Karlsruher Institut für Technologie

International Beam Instrumentation Conference
Monterey, California, USA September 14–18, 2014

A Picosecond Sampling Electronics "KAPTURE" for Terahertz Synchrotron Radiation

International Beam Instrumentation Conference, 14-18 September 2014, Monterey, USA

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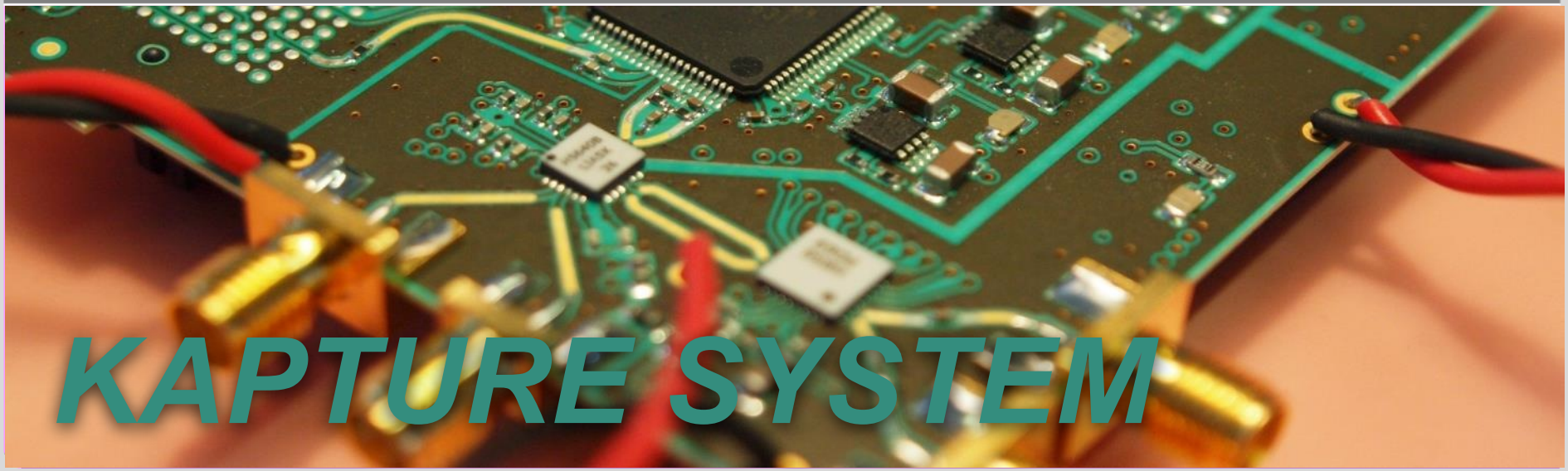
KIT, Institute for Data Processing and Electronics
Michele Caselle

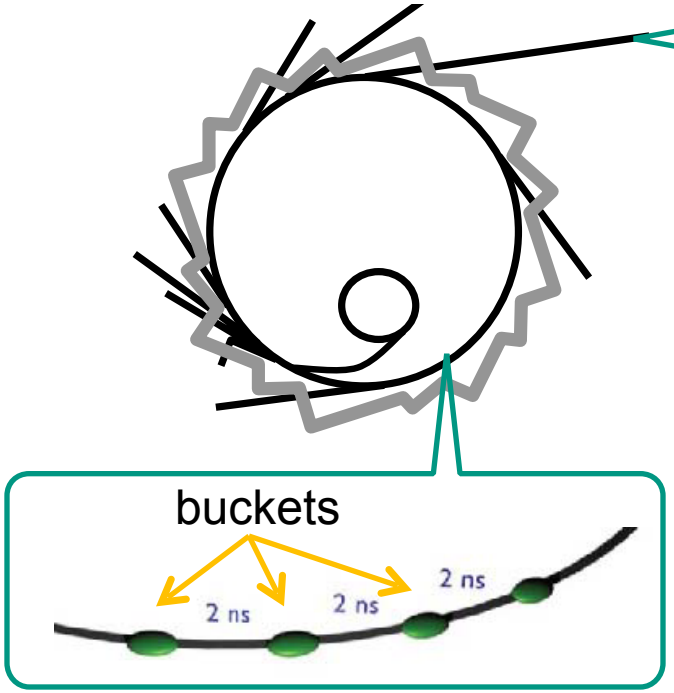


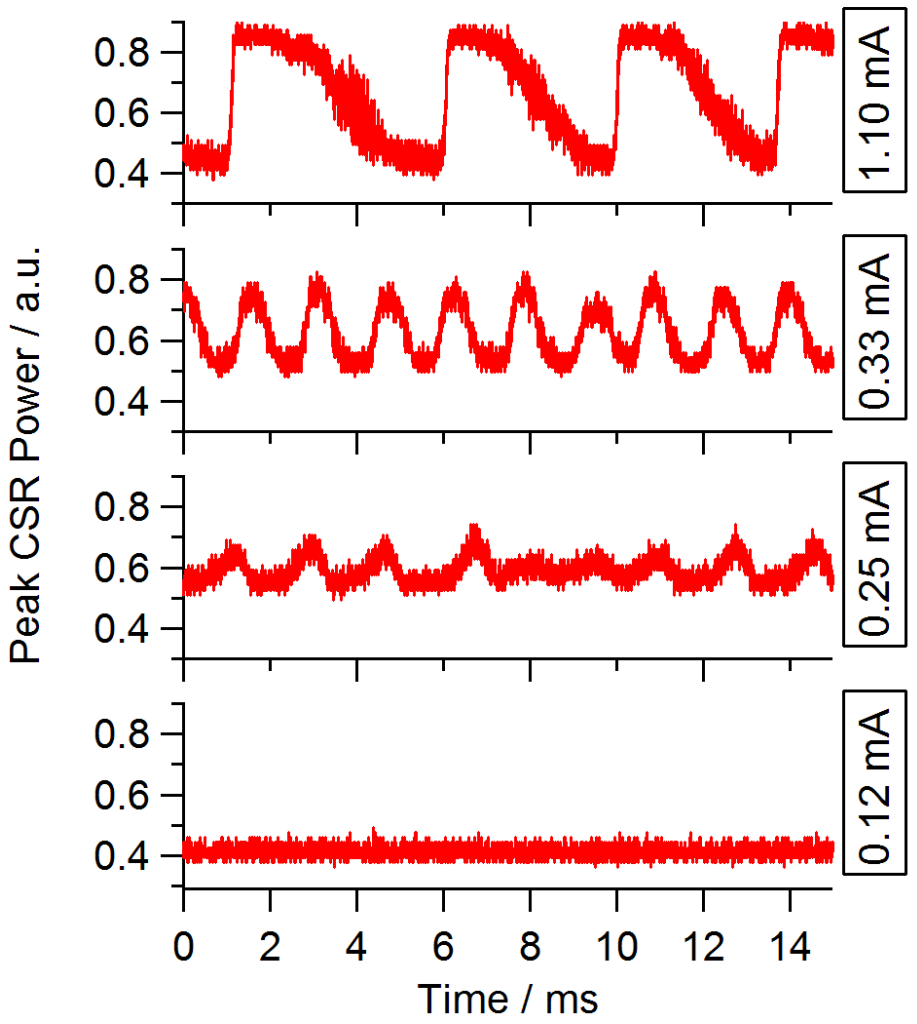
Outline

- Motivation & Introduction: What did we develop KAPTURE for?
  - Coherent Synchrotron Radiation (CSR) in the THz Range
  - Ultra-Fast Terahertz Detectors
- The KAPTURE System
- CSR Studies with KAPTURE
- Summary

Bursting CSR Emission During Low-α_c-Mode

- ANKA - storage ring
  - 0.5 - 2.5 GeV electron energy
  - 184 RF Buckets
  - 2 ns bunch spacing
  - bunch lengths down to 1-2 ps

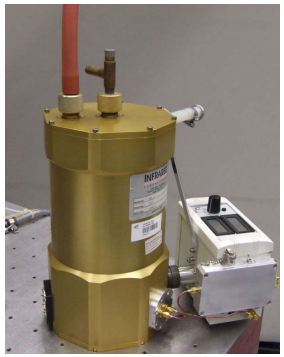




Peak signal for a single bunch recorded at each revolution.

Ultra-Fast THz Detectors

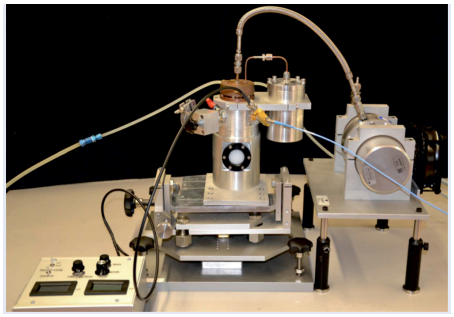
Hot-Electron-Bolometer (NbN)



- Response time < 165 ps
- LHe cooling
- Developed at DLR

[1]

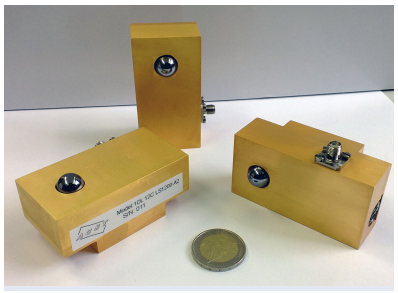
YBCO-Detector



- Response time < 15 ps
- LN2 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

Study of the Bursting Behavior in Multi-Bunch

- Idea: Monitor the THz-radiation from every bunch for every revolution. Continuously!

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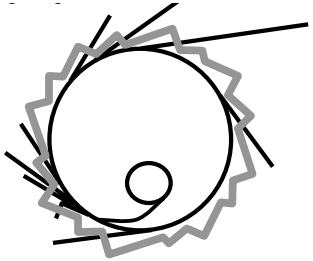

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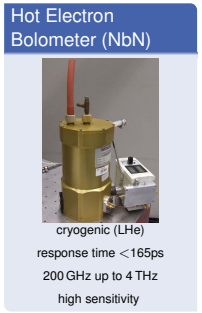

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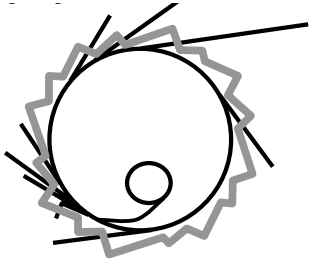

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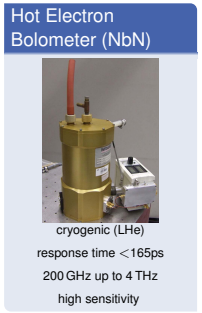

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Oscilloscope with enormous memory & fast readout?

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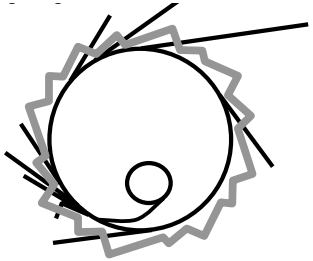

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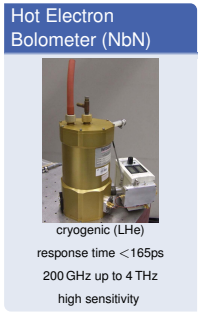

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Oscilloscope with enormous memory & fast readout?

→ **Solution**

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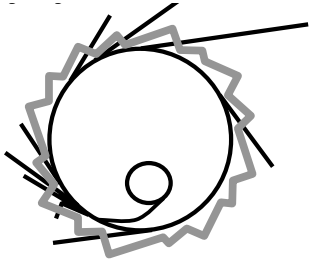

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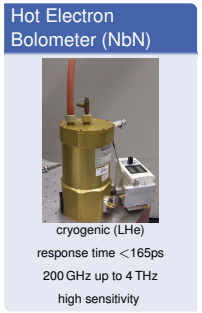

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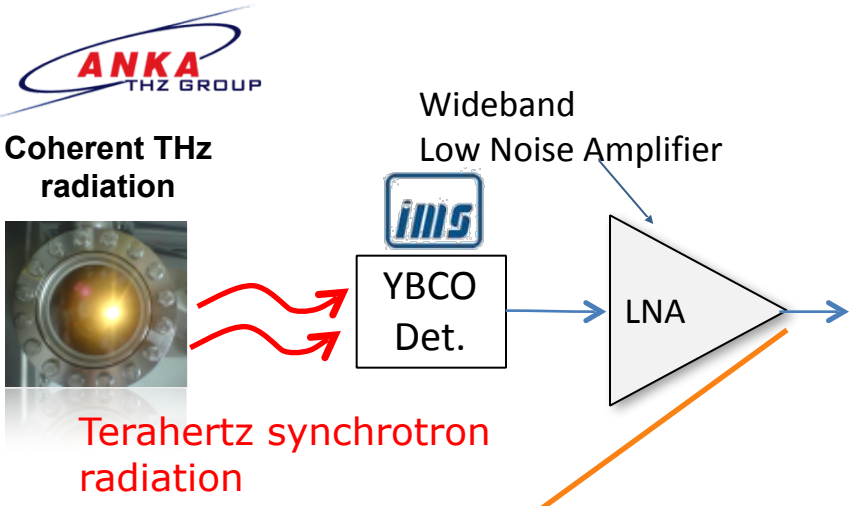
Oscilloscope with enormous memory & fast readout?

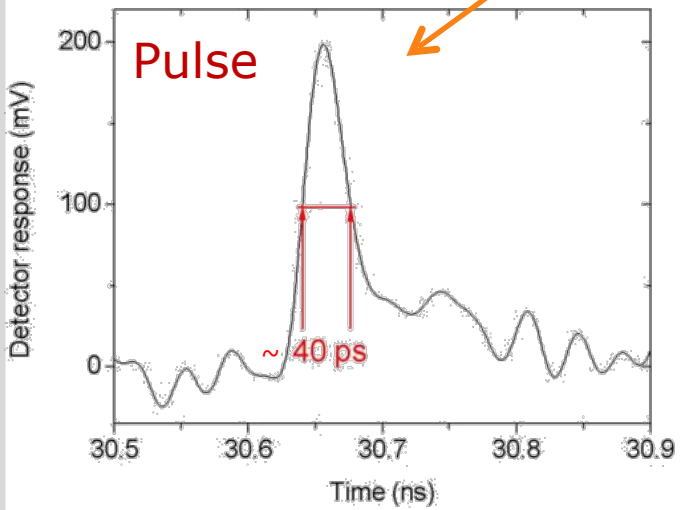
→ **Solution**

KAPTURE SYSTEM

Karlsruhe Pulse Taking Ultra-Fast Readout Electronics

Picosecond pulse sampling requirements





Pulse measured with a real-time oscilloscope (bandwidth 60GHz)

Requirements:

1. **measuring amplitude and peaking time of each pulse,** pulse width of 20 – 100 ps
2. **Pulse repetition rate of 500 MHz**
3. **Continuous acquisition for long observation time:** seconds, minutes…
4. **Wideband circuitries,** bandwidth DC-60GHz

Picosecond pulse sampling system for CSR

KAPTURE system

Coherent THz radiation

Terahertz synchrotron radiation

Wideband Low Noise Amplifier

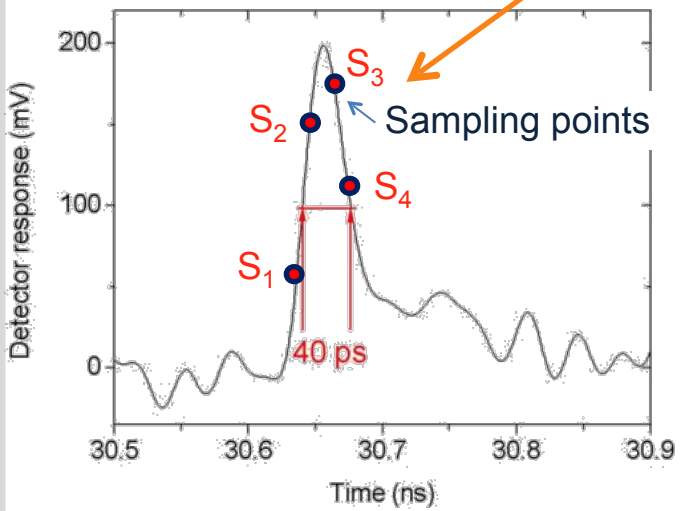
YBCO Det.

LNA

KAPTURE

pulse sampling

(1)



Pulse with repetition rate 500 MHz

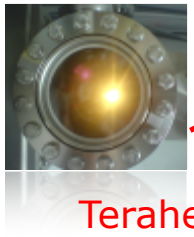
1. Sampling: each pulse sampled with 4 samples by **KAPTURE** system , minimum sampling time of 3 ps.

Picosecond pulse sampling system for CSR

KAPTURE system

High throughput readout electronics

Coherent THz radiation



Terahertz synchrotron radiation

Wideband Low Noise Amplifier

YBCO Det.

LNA

KAPTURE

pulse sampling

(1)

DDR3

DMA/PCIe

FPGA

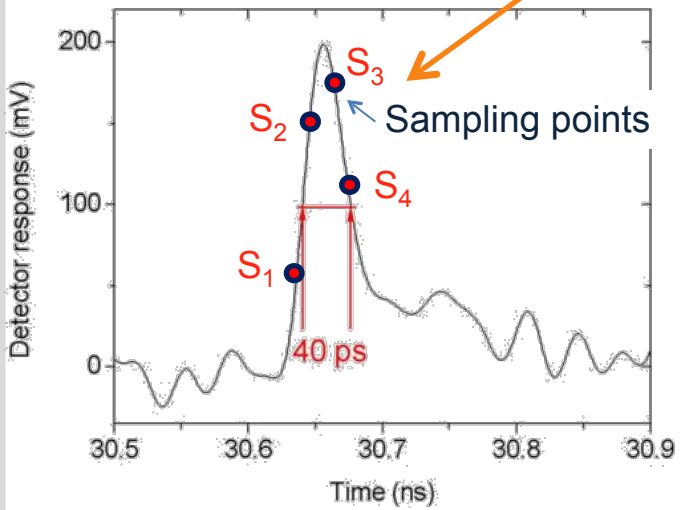
PCIe

32 Gb/s

(2)

GPU-DAQ

Continuous data streaming



Pulse with repetition rate 500 MHz

1. Sampling: each pulse sampled with 4 samples by **KAPTURE** system , minimum sampling time of 3 ps.

2. Data transfer: digital samples transferred to high-end GPU (Graphics Processing Units) by a PCIe-DMA architecture

Picosecond pulse sampling system for CSR

KAPTURE system

High throughput readout electronics

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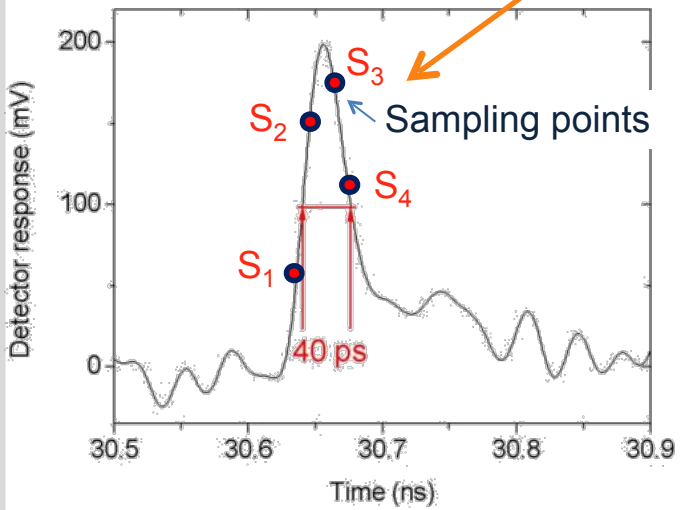

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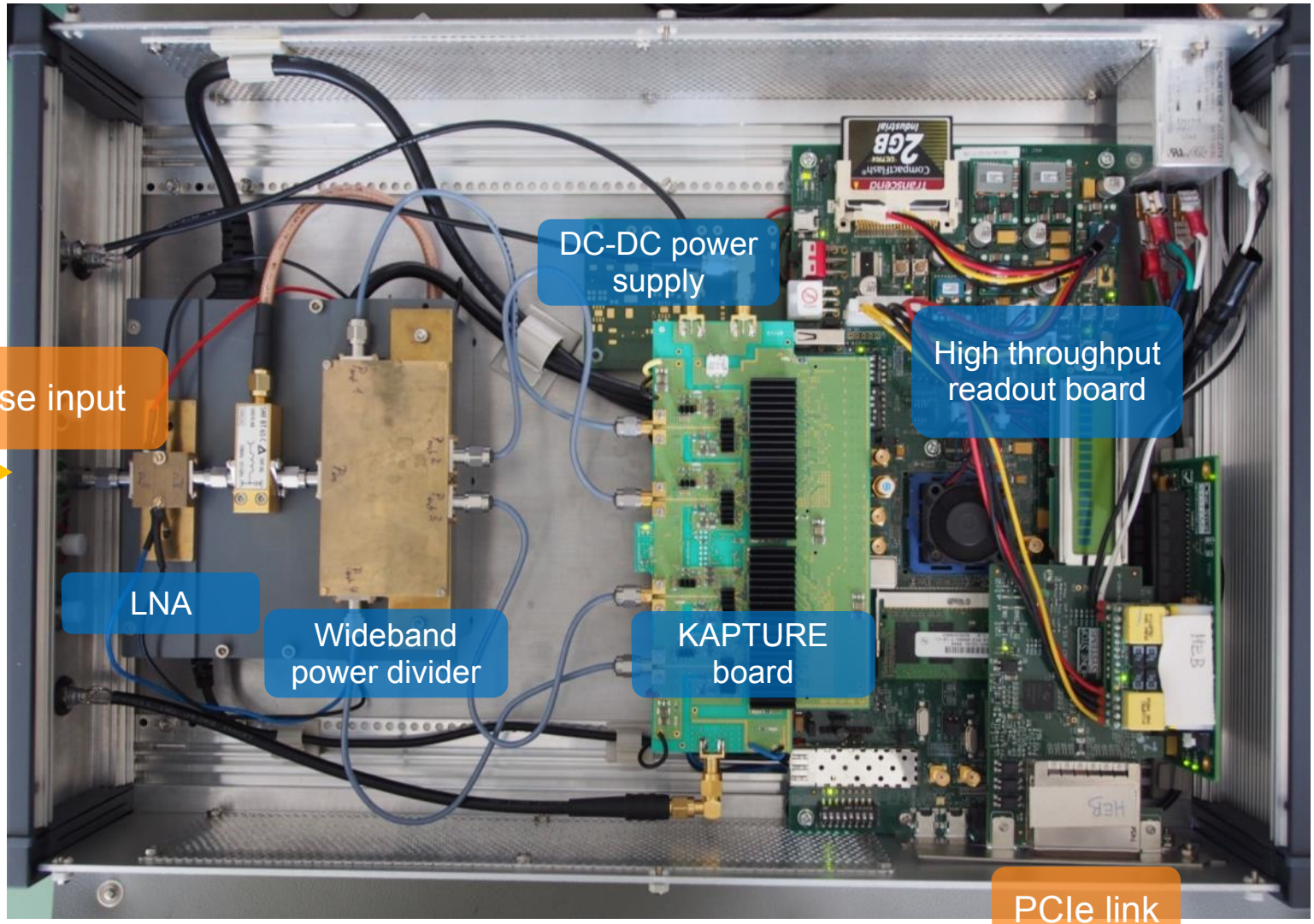
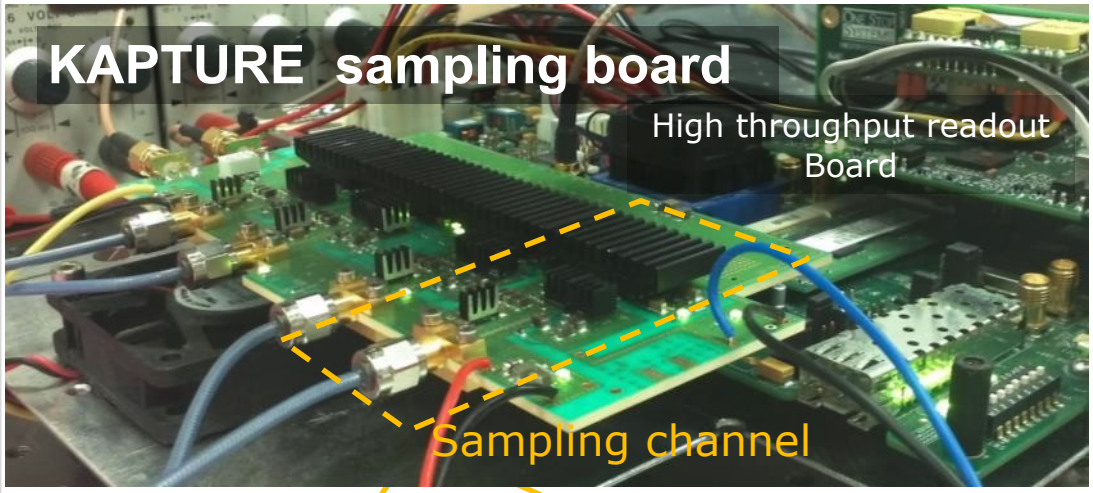
3. Real-time GPU data elaboration: pulses reconstruct, amplitude and peaking time respectively with "mV" "picosecond" accuracy are evaluated

KAPTURE Box

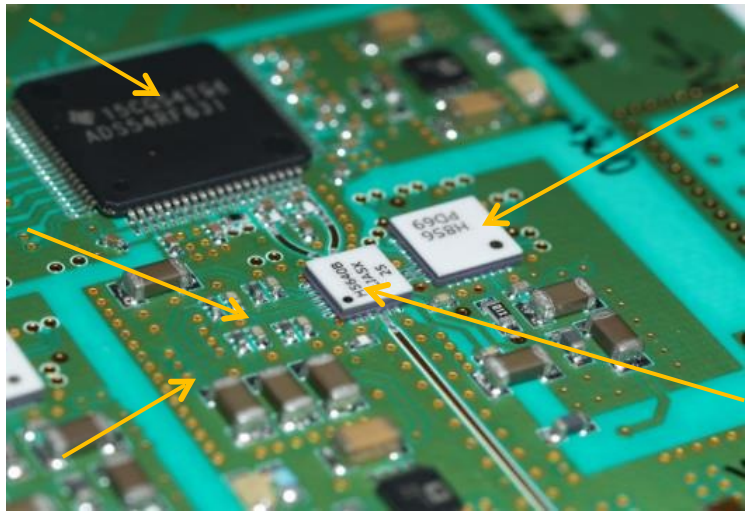

DC-DC power supply
High throughput readout board
Pulse input
LNA
Wideband power divider
KAPTURE board
PCIe link

KAPTURE Board

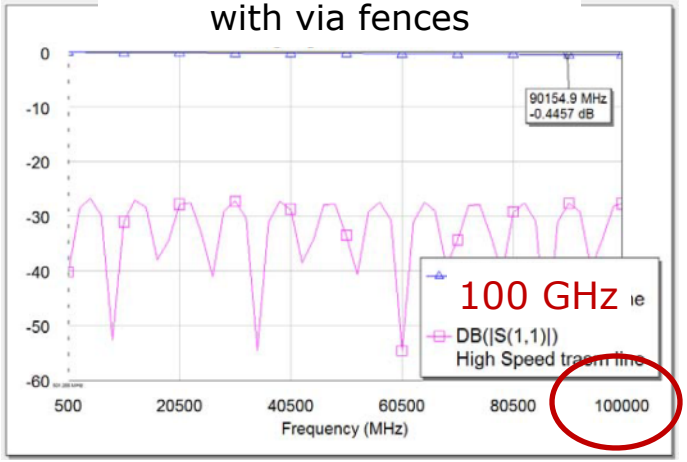


- ✓Minimum sampling time: 3 ps (min. equiv. sampling time 300GS/s)
- ✓RMS time jitter noise < 1.7 ps
- ✓RMS noise (ADC) < 1 mV
- ✓Dynamic range: ± 800 mV per channel
- ✓Max pulse rate up to 550 MHz

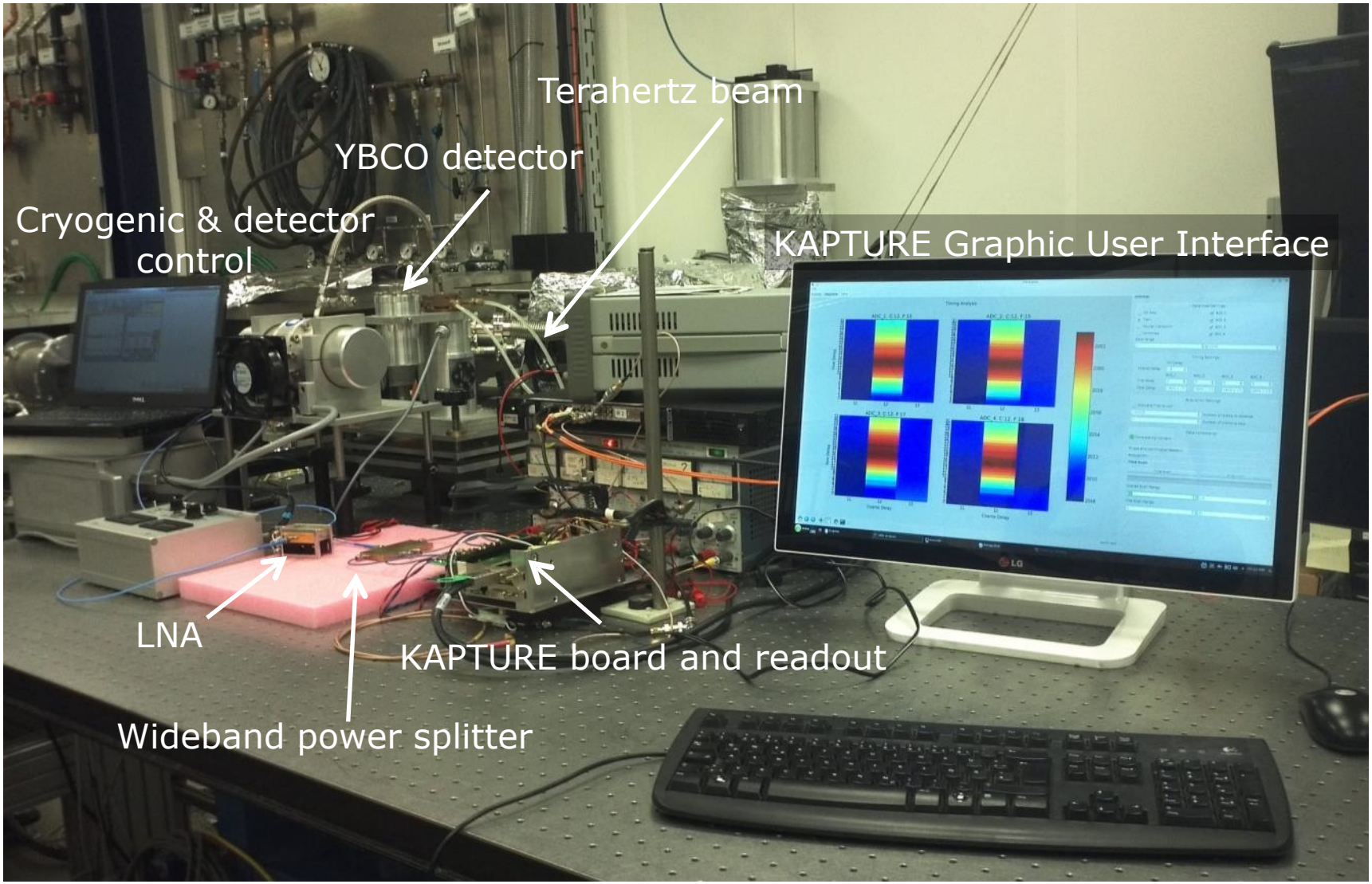
Sampling stage



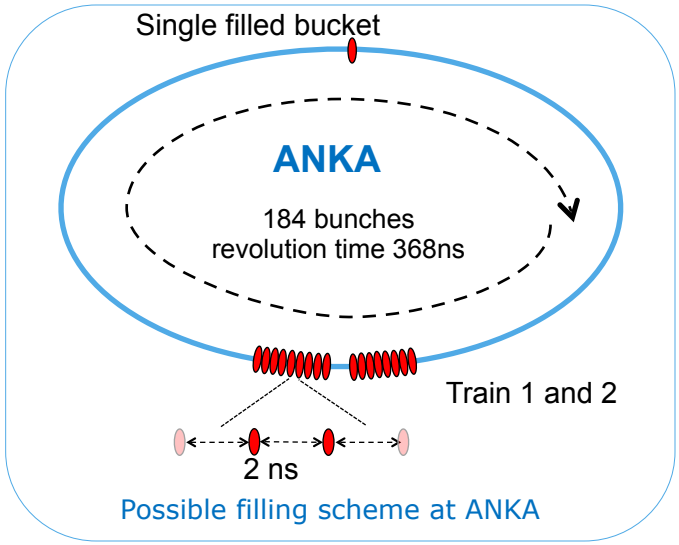
Wideband CPW trans. line with via fences

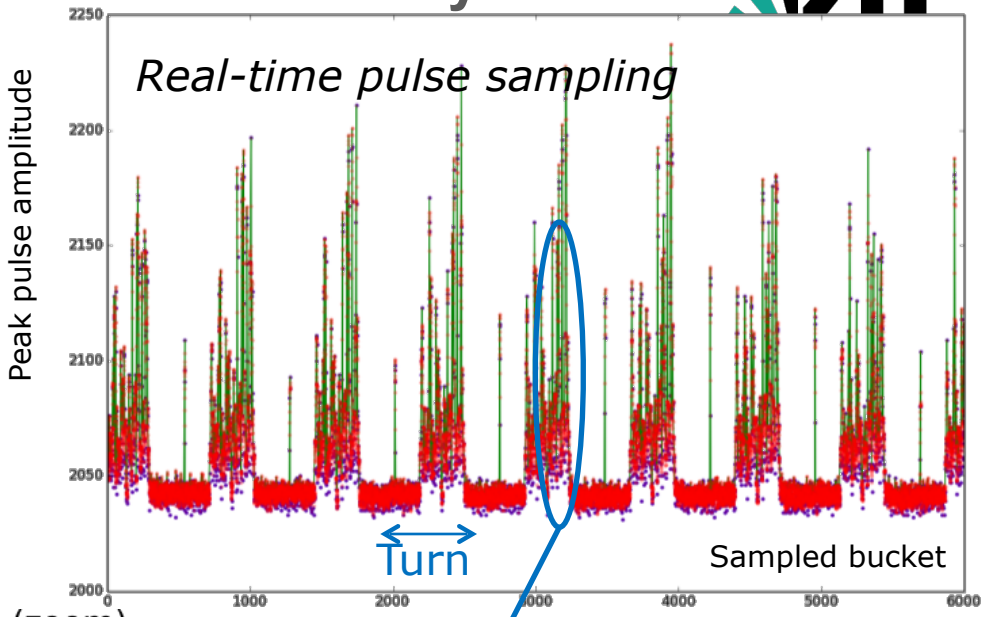


Beam Test Setup at IR2 Beamline at ANKA in May 2014

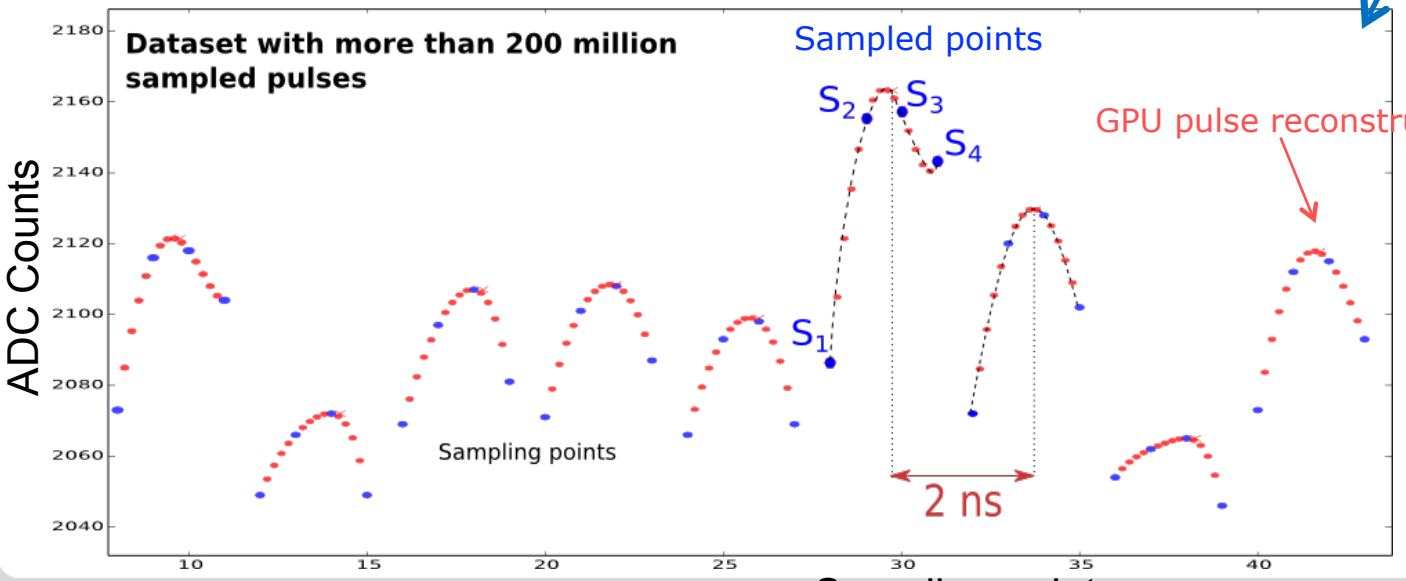


Beam test with YBCO detector and KAPTURE system





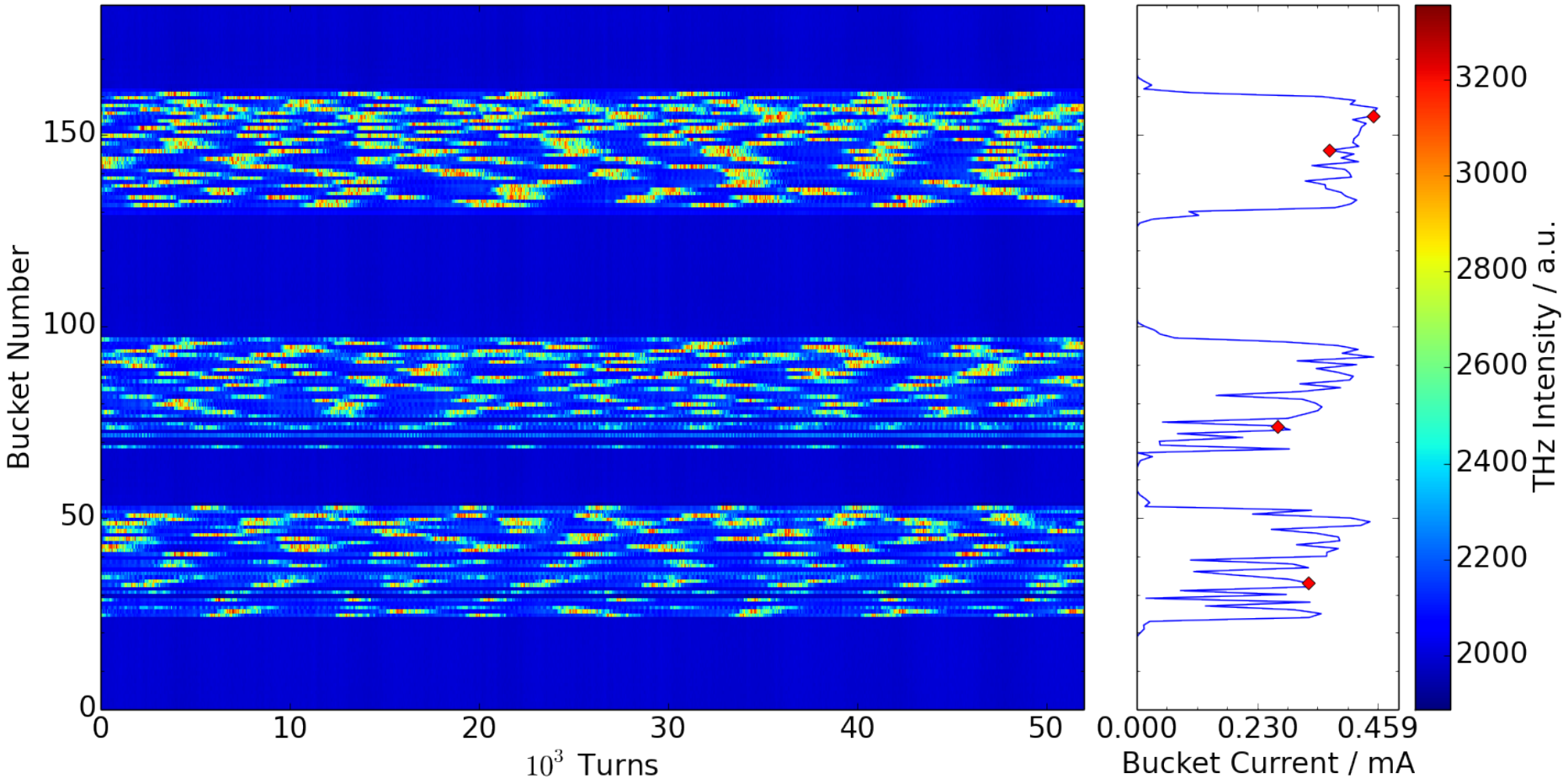
Real-time sampling pulses (zoom)



$t_{S2} - t_{S1}$ = 15 ps
$t_{S3} - t_{S2}$ = 9 ps
$t_{S4} - t_{S3}$ = 15ps

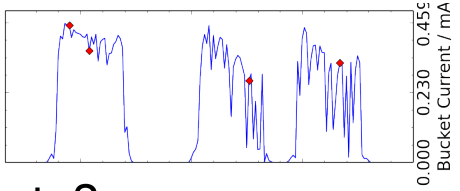
Peak height, time and pulse width can be retrieved!

CSR Studies with KAPTURE

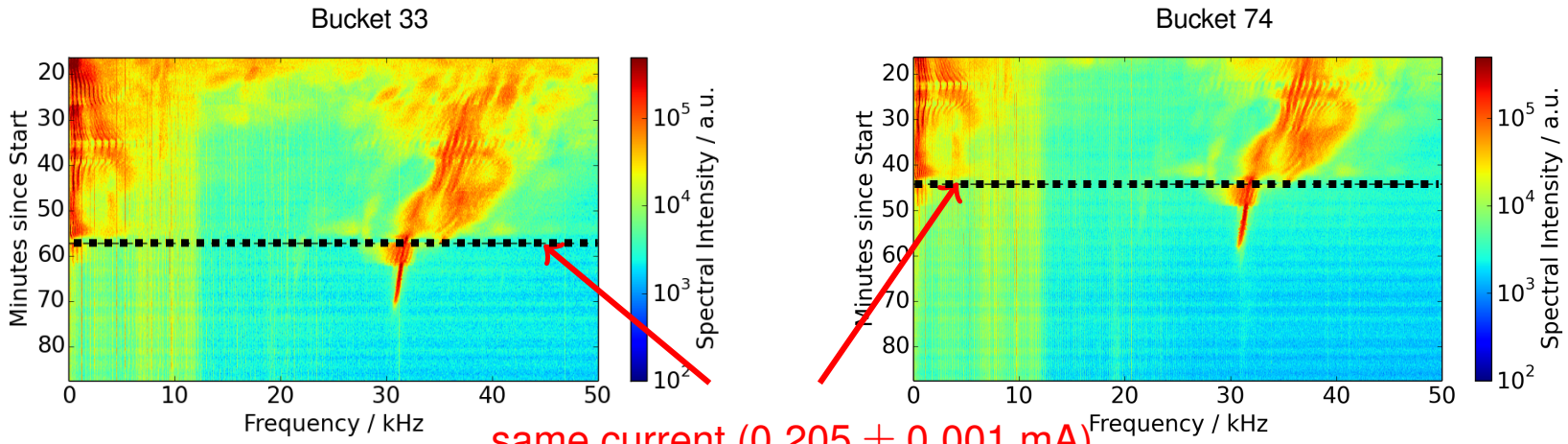


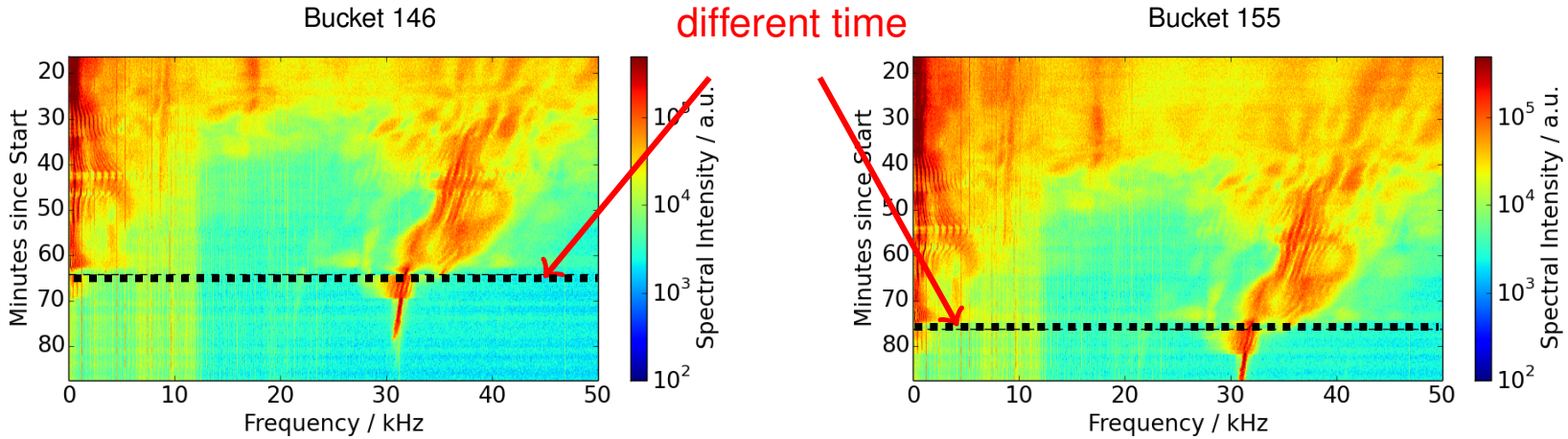
Can record > 10^6 turns

CSR Studies with KAPTURE



Do all bunches show a similar behavior for same bunch currents?





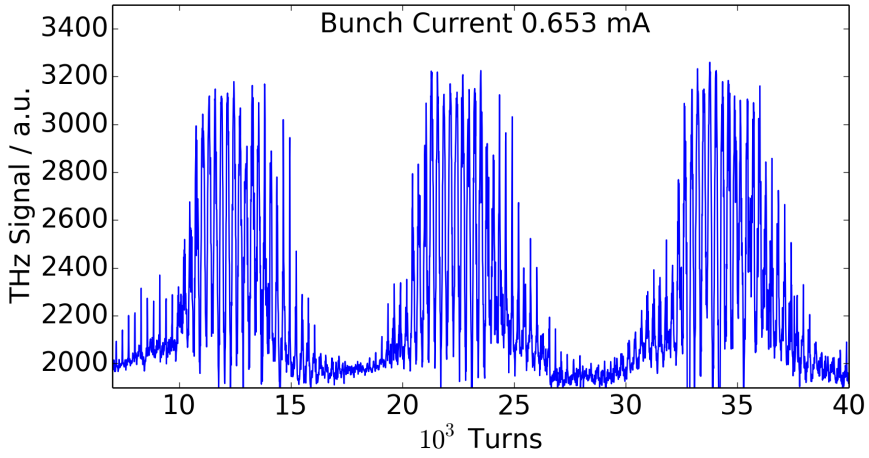
Ongoing investigation of bunch-bunch effects.

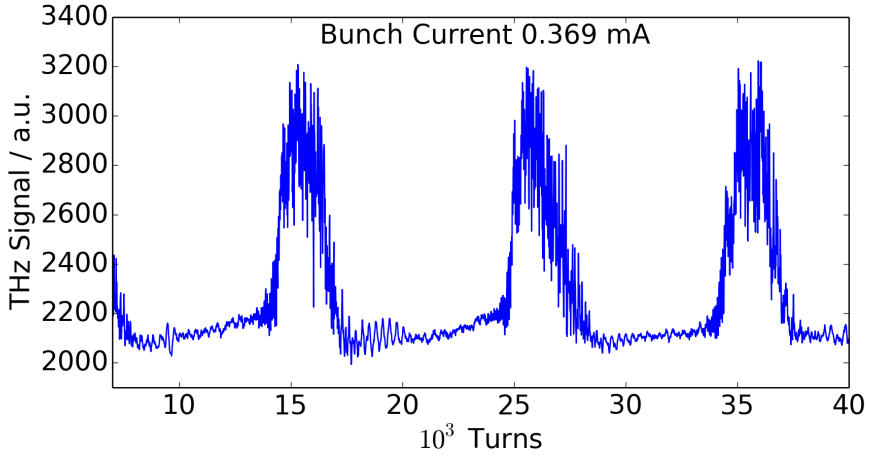
Simultaneous Acquisition with 2 “identical” detectors (e.g. for balanced detection)

1 Sample point per detector.

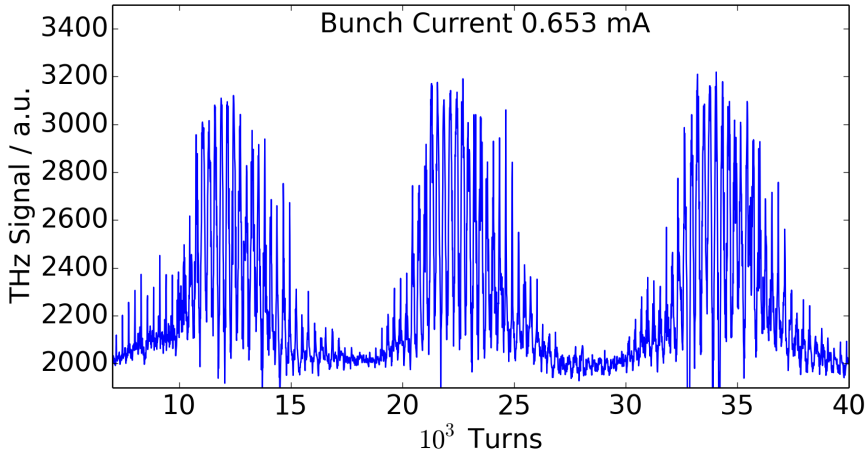
Possible to connect up to 4 detectors!

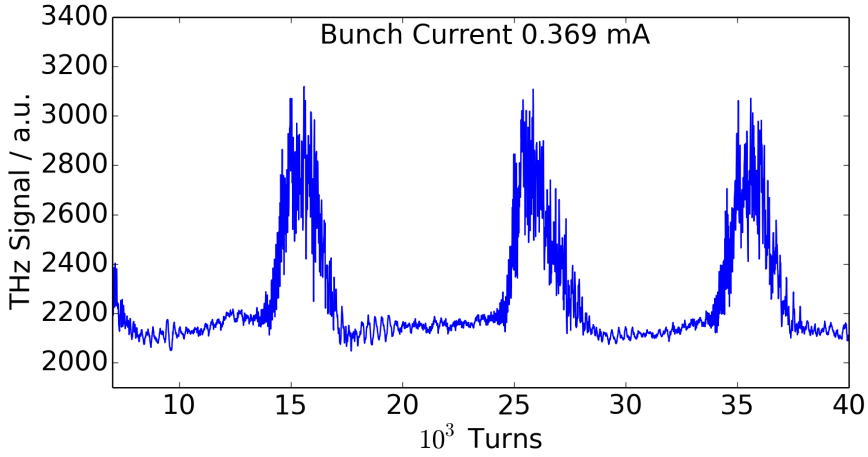
ADC0





ADC1

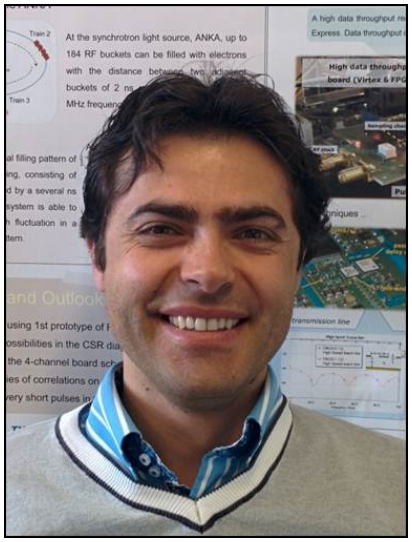




Summary - KAPTURE Features

- Dynamic range of ± 800 mV (per channel) with RMS noise < 1 mV
- Very low time jitter (RMS < 1.7 ps) ➜ sampling time accuracy of 3 ps
- High data throughput readout board based on PCIe-DMA (32Gb/s)
- Real-time data elaboration based on high-end Graphics Processing Units (GPUs)
- Under final commissioning at ANKA
- Flexible measurement opportunities
  (e.g. 4 sample points for 1 detector or up to 4 detectors with 1 sample point each)
- Can be adapted for other scientific applications and/or synchrotron facilities

Thank you for your attention!



Michele.Caselle@kit.edu

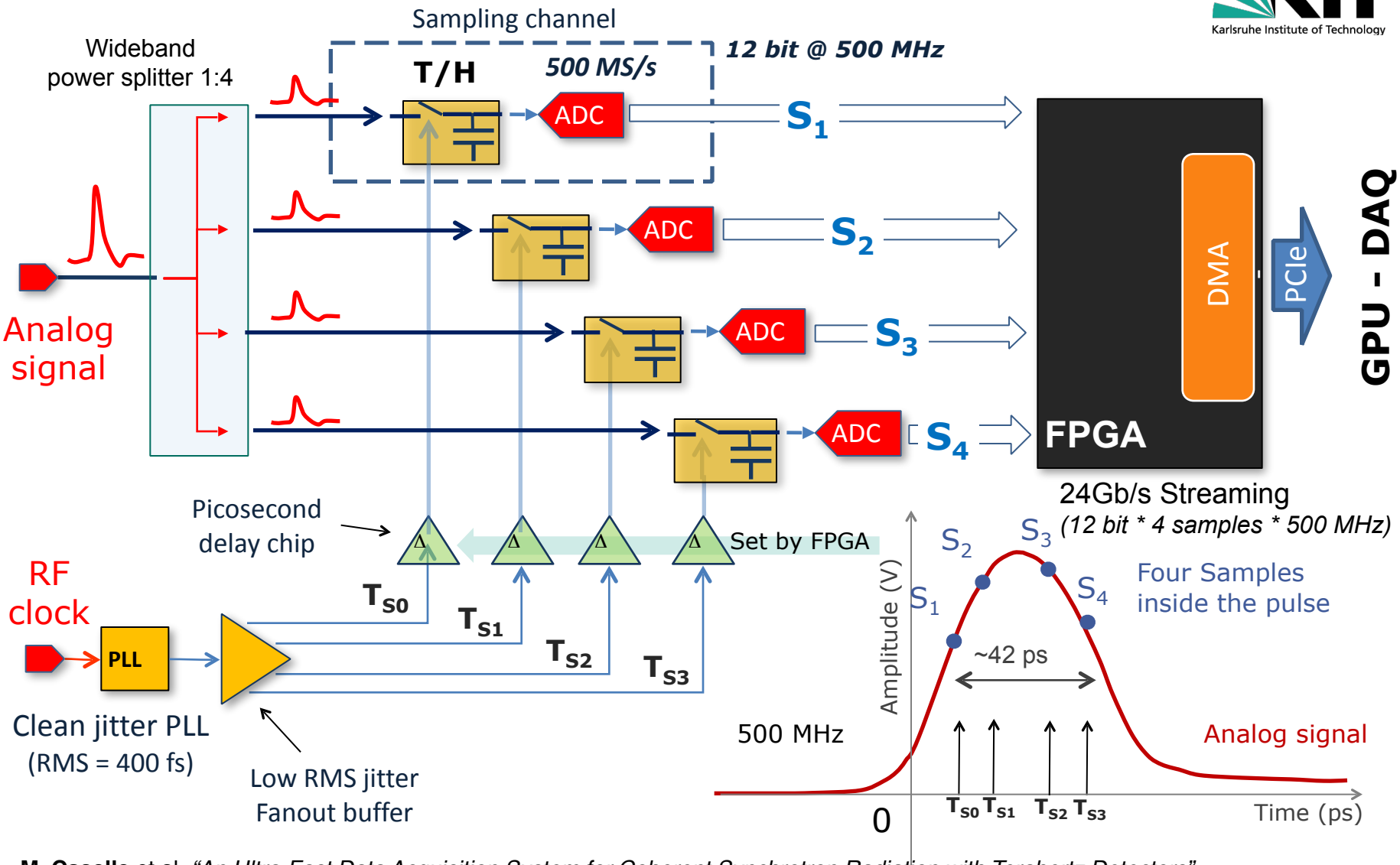
(will happily answer all your technical questions)

Lorenzo.Rota@kit.edu

(PhD student, also here at IBIC'14 ➜ TUPD10)

Backup slides

KArlsruhe Pulse Taking Ultra-fast Readout Electronic



M. Caselle et al. *"An Ultra-Fast Data Acquisition System for Coherent Synchrotron Radiation with Terahertz Detectors"*, Proceeding of Topical Workshop on Electronic for Particle Physics, Perugia 23-27 September 2013. JINST_124P_1113