Particle-in-cell study on positron production using lasers

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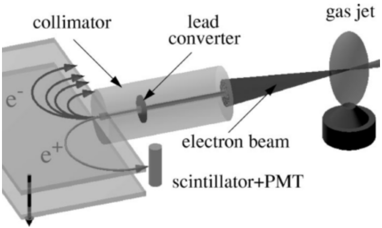
Contents

Positrons with lasers

- Compact high-intense laser systems (Ti:Sapphire)
  - Easy electron acceleration - high density, high energy

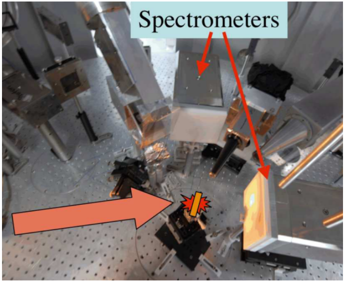
Design of experiments:

1. Electron acceleration in gas jet, positrons in heavy solid target



C. Gahn et al., 2002

2. Direct production in solid target



H. Chen et al., 2009.

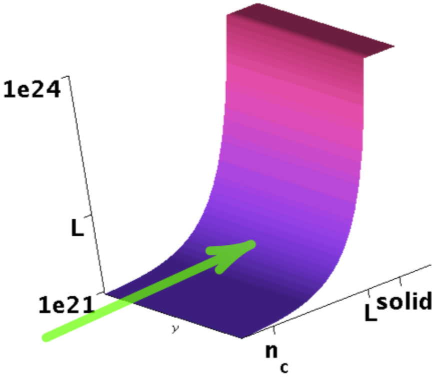
Laser absorption

Solid targets

- Laser prepulse causes evaporation of target surface
- Main laser pulse arrives at exponential density profile

$$n = n_{\text{solid}} \exp(-\frac{x}{L})$$

- Preplasma length has influence on laser absorption
  - *critical density* n_c
  - laser is reflected by region $n > n_c$



Electron acceleration mechanisms

- **Ponderomotive**
  - general mechanism, caused by steep gradient of laser electric field: $\mathbf{F} \propto \nabla \mathbf{E}^2$
- **Wake-field**
  - underdense plasma, gas targets
- **$\mathbf{j} \times \mathbf{B}$ heating**
  - high intensity, steep gradient of electron density required

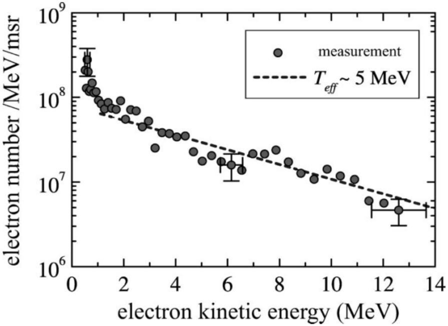
Will not occur in 1D PIC:

- **Vacuum heating**
- **Resonant absorption**

V. S. Belyaev et al., 2008.

Hot electron properties

- **Thermal electrons:**
  - in thermal equilibrium with ions
  - low temperature
- **Hot electrons:**
  - not in thermal equilibrium with ions
  - follow Maxwell-Boltzmann distribution
  - characterized with temperature too
  - higher temperature



C. Gahn et al., 2002

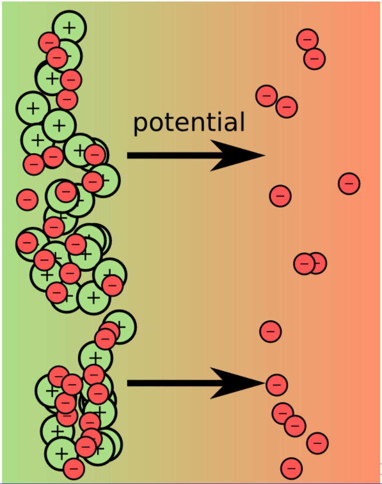
Electron refluxing

Simple model for electron charge separation from plasma:

Capacitor model:

- Escaped electron create potential
- This potential prevents others to escape
- Only those with energy higher than potential barrier escape
- Gives us: *refluxing efficiency*

$$\eta = \exp\left(-\frac{e\phi}{T_{\text{hot}}}\right)$$

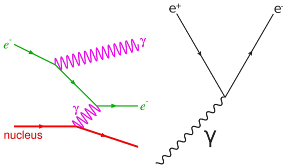


Production of positrons

- Two ways how the positrons are created:

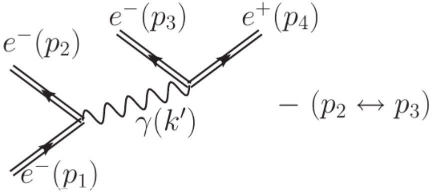
1. Bethe-Heitler process

- Bremstrahlung production
- Pair production from photon



physik.uni-bonn.de

2. Trident process

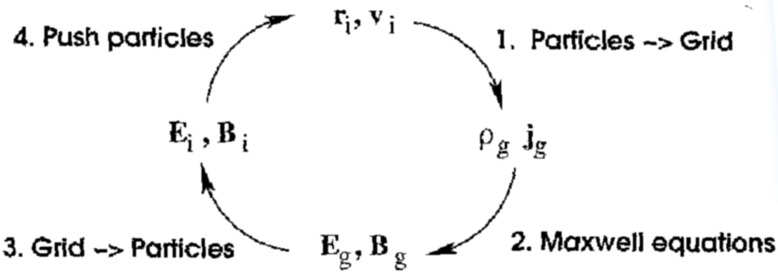


A. Ilderton, 2011

- Both processes need heavy nucleus -> high Z targets

Particle-in-cell

- Simulates motion of particles in electromagnetic field
- It is not possible to compute every interaction
  - Particles -> macroparticles
  - Space divided by grid



P. Gibbon, Short pulse laser interactions with matter

Computer experiments

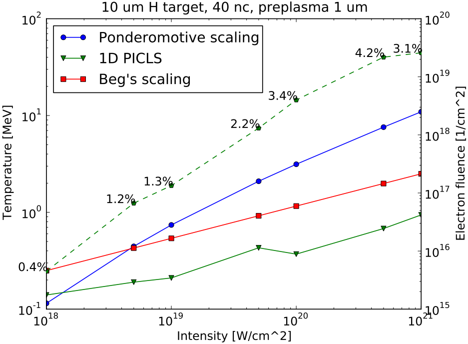
Using particle-in-cell code PICLS:

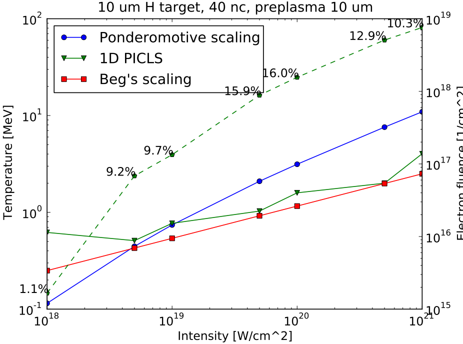
1. I studied dependence of electron temperature and energy conversion efficiency on:
   1. Laser intensity
   2. Length of preplasma
   3. Initial electron density
2. I tried to validate capacitor model
   1. Comparison of potential barrier height from PIC and from analytical model

Hot electrons characteristics 1

Preplasma length depence, lower density

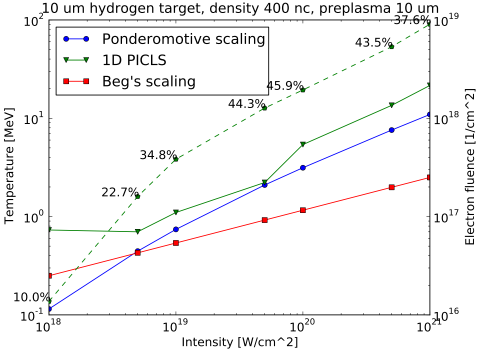
Ponderomotive: $T_{\mathrm{hot}} = m_e c^2 \left(\sqrt{1 + \frac{I_{18} \lambda_\mu^2}{1.37}} - 1 \right) \mathrm{MeV}$ Beg's: $T_{\mathrm{hot}} = 0.46 \left(I_{19} \lambda_\mu^2 \right)^{1/3} \mathrm{MeV}$

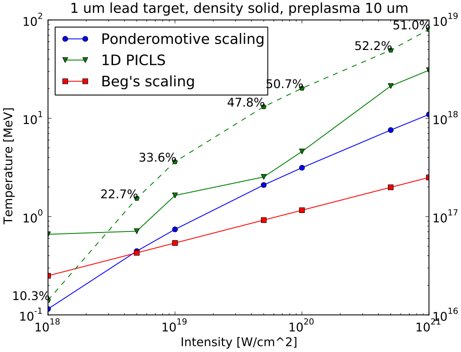




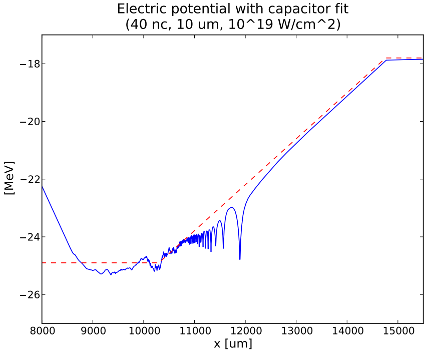
Hot electrons characteristics 2

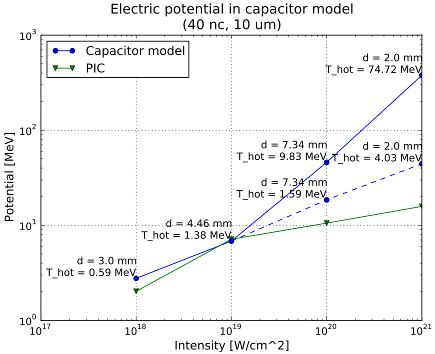
Higher density, H and Pb targets





Capacitor model in PIC





- In all cases refluxing efficiency is higher than 99 %

Positron calculations with PIC

Steps to follow:

1. PIC simulation with trident calculation in thin solid target
2. Calculate analyticaly radiation yield from from electrons bounded in target
3. Take number of escaped electrons from refluxing efficiency
4. Monte Carlo transport simulation for the escaped electrons and for the radiation

Summary

- My comprehension of laser-matter interaction is better
- I learned using 1D version of PICLS, processing of outputs using Python
- I explored dependence of electron properties on some parameters
- Simple analytical model has been validated
- Future working procedure was proposed

Acknowledgements

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