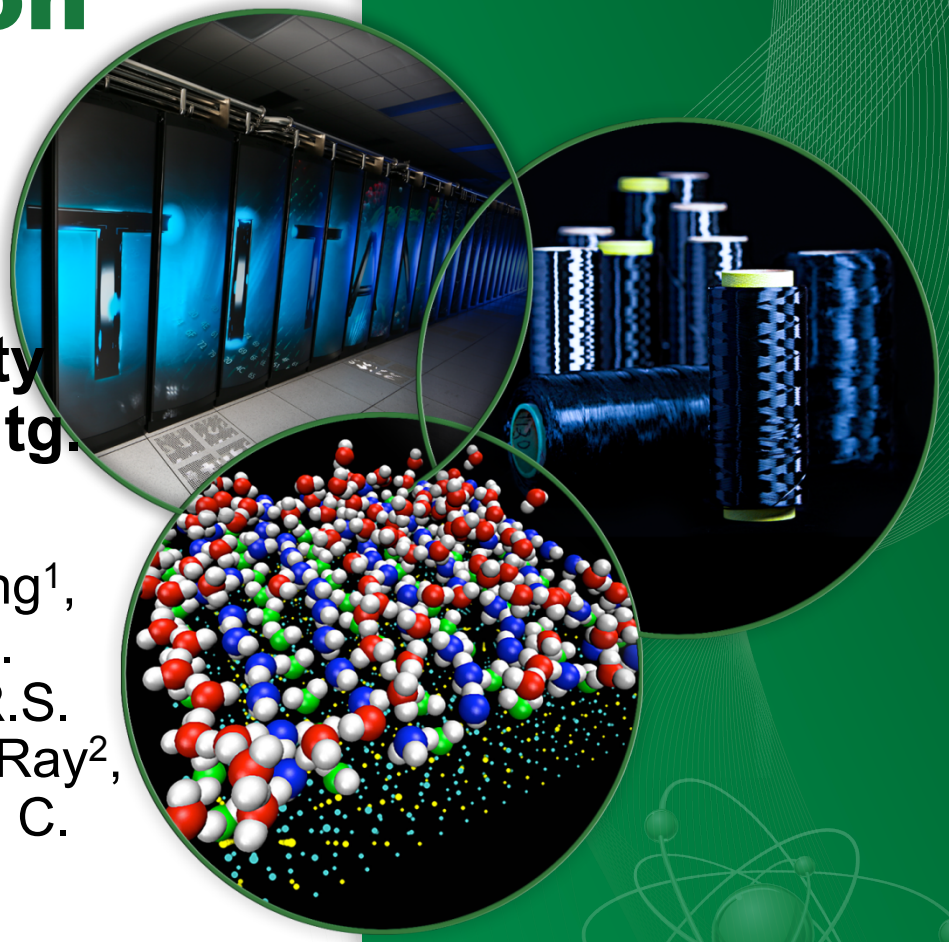
Overview of Diagnostic Implementation on Proto-MPEX at ORNL

TP12.154

Presented at the:

57th American Physical Society Division of Plasma Physics Mtg.



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November 16-20th, 2015 Savannah, USA

ORNL is managed by UT-Battelle for the US Department of Energy

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Abstract

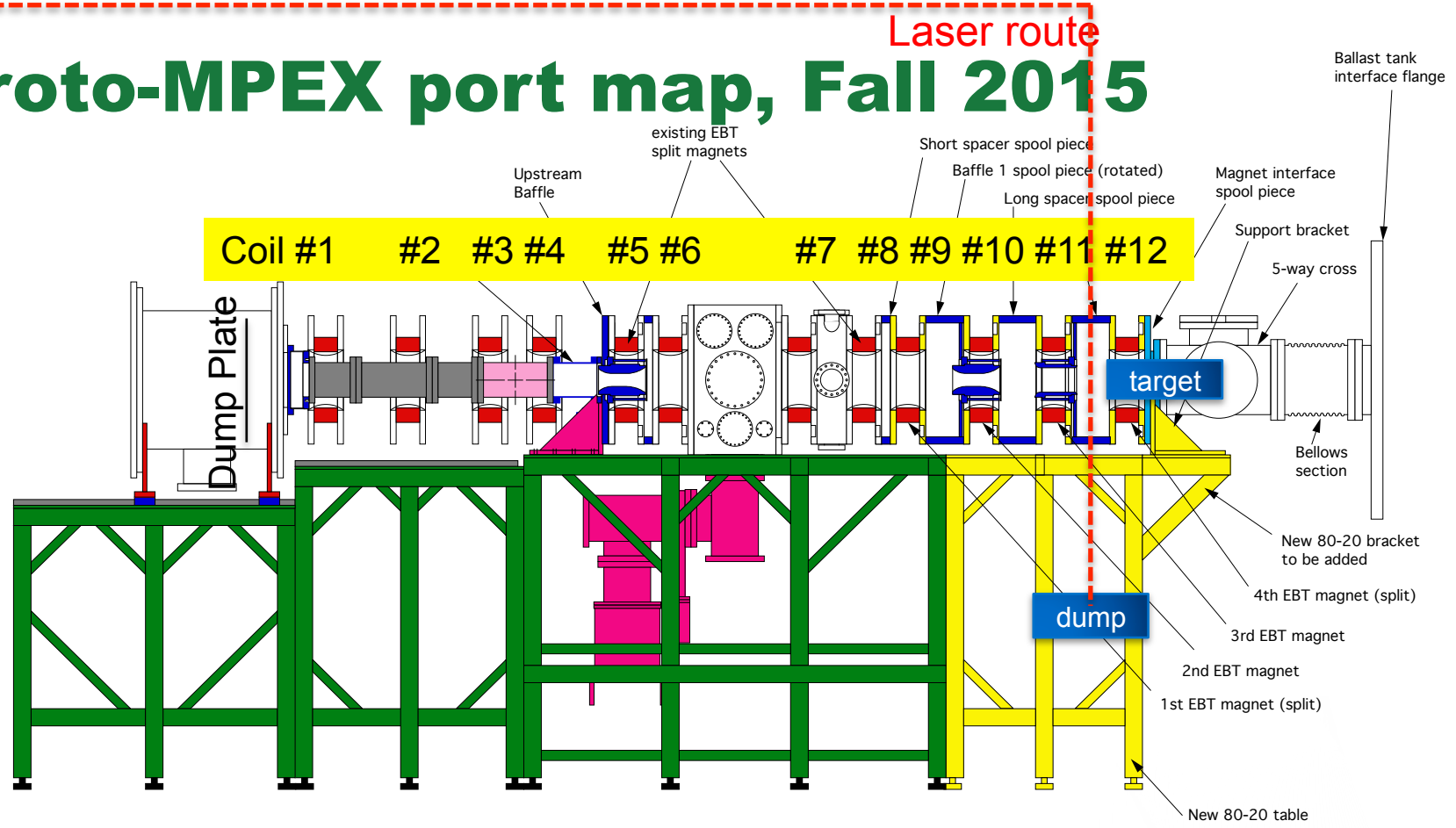
The Prototype Material Plasma Exposure eXperiment (Proto-MPEX) recently began operating with an expanded diagnostic set. Approximately 100 sightlines have been established, delivering the plasma light emission to a “patch panel" in the diagnostic room for distribution to a variety of instruments: narrow-band filter spectroscopy, Doppler spectroscopy, laser induced breakdown spectroscopy, optical emission spectroscopy, and Thomson scattering. Additional diagnostic systems include: IR camera imaging, in-vessel thermocouples, ex-vessel fluoroptic probes, fast pressure gauges, visible camera imaging, microwave interferometry, a retarding-field energy analyzer, rf-compensated and ”double" Langmuir probes, and B-dot probes. A data collection and archival system has been initiated using the MDSplus format. This effort capitalizes on a combination of new and legacy diagnostic hardware at ORNL and was accomplished largely through student labor.

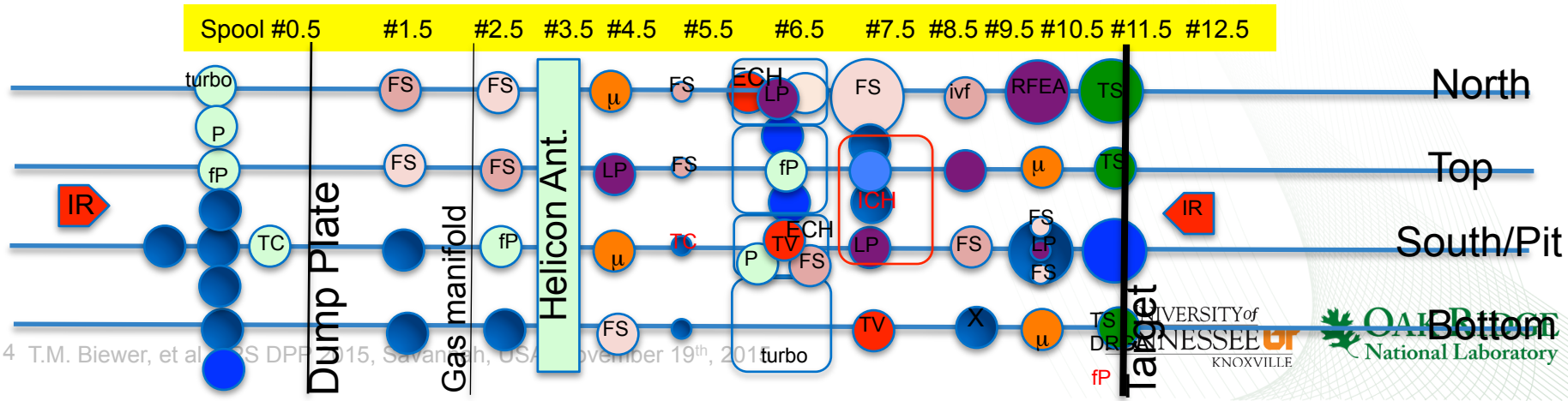
This material is based upon work supported by the U.S. D.O.E. Office of Science under Award Number DE-AC05-00OR22725.

Outline

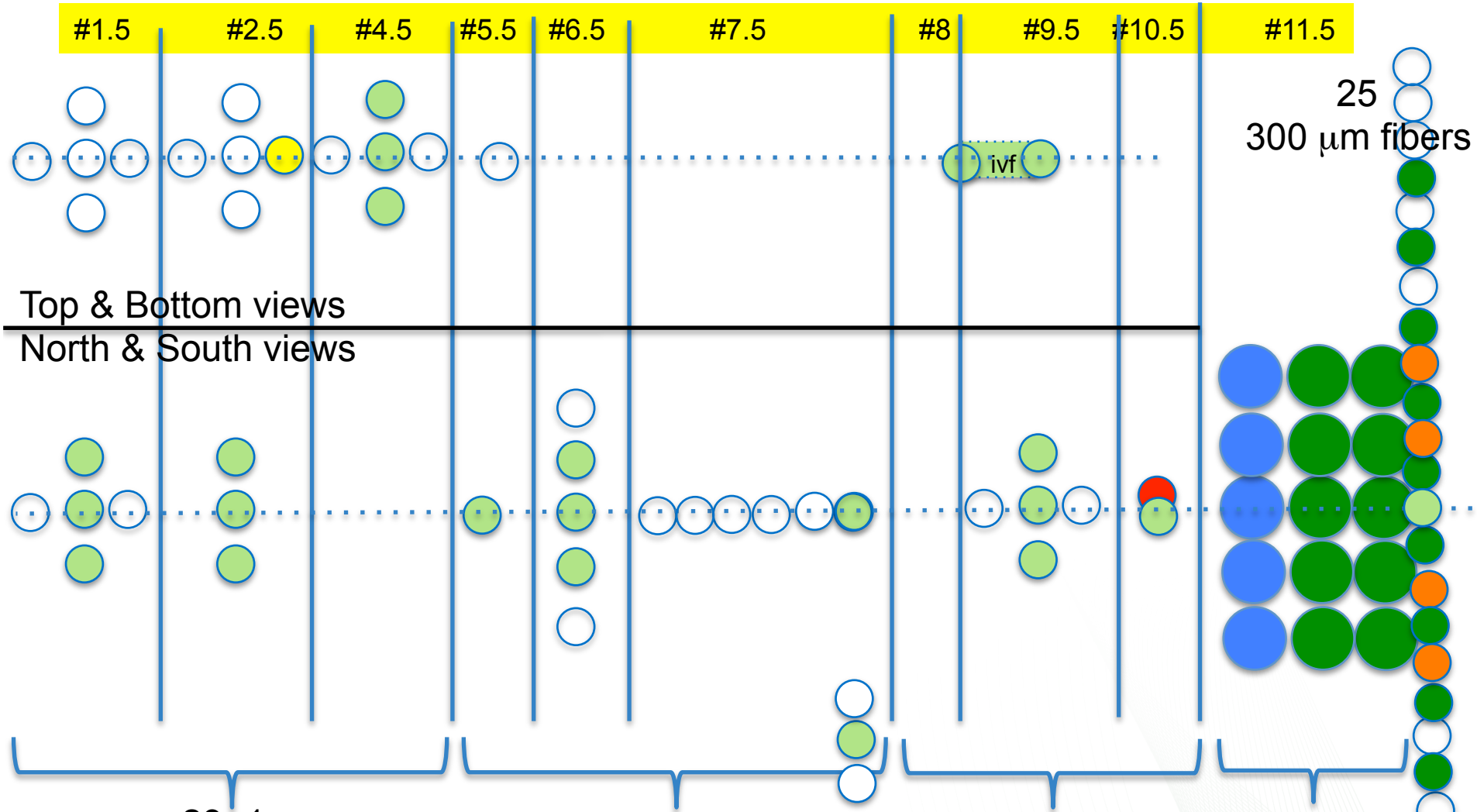
- Machine layout and geometry
- Plasma diagnostic “highlights”
  - Survey Spectroscopy
  - Filterscopes
  - Fast, Color Camera Imaging
  - Thomson Scattering
- Surface diagnostic “highlights”
  - Infra-red Camera Imaging
  - Laser Induced Break-down Spectroscopy
- Staffing (Thanks!)
  - Majority of diagnostic systems have been implemented and are maintained by student support, particularly through a partnership with the University of Tennessee-Knoxville

Proto-MPEX port map, Fall 2015





Line-of-sight utilization: May 2015



103+1 fibers joining Rm. 108 to Proto-MPEX
87 lines-of-sight into Proto-MPEX; 43 instrumented

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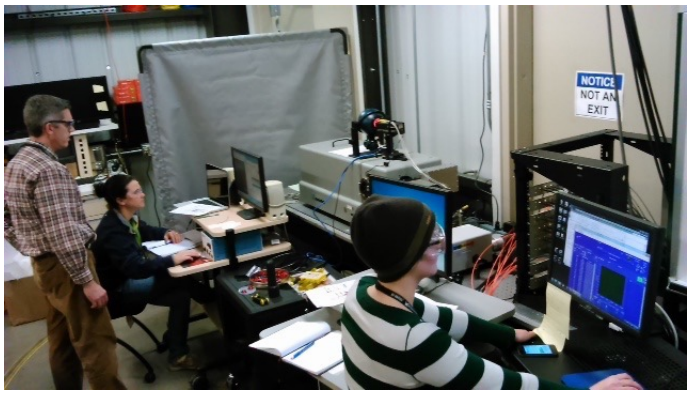
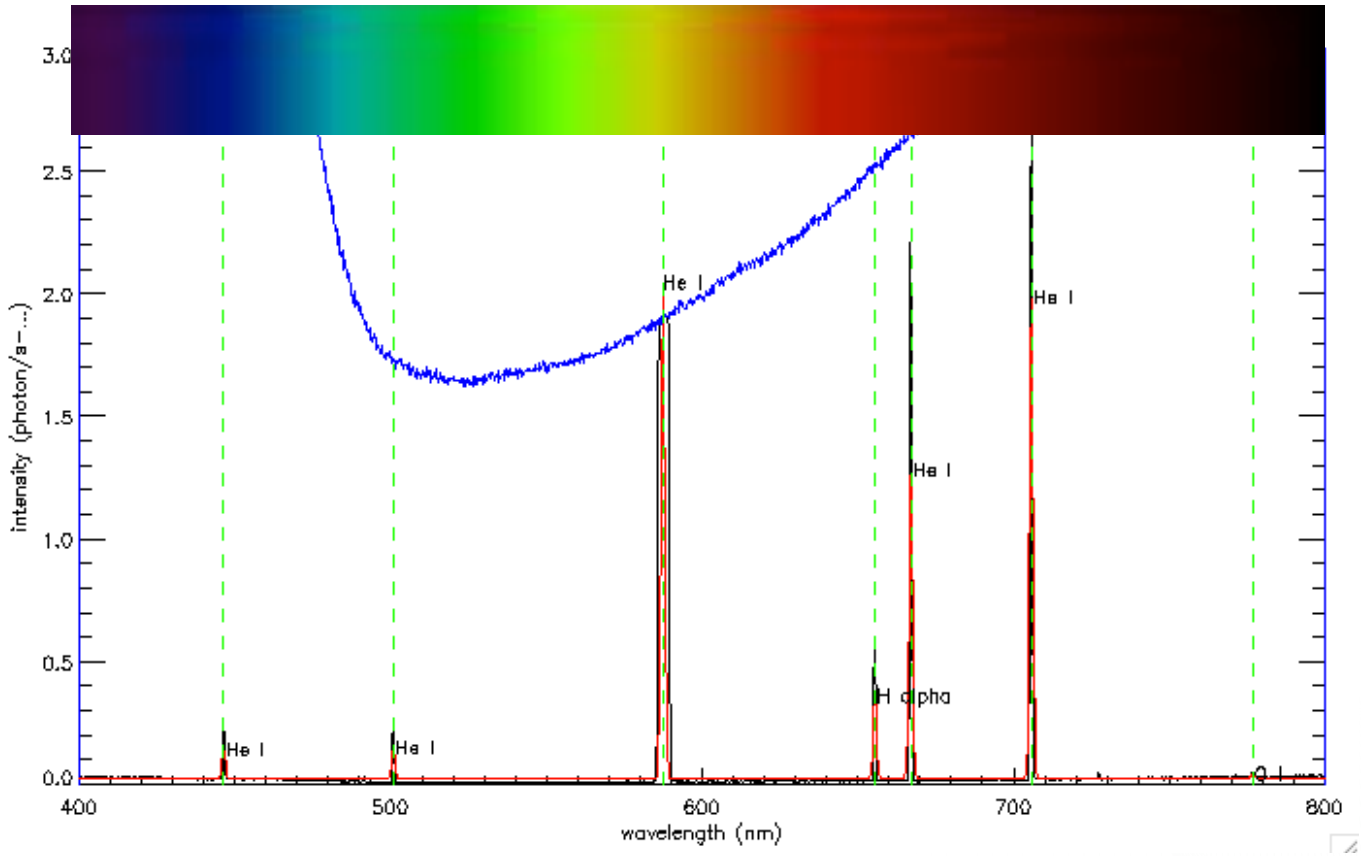
Collected plasma light distributed to instrumentation at a fiberoptic patch pannel



- Survey spectrometer
  - 1 channel, 200-1100 nm
  - Ocean Optics USB4000-UV-VIS
- High resolution spectrometer
  - 5 channels, 3 nm passband at high dispersion
  - 1 m McPherson 2051 CZ with PhotonMAX 512 EMCCD
- High through-put spectrometer
  - 20 channels, fixed grating at “high” or “low” dispersion
  - KOSI Holospec f/1.8 with PI-MAX3 intensified CCD
- Narrow-band pass filter “Filterscope”
  - 24 channels, high gain PMTs, 100 kHz digitization

For more information see: K. Baldwin JP12.008 in Tuesday session.

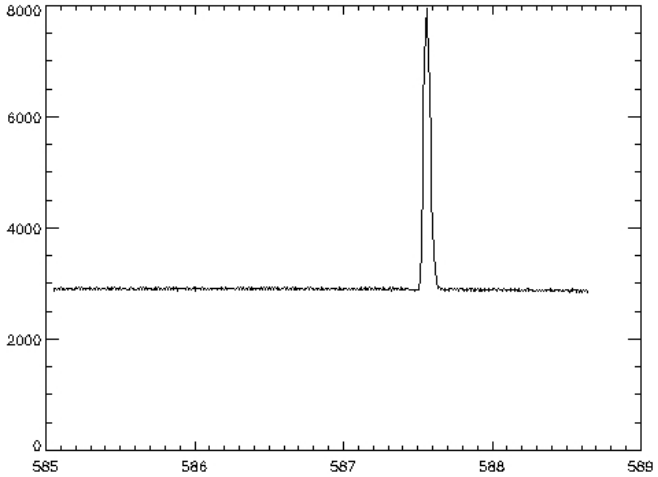
Helium spectral data (Ocean Optics)



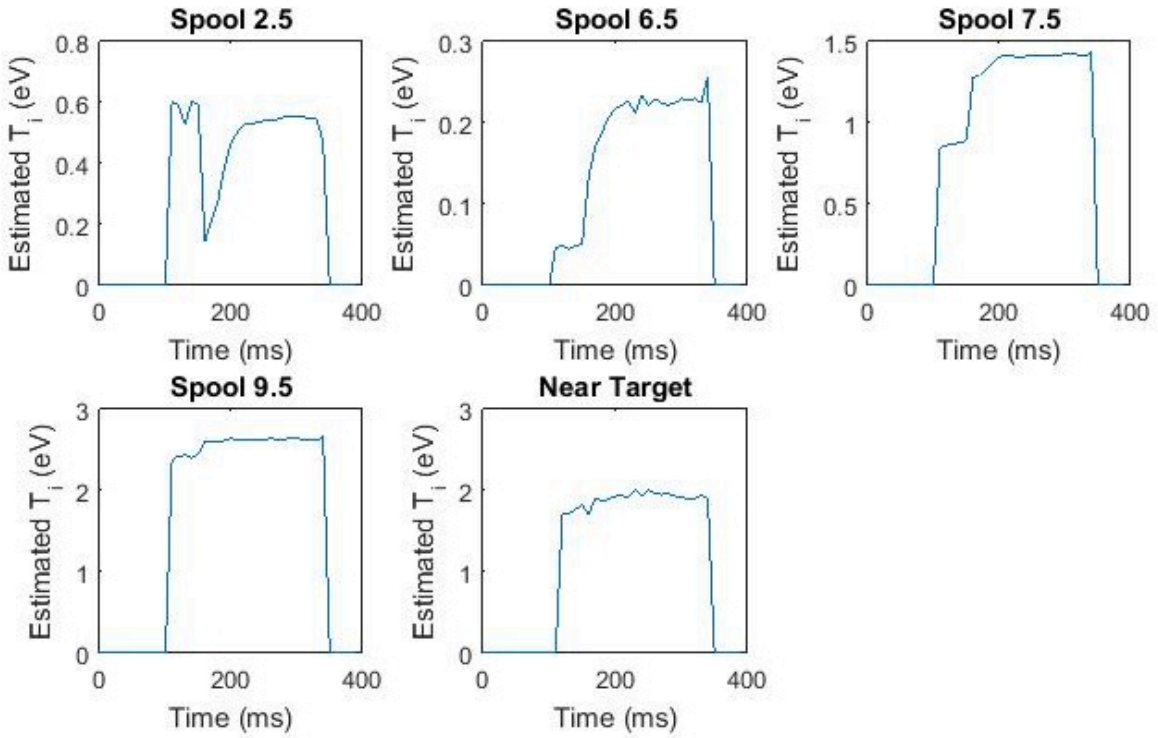
- Time integrated over the entire ~400 ms plasma pulse.
- Emission lines vary strongly by location in the plasma column.
- Blue curve is sensitivity adjusted “saturation” level.
- Note: 587 nm “yellow” is dominant emission line.

For more information see: V. Dhaliwal TP12.157 in this session.

High resolution Doppler Spectroscopy to measure ion dynamics



- Initial results are based on simplified analysis – plots shown here are for the He I line at 587 nm
- Qualitative understanding of ion behavior rather than quantitative values for key parameters

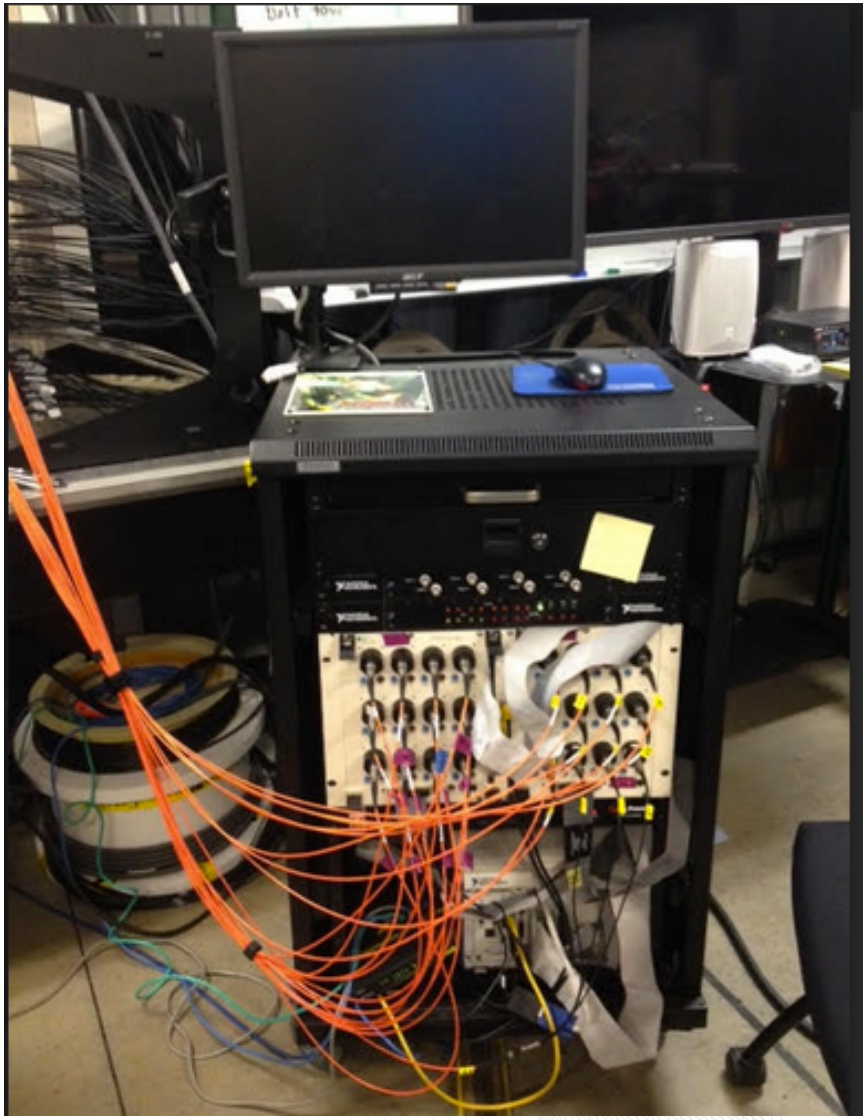


- Ion emission is low, so emission by atoms is used instead – conclusions might not be strictly valid
- Gaussian fits to each spectral line

For more information see: H. Ray TP12.150 in this session.

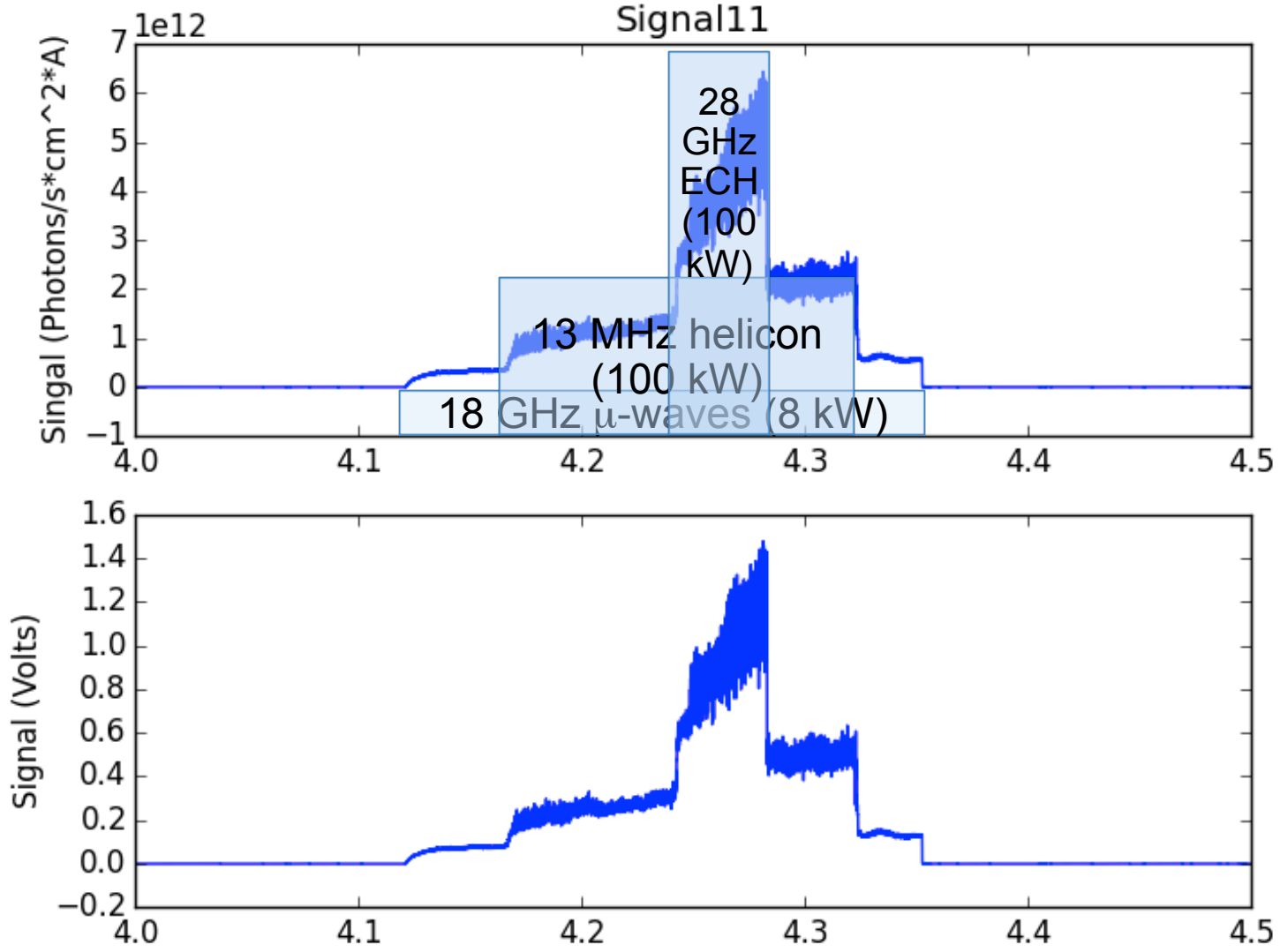
Filterscopes: high time resolution, narrow λ information

- A photomultiplier tube (PMT) based diagnostic samples light from Proto-MPEX
- 24 channel system
  - Hammatsu: Model # H5783-01
  - Spectral response: 300 – 850 nm
  - 100 kHz digitization
- Narrow-band transmission optical filters
  - filters ~1 nm wide (1 inch diam.)
  - He I – 667.9, 706.7, 723.6, 501 nm
  - D_α – 656 nm
- Compact Light Collection Optics
  - Collimating Lens (74-ACR)
    - 5 mm diameter, f/2
  - Transfer Fibers
    - Numerical Aperture = 0.37
    - 600 micron diameter



For more information see: H. Ray TP12.150 in this session.

D_α emission at 100 kHz (24 channels)



For more information see: R. Mosby JP12.009 in Tuesday session.

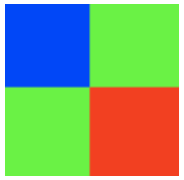
"Fast" visible, color imaging camera

Edgertronic by Sanstreak, Inc.

- Observes the plasma through windows, screened to prevent μ-wave leakage

Features

- 1280 x 1024 chip
  - Reduced at high frame rates
  - 28 μm pixels, 10-bit depth
- "Bayer filter" for RGB color



- Up to 18k fps
- Global shutter
- Minimum exposure 1/250k
- 8GB onboard memory
- Network interface
- Nikon lens mount

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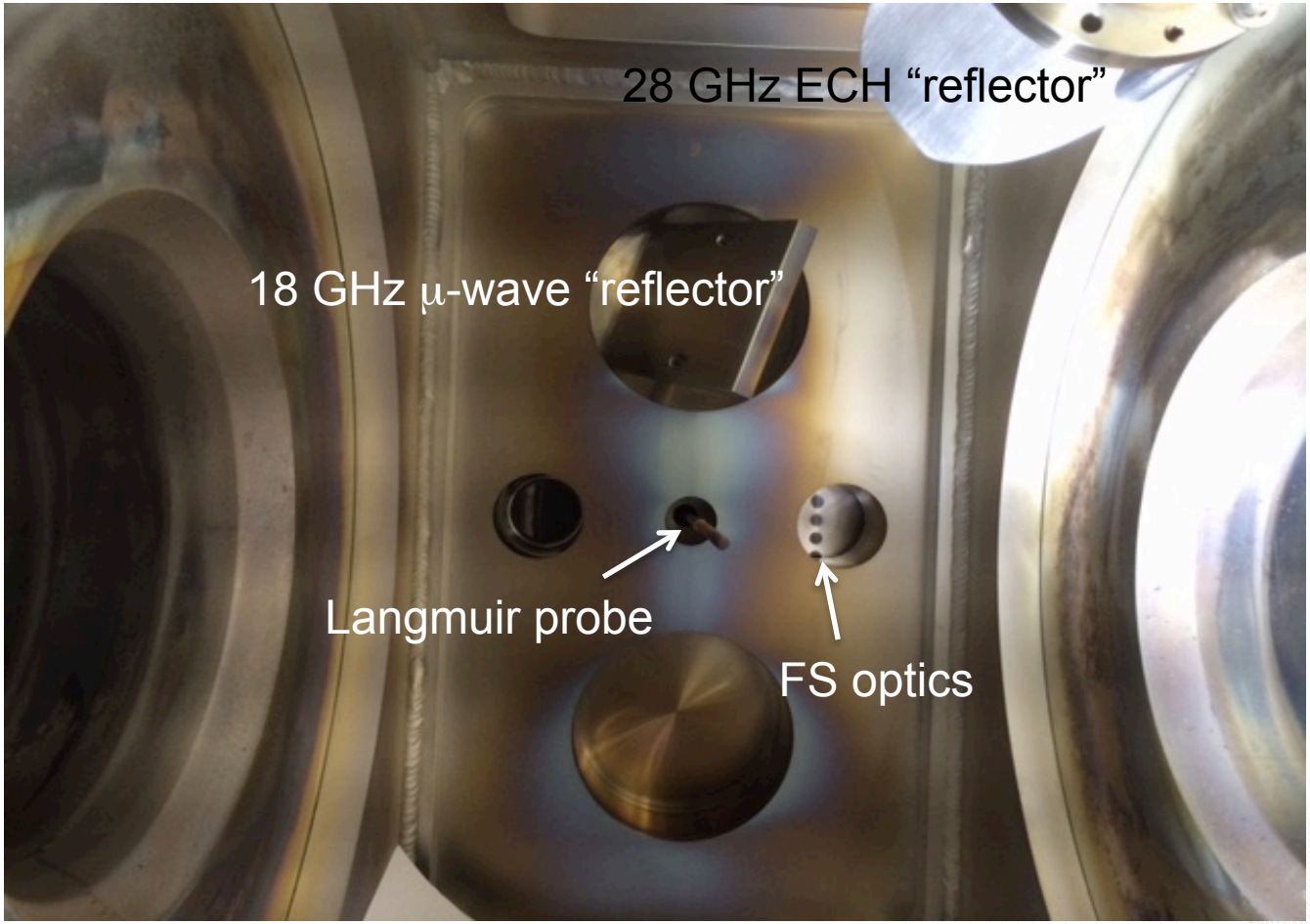
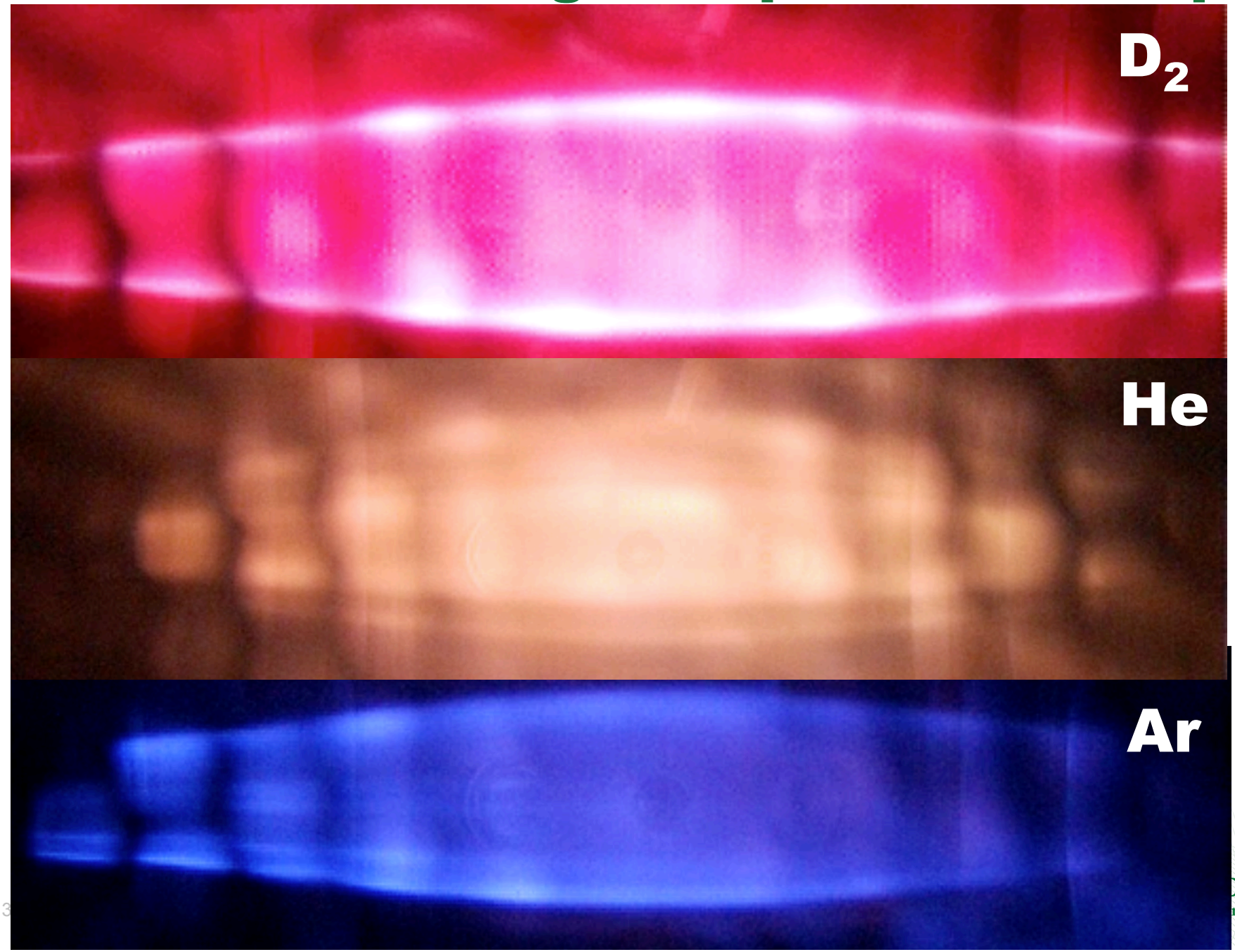
For more information see: R. Mosby JP12.009 in Tuesday session.

Views the plasma through 6 inch window on "central chamber". (Other ports also utilized for viewing.)



“fast camera” images of plasma 3000 fps



For more information see: R. Mosby JP12.009 in Tuesday session.

Plasma parameters are measured with a variety of probes and "non-invasive" techniques.

- Probes
  - Langmuir probes
    - Standard, rf compensated, "double"
  - B-dot probes
  - Retarding Potential Energy Analyzer probe
- Non-invasive
  - Imaging and spectroscopy (as described)
  - μ-wave interferometry
  - Doppler spectroscopy
  - Thomson Scattering

Thomson Scattering System

Laser System

- Nd:YAG laser: Newport Quanta Ray Pro 350
  - 10 ns pulse, 10 Hz rep. rate
  - Frequency doubled to produce 532 nm (green) light
  - Up to 1.4 J/pulse
- Laser beam handling
  - 2.5x Galilean beam expander to traverse 60 feet to Proto-MPEX, focusing lens 1.5 m from axis.
  - Remote controlled steering mirrors
  - Brewster windows, baffles, and "spectral black" foils

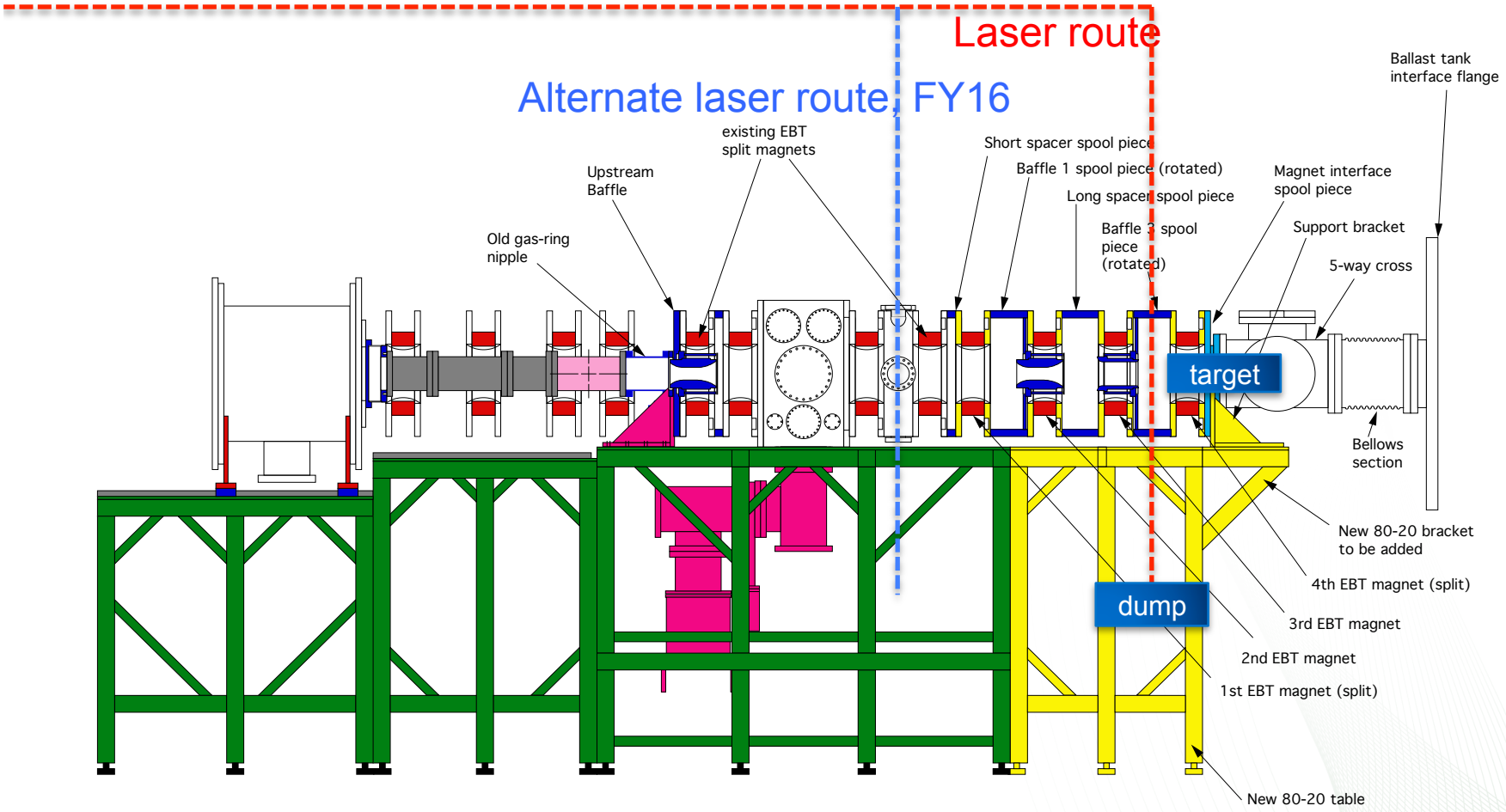
Detection System

- Kaiser Optical Systems Holospec f/1.8 spectrometer
  - "low dispersion" grating, center λ =529 nm
- Princeton Instruments PI-Max3 intensified CCD camera
  - Gen III intensifier (minimum gate 2 ns)
  - 1024x1024 pixels (12 μm ea.) binned to 10 channels on-chip

Special thanks to Hennie Van der Meiden for advice in implementation!

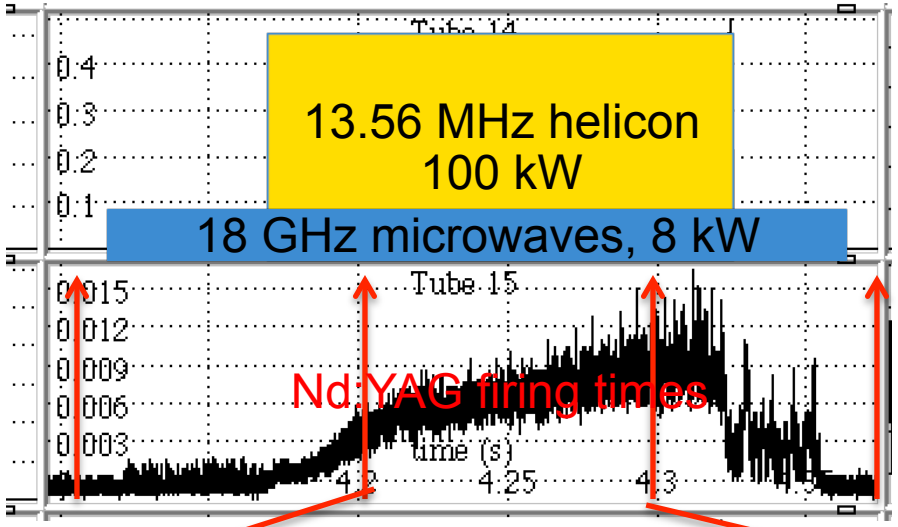
Layout for Proto-MPEX of Nd:YAG beam path for Thomson Scattering

T.M. Biewer, G. Shaw, "Initial implementation of a Thomson scattering diagnostic for Proto-MPEX." Review of Scientific Instruments **85** 11D812 (2014)



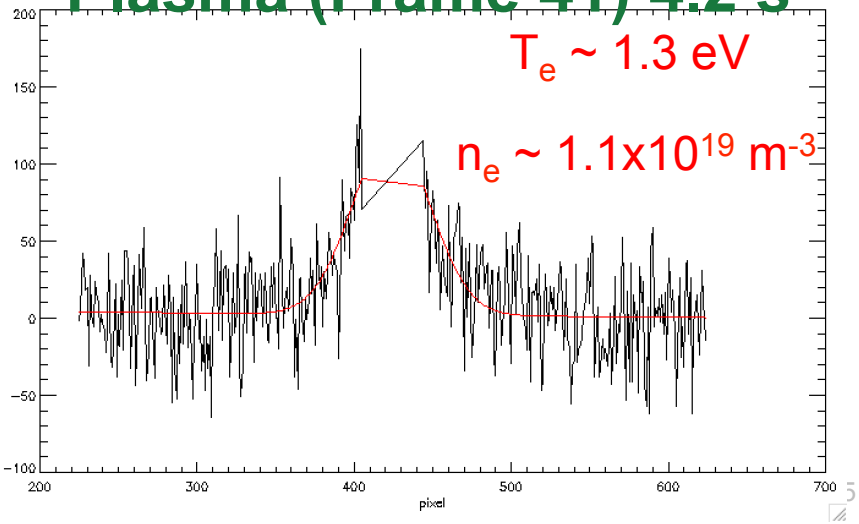
Electron temperature and density of plasma measured by Thomson Scattering of Nd:YAG laser in Proto-MPEX

Partial fulfillment of the P.E.M.P milestone for FY15

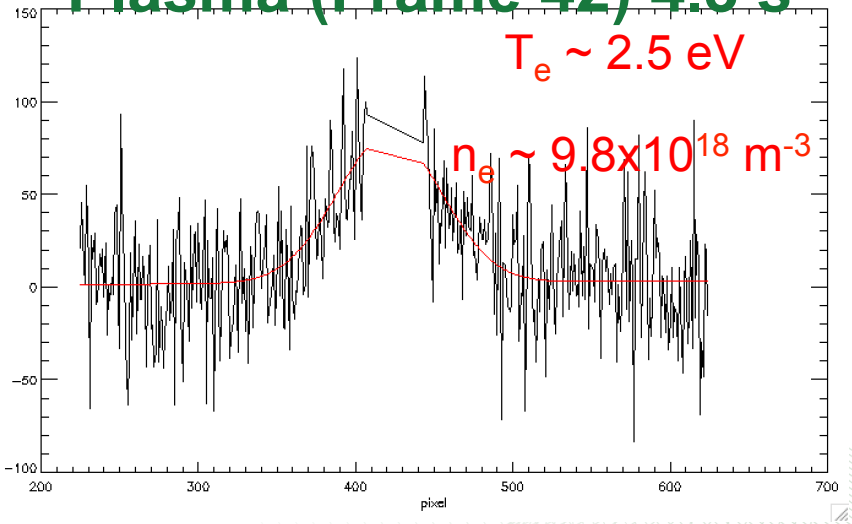


T.M. Biewer, G.C. Shaw, J.B.O. Caughman, J. Rapp, *et al.*

Plasma (Frame 41) 4.2 s



Plasma (Frame 42) 4.3 s



Progress being made to examine plasma-material interface

- IR imaging of “dump” plate and target plate
- In-vessel thermocouples
- In situ Laser Induced Break-down Spectroscopy (LIBS)

For more information see: M. Showers TP12.155 in this session.

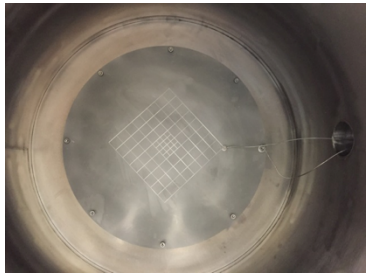
Infrared Imaging Camera – FLIR A655sc

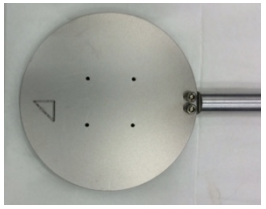
- **Specs**:
- Wavelength: 7.5-14.0 μm
- Resolution: 640x480; 17μm pixels
- Frame rate: 50-200Hz*
- Temperature range:
  - -20°C - 150°C
  - 0°C - 650°C
- Accuracy: ±2°C or ±2% of reading

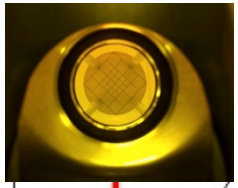
*At minimum window frame (640x120)

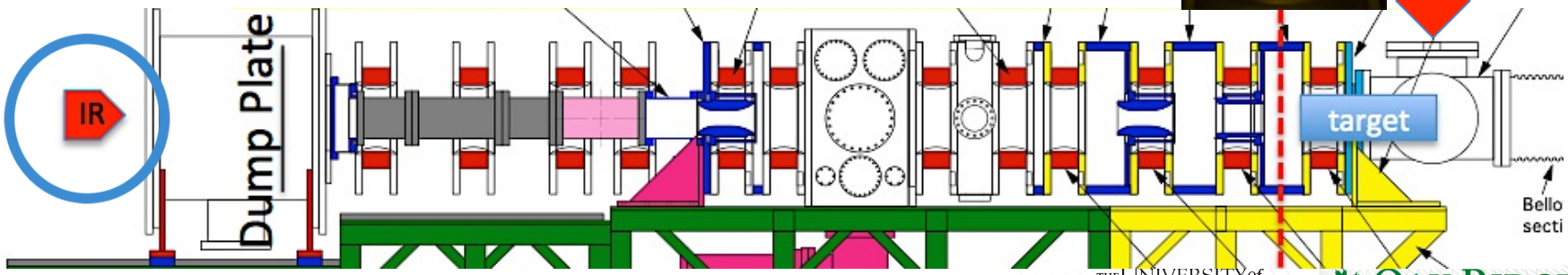
Set up:

- View: back side of dump plate
  - Location: upstream end of Proto-MPEX
- View: back side of target plate
  - Downstream at “11.5”
  - Downstream at “7.5”







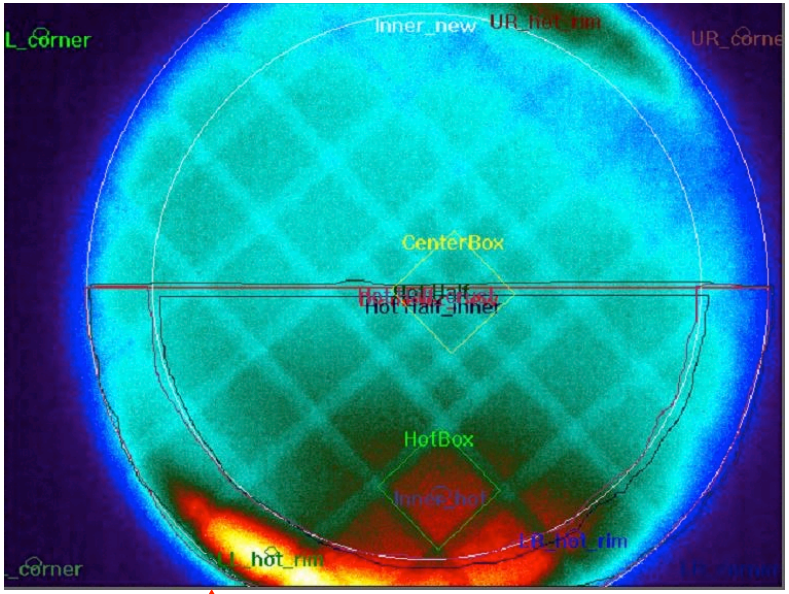


Source: http://www.flir.com/

For more information see: M. Showers TP12.155 in this session.

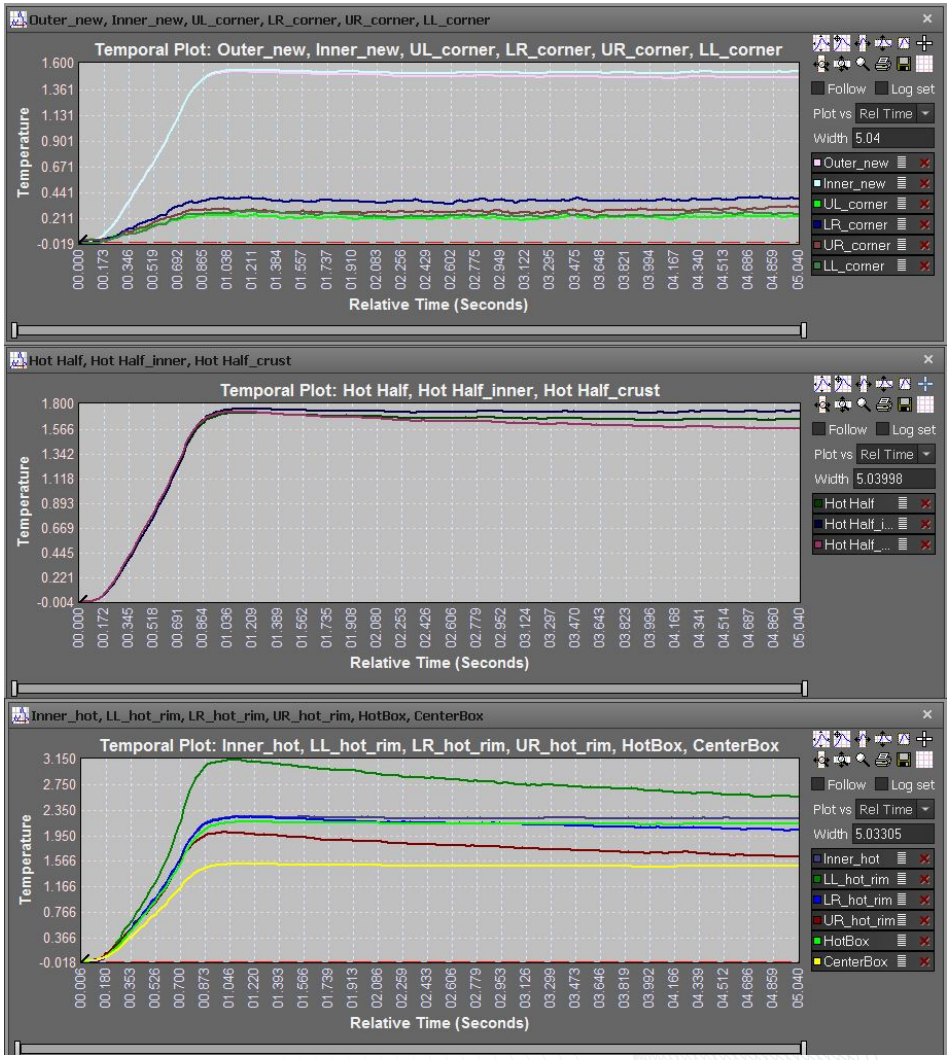
Infrared Camera – "dump" plate

Shot 5104: Helium plasma



Frame 49 (of 250)
Scale: $\Delta T = 0 - 3.25$
ROI's displayed

ΔT over time for each Region of Interest (ROI)



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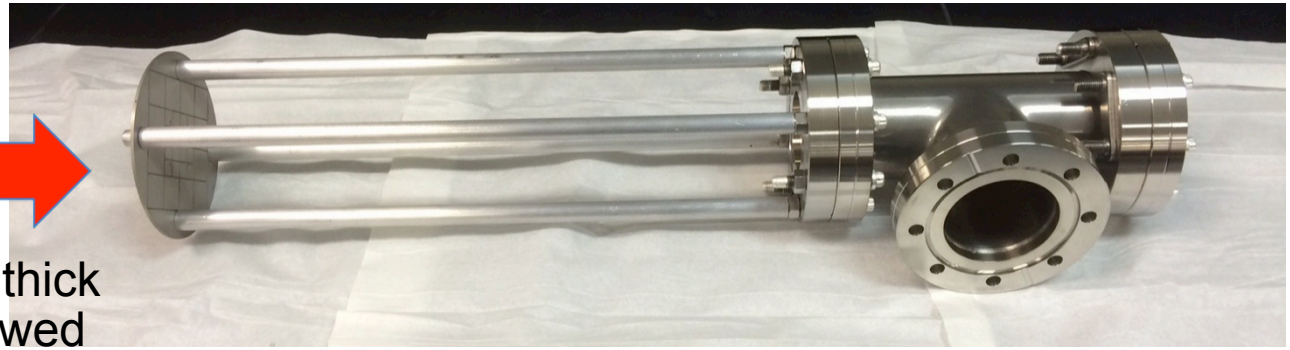
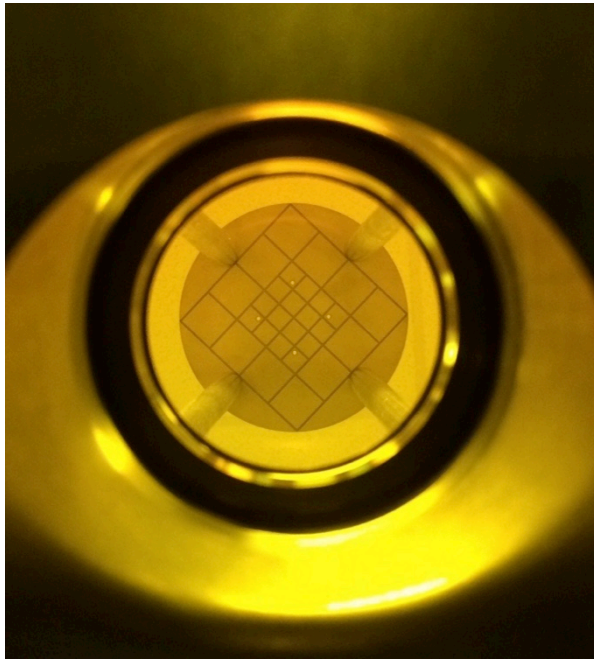
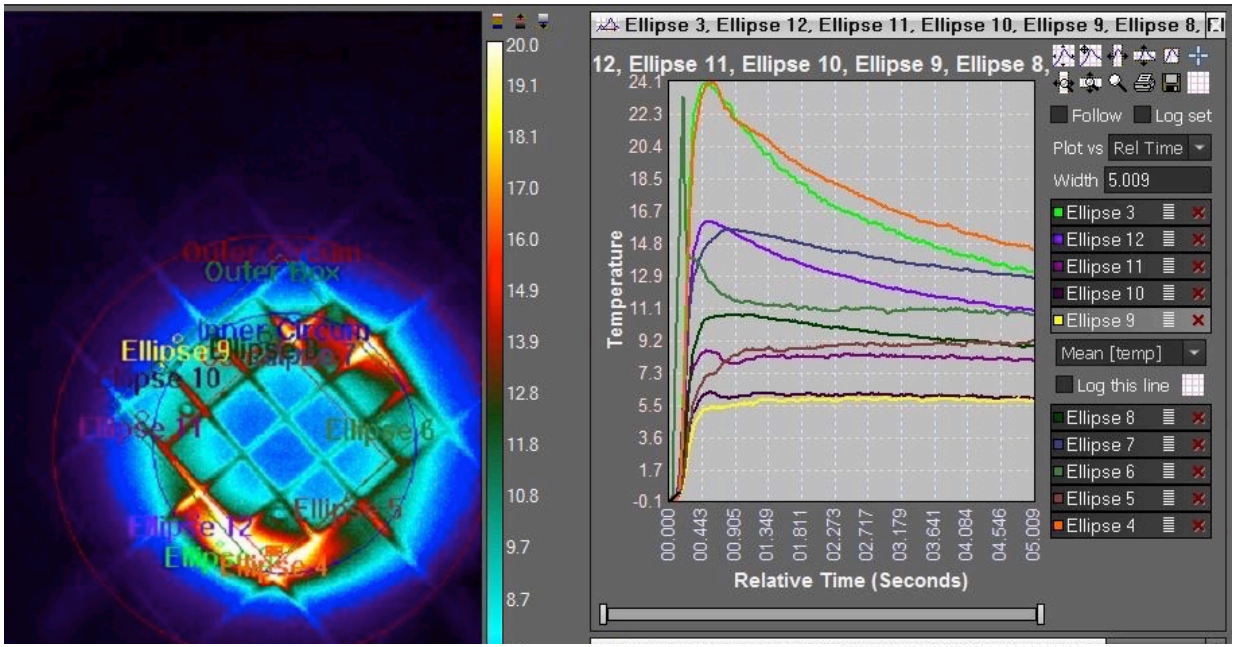
For more information see: M. Showers TP12.155 in this session.

"Thin plate target" back-viewing



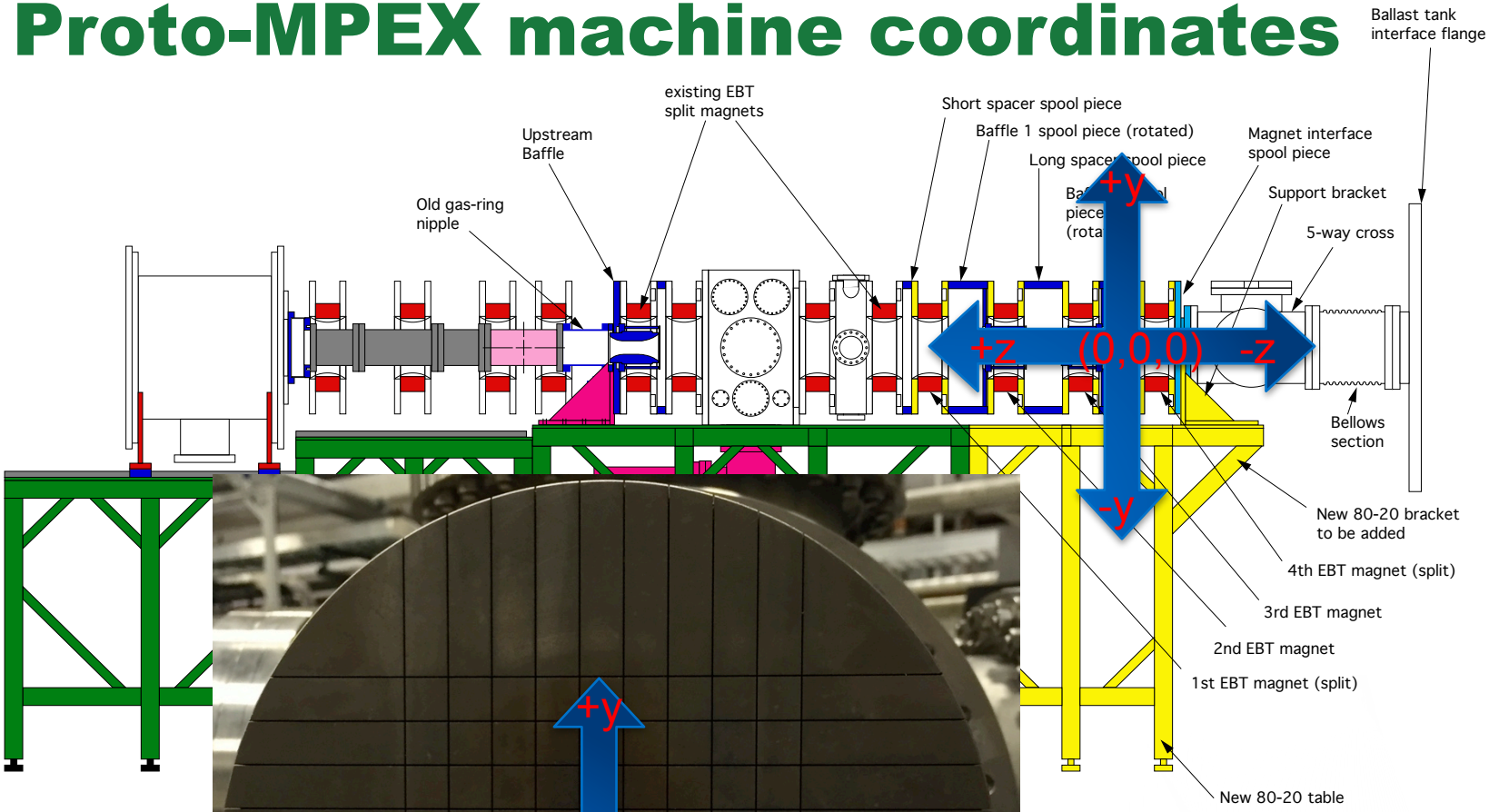
Plasma impacts 1/16" thick St.Stl. target plate viewed from back side.

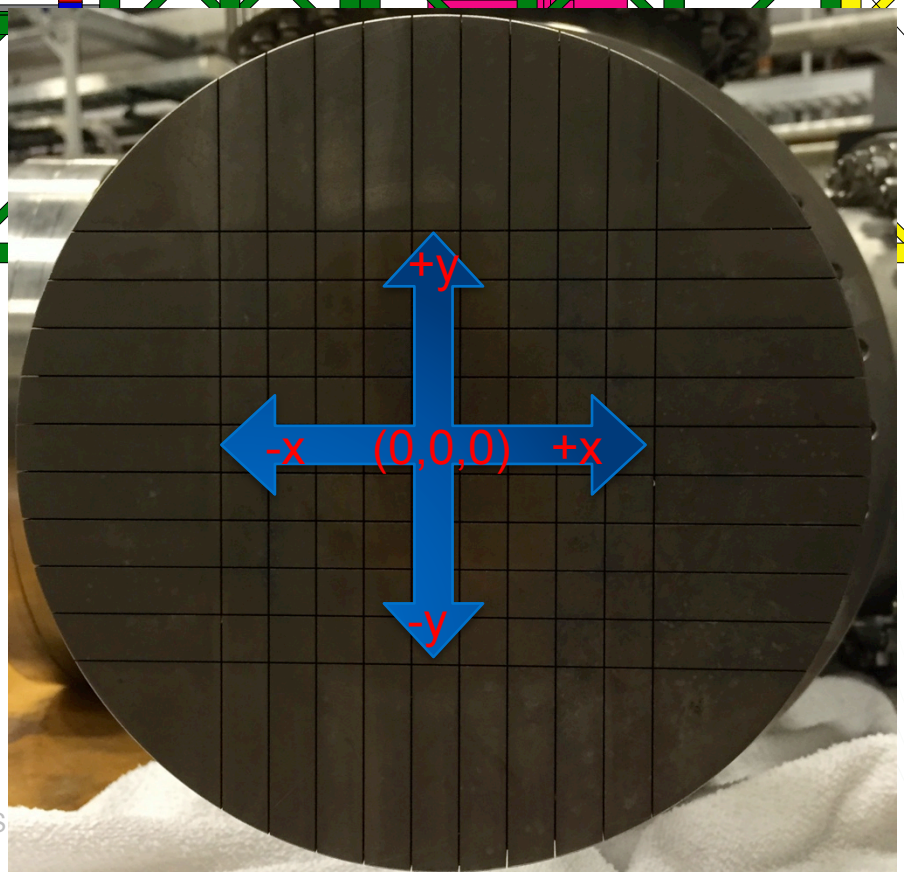




ΔT~20 C observed on a single ~100 kW discharge.

Proto-MPEX machine coordinates





coordinate system

-x = ~ North, +x =~South

-y=Down, +y=Up

-z=~East, +z=~West

(0,0,0)=center of #11.5

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For more information see: G. Shaw TP12.156 in this session.

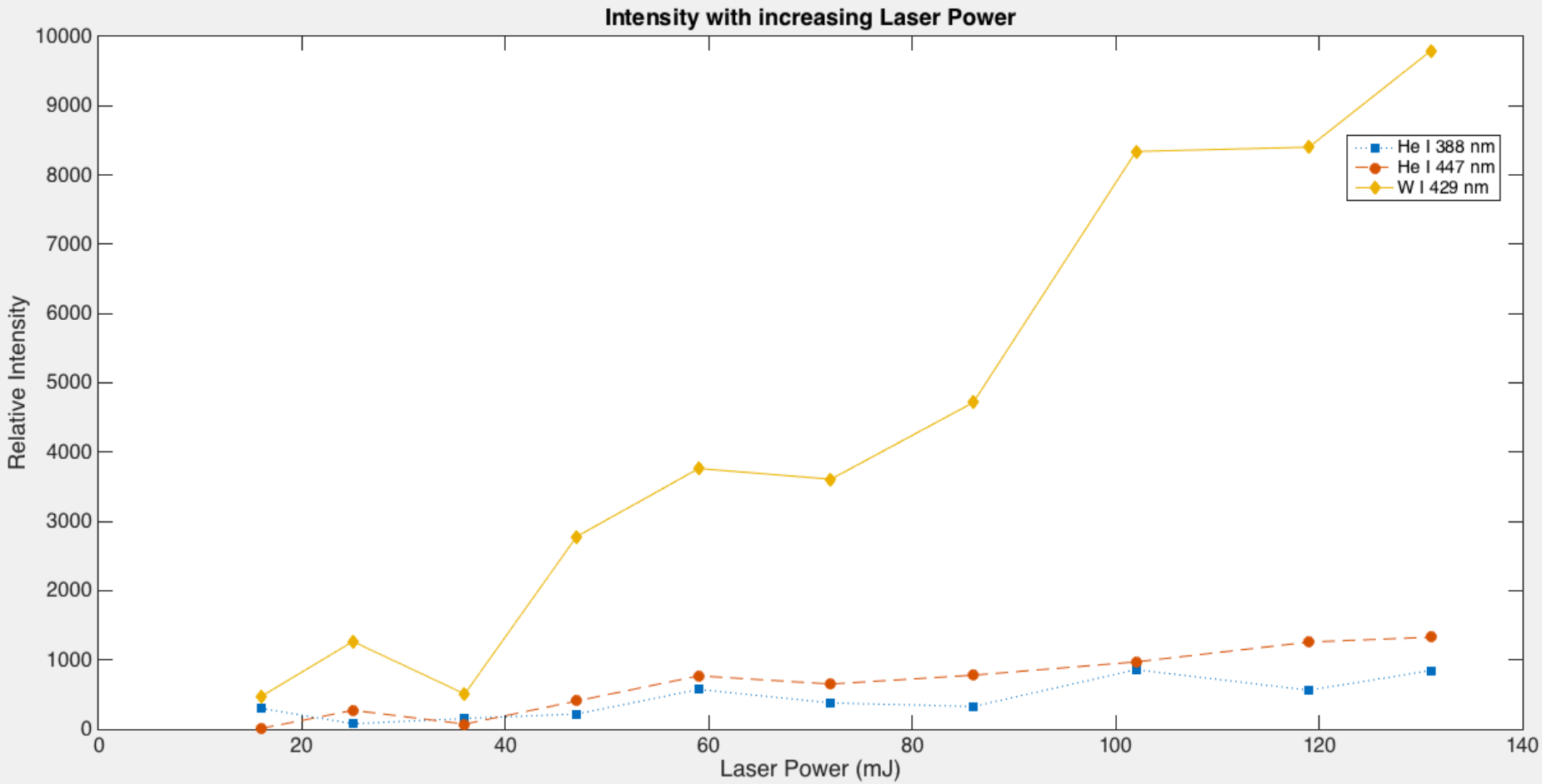
Laser Induced Break-down Spectroscopy

- Q-smart 450 Laser
  - 1064 nm, ~300 mJ, 10 Hz adjustable
  - 532 nm adaptation (potential)
- 6-channel LIBS Module
  - Focusing optics for fibers and laser
- *Ex situ* XYZ- Sample Chamber
  - 75x75x75 mm XYZ travel stage
- LIBS Software
  - LIBSoft: Interfaces Laser, Spectrometer, and Sample Chamber
  - SpecLine: Spectral Analysis and Line Identification

In situ implementation on Proto-MPEX planned for FY16.

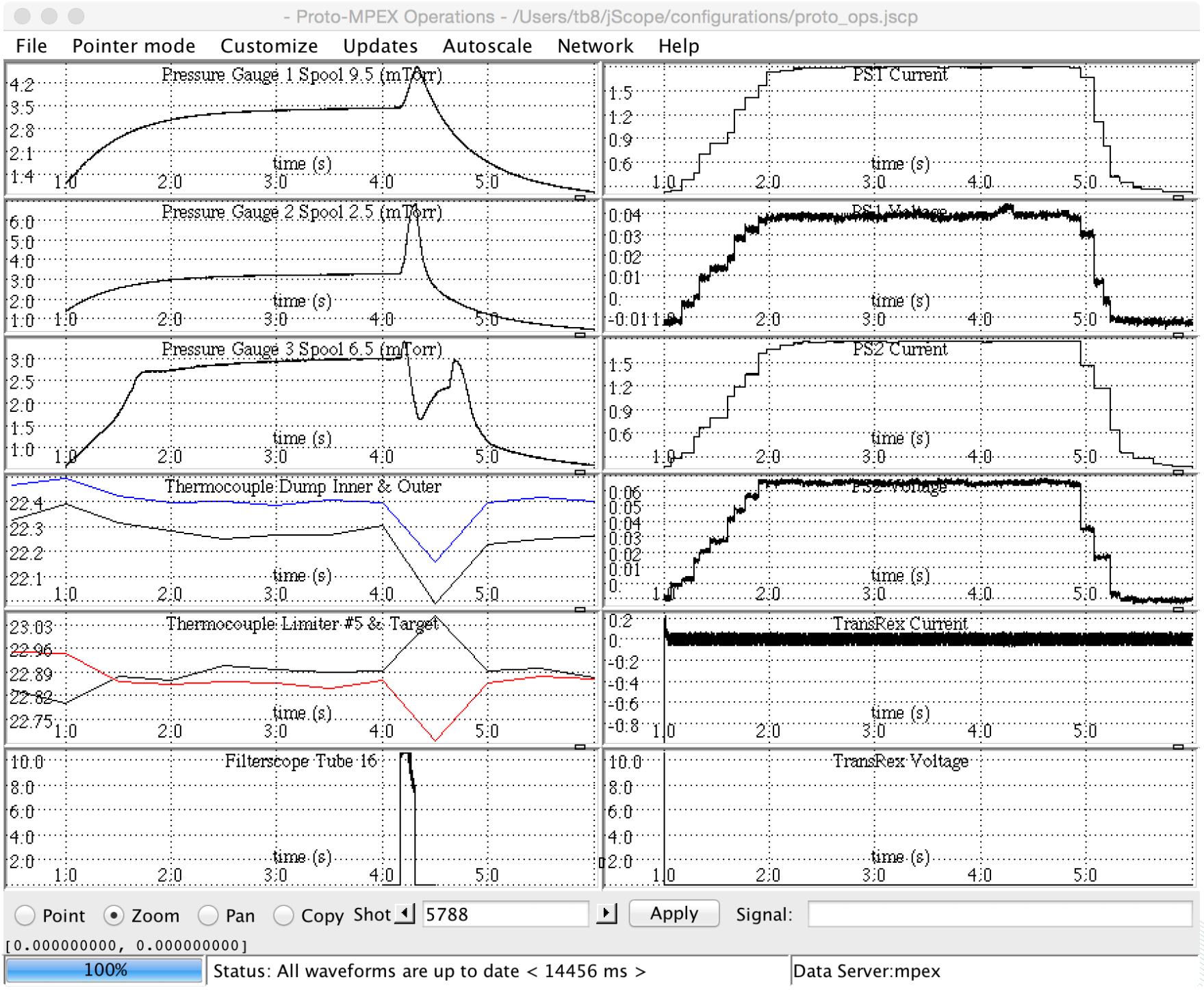
For more information see: G. Shaw TP12.156 in this session.

LIBS calibration data on W sample with ion beam implanted He

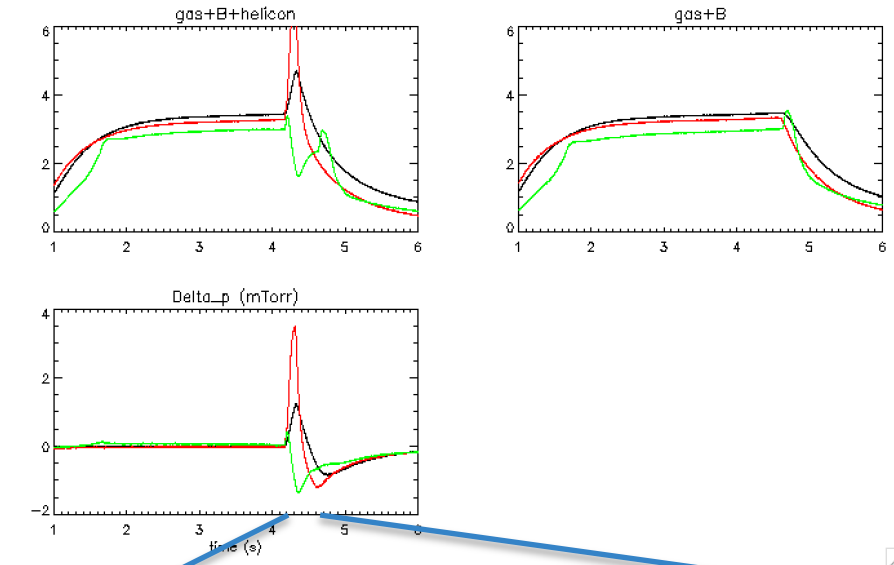


Centralized data acquisition & timing

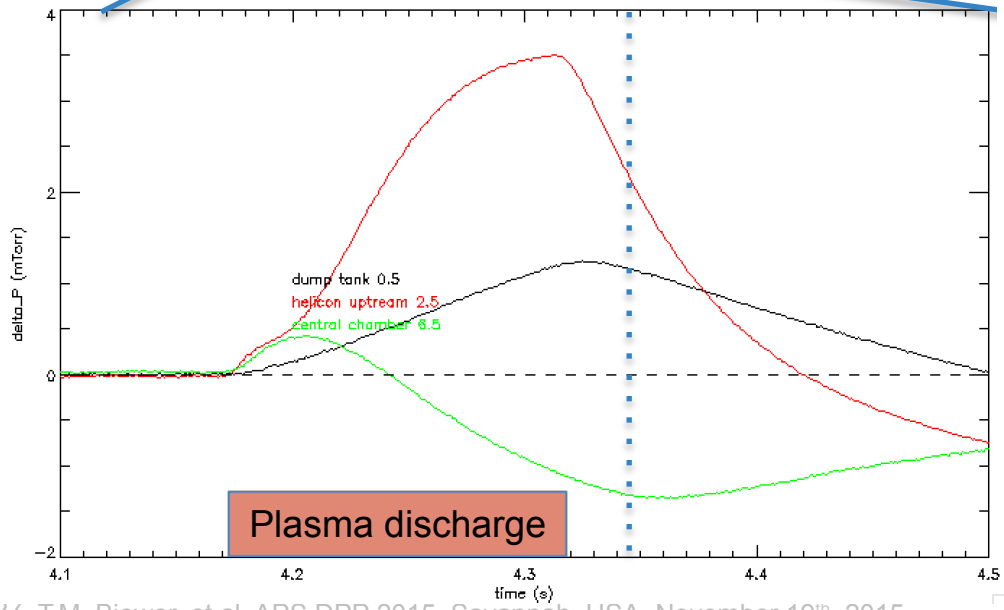
- National Instruments PXI chassis for centralized timing and control
  - Labview Visual Interface for discharge programming
  - Process Logic Controller subsystem for magnets
  - Some systems still “analogue” and being transitioned to the Plasma Control System
- MDSplus format database
  - “standard” access and archiving of data
  - Some diagnostics (e.g. spectroscopy) still measured on “local” PC’s, then ported “by hand” to server.
  - Data accessible via IDL, MATLAB, PYTHON, etc.

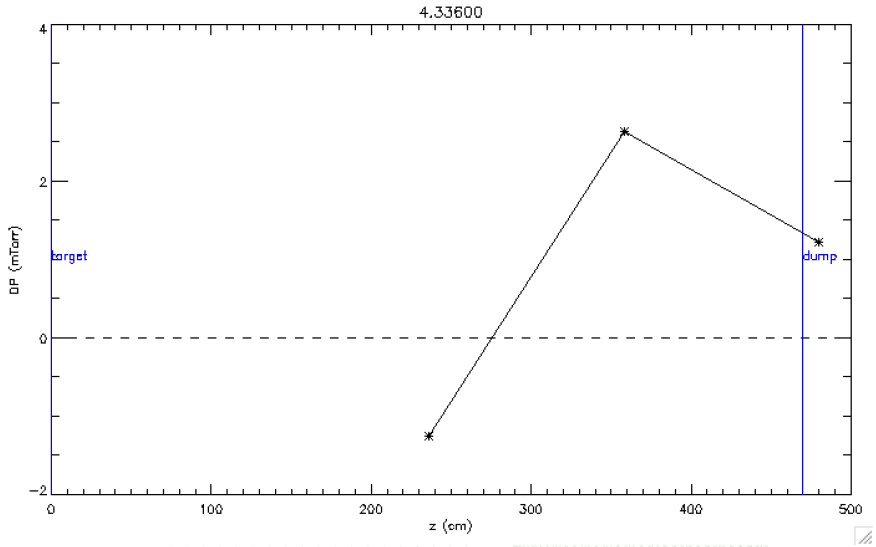

- Proto-MPEX Operations - /Users/tb8/jScope/configurations/proto_ops.jscp
File
Pointer mode
Customize
Updates
Autoscale
Network
Help
Pressure Gauge 1 Spool 9.5 (mTorr)
PS1 Current
Pressure Gauge 2 Spool 2.5 (mTorr)
PS1 Voltage
Pressure Gauge 3 Spool 6.5 (mTorr)
PS2 Current
Thermocouple Dump Inner & Outer
PS2 Voltage
Thermocouple Limiter #5 & Target
TransRex Current
Filterscope Tube 16
TransRex Voltage
time (s)
Point
Zoom
Pan
Copy
Shot
5788
Apply
Signal:
[0.000000000, 0.000000000]
100%
Status: All waveforms are up to date < 14456 ms >
Data Server:mpex

“fast” pressure gauge set implemented



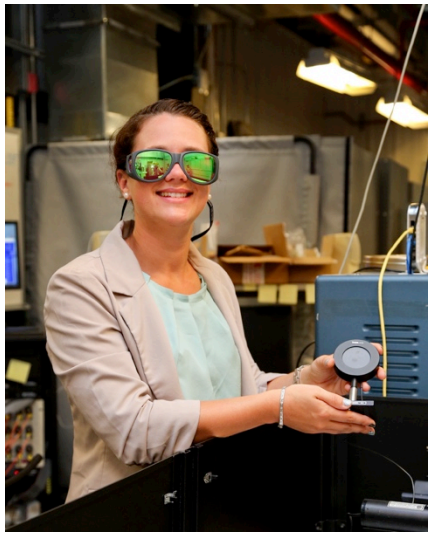
- Fast, total pressure 3-gauge set implemented at multiple locations along Proto-MPEX
- MKS Baratron 627C capacitive manometer(s)
- Shielded with μ-metal
- Digitized at 1 kHZ

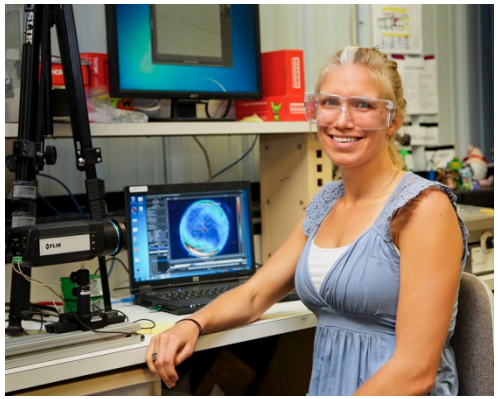


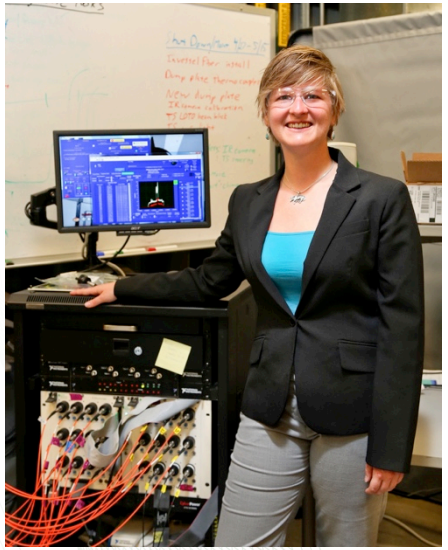


Diagnostic staffing: THANKS!!!

- Scientific Staff
  - T.M. Biewer, J.B.O. Caughman, R. Goulding
- Technical Support
  - D. Fehling, C. Marcus, R. Renfro, et al.
- Postdocs
  - E. Martin
- Graduate Students (Univ. Tenn.-Knoxville)
  - N. Kafle, H. Ray, G. Shaw, M. Showers
- Summer Interns
  - K.-C. Baldwin, R. Dhaliwal, R. Hardin, S. Johnson, A. McCleese, R. Mosby, J. Powers, C. Skeen







Diagnostic Suite for Proto-MPEX

- Diagnostics currently implemented:
  - Langmuir probes
    - standard, rf compensated, and “double”
  - RFEA probe
  - B-dot probes
  - μ-wave interferometers
  - Filterscopes
  - Survey Spectrometer
  - High-Resolution Spectrometer
  - IR imaging of material target surfaces
  - Ex-vessel thermal imaging
  - In-vessel Thermocouples
  - Fast Camera Imaging
  - Thomson Scattering
  - Baratron pressure gauge set
- Diagnostics to be implemented in FY16:
  - *In-situ* LIBS/LIDS/LIAS
  - ITER DRGA prototype (as available)
  - Surface eroding thermocouples
- Diagnostics available at ORNL:
  - *Ex-situ* LIBS
  - Electron microscopy
  - Depth profiling
  - Positron emission spectroscopy
- Diagnostics to be pursued:
  - (Stark) Antenna Spectroscopy
  - Digital Holography (w/ 3DT)
  - TALIF (w/ WVU?)
  - HELIOS (w/ UW-Madison?)
  - Others . . .?

Summary

- The Fusion & Materials for Nuclear Systems Division (FMNSD) was organized to highlight the facilities and expertise that ORNL can apply to the international effort to address the PFC problems of fusion reactors through PMI research.
- This includes applying diagnostic tools and expertise from the plasma boundary of mainline tokamaks worldwide to Proto-MPEX at ORNL.
  - Underscores an important link between tokamak divetor/SOL physics and linear machines (“divertor simulators”).
- Materials Science (particularly irradiated samples) is a strong suit of ORNL; these resources can/should be leveraged to enable the PMI mission of MPEX.
- Proto-MPEX expected to be sufficiently equipped/diagnosed to enable ORNL to more fully participate in the international conversation on PMI research.

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Supplemental Material

Fiber periscope for ICH measurements