Interpenetration and Kinetic Mix in Weakly Collisional, Fully-ionized Plasma Jets

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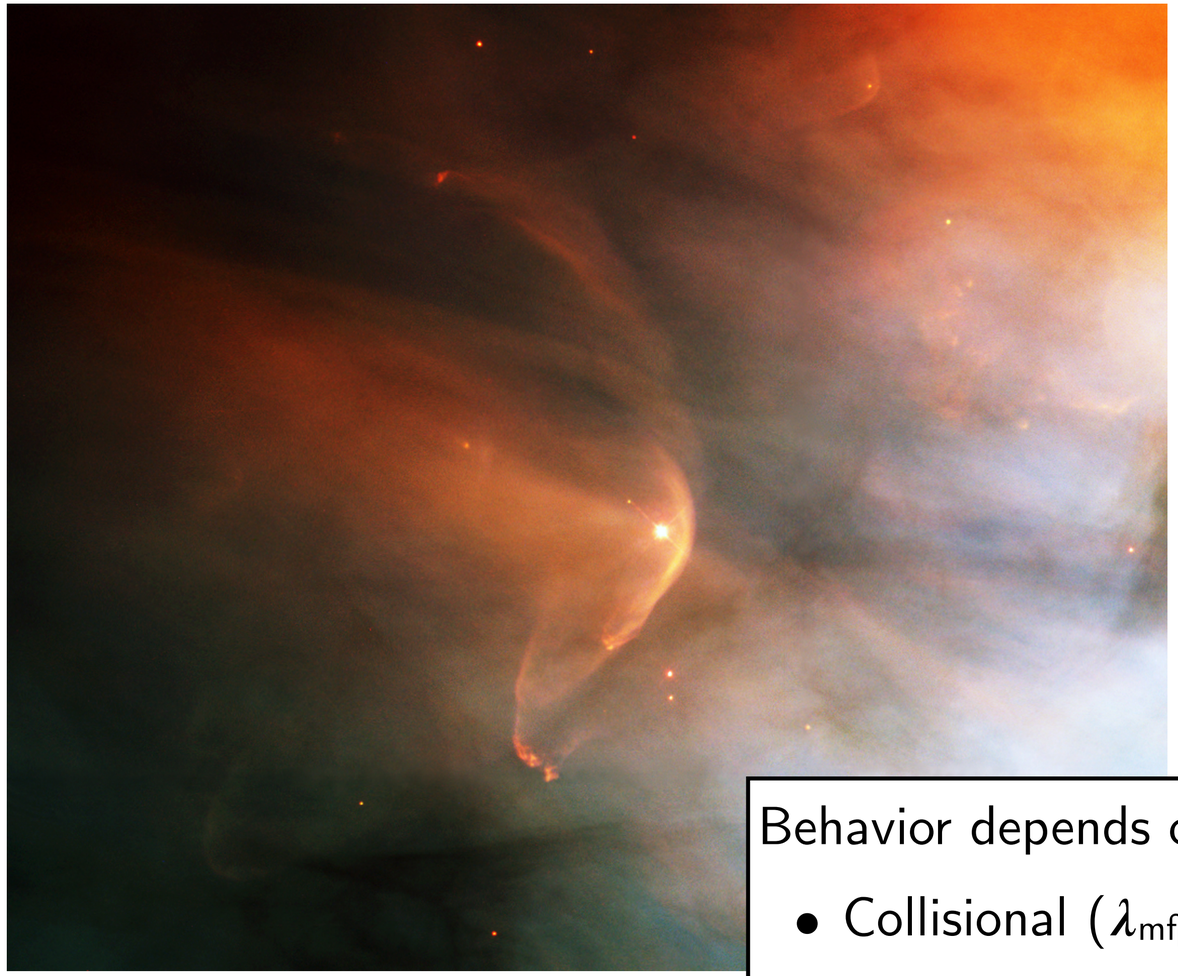
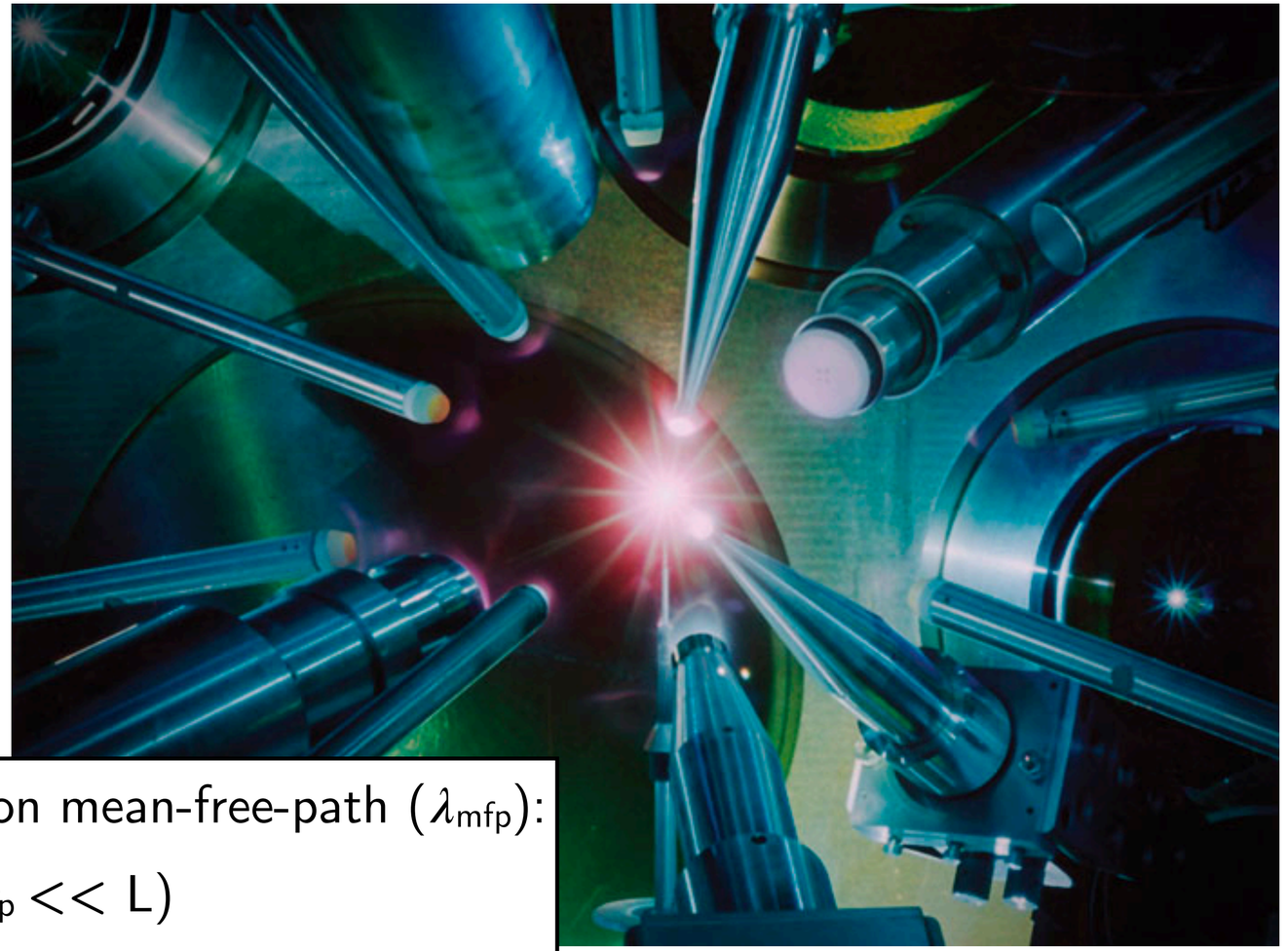
Coulomb collisions play an important role in the interaction of unmagnetized, fully ionized plasma jets

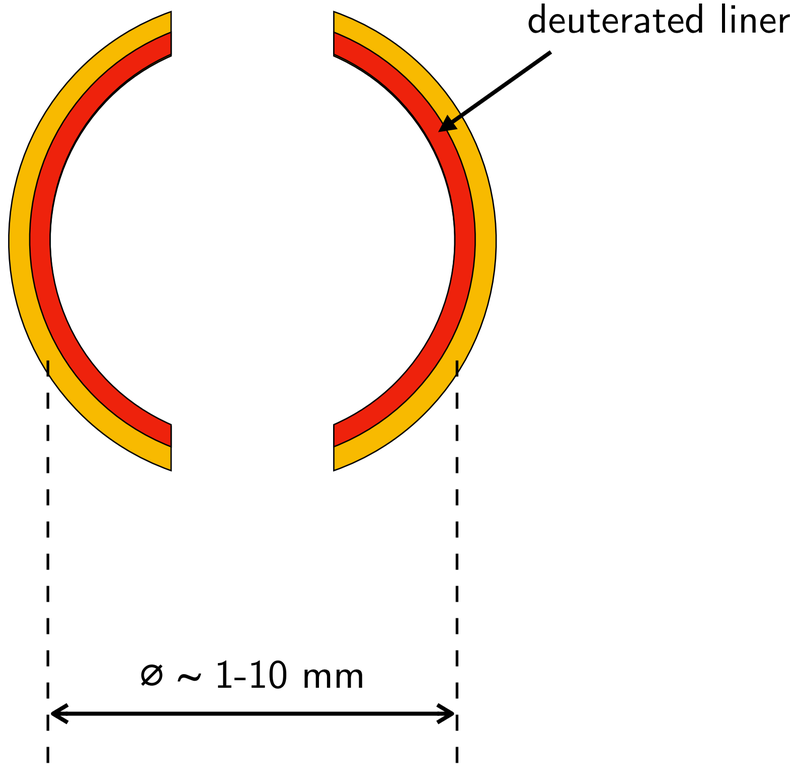




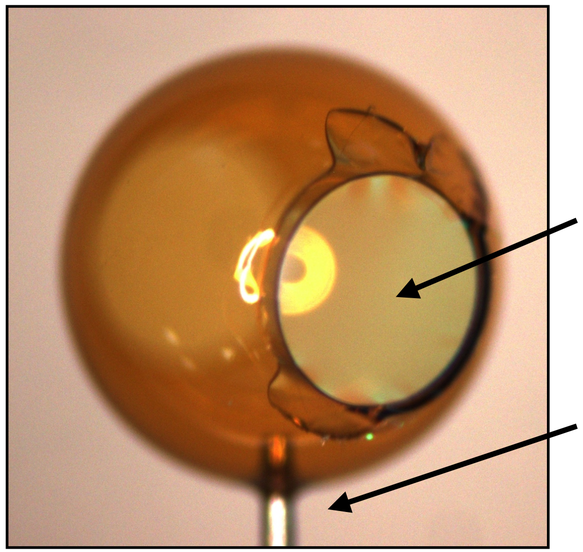
Behavior depends on mean-free-path (λ_{mfp}):

- Collisional ($\lambda_{mfp} << L$)
- Collisionless ($\lambda_{mfp} >> L$)
- Intermediate ($\lambda_{mfp} \sim L$)

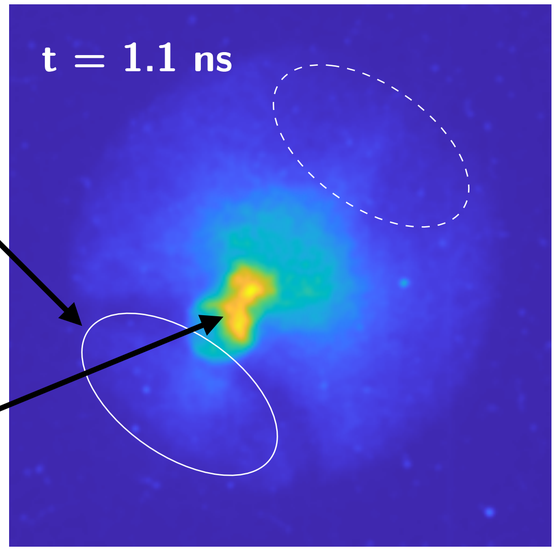
We use “inverted corona” targets to study converging plasma jets



Gas-filled target



X-ray emission



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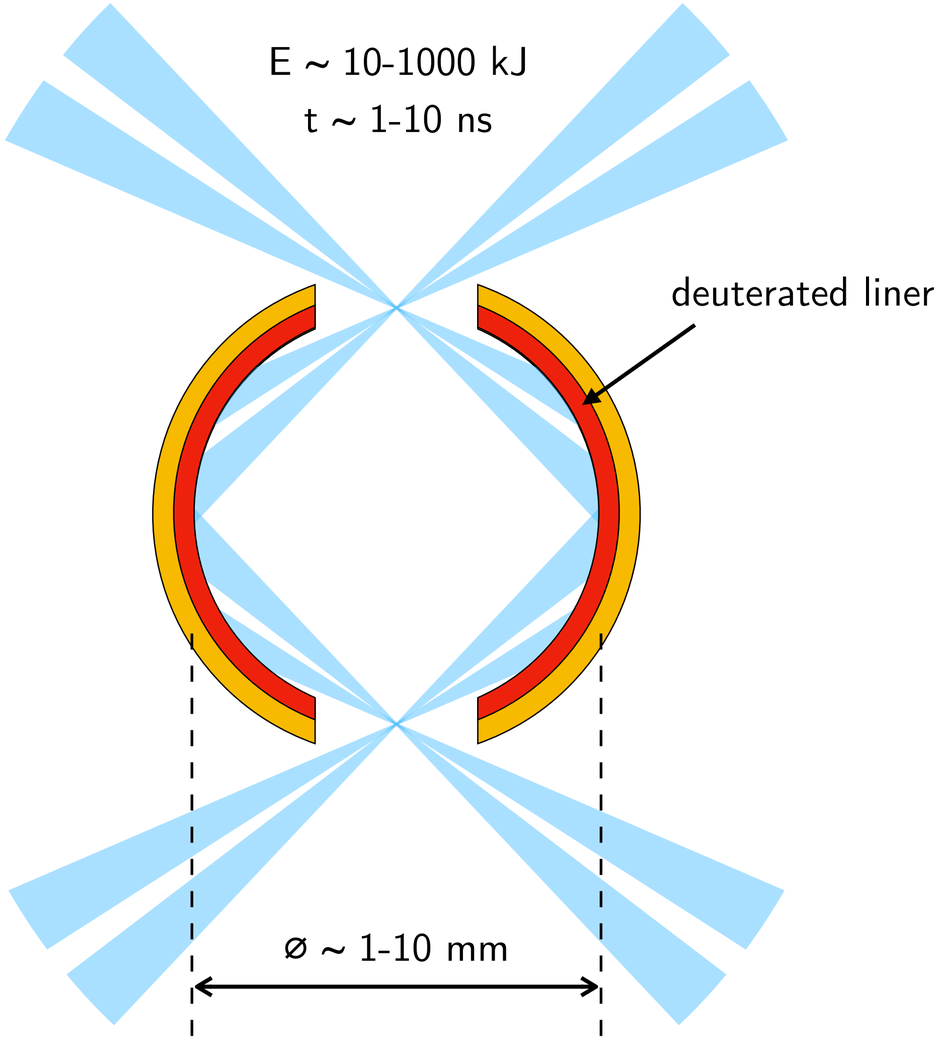

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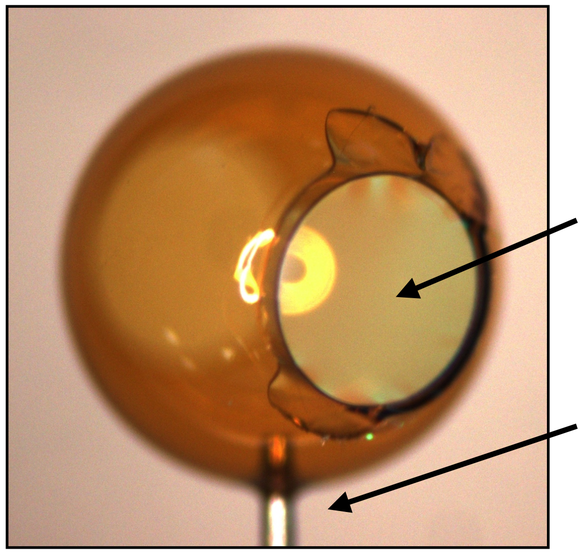

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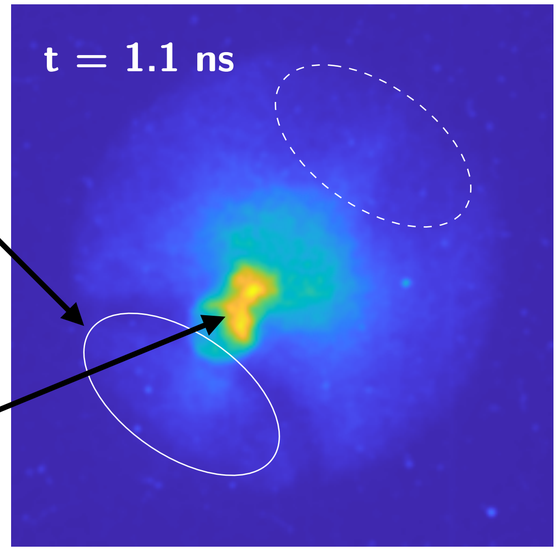

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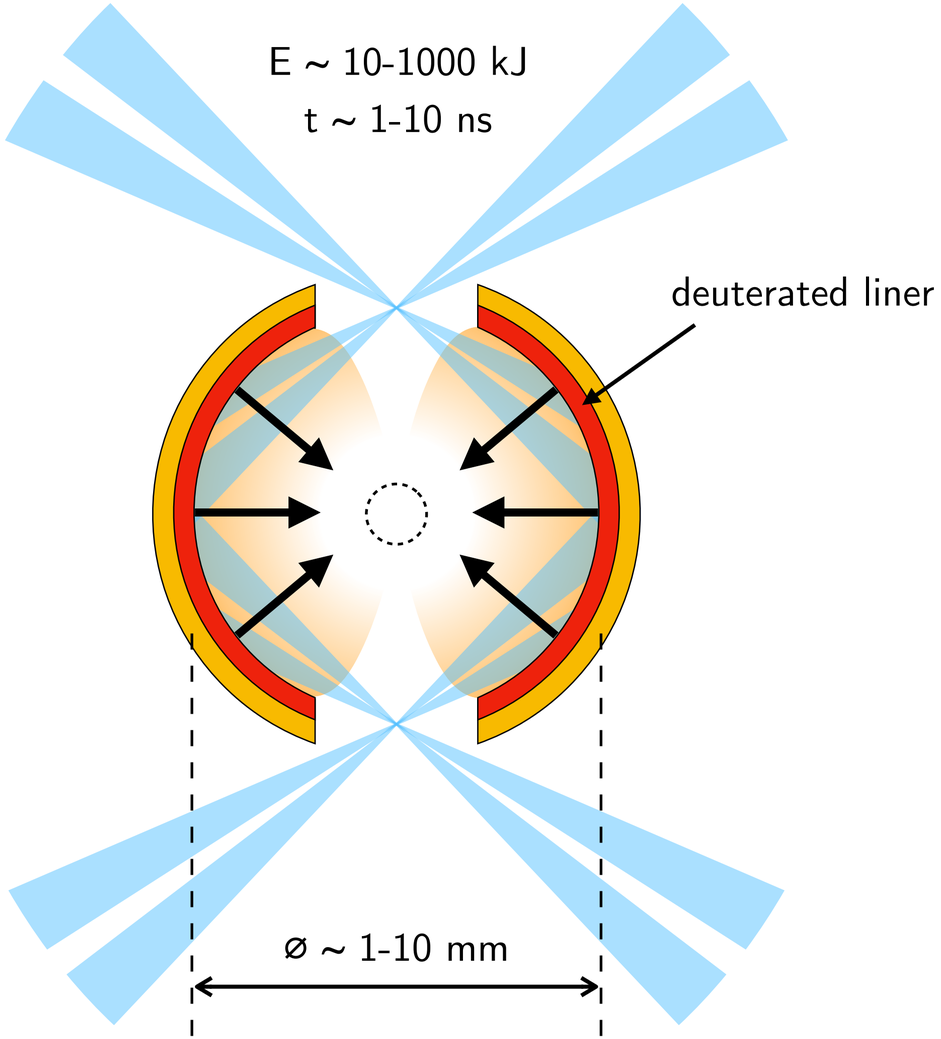

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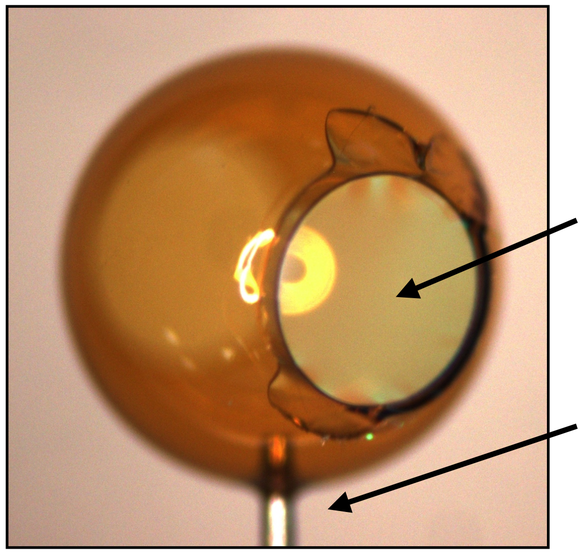

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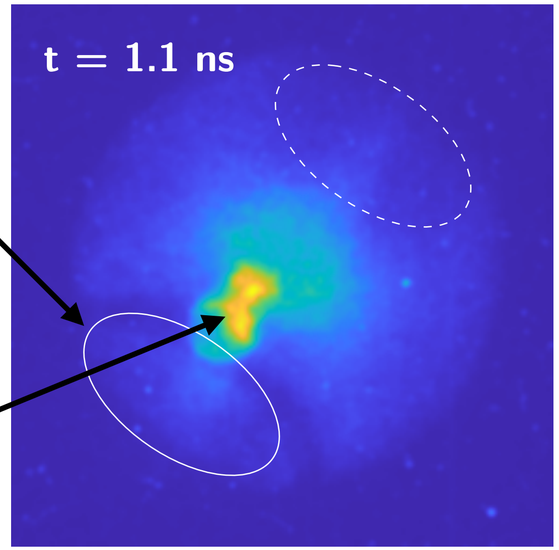
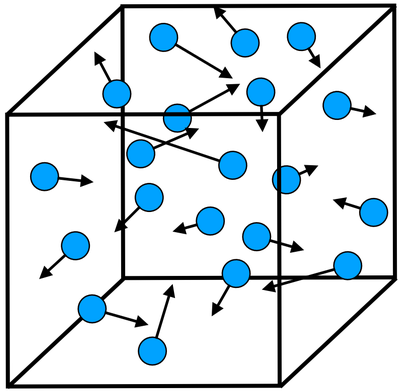
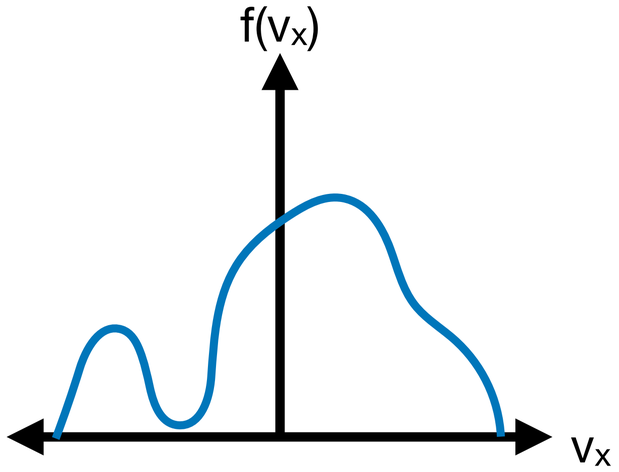


The fluid approximation



Velocity Distribution Function (VDF)



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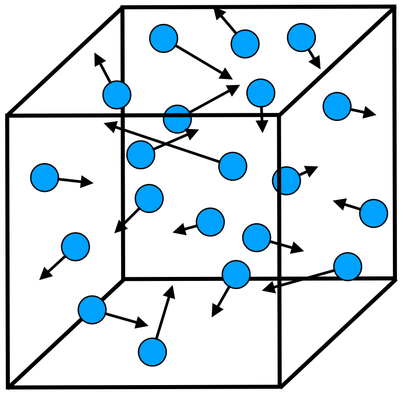
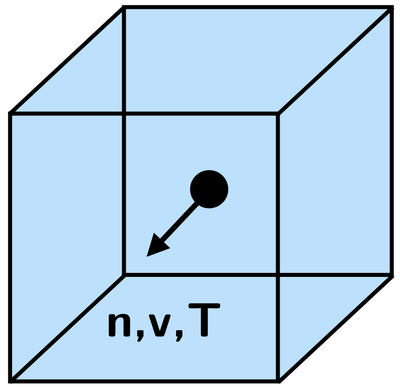
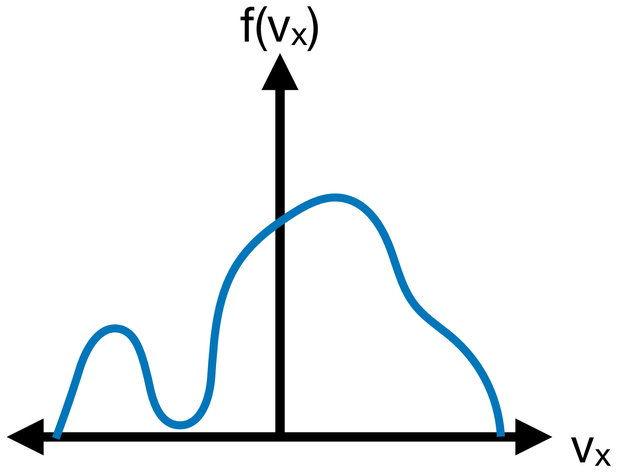
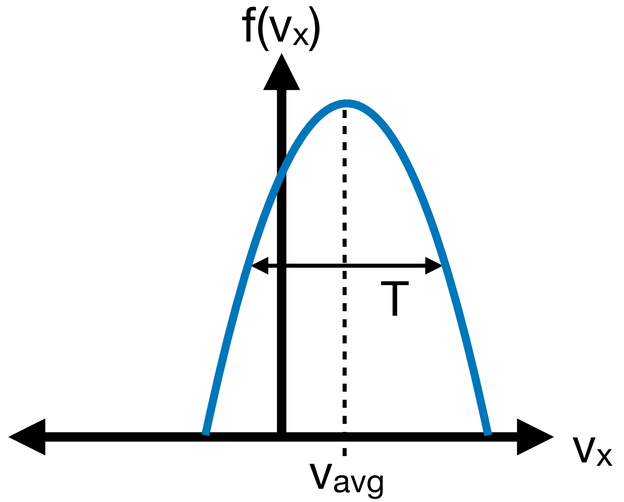


If $\lambda_{mfp} << L$



Velocity Distribution Function (VDF)

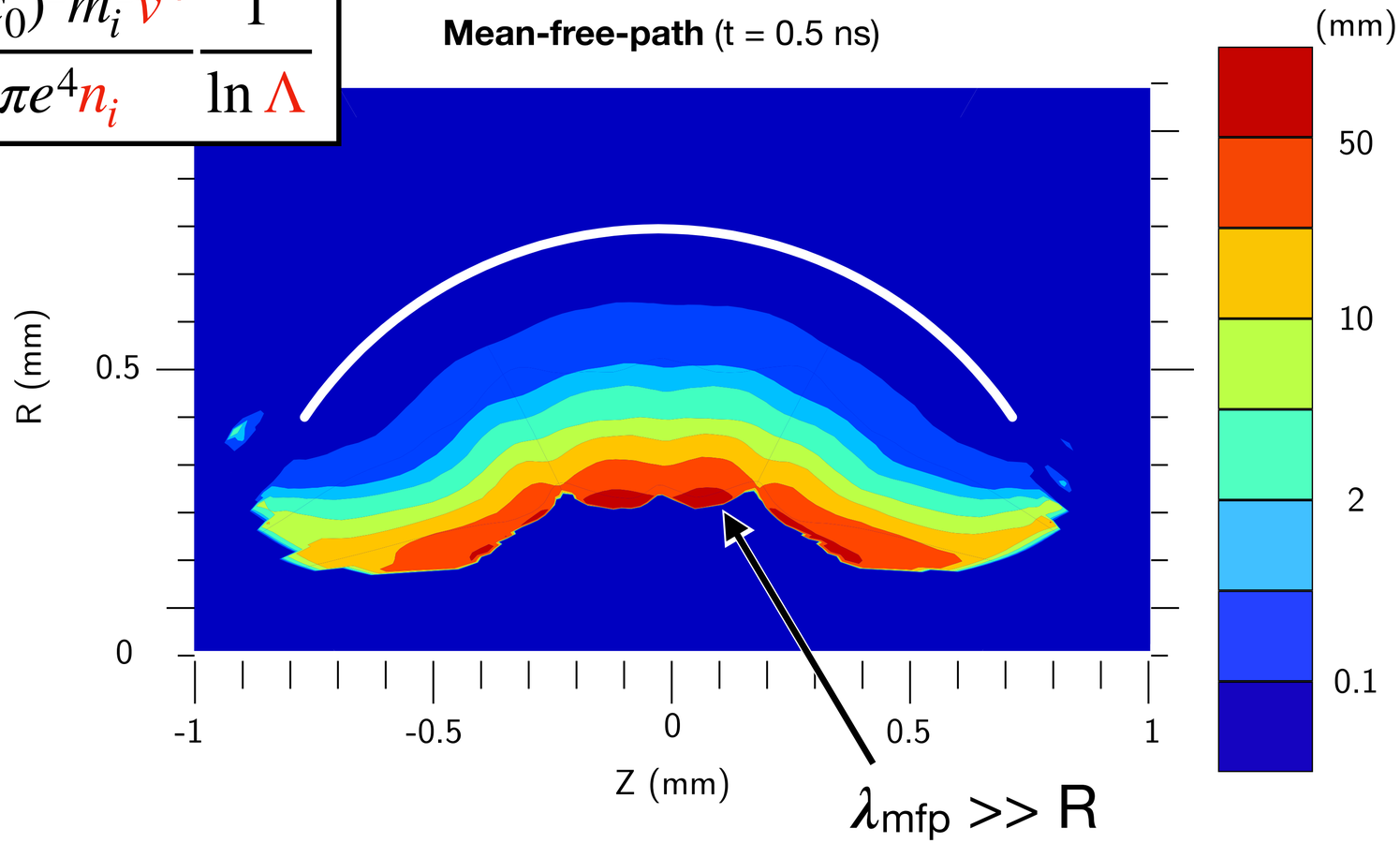




- If collisions are rapid, plasma can be assumed in local thermodynamic equilibrium

The collisional assumption is violated in the converging plasma

$$\lambda_{mfp} = \frac{(4\pi\epsilon_0)^2 m_i^2 v^4}{4\pi e^4 n_i} \frac{1}{\ln \Lambda}$$



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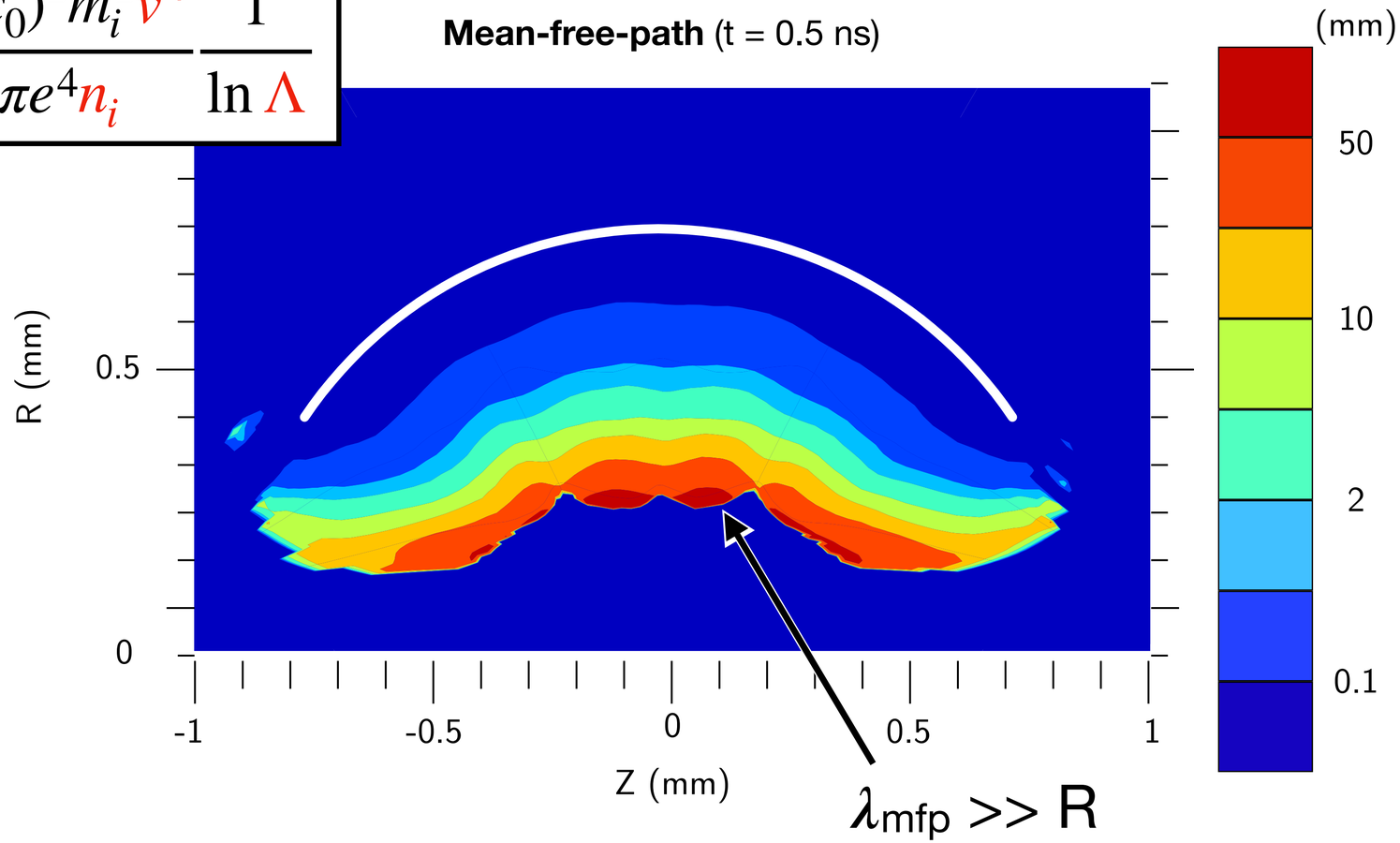
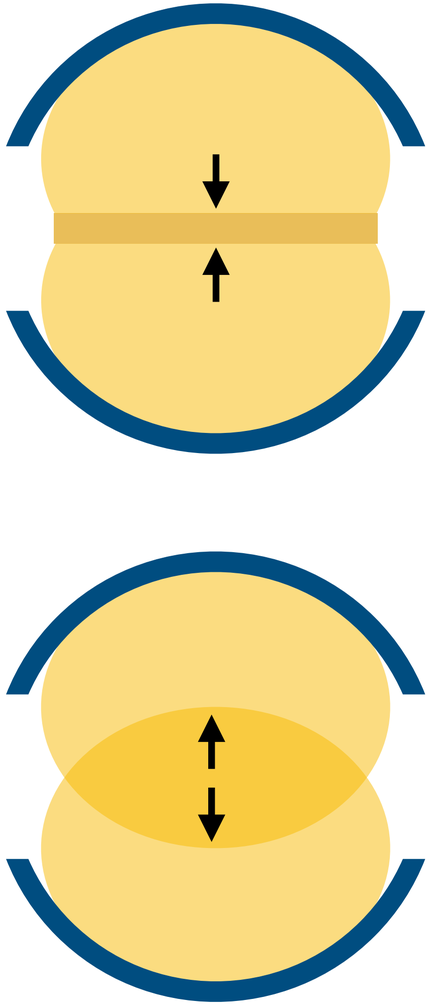
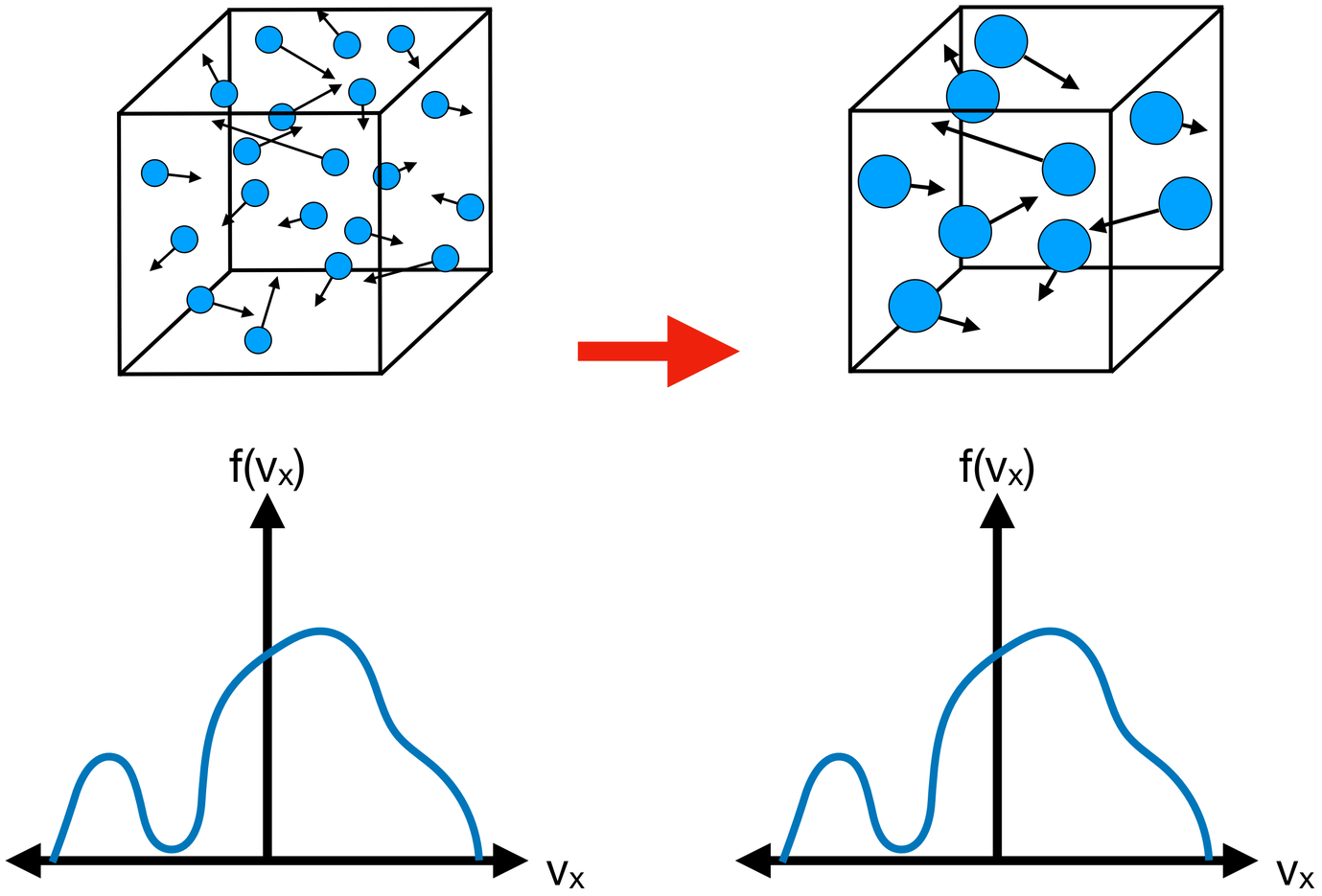




- Fluid simulations will not capture interpenetration/diffusion/mixing

The kinetic (particle-in-cell) approach



- Treat plasma as collection of macroparticles that sample VDF

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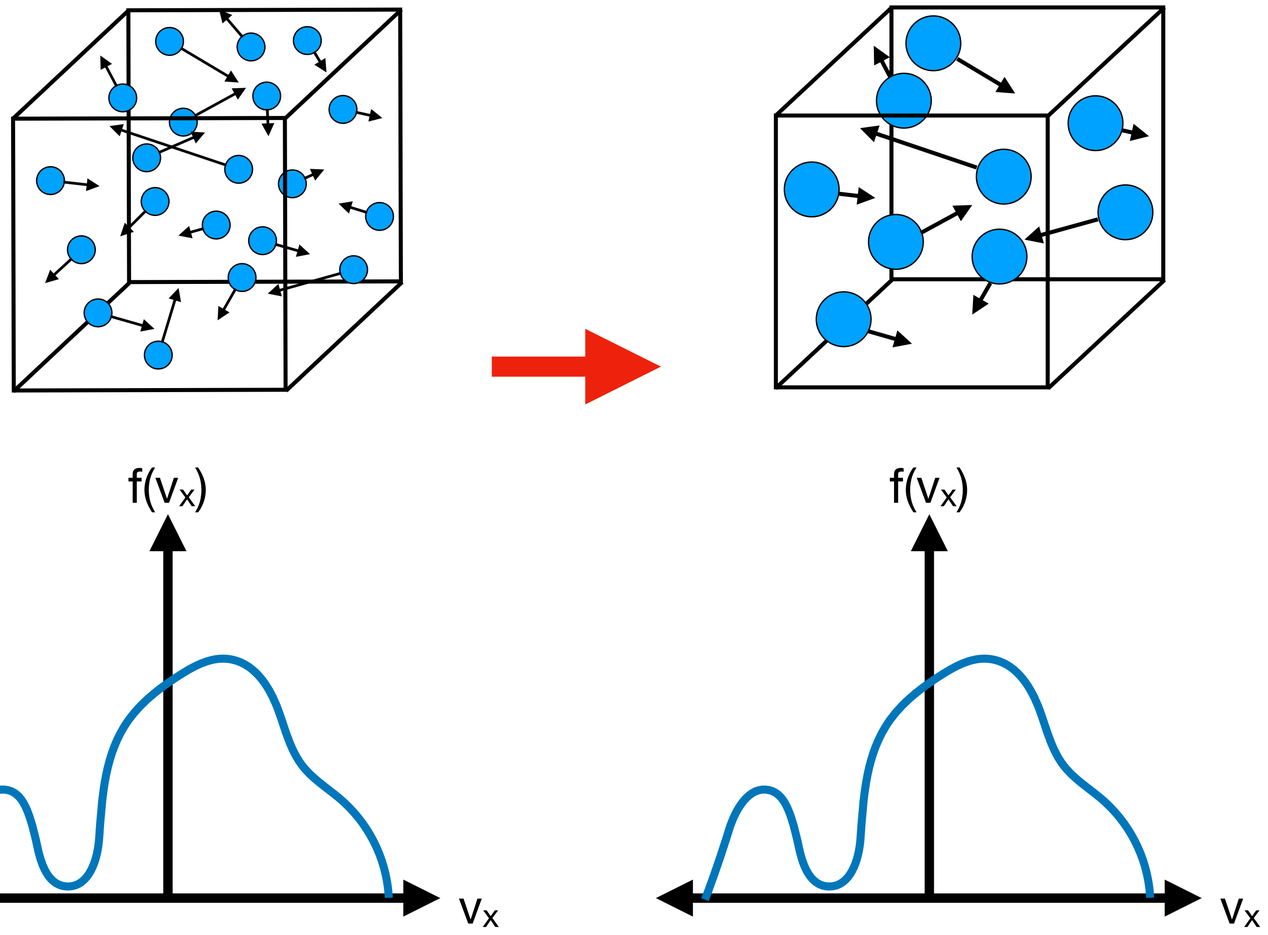
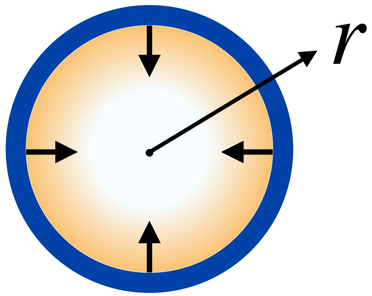


- Here we use hybrid-PIC code Chicago[1]:
  - Kinetic ions, massless fluid electrons
  - Includes laser ray-tracing package and binary fusion algorithm
  - Primarily focusing on 1D

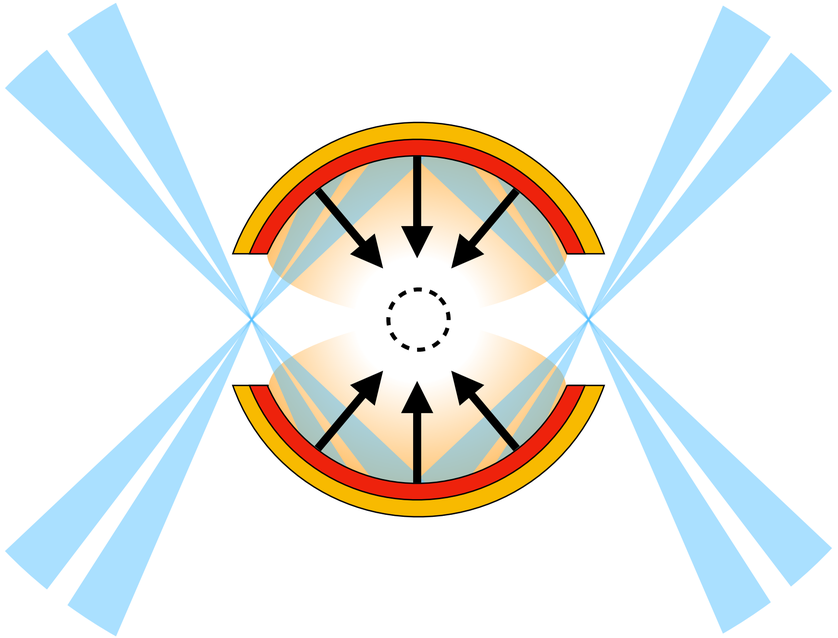


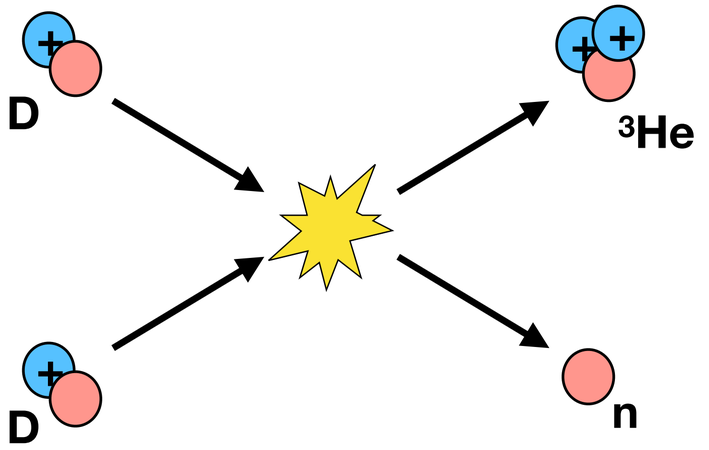
- Treat plasma as collection of macroparticles that sample VDF

[1] C. Thoma et al., Phys. Plasmas 24, 062707 (2017).

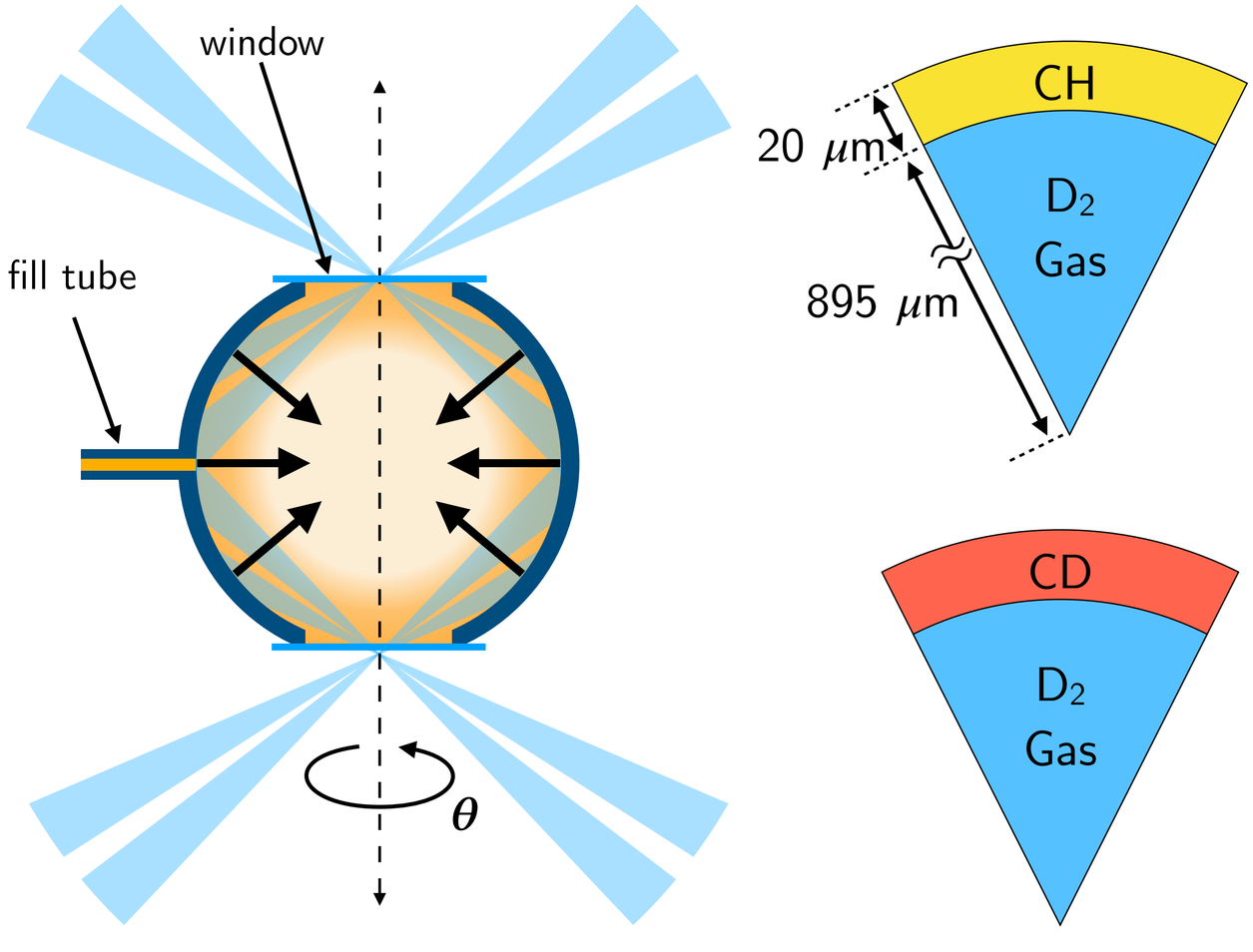
Fusion neutrons as a diagnostic

- Colliding atoms can undergo nuclear fusion reactions
- Can measure neutrons produced
- Use plastic for shell material:
  - Non-reactive hydrogen plastic (CH)
  - Deuterated plastic (CD)





We include fill-gas to increase yield and study gas-shell interaction



- Comparing neutron yield between targets with/without deuterated liners provides insight into mix

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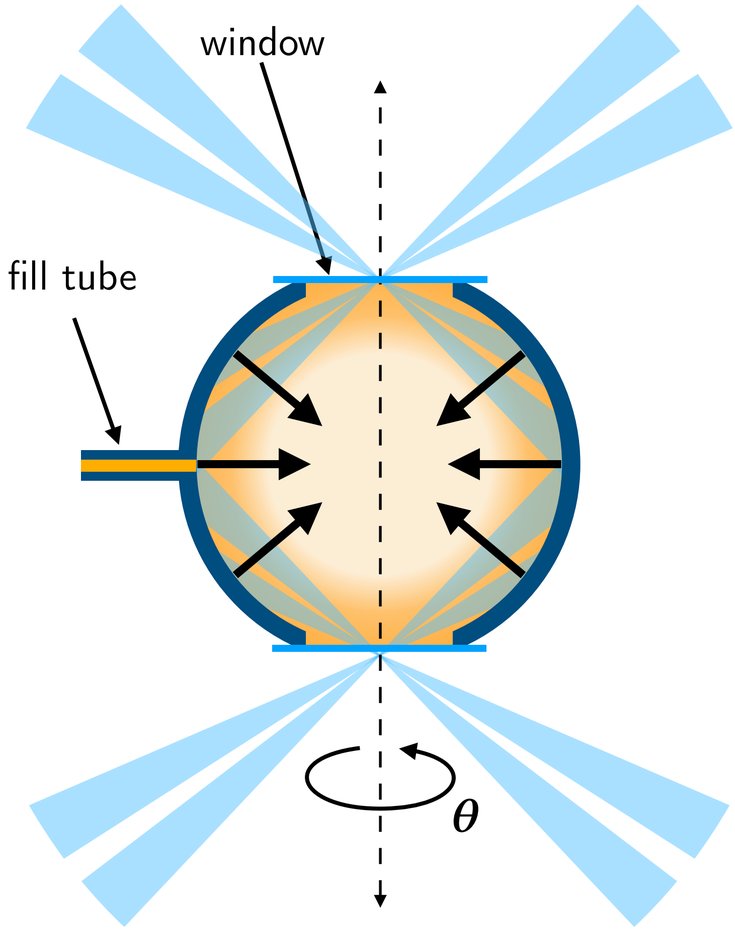
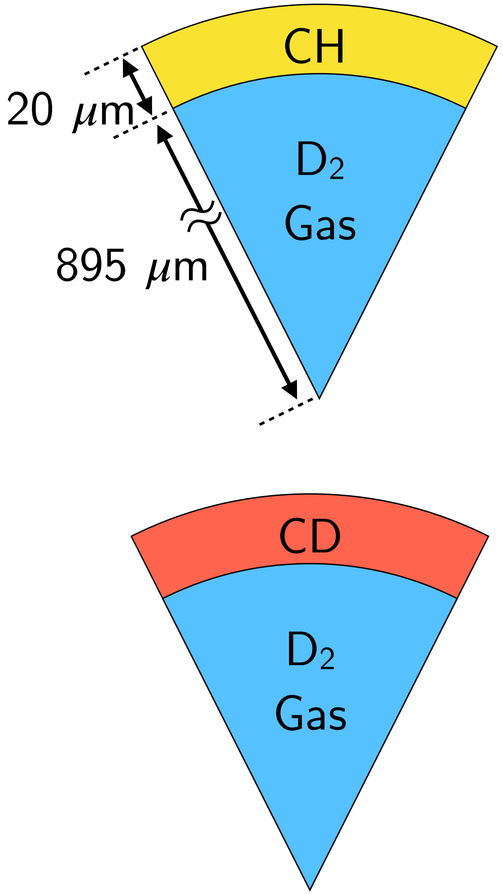
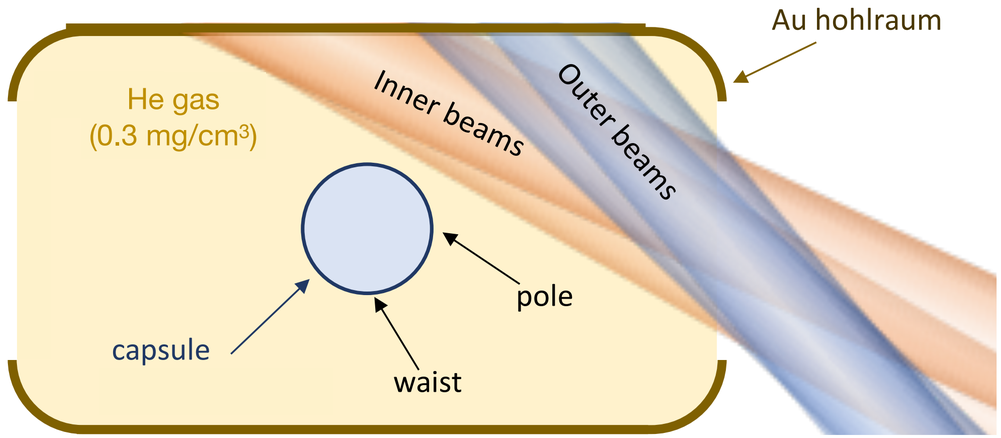




NIF Ignition Target



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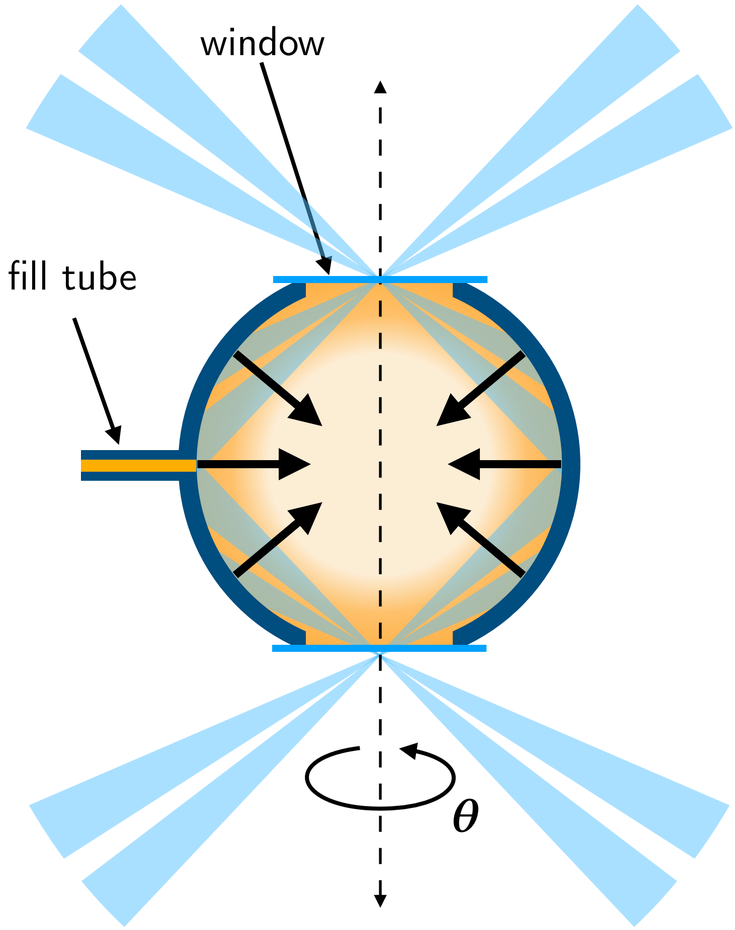

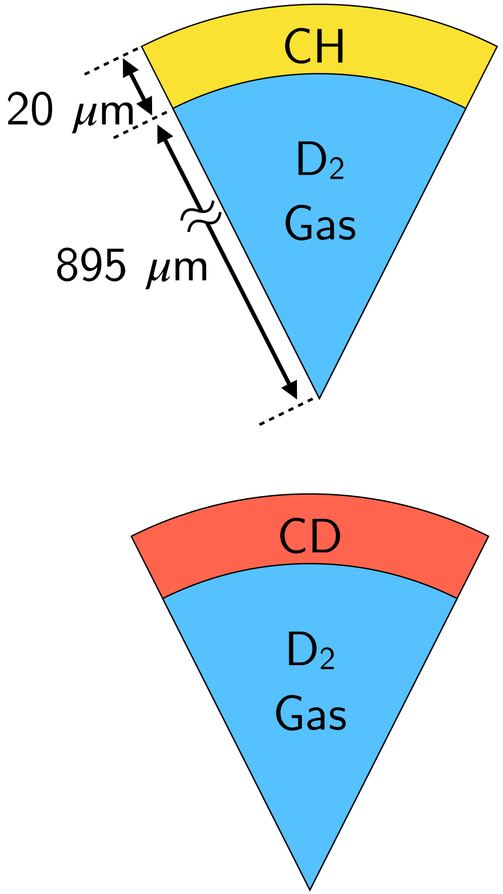

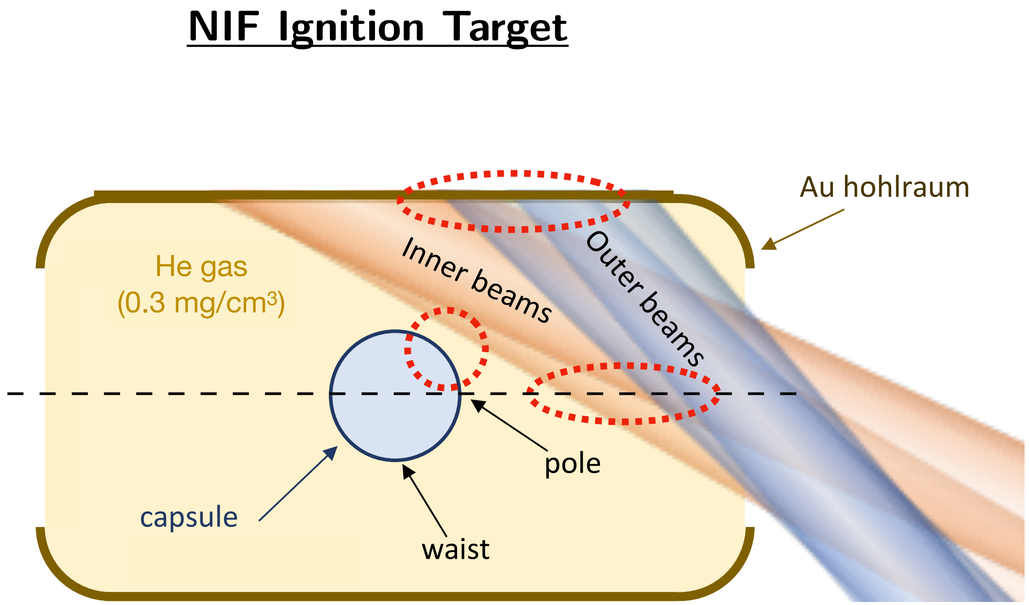

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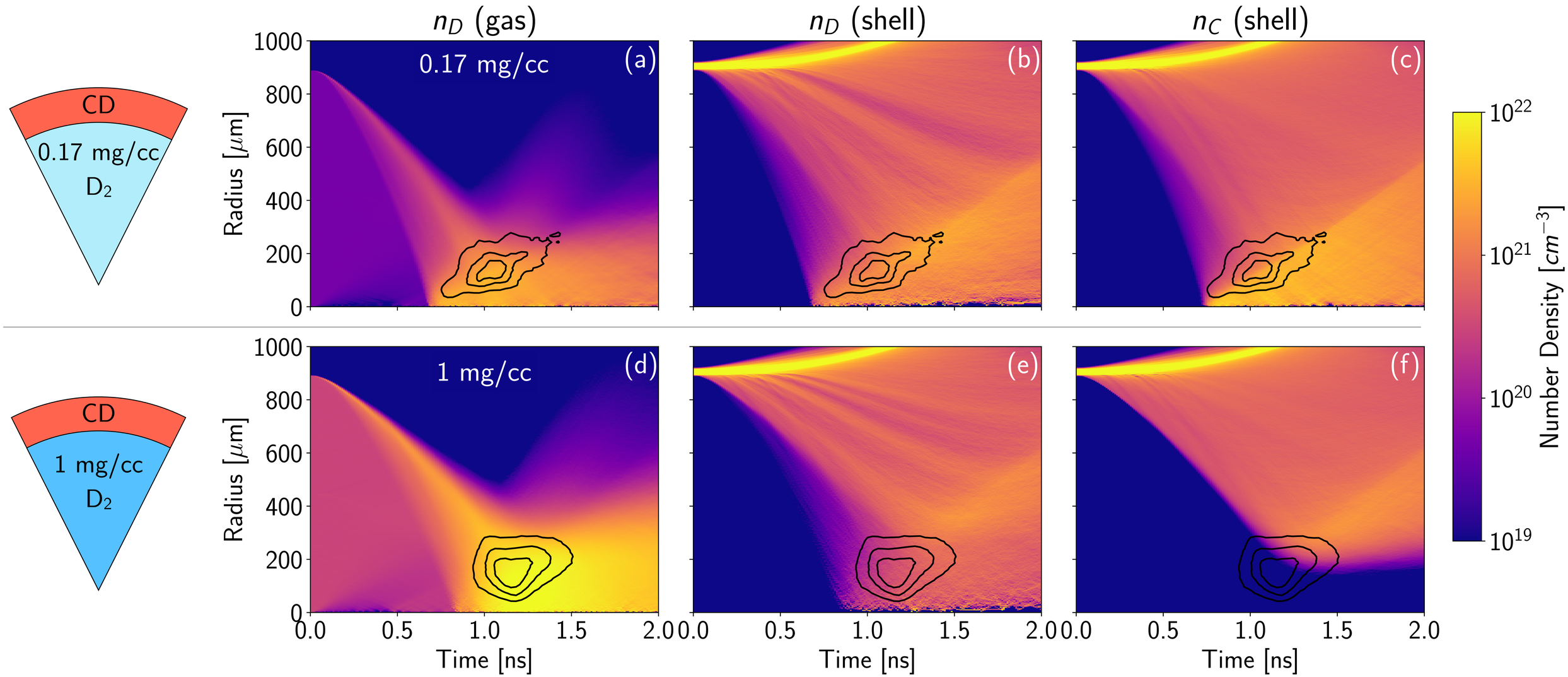
Density contours show wide mix region at lower fill pressure



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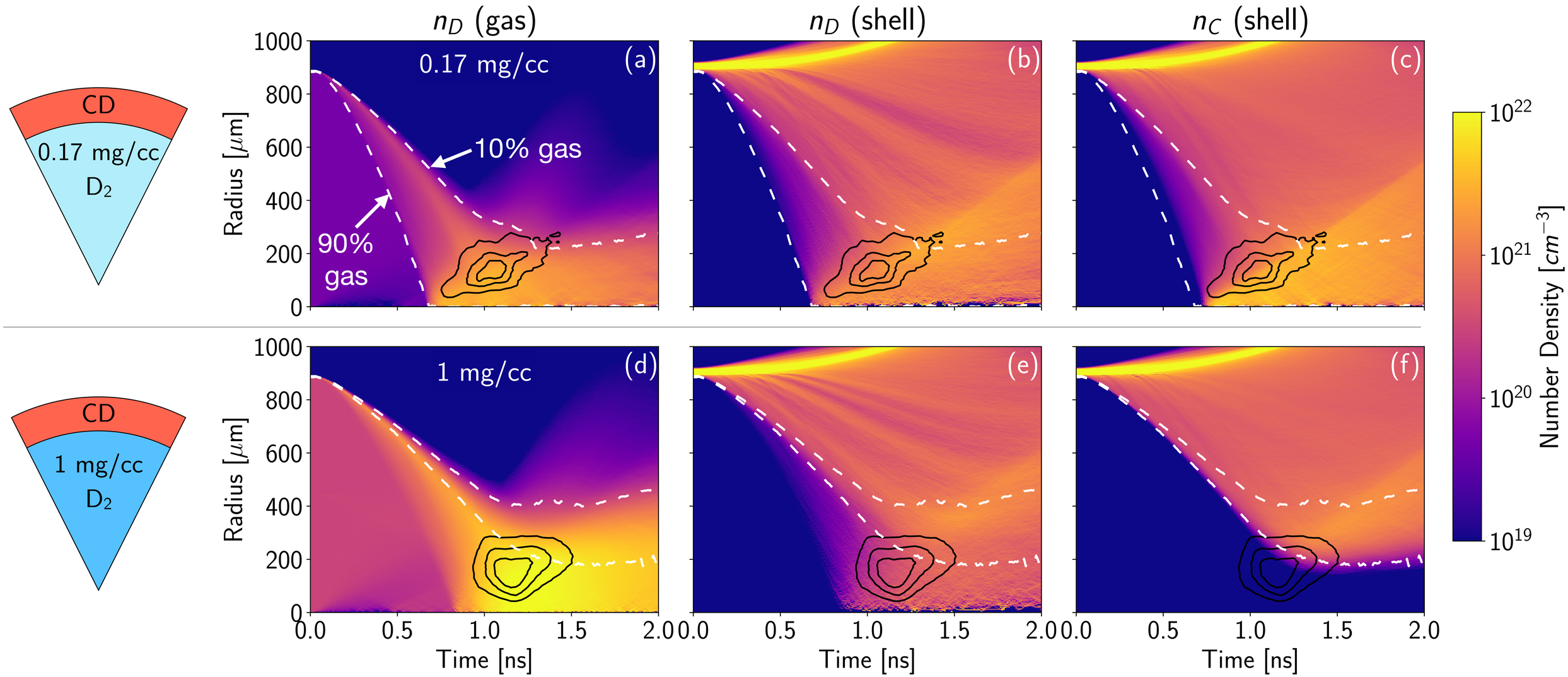
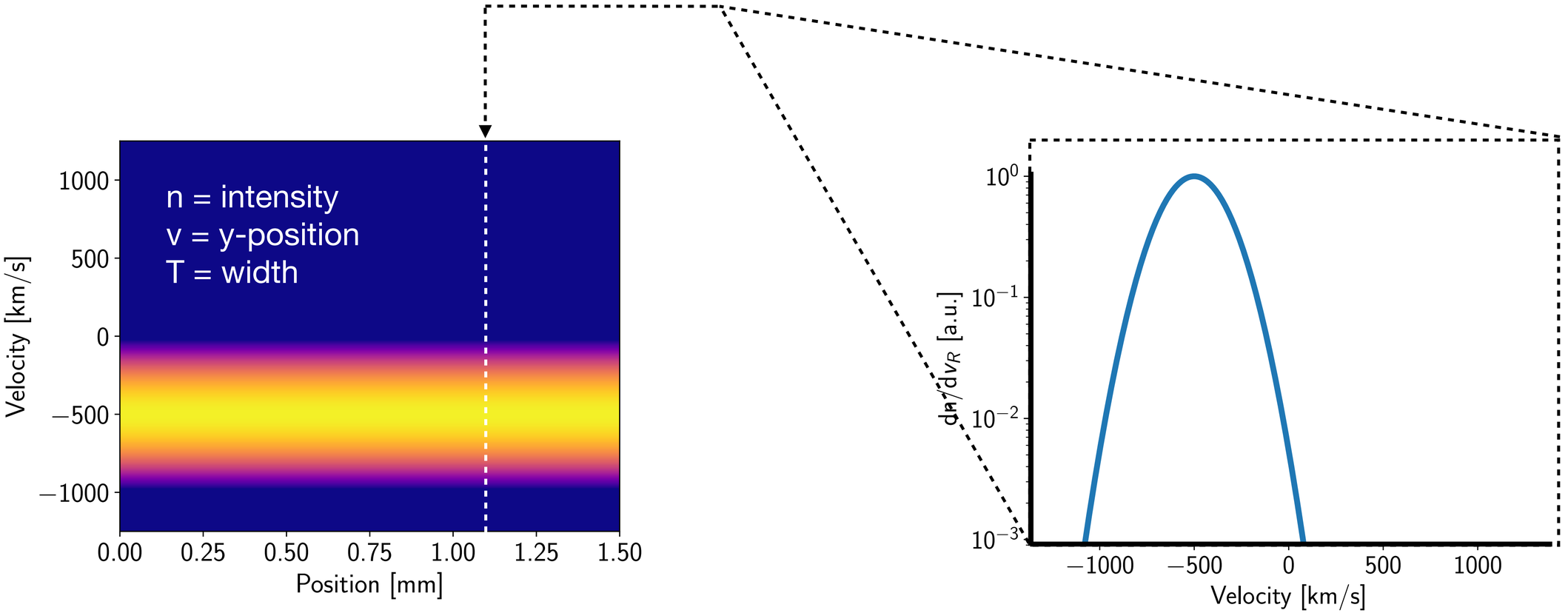


Phase-space diagrams



- A vertical lineout of the plot shows the VDF of the plasma at that position in space

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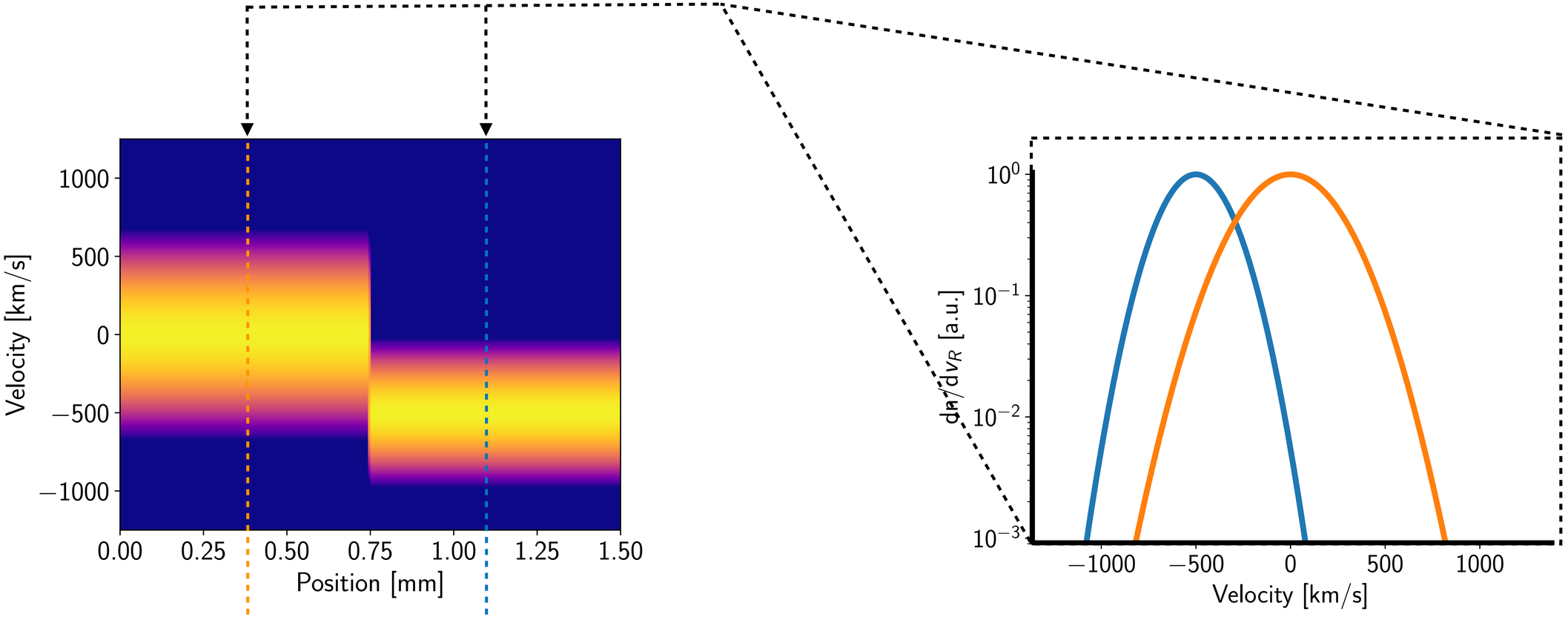
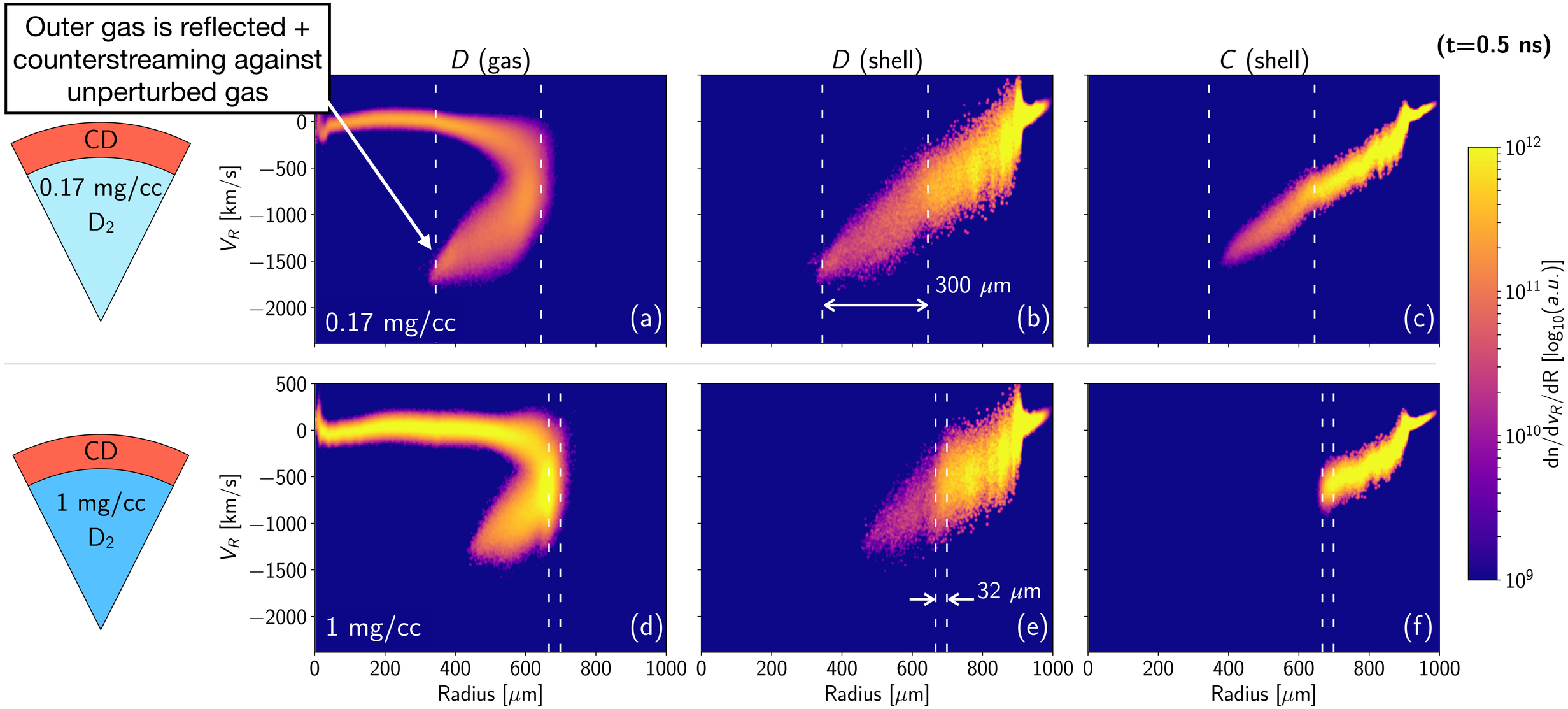


- A vertical lineout of the plot shows the VDF of the plasma at that position in space

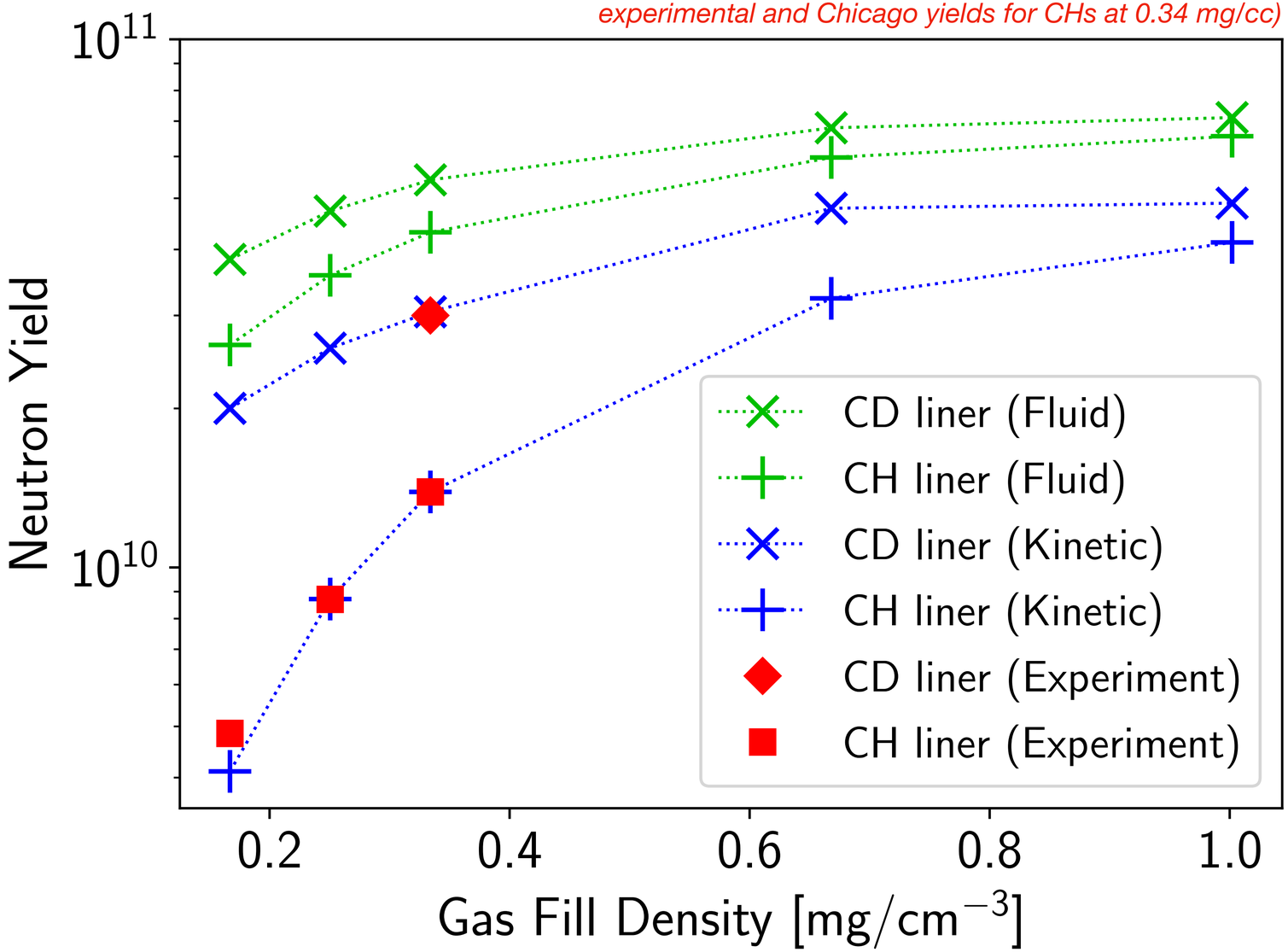
There is significant non-Maxwellian behavior at gas-shell interface



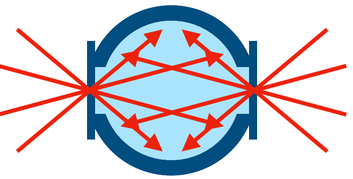
Gas-shell mix reduces yield for targets with non-reactive shell

- Experimental data matches simulated pressure scaling well
- Suggests 1D kinetic treatment is sufficient to capture mix process

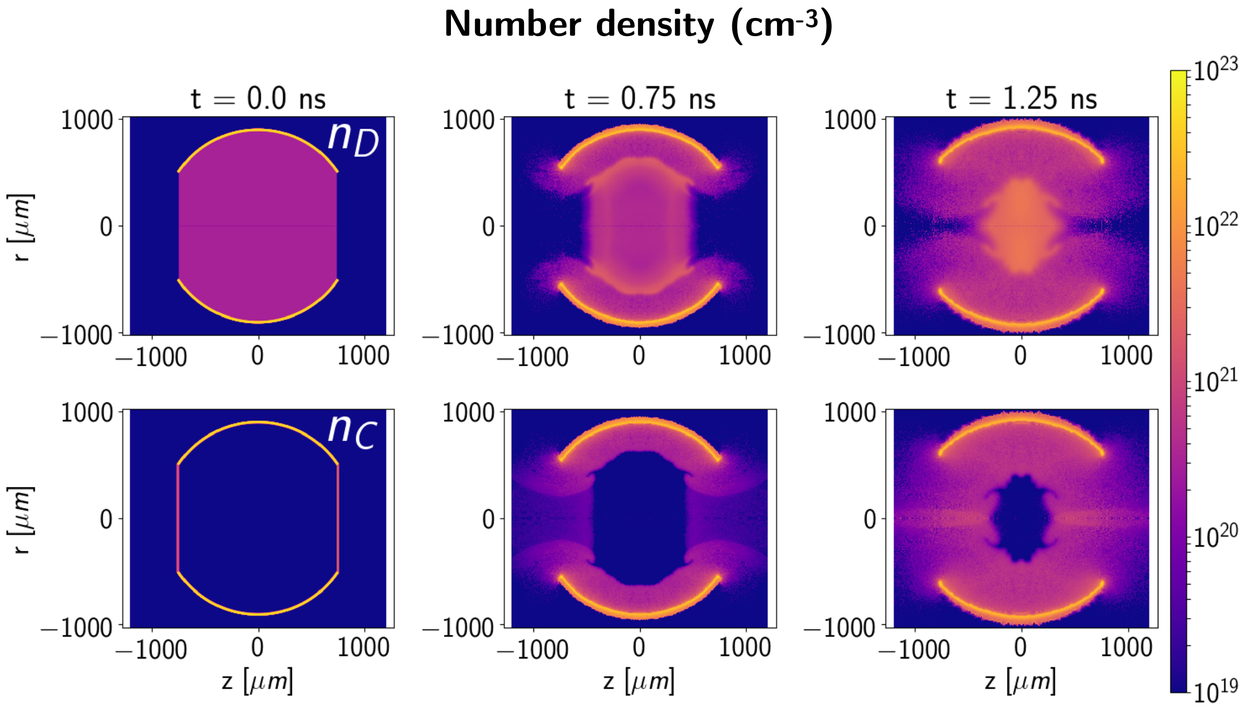
Note: all simulations scaled down by a factor of 6.5 (to match experimental and Chicago yields for CHs at 0.34 mg/cc)

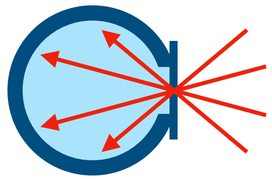


We extend simulations to 2D to investigate shape effects

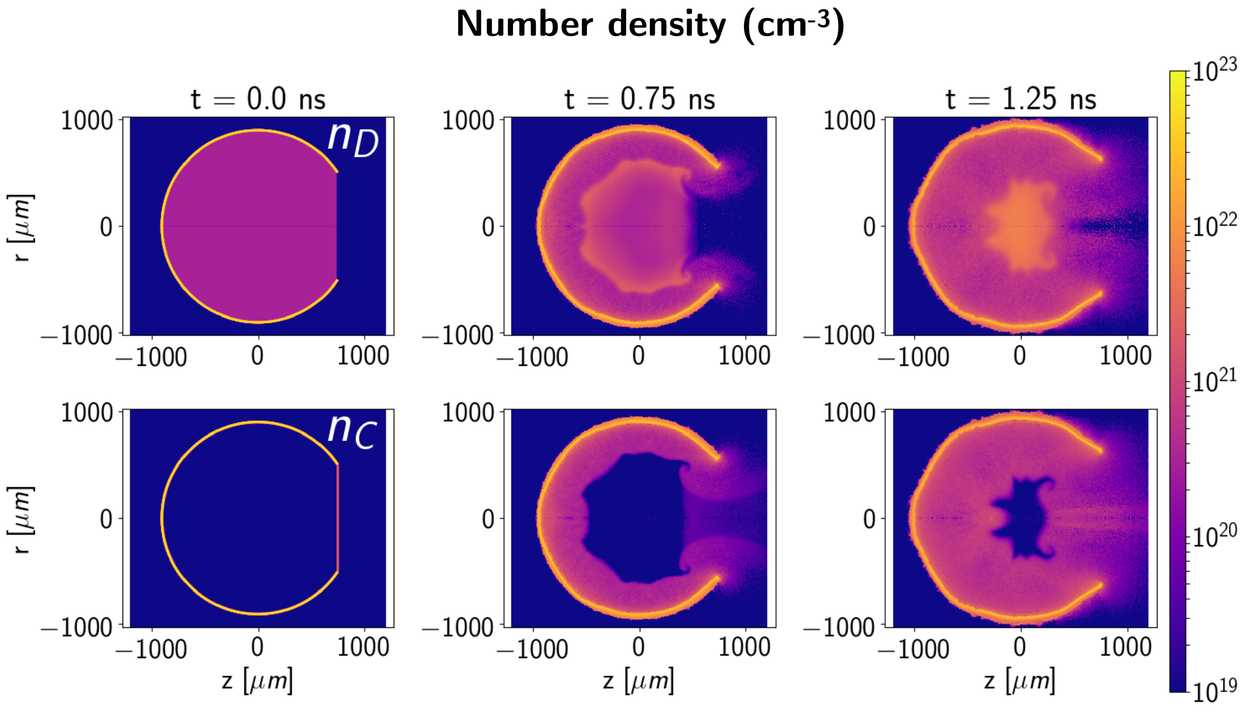


Gas-fill Target: 2 LEH



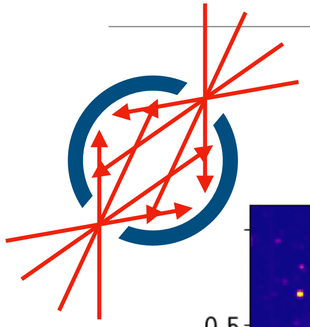


Gas-fill Target: 1 LEH

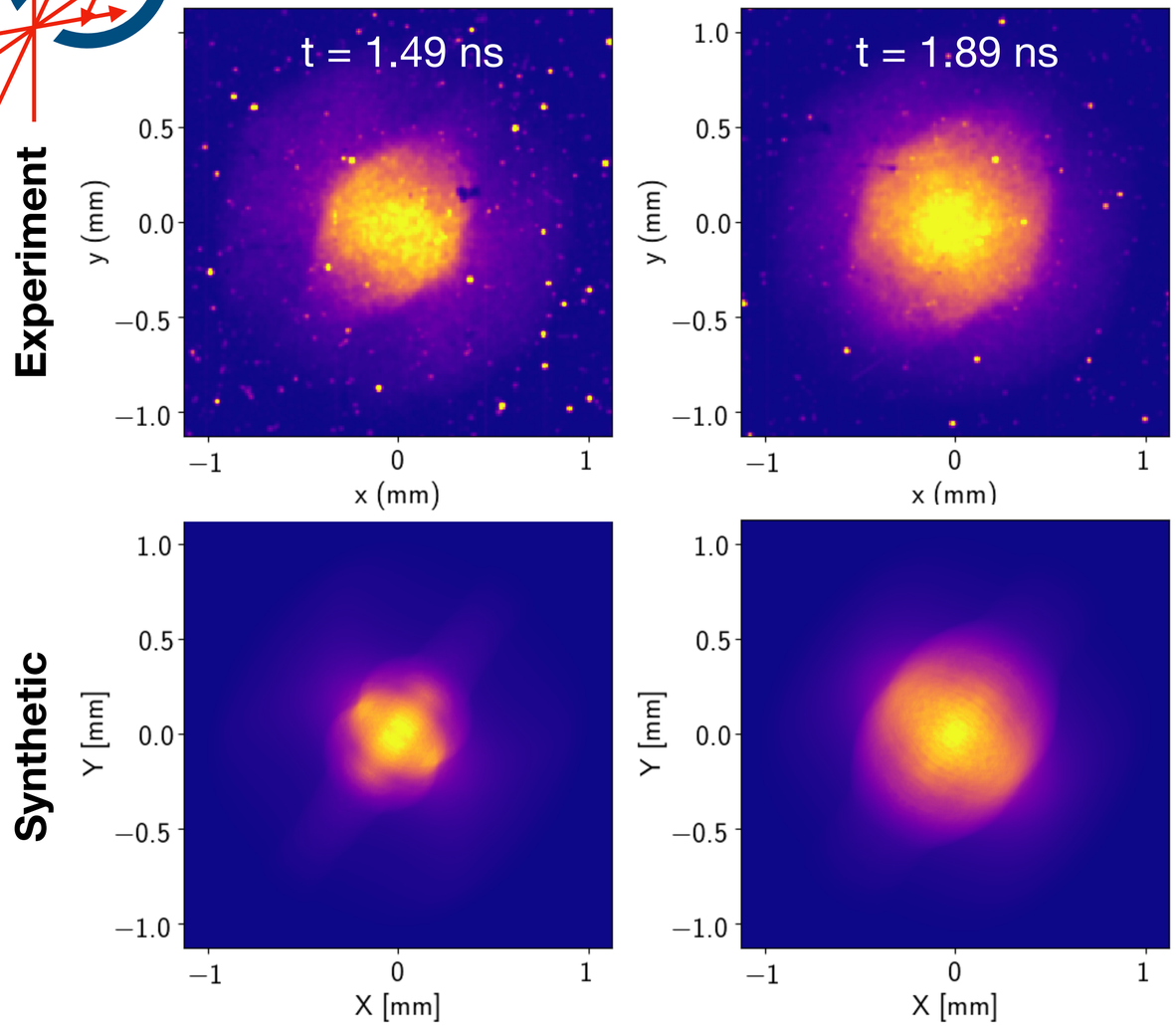


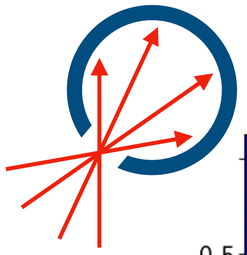
- No significant yield degradation with single-sided illumination

Synthetic x-ray images show good agreement with experiment



Vacuum Target: 2 LEH





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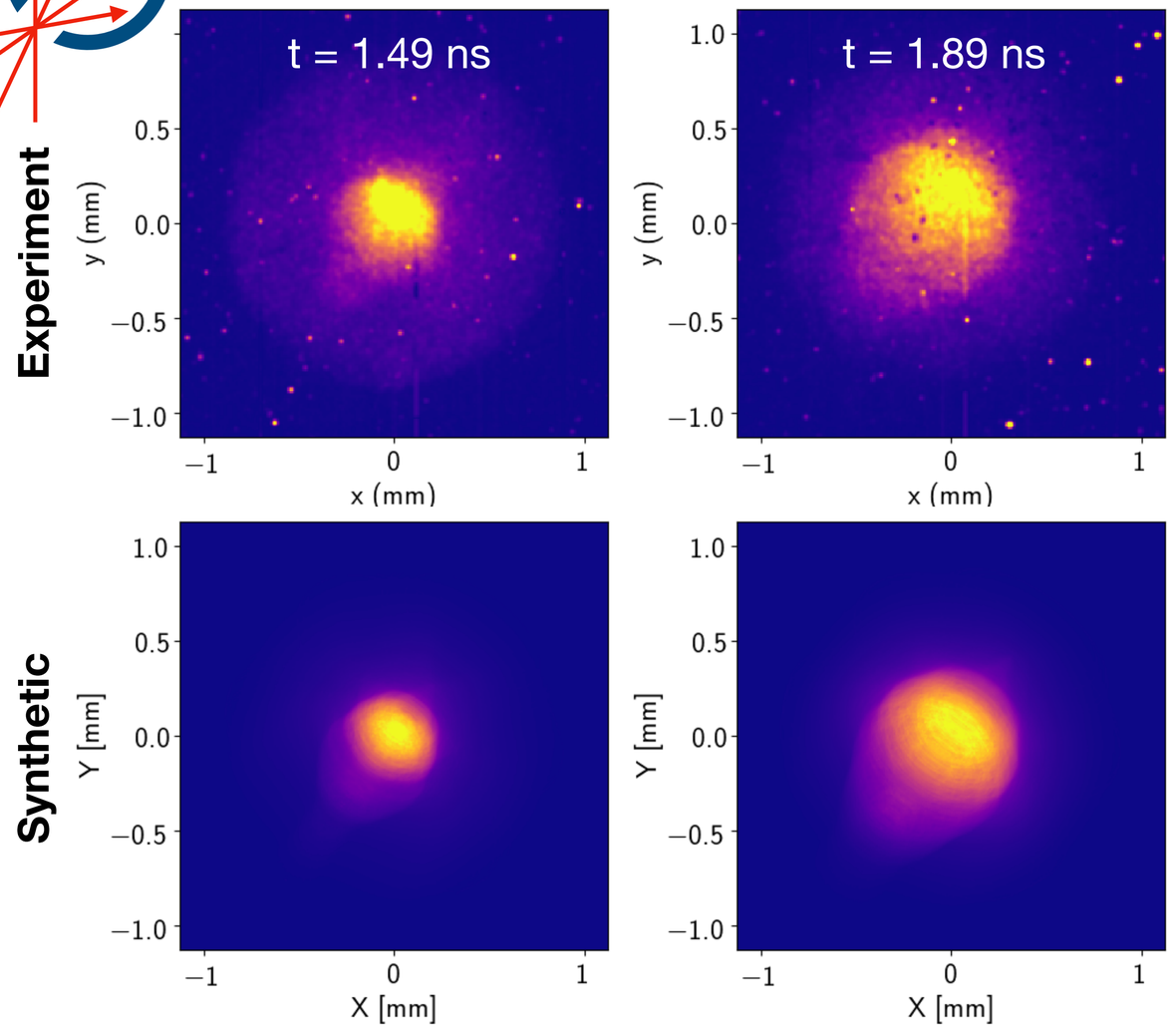
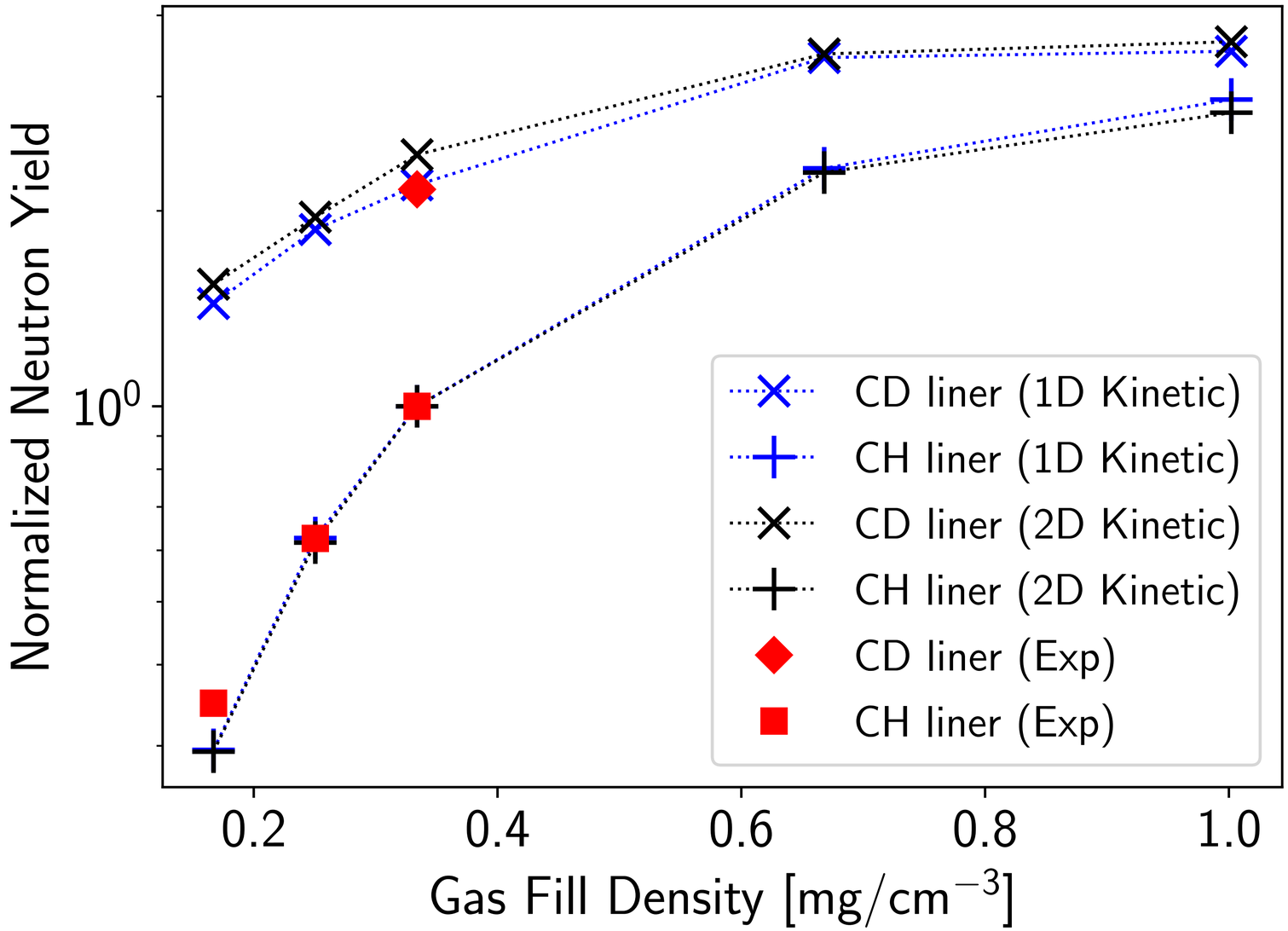


Relative yield scaling is still reproduced

- Yield is reduced by ~2X when modeled in 2D (still overpredicting by ~3X)
- Relative yield behavior is consistent

Note: all simulations normalized to the value of a CH liner target at 0.3 mg/cc



Conclusions

- Fluid approximation breaks down in certain regimes of ICF
- Consequences of interpenetration and mix can be observed experimentally
- Kinetic-ion simulations can predict observed plasma behavior more accurately than typical fluid approach

Acknowledgments

- Mark Cappelli
- Nathan Meezan
- Drew Higginson
- Matthias Hohenberger