A new quasi mono-energetic ultra short and highly charged electron beam of interest for high energy femtochemistry

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Laser  
Plasma  
Electron Beam  
Gas-Jet  
Nozzle

170 +/-20MeV  
500 pC  
6 mrad

International Conference on  
Transient Chemical Structures in Dense Media.  
14-16 march 2005
<table>
<thead>
<tr>
<th>SPL</th>
<th>FBC</th>
<th>ELF</th>
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<tbody>
<tr>
<td>Y. Glinec</td>
<td>B. Brozek-Pluska</td>
<td>F. Burgy</td>
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<tr>
<td>J. Faure</td>
<td>A. Hallou</td>
<td>B. Mercier</td>
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<td>J.J. Santos</td>
<td>B. D. Gliger</td>
<td>J.Ph. Rousseau</td>
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<tr>
<td>S. Fritzler</td>
<td>Y. Gauduel</td>
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<td>V. Malka</td>
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**Collaborators**

- A. Pukhov
- CEA/DAM Ile-de-France, France
- E. Lefebvre (simulations)

T. Hosokai  University of Tokyo, Japan

**Founding**: CARE EEC contract FP6
Why use a Plasma?

- Superconducting RF-Cavities: $E_z = 55 \text{ MV/m}$
- Plasma is an Ionized Medium $\rightarrow$ High Electric Fields

\[ E_z \sim n_e \sim \sqrt{n_e} \]

for 1% Density Perturbation at $10^{17} \text{ cc}^{-1}$ $0.3 \text{ GV/m}$
for 100% Density Perturbation at $10^{19} \text{ cc}^{-1}$ $300 \text{ GV/m}$

And now $> 1 \text{ TV/m}$

$\Rightarrow$ Size and of cost Reduction
How to excite Relativistic Plasma waves?

The laser wake field

Electron density perturbation

Laser pulse

\[ F \approx -\text{grad } I \]

Phase velocity \( v_{\phi_{\text{pw}}} \approx v_{\text{glaser}} \)

\( \approx \) close to \( c \)

Analogy with a boat

\[ \tau_{\text{laser}} \approx \frac{T_p}{2} \]

\( \Rightarrow \) Short laser pulse

\( \tau_{\text{laser}} \approx 200 \text{ fs for } n_e = 10^{17} \text{cm}^{-3} \)

Tajima&Dawson, PRL79
Review of some Former Experiments on Electron Beam Generation

<table>
<thead>
<tr>
<th>Lab</th>
<th>Year</th>
<th>Process</th>
<th>$E_L$</th>
<th>Rate</th>
<th>$E_e$</th>
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<td>SMLWF</td>
<td>50 J</td>
<td>20 min</td>
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<td>MPQ</td>
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<td>DLA</td>
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<td>LOA</td>
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<td>FLWF</td>
<td>1 J</td>
<td>10 Hz</td>
<td>200 MeV</td>
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</table>

Large scale, energetic laser, with low repetition rate
Salle Jaune Laser

5-pass Amp. : 200 mJ

8-pass pre-Amp. : 2 mJ

Stretcher : 500 pJ, 400 ps

Oscillator : 2 nJ, 15 fs

Nd:YAG : 10 J

4-pass, Cryo. cooled Amp. : < 3.5 J, 400 ps

After Compression :
1 J, 30 fs, 0.8 mm,
10 Hz, 10⁻⁷
Interaction chamber (inside)
Summary of FLWF previous results

Experiments

3D PIC simulations

Low Normalized Emittance

Emittance is indeed comparable with todays Accelerators

$E_{e^-} = \sim 55 \text{ MeV}$  $\epsilon^n = \sim 3 \pi \text{ mm mrad}$

S. Fritzler et al., PRL 04
Experimental Setup: single shot measurement

- Laser
- Nozzle
- Magnets
- Lanex
- ICT
- CCD
Recent results on e-beam: Energy distribution improvements

Charge in [150–190] MeV: (500 ± 200) pC

Divergence = 6 mrad
J. Faure et al., C. Geddes et al., S. Mangles et al., in Nature 30 September 2004
Laser particle acceleration could help in reducing the size of accelerators

- fs/ps: higher rep. Rate, lower cost, better e-beam
- Laser particle acceleration has been demonstrated
  - Energy gains of 1 MeV to 200 MeV
  - E-fields of 1 GV/m to 1000 GV/m
  - Good quality
- And now: mono energetic high quality e-beam
- Bullet regime: promising for multi or single stage accelerator (charge, duration)

Next Step:
- Stability & reproducibility
- Electron sources up to $\approx 1$ GeV, 1cm ($nC, <1$ ps)
- Compact X ray beam and compact (synchrotron, XFEL)
Some Applications ...

1) Based on the ultra short property of the electron bunch

Chemistry
Radiolysis
Some applications:

1) Based on the ultra short duration of the e-bunch:

\[
\text{H}_2\text{O} \quad \overset{\text{e}^-}{\longrightarrow} \quad \text{(e}^-, \text{OH}^-, \text{H}_2\text{O}_2, \text{H}_3\text{O}^+, \text{H}_2, \text{H}^+) 
\]

Very important for:
- Biology
- Ionising radiations effects

In collaboration with Y. Gauduel’s group
Recent results on Femtolysis:

Water radiolysis with femtosecond electron pulses

B. Brozek-Pluska et al., Radiation and Chemistry, 72, 149-159 (2005)
Some Applications ...

2) Based on the collimated property of the electron beam

Non destructive Material inspection

\( \gamma \) Radiography
Example of applications: on the spatial quality benefit
High resolution $\gamma$ radiography

2.5mm tantalum at 3mm of the nozzle center
Aluminium 7.5mm thick to scatter electrons
BGO screen at 1.6m from the nozzle, 600 $\mu$m pixels size
17cm magnet length (B of 0.1T)
20 mm diameter object in Tungsten, at 35cm of the nozzle

In collaboration with L. Le-Dain, S. Darbon from CEA Mourainviller and DAM
\( \gamma \)-radiography results

Higher resolution: of the order of 400 \( \mu \text{m} \)

Some Applications ...

X-rays: diffraction, medicine, \(\gamma\)-rays: radiography

Medicine
Radiotherapy
Proton-therapy
PET

Electrons and Protons
generated by
Laser-Plasma Interactions

Accelerator Physics

Chemistry
Radiolysis

LOA
A revolution is coming...one of the most evolving field in Science, a wonderful tool for academic formation.