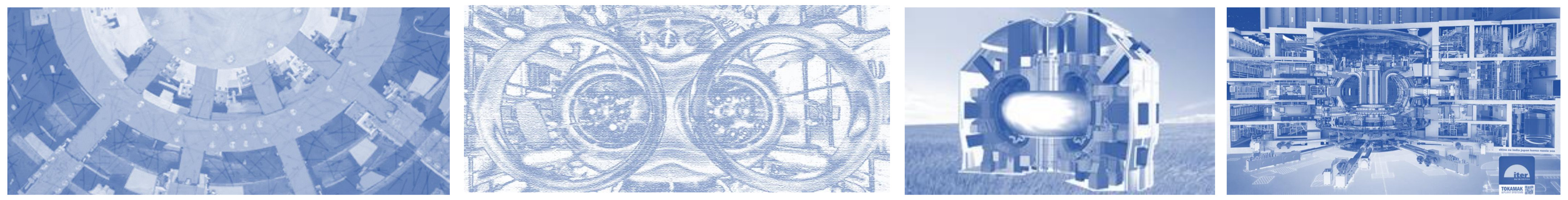

Highly electronegative plasma conditions in the SPIDER negative ion source

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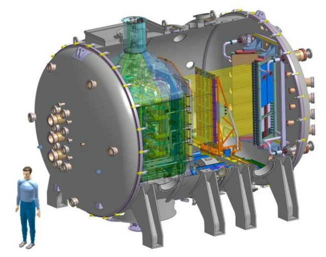
INTRODUCTION



SPIDER [1] is the prototype RF ion source for ITER Heating and Diagnostic Neutral Beams

- Up to 350 A/m^2 of 100 keV H$^-$, divided in 1280 beamlets, distributed over approximately 1 m^2
- The beam is extracted from an RF plasma, generated in 8 drivers (up to 100kW RF power/driver)
- The plasma is cooled in the *expansion region* by a transverse magnetic filter field
- The formation of negative ions is enhanced by the injection of cesium

The increased negative ion density in the vicinity of the PG can be measured using various source diagnostics, such as CRDS and OES, which are currently used on SPIDER [2]. We present here the measurements of the Langmuir probes embedded in the ion source plasma grid and bias plate [3,4], focussing on the effect of the increased electronegativity on the electron saturation branch of the characteristics.

MODELING THE LANGMUIR PROBES SIGNAL

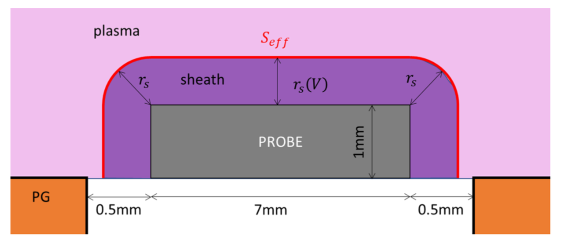
Cylindrical probes, $R_{pr} = 3.5mm$, protruding $h = 1mm$ inside the plasma w.r.t. the surface. The collected current is [5]:

$V < V_p$	$V \geq V_p$
$I_e(V) = \frac{1}{4} e S_{eff}^e v_e \frac{n_+^s}{1+\alpha_s} \exp\left(\frac{V-V_p}{T_e}\right)$	$I_e(V) = \frac{1}{4} e S_{eff}^e v_e \frac{n_+^s}{1+\alpha_s} \left(2\sqrt{\frac{V-V_p}{\pi T_e}} + \exp\left(\frac{V-V_p}{T_e}\right) \mathrm{erfc}\left(\sqrt{\frac{V-V_p}{T_e}}\right)\right)$
$I_-(V) = S_{eff}^-(V_p) \frac{n_+^s \alpha_s}{1+\alpha_s} e u_B^- \exp\left(\frac{V-V_p}{T_-}\right)$	$I_-(V) = e S_{eff}^-(V) \frac{n_+^s \alpha_s}{1+\alpha_s} u_B^-$
$I_+(V) = e S_{eff}^+(V) n_+^s u_B^+$	$I_-(V) = S_{eff}^-(V_p) n_+^s e u_B^+ \exp\left(\frac{V-V_p}{T_+}\right)$

$S_{eff}^+, S_{eff}^-, S_{eff}^e$: effective areas
S_{geom}: geometrical surface
$S_\perp$: surface $\perp \vec{B}$
m_+, m_-, m_e: (effective) masses for +,-,e
T_+, T_-, T_e: temperatures
n_+^s, n_-^s, n_e^s: sheath densities
$\gamma = T_e/T_-$, $\alpha_s = n_-^s/n_e^s$
$n_+^s = n_e^s + n_-^s$ quasineutrality

with $v_e = \sqrt{\frac{8}{\pi}\frac{T_e}{m_e}}$, $u_B^+ = \sqrt{\frac{T_e}{m_-}}\sqrt{\frac{1+\alpha_s}{1+\gamma\alpha_s}}$, $u_B^- = \sqrt{\frac{T_+}{m_-}}$

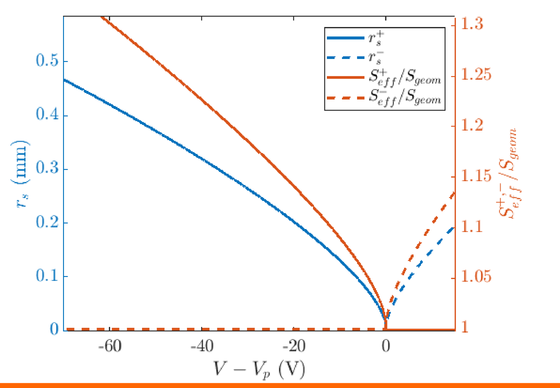
The estimation of $S_{eff}^+, S_{eff}^-, S_{eff}^e$ is crucial. S_{eff}^+, S_{eff}^- depend on V, as it increases the sheath size. A Child-Langmuir model was used to estimate the sheath expansion [5], and the effective area was calculated as shown in the right figure.

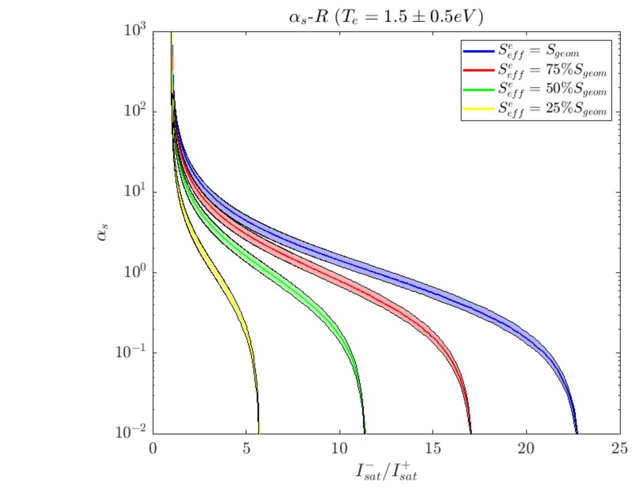


$$S_{eff}^{+,-} = S_{geom} + 2\pi r_s(V)h + \pi^2 R_{pr} r_s(V) + 2\pi r_s^2(V)$$

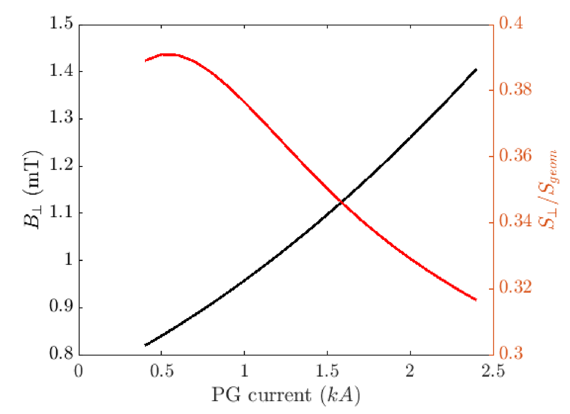
Child-Langmuir model
In cartesian coordinates

$$\begin{cases} \frac{du}{dx} = \frac{eE}{m_{+,-}u(x)} \\ \frac{dE}{dx} = \frac{n_{+,-}^s e u_B^{+,-}}{\epsilon_0 u(x)} \end{cases}$$





α_s VS I_{sat}^-/I_{sat}^+ for various S_{eff}^e and T_e

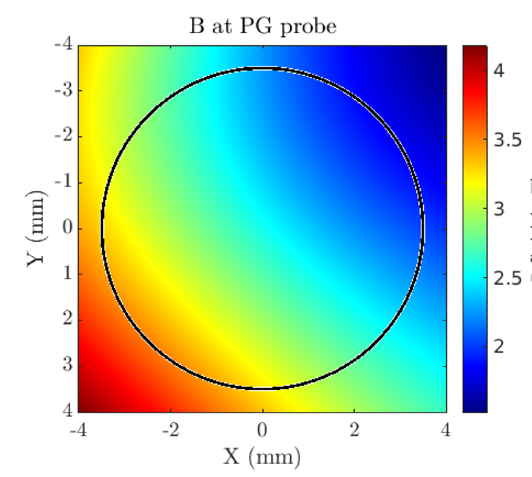


$B_\perp$, $S_\perp/S_{geom}$ VS PG current

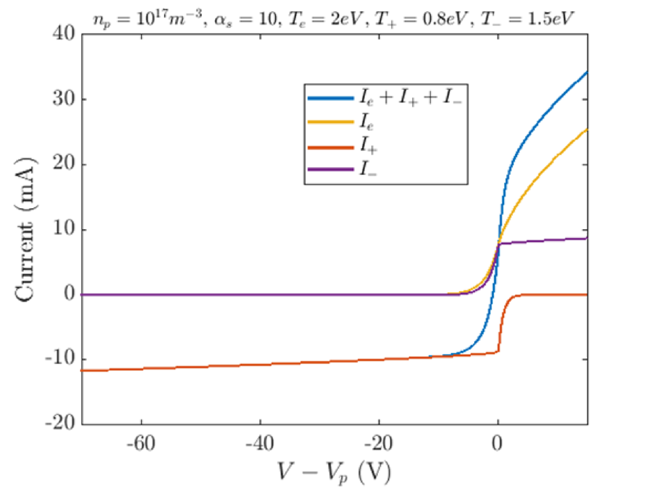
S_{eff}^e is instead assumed to not depend on V and be mostly determined by the $\vec{B}$ configuration, given by the superposition of the PG filter field and the field generated by the CESM in the EG. The important term is the the average field perpendicular to the surface, which determines the surface perpendicular to the field. In the following $S_{eff}^e = S_\perp$.

$$S_\perp = \int_{A_{geom}} \frac{|\hat{n}\cdot\vec{B}|}{B} dS$$

$$B_\perp = \int_{A_{geom}} \frac{|\hat{n}\cdot\vec{B}|}{A_{geom}} dS$$

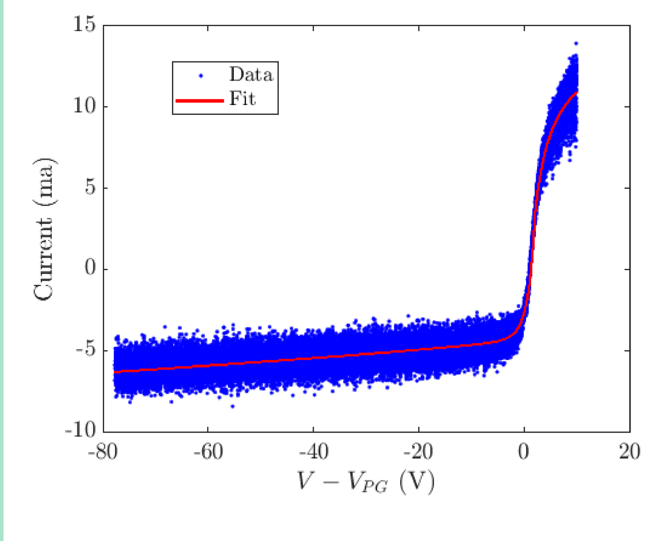


Map of B field produced by CESM and PG filter (1kA)



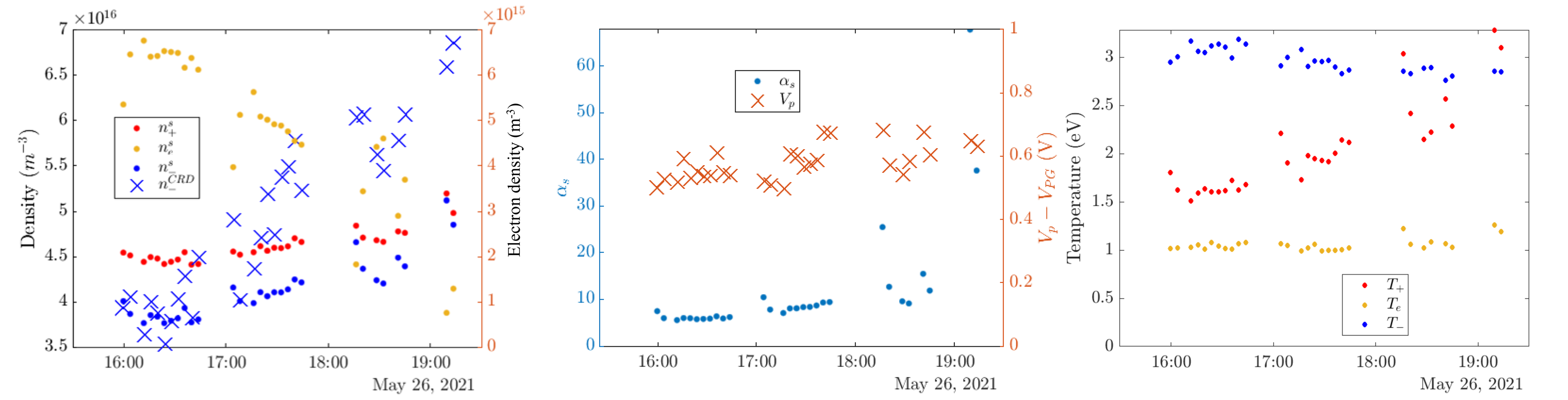
Example of the model fitted to the data.

ELECTRONEGATIVITY IN THE VICINITY OF THE PLASMA GRID



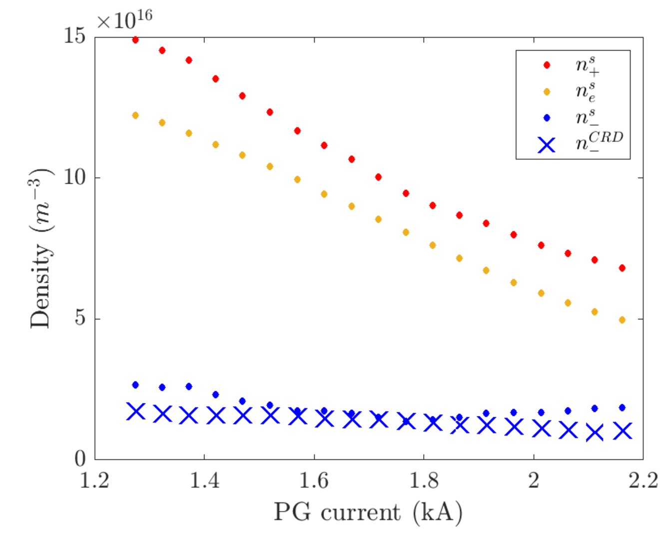
Example of fit for a 45kW, 0.4Pa shot, giving $\alpha_s = 23$, $n_+^s = 4.8 \times 10^{16} m^{-3}$, $T_e = 0.86eV$, $T_+ = 2.0eV$, $T_- = 2.0eV$, $V_p = 2.0eV$

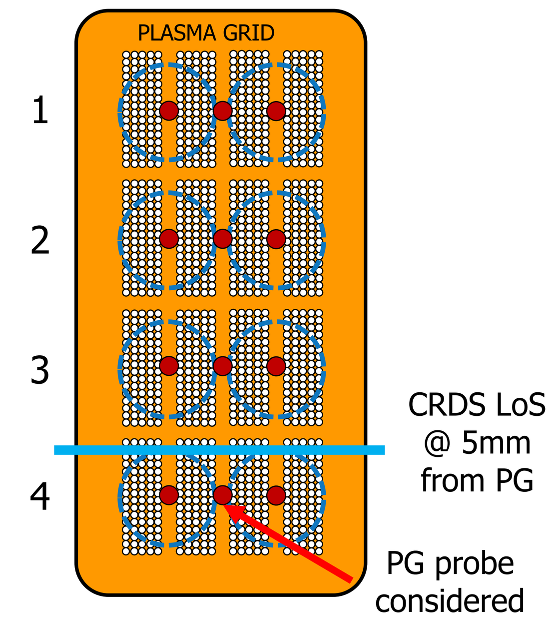
Results for a cesiation day at $400kW$, $0.4Pa$, $I_{PG} = 1.5kA$, $I_{BI} = I_{BP} = 80A$, $12mg/h$ of Cs, $4min$ repetition rate. The electronegativity increases from 8 up to 65, due to the decrease of n_e, and a smaller increase of n_-. This is different w.r.t. to the CRDS variation, which is measuring at 25mm from the PG.

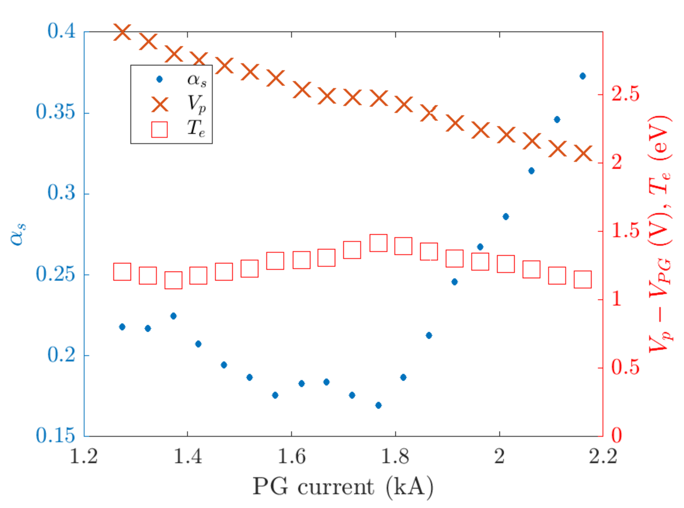


CESIUM-FREE CONDITIONS

The model was tested on data collected before the injection of Cs, and compared with the CRDS results placed in correspondence of the same segment of the considered probe. Results for $400kW$, $0.4Pa$, floating biases are shown for various PG current values. $T_+ = 0.8eV$ and $T_- = 1.5eV$ were kept constant.

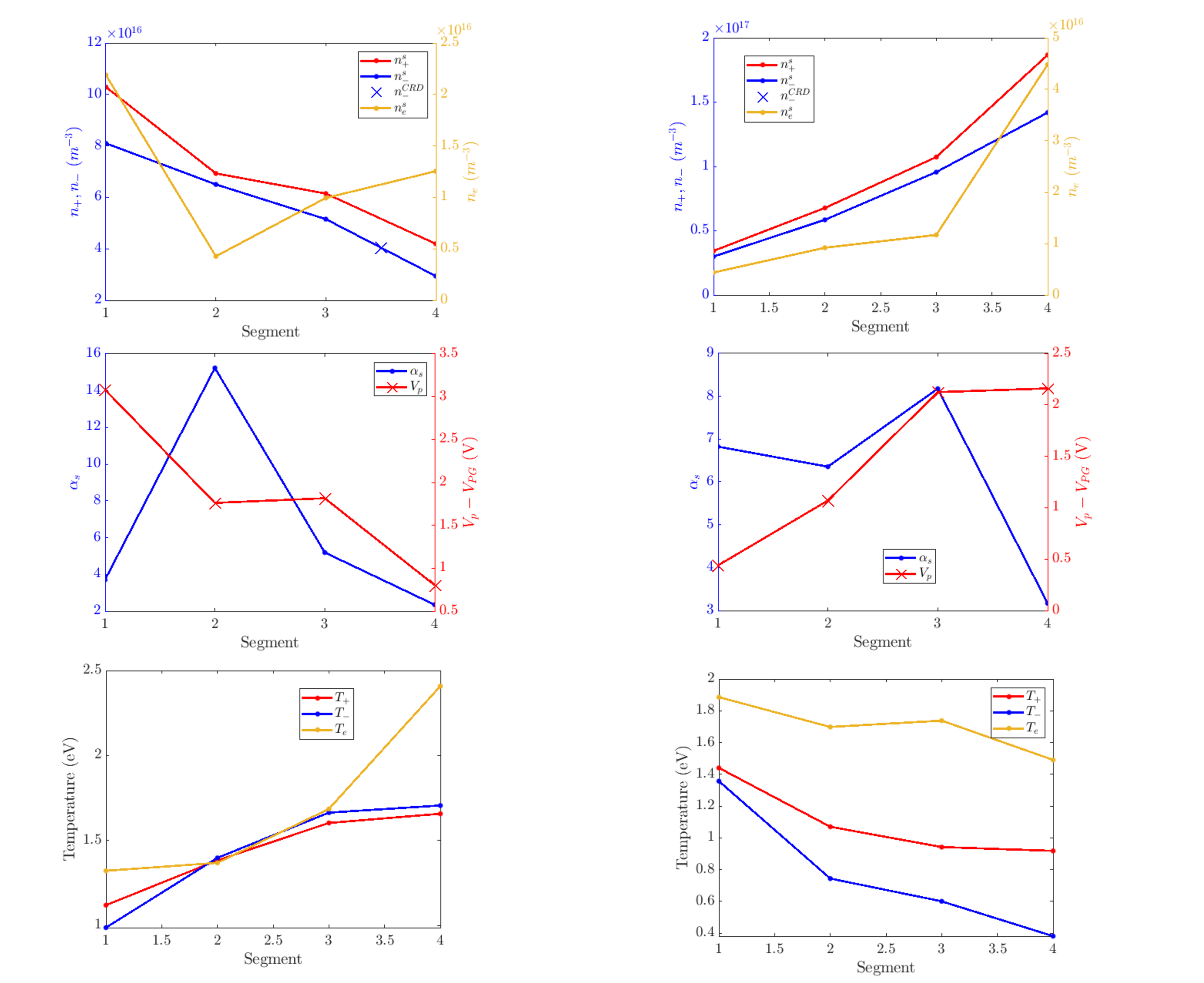






VERTICAL PROFILES

$100kW$, no bias, $0.4Pa$, $1.5kA$ PG filter in standard (left) and reversed (right) configuration.



CONCLUSIONS AND FUTURE WORK

A model to interpret the Langmuir probe characteristics at the PG was developed and applied to experimental data to assess plasma electronegativity. It was tested on Cs-free data, giving results comparable to CRDS measurements. It was then applied to Cs data, obtaining plasma trends for cesiation days, and confirming the top-bottom non-uniformity observed by other diagnostics.
The model will be used extensively to investigate the evolution of negative ion density at the PG and will be applied to BP probes.

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