Simulation of the neutral inventory in the Pilot-PSI beam

Rob Wieggers
Pieter Willem Groen
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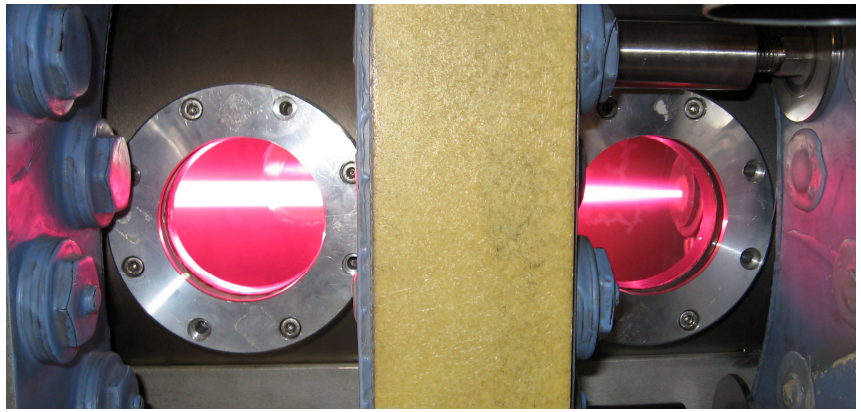
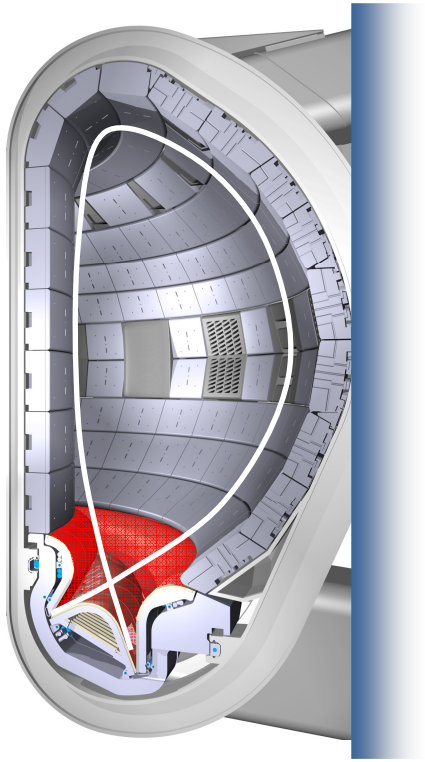
Wim Goedheer

Simulating neutrals in PSI



- $N_e = 10^{20} - 10^{21}\ m^{-3}$
- $T_e < 5\ eV$
- $\Gamma = 10^{24} - 10^{25}\ m^{-2}s^{-1}$



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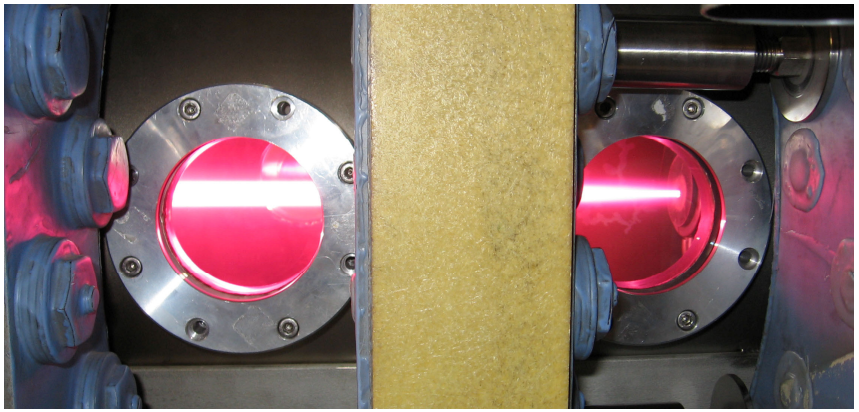

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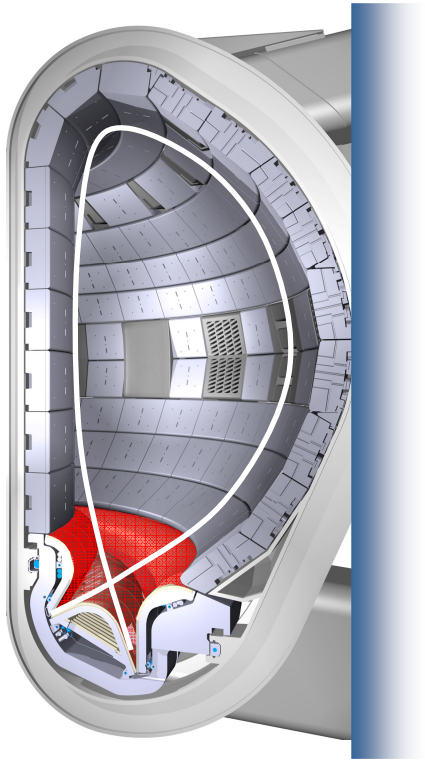


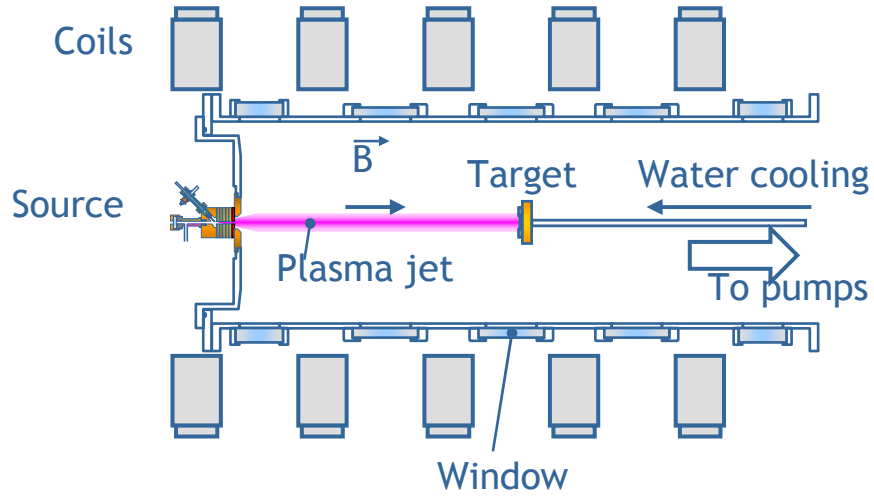
The codes:

- B2.5: plasma fluid code
- Eunomia: kinetic Monte Carlo code for neutral species

Numerical simulations are essential to compare Pilot-PSI and its successor Magnum-PSI to the ITER divertor and other experiments.

Pilot-PSI simulations

schematic of Pilot-PSI



Challenges

- Low temperature
- High density
  → non-linear simulation
- Strongly inhomogeneous background

Neutrals are an important diagnostic for plasma species

→ detailed, high resolution modeling of neutrals needed

Eunomia – Monte Carlo modeling of neutrals

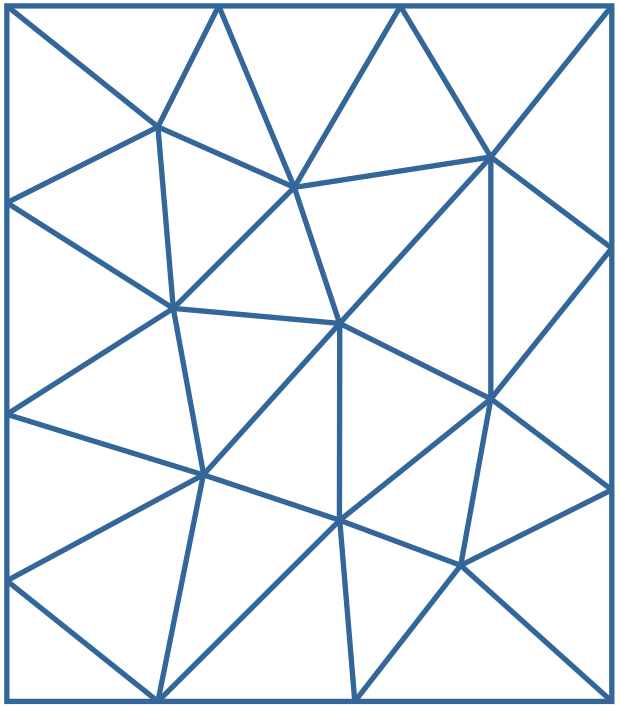
- Monte Carlo equilibrium code for neutrals
- Random walks of neutral test-particles
- Test-particles collide with background (plasma and neutral)
- Test-particles generate a new neutral background

Obtained data:

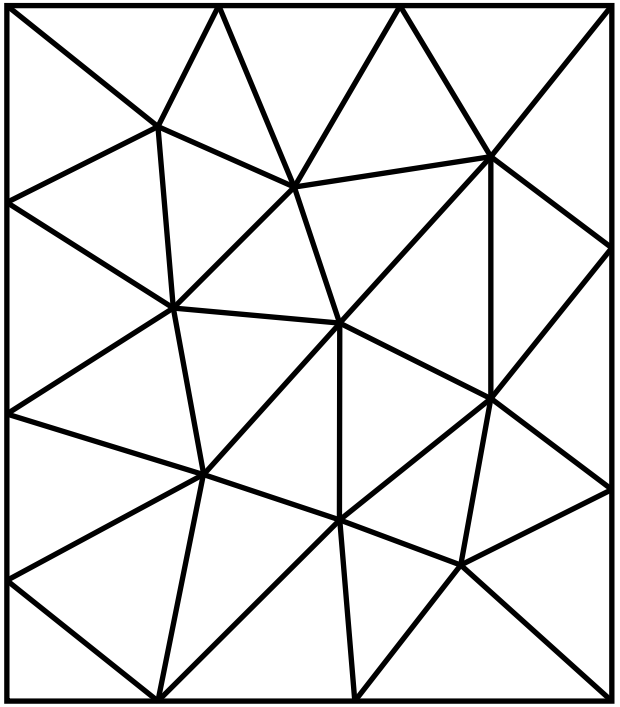
- Neutral background: N_n, T_n, v_n
- Plasma sources and sinks of N_i, N_e, T_i, T_e, $m_i v_i$
- Effective collision rates

Eunomia basics (2D)

current background



new background



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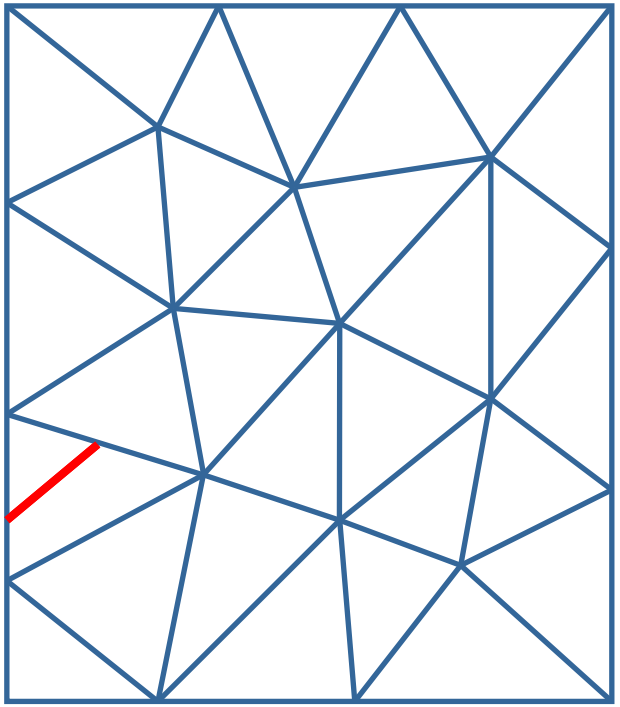

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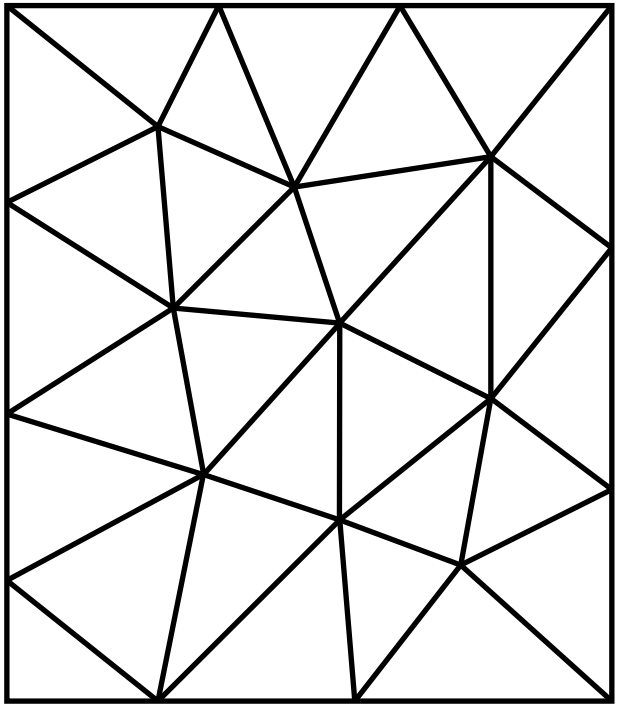

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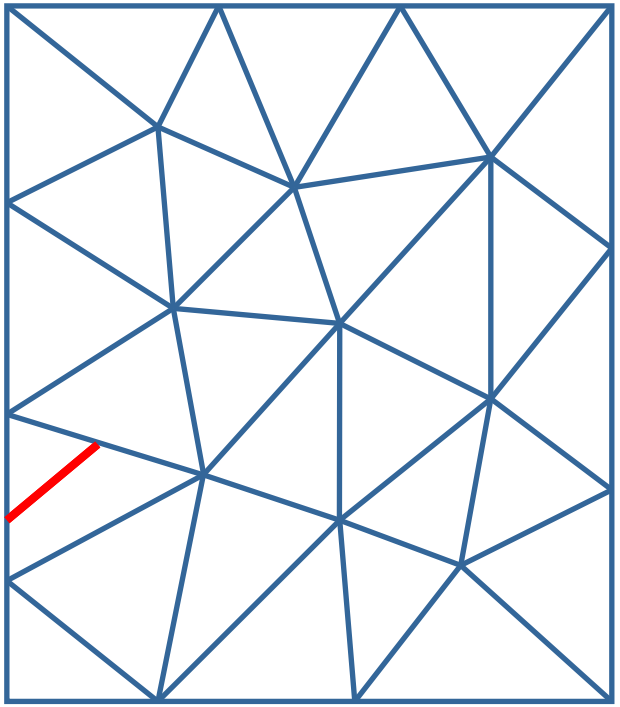

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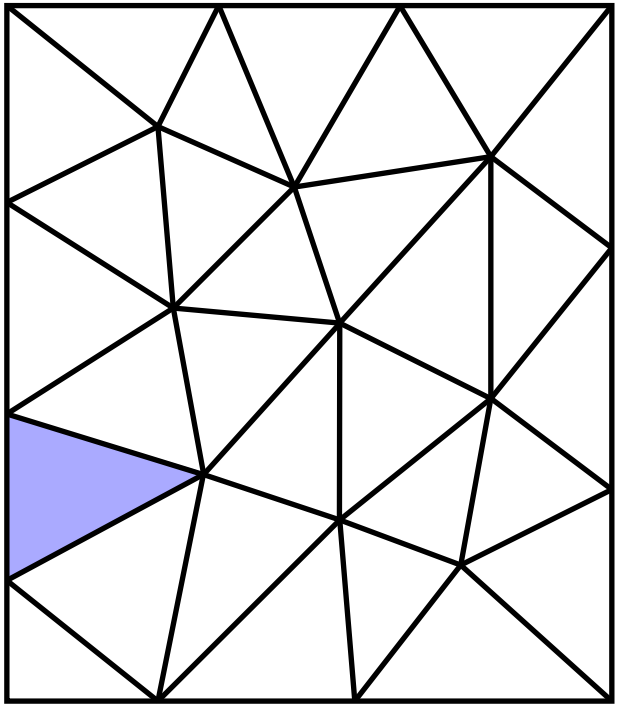

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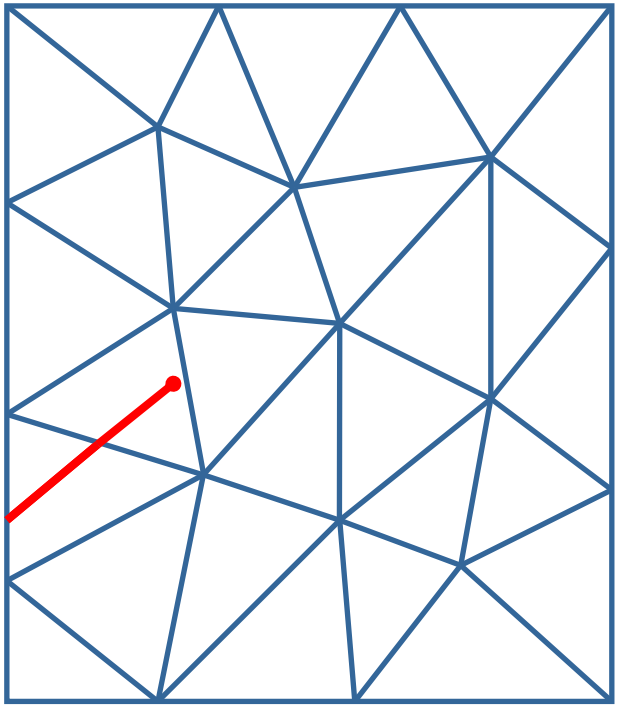

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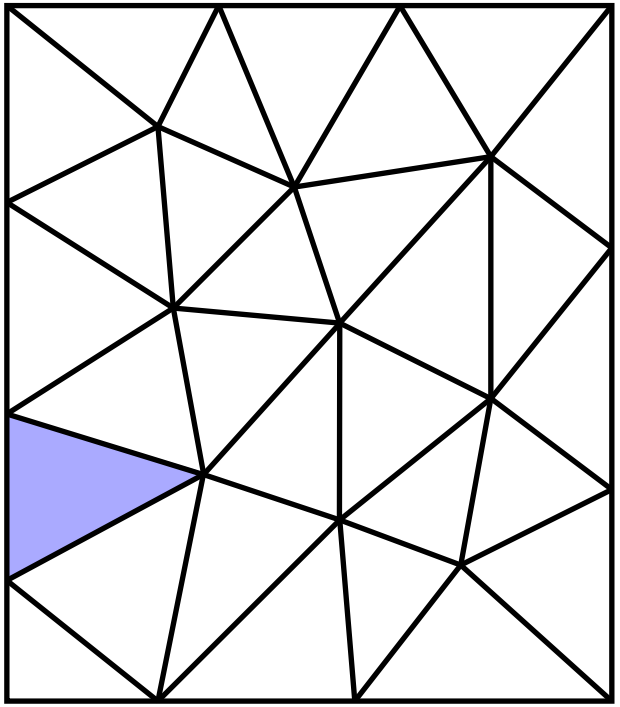

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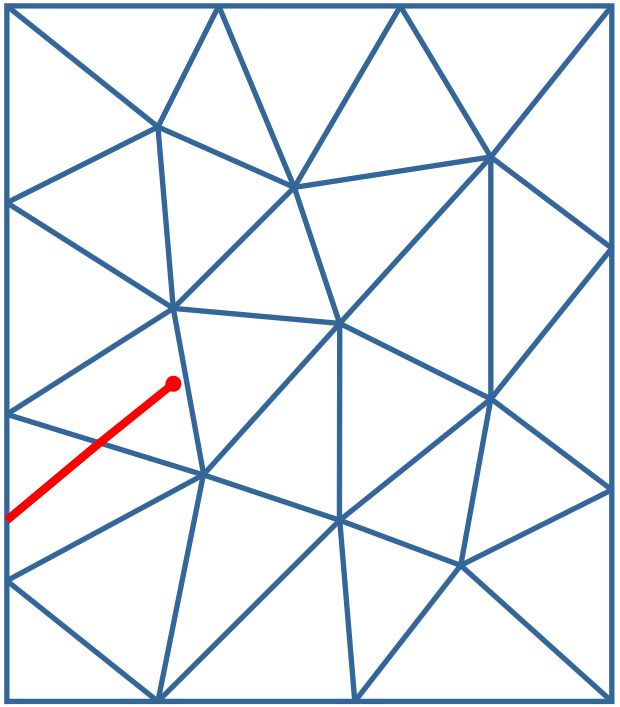

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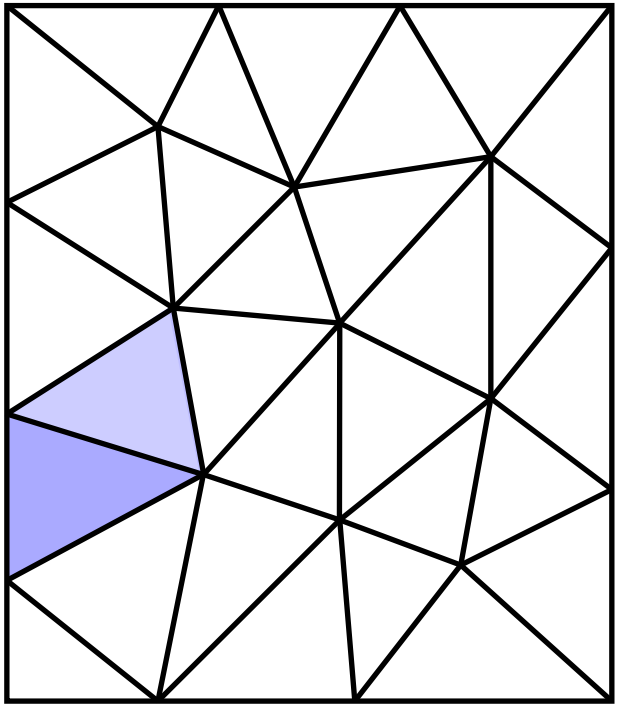

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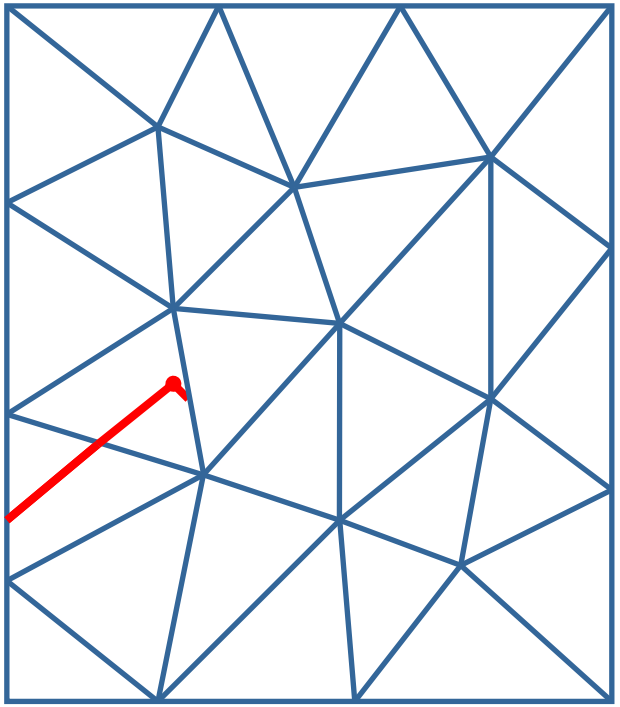

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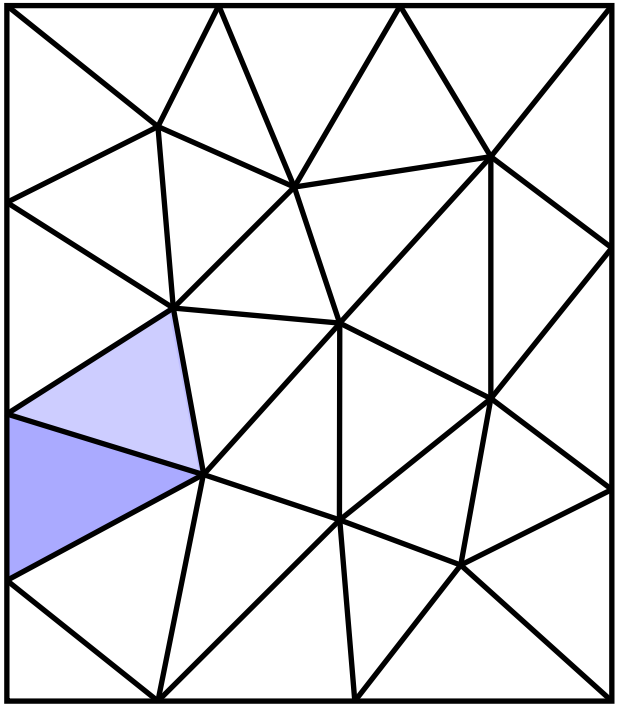

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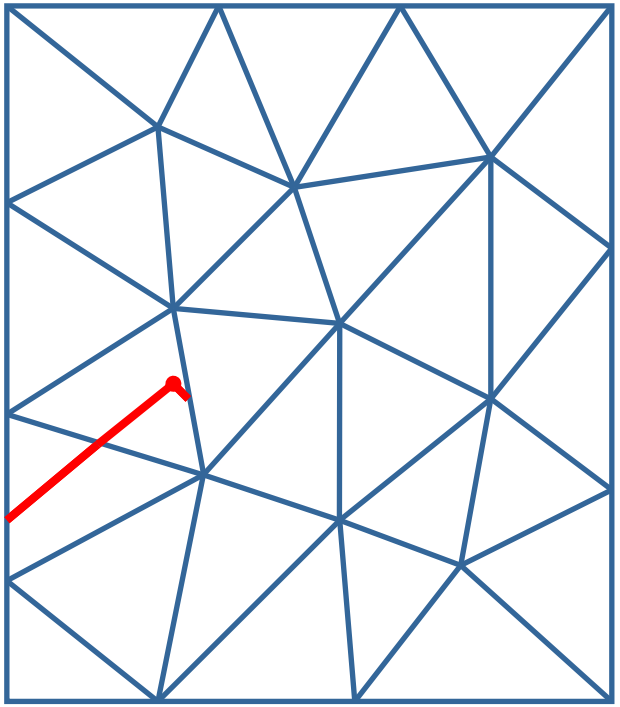

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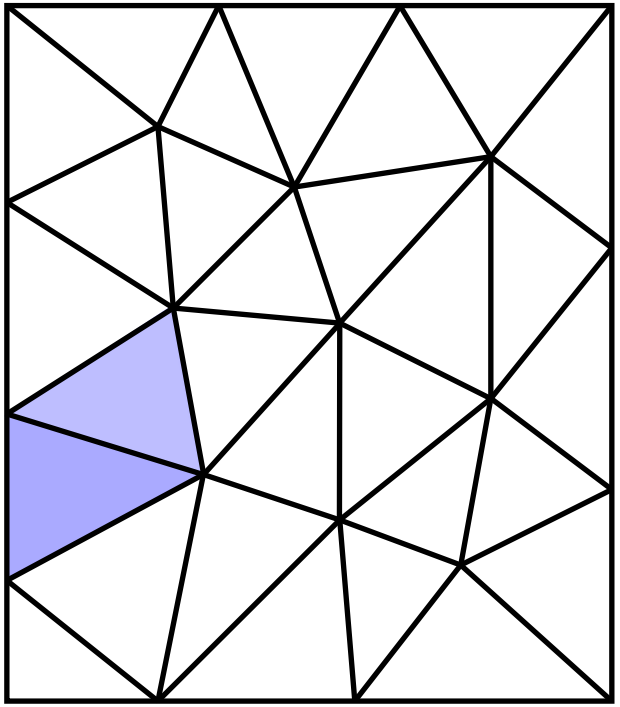

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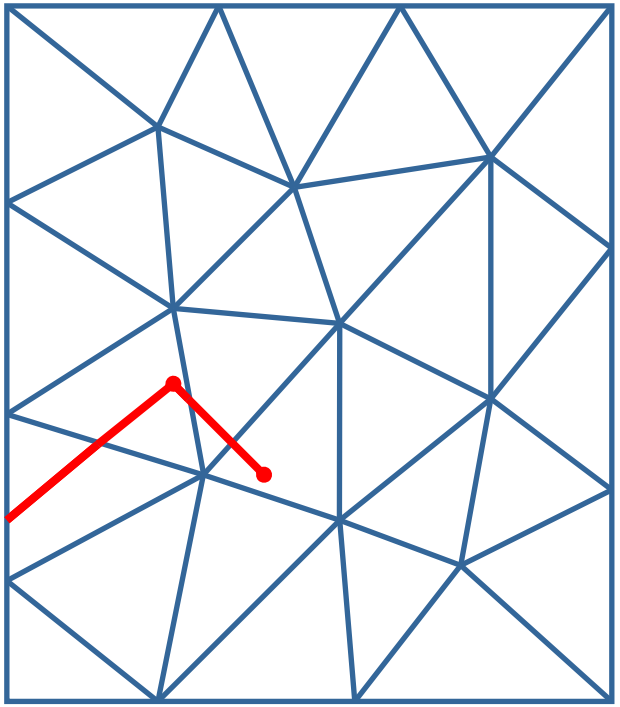

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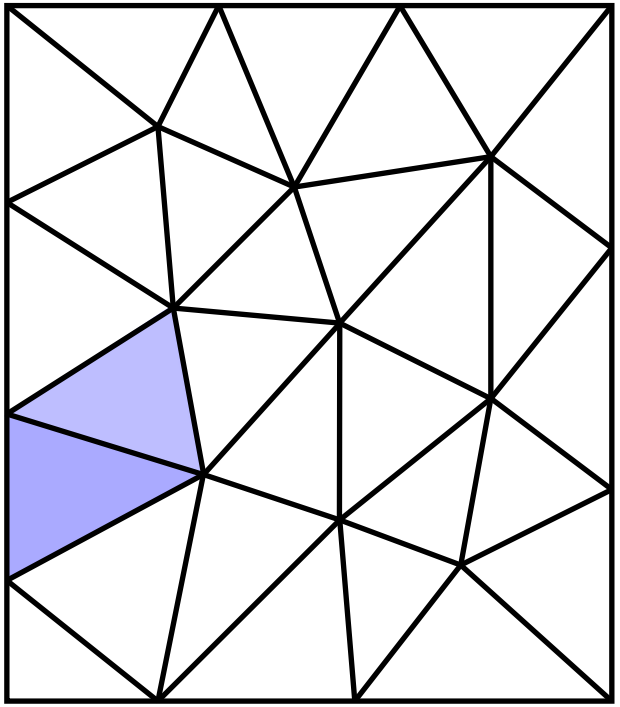

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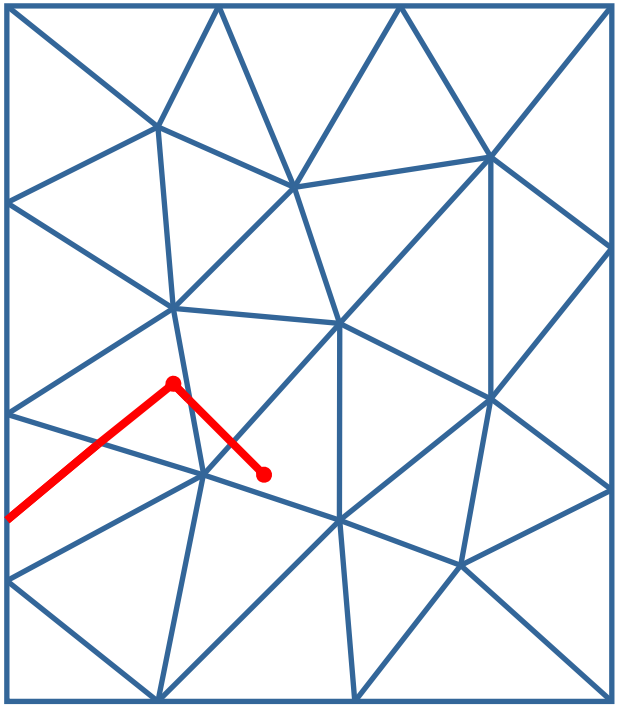

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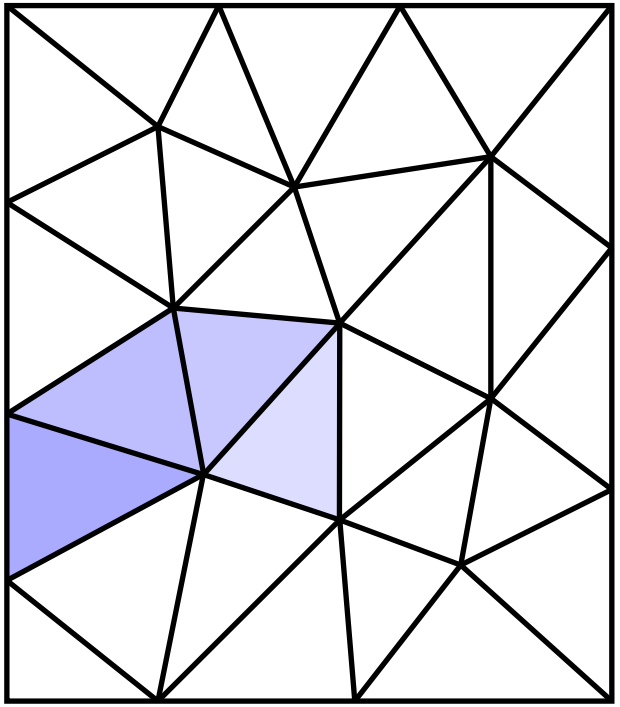

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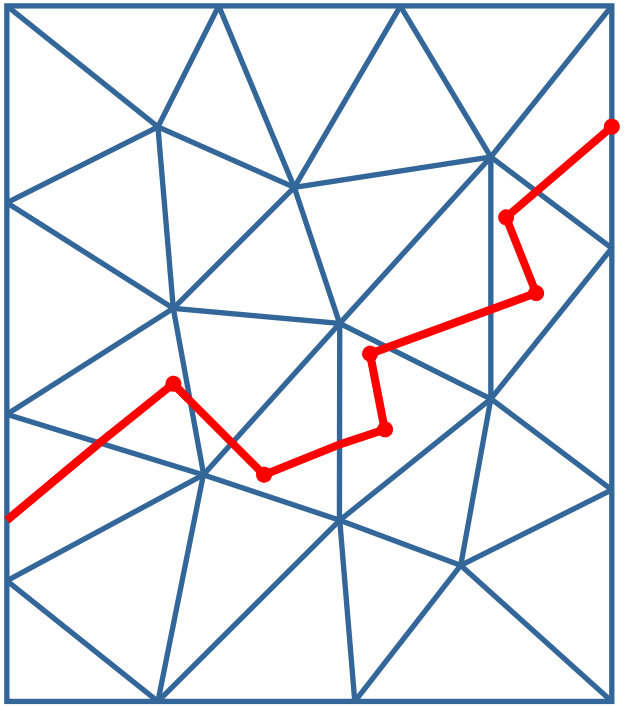

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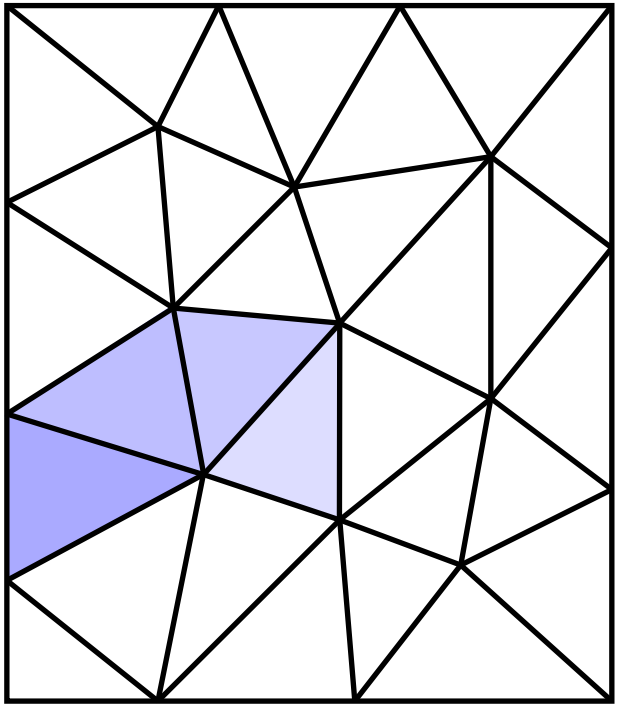

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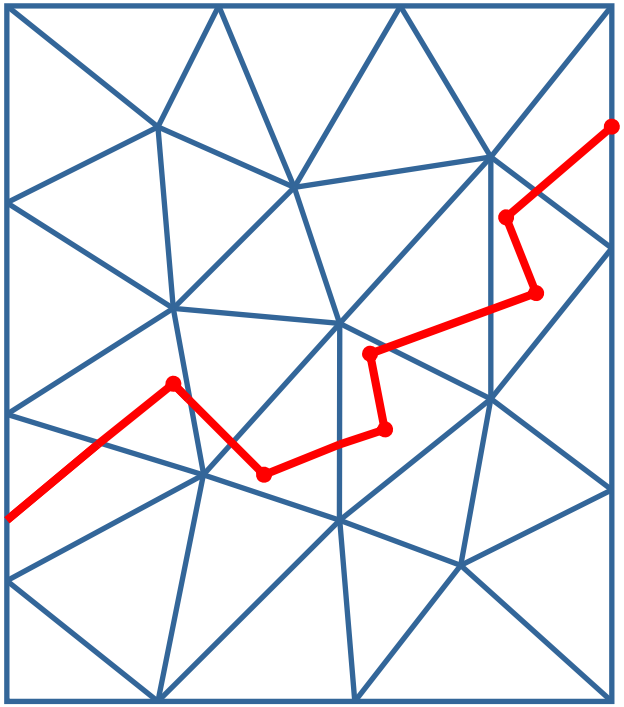

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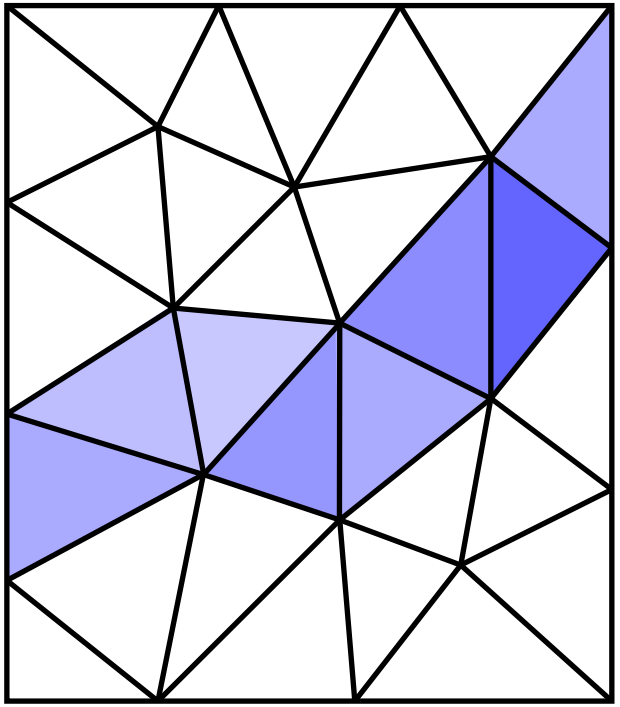

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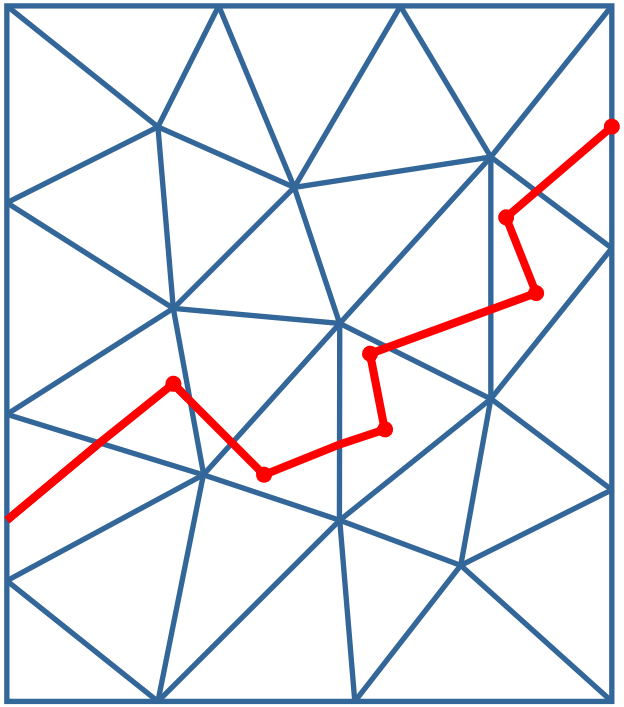

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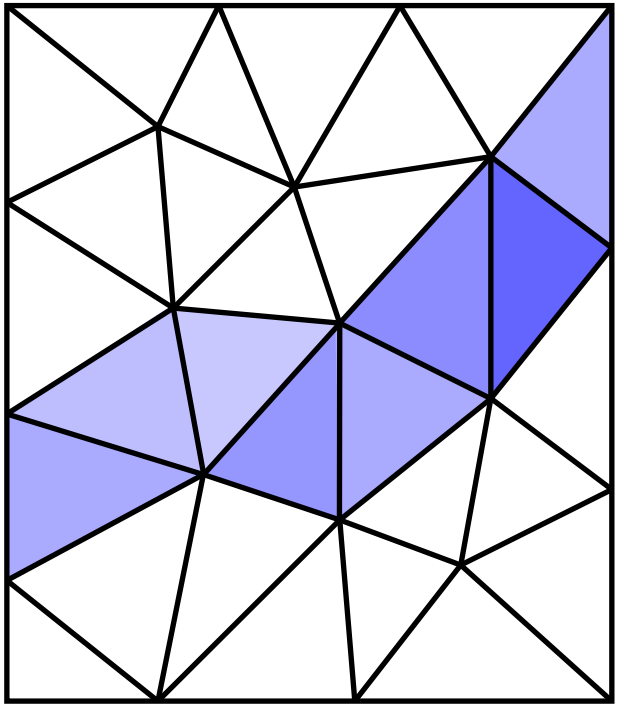

- Also 'score' T_n, v_n and more
- Simulate many test-particles → new background
- Repeat this on new background until converged

Statistical demands

Demands on

- Cell level: number of particle visits in cell
- Global level: average residence time of particles

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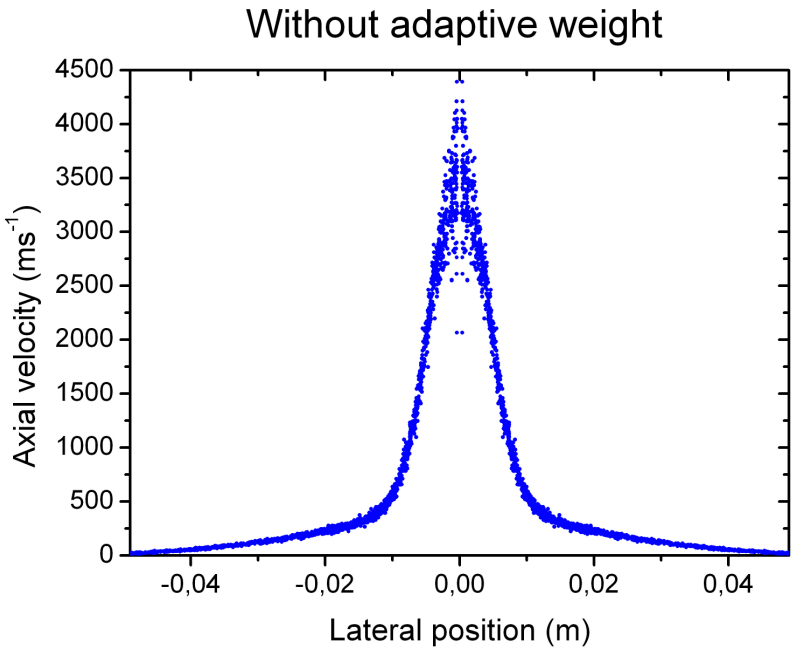
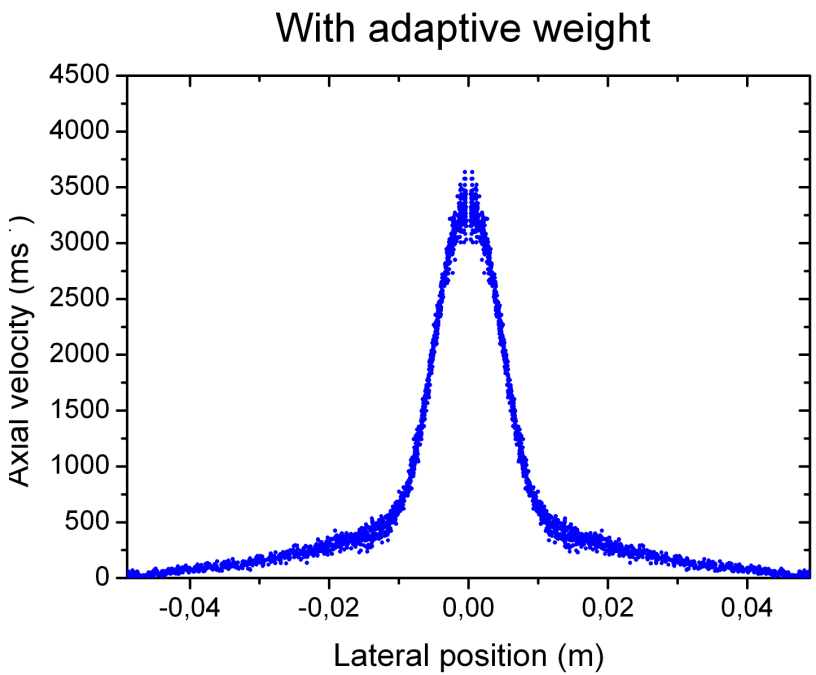
Solution:

- Follow particles until wall
- Simulate wall source generated by neutral flux on wall

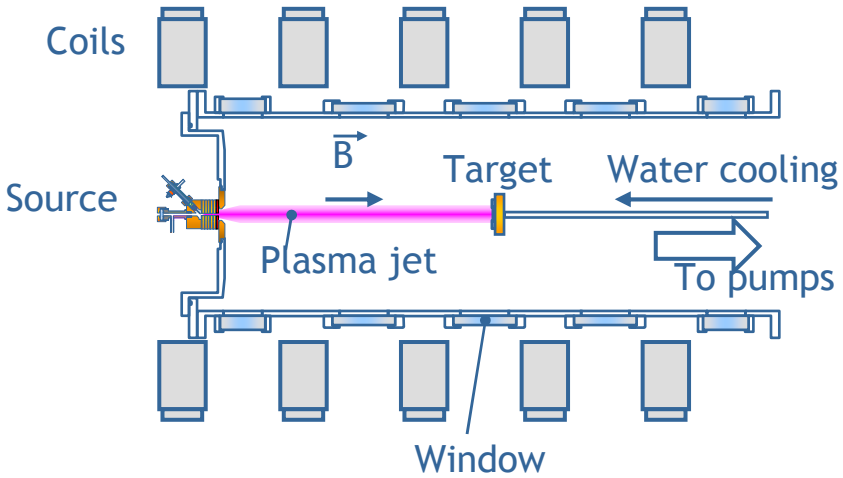
Adaptive weight

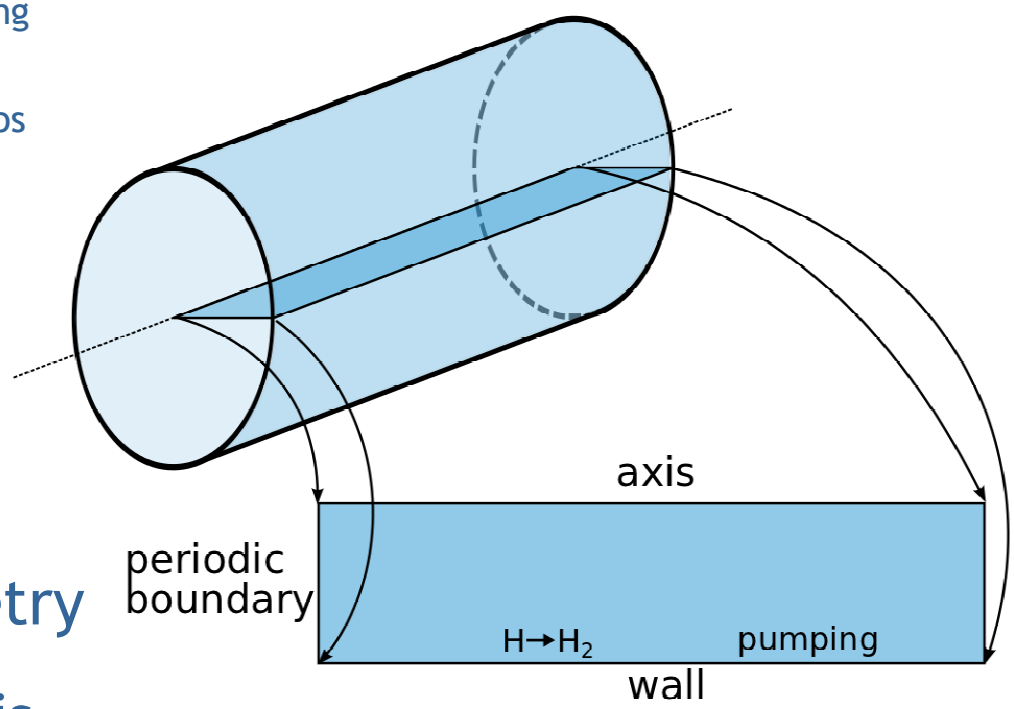




Adaptive weights of test particles strongly improve statistics in most challenging and important region.

Simulations of Pilot-PSI





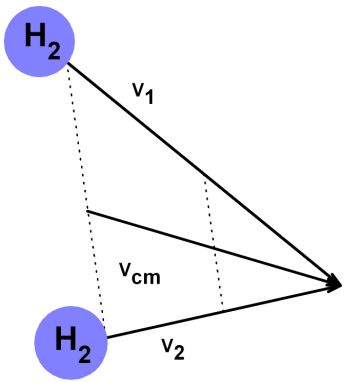
- Take part of beam
- Assume cylindrical symmetry
- Assume constant along axis

→ Data as function of radius

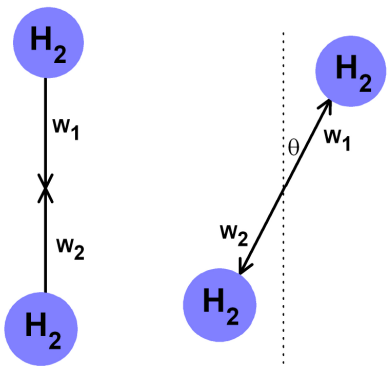
Modeling collisions

- Electrons: $\sigma v(T_e)$ or $\sigma v(N_e, T_e)$
- Other: $\sigma(E)$
  - Center of mass frame
  - Null collision method
- Same databases as used by Eirene and BIT

laboratory



center of mass



Hydhel & Amjuel databases, Janev et al., www.eirene.de
BIT code, D. Tskhakaya

Important collisions

Volume recombination

- $H^+ + e \rightarrow H$
- $H^+ + 2e \rightarrow H + e$

Elastic

- $H + H \rightarrow H + H$
- $H_2 + H_2 \rightarrow H_2 + H_2$
- $H + H_2 \rightarrow H + H_2$
- $H + H^+ \rightarrow H + H^+$
- $H_2 + H^+ \rightarrow H_2 + H^+$

Charge exchange

- $H + H^+ \rightarrow H^+ + H$
- $H_2 + H^+ + e \rightarrow H_2^+ + H + e \rightarrow H^* + H + H$ (MAR)

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P.L. Bhatnagar, E.P. Gross, M. Krook, Phys. Rev. **94**: 511–525 (1954)

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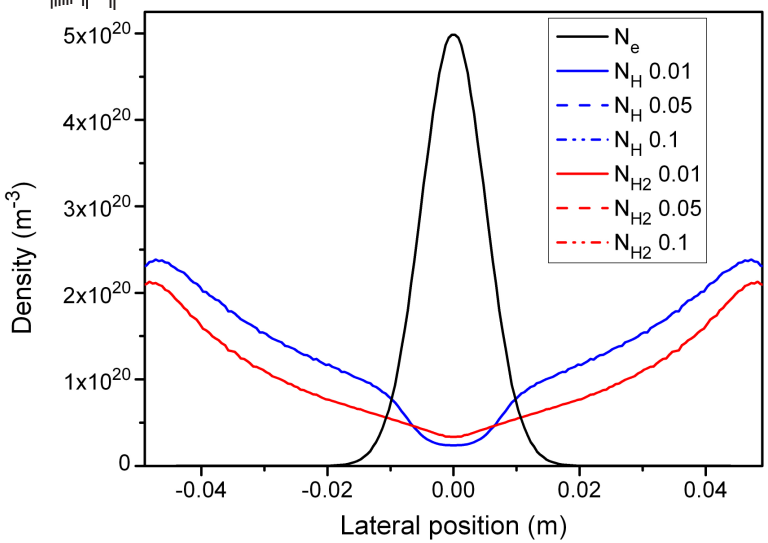
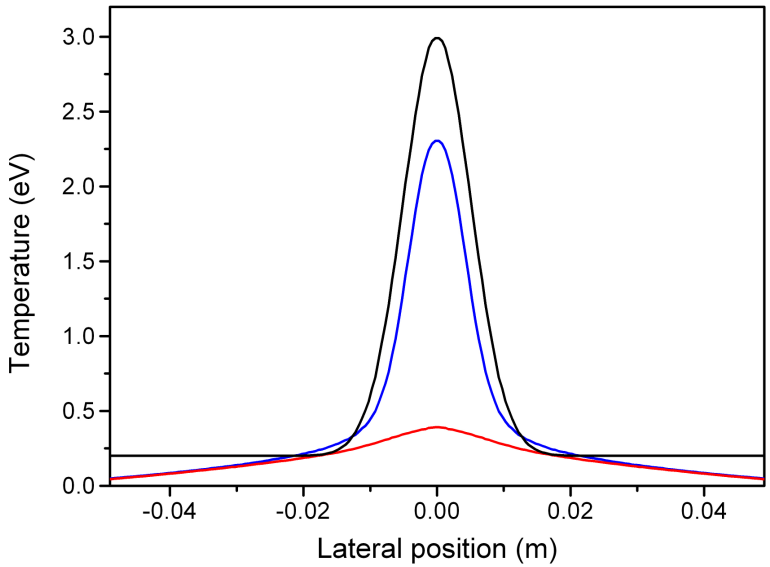
Elastic collisions with plasma





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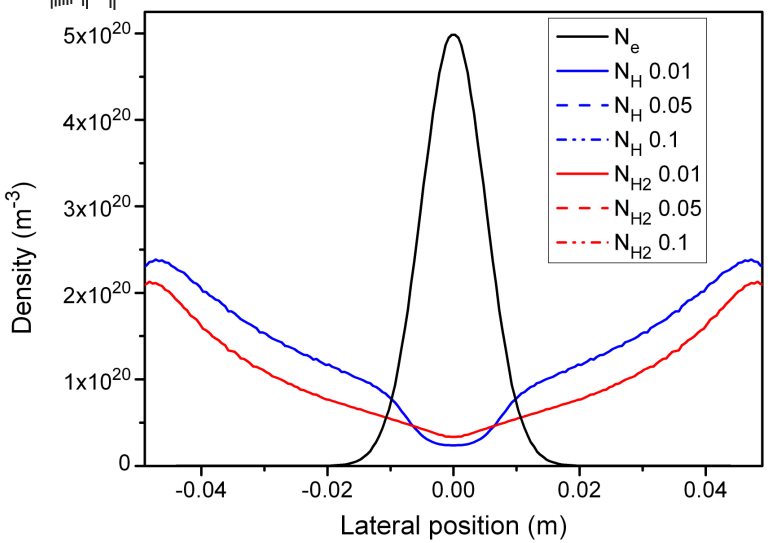

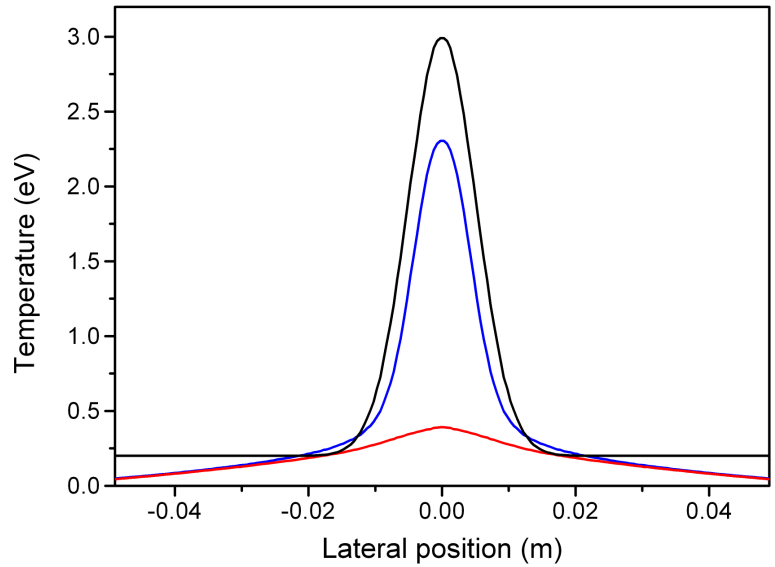

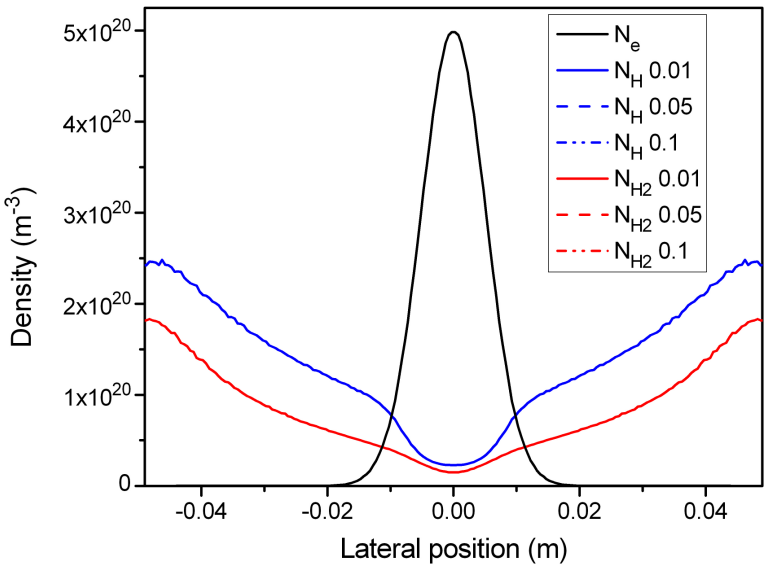

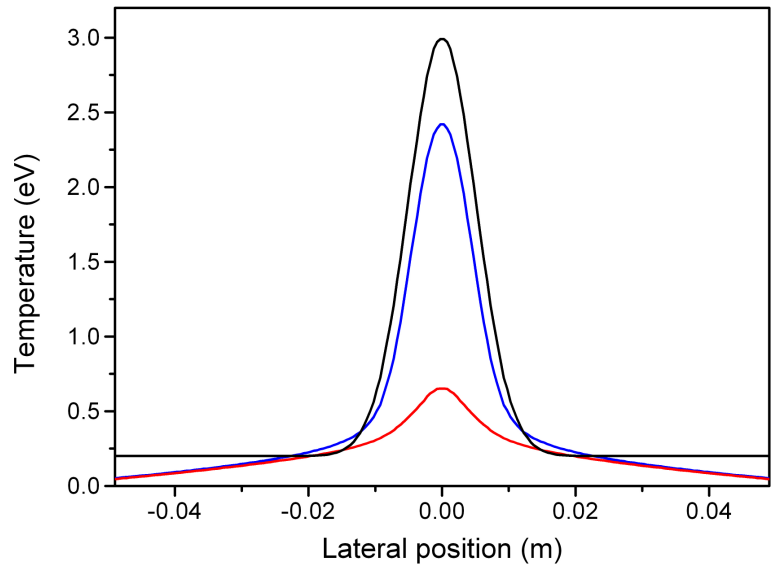

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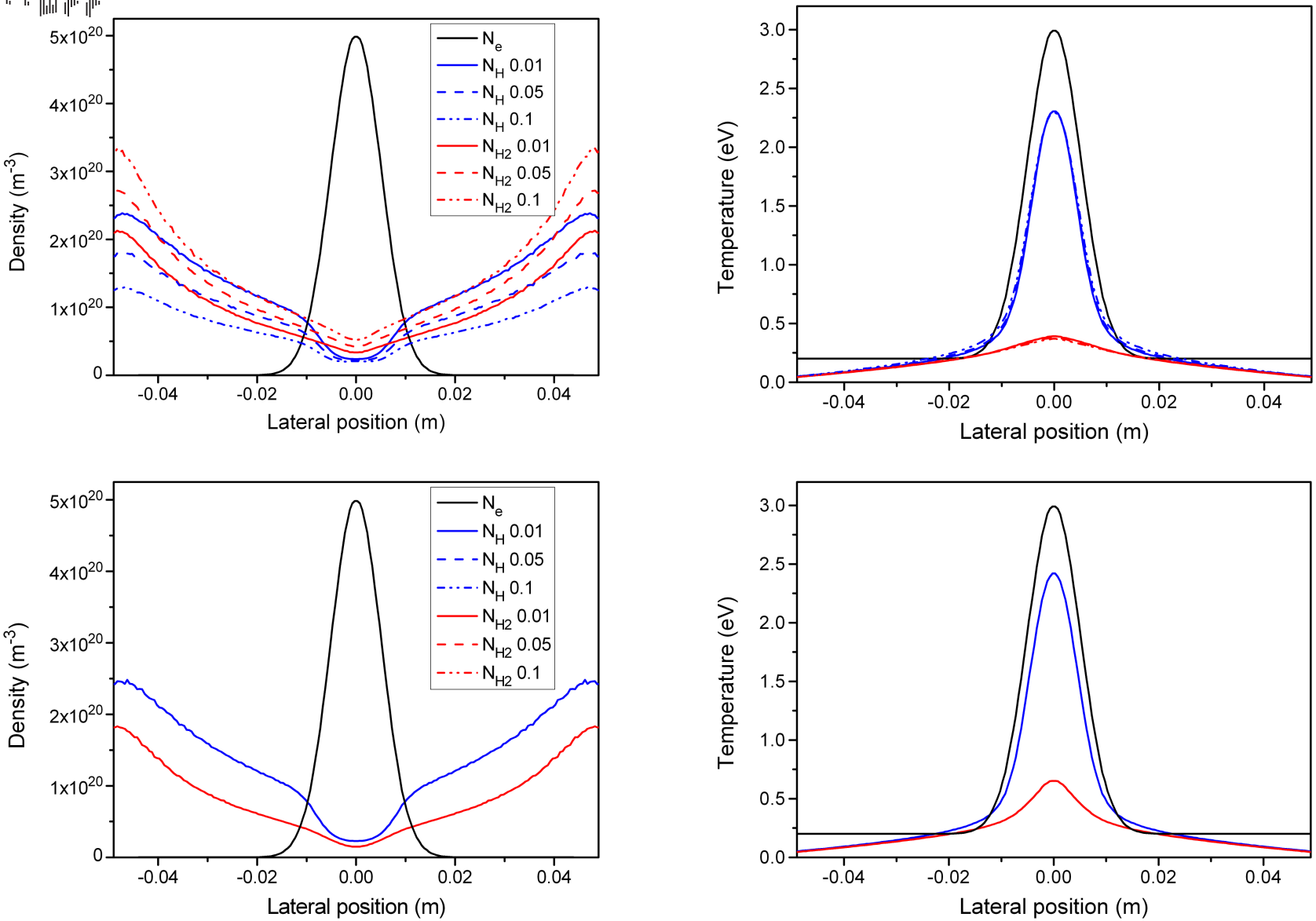

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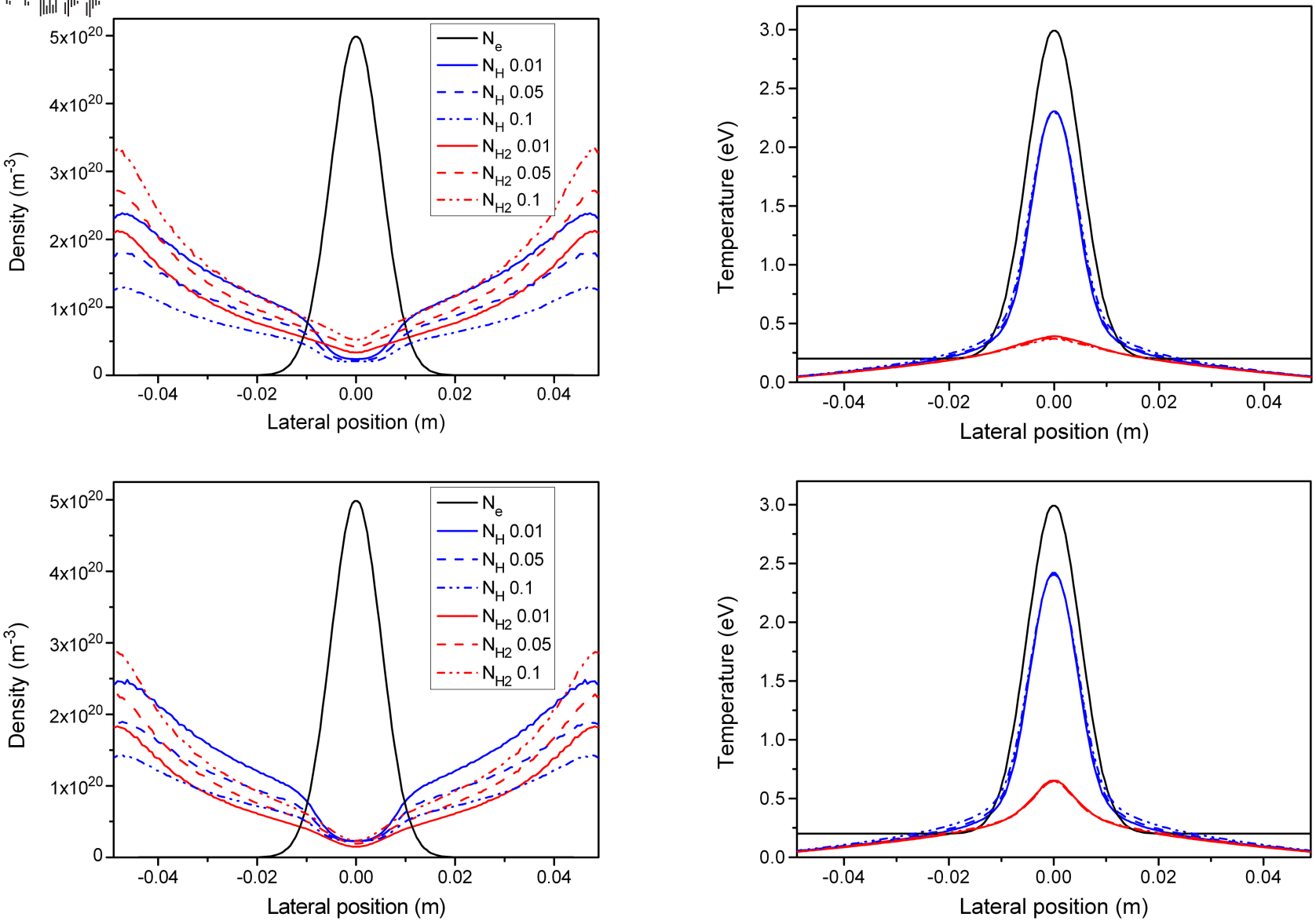

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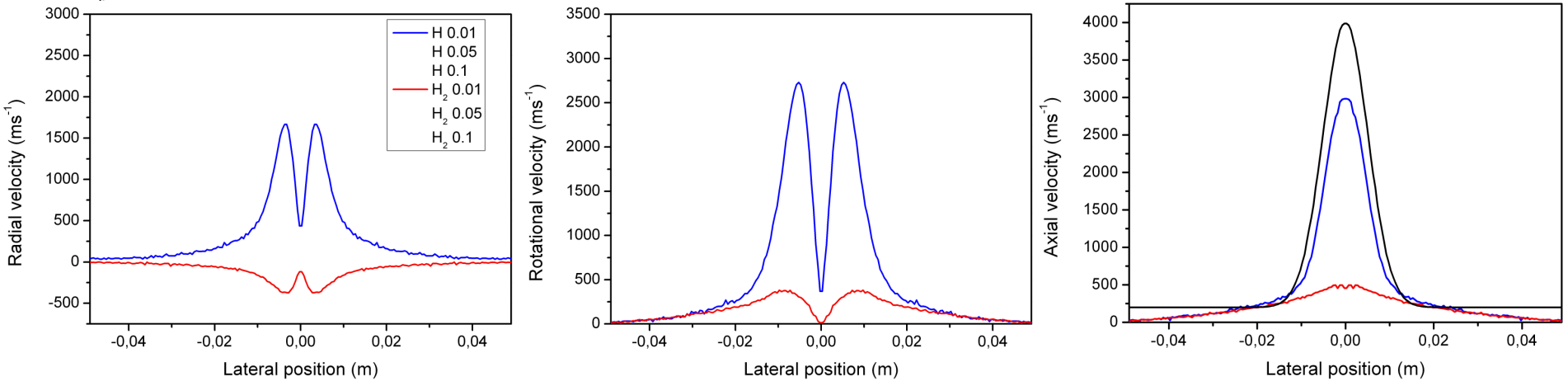

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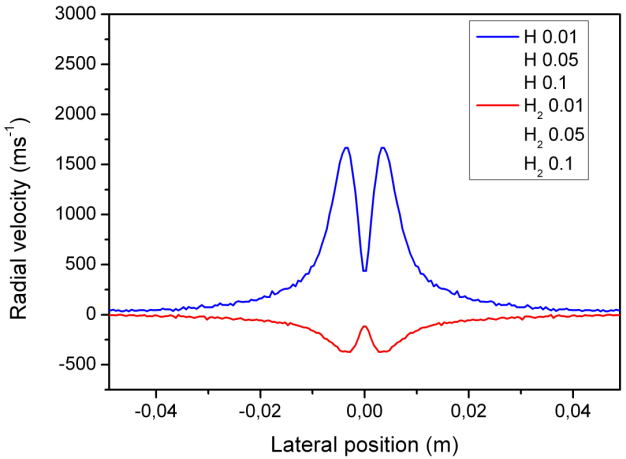
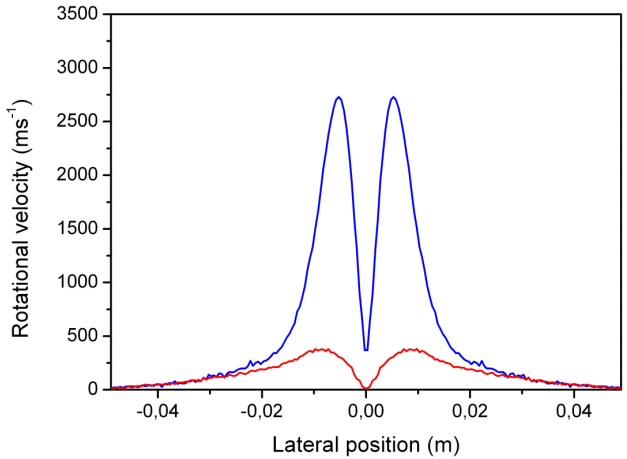
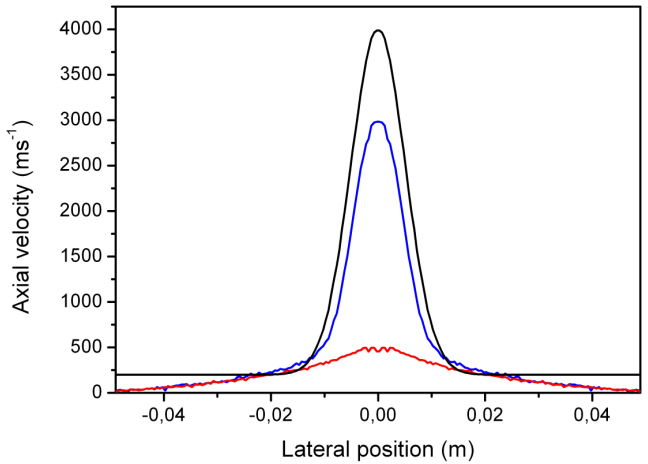
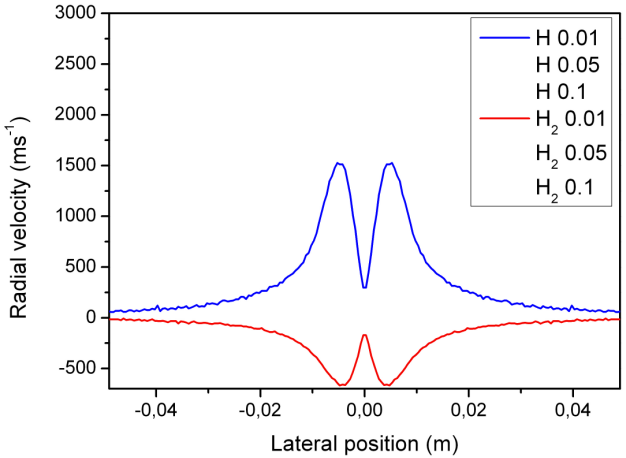
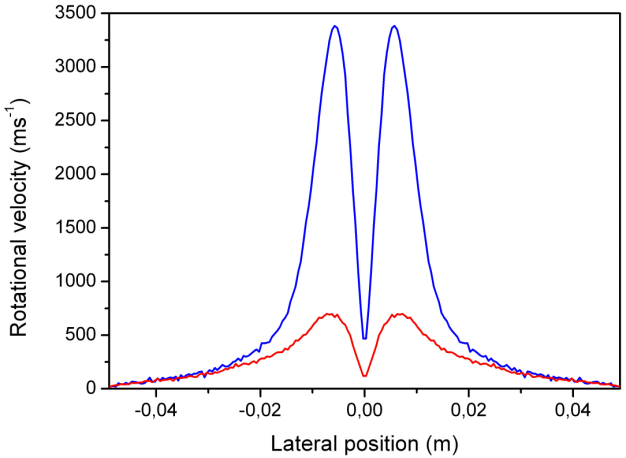
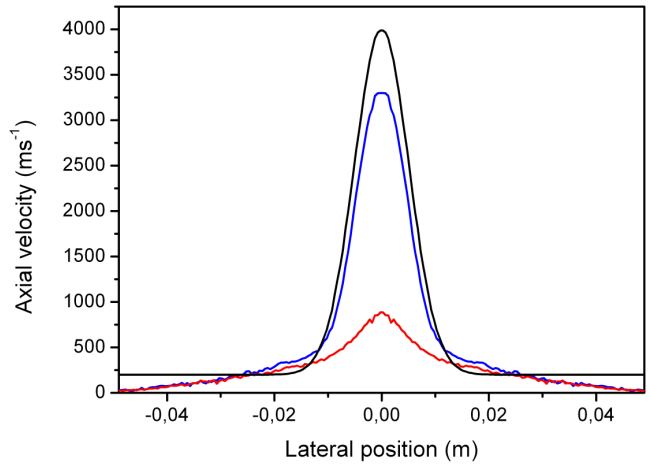




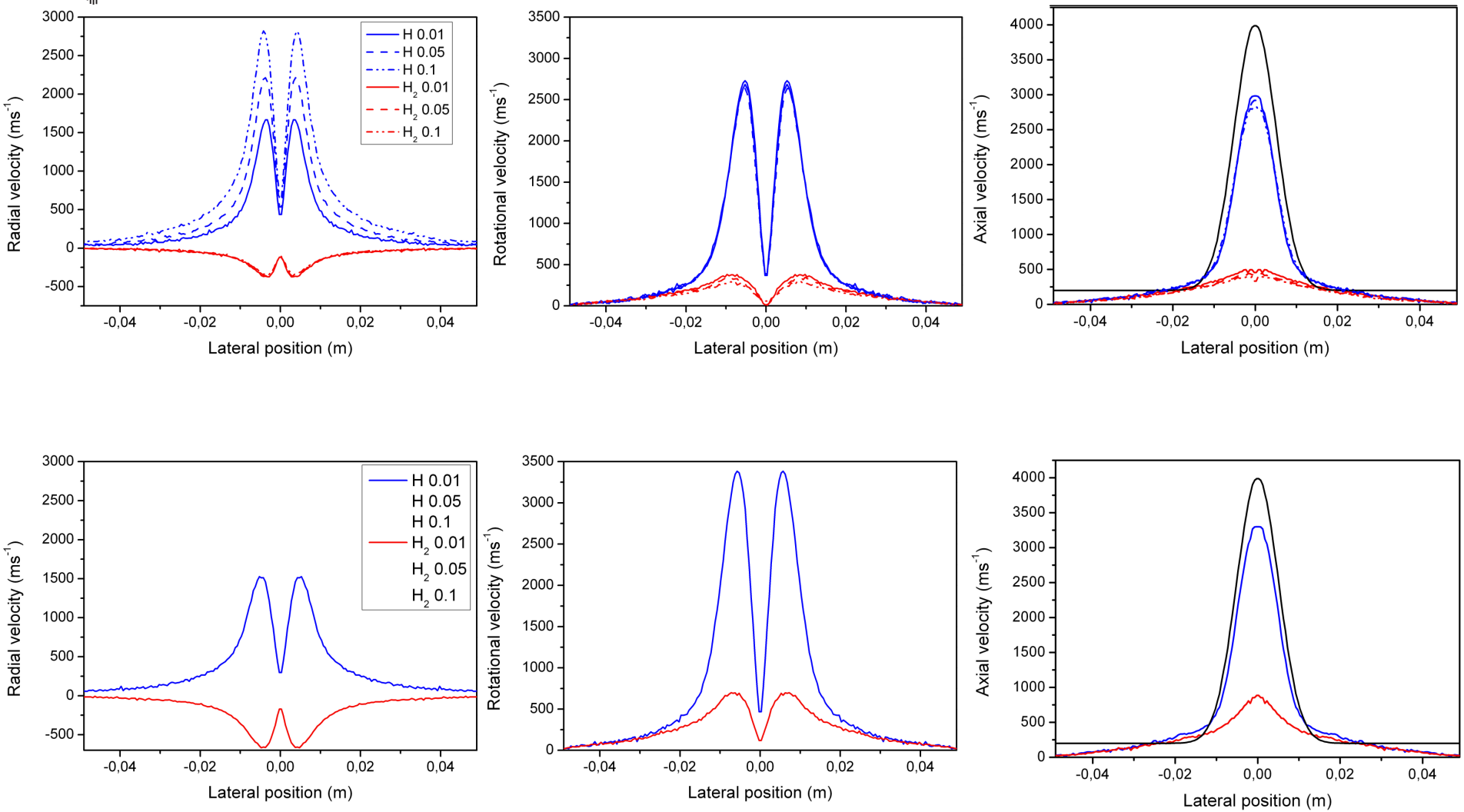




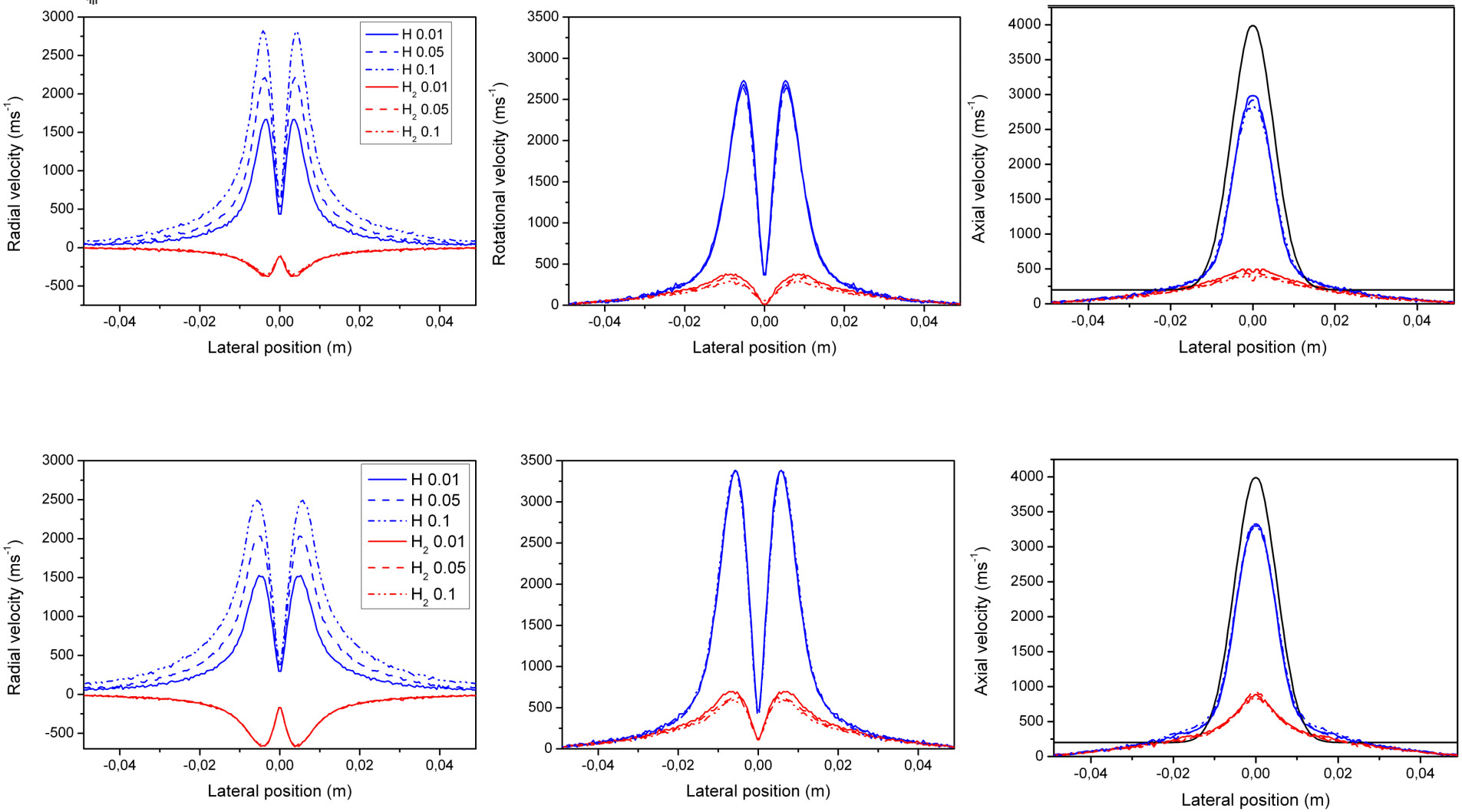




Elastic collisions with plasma



Elastic collisions with plasma



Molecule Assisted Recombination

We do not simulate individual excited states.
What do we do with the H*?

- Distribution of H*(n≥2) is known [1]
- We need to determine the probability of producing 3 H vs. 2 H + H^+

Simple Approach:

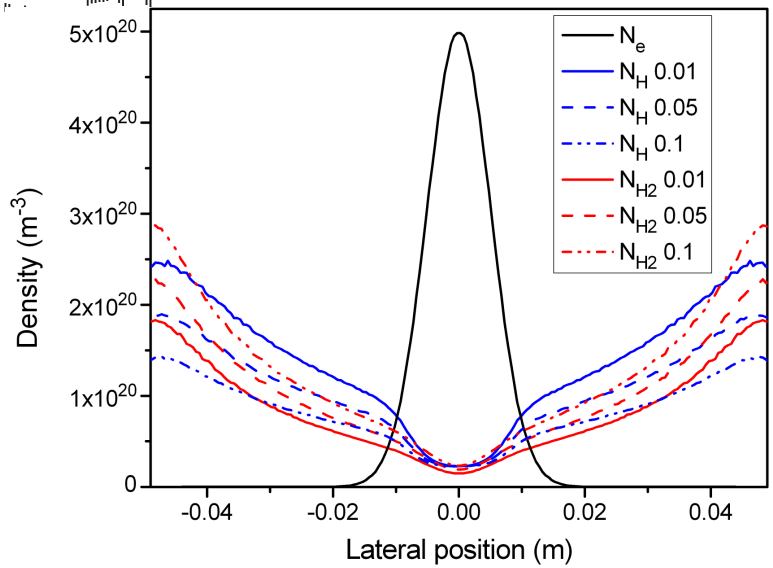
- Assume H*(n≥3) will finally ionize [2]
- The ratio between excitation and deexcitation of H*(n=2) can be calculated from available rates

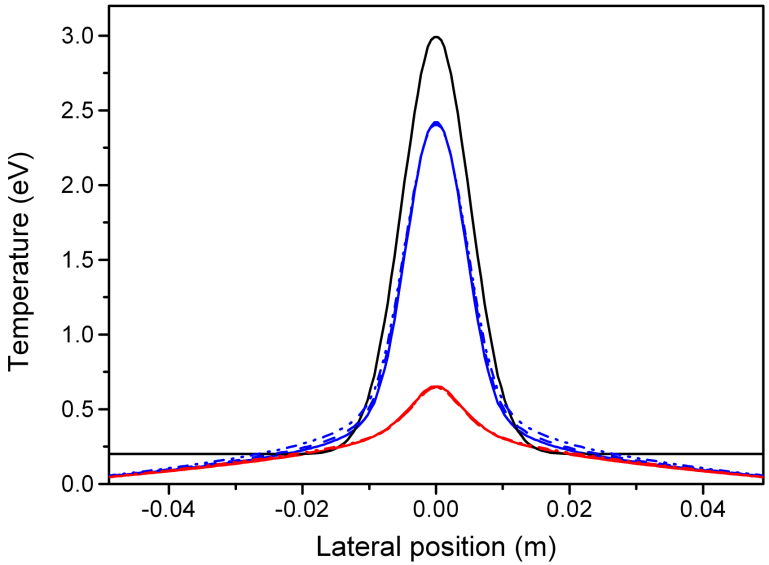
CR Approach:

- Probability of ionization calculated by a collisional radiative model

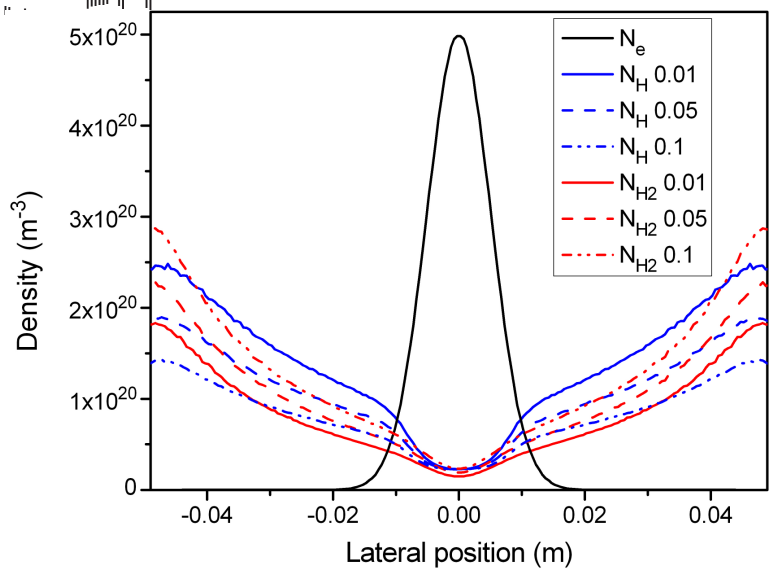
[1] Hydhel database, Janev et al., www.eirene.de
[2] PhD thesis Van der Mullen

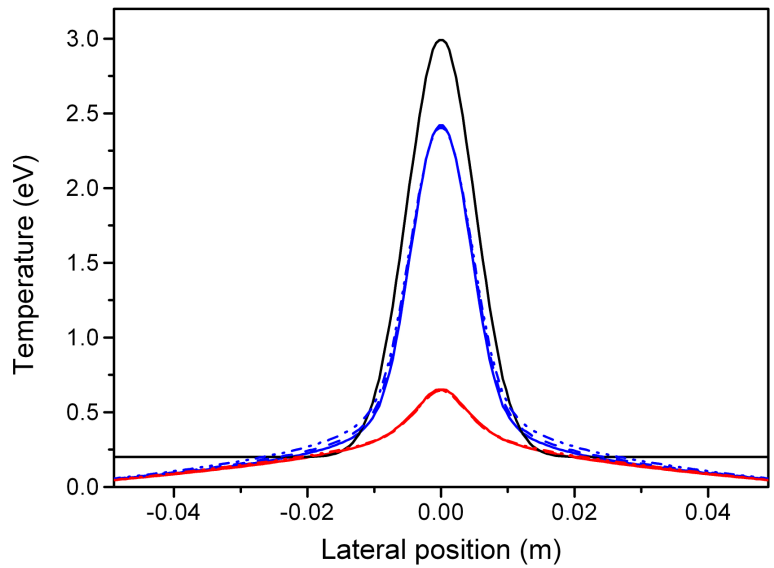
Model for H*

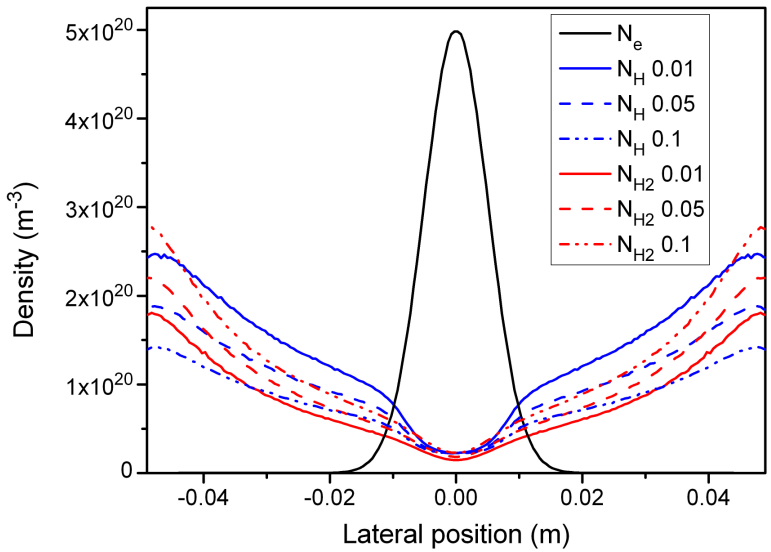

Density (m-3)
5x10^20
4x10^20
3x10^20
2x10^20
1x10^20
0
-0.04
-0.02
0.00
0.02
0.04
Lateral position (m)
Ne
NH 0.01
NH 0.05
NH 0.1
NH2 0.01
NH2 0.05
NH2 0.1

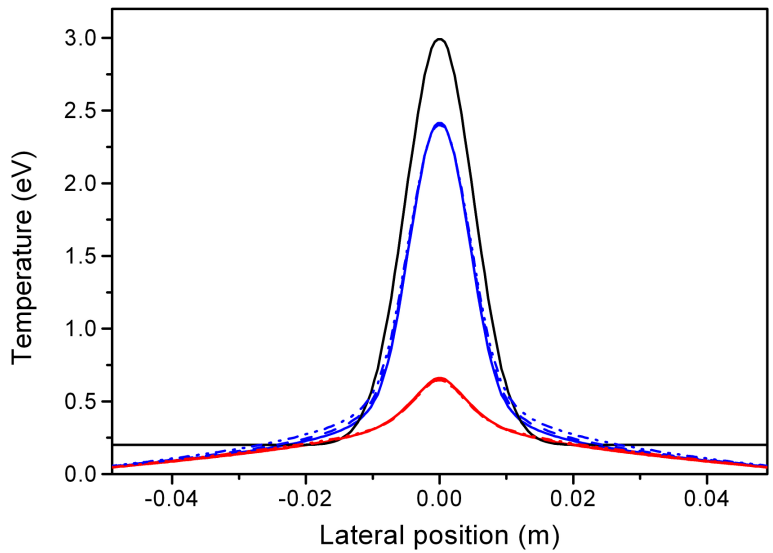

Temperature (eV)
3.0
2.5
2.0
1.5
1.0
0.5
0.0
-0.04
-0.02
0.00
0.02
0.04
Lateral position (m)

Model for H*


Density (m^{-3})
Lateral position (m)
N_e
N_H 0.01
N_H 0.05
N_H 0.1
N_{H2} 0.01
N_{H2} 0.05
N_{H2} 0.1

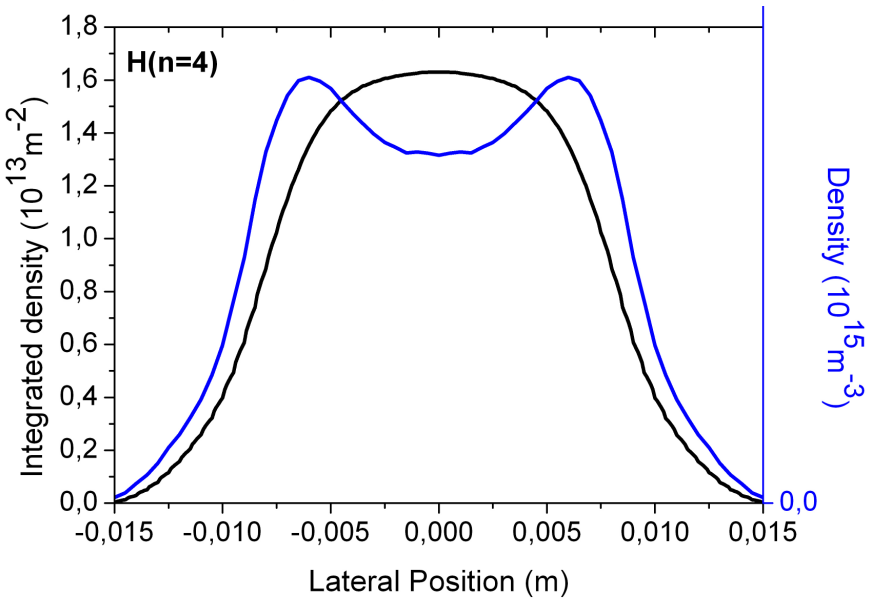

Temperature (eV)
Lateral position (m)


Density (m^{-3})
Lateral position (m)
N_e
N_H 0.01
N_H 0.05
N_H 0.1
N_{H2} 0.01
N_{H2} 0.05
N_{H2} 0.1

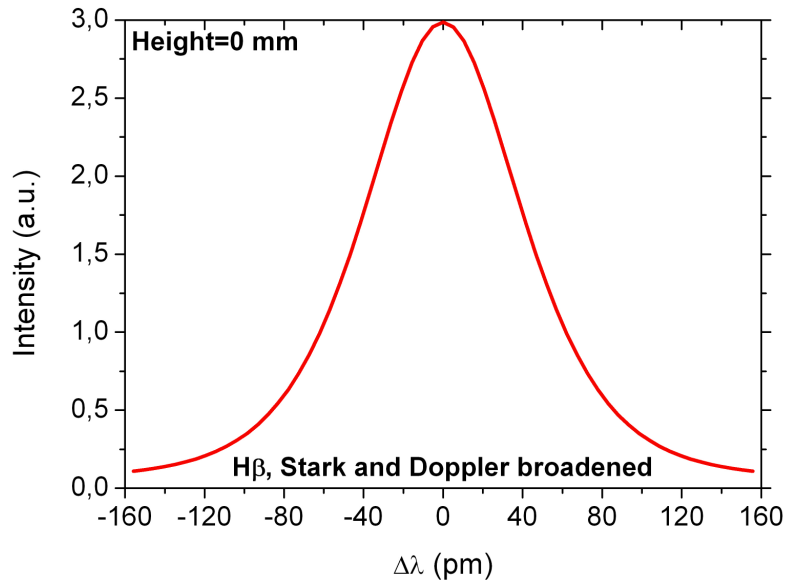

Temperature (eV)
Lateral position (m)

Collisional Radiative model

$H_{(n=4)}$ density



H_β profile



Conclusions / Outlook

- Significant effects of elastic collisions between neutrals and protons in low temperature plasmas:
  - Reduced H_2 density in plasma beam
  - Increased H_2 temperature in beam
  - Broader velocity profiles, higher amplitude for H_2
- Wall processes do influence neutrals in plasma beam
  - Increased H_2 density in plasma
  - Changed radial velocity profiles
- Application of a CR model for H* modeling does not strongly influence results. However, it is important for comparison to experiments