Photoinjector Laser Operation and Cathode Performance

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- Laser operational experience
- Laser beam properties
- Cathode performances
- Outlook
TTF and VUV-FEL Injector

- Upgrade of injector II (Ph. Piot et al)
- Booster with 4 SC cavities + 4 to further accelerate
- 3rd harmonic cavity to straighten out the RF banana
- Laser with longitudinal flat-hat profile
- Commissioning up to ACC2

- operated all 8 cavities at 12 MV/m
  -> 100 MeV
- 3rd harmonic cavity not yet installed
- Laser with longitudinal gaussian profile
- Commissioning up to ACC2

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Laser Upgrade

Together with Max-Born-Institute, Berlin (I. Will et al.). Upgrade has been tested at PITZ.

Pulse shaper not available yet, since it requires frequent tuning using an on-line streak camera.
Laser Beam Transport Line

- Laser
- Tunnel wall
- Vacuum window (fused quartz)
- Iris aperture (x, y, θ, ϕ)
- Dielectric mirror with Al back coating
- Fluorescent crystal (Ce:YAG)
- RF gun
- Virtual cathode
- Imaging of the beam profile at the laser (doubling crystals) onto the cathode with a magnification of 5
- Stepper motors, fine adjustment with truly x, y moving mirrors, iris movable x, y and radius
- Scintillating cathode for alignment

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DOOCS Laser Control Panels

- remote adjustment of the laser parameters
- Beam line elements (lenses, mirrors and iris) fully controllable from DOOCS panel
Beam in the straight section (3GUN)

without steering

on scintillating cathode

with darkcurrent ring (bucking = 50 A)

with steering

Scintillating cathode and darkcurrent ring used to initially center laser beam on cathode

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Charge Measurement

- With Faraday cups or toroids
- FCup close to T1 reads about 20% less charge than T1
- Charge jitter measured with the toroids about 1% rms

Toroid signals of a single bunch and of a bunch train (30 bunches, 1 MHz)

Correlation between the toroids T1, T2, and T3

RMS = 0.014 nC

Charge distribution measured with T2 over 1000 shots

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Phase Scans

Fit used to set the phase in a reproducible way: ± 1.3 deg (rms)

Several scan in a row:

1 deg
Phase vs Master RF

Measurement of laser phase in respect to the master RF started (Simrock et al) but no conclusion yet.

From the phase scans we know that the phase reproducibility shot-to-shot of the first few bunches is smaller than 1.3 deg.

From measurements at MBI and PITZ the phase is stable within 0.5 ps and its drift over 800 bunches is less than 2 ps.

A new quartz rod in the PTO with an even better stability will be installed soon.
Transverse bunch Size and Shape

The transverse shape of the UV laser beam has been measured using a Ce:YAG (thanks to Hasylab) to convert the UV into visible radiation. The laser beam size at the exit of the laser is smaller than expected and has a Gaussian shape and is slightly elliptical: $\sigma_x = 0.18$ mm, $\sigma_y = 0.23$ mm.

In consequence, the designed magnification of 5 gives 0.9 x 1.1 mm at the cathode (measured: $\sigma_x = 0.9$ x $\sigma_y = 1.0$ mm).
Effect of the Iris

For convenience, the iris is not placed in an image point, thus interference fringes are not avoidable.

We expected to have a beam size of 3 mm diameter with an iris diameter of 3.5 mm. However, we measured a larger reduction of 0.75 yielding 2.6 mm.

The pictures show the shape a week after the shutdown - the beam may have been misaligned already during the end of the run.

\[
\begin{align*}
\sigma_x &= 0.74 \text{ mm} \\
\sigma_y &= 0.65 \text{ mm} \\
\text{(PITZ 0.6 mm)}
\end{align*}
\]

\[
\begin{align*}
f\text{whh} &= 2.2 \text{ mm} \\
f\text{whh} &= 1.4 \text{ mm}
\end{align*}
\]
Bunch Length and Shape

The bunch length has been measured with the streak camera (FESCA 200)

Average over 50 measurements gives $\sigma_L = 4.4 \pm 0.1$ ps as expected

Pulse stacker is available to stack 2 or 4 pulses

Pulse shaper still not stable enough
Example of stacked longitudinal profile

measured with a streak camera

Fits:
1. four gaussians, \( \sigma \) same for all 4
2. flat hat
   \( \sigma \) and intensities are the for same for all

Ideal profile:
- distance of pulses = 2.25 \( \sigma \)
- \( \sigma = 7 \) ps

Results:
- from flat hat fit:
  - rise time = 14.8 ps
  - flat top width = 23 ps
- from multiple gauss fit (same sigma for each gauss):
  - rise time = 14.2 ps
  - flat top width = 27 ps
Quantum Efficiency

Charge at T1 measured for various laser energies and RF power in the gun (laser $\phi = 3$ mm)
QE is astonishingly high $\Rightarrow$ we must have a good vacuum!!!!
Reconfirmation of the laser energy measurement required (TTF1 we usually measured 0.5 %)

On-line QE monitoring after first insertion

Drop in QE due to vacuum conditions in the gun during operation, stabilization with a slight increase

$\text{QE} \, (\%) = 0.47 \times \frac{Q(nC)}{E(\mu J)}$

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DC Quantum Efficiency @ DESY

QE measured with a Hg-lamp at different wavelengths
QE value extrapolated at 262 nm

- 2.9% for 42.2 nm
- 6.8% for 37.2 nm

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NEW Cathode DB Interface

http://www.lasa.mi.infn.it/ttfcathodes

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<td>Long 2</td>
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Post Transportation Cathode Analysis

QE maps

Cathode Views

After Production

Back at LASA after 3 years
Never used in the gun

21.2

22.2

After Air Exposure
Zoomed View

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Cs$_2$Te Thermal Emittance

**4th harmonic ($\lambda = 264$ nm)**

$\varepsilon_{th} = 0.5 \pm 0.1$ mm mrad
for 1 mm rms spot radius

The spectrum of the photoemitted electrons at the 4th harmonic has an electron count maximum at 0.5 eV, whereas at the 5th harmonic it has a maximum at 0.9 eV.

The position of this maximum is related to the possible electron transitions and their probabilities in the material after laser excitation.

Assuming that the thermal emittance scales as the square root of the most probable energy, the ratio between the estimated thermal emittances at the 4th and 5th harmonic varies according to this simple scaling.

**5th harmonic ($\lambda = 211$ nm)**

$\varepsilon_{th} = 0.7 \pm 0.1$ mm mrad
for 1 mm rms spot radius

Presented at EPAC '04 – MOPKFO45
Reliability and other Issues

Just a list of common problems with the laser system during the run:

• Frequent problems with the cpu/VME crate which controls the laser system
• Two times flashlamps had to replaced (life time of flashlamps between $10^7$ and $10^8$ shots = 23 to 230 days at 5 Hz)
• TTF1 laser rod leaked after 7 years, complete head replaced
• Pump diodes stopped two or three times with overload → reset
• No pulse train security yet (short gun RF pulse length secured short pulse trains)
• ‘Virtual cathode’ has not been available, only at end of run
• transverse laser beam spot not satisfactory

😊 No cooling water problem so far
Running time

RF Gun:
- 21-Feb-2004: start conditioning
- 6-Mar-2004: 5 Hz, 900 us, 3 MW
- 16-Mar-2004: 10 Hz, 450 us, 3 MW
- 17-Mar-2004: first beam in gun section

Injector:
- 15-Apr-2004: start injector commissioning
- 7-Jun-2004: end commissioning

Laser:
- Running for about 80 days (2000 h) with 5 Hz → 3.5 × 10^7 possible shots, we actually counted 1.7 × 10^7 (about 50% beam)
Laser Performances

😊 Laser upgrade finished mid February
RF gun start-up smoothly
First beam 16-Mar-2004

😊 Upgraded laser was running with 5 Hz and did 1.7 $10^7$ shots

😊 Laser pulse
  • Longitudinal gaussian with 4.4±0.1 ps sigma
  • Transverse neither gaussian nor flat, diameter smaller than expected
    $\sigma_x = 0.74$ mm, $\sigma_y = 0.65$ mm, fwhh = 2.2 mm - requires improvement
  • Phase measurements in respect to master RF started

😊 Pulse stacker not tried out yet
Virtual cathode now ready to be installed
Mirror inside the vacuum has been replaced by an all metal Al mirror
to avoid charging up
Future Plans

😊 Pockells Cell controller for BIS and BIC hopefully in September
😊 One flashlamp pumped amplifier replaced with a diode version
😊 Integrate longitudinal pulse shaper when operation at PITZ stable
😊 Long pulse train amplitude feedback installation
😊 Second laser system as back-up
Pulse Stacker

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