FLASHForward▸▸ Plasma Targets and Diagnostics

Report from Working Group 3

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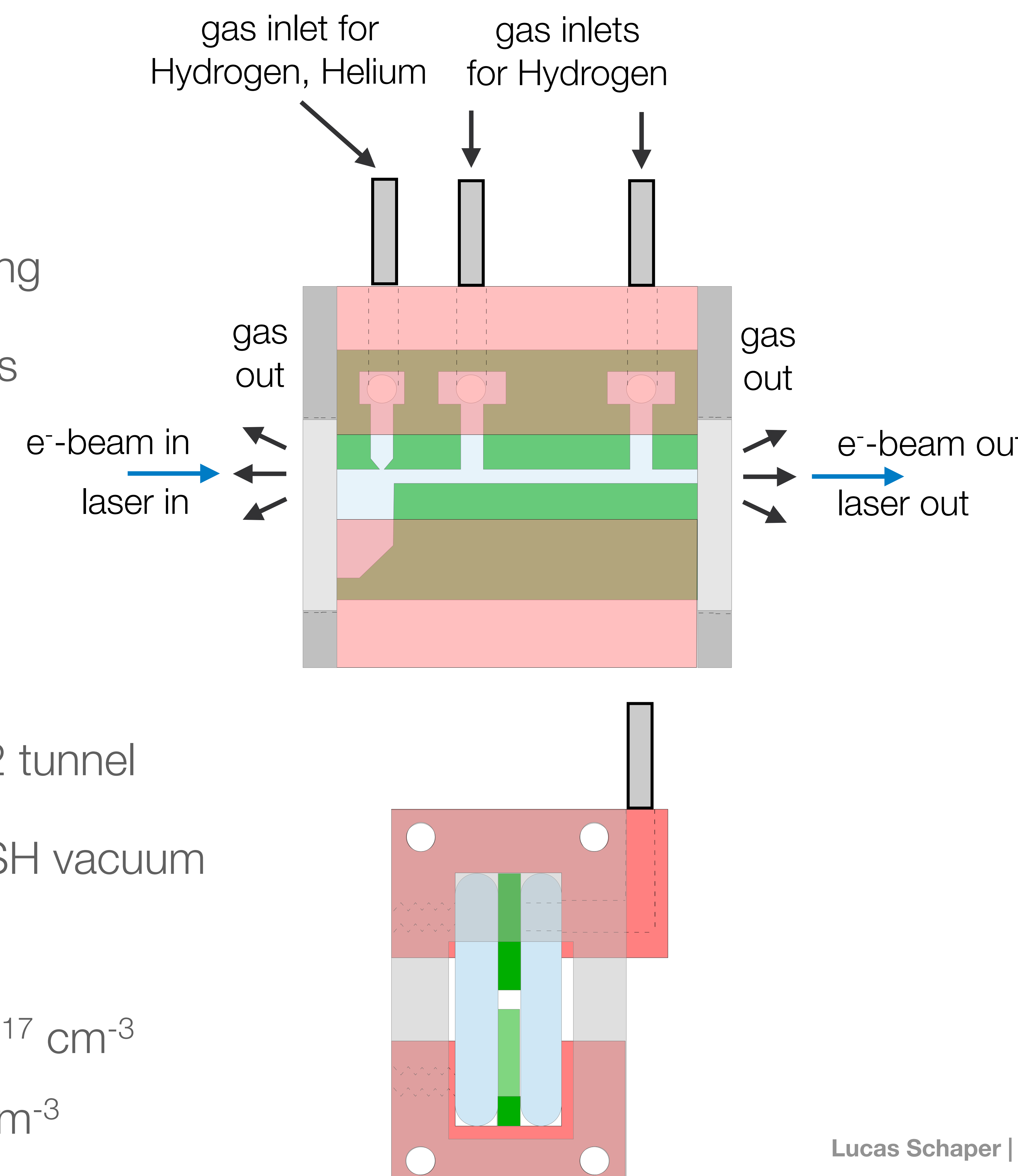
MATTER AND TECHNOLOGIES
ACCELERATOR RESEARCH AND DEVELOPMENT

Requirements and resulting target concept

Design requirements:

- no emittance spoilers
- full transverse (optical) probing
- Compatible with experiments
  - X1: Density-Downramp
  - X2: External injection
- easily replaceable (8h)
  - limited access to FLASH2 tunnel
  - no contamination of FLASH vacuum
- plasma density
  - acceleration: up to 5 x 10^{17} cm^{-3}
  - injection: up to 5 x 10^{18} cm^{-3}



Target concept:

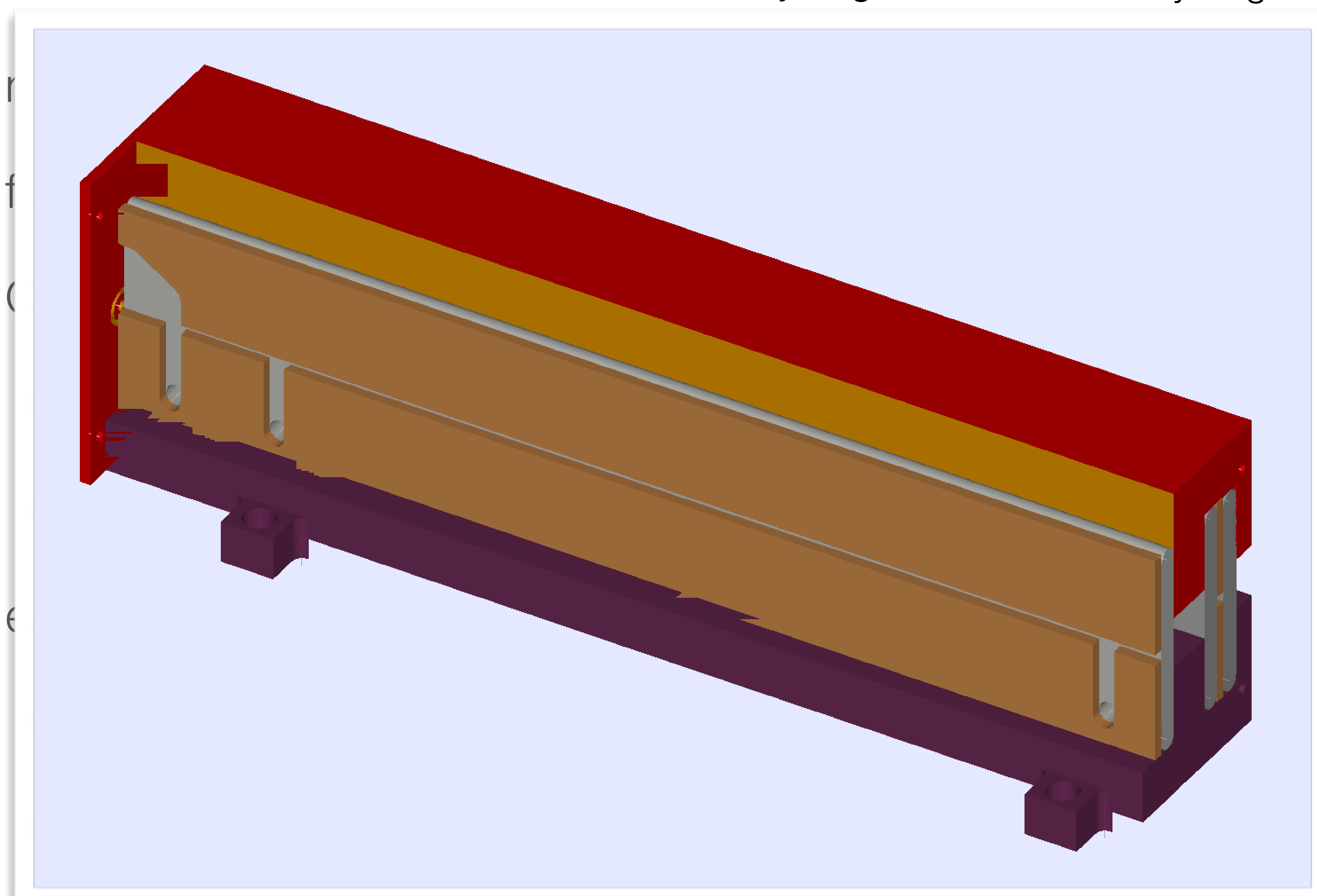
- Gas filling
  - multiple species operation
  - localised density peak and downramp possible
- Continuous gas flow design
  - no windows required
  - compatible with FLASH vacuum standards
  - no “soft” materials
- Optical probing
  - no obstructions, passive and active diagnostics possible

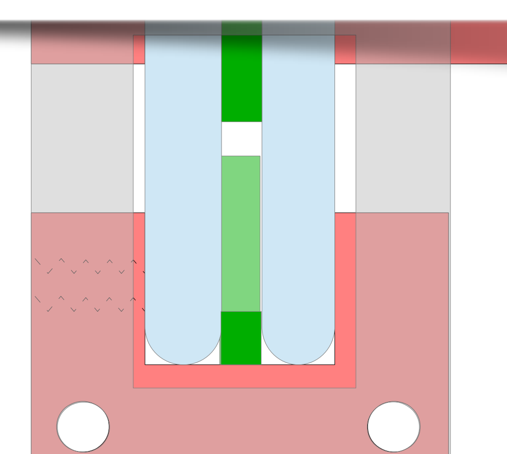
Requirements and resulting target concept

Design requirements:

gas inlet for Hydrogen, Helium

gas inlets for Hydrogen





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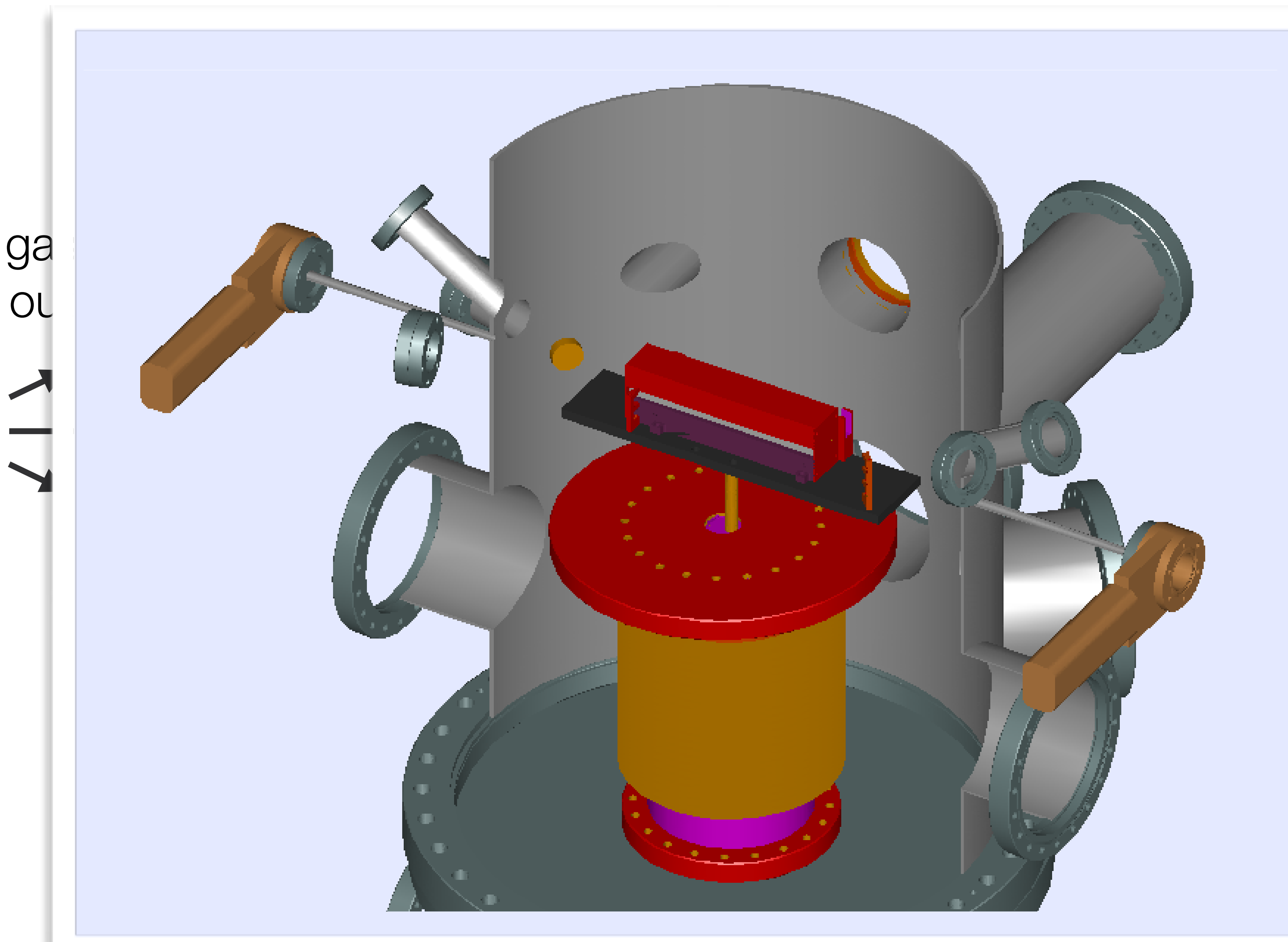
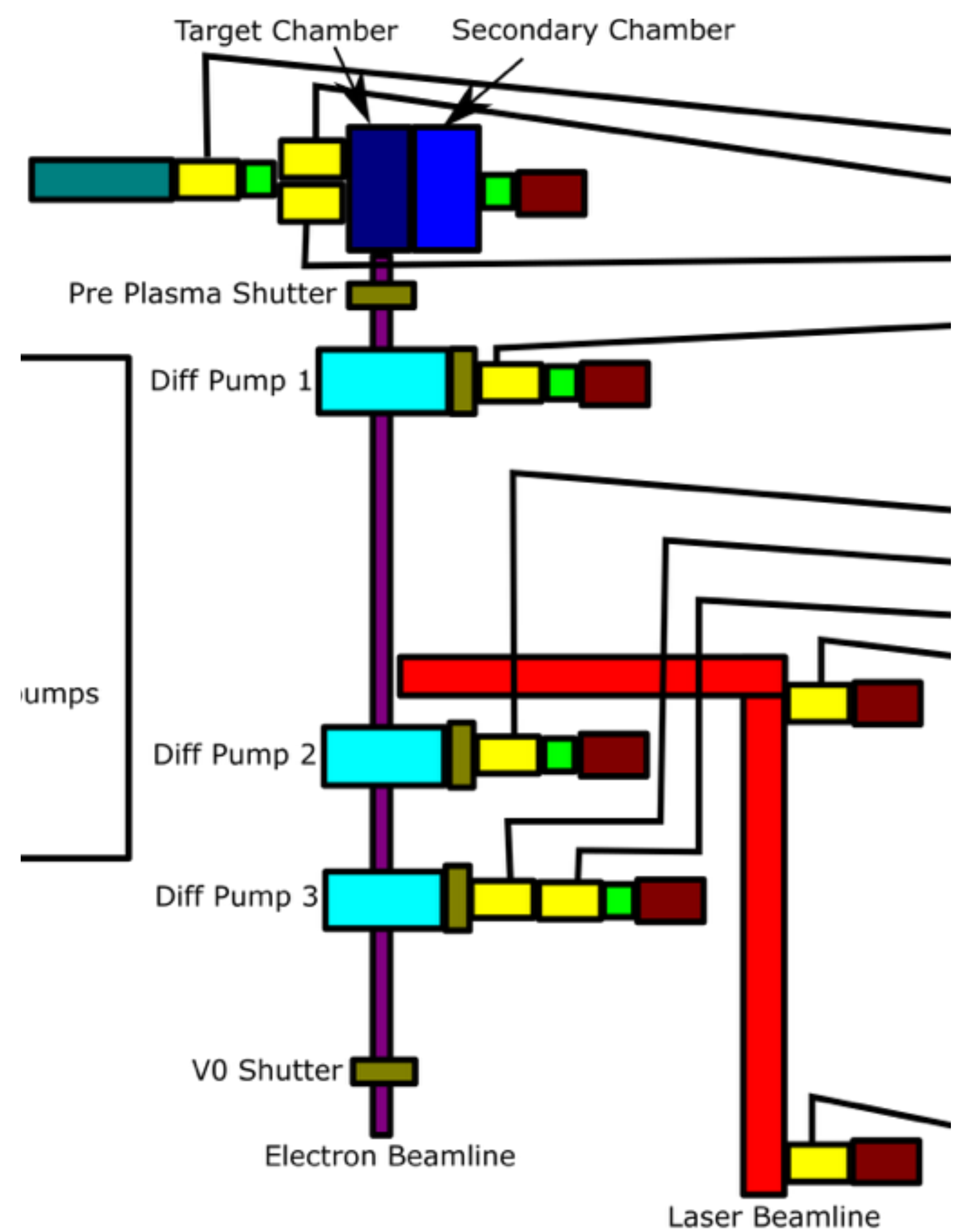


- Optical probing
  - no obstructions, passive and active diagnostics possible

Gas removal

- Maximum continuous gas flow of **20 mbar l/s** hydrogen into main chamber
- at beamline intersection (V0) to FLASH2 pressure has to be < **10^{-8} mbar**
- additionally to main chamber 3 differential pumping sections in beam-line
- beam pipe diameter adjusted for efficient pumping



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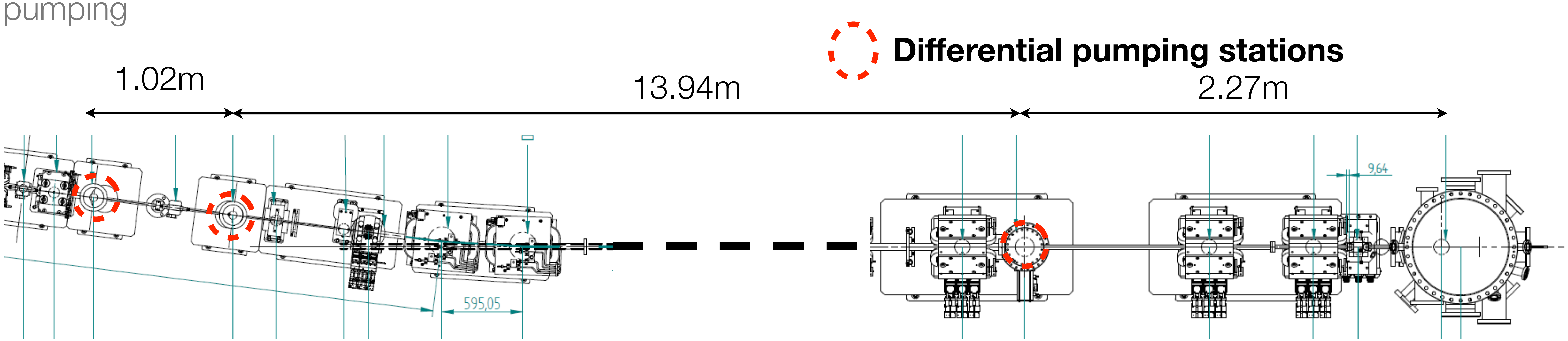
- Due to delivery problems of original vendor change of vendor just before shutdown.
  - Vacuum pumps connected to the beam line and operational.
  - required safety system is being installed.
- For experiments not requiring high emittance beams additional foils can be inserted, relaxing pumping requirements



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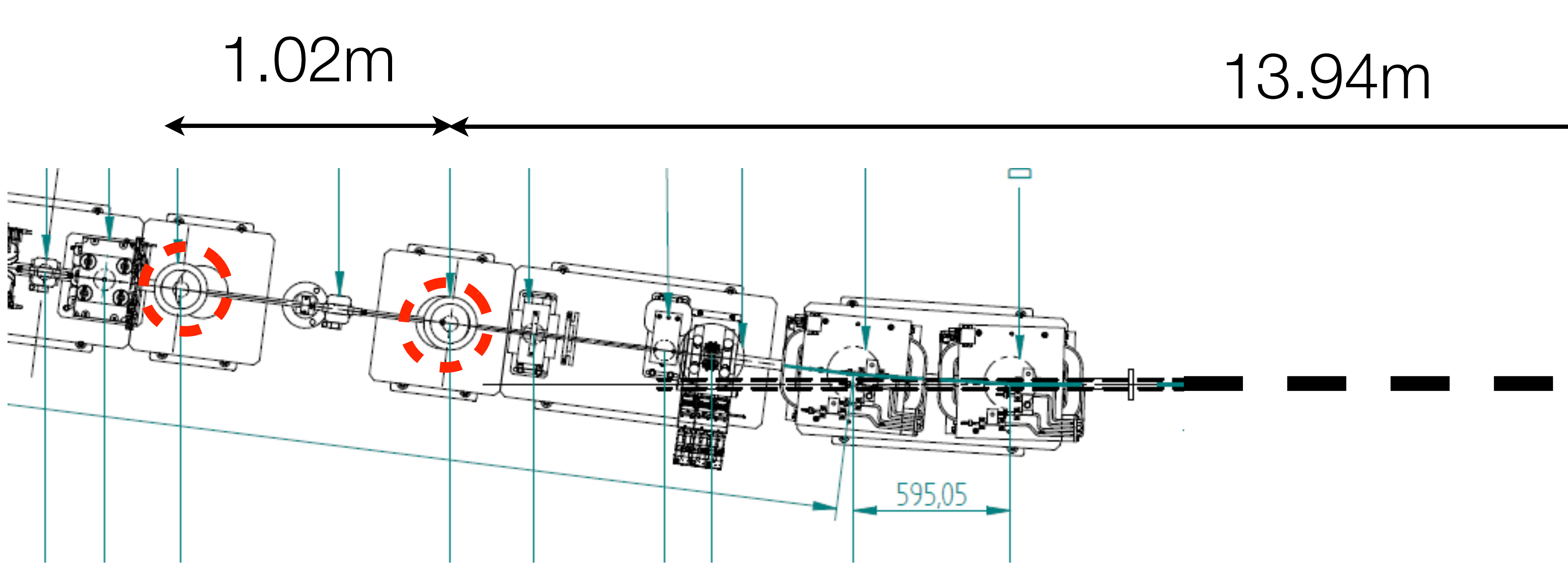

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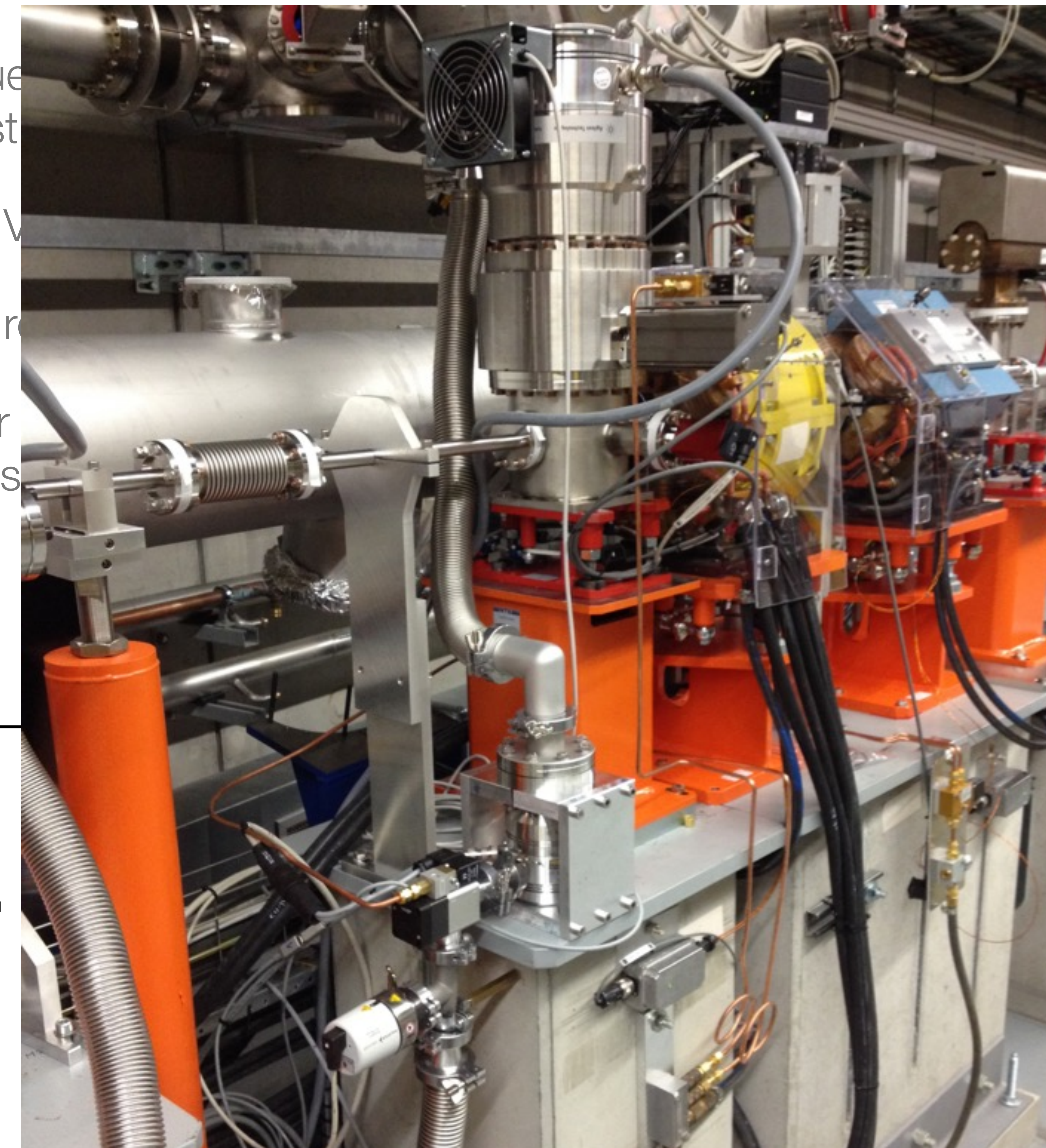
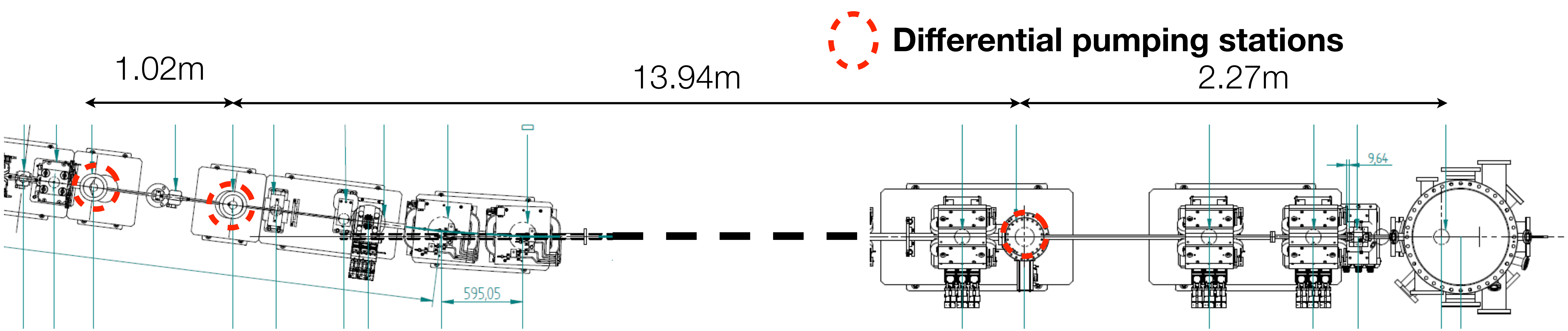


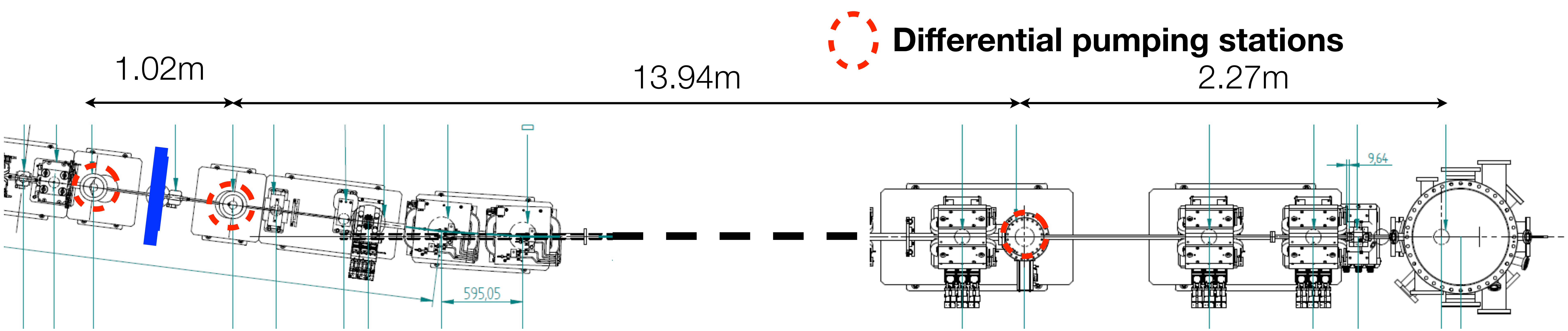
Further gas removal

- Ion getter pumps are installed and working upstream of V0 (FLASH vacuum)
- Pump type adjusted such that we can operate noble gases, total flow limit still 20 mbar l/s



Thin window option

- thin foil, originally intended to assist in mitigating hosing can also serve as vacuum window
- several foil options being investigated, for now: Kapton foil of few micron thickness
- optional: double sided metal coating to decrease gas permeation
- Similar solutions have already been tested at PITZ and proved successful [1]



1) O. Lishilin et al. – 2016 - First results of the plasma wakefield acceleration experiment at PITZ

Ionisationlaser in-coupling

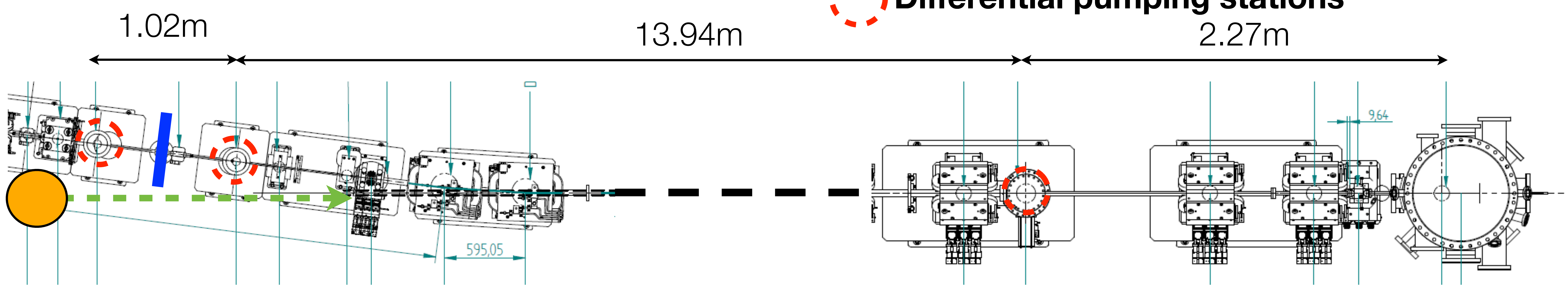
- FLASH beam does not ionize by itself
- laser inserted at final bending magnet
- laser vacuum separated from beam line vacuum
- switched to all reflective focussing optics and thin window to allow for small B-inetgral
- focal length ~ 18m

- Aim: generate homogenous plasma with
  25cm length
  500µm diameter
- Similar setup with transmissive optics installed in the preparation lab

Focussing optics chamber

Beampath of ionisation laser

Differential pumping stations



Ionisationlaser in-coupling

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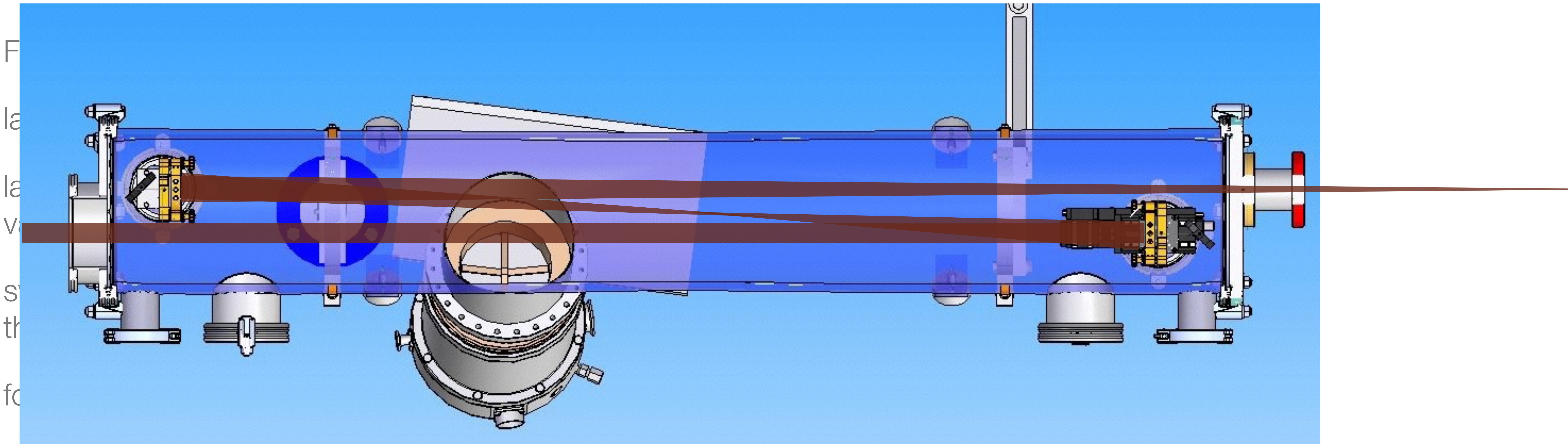

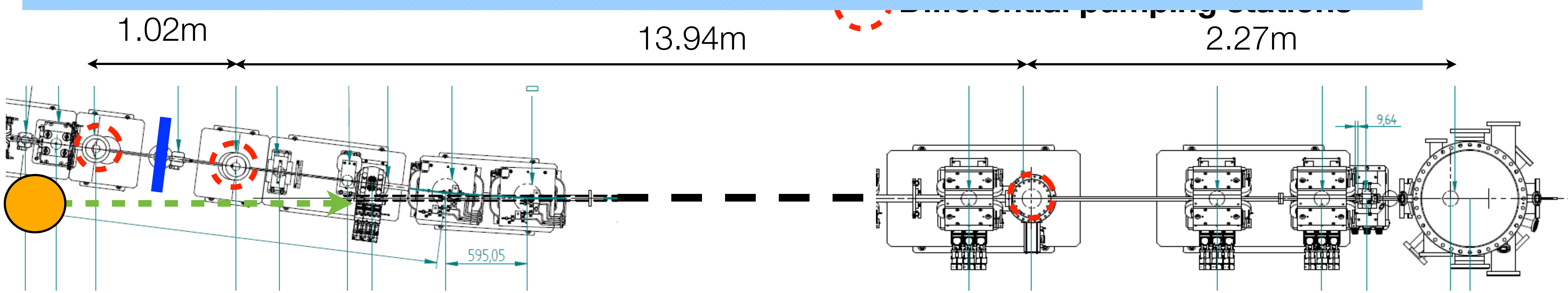

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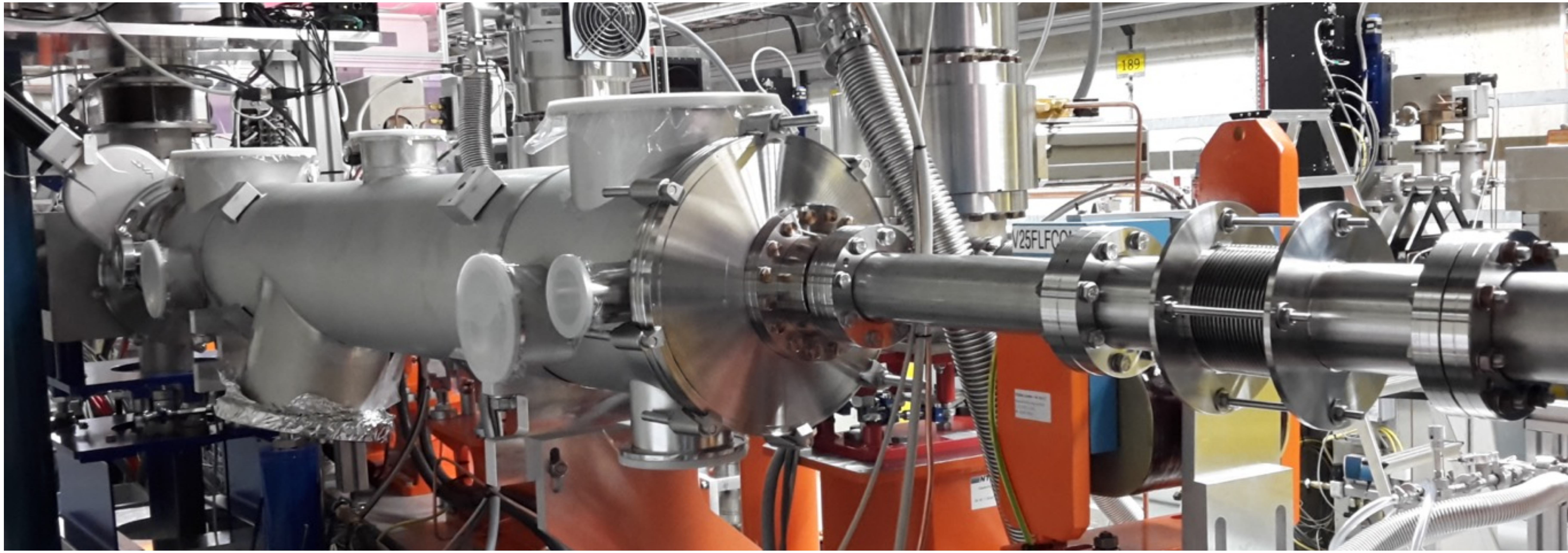
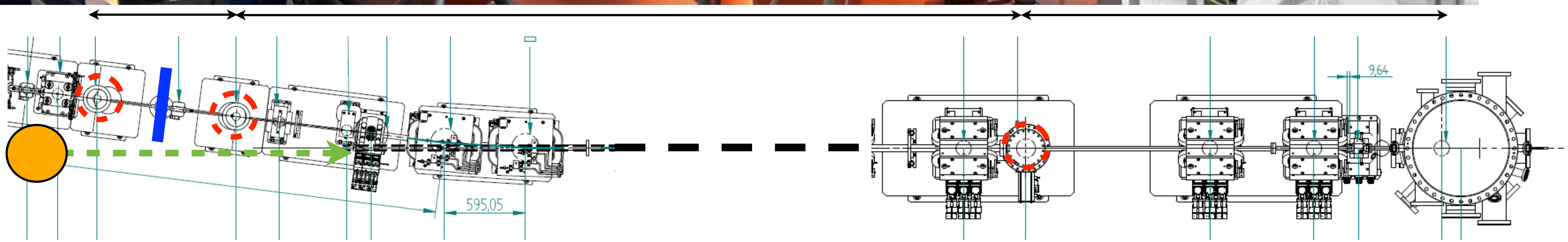




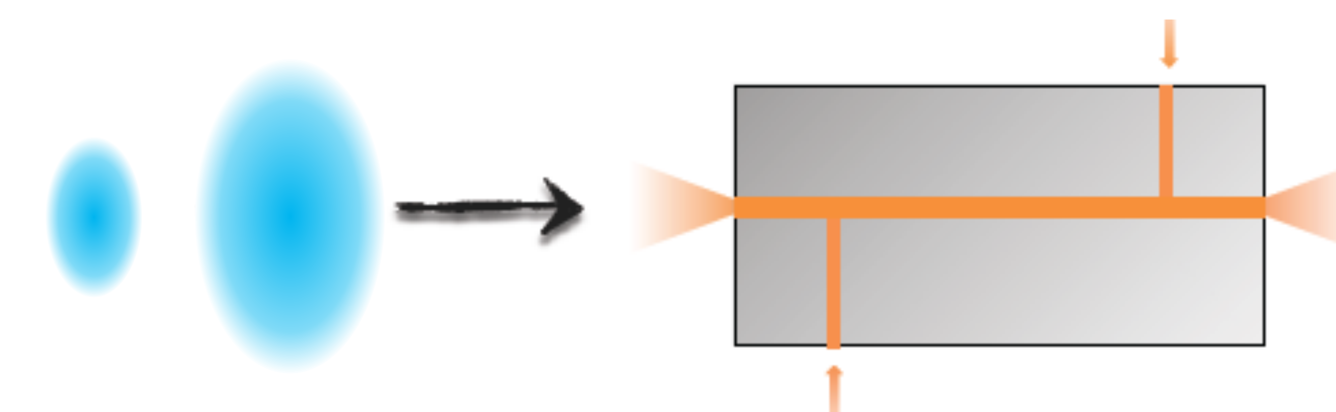
> Laser to electron beam vacuum window arrived quite late, thus also discharge based plasma possible now

Controlled witness-bunches

> Quality of accelerated beam strongly linked to control over initial population of wake-phase space at injection

> *X-2 experiment: plasma booster* (witness generation by scraper)

→ Experiments: staging studies, bunch emittance evolution

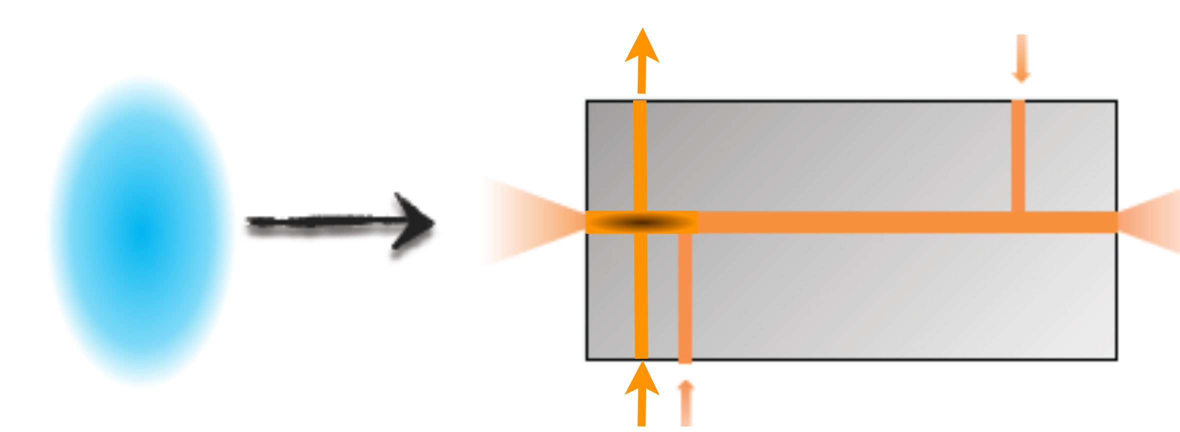


> *X-1 experiment: plasma cathode* (density-downramp injection)

→ J. Grebenyuk *et al.*, NIM A **740**, 246 (2014)

→ injection on negative density gradient

→ demonstrated only in LWFA, new concept to PWFA



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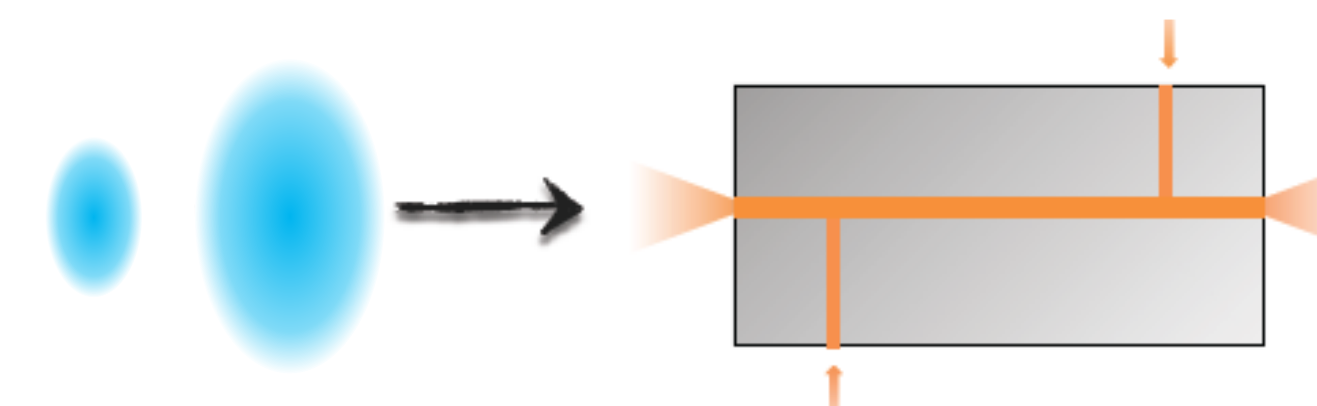

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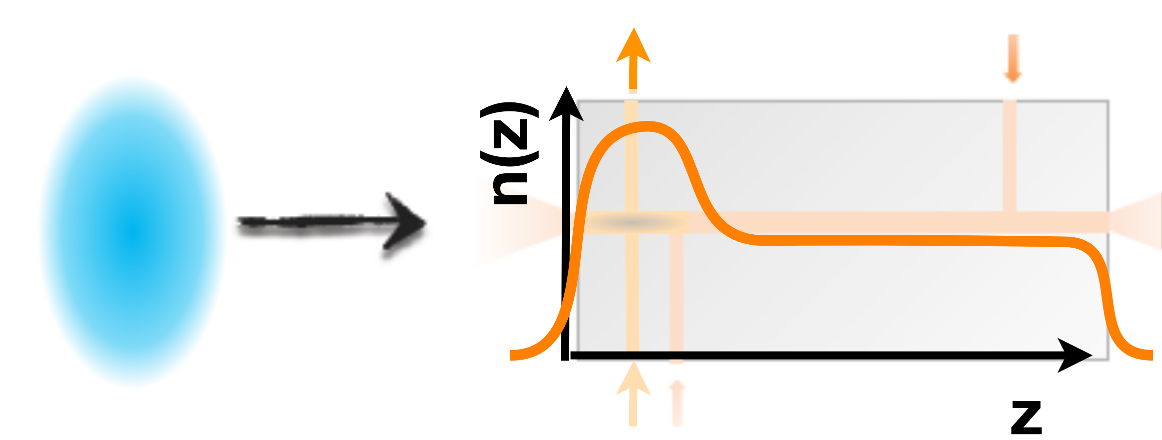
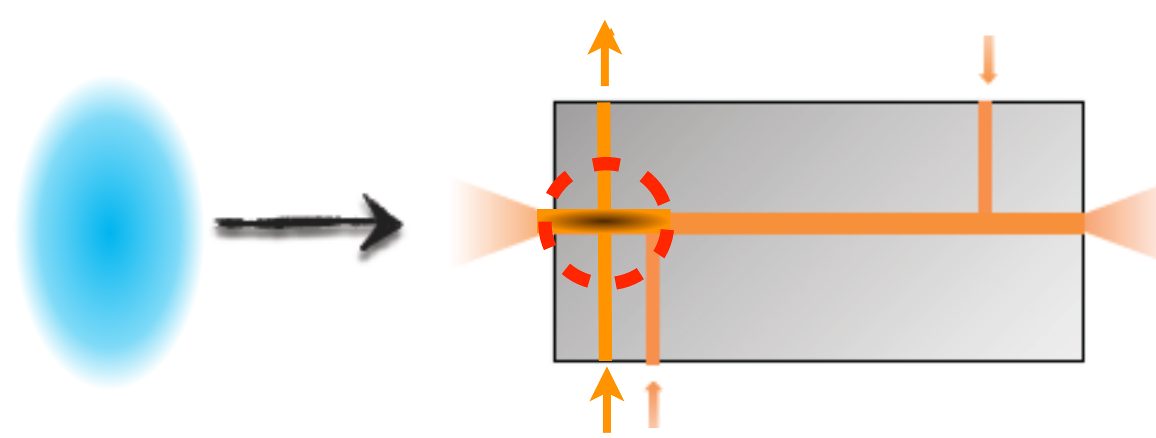
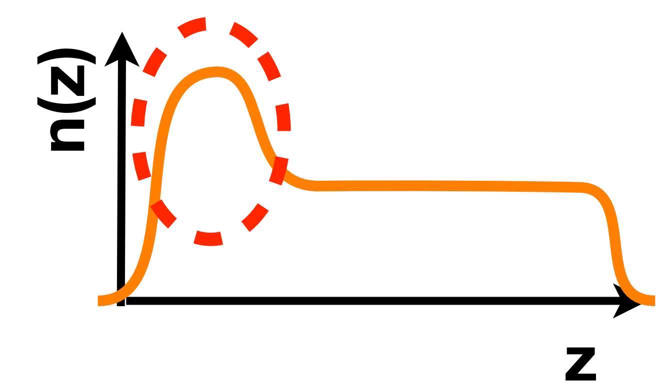


Density-downramp options

Fluid dynamic downramp concepts:

- single gas species, all ionized via pre-ionisation laser
- gas velocity based, require higher pressure applied to a dedicated gas distribution port
- concept: expansion to increase from nozzle (jet like)





- downramp length determined by hydrodynamic properties
- here: DC operation required since no fast gas valves allowed (vacuum requirements)
- result: high gas flux required, demanding for vacuum pumps!
- Flow can be reduced by modifying density transition. e.g. razorblade, …

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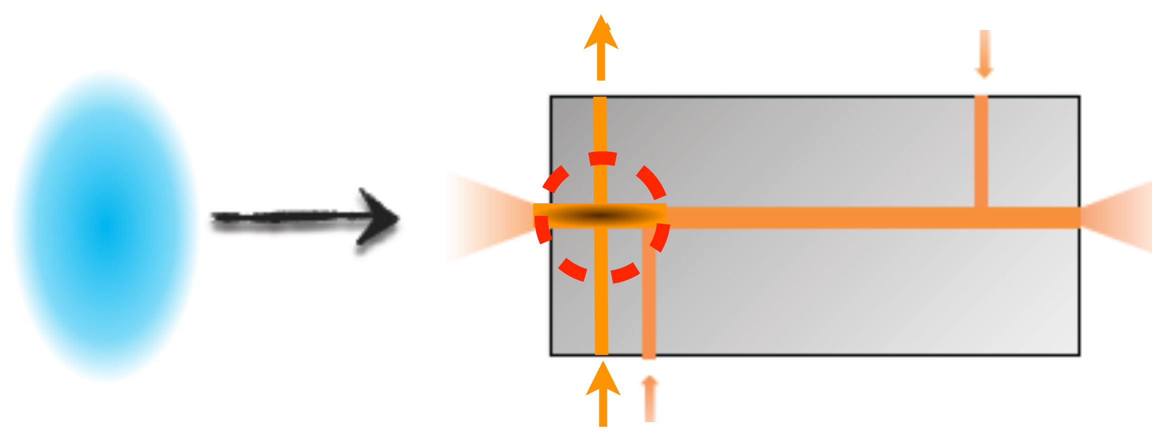
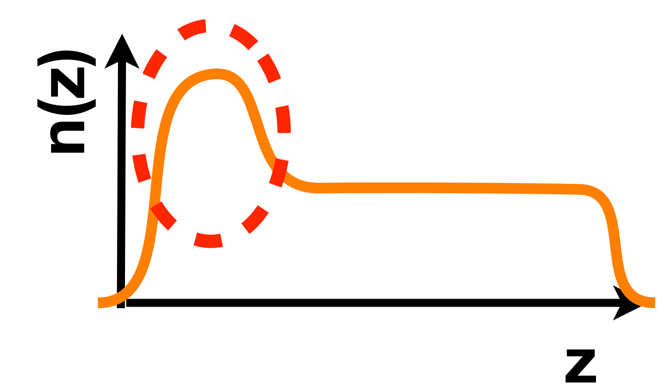
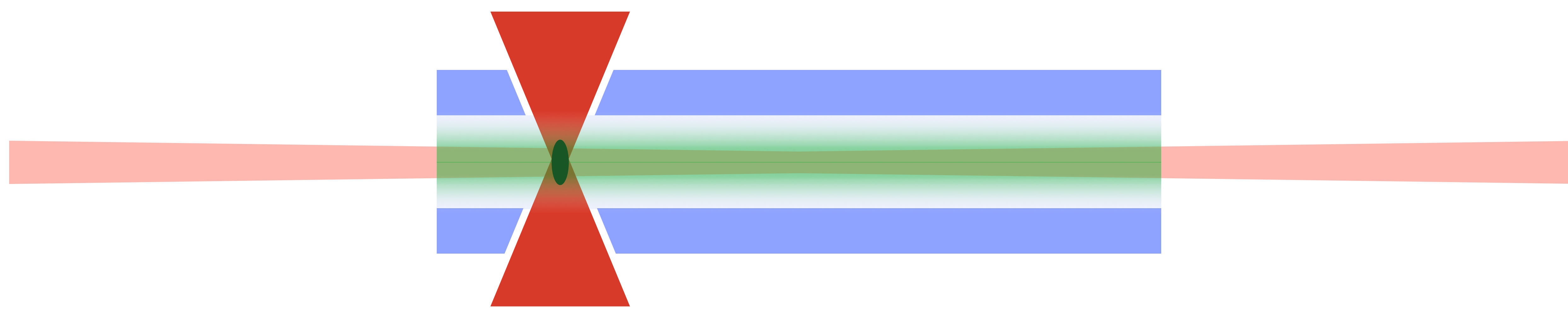




Ionisation based downramp concepts:

- multi-species gas density distribution, either with pre-mix or localized addition
- pre-ionization laser only ionizes single species, second species ionized by transverse laser pulse
- strongly localized ionisation, ionisation volume and density gradient determined by laser-properties

X-1 Experiment: plasma cathode



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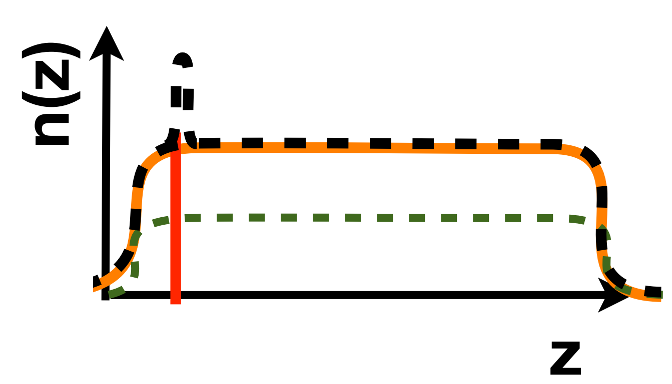

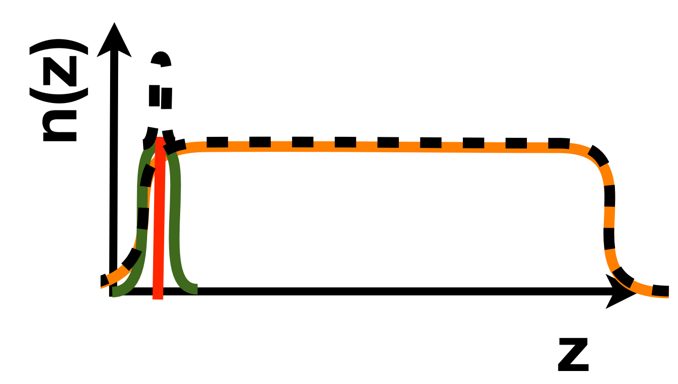

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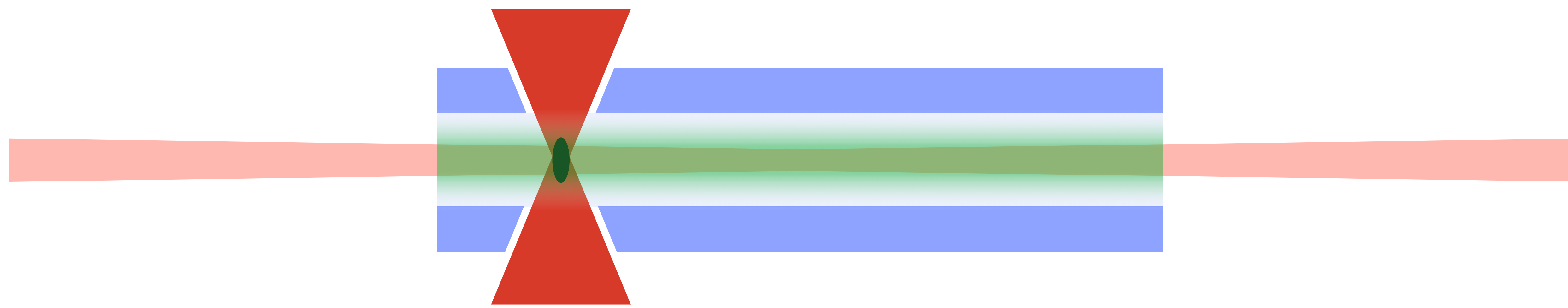
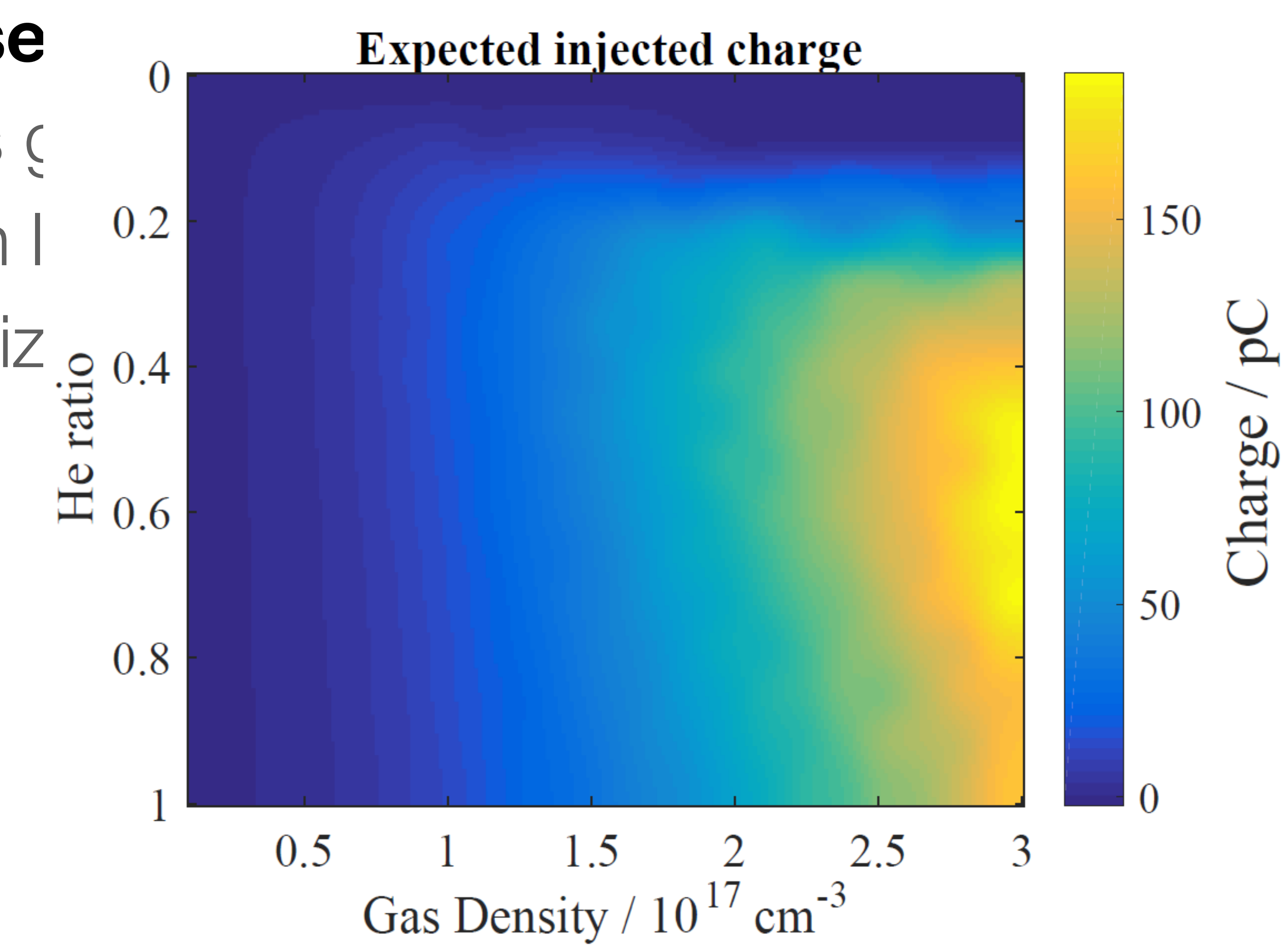
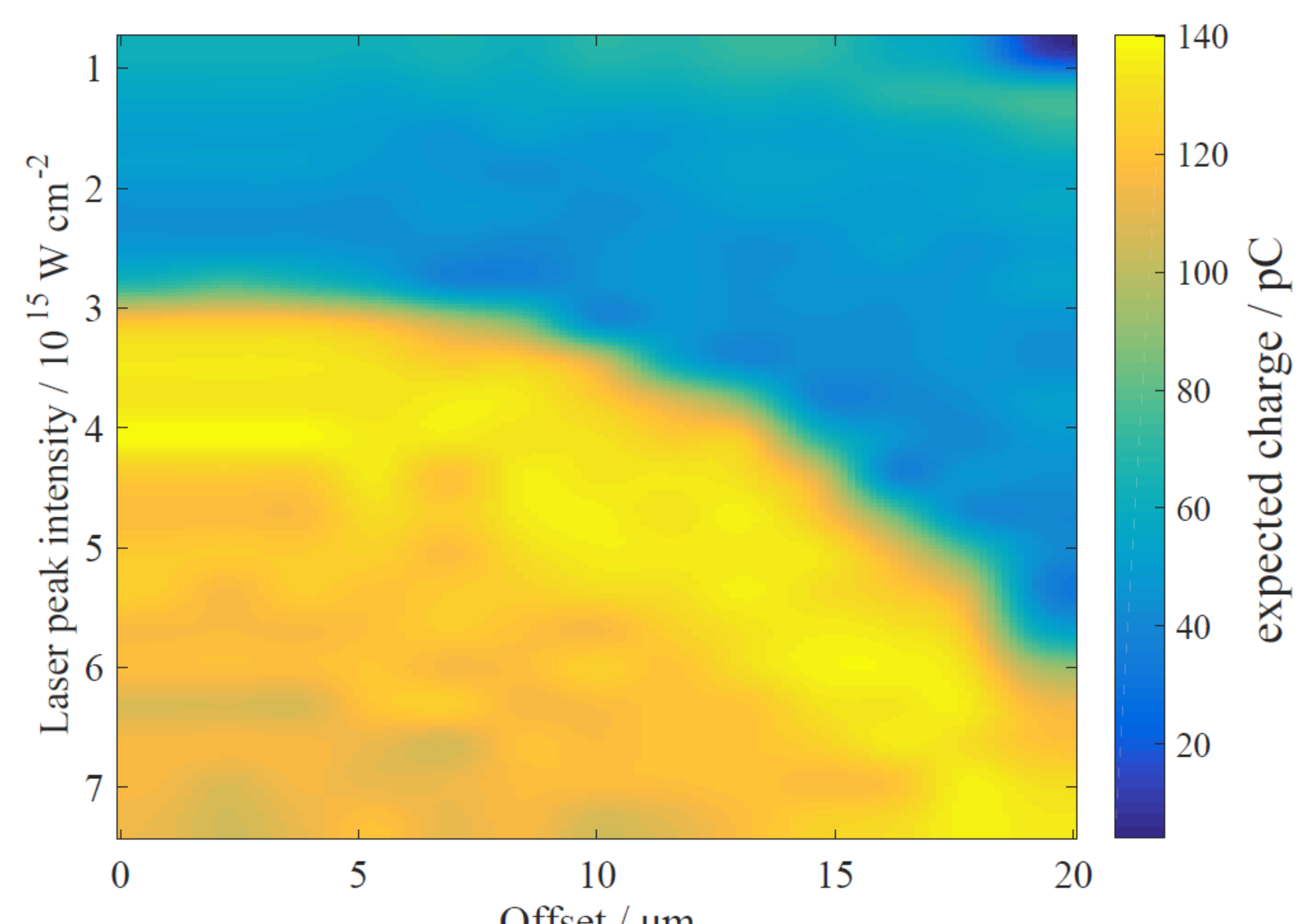


Ionisation base

- multi-species g
- pre-ionization l
- strongly localiz





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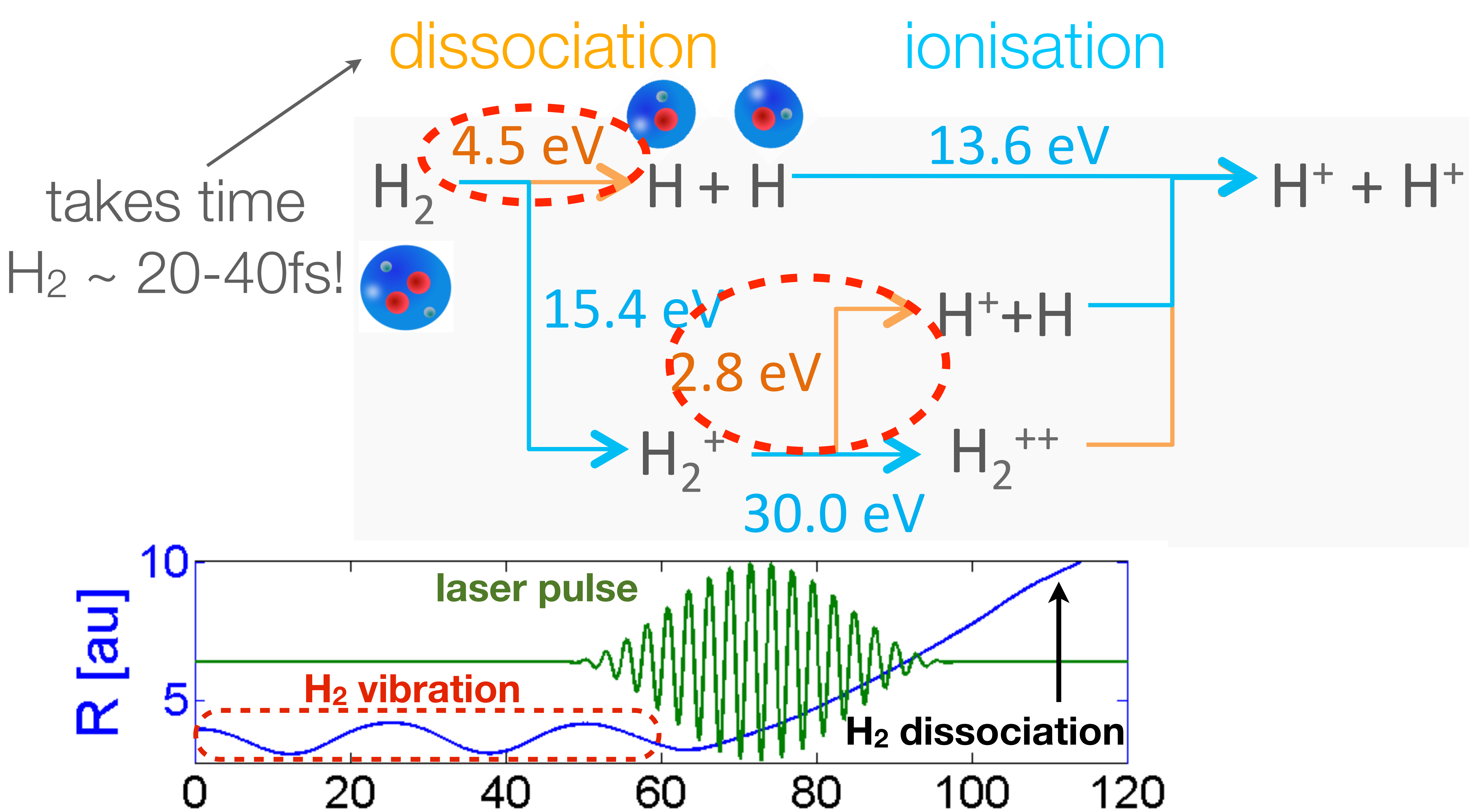
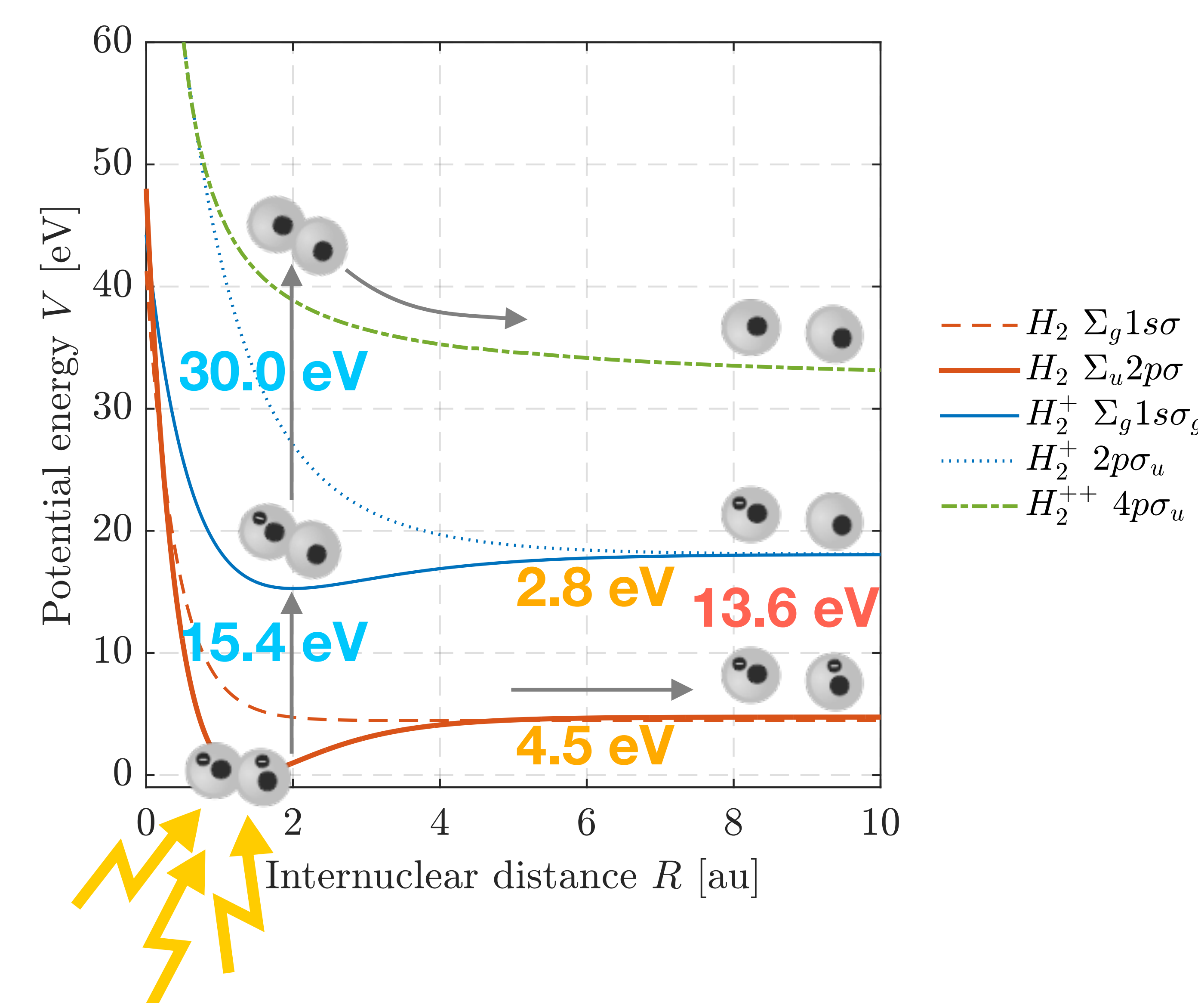
Ionisation: Atomic vs. molecular treatment

- So far atomic ionization potential used

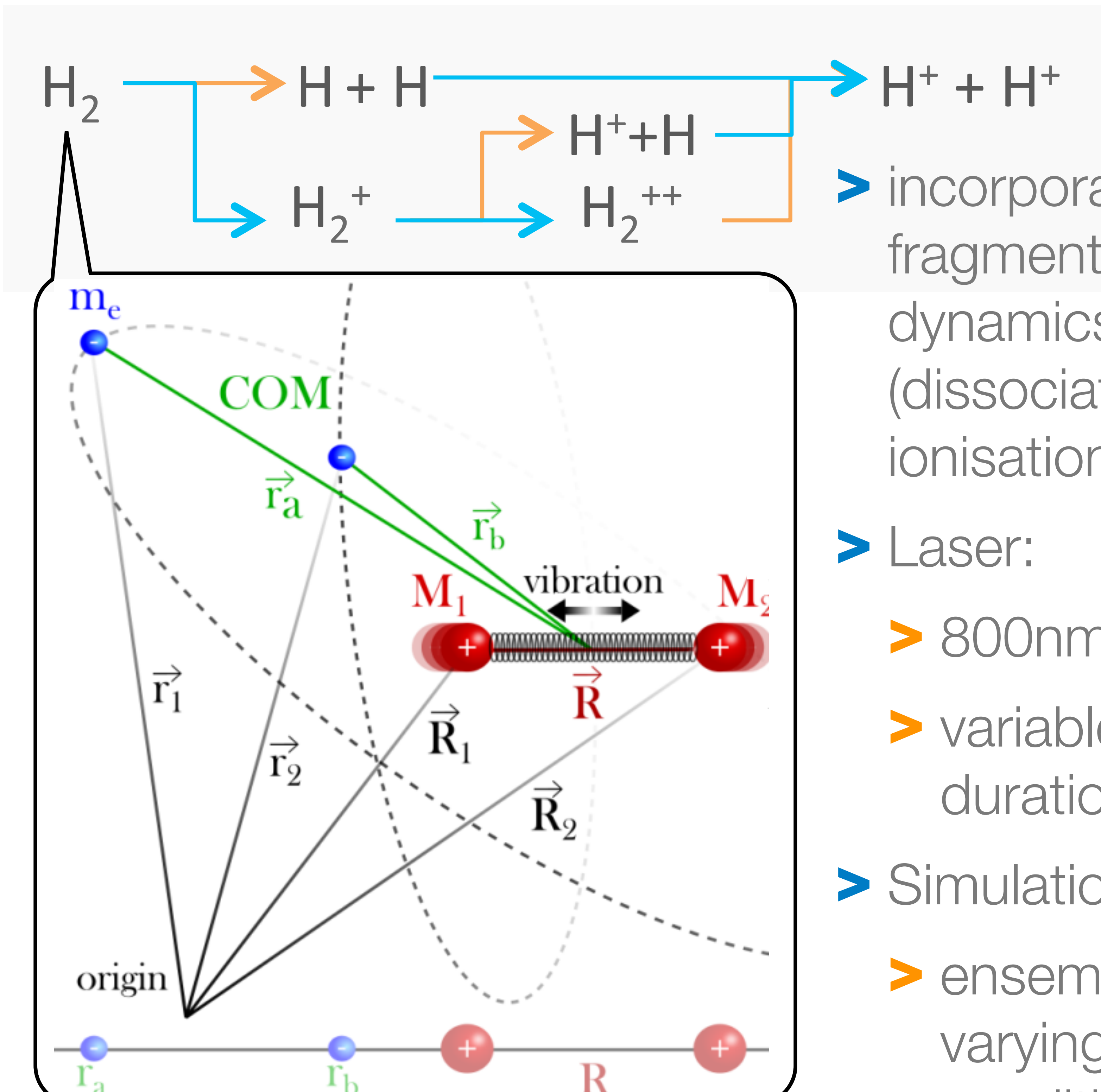
$$H \xrightarrow{13.6\ eV} H^+ + e^-$$

- molecular fragmentation dynamics are more complex



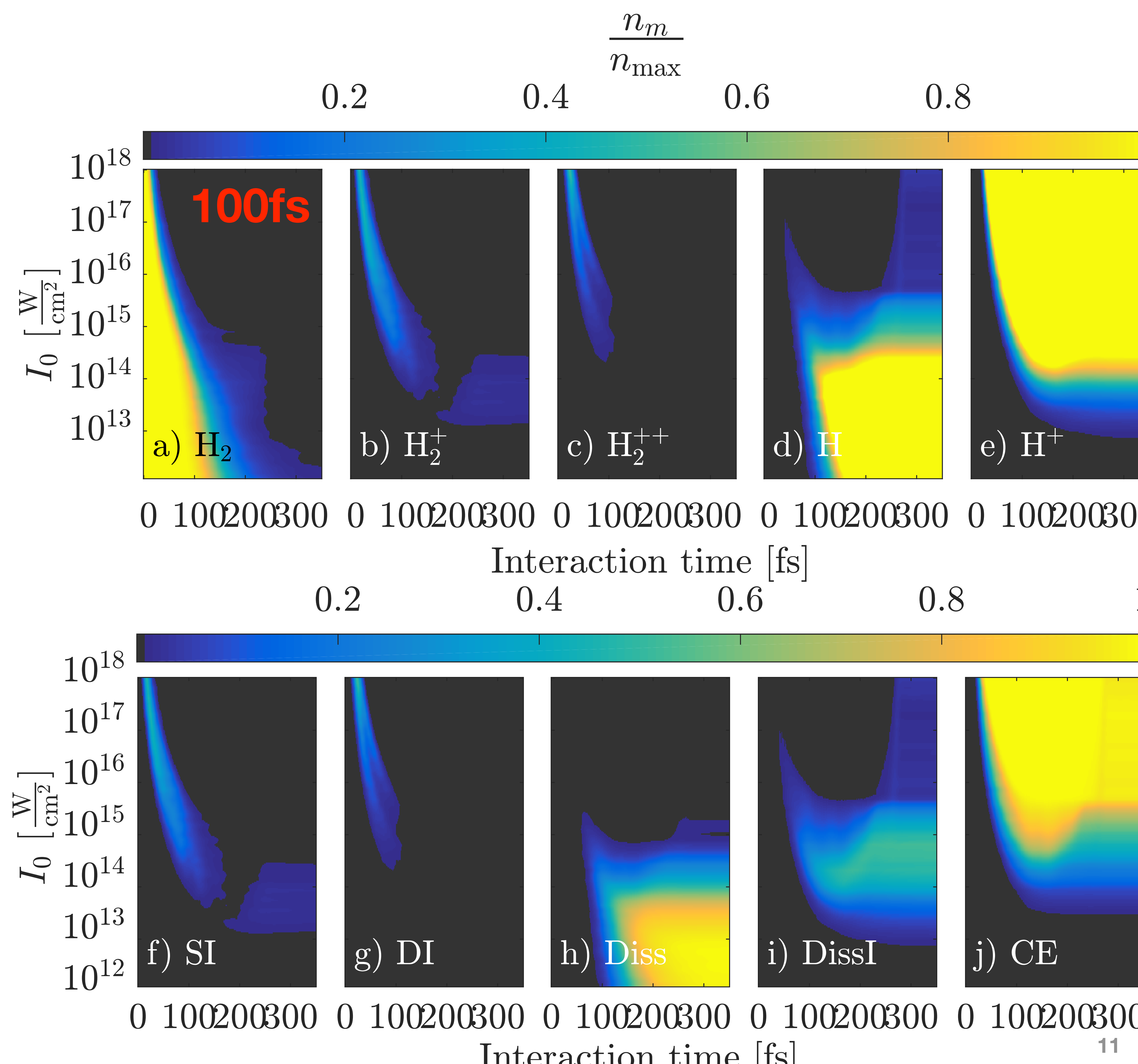


Fragmentation - Classical 1D model



[1] Qu et al., Phys. Rev. A vol. 57 no. 6 (1998)

- incorporating full fragmentation dynamics (dissociation & ionisation)
- Laser:
  - 800nm
  - variable pulse duration
- Simulation:
  - ensemble with varying initial conditions



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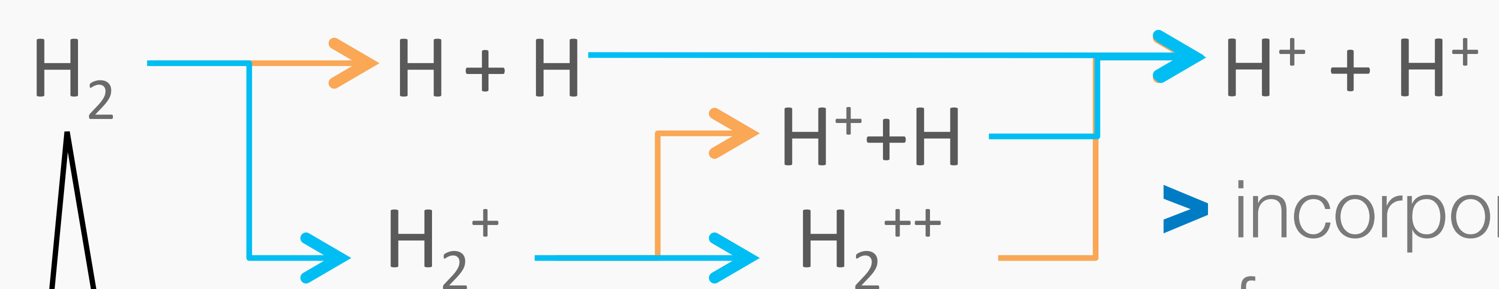

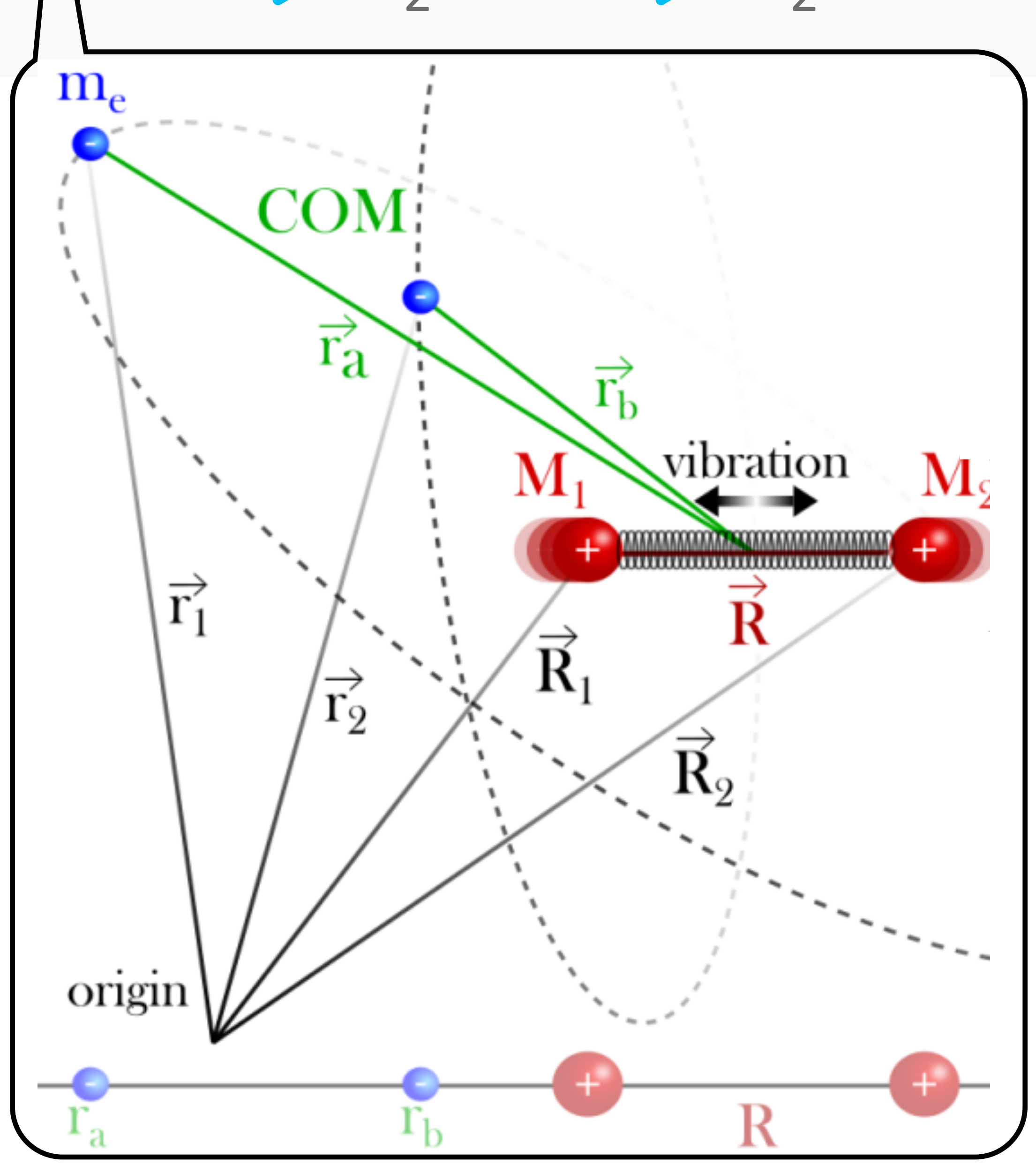

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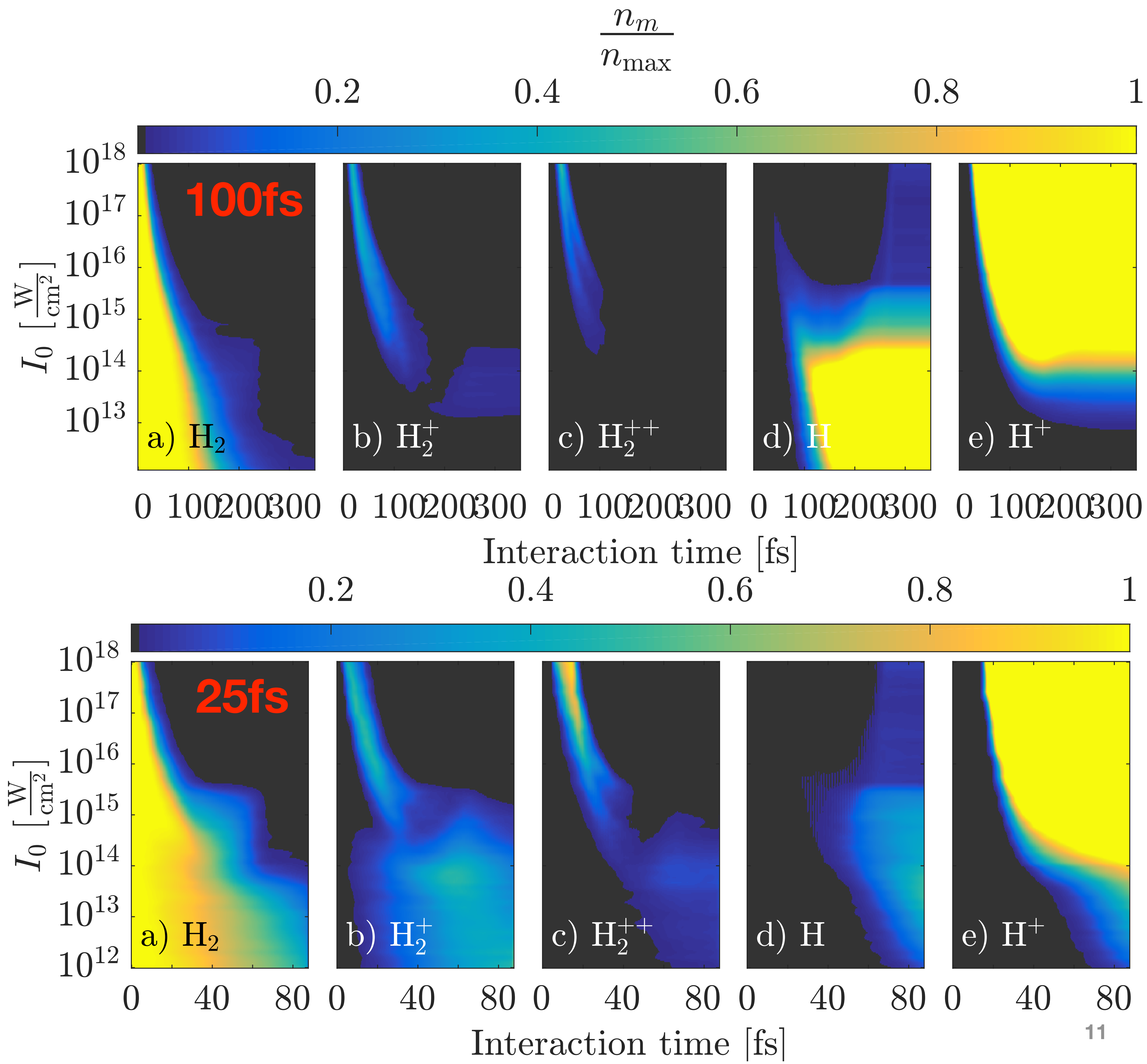

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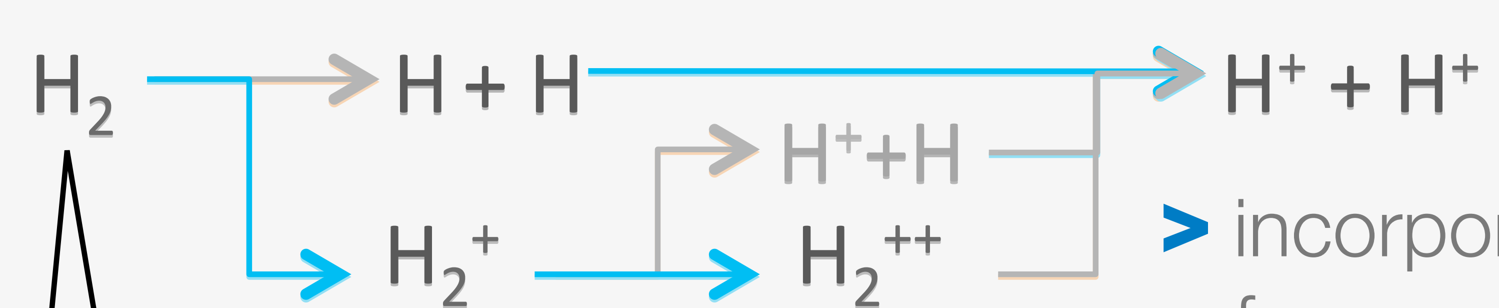

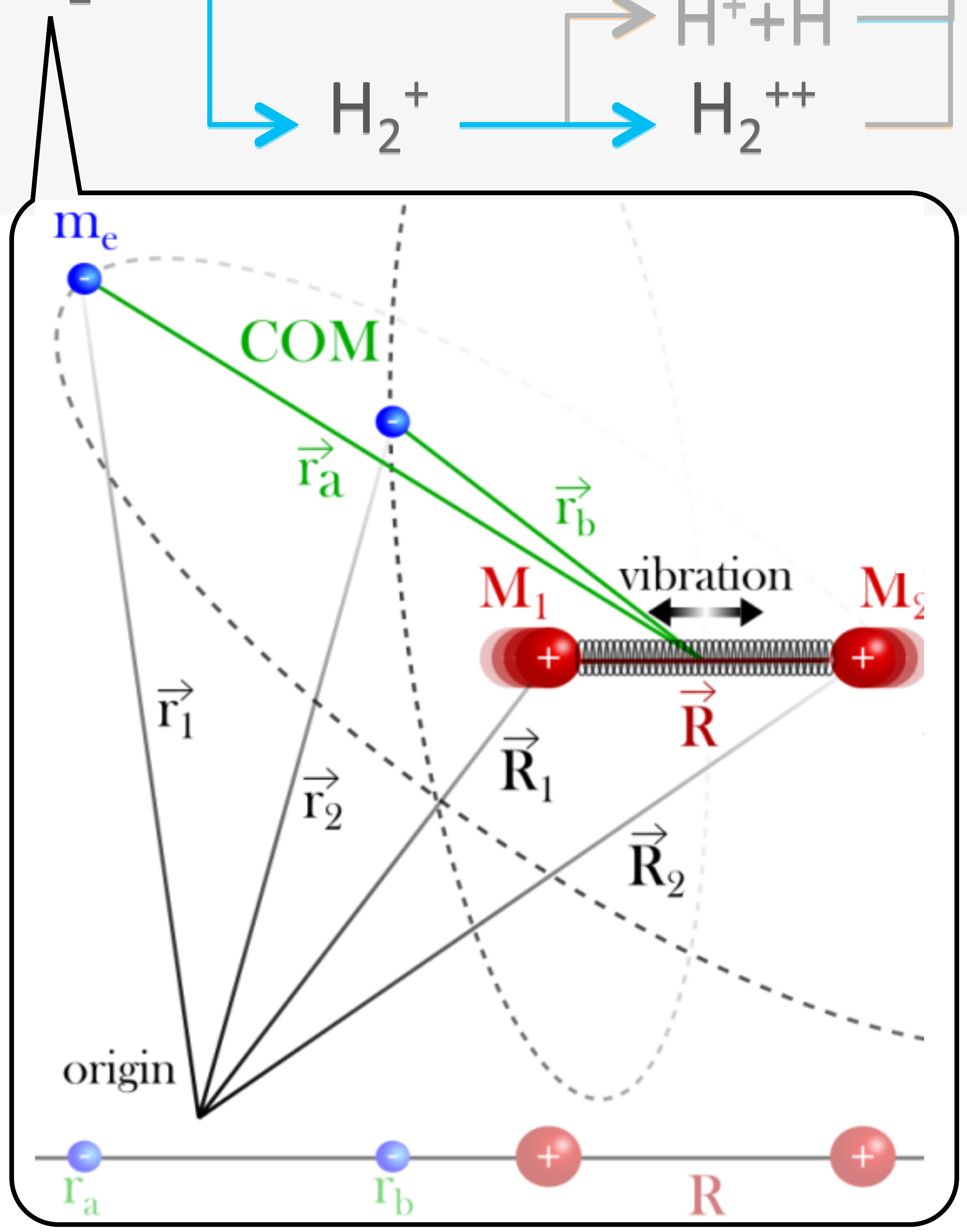

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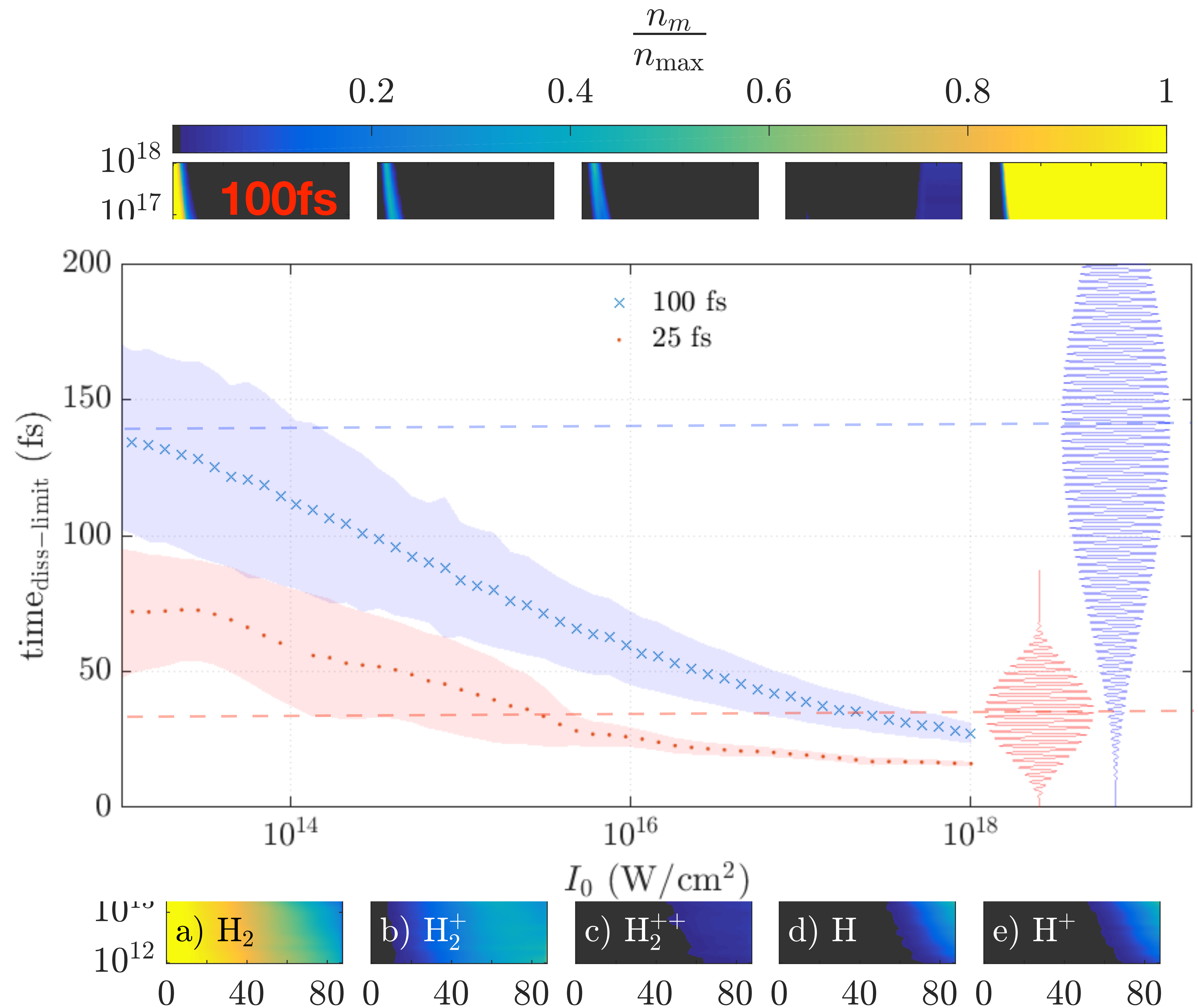
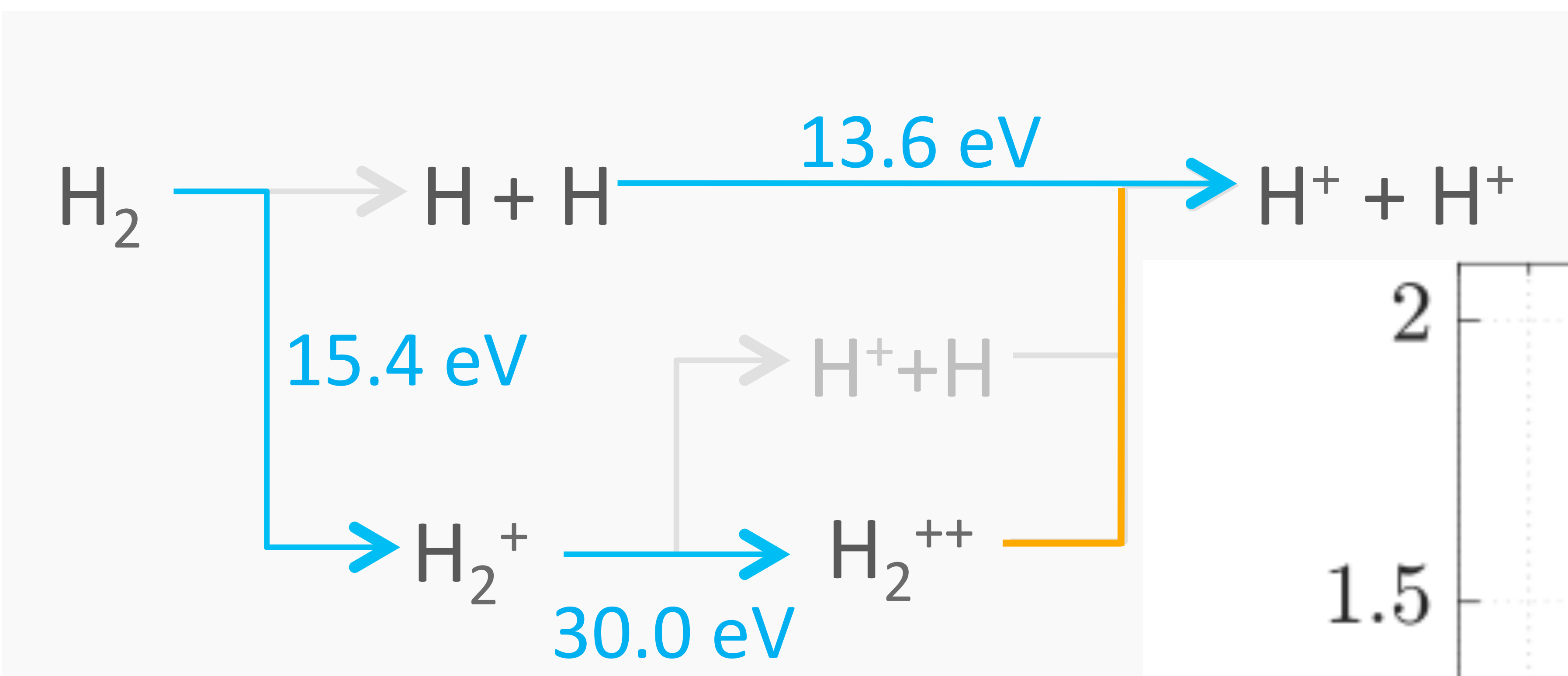
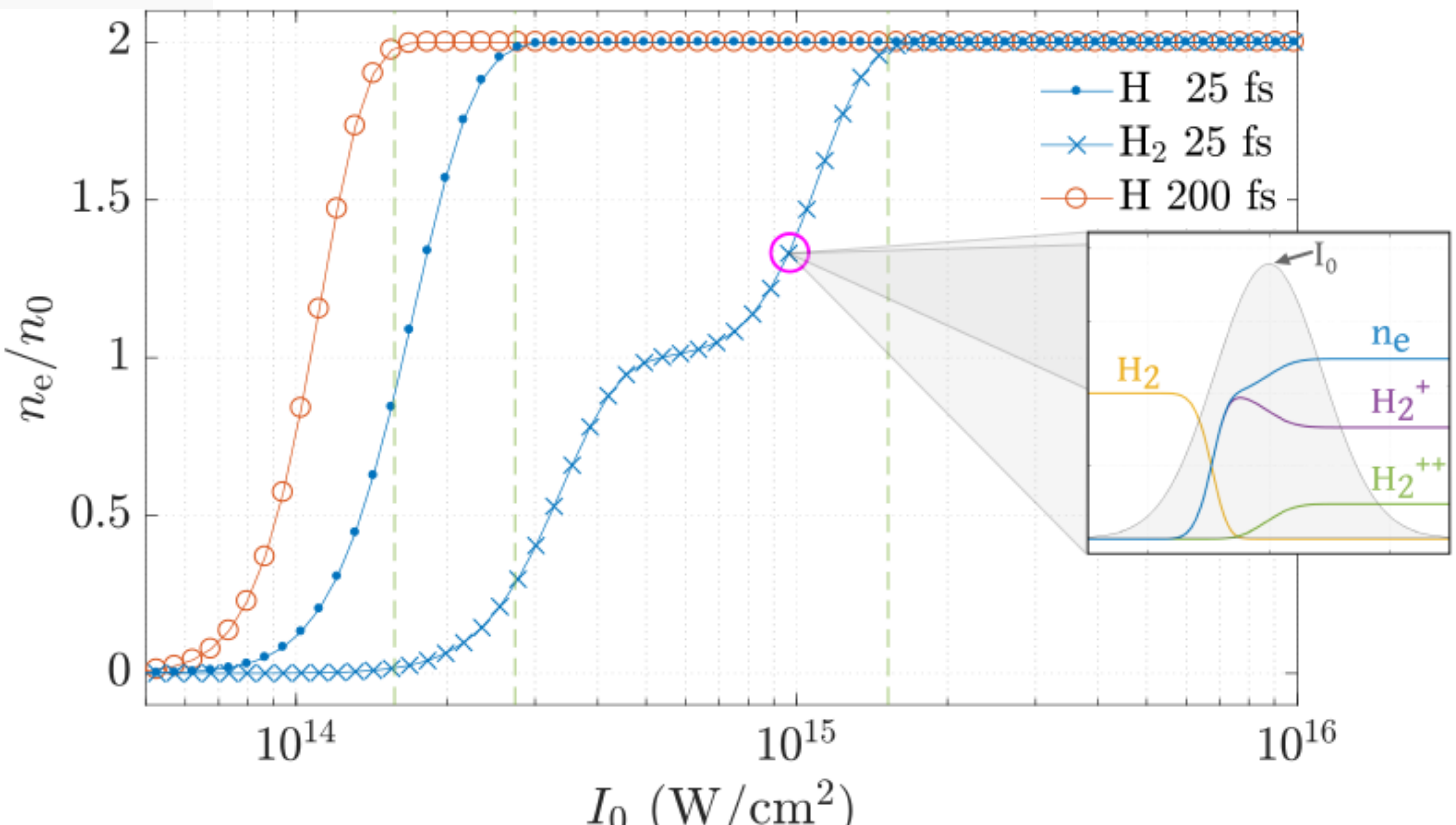


- Short pulses: Dissociative path does not contribute for full ionisation cases.

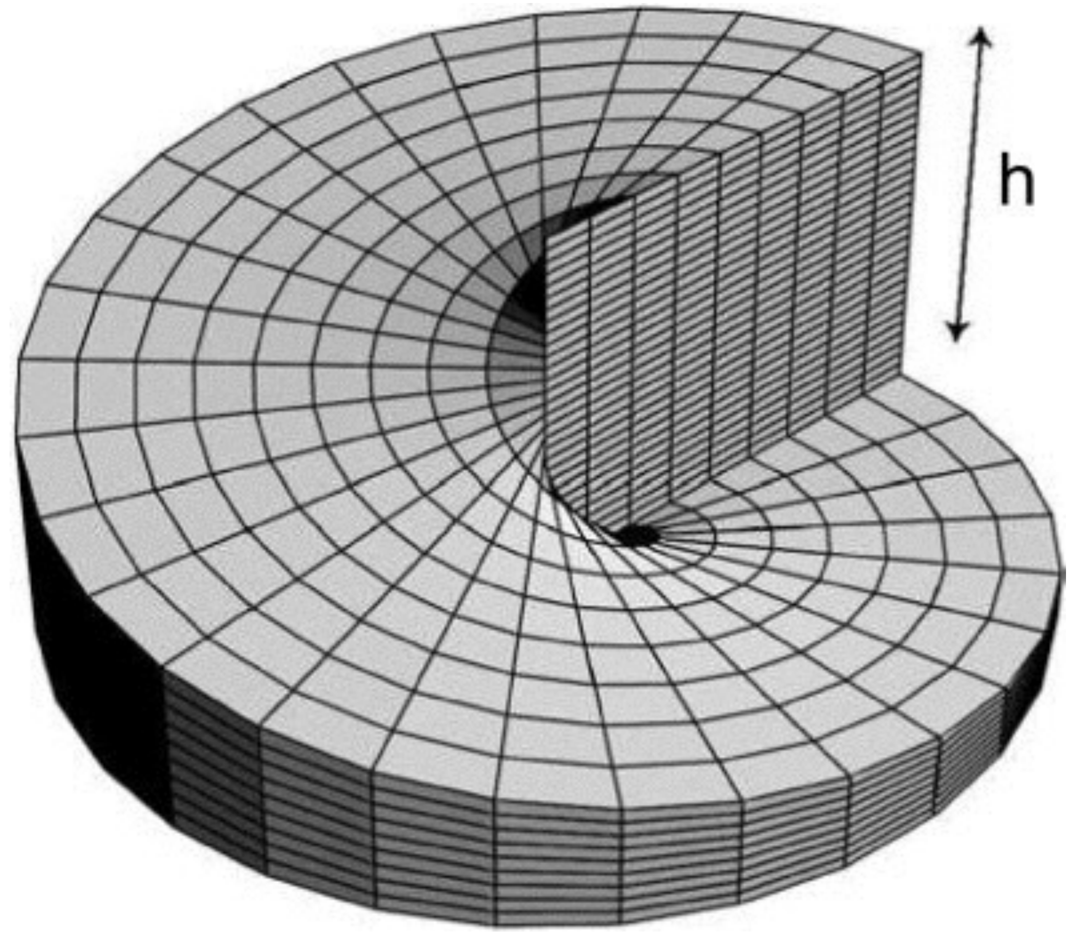
Pure ionisation channels - atomic vs molecular

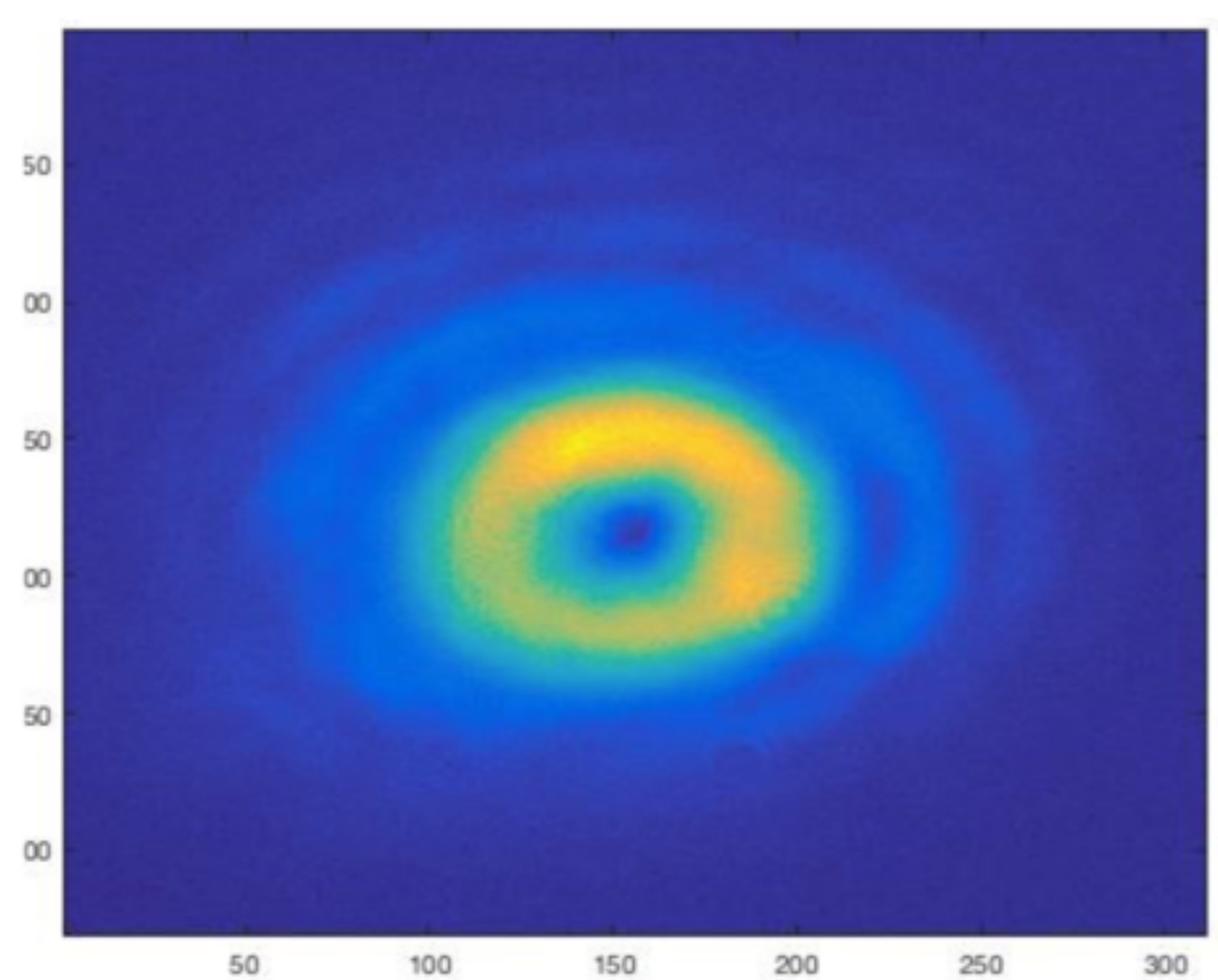


- Ionisation treatment
  - Rate equations describing population
  - Γ_{TBSI} : ionisation rates via extended ADK theory
- Experimental setup ready
  - high spatial resolution (4 um)
  - data taken just before conference, analysis ongoing

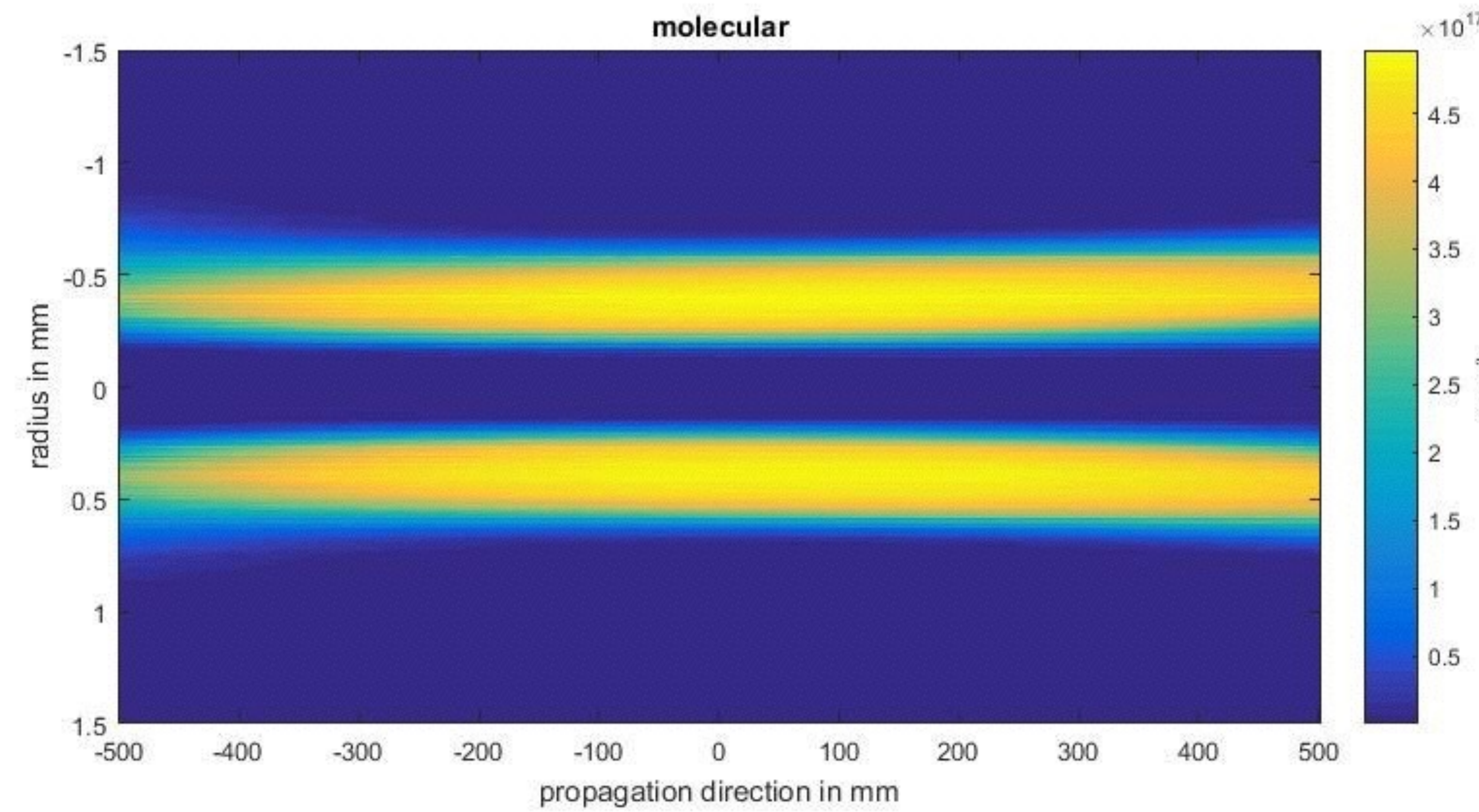


Hollow core plasma channel



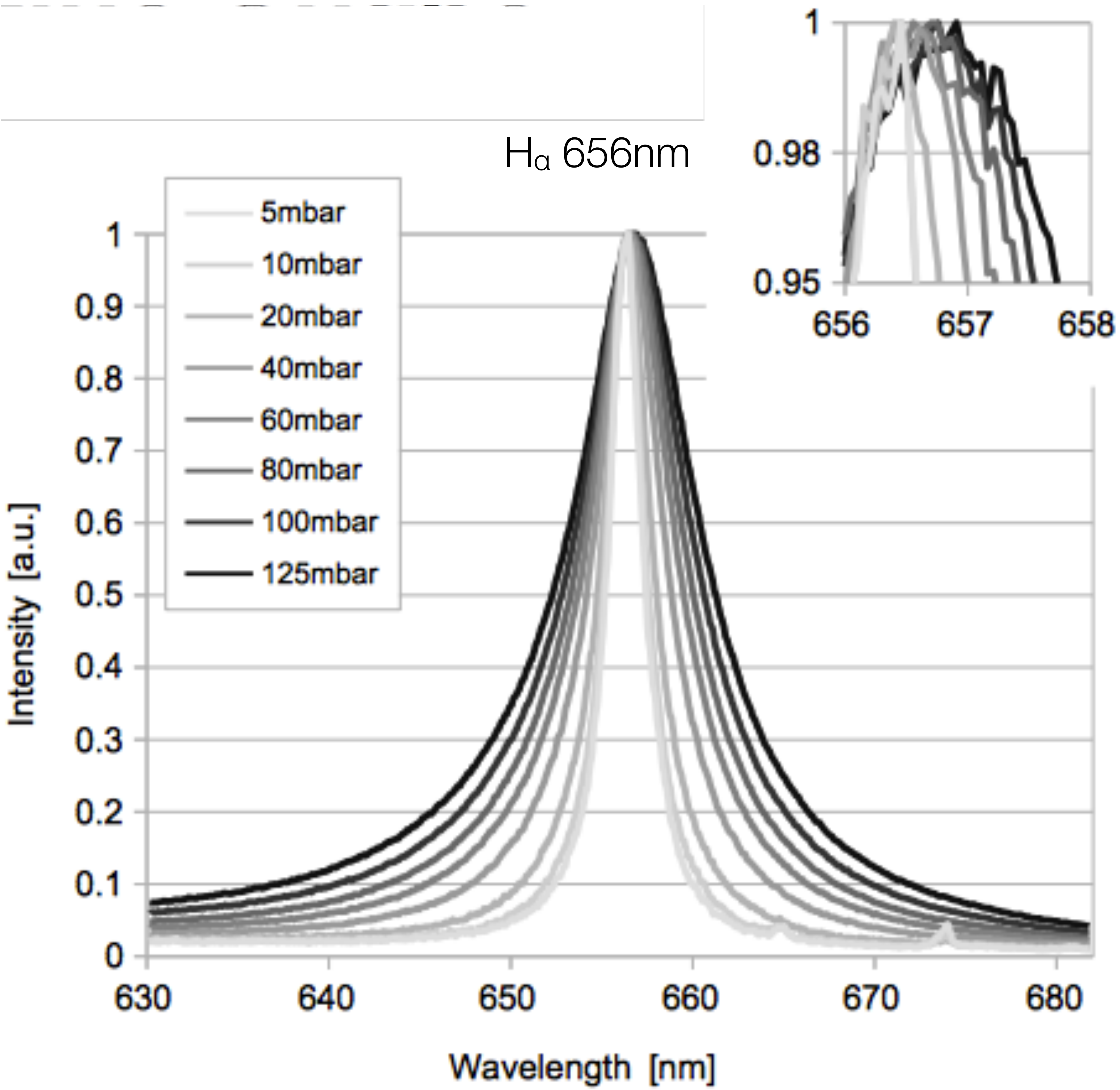


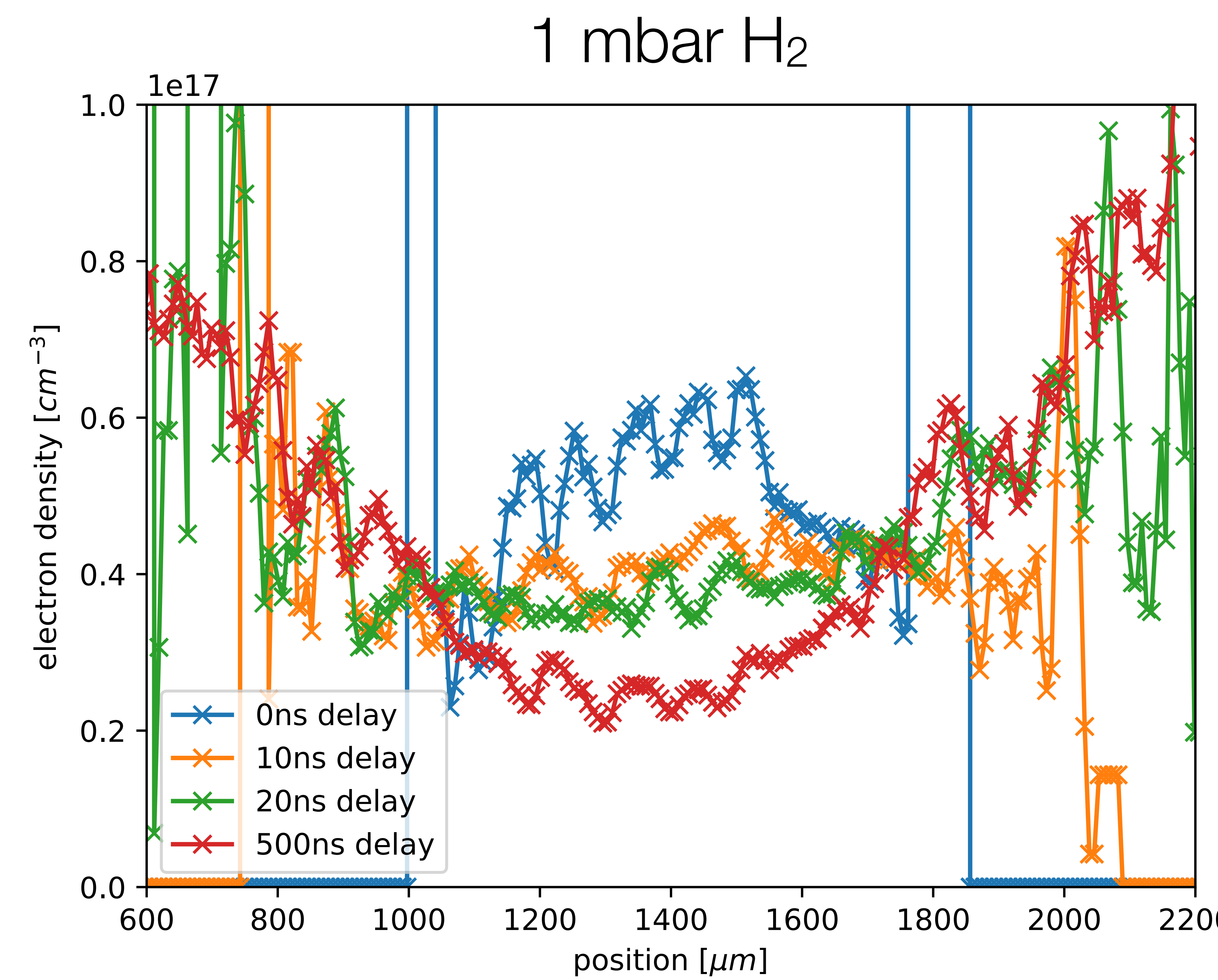
- Spiral phase plat to transform laser mode from TEM00 to LG01
  - real phase plate: discrete phase steps
  - Simulation shows nice channel in 10 mbar H2



- First experiments showed a nice donut intensity structure
  - initial beam wasn't a perfect gaussian, thus some distortion expected
  - electron density to be measured

n_e: Density dependent line width and wavelength



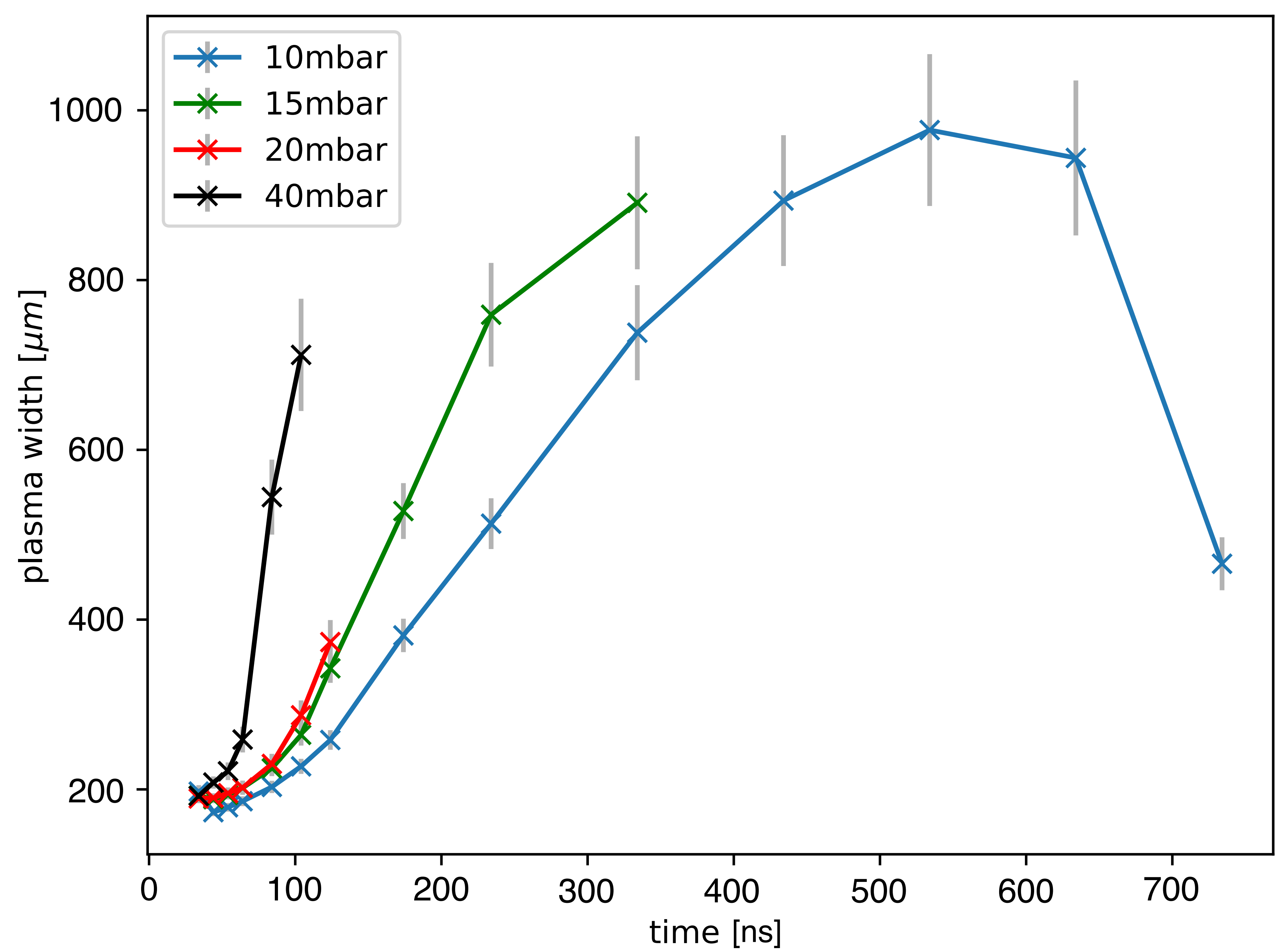


> Almost full ionisation

> plasma column expands over time

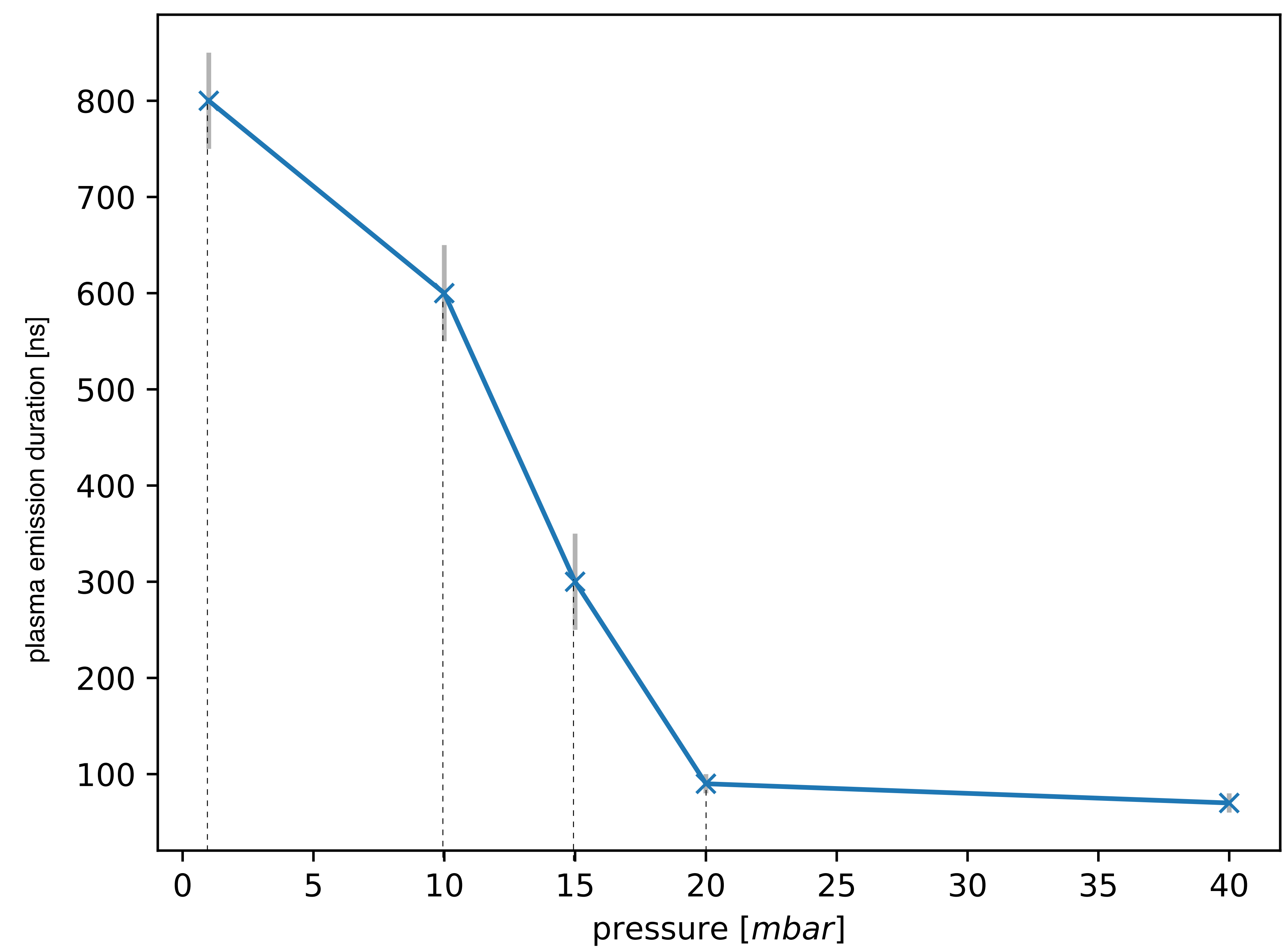
n_e: Density dependent line width and wavelength

> Plasma channel width vs pressure



> plasma emission duration vs pressure

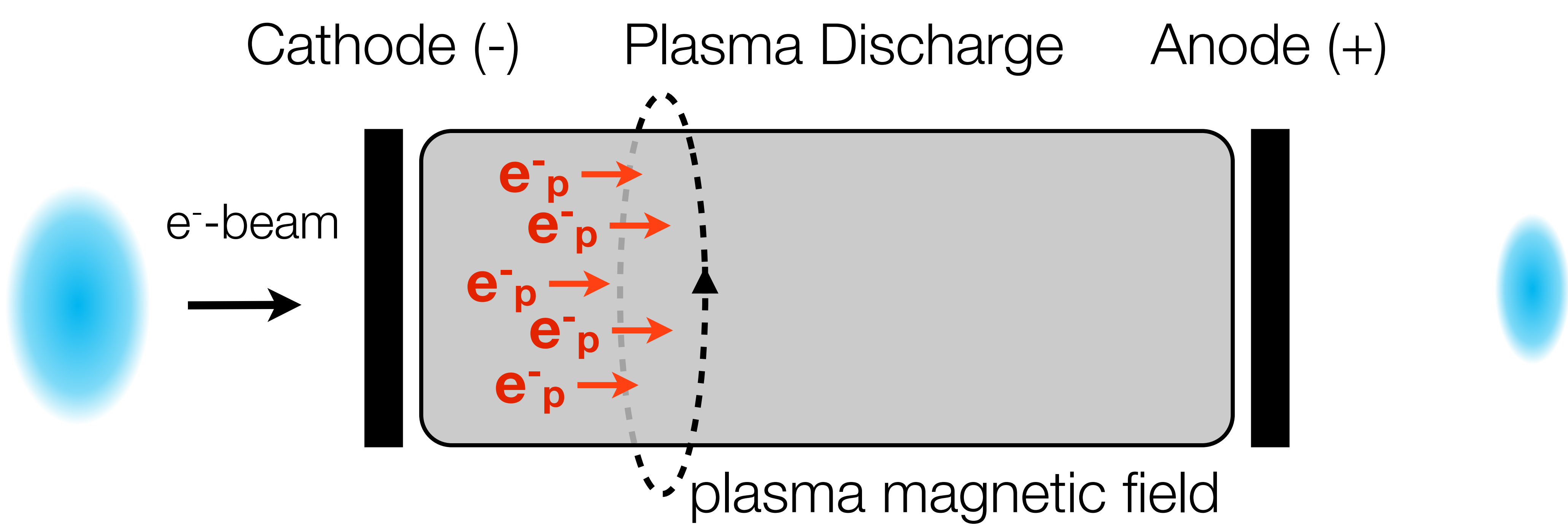
> measure self quenching coefficients?



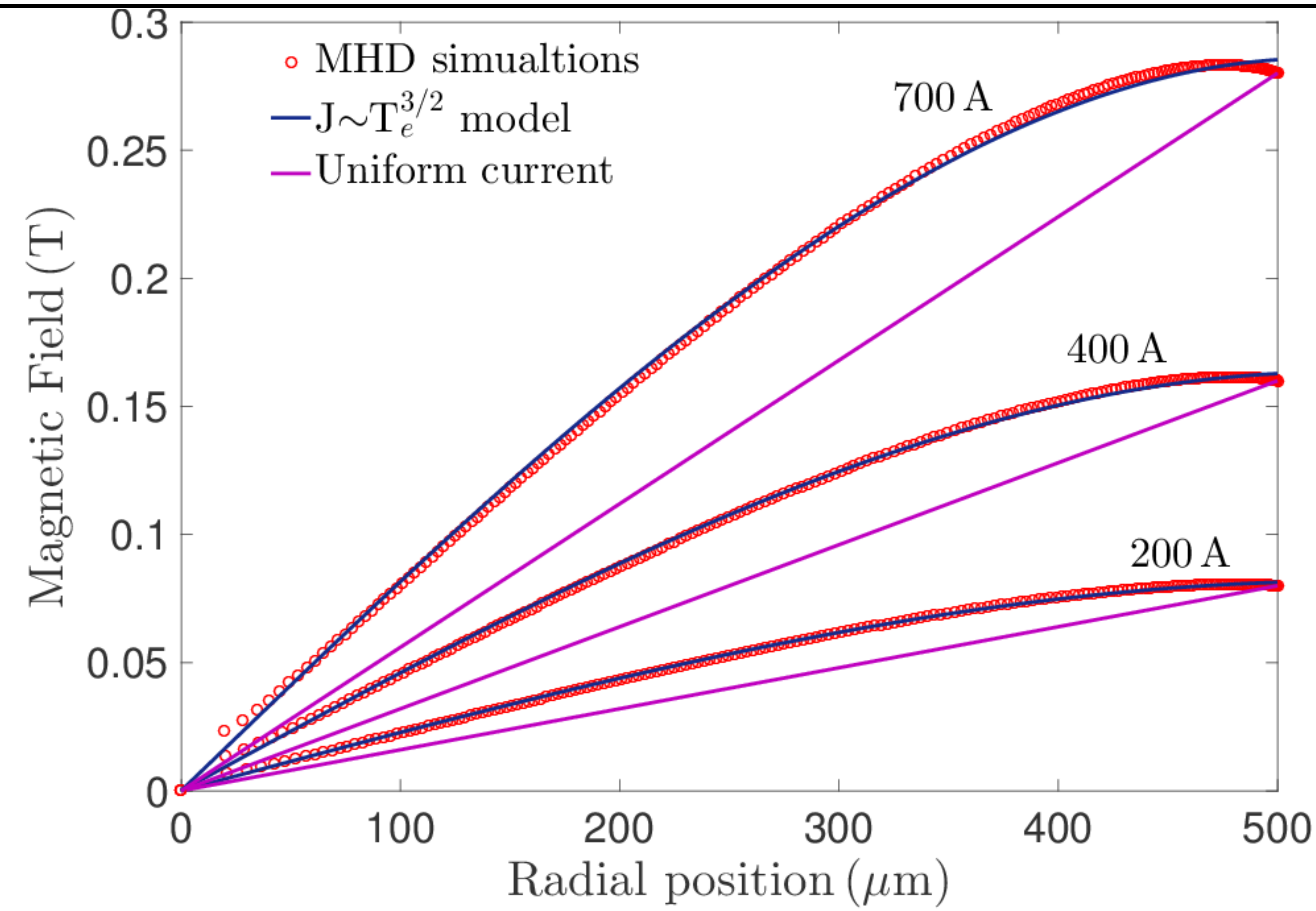
> Problem: Severe b-inegral issues because of transmissive focussing geometry

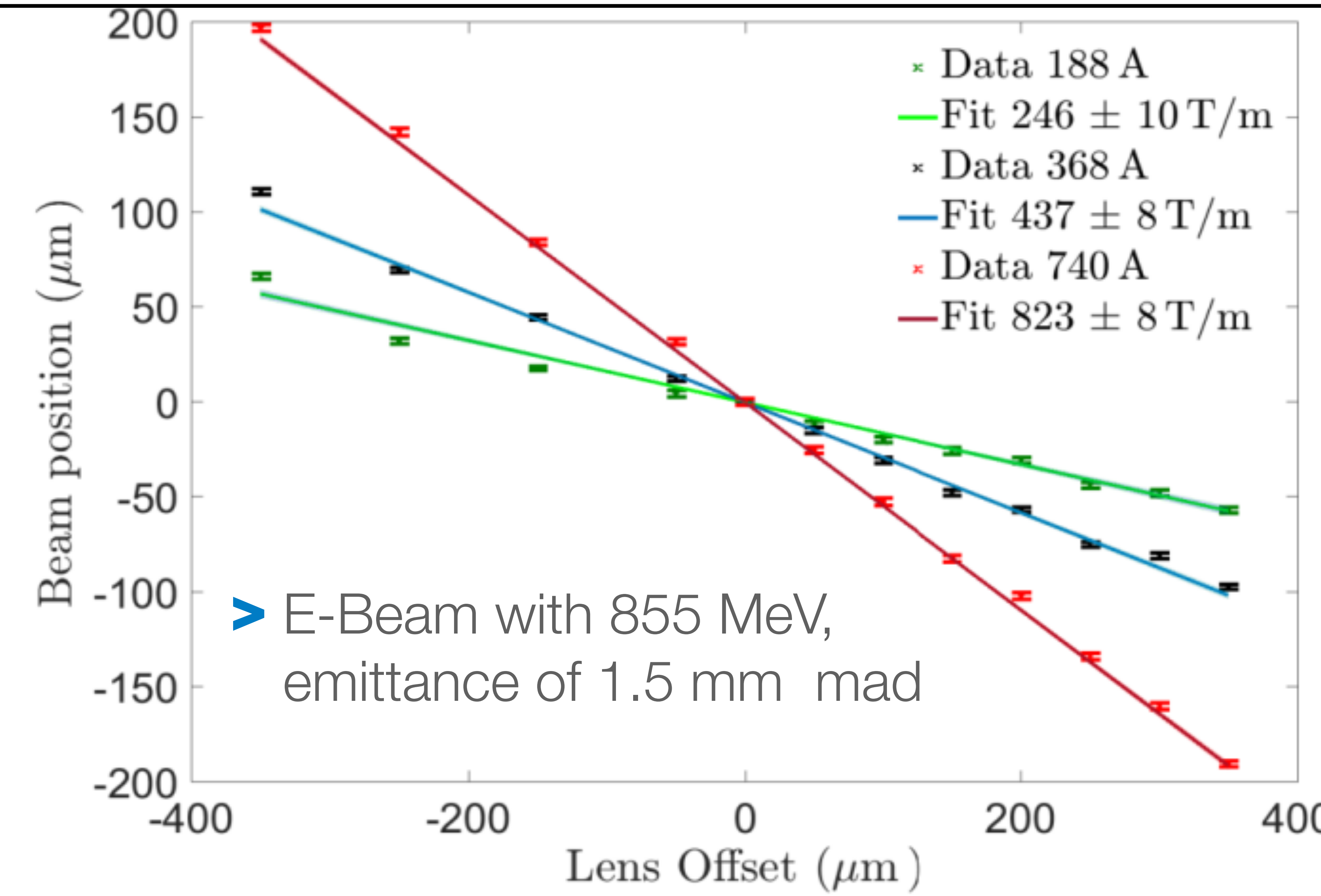
> Change focussing setup to all reflective also in the test lab!

Plasma lensing



- plasma electron current generates magnetic field
- result: F= I x B , focussing force for e-beam
  - focussing is symmetric in all directions!



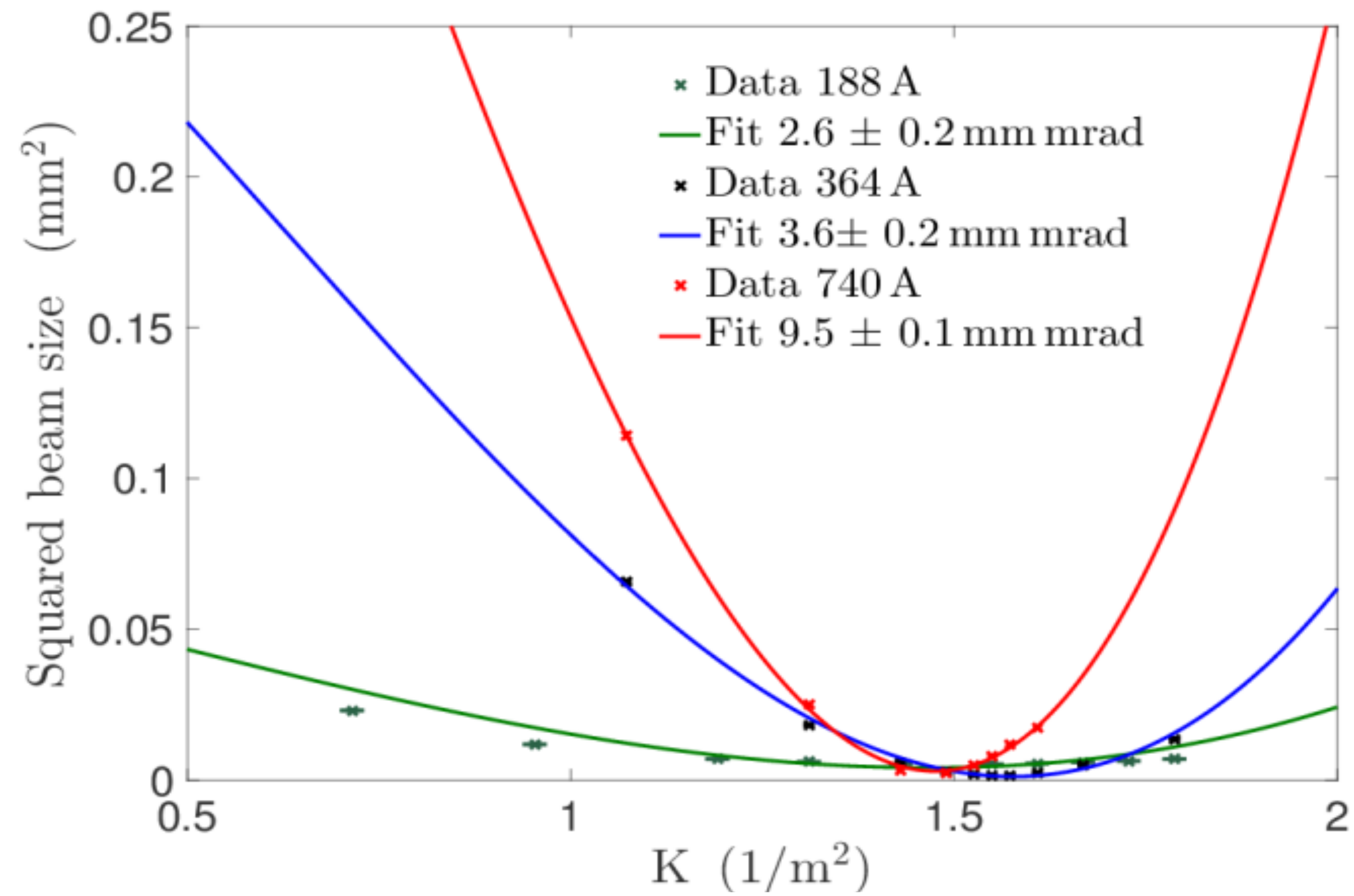


- E-Beam with 855 MeV, emittance of 1.5 mm mad

Emittance measurement of active plasma lens

Plasma Current [A]	Normalized Emittance [mm mrad]	
	Measured	ASTRA
188	2.6 ± 0.2	3.3 ± 0.3
368	3.6 ± 0.2	4.7 ± 0.1
740	9.5 ± 0.1	7.4 ± 0.2

- Emittance measurements show degradation
- ASTRA particle tracking simulations performed using results from gradient scans



- First direct magnetic field gradient measurements performed
- Emittance measured after plasma lens interaction
- No pointing or orbit stability degradation through plasma lens observed
- Collaborative campaign at CERN, lead by Oslo, on plasma lens studies

Summary

- Plasma-target infrastructure
  - differential pumping stages fully installed
  - laser focussing chamber attached, discharge as backup solution prepared
  - new solutions allowing for noble gas usage, important for ionisation based down ramp generation
- Gas ionization and dissociation
  - understanding of ionization process further advanced
  - experiment performed to benchmark the code, data analysis pending
- Diagnostics
  - plasma spectroscopy offers insight into plasma parameters
  - electron density measurements give insight into plasma density in the 10^{16} cm^{-3} regime
- Plasma lensing
  - first directly measured gradients in active plasma lenses
  - observed emittance degradation and confirmed simulation results.
  - further investigation in experiments at CERN(Califes, CLIC) 2017 and FFWD

On behalf of WG3: Thank you…