High energy gains in field-ionized noble gas plasma accelerators

Laser and Plasma Accelerators Workshop 2013

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Outline

- High energy gains in Ar
  - Energy Doubling, up to 30 GeV energy gain
  - Dependance of interaction with plasma density
  - QuickPIC simulations: use of high density plasma with > 100 GV/m fields, extended acceleration length to ~ 20 cm

- Beam-plasma interaction in He
  - More than 90% energy loss
  - No acceleration

- Beam-plasma interaction in He/Ar mixture and in Li
  - Energy gain threshold at Ar partial pressure of 16 Torr
  - Almost energy doubling in Li by disabling Ar/He ionization
  - Energy gain suppression in Li by enabling Ar/He ionization
The E200 experimental setup

Here, the gas is field-ionized by the electron beam itself. A few important numbers:

- Ionization potential.
  - Ar: 15.8 eV
  - Rb: 4.2 eV

- E-field required for ionization.
  - Ar: ~40 GV/m
  - Rb: ~4 GV/m

- Head Erosion velocity: 10x faster in Ar compared to Rb.

\[
V[\mu m/m] = 3.6617 \times 10^4 \epsilon_i^{1.73} [eV] \frac{\epsilon_N [mm \cdot mrad]}{\gamma} \frac{1}{I^{3/2} [kA]}
\]
High energy gains in Ar

Ar results with fully compressed electron beam:

- The Facet electron beam is able to consistently field-ionize Ar.

- More than Energy Doubling in Ar! Acceleration from 20 GeV to ~47 GeV.
High energy gains in Ar

P = 20 Torr
High energy gains in Ar

- **P = 2 Torr**
- **P = 4 Torr**
- **P = 8 Torr**
- **P = 16 Torr**
- **P = 32 Torr**
High energy gains in Ar

QuickPIC simulation:

Field-ionized argon, simulation starts before waist (with no ionization), 10x10x20 $\text{um}^3$ beam, $2 \times 10^{10}$ e$, 50\text{ um} \times 5\text{ um}$ normalized emittances, density: $5 \times 10^{17}\text{ cm}^{-3}$. 

Ar 16 Torr
Energy gain = 29.9 GeV
Energy loss = 20 GeV

$E_z$: up to 150 GV/m (around the waist position)
Length with ionization: 32 cm
Length with useful fields (>75 GV/m): ~ 20 cm
High energy gains in Ar

\[ P = 16 \text{ Torr} \]
\[ \text{Loss} = 20 \text{ GeV} \]
\[ \text{Gain} = 29.9 \text{ GeV} \]

\[ P = 2 \text{ Torr} \]
\[ \text{Loss} = 7.9 \text{ GeV} \]
\[ \text{Gain} = 0 \text{ GeV} \]

\[ P = 4 \text{ Torr} \]
\[ \text{Loss} = 11.9 \text{ GeV} \]
\[ \text{Gain} = 0 \text{ GeV} \]

\[ P = 8 \text{ Torr} \]
\[ \text{Loss} = 16.9 \text{ GeV} \]
\[ \text{Gain} = 4.7 \text{ GeV} \]

\[ P = 16 \text{ Torr} \]
\[ \text{Loss} = 20 \text{ GeV} \]
\[ \text{Gain} = 29.9 \text{ GeV} \]

\[ P = 32 \text{ Torr} \]
\[ \text{Loss} = 20 \text{ GeV} \]
\[ \text{Gain} = 31.6 \text{ GeV} \]

\( > 200 \text{ GV/m fields} \)
Beam-plasma interaction in He
Beam-plasma interaction in He

He results with fully compressed electron beam:

- The Facet electron beam is able to consistently field-ionize He (ionization potential = 24.6 eV).
- More than 90% of energy loss in He. Deceleration from 20.35 GeV to below 2.5 GeV.
- Head erosion 25x faster in He compared to Rb.
He results with fully compressed electron beam:

- The Facet electron beam is able to consistently field-ionize He (ionization potential = 24.6 eV).

- More than 90% of energy loss in He. Deceleration from 20.35 GeV to below 2.5 GeV.

- Head erosion 25x faster in He compared to Rb.
Beam-plasma interaction in He/Ar mixture and in Li
Beam-plasma interaction in He/Ar mixture and in Li

Ar 21.3%, He 78.7%
P = 32 Torr
Beam-plasma interaction in He/Ar mixture and in Li

Ar 50%, He 50%
P = 32 Torr

Energy gain threshold at Ar 16 Torr partial pressure
Beam-plasma interaction in He/Ar mixture and in Li

Li oven
P = 32 Torr

Disabling Ar/He ionization (Spoiler Foil In)
Almost energy doubling
Beam-plasma interaction in He/Ar mixture and in Li

Li oven
P = 32 Torr

Enabling Ar/He ionization (Spoiler Foil Out)
Energy gain suppression
Conclusion

- Impressive results in a high ionization potential, field-ionized argon plasma. More than energy doubling, with up to 30 GeV energy gain observed.

- Pressure scan experimental and simulation data in good agreement.

- > 200 GV/m field achievable at high density. Made possible with self-focusing.

- > 20 cm of interaction possible due to extended head erosion length, by using large beta functions.

- Strong beam-plasma interaction in He, though no acceleration.

- In Li: energy doubling suppressed when enabling Ar/He ionization.
The E200 Collaboration


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