Ion Heating in MST

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Outline

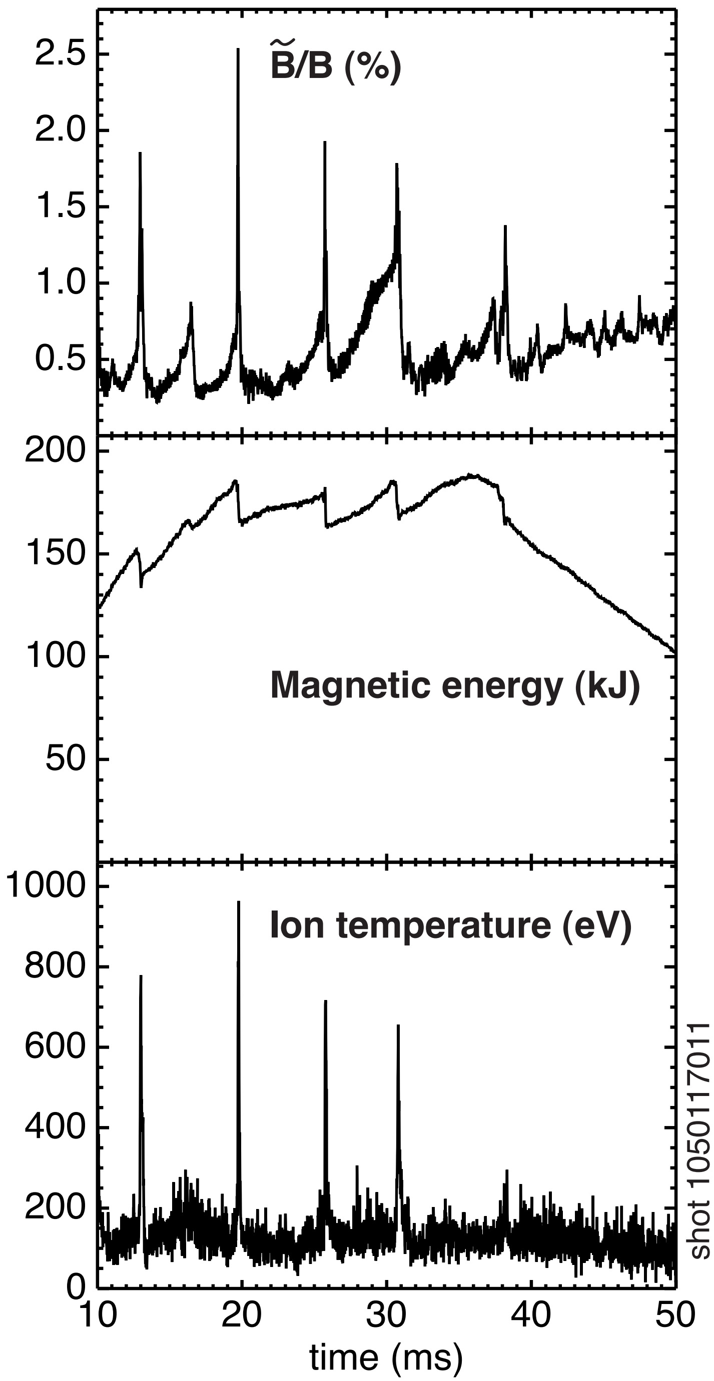
- Introduction
  - Previous observations of ion heating
  - Goals of new studies

- Diagnostic description

- Temperature measurements during a sawtooth crash
  - Radial dependence
  - Comparison between impurity and bulk ions

- Future Work & Summary

MST plasmas are characterized by fast, large transients



- Plasma has periods of both impulsive change (sawtooth crash) and of quiescence
  ==> Impulse occurs over ~ 100 μs
- Magnetic fluctuation amplitudes increase significantly during impulse
- Magnetic energy decreases by a few percent during impulse
- Strong ion heating is observed (from line-integrated T_i measurement) during impulse
  ==> Drop in magnetic energy (~ 10 kJ) consistent with power needed to explain temperature rise
  ==> Energy transfer over short time scale requires explantion

Better physics understanding would be available from *local* ion measurements

- Difficult to determine nature of heating from line-integral measurement
  ==> Effect of line-broadening from rapid velocity variations along line-of-sight
  ==> Effect of radial impurity ion distribution

- Spatially resolved temperature measurements would be more useful
  ==> Localization of heat source
  ==> Effects of ion transport

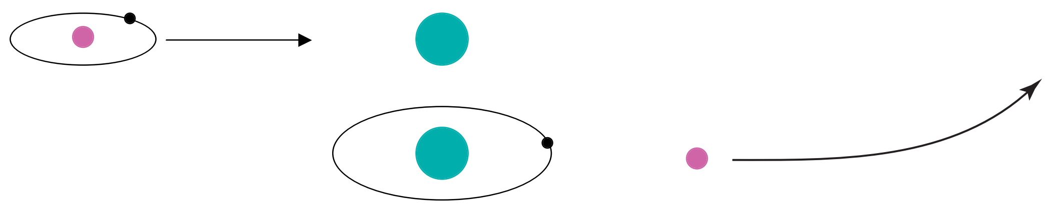
- Characterizing impulsive behavior requires fast time resolution
  ==> Need high throughput system with good signal-to-noise

- Such a system has been developed for MST, employing **Charge Exchange Recombination Spectroscopy** (**CHERS**)

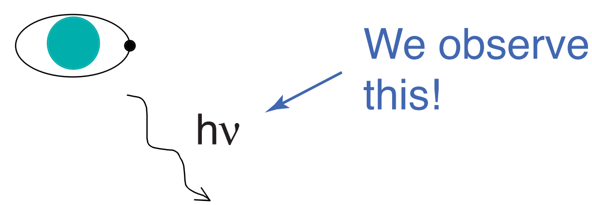
CHERS utilizes *active* spectroscopy to produce localized measurements

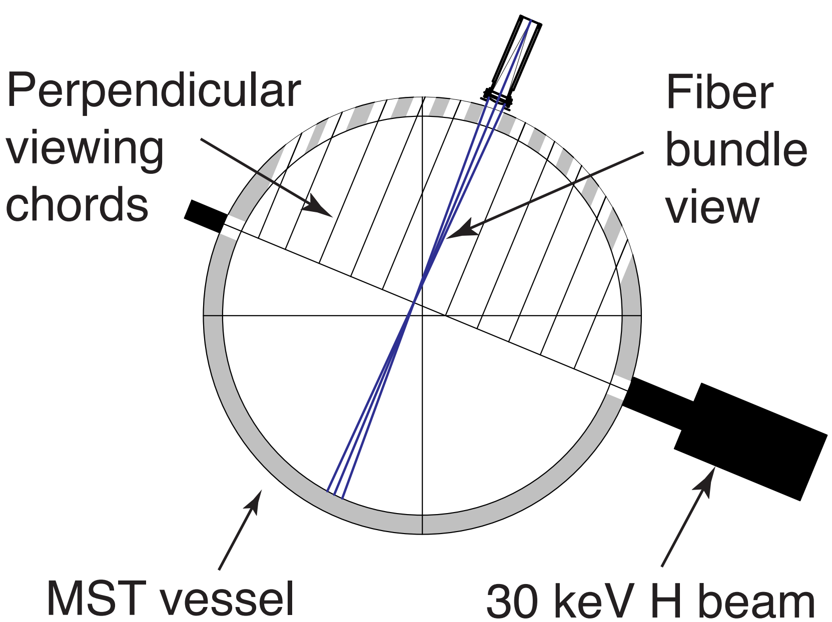
- Basic principles of CHERS:

(1) *Charge exchange*: $H^0 + A^{Z+} \longrightarrow H + A^{(Z-1)+}(n,l)$



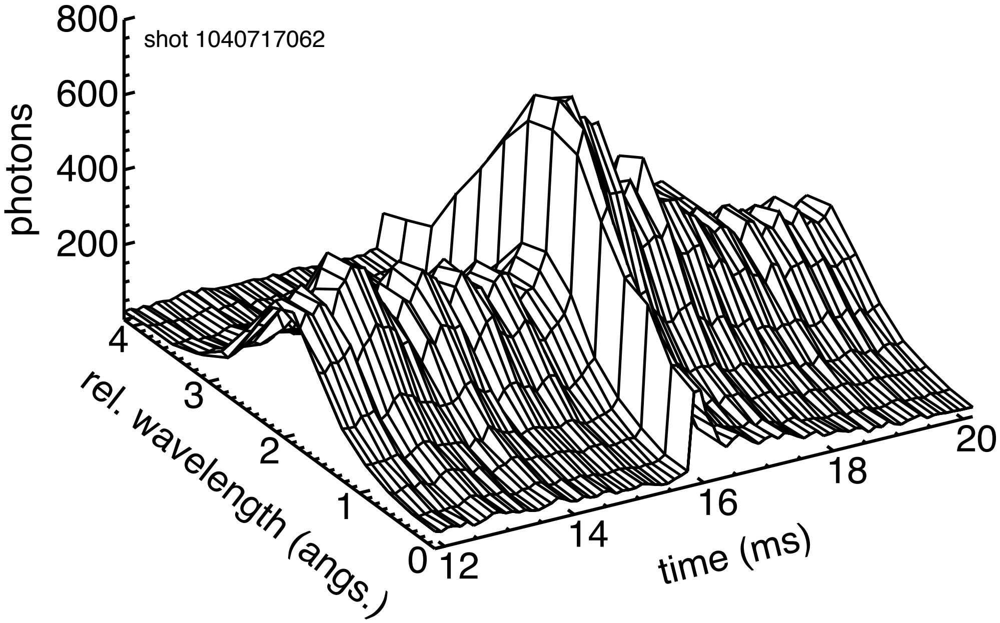
(2) *Radiative decay*: $A^{(Z-1)+}(n,l) \longrightarrow A^{(Z-1)+}(n',l') + h\nu$



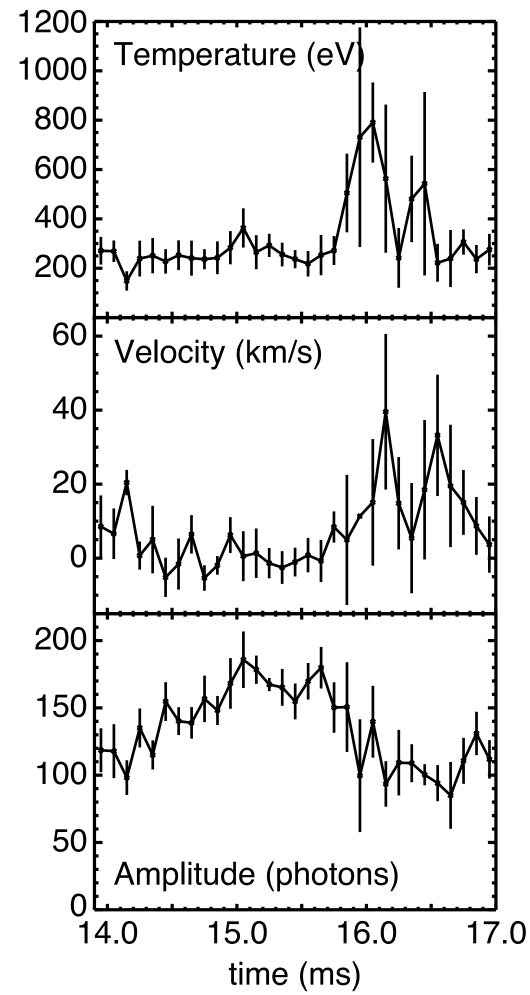


- Intersection between neutral beam and fiber views is small
  ==> emission measurements are *spatially resolved* (sample volume ~ 2 cm; plasma radius = 52 cm)

High resolution measurements of the impurity emission lineshape are used to extract T_i, v_i (and n_i)

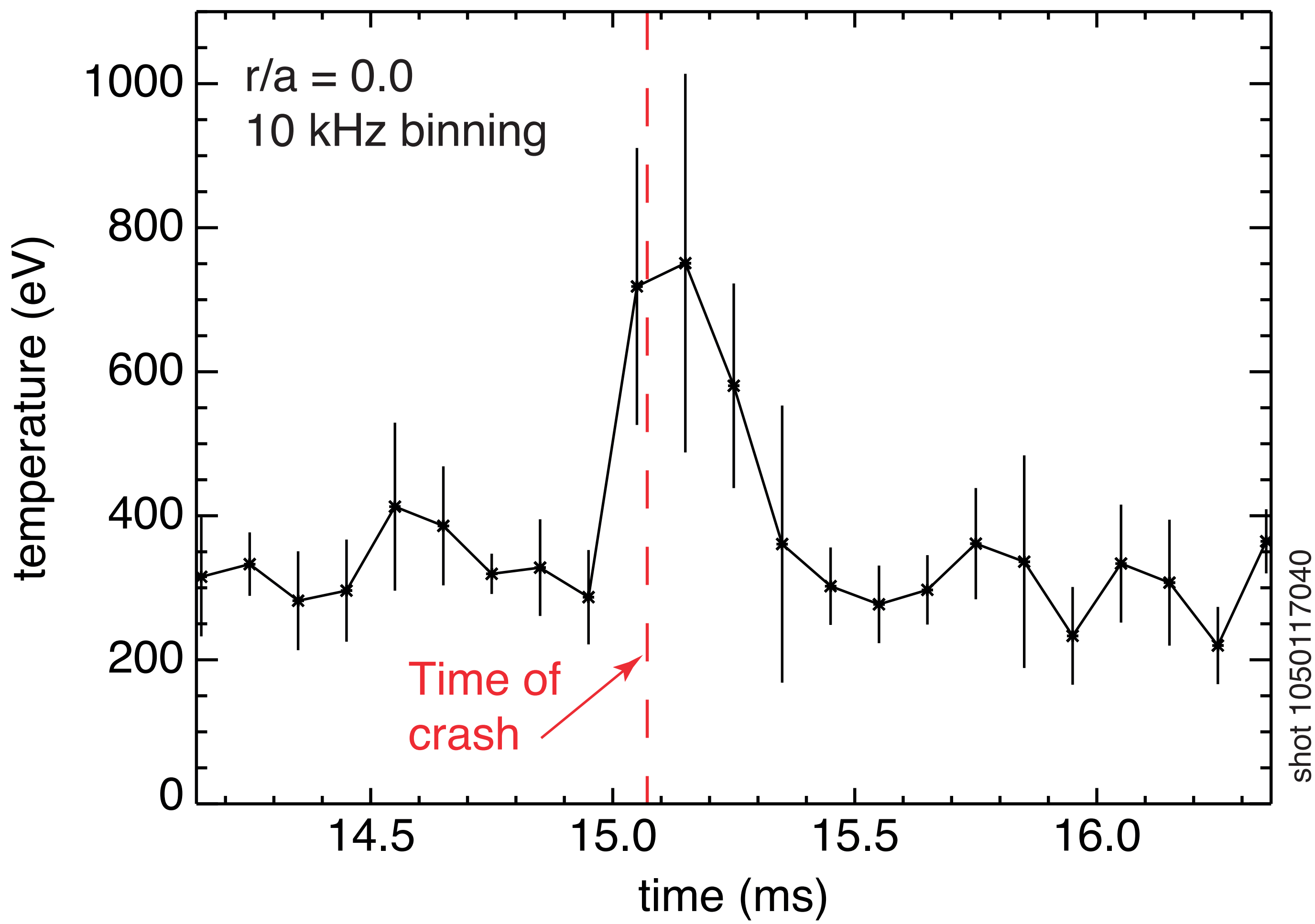


Fitting (using atomic model)



- Emission is from carbon ions
- Accurate results require binning raw data to 10-100 kHz (signal-to-noise limited)

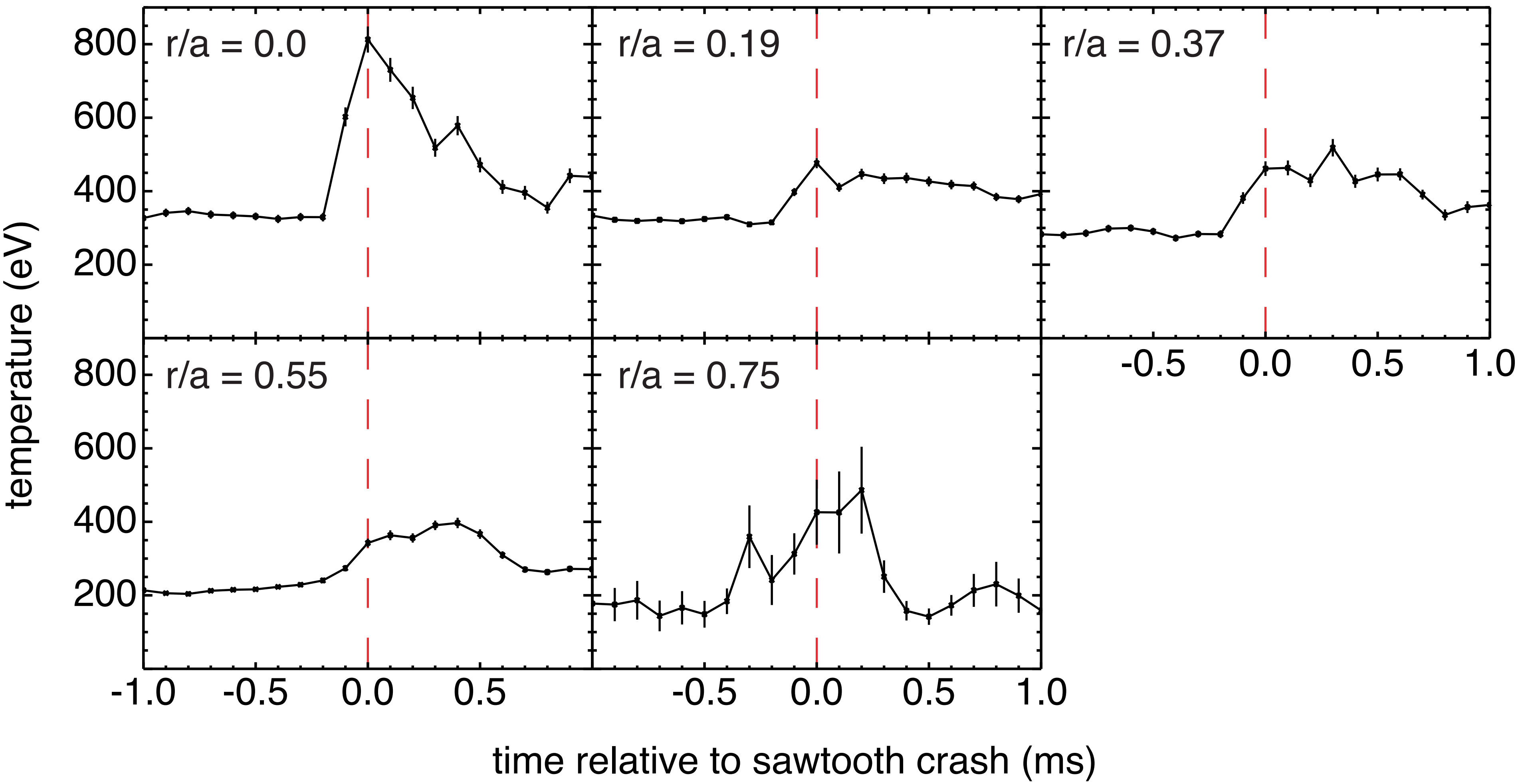
Local ion temperature is seen to rise during a sawtooth crash



- Increase in ion temperature is significant (factor of ~ 2)
- Larger uncertainty for T_i near sawtooth crash (resulting from irregularities in emission lineshape)

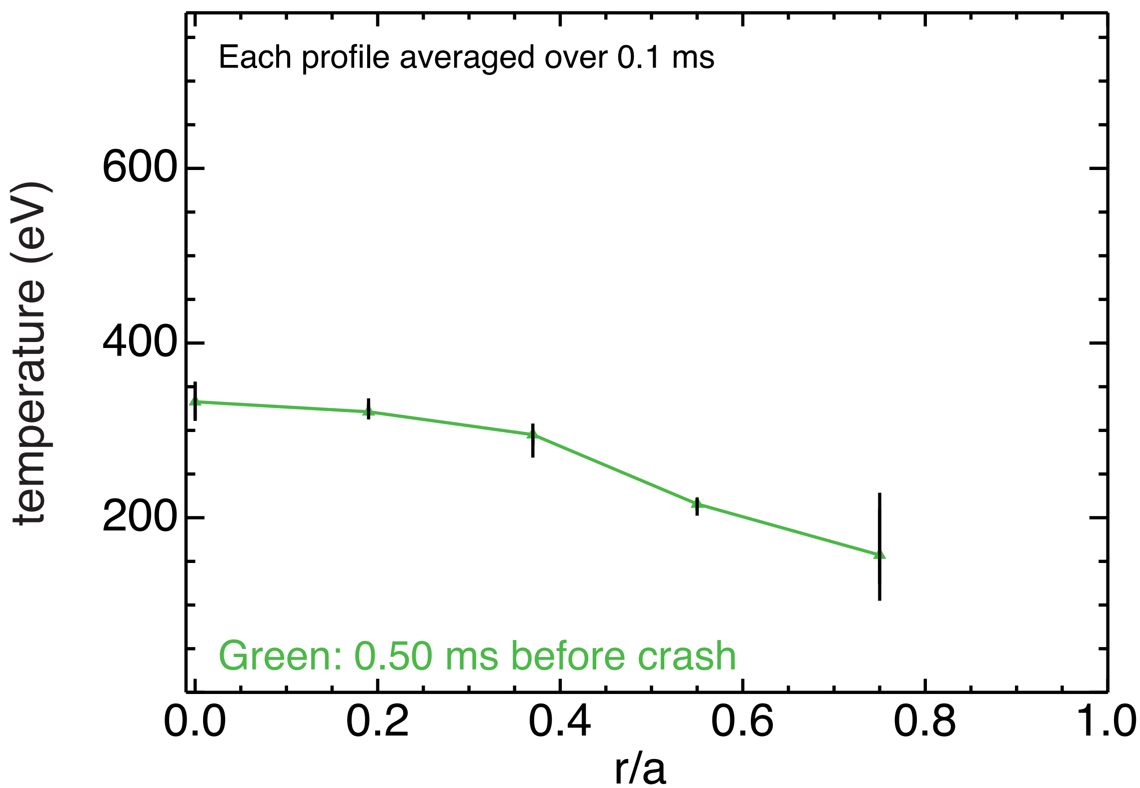
  ==> Improve measurement by averaging over many events

Measurements of T_i from multiple plasma radii indicate that ion heating is *global* during a sawtooth crash



- Temperature begins to rise at similar times for all locations
- Time scale for heating is comparable for all radii
- "Cooling" time scale longer than heating time scale, except in edge

Profile measurements obtained during a sawtooth crash suggest a broad heating source



- T_i profile is slightly peaked before crash
- Core T_i profile exhibits small variations during crash (except near r=0)
- Heating is strongest in the center, then at the edge
- Peak temperature reaches similar value for most radii (r/a > 0)
- Edge cooling is rapid; cooling rate is much slower at other radii

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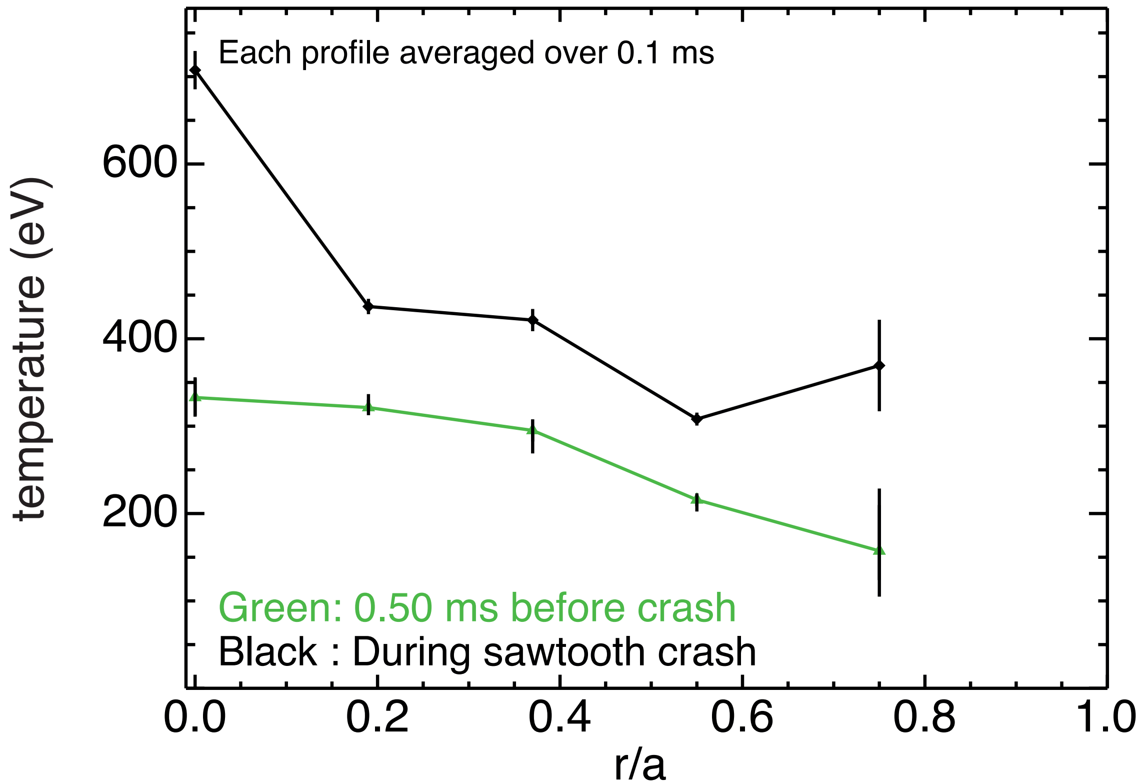

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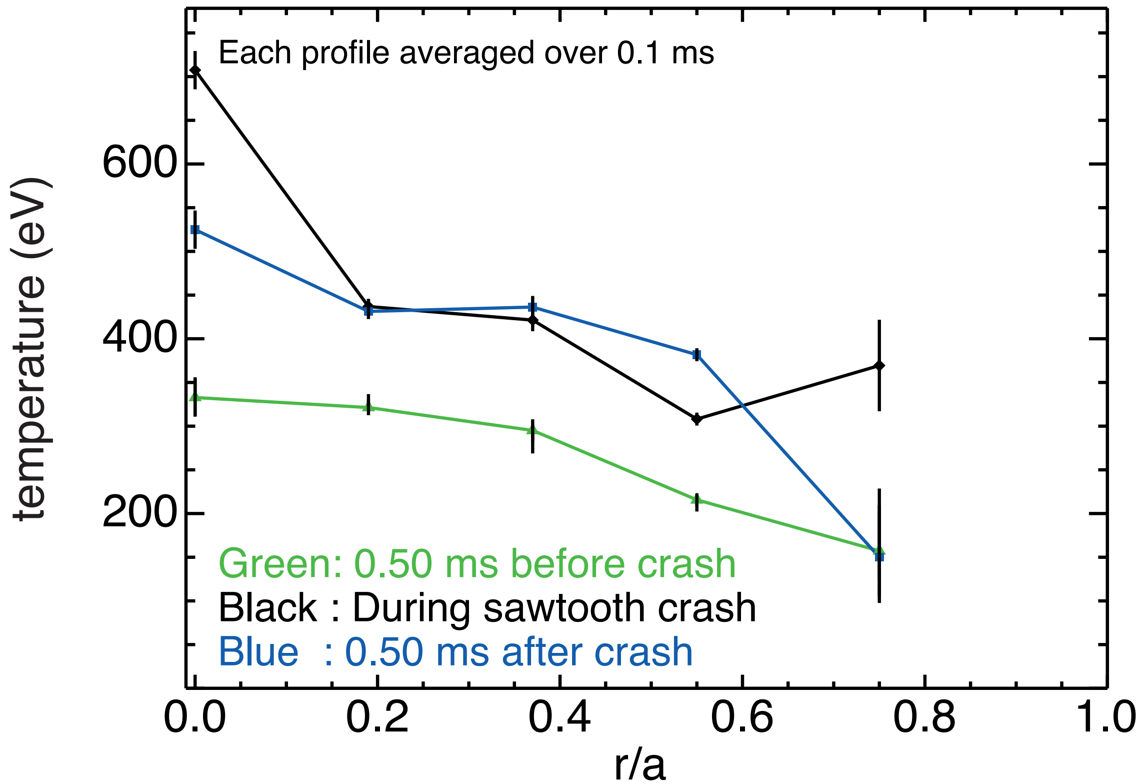

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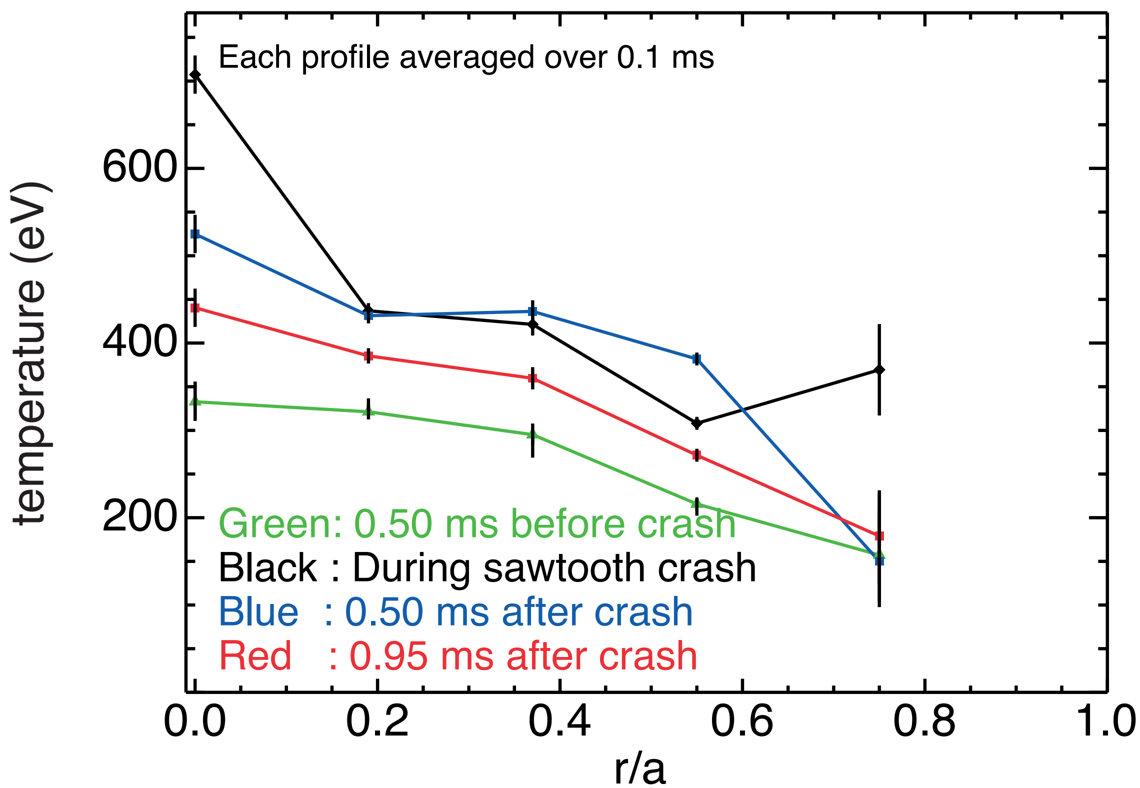

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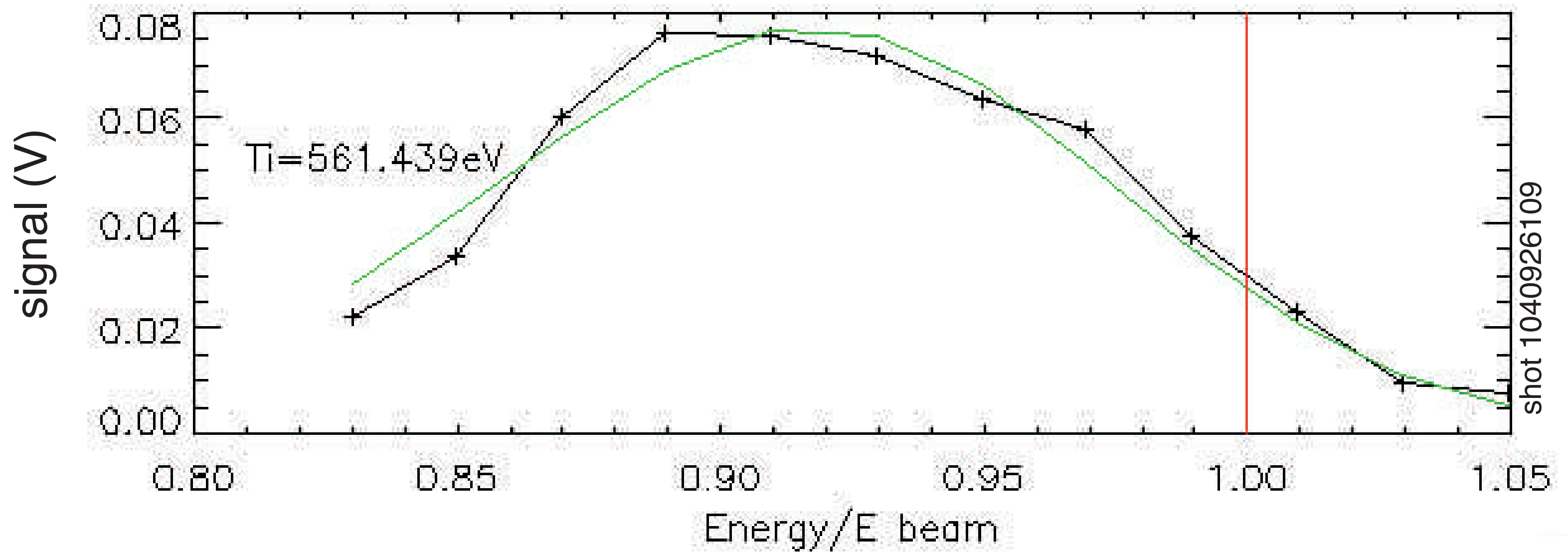
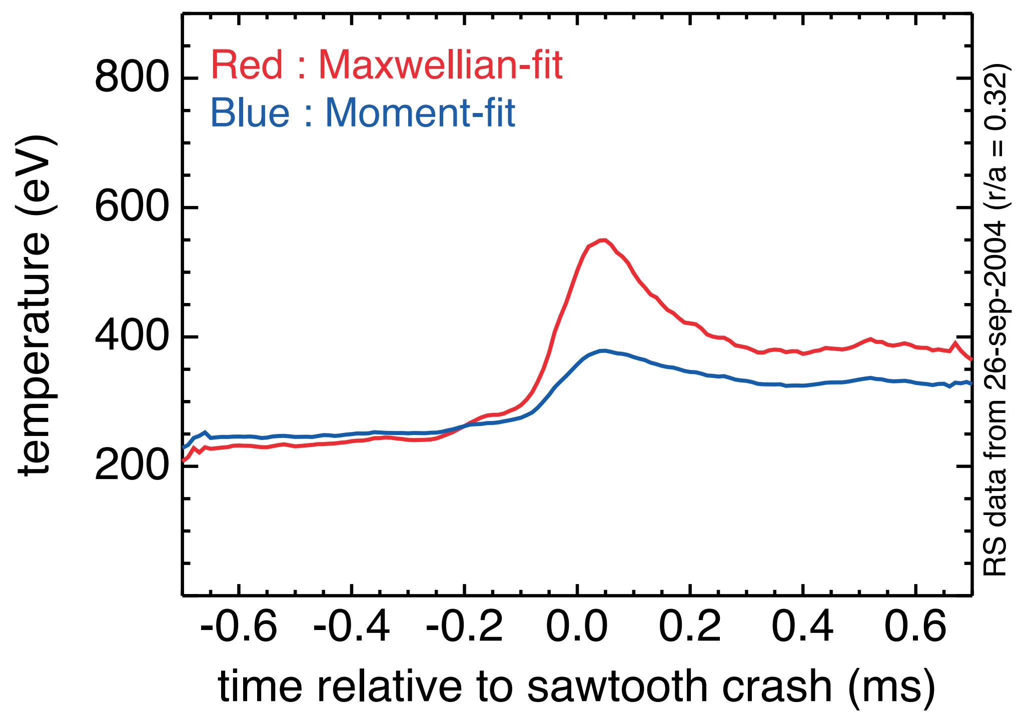
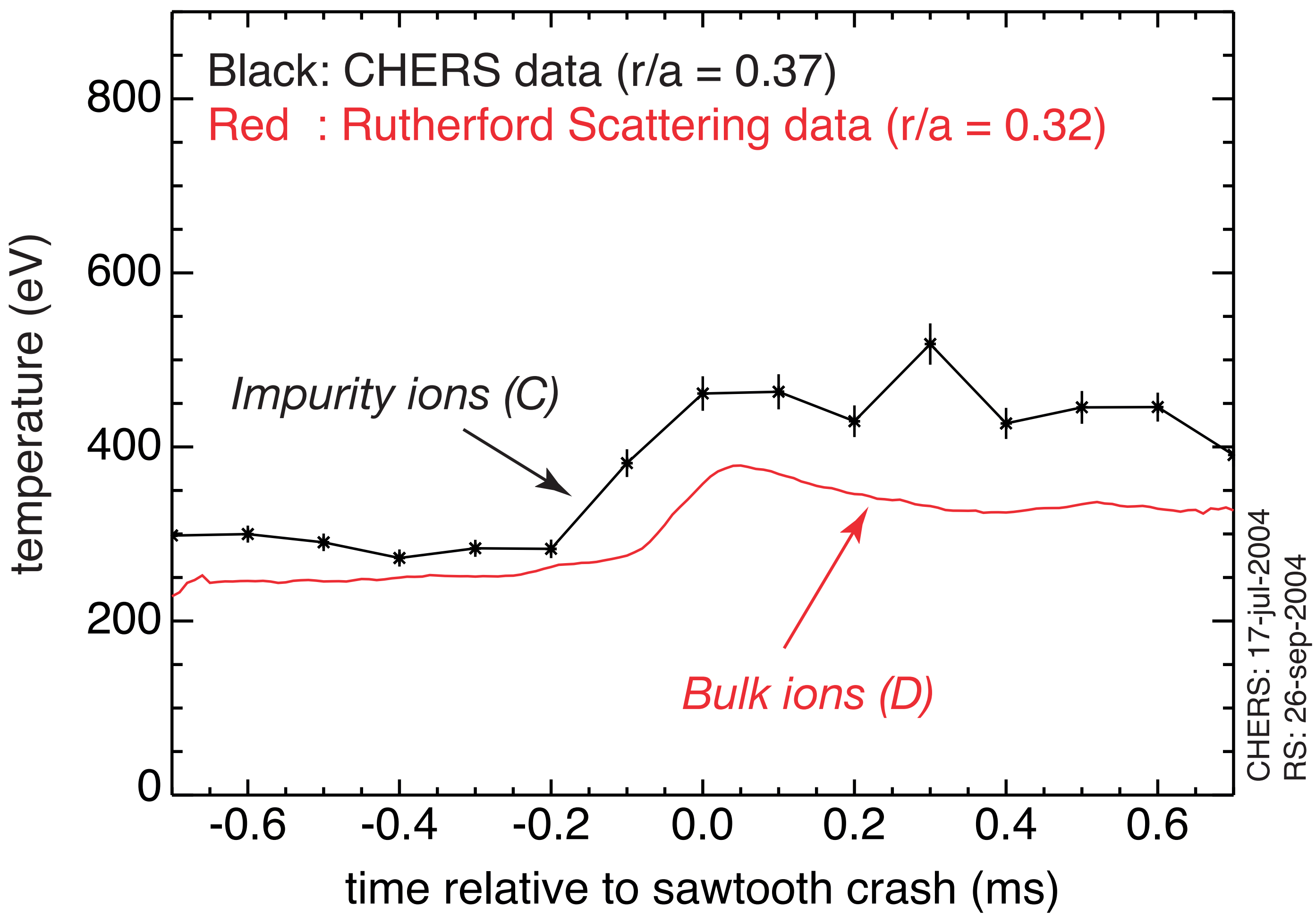
Bulk measurements suggest non-Maxwellian features in ion distribution during time of sawtooth crash



- Maxwellian provides poor description of data during crash
  ==> Not seen for impurities; may not be sensitive
- ΔT is lower when estimated from second moment



Comparison between bulk and impurity T_i suggests impurities are more strongly heated than bulk during sawtooth crash



- Measured ΔT is bigger for carbon (factor of ~ 2)
- Cooling rate appears to be similar for both species

Future Work

- Match experimental results to theoretical predictions for ion heating (to validate or eliminate), *e.g.*
  - Electric field acceleration
  - Viscous damping of fluctuations

- Add new experimental views to measure T_i anisotropy ($T_{||} / T_{\perp}$) during sawtooth crash
  ==> Important parameter for many heating theories

- Install new diagnostic beam
  - Higher beam energy: improve signal-to-noise
  - Increased pulse length: accumulate much more sawtooth crash data in a single run

- Study/model ion heating during other plasma phenomena, to increase understanding of sources/sinks and transport

  - ***m=0 bursts***:
    Non-uniform ion heating is observed

  - ***Plasmas with reduced relaxation***:
    Observations suggest anomalous heating may be small

Summary

- Ion temperature measurements with good spatial (2 cm) and temporal (0.1 ms) resolution have been made for the first time on MST

- *Local* ion heating has been observed during a sawtooth crash at multiple plasma radii
  - Heating appears to be strongest at the center, but is significant for all locations
  - Peak temperature is similar for $r/a > 0$
  - Time of peak T_i is delayed for outer radii
  - Cooling following crash is fastest in the edge

- Comparisons between bulk and impurity ion measurements indicate that impurity heating is stronger than bulk heating during crash

- Bulk measurements suggest ion distribution is non-Maxwellian during sawtooth crash

- Experimental results will be compared to various theoretical predications, to validate (or eliminate) possible heating mechanisms
  - Aided by upgrade in measurements