Conception of photo-injectors
for the CTF3 experiment

R. Roux

Team: G. Bienvenu, M. Bernard, B. Jacquemard, B. Mouton, J. Prevost
M. Desmons, B. Mercier, C. Prevost, R. Roux, J. Brossard
1. Introduction

2. Drive Beam photo-injector (financed by CARE, JRA PHIN)
   - RF simulations
   - Beam dynamic simulations

3. Probe beam photo-injector

4. Conclusion
Introduction

- Past: two 1.5 cells photo-injectors built, CANDELA in 1987, ELYSE in 2002

- Now: one 2.5 cells RF gun αX for Strathclyde University
fabrication: J. Rodier

Two 2.5 cells RF gun for the CLIC-Test-Facility 3 at CERN: valid the concepts of the
CLIC linear collider
### Drive beam specifications

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>HF frequency (GHZ)</td>
<td>2.99855</td>
</tr>
<tr>
<td>HF Power (MW)</td>
<td>30</td>
</tr>
<tr>
<td>Beam energy (MeV)</td>
<td>5 – 6</td>
</tr>
<tr>
<td>Beam current (A)</td>
<td>3.51</td>
</tr>
<tr>
<td>Charge/bunch (nC)</td>
<td>2.33</td>
</tr>
<tr>
<td>Macro-pulse duration (µs)</td>
<td>1.548</td>
</tr>
<tr>
<td>total extracted Charge (µC)</td>
<td>5.43</td>
</tr>
<tr>
<td>Bunch length FWHM (ps)</td>
<td>10</td>
</tr>
<tr>
<td>Energy spread rms (%)</td>
<td>&lt; 2</td>
</tr>
<tr>
<td>normalised emittance (πmmmrad)</td>
<td>&lt; 25</td>
</tr>
<tr>
<td>Residual pressure (mbar)</td>
<td>2.10^{-10}</td>
</tr>
</tbody>
</table>

1. Gun type 4 used in CTF2 as a start point
2. Symmetrical coupling taking into account beamloading
3. No tuners
4. Coils for emittance compensation
5. Improve the vacuum: critical issue

**Worrying!**
2D HF simulation: Superfish

Angle of the wall
⇒ Emittance slightly improved
For I = 5 A

$F_r = 3.003$ GHz
$R_s = 6$ MΩ
$Q = 14530$
Beam loading and coupling

\[ V_{\text{ind}}(t) = V_{\text{sat}} \left(1 - \exp\left(-\frac{t}{\tau}\right)\right) \]

\[ V_{\text{sat}} = \frac{R_s T^2 I_{\text{harm}}}{(1 + \beta)} \]

\[ \tau = \frac{2Q_c}{\omega_r} \]

\[ Q_c = \frac{Q_0}{1 + \beta_1 + \beta_2} \]

\[ \beta = \frac{\beta_0}{1 + \beta_{\text{beam}}} \quad \text{with} \quad \beta_{\text{beam}} = \frac{P_{\text{beam}}}{P_{\text{cav}}} \]

\[ \beta = 2.9 \quad \text{to match the gun in presence of the beam} \]

\[ P_{\text{beam}} = 3.51 \, \text{A} \times 5.5 \, \text{MV} = 19.3 \, \text{MW} \]

\[ P_{\text{cav}} \approx 10 \, \text{MW for 85 MV/m} \]

\[ P_{\text{RF}} = 30 \, \text{MW} \]
3D HF simulations: HFSS

Coils

Hole coupling:
- overcoupled
- symmetrical

Dimensions of the cells and of the coupling hole

3 conditions:
- $F_r$
- Coupling
- Field equilibrium

Coaxial coupling
Possible but:
Antenna goes deeply into the gun
+ strong gradient
=> Breakdown hazards
Results of the HFSS simulations

$E_z [\text{MV/m}]$

160
140
120
100
80
60
40
20
0

$E_z$ (arb. uni.)

10
8
6
4
2
0

$z \text{ (cm)}$

1.0
0.9
0.8
0.7
0.6
0.5

$S_{11}$

0.9
0.8
0.7
0.6
0.5

$f \text{ (GHz)}$

3.000
3.001
3.002
3.003
3.004

$S_{11} = 0.486$

$\beta = 2.9$

$\Delta f = 640 \text{ kHz}$

$R_{1/2} = 43.9 \text{ mm} \quad R_1 = 44.7 \text{ mm} \quad R_2 = 43.6 \text{ mm} \quad \text{coupling hole: } 25 \times 10 \text{ mm}$

Field Asymmetry

In the coupling cell
Dynamic of the electron beam

Electric field
From Superfish

PARMELA

I = 3.51 A

<table>
<thead>
<tr>
<th>$\sigma_{\text{laser}}$ (mm)</th>
<th>0.6</th>
<th>0.8</th>
<th>1</th>
<th>1.4</th>
<th>2.8</th>
</tr>
</thead>
<tbody>
<tr>
<td>Particle loss (%)</td>
<td>1</td>
<td>0.3</td>
<td>0.3</td>
<td>0</td>
<td>0</td>
</tr>
<tr>
<td>$\varepsilon_x$ (\text{\pi} \text{mmrad})</td>
<td>13.</td>
<td>16</td>
<td>17.6</td>
<td>19.6</td>
<td>21.</td>
</tr>
<tr>
<td>$\sigma_z$ (ps)</td>
<td>-</td>
<td>9.6</td>
<td>9</td>
<td>8.4</td>
<td>7.9</td>
</tr>
<tr>
<td>$\sigma_\gamma/\gamma$ (%)</td>
<td>0.5</td>
<td>0.4</td>
<td>0.4</td>
<td>0.36</td>
<td>0.4</td>
</tr>
</tbody>
</table>

But increase continuously due to Space charge forces

$\Phi_{\text{opt}} = 35 ^\circ$

$E_{\text{RF}} = 85 \text{ MV/m}$ set by beamloading!
Compensation of the emittance growth due to space charge

Optimum: Coils on the gun
Influence of the laser profile’s shape

Start point, gaussians: $\sigma_z = 3.56 \text{ ps}$, $\sigma_\gamma/\gamma = 0.36 \%$, $\varepsilon_x = 19.6 \, \text{\textmu mrad}$, $\varepsilon_y = 20.7 \, \text{\textmu mrad}$

transversally flat, longitudinal profile is gaussian

\[ \varepsilon_x = 14 \, \text{\textmu mrad} \]
\[ \varepsilon_y = 14.2 \, \text{\textmu mrad} \]
\[ \sigma_z = 3.7 \, \text{ps} \]
\[ \sigma_\gamma/\gamma = 0.36 \% \]

All profiles are flat

\[ \varepsilon_x = 10.8 \, \text{\textmu mrad} \]
\[ \varepsilon_y = 10.9 \, \text{\textmu mrad} \]
\[ \sigma_z = 4.6 \, \text{ps} \]
\[ \sigma_\gamma/\gamma = 0.5 \% \]
Vacuum

Monte-Carlo based Simulations of the residual pressure

Weak conductance \(\Rightarrow \sim 2.10^{-9}\) mbar not satisfying!

Solutions: NEG pumping + high \(t^\circ\) treatment

42 holes, \(\phi = 4\) mm,
NEG coated envelop around the gun

Baking at \(500^\circ\text{C} \Rightarrow P < 10^{-10}\)
Probe beam photo-injector

Specifications are the same as for the drive beam except:
- charge/bunch = 0.5 nC
- bunches 1-64 => No beamloading

Constraints less severe  Simplified design

\[ Q = 14400, \, R_s = 7.84 \, \text{MW} \Rightarrow P_{HF} = 5.2 \, \text{MW} \]
for 80 MV/m

\[ 6.5 \varepsilon (\pi \text{mmrad}) \]
\[ 0.33 \sigma_{\gamma} / \gamma \text{rms} (\%) \]
\[ 5.35 \text{FWHM}_z (\text{ps}) \]
\[ 2.33 \sigma_r (\text{mm}) \]
\[ \sim 10^{-10} \text{ mbar in the gun} \]

<table>
<thead>
<tr>
<th>E (MeV)</th>
<th>5.35</th>
</tr>
</thead>
<tbody>
<tr>
<td>( \sigma_r ) (mm)</td>
<td>2.33</td>
</tr>
<tr>
<td>FWHM(_z) (ps)</td>
<td>8</td>
</tr>
<tr>
<td>( \sigma_{\gamma} / \gamma ) rms (%)</td>
<td>0.33</td>
</tr>
<tr>
<td>( \varepsilon ) (\pi \text{mmrad})</td>
<td>6.5</td>
</tr>
</tbody>
</table>
1) Drive beam photo-injector

Prototype is due to be delivered very soon, the RF gun fully equipped should be installed in the CTF3 drive beam linac before summer 2006.

2) Probe beam photo-injector

- HF simulations almost finished
- Electron beam simulations are still under way
- Technical drawings should be ready by the end of the year
- Call for tenders in January 2006
- Delivery in the beginning of 2007