Modeling Turbulent Mixing in Inertial Confinement Fusion Implosions

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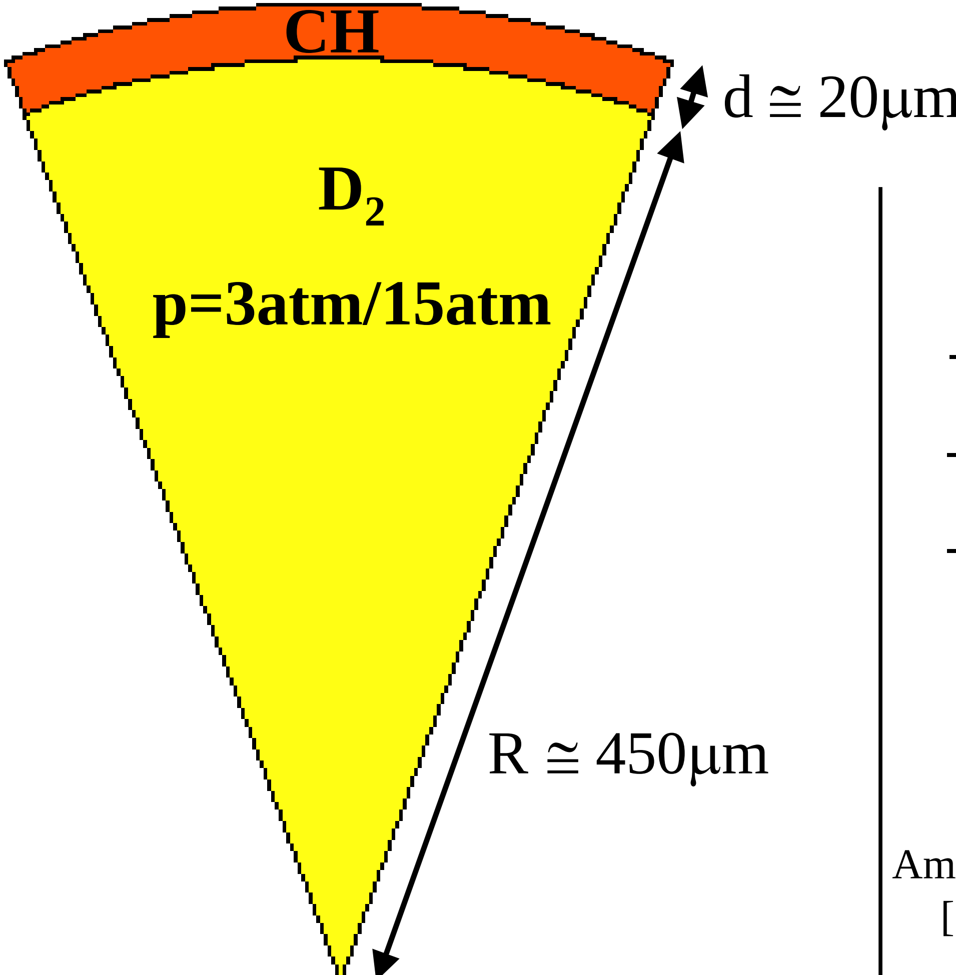
Experiments



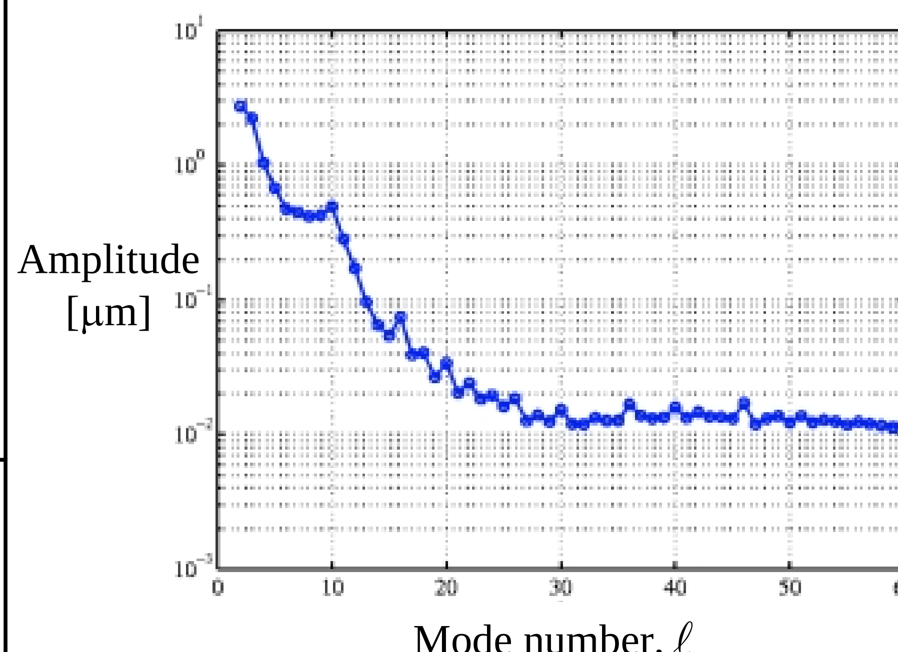
Experiments held at Laboratory for Laser Energetics, U. of Rochester

Laser :

E ≅ 20kJ t ≅ 1ns

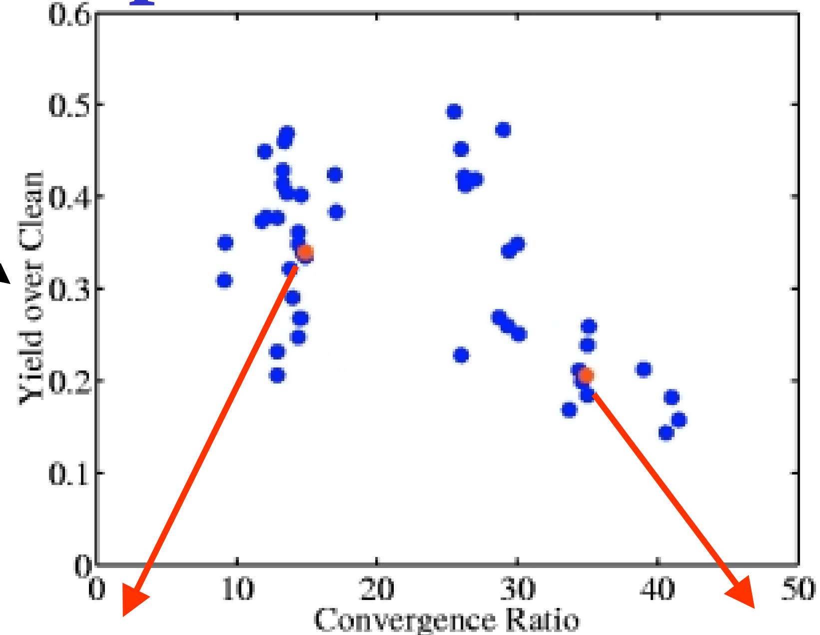
Perturbations :

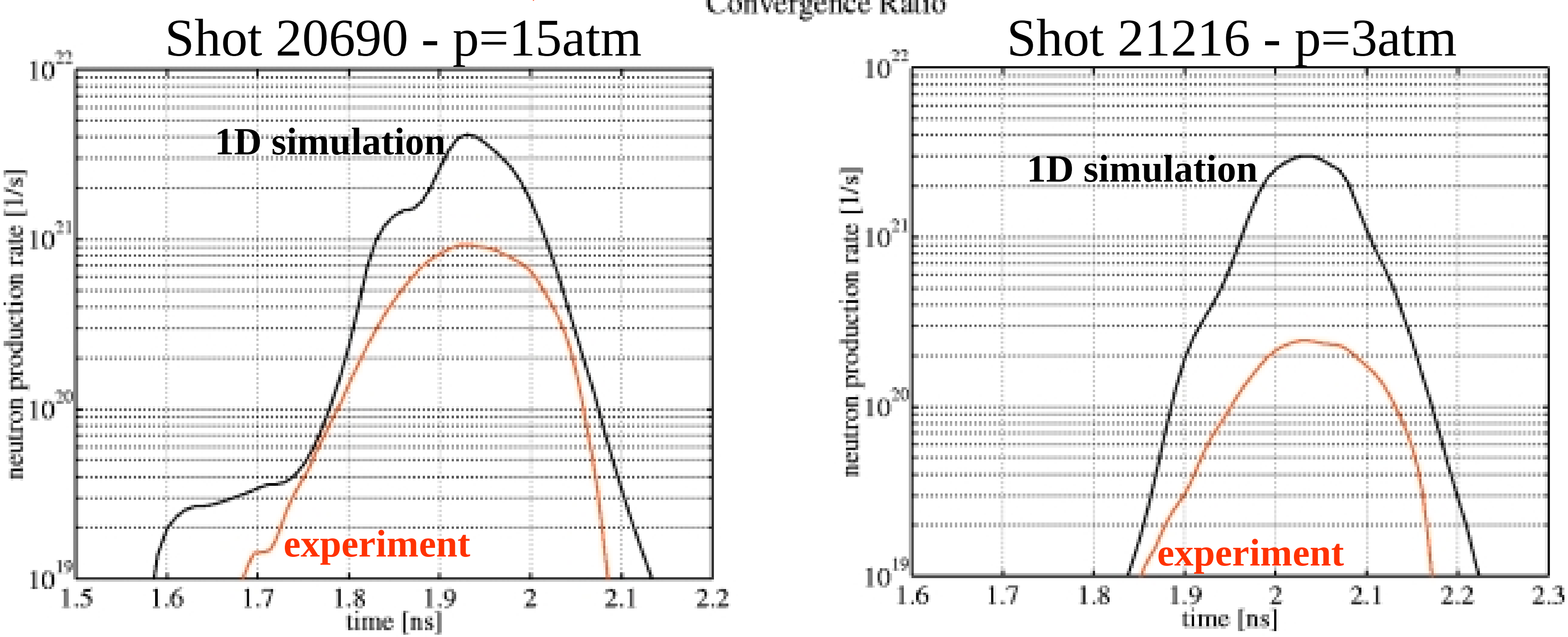
- Surface roughness (outer and inner)
- Power imbalance between beams
- Beam nonuniformity (1THz 2D-SSD)



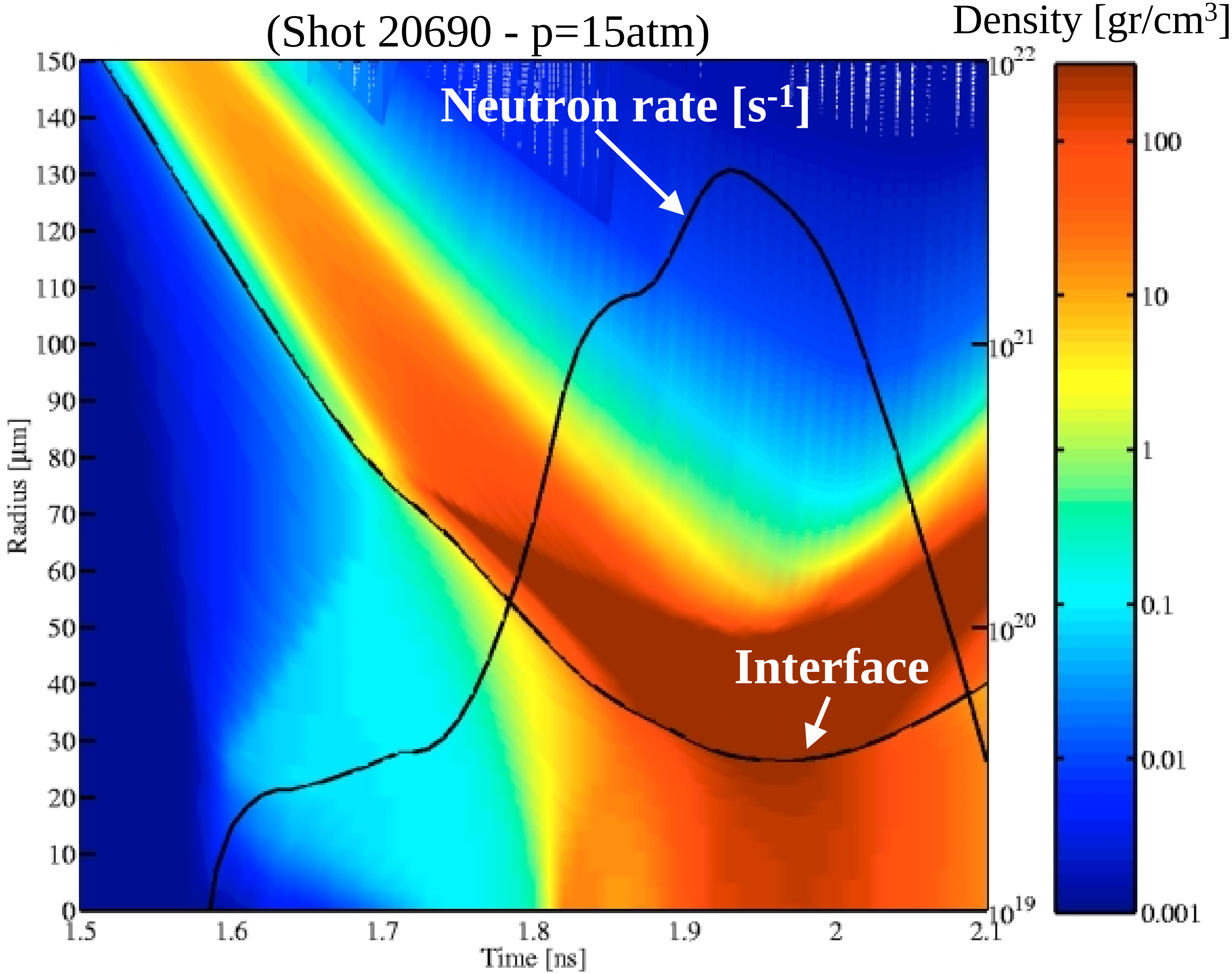
Experimental results

$$\text{Y.O.C.} = \frac{Y_{exp}}{Y_{1D}}$$





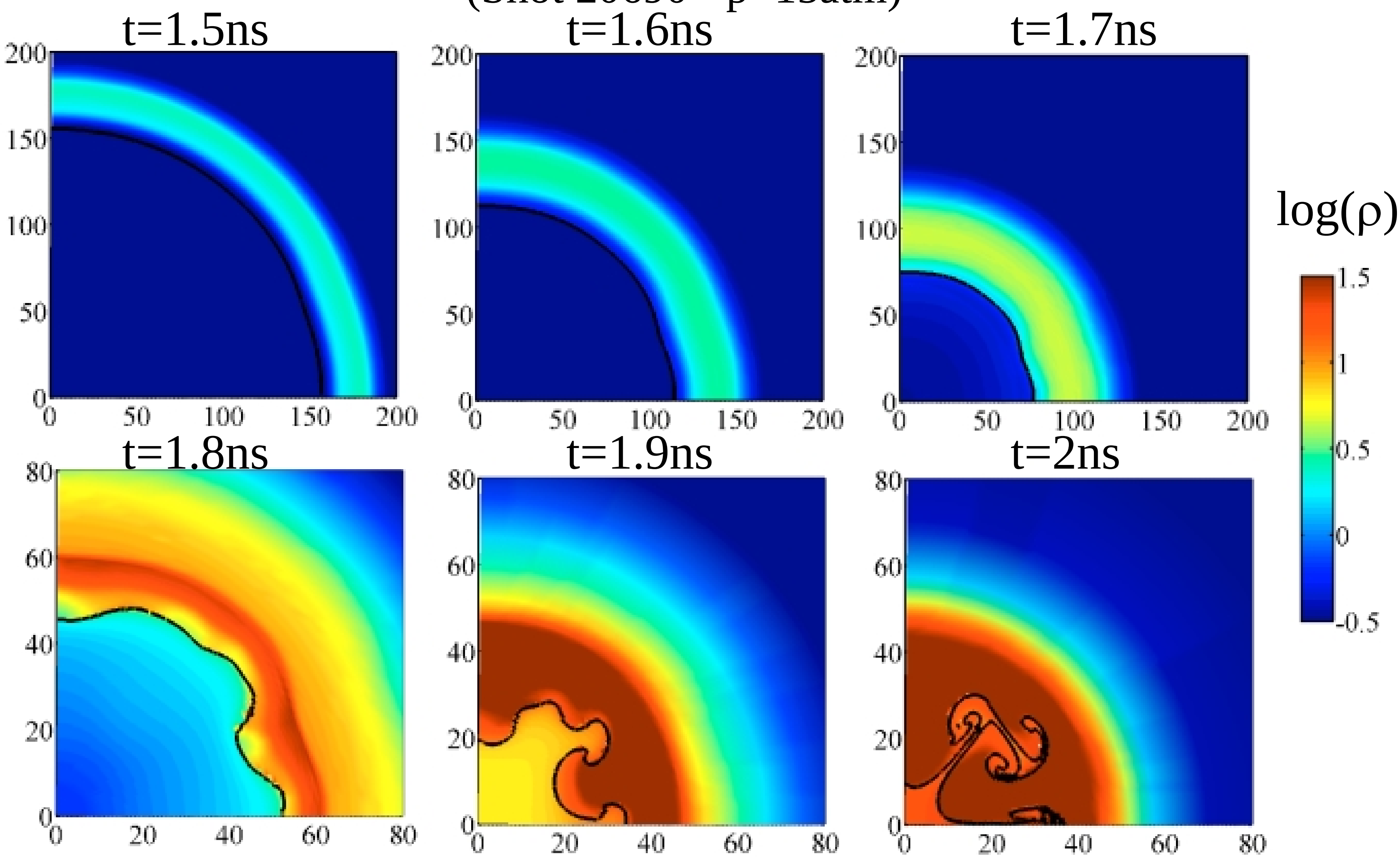
1D Simulation



Fusion rate is dominated by shock dynamics

2D multi-mode simulation

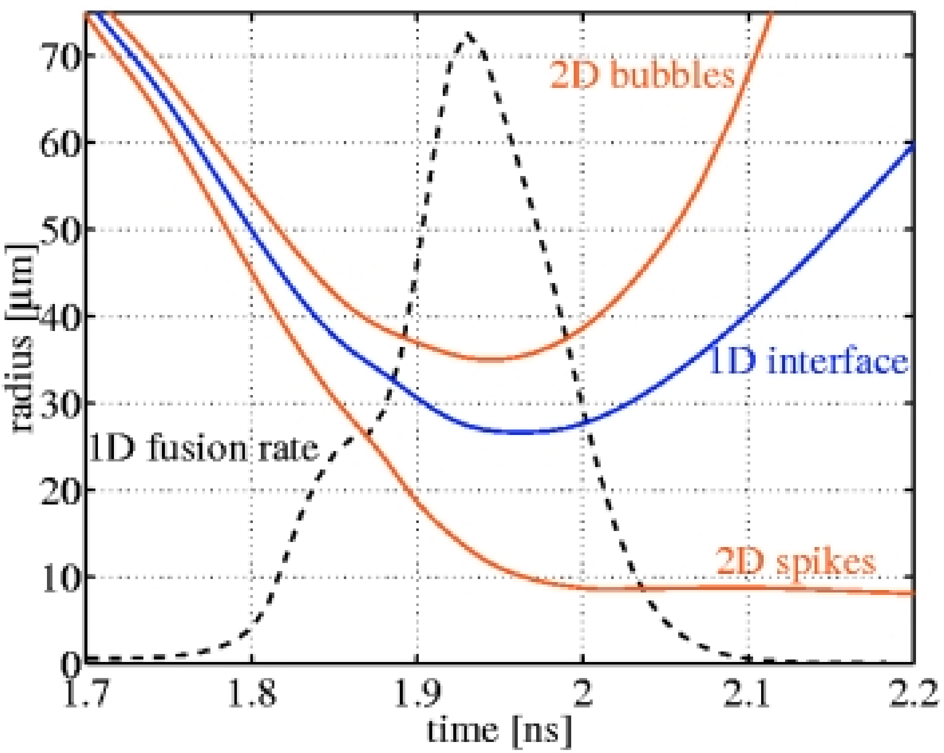
(Shot 20690 - p=15atm)



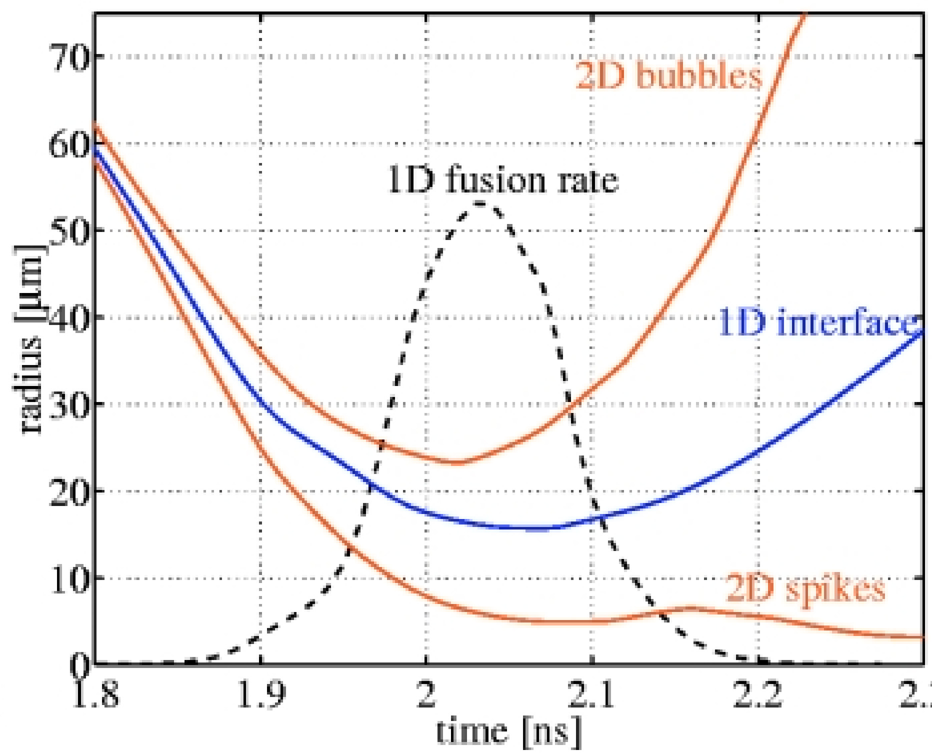
Perturbation dominated by power imbalance ($\ell \approx 6$)

Bubble and spike growth

Shot 20690 - p=15atm

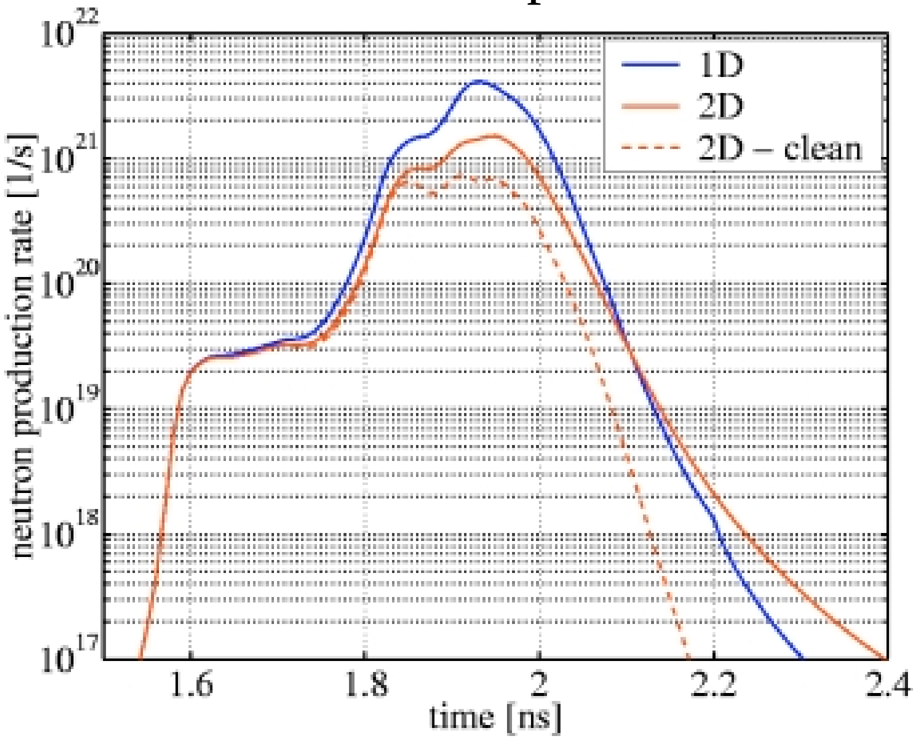


Shot 21216 - p=3atm

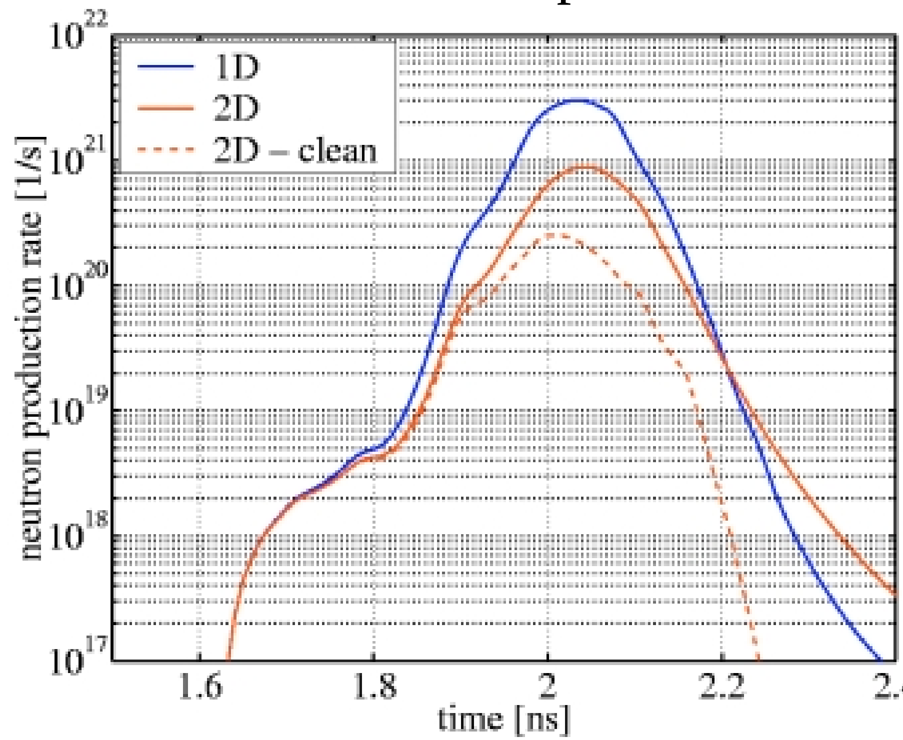


Neutron yield

Shot 20690 - p=15atm

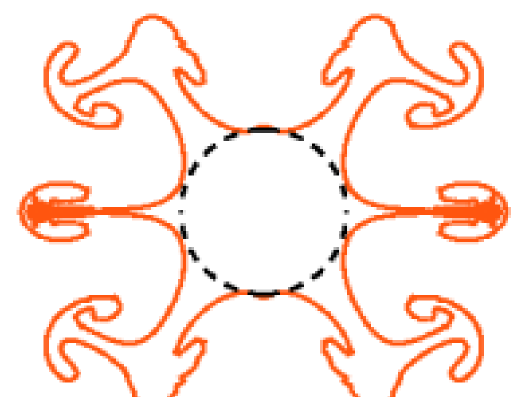


Shot 21216 - p=3atm

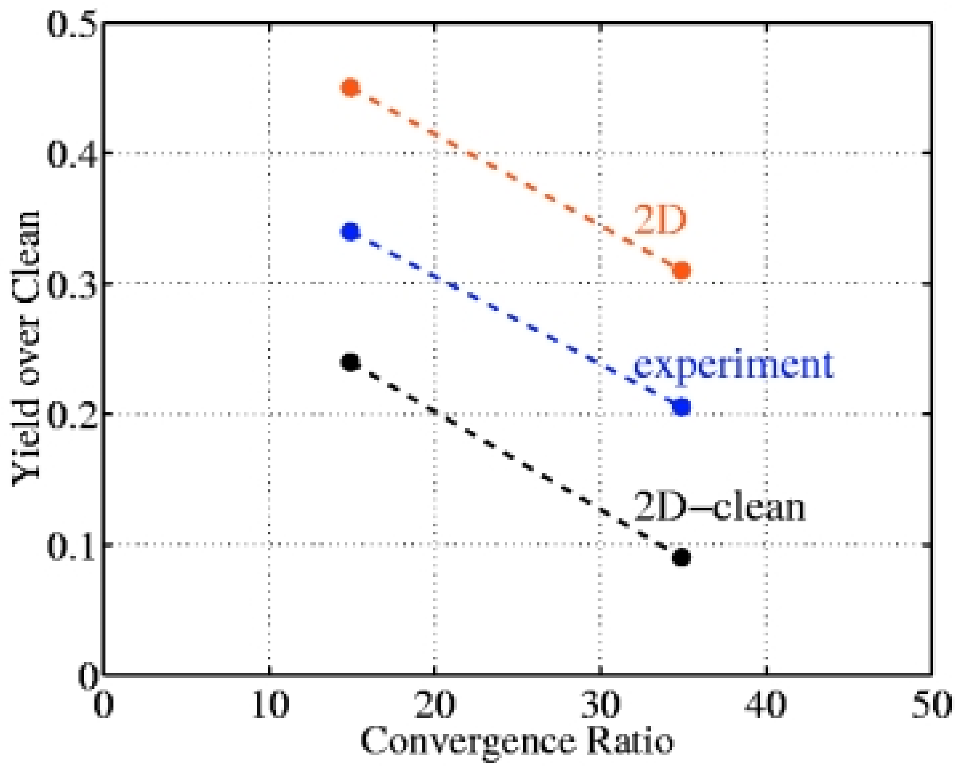


- 2D yield lower by factor 2-3 from 1D.
- Fully developed turbulent mixing:

Worst case - fusion only in clean zone defined by most penetrating spike.



Neutron yield degradation

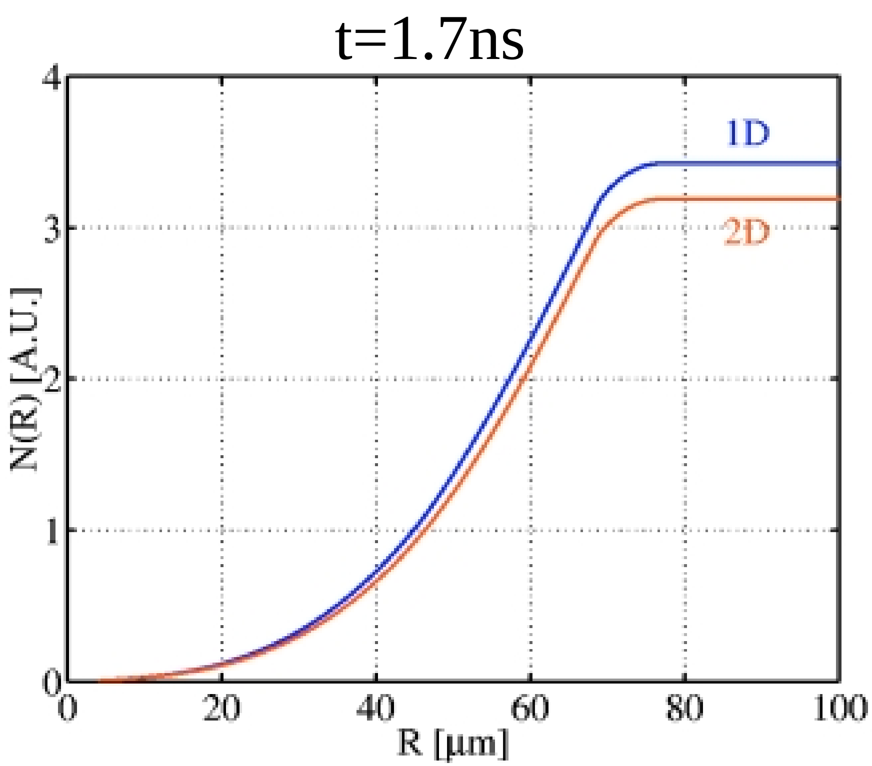


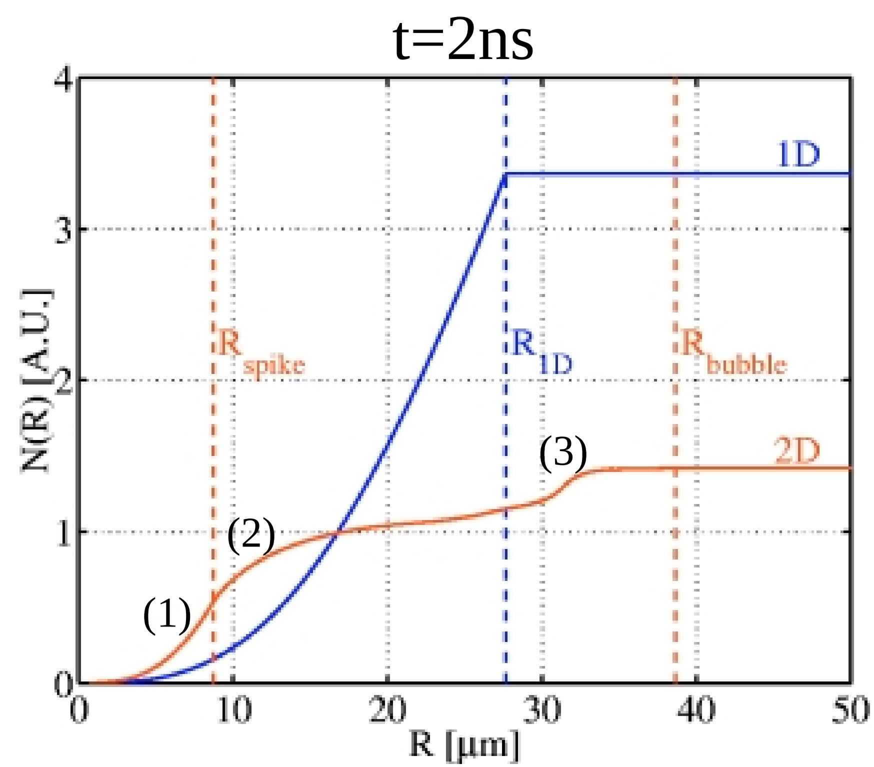
- 2D simulations underestimate degradation.
- Assuming fusion only in clean area overestimates degradation.

Cumulative fusion rate

$\left(N(R) = \int_0^R n(r)d^3r\right)$

(shot 20690 - p=15atm)



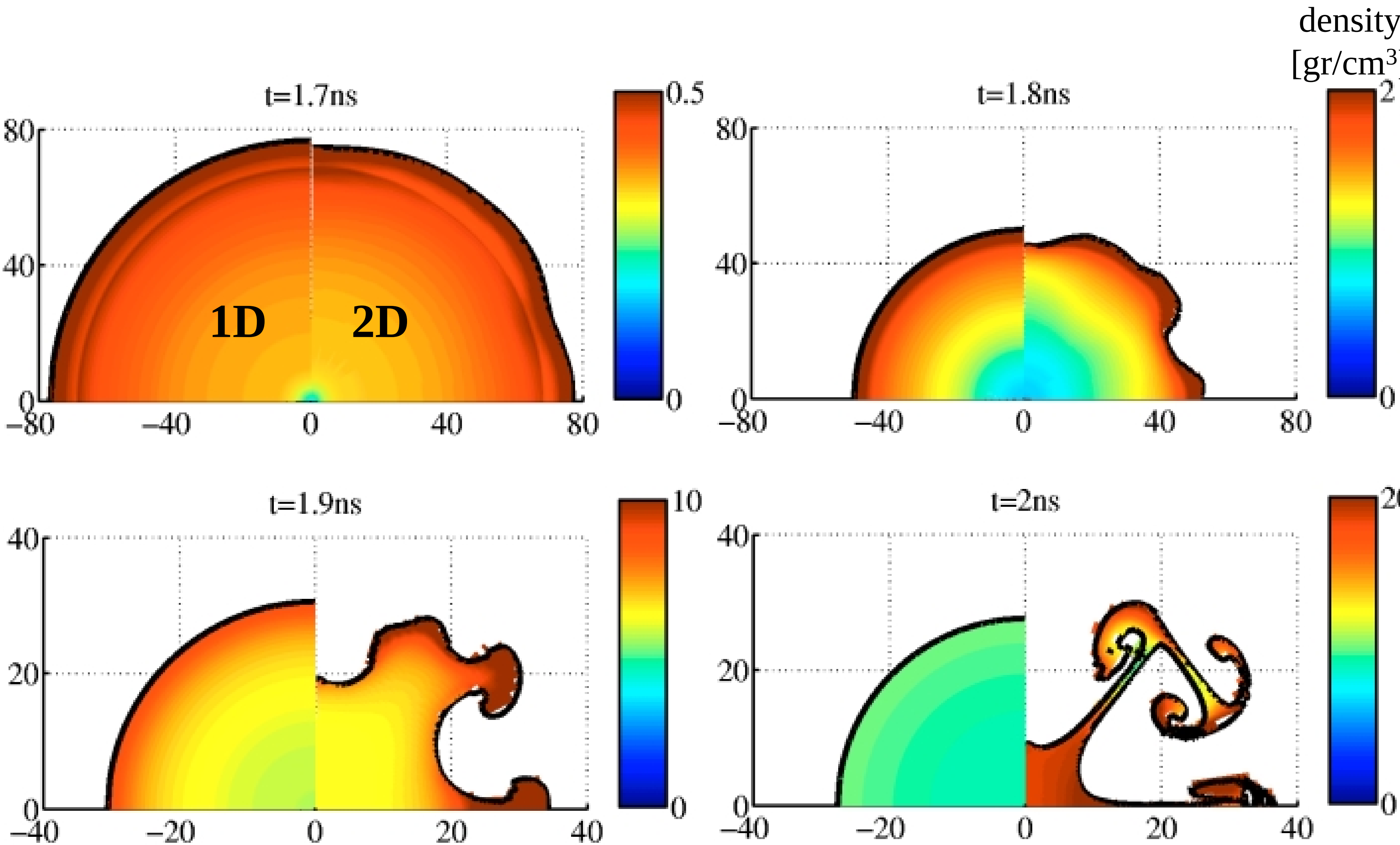


1) Higher 2D yield from central region.

2) Slight redefinition of R_{clean} will significantly change yield.

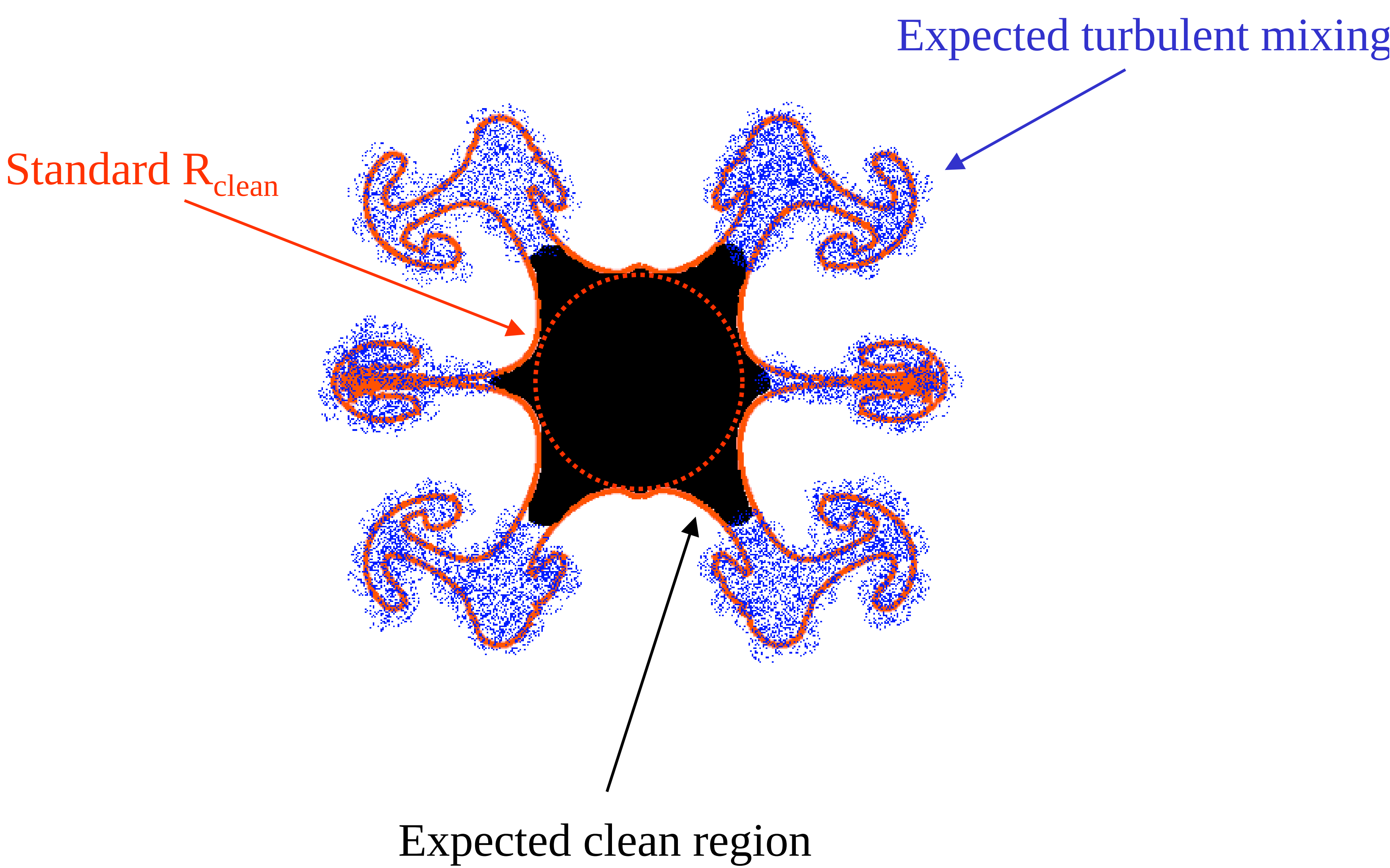
3) Contribution of bubbles to fusion yield.

Difference in yield from central region

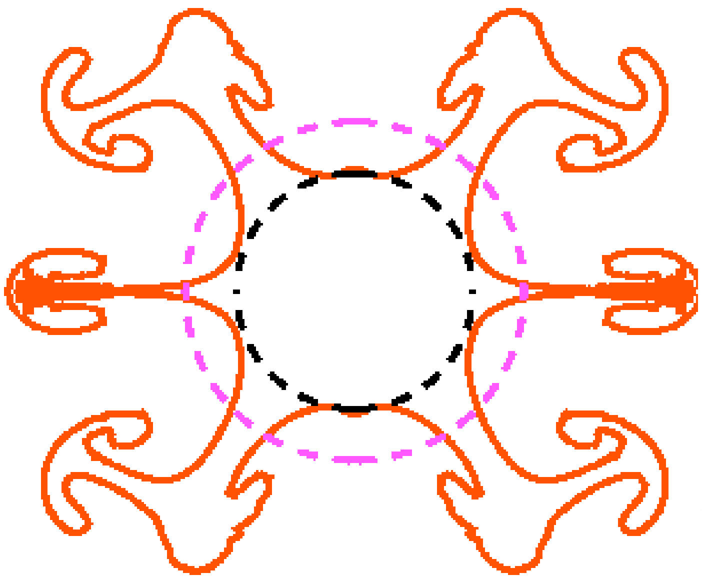


2D central density is higher due to differences in shock dynamics.

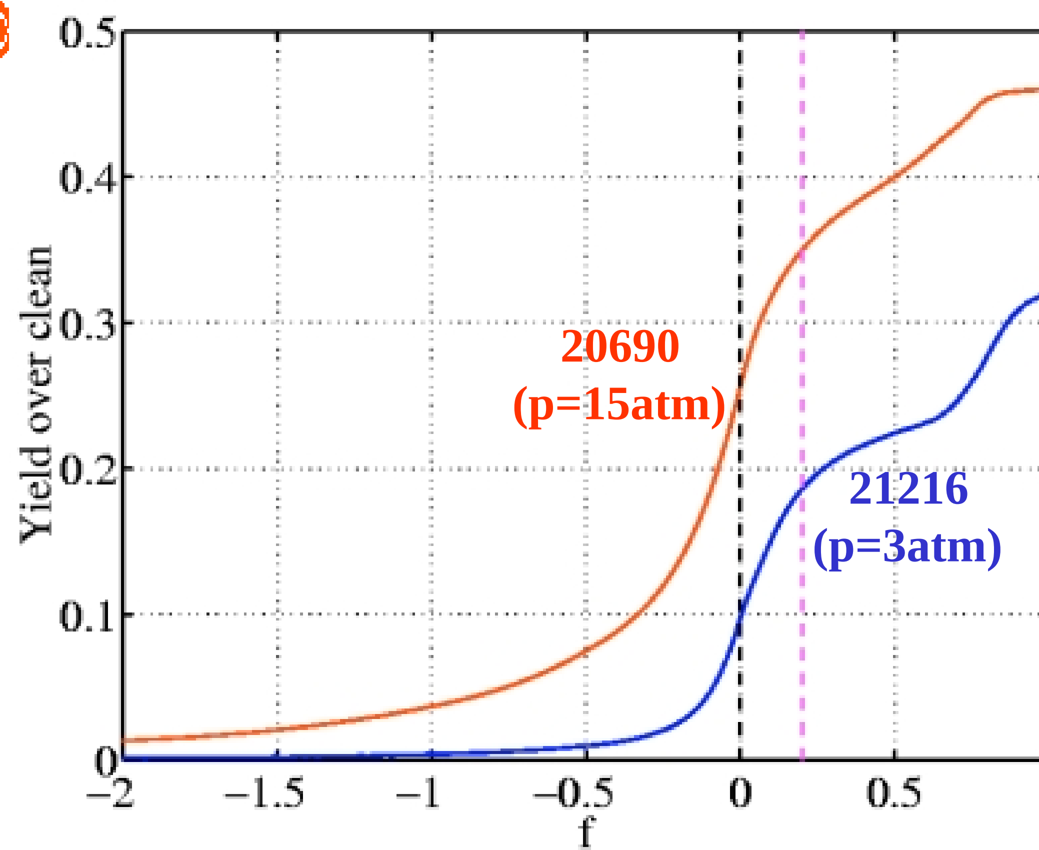
Redefinition of clean region



Redefinition of R_{clean}

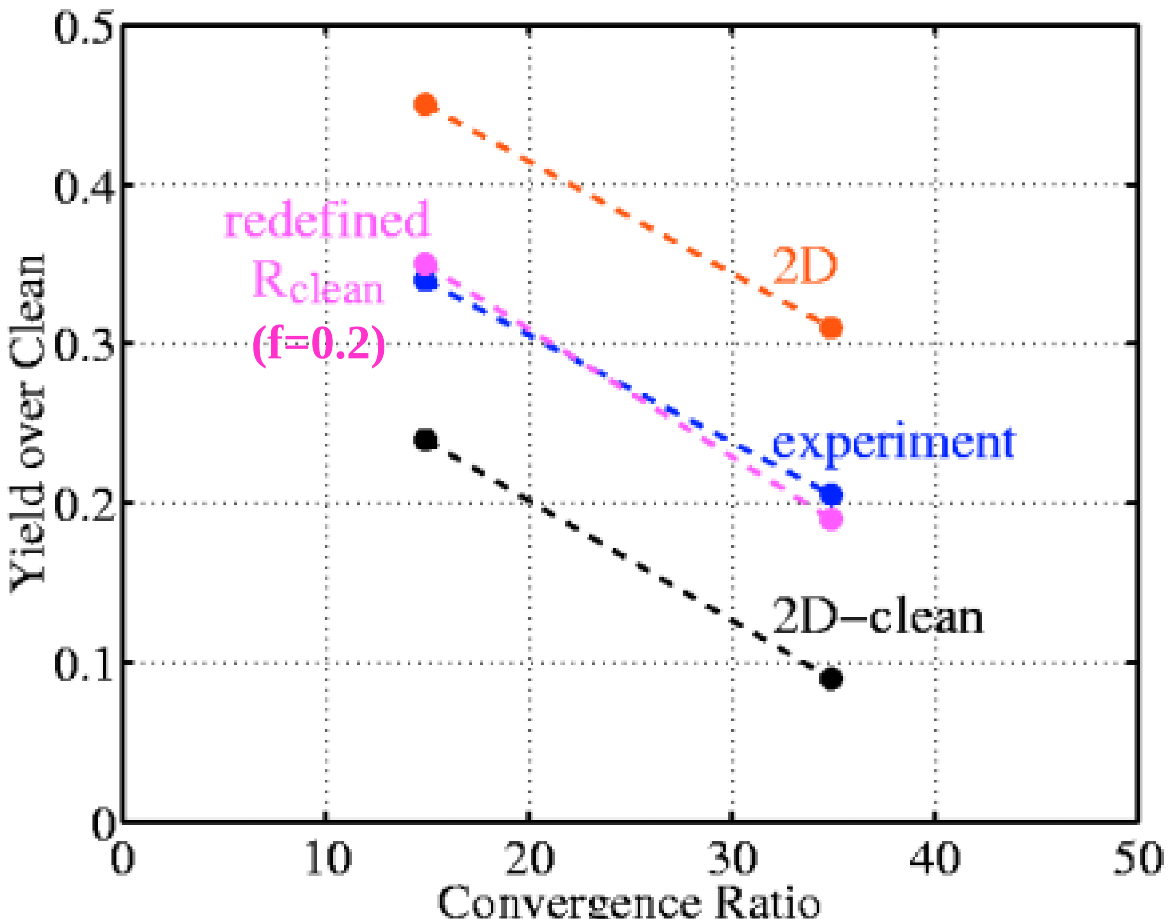


$$R_{clean}=R_{spike}+f(R_{bubble}-R_{spike})$$



Sharp rise ends at f=0.2, coinciding with clean region boundaries.

Re-definition of clean region improves agreement with experimental results



Conclusions

- Recent ICF experiments have been analyzed by comparing full 2D and 1D numerical simulations.

- Assuming no mixing, bubbles raise fusion yield above experimental results.

- Differences in central pressure, density and fusion rate at high perturbation amplitudes imply that mix effects are not limited to the mix region, hence full 2D simulations are needed.

- Regions slightly beyond R_{clean} contribute significantly to fusion yield. New definition for R_{clean} improves agreement with experimental results.