Studies for Particle Driven Plasma Acceleration at PITZ

Experiments planned utilizing PITZ (Photo Injector Test facility at DESY, Zeuthen site)

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EAAC 2013 workshop

3.-6. June 2013

HELMHOLTZ ASSOCIATION

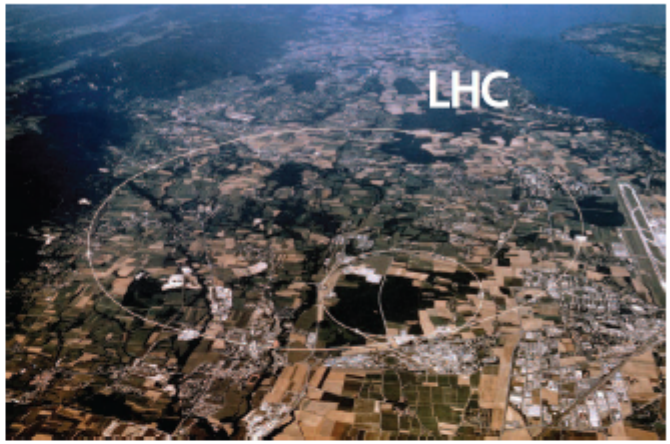
PITZ Photo Injector Test Facility Zeuthen

DESY

Background

Background: Proton-driven PWFA experiment proposed at CERN:

- Use high energy proton beams to drive wake (plasma wave)
- Convert proton beam energy into e^- or e^+ beam in a **single** stage



Courtesy of Carl Schröder, LBNL

Caldwell *et al.*, Nature Physics (2009); Lotov, PRST-AB (2010)

$\Rightarrow$ high gradient requires high density: $E_z \propto n^{1/2}$

$\Rightarrow$ large wake requires resonance beam: $L_b \sim \lambda_p \propto n^{-1/2}$

$$E_{z,\max} \approx 3\ \mathrm{GV/m} \left(\frac{N_b}{10^{10}}\right) \left(\frac{100\mu\mathrm{m}}{\sigma_z}\right)^2 \ln(\sigma_z/\sigma_r)$$

$\Rightarrow$ high accelerating gradient requires **short** bunches $\sigma_z \lesssim 100\ \mu$m

$\Rightarrow$ existing proton machines produce **long** bunches $\sigma_z \sim 10$ cm

- Use beam-plasma instability to modulated the beam at λ_p, driving large plasma waves for acceleration Kumar *et al.*, PRL (2010); Lotov, Phys. Plasmas (2011)

Does this work ?
→Dephasing ?
→Hose instability ?

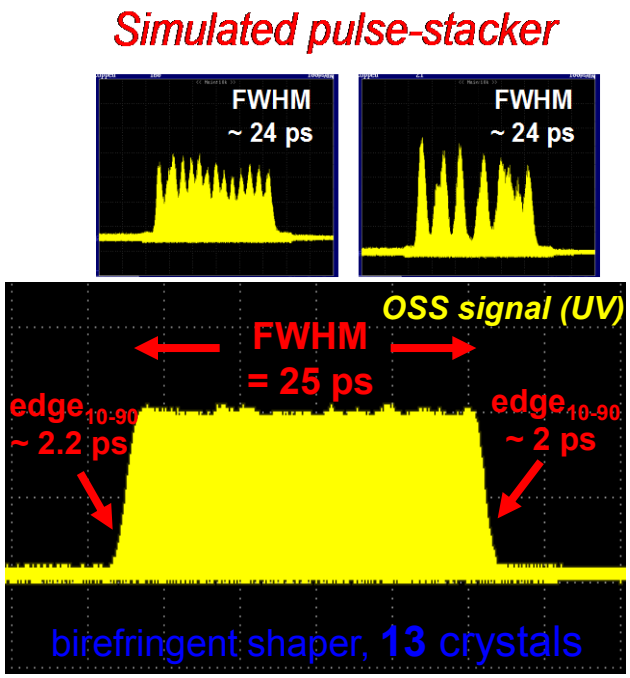
DESY

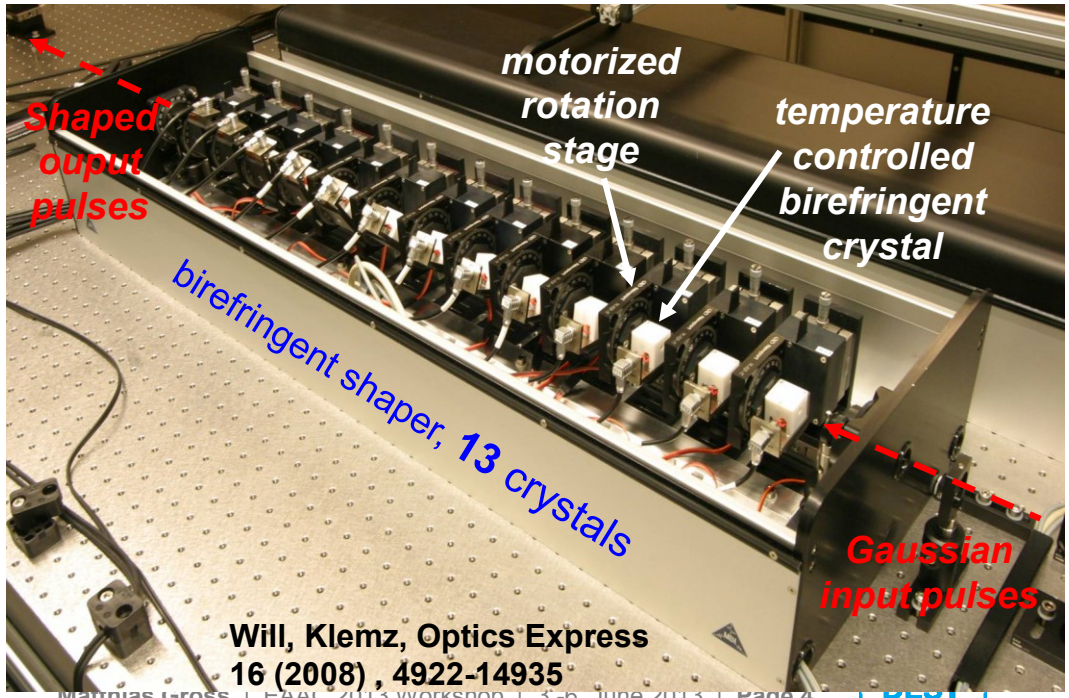
Why Experiments at PITZ?

- Favorable circumstances
  - Pure R&D facility (no users)
  - Unique laser system (pulse shaper)
  - Well developed diagnostics (high resolution electron spectrometer, etc.); soon: transverse deflecting cavity + dispersive section for longitudinal phase space measurements
- Possible contribution from PITZ:
  - Self modulation of electron beam
  - Later: High transformer ratio (needs bunch compressor)

Flexible Laser Pulse Formation at PITZ

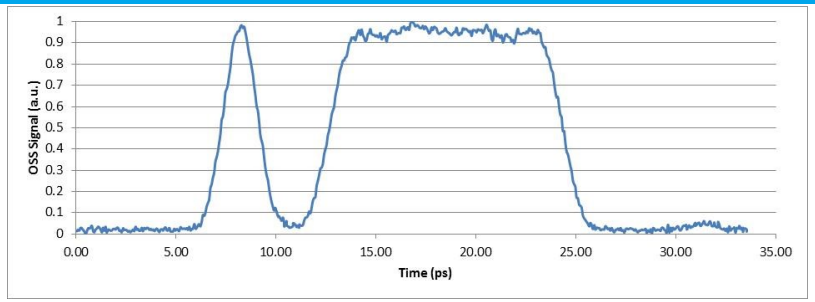
- Photoinjector laser
- Developed and built by Max-Born Institute Berlin
- Key element: the pulse shaper
  - Contains 13 birefringent crystals. Pulses are split according to polarization. Delay is given by crystal thickness; relative amplitude can be varied freely by adjusting relative angle between crystals

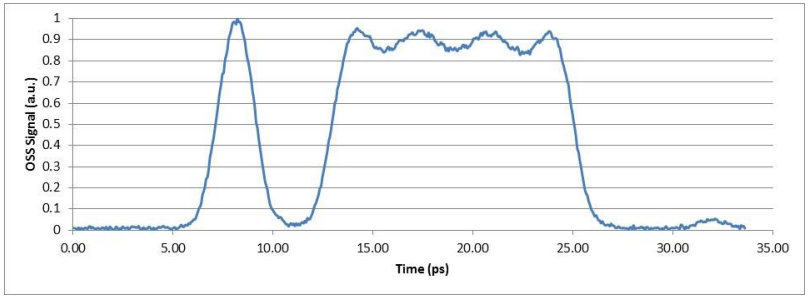


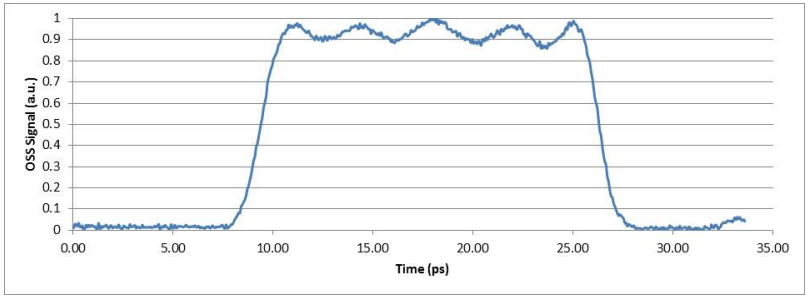


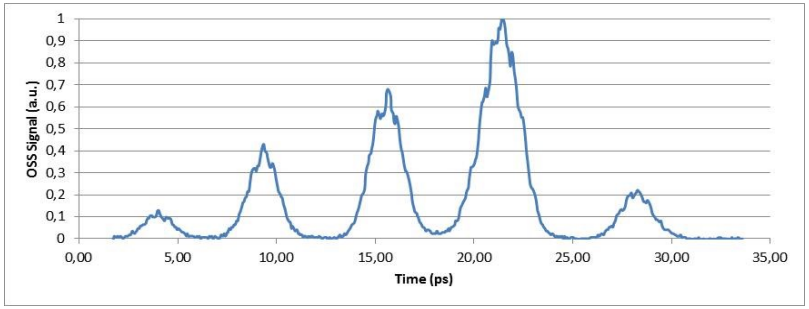
Experimentally Demonstrated Pulse Shapes

- Driver + witness bunch
- Modulated driver + witness bunch
- Modulated driver
- Multi bunches



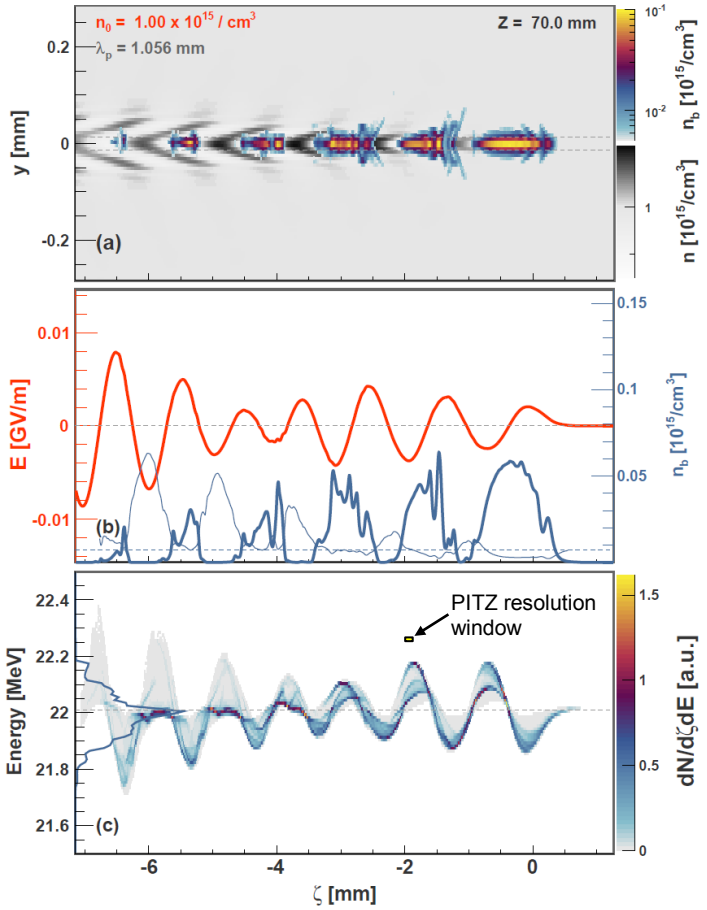






3D PIC (Particle in Cell) Simulation of PITZ Experiment

Beam parameters	Setup 1
Total charge, pC	100
Longitudinal beam position, m	6.44
Horizontal rms beam size, um	42.0
Vertical rms beam size, mm	42.0
Bunch length in FWHM, mm	5.93
Average kinetic energy, MeV	21.5
Peak slice current, A	5.3
Horizontal rms emittance, mm mrad	0.372
Vertical rms emittance, mm mrad	0.372
Peak beam density, 10^13 e / cm^3	1.9

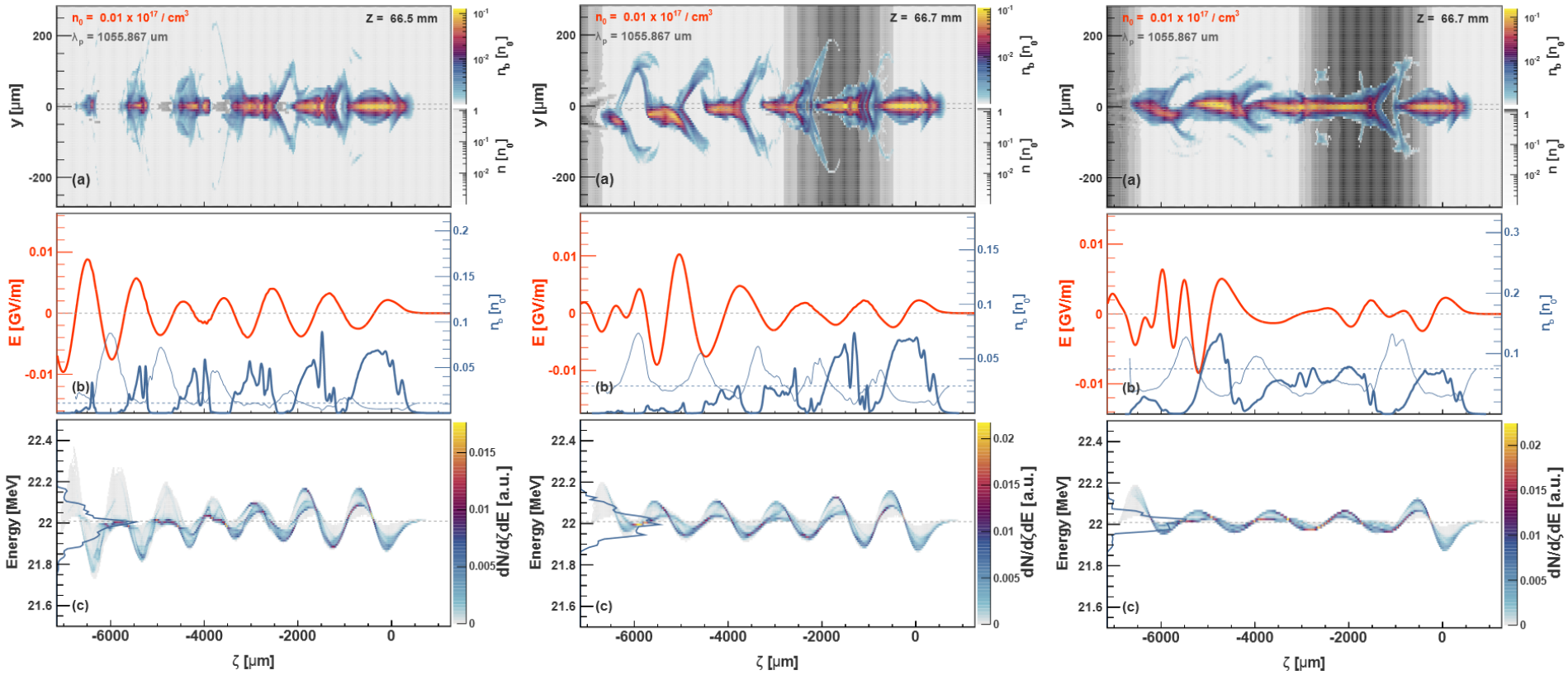


> Expected energy modulation ≈400 keV. PITZ beam energy spread as low as ≈60keV. Resolution of TDS/HEDA2: 10keV and 100μm (Malyutin et al. "Simulation of the Longitudinal Phase Space Measurements With the Transverse Deflecting Structure at PITZ", *Proc. of IPAC 2012, MOPPP034* → Measurable

Simulations:
Alberto Martinez de la Ossa

Summary panel

$\Delta n_f = 0$ $\Delta n_f = 0.25$ $\Delta n_f = 0.5$



Length of plasma: L_p = 66.5 mm

- Self modulation still well visible at 25% perturbation amplitude, strongly suppressed at 50%

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

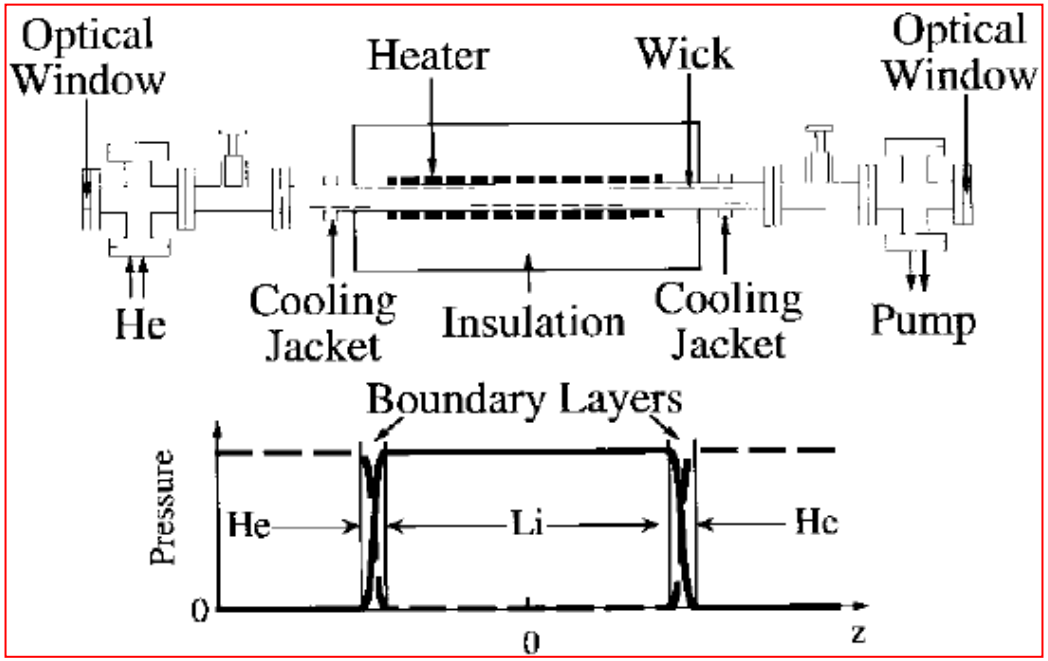


Figure from: P. Muggli et al. “Photo-Ionized Lithium Source for Plasma Accelerator Applications”, *IEEE Trans. Plasma Science* **27** (1999), pp. 791-799

Ionization Laser for Plasma Cell Experiment at PITZ

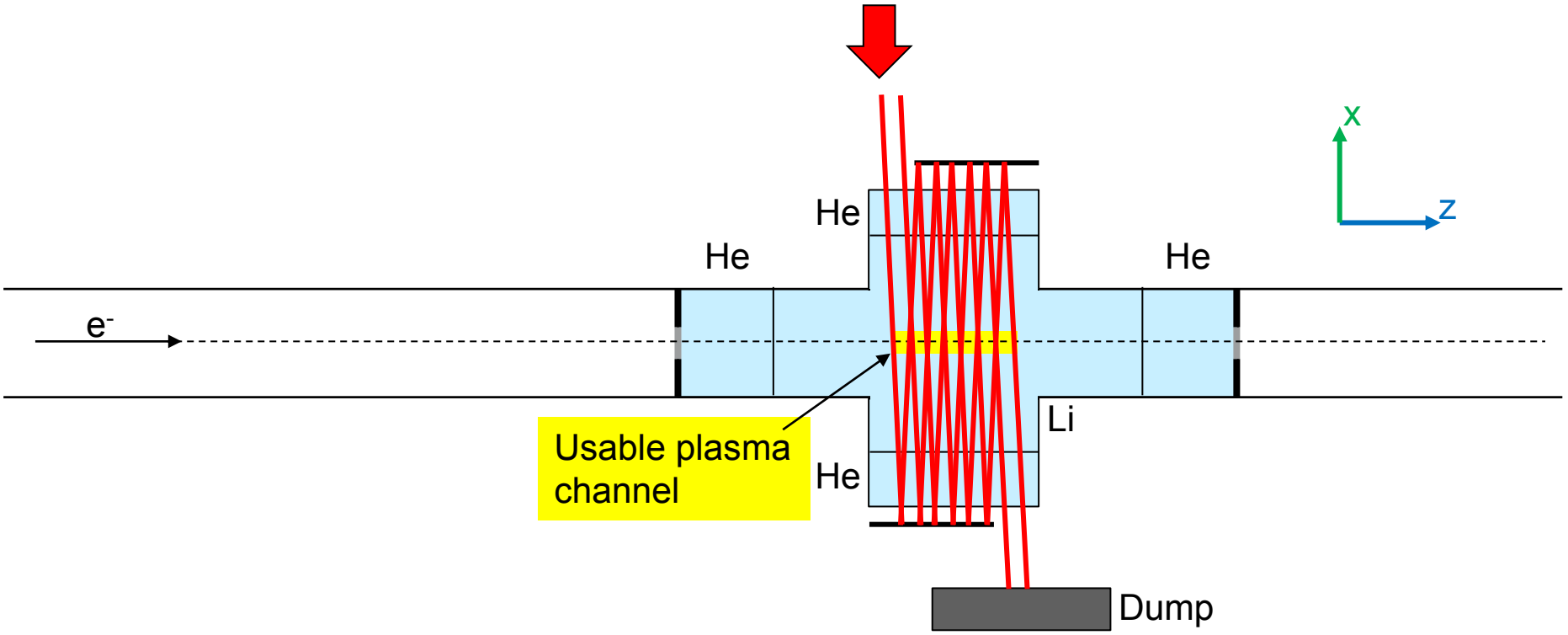
	COMPexPro 201	CENTAURUS
Manufacturer	Coherent	Amplitude
Type	ArF	Ti:Sa
Wavelength	193nm	785nm
Repetition rate	max. 10 Hz	10 Hz
Max. pulse energy	400 mJ	100 mJ → peak power 1 TW*
Pulse duration	typ. 25 ns	<100 fs (typ. 85 fs)
Pulse to pulse stability	<1% rms	<2% rms

	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€)

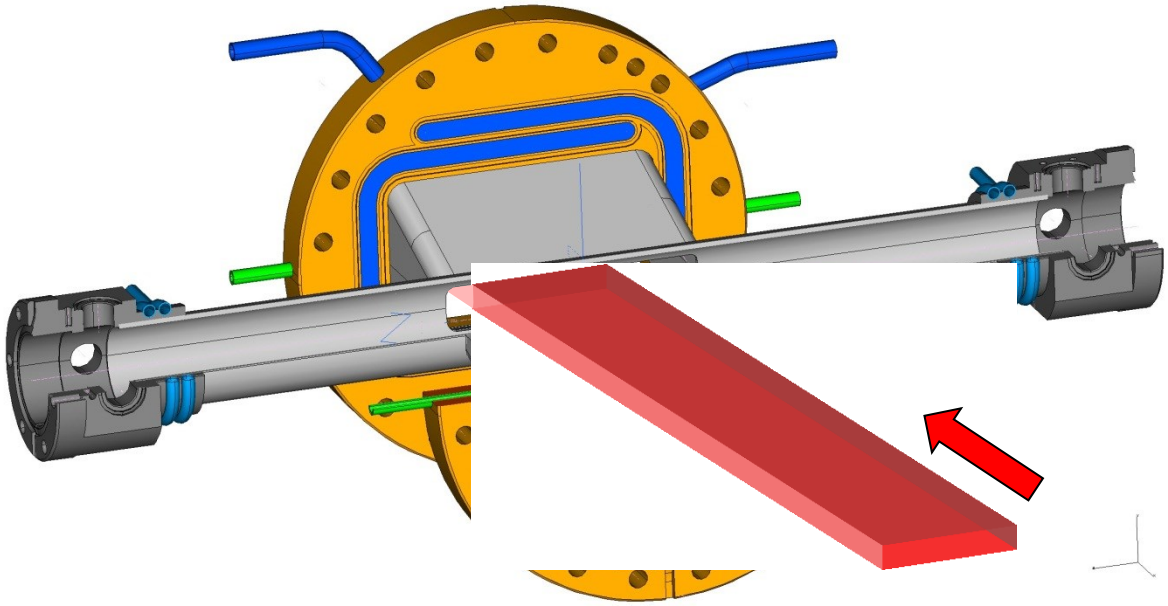
Plasma Ionization –Side Coupling

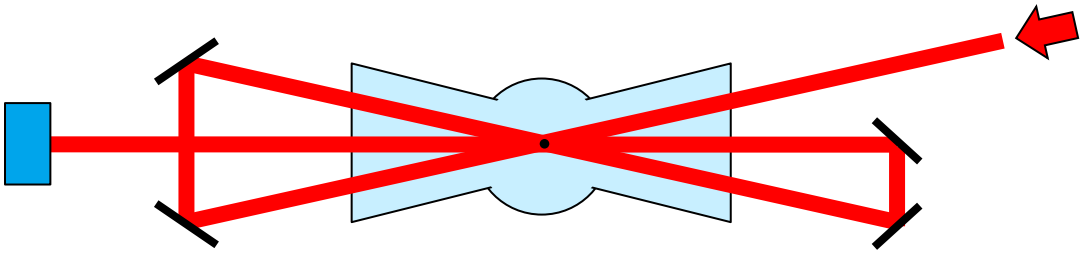
- Independent optimization of electron and laser paths possible
- Setup:



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}





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
- Plasma diagnostics — May – Jun 2013
  - Vacuum feedthrough for temperature sensor
- 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)