# Characterization of plasmas in negative ion sources using a Cs-H Collisional Radiative model

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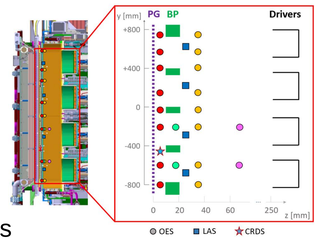
## Introduction

- The Neutral Beam Test Facility (NBTF) in Padova, Italy, hosts two negative ion sources : SPIDER, the prototype for the ITER NBI ion source[1], and NIO1[2].
- Both sources make use of caesium evaporation in order to enhance the production of negative ions
- A collisional radiative (CR) model for Caesium-Hydrogen plasmas was recently developed in order to interpret the intensities of the Cs emission lines measured with Optical Emission Spectroscopy (OES)[3]
- This contribution describes the use of OES with the CR model to characterize the plasmas of SPIDER and NIO1 thanks to the different lines of sight (LoS) available

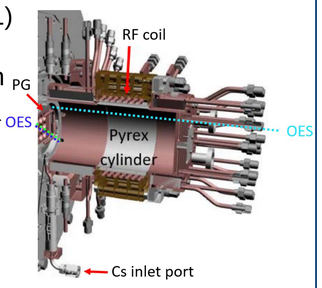
## Experimental setup and method in SPIDER

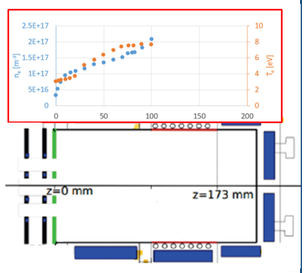
- SPIDER is equipped with many LoSs for OES parallel to PG at 5, 17, 35 & 65 mm
- Four LoSs at 25 mm from PG are dedicated to LAS measurements of $n_{Cs}$[4]
- One LoS at 5 mm from PG is dedicated to CRDS measurements of $n_{H^-}$[5]
- During SPIDER's first campaign with Cs injection, only 852 nm emission line was measured → insufficient to provide a $n_{Cs}$ estimation using only OES → OES & CR model can be used to provide profiles of $n_e$ if assumptions are made on $n_{Cs}$ (from LAS), $n_{H^-}$ (from CRDS & STRIKE[6]), $T_e$ (set at a constant value of 2 eV) and $n_{Cs+}/n_{Cs0}$




## Experimental setup and method in NIO1

- NIO1 (Negative Ion Optimization phase 1) is a compact RF ion source built to study and optimize production and acceleration of $H^-$ ions in continuous operation
- Cs-relevant diagnostics :
  - LAS (Laser Absorption Spectroscopy) LoS parallel to PG (Plasma Grid), at 19 mm distance
  - OES LoS perpendicular to PG going through driver, can be changed to LoS parallel to PG at 19 mm distance
- OES measures many different Cs lines, from which Cs excited state densities can be recovered
  - With OES LoS at PG, direct comparison with $n_{Cs}$ measured by LAS can be made
  - With OES LoS through driver, assumptions can be made on plasma to estimate neutral Cs density



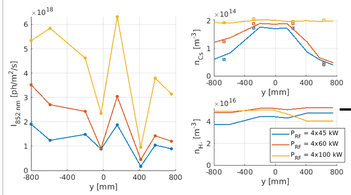




Measurements from P. Veltri et al. [7]

## Results in SPIDER

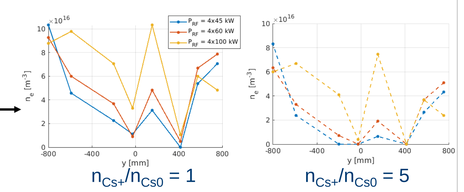
### Effect of changing RF power (LoSs at **35 mm** from PG)

Measurements & hypotheses



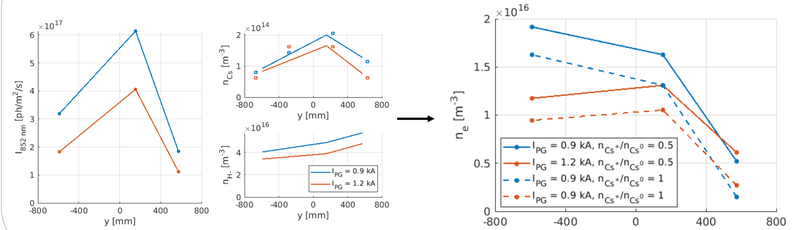
ISBI = ISBP = 80 A, $I_{PG}$ = 1.05 kA
(1.2 kA for case $P_{RF}$ = 4x100 kW)

Resulting $n_e$

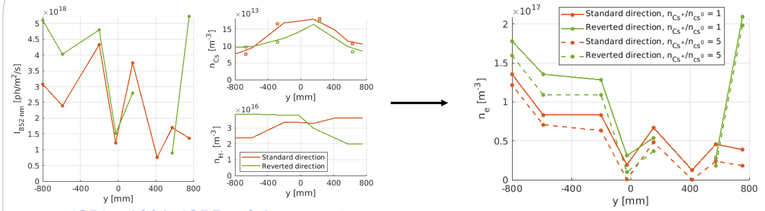



*We give the results with different assumptions on $n_{Cs+}/n_{Cs0}$ as the density of $Cs^+$ is unknown and mutual neutralization between $Cs^+$ and $H^-$ is an important process[8], especially if $n_{H^-} \sim n_e$*

### Effect of changing PG filter field (LoSs at **5 mm** from PG)

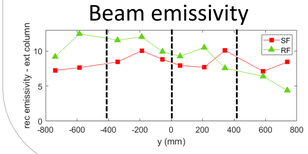



### Effect of reverting the direction of filter field current (LoSs at **35 mm** from PG)




ISBI = 190A, ISBP = 0 A,
$P_{RF}$ = 4 x 45 kW, , $I_{PG}$ = 1.05 kA

Beam emissivity

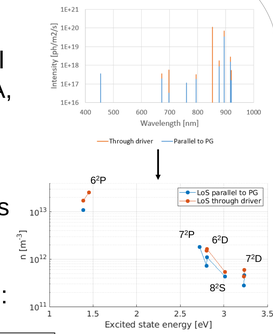



- Inverting of filter field direction causes increase of $n_e$ at top of the source
  Consistent with behavior of the beam ← (e.g. emissivity from beam tomography[9])
  extracted $H^-$ current decreased at top after inverting $I_{PG}$
- Slight increase of $n_e$ at bottom

## Results in NIO1

### Comparing LoS at PG and LoS through driver

- Comparing OES LoS through driver or parallel to PG (with P = 1600 W, p = 1.5 Pa, $I_{PG}$ = 10 A, $T_{Cs}$ = 210 °C, Bias = 25 V)
- LAS measures $n_{Cs0} \sim 1.5 \times 10^{16}$ - $2 \times 10^{16}$ $m^{-3}$ at PG
- Cs emission lines → Cs excited state densities



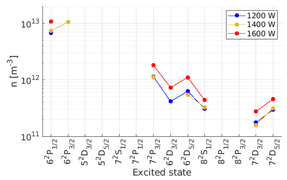

- Estimations of $n_{Cs0}$ using OES and CR model :

| | Hypotheses | | | | | |
|---|---|---|---|---|---|---|
| LoS | Length LoS | $n_e$ [$m^{-3}$] | $T_e$ [eV] | $n_{H^-}$ [$m^{-3}$] | $n_{Cs+}/n_{Cs0}$ [-] | $n_{Cs0}$ (ground state) [$m^{-3}$] |
| Driver | 13 cm | 5.0 x $10^{17}$ | 9 | Mutual neutralization irrelevant | | 2.5 x $10^{15}$ |
| PG | 10 cm | 1.0 x $10^{17}$ | 3.5 | 5 x $10^{15}$ | 5 | 2.6 x $10^{16}$ |

We assumed that Cs lines seen by LoS perpendicular to PG come from rear part of the source. Estimate of $n_{Cs0}$ seems large & excited state distribution similar to case parallel to PG → maybe this LoS collects mostly light from cold plasma in extraction region ?

### Characterization of the plasma during a RF power scan

- As in SPIDER, the Cs OES data can be used to estimate $n_e$ near the PG by making assumptions on the other plasma parameters and $n_{Cs0}$
- During previous power scans, LAS measurement showed no substantial change when power was increased : we assume $n_{Cs0}$ is constant
- Results show almost no difference in $n_e$ for P = 1200 W and 1400 W, but increases when raising to 1600 W




| | Hypotheses | | | | |
|---|---|---|---|---|---|
| Power [W] | $T_e$ [eV] | $n_{H^-}$ [$m^{-3}$] | $n_{Cs+}/n_{Cs0}$ [-] | $n_{Cs0}$ (ground state) [$m^{-3}$] | $n_e$ [$m^{-3}$] |
| 1200 | 3.5 | 3 x $10^{15}$ | 5 | 1.5 x $10^{16}$ | 1.05 x $10^{17}$ |
| 1400 | | 4 x $10^{15}$ | | | 1.0 x $10^{17}$ |
| 1600 | | 5 x $10^{15}$ | | | 1.55 x $10^{17}$ |

Other machine parameters : p = 1.5 Pa, $T_{Cs}$ = 210 °C, $I_{PG}$ = 10 A, Bias = 25 V
*(Estimations of $n_{H^-}$ based on the beam current [10] )*

## Conclusion

- A CR model was used with data from Optical Emission Spectroscopy to characterize the plasma of two negative ion sources
- In SPIDER vertical profiles of $n_e$ were performed and showed the effect that increasing RF power and modifying the PG filter field has on the electron density
- In NIO1 estimations showed a smaller neutral Cs density in the driver region than at the PG, and the Cs excited state densities were showed to increase with RF power in accordance to an increase of $n_e$

## References

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