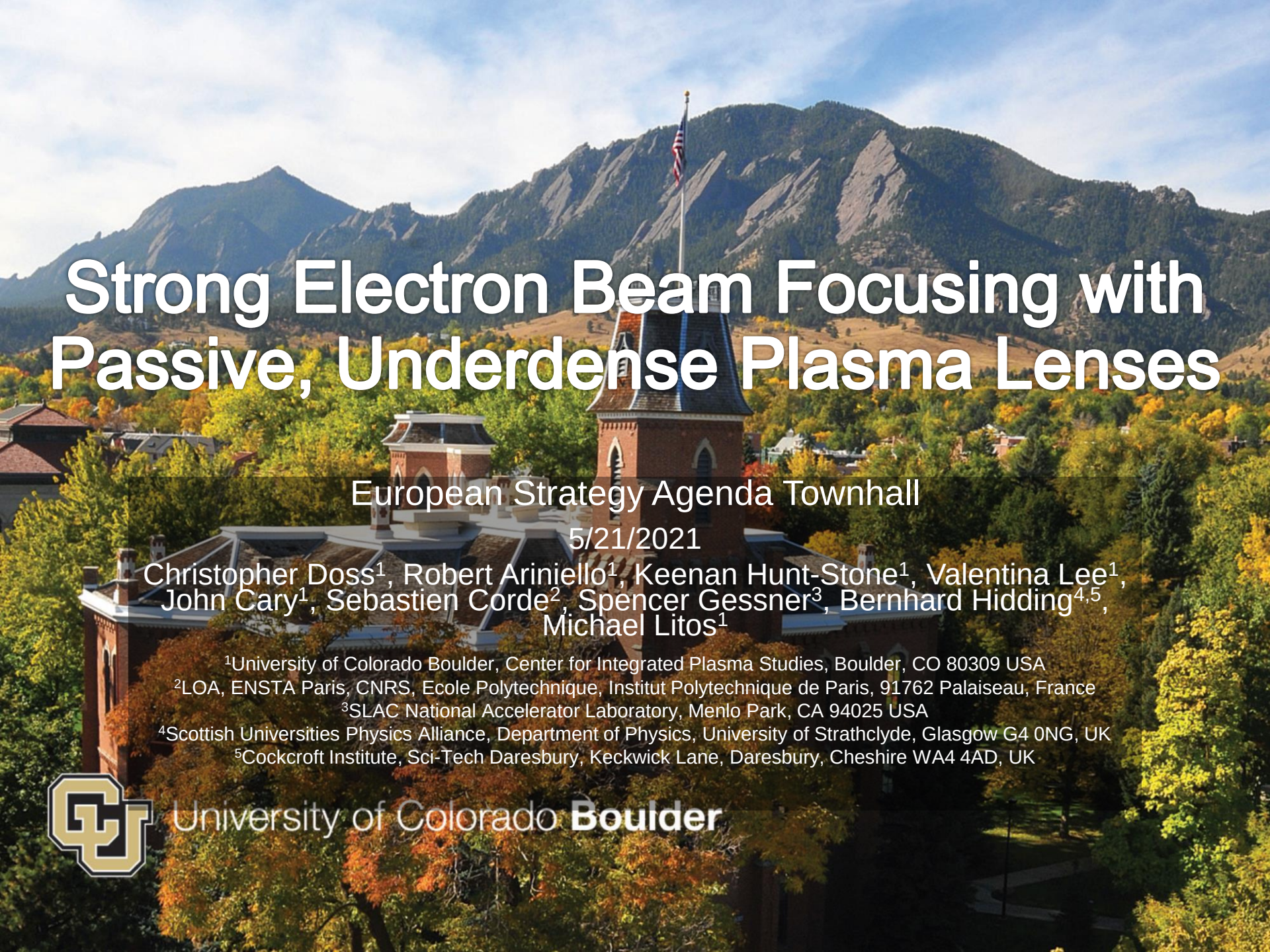

Strong Electron Beam Focusing with Passive, Underdense Plasma Lenses

European Strategy Agenda Townhall

5/21/2021

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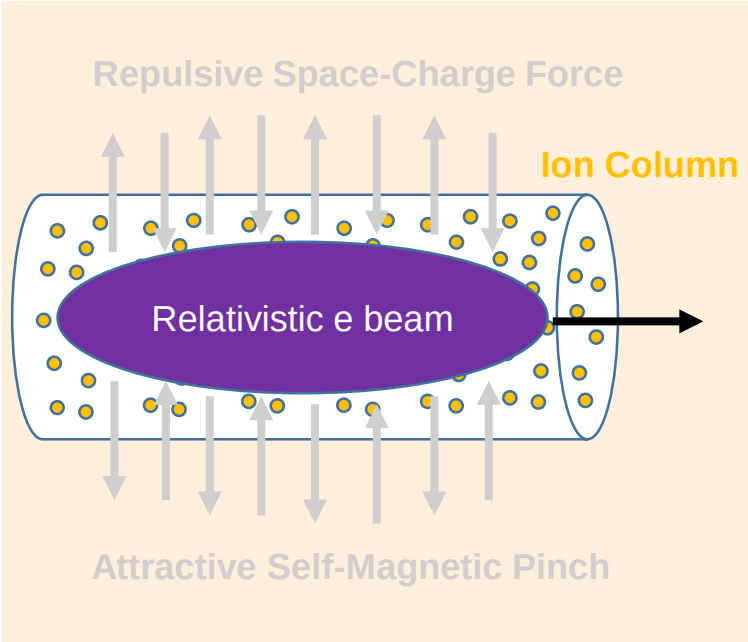
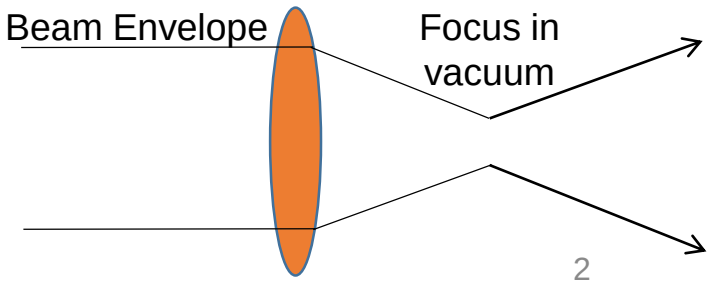
Underdense Passive Plasma Lens

- High density beam blows out plasma electrons, creating an ion column.
- Ion column provides focusing force on beam
- Linear focusing force which depends on uniform background ion density
- While quadrupoles have magnetic gradients of ~3 T/m, the equivalent magnetic gradient in a plasma wake can be ~1.5 MT/m

$$n_{beam} \gtrsim n_{plasma}$$

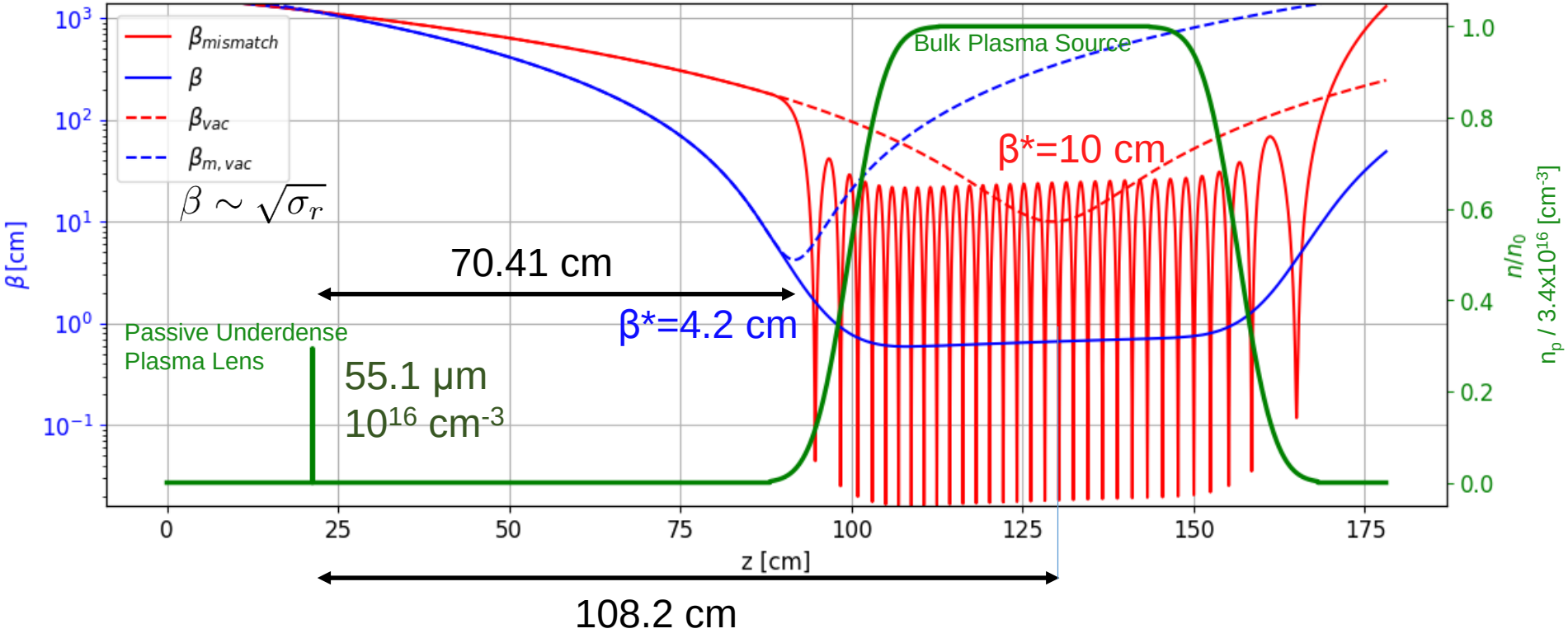


$$F_r/r = 2\pi n_p e^2$$



PWFA Matching Example

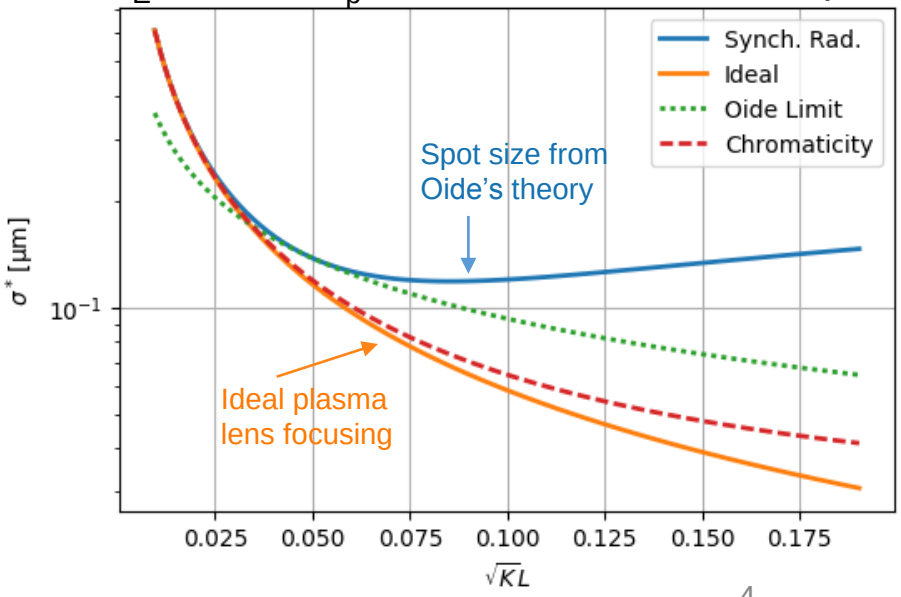
- Matching into a PWFA requires extremely small beam size for emittance preservation.
- Plasma lenses are one option to reach this goal.



Synchrotron Radiation and Oide Limit

- Theory described by Oide details a minimum achievable spot size known as the “Oide Limit”
  - Katsunobu Oide, Phys. Rev. Lett. **61**, 1713 – Published 10 October 1988
- Important for future colliders, but this limit has yet to be reached experimentally.
- We expect to be able to study this experimentally at FACET-II using underdense plasma lenses.

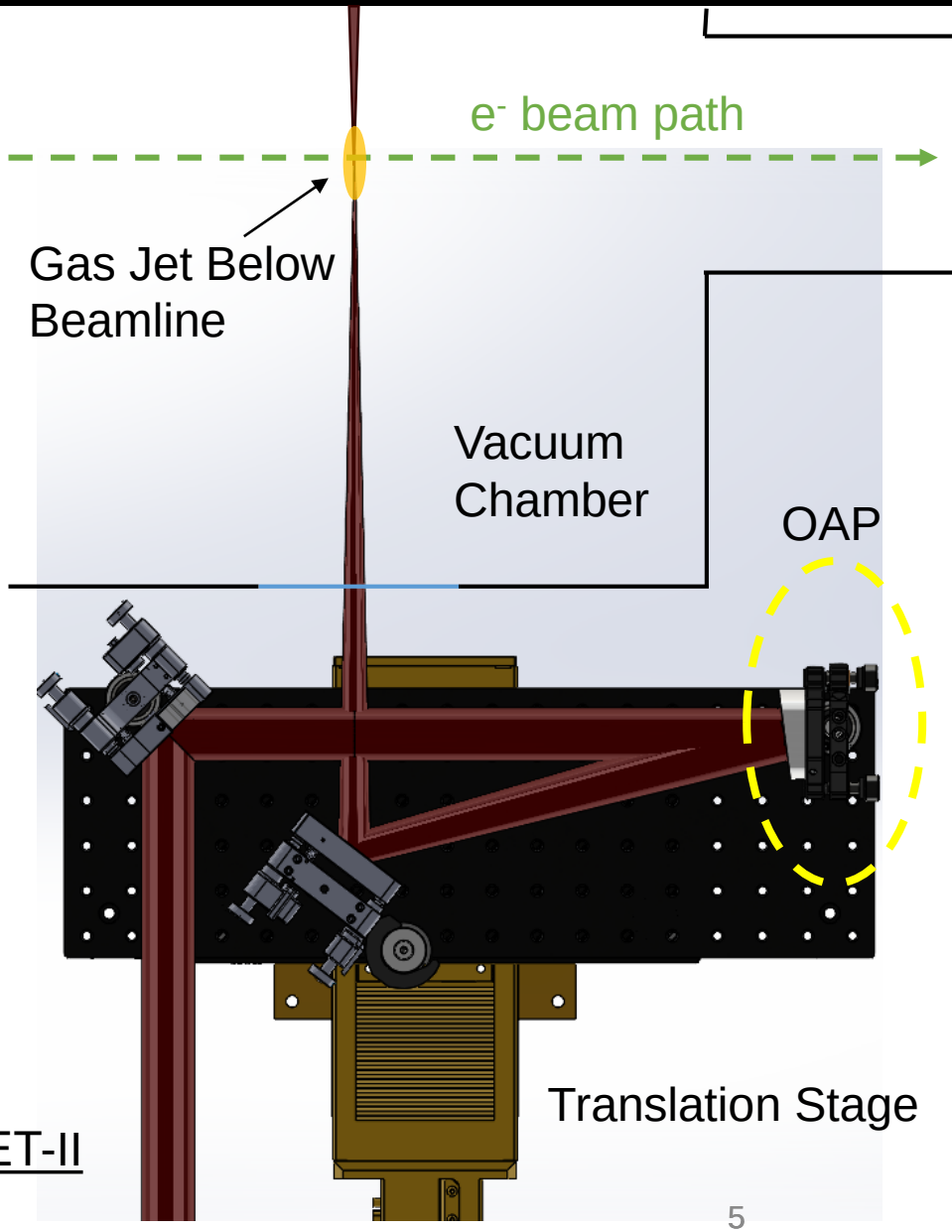
E = 10 GeV, β_i = 5 m, ε_N = 3 μm-rad,
σ_E = 0.1%, n_p = 10^{18} cm^{-3}, L = 20-200 μm



Plasma Lenses at FACET-II

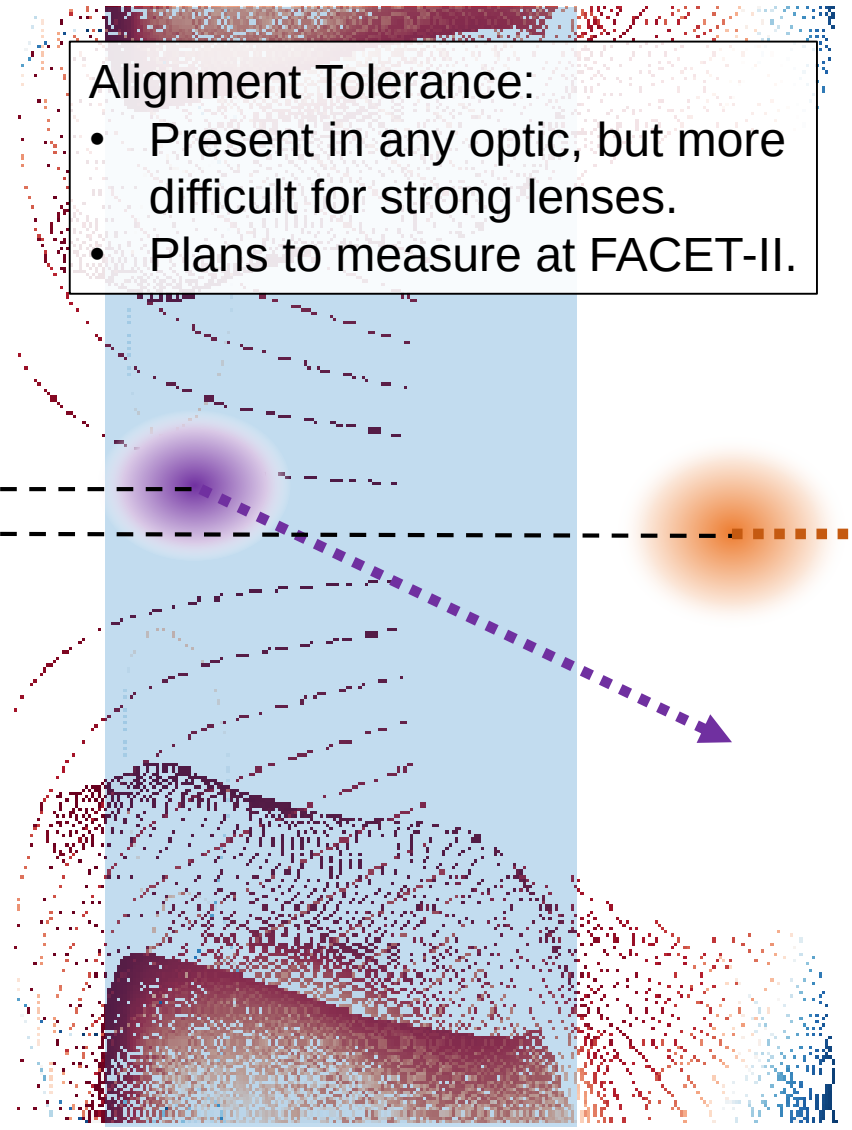
- Gas jet is ionized with compressed laser
- Adjust plasma lens density through gas jet pressure.
  - 10^{16} cm^{-3} - 10^{18} cm^{-3}
- Adjust plasma lens thickness through position of focus.
  - 35 μm - 100's μm
- e beam diagnosed with imaging spectrometer.

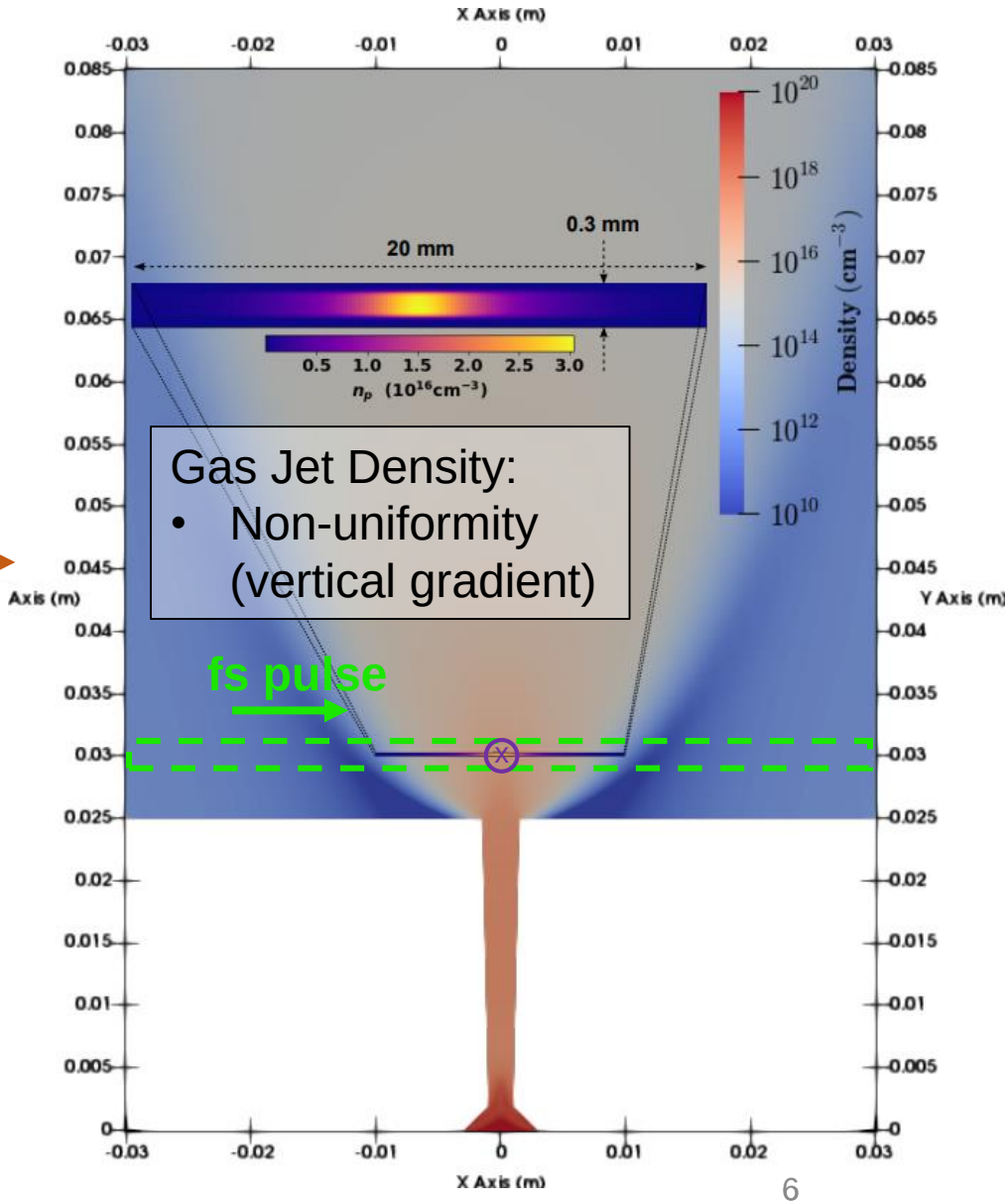
*See Mark Hogan's talk @ 15:15 on FACET-II



Further Studies

Alignment Tolerance:
- Present in any optic, but more difficult for strong lenses.
- Plans to measure at FACET-II.

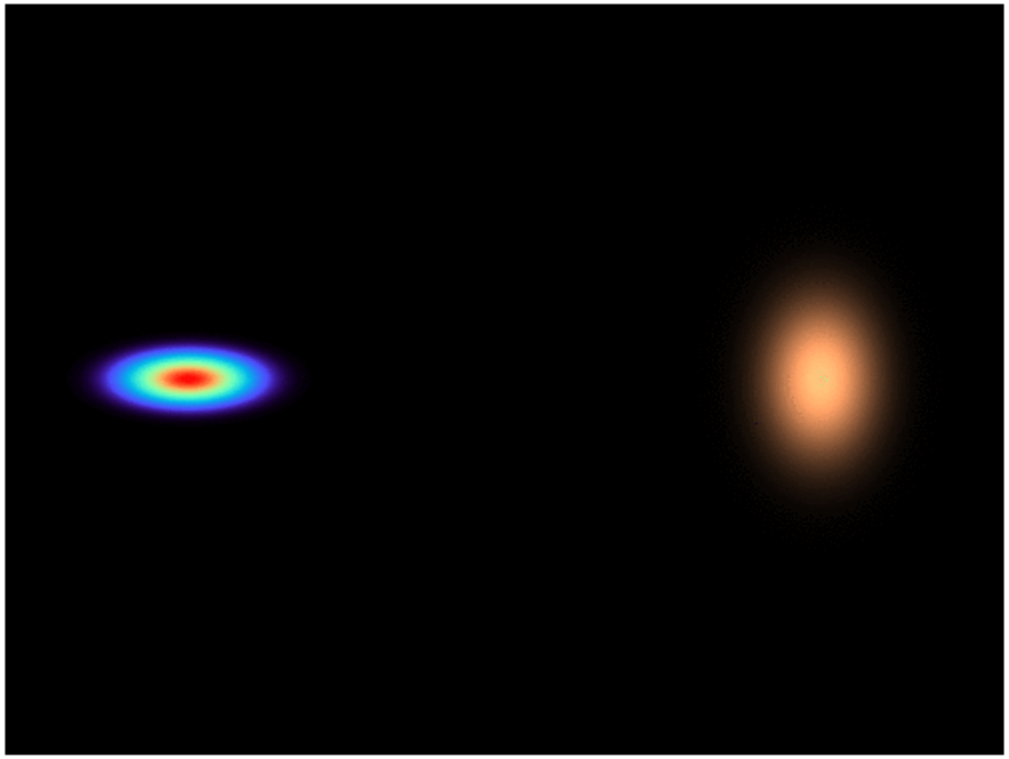


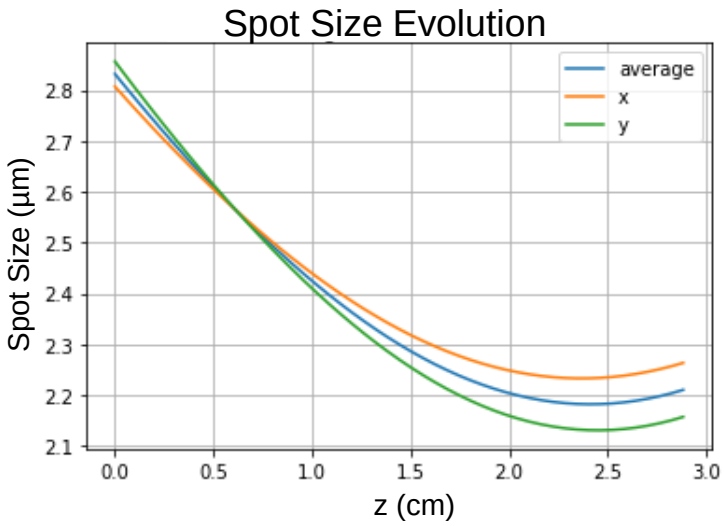


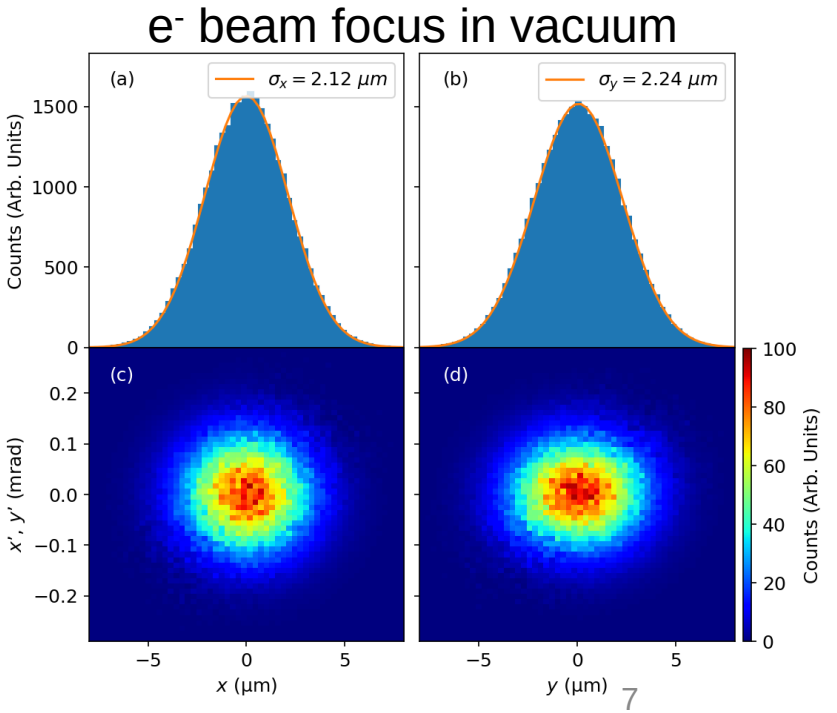
Gas Jet Density:
- Non-uniformity (vertical gradient)

Further Studies

- Can attempt to operate with witness in 2nd bucket.
- VSim plasma lens with thickness 40 μm at $5x10^{17}cm^{-3}$







Q&A 1

- I think advanced accelerator applications in HEP will converge on (1) TeV electron-positron collider and (2) compact light sources
- Steps to get to HEP linear collider:
  1. High quality PWFA w/ emittance preservation, drive bunch depletion, optimized beam loading
  2. Development of ideal staging between PWFA stages
  3. Steps 1 & 2, but with positrons
- Plasma lenses can assist with matching into PWFA and with staging between PWFA stages. (blue)

Q&A 2

- Passive plasma lens milestones in the next 10 years:
  1. Demonstration of aberration-free focusing
  2. Use of plasma lens to match into PWFA.
  3. Studying the Oide limit with passive plasma lens
  4. Compact staging between two PWFA stages
  5. Advanced nonlinear focusing applications of underdense plasma lenses
  6. Demonstration of passive plasma lens regime for positrons

Q&A 3

- Deliverables until 2026
  - Theoretical design studies for target applications.
  - Experimental demonstration of focusing superiority with respect to magnetic focusing
  - Demonstration of use in PWFA matching
  - Initial studies of Oide effect
- Plasma lenses with current funding and R&D
  - The above deliverables are planned for FACET-II (SLAC)
  - FLASH Forward (DESY) has capabilities
  - LWFA / PWFA hybrid experiments?

Q&A 4

- Plasma lenses with future funding and R&D
  - Ultralow emittance measurements (e_N < 1 mm-mrad)
  - Ultrasmall spot size measurements (σ_r < 100 nm)
  - Laser-driven underdense plasma lens
- Are any new facilities or structures needed?
  - Funding for positron capabilities at FACET-II
    - Talk by Spencer Gessner @ 15:00 on this topic
  - Facility for true staging experiments in PWFA
    - Multiple plasma stages, independent drive beams for each stage
    - Talk by Carl A Lindstrøm @ 16:45 for more on staging

Thanks!

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