Karlsruher Institut für Technologie

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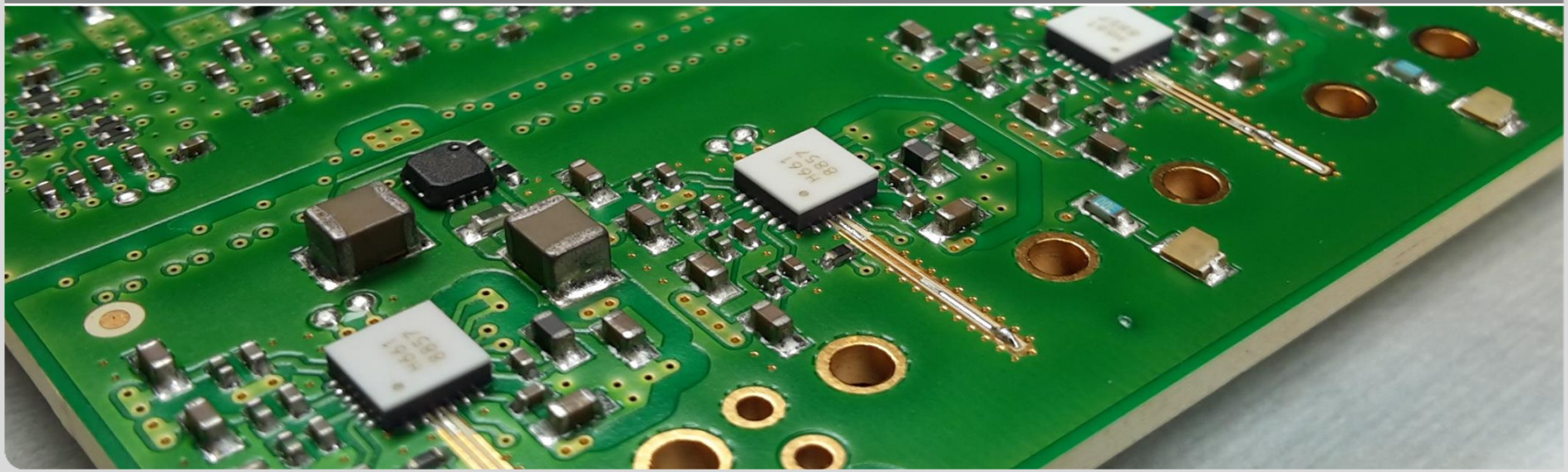
BMBF-Verbund Speaker
A.-S. Müller, 2016 - 2019

Single-shot longitudinal beam profile and THz diagnostics at MHz- towards GHz-rates with high-throughput electronics

L. Rota, M. Caselle, M. Balzer, M. Brosi, E. Bründermann, S. Funkner, B. Kehrer, M.J. Nasse, G. Niehues, M. Patil, P. Schönfeldt, M. Schuh, J. Steinmann, M. Weber, M. Yan, A. S. Müller (***KIT***)

M. Boscardin, G. Borghi and S. Ronchin (***FBK Trento***)

KIT, Institut für Prozessdatenverarbeitung und Elektronik



Beam diagnostics at KIT:

development of ultra-fast detectors, readout electronics and DAQ systems, tested in an accelerator environment at KARA and FLUTE

IBPT

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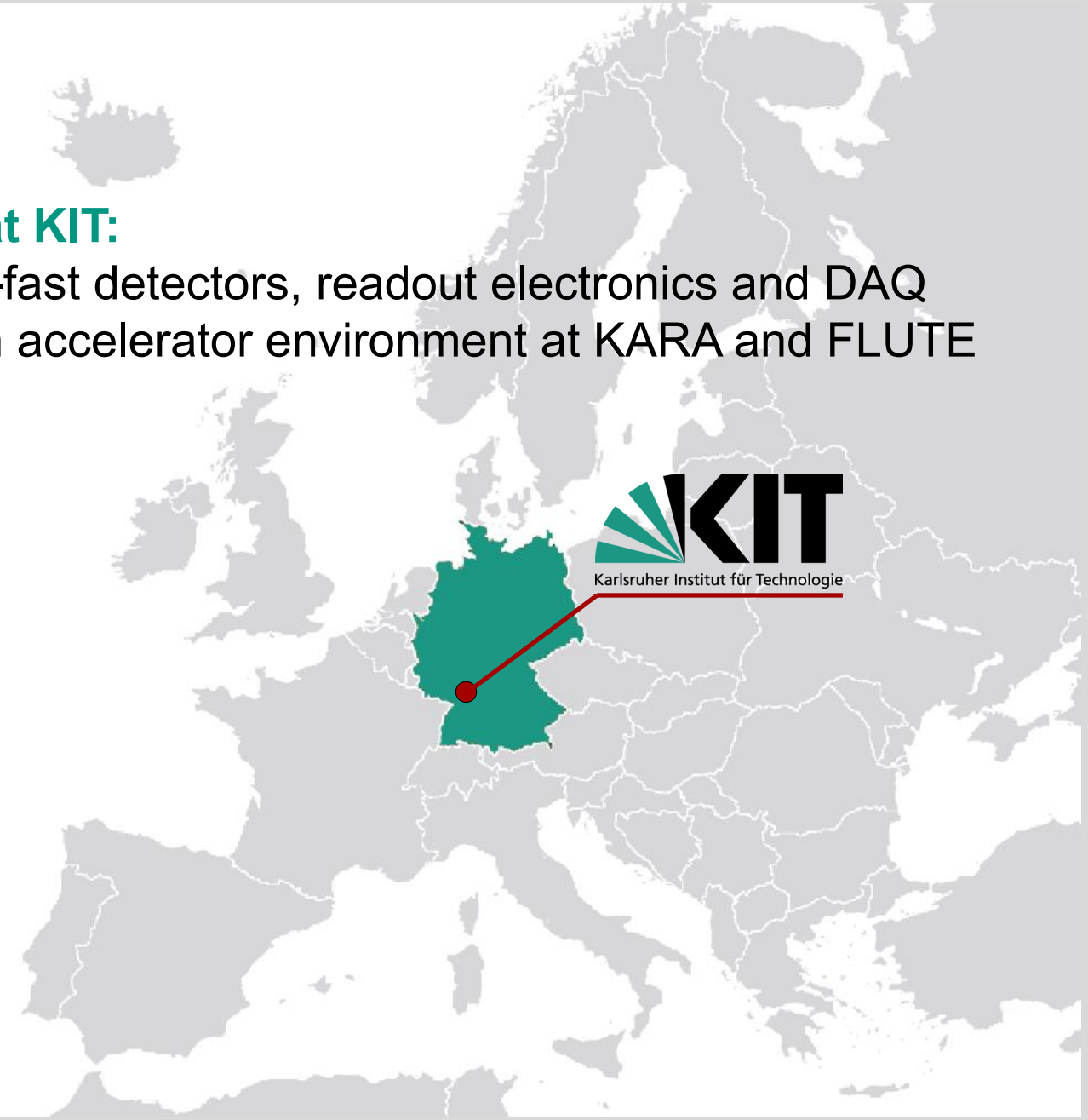

www.ipe.kit.edu

www.ibpt.kit.edu/kara

www.ims.kit.edu

Micro-bunching instabilities

- Complex and nonlinear dynamics in longitudinal phase space
- Can lead to bursts of very intense, coherent synchrotron radiation (CSR)
- Observation of, e.g.,
  - Longitudinal bunch profiles
  - Transverse bunch profiles
  - Emitted (coherent) radiation
- Relevant timescales
  - Bunch length
  - Dimension of micro-structures
  - Distinguish between individual bunches
  - Follow bursting behaviour
  - Observe slow changes (e.g., with current)

[1] A.-S. Müller, TUAL01, IBIC'16

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Fast detectors

Dedicated front-end

High-speed data-links & real-time data processing

New detectors, readout electronics and data-processing

[1] A.-S. Müller, TUAL01, IBIC'16

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KALYPSO

KAPTURE

- Relevant timescales
  - Bunch length
  - Dimension of micro-structures
  - Distinguish between individual bunches
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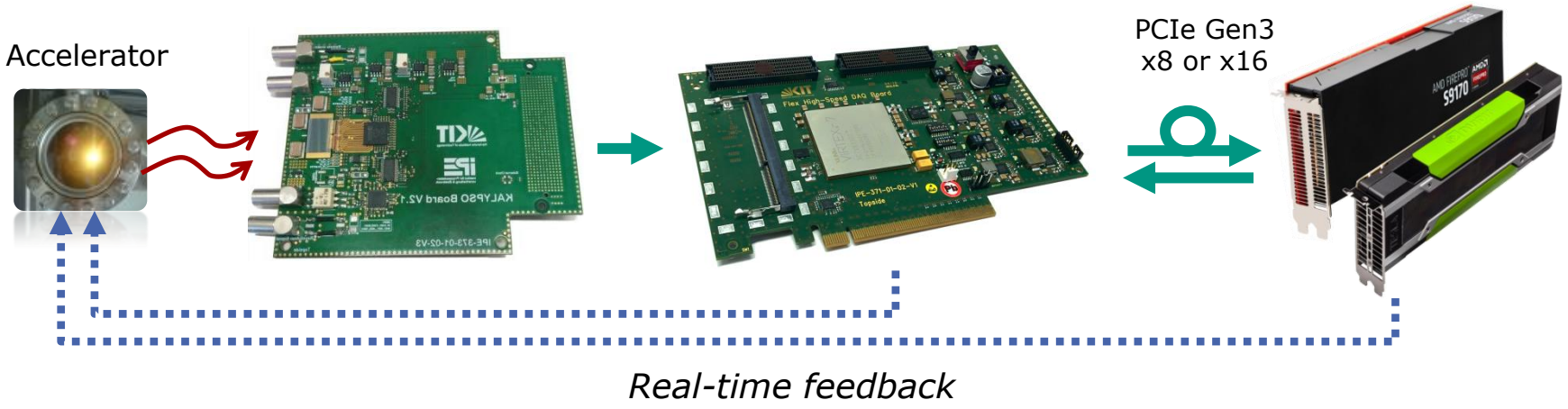
  - Observe slow changes (e.g., with current)

(sub-) ps	Fast detectors
2 ns/500 MHz	Dedicated front-end
10 ms sec – hrs	High-speed data-links & real-time data processing

New detectors, readout electronics and data-processing

[1] A.-S. Müller, TUAL01, IBIC'16

Common detector readout architecture



- Mezzanine card with fast detectors and front-end electronics
- FPGA readout card for pre-processing and fast data-link
  - “High-Flex” custom FPGA board [1]
- Real-time data processing with Graphics Processing Unit (GPUs) [2]
  - Throughput: 7 GBytes/s
  - Latency: down to 2 µs

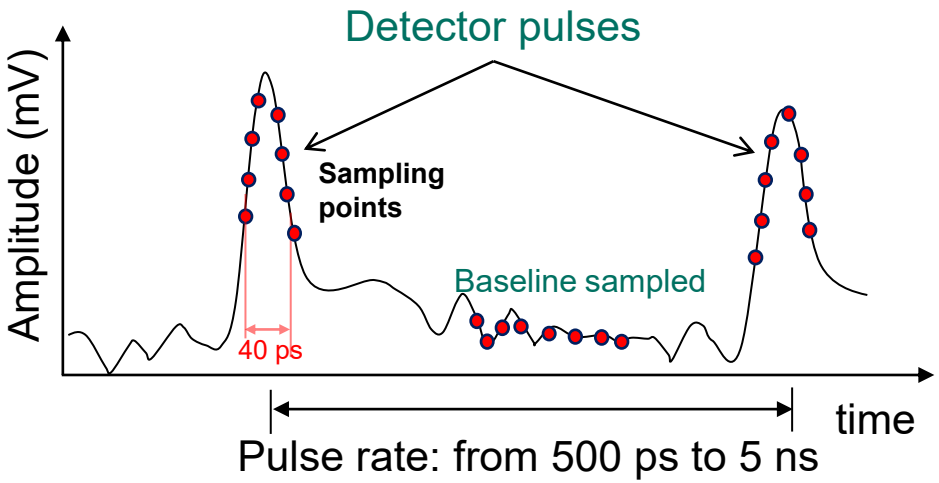
[1] M. Caselle , “A High-speed DAQ Framework for Future High-Level Trigger and Event Building Clusters”, JINST (2017)
[2] M. Vogelgesang., WEPG07, IBIC'16

KAPTURE II

KArlsruhe Pulse Taking Ultra-fast Readout Electronics

- Wide-band front-end electronics for ultra-fast detectors:
  - Compatible with various detectors:

    THz detectors (YBCO, Schottky diodes), BPMs, diamond detectors, photodiodes…
  - Pulse amplitude and arrival time with “mV” and “ps” accuracy
  - Continuous acquisition, up to 8 sample points per pulse, pulse rep-rate up to 2 GHz

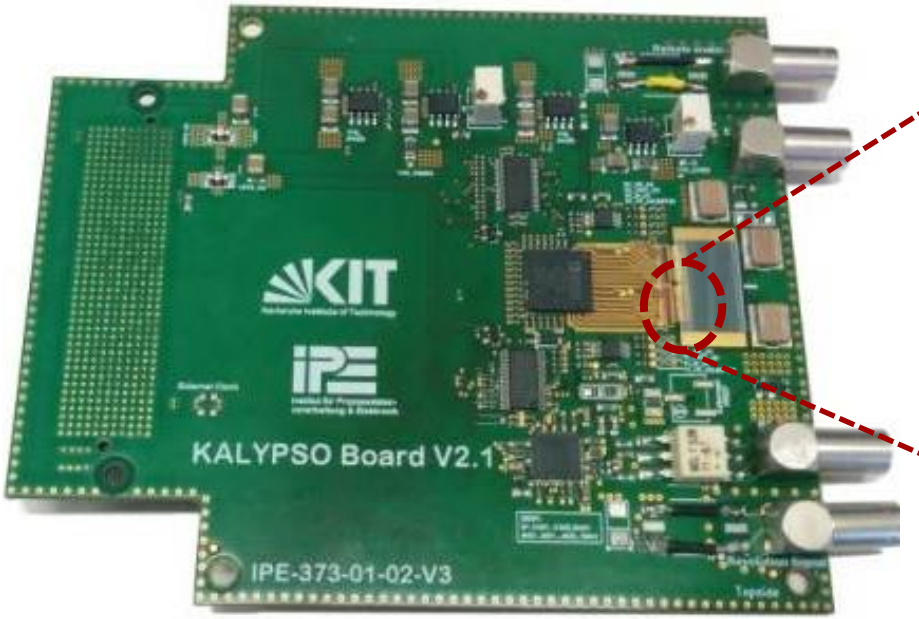


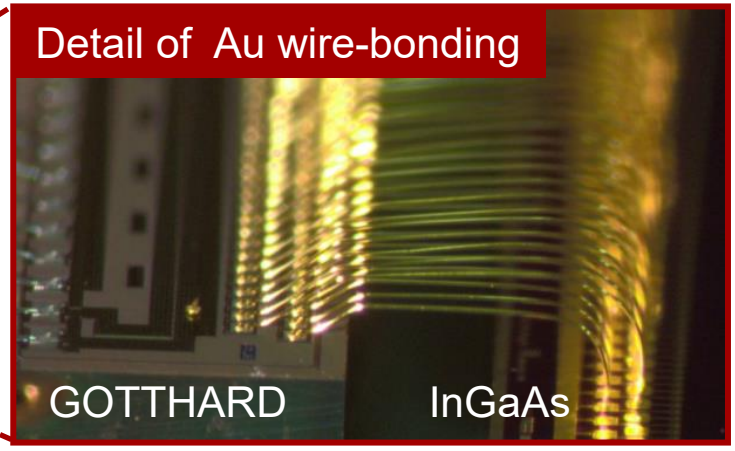
[1] M. Caselle, “KAPTURE-2. A picosecond sampling system for individual THz pulses with high repetition rate”, JINST 2017

KALYPSO II

KArlsruhe Linear arraY detector for MHz-rePetition rate SpectrOscopy

- Ultra-fast 1D camera:
  - Frame rate up to 2.7 MHz, continuous acquisition
  - InGaAs/Si sensors for near-IR/visible light
  - Pixel size up to 256 pixels, pitch of 50 µm
  - Front-end chip: GOTTHARD [1] (A. Mozzanica, PSI)



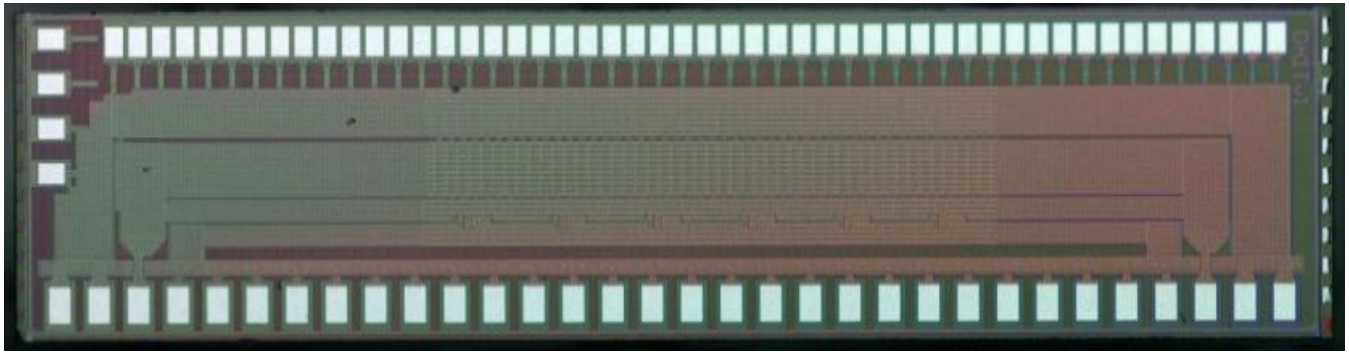


[1] L. Rota, WEPG46, IBIC'16

Towards 10 MHz: readout electronics

- New Application Specific Integrated Circuit (ASIC) for KALYPSO:
  - Designed on CMOS 110 nm from UMC
  - Frame rate up to 10 MHz, meet requirements EuXFEL/TELBE
  - Compatible with different sensors and signal polarities
  - Fully-differential architecture

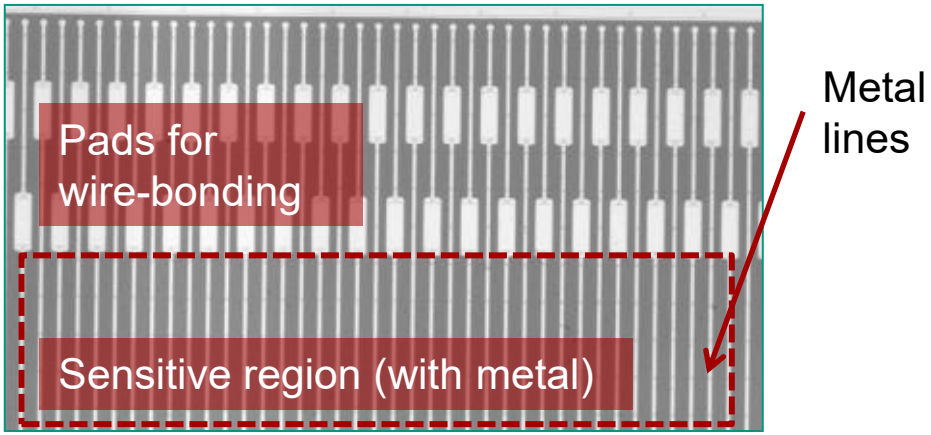
- First prototype received Dec. 2016, fully functional even at 12 MHz
- Final version will be submitted to foundry in late 2017



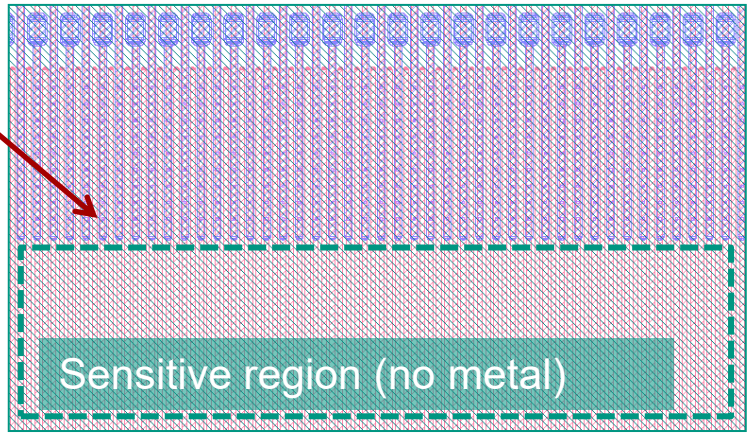
Towards 10 MHz: Si sensors

- Multi-purpose design
- ARC layers for different wavelenght:
  - Visible light
  - Near-IR (1050 nm)
  - Near-UV (400 nm)
- High resolution: 25 and 50 µm pixel pitch
- Size: 512/1024/2048 pixels

Current sensor, developed for X-rays (PSI)

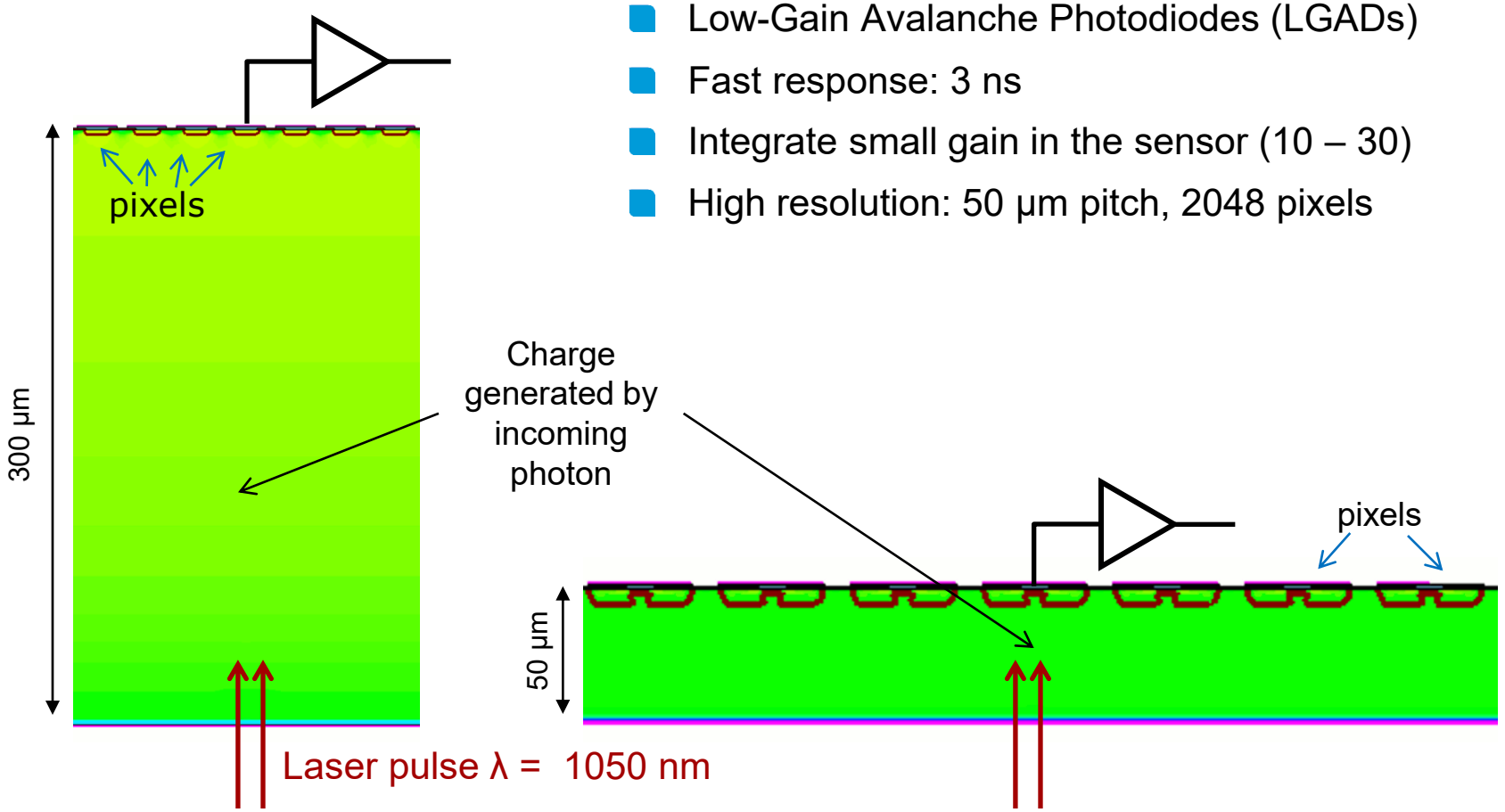


Layout of new sensor

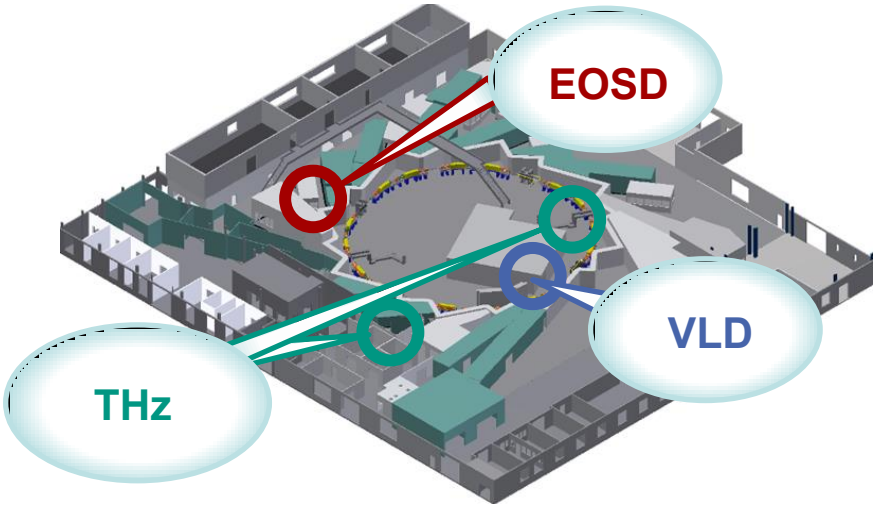


Si sensors beyond 100 MHz

- Traditional Si detector
  - Response: 15 ns
- Ultra-fast Silicon Detectors
  - Under development for HEP tracking detectors
  - Low-Gain Avalanche Photodiodes (LGADs)
  - Fast response: 3 ns
  - Integrate small gain in the sensor (10 – 30)
  - High resolution: 50 µm pitch, 2048 pixels

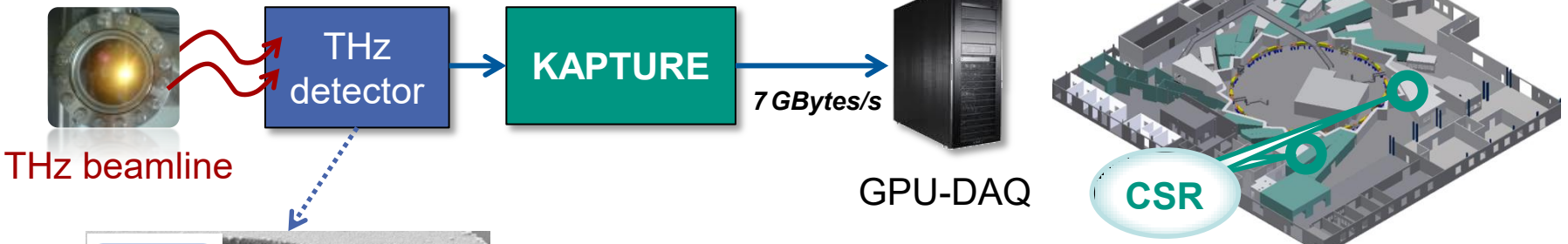


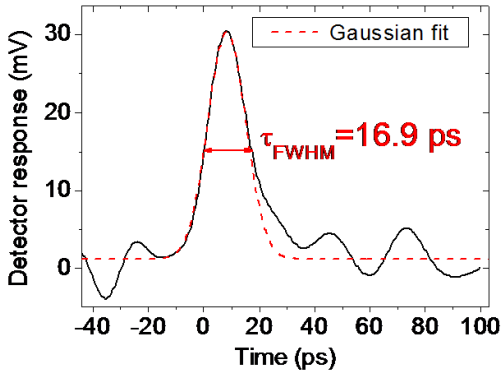
Application examples at KARA

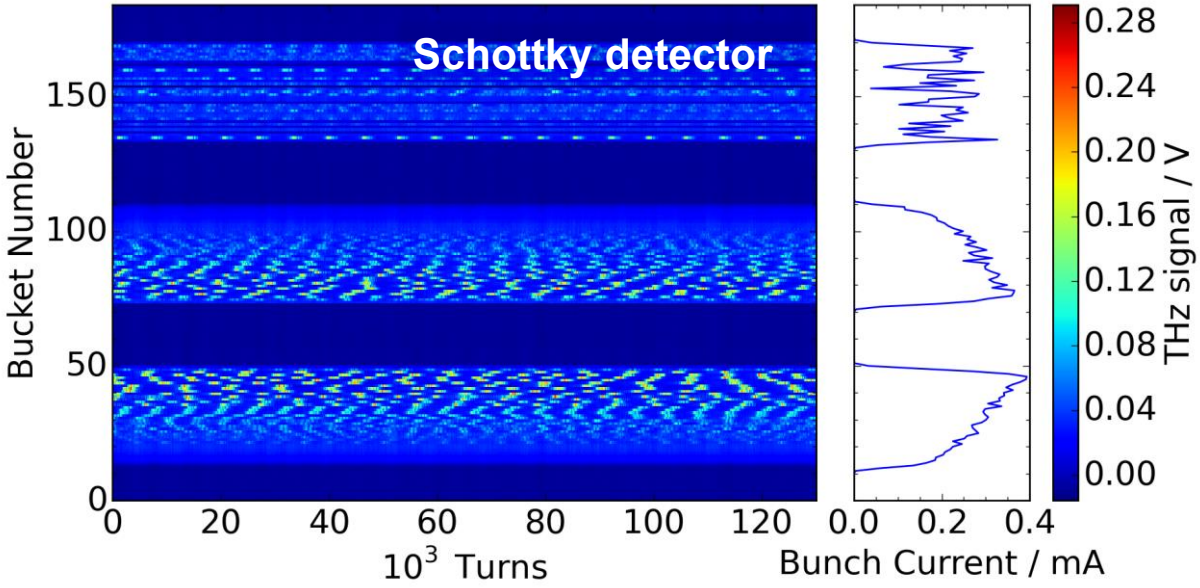


- **KAPTURE + THz detectors:**
  - Intensity of Coherent Synchrotron Radiation @ 500 MHz / 2 GHz
- **KALYPSO + near-field Electro Optical Spectral Decoding setup:**
  - Longitudinal bunch profile @ 2.7 MHz
- **KALYPSO + Visible Light Diagnostics port:**
  - Horizontal bunch profile @ 2.7 MHz

THz diagnostics with KAPTURE





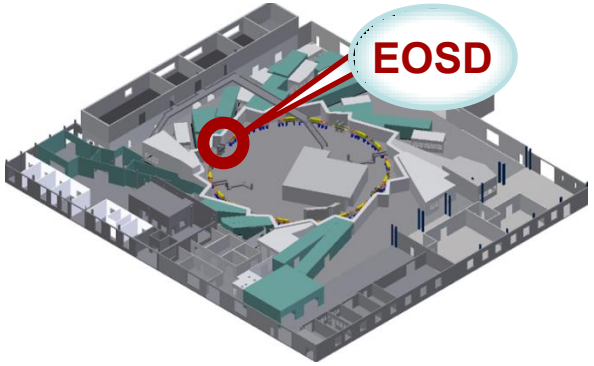


[1] J. Raasch, WEPG56, IBIC'16

[2] M. Brosi, IPAC '15, MOPHA042

Longitudinal beam profile with KALYPSO

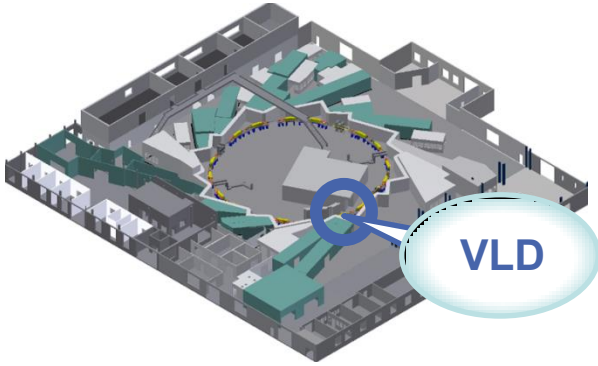
- Installed at near-field EOSD setup [1,2]
- Si / InGaAs version
- Single-shot, turn-by-turn @ 2.7 MHz
- Continuous data taking



[1] N. Hiller *et al.*, IBIC'14, MOPD17
[2] P. Schönfeldt *et al.*, IPAC'17, MOPAB055

Horizontal beam profile with FGC

- Current setup:
  - Fast Gated Camera (FGC) + rotating mirror
  - 1 profile every 6 turns, max 100 profiles
- Upgrade with KALYPSO (Si):
  - Turn-by-turn
  - Unlimited number of profiles

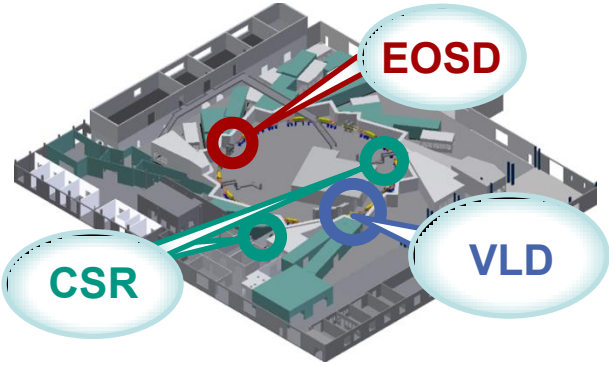


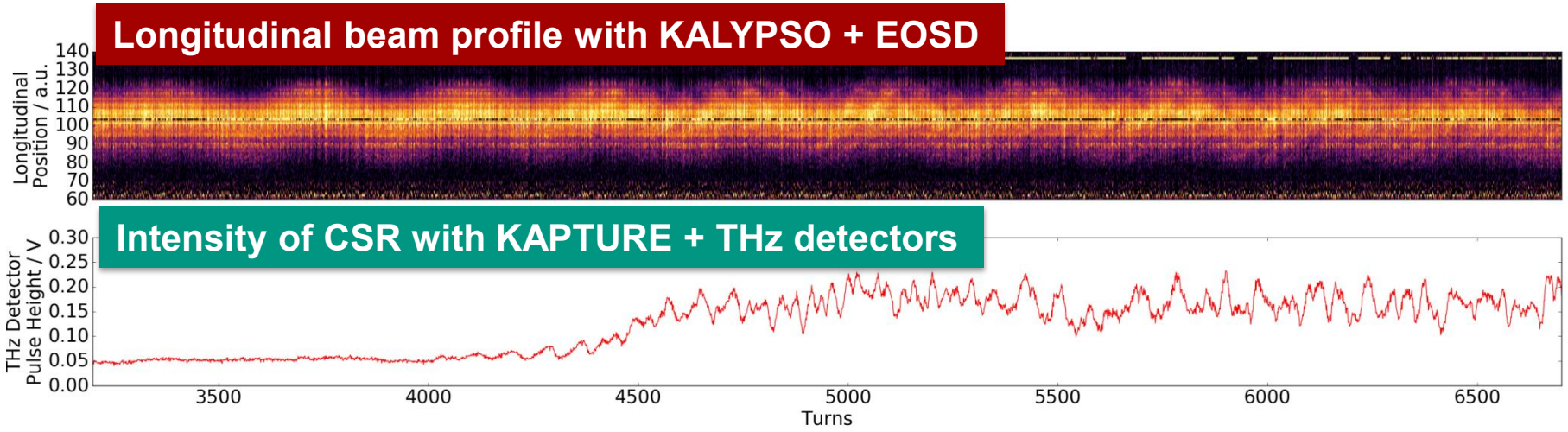
[*] limited by storage memory of host PC

[1] B. Kehrer *et al.*, IPAC'2017, MOOCB1

Synchronized measurements

- **KAPTURE + THz detectors:**
  - Intensity of CSR @ 2 GHz
- **KALYPSO + EOSD:**
  - Longitudinal bunch profile @ 2.7 MHz
- **KALYPSO + VLD:**
  - Horizontal bunch profile @ 2.7 MHz





[1] B. Kehrer *et al.*, IPAC'16, MOPMB014
[2] A.-S. Müller *et al.*, IBIC'16, TUAL01

KALYPSO @ European XFEL

- Integrated in MTCA with custom FPGA board from DESY/Uni Łódź
- Measurements from the XFEL injector @ 1MHz, one bunch train

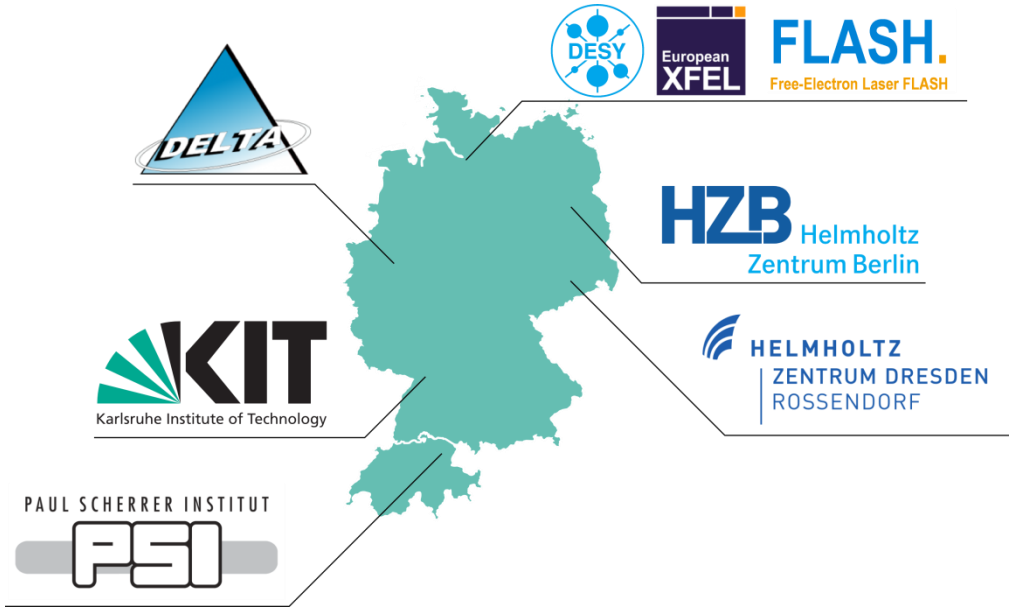
[1] bernd.steffen@desy.de

Summary

- KAPTURE: wide-band readout electronics for ultra-fast detectors @ 2 GHz
  - THz diagnostics
- KALYPSO II: ultra-fast 1D camera for visible/near-IR @ 2.7 MHz
  - Longitudinal / transverse bunch profiles
- KALYPSO III under development: 10 MHz, from near-UV to near-IR

- **Ongoing collaborations:**

  European XFEL (DESY)
  DELTA (TU Dortmund)
  TELBE (HZDR Dresden)
  BESSY II (HZB)
  SLS (PSI)
  FLASH (DESY)



Thank you for your attention

Additional references about beam diagnostics with KAPTURE and KALYPSO:

- 4-Channel Single Shot and Turn-by-Turn Spectral Measurements of Bursting CSR
  J. L. Steinmann, IPAC" 17, MOPAB056
- Studies of the Micro-Bunching Instability in Multi-Bunch operation at the Storage Ring
  M. Brosi, IPAC" 17, THOBA1
- Simultaneous Detection of Longitudinal and Transverse Bunch Signals at Storage Ring
  B. Kehrer, IPAC" 16, MOPMB014
- Fast Mapping of Terahertz Bursting Threshold and Characteristic at Synchrotron Light Source.
  M.Brosi, DOI: 10.1103/PhysRevAccelBeams.19.110701
- Influence of Filling Pattern Structure on Synchrotron Radiation Spectrum at ANKA
  Steinmann, J.L, Physical Review Letters (2016), DOI: 10.1103/PhysRevLett.117.174802
- Online Studies of THz-radiation in the Bursting Regime at Storage Ring
  M. Brosi, IPAC "15, MOPHA042
- Non-interferometric Spectral Analysis of Synchrotron Radiation in the THz regime at Storage Ring
  J. L. Steinmann, IPAC" 15, TUPWA043
- Studies of Bunch-bunch Interactions in the Storage Ring with Coherent Synchrotron Radiation using an Ultra-fast Terahertz Detection System.
  A.-S. Müller, IPAC„13, MOPEA019