# Status of LAOLA@PITZ

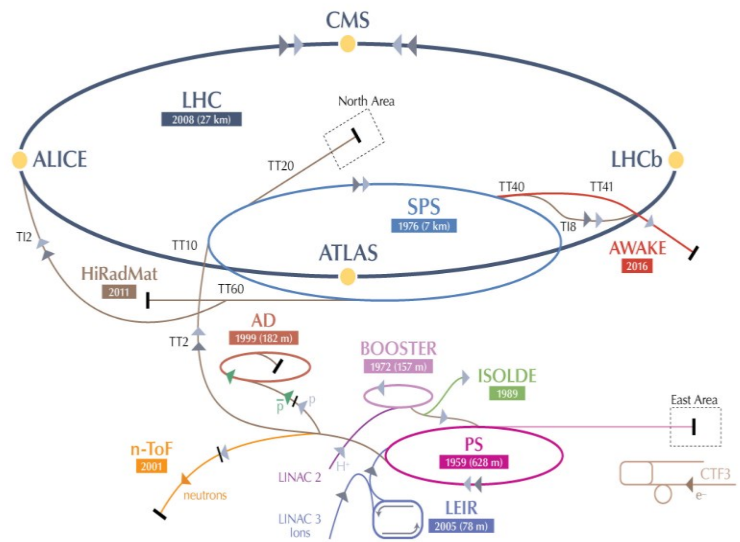
## Matthias Groß for the LAOLA@PITZ team

Matthias Groß
LAOLA workshop
Wismar, 21. June 2016

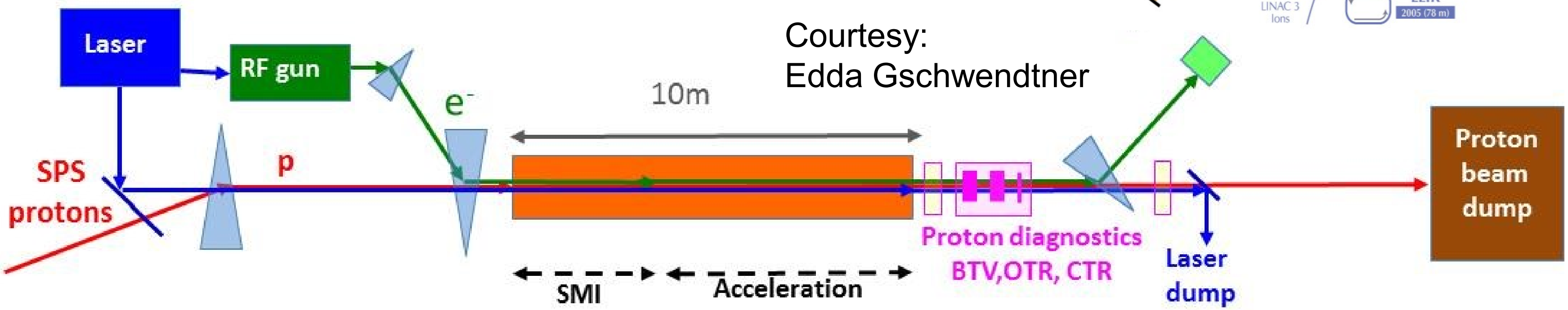
HELMHOLTZ
ASSOCIATION

# 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 ($\sigma_z$ 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!**

# State of the Art – Other Experiments

## > BNL: Energy modulations shown

PRL **112**, 045001 (2014) PHYSICAL REVIEW LETTERS week ending 31 JANUARY 2014

**Seeding of Self-Modulation Instability of a Long Electron Bunch in a Plasma**

Y. Fang,[1,*] V.E. Yakimenko,[2] M. Babzien,[3] M. Fedurin,[3] K.P. Kusche,[3] R. Malone,[3] J. Vieira,[4] W.B. Mori,[5] and P. Muggli[1,6]
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(Received 9 August 2013; published 28 January 2014)

We demonstrate experimentally that a relativistic electron bunch shaped with a sharp rising edge drives plasma wakefields with one to seven periods along the bunch as the plasma density is increased. The plasma density is varied in the $10^{15}$–$10^{17}$ cm$^{-3}$ range. The wakefields generation is observed after the plasma as a periodic modulation of the correlated energy spectrum of the incoming bunch. We choose a low bunch charge of 50 pC for optimum visibility of the modulation at all plasma densities. The longitudinal wakefields creating the modulation are in the MV/m range and are indirect evidence of the generation of transverse wakefields that can seed the self-modulation instability, although the instability does not grow significantly over the short plasma length (2 cm). We show that the seeding provides a phase reference for the wakefields, a necessary condition for the deterministic external injection of a witness bunch in an accelerator. This electron work supports the concept of similar experiments in the future, e.g., SMI experiments using long bunches of relativistic protons.

DOI: 10.1103/PhysRevLett.112.045001 PACS numbers: 52.35.Qz, 07.77.Ka, 29.20.Ej, 29.27.Bd

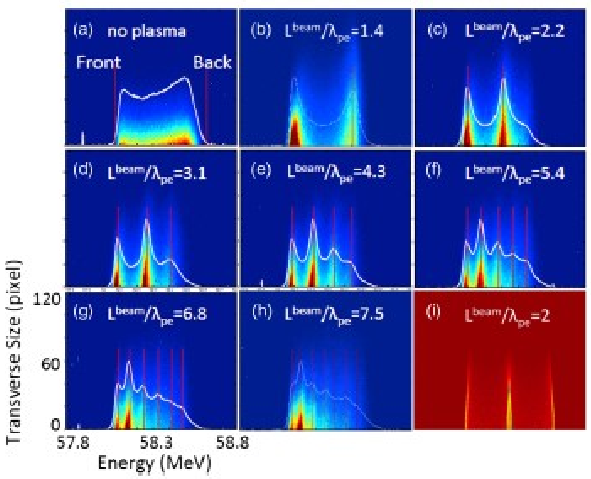


FIG. 2 (color online). Energy spectra obtained at various plasma densities. Spectra (a) with $n_e = 0$ (no plasma) and

## > SLAC: Transverse modulations shown

Contents lists available at ScienceDirect
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**Progress of plasma wakefield self-modulation experiments at FACET**

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ABSTRACT

Simulations and theory predict that long electron and positron beams may under favorable conditions self-modulate in plasmas. We report on the progress of experiments studying the self-modulation instability in plasma wakefield experiments at FACET. The experimental results obtained so far, while not being fully conclusive, appear to be consistent with the presence of the self-modulation instability.

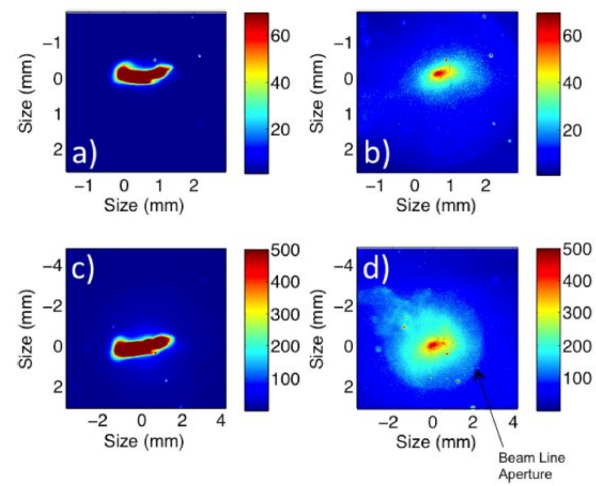




**Fig. 4.** Electron-lithium results: (a), (c) The measured transverse beam profile of the electron beam not passing through plasma. (b), (d) The measured transverse beam profile of the electron beam having passed through plasma. A significant amount of the charge is located at large radii, for many shots up filling the available beam line aperture.

## > Self-modulation exists, but needs characterization → experiments at PITZ

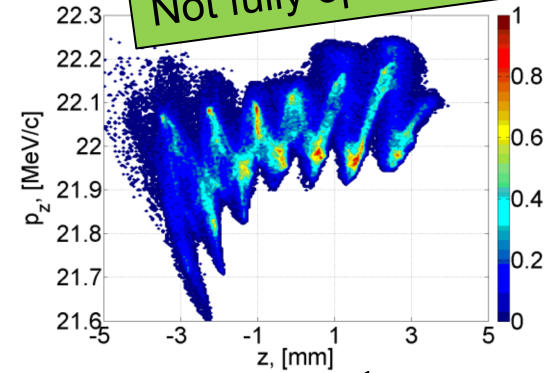
# Simulated Self-modulation Experiment at PITZ

## Longitudinal Phase-space studies

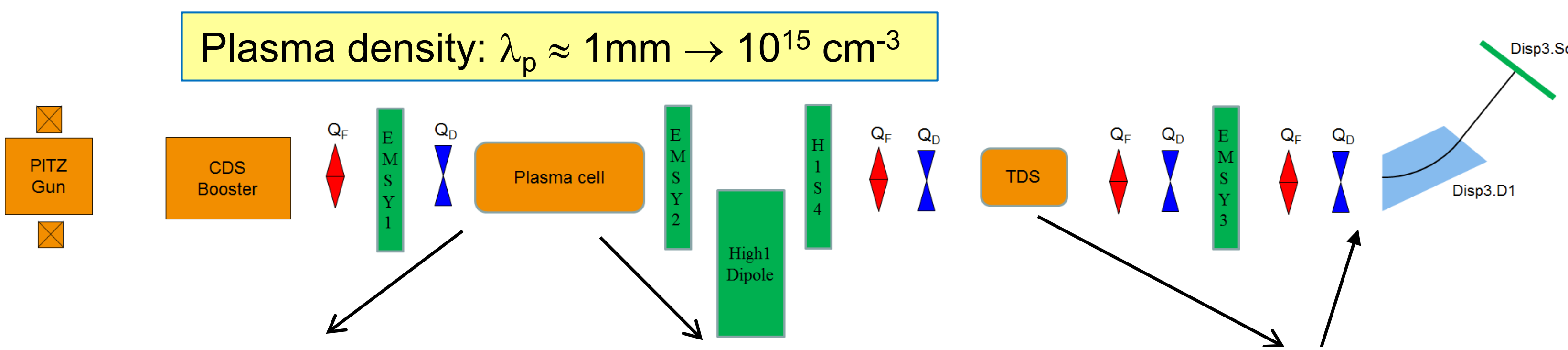
Simulations:
Martin Khojoyan /
Dmitriy Malyutin

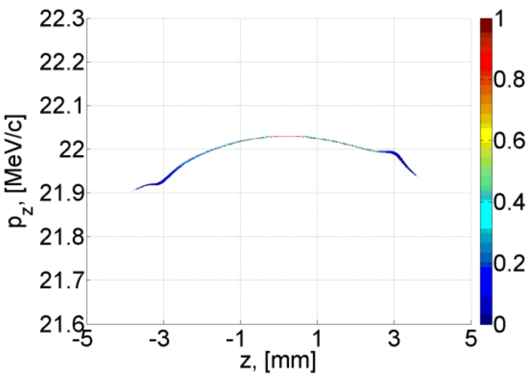
Not fully optimized

Expected phase space ←

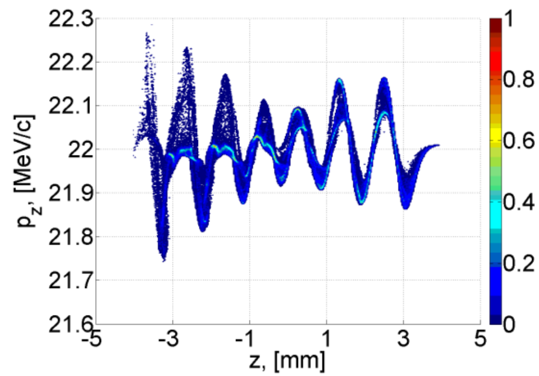



Plasma density: $\lambda_p \approx 1\text{mm} \rightarrow 10^{15}\ \text{cm}^{-3}$

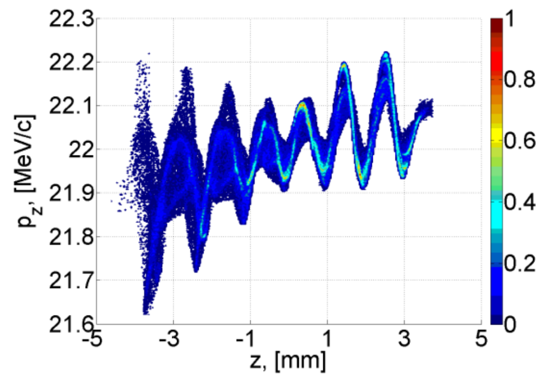



In front of plasma cell



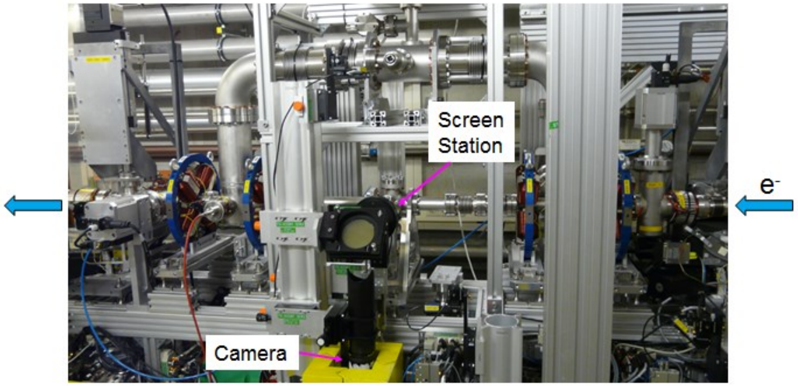

After plasma cell
(assuming zero initial energy spread)



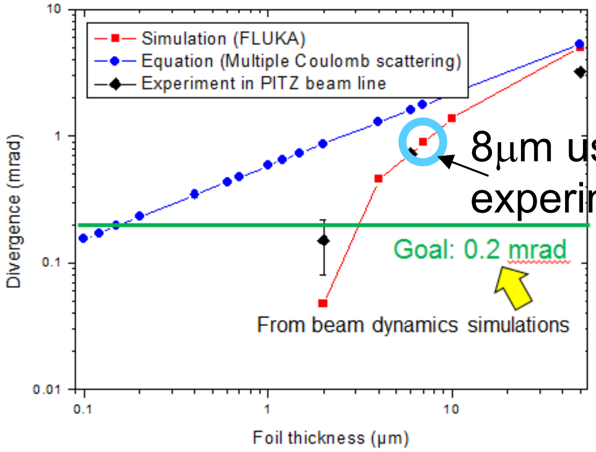

In front of dipole

# Status: Experimental results of 2015 run

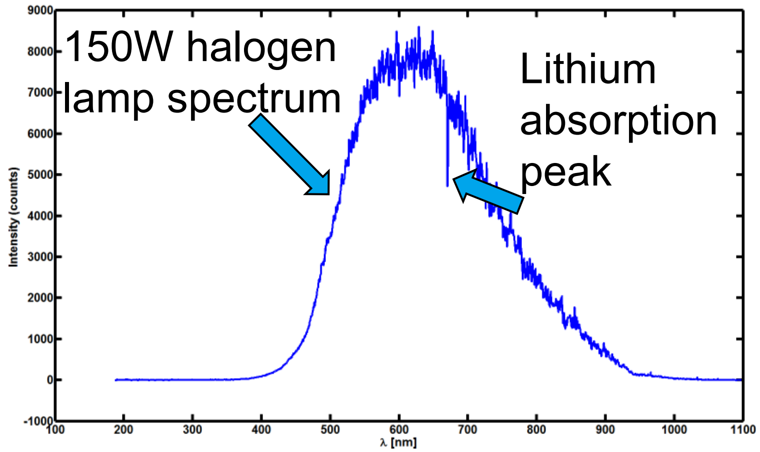
Focusing into plasma cell position: <100μm rms
- sufficient according to PIC simulations




Measured scattering of thin foils (e- windows)

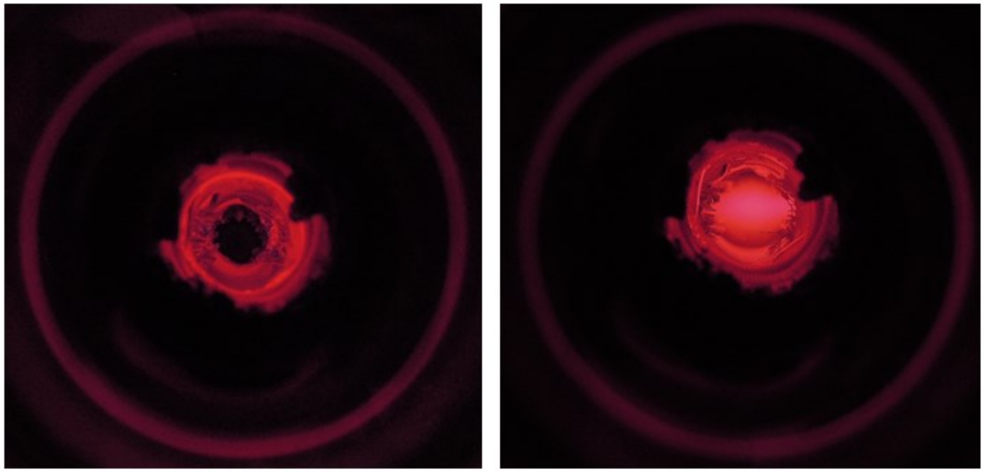



Measured Li vapor density: ≈$10^{14}$ cm$^{-3}$




> Laser off (heat glowing)

> Laser on (plasma)



# Plan for Upgrade

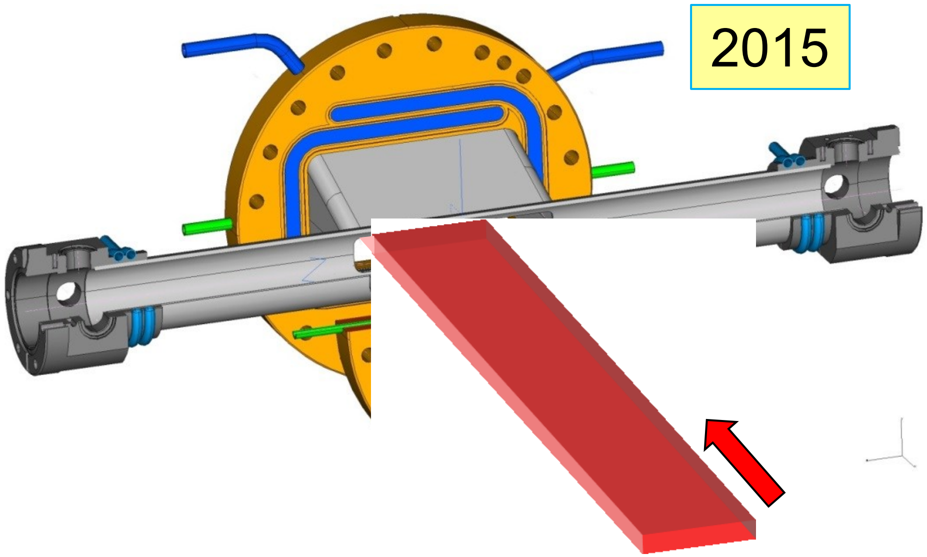
| Problems | Solutions |
|---|---|
| Heating wires overpowered | Stronger heater / better heat insulation |
| Lithium accumulation in cooling zones | • Finer mesh $\rightarrow$ better lithium transport<br>• Longer side arms |
| Only 10% laser pulse energy delivered to plasma cell | • Better optics (e.g. cylinder lenses; antireflection coating)<br>• Increase gas tightness of nitrogen beamline |
| Electron windows increase achievable focus size | Thinner electron window foils |

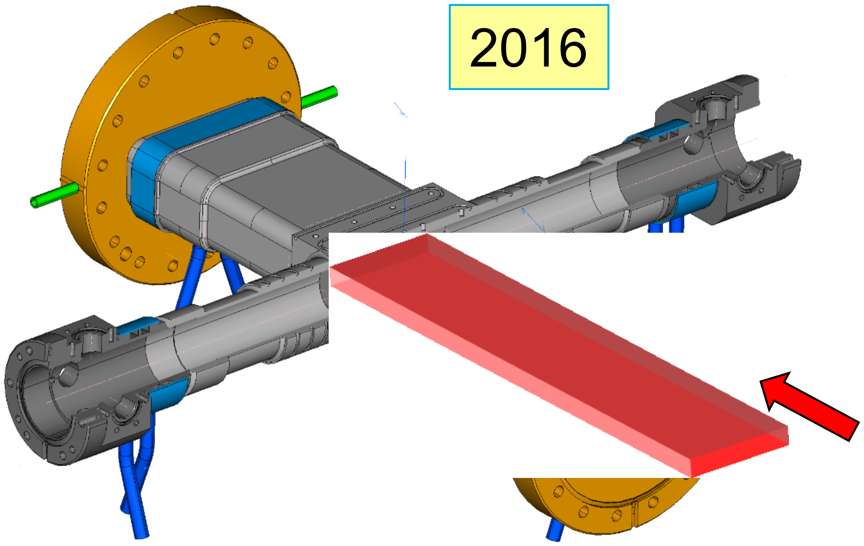
> **Continue plasma experiments in 2016 with improved hardware**
(estimated investment costs for upgrade ≈ 7500 €)

# Plasma Cell Design: New Side Arm Shape

Poster:
Sebastian Philipp

Update: Side arms are straight (not funnel shaped) and have same length as beam tube – now optimized for existing ArF ionization laser (Ti:sapphire not possible any more)



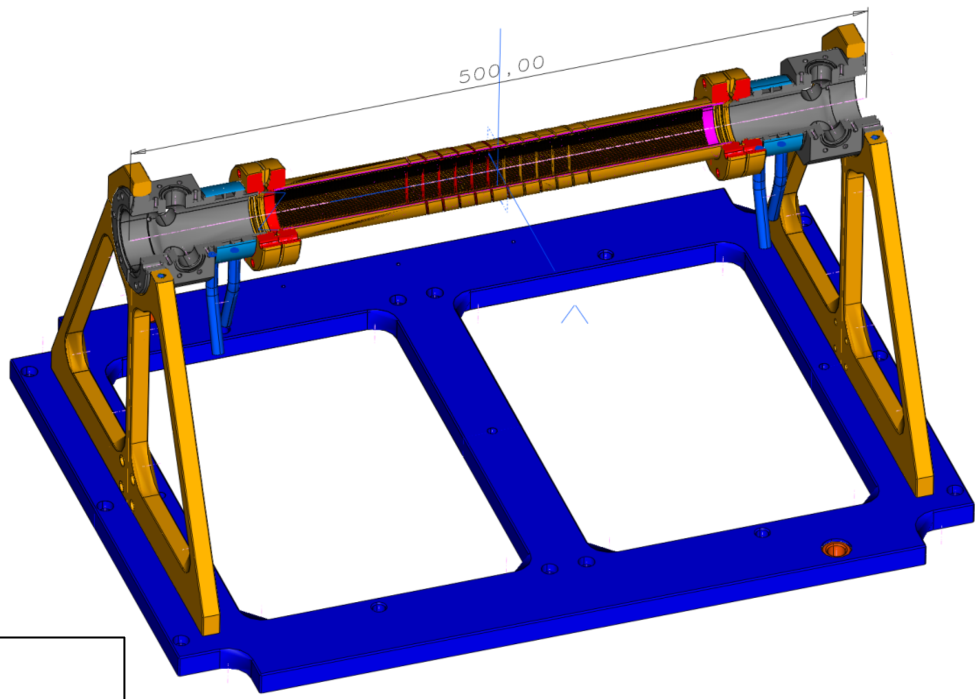




- Stronger heating wires can be fitted into new design
- Heat insulation will be adjusted

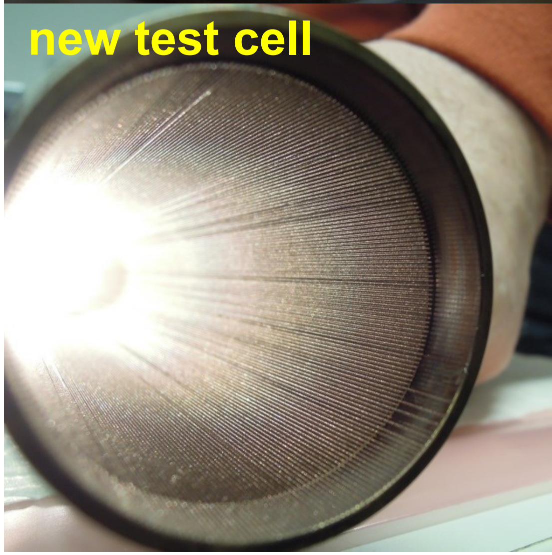
Design:
Gerald Koss

# Test: Replace Wire Mesh with Grooves

- Mesh did not provide stable lithium transport last year
- A small heat pipe setup was manufactured to study the lithium transport in grooves and optimal parameters of the heat pipe operation

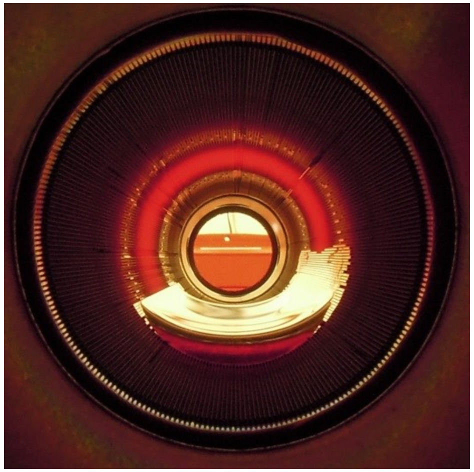



Design:
Gerald Koss

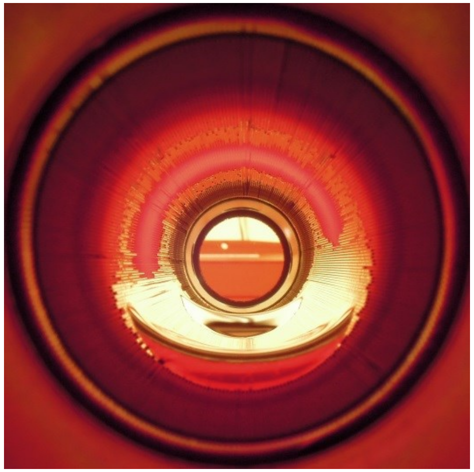
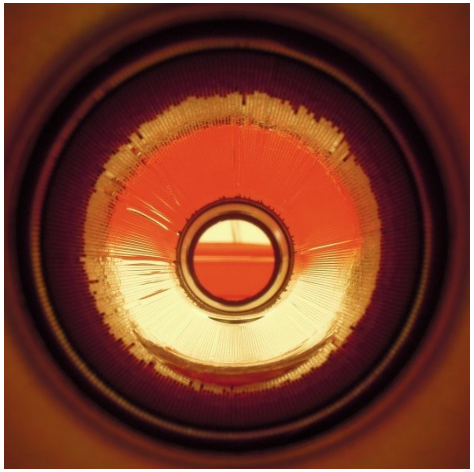
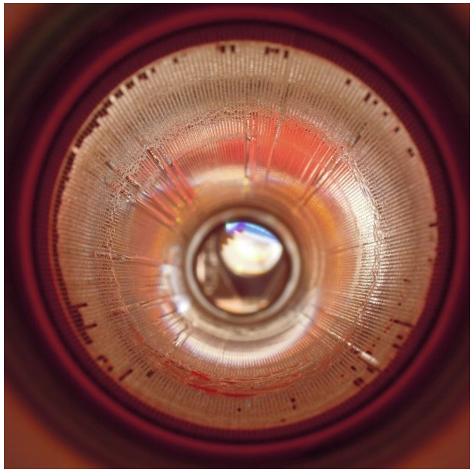



# Lithium Transport Works Well in Groove Pipe





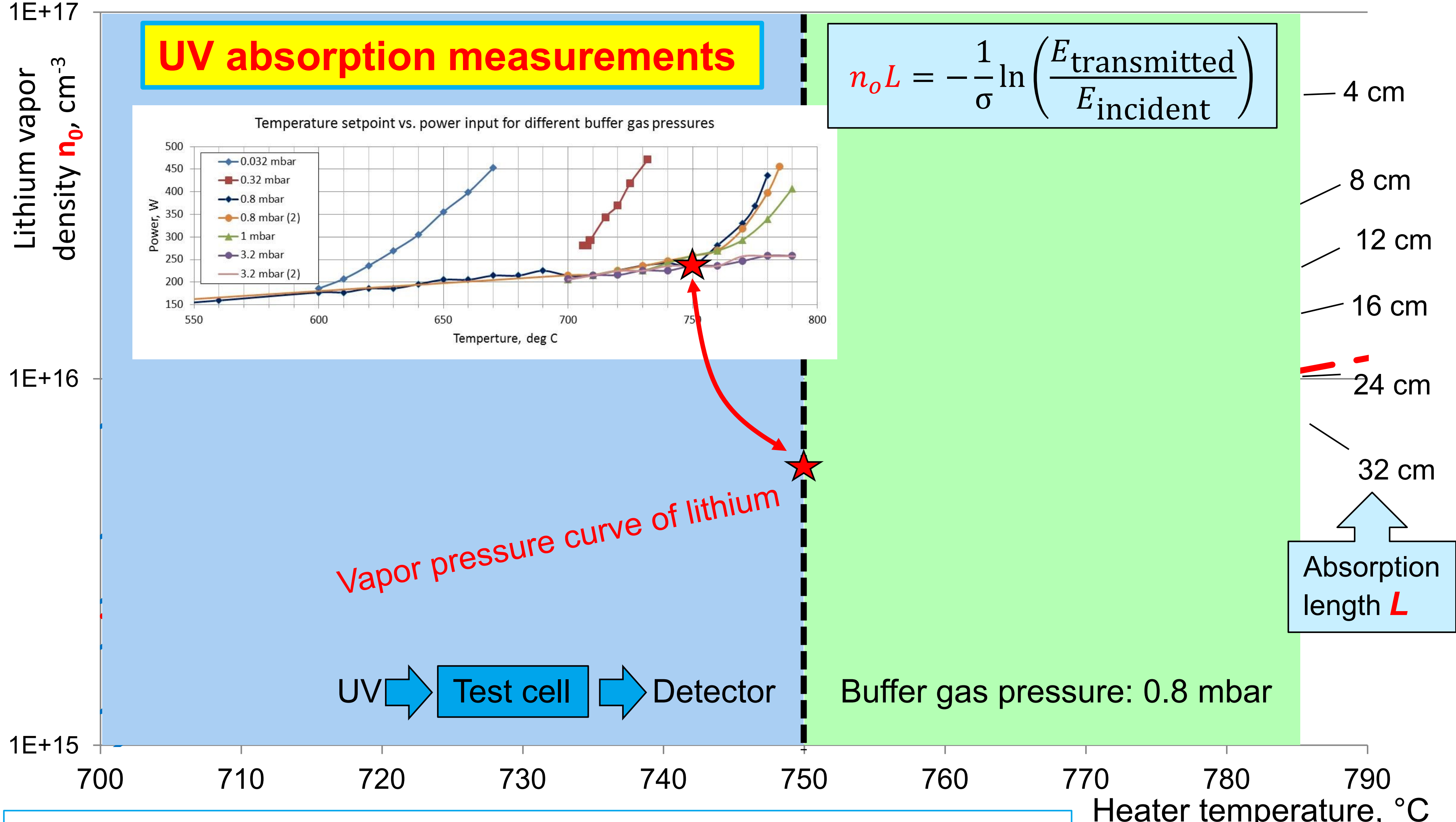
> 560 °C | 605 °C | 650 °C

> 700 °C | 1 day at 700 °C | 1 week at 700 °C

Buffer gas pressure: 0.32 mbar

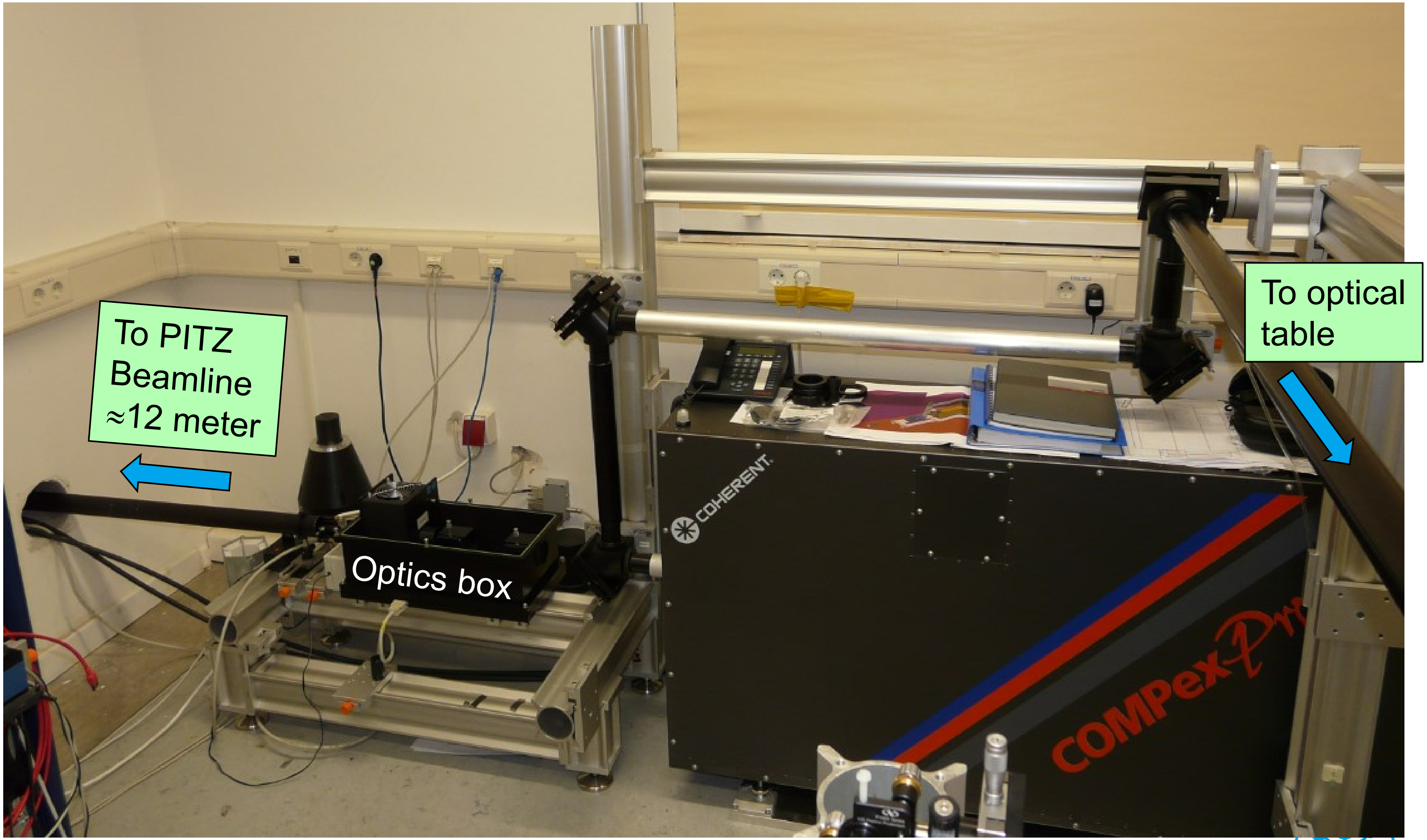
# Improved Lithium Transport → Higher Vapor Density




> Measured lithium gas density: ≈$10^{16}$ $cm^{-3}$ (target value)

# Ionization Laser (ArF Excimer Laser; 193 nm)

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

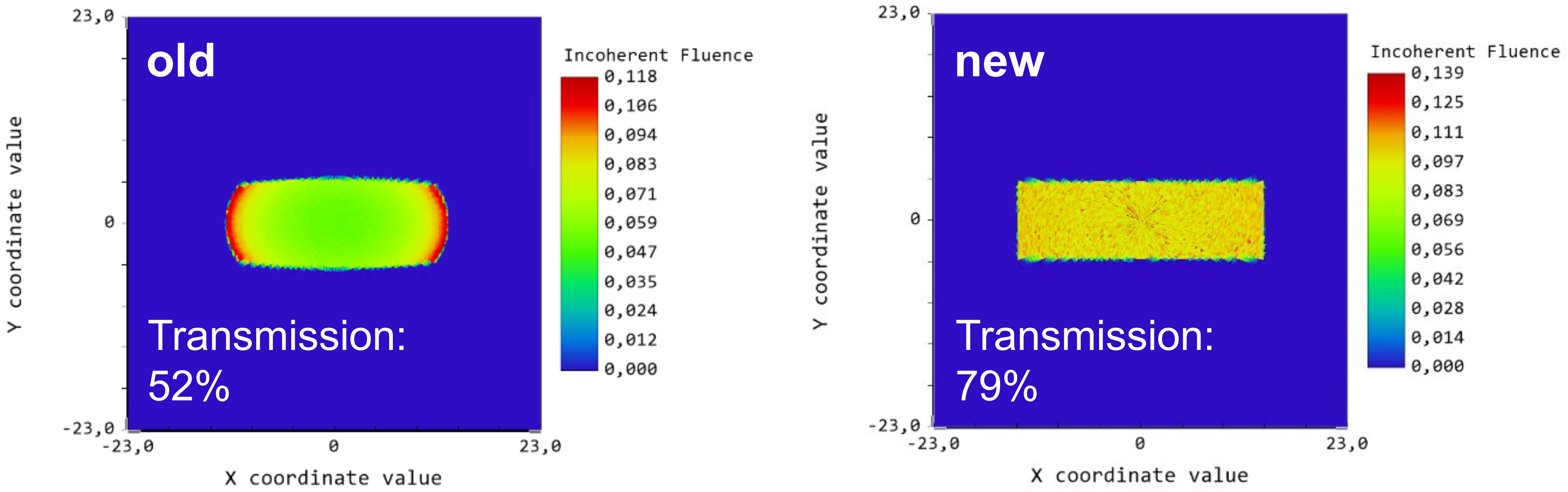





* partially financed by Bernhard Hidding (UHH)

# Better Optics for ArF Laser Beam Line

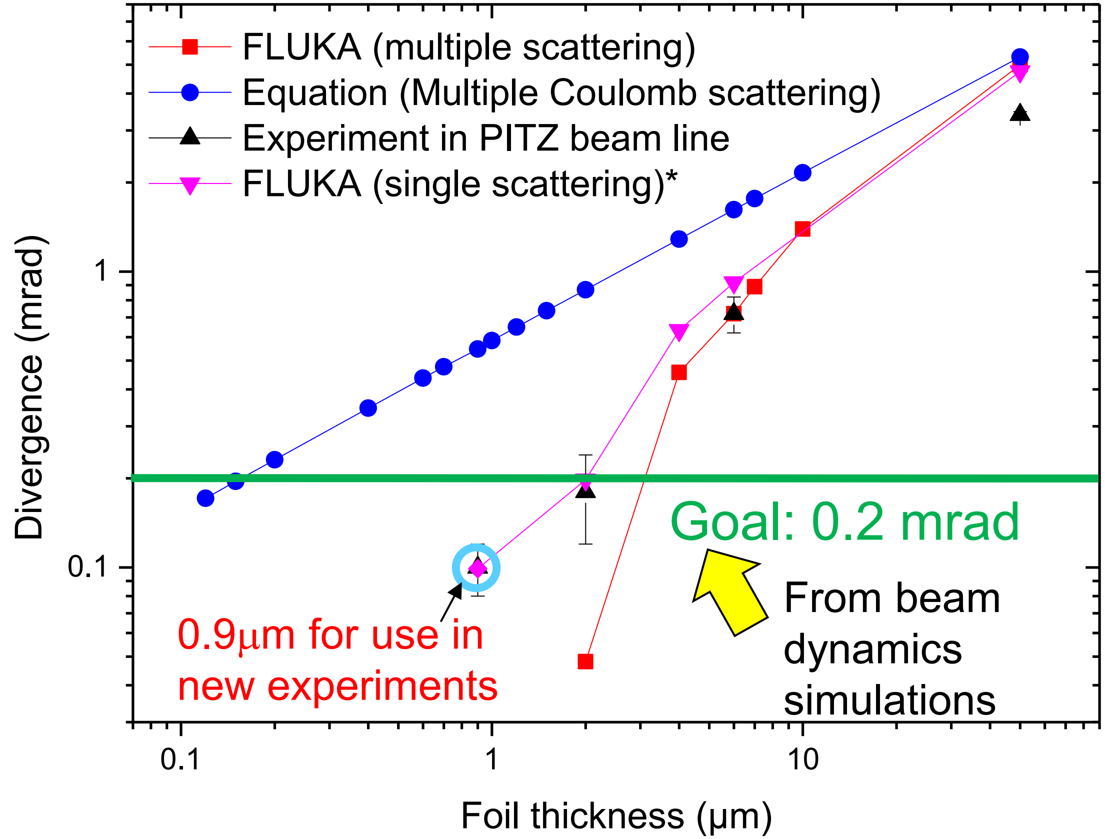
- Laser output: 24mm x 10mm with 3mrad x 1mrad divergence
  - Beam transport over ≈12m from laser aperture to plasma cell
  - Compensation of divergence done so far with spherical lenses → cutting at apertures
  - Now: 4 cylinder lenses (2 per axis) with AR coating for individual compensation




- ZEMAX simulated laser distribution at plasma cell position (before beam expander) – no atmospheric transmission losses
  - With cylinder lenses: rectangular, homogeneous

# Electron Window Foil

- Better candidate foil for experiment was found: 0.9μm PET, coated with 37.5nm aluminum on both sides (stress test in dummy cell with electron beam soon)




*for the last point (0.9 μm) a coated foil is simulated

- FLUKA (single scattering): FLUKA is forced to calculate each scattering event one by one instead of averaging, which is default → good agreement with experimental results

# Summary

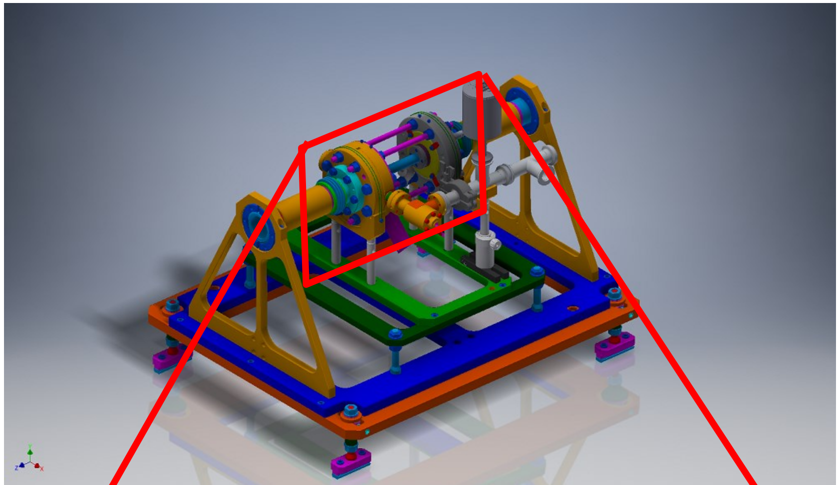
- Further experiments to demonstrate and characterize self-modulation are in preparation for this summer
- Several significant upgrades have been done compared to last year:
  - New plasma cell design (better heating, no loss of lithium)
  - Grooves replacing wire mesh (better lithium transport) $\rightarrow$ in test cell we already measured much higher gas density
  - Better ionization laser beam transport: less clipping, less absorption
  - Window foil candidate with very low scattering was found (has to pass stress test)
- New experimental results
  - Lithium gas density of $\approx 10^{16}$ $cm^{-3}$ (target value)
  - Negligible gas leakage in test setup of ionization laser beam line
  - Electron beam scattering at window foil: 0.1 mrad (2x better than target)
- We are optimistic to be able to see self-modulation this year!



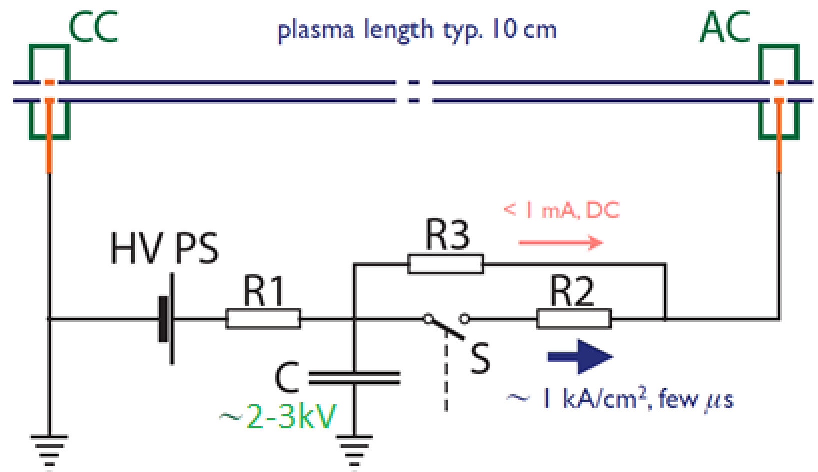
DESY

# Gas Discharge Plasma Cell for HTR

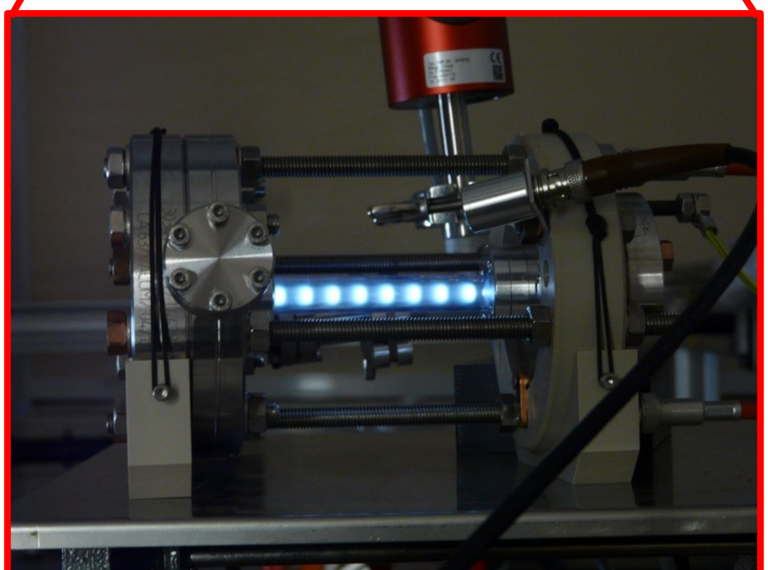
Poster:
Gregor Loisch



Design of the discharge plasma cell




Layout of the discharge circuit



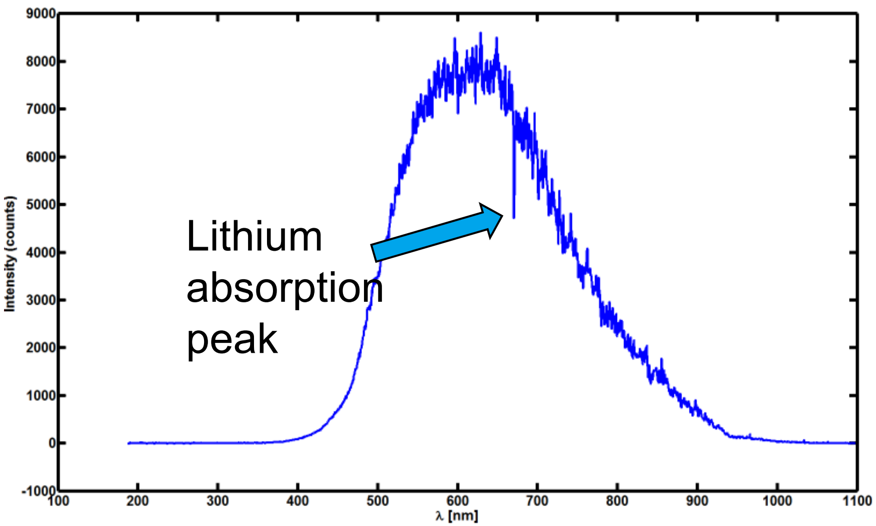
- Cell was manufactured
- Electronics and vacuum parts taken into operation
- Electronics tested until 2 kV, 550 A (max. 3 kV, 600 A)
- No major problems observed

# Backup

# Improved Lithium Transport → Higher Vapor Density

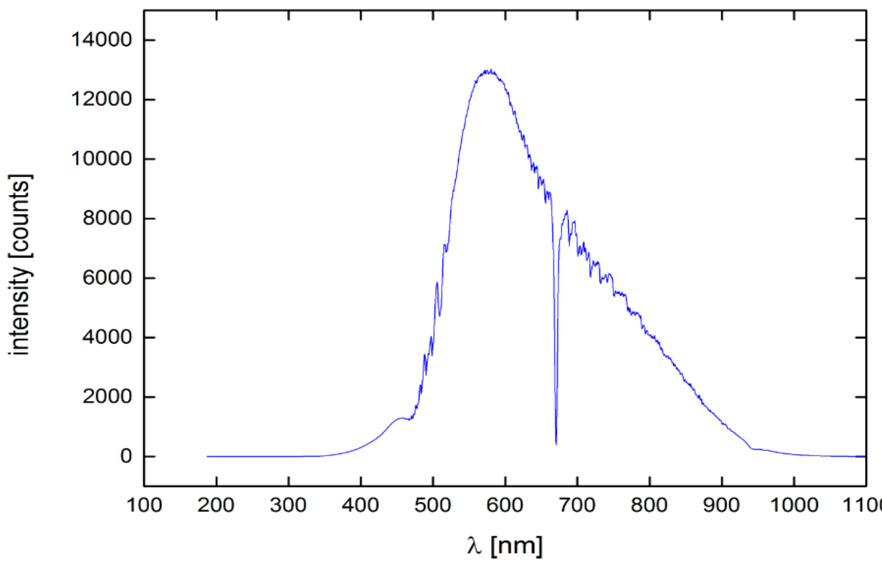
- First white light (halogen lamp) absorption density measurements with grooved cell indicate much higher lithium density vapor densities
  - Target density for experiment: $10^{16}$ cm$^{-3}$

Old:



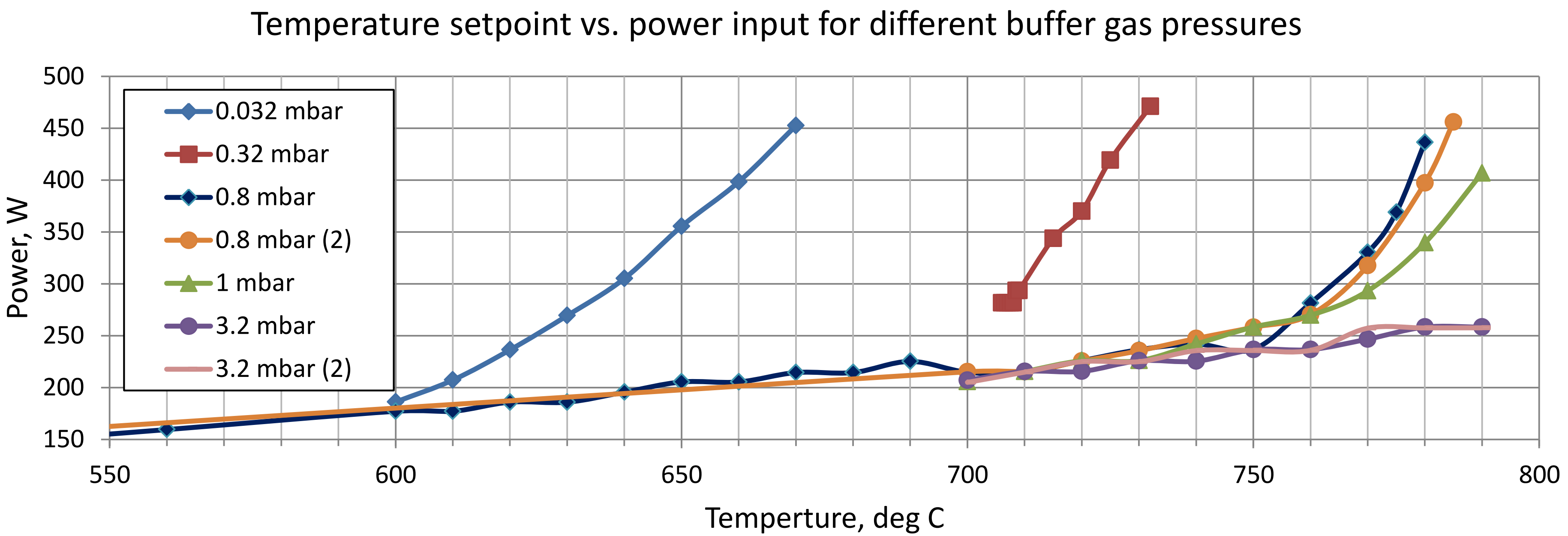

Measured Li vapor density: ≈$10^{14}$ cm$^{-3}$

New (different lamp):

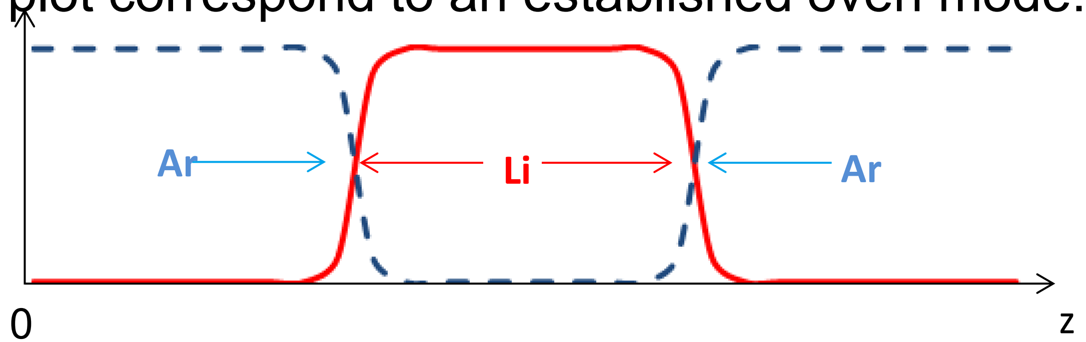



Measured Li vapor density: ≈$10^{16}$ cm$^{-3}$

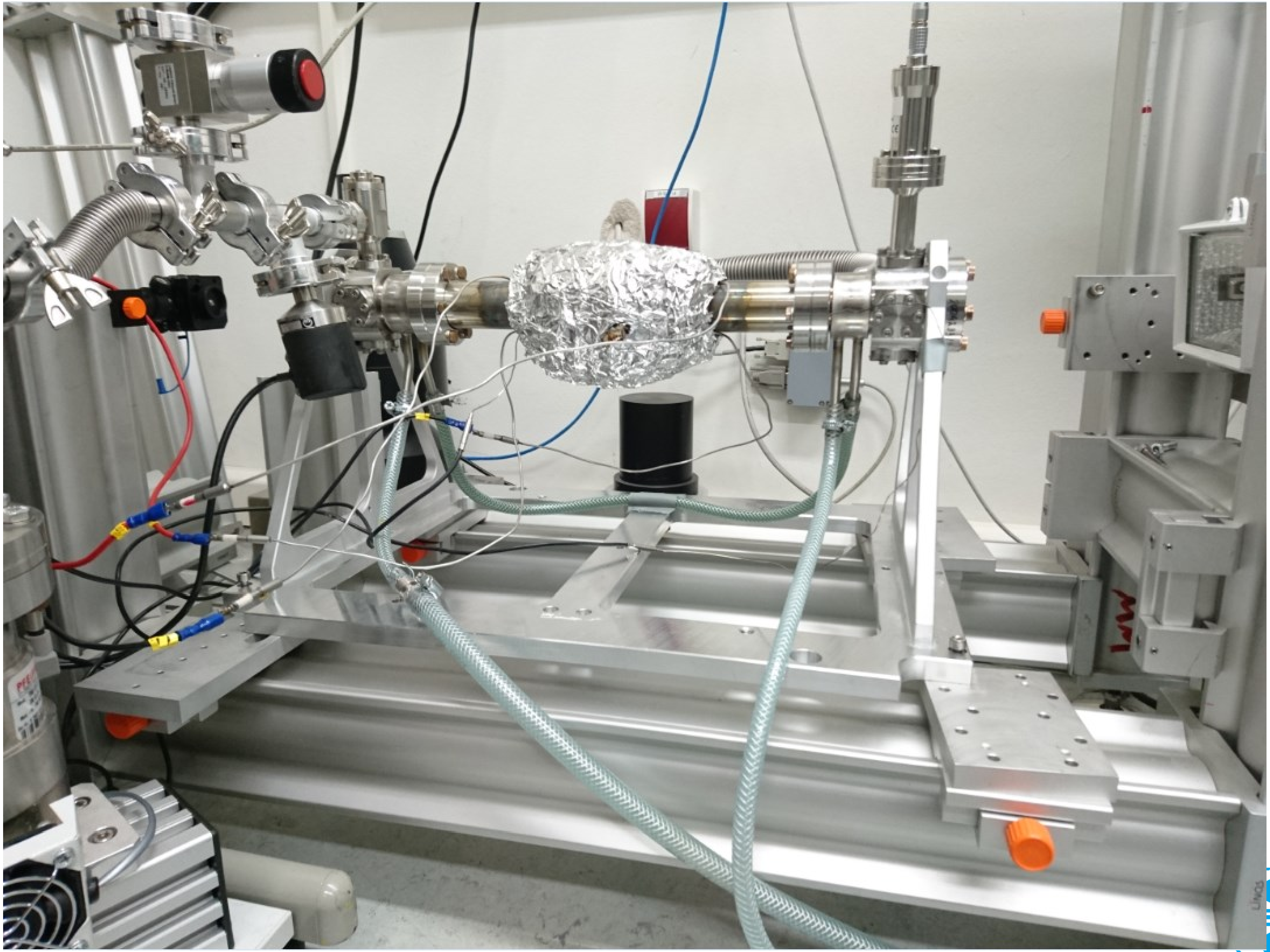
# Heat pipe regimes



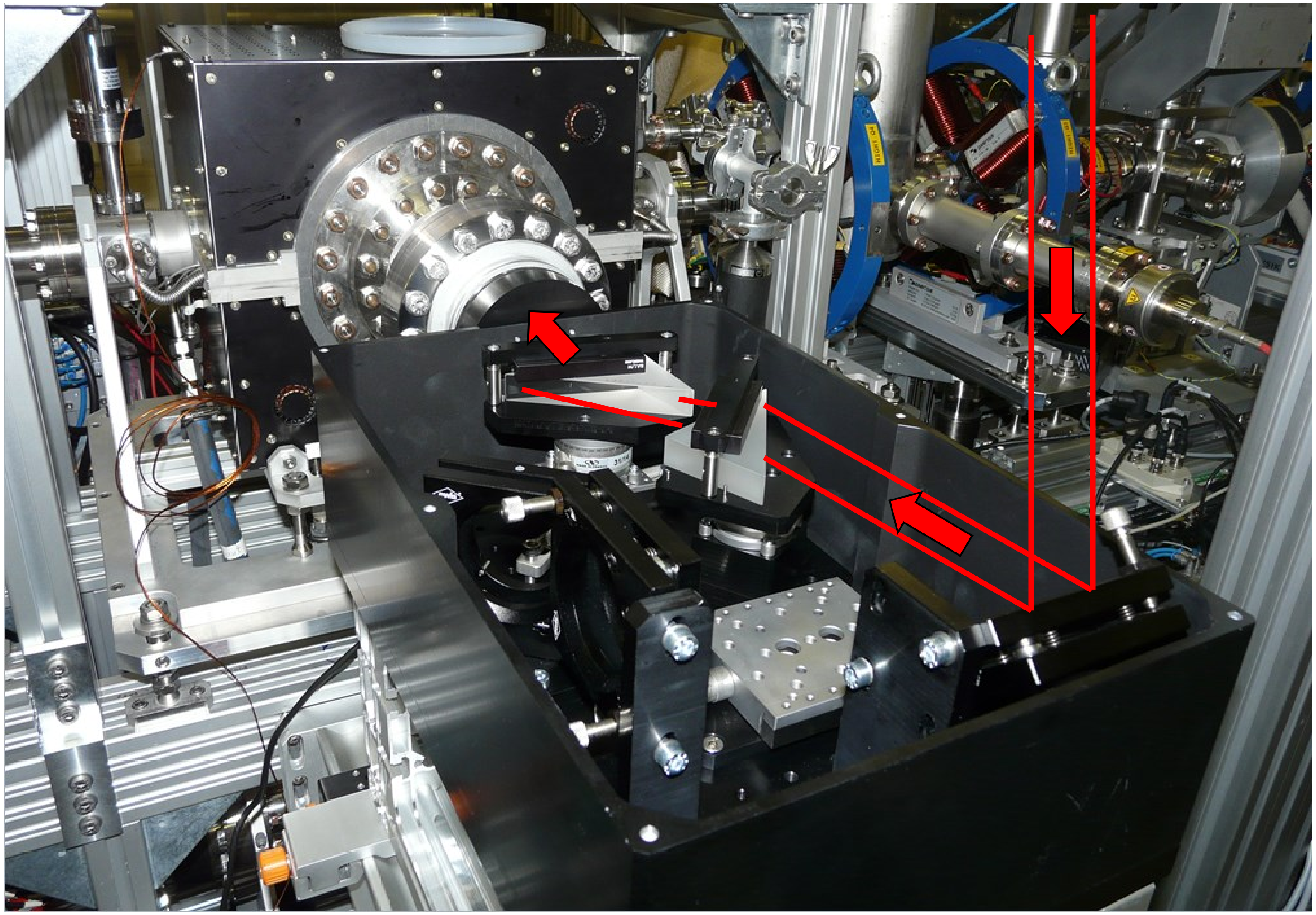

- 0.8 mbar was selected as an optimal pressure
- Kinks on the plot correspond to an established oven mode:



# Picture of Heat Pipe Test Tube Setup



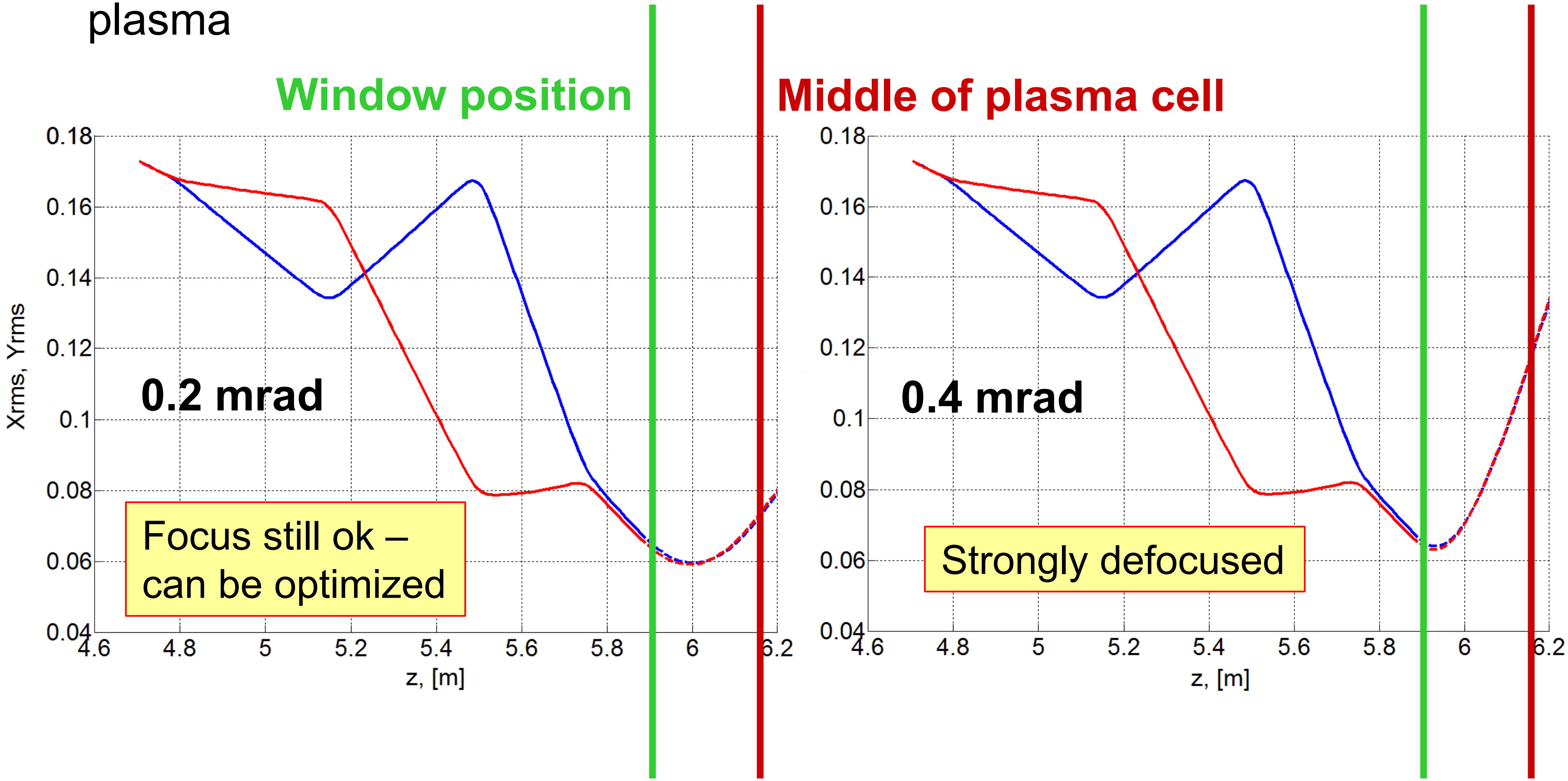
# Plasma Cell with Ionization Laser Beam Expander



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

# Scattering at Electron Window

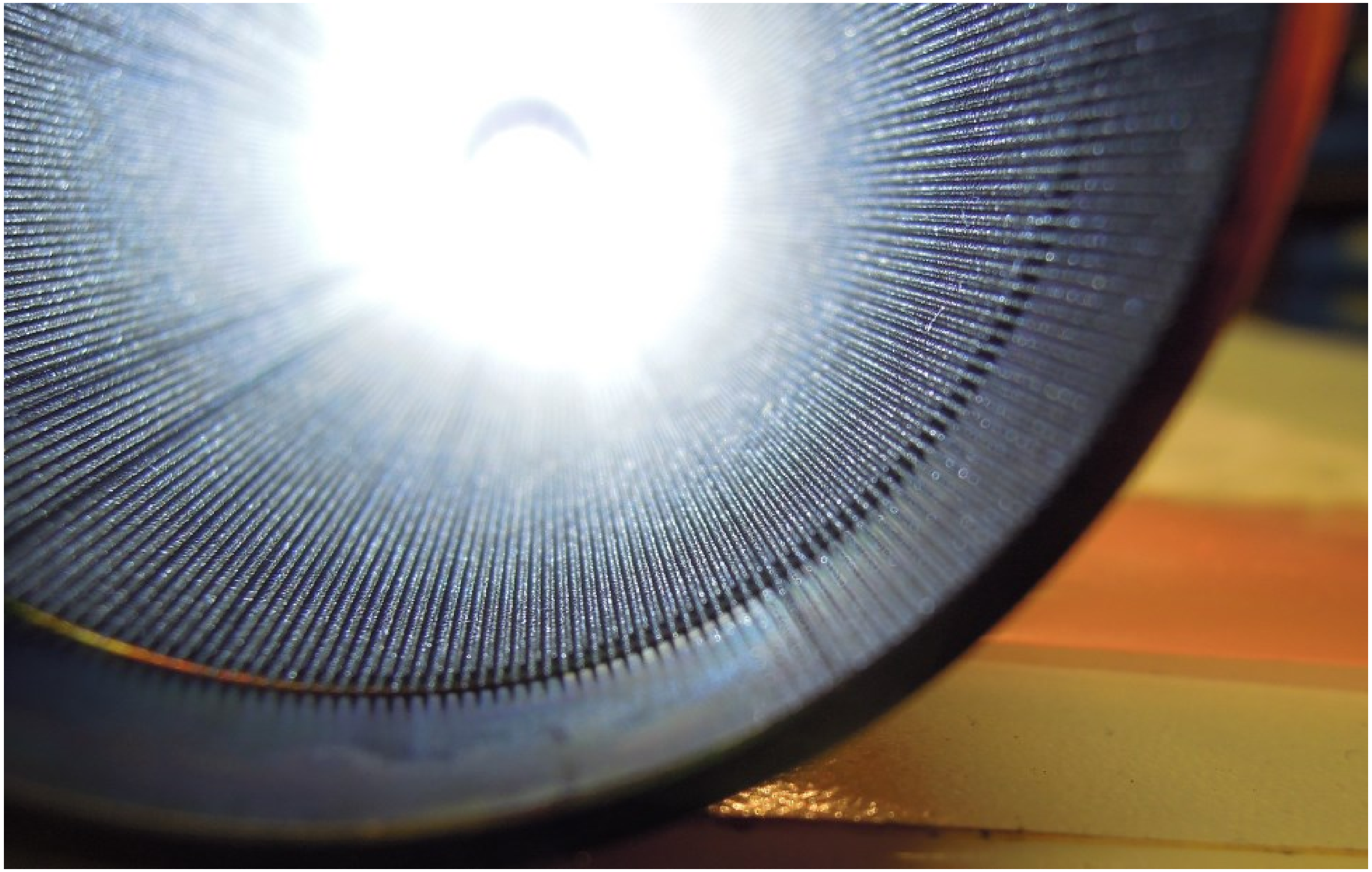
> ASTRA simulations: electron beam scattering impedes focusing into the plasma



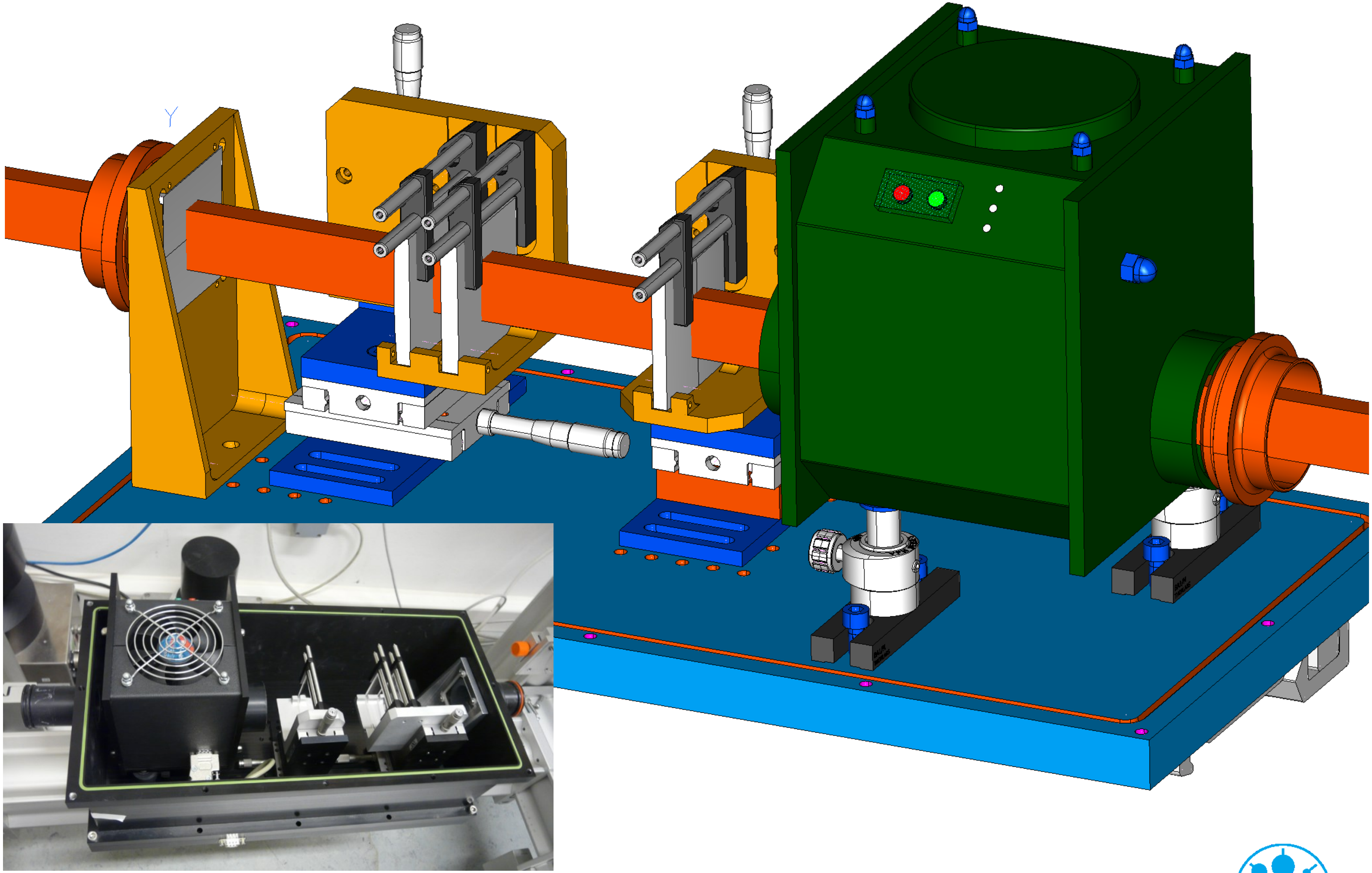

> Maximal agreeable scattering angle: 0.2 mrad

# Test: Replace Wire Mesh with Grooves

- Advantage: better suited to complicated geometry in cross-shaped plasma cell



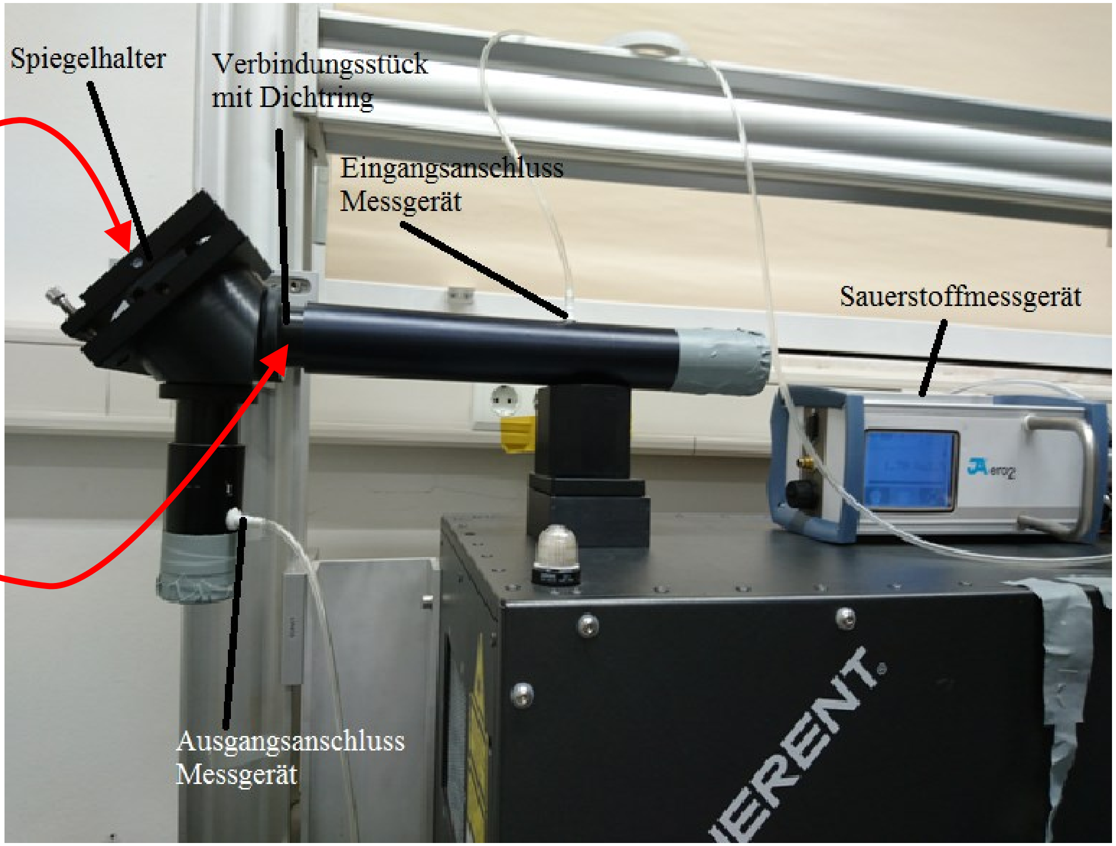
# New Setup of Optics Box with Cylinder Lenses



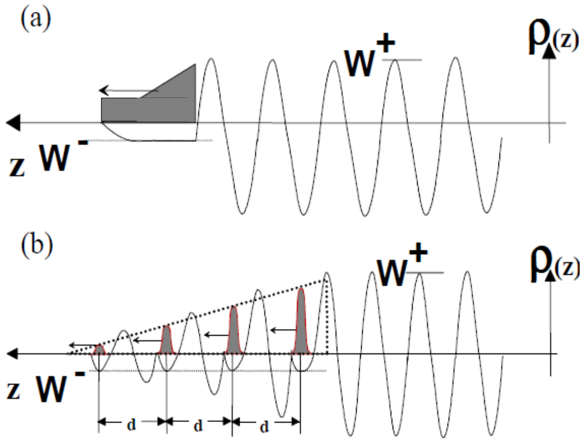
# Gas Tightness of Beam Tube

- Problem: 193nm light is strongly absorbed by oxygen
- Solution: piped laser beam line with nitrogen atmosphere

- Main problem: mirror holders
- Biggest leaks at
  - Mirror edges
  - Connector between mirror holder and tube (especially problem under mechanical stress)
- Solutions:
  - Seal rings for mirrors
  - Bellows for connectors

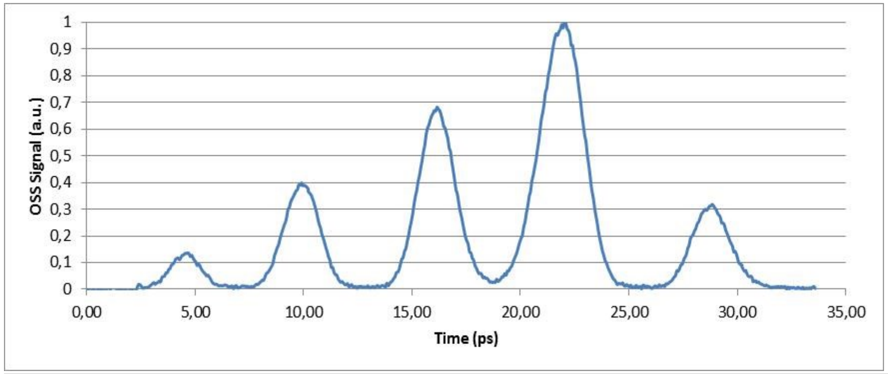


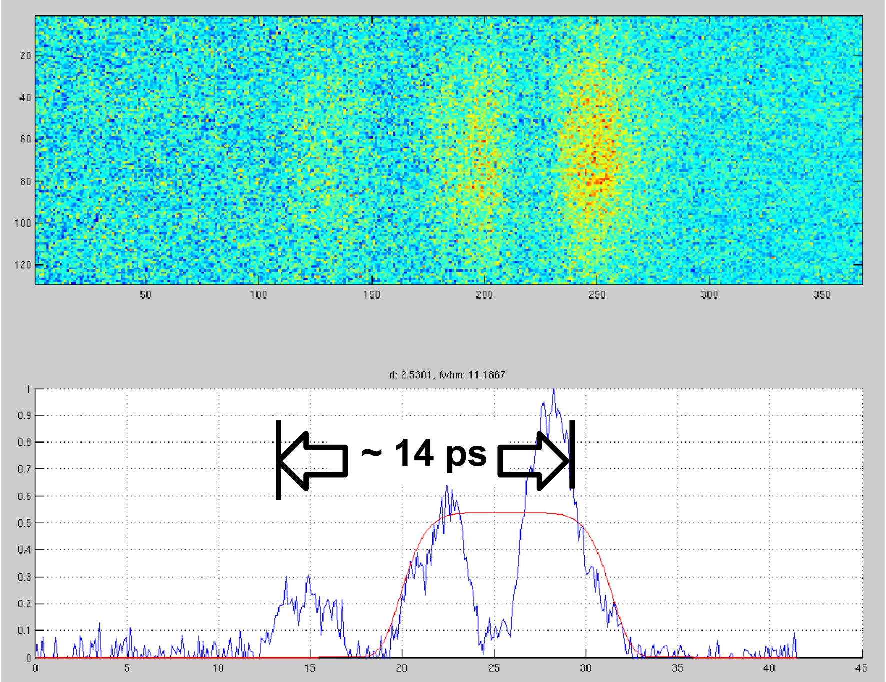
# Overview of High Transformer Ratio Plasma Wake Field Acceleration @ PITZ




**HTR:**

**W+/ W- > 2**




- Flexible, photocathode-shaped bunches offer many oportunities for high transformer ratio experiments
- Preliminary studies conducted
- So far ramped bunches look more promising