Status Report
100 keV DC Gun Test Stand

August 11, 2006

What Happened Since the Last LEG Project Meeting

- Improved solenoid scan with non-linear fitting routine
- Single slit emittance measurements
- Pinhole array emittance measurements

Solenoid Scan Measurement Method (I)

- As demonstrated in the last LEG Meeting, in thin lens approximation the fit applied to the measured data is quadratic in k:

$$
\begin{aligned}
\sigma^2 &= \varepsilon\beta = C^2\varepsilon\beta_s - 2SC\varepsilon\alpha_s + S^2\varepsilon\gamma_s \\
&\vdots \\
&= k^2 \underbrace{\left(L^2 l^2 \varepsilon\beta_s\right)}_{c_2} + k \underbrace{\left(2L^2 l \varepsilon\alpha_s - 2Ll\varepsilon\beta_s\right)}_{c_1} + \underbrace{\left(\varepsilon\beta_s - 2L\varepsilon\alpha_s + L^2\varepsilon\gamma_s\right)}_{c_0}
\end{aligned}
$$

- However, due to the strong focussing applied with the solenoid, the thin lens approximation is not appropriate:

$$l_{\mathrm{eff}} \overset{?}{\ll} f_{\mathrm{sol}} = 1/(k \cdot l_{\mathrm{eff}})$$

Solenoid Scan Measurement Method (II)

- Treat solenoid (focussing strength k, rotation angle ϕ) and subsequent drift (length L) as a thick lens (better yet: thick slices as originally calibrated)

$$\mathcal{M} = \begin{pmatrix} \cos\phi - L\sqrt{k}\sin\phi & \frac{1}{\sqrt{k}}\sin\phi + L\cos\phi \\ -\sqrt{k}\sin\phi & \cos\phi \end{pmatrix}$$

$$\text{where} \quad k = \left(\frac{\hat{B}}{2\,p/e}\right)^2 \quad \text{and} \quad \phi = \frac{\int B\,ds}{2\,p/e} \quad \text{are functions of } I_{\mathrm{sol}}$$

- Use Levenberg-Marquardt Method to solve the non-linear problem

$$\sigma = \sqrt{\varepsilon\left(\beta_0 {\mathcal{M}_{1,1}}^2 - 2\alpha_0 \mathcal{M}_{1,1}\mathcal{M}_{1,2} + \frac{1+\alpha_0^2}{\beta_0}{\mathcal{M}_{1,2}}^2\right)}$$

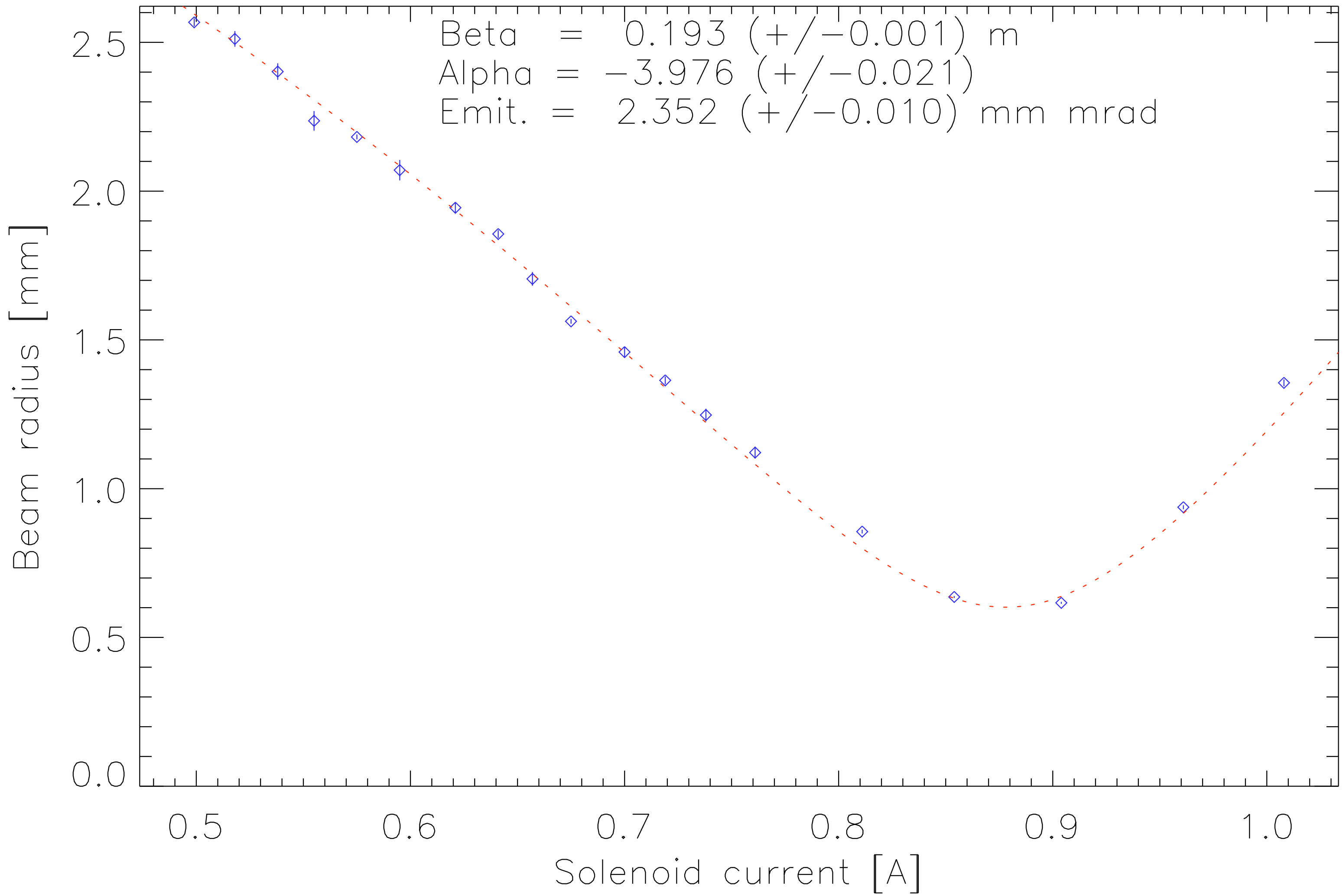
measure

I_{sol}

output from fit

Solenoid Scan Measurement Method (III)

- Example taken at 40 kV, U_g = -173 V, Q_{tot} = 39 pC, Î = 637 µA, 5 shot average
- Levenberg-Marquardt routine implemented in IDL
  (recycled old code originally written by Andreas Streun in 1999)



Solenoid Scan Measurement Method (IV)

- Comparing methods shows how emittances are estimated too low by using the thin lens approximation

	ϵ_x [mm mrad]	ϵ_y [mm mrad]
thin lens	1.73 ± 0.07	2.26 ± 0.11
thick lens (hard-edge)	1.89 ± 0.08	2.47 ± 0.01
thick lens (slices as calibrated)	2.35 ± 0.01	3.07 ± 0.02

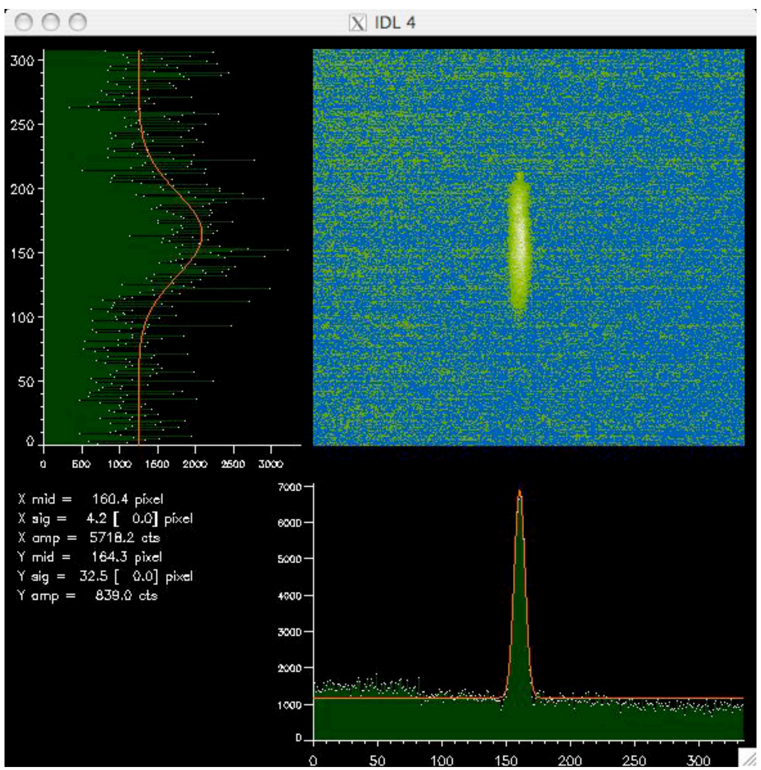
+36%

Single Slit Emittance Measurement

- Measure RMS beam size at location of single slit (YAG)
- Measure RMS width of emerging beamlet downstream ($d \ll \sigma_x$)
- Calculate emittance directly according to:

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

Single Slit Image @ 40kV, Q=40pC



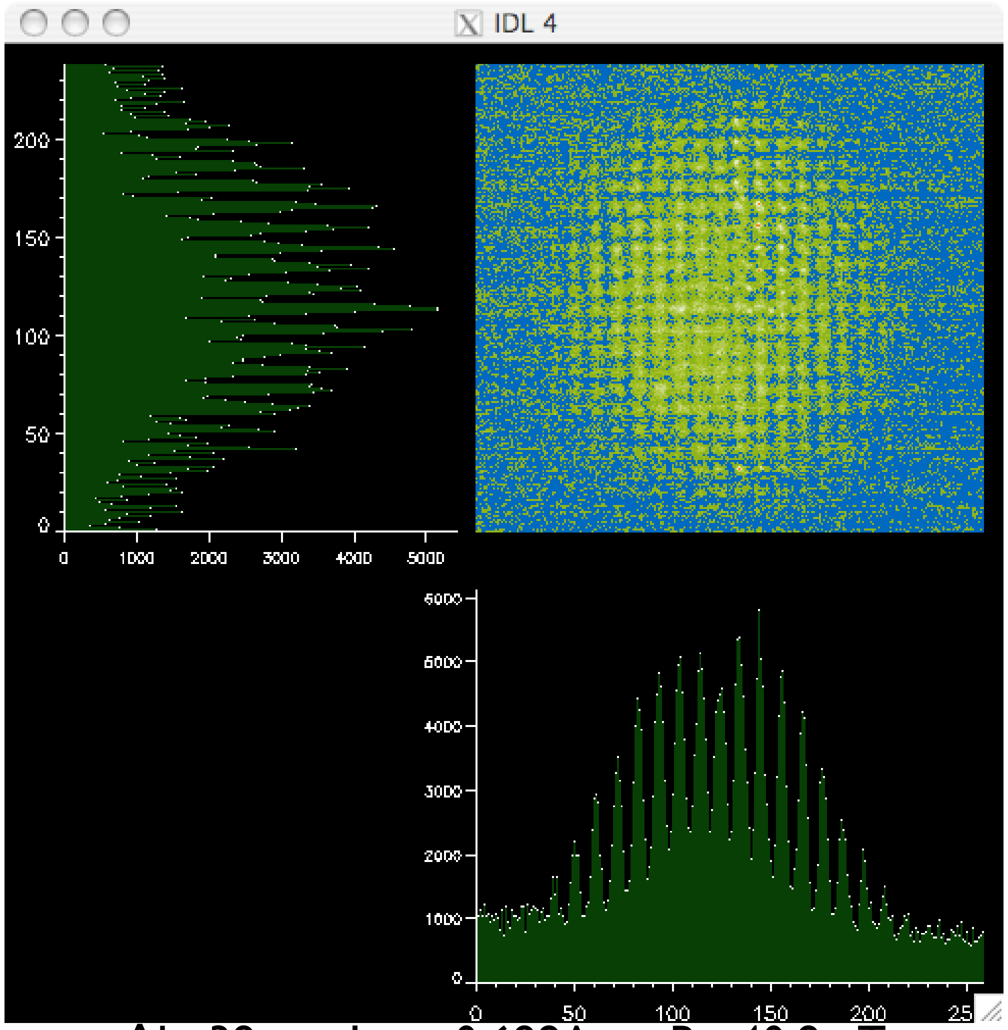
ΔL=39mm, I_{sol}=+0.81A → B_z=47.3mT
Beam size at slit: σ_x=715μm

- ϵ_x = (2.54 ± 0.29) mm mrad
- In agreement with solenoid scan results
- Pro: Calculate emittance from a single image
- Con: No Courant-Snyder parameters or phase space distribution information

Pinhole Array Emittance Measurement (I)

- Beamlets emerge from pinhole
- Measure beamlet intensity distribution downstream (P43)

40kV, Q=56pC



ΔL=39mm, I_{sol}=+0.698A → B_z=40.8mT

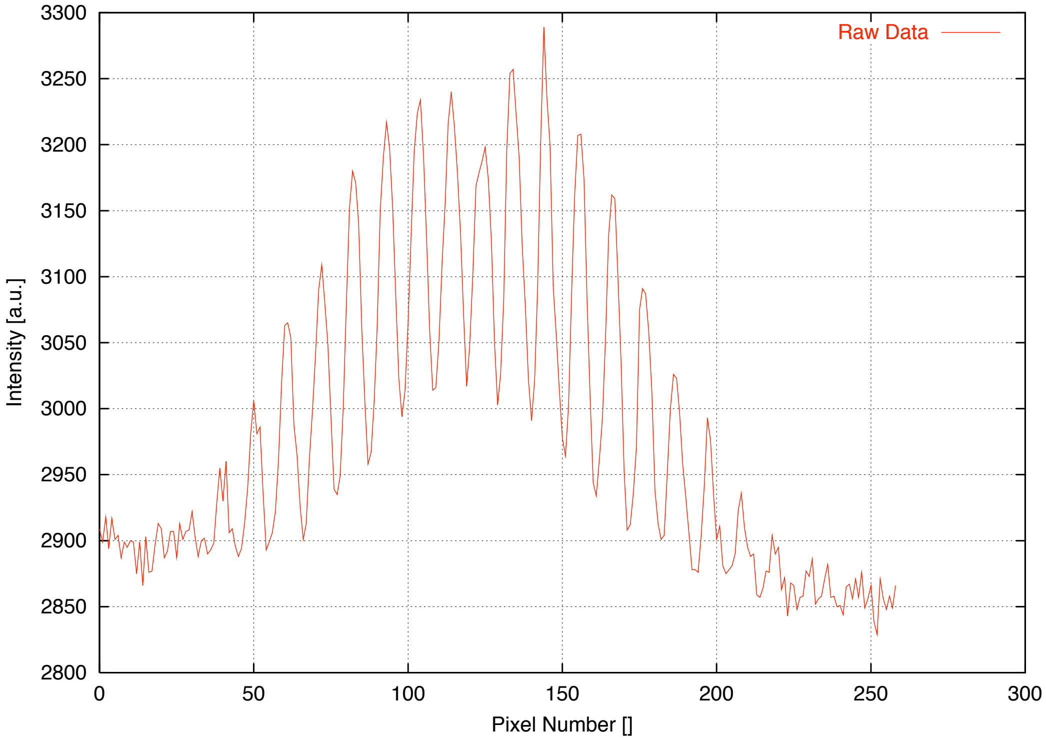
Pinhole Array Emittance Measurement (II)

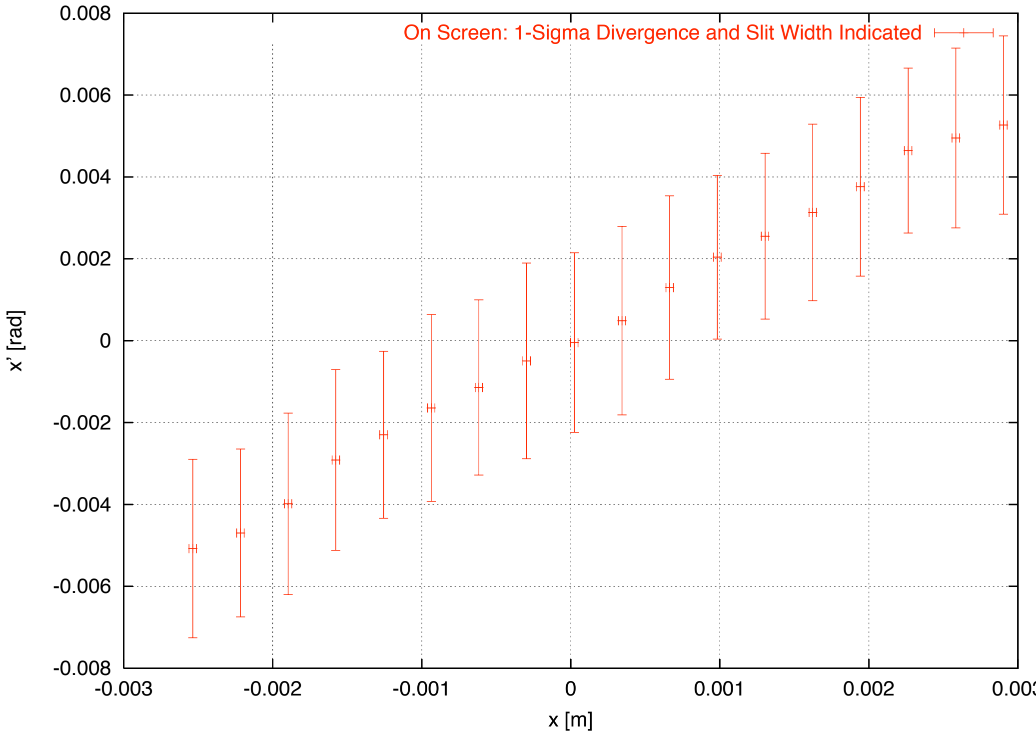
- Measure position of beamlet centroids → divergence centroids

$$\overline{x}_i' = \langle x_i - \overline{x}_i \rangle / L$$

- Measure RMS beamlet width → divergence spread for each slice (d << σ_x)

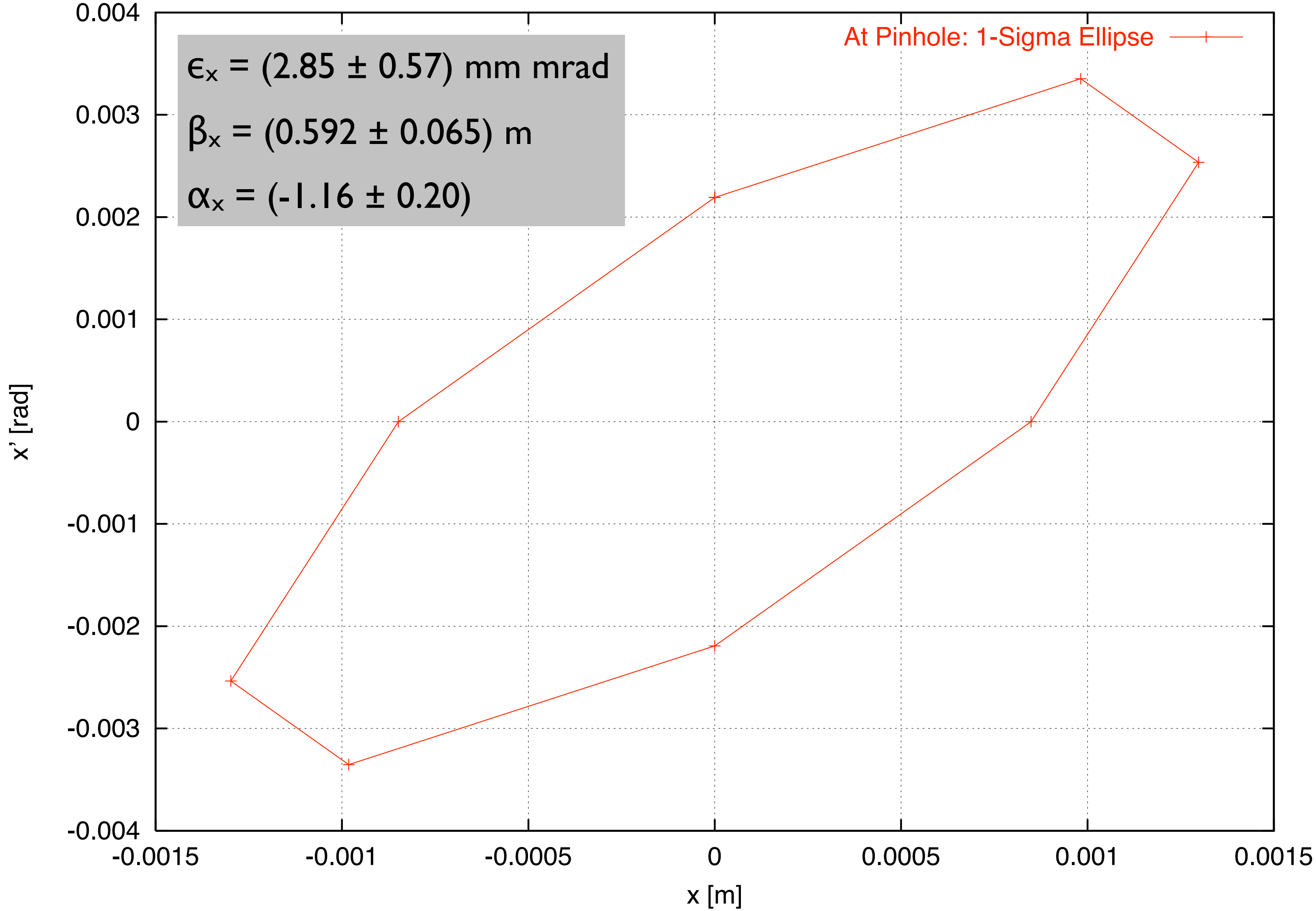
$$\sigma_i' = \sqrt{\langle (x_i - \overline{x}_i)^2 \rangle / L^2 - (\overline{x}_i')^2}$$





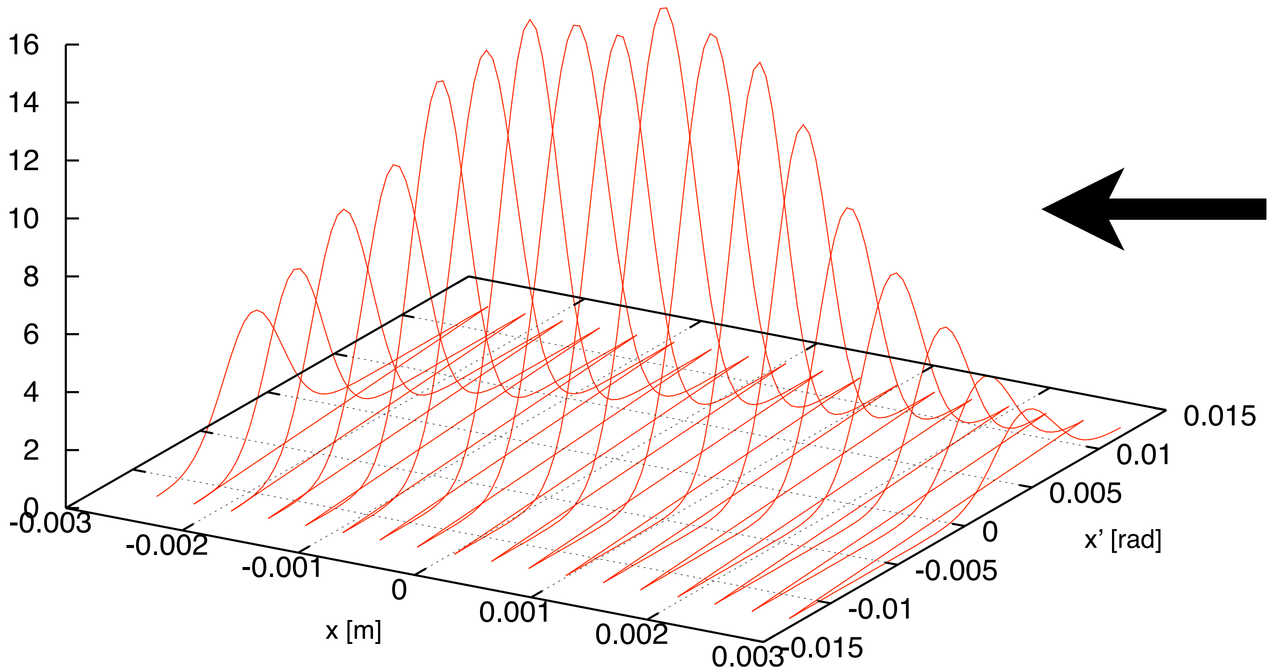
Pinhole Array Emittance Measurement (III)

- 1-sigma ellipse slices → second order moments → Courant-Snyder parameters



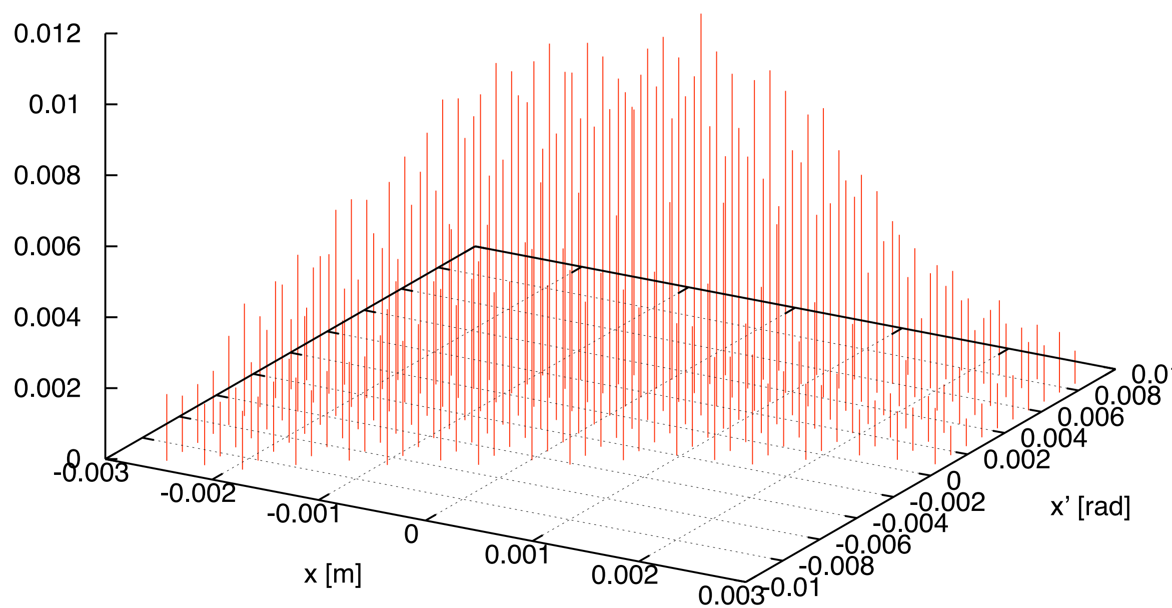
Pinhole Array Emittance Measurement (IV)

- Reconstruct not just twiss parameters, but full phase space distribution!

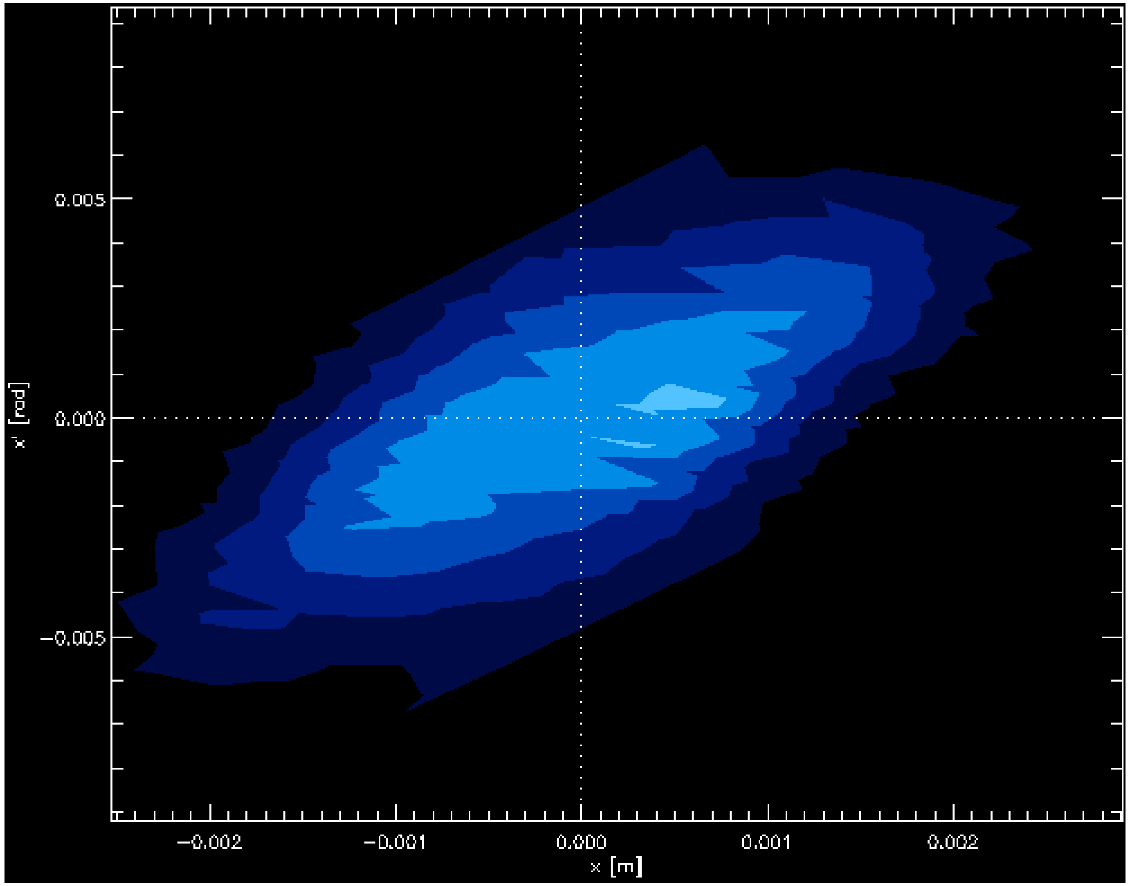


Relative intensities of beamlets correspond to relative intensities of bunch slices

Every pixel of the CCD image can be back-transformed to its source point in phase space!



Pinhole Array Emittance Measurement (V)



- Pinhole array emittance measurements in agreement with single slit and solenoid scan measurements
- Pro: One image allows reconstruction of full transverse phase space; when used in pepper-pot configuration measure emittance evolution along beam path!
- Con: SNR is crucial: low SNR increases error margins and introduces systematic errors (background subtraction!)

Conclusion & Outlook

- Different emittance measurement methods are in agreement
- Transverse phase space can be reconstructed
- Beam intensity remains a problem (better SNR → lower errors on results)
- Install 3D manipulator
  - Correct for misalignment
  - Change accelerating gap → modify focussing properties of diode structure
- Test stand can now be used to compare beam quality of different sources
  - Spindt-type FEAs (SRI)
  - LMN FEAs (focussing layer!)
  - Single tip, laser-induced field emission