A steady-state approach to implementing laser-plasma instabilities in hydrodynamics codes

Arun Nutter[1*], Robbie Scott[2], Alessandro Ruocco[2], Nigel Woolsey[1]

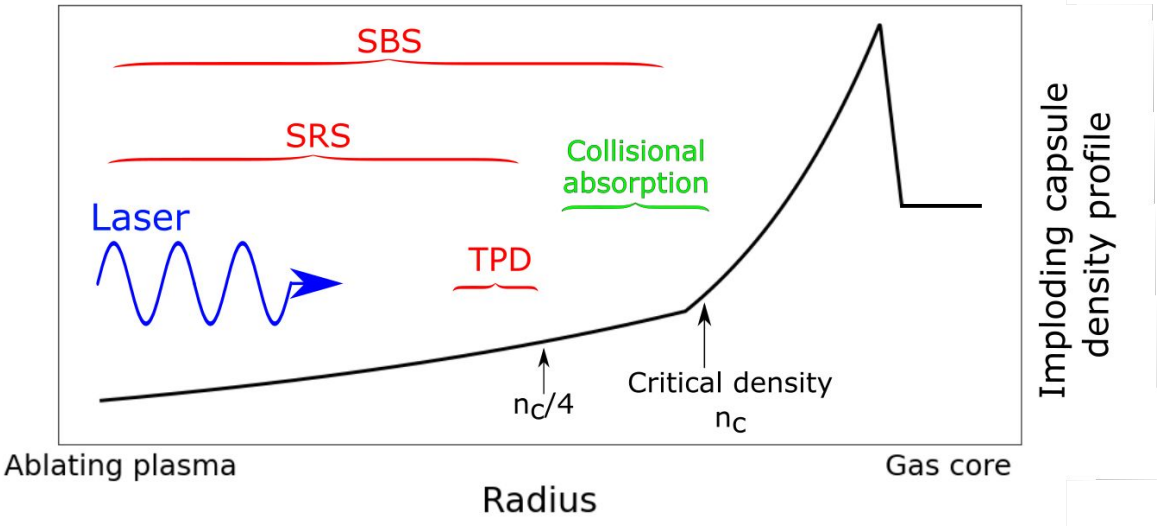
[1] York Plasma Institute, University of York
[2] Central Laser Facility, STFC Rutherford Appleton Laboratory
*avnn500@york.ac.uk

Modelling Inertial Confinement Fusion

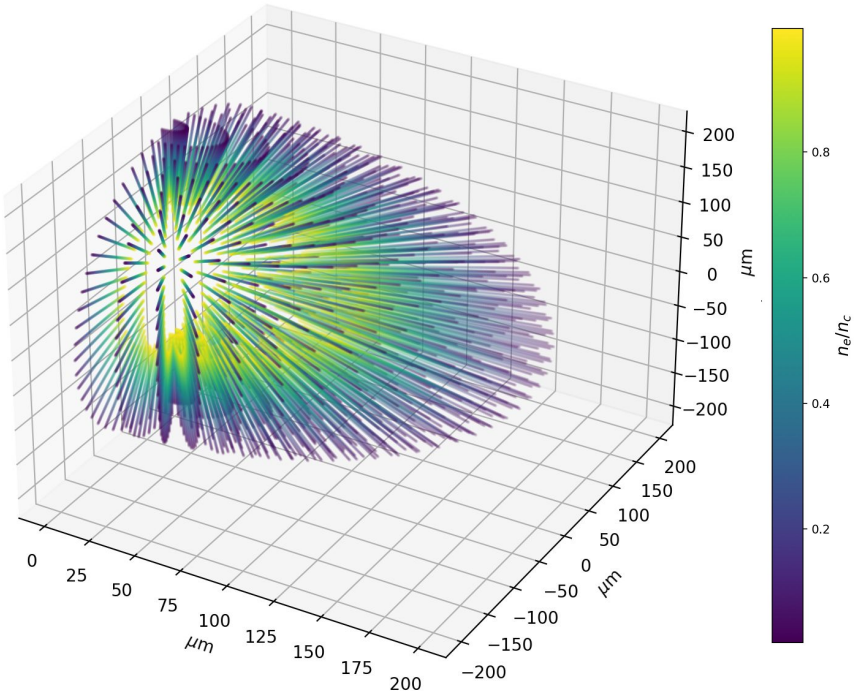
- Experiments are hard to design and analyse due to complexity
- Codes rely on empirical tuning factors
- ICF requires predictive codes to explore wider parameter space
- We are developing a model for laser-plasma instabilities to be included in radiation-hydrodynamics codes

Laser Plasma Instabilities in Direct Drive

- LPI
  - Reduce drive efficiency
  - Absent from implosion simulations
- Our Models
  - Focused on computational efficiency
  - Based on linear theory



Computational methods



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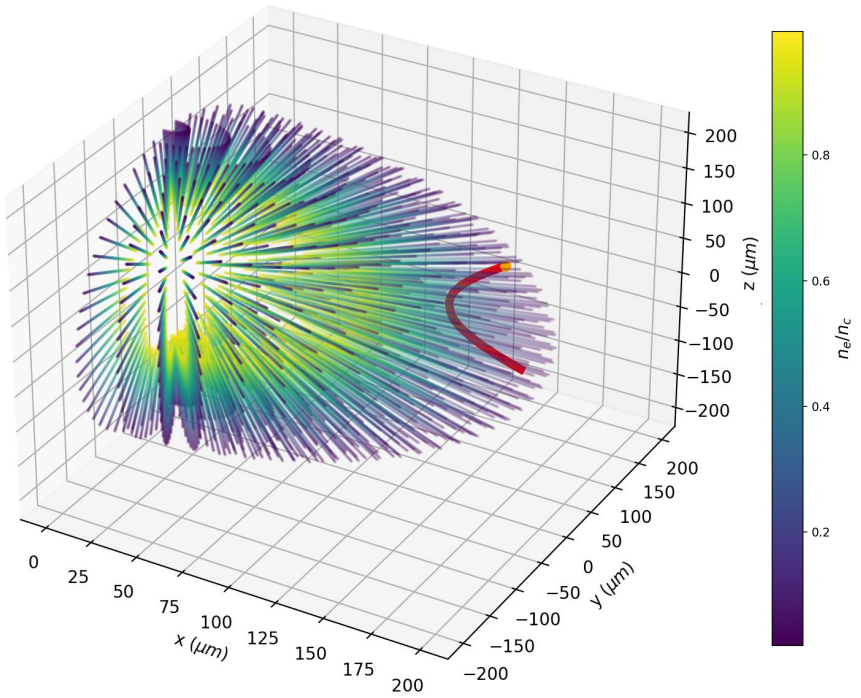

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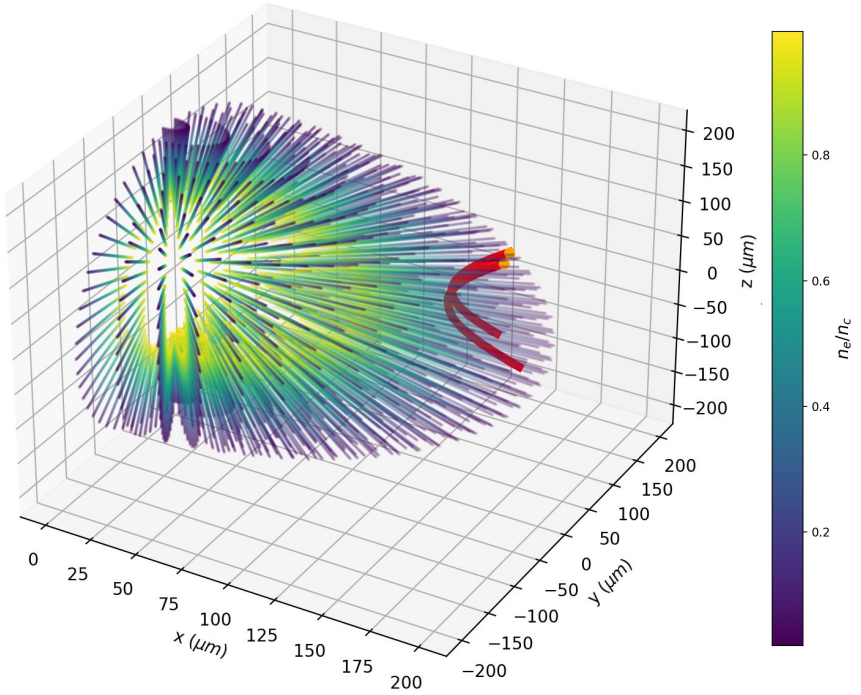

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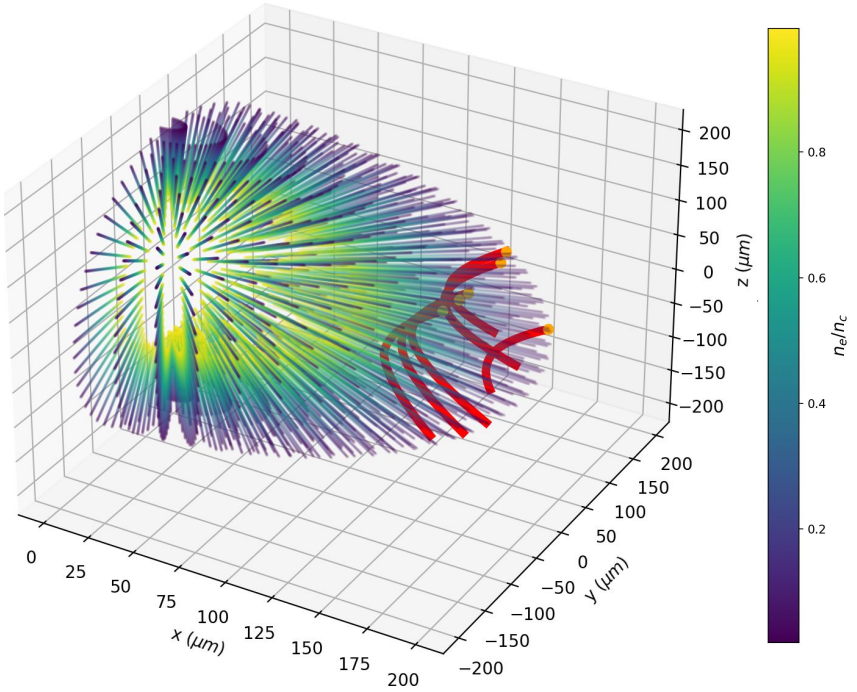
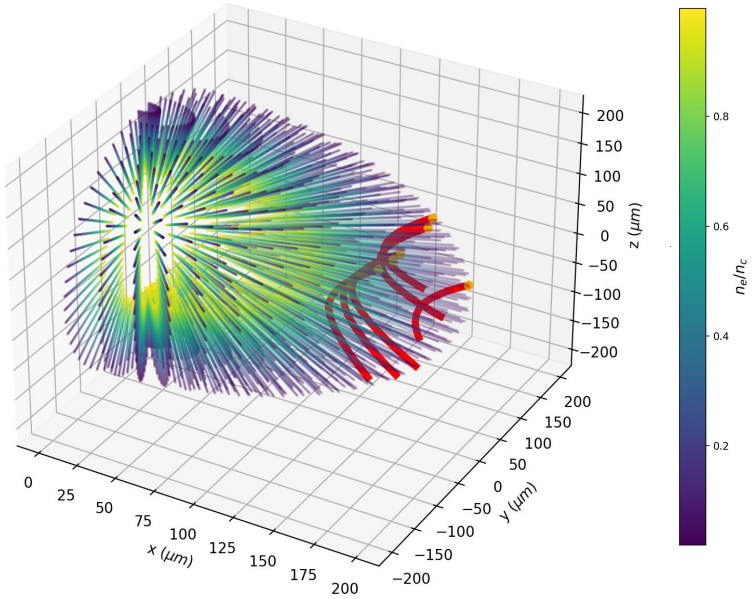


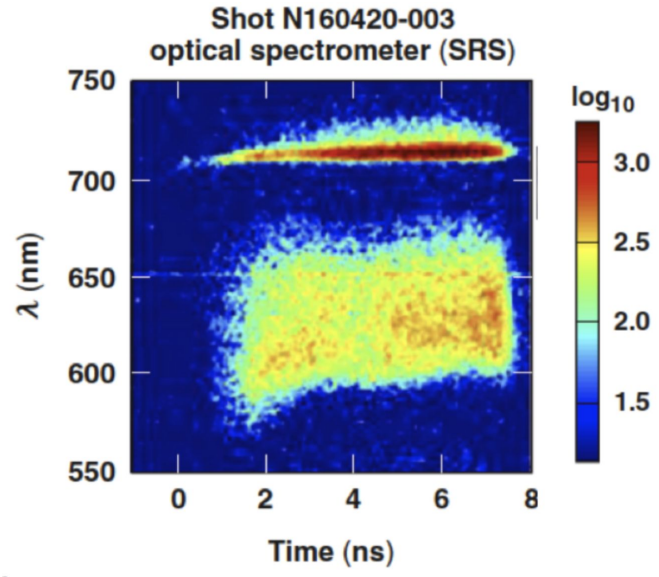
- 900 rays
- Beam power: 2 TW
- Beam intensity: ~5×10^{15} W/cm^2
- L_n ~ 50 μm
- 0.3 keV < T_e < 4 keV
- $T_i = T_e/3$

LPI evaluation

- Growth rates depend on plasma profiles along ray paths
- Steady state LPI levels calculated at each timestep of hydrocode
- Return non-linear LPI effects to hydrocode
  - Ray depletion
  - Hot electrons
  - Electron and ion heating

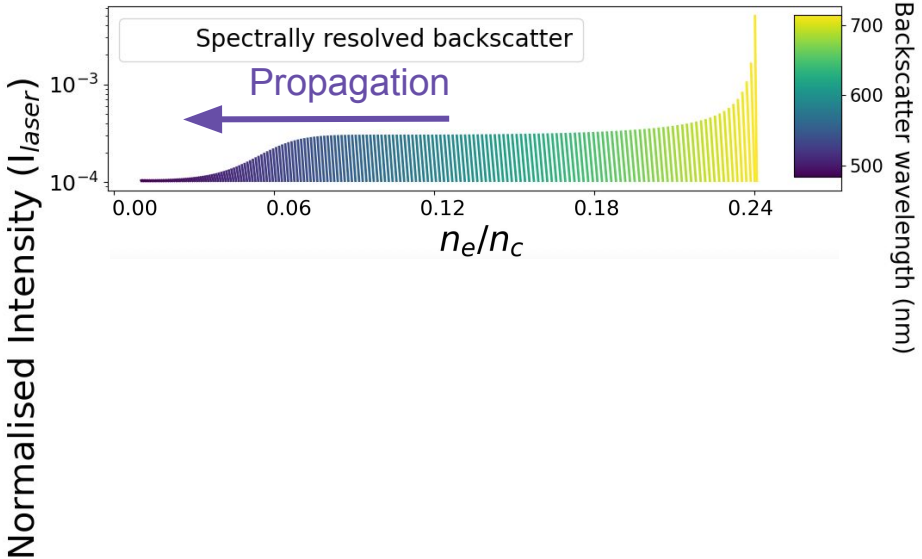


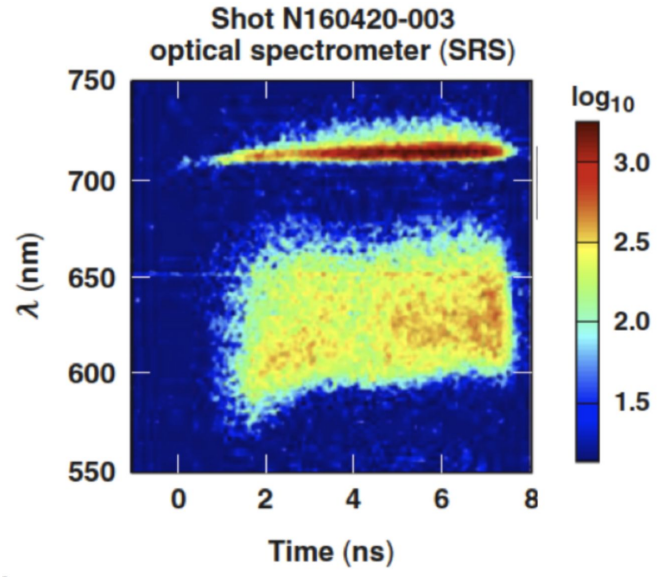
Stimulated Raman Scattering



M. J. Rosenberg, A. A. Solodov, W. Seka, et al. Phys. Plasmas **27**, 042705 (2020).

Convective Stimulated Raman Scattering





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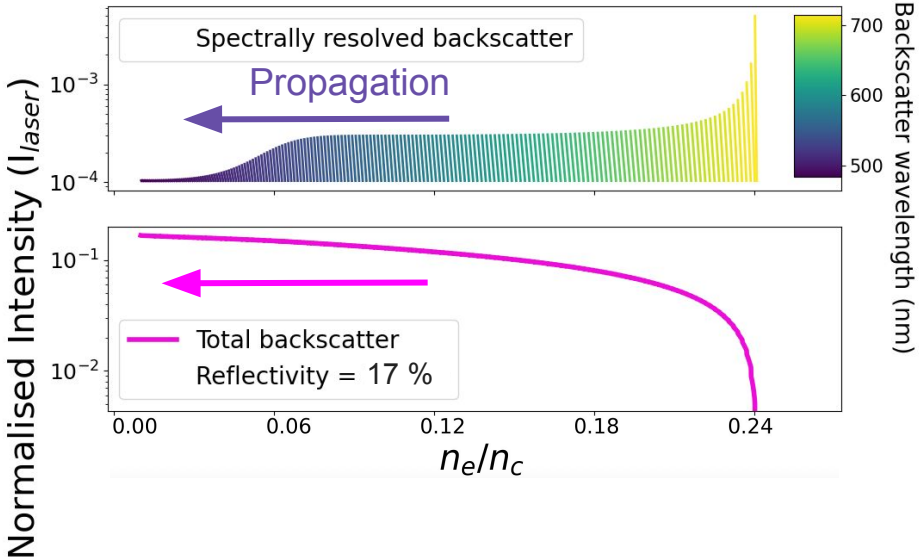
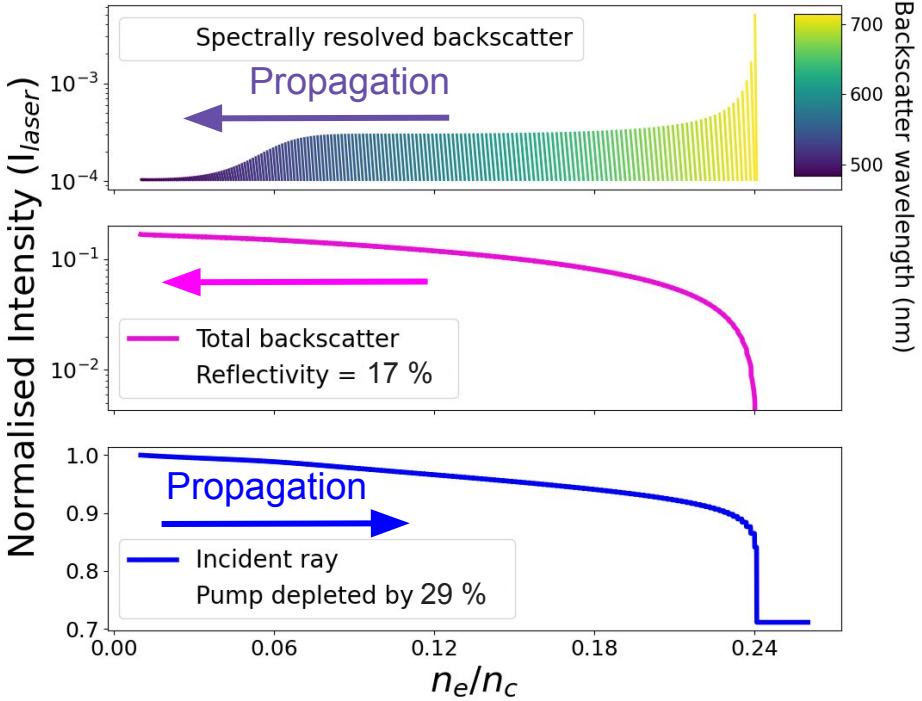


- Sum the scattered light waves to find reflectivity

Convective Stimulated Raman Scattering



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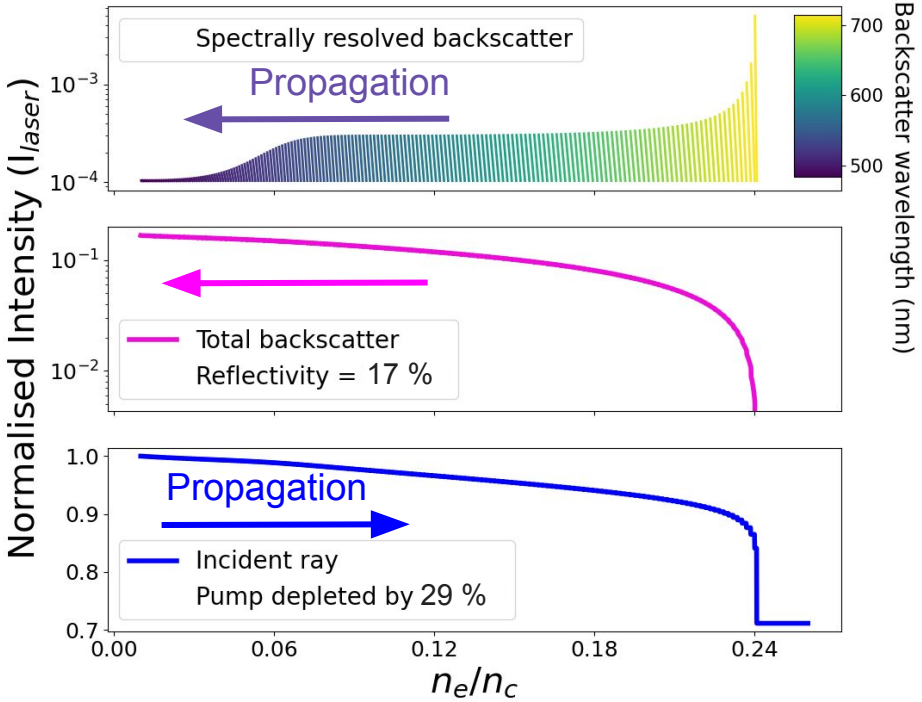


- Sum the scattered light waves to find reflectivity
- Deplete ray by conserving the quanta (photon, plasmon) density in each wave
- Iterate over gain calculation for intensity convergence

Physics applied to each ray

Absorption processes

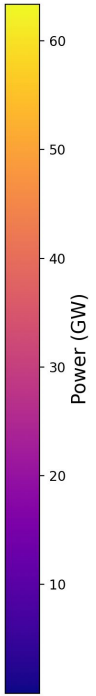
- Inverse bremsstrahlung (IB)
- SRS
- SBS
- TPD

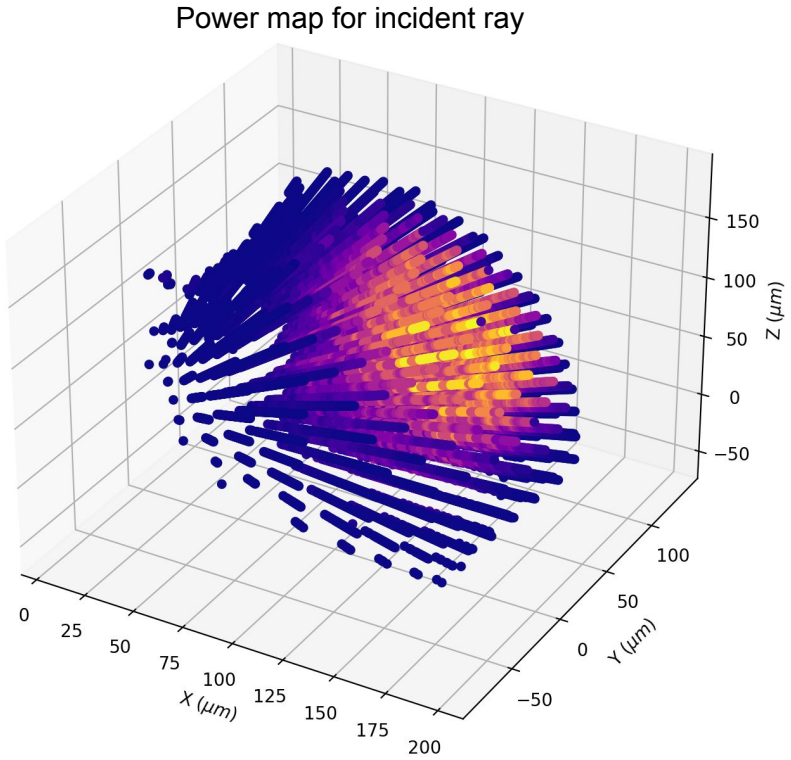
LPI saturation mechanisms

- Dephasing
- Langmuir decay instability
- Pump depletion

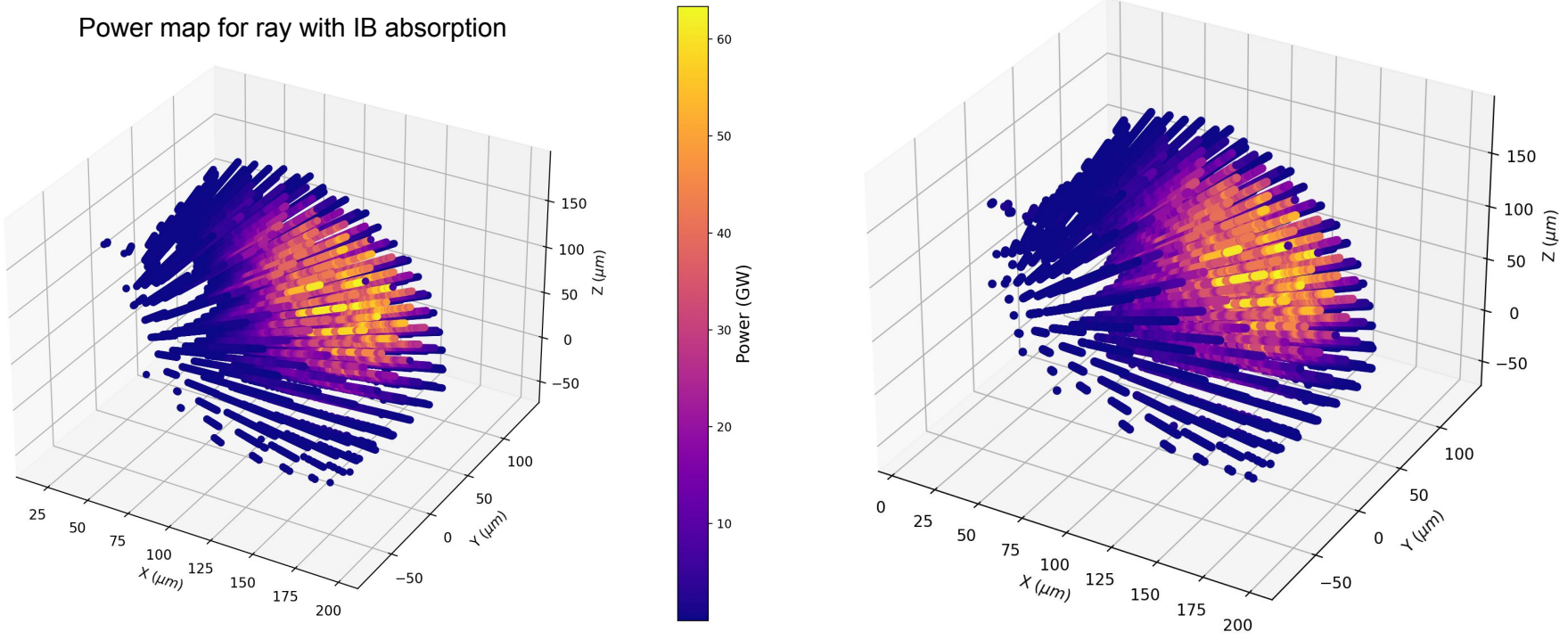
Map of incident ray power

- Power maps are the summed power of rays in each cell
- Here we are only considering rays up to their turning point
- Iterate over the whole map for non-linear LPI depletion of laser

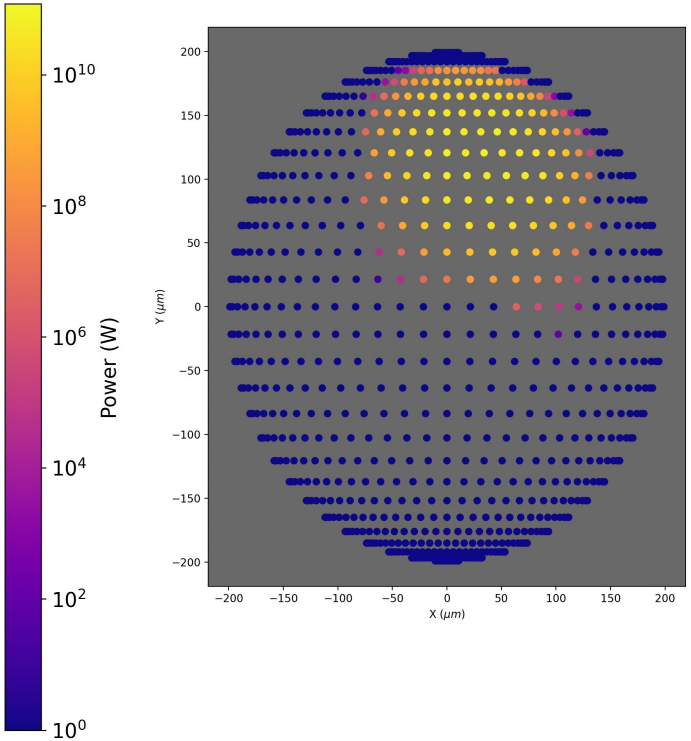




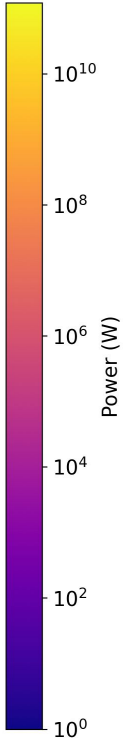
Ray power maps

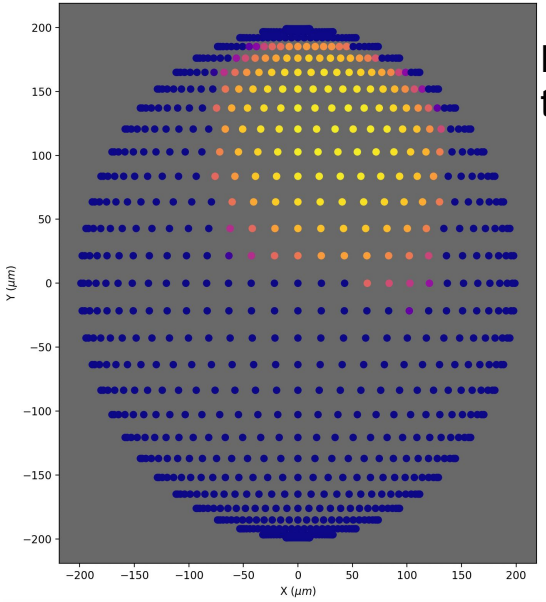


Outer radial layer of power maps



Power entering the grid





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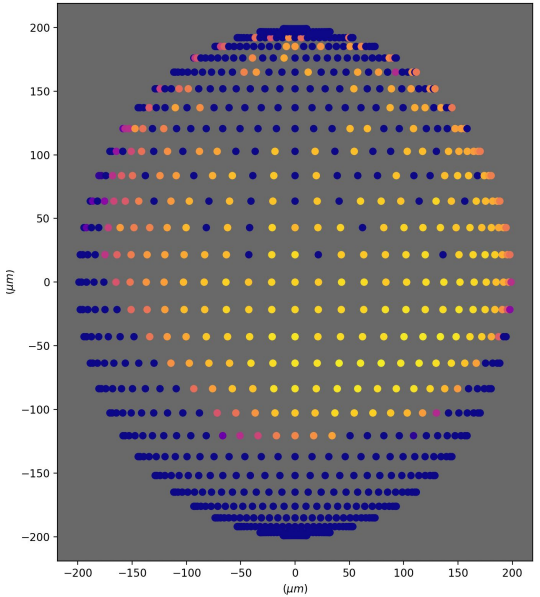
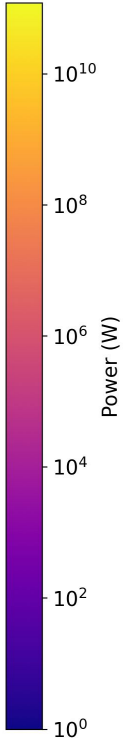
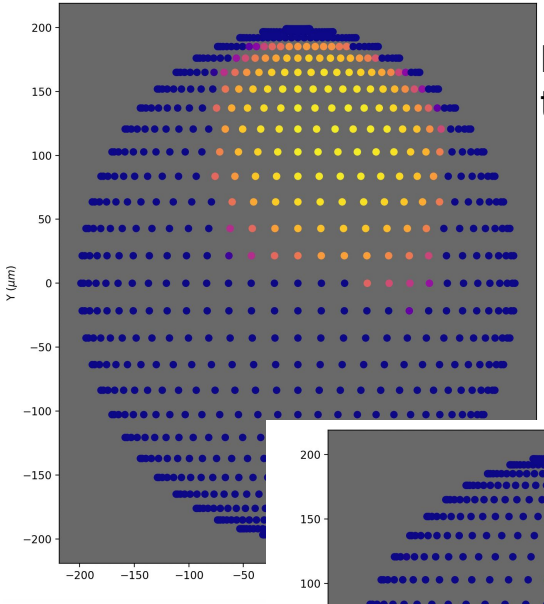


Power exiting the grid (no absorption)





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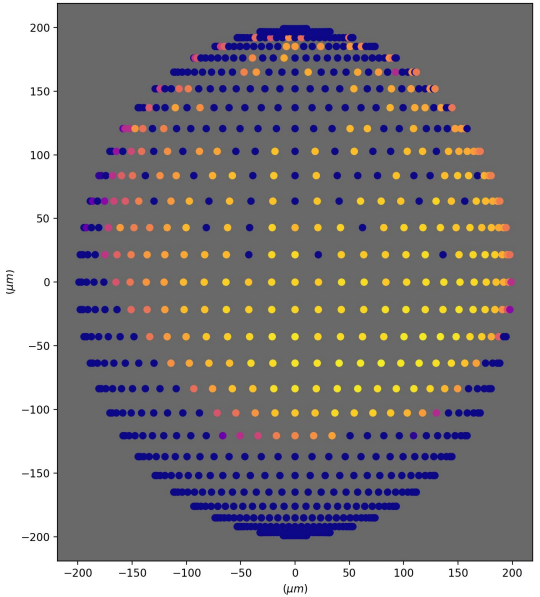

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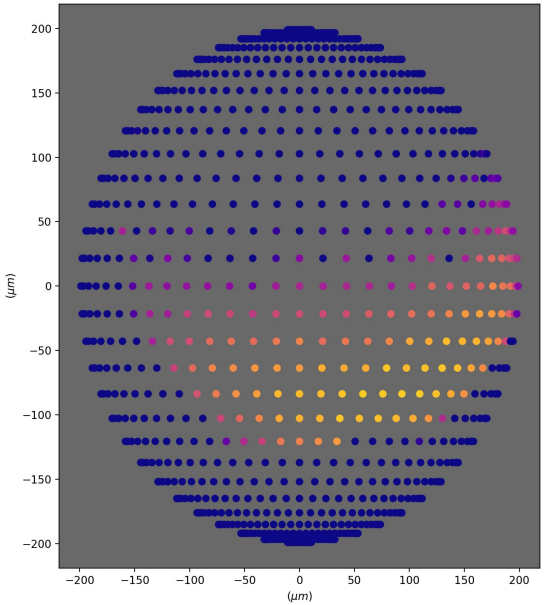
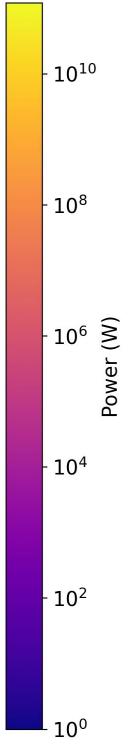
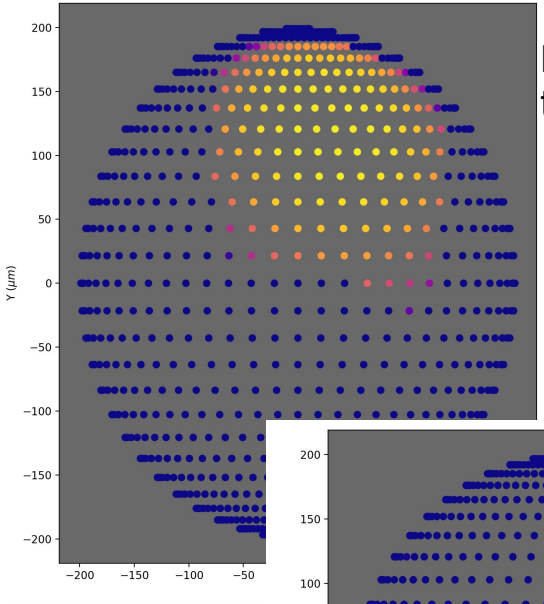


Power exiting the grid after IB





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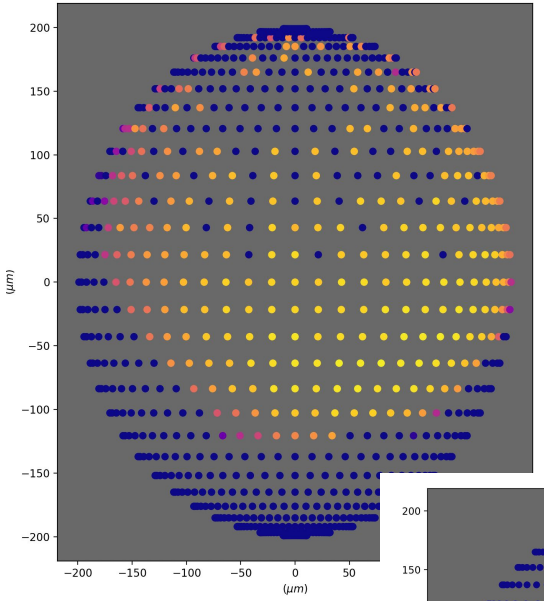

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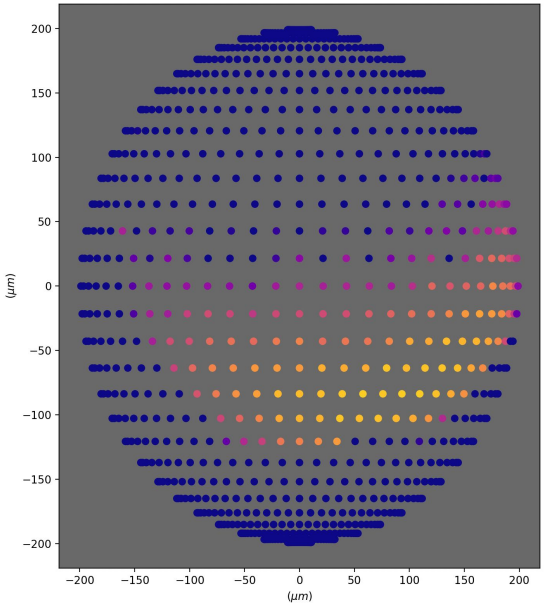

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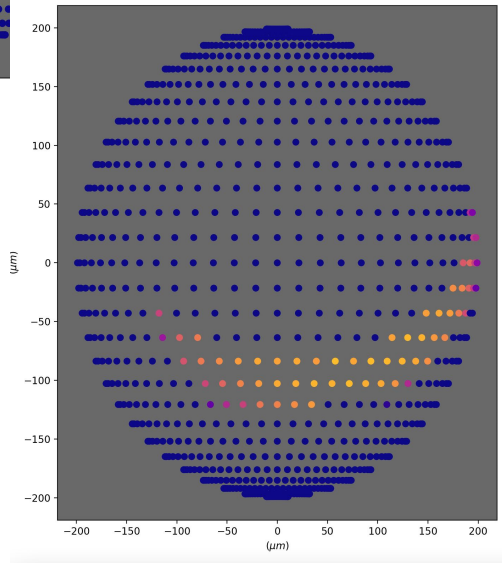
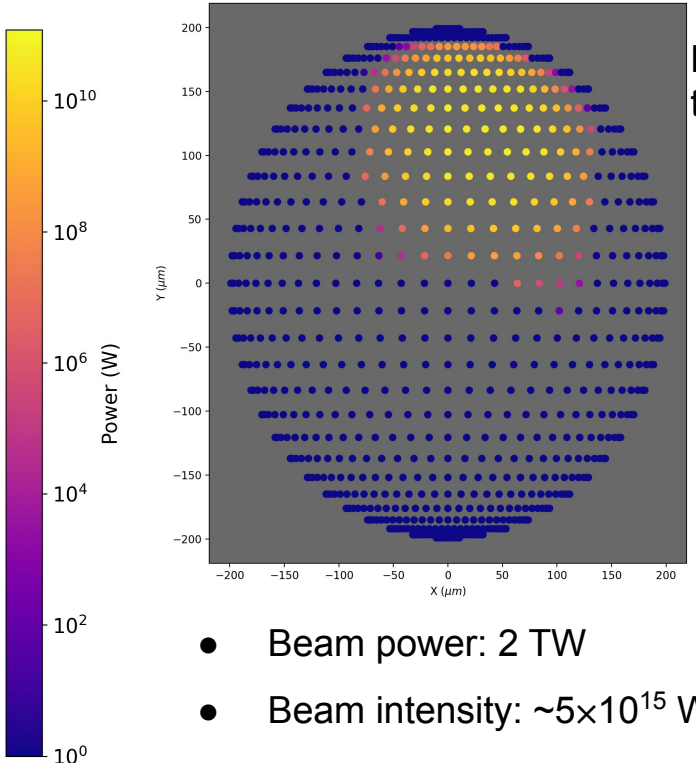


Power exiting the grid after IB, SRS & SBS



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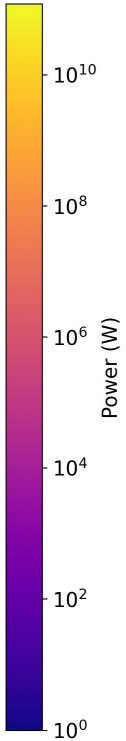

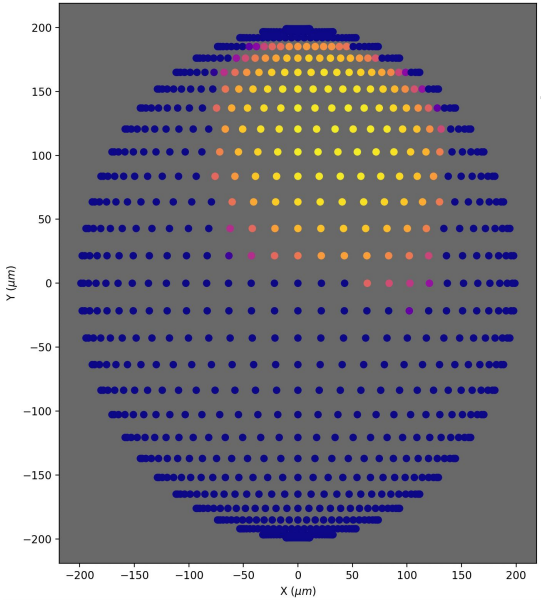

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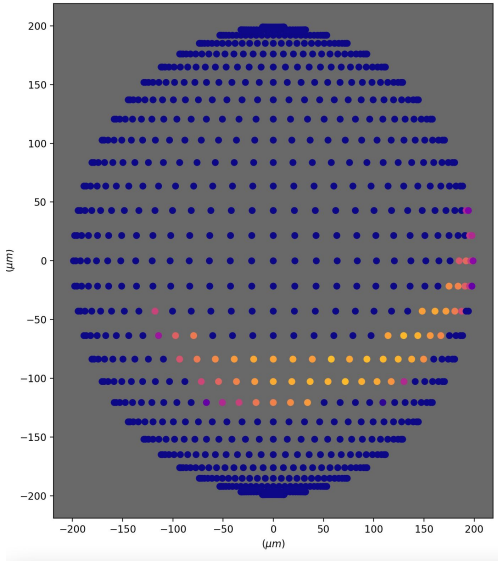
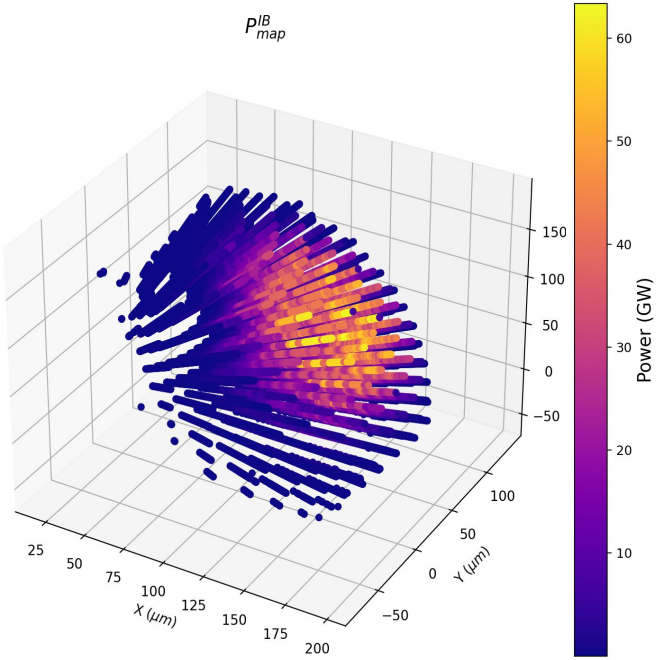
- 2% of beam power refracted out of plasma
- 65% absorbed by IB
- 27% absorbed by SRS
- 6% absorbed by SBS



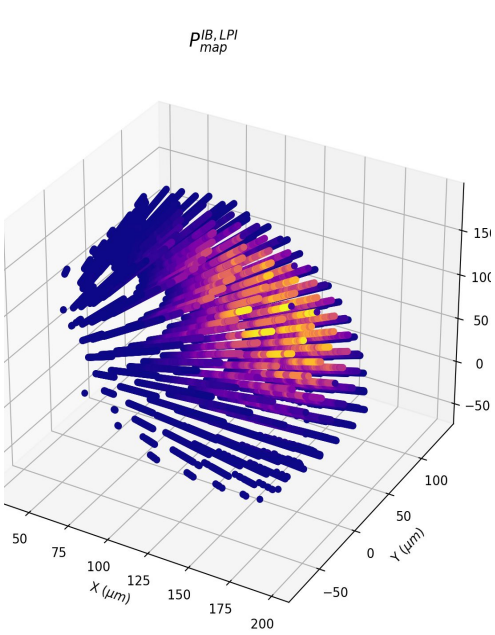
Power exiting the grid after IB, SRS & SBS

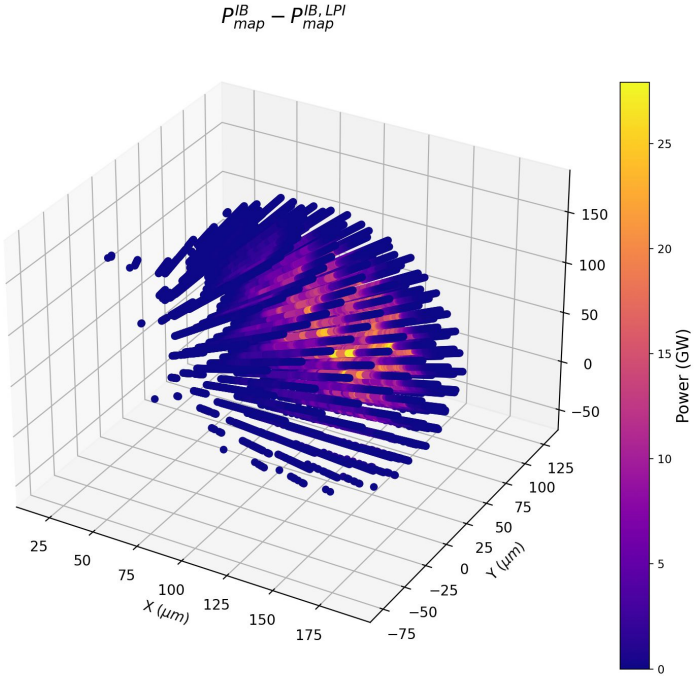
Incident ray power maps

Power map for ray with IB absorption



Power map for ray with IB, SRS & SBS





Summary

- We are developing a ray based LPI model
- It functions with 3D ray paths
- Using pump depletion, dephasing and Langmuir decay to saturate instabilities
- Iterative solution for nonlinear pump depletion
- Next we will benchmark by simulating experiments
- Implement in rad-hydro code in the future