ABSTRACT

Determination of the plasma space potential profile in the core of the Madison Symmetric Torus is one the primary purposes of the MST-HIBP. Preliminary measurements inside the core indicate that the plasma potential is in the range of positive 0.8 kV to 1.6 kV for a 400kA standard MST discharge. Initially, experimental emphasis has been on finding the potential at some representative core plasma locations in standard discharges. To accomplish this it is necessary to measure the analyzer and accelerator voltages and calibrate the angular dependence of the energy analyzer to an accuracy of at least 0.1%. It must also be demonstrated that the probing ions can be detected without passing too near to any obstacles in the beamline vacuum chambers. It is not, however, necessary to know exactly the beam ion trajectories. Once an accurate field model is developed (by comparing conditions under which HIBP signal is obtained to trajectory calculations made with the best available magnetic field model), radial profile measurements will be made by either combining single point measurements for several similar discharges or by varying the beam injection angle during a single discharge. The latter approach requires additional computer control of the ion beam sweep system, which is also under development.

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OULINE OF POSTER

- First ever measurement of plasma potential in the core of an RFP (+1.2 to1.4 kV)
- Importance of measurement of plasma potential in an RFP
- Plasma potential measurement technique with the HIBP on an RFP device
- Prediction of radial electric field (E_r) from the ion momentum equation
- Future work
- Conclusion

THE POTENTIAL IN THE CORE OF AN RFP IS POSITIVE

The HIBP measurements indicate that plasma potential in the core is positive unlike in Tokamaks

The relatively high value of plasma potential of 1.2-1.4 kV indicates that ions are well confined compared to electrons in the core

Positive potential is expected if transport is dominantly due to stochastic magnetic field

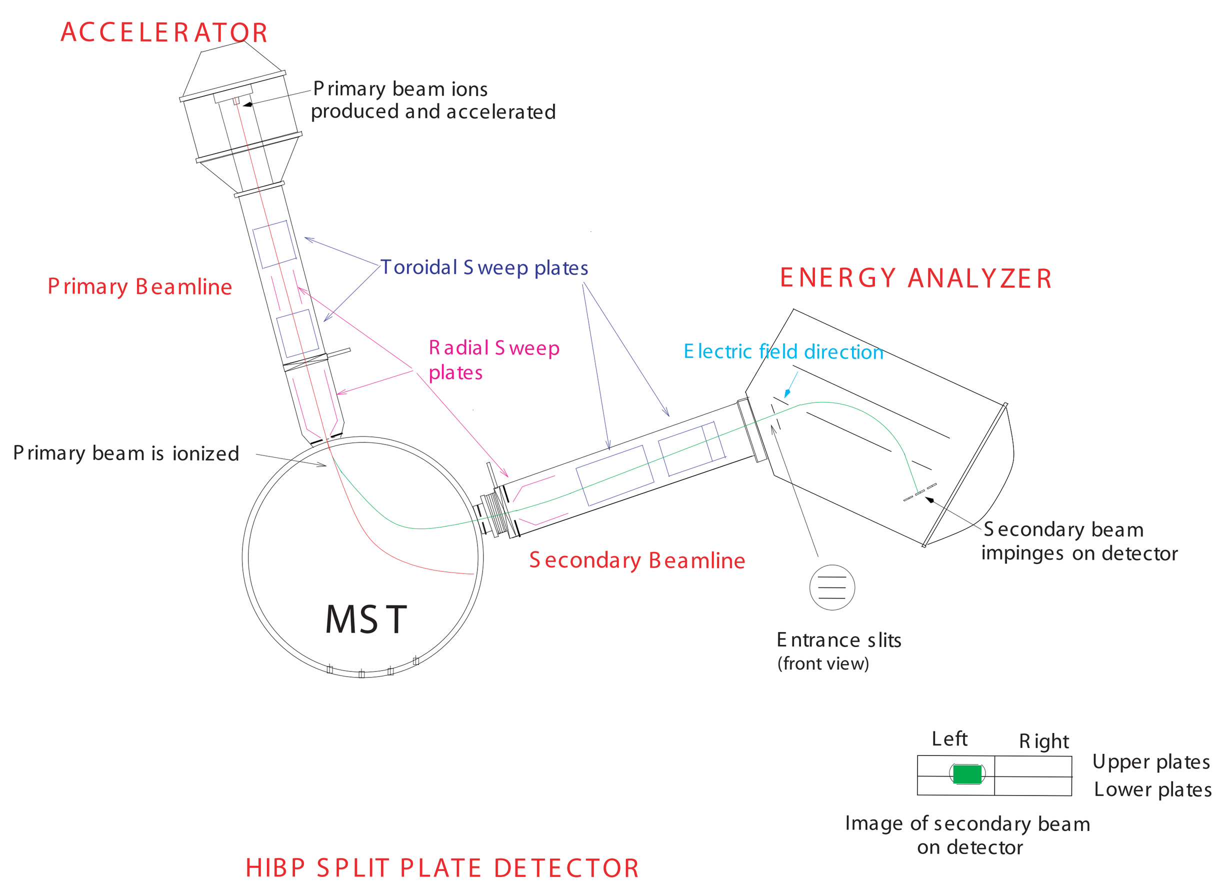
Potential measured is 3-4 times that of the central electron temperature

MEASUREMENT OF THE PLASMA POTENTIAL (and E_r) is IMPORTANT IN THE RFP BECAUSE:

- Measurement of E_r will improve our understanding of core confinement in the RFP
  - Ambipolar electric field is governed by electron vs. ion confinement
  - E_r factors into the heat equationas a source or sink term for electron or ion energy
  - How does E_r change in enhanced confinement
- Relation of the dynamics of plasma flow to the radial electric field can be directly studied
  - Eg. How does E_r change with mode locking?
- The question of whether ExB shear exist and is important in the core of an RFP could be answered

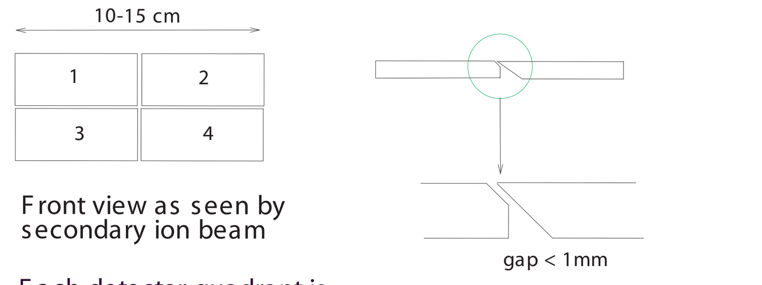
THE HIBP

PRINCIPLE OF POTENTIAL MEASUREMENT



HIBP SPLIT PLATE DETECTOR

Four split plates comprise a detector set



Front view as seen by secondary ion beam

Side view: Main cut prevents the m from passing through charged insulators. The second cut reduces capacitive coupling

Each detector quadrant is given a specific name

Plate #	Name
1	Upper left
2	Upper right
3	Lower Left
4	Lower right

From T.P. Crowley et all, IEEE Transactions on Plasma Science 22,August 1994

EQUATION FOR MEASUREMENT OF POTENTIAL

Wd= beam energy of the secondary ion beam

Wb=beam energy of the primary ion beam

qs= charge state of the secondary ion species

qp=charge state of the secondary beam ion species

In terms of HIBP quantities the equation for plasma potential is:

Va= analyzer voltage

Vg= accelerator voltage

Iu,l= current on upper and lower plates respectively

G= Gain of analyzer (a measure of how much analyzer voltage is required to center the beam on detector plates)

F= Offline processing term (provides a measure of the plasma potential in the event of fluctuations)

SUCCESSFUL MEASUREMENT OF THE POTENTIAL DEMANDS THAT THE FOLLOWING REQUIREMENTS BE MET:

- Energy analyzer must be well calibrated (to within 0.1% accuracy to reduce errror in potential mesurement to less than 70V)

  The parameter G has been experimentally measured on-site using a singly charged ion beam using the following relation:

  G= Accelerator Voltage/ Analyzer Voltage

  The analyzer voltage was recorded when the beam was centered on intersection between the upper and lower detector plates.

  The plot of G versus the entrance angle theta of the incoming beam, is shown below

- Precise measurements of analyzer and accelerator voltages:

  Two precision high voltage dividers are utilized to measure accelerator and analyzer voltages to an accuracy of better than 0.05%

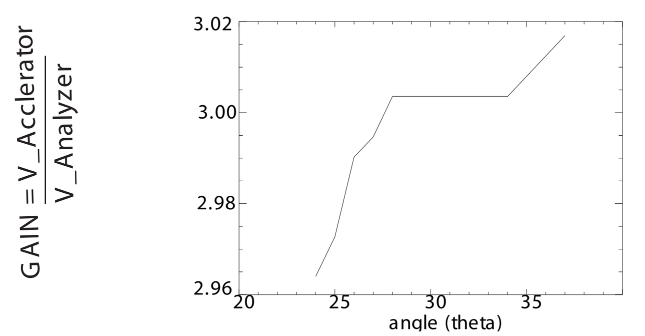
- Good signal strength

  Signal must be clearly resolvable from electronic noise and noise due to UV from the plasma. Signal level on one detector plate is typically over 40 nA.

  Plasma UV burst during sawteeth can raise noise levels to well over 40nA. However, if machine is relatively clean this level is less than 30 nA per detector plate

  Beam scrape off in beamline and analyzer should be analyzed

ANALYZER GAIN CURVE MEASUREMENT



THE EXPERIMENT AND RESULTS

MST and HIBP PARAMETERS FOR THIS MEASUREMENT:

HIBP :

Accelerator voltage:	70.05 keV
Analyzer voltage:	11.96 kV
Probing species:	Sodium ions
Detectors used in analyzer:	2 sets (4 electrically isolated plates per set)
Sweep system:	The primary ion beam injection angle was constant over the discharge. DC sweeps were used for this purpose

MST:

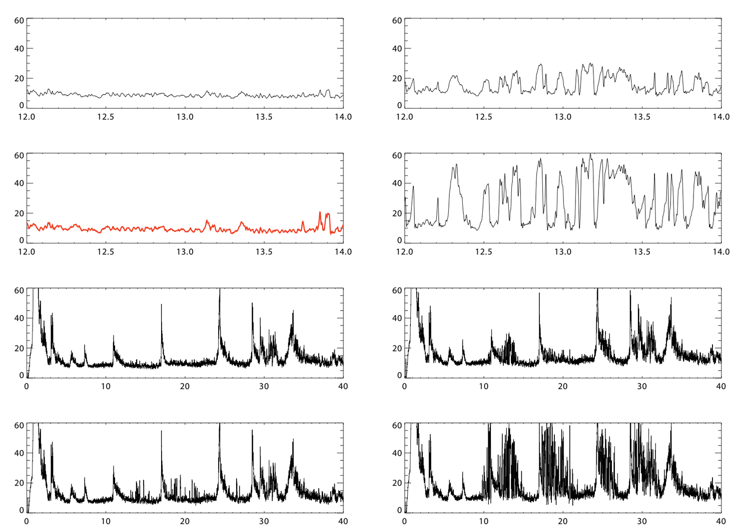
Plasma current:	373 kA
Density:	1.3x10^13/cm3 (fairly high)
T_e:	350-400 ev
B_max:	0.38 T (on axis)
Discharge type:	Typical moderately high standard discharge (ohmically heated), no auxillary heating

Excellent reproducibility of MST discharges facilitated these measurements greatly.

SIGNAL DETECTION

The plots below show RAW HIBP secondary signal detected on four split plate detectors of the center detector set.

The top four plots show signal levels on the four plates. The appearance of signal at particular instances co-relates very closely with the sweep voltage on the radial sweep plate that is closest to MST. Although the sweep voltage on this plate was held constant, UV loading from the plasma on the plates caused this applied voltage to change. Hence, the direction of the injection angle of the ion beam changed and signal was detected for only particular values of the sweep voltage. This choppy nature of the signal is co-related with the radial sweep and is shown in figure 4.



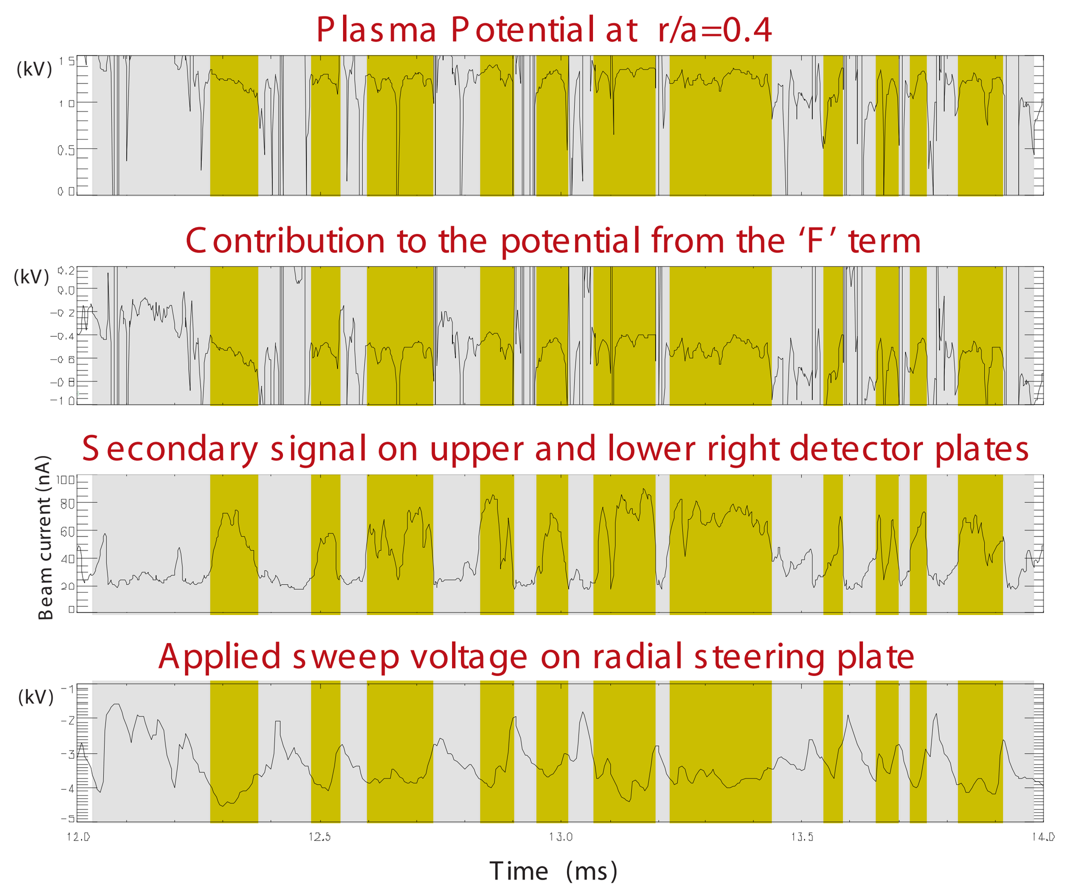
CALCULATION OF PLASMA POTENTIAL FROM SIGNAL IN FIGURE 3

Figure 4a shows a plot of the plasma potential calculated from equation 2. The instances when signal was detected is highlighted in the plot. The plasma potential varies from 1.2 to 1.4 kV.

Figure 4b shows a plot of the contribution of the F term in the equation for plasma potential.

Figure 4c shows the total signal level on the upper and lower right plates of the detector. Maximum ion beam current is 80 nA.

Figure 4d shows the voltage applied on the radial sweep plate. It is clear from this plot that signal is only detected for a small range of applied sweep voltage.



MEASUREMENT LOCATION

- Sample volume is calculated using the best available magnetic field model for this shot.

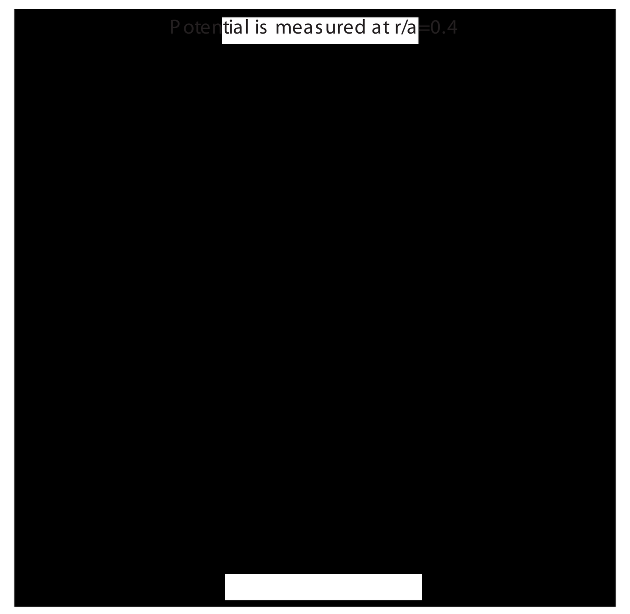
  * Constant improvements in the magnetic field calculation utilitize HIBP trajectory information

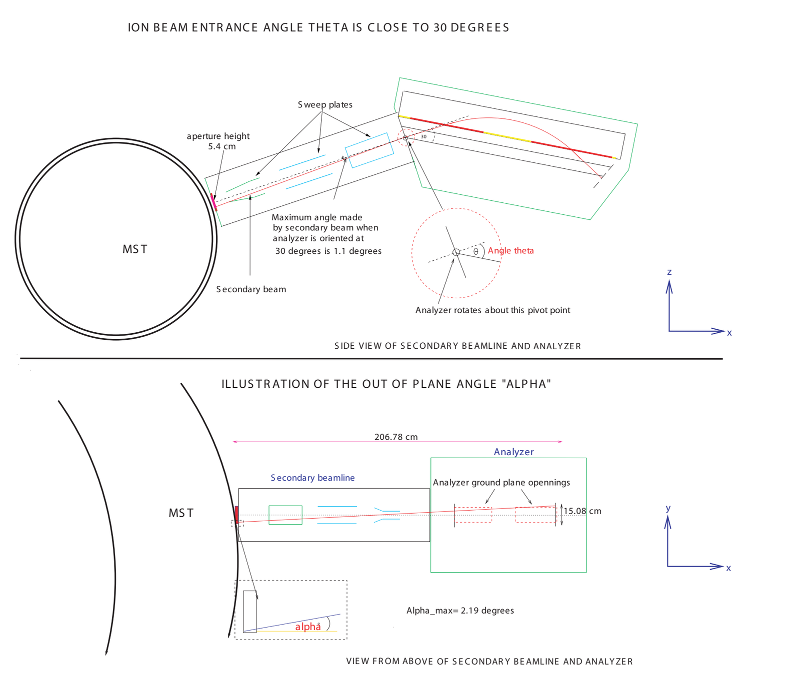
- HIBP sample volumes are extremely sensitive to magnetic fields
  * Sample volume for this case is spatially resolved to within 5 cm.

- The dynamic character of MST magnetic field profile in MST influences trajectory computation
  * Time information during signal detection is used to compute a field profile specific to that time interval Different times even within the same shot can alter the models by 10%

- An equilibrium reconstruction code ,MSTFIT, that solves the Grad-Shafranov equation is used to generate the equilibrium fields

PLOT OF MEASUREMENT LOCATION





SOURCES OF ERROR IN MEASUREMENT

(a) Gain curve calibration
An error of 1% in calibration can lead to a change of over 700 V in plasma potential measurement

(b) F
The uncertainty and angular variation F contributes up to 25-50 V to the uncertainty in the measurement.

(c) Uncertainty in entrance angles (see figure 7)
Theta
The analyzer is oriented at approximately 30 degrees. Uncertainty in the entrance angle in the range: 27-34 degrees contributes to an error of less than 10 V. If the analyzer is oriented at 30 degrees then the incoming beam can enter the center entrance slit at a maximum angle variation of 30 +/-1.1 degrees, thus keeping the overall angle to within the 27-34 degree range

Alpha (lateral angle):
The maximum out of plane angle in this system (with no beam steering in the secondary beamline) is 2.19 degrees. If the exact location of the beam on the detector is not known from trajectory calculations then the maximum error is 100 V (for this case)

(d) Accelerator and analyzer voltages:
Although both of these quantities are measured with high precision meters, the resolution of these signals is limited by the bit resolution of the digitizer. Presently, these contribute errors of up to 100V in accelerator voltage and 25 V in the analyzer voltage.

(e) Ion beam scrape off
Further data analysis will be carried out to determine whether beam scrape off is an issue

Total error bar of measurement:
If gain curve is accurate to within 0.1% then a conservative error bar is 250-300 V.