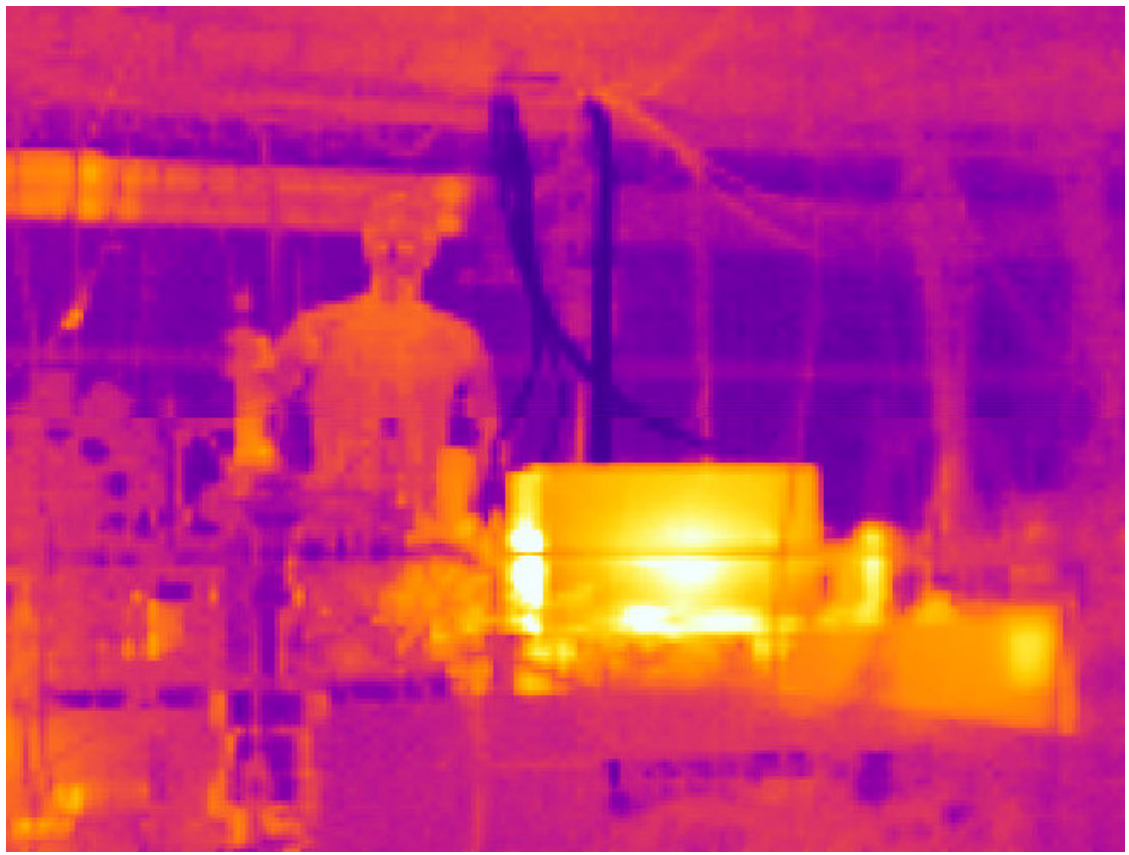
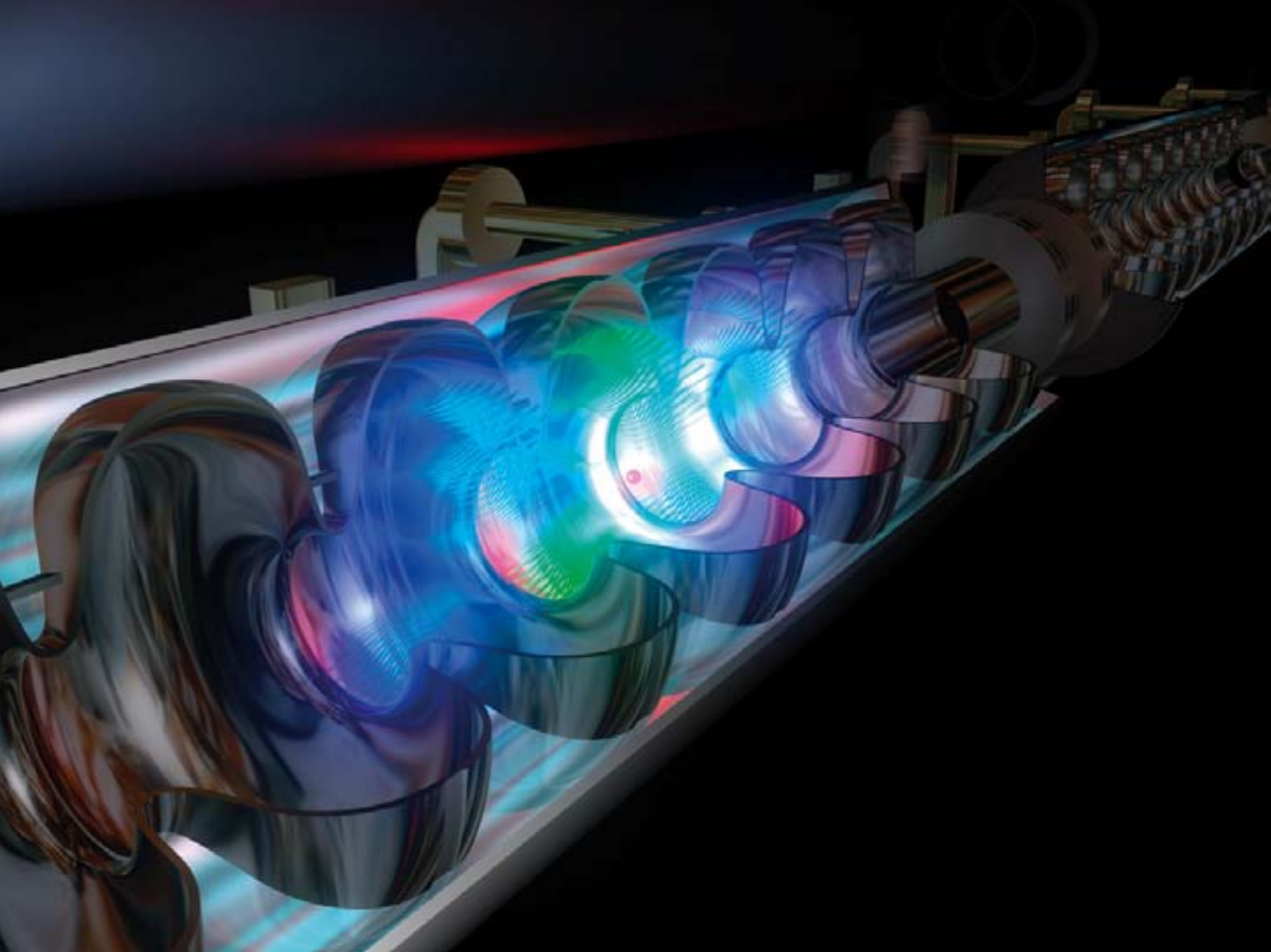
Energy Doubling of 42 GeV Electrons

Rasmus Ischebeck, for the E-167 Collaboration





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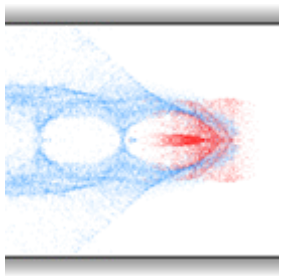


- Plasma Wakefield Acceleration

- Experimental Setup

- Results

Plasma Wakes – Theory

- In conventional accelerators, the accelerating fields are limited by the damage threshold of the cavities

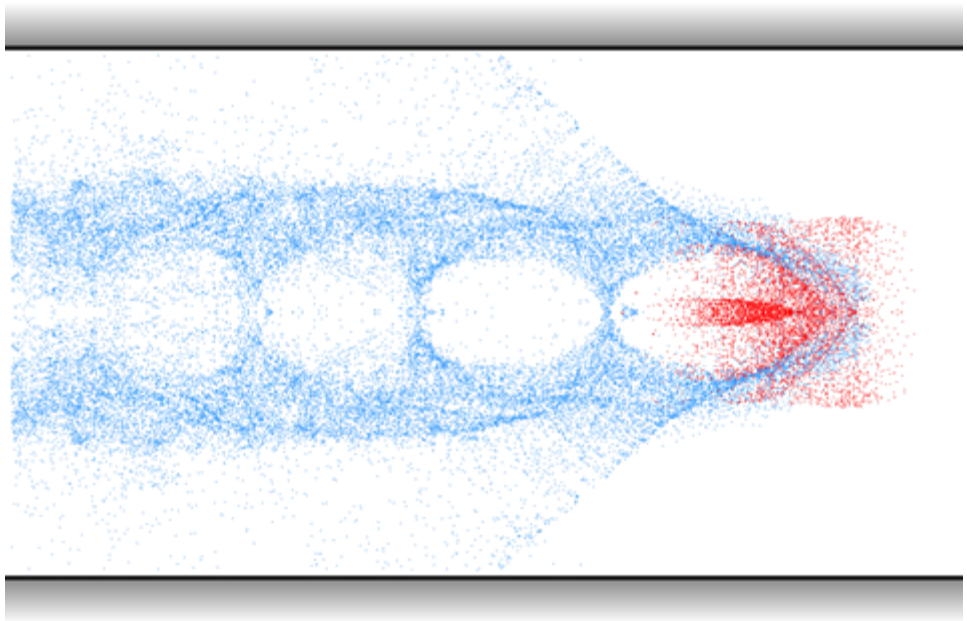
- Unlike electromagnetic waves in vacuum, plasma wakes can have a longitudinal electric field

  - Linear plasma wake: $\lambda_p \approx \sqrt{\frac{10^{15}\mathrm{cm}^{-3}}{n_p}} \quad \mathrm{mm}$

    - Limit: $E_0 = \frac{4\pi\,\varepsilon_0\,c\,m_e}{e}\,\omega_p \quad \approx \sqrt{\frac{n_p}{\mathrm{cm}^{-3}}} \quad \frac{\mathrm{V}}{\mathrm{cm}}$

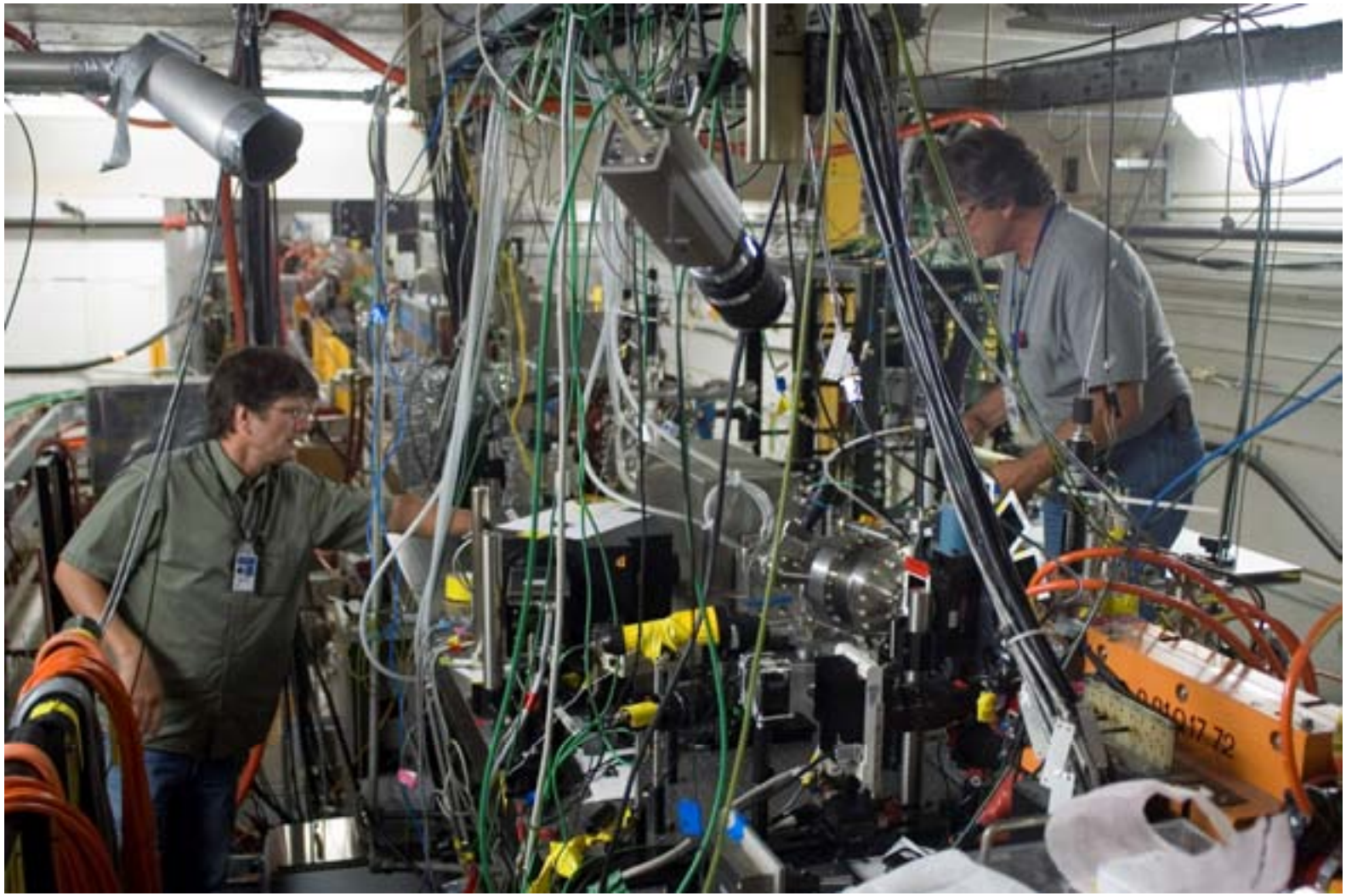
Plasma Wakes – Theory

- Above this limit: non-linear wakes, “Blow-out regime”
- Fields can be calculated only with numerical methods



- Typical wavelength: 50 μm
- Accelerating fields up to 50GV/m

Plasma Wakes – Reality

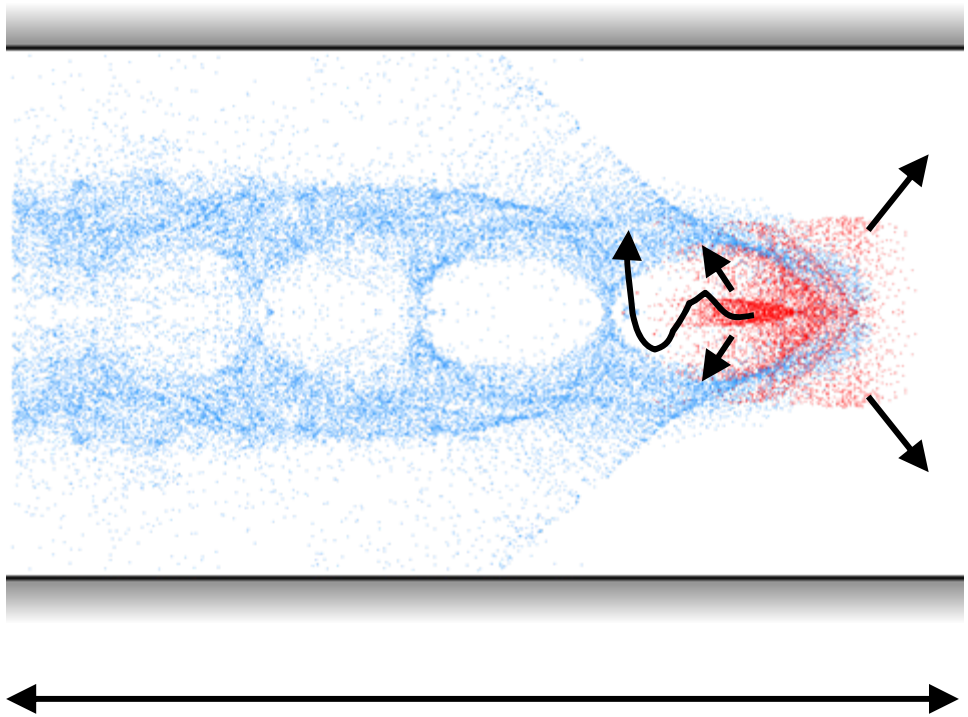


Numerical Modeling

- Need to model large number of particles, and resolve hundreds of betatron oscillations
- Particle-In-Cell codes:
  - full PIC code: approximately 132,000 CPU hours
  - QuickPIC: quasi-static approximation, 2760 CPU hours
- Parallel processing
- Take into account ionization and energy loss through synchrotron radiation

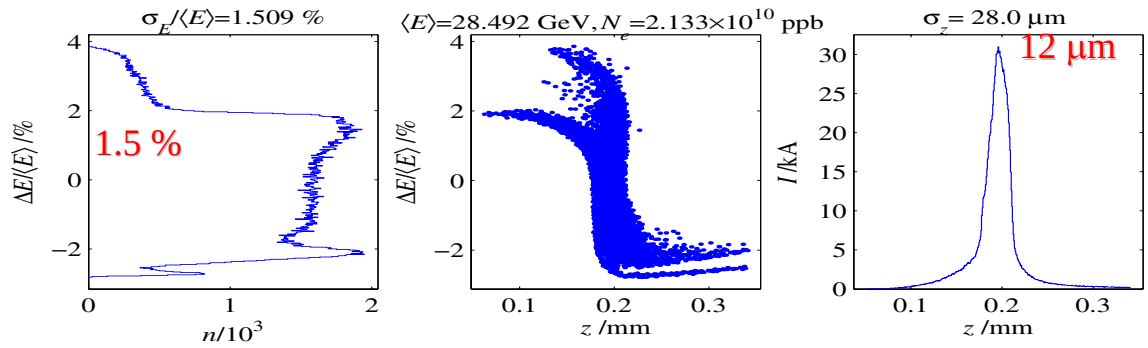
What Determines the Maximum Energy?

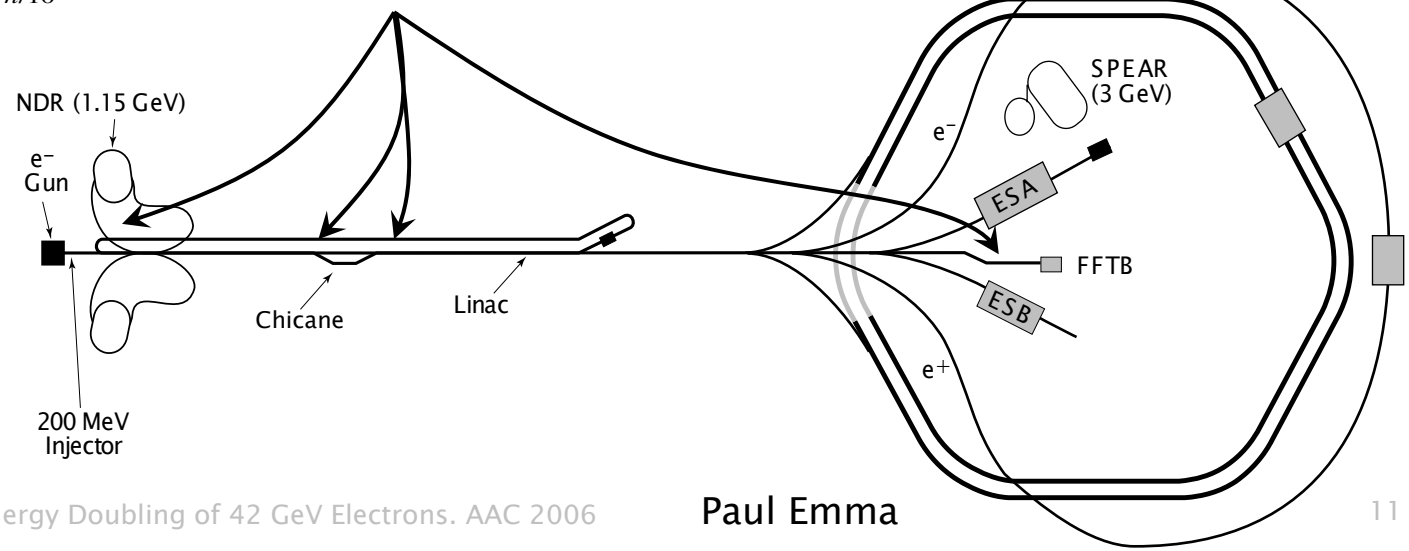
- Plasma length
  - Oven length
  - Head erosion
- Hose instability
- Mobile ions
- Energy depletion of the drive beam (transformer ratio)



Plasma Acceleration at SLAC

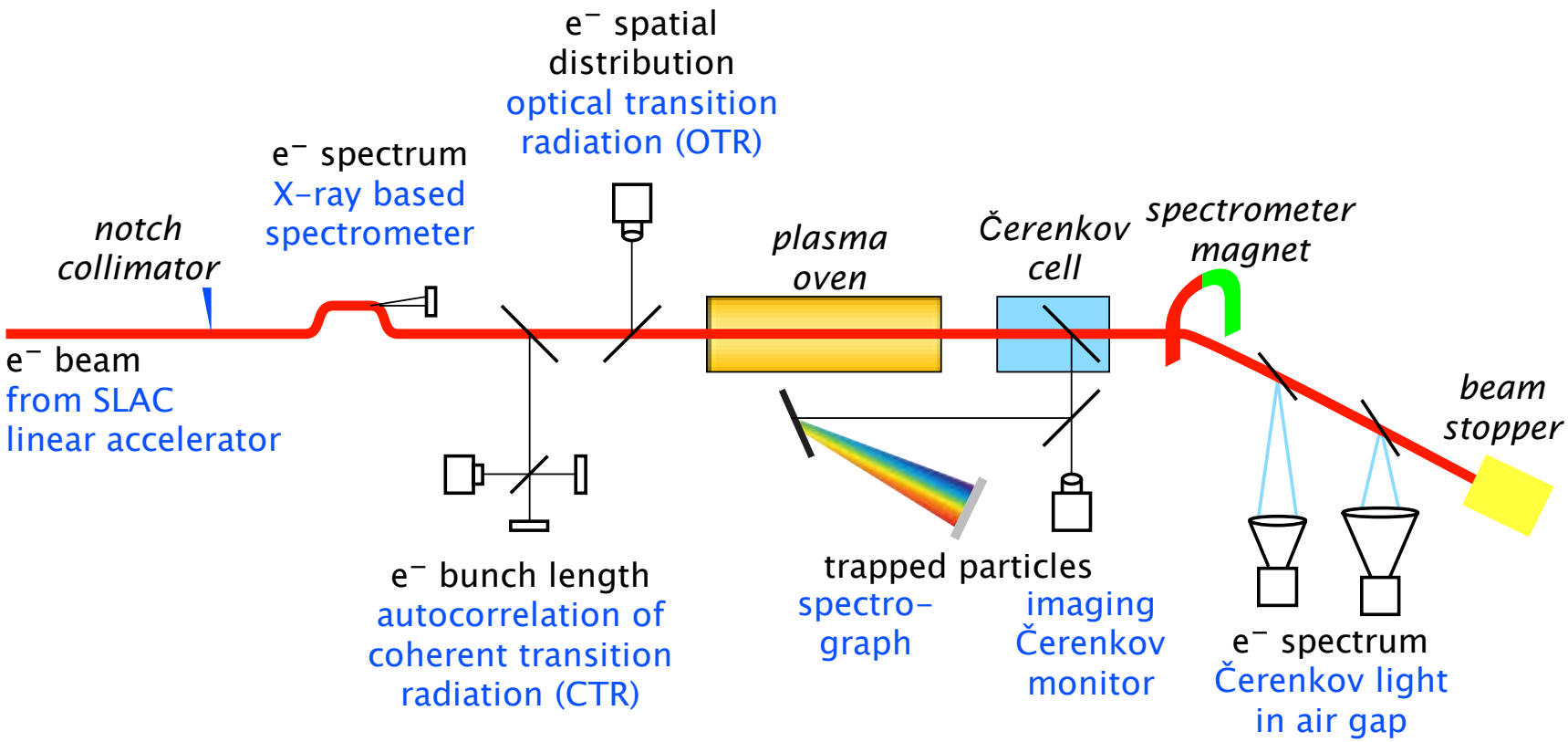
Acceleration, compression and focusing
to a peak power density of 5 YW/m²





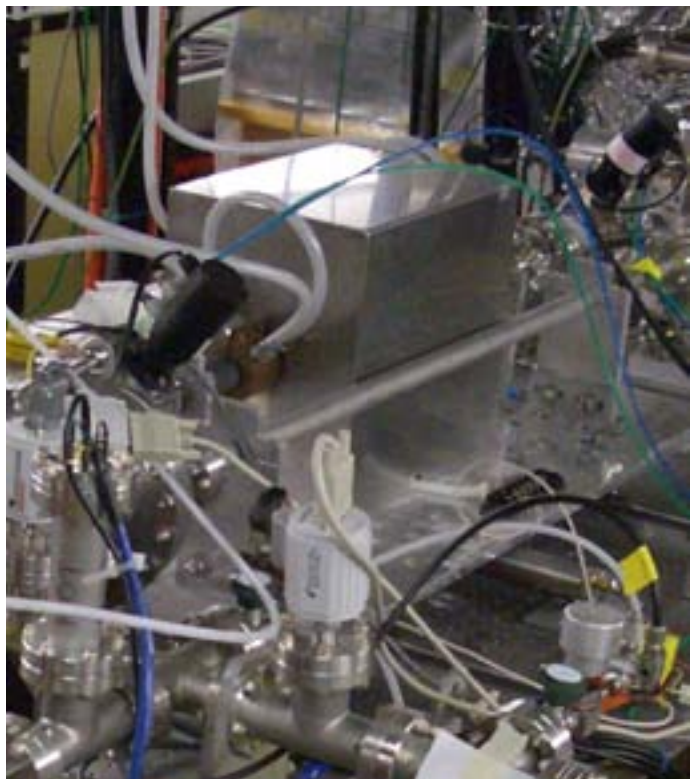
Paul Emma

Experimental Setup: E-167



Previous Results

More than 3 GeV energy gain in 10 cm plasma length



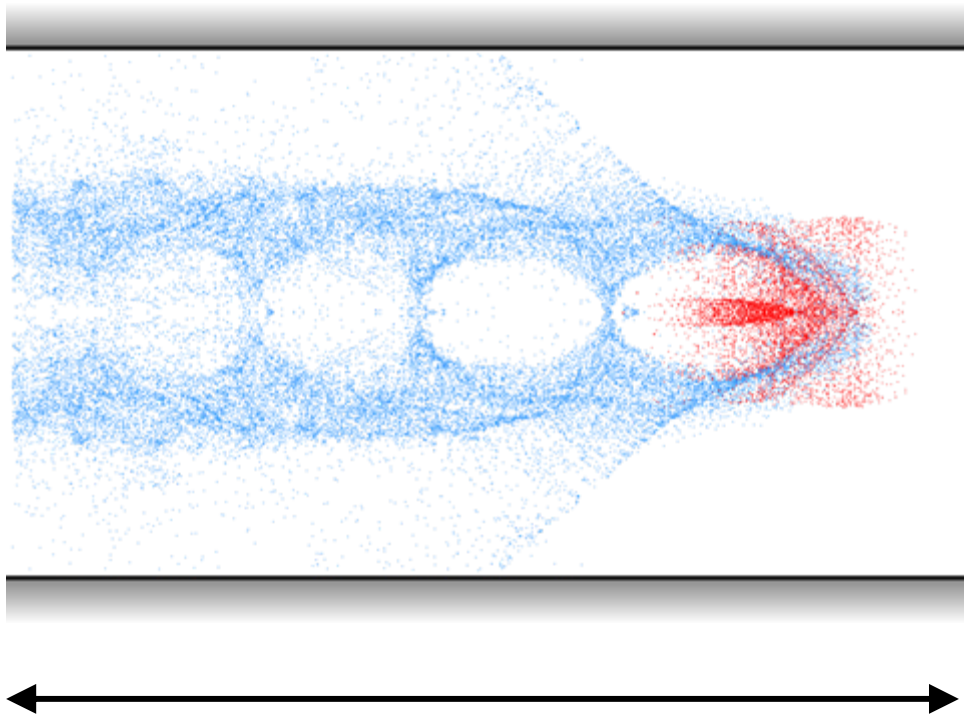
Increasing the Plasma Length to 30.5 cm

This plot contains unpublished data.

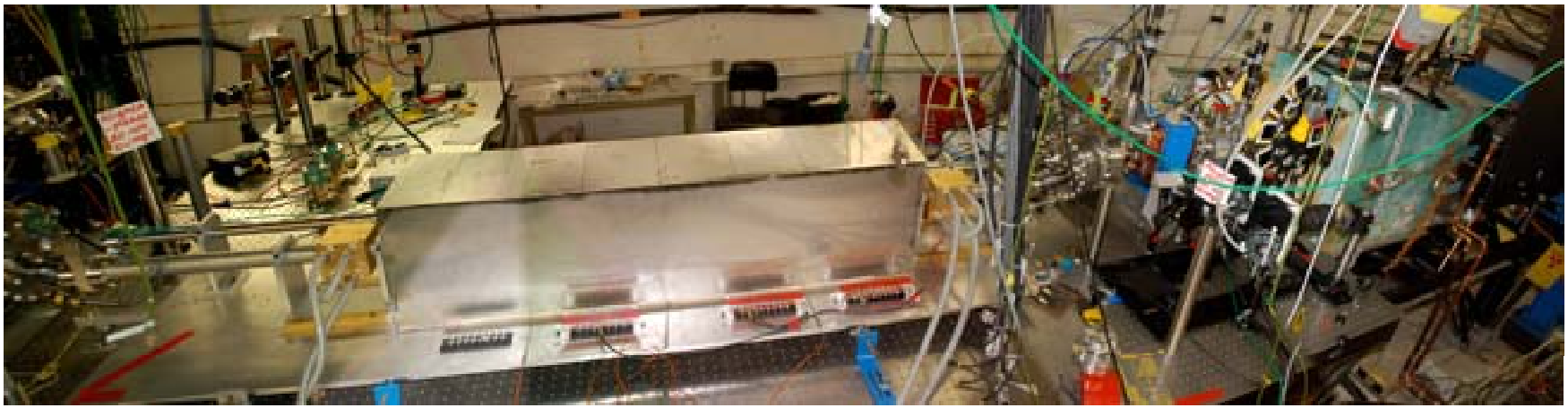
Send an e-mail to rasmus@slac.stanford.edu
for an updated version of this file.

What Determines the Maximum Energy?

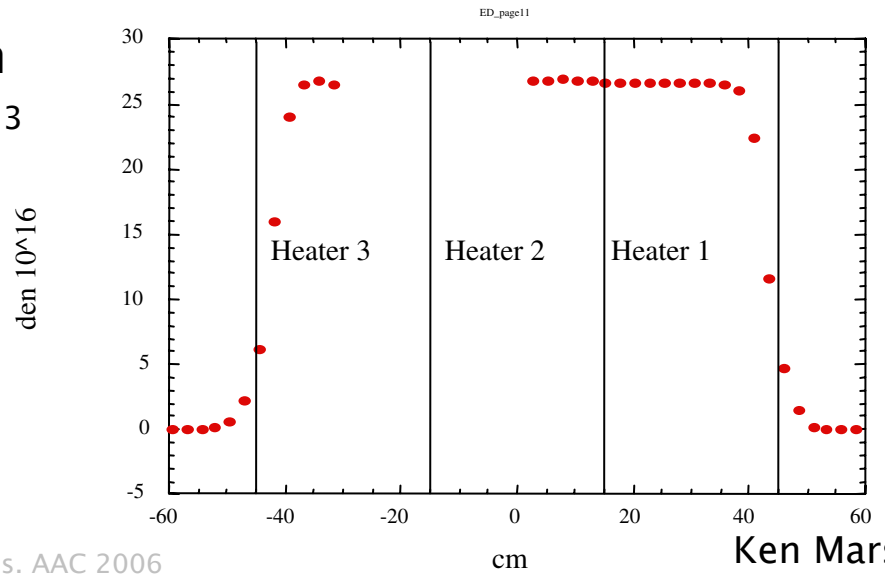
- Plasma length
  - Oven length
  - Head erosion
- Hose instability
- Mobile ions
- Energy depletion of the drive beam (transformer ratio)



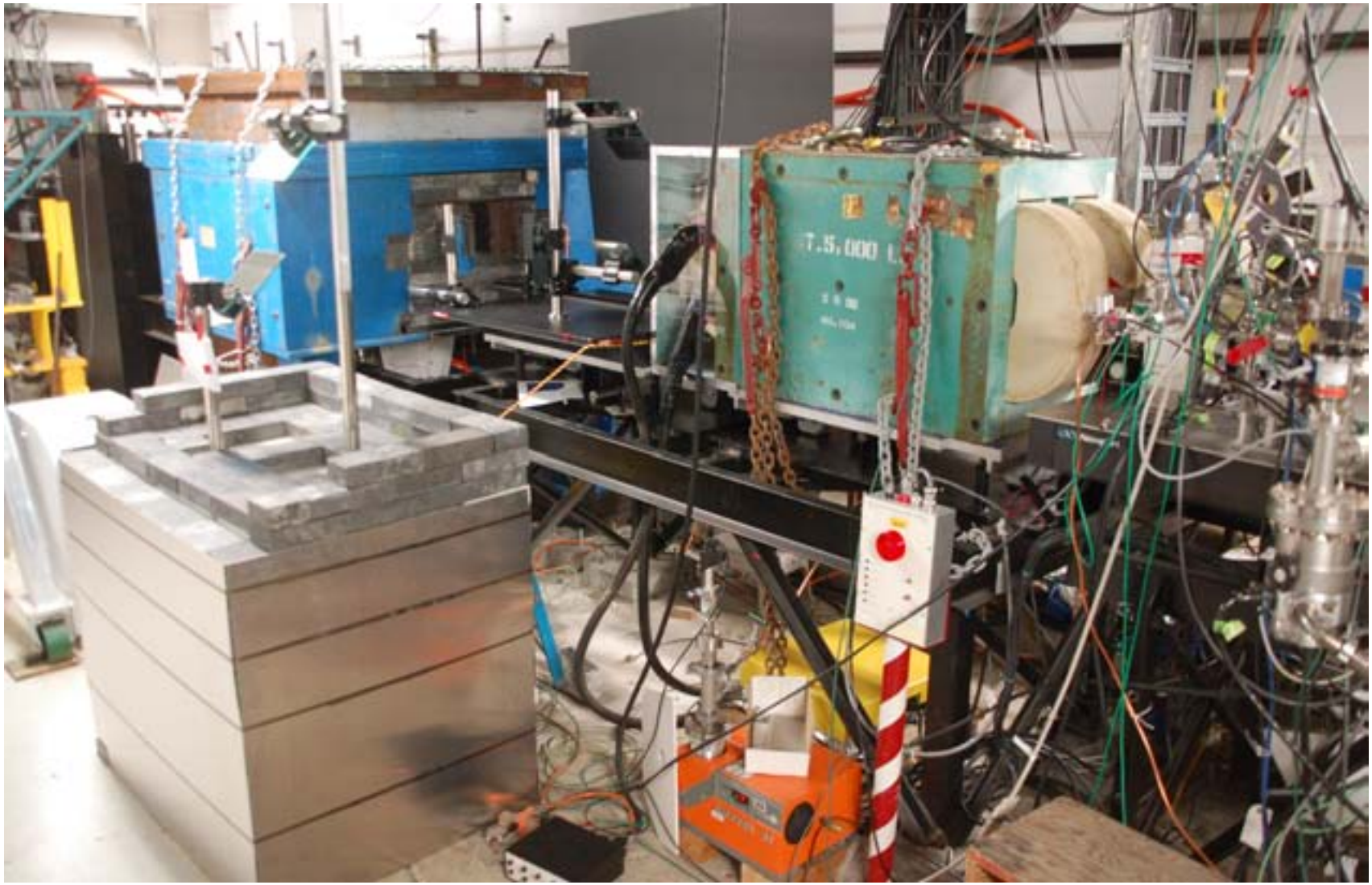
Build New Plasma Oven



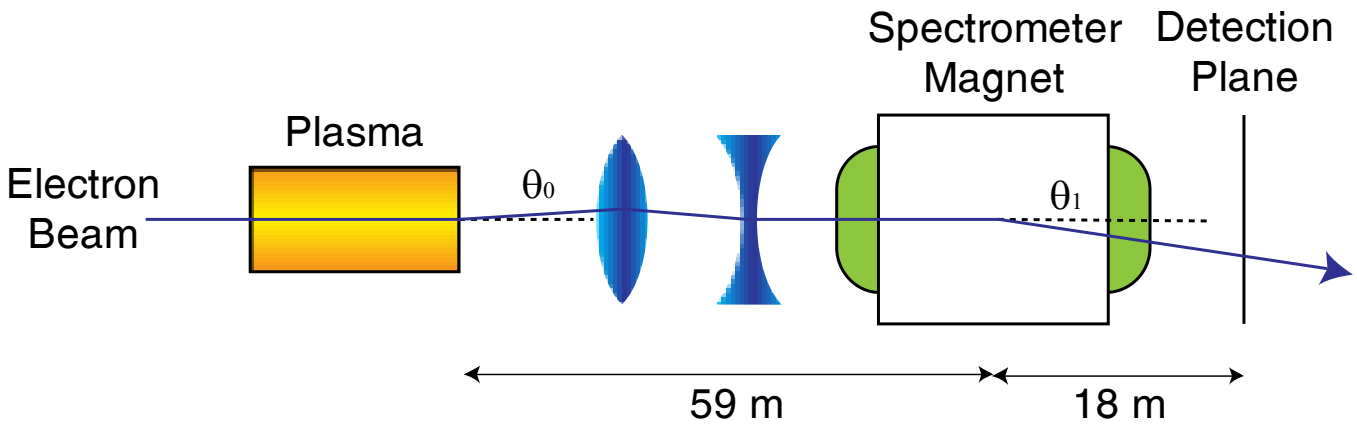
- Up to 1.13 m plasma length
- Plasma density: $3 \cdot 10^{17}$ cm^{-3}



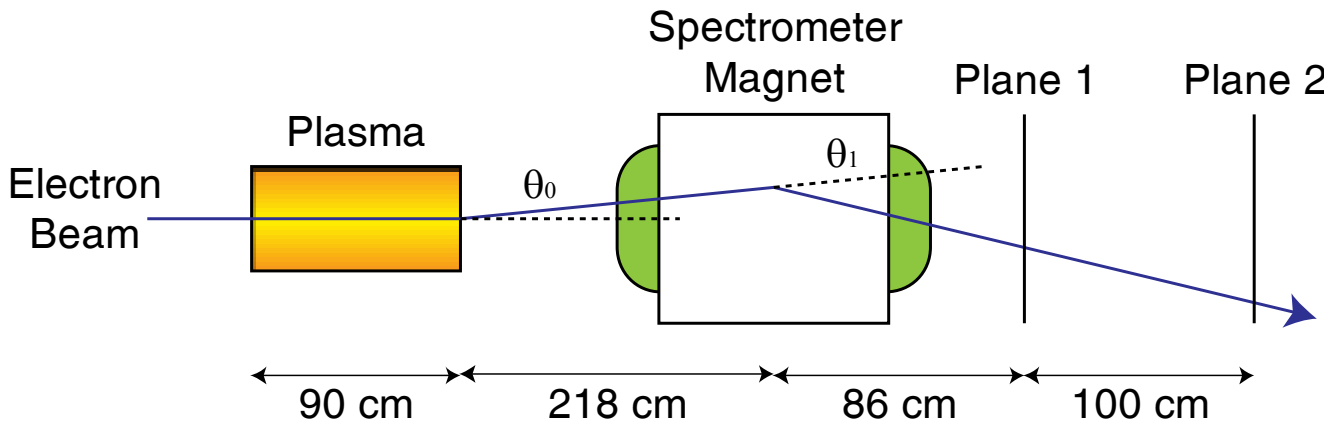
New Spectrometer



Imaging Spectrometer

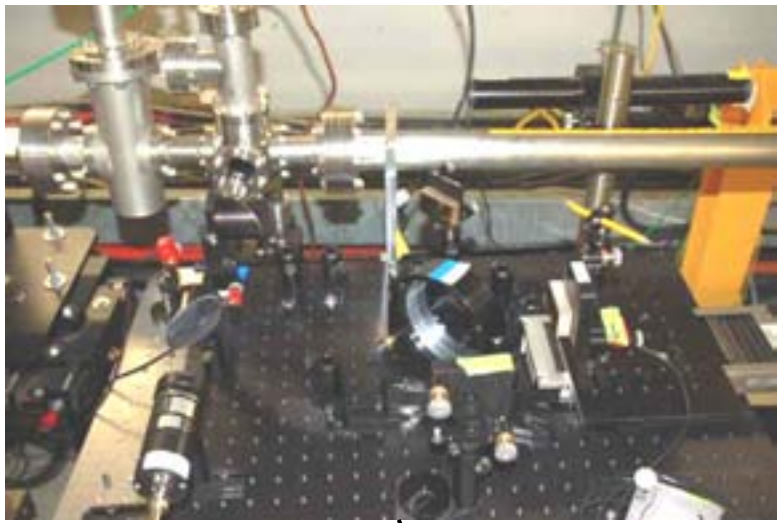


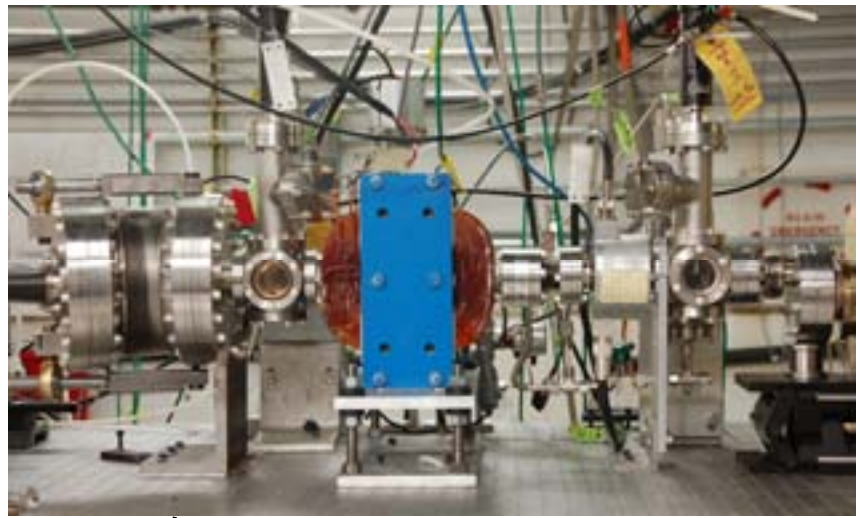
Two-Plane Spectrometer

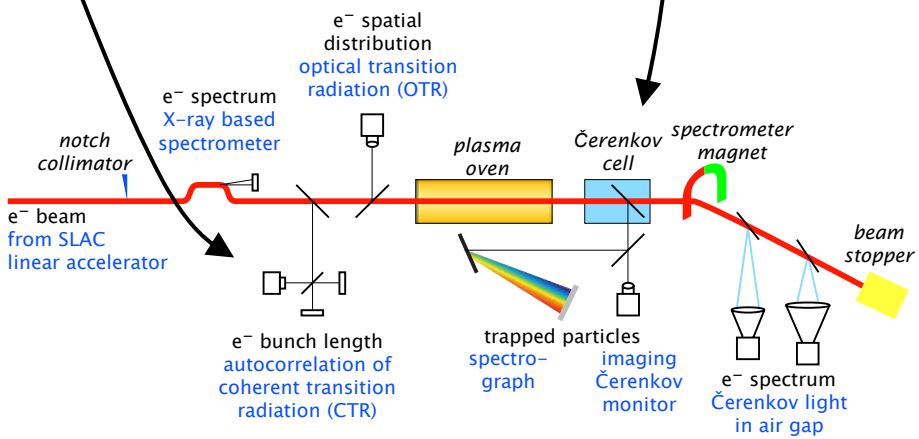


More Energy in the Drive Beam

More Diagnostics







Energy Doubling

- Plasma length: 85 cm
- Density: $2.7 \cdot 10^{17}\,\mathrm{cm}^{-3}$
- Incoming energy: 42 GeV
- Peak energy: (unpublished)

This plot contains unpublished data.

Send an e-mail to rasmus@slac.stanford.edu
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Stability

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Simulations

- Match the phase space from LiTrack simulation to the measured energy spectrum before the plasma
- Use the corresponding longitudinal profile and a measurement of the vapor density for QuickPIC:
  - ⇒ field ionization
  - ⇒ motion of beam and plasma electrons
  - ⇒ wake formation
  - ⇒ acceleration
  - ⇒ energy spectrum

Comparison to Simulations

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- By the way: we are still limited by oven length!

113 cm Plasma

- Peak energy is lower than for the 85 cm oven!
- Beam appears also less focused

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Simulations

- Determine head erosion as the reason for energy gain limitation

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Simulated Peak Energy

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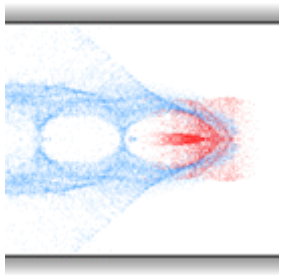

- Plasma Wakefield Acceleration
  - Plasma Wakes
  - What determines the maximum energy?
  - Numerical Models

- Experimental Setup
  - New plasma oven
  - New spectrometer
  - Higher energy in the drive beam

- Results
  - Increased the energy from 42 to 80 GeV
  - Head erosion limits energy gain at 85 cm in present setup
  - Excellent agreement with simulations

One More Thing…

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Future Experiments

- Possibilities to overcome head erosion
  - Emittance of the drive beam
  - Pre-ionize the plasma
- Accelerate positrons
- Two-bunch scheme
- More experiments on head erosion
  - See Mark Hogan's talk!

Presented by the E-167 Collaboration

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