A Laser Ionized Plasma Source for Plasma Wakefield Accelerators

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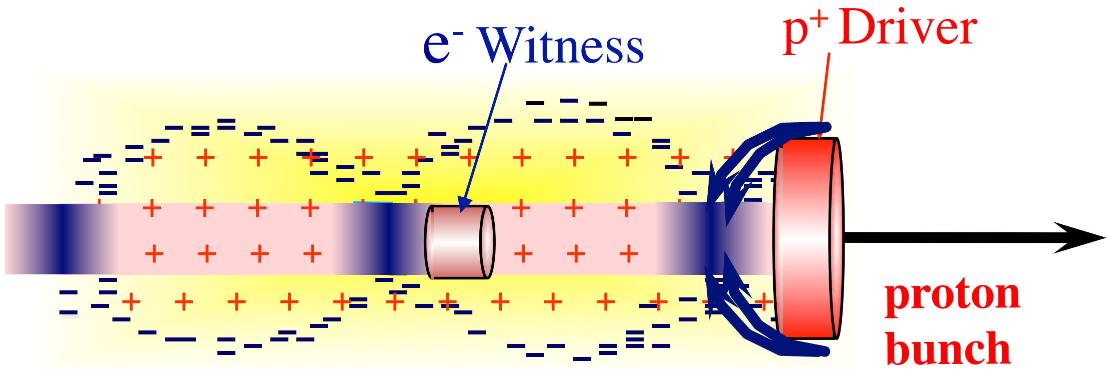
P^+-Driven Plasma Wakefields



- **Wake amplitude** $\boxed{\propto N_b/\sigma_z^2}$ $\left(\boldsymbol{for\ 2\sigma_z \approx \lambda_p \propto \frac{1}{\sqrt{n_o}}}\right)$

- Plasma wakefield accelerator uses energy of the driver to accelerate
- Both electron and laser driven schemes rely on staging, since there is not enough energy to drive an e^-/e^+ to TeV scale. SLAC-like driver for staging (FACET= 1 stage, collider 50^+ stages)

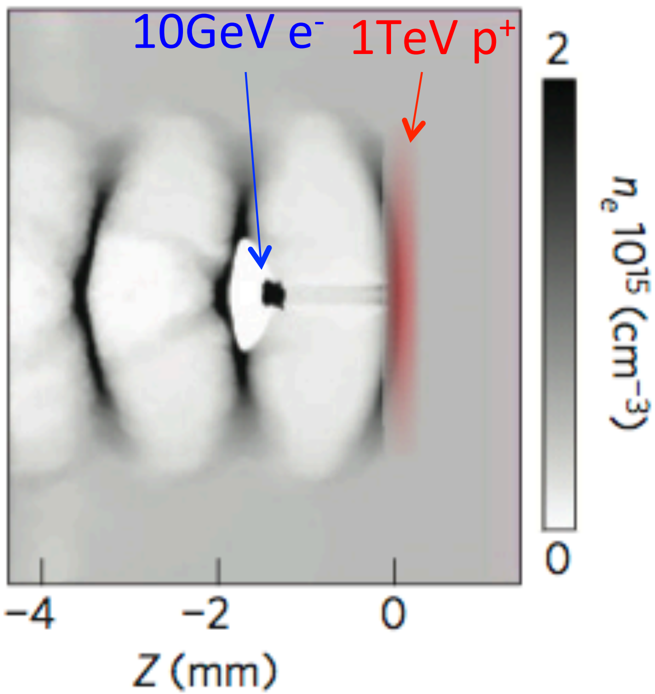
- Proton beams carry much more energy
- CERN SPS ring, 400GeV bunch with $3\text{x}10^{11}p^+$ ~19.2kJ energy compared to a SLAC e bunch ~60 J
- CERN LHC ring, 7 TeV bunch with $10^{11}p^+$ ~112kJ
- A single bunch from SPS or LHC ring at CERN could produce an ILC bunch in a single PWFA stage!

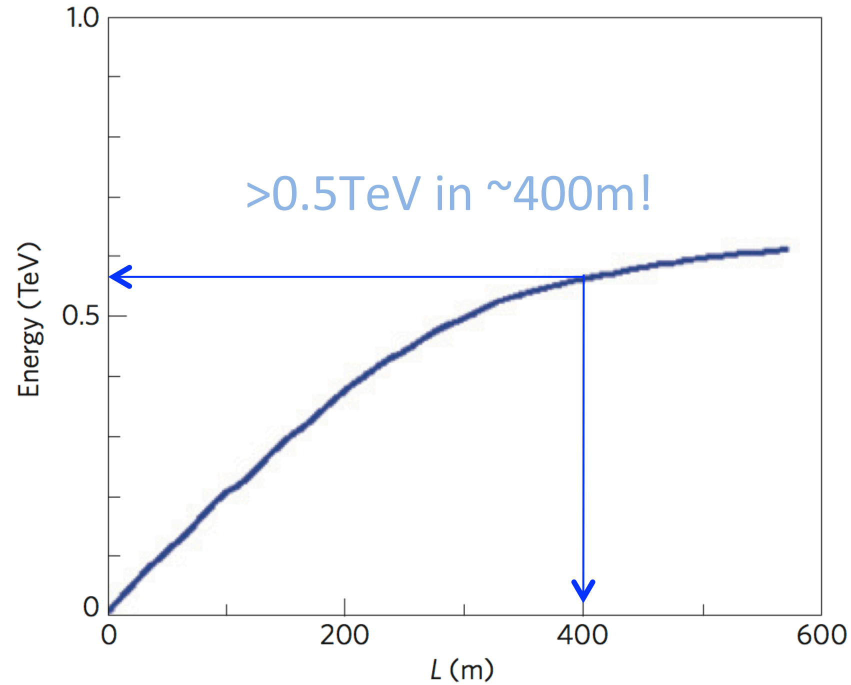
Really?

P⁺-Driven Plasma Wakefields

A. Caldwell, K. Lotov, A. Pukhov, F. Simon Nat. Phys. 5, 363, (2009)

2D Simulations





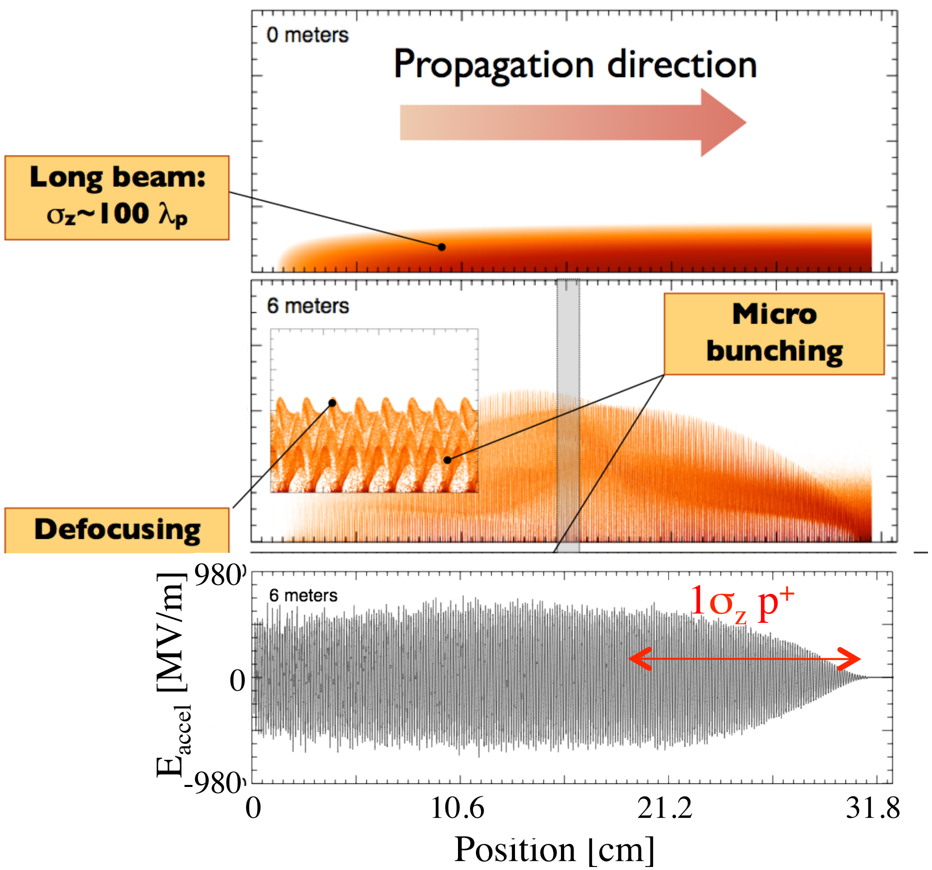
- Loaded gradient ~1.5GV/m
- ILC-like e⁻ bunch from a single p⁺-driven PWFA
- $\sigma_z \approx 100\mu m$ do not exist!

What is the solution?

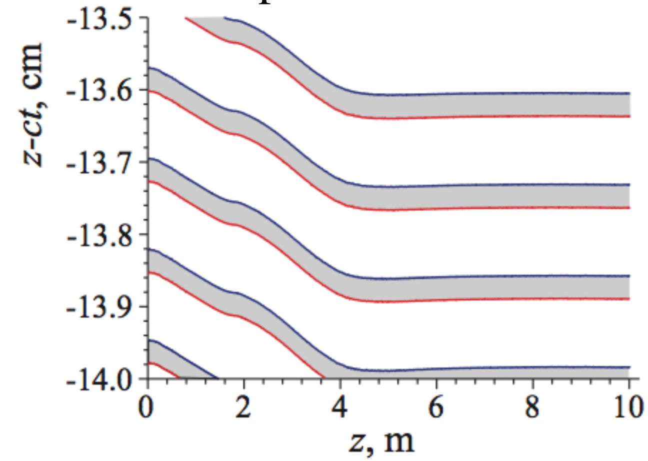
Self-Modulation-Instability (SMI)

- Initial small transverse wakefields modulate the bunch density
- The modulation of the proton density on axis results from the transverse focusing and defocusing field along the bunch.
- Longitudinal wakefields reach large amplitude through resonant excitation
  - SMI of long (~12cm), 450GeV SPS bunch @ $\lambda_{pe} \approx 1.2$mm

Simulations: J. Vieira



- Stable phase after 4 meters



AWAKE

For more on self modulation visit

Prospects for proton-driven plasma acceleration

Presented by **Prof. Allen CALDWELL** on **16 Sep 2015** from **11:30** to **12:00**

Type: invited talk

Session: Plenary 6

Place

Location: Hotel Hermitage

Room: SML Sala Maria Luisa

Primary authors

Allen CALDWELL Max-Planck-Institute

Electron acceleration behind self-modulating proton beam in plasma with a density gradient

Presented by **Alexey PETRENKO** on **16 Sep 2015** from **18:50** to **19:10**

Type: talk

Session: WG1 - Electron beams from plasmas

Track: WG1 - Electron beams from plasmas

Place

Location: Hotel Hermitage

Room: SML Sala Maria Luisa

Primary authors

Self-modulation of long particle beams in plasma wakefield accelerators

Presented by **Prof. Konstantin LOTOV** on **16 Sep 2015** from **18:40** to **19:00**

Type: talk

Session: WG6 - Theory and simulations

Track: WG6 - Theory and simulations

Place

Location: Hotel Hermitage

Room: SB2 Sala Bonaparte 2

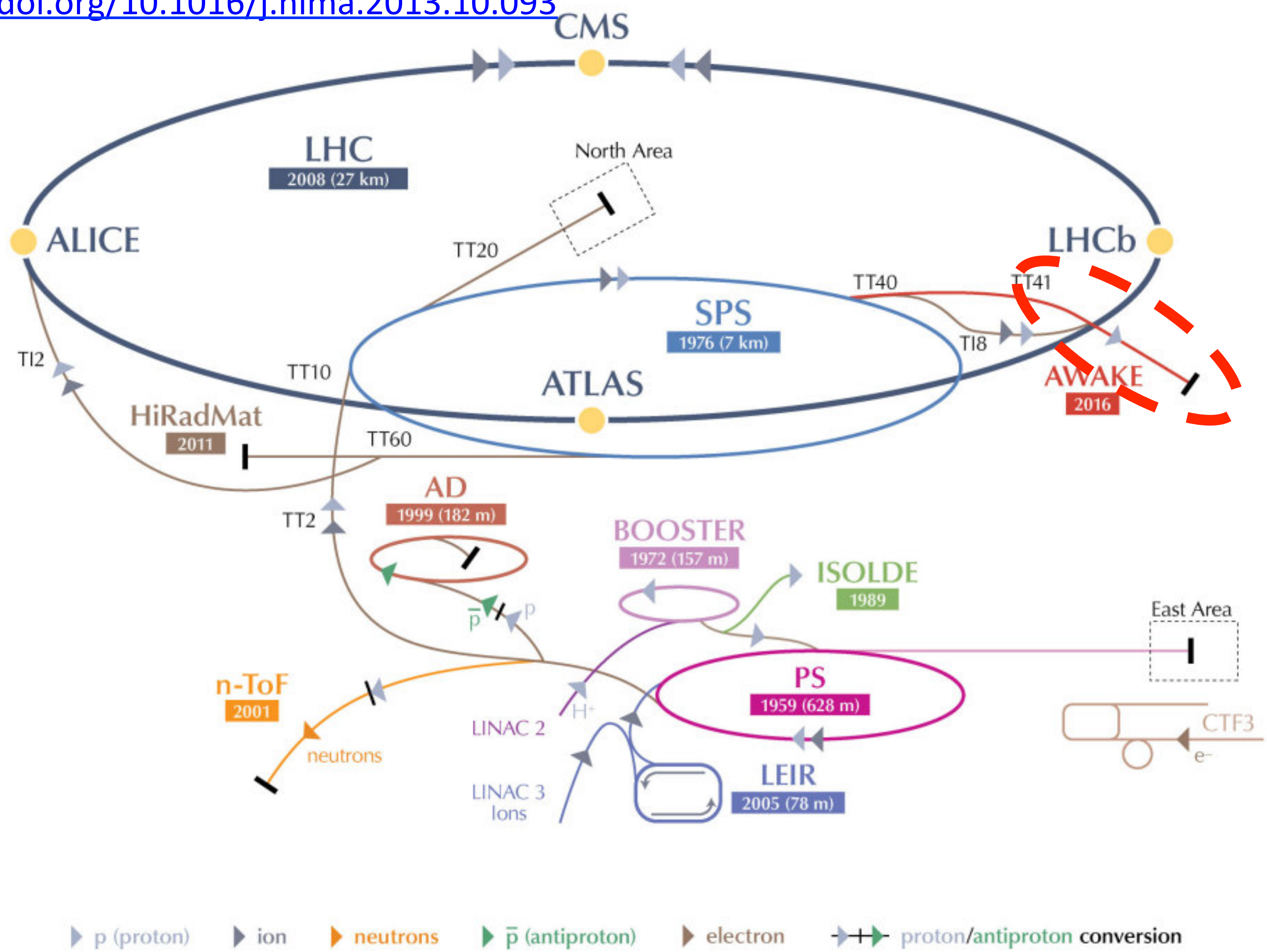
Primary authors

Konstantin LOTOV Novosibirsk State University

More

AWAKE @ CERN

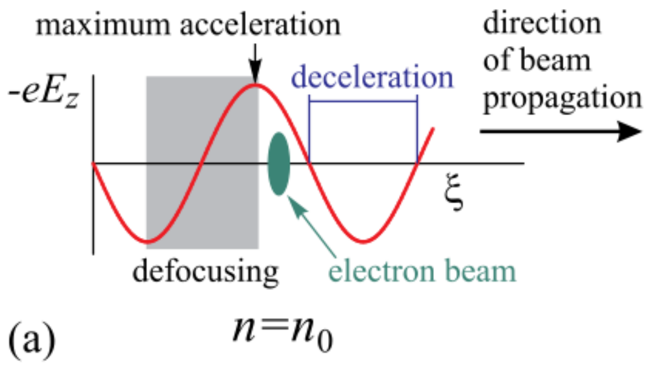
- http://home.web.cern.ch/about/experiments/awake
- http://awake.web.cern.ch/awake/
- http://dx.doi.org/10.1016/j.nima.2013.10.093



Self modulation comes with a price?

Self-Modulation Imposes a Strict Requirement on Density Uniformity (0.2 %)

- The maximum allowed phase shift so that the injected bunch stays in the accelerating and focusing phase of the wake**



$$allowed\ total\ shift : \frac{\lambda_p}{8}$$

$$\lambda_p \alpha \frac{1}{\sqrt{n}} \Rightarrow d\lambda_p = \frac{\lambda_p dn_p}{2n_p}$$

- If the injected bunch is located at Nl_p

$$total\ shift\ at\ N\lambda_p : N\lambda_p \frac{\Delta n_p}{2n_p} = \frac{\lambda_p}{8}$$

$$\therefore \frac{\Delta n_p}{n_p} \le \frac{0.25}{N}; N = 100$$

- for a 12 cm long CERN proton bunch, and optimum plasma density of 7 × 10^14 cm−3 ($\sigma_z \approx 100\lambda_{pe}$)

$$\frac{\Delta n_p}{n_p} \le 0.0025$$

For 0.1-1 × 10^15 cm−3 we require: $\frac{\Delta n_p}{n_p} \le 0.002$

How do we create such a uniform Plasma?

*Investigated both numerically and theoretically (N. Kumar, A. Pukhov, and K. V. Lotov, Phys. Rev. Lett. 104, 255003 (2010)).
** Phys. Plasmas 20, 013102 (2013); http://dx.doi.org/10.1063/1.4773905

Overview of the Plasma Source

- For a gas in a closed system density uniformity is equal to temperature uniformity

T T T T

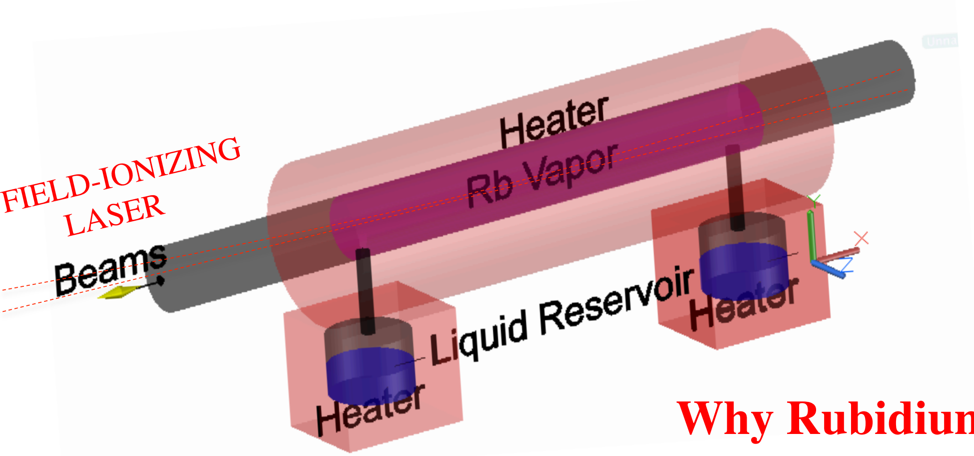
$$\boxed{\frac{\Delta n}{n} = \frac{\Delta T}{T} \leq 0.002}$$

- Solution to density uniformity is to provide uniform temperature
- plasma source length is chosen to be 10 m source

in order for Self Modulation Instability to reach Saturation (~4 m) and to demonstrate high electron acceleration (>1 GeV)

- Plasma radius (1 mm) and density (~10^{15} cm^{-3}) is chosen in order to satisfy
  $k_{pe}\sigma_r < 1$ $(k_{pe} = \omega_{pe}/c)$ $\sigma_r = 200\,\mu m$

Field Ionized Rubidium Vapor Cell with Oil Heating and Continuous Rb Flow Satisfies This Condition*



Why Rubidium?

- Plasma formed by field ionization of Rubidium (Rb) Vapor. Above threshold (~10^12 W/cm^2) we ionize % 100

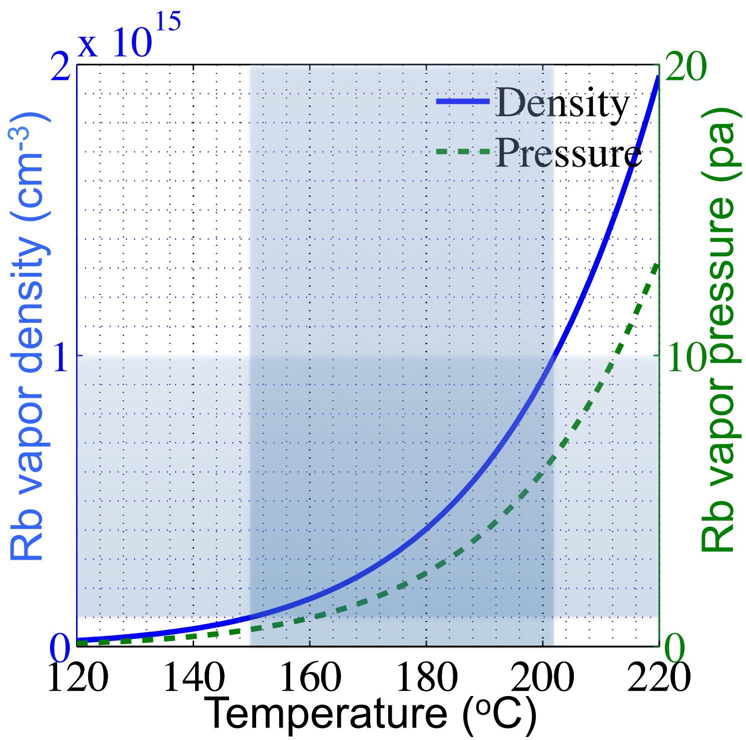
  Plasma density = Vapor Density (n)

  Plasma density uniformity = Vapor Density uniformity
- System is oil (Duratherm G) heated

*Details: E. Oz and P. Muggli, Nucl. Instrum. Methods Phys. Res., Sct. A 740, 197 (2014).

Rubidium

- Laser intensity required to tunnel ionize Rb is low ($I=1.7\times10^{12}$ Wcm^{-2}) because of low ionization potential (4.177 eV)
- Rb with melting point 38.89 ^{o}C is solid at room temperature.
- Required temperature of vapor is determined from the Vapor pressure curve for Rb



$$\frac{\Delta T}{T} \leq 0.002$$

$$T \pm \Delta T$$

$$T : 180 - 220\ ^{o}C$$

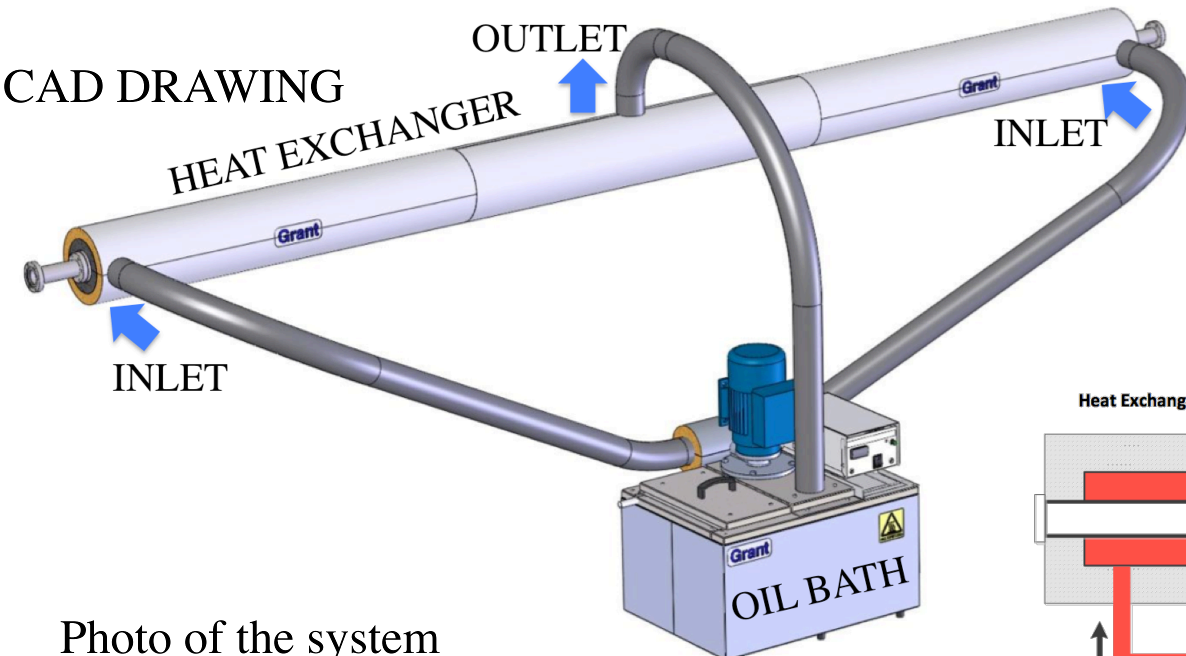
$$\Delta T < 0.5\ K$$

- **How do we provide such uniform temperature?**

With an Oil Bath and a Heat Exchanger

- 3 m Prototype Oil Heater purchased from GRANT INSTRUMENTS of satisfied this requirement

CAD DRAWING



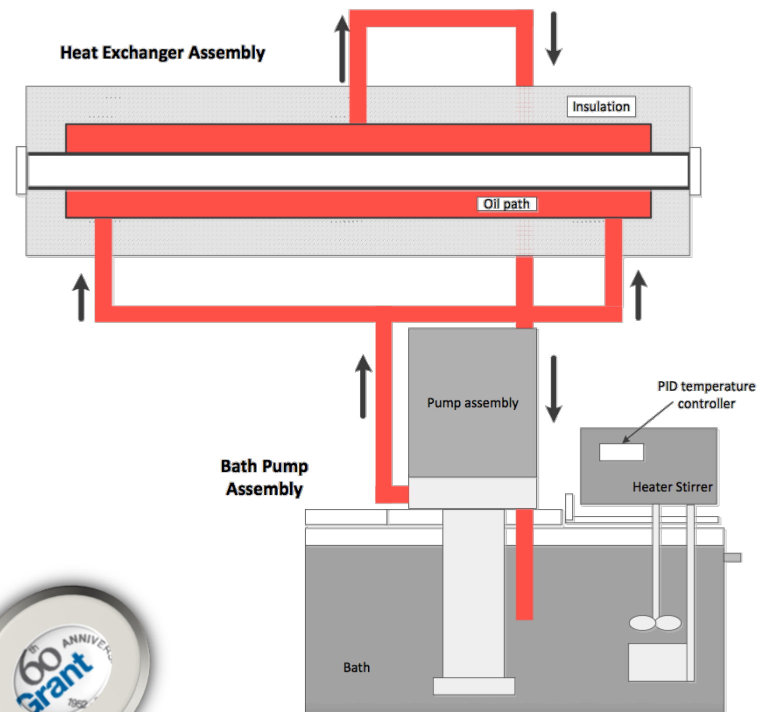
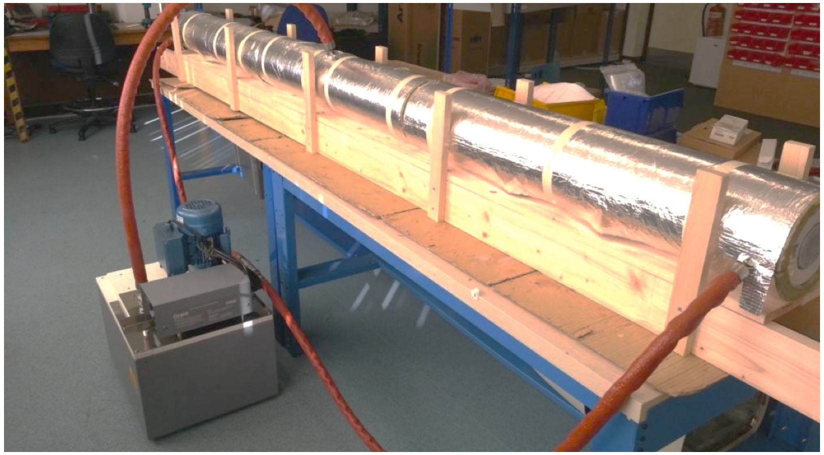
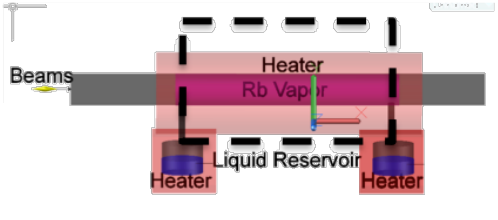


Photo of the system

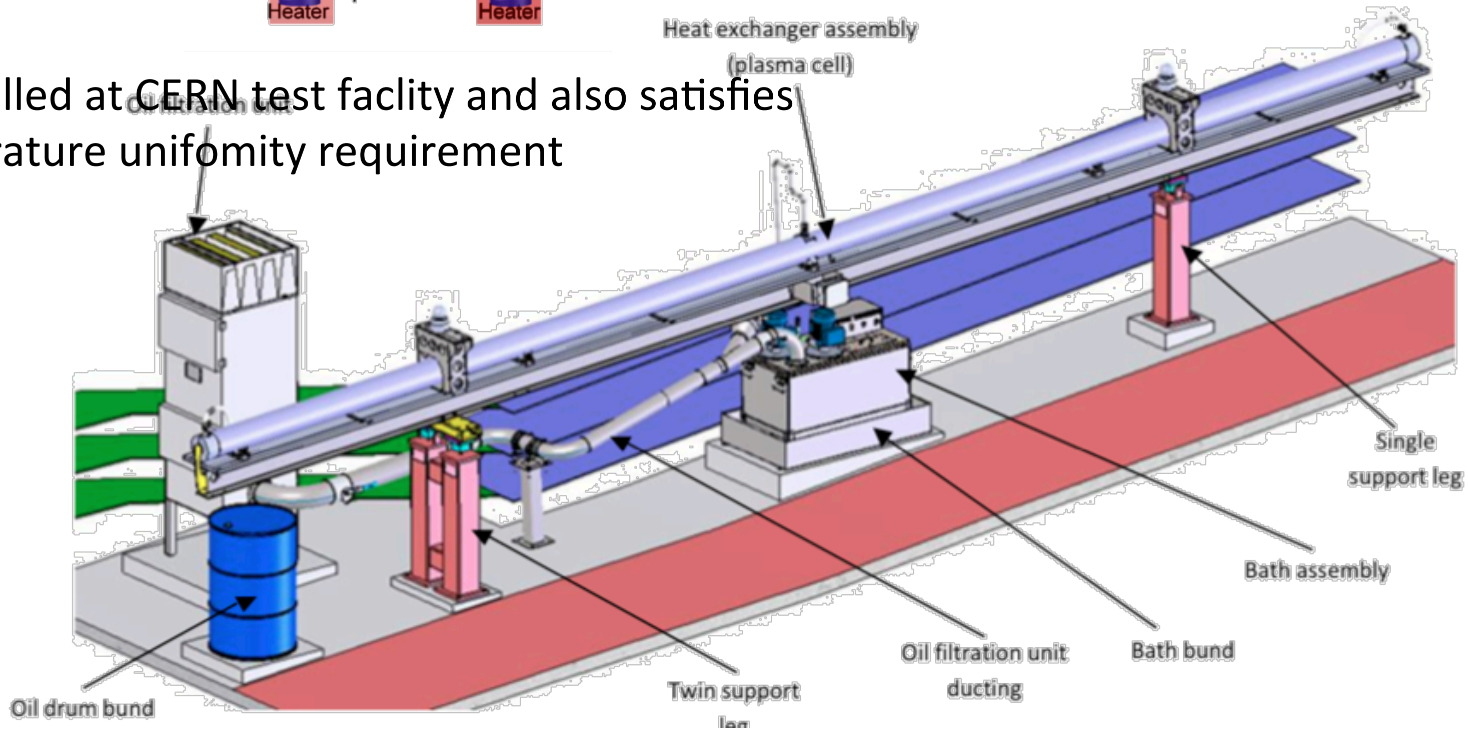


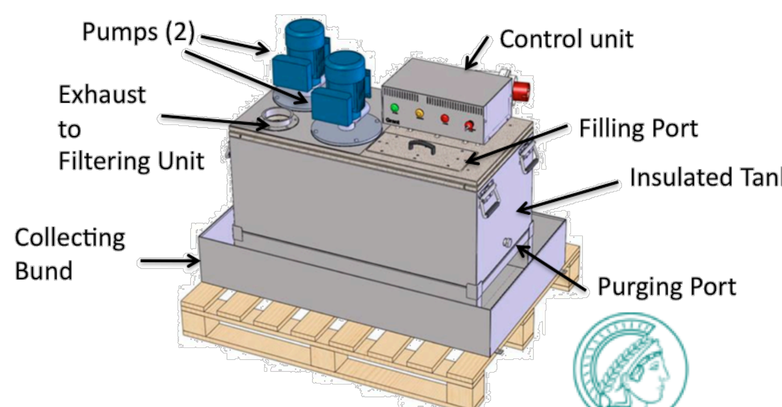
- **10 m version**

10 m Heat Exchanger

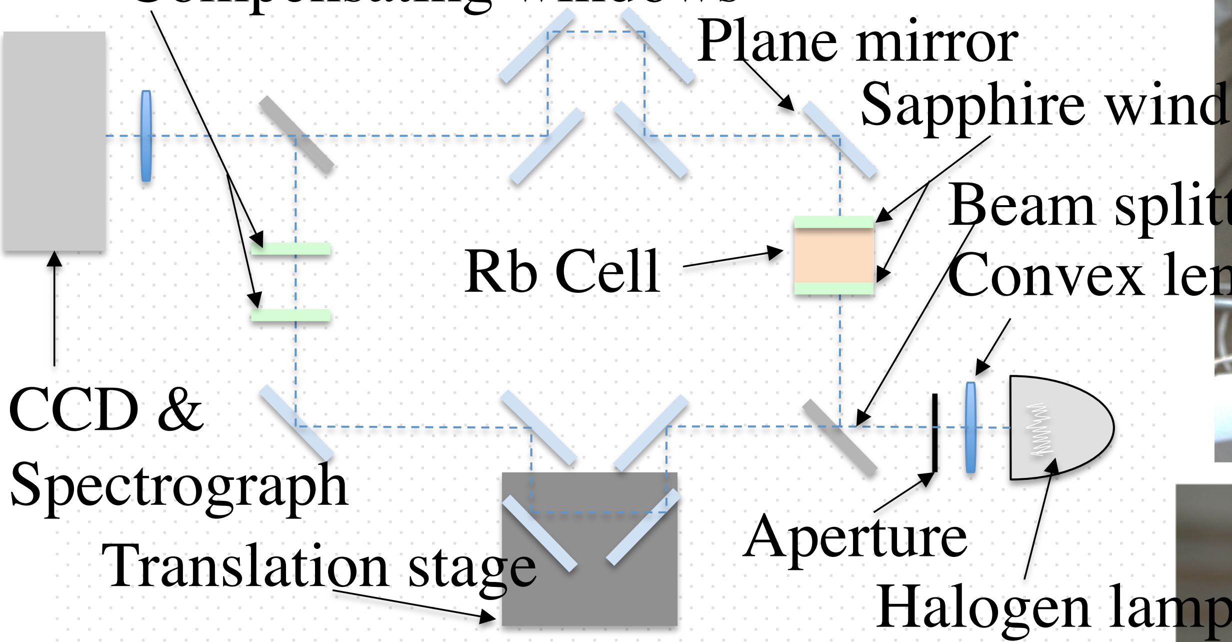


- Installed at CERN test faclity and also satisfies temperature unifomity requirement





Test Set-Up for Liquid Rb Reservoir and Hook Interferometry Density Measurement



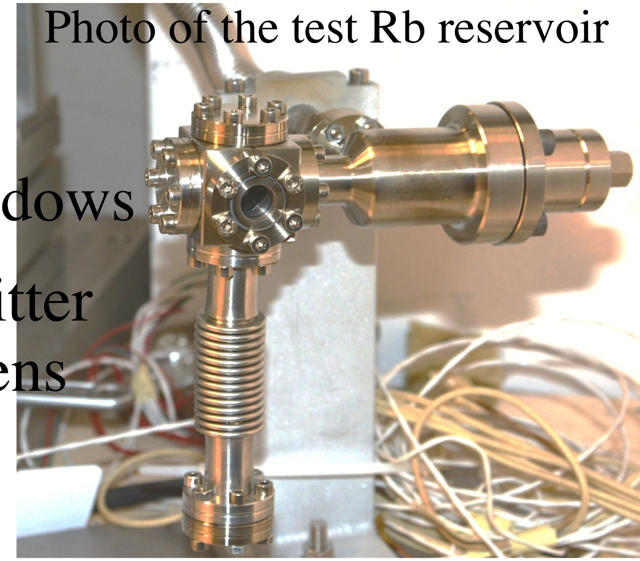


Photo of the test Rb reservoir

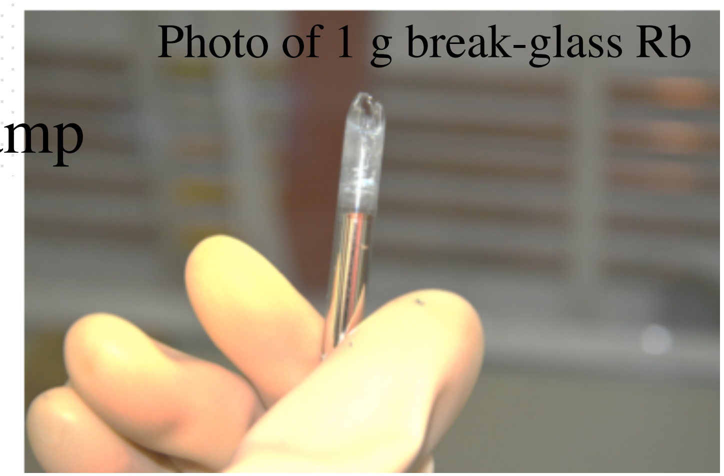
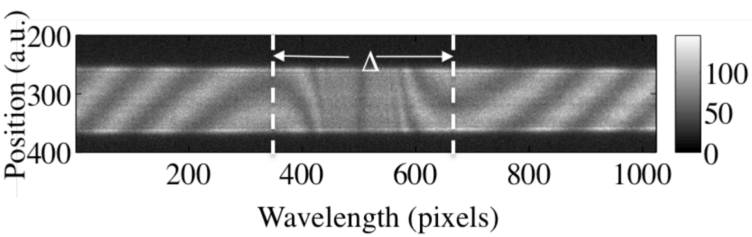


Photo of 1 g break-glass Rb

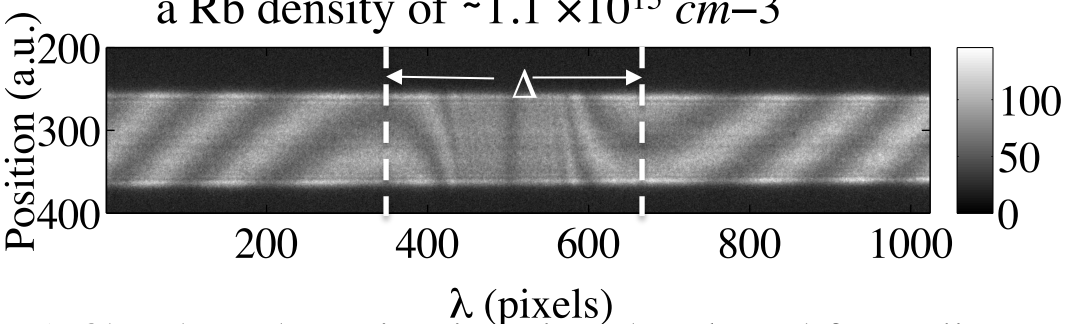
- Spectrograph Image



Test Results

Envisioned Density Range was achieved

- hook distance of ~320 pixels corresponds to a Rb density of ~$1.1 \times 10^{15}\ cm{-3}$



- In cgs units, the Rb number density (n)

$$n = \frac{\Delta^2 \pi K}{l r_0 f \lambda_0^3}$$

$$K = p\frac{\lambda}{\Delta\lambda}$$

- A fiber based version is being developed for online accurate (~1 %) density measurement

- Fitting Function

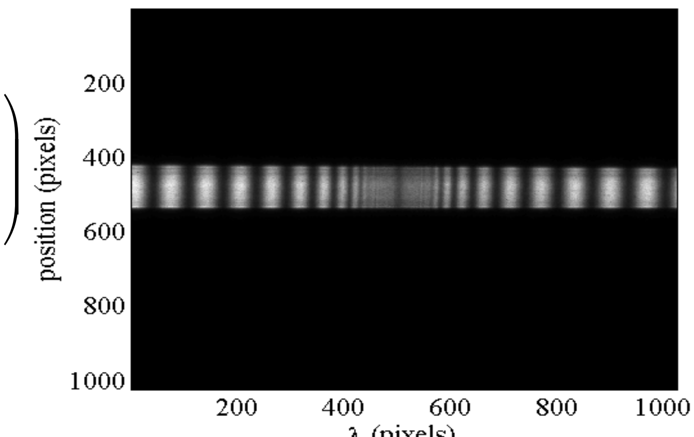
The laser:

$$S(\lambda) = offset + A \cdot \cos\left(\frac{2\pi}{\lambda} \cdot \left[\frac{n l r_0 f \lambda_0^3}{4\pi(\lambda - \lambda_0)} + \xi\right]\right)$$

- **WhiteLase micro** Compact Supercontinuum from Fianium
- Placed the laser in the interferometer to get fringes
- http://www.fianium.com/pdf/Whitelase_micro_v2_1.pdf

KEY FEATURES
- Spectrum from **<450nm** to **>2000nm**
- Output power **>200mW**
- Turnkey operation
- Single spatial mode at all wavelengths
- **20MHz** repetition rate with ps pulses
- Optical bench mountable & small footprint
- Robust OEM-ready design

- A CLASS 4 laser → not so easy to handle like a halogen lamp



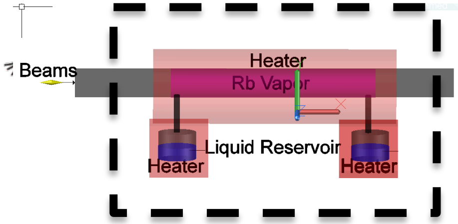
For more Visit Fabian's Poster

A diagnostic to measure rubidium vapor density during the AWAKE experiment at CERN

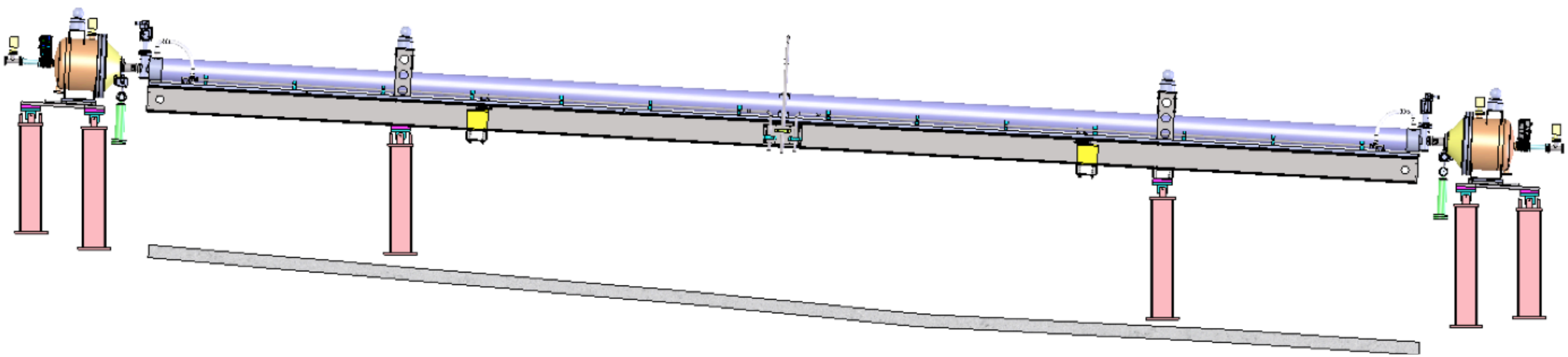
Presented by **Mr. Fabian BATSCH** on **16 Sep 2015** from **19:30** to **20:00**
Type: poster
Session: Poster Session 2 (WG5-WG6-WG7) and Wine

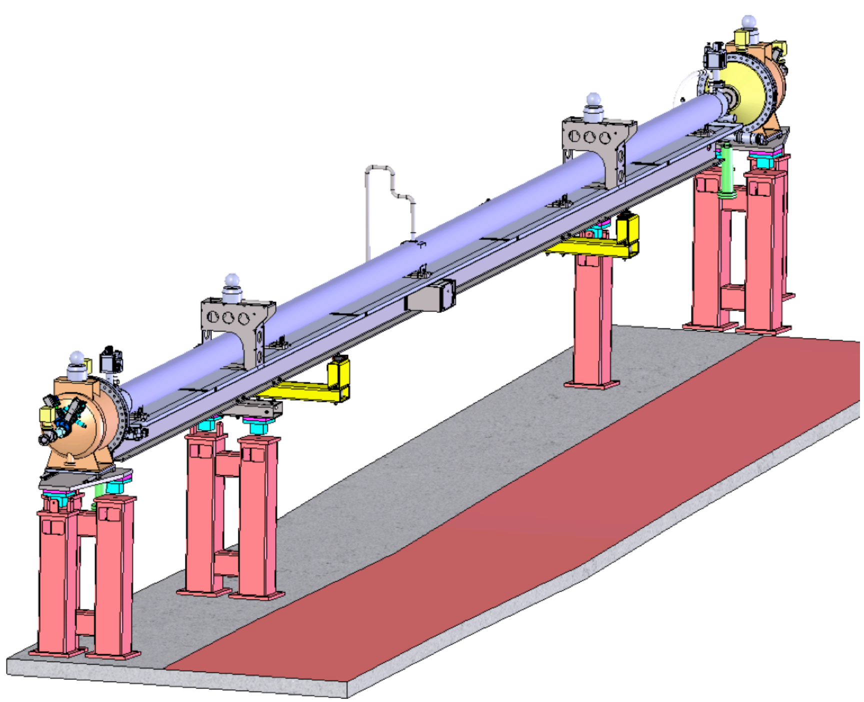
Place
Location: Hotel Hermitage
Room: Parking Area

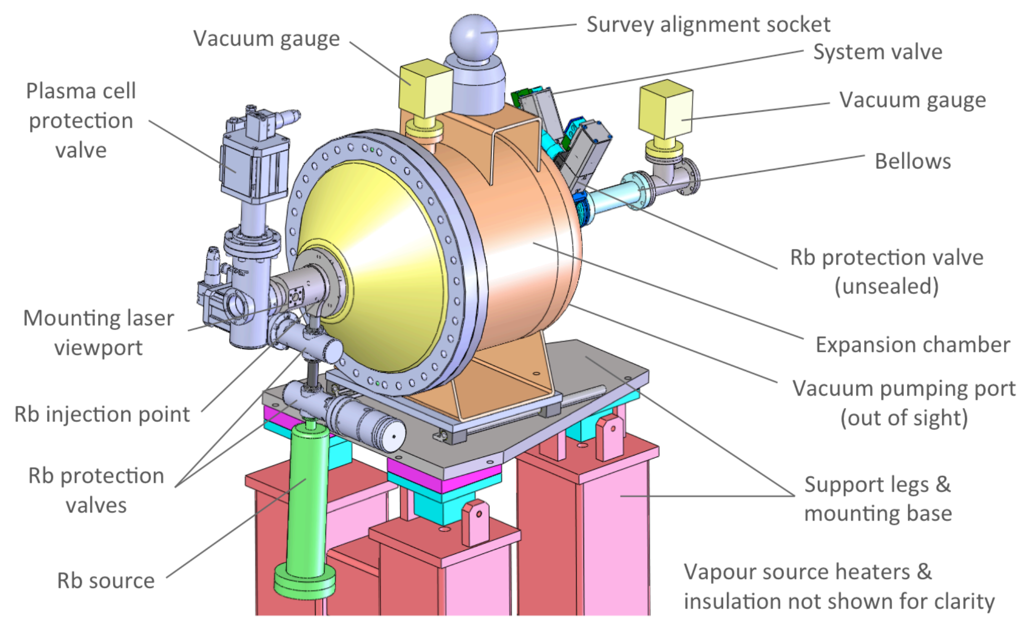
Putting it together



10 m Heat Exchanger and Rb Reservoirs





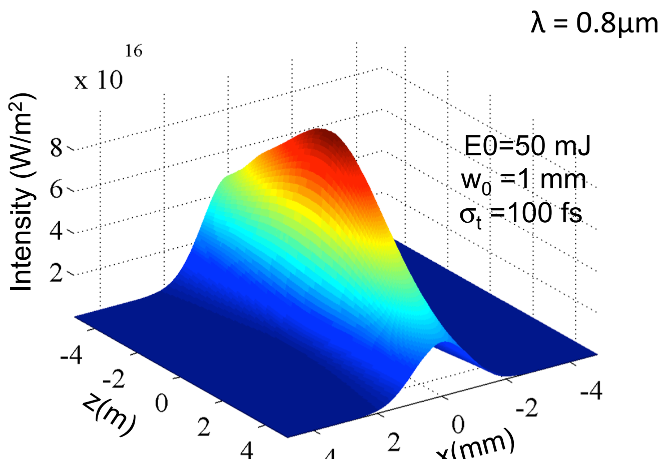


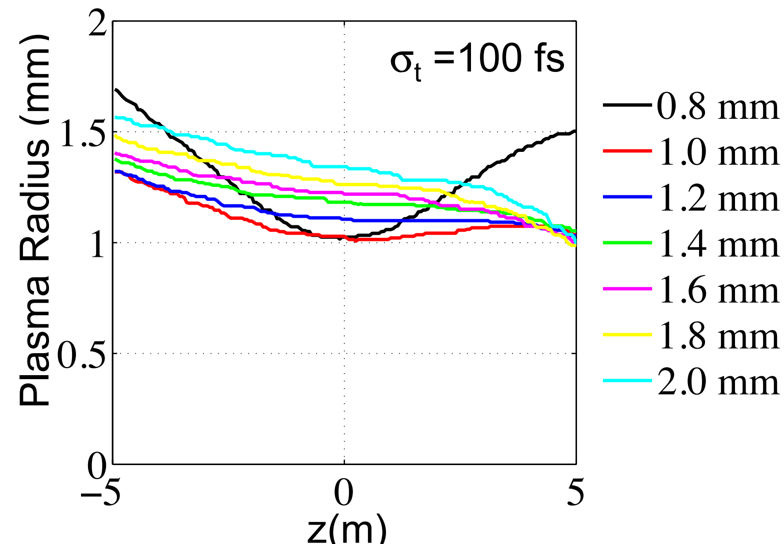
www.grantinstruments.com

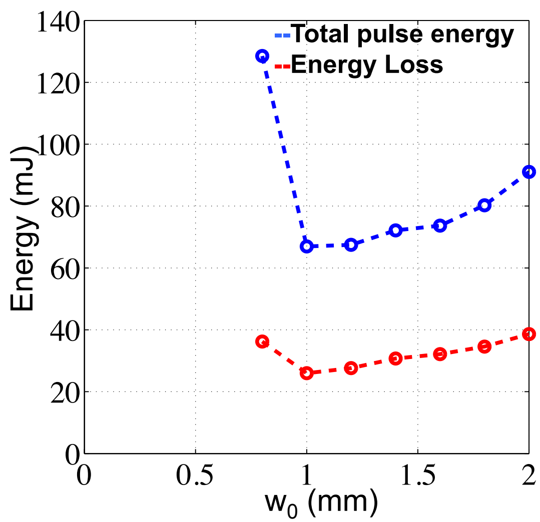
How do you produce plasma?

Minimum Laser Parameters to create a 10 m long 2 mm diameter Plasma Channel

- Effect of **ionization depletion** can be added as a source term to the paraxial wave equation* and initial Gaussian pulse is propagated using **split step method***







- The minimum energy for the σ_t = 100 fs laser pulse is with w_0 ~ 1 mm is ~67 mJ, the depletion loss is ~26 mJ.

- Based on these calculations and taking a safety factor into account we purchase a 450 mJ 120 fs 780 nm Ti:Sapphire System

*PHYSICAL REVIEW E 66, 046418 2002, P. Sprangle, J. R. Peñano and B. Hafizi

Test Experiments at Max Planck

Laser Propagation Experiments at MPP

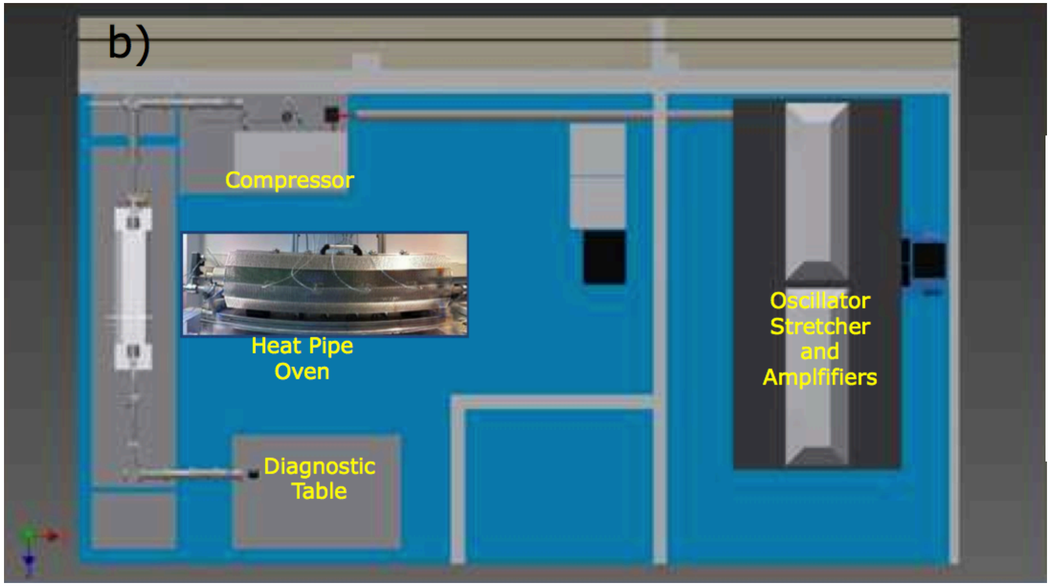


Table 1: AWAKE and MPP Phase B Parameters

Parameter	AWAKE	MPP Phase B
Laser Pulse Energy	450 mJ	100 mJ
Rayleigh Range	3.5 m	35 cm
Rubidium Vapor Length	10 m	1 m

LASER PROPAGATION EFFECTS DURING PHOTOIONIZATION OF METER SCALE RUBIDIUM VAPOR SOURCE

J. Moody, F. Basch, A. Joolaei, E. Oez, P. Muggli, Max Planck Institute for Physics, Munich, Germany
N. Berti, J. Kasparian, University of Geneva, Switzerland

- https://jacowfs.jlab.org/conf/y15/ipac15/prepress/WEPWA006.PDF

Experimental Characterization of Rubidium Vapor Photoionization in a Meter-Scale Rubidium plasma source

Presented by **Dr. Joshua MOODY** on **16 Sep 2015** from **19:30** to **20:00**

Type: poster

Session: Poster Session 2 (WG5-WG6-WG7) and Wine

Track: WG5 - High-gradient plasma structures/Advanced beam diagnostics

Place

Location: Hotel Hermitage

Room: Parking Area

Primary authors

Joshua MOODY Max Planck Institute

To be contuned!