Proposal of a photo-injector for CTF3

1. Previous results
2. CTF3 photo-injector specifications
3. Realization inside European Union program FP6
4. Remaining Laser and Photocathode work
5. Common developments RILIS-CTF3
6. Conclusion
A simple design of amplifier capable of high power and based on Nd:YLF has been constructed and tested. Its performance provided good verification for the analytical predictions for gain and efficiency, and the optical quality of the amplifier at high average power was assessed. The most promising aspect of this amplifier has been the measured output pulse stability. At 0.7% rms over 1 hour this already competes favourably with the best previous measurements on lasers and we know this can be improved using a more stable diode-laser power supply and improved coolant temperature stabiliser. Additional stabilisation is also achievable using a closed cycle feedback control system.
BUT

To be taken into account the photo-injector MUST also demonstrate the feasibility for CLIC

From CTF3 Review 2/10/2001

- On paper for the laser and with the today technology
  ⇒ This has been done : see CLIC Note 462

- As close as possible of the CLIC working point for the photocathode
  ⇒ This has been done : see CTF3 Note 020

↓

The photo-injector should be an option for CTF3 and CLIC

↓

see CLIC Note 487
Previous result: Feasibility of the photo-cathode

- Cs$_2$Te photocathode produced by co-evaporation on an RF conditioned copper plug cleaned by argon ion bombardment
- Demonstrated for all CTF3 parameters excepted the number of bunches (not possible to test)
- Minimal quantum efficiency: 3%
- Minimal lifetime: 1 week
- If the RF gun pressure is less than $2 \times 10^{-10}$ mbar with the full RF power
Previous result: Feasibility of the RF gun

No special issue to build the CTF3 RF gun

But

Special attention must be paid to the vacuum
CTF3 photo-injector specifications

<table>
<thead>
<tr>
<th>NOMINAL</th>
<th>OPTIONAL</th>
<th>Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Pulse train duration (1)</td>
<td>1.548</td>
<td>µs</td>
</tr>
<tr>
<td>Pulse train charge (1)</td>
<td>5434</td>
<td>nC</td>
</tr>
<tr>
<td>Average current in the pulse train</td>
<td>3.51</td>
<td>A</td>
</tr>
<tr>
<td>Number of bunches in the sub-pulse</td>
<td>212</td>
<td>106</td>
</tr>
<tr>
<td>Odd/even sub-pulse width (FWHH)</td>
<td>140.735</td>
<td>ns</td>
</tr>
<tr>
<td>Number of bunches in the pulse train (1-2)</td>
<td>2332</td>
<td>1166</td>
</tr>
<tr>
<td>Distance between bunches</td>
<td>0.667</td>
<td>1.334</td>
</tr>
<tr>
<td>Charge / bunch</td>
<td>2.33</td>
<td>3</td>
</tr>
<tr>
<td>Bunch width (FWHH)</td>
<td>10</td>
<td>10</td>
</tr>
<tr>
<td>ε_f normalized (rms)</td>
<td>≤ 25</td>
<td>π.mm.mrad</td>
</tr>
<tr>
<td>Δp/p (rms)</td>
<td>≤ 2</td>
<td>%</td>
</tr>
<tr>
<td>charge stability</td>
<td>≤ 0.25</td>
<td>%</td>
</tr>
<tr>
<td>Repetition rate</td>
<td>1 - 50</td>
<td>Hz</td>
</tr>
<tr>
<td>Mean current @ 50 Hz</td>
<td>271.68 mA</td>
<td></td>
</tr>
<tr>
<td>RF frequency</td>
<td>2.99855</td>
<td>GHz</td>
</tr>
<tr>
<td>RF power</td>
<td>≤ 30</td>
<td>MW</td>
</tr>
<tr>
<td>Beam energy</td>
<td>≥ 5</td>
<td>MeV</td>
</tr>
<tr>
<td>Beam current</td>
<td>3.51</td>
<td>A</td>
</tr>
<tr>
<td>Vacuum pressure @ nominal charge</td>
<td>≤ 2x10^{-10}</td>
<td>mbar</td>
</tr>
<tr>
<td>Cs2Te : QE</td>
<td>≥ 3</td>
<td>3</td>
</tr>
<tr>
<td>Wavelength</td>
<td>262</td>
<td>262</td>
</tr>
<tr>
<td>Lifetime</td>
<td>&gt; 40</td>
<td>working hours</td>
</tr>
<tr>
<td>UV energy / bunch @ the cathode</td>
<td>0.368</td>
<td>0.473</td>
</tr>
<tr>
<td>Beam radius - min @ the cathode</td>
<td>1</td>
<td>1.4</td>
</tr>
<tr>
<td>Beam radius - max @ the cathode</td>
<td>2</td>
<td>2.8</td>
</tr>
<tr>
<td>Energy stability @ the cathode (rms)</td>
<td>≤ 0.25</td>
<td>%</td>
</tr>
<tr>
<td>Pointing stability</td>
<td>≥ 0.5</td>
<td>mm</td>
</tr>
<tr>
<td>Odd/even sub-pulse width (FWHH)</td>
<td>140.74</td>
<td>ns</td>
</tr>
<tr>
<td>Odd-even sub-pulse rise/fall time (10%-90%)</td>
<td>2 - 30</td>
<td>ns - adjustable</td>
</tr>
<tr>
<td>IR-UV conversion efficiency</td>
<td>0.15</td>
<td></td>
</tr>
<tr>
<td>Safe margin</td>
<td>0.5</td>
<td></td>
</tr>
<tr>
<td>Laser beam transport transm.</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>Pulse shaping and coding transm.</td>
<td>0.7</td>
<td></td>
</tr>
<tr>
<td>UV cath. energy / Output IR energy</td>
<td>0.03675</td>
<td>0.03675</td>
</tr>
<tr>
<td>Output IR energy / bunch</td>
<td>≥ 10</td>
<td>13</td>
</tr>
<tr>
<td>Bunch width (FWHH)</td>
<td>≤ 10</td>
<td>10</td>
</tr>
<tr>
<td>Wavelength</td>
<td>1047 nm</td>
<td></td>
</tr>
<tr>
<td>Repetition rate</td>
<td>1 - 50</td>
<td>Hz</td>
</tr>
<tr>
<td>Timing jitter</td>
<td>± 1 ps</td>
<td></td>
</tr>
</tbody>
</table>

(1) With starting bunches

(2) The photo-injector must be able to produce only one electron pulse
Train production

Time structure generation of the CTF3 Drive Beam Photoinjector

RF = 2.99855 GHz

Delay of 1 rf period and recombination

Starting sub-pulse

Even sub-pulse
212 bunches : 140.74 ns

Second splitting

Odd sub-pulse
212 bunches : 140.74 ns

I = Laser bunch intensity

2xI

1.334 ns

2120 bunches + starting bunches

2xI

First splitting

Starting bunches

53 bunches

Two train generation

Pulse shaping: T = starting sub-pulse + 5 odd sub-pulse + 5 even sub-pulse = 1.548 µs

2120 bunches + starting bunches

PC Driver

4xI

1.334 ns

2xI

106 bunches

I

333 ps

667 ps

1 ns

333 ps

I

RF = 2.99855 GHz

Train production
CTF3 photo-injector synoptic

Master oscillator
\( \lambda = 1047\,\text{nm} \)
\( f = 375\,\text{MHz} \)
\( P = 1\,\text{W} \)
\( W/\mu\text{Pulse} = 2.7\,\text{nJ} \)

Pre-amplifier
\( \lambda = 1047\,\text{nm} \)
\( P_{\text{OCW}} = 50\,\text{W} \)
\( W/\mu\text{Pulse} = 133\,\text{nJ} \)

Time interval division
\( \Delta t = 0.667\,\text{ns} \)

Phase coding

3 GHz RF source
3 GHz

KLYSTRON
3 GHz - 30 MW

RF Network

Laser Beam Line
0.37\( \mu \text{J/\mu Pulse} \)
2310\( \mu \text{Pulses} \)

Cs2Te cath
\( \text{QE} = 3\% \)

Transport carrier

Total efficiency
\( \text{IR}_{\text{OUT}} \Rightarrow \text{UV}_{\text{cath}} = 3.6\% \)

Power Amplifier
\( W_{\text{train}} = 1.6\,\text{J} ; P_{\text{train}} = 16\,\text{kW} \)
\( \lambda = 1047\,\text{nm} \)
10.3\( \mu \text{J/\mu Pulse} \)
Pulse width \( \leq 10\,\text{ps} \)
Pulse duration = 100\,\mu\text{s} 

Freq. X 4
\( \lambda = 262\,\text{nm} \)

Photocathode preparation chamber

Under the responsibility of CLF-RAL

Under the responsibility of LAL-Orsay

Under the responsibility of CERN

In collaboration with RAL

Electron Beam
2.33\,\text{nc/\mu Pulse}
Title: Charge production with Photo-injectors

Acronym: PHIN  Coordinator: A. Ghigo (INFN-LNF)

Main Objectives: Perform Research and Development on charge-production by interaction of laser pulse with material within RF field and improve or extend the existing infrastructures in order to fulfill the objectives. Coordinate the efforts done at various Institutes on the photo-injectors.

<table>
<thead>
<tr>
<th>Total Expected Budget</th>
<th>Requested EU Funding</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 M€ (FC) + 2.5 M€ (AC) Total = 5.5 M€</td>
<td>4.0 M€</td>
</tr>
</tbody>
</table>

One objective is to develop built and install the CTF3 photo-injector in a time scale of 2.5 years and for a requested budget of 1240 k€

Web site: http://esgard.lal.in2p3.fr/
<table>
<thead>
<tr>
<th>Institute</th>
<th>Acronym</th>
<th>Country</th>
<th>Coordinator</th>
<th>PHIN Scientific Contact</th>
<th>Associated to</th>
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<tbody>
<tr>
<td>CCLRC Rutheford Appletone Lab. (22)</td>
<td>CCRLC-RAL</td>
<td>UK</td>
<td>P. Norton</td>
<td>I.N. Ross</td>
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<td>CERN Geneva (19)</td>
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<td>CH</td>
<td>H. Haseroth</td>
<td>G. Suberlucq</td>
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<tr>
<td>CNRS-IN2P3 Orsay (3)</td>
<td>CNRS-Orsay</td>
<td>F</td>
<td>T. Garvey</td>
<td>G. Bienvenu</td>
<td>CNRS</td>
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<tr>
<td>CNRS Lab. Optique Appl. Palaiseau (3)</td>
<td>CNRS-LOA</td>
<td>F</td>
<td>T. Garvey</td>
<td>V. Malka</td>
<td>CNRS</td>
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<tr>
<td>ForschungsZentrum ELBE (10)</td>
<td>FZR-ELBE</td>
<td>D</td>
<td>J. Teichert</td>
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<tr>
<td>INFN-Lab. Nazionali di Frascati (11)</td>
<td>INFN-LNF</td>
<td>I</td>
<td>S. Guiducci</td>
<td>A. Ghigo</td>
<td>INFN</td>
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<td>INFN- Milan (11)</td>
<td>INFN-MI</td>
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<td>S. Guiducci</td>
<td>I. Boscolo</td>
<td>INFN</td>
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<tr>
<td>Twente University- Enschede (13)</td>
<td>TEU</td>
<td>NL</td>
<td>A. den Ouden</td>
<td>J. Verschuur</td>
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</tbody>
</table>
# JRA 3 organization

- **Coordinator**: A. Ghigo (INFN-LNF)
- **Deputy**: L. Rinolfi (CERN)

<table>
<thead>
<tr>
<th>Work Package</th>
<th>Full name</th>
<th>Short name</th>
<th>Coordinator</th>
<th>Laboratory</th>
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<tbody>
<tr>
<td>WP1</td>
<td>Management and Communication</td>
<td>M&amp;C</td>
<td>A. Ghigo</td>
<td>INFN-LNF</td>
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<tr>
<td>WP2</td>
<td>Charge Production</td>
<td>CP</td>
<td>J. Teichert</td>
<td>FRZ-ELBE</td>
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<tr>
<td>WP3</td>
<td>Lasers</td>
<td>LAS</td>
<td>I. Ross</td>
<td>CCRLC-RAL</td>
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<tr>
<td>WP4</td>
<td>RF Guns and Beam Dynamics</td>
<td>GUN</td>
<td>G. Bienvenu</td>
<td>CNRS-LAL</td>
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## CTF3 photo-injector Milestones

<table>
<thead>
<tr>
<th>No</th>
<th>Date</th>
<th>Tasks or sub-tasks to be completed by milestone date</th>
<th>Task number</th>
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<tbody>
<tr>
<td>1</td>
<td>30/06/2004</td>
<td>Report on photocathode studies</td>
<td>2.1</td>
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<td>Report on laser oscillator design</td>
<td>3.1.1</td>
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<td>01/12/2004</td>
<td>Report on 3 GHz RF gun design</td>
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<td>Laser oscillator test results</td>
<td>3.1.1</td>
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<td>3</td>
<td>31/03/2005</td>
<td>Report on laser amplifier design</td>
<td>3.1.2</td>
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<td>Report on UV conversion crystal comparison</td>
<td>3.1.4</td>
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<td>5</td>
<td>30/09/2005</td>
<td>Amplifier test results</td>
<td>3.1.3</td>
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<td></td>
<td>3 GHz RF gun test result and delivery to CERN</td>
<td>4.2.3</td>
</tr>
<tr>
<td>7</td>
<td>31/03/2006</td>
<td>Laser system test results and delivery at CERN</td>
<td>3.1.5</td>
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<tr>
<td>9</td>
<td>01/12/2006</td>
<td>Report on 3 GHz RF gun commissioning at CERN</td>
<td>4.2.3</td>
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<tr>
<td></td>
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<td>Report on new photocathode materials tests</td>
<td>2.1</td>
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</table>
Resources

- Requested E.U. funding by work package and over JRA duration for the CTF3 photo-injector (k€)

<table>
<thead>
<tr>
<th>WP1 : M&amp;C</th>
<th>WP2 : CP</th>
<th>WP3 : LAS</th>
<th>WP4 : GUN</th>
<th>TOTAL</th>
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<tbody>
<tr>
<td>15</td>
<td>55</td>
<td>970</td>
<td>200</td>
<td>1240</td>
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<table>
<thead>
<tr>
<th>2004</th>
<th>2005</th>
<th>2006</th>
<th>2007</th>
<th>Total</th>
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<tr>
<td>518</td>
<td>518</td>
<td>208</td>
<td>6</td>
<td>1240</td>
</tr>
</tbody>
</table>

- During the same period the CERN contribution to the Photo-injector (included commissioning) will be: 1370 k€
  - Material: 170 k€
  - Personnel: 1200 k€
  - Civil engineering is not included

E.U. decision in October 2003
Remaining Laser and Photocathode work

- Acquisition of knowledge in Diode Pumped Solid State Laser (DPSSL)
- Pockel’s cell study and train manipulation
- Harmonic conversion efficiency study
- Laser monitoring
- Feedback control, amplitude regulation
- Automatic control of the laser beam position
- Maintenance of preparation chambers both for probe and drive beam
RILIS: principle and general set-up

Main features of RILIS:
- Isobar and isomer selectivity
- Ionization efficiency: 2 - 27%
- Feasibility for 80% of chemical elements

RILIS IN 2002:
- 1787 working hours
- 12 ionized elements
- 20 experiments

RILIS ion beams:
Be, Mg, Al, Ca, Sc, Mn, Co, Ni, Cu, Zn, Ga, Y, Ag, Cd, In, Sn, Sb, Tb, Tm, Yb, Tl, Pb, Bi
RILIS: Automatic Laser Beam Position Control project

Copper Vapor Laser System
- CV-Laser 3 (Oscillator)
- CV-Laser 2 (Amplifier)
- CV-Laser 1 (Amplifier)

Dye Laser System
- Dye-Laser 3 (optional)
- Dye-Laser 2
- Dye-Laser 1

Remote Controlled Mirror Mounts

Digital Scope
- CUADLA
- DLA
- Diffraction Grating

Fast Photodiodes
- PD1-PD15 inputs

Dye laser control:
- a) Local
- b) Remote via RS232

Multichannel Power Monitor

PLC

Picomotor Driver

LINUX PC

Frame-grabber

CCD Cameras

Digital Scope

CCD Cameras

Fast Photodiodes (to the Digital Scope)

Diffraction Grating

Dye-Laser 2

Dye-Laser 1

Multichannel Power Monitor

PLC

Picomotor Driver

Remote Controlled Mirror Mounts

Dye laser control:
a) Local
b) Remote via RS232

Windows PC

Lambdameter

Fiber switch

BBO

Dye-Laser 2

Dye-Laser 3 (optional)

Remote Controlled Mirror Mounts

Dye-Laser 1

Dye-Laser 3 (optional)

Remote Controlled Mirror Mounts

Dye-Laser 2

Dye-Laser 1

Dye-Laser 3 (optional)
Common developments RILIS-CTF3

- Acquisition of knowledge DPSSL – some material exist
- Laser monitoring – material exist – in progress for RILIS
- Automatic control of the laser beam position – material exist - in progress for RILIS
- Harmonic conversion efficiency study – material exist
Conclusion

- The CTF3 photo-injector is feasible
- A suitable parameter list is proposed
- Realization in collaboration with CNRS-LAL and CCLRC-RAL
- Inside well define resources and schedule
- Could be in the CARE E.U. framework
- Possible synergy with RILIS for the CERN part