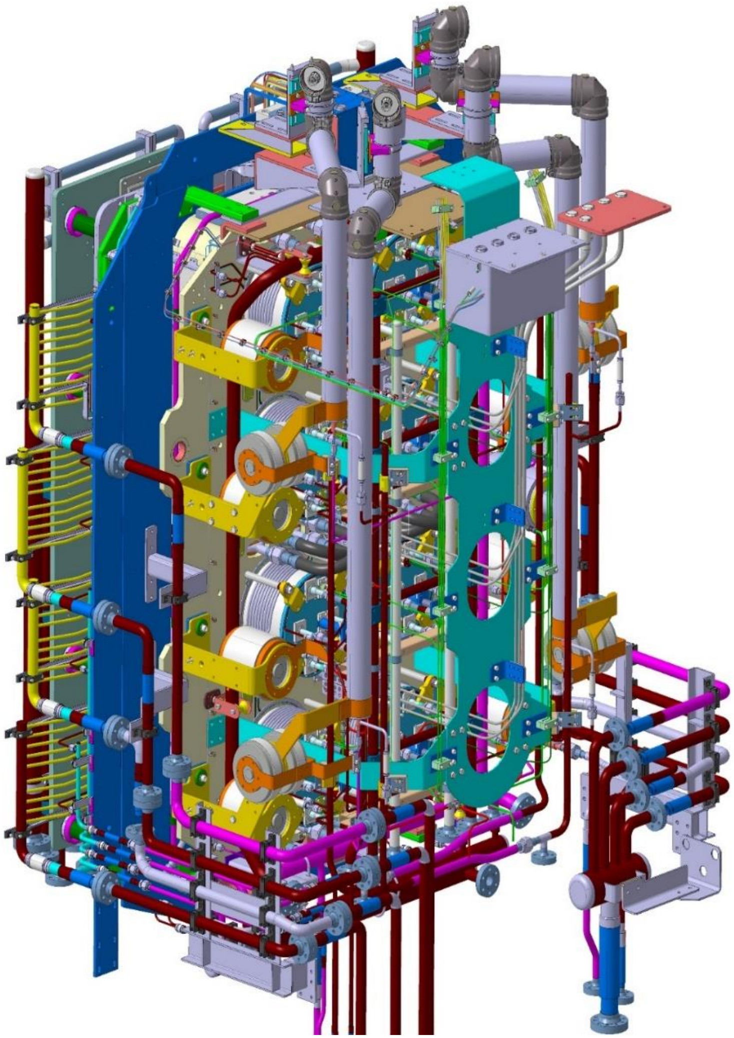
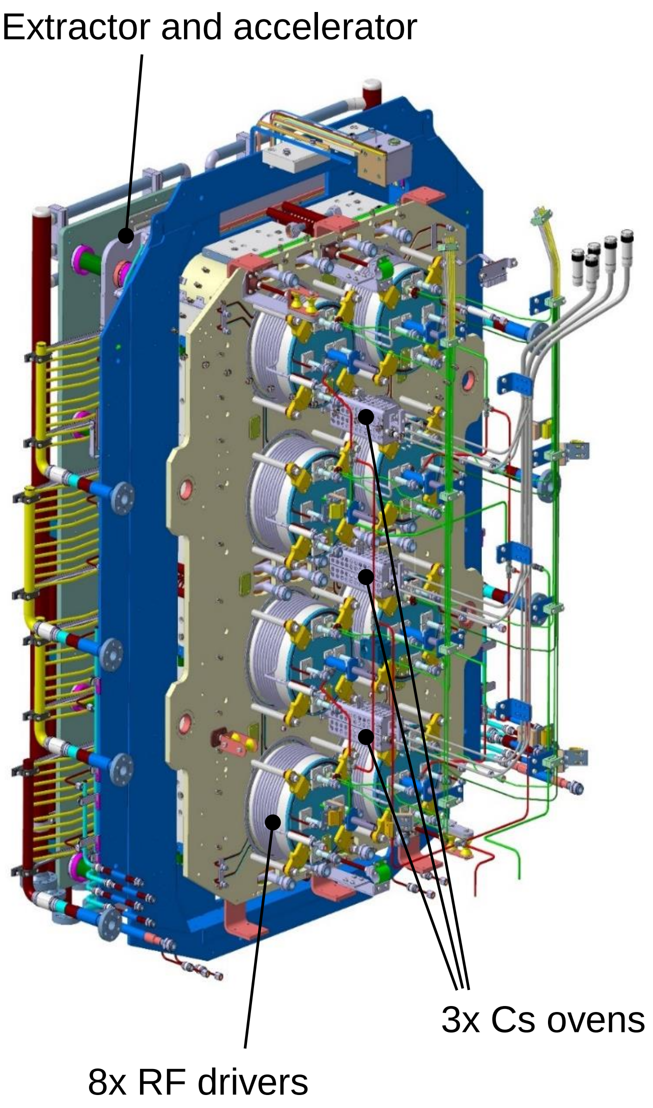


STUDY OF CAESIUM-WALL INTERACTION PARAMETERS WITHIN A HYDROGEN PLASMA

E. Sartori[1,3], V Antoni[1], M. Fadone[1], S Gorno[2], M. Rutigliano[4], G. Serianni[1]

[1]Consorzio RFX, Corso Stati Uniti 4 – 35127, Padova (Italy)
[2]Imperial College London
[3]University of Padova, Dept. of Management and Engineering, Strad. S. Nicola 3, 36100 Vicenza, Italy
[4]CNR-NANOTEC (P.LAS.M.I. Lab), Via Amendola 122/D, 70126 Bari, Italy

CONTEXT AND MOTIVATION FOR THE STUDY

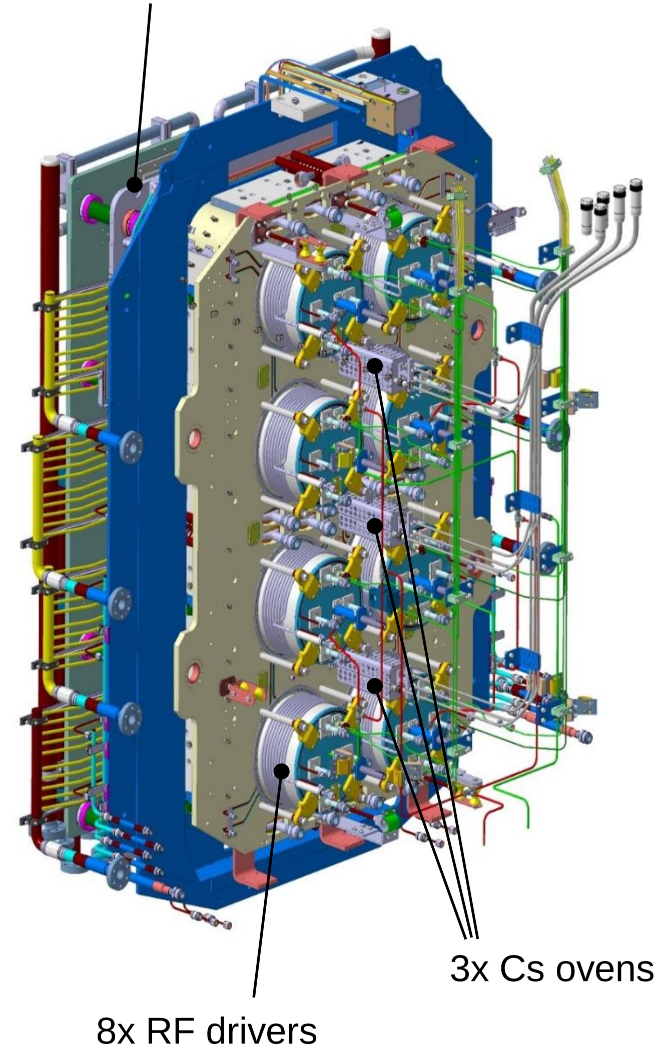


SPIDER is the full-size prototype of the negative ion source for the ITER heating neutral beam.

The ITER milestone was met, with first hydrogen plasma discharges in may 2018.
The next priorities are Commissioning and integration of diagnostics, ramp up of RF driver performance, replacement of faulty components.

Next, high-current beam operation shall start with the use of caesium vapor.

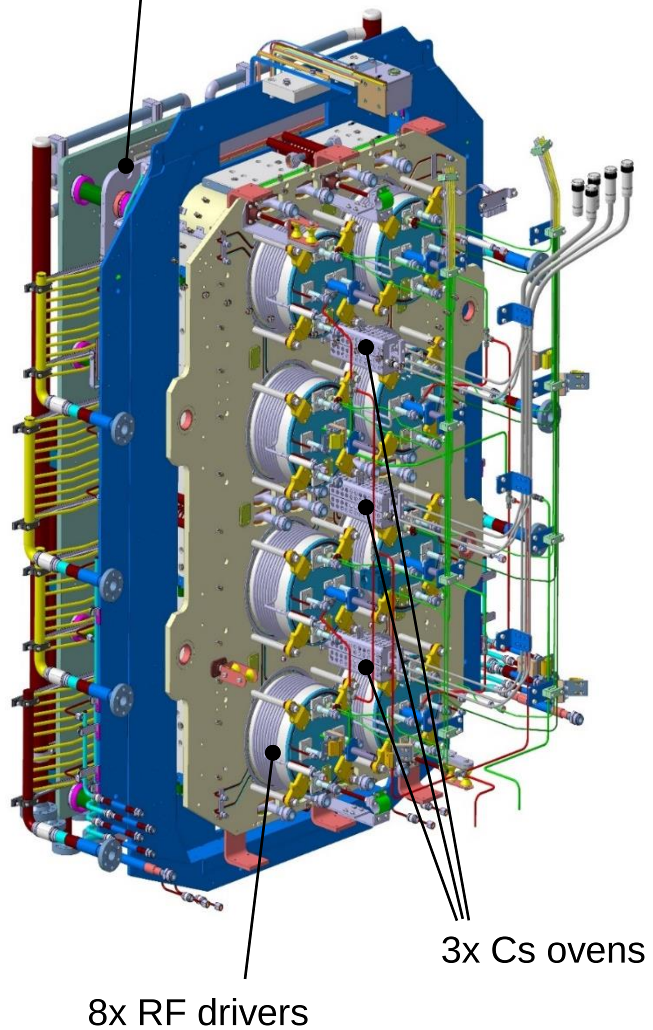
CONTEXT AND MOTIVATION FOR THE STUDY



Preparation to the use of caesium in SPIDER

Use of Cs in the ion source

CONTEXT AND MOTIVATION FOR THE STUDY



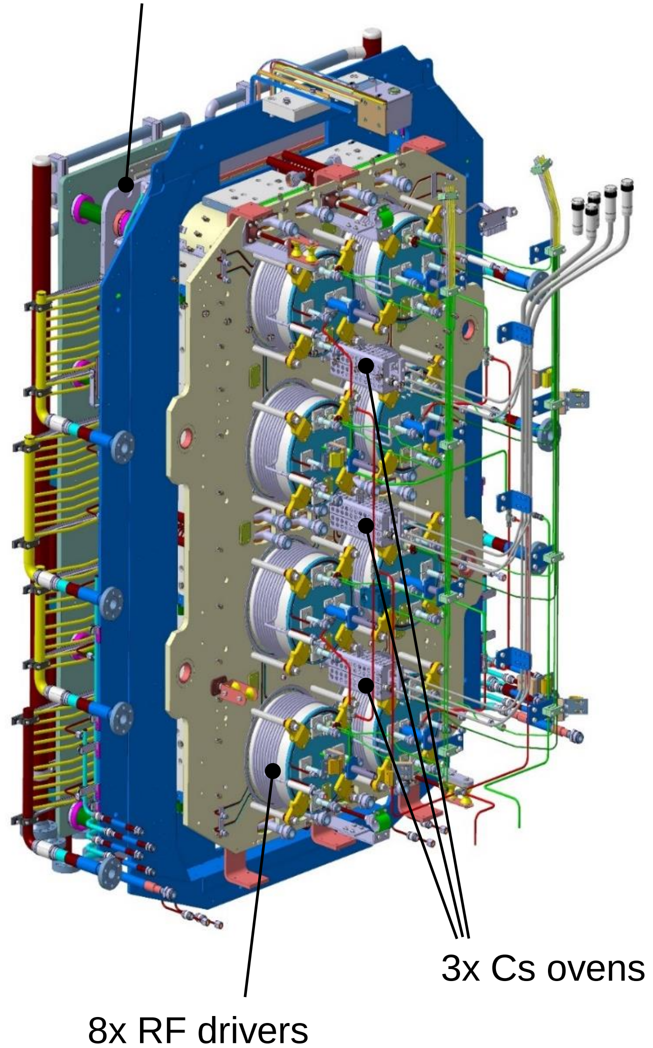
Preparation to the use of caesium in SPIDER

Results from NI community

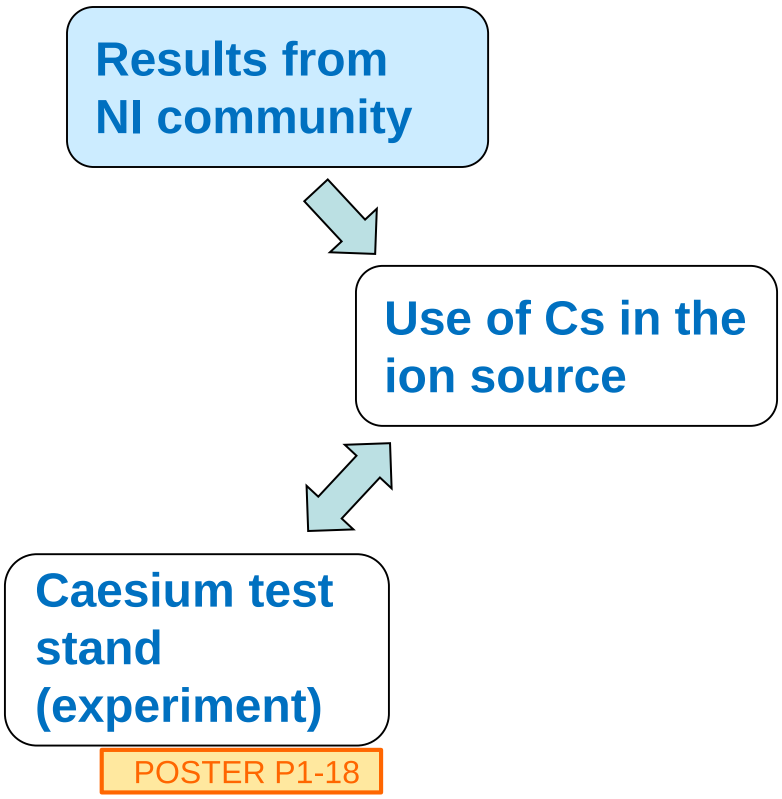
→

Use of Cs in the ion source

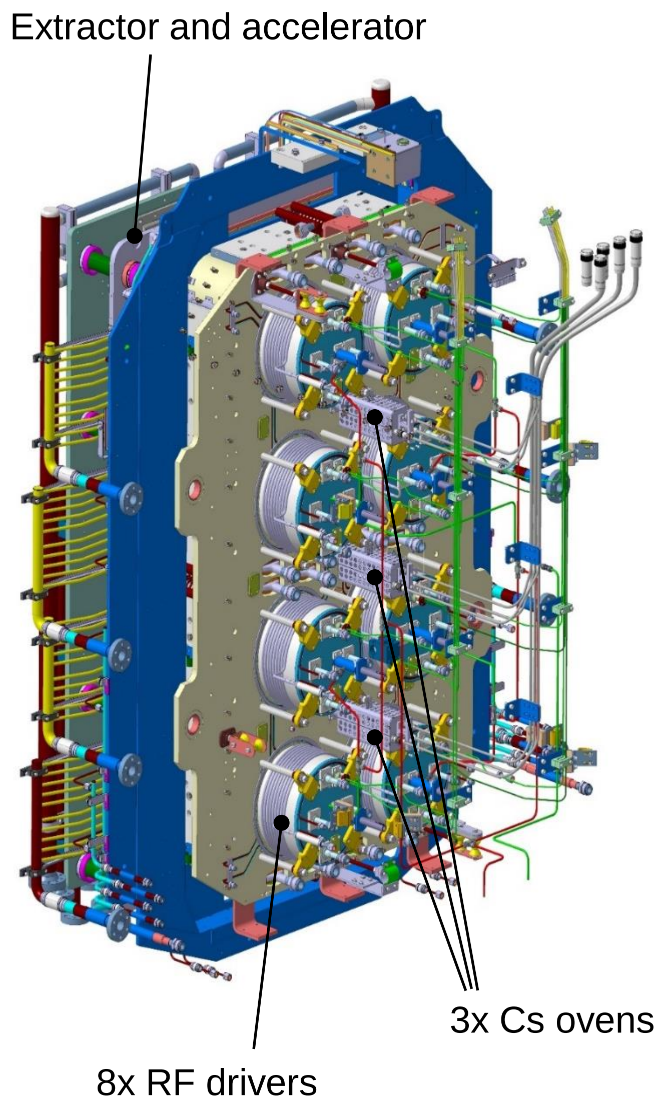
CONTEXT AND MOTIVATION FOR THE STUDY



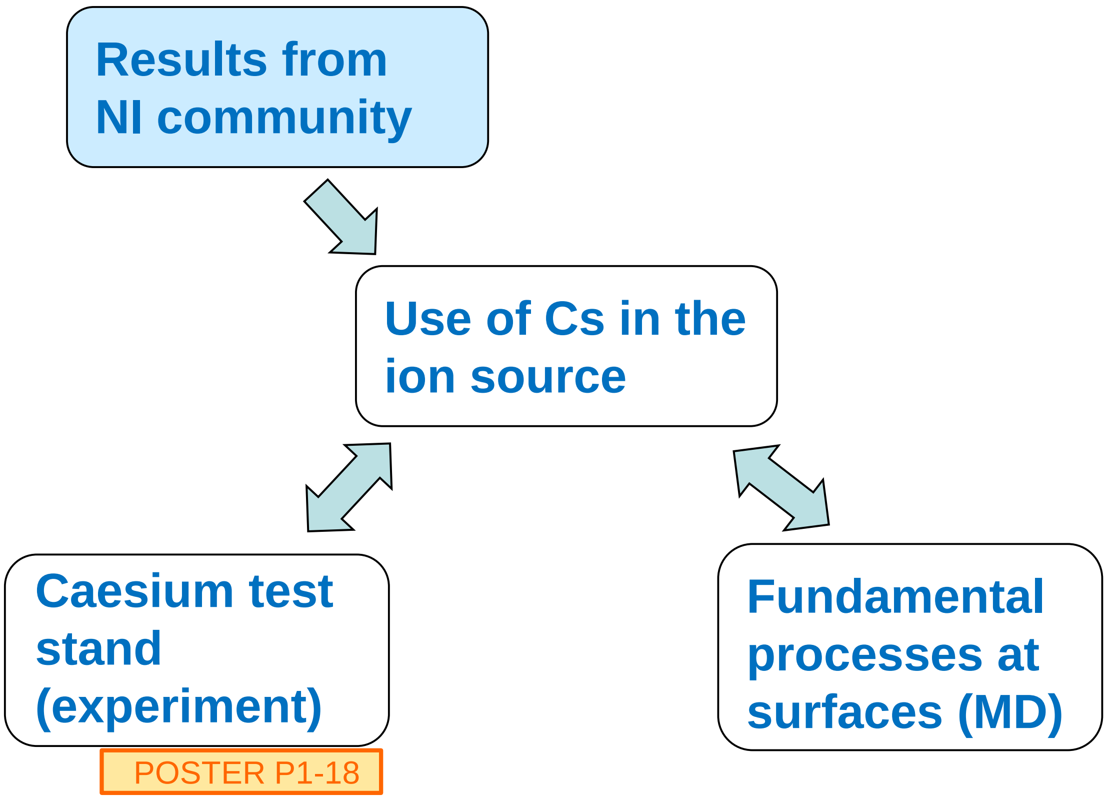
Preparation to the use of caesium in SPIDER



CONTEXT AND MOTIVATION FOR THE STUDY



Preparation to the use of caesium in SPIDER



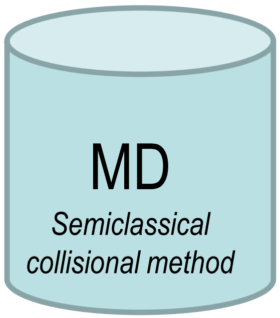
H^- scattering from a MoCs surface: *Ab initio* Molecular Dynamics calculations

INTPUT

- 3D Surface 'model' (A.Damone et al., 2015)
- Surface Temperature (1000K)
- Gas-phase particle mass
- Incidence angles(θ=0° ϕ=0°)
- Initial kinetic energy (E_{kin}) ([0.3:5.0]eV
- Interaction Potentials

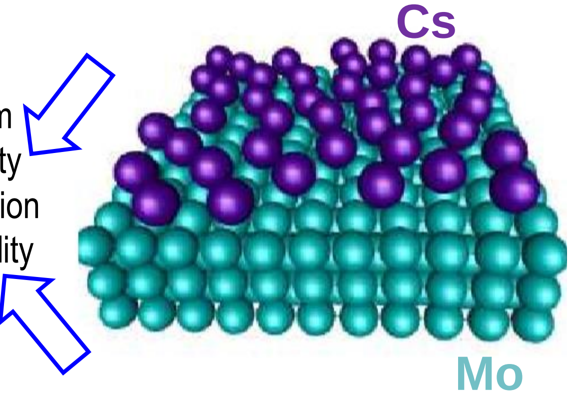
obtained via

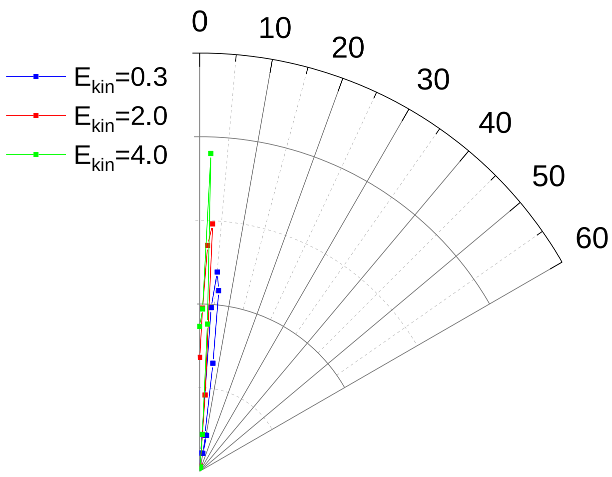
DFT calculations

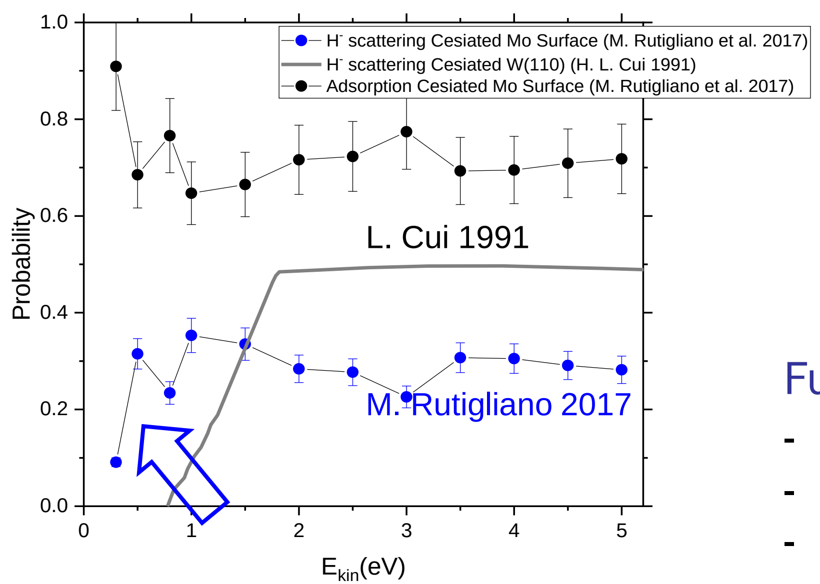


OUTPUT

- Interaction mechanism
- H^- scattering probability
- Final angular distribution
- H adsorption probability





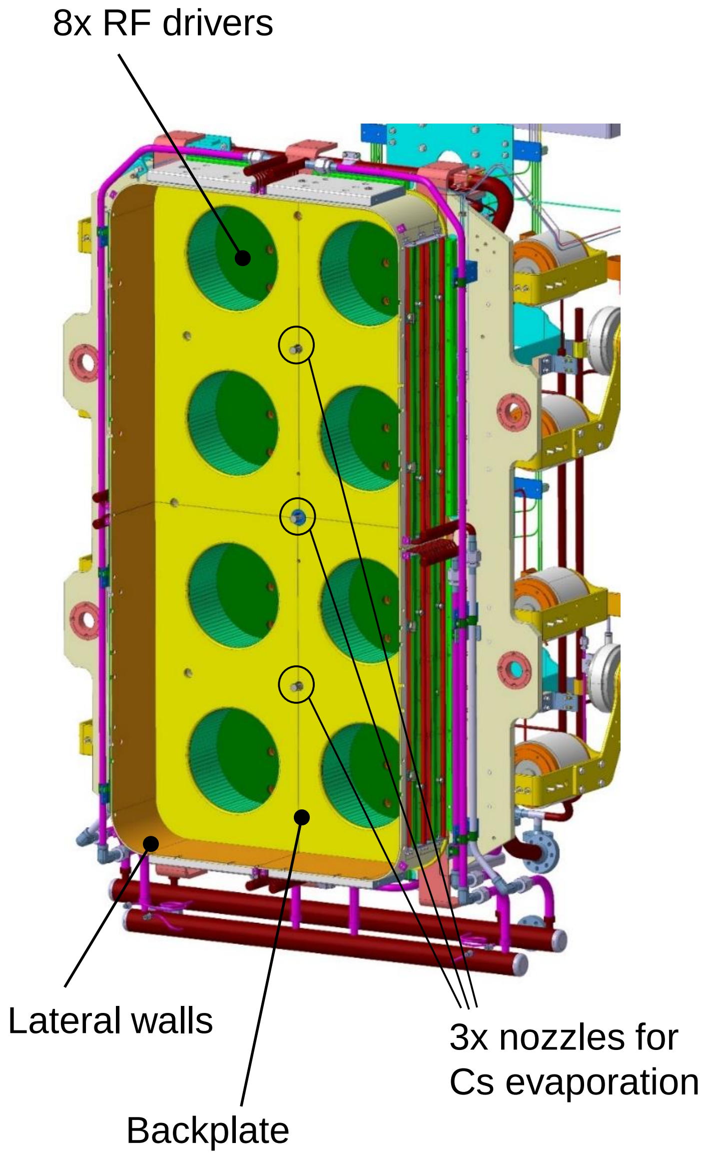


M. Rutigliano et al. Surface Science 664 (2017) 194–200

Future perspectives

- D, D^- scattering;
- Oxygen interaction dynamics investigation
- Investigation of H^- scattering from another surface model and/or a realistic surface determined in experiments.

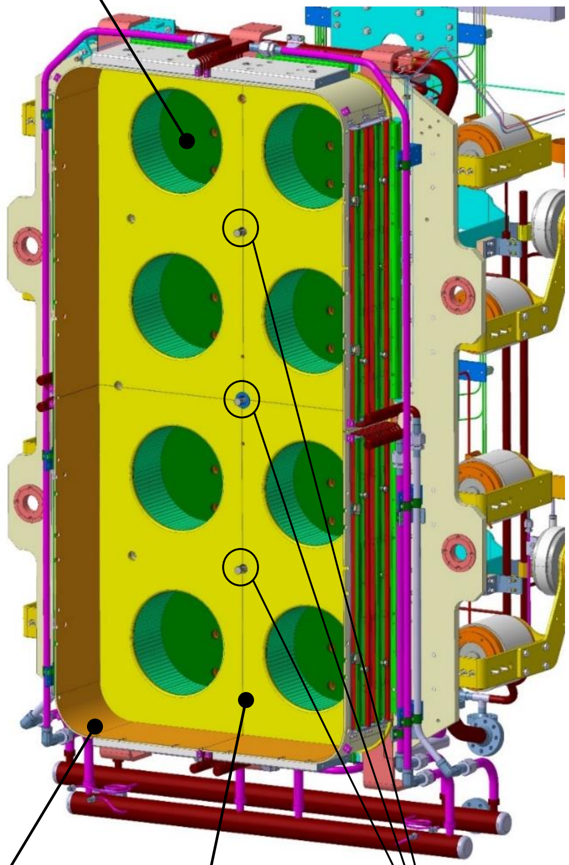
CONTEXT AND MOTIVATION FOR THE STUDY



Aim of this work:

- **Review of phenomena** influencing Cs adsorption and desorption in a hydrogen plasma discharge
- Collect the data concerning the **specificity of SPIDER** design
- Identify the principal **contributions** to the many phenomena involved
  (SPIDER is a very complex and very «rigid» device, we cannot explore the complete space of parameters looking for an influence on caesium effect)

CONTEXT AND MOTIVATION FOR THE STUDY



Aim of this work:

- Review of phenomena influencing Cs adsorption and desorption in a hydrogen plasma discharge
- Collect the data concerning the specificity of SPIDER design
- Identify the principal contributions to the many phenomena involved
(SPIDER is a very complex and very «rigid» device, we cannot explore the complete space of parameters looking for an influence on caesium effect)

⇩

Purpose of this study is not
to find answers,
but to find
the correct questions!

OUTLINE

1 **Surface processes concerning Cs ads/desorption**

$$\Gamma_{des,Cs} = \underline{\Gamma_{th}(T_w)} + \underline{\Gamma_{sput}^{(+)}} + \underline{\Gamma_{sput}^{(BSI)}}$$

- **Sputtering low/energy high energy**
- **Thermal desorption**

2 Transmission probability to plasma bulk

3 Case of SPIDER

Effect of plasma particles:
Cs physical sputtering at low energies (<50eV)

- Dependence on binding energy U_B and impact energy E_i is clear in the eq. of sputtering[1)] for single-specie target

α_N Momentum transfer factor (semiempirical)

Binding energy

Threshold energy:

Binding energy

Sputter yield: $$Y = \frac{0.42}{U_B}\alpha_N S_N\left(1-\frac{E_{th}}{E_i}\right)^2$$

$$E_{th} = 1.5\frac{U_B}{\gamma}(1+1.38\mu^h)^2$$

Sputter coefficient in the low energy regime C_m=C_{m0}=0.039

Stopping potential: $$S_N = C_m\gamma E_i$$

Incident energy

Reduced mass

[1] P Sigmund, et al., Phys. Rev. 184 (2), 383 (1969); N Matsunami, et al., Rad, Eff. Lett. S7, 15 (1980); Y Yamamura, et al., Radiat. Eff. Lett 68, 83 (1982)
[2] M. Wada, et al, Rev Sci Instrum 89, 052103 (2018)
[3] M Wada, et al., AIP Conf. Proc 1869, 020003 (2017)

Effect of plasma particles: Cs physical sputtering at low energies (<50eV)

- Dependence on binding energy U_B and impact energy E_i is clear in the eq. of sputtering[1)] for single-specie target
- To obtain α_N we fitted sputtering yields by Wada [2,3] which are given at fixed U_B

α_N momentum transfer factor (semiempirical)

Sputter yield:

$$Y = \frac{0.42}{U_B}\alpha_N S_N\left(1-\frac{E_{th}}{E_i}\right)^2$$

Binding energy: U_B

Threshold energy:

$$E_{th} = 1.5\frac{U_B}{\gamma}(1+1.38\mu^h)^2$$

Stopping potential:

$$S_N = C_m \gamma E_i$$

Sputter coefficient in the low energy regime C_m=C_{m0}=0.039

Incident energy: E_i

Reduced mass: γ

[1] P Sigmund, et al., Phys. Rev. 184 (2), 383 (1969); N Matsunami, et al., Rad, Eff. Lett. S7, 15 (1980); Y Yamamura, et al., Radiat. Eff. Lett 68, 83 (1982)
[2] M. Wada, et al, Rev Sci Instrum 89, 052103 (2018)
[3] M Wada, et al., AIP Conf. Proc 1869, 020003 (2017)

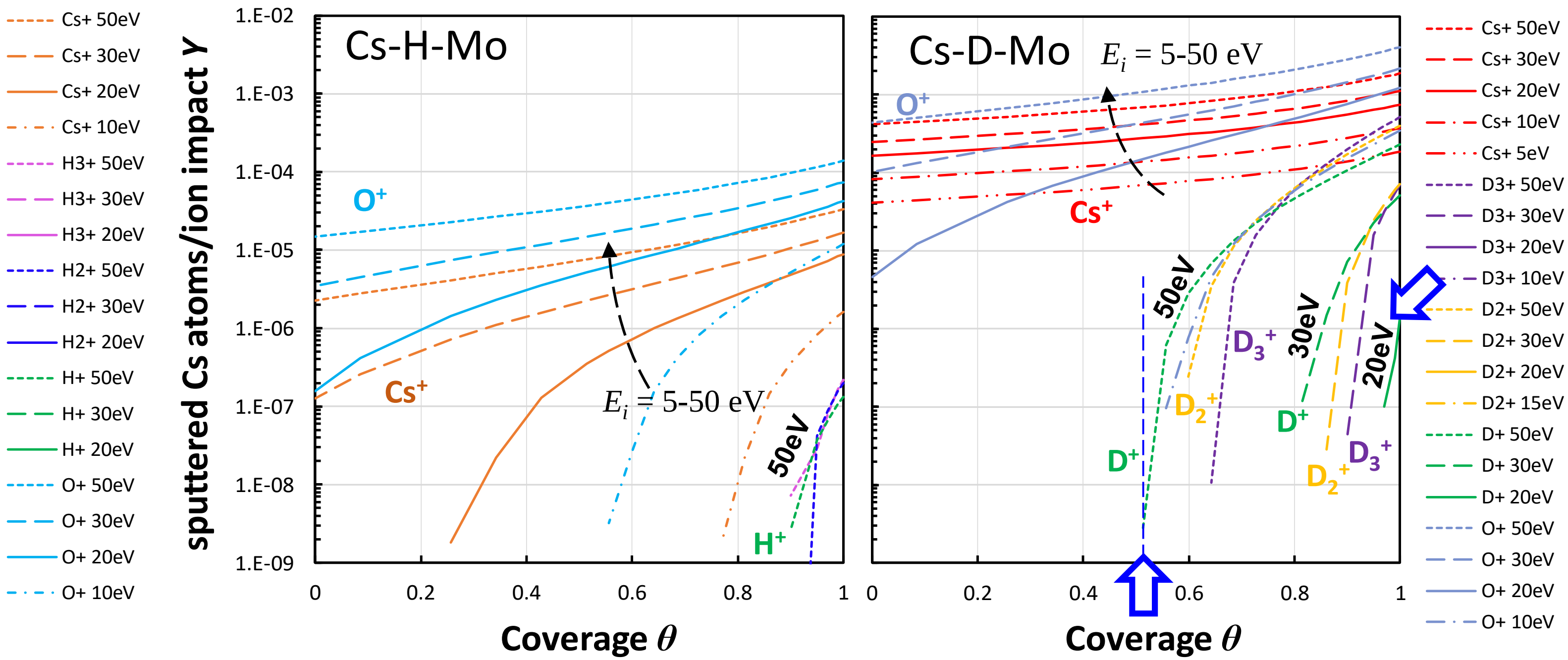
Effect of plasma particles: Cs physical sputtering at low energies (<50eV)

- Dependence on binding energy U_B and impact energy E_i is clear in the eq. of sputtering[1)] for single-specie target
- To obtain α_N we fitted sputtering yields by Wada [2,3] which are given at fixed U_B

NOTES:

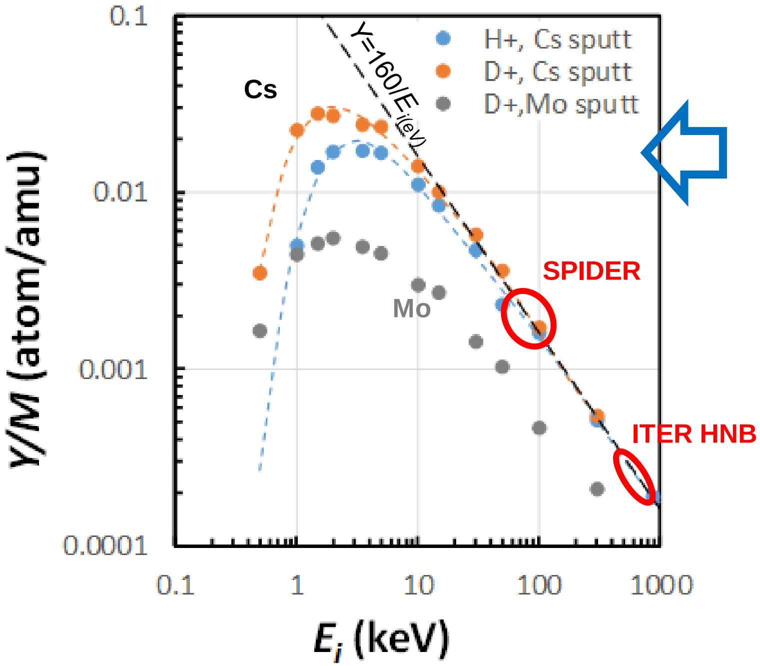
1- Minimum energy for Cs sputtering by D (~20eV)

2- Minimum fractional coverage θ below which sputtering by deuterium seems uneffective



[1] P Sigmund, et al., Phys. Rev. 184 (2), 383 (1969); N Matsunami, et al., Rad, Eff. Lett. S7, 15 (1980); Y Yamamura, et al., Radiat. Eff. Lett 68, 83 (1982)
[2] M. Wada, et al, Rev Sci Instrum 89, 052103 (2018)
[3] M Wada, et al., AIP Conf. Proc 1869, 020003 (2017)

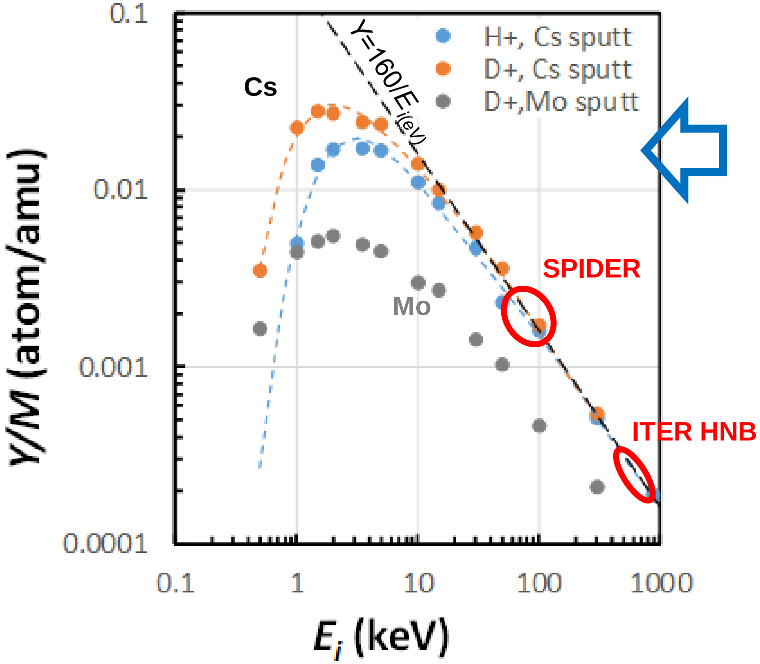
Effect of high energy particles: Cs physical sputtering at high energies (> 1keV)



Sputtering yield *Y* TRIM calculation for a single closed-packed Cs layer on a Mo thick wall

- Cs binding energy of 0.8eV for closely-packed monolayer, Mo atom displacement energy of 34eV for bulk Mo.
- Calculations for a Cs coverage of 20 monolayers showed slightly lower yield per amu, but identical asymptotic behavior at relatively high energies.
- Mo sputtering yield is one order of magnitude less

Effect of high energy particles: Cs physical sputtering at high energies (> 1keV)



Sputtering yield *Y* TRIM calculation for a single closed-packed Cs layer on a Mo thick wall

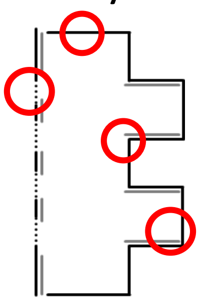
- Cs binding energy of 0.8eV for closely-packed monolayer, Mo atom displacement energy of 34eV for bulk Mo.
- Calculations for a Cs coverage of 20 monolayers showed slightly lower yield per amu, but identical asymptotic behavior at relatively high energies.
- Mo sputtering yield is one order of magnitude less

ISSUE:

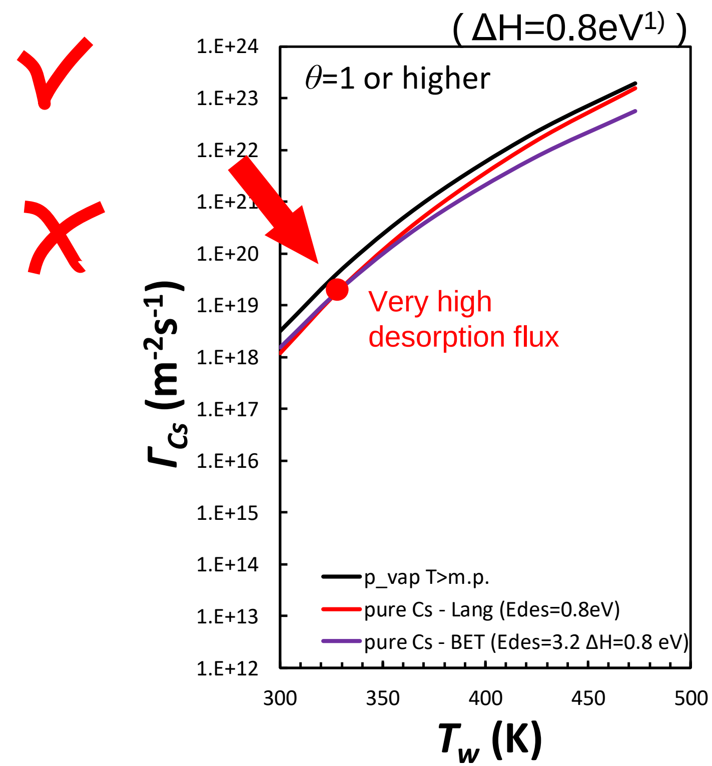
- DOES NOT CONSIDER INTEGRATED DAMAGES AT THE MICROSCALE

Thermal desorption, and adsorption

- At converter: partial coverage → modified Langmuir isotherm. (or Temkin) linear decrease of desorption energy following Fedorus [2)]
- Other surfaces: Transition state theory as a generalization of desorption proc., B.E.T. theory for multilayer adsorption, condensation…



If we use this flux for all surfaces → steady state, only 6min eq. of Cs evaporation is kept in the source!
→ does not describe reality

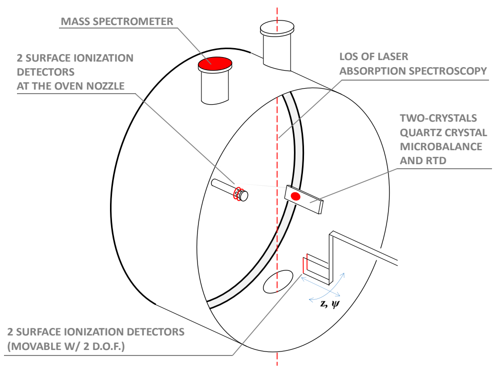


[1] R G. Behrens, et al., J. Chem. Thermodynamics 77,9, 1035-1044

Temperature Programmed Desorption in CATS (preliminary)

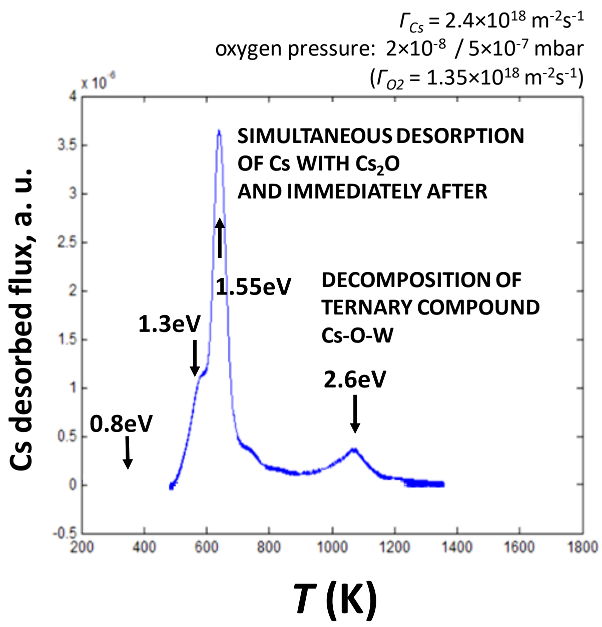
CAesium Test Stand «CATS»
Main purpose: test SPIDER Cs ovens

Diagnostics:
- Cs evap rate: SID at oven nozzle
- Cs density: movable SID
- Cs line integr density: LAS
- Cs sticking: QCM and TC



POSTER P1-18

- TPD gives information about rate of desorption, kinetic order of desorption, Energy of desorption… measurement in CATS and interpretation following 1st order desorption analysis by Redhead[1)]:

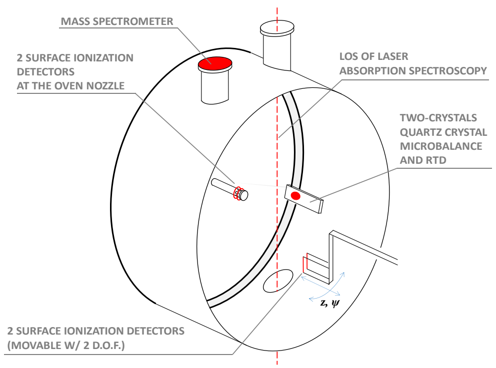


[1] P. A. Redhead, *Vacuum*, **12**, 203-211 (1962)

Temperature Programmed Desorption in CATS (preliminary)

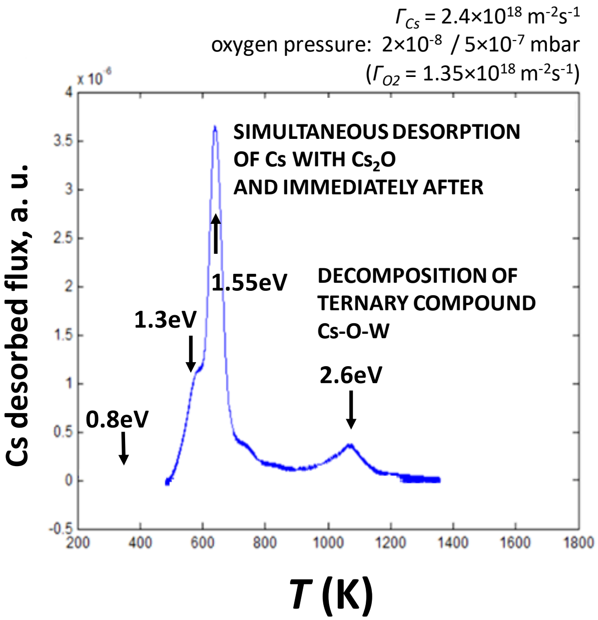
CAesium Test Stand «CATS»
Main purpose: test SPIDER Cs ovens

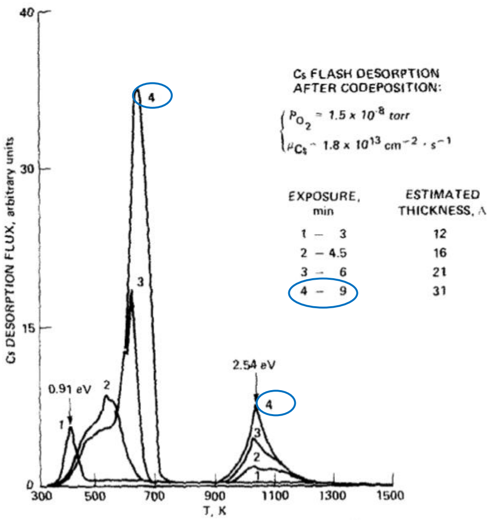
Diagnostics:
- Cs evap rate: SID at oven nozzle
- Cs density: movable SID
- Cs line integr density: LAS
- Cs sticking: QCM and TC



POSTER P1-18

- TPD gives information about rate of desorption, kinetic order of desorption, Energy of desorption… measurement in CATS and interpretation following 1st order desorption analysis by Redhead[1)]:





[2] C.A. Papageorgopoulos, J.L. Desplat, Surface Science 92 (1980) 119-132.

- similar spectra and desorption energies found in literature, with simultanous desorption of Cs_2O, **Cs_2O** zero order desorption energy **1.2eV** [2)]

[1] P. A. Redhead, *Vacuum*, **12**, 203-211 (1962)

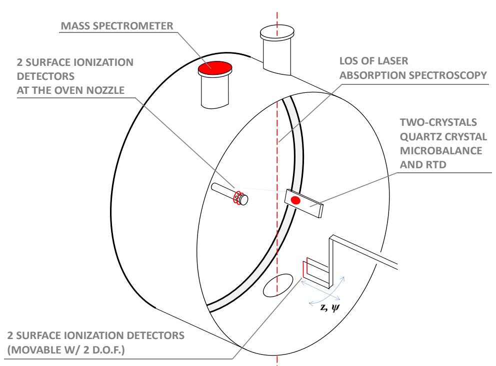
Temperature Programmed Desorption in CATS (preliminary)

CAesium Test Stand «CATS»

Main purpose: test SPIDER Cs ovens

Diagnostics:

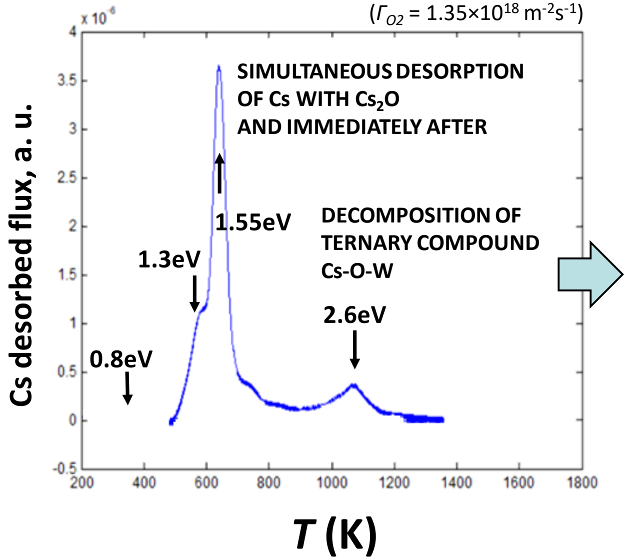
- Cs evap rate: SID at oven nozzle
- Cs density: movable SID
- Cs line integr density: LAS
- Cs sticking: QCM and TC

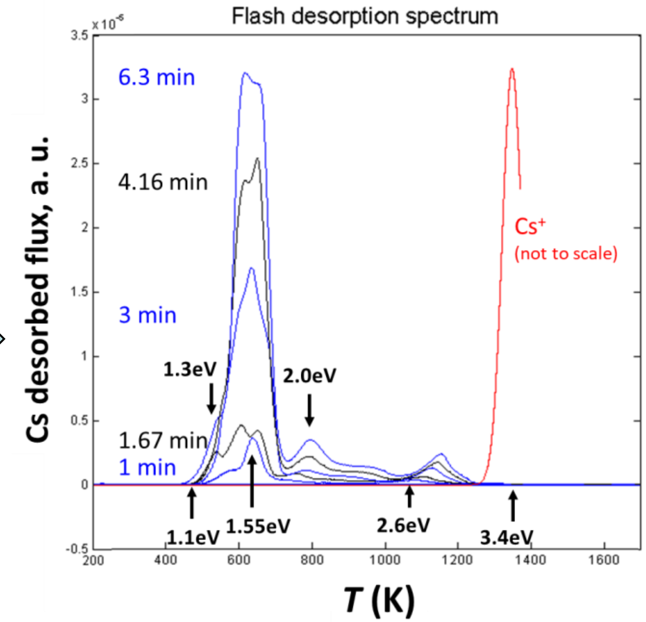


POSTER P1-18

- TPD gives information about rate of desorption, kinetic order of desorption, Energy of desorption… measurement in CATS and interpretation following 1st order desorption analysis by Redhead[1]:

$\Gamma_{Cs} = 2.4\times10^{18}$ m^{-2}s^{-1}
oxygen pressure: 2×10^{-8} / 5×10^{-7} mbar
($\Gamma_{O2} = 1.35\times10^{18}$ m^{-2}s^{-1})





- similar spectra and desorption energies found in literature, with simultanous desorption of Cs_2O, Cs_2O zero order desorption energy **1.2eV** [2]
- TPD spectra with increasing coverage shared the leading edge; if zero order desorption, **Cs** desorption energy is approx **1.1 eV**
- *Cs+Cs2O confirmed by XPS analysis (but air and long time in between)*

[1] P. A. Redhead, *Vacuum*, **12**, 203-211 (1962)
[2] C.A. Papageorgopoulos, J.L. Desplat, Surface Science 92 (1980) 119-132.

Thermal desorption, and adsorption

- At converter: partial coverage → modified Langmuir isotherm. (or Temkin) linear increase of ads energy
- At other surfaces:

  as working hypotheses:
  (measurements to be done also in conditions more relevant to the ion source environment)

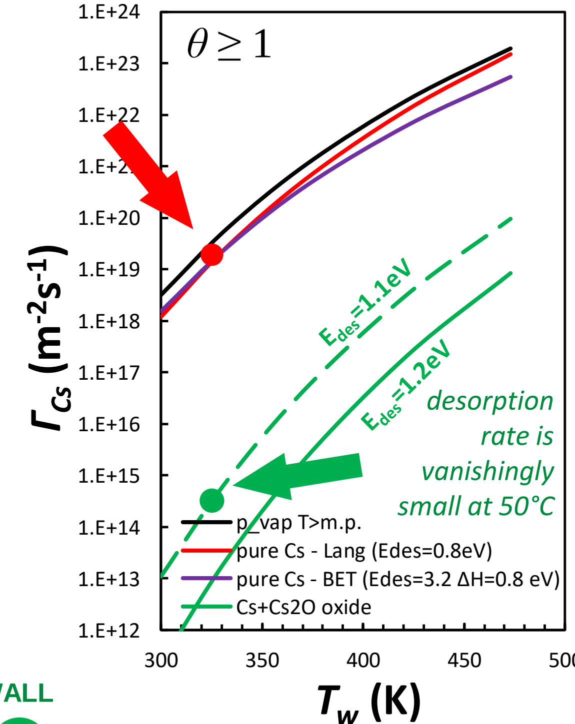
  $s(T_w=50°C)=0.09$

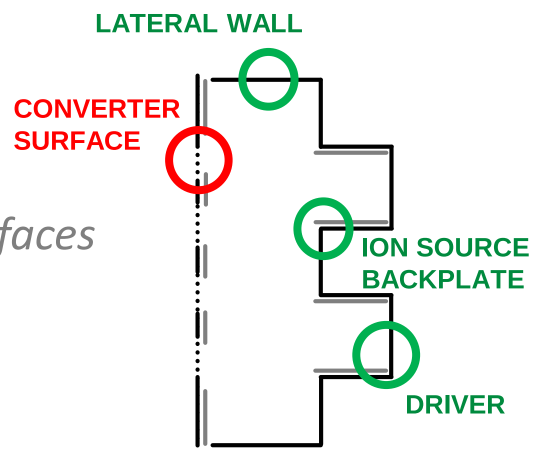
  $E_{des}=1.1\text{-}1.2eV$

  } QCM and TPD measurements in «CATS»

$$\Gamma_{Cs,th} = \frac{kT}{h}\frac{F^*}{F}\exp\left(-\frac{E_{des}(\theta)}{kT}\right)\theta\sigma$$

calculation for 0D ion source →
e.g. 27mg/h evaporation in vacuum,
~20mg/h are detained by adsorption at 50°C surfaces





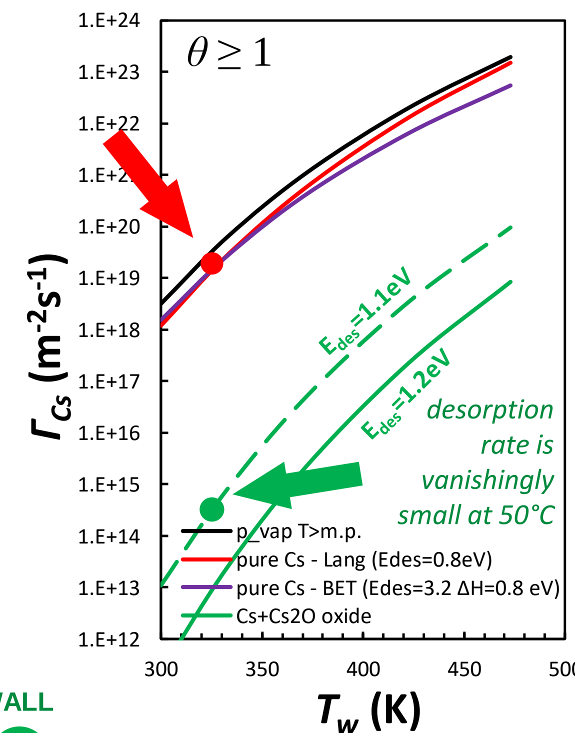
Thermal desorption, and adsorption

- At converter: partial coverage → modified Langmuir isotherm. (or Temkin) linear increase of ads energy ✓

- At other surfaces: ✓

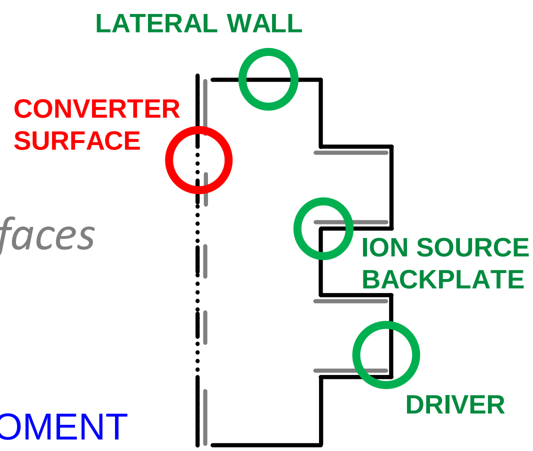
  as working hypotheses:
  (measurements to be done also in conditions more relevant to the ion source environment)

  $s(T_w=50°C)=0.09$
  $E_{des}=1.1\text{-}1.2eV$
  } QCM and TPD measurements in «CATS»



$$\Gamma_{Cs,th} = \frac{kT}{h}\frac{F^*}{F}\exp\left(-\frac{E_{des}(\theta)}{kT}\right)\theta\sigma$$

calculation for 0D ion source →
e.g. 27mg/h evaporation in vacuum,
~20mg/h are detained by adsorption at 50°C surfaces

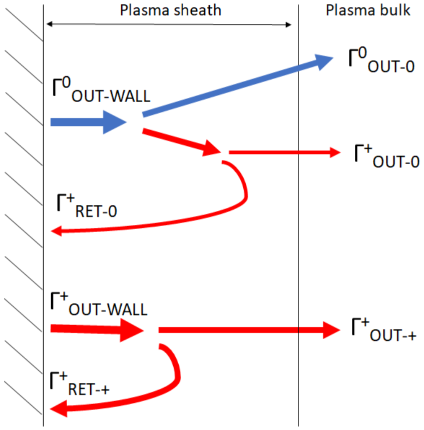


NOTE:
E_{des}=1.1eV IS JUST A WORKING HYPOTHESIS AT THE MOMENT

OUTLINE

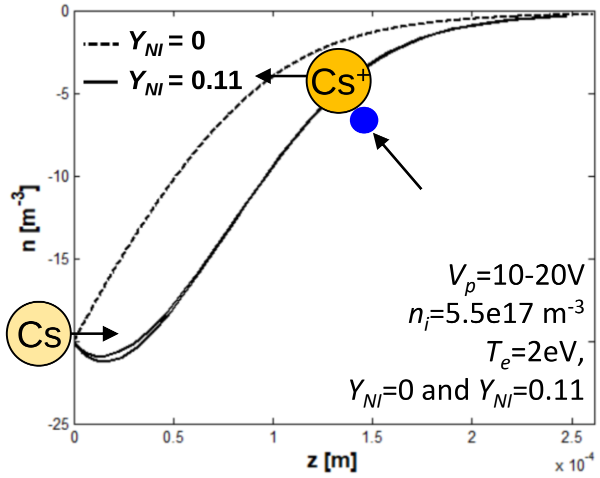
1. Surface processes concerning Cs ads/desorption

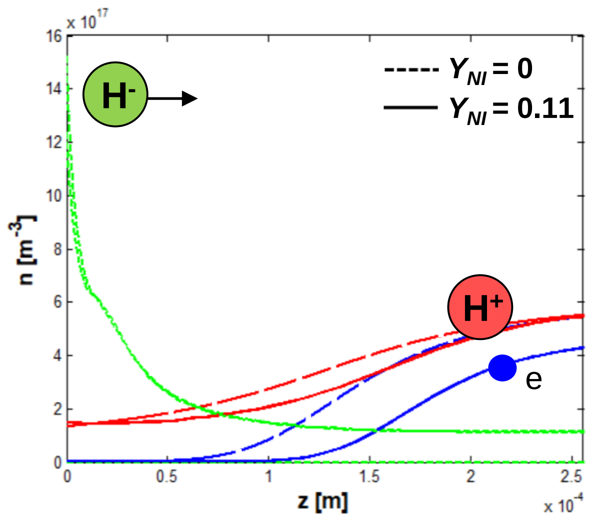
2. **Transmission probability to plasma bulk**
   - **Velocity of desorbed Cs atoms (phys. sputt. or therm. desorp.)**
   - **Transmission through plasma sheath**



3. Case of SPIDER

Transmission probability to the plasma bulk



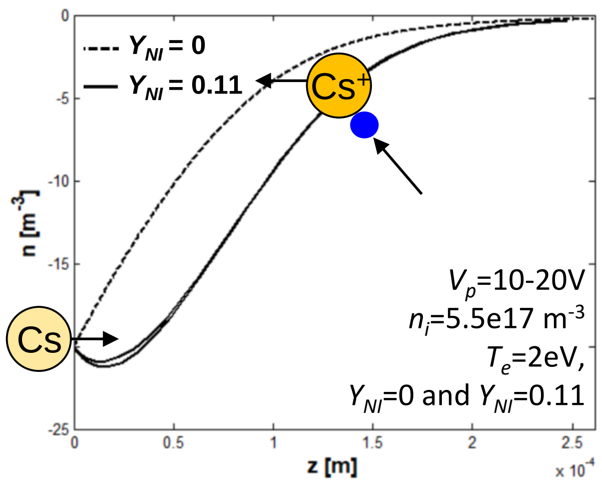


- Sheath model in presence of NI formation at the wall by McAdams [1)]
- Transmission of **neutral Cs** to the plasma: use test particle of Cs to calculate the overall probability of ionization before reaching V_p , depends on Cs velocity v_z and n_e(z), T_e

[1] R McAdams *et al* 2011 *Plasma Sources Sci. Technol.* **20** 035023

[2] Eckstein, W., Nucl. Instrum. and Methods in Physics Research B18, 344–348 (1987)

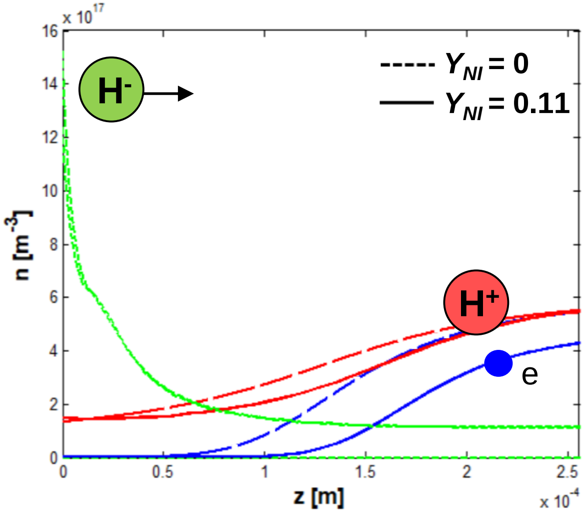
Transmission probability to the plasma bulk

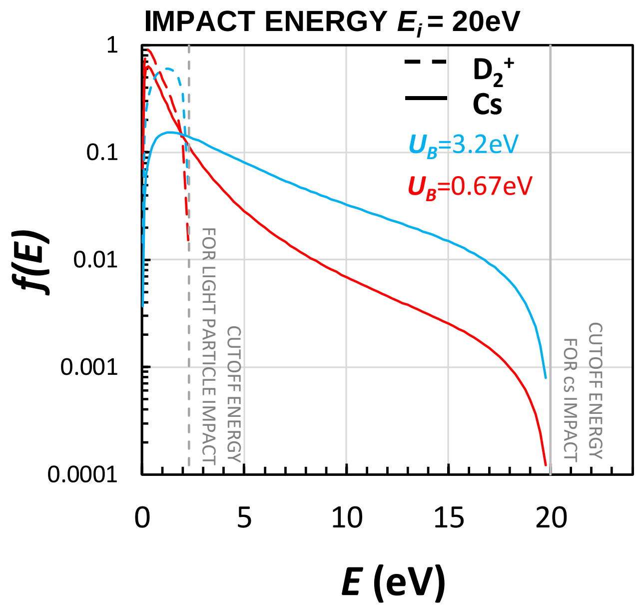


- Sheath model in presence of NI formation at the wall by McAdams [1)]
- Transmission of **neutral Cs** to the plasma: use test particle of Cs to calculate the overall probability of ionization before reaching V_p , depends on Cs velocity v_z and n_e(z), T_e

Thermal desorption: Cs at wall temperature

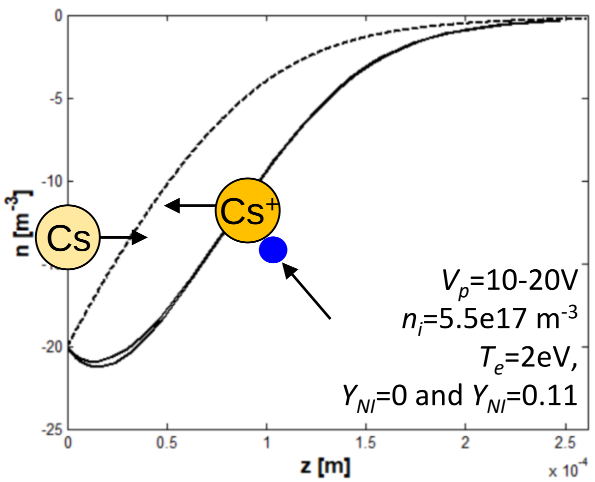
Physical sputtering: much higher energy [2)]
(f(E) of Cs particles peaks at desorption energy)

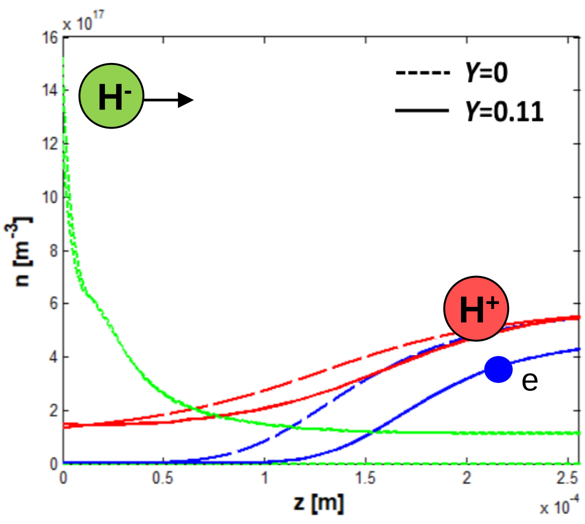




[1] R McAdams *et al* 2011 *Plasma Sources Sci. Technol.* **20** 035023
[2] Eckstein, W., Nucl. Instrum. and Methods in Physics Research B18, 344–348 (1987)

Transmission probability to the plasma bulk





- Sheath model in presence of NI formation at the wall by McAdams [1)]
- Transmission of **neutral Cs** to the plasma: use test particle of Cs to calculate the overall probability of ionization before reaching V_p , depends on Cs velocity v_z and $n_e(z)$, T_e

V_s (V)		$T_{des,Th}$	$T_{des,sputt}$
20	No NI yield	0.84	0.96
20	NI yield	0.86	0.97
10		0.85	0.96

n_i=5.5e17 m^{-3}

- Immediate recycling back to the wall might affect 15% of thermally desorbed Cs

NOTE:
- TRANSMISSION ANYWAY CLOSE TO UNITY → NOT SO EFFECTIVE COMPARED TO DESORPTION PROCESSES

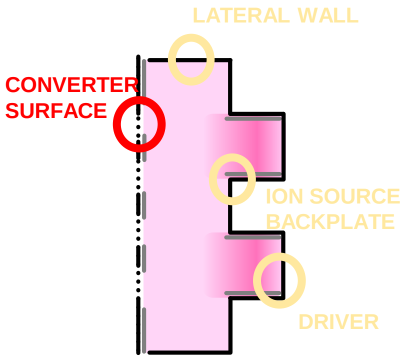
OUTLINE

1 Surface processes concerning Cs ads/desorption

2 Transmission probability to plasma bulk

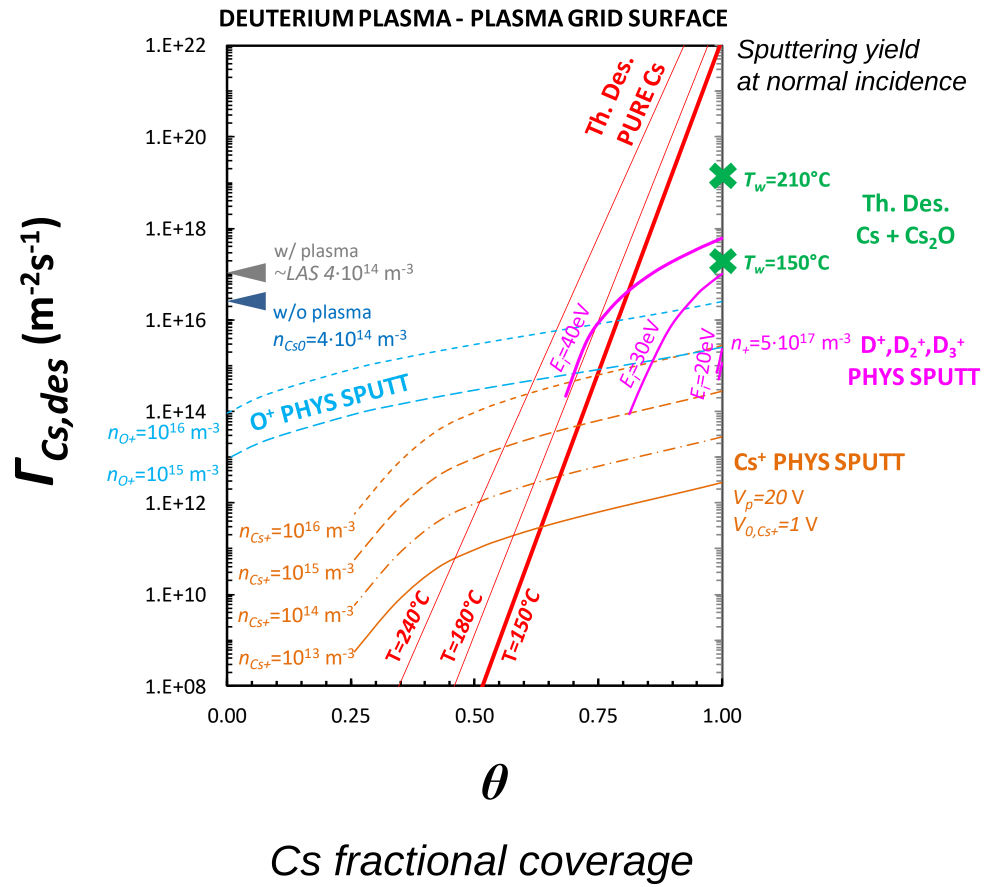
3 **Case of SPIDER**

At plasma grid surface

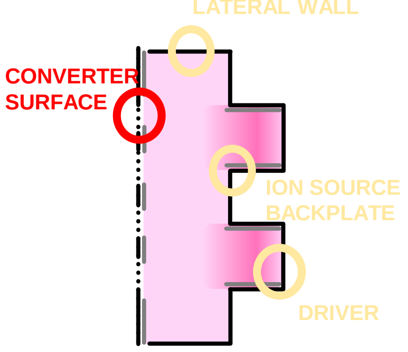


- contributions to Cs desorption flux:

$$\Gamma_{des} = \Gamma_{th}(T_w) + \Gamma_{sput}^{(D^+)} + \Gamma_{sput}^{(Cs^+)} + \Gamma_{sput}^{(X^+)}$$



At plasma grid surface

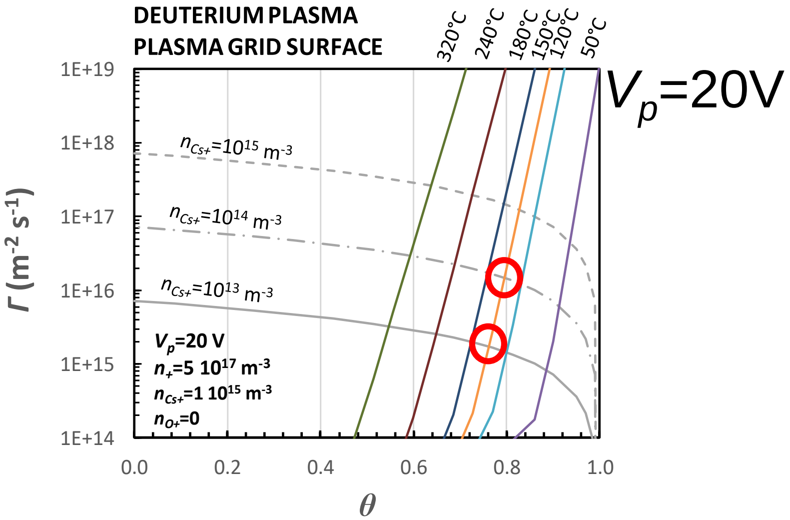


- contributions to Cs desorption flux:

$$\Gamma_{des} = \underline{\Gamma_{th}(T_w)} + \underline{\Gamma_{sput}^{(D^+)}} + \underline{\Gamma_{sput}^{(Cs^+)}} + \underline{\Gamma_{sput}^{(X^+)}}$$

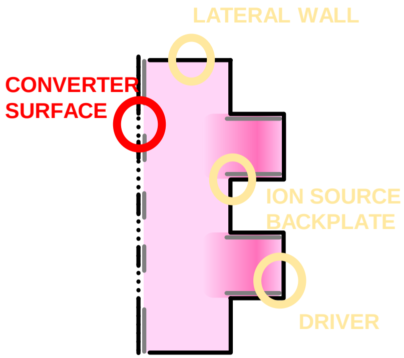
- Try comparison with local incoming flux:
  (first order adsorption $s=s_0(1-\theta)$, negligible incoming neutrals)

$$\Gamma_{Cs,ads} = s(\theta)\Gamma_{Cs^+} + s\Gamma_{Cs^0} \approx \underline{s(\theta)0.6 \cdot n_{Cs^+}\left(\frac{2V_0}{m_{Cs}}\right)^{\frac{1}{2}}}$$



But this is D plasma! Yet the effect of sputtering is not significant

At plasma grid surface

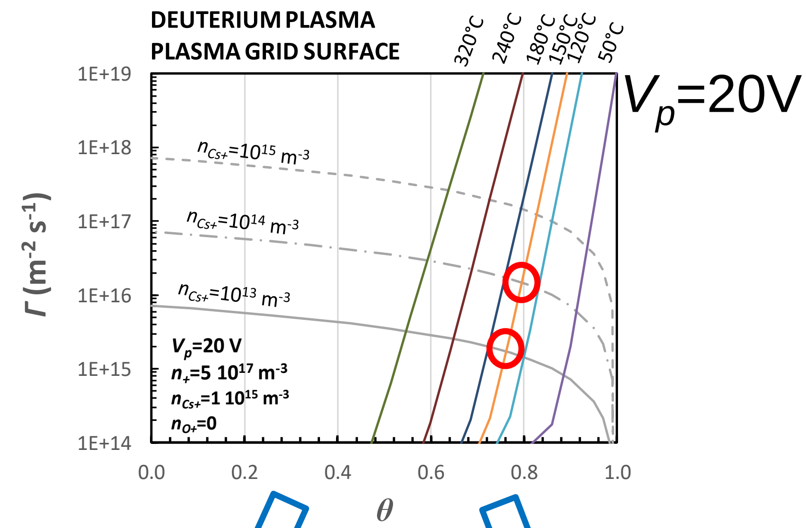


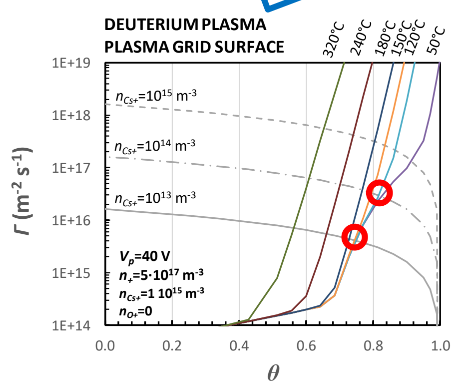
- contributions to Cs desorption flux:

$$\Gamma_{des} = \underline{\Gamma_{th}(T_W)} + \underline{\Gamma_{sput}^{(D^+)}} + \underline{\Gamma_{sput}^{(Cs^+)}} + \underline{\Gamma_{sput}^{(X^+)}}$$

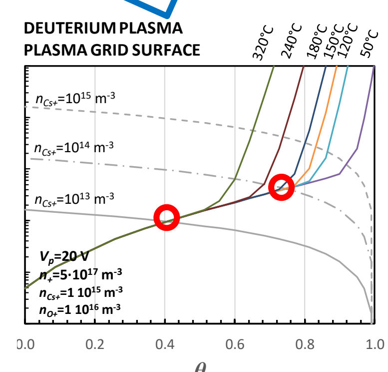
- Try comparison with local incoming flux:
  (first order adsorption $s=s_0(1-\theta)$, negligible neutrals)

$$\Gamma_{Cs,ads} = s(\theta)\Gamma_{Cs^+} + s\Gamma_{Cs^0} \approx \underline{s(\theta)0.6 \cdot n_{Cs^+}\left(\frac{2V_0}{m_{Cs}}\right)^{\frac{1}{2}}}$$



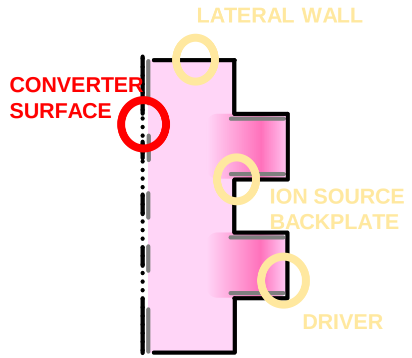


2x impact energy (V_p=40V)



Very large impurity concentration
(equivalent O^+ density $5x10^{16} m^{-3}$)

At plasma grid surface



- contributions to Cs desorption flux:

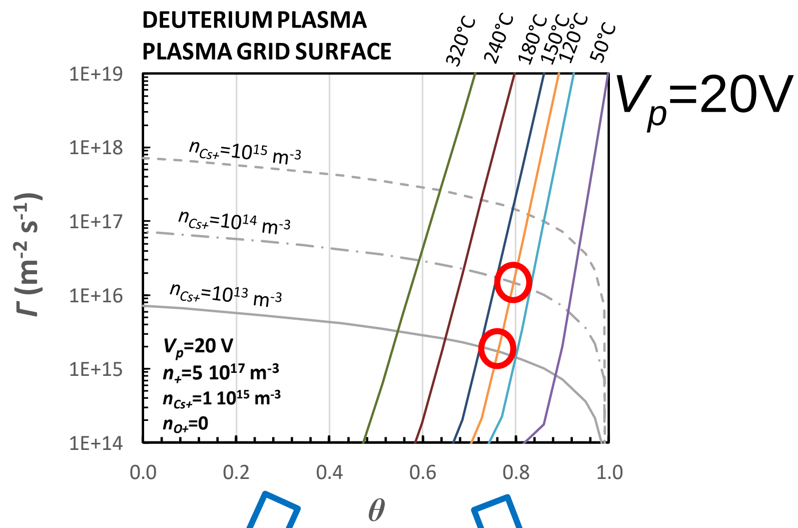
$$\underline{\Gamma_{des}} = \Gamma_{th}(T_w) + \Gamma_{sput}^{(D^+)} + \Gamma_{sput}^{(Cs^+)} + \Gamma_{sput}^{(X^+)}$$

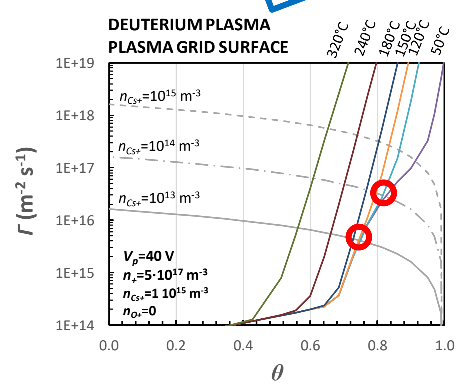
- Try comparison with local incoming flux:
(first order adsorption $s=s_0(1-\theta)$, negligible neutrals)

$$\Gamma_{Cs,ads} = s(\theta)\Gamma_{Cs^+} + s\Gamma_{Cs^0} \approx s(\theta)0.6 \cdot n_{Cs^+}\left(\frac{2V_0}{m_{Cs}}\right)^{\frac{1}{2}}$$

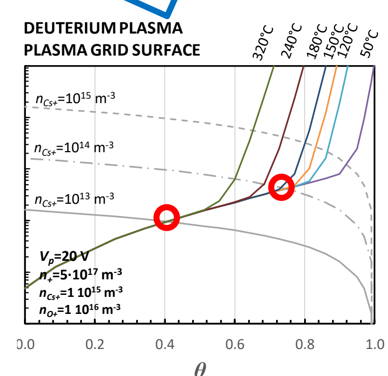
TO BE CLARIFIED:

- terms in sputtering yield:
  - angle of impact (E_{sheath} not parallel to $E_{presheath}$)
  - dependence of Y on surface temperature (MD)
  - chemical sputtering
- terms in sticking s_0
(surface temperature T_w, angle of incidence, impurities)



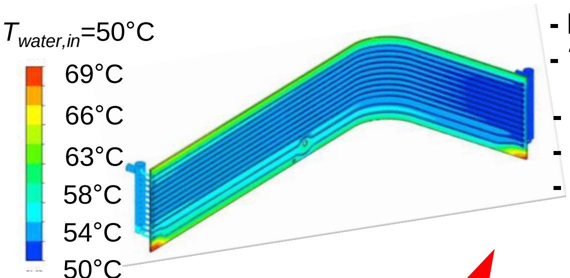


2x impact energy (V_p=40V)



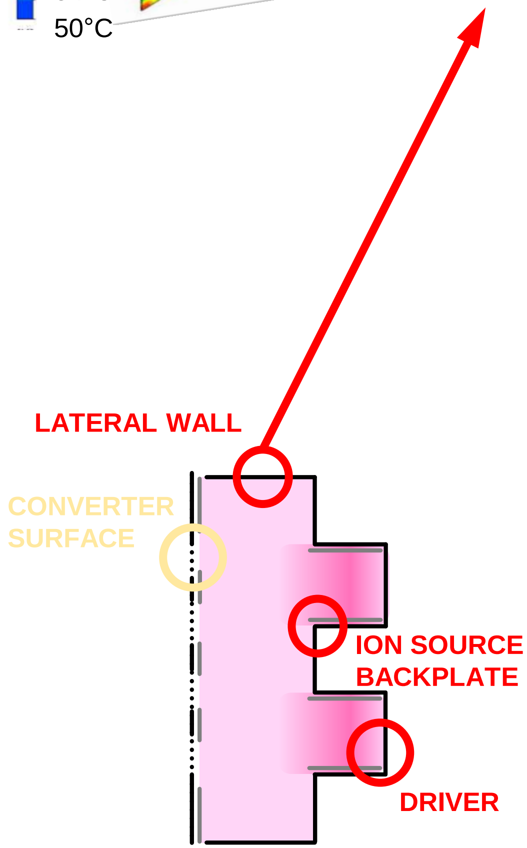
Very large impurity concentration
(equivalent O^+ density $5x10^{16}$m^{-3})

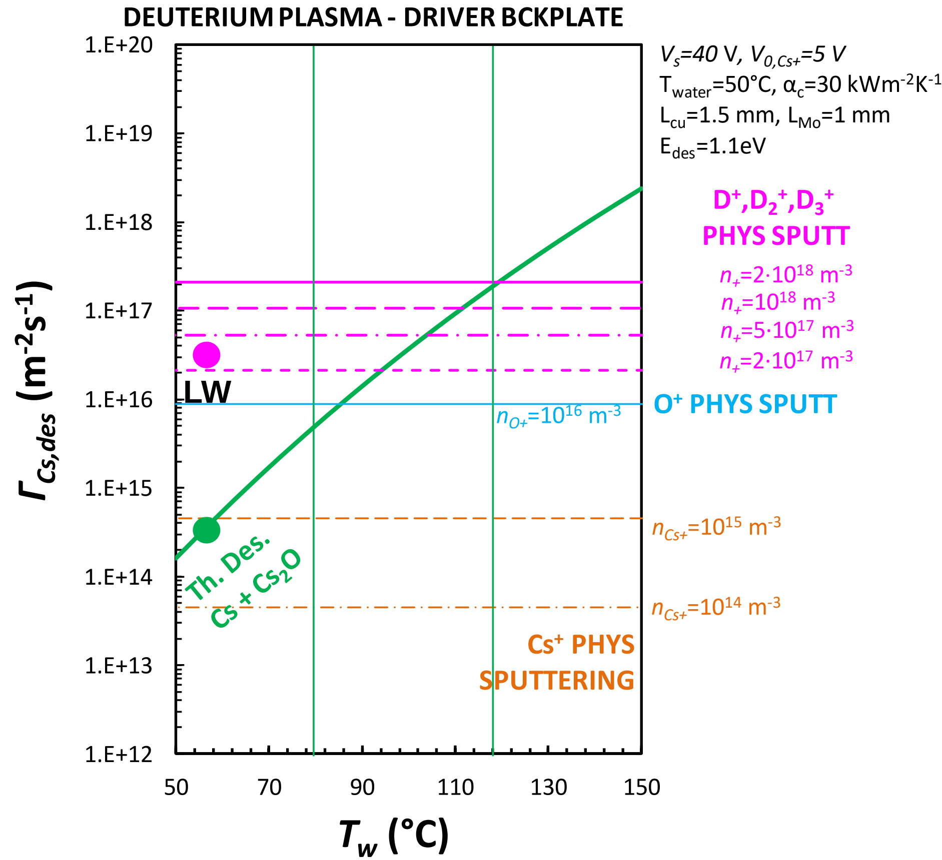
At lateral wall, backplate, driver plate during plasma discharge



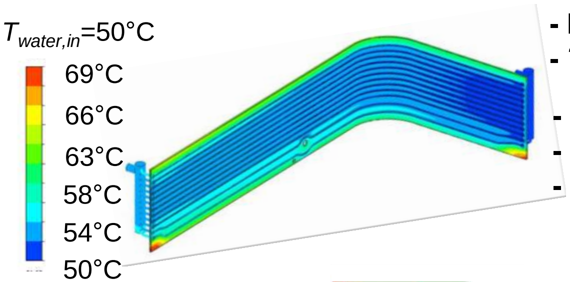
LATERAL WALL

- **Heat flux 20 kW/m²**
- **T_w 50-65 °C**
- **n_+=2·10^{17} m^{-3}**
- **V_p ~ 40 V**
- **(V_0 ~ 2 V)**





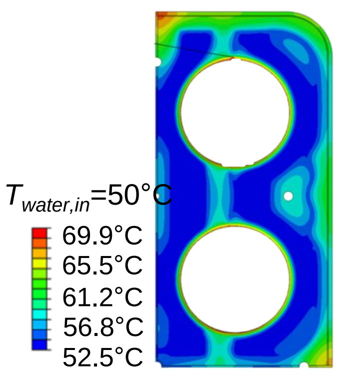
At lateral wall, backplate, driver plate during plasma discharge



LATERAL WALL

- Heat flux 20 kW/m²
- T_w 50-65 °C

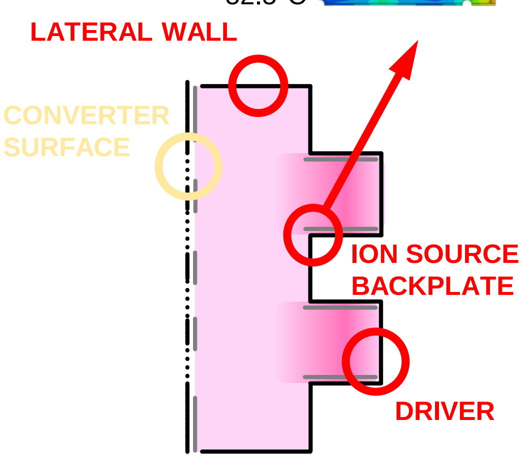
- $n_+=2\cdot10^{17}$ m^{-3}
- V_p ~ 40 V
- (V_0 ~ 2 V)

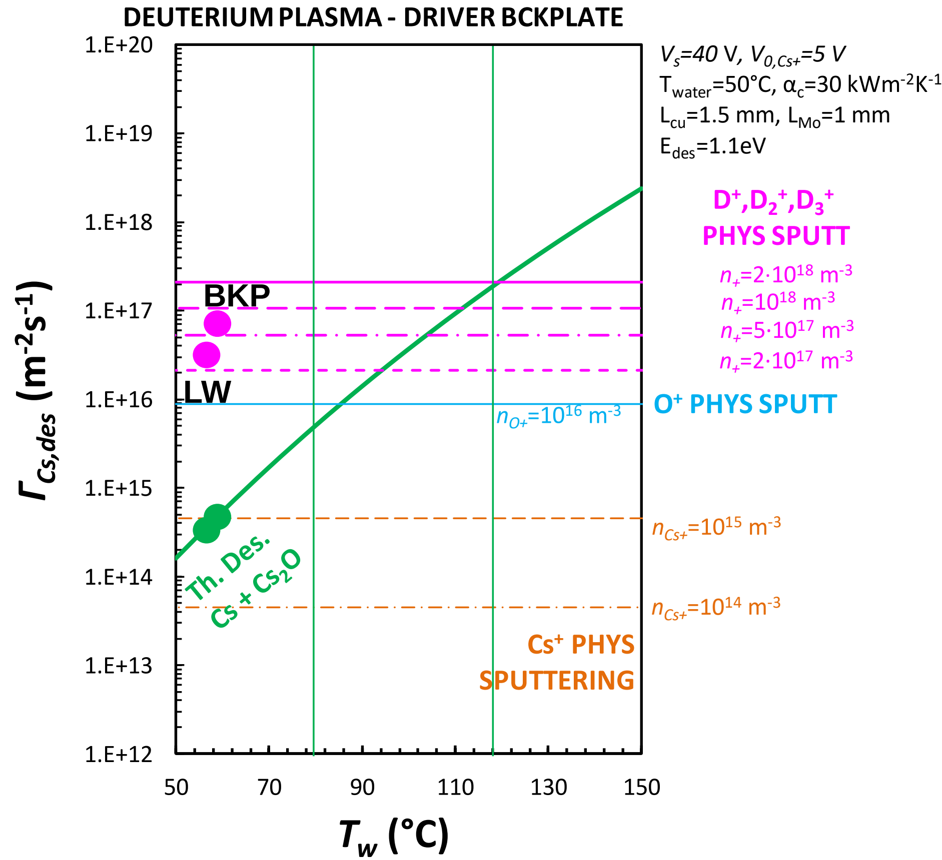


ION SOURCE BACKPLATE

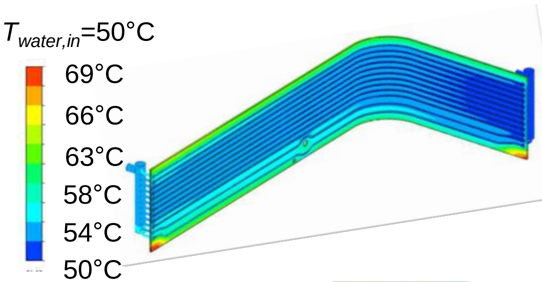
- Heat flux 20-100 kW/m²
- T_w 50-65 °C

- $n_+=2/5\cdot10^{17}$ m^{-3}
- V_p ~ 40 V
- (V_0 ~ 5 V)





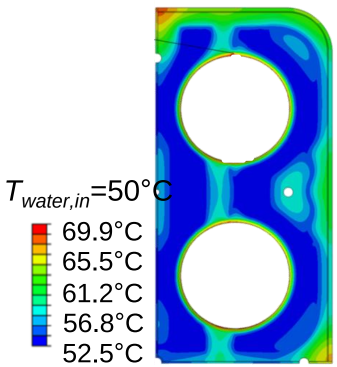
At lateral wall, backplate, driver plate during plasma discharge



LATERAL WALL

- **Heat flux 20 kW/m²**
- **T_w 50-65 °C**

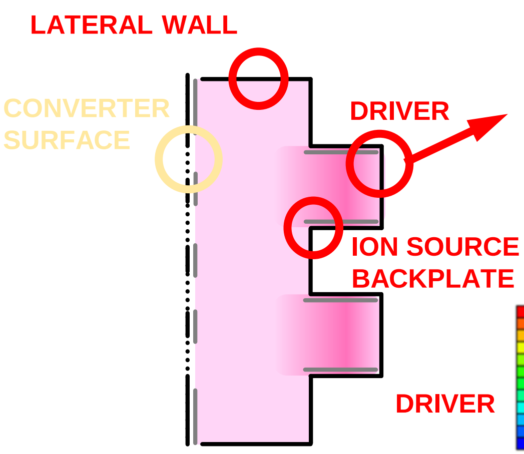
- **$n_+=2\cdot10^{17}$ m⁻³**
- **$V_p \sim 40$ V**
- **($V_0 \sim 2$ V)**



ION SOURCE BACKPLATE

- **Heat flux 20-100 kW/m²**
- **T_w 50-65 °C**

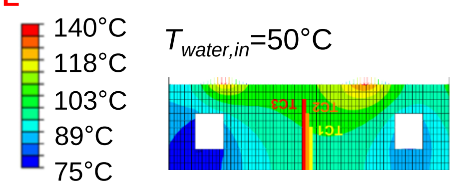
- **$n_+=2/5\cdot10^{17}$ m⁻³**
- **$V_p \sim 40$ V**
- **($V_0 \sim 5$ V)**

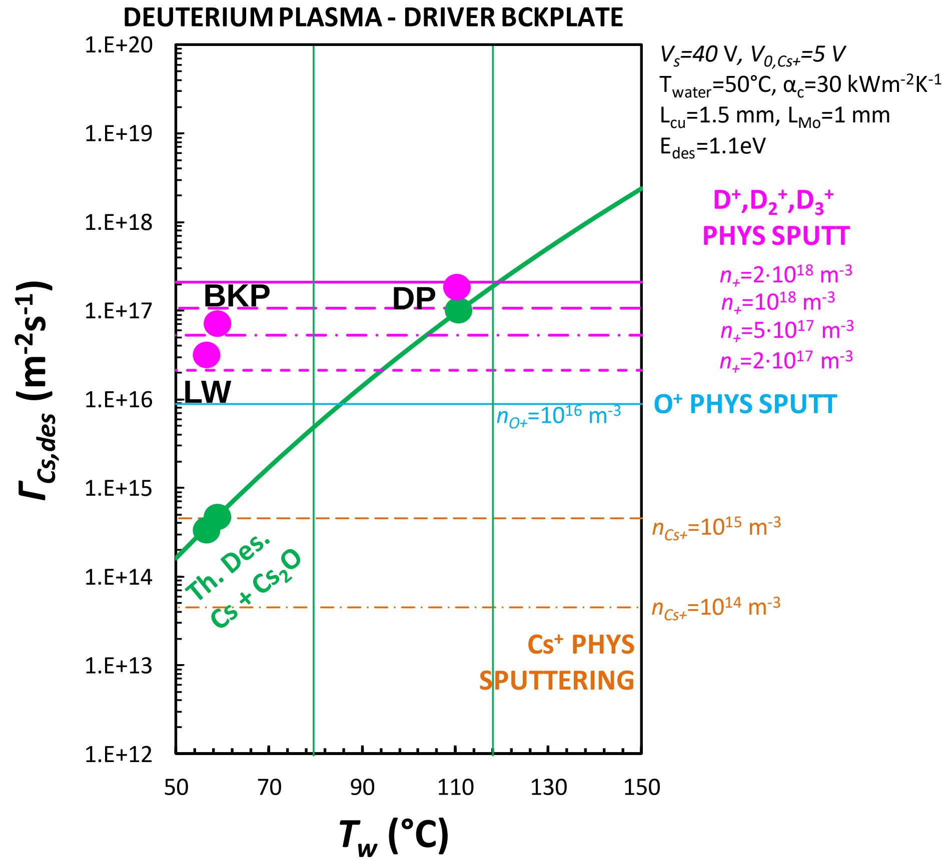


DRIVER PLATE

- **Heat flux 200-300 kW/m²**
- **T_w 75-140 °C**

- **$n_+=10/20\cdot10^{17}$ m⁻³**
- **$V_p \sim 40$ V**
- **($V_0 \geq 5$ V)**

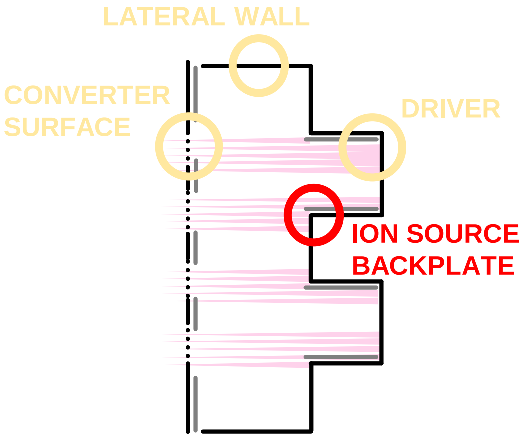


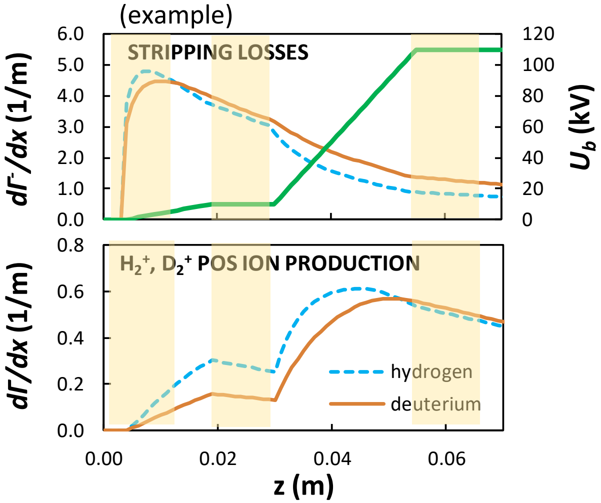


TO BE CLARIFIED:

- sputtering yield for Cs compounds
- desorption energy E_{des}

At backplate during plasma discharge and beam extraction: physical sputtering due to BSI



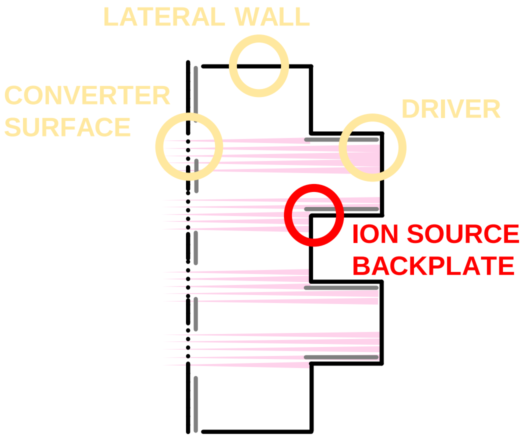


Example of stripping & ionization rates along the accelerator

Physical sputtering

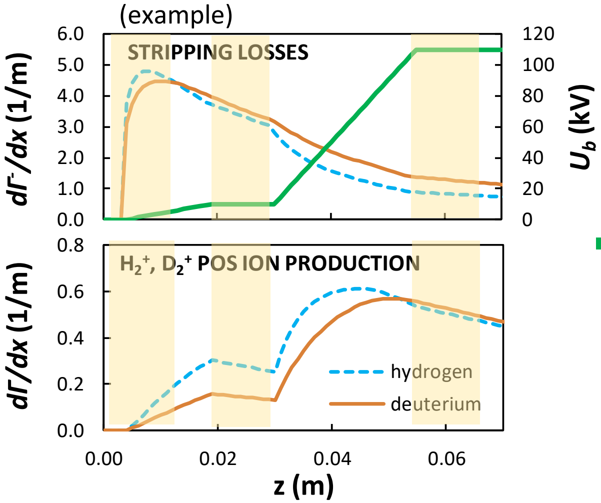
- Creation of pos. Ions in the electric field of the accelerator, or entering from downstream the accelerator → production of H_2^+ slightly larger

At backplate during plasma discharge and beam extraction: physical sputtering due to BSI

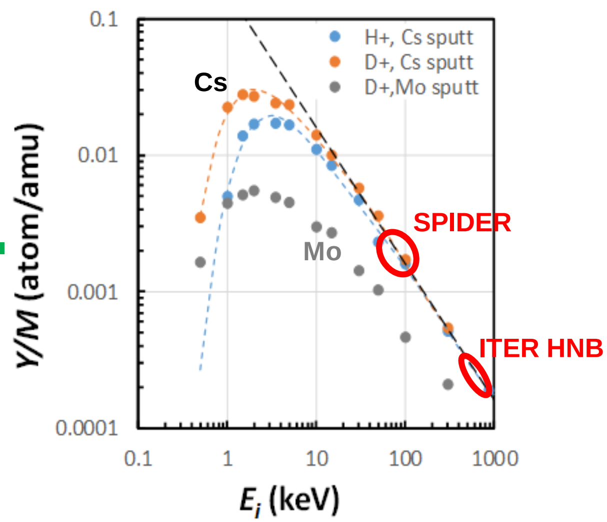


Physical sputtering

- Creation of pos. ions in the electric field of the accelerator, or entering from downstream the accelerator → production of H_2^+ slightly larger
- physical sputtering $Y(E_i)$ → D_2^+ more effective

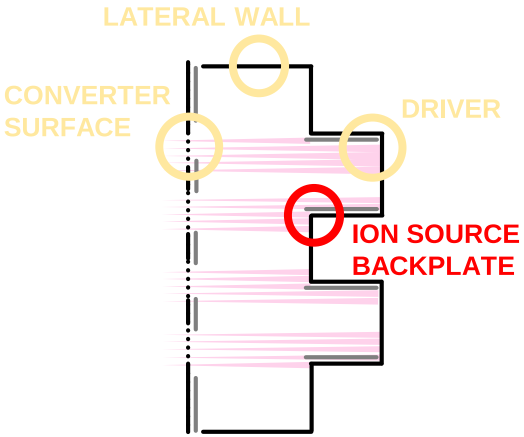


Example of stripping & ionization rates along the accelerator



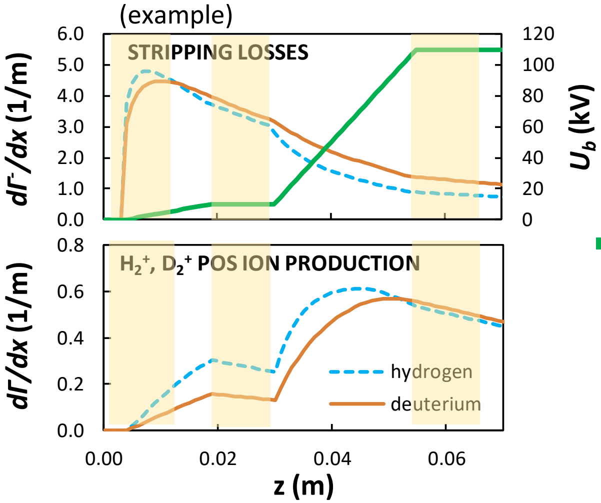
Sputtering yield at high energies (TRIM calculations)

At backplate during plasma discharge and beam extraction: physical sputtering due to BSI

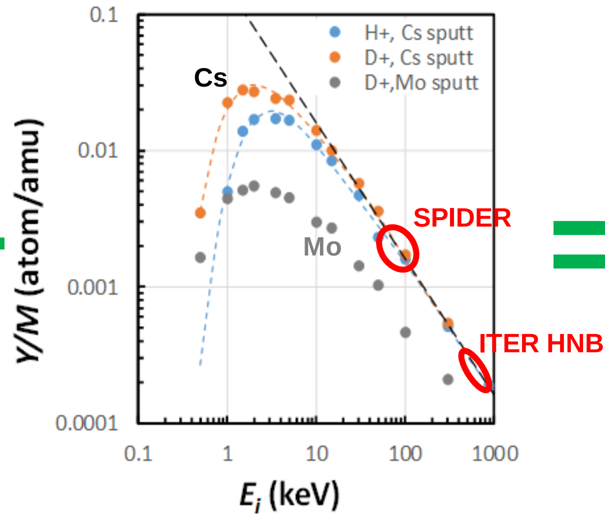


Physical sputtering

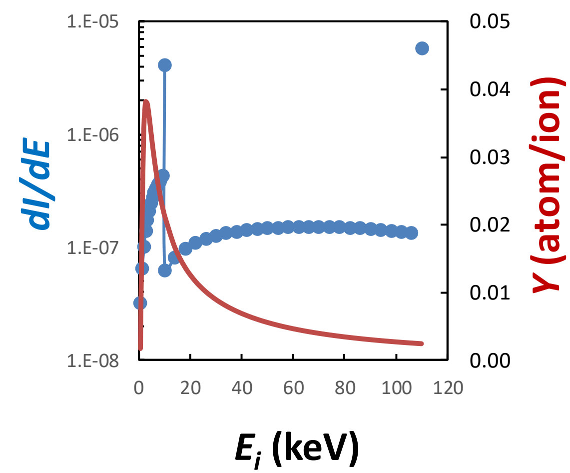
- Creation of pos. ions in the electric field of the accelerator, or entering from downstream the accelerator → production of H_2^+ slightly larger
- physical sputtering $Y(E_i)$ → D_2^+ more effective
- calculation of <Y> from energy spectra of backstreaming H_2^+ / D_2^+



Example of stripping & ionization rates along the accelerator



Sputtering yield at high energies (TRIM calculations)

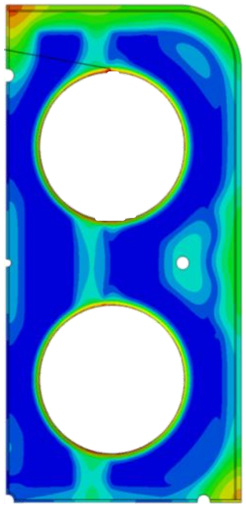


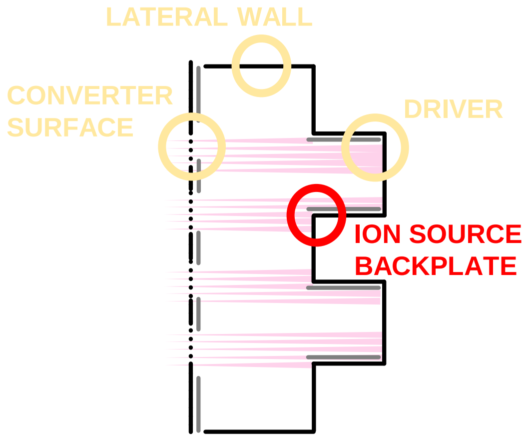
IEDF assuming transmission $T_0(z)=1$ (comparison against EAMCC at optim. perv. showed 40% overestimation of the total current)

At backplate during plasma discharge and beam extraction: thermal desorption due to BSI

$T_{water,in}$=50°C

Thermal submodel of BSI impact position can be done (22x20 mm) to simulate local heating

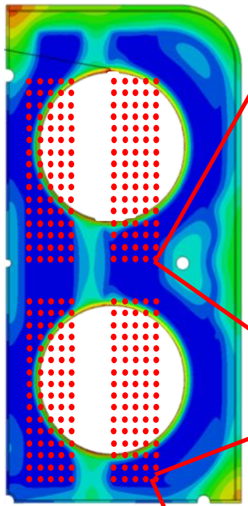


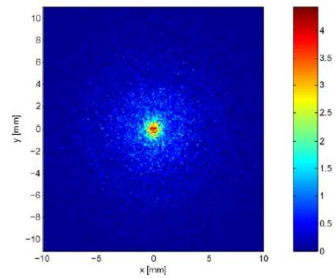


At backplate during plasma discharge and beam extraction: thermal desorption due to BSI

$T_{water,in}$=50°C

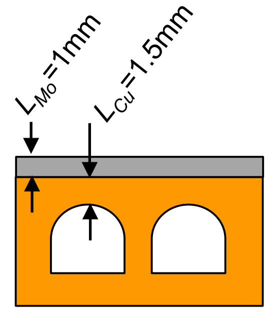
Thermal submodel of BSI impact position can be done (22x20 mm) to simulate local heating

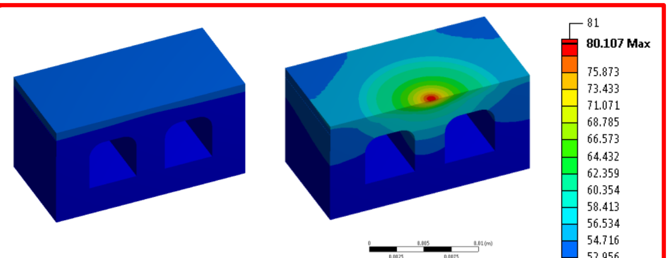




BACKSTREAMING POS. ION. FOOTPRINT AT -200mm

«HIGH PERFORMANCE» COOLING SYS

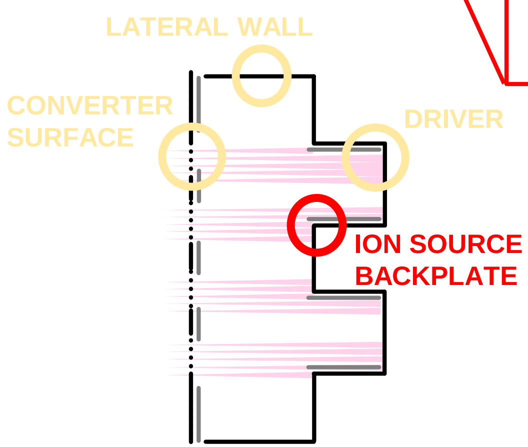




PLASMA DISCHARGE ONLY (up to 100kW/m²)

PLASMA DISCHARGE + BACKSTR POS IONS (up to 4 MW/m²)

What is the dependence on the size of the footprint?

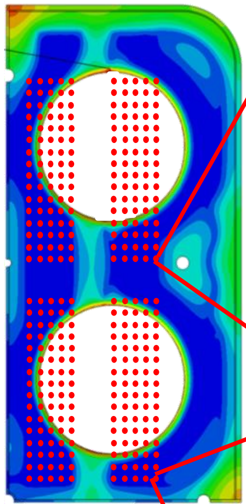


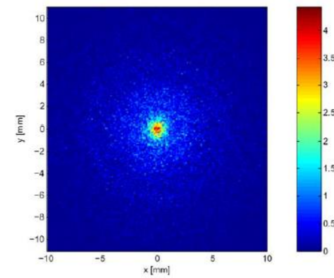
- Effect of backstreaming ions heatload
- Small local temperature increase (51→80°C) due to very good cooling capability (designed for thermal load of ITER HNB)

At backplate during plasma discharge and beam extraction: thermal desorption due to BSI

$T_{water,in}$=50°C

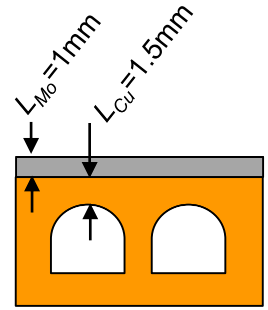
Thermal submodel of BSI impact position can be done (22x20 mm) to simulate local heating



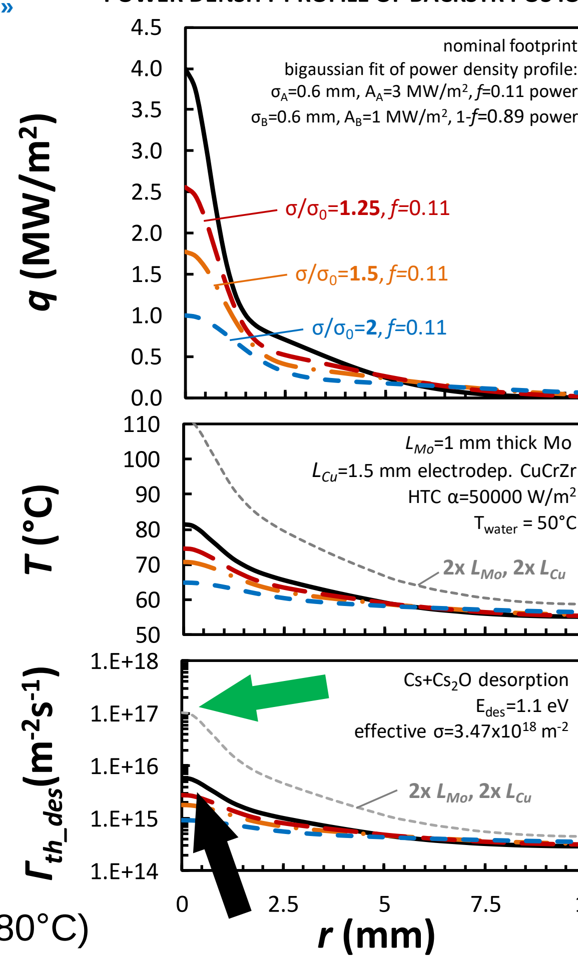


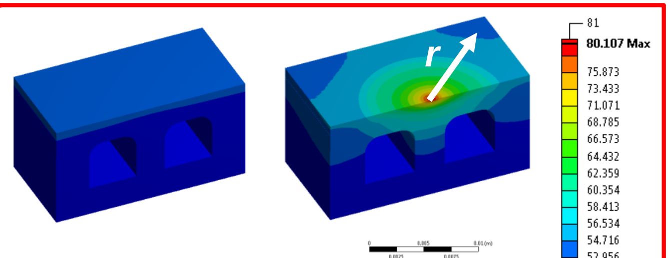
BACKSTREAMING POS. ION. FOOTPRINT AT -200mm

«HIGH PERFORMANCE» COOLING SYS



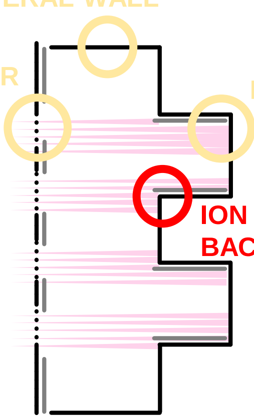
POWER DENSITY PROFILE OF BACKSTR POS IONS





PLASMA DISCHARGE ONLY (up to 100kW/m²)

PLASMA DISCHARGE + BACKSTR POS IONS (up to 4 MW/m²)

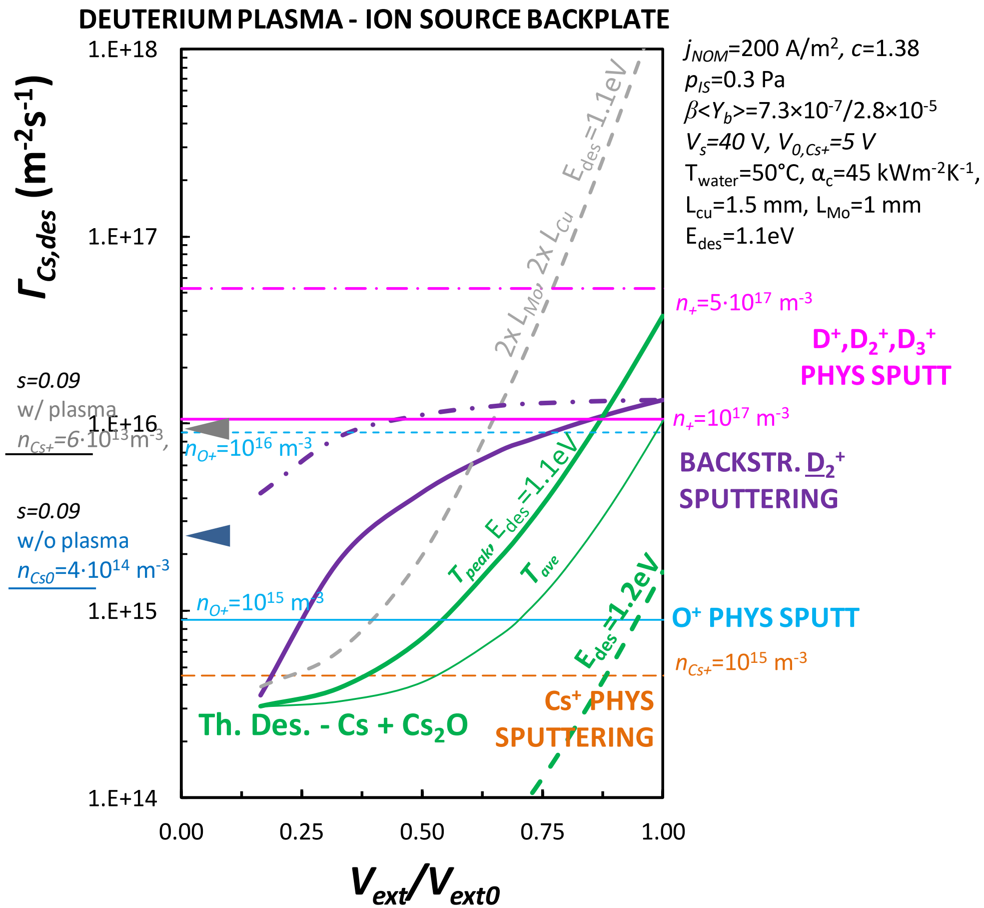


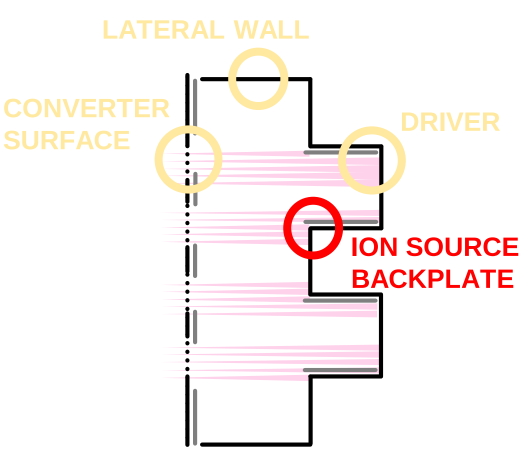
- Effect of backstreaming ions heat load
- Small local temperature increase (51→80°C) due to very good cooling capability (designed for thermal load of ITER HNB)
- Locally, **thermal desorption is enhanced up to 10x** (averaged on the 0.22x0.02 surface **2.7x**)

note the case the thickness of Cu and Mo are doubled: local increase 100x

At backplate during plasma discharge and beam extraction

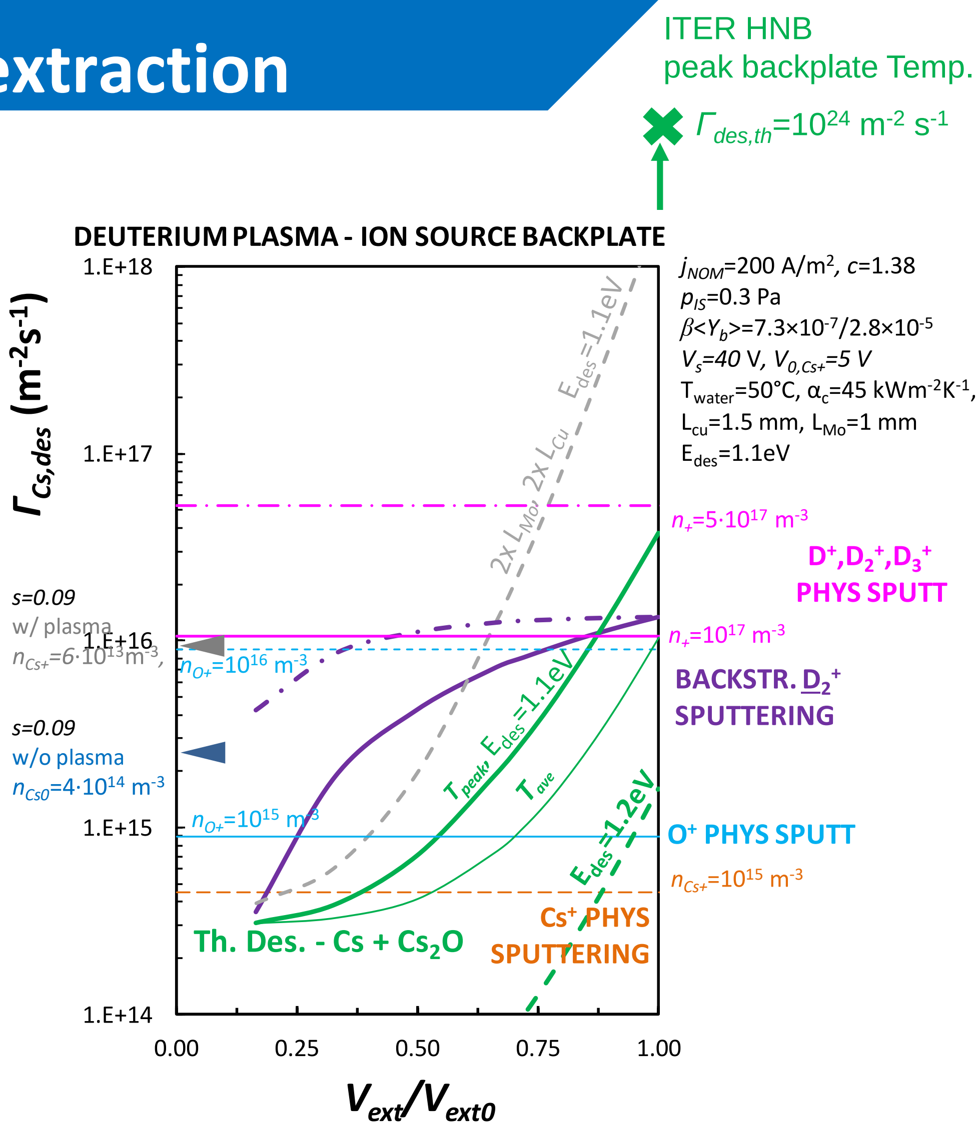
- fast BSI: in SPIDER, Cs thermal desorption due to localized heating might have the same order of magnitude of Cs physical sputtering
- probably, sputtering by plasma ions is anyway more effective (and applies to much larger area)

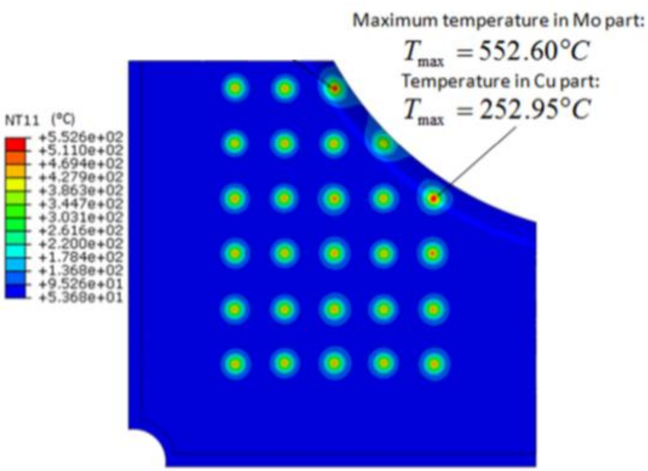




At backplate during plasma discharge and beam extraction

- fast BSI: in SPIDER, Cs thermal desorption due to localized heating might have the same order of magnitude of Cs physical sputtering
- probably, sputtering by plasma ions is anyway more effective (and applies to much larger area)
- *Fast BSI in **ITER HNB**: Cs thermal desorption has huge contribution, Mo surface peak temperature up to 550°C (Γ_{des}~10^{24} $m^{-2}s^{-1}$); (average T is much less maybe about 90-100°C)*

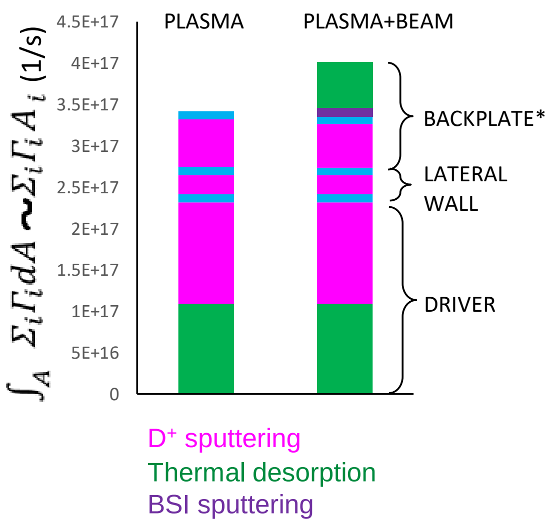




SUMMARY

- Started a review of processes related to Cs redistribution
- TPD analysis for Cs compounds seems promising but should be done in ion-source relevant atmosphere to obtain reliable E_{des} (and pre-exponential factor)
- Cs sputtering yields in the 10eV energy range;
  electric fields in the plasma (presheath) are important for sputtering and for Cs redistribution;
  question of impurities;
  BSI contribute to Cs redistribution by thermal desorption rather than physical sputtering;
- Ab initio MD can provide quantitative results, but can be used only to study well «delimited» problems → from experimental observation we get the correct questions to ask
- SPIDER ion source is designed for thermal loads of ITER HNB → temperature control very «robust»

estimated contributions to total desorbed Cs



SUMMARY

- TPD analysis for Cs compounds might provide Edes, etc
  - hydrogen atmosphere and/or hydrogen discharge
- MD analysis
  - NI yield
  - Cs sticking at PG (Cs+, Cs+ energy, presence of impurities?)
- In SPIDER temperature-induced effects shall be less than other machines (cooling system designed for the loads of ITER HNB) both without (plasma only) and with beam extraction
- Sputtering seems the main mechanism for Cs redistribution: sputt. yields for D and impurities are key factors
- IEDF at walls: electric fields in the plasma (presheath) are important for sputtering and for Cs redistribution
- 0D approach based on averaged quantities might provide overall

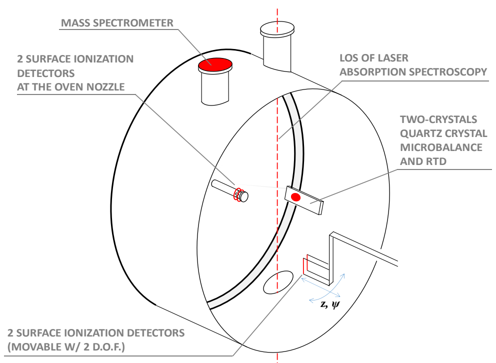
Help from caesium test stand measurements

CAesium Test Stand «CATS»

Main purpose: test SPIDER Cs ovens

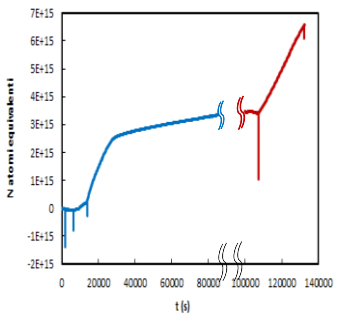
Diagnostics:

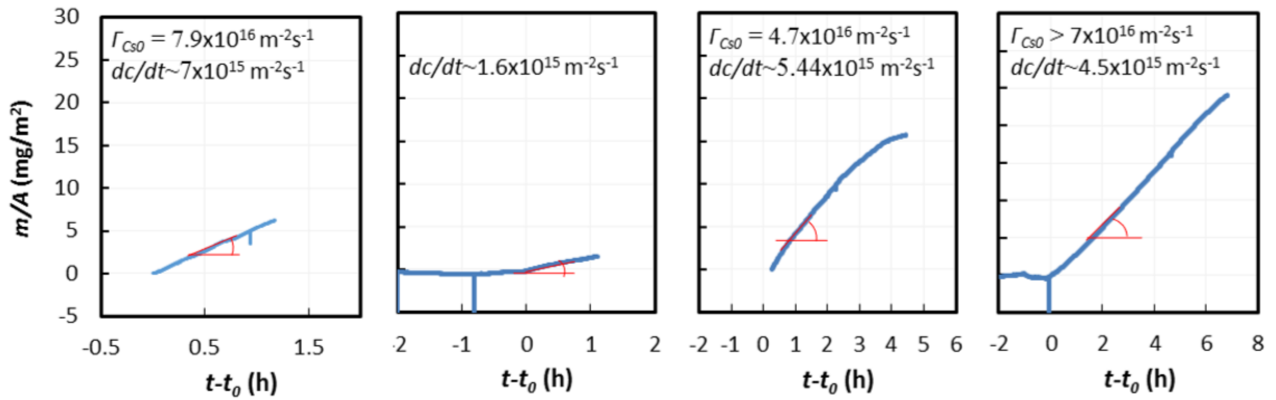
- Cs evap rate: SID at oven nozzle
- Cs density: movable SID
- Cs line integr density: LAS
- Cs sticking: QCM and TC



POSTER P1-18

- Three dimensional growth of Caesium stable compounds on the QCM (mass equivalent to tens of closed-packed Cs layers)
- At 48°C, mass increase is equivalent to **sticking s=0.09** (using mobile SID to measure Cs flux density in the volume and neglecting O mass)



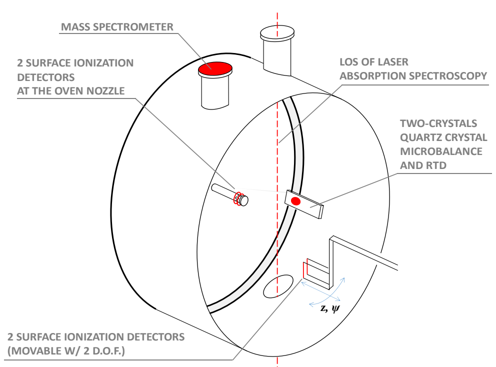


Help from caesium test stand measurements

CAesium Test Stand «CATS»
Main purpose: test SPIDER Cs ovens

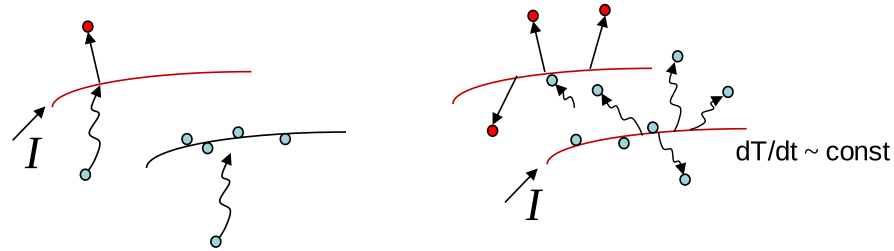
Diagnostics:

- Cs evap rate: SID at oven nozzle
- Cs density: movable SID
- Cs line integr density: LAS
- Cs sticking: QCM and TC

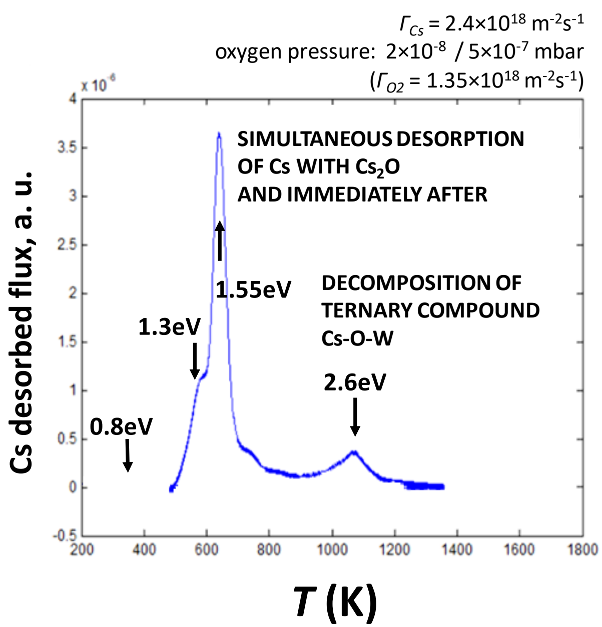


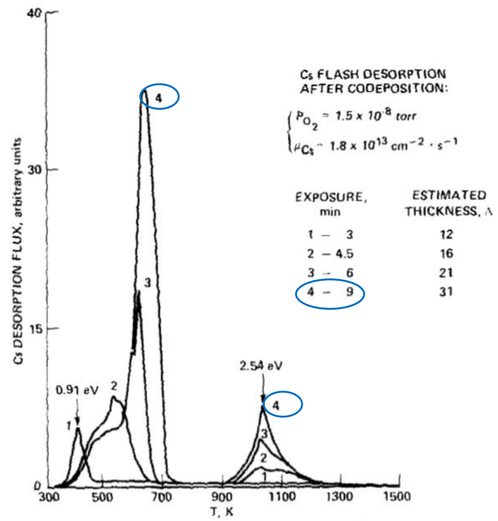
POSTER P1-18

- flash desorption carried out to obtain energy of desorption (very preliminary)



- similar spectra and desorption energies found in literature XX, with simultanous desorption of Cs_2O
- **Cs_2O** zero order desorption energy **1.2eV** XX





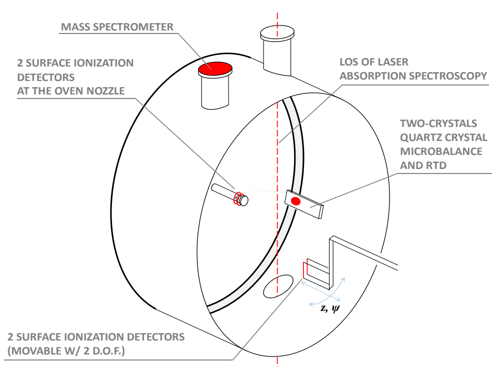
Help from caesium test stand measurements

CAesium Test Stand «CATS»

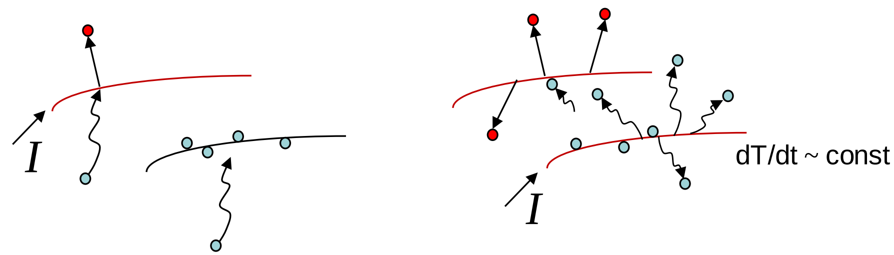
Main purpose: test SPIDER Cs ovens

Diagnostics:

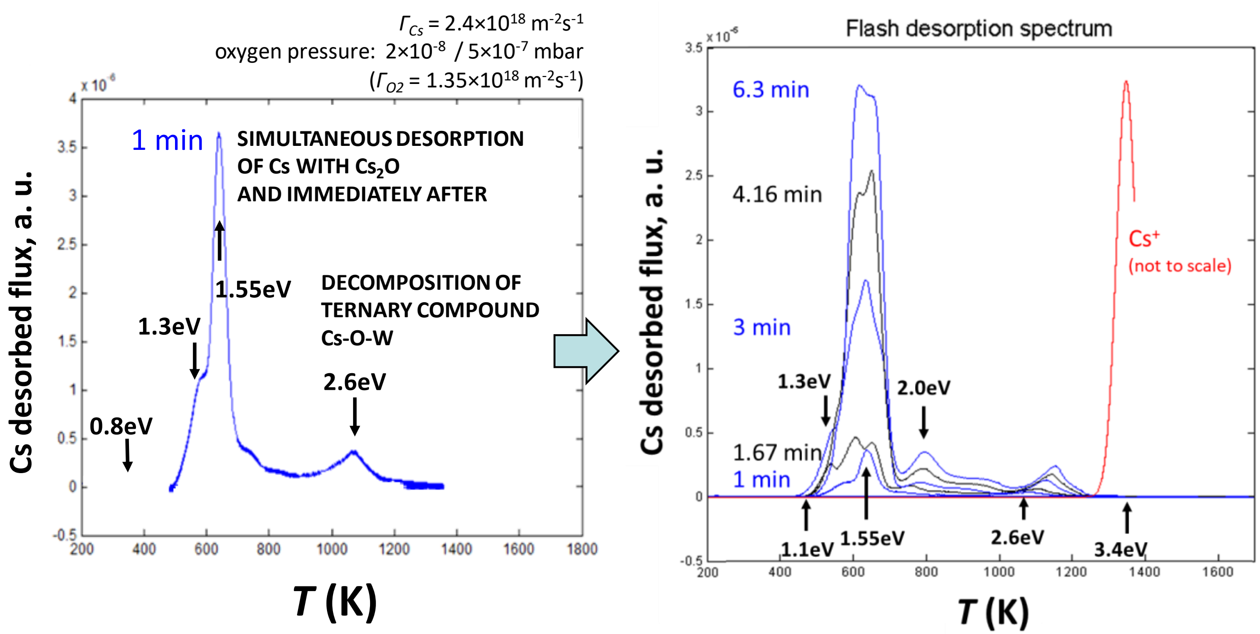
- Cs evap rate: SID at oven nozzle
- Cs density: movable SID
- Cs line integr density: LAS
- Cs sticking: QCM and TC



- flash desorption carried out to obtain energy of desorption (very preliminary)



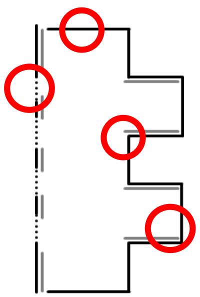
- similar spectra and desorption energies found in literature XX, with simultanous desorption of Cs_2O
- **Cs_2O** zero order desorption energy **1.2eV** XX
- with increasing coverage exhibits a shared leading edge; if zero order desorption, **Cs** desorption energy is approx **1.1 eV**, if first order 1.3 eV…



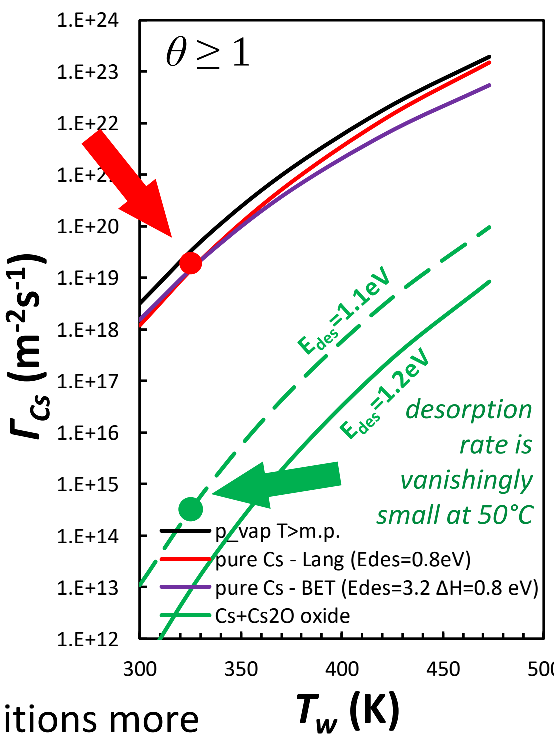
POSTER P1-18

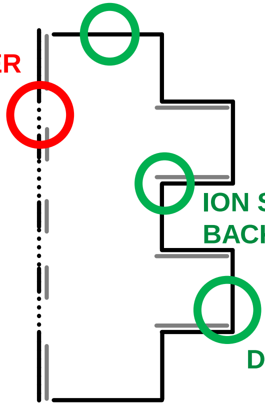
Thermal desorption, and adsorption

- At converter: partial coverage → modified Langmuir isotherm. (or Temkin) linear increase of ads energy ✓
- Other surfaces: TST as a generalization of desorption rate , BET theory for multilayer adsorption, condensation … (ΔH=0.8eV XX) ✗



If we use this flux for all surfaces → steady state, only 6min eq. of Cs evaporation is kept in the source!
→ does not describe reality





<u>as working hypotheses</u>:
(measurements to be done also in conditions more relevant to the ion source environment)

$s(T_w\text{=50°C})=0.09$
E_{des}=1.1-1.2eV
} QCM and TPD measurements

Same 0-D calculation →
e.g. 27mg/h evaporation in vacuum,
~20mg/h are detained by 50°C surfaces ✓

Plasma discharge and beam extraction: transmission probability through the sheath

- high Vp, high Te / low Vp, low Te
- low Vp, low Te, w/ NI
- Example of LAS for th desorption & phys sputtering

grafico dello strato

Attenuazione segnale LAS in funzione di z e della f(E) dei desorbiti

Vista delle aperture la
che permettono misu
diverse posizioni

Energy distribution of sputtered Cs atoms

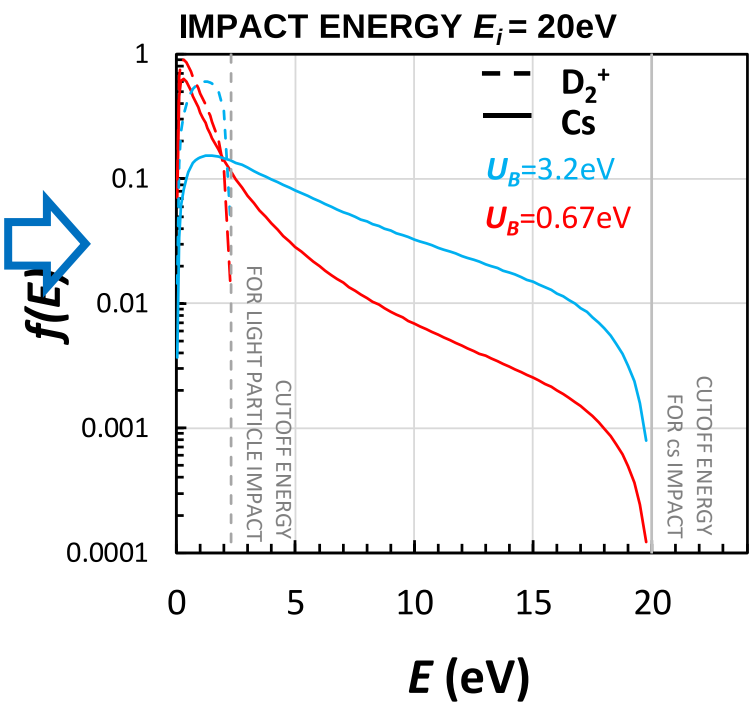
- Perpendicular velocity of Cs atoms depends on the process that caused desorption:

- **Energy distribution of the sputtered Cs atoms** [1)] caused by D2+ impact or Cs+ impact (in figure, EDF for impact energy of 20eV)

$$f(E) = \frac{E}{(E + U_B)^{3+2m}} cos\left(\frac{\pi}{2}\left(\frac{E}{E'}\right)^4\right)$$

Energy distribution peaked at binding energy U_B and extends to infinite

Cutoff to limit the distribution to the maximum transferrable energy $E' = \gamma E_{in}$ (reduced mass γ)



[1] Eckstein, W., Nucl. Instrum. and Methods in Physics Research B18, 344–348 (1987)