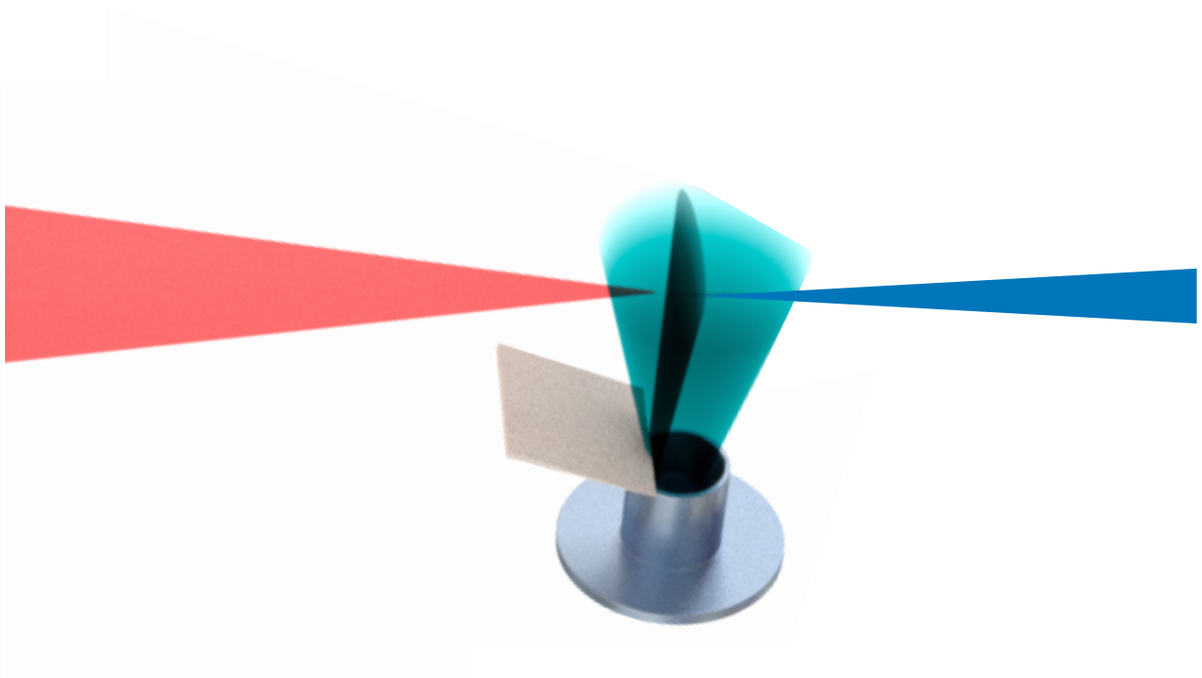
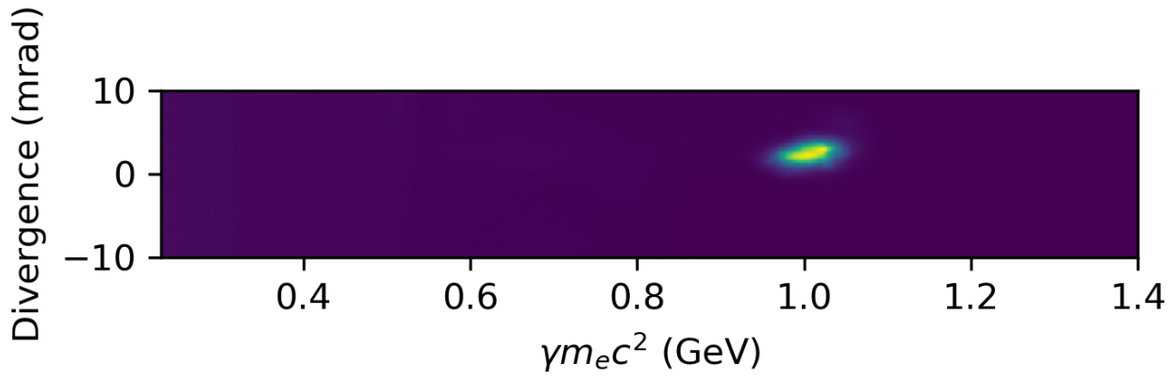
Narrow energy spread, GeV electron beams from shock injection in a laser wakefield accelerator

Cary Colgan





Acknowledgements

[1]N. Bourgeois, [1]P.P. Rajeev, [1]D.R. Symes
[2]J.M. Cole, [2]E. Gerstmayr, [2]B. Kettle, [2]E. Los, [2]M.J.V Streeter, [2]R. Watt, [2]Z. Najmudin, [2]S.P.D. Mangles
[3]G. Sarri, [3]G.M. Samarin, [3]A. Alejo,
[4]M. Zepf, [4]C. Roedel, [4]D. Hollatz, [4]Harsh, [4]F. Salgado,
[5]C.D. Murphy, [5]C.D. Baird, [5]C.I.D. Underwood, [5]C.P. Ridgers, [5]C. Arran
[6]J.A. Cardarelli, [6]M. Balcazar, [6]A.G.R. Thomas,
[7]M. Marklund, [7]T.G. Blackburn

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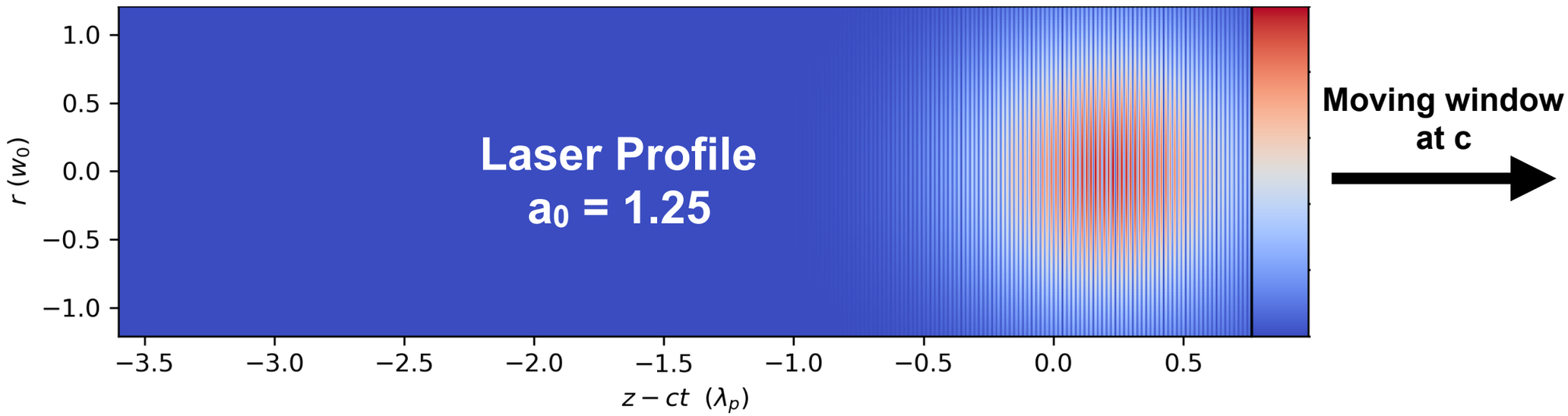
[3] School of Maths and Physics, The Queens University of Belfast
[4] Institut für Optik und Quantenelektronik, Friedrich-Schiller-Universität
[5] York Plasma Institute, University of York
[6] Center for Ultrafast Optical Science, University of Michigan
[7] Department of Physics, Chalmers University

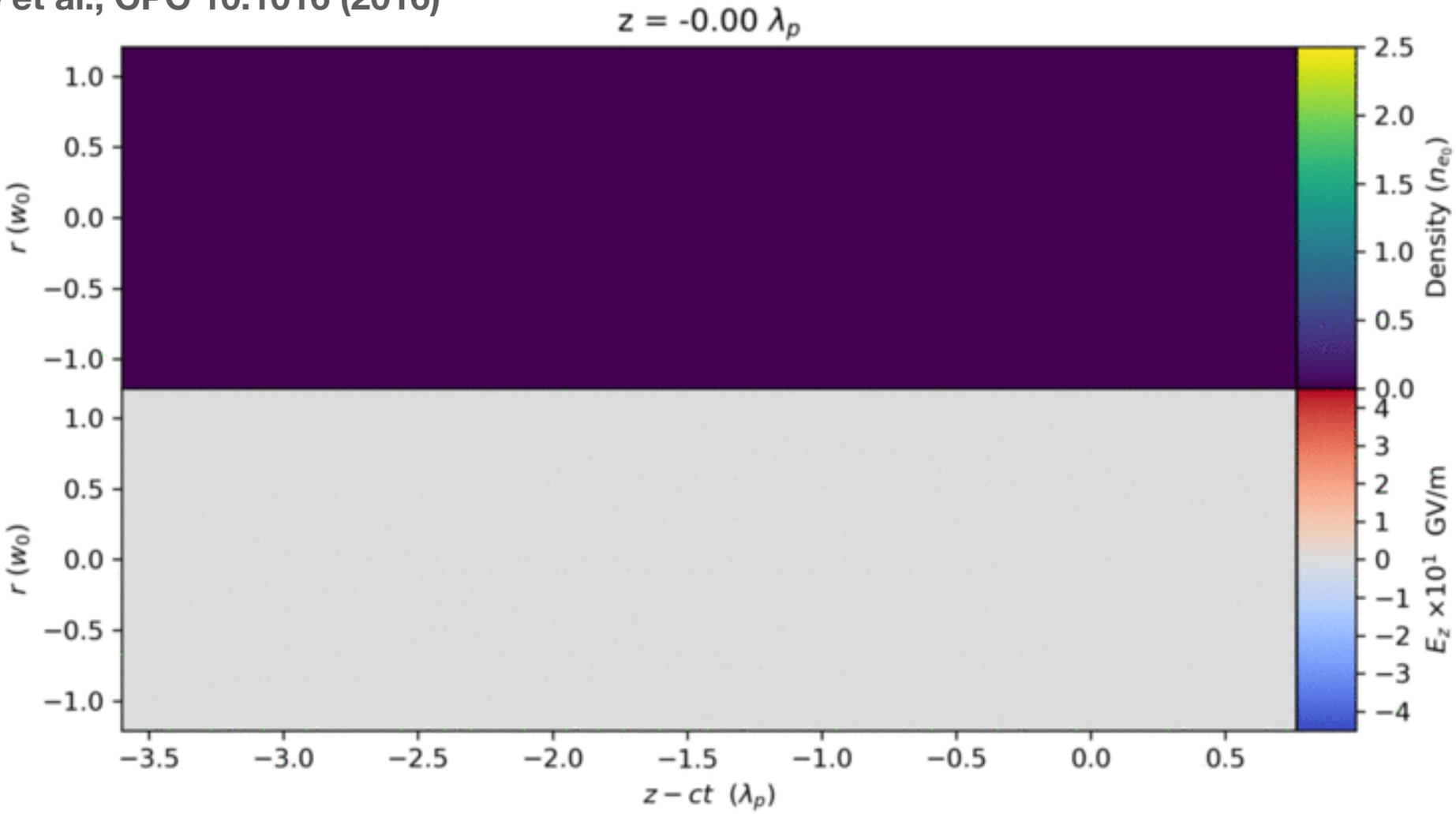
Laser wakefield accelerator has strong accelerating fields

R. Lehe et al., CPC 10.1016 (2016)



Laser wakefield accelerator has strong accelerating fields

R. Lehe et al., CPC 10.1016 (2016)



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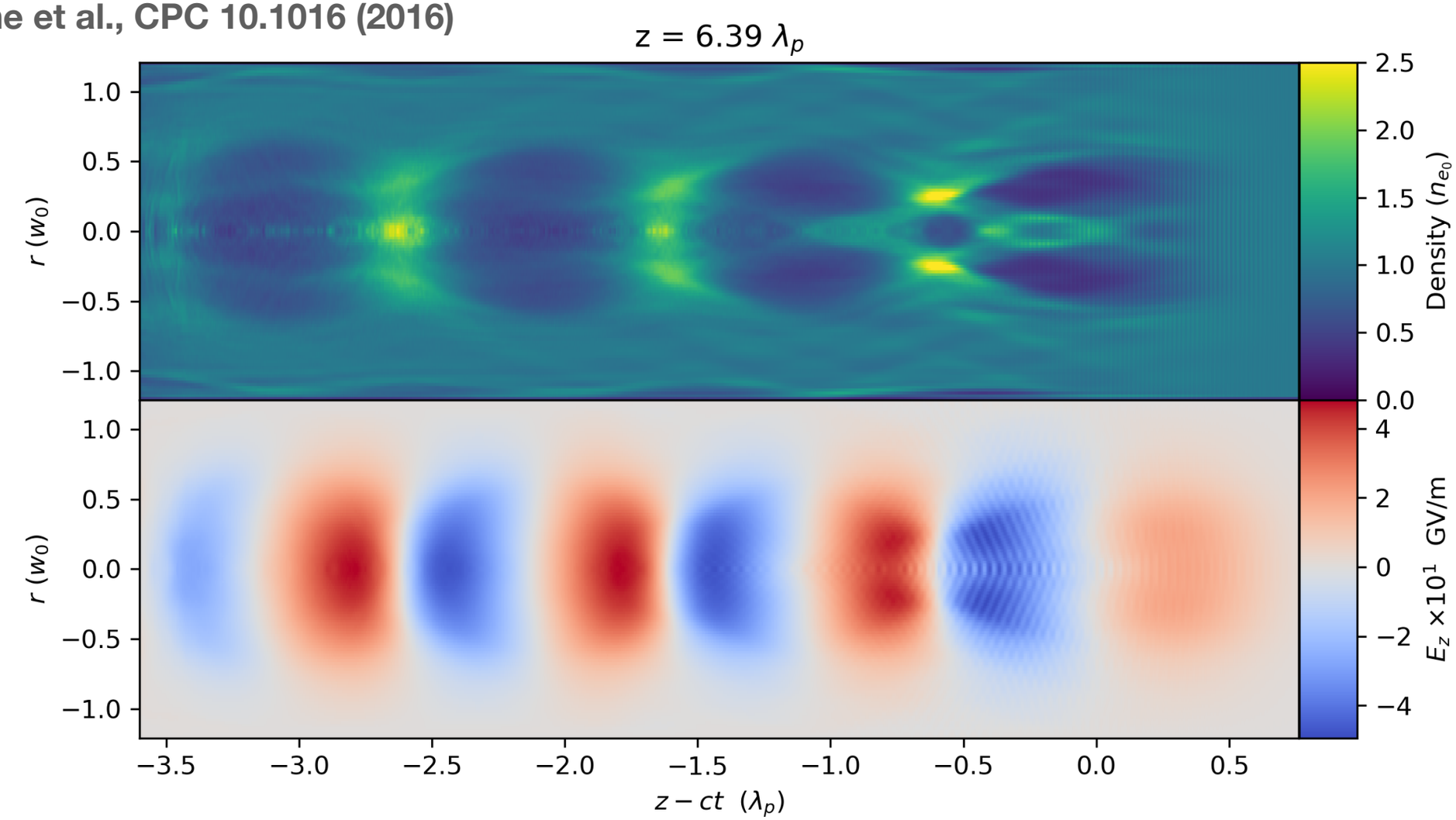
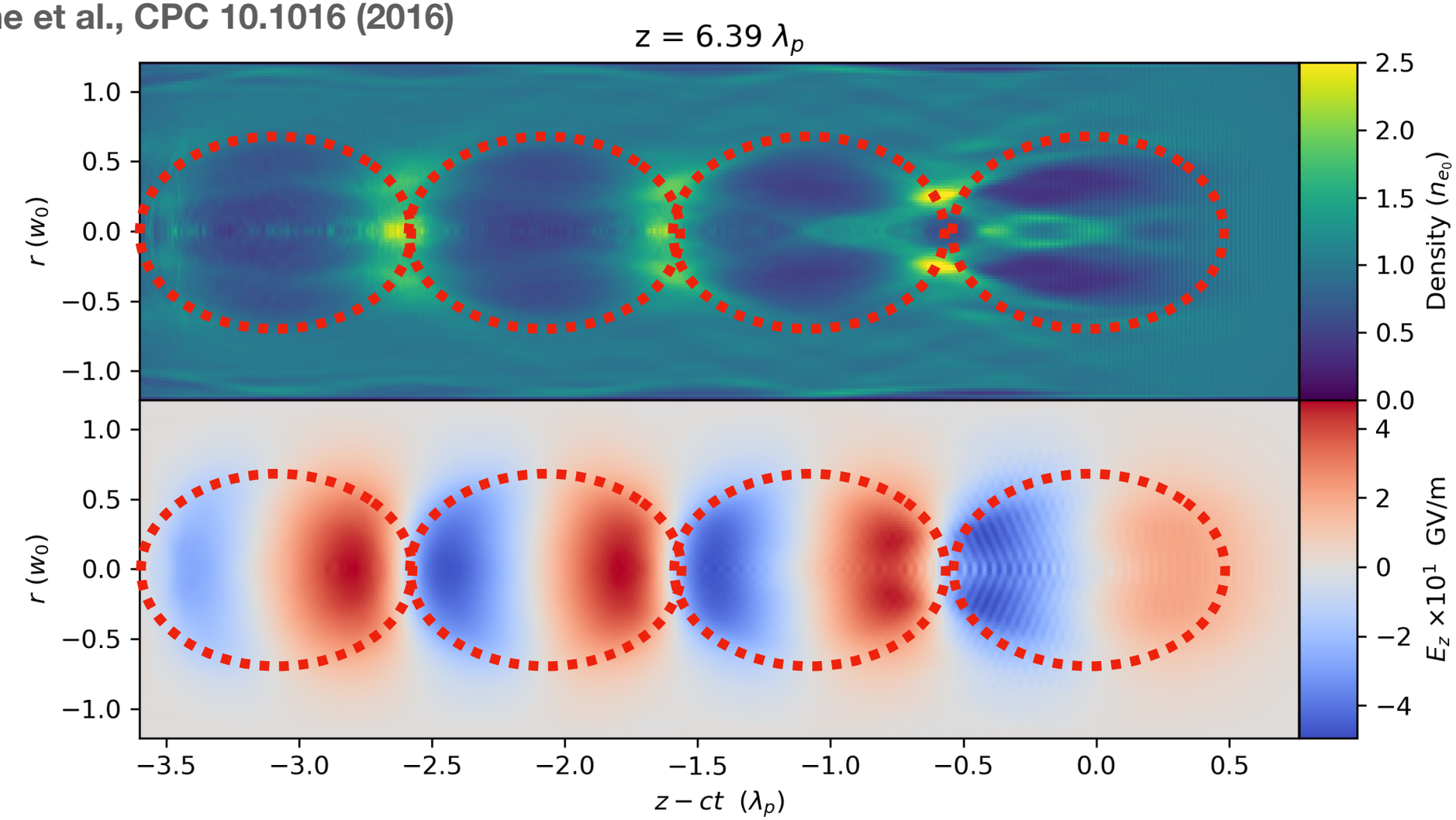
R. Lehe et al., CPC 10.1016 (2016)



Laser wakefield accelerator has strong accelerating fields

R. Lehe et al., CPC 10.1016 (2016)

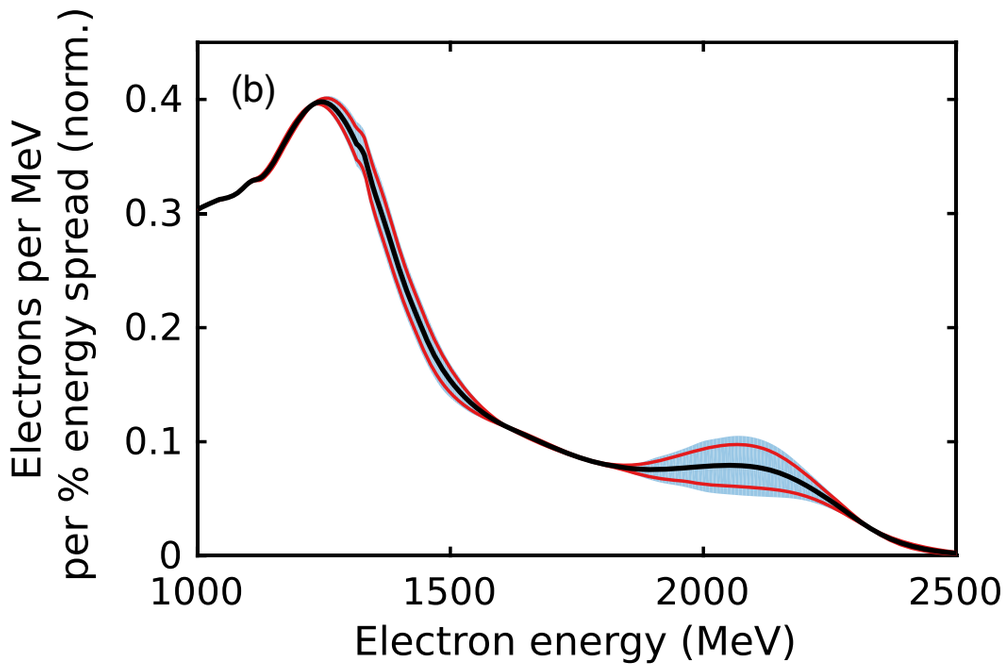


$$\lambda_p = 33\ \mu m \cdot n_e^{-1/2}\ [10^{18}\ cm^{-3}]$$

Electron beam properties dependent on injection

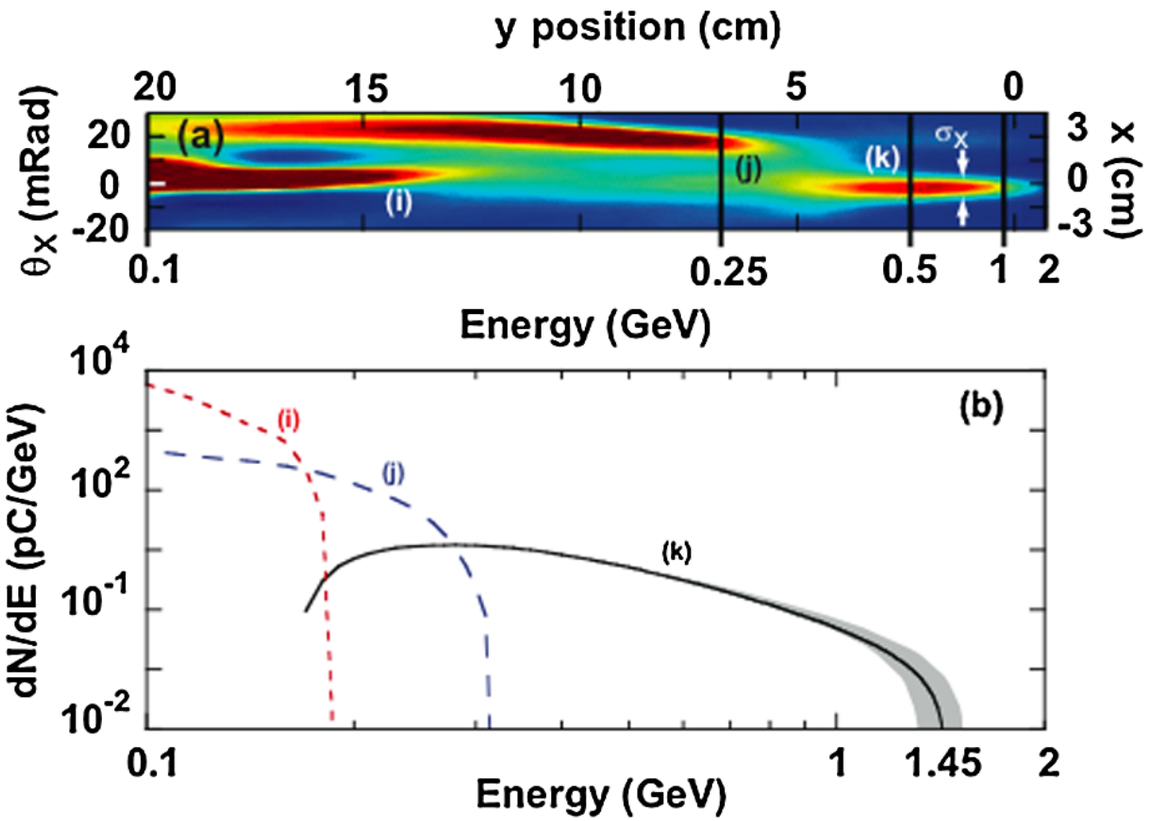
Electron beam properties dependent on injection

Self Injection



K. Poder et al., PRX 8.031004 (2018)

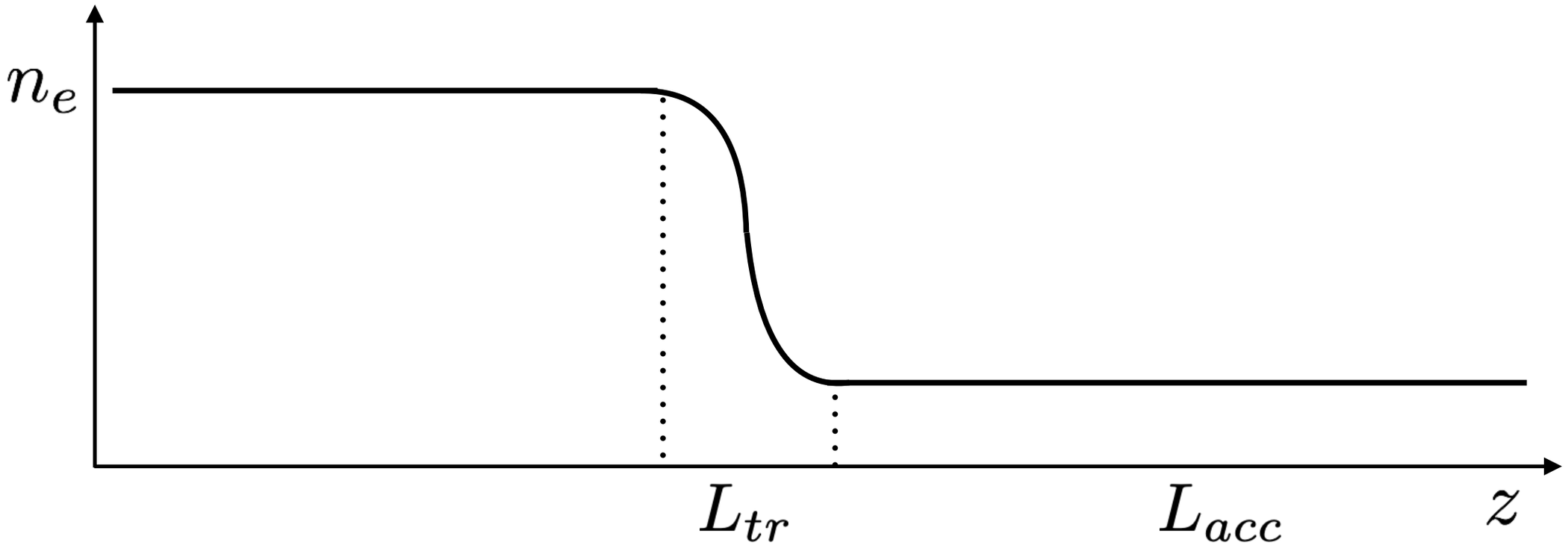
Ionisation Injection



C. Clayton et al., PRL 105.105003 (2010)

Alternative shock injection method

- Sharp density transition (shock) injects electrons over L_{tr}.



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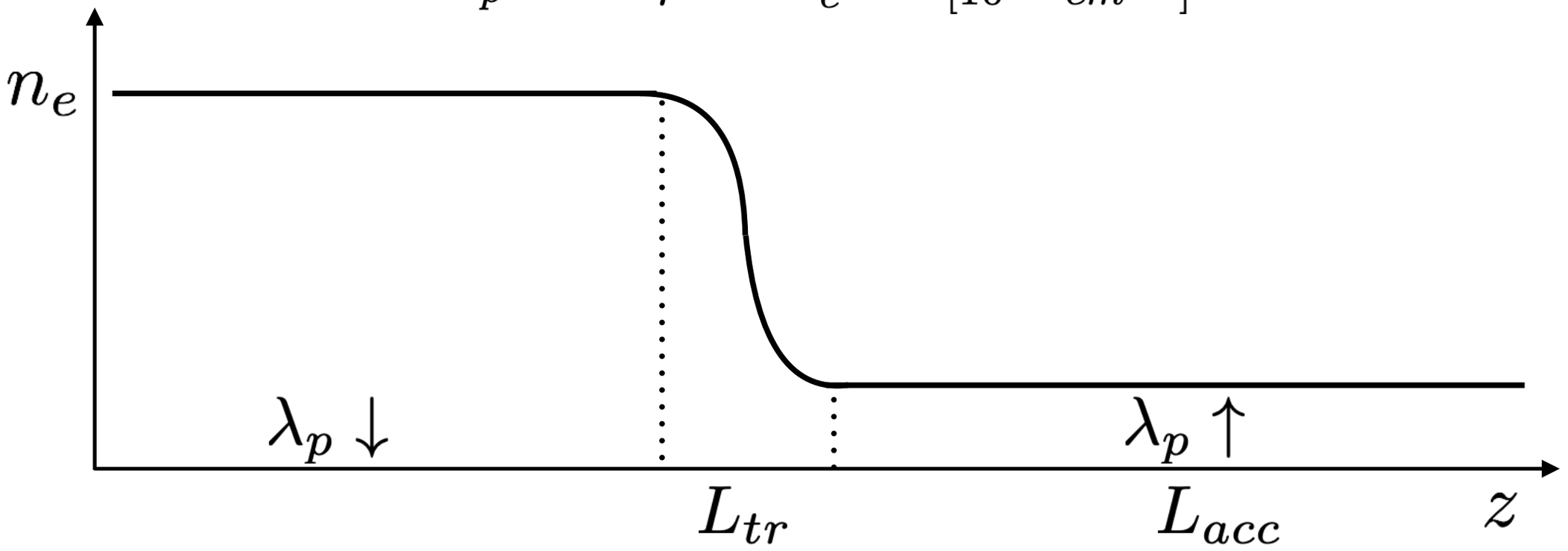

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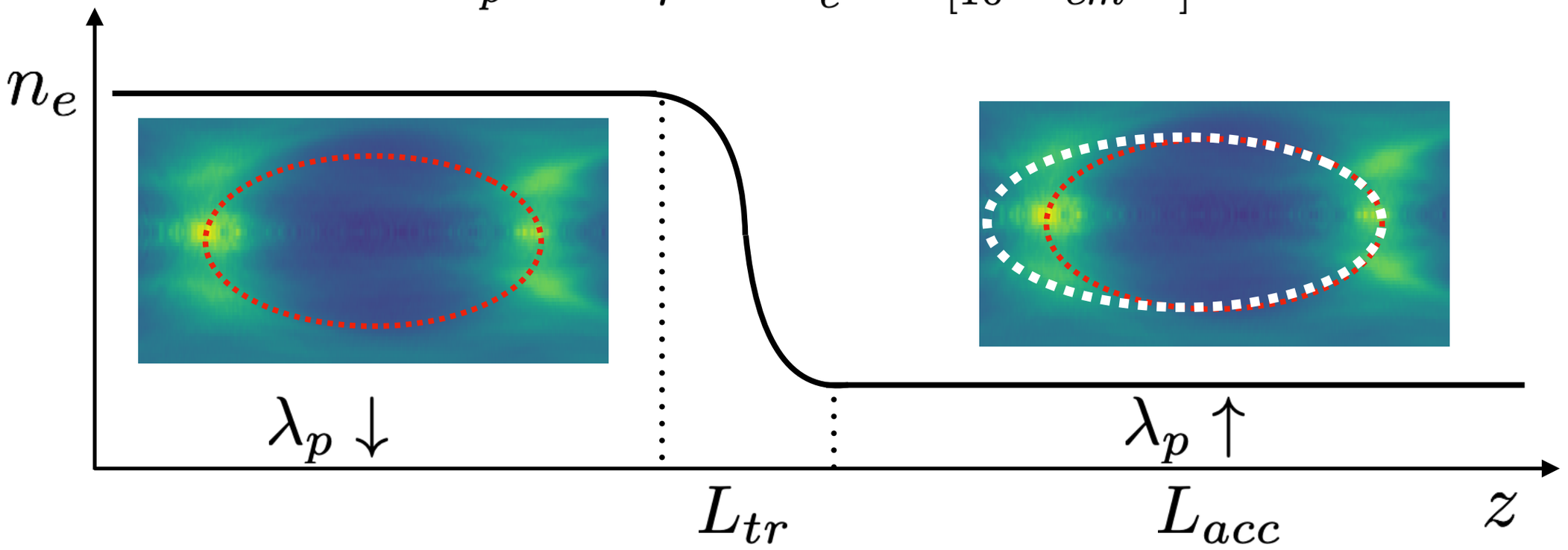

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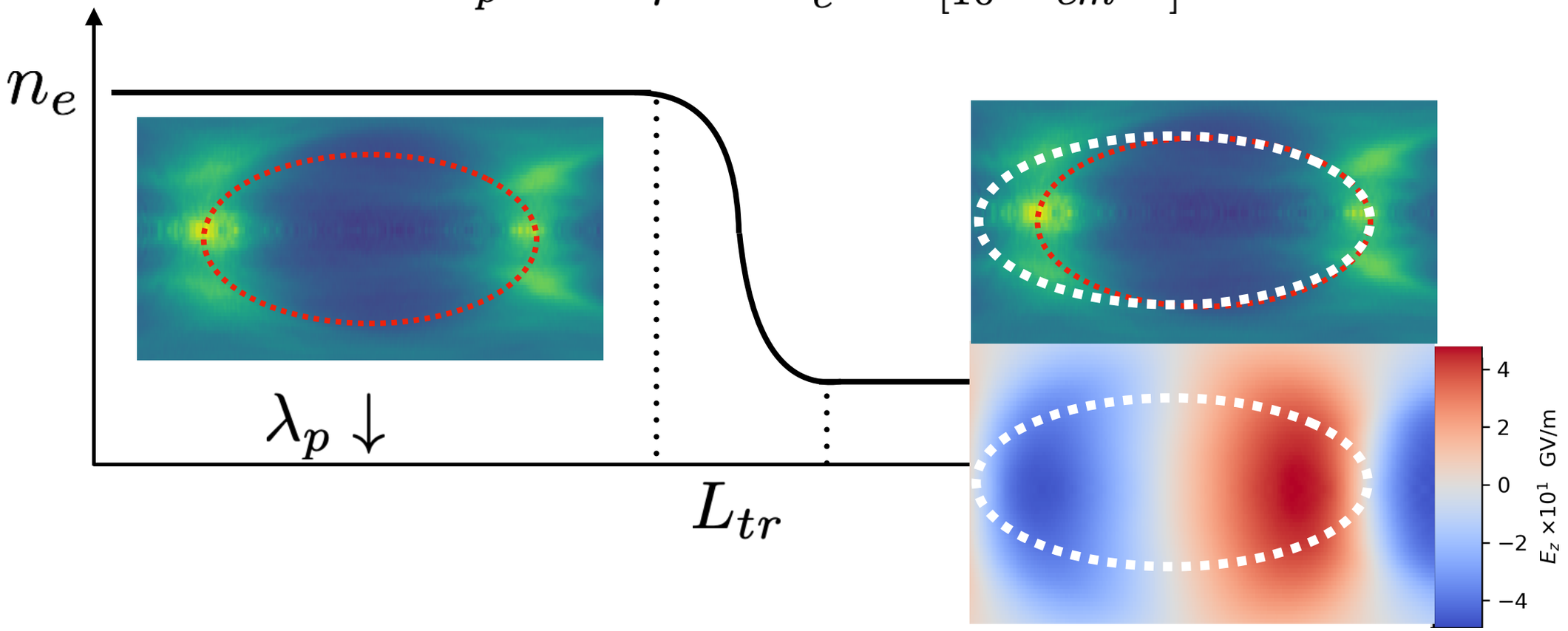
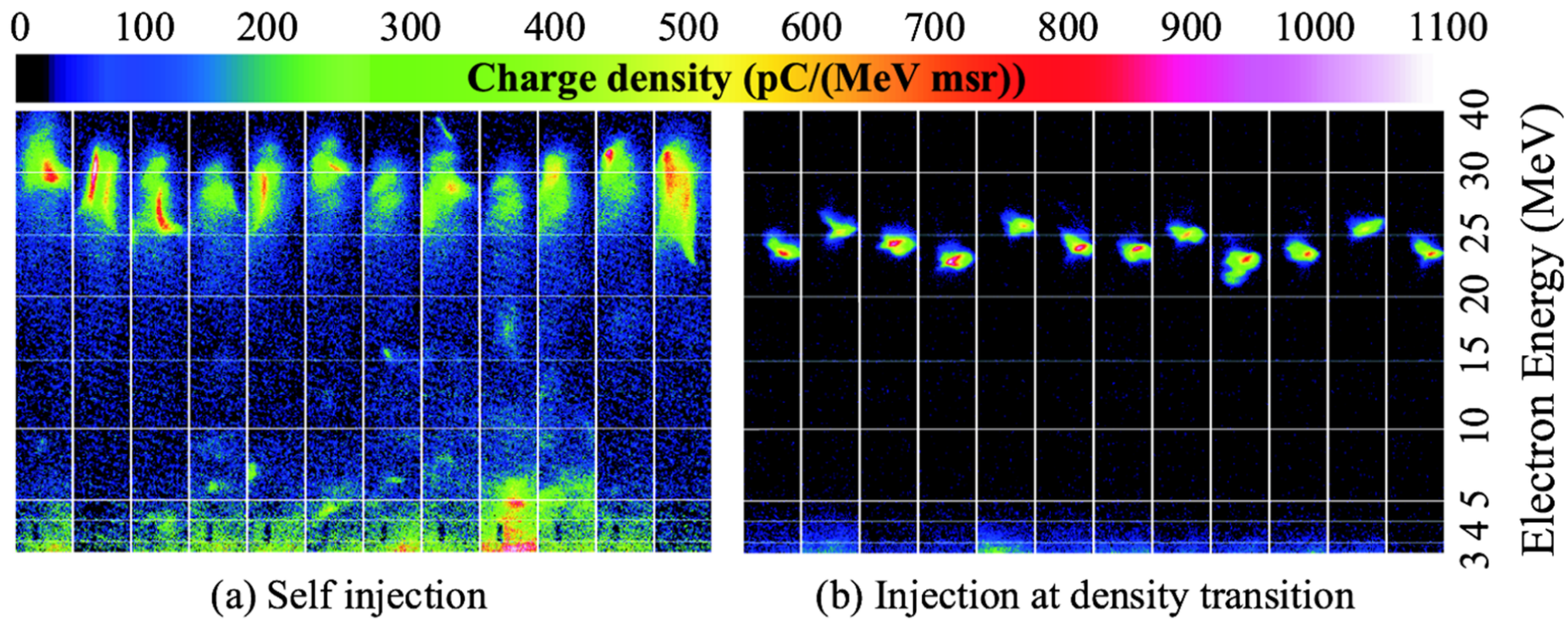


Comparing single beam injection techniques

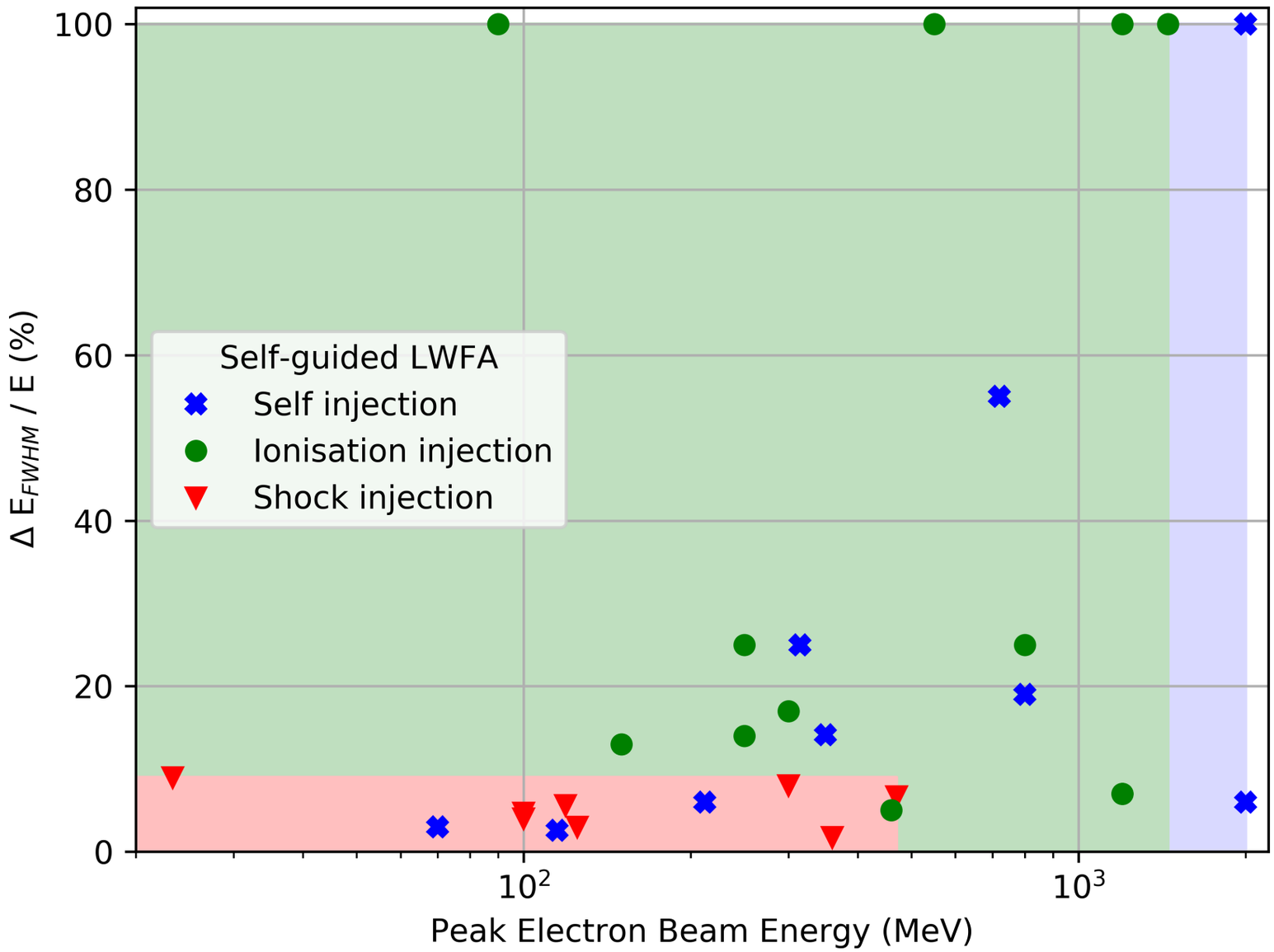
K. Schmid et al., PRSTAB 13, 091301 (2010)



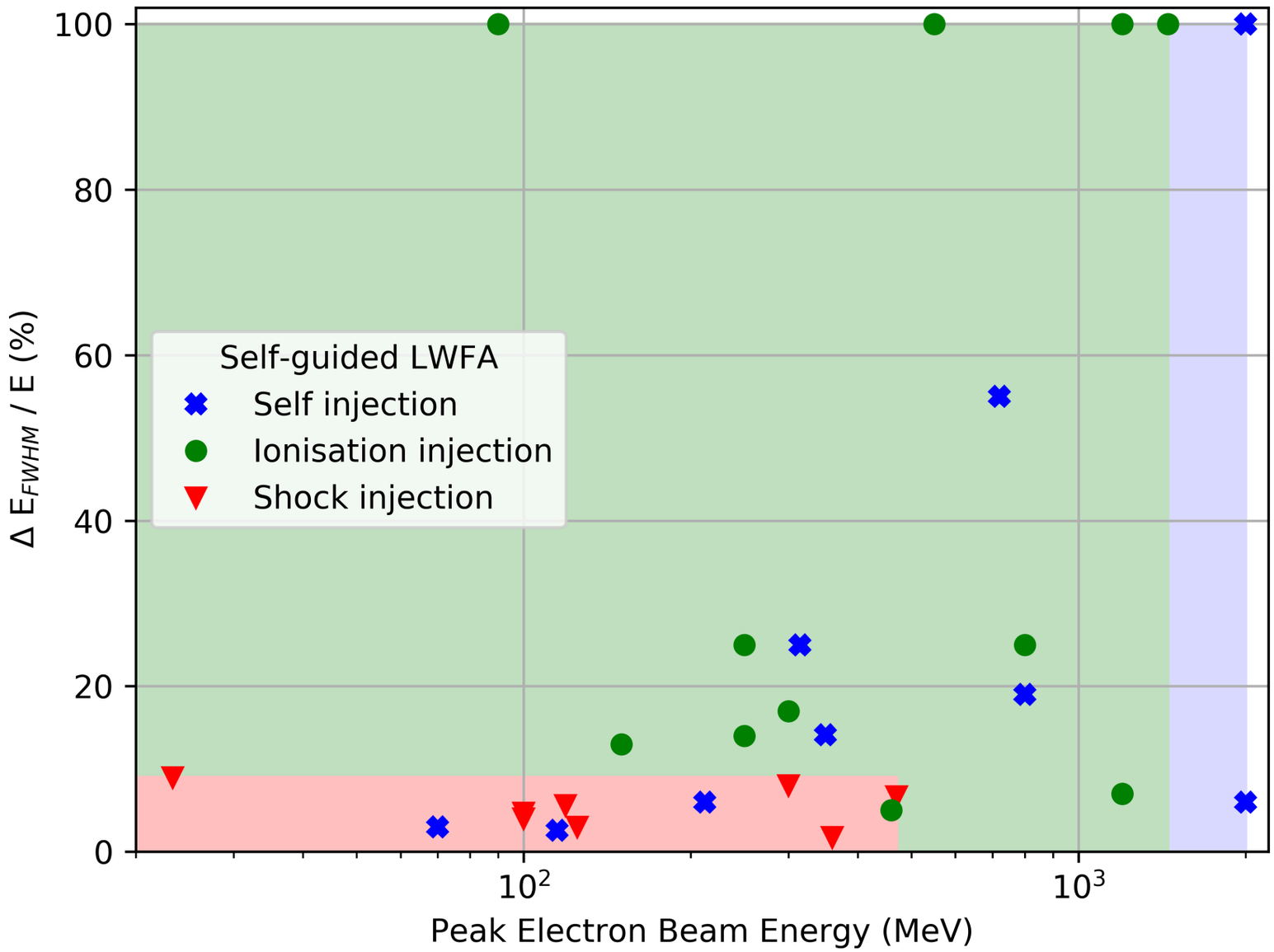
(a) Self injection (b) Injection at density transition

3 TW Laser
25 MeV electrons
4 % Energy spread

Comparing single beam injection techniques

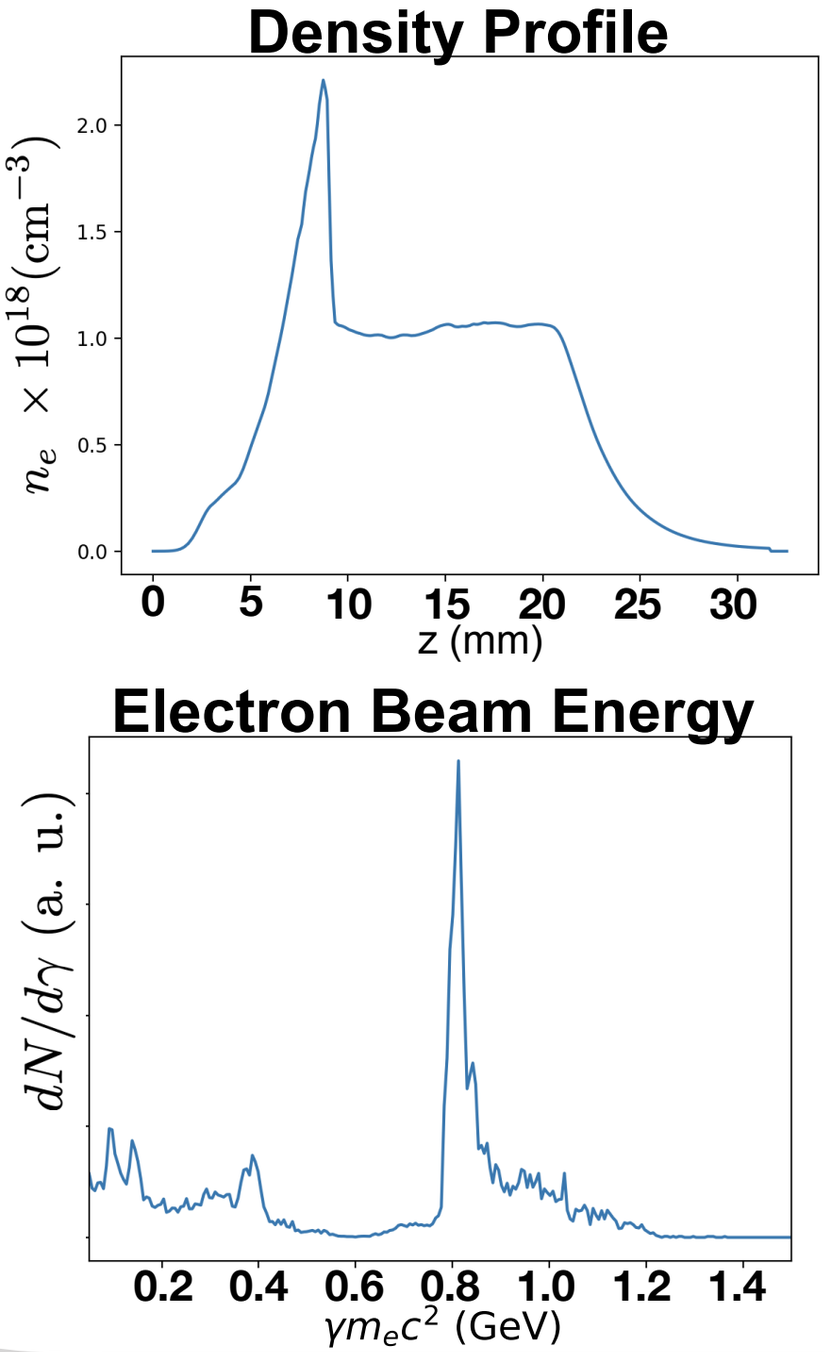


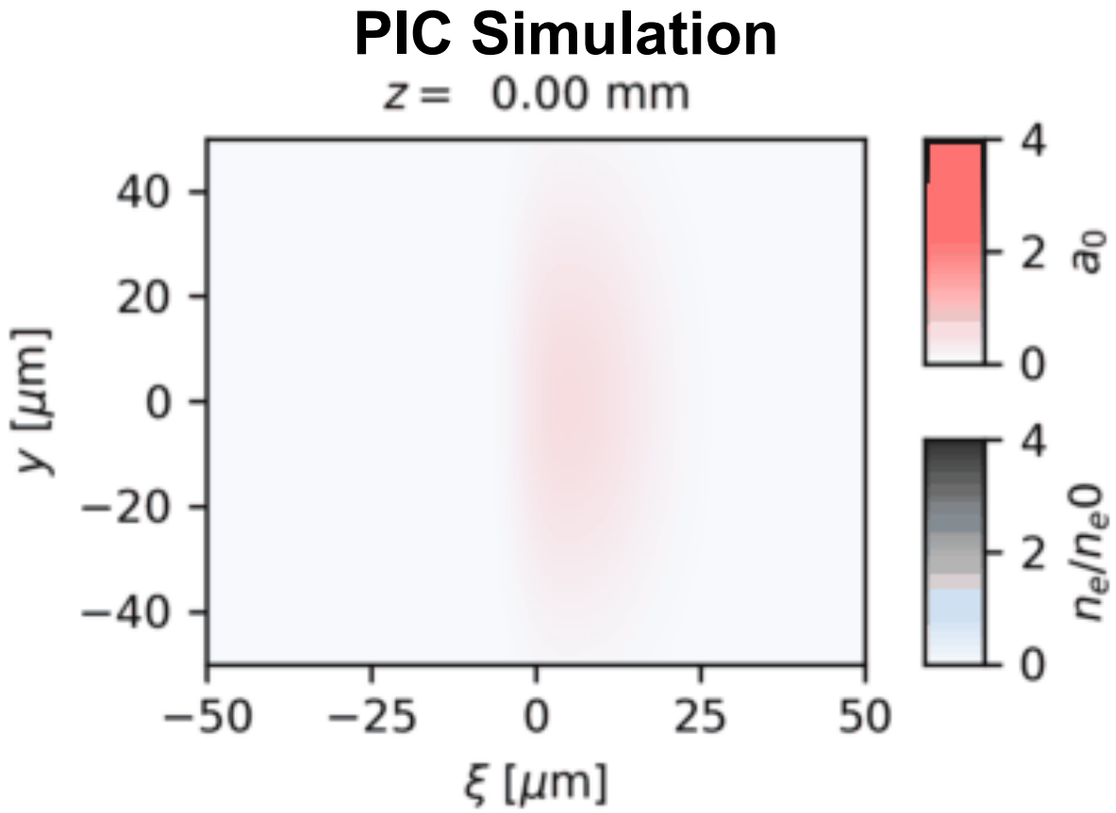
Comparing single beam injection techniques



Can we scale shock injection up to GeV?

Simulating shock injection with 165 TW laser

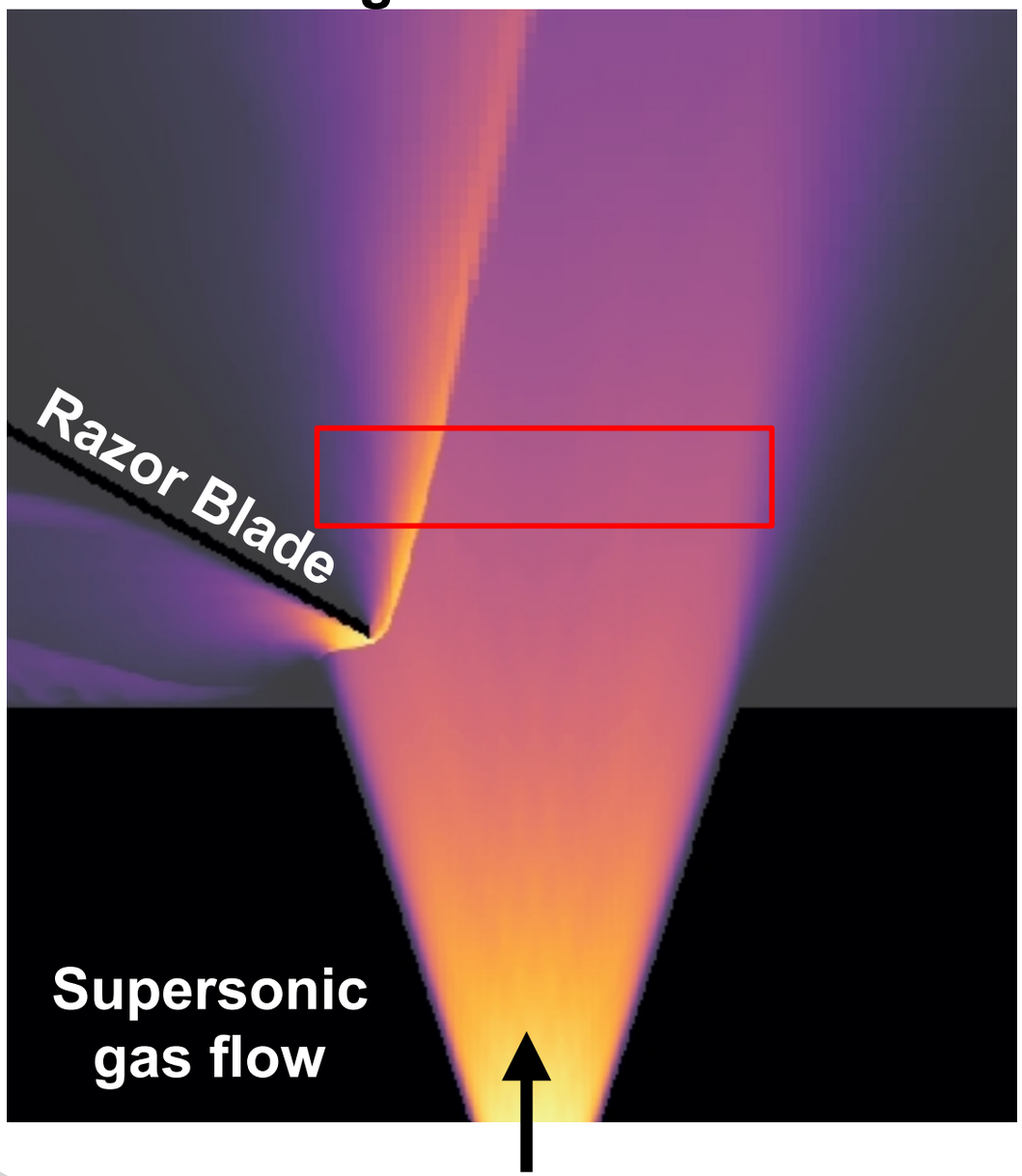




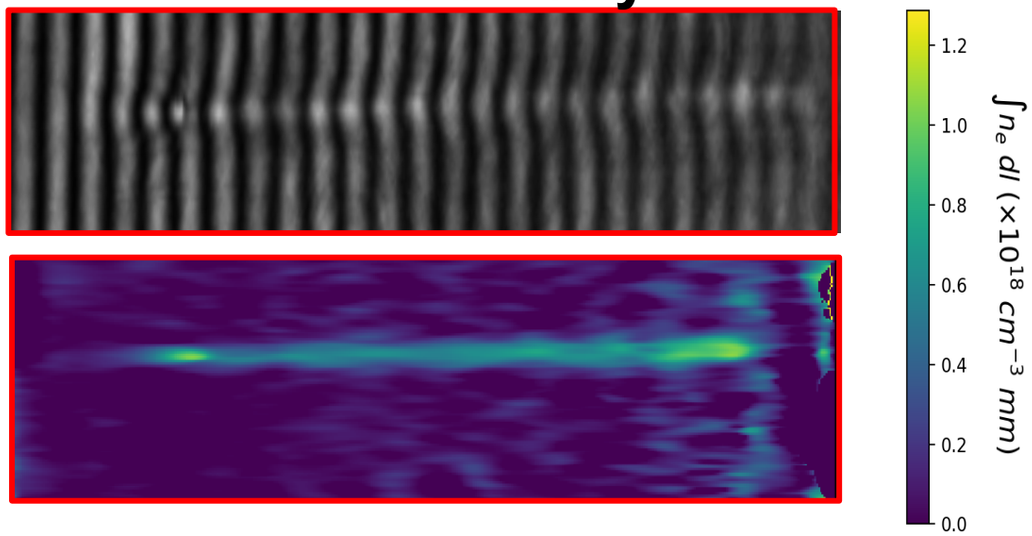
R. Lehe et al., CPC 10.1016 (2016)

Density profile from shocked supersonic gas flow

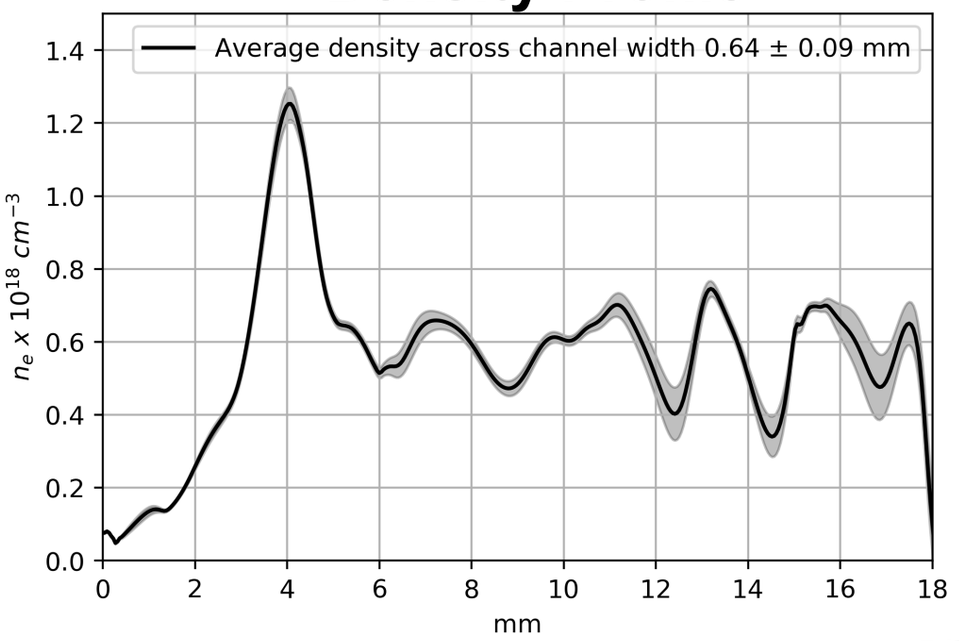
Target Schematic



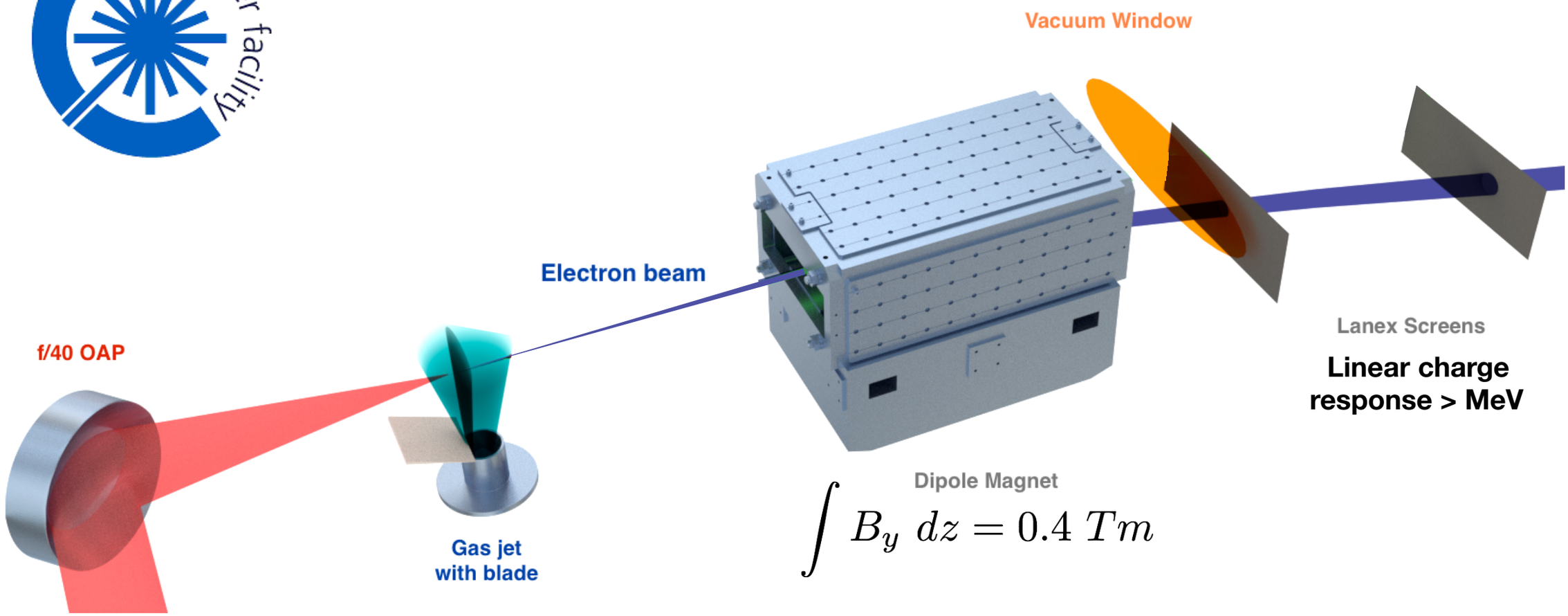
Interferometry



Density Profile



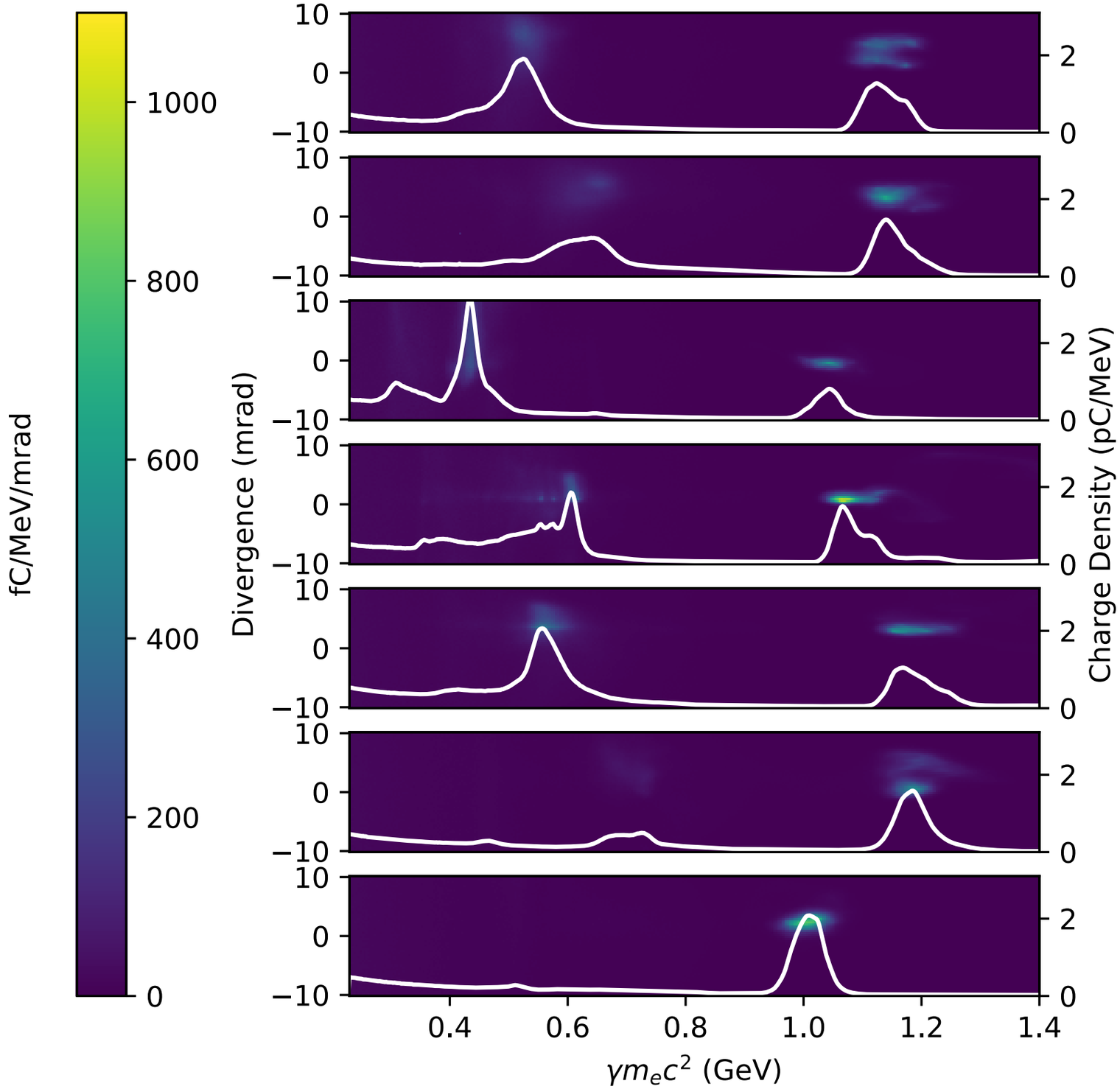
Shock injection at Gemini Laser Facility



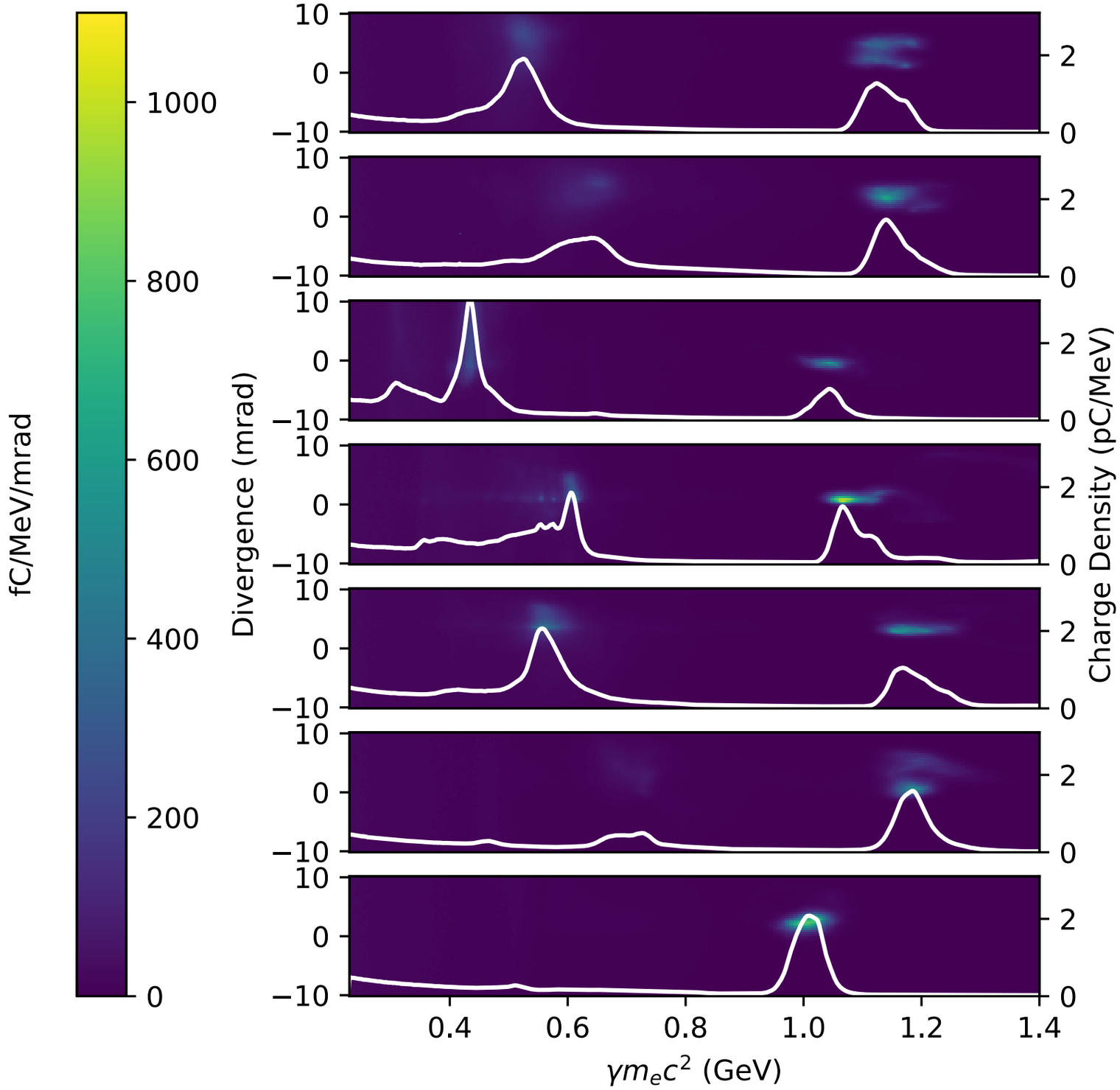
Focal spot:
(49 ± 1) μm x (39 ± 1) μm

a_0 = 1.8

Narrow energy spread, GeV beams



Narrow energy spread, GeV beams

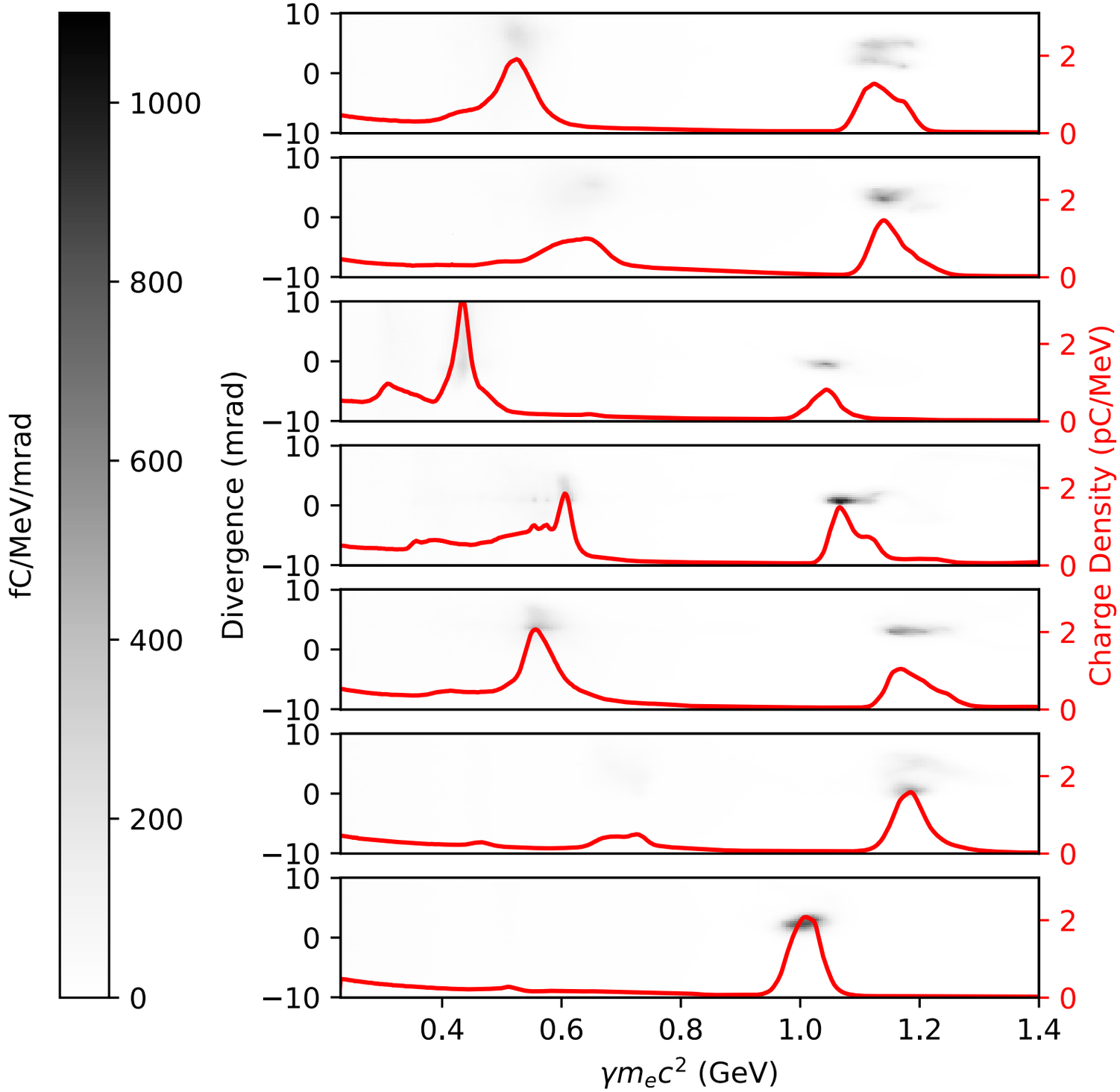


7 / 11 consecutive shots in parameter scan

Average Energy 1.11 ± 0.06 GeV

Energy Spread 6 ± 1 % (FWHM)

Narrow energy spread, GeV beams



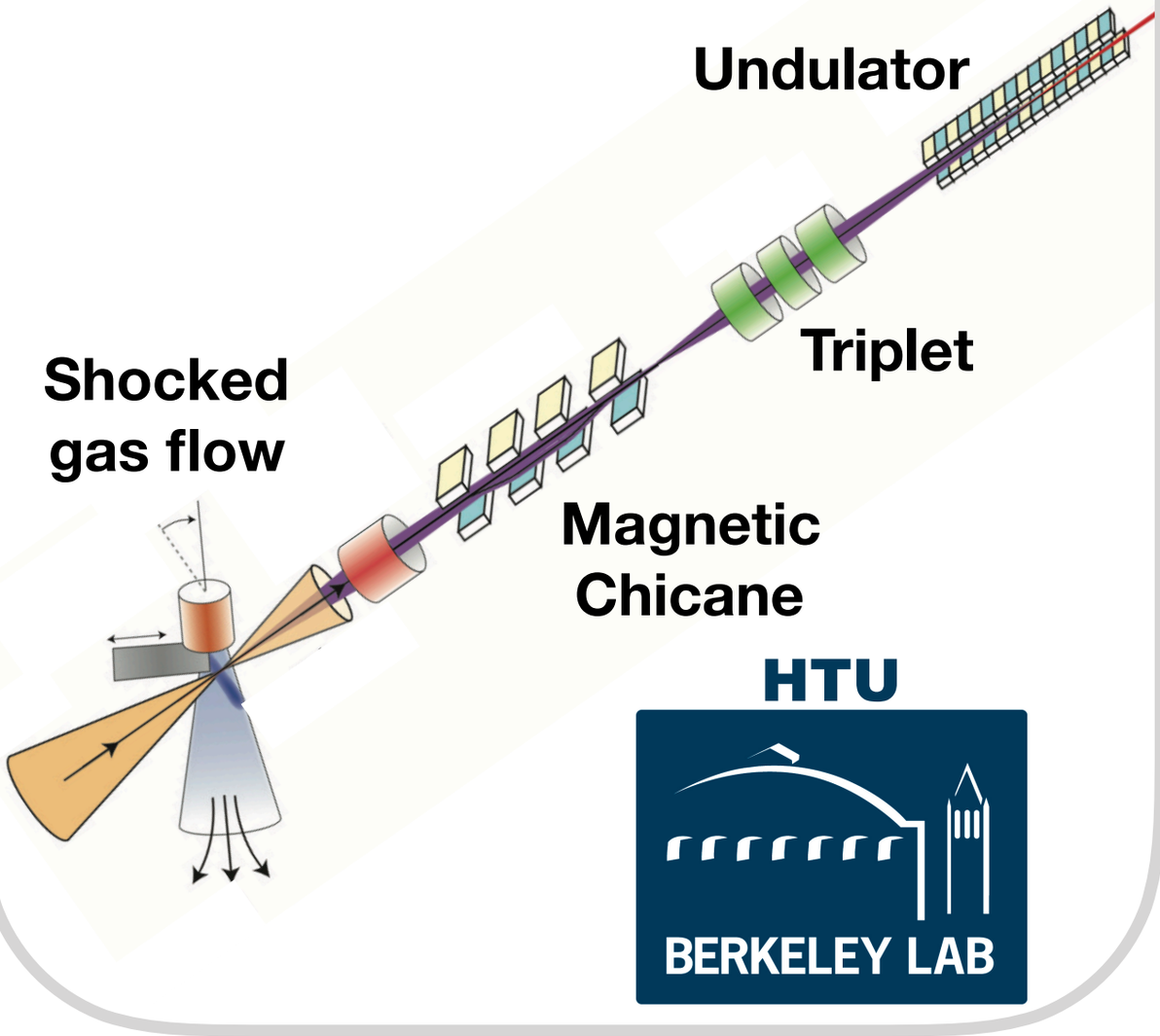
7 / 11 consecutive shots in parameter scan

Average Energy
1.11 ± 0.06 GeV

Energy Spread
6 ± 1 % (FWHM)

Applications of narrow energy spread beams

Free Electron Lasers

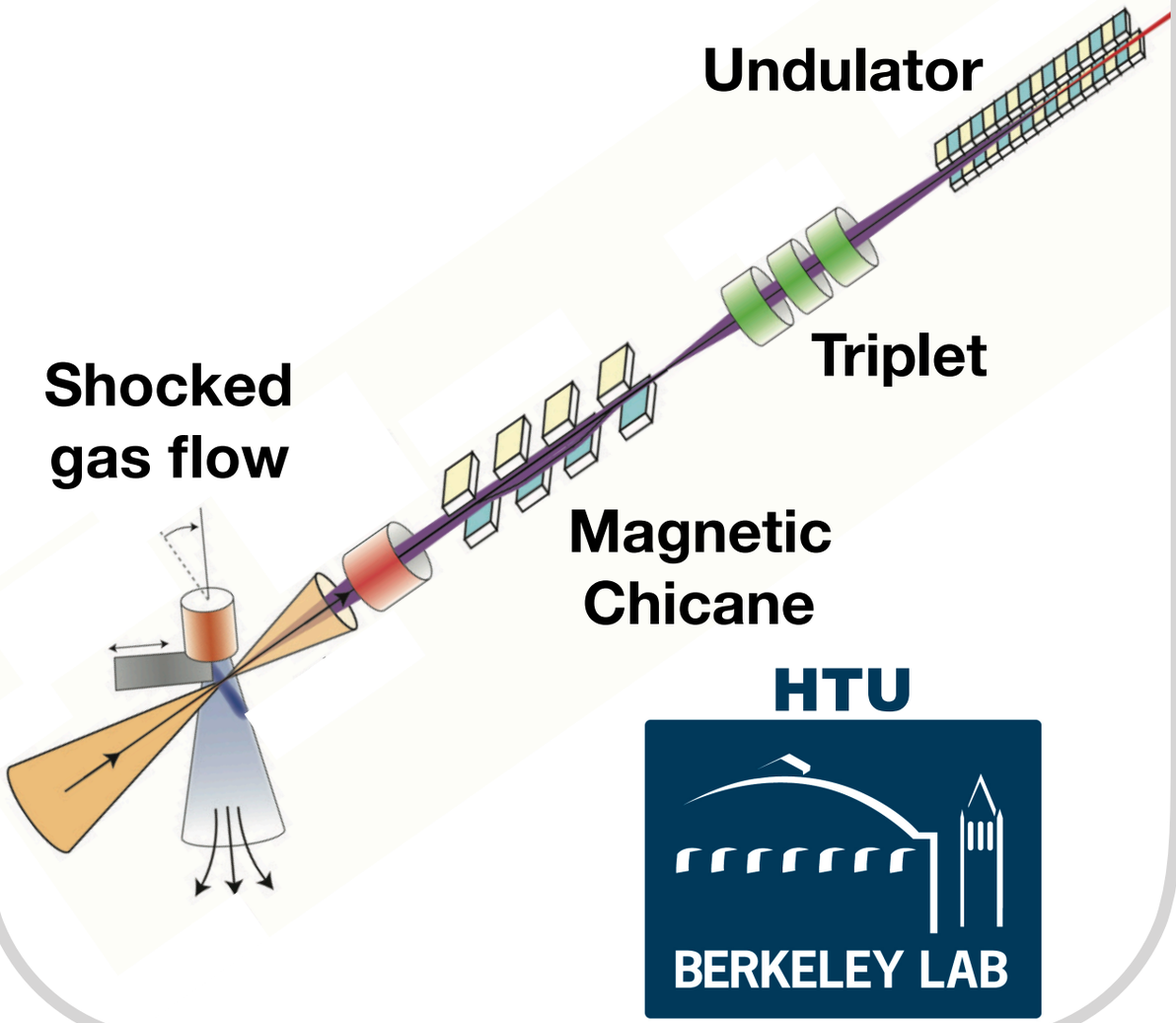


HTU

BERKELEY LAB

Applications of narrow energy spread beams

Free Electron Lasers



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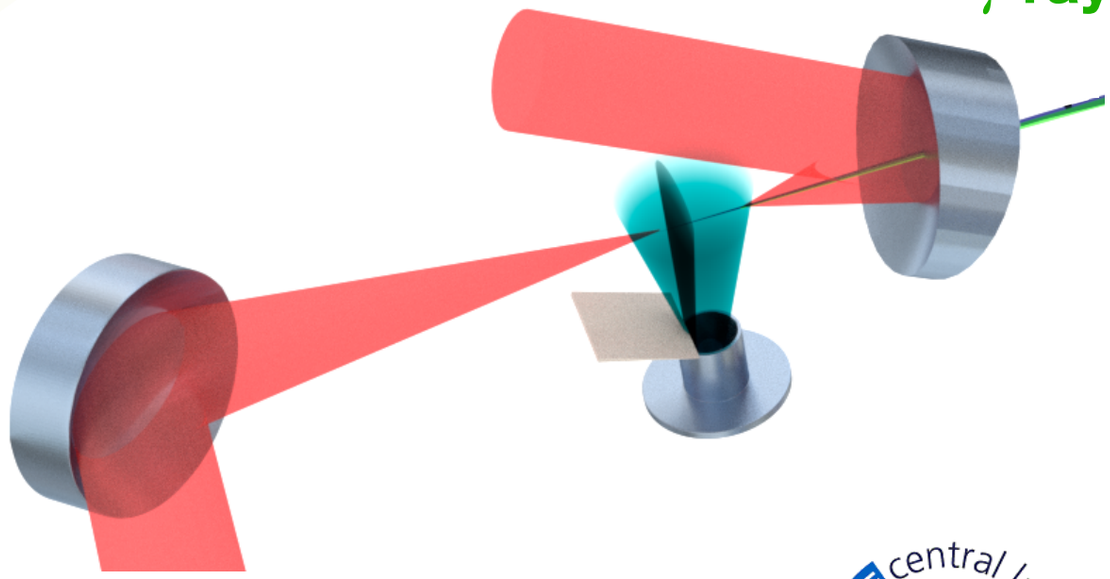
Radiation Reaction

Scattering beam

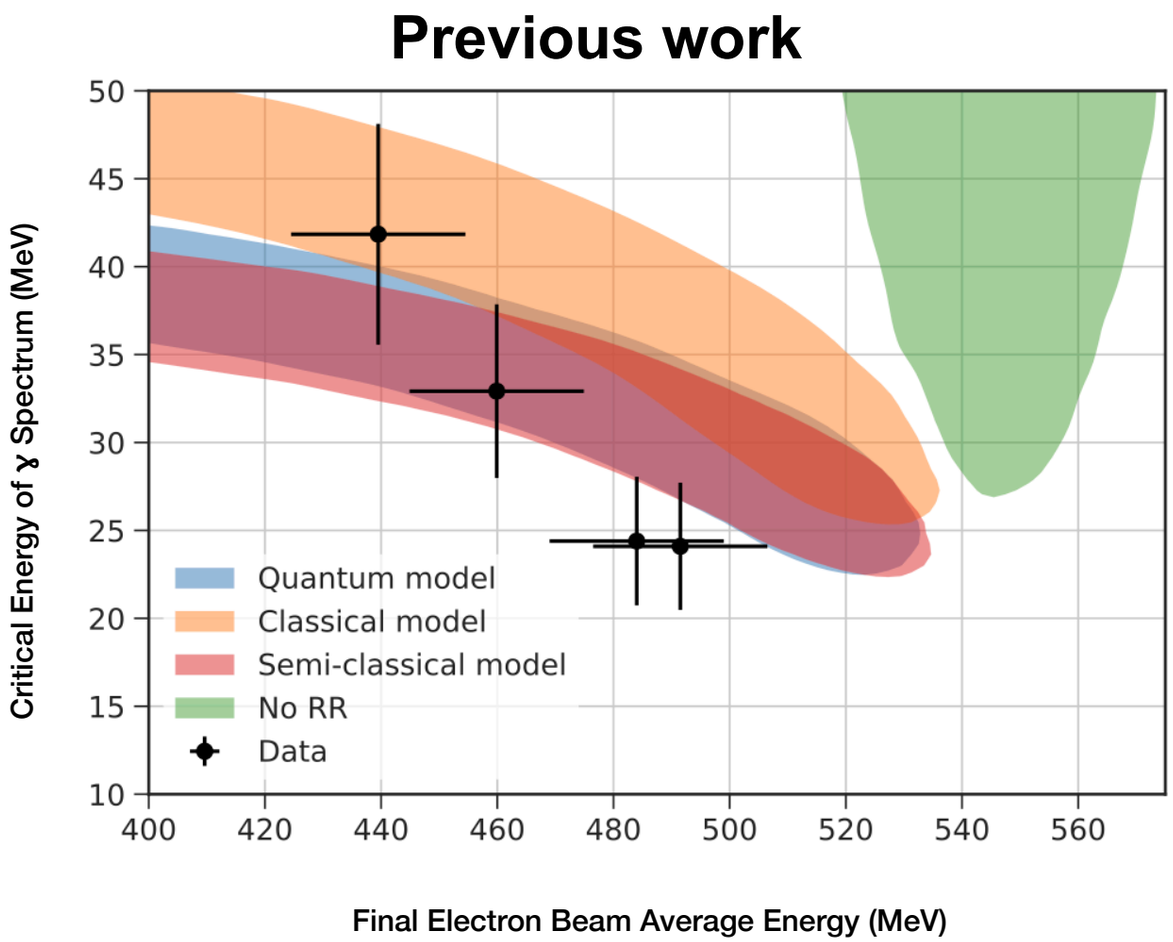
γ rays



Laser wakefield drive beam

CLF central laser facility

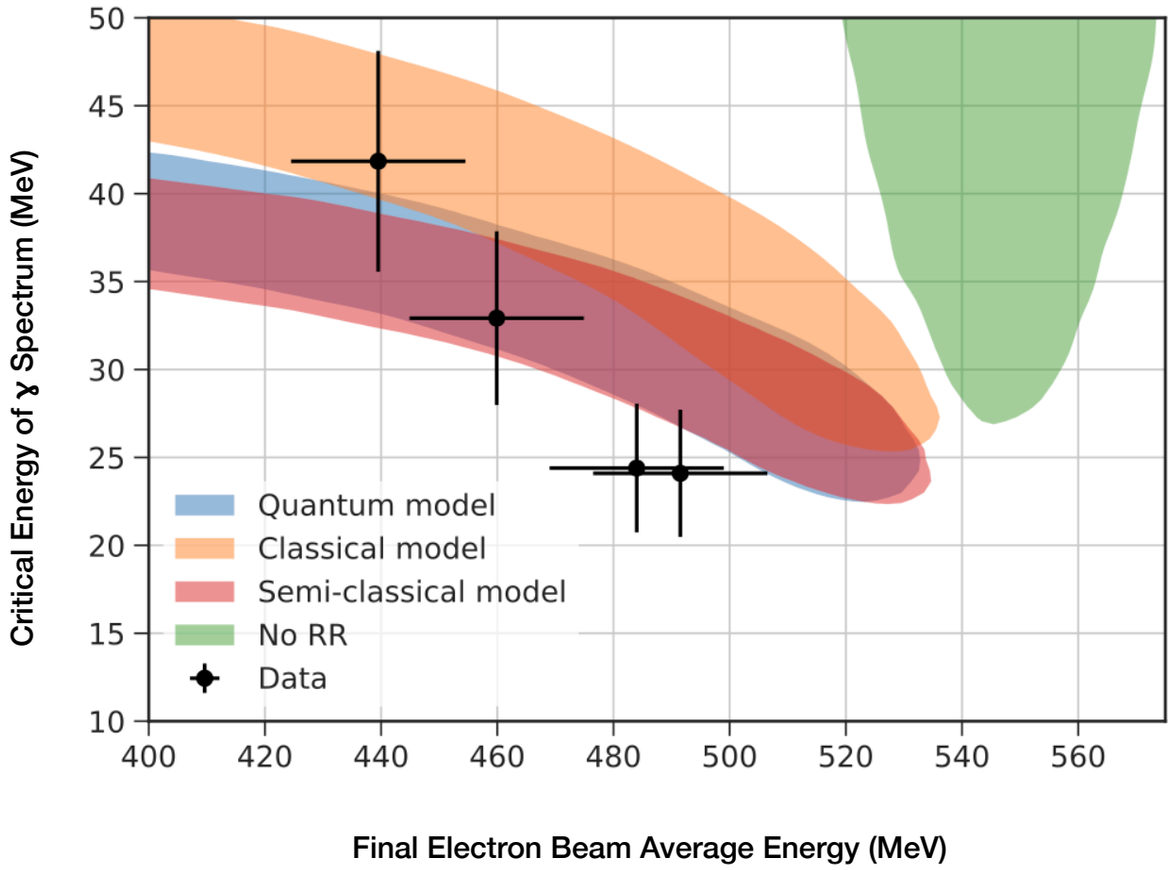
Applications to Radiation Reaction



J. Cole et al., PRX 8.011020 (2018)

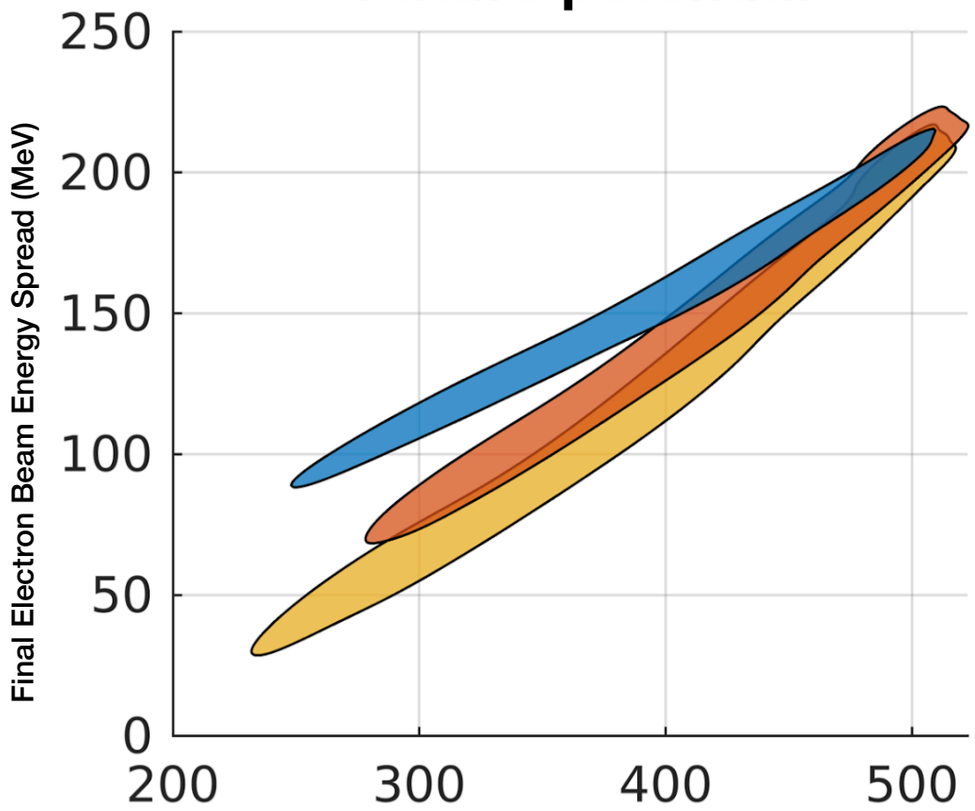
Applications to Radiation Reaction

Previous work



J. Cole et al., PRX 8.011020 (2018)

Future potential



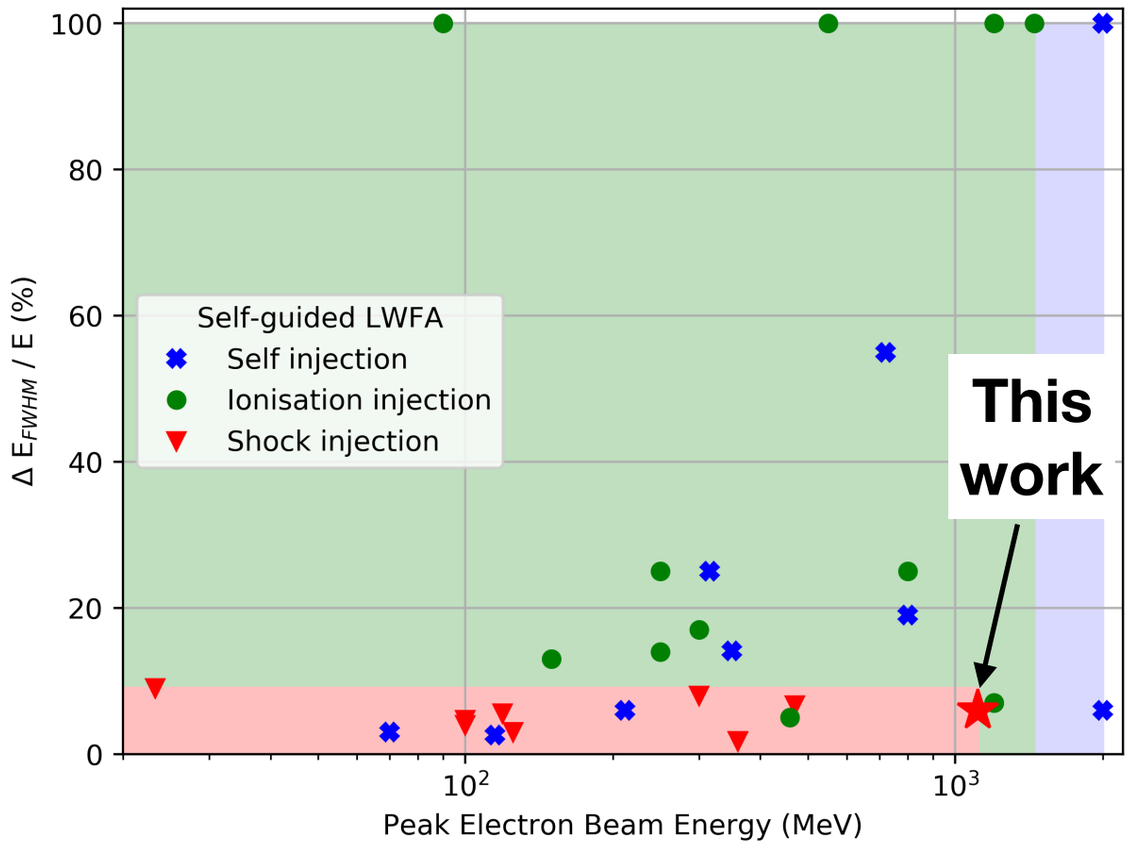
C. Arran et al., PPCF 61.074009 (2019)

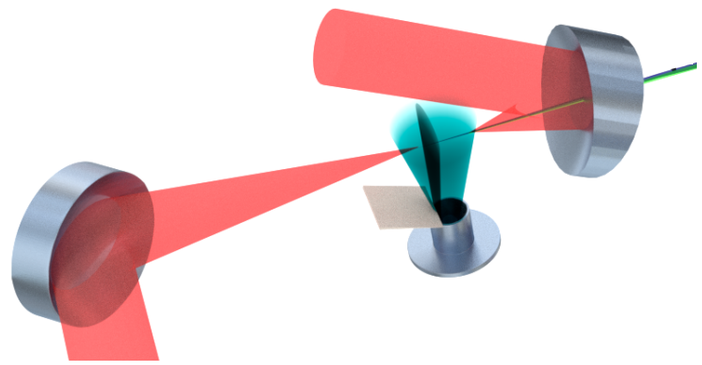
Conclusion

- Demonstrated shock injection on 150 TW system.

- Narrow energy spread, electron beams **(1.1 GeV, 6% spread)** have been produced.

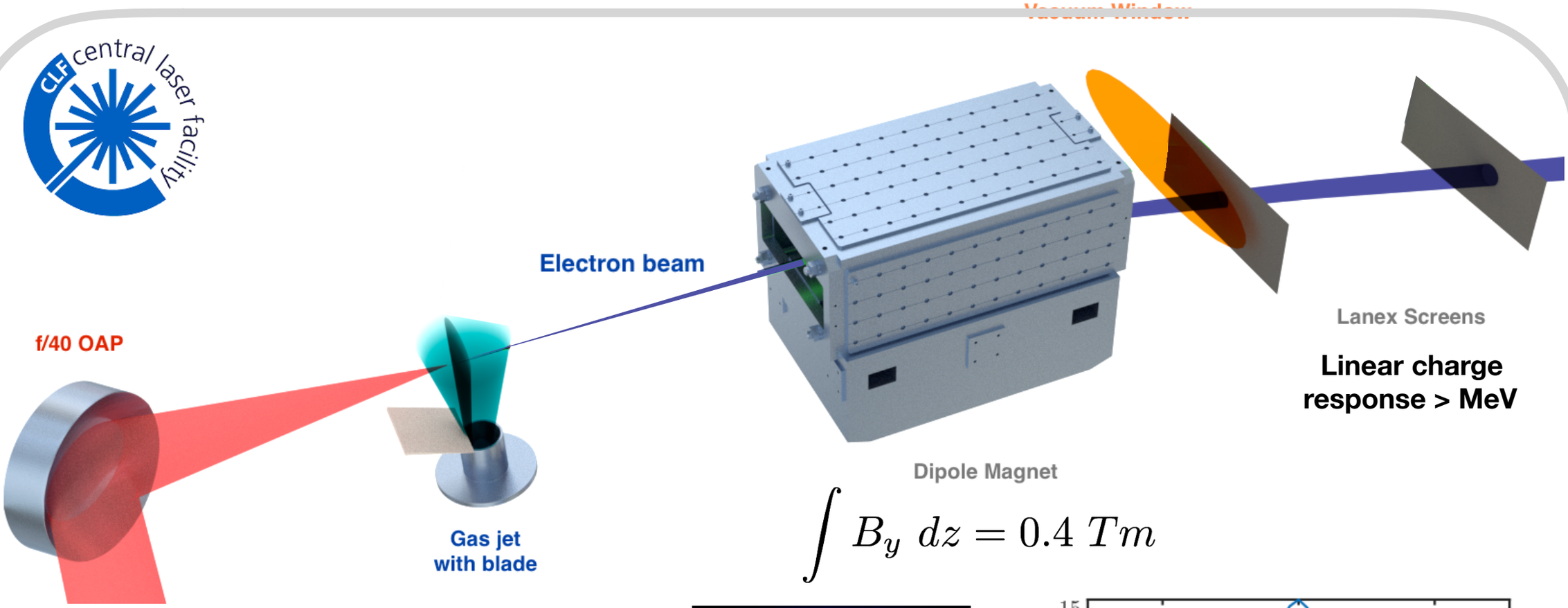
- Potential applications to QED studies, free electron lasing and Thomson scattering.

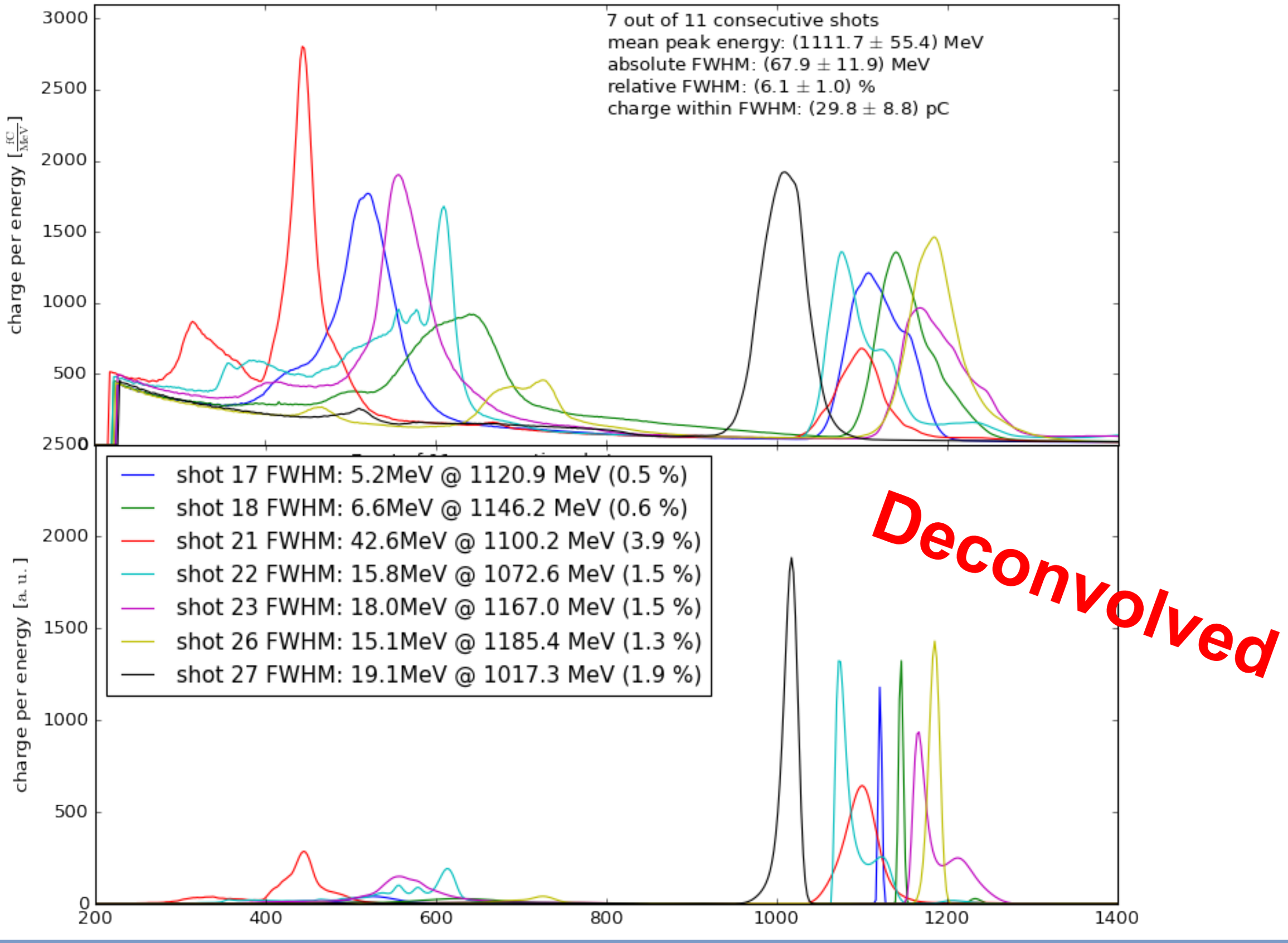




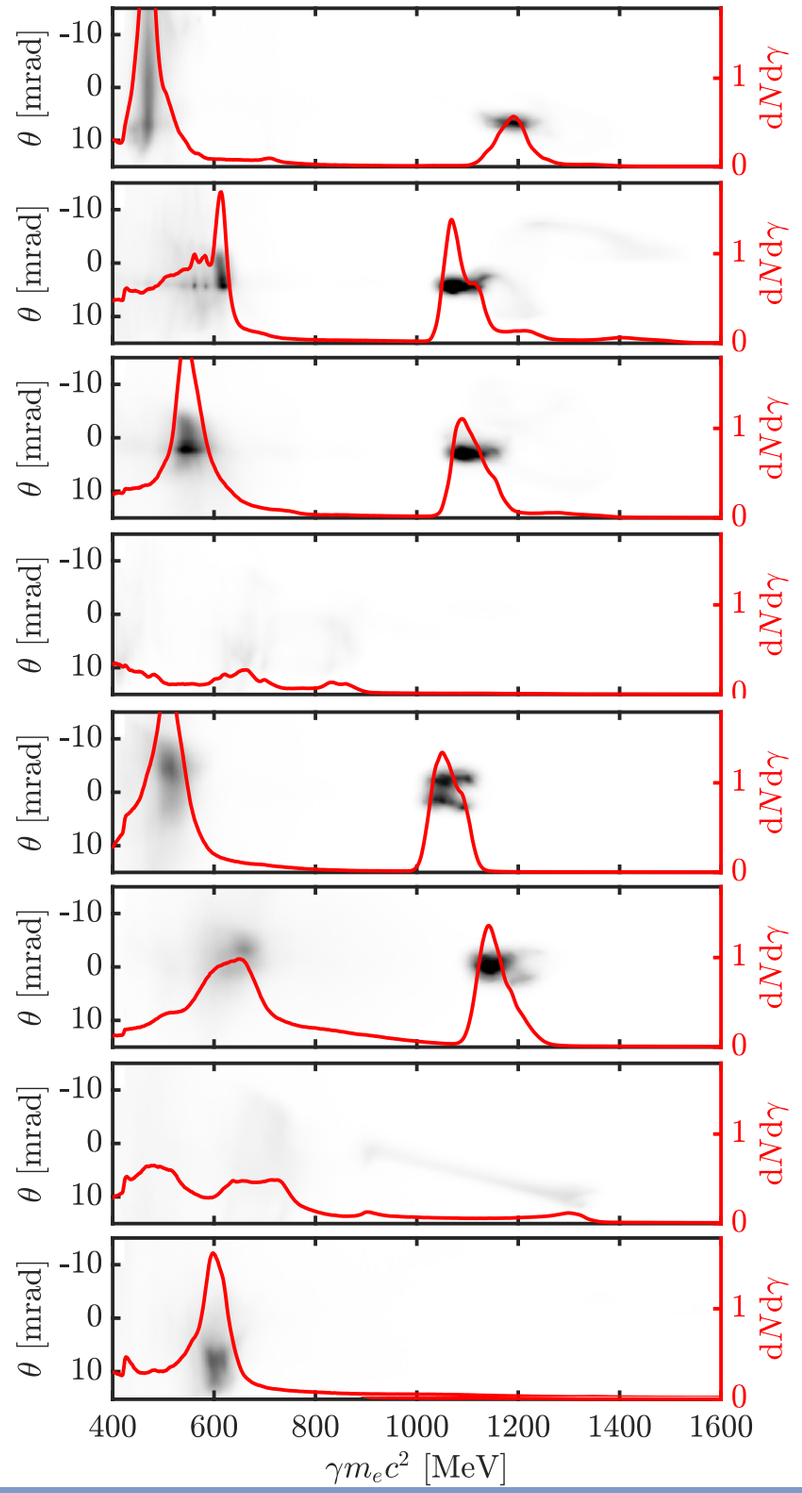
Extra Slides

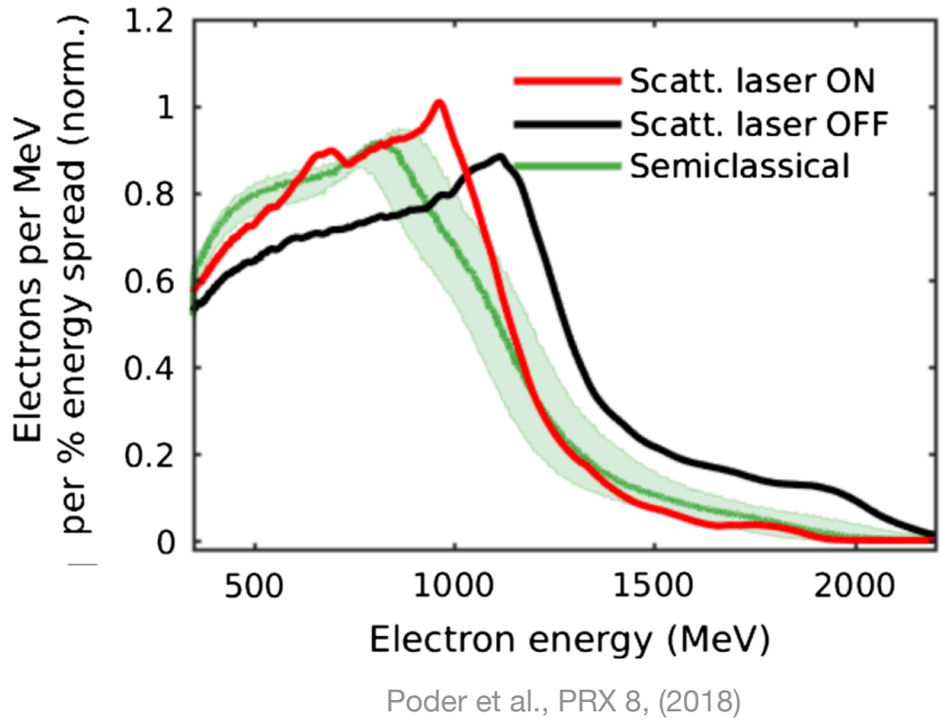
Experimental Setup



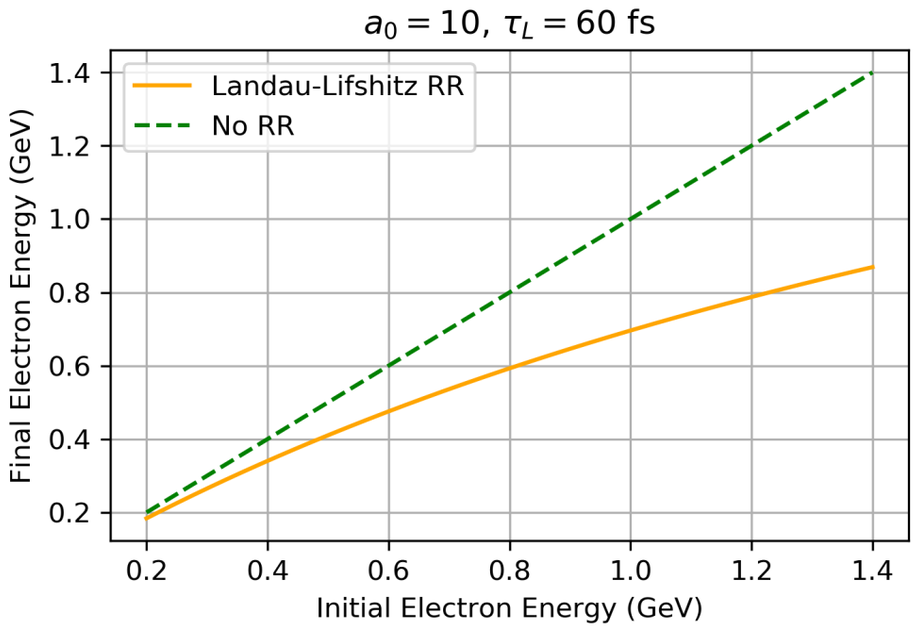

7 out of 11 consecutive shots
mean peak energy: (1111.7 ± 55.4) MeV
absolute FWHM: (67.9 ± 11.9) MeV
relative FWHM: (6.1 ± 1.0) %
charge within FWHM: (29.8 ± 8.8) pC
charge per energy [fC/MeV]
shot 17 FWHM: 5.2MeV @ 1120.9 MeV (0.5 %)
shot 18 FWHM: 6.6MeV @ 1146.2 MeV (0.6 %)
shot 21 FWHM: 42.6MeV @ 1100.2 MeV (3.9 %)
shot 22 FWHM: 15.8MeV @ 1072.6 MeV (1.5 %)
shot 23 FWHM: 18.0MeV @ 1167.0 MeV (1.5 %)
shot 26 FWHM: 15.1MeV @ 1185.4 MeV (1.3 %)
shot 27 FWHM: 19.1MeV @ 1017.3 MeV (1.9 %)
charge per energy [a. u.]
Deconvolved

Detecting Radiation Reaction



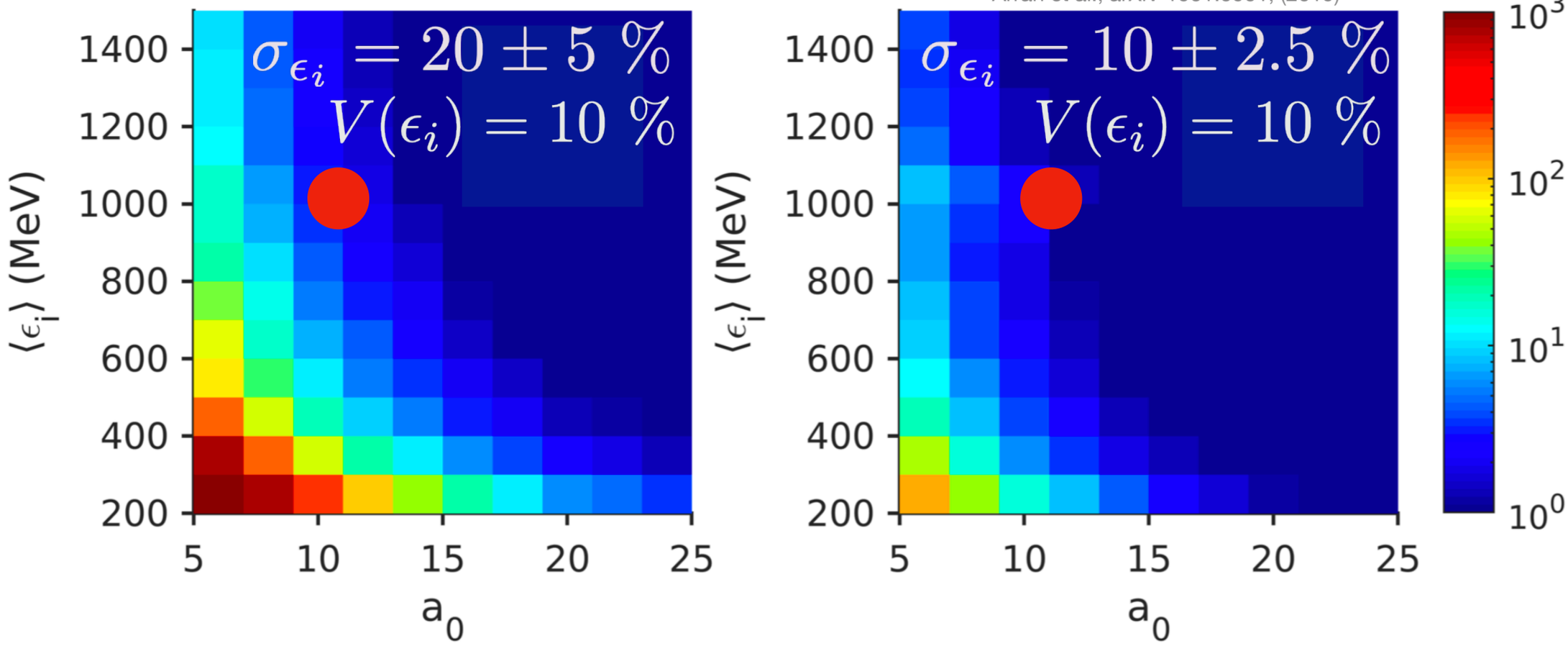


Poder et al., PRX 8, (2018)



Detecting Radiation Reaction

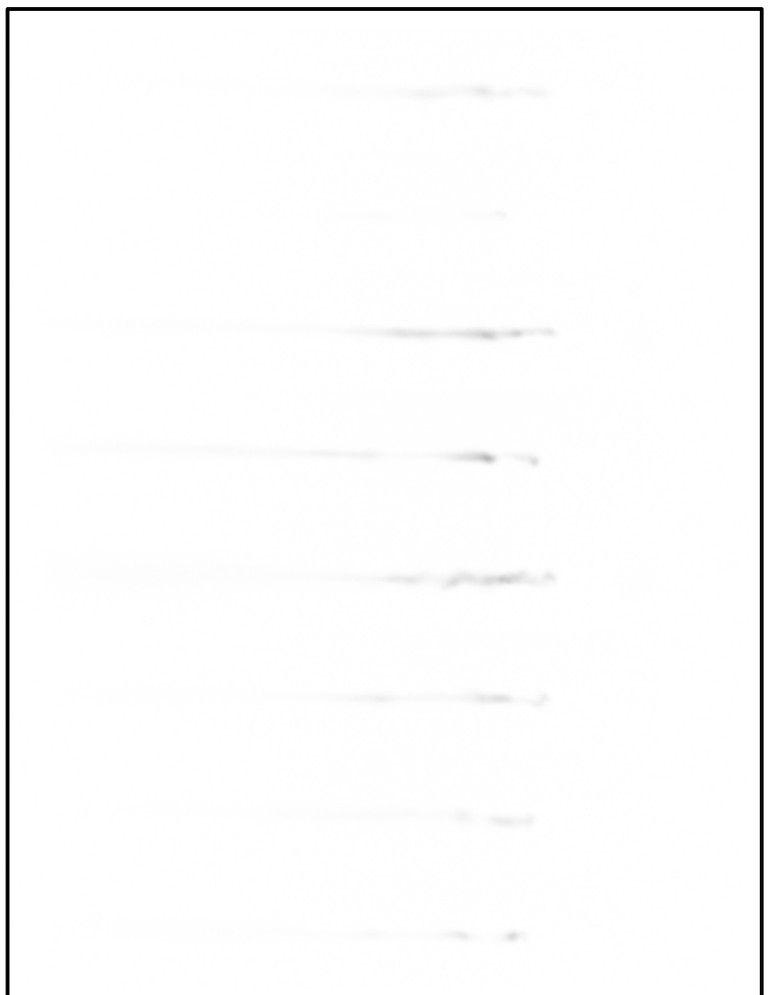
Arran et al., arXiV 1901.0901, (2019)



- According to EPOCH sims, the minimum number of shots required to distinguish between **semi-classical** and fully **quantum** radiation reaction models (p=0.3%, 2.97σ).

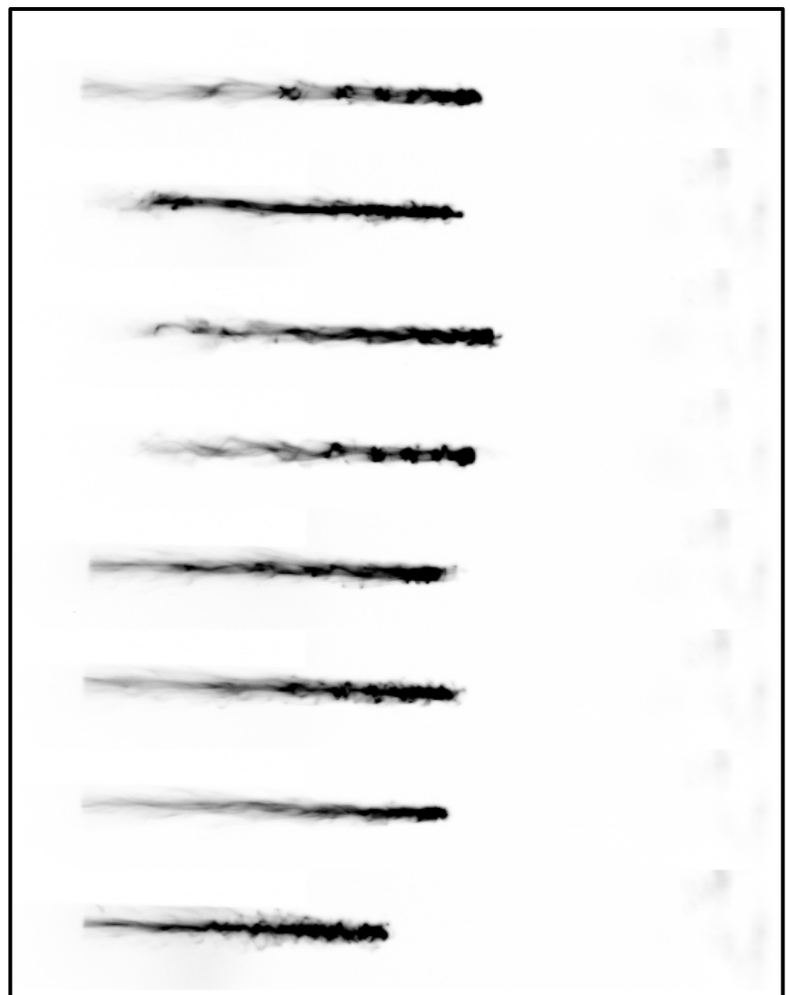
Experimental $\begin{cases} \sigma_{\epsilon_i} = 6 \pm 1\ \% \\ V(\epsilon_i) = 4\ \% \end{cases}$

Sensitivity to shock position



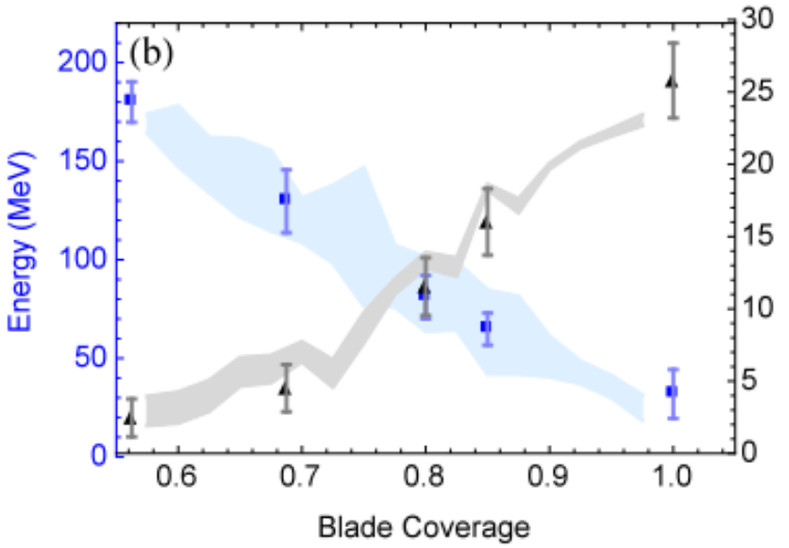
Blade out

Blade in

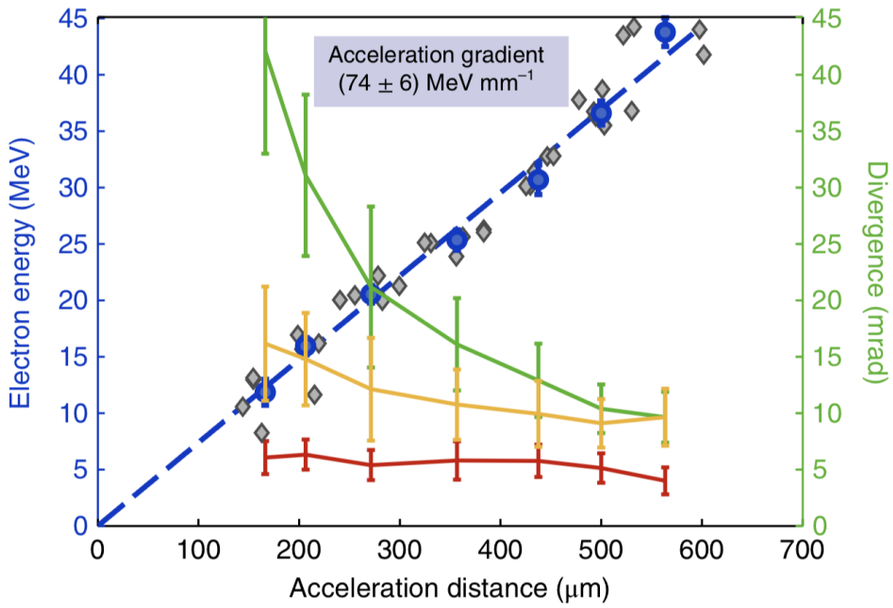


Blade further in

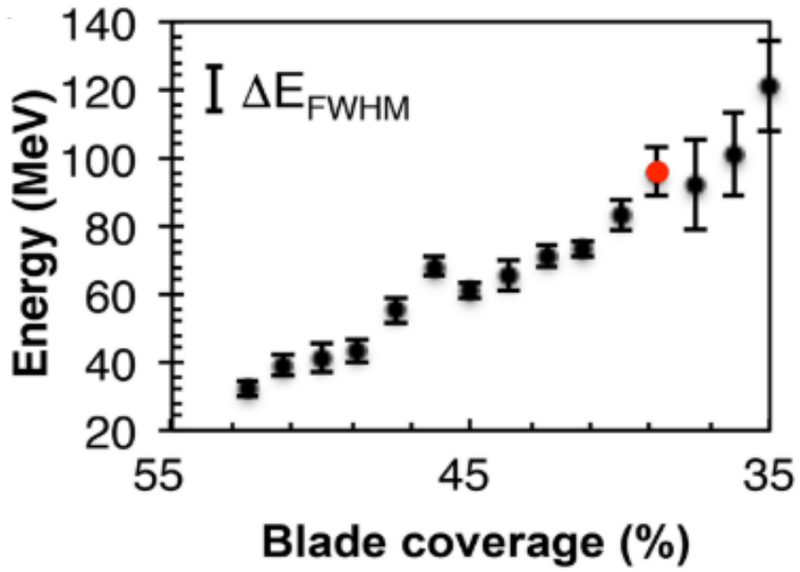
Sensitivity to shock position



Swanson et al., PRAB, (2017)

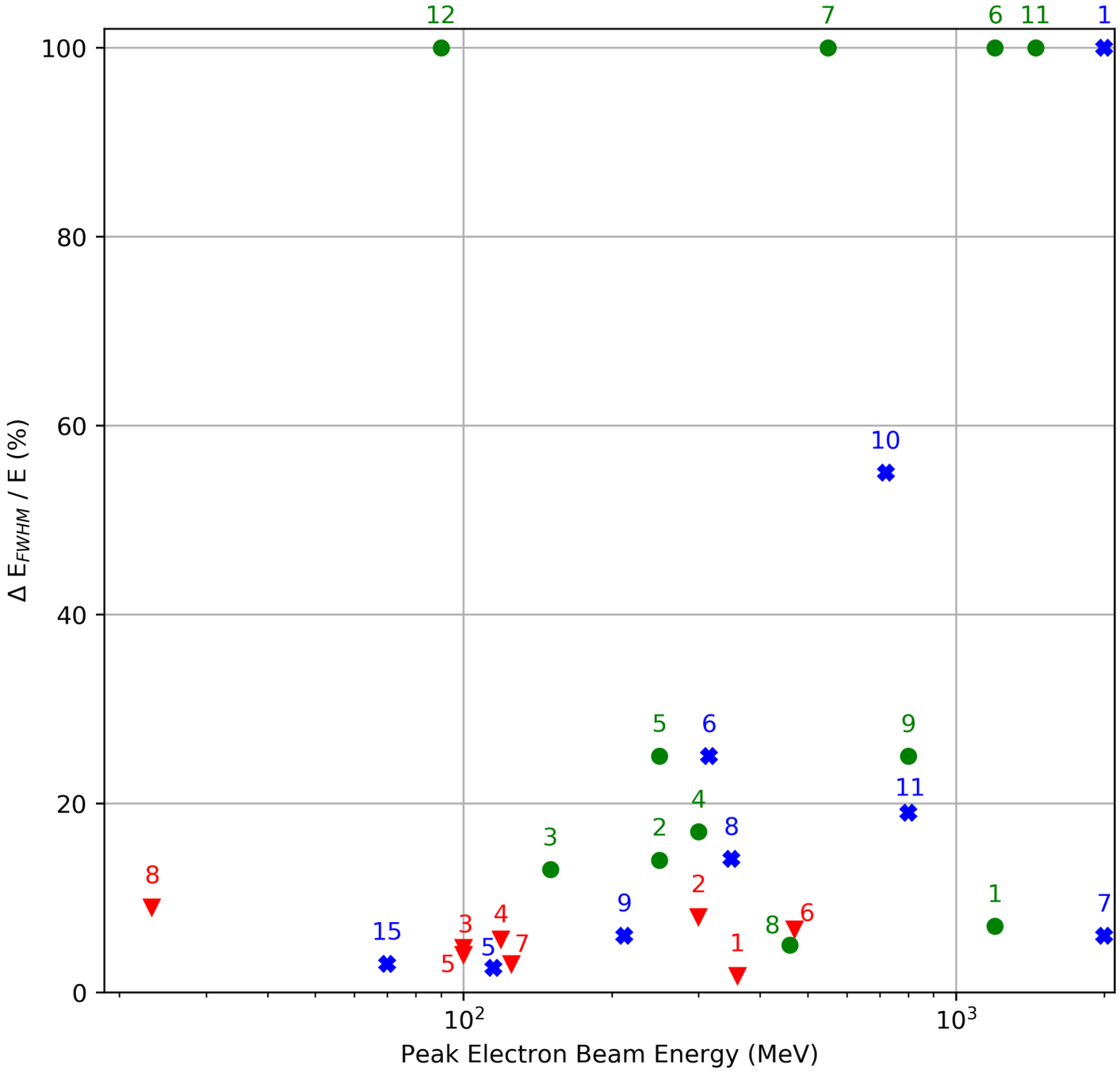


Wenz et al., NatPhot, (2019)



Tsai et al.,PoP, (2018)

All refs



Down-ramp Injection

1. Qin et al. PhysPlas (2018)
2. Tsai et al. POP (2018)
3. Swanson et al. PRSTAB (2017)
4. Buck et al. PRL (2013)
5. Burza et al. PRSTAB (2013)
6. Fourmaux et al. APL (2012)
7. Brijesh et al. POP (2012)
8. Schmid et al. PRSTAB (2010)

Self Injection

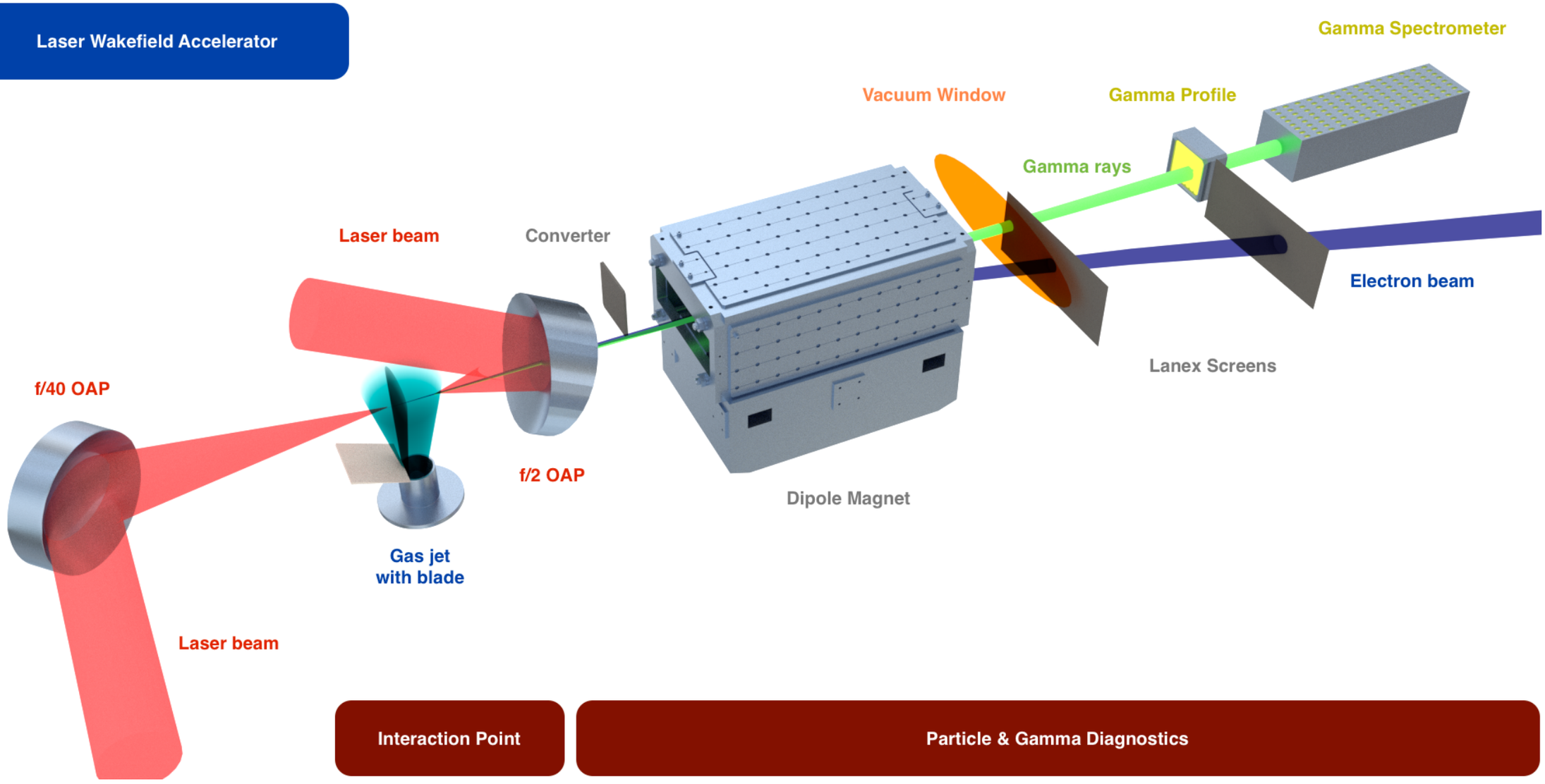
1. Poder et al. PRX (2018)
2. Ferri et al. SciRep (2016)
3. Ferri et al. SciRep (2016)
4. Ferri et al. SciRep (2016)
5. Schnell et al. JPP (2015)
6. Banerjee et al. PRSTAB (2013)
7. Wang et al. NatCom (2013)
8. Weingartner et al. PRSTAB (2012)
9. Kneip et al. PRSTAB (2012)
10. Froula et al. PRL (2009)
11. Kneip et al. PRL (2009)
12. Kneip et al. PRL (2009)
13. Kneip et al. PRL (2009)
14. Kneip et al. PRL (2009)
15. Mangles et al. Nature (2004)

Ionisation Injection

1. Mirzaie et al. SciRep (2015)
2. Couperus et al. NatComms (2017)
3. Kuschel et al. PRAB (2016)
4. Golovin et al. PRSTAB (2015)
5. Powers et al. Natphot (2014)
6. Mo et al. APL (2013)
7. Mo et al. APL (2012)
8. Pollock et al. PRL (2011)
9. Liu et al. PRL (2011)
10. McGuffey et al. PRL (2010)
11. Clayton et al. PRL (2010)
12. Pak et al. PRL (2010)

Ref. Material

Laser Wakefield Accelerator



Interaction Point

Particle & Gamma Diagnostics