FIRST MEASUREMENTS OF BEAM PLASMA IN NIFS TEST STAND

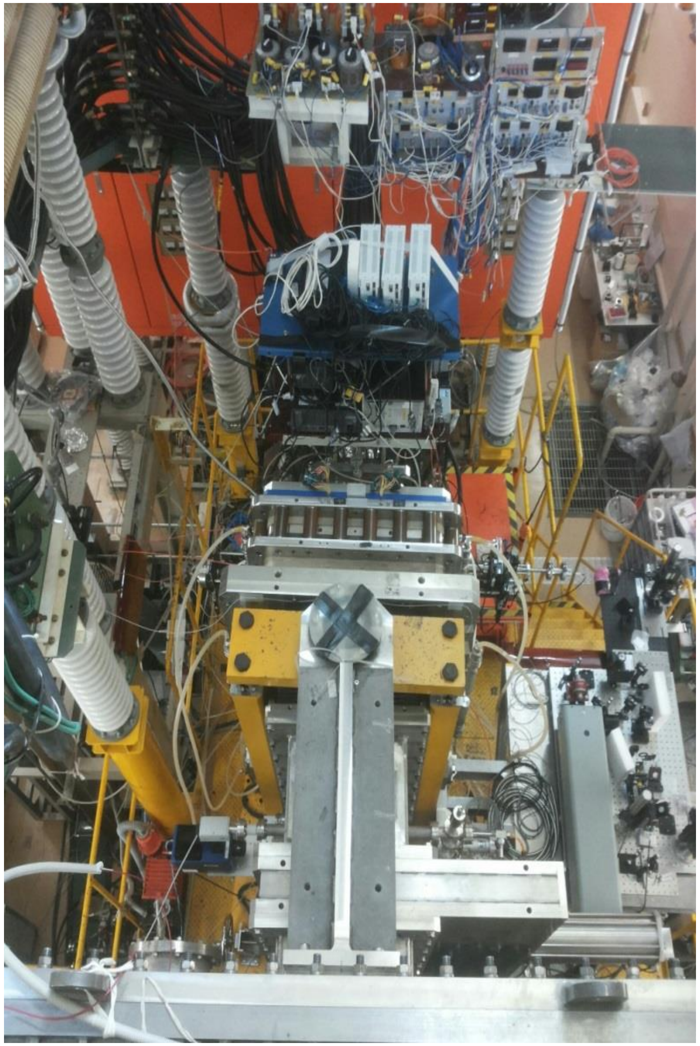
E. Sartori[1,3], H. Nakano[2], P. Veltri[1,4], M. Kisaki[2], A. Pimazzoni[1], M. Brombin[1], V. Antoni[1], K. Ikeda[2], K. Tsumori[2] and G. Serianni[1]

[1]Consorzio RFX, Corso Stati Uniti 4 – 35127, Padova (Italy)
[2]National Institute for Fusion Science, 322-6 Oroshi, Toki, Gifu 509-5292, Japan
[3]University of Padova, Dept. of Management and Engineering, Strad. S. Nicola 3, 36100 Vicenza, Italy
[4]INFN-LNL, Viale dell'Università 2, I-35020, Legnaro (Italy)

Introduction

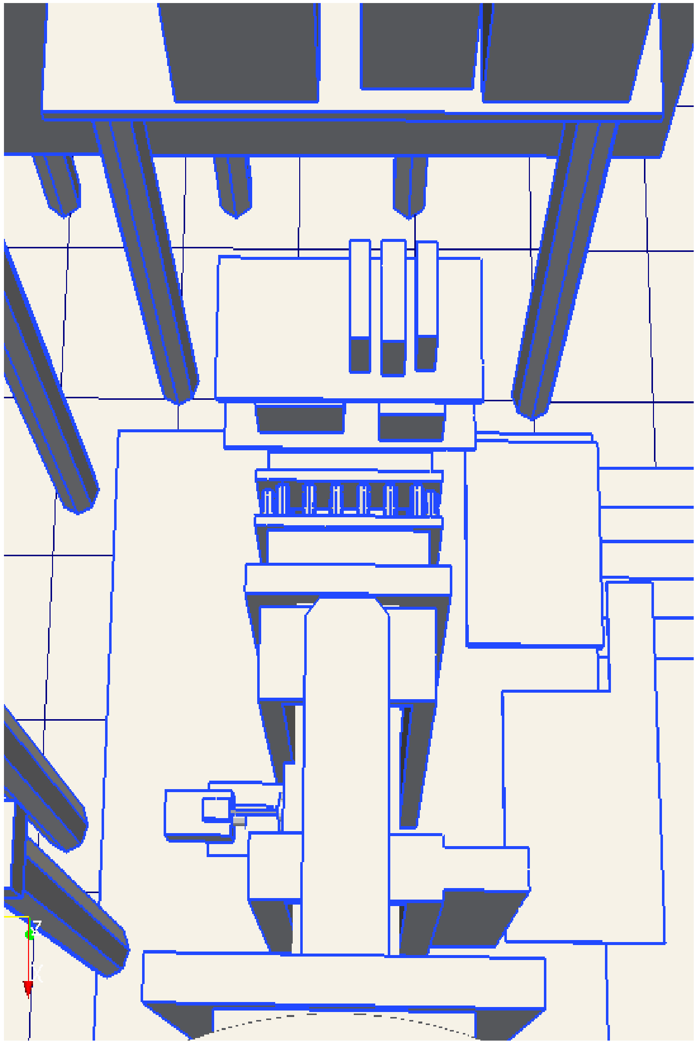
- Beam-generated plasma important for
  - Space Charge Compensation (propagation, optics & focusing)
  - positive ions backstreaming in the accelerator (heat load)
  - neutralization (efficiency)
  - Ion beam tranport al low pressures (photoneutralizer?)
- **Effect of background gas pressure**
- **Multibeamlet H^- beam for Neutral Beams**
- Experimental study in multibeamlet negative ion beams: *R&D Negative Ion Source* in NIFS, Japan
  - Retarding Field Energy Analyser was designed and build to the purpose
- PIC Numerical simulations to support the experimental campaign

EXPERIMENTAL SETUP: RNIS at NIFS



- H- beam
- Cesiated surface-plasma negative ion source
- Hundreds of independent beamlets
- Beam energy for this campaign: ~48kV

EXPERIMENTAL SETUP: BEAMLINE DIAGNOSTICS



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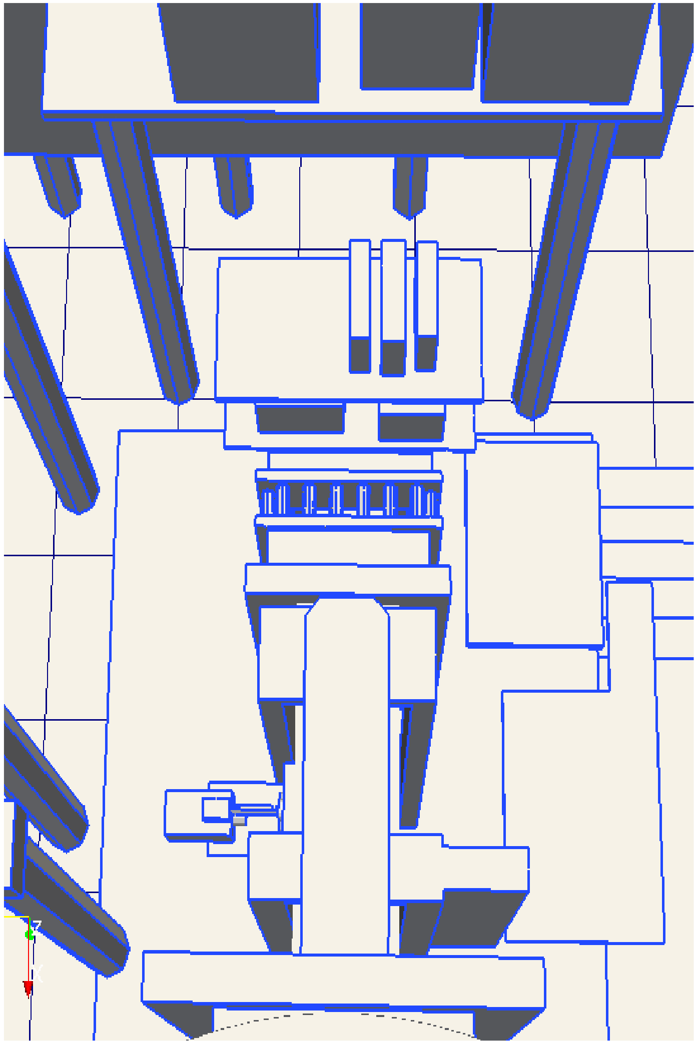

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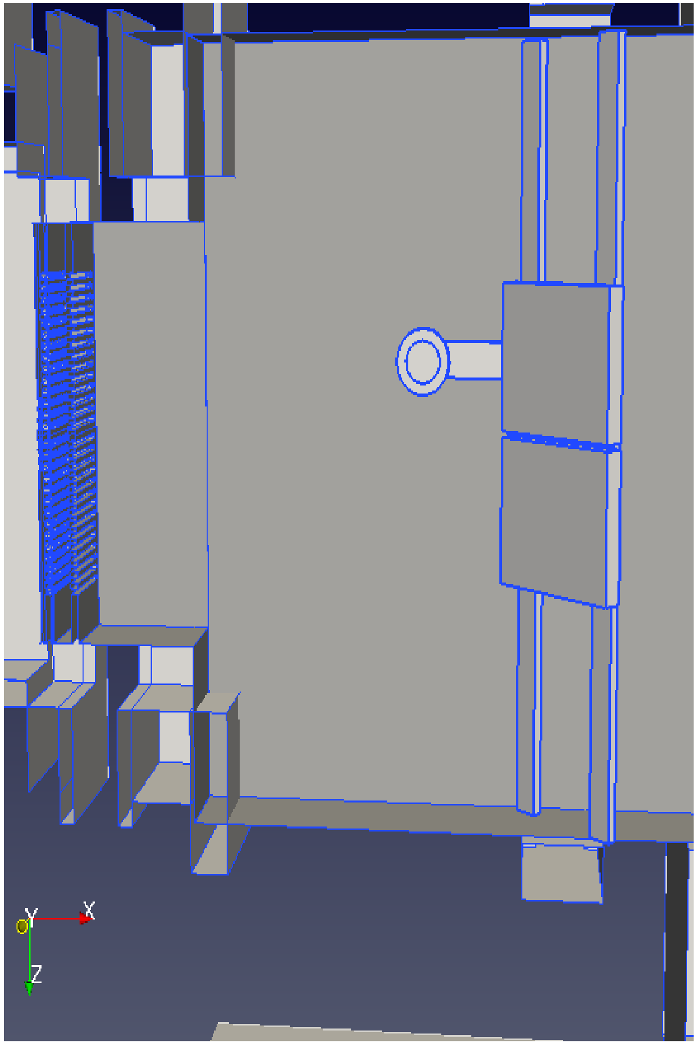
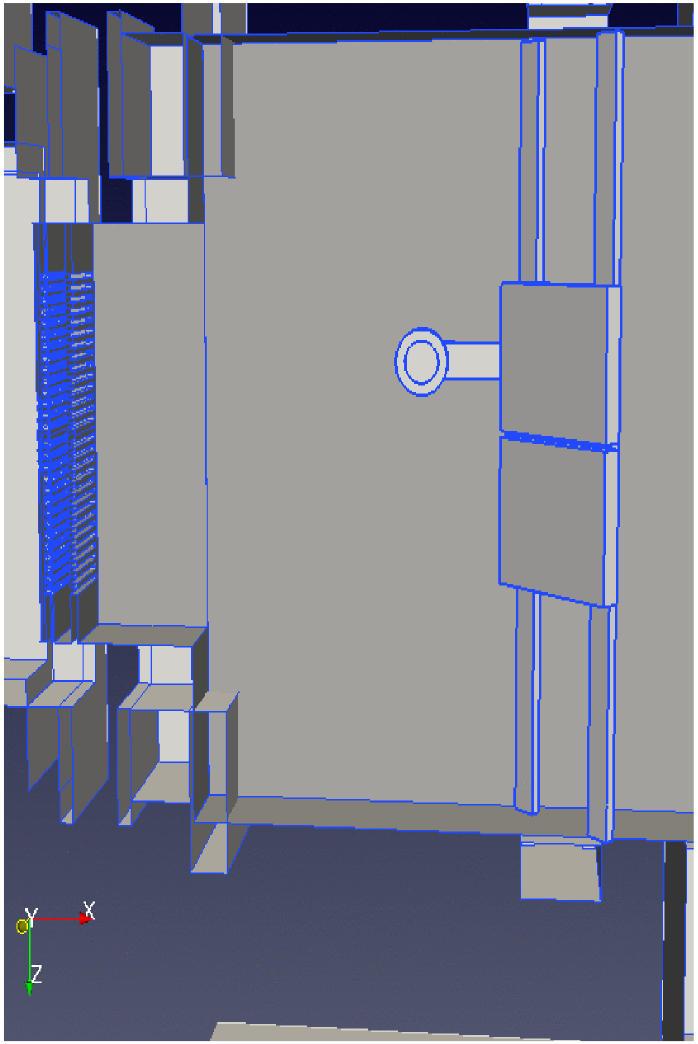


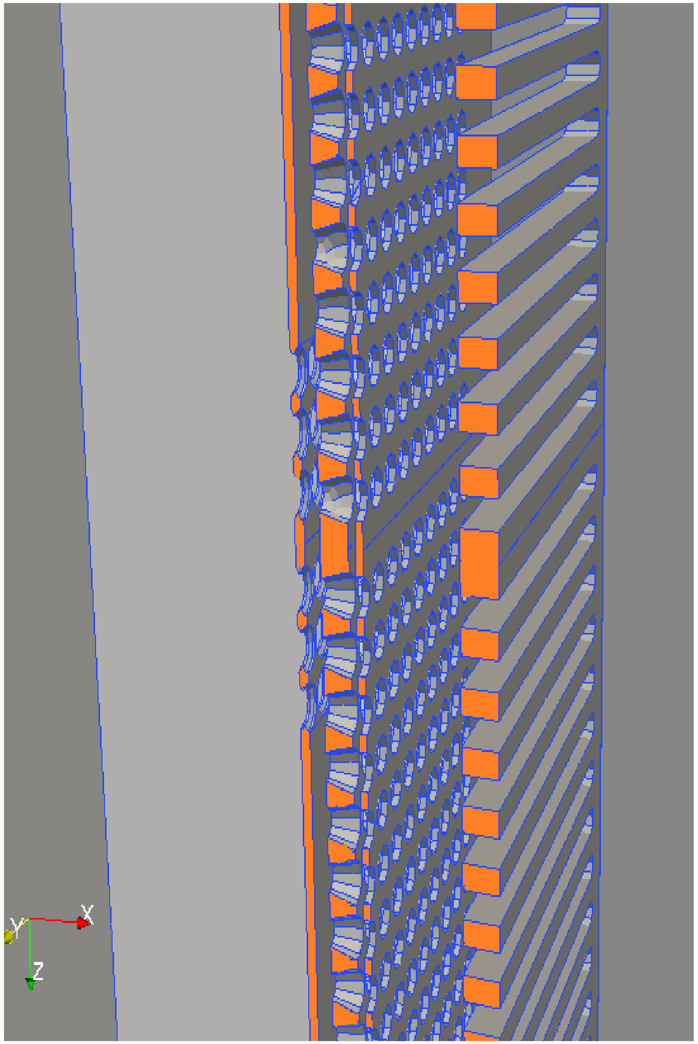
ACCELERATOR & MULTI-BEAMLET PATTERN



Four multiaperture electrodes:

- Plasma Grid (PG)
- Extraction Grid (EXG)
  Steering Grid (ESG)
- Grounded Grid (GG)

ACCELERATOR & MULTI-BEAMLET PATTERN

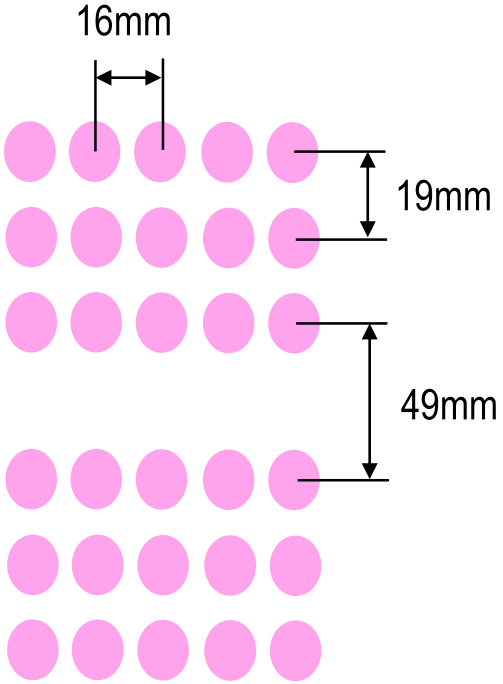


Four multiaperture electrodes:

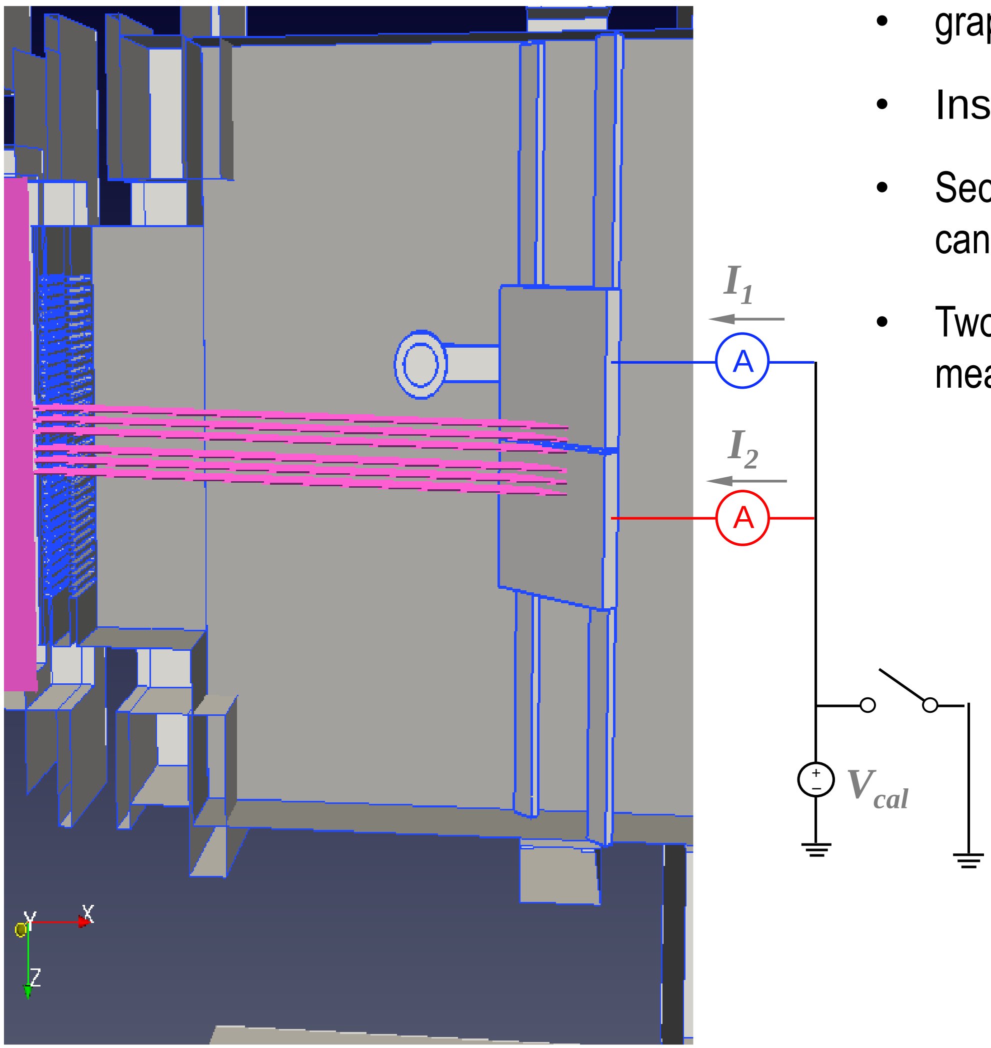
- Plasma Grid (PG)
- Extraction Grid (EXG)
  Steering Grid (ESG)
- Grounded Grid (GG)

PG mask: reduced number of apertures:

- 30 beamlets
- Two 5x3 beamlet groups



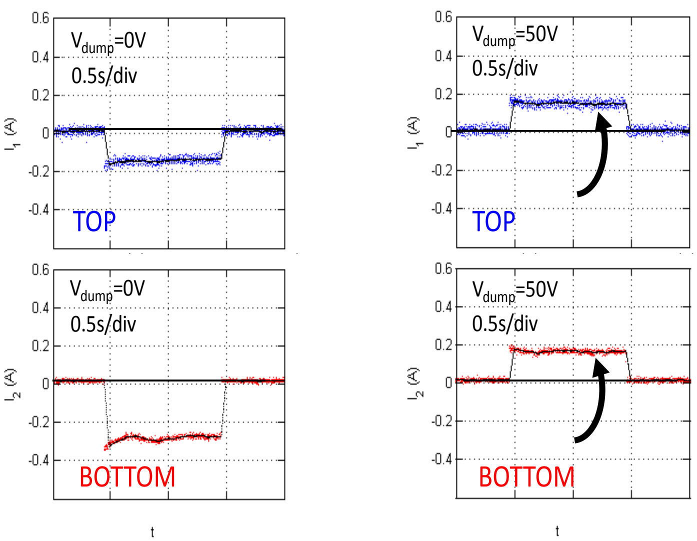
BEAMLET MONITOR



- graphite tiles, 45° to beam axis
- Insulated,
- Secondary electron emission: can be biased V_{cal}
- Two independent current measurements I_1 , I_2

V_{cal} = 0V

V_{cal} = 50V



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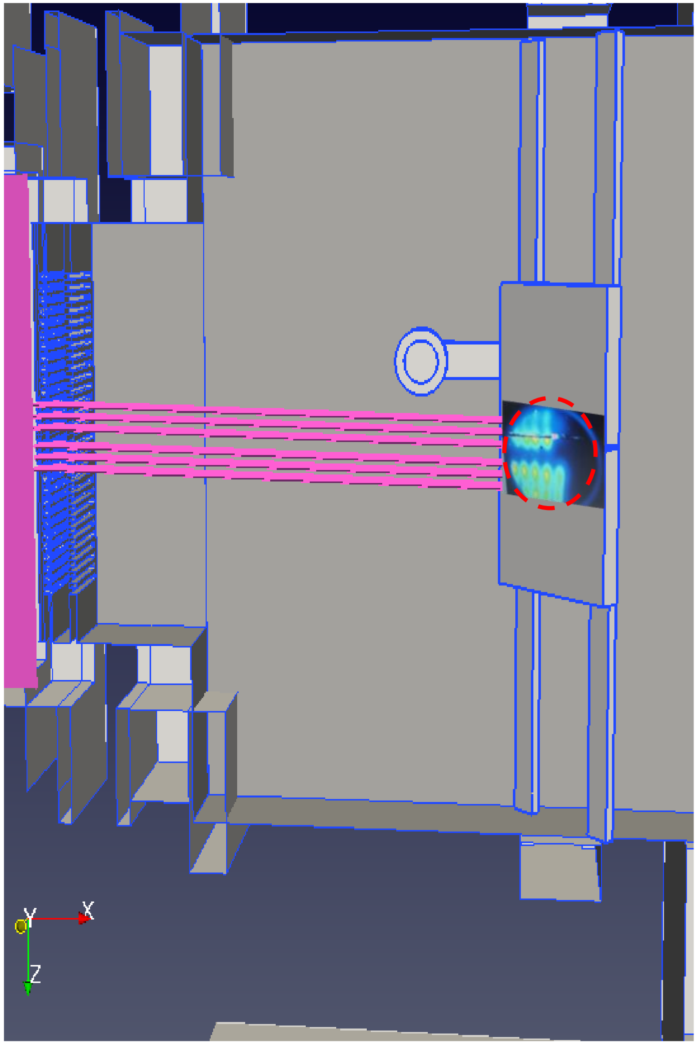
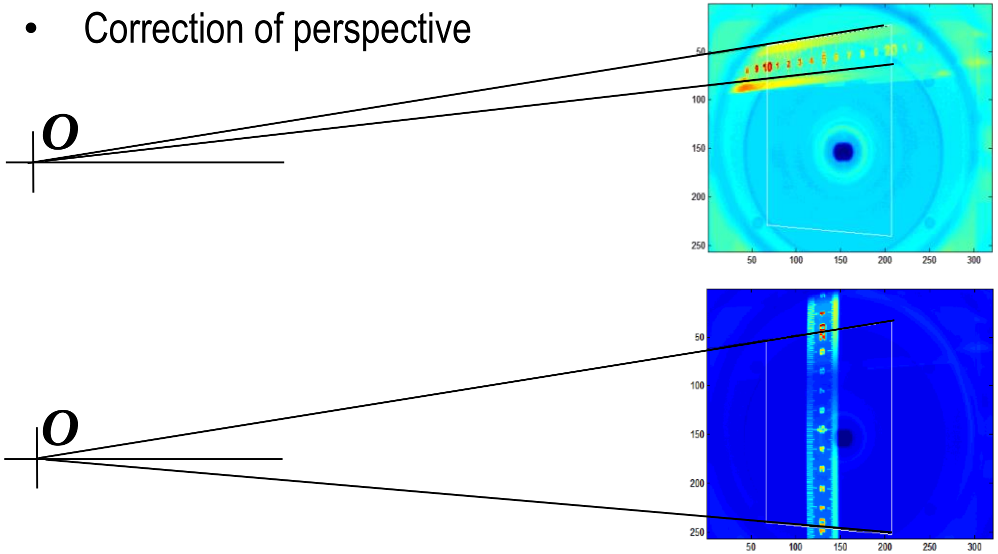
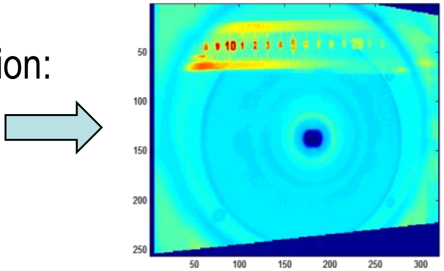


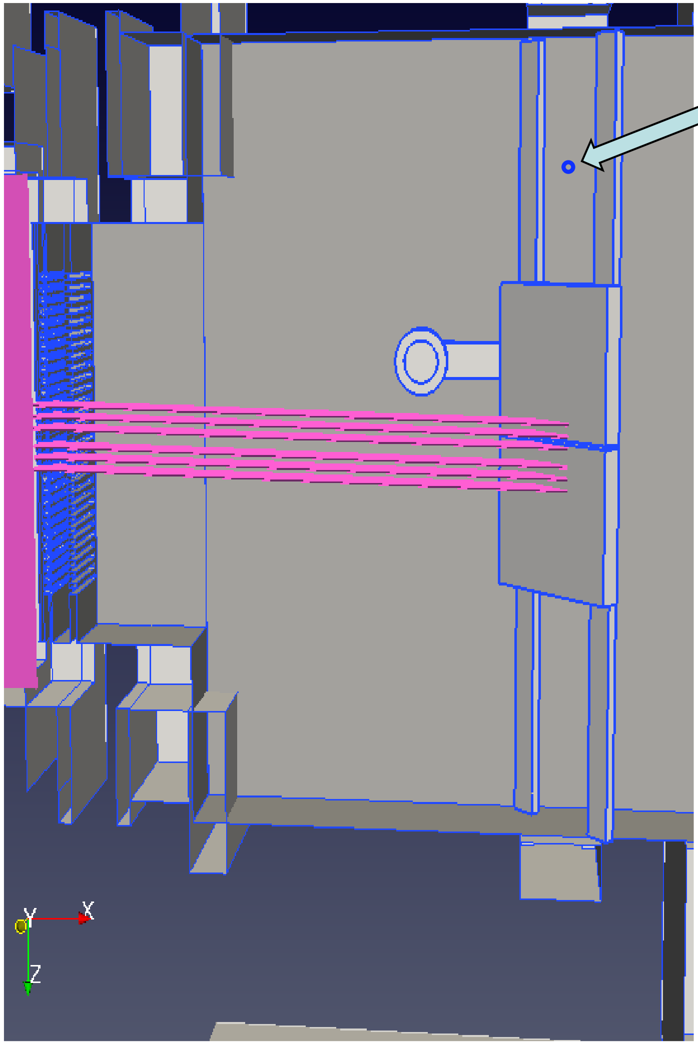
- Correction of perspective



- Calibration of IR image resolution:
~2 pixel/mm
(along transverse direction x)



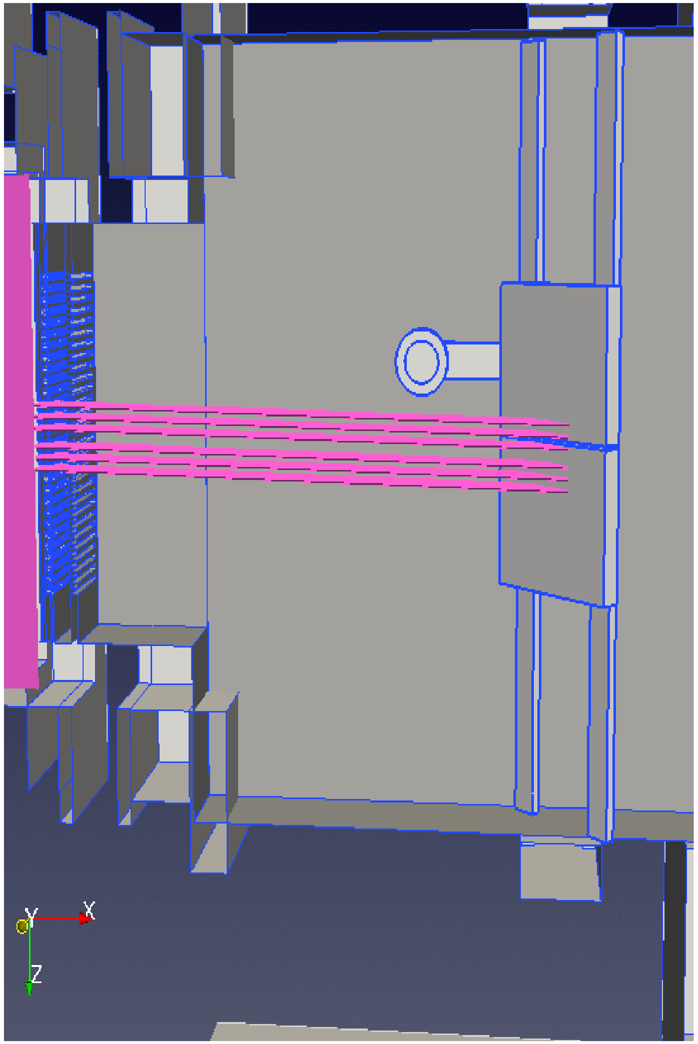
GAS INJECTION in DRIFT TUBE

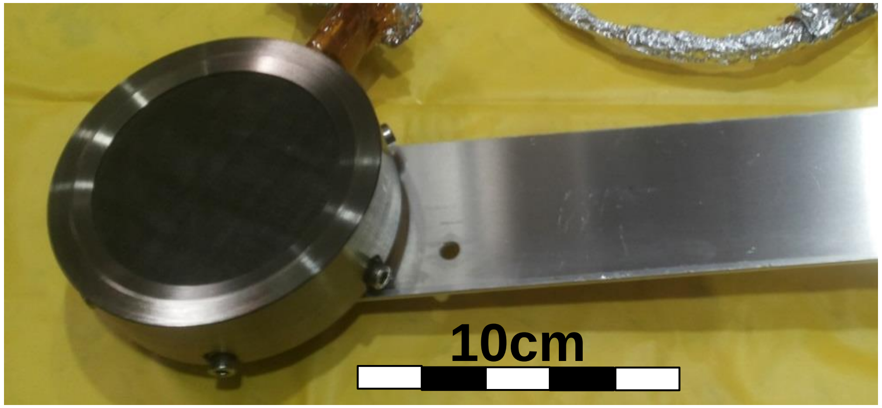


- Gas injection nozzle
- Control the gas density in drift region separately from the ion source

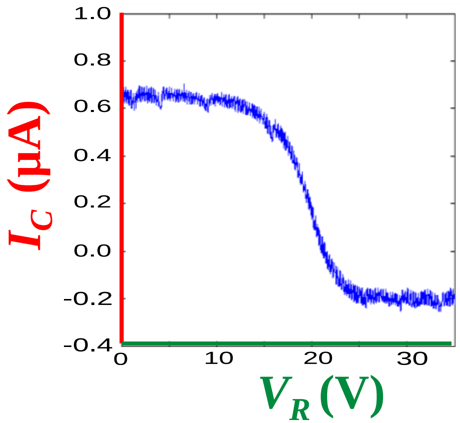
1.8 mPa < p < 30 mPa

4-GRIDS RETARDING FIELD ENERGY ANALYSER

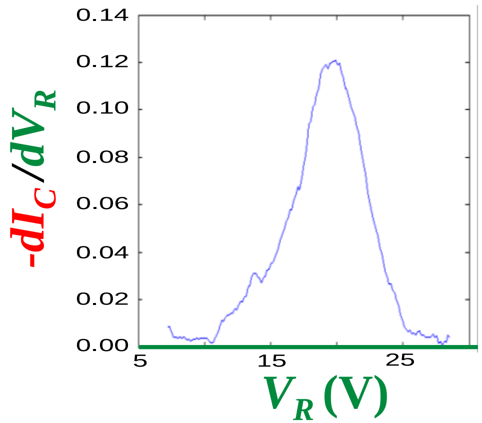




Discriminates ions according to their energy.
Measures the integral ion parallel energy distribution:

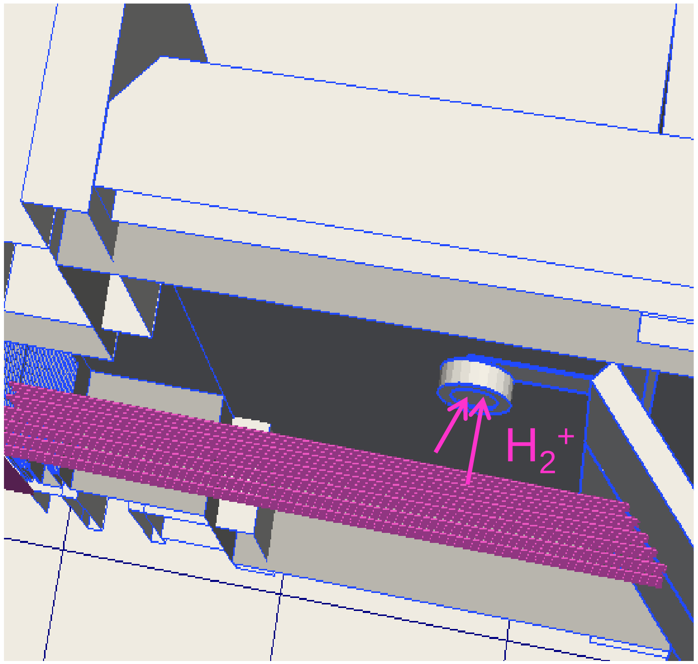


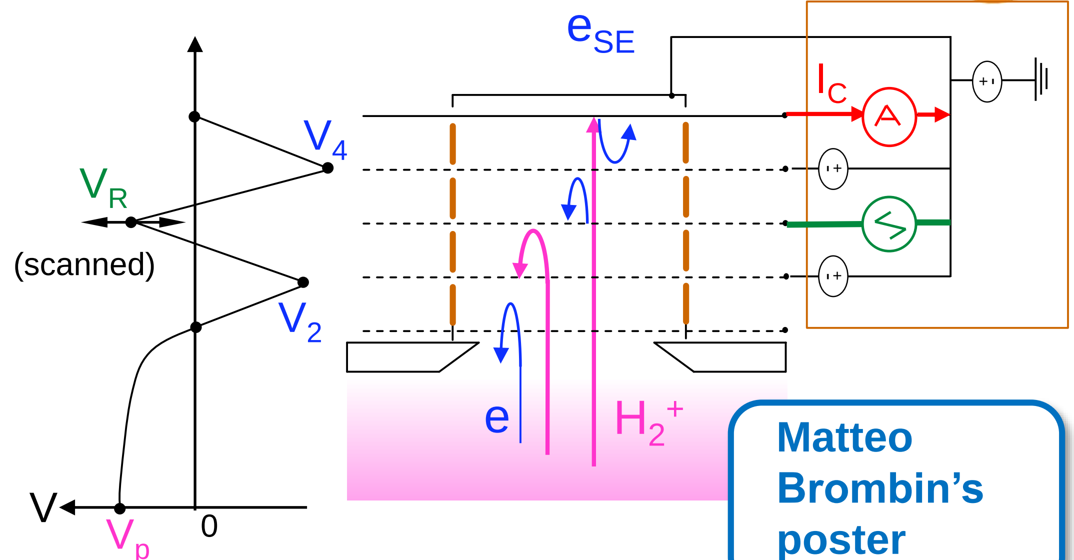
Current-voltage characteristic



numerical differentiation of the characteristic

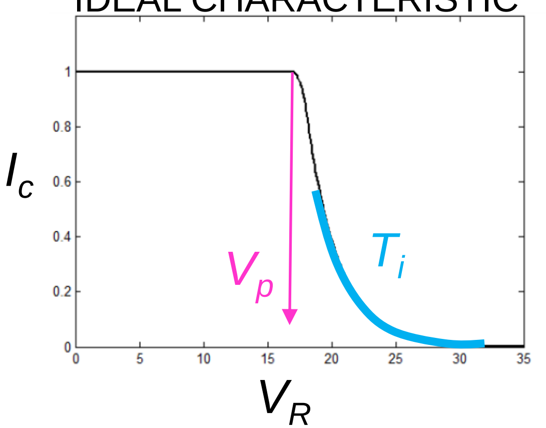
4-GRIDS RETARDING FIELD ENERGY ANALYSER





Matteo Brombin's poster

IDEAL CHARACTERISTIC



Collects positive ions exiting from the compensation plasma: integral parallel velocity distribution

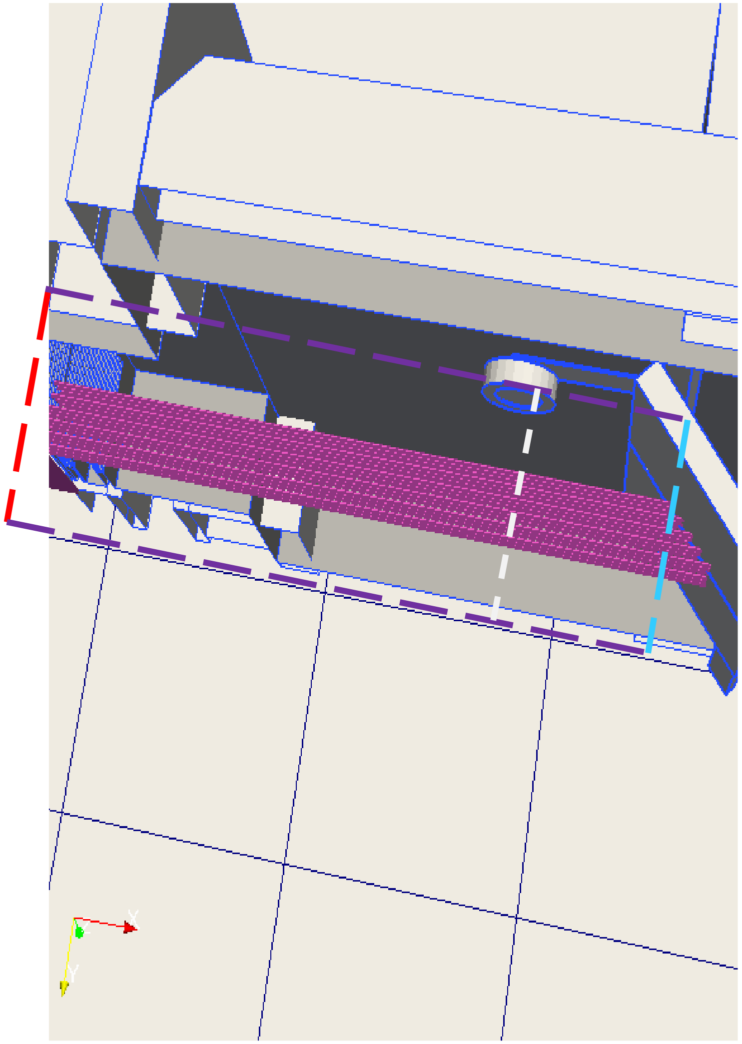
$$j_c = j_0 q_i K \int_u^{\infty} v_{//} f(v_{//}) dv_{//}$$

Non collisional sheath, Maxwellian plasma:

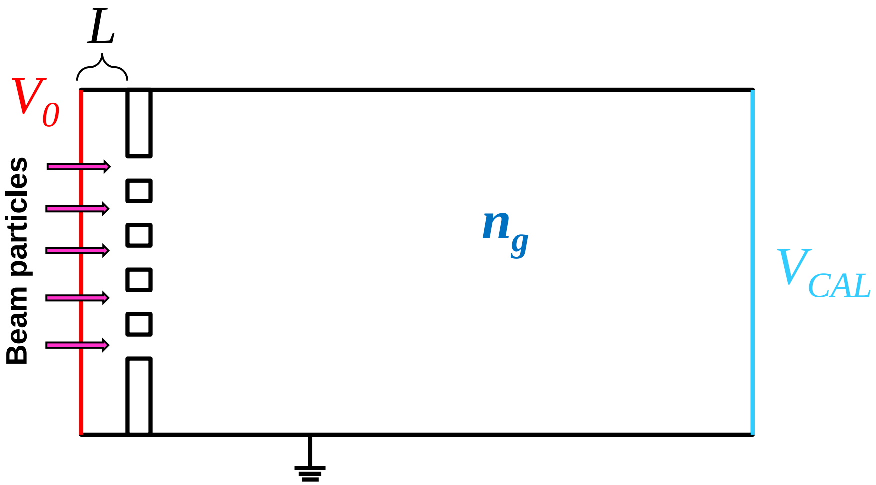
$$j_c = K \exp\left(-\frac{q_i (V_R - V_P)}{kT_i} \right), \text{ for } V_R > V_P$$

Complex transfer function may deform characteristics

ADDITIONAL DIAGNOSTICS: NUMERICAL SIMULATION



- 2D 3V PIC-MCC code, GPGPU (CUDA)
- 6 species: e, H^-,H,H^+,H_2^+,H_3^+
  26 processes
  differential cross-sections
- Beam dump with bias (V_{cal}) and **secondary emission electrons**
- **Acceleration field**: $V_0 = -V_{acc} \frac{L}{L_{EXG-GG}}$



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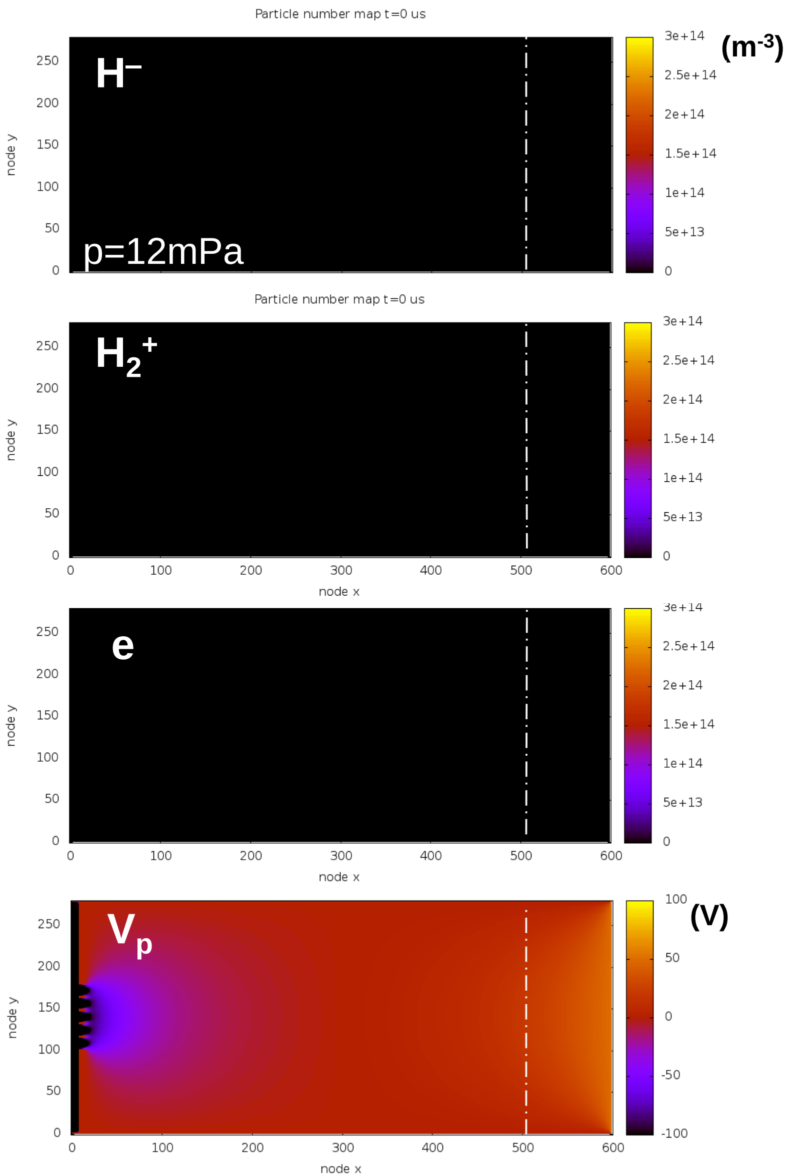

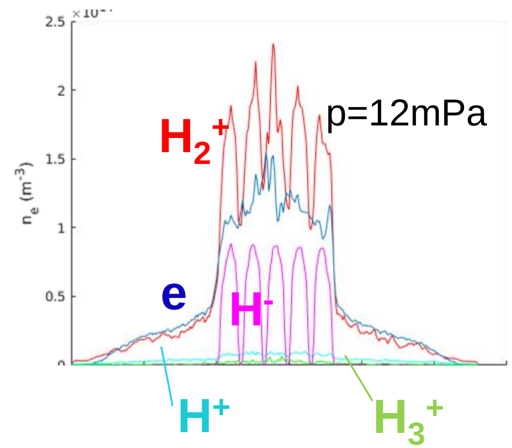

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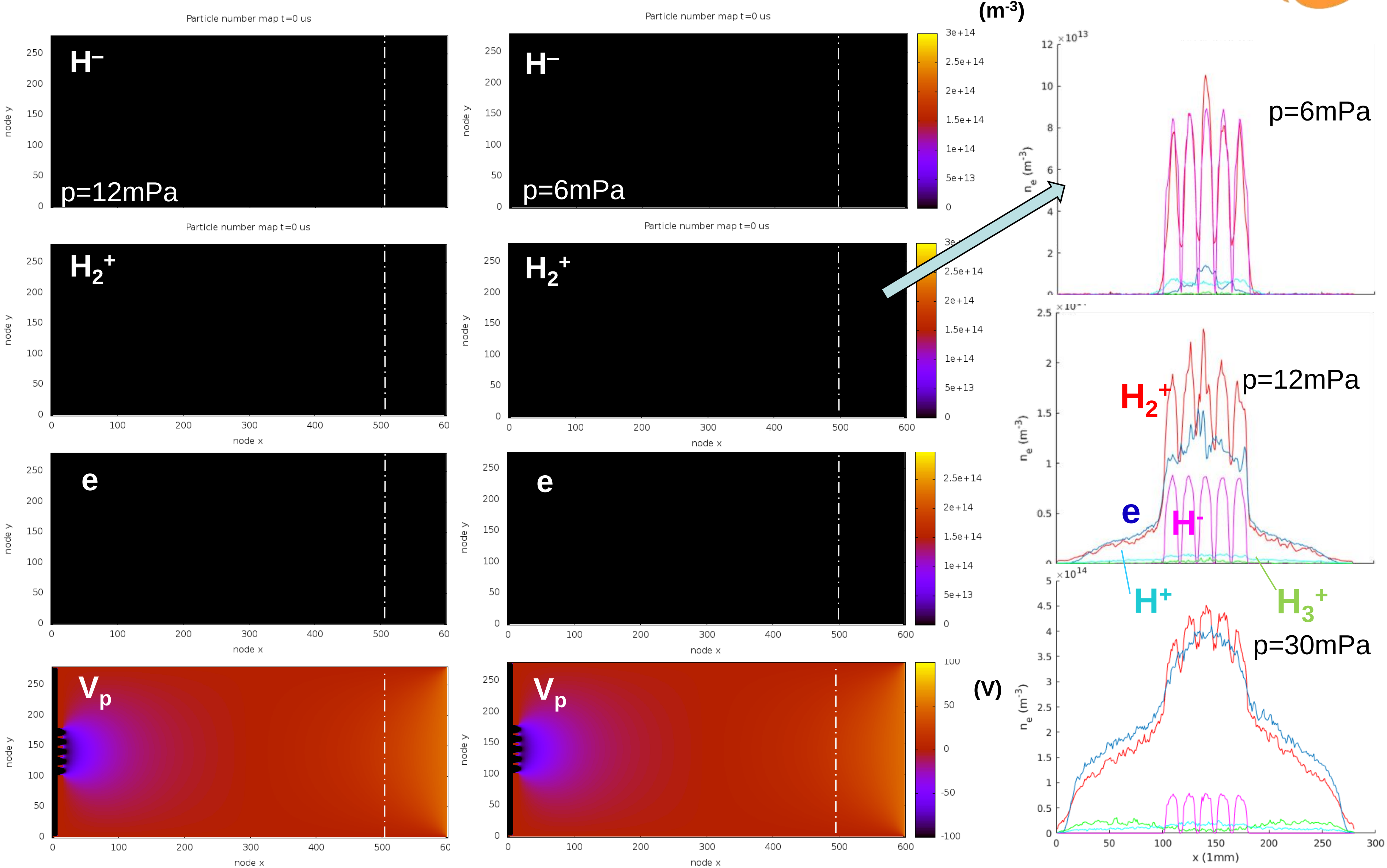


EXPERIMENTAL RESULTS:

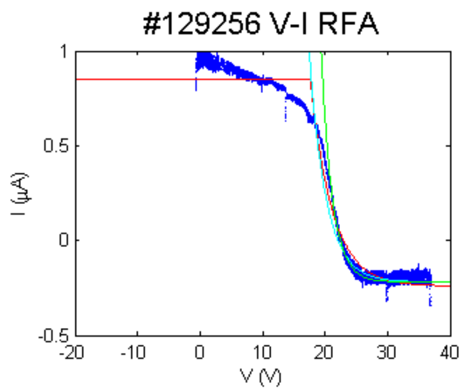
1) Plasma potential

2) Temperatures

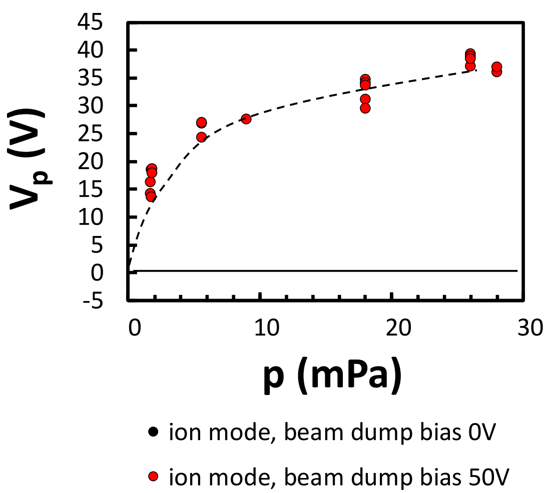
3) Effect on beam optics

1) RFA CHARACTERISTICS: PLASMA POTENTIAL

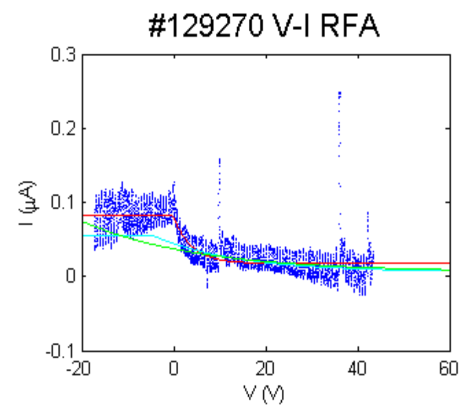
ION MODE



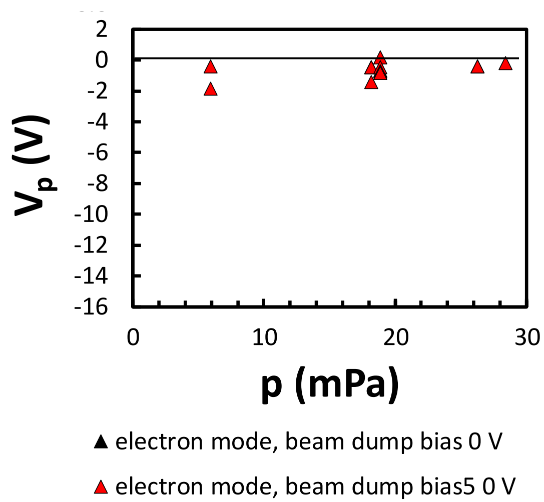
IEDF Vb=50V p=26mPa



ELECTRON MODE



EEDF Vb=50V p=28.4mPa



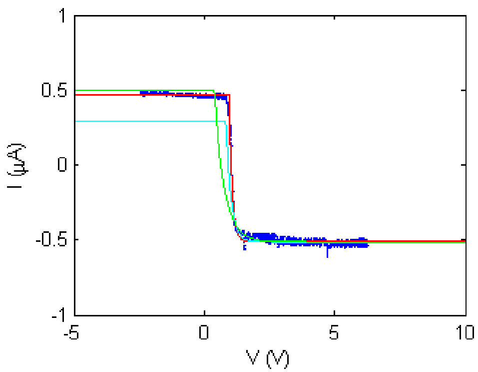
●, ▲ calorim. 50V

Plasma potential from ion mode: $0 < V_p < V_{cal}$

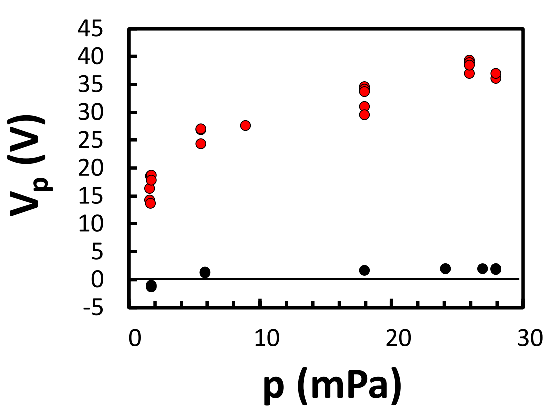
1) RFA CHARACTERISTICS: PLASMA POTENTIAL

ION MODE

#129282 V-I RFA



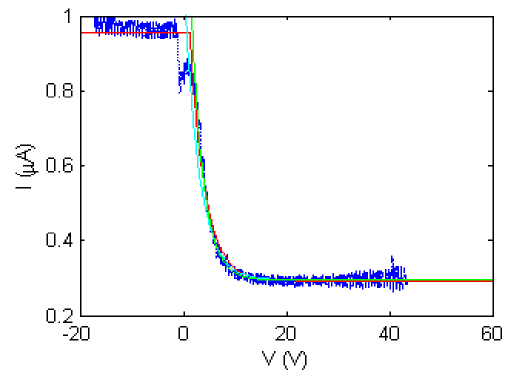
IEDF Vb=0V p=28mPa



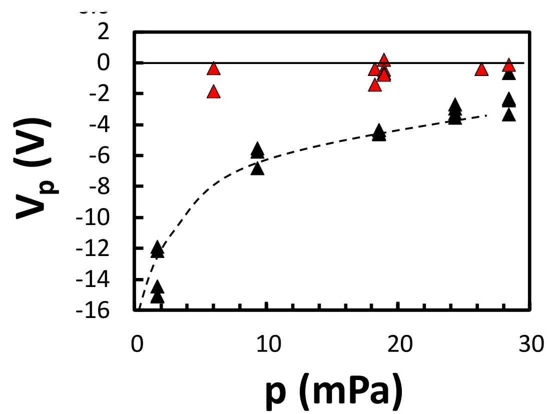
- ion mode, beam dump bias 0V
- ion mode, beam dump bias 50V

ELECTRON MODE

#129271 V-I RFA



EEDF Vb=0V p=28.4mPa



- ▲ electron mode, beam dump bias 0 V
- ▲ electron mode, beam dump bias5 0 V

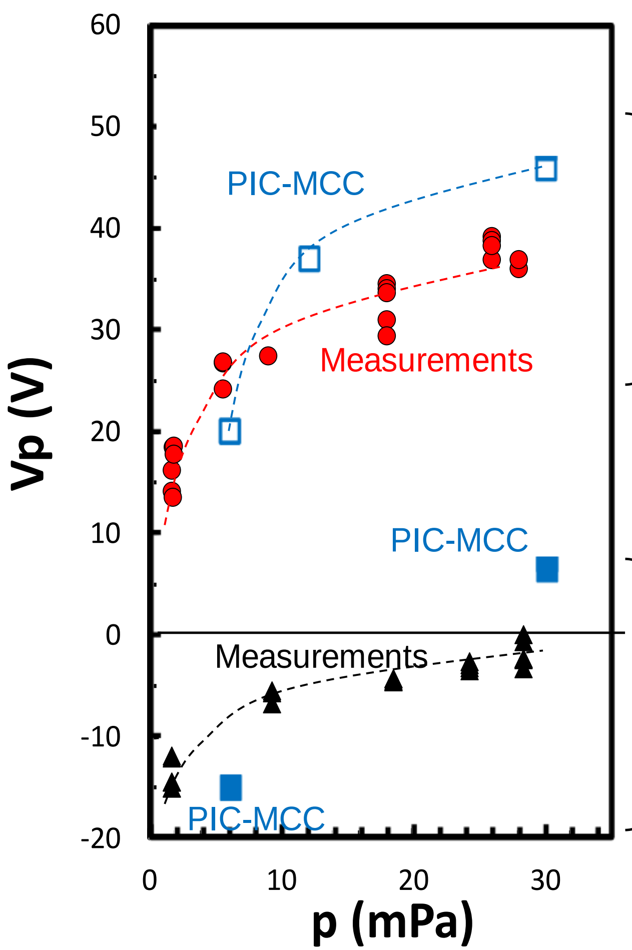
●, ▲ calorim. 50V

Plasma potential from ion mode: $0 < V_p < V_{cal}$

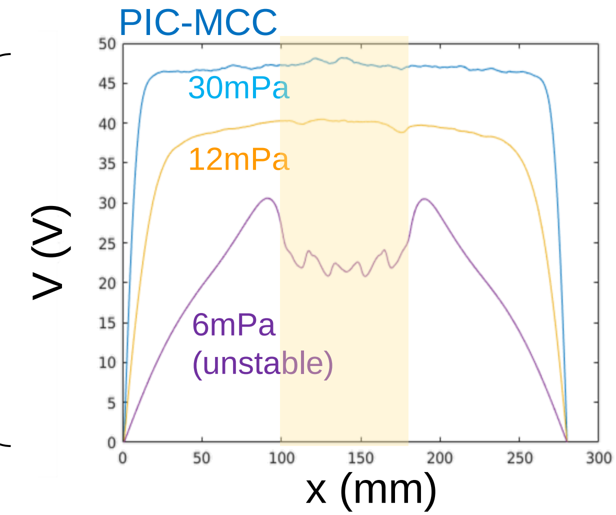
●, ▲ calorim. 0V

Plasma potential from electron mode: $V_p < V_{cal} = 0V$

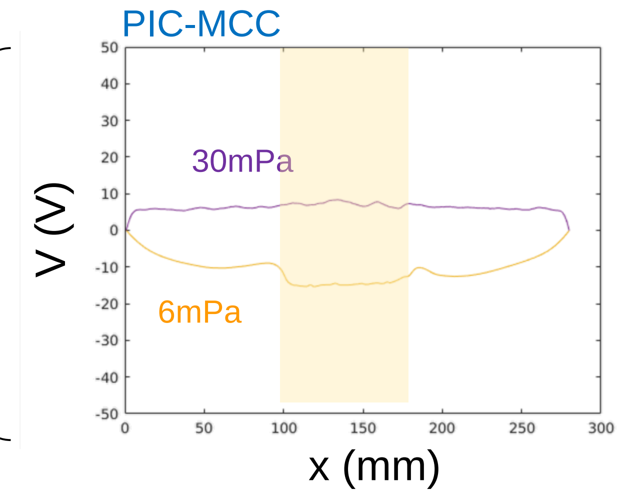
Measurements vs. PIC-MCC



V_{cal}=50V



V_{cal}= 0V

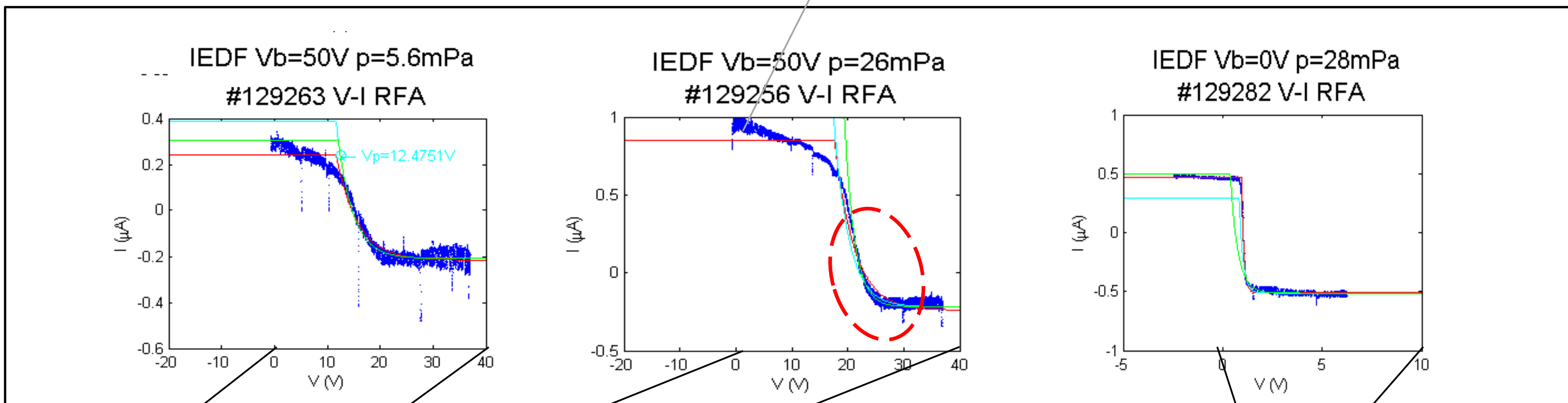


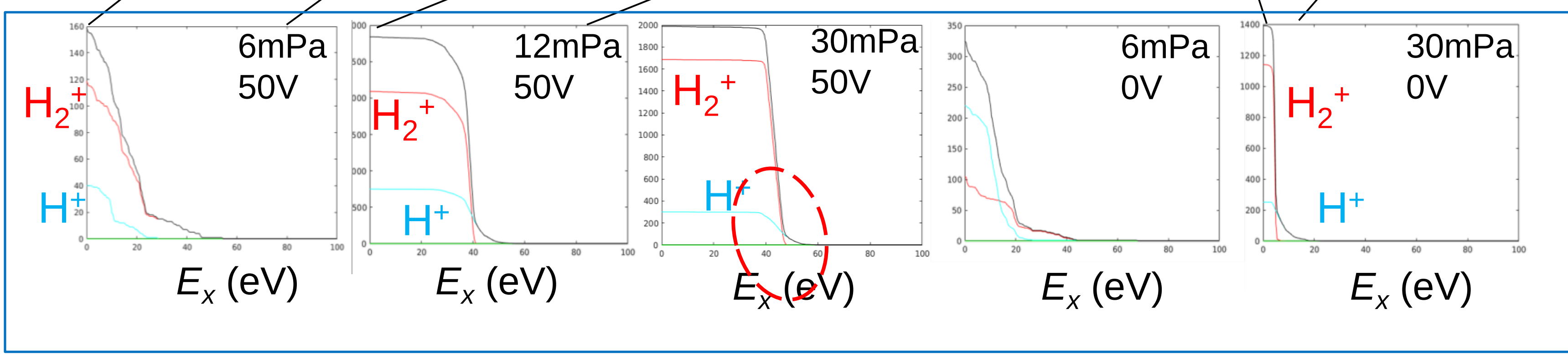
2) RFA CHARACTERISTICS: ION TEMPERATURE

Energy distribution of H_2^+ and protons is overlapped

Measurements: RFA characteristic

saturation affected by transfer function of RFA

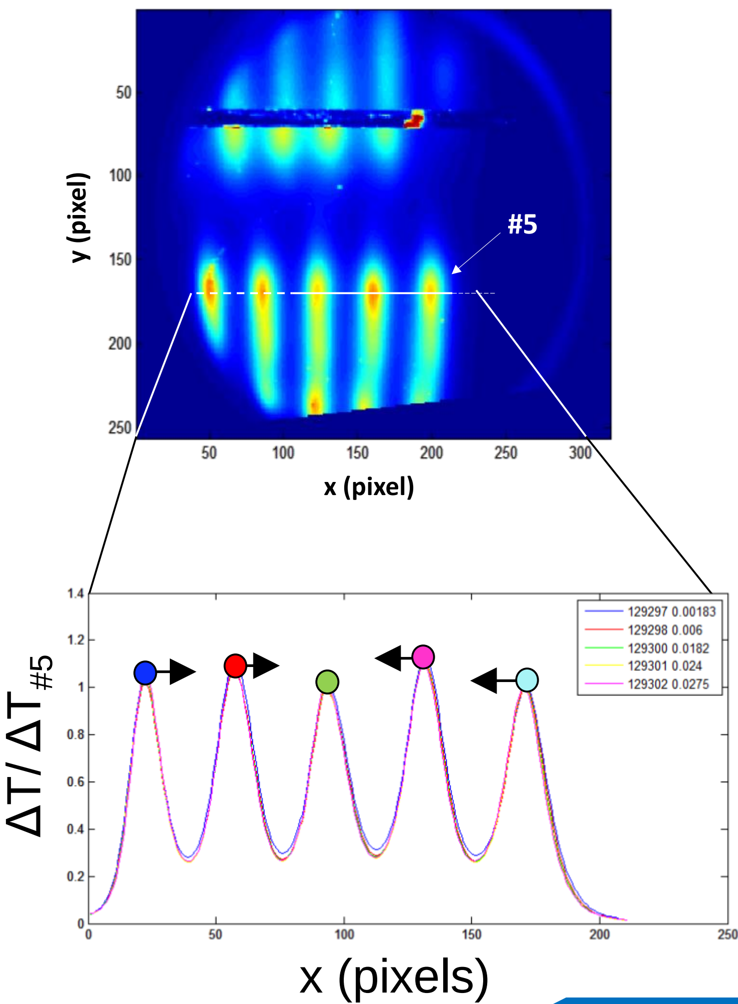


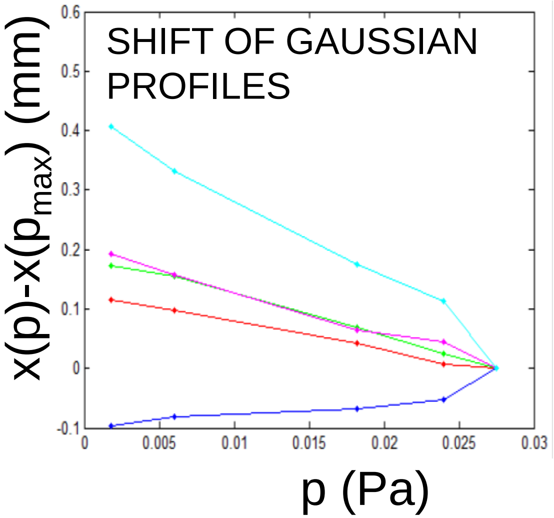


PIC-MCC: energy distribution of particles exiting from side walls

3) EFFECTS ON BEAM: MULTIBEAMLET OPTICS

Fitting ΔT profile produce **beamlet centre** : beamlet are getting closer one to the other





The centre of the edge beamlet footprint moves by about 0.5 mm/25mPa

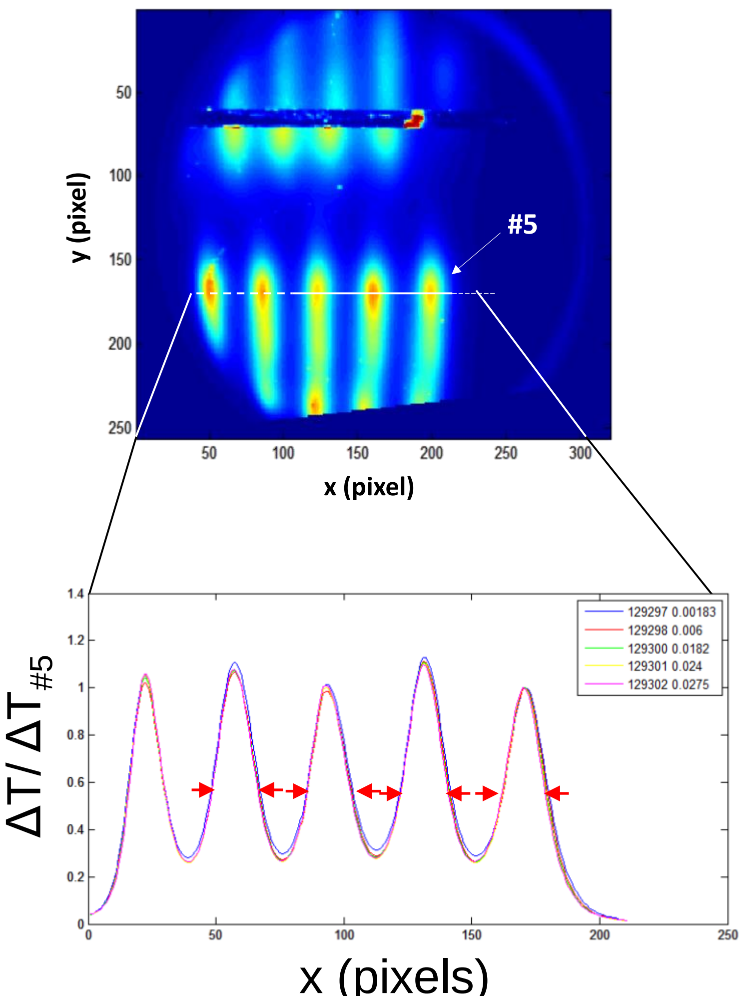
FILTER BEAM PULSES:

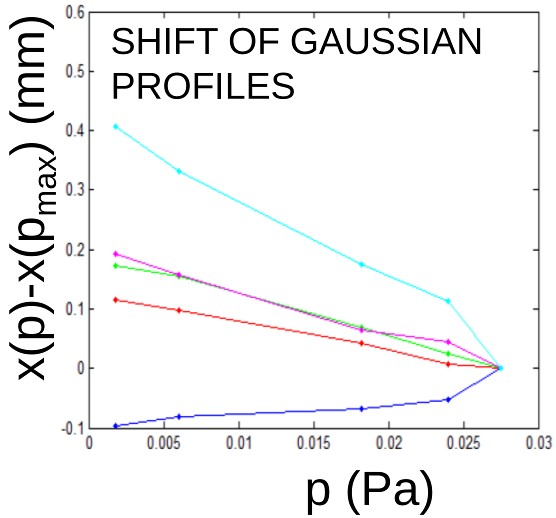
- arc power within +/- 5%,
- of +/- 3.5% with respect to the average ΔT was chosen
- initial temperature of the graphite tile was within +/- 4% with respect to the average one

3) EFFECTS ON BEAM: SINGLE BEAMLET OPTICS

Fitting ΔT profile produce **beamlet centre** : beamlet are getting closer one to the other

Fitting ΔT profile produce **beamlet width:** focusing effect increasing pressure





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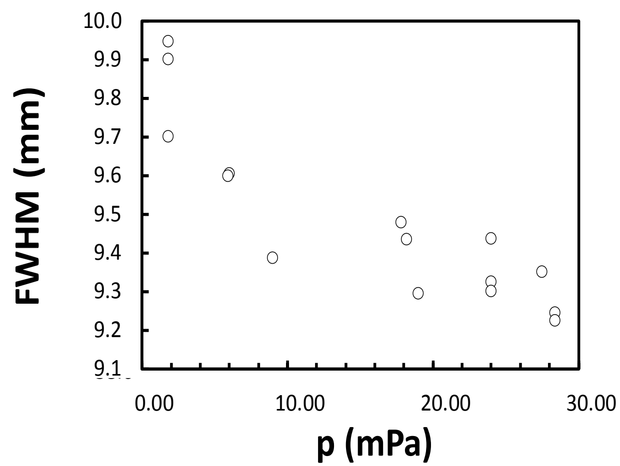

The beamlet FWHM is reduced by >5% in the pressure interval between 2mPa and 28mPa.

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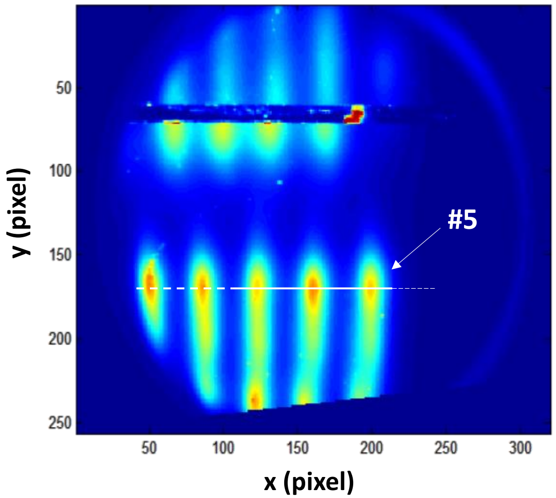
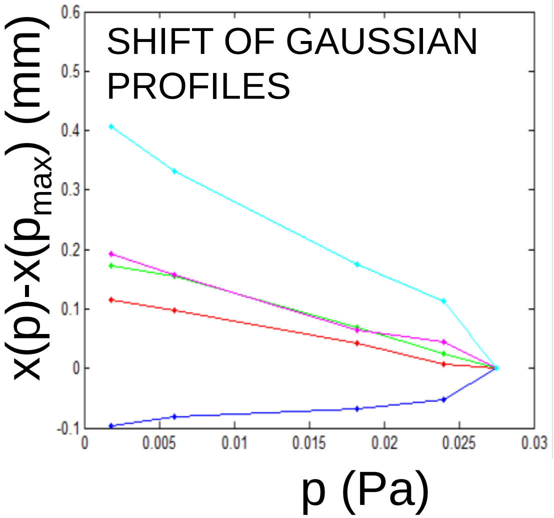
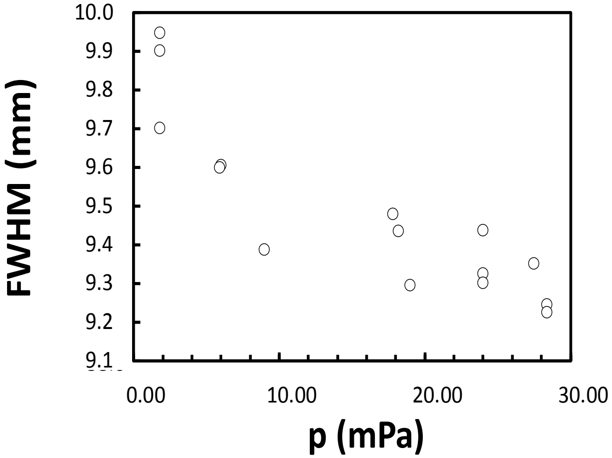




The centre of the edge beamlet footprint moves by about 0.5 mm/25mPa

Multi-beamlet → decreasing repulsion
- transverse electric field **1 V/cm** along 1m

Single-beamlet → focusing
- vary compensation degree ψ by +0.7%

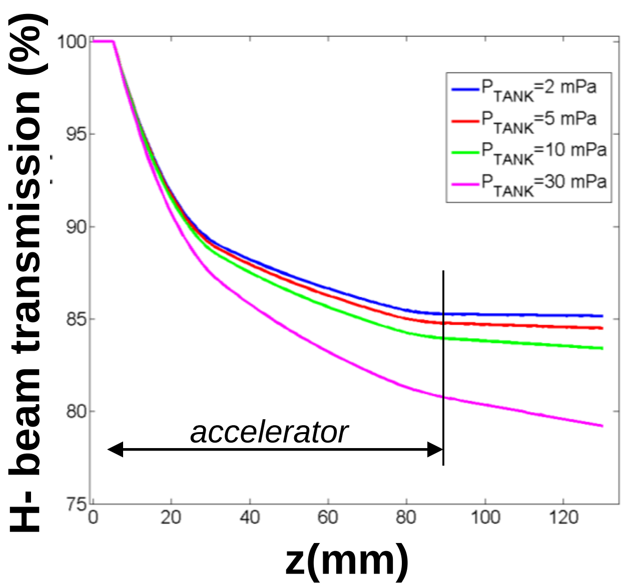


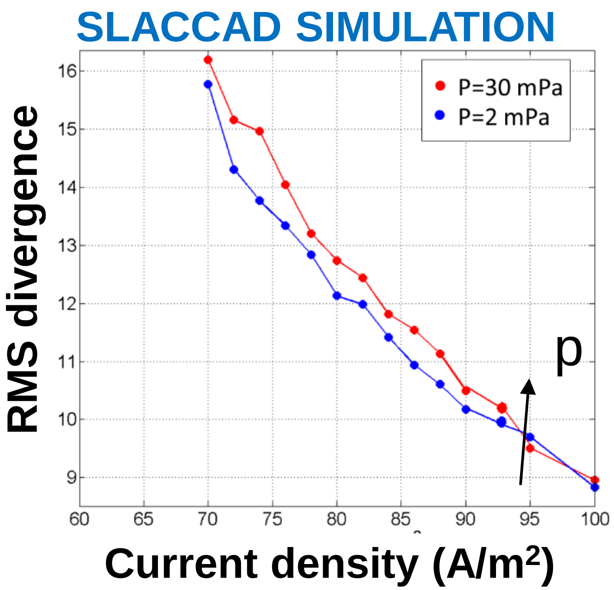
The beamlet FWHM is reduced by >5% in the pressure interval between 2mPa and 28mPa.

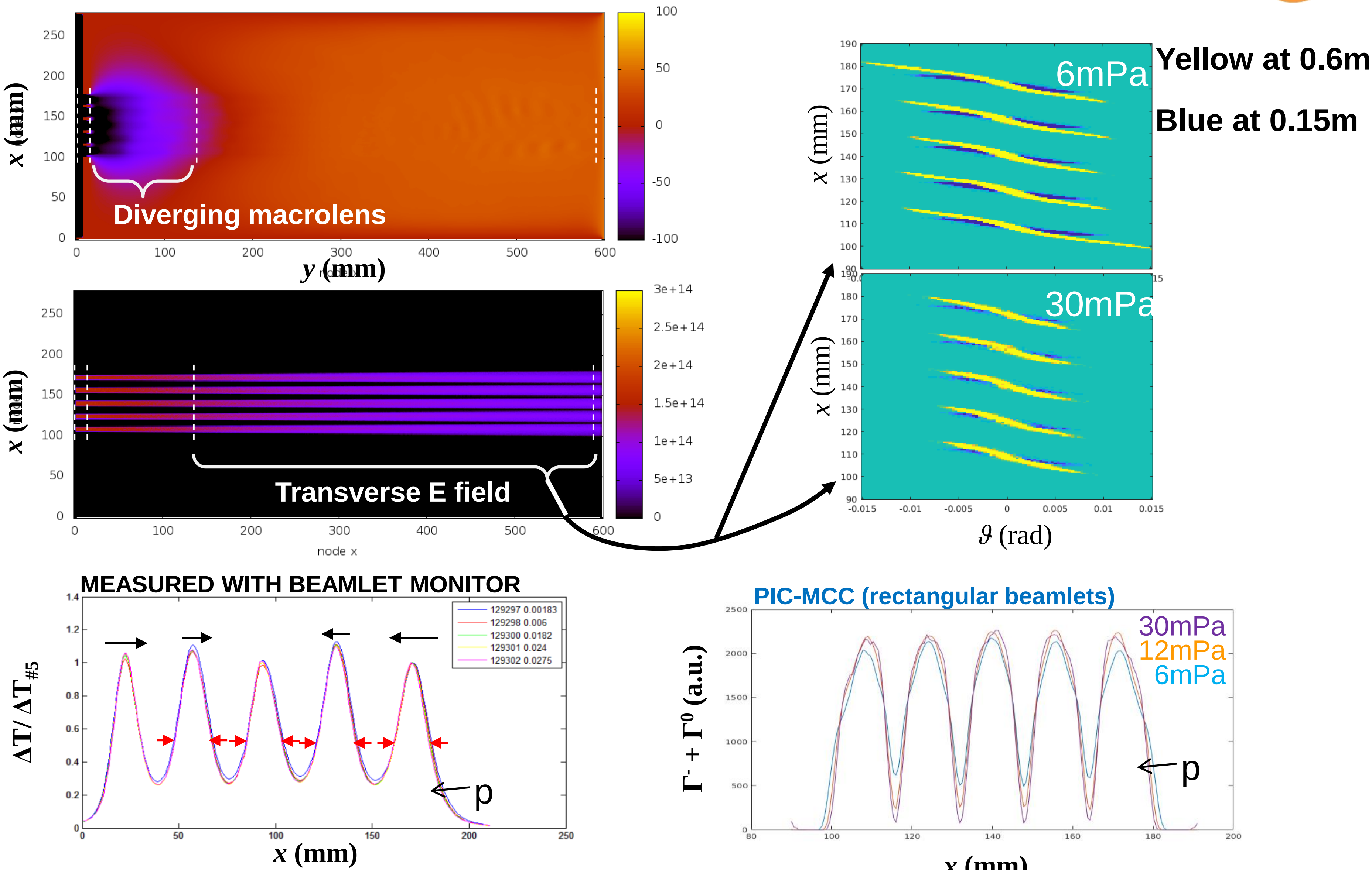
3) EFFECTS ON BEAM OPTICS

Very small effect but the trend is always present – hot to distinguish between space charge effects inside the accelerator or after?

Ray-tracing iterative poisson solver SLACCAD simulations of the accelerator, including stripping: optics getting worse when increasing tank pressure



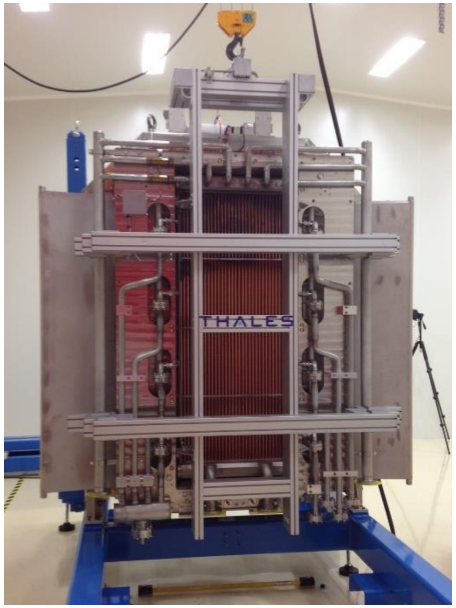




Diverging macrolens
y (mm)
x (mm)
Transverse E field
node x
6mPa
30mPa
Yellow at 0.6m
Blue at 0.15m
ϑ (rad)
MEASURED WITH BEAMLET MONITOR
129297 0.00183
129298 0.006
129300 0.0182
129301 0.024
129302 0.0275
ΔT/ΔT#5
x (mm)
p
PIC-MCC (rectangular beamlets)
30mPa
12mPa
6mPa
Γ- + Γ0 (a.u.)
x (mm)
p

SUMMARY

- Beam plasma: plasma potential set by beam dump bias (lower than calorimeter potential due to secondary emission electrons); cold H_2^+ and relatively hot H^+
- Beam focusing when increasing tank pressure from 2 to 30mPa: small multi-beamlet steering effect (0.5mm/m); small single-beamlet focusing by 0.5mrad (SLACCAD calculations gives increasing divergence when increasing stripping losses!)
- PIC-MCC in agreement w/ measurements: scaling to ITER HNB and the two prototypes SPIDER and MITICA



ITER BEAM SOURCE (SPIDER) – SEPT 2017

ITER NEUTRAL BEAM TEST FACILITY - PADOVA

ADDITIONAL DIAGNOSTICS: NUMERICAL SIMULATION

Reaction	notes
$\underline{H}^-, H_2 \rightarrow \underline{H}^+, \underline{2e}, H_2$	Fast electron
$\underline{H}^-, H_2 \rightarrow \underline{H}, \underline{e}, H_2$	fast electron
$\underline{H}^-, H_2 \rightarrow \underline{H}^-, H_2^+, e$	slow ion at RT, Rudd electrons
$\underline{H}^-, H_2 \rightarrow \underline{H}^-, H^+, e, H$	
$\underline{H}^-, H_2 \rightarrow \underline{H}^-, H^+, H^+, 2e$	
$\underline{H}, H_2 \rightarrow \underline{H}^+, \underline{e}, H_2$	
$\underline{H}, H_2 \rightarrow \underline{H}^-, H_2^+, e$	slow ion at RT, Rudd elecrons
$\underline{H}, H_2 \rightarrow \underline{H}^-, H_2^+$	slow ion at RT
$\underline{H}, H_2 \rightarrow \underline{H}, H^+, e, H$	slow ion at 7eV, peak at 90° and 270°
$\underline{H}, H_2 \rightarrow \underline{H}, H^+, e, H$	cold slow ions
$\underline{H}, H_2 \rightarrow \underline{H}, H^+, H^+, 2e$	slow ions at 9eV, isotropic
$\underline{H}^+, H_2 \rightarrow \underline{H}^+, H_2^+, e$	slow ion at RT, Rudd elecrons
$\underline{H}^+, H_2 \rightarrow \underline{H}, H_2^+$	slow ion at RT
$\underline{H}^+, H_2 \rightarrow \underline{H}^+, H^+, e, H$	
$\underline{H}^+, H_2 \rightarrow \underline{H}^+, H^+, H^+, 2e$	slow ions at 10eV, isotropic
$\underline{H}^+, H_2 \rightarrow \underline{H}^+, H_2$ (elastic)	
$H_2^+, H_2 \rightarrow H^+, H, H_2$	
$H_2^+, H_2 \rightarrow H_3^+, H$	Ion at RT (rotational exc.)
$H_2^+, H_2 \rightarrow H_2, H_2^+$	slow ion at RT
$H_2^+, H_2 \rightarrow H_2^+, H_2$ (elastic)	
$H_2^+, H_2 \rightarrow H_2^+, H_2$ (elastic)	
$H_3^+, H_2 \rightarrow H, H_2^+, H_2$	
$H_3^+, H_2 \rightarrow H_2, H^+, H_2$	
$H_3^+, H_2 \rightarrow H^+, H_2, H_2$	
$H_3^+, H_2 \rightarrow H_2^+, H, H_2$	
$H_3^+, H_2 \rightarrow H_3^+, H_2$ (elastic)	