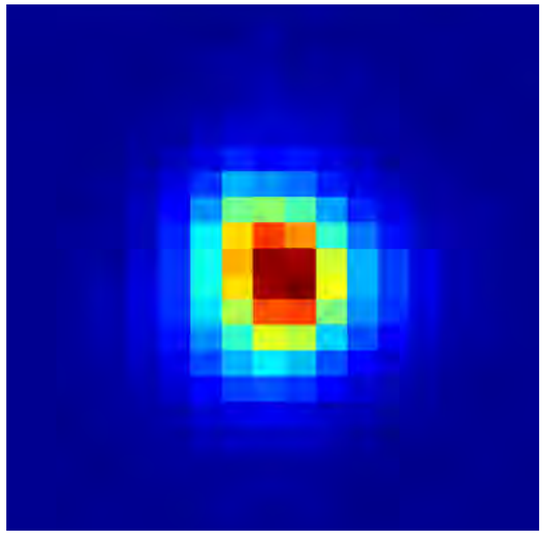
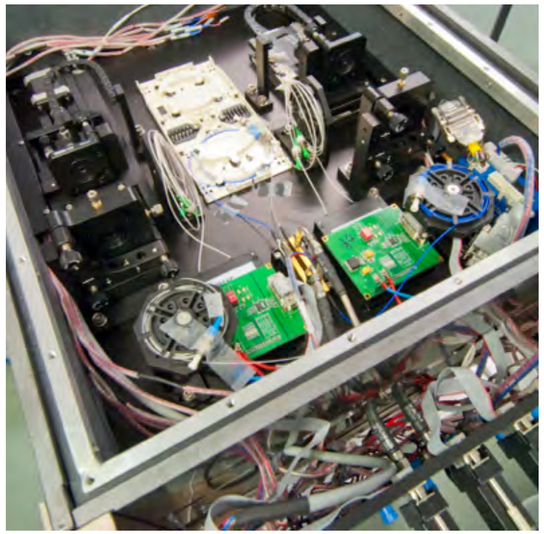
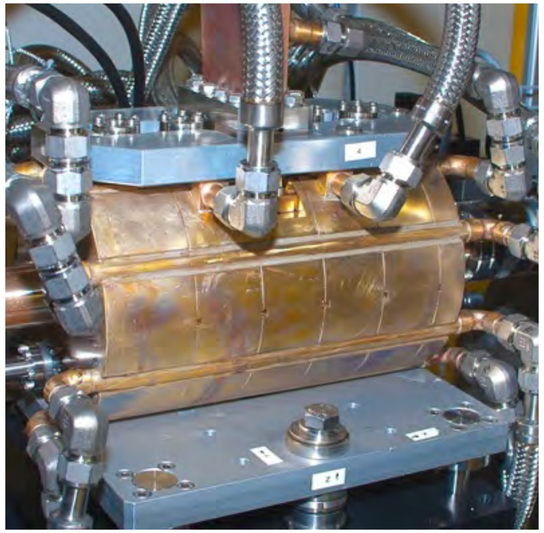
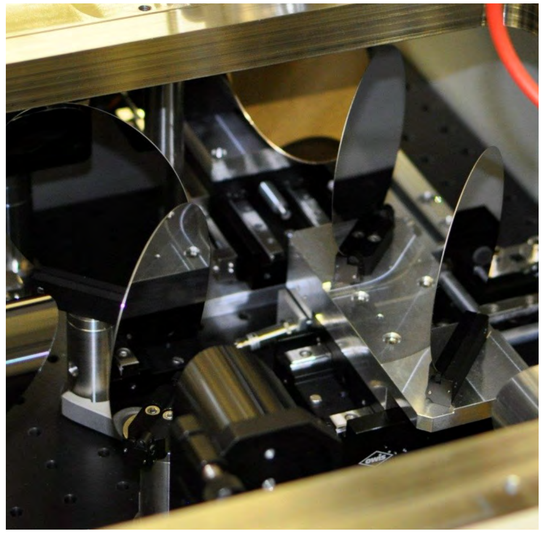
PAUL SCHERRER INSTITUT









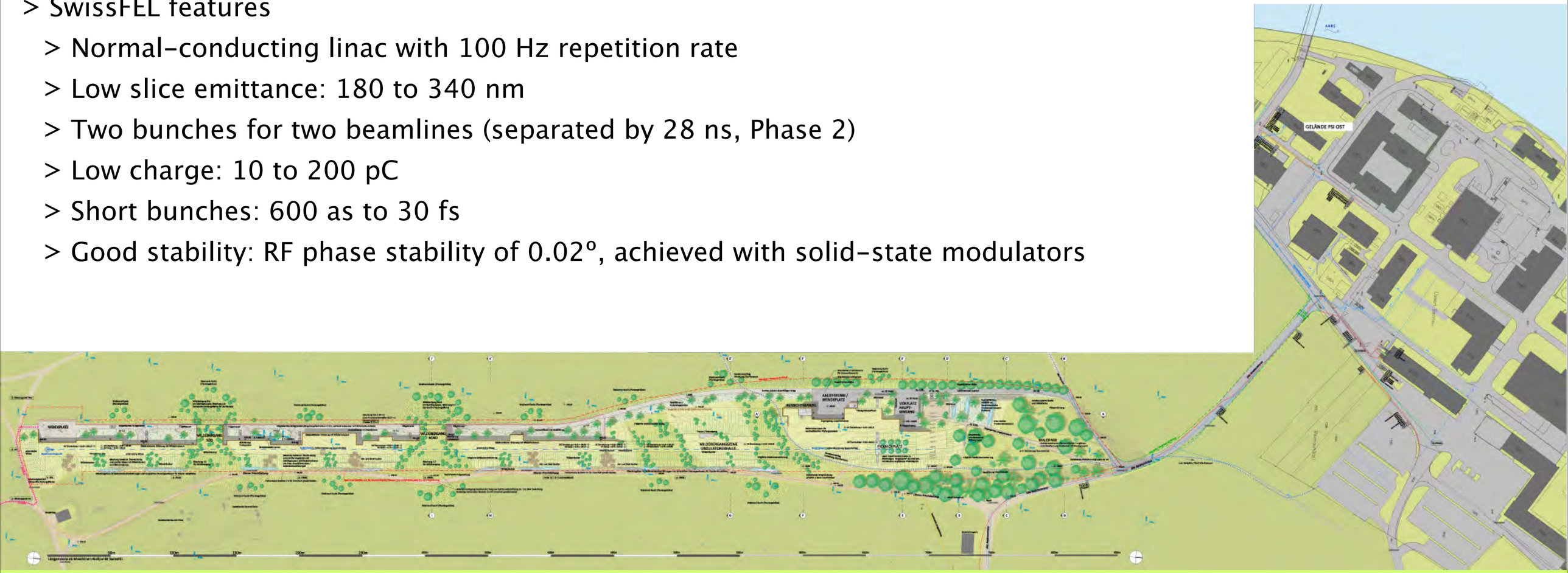
Electron Beam Instrumentation for SwissFEL

Rasmus Ischebeck, for the SwissFEL Team

SwissFEL

> SwissFEL: X-ray laser for hard X-rays (0.1 to 7 nm)
  > Construction has started in the forest near PSI
  > First user beam in summer 2017

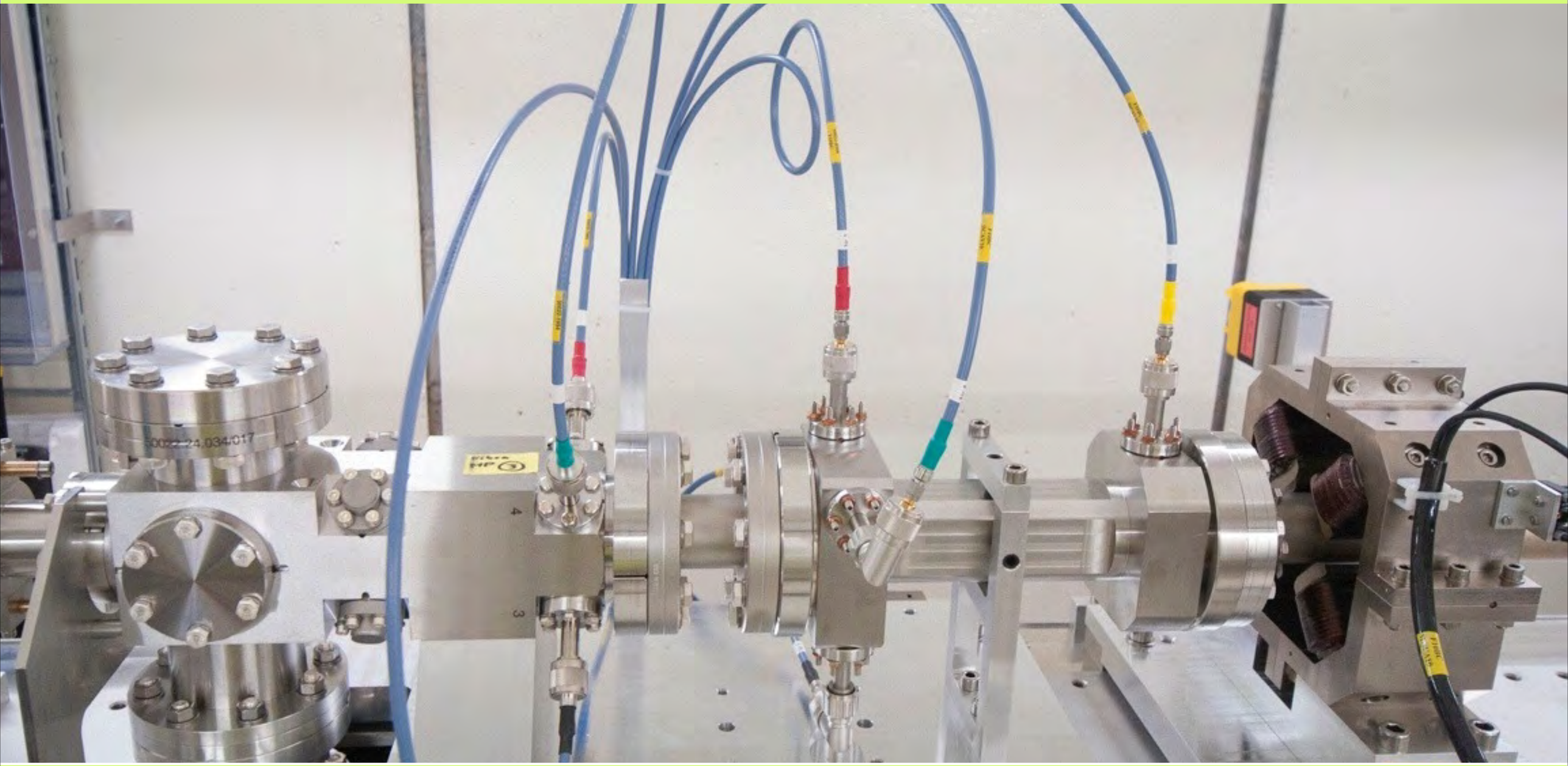
> SwissFEL features
  > Normal-conducting linac with 100 Hz repetition rate
  > Low slice emittance: 180 to 340 nm
  > Two bunches for two beamlines (separated by 28 ns, Phase 2)
  > Low charge: 10 to 200 pC
  > Short bunches: 600 as to 30 fs
  > Good stability: RF phase stability of 0.02°, achieved with solid-state modulators



Electron Beam Instrumentation for SwissFEL

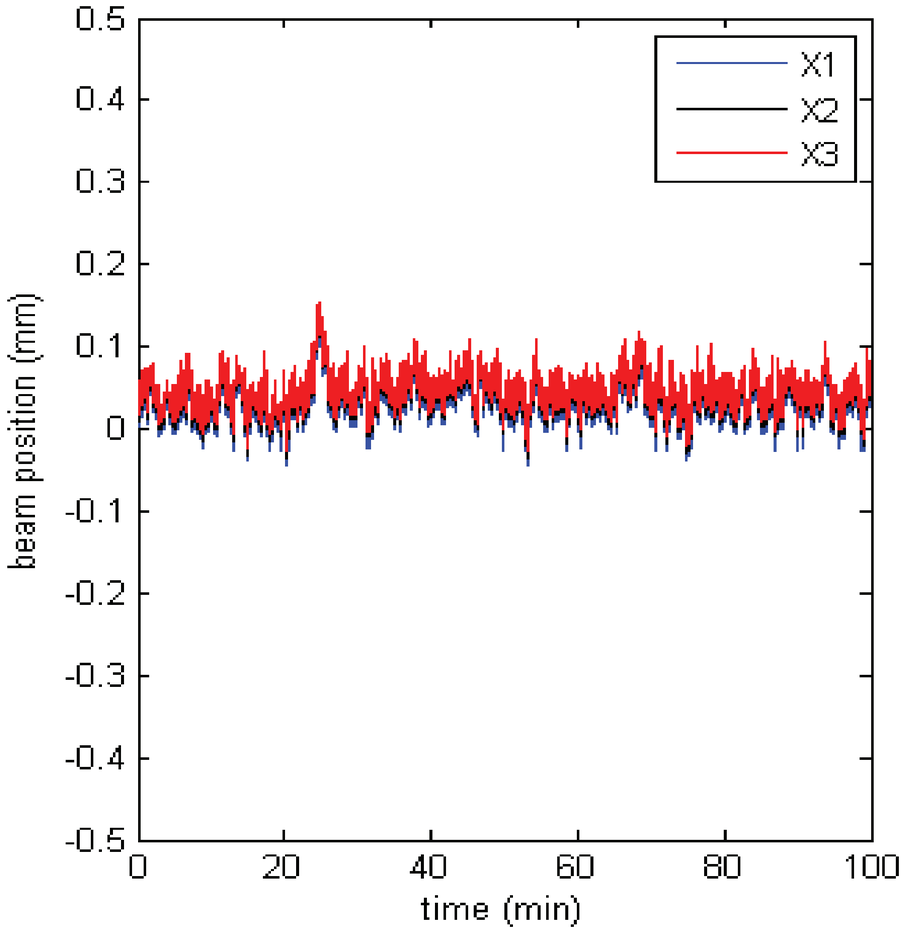
- > Beam Position Monitors
- > Charge Monitors
- > Time-Resolved Measurements
  - > Arrival Time Monitor
  - > Compression Monitor
  - > Electro-Optical Monitor
  - > Transverse Deflecting Cavity
- > Optical Spectrum of Transition Radiation
- > Profile Monitors
  - > Wire Scanner
  - > Synchrotron Radiation Imager
  - > Screen Monitor

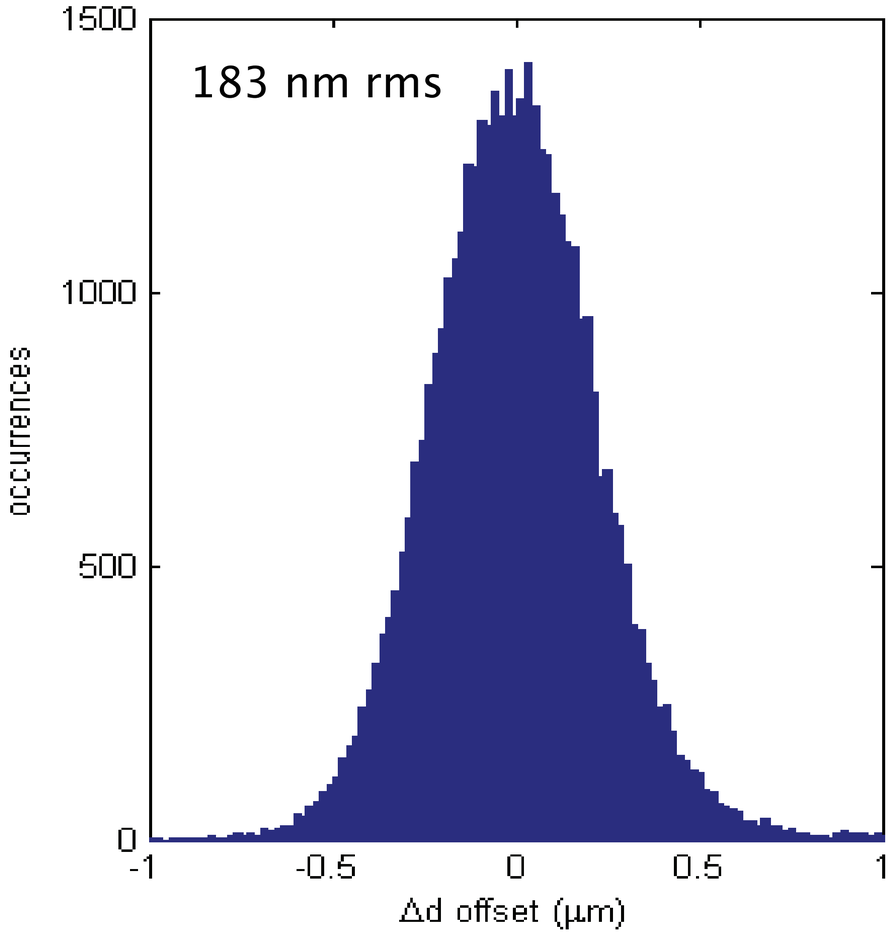
Beam Position Monitors



Cavity Beam Position Monitors

> SwissFEL will use only cavity beam position monitors
> The same electronics as for the European XFEL will be used
> Sub-micrometer resolution has been demonstrated

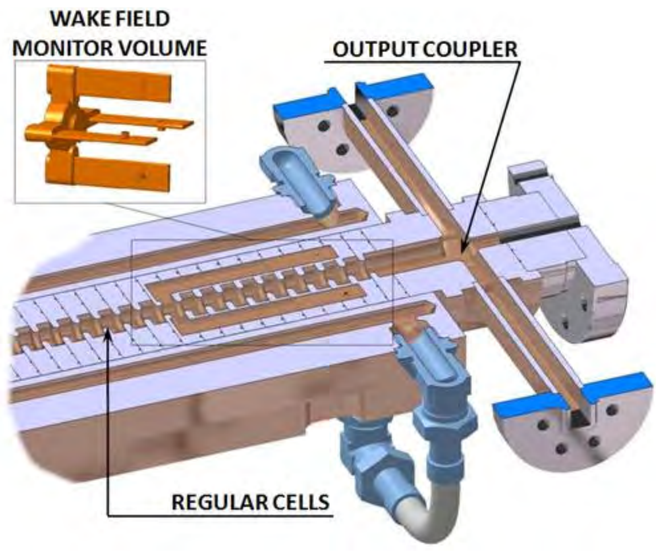


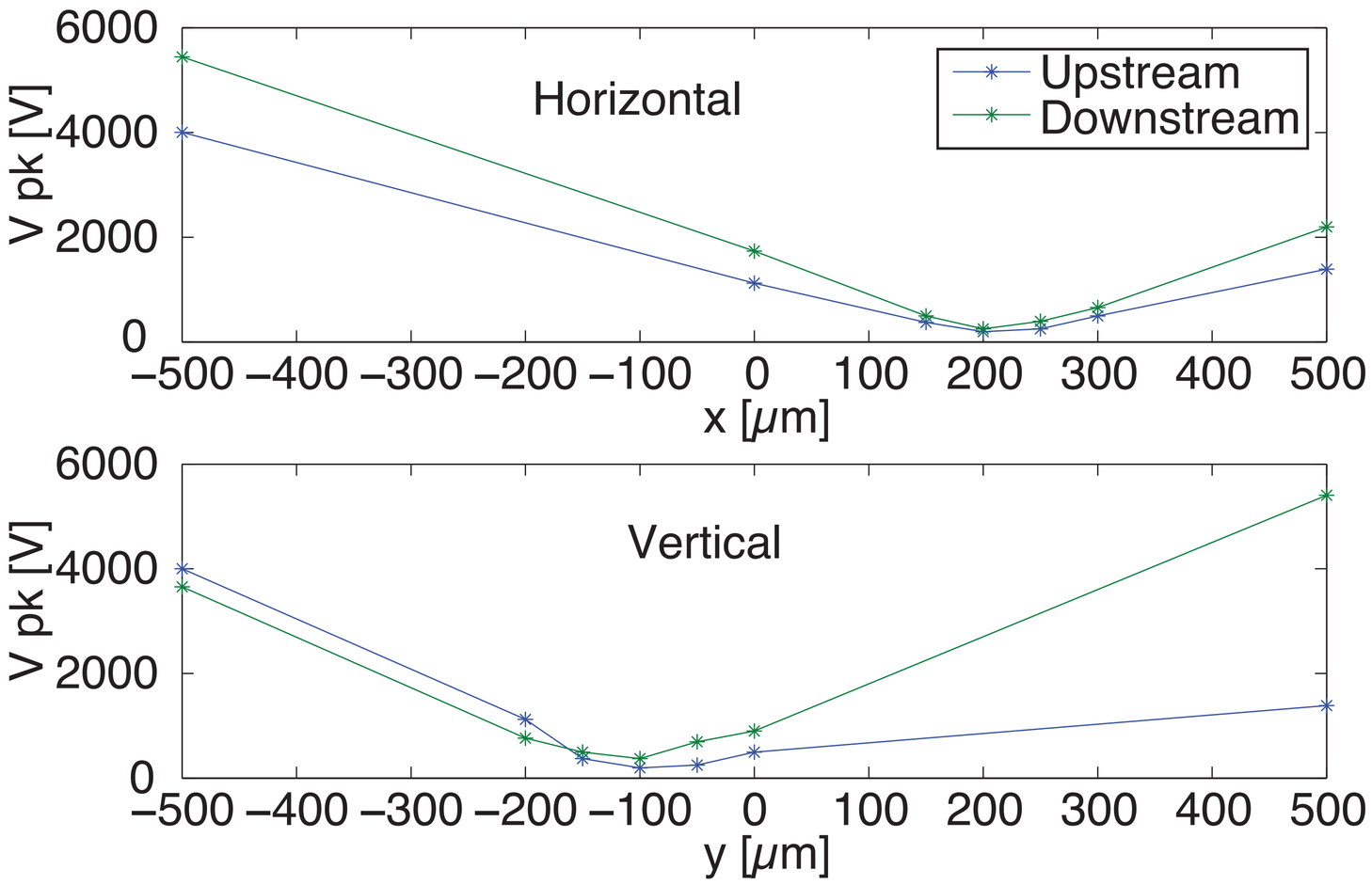


Position Measurement: Wakefield Monitor

> Position in X band linearizing cavity is important to reduce effects of wake fields

> Wake fields can be measured directly





> Outcoupling of wakefields at frequencies above 10 GHz requires special care in

> couplers

> cables

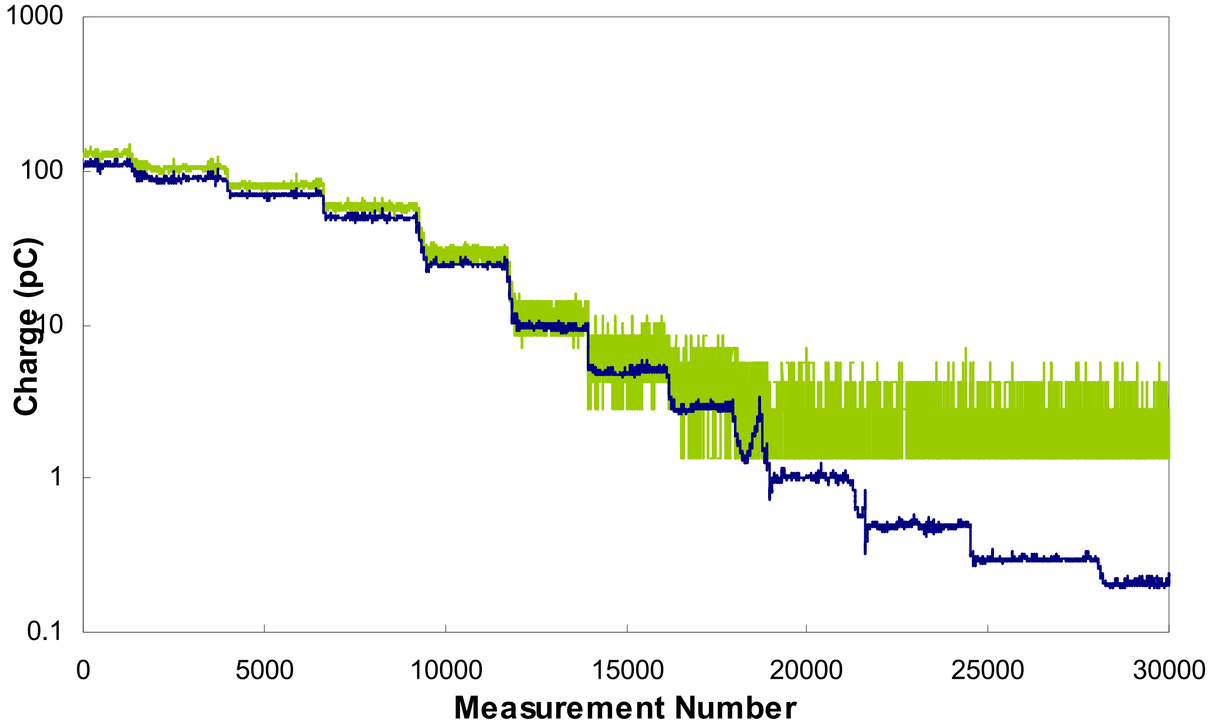
> data acquisition

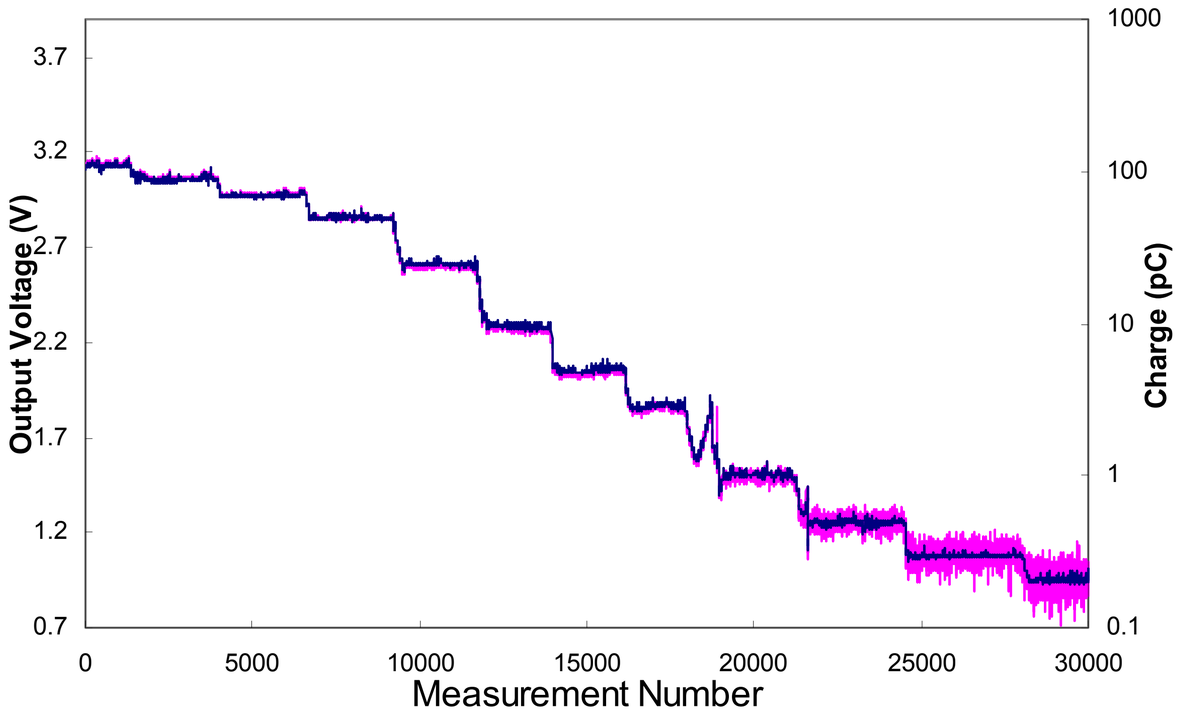
Charge Monitors

> Absolutely calibrated integrating current transformers

> New and improved model shows superior noise at low charge

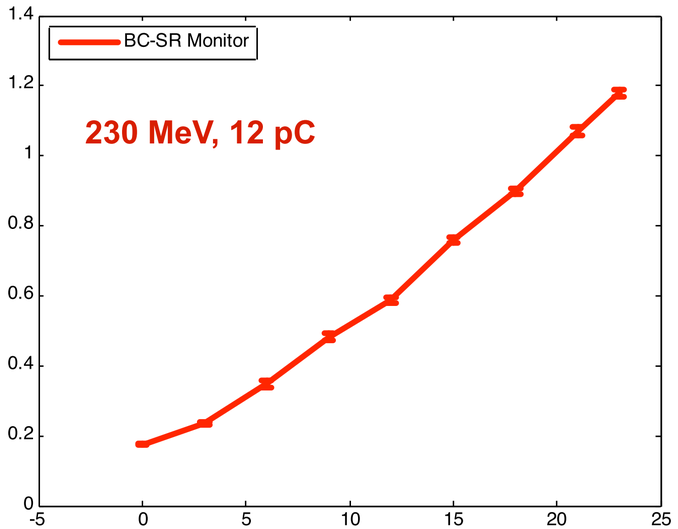
> Resolution: 1% at 120 pC

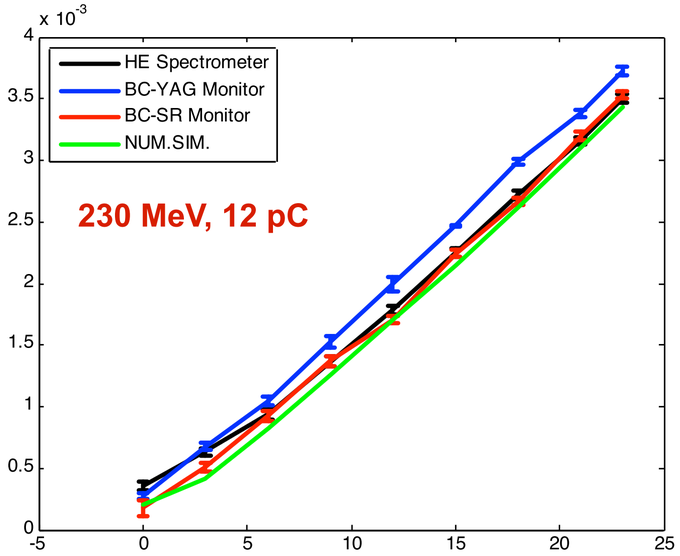


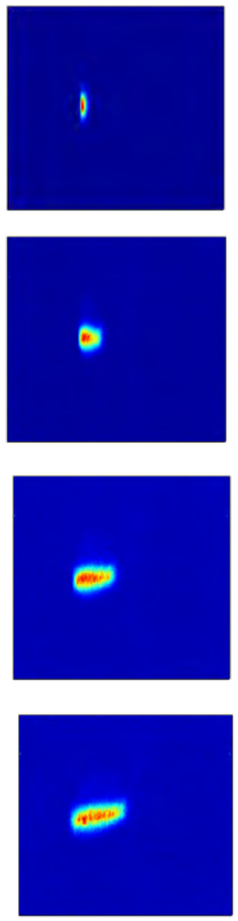


Synchrotron Radiation Imager

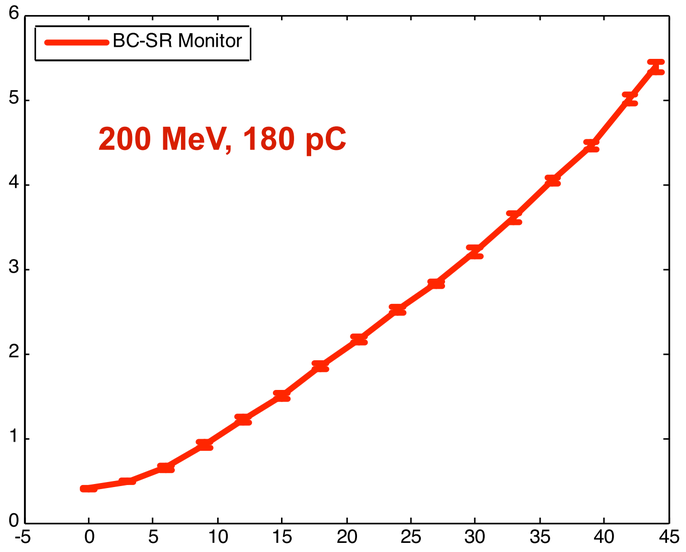
Synchrotron Radiation Imager

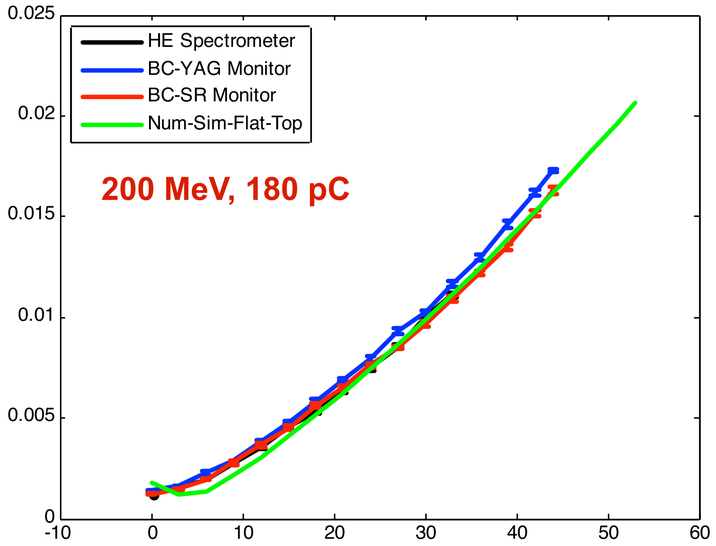






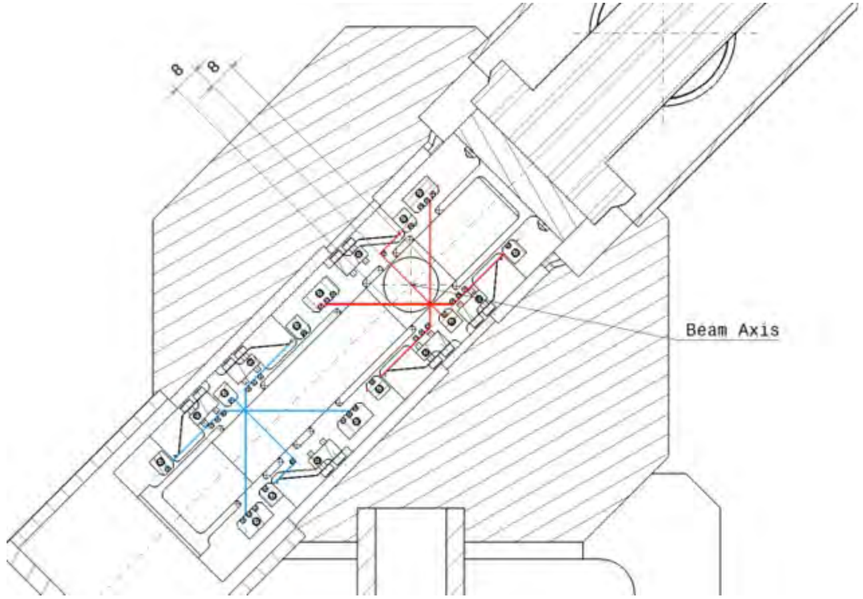
12 pC, SR Monitor images,
0- 23 deg OFF RF Crest

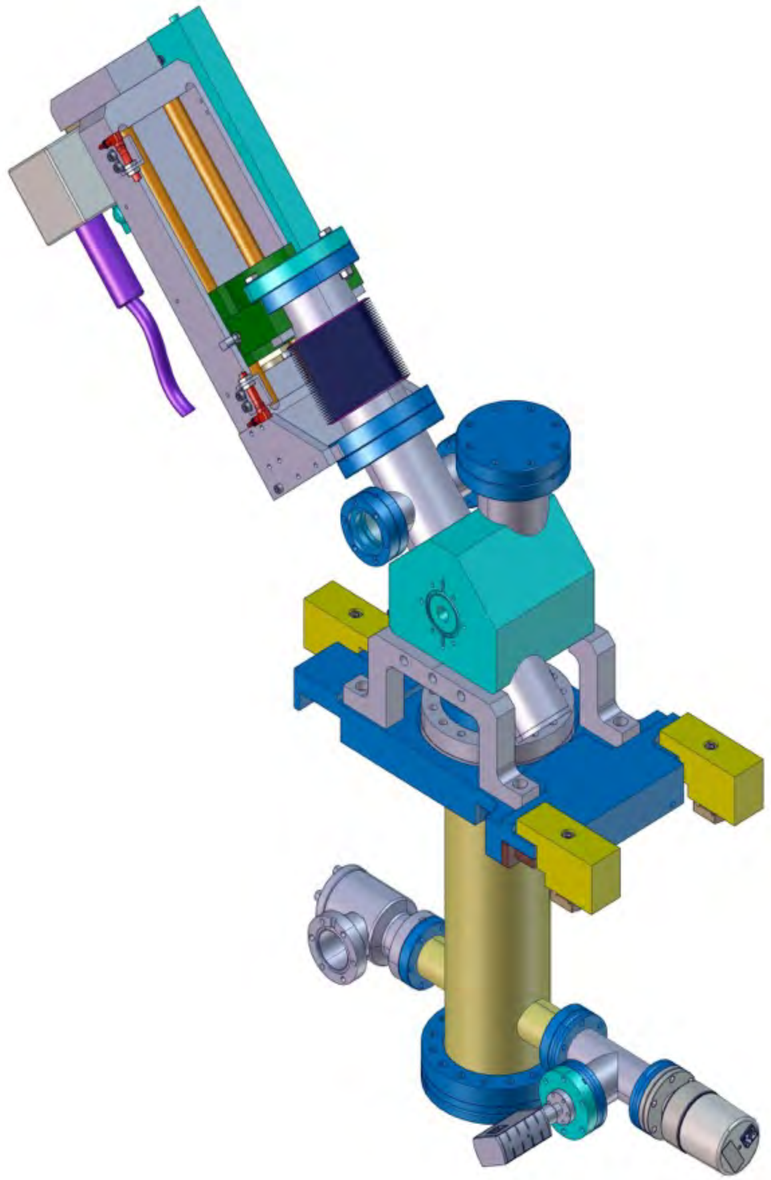




Wire Scanners

> SwissFEL version:
  > Inserted at 45° → measurement of horizontal beam size possible
  > Can be used in a quasi-parasitic mode





3 different pin positions ↔ 3 different Wire separations (8, 5 or 3.5 mm) ↔
3 different scan time (for a fixed wire velocity)

Wire Scanners

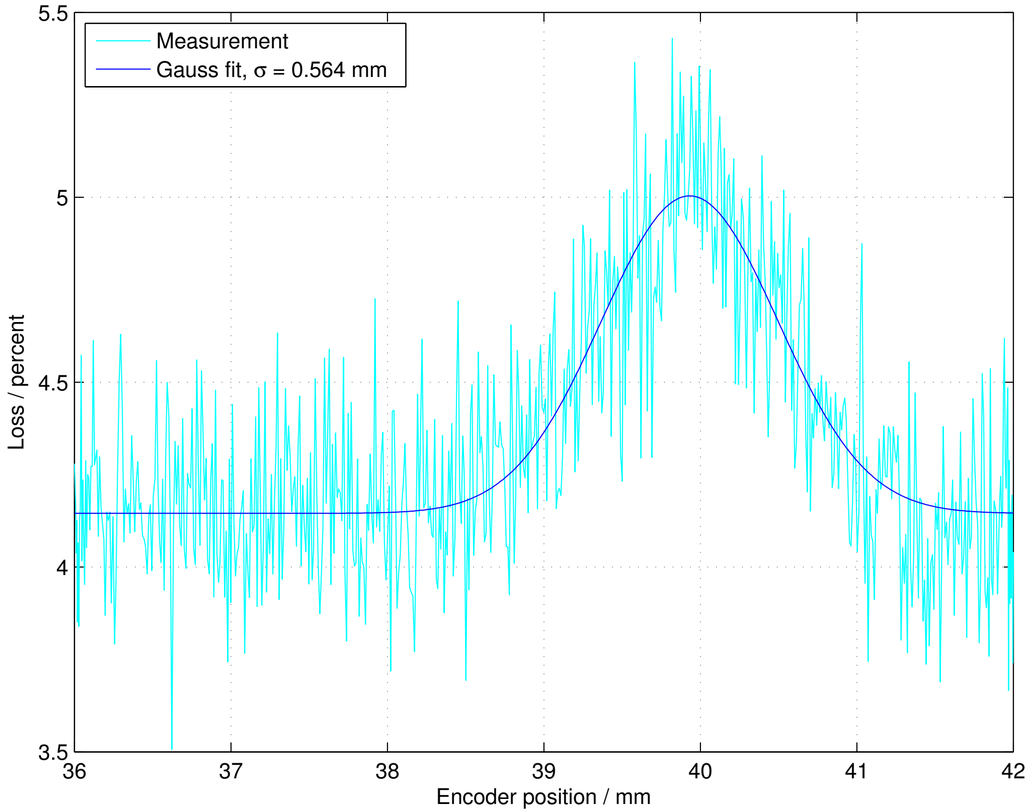
> Wire scannersinstalled at all screen stations > 100 MeV

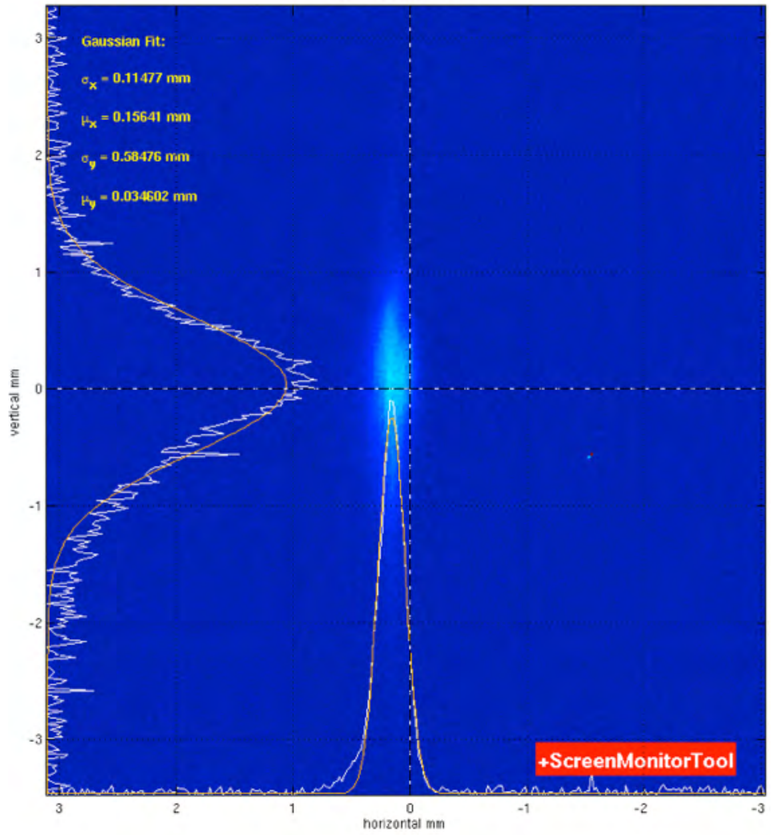
> Measurements performed with horizontal wire:

  > Charge measurement before and after wire

  > Using beam synchronous data acquisition for encoder and charge (BPMs)

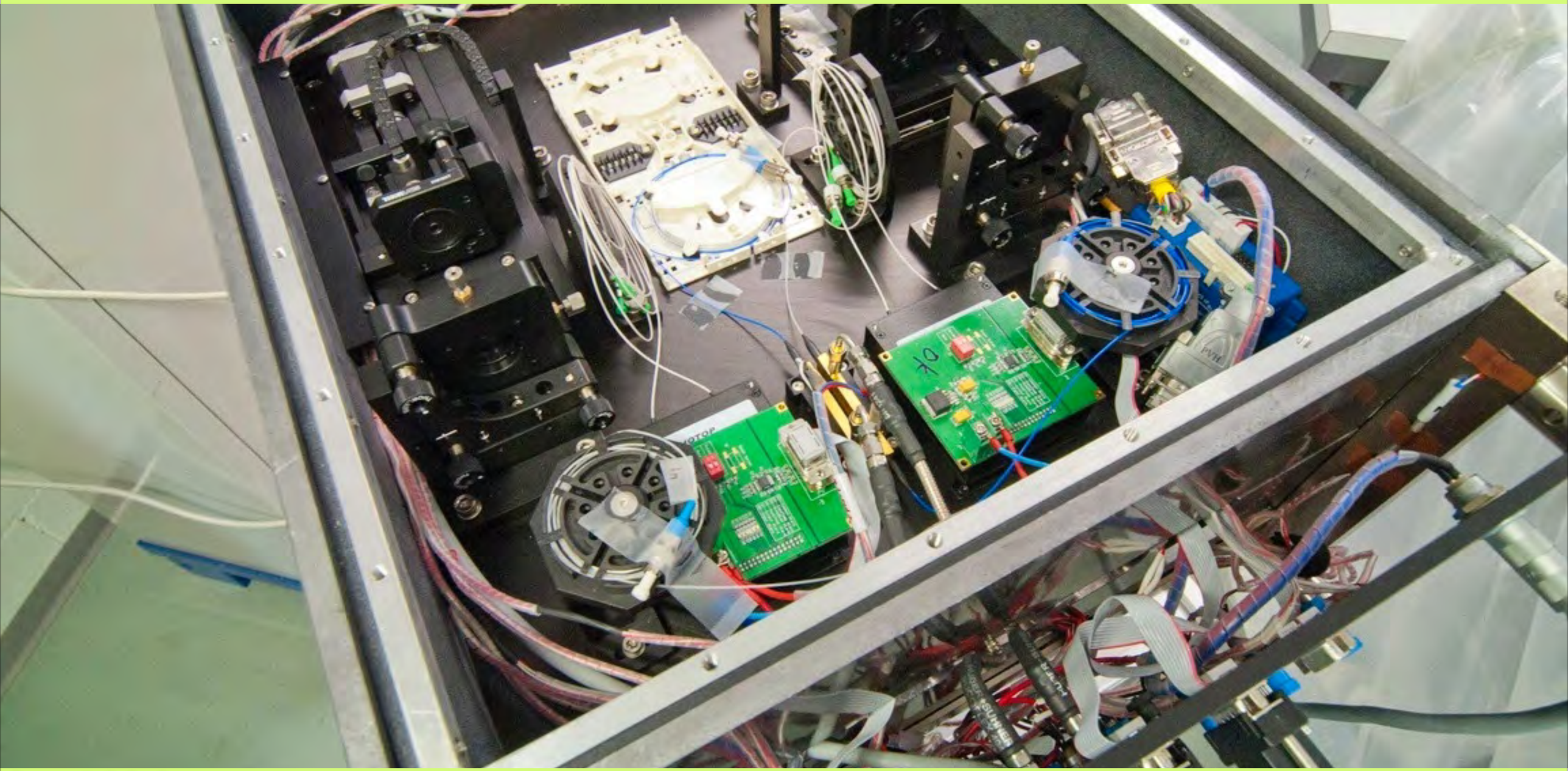
  > Comparison to OTR measurements





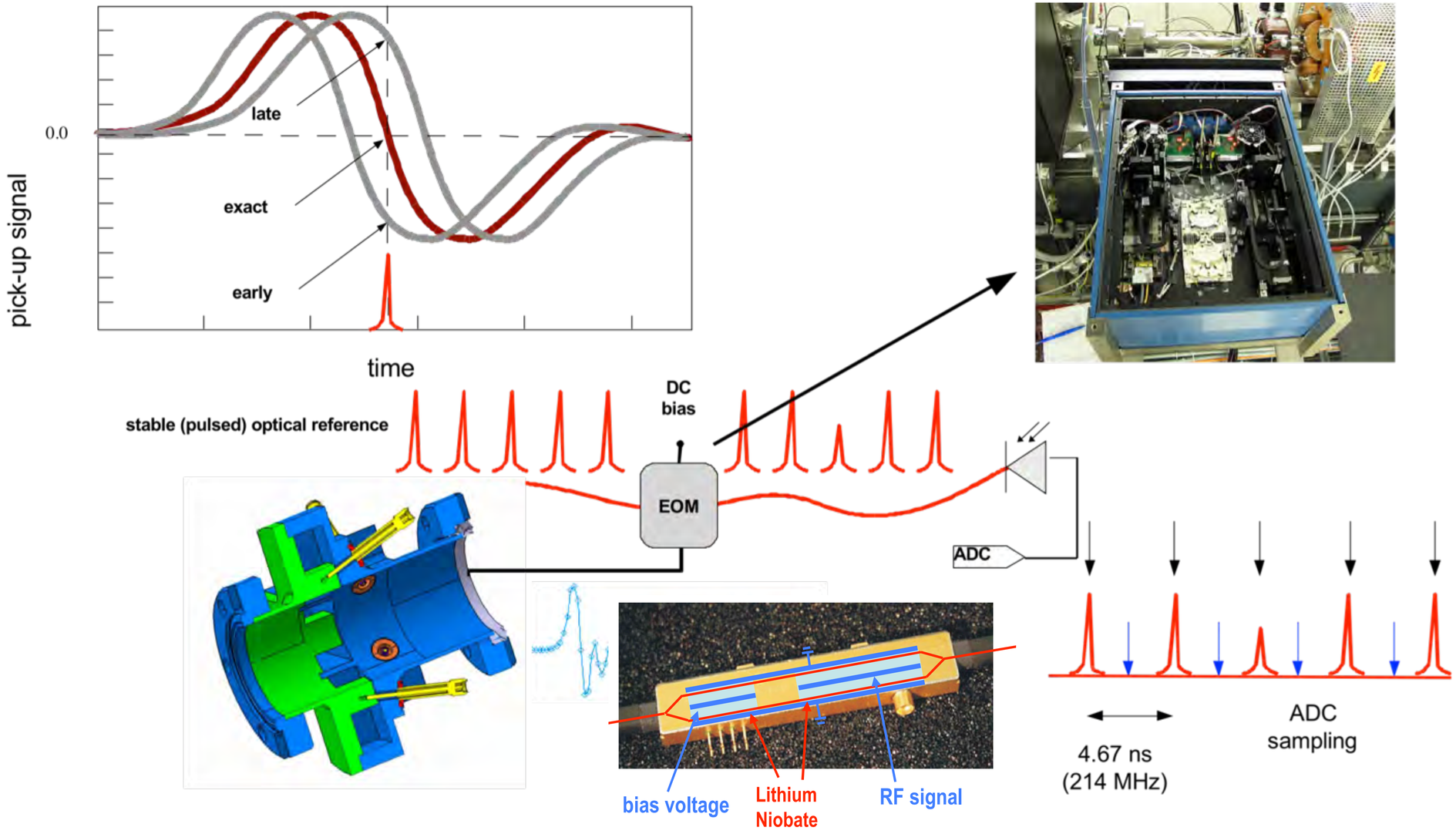
GL Orlandi, P Mohanmurthy

Bunch Arrival Monitor



Bunch Arrival Monitor

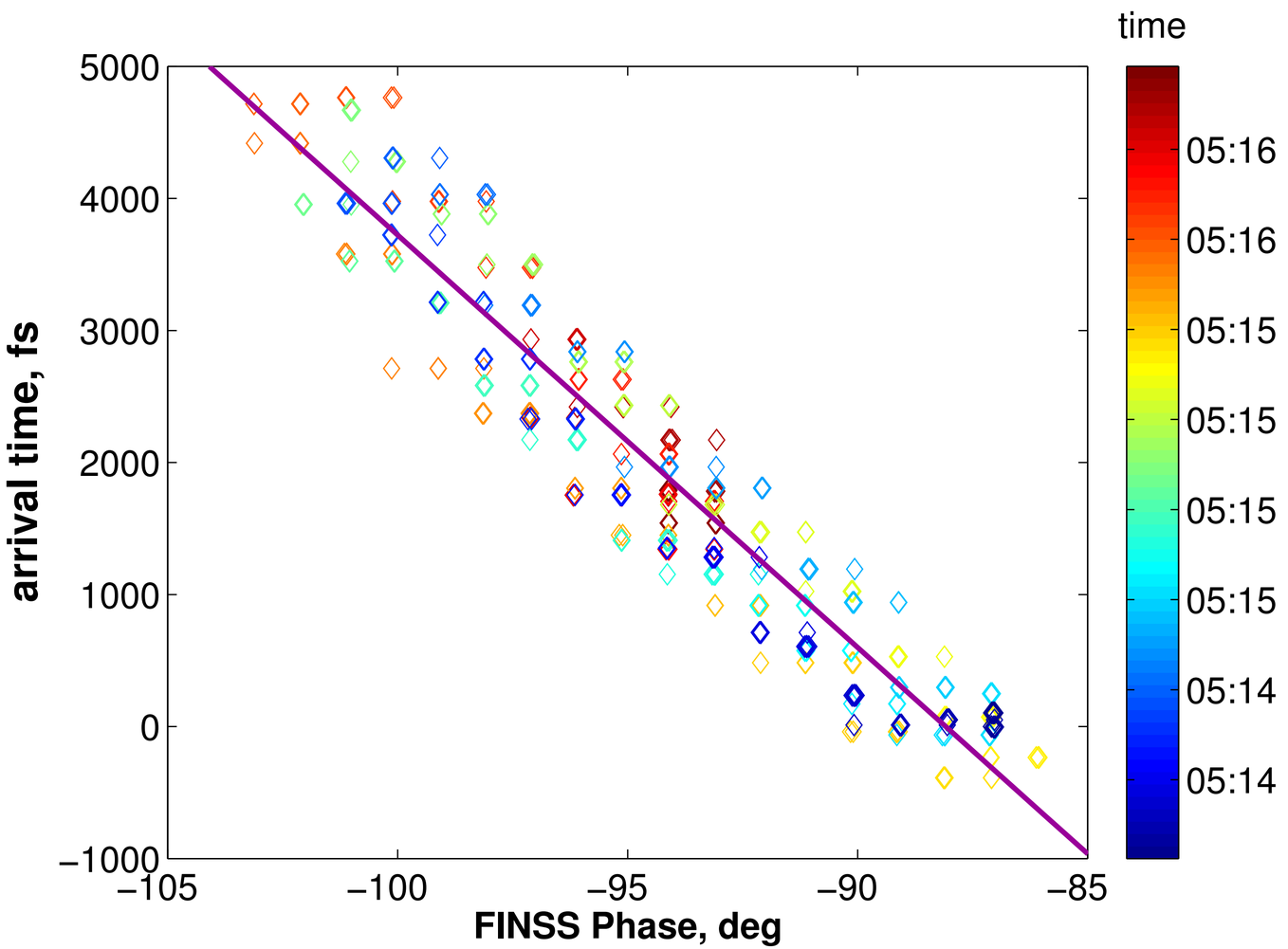
> Arrival time signal generated at pickup is transferred onto an electro-optical modulator



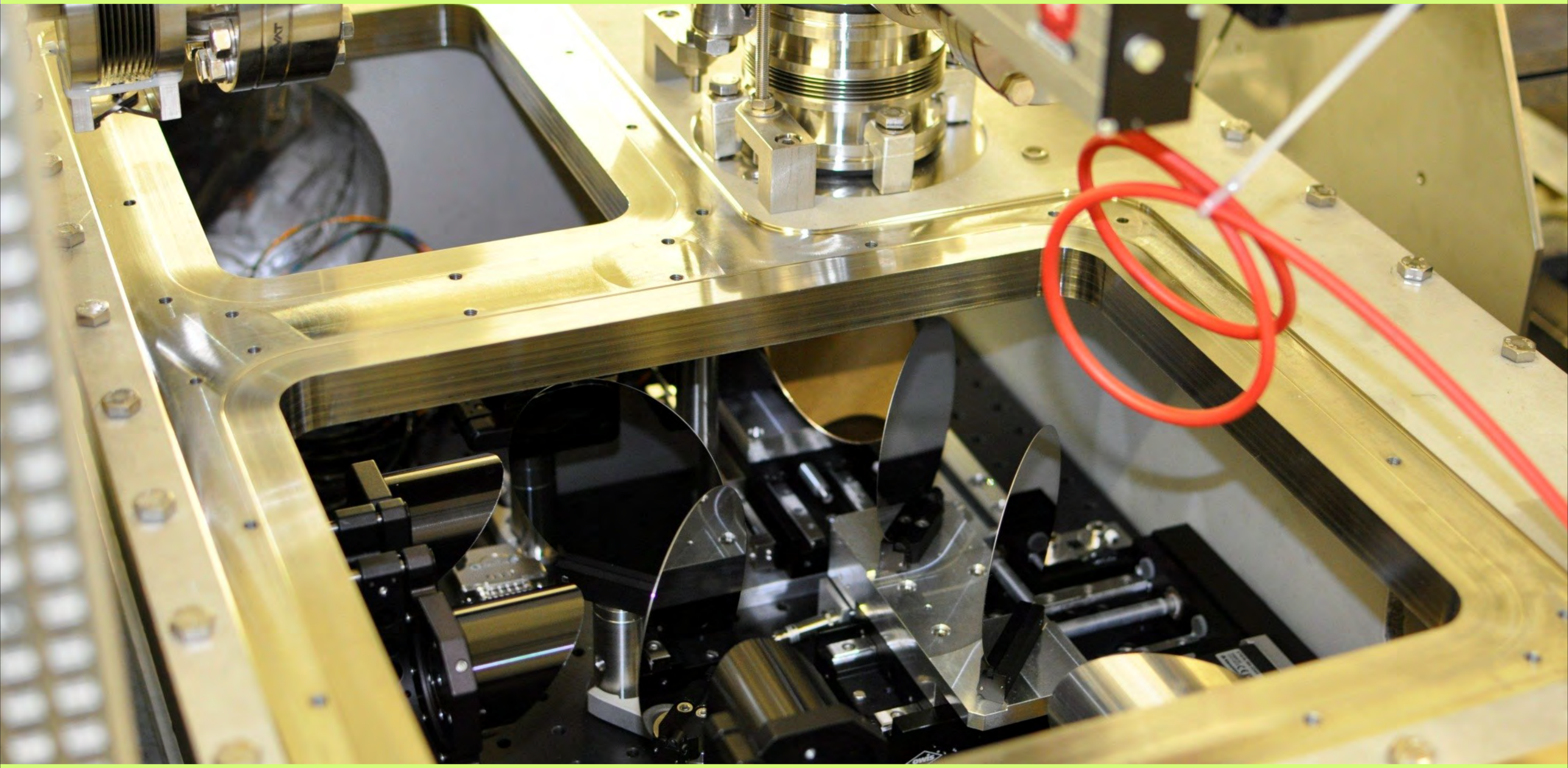
Bunch Arrival Monitor

> Dependence of arrival time on gun phase

> Resolution of BAM: 18 fs rms

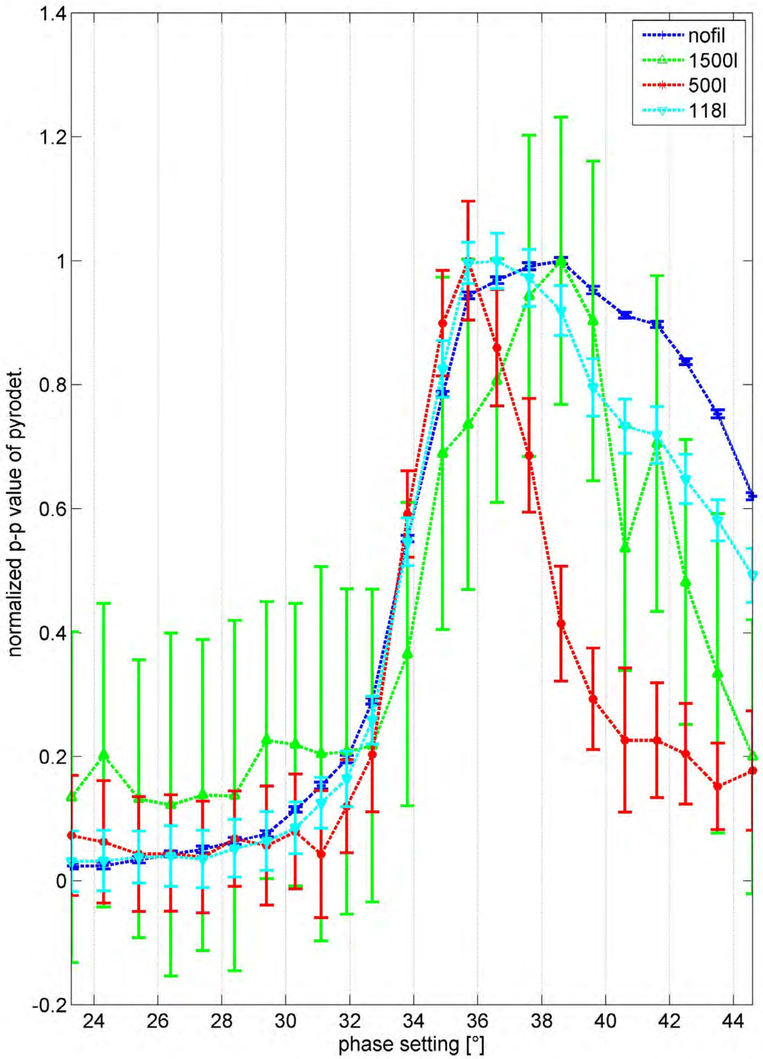


Form Factor Monitor

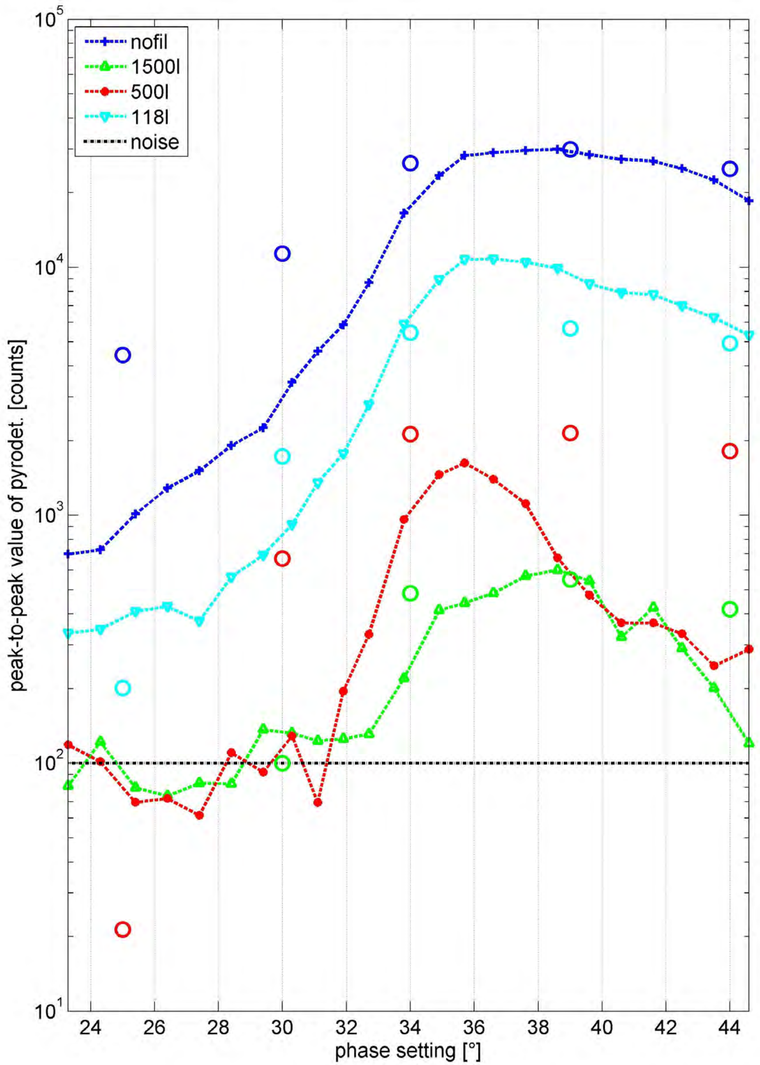


Form Factor Monitor

Normalized signals from pyros with different filters



Pyro signals compared to expected response

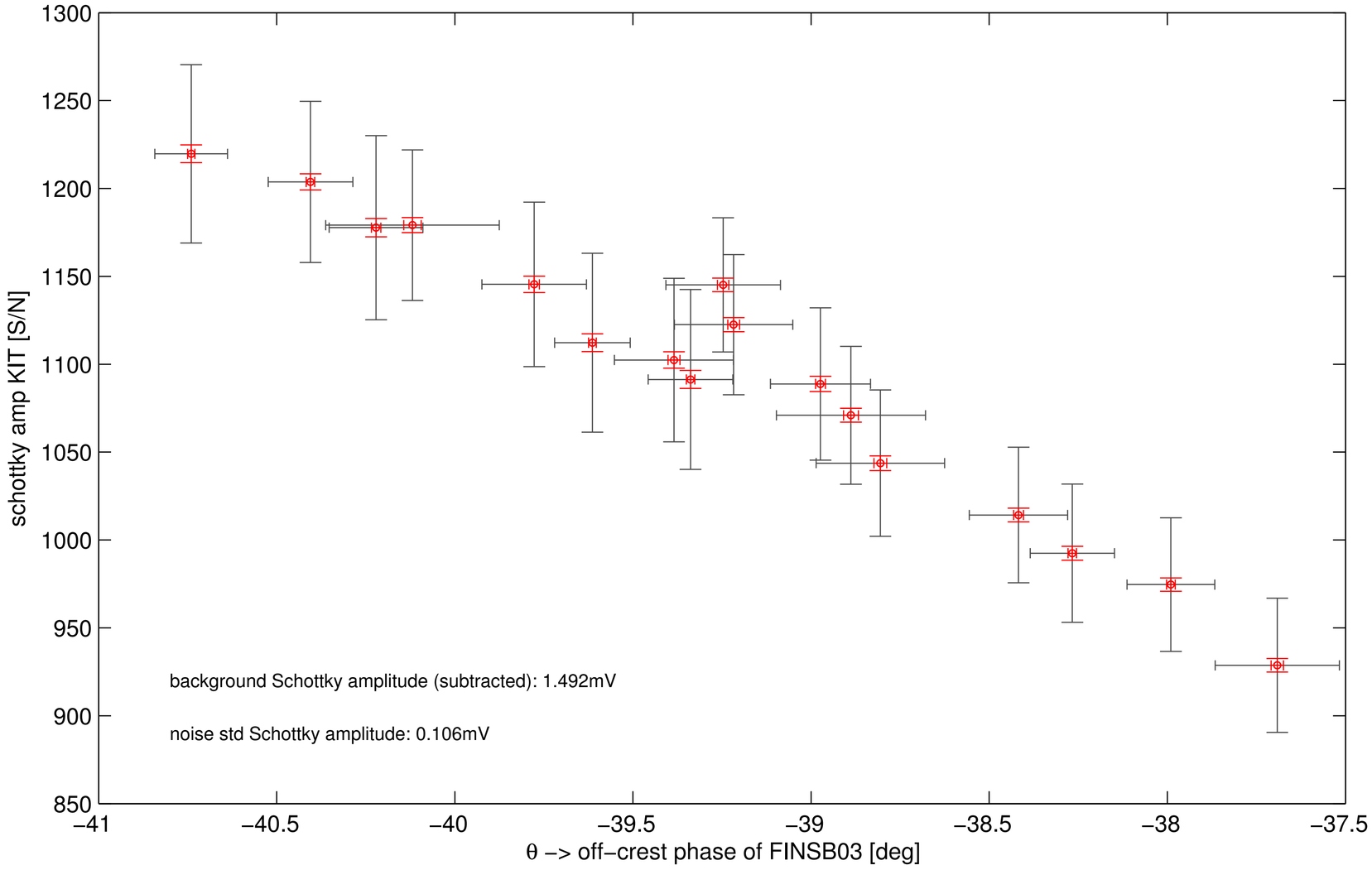


I. Gorgisyan, F. Frei

Form Factor Monitor

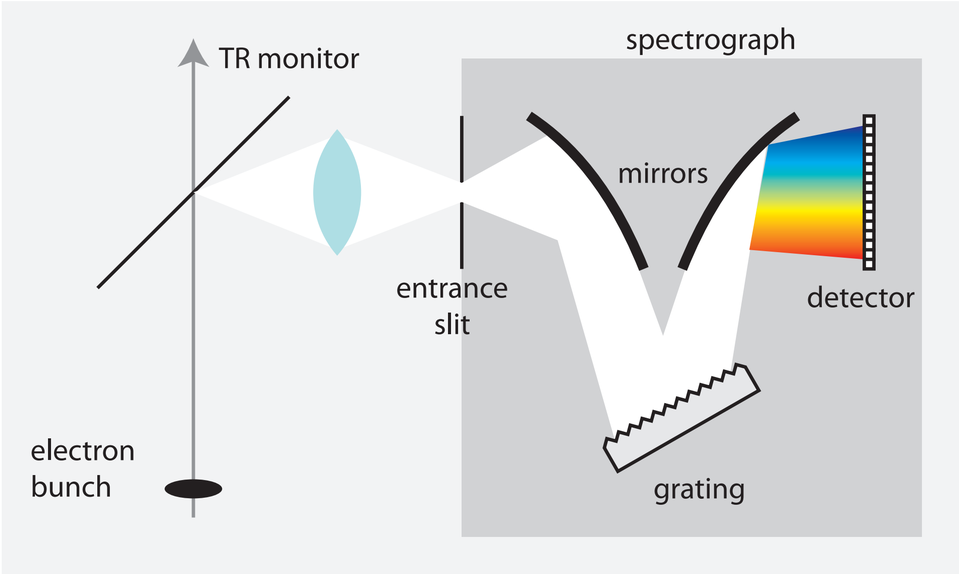
> New detector with improved signal-to-noise at 10 pC bunch charge

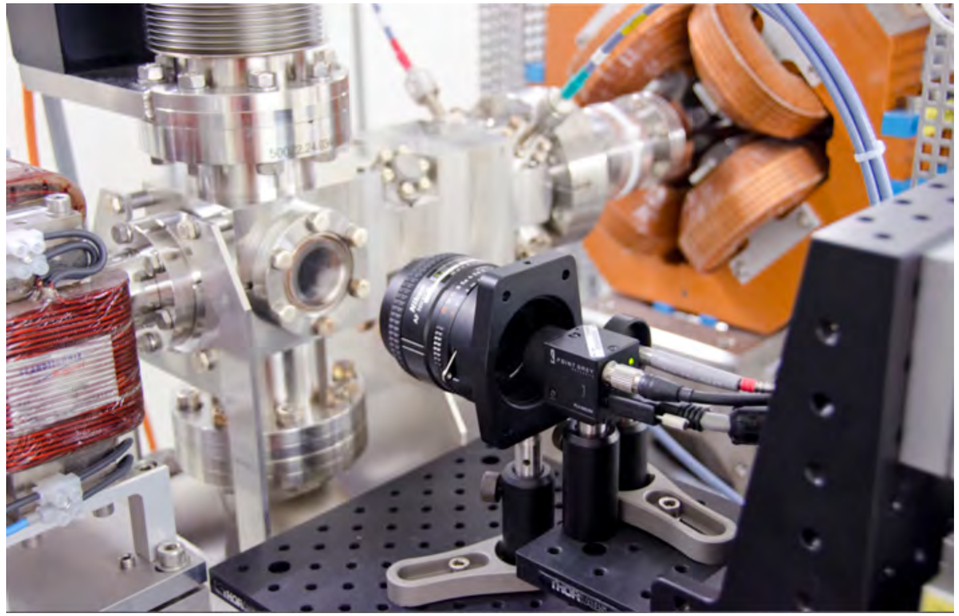
☞ WEPC36



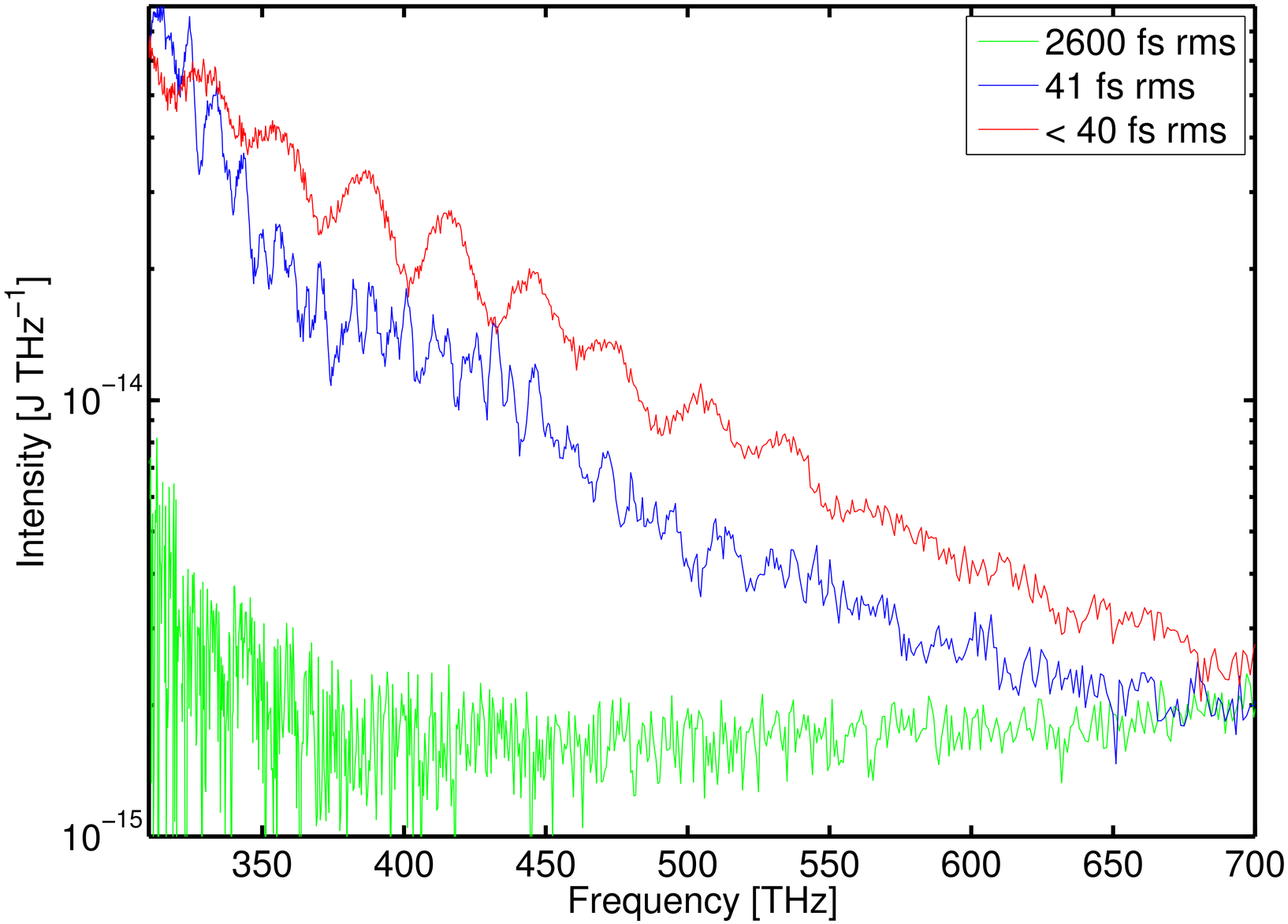
Optical Spectrum of Transition Radiation

> Experimental Setup in the SwissFEL Injector Test Facility
  > Transition radiation from aluminum coated silicon screen
  > Focusing with lens, now replaced by mirror
  > Commercial spectrometer with wide spectral range from 316 to 1363 THz

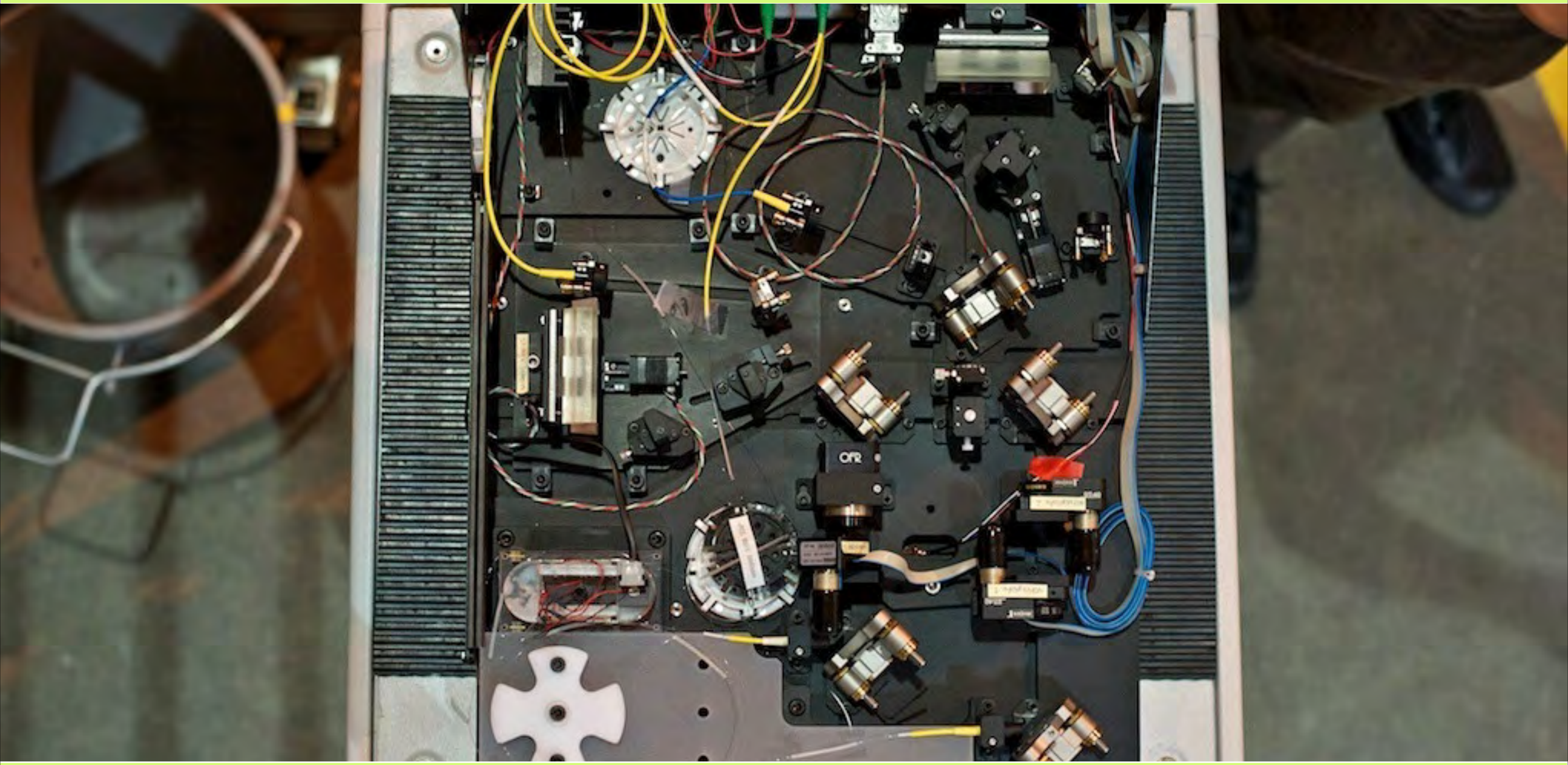




Optical Spectrum of Transition Radiation

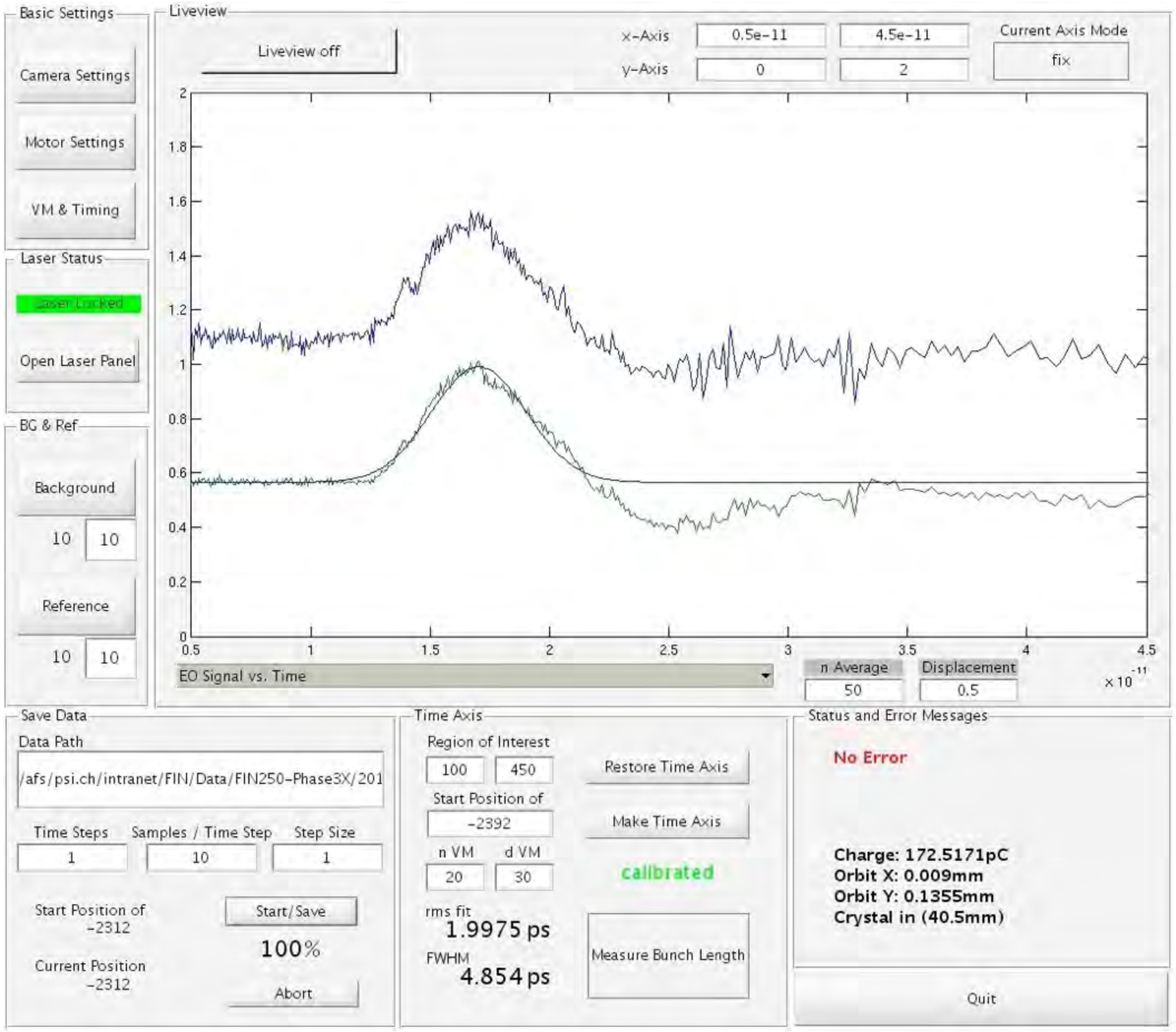


Electro-Optical Monitor



P. Peier, Y. Ivanisenko

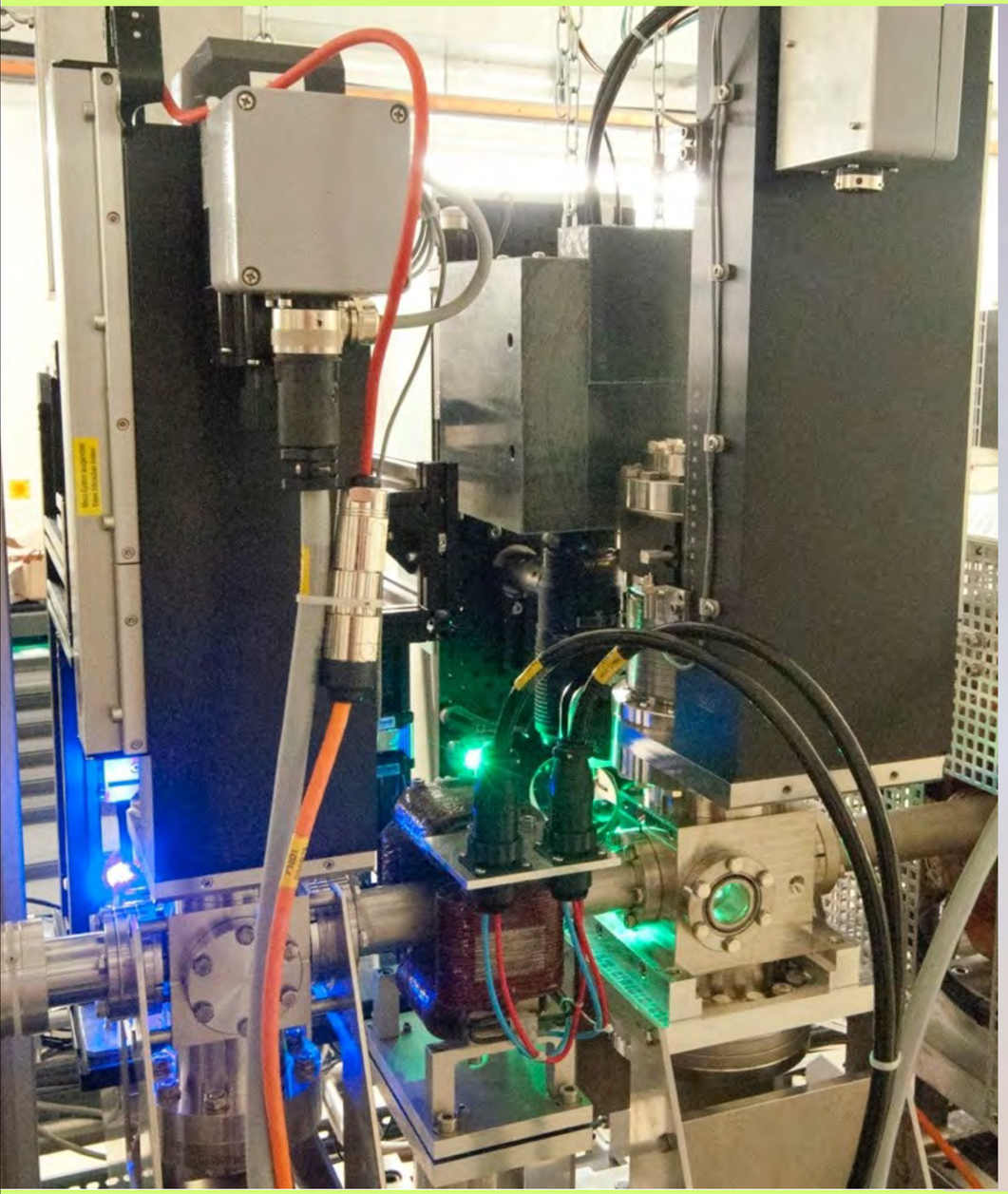
Electro-Optical Monitor

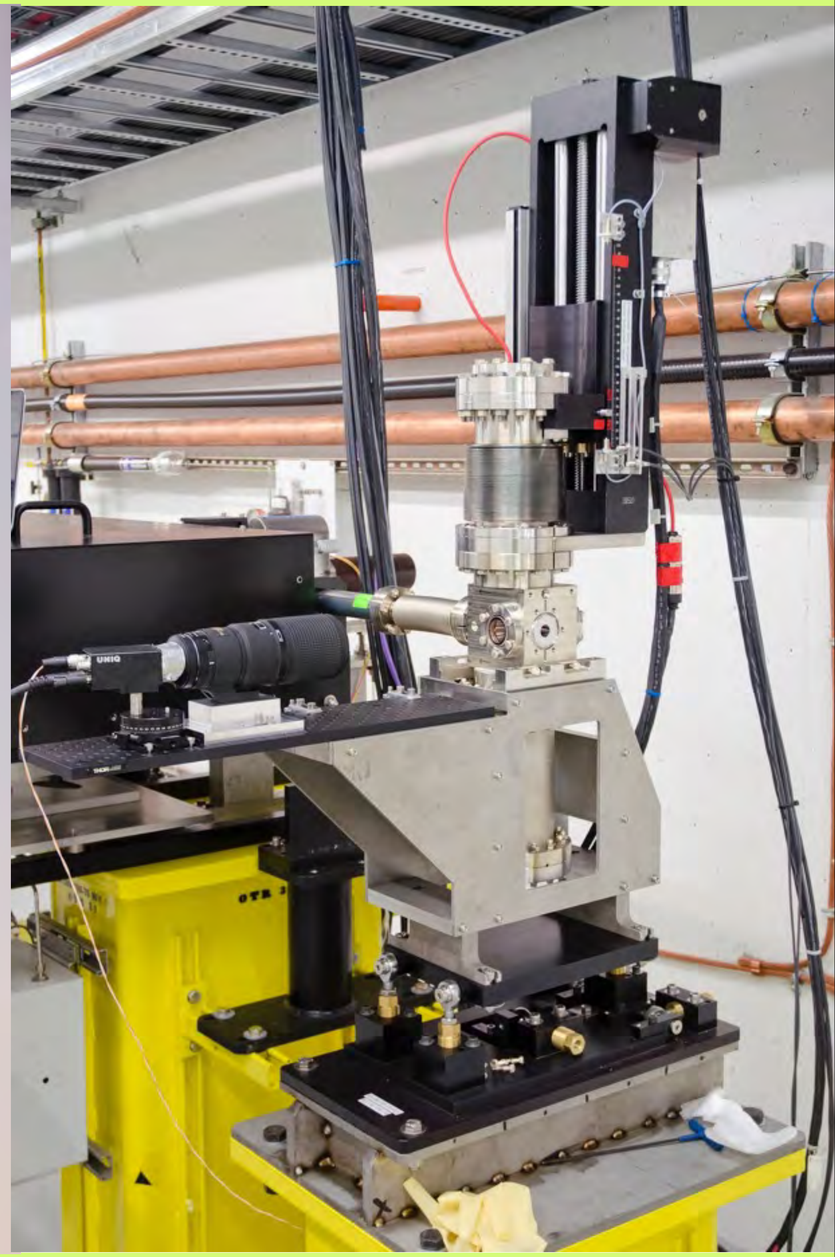


☞ WEPC37

Transverse Profile: Screen Monitor

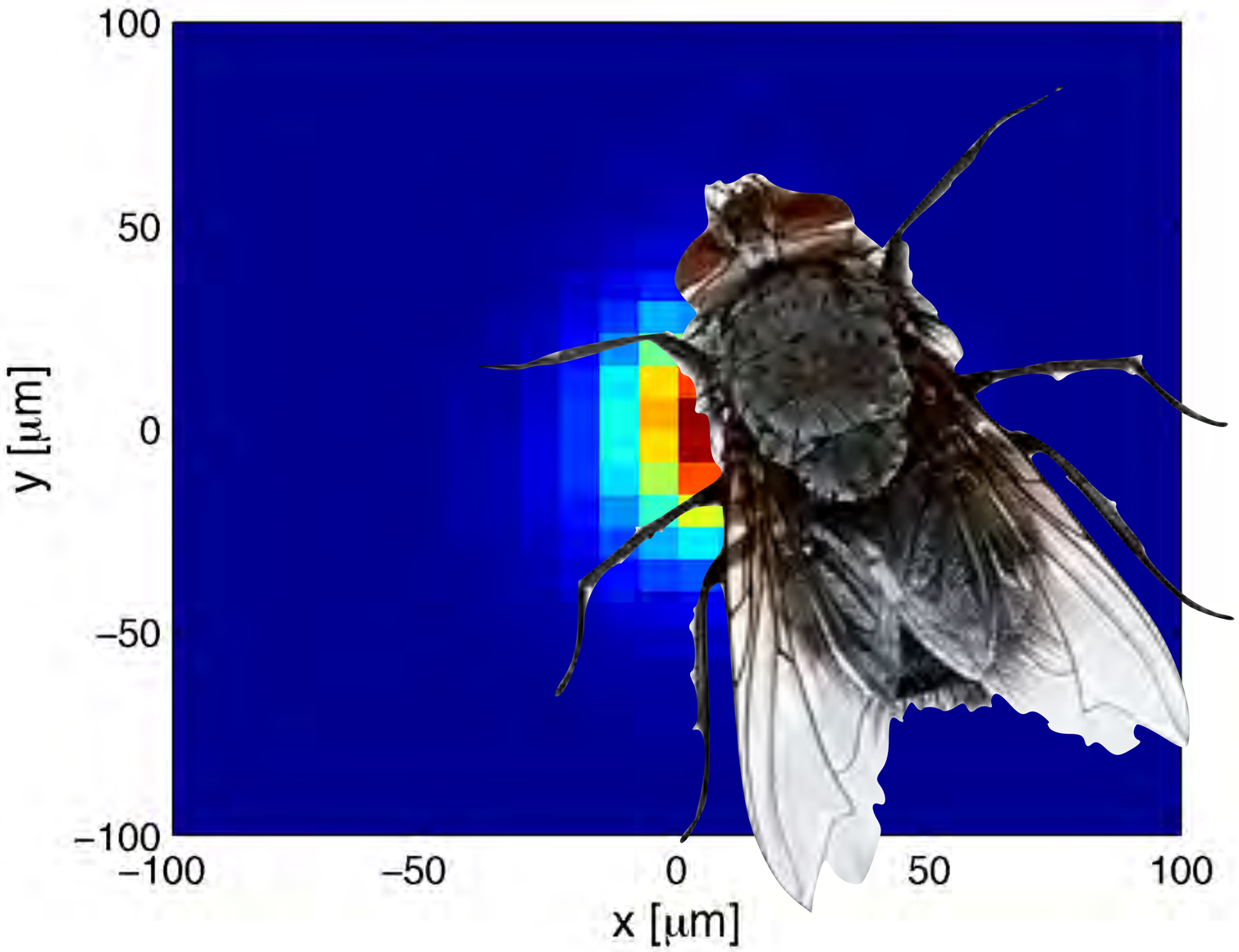
Transverse Profile: Screen Monitor





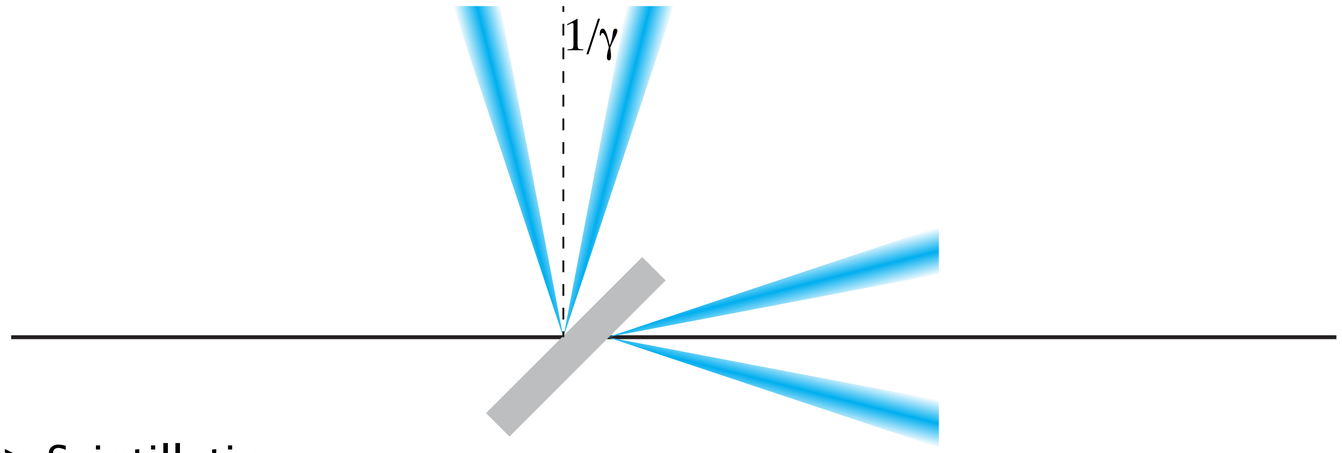
Transverse Profile: Screen Monitor

> Goal:
Measurement of small beams (10 μm rms)

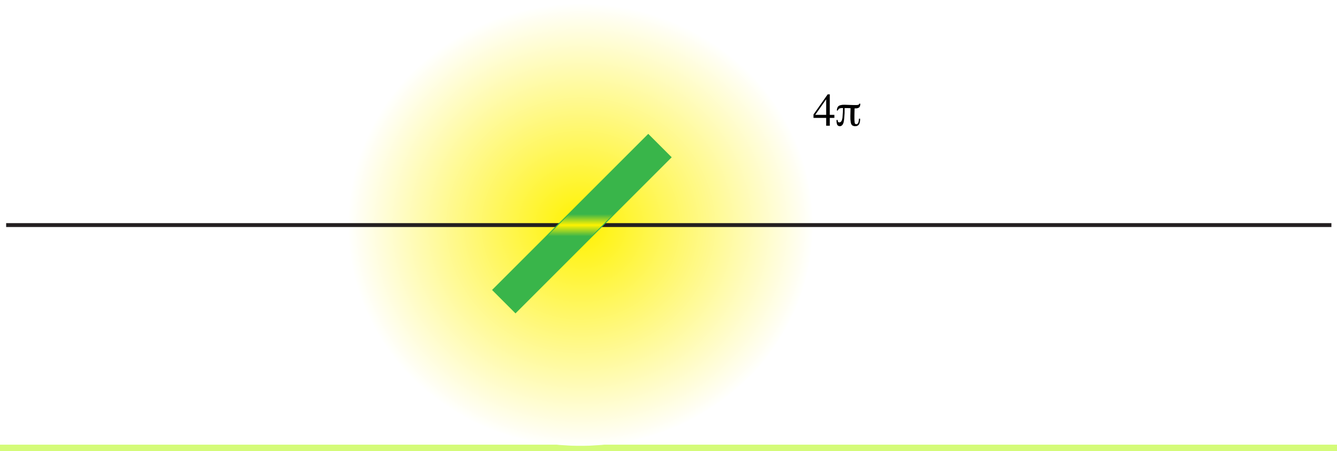


2-Dimensional Profile Monitors

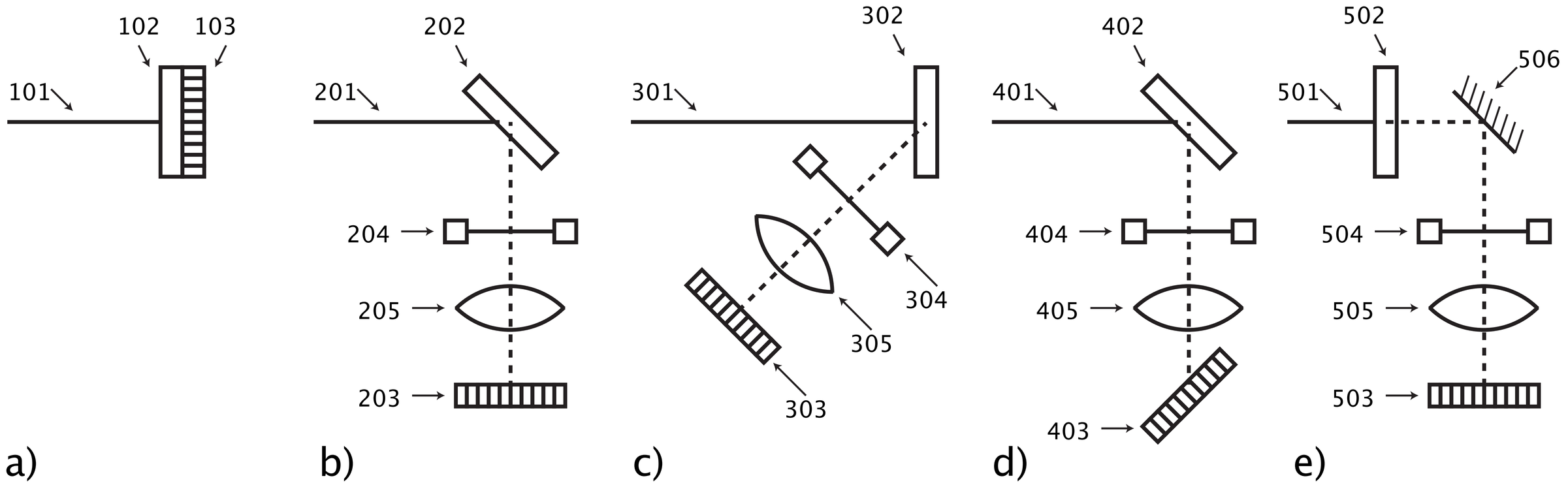
> Optical transition radiation (OTR)



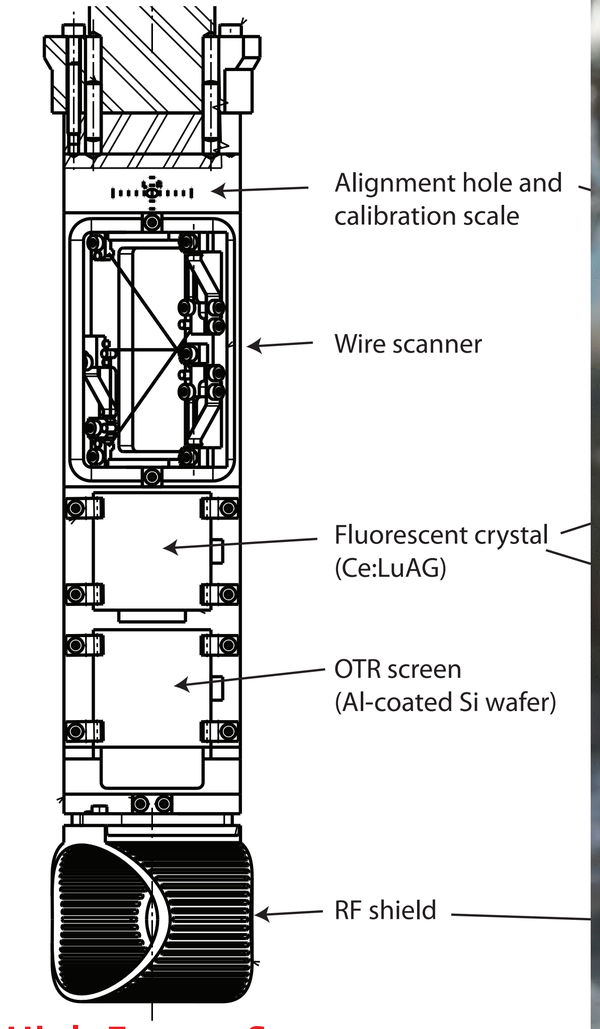
> Scintillation

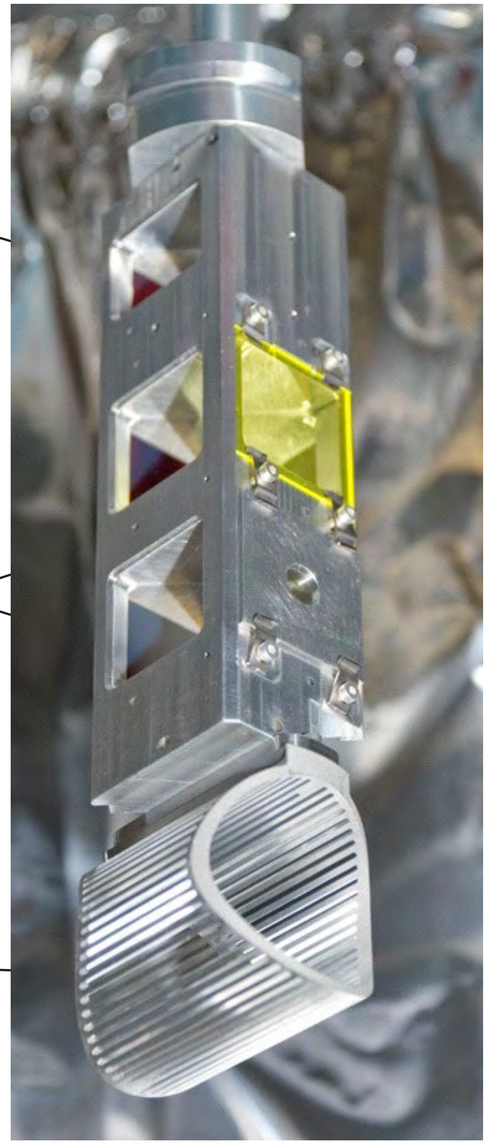


Imaging Scintillators



Electron Beam Profile Monitors for the SwissFEL Injector Test Facility





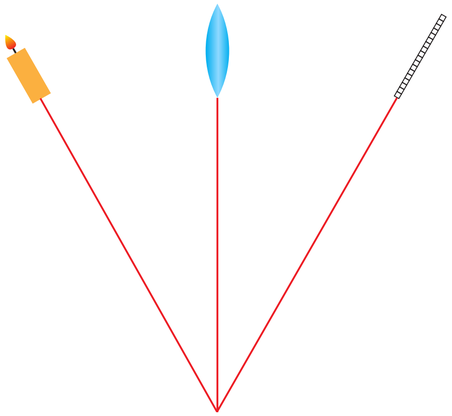
Installed scintillators

- Ce:YAG
  - 5 µm
  - 20 µm
  - 200 µm
- Ce:LuAG
  - 200 µm

Design Considerations

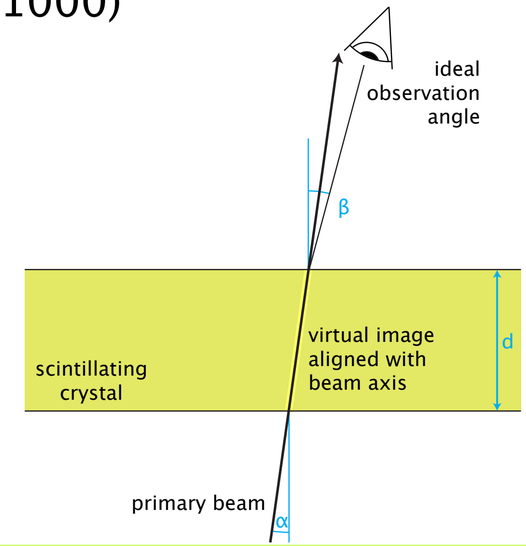
> Scheimpflug imaging principle — Theodor Scheimpflug (1865—1911)

Fig. 1. Theodor Scheimpflug, May 1, 1888, in Pola, when he became a petty officer.



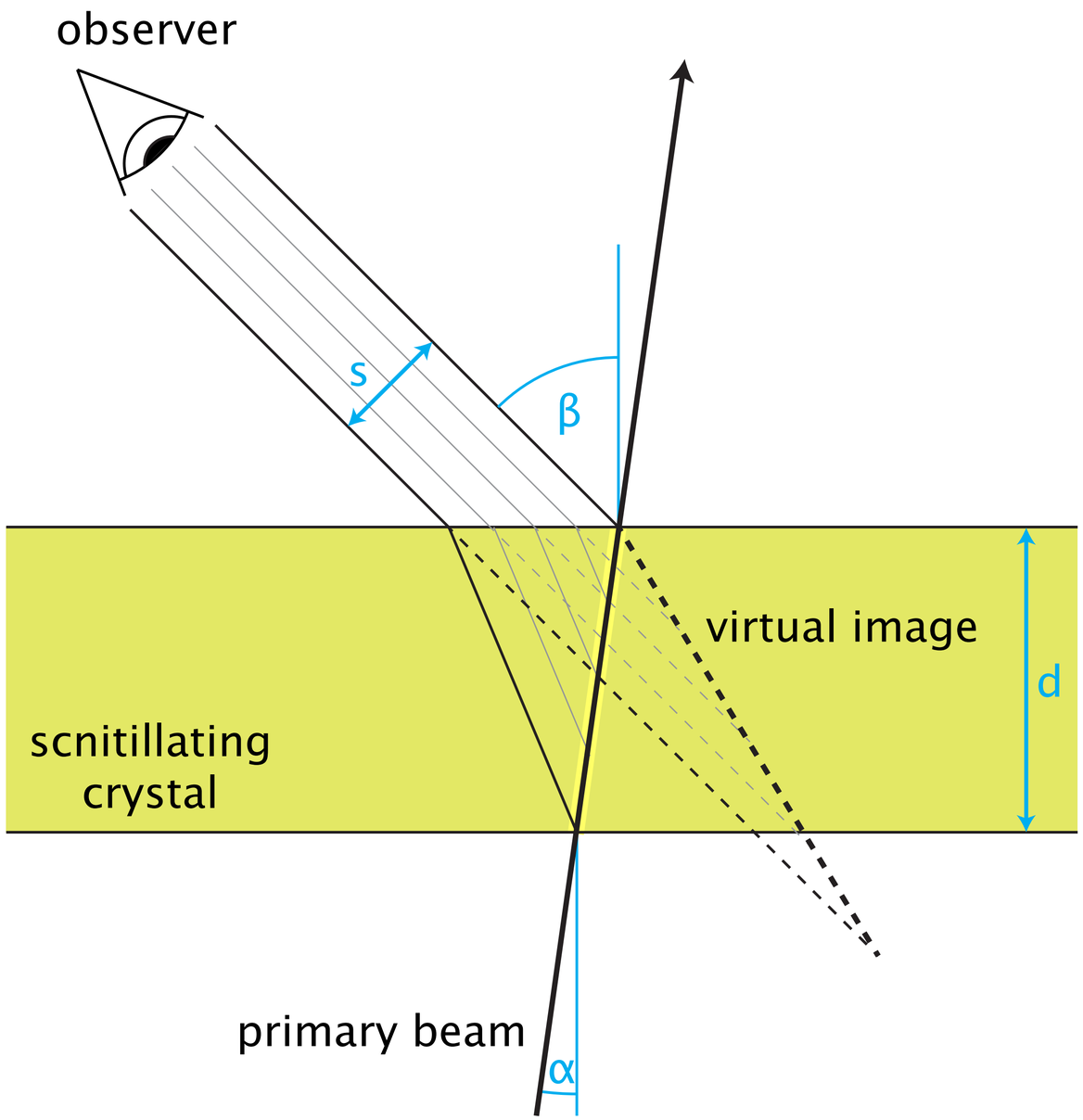
Observation of the Scheimpflug imaging principle allows to image the entire screen without depth-of-field issues.
To avoid astigmatism, the lens is not tilted, but the detector is tilted. For a 1:1 imaging, we tilt the CMOS sensor by 15°.

> Snell's law of refraction — Willebrord Snellius (1580—1626)
Abu Sad al-Ala ibn Sahl (940—1000)

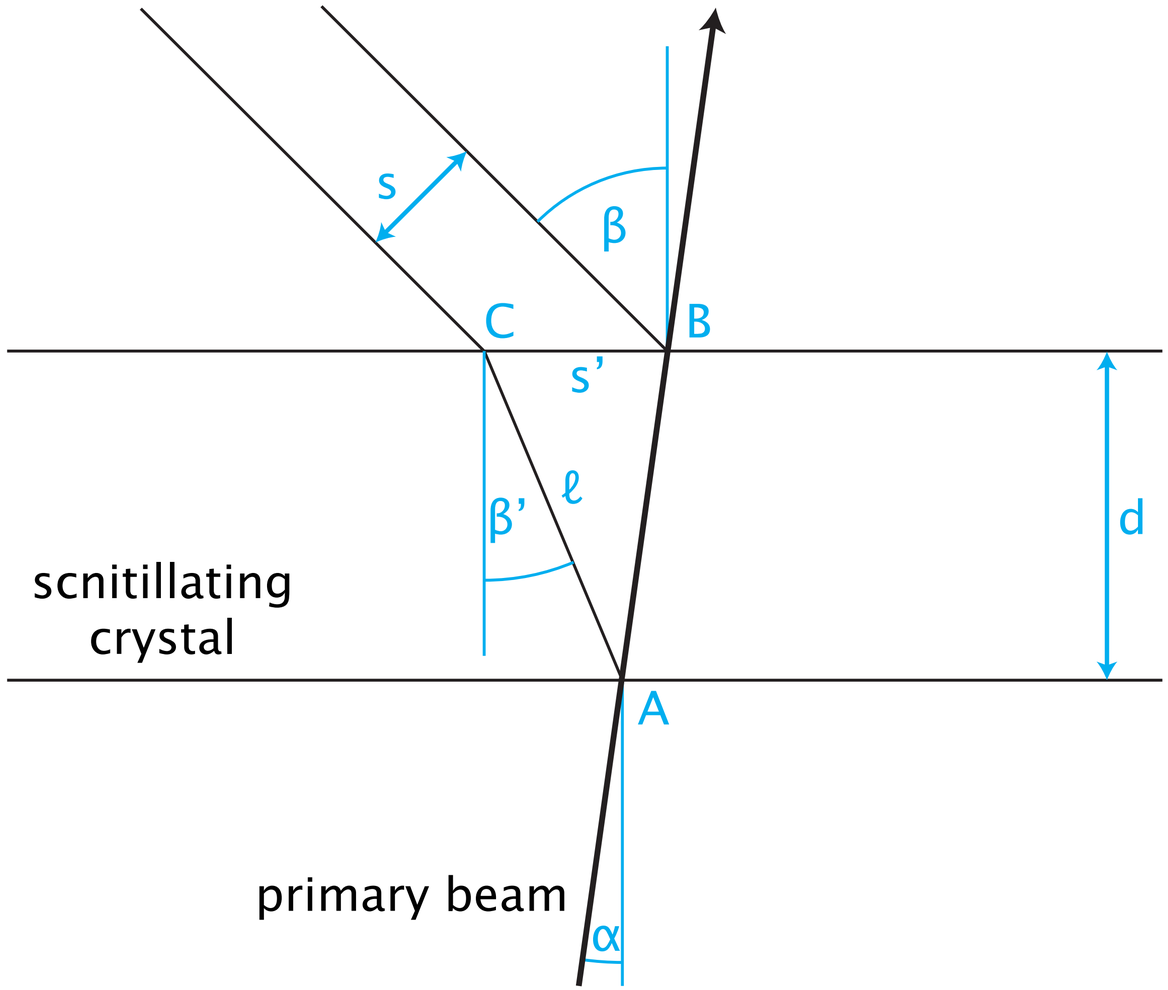


The YAG scintillator is observed at such an angle that Snell's law of refraction is observed.
As a consequence, we can image beams that are smaller than the thickness of the scintillator.

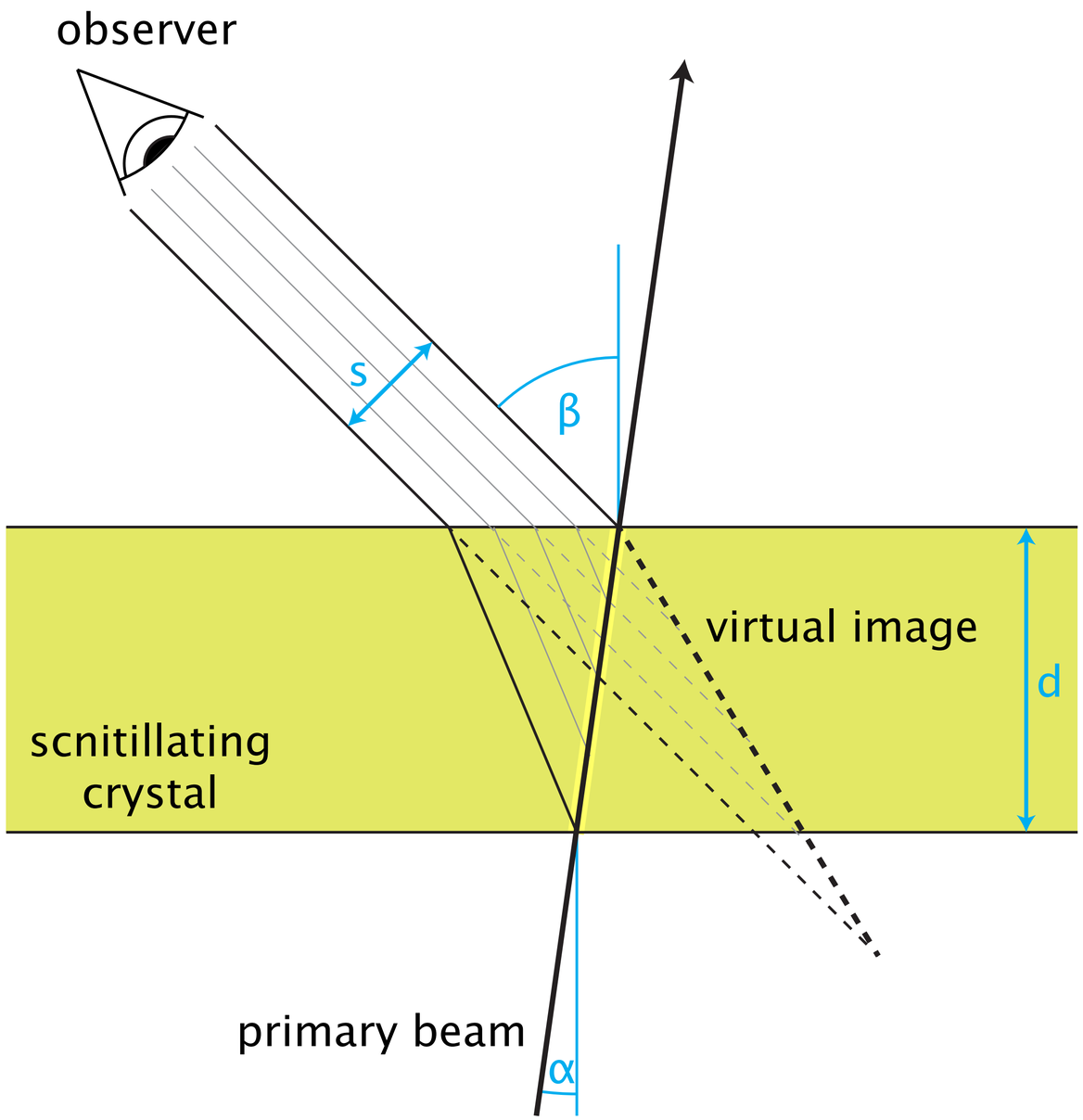
Imaging Scintillating Crystals



Imaging Scintillating Crystals

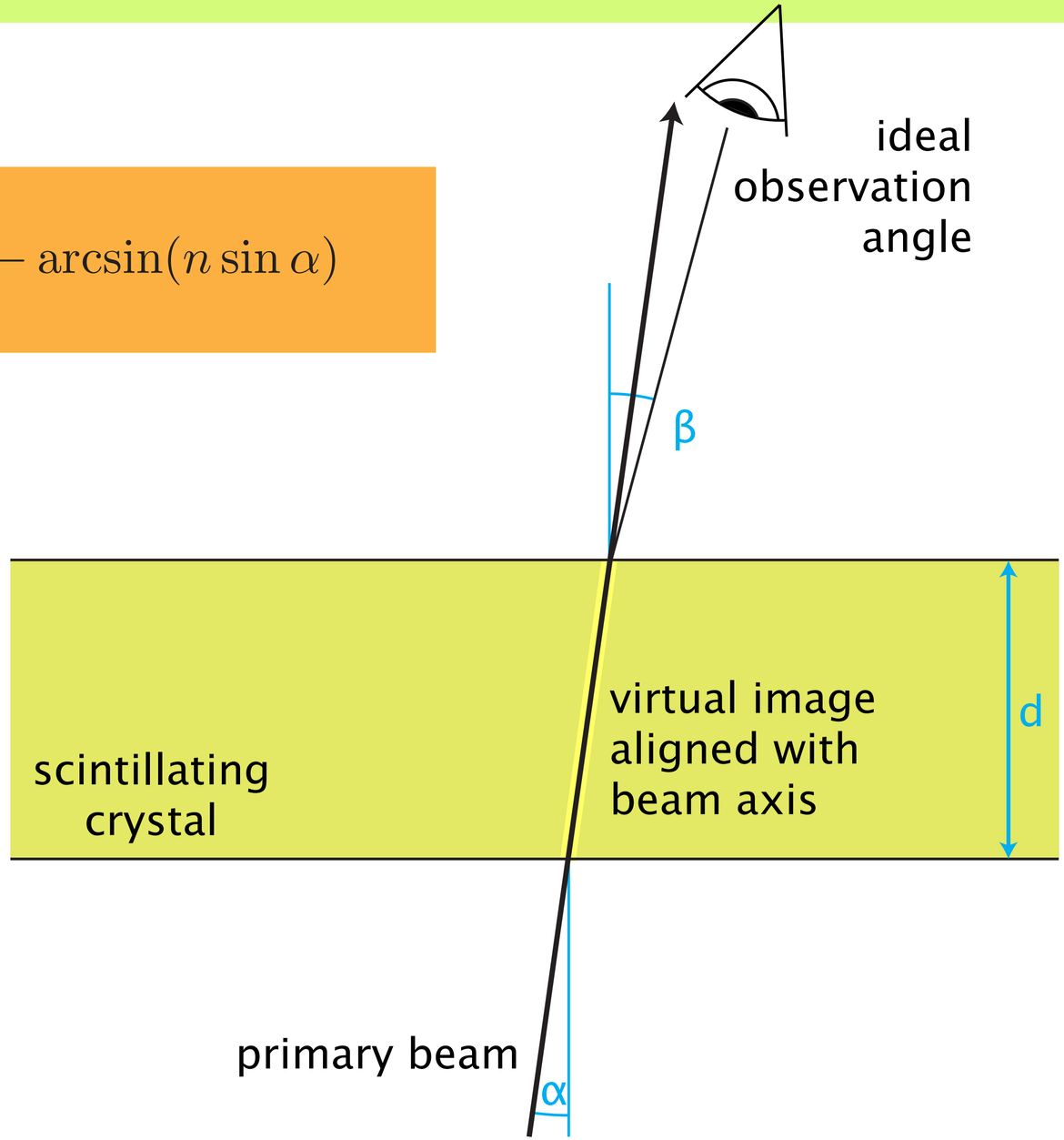


Imaging Scintillating Crystals



Imaging Scintillating Crystals

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



Trigonometry...

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

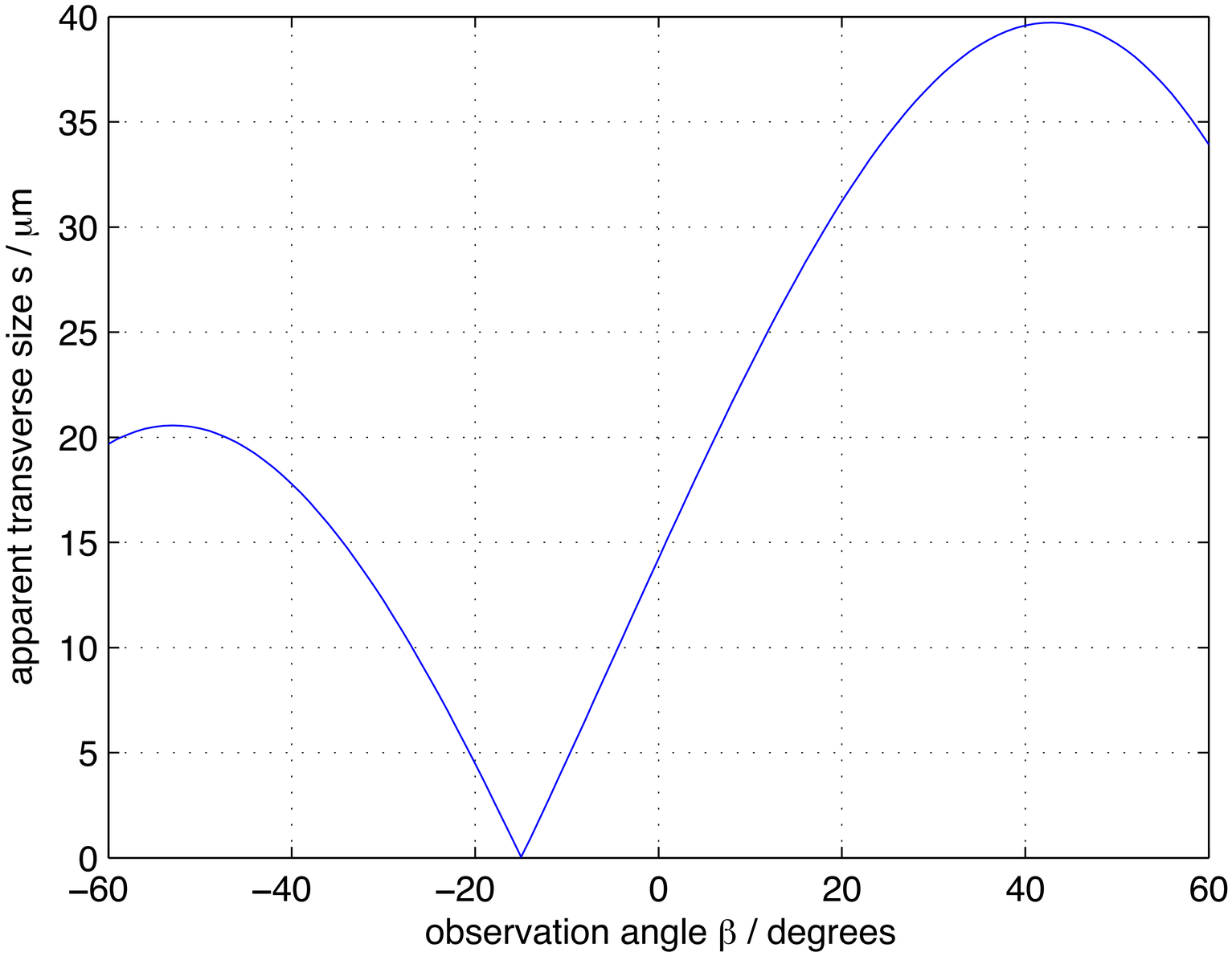
$$\ell := \overline{AB} = \frac{d}{\cos\beta'}$$

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

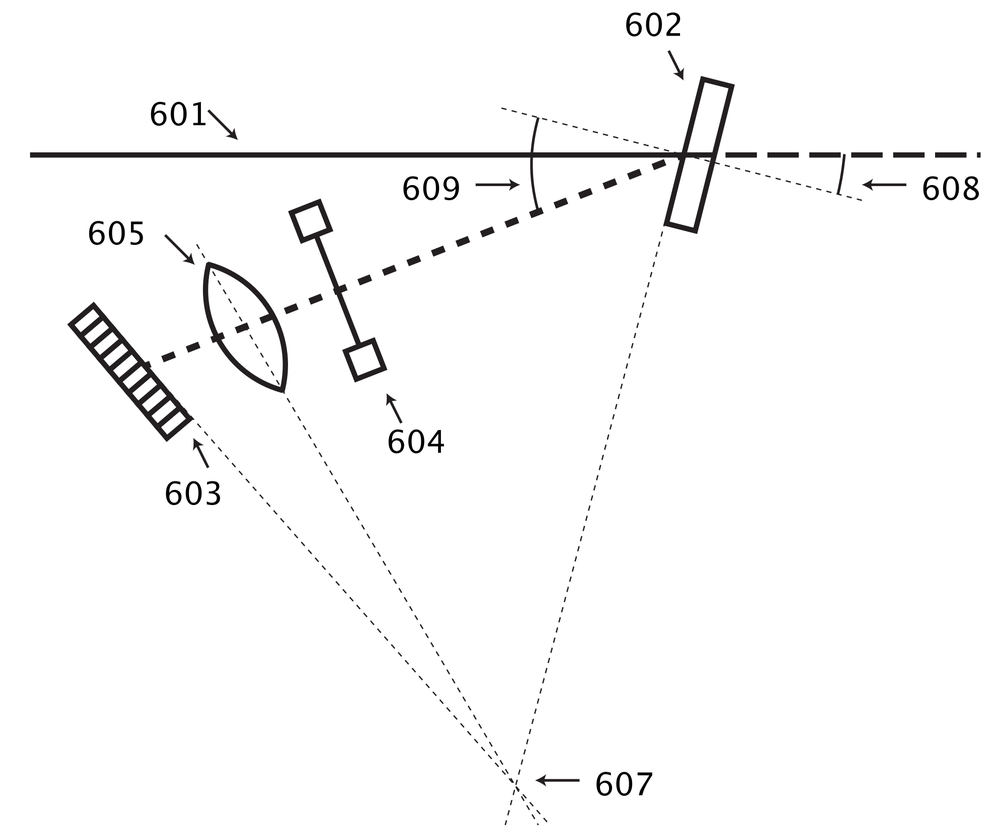
$$s'^2 = \ell^2 + \left(\frac{d}{\cos\alpha}\right)^2 - 2\ell\frac{d}{\cos\alpha}\cos(\alpha+\beta')$$

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

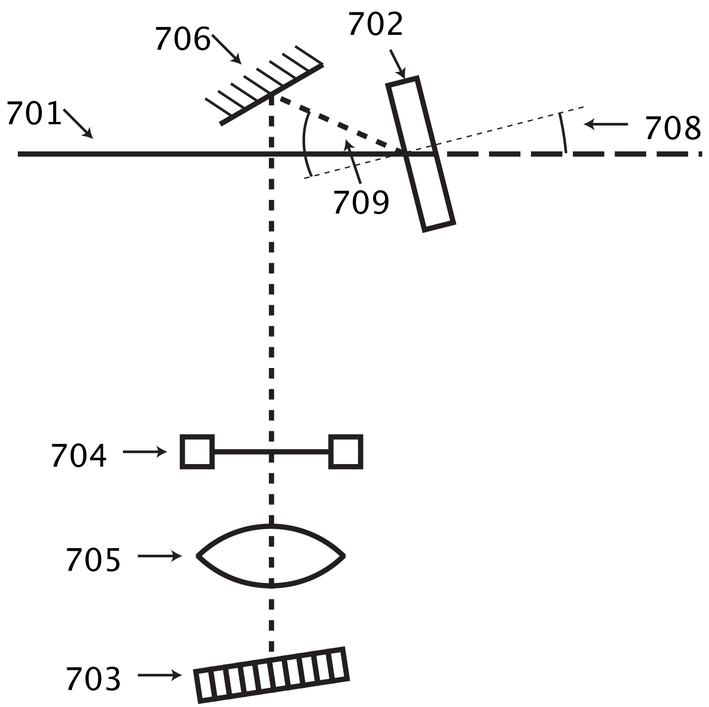
Observed Beam Size



Ideal Observation Angle



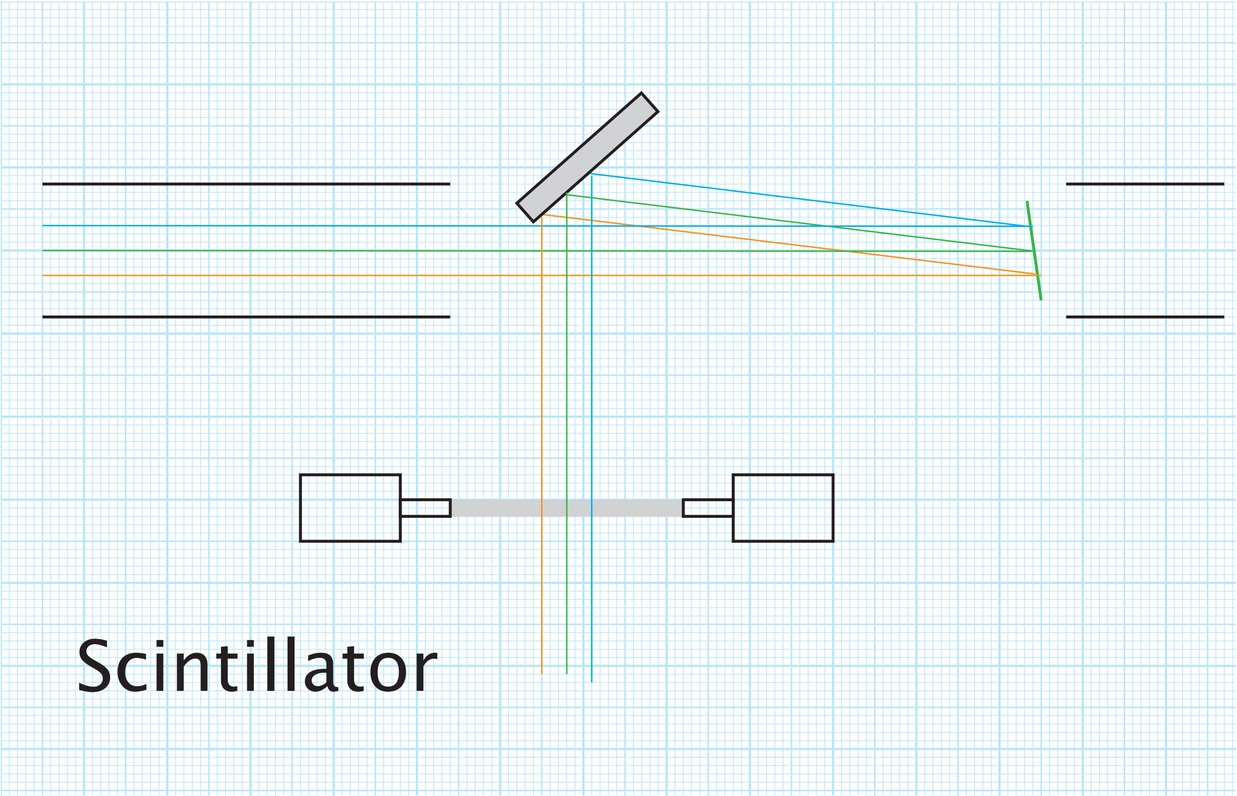
a)

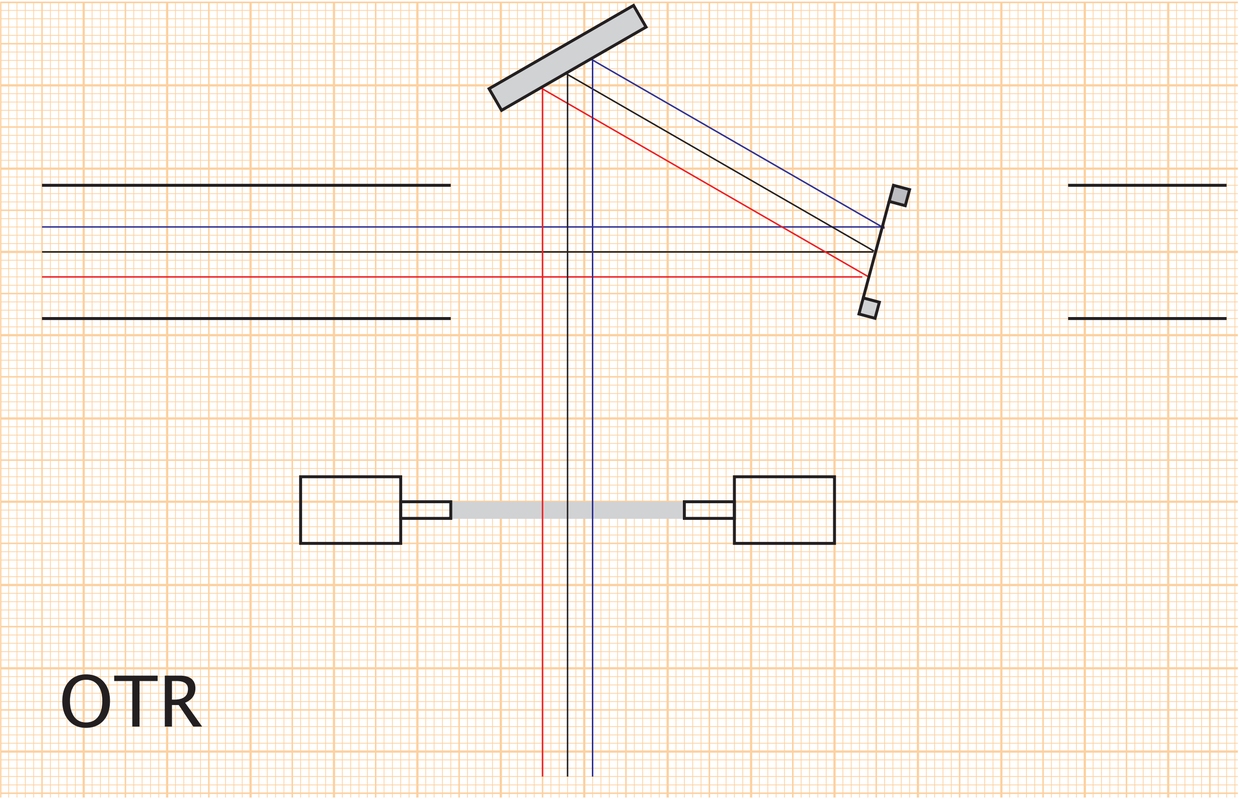


b)

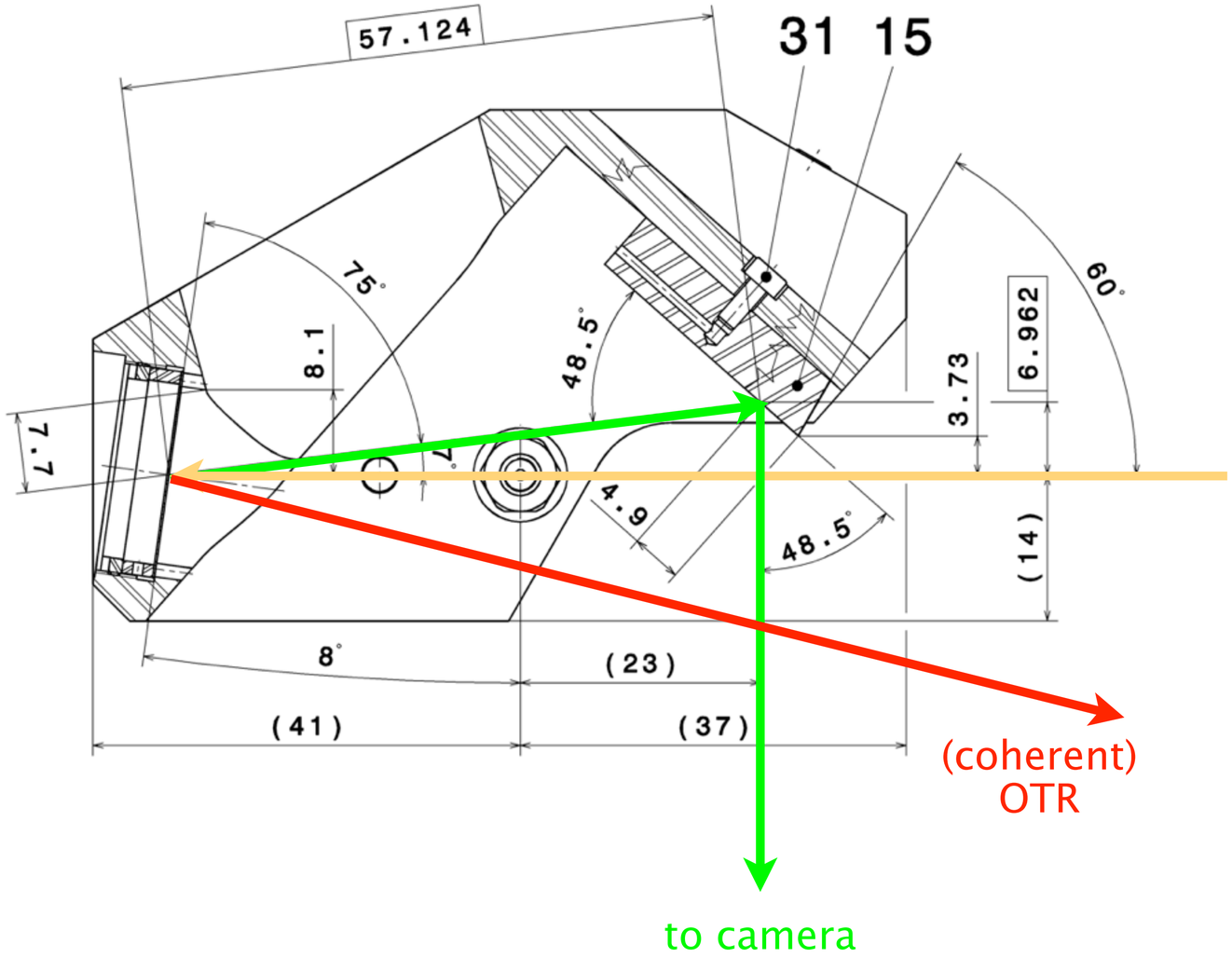
Measurement Principle

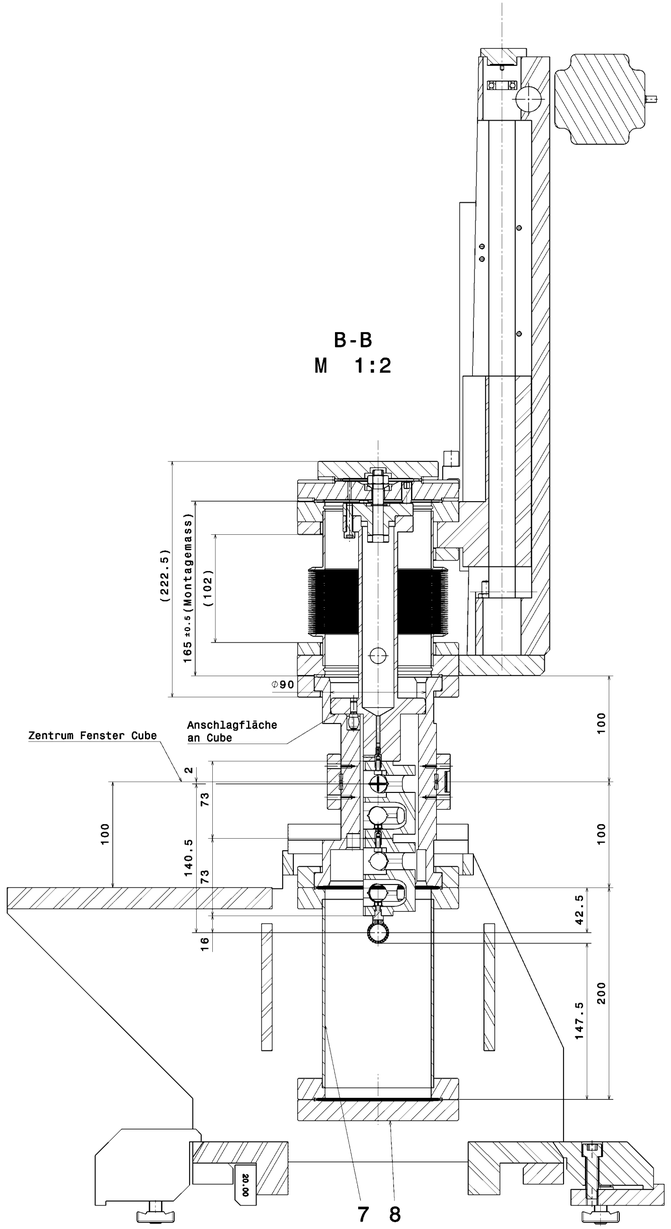
> Combination of two monitors:
  > Scintillating crystal
  > Optical transition radiation





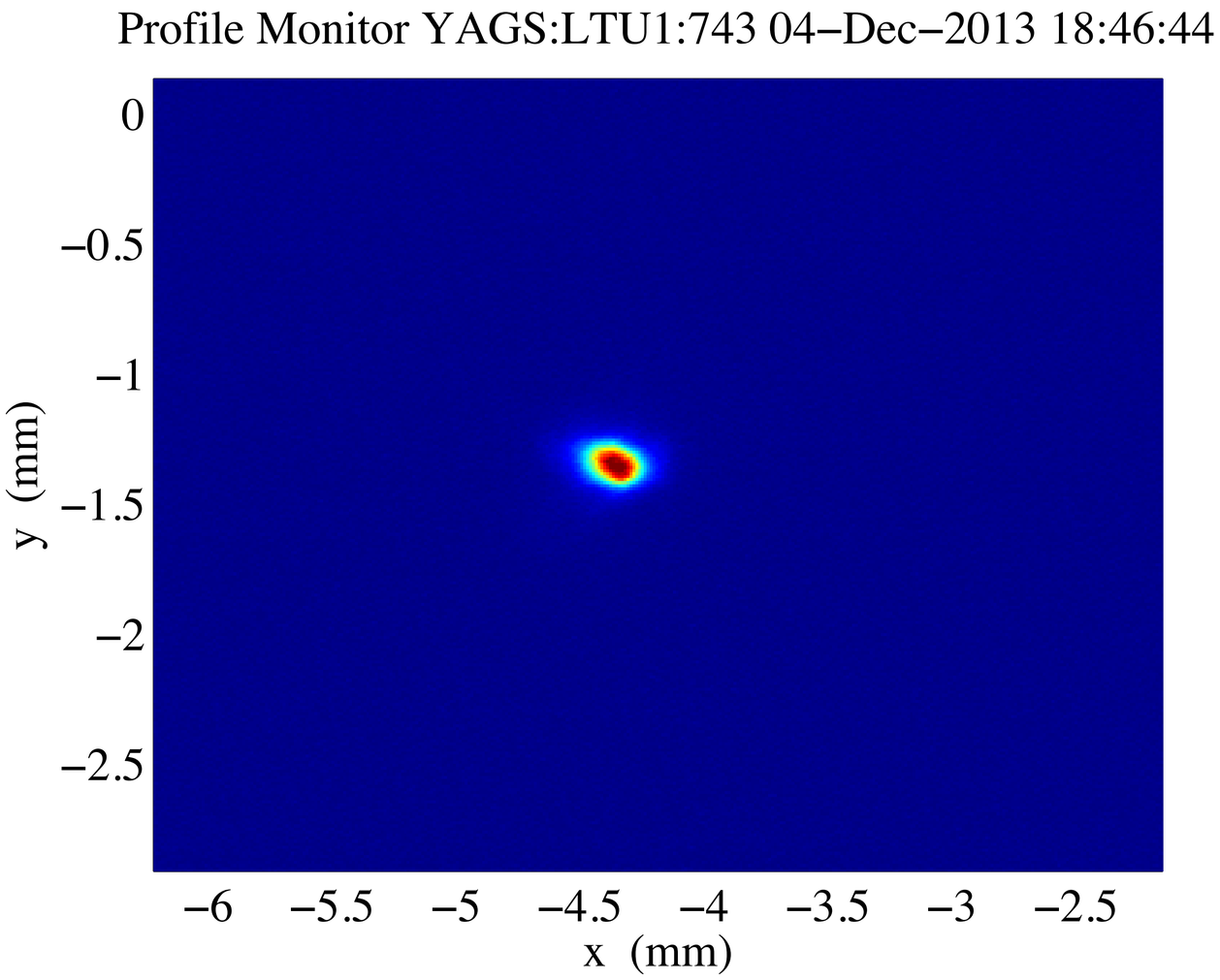
Implementation



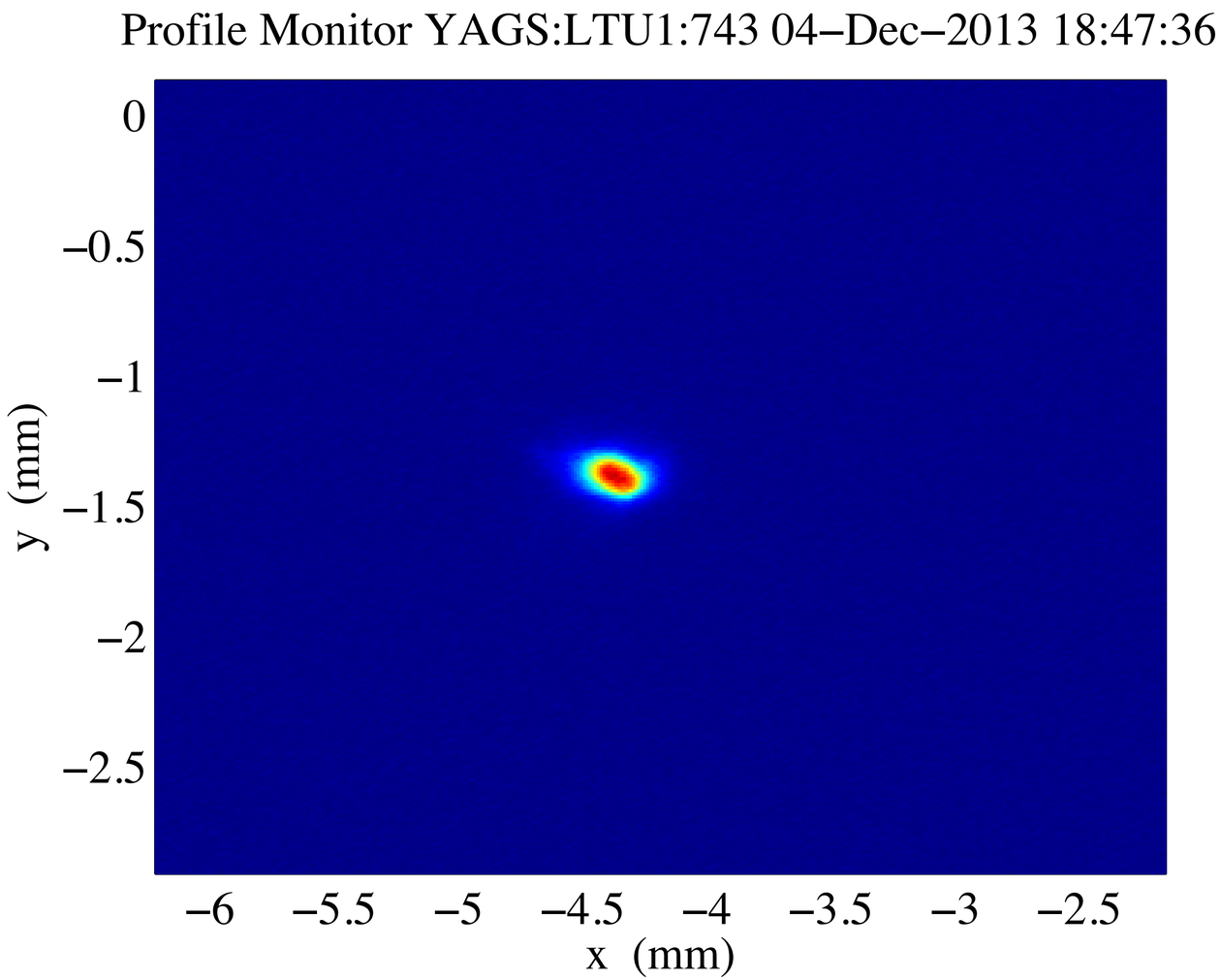


Suppression of Coherent Optical Transition Radiation

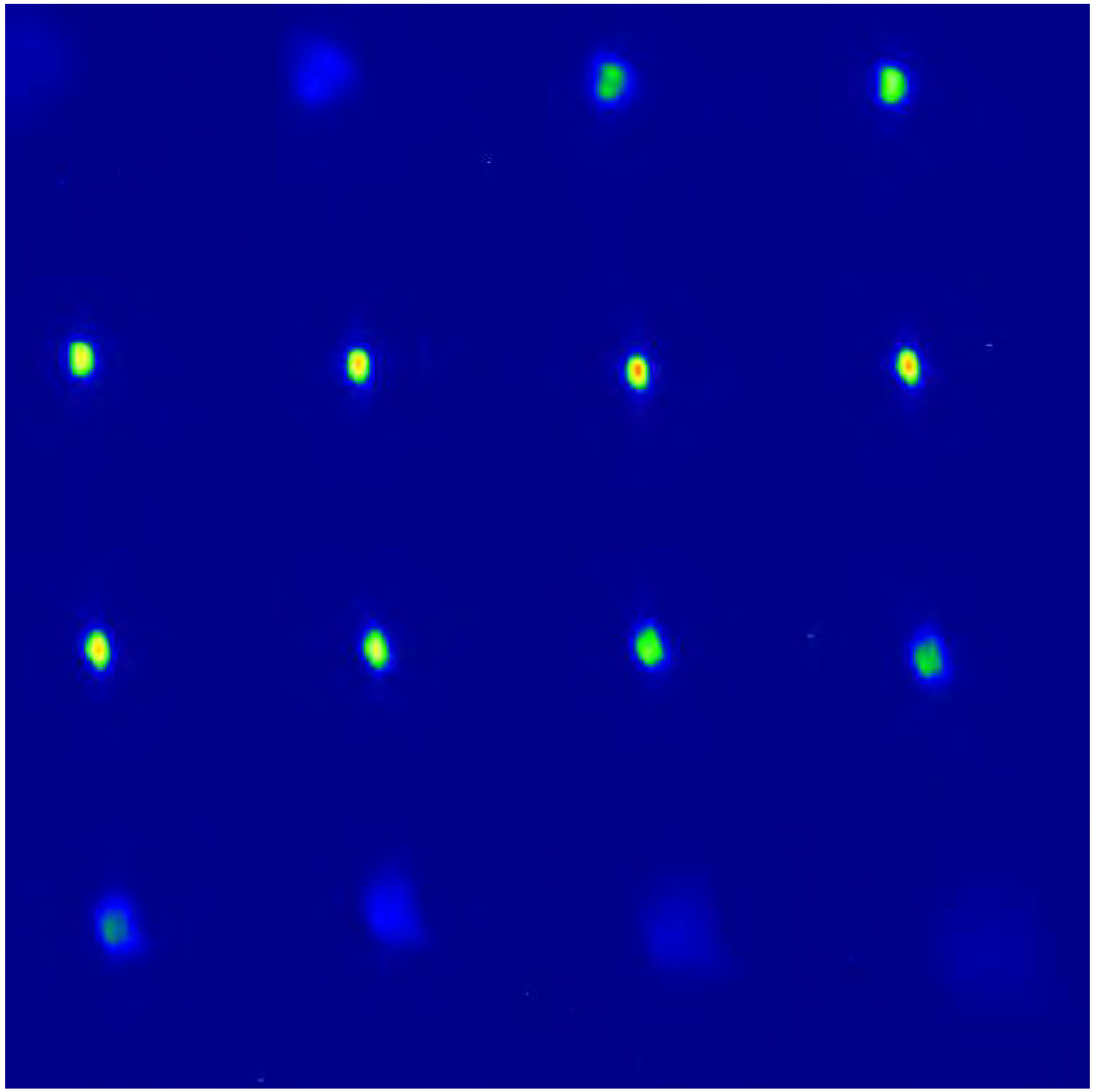
> Laser heater ON

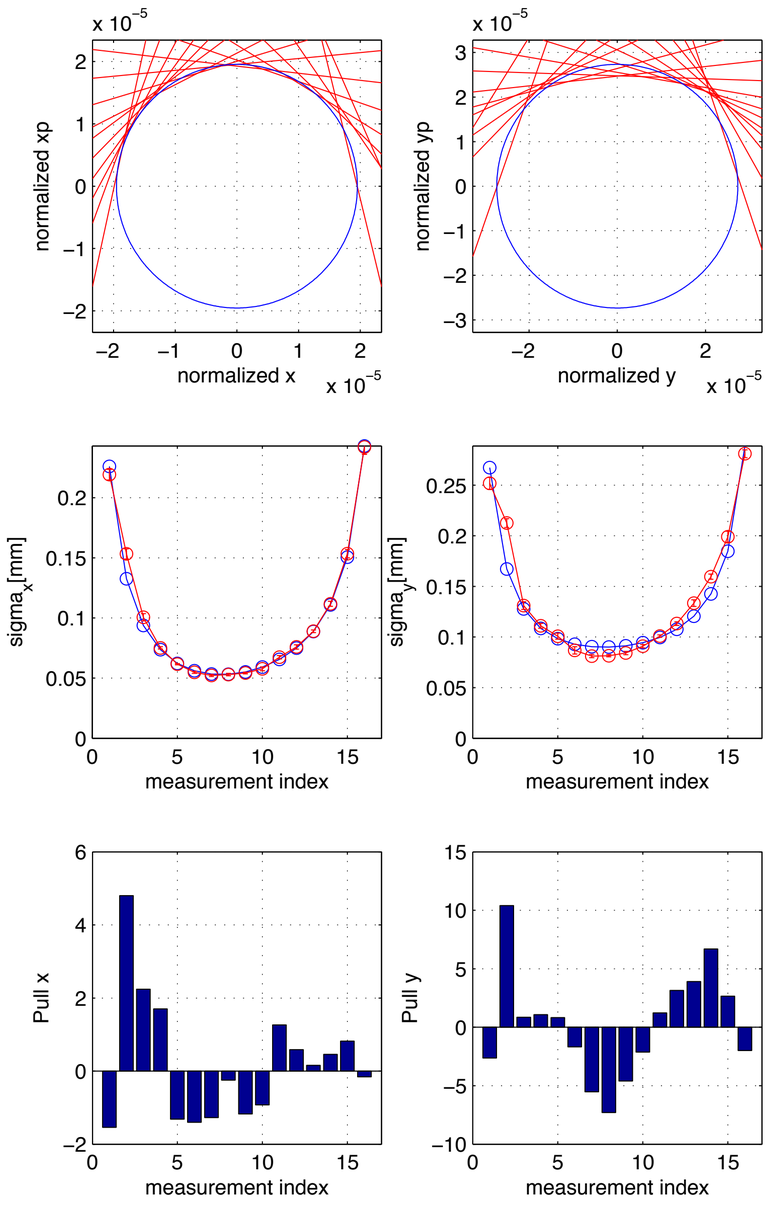


> Laser heater OFF



Transverse Profiles: Quadrupole Scan

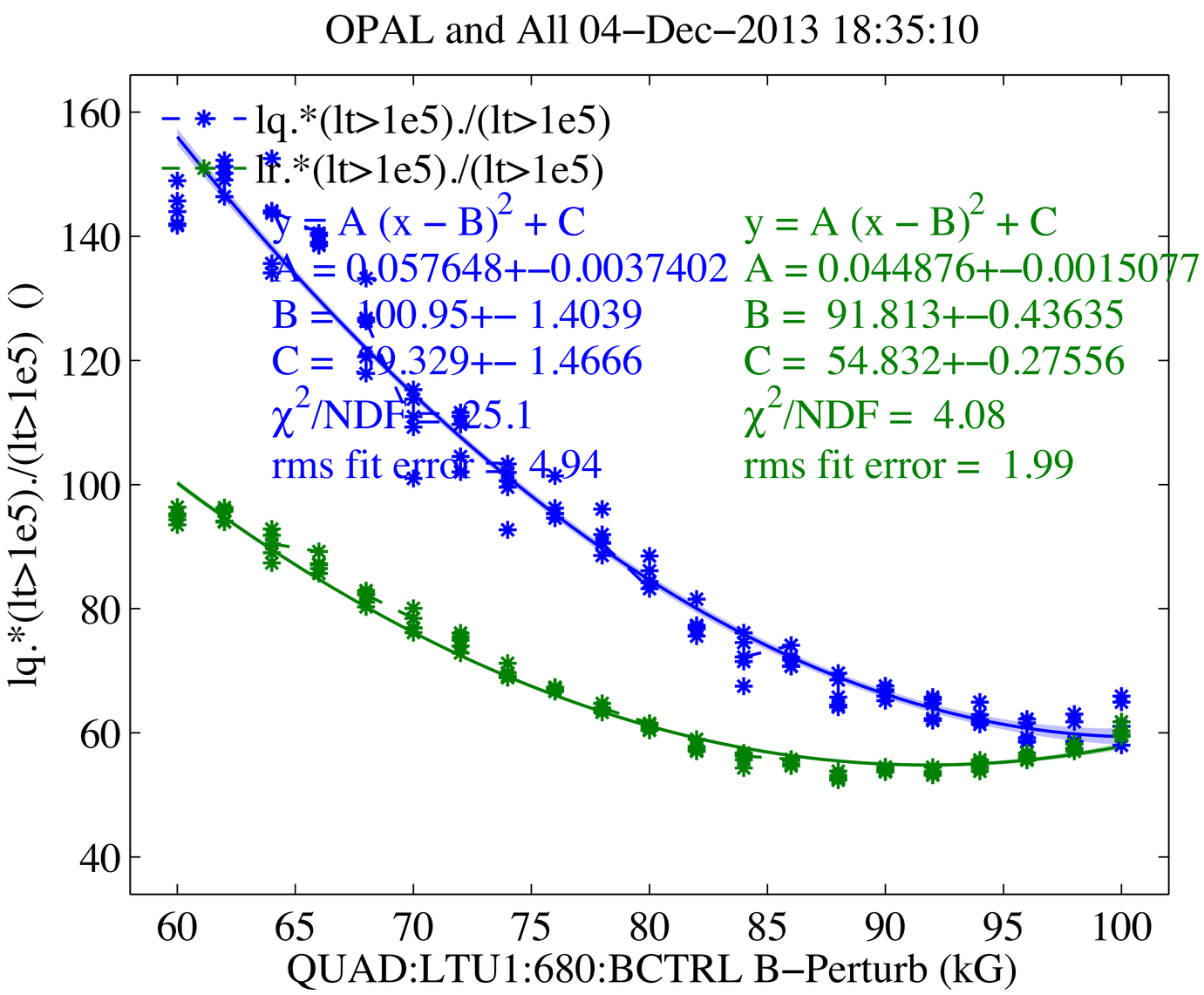




Quadrupole Scan

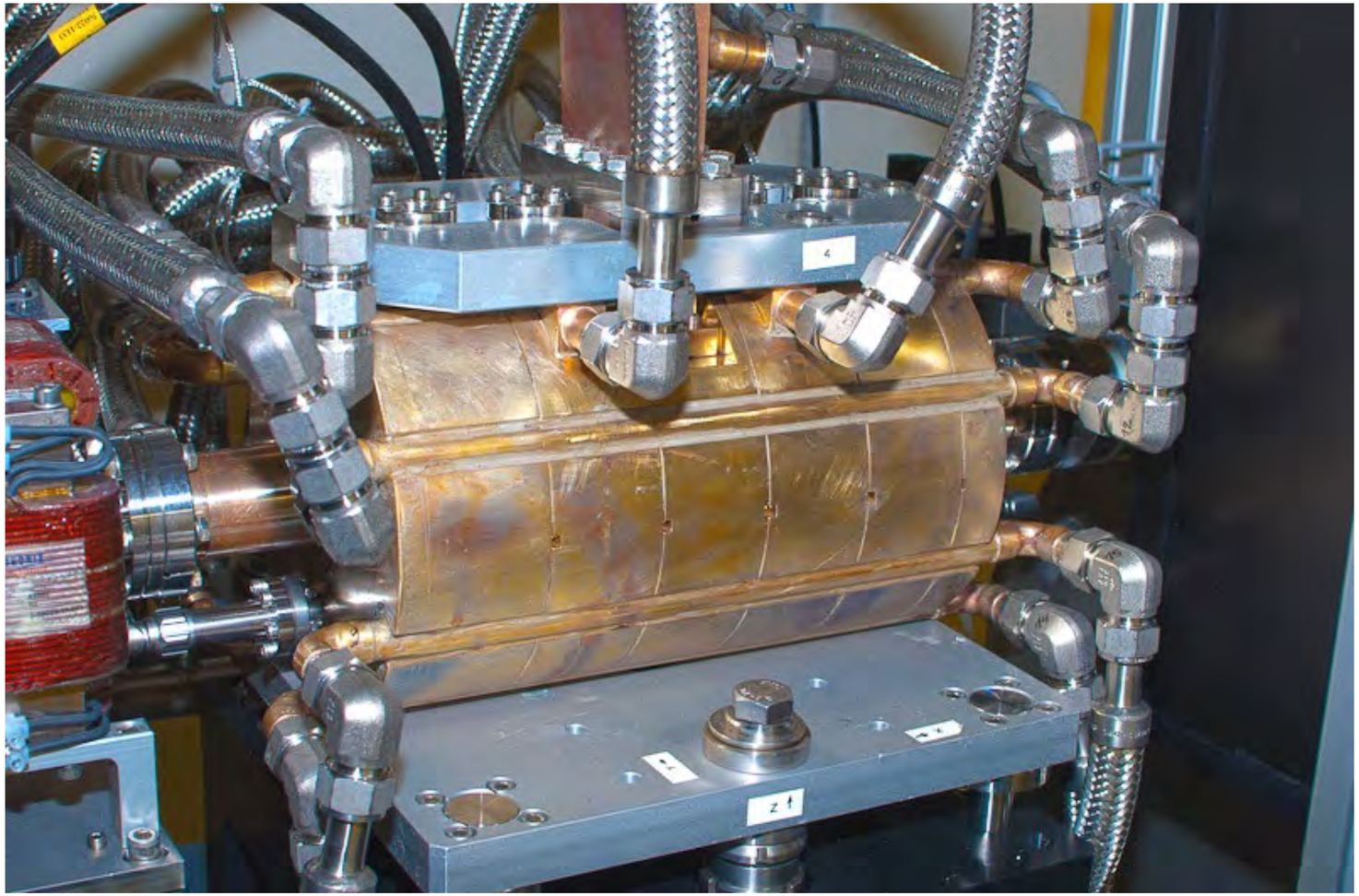
> Scan single quadrupole

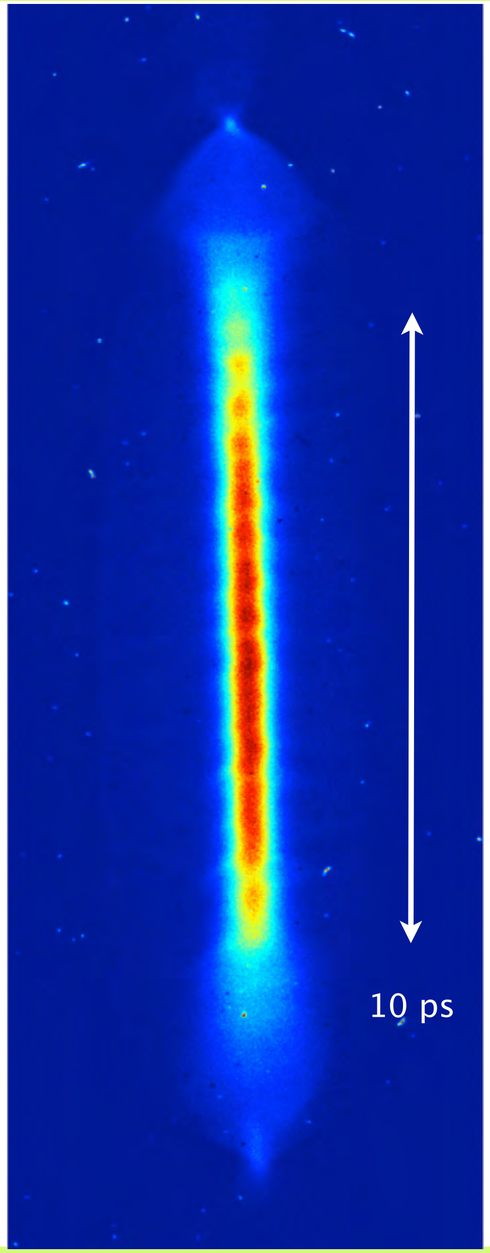
> Beam size (horizontal and vertical) as a function of quadrupole field gradient



Direct Streaking of the Electron Beam

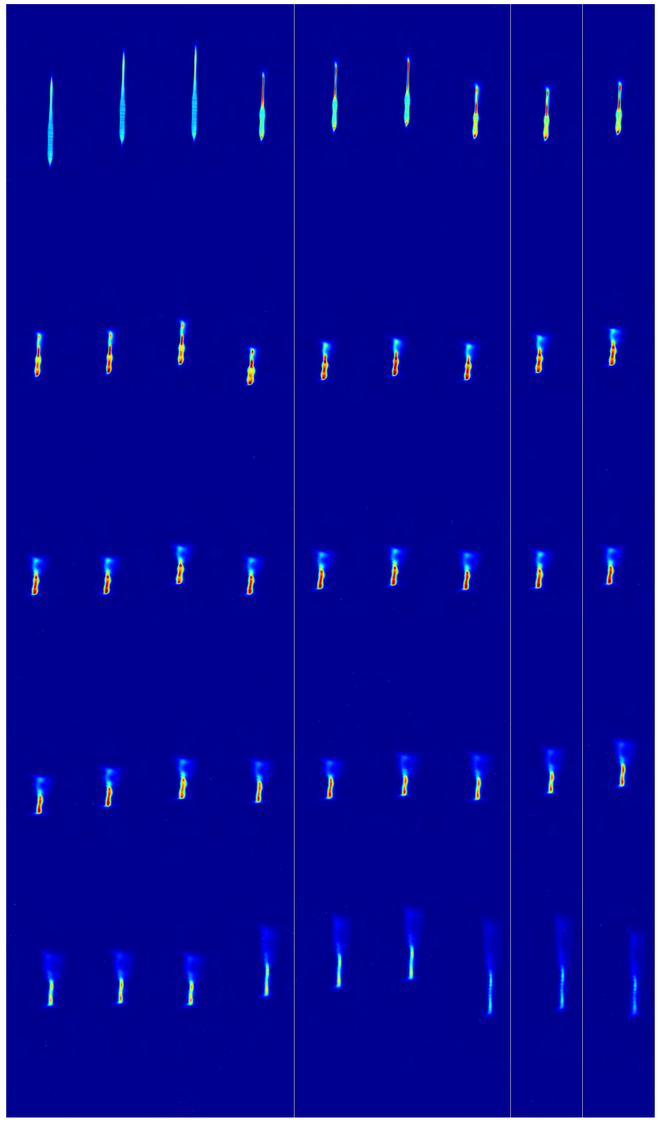
> Requires integrated transverse field of several MV
> Use transverse deflecting RF structure, powered by klystron
> Two-dimensional measurements possible

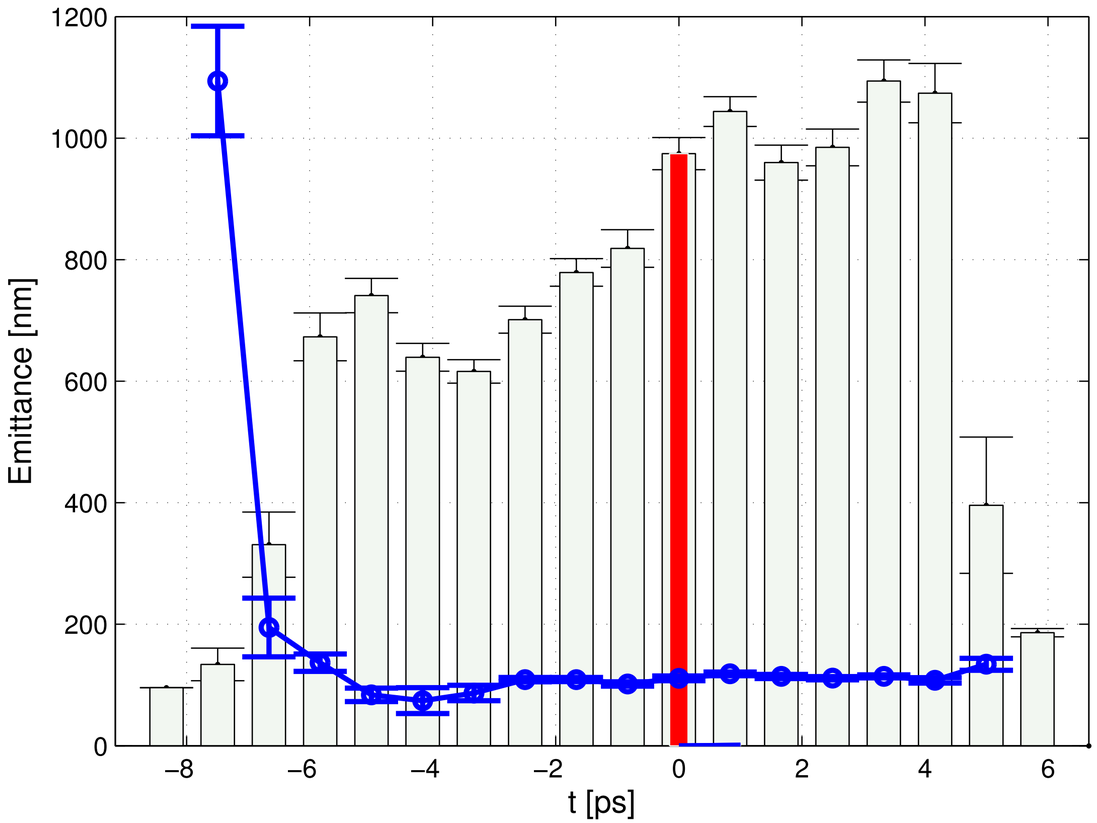




3-Dimensional Measurements

> Reconstruction from a series of 2-d measurements: Slice emittance





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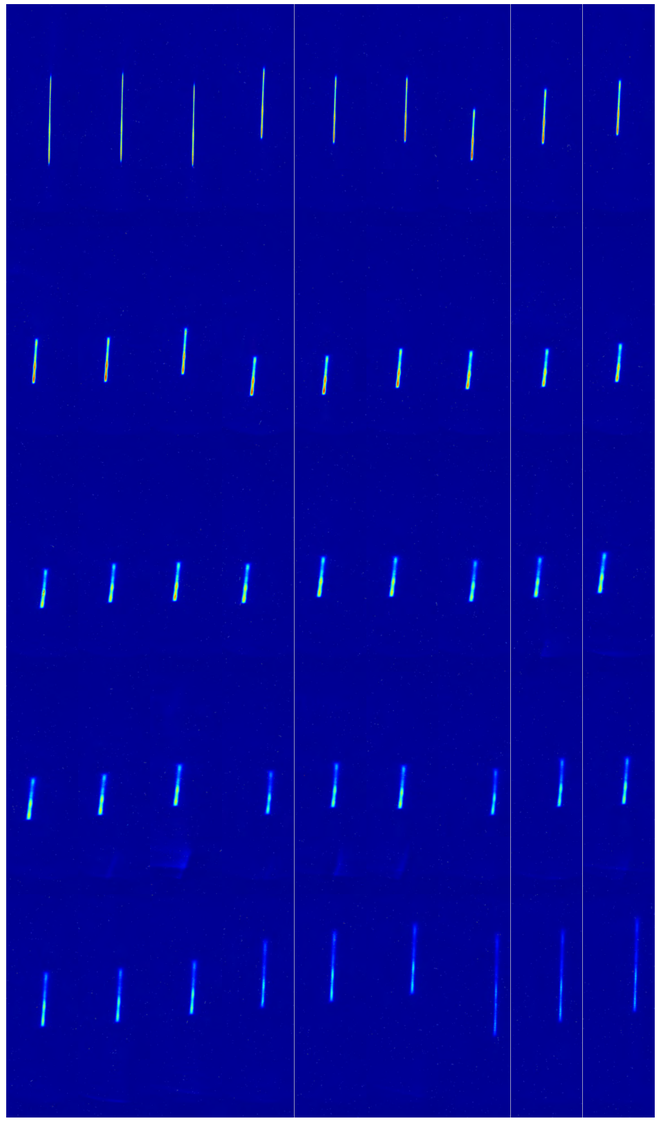
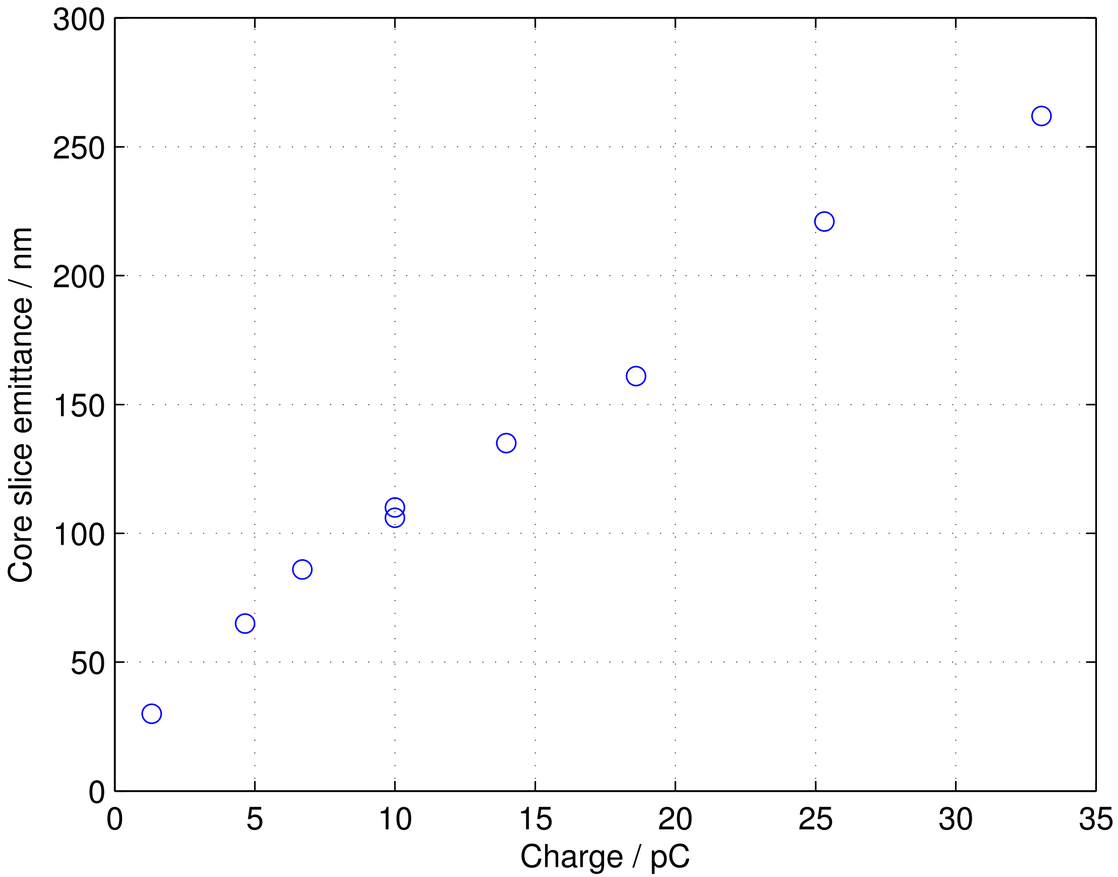
3-Dimensional Measurements

> Slice emittance measurement of a 1.3 pC beam





E. Prat, M. Divall

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Slides available at http://people.web.psi.ch/ischebeck