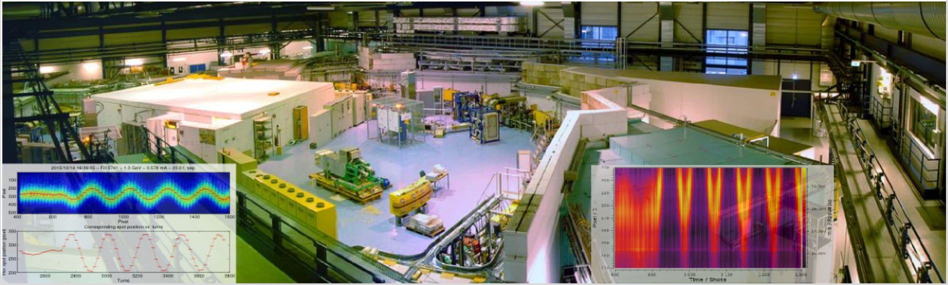
Karlsruhe Institute of Technology

ANKA THZ GROUP

Simultaneous detection of longitudinal and transverse beam signatures at ANKA

Benjamin Kehrer - February the 10th, 2016

Laboratory for Applications of Synchrotron Radiation



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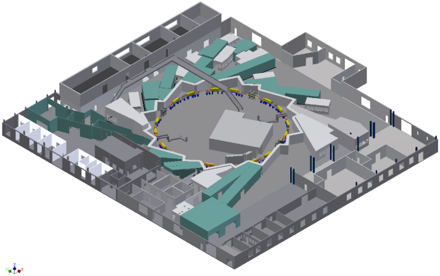

- Circumference: 110.4 m
- f_{RF}: 500 MHz
- Energy: 0.5 - 2.5 GeV
- Single or multi bunch mode
- Beam current: up to 180 mA

Short bunch mode

- Lower momentum compaction factor α_c
  $\rightarrow$ Reduce bunch length
- Coherent Synchrotron Radiation (CSR)
  $\rightarrow$ Micro-bunching instabilities

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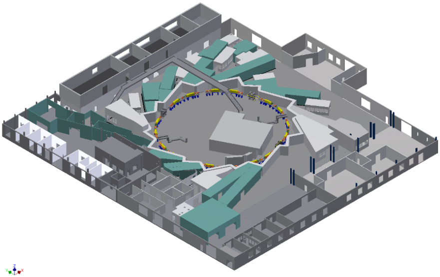

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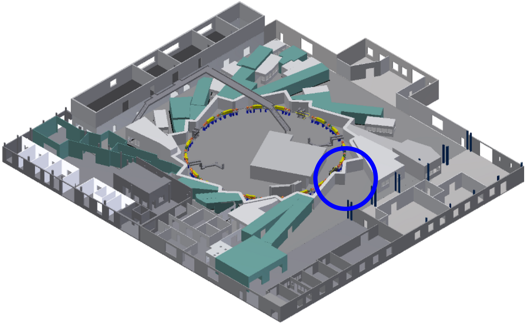
Diagnostics requirements

- Single turn resolution
- Single bunch resolution
- Long time range

Detector systems

- Horizontal bunch profile: Fast-gated intensified camera (FGC)



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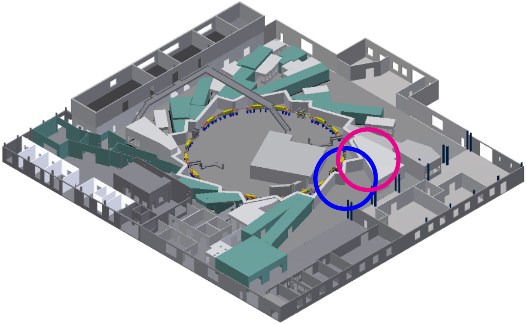

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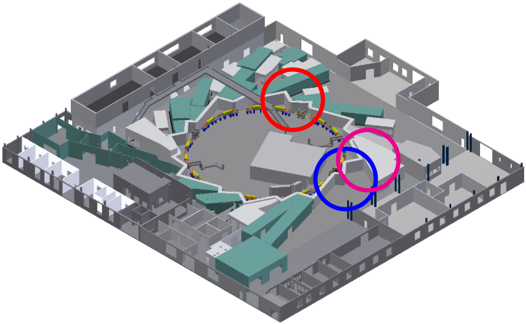
- Longitudinal bunch profile: Electro-optical monitor



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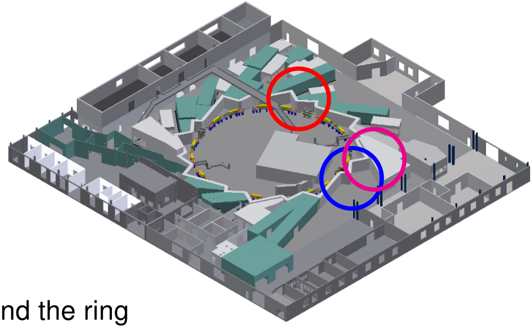

- Systems distributed around the ring
- Recently implemented: synchronization

Horizontal bunch profile: Fast-gated intensified camera (FGC)

- Setup at visible light diagnostics beamline[1,2]
- Camera
  - Andor iStar 340T
  - 1300 x 512 pixel
  - Gate width: 1.55 ns FWHM
  - At least every 6th turn

[1] **P. Schuetze et al.; IPAC'15 (MOPHA039)**.

[2] **B. Kehrer et al.; IPAC'15 (MOPHA037)**.

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  - Voltage ramp from waveform generator

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- Mirror
  - 7 mm aperture
  - Galvo drive
  - Voltage ramp from waveform generator
- Time range and gate repetition rate set by software
  - ~ 65 spots on CCD image
  - Also possible: 'Streak images'

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Fast-gated intensified camera: Basic principle

Measuring the horizontal bunch position and size

- Pick & Track
  - Pick one bunch
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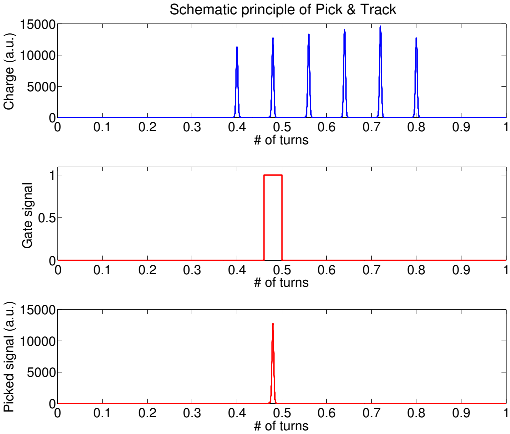

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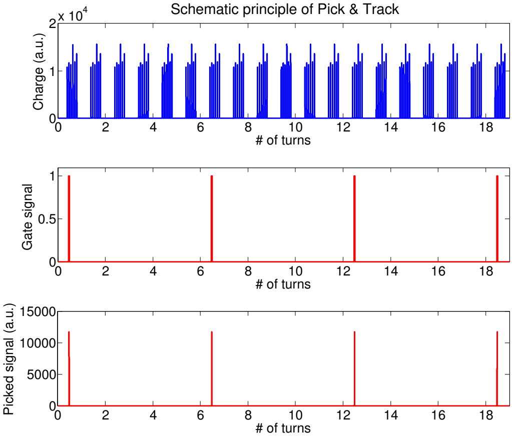

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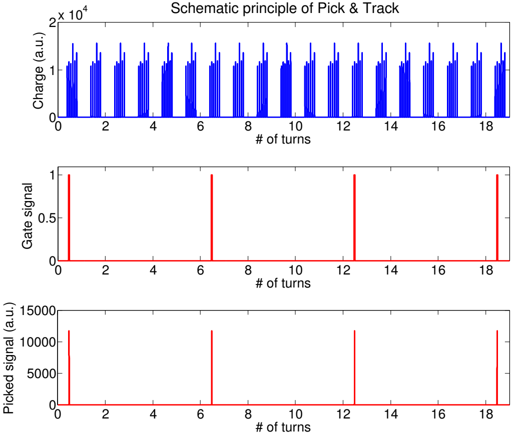

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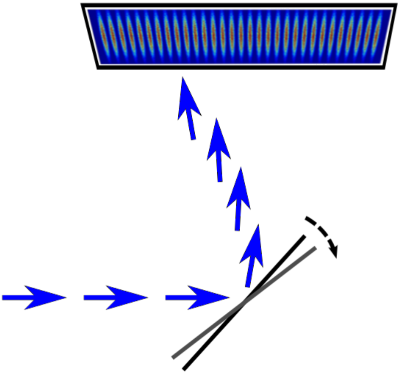
Sweep images over CCD sensor



Courtesy: Paul Schütze

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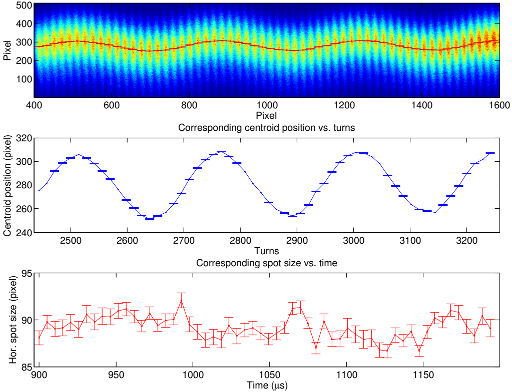
Sweep images over CCD sensor

Sample picture: Gate separation set to 14 turns



CSR emission: THz detectors

Karlsruhe Institute of Technology

- Hot electron bolometer (NbN)[3]
  - Cryogenic (LHe)
  - Response time $< 165\,\mathrm{ps}$
  - 200 GHz up to 4 THz
  - High sensitivity

[3] A.D. Semenov et al.; IEEE Transactions on Microwave Theory and Techniques 55 (2007) 239.

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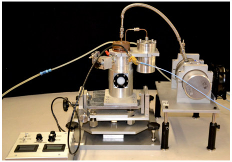

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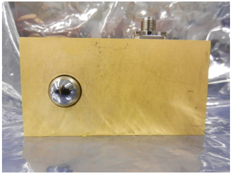
  - Room temperature
  - Response time $< 200\,\mathrm{ps}$
  - 50 GHz up to 1 THz + narrowband detectors
  - Commercially available (ACST, VDI)



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Fast readout: KAPTURE

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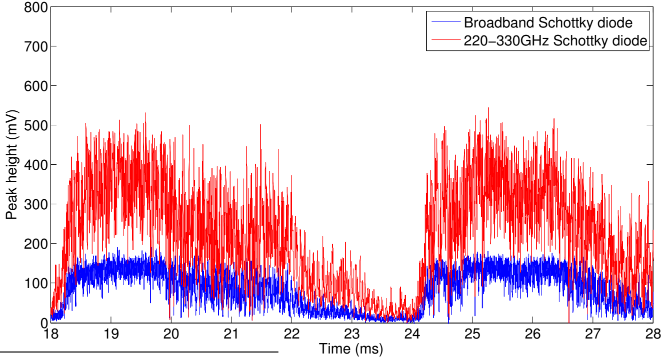
KAPTURE

- **KA**rlsruhe **P**ulse **T**aking **U**ltra-fast **R**eadout **E**lectronics
- FPGA based read-out for fast detectors[5] (see also talk by M. Brosi)
- 4 ADC with turn-by-turn and bunch-by-bunch capability
  $\longrightarrow$ Here: 2x Schottky diodes



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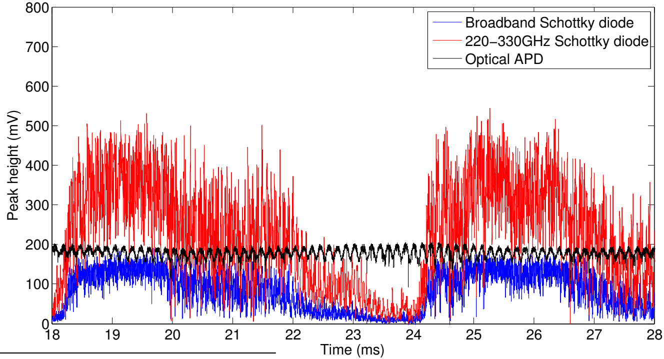

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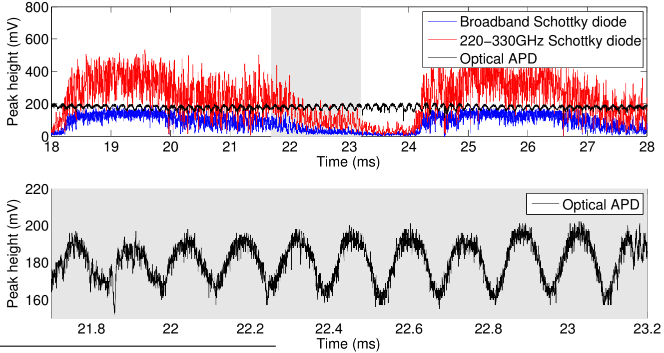

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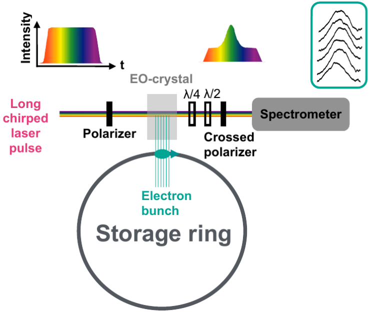
Longitudinal bunch profile: Electro-optical monitor

- Electro-optical spectral decoding (EOSD)[6]
  - Sampling the near field
  - Imprint bunch profile in chirped laser pulse
- Spectrometer based on KALYPSO (**KA**rlsruhe **L**inear arra**Y** detector for MHz-re**P**etition rate **S**pectr**O**scopy)
  - 256 pixel line array (50 μm)
  - Sample up to every 3rd turn (Upgrade to higher rate planned)



Courtesy: Nicole Hiller

[6] **N. Hiller et al; IPAC'13 (MOPME014)**.

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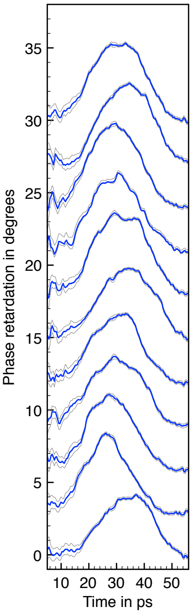
EOSD bunch profiles[7]



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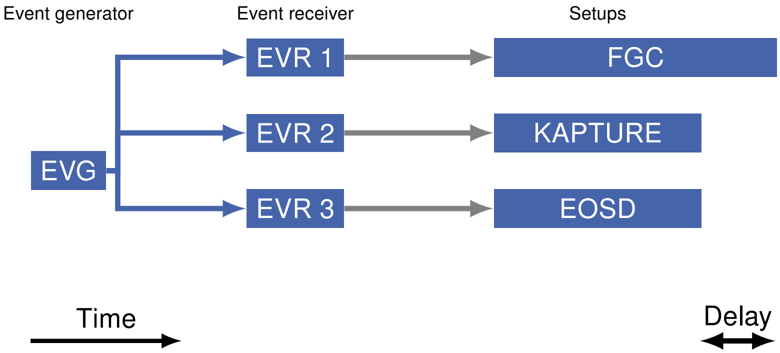
[7] **N.Hiller; PhD thesis; 2013.**

Synchronization

- Main goal: Synchronous measurement
- Use Timing system[8] for common trigger
  → Arm trigger: *Acquisition starts with next revolution trigger*



[8] MRF, www.mrf.fi

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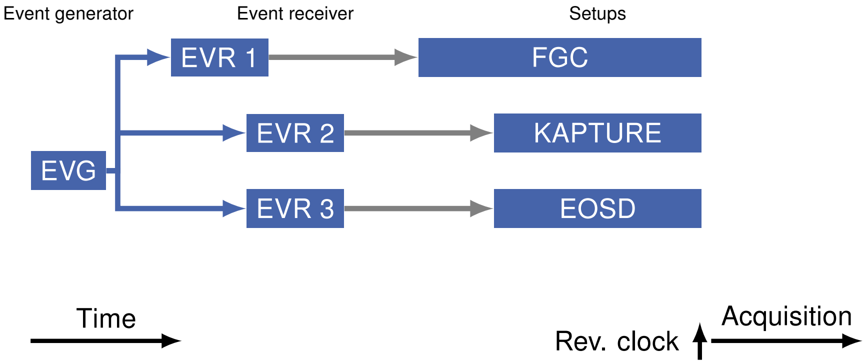

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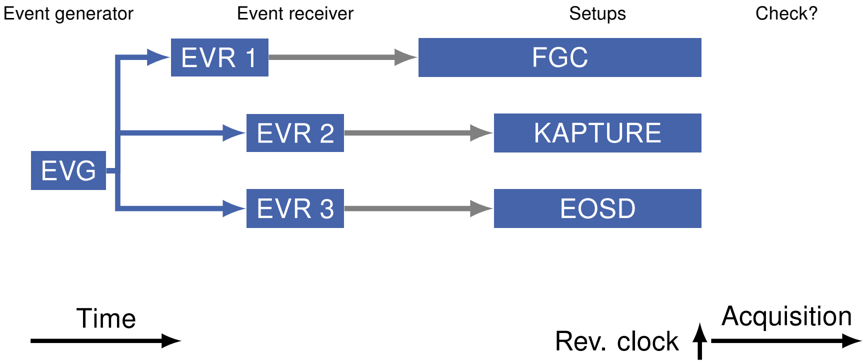

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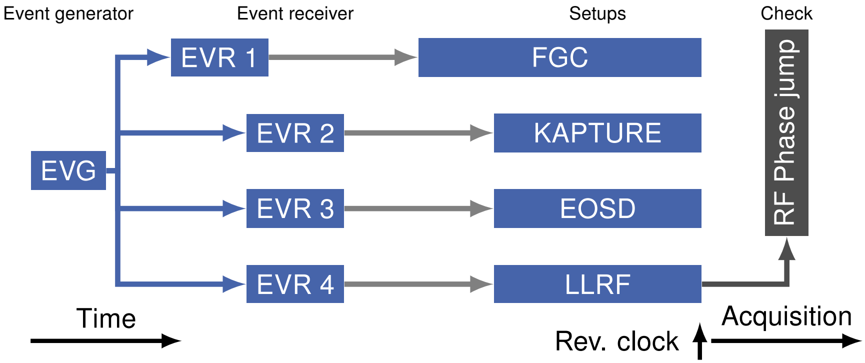

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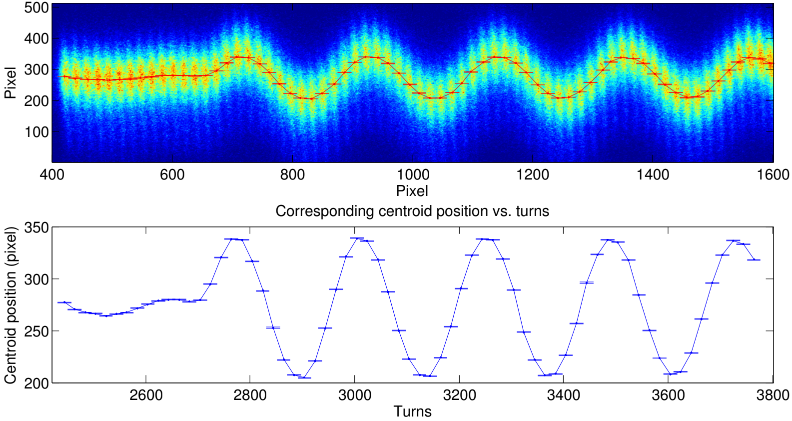
Calibration: RF phase jump

- Induce RF phase jump
- Fast Gated Camera



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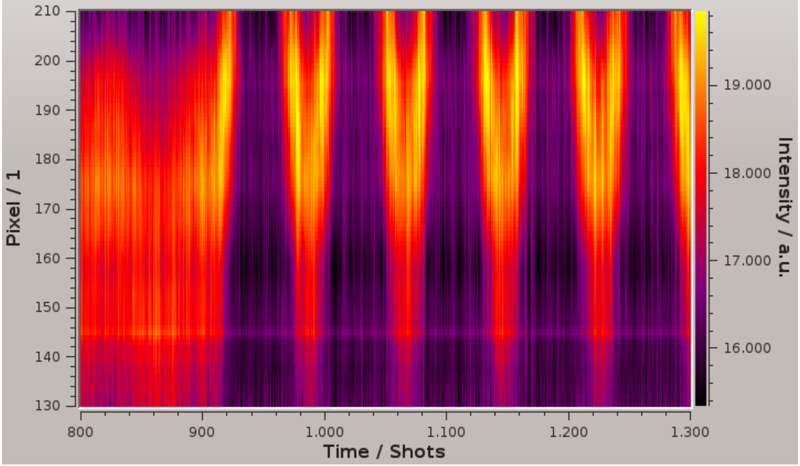

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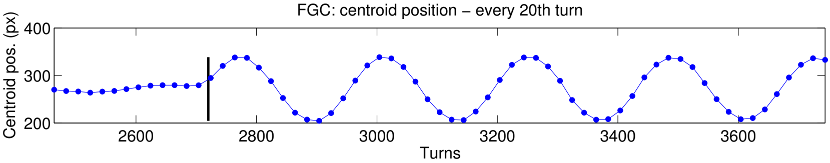

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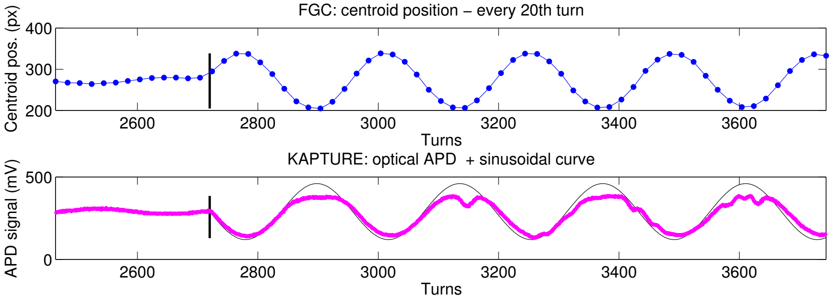

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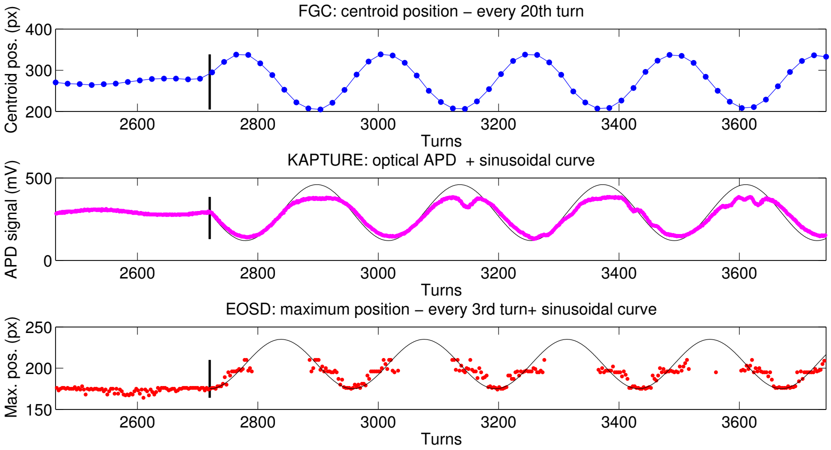

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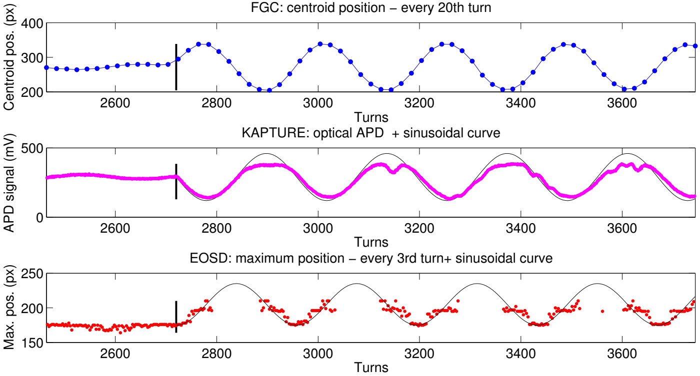
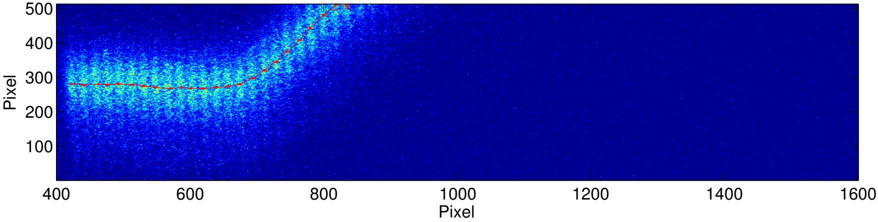


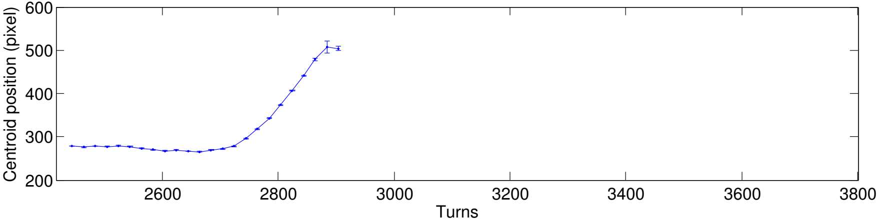
- FGC + KAPTURE in phase
  EOSD phase shifted by quarter synchrotron period
- Measurements successfully synchronized

Calibration: beam loss I

- Trigger a beam loss (switch off RF)



Corresponding centroid position vs. turns



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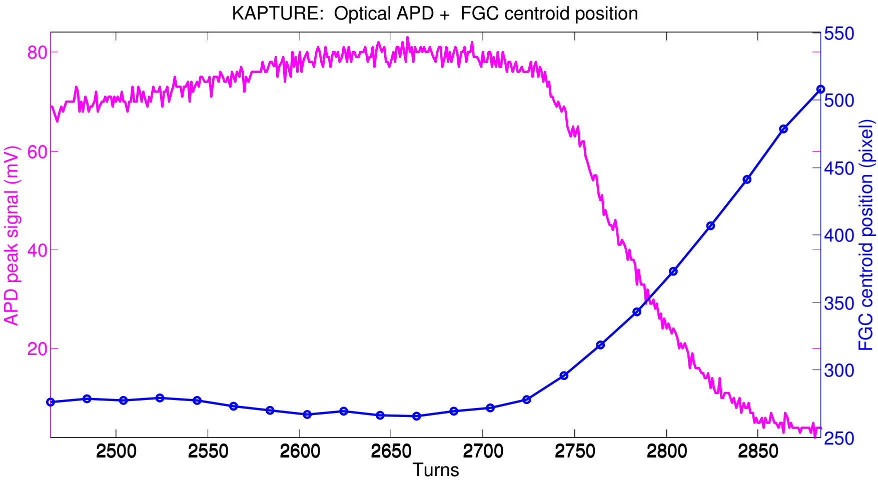
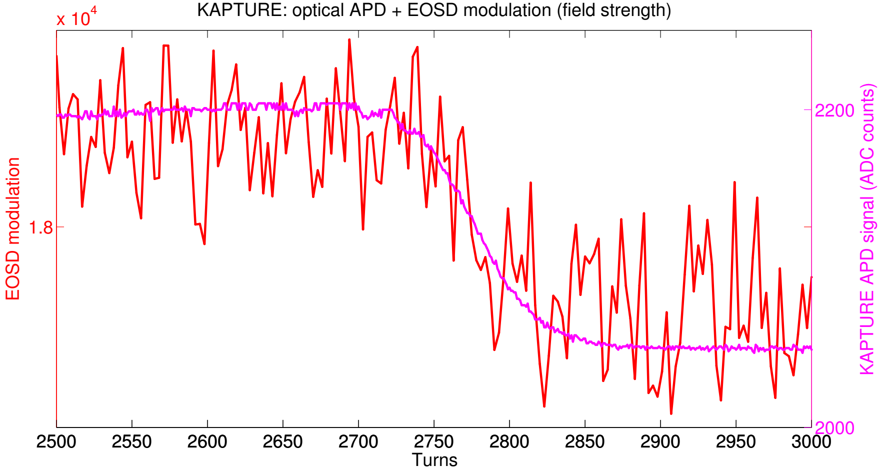


Calibration: beam loss II

- Trigger a beam loss (switch off RF)



Acknowledgements

- **KIT THz-Team** (from IBPT, IMS, IPE, IPS and LAS):
  M. Balzer, E. Blomley, A. Borysenko, M. Brosi, E. Bründermann, M. Caselle, C. Chang*, N. Hiller, S. Höninger, M. Hofherr, E. Huttel, K.S. Ilin, V. Judin*, M. Klein*, S. Marsching, Y.-L. Mathis, M.J. Nasse, G. Niehues, A. Plech, J. Raasch, P. Rieger*, L. Rota, R. Ruprecht, M. Schedler, A. Scheuring, P. Schönfeldt, M. Schuh, P. Schütze*, M. Schwarz, M. Siegel, N.J. Smale, B. Smit, J. Steinmann, P. Thoma*, S. Walter, M. Weber, S. Wuensch, M. Yan, and A.-S. Müller
  * *THz-Alumni*
- **For interesting discussions, good ideas and a lot of fun:**
  F. Caspers (CERN), S. Khan (DELTA), P. Peier, B. Steffen (DESY), H.-W. Hübers, A. Semenov (DLR), P. Kuske, G. Wüstefeld (HZB), V. Schlott (PSI) ,Y. Cai, J. Corbett, R. Warnock (SLAC), S. Bielawski, C. Evain, E. Roussel, C. Szwaj (U. Lille)

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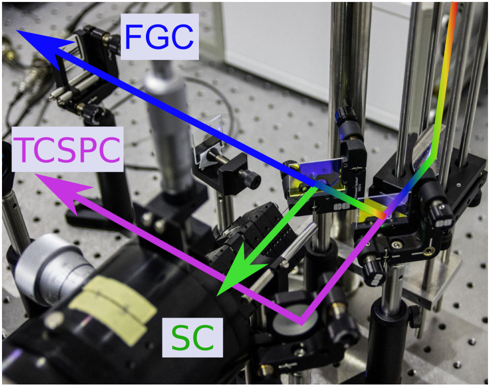
Conclusion

- Different setups for time-resolved studies in operation
  - Fast-gated intensified camera $\rightarrow$ horizontal bunch profile
  - Fast THz detectors $\rightarrow$ coherent synchrotron radiation (CSR)
  - Electro-optical bunch length monitor $\rightarrow$ longitudinal bunch profile
- Single turn and single bunch resolution
- Measurements successfully synchronized
- Confirmed by
  - RF phase jumps
  - Triggered beam loss

Backup

Visible Light Diagnostics Beamline

- 5° port of a dipole magnet
- Parallel operation of different devices required
  $\rightarrow$ Split in different wavelength regions



TCSPC

- Time-Correlated Single Photon Counting
- $\lambda < 400\,\text{nm}$

FGC

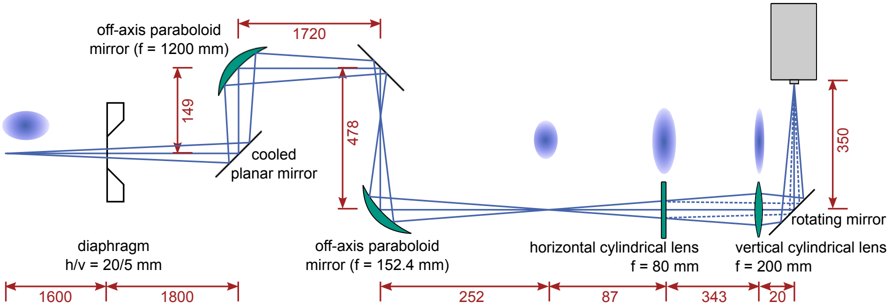
- Fast-gated Intensified Camera
- $400\,\text{nm} < \lambda < 500\,\text{nm}$

SC

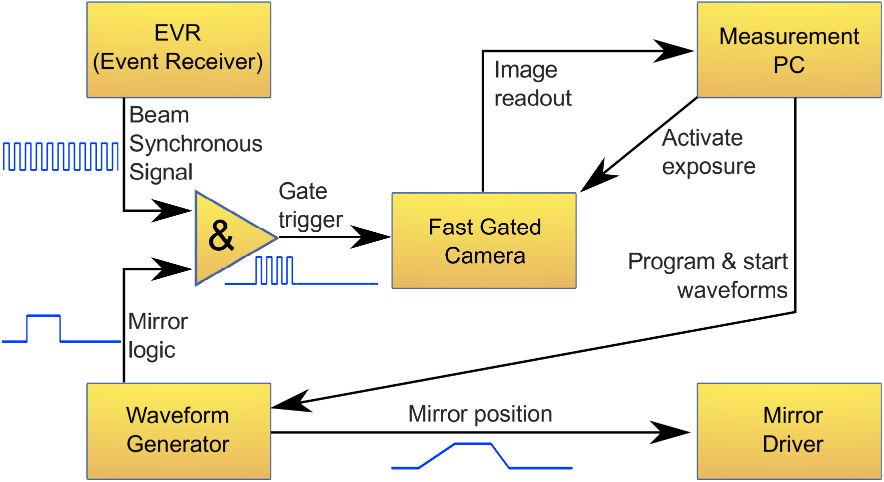
- Streak Camera
- $\lambda > 500\,\text{nm}$

Fast-gated intensified camera: optical path

- 5° port of a dipole magnet
- 4 Mirror form intermediate image on optical table
  - 2 planar mirror
  - 2 off-axis paraboloid mirrors
- Magnification:
  - $M_h = 2.6$
  - $M_v = 0.29$

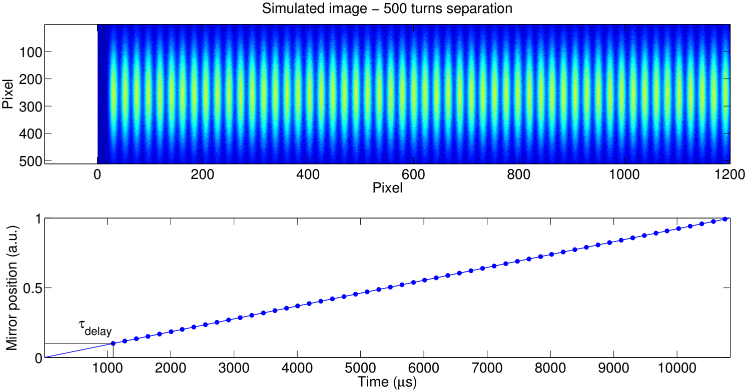


Fast-gated intensified camera: control scheme



Fast-gated intensified camera: time to reach CCD

- Mirror needs certain time τ_{delay} before light hits the CCD



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