First Commissioning Experience at the SwissFEL Injector Test Facility

SwissFEL

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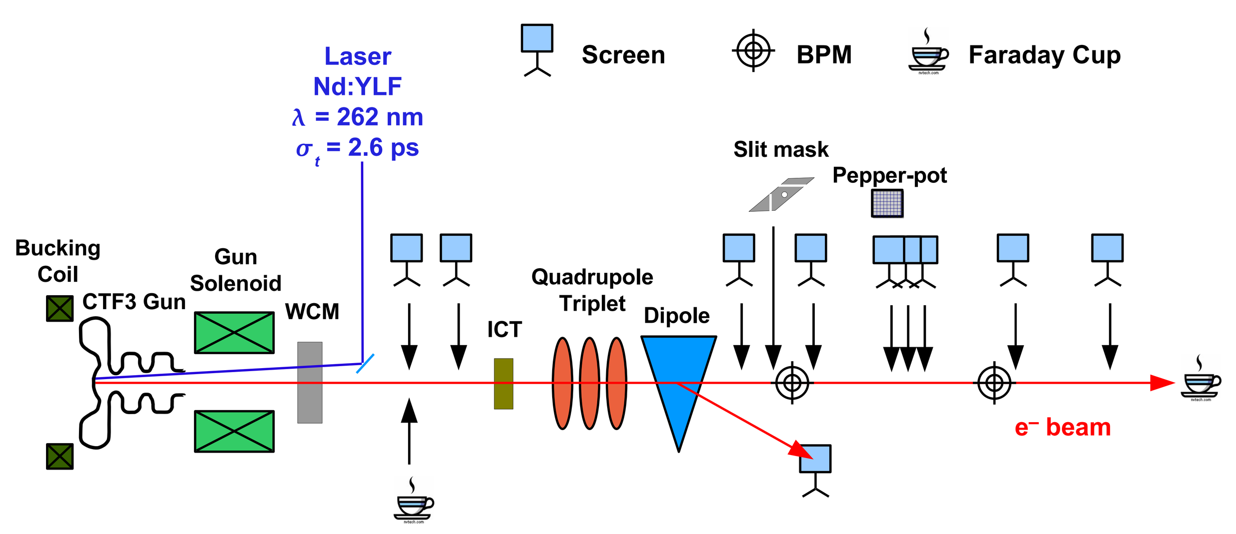
Abstract

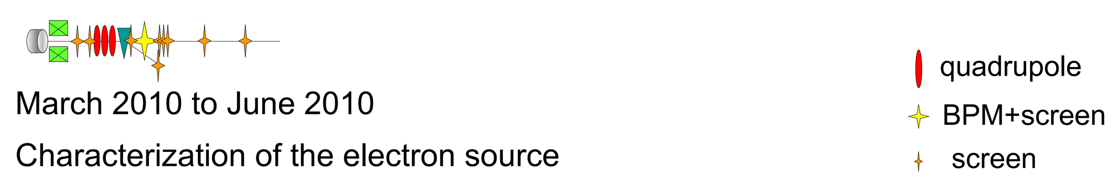
The Paul Scherrer Institute is commissioning a 250 MeV injector test facility in preparation for the SwissFEL project. Its primary purpose is the demonstration of a high-brightness electron beam meeting the specifications of the SwissFEL main linac and undulator complex. At the same time it is advancing the development and validation of the accelerator components needed for the realization of the SwissFEL facility. We report the results of the first commissioning phase, which includes the gun section of the injector up to 7 MeV electron energy. Electrons are generated by a 2.6-cell laser-driven photocathode RF gun operating at 3 GHz followed by an emittance compensating focusing solenoid. The diagnostic system for this phase consists of a spectrometer dipole, a series of screens and beam position monitors and several charge measuring devices. Slit and pinhole masks can be inserted for phase space scans and emittance measurements. The completion of the entire injector facility proceeds in three stages, culminating with the integration of the magnetic compression chicane expected for early 2011.

Schematic overview (phase 1)



Commissioning phases

Phase 1: Electron source and diagnostics

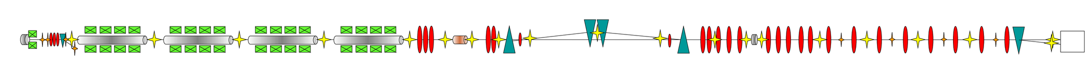


March 2010 to June 2010
Characterization of the electron source
Installation of remaining machine behind shielding wall

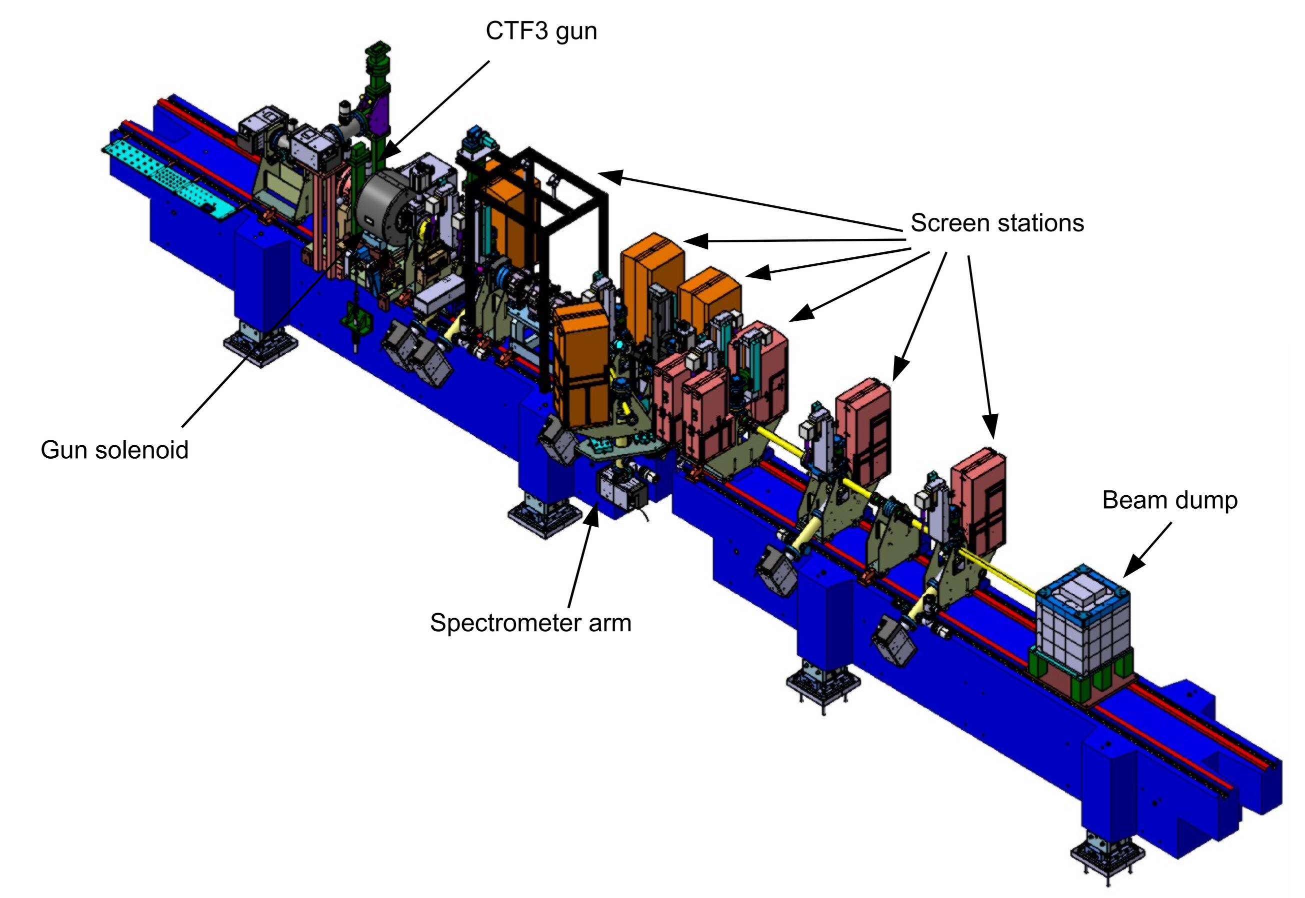
Phase 2: Phase 1 + S-band acceleration

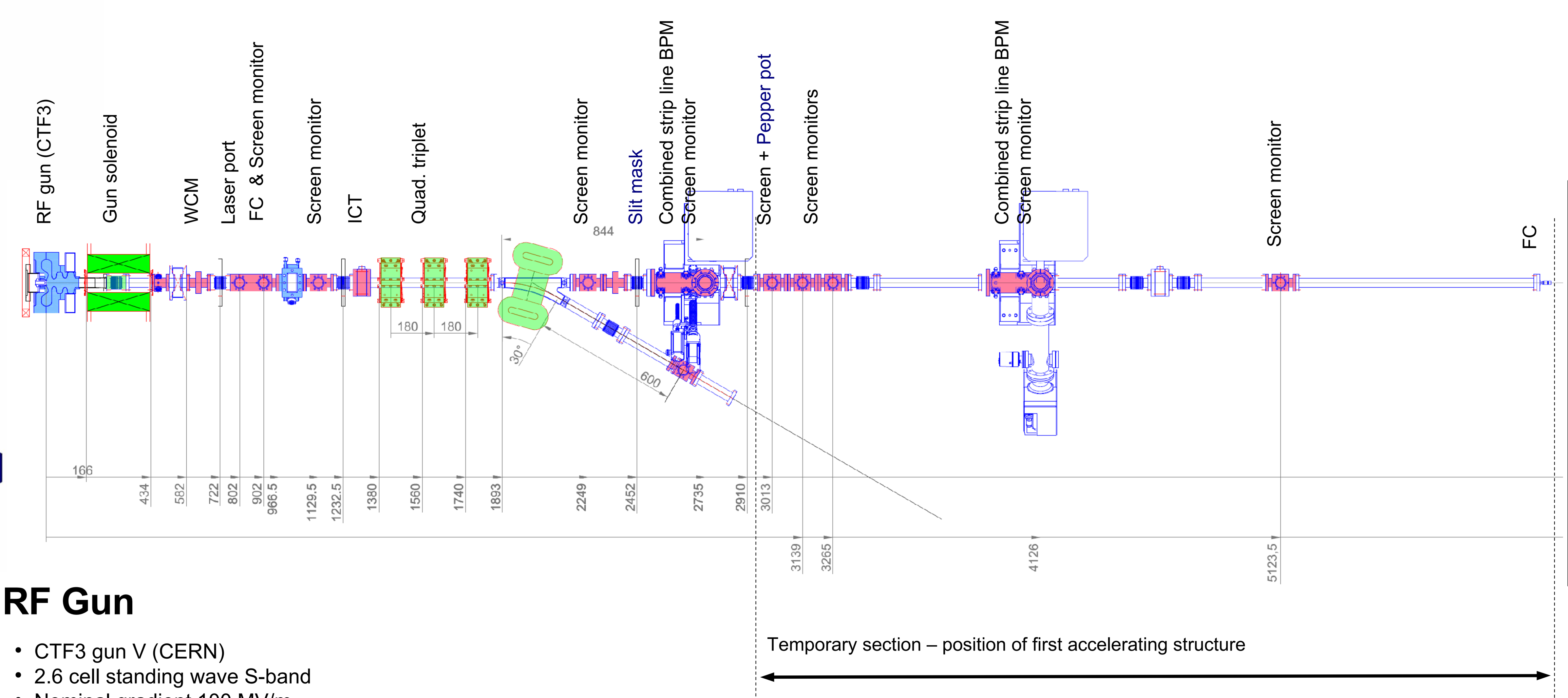
August 2010 to March 2011 (official injector inauguration 24 August)
Emittance damping in S-band booster (invariant envelope)
Jaguar (Nd:YLF) laser

Phase 3: The full machine



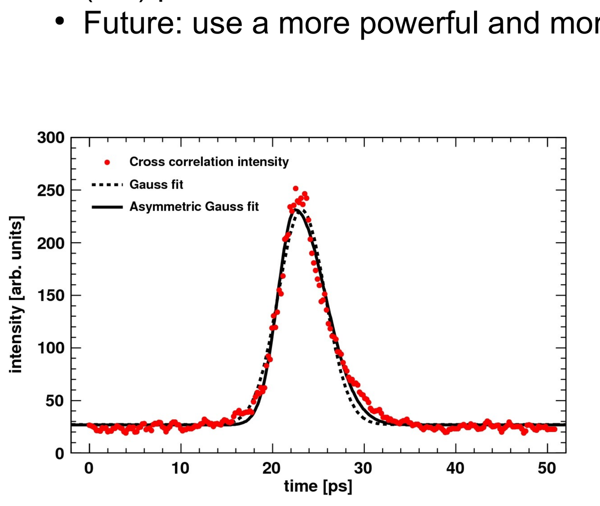
Starting mid-2011 (installation bunch compressor and X-band cavity)
Pulsar (Ti:Sapph) laser

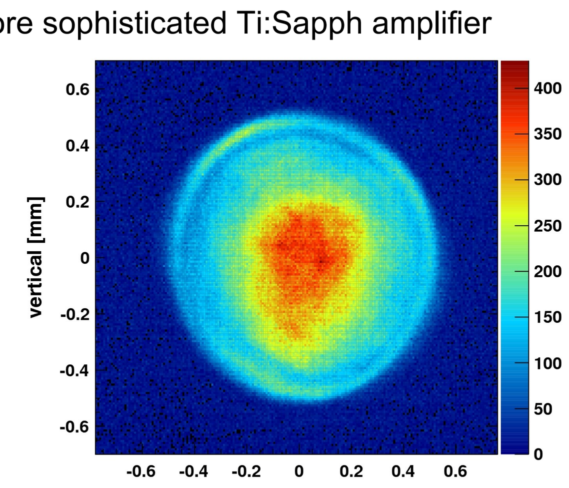




Laser system

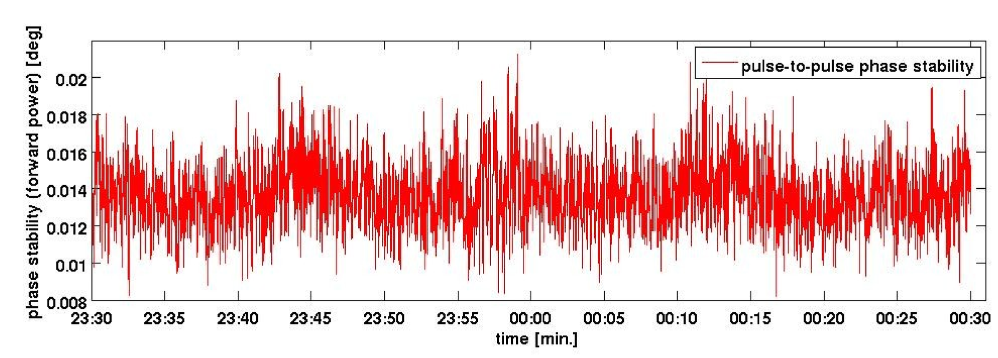
- Compact, turn-key Nd:YLF amplifier
- Oscillator delivers 2.2 mJ, 10.4 ps pulses (FWHM, Gaussian profile) at 1048 nm
- Sequential frequency doubling in a 3 mm and 2 mm BBO crystal, respectively, and transfer to the beamline results in an available pulse energy at the cathode of about 70 μJ at 262 nm wavelength
- Pulse length at 262 nm is 6 ps (FWHM)
- Suppression of higher-order spatial modes with 50 cm long capillary of 300 μm diameter
- Transverse pulse shaping: expand Gaussian-like intensity profile transversely and select central part (~50%) with an aperture mask
- Horizontal (vertical) rms laser beam pointing stability at the cathode: 3.6 (5.5) μm
- Future: use a more powerful and more sophisticated Ti:Sapph amplifier

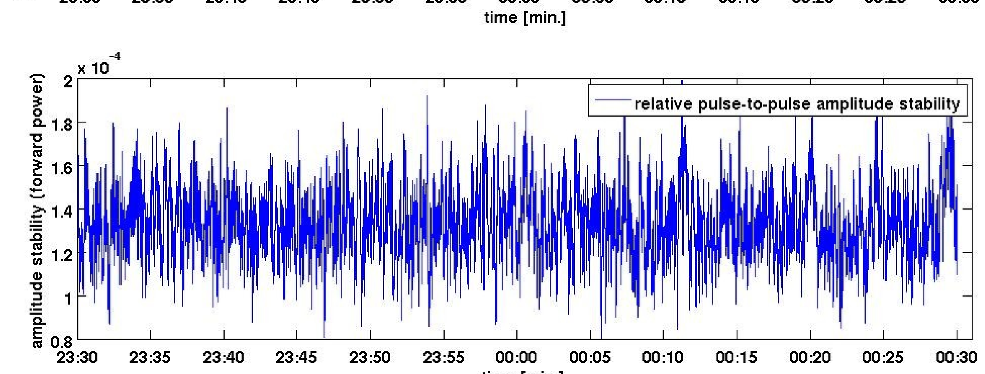




RF Gun

- CTF3 gun V (CERN)
- 2.6 cell standing wave S-band
- Nominal gradient 100 MV/m
- 21 MW peak power
- 10 Hz repetition rate
- Pulse-to-pulse jitter < 0.02° (phase), < 0.019% (amplitude)





Diagnostics

- Transverse profile: 10 screen monitors (YAG:Ce, 20 and 200 μm)
- Orbit: 500 MHz resonant stripline BPMs with position resolution of 7 μm between 5 and 500 pC (20 μm at 2 pC)
- Bunch charge measured by wall current monitor (WCM), Integrating current transformer (ICT), Faraday cups
- Momentum and momentum spread: 30° deflecting dipole
- Emittance measurement with "pepper pot" and movable slit mask:

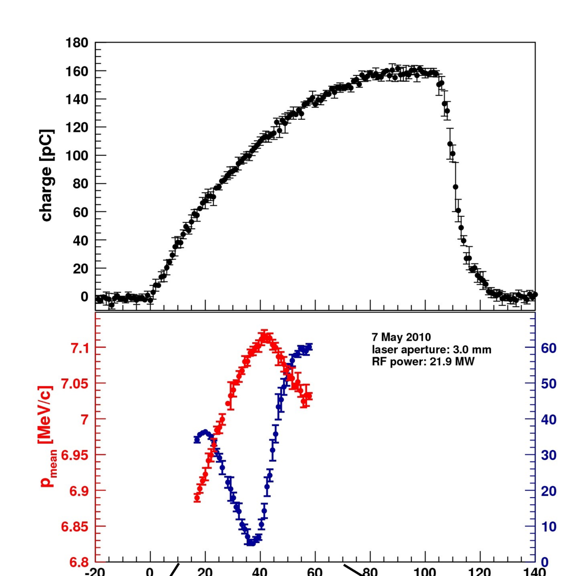
Pepper pot

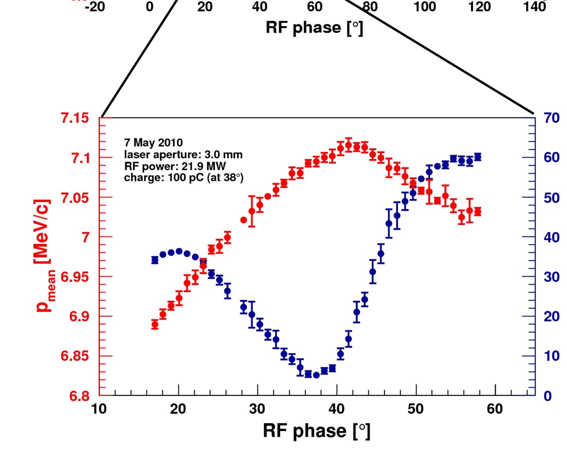
- 25 μm hole diameter
- 150 μm pitch

Slit mask

- 20 μm and 50 μm width

Phase scans





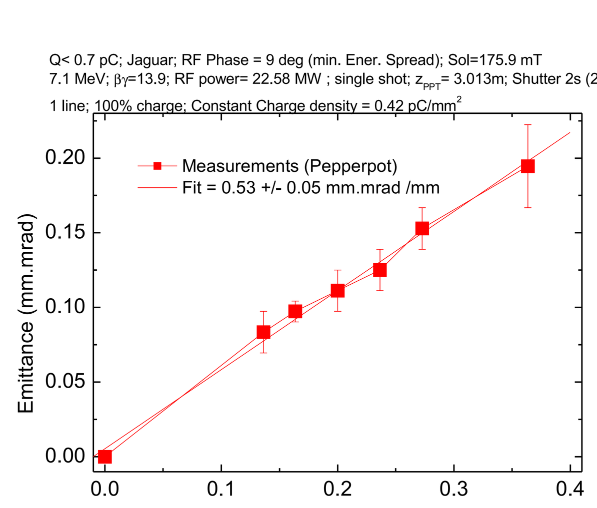
Emittance measurements

Lowest measured emittances for different bunch charges (slit scan method)

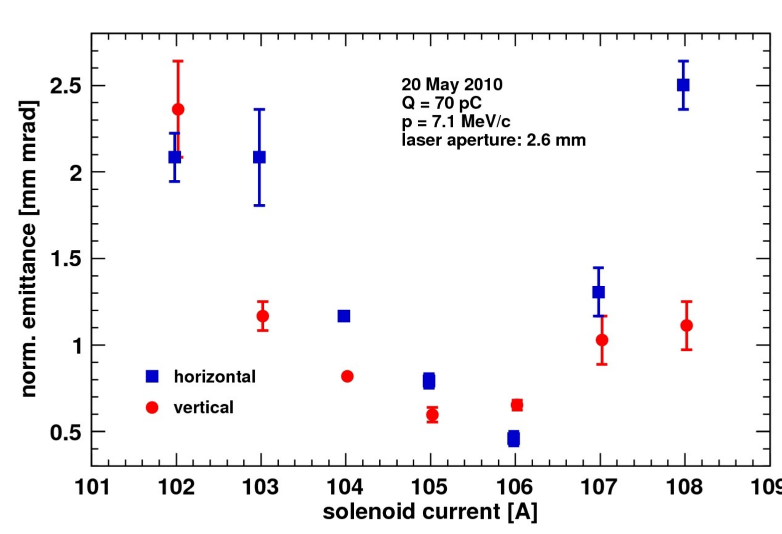
Q [pC]	σ_{laser} [mm]	ε_{hor} [μrad]	ε_{ver} [μrad]
~10	0.16	0.64 ± 0.06	0.56 ± 0.14
~100	0.27	0.46 ± 0.04	0.60 ± 0.04
~200	0.36	1.04 ± 0.01	0.78 ± 0.04

Intrinsic emittance

(Pepper-pot method)

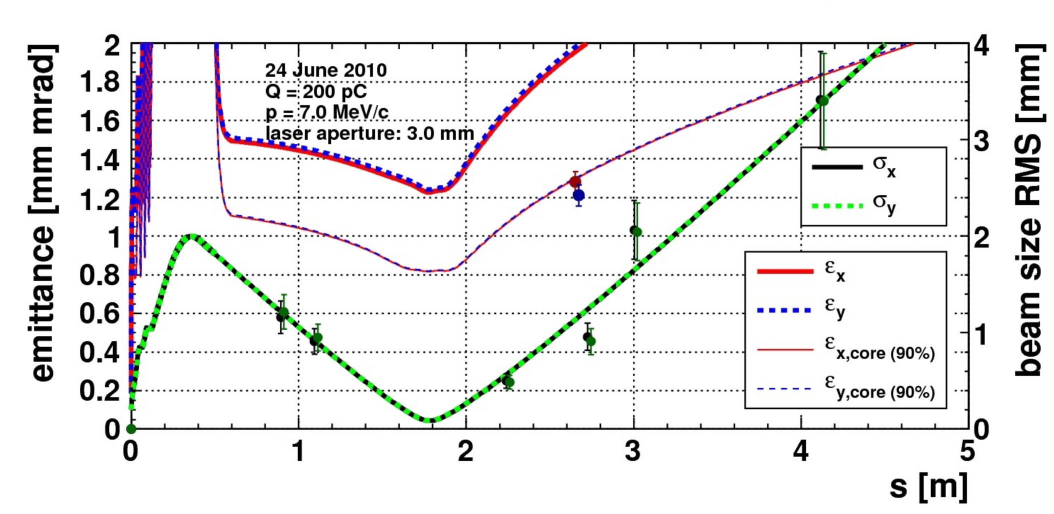


Gun solenoid scan (slit-scan method)

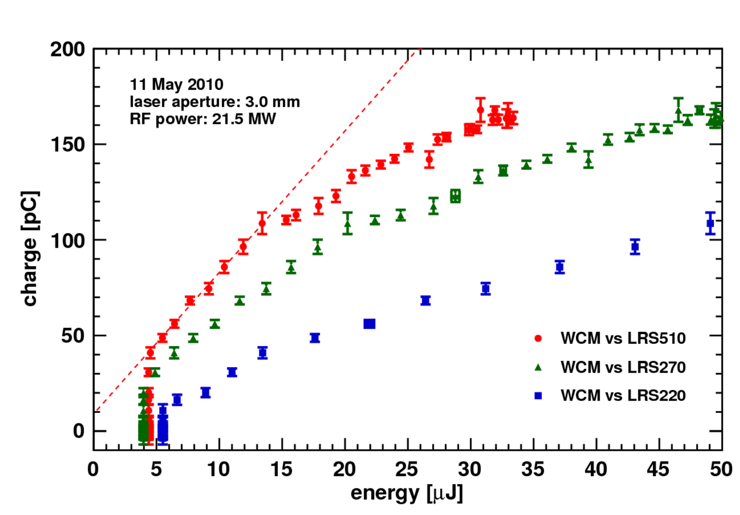


Beam envelope

- Comparison with 3D particle tracking code (OPAL)
- 90% core emittance removes 10% of the bunch charge in head and tail



Quantum efficiency



$$\mathrm{QE}\ [\%] \approx 0.124 \frac{1}{\varepsilon\lambda\ [\mathrm{nm}]} \frac{dQ}{dE_{\mathrm{laser}}}\ [\mathrm{pC}/\mu\mathrm{J}]$$

- From the slope between 5 and 15 μJ determine dQ/dE = 7.4 pC/μJ
- Attenuation from vacuum window and UHV mirror: ε = 0.9 × 0.94 = 0.864
- RF power 21.5 MW corresponds to 100 MV/m peak field, 85 MV/m on cathode (2 μs pulse length)

QE = 4.05 × 10^{-5}

Conclusion and outlook

- Commissioning of the gun section (phase 1) concluded in June 2010.
- Phase 2 started in August 2010 with two traveling-wave S-band structures accelerating the beam to 162 MeV.
- Installation of remaining accelerating structures and bunch compressor in 2011.

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