Matter and Technologies

Sensors and Electronics for Beam Diagnostic

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2th Annual MT Meeting – 8- 10 March 2016, KIT Karlsruhe

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Development of Beam diagnostic

ARD ⇄ DTS

Scientific Research Proposal …

Many thanks to prof. Anke Susanne Müller

Commissioning @ experimental station

Engineering study

Electronic design
- ✓ RF Microwave, PCBs, ASICs ..
- ✓ Production ..
- ✓ Multi-Chip-Module, wire-bonding, bump-bonding technologies

Software design
- ✓ Low level driver
- ✓ High level application (GUI)
- ✓ On-line data processing

System integration

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System dissemination

System integration

European XFEL

ELBE

FLASH
Free-electron laser FLASH

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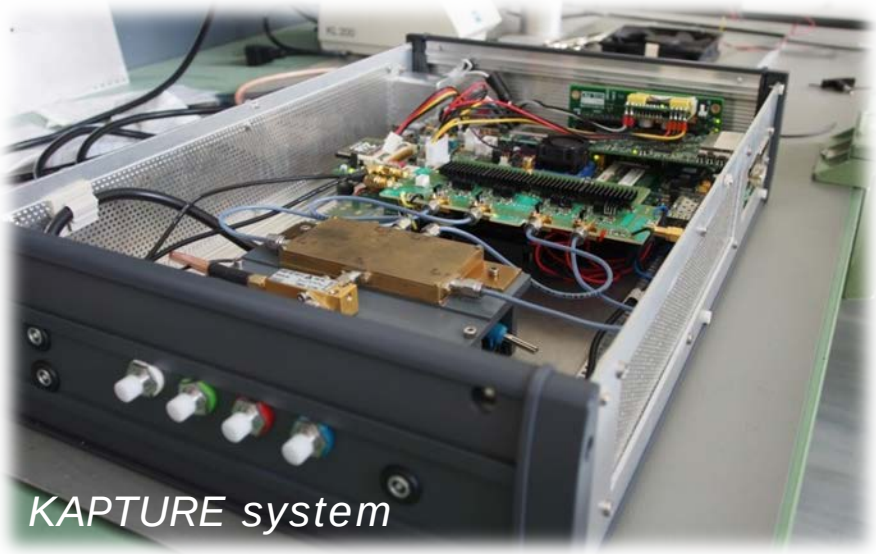
KAPTURE: KArlsruhe Pulse Taking Ultra-Fast Readout Electronics



Readout system compatible with: YBCO, HEB, and Schottky diode detectors

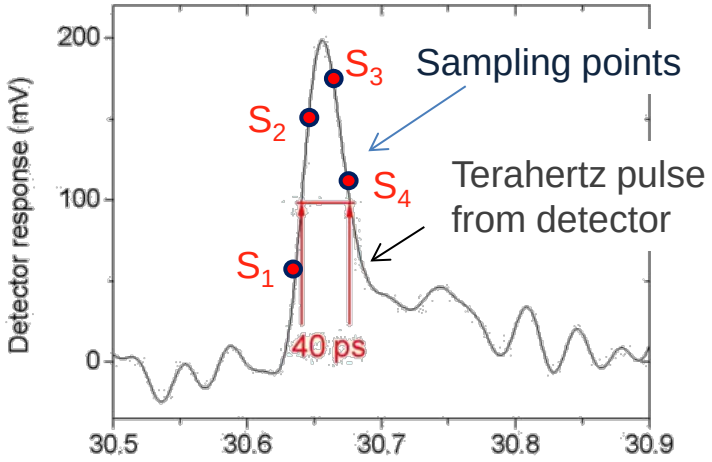
Pulse amplitude and arrive time measurements with “mv” and “ps” accuracy

Simultaneous acquisition of all buckets turn-by-turn in streaming mode

Continuous acquisition for long observation time.

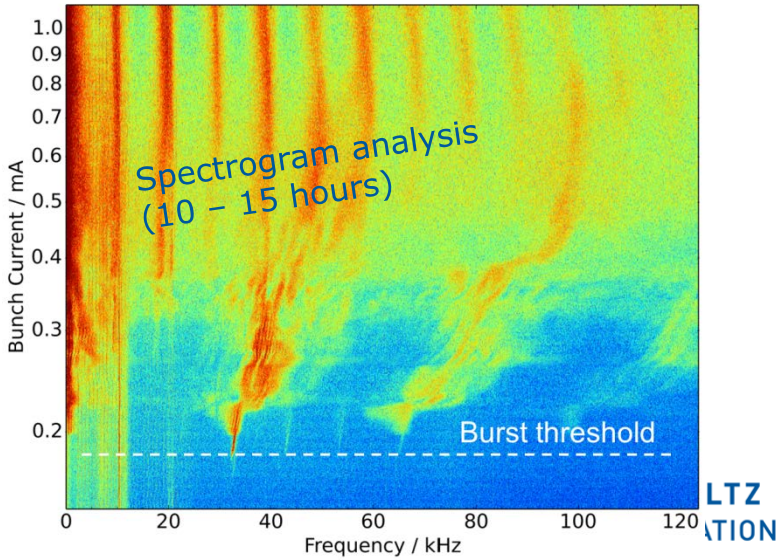
Real-time data elaboration by GPUs

KAPTURE - Basic concept



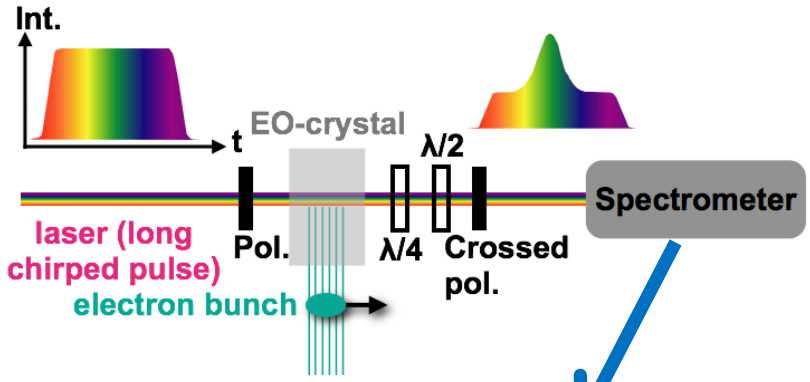
Pulse rate @ 500 MHz

Frequency behaviour of CSR @ different bunch current

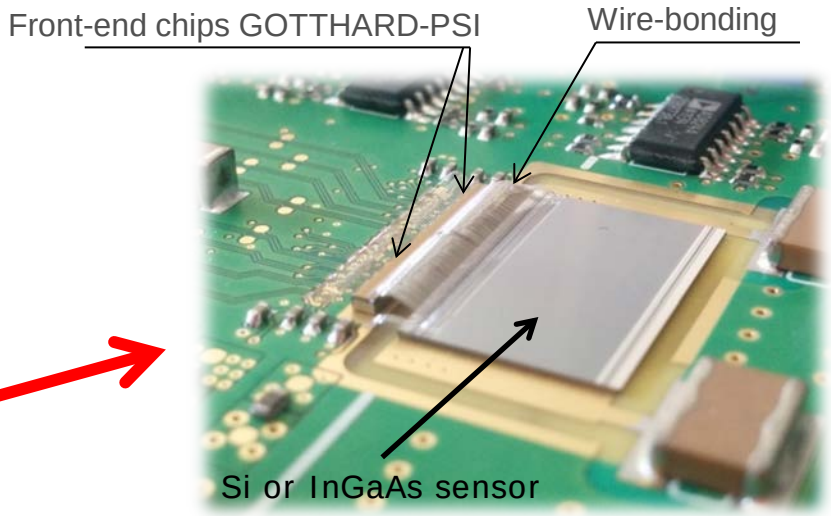


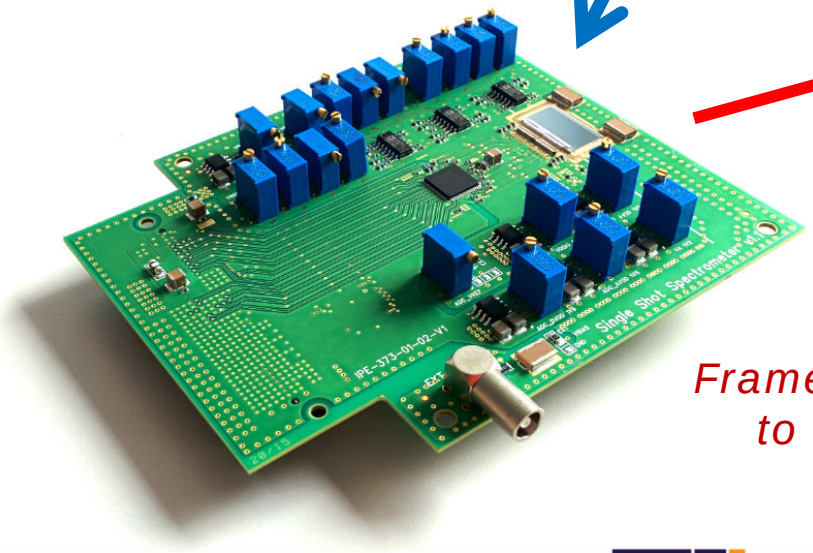
KALYPSO: Karlsruhe Linear Array Detector for MHz-Repetition Rate Spectroscopy

Electro-Optical Diagnostic (EOD) → measure the longitudinal bunch profile and Synchrotron Radiation Monitor



DTS Lorenzo's talk





Frame rate up to 1Mfps

Delivered systems:

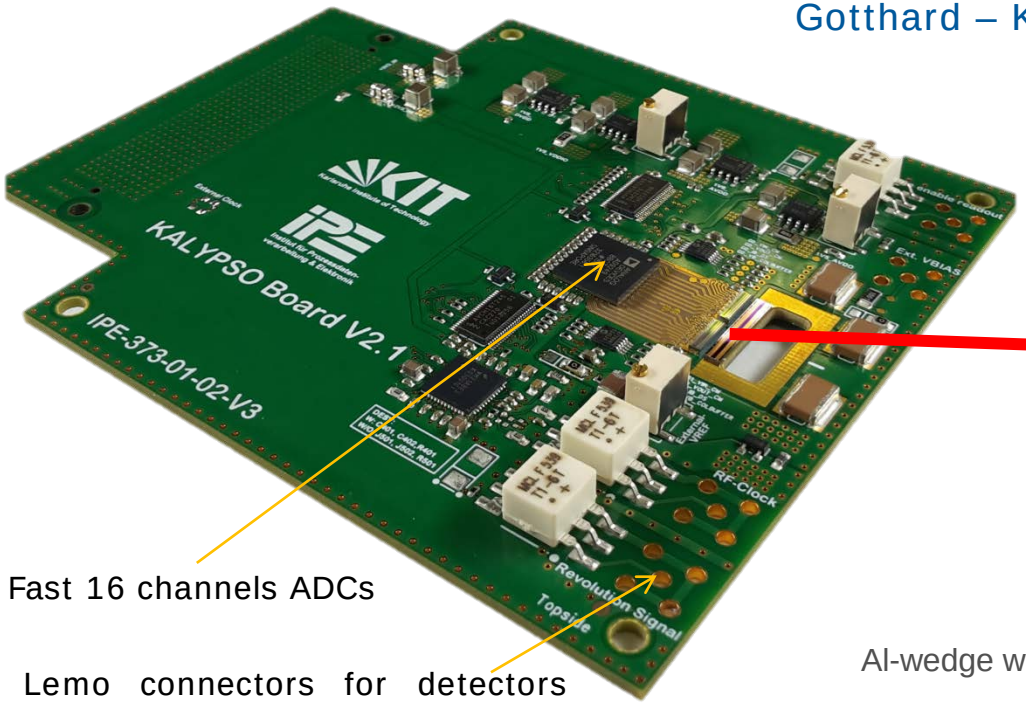
B1: Si-sensor (KIT)
B2: InGaAs-sensor (KIT)
B3: Si-sensor (XFEL)
B4: InGaAs-sensor (XFEL)
B5: Si-sensor (ELBE)

Facilities:

ANKA THZ GROUP · European XFEL · ELBE · FLASH Free-electron laser FLASH · HELMHOLTZ ASSOCIATION

KALYPSO version 2: production started

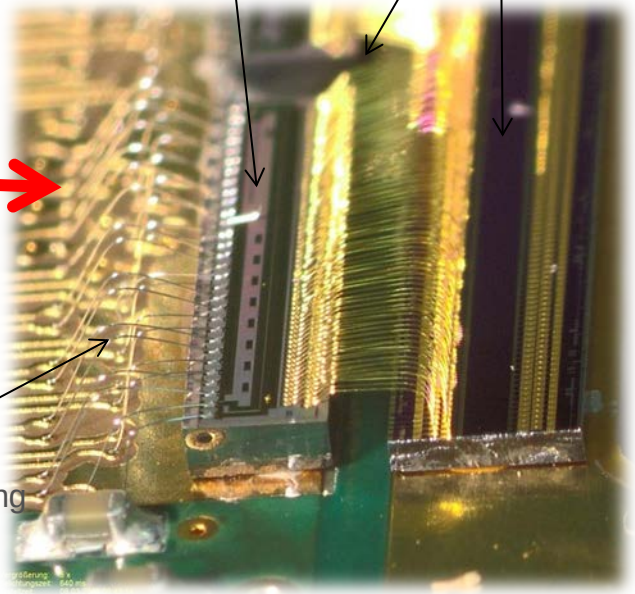
Improved the **SNR** (Signal-to-Noise Ratio), increasing the frame rate of up to **2.7 MHz**



Fast 16 channels ADCs

Lemo connectors for detectors bias and time synchronization with accelerator machine

Gotthard – KIT ASICs version 1.6



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Systems to be produced:

3: Si/InGaAs → KIT

8: Si/InGaAs → DESY (XFEL + FLASH)

2: Si → ELBE

European XFEL

FLASH Free-electron laser FLASH

ELBE.

Continuously data taking > 10 Gb/s

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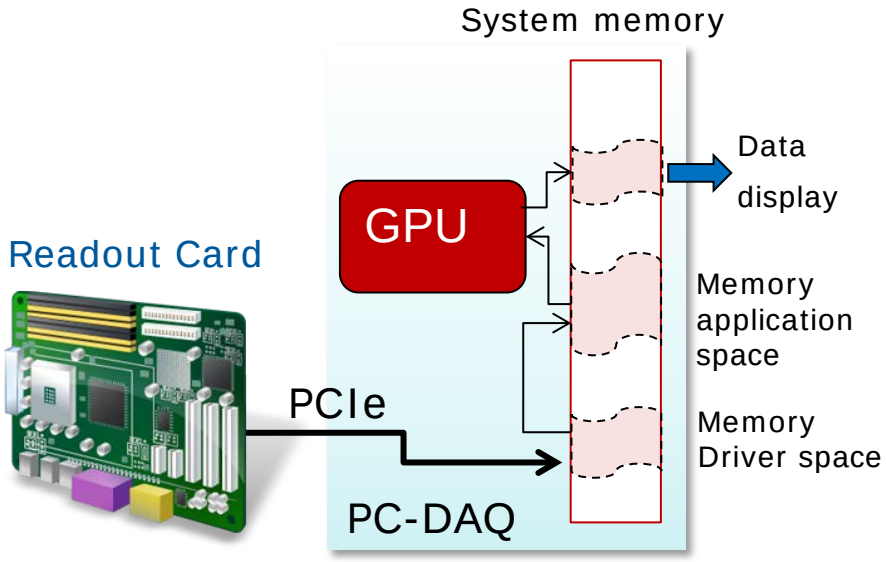
Direct Memory Access from FPGA to GPU

Traditional system memory DMA



More than 4 accesses to system memory of PC-DAQ, b*ottle neck for real-time data elaborations*

Direct Memory Access from FPGA to GPU

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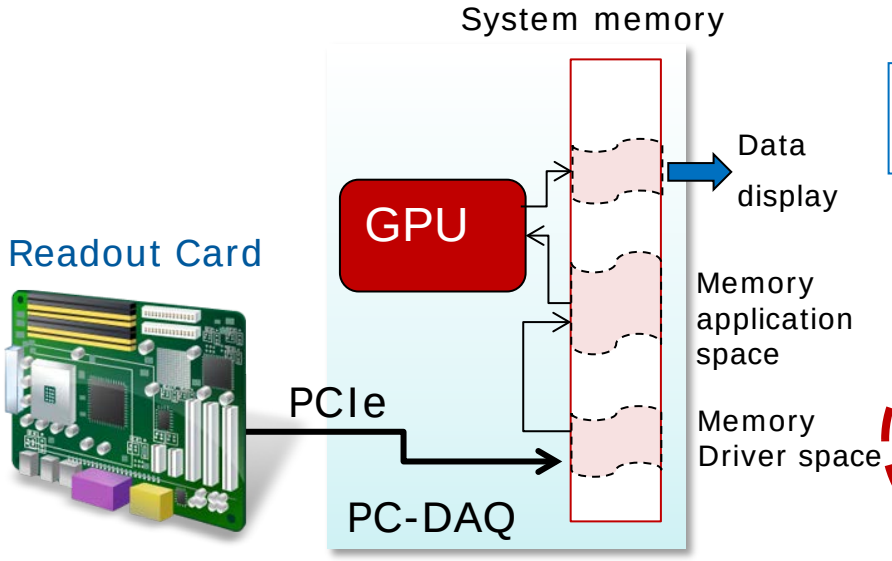
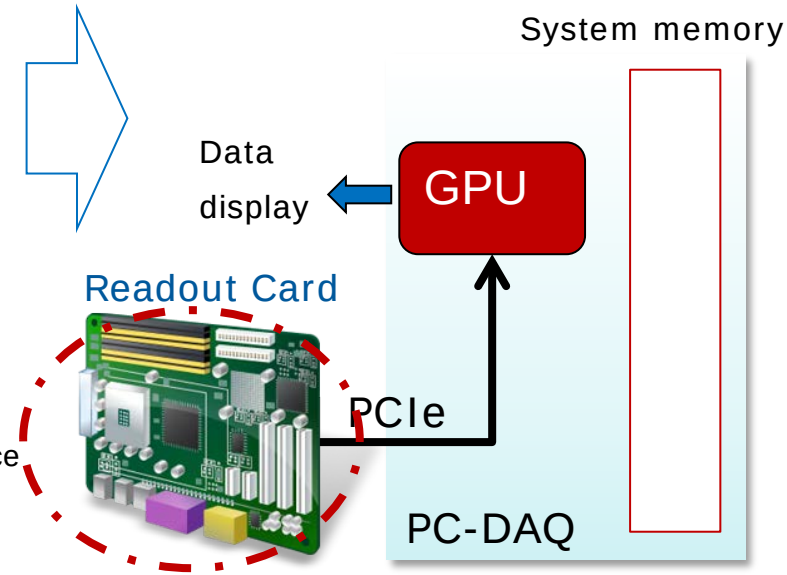


More than 4 accesses to system memory of PC-DAQ, b*ottle neck for real-time data elaborations*

DirectGPU access DMA



FPGA sends the data to GPU memory system. Both system memory and CPU are not involved in data flow

AMD card use **DirectGMA**™, and NVIDIA **GPUDirect**™ → is a capability that enables GPUs to exchange data directly without needing to go to CPU/system memory.

After GPU has allocated memory (GDDR5) it can be directly accessed by physical address and the FPGA is programmed in order to map the GDDR5 memory.

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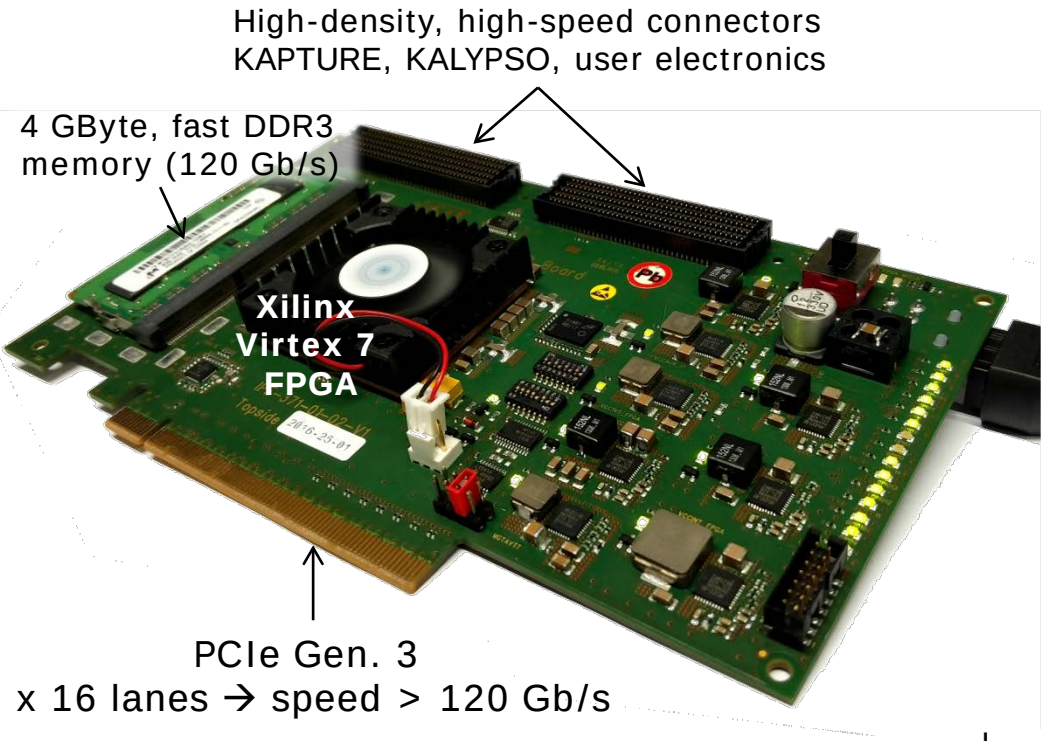
High-flexibility (HighFlex) readout card



Multi-purpose readout card for high-speed data transfer and real-time data elaboration

+

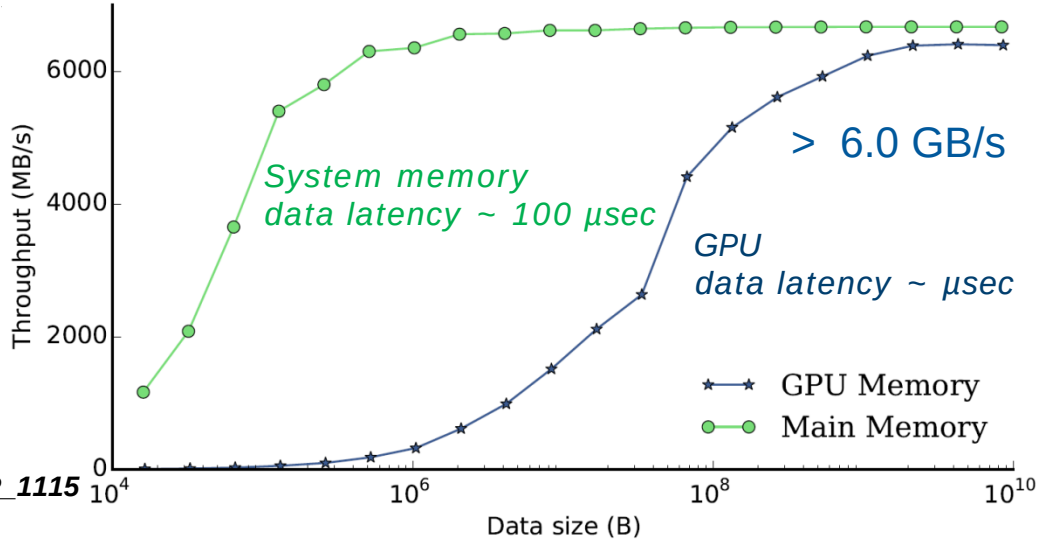
Fast FPGA firmware based on high performance DMA-PCIe

+

Driver 32/64 – Linux → available

Operating up to 6.5 Gbyte/s continuously by both System memory and "Direct GPU" technology.

Preliminary results of a DMA – PCIe based on ***GEN 3 – x 8 lanes***



L. Rota & M. Caselle. ***IEEE-Trans. Nuclear Science, 2014, DOI:*** *:*

L. Rota & M. Caselle , ***Journal Instrumentation, 2015. JINST 114P_1115***

New R&D under developing in 2016..

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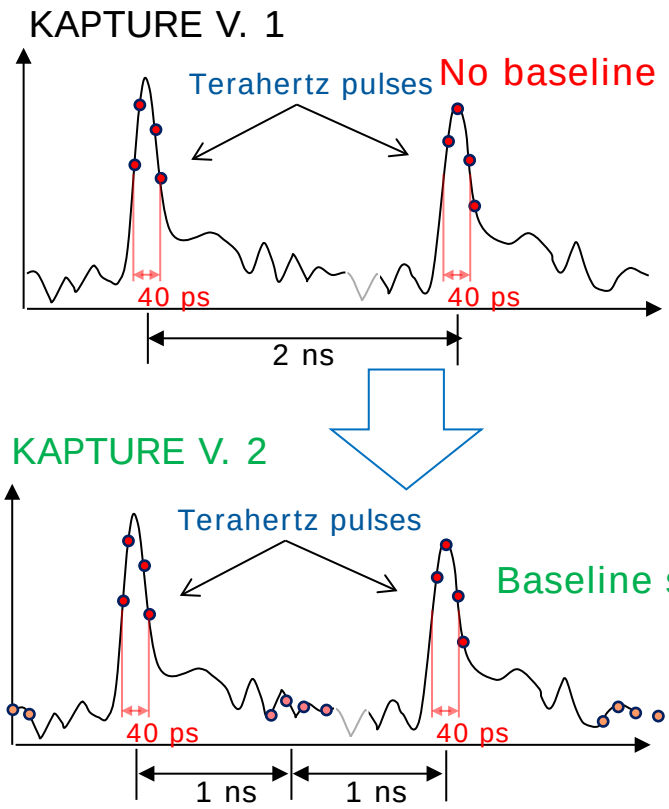
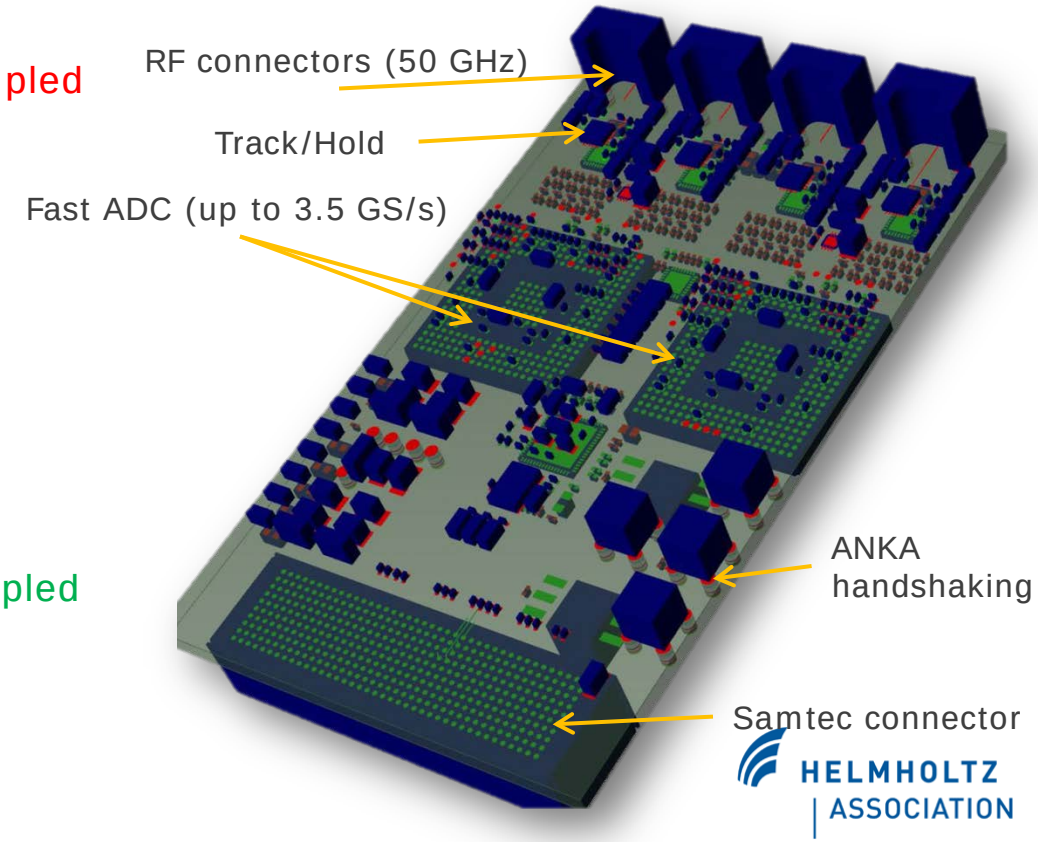
KAPTURE version 2: compact + high sampling rate design

Target design:

- Very wide operating frequency from **0.2** to **3.5** GS/s per sampling channel (ANKA @ 1 GS/s)
- Modular design for multiple KAPTURE connections → to extend the sampling points over 4 samples
- PCB size reduced by factor 2, two KAPTURE connected to one readout card
- Form factor mechanically/electrically compatible with µTCA system





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KALYPSO version 3: Advanced assembly technologies

New GOTTHARD-KIT (ASICs) under designing, target design:

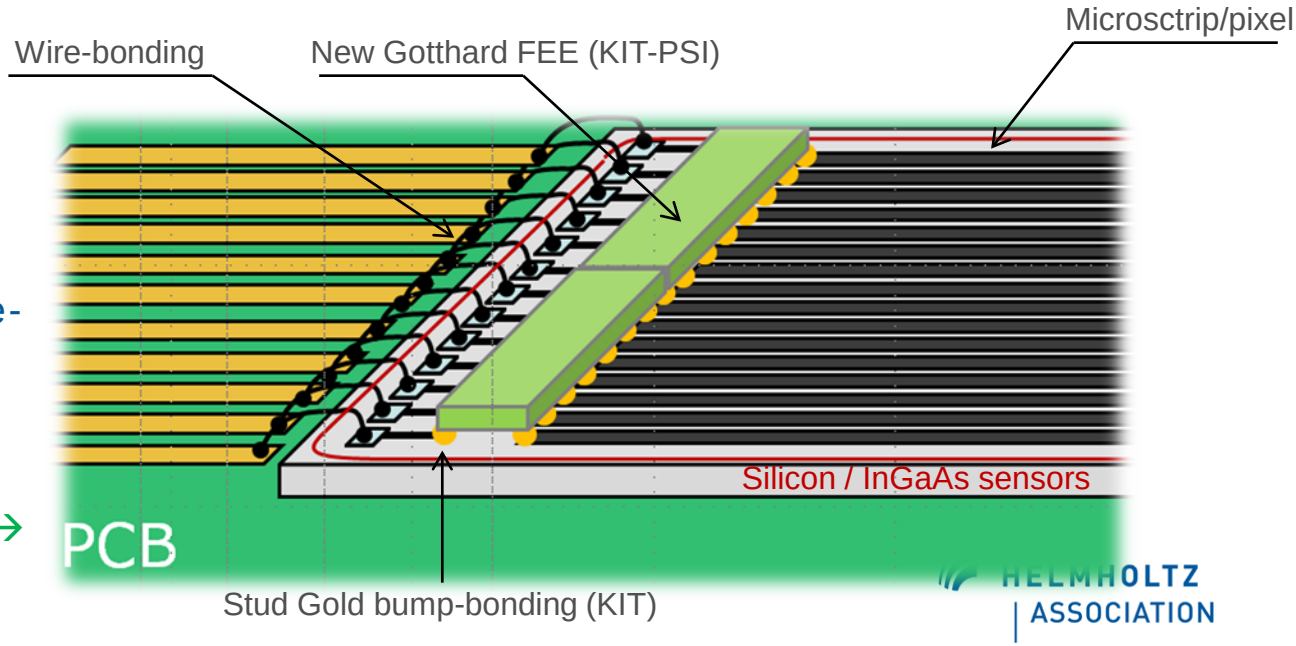
- Optimized SNR → with InGaAs / Si sensors
- Frame rate up to 10 Mfps
- Gotthard connected to sensor by bump-bonding (not wire-bonding)
- Improving of pixel pitch (down to 50um)
- Increasing of number of pixels (256 → 512 or more..)

New Gotthard – KIT will be ready at the end of 2016

New KALYPSO system (possible implementation)

- ✓ Drastically reduction of noisy at the input collection charge
- ✓ Limited number of wire-bonding

Novel:
First microstrip detectors → connected by bump-bonding



Conclusion

- Different technologies are required:
  - RF/Microware, ASICs, packaging PCB assembly and wire-bonding and bump-bonding technologies.
  - High-speed PCB and FPGA firmware design
  - High-speed data links, low level driver and high level data processing based on GPUs
- High-speed readout system based on GPU-direct technology → for High Luminosity LHC CMS detectors for low/high level triggers
- Thanks to ANKA-Terahertz group, and IMS-KIT, Data processing and embedded processing groups IPE-KIT

Thank you for your attention

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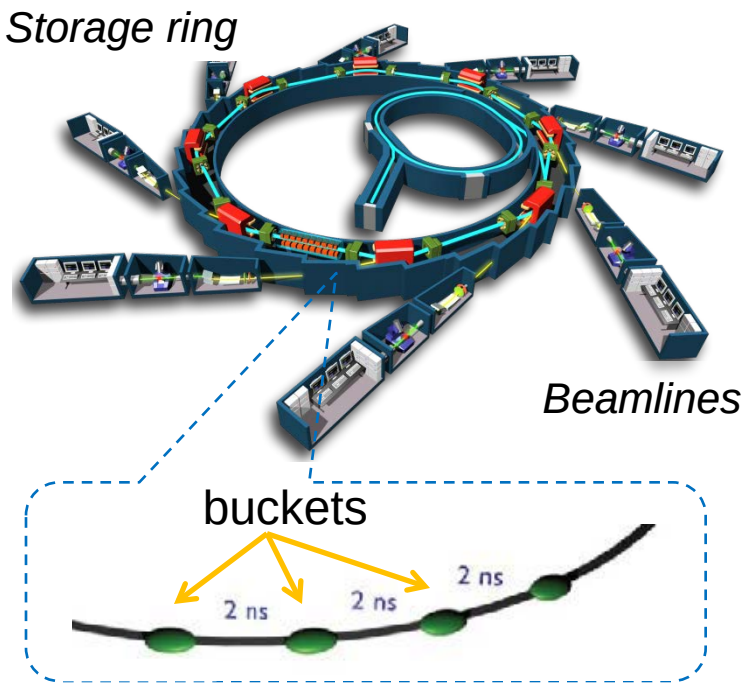
Back-up slides

Terahertz Coherent Synchrotron Radiation at ANKA

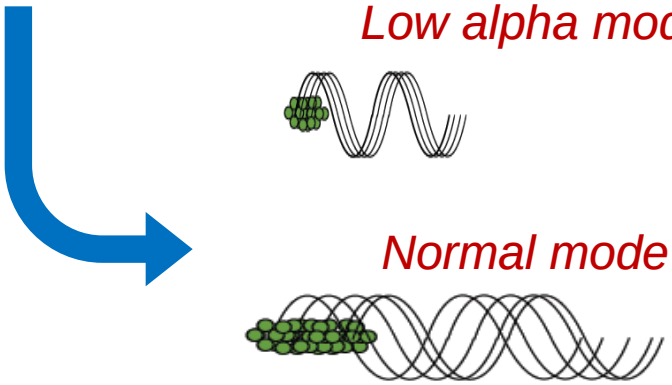


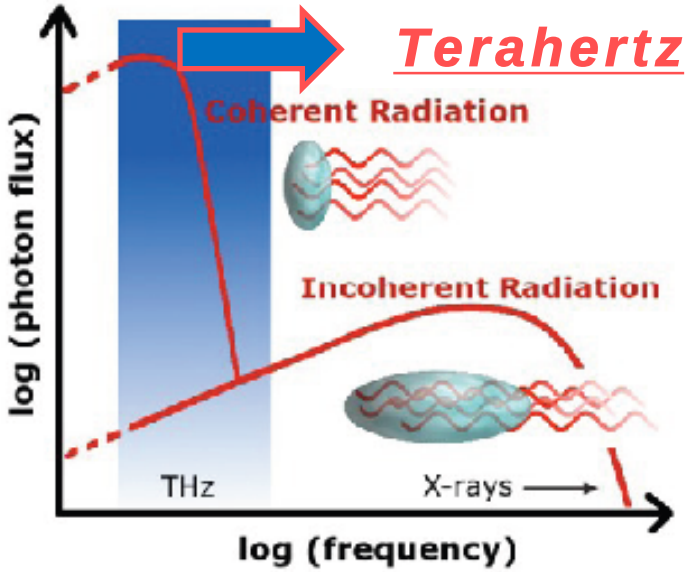
ANKA is the Synchrotron Radiation Facility at the Karlsruhe Institute of Technology (KIT)

- Circumference: **110.4 m**
- RF-system: **500 MHz**
- Harmonic number: **184**

ANKA THZ GROUP

Micro-bunching instability causes time-dependent fluctuations and strong bursts intensity in THz radiations → with a characteristic threshold and frequencies





Reference:
A.-S. Müller, et al. Observation of Coherent THz Radiation from the ANKA and MLS Storag Electron Bolometer. (TU5RFP027), 2009. 23rd Particle Accelerator Conference PAC09 Vancouver, Canada.

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Ultra-fast THz Detectors

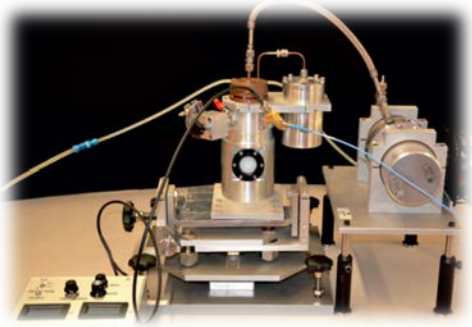
To detect and study of the emission characteristics of CSR in the THz range →
high time accuracy detector, spectrum of hundred GHz -> Terahertz

Hot-Electron-Bolometer (NbN)

- Response time < 165 ps
- Liquid He cooling
- Developed at DLR

[1]

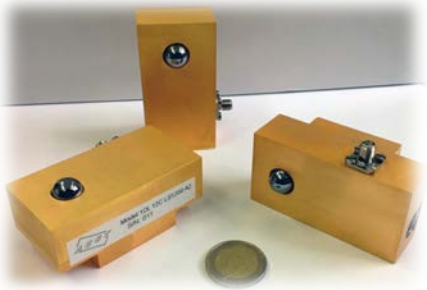
YBCO-Detector



- Response time < 15 ps
- Liquid N_2 cooling
- Developed at KIT-IMS

[2]

Quasi-Optical Broadband Detector (Schottky diodes)



- Response time < 200 ps
- No cooling required
- Commercially available (ACST, VDI)

[3]

[1] A.D. Semenov, et al., IEEE Transactions on Microwave Theory and Techniques 55 (2007) 239
[2] P. Thoma, J. Raasch, et al., IEEE Trans. Appl. Supercond., Vol. 23, No 3, pp2400206, June 2013
[3] A. Semenov, et al., IEEE Electron Device Letters 31, (674) 2010

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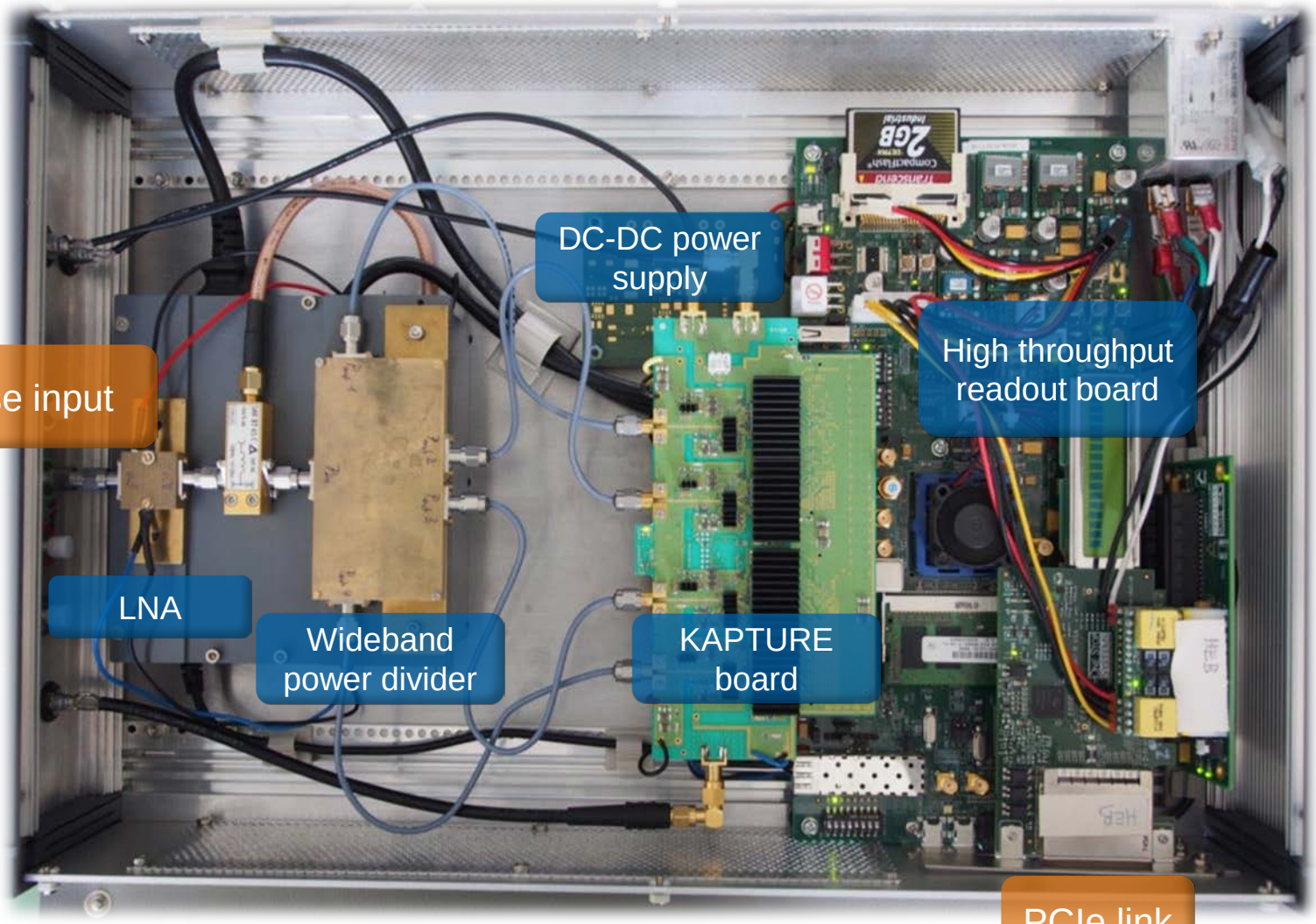
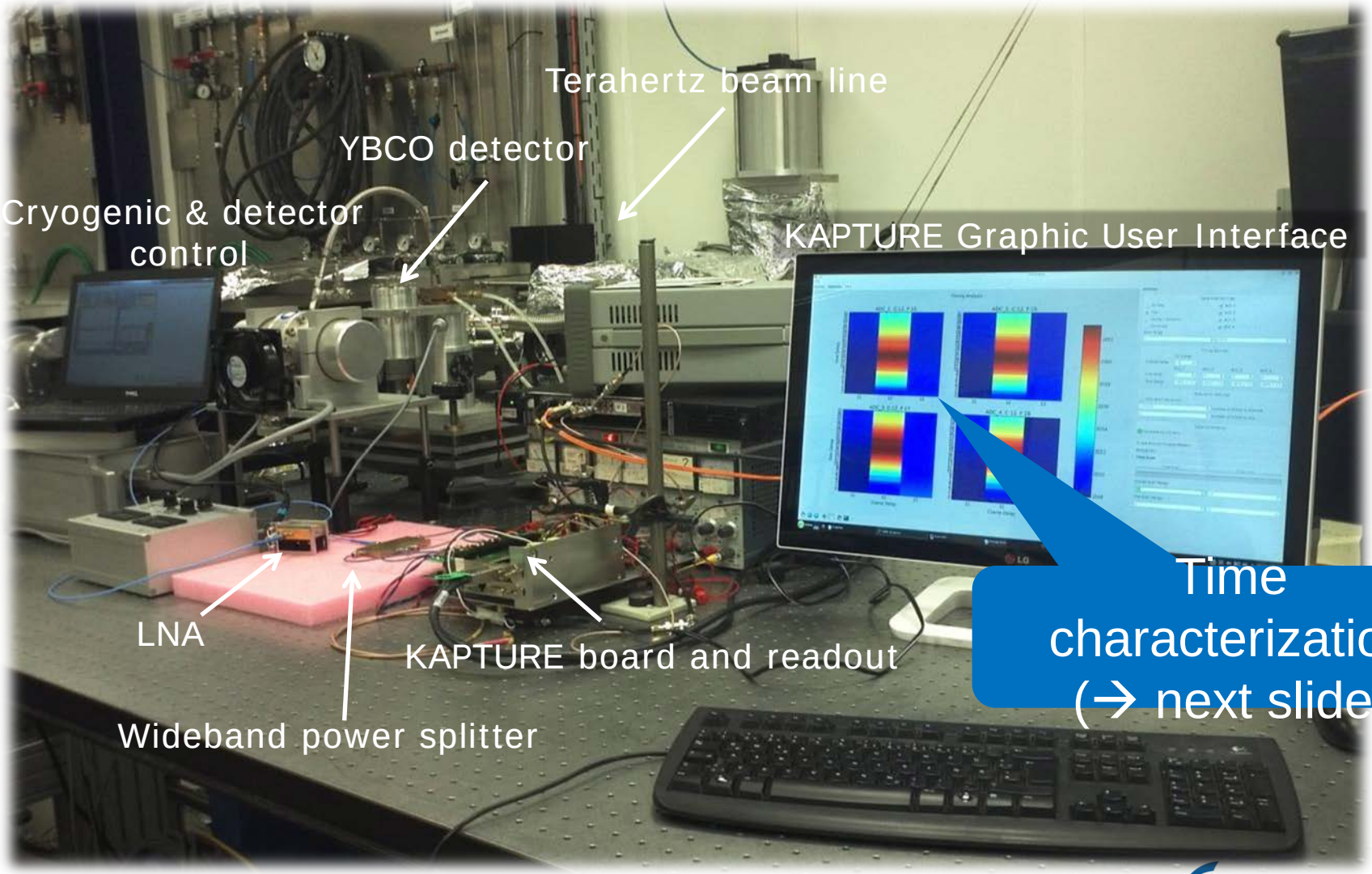
KAPTURE - system



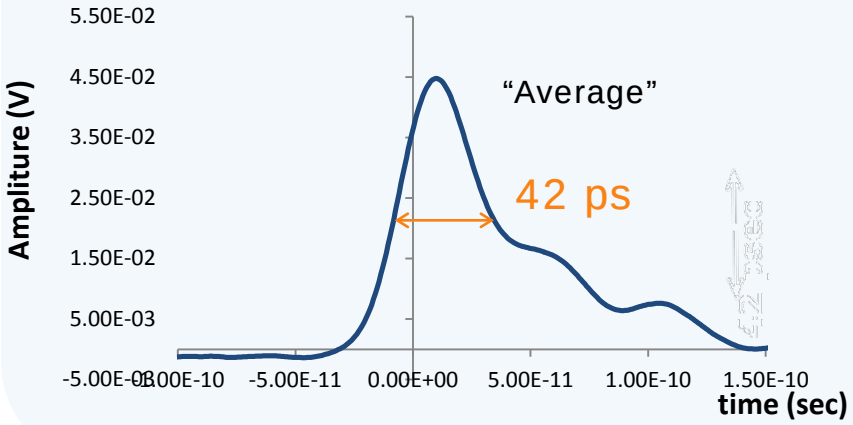
Beam test setup May 2014



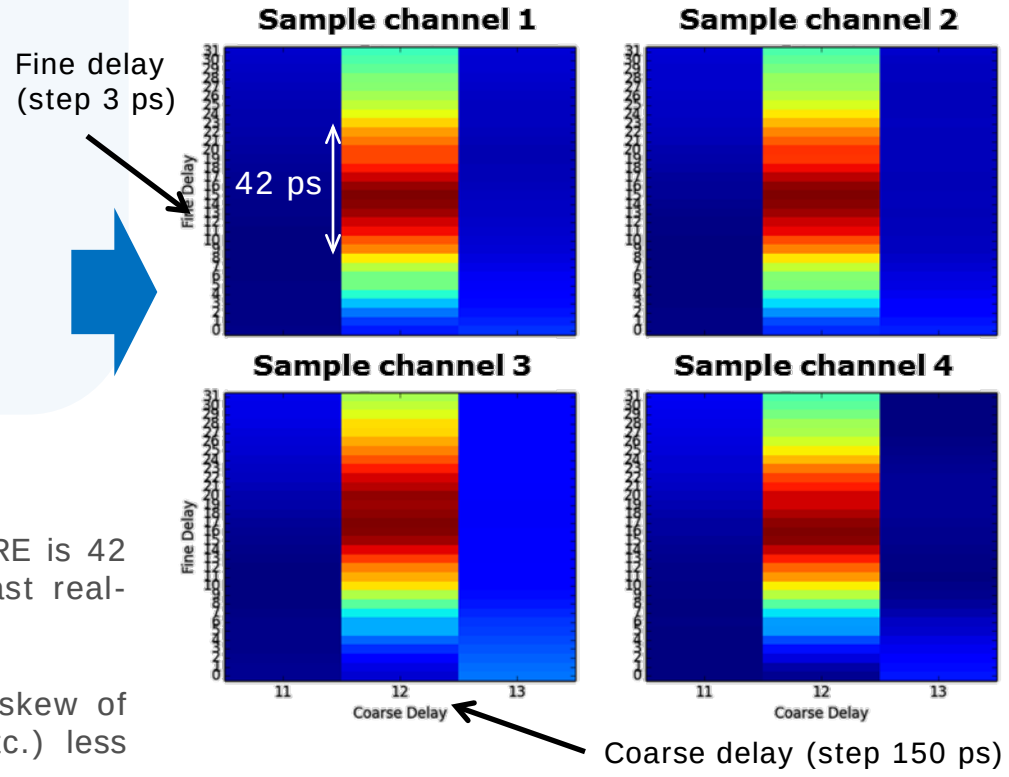
Time characterization with YBCO detector pulse

YBCO detector pulse acquired using equivalent sampling method by KAPTURE: sampling time **3 ps,** pulse repetition rate **500 MHz**

Pulse measured by real-time oscilloscope (bandwidth 60GHz)



Pulse measured by KAPTURE, each channel operating at same sampling timing



Results:

- ✓ The pulse width (FWHM) measured by KAPTURE is 42 ps in agreement with the measurement by fast real-time oscilloscope
- ✓ Total skew between channels (including: the skew of the power splitter, cable, readout system, etc.) less than 6 ps *(can be corrected by FPGA)*

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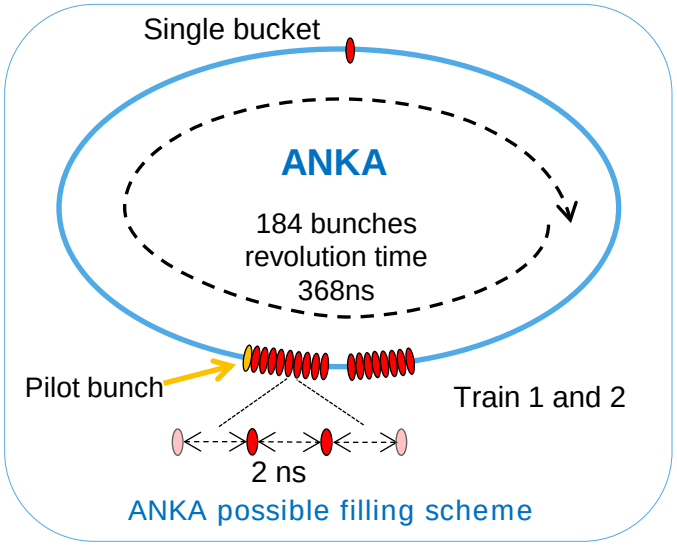
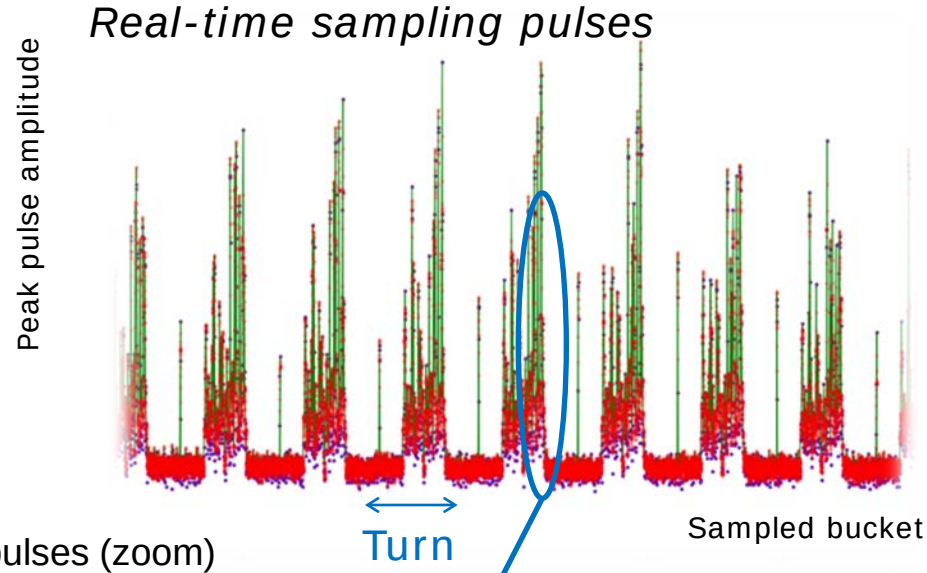
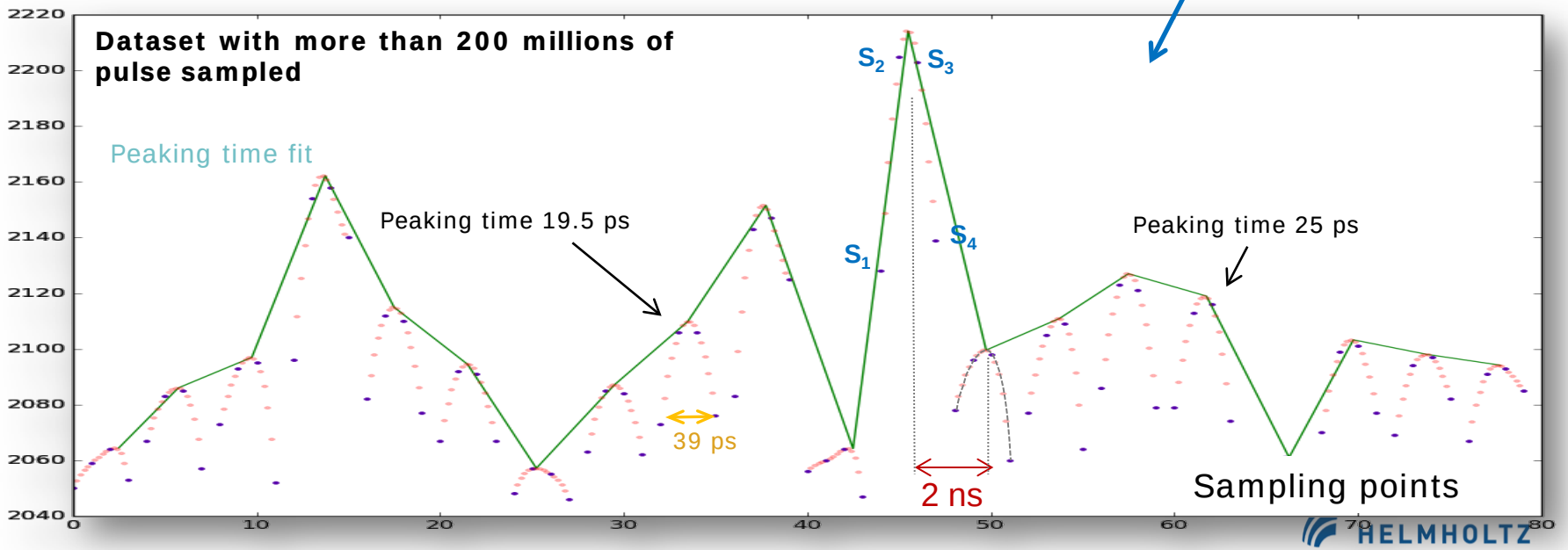
Beam test with YBCO detector and KAPTURE system



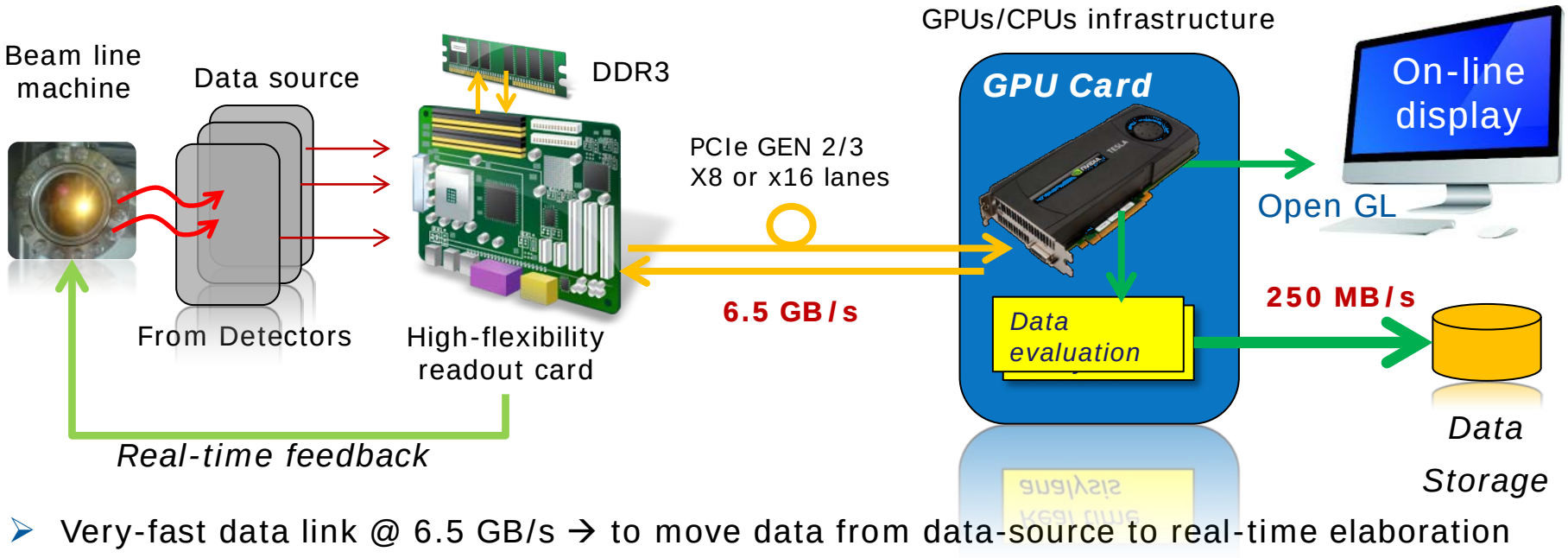


Real-time sampling pulses (zoom)

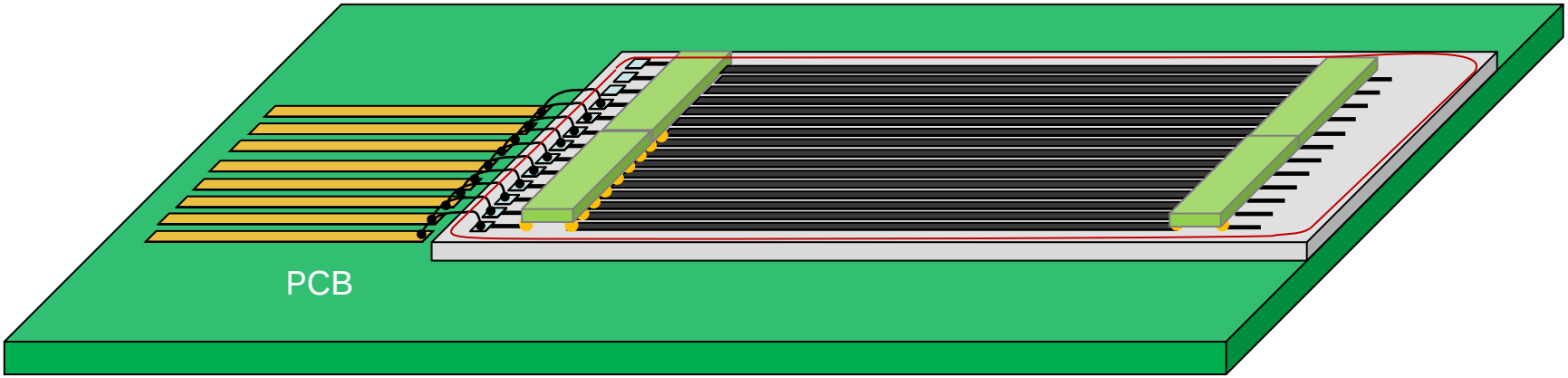


High-speed readout architecture and real-time elaboration (I)

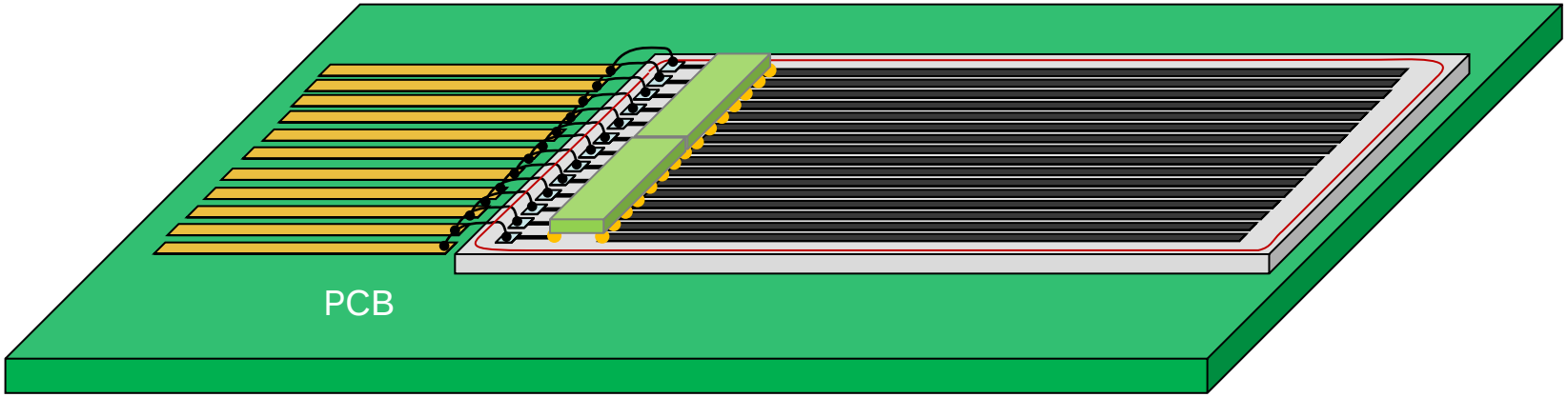
- High flexibility readout card → based on **FPGA**
- Fast data throughput → based on last generation of "commercial" data link **PCIe / InfiniBand**
- High-flexibility real-time elaboration → based on **GPU**



- Very-fast data link @ 6.5 GB/s → to move data from data-source to real-time elaboration
- Real-time data elaboration → by Graphics Processing Unit (GPU)
- Data processed by GPU for:
  - Real-time "On-line" data display, to save only interesting measurements/events
  - Low latency → fast feedback (µs) for beam or machine settings



Fine pitch KALYPSO implementation



KALYPSO implementation

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