Radiation and Particle Secondary Sources based on electron Laser Plasma Acceleration

Danilo Giulietti
Physics Department of the University and INFN, Pisa, Italy.

danilo.giulietti@df.unipi.it

INFN
Istituto Nazionale
di Fisica Nucleare

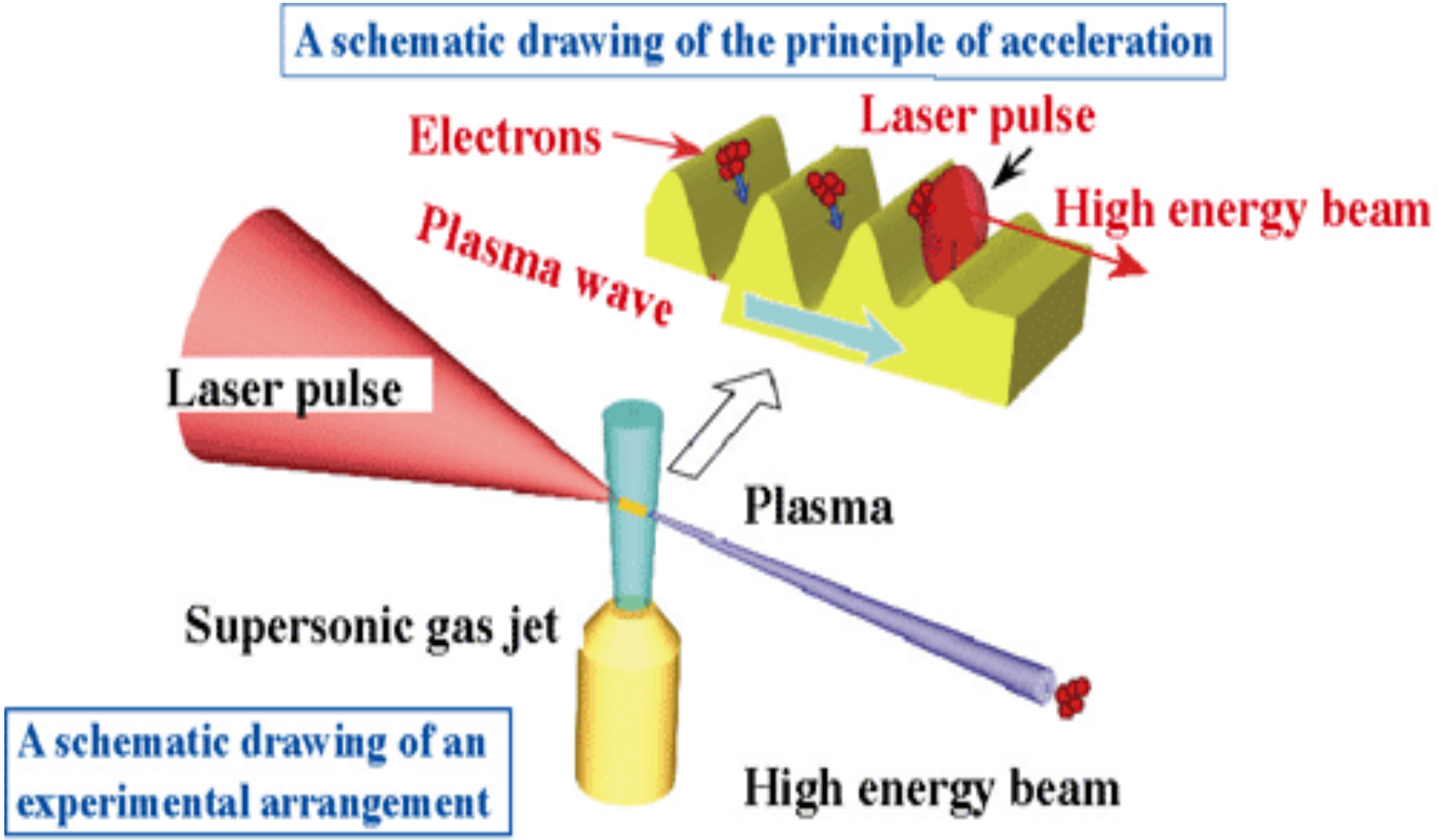
Università degli Studi di Pisa
1343

LASER-PLASMA ACCELERATION

Ultra-short Ti:Sa laser pulses at relativistic intensities (greater than 10^{18}W/cm^2), propagating in plasmas at densities of the order of 10^{18-19} el/cm^3, can induce accelerating electric fields up to 10^4 times the maximum fields available in the conventional accelerators.

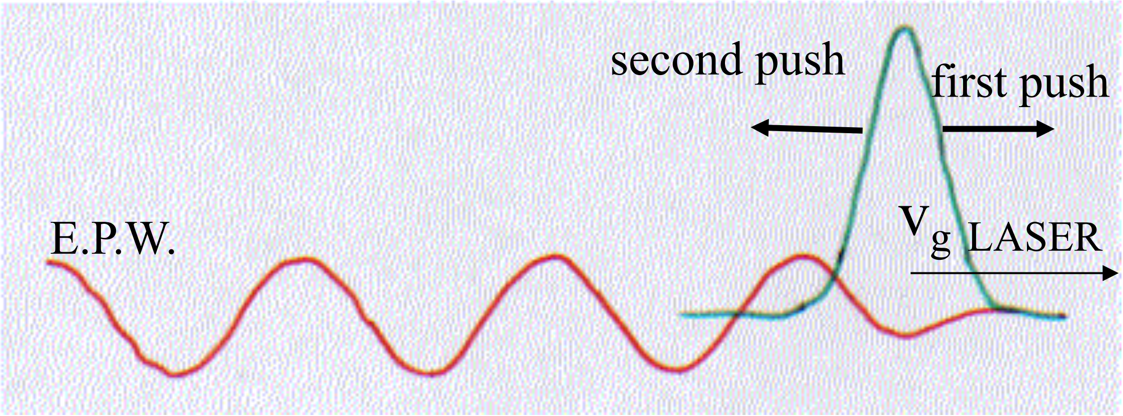
Refer to V. Malka and M. Borghesi contributions in this Conference

The ponderomotive force related to the laser pulse produces the Wake Field and the Coulomb force related to the Electron Plasma Wave accelerates the electrons



danilo.giulietti@df.unipi.it

LASER WAKE FIELD



$$\tau \cdot c \approx \frac{\lambda_p}{2} \quad \Leftrightarrow \quad \tau \approx \frac{T_p}{2} \quad \Rightarrow \quad n_e\left(cm^{-3}\right) \approx \frac{3 \cdot 10^{-9}}{\tau_{(s)}^2}$$

$$example: \;\; \tau = 30\,fs \;\; \Rightarrow \;\; n_e \approx 3.3 \cdot 10^{18}\,cm^{-3}$$

$$v_{\phi,epw} = v_{g,laser} = c\left(1 - \frac{\omega_{pe}^2}{\omega^2}\right)^{\frac{1}{2}}$$

ELECTRON ACCELERATION IN E.P.W.

1D MODEL

multi-GeV electrons in a few cm @ $n_e \approx 10^{18}\,\mathrm{cm}^{-3}$, with 100TW class Ti:Sa lasers

$$\text{for } \gamma_p \approx \frac{\omega}{\omega_{pe}} >> 1 \Rightarrow \Delta W_{\max} = 4\gamma_p^2 \frac{\delta n_e}{n_e} mc^2 \quad \text{is the max. energy gain}$$

$$\text{along a distance } L_{deph} \approx \gamma_p^2 \lambda_p = \lambda_0 \left(\frac{n_c}{n_e} \right)^{\frac{3}{2}} \qquad \lambda_p \approx \frac{2\pi c}{\omega_{pe}}$$

$$\Delta W_{\max} \approx eE_{\max} \cdot L_{deph} \propto n_e^{\frac{1}{2}} \cdot \frac{1}{n_e} \cdot n_e^{-\frac{1}{2}} = \frac{1}{n_e}$$

LPA Secondary Sources

The drastic **reduction of the dimensions and costs** of the Laser Plasma Acceleration apparatus, open to **several applications**. In fact, once energetic electron bunches at rep rate of a few Hz are produced, X-γ radiation and particle secondary sources can be carried out.

Beside their compactness these sources are easily synchronized with other laser systems, fulfilling the best conditions for **femtosecond time resolved pump and probe experiments**.

Radiation Secondary Sources

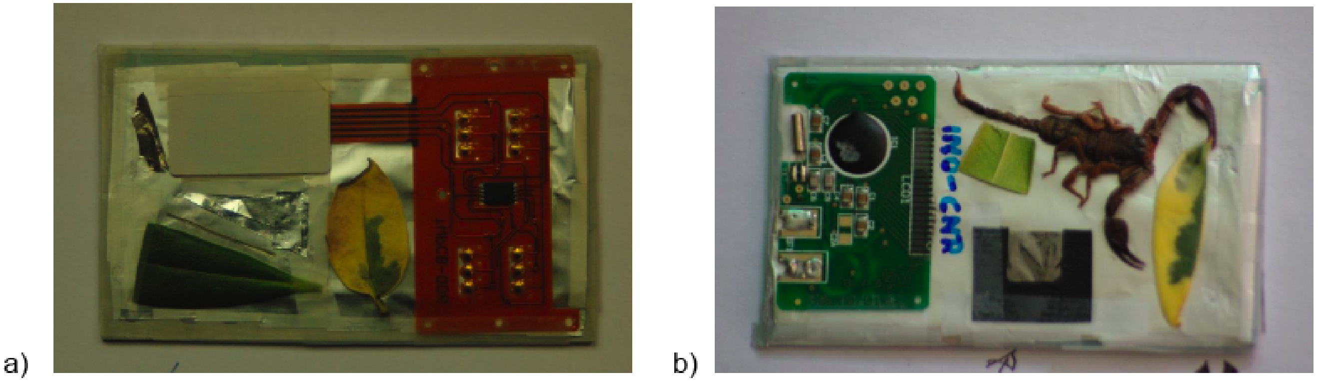
- Bremsstrahlung
- K-α radiation
- Betatron radiation
- Thomson Scattering (V. Malka contribution in this Conference)
- FEL
- Terahertz

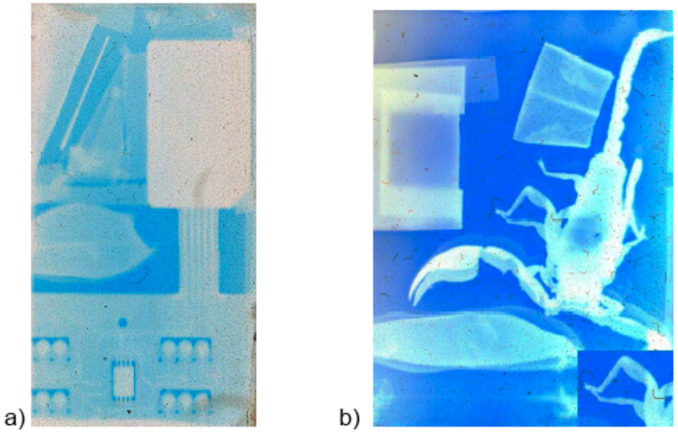
Particle Secondary Sources

- Ions (M. Borghesi talk; G.P. Cirrone et al poster PS2-02)
- $\gamma \longrightarrow e^{+} + e^{-}$
- Neutrons, μ, ….

danilo.giulietti@df.unipi.it

Electron Radiography





G.C. Bussolino et al,
submitted to Medical Physics

Alghero, Channeling 2012
danilo.giulietti@df.unipi.it

LPA: the Control of Electron Bunches

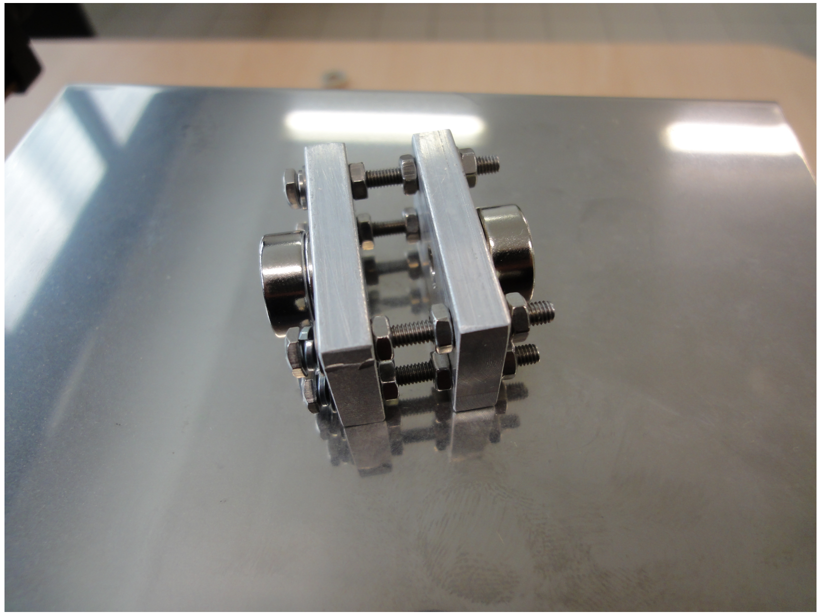
- Plasma shaping
- Laser guiding
- Ionization process
- Multi-stage LPA
- Static Magnetic Field

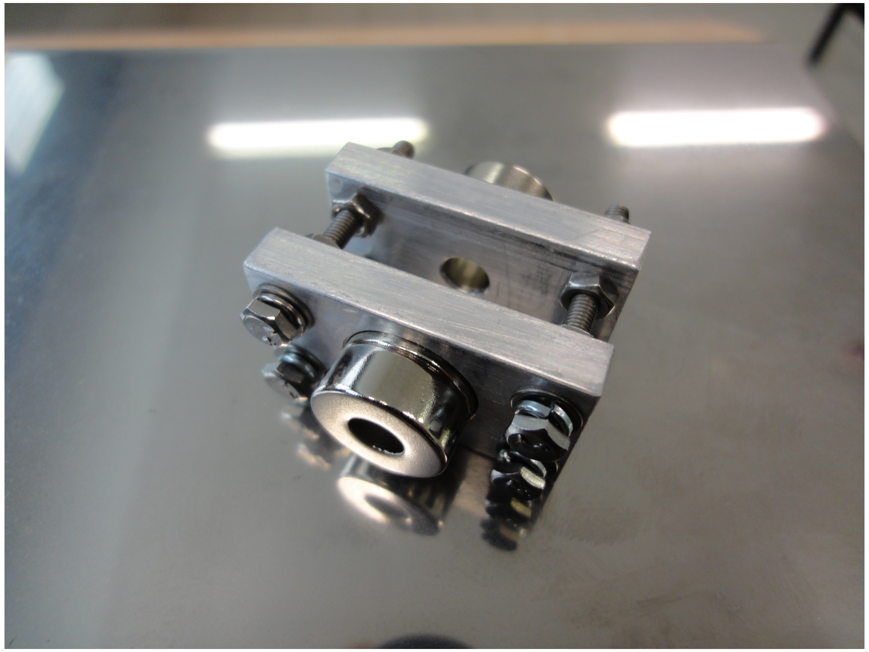
  (**T.Hosokai et al**, PRL, 97, 075004, 2006)
- ……

danilo.giulietti@df.unipi.it

The magnetic device

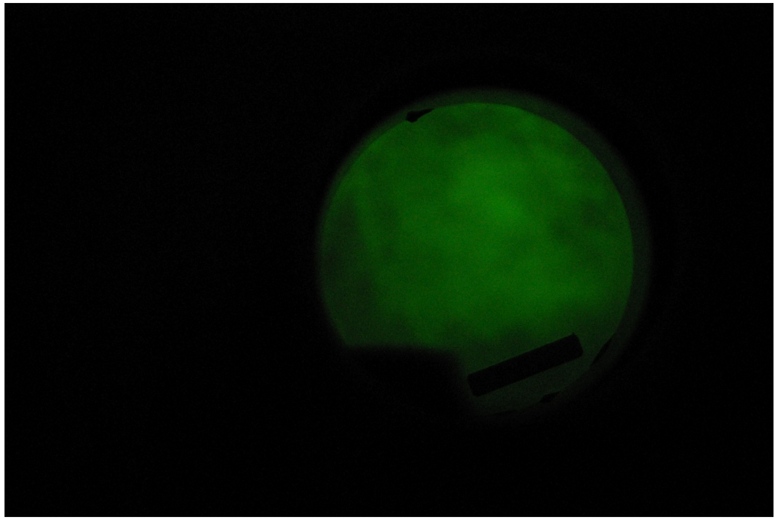
B≈0.2 Tesla





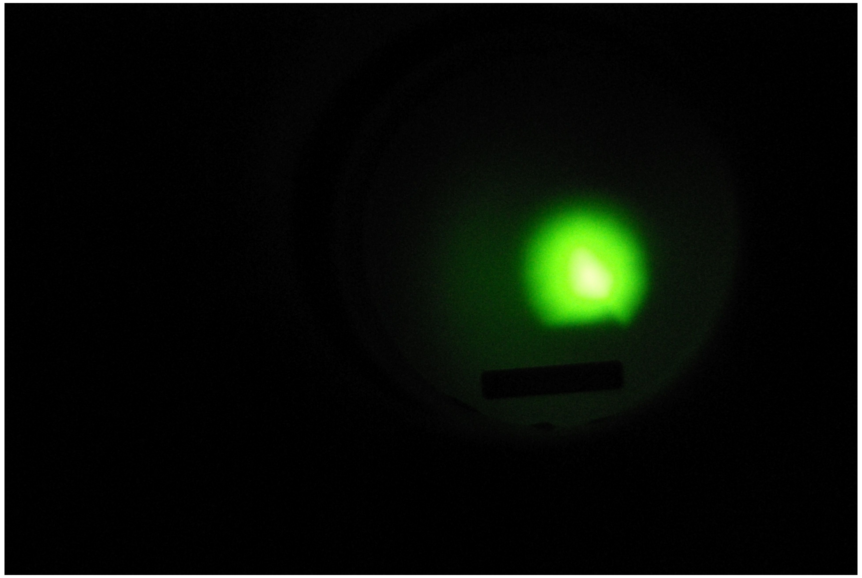
Equipment projected by Y. Oishi and
D. Giulietti at INFN-Pisa

Static Magnetic Field in LPA Experiments



N_2=38 bar

B=0.2 T in the interaction region, along the laser axis →



Alghero, Channeling 2012
danilo.giulietti@df.unipi.it

Influence of static magnetic field on LPA mechanism ?

Comparing the magnetic pressure with the plasma pressure

$$\frac{B^2}{2\mu_0} = nKT \quad \rightarrow B = \sqrt{2\mu_0 KTn} = 20 \div 50\ Tesla$$

We see that the magnetic field required to have confinement of typical **laser produced plasmas** ($n_e \approx 10^{19} cm^{-3}$, $T \approx 100 eV$) is of a few 10's Tesla: much more high the one we use in the magnetic device (0.1-0.2 Tesla).

Magnetized Plasmas ?

The condition for magnetized plasma holds in the regions were the temperature is high and the density low:

$$\omega_L \tau_{ei} \geq 1 \; or \; \frac{l_{mfp}}{r_L} \geq 1$$

$$\omega_L = \frac{eB}{m}, \;\; \tau_{ei} = \frac{3.4 \times 10^5 T_e^{\frac{3}{2}}}{Z^2 n_i \Lambda}$$

$$T_e(eV),\; n_i(cm^{-3}),\;\; Z = ioniz.\ number,\;\; \Delta = Coulomb \log$$

$$l_{mfp} = \text{mean free path; } \mathrm{r}_L = \text{Larmor radius}$$

For B≈0.2 Tesla such conditions could be satisfied in low density plasma channels as those we evidenced in recent experiments performed in Pisa and CEA-Saclay, or in the pre-plasma produced by the pre-pulse accompaining the ultra-intense laser pulse as suggested by T. Hosokai in PRL, **97**, 075004, 2006.

LPA electrons affected by electromagnetic lens effects ?

When an electron passes through an electromagnetic lens it is subjected to two forces at any particular moment: a force (F_z) parallel to the core (Z axis) of the lens, and a force (F_r) parallel to the radius of the lens. These two forces are responsible for two different actions on the electrons, **spiraling** and **focusing**, as they pass through the lens. An electron passing through the lens parallel to the Z axis will experience the force F_z causing it to spiral through the lens. This spiraling causes the electron to experience the force F_r which causes the beam to be compressed toward the Z axis. The **magnetic field is inhomogeneous** in such a way that it is weak in the center of the gap and becomes stronger close to the bore. **Electrons close to the center are less strongly deflected than those passing the lens far from the axis.**

danilo.giulietti@df.unipi.it

CONCLUSIONS

- New Acceleration Techniques
- High brightness sources of electrons, protons, ions, neutrons, positrons, X & γ-rays, …
- Applications in HEP, medicine, ICF, material science, astrophysics, femtochemistry, attosecond science, …
- **The control of the LPA process and the manipulation of produced electron bunches required**

danilo.giulietti@df.unipi.it

Acknowledgements

(in alphabetic order)

M. Anania [1]
F. Baffigi [2]
G. Bussolino [2]
G. Cristoforetti [2]
G. Di Pirro [1]
A. Esposito [1]
L. Fulgentini [2]
G. Gatti [1]
A. Giulietti [2]
D. Giulietti [2,3,4]
L. Gizzi [2,4]
T. Hosokai [5]
M. Kando [6]
P. Koester [2]
L. Labate [2,4]
T. Levato [1,2]
Y. Oishi [4,7]

1) Laboratori Nazionali di Frascati, INFN, Italy
2) INO-CNR, Pisa, Italy
3) Dipartimento di Fisica dell’Università di Pisa, Italy
4) Sezione INFN, Pisa, Italy
5) Osaka University, Japan
6) JAEA, Japan
7) CRIEPI, Japan

Alghero, Channeling 2012
danilo.giulietti@df.unipi.it