First results from the Thomson Scattering diagnostic on Proto-MPEX.

OAK RIDGE National Laboratory

THE UNIVERSITY of TENNESSEE KNOXVILLE

U.S. DEPARTMENT OF ENERGY

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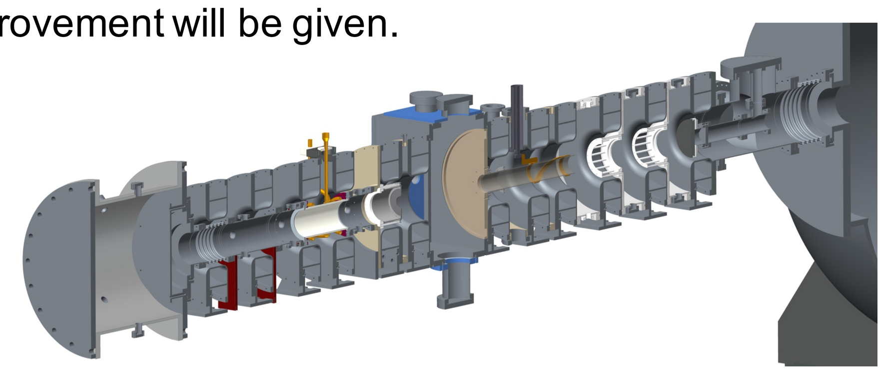
Abstract & Motivation

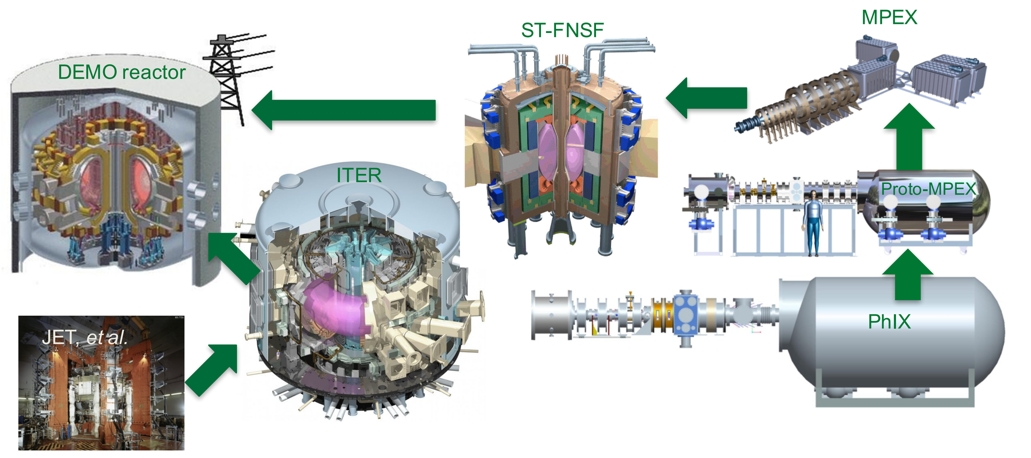
A Thomson scattering diagnostic has been successfully implemented on the prototype Material Plasma Exposure eXperiment (Proto-MPEX) at Oak Ridge National Laboratory. Thomson scattering is a technique used on many devices to measure the electron temperature (T_e) and electron density (n_e) of the plasma. A challenging aspect of the technique is to discriminate the small number of Thomson scattered photons against the large peak of background photons from the high-power laser used to probe the plasma. A variety of methods are used to mitigate the background photons in Proto-MPEX, including Brewster angled windows, viewing dumps, and light baffles. With these methods, first results were measured from Argon plasmas in Proto-MPEX, indicating T_e ~ 2 eV and n_e ~ 1×10^{19} m^{-3}. The configuration of the Proto-MPEX Thomson scattering diagnostic will be described and plans for improvement will be given.



Viable fusion energy source depends on solving "plasma facing component" gap

- Fusion needs a PFC solution, which motivates plasma material interaction (PMI) research.
- Research device trajectory (ORNL) for fusion energy:

–DEMO 🡐 ITER 🡐 FNSF 🡐 MPEX 🡐 Proto-MPEX 🡐 PhIX

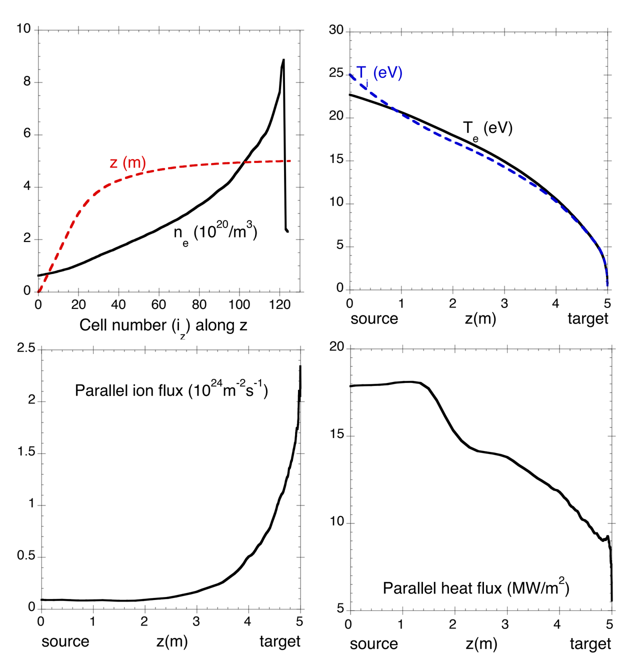


Validate plasma models used in design of MPEX

B2-Eirene: fluid model for plasma transport (B2) coupled to Monte-Carlo code for neutrals (Eirene)

ITER-relevant parameters appear feasible
- power fluxes of 10 MW/m^2
- ion fluxes of 10^{24} $m^{-2}s^{-1}$,
- densities of ~ 10^{21} m^{-3}
- temperatures of 1 – 2 eV

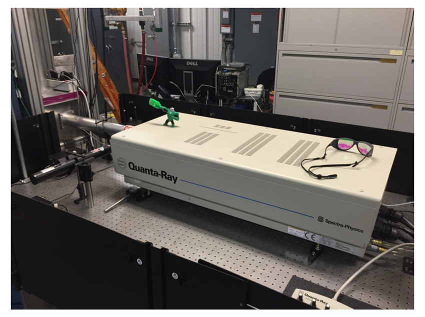
Achieving these parameters depends critically on the "strength" of the axial gradients as the plasma reaches the target.

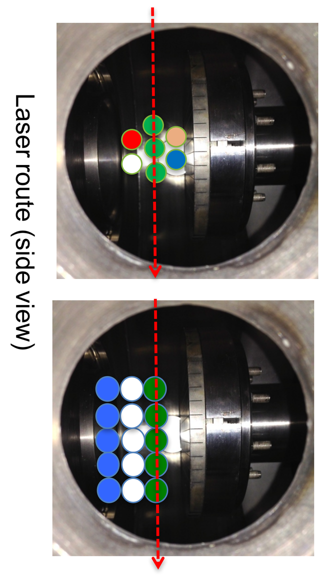


Hardware Implementation

Nd:YAG laser system:

- Newport (Spectra Physics) Quanta Ray Pro 350
  - 10 ns pulse, 10 Hz rep. rate
  - Up to 1.4 J/pulse
  - Frequency doubled to produce 532 nm (green) light

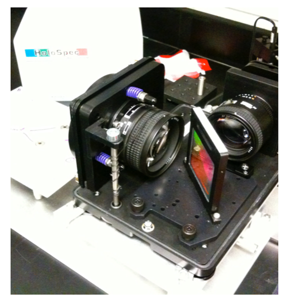




Collection optics:

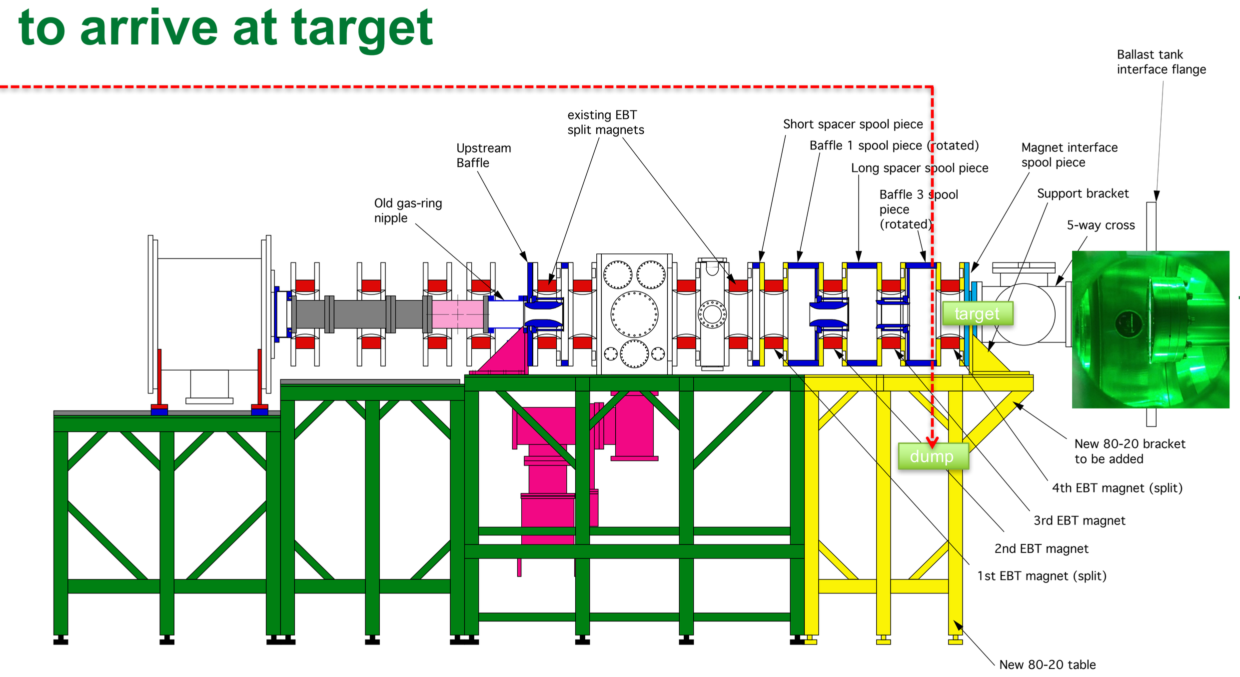
- 180 mm f/1.8 collection lens mounted for 90 degree scattering
- Fiber optic bundle:
  - 7 fibers, 25 m long, 600 micron diameter
  - 15 fibers, 25 m long, 400 micron diameter

Detection system:



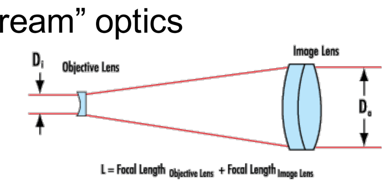
- Kaiser Optical Systems Holospec f/1.8 spectrometer
  - "low dispersion" grating, center λ = 529 nm
  - Dispersion ~ 0.05 nm/pixel
  - 10 fibers/slit (75 micron wide, dual slit)
- Princeton Instruments PI-Max3 intensified CCD camera
  - Gen III intensifier (gate-able >2 ns)
  - 1024 x 1024 pixels (12 μm ea.), binned to 10 "tracks"

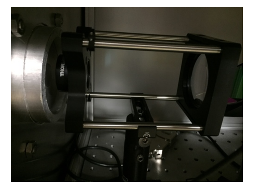
Laser route traverses ~60 ft of beam enclosure to arrive at target



Stray Light Reduction

- The reduction of stray (background) light is critical to being able to observe TS photons.
  - Beam Expanding Telescope and focusing optics
    - A 3x Galilean BET is used to reduce the laser beam divergence (by 1/3) while also reducing the laser power density on "downstream" optics





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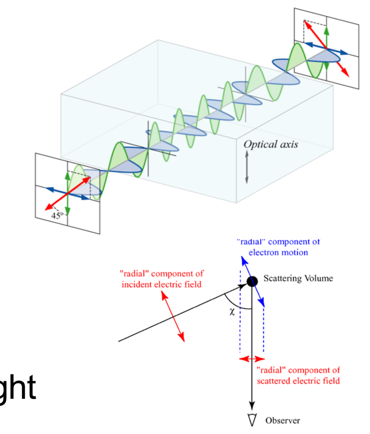
    - A focusing lens (1.5 m) is used to effect a narrow beam-waist in front of the Proto-MPEX target.
  - Polarization optics
    - The laser is emitted vertically polarized.
    - A half-wave plate is used to rotate the polarization such that the beam is horizontally polarized as it crosses the plasma column.
    - Thin film polarizer passes all of the TS photons, while rejecting ½ of the stray light photons.



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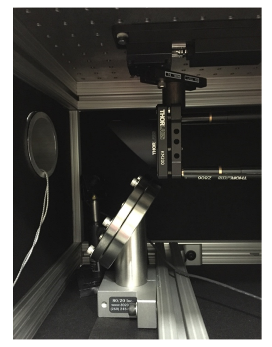
  - Brewster angled vacuum windows
    - At air/vacuum interface, Brewster angled windows ensure preferential transmission of laser light polarized for TS use.
    - Stray light from "upstream optics" is rejected.



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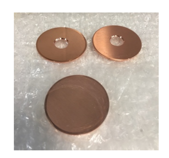
  - Light baffling in vacuum
    - Focusing lens effects a beam-waist at the target
    - Vacuum "flight-tubes" are mounted with apertures of varying diameters to match beam waist and reject stray light photons.



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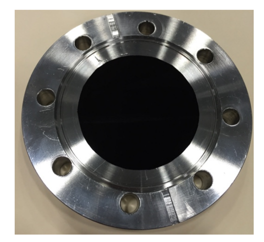
  - Acktar black foils for light absorption and viewing dumps
    - Vacuum compatible "spectral black" foils are used within flight-tubes to absorb photons rejected by baffles
    - Viewing dump of similar foils is located opposite to the TS collection optics to terminate lines-of-sight on light absorbing surfaces (reduces reflected light in optics).



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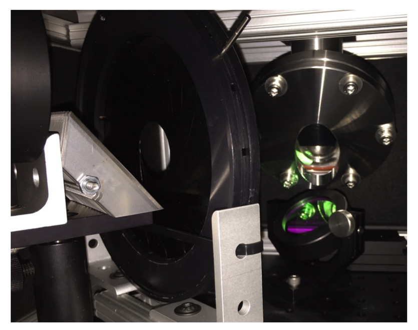
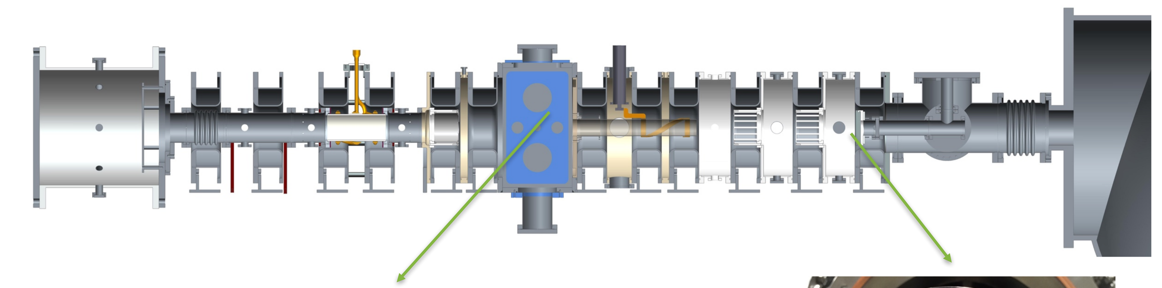
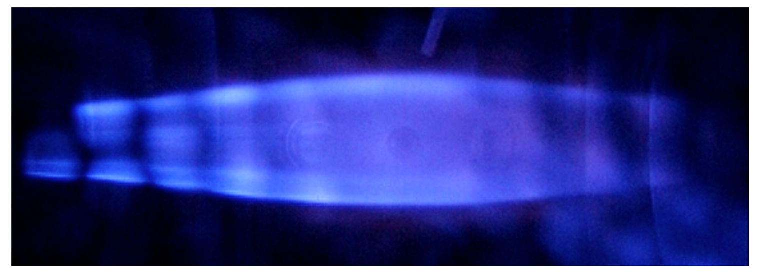
  - Razor blade beam dump
    - Exiting light is deflected by 90 degrees prior to impacting laser beam dump to reduce back-scatter into flight-tube.
    - Beam in inclined to a razor-blade dump.
    - Beam dump is baffled to further reduce back-scatter path into vacuum vessel.
    - Entire dump box has interior surfaces blackened to absorb stray light.

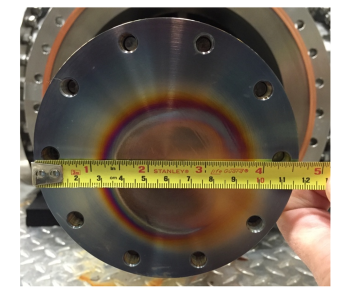


Results

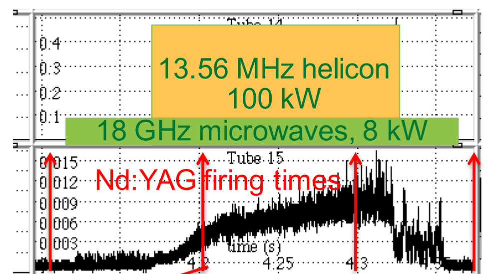
- Argon plasma discharges were used to produce a high electron density plasma.
  - Proto-MPEX typically operates with light ion gases: H_2, D_2, He
- Repetitive discharges were produced with time-synchronized laser pulses to ensemble (~75) multiple TS measurements.

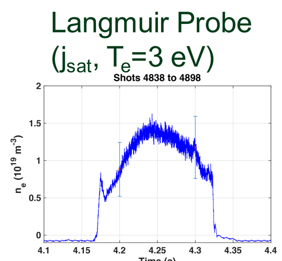


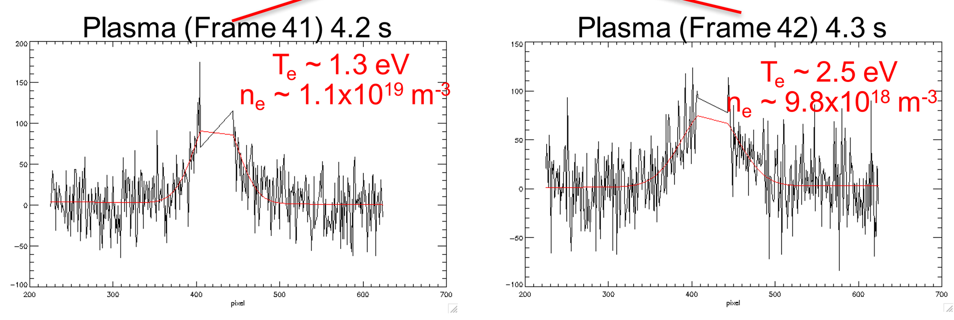




T_e and n_e measured using Thomson Scattering are in agreement with Langmuir Probe measurements





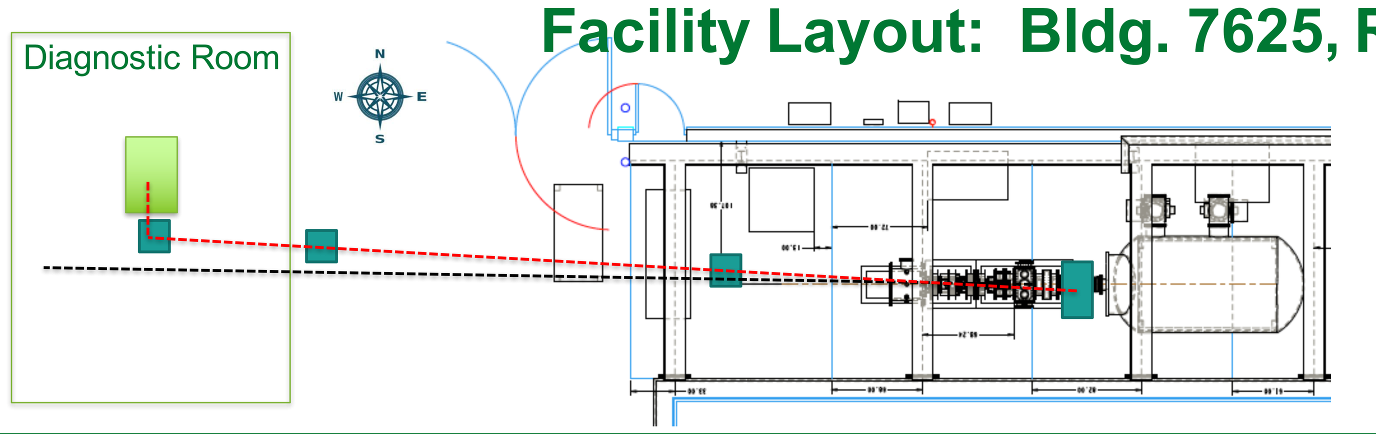


Summary & Future Work

- Reprints: http://sprott.physics.wisc.edu/biewer/HTPD2016poster.pdf
- First measurements from the Proto-MPEX Thomson Scattering diagnostic have been achieved in Argon plasmas.
- Electron temperature and density measurements from the TS are in agreement with measurements from Langmuir probes, when both are available.
- Signal-to-Noise is still very low, and single-pulse TS measurements are not reliable.
- The number of TS pulses needed to produce reliable measurements can be reduced by:
  - High-electron density operation of Proto-MPEX.
  - Redesigning TS diagnostic for measurements near the helicon antenna.
  - Improved stray-light reduction in the vacuum vessel.

- T.M. Biewer, G. Shaw, Rev. Sci. Instrum. **85**, 11D812 (2014).
- J. Rapp, *et al.*, J. Nucl. Mater. **510**, 390-391 (2015).
- D.J. Schlossberg, *et al.*, Rev. Sci. Instrum. **83**, 10E335 (2012).
- H.J. van der Meiden, *et al.*, Rev. Sci. Instrum. **83**, 123505 (2012).
- J.B.O. Caughman, *et al.*, submitted to proceedings of the 22nd International Conference on Plasma Surface Interactions, Rome, 2016.
- R. Goulding, *et al.*, Appl. Phys Lett., to be submitted.

Facility Layout: Bldg. 7625, Rms. 108 to 106



Power (kW)	PhIX (2s)	Proto-MPEX (2s)
Helicon	100	100
Whistler/EBW	20 (18 and 15.3 GHz)	200 (28 GHz)
ICH		30 – 200
TOTAL	120	330 – 500