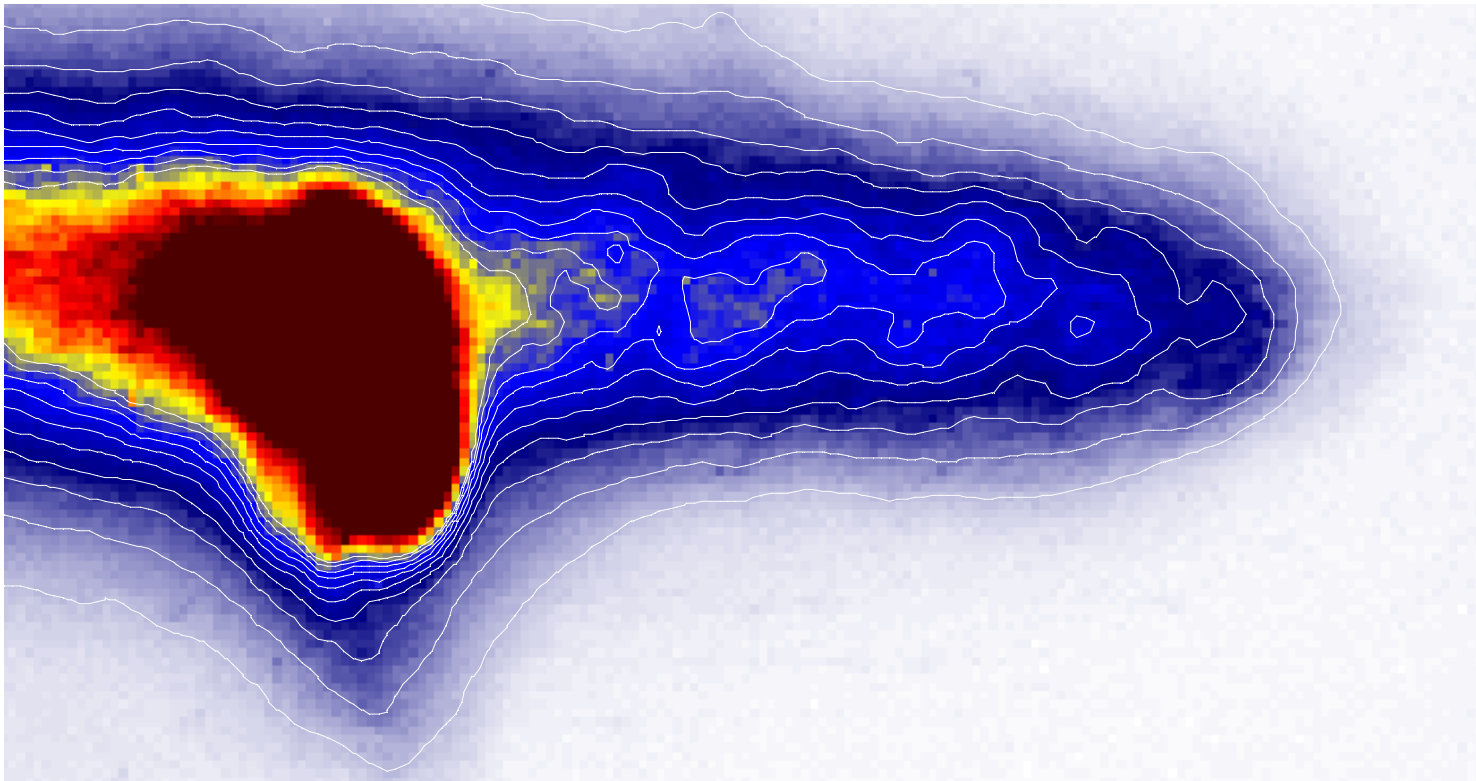
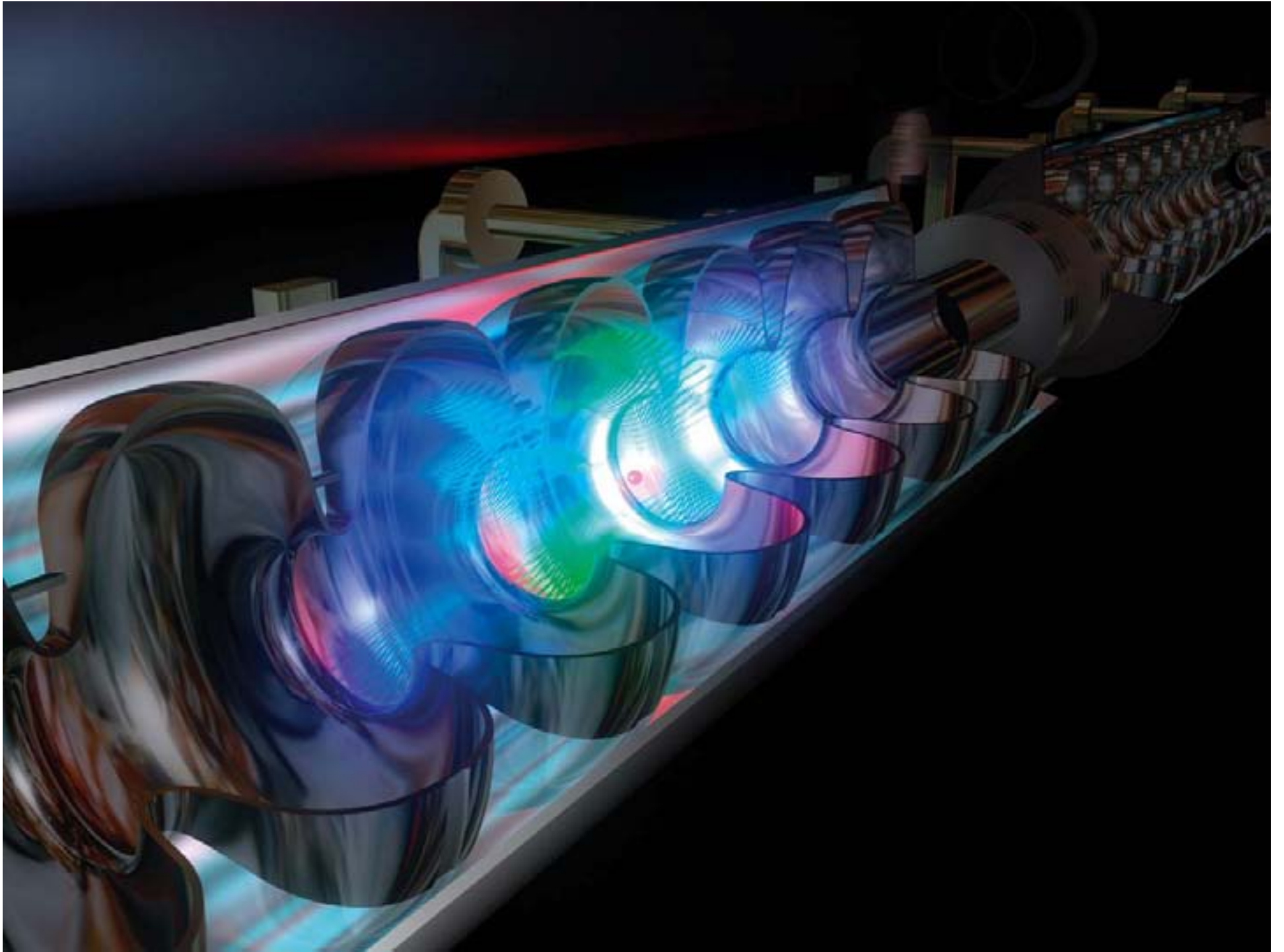


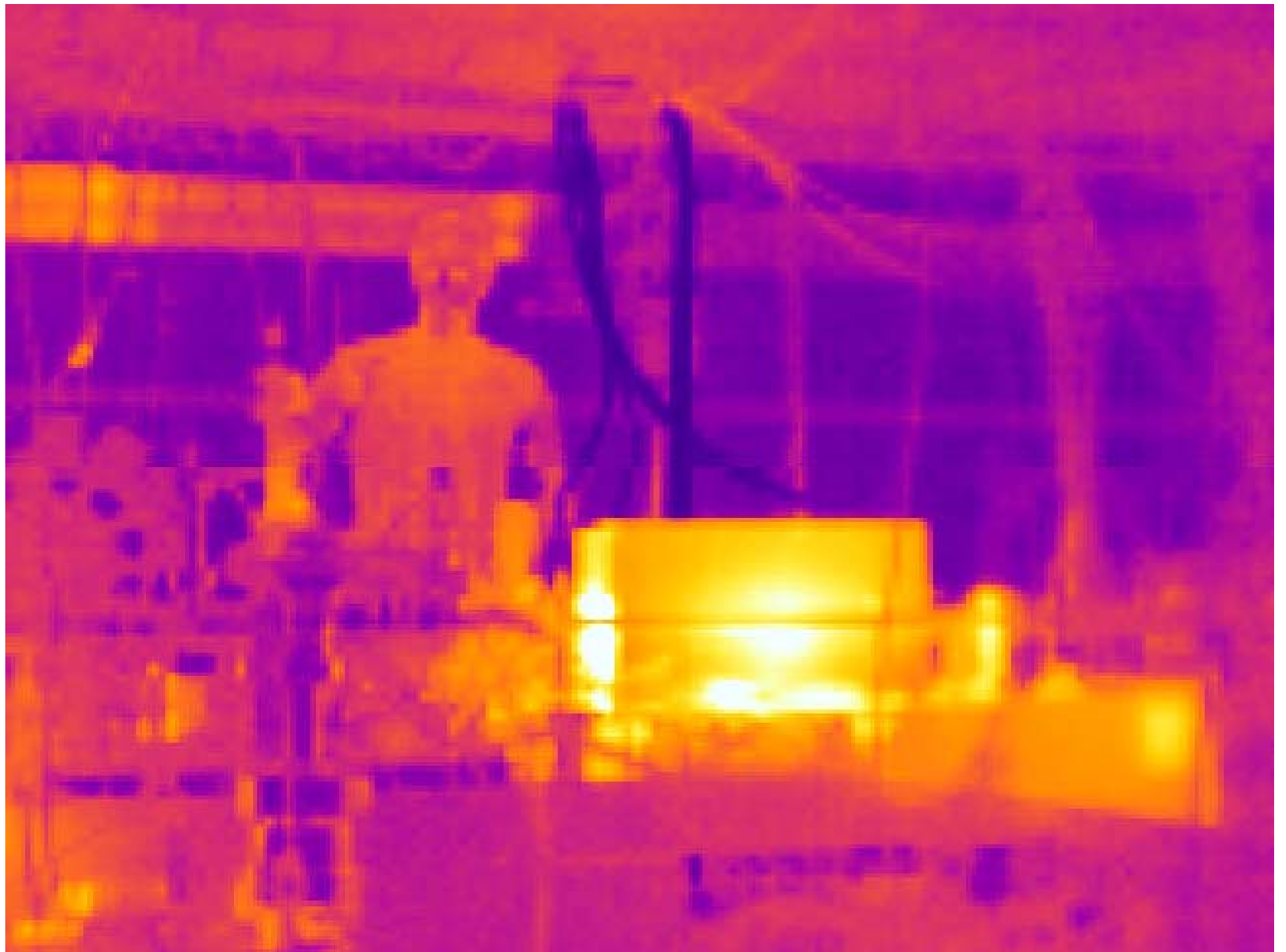
# Energy Doubling of 42 GeV Electrons

Rasmus Ischebeck, for the E-167 Collaboration



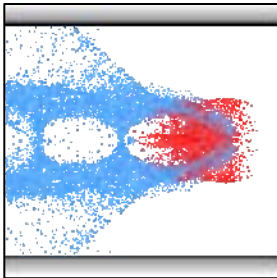






# Energy Doubling of 42 GeV Electrons

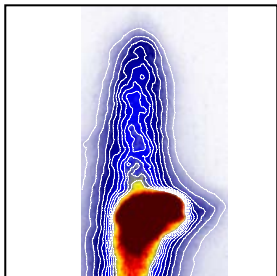
Rasmus Ischebeck, for the E-167 collaboration



- Plasma Wakefield Acceleration



- Experimental Setup



- Results

# Plasma Wakes – Theory

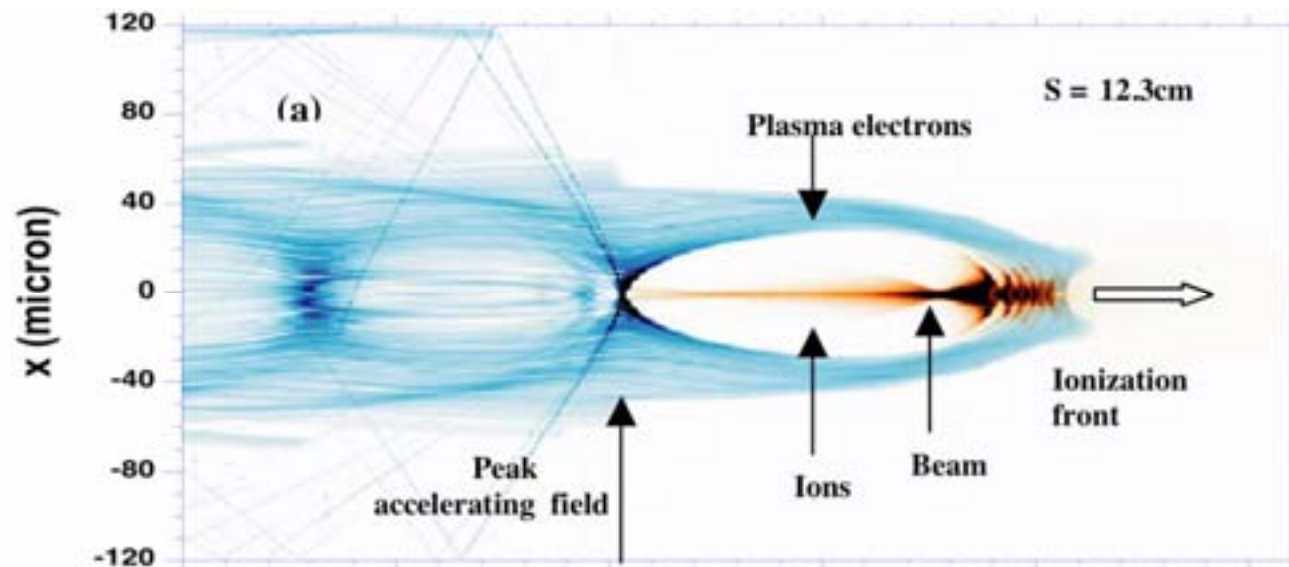
- In conventional accelerators, the accelerating fields are limited by the damage threshold of the cavities
- Unlike electromagnetic waves in vacuum, plasma wakes can have a longitudinal electric field

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

- Limit:  $E_0 = \frac{4\pi \epsilon_0 c m_e}{e} \omega_p \approx \sqrt{\frac{n_p}{\text{cm}^{-3}}} \frac{\text{V}}{\text{cm}}$

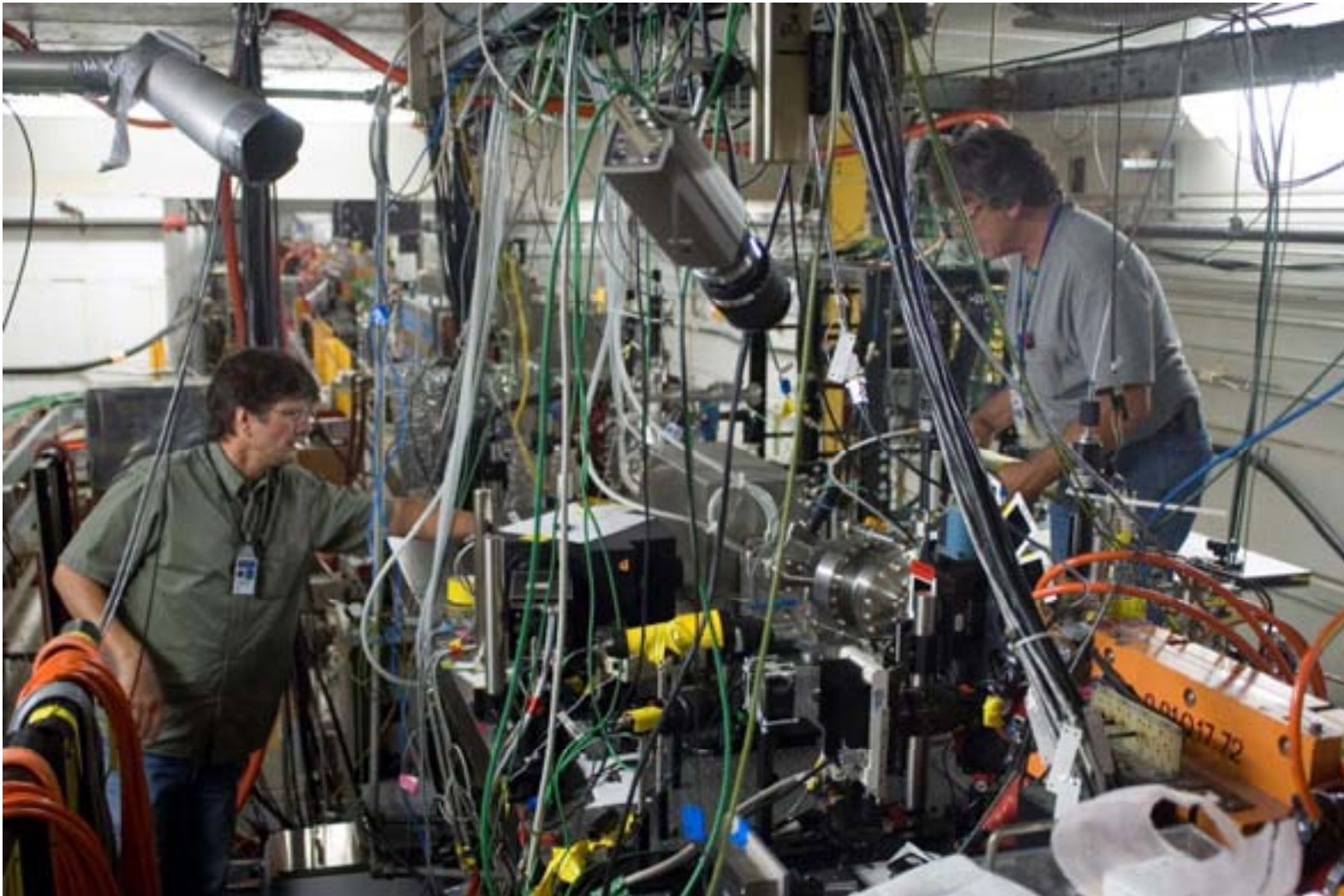
# Plasma Wakes – Theory

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



- Typical wavelength:  $50\ \mu\text{m}$
- Accelerating fields up to  $50\text{GV/m}$

# Plasma Wakes – Reality



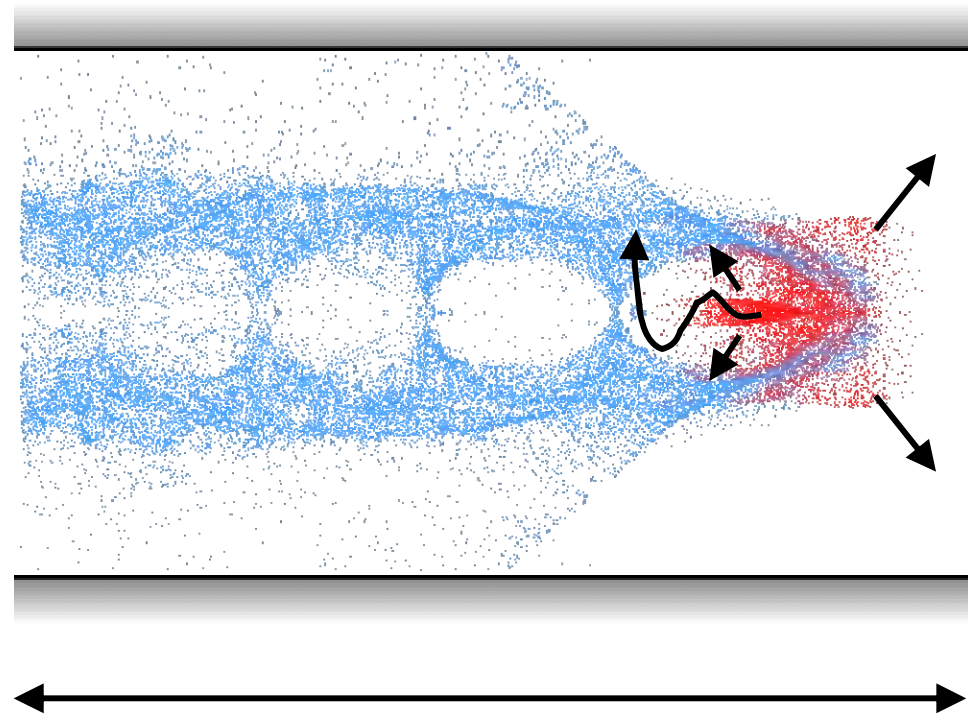
Rasmus Ischebeck, Energy Doubling of 42 GeV Electrons. AAC 2006

# 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

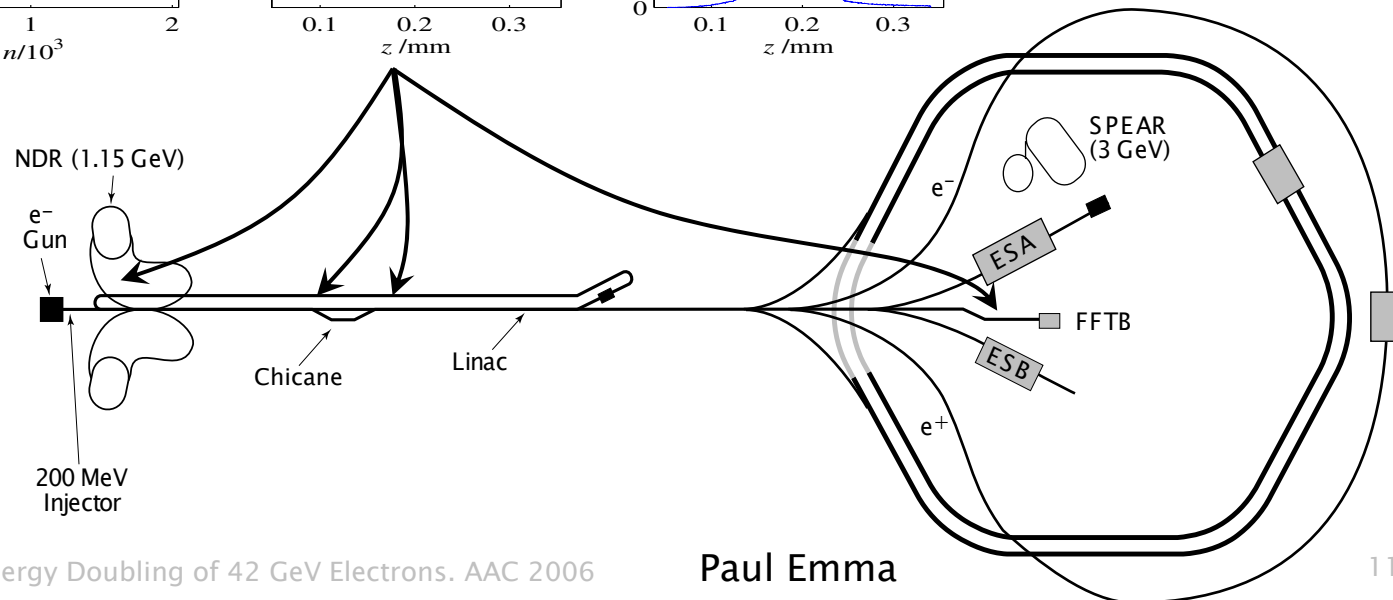
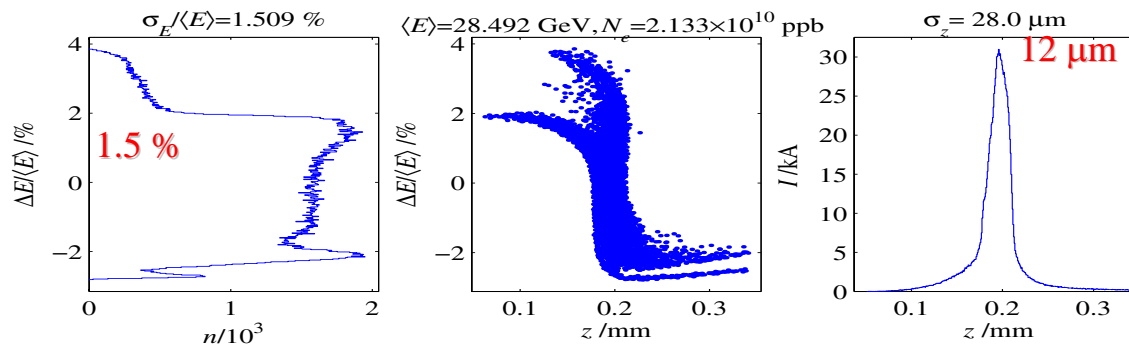
# What Determines the Maximum Energy?

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

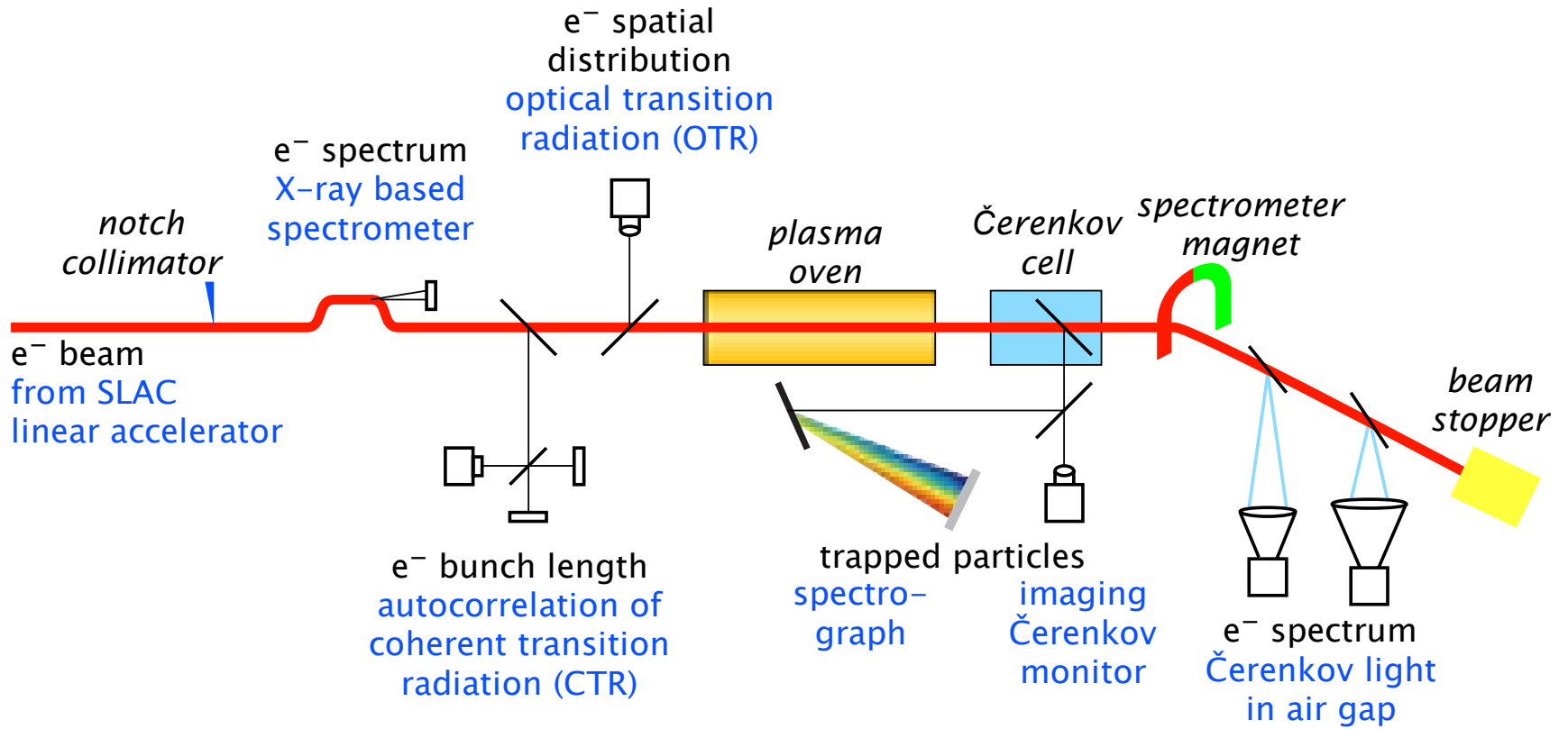


# Plasma Acceleration at SLAC

Acceleration, compression and focusing  
to a peak power density of 5 YW/m<sup>2</sup>



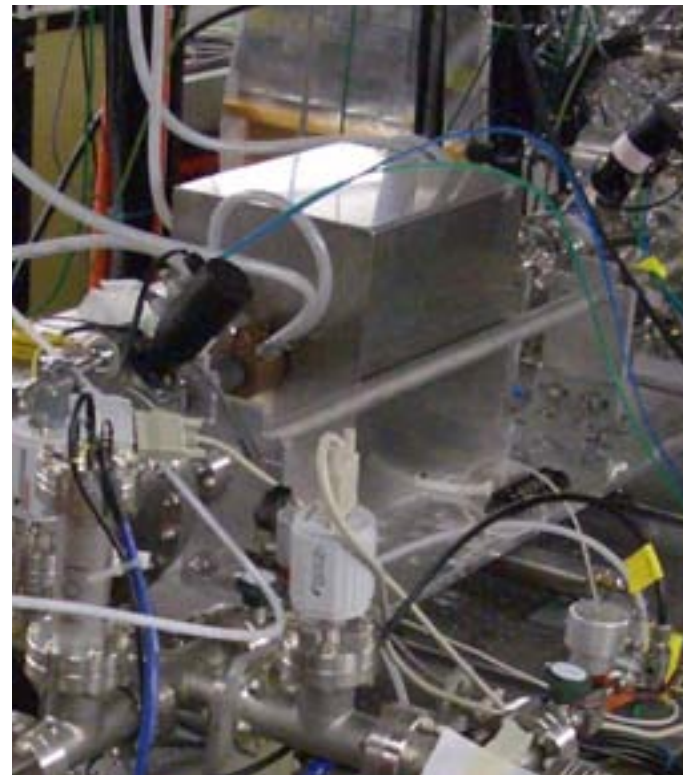
# Experimental Setup: E-167



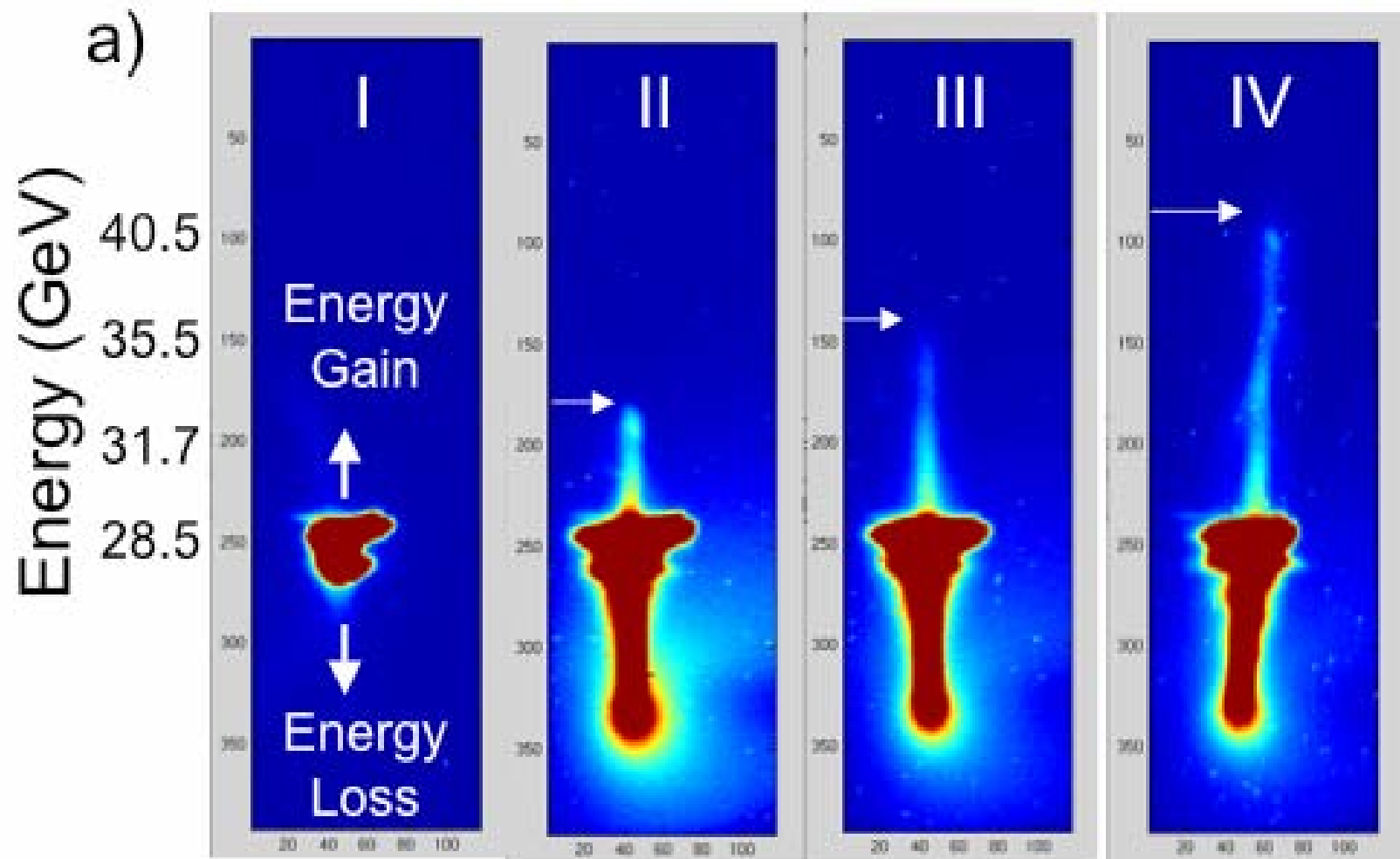
# Previous Results



More than 3 GeV energy gain  
in 10 cm plasma length

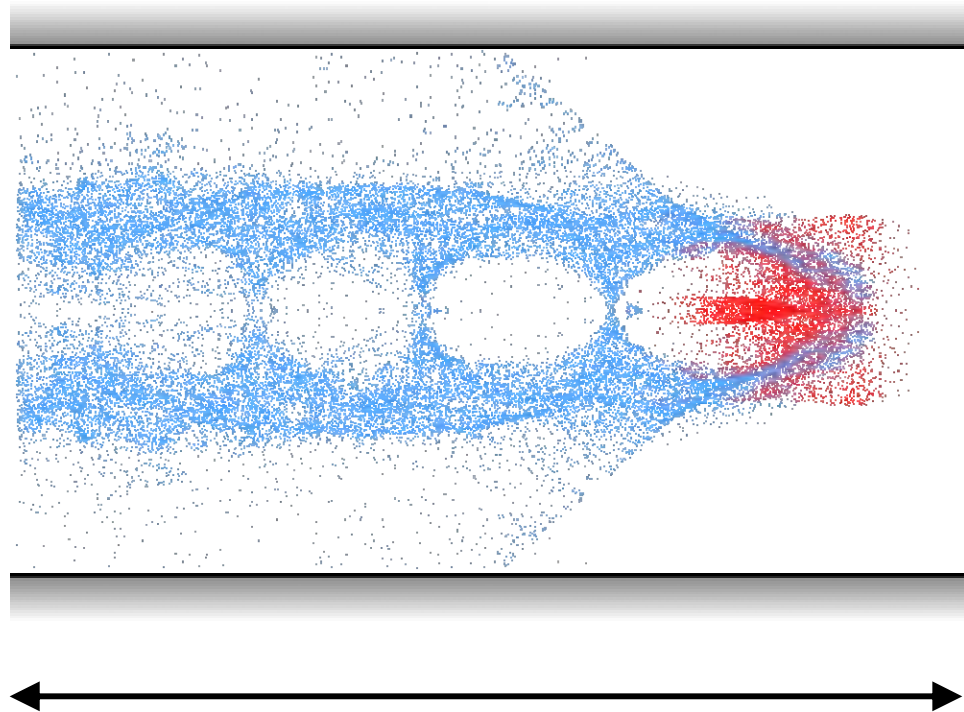


# Increasing the Plasma Length to 30.5 cm



# What Determines the Maximum Energy?

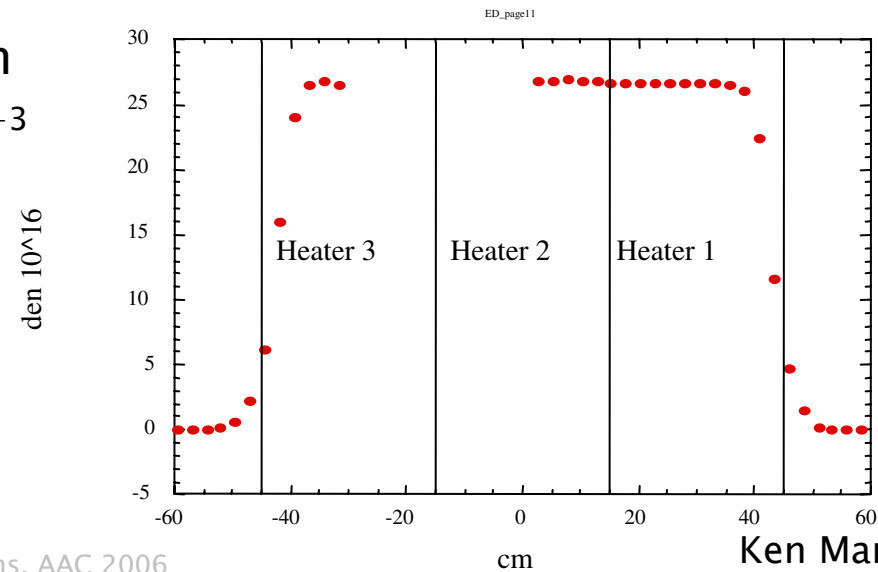
- Plasma length
  - Oven length
  - Head erosion
- Hose instability
- Mobile ions
- Energy depletion of the drive beam (transformer ratio)



# ⇒ Build New Plasma Oven



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

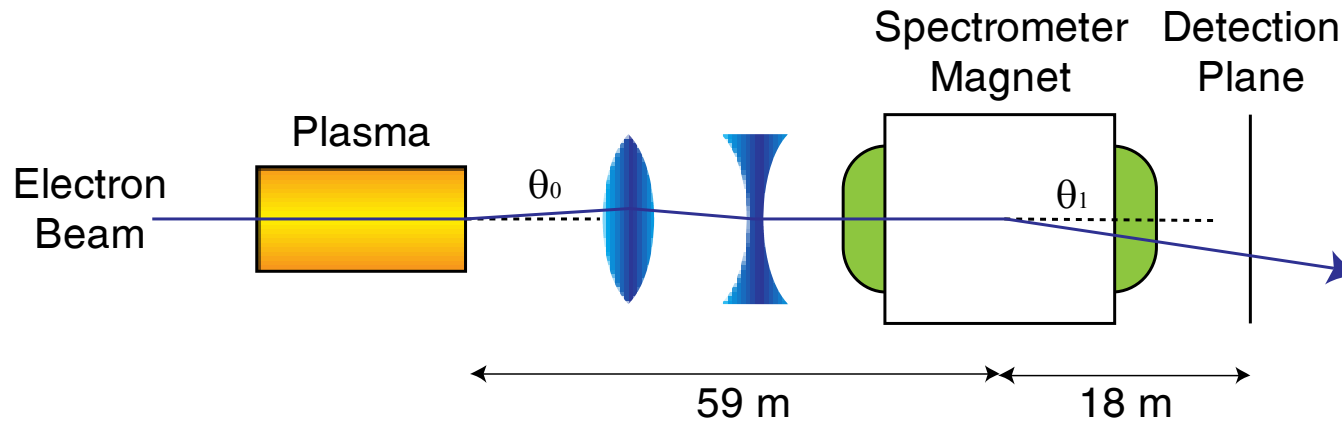


# New Spectrometer

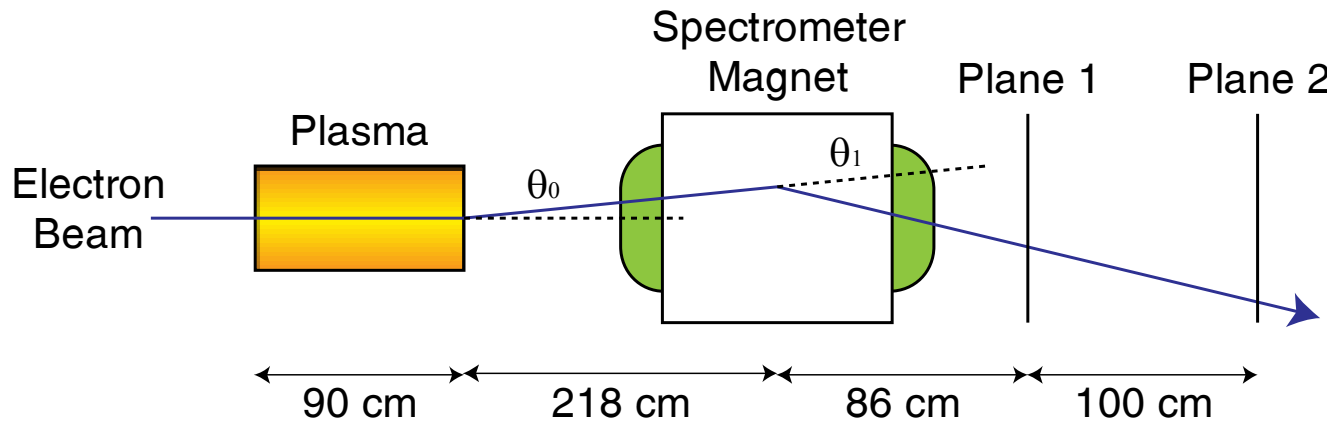


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# Imaging Spectrometer



# Two-Plane Spectrometer

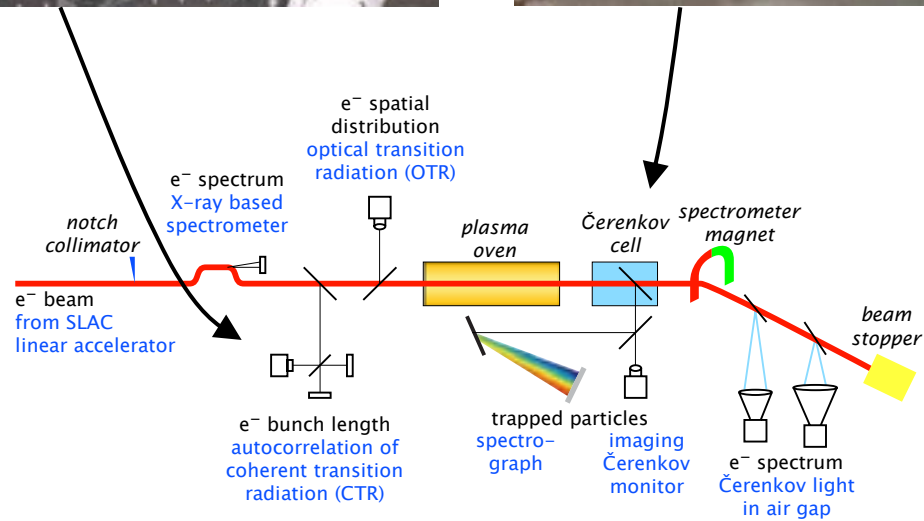
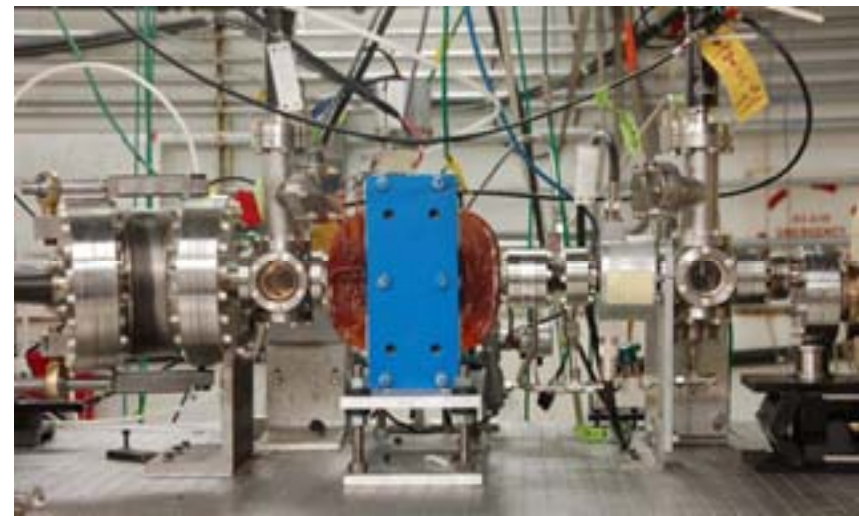
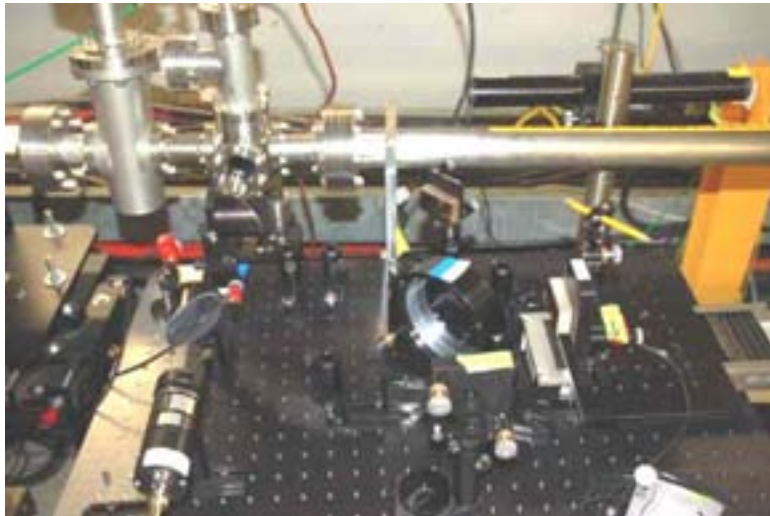


# More Energy in the Drive Beam



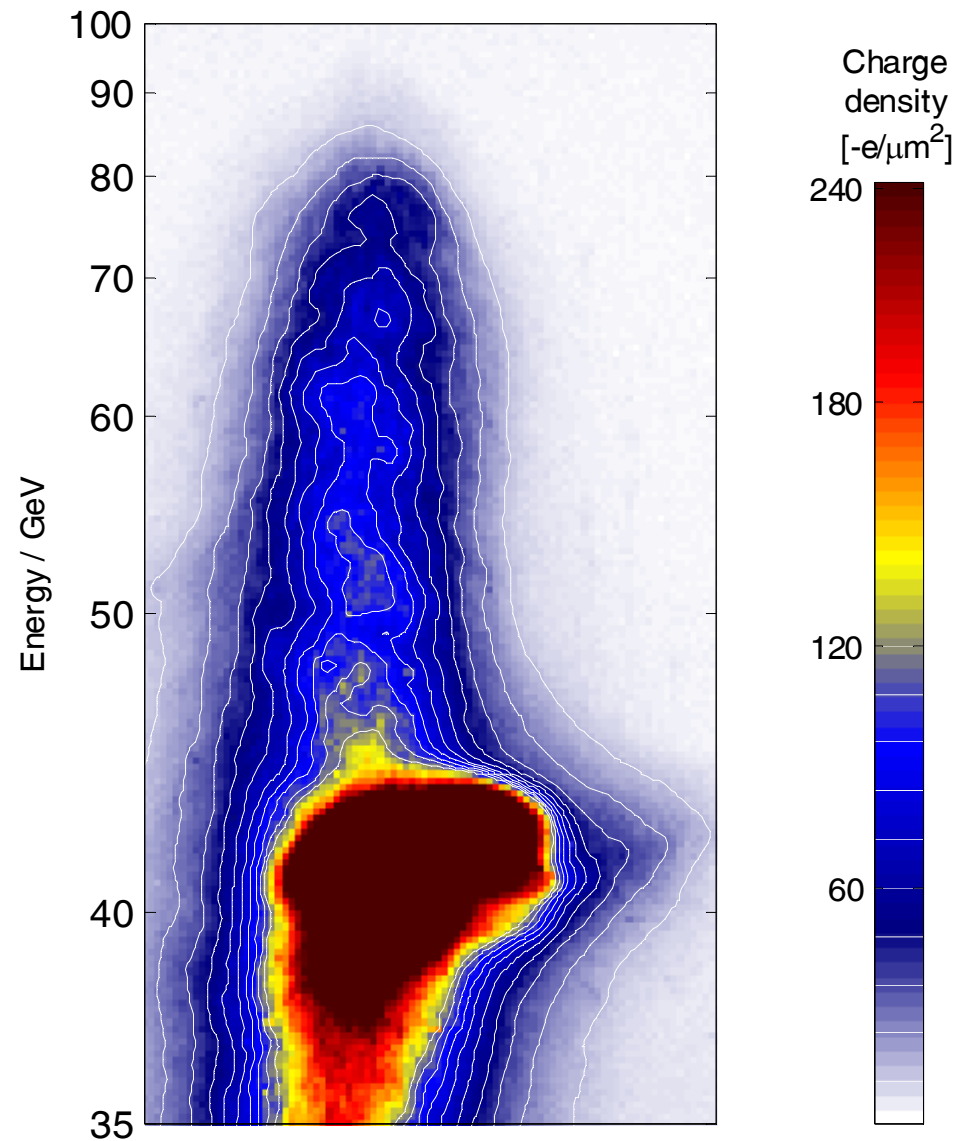
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# More Diagnostics

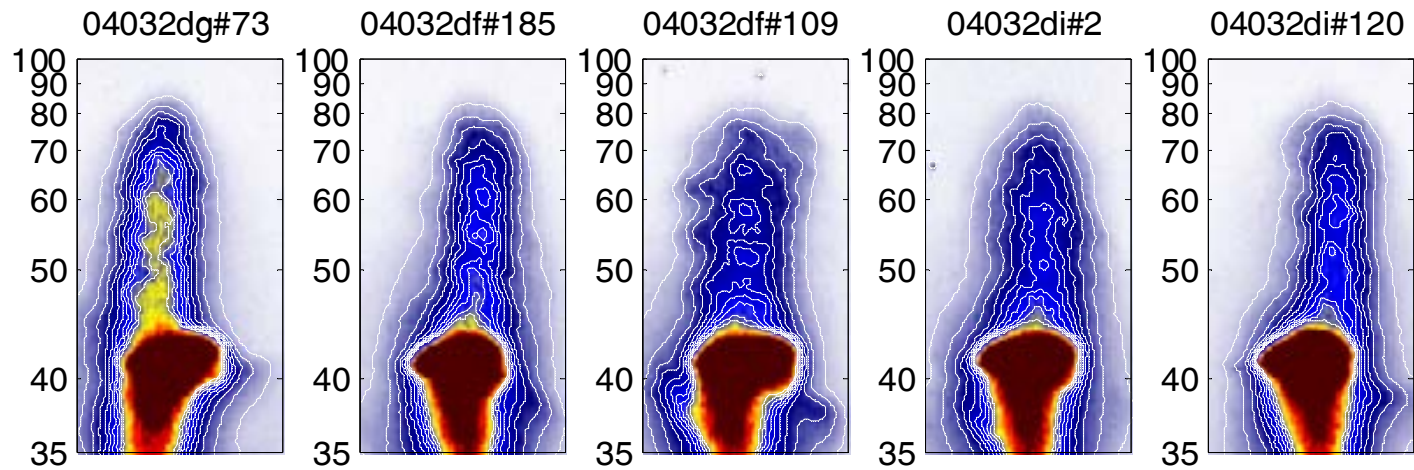
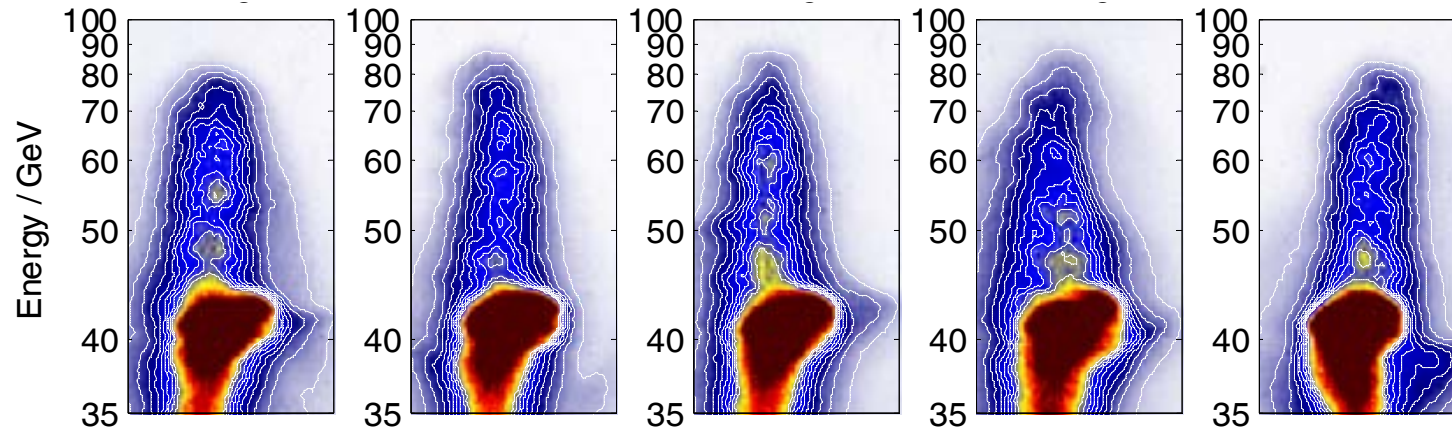


# Energy Doubling

- Plasma length: 85 cm
- Density:  $2.7 \cdot 10^{17} \text{ cm}^{-3}$
- Incoming energy: 42 GeV
- Peak energy: 80 GeV



# Stability

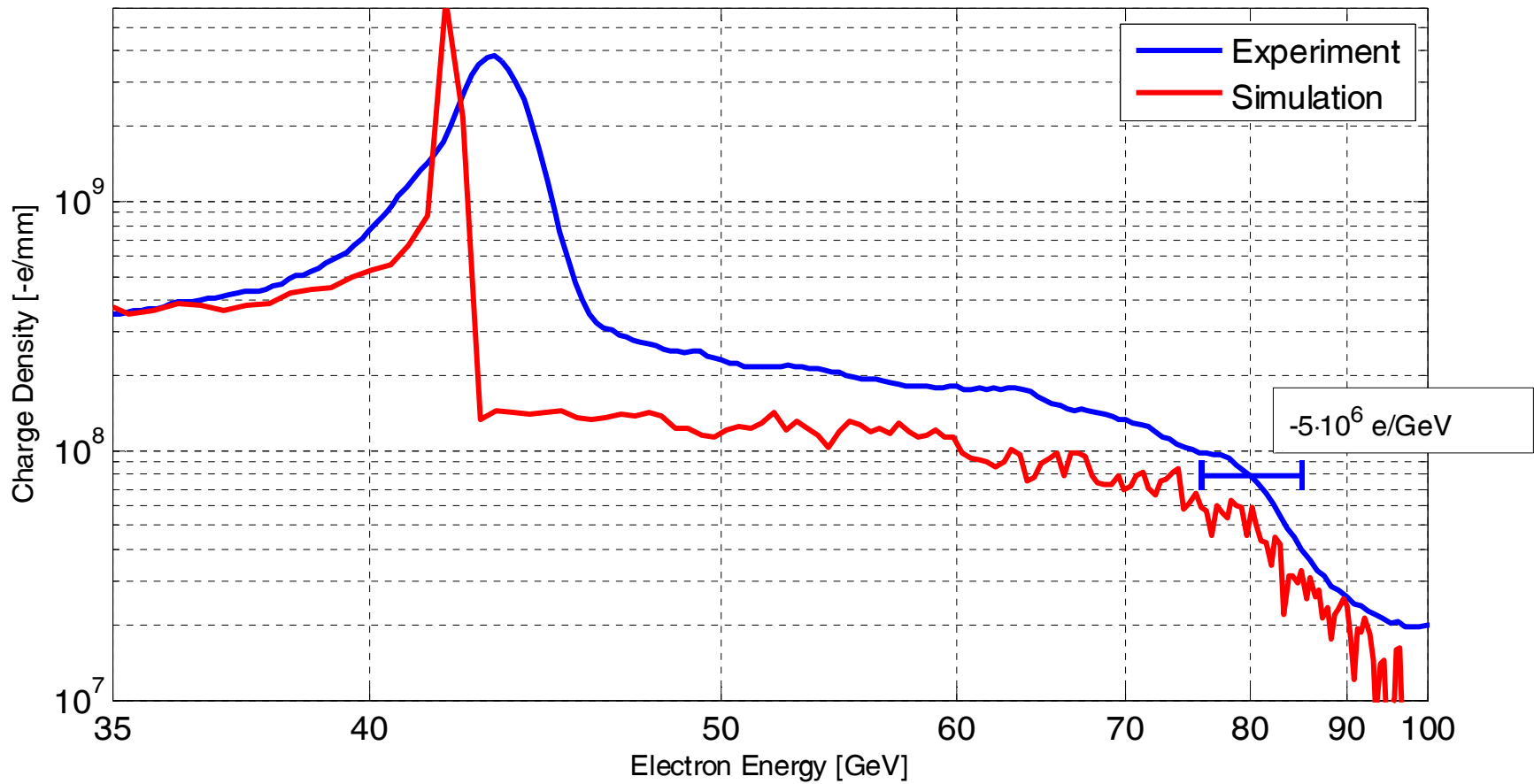




# Simulations

- 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

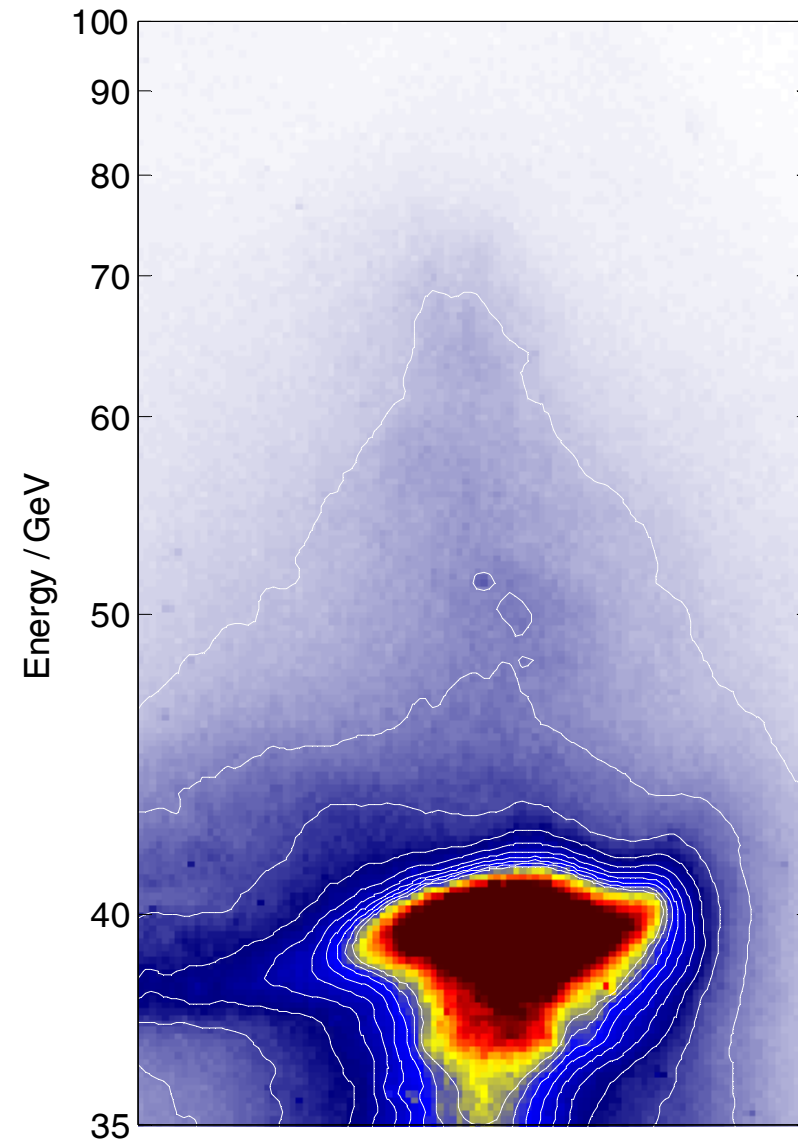
# Comparison to Simulations



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

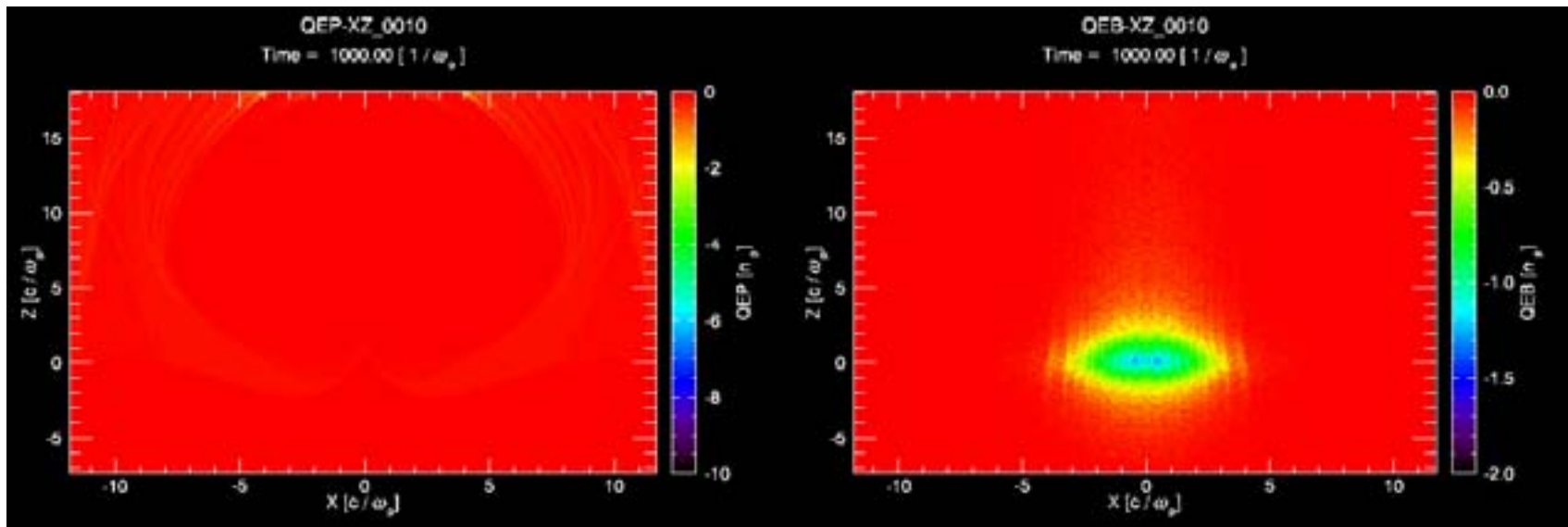
# 113 cm Plasma

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

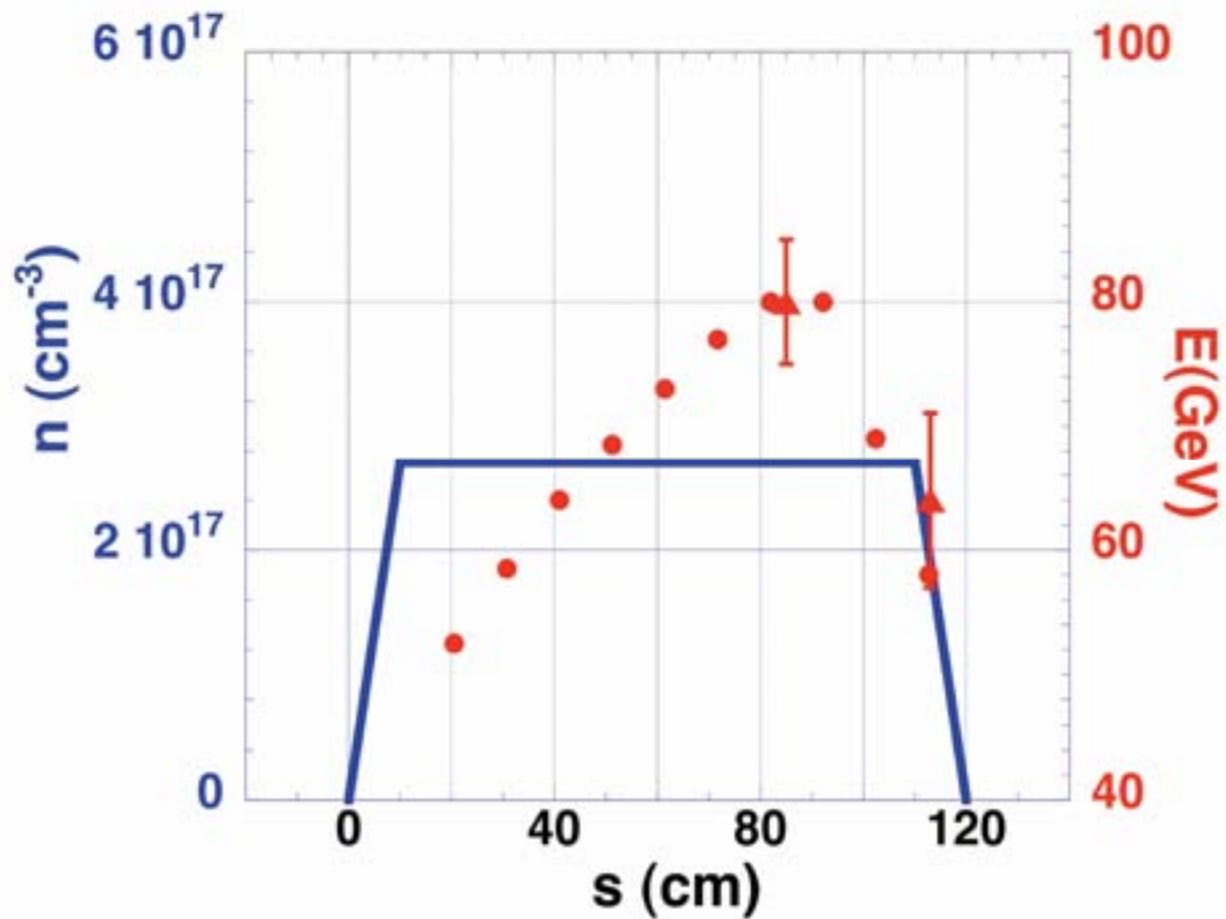


# Simulations

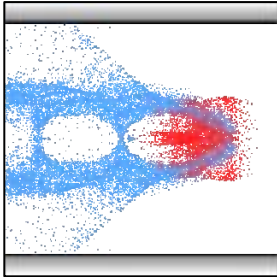
- Determine head erosion as the reason for energy gain limitation



# Simulated Peak Energy



# Energy Doubling of 42 GeV Electrons



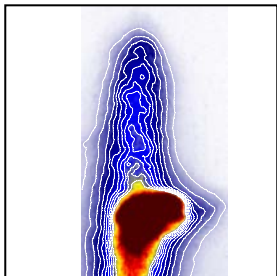
- **Plasma Wakefield Acceleration**

- 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

# 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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Please see: <http://www.slac.stanford.edu/~rasmus>

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