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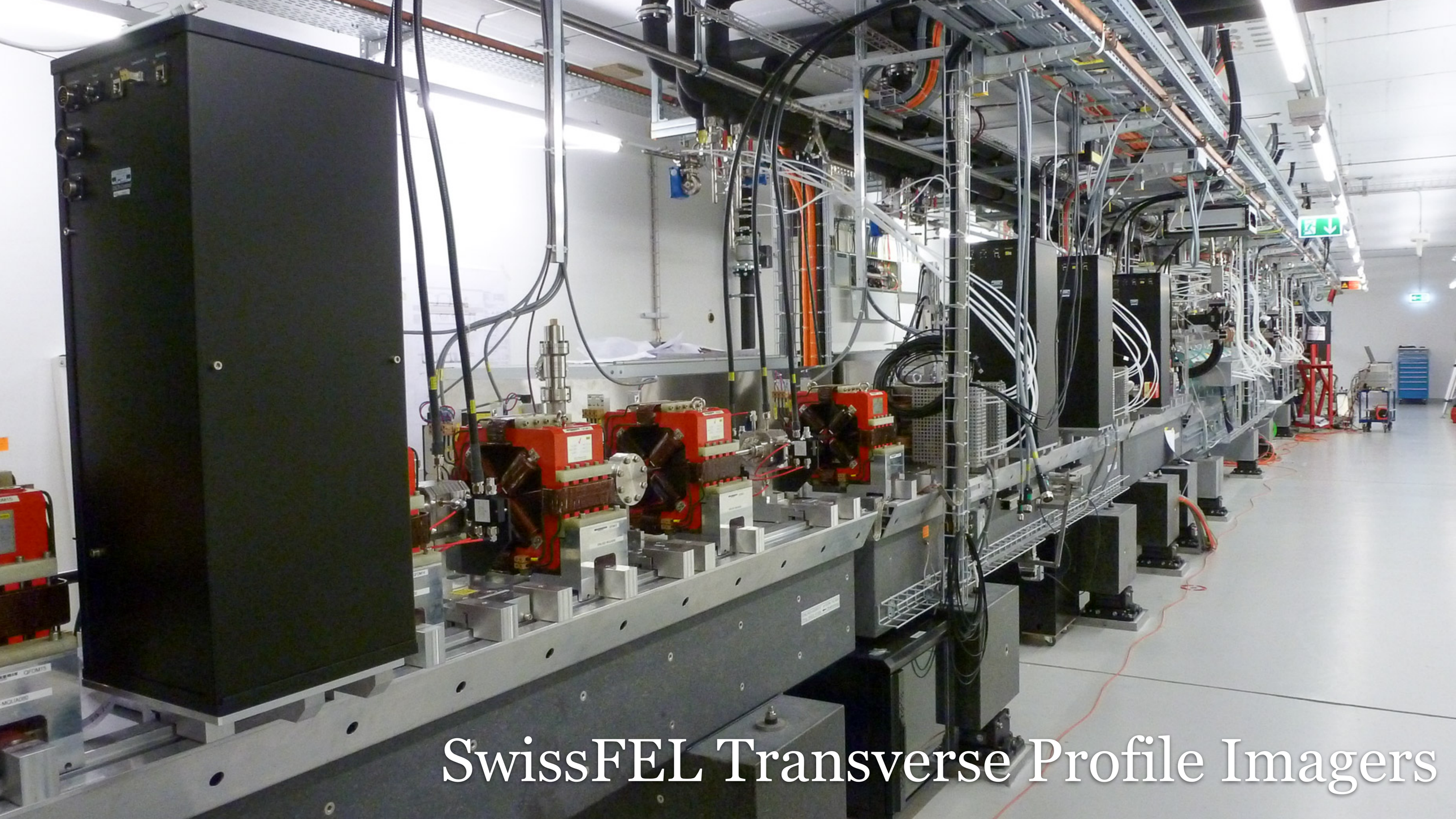
PSI

Rasmus Ischebeck

Screen Monitors in SwissFEL



SwissFEL Transverse Profile Imagers

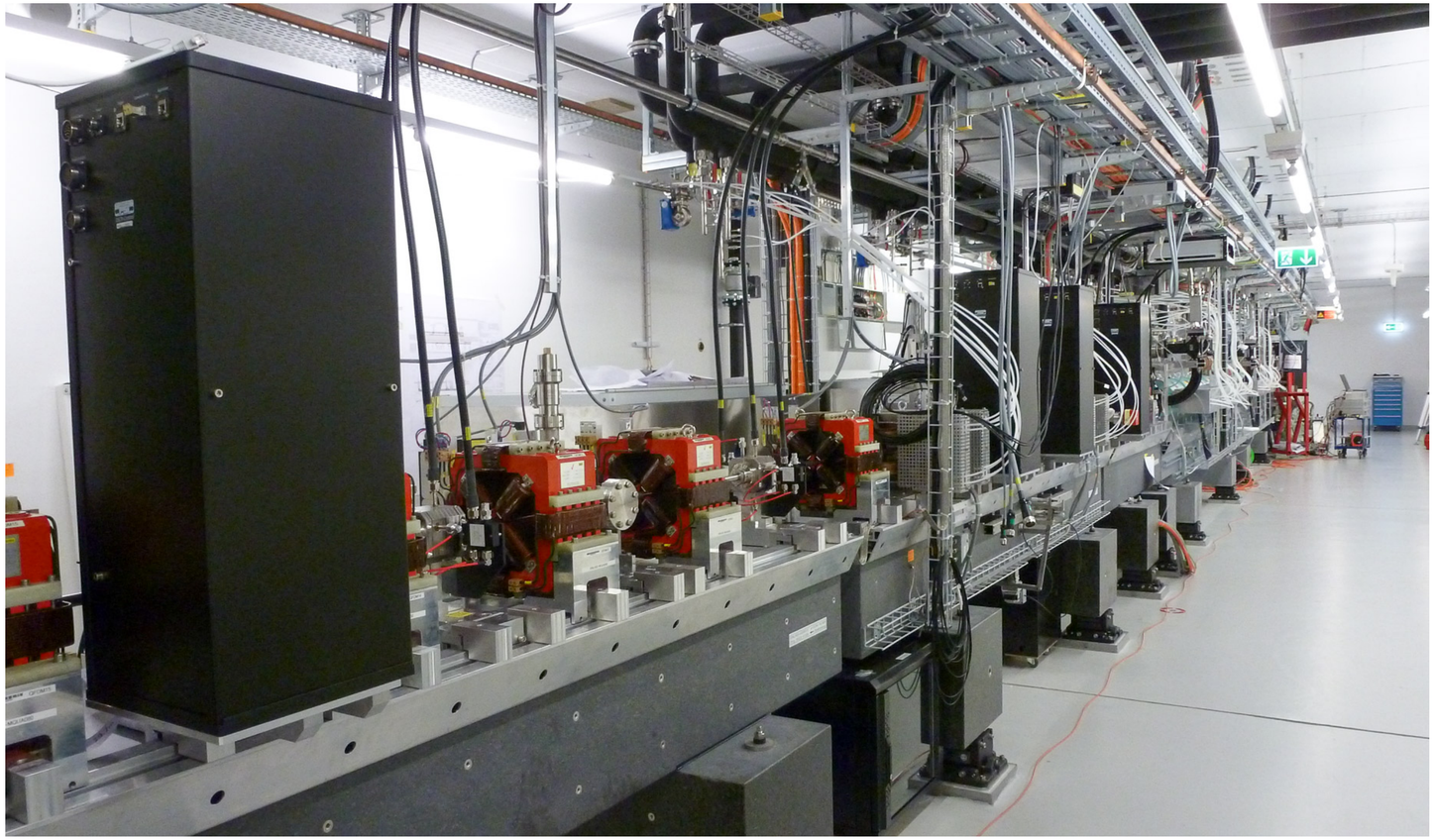
Electron Beam Parameters

- Typical values in SwissFEL:

Particle energy	5 MeV … 6 GeV
Bunch charge	10 … 200 pC
Beam size	30 µm … 1 mm rms
Pulse duration	10 fs … 10 ps
Peak current	up to few kA
Repetition rate	1 … 100 Hz

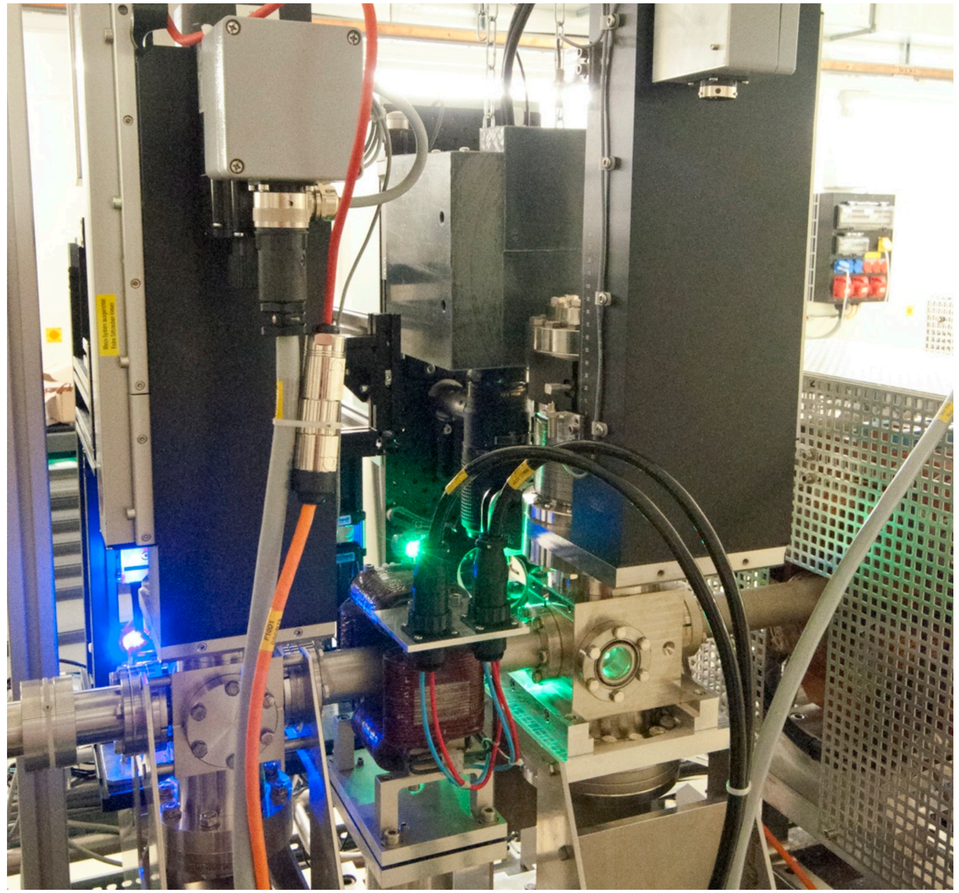
SwissFEL Transverse Profile Imagers

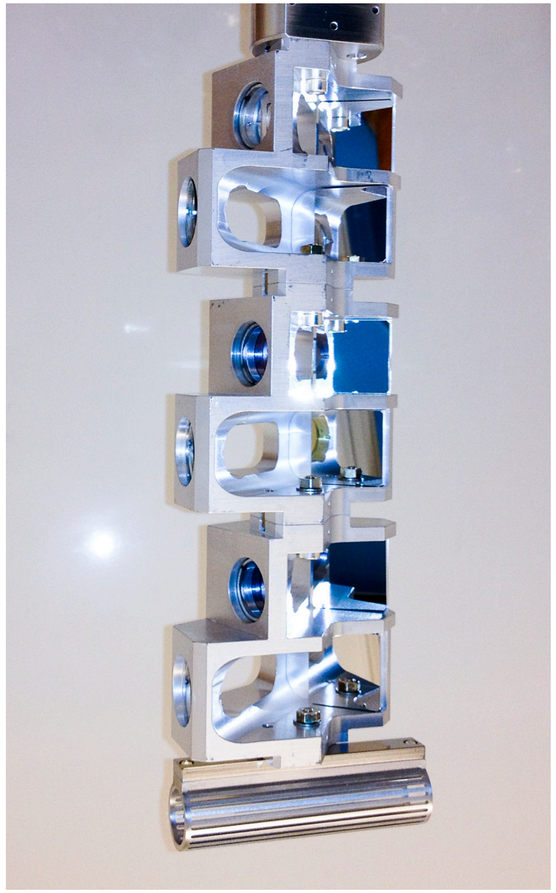
- 27 Transverse profile imagers for the electron beam installed in SwissFEL
- In routine operation since 2016



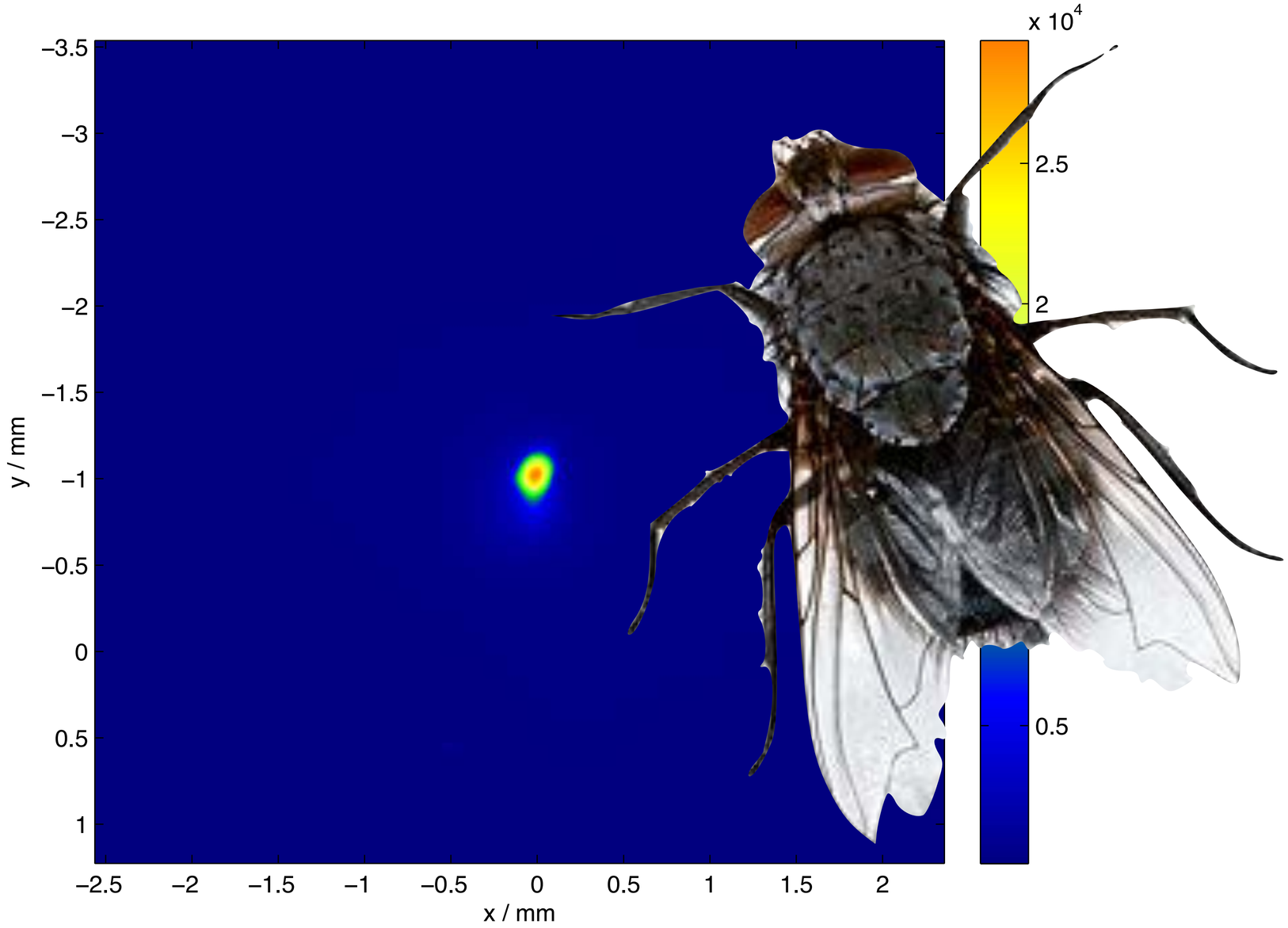
SwissFEL Transverse Profile Imagers

- Development in the SLS Injector and the SwissFEL Injector Test Facility in the years 2008 to 2014
- Test of different cameras, different scintillators and imaging geometries





Profile Measurement in FELs

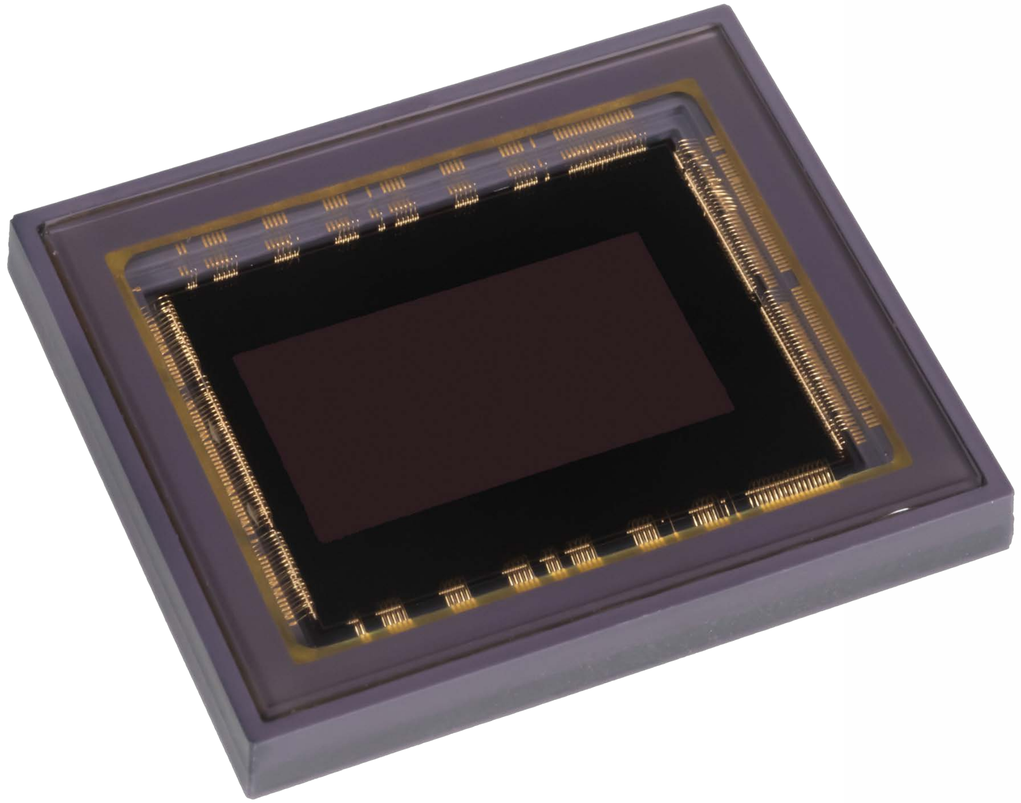


Design Goals

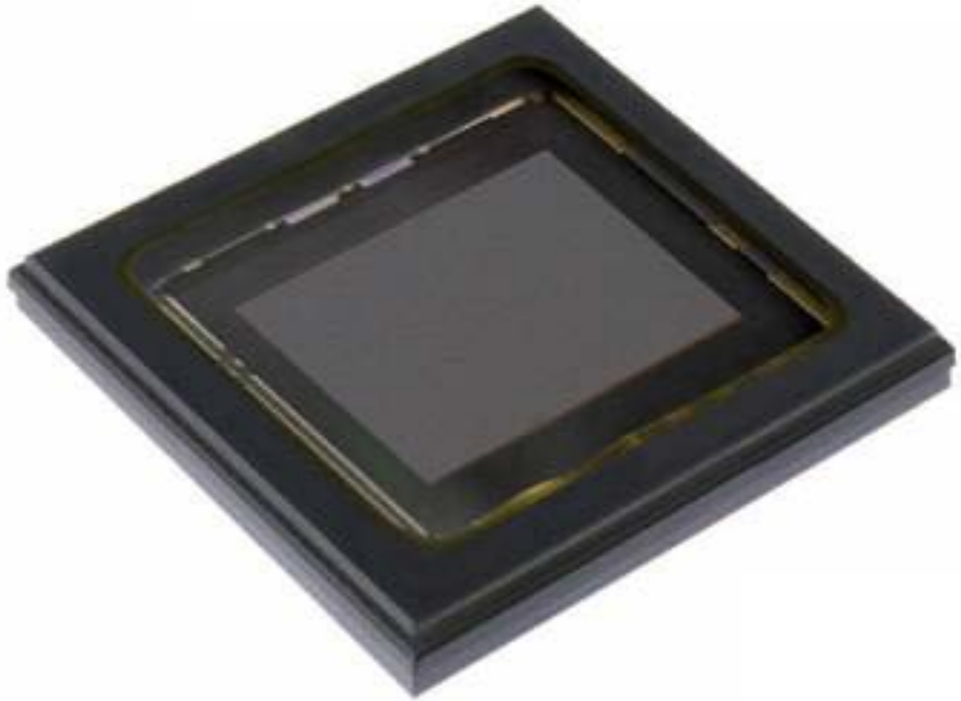
- Sensitivity for 10…200 pC
- Good linearity, high dynamic range
- 100 Hz readout
- 10 µm resolution
- Immunity to coherent optical transition radiation
- Radiation protection of lens and image sensor

Sensitivity, Linearity and Dynamic Range

- Scientific CMOS image sensor
- 16 bit ADC
- 5.5 megapixels, 50 frames per second (RS)



- CMOS image sensor
- 12 bit ADC
- 2.3 megapixels, 25 frames per second (12 bit)



Fairchild, Sony

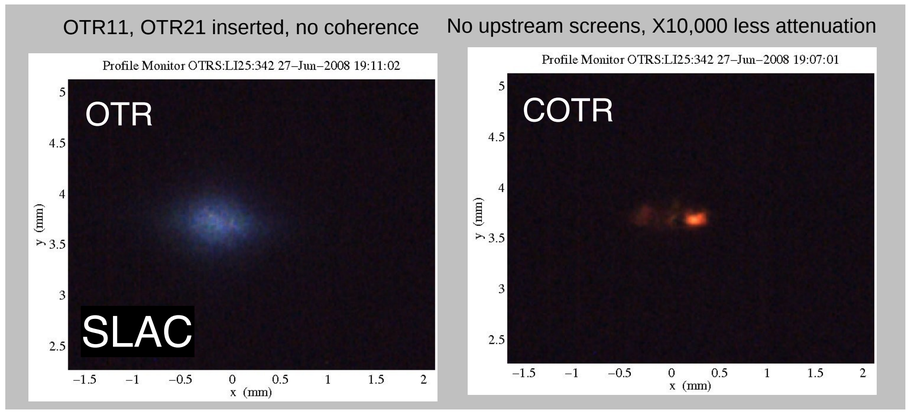
Camera Readout

- CameraLink HS

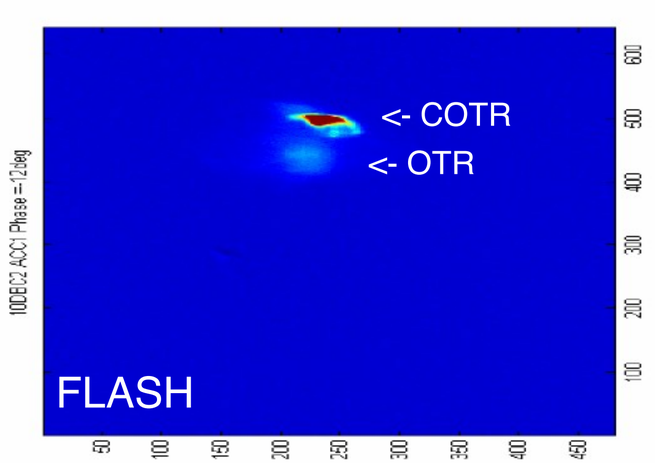
- Gigabit Ethernet

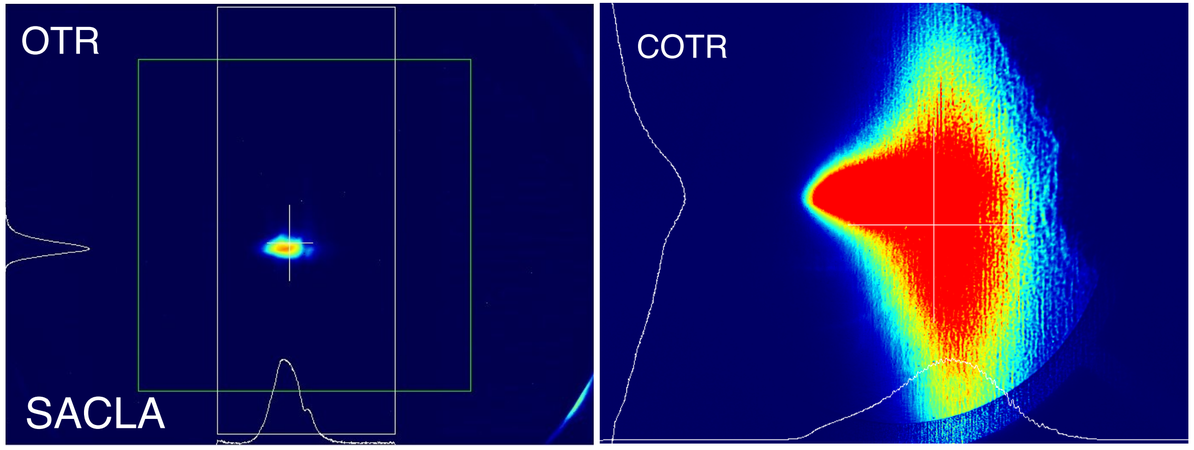
Immunity to Coherent Optical Transition Radiation

- Traditionally, we use optical transition radiation monitors to measure beam profile
- Highly compressed beams emit coherent radiation that disturbs the measurement
- First observed at LCLS, meanwhile also at FLASH and SACLA:



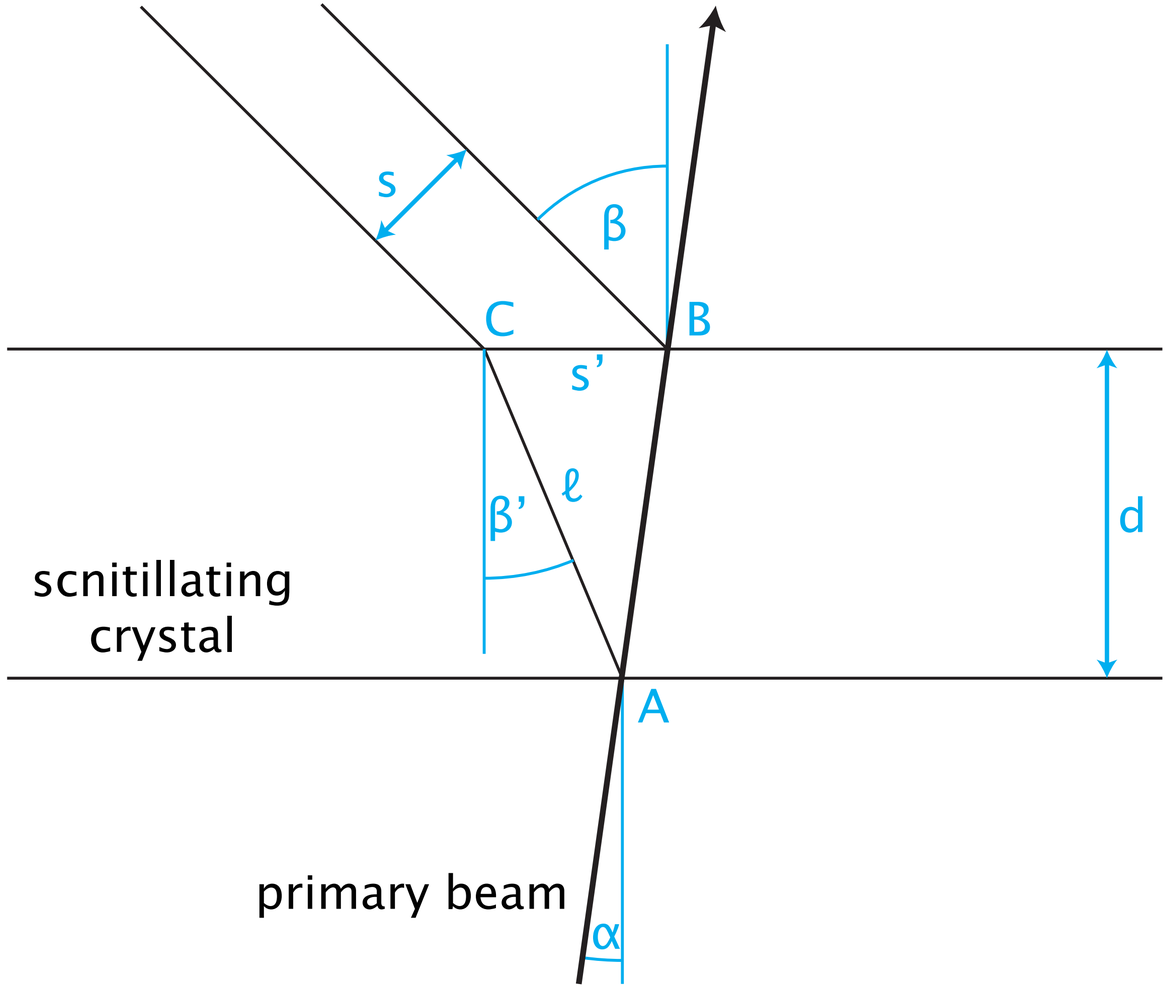
Joe Frisch, SLAC



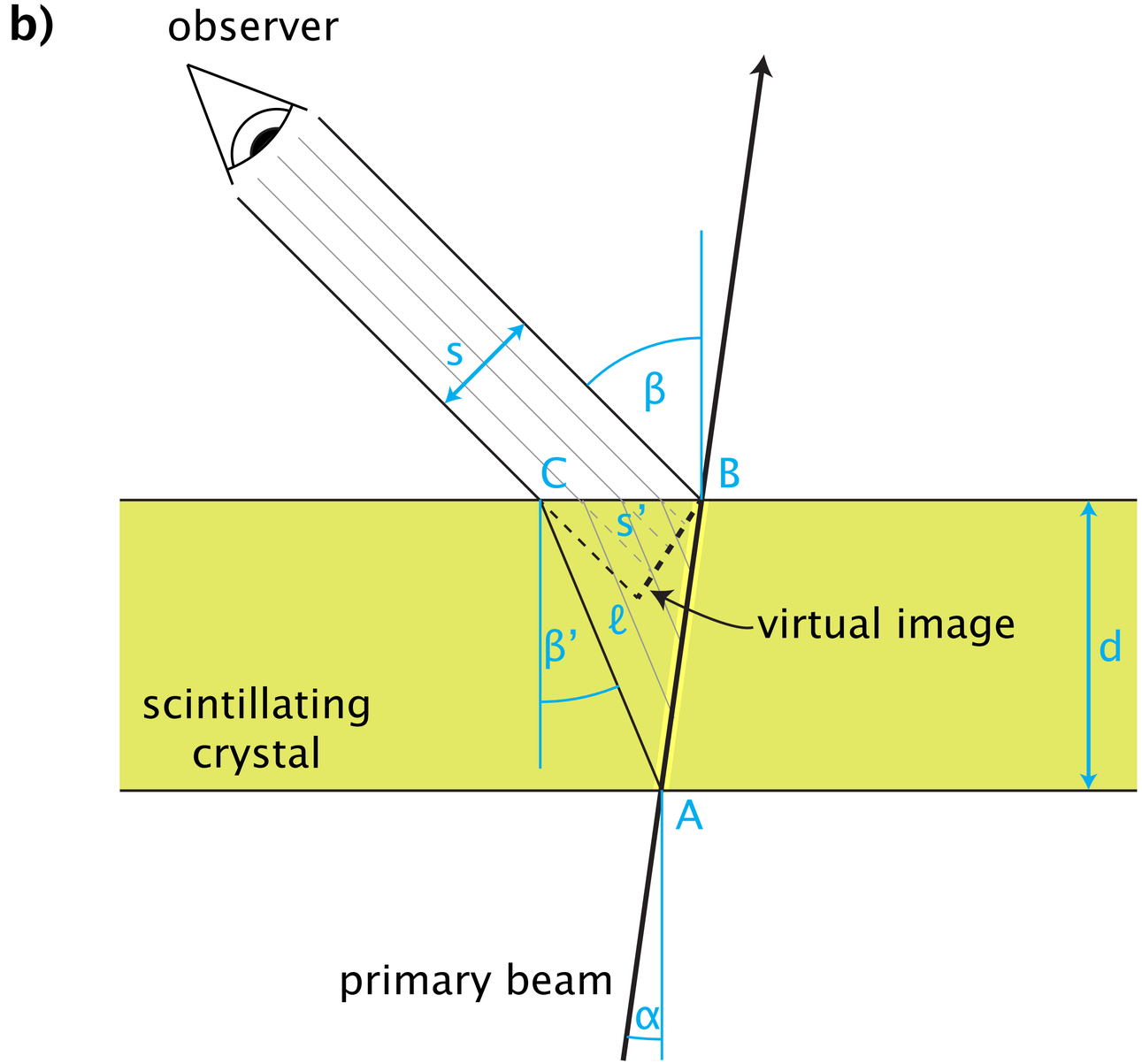


Yuji Otake, SACLA

Imaging Scintillating Crystals



Imaging Scintillating Crystals



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Trigonometry...

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

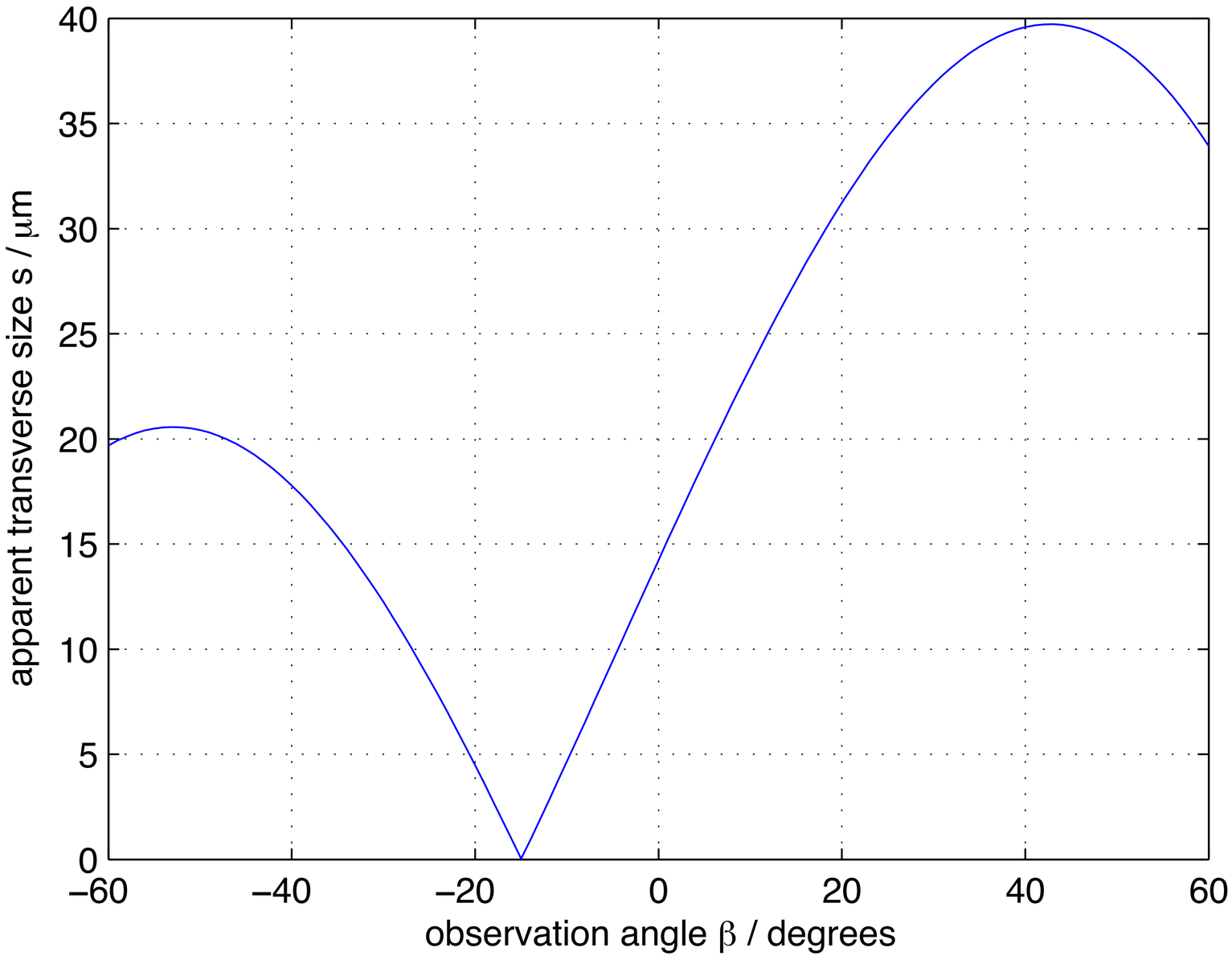
$$\ell := \overline{AB} = \frac{d}{\cos\beta'}$$

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

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

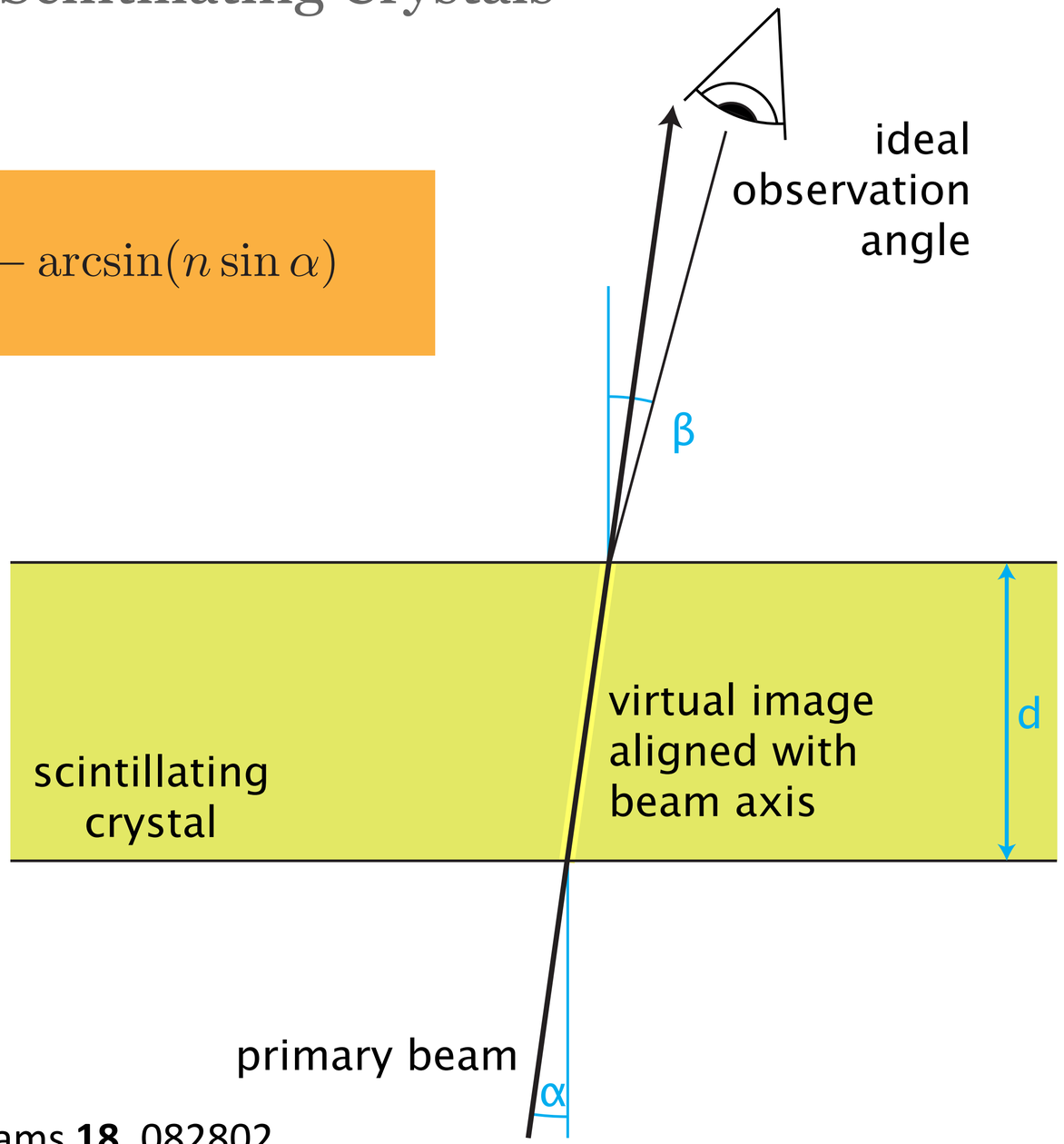
$$s = d\cos\beta \cdot \sqrt{\frac{1}{1-\frac{\sin^2\beta}{n^2}} + \frac{1}{\cos^2\alpha} - 2\frac{\cos\left(\arcsin\left(\frac{\sin\beta}{n}\right)+\alpha\right)}{\sqrt{1-\frac{\sin^2\beta}{n^2}}\cos\alpha}}$$

Observed Beam Size



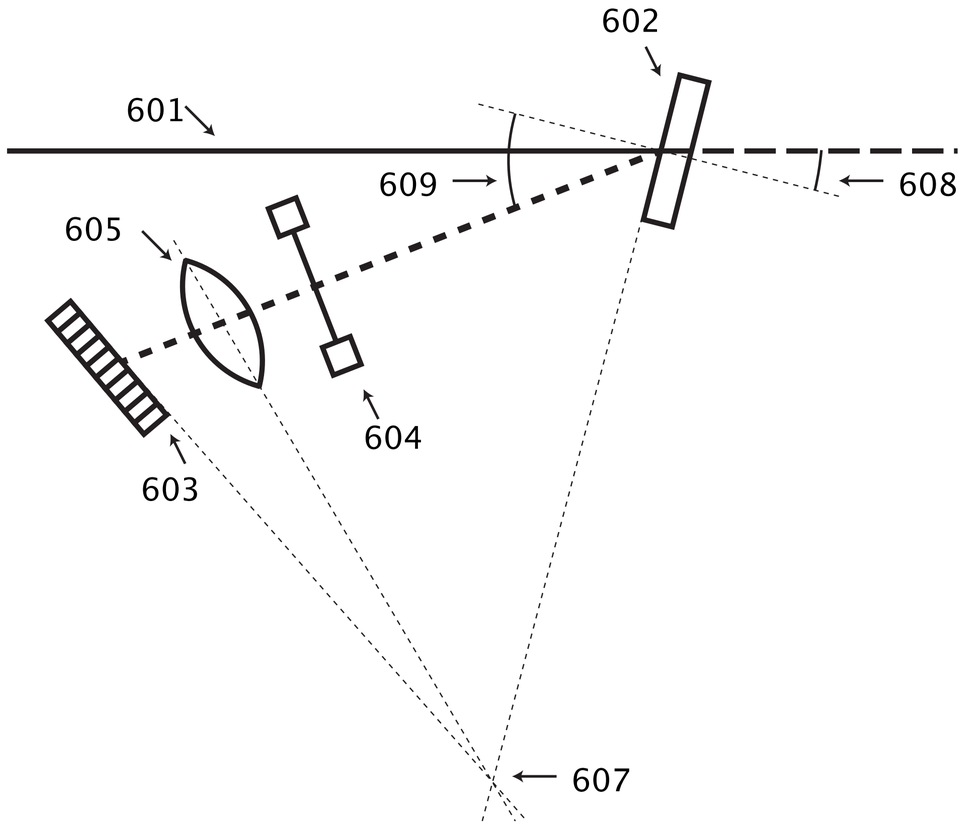
Imaging Scintillating Crystals

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

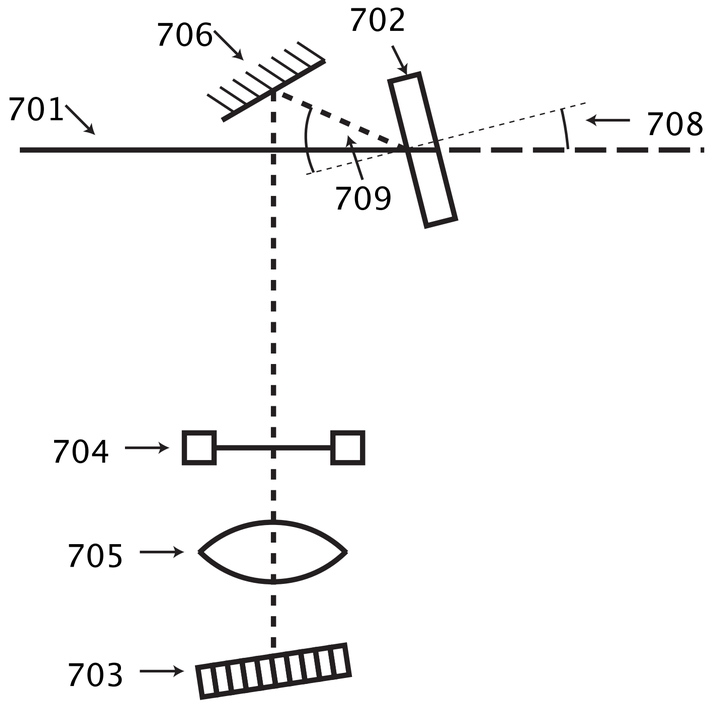


- Phys. Rev. ST Accel. Beams **18**, 082802

Ideal Observation Angle

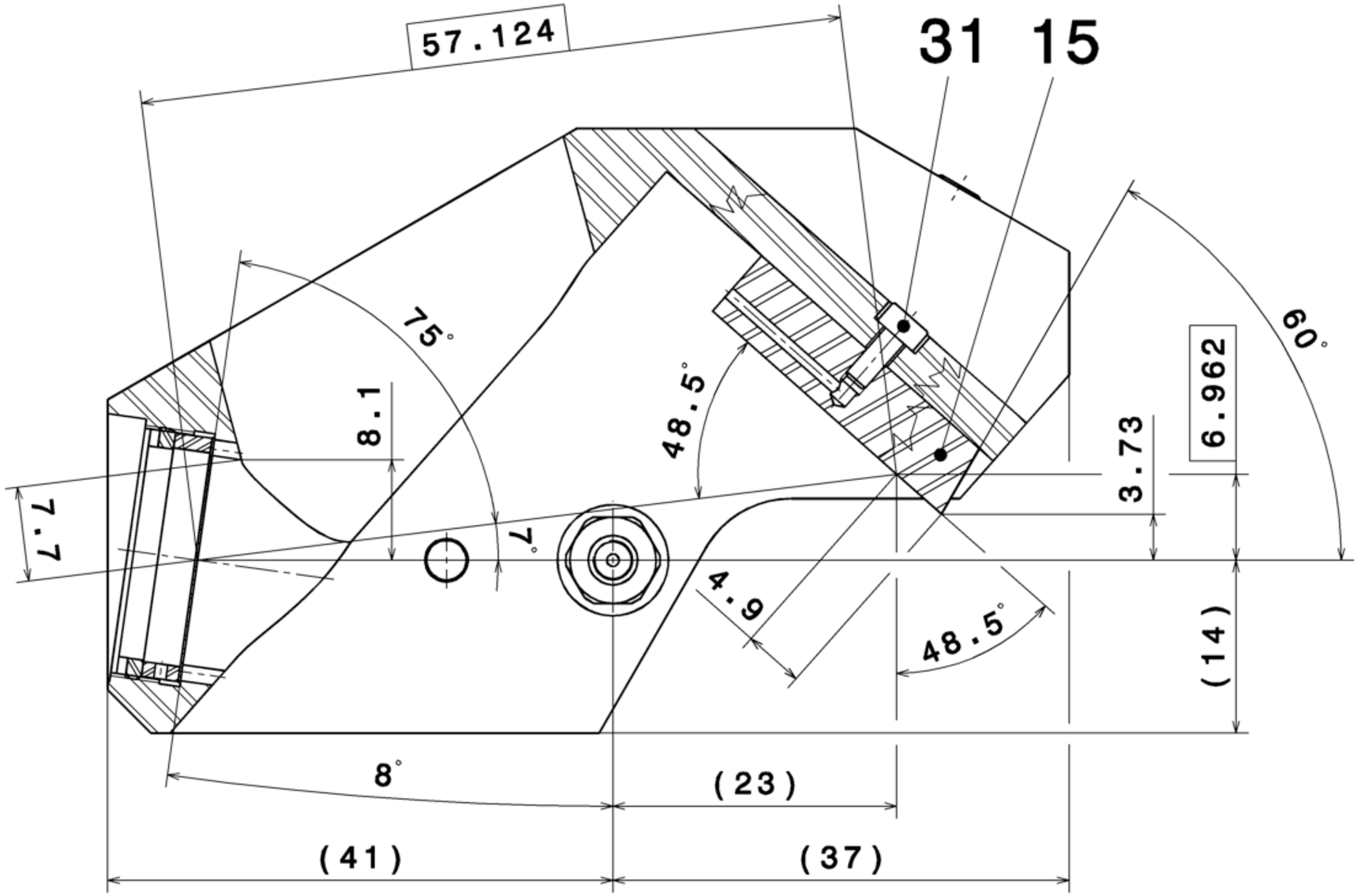


a)



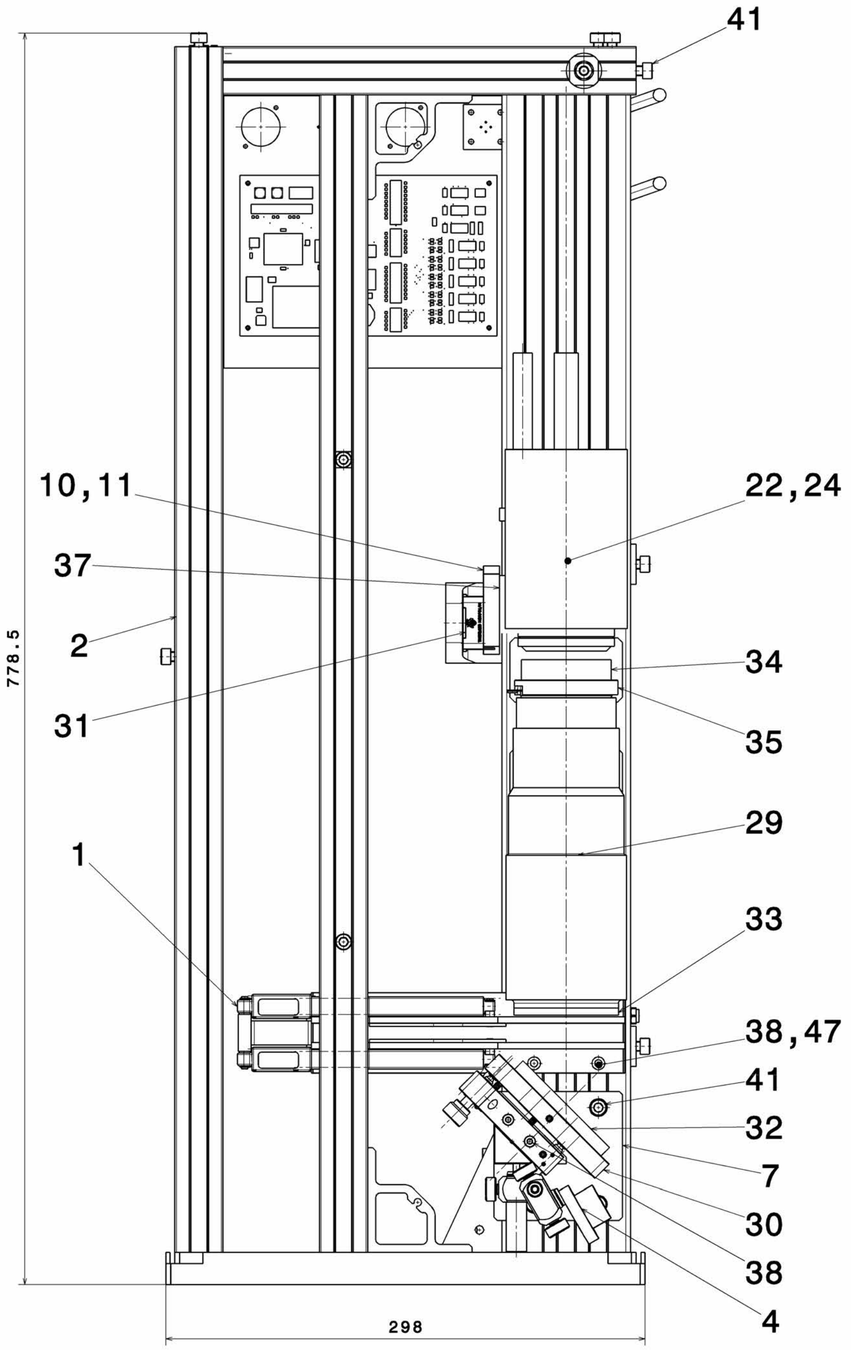
b)

Screen Holder



Camera Box

- Image sensor: tilted to fulfill Scheimpflug criterion
- Filters: increase dynamic range by a factor 1000



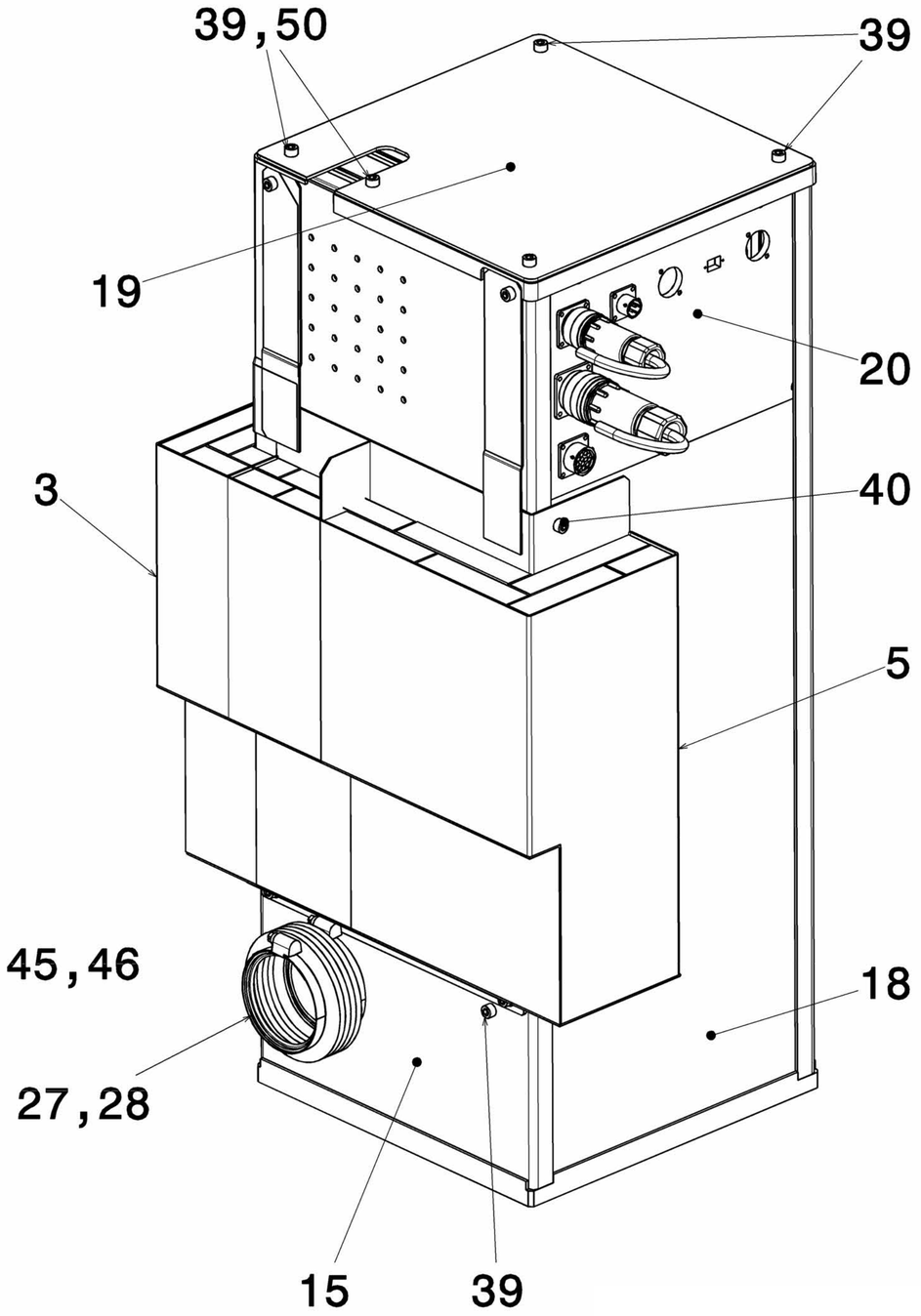
Shielding of the Camera

- Mirror to reflect light: radiation protection (ionizing radiation is not reflected, camera and lens can hide behind shielding

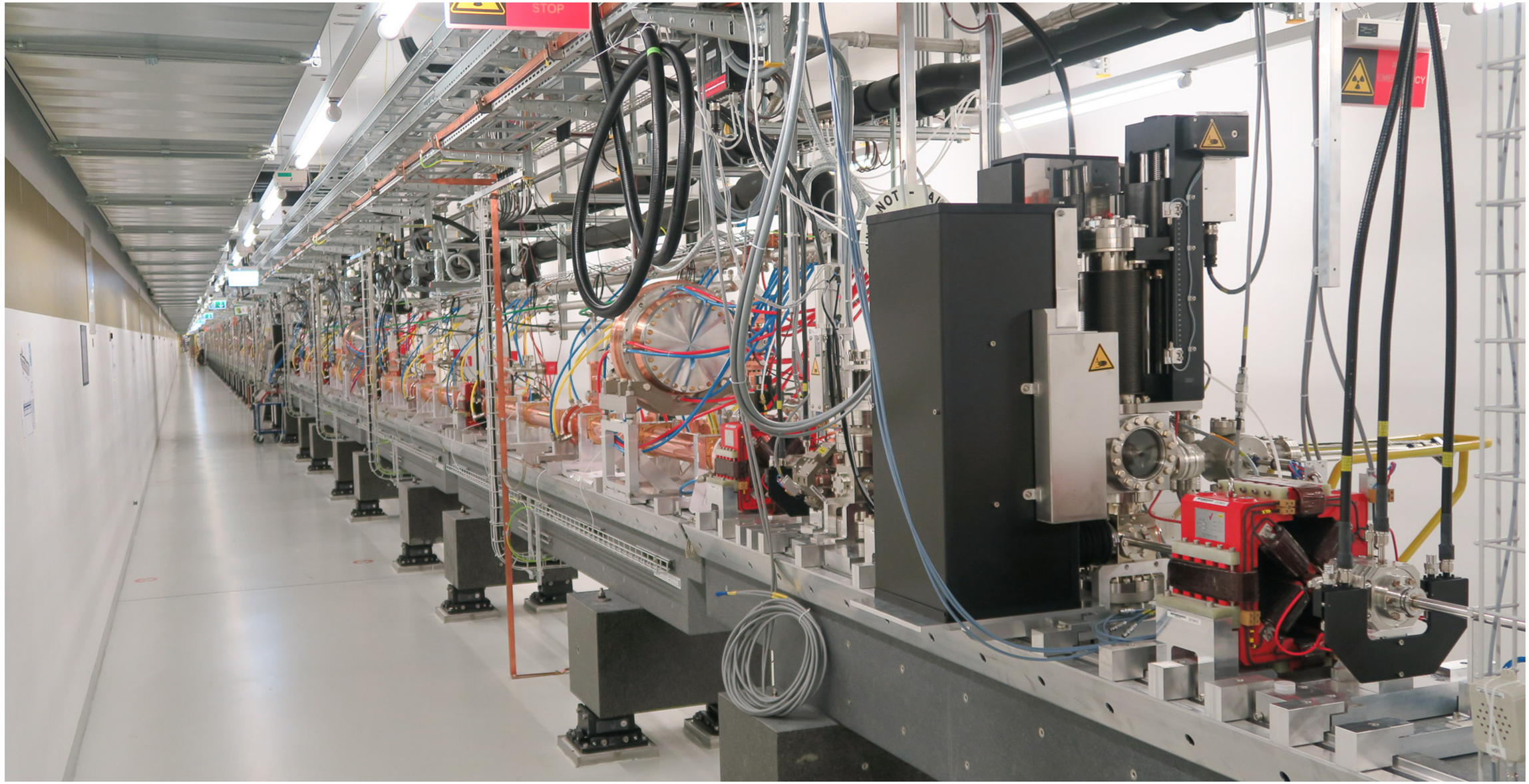
- 3 Components:
  - Lead: shield X-rays
  - Boron and polyethylene: shield neutrons

- Total weight of the camera box with shielding: 70 kg

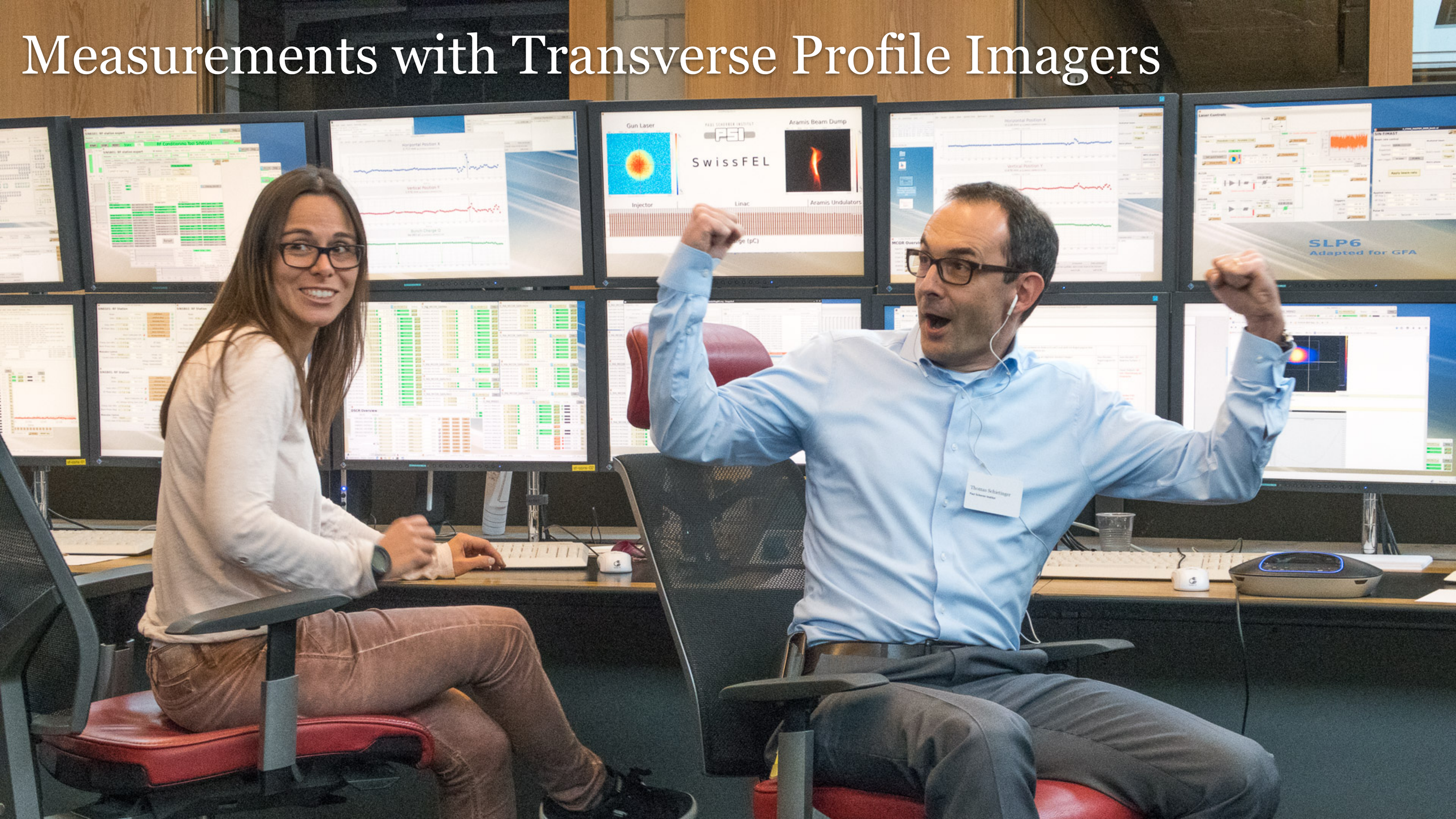
- Radiation is monitored with gafchromic paper



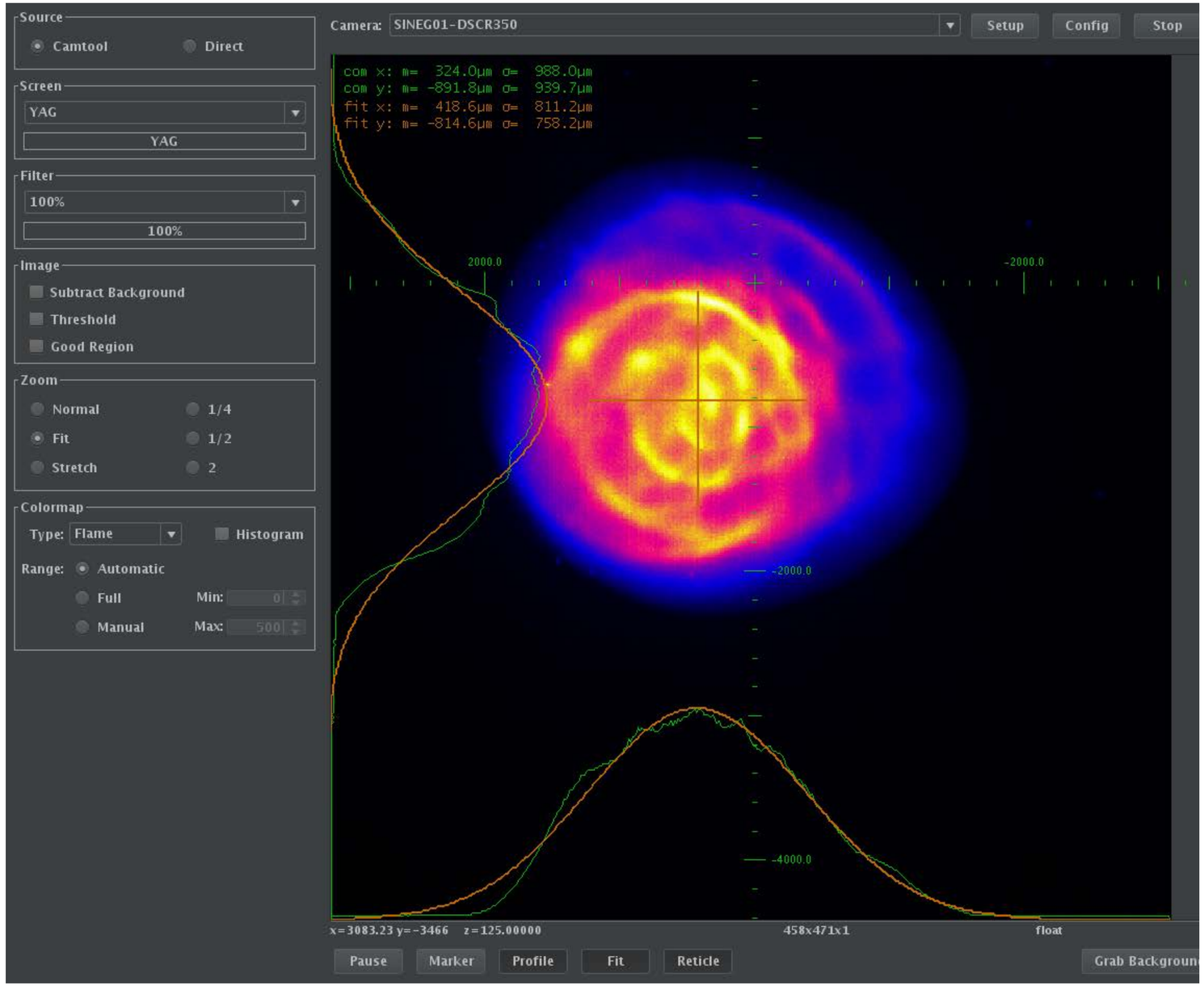
Shielding of the Camera

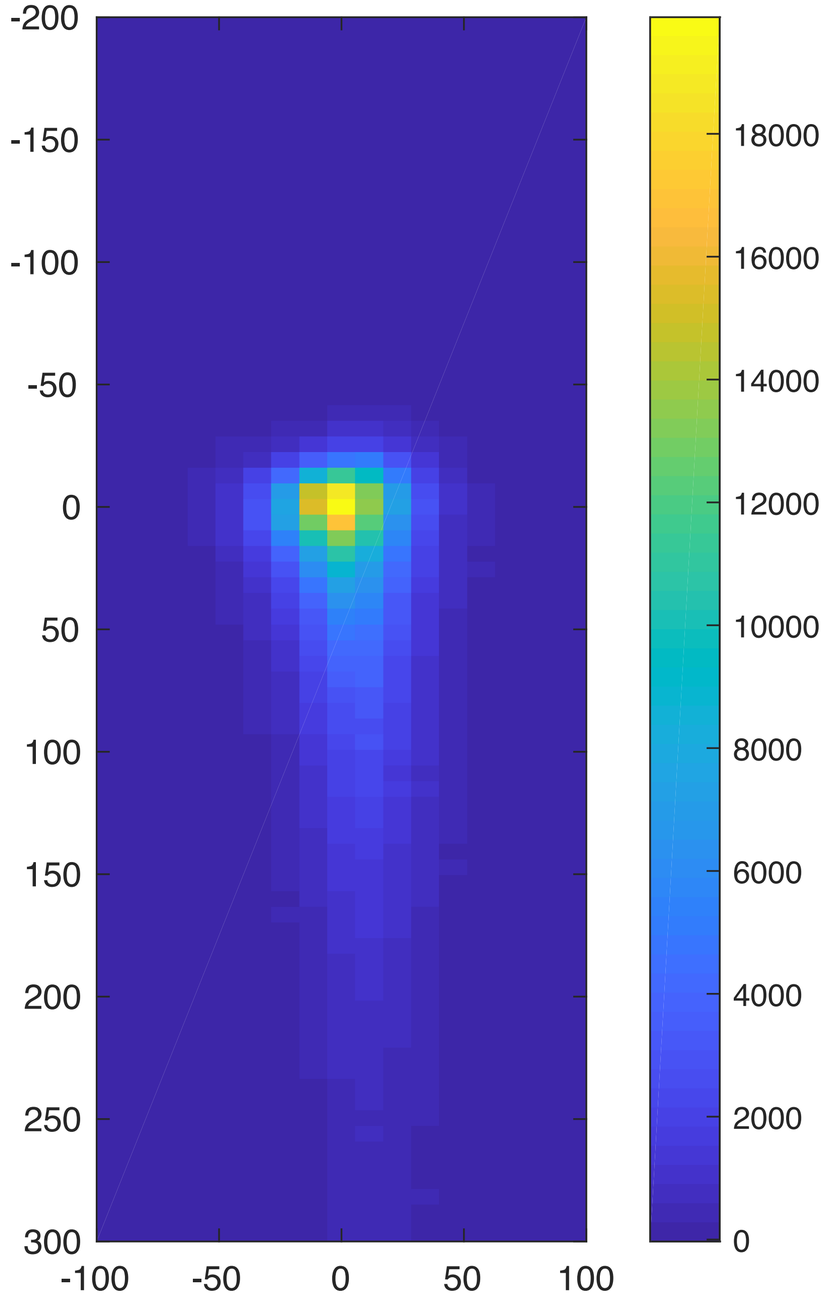


Measurements with Transverse Profile Imagers



Imaging of the Beam





Small beam (14 µm × 27 µm)

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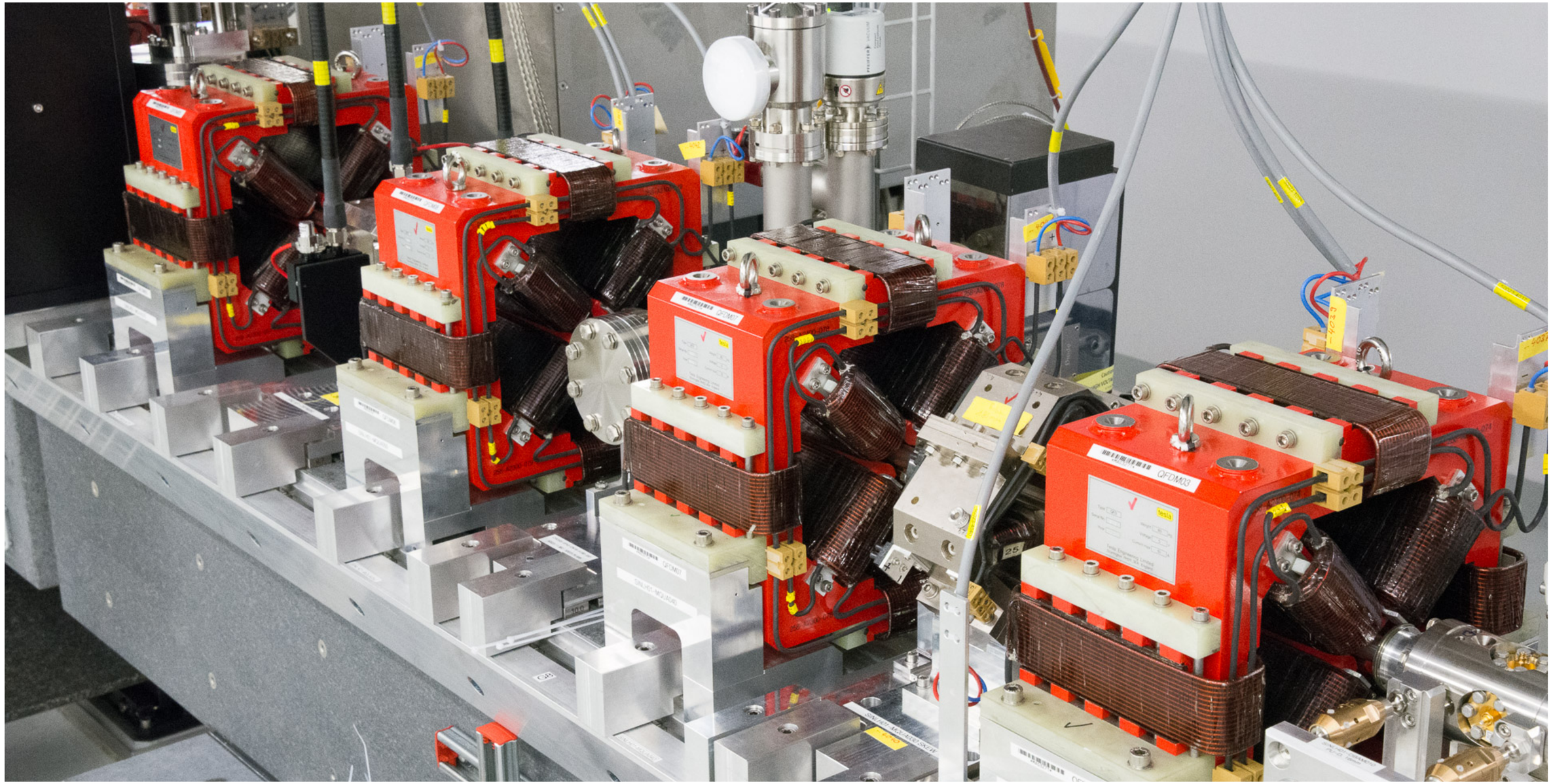
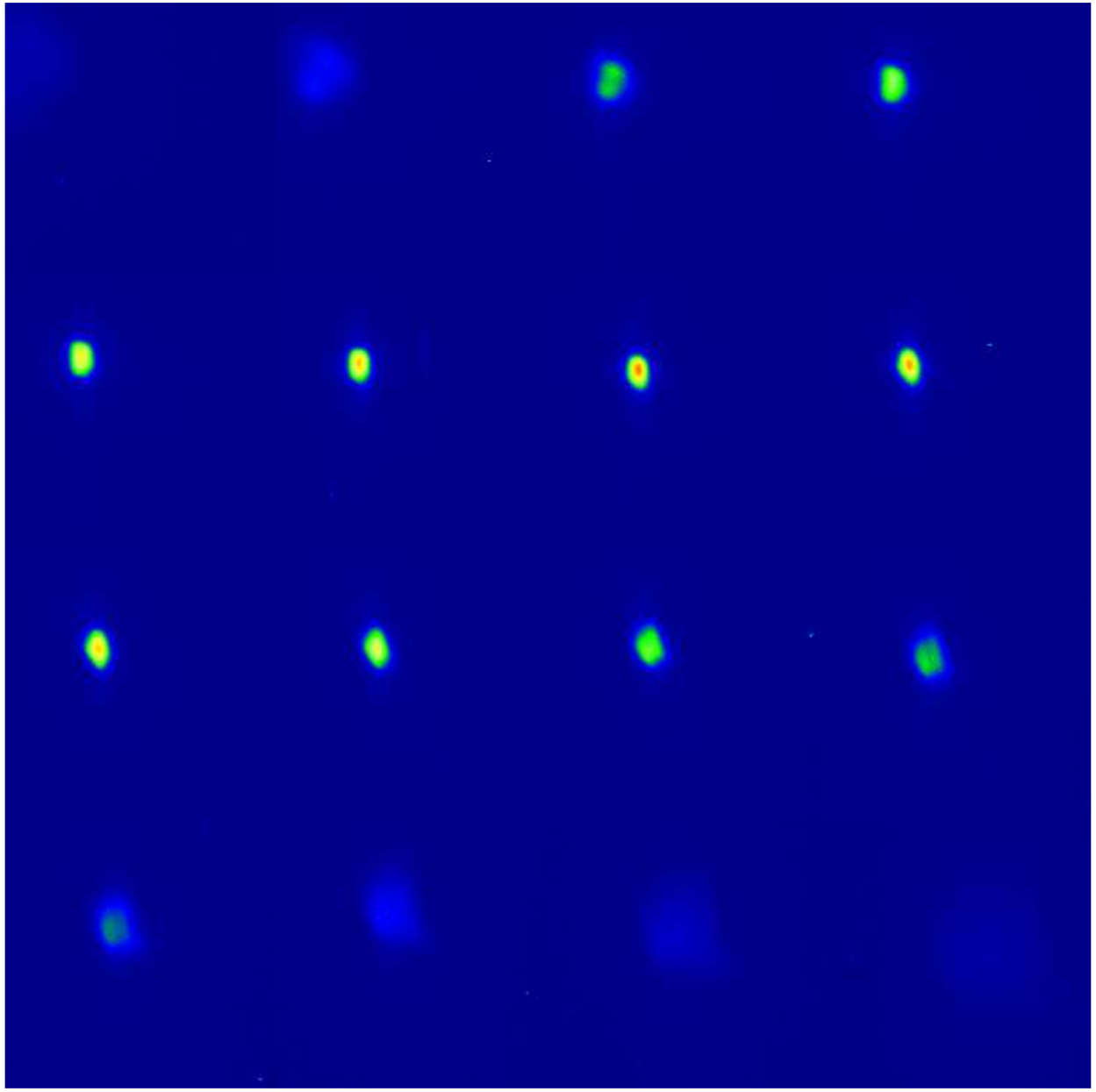
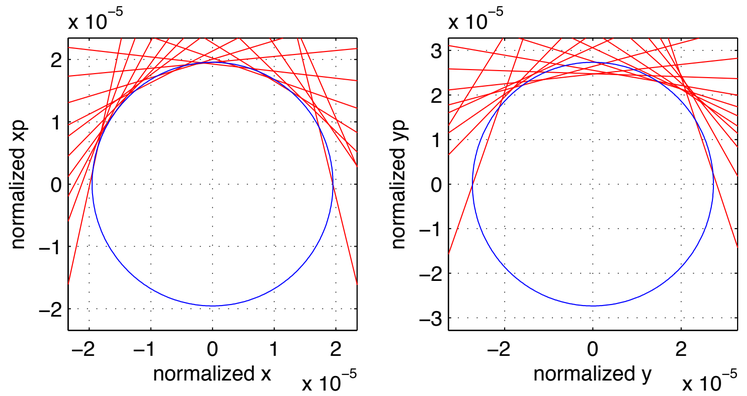
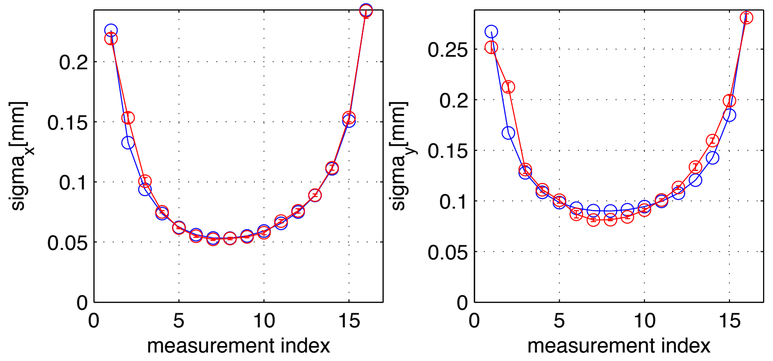
Quadrupole Magnets

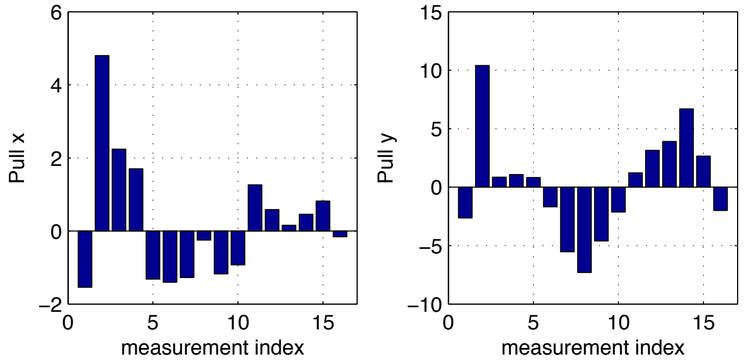


Emittance Measurement: Quadrupole Scan

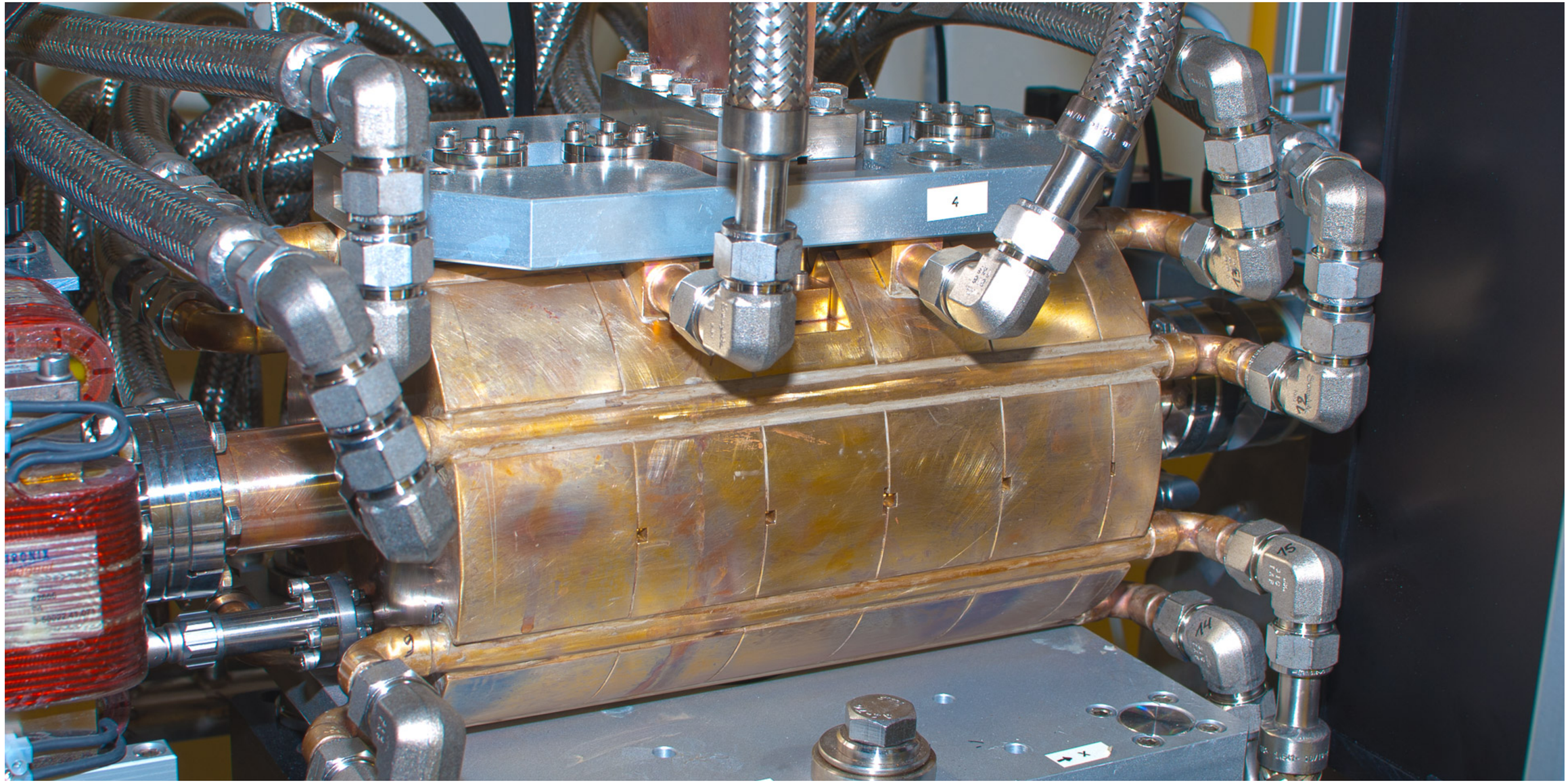






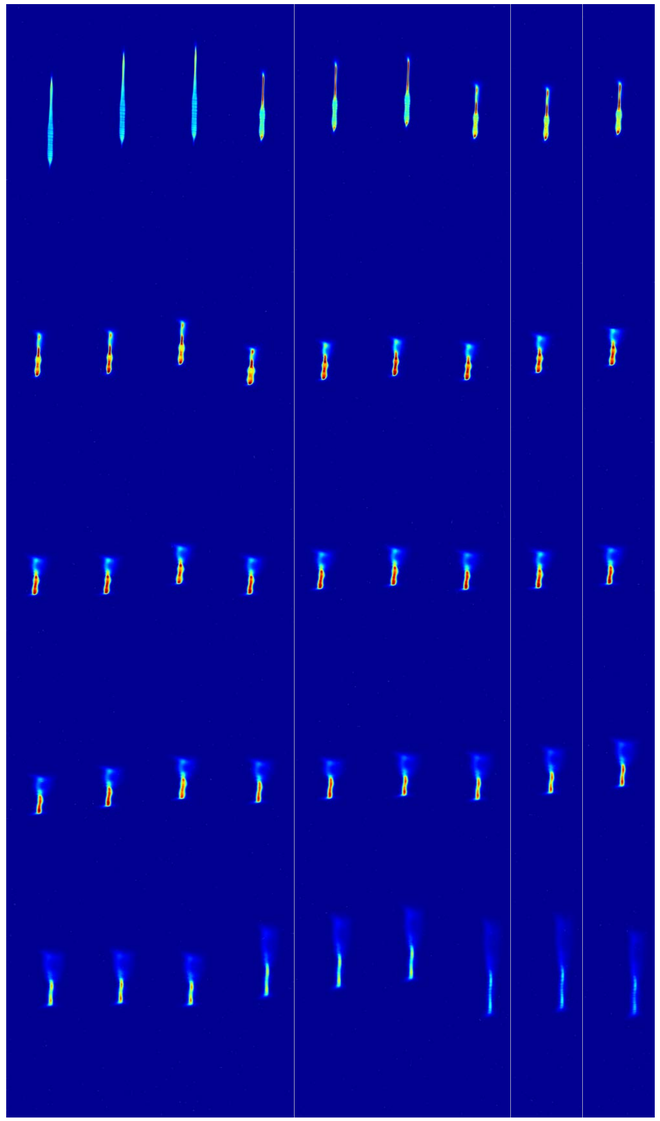


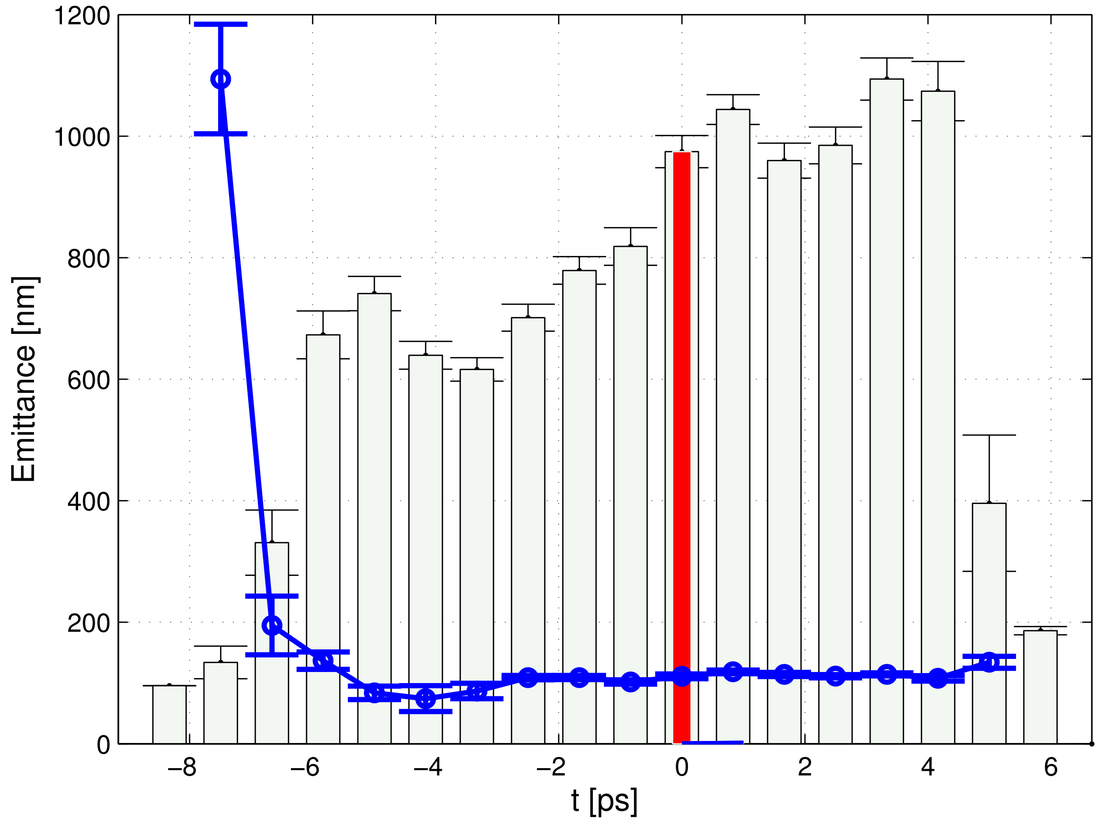
Deflecting Cavity



Measurements with the Prototype

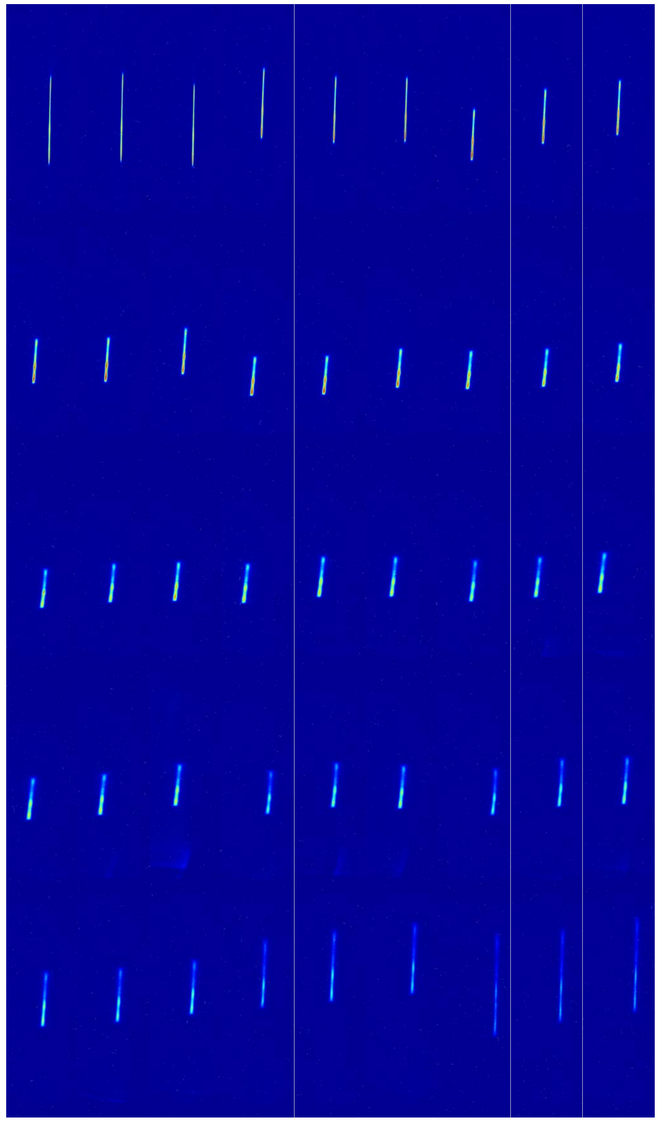
- Slice emittance measurement of a 10 pC beam

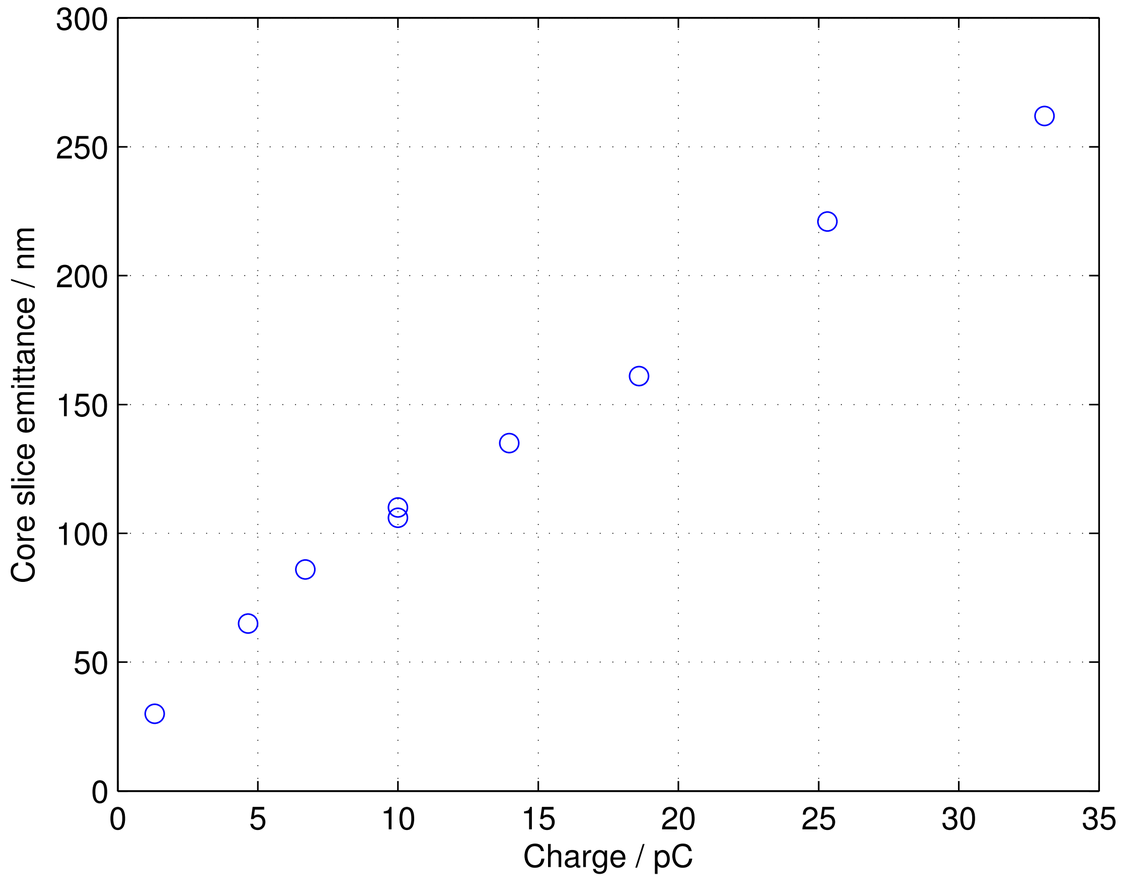




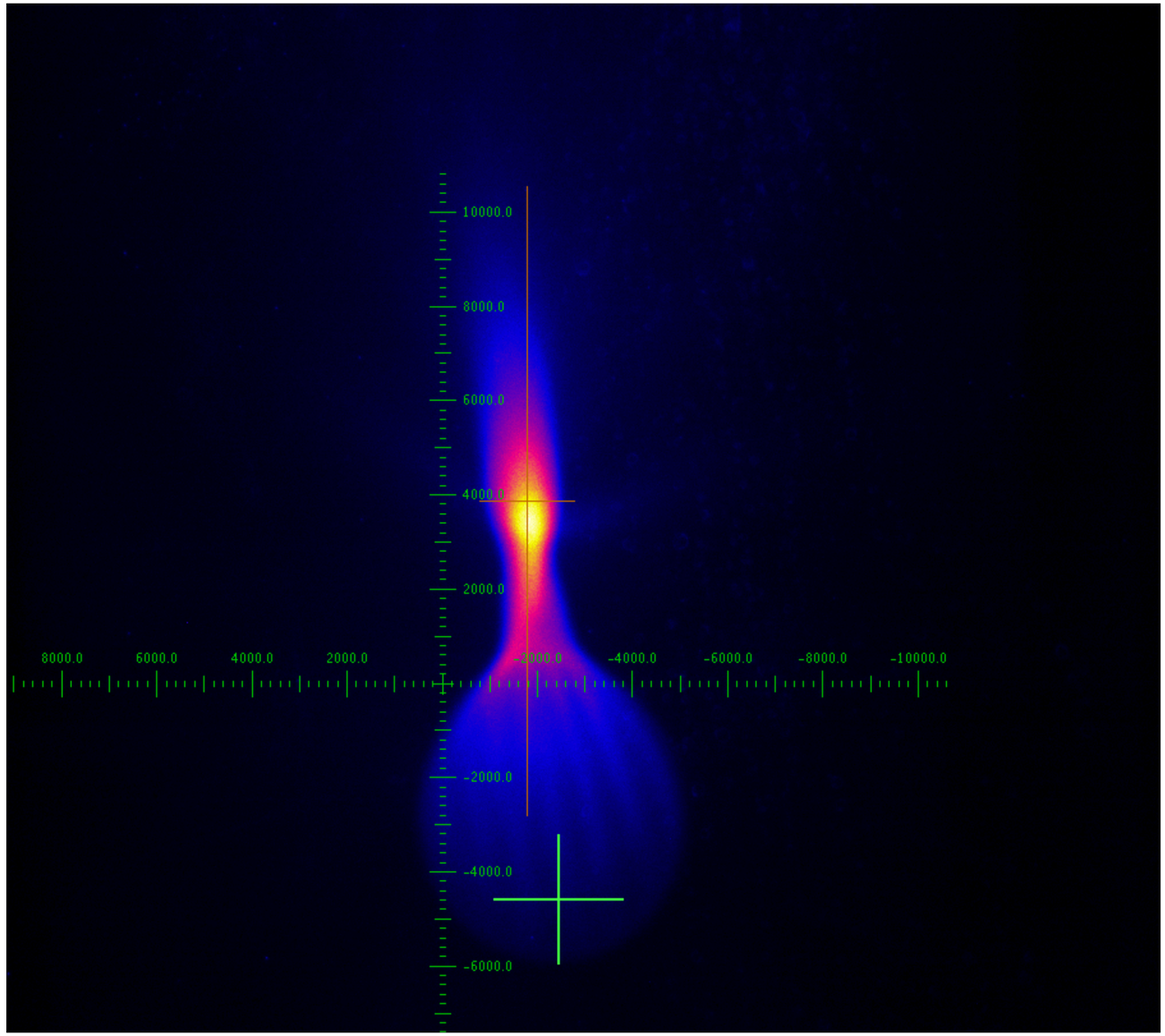
Measurements with the Prototype

- Slice emittance measurement of a 1.3 pC beam





Slice Mismatch



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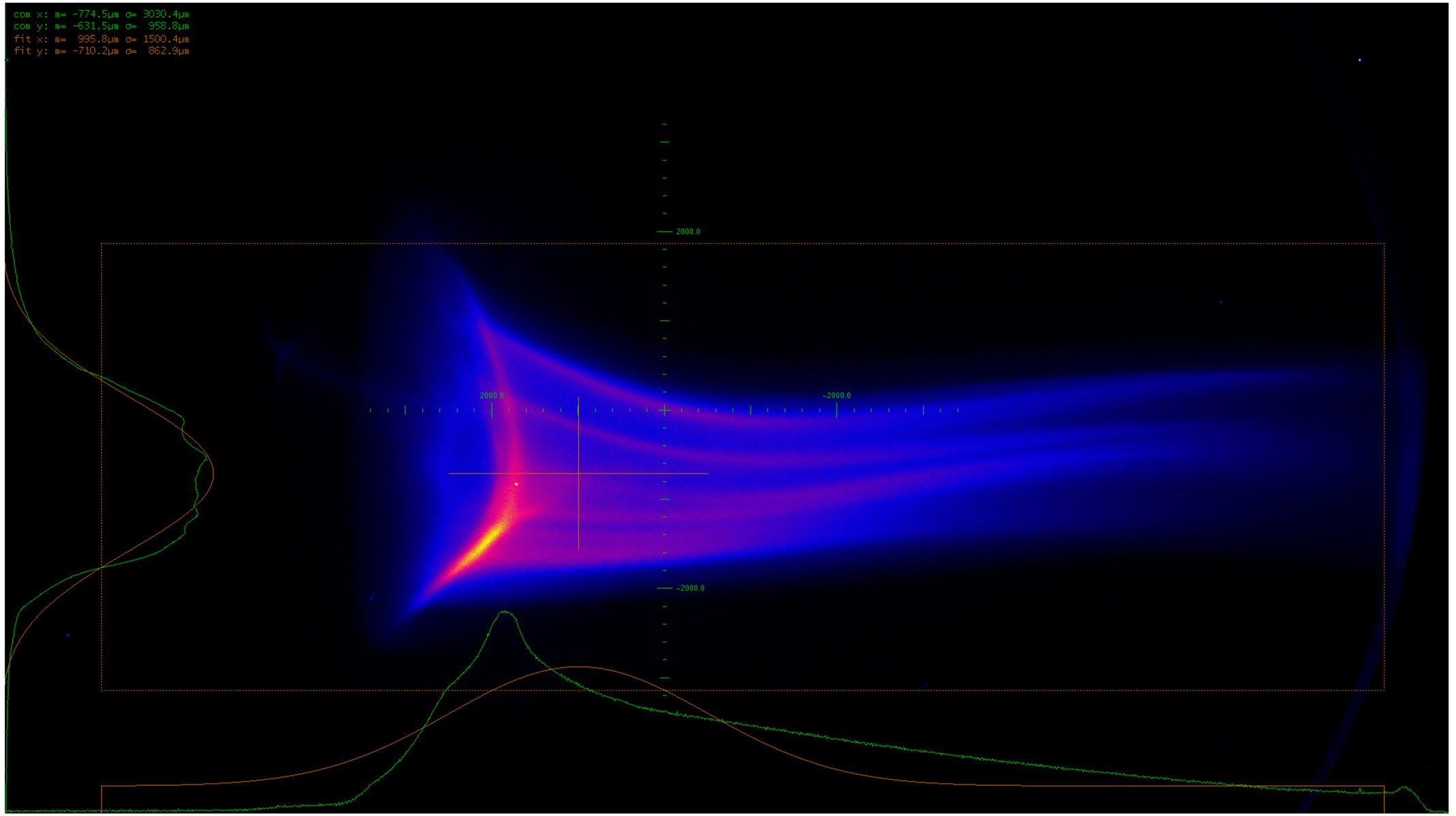
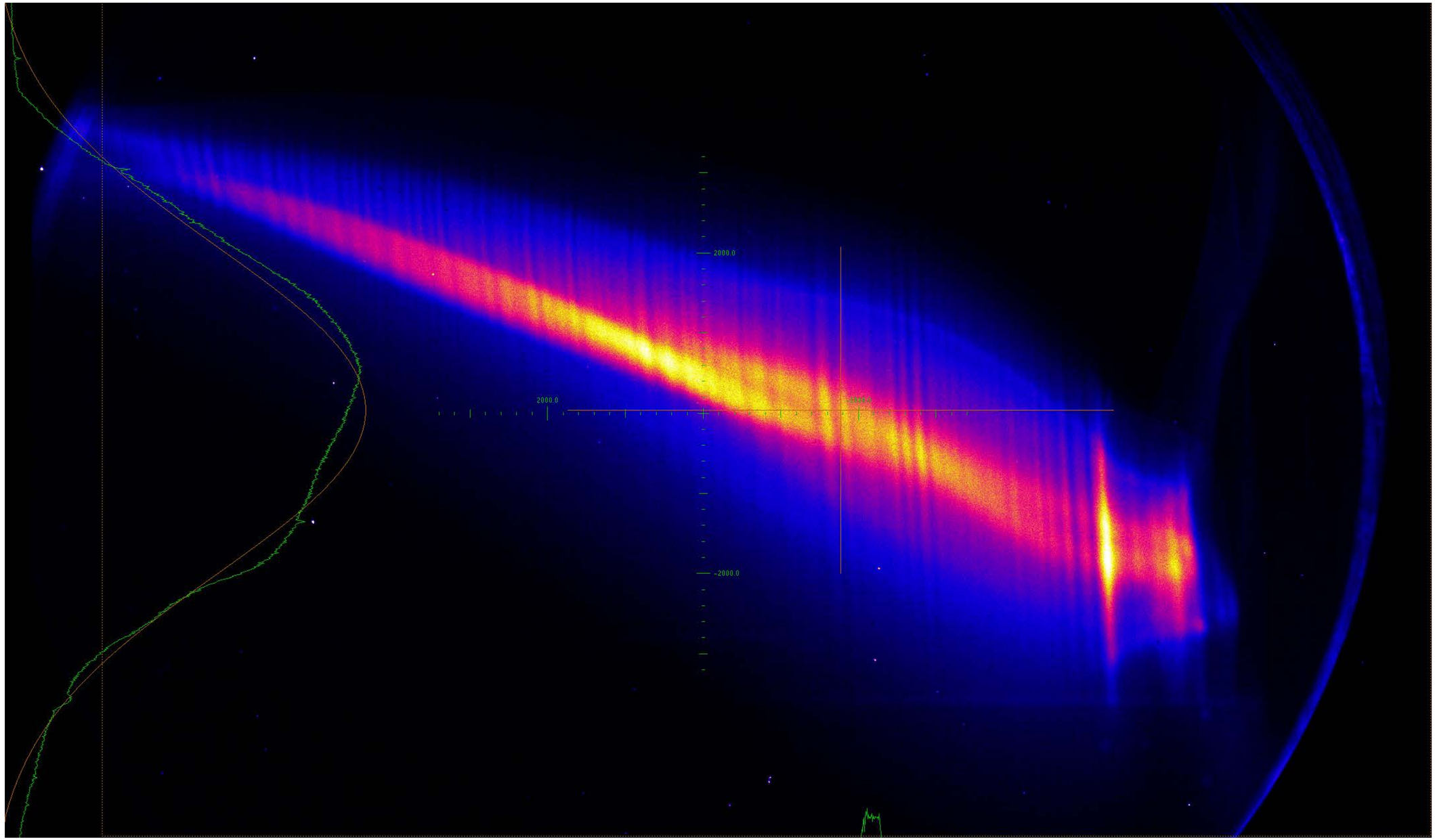
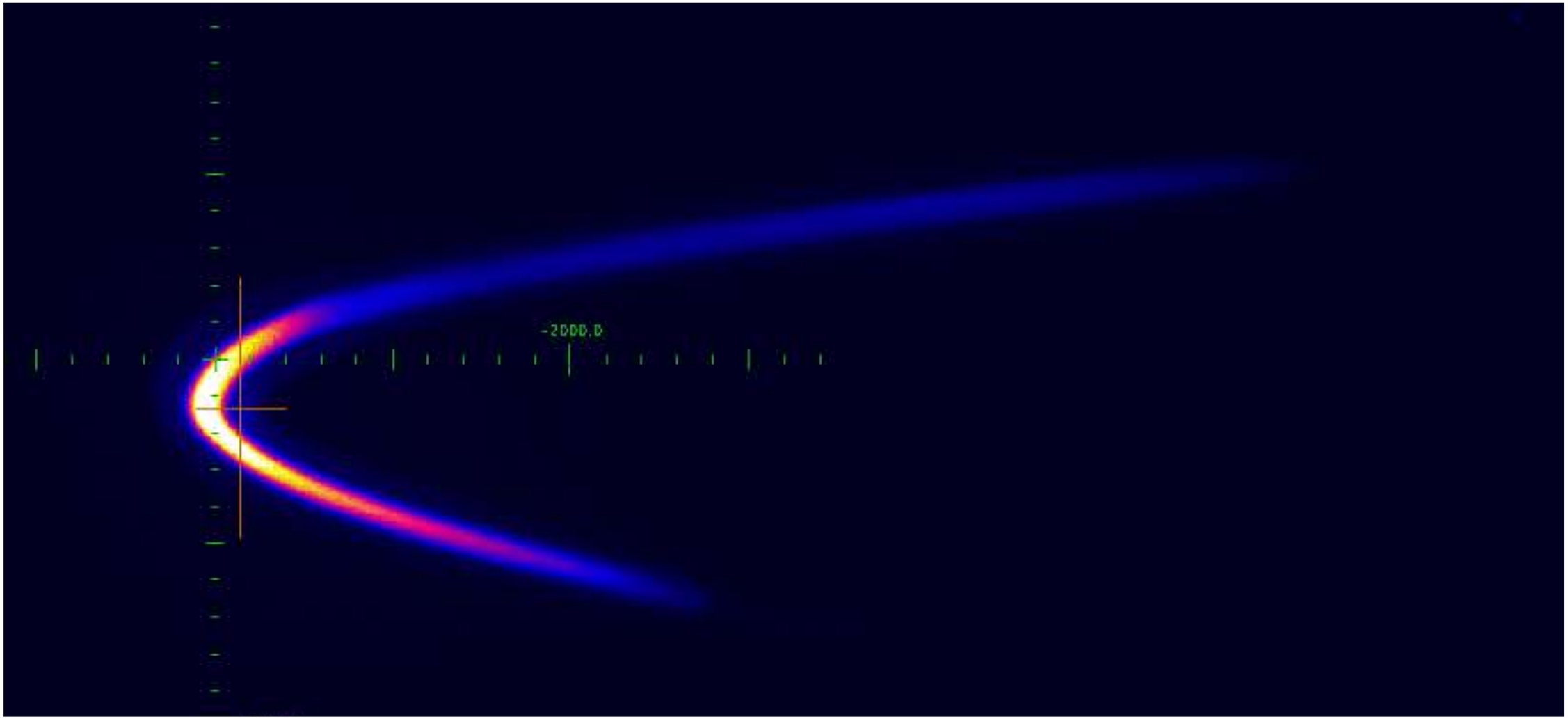
Measurement of Energy Spectrum



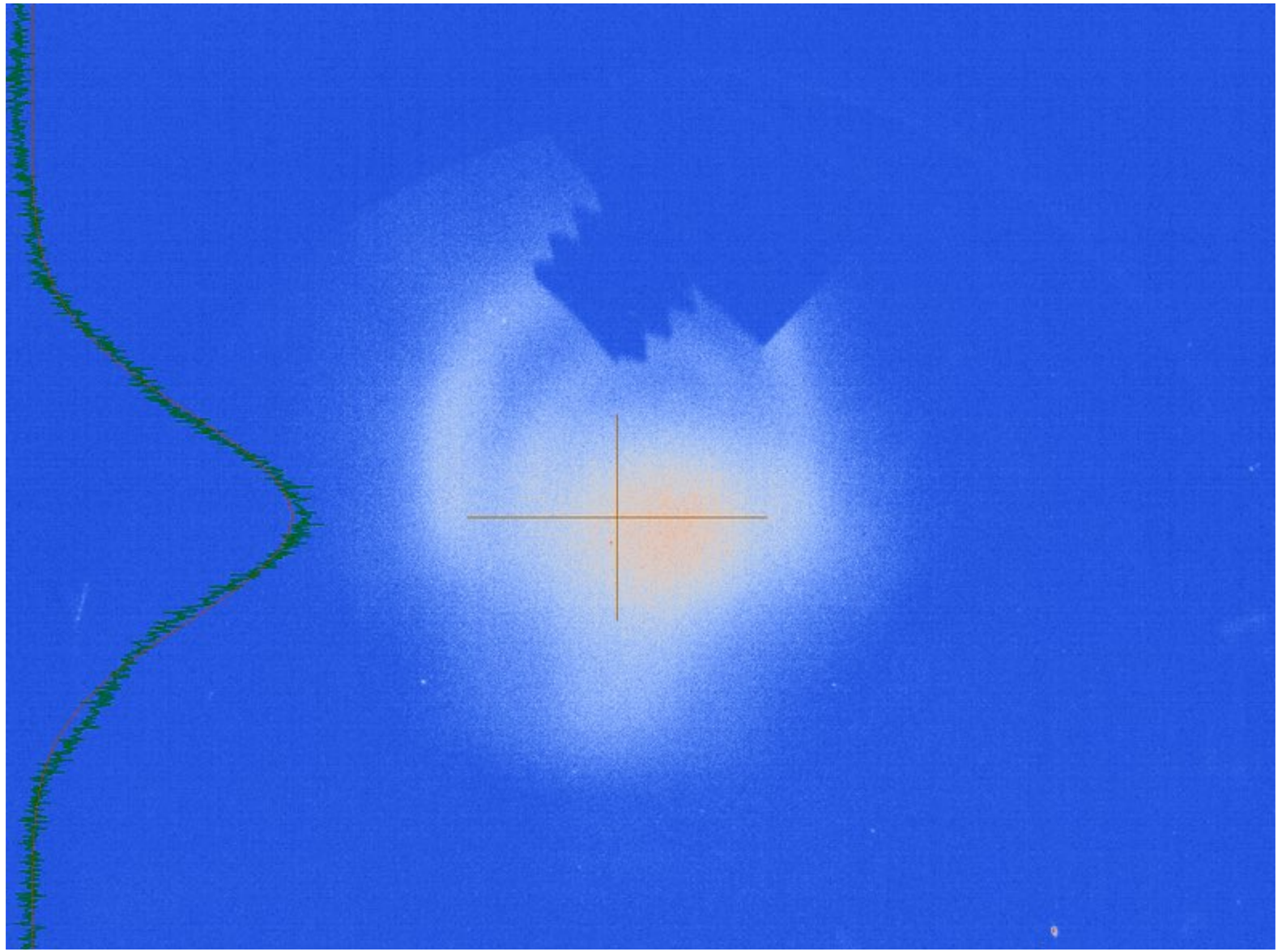
Energy Spectrum: Beam Affected by CSR



Measurement of Longitudinal Phase Space

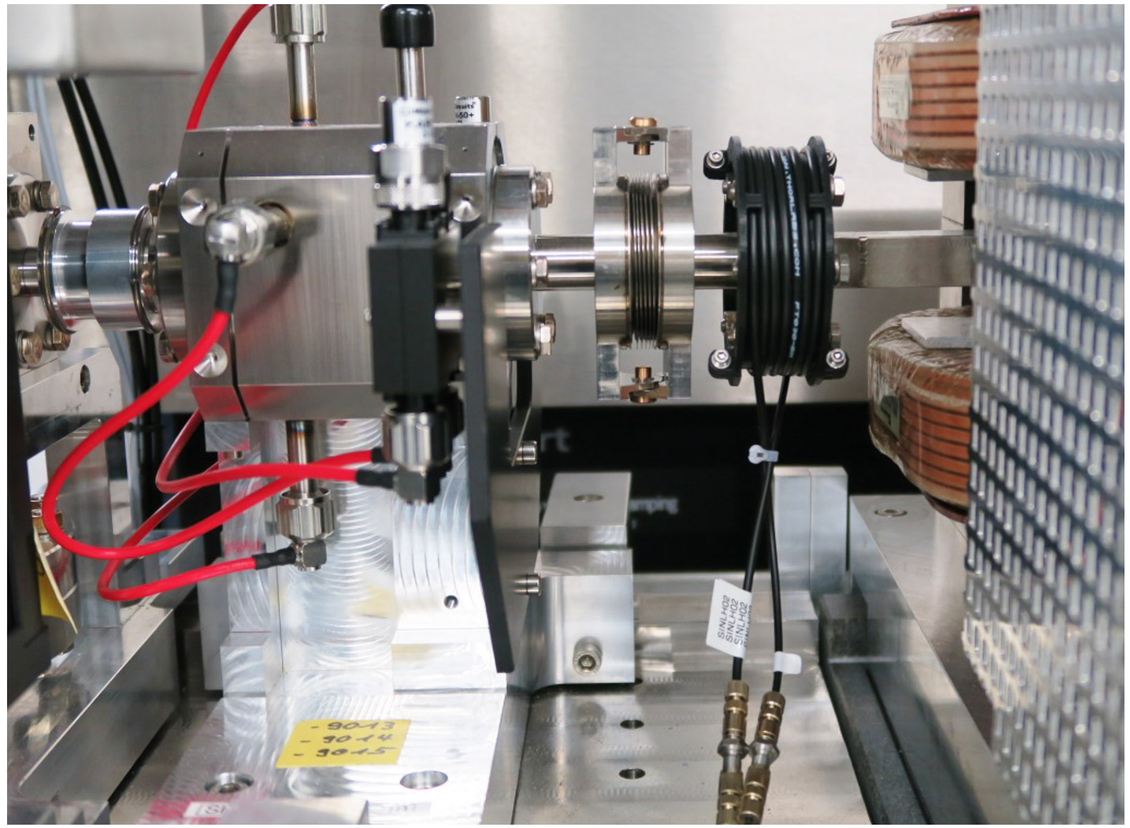


Diagnostics of Errors

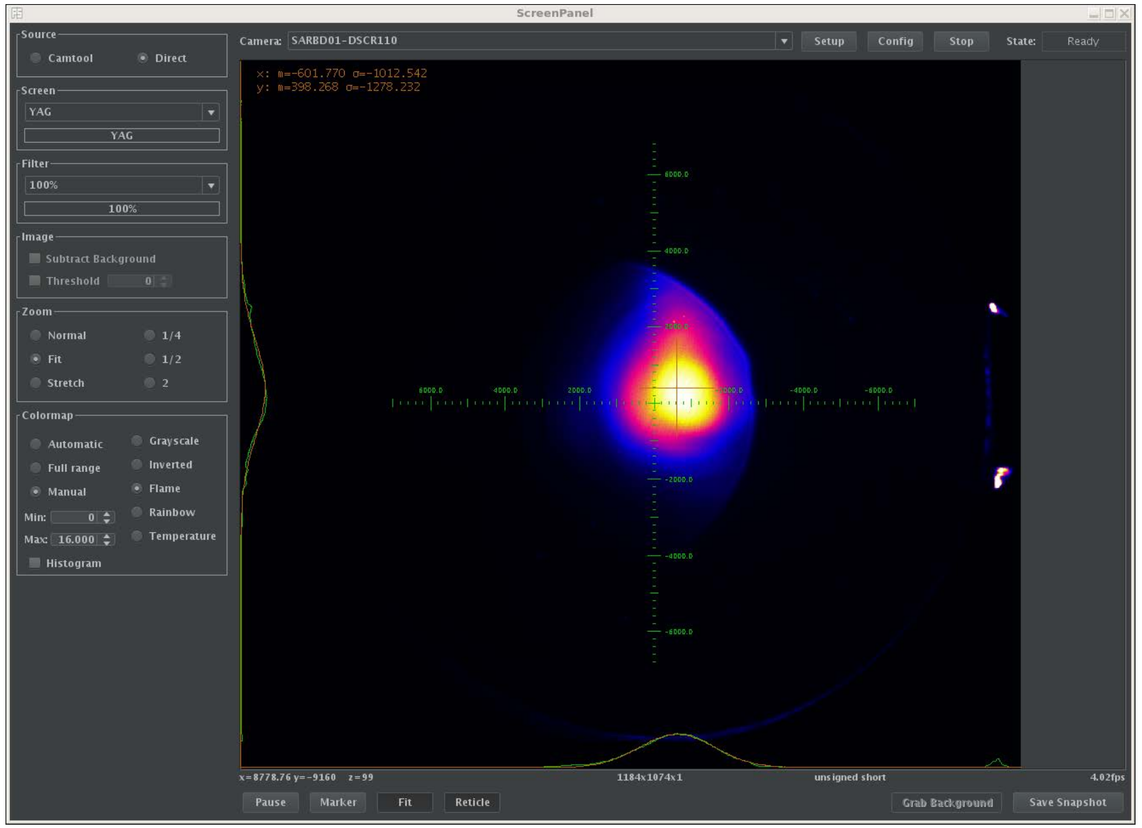


Other Uses of Scintillators in SwissFEL

- Beam Loss Monitors

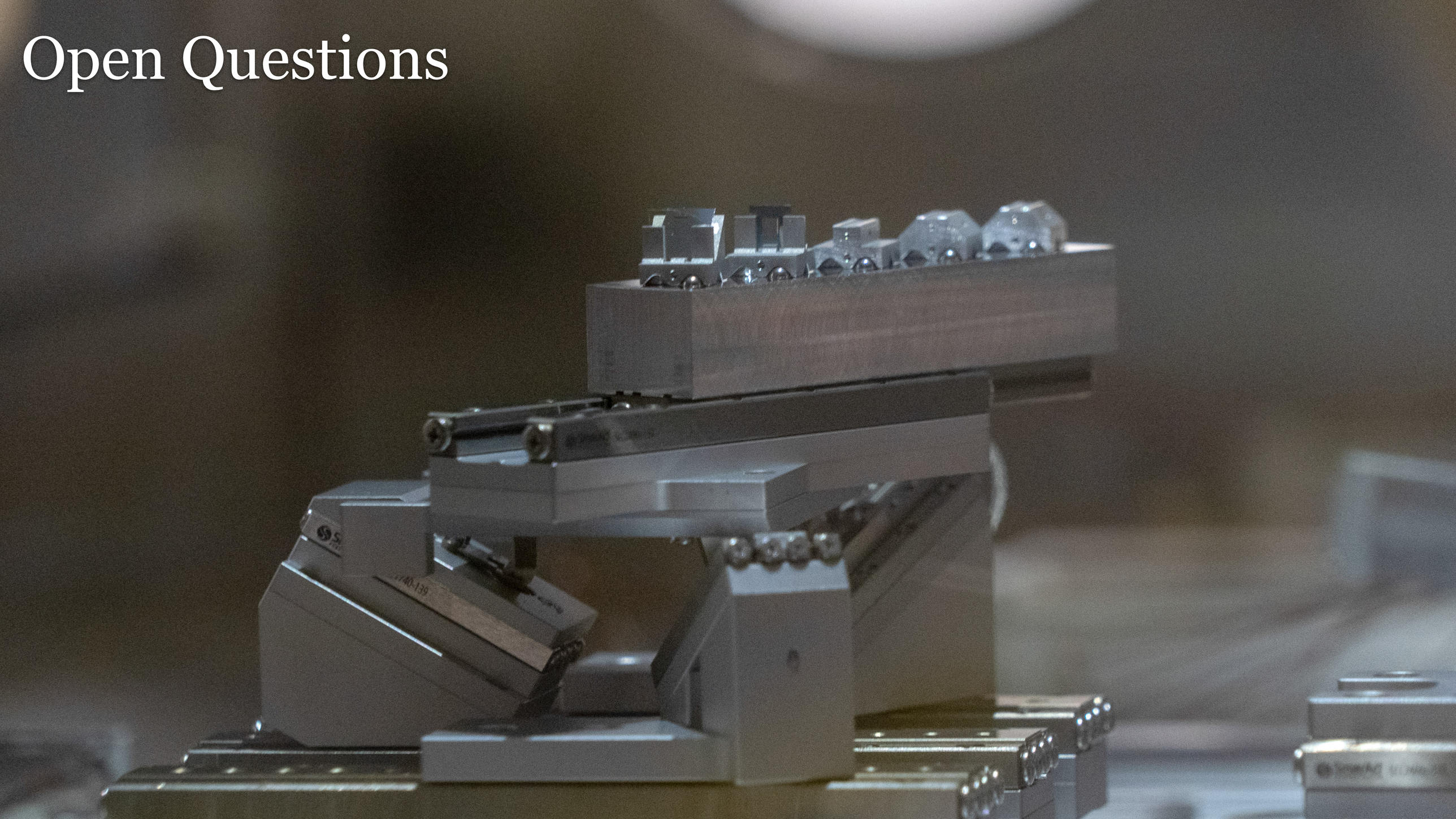


- Scintillators for X-Ray Profile Monitors

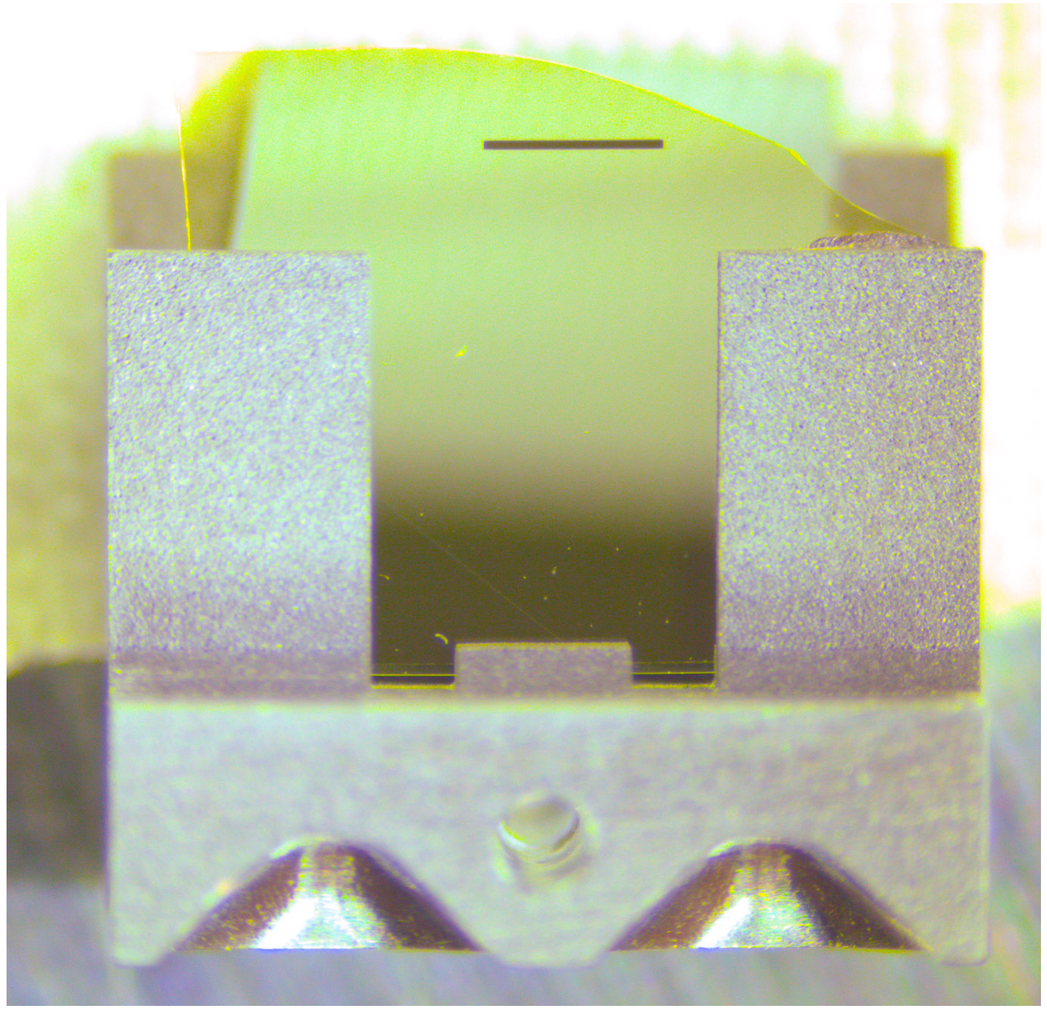


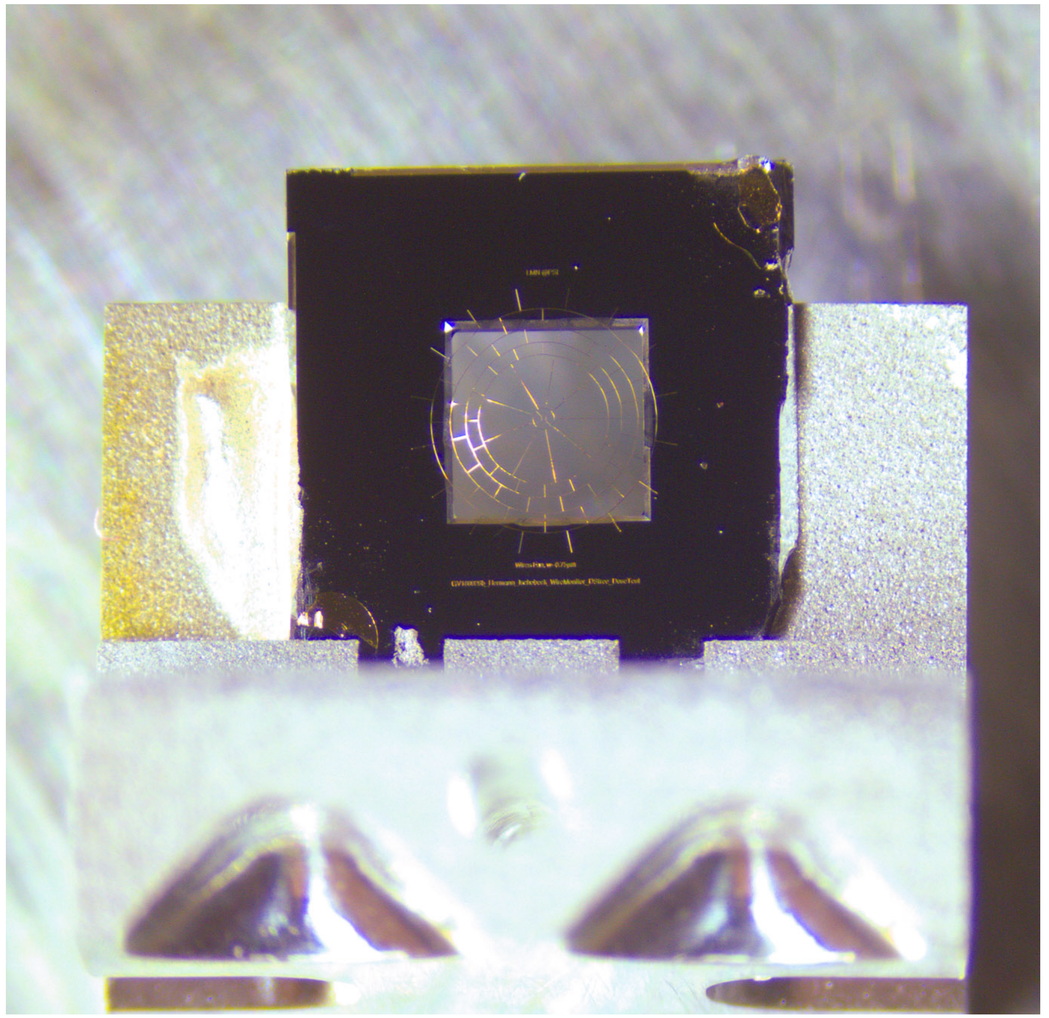
First Lasing at 4.1 nm

Open Questions



Comparison of Scintillating Screen with Wire Scanner





- Borrelli et al., Generation and measurement of sub-micrometer relativistic electron beams. Communications Physics **1**, 52 (2018)

Suppliers

- Scintillators: Crytur (YAG), Shalom EO (LYSO), BCE Special Ceramics (Chromox)
- Vacuum chamber: Heinz Baumgartner AG
- Pneumatic feedthroughs: UHV Design
- In-vacuum mirrors: LT Ultra
- Out-of-vacuum mirrors: ThorLabs
- LEDs: ledxon
- Filters: Kodak Wratten
- Actuators for filters: Firgelli
- Lenses: Nikon Micro Nikkor 200 mm f/4, Jenoptik Coastal UV-VIS-IR Apo Macro, Zeiss Makro Planar T2 100 ZF, Nikon Perpsective Control Micro Nikkor 85 mm
- Cameras: pco.edge 5.5 with CameraLink HS, Basler acA1920-50gm, Basler acA1300-60gmNIR
- Assembly camera box: Heinz Baumgartner AG

Thank You!

- Benedikt Hermann
- Nicole Hiller
- Eduard Prat