FLASHForward▸▸

WG 3 plasma targets and diagnostics

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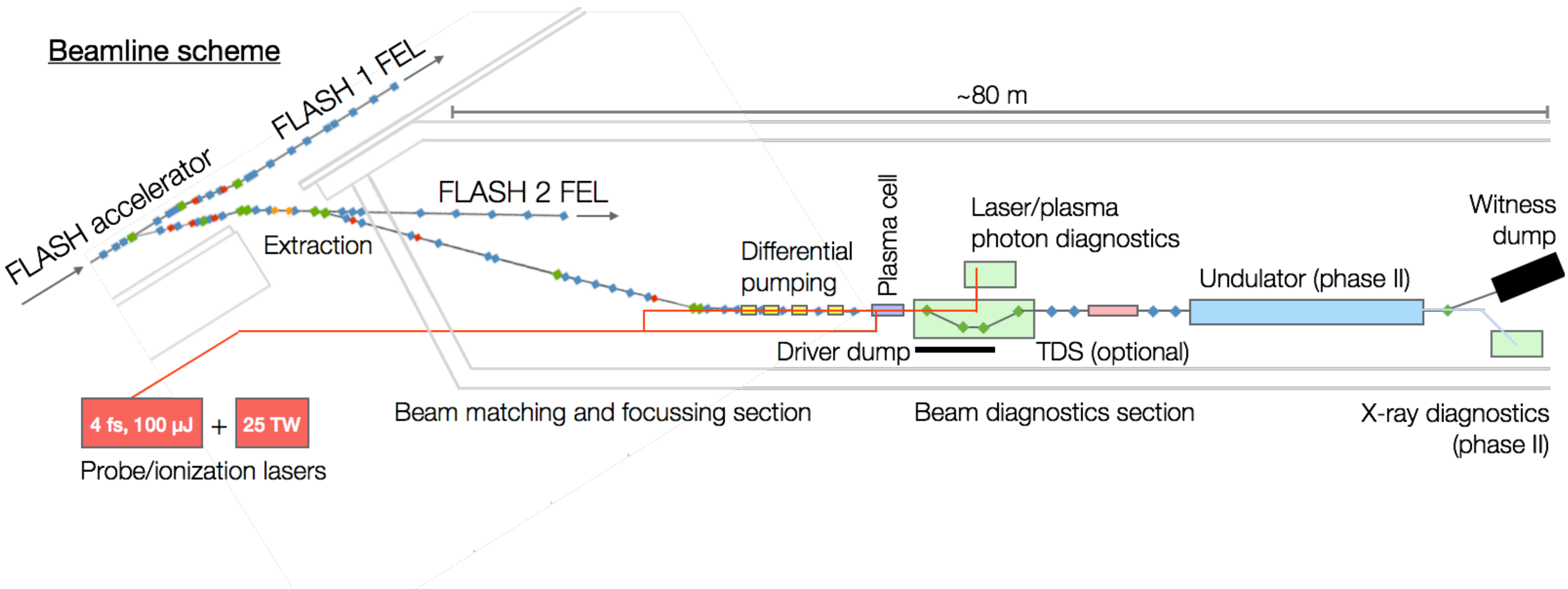
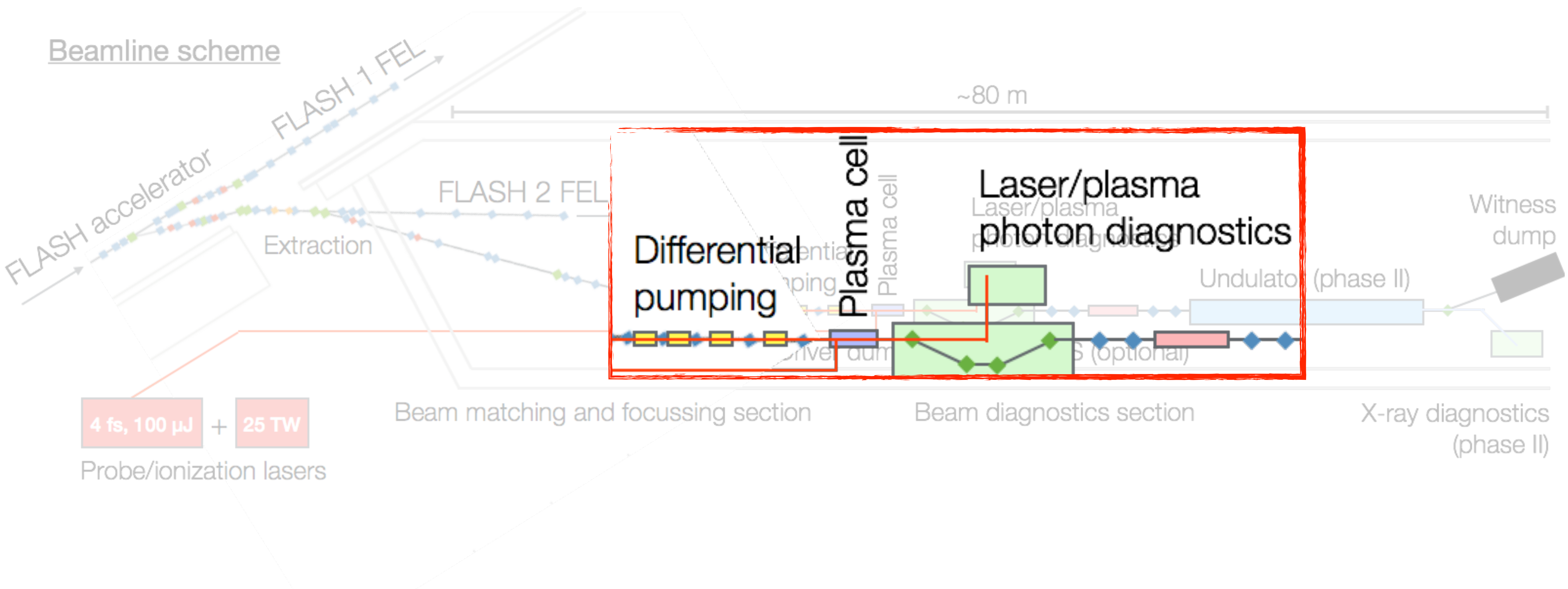
Alexander von Humboldt Stiftung/Foundation
HELMHOLTZ | GEMEINSCHAFT
DESY

Part of the
LAOLA. collaboration

FLASHForward beamline



FLASHForward beamline



Scientific scope

1. **Gas-target and supply-system design**
    - > Designing gas-targets for stable, reproducible plasma density profiles
    - > Allowing for flexibility in (novel) injection mechanisms (WG1)
2. **Gas ionisation and dissociation**
    - > Importance for ionisation injection experiments (WG1)
    - > Dissociation timescales can be similar to laser pulse duration
3. **Plasma density manipulation**
    - > Understanding the influence of plasma properties on electron beam quality (WG1)
    - > Realising controlled electron release into vacuum (WG2+4)
4. **Diagnostics**
    - > Implementing suitable (online) diagnostics for important parameters

Milestones

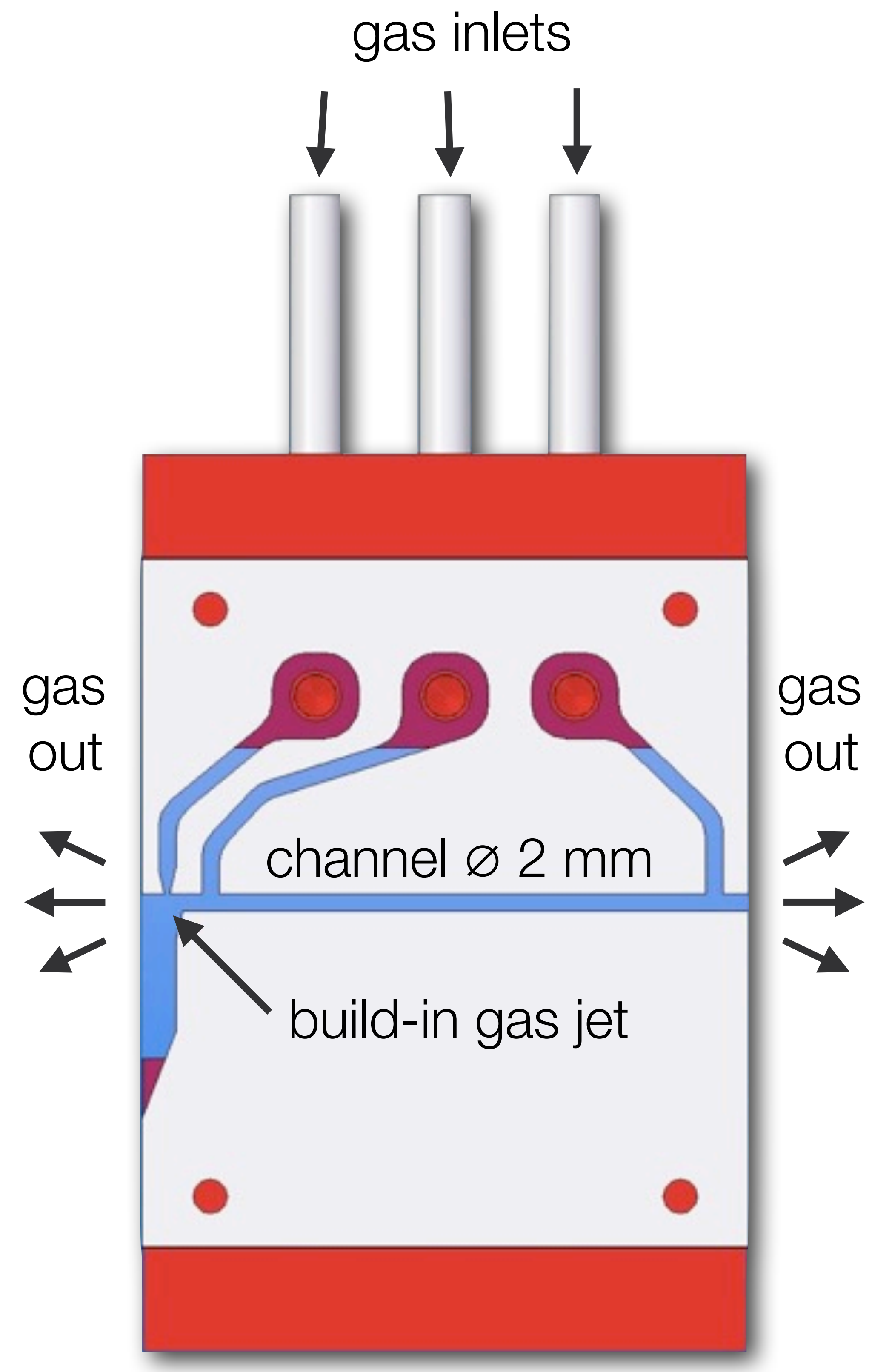
Q1 2013	**Establishment of VI WG 3** Aim: Establishment of VI WG 3 network, setting up of communication channels. Status: Task completed as planned.
Q2 2013	**Develop alternate preionisation solution for FLASHForward** Aim: Backup solution in case laser pre ionisation proves impossible Status: Task completed, high voltage discharge via PFN build.
Q2 2014	**Design of target prototype** Aim: Define target interfaces and dimensions, allow for simulation of gas outflow. Status: Task completed. Prototype in manufacturing
Q4 2014	**Identify components for gas supply system** Aim: Gas feed to plasma target with few percent accuracy in the 10^{17} cm^{-3} regime, needs to comply with restrictions imposed by FLASH vacuum Status: Task completed.
Q3 2014	**Design of differential pumping** Aim: Remove gas load introduced to beam line, achieve pressure given by FLASH authorities at intersection to FLASH Status: Task completed with slight delay (Q4 2014)
Q2 2013	**Implement diagnostic for absolute gas density profiling** Aim: Diagnostic allowing for longitudinal gas density profile analysis, increase lower detection limit to below 10^{18} cm^{-3}, allow for species selectivity Status: Task achieved, Raman scattering diagnostics implemented, densities of few 10^{17} cm^{-3} can be measured, since non resonant discrimination between gas species possible.

Q1 2015	**Implement electron density diagnostic** Aim: Characterise electron density to see how it compares to gas density. If possible time resolved. Status: In progress. First results using Stark broadening and shift. Temporal resolution of 10 ns.
Q3 2015 (new)	**Study of ionisation- and dissociation dynamics** Aim: Understand timescales and properties of ionisation and dissociation. Of major importance for ionisation injection Status: Activities started
Q4 2015 (new)	**Experiments to ionisation- and dissociation dynamics** Aim: Validate findings for theoretical investigation and simulations Status: investigation of possible diagnostics started
Q2 2015	**Cross calibration of Stark broadening diagnostics** Aim: Validate the accuracy of the Stark broadening measurements. Status: Delayed to Q3 2015 owing to delayed construction of new labs
Q4 2015	**Finished gas supply system for FLASHForward** Aim: Gas supply for the FLASHForward experiments ready Status: Parts specked, ready to order.
Q1 2016	**Finished gas target for FLASHForward** Aim: Refined prototype of FLASHForward gas target ready for installation Status: To be started after prototype testing
Q2 2016	**Hollow core plasma channels** Aim: Generation of a hollow core plasma channels for electron acceleration Status: To be started once studies of ionisation and dissociation dynamics have finished
Q4 2016	**Investigation of alternate diagnostic methods for characterisation** Aim: Improving knowledge about plasma parameters yielding insight into their contribution to the acceleration processes. Status: first research on possible diagnostics and their advantages started

1. Requirements and resulting target concept

Design requirements:

- no emittance spoilers
- full transverse (optical) probing
- operation with separated gas species
- tunable density profiles (ramps/peaks)
- easily replaceable (8h)
- plasma density
  - acceleration: up to 5 x 10^{17} cm^{-3}
  - injection: up to 1 x 10^{19} cm^{-3}

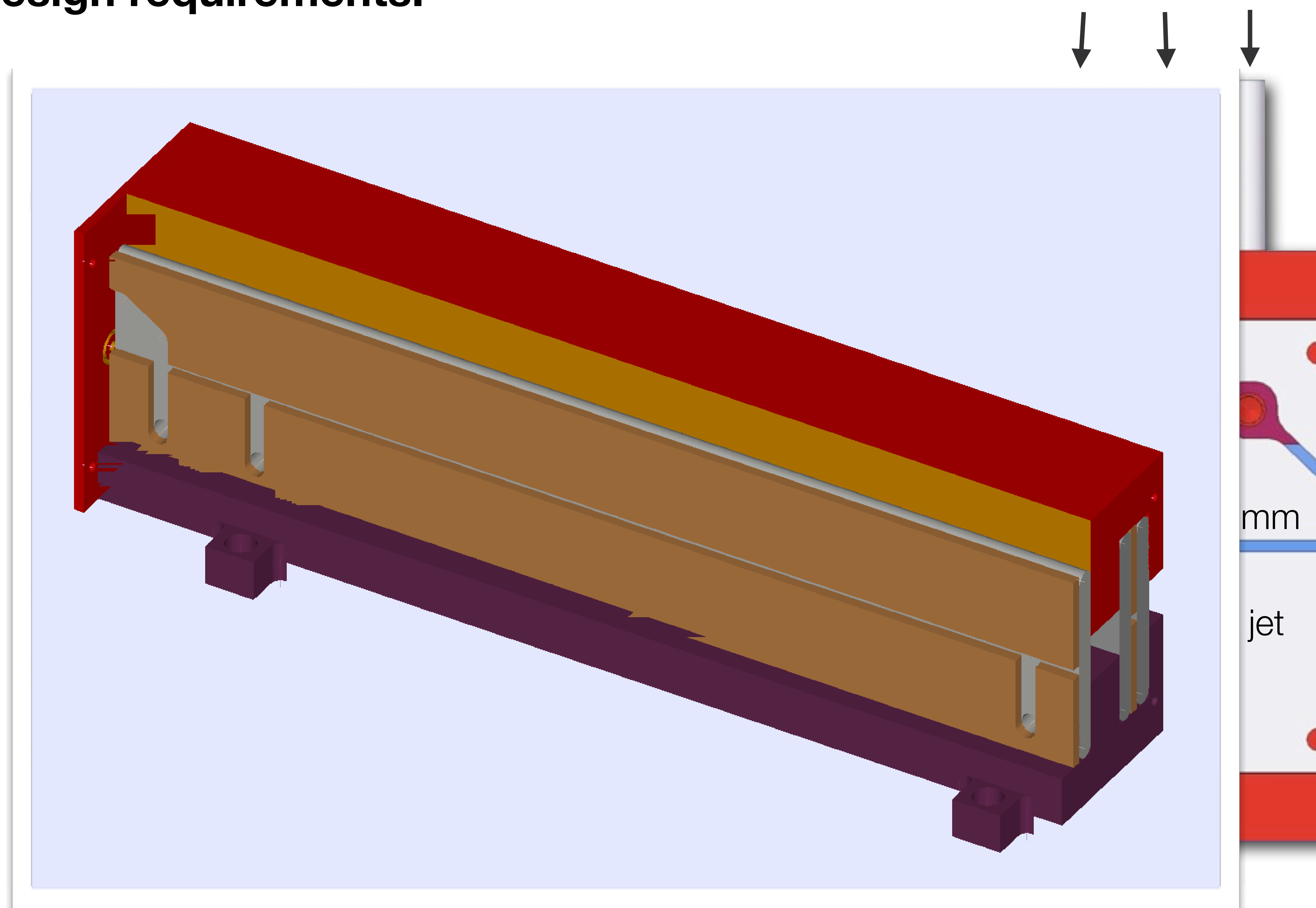


Developed target:

- Multiple inlets
  - separate pressure control
  - flexible density profile
  - multiple species operation
- Continuous gas flow design
  - no windows required
- Nozzle inlet included
  - DDR injection
  - Spatially confined species
- Transverse optical access
  - full profile diagnostics

1. Requirements and resulting target concept

Design requirements:



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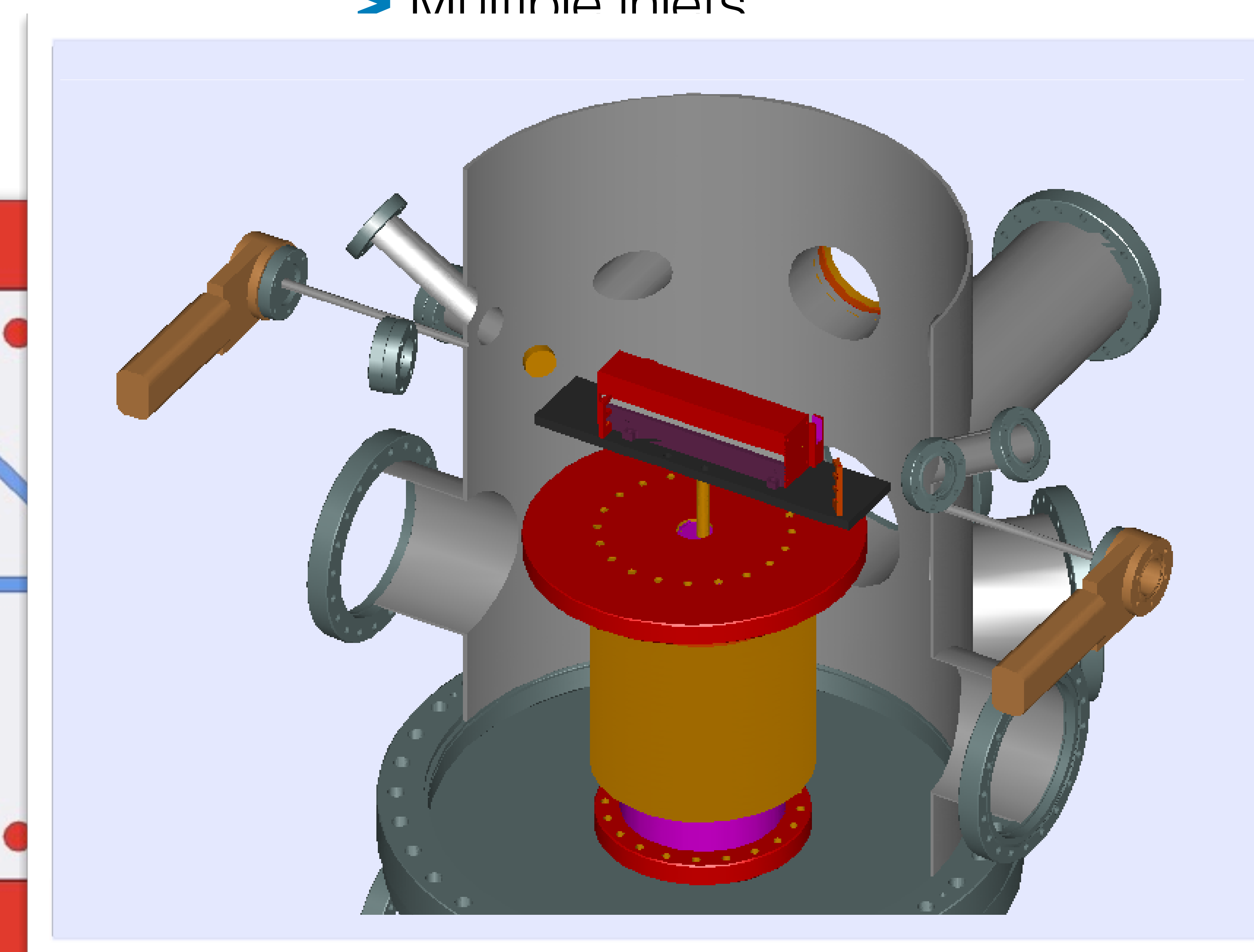
- Multiple inlets



- Transverse optical access
  - full profile diagnostics

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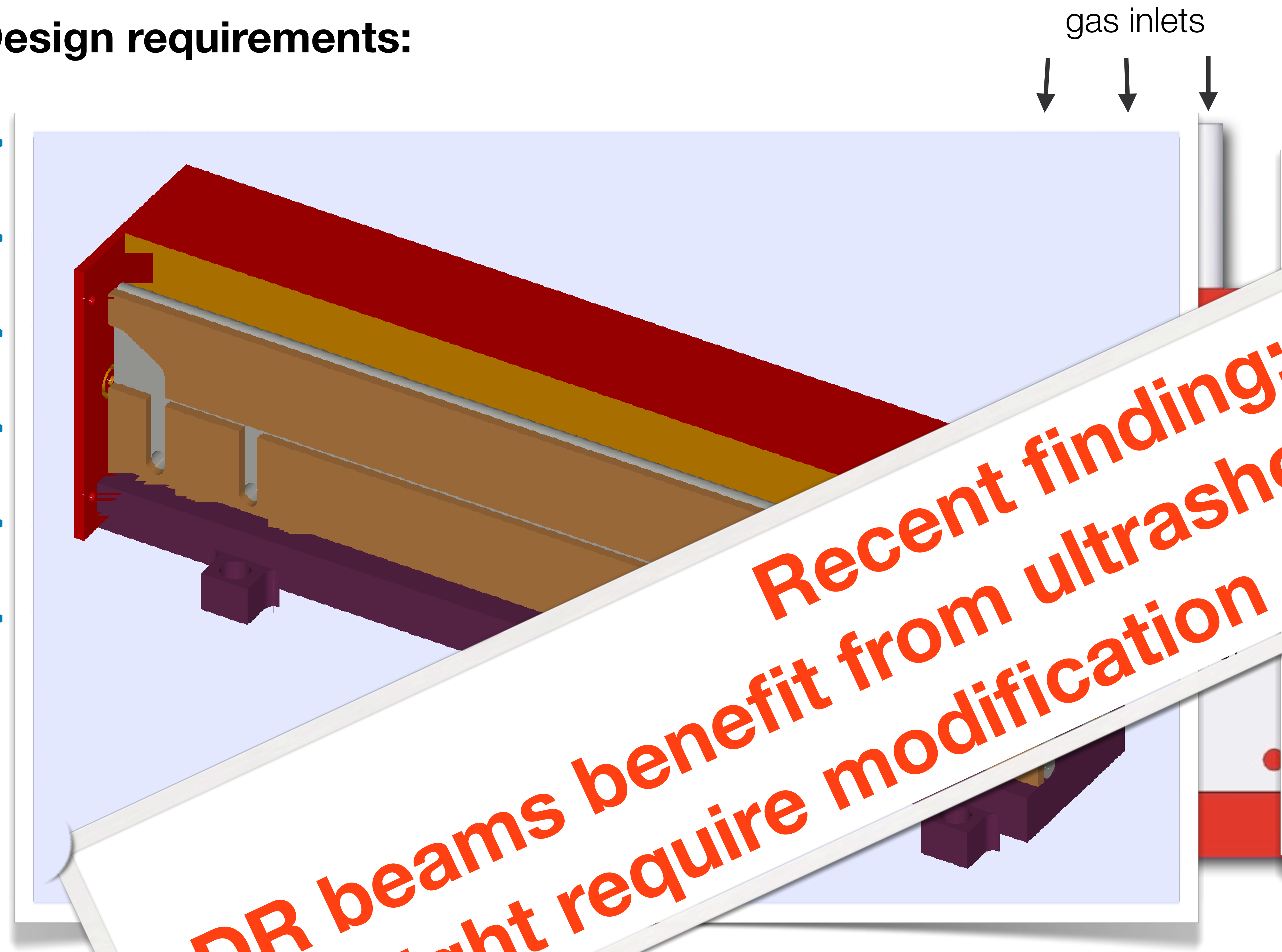

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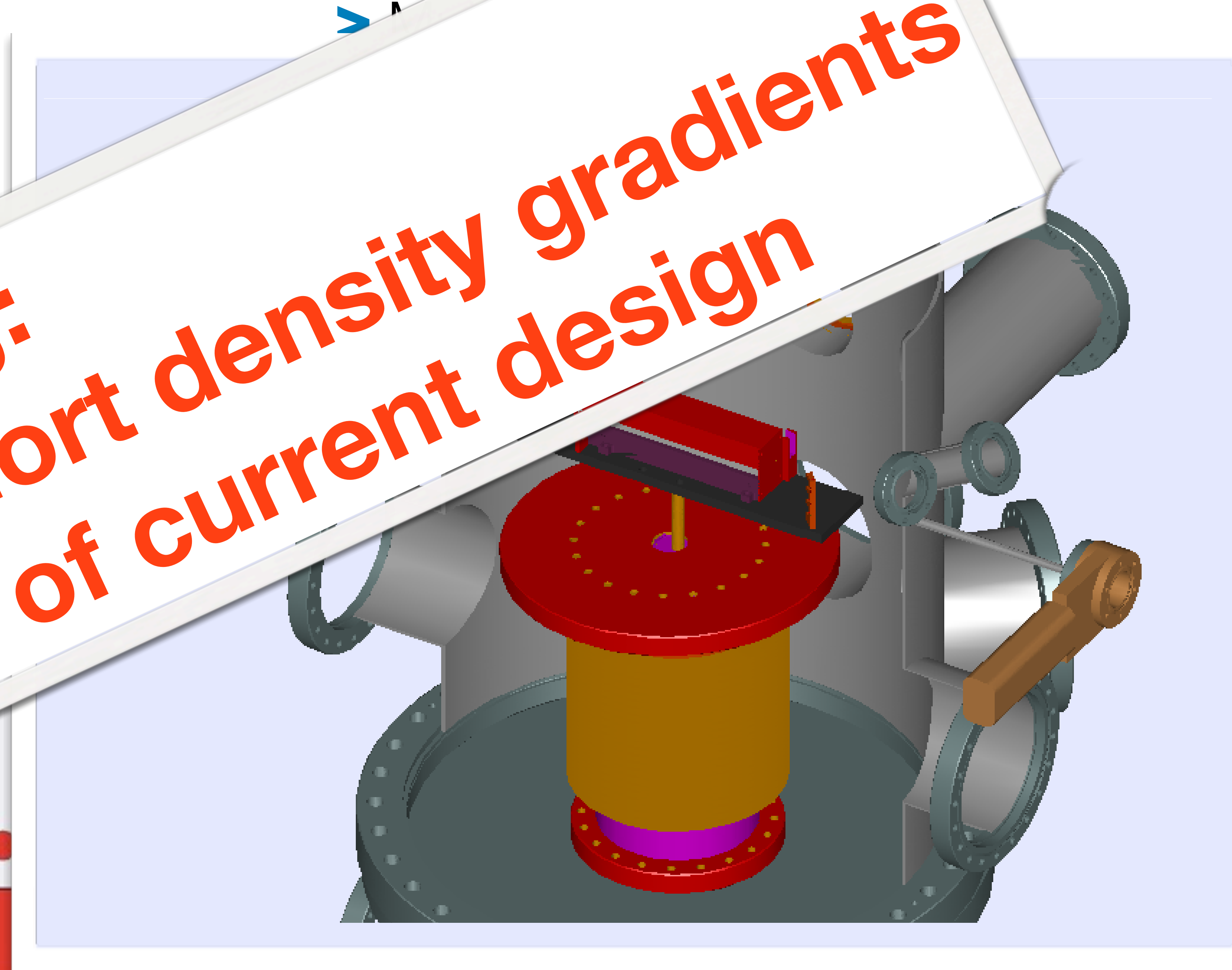
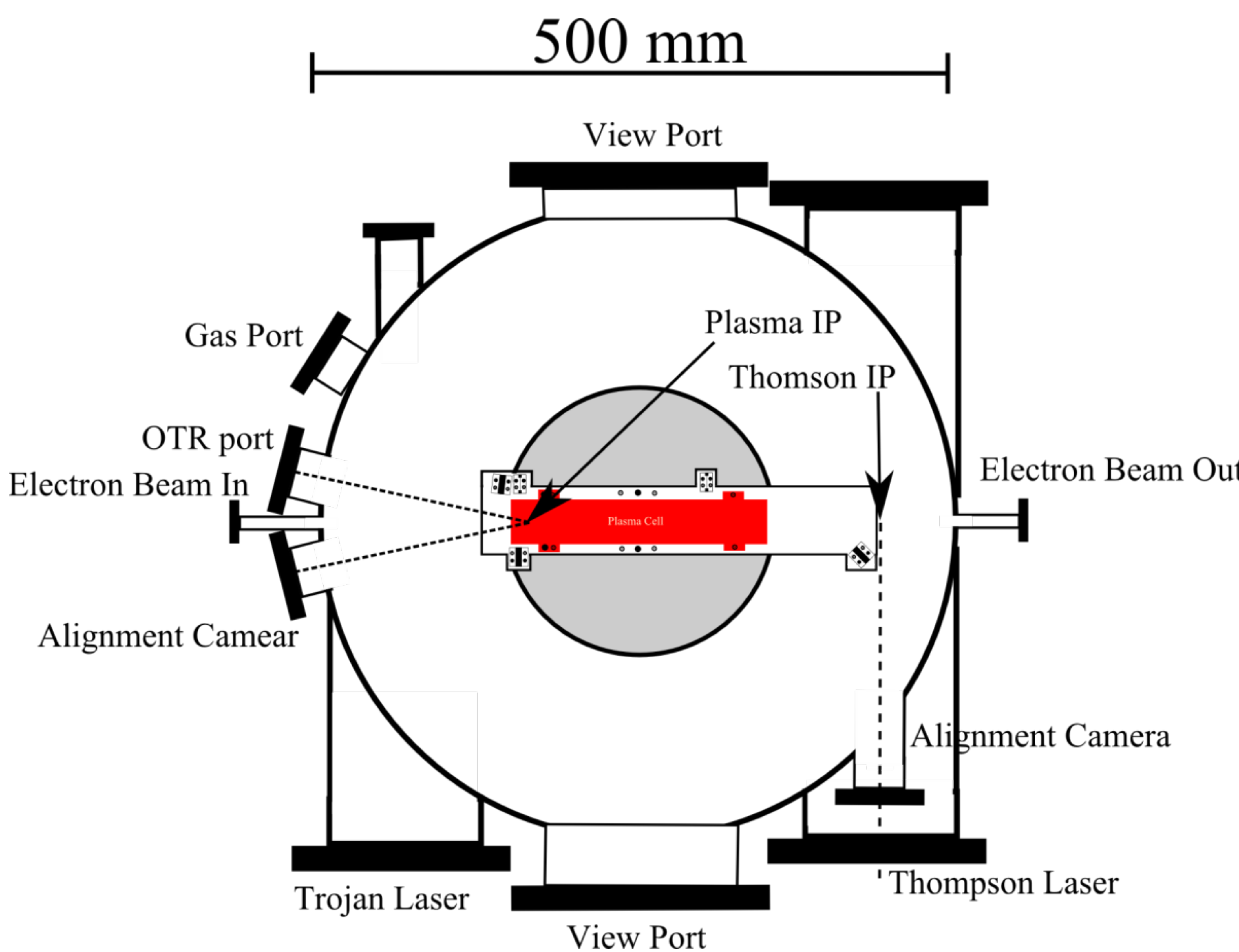


- Transverse optical access
  - full profile diagnostics

1. FLASHForward target chamber

Current status:

- 6D movement of structures on support plate in Chamber
- Hexapod: 3D spatial plus pitch & roll
  Yaw: rotating the chamber
- Currently testing the mover system
- Design is being upgraded to incorporate a high power laser input



1. Gas removal from beamline

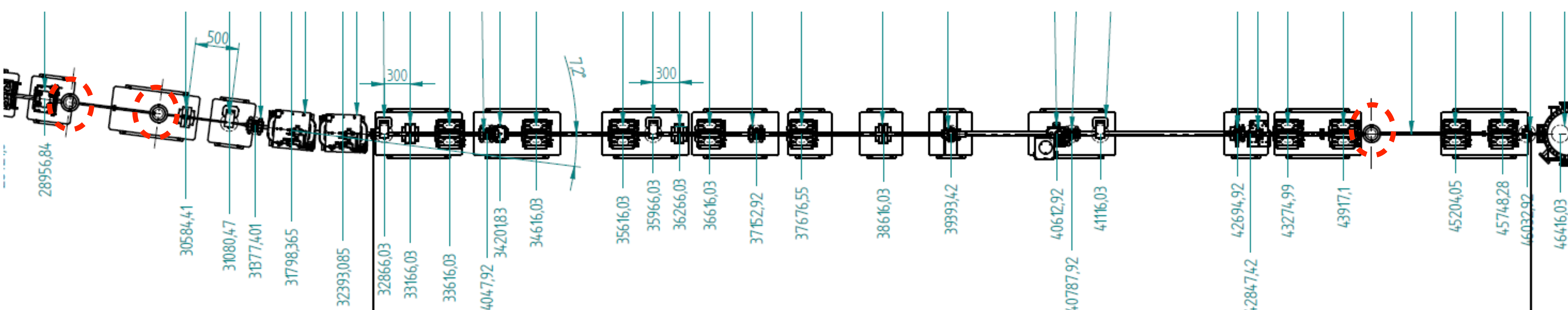
Current status:

- Differential pumping sections now in the beam line design
- MoFlow simulations show pressure below 10^{-8} achievable
- original purge gas problem solved

To Do:

- Order pumps once beamline design is frozen

Differential pumping stations



2. Ionisation: Atomic vs. molecular treatment

[1] M Ammosov et al., Sov. Phys. JETP 64, 1191–1194, (1986)
[2] Chen et al., J. Appl. Phys. 99, 056109 (2006)
[3] H.-X. He et al., Journ. Chem. Phys. 136, Vol.143, No.1 (2012)

Current status:

- So far atomic ionisation potential used
  - molecular behaviour differs
- Ionisation rates[1] for hydrogen and helium compared
- Ionisation injection[2] using hydrogen and helium
- Dissociation of H_2 ~ 20-40 fs [3], can be on the timescale of laser pulse duration
- Simulations show longer pulses double-ionise at lower Intensity

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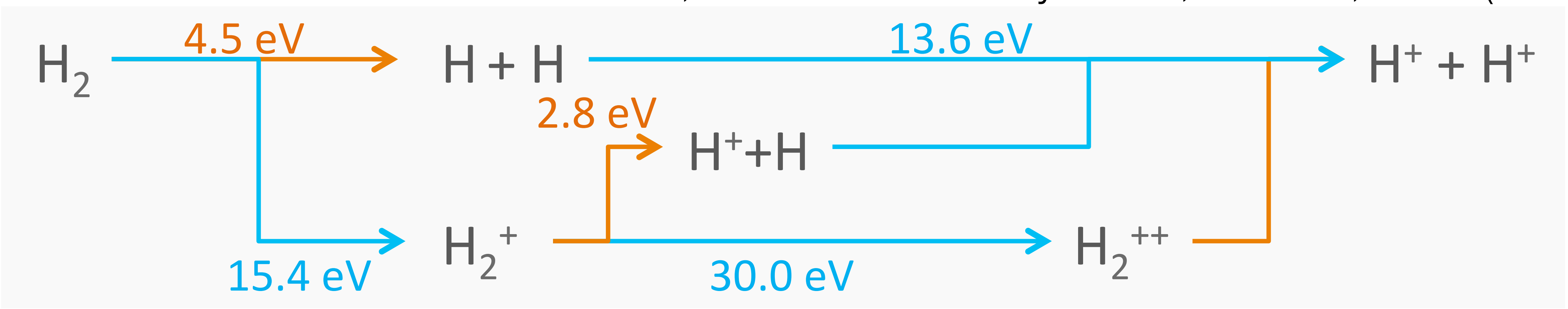

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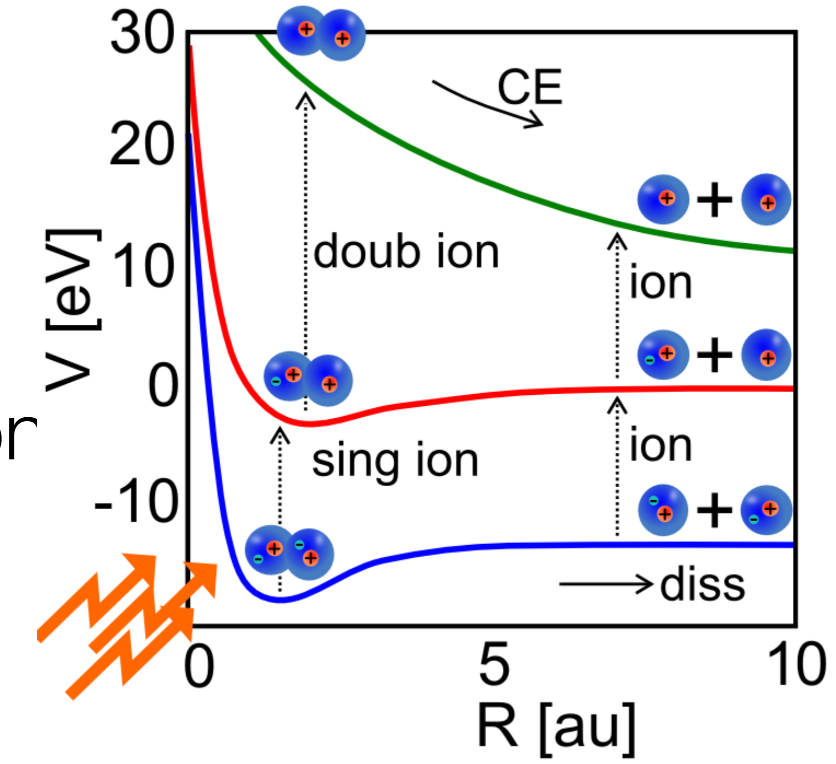

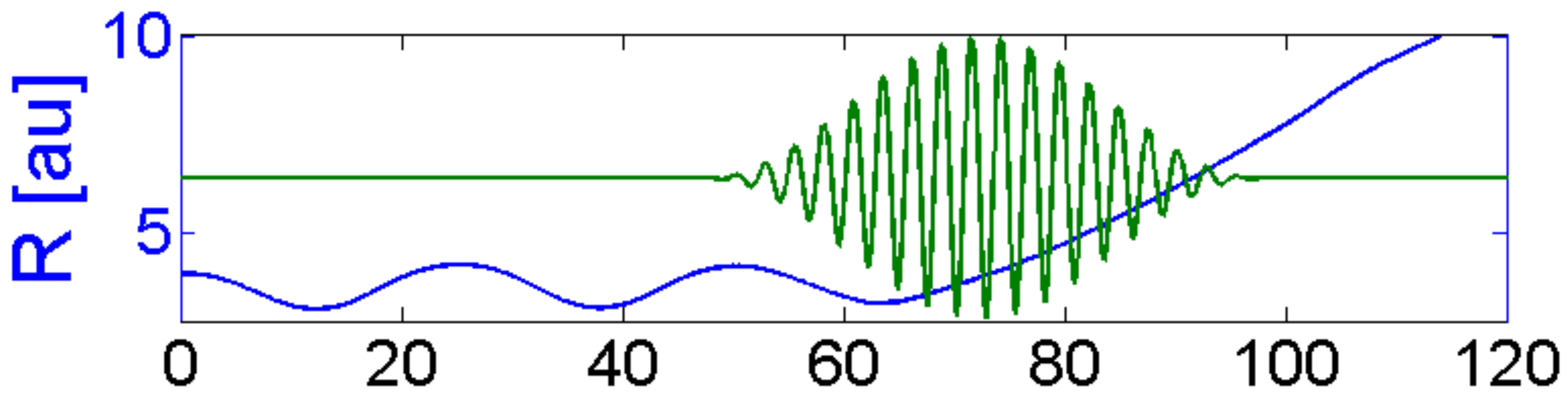

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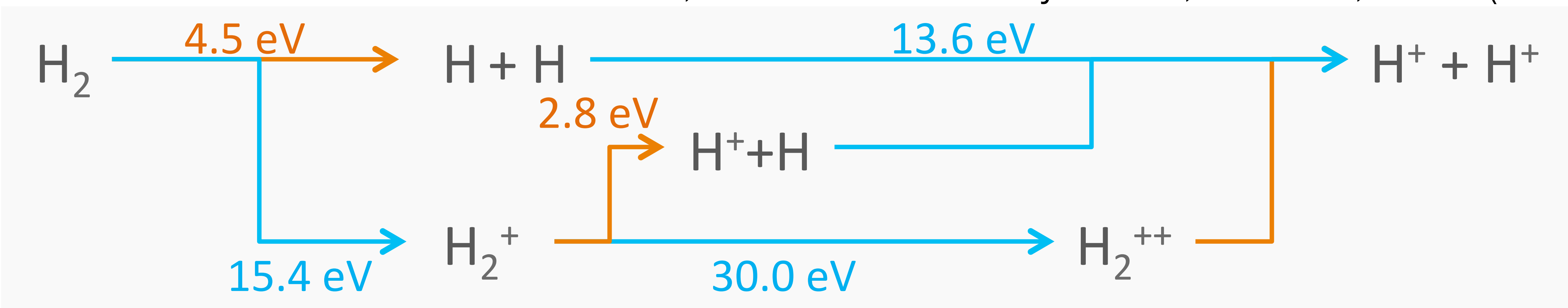

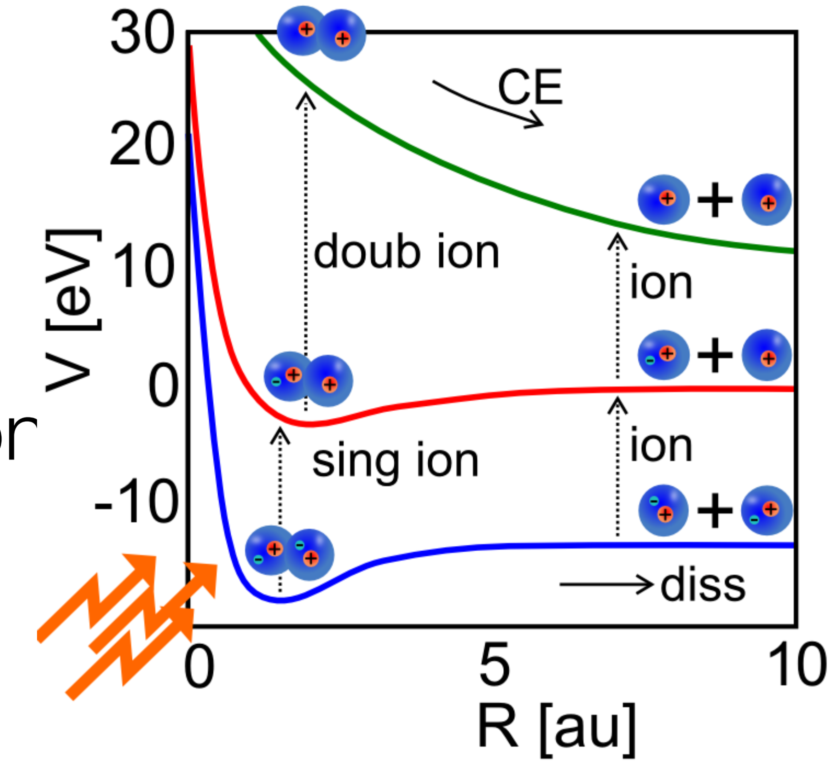

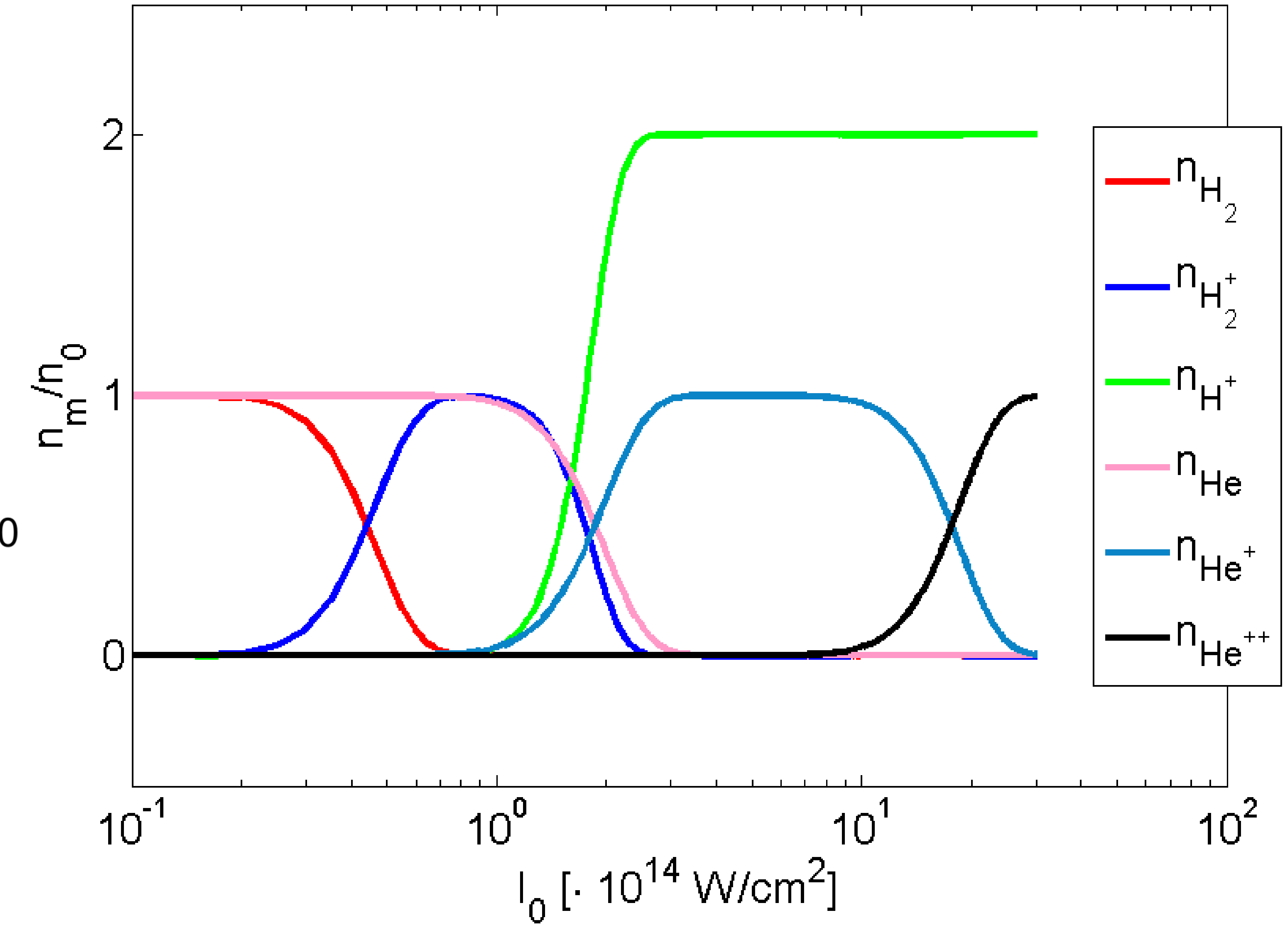

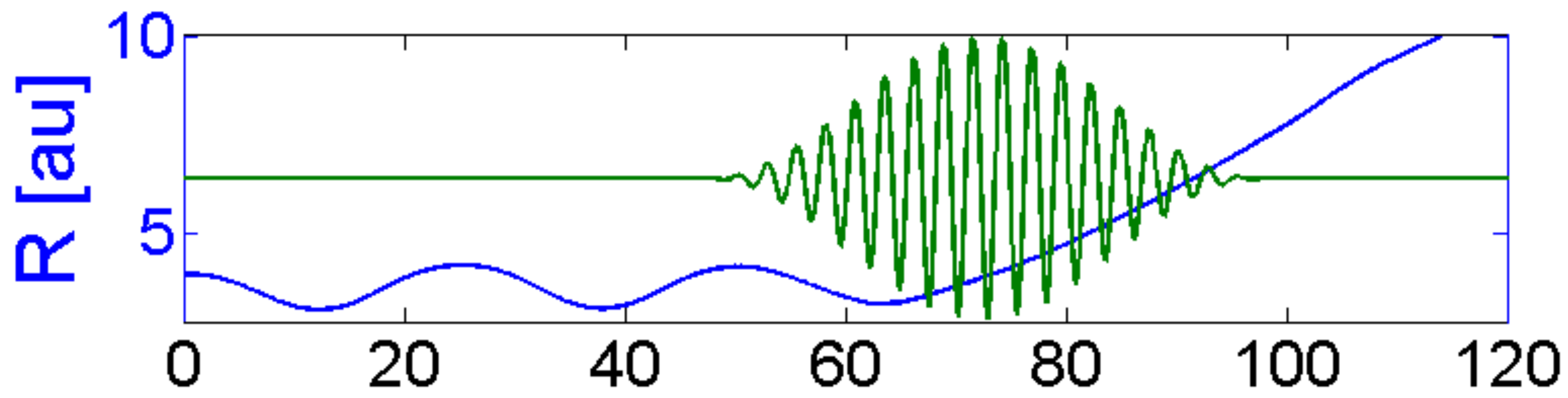

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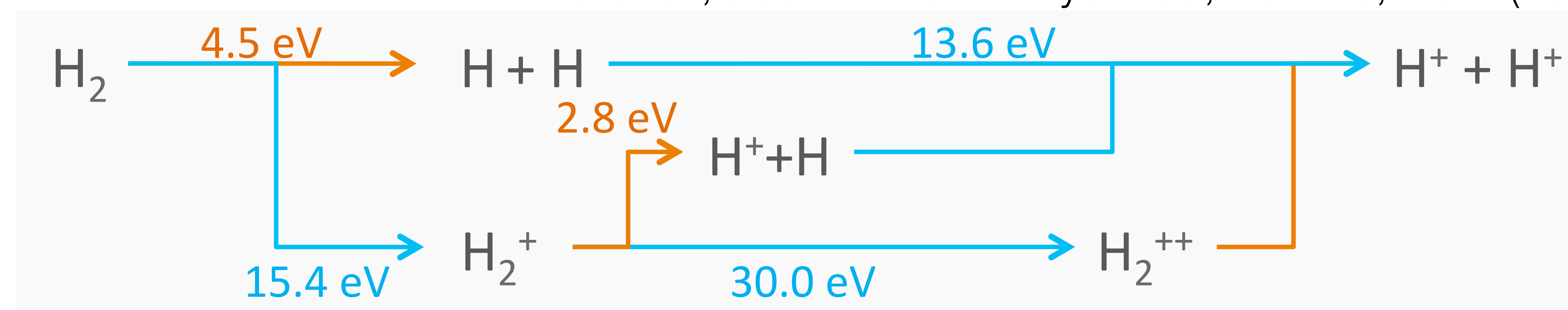

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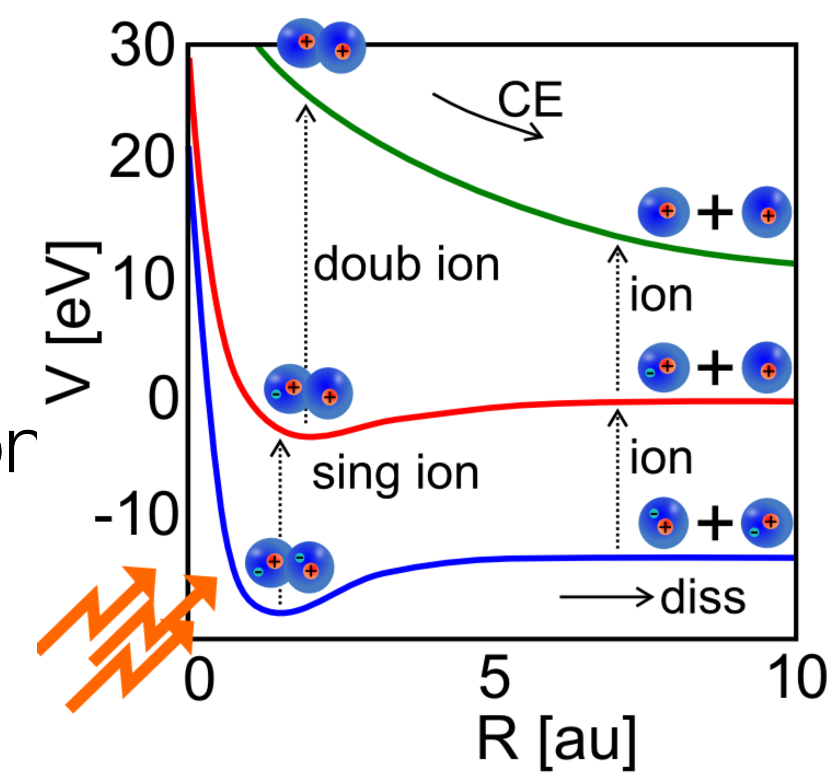

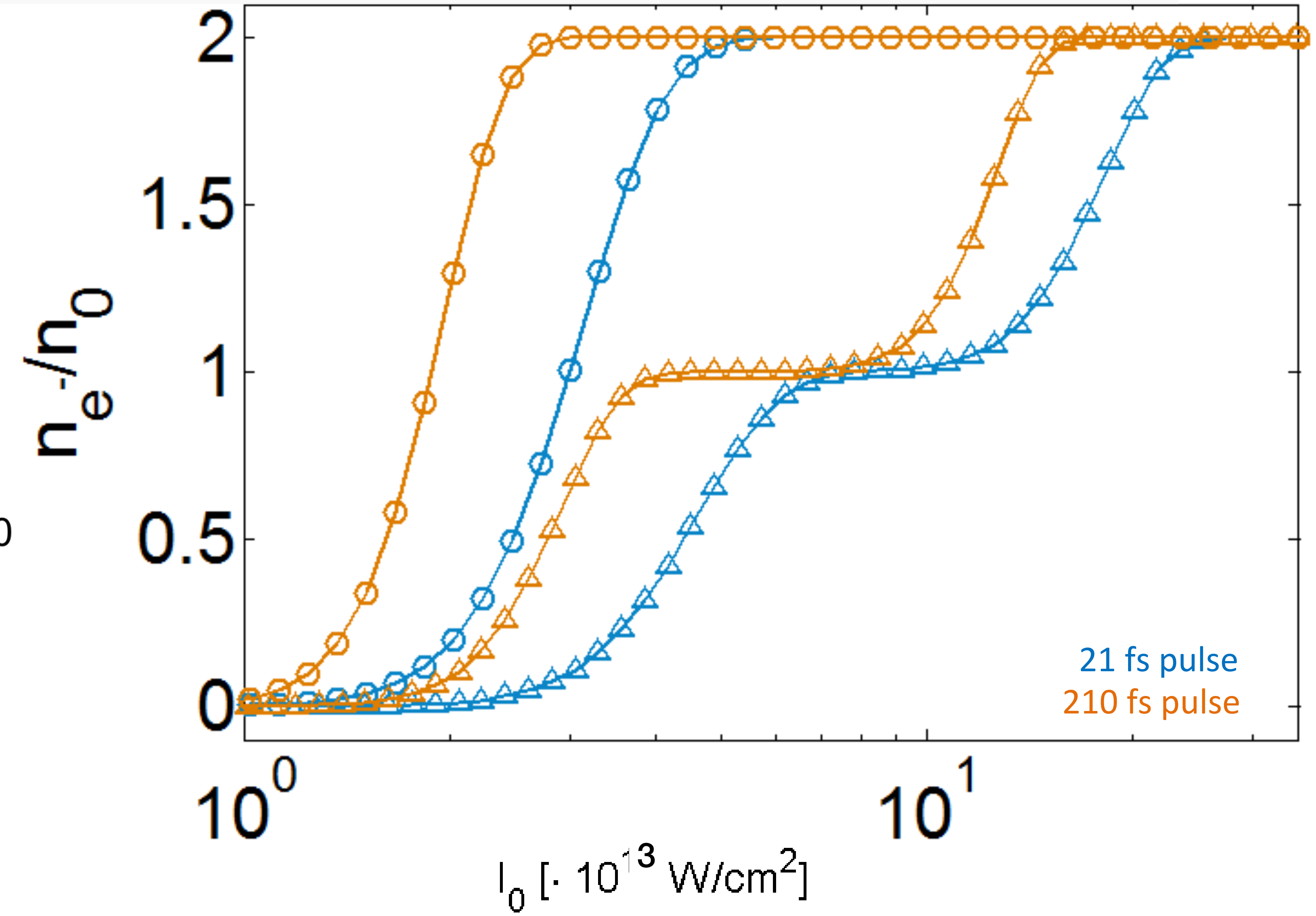

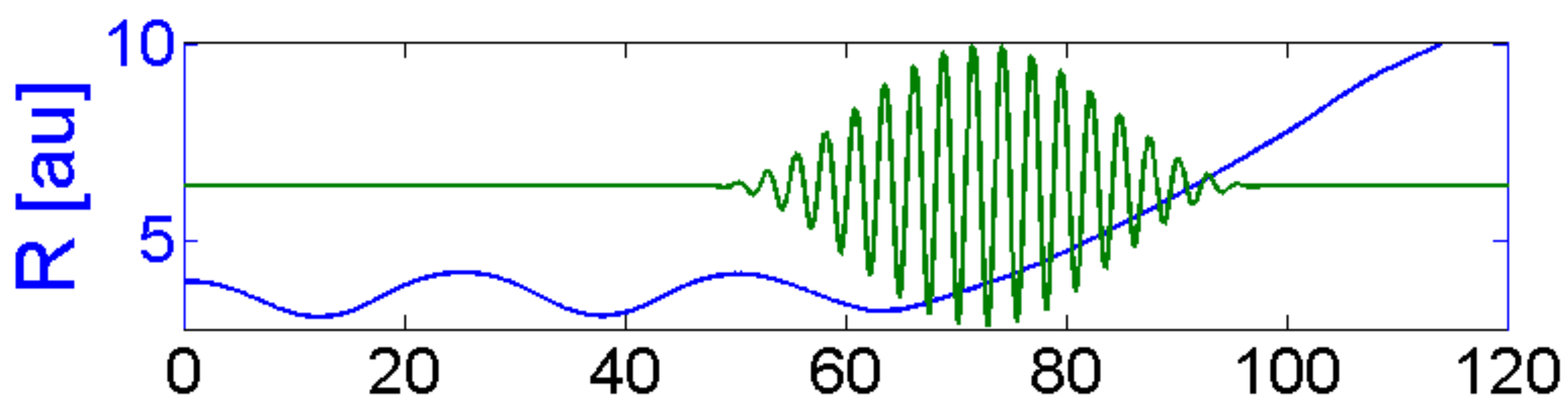

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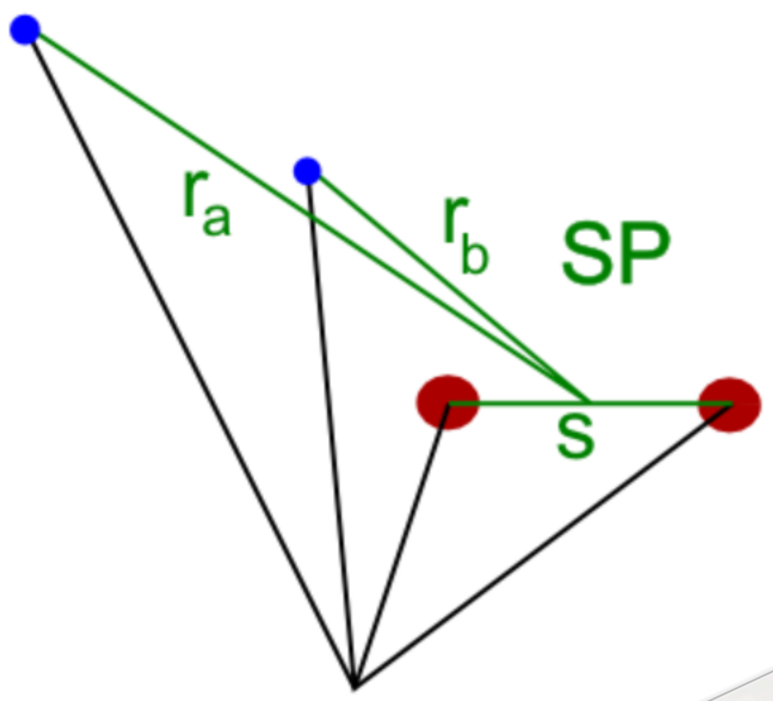

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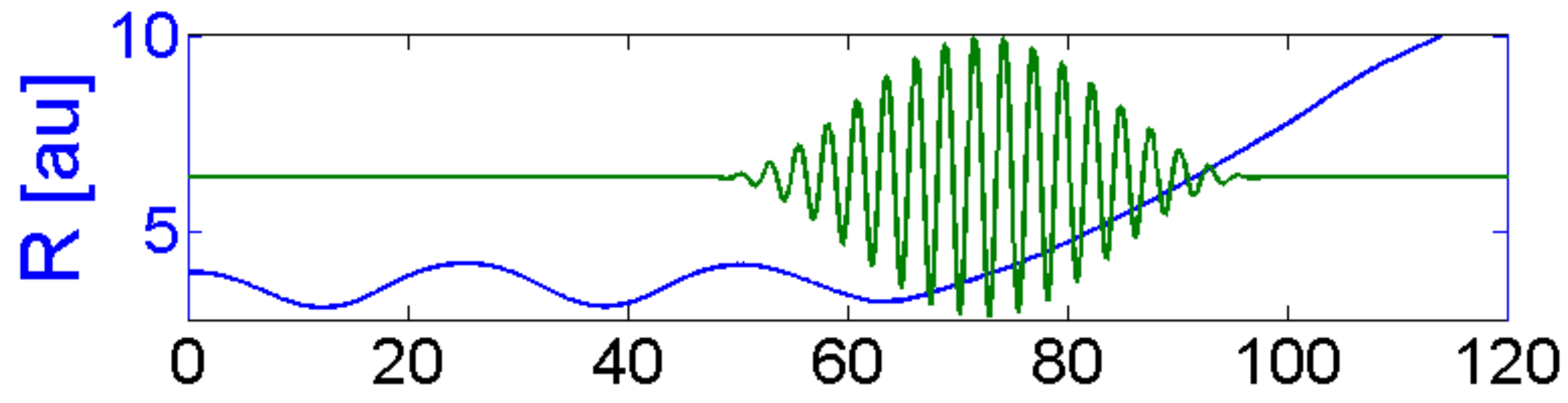
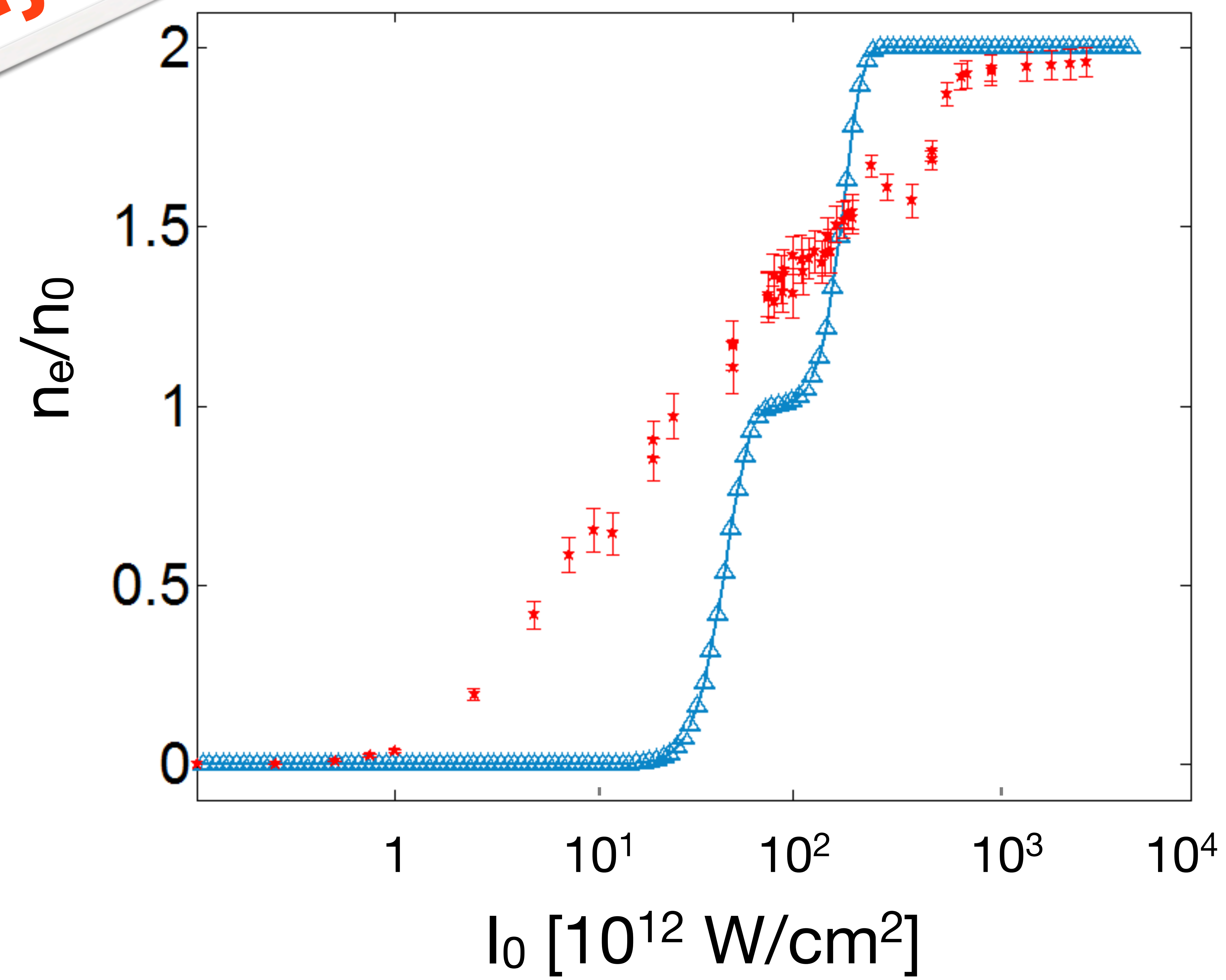


Also: classical 1D simulation incorporates all fragmentation dynamics!

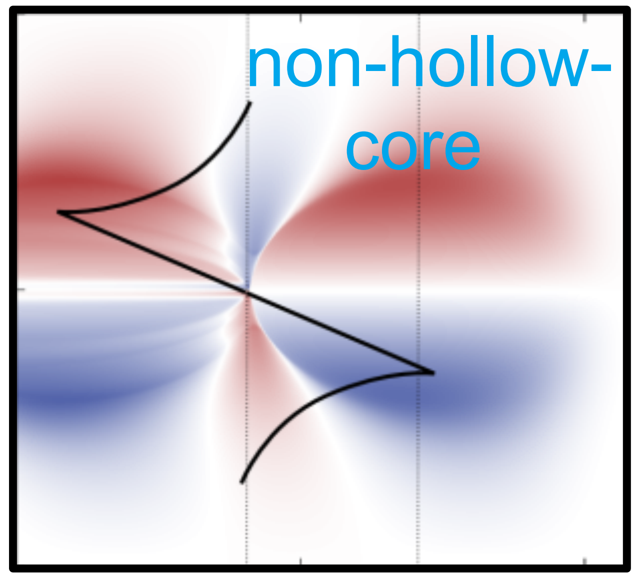


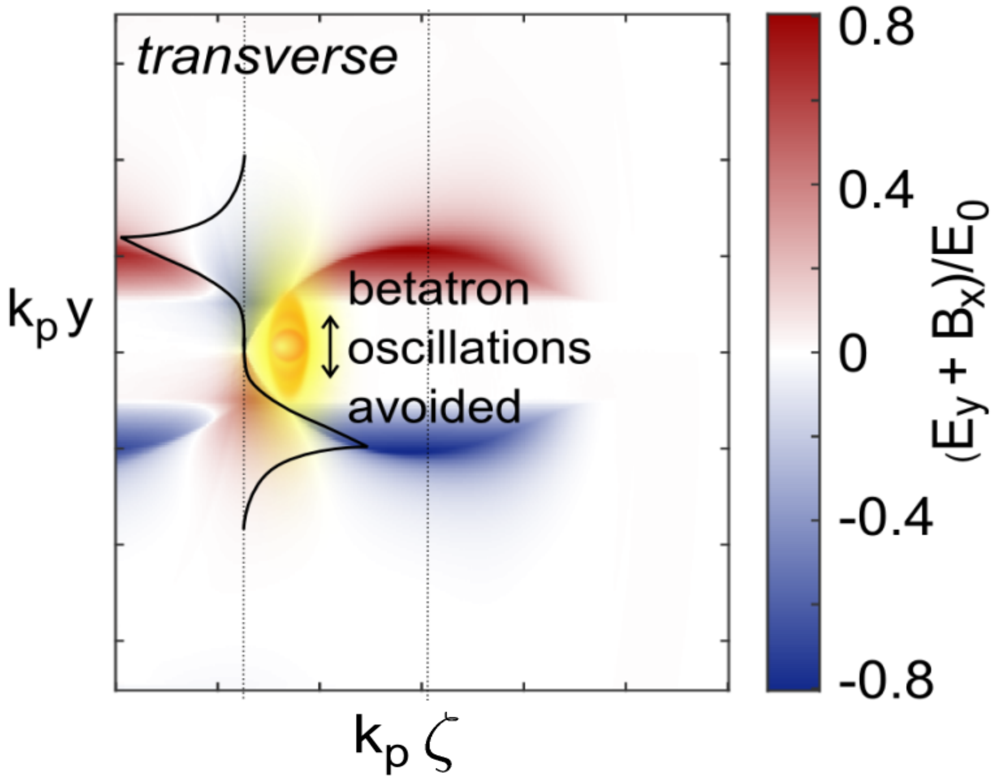
2. Hollow core plasma channels

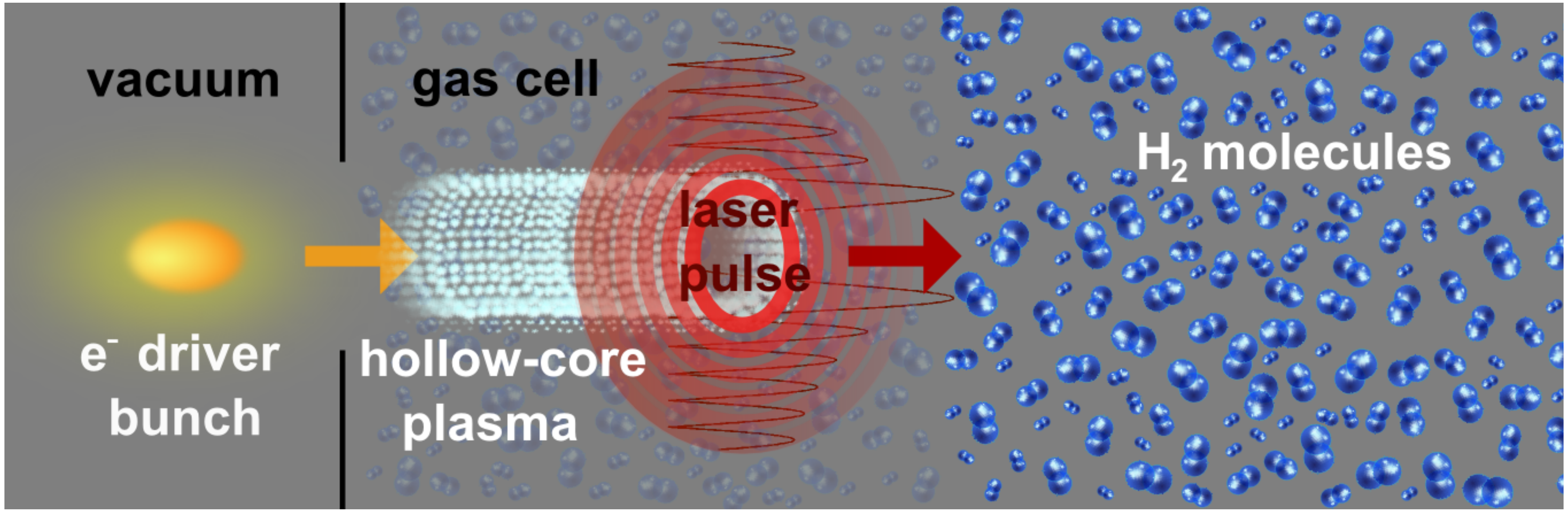
> Understanding of ionisation mechanics especially important for hollow core plasma channels

    > separation of accelerating and focussing forces

> activities starting soon...

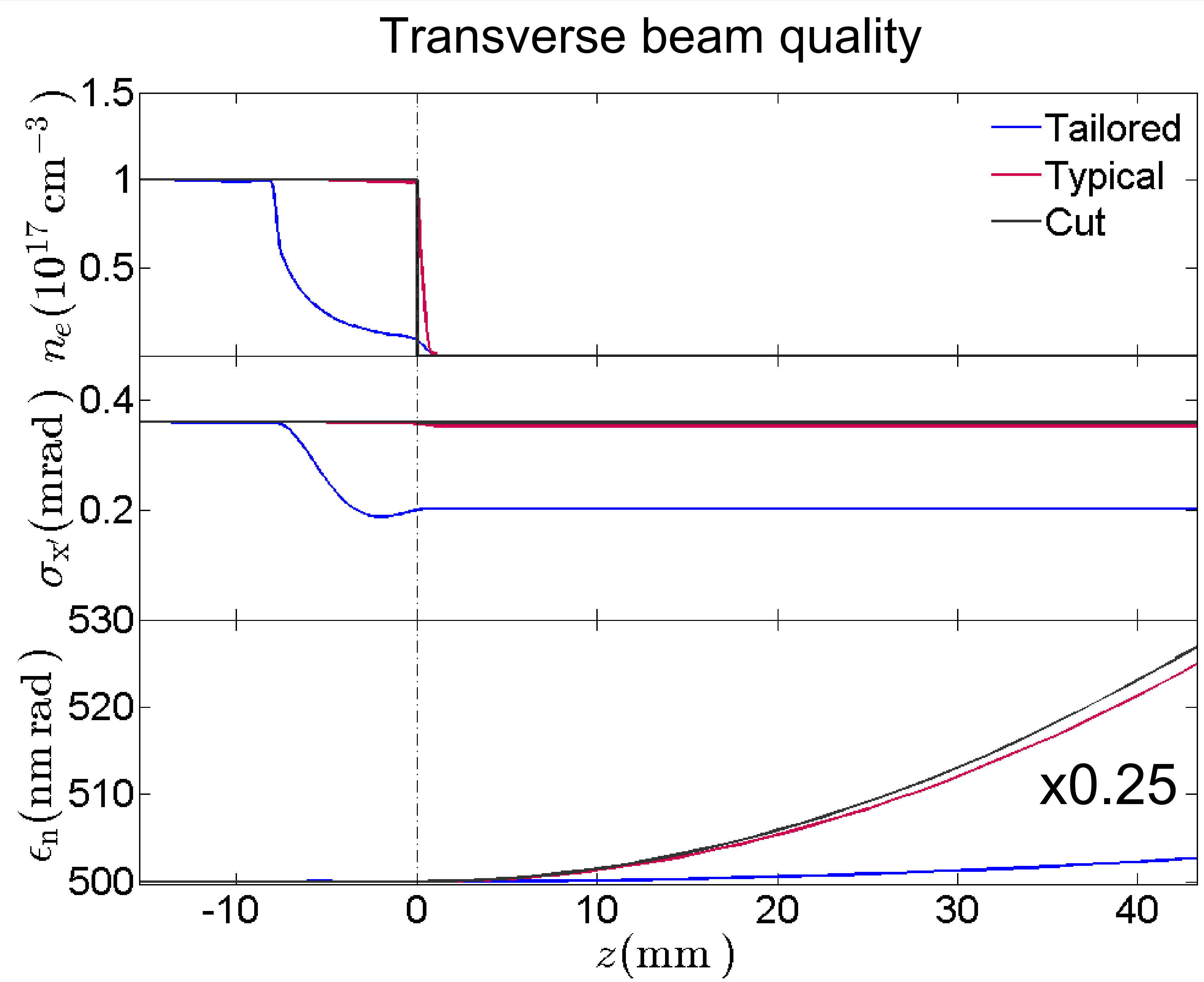


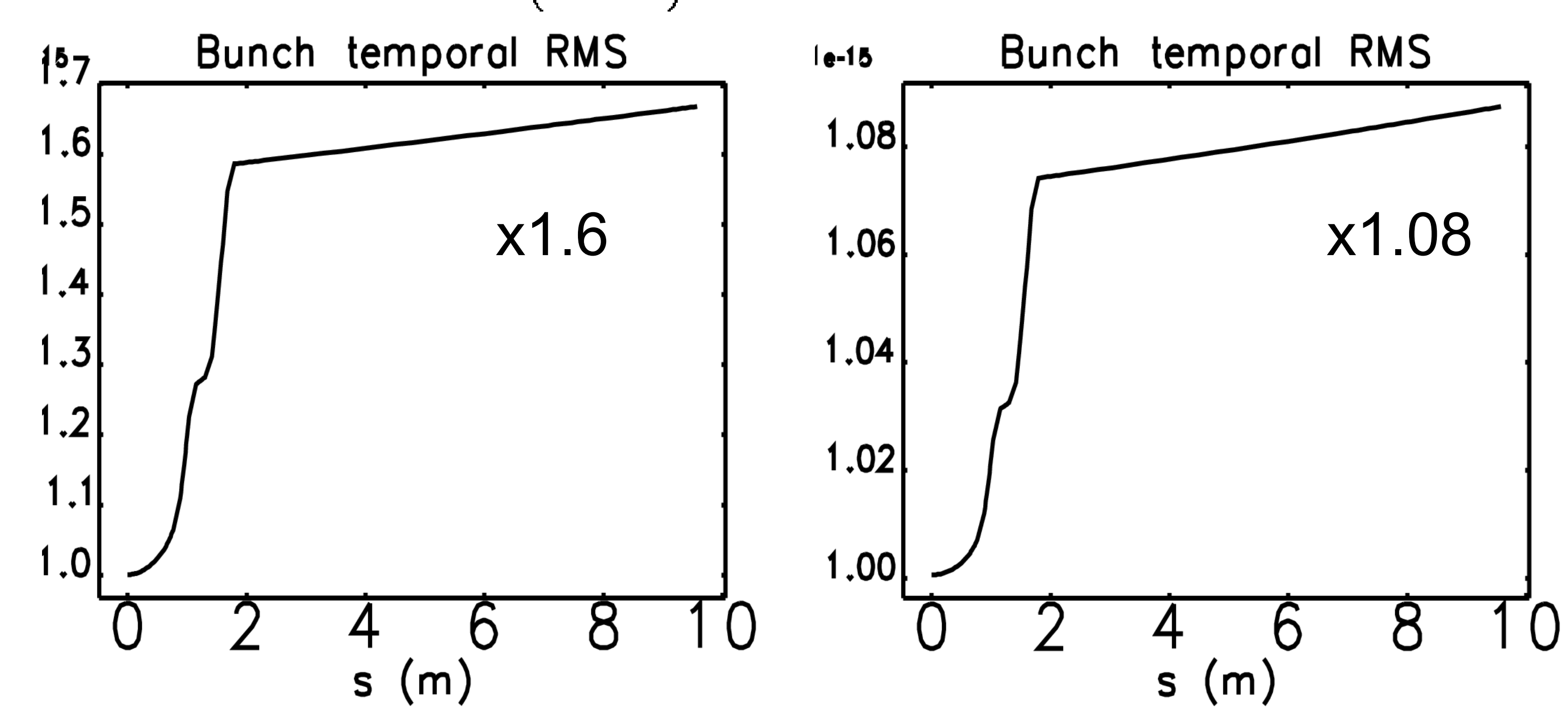




3. Beam quality preservation

- Strong focusing fields inside plasma
  - small beam size (βm ~ 1mm)
  - large divergence
- Emittance growth[1] and pulse stretching after release
  - geometric stretching due to path length
  - emittance growth due to chromatic effects
- Adiabatic plasma-to-vacuum transition
  - preserves emittance
  - decreases divergence

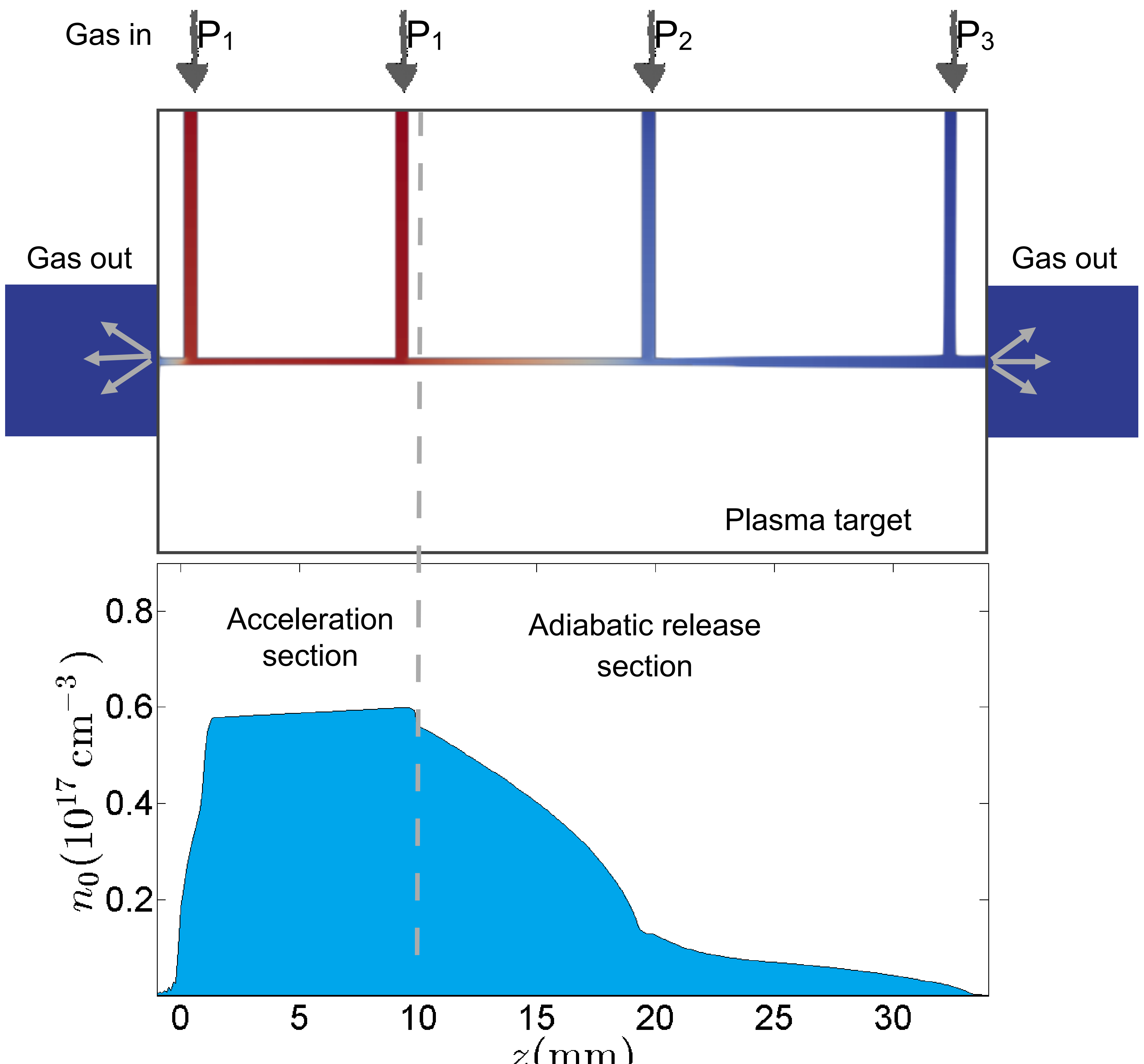




[1] K. Floettmann, Phys. Rev. ST Accel. Beams 6, 034202 (2003)

3. Implementation

- Target modification adding adiabatic release section
- Density calculated via CFD code **Open∇FOAM**
- here: P1 = 2.5 mbar, P2 = P3 = 0.1 mbar



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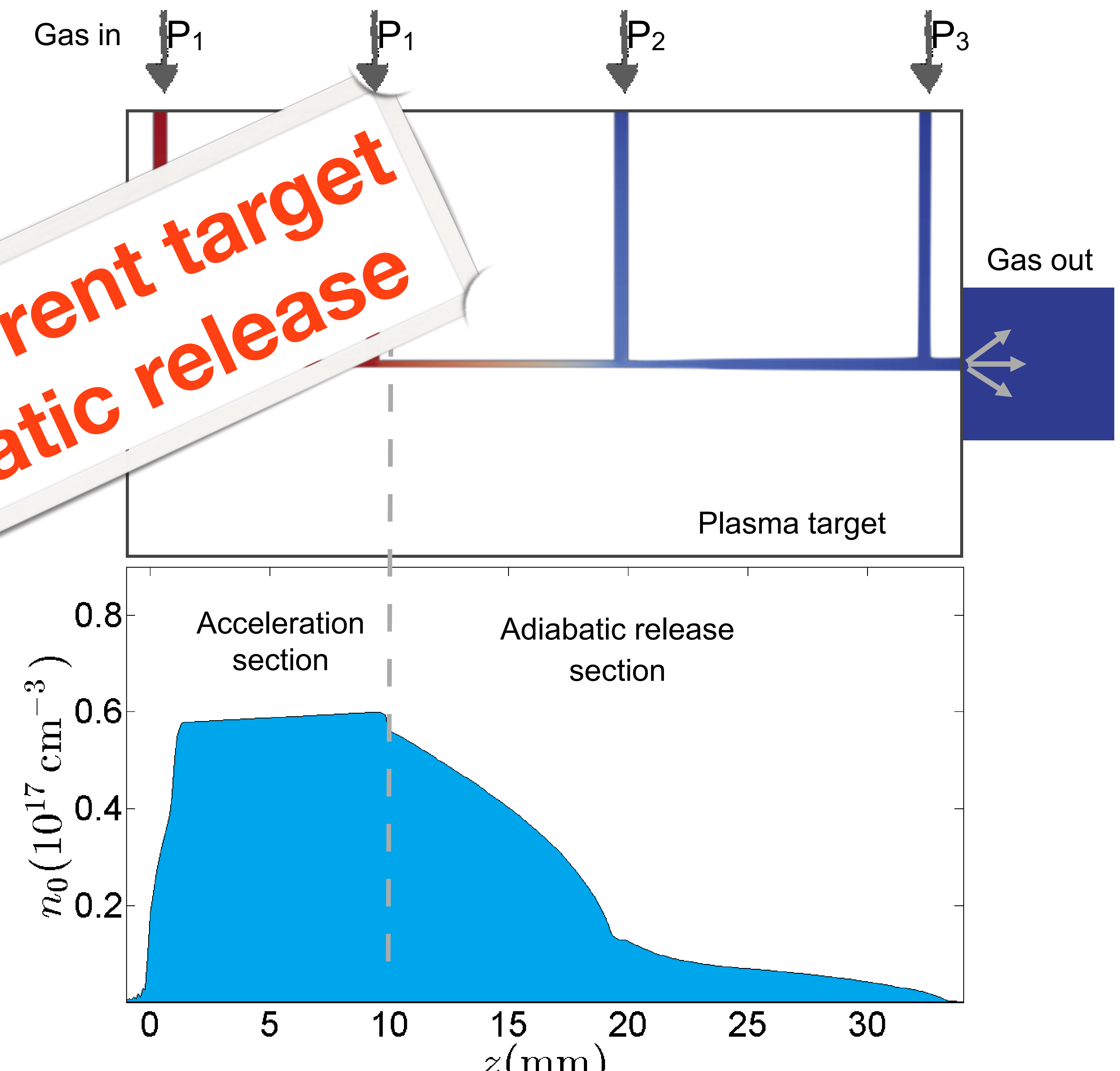


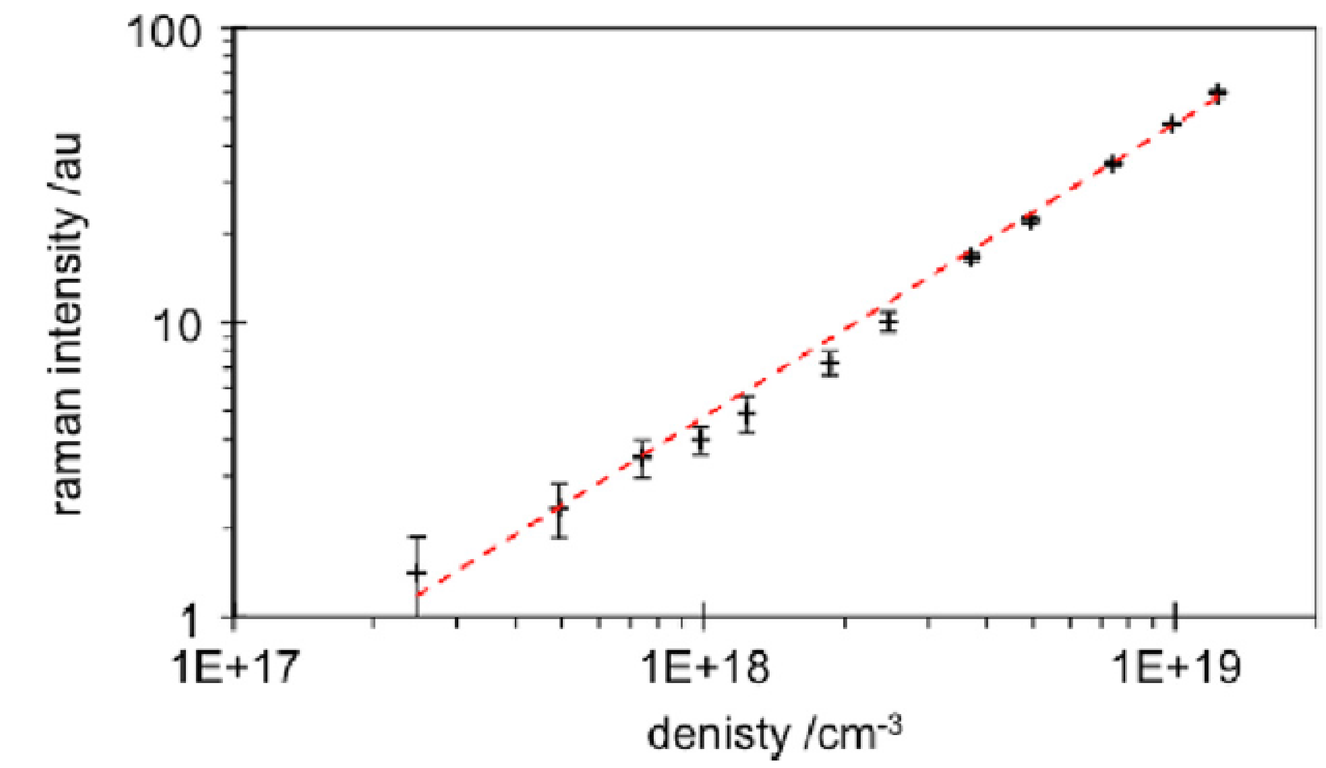
possible to modify current target implementing adiabatic release

4. Diagnostics: Considerations

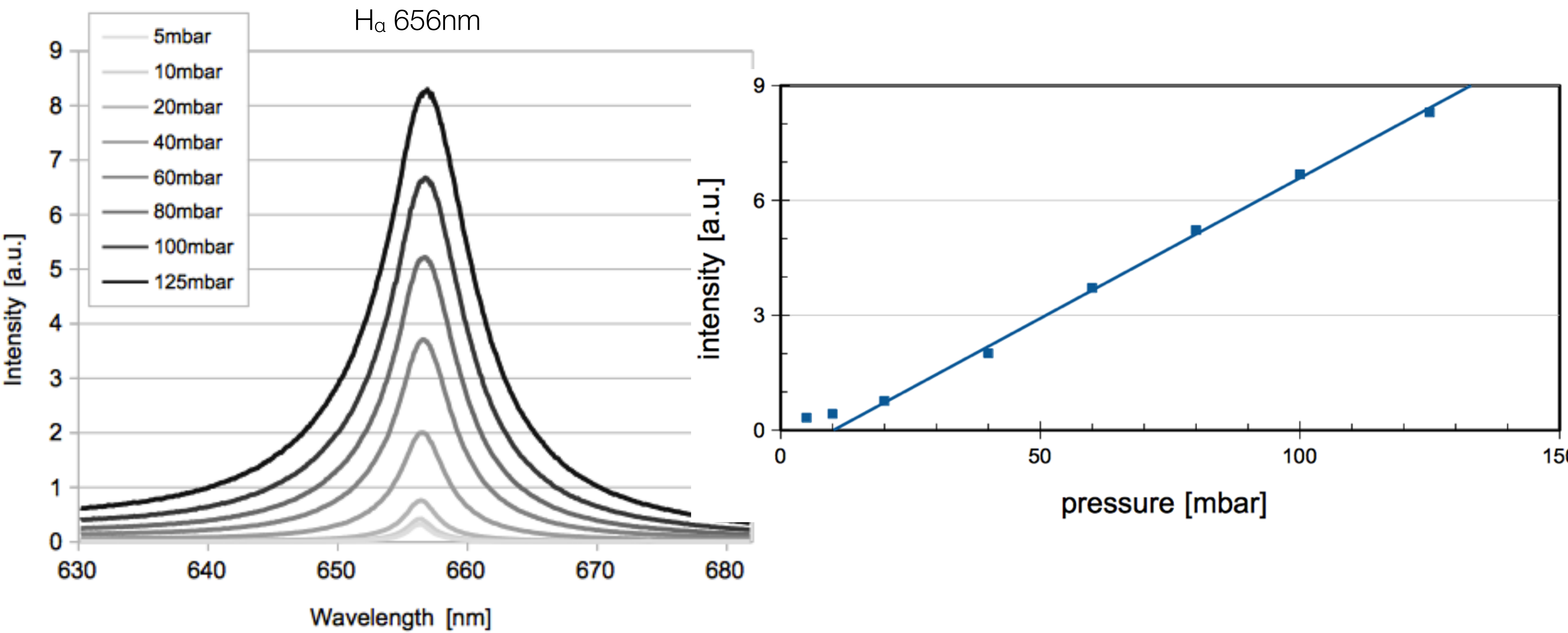
- Low density requires novel diagnostic techniques
  - Interferometry reliable down to ~ 10^{18} cm^{-3}
- Gas profilometry as a first characterisation
  - Initial species-specific gas distribution
  - Photon scattering on gas molecules
  - Benchmark for CFD simulations
- Use emitted light for diagnostics: Plasma spectroscopy
  - Plasma parameters determine emission
  - Idea: Online measurement
- Data analysis relies on reliable plasma density data
  - Sufficient spatiotemporal resolution to resolve plasma features

Longitudinal interferometry: No local information

Raman scattering: shown effective down to ~ 10^{17} cm^{-3}



4. n_e: Density dependent line width and wavelength



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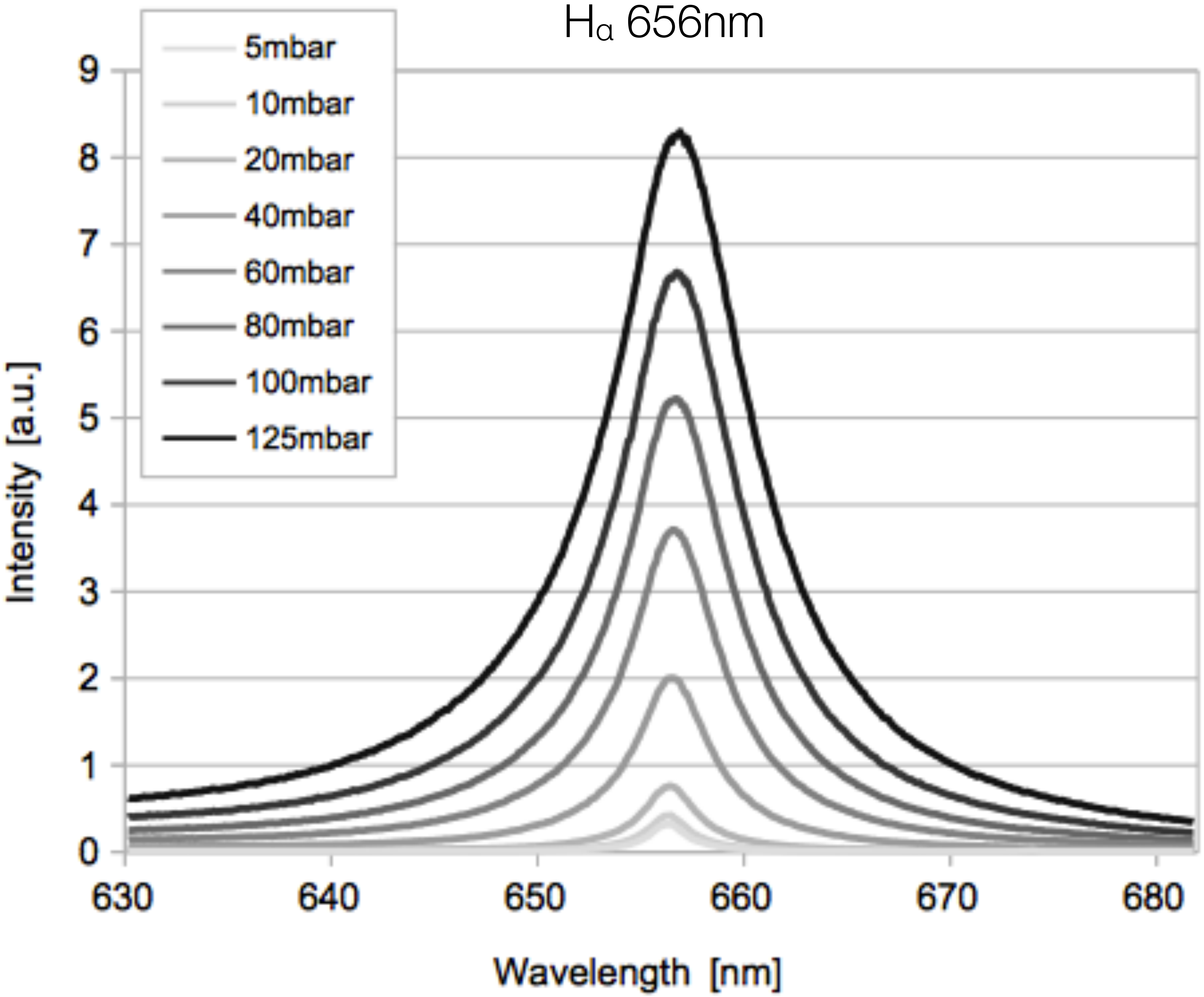
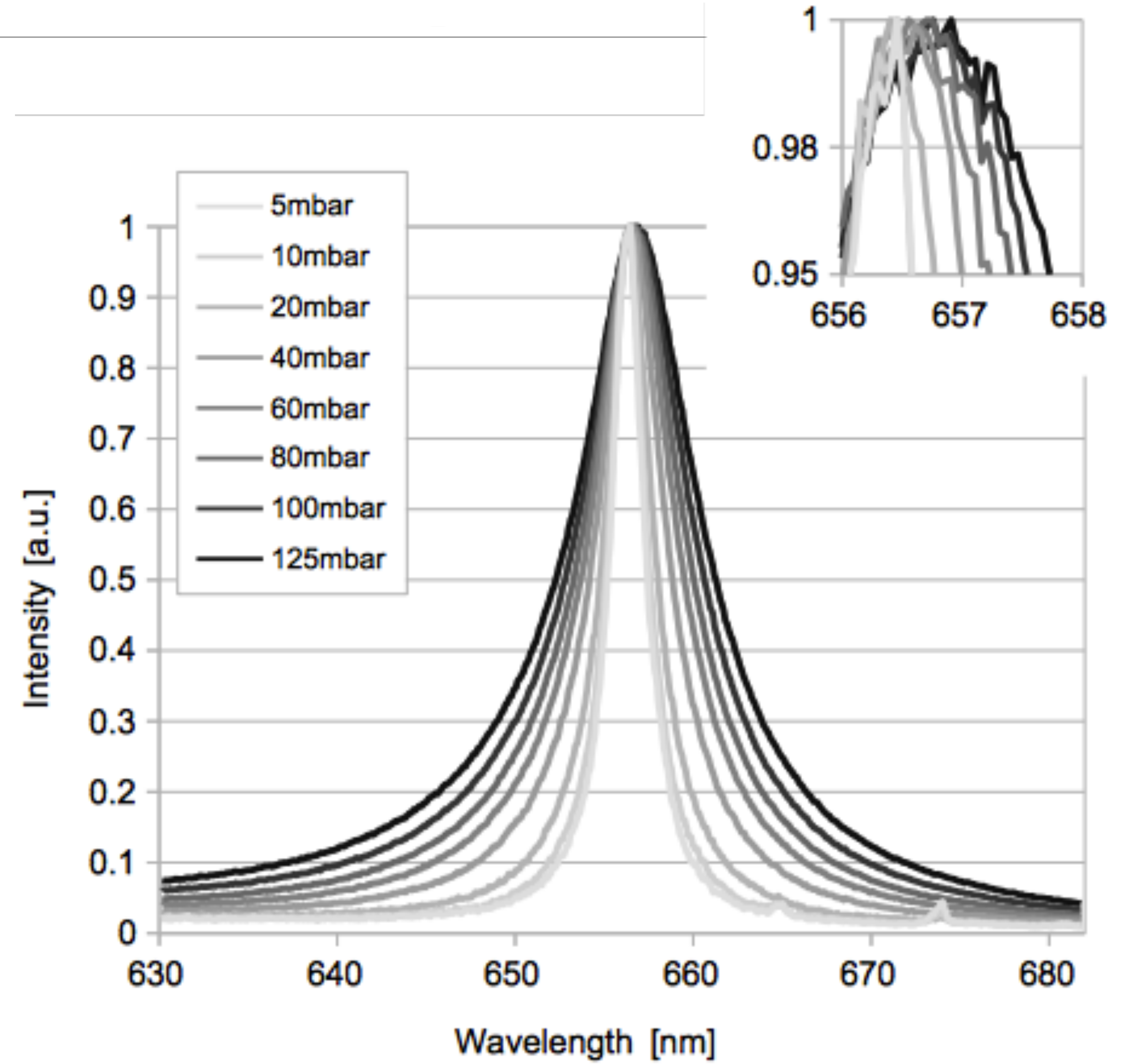
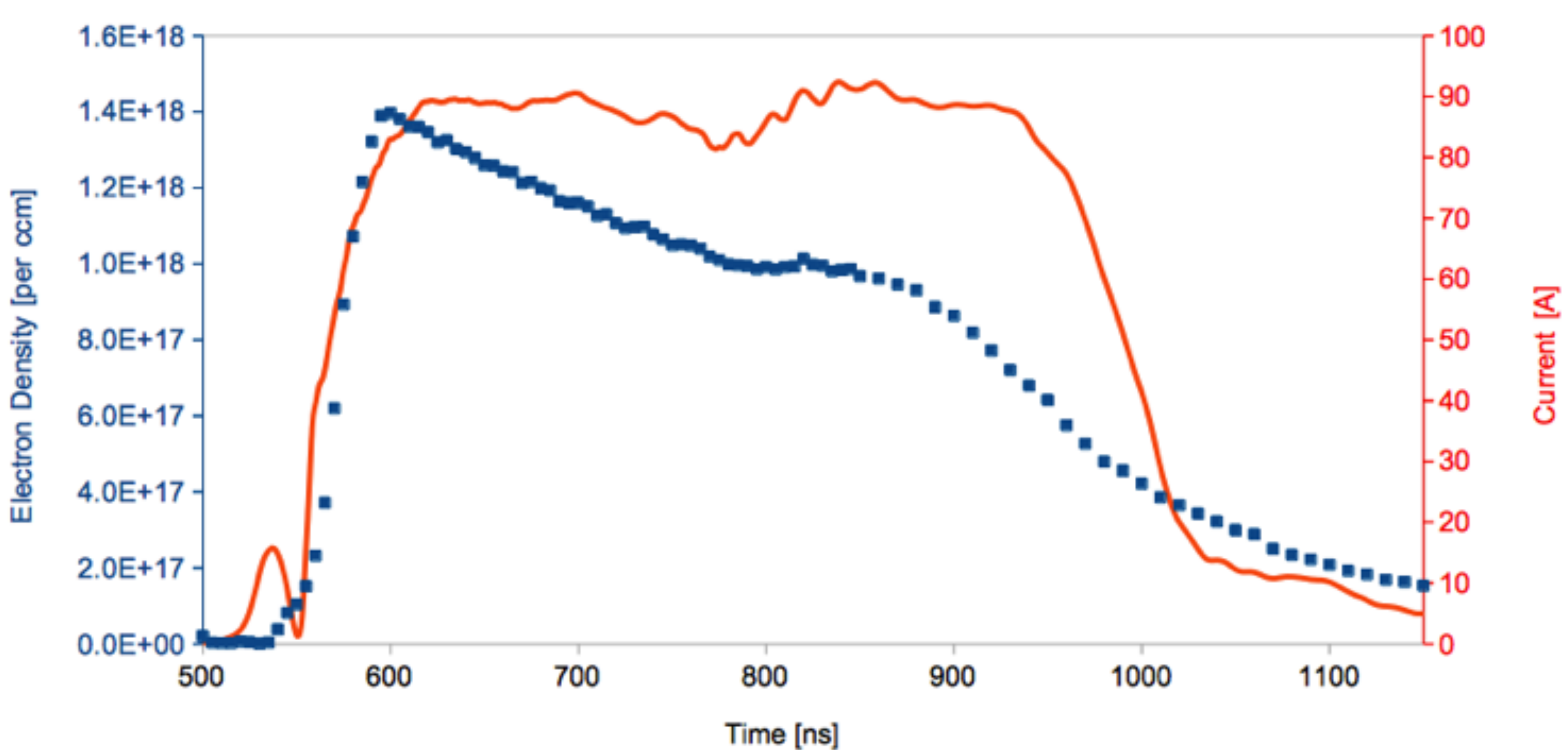
H_α 656nm

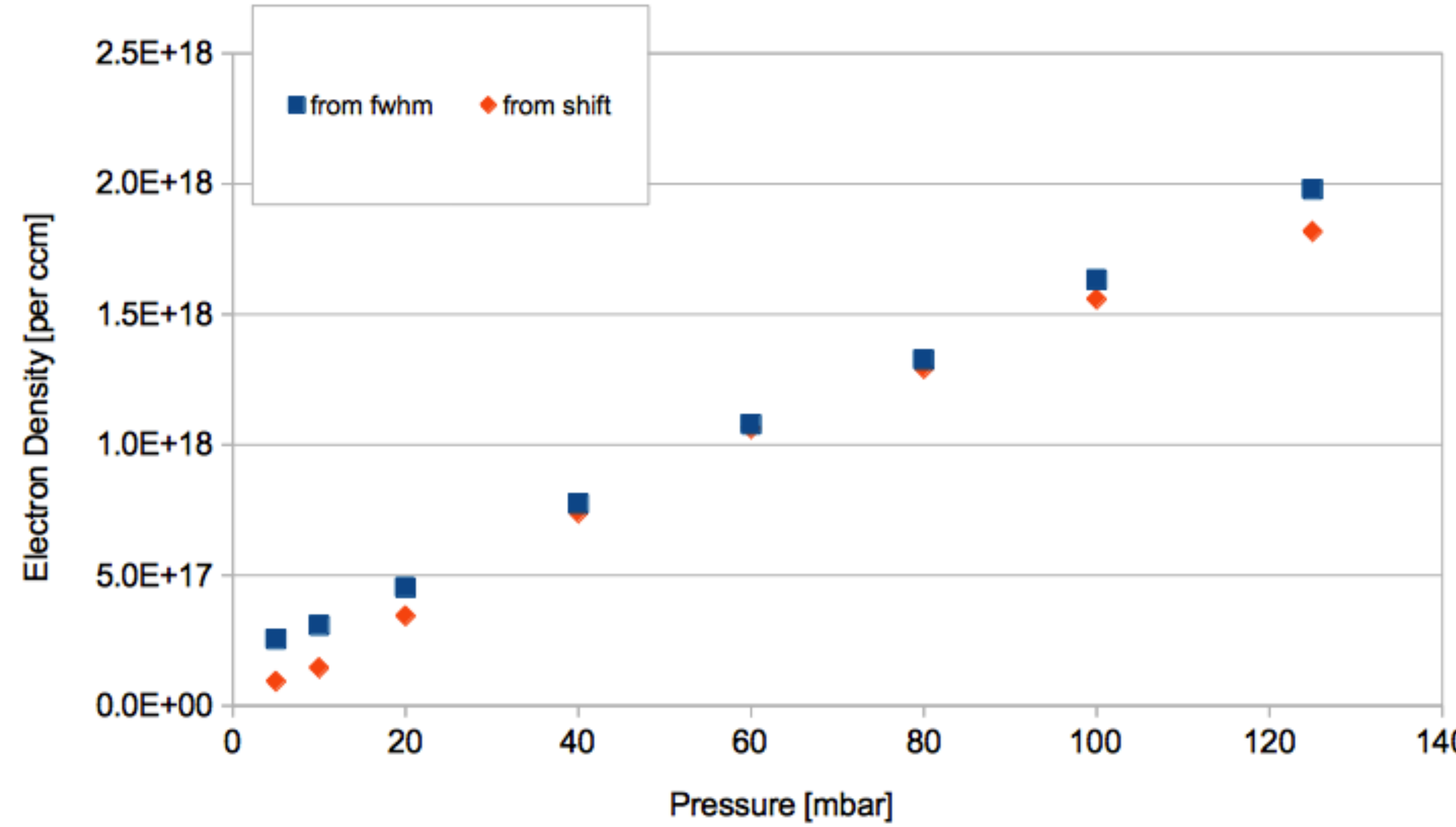


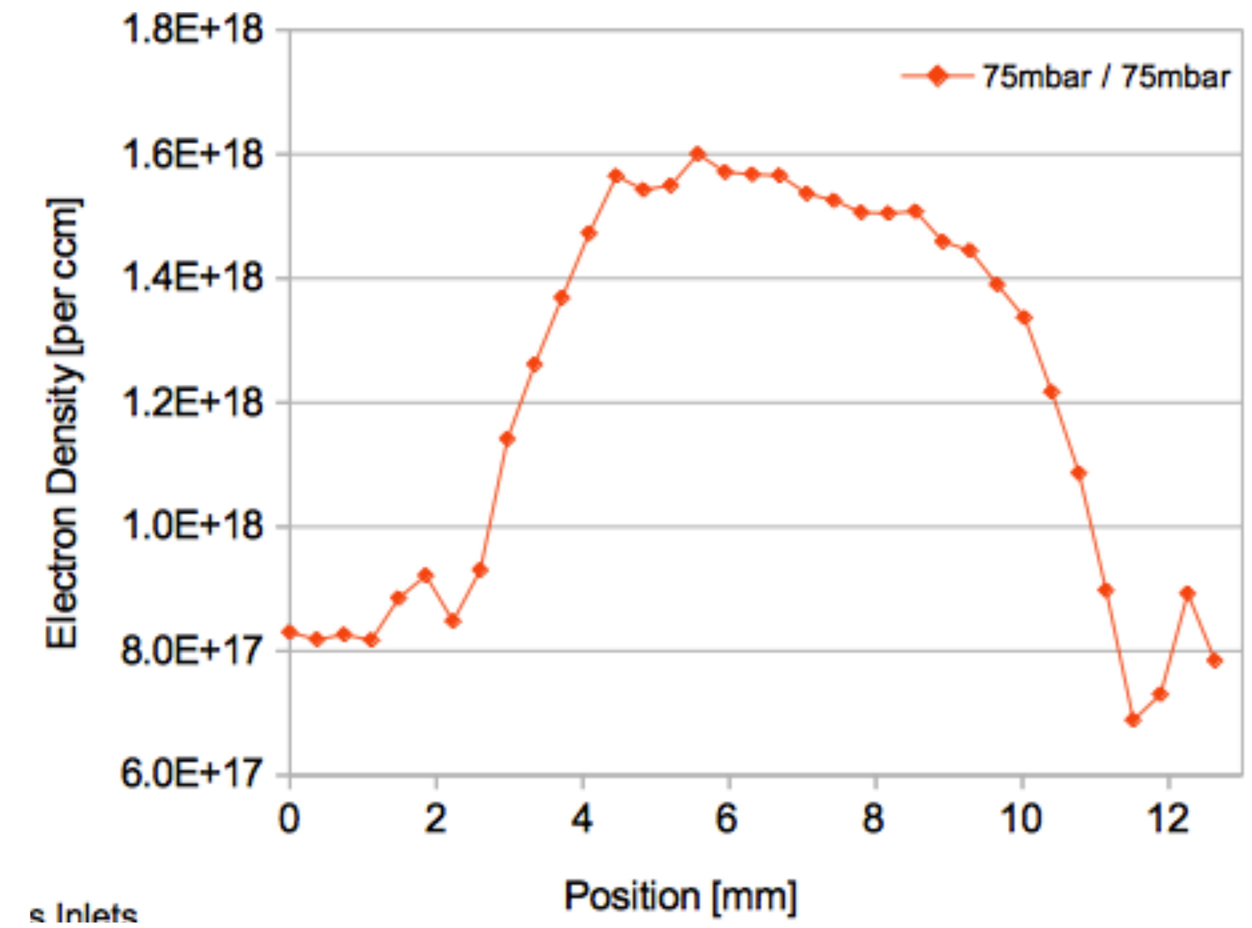


4. Density determination via Stark Broadening

- FWHM[1,2] and shift linked to electron density
  - $n_e = C(T,n_e)\ \Delta\lambda_{FWHM}^{3/2}$
- Instrument resolution (currently) $2.5\text{x}10^{15}\ \text{cm}^{-3}$
- 5fs temporal, down to few µm spatial resolution
- currently: $C(T,n_e)$ via cross calibration







[1] H. Griem et al., Phys. Rev. 116, 4-16 (1959)
[2] J. Ashkenazy et al., Phys. Rev. A 43, 5568-5574 (1990)

Summary

- 1. Plasma-target and gas-system design
  - First gas-target has been designed
  - Optimisation studies for applications currently running
- 2. Gas ionisation and dissociation
  - Understanding of ionisation process was advanced
  - Multi-species challenges are being studied
  - Simulations suggest feasibility of hydrogen and helium operation
- 3. Plasma density manipulation
  - Plasma density ramps shown in CFD simulations
  - Targets design checked to allow tailored release into vacuum designed
- 4. Diagnostics
  - Plasma spectroscopy offers insight into plasma parameters
  - First measurements promising for low density

Thank you...