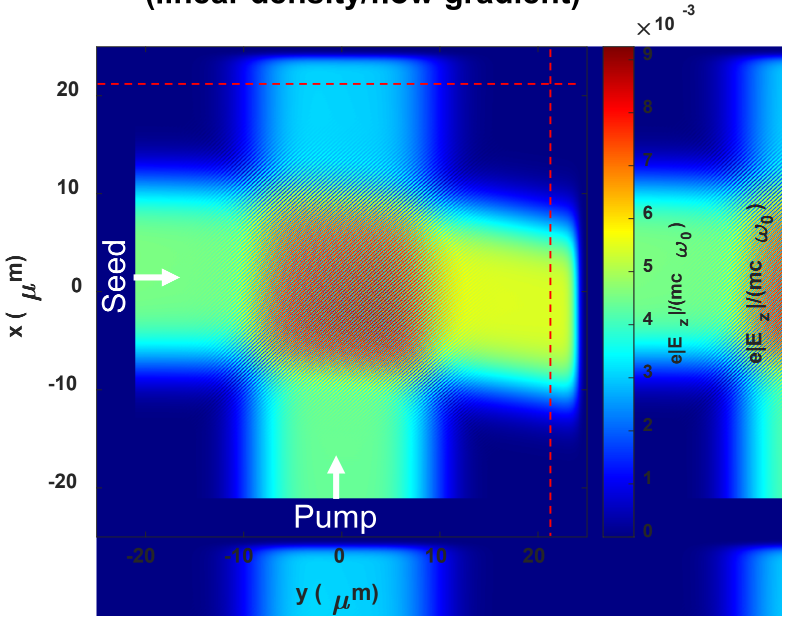
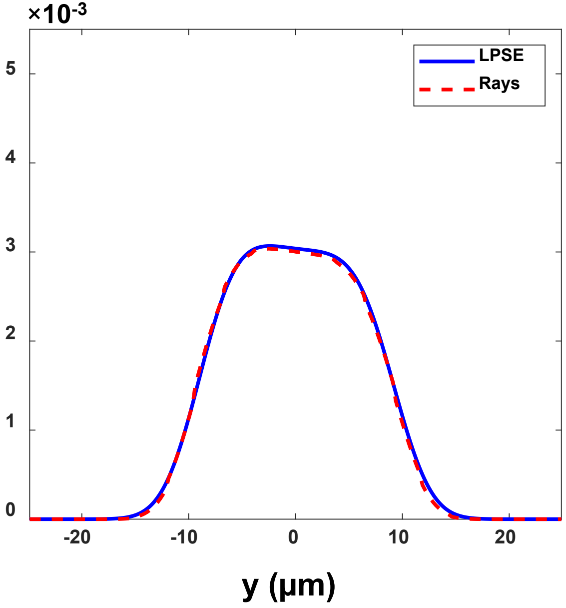
Validation of ray-based cross-beam energy transfer (CBET) models

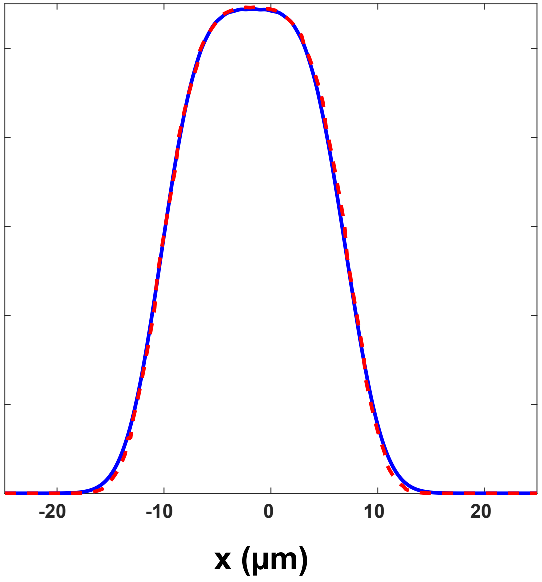
Electric field in 2-beam CBET interaction (linear density/flow gradient)



Lineout of outgoing pump (x-max)



Lineout of outgoing seed (y-max)



R. K. Follett
University of Rochester
Laboratory for Laser Energetics

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Implementations of ray-based CBET models vary significantly between codes and artificial multipliers are often required

- Wave-based CBET codes like LPSE provide an excellent platform for validating ray-based models

- A series of test cases were developed for the purpose of validating ray-based CBET models

- Getting the right answer requires correctly modeling the field at caustics
  - Field-limiter (FL) or Etalon Integral (EI) approach
  - Coherent caustic (CC) correction

LPSE field data from many of the test cases is available at http://dx.doi.org/10.5281/zenodo.6962934

Collaborators

D. Turnbull, D. H. Froula, and J. P. Palastro

University of Rochester

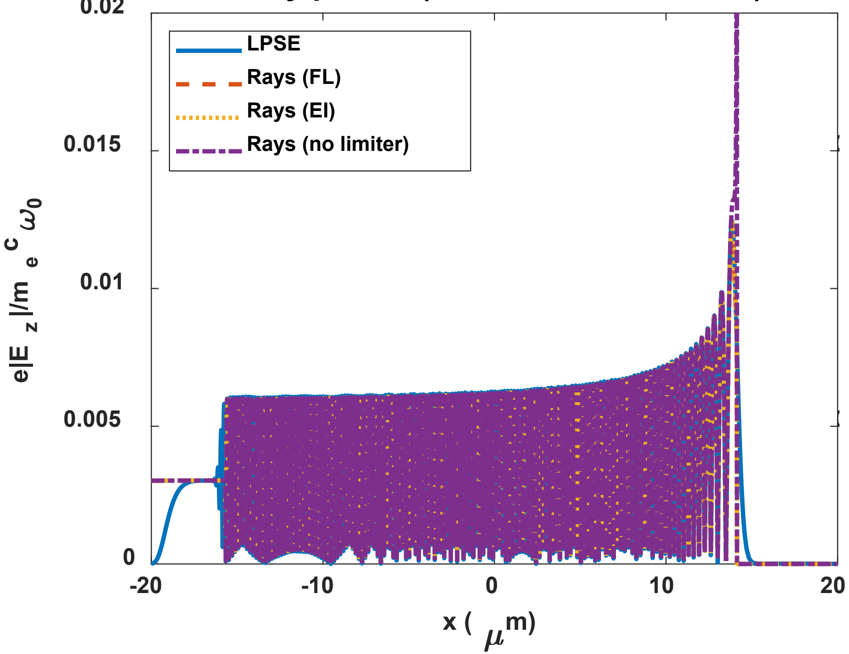
Laboratory for Laser Energetics

A. Colaitis

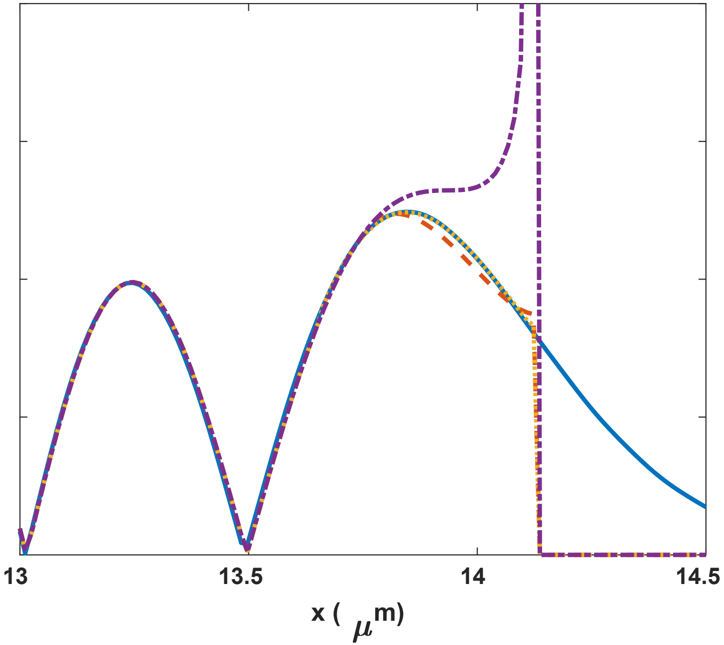
Centre Lasers Intenses et Aplications

Getting the correct field amplitude in the caustic region: Electric field of a reflected beam in 1-D (no CBET/absorption)

Electric field of a beam reflected in a 1-D LILAC density profile (1/16th scale, no CBET)



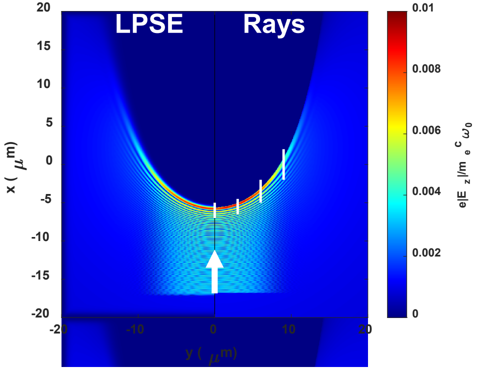
Closeup of caustic region



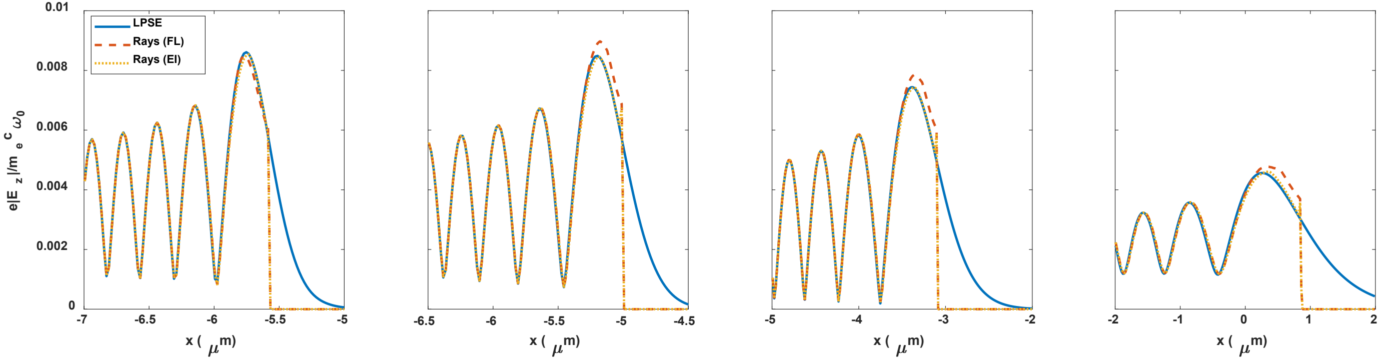
FL: field-limiter
EI: etalon integral

Getting the correct field amplitude in the caustic region: Electric field of a reflected beam in 2-D azimuthally symmetric profile

Electric field of a single beam reflected in a 2-D spherical LILAC density profile ($1/64^{th}$ scale, no CBET)



Lineouts of caustic region

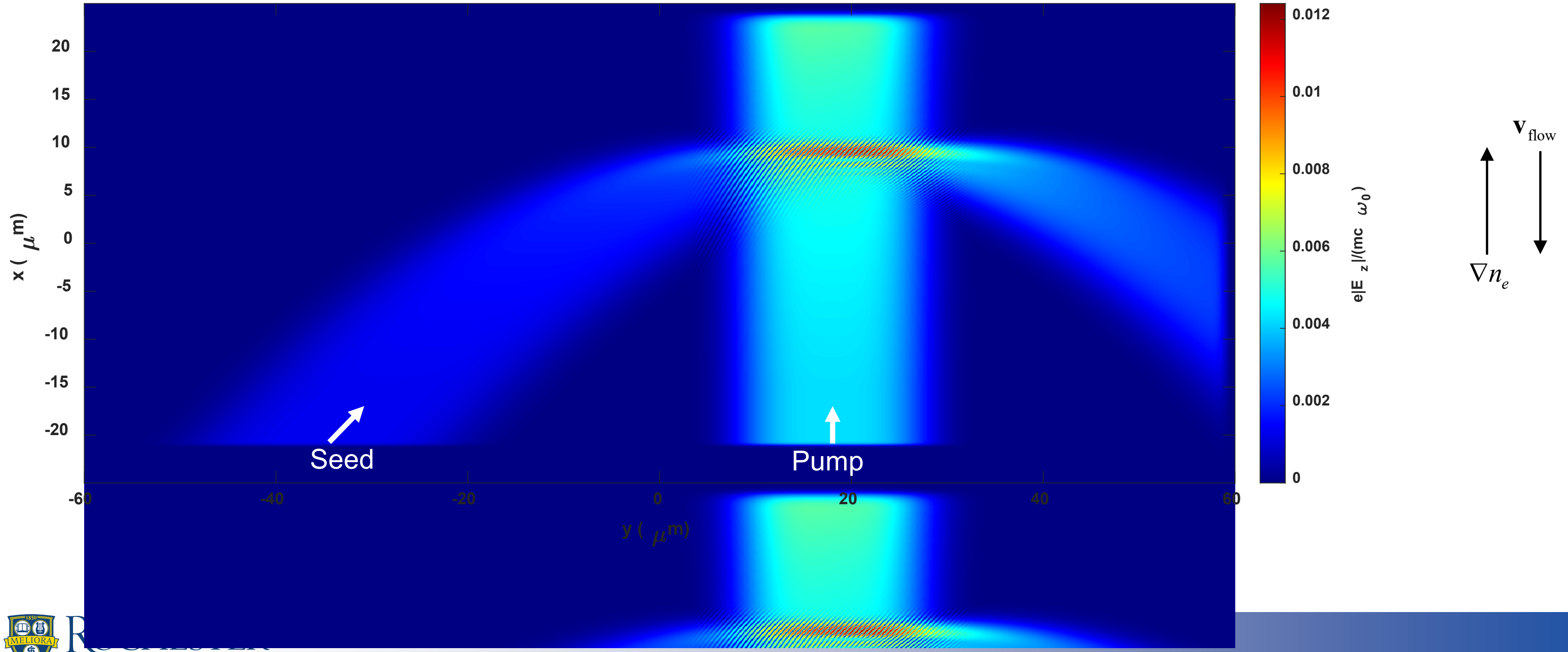


The etalon integral (EI) method is more accurate than the field-limiter (FL) approach in spherical plasma profiles

FL: field-limiter
EI: etalon integral

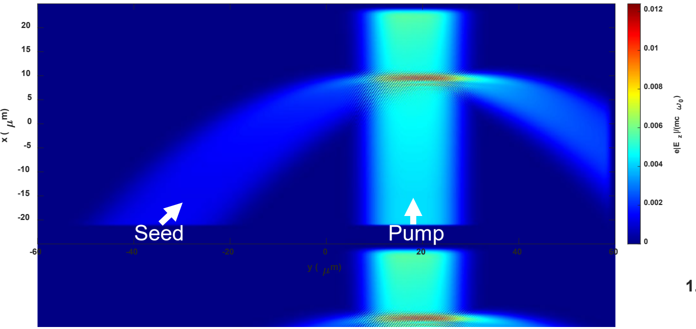
Dealing with the coherent nature of the fields near the caustic: Two-beam CBET at a caustic

Electric field of 2-beam caustic interaction (linear density gradient)

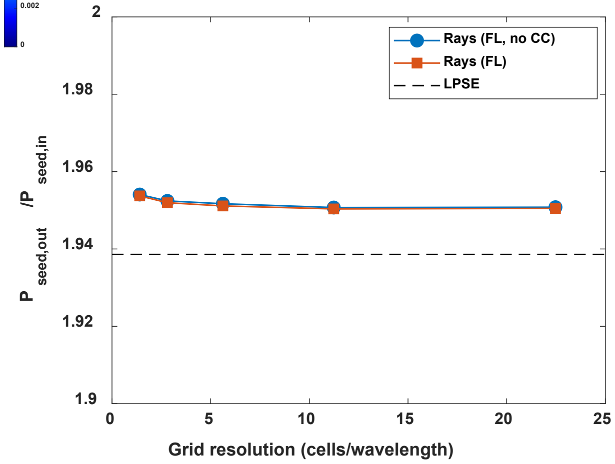


Dealing with the coherent nature of the fields near the caustic: Two-beam CBET at a caustic

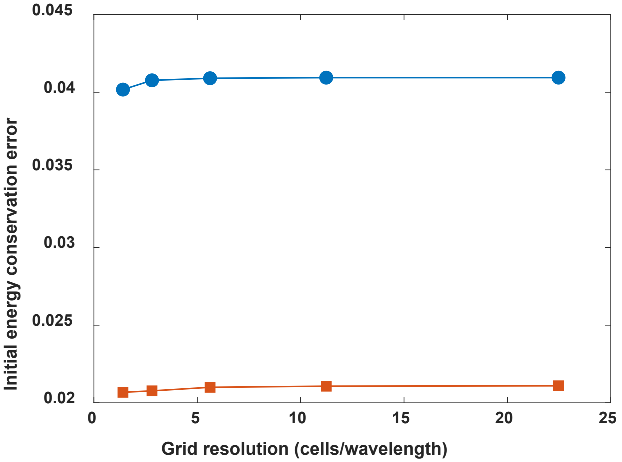
Electric field of 2-beam caustic interaction



Seed amplification



Energy conservation error

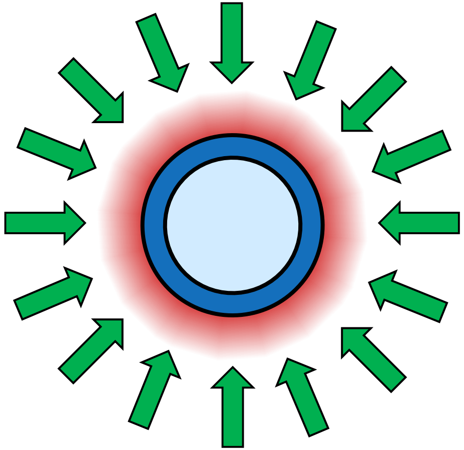


$$\text{Energy conservation error} = \frac{P_{\text{out}} + P_{\text{abs}} - P_{\text{in}}}{P_{\text{in}}}$$

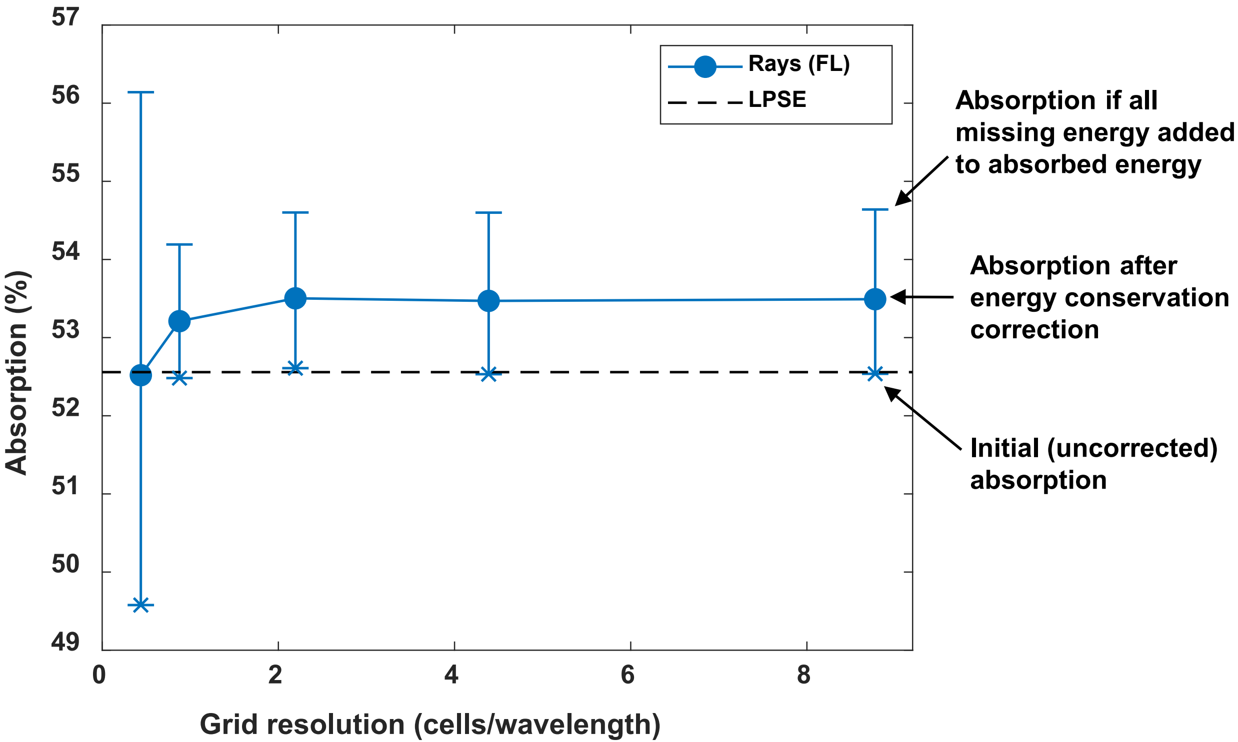
CC: coherent caustic

Test case: 16-beam CBET in 2-D using fits to LILAC hydro profiles

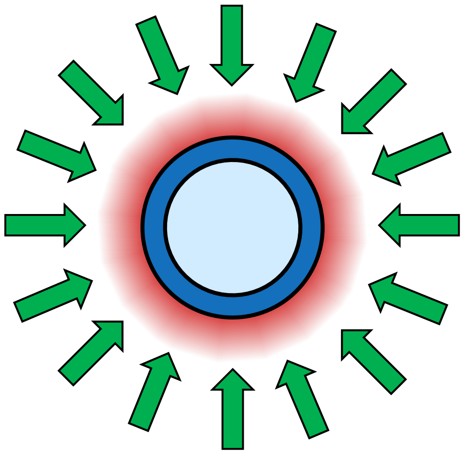
16-beam configuration

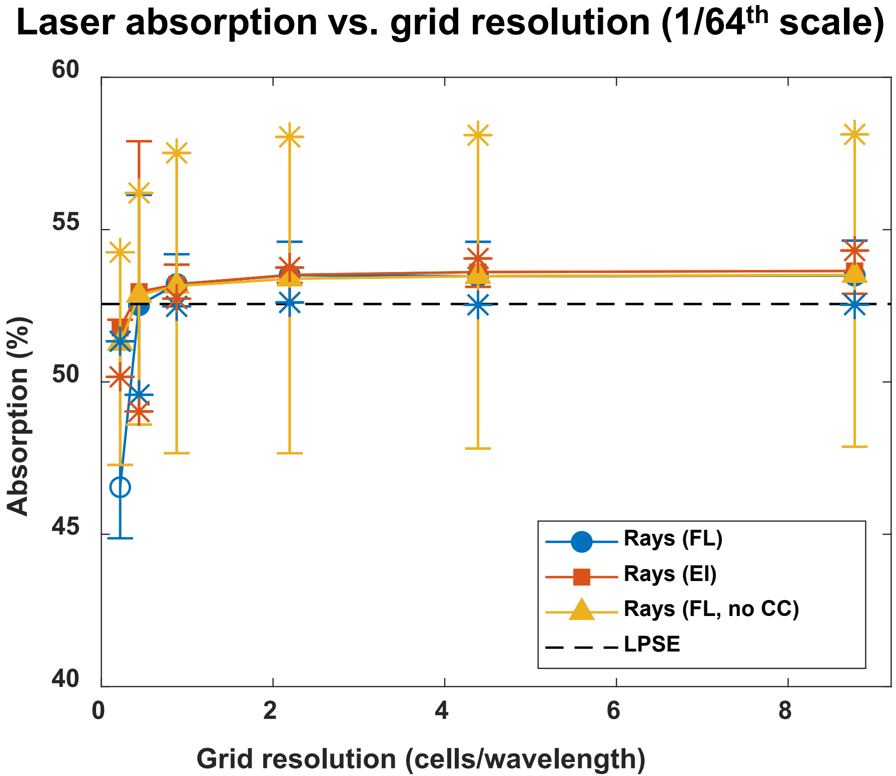


Laser absorption vs. grid resolution (1/64th scale)



Test case: 16-beam CBET in 2-D using fits to LILAC hydro profiles





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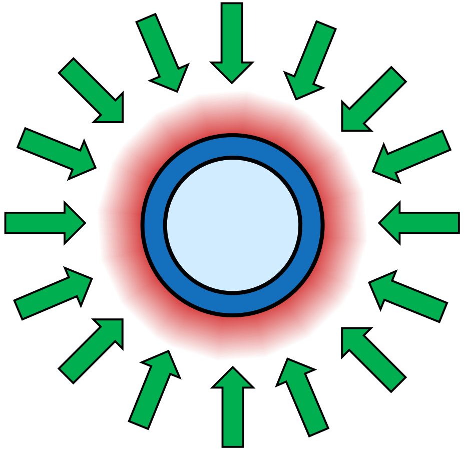
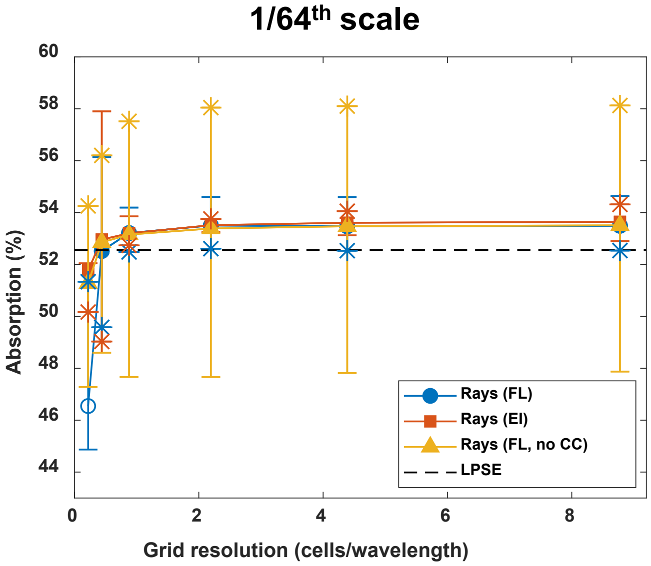
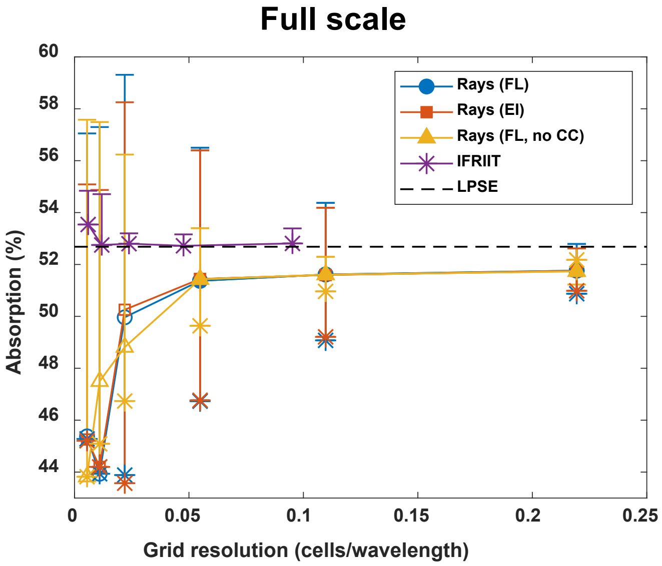
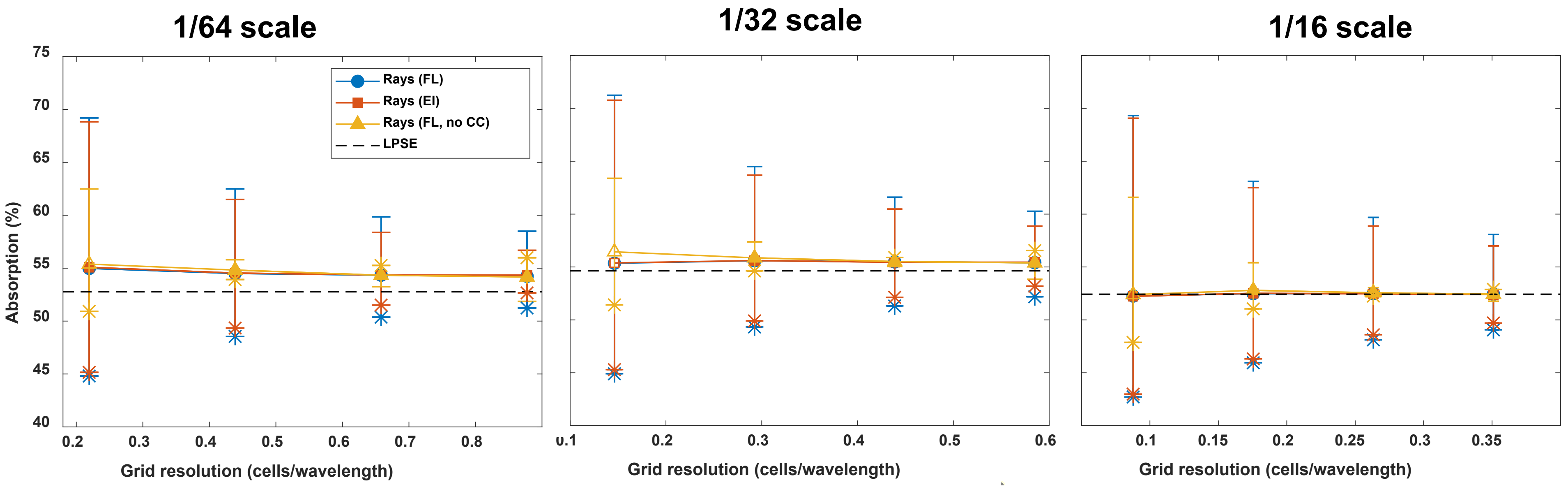






Test case: 60-beam CBET in 3-D using fits to LILAC hydro profiles



The EI method generally has the best performance over the range of test cases (but at a higher computational cost and implementation complexity)

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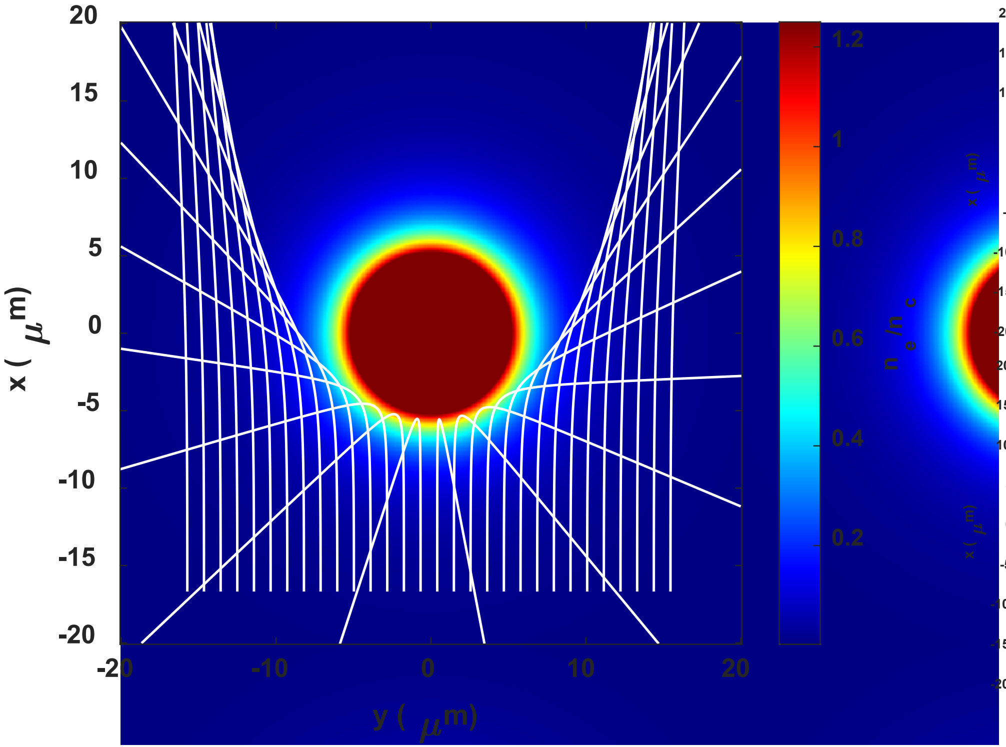
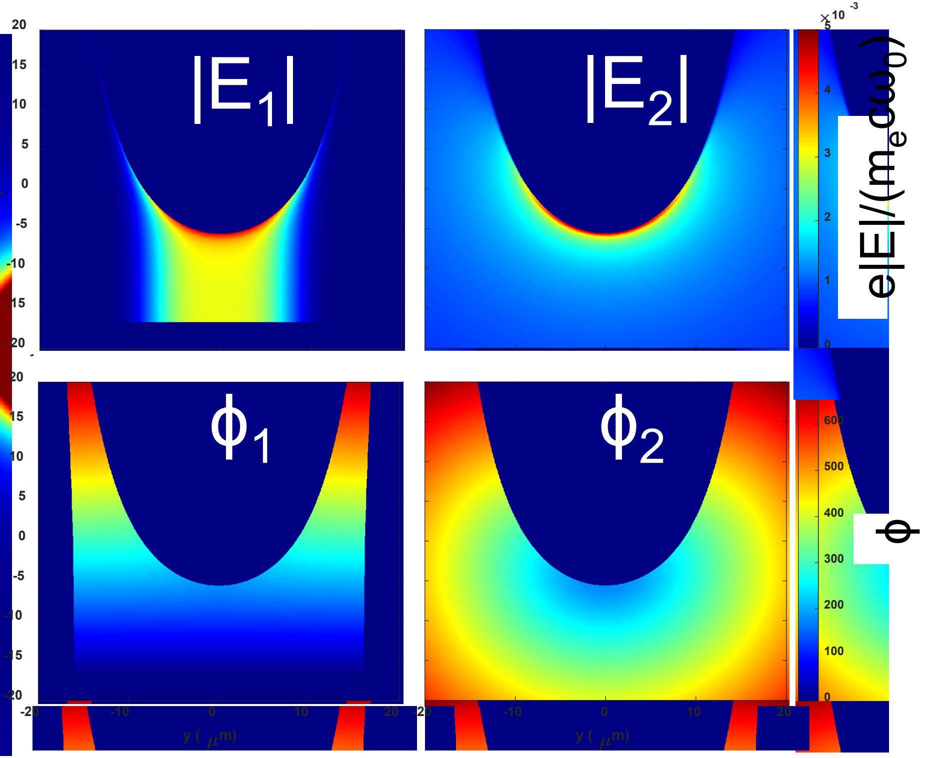
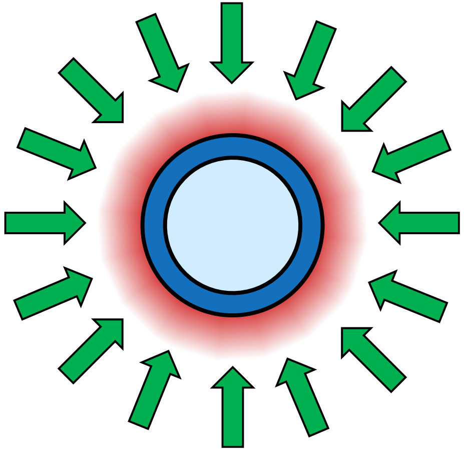


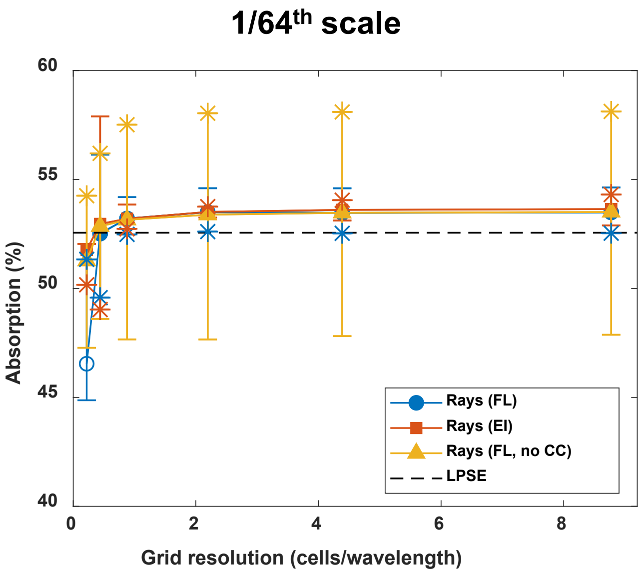
20
15
10
5
0
-5
-10
-15
-20
x (μm)
-20
-10
0
10
20
y (μm)
1.2
1
0.8
0.6
0.4
0.2
n_e/n_c

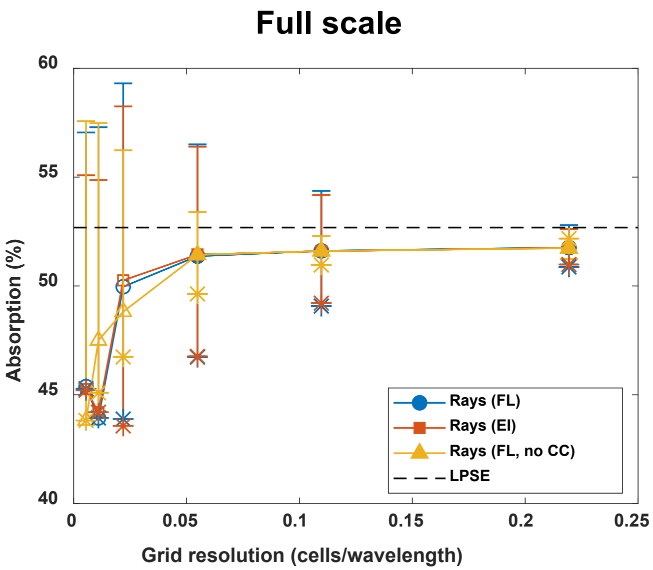


|E1|
|E2|
ϕ1
ϕ2
×10^-3
5
4
3
2
1
0
e|E|/(m_e c ω_0)
600
500
400
300
200
100
0
ϕ
x (μm)
y (μm)

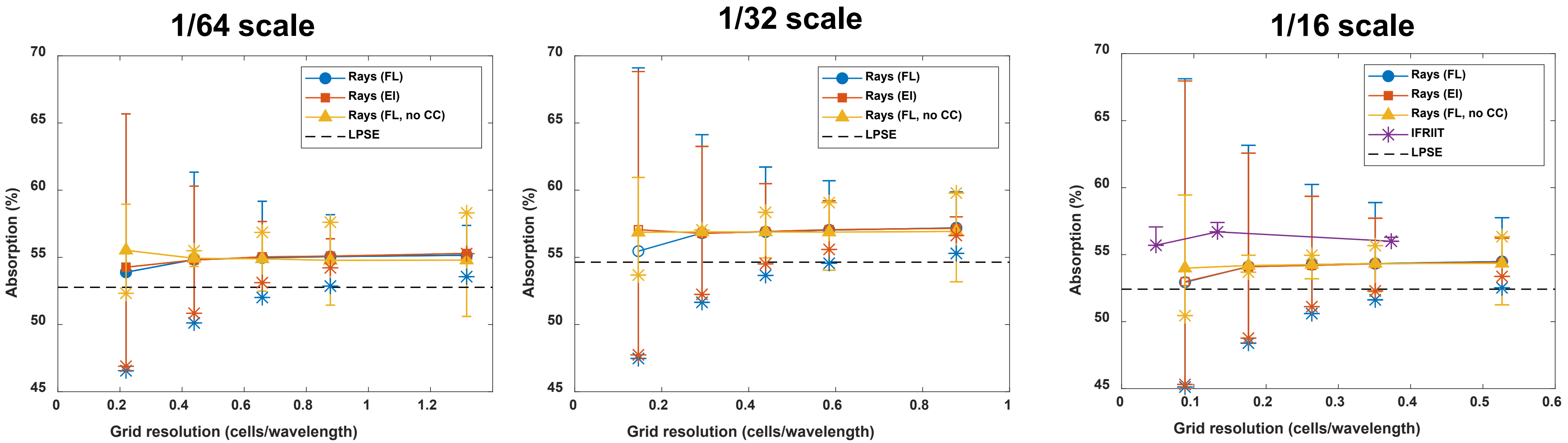
Test case: 16-beam CBET in 2-D using fits to LILAC hydro profiles







Test case: 60-beam CBET in 3-D using fits to LILAC hydro profiles



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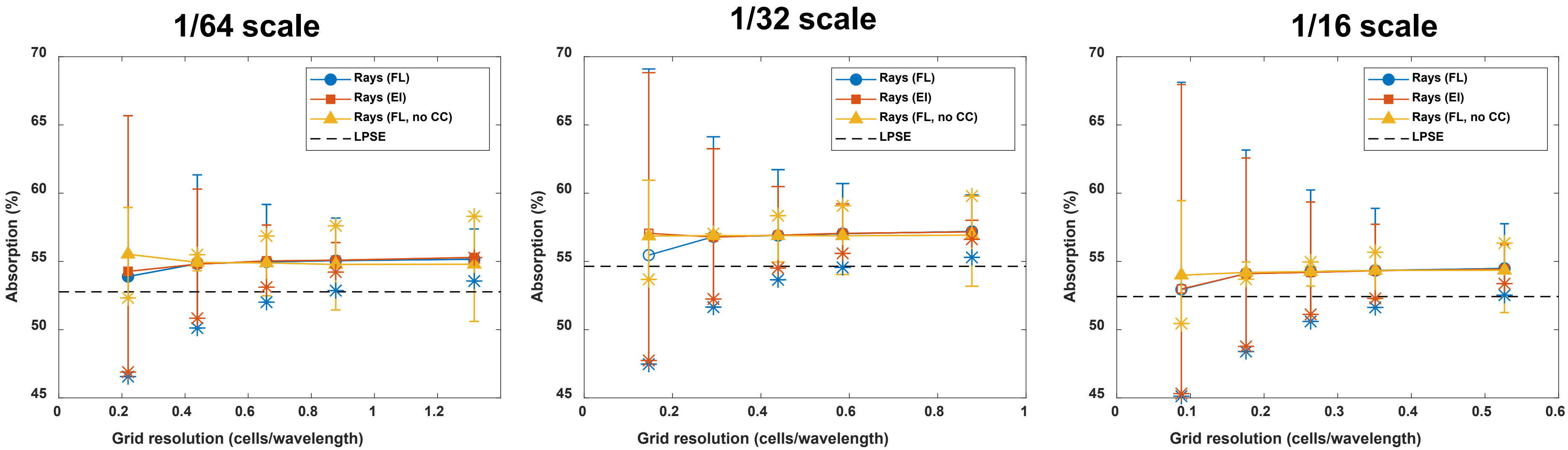


The first step to a good ray-based model is an accurate model for the electric field in the absence of CBET

Field-limiter (FL) approach (used in LILAC):

$$\frac{|E_j|}{|E_{j,0}|} = \sqrt{W_j}\min\left[A_j,\ 0.95\left(k_0 L\right)^{1/6}\left(\frac{n_t}{n_c}\right)^{1/4}\right]$$

Ray energy ($\sqrt{W_j}$); Ray amplitude (A_j)

$$A_j = \epsilon^{-1/4}\left(\frac{dS_{j,0}}{dS_j}\right)^{1/2} \qquad \epsilon = 1 - \frac{n_e}{n_c}$$

Etalon integral (EI) method (used in IFRIIT):

$$\frac{|E_j|}{|E_{j,0}|} = \frac{\sqrt{W_j}\,|E_T|}{\sqrt{2}\left[1+\sin(\varphi_2-\varphi_1)\right]^{1/2}}$$

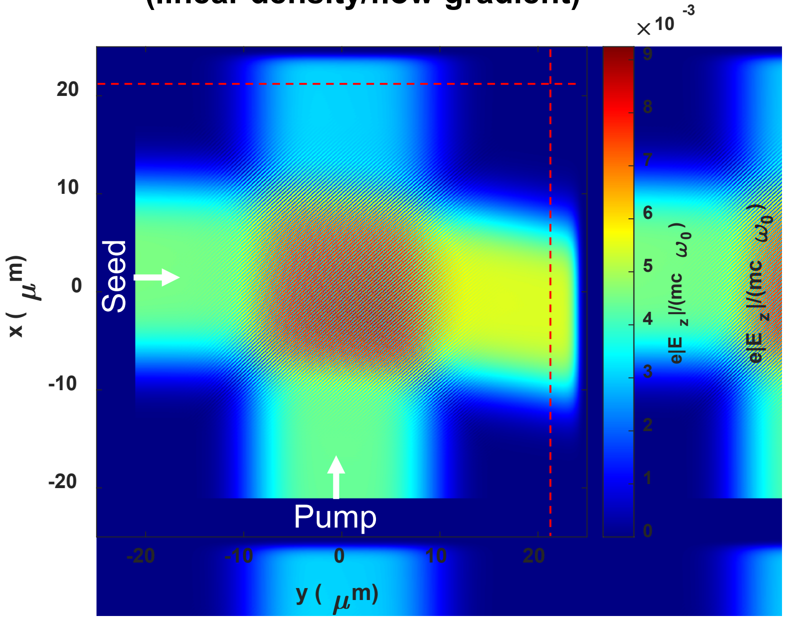
$$|E_T| = \sqrt{\pi}\,|(-\xi)^{1/4}(A_1+A_2)\mathrm{Ai}(\xi) - i(-\xi)^{1/4}(A_1-A_2)\mathrm{Ai}'(\xi)|$$

$$\xi = -\left[\frac{3}{4}(\varphi_2-\varphi_1)\right]^{2/3}$$

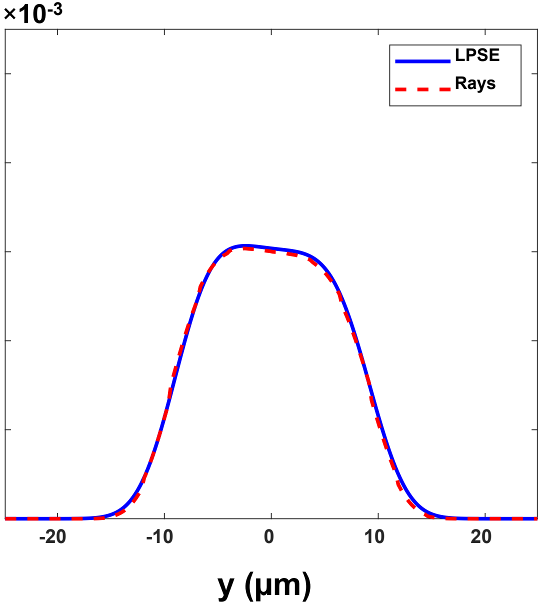
Restricted to caustic region defined by $|\varphi_2-\varphi_1| \le \pi$

Test case 3: Two-beam CBET interaction in a linear density and flow gradient

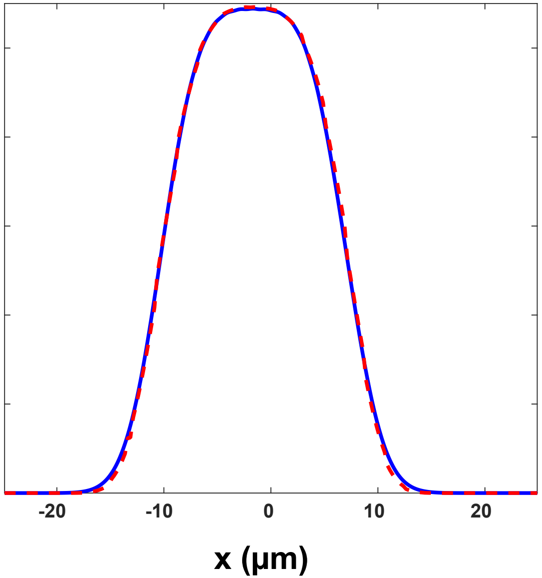
Electric field in 2-beam CBET interaction (linear density/flow gradient)



Lineout of outgoing pump (x-max)



Lineout of outgoing seed (y-max)



Traditional ray-based CBET algorithms over predict energy transfer near caustics due to the inclusion of unphysical gain regions

The geometry of ray-based CBET