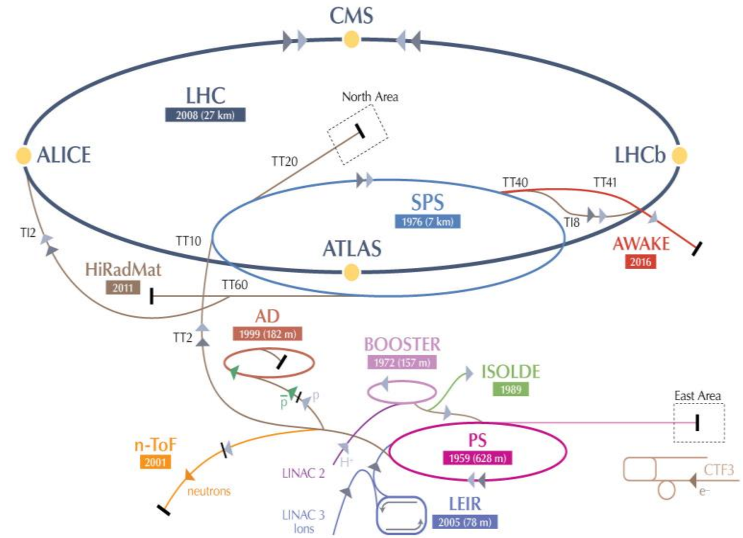
time

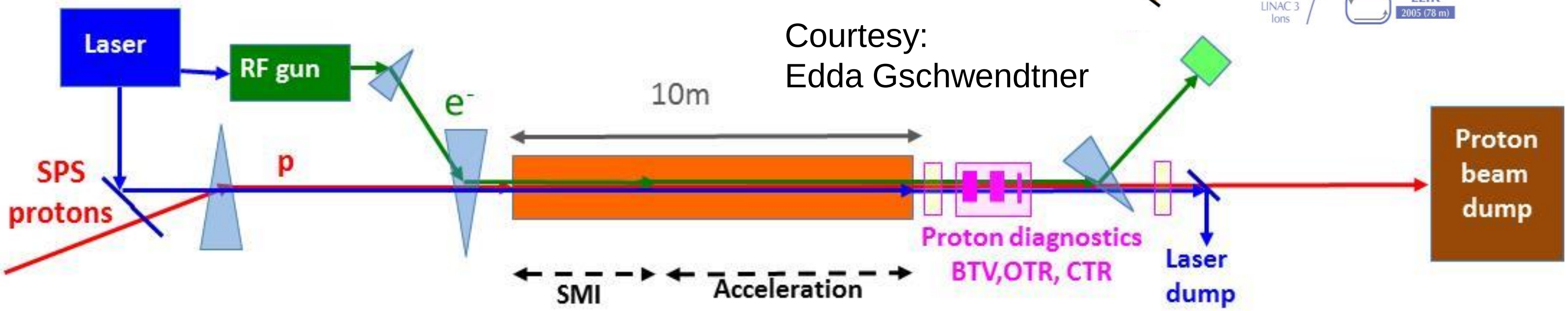
Outline

- Motivation
- Plasma cell
- Several experiments for preparation
  - 1) Beam dynamics (focusing into plasma cell)
  - 2) Electron beam – plasma cell interaction
  - 3) Electron beam scattering
- First run with plasma cell

EAAC Workshop 2015: Edda Gschwendtner – The AWAKE Facility at CERN

- Use high energy proton beams from SPS to drive plasma wave
- Convert proton beam energy to accelerate electron beam in single stage





Courtesy:
Edda Gschwendtner

- High accelerating gradient requires **short** bunches (σ_z less than 100µm)
- Existing proton machines produce **long** bunches (10cm)

Caldwell et al., Nature Physics (2009):

$$E_{z,max} = 240(MV\,m^{-1})\left(\frac{N}{4x10^{10}}\right)\left(\frac{0.6}{\sigma_z(mm)}\right)^2$$

Self-modulation!

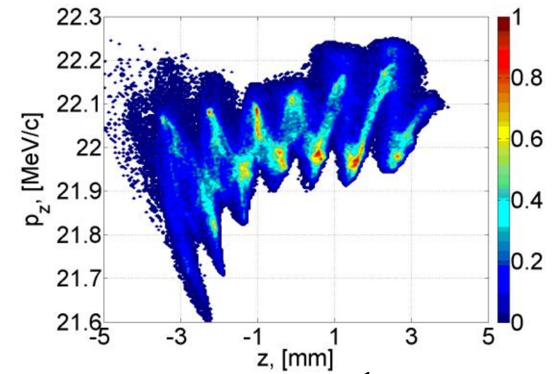
Simulated Self-modulation Experiment

Not fully optimized

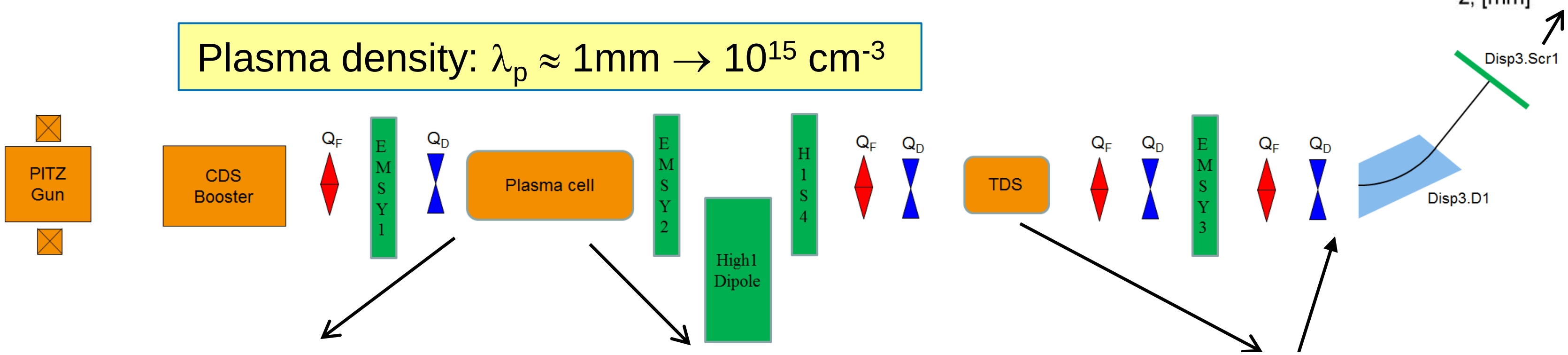
Longitudinal Phase-space studies

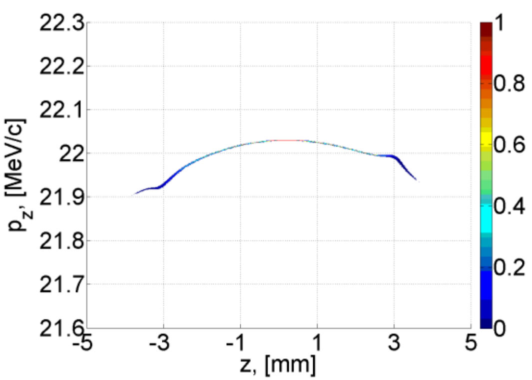
Simulations:
Martin Khojoyan /
Dmitriy Malyutin

Expected phase space ←

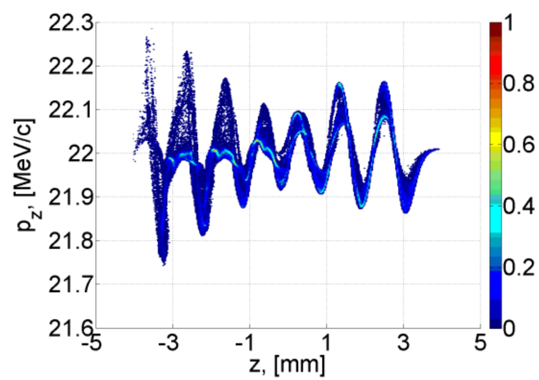


Plasma density: $\lambda_p \approx 1\text{mm} \rightarrow 10^{15}\ \text{cm}^{-3}$

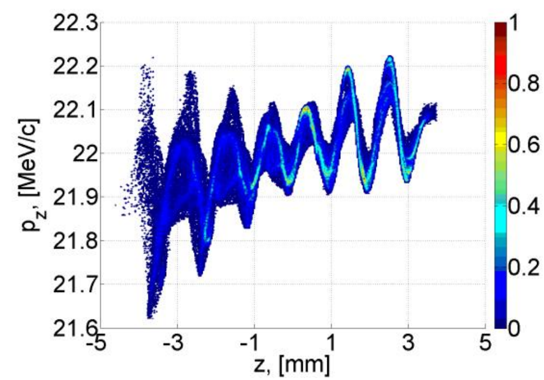




In front of plasma cell



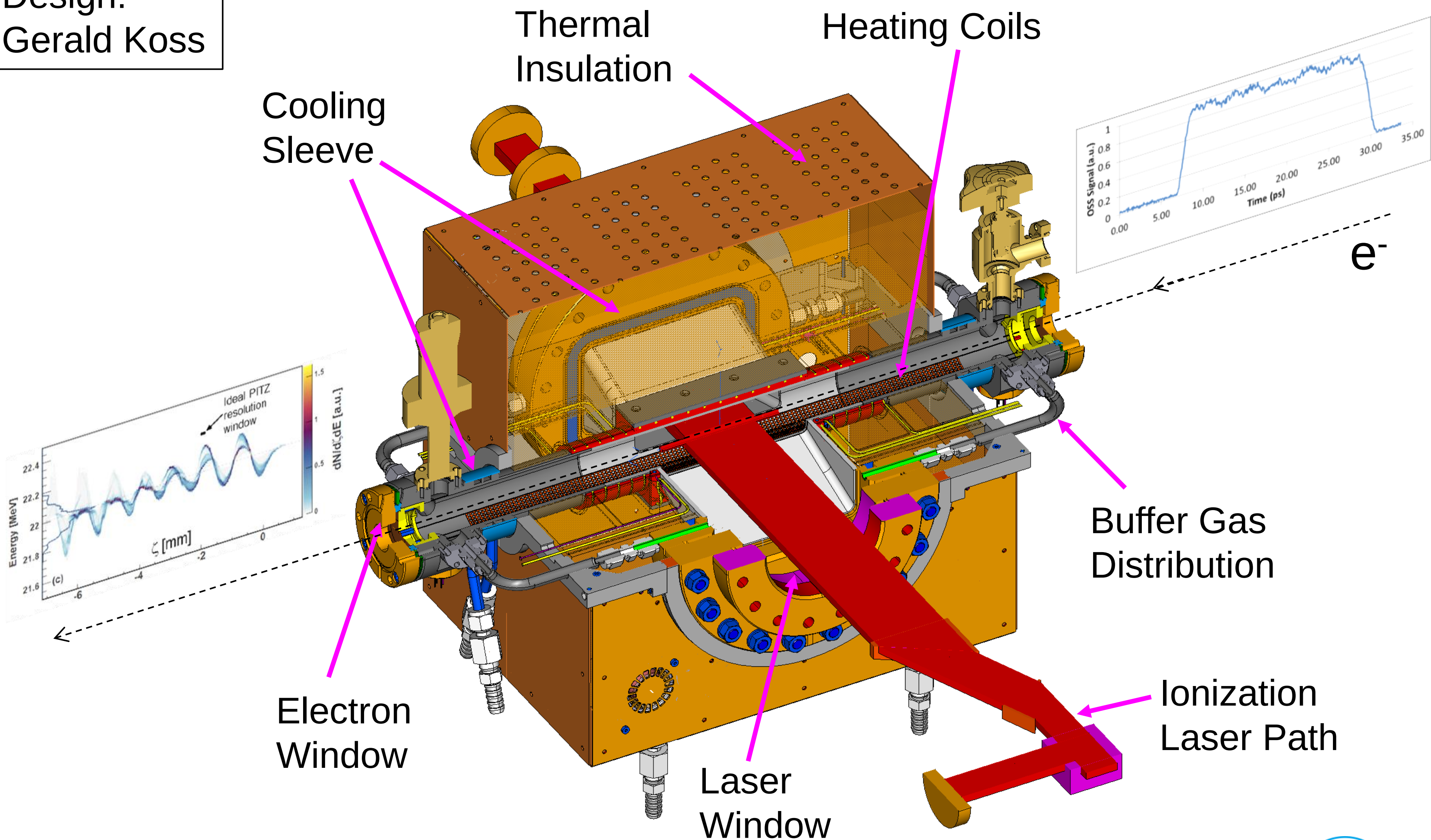
After plasma cell
(assuming zero initial energy spread)



In front of dipole

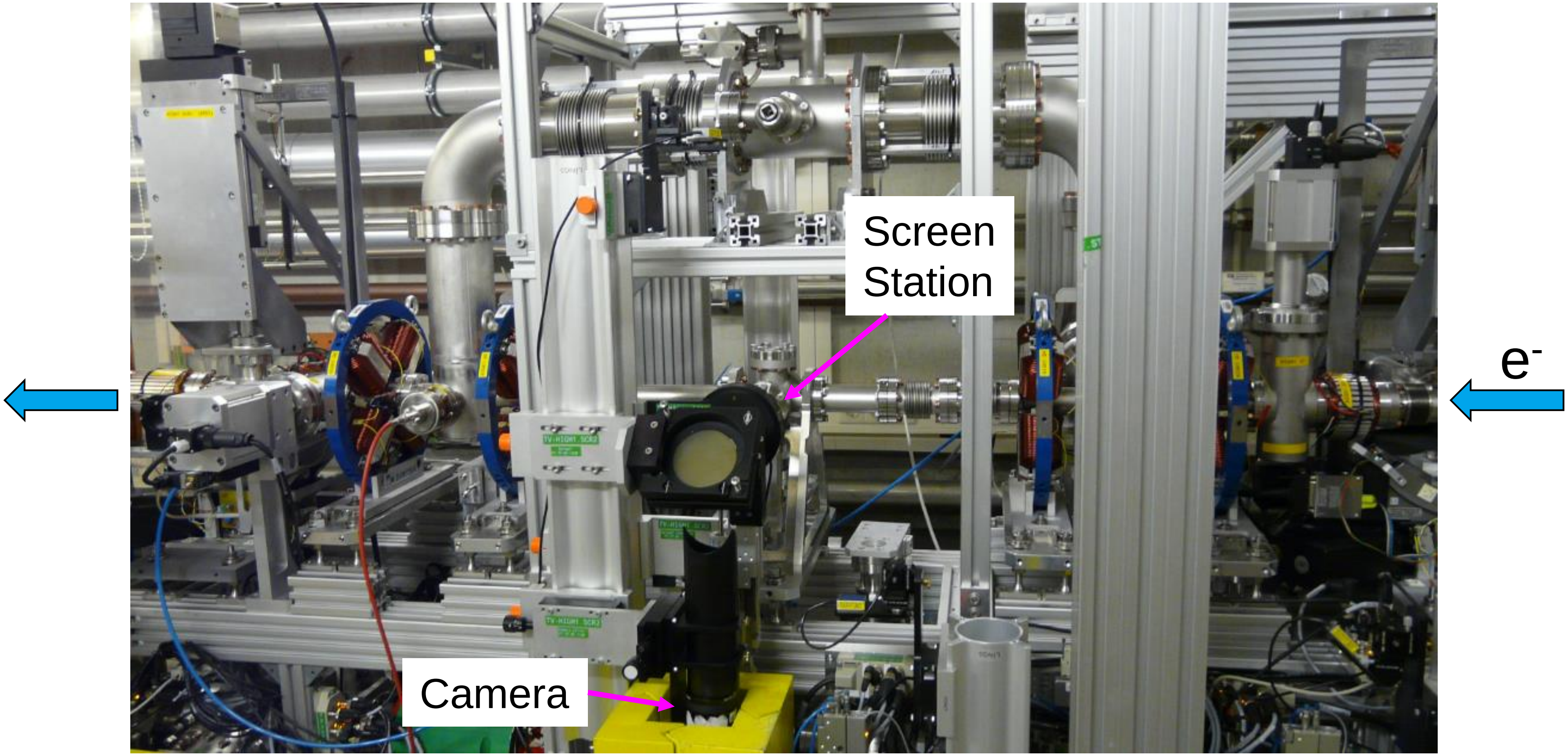
Plasma Cell Design: Novel Cross Shape

Design:
Gerald Koss



Pre-experiment #1: Screen station

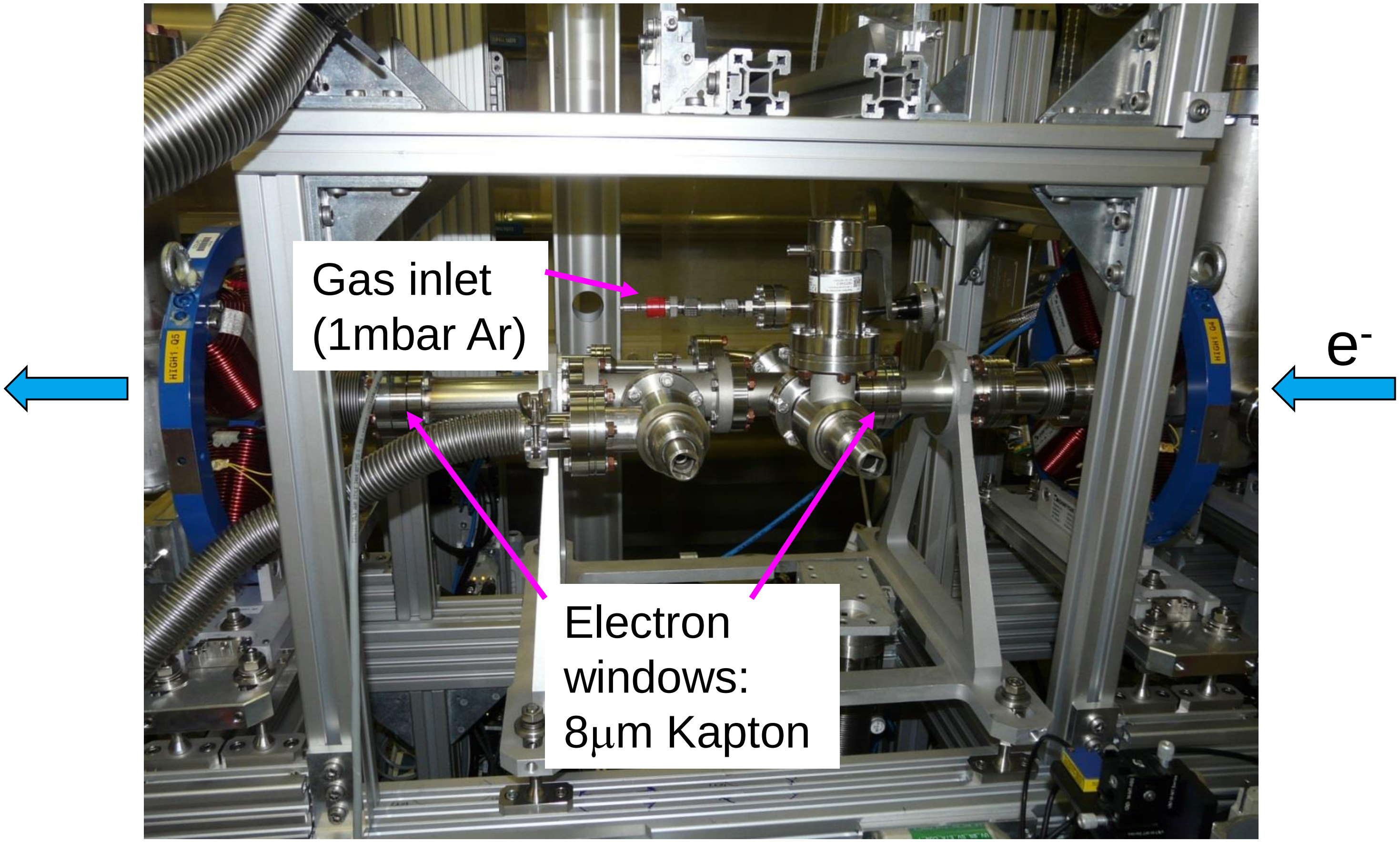
- Purpose: find quadrupole settings for best focusing



- Best result: <100μm spot size (100 pC bunch charge; 22 MeV; no window foil)

Pre-experiment #2: Dummy Plasma Cell

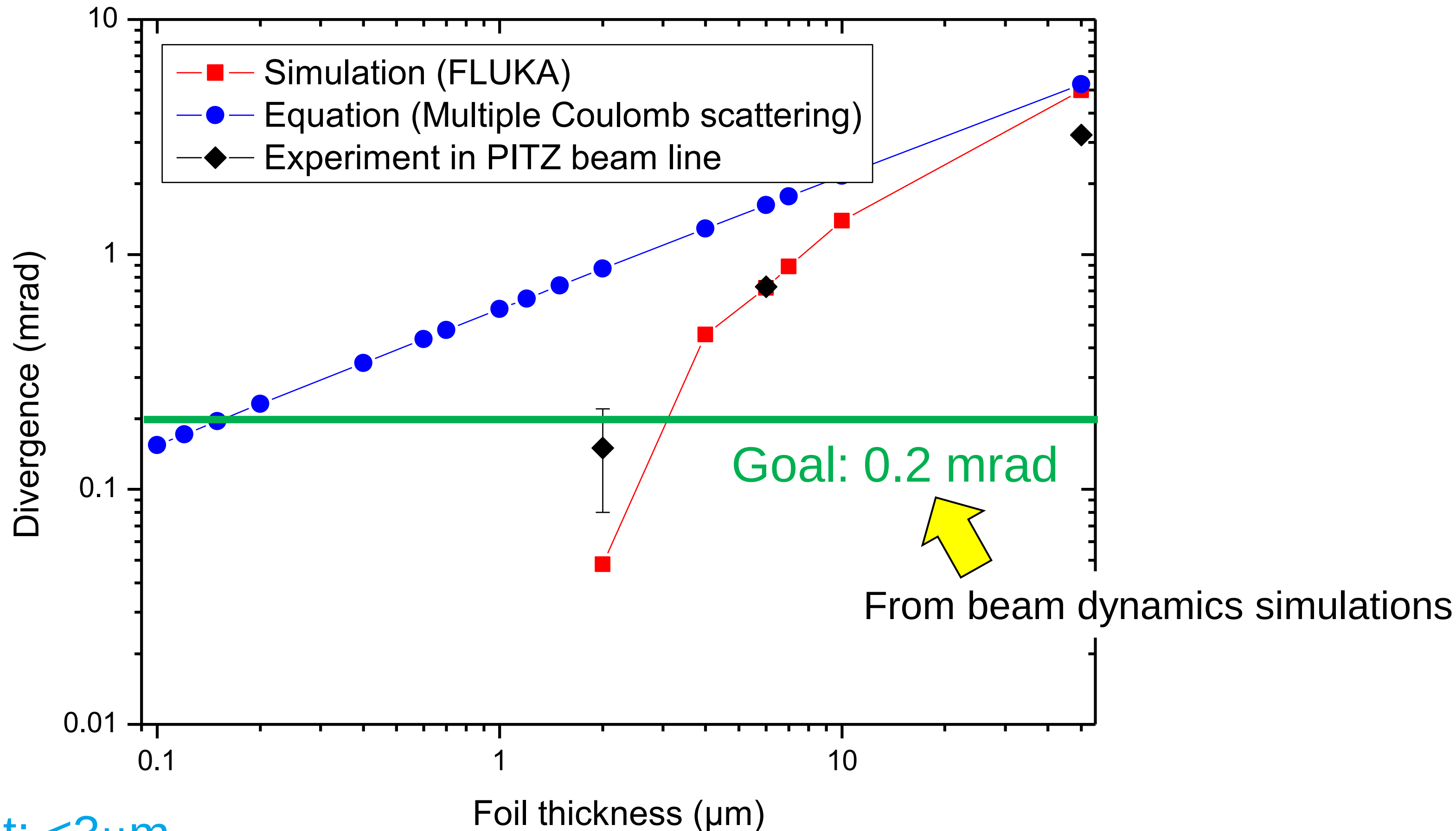
- Purpose: test of interaction electron beam ↔ electron window foils



- 1) No damage after several hours of continuous run (nominal conditions and factor 100 more); negligible gas diffusion

Pre-experiment #3: Electron Beam Scattering

- Purpose: Find maximal allowable polymer window foil thickness

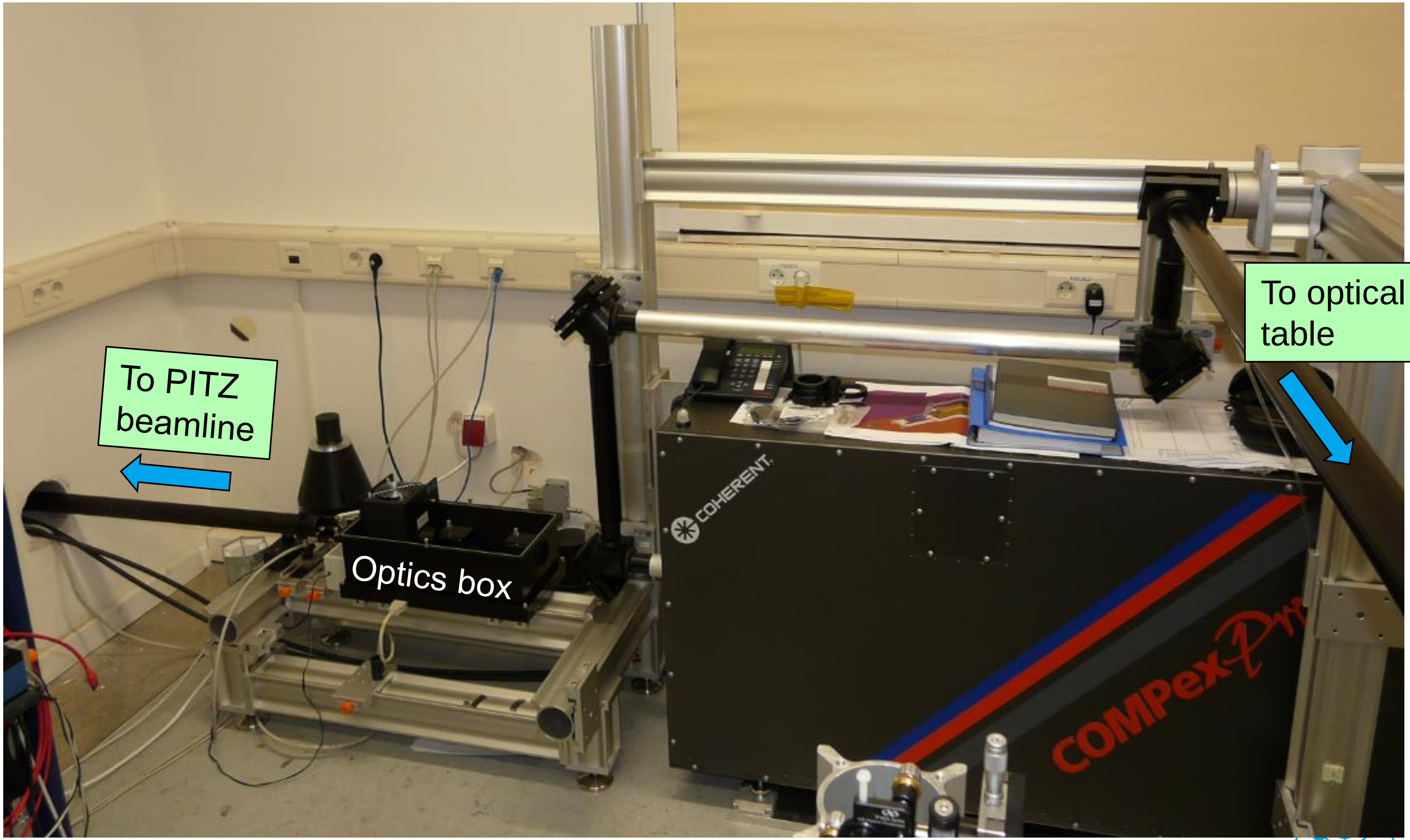


- Result: <3µm
  - Recent candidate: 0.9µm with 2x37.5nm Al coating → gas diffusion was measured (ok)

DESY

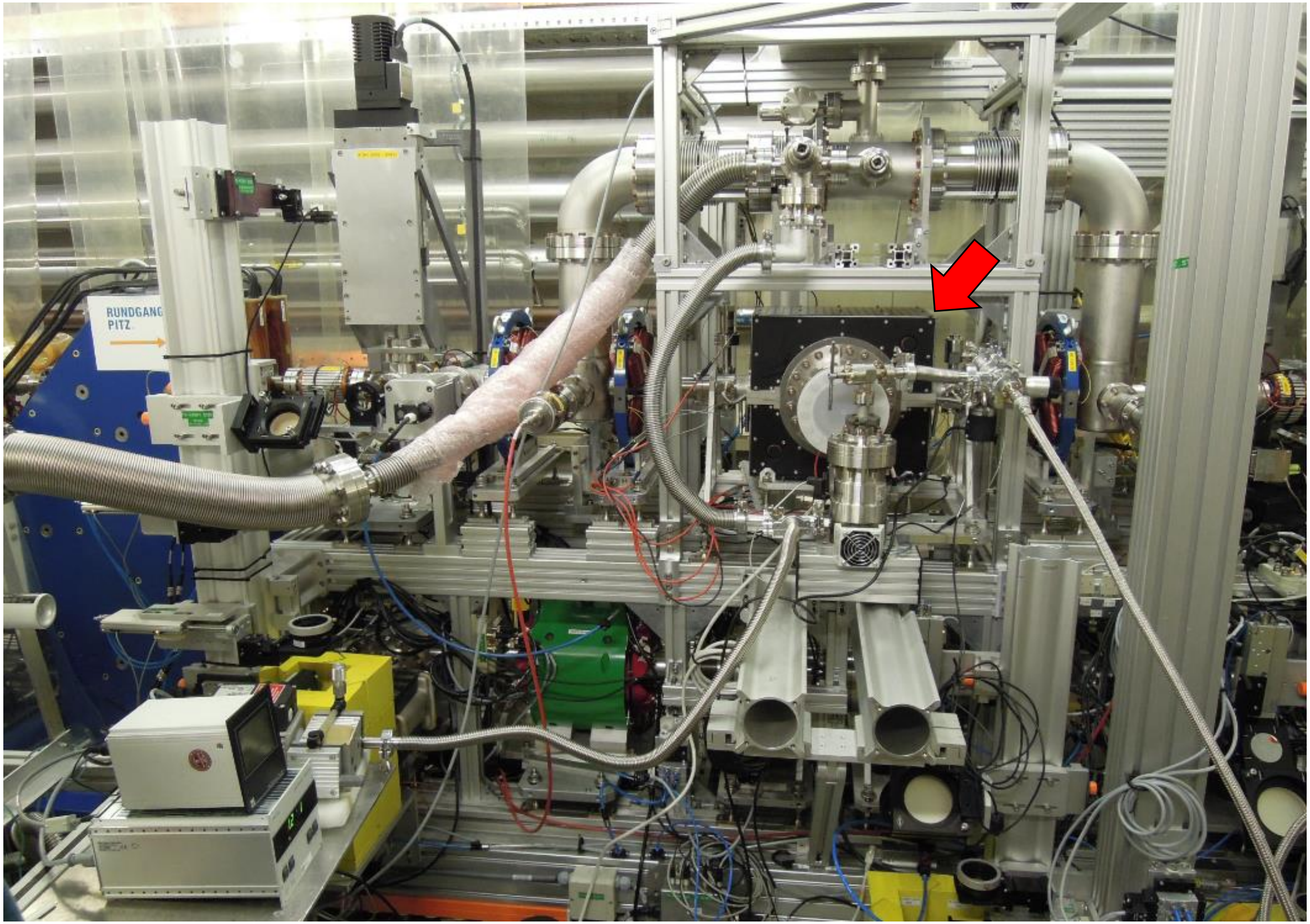
Ionization Laser (ArF Excimer Laser; 193 nm)

- Coherent COMPexPro 201: up to 400 mJ / pulse; 10 Hz

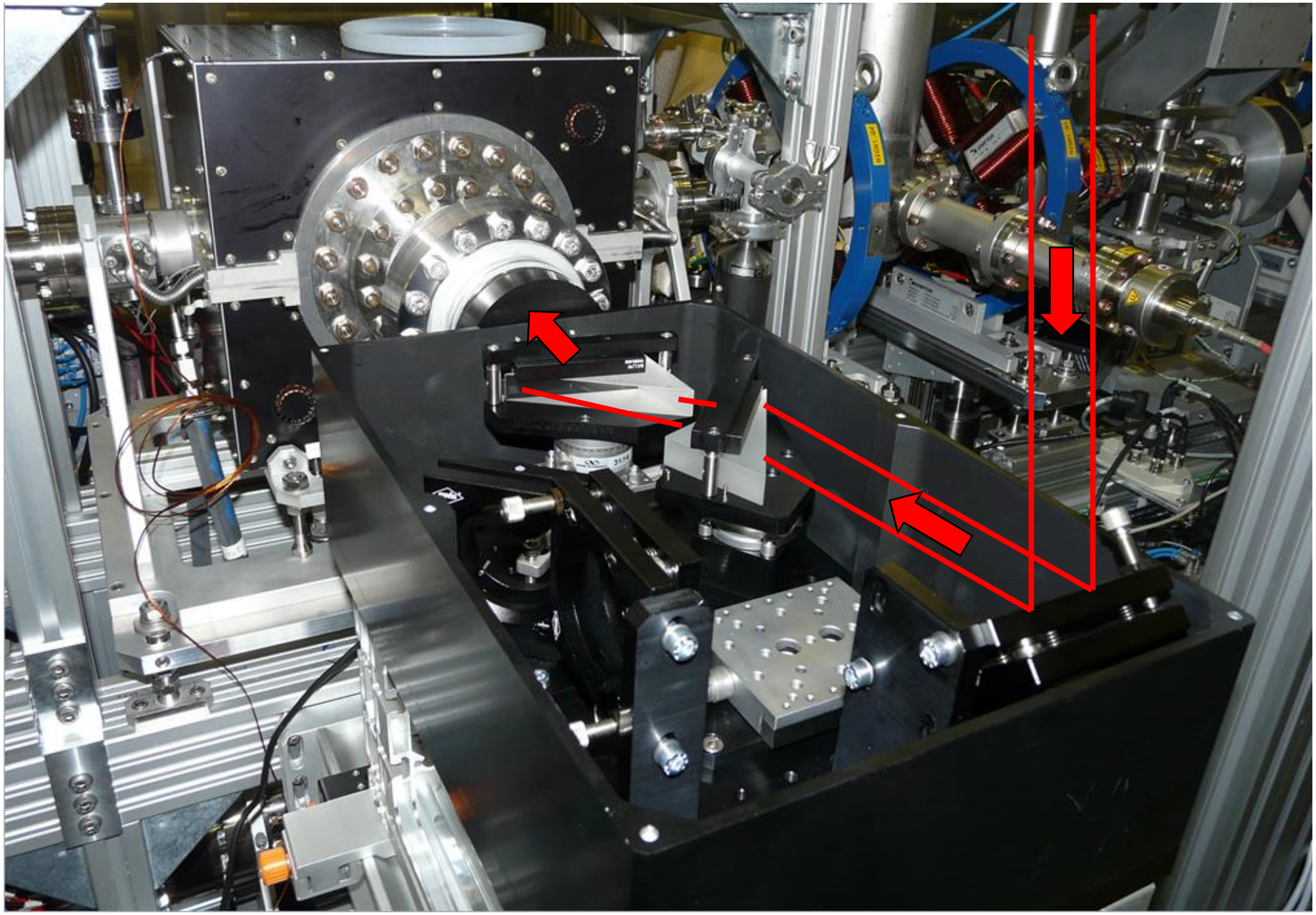


Plasma Cell installed into PITZ Beamline

- Vacuum preparation: Fill with Argon buffer gas



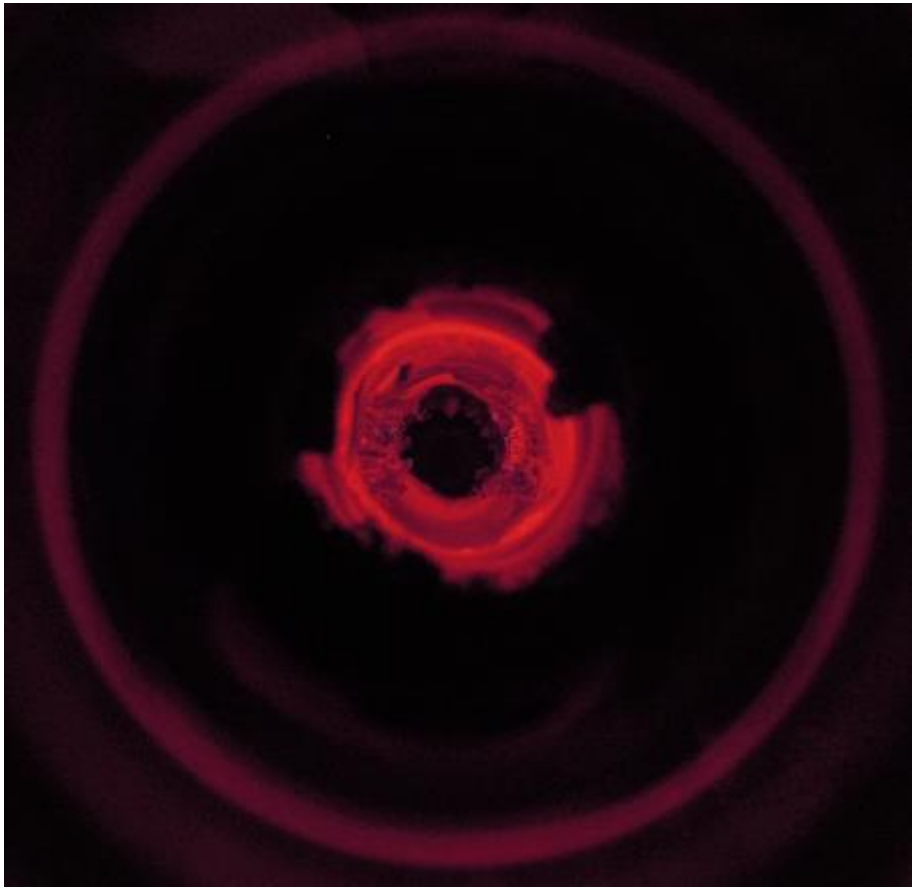
Plasma Cell with Ionization Laser Beam Expander



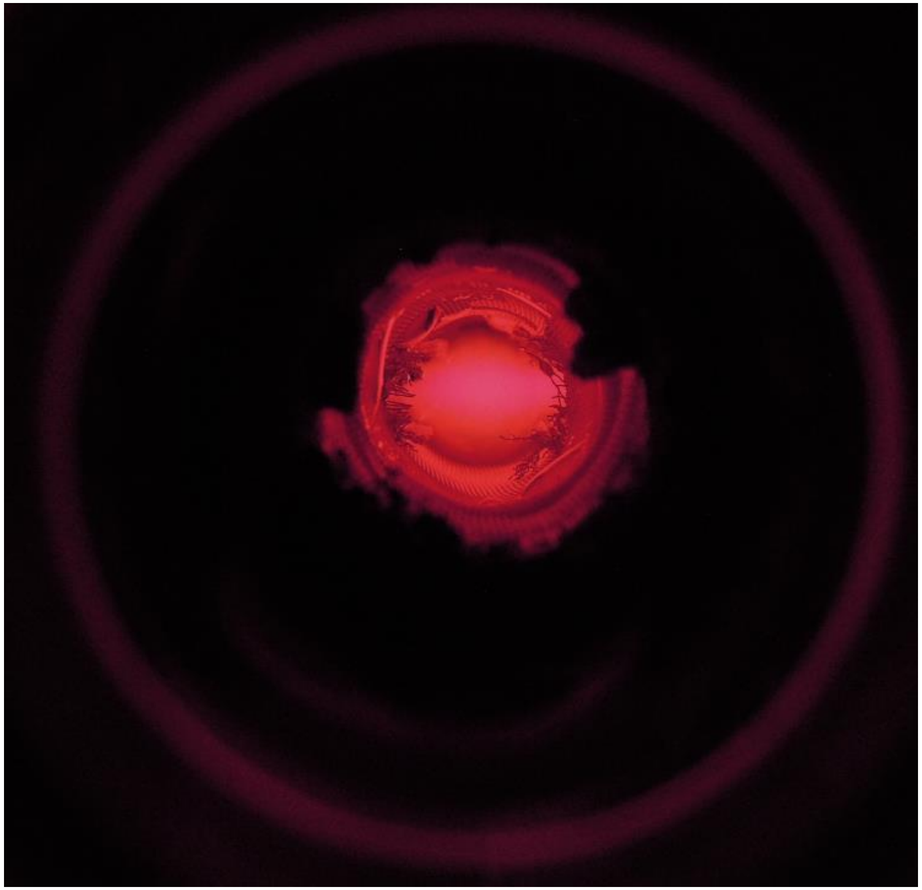
> Advantage: Well defined and adjustable plasma channel length
  - Option: Add filter to implement density ramps or other plasma profiles

Generation of Lithium Plasma (In Laboratory)

> Laser off (heat glowing)

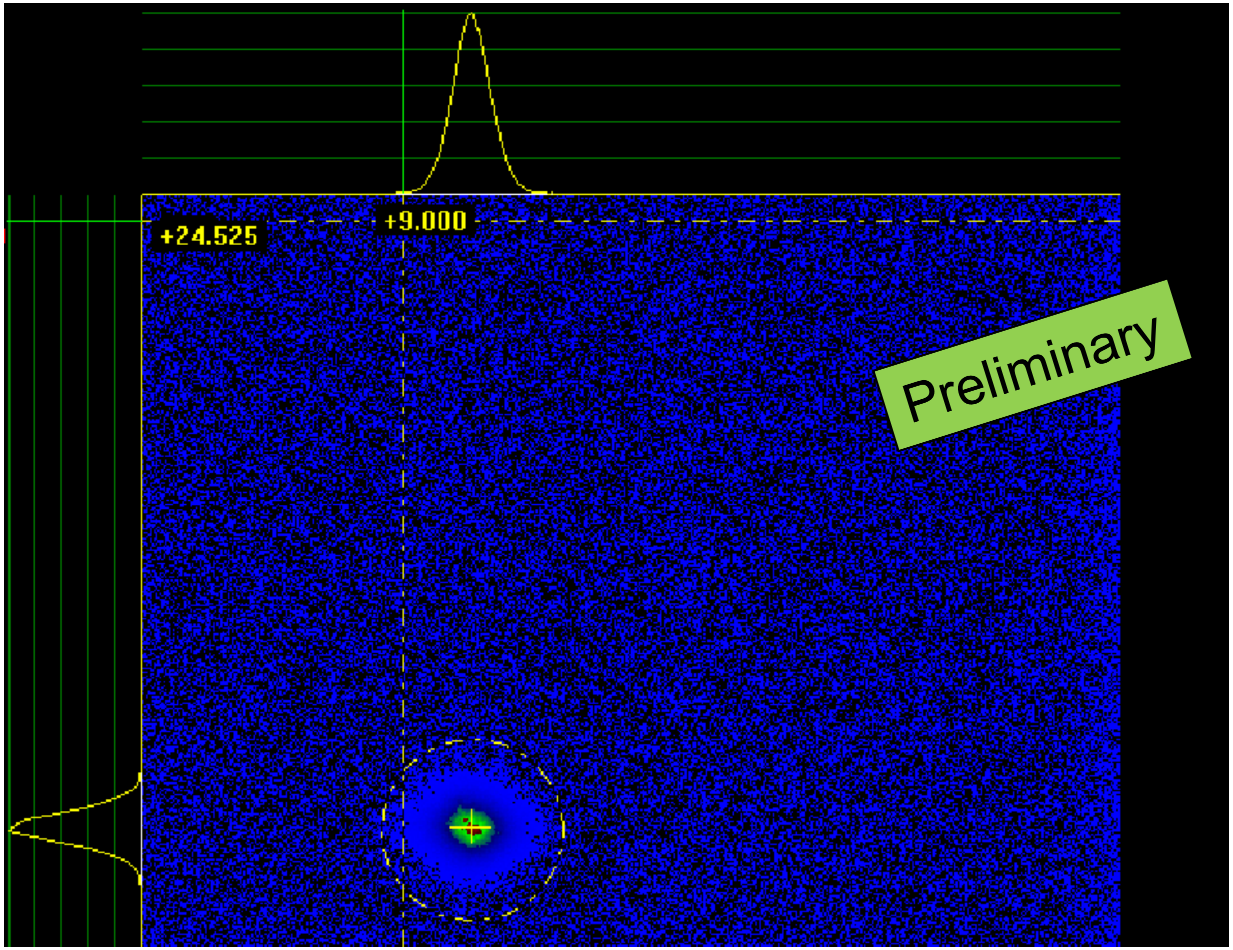


> Laser on (plasma)



First Run with Plasma Cell: Electron Beam Transport

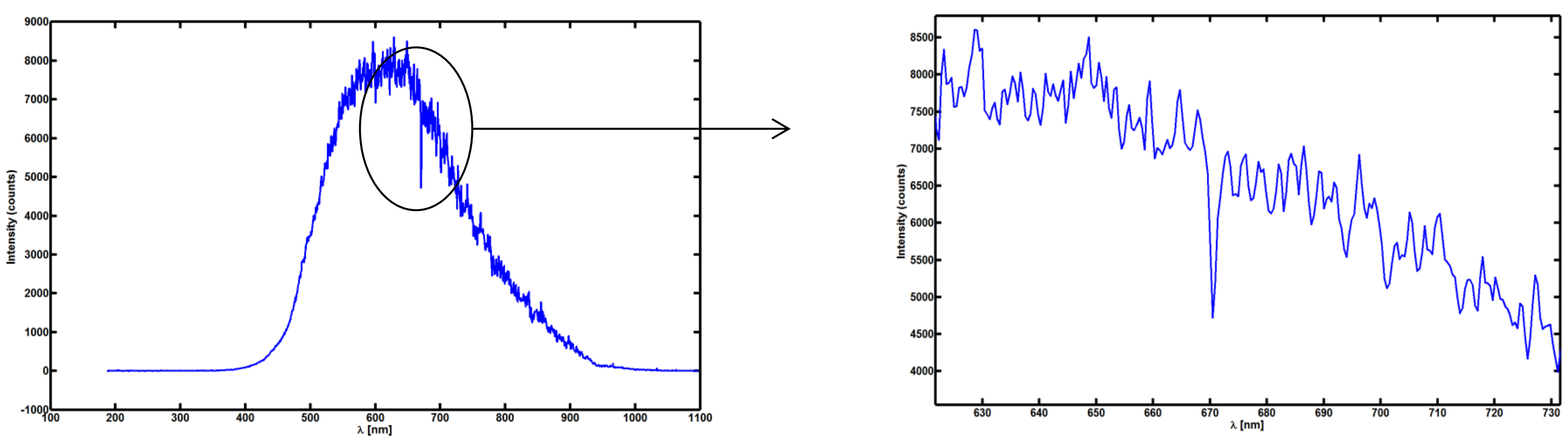
- Interaction electron beam ↔ electron window foils (2x 8 µm Kapton)



- Capturing of focused beam behind plasma cell

First Run with Plasma Cell

- No self-modulation signature seen after 1 week of experimenting (limited by Lithium accumulation in beam pipe → finer mesh?!)
- Possible shortfalls:
  - Lithium gas density too low? → Adjust buffer gas pressure / oven temperature
  - Not enough ionization laser energy? → Decrease attenuation in laser beamline
  - Electron beam rising edge not sharp enough? → Optimize flat top
  - Too much scattering by window foils? → Use thinner foils



Spectrum @ 680 °C → Lithium absorption line

Summary

- PITZ plasma cell (novel concept: heat pipe oven with side ports)
  - Designed and fabricated
- Several preparatory experiments have been performed
  - 1) Beam dynamics: <100μm focusing into plasma cell was achieved (without windows)
  - 2) Electron beam – plasma cell interaction: 8μm Kapton foil was used for first experiments
  - 3) Electron beam scattering: Simulation and Experiment show goal of <3μm window thickness
- Ionization laser is set up
- **First successful operation of a cross-shaped Lithium plasma cell**
- Current status: first experimental run (hunting for self-modulation signature) finished – no signature yet

Outlook

- Next experimental run is planned for early 2016 with lessons learned from the first trial:
  - Plasma cell upgrade
    - Longer side arms with constant cross section
    - Finer mesh for improved Lithium transport
    - Thinner electron window foils
  - Other improvements
    - Decrease absorption in ionization laser beamline
    - Better diagnostics of ionization laser at plasma cell (pulse energy, timing…)
    - Improve other conditions (Laser pulse shape, electron beam transport etc.)
- Scheduled experiments: self-modulation, then high transformer ratio (multi-pulse structure)
- More details: Poster Osip Lishilin (Monday poster session)
- Also: Poster Tino Rublack (Wednesday poster session) $\rightarrow$ generation of ellipsoidal laser pulses
- Further input is welcome!

Permanent position open at PITZ

> If interested, please contact Frank Stephan

PHOTO INJECTOR.

DESY, Zeuthen location, is seeking:
Scientist (f/m) accelerator physics permanent position

DESY
DESY is one of the world's leading research centres for photon science, particle and astroparticle physics as well as accelerator physics.

The Photo Injector Test Facility PITZ in Zeuthen (near Berlin) develops high brightness electron sources for Free Electron Lasers (FELs) like FLASH and the European XFEL. As part of the accelerator R&D program of the Helmholtz Association we additionally work on the ultimate optimization of high brightness electron beams by generating 3D ellipsoidal electron bunches and on beam driven plasma acceleration experiments.

The position
- Work in one of the leading groups developing and testing photo injectors in a team of physicists and engineers of different nationalities
- Take responsibility in defining, performing and analysing the scientific shift operation at PITZ
- Be in charge for simulation studies, diagnostics hardware and analysis procedures
- Develop innovative concepts, techniques and applications for PITZ and other accelerator facilities

Requirements
- Excellent university degree in physics or engineering, with PhD
- Deep knowledge in accelerator physics and experience in accelerator techniques and beam dynamics
- Interest in and capability of guiding small teams of PhD students and postdocs
- Good knowledge of English is required as well as the willingness to learn German

For further information please contact Dr. Frank Stephan, frank.stephan@desy.de or +49-33762-77338.

Salary and benefits are commensurate with those of public service organisations in Germany. Classification is based upon qualifications and assigned duties. DESY operates flexible work schemes. Handicapped persons will be given preference to other equally qualified applicants. DESY is an equal opportunity, affirmative action employer and encourages applications from women.

We are looking forward to your application quoting the reference code preferably via our electronic application System: Online-Application or by email recruitment@desy.de

Deutsches Elektronen-Synchrotron DESY
Human Resources Department | Code: EM122/2015
Notkestraße 85 | 22607 Hamburg | Germany | Phone: +49 40 8998-3392
Deadline for applications: Screening of the applications will start mid of October 2015 and continues until the position is filled.
www.desy.de

The Helmholtz Association is Germany's largest scientific organisation.
www.helmholtz.de

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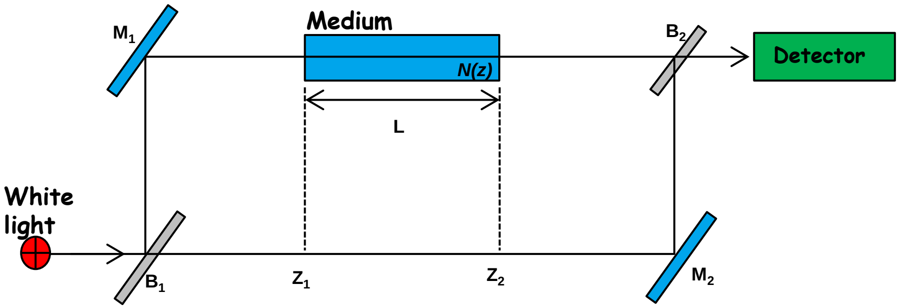
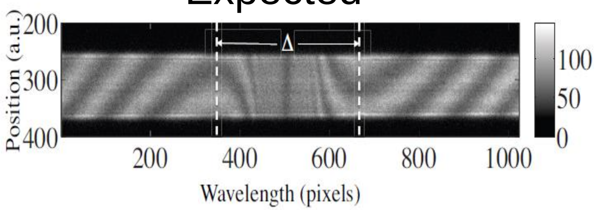
- Backup

Hook method results before the pressure and Li amount was increased in the plasma cell

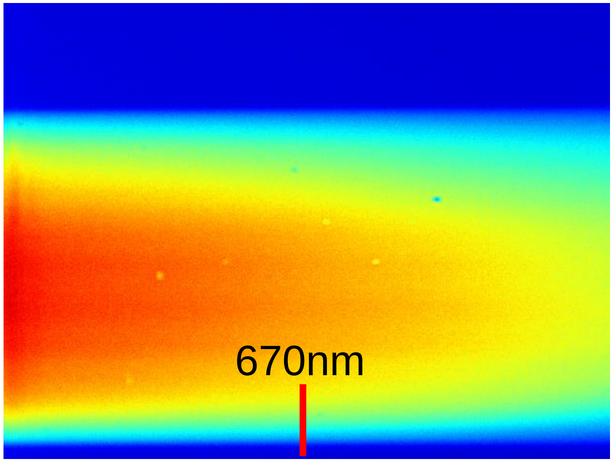


Expected

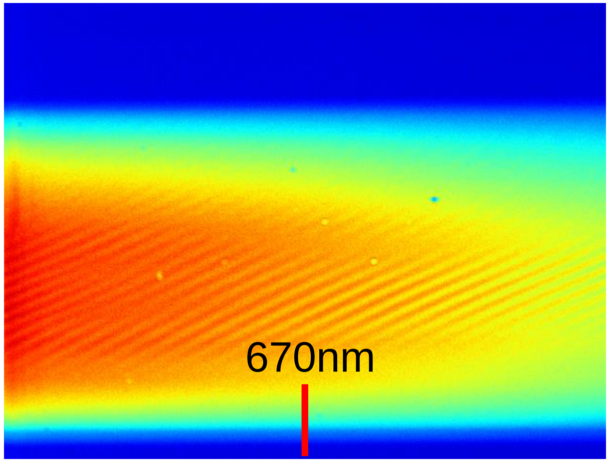


Hook's interferogram for Rubidium (E. Öz, IPAC 2014)

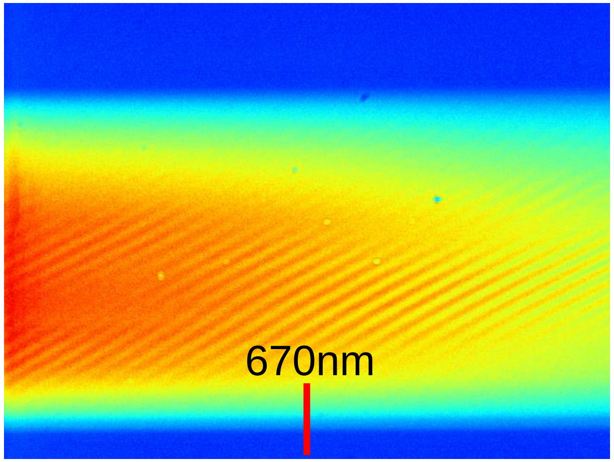
$n_e \propto \Delta^2$



One arm of interferometer is closed



@350 ^{o}C



@650 ^{o}C