Karlsruhe Institute of Technology

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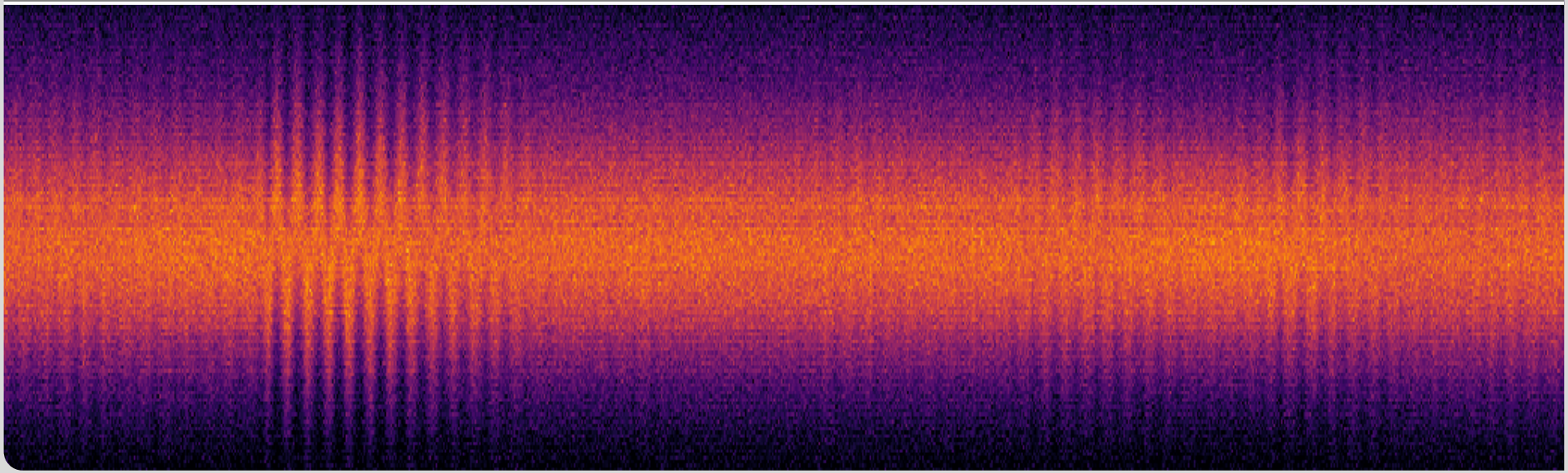
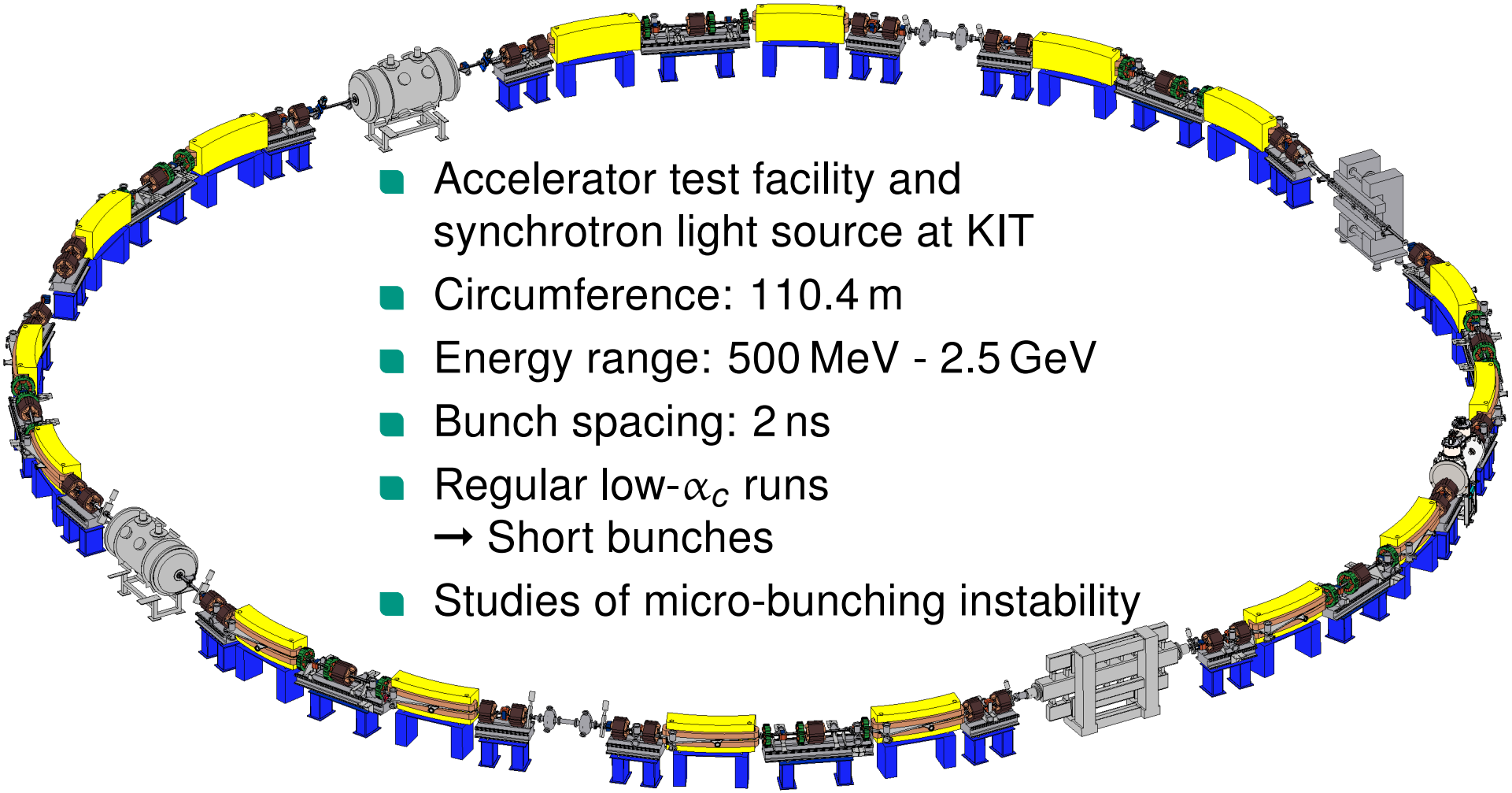
Diagnostics of longitudinal bunch instabilities at KARA

Benjamin Kehrer, M. Brosi, E. Bründermann, S. Funkner, G. Niehues M.J. Nasse, M.M. Patil, J.L. Steinmann, A.-S. Müller

LAS - Laboratory for Applications of Synchrotron Radiation



Karlsruhe Research Accelerator (KARA)



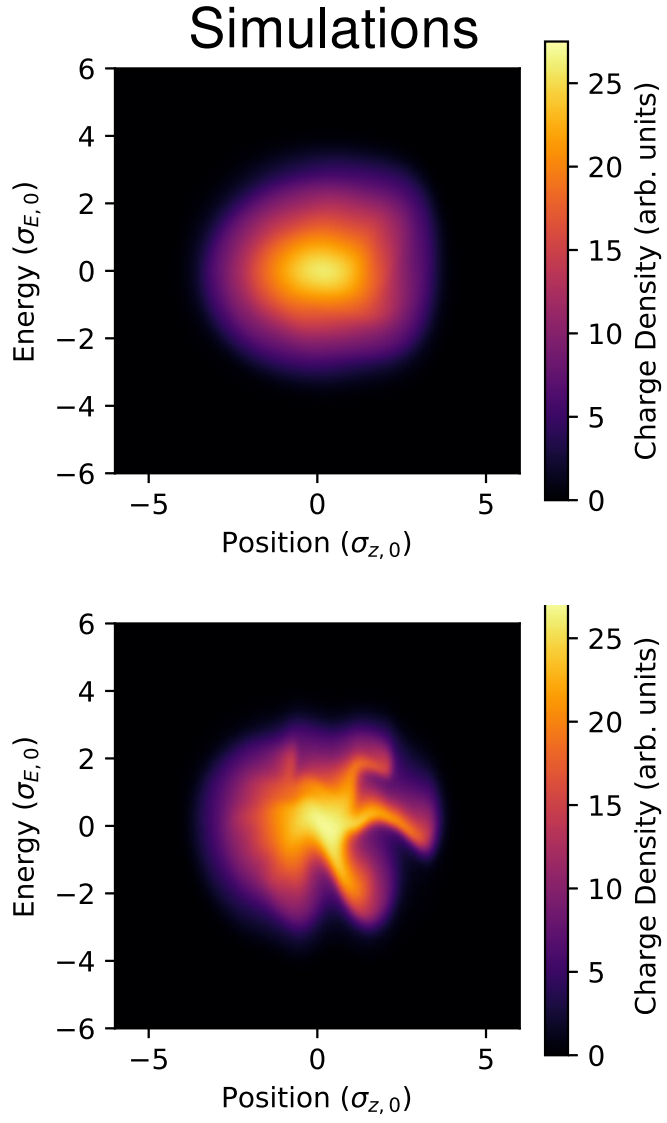
- Accelerator test facility and synchrotron light source at KIT
- Circumference: 110.4 m
- Energy range: 500 MeV - 2.5 GeV
- Bunch spacing: 2 ns
- Regular low-α_c runs
  → Short bunches
- Studies of micro-bunching instability

Micro-bunching instability

- Self-interaction of bunch with its own field

Micro-bunching instability

- Self-interaction of bunch with its own field
- Deformation of longitudinal phase space

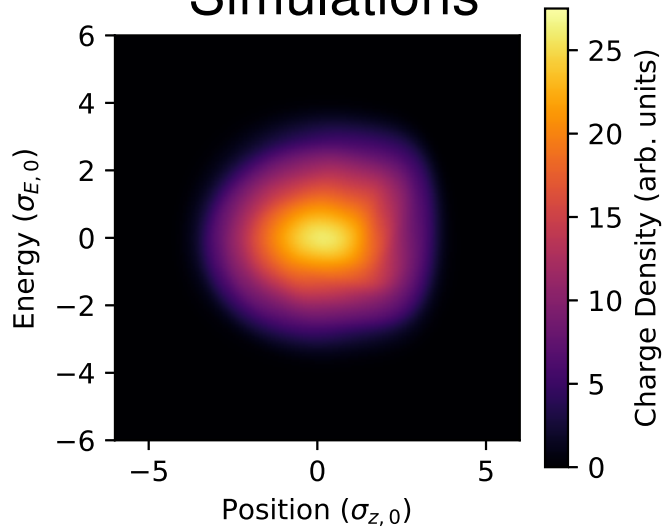


Courtesy: Patrik Schönfeldt

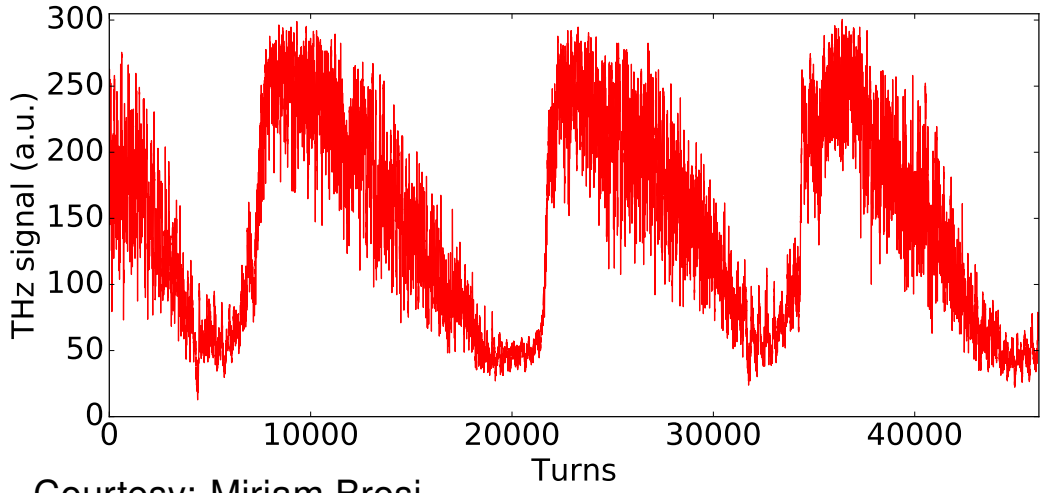
Micro-bunching instability

- Self-interaction of bunch with its own field
- Deformation of longitudinal phase space
- Can lead to *bursting* behaviour of the bunch

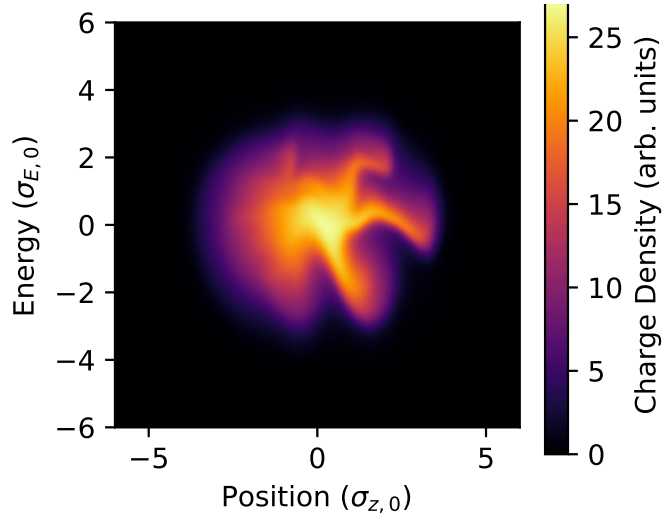
Simulations



Measurement



Courtesy: Miriam Brosi

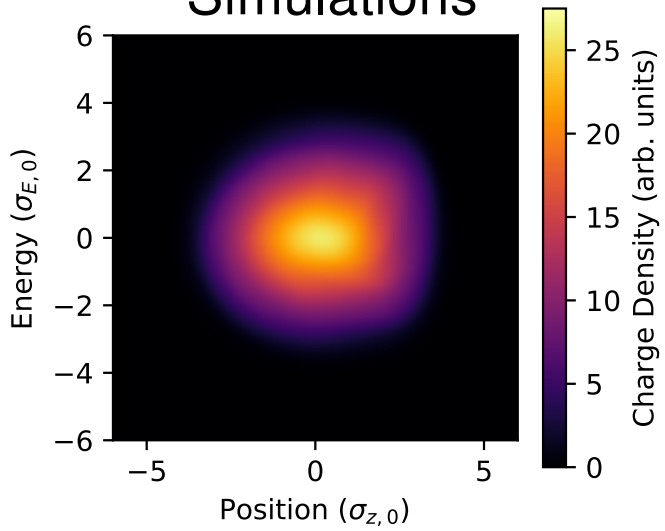


Courtesy: Patrik Schönfeldt

Micro-bunching instability

- Self-interaction of bunch with its own field
- Deformation of longitudinal phase space
- Can lead to *bursting* behaviour of the bunch
- Aim: Understand and control
  → Studies of the longitudinal phase space

Simulations



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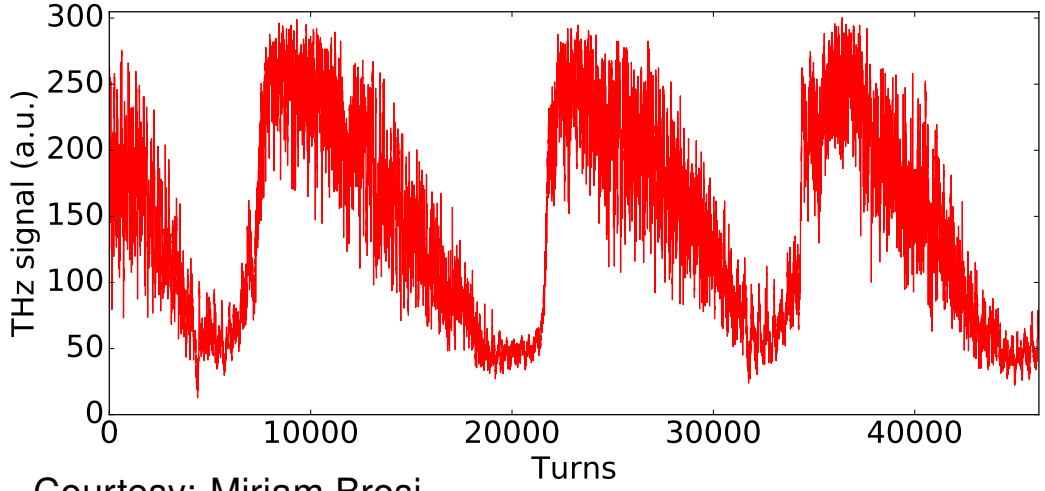

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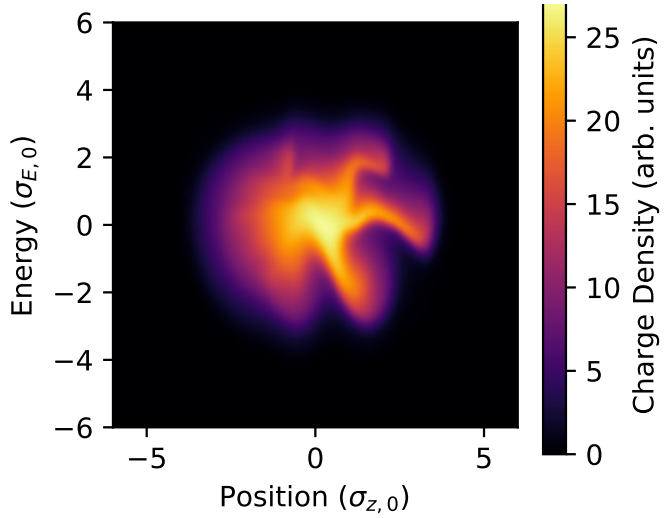

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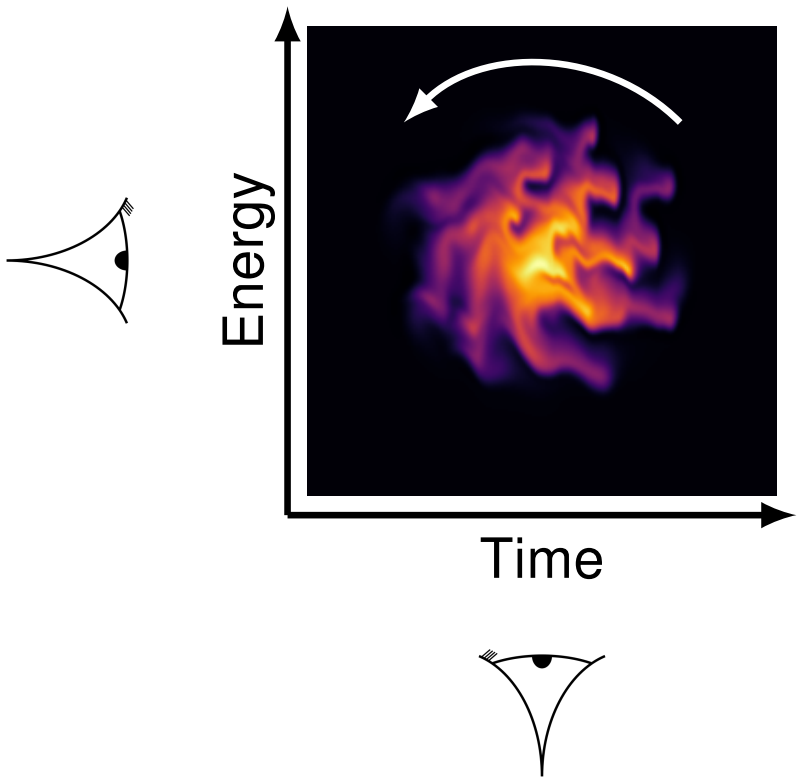
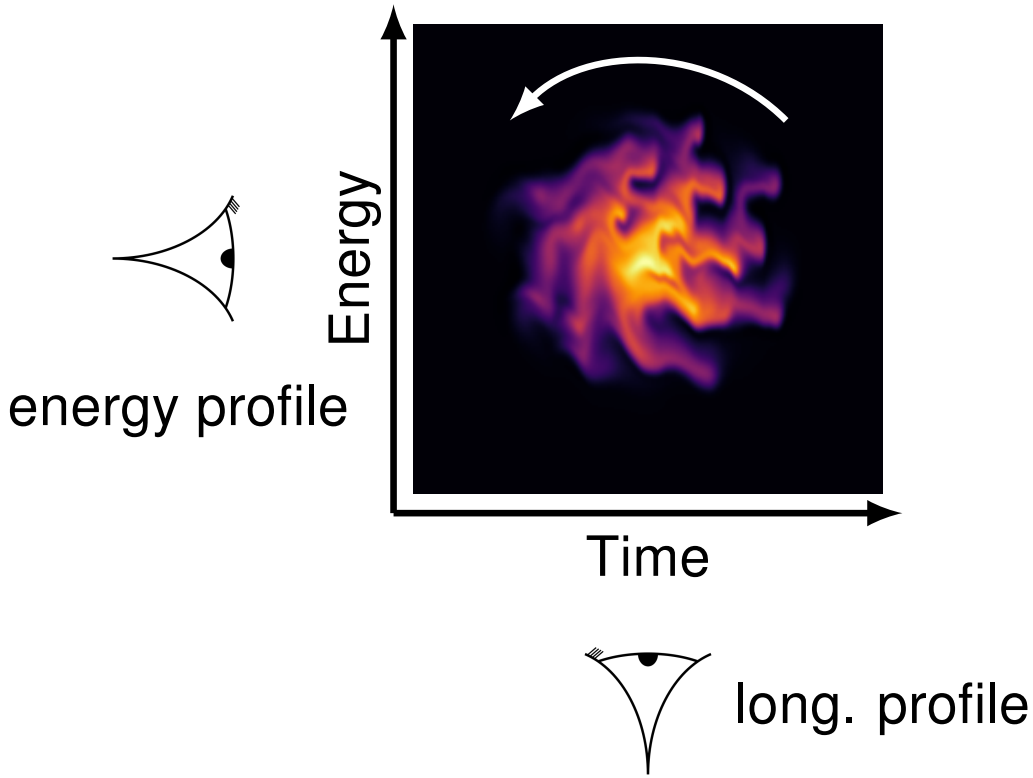
Longitudinal phase space studies

- Long term goal: reconstruction of long. phase space



Longitudinal phase space studies

- Long term goal: reconstruction of long. phase space
- Projections: longitudinal and energy profile



Longitudinal phase space studies

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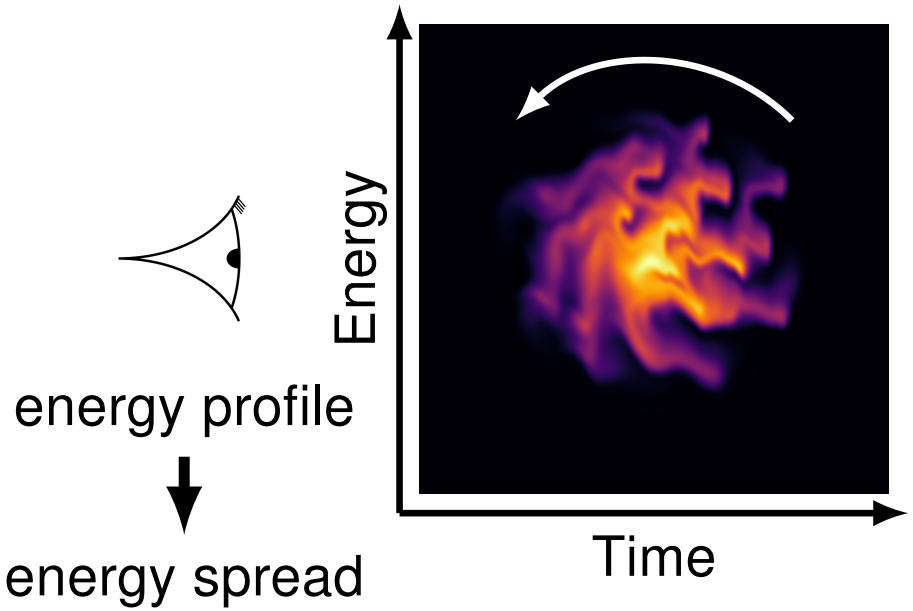
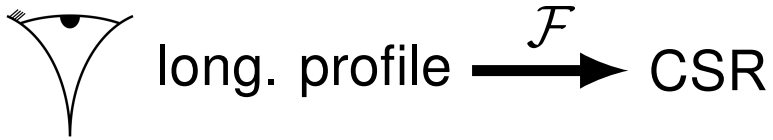
- Projections: longitudinal and energy profile
- First step: scalar parameter for profiles





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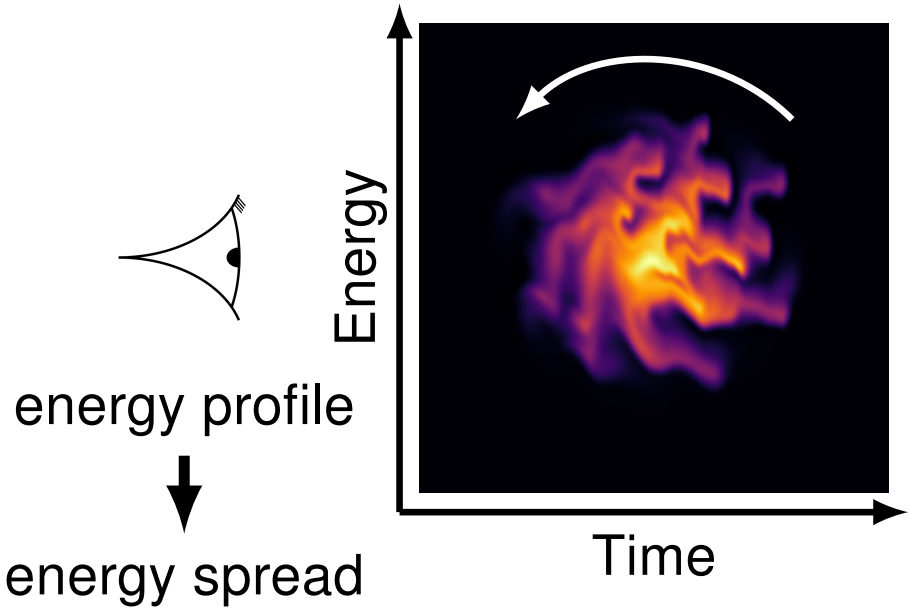
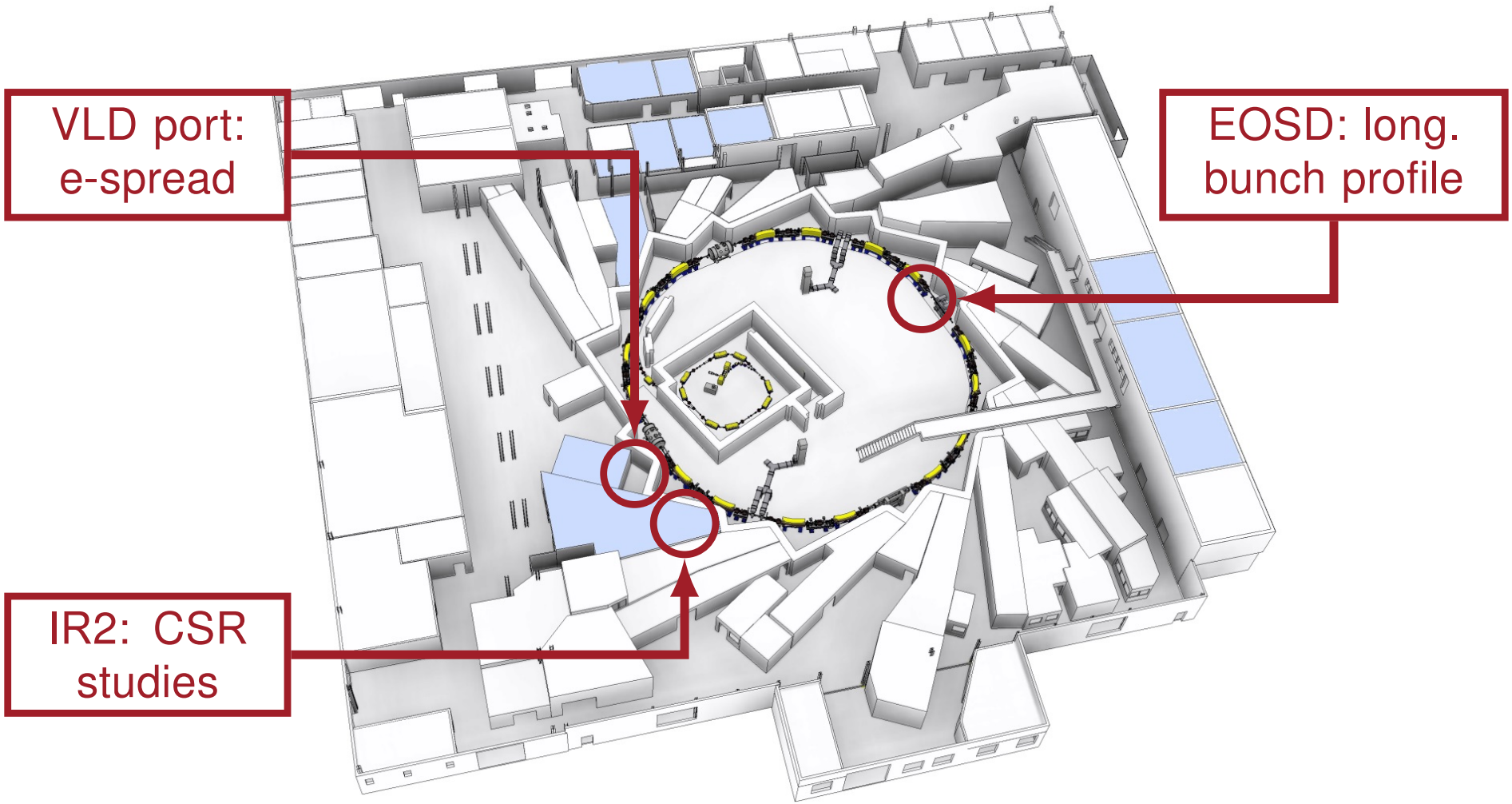


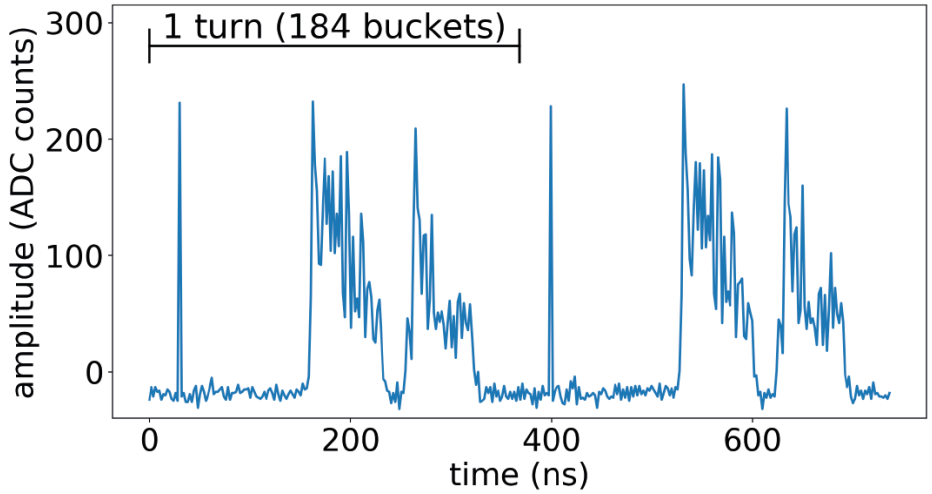
Additional requirement:
turn-by-turn & bunch-by-bunch
T_{rev} = 368 ns
T_{RF} = 2 ns
→ Stringent requirements

Distributed sensor network



CSR measurements

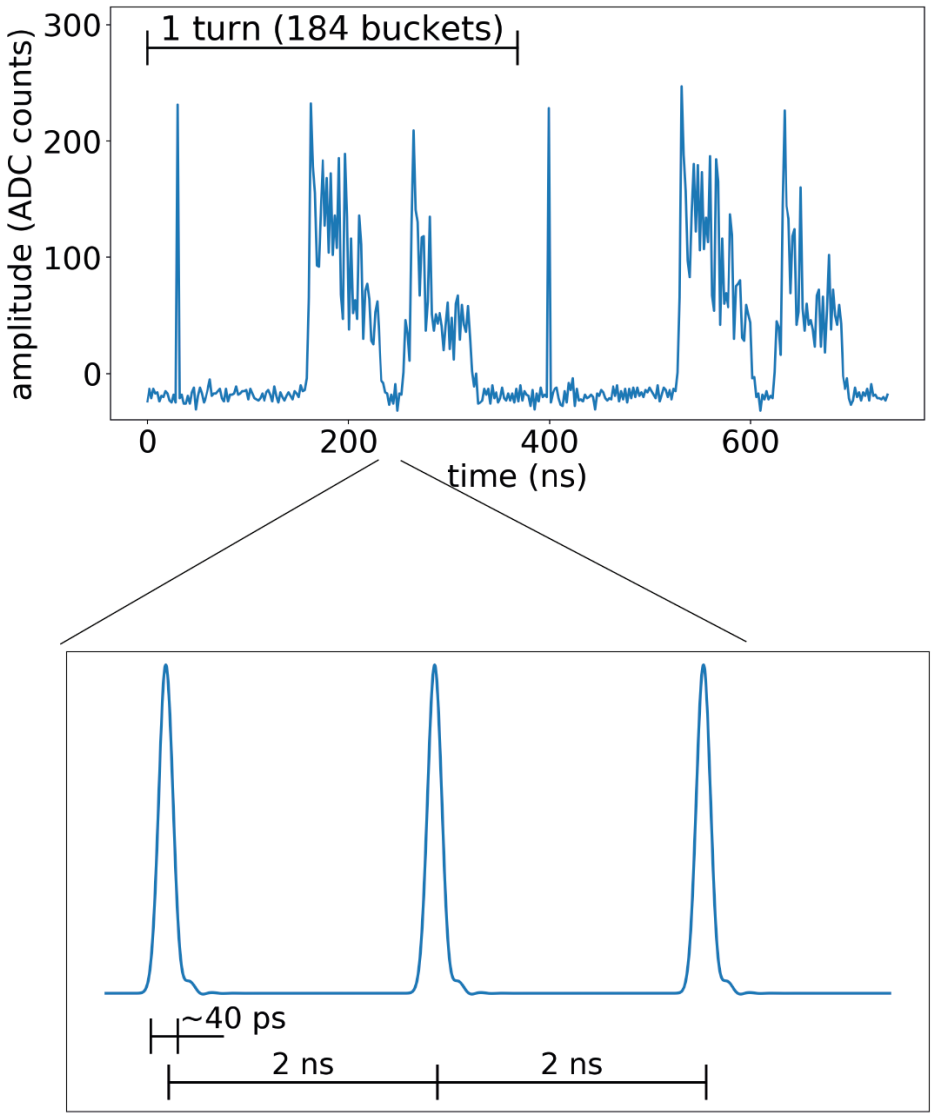
- Short photon pulses



Courtesy: Matthias Martin

CSR measurements

- Short photon pulses
- 2 ns pulse separation



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CSR measurements

- Short photon pulses
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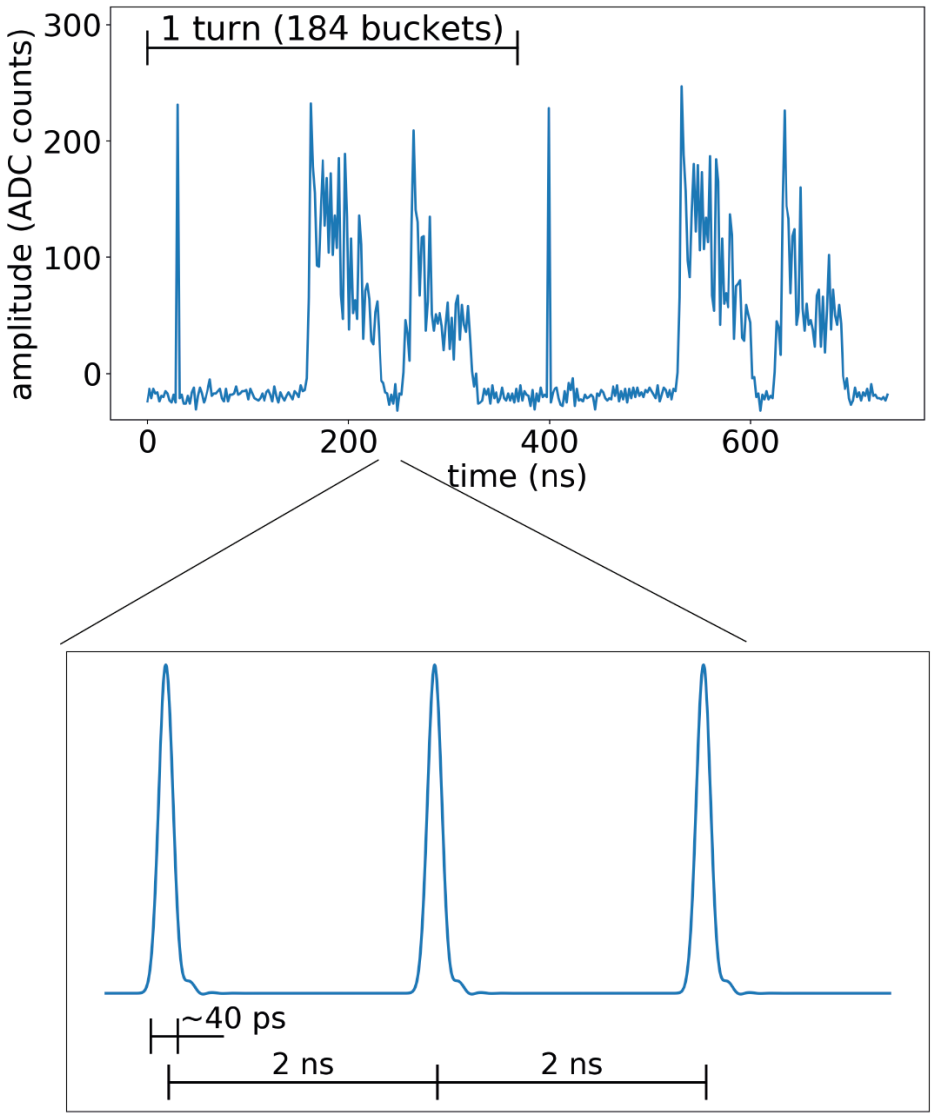
- Detectors: fast Schottky diodes
  - Work at room temperature
  - Response time: 40 ps



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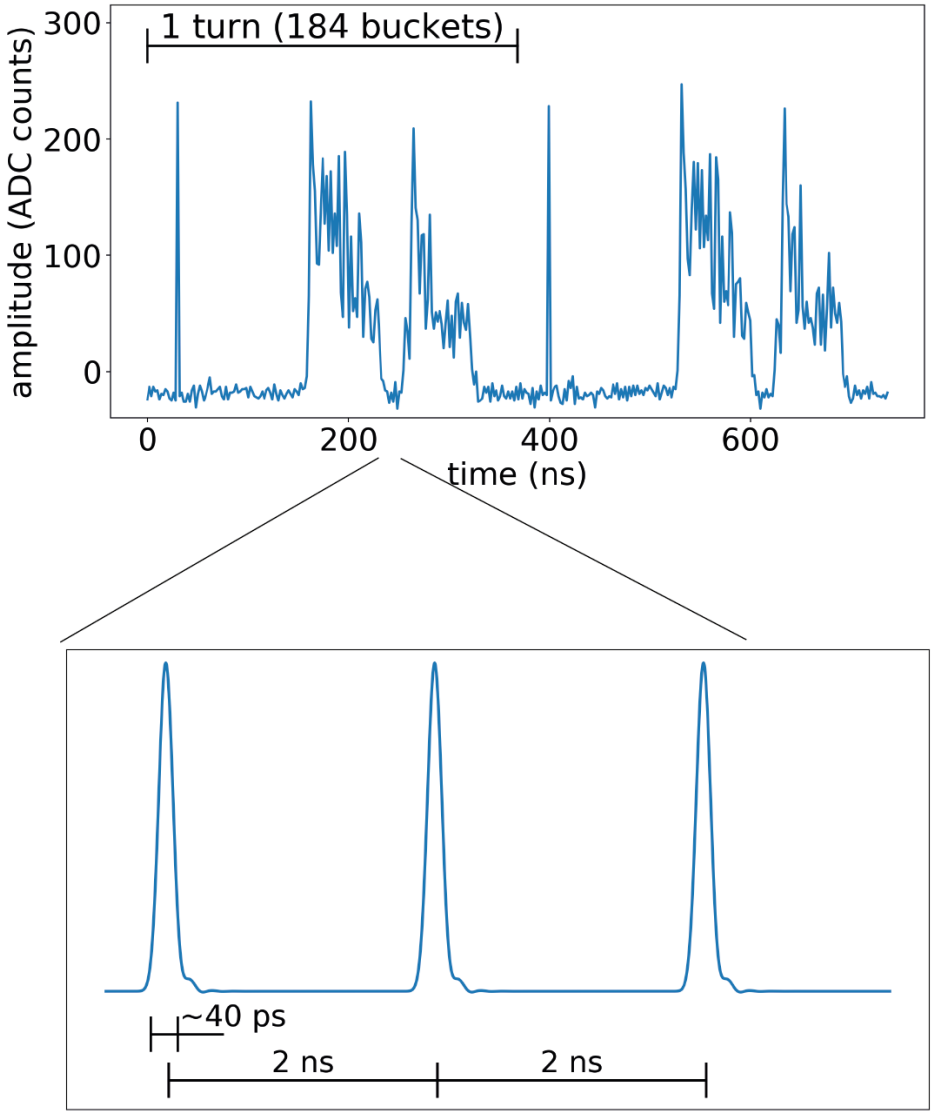
CSR measurements

- Short photon pulses
- 2 ns pulse separation
- Detectors: fast Schottky diodes
  - Work at room temperature
  - Response time: 40 ps
- Oscilloscopes not usable
  - Trigger dead-time >2 ns
  - Limited memory

→ KAPTURE



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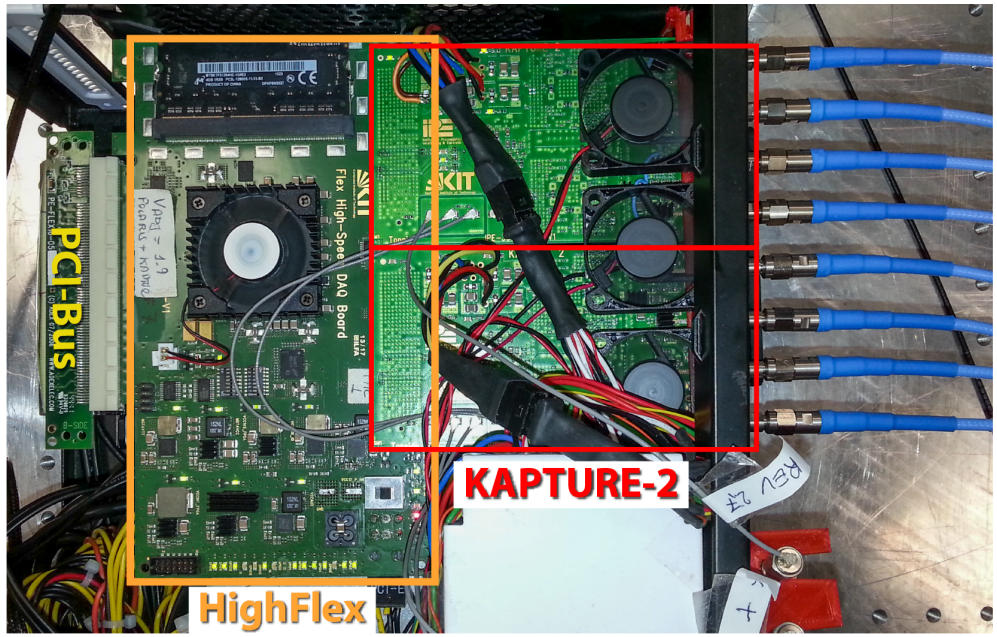
KAPTURE

KArlsruhe Pulse Taking and Ultrafast Readout Electronics

- Picosecond sampling system for individual THz pulses with high repetition rate (500 MHz)



Courtesy: Matthias Martin

[1] **M. Caselle et al., IBIC'14 (MOCZB1)**.

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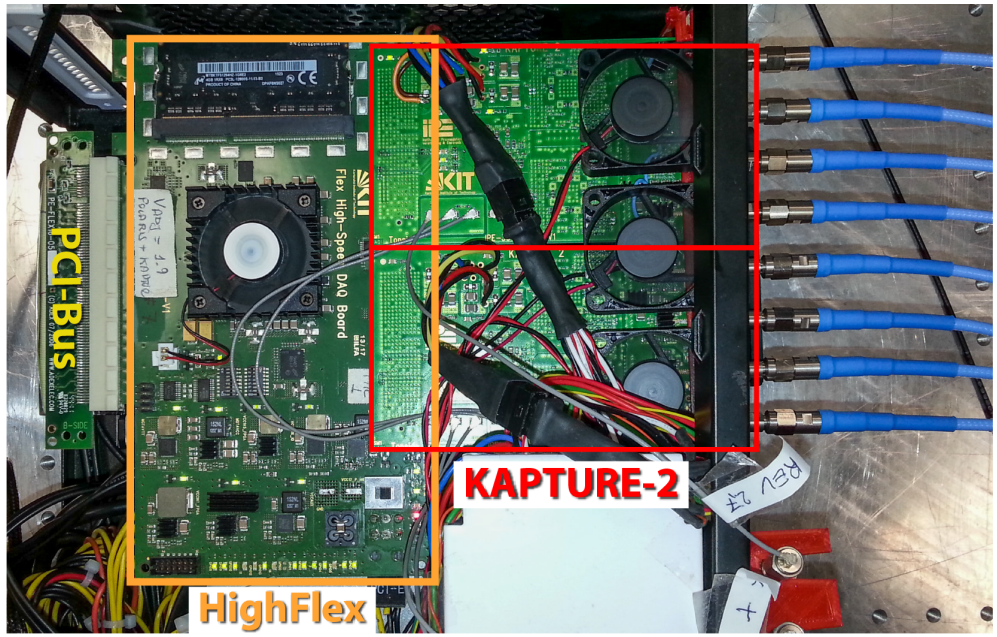

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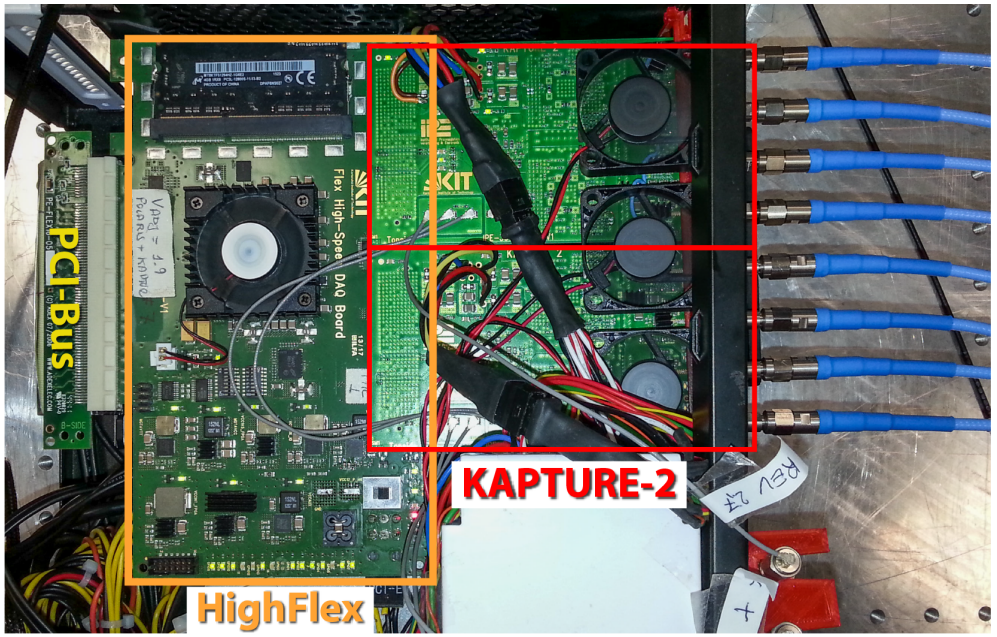
KAPTURE

KArlsruhe Pulse Taking and Ultrafast Readout Electronics

- Picosecond sampling system for individual THz pulses with high repetition rate (500 MHz)
- Developed at KIT[1,2]
- 18 GHz analog bandwidth
- 8 channels
- 12 Bit ADC
  → 8 GB/s



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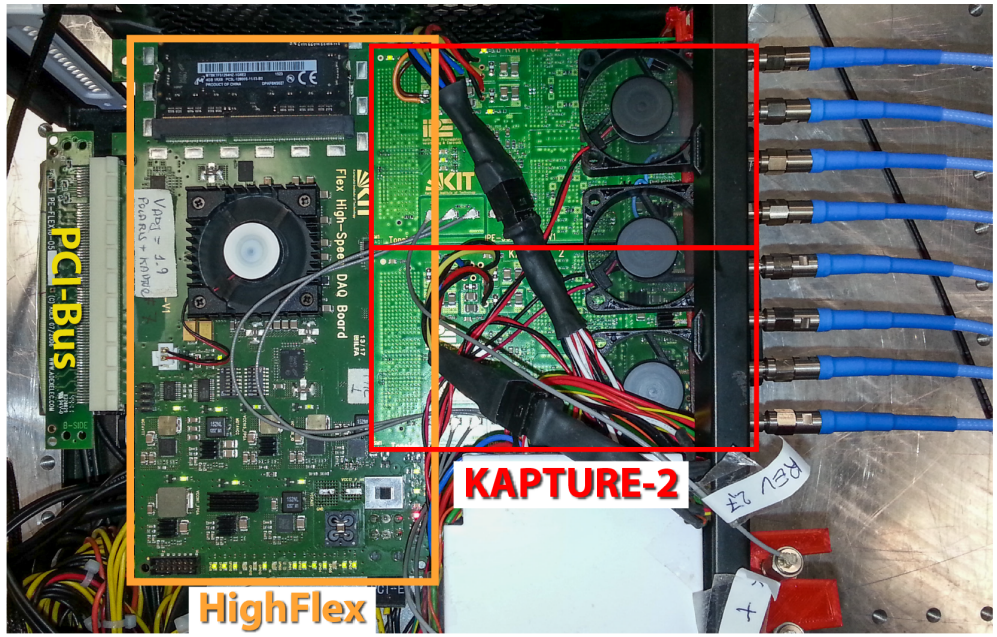
- Picosecond sampling system for individual THz pulses with high repetition rate (500 MHz)
- Developed at KIT[1,2]
- 18 GHz analog bandwidth
- 8 channels
- 12 Bit ADC
  → 8 GB/s
- Mechanically/electrically compatible with FMC / μTCA



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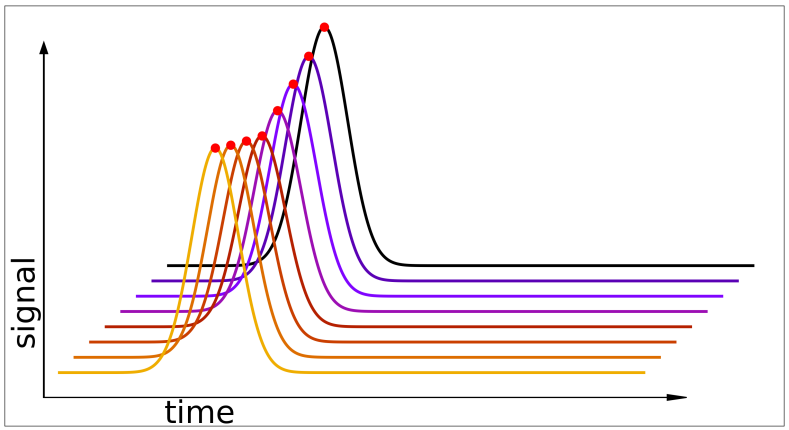
KAPTURE

Single shot spectrometer

- 8 detectors
- e.g. for different frequencies
- measuring spectrum [3]



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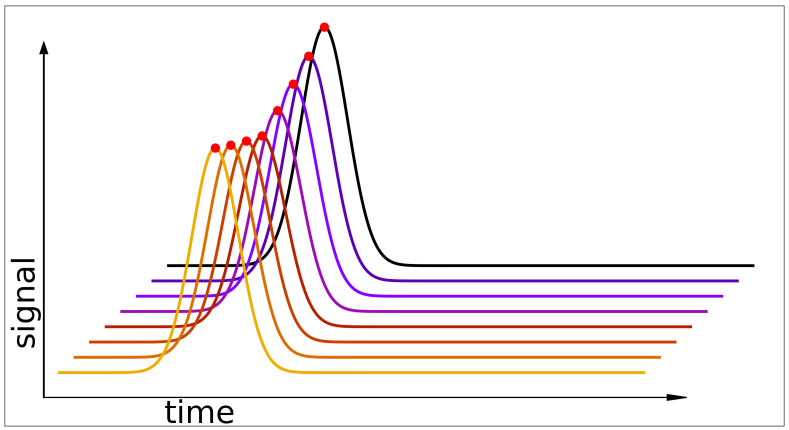

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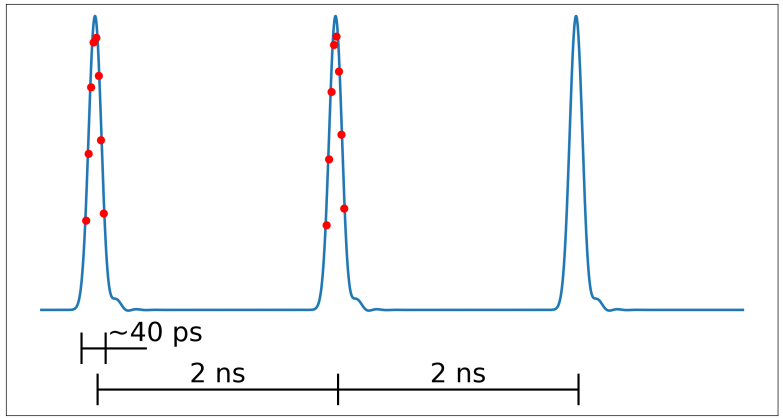
Peak reconstruction

- 1 detector
- power-splitter
- measuring pulse shape



[3] **J.L. Steinmann et al., Phys. Rev. Accel. Beams 21 (11 2018), p. 110705.**

Longitudinal bunch profile

- Sampling the electric field in the near-field regime
  - GaP crystal
  - Laser wavelength: 1050 nm

[4] **N. Hiller et al., IBIC'14 (MOPD17).**

[5] **S. Funkner et al., Phys. Rev. Accel. Beams 22, 022801 (2019).**

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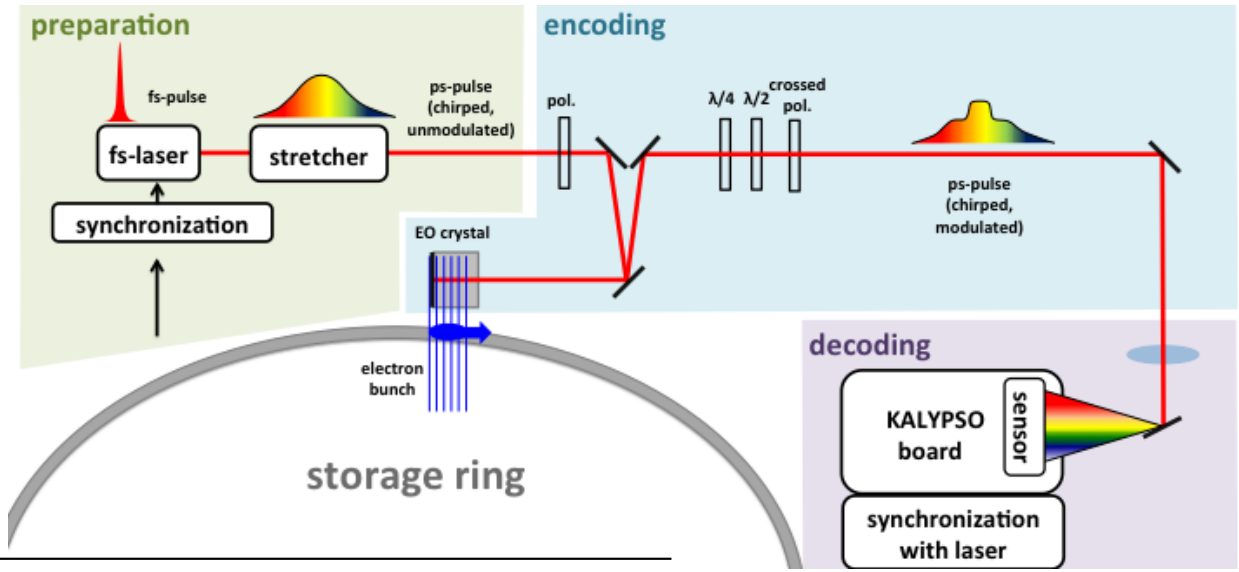

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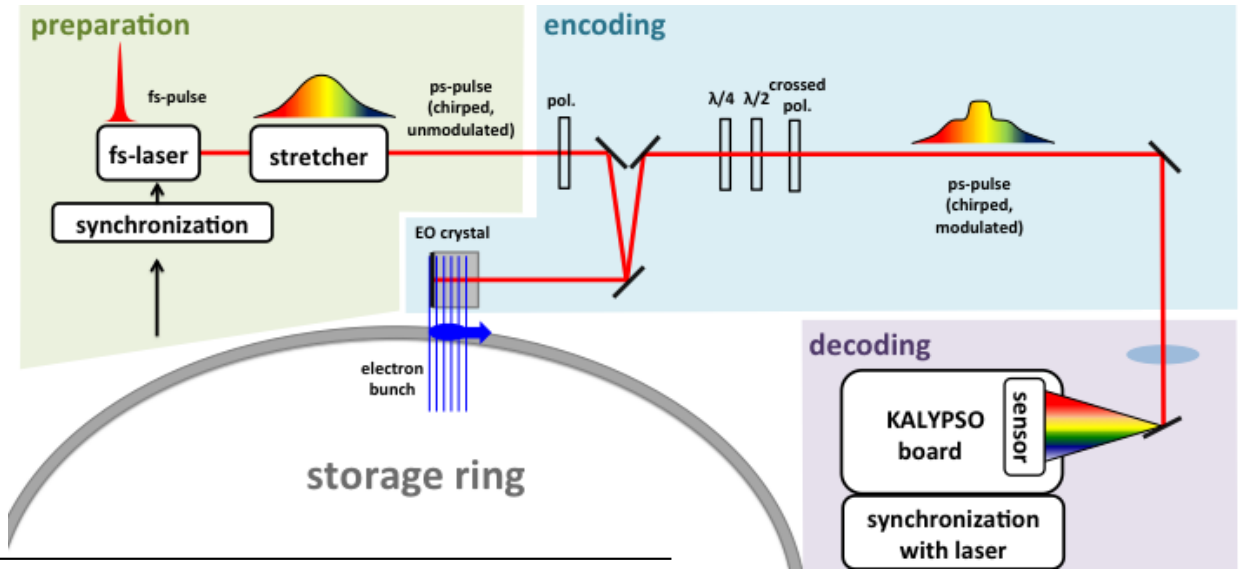

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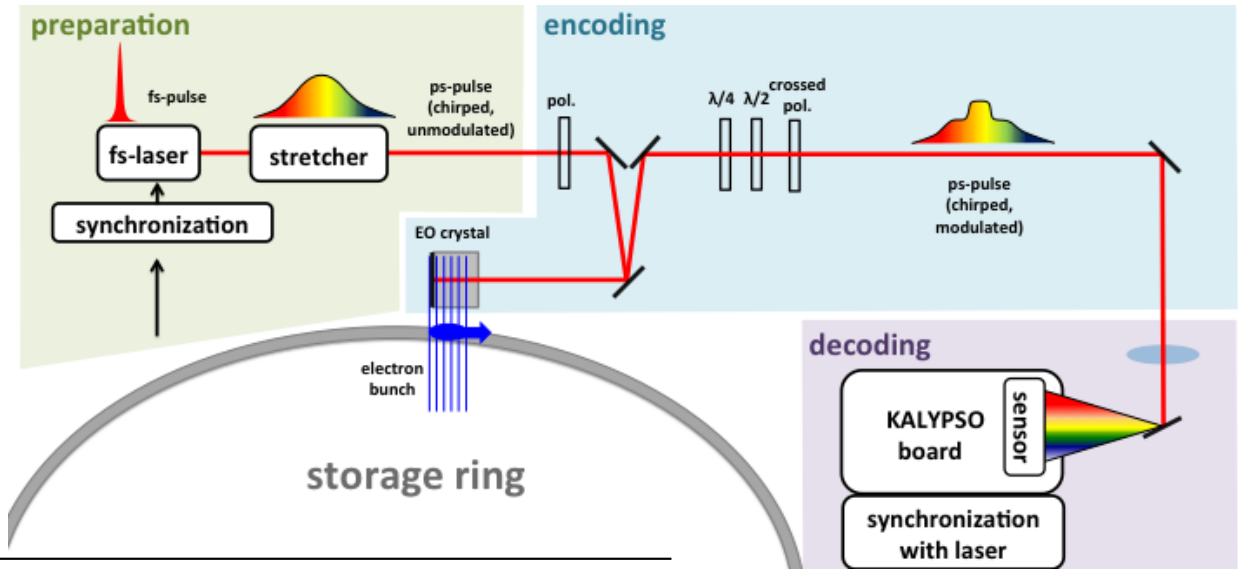
  - GaP crystal
  - Laser wavelength: 1050 nm
- Spectral decoding → Single shot
- First near-field setup at a storage ring[4,5]



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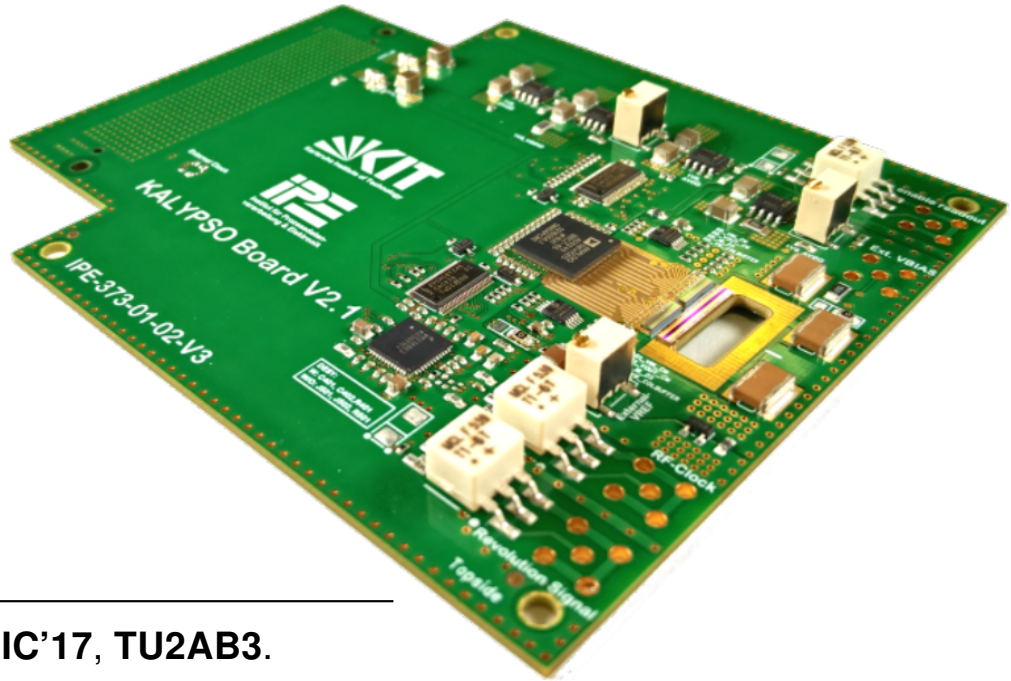
KALYPSO

KArlsruhe Linear arraY detector for MHz-rePetition rate SpectrOscopy

- High speed line array developed at KIT[6]



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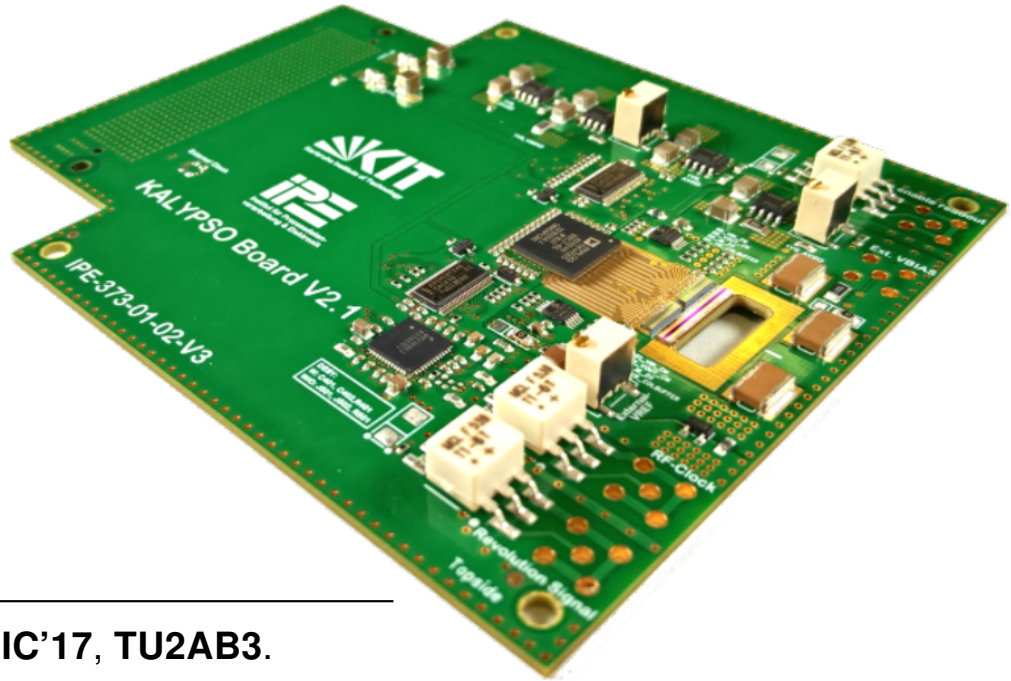

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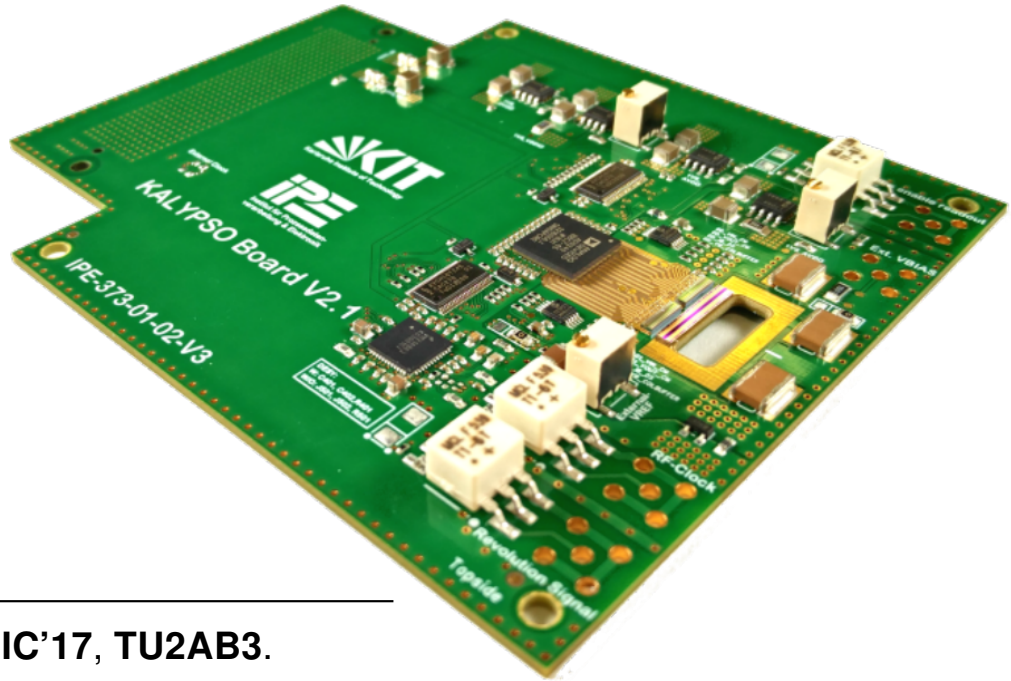
- Variable design: sensor and number of micro-strips (up to 1024)
- Maximum frame rate >10 Mfps
  → Turn-by-turn studies at KARA (f_{rev} = 2.7 MHz)



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Energy spread measurement

- Horizontal bunch size measurements in dispersive section

$$\sigma_x = \sqrt{\beta_x \epsilon_x + (D_x \sigma_\delta)^2}$$

[7] **B. Kehrer et al., IPAC'15 (MOPHA037).**

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- Visible light diagnostics port at KARA[7]
  → Incoherent bending radiation from dipole magnet (400 nm to 500 nm)

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  - KALYPSO system

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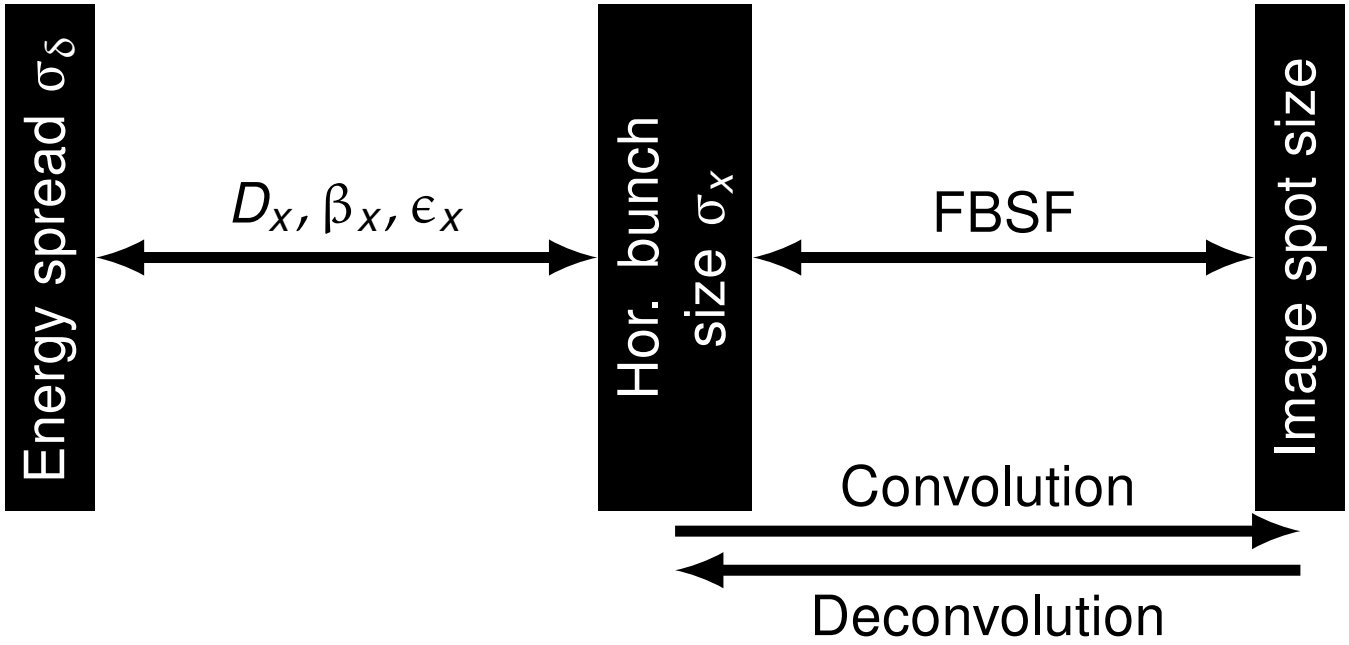
From the energy spread to the image...

... and vice versa



[8] **A. Andersson et al., EPAC'06 (TUPCH090).**

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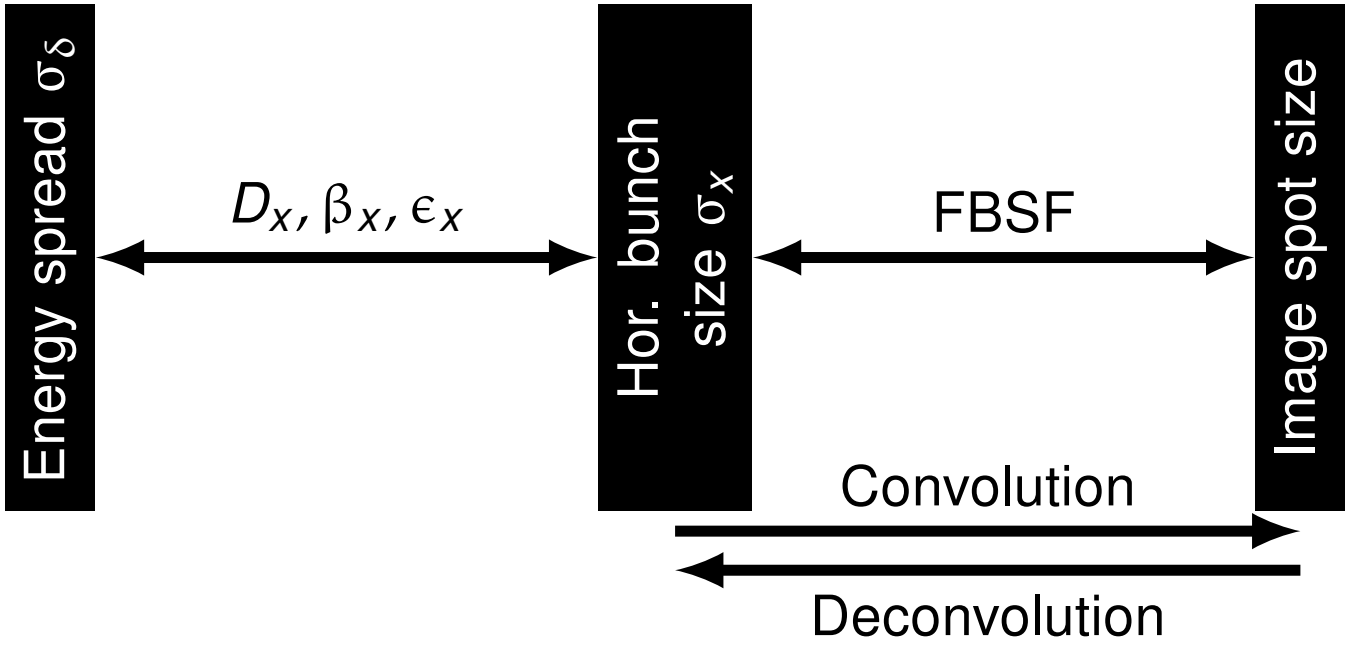

- D_x, β_x, ϵ_x from AT & LOCO, FBSF[8] from OpTaliX

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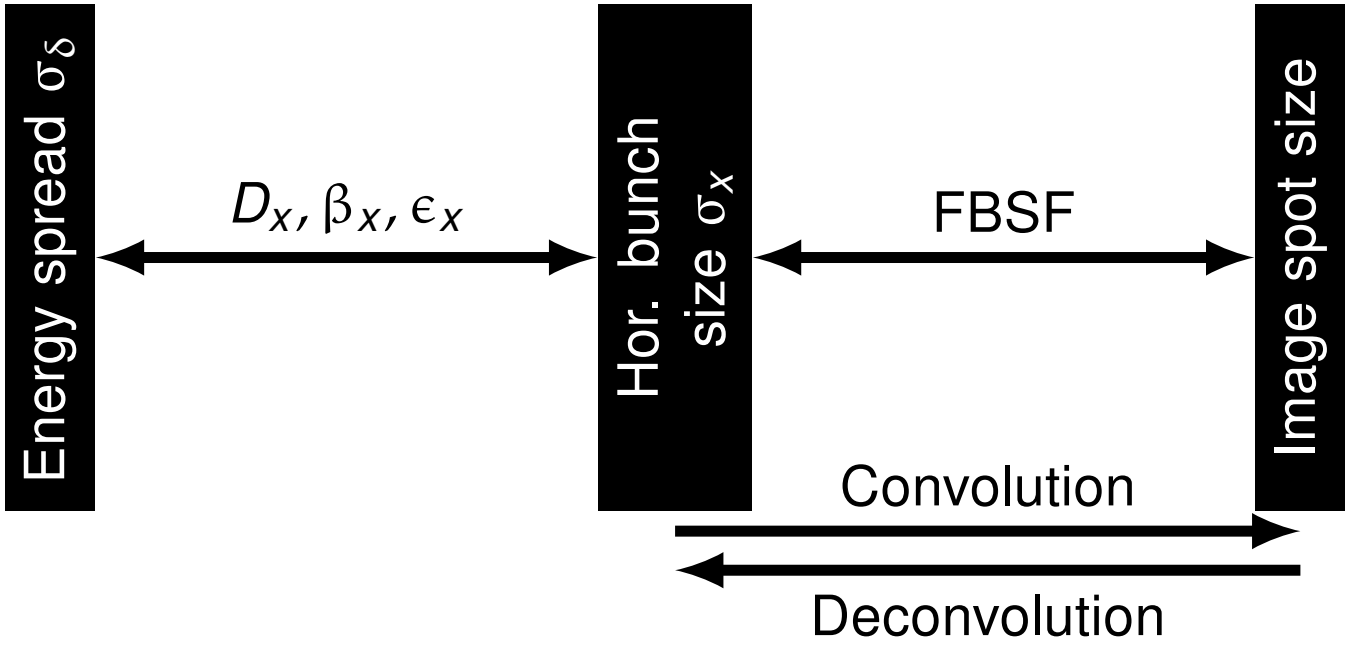

- D_x, β_x, ϵ_x from AT & LOCO, FBSF[8] from OpTaliX
- Retrieve bunch size

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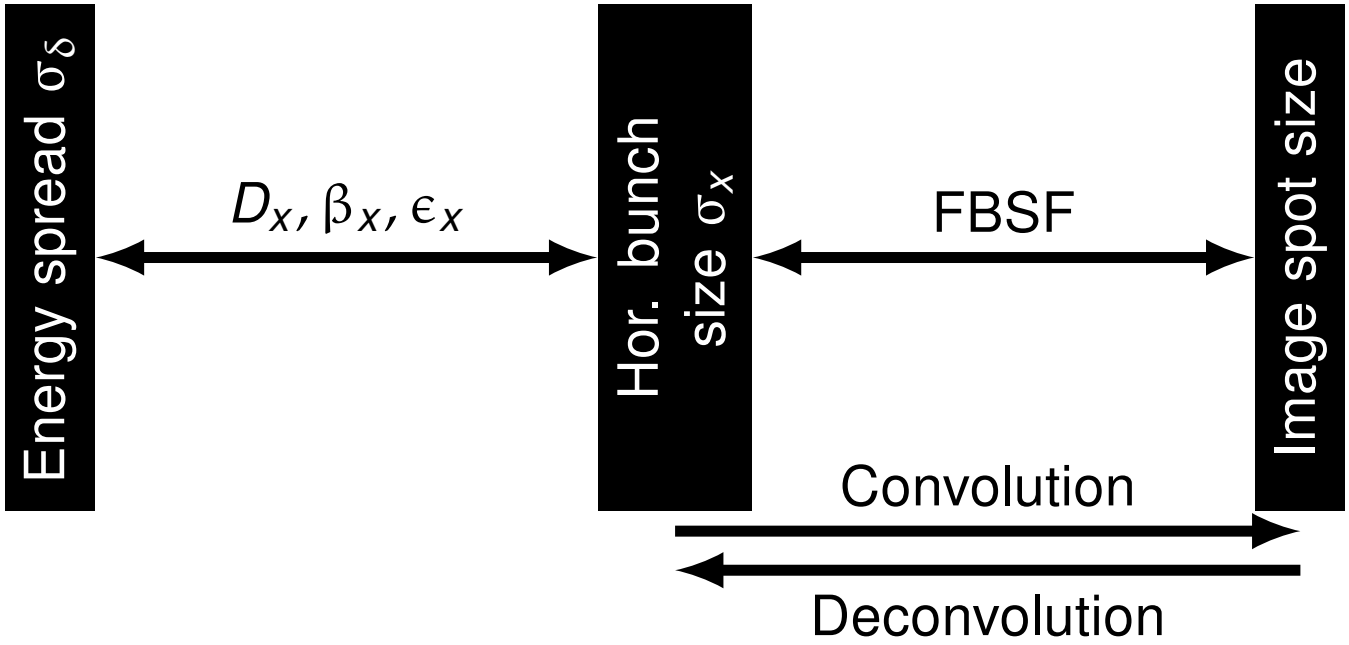

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  - Deconvolution and Gaussian fit / RMS calculation

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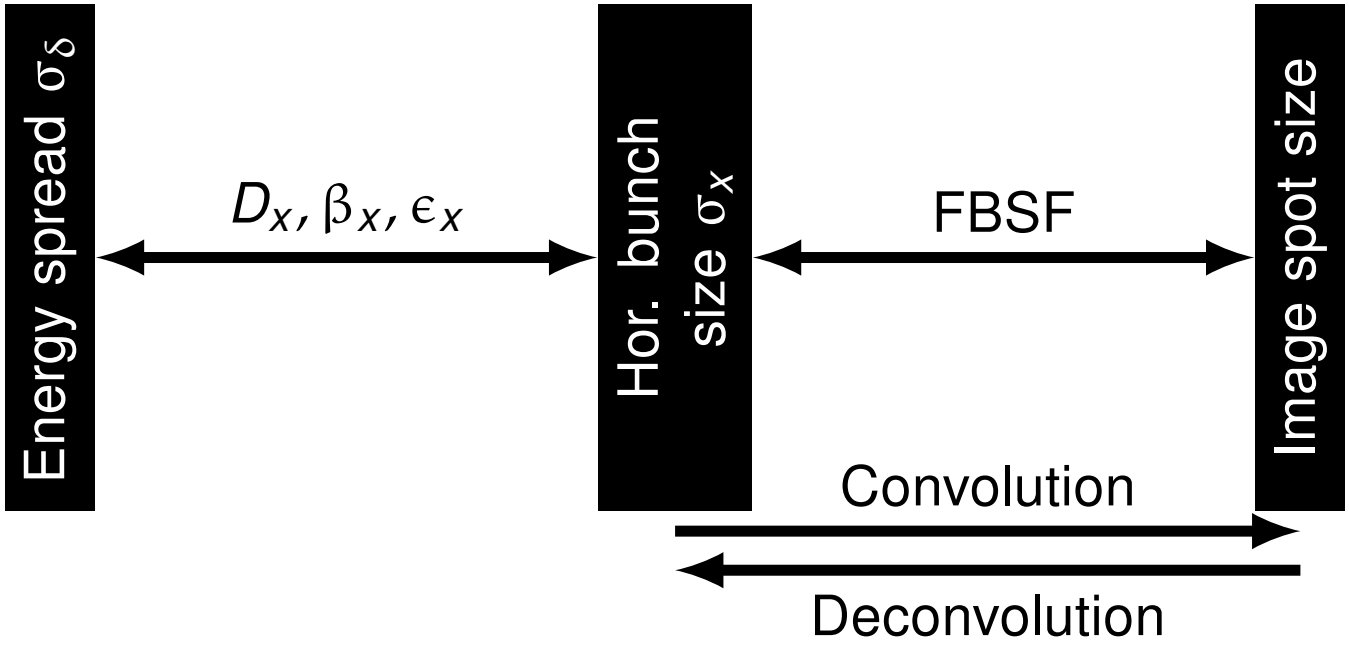

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  - Fit function: $f_{\text{fit}} = f_{\text{Gauss}} * f_{\text{FBSF}}$

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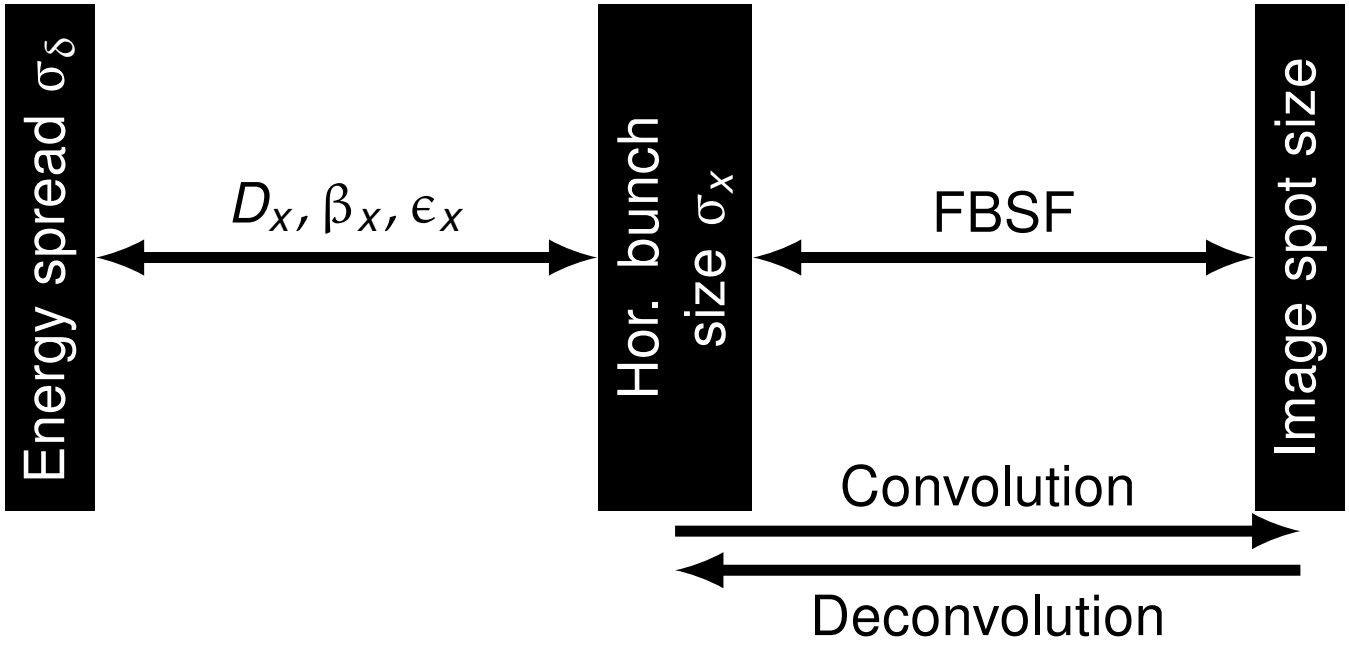

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  - Fit function: $f_{\text{fit}} = f_{\text{Gauss}} * f_{\text{FBSF}}$ → More stable and faster

[8] **A. Andersson et al.**, **EPAC'06 (TUPCH090)**.

KALYPSO for hor. beam size studies

- Silicon sensor

[9] **B. Kehrer et al., IPAC'19 (WEPGW016).**

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- No fast shutter / gate → Single bunch, but **turn-by-turn**

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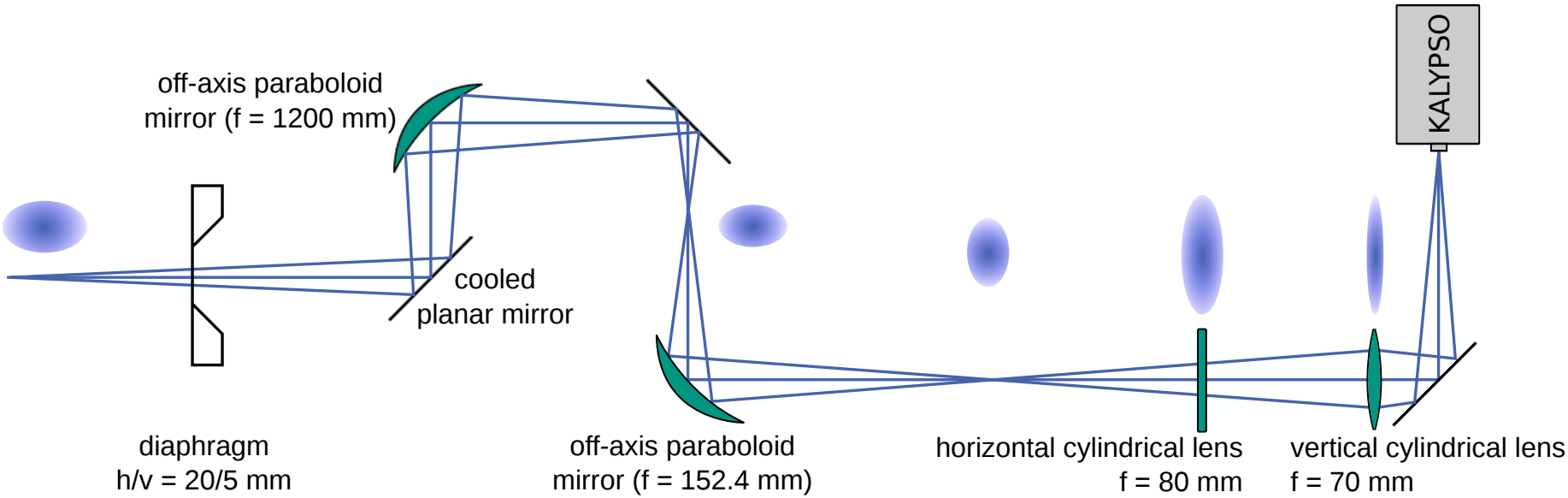

[9] **B. Kehrer et al., IPAC'19 (WEPGW016).**

Courtesy: Paul Schütze

Synchronisation scheme

- Multiple detector systems at different places along the storage ring

[10] **B. Kehrer et al., IPAC'16 (MOPMB014)**

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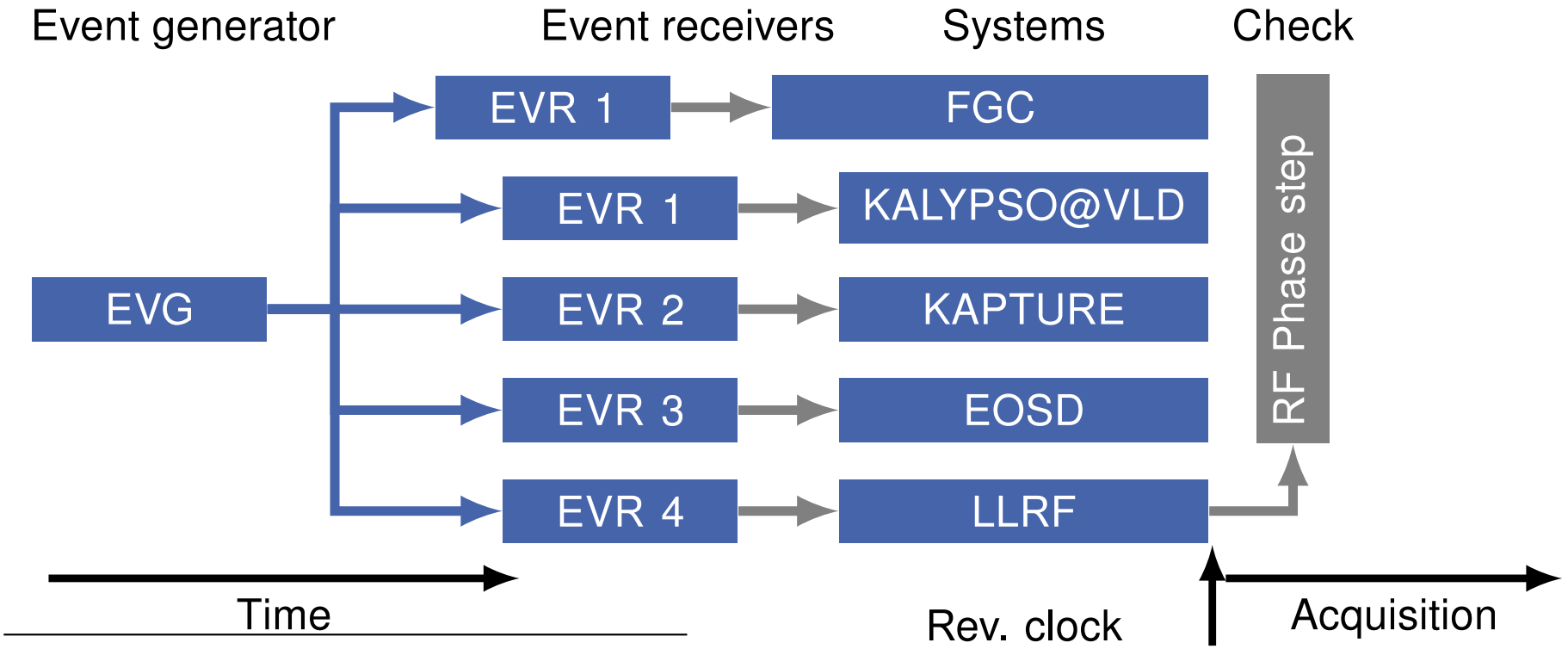

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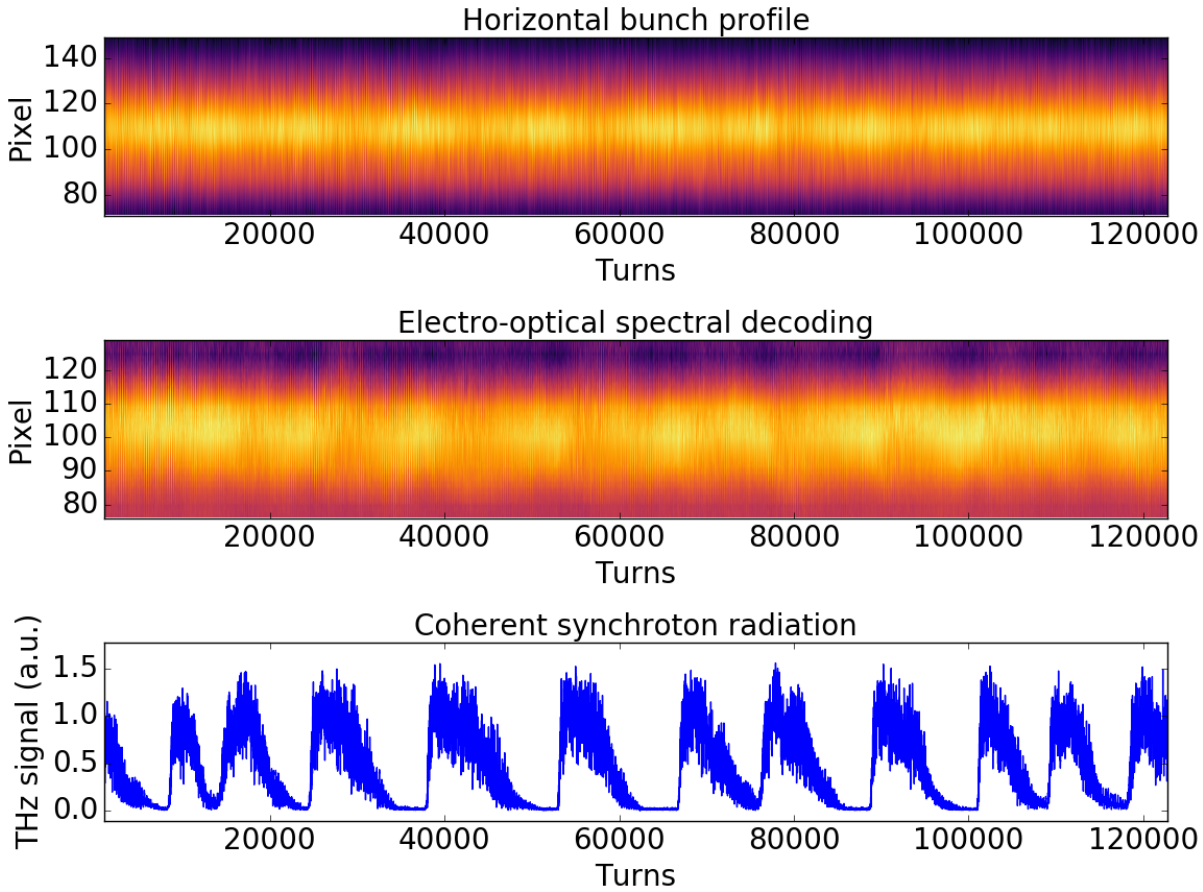
Synchronous measurements with 2 KALYPSO + Schottky diodes[11]



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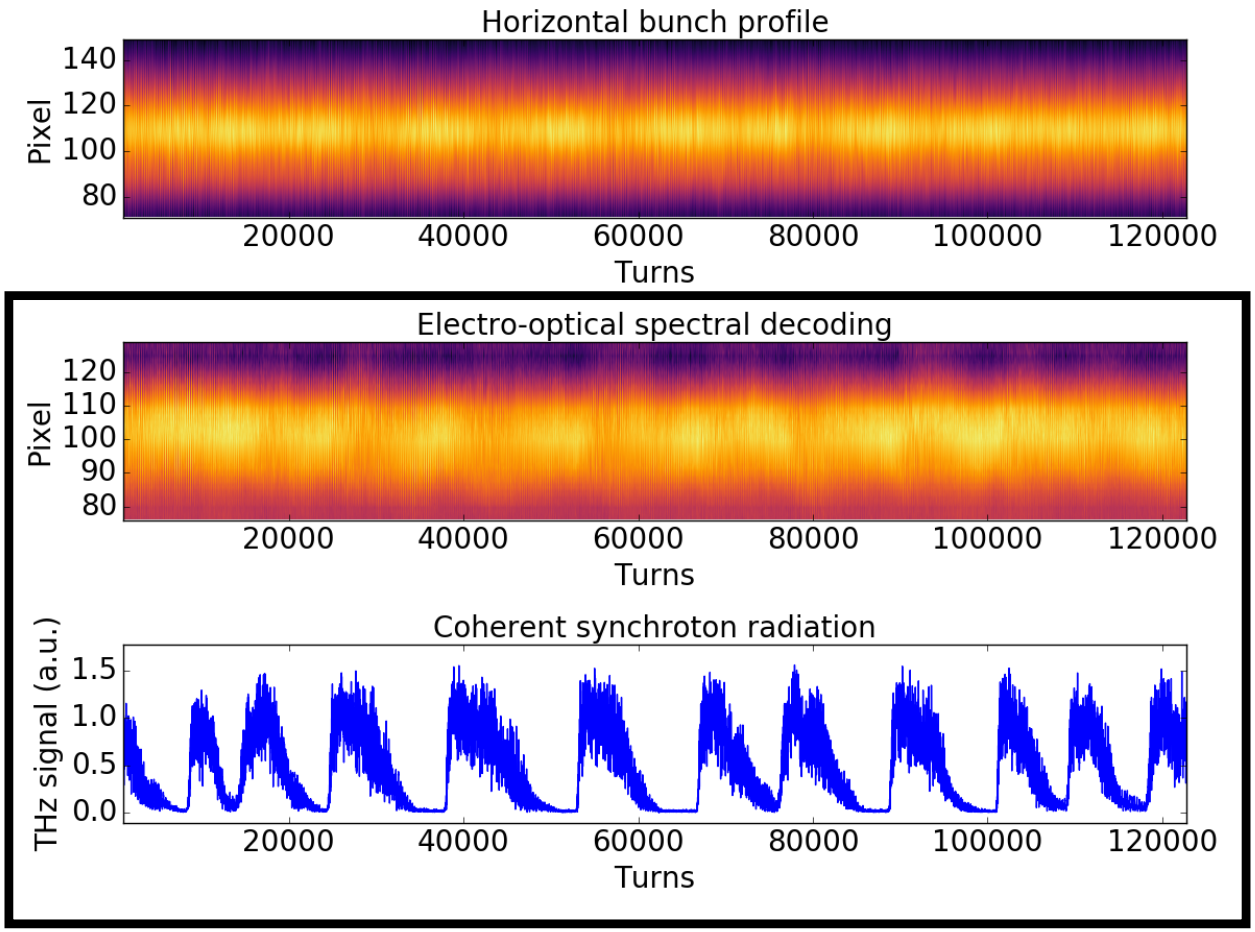

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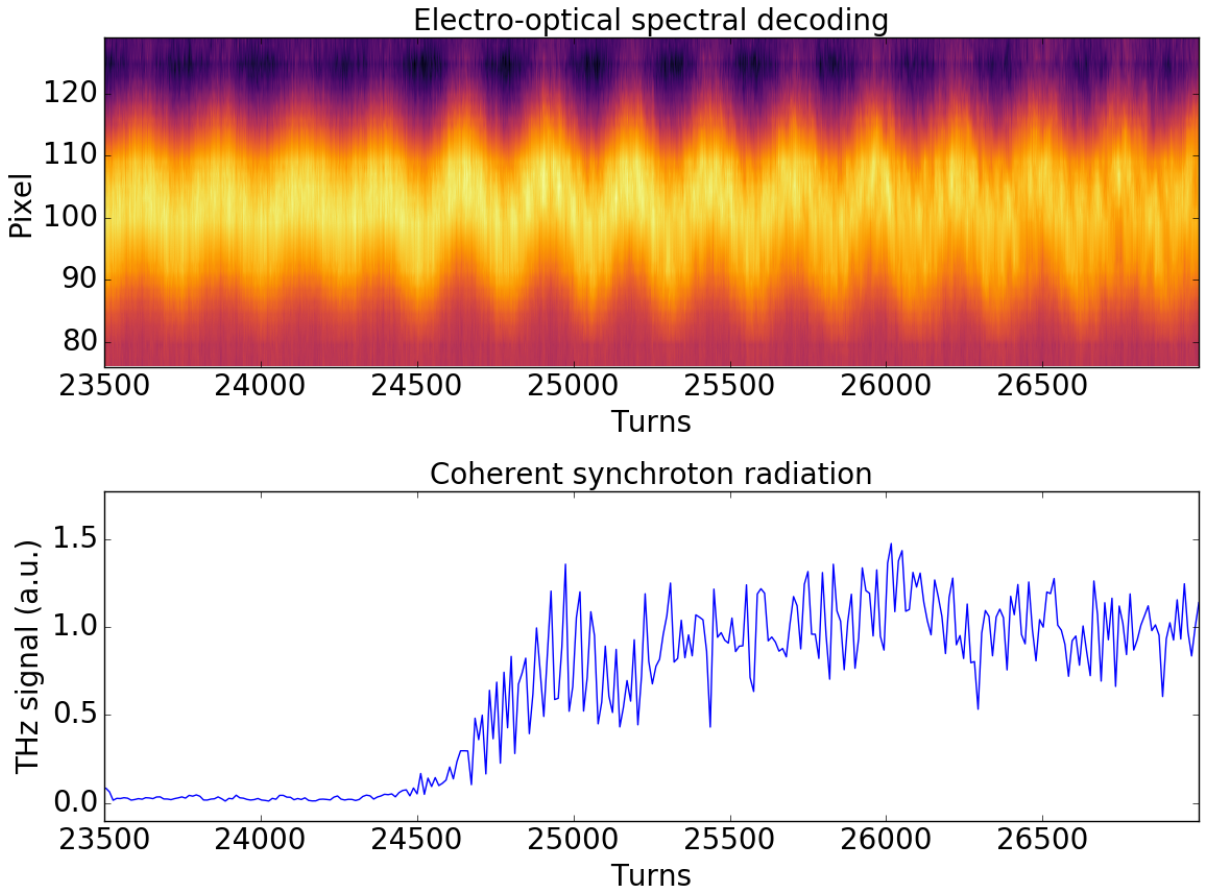

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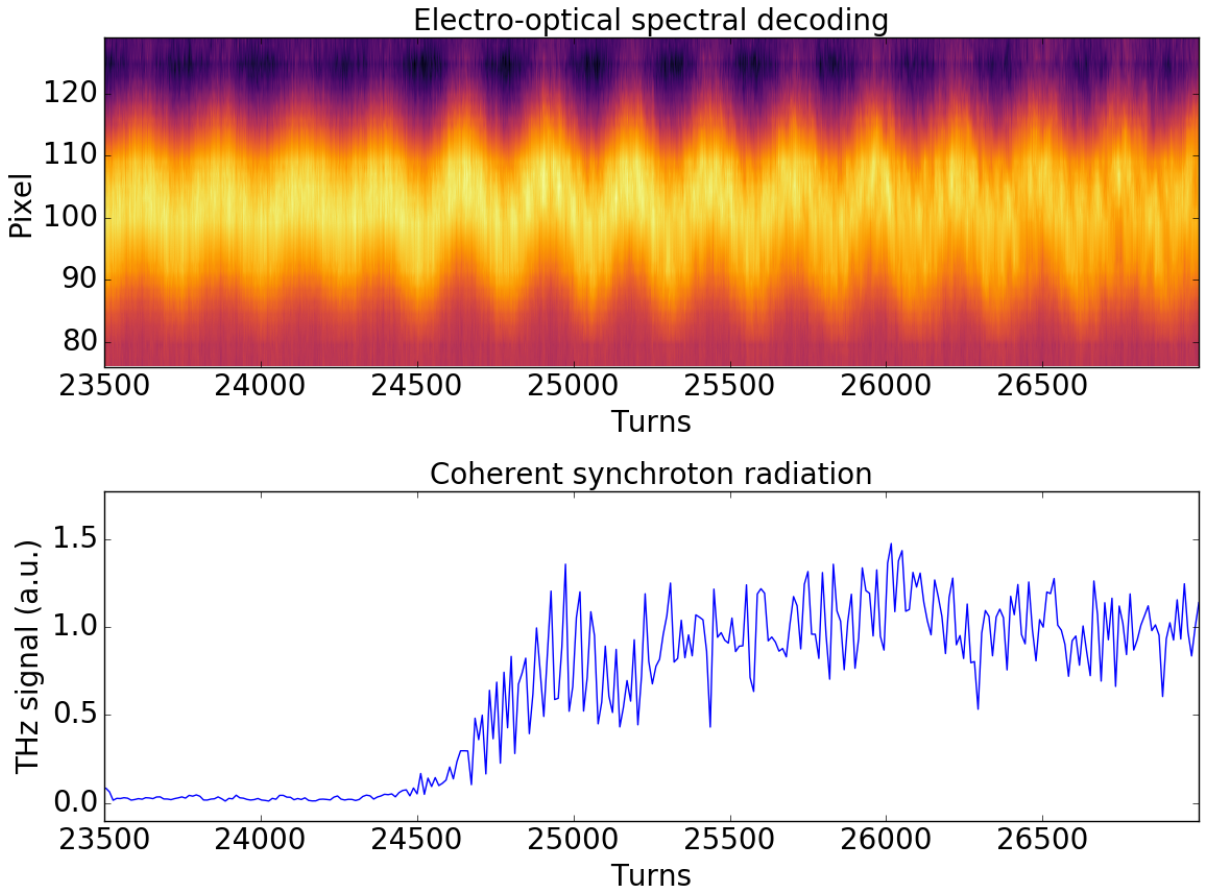

Substructures on long. bunch profile
→ Onset of CSR burst

[11] **M. Brosi et al., IPAC'19 (WEPTS015).**

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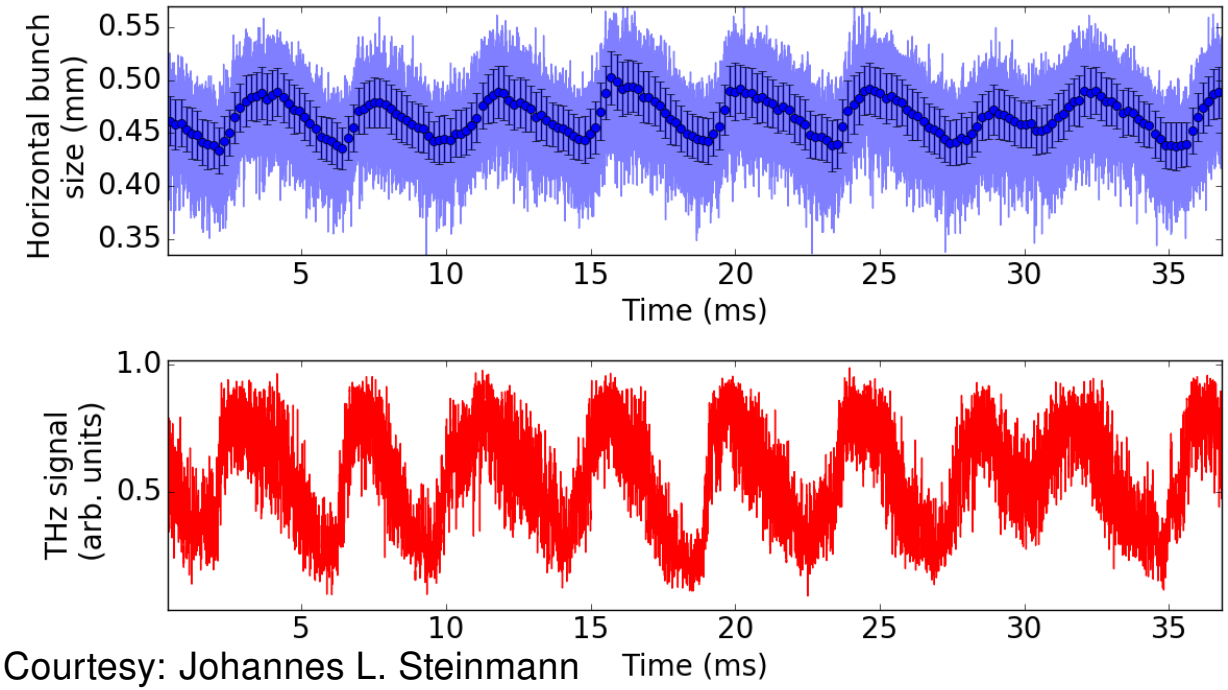
Synchronous measurements[12]

- KALYPSO for horizontal bunch size
- Schottky diode for CSR



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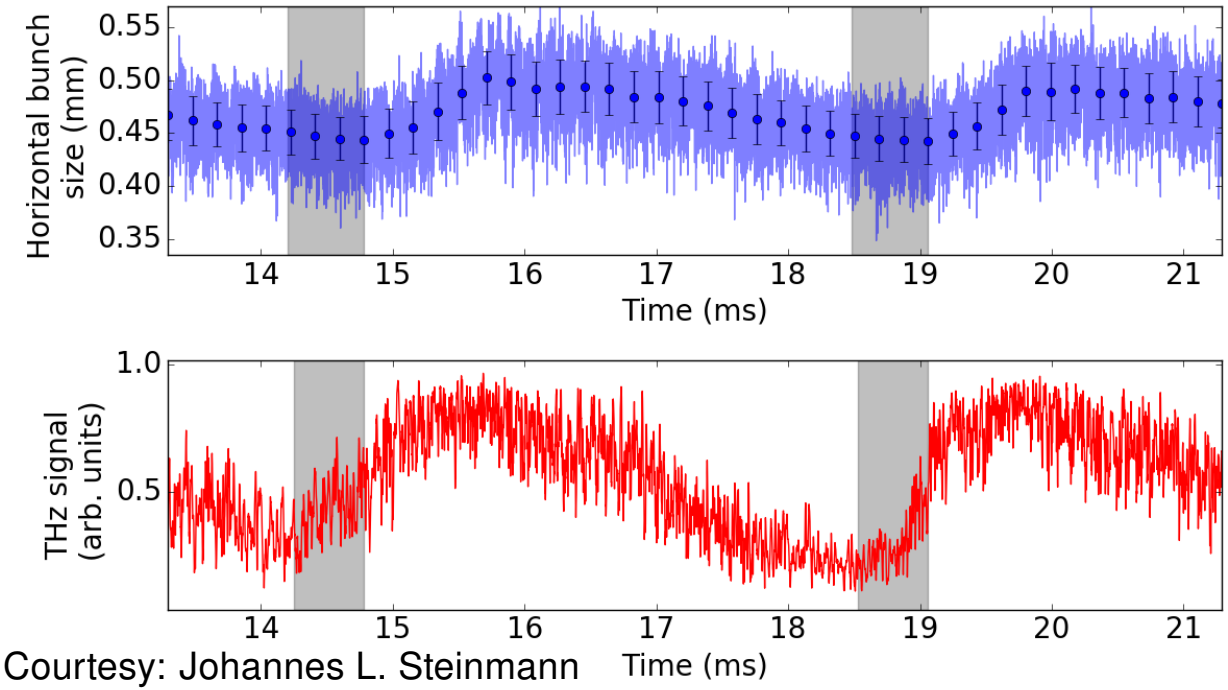

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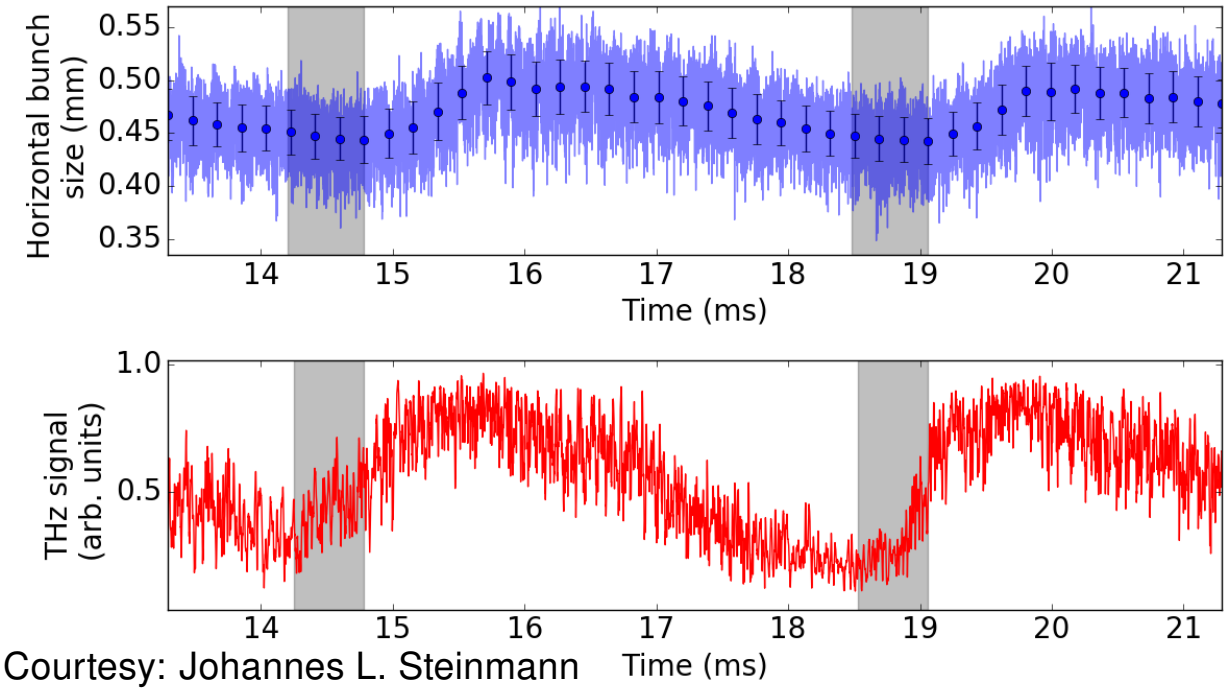

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✔ Long time range **and**
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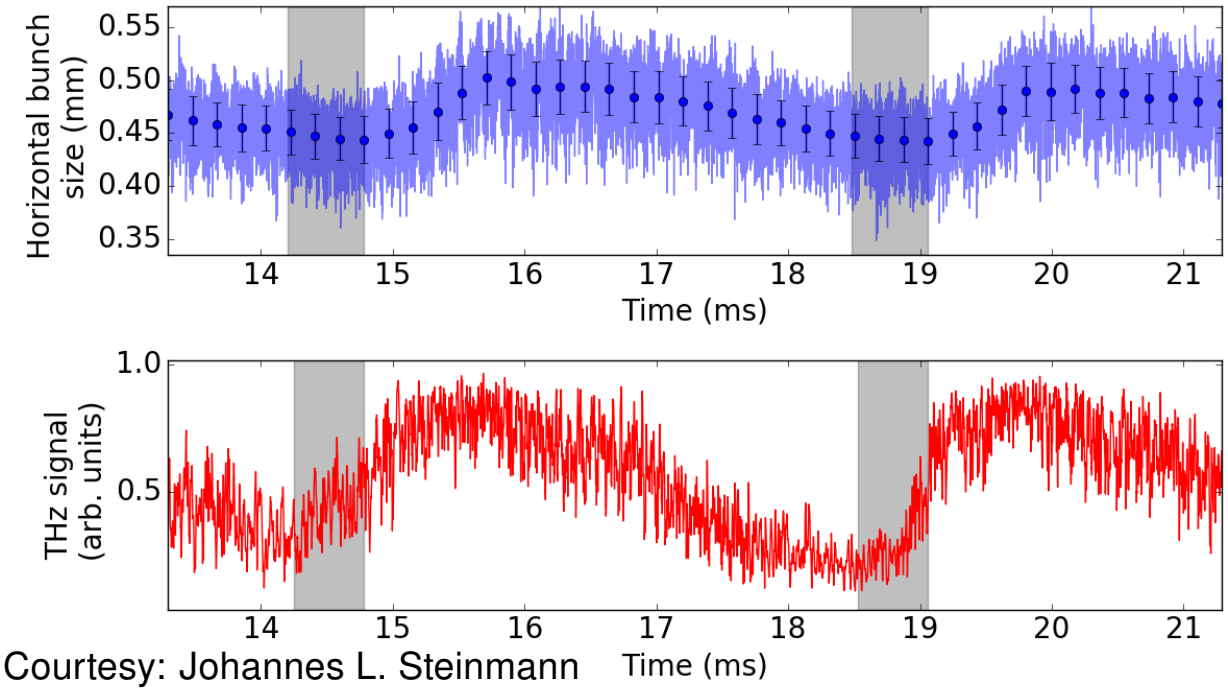

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✔ Long time range **and**
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✔ Systematic studies of longitudinal phase space

[12] **B. Kehrer et al., Proceedings of IPAC'19 (WEPGW016).**

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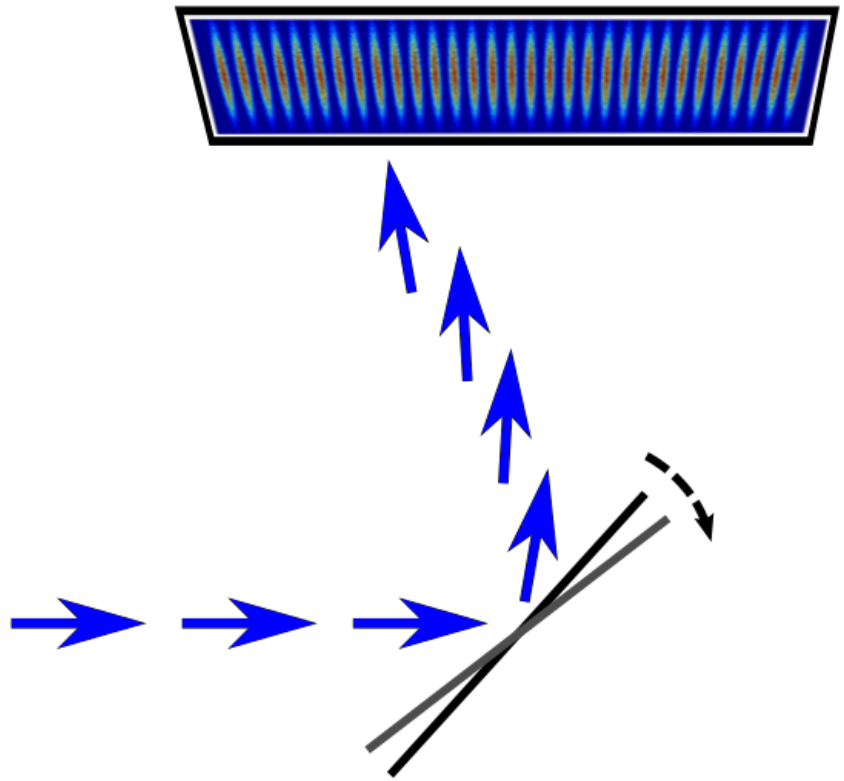
- Detector systems synchronised on single-turn base
  → First steps towards phase space reconstruction
- Challenge
  - Fast data analysis
  - Potential feedback → Talk of Tobias Boltz (2016/09/26 11:30)


Thank you for your attention!

Backup

Fast-gated intensified camera (FGC)

- Setup at visible light diagnostics port[13]
- Combination of sweeping and gating
  - Galvo mirror sweeps light over CCD sensor during illumination
  - Camera gate acts as pulse picker
    → Single turn image of one bunch



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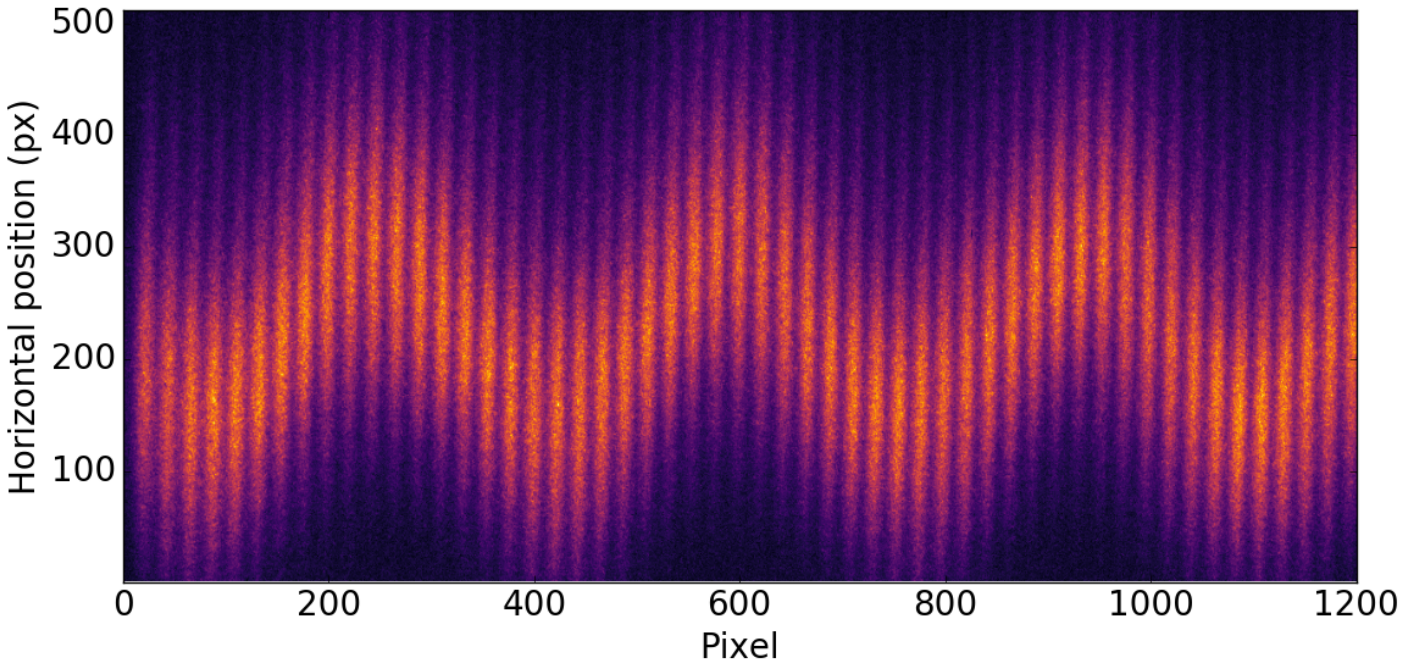

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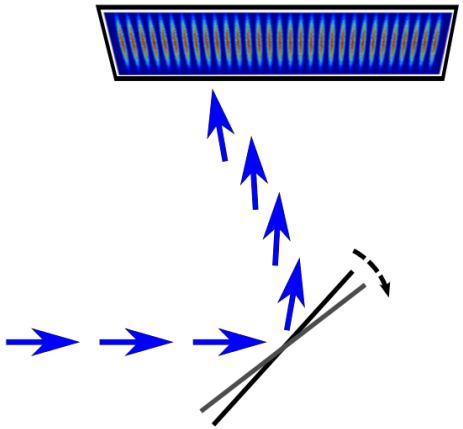
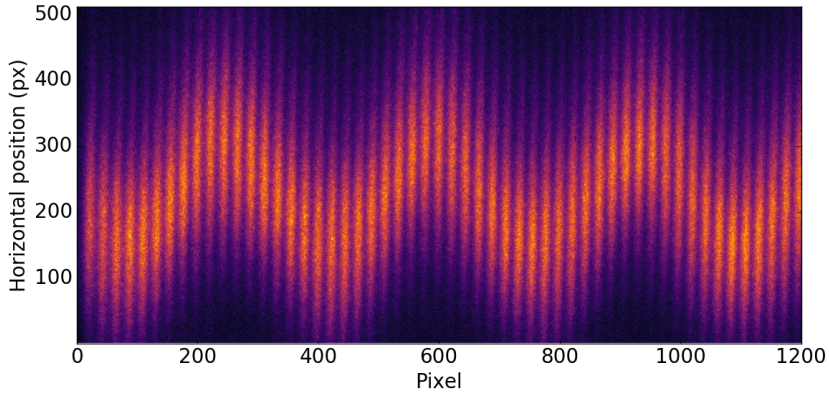
  - Camera gate acts as pulse picker
    → Single turn image of one bunch
- Limited number of data points:
  Trade-off between resolution and time range
  ☛ **beforehand** of a measurement





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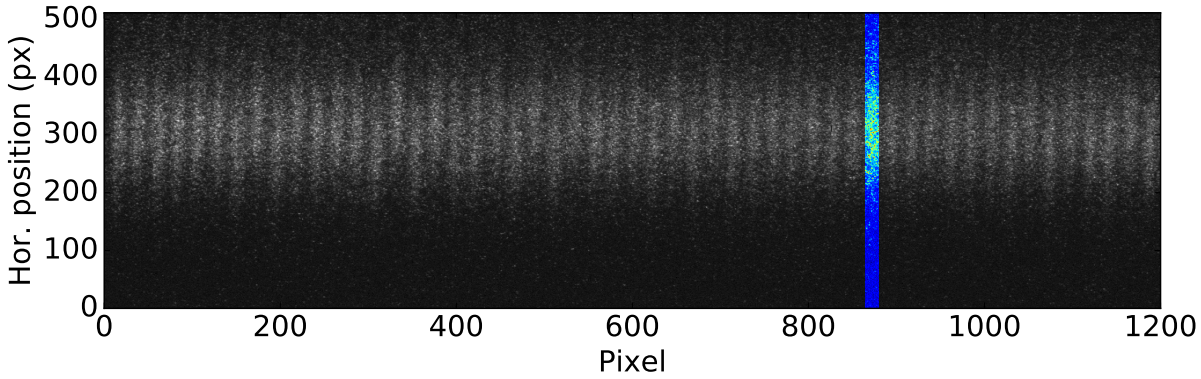
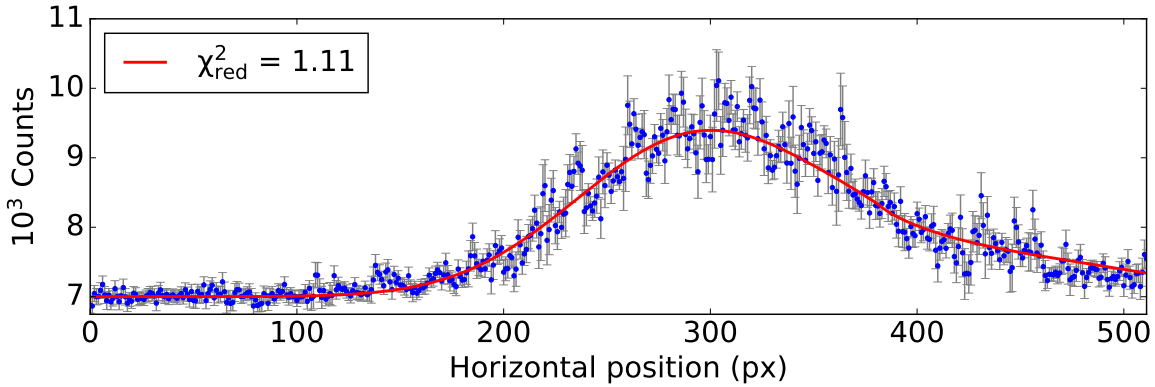
Fast-gated intensified camera: data analysis

- Measured profile: convolution of bunch profile and FBSF
- FBSF determined by optics simulation (OpTaliX)
- Fit function: convolution of Gaussian with FBSF

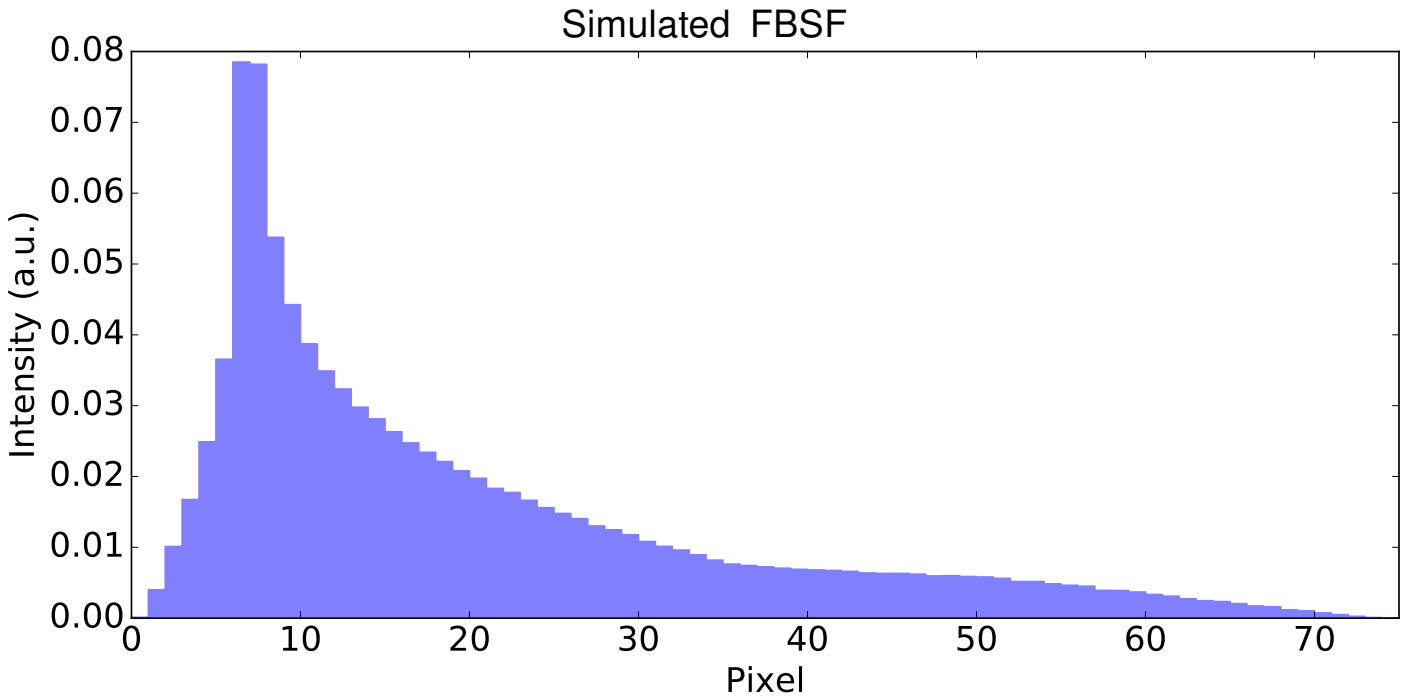




✔ Good fit → χ^2_{red}
✔ Robust
✔ 'Fast' → ~3 s/image

KALYPSO: Data analysis

- Same ansatz as for FGC
- Fit function: $f_{\text{fit}} = f_{\text{Gauss}} * f_{\text{FBSF}}$
- Good representation of the profile
- Drawback: Too slow for *productive* use
  → >100.000 profiles per file or even continouous streaming...



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