Ion Temperature Measurements from Rutherford Scattering on MST

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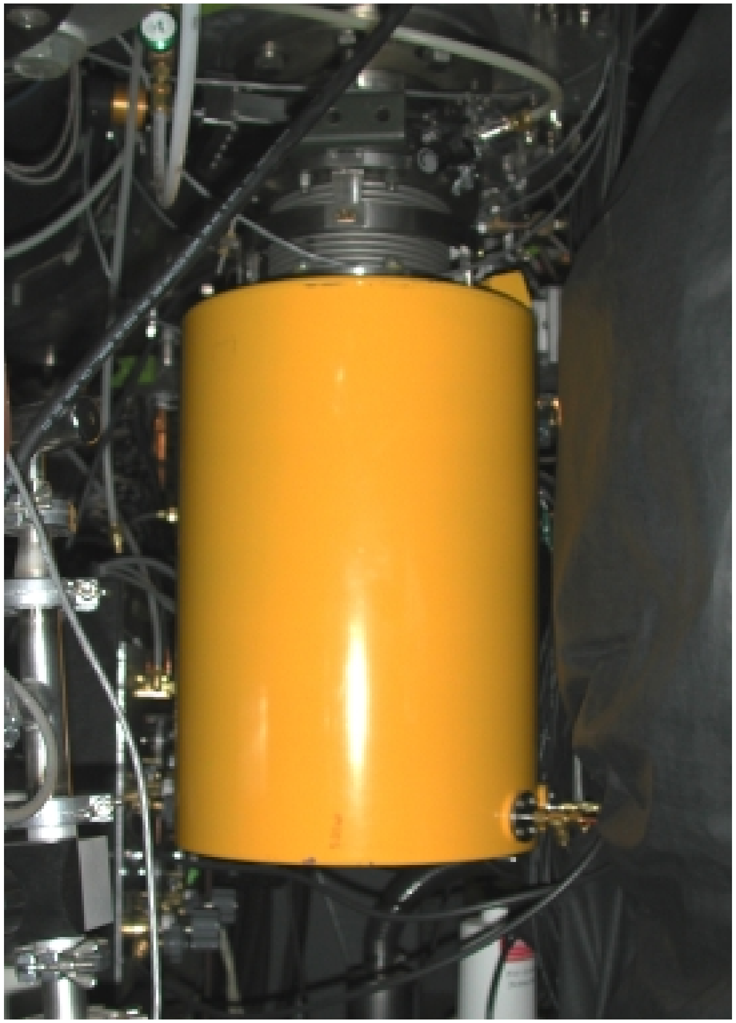
Rutherford Scattering (RS) of injected neutral beam atoms measures properties of the bulk majority ion population. In this poster are presented measurements of the central ion temperature. The ion temperature is observed to increase with plasma current and decrease with plasma density. Ion temperatures are observed to be similar in standard 200 kA deuterium discharges and 200 kA Pulsed Poloidal Current Drive discharges, even though electron temperatures are higher in the latter. An abrupt rise in ion temperature at the time of a sawtooth crash has been observed in 400 kA discharges, providing further evidence of anomalous ion heating. Comparison of ion temperatures with simultaneously measured electron and impurity temperatures will be presented, showing T_i~T_e over a wide range of conditions.

Diagnostic Neutral Beam Source



20 KeV Helium

4 A equivalent current

3 ms beam duration

Energy spread $\Delta E \sim 300$ eV

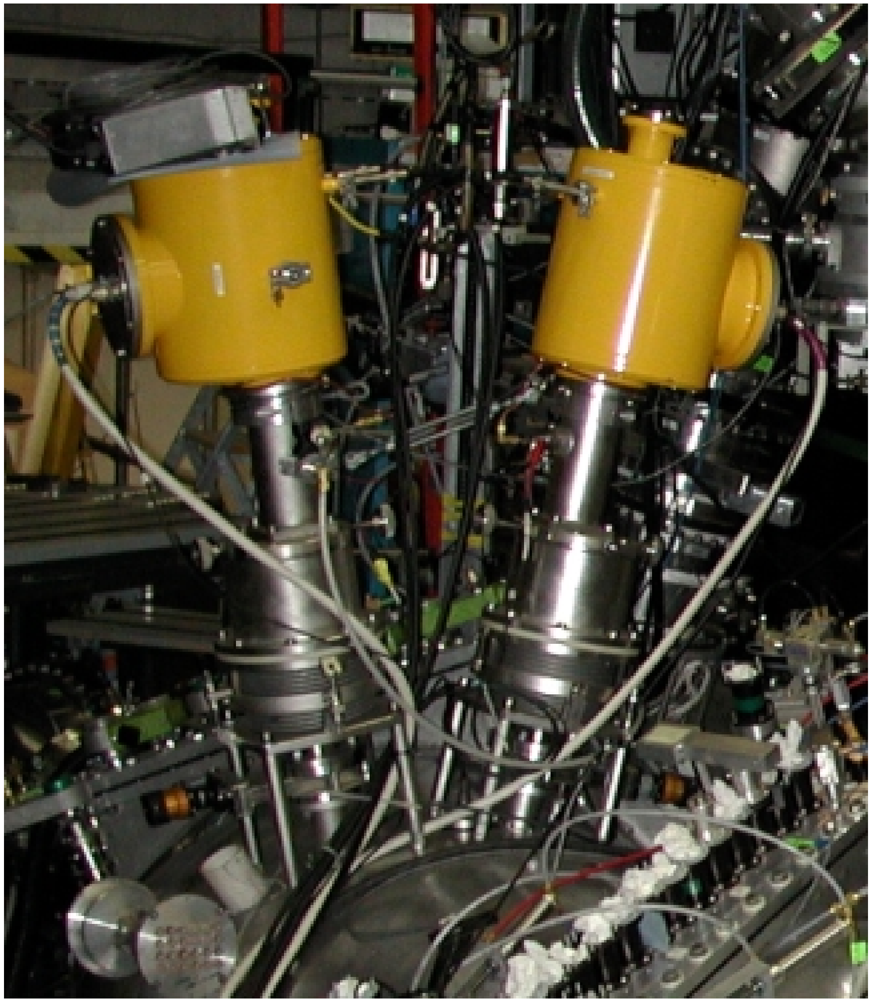
Angular spread $\Delta\theta \sim 0.03$

Built at Novosibrsk

Operated reliably on MST
since December 1999

Weight: 40 kg

Rutherford Analyzers



2 independent 12-channel electrostatic neutral particle analyzers

Each analyzer axis can be tilted (in toroidal and poloidal planes) or translated (in poloidal plane)

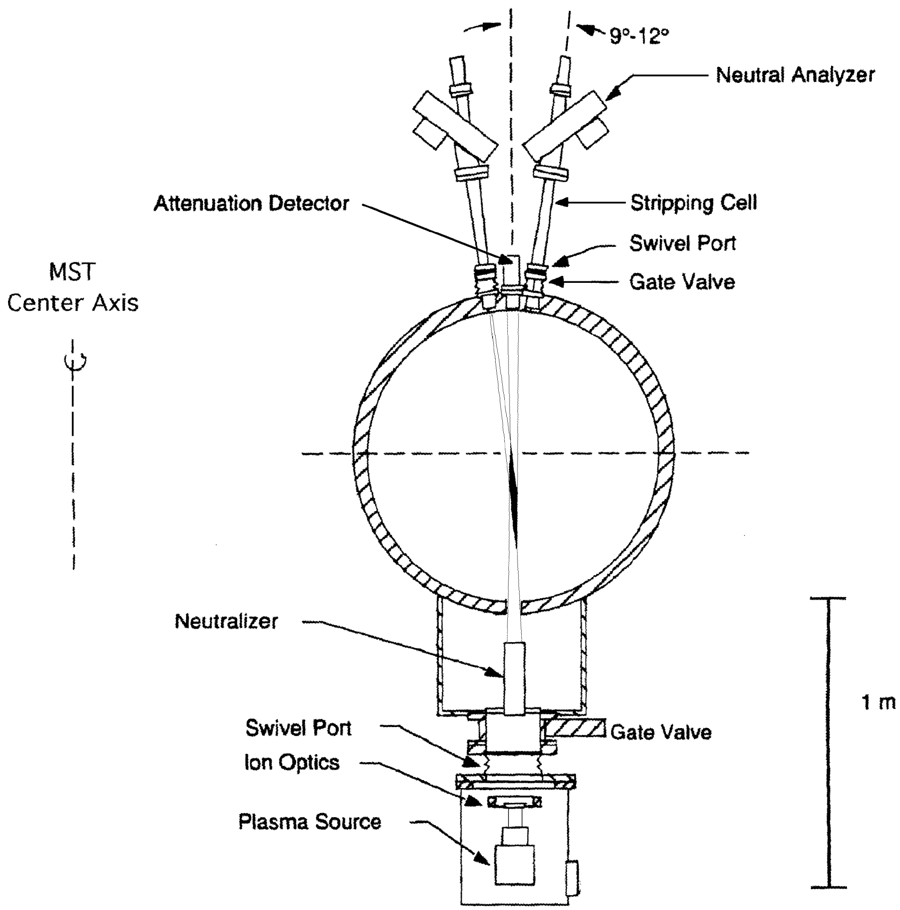
Transimpedance = 10^9 V/A

Built at Novosibrsk

Operated reliably on MST since December 1999

Weight: 60 kg

Rutherford Scattering on MST

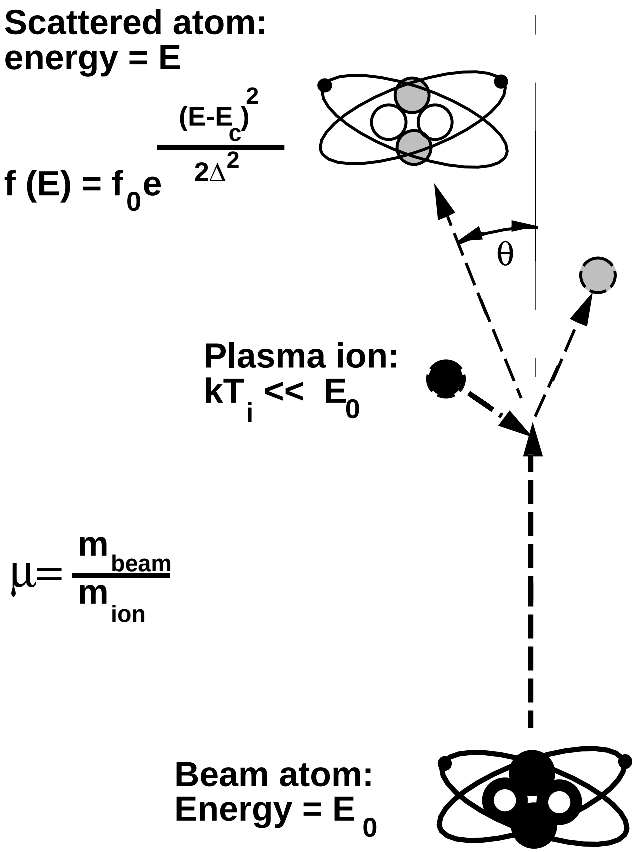


Rutherford scattering diagnostic on MST.

- Small-angle scattering of beam atoms by plasma ions
- Scattering volume ~ 30 cm in minor radius

Principle of Rutherford Scattering

T_i found from width of energy spectrum of scattered atoms



Assume ideal beam (monoenergetic, zero angular dispersion)

For scattering angle q, energy spectrum of scattered atoms is approximately Gaussian:

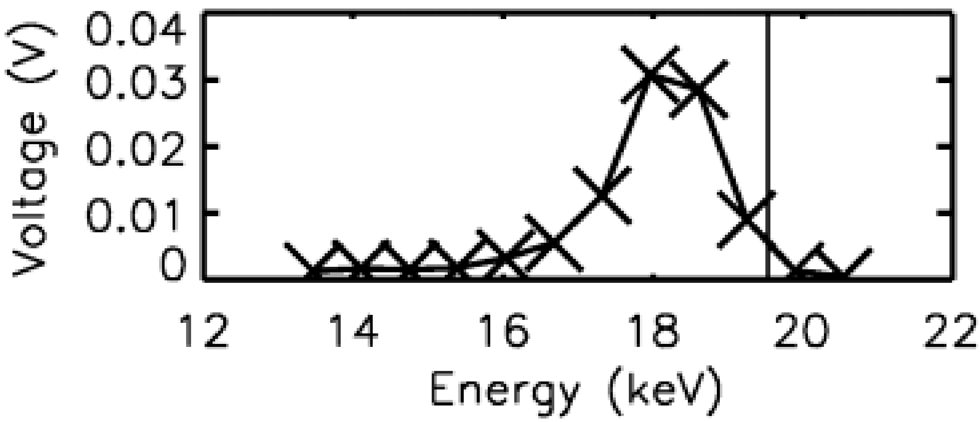
Variance Δ :

$$\Delta = \sqrt{2\mu E_o T_i \theta^2}$$

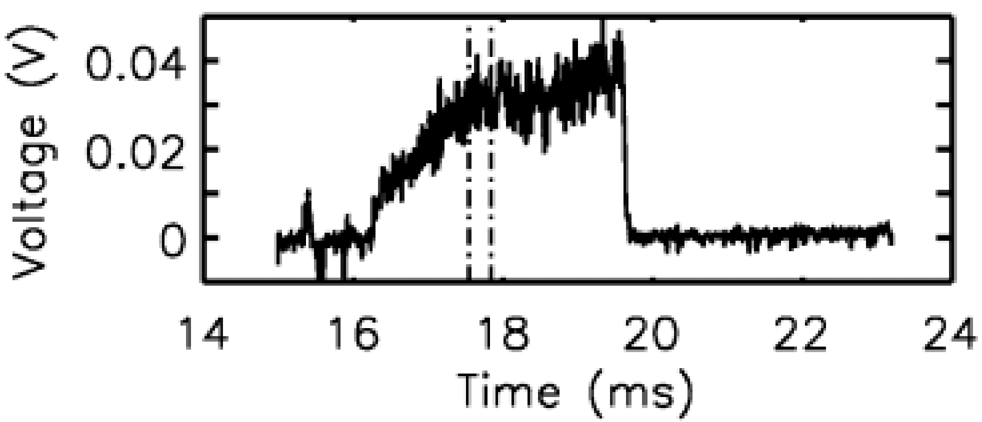
Centroid E_c :

$$E_c = E_0(1 - \mu\theta^2)$$

Rutherford Scattering Raw Data



Typical spectrum:
- vertical line is beam energy
- averaging time 300 μs



Signal from channel 8
(averaging done over interval between dot-dash lines)

Rutherford Scattering: History

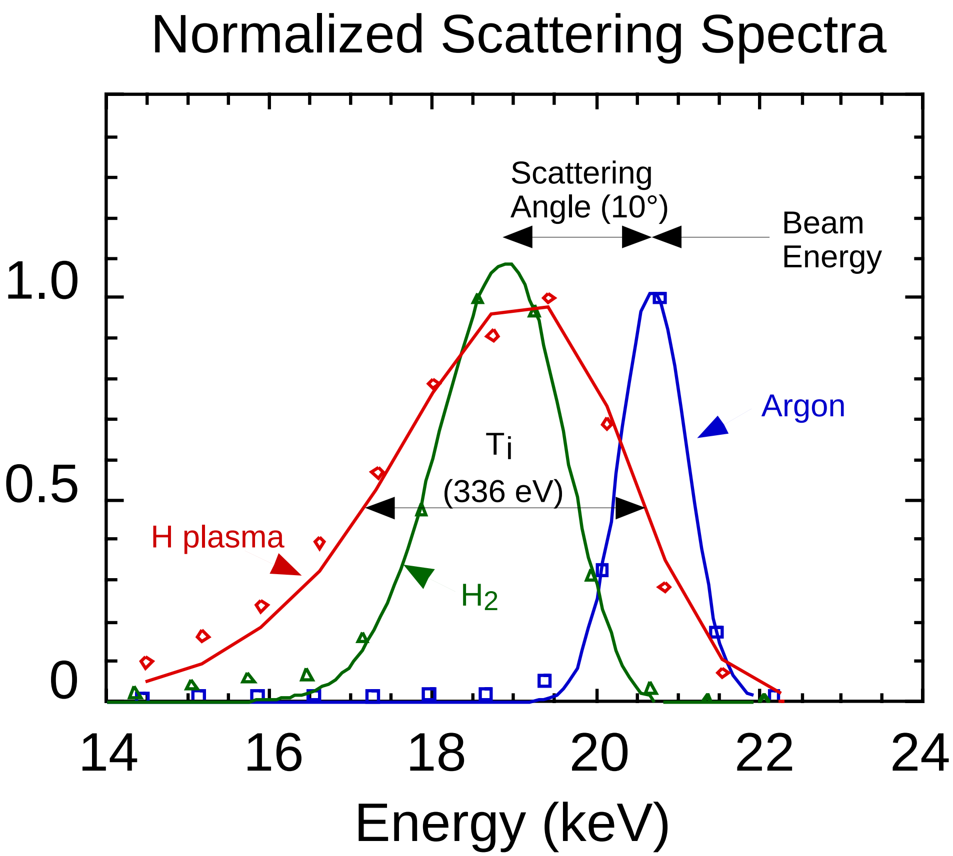
First described: E. Rutherford, Philos. Mag. **21**, 669 (1911).

First proposed as a T_i diagnostic:
Abramov et al, Sov. Phys. Tech. Phys. **16,** 1520 (1972).

Uses by fusion community:

• T-4	Aleksandrov, et al., JETP Letters **29**, 1 (1979).
• JT-60	Tobita, et al., Nucl. Fus. **28**, 1719 (1988).
•TEXTOR	van Blokland et al., RSI **63**, 3359 (1992).
•GDT (mirror)	Anikeev et al., Phys. Plas. **4**, 347 (1997).
•MST (RFP)	This poster!

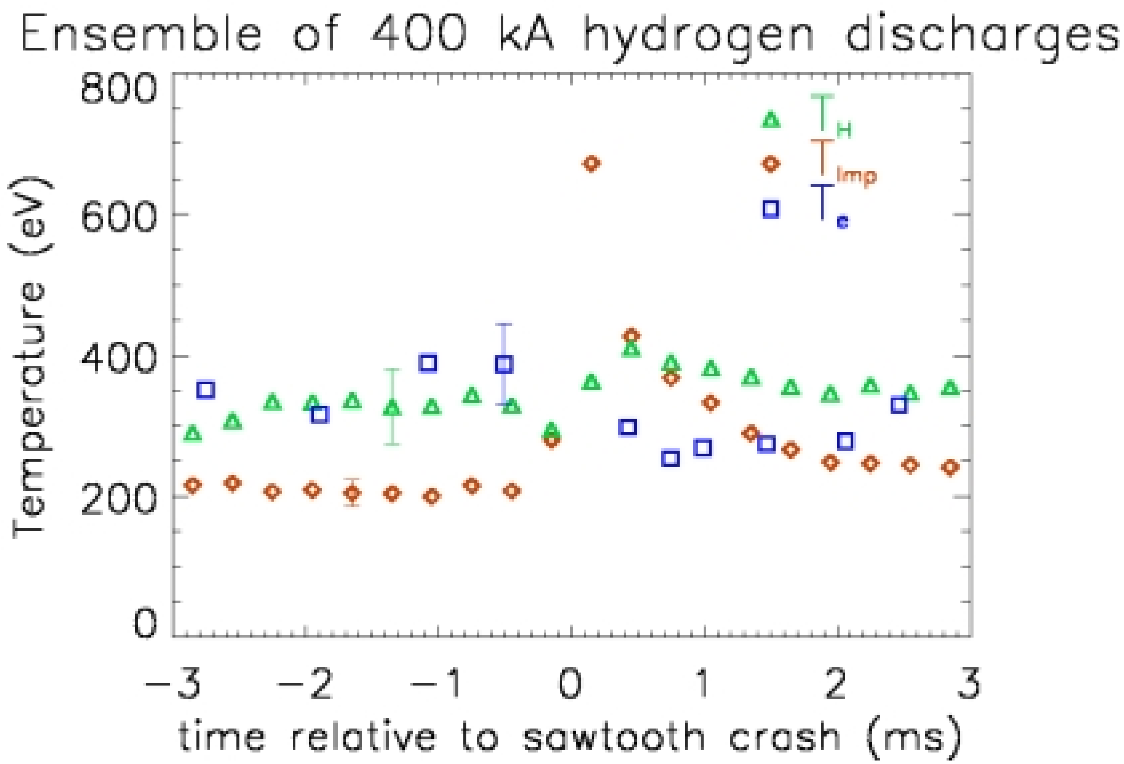
Calibration



- Argon Peak
  - Position - beam energy
- Hydrogen Peak
  - Position - scattering angle
  - Width - instrumental width
- Plasma Peak
  - Width - ion temperature

For more information on RS calibration and analysis, see Reardon et al., RSI **72** 1 (2001)

Hydrogen Heating at Sawtooth Crash

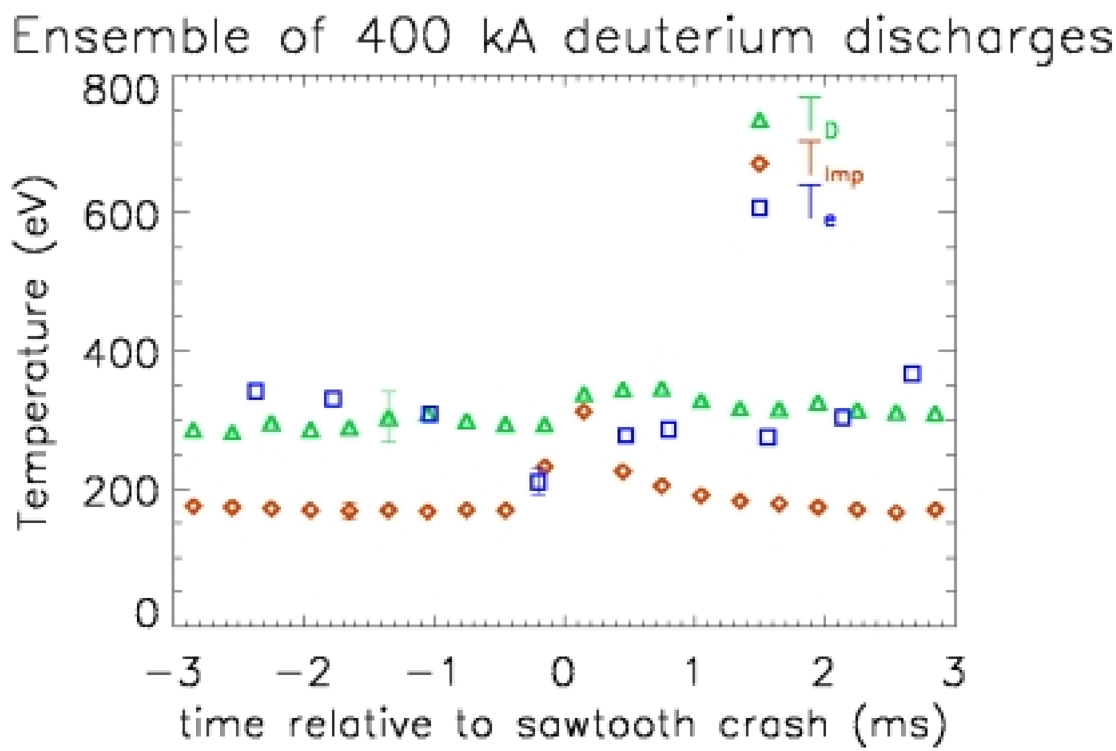


Ensemble parameters:

- 50 shots
- low density ($n_e \sim 0.8 \times 10^{13}$ cm^{-3})
- deeply reversed (f ~ –0.35)

T_H measured by RS,
T_{Imp} from C^V line emission,
T_e from Thomson scattering

Deuterium Heating at Sawtooth Crash



Ensemble parameters:

- 50 shots
- medium density (n_e ~ 1.2 x 10^{13} cm^{-3})
- deeply reversed (f ~ –0.35)

T_D measured by RS,
T_{Imp} from C^V line emission,
T_e from Thomson scattering

Ion Heating at Sawtooth Crash

A sudden anomalous increase in T_I at the time of the sawtooth crash has been well documented on MST using

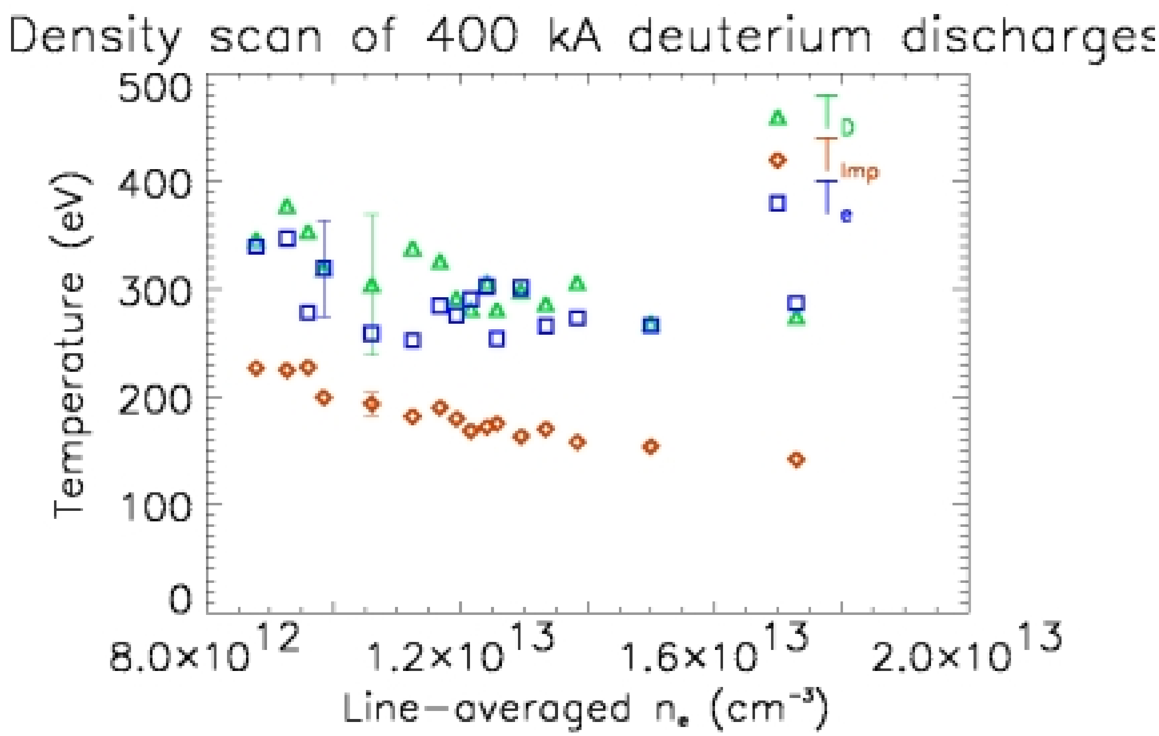
- •Passive Charge Exchange — Scime et al., Phys. Fluids B. **4** (12), 4062 (1992)
- •Impurity line radiation — Den Hartog and Fonck, RSI **65** (10), 3238 (1994)

The RS measurement demonstrates that the bulk majority ion species also partakes of this heating.

For a contemporary theoretical analysis of this anomalous heating, see Gatto and Terry (UW Plasma Physics report DOE/ER/53291-327, soon to be available at http://sprott.physics.wisc.edu/theory/home.htm).

Has anyone looked for this effect in a tokamak?

High-current Density Scan in D



Each data point represents the average of 5 shots (all shots f ~ –0.35).

Notes on the Diagnostics

Rutherford Scattering

- Time resolution ~300 μs, limited by plasma electrical noise
- Spatial resolution +/- 15 cm (centered at r/a=0.3)
- Signal increases with density and decreases with temperature

Thomson Scattering

- Time resolution 100 ns, limited by counting statistics
- Spatial resolution +/- 4 cm (centered at r/a =0.0)
- Signal increases with density and decreases with temperature

C^{V} Line Emission (Impurity Dynamics Spectrometer)

- Time resolution ~10 μs, limited by digitization
- emitting region can be far from the core and move during the shot
- T_{IMP} calculated from average of anti-parallel tangential views

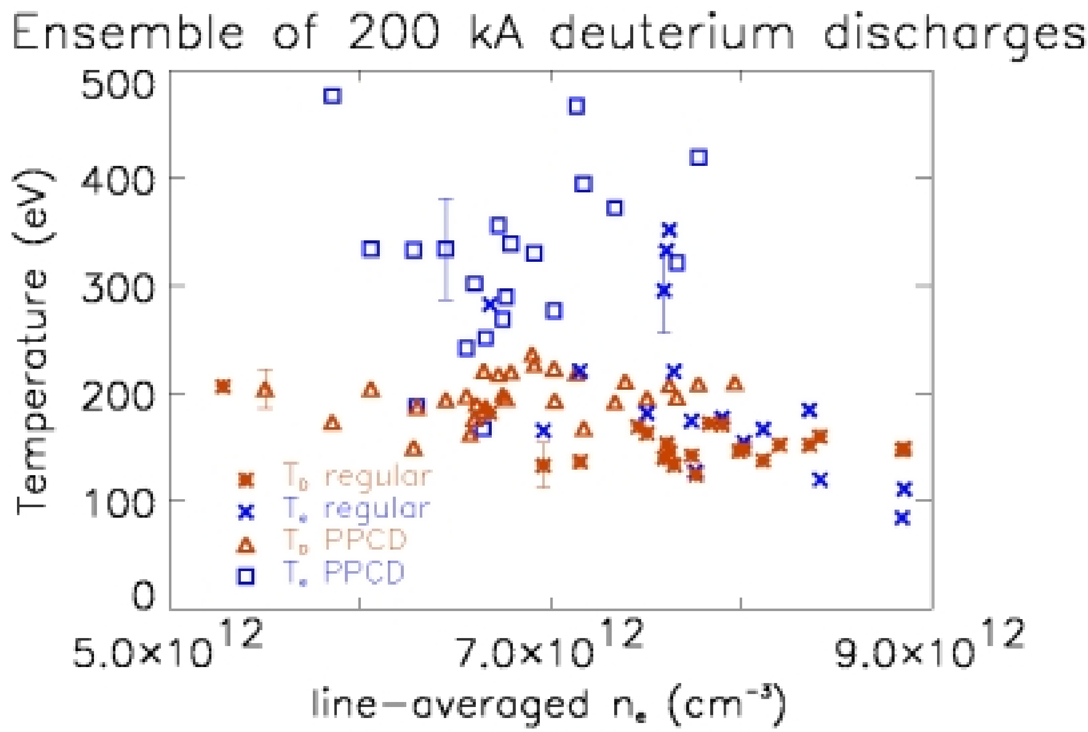
Ion Heating at Sawtooth Crash: scaling

We expect the anomalous ion heating to increase with:

- deeper reversal (more negative f)
- decreasing density
- decreasing ion mass
- plasma current

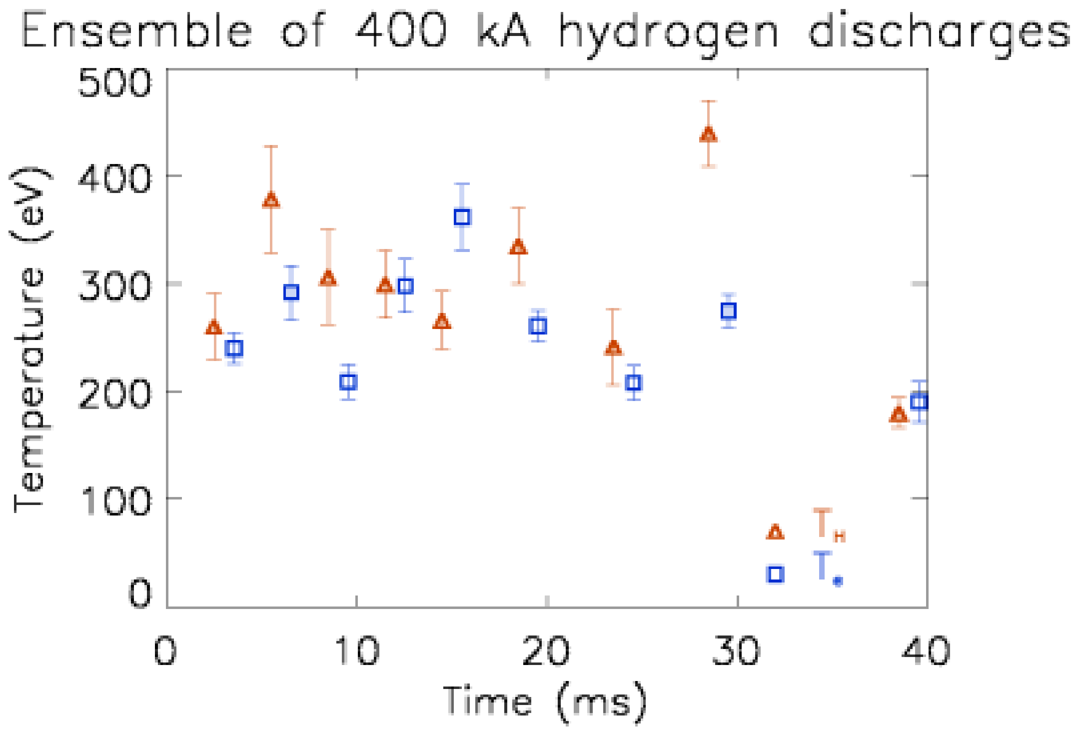
More experiments planned for after APS...

$T_{D,}$ T_e in Standard/PPCD Discharges



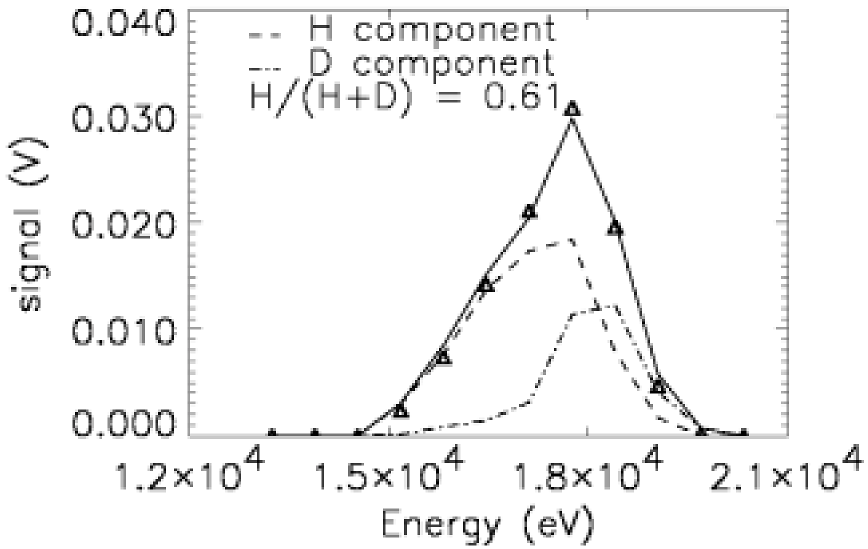
Deuterons are the same temperature in PPCD and regular discharges.
Electrons are hotter in PPCD discharges than in regular discharges.

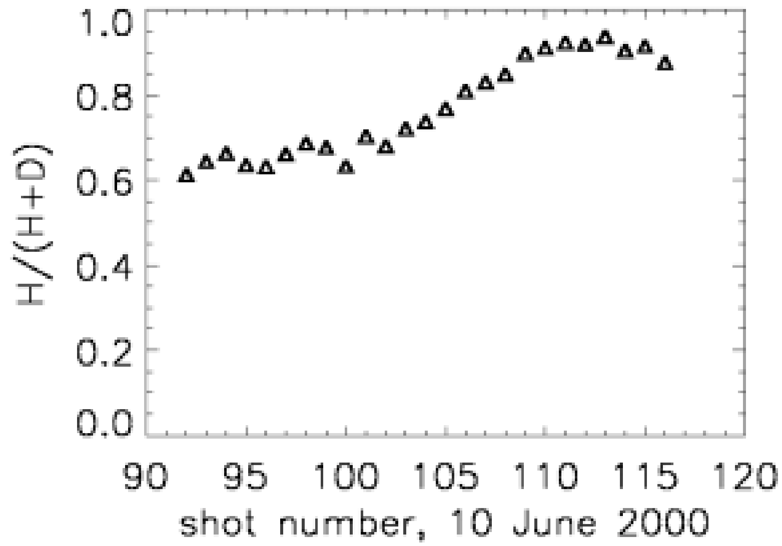
Temperature Histories: $T_{H,}$ T_e



10 shots per data point.
Current flattop lasts from 10 ms to 35 ms.

RS can measure H-to-D ratio





On 10 June 2000, deuterium discharges were run in the morning, and hydrogen discharges in the afternoon. The left-hand plot shows the RS spectrum from the first afternoon discharge (triangles). A two-parameter fit (solid line) gives the H and D concentrations (T_H and T_D are both assumed to be 200 eV). The right-hand plot shows the evolution of the fit H-to-D ratio during the afternoon.

Conclusions and future work

Conclusions:

- $T_I \sim T_e$ in a wide range of conditions
- Anomalous ion heating observed at the sawtooth crash
- PPCD observed to heat electrons but not ions

Future Work:

- Use T_i and T_e (from Thomson Scattering) as constraints on simple transport model.
- Upgrade analysis routine to include estimation of ion poloidal flow velocity (ie use both analyzers).
- Modify analyzers to improve signal-to-noise ratio.

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