# First Thomson Scattering Results on HSX

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## 1. Abstract

Based upon the GA divertor TS system design, the HSX TS system consists of several interdependent subsystems; YAG laser, beam transportation, collection optics, fiber optics, polychromators, and data acquisition. It is capable of providing a 10-point radial profile. The central channel is now operational and the rest of the channels will soon be implemented. HSX is currently using 28GHz ECRH at the second harmonic x-mode for plasma production and heating. It is found that the central electron temperature rises linearly with heating power from 30 KW to 100 KW at a fixed density of $1.5\times10^{12}cm^{-3}$; in the QHS mode from 300eV to 700eV, and in the Mirror mode from 200eV to 500eV. At 40KW heating power, the electron temperature decreases with increasing plasma density, consistent with the diamagnetic measurement of the stored energy. The operation of the system and the detailed results of density scan and power scan for both QHS and Mirror modes will be presented.

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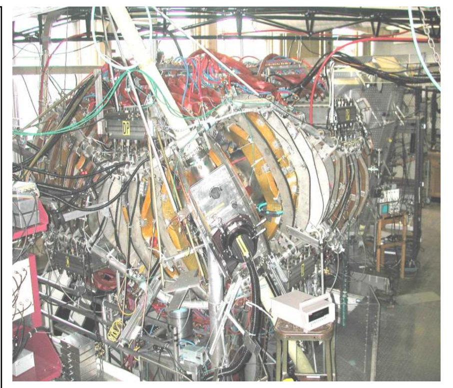
## 2.The HSX Device

| | |
|---|---|
| Major Radius | 1.2 m |
| Average Plasma Minor Radius | 0.15 m |
| Plasma Volume | ~.44 $m^3$ |
| Rotational Transform | |
| Axis | 1.05 |
| Edge | 1.12 |
| Number of Coils/period 12 | |
| Magnetic Field Strength (max) | 1.25 T |
| Magnet Pulse Length (full field) | 0.2 s |
| Auxiliary Coils (total) | 48 |



| | |
|---|---|
| Heating source | 28GHz |
| | 200 kW |
| Power Density | .45 W/cm3 |
| Density (cut-off) | $1\times10^{13}$ $cm^{-3}$ |

## 3. The HSX TS system

The HSX TS system is a ten points measurement system designed for HSX plasma electron temperature and density measurement. The whole system consists of the following subsystem.

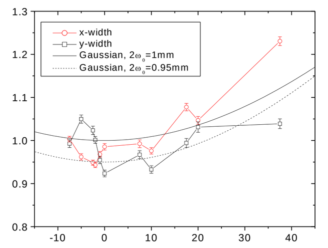
- Laser system
- Beam transportation and stray light control
- Collection optics of the scattered light
- Spectrum dispersion and detection system
- Signal handling and data acquisition
- Control system

### 3.a Laser system

A commercial YAG laser is used as the scattering source.

•10ns and 1J per pulse at 1.06μm

YAG laser and the alignment HeNe laser are placed on an optical table inside a dust-free air-conditioned room

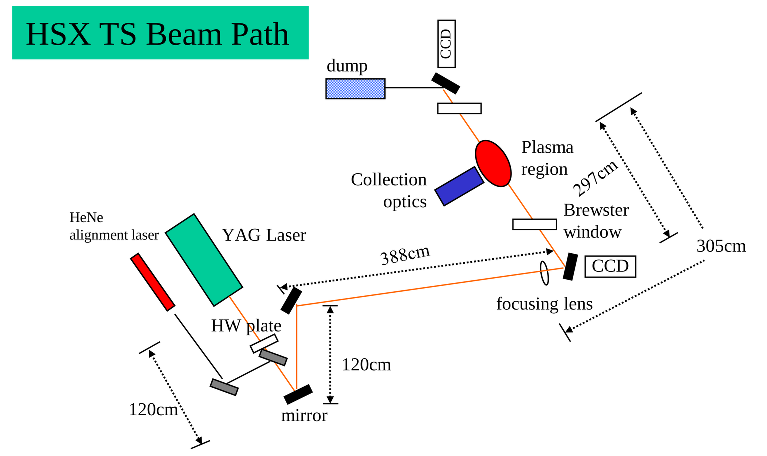



Laser spot size versus to the distance from the focus (cm). viewed on a ceramic disc with a CCD camera and video capture card.

### 3.b Beam Transportation and Stray Light Control

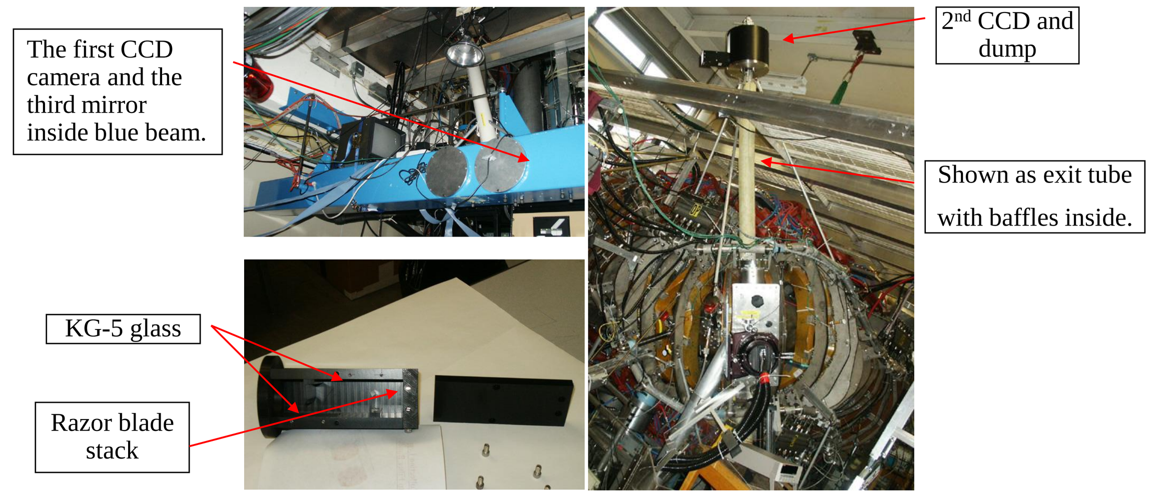
- Beam is guided by three laser mirrors and is focused to the HSX vessel with an f=3.05m focus lens.
- A 1/2 waveplate is used to adjust the beam polarization.
- Entrance and exit tubes are specially designed with baffles to control the stray light.
- Entrance and exit windows are Brewster angle orientated fused silica windows.
- A HeNe alignment laser is used to align the collection optics,
- Two CCD cameras are used to monitor the beam position.
- Two KG-5 glass groups and a razor blade stack are used as beam dump.
- The whole laser path is enclosed inside solid material for safety reason.

HSX TS Beam Path



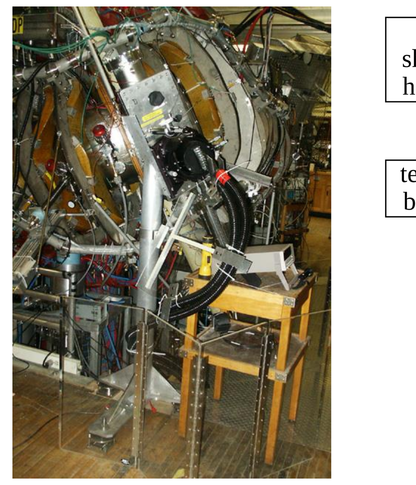

Total length from laser exit to focal point: 925cm Lens focus length: 305cm

HSX TS Beam Transportation Enclosure

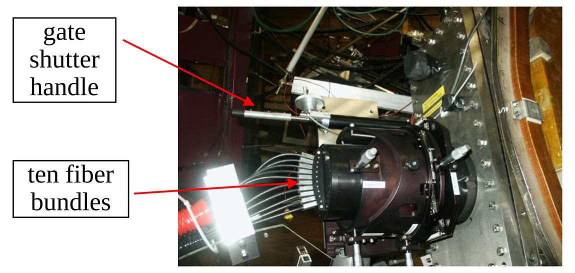


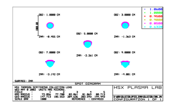

### 3.c Collection Optics

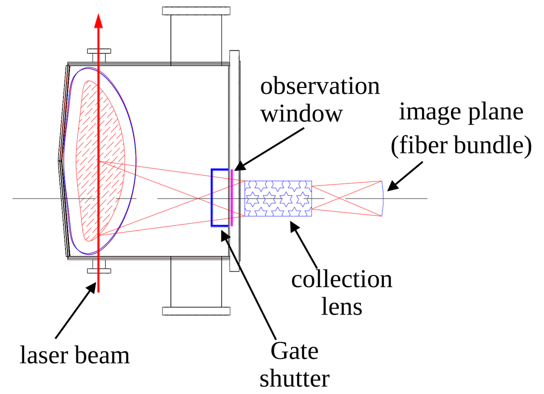
Collection Lens and its alignment with the laser beam



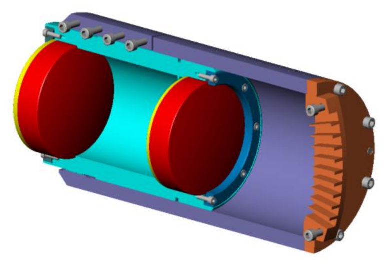
Collection optics are mounted on the lab floor, separated from vessel to prevent misalignment from vessel position change due to the venting of the machine.

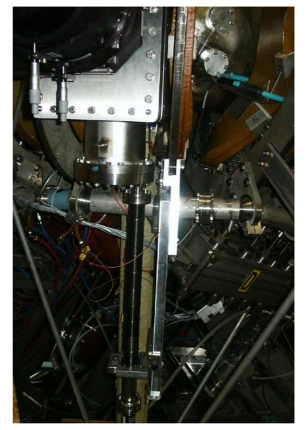


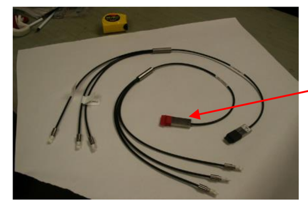



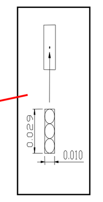



- Collection lens consist two doublets made of BK7 and SF1 glass. The image spot is less than 100 microns for all the ten channels.
- At plasma density of $10^{12}/cm^3$, the collection lens collect around 20000 photons for each of the ten fibers, which then couple the photons to the ten polychromators through fiber bundles.



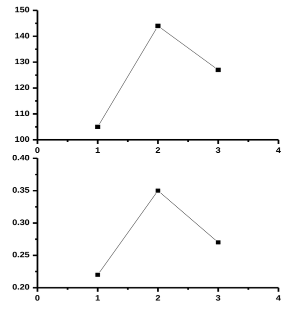






Unit: inch

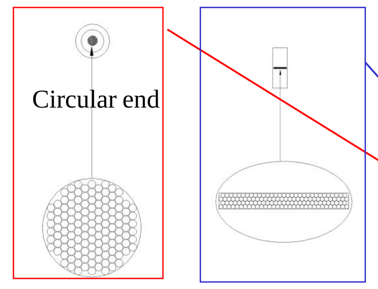
A 3-to-1 fiber bundle is used to align the collection optics to the laser beam. An *in situ* alignment target scatters the alignment HeNe laser light, the scattered light is then collected through the fiber bundle and monitored with a silicon detector. This provides precise outside vessel alignment.

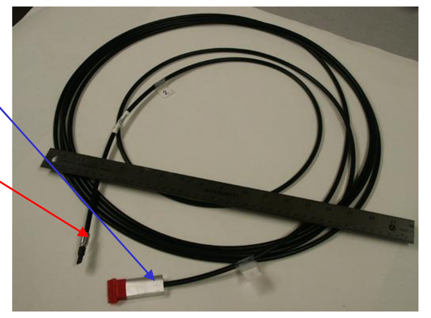


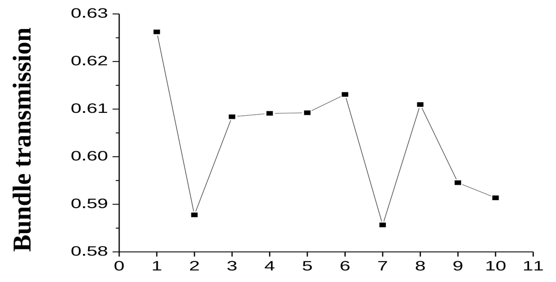
Signal level from 3 fiber with silicon detector

Fiber Optics

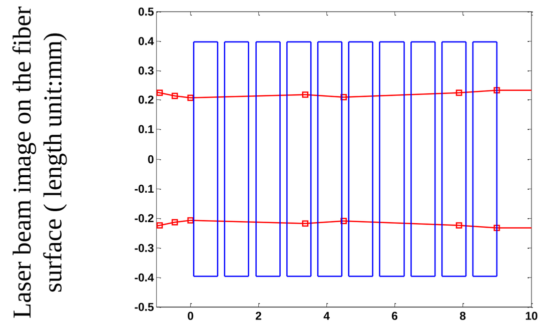
There are 126 individual fibers in each bundle, each one is selected with a numeral aperture around 0.24-0.25 to match the output collection lens and the input of the polychromator. Total length is 7 meters for each bundle.






Ten fiber bundles corresponding to ten radial channels.




Length unit: cm

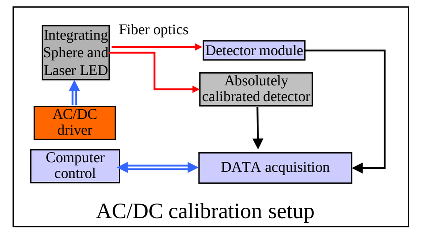
Each square corresponds to an individual fiber bundle's rectangular surface of 0.8mm*7mm

### 3.d Spectrum Dispersion and Detection System

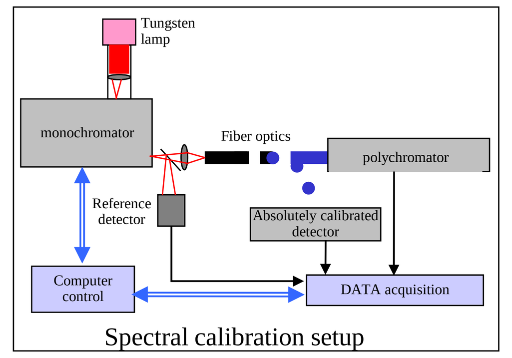
Ten identical polychromators designed and manufactured by GA are used to disperse the scattered light.Four wavelength channels in each polychromator optimized for the measurement of the electron temperature range from 10eV to 2keV.

Polychromator calibration bench has been set up in the HSX lab. Basically, there 3 stages to calibrate the polychromator.

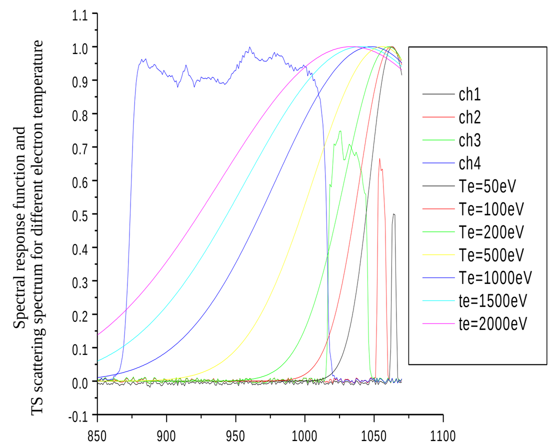
1. Ratio between the pulsed and DC response
2. Spectral response
3. Absolute sensitivity of the instrument.

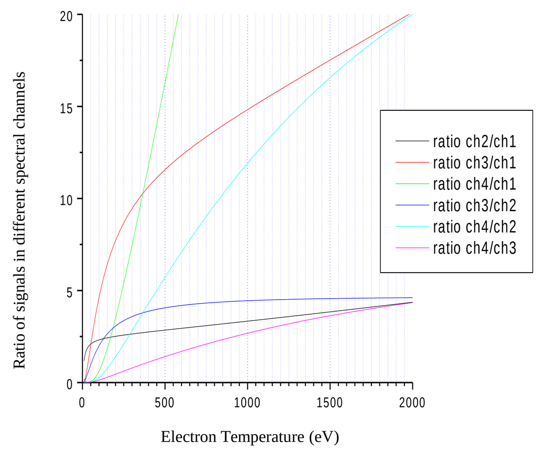



AC/DC calibration setup




Spectral calibration setup

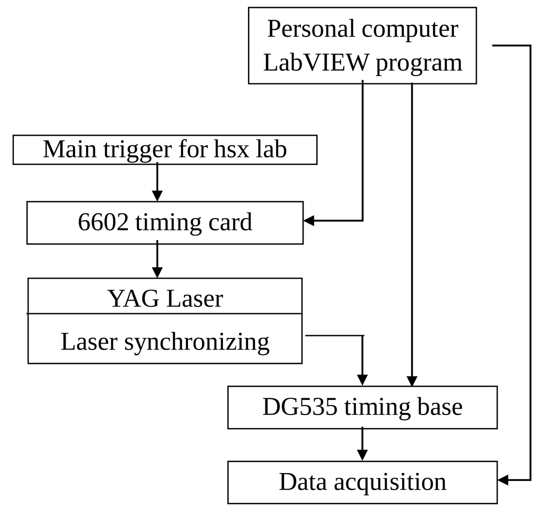



### 3.e Signal Handling Data System and Control system

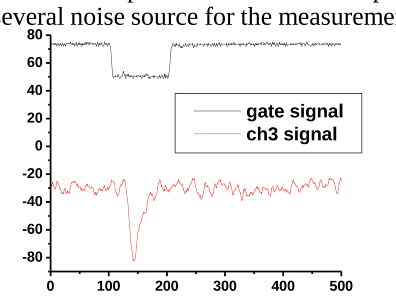
A labVIEW program control the timing and data acquisition of the system.

- A GPIB crate controller from KINETICS SYSTEM is used to communicate between the CAMAC crate and the computer.
- The signal is recorded by gating Leroy Model 2250 charge integrating digitizer. These digitizers have a sensitivity of 0.5pC/count, with a range of 512 counts.
- System synchronized with HSX timing with a NI6602 timing card and a DG535 digital pulse generator from Stanford Research Systems.




## 4. Experiment Results

Electron temperature is measured upon the ratio between each wavelength channel. There are several noise source for the measurement,




Raw signal of channel 3, Shot 22, March 7, 2003

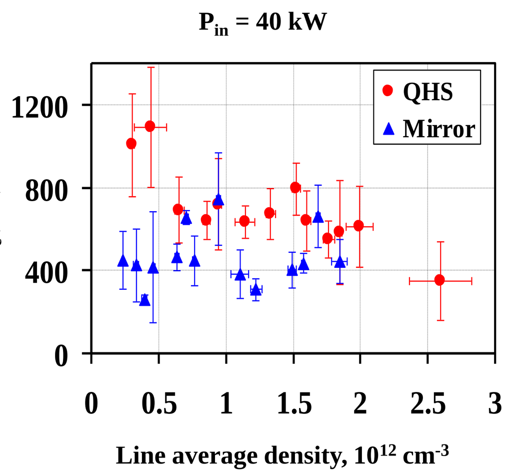
- Detector and electronic noise
- Calibration error
- Photons statistics

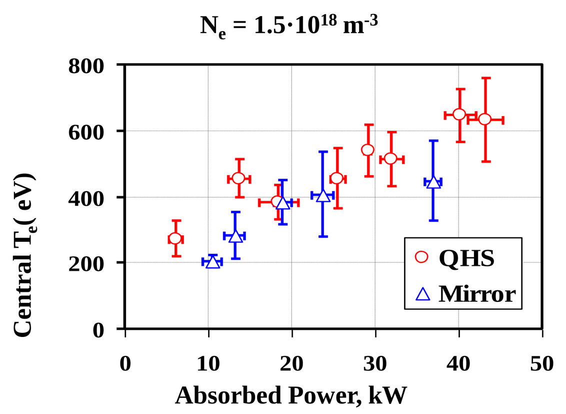
The 100ns gate covers the signal period which is integrated to get the ratio.

- The first channel got saturated. (stray light?)

Electronic noise

### 4.a Density and Power Scan

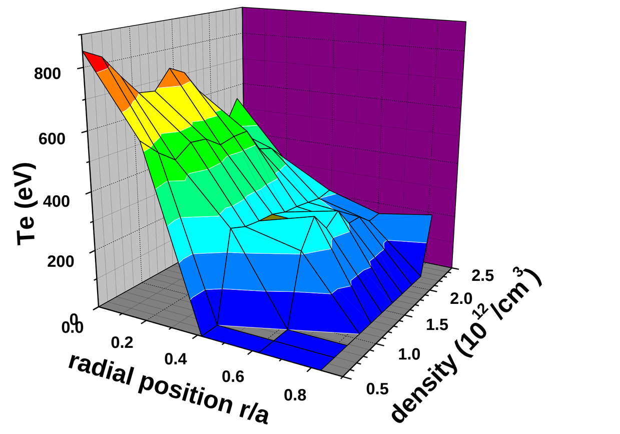


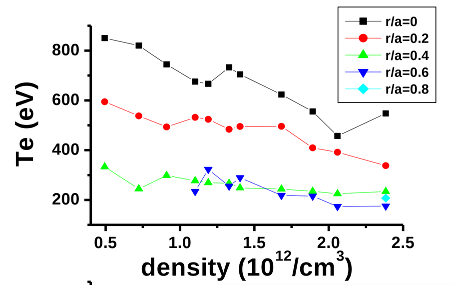



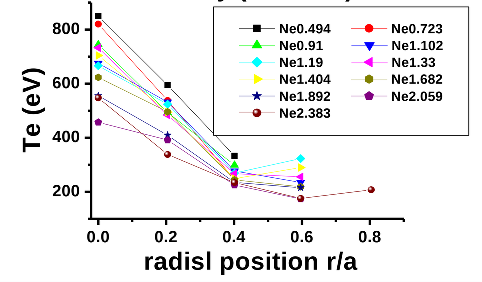

- **Central electron temperature is higher in QHS mode than in Mirror mode.**

- **Central electron temperature linearly increases with heating power for both QHS mode and Mirror mode.**

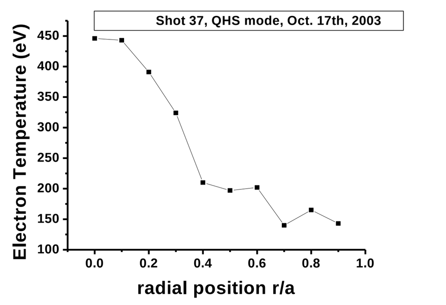
### 4.b Five Channel measurement for QHS Density Scan



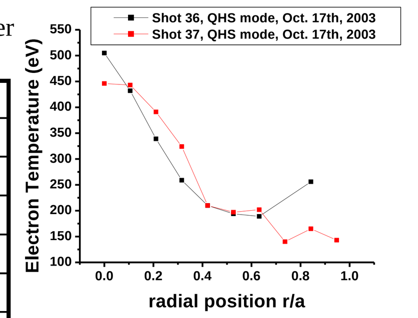

### 4.c Ten Channel Profile Measurement



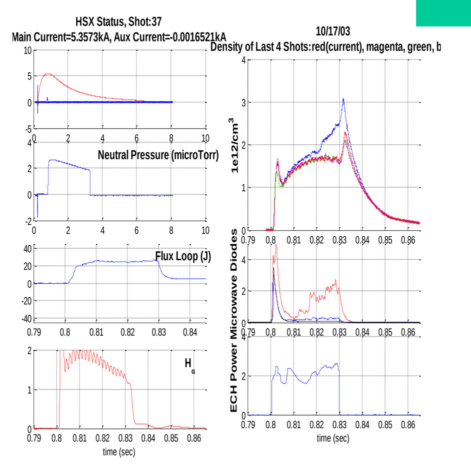

At 825 ms when the TS laser is fired, density is around 1.7×1012/cm3. Raw signal from the digitizer is shown at right table. Signal in Channel 1 always got saturated.

Raw signal from digitizer

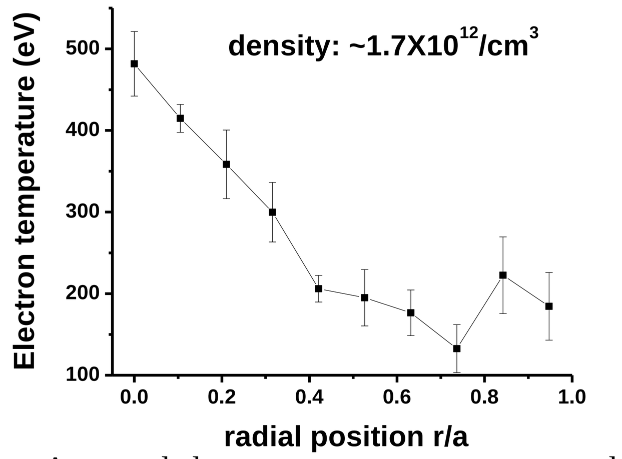
| Ch2 | Ch3 | Ch4 |
|---|---|---|
| 10 | 38 | 38 |
| 10 | 53 | 58 |
| 9 | 44 | 38 |
| 13 | 53 | 37 |
| 15 | 42 | 17 |
| 16 | 33 | 10 |
| 13 | 29 | 8 |
| 6 | 14 | 2 |
| 13 | 10 | 1 |
| 4 | 4 | 1 |




For similar shots (shot 36 and 37) on Oct. 17, 2003, the measured electron temperature looks similar except for the edge region where signal level is low.




Temperature Profile on HSX




Averaged electron temperature over several similar shots of density $1.7\times10^{12}/cm^3$.

## 5. Summary

- The HSX TS system has been established and calibrated.
- Initial results of the electron temperature profile measurement using TS system has been committed on The HSX machine.
- It is found that the central Te increase linearly with heating power for both QHS mode and Mirror mode. At same density, electron temperature is higher in QHS mode than in Mirror mode.