CP9.00048: Spectral Line Emission from Helicon Heated Plasmas

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Abstract

There has been a resurgence of interest in linear plasma devices as a method to study plasma-material interfaces under high power and particle flux. As the size and power of the linear machines is increased they yield important results for fusion-grade toroidal devices such as ITER and DEMO. A 5 cm diameter helicon plasma source developed at ORNL routinely provides high density ($n_e \geq 10^{19}$ m^{-3}) hydrogen plasmas for ion source development and other work. Recently, a 15 cm diameter, 1.5 m long linear machine has been built at ORNL using a new helicon antenna designed for input powers up to 100 kW, producing a plasma that will be used to bombard material targets. Visible spectroscopy has been used to measure emission line spectra of the helicon heated plasma from 200 nm to 1100 nm in real time at low resolution. Moreover, a separate diagnostic has been used to measure the intrinsic spectra of He II light from 10 sightlines to estimate the ion temperature and flow velocities (radial, axial, and azimuthal) at multiple axial locations in the device. Data from these diagnostics will be shown and their interpretation discussed.

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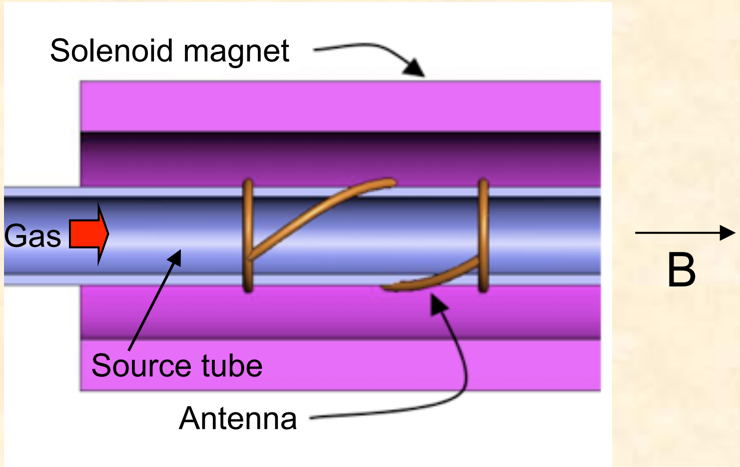
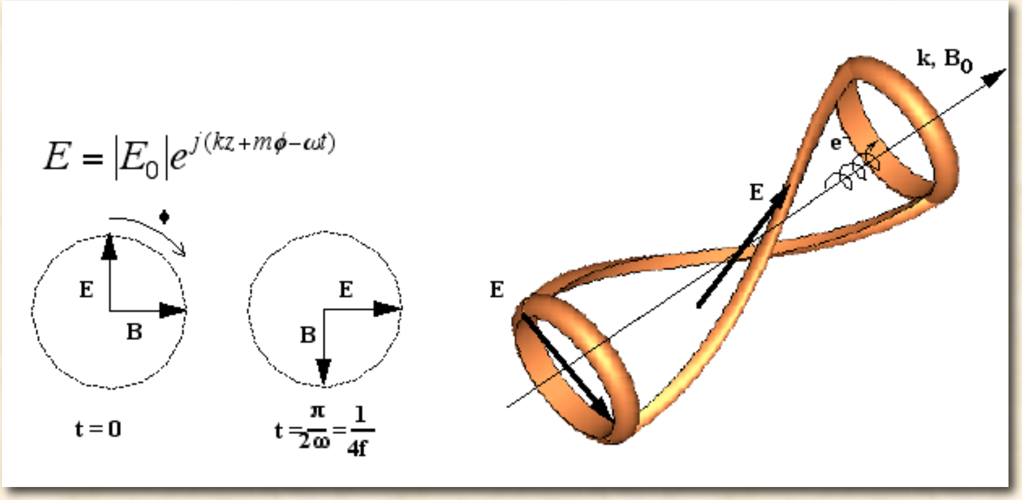
Since their invention, helicon devices have been found to be highly efficient magnetized plasma sources

- First investigated by R. W. Boswell in late 1960s (for early history, see IEEE Trans. Plasma Sci. 25, 1997,p. 1229)
- Typically operate in regime $\omega_{ci} \ll \omega \ll \omega_{ce}$
- Fast (electromagnetic) wave typically referred to as helicon wave, propagates along B, circularly polarized with m = +1 (right hand) polarization
- Simple device requires only axial magnetic field (very low value in comparison to ECR sources), dielectric source tube, and antenna that couples efficiently to helicon mode
- Half-turn dual-helix antenna found to be very efficient

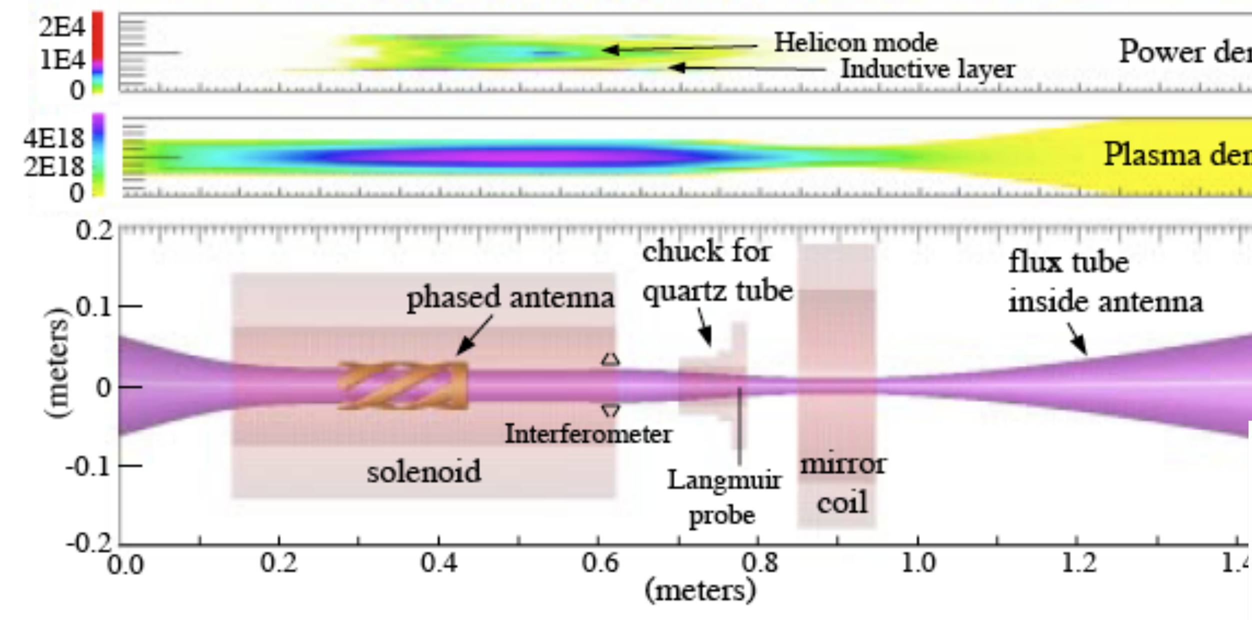




Electromagnetic helicon wave couples power to the plasma core

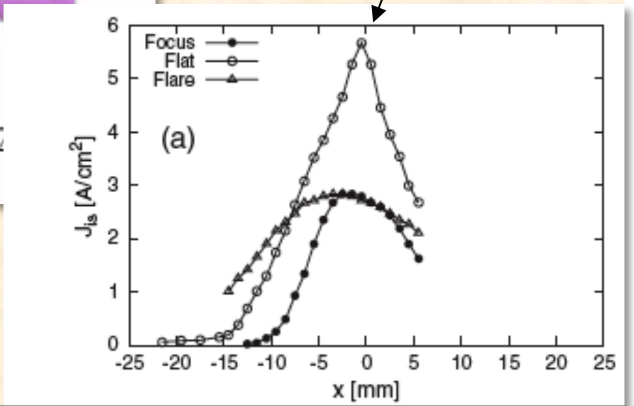
- **Produces peaked density profile**
- **In contrast, inductive coupling occurs at large radius**

Theoretical calculation of rf power absorption and plasma density made with MORRFIC code



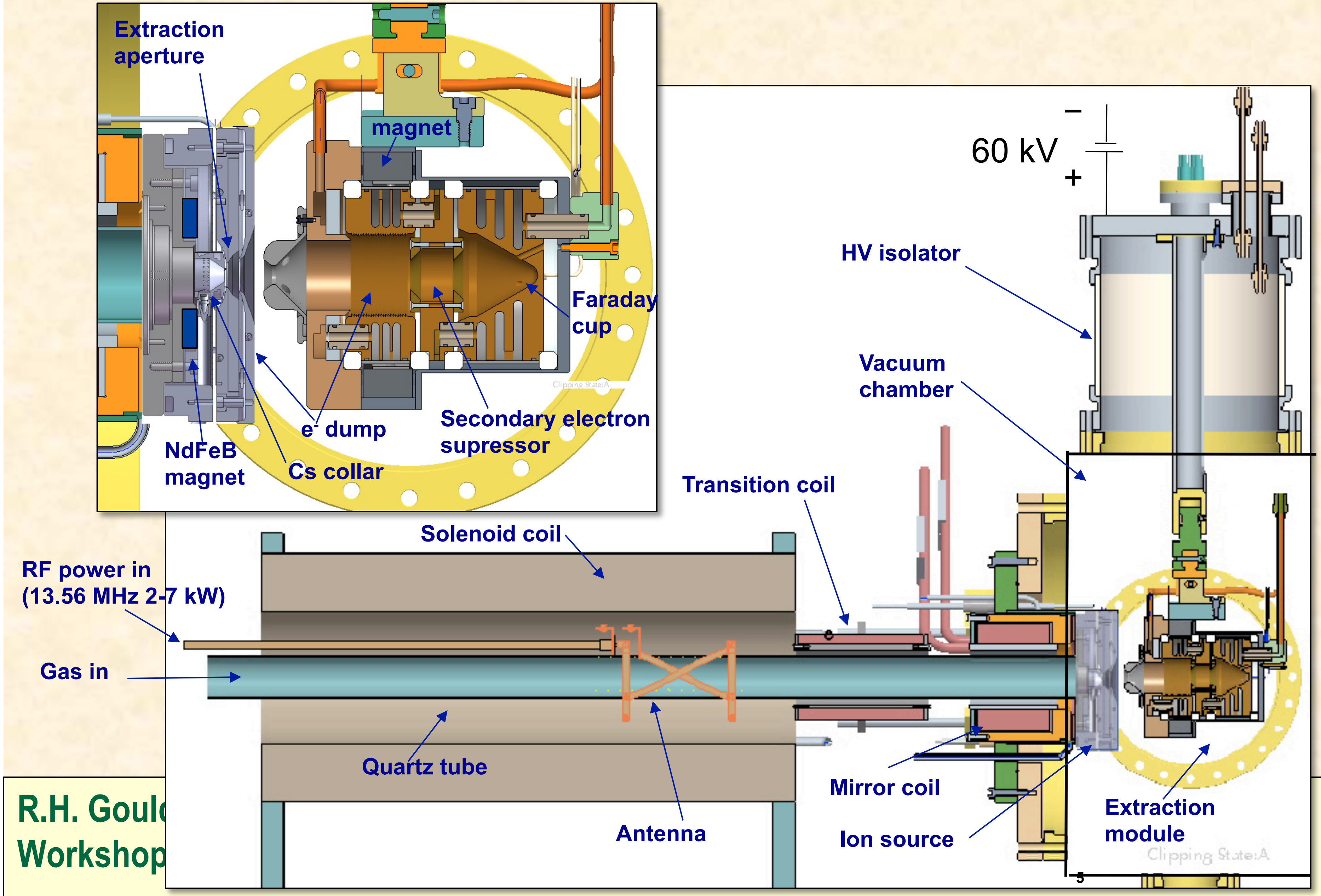
M. D. Carter et al., Phys Plasmas 9, 2002, p. 5097

Experimentally measured radial profile of ion saturation current varies with magnetic field configuration



R.H. Goulding, R. F. Welton, S. Murray, T. Pennisi, D. O. Sparks, RF-IS'09 RF Ion Source Workshop, ORNL- SNS, Oak Ridge, TN, September 28, 2009

The ORNL 5 cm helicon negative ion source



Extraction aperture

magnet

Faraday cup

Secondary electron supressor

e^- dump

NdFeB magnet

Cs collar

60 kV

−

+

HV isolator

Vacuum chamber

Transition coil

Solenoid coil

RF power in (13.56 MHz 2-7 kW)

Gas in

Quartz tube

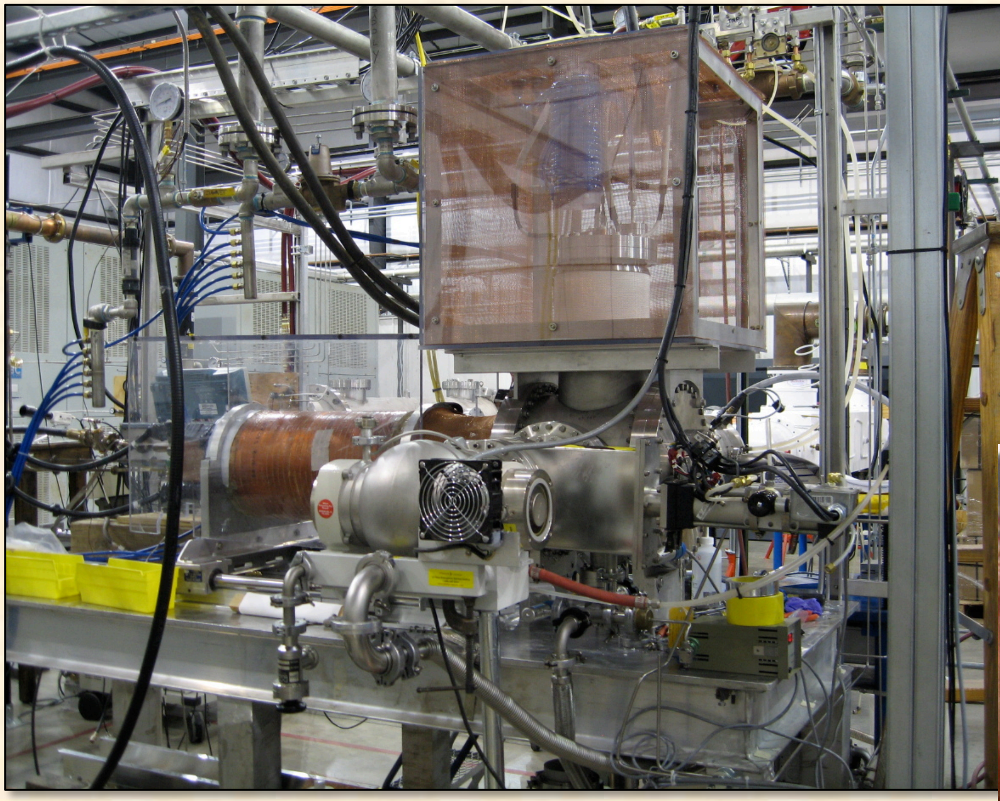
Antenna

Mirror coil

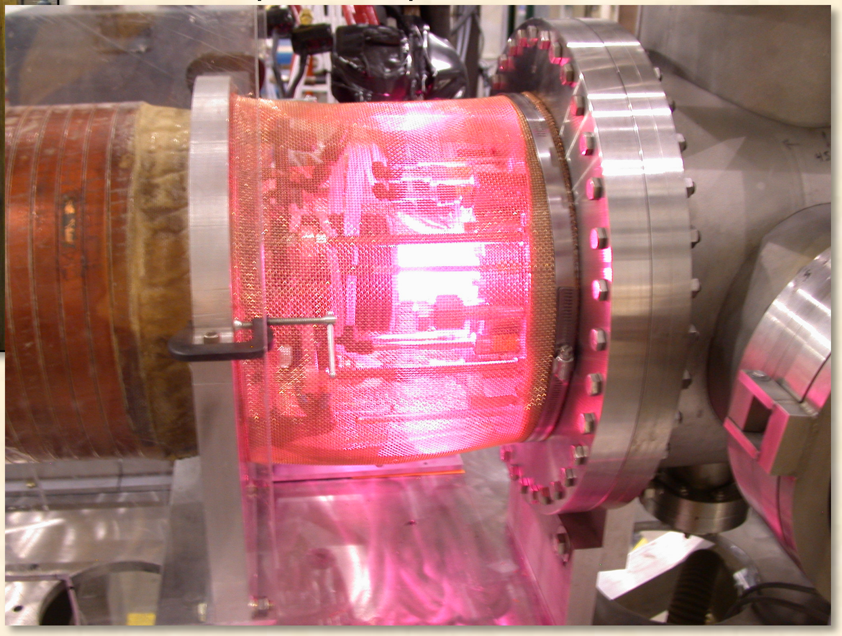
Ion source

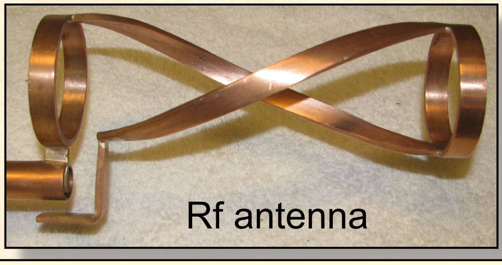
Extraction module

ORNL 5 cm helicon negative ion source



High density hydrogen
plasma operation



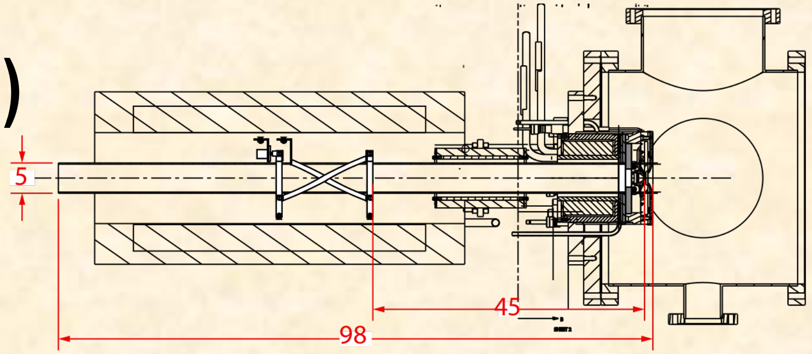


Rf antenna

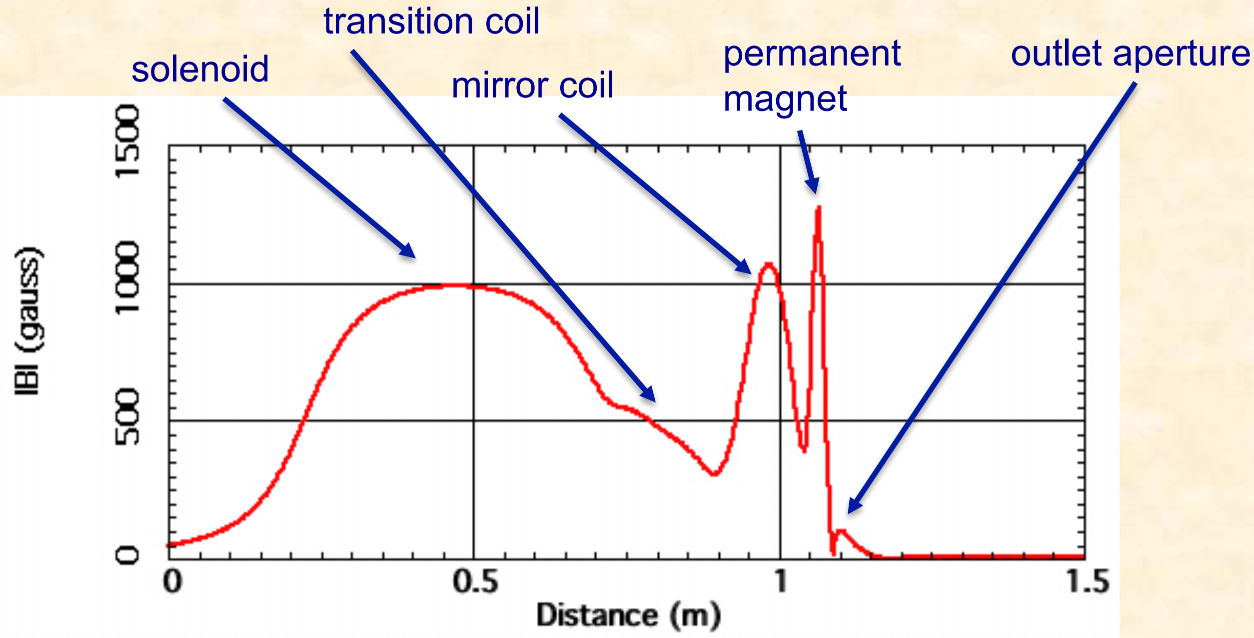
R.H. Goulding, R. F. Welton, S. Murray, T. Pennisi, D. O. Sparks, RF-IS'09 RF Ion Source Workshop, ORNL- SNS, Oak Ridge, TN, September 28, 2009

Device dimensions and magnetic field profile

- Dimensions (cm)

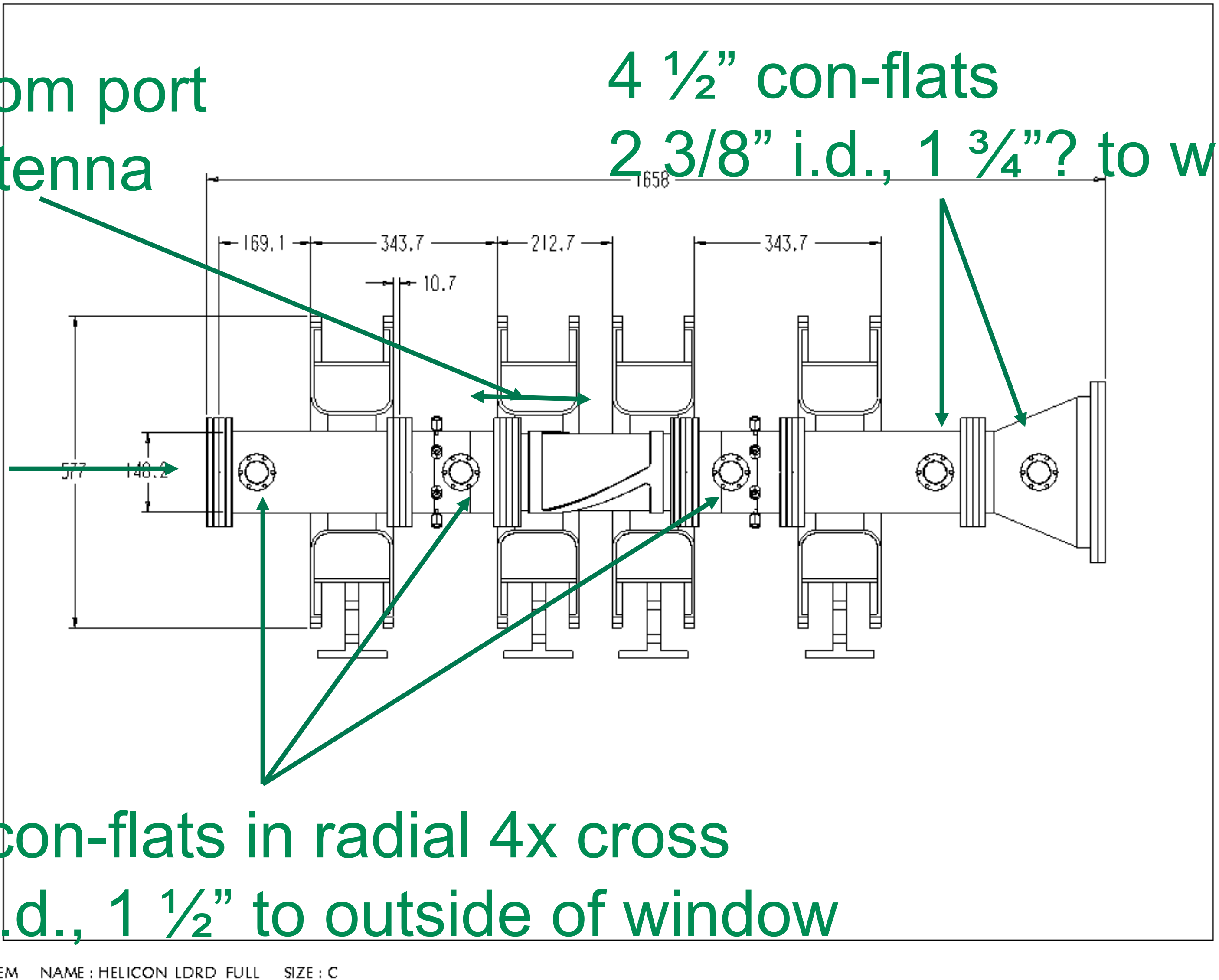


- |B| on axis



R.H. Goulding, R. F. Welton, S. Murray, T. Pennisi, D. O. Sparks, RF-IS'09 RF Ion Source Workshop, ORNL- SNS, Oak Ridge, TN, September 28, 2009

New, 15 cm diameter helicon source



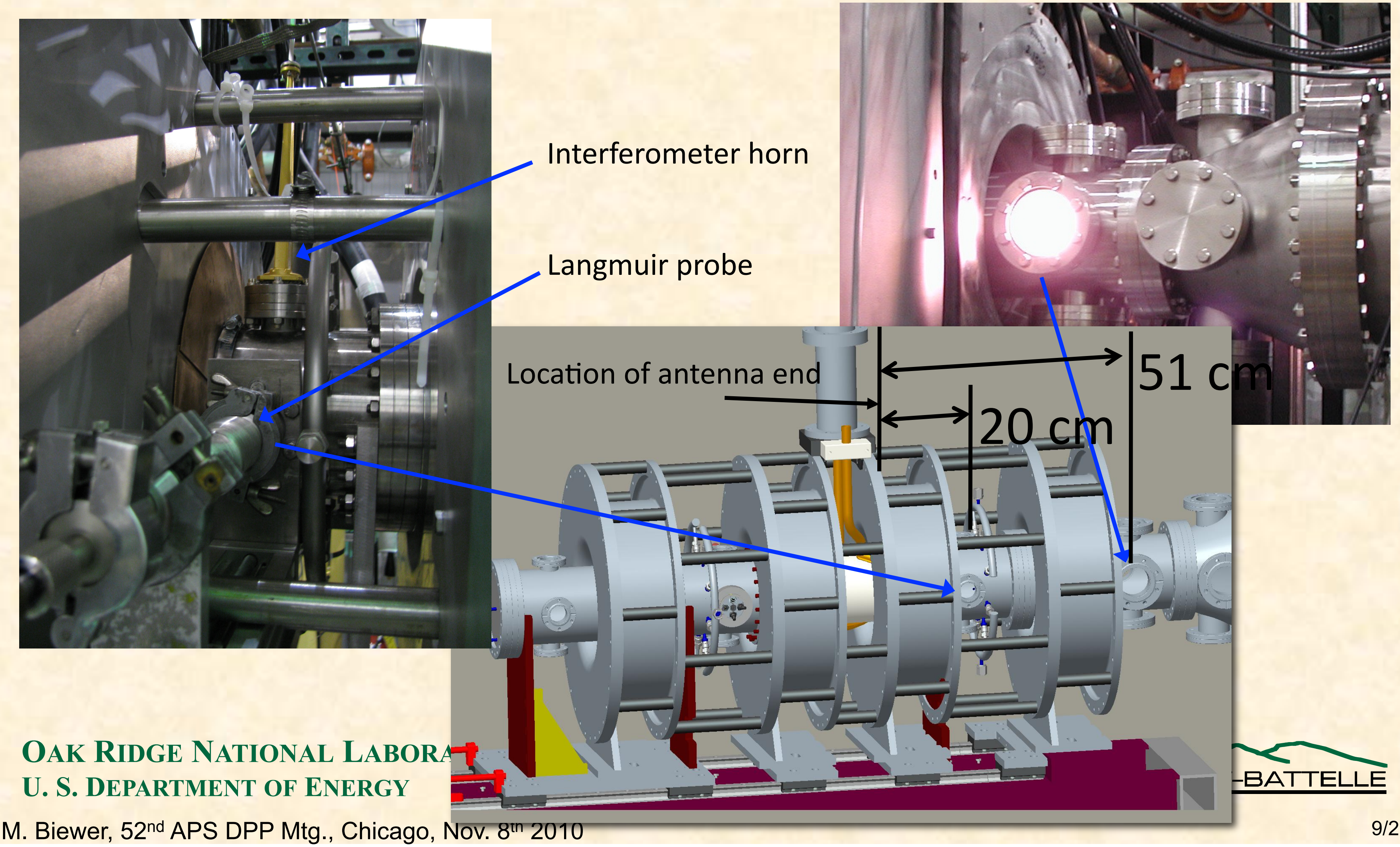
~8" from port
To antenna

4 ½" con-flats
2 3/8" i.d., 1 ¾"? to window

6" o.d.

2 ¾" con-flats in radial 4x cross
1 ½" i.d., 1 ½" to outside of window

Location of density measurements and view from downstream port

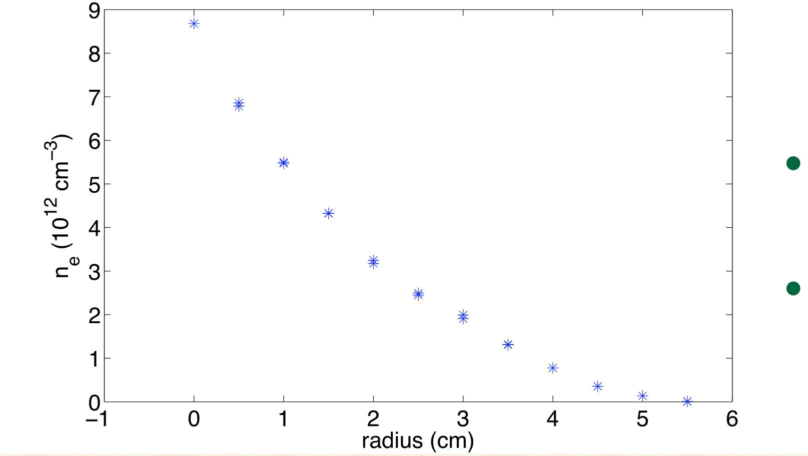


Achieved operating parameters

- Gas: He and H
- Tank pressure: 10 mTorr
- Inner coil currents – 710 A
- |B|under helicon antenna ~ 0.14 T
- Frequency: 13.56 MHz
- Forward power: 2 kW
- Pulse length: 0.1 to 0.5 s to 2 s

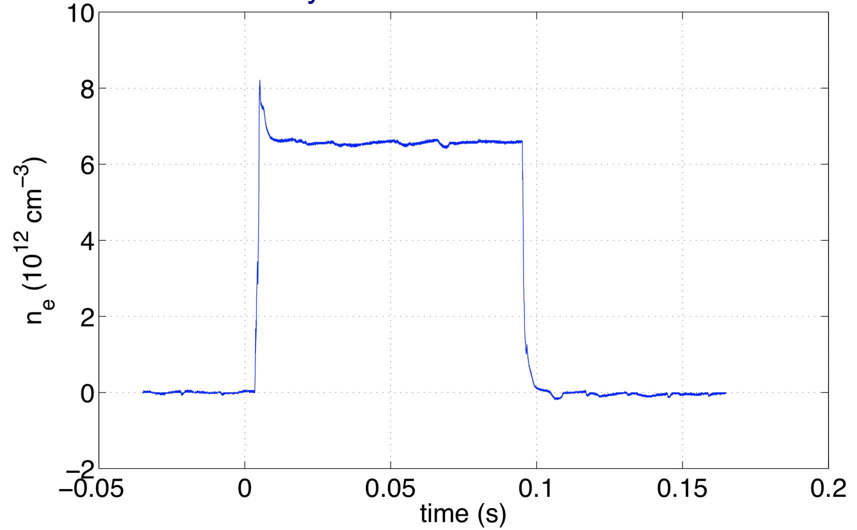
Langmuir probe and interferometer density data agree well (Preliminary)

Radial density profile from Langmuir probe I_{sat} measurements

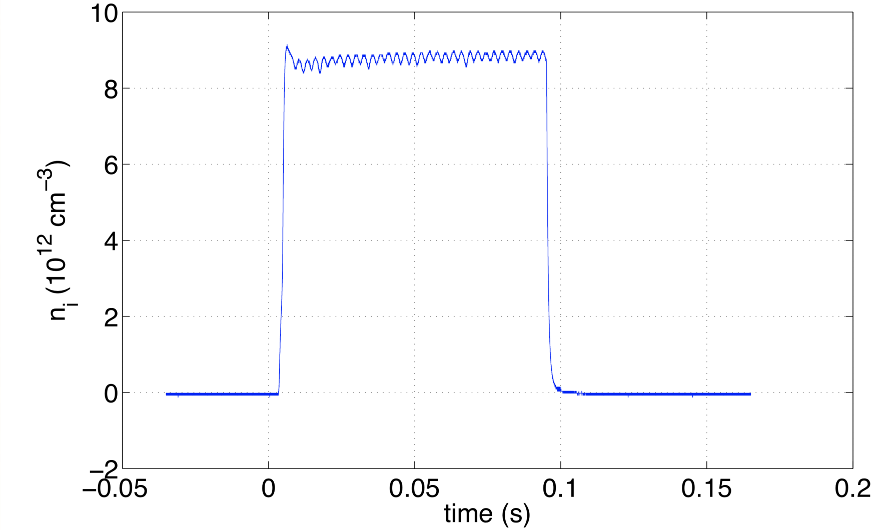


- Radial profile determined with Langmuir probe, used to determine interferometer chord length (= 3.6 cm)
- Peak density from interferometer: ~7 X 10^{12} cm^{-3}
- Peak density from Langmuir probe (assuming T_e = 6eV): ~ 9 X 10^{12} cm^{-3}

On axis density from interferometer measurement



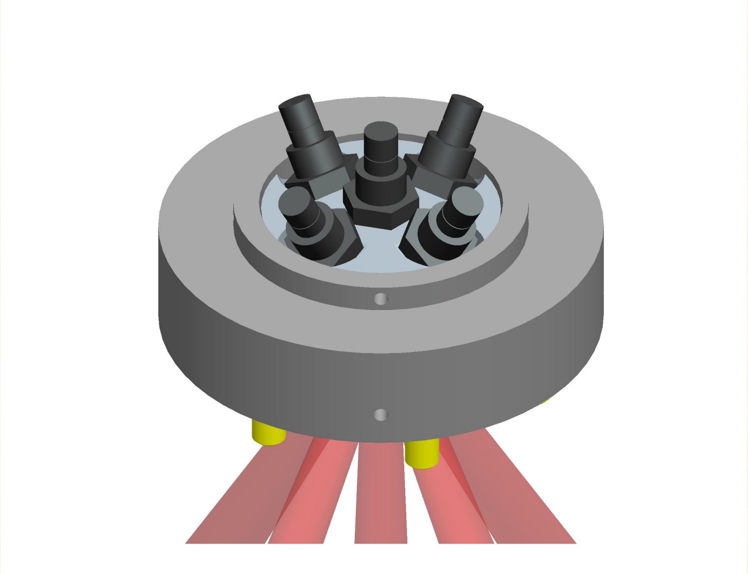
On axis density from Langmuir probe I_{sat} measurement

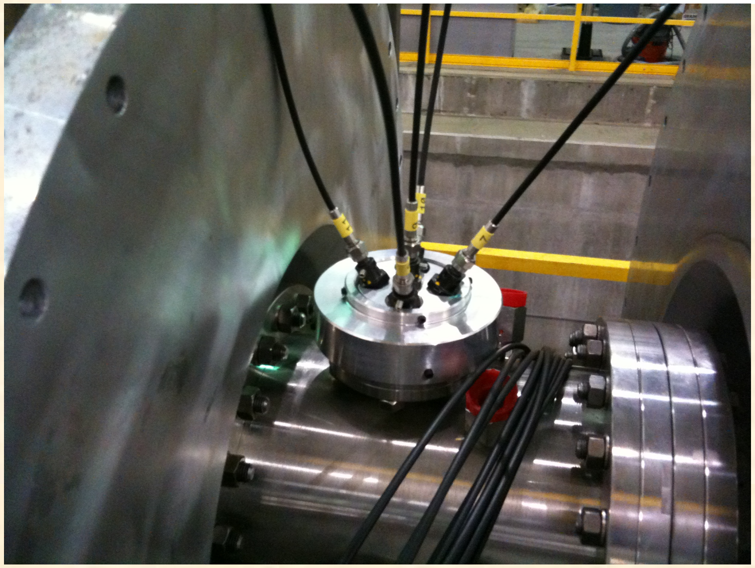


For more information on ORNL helicon sources:

- **Poster PP9.00003 (Wed. Nov. 10, 2010 2pm): R.H. Goulding, *et al*.,** Progress on the ORNL high power, high particle flux helicon hydrogen plasma source
- **Poster PP9.00006: L.W. Owen, *et al*.,** Transport modeling of the ORNL high intensity linear RF plasma source

Multi-chord viewing optics





- Collimating (fused silica) lens attaches to fiber (SMA mount).
- Pucks positioned at multiple locations along axis of device.
- Kaiser Optical Holospec f/1.8
  - High dispersion grating for 4686 He
  - 600 μm PCS fiber
  - PI 512B PhotonMax CCD camera
  - 10 channels
- Ocean Optics HR4000CG UV-NIR
  - 1 channel
  - 200 – 1100 nm coverage

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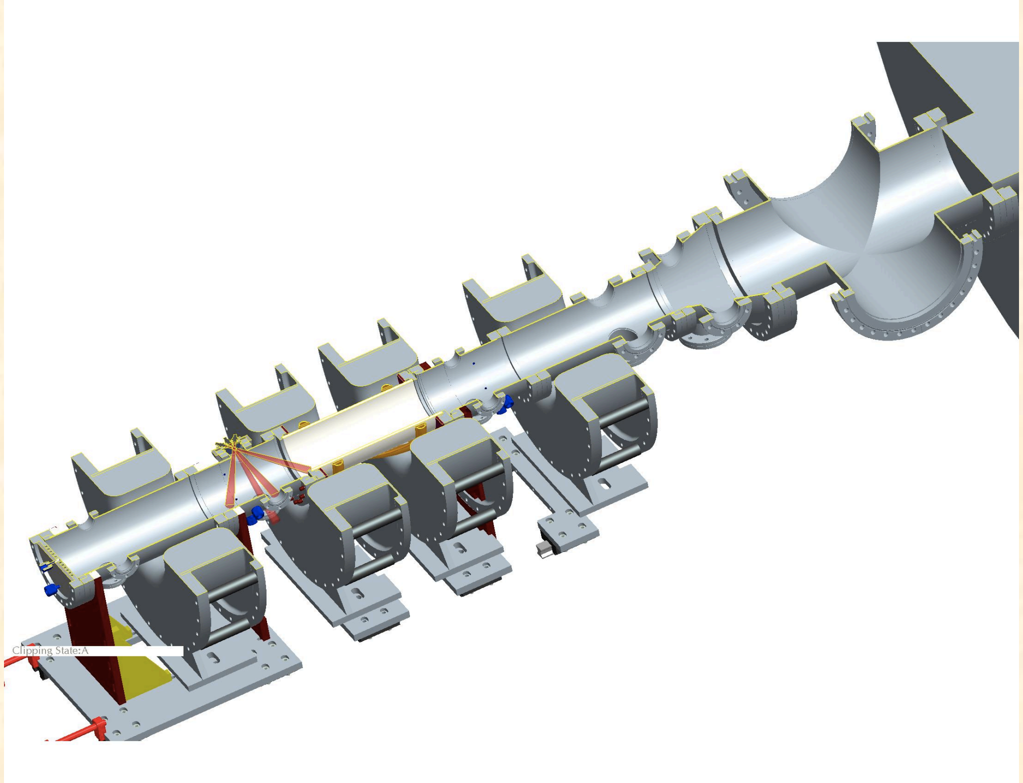
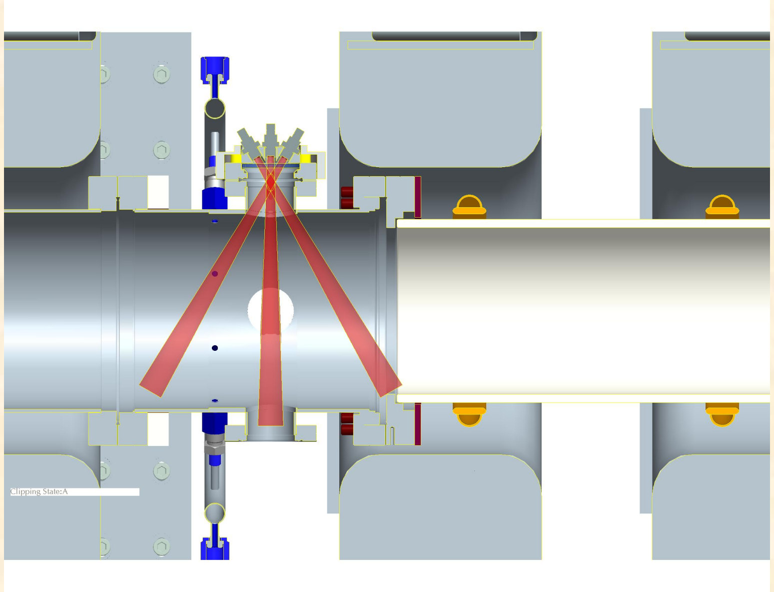
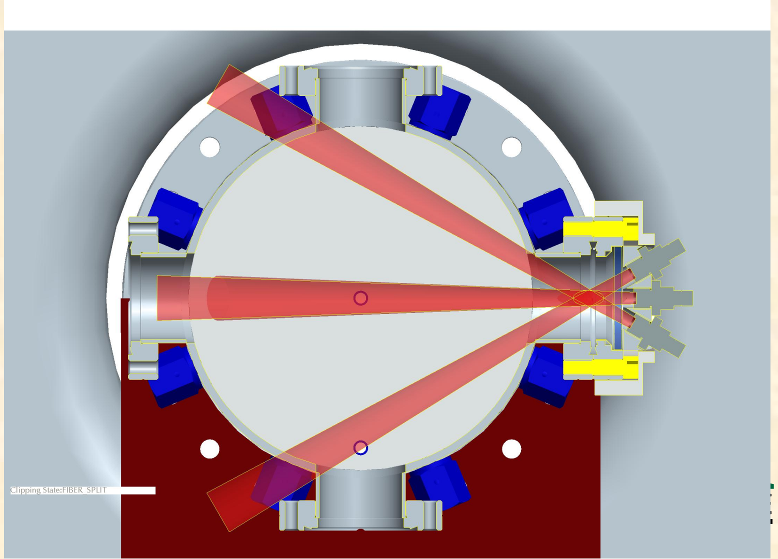
Multi-chord viewing geometry

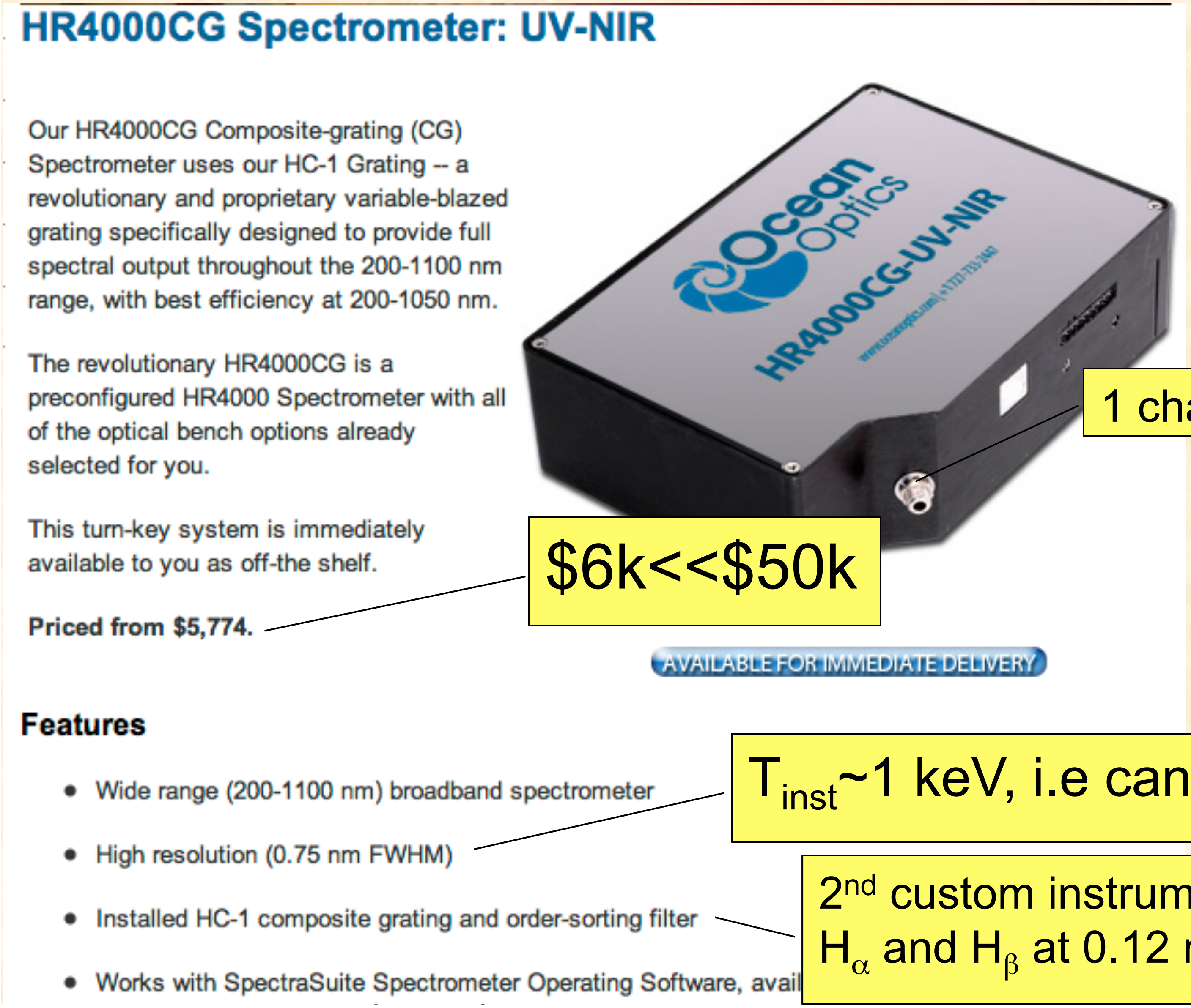






- **Sightlines allow for measurement of radial, axial, and azimuthal flows**
- **Multiple positions along device axis**

"Pocket" survey spectrometer



HR4000CG Spectrometer: UV-NIR

Our HR4000CG Composite-grating (CG) Spectrometer uses our HC-1 Grating -- a revolutionary and proprietary variable-blazed grating specifically designed to provide full spectral output throughout the 200-1100 nm range, with best efficiency at 200-1050 nm.

The revolutionary HR4000CG is a preconfigured HR4000 Spectrometer with all of the optical bench options already selected for you.

This turn-key system is immediately available to you as off-the shelf.

Priced from $5,774.

Features

- Wide range (200-1100 nm) broadband spectrometer
- High resolution (0.75 nm FWHM)
- Installed HC-1 composite grating and order-sorting filter
- Works with SpectraSuite Spectrometer Operating Software, avail

1 channel<<10 channels

$6k<<$50k

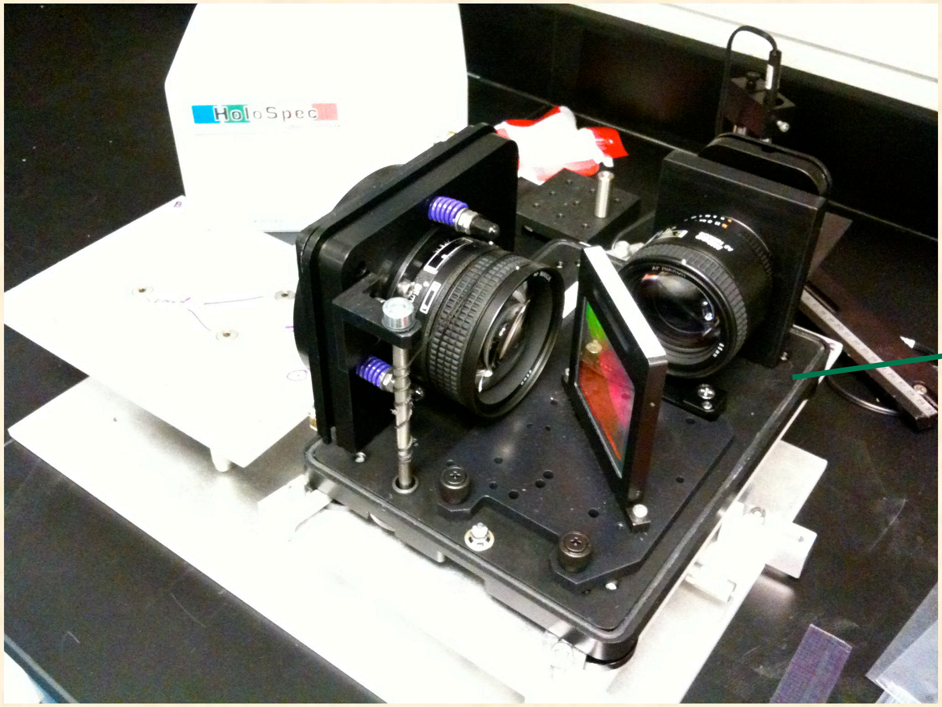
T_{inst}~1 keV, i.e can't measure T_i

2nd custom instrument: 1200 g/mm for H_α and H_β at 0.12 nm FWHM

Single fiber for pocket spectrometer

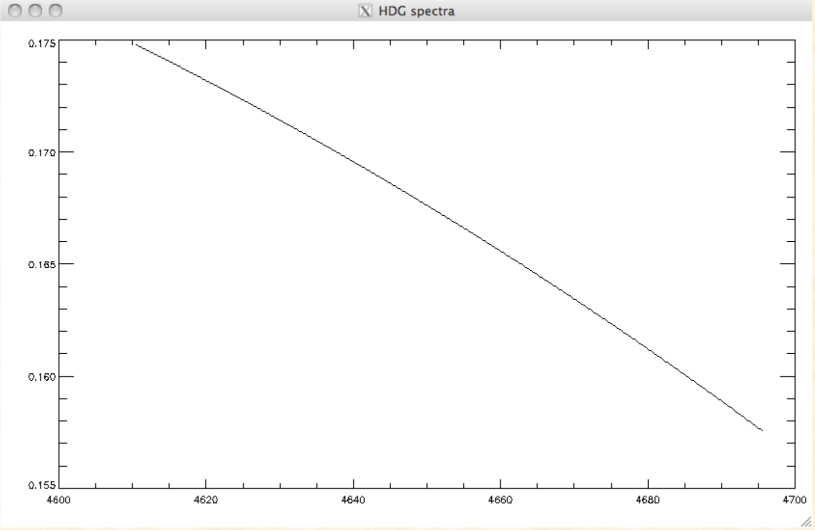
- Have 400 μm 1.5 m 0.22 NA gold jacketed fiber (700 °C), collimated with sapphire lens to SMA.
- Could also use commercial SMA collimating lens, as with Kaiser spect. and 600 μm 15 m fiber.

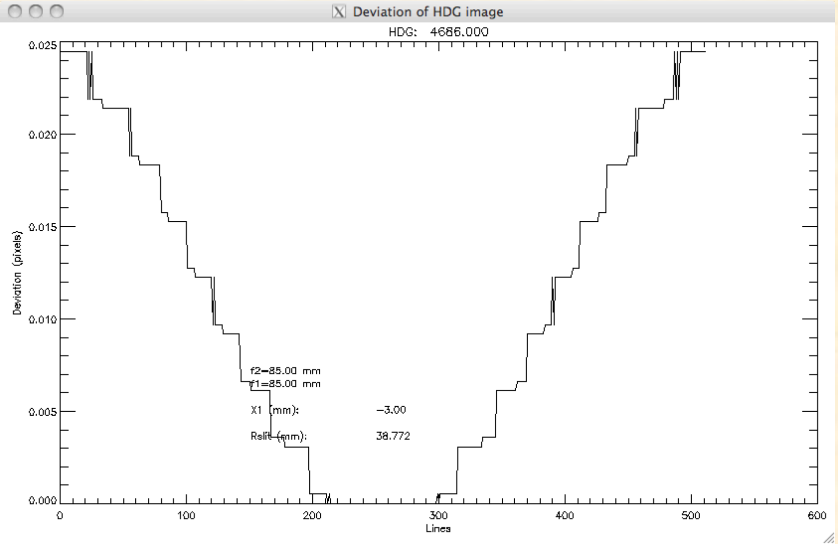
Short focal length spectrometer



- Kaiser Optical Holospec f/1.8
  - HD grating for 4686 He
- PC and mounting plates
- Fiberbundle: 17 channel SMA bundle for C 5290
  - 600 μm PCS (100 °C), 7 m
  - Is OK for this application
- Configuration
  - 10 views: 85 mm exit lens
  - 15 views: 58 mm lens
  - 17 views: 50 mm lens (buy, $800)
- CCD camera?
  - From JET: Cascade 512B or PhotonMax 512
  - Buy: ProEM ~$35k

Spectrometer simulation



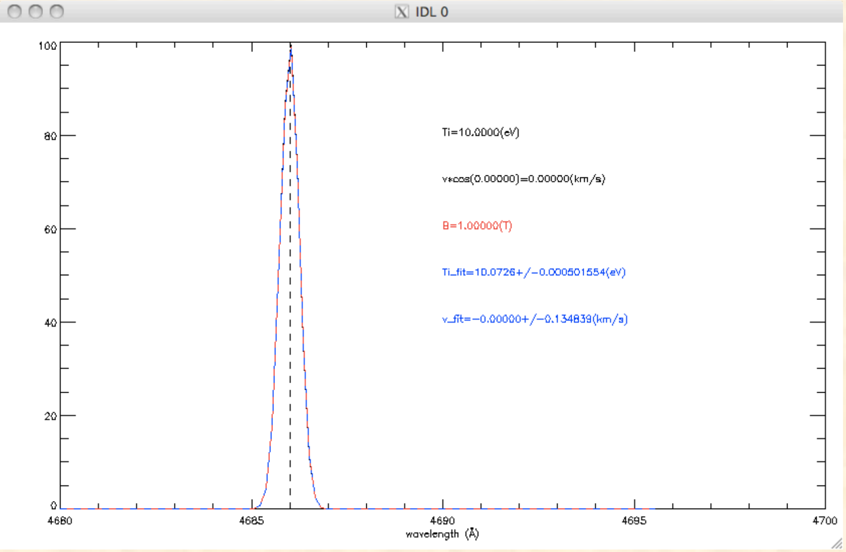


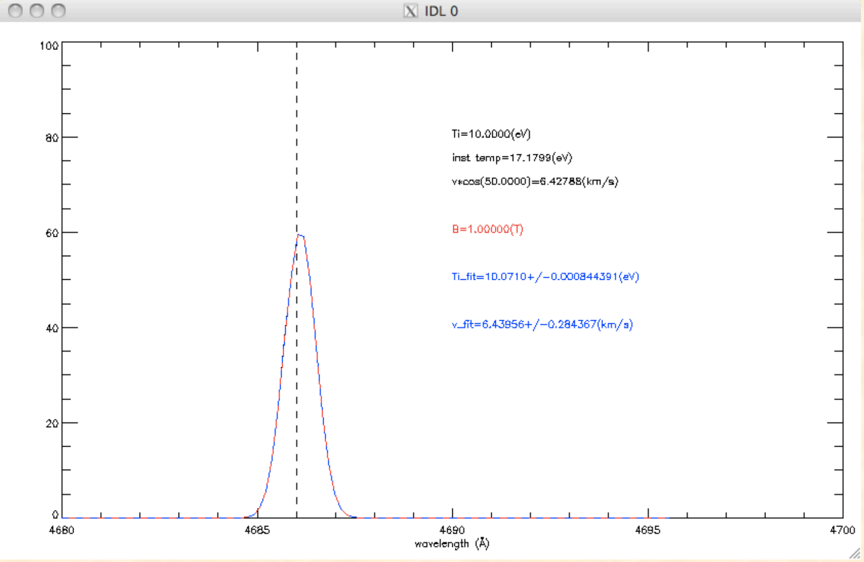
HDG: 4686.000

f2=85.00 mm
f1=85.00 mm
X1 (mm): -3.00
Rslit (mm): 38.772

- **Existing slits & bundle made for C 5290 HD grating with 50mm exit lens**
  - **Optimized for JET CXRS T_i and v measurements**
- **Use with He 4686 HD grating and 85 mm lens (for maximum resolution) is OK**

Spectral simulations (Holospec)

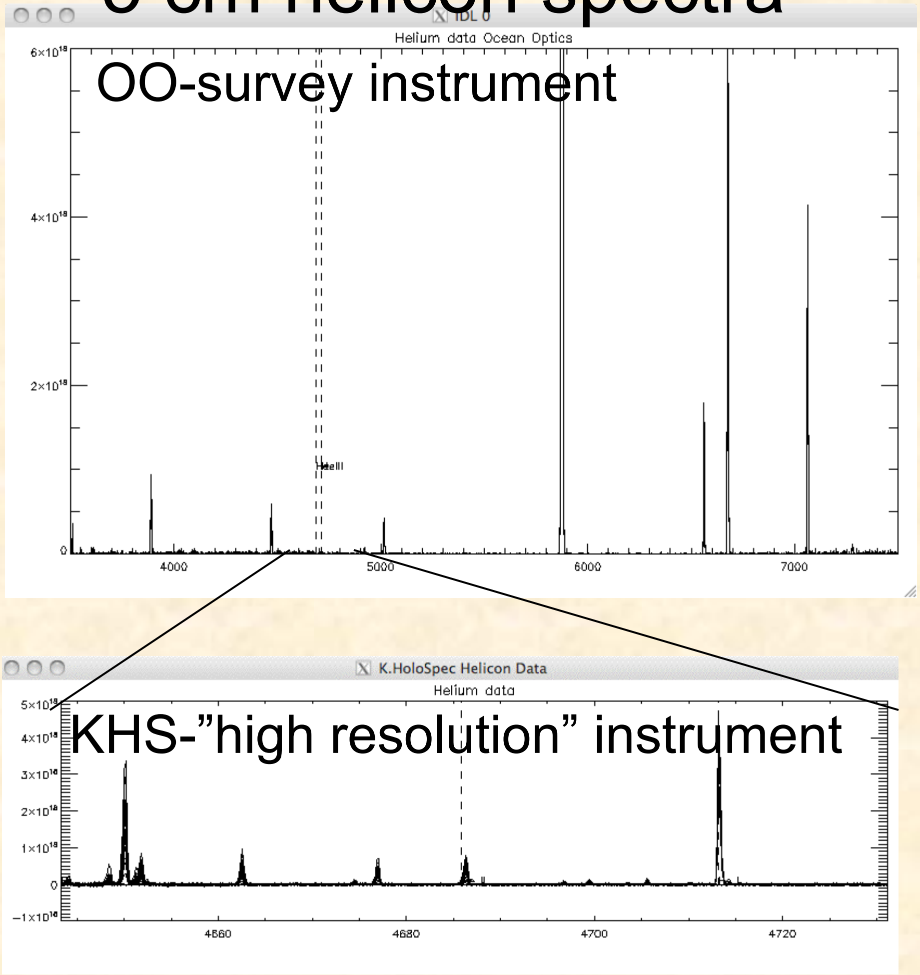




- “normal” Zeeman splitting effects
  - ~1% error at 1 T for 10 eV
  - ~10% error at 1T for 1 eV
  - ~100% error at 3 T for 1 eV
- Realistic inst. function
  - 75 μm slit = ~17 eV T_{inst}
- Resolution:
  - T_i ~ 1 eV probable
  - V ~ 300 m/s
    - matched views helpful

Instrument comparison

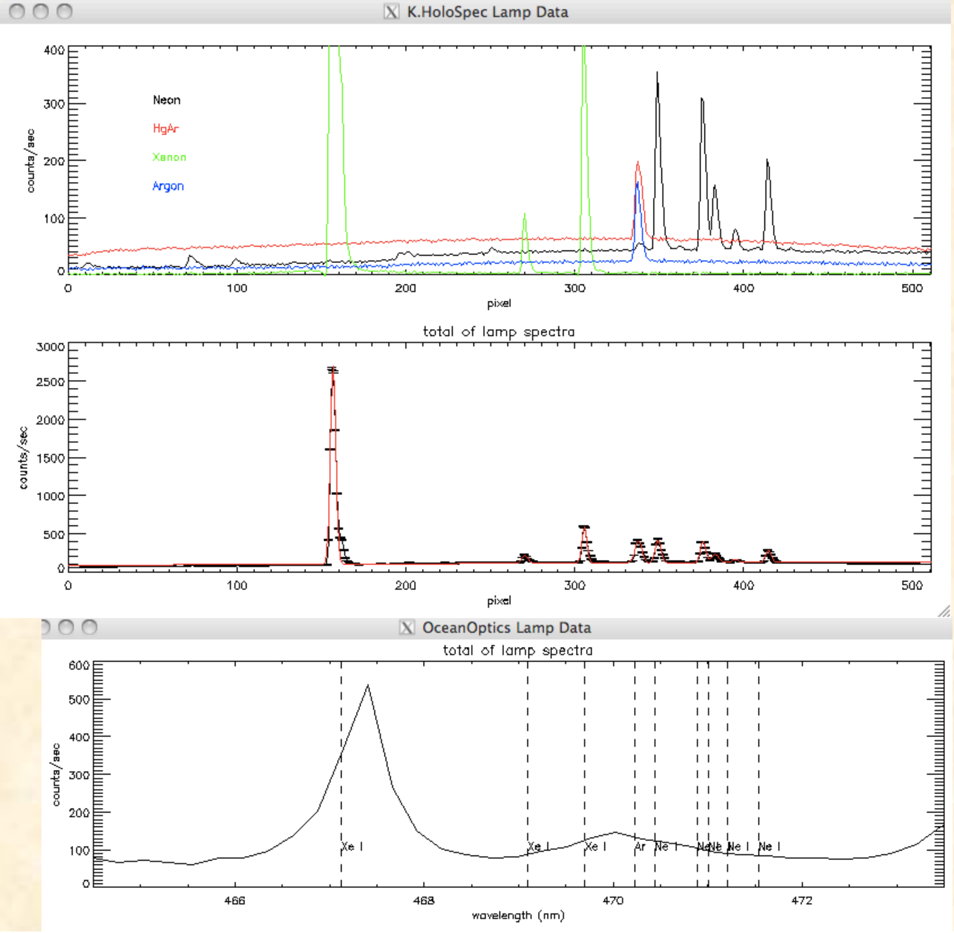
5 cm helicon spectra



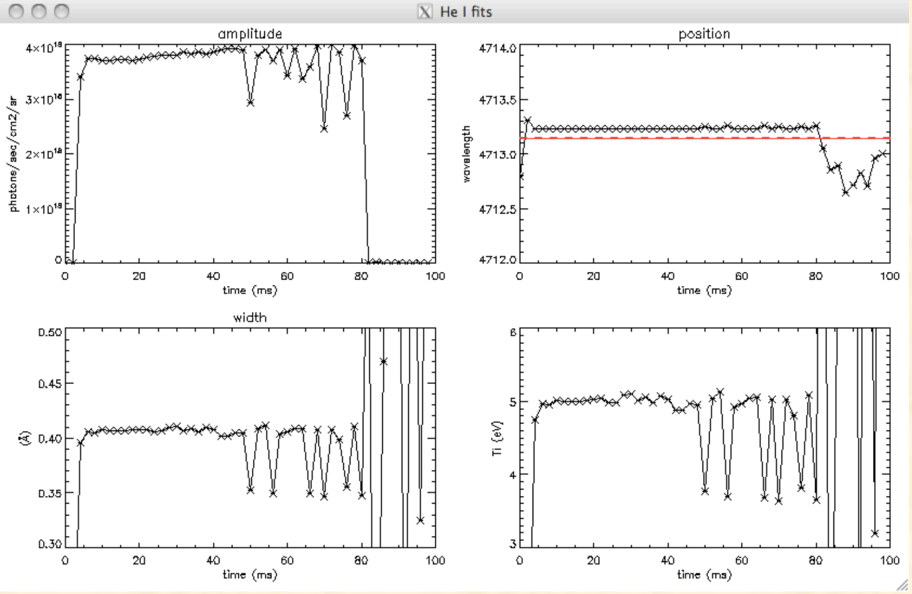
OO-survey instrument

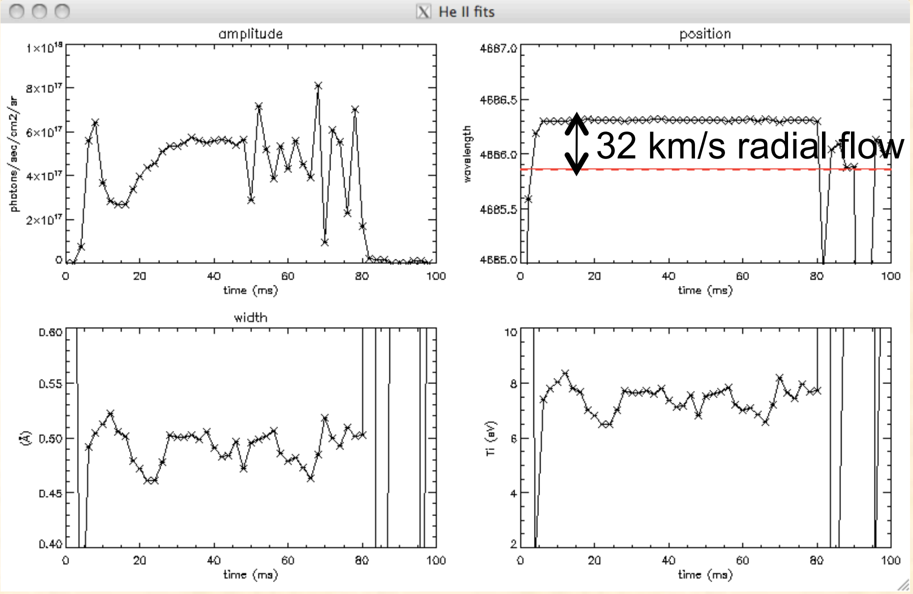
KHS-”high resolution” instrument

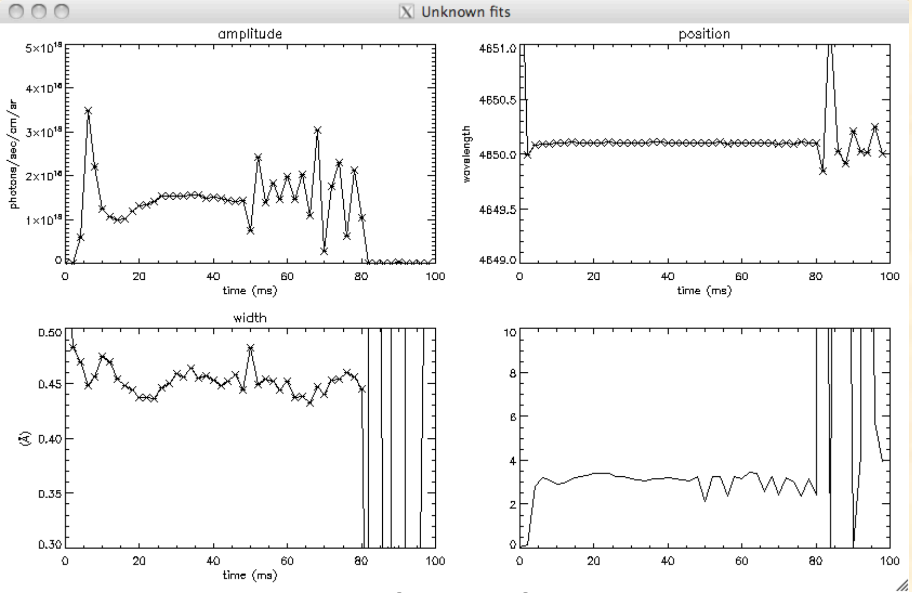
Pen-lamp calibration



Temporal evolution of 5 cm helicon discharge (“radial” line of sight)







- **Measurements made 25 cm “downstream” from antenna with radial line of sight**
- **He I evolution representative of background gas**
- **He II evolution more dynamic**
  - **T_i ~ 2 eV?**
  - **V_r ~ 26 km/s?**

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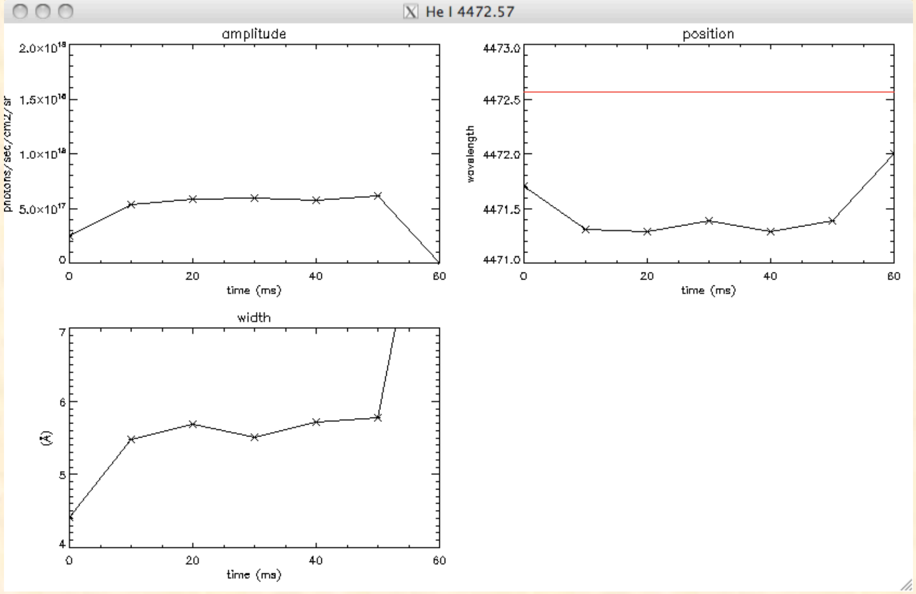
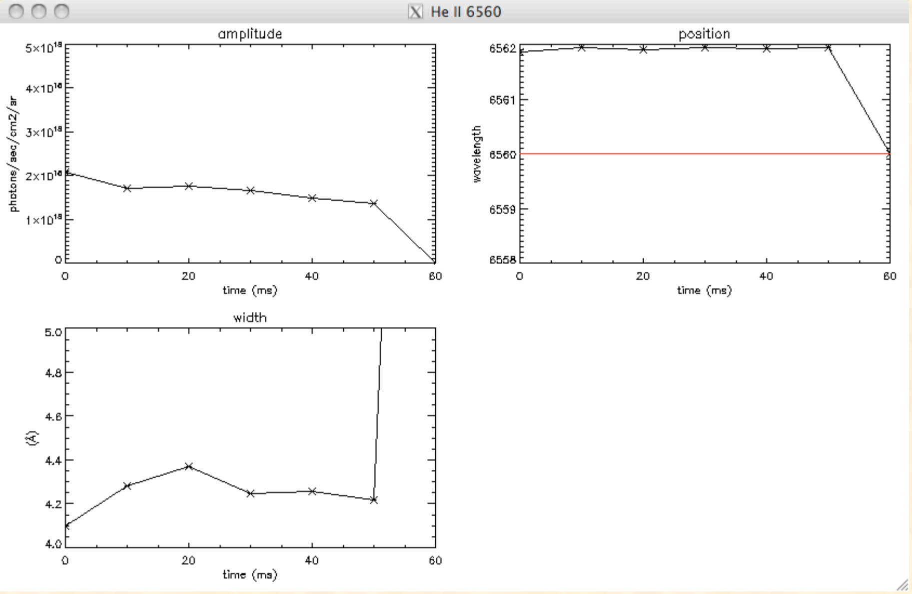
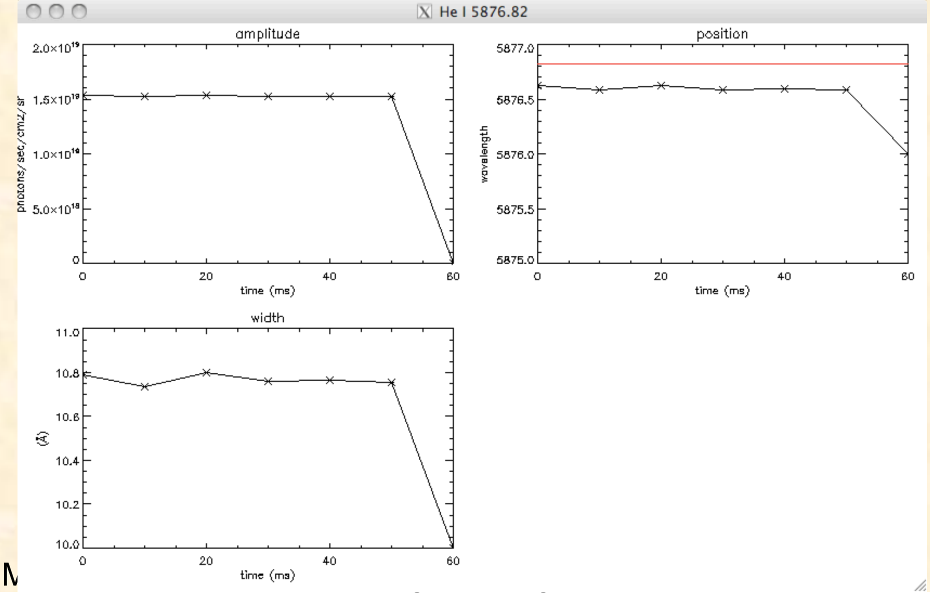
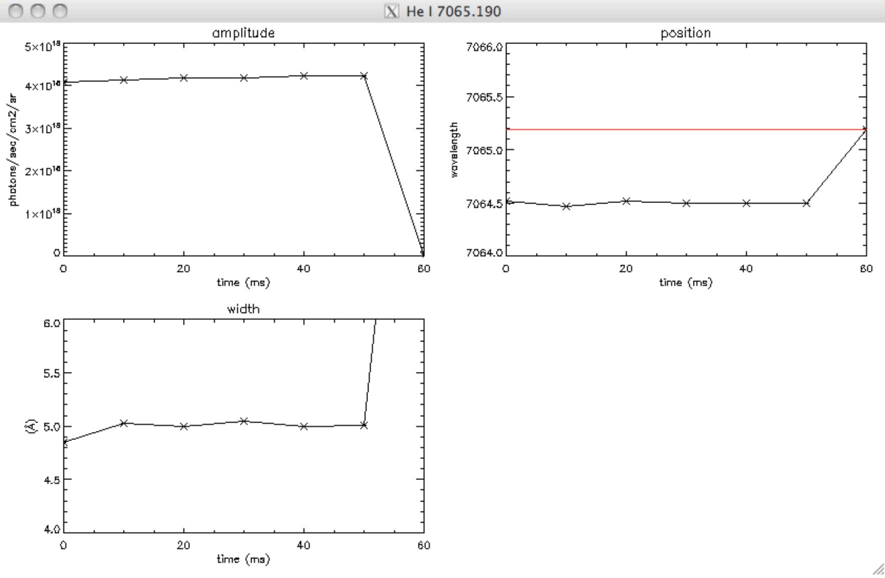
Temporal evolution of 5 cm helicon discharge (continued)

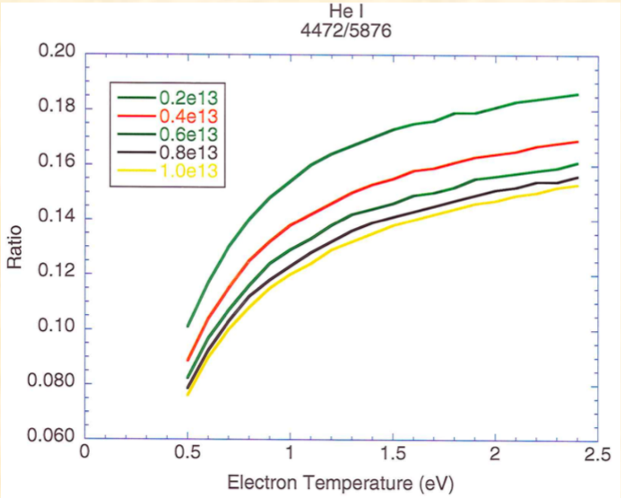


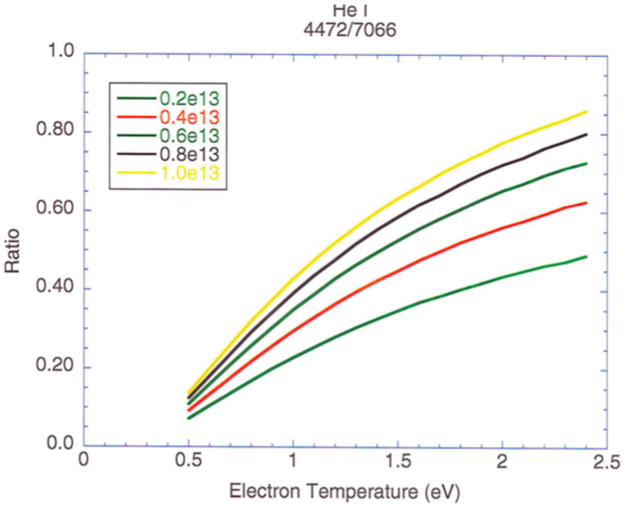


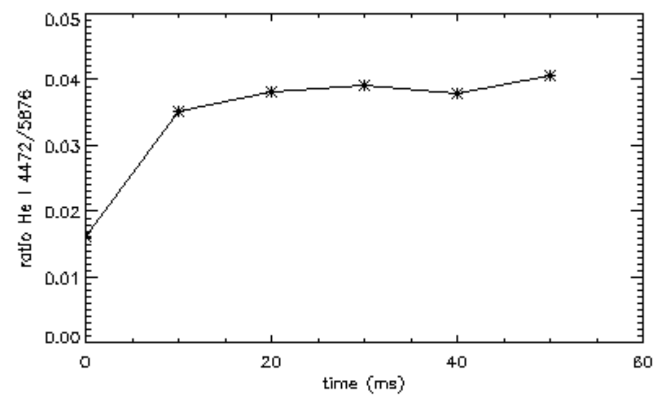


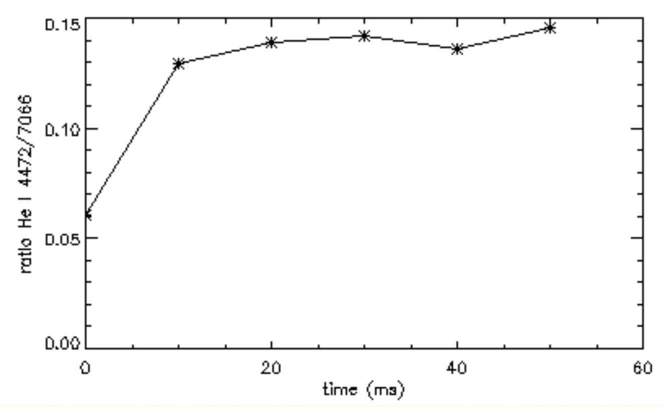


T_e, n_e estimation from line ratios



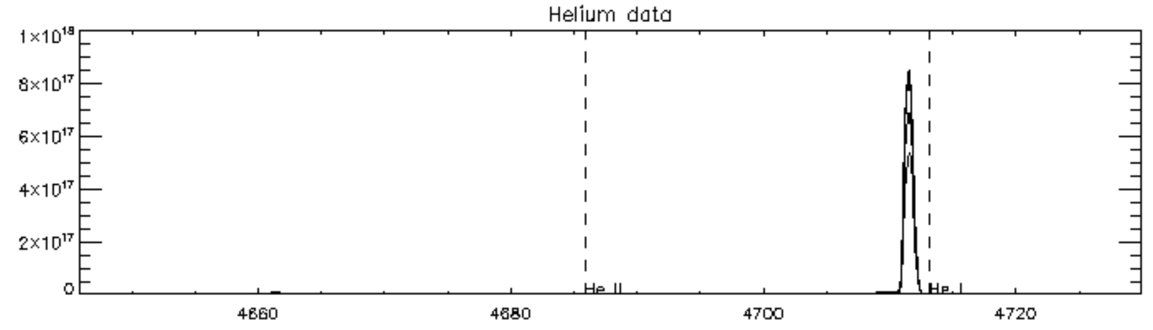


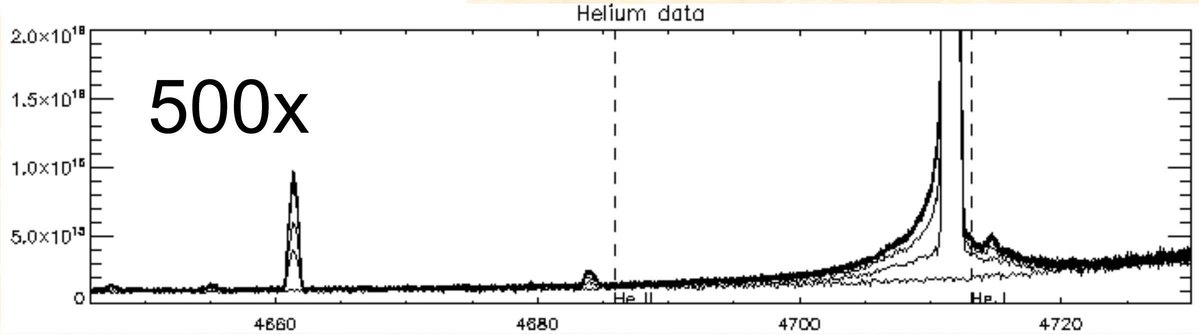




- The ratio of spectral line intensities can be compared to calculations to estimate T_e and n_e
  - T_e ~< 0.5 eV
  - Cannot determine n_e from this data

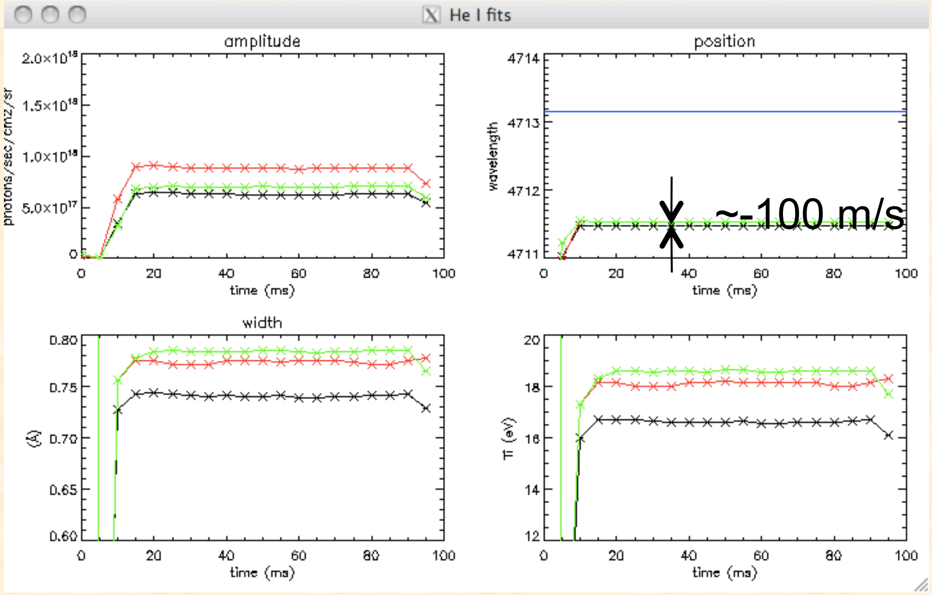
15 cm helicon results

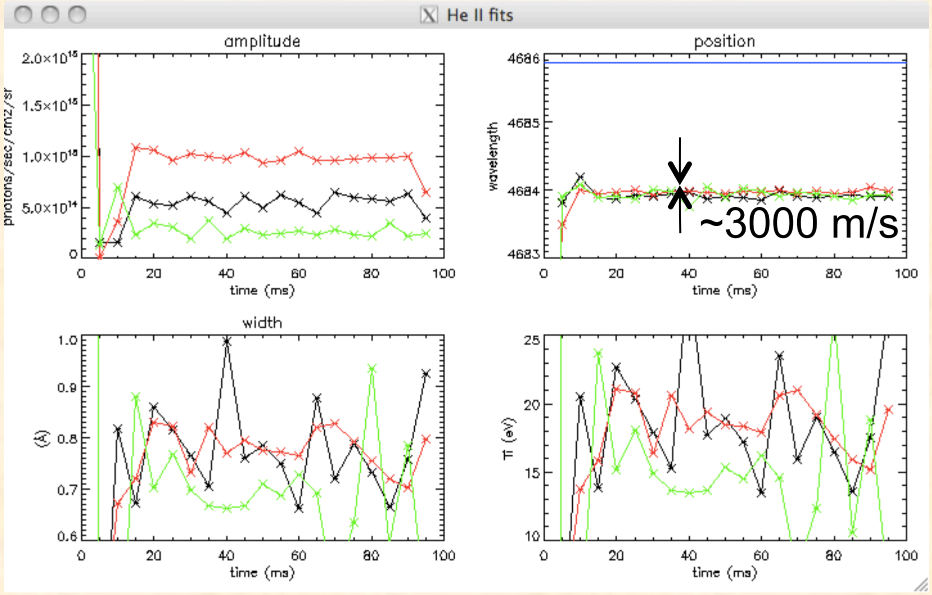


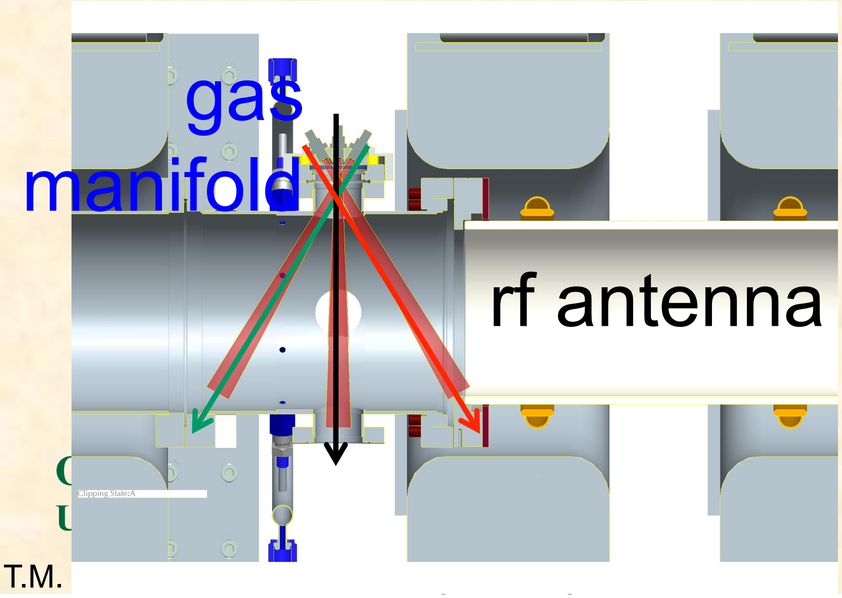


- **Initial operation limited to 2 kW (compare to 7.5kW in 5cm)**
- **He I @ 4713 brightness ~same for 5 and 15 cm helicons**
- **He II @ 4686 is 1000x dimmer on 15 cm helicon**
- **“Unknown” impurities are not present in 15 cm helicon**

He II ionization increases near antenna

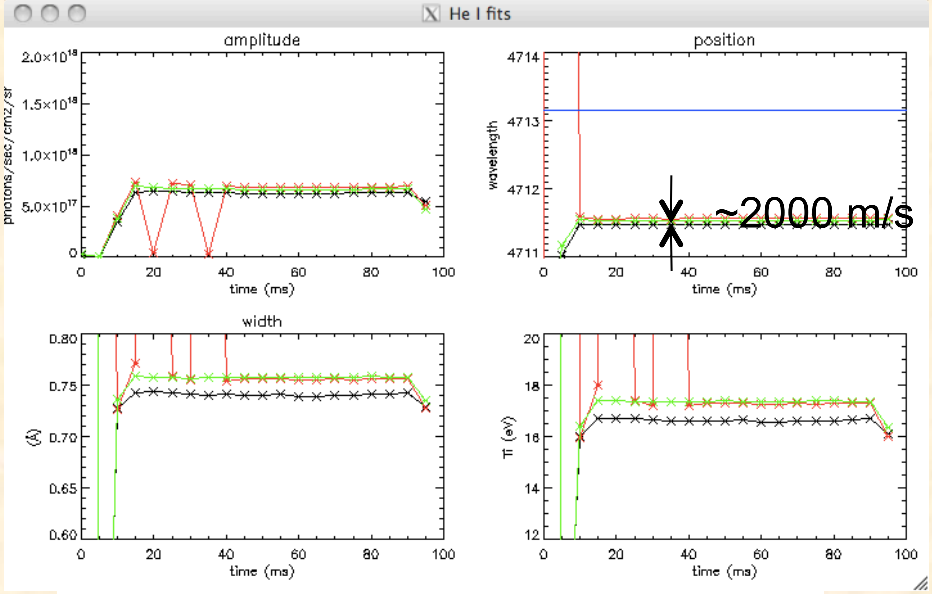


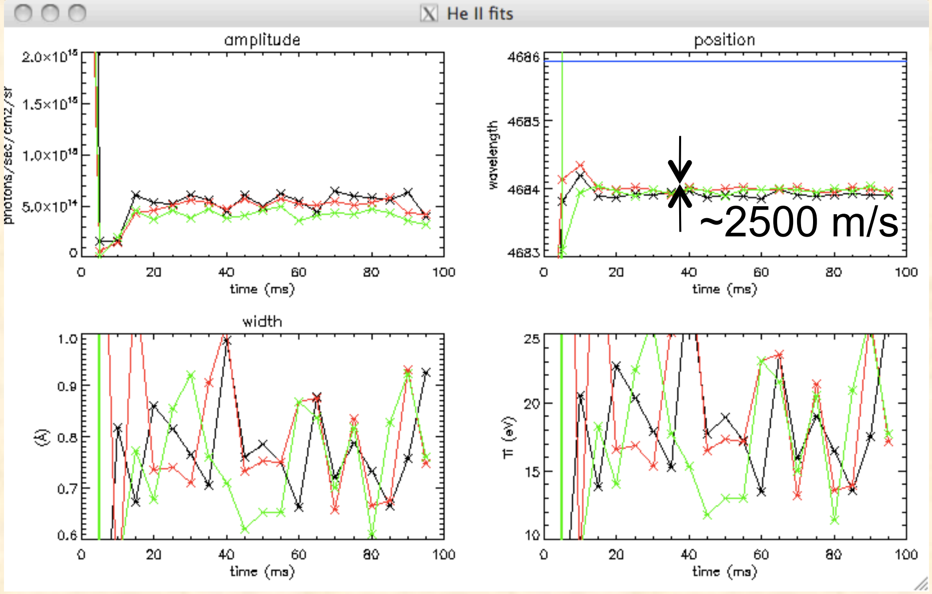


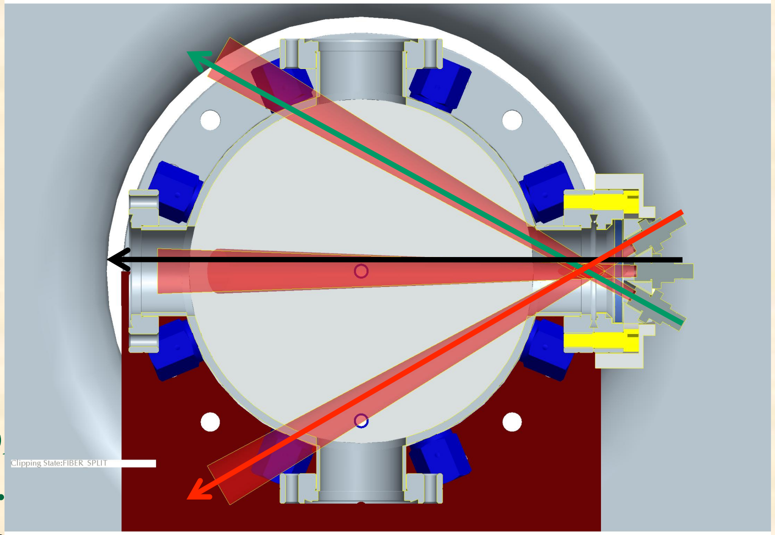


- **Both He I and He II enhanced near antenna**
- **He II diminishes upstream**
- **No measurable radial flow**
- **Small (downstream) axial flow**

Cross-section shows uniformity







- Up-stream of antenna
- No observable radial intensity profile
- “No” observable azimuthal flow

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Summary

- ORNL has a 5 cm diameter (~10 kW) and a 15 cm (~100 kW (2 kW achieved)) helicon plasma source
- Spectroscopic measurements were made on both of these helicon sources for the first time
  - 5 cm diameter source (7.5 kW)
    - $T_i \sim 2$ eV, $T_e \sim< 0.5$ eV
  - 15 cm diameter source (2 kW)
    - Measurements made last week
- Further analysis pending
- Copies of this poster are available online:
  - http://sprott.physics.wisc.edu/biewer/APS2010poster.pdf

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