COMMISSIONING OF THE SPARC PHOTO-INJECTOR

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Authors: SPARC team @ INFN
PRESENTATION OVERVIEW

- INTRODUCTION
  - Sparc project
  - installation status
  - laser system
  - SPARC hall

- LASER SYSTEM CHARACTERIZATION
  - longitudinal measurements
  - transverse uniformity & QE
  - tilt correction
  - Laser synchronization

- e- BEAM CHARACTERIZATION
  - diagnostic description
  - longitudinal charact.
  - transverse charact.
  - best results and future plans
### SPARC parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electron Beam Energy (MeV)</td>
<td>155</td>
</tr>
<tr>
<td><strong>Bunch charge (nC)</strong></td>
<td>1.1</td>
</tr>
<tr>
<td>Repetition rate (Hz)</td>
<td>1-10</td>
</tr>
<tr>
<td>Cathode peak field (MV/m)</td>
<td>120</td>
</tr>
<tr>
<td>Peak solenoid field @ 0.19 m (T)</td>
<td>0.273</td>
</tr>
<tr>
<td><strong>Photocathode spot size (mm, hard edge radius)</strong></td>
<td>1.13</td>
</tr>
<tr>
<td>Central RF launch phase (RF deg)</td>
<td>33</td>
</tr>
<tr>
<td>Laser pulse duration, flat top (ps)</td>
<td>10</td>
</tr>
<tr>
<td>Laser pulse rise time (ps) 10%→90%</td>
<td>1</td>
</tr>
<tr>
<td>Bunch energy @ gun exit (MeV)</td>
<td>5.6</td>
</tr>
<tr>
<td><strong>Bunch peak current @ linac exit (A) (50% beam fraction)</strong></td>
<td>100</td>
</tr>
<tr>
<td><strong>Rms normalized transverse emittance @ linac exit (mm-mrad); includes thermal comp. (0.3)</strong></td>
<td>&lt; 2</td>
</tr>
<tr>
<td><strong>Rms slice norm. emittance (300 μm slice)</strong></td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Rms longitudinal emittance (deg keV)</td>
<td>1000</td>
</tr>
<tr>
<td><strong>Rms total correlated energy spread (%)</strong></td>
<td>0.2</td>
</tr>
<tr>
<td><strong>Rms uncorrelated energy spread (%)</strong></td>
<td>0.06</td>
</tr>
<tr>
<td>Rms beam spot size @ linac exit (mm)</td>
<td>0.4</td>
</tr>
<tr>
<td>Rms bunch length @ linac exit (mm)</td>
<td>1</td>
</tr>
</tbody>
</table>

\[ B_\perp = 100 \, \frac{A}{\mu m^2} \]
**Sparc Ti:Sa laser system**
Modulators and klystrons

Present situation:

- Klystron, waveguides and gun conditioning ended
- 120 MV/m in the gun, 10 Hz
- E = 5.5MeV e-beam
Sparc hall
Sparc hall

Faraday cup
Sparc hall
Sparc hall

Spectrometer Magnets cross
Sparc hall

Beam BCM
dump
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LASER SYSTEM
- longitudinal measurements
- transverse uniformity & QE
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- Laser synchronization

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Longitudinal diagnostic

- 0.02 nm resolution spectrometer
- 200 fs resolution UV xcorrelator
Longitudinal diagnostic

0.02 nm resolution spectrometer

30 cm lens

4350 g/mm grating

CCD

UV beam

200 fs resolution UV xcorrelator

SPARC
Longitudinal diagnostic

With longitudinal pulse shaping, but not optimized
QE & transverse uniformity

- In order to have uniform density beam charge distribution a uniform QE and a uniform transv. profile are needed.
- QE map done by scanning cathode surface with a small beam (100 um) and looking at the charge on the faraday cup.
- Red zone is the higher QE zone, and it’s also the actual working point, so cathode has been cleaned during operations.
- To run at higher charge we need bigger laser spot sizes.
- Lot of work has been done on transverse laser uniformity.
- Charge is variable (min=50pC, max=1.5nC)

\[
QE = 7 \times 10^{-5}
\]

LASER CLEANING

0.3X0.26 mm rms
Two unwanted effects:
- elliptical spot on the cathode
- Time skew

- 72 deg tilted wavefront after grating
- Lens to image the beam @ grating exit to cathode

ZEEMAX simulation

2:1 telescope
3600 g/mm grating
M = mirror
laser port
Streak camera
Synchronization

On time scale of few minutes (enough to see possible drifts) the phase jitter is within $\sigma_{\text{RMS}}$ 0.63 deg 0.61 ps.
Present situation

- Energy ok
- Gaussian transverse and longitudinal profile (dazzler in autocompensation mode)
- Tilt compensation works but critical

Future plans

- Laser cleaning
- Longitudinal pulse shaping
- Transverse homogenization
- 0 deg incidence?
Present situation

• laser cleaning
• longitudinal pulse shaping
• transverse homogenization
• 0 deg incidence?
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Diagnostic overview

- 60 cm: faraday cup to measure the charge at gun exit, and Cromox screen to see and center the beam;
- 85-200 cm: E-meter (slits cross, Yag and CCD cross): Emittance, beam envelope, beam parameters as function of transv. coordinates;
- 220 cm: aerogel + streak camera; beam duration;
- 250-280 cm: FODO: \{ prepares the beam to E & ΔE meas.
- 300 cm: dipole;
- 330 cm: spectrometer cross (Yag+ CCD): E & ΔE meas.
- 350 cm: BCM (beam charge)
Longitudinal e-beam characterization

120MV/m

Streak image of Cherenkov Light coming from aerogel

T=12 ps
E dependencies on Q

Possible Causes
- Longitudinal wakefields due to the bellows
- Longitudinal space charge
- Image charge on cathode

Q = 200 pC
Fixed phase

Low charge 200 pC
High charge from 400 to 1000 pC
E dependencies on Q

POSSIBLE CAUSES
• longitudinal wakefields due to the bellows
• longitudinal space charge
• image charge on cathode

Q=840 pC, Fixed phase

Low charge 200pC
High charge from 400 to 1000pC
Reducing the charge by cutting the central part of the beam with 50 μm slit, lets the beam after the cut propagate without longitudinal SP and WF anymore.

One can say that the energy spread freezes after cut.

Energy spread Vs Z

![Graph showing energy spread vs Z]

- data
- linear fit of data

whole beam at spectrometer

bellows end
Transverse emittance measurements

HBUNCH.OUT

emittance

envelope
Measuring the emittance

\[ \varepsilon_n = \langle \gamma \rangle \sqrt{\langle x^2 \rangle \langle x'^2 \rangle - \langle xx' \rangle^2} \]

where \( \varepsilon_n \) is the normalized emittance, \( \gamma \) is the relativistic factor, and \( x \) and \( x' \) are the transverse coordinates.
Sampling the beam

Multislits
Comparison:

- Measure with both single slits and multi slits
- Multi slits is a single shot measure, single slit gives more sampling points
- Excellent agreement between single slit and multi slits.
- Multi slit not so good with convergent and too small beams (fixed distance between slits)

- Excellent the agreement between the measured (with a screen) RMS beam size and the estimated from $\sqrt{\beta \varepsilon}$
Transverse phase space

Two beam envelopes
With same solenoid current
But different beam charge

We are able to measure
Beam envelopes without
Stopping E--meter
Transverse phase space

We are able to measure beam envelopes without stopping E--meter.

Two beam envelopes with same solenoid current but different beam charge.

- X envelope
- Y envelope
Emittance behavior along z

Sol 125 A
Q=200 pC
“low charge” data

No direct emitt. Scaling with Q; increase charge just increasing electron density (laser energy);
Linear fit just “for show”
With single slit method, phase space reconstruction is possible; Using E-meter one can investigate its evolution.
Simulations

Elliptical input beam

emittances_elliptical beam

Thanks to Titti Ronsivalle
Conclusions & future plans

• **Best achieved results**
  – 2.1 mm-mrad @ 700 pC, 10 ps
  – 0.7 mm-mrad @ 160 pC, 10 ps
• More work on laser beam
• Understanding dipole and quadrupole components in solenoid (mask, different fields in each coil and different configurations,…)
• high charge (up to 1.1 nC) emittance measurements
• Comparison with simulation ongoing (next step real transverse and longitudinal profile)
• Main linac installation scheduled to start in the summer