LAOLA@PITZ Experiment: Current Status

Plasma cell, Ionization laser, Diagnostics

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LAOLA Workshop
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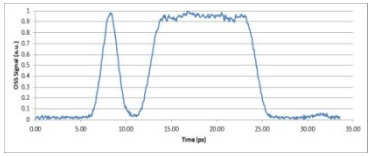
HELMHOLTZ ASSOCIATION

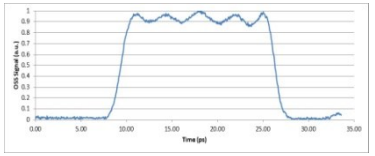
DESY

LAOLA @ PITZ: Studies for Particle Driven Plasma Acceleration

1) Self-modulation of electron beam (proof of principle for CERNs AWAKE exp.)

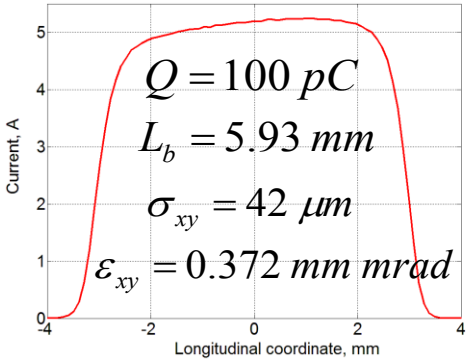
- use high flexibility of photo cathode laser system:



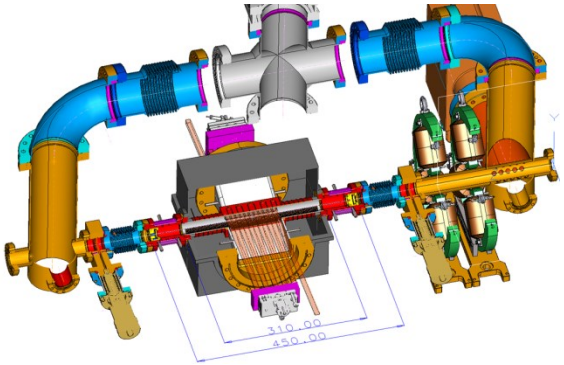


- **Example: flat-top e-beam through plasma cell:**

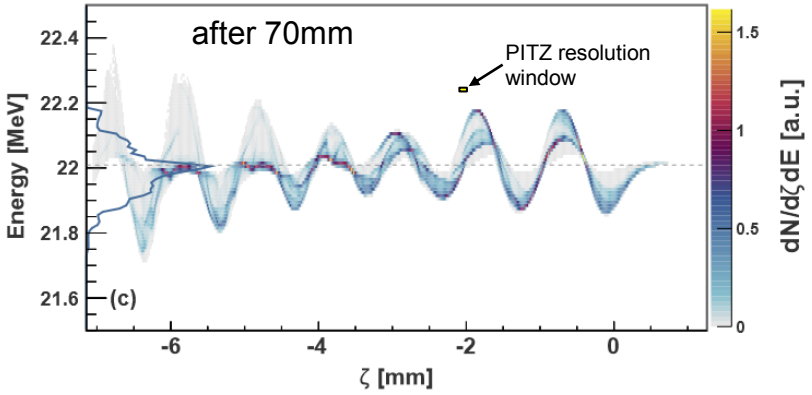
Bunch 6.35m from cathode:



Peak density ≈10^{13} e^-/cm^3



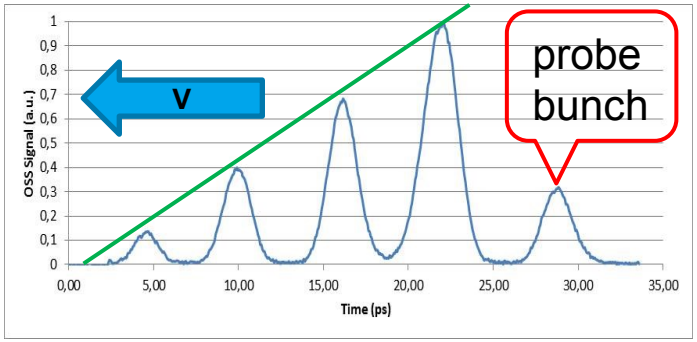
Plasma density ≈$10^{15}/cm^3$



2) Study high transformer ratio

- resonantly drive plasma wave with specially shaped electron bunch (5 bunchlets inside the bunch)

→ high transformation ratio:



to be sent to bunch compres-sor

Lithium Plasma Cell

- Principle:
  - Evaporate Lithium in central pipe (700°C)
  - Define beginning and end of Lithium zone with steep temperature gradient and Helium buffer gas
  - Once pressure regions have stabilized:
    - Ionize Lithium gas with laser
    - Inject particle beam for PWA experiment

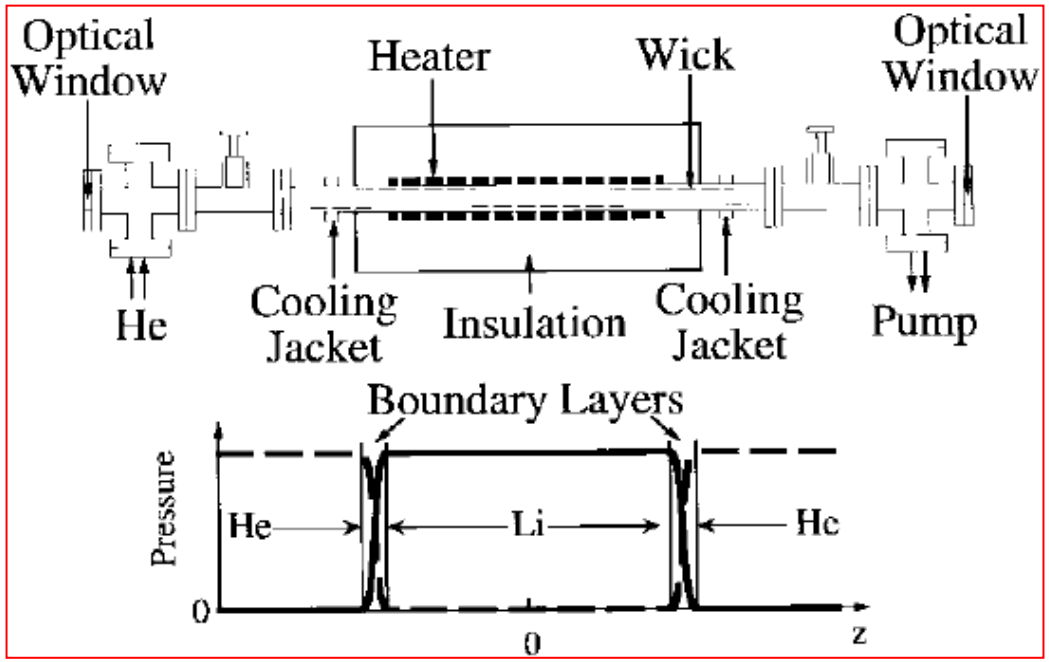
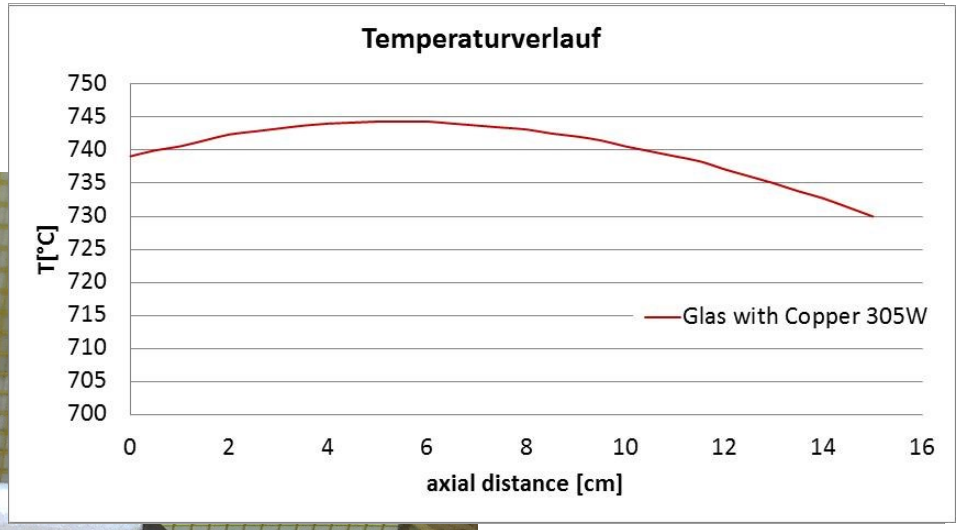
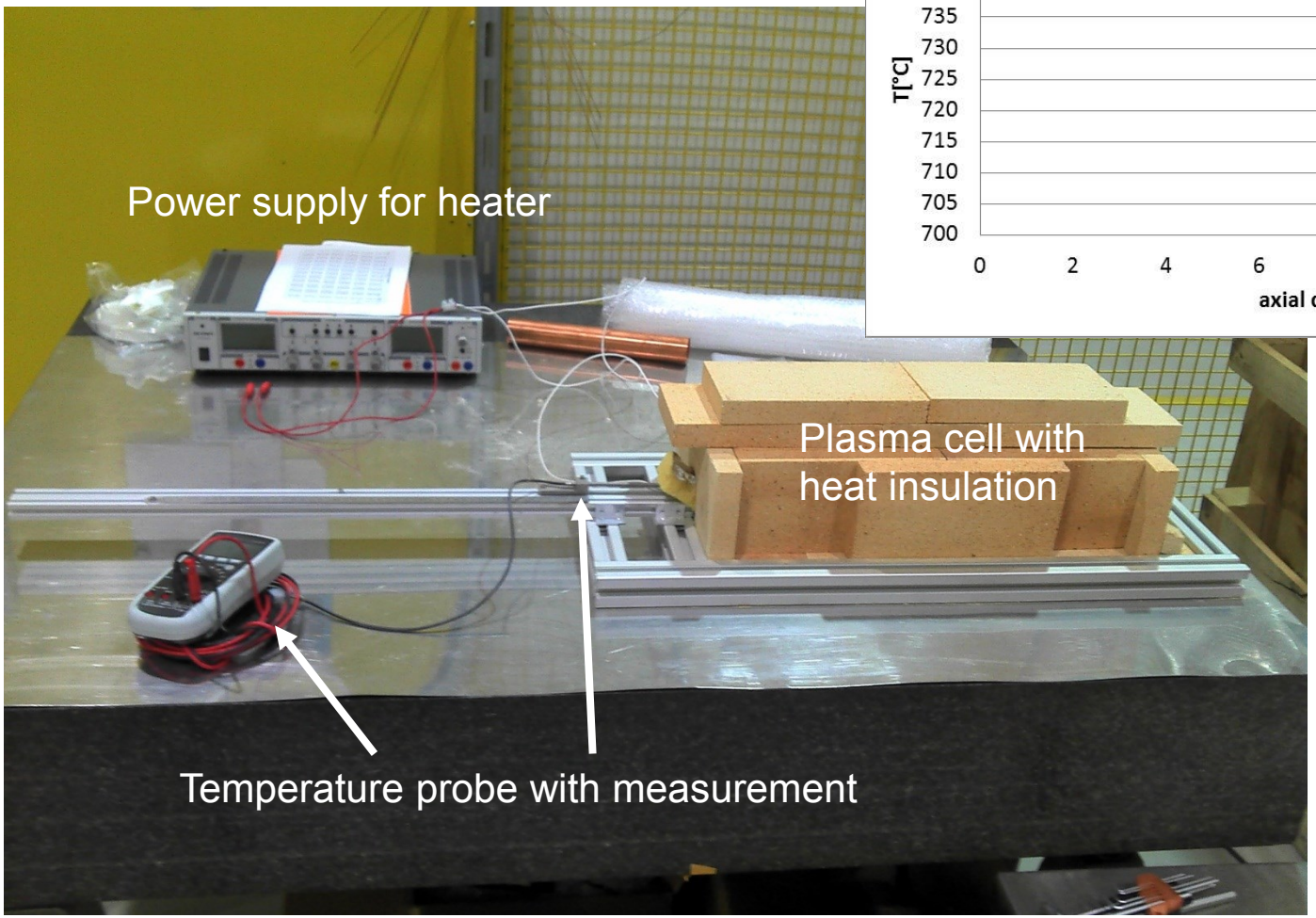


Figure from: P. Muggli et al. “Photo-Ionized Lithium Source for Plasma Accelerator Applications”, *IEEE Trans. Plasma Science* **27** (1999), pp. 791-799

Experiments have started with Plasma Cell Prototype

- First: Measurement of temperature profile with air in plasma cell tube





- Copper tube helps to homogenize temperature distribution: ±2°C (<1%) over 10cm
- Temperature is high enough: need ≈650°C in PITZ experiment

Ionization Laser for Plasma Cell Experiment at PITZ

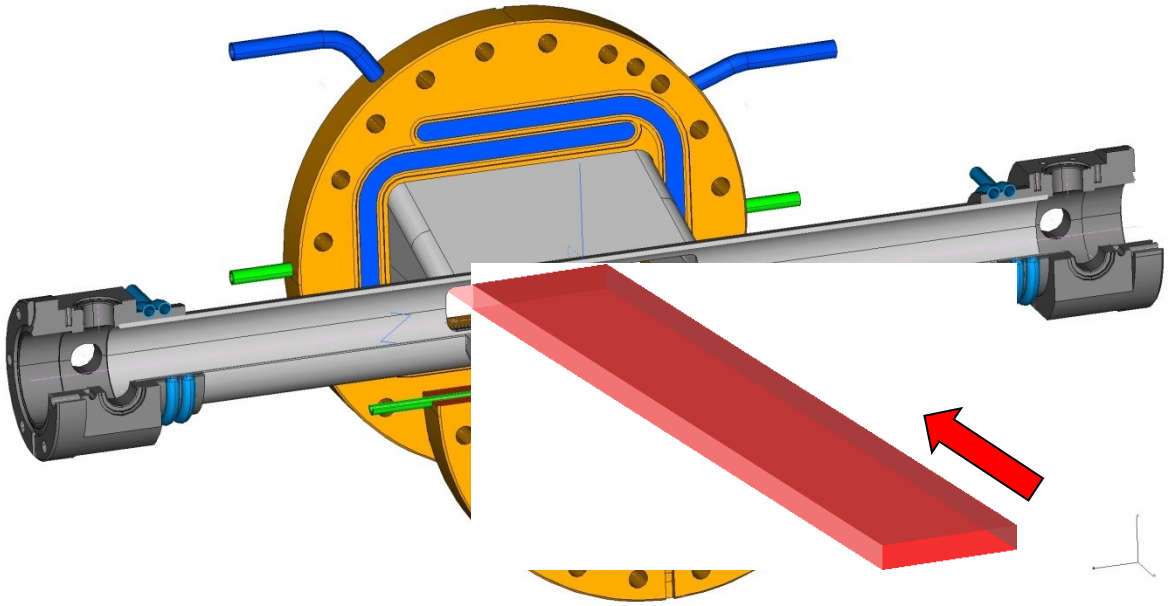
	COMPexPro 201	CENTAURUS
Manufacturer	Coherent	Amplitude
Type	ArF	Ti:Sa
Wavelength	193nm	785nm
Repetition rate	max. 10 Hz	10 Hz
Max. pulse energy	400 mJ	100 mJ → peak power 1 TW*
Pulse duration	typ. 25 ns	<100 fs (typ. 85 fs)
Pulse to pulse stability	<1% rms	<2% rms

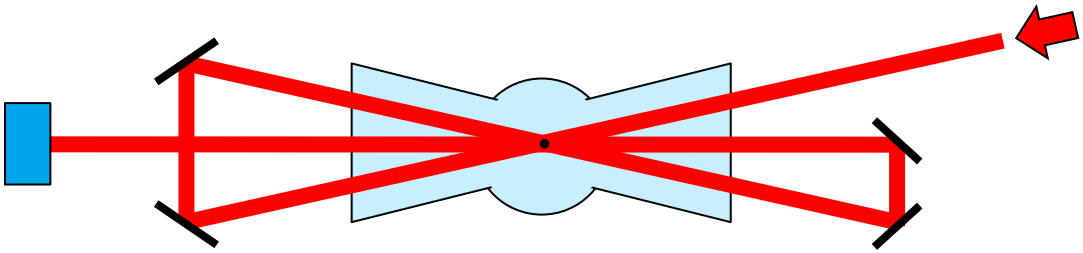
	COMPexPro 201	CENTAURUS
Pointing stability	±20 µrad	±2.5 µrad
Timing jitter	<100 ns	10 ns
Beam profile	Multimode 24mm x 10mm	Single mode $M^2 < 1.5$
Dimensions	168x38x79 cm^3	165x120x30 cm^3 on optics table
Periphery	Gas Panel	Electronics Rack
Price	86k€…92k€	330k€…350k€
Lead time	2..3 months	5..6 months

* Laser is modular – peak power can be increased to 2 TW by upgrading pump laser (30 k€)

Ionization laser coupling: ArF

- Homogeneous plasma by single beam side coupling
- Increase plasma density by multiple passes
- Estimation:
  - Li density 10^{16} cm^{-3}
  - Pulse energy 100mJ
  - Plasma channel: 1cm high, 6cm long
  - Need 3 to 4 passes to achieve plasma density of about 10^{15} cm^{-3}

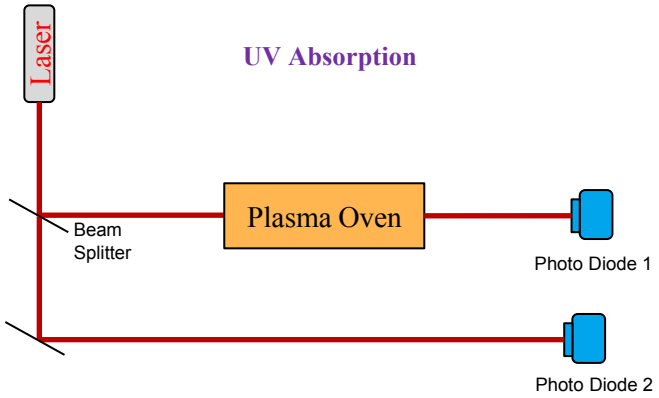




Neutral Density Measurements

A. UV Absorption

- A low energy laser pulse of 5.83eV (UV) photons will be sent along the heat pipe oven axis ionizing the Li vapor through a single-photon process.
- A line-integrated neutral density $n_o L$ can be calculated by measuring the ratio of transmitted to incident UV energy



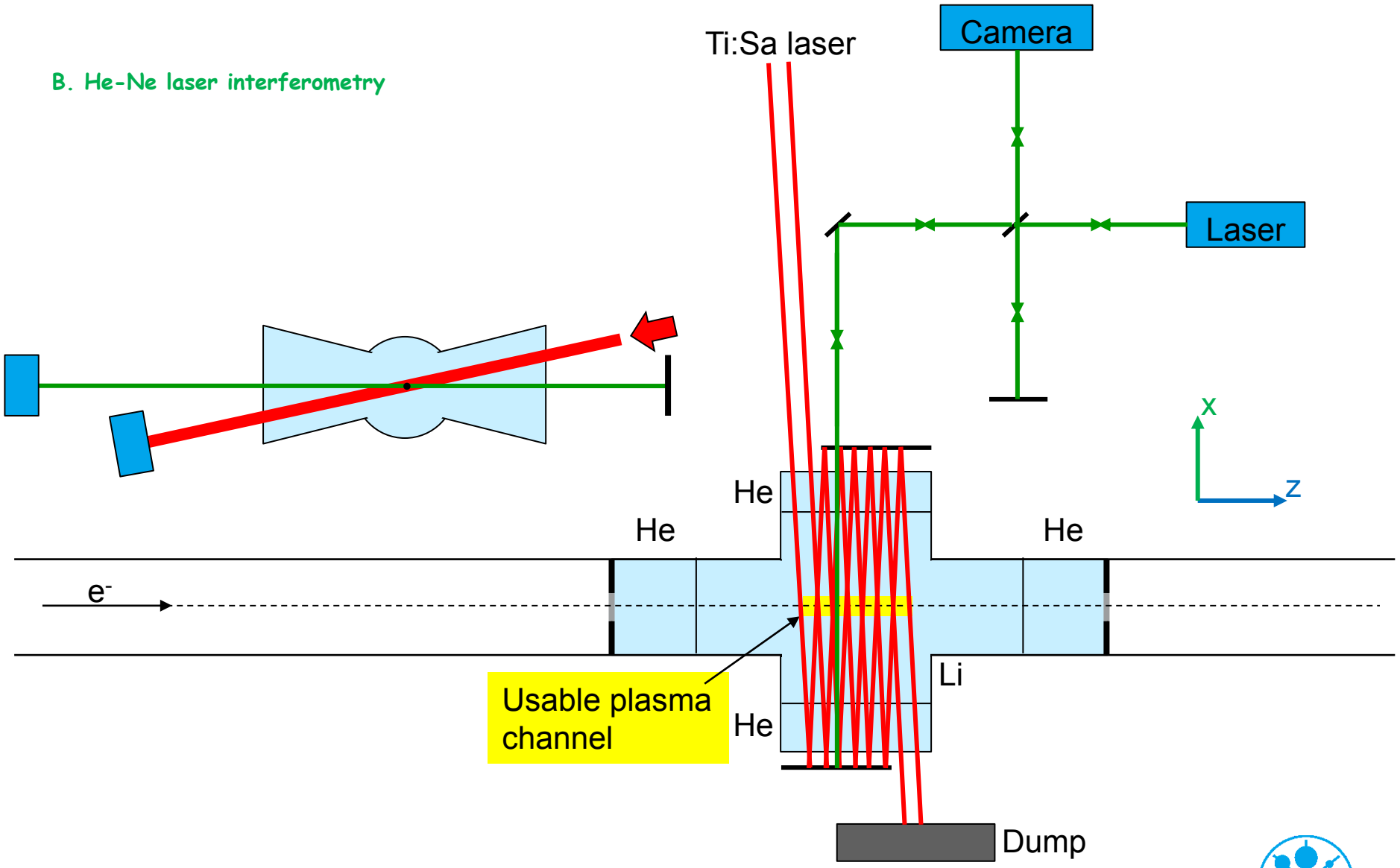
$$n_o L = -\frac{1}{\sigma} ln\left(\frac{E_{transmitted}}{E_{incident}}\right)$$

Where n_o = neutral density, L = Plasma column length,
$\sigma = 1.8 \times 10^{-18} cm^{-2}$ is the ionization cross section for $h\nu = 5.83eV$

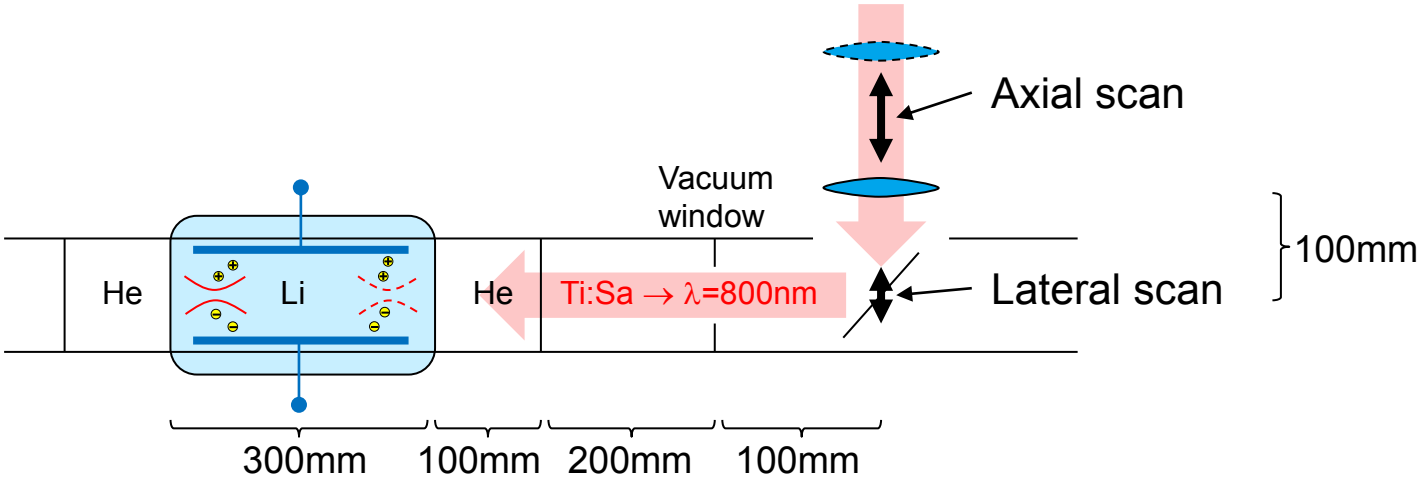
- Many shots would be required at each oven temperature and the ratio should be averaged for statistical interpretation of the outcome.

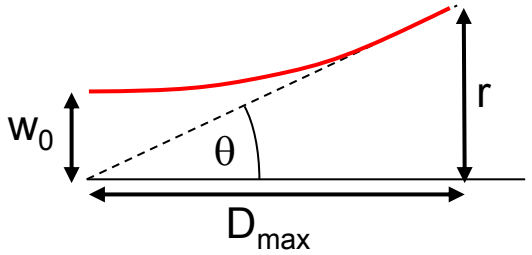
Plasma Density Measurements

B. He-Ne laser interferometry



Plasma Diagnostics with Ti:Sa Laser





- Assume: Gaussian beam
  - D_{max} = (300+100+200+100+100)mm = 800mm
  - r = 5mm (half diameter of vacuum window – worst case: put at D_{max})
  - $\rightarrow \theta_{max}$ = 6 mrad
  - Lateral resolution: $2w_{0,max} = 2\lambda/\pi\theta \approx 80\mu m$
  - Calculation of axial resolution also leads to value <100μm
- **High resolution 3D measurement possible**

Time Plan for Plasma Cell Experiments (Self Modulation)

- Design of plasma cell (could be preliminary) — ongoing – Jun 2013
  - Mechanical structure including gas feed, heating coils, water cooling
- Construction of plasma cell — Jul – Aug 2013
- Setup of experiment in lab — ongoing – Sep 2013
  - Lithium filling
  - Test of diagnostics
- Lab experiments — Oct – Dec 2013
- Setup of experiment in PITZ tunnel — Jan – Feb 2014
- Beamline experiments — Mar 2014 – Jun 2015
  - Requirements: Availability of
    - Gun (Conditioning and Characterization work for FLASH, E-XFEL)
    - TDS (Startup, calibration)

Summary

- PWA Experiments are planned at PITZ
  - Now: Characterization of electron beam self modulation
  - Later: High transformer ratio
- Utilization of good diagnostics and unique laser system
- Currently:
  - First experiments with plasma cell prototype
  - Design of plasma cell with sideports
- Diagnostics considered at PITZ
  - UV absorption (1D gas density)
  - Interferometry (1D gas and plasma density)
  - Localized ionization (3D gas density)