The LEG Project's 100 keV DC Gun Test Stand

July 5, 2006

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Motivation Behind the Test Stand

- The Low Emittance Gun Project (LEG) at PSI aims at developing a high-brightness, high-current electron source: a 20-fold improved brightness compared to present state-of-the-art electron guns
- The source is intended to form the basis for a cost-efficient implementation of a high-power X-ray FEL light-source for scientific research at PSI
- A field emitter array (FEA) cathode is being considered a source candidate
- 100 keV DC Gun Test Stand built in order to
  - Study pulsed field emission from a FEA cathode
  - Investigate space charge compensation techniques (low emittance!)
  - Develop diagnostic procedures to characterize the electron beam resulting from an FEA cathode

Test Stand Setup

- The test stand consist of:
  - DC gun that holds the FEA cathode
  - HV supply for the gun and digital pulser
  - Solenoid focussing magnet that focusses the beam and compensates space charge blow-up
  - Diagnostic module that holds various diagnostic equipment
  - Dedicated vacuum system to ensure UHV conditions
  - EPICS control system
- Modular design → simple replacements, optimizations, exchanges
- The test stand gun and diagnostics have been modeled with the codes MAFIA and GPT
- From extensive parameter studies an emittance-optimized design has been derived

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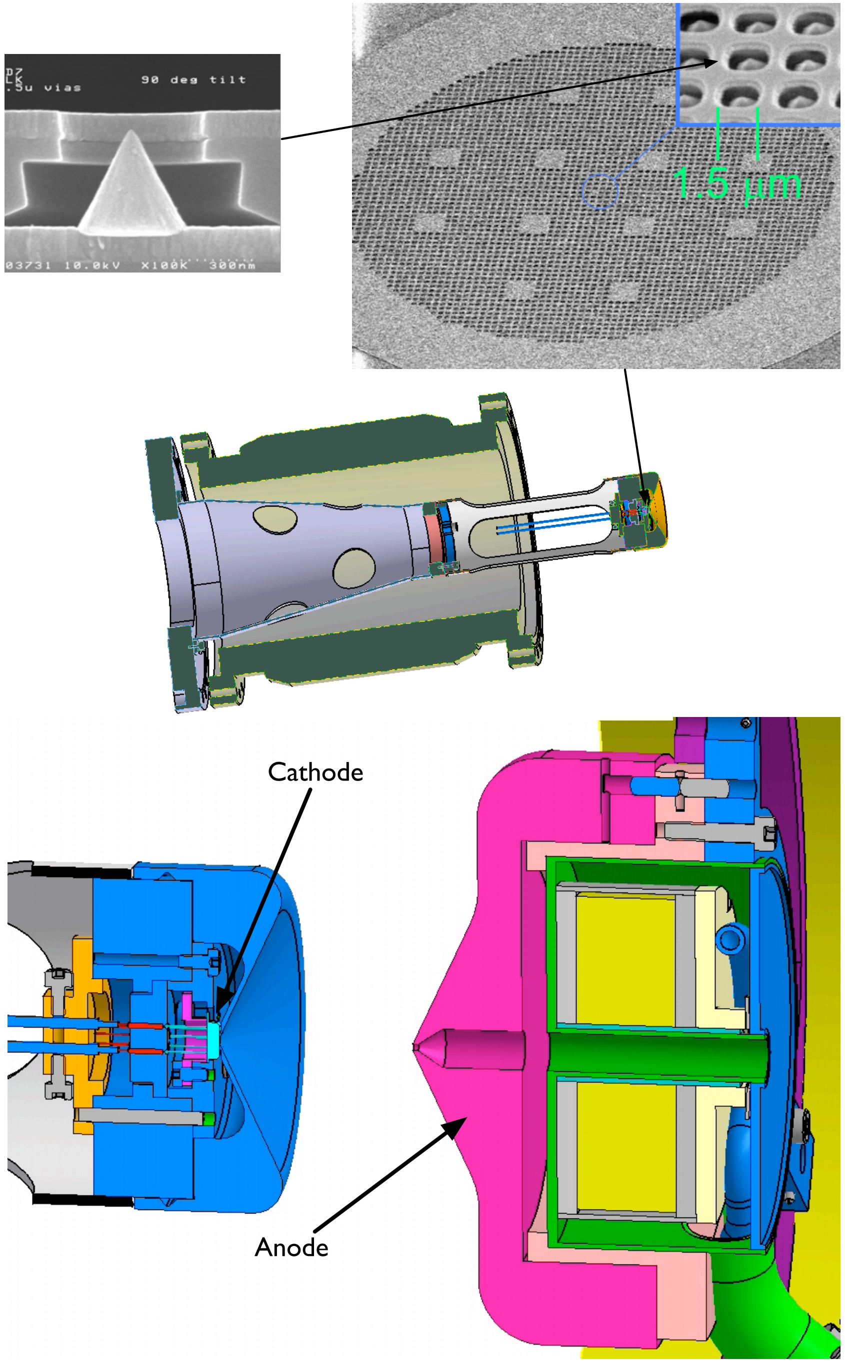
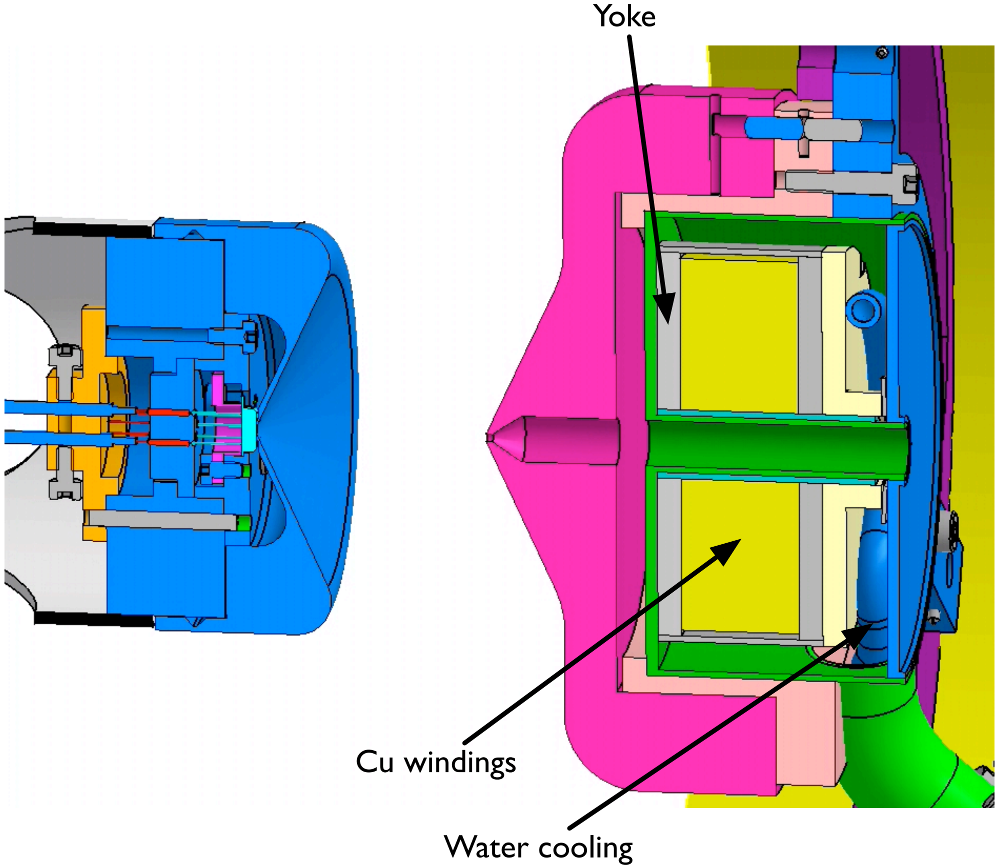
Gun

- Spindt-type FEA consists of thousands of Mo nano-tips and a Mo gate layer (active emitting area has 500 μm radius)
- DC gun: Diode structure with a cathode electrode on -100 kV potential with respect to the grounded anode
- FEA inserted at center of cathode electrode through insertion port (1.5 mm diameter)
- FEA gate layer connected to pulser in the HV deck; pulser can deliver 320 V (with respect to the FEA potential) pulses with 5 ns minimum pulse length
- Accelerating gap large enough (~ 11 mm) to avoid peak electric field strength higher than 20 MV/m on anode iris
- Anode iris has a diameter of 1.5 mm → beam passes without particle loss



Solenoid

- DC Solenoid magnet
  → Focus beam
  → Compensate space-charge blow-up
- 1000 copper windings are capable of delivering 200 mT of longitudinal magnetic field strength on axis
- Actively cooled by in-vacuum water circuit dissipating roughly 50W of heat from within the iron yoke case
- Proper tuning of the solenoid current (digital power supply) → beam foci can be produced at any location within the diagnostic module (433 mm long drift section behind the solenoid magnet)



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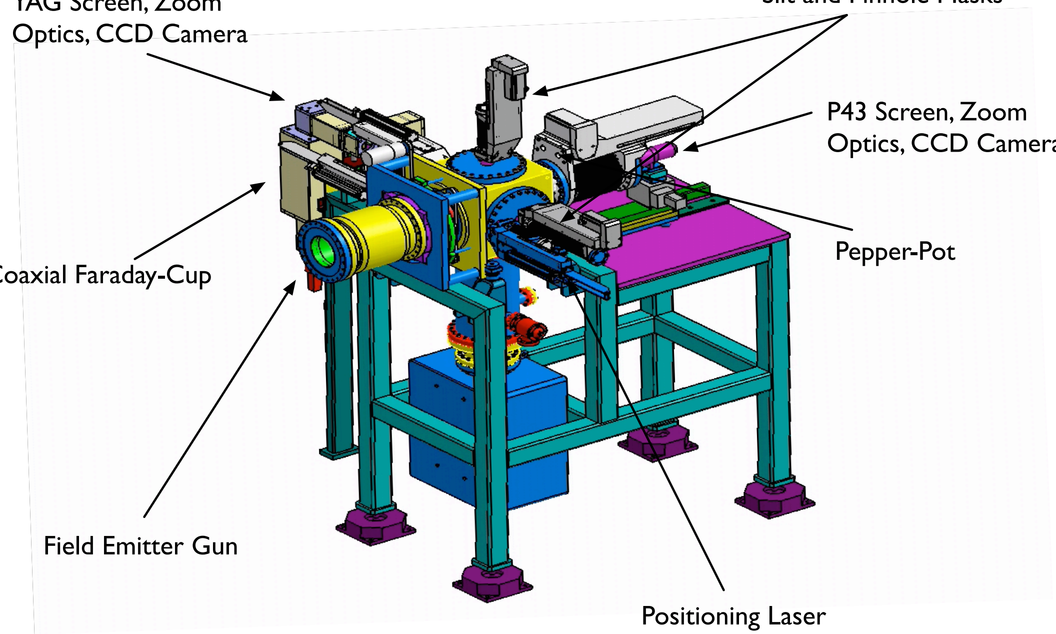
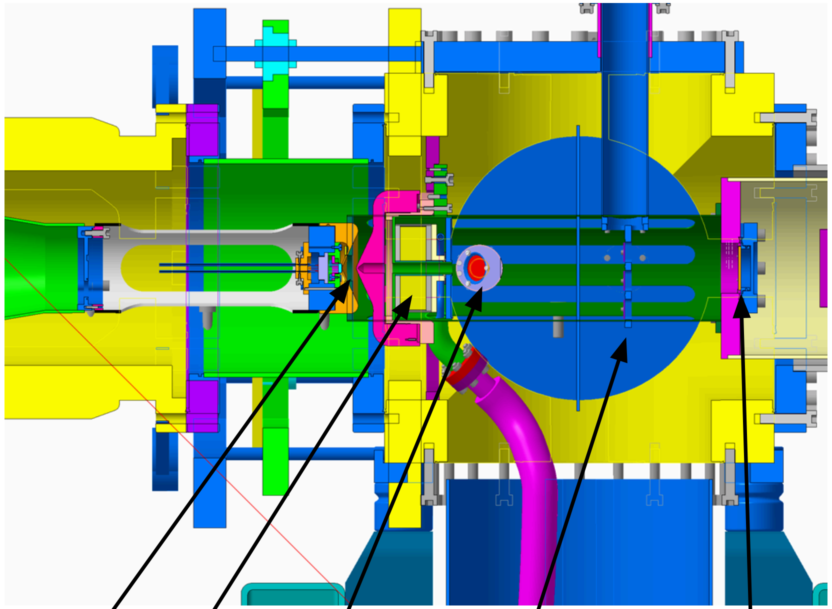
Diagnostics





- Faraday cup (coaxial, 20 mm diameter, bandwidth > 4 GHz) to read out charge and time structure (2 GHz, 20 GS/s digital oscilloscope)
- YAG screen (30 mm diameter) with CCD camera and zoom optics visualizes transverse beam distribution at the location of the slit and pinhole arrays
- Slit and pinhole arrays (3 vertical and 3 horizontal masks (single slit, slit array, pinhole array), laser eroded substrates of 100 μm tungsten)
- P43 phosphor screen (6-8 μm thickness, granularity is ~ 3 μm, aluminized substrate) with CCD camera and zoom optics (ultimate optical resolution of this system is ~ 3 μm)

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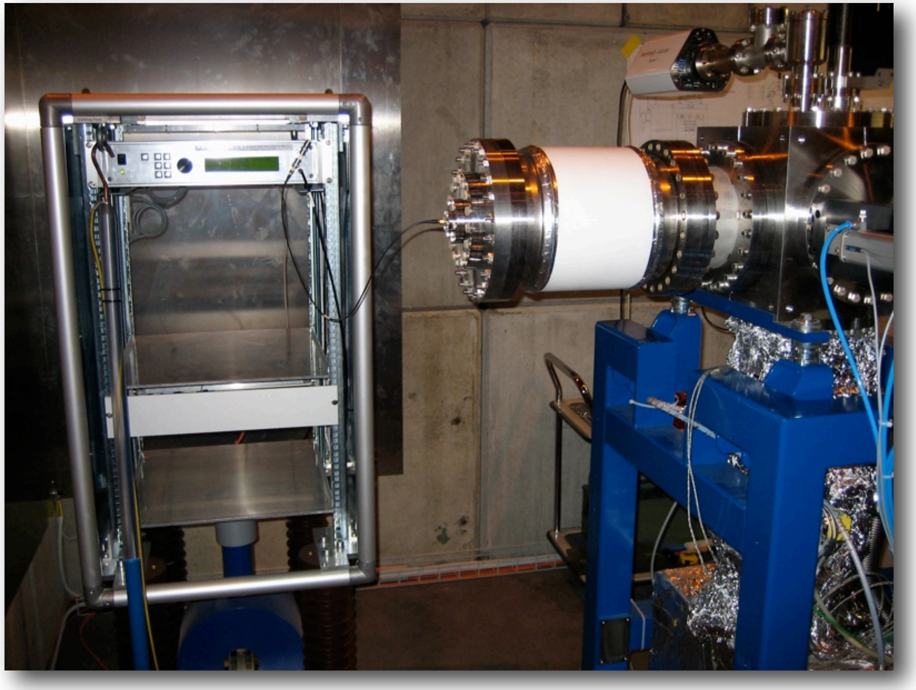
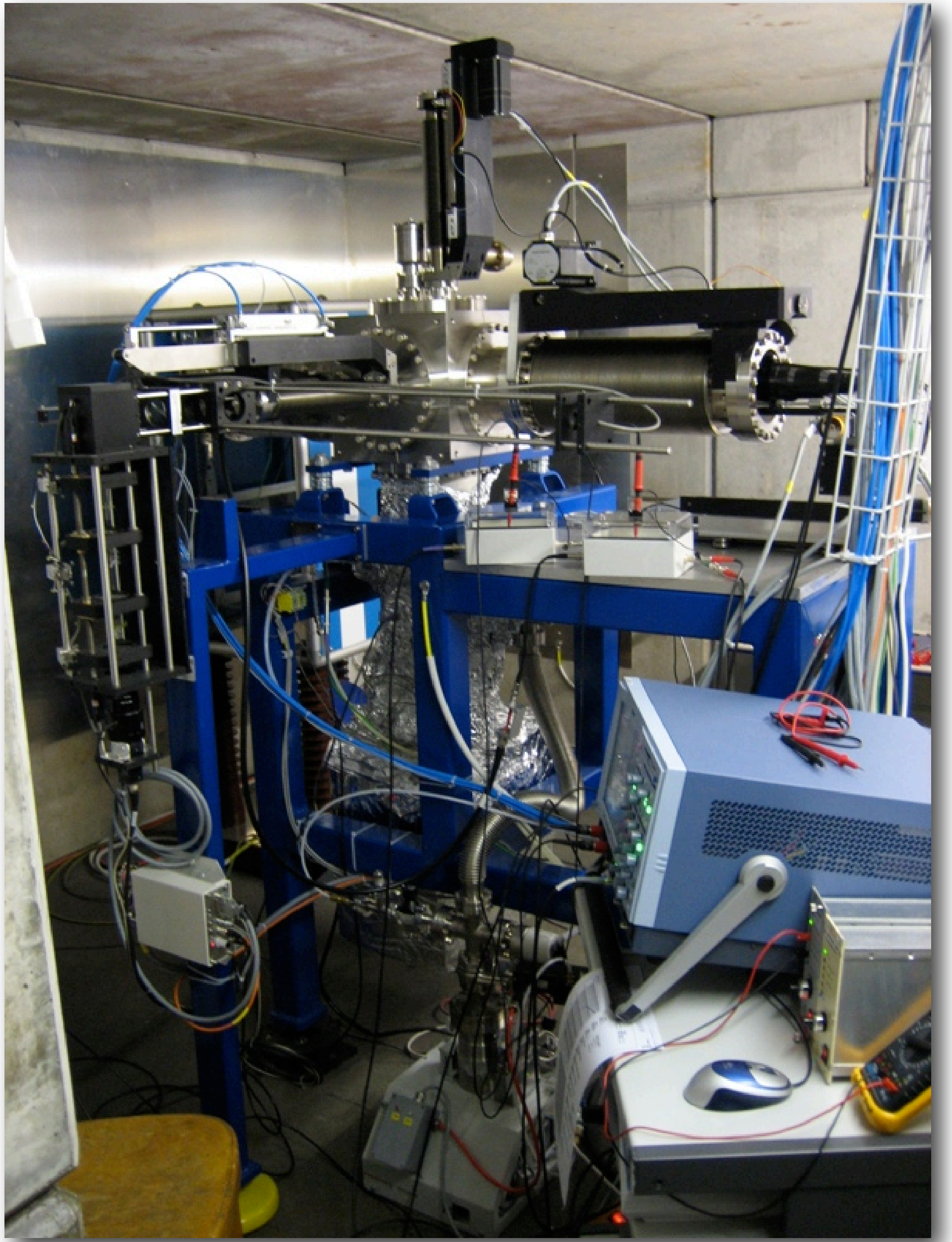
Some Photos

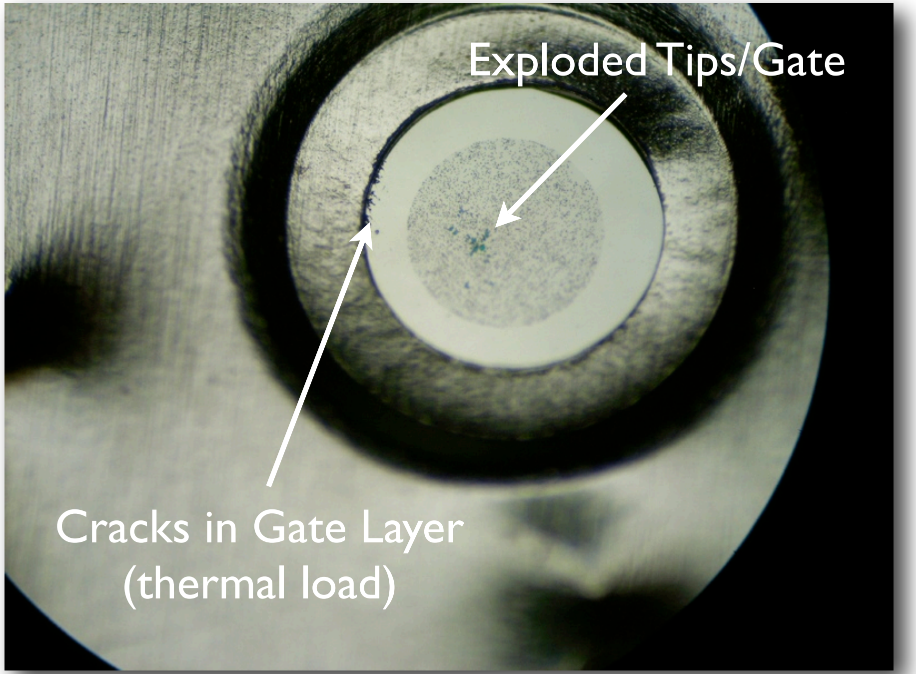


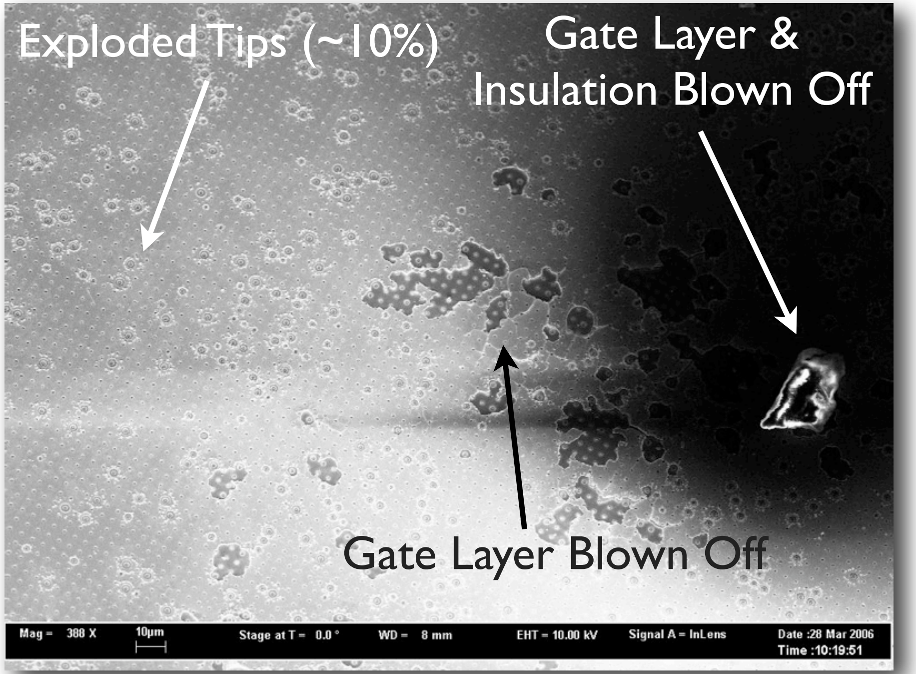


Commissioning (I)

- FEAs are very fragile (UHV conditions!) and unforgiving (bridging)
- Parasitic emission from gate or tip-to-gate discharge → strong local heating → ions released → acceleration and back-bombardment onto the FEA → partial or complete FEA destruction
- Bad local vacuum can trigger HV breakdown → partial or complete FEA destruction

→ Ramp up HV slowly; avoid arcs at all cost



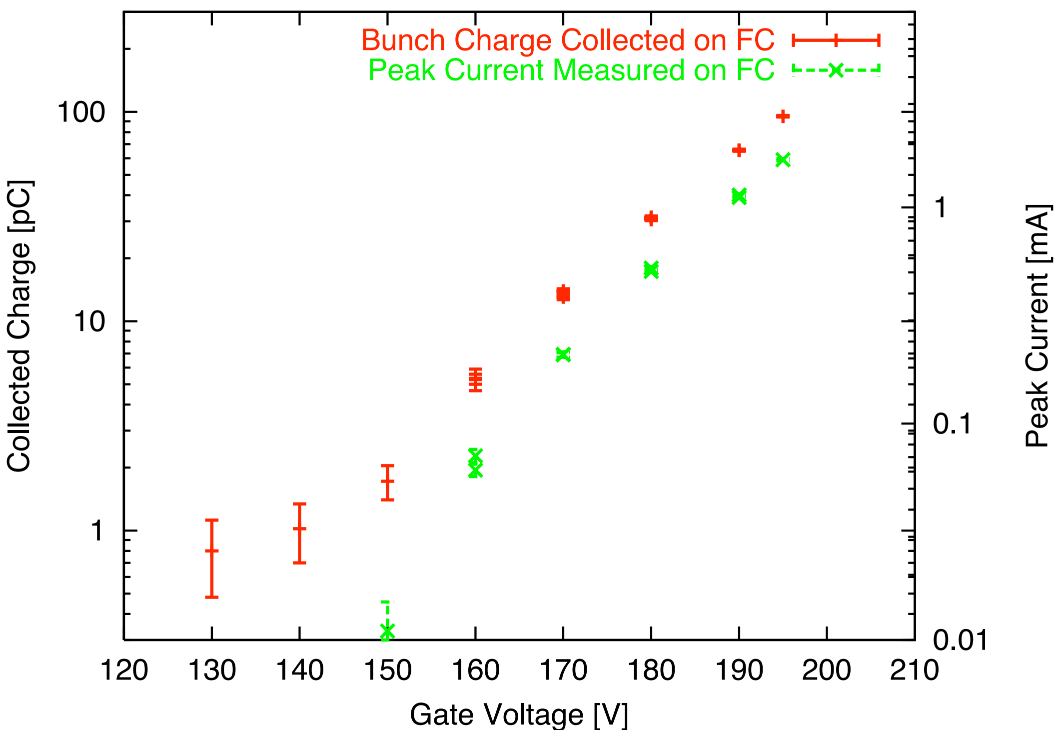


SEM image courtesy of E. Kirk, LMN

Commissioning (II)

- At U_g=200 V strong fluctuations and bursts of the emitted current
- Such bursts normally precede a discharge from tips to gate which can trigger HV breakdown and ultimately destroy the FEA
- Peak currents obtained are well below the originally targeted 100 mA → the repulsive space-charge forces within the bunch are dramatically reduced and the gun design becomes inherently over-focussing
- Beam enters solenoid immediately after reaching a 0.1 mm waist due to the electrostatic over-focussing → solenoid only capable of producing a beam waist within few cm of its exit

FEA Calibration @ 40kV



FLAC Presentation March 2006
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Emittance Measurements

- Several methods are used to measure transverse bunch properties
  - Solenoid Scan: Measure beam size as a function of solenoid setting (requires several shots; delivers emittance and twiss parameters at solenoid entrance)
  - Single slit: Measure downstream image of a beamlet emerging from a slit obstruction (requires beam size at location of slit; delivers emittance at slit location in one shot per plane)
  - Slit arrays: Measure downstream image of beamlets emerging from a multi-slit obstruction (emittance, twiss parameters and phase space distribution can be acquired in one shot per plane)
  - Pinhole Arrays: Like slit array, but measure both planes in one shot
  - Pepper-pot: Like pinhole, but can be moved along beam path to measure at arbitrary longitudinal position
- Compare methods (precision, availability)

EPAC 2006 Paper
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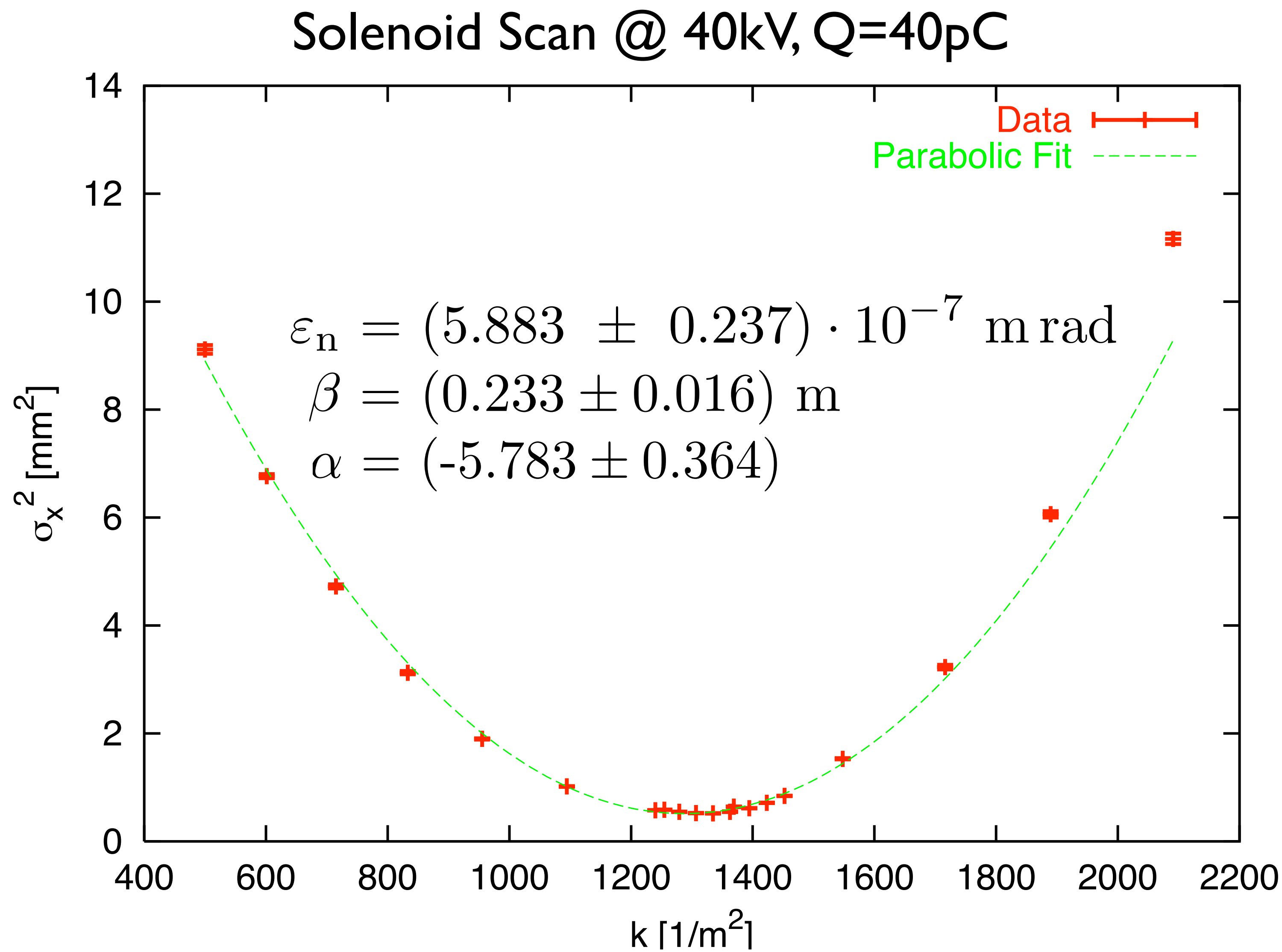
Emittance Measurements: Solenoid Scan

- Measure downstream beam size as a function of solenoid current
- From non-linear fit derive emittance and twiss parameters at solenoid location

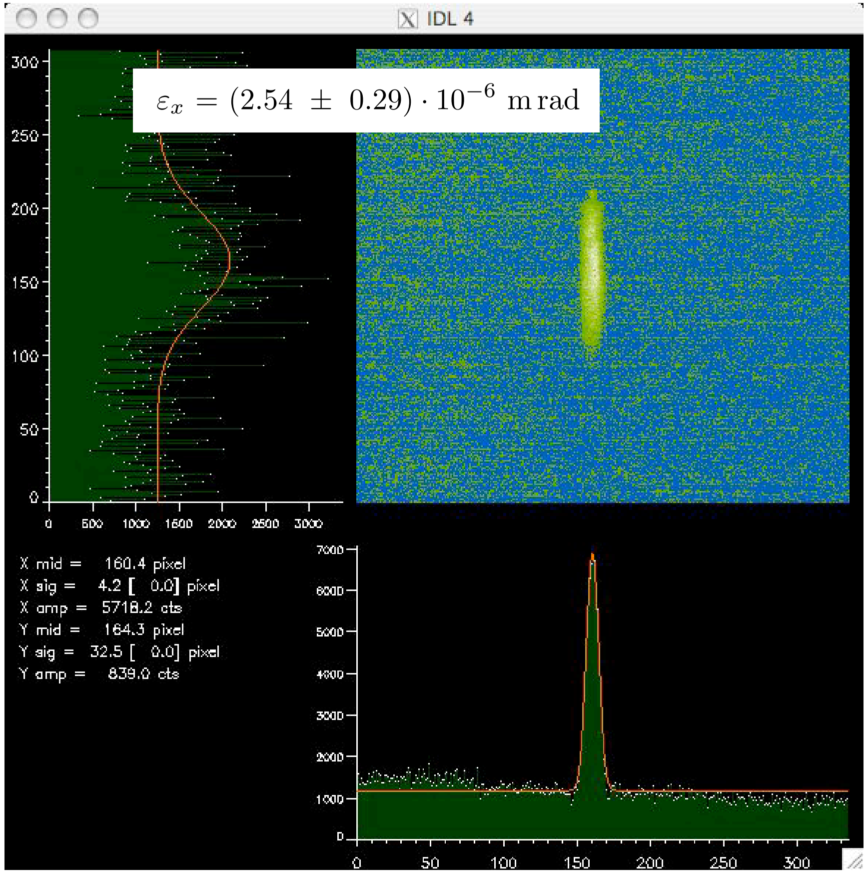


Emittance Measurements: Single Slit

- If beam size at slit is known, measuring the downstream beamlet width gives emittance in one shot (per plane)

$$\varepsilon_x = \sqrt{\langle x^2 \rangle \cdot \langle x'^2 \rangle}\ , \quad \text{where} \langle x'^2 \rangle = \sigma_x^2 / L^2$$

Single Slit Image @ 40kV, Q=40pC



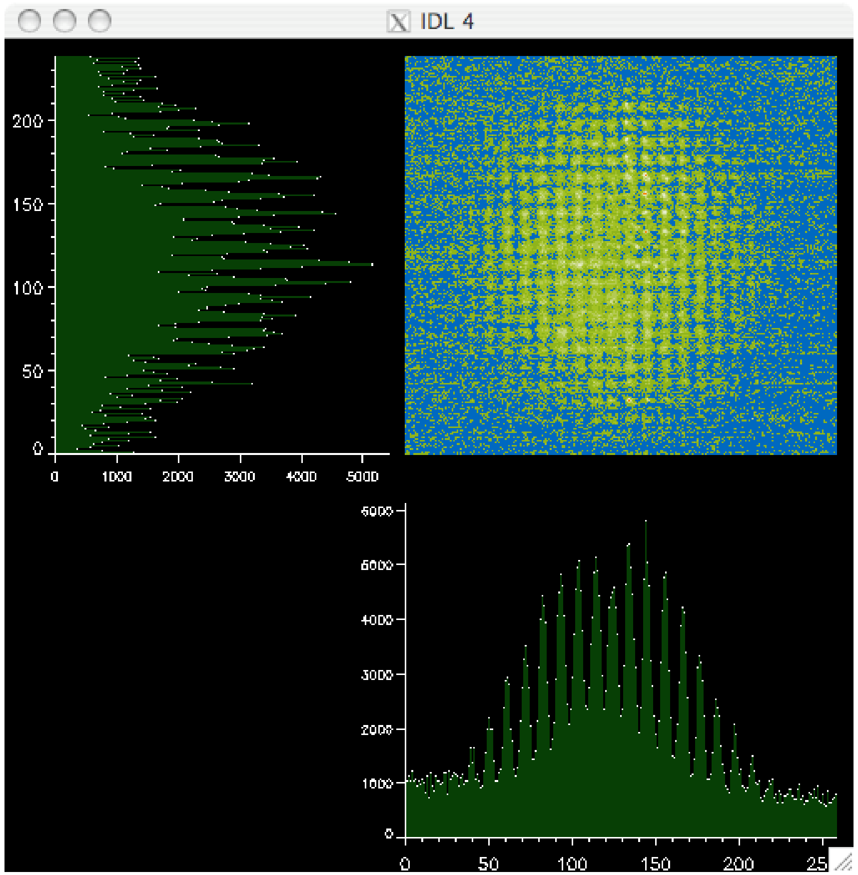
ΔL=39mm, I_{sol}=+0.81A → B_z=47.3mT

Beam size at slit: σ_x=715μm

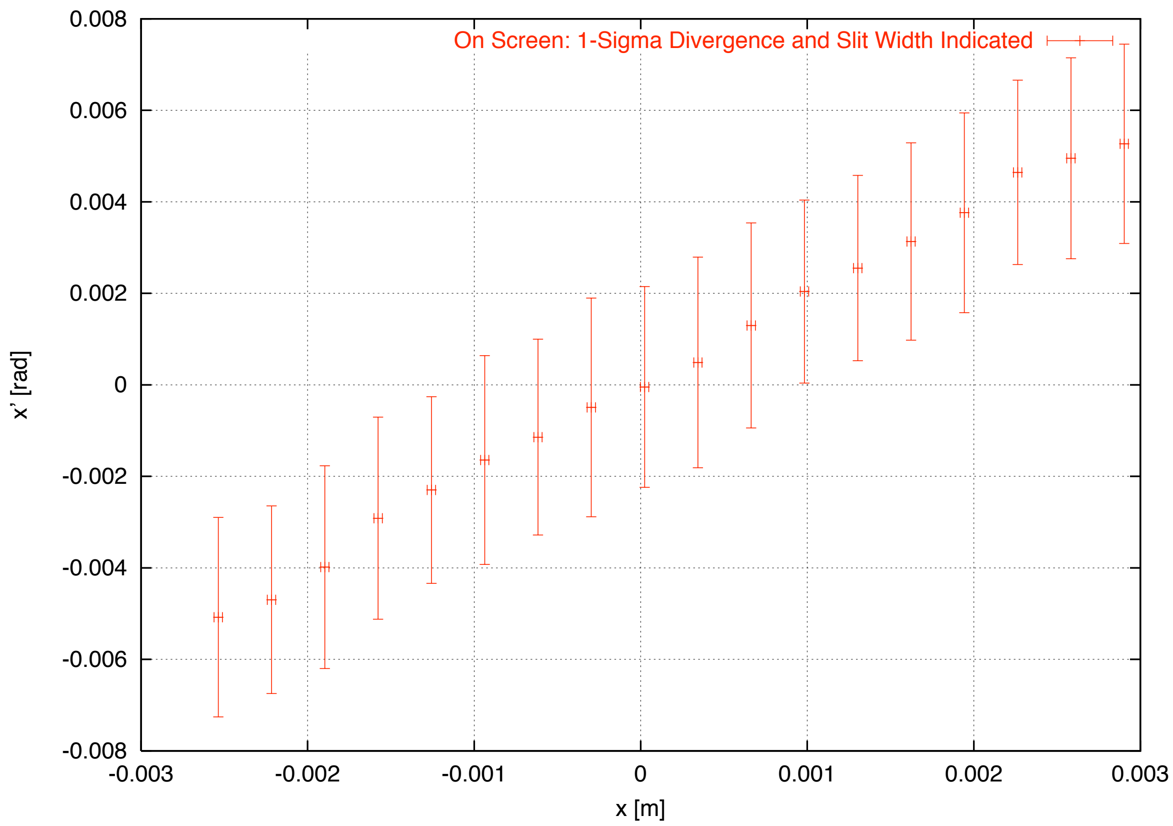
Emittance Measurements: Pinhole Arrays (I)

- Measure beamlet distributions and relative intensities
- Beamlet widths give momentum spread within each slice; correlated momentum spread of the entire bunch given by envelope over all beamlets

40kV, Q=56pC

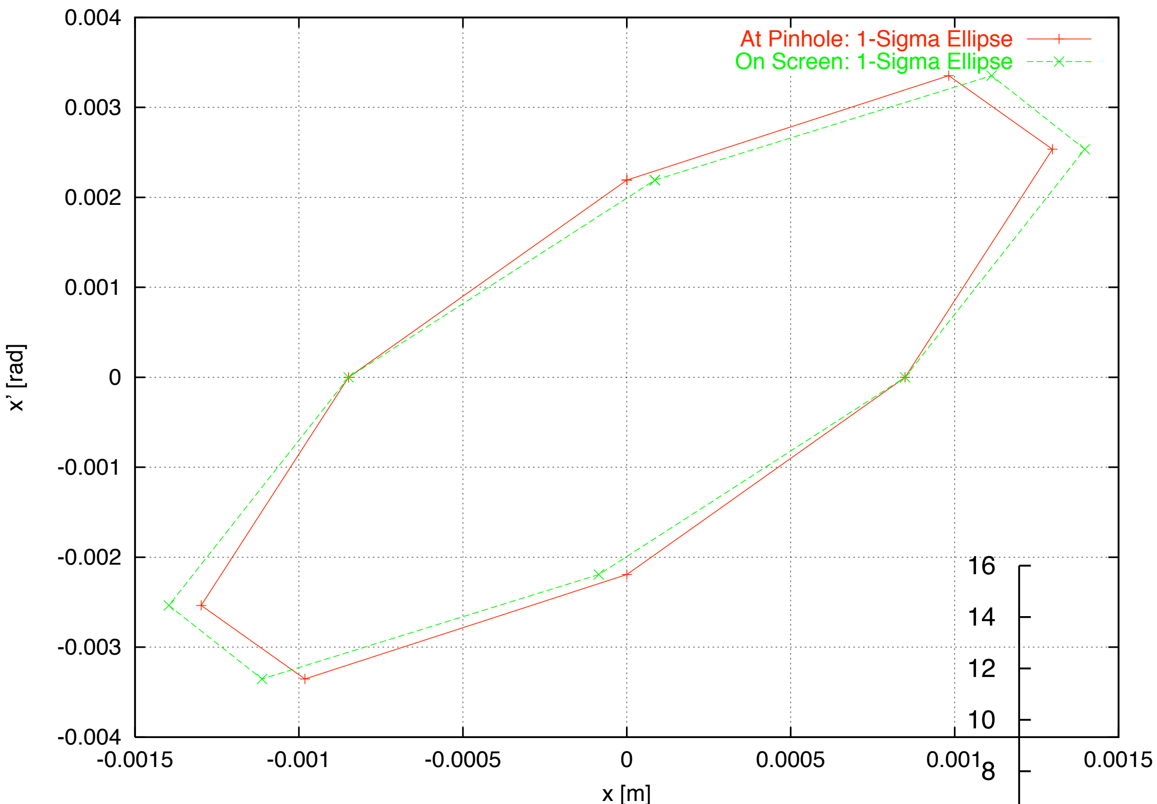


ΔL=39mm, I_{sol}=+0.698A → B_z=40.8mT



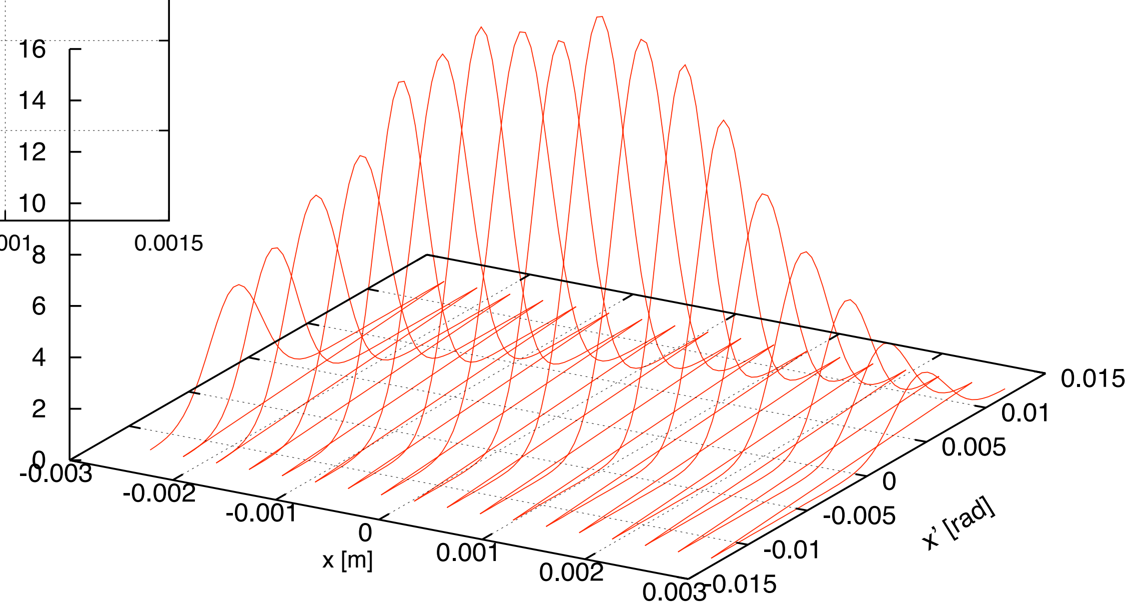
Emittance Measurements: Pinhole Arrays (II)

- Pinhole array not only gives emittance for both planes in one shot, but allows full phase space distribution reconstruction



$$\beta_x = (0.592 \pm 0.065)\ \mathrm{m}$$
$$\alpha_x = (-1.16 \pm 0.20)$$
$$\beta_y = (0.654 \pm 0.072)\ \mathrm{m}$$
$$\alpha_y = (-1.10 \pm 0.19)$$

$$\varepsilon_x = (2.85 \pm 0.57) \cdot 10^{-6}\ \mathrm{m\,rad}$$
$$\varepsilon_y = (3.46 \pm 0.69) \cdot 10^{-6}\ \mathrm{m\,rad}$$



Conclusion & Outlook

- Test stand diagnostics deliver a full transverse phase space characterization of a FEA-based beam
- In the scope of the LEG project improved FEAs are required
- In-house fabrication of FEAs optimized for use as electron sources has started (LMN)
- Higher bunch charges will improve the SNR (single shot measurements)
- By introducing a focussing layer in addition to the gate layer, the initial divergence spread will be reduced
- Together with the increased beam size at solenoid entry (due to the increased bunch charge), the solenoid should be able to properly focus the beam at the location of the diagnostic equipment as originally intended

Acknowledgments

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