CXRS/MSE/BES on the MST Reversed-Field Pinch

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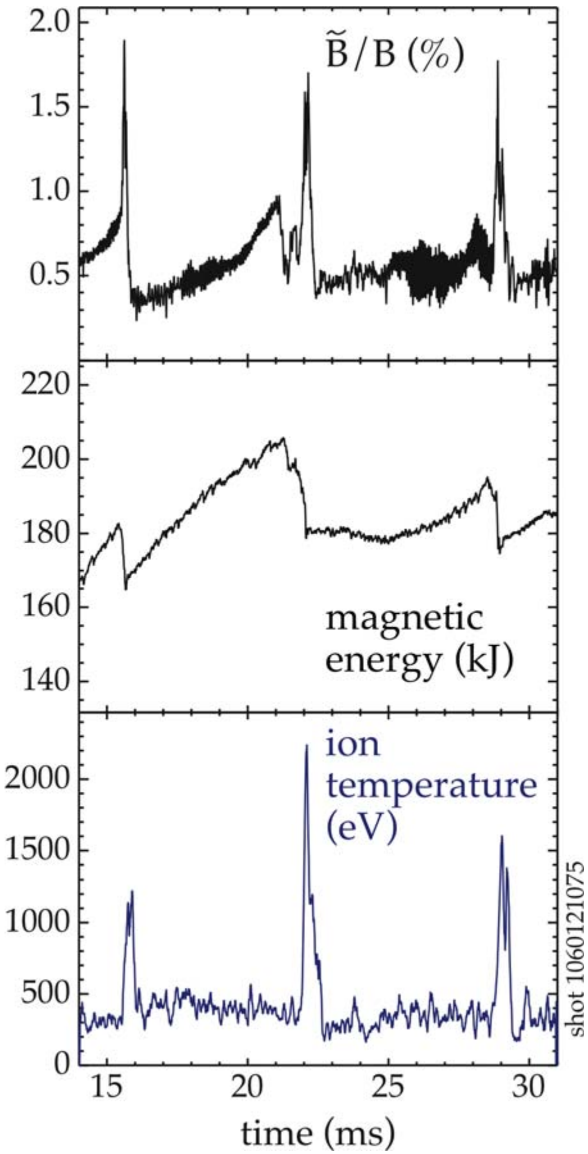
13 November 2006

Measurement of fast plasma dynamics in MST requires innovative high-speed spectroscopic diagnostics.



- Plasma parameters change dramatically during fast reconnection events ("sawtooth crashes")
  - fluctuations increase, stored magnetic energy drops, ions are heated, ….
  - timescales of 10–100 μsec
- Detailed physics understanding requires spatially and temporally resolved measurements of temperature, flow, and **B**
  - energy and momentum transport
  - MHD dynamo ($\tilde{\mathbf{v}} \times \tilde{\mathbf{B}}$)
  - equilibrium reconstruction
  - ….

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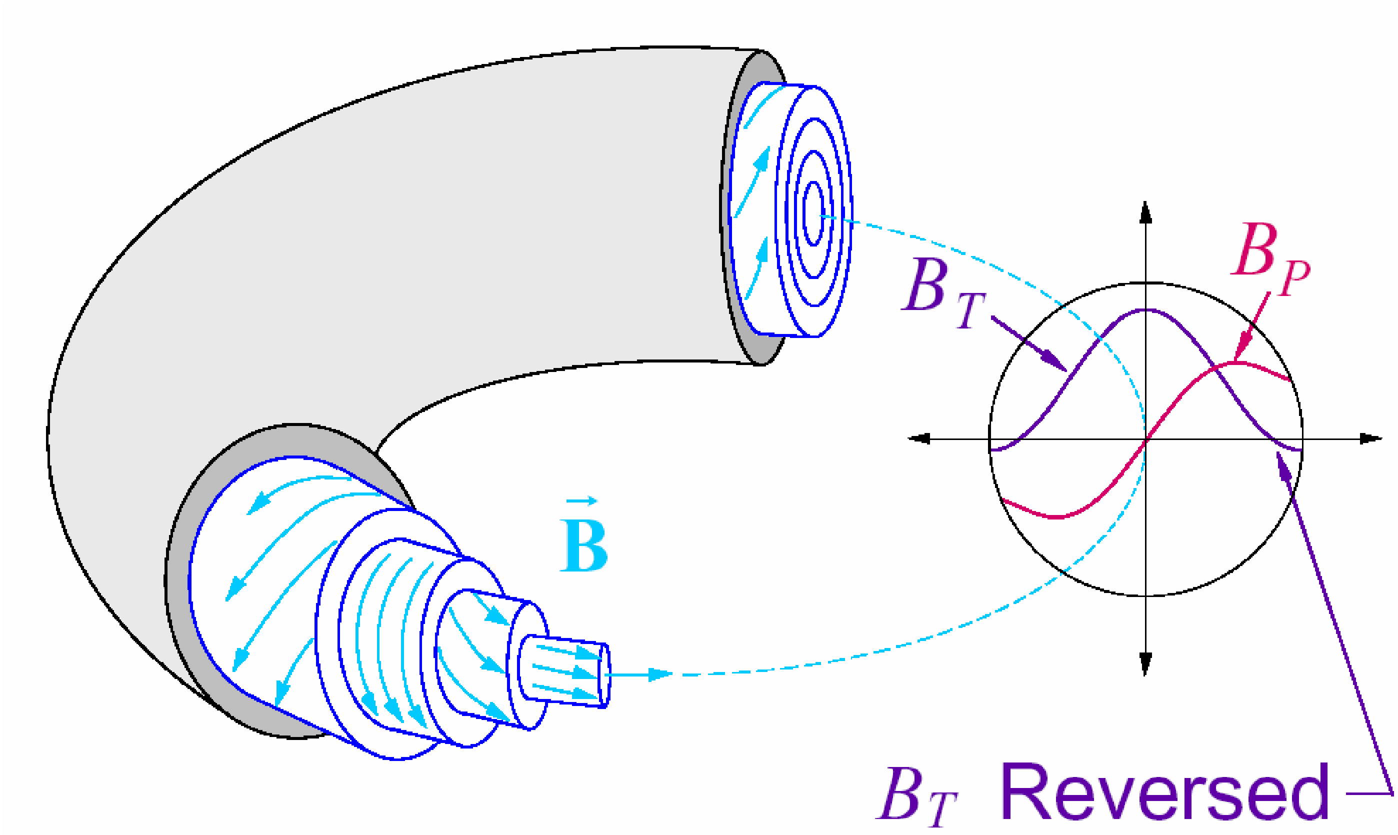
This work is supported by the U. S. Department of Energy and the National Science Foundation.

Outline

- Brief introduction to the Reversed-Field Pinch and MST
- Beam-based diagnostics
  - Charge-exchange recombination spectroscopy (CXRS)
  - Spectral motional Stark effect diagnostic (MSE)
  - Fast He beam emission spectroscopy (BES)
- Summary

The RFP: toroidal confinement at low |B|.

- Toroidal field B_T is ~10X smaller in RFP than same-current tokamak
  - $B_T \approx B_P$ with high total β (typically ≥10%)
  - equilibrium substantially determined by plasma dynamics

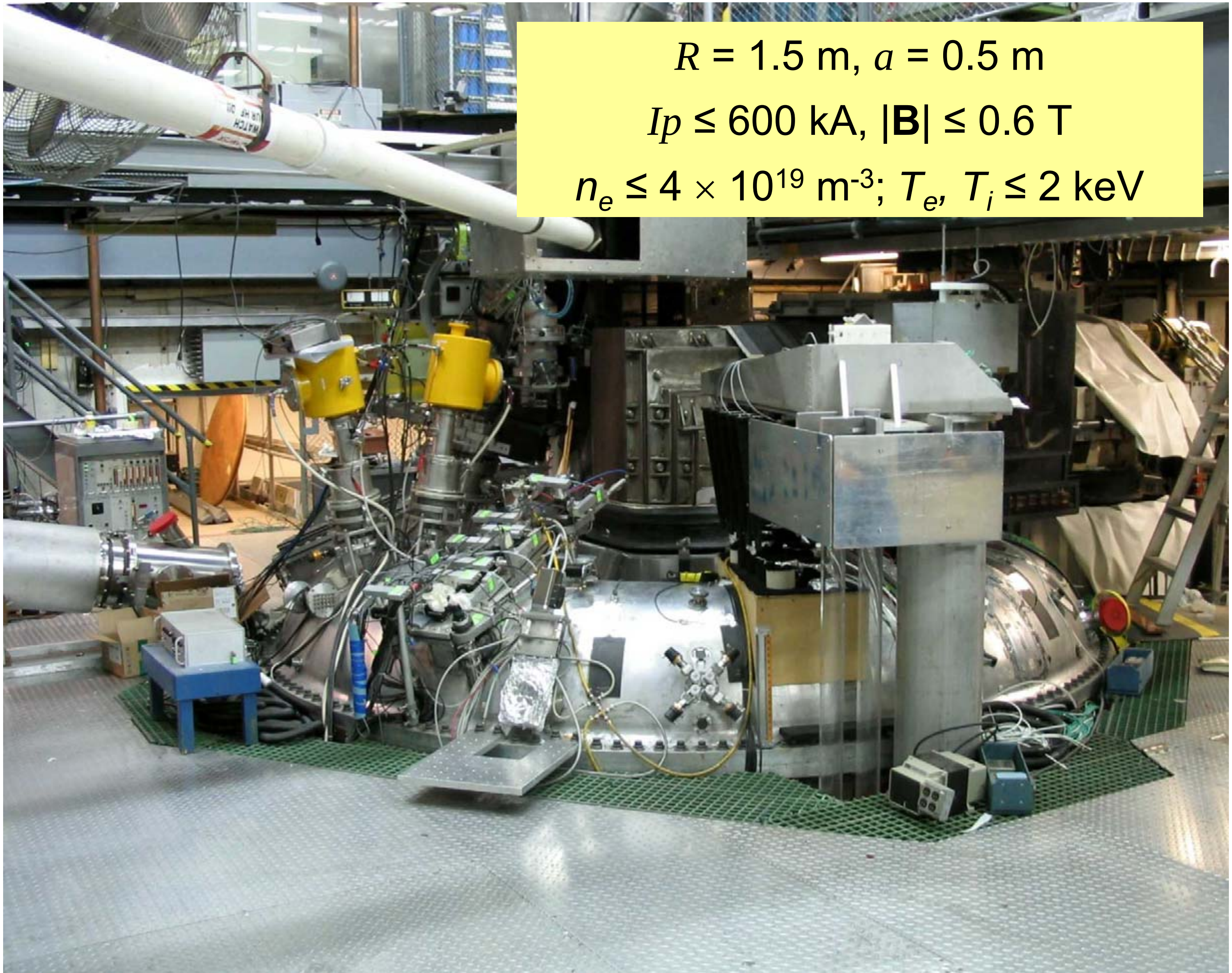


MST is an ohmic RFP operated at moderate current.

R = 1.5 m, a = 0.5 m

$Ip \leq$ 600 kA, $|\mathbf{B}| \leq$ 0.6 T

$n_e \leq 4 \times 10^{19}$ m^{-3}; T_e, $T_i \leq$ 2 keV



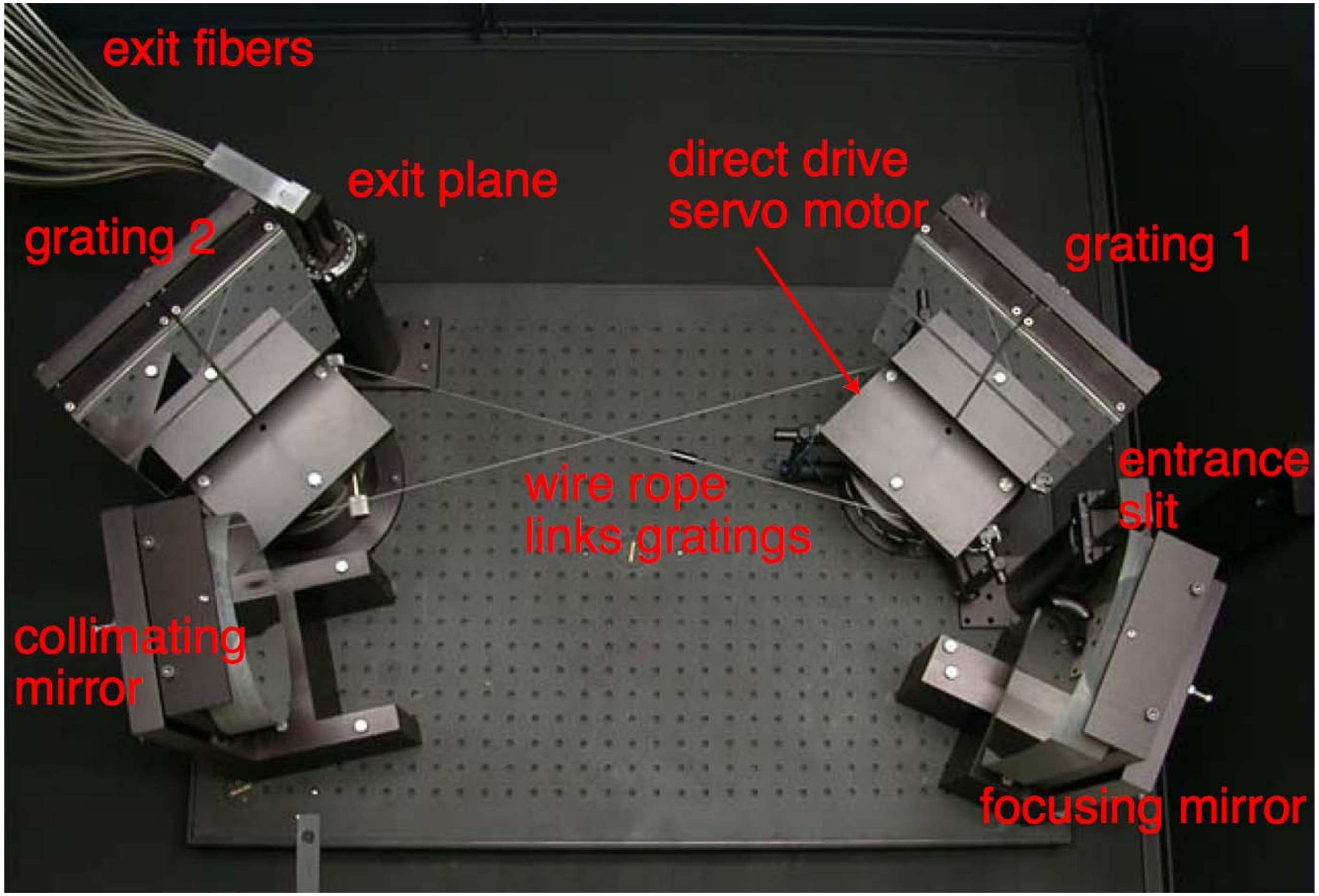
CXRS

CXRS measurements can be made at 11 radial points on a poloidal cross-section of MST.

Both CX and background emission are recorded simultaneously

Custom high throughput CXRS duo-spectrometer is the key to measuring fast ion dynamics in MST.

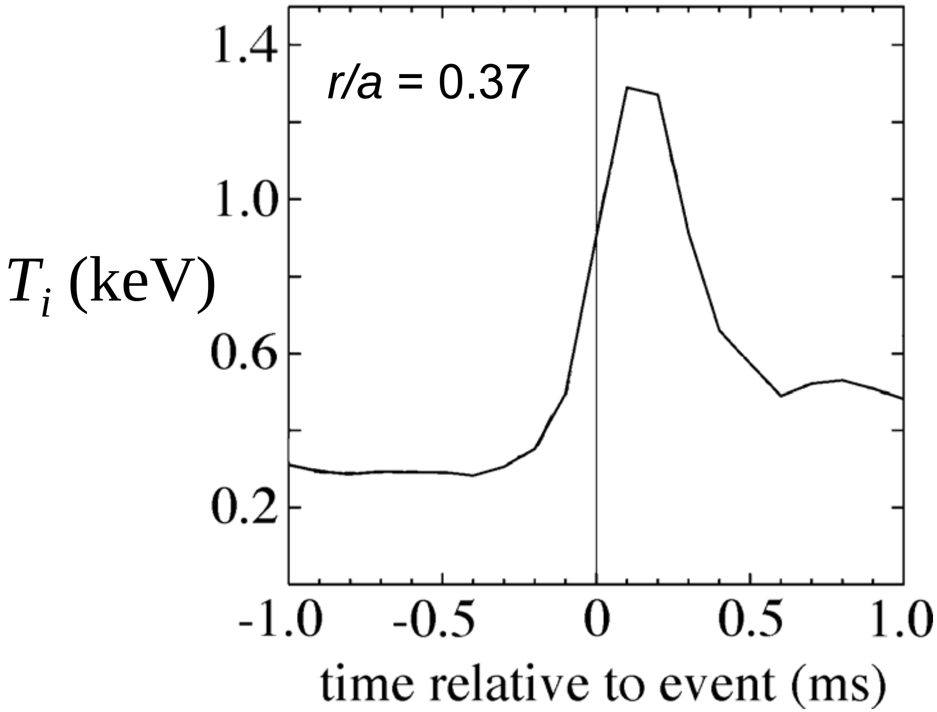
- Double-grating Czerny-Turner design provides required dispersion
  - each grating is a mosaic, 220 x 220 mm, 3600 g/mm
  - directly coupled fiber optic input and output



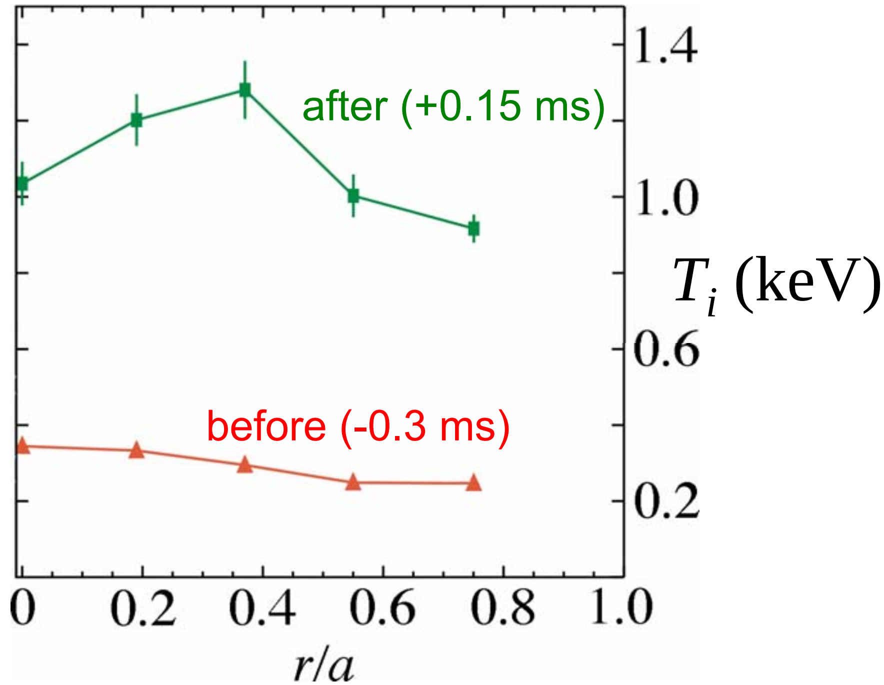
D. Craig *et al.*, to be published in *Rev. Sci. Instrum.*

Ion heating (“self-heating”) occurs in ~0.1 ms throughout the plasma during a global reconnection event.

T_i versus time



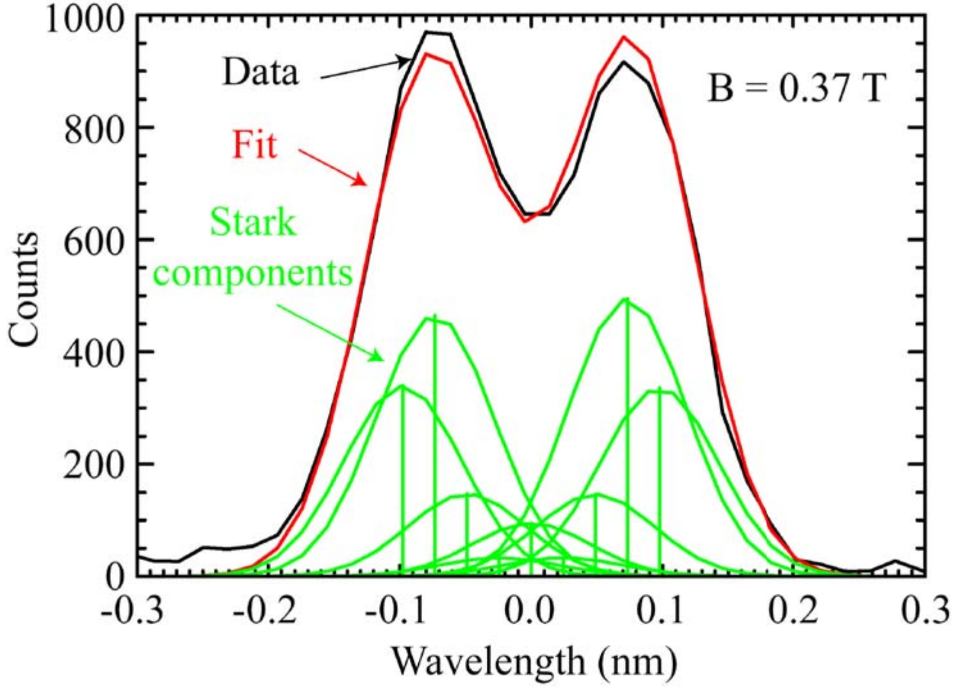
T_i versus radius



Spectral MSE

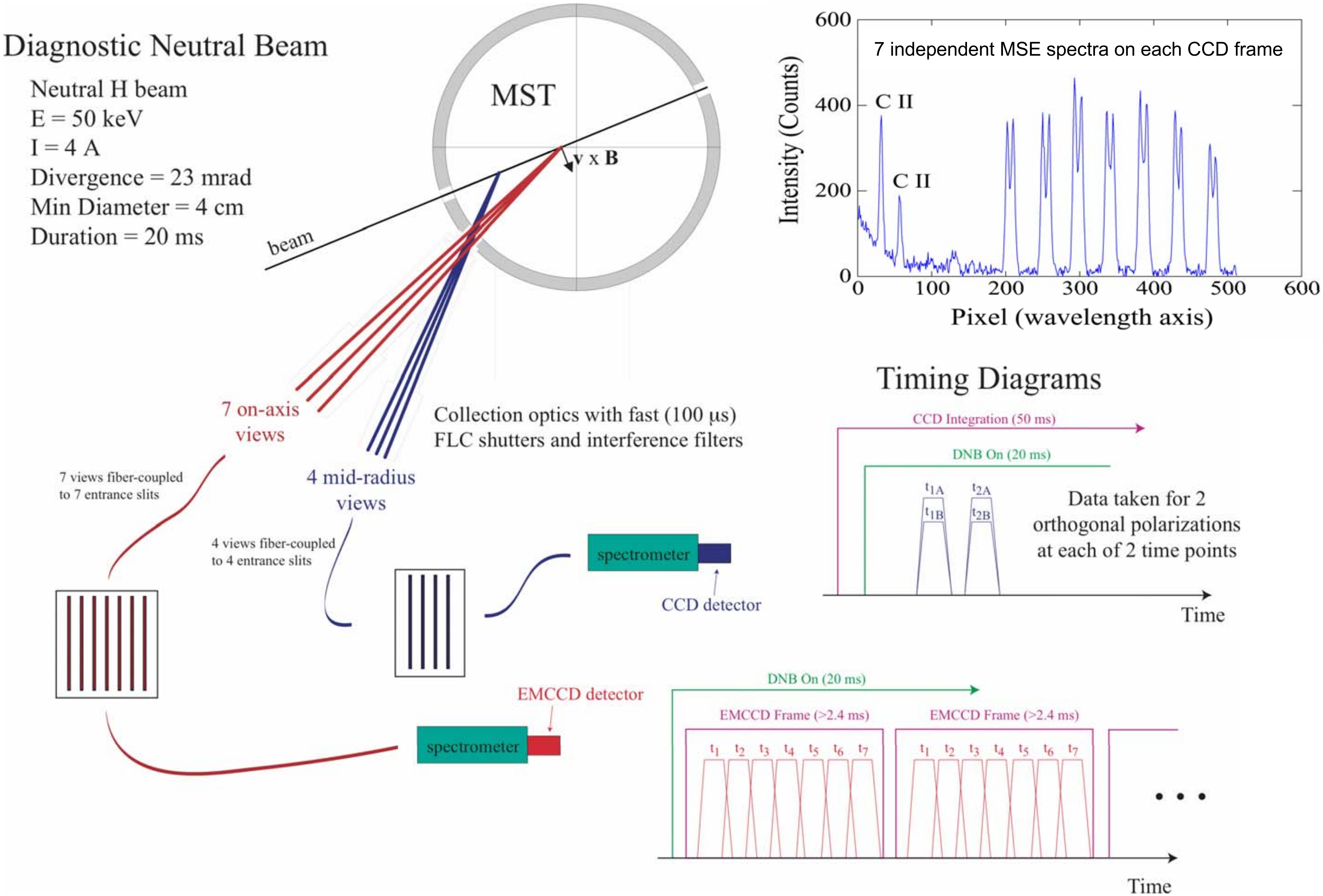
Spectral MSE technique measures B ≥ 0.2 T.

- In MST, $\mathbf{v}_{beam} \times \mathbf{B}$ is small (~1 MV/m), so Stark components overlap
- Solution: measure full Stark spectrum
  - Fit with model assuming statistical population of excited levels
  - From component separation derive local |**B**| to 2% precision



- An atomic model is being developed for MSE at low |**B**| as part of ADAS
  - Cause of small structural asymmetries in the MSE spectrum still not resolved

The spectral MSE system achieves 100 μsec time resolution with arrays of FLC shutters and CCD spectrometers.



Fast He BES

Fast He beam emission spectroscopy offers possibility of local measurement of T_e and n_e in plasma core.

MST

- Thermal He or fast Li BES is a well-established diagnostic technique
  - record ratio of emission intensity of two visible lines
    - lines chosen such that ratio dependent on local plasma parameters
  - used to measure T_e and n_e in plasma edge
  - beam typically does not penetrate to plasma core

- Similar technique proposed for emission from fast He neutral beam
  - **but** fast neutral beams have *substantial metastable fraction*
    - result of neutralization following ion acceleration
  - metastable fraction alters beam emission ratios
    - either quantify metastable fraction (difficult)
    - or select emission ratios relatively insensitive to metastable fraction

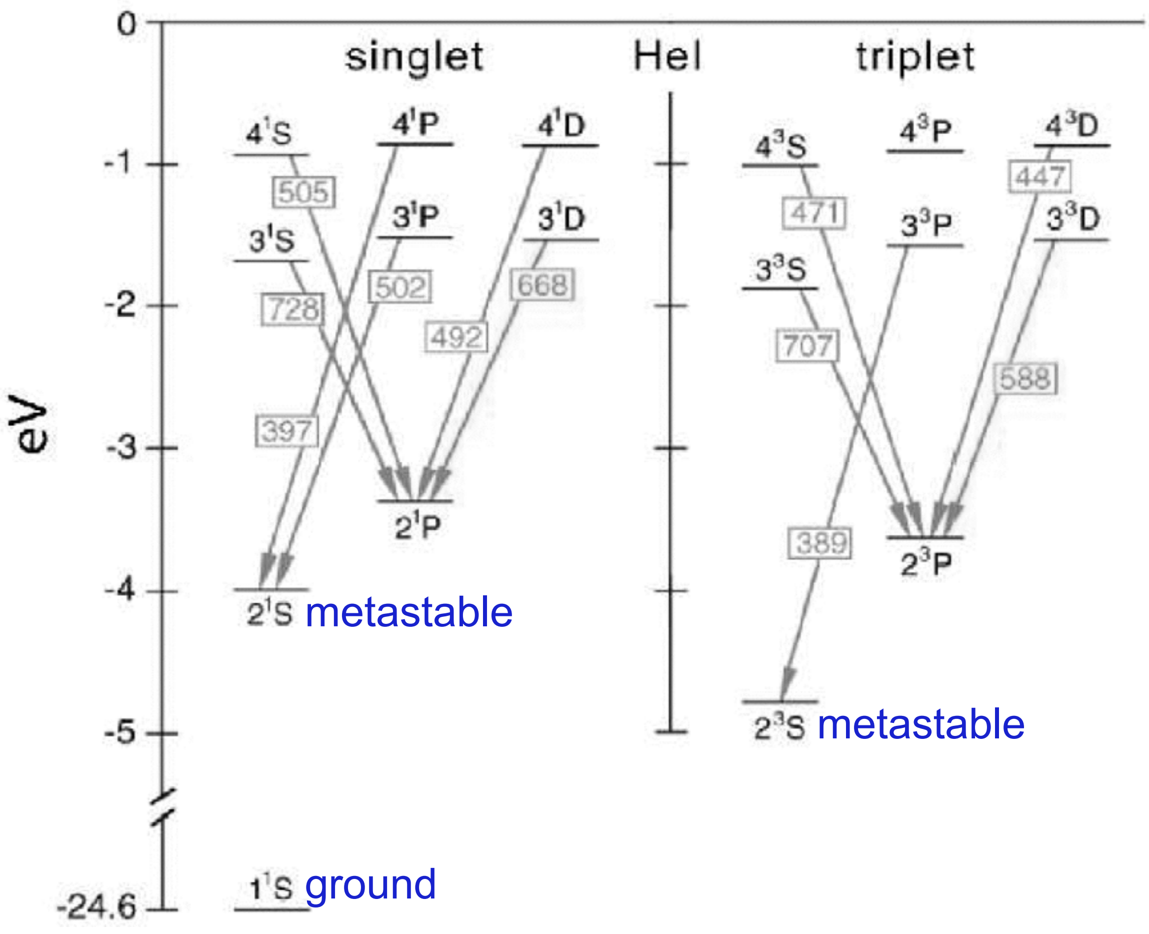
Fast He BES has been tested in MST.

- He neutral beam
  - primarily used for Rutherford scattering diagnostic
  - He beam diameter ~5 cm at observation point
  - $N_{beam} \sim 1.6 \times 10^{10} cm^{-3}$
  - operated at ~16 keV for He BES

- Line of sight intersected beam at r/a = 0.12 (58 cm from beam entry to plasma)
  - oblique viewing angle Doppler shifted emission away from background
  - simultaneously recorded two emission lines

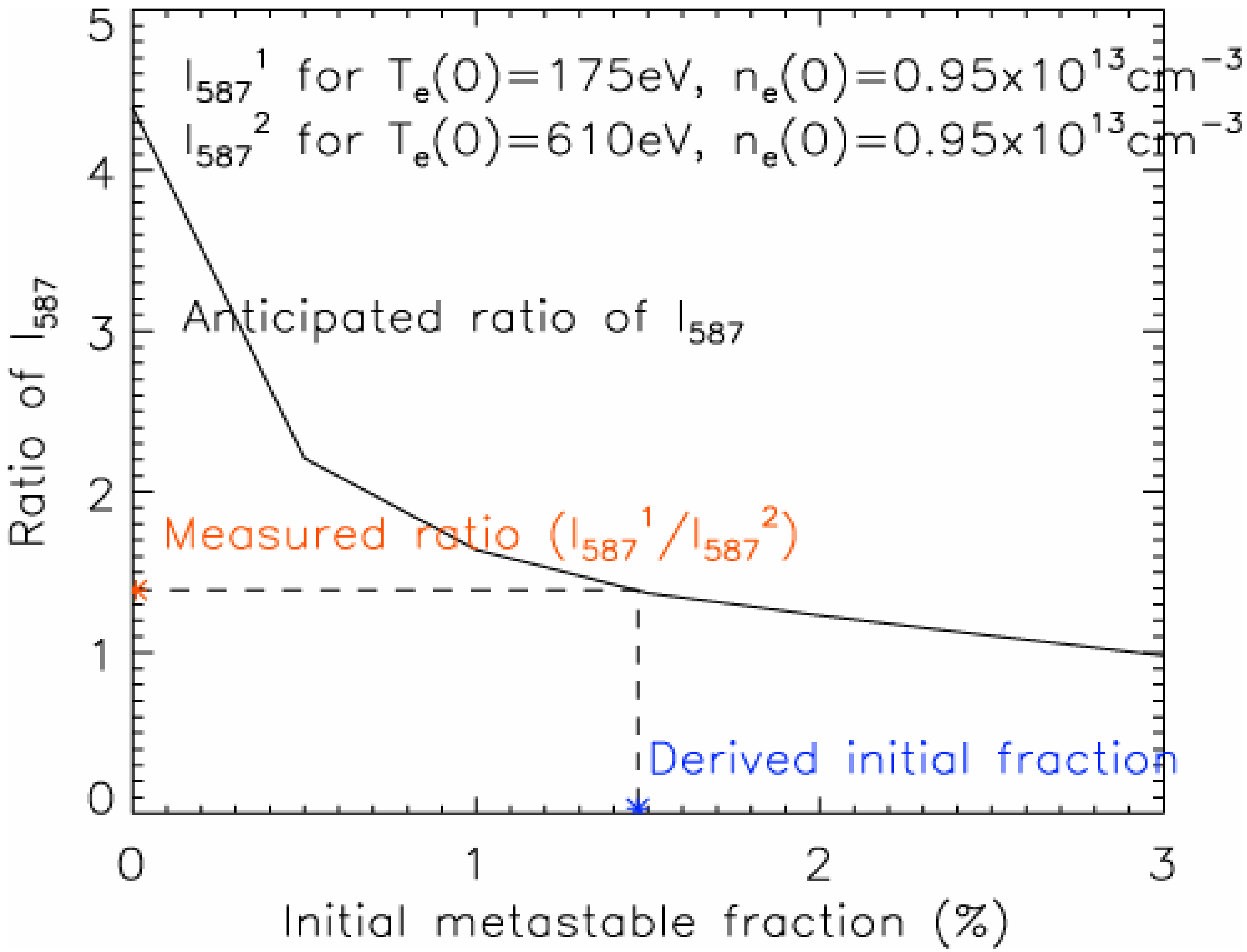
A collisional-radiative model has been applied to the He beam.

- 1^1S, 2^1S, and 2^3S populations
  - obtained by solving spatially dependent balance equations
- Other excited state populations
  - equilibrium solutions relative to the above three populations



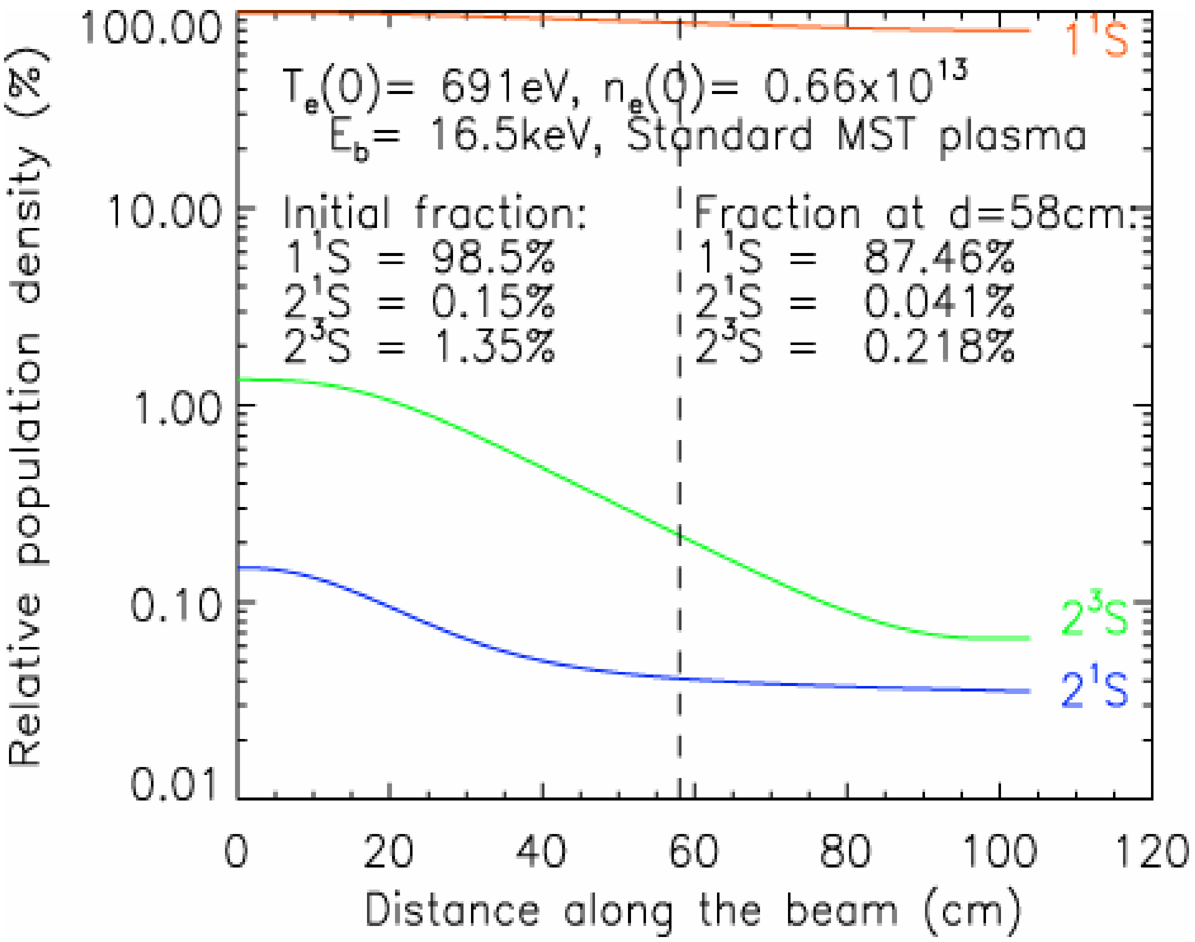
The metastable fraction for the fast He beam was estimated to be 1.5%.

- Measured ratio of emission intensities for plasmas with different T_e
  - compare with theoretical values calculated for various initial fractions

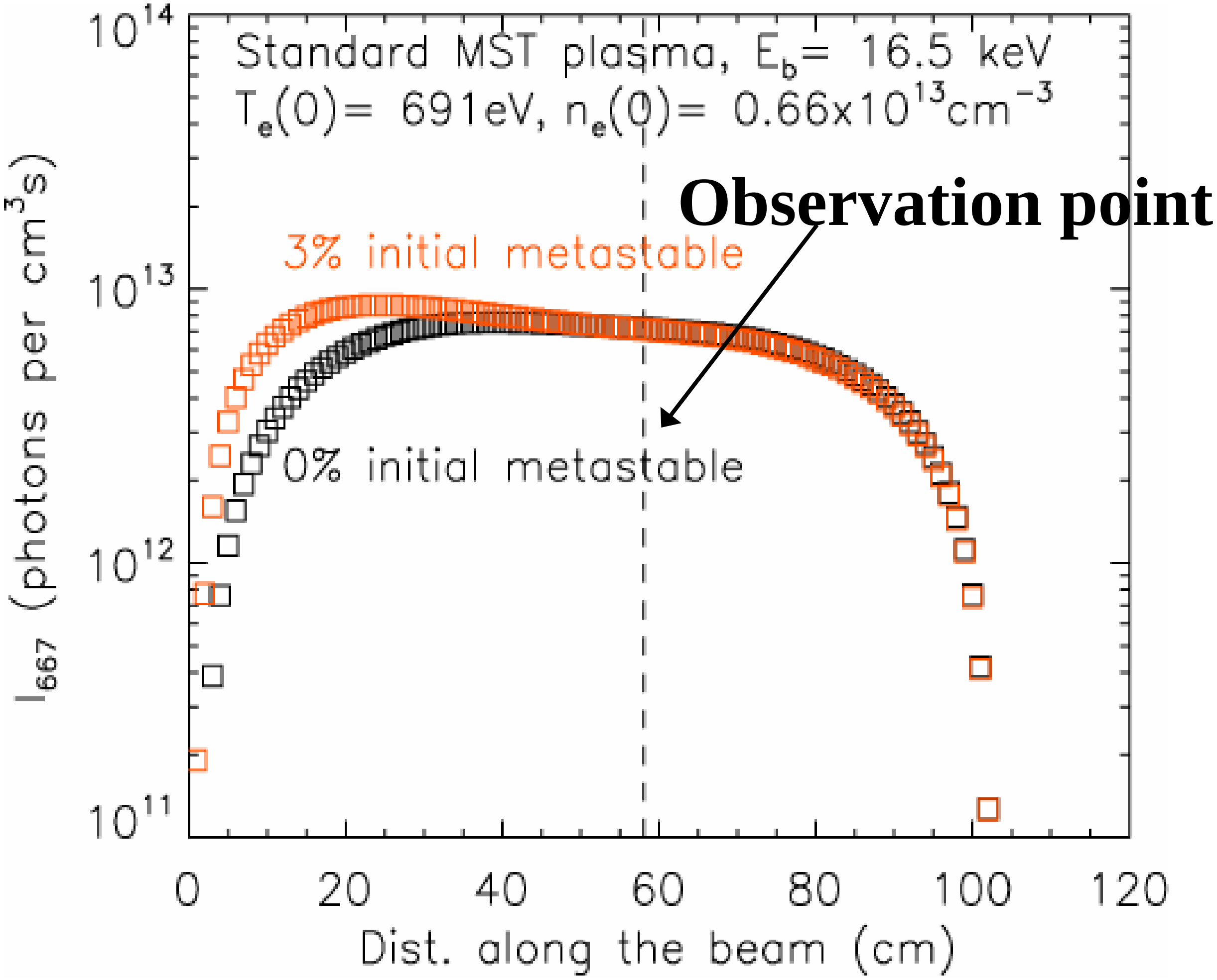


Metastable fraction drops substantially as beam passes through MST plasma.

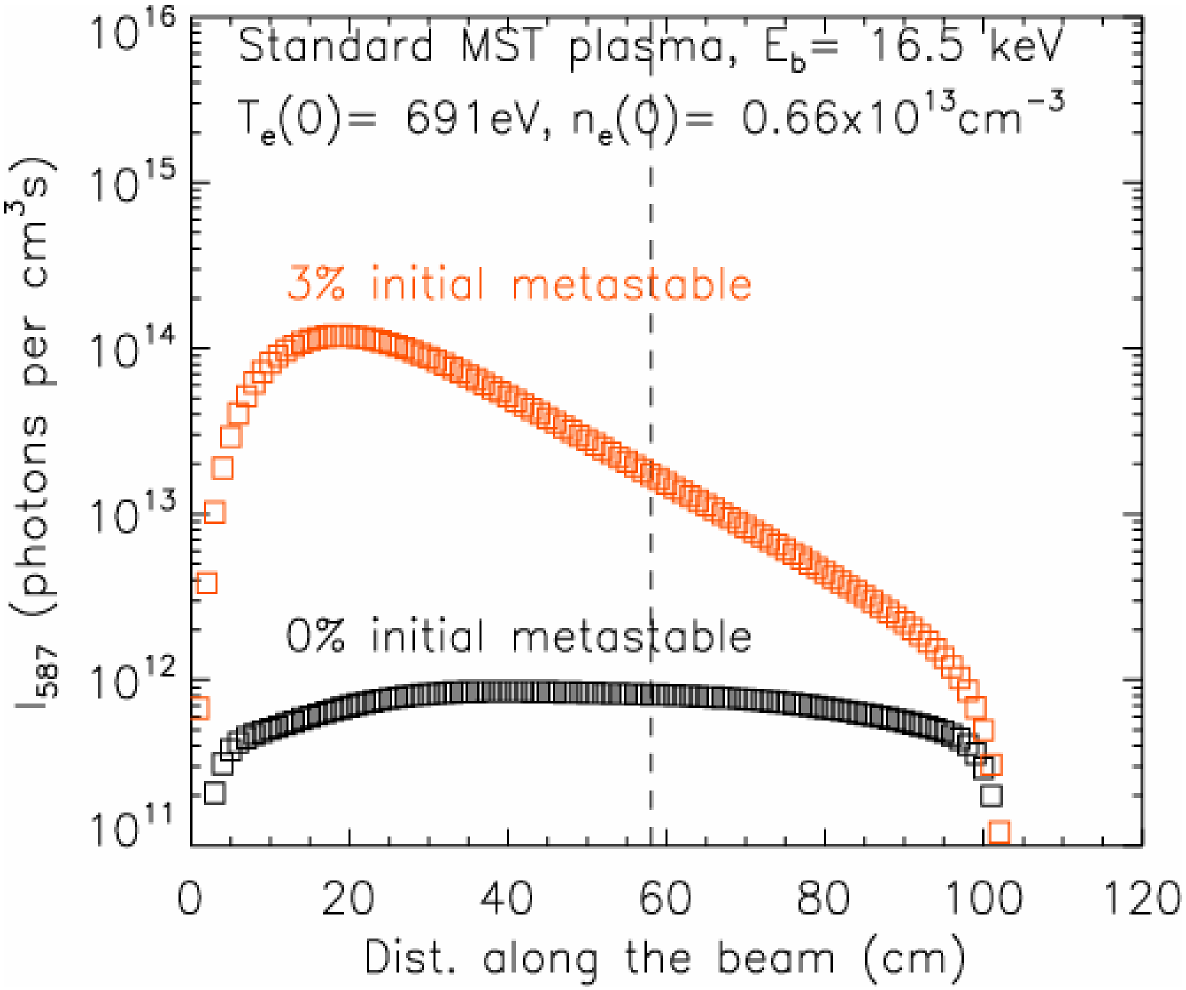
- Ground state atoms are relatively unaffected
  - ~80% pass across the whole cross section



Singlet line emission is not sensitive to the initial metastable fraction, particularly at the observation point in MST.



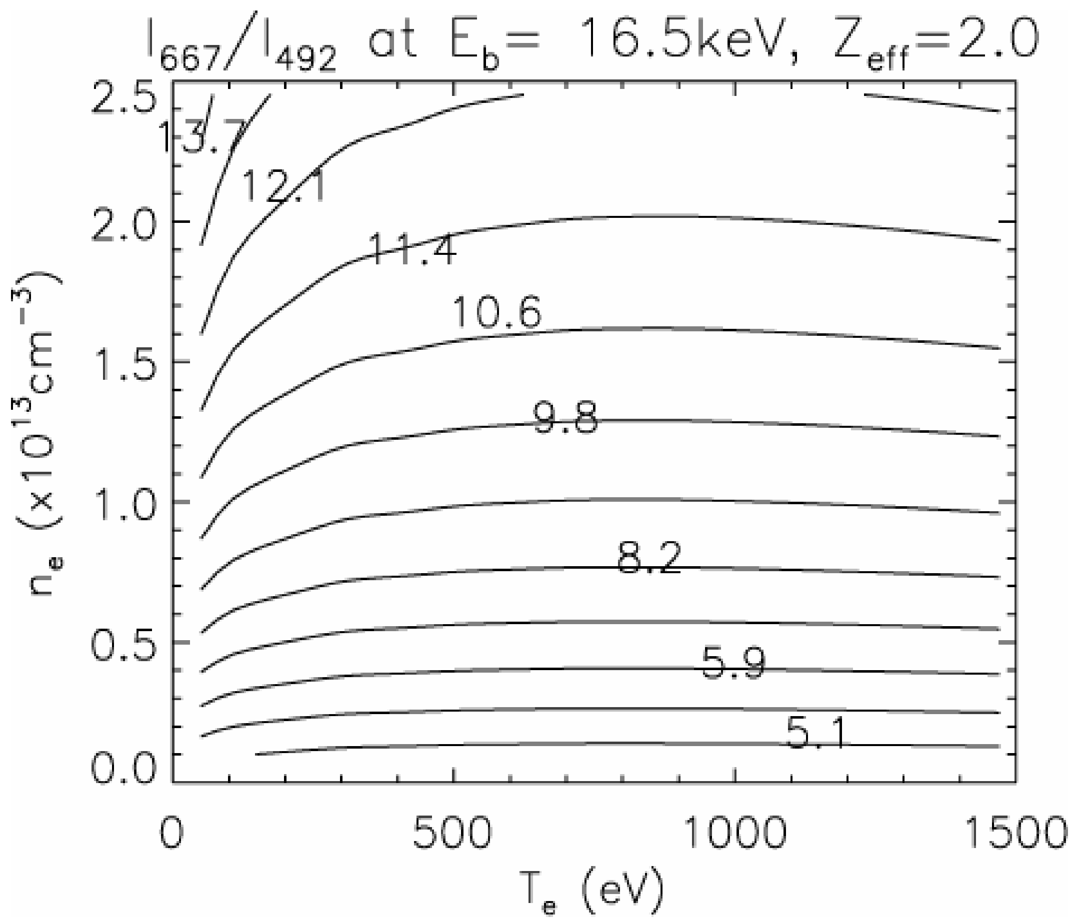
Triplet line emission is very sensitive to the initial metastable fraction.



If the initial metastable fraction is low enough (< 5%), singlet line ratios may yield measurement of local density.

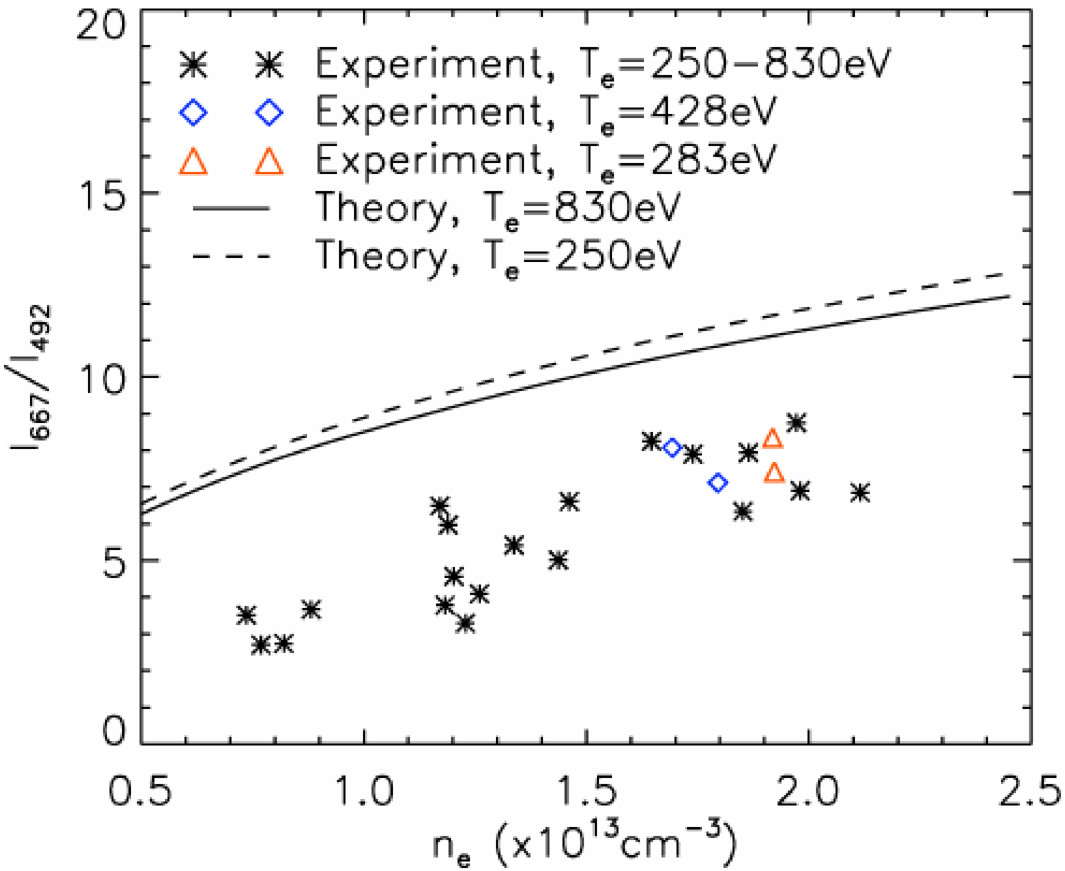
MST

- Ignore the relatively small effect on singlet emission from metastable populations



Comparison of measurement to modeling has not yielded conclusive results on MST.

- Modeling suggests that I_{667}/I_{492} should have a strong n_e dependence and a weak T_e dependence.
- Measurements reproduce the qualitative feature of positive dependence on n_e.
  – The ratio from modeling is consistently twice that from experiment.



Summary

MST

- Advanced CXRS and spectral MSE diagnostics are routinely operated on MST to measure fast plasma dynamics
  - ADAS is one of the keys to the success of spectroscopic diagnostics on MST
- Fast He BES has been tested on MST
  - He I singlet line intensities are weakly affected by metastable fractions
    - may be possible to use to derive local n_e
    - J.-W. Ahn *et al.*, Rev. Sci. Instrum. **77**, 10F114 (2006)

Diagnostic	Plasma parameters measured	Spatial and temporal resolution
CHERS	Impurity (C) T_i and v_i	2 cm, 100 kHz
Spectral MSE	$\|\mathbf{B}\| \geq 0.2$ T, ~2% precision	~8 cm, 10 kHz