Electron Beam Focusing of ~1.5 GeV Laser Plasma Accelerators for High Capture Efficiency Staging

E. Park[1,2], A. McIlvenny[1], C. Benedetti[1], R. Li[1,2], T. Mandal[1], J. Ramirez[1,2], K. Nakamura[1], A. Picksley[1], D. Terzani[1], H. E. Tsai[1], C. B. Schroeder[1,2], J. van Tilborg[1], J. Osterhoff[1], A. J. Gonsalves[1]

[1]Lawrence Berkeley National Laboratory, Berkeley, CA 94720

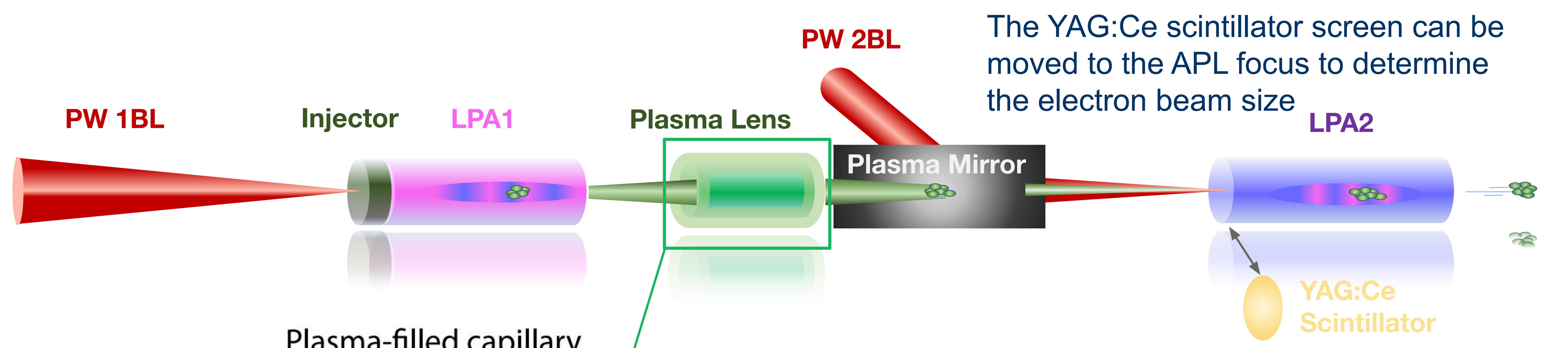
UC Berkeley, Berkeley, CA 94720

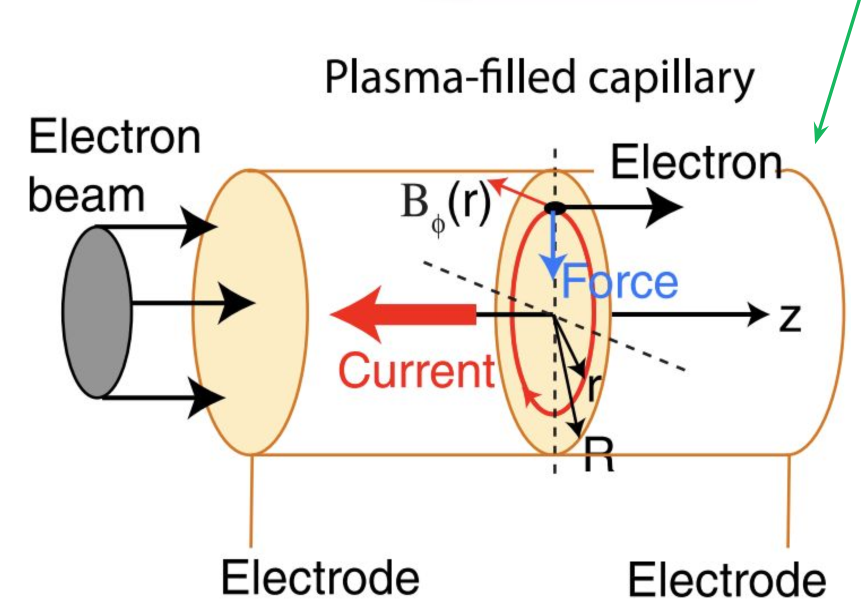
Introduction

- Laser-plasma accelerator (LPA) staging:
  - Couples 2+ LPAs
  - Overcomes laser depletion and increases the electron beam energy
  - Applicable for future multiple-staged high-energy particle colliders and high average power khz-class LPA concepts[1], [3]
- Precision e-beam focusing critical for high charge coupling efficiency between stages
- Advantages of Active Plasma Lenses (APLs) [2] in LPA staging: strong focus over ~ cm scales, single-element, tunable, radially symmetric focusing [4]

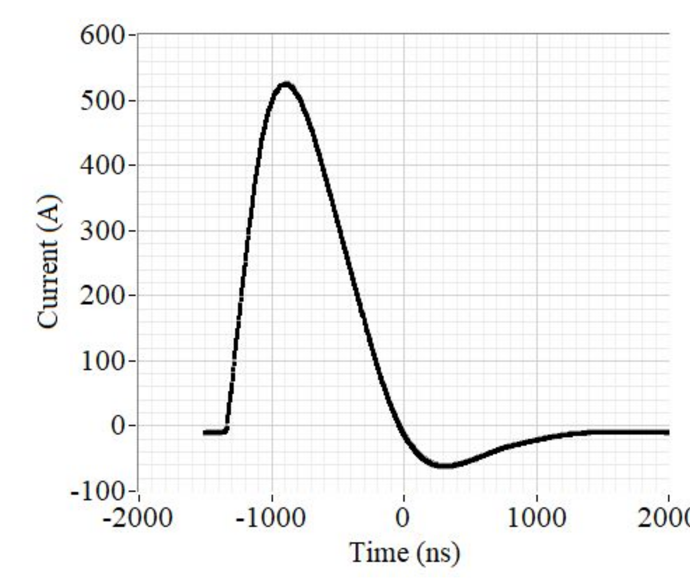
Here we present results from using an APL to focus GeV beams over cm scales for staging

Experimental layout: APL focuses beam from LPA1 to plasma mirror





Schematic of the focusing force in an APL. From Figure 1(a) of [4]

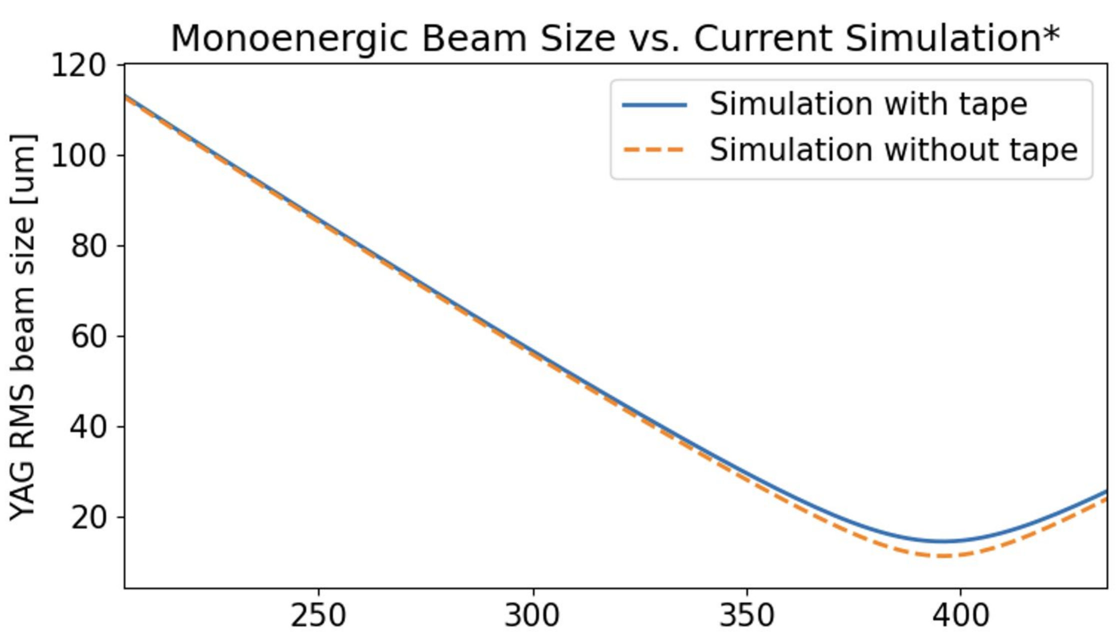


Current trace example for the APL discharge. Jitter of 200 shots ± 2 A

- APL used Argon for mitigating emittance growth [5]
- Delay between laser arrival time and current peak determines the electron beam focus strength

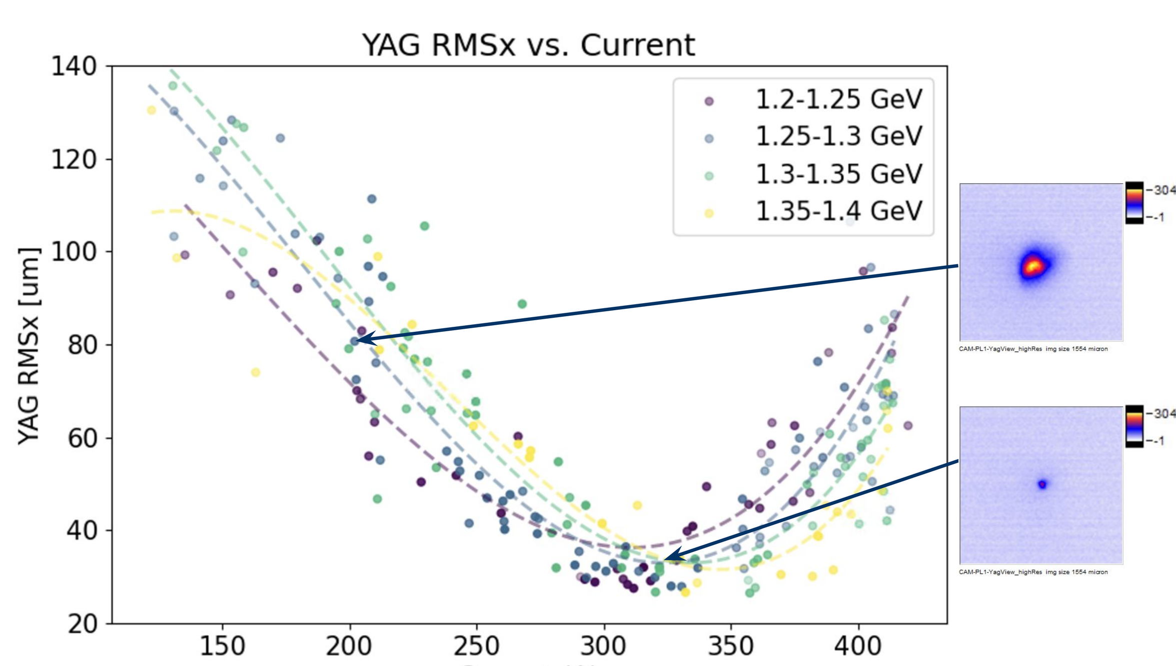
Use of 25 μm thick tape is a small factor in larger focused spot size

- Tape plasma mirror scatters electron beams and causes some emittance growth [6]
- Energy spread is small factor in higher beam size; simulations* of rms beam sizes show:
  - At min ΔE/E=3%, beam size = 15.6 μm
  - At typical ΔE/E=8%, beam size = 16.8 μm
  - At worst ΔE/E = 18%, beam size = 17.6 μm

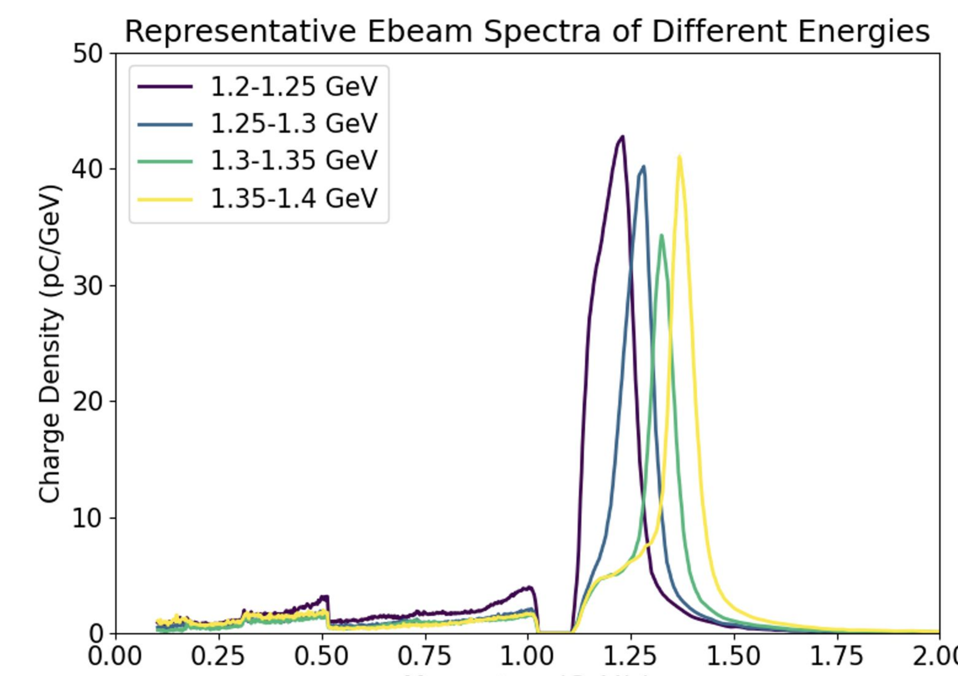


Electron beam size sensitive to electron energy by ~ 25 μm at 330 A

- Minimum beam size ≈ 25 μm rms at 330 A
  - λ_p (μm) ≈ 3.3 × 10^{10} / $(n_0(\text{cm}^{-3}))^{1/2}$ ≈ 100 μm for $n_0 = 10^{17}$ cm^{-3}
- At 330 A, electron energy jitter changes electron beam size by ~ 25 μm RMS
- High opacity = low variance about optimum electron energy at each current

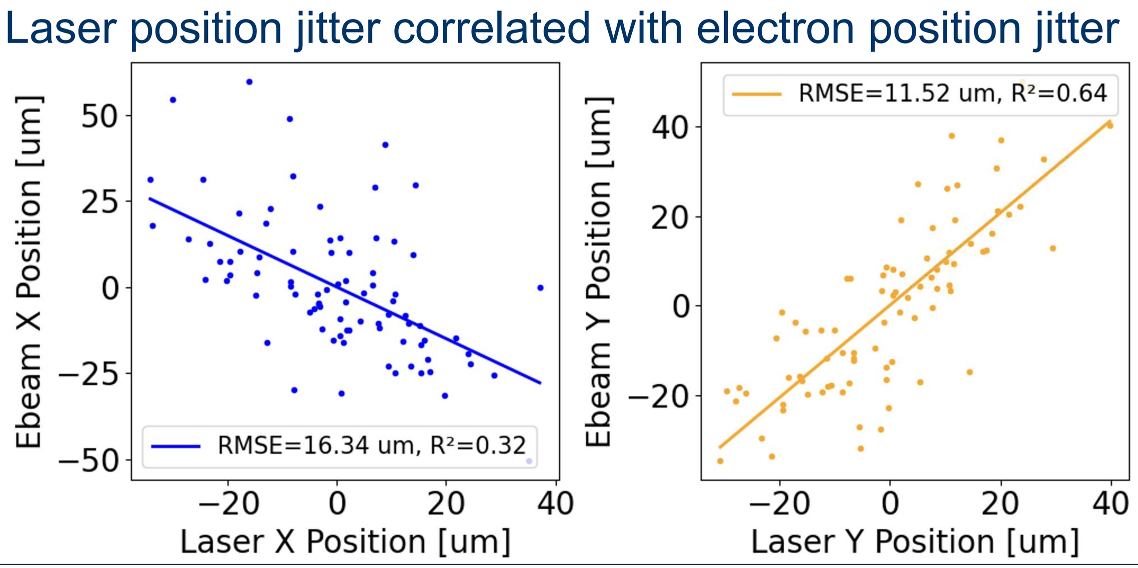


- We can simultaneously measure the electron beam spectrum and focus spot size
- Electron beam energy after 1st stage determines APL focal length
- Optical resolution of the YAG is 2 μm
- YAG:Ce screen is 100 μm thick but depth of field of imaging system ~ 10 μm, limiting effective resolution



Transverse electron beam position control needed for effective staging

Laser position jitter correlated with electron position jitter



Next Steps

- Use the APL in future LPA staging
- Develop laser transverse jitter stabilization for transverse electron beam control in staging
- Replace plasma mirror tape with liquid crystal

* Simulation parameters: 1.3 GeV electrons, uniform APL current density, 5 μm sized 0.3 mrad divergence beam at the first stage, 10 um quadrature for YAG resolution

References

[1] W. Leemans and E. Esarey, Physics Today 62, 44 (2009).
[2] W. K. Panofsky and W. R. Baker, Review of Scientific Instruments 21, 445 (1950).
[3] S. Steinke, J. van Tilborg, C. Benedetti, C. G. Geddes, C. B. Schroeder, J. Daniels, K. K. Swanson, A. J. Gonsalves, K. Nakamura, N. H. Matlis, B. H. Shaw, E. Esarey, and W. P. Leemans, Nature 530, 190 (2016).
[4] J. van Tilborg, S. Steinke, C. G. R. Geddes, N. H. Matlis, B. H. Shaw, A. J. Gonsalves, J. V. Huijts, K. Nakamura, J. Daniels, C. B. Schroeder, C. Benedetti, E. Esarey, S. S. Bulanov, N. A. Bobrova, P. V. Sasorov, and W. P. Leemans, Physical Review Letters 115, (2015).
[5] C. A. Lindstrøm, E. Adli, G. Boyle, R. Corsini, A. E. Dyson, W. Farabolini, S. M. Hooker, M. Meisel, J. Osterhoff, J.-H. Röckemann, L. Schaper, and K. N. Sjobak, Physical Review Letters 121, (2018).
[6] M. B. Reid, Journal of Applied Physics 70, 7185 (1991).

This work was supported by the United States Department of Energy Office of Science, Offices of HEP under Contract No. DE-AC02-05CH11231 and the Defense Advanced Research Projects Agency (DARPA) under the ASSERT Program.