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AWAKE

First Full Scale Laser Propagation Results Through the 10 Meter Rb Vapor Source at AWAKE

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05 May 2017

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Photoionization Requirements for AWAKE

Ionization laser must do three things:

- Provide a singly ionized plasma from the Rb vapor that has a density profile identical to that of the vapor **for the entire length of the vapor source**
- The radial extent of the plasma must be greater than trajectory of plasma electrons
- Seed the Self Modulation Instability (SMI) by turning on the plasma at a timescale at or shorter than the plasma period in the middle of the proton beam

How Can We Demonstrate Ionization?

- Charge gathering electrodes:
  - Nothing currently installed
  - Difficult to have in the vapor source (perturb uniformity of temperature)
  - Can't demonstrate plasma density, just that some ionization has occurred
- What can we infer about the ionization from the laser propagation?

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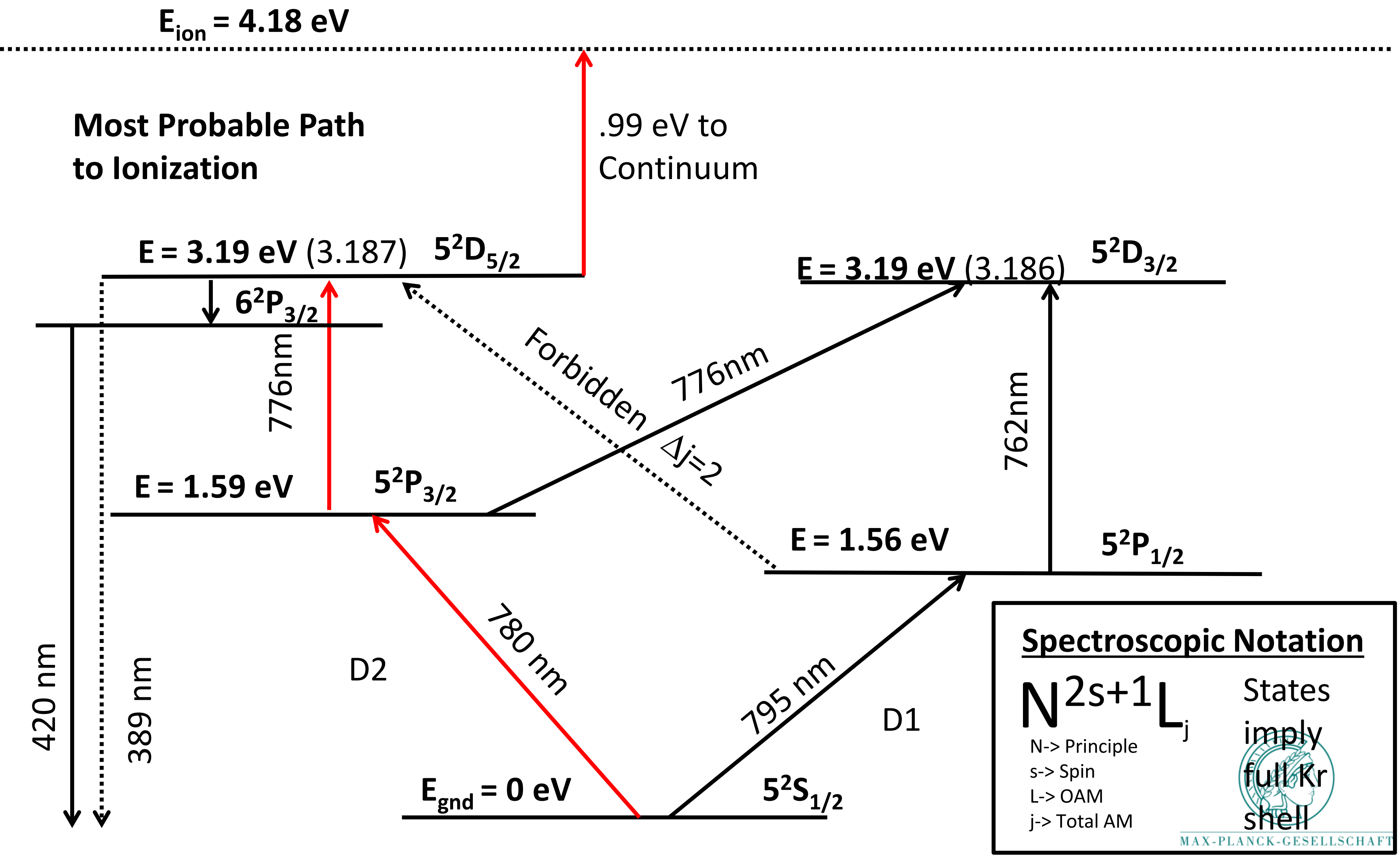
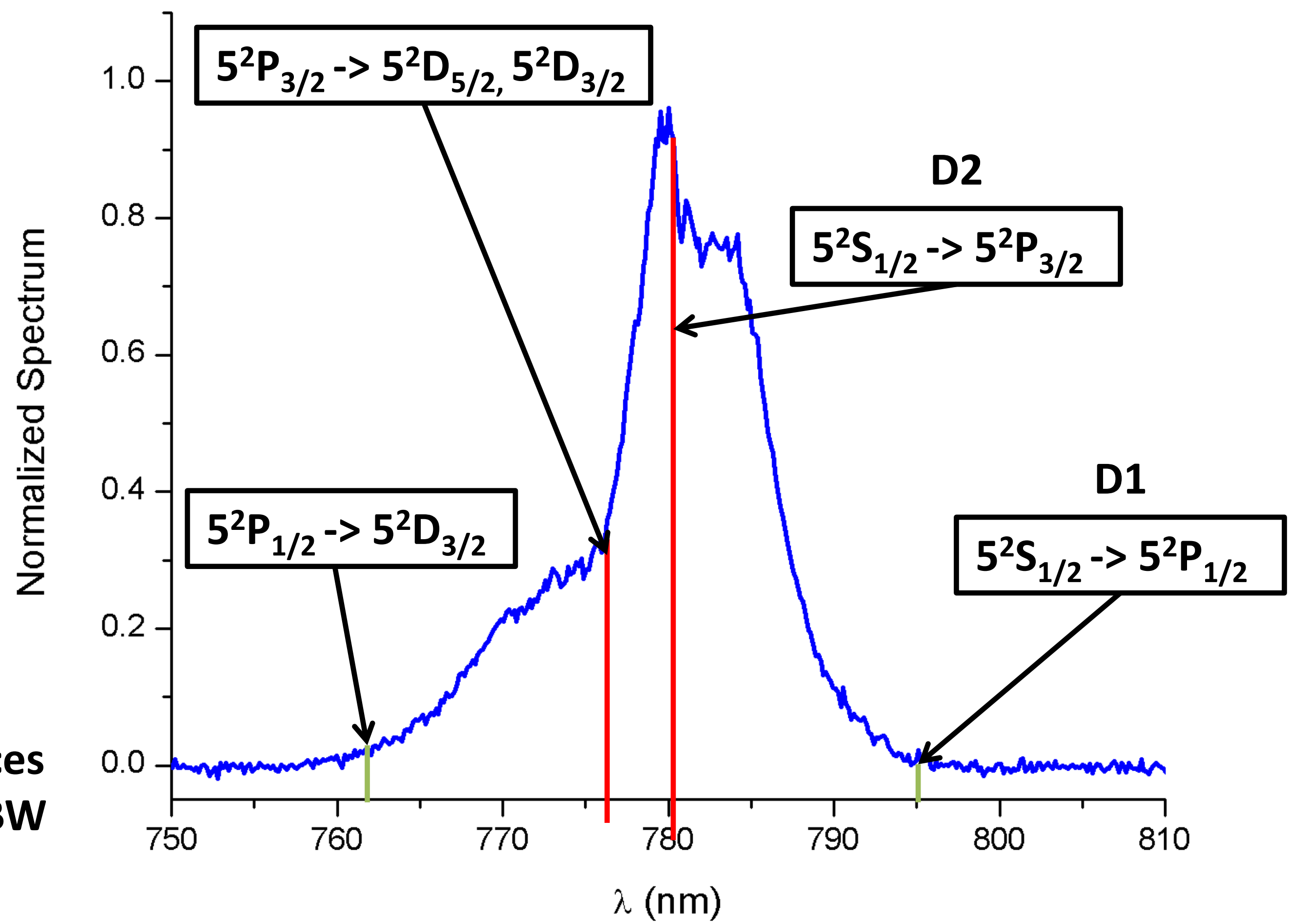
Rubidium Valence Electronic States



Input Spectrum

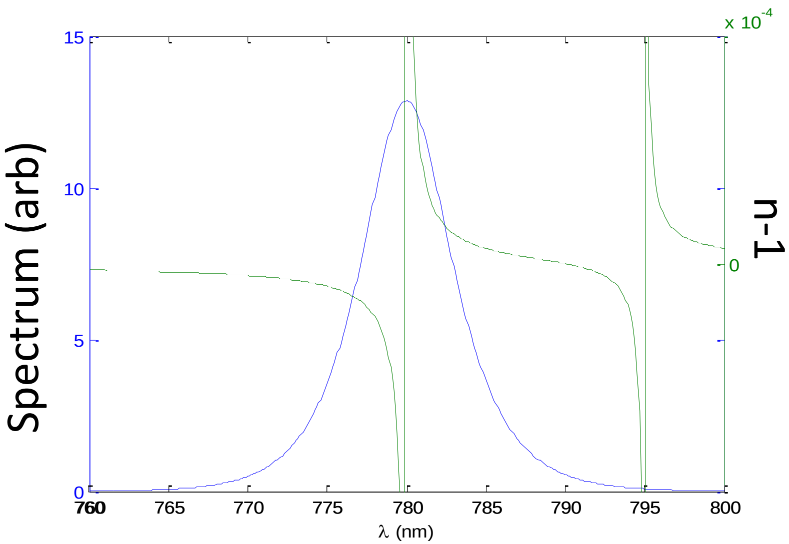


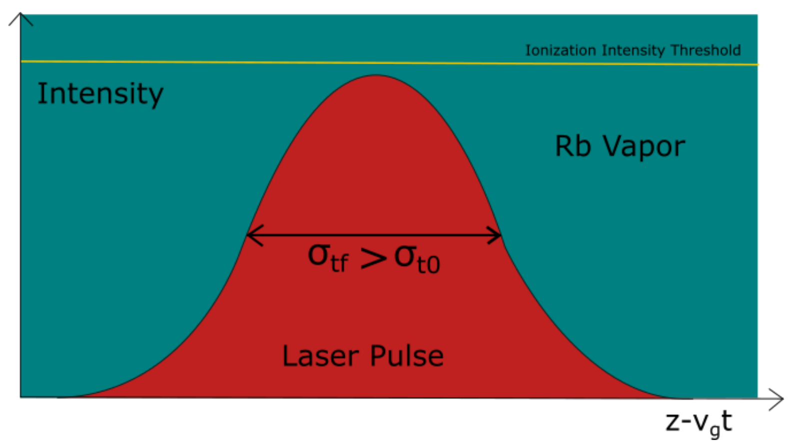
Two Resonances near peak of BW

Pulse Propagation in the "Linear Regime"

$$\chi_{bound} = \frac{Ne^2}{m\varepsilon_0}\left(\frac{f_1}{\omega_{01}{}^2 - \omega^2 - i\Gamma_1\omega} + \frac{f_2}{\omega_{02}{}^2 - \omega^2 - i\Gamma_2\omega}\right)$$

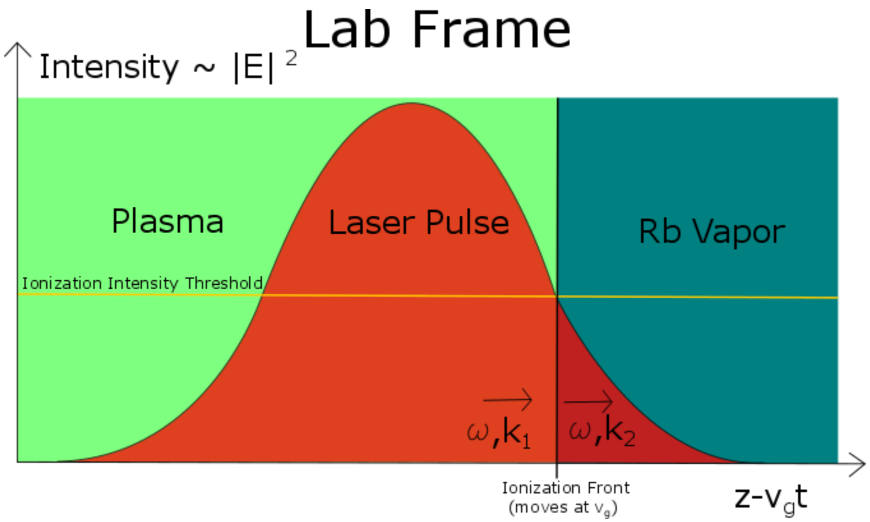
$$k_{bound} = \frac{\omega}{c}\sqrt{1+\chi(\omega)}$$





Two resonances would cause anomalous dispersion, pulse stretching, etc. If it is different across the beam then the beam can blow up, multifilament, etc.

High Intensity Laser pulse



$$k_{bound} = \frac{\omega}{c}\sqrt{1+\chi(\omega)}$$

$$k_{plasma} = \frac{\omega}{c}\sqrt{1-\frac{\omega_p^{\;2}}{\omega^2}}$$

- Leading edge of the pulse ionizes or saturates the transition
- Most of the pulse travels through plasma, samples plasma dispersion, which has a differential index on the scale of 10^{-8}

If beam does not deplete, it can make it through without stretching

Gabor's Previous 1D Results

- Previously Gabor's 1D laser pulse simulation suggested the phenomenon of "beam crash" in which a laser pulse depletes as it travels through the vapor.
- The laser initially propagates through with plasma dispersion, but when depletion occurs and there are significant ground and first excited state populations, the beam slows way down
- If this occurs transversely we could imagine the beam blowing up as the wings slow down first, the core of the beam propagating further, becoming smaller and diffracting out

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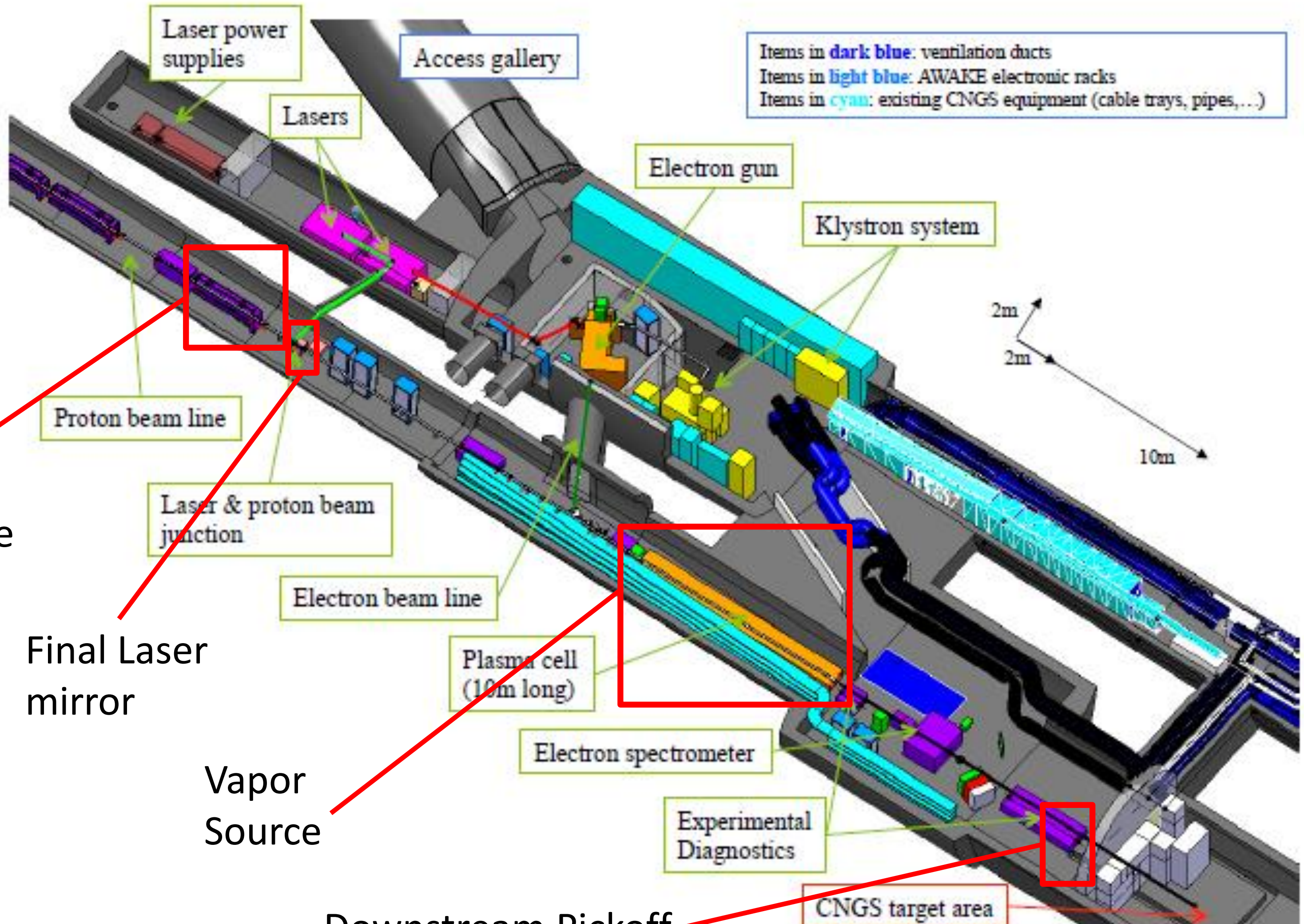
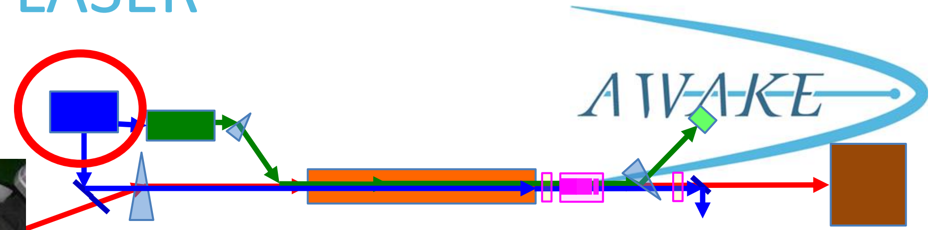
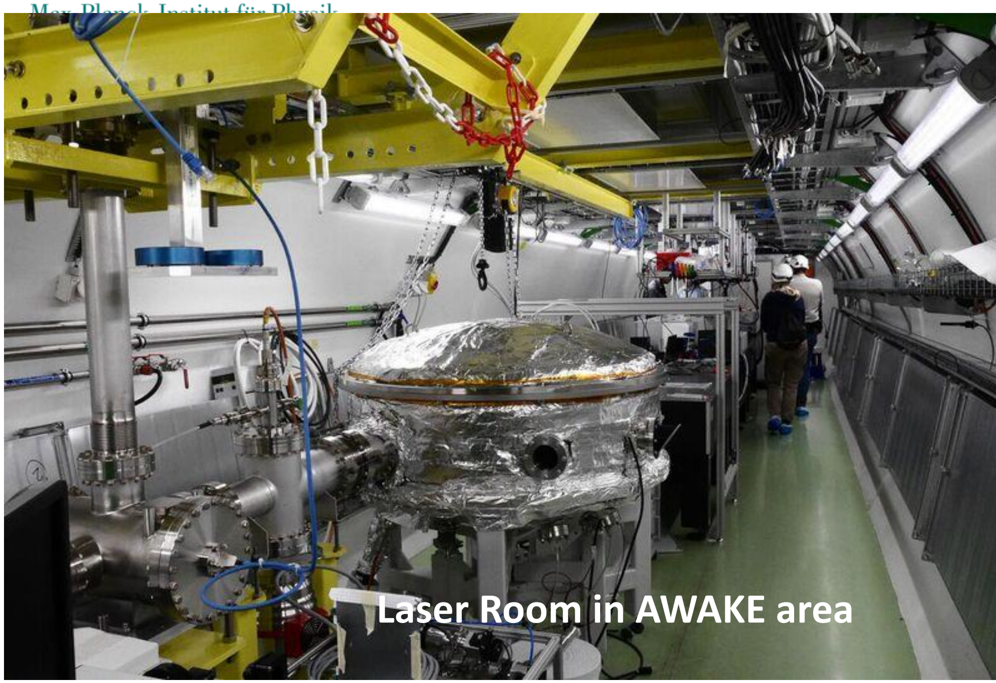
AWAKE Experimental Area

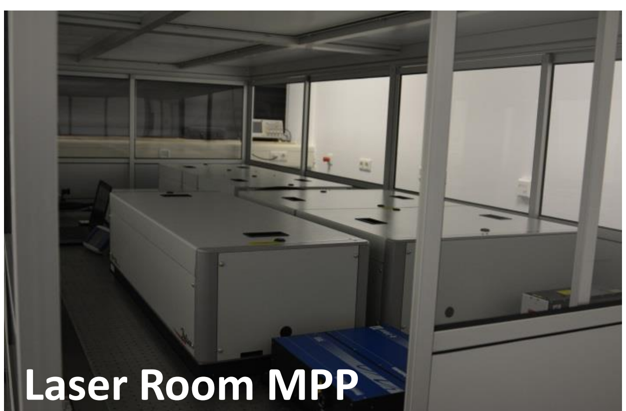


TW LASER




Laser Room in AWAKE area

Laser System	
Laser type	Er:Fiber/ OscillatorTi:Sapphire
Pulse wavelength	λ_0 = 780 nm
Pulse length	120 fs FWHM
Pulse energy (after compressor)	**450 mJ**
Laser power	**4.5 TW**
Focused laser size	$\sigma_{x,y}$ **= 1 mm**
Rayleigh length Z_R	~3.5 m
Energy stability	±1.5% r.m.s.
Repetition rate	10 Hz


Laser Room MPP

Laser is a commercial system purchased by Amplitude Technologies. It is installed on site at AWAKE and laser transport line commissioning will occur in the next few weeks

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TW LASER System Parameters

AWAKE

Performance	Specified value	Measured value
Repetition rate	10 Hz	10 Hz
Central wavelength	Tunable from 780nm to 785nm	780nm to 785nm
Spectrum bandwidth	≥ 10nm	24nm
Pulse Duration	100 to 120 fs	81 fs
Main output Energy (uncompressed)	>650 mJ	663 mJ
Secondary output energy (uncompressed)	>2,5 mJ	3.0 mJ
Main Output energy (after compression)	≥250 mJ @785 nm	250 mJ with attenuator @ 50%
Energy stability	≤ 1,5 % RMS	1.02%
Beam pointing stability	<20 µrad	4.2 µrad
Temporal intensity contrast	$\leq 10^{-4}$ @ 10 ps	2.10^{-7}
	$\leq 10^{-6}$ @ >50 ps (ASE level)	2.10^{-7}
	$\leq 10^{-3}$ (replica)	$7.9\ 10^{-4}$
Polarization of the output beam (Linear)	100:1	250 :1

Laser Parameters from On-site acceptance testing

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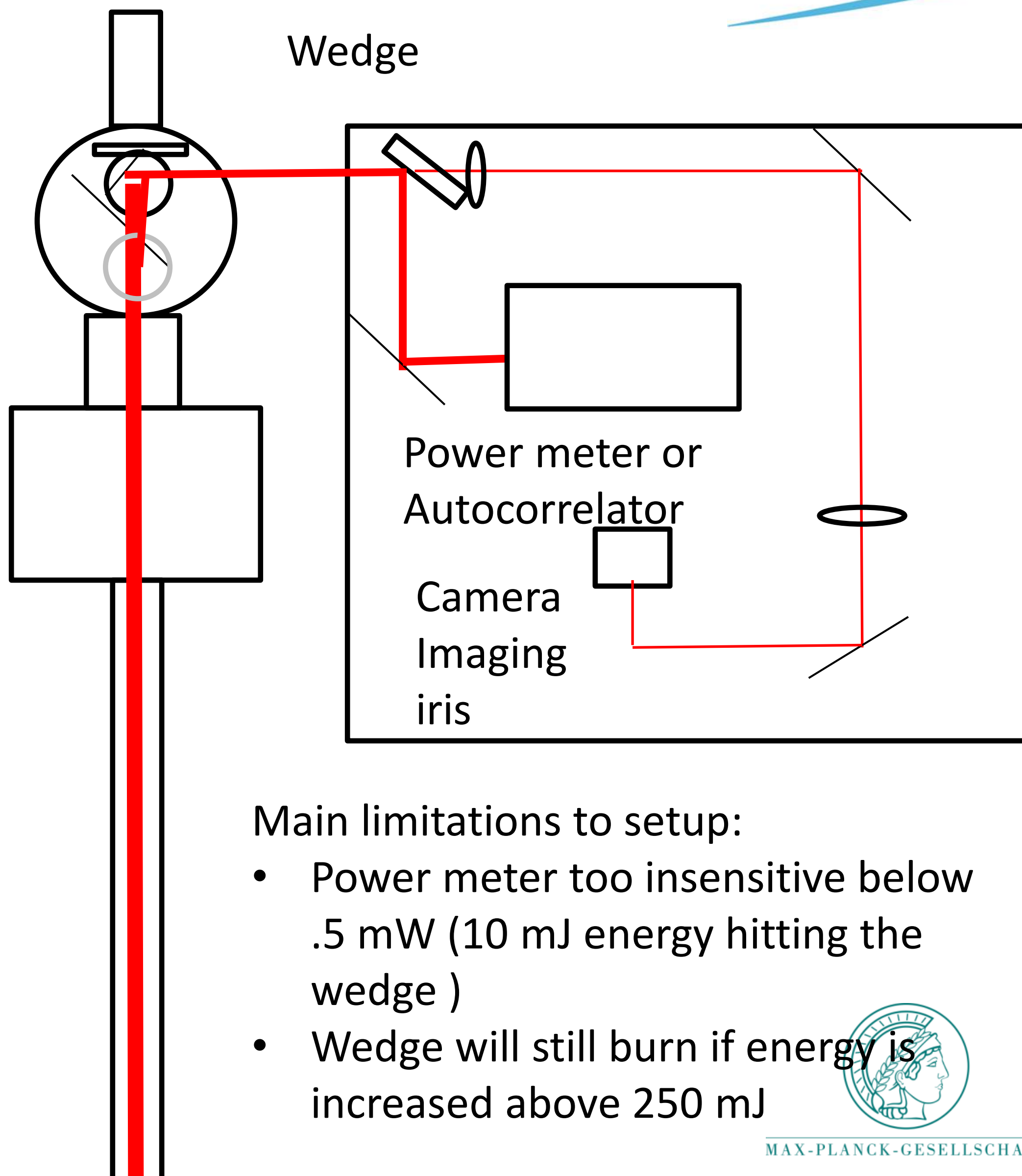
Pickoff Setup

- Wedge picked off .5% of laser
- Mirror splits beam to autocorrelator or power meter and bleedthrough goes to transverse measurement
- Telescope images downstream iris of the vapor source



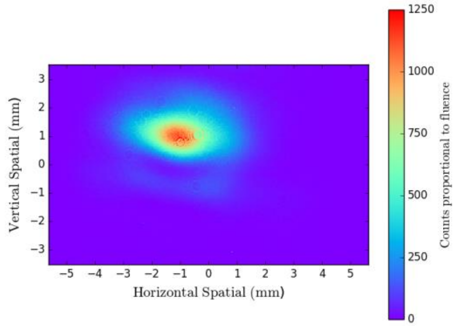
Main limitations to setup:

- Power meter too insensitive below .5 mW (10 mJ energy hitting the wedge)
- Wedge will still burn if energy is increased above 250 mJ

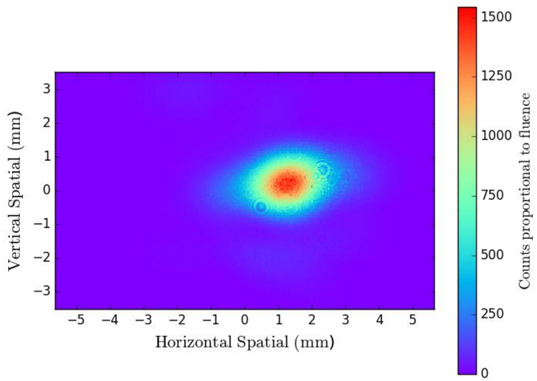
Diagnostics

– Power meter
– Cameras imaging downstream iris (gated and profiler)
– SHG Autocorrelator (pulse length measurement)
– Virtual Line for initial transverse profile conditions
    - Bleed-through of mirror, cameras placed at virtual Entrance, Center and Exit of vapor source

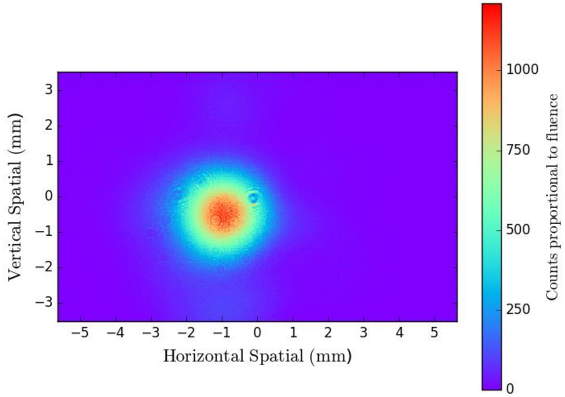
Virtual Line Images
Initial Conditions of Laser / Vacuum Behavior



Virtual Entrance



Virtual Center



Virtual Exit
Pick off imaged about here

Notes on Measurement

- Data collected in only two days
- Measured at two vapor densities measured by Fabian's diagnostic:
  - 1e14 /cc
  - 7e14/cc (baseline)

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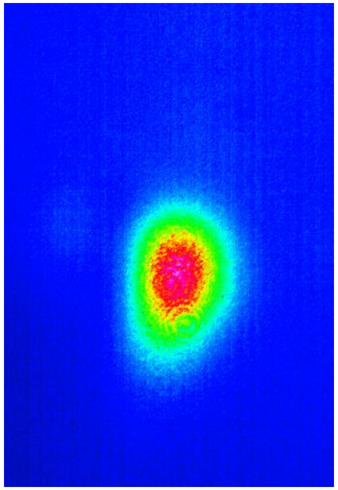
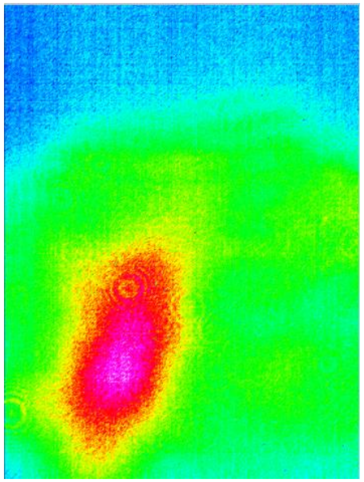
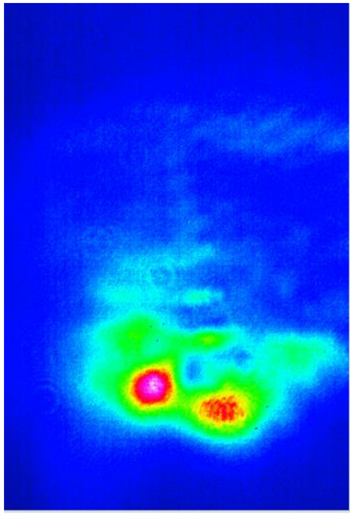
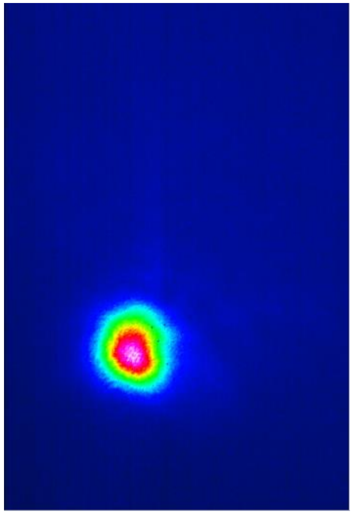
Preliminary Results

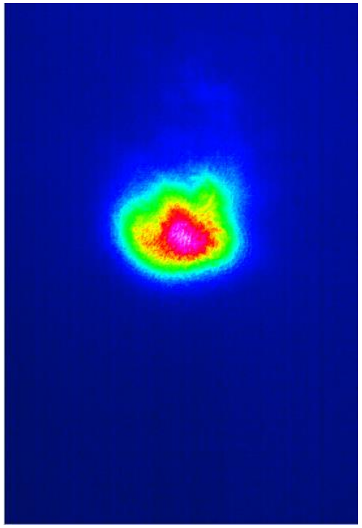
Rb 7e14 / cc











Vacuum

En = 40 mJ

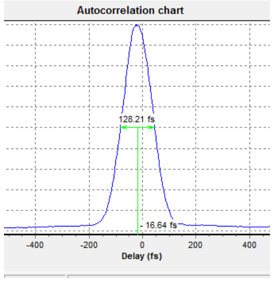
En = 55 mJ

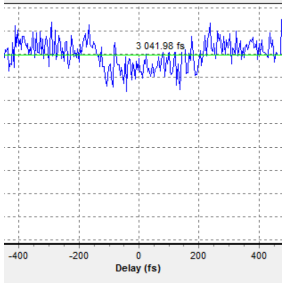
En = 60 mJ

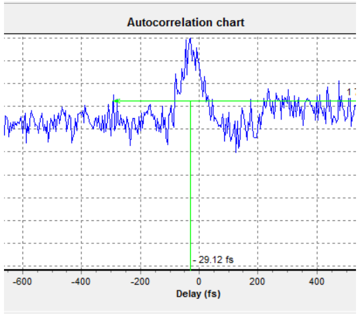
En = 240 mJ

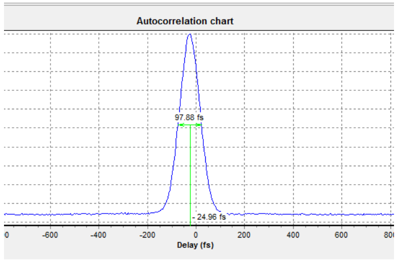
Beam Blowup, multifilamentation

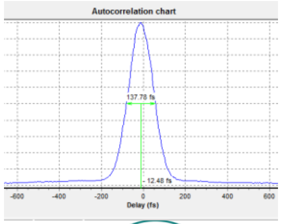
Beam Stable











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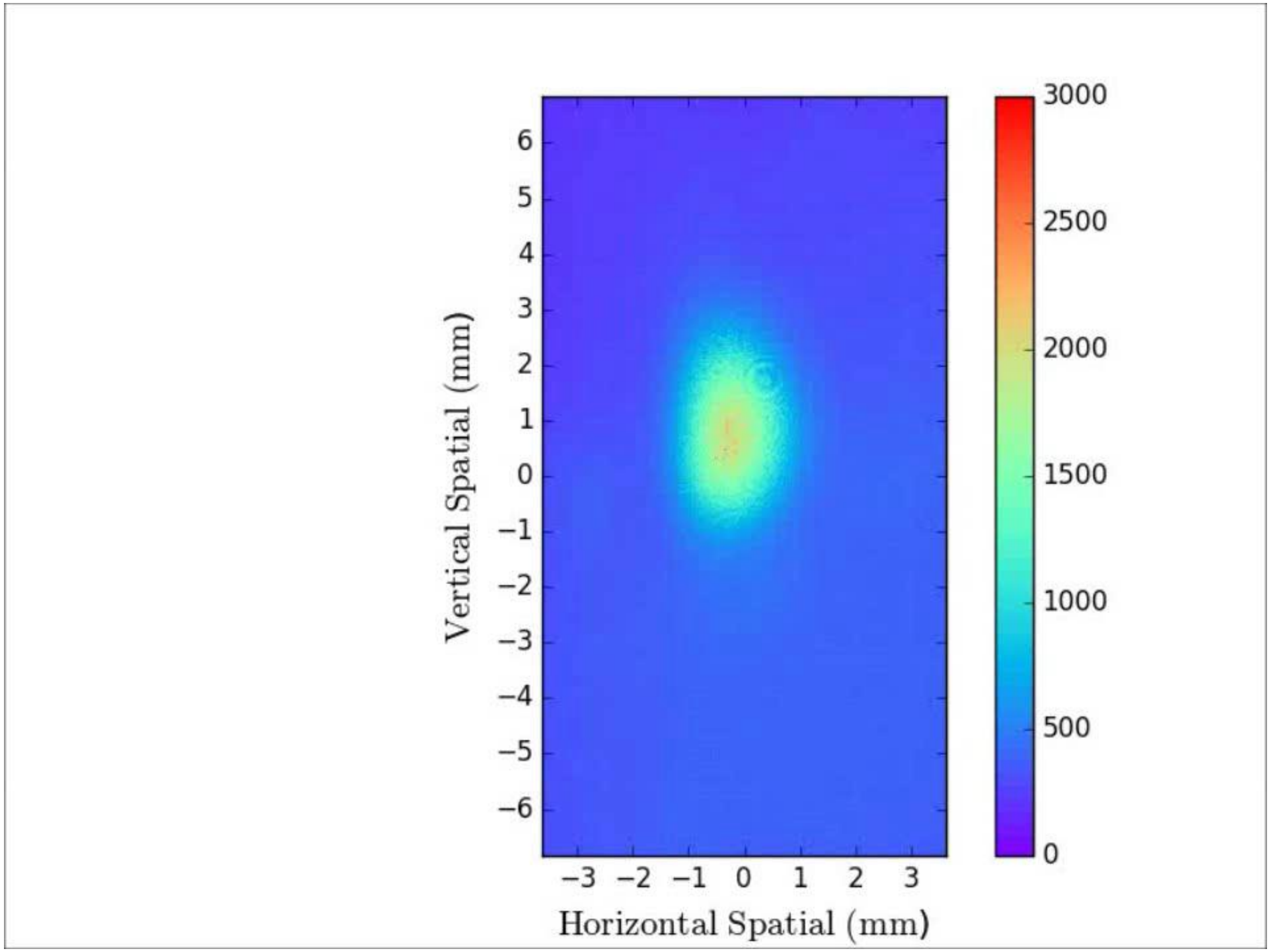
Where does threshold occur?

- n=1e14 /cc : ~10mJ
- n=7e14 /cc : ~60 mJ

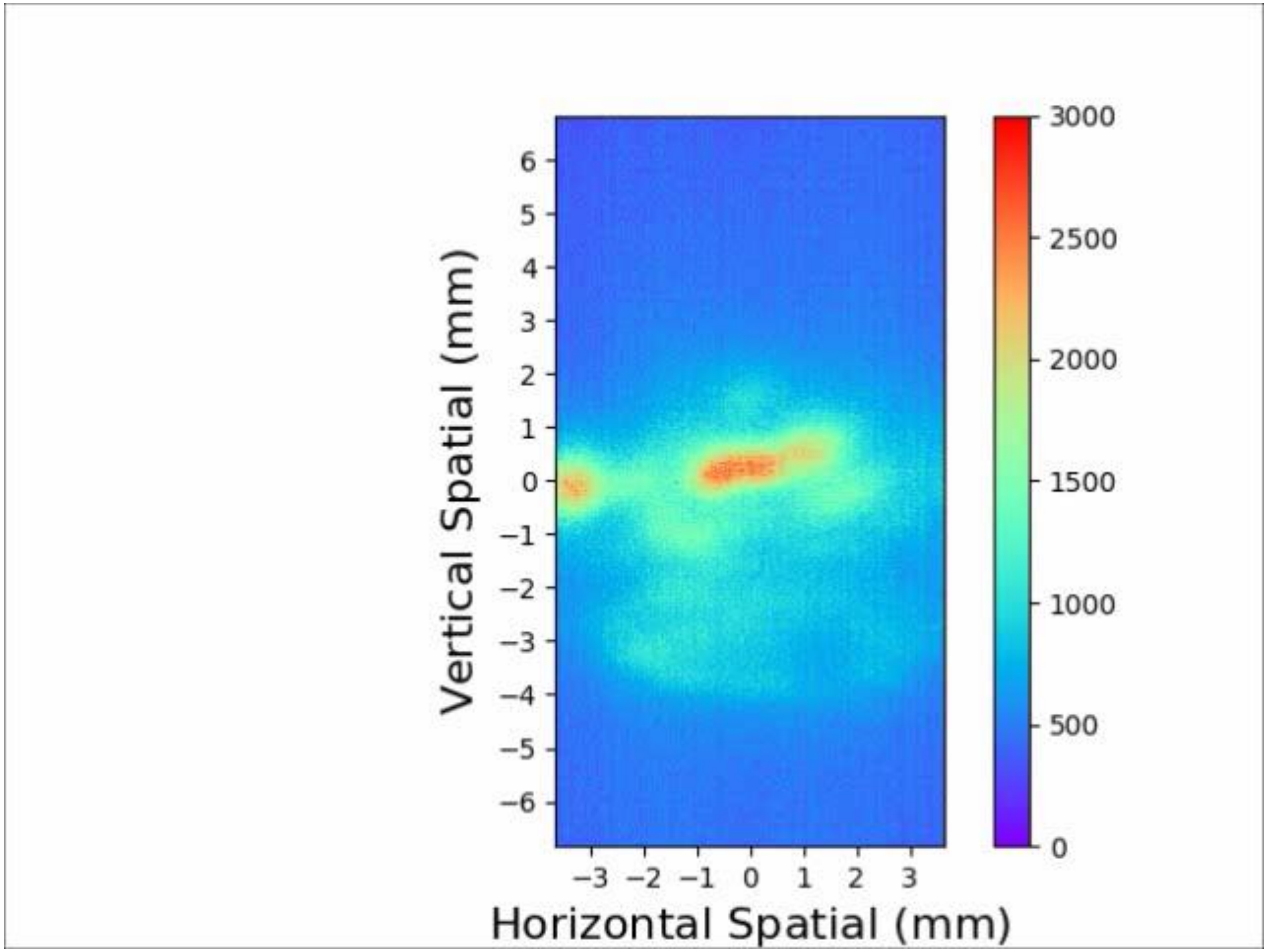
Movie Time!

- Show some of the beamage files:
  - Vacuum
  - Rb density: 7e14 /cc
    - Well below threshold
    - At threshold
    - Above threshold
    - Well above threshold
    - Close to upper limit energy (240 mJ)
  - Closing of Rb reservoir valve

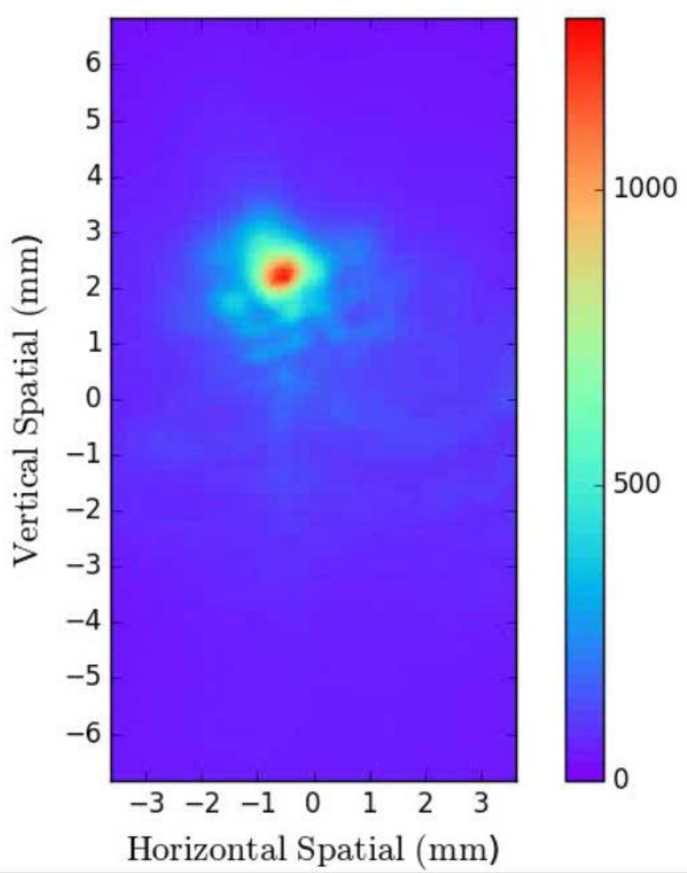
Vacuum Pickoff (No Rb)



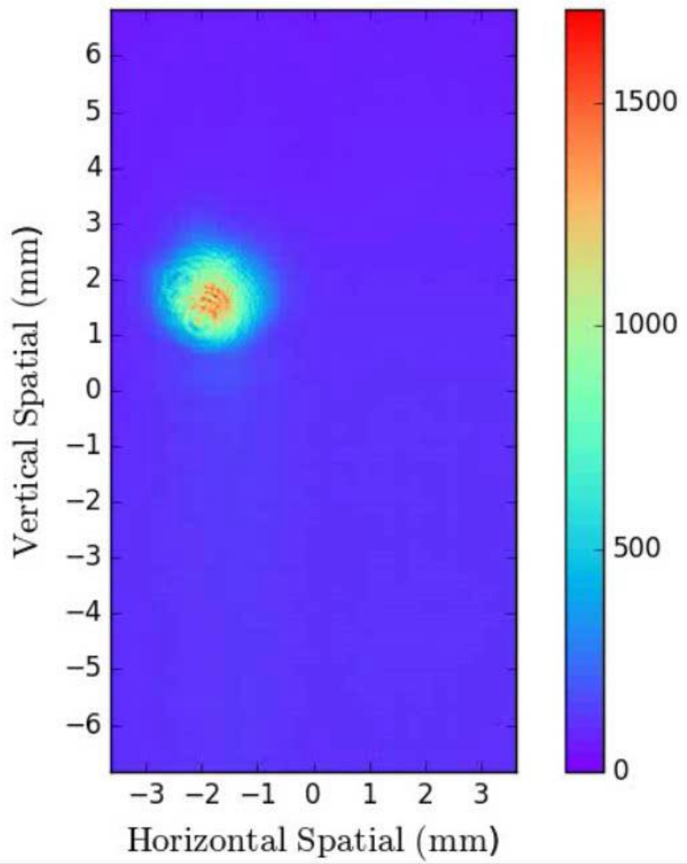
Well below threshold



At Threshold



Above Threshold



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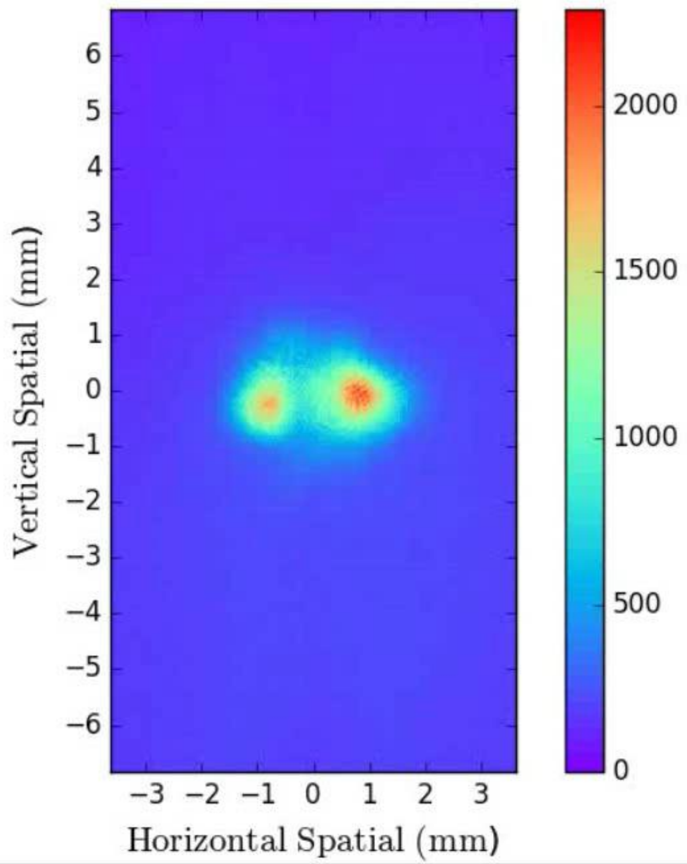
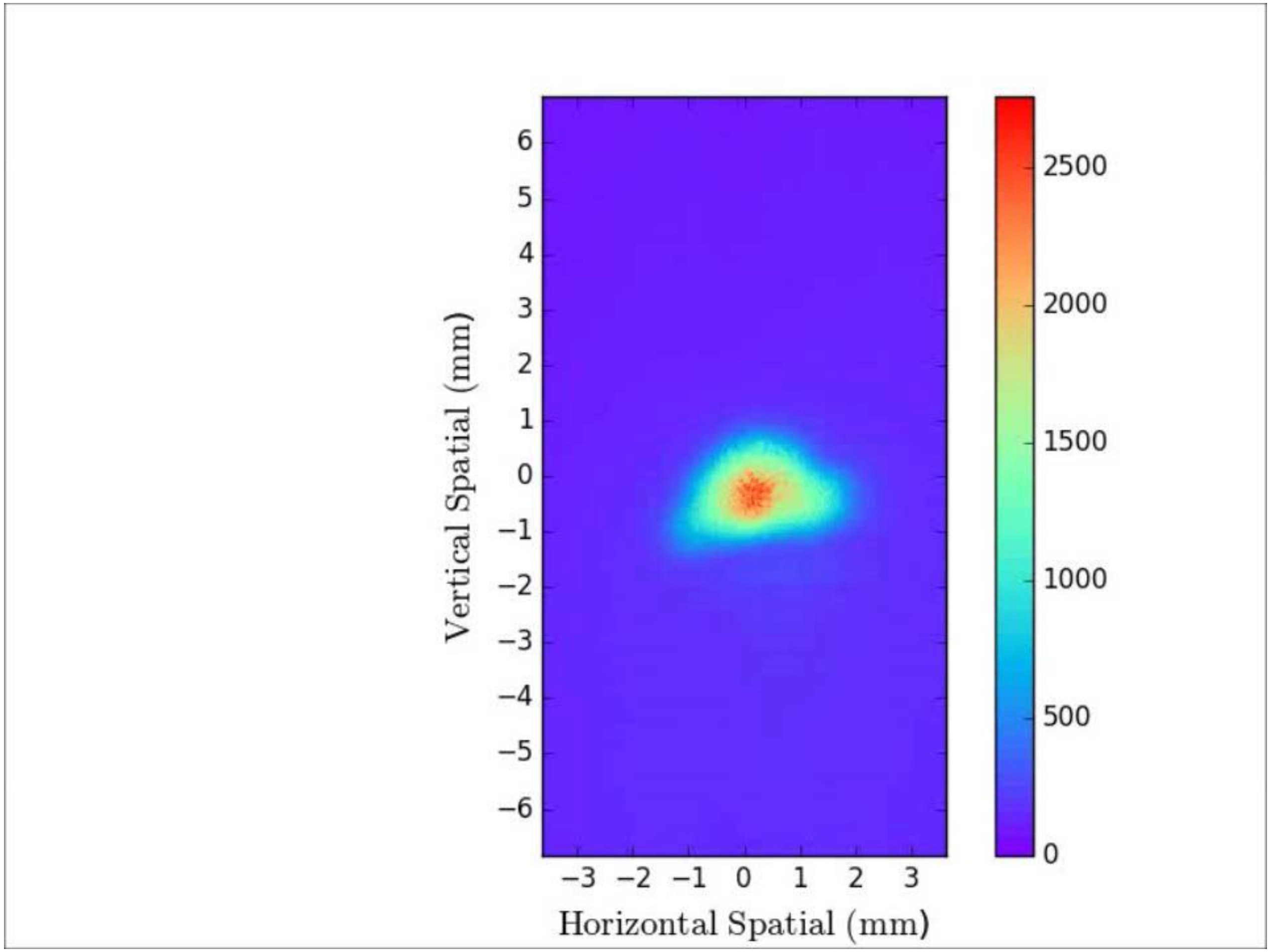
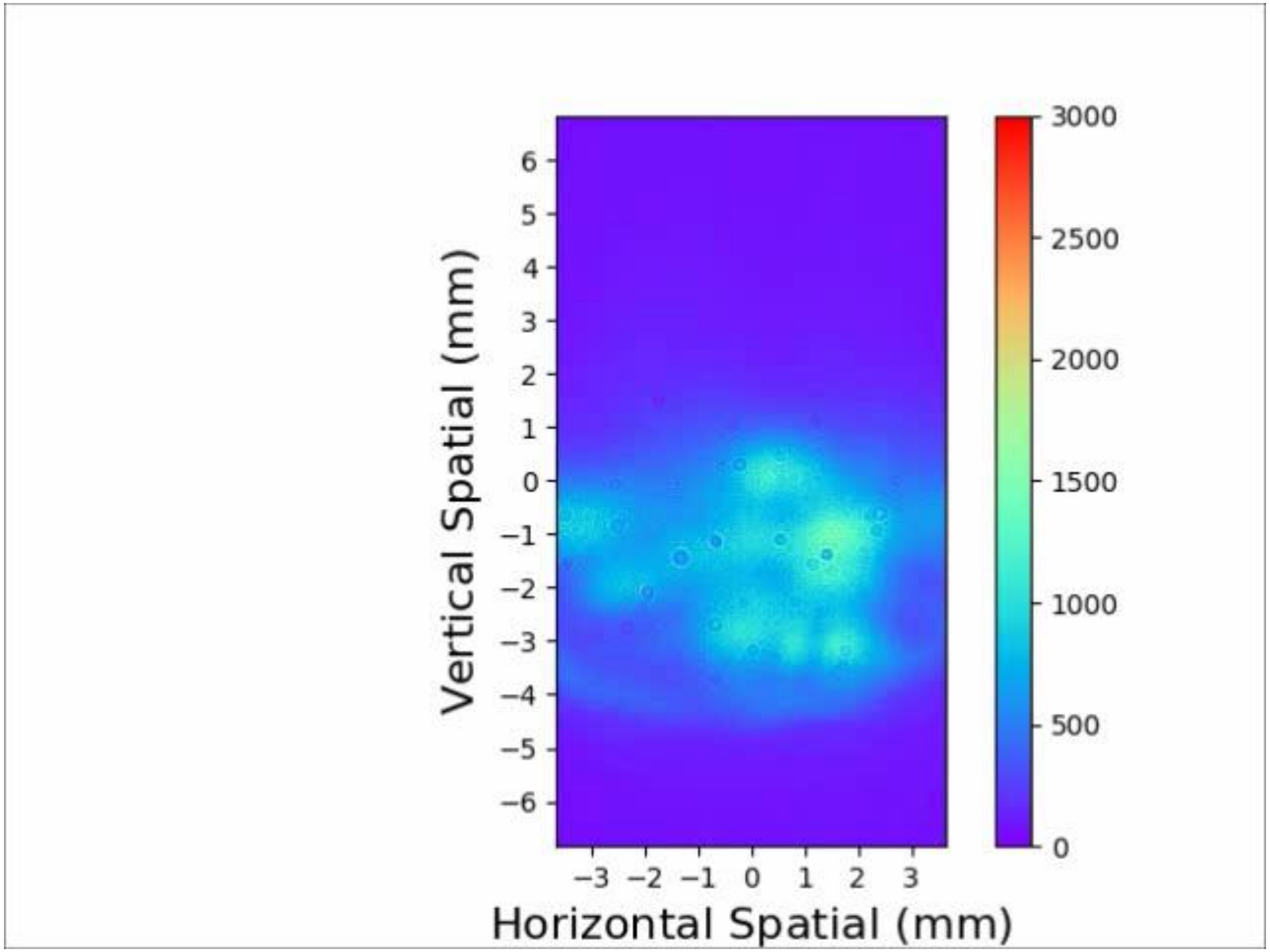
Well Above Threshold



Energy Limit of pickoff (Damage thresh)



Closing of Rb Reservoir Valve Below Threshold n0: 1e14/cc



Conclusions of Initial Rb Propagation Measurement and Outlook

- Beam crash / blowup threshold measured with current focusing:
  - 60 mJ @ Rb n = 7e14/cc
  - 10 mJ @ Rb n= 1e14/cc
  - This is consistent with depletion
- Above thresholds the beam propagates through without stretching and too much mode alteration so intensity stays high
- If much of the laser pulse experienced Rb valence electrons in the ground or first excited state there would be significant anomalous dispersion → beam blow up
- Either we are completely populating the second excited state or this is ionization, but from the intensity of the beam it is very likely ionization:
  - With the resonance assistance only 1 eV to ionization threshold from the second excited state, Keldysh models (non resonant) would predict >99.9 % ionization.
- What can we do to show that we have > 99.8% ionization in the channel?
  - Perhaps showing energy saturation with a lineout, i.e. the on axis fluence scales linearly with energy increase above threshold, meaning no additional energy loss (Patric's suggestion)