Laser plasma channel length estimates

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Recap: Laser propagation simulations for AWAKE

Maxwell for E:

$$\nabla^2 E(r,t) - \frac{1}{c^2}\frac{\partial^2 E(r,t)}{\partial t^2} = \mu_0 \frac{\partial^2 P}{\partial t^2}$$

$\Rightarrow$

Schrödinger for atoms:

$|\Psi\rangle = \sum \alpha_i |i\rangle$, $\hat{H}_I = -\hat{d}E$

phenom. loss terms

$\Downarrow$

Material optical response:

$$P(r,t) = \mathcal{N}\langle\Psi|\hat{d}|\Psi\rangle + \text{ionization loss} + \text{plasma dispersion}$$

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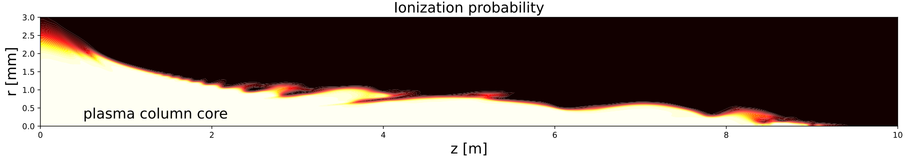

Laser propagation simulations vs. Laser propagation measurements:
Qualitative agreement, quantitative discrepancies

- *Quantitative* questions:
  - laser plasma length potential
  - Jan: laser energy deposition to calibrate plasma light measurements?
- Can we have a simple model ″inspired by″the simulation results?

Simulation inspired model

- Define the plasma *equivalent radius* R_{eq} as:

$$R_{eq}^2\pi = \int_0^\infty P_{ion}(r,z)2r\pi dr$$

- Approximate pulse energy loss as:

$$\frac{dE}{dz} = \mathcal{N}3\hbar\omega R_{eq}^2\pi$$

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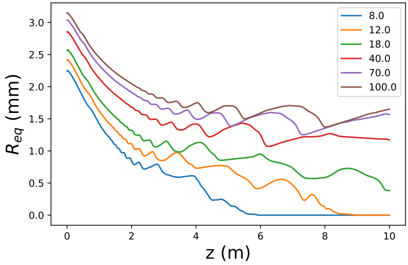

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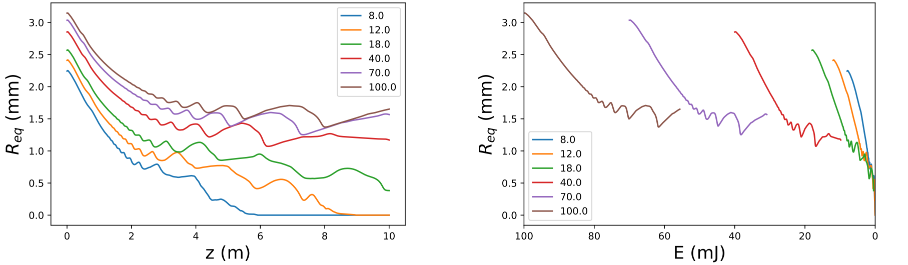
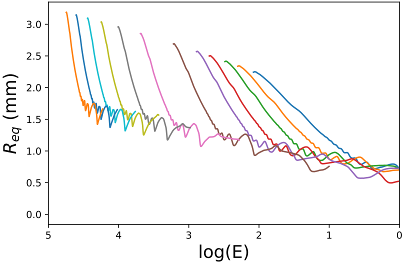
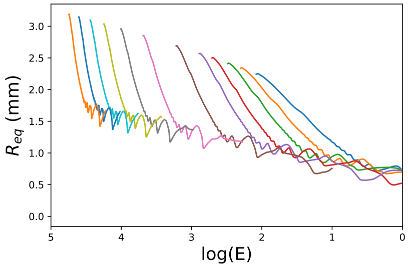
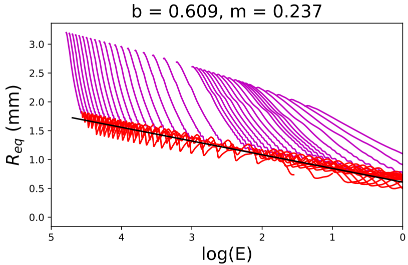




3.0
2.5
2.0
1.5
1.0
0.5
0.0
R_{eq} (mm)
5
4
3
2
1
0
log(E)





- Approximate attractor as:

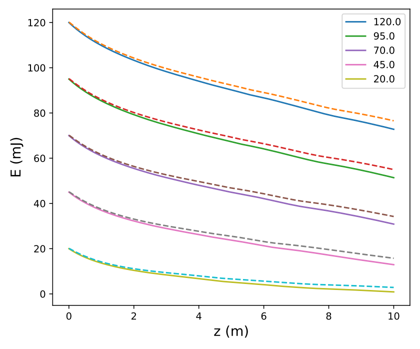
$$\tilde{R}_{eq} = m \log(E) + b$$

- Approximate pulse energy loss as:

$$\frac{dE}{dz} = \mathcal{N} 3 \hbar \omega \tilde{R}_{eq}^2 \pi$$

Verify approximation:

Propagate with R_{eq} to check first step:



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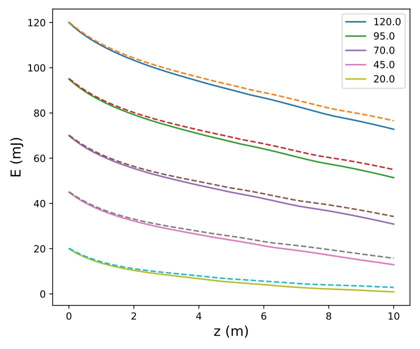

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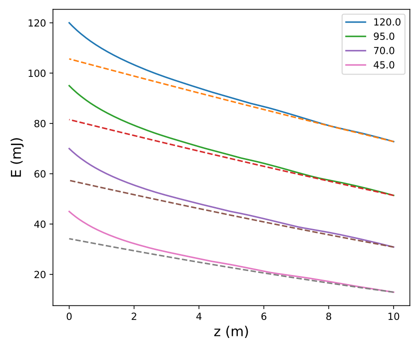

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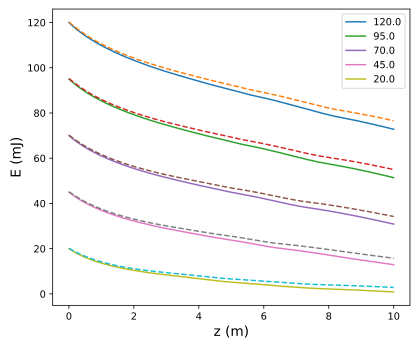

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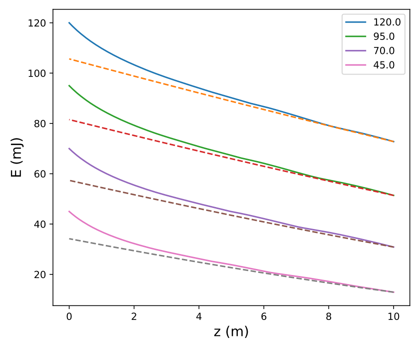
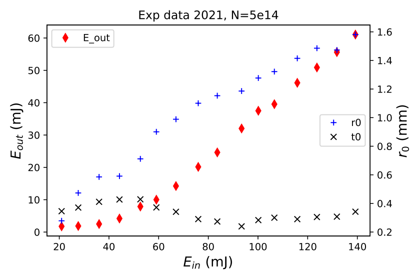


But this is still all in the realm of numbers...

Connecting with experiments

2021 Propagation measurements:

Laser pulse and plasma channel data $@z = 10$



J. T. Moody, M. A. Kedves, F. Batsch, M. Bergamaschi, V. Fedosseev, E. Granados, P. Muggli, H. Panuganti, G. Zevi Della Porta

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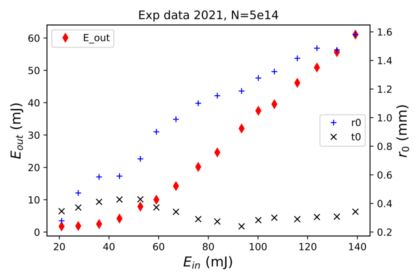

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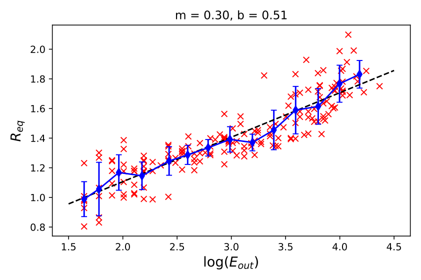
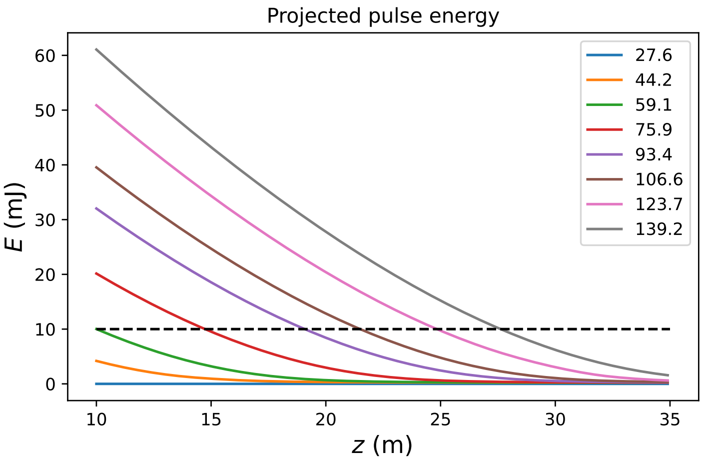
- $R_{eq} = \sqrt{r_0^2 + t_0^2 + r_0 t_0 \sqrt{\pi}}$
- fit data to obtain m, b

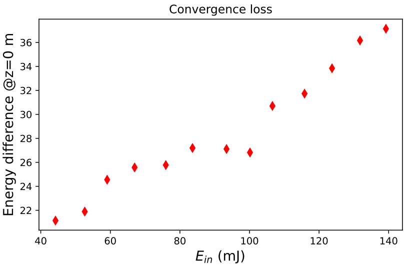


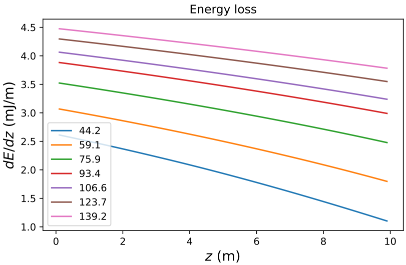
Possible use:

Project energy forward to get potential plasma channel length:



Backtrack pulse energy to obtain convergence loss and dE/dz





Outlook and questions

Questions

- Rough ideas, debatable, can the model be turned into something useful?
- Connecting with experiment II: Plasma-light measurements?

Possible improvements

- Re-evaluate propagation measurements —fit $\tilde{R}_{eq}$ directly to get better accuracy
- Correct model with contribution for excited state atoms
- Get some approximate formula for the convergence region

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Thank you for your attention!