



Measurement of toroidal plasma rotation and electron temperature by double tunnel probe on the GOLEM tokamak

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GOMTRAIC, Prague, 4.-8. March 2019

Prague GOLEM

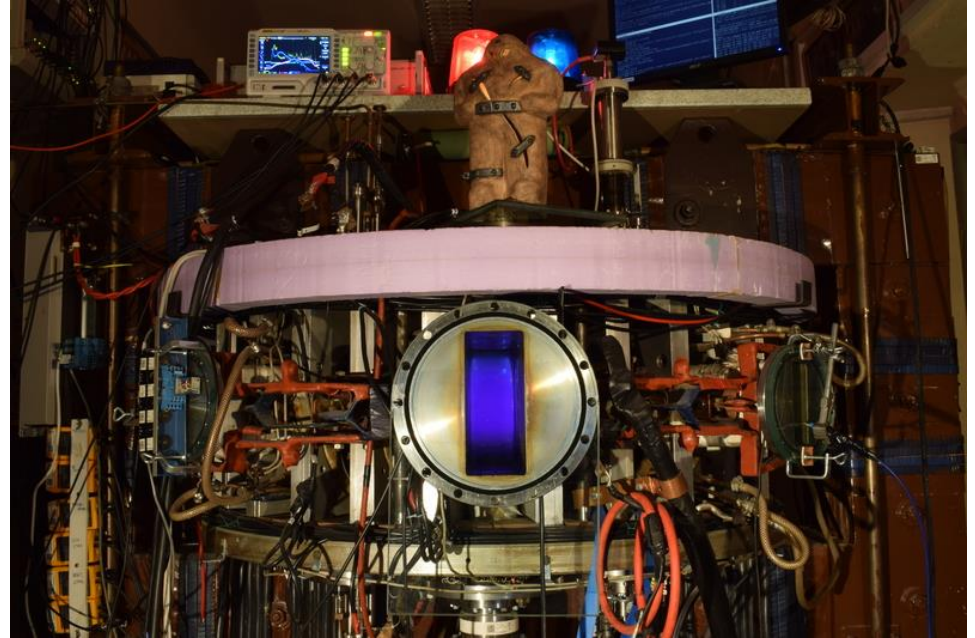
The word *golem* is used in the Bible to refer to an embryonic or incomplete substance: Psalm 139:16 uses the word גלמי, meaning *my unshaped form*. The Mishnah uses the term for an uncultivated person.

Similarly, golems are often used today in metaphor as entities serving man under controlled conditions but hostile to him in others.

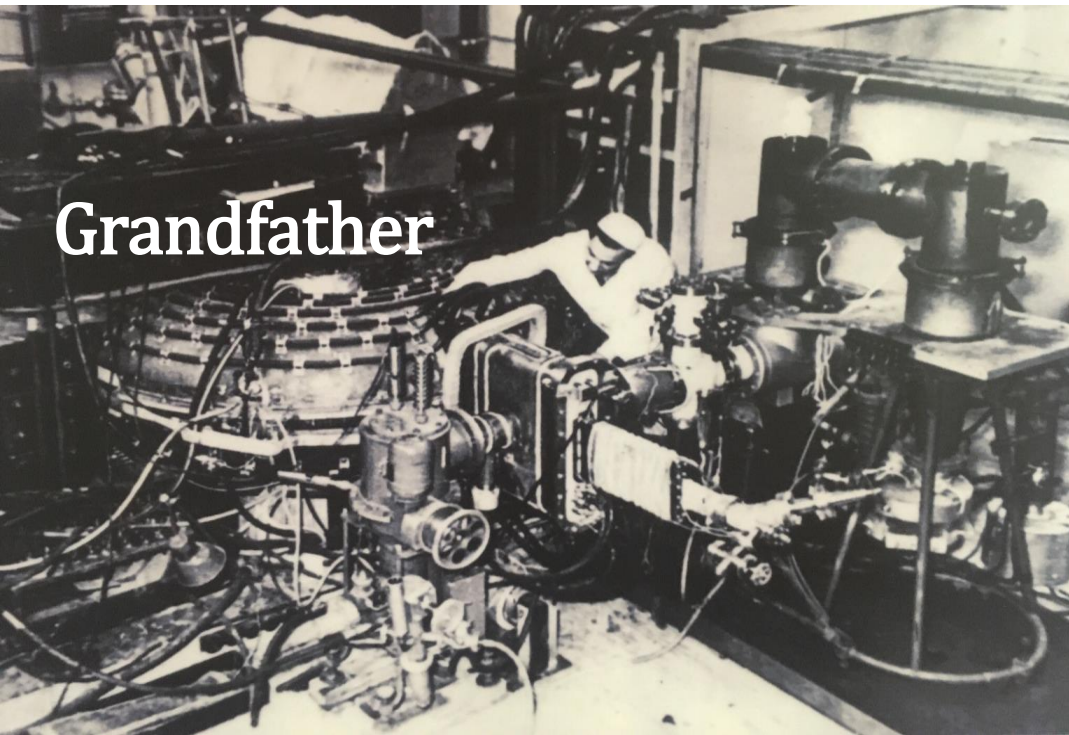


The GOLEM tokamak

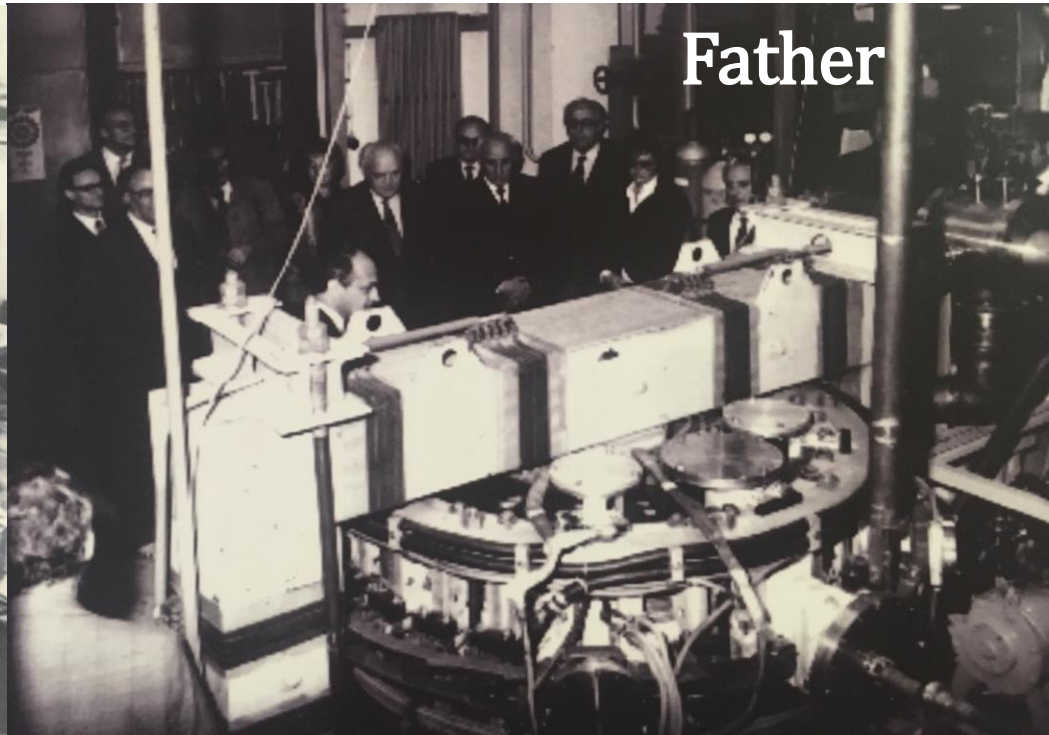
- Major radius $R = 0,4$ m
- Minor radius $a = 0,085$ m
- Toroidal magnetic field $B_t < 0,5$ T
- Plasma current $I_p < 6$ kA



History of GOLEM



Tokamak TM-1 1963-1968
Kurchatov Institute, Moscow



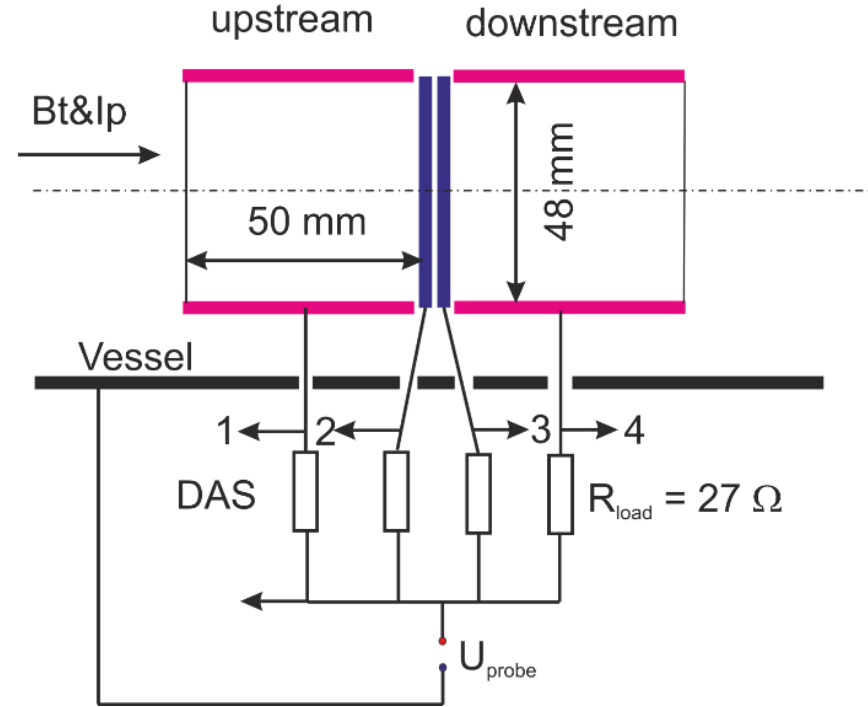
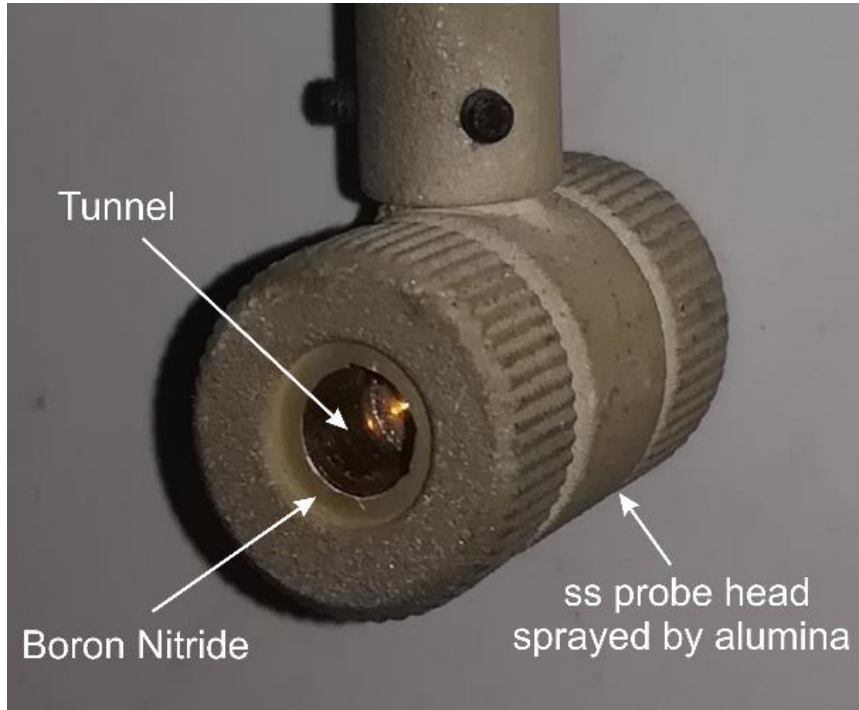
Tokamak CASTOR 1977-2007
IPP Prague

Experimental Tasks During GOMTRAC

Goal: Exploitation of novel electric probe – double tunnel probe to study

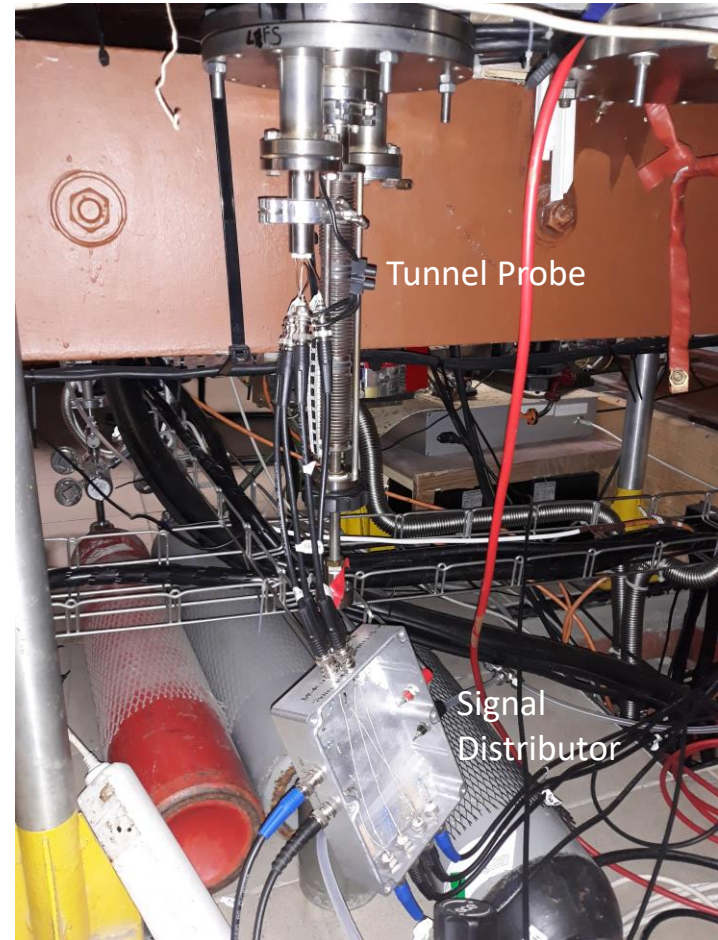
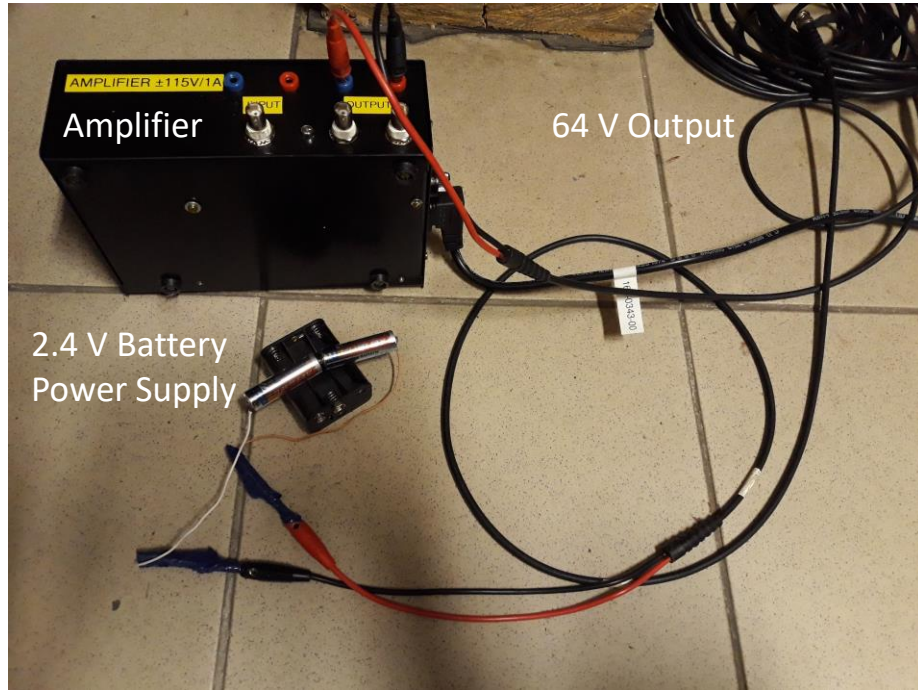
1. Edge plasma rotation using Mach Number
2. Electron temperature at the plasma edge

Double Tunnel Probe

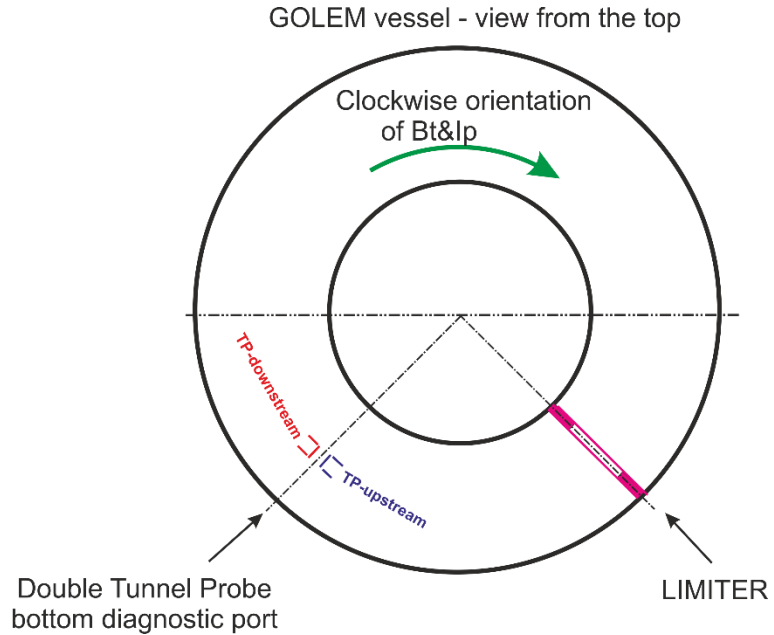


$$U_{probes} = -64 \text{ V}$$

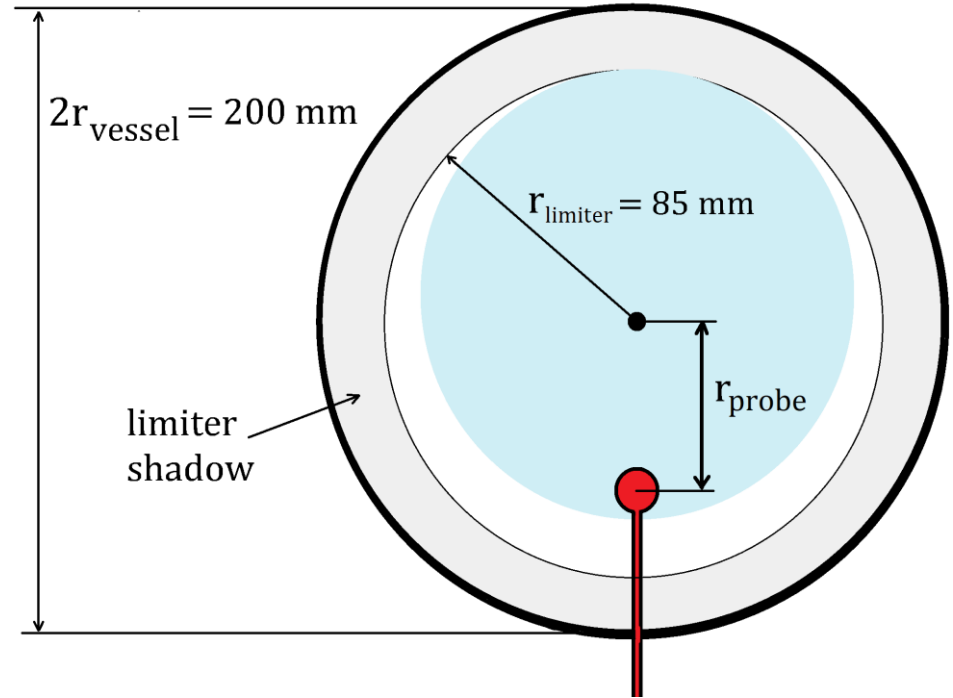
Tunnel Probe Set-Up



Tunnel Probe Location in GOLEM



Top View



Side View

Shot List for GOMTRAIC

Measurements taken on a shot to shot basis, by moving the probe 5 mm each trial

Input Parameters: no plasma stabilization, $U_{bt} = 1300V$, hydrogen gas pressure = 8mpa, $U_{cd} = 500V$, pre-ionization, and no time delay

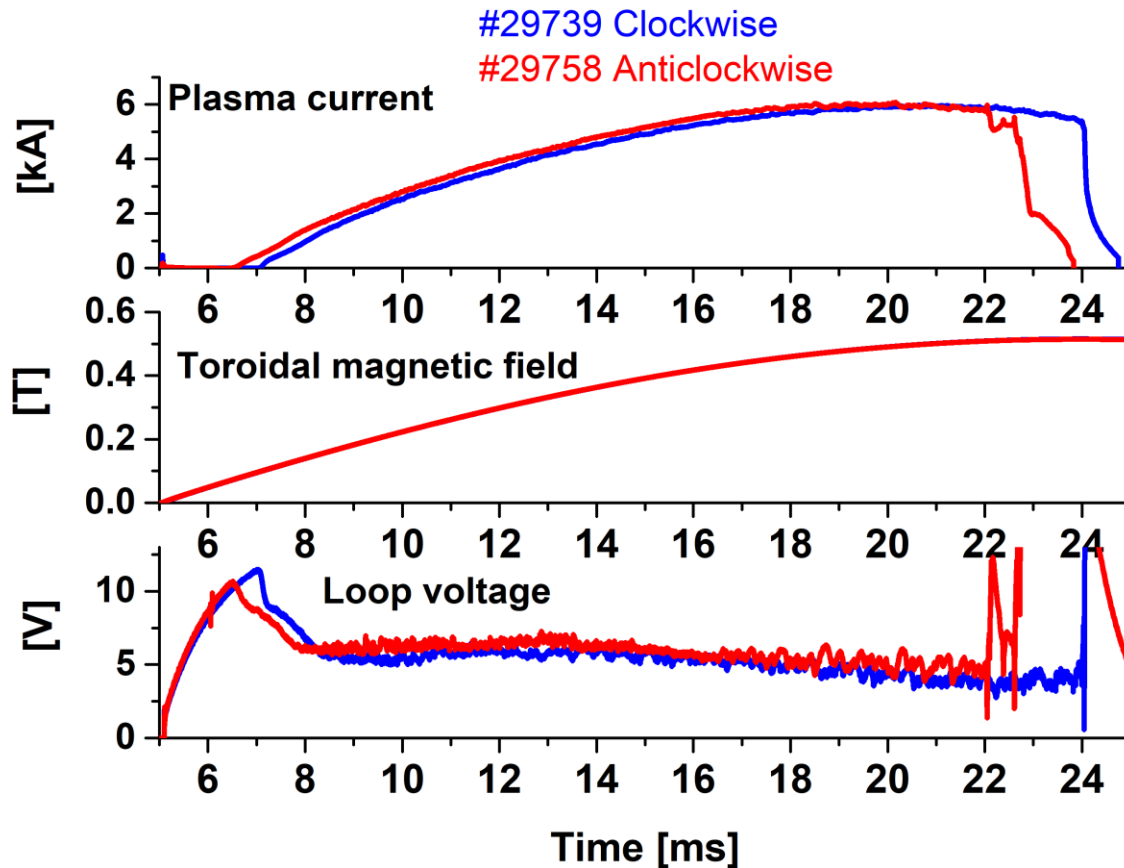
Clockwise Orientation

Anticlockwise Orientation

Shot Number	Probe Depth (mm)	Shot Number	Probe Depth (mm)
29739	95	29754	95
29740	90	29757	90
29741	85	29758	85
29742	80	29759	80
29743	75	29760	75
29745	70	29762	70
29746	65	29763	65
29747	60	29771	60

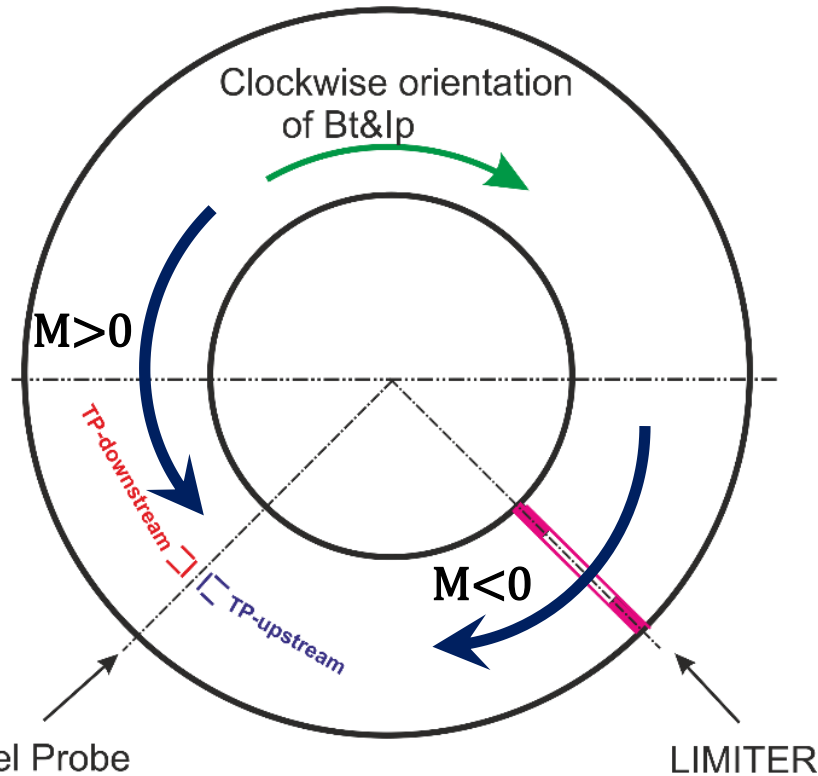
Main Parameters of Discharges

comparison of clockwise and anticlockwise orientation of I_p & B_{tor}



Toroidal Plasma Rotation and Parallel Mach Number

GOLEM vessel - view from the top



Double Tunnel Probe
bottom diagnostic port

LIMITER

Mach number $M = \frac{v}{c_s}$,
where *ion sound velocity*

$$c_s = \sqrt{\frac{T_e + \gamma T_i}{m_i}}$$

Typically $c_s \sim 45$ km/s
at the plasma edge
($T_e \approx T_i \approx 10$ eV)

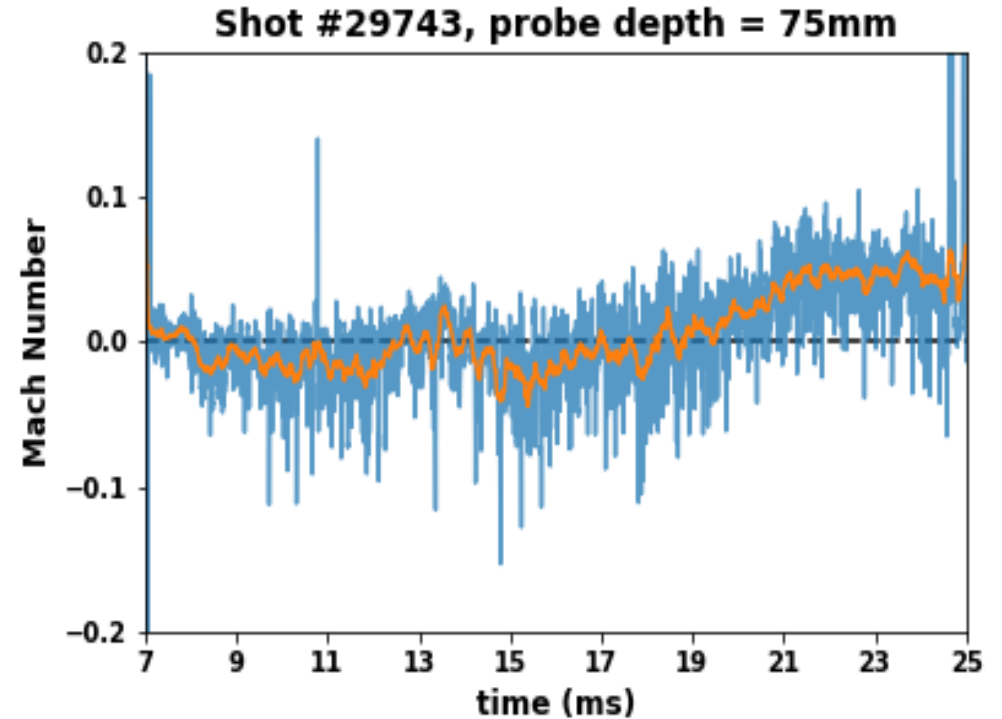
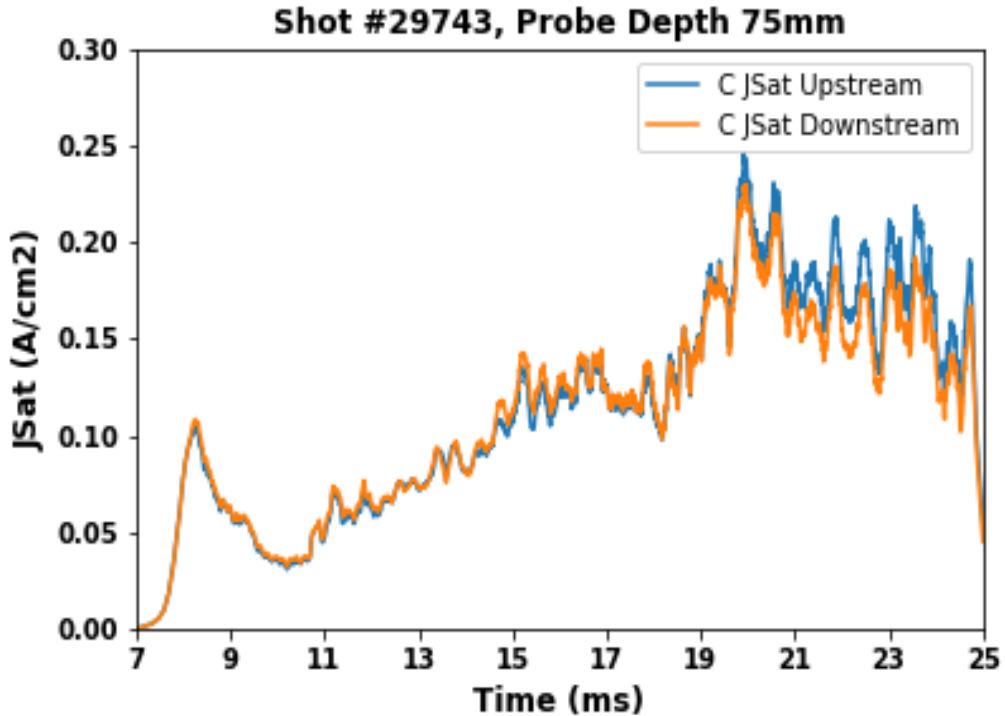
Calculation of Parallel Mach Number

Mach number $M_{\text{par}} = 0,4 \cdot \ln \frac{J_{\text{sat}}^{\text{limiter}}}{J_{\text{sat}}^{\text{op.limiter}}}$

Ion saturation current density $J_{\text{sat}} = \frac{I_{\text{sat}}^{\text{T}} + I_{\text{sat}}^{\text{BP}}}{\pi a^2}, \left[\frac{\text{A}}{\text{cm}^2}, \text{A}, \text{cm} \right]$

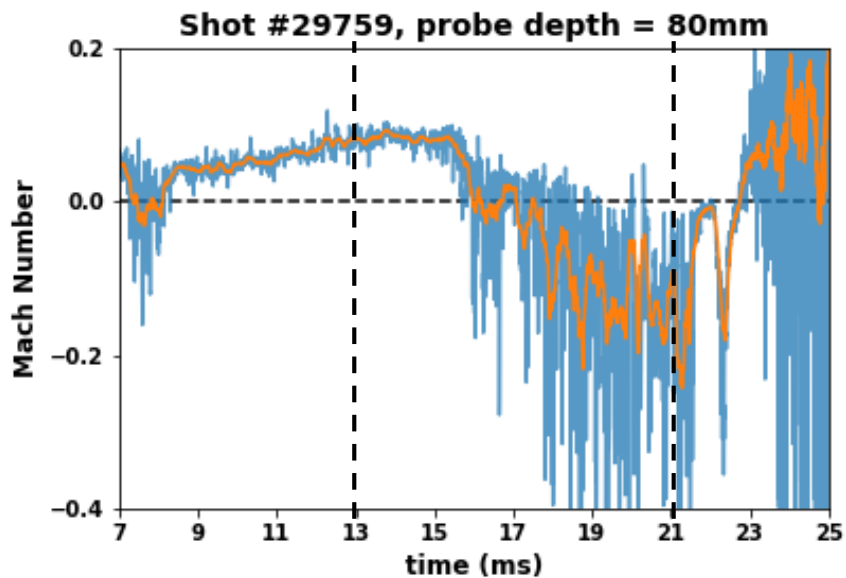
Probe radius $a = 0,25 \text{ cm}$

Mach Number for Clockwise Plasma Orientation

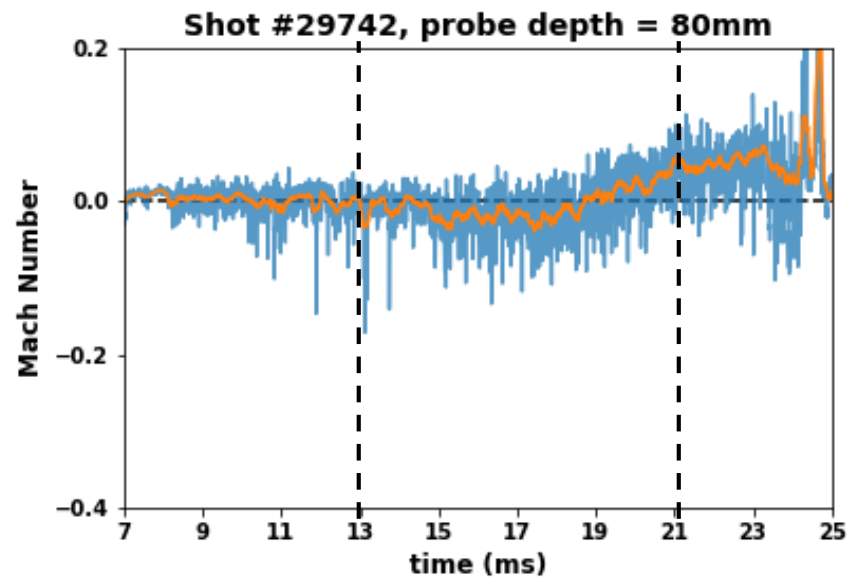


The upstream and downstream current densities are similar, so the Mach number is roughly zero

Mach Number Evolution



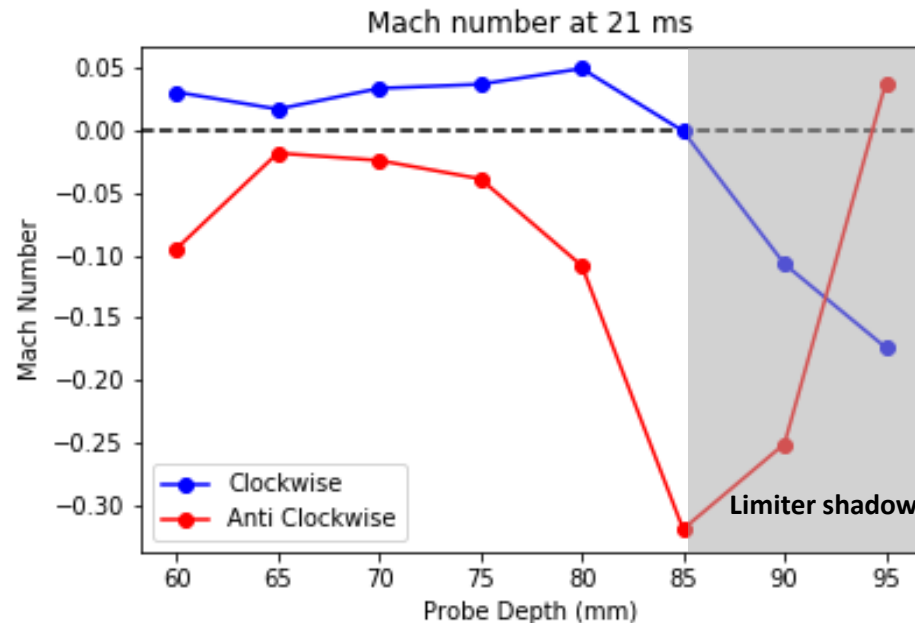
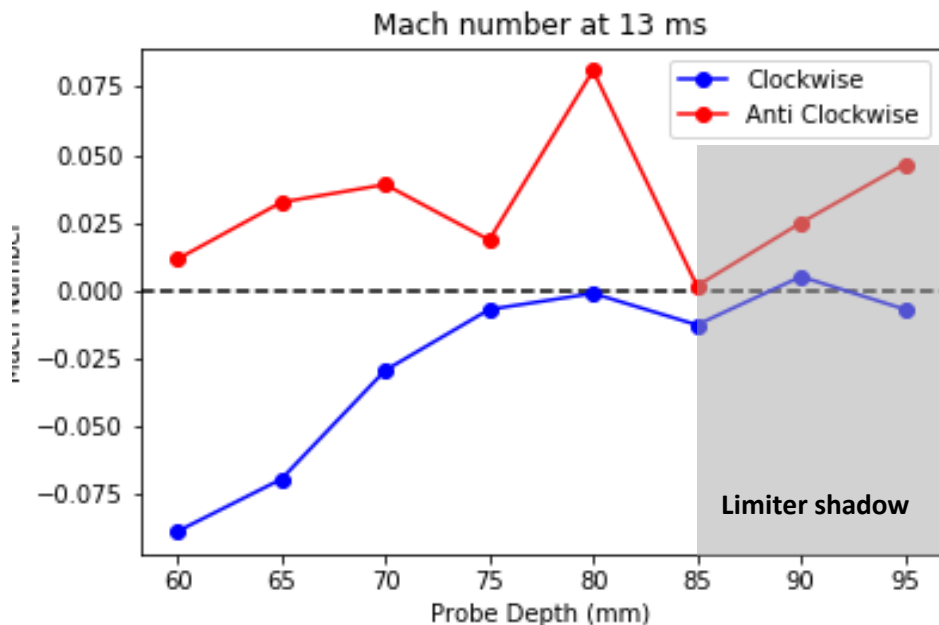
Anticlockwise



Clockwise

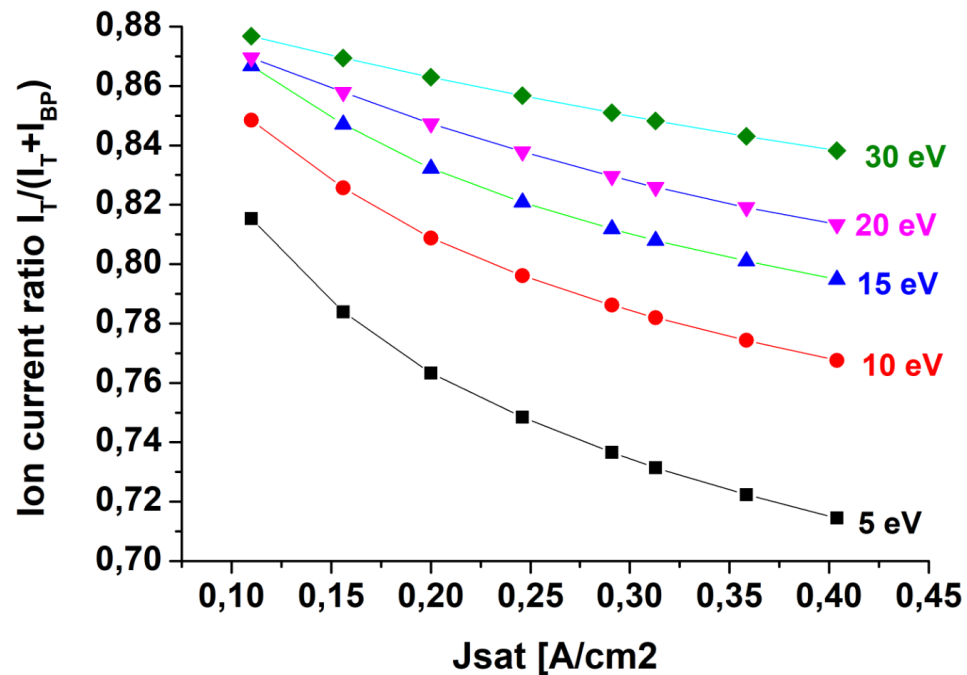
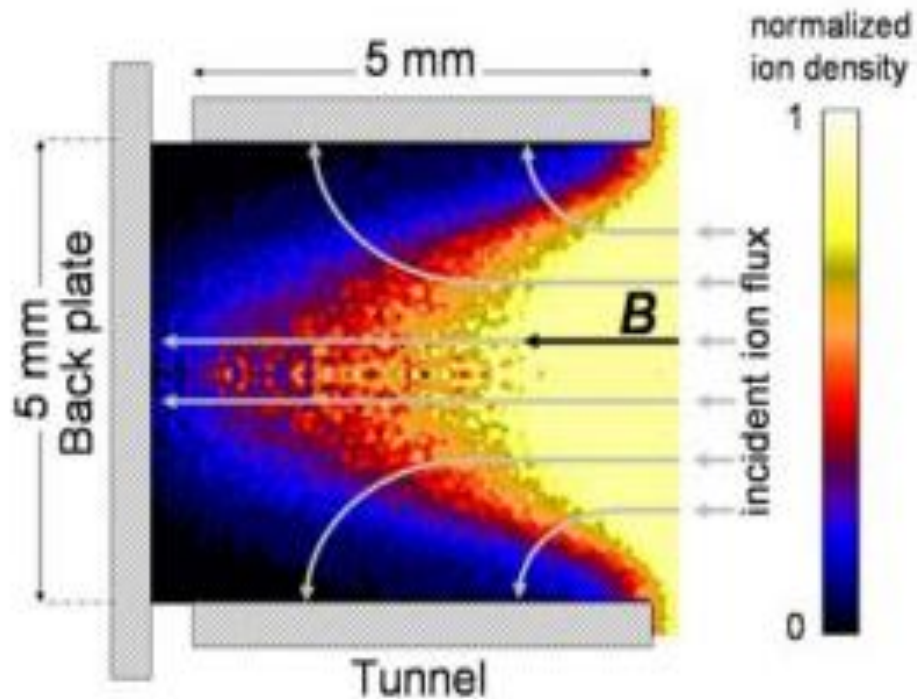
The plasma current orientation reverses direction for both clockwise and anticlockwise schemes

Radial Profile of Mach Number



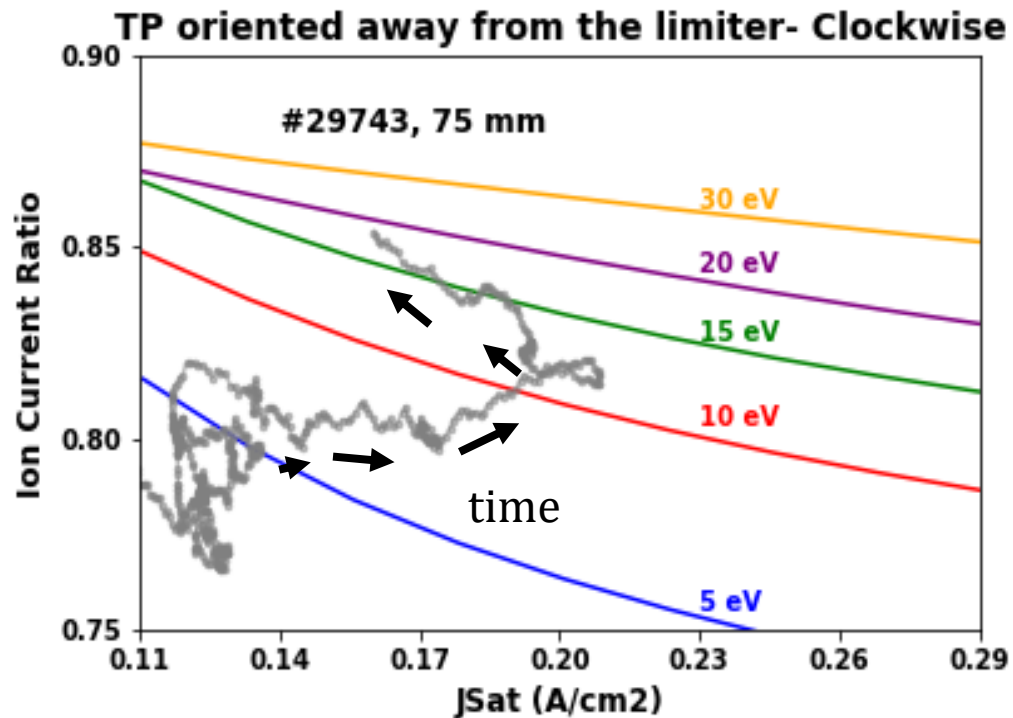
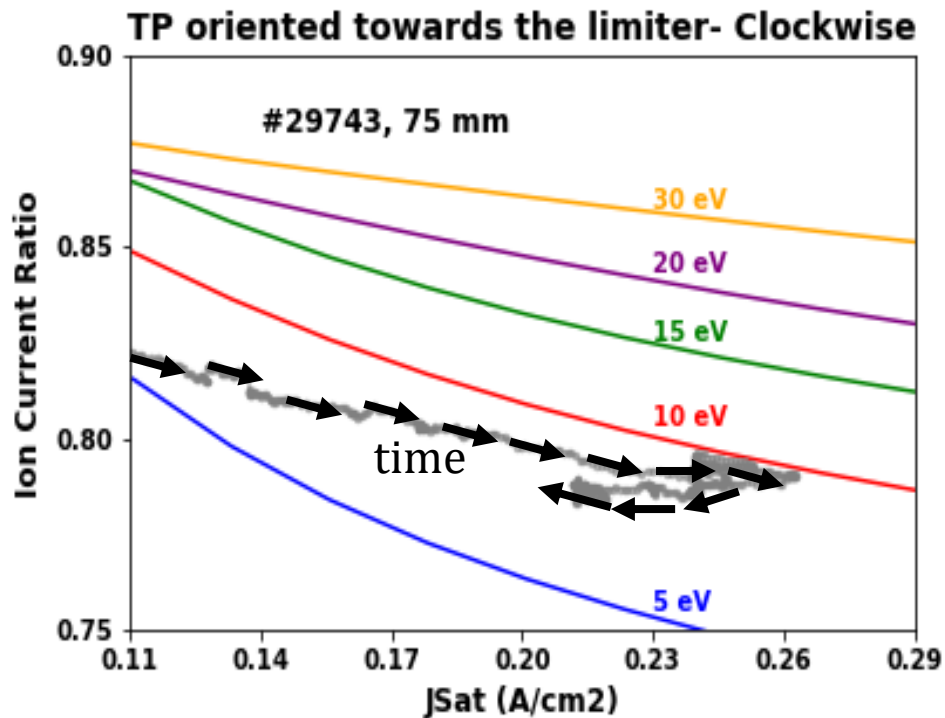
Mach number changes sign for plasma current orientation
Mach number changes sign during discharge

Principle of Electron Temperature Measurements by Tunnel Probe



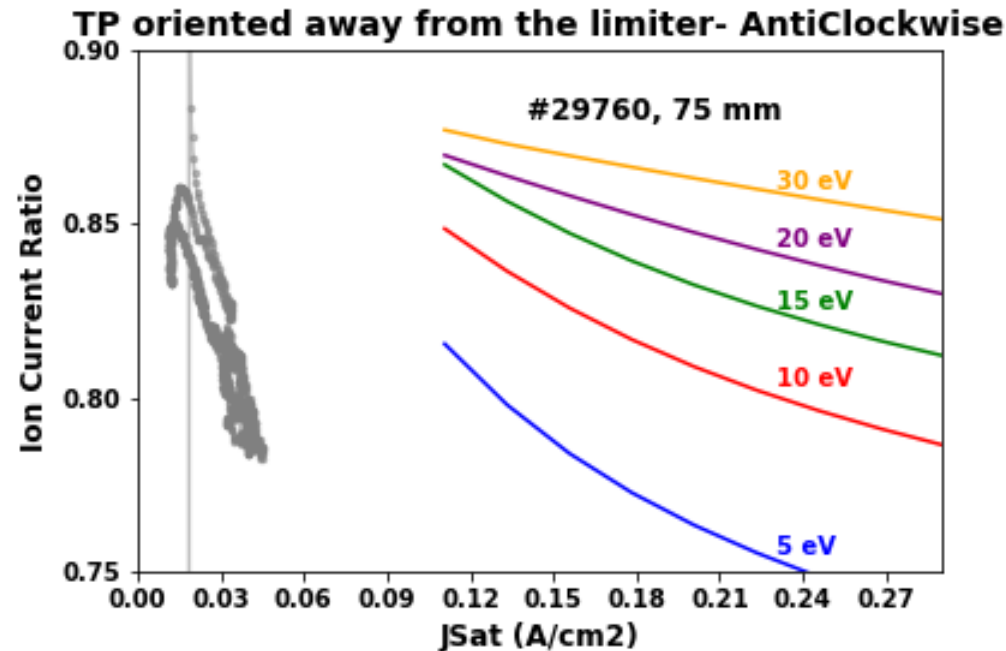
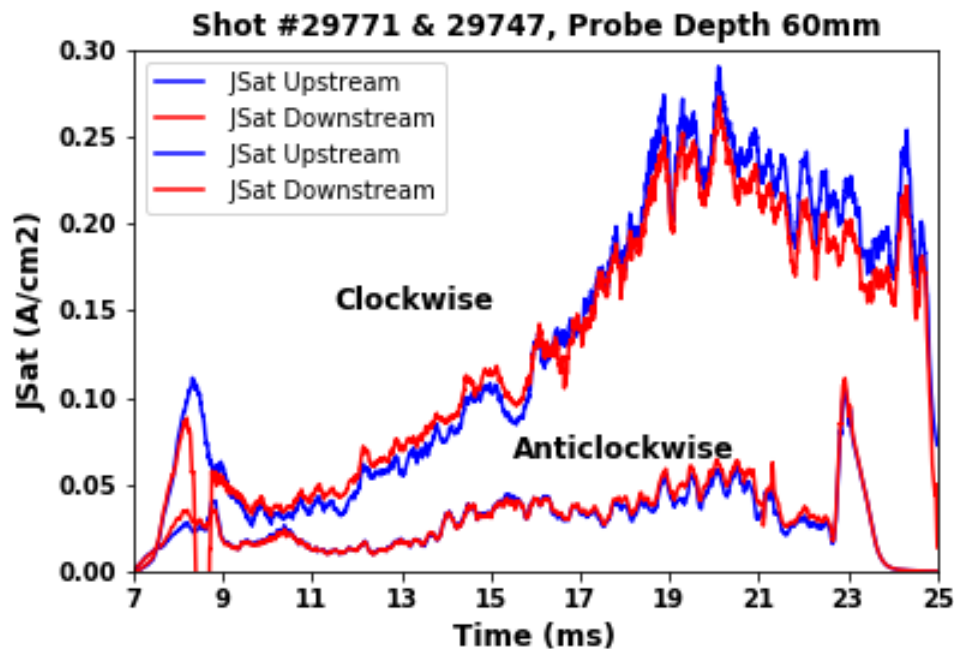
Results from particle-in-cell numerical simulation of James Paul Gunn₁₆

Electron Temperature Measurement



Electron temperature increases over time

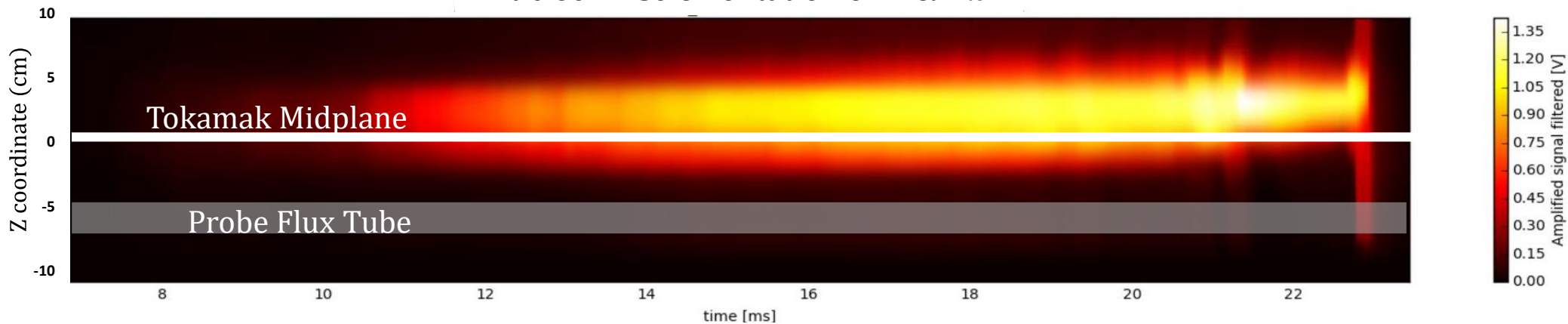
Current Density for both Plasma Orientations



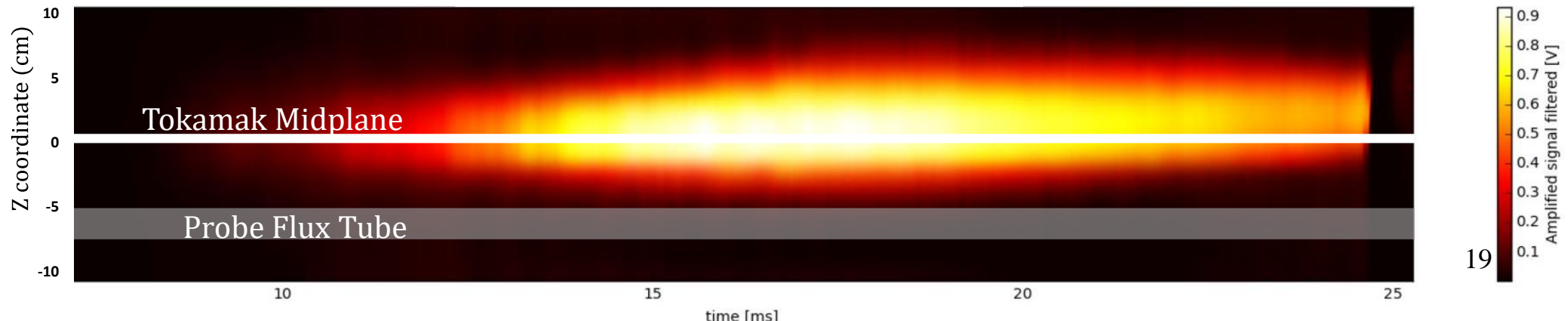
Electron temperature cannot be determined from the current PIC model because ion current density is out of the modelling range

Relative Position of Tunnel Probe to Plasma

Anticlockwise Orientation of I_P & B_{tor}



Clockwise Orientation of I_P & B_{tor}



Conclusion

- Tunnel Probe can be used to measure edge plasma rotation [Mach number] and electron temperature
- Mach number ranged from -0.4 to 0.2, corresponding to real velocities up to 18 km/s, and showed some reversal of rotation of plasma
- Electron temperature for clockwise plasma orientation was determined, and some asymmetry was observed for probe orientation towards versus away from the limiter
- Electron temperature could not be determined for the tunnel probe at the anticlockwise plasma orientation

Future Experiments

- Repeat experiments (preferably in the same day) so plasma conditions are more comparable and error can be determined
- Complete more simulations to determine the electron temperatures for a broader range of current densities and lower toroidal magnetic field

18:05, Thursday, March 7th



We did it!