# Localized measurements of impurity ion dynamics in MST

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Fast passive Doppler spectroscopy has been used extensively in the Madison Symmetric Torus (MST) to study impurity ion dynamics. Measuring ion flow and temperature with good time resolution is crucial to understanding anomolous ion heating, momentum relaxation, fluctuation induced particle transport, and the MHD dynamo. However, quantitative measurements have been difficult due largely to uncertainties in the spatial structure of the emission. Using charge exchange recombination spectroscopy (CHERS), we have made good progress toward the measurement of impurity ion dynamics with good spatial localization while maintaining high temporal resolution. CHERS is done using a 30 keV neutral hydrogen beam and collecting C VI emission at 343.4 nm which is analyzed to yield information on the density, flow, and temperature of fully stripped carbon ions throughout the plasma. Background emission is large in MST and must be dynamically subtracted by views which do not intercept the neutral beam. Use of a duo-spectrometer enables this subtraction to be done at each wavelength along the line profile. Equilibrium measurements in standard 400 kA MST discharges yield carbon ion temperatures of about 300 eV. A high throughput, high resolution spectrometer is under construction for fluctuation measurements.

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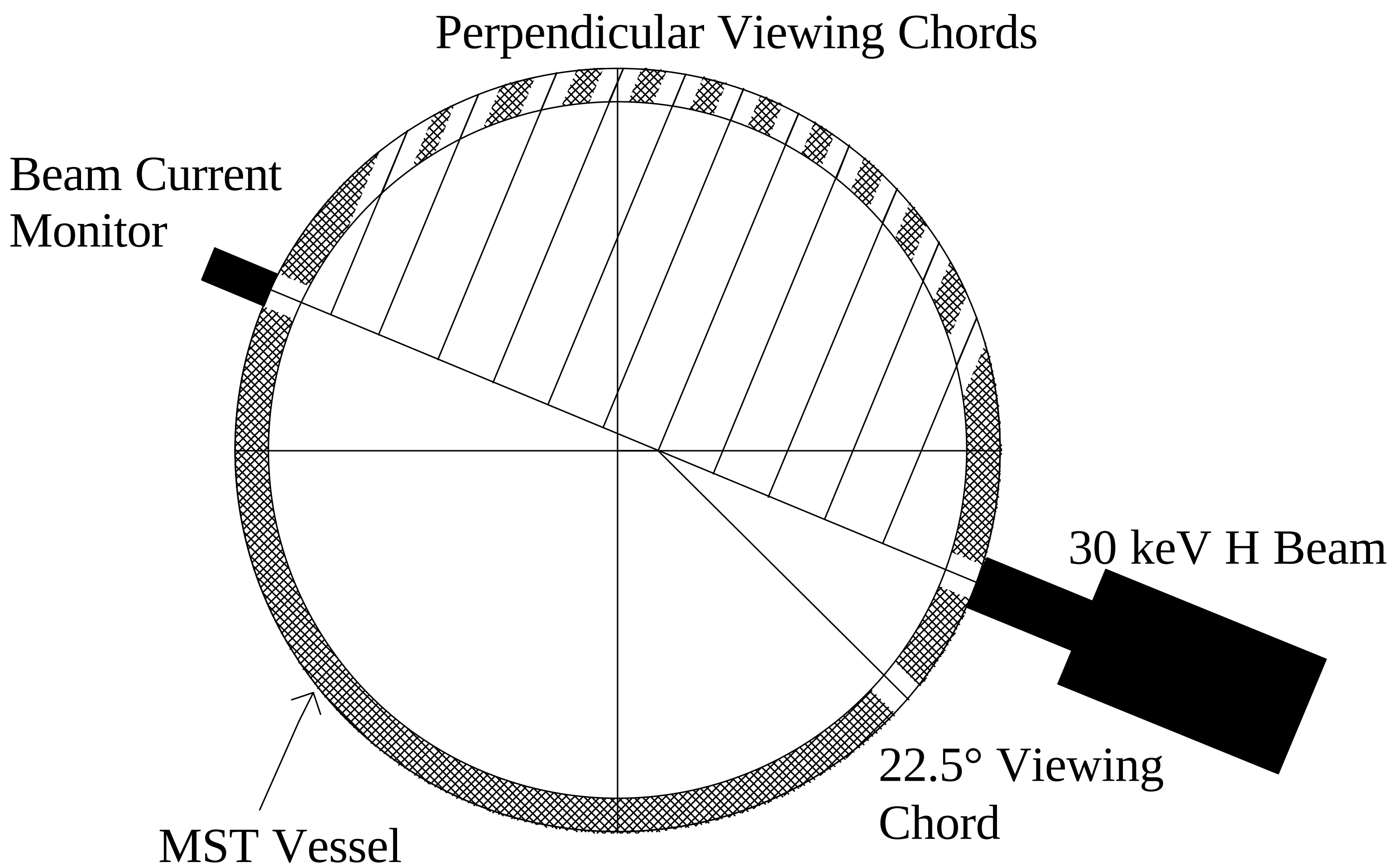
# Physics Questions to Address

- What is the ion temperature profile in MST and how does it change during relaxation events?
- What is the momentum profile in MST and how does it change during relaxation events?
- What is the radial structure of core-resonant flow fluctuations?
- What is the magnitude and radial structure of the MHD dynamo ($\tilde{v}\times\tilde{b}$)? Is the contribution from each mode localized or broad?
- What is the transport from flow fluctuations in the core?

# Main Points

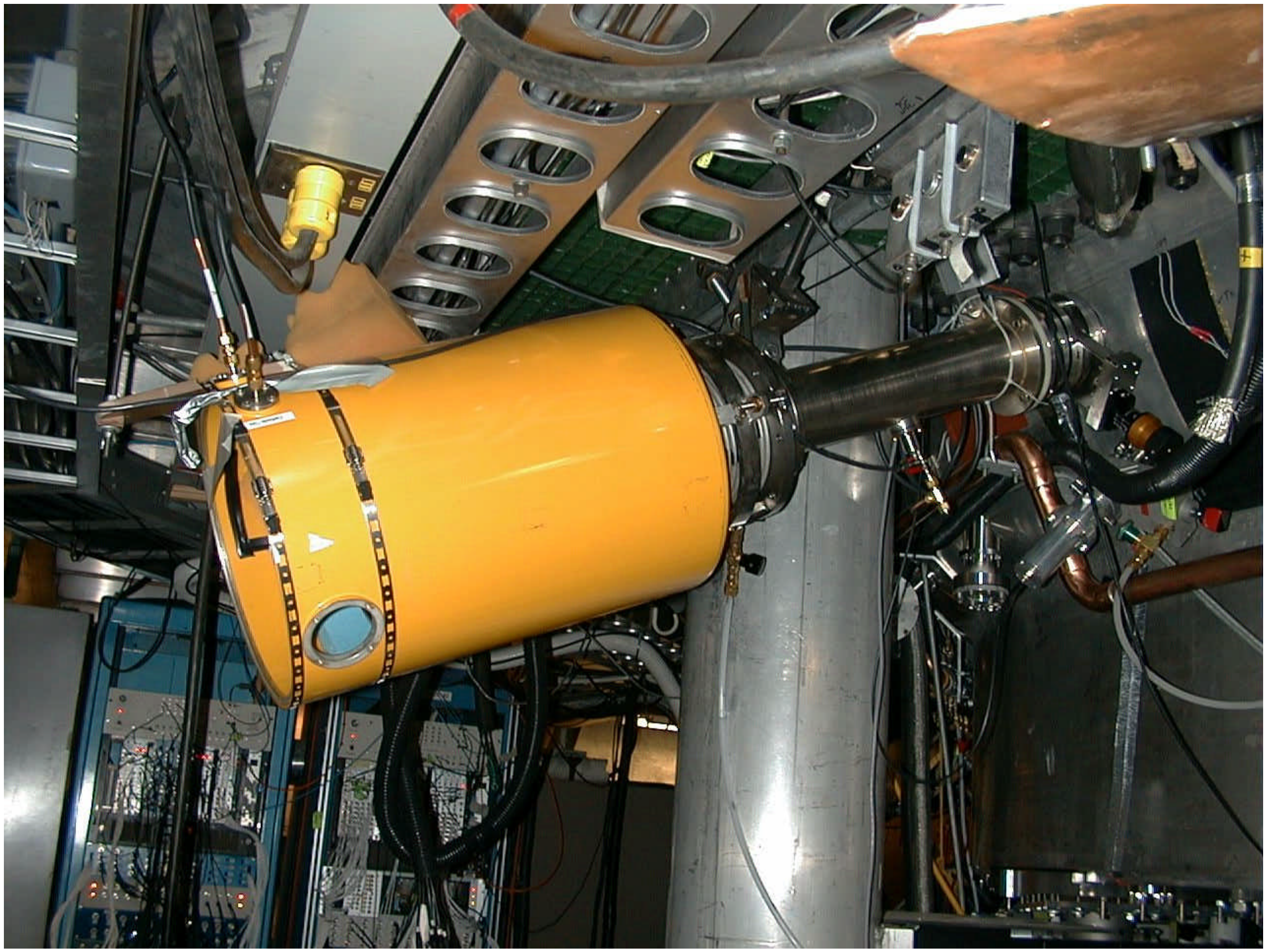
- Localized ion temperature measurements are now underway in MST.
- First results indicate central $T_i$ = 0.7-0.8 $T_e$ in standard plasmas and 0.3-0.5 $T_e$ in improved confinement plasmas.
- Increased time resolution and flow measurements will rely on a new high throughput spectrometer under construction.

# Experimental Layout




*Poloidal Cross-section*

# CHERS Made Possible by Diagnostic Neutral Hydrogen Beam



# Diagnostic Neutral Beam Characteristics

- 30 keV, 4 A neutral H beam
- Low divergence (15 mrad)
- Small diameter (4 cm)
- High beam density (0.4 $A/cm^2$)
- 3 ms duration

# CHERS Principles of Operation

- CHERS allows localized measurement of impurity ion density, flow, and temperature via observation of the shape and intensity of line emission from:

$$\mathbf{H}^{\mathbf{0}} + \mathbf{A}^{\mathbf{Z+}} \rightarrow \mathbf{H} + \mathbf{A}^{\mathbf{(Z\text{-}1)+}}(\boldsymbol{n},\boldsymbol{l})$$

$$\mathbf{A}^{\mathbf{(Z\text{-}1)+}}(\boldsymbol{n},\boldsymbol{l}) \rightarrow \mathbf{A}^{\mathbf{(Z\text{-}1)+}}(\boldsymbol{n}',\boldsymbol{l}') + \boldsymbol{h}\nu$$

Transitions Surveyed in MST

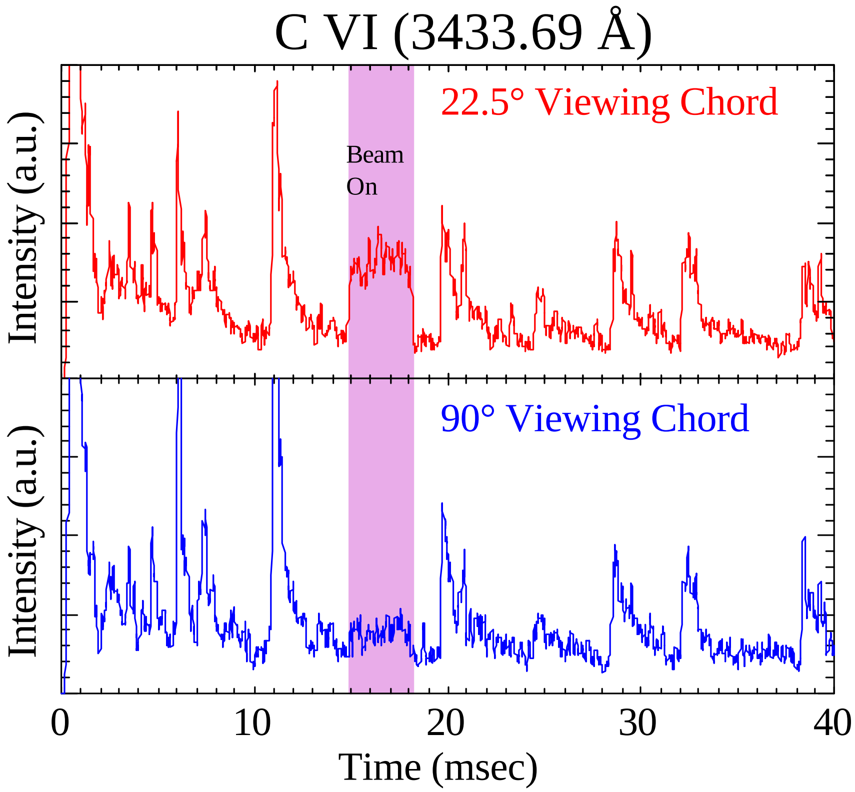
| | | |
|---|---|---|
| He II | 4-3 | 4685.24 Å |
| B V | 7-6 | 4944.7 Å |
| | 6-5 | 2981.4 Å |
| C VI | 8-7 | 5290.53 Å |
| | 7-6 | 3433.69 Å |
| O VII | 9-8 | 4340.58 Å |
| | 8-7 | 2975.83 Å |

# C VI Transition @ 3434 Å Best in MST

- The C VI line at 3434 Å gives the highest signal-to-noise of any candidate line surveyed in MST.
  - -Important for getting good time resolution.
- The only possible contamination is from O VI which can likely be removed with off-beam views.
  - -Off beam views necessary for dynamic C VI background subtraction as well.
- Best signal in Deuterium plasmas with low core neutral density and high electron temperature.
  - -Lower background C VI, higher $C^{6+}$ density.

# Examples of Emission From MST

- Use monochromators with PMT's to examine strength of charge-exchange signal.



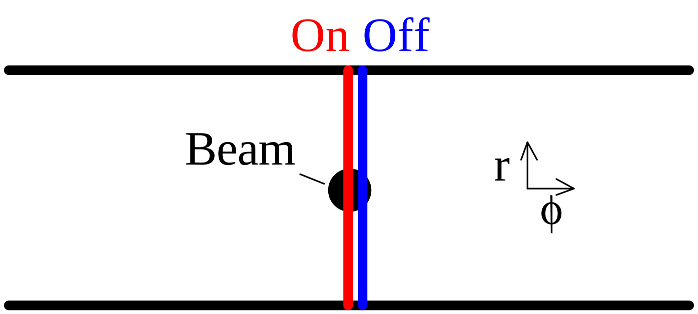

22.5º viewing chord
Intercepts large beam volume ⇒ large signal

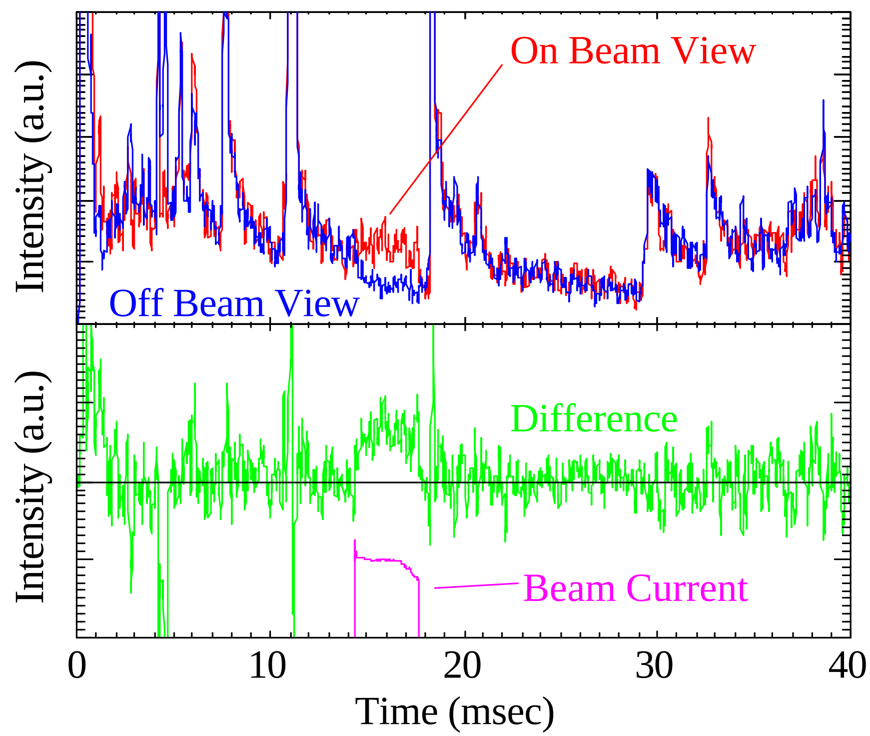
90º viewing chord
Better spatial resolution
Lower signal

# Dynamic Background Subtraction Tested

- Comparing 2 central perpendicular views on and off of the beam gives improved sensitivity.

- 2 Monochromators with PMT's view through the same porthole

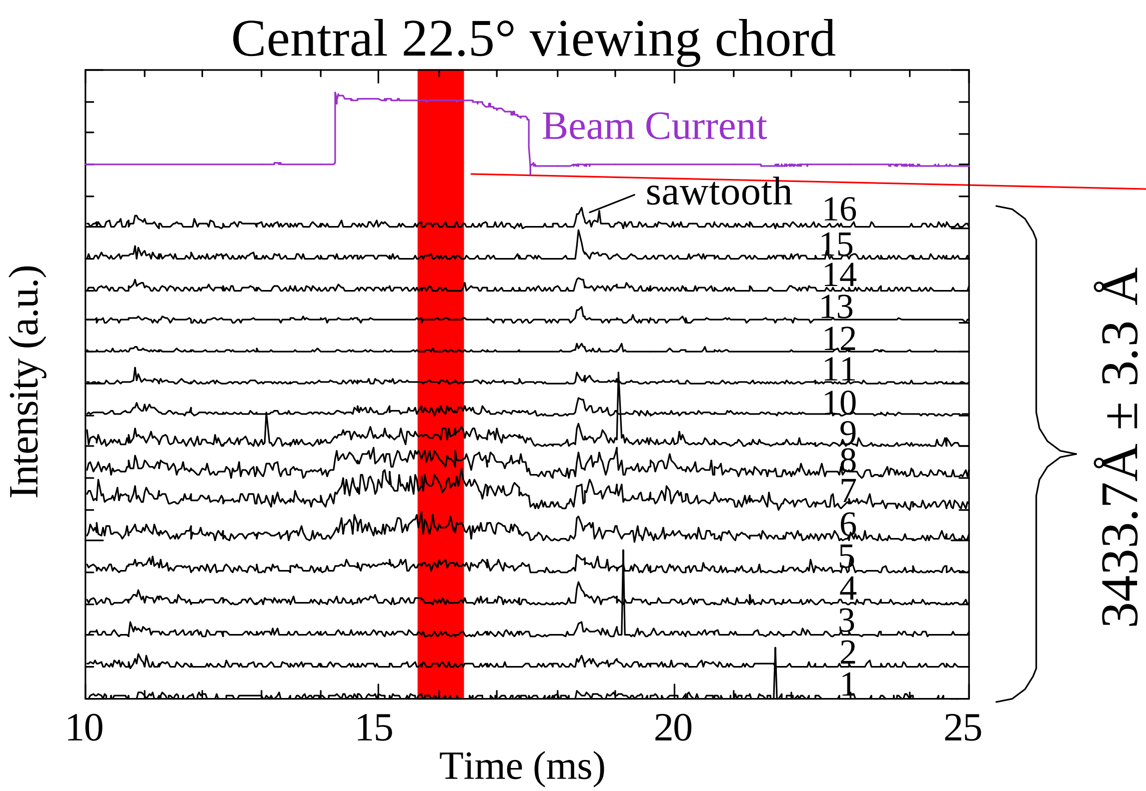


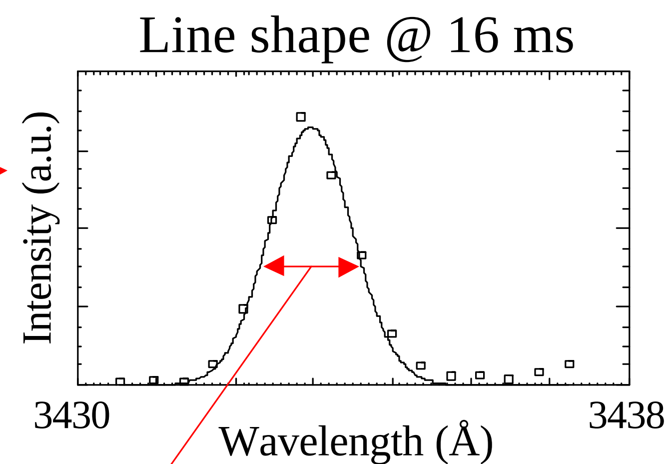




- Expect better difference signal when subtraction is done on finer wavelength scale.

# Preliminary CHERS Measurements Using Existing Fast Doppler Spectrometer

- 1m focal length, Czerny-Turner with 16 fiber bundles (wavelength channels) on exit plane.
- 16 PMT's detect light in all channels simultaneously.

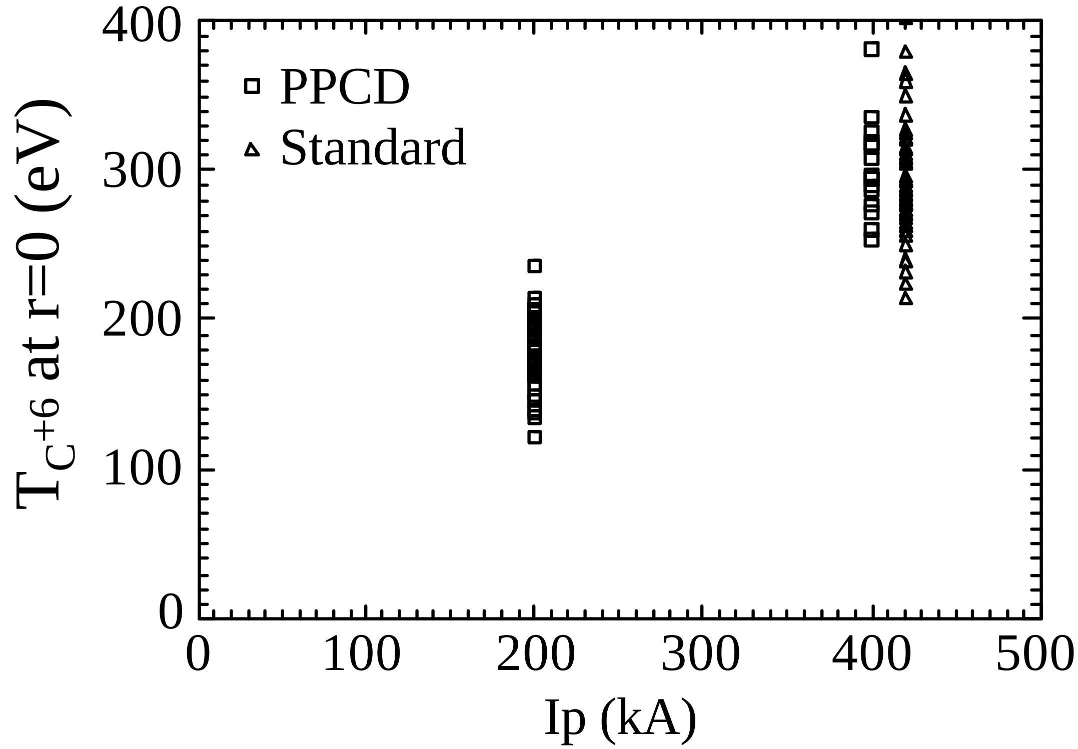



Ti ~ 300 eV

# Summary of Initial Ti Measurements

- In standard RFP discharges, $T_i \sim 0.7\text{-}0.8\ T_e$ on axis.
- During PPCD, $T_e$ increases but $T_i$ is unchanged.
  (see poster by B.E. Chapman for more on PPCD)
- Equilibrium $T_{majority} \approx T_{minority}$ for cases studied.
  (see poster by J. Reardon for $T_{majority}$)



# Estimates of Local Impurity Density

- The total detected signal is given by:

$$V \approx G \cdot T \cdot E \cdot \frac{1}{4\pi} \langle \sigma v \rangle_{CX}^{\lambda} \, n_C \cdot n_{beam} \cdot W \cdot \Delta t$$

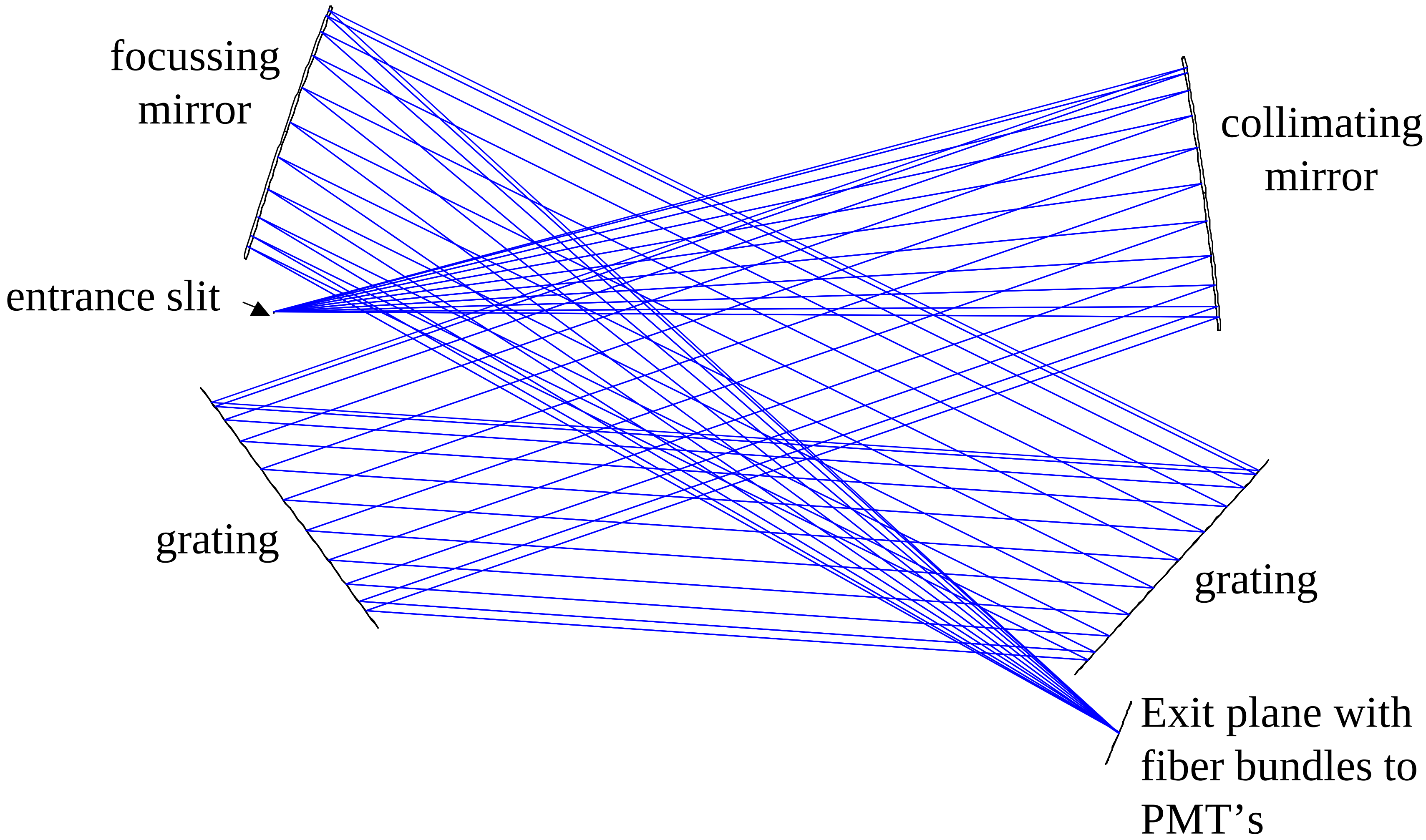
- Gains ($G$)
- Transmission of optical system ($T$)
- Entendue ($E$)
- Charge exchange emission cross-section ($\langle \sigma v \rangle_{CX}^{\lambda}$)
- $C^{+6}$ density ($n_C$)
- Beam density ($n_{beam}$)
- Beam width ($W$)
- Sample time ($\Delta t$)

- Plugging in all the numbers, with ~ 0.1 V signal gives $n_C \approx 1\%\ n_e$ in rough agreement with other measurements

# Improved Time Resolution Requires a New Spectrometer

- To get time resolution of 10 μs need more efficient spectrometer with:
  - High throughput
  - High dispersion
- Duo-spectrometer design will be used with one half viewing the beam and the other half for dynamic background subtraction.
- Estimated first light - June 2001.

# View of Spectrometer Design



# Expected Performance of New Spectrometer

- Spectrometer has large etendue (0.3 $mm^2$ sr) and is optimized for 343 nm.
- Expect signal ~ 100x that of existing system.
- Monte Carlo modeling implies Ti should be well measured from 50 eV - 2 keV.
- Velocity measurements should be good to 0.1 km/s with an ensemble of shots.

# Future Work

- Evaluate the importance of atomic structure on temperature and velocity measurements in MST and include this in analysis.
- Determine profile and sawtooth cycle evolution of background emission.
- Use existing spectrometer to look at mean ion temperature profile in MST.
- Construct new spectrometer and begin velocity measurements.

# Summary

- Localized measurements of impurity ion dynamics are now underway in MST.
- First results indicate central $T_i$ = 0.7-0.8 $T_e$ in standard plasmas.
- During periods of improved confinement, $T_e$ increases dramatically but $T_i$ remains almost constant.
- Increased time resolution and flow measurements will rely on a new high throughput spectrometer under construction.

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