A Transverse Profile Imager for Ionizing Radiation

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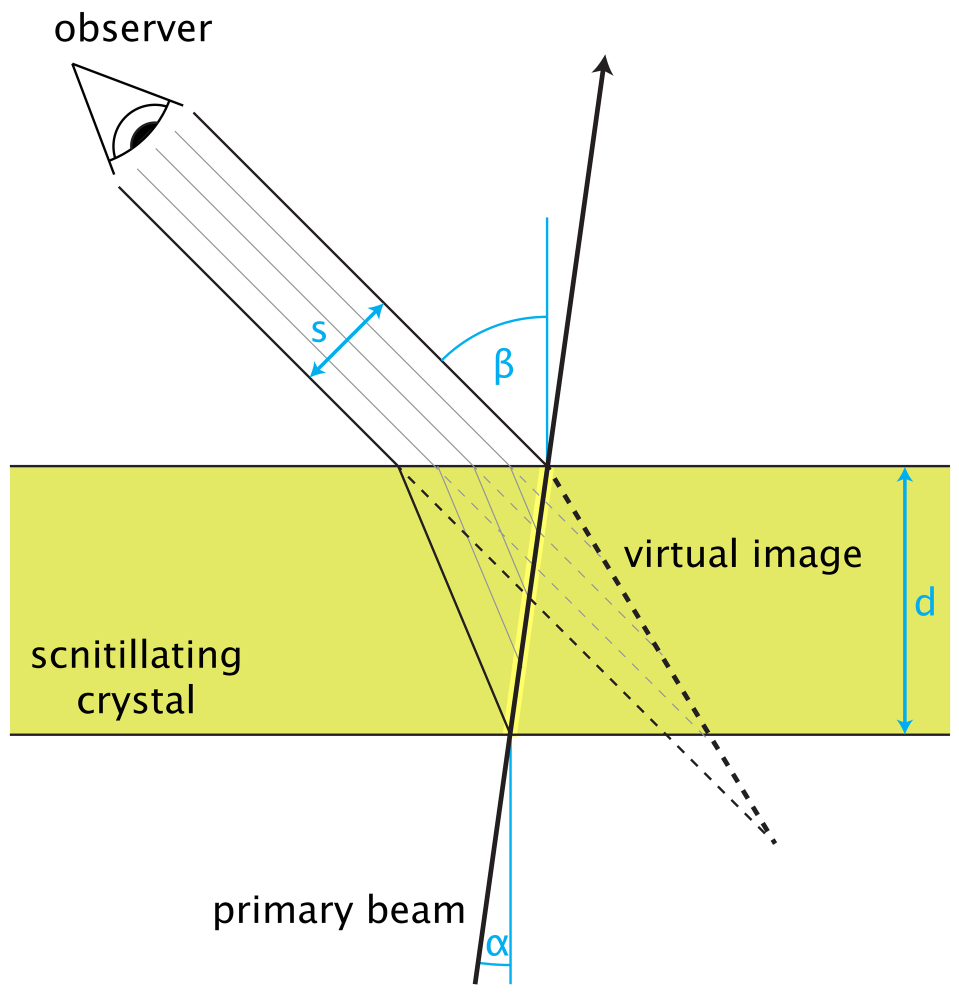
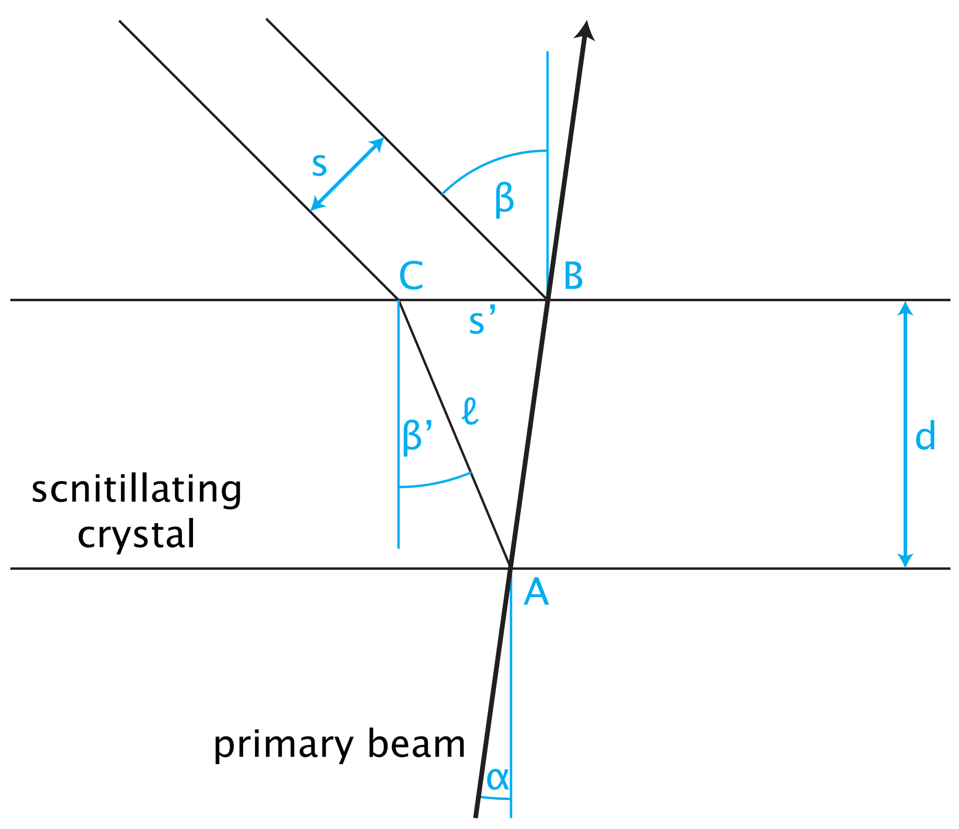
Imaging of Scintillating Crystals

Energy deposited in a scintillating crystal leads to the emission of light, which is then imaged onto an image sensor such as a CCD or CMOS sensor.



The primary beam produces a uniformly radiating slab of length $d \cos \alpha$, which is observed at a distance much larger than d, under an angle β to the normal. We assume an index of refraction n in the crystal, surrounded by vacuum. Because of refraction on the surface of the crystal, the observer sees a virtual image of this slab, shown by a dashed line.



From the Snell-Descartes law of refraction (actually first described by Ibn Sahl: On Burning Mirrors and Lenses (984)), and from basic trigonometry...

$$\frac{\sin\beta}{n} = \sin\beta'$$

$$\ell := \overline{AB} = \frac{d}{\cos\beta'}$$

$$s' := \overline{BC} = \frac{s}{\cos\beta}$$

$$s'^2 = \ell^2 + \left(\frac{d}{\cos\alpha}\right)^2 - 2\ell\frac{d}{\cos\alpha}\cos(\alpha+\beta')$$

...one can derive an expression for the apparent transverse beam size s:

$$s = d\cos\beta \cdot \sqrt{\frac{1}{1-\frac{\sin^2\beta}{n^2}} + \frac{1}{\cos^2\alpha} - 2\frac{\cos\left(\arcsin\left(\frac{\sin\beta}{n}\right)+\alpha\right)}{\sqrt{1-\frac{\sin^2\beta}{n^2}}\cos\alpha}}$$

One can convince oneself that there is an observation angle β_{ideal} where $s = 0$:

$$\beta_{\text{ideal}} = -\arcsin(n\sin\alpha)$$

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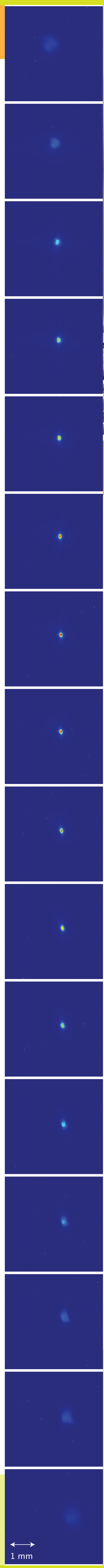
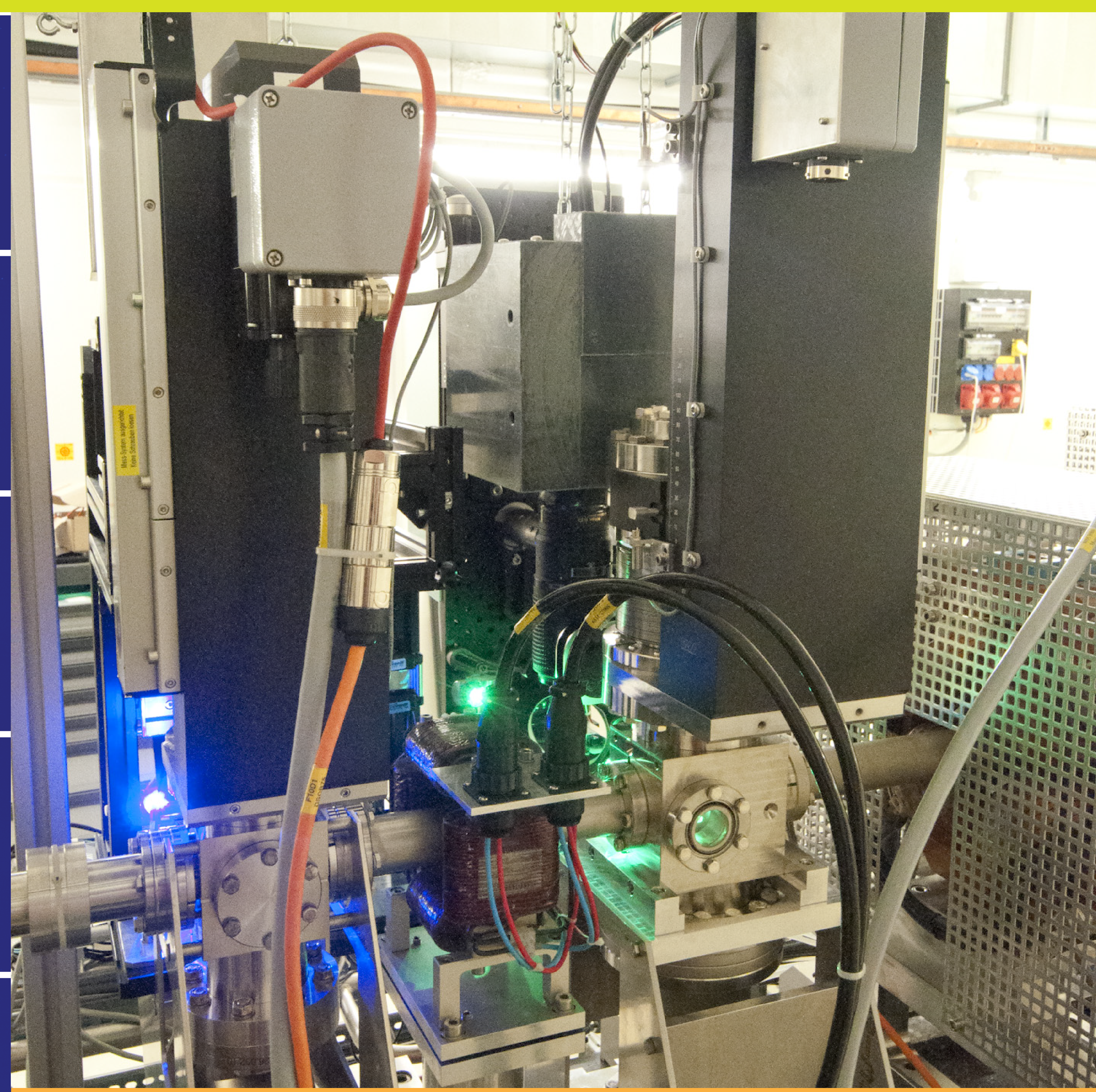


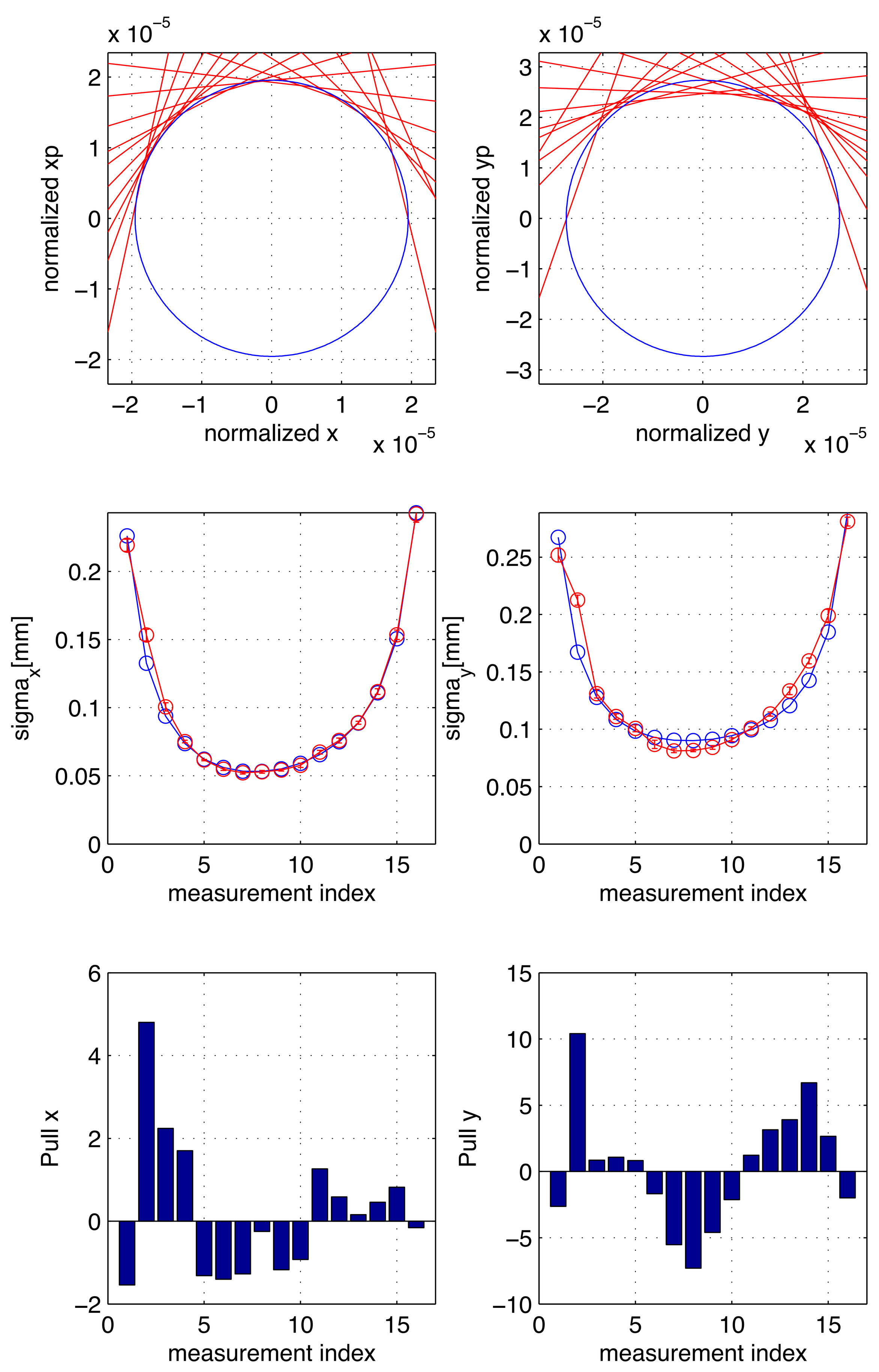


Measurements

Measurements were performed at the SwissFEL Injector Test Facility, using a 230 MeV electron beam of 10 pC bunch charge.

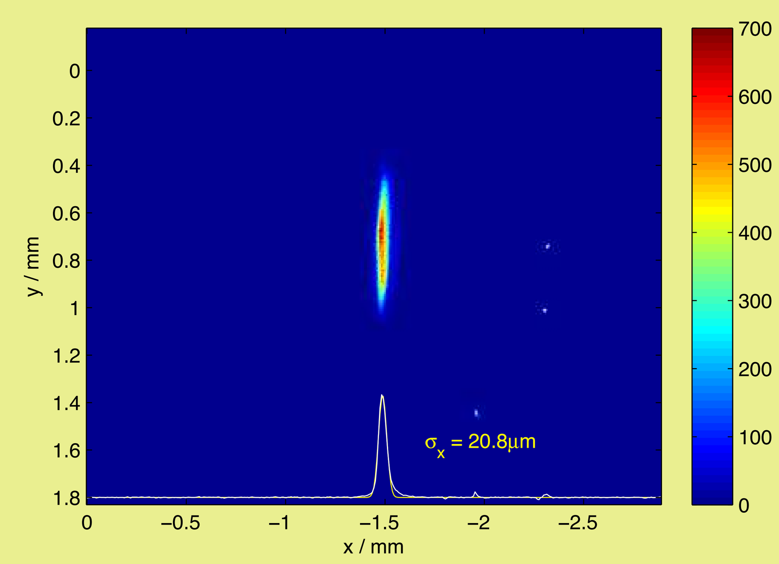
A quadrupole scan was used to measure emittance. The distance between the quadruple and the screen is 11.2 m, the scan covers a phase advance of 150°.

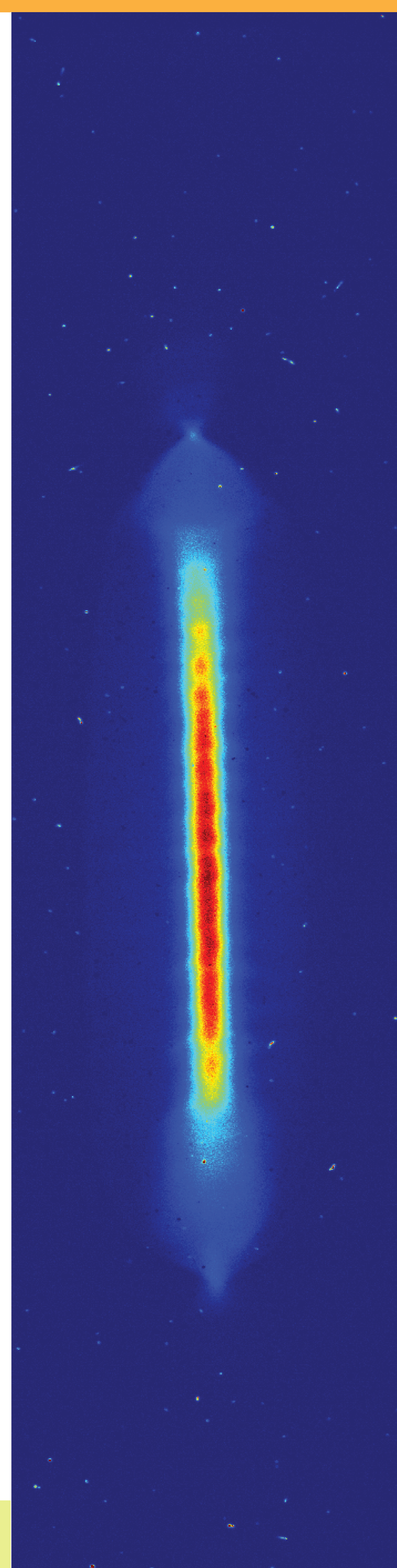
During the scan, the beam size varies between 50 and 250 µm.



From this measurement, ε_x = 172 nm and ε_y = 336 nm.

A smaller horizontal beam size was generated by sending the electron bunches through a 20 µm slit at an energy of 7 MeV. The remaining bunch has a charge of 100 fC. Acceleration to an energy of 230 MeV and imaging the slit onto the screen results in a horizontal beam size of 20.8 µm, well below the thickness of the scintillator.





Streaking the beam with an RF deflector allows to measure the slice emittance of 10 pC bunches.

For the present measurement, the bunch compressor was off.

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