Current Status of the Plasma Acceleration Experiment at PITZ

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LAOLA technical seminar
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HELMHOLTZ
ASSOCIATION

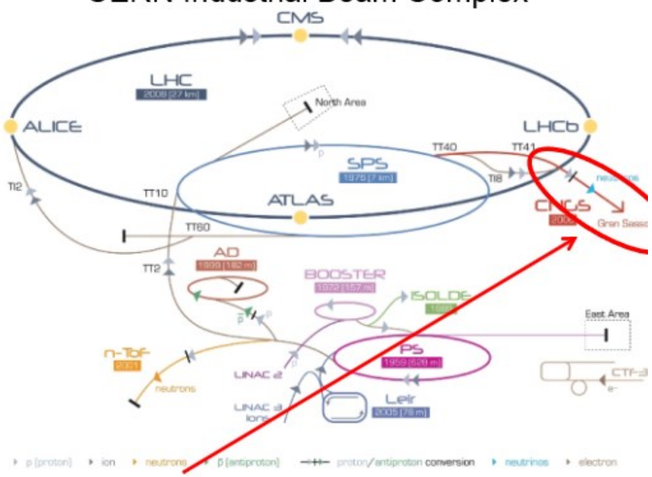
Outline

- Motivation
- Preparatory experiments
  - Electron beam scattering
  - Plasma generation
- First run
- Summary

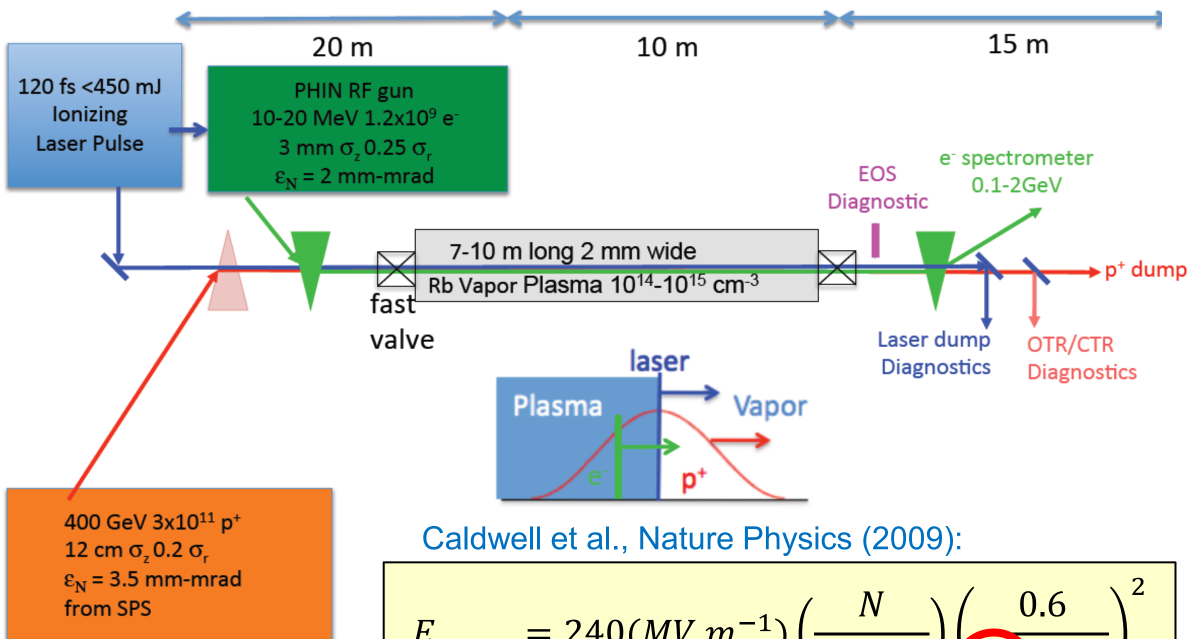
EAAC Workshop 2013: Patric Muggli, AWAKE: A Proton-Driven Plasma Wakefield Experiment at CERN

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

CERN Industrial Beam Complex



CNGS experimental area



Caldwell et al., Nature Physics (2009):

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

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

Self-modulation!

Courtesy:
Patric Muggli, Erdem Öz

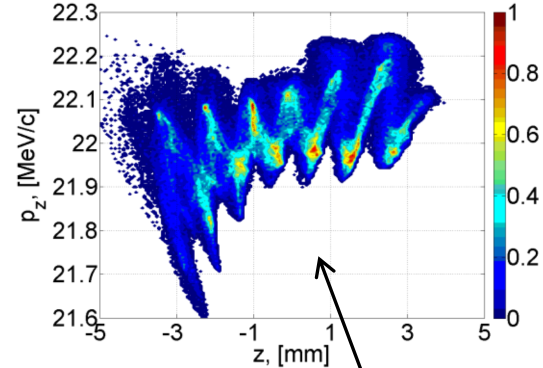
Simulated Self-modulation Experiment

Not fully optimized

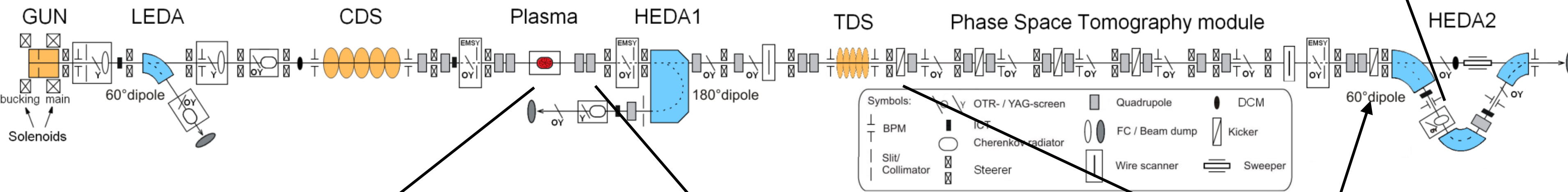
Longitudinal Phase-space studies

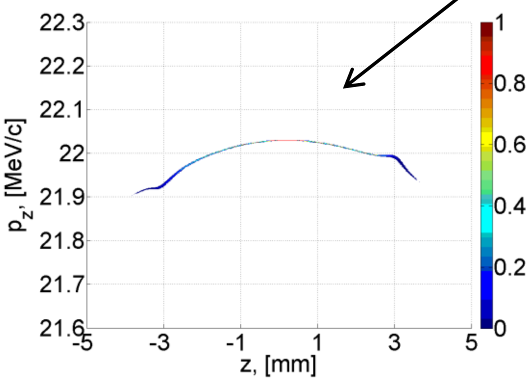
Simulations:
Martin Khojoyan /
Dmitriy Malyutin

Expected phase space ←

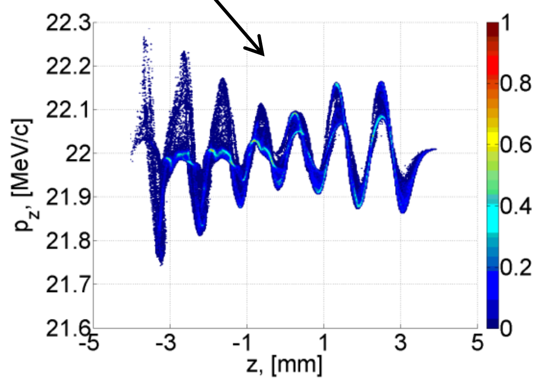


Plasma density: 10^{15} cm^{-3} → $\lambda_p \approx 1mm$

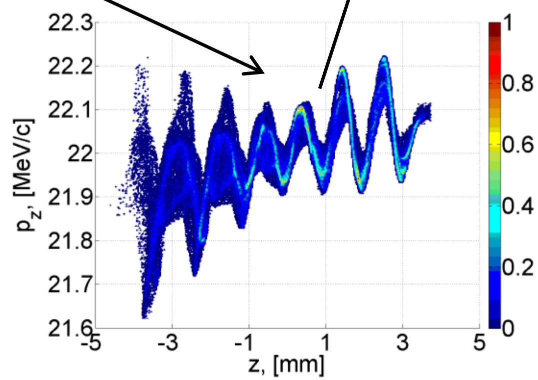




In front of plasma cell

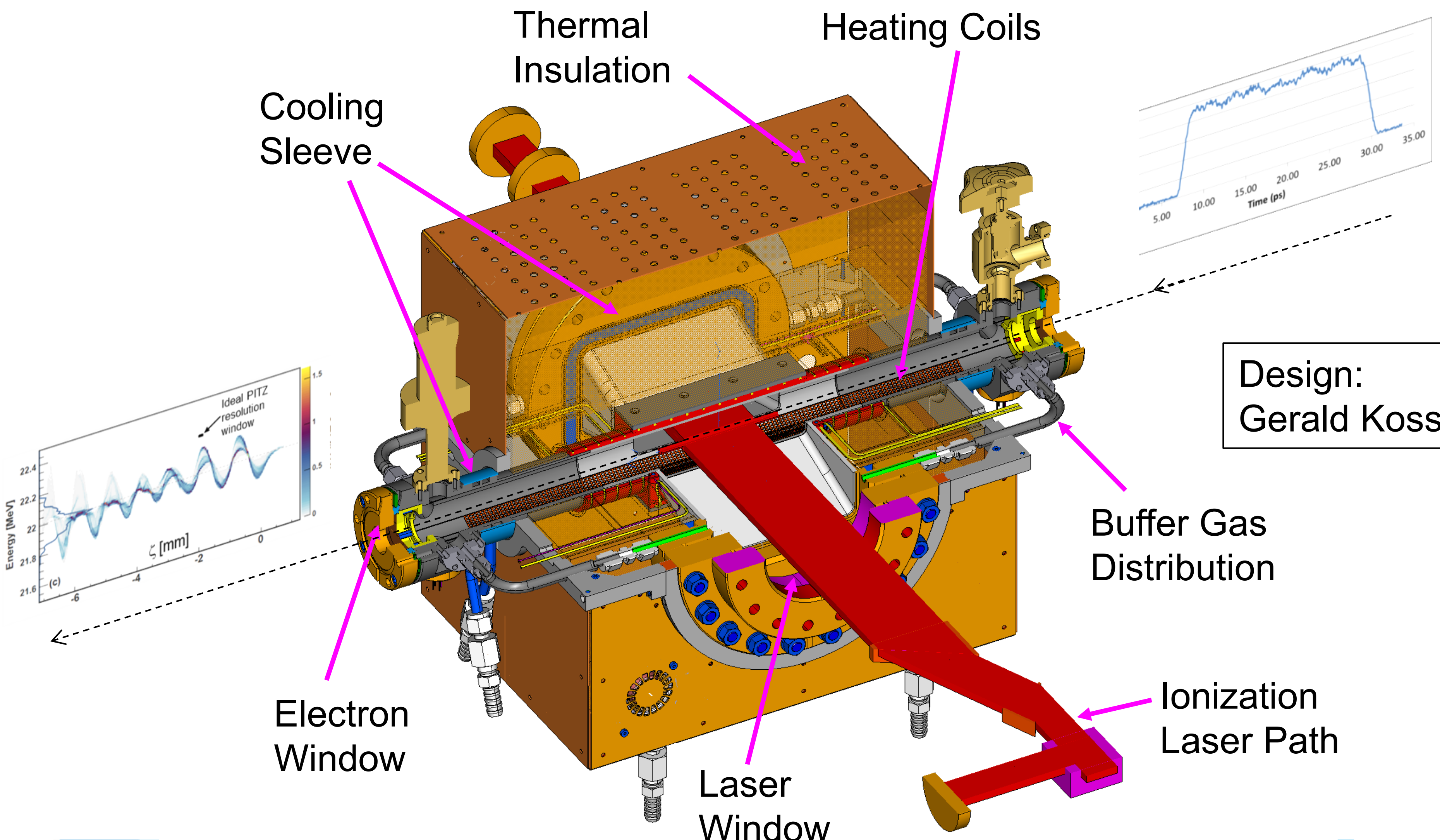


After plasma cell
(assuming zero initial energy spread)



In front of dipole

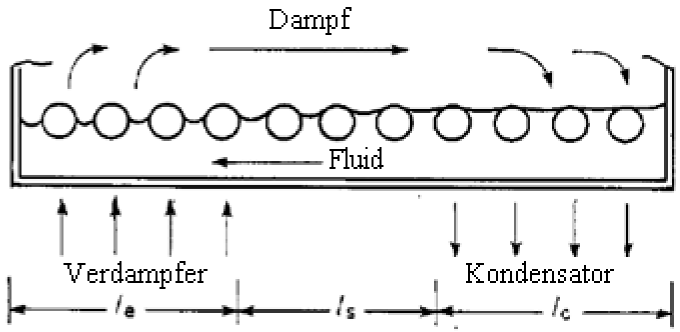
Plasma cell design



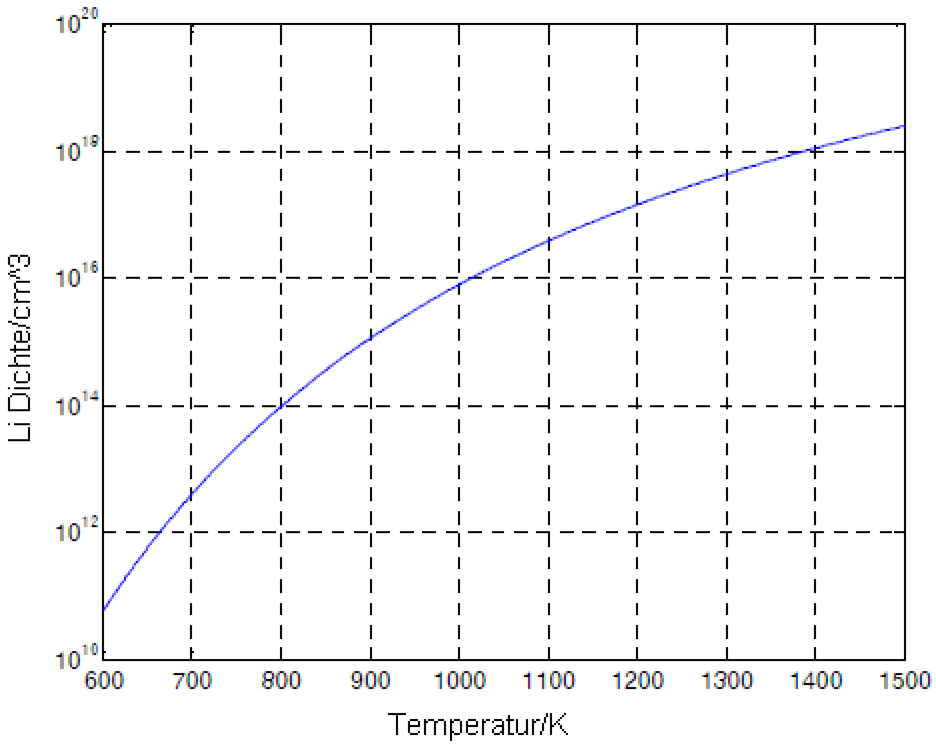
Design:
Gerald Koss

Heat pipe oven

- The plasma cell is designed as a heat pipe with a metal mesh inside the oven acting like a wick.

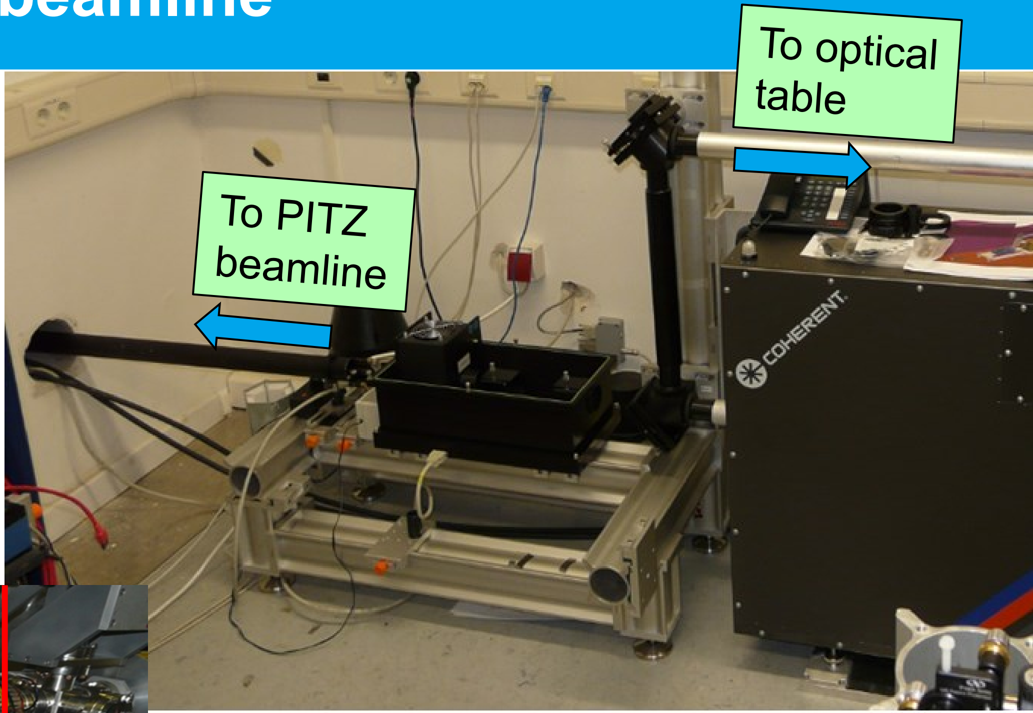


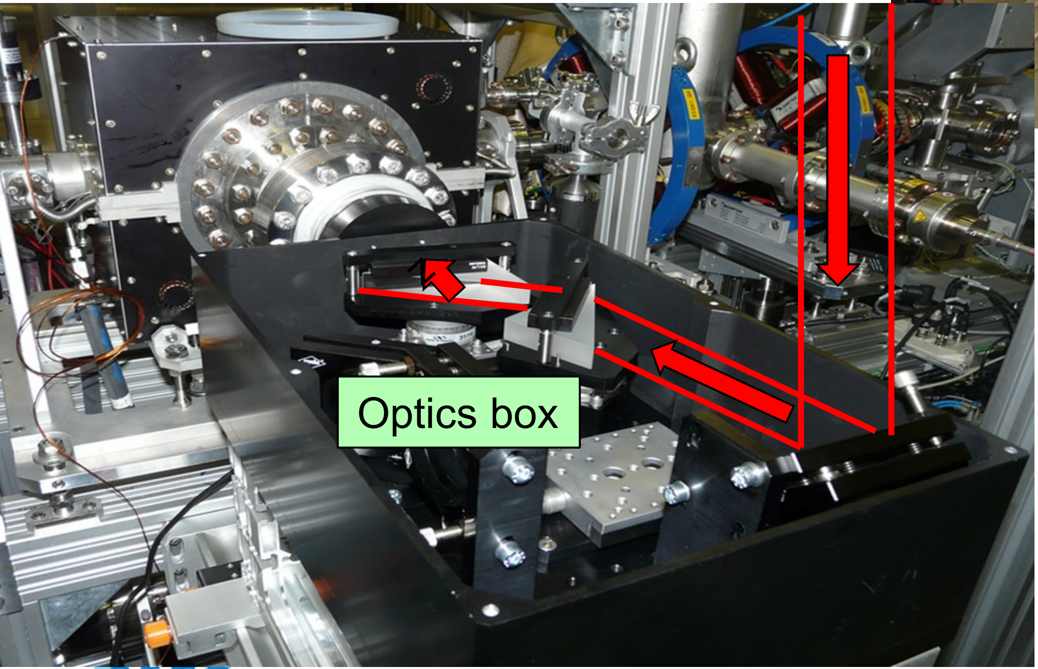
- Desired vapor density of 10^{16} cm^{-3} corresponds to 1000 K



Ionization Laser and laser beamline

- Coherent COMPexPro 201: ArF Excimer Laser, 193 nm, up to 400 mJ / pulse, 10 Hz

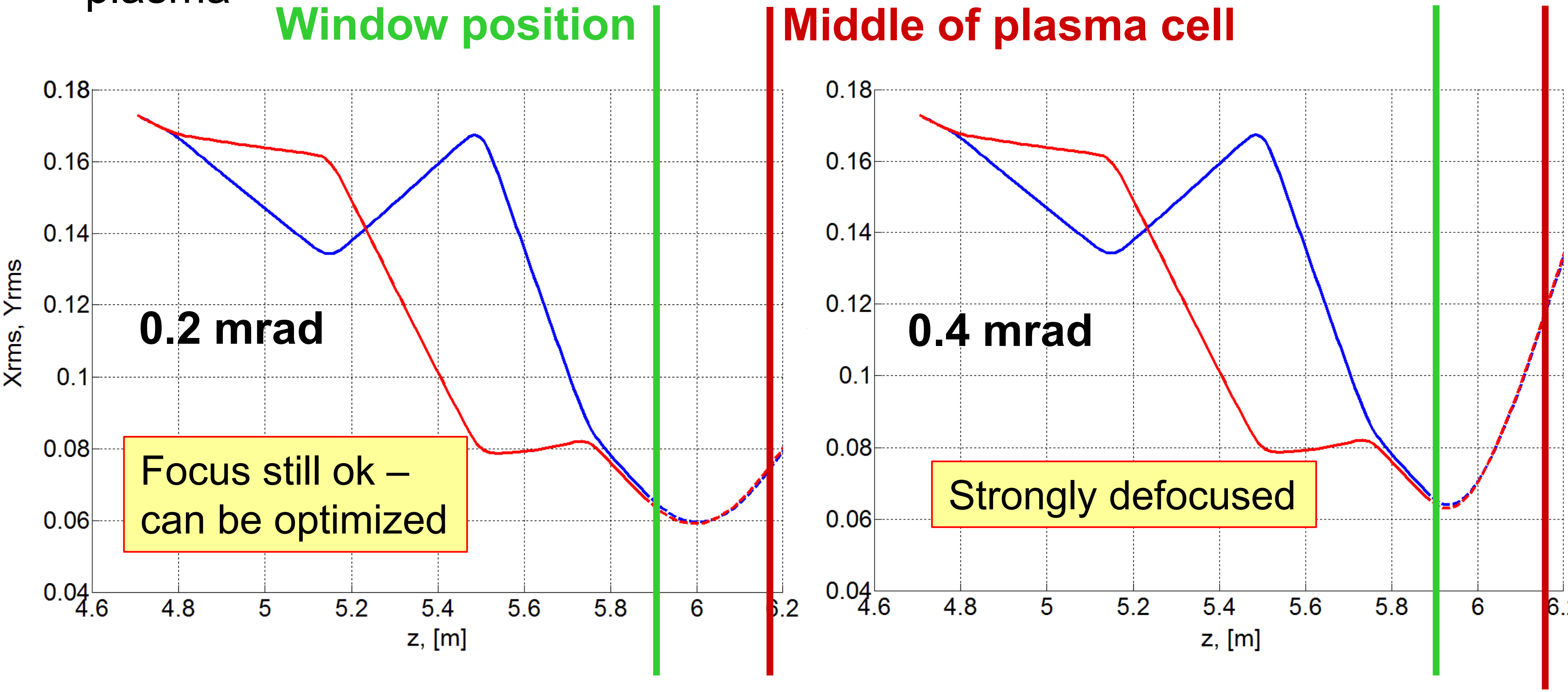




- Side coupling advantage: Well defined and adjustable plasma channel length
  - Option: Add filter to implement density ramps or other plasma profiles

Scattering at Electron Window

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

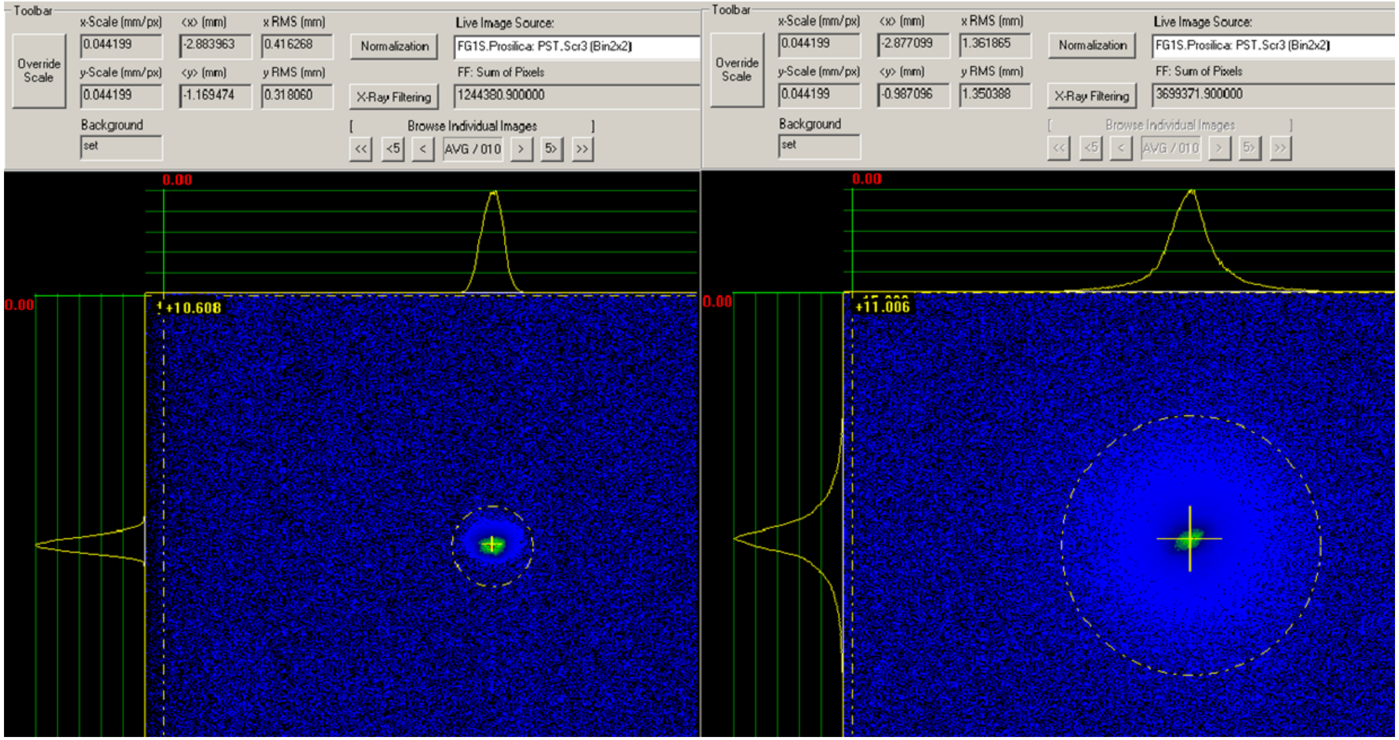


- Maximal agreeable scattering angle: 0.2 mrad

Simulations: Yves Renier

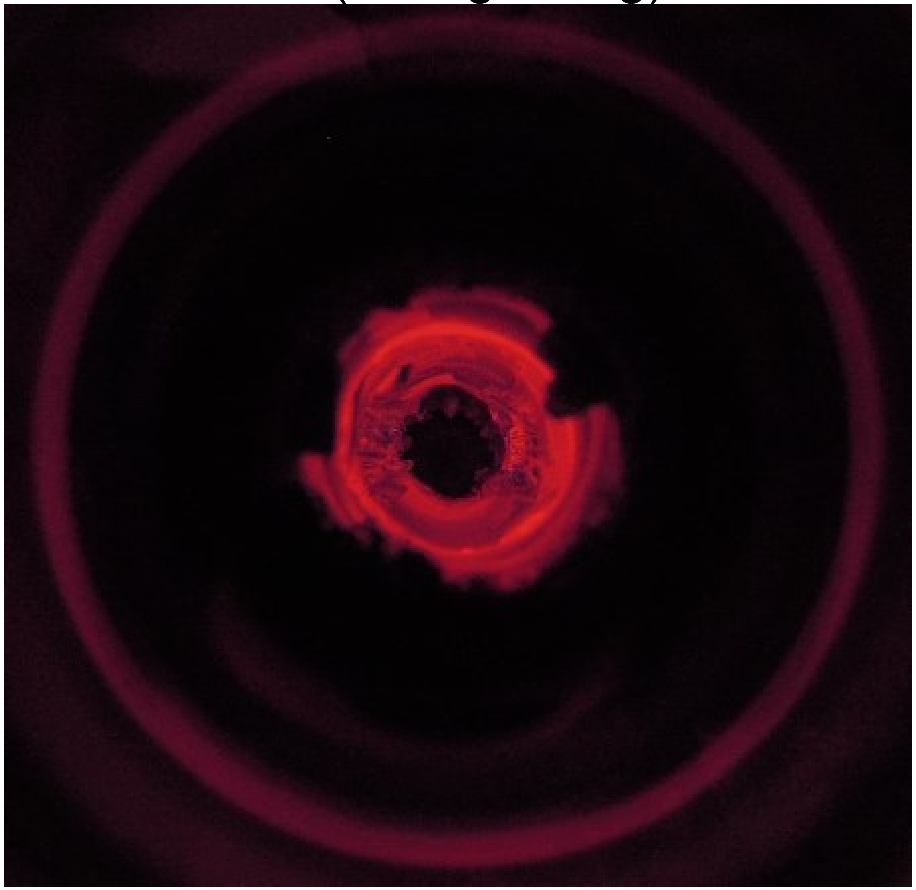
Scattering at Electron Window

- 0.9 µm PET, coated with Al (37.5 nm) both sides
  - Experimental: less than 0.1 mrad beam divergence
  - Scattering values preliminary confirmed by FLUKA simulation
  - Gas permeability is acceptable
  - Not yet tested with dummy plasma cell (mechanical and thermal stress)

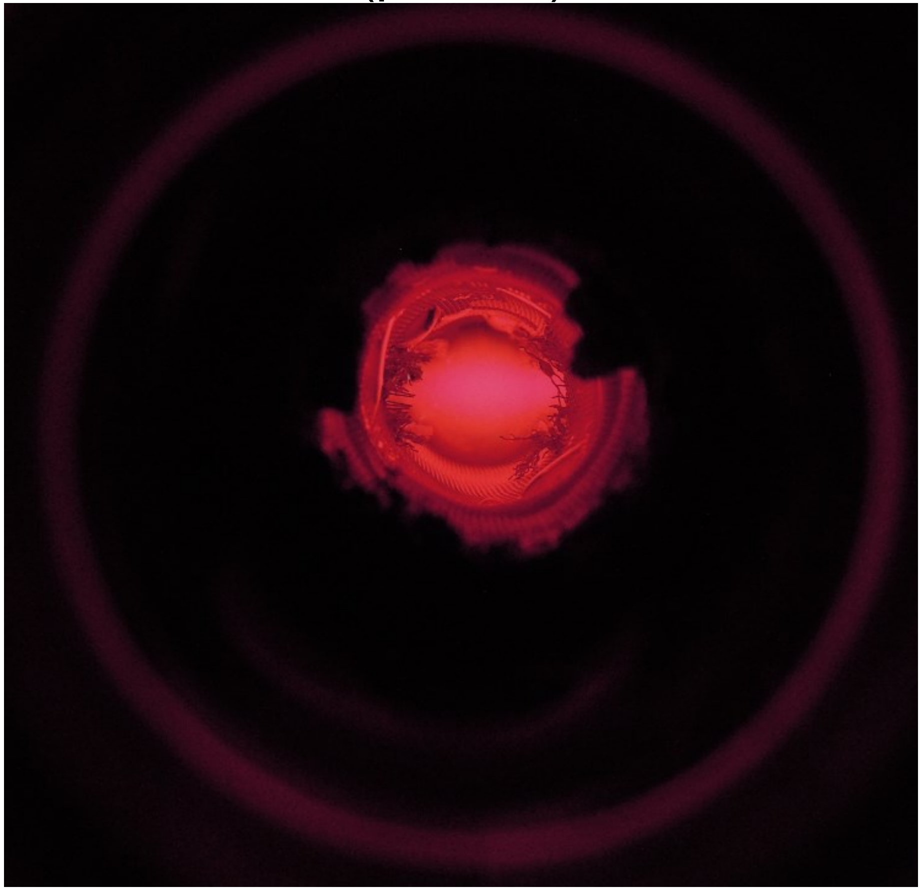


Generation of Lithium Plasma In Laboratory

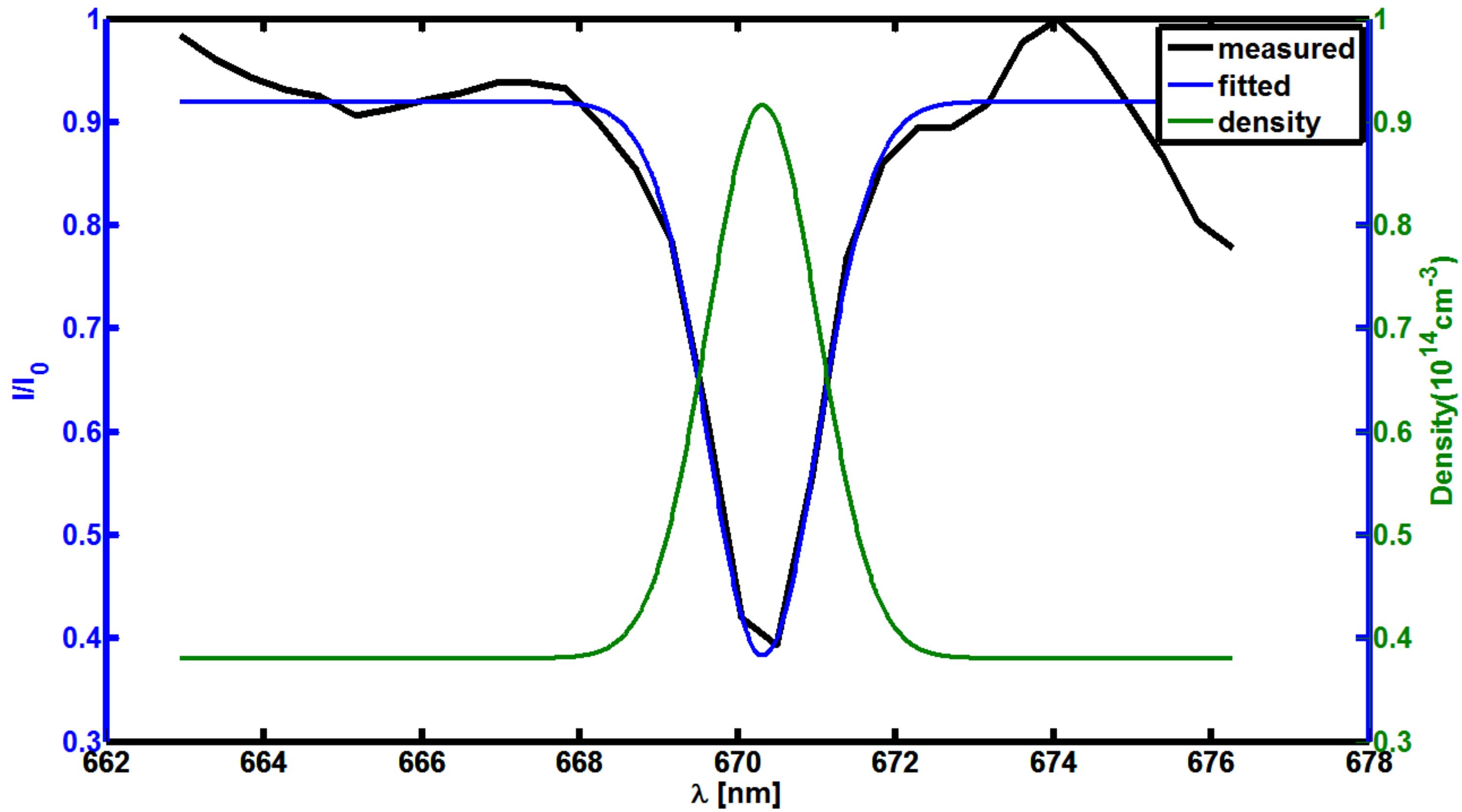
> Laser off (heat glowing)



> Laser on (plasma)



Density measurement: white light absorption



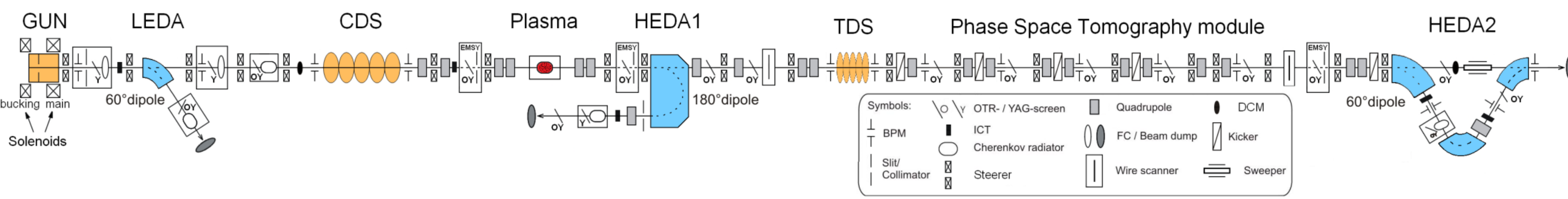
- Calculation shows vapor density about $1 \times 10^{14} cm^{-3}$, which depends strongly on a length of Li vapor column

Experiment:

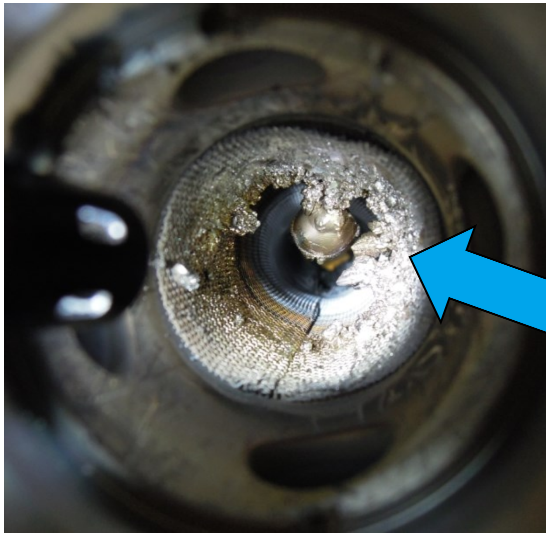
- Two experimental runs with:
  - KW30: 62.5 hours of operation, interrupted by blockade of the beam path
  - KW36-37: 131 hours of the operation, interrupted by run out of N_2 for the ionization laser beamline, loss of beam intensity and breakdown of the plasma cell heater
- Experimental conditions:
  - 8 µm Kapton windows
  - Gun: 6MW; on-crest; 250 µs pulse length
  - Photocathode laser running with flat top profile
  - Booster: 3.1MW; on-crest; 200 µs pulse length
  - 100 pc bunch charge; 22 MeV; 1-2 pulses
  - Ionization laser: 300 mJ, but big fraction of energy was lost due to laser beamline imperfections

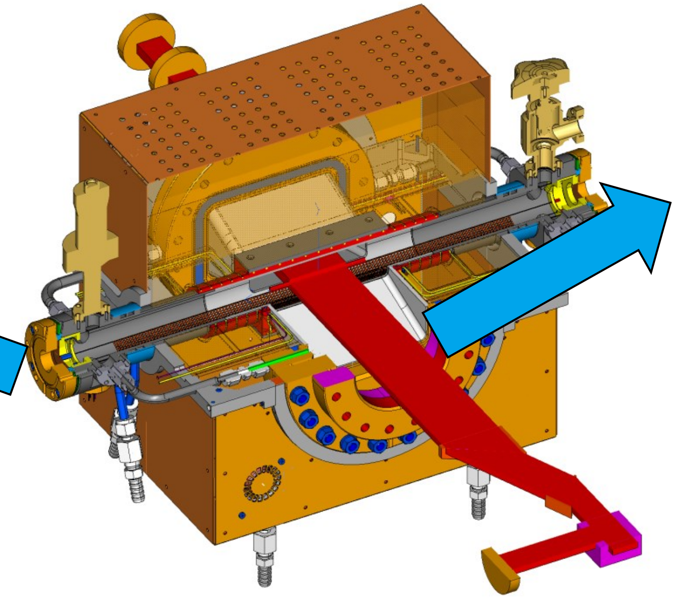
Experiment: no self-modulation found

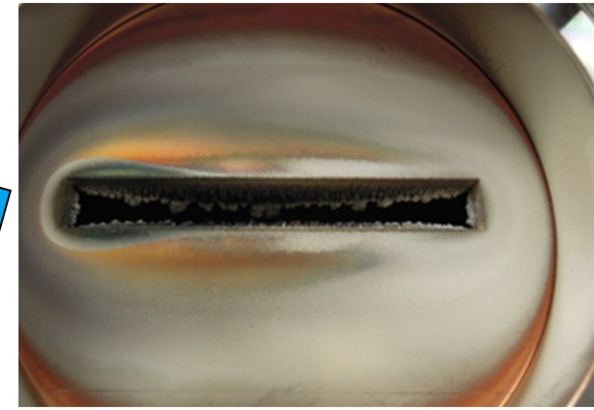
- What was scanned:
  - High1.Q1-Q4
  - Main solenoid current
  - Ionization laser timing
- What we were looking for:
  - High1.Scr5 and Disp3.Scr1: Mean position, RMS sizes and sum of pixels
  - HEDA1: Energy and energy spread
  - TDS: Temporal beam profile



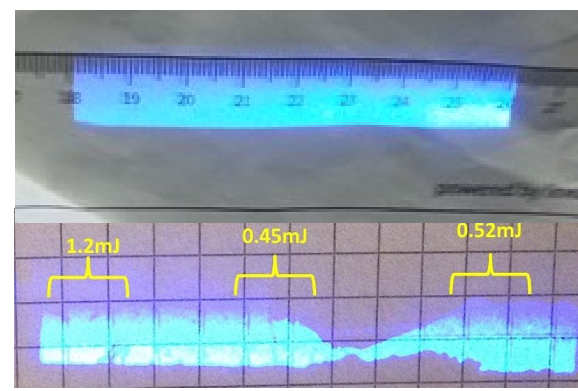
Plasma cell status after extraction from the tunnel







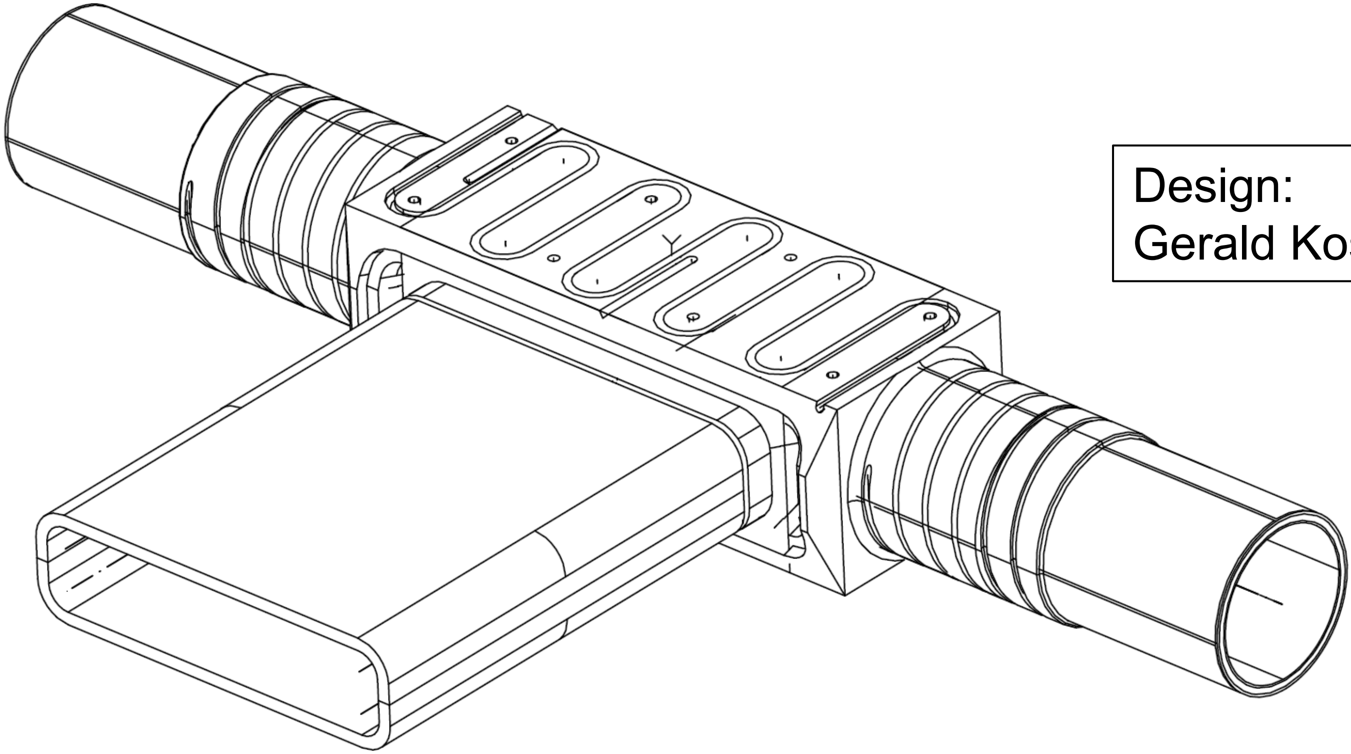
- Ionization laser profiles before and after few days of operation:



- The problem of lithium condensation was partially solved by adjusting the buffer gas pressure and extending side arms.

Improved plasma cell design

- Cut from solid block of metal to prevent possible weaknesses at the welding joints
- Elongated and simplified side arms
- Metal grooves inside instead of metal mesh for capillary action



Design:
Gerald Koss

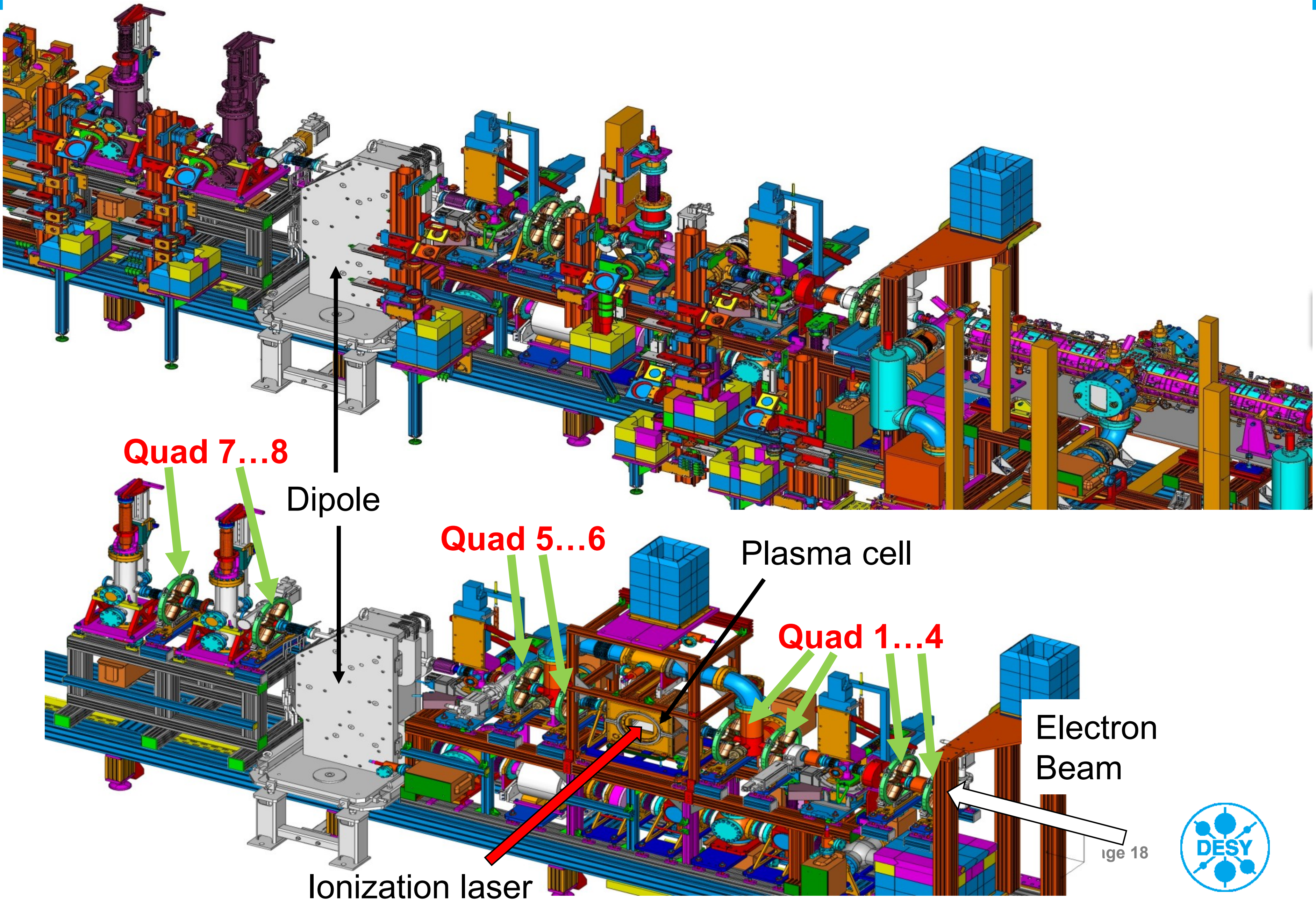
Summary

Problems	Solutions
Heating wires overpowered	• Stronger heater / better heat insulation
Lithium accumulation in cooling zones	• Axial grooves or finer mesh→ better lithium transport • Longer side arms
Insufficient density of lithium vapor	• Stronger heater / better heat insulation • Fine adjustment of buffer gas pressure
Only 10% laser pulse energy delivered to plasma cell	• Better optics (e.g. cylinder lenses; antireflection coating) • Better beamline sealing
Electron windows increase achievable focus size	• Thinner electron window foils

- **Continue plasma experiments in summer 2016 with improved hardware** (estimated costs for upgrade ≈ 5000 €)
- Gas discharge plasma cell is in preparation

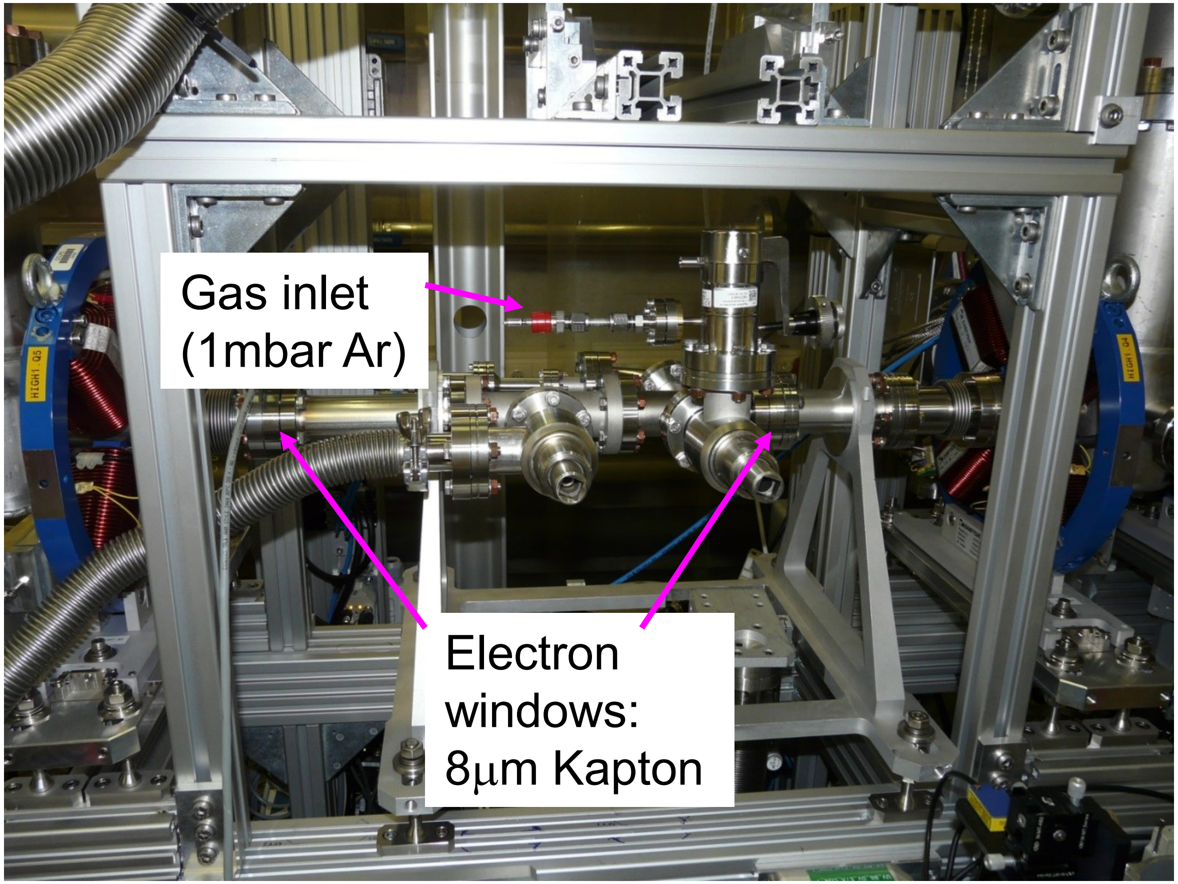
Backup

Beam Line Remodeling



Pre-experiment #2: Dummy Plasma Cell

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



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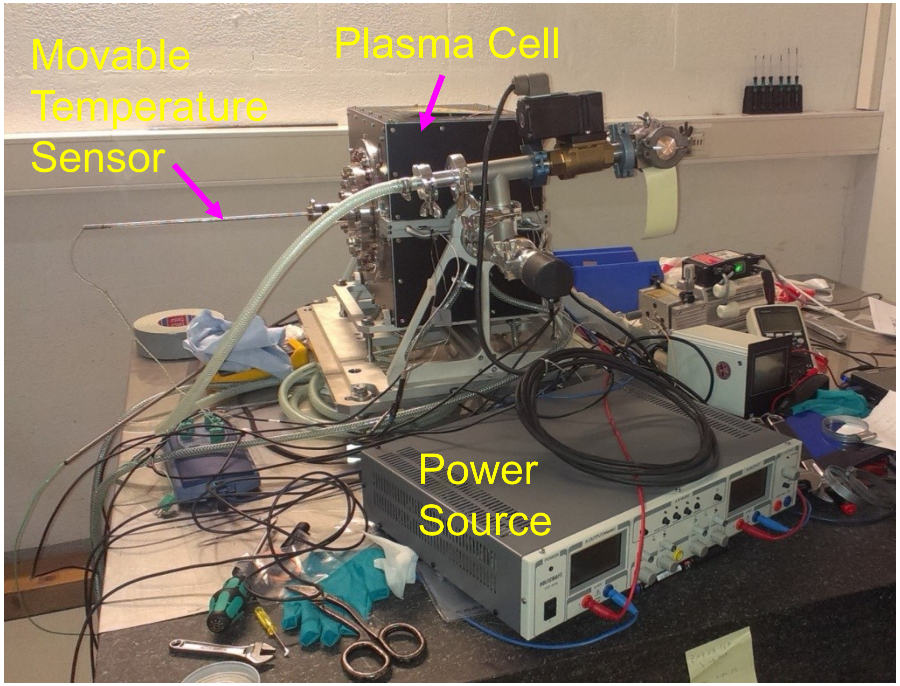
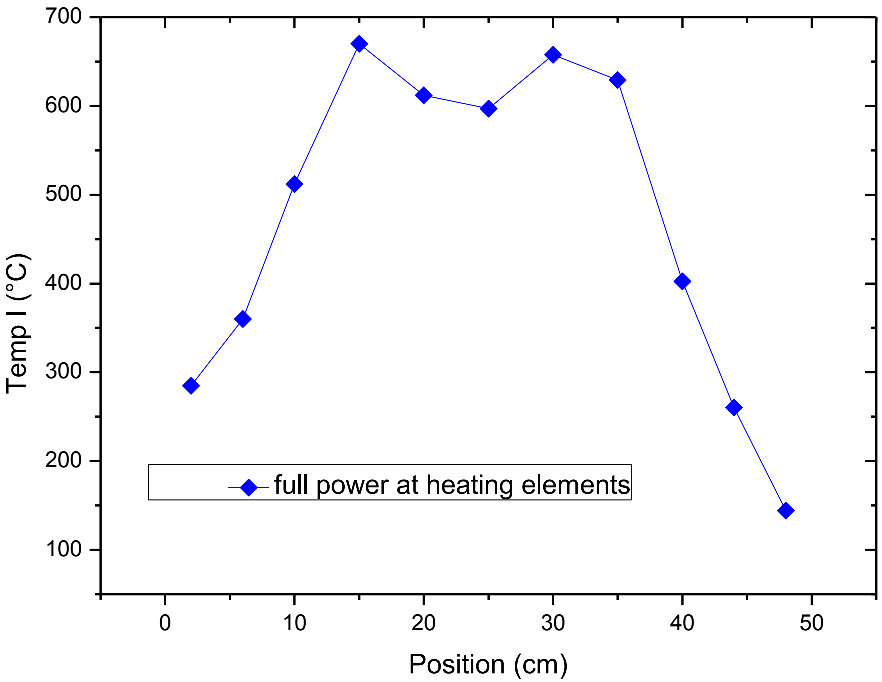
Commissioning of PITZ Plasma Cell

> Measurement of longitudinal temperature profile

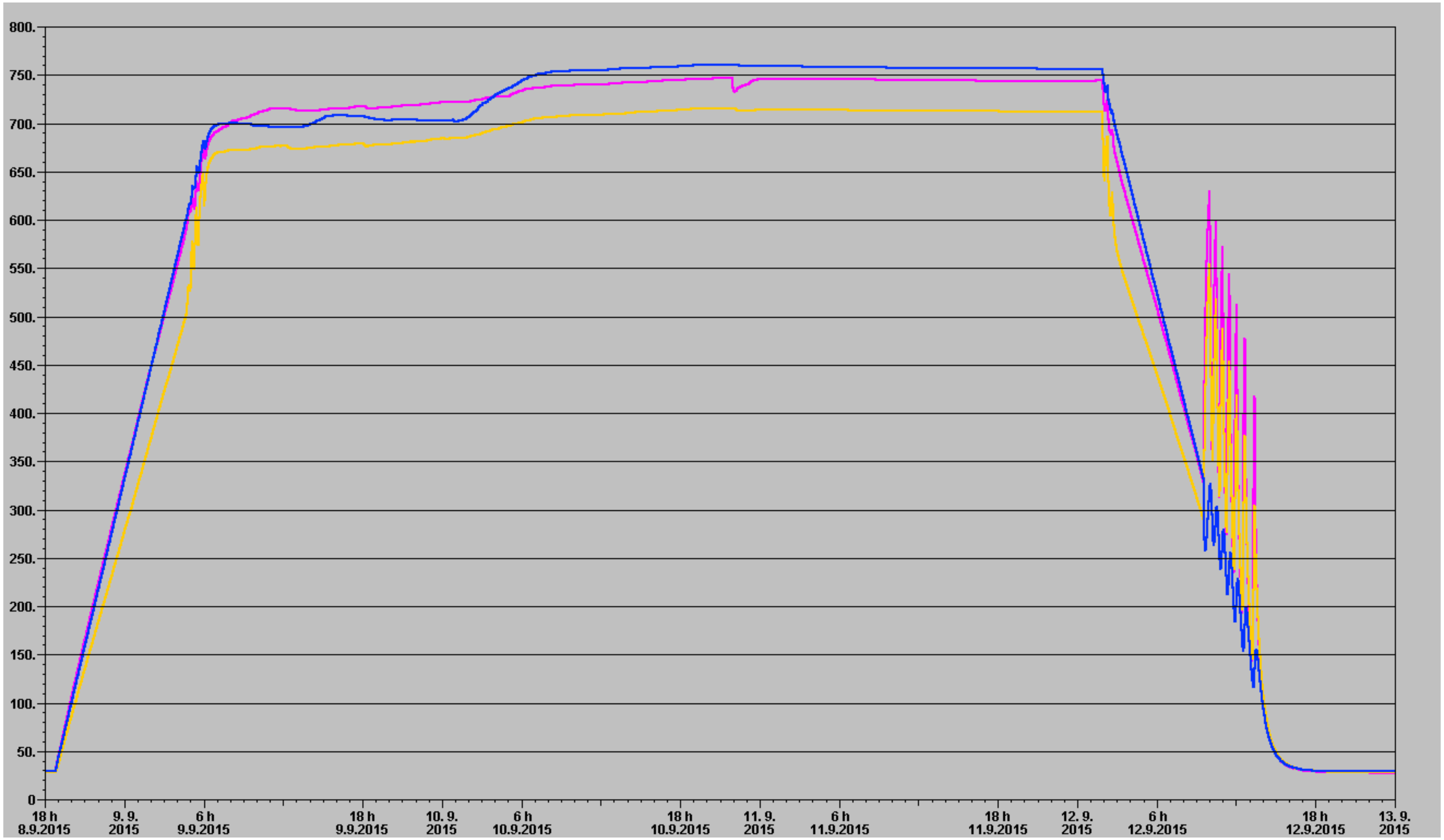
- Preliminary results





- Maximal temperature ≈700°C → enough to reach Li gas density of $\approx 10^{16}$ cm^{-3}
- Temperature dip: influence of cross-shaped plasma cell

Plasma cell temperature history



Theory: Multiple Coulomb Scattering

- From: Claus Grupen “Teilchendetektoren”: Multiple Coulomb Scattering

The rms of the projected scattering angle distribution:

$$\theta_{rms} = \frac{13.6MeV}{\beta pc} z \sqrt{\frac{x}{X_0}} \left[1 + 0.038 \ln\left(\frac{x}{X_0}\right)\right]$$

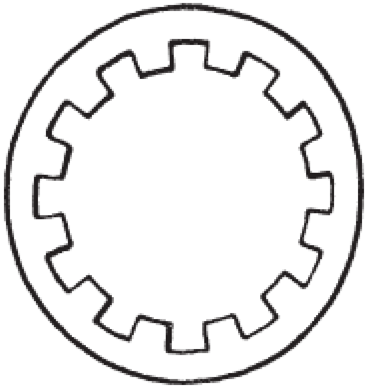
$$\beta pc = 22MeV;\ z = 1;\ X_0 = 0.28m$$

- Important: Radiation length X_0
  - Gold: 0.3 cm
  - Kapton (Polyimide): 28.6 cm
  - Beryllium: 35.3 cm
  - Polyethylene: 50.3 cm

Heat pipe: transport limitations

Table 3: Heat pipe transport limitations

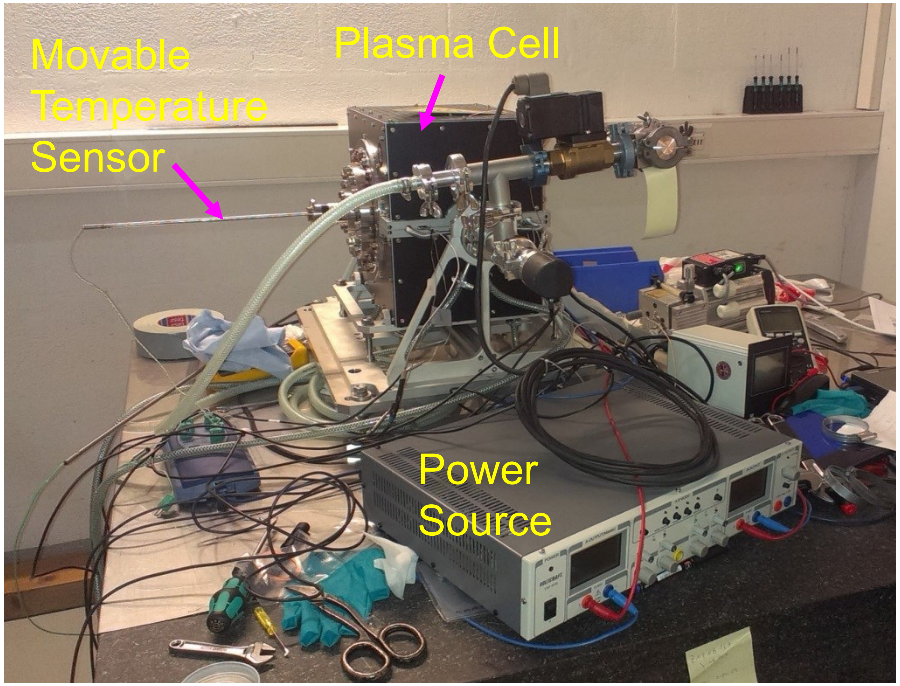
Limitation	Mesh screen	Axial grooves
Capillary limitation	1282.1 Pa > 172.1598 Pa	4230.7 Pa > 41.8974 Pa
Sonic Limit	635.25 J/s	676.66 J/s
Entrainment Limit	2457 J/s	5422 J/s
Boiling Limit	4.387×10^6 J/s	5.7295×10^7 J/s
Viscous Limit	1043 J/s	1198.7 J/s

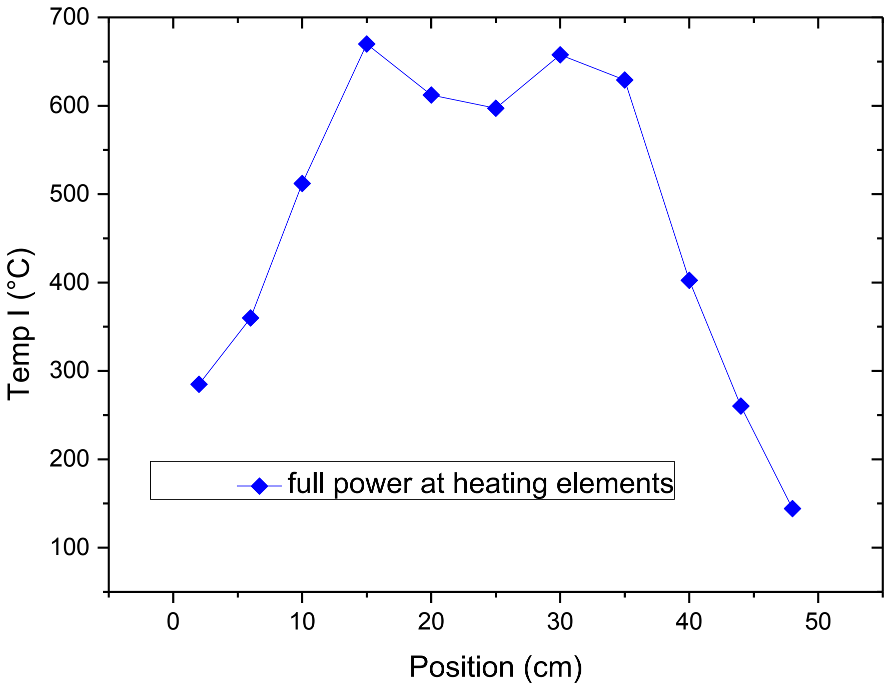


PITZ Plasma Cell preparation

> Measurement of longitudinal temperature profile

- Preliminary results





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