Karlsruher Institut für Technologie

KALYPSO, a linear array detector with MHz line-rate for real-time beam monitoring applications

Lorenzo Rota

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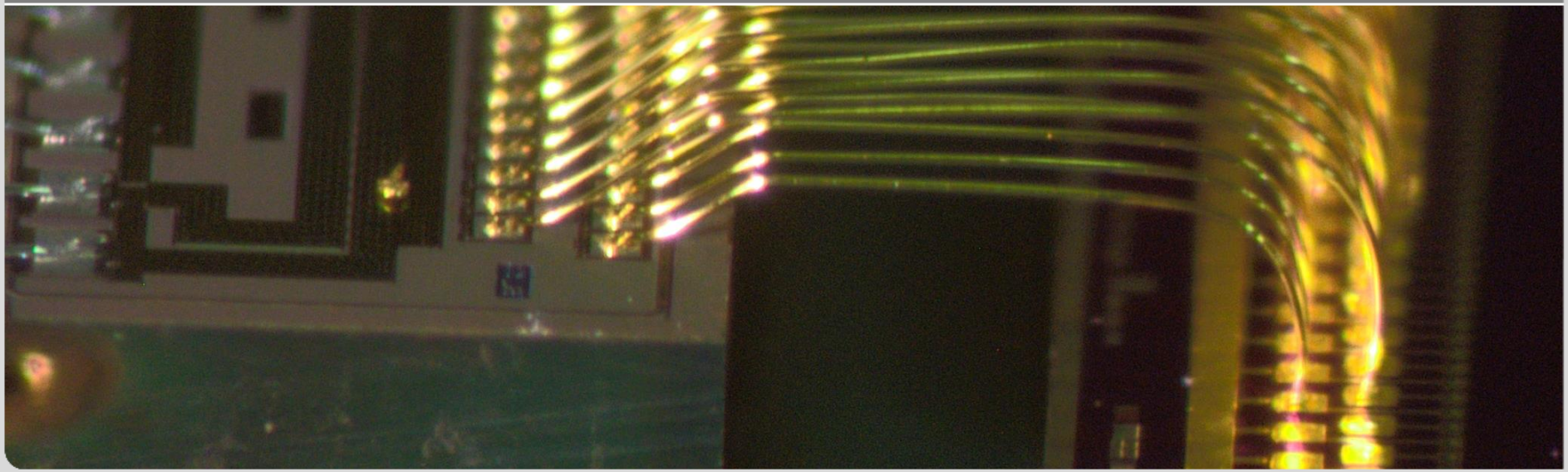
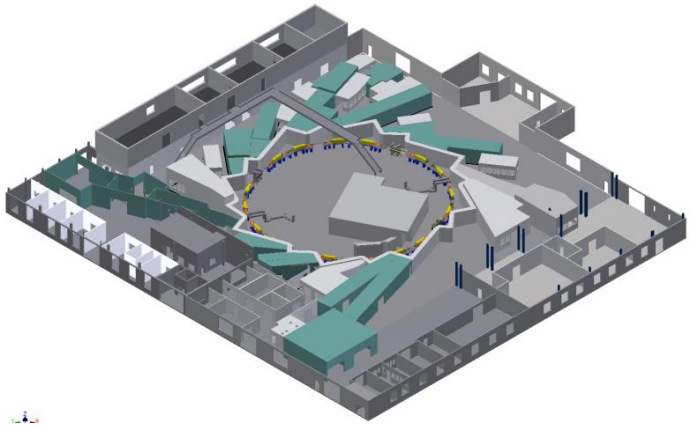


Outline

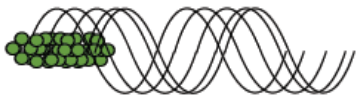
- Motivation
- KALYPSO detector
- Results at light sources

Emission of THz radiation at ANKA

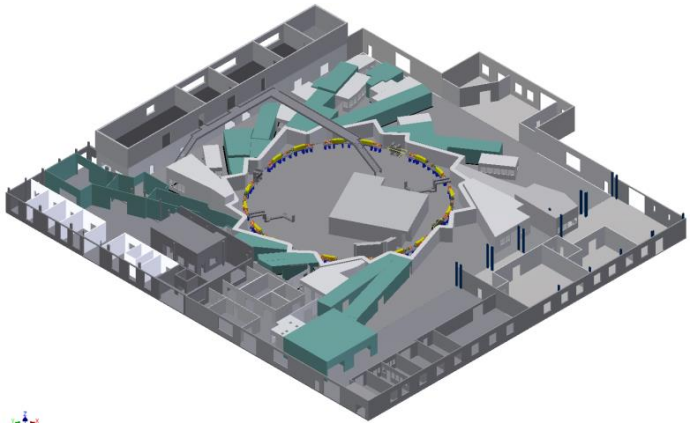


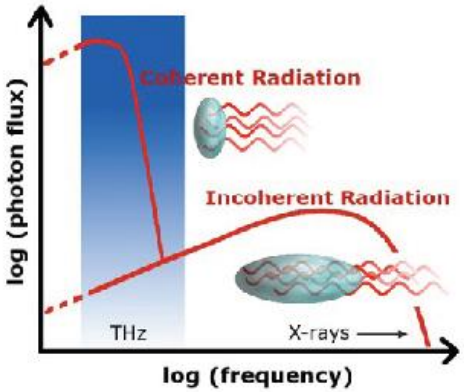
Normal “user operation” mode:

- Incoherent Synchrotron Radiation (SR)
- X-rays used for different experiments



Emission of THz radiation at ANKA





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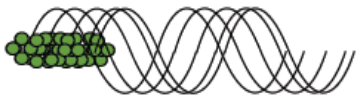

"low-α_c" mode:

- SR + Coherent Synchrotron Radiation (CSR)
- Bursts of very intense radiation in THz domain

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Emission of THz radiation at ANKA

Physical phenomena:

- Complex and nonlinear dynamics of electron bunches
- Observation of:
  - Emitted CSR (THz)
  - Bunch profiles
- Wide span of timescales:
  - bunch lengths to be measured ~ sub-ps
  - observe slow changes (*e.g.*, with current) ~ hours

Detectors requirements:

- High resolution and low noise
- High rate (2.7 MHz for turn-by-turn measurements)
- Long term data acquisition (several seconds) → high data rates (64 Gb/s)

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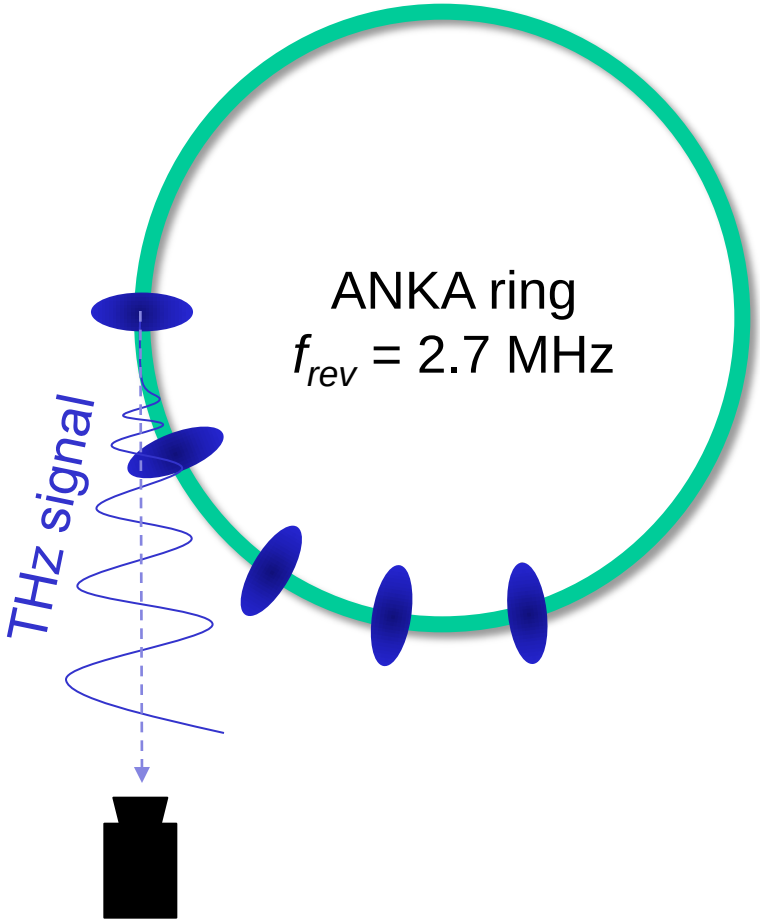
Emission of THz radiation at ANKA

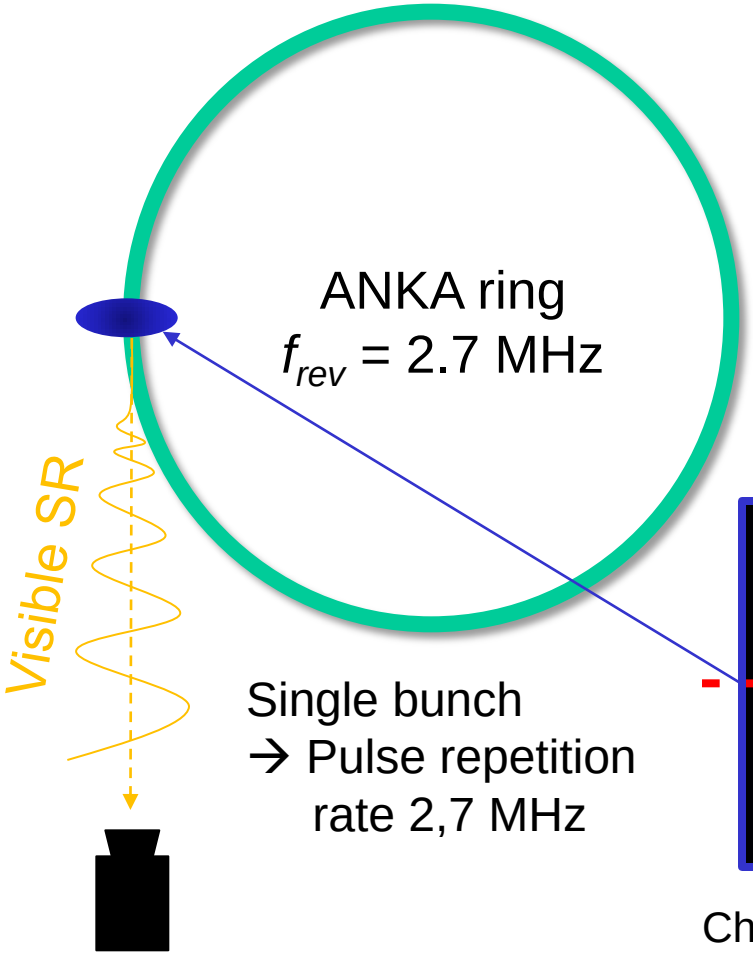


1. Measure emission of CSR:

- THz detectors
- Measure intensity of THz radiation

See Juliane's talk On Wednesday

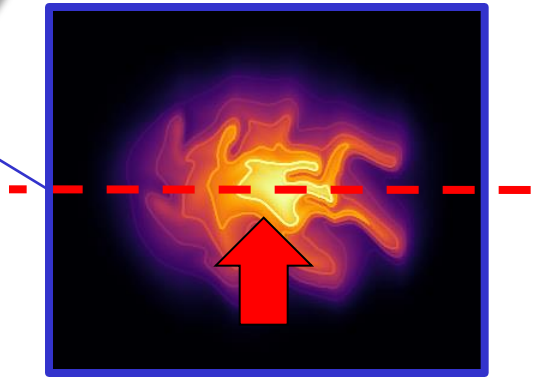
Emission of THz radiation at ANKA



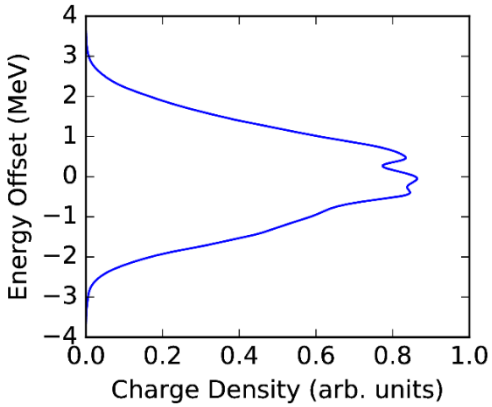
Single bunch
→ Pulse repetition rate 2,7 MHz

2. Measure transversal bunch profile:

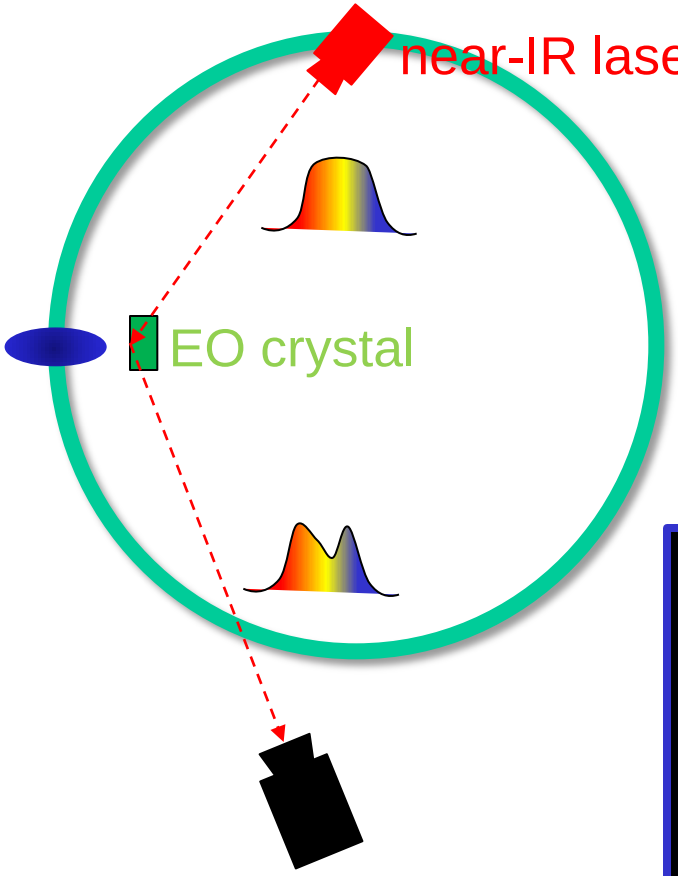
- Visible Light Diagnostics port
  + **KALYPSO (visible)**
- Measure “beam spot” of incident visible light



Charge density in e^- bunch

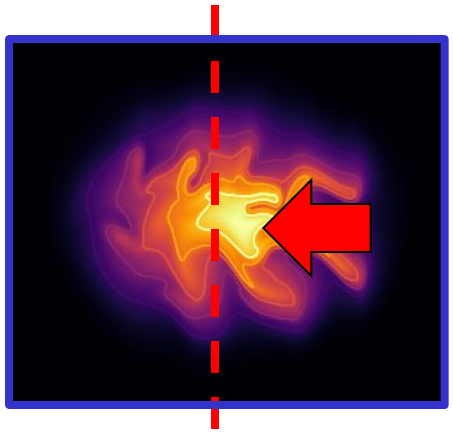


Emission of THz radiation at ANKA

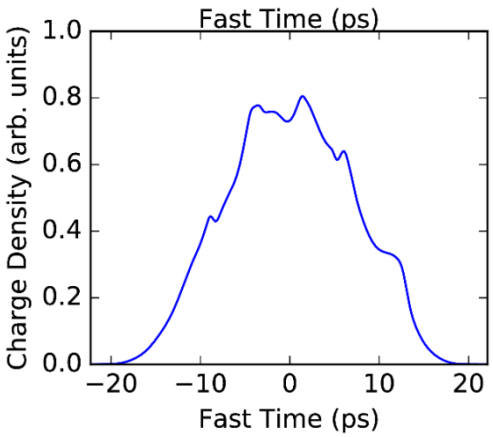


3. Measure longitudinal bunch profile:

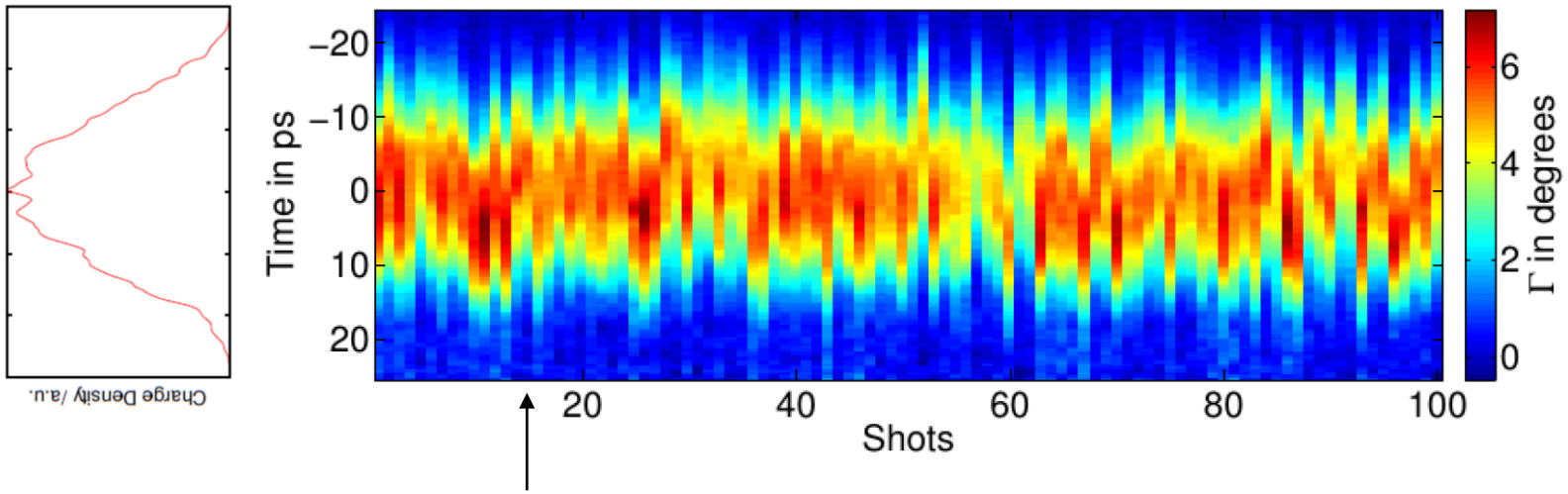
- Electro Optical Spectral Decoding + **KALYPSO (near-IR)**
- Measure modulation on laser spectrum



Charge density in e^- bunch



Motivation: previous detector at ANKA



1 shot (vertical line) every 71 ms

Frame-rate of previous setup (14 fps) does not allow to study dynamics:

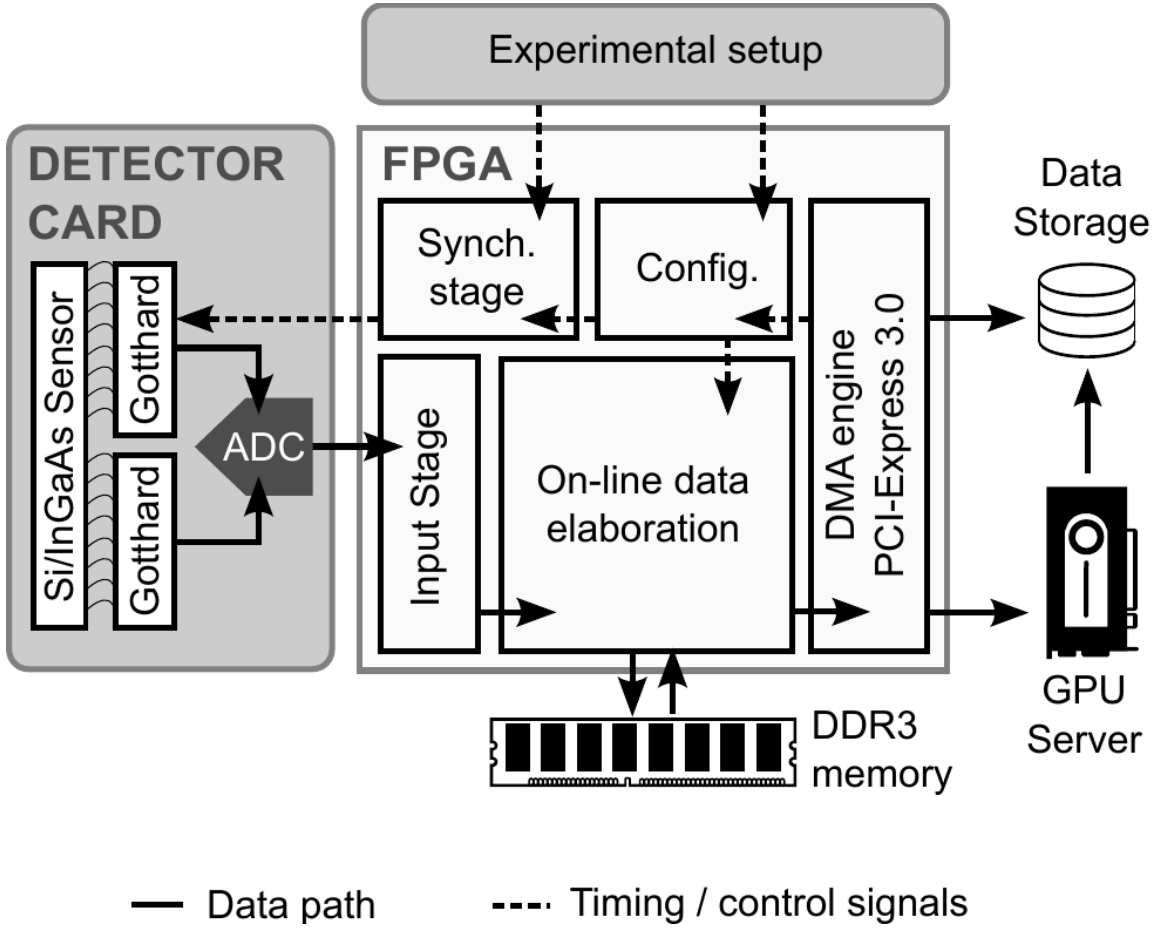
- Fast dynamics (e.g. synchrotron motion, < 1 ms)
- Slower dynamics (e.g. damping, > 10 ms)

[1] Andor iDus A-DU490A-1.7

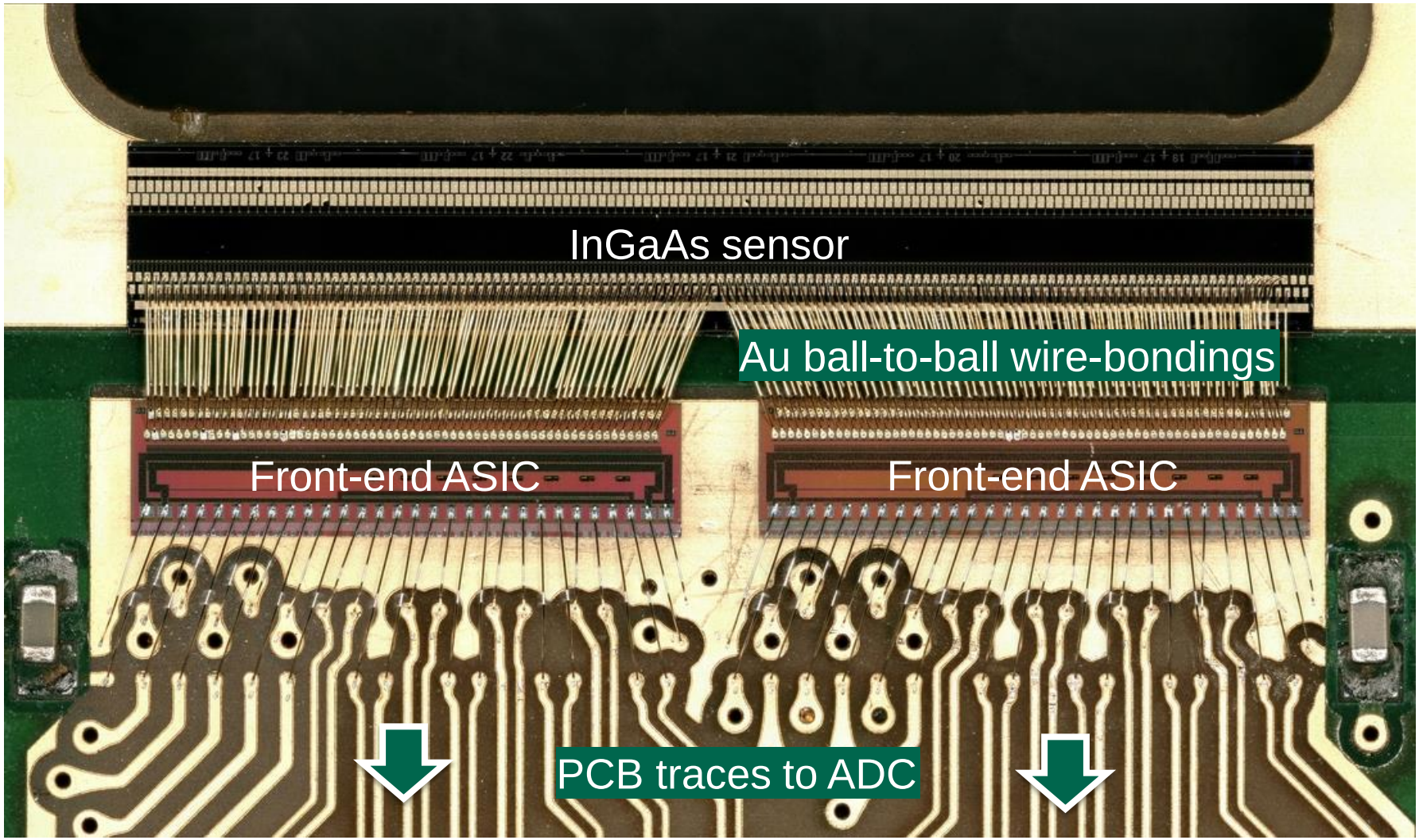
Outline

- Motivation
- **KALYPSO detector**
- Results at light sources

KALYPSO: architecture



KALYPSO II



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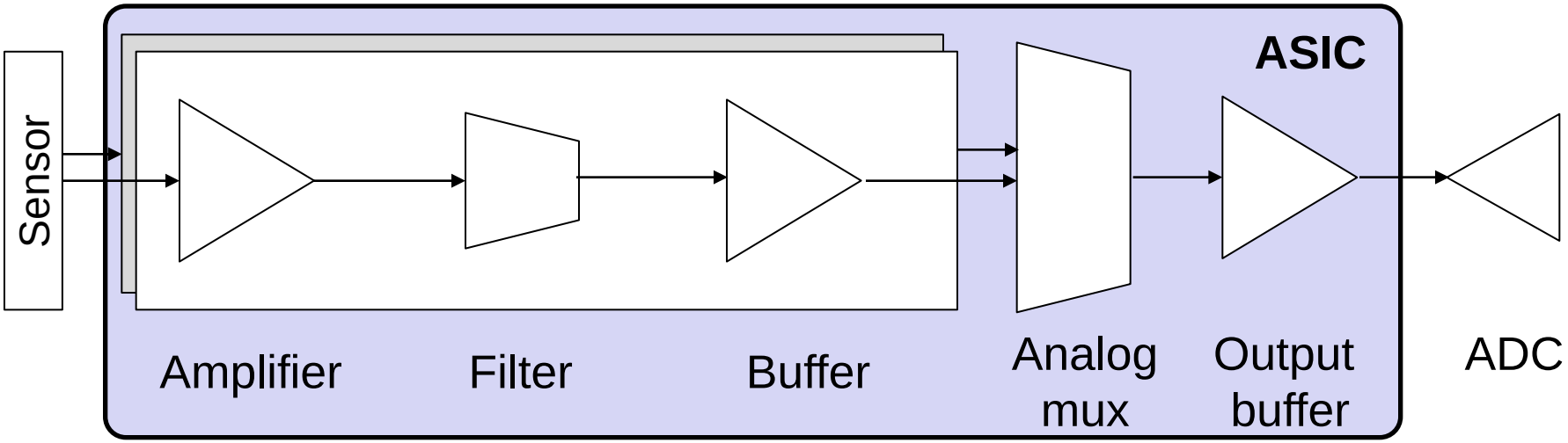
Why an ASIC?

Requirements:

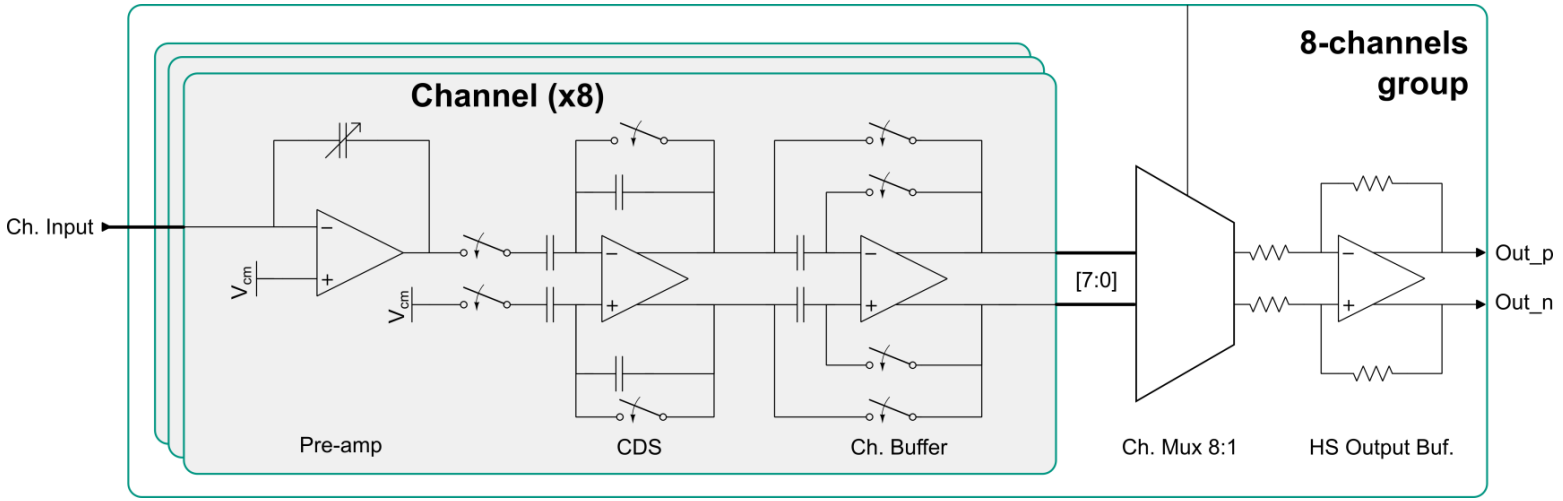
- High number channels: > 256 pixels
- High density interconnections: 25/50 µm
- Low noise:
  - dedicated front-end amplifier
  - keep connections “sensor → front-end” as short as possible
- High-framerate: not available commercially/literature



New ASIC on CMOS 110 nm

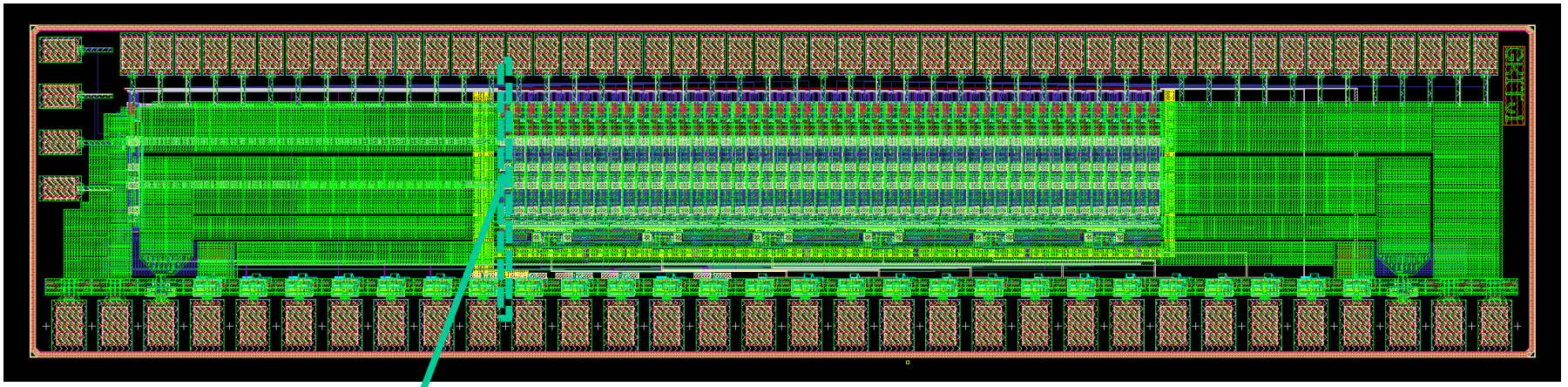
Specifications:

- Max. framerate: 5-10 Mfps (integrate while read)
- 128 inputs, 8/16 analog outputs
- High dynamic range, different sensors: 1-10 pF
- Low noise: ENC 300 e^- @ 1pF and max. frame-rate
- High CMRR & PSRR

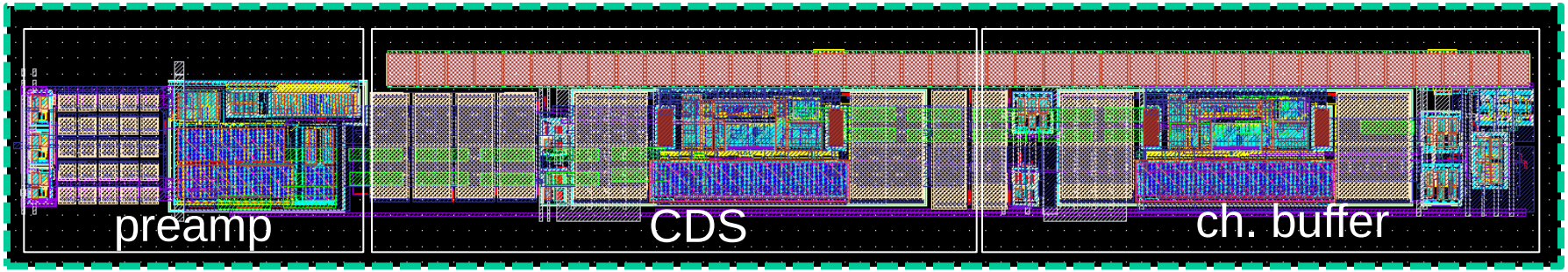


x16 = 128 channels each chip

New ASIC on CMOS 110 nm



Chip layout: 1200 µm x 5000 µm



Channel layout: 45 µm x 450 µm

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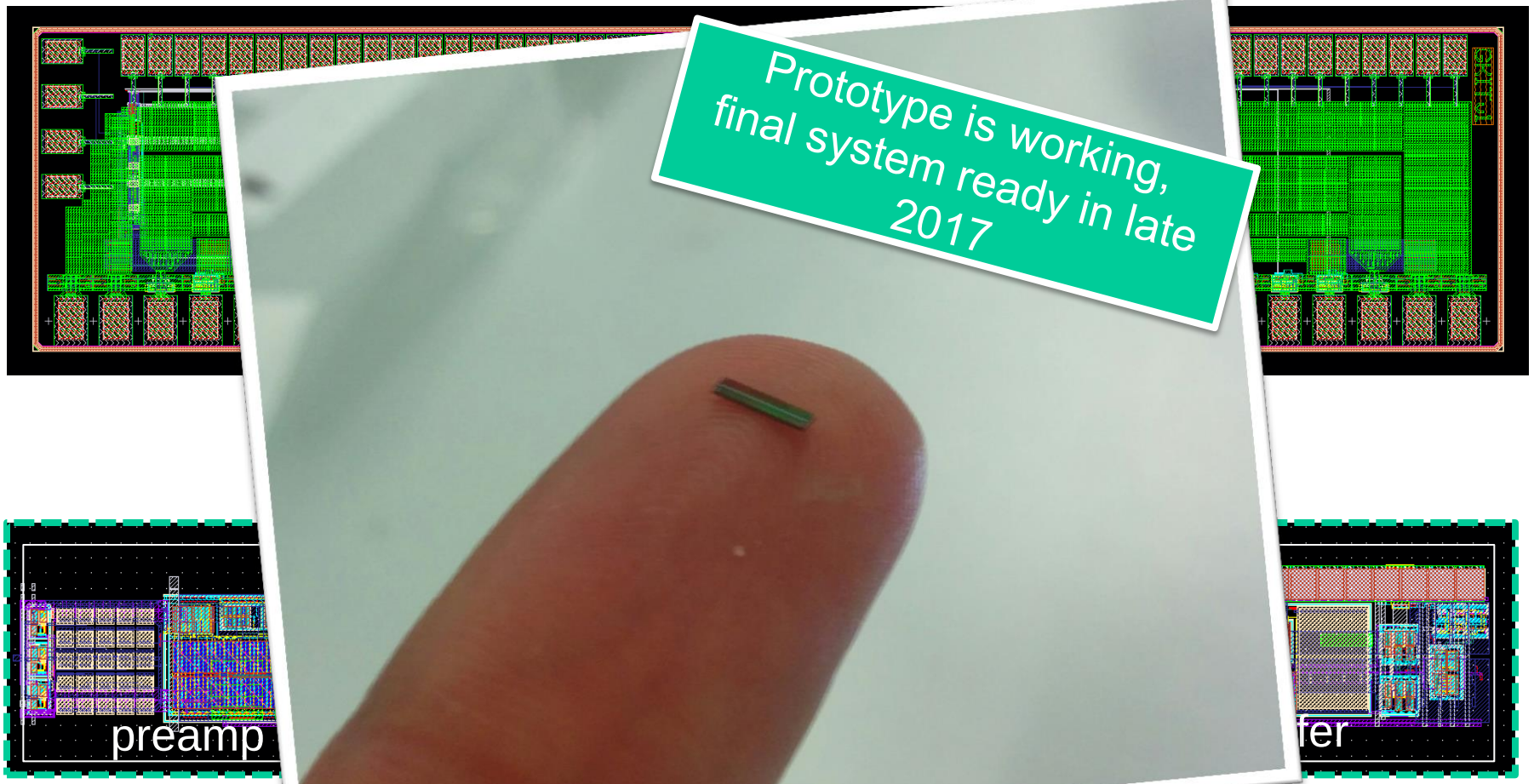
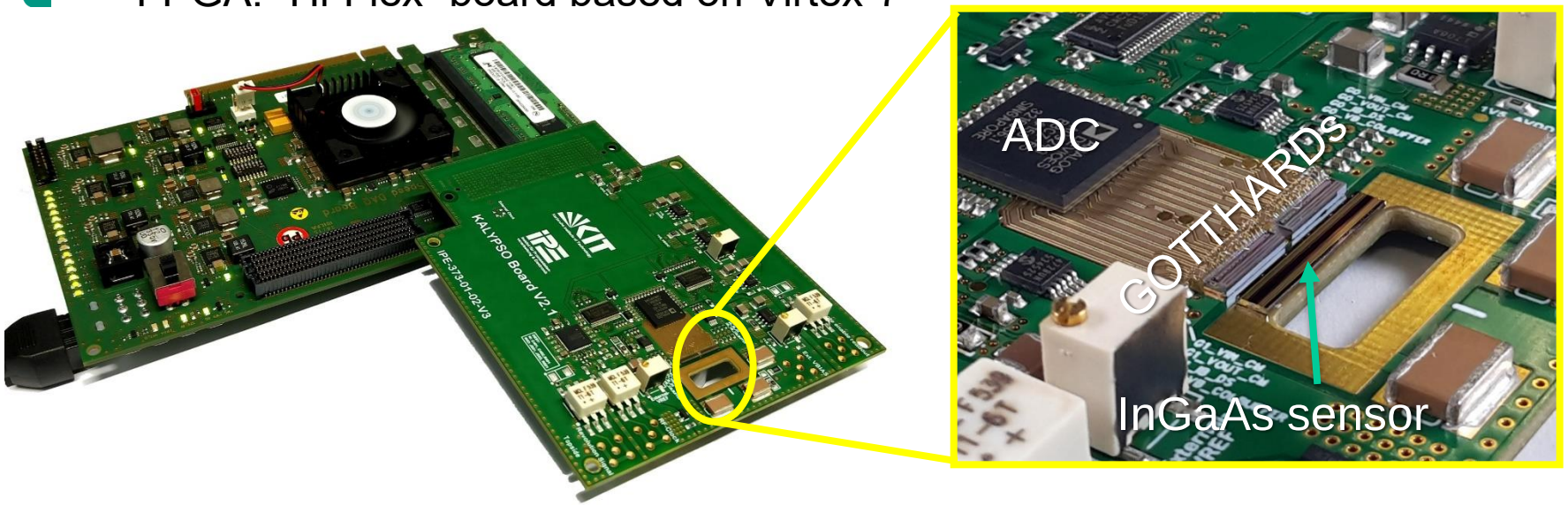
New ASIC on CMOS 110 nm



KALYPSO II: 2.7 MHz

Features:

- 256 pixels, 50 µm pitch, visible (Si) & near-IR (InGaAs)
- Front-end chip: GOTTHARD 1.6
  - Originally developed for charge-integrating X-ray detectors (PSI)
  - Custom design for KALYPSO
- Commercial ADC, 16 channels @ 62.5 MSPS
- FPGA: “Hi-Flex” board based on Virtex-7



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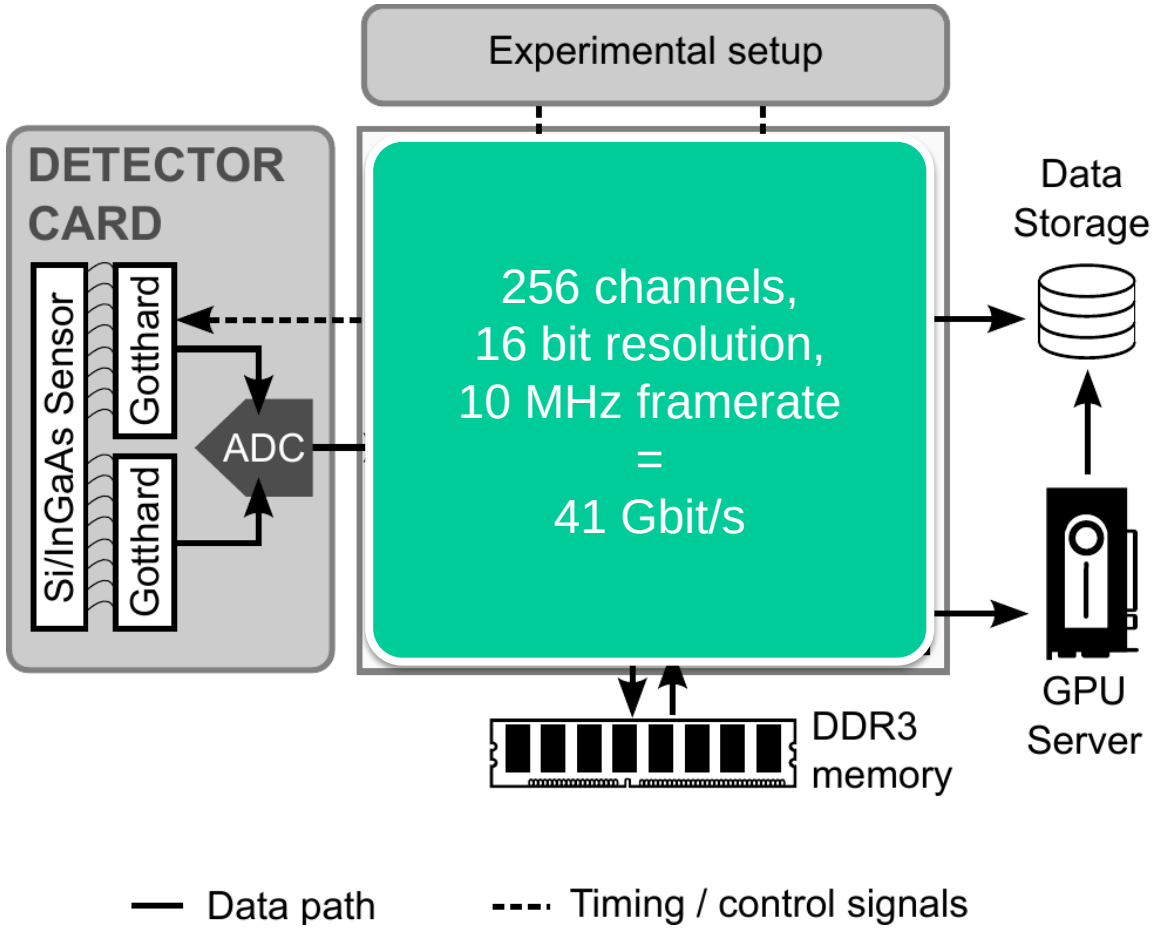
FPGA-GPU architecture

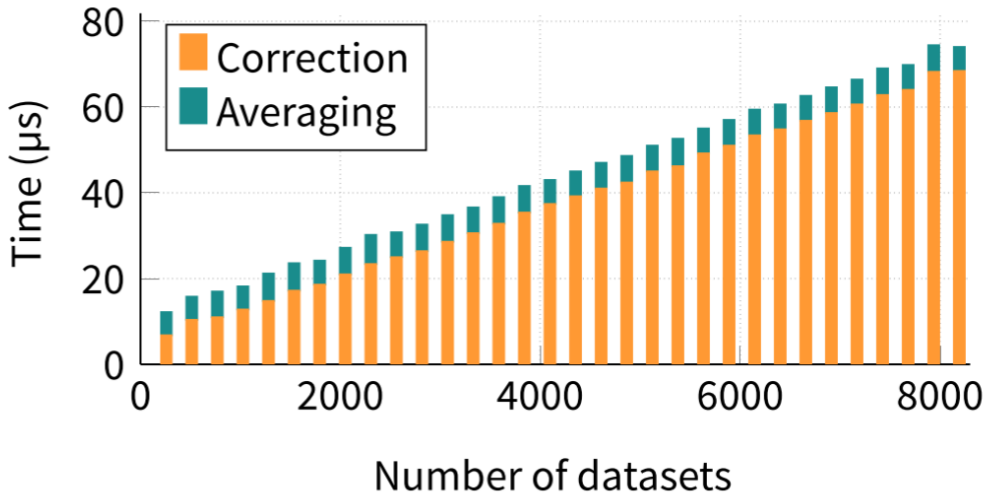


FPGA-GPU architecture

Heterogeneous FPGA-GPU architecture

See Timo's talk on Wednesday

- **Exploit benefits of each technology:**
  - FPGA: low-latency, high I/O
  - GPU: flexibility, high processing power



FPGA-GPU architecture

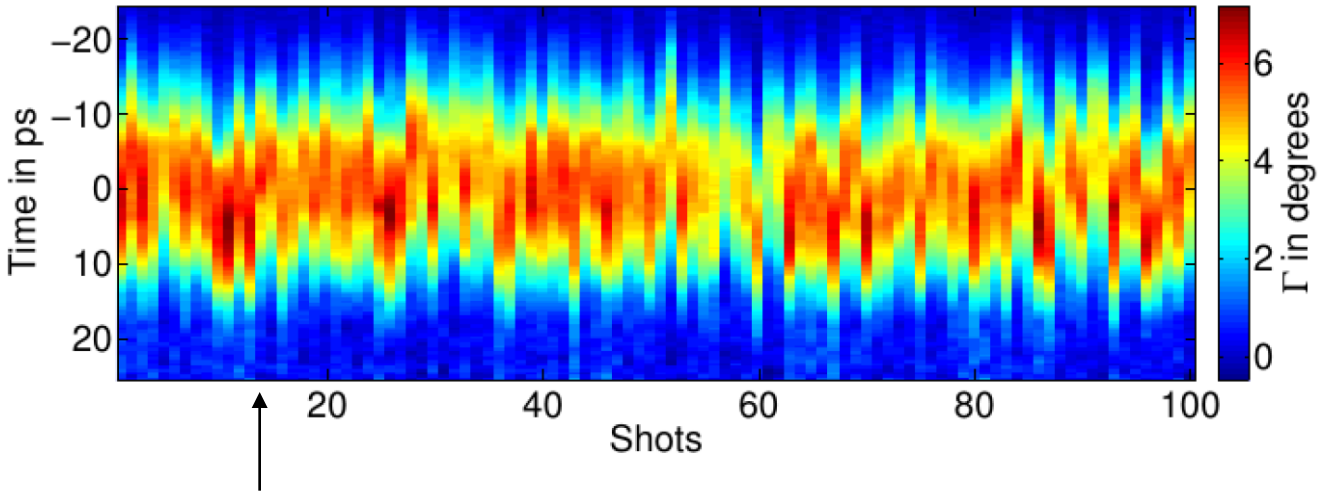
Direct Memory Access (DMA) controller compatible with Xilinx PCIe cores (Gen2 and Gen3)

- **High-throughput:**
  - Gen3: 7 GB/s
- **Low-latency:**
  - 2-3 µs round-trip
- **Supports direct data transfers to/from:**
  - system memory
  - GPU (NVIDIA's "GPU-Direct" and AMD's "DirectGMA" technologies)
  - Infiniband *(still under optimization)*

Outline

- Motivation
- KALYPSO detector
- **Results at light sources**

… before KALYPSO



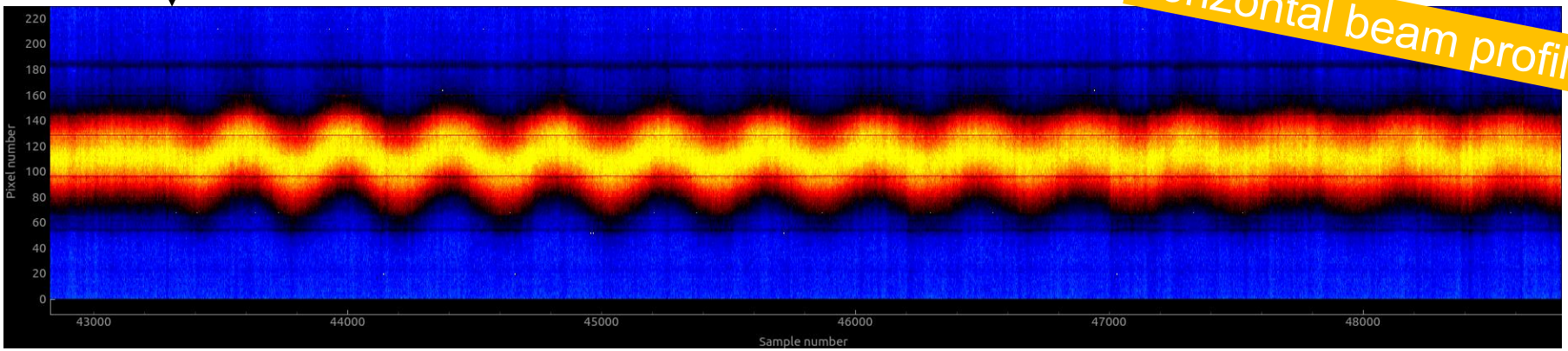
1 shot (vertical line) every 71 ms

KALYPSO II: measurements at ANKA

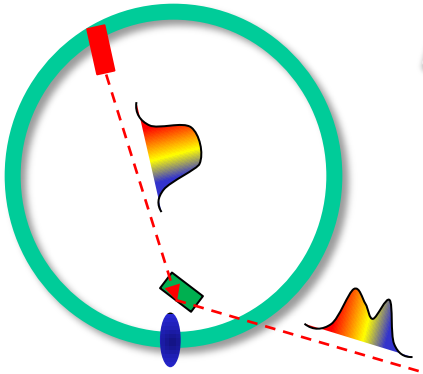
Preliminary: courtesy of ANKA THz group

1 shot (vertical line) every 370 ns

Horizontal beam profile



KALYPSO II: measurements at ANKA



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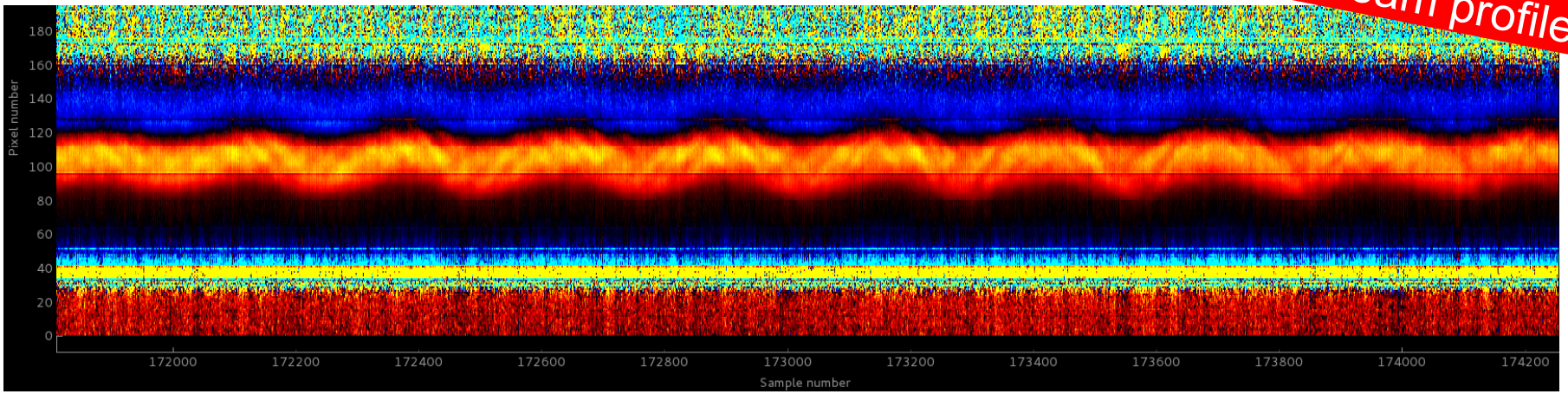
Electro-Optical Spectral Decoding

Longitudinal beam profile



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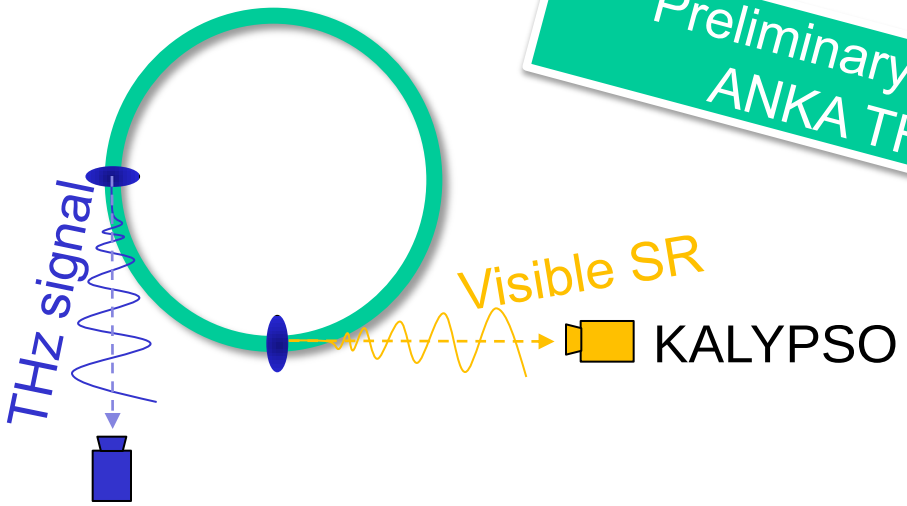
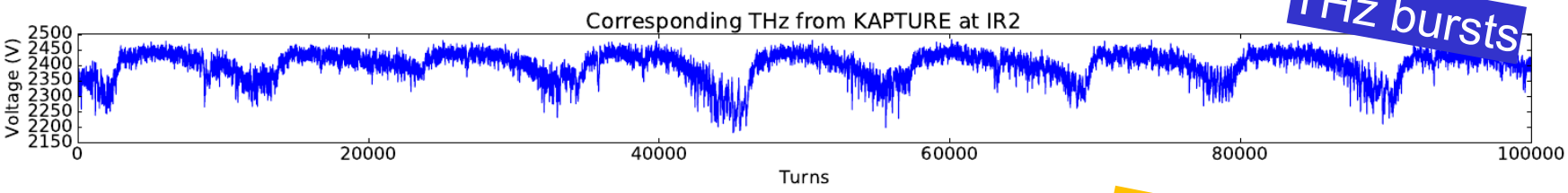
KAPTURE & KALYPSO

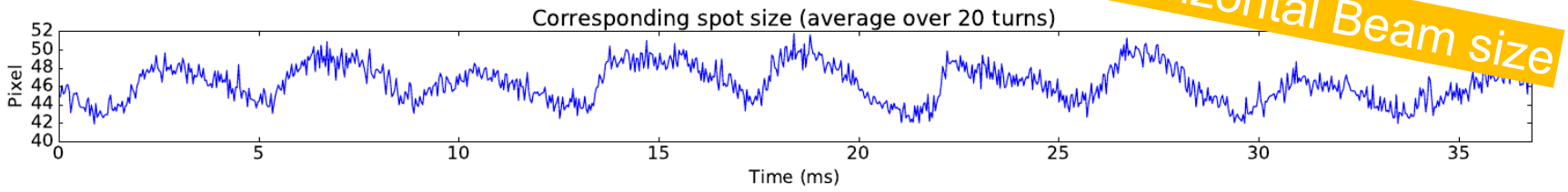
Preliminary: courtesy of ANKA THz group



THz bursts



Horizontal Beam size



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KAPTURE & KALYPSO

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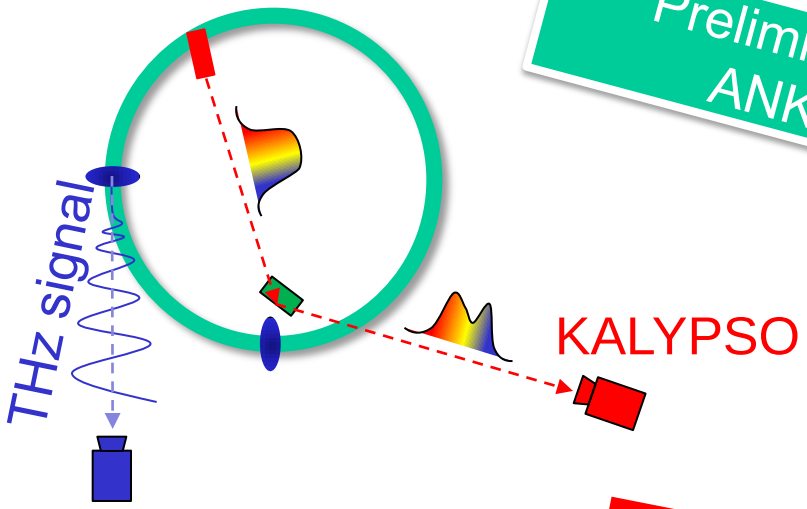
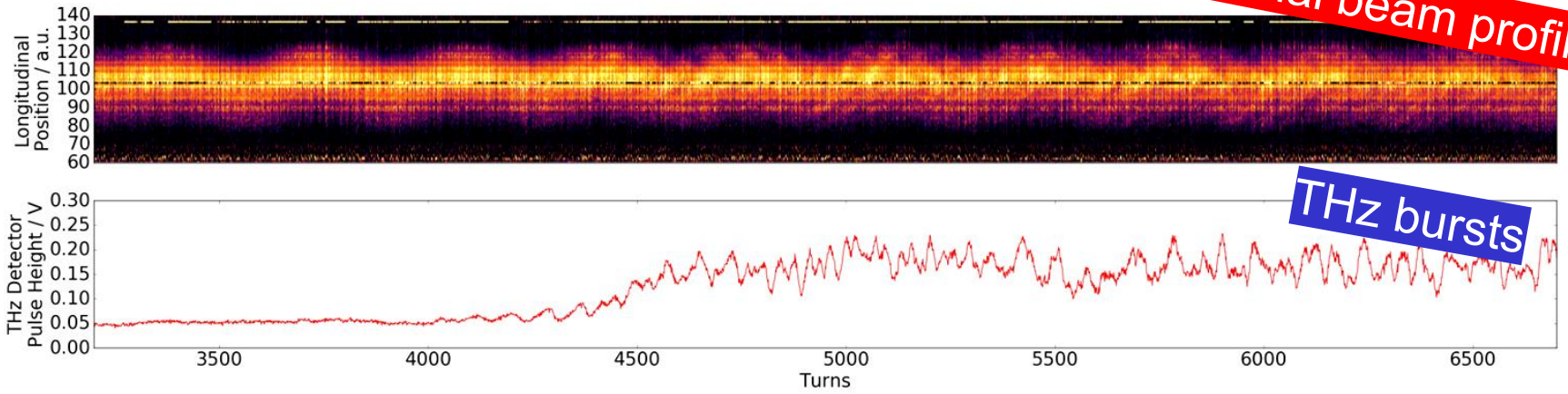


Longidutinal beam profile



THz bursts

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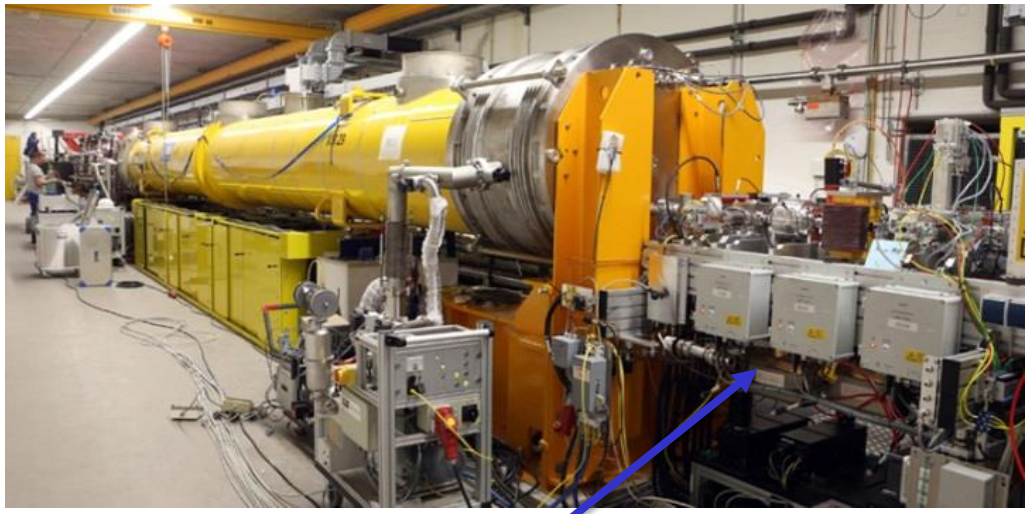
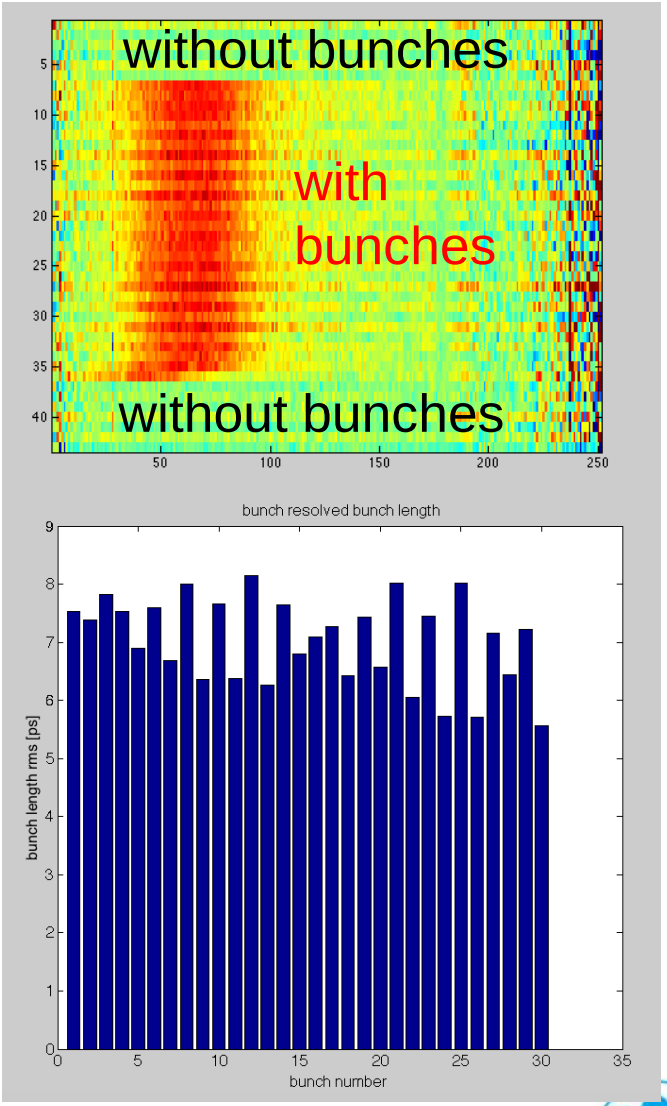
Electro-Optical bunch length Detection at XFEL Injector with 1 MHz bunch rate





KALYPSO in operation at DESY:

- Provides bunch-length measurements after main injector of Eu-XFEL at 1.13 MHz
- KALYPSO 2 is currently being integrated by TUL-DMCS

Thank you for your attention

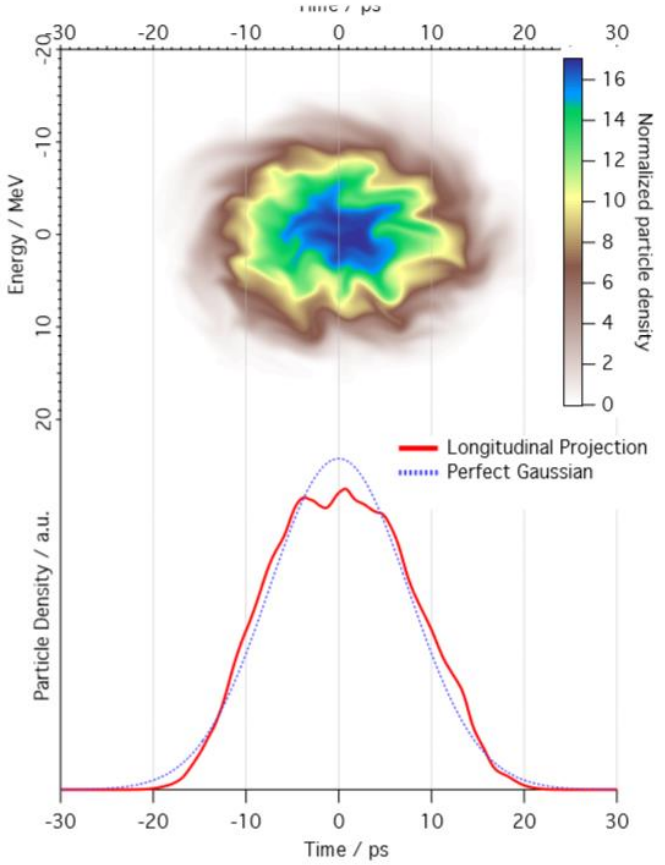
EOSD at ANKA: motivation

Generation of coherent synchrotron radiation:

- Intense bursts of THz radiation are explained by micro-bunching
- Wanted: **measure longitudinal bunch profile with sub-ps res.**

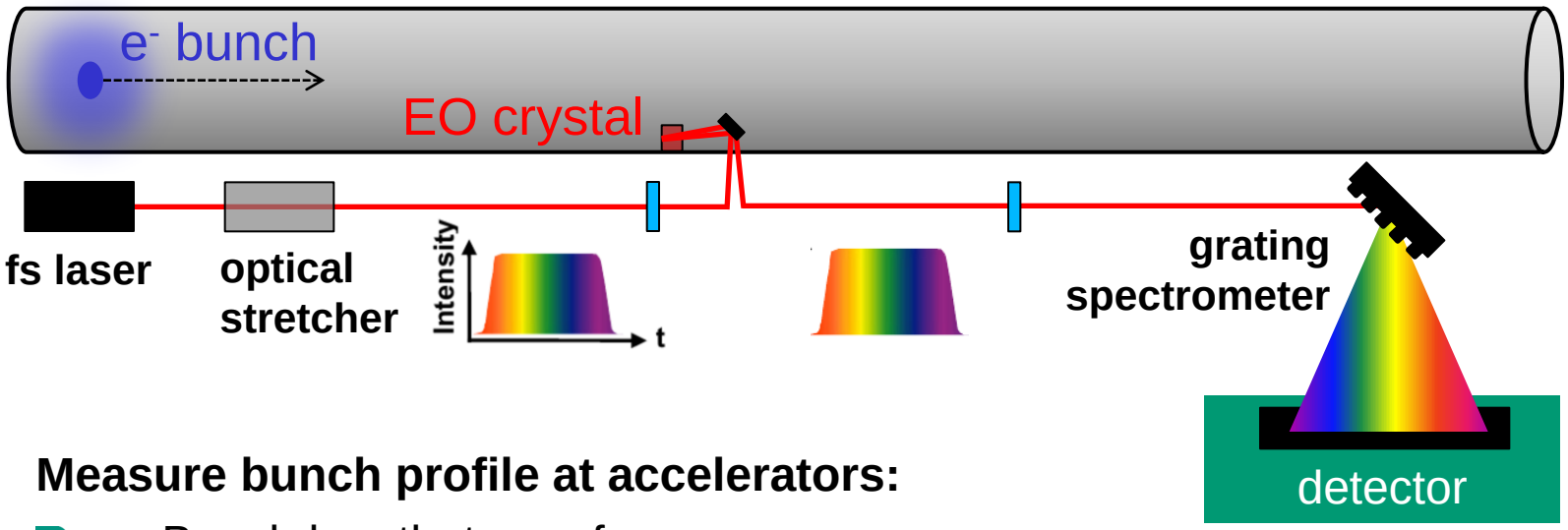
- **“Ideal” measurement:**
  - Single-shot (non-averaging)
  - Every turn @ f_{rev} = 2.7 MHz
  - Continuous acquisition (map instability behavior)

simulated phase space



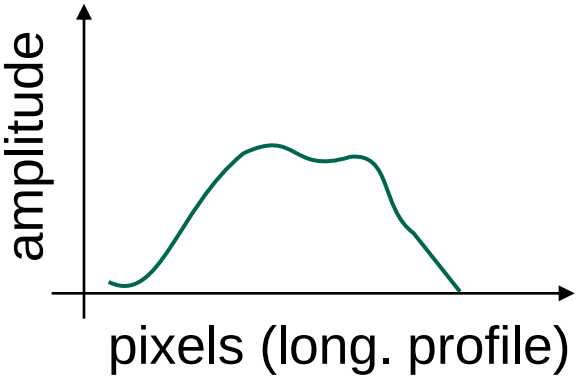
courtesy J. Steinmann, P. Schönfeldt

Electro-Optical Spectral Decoding

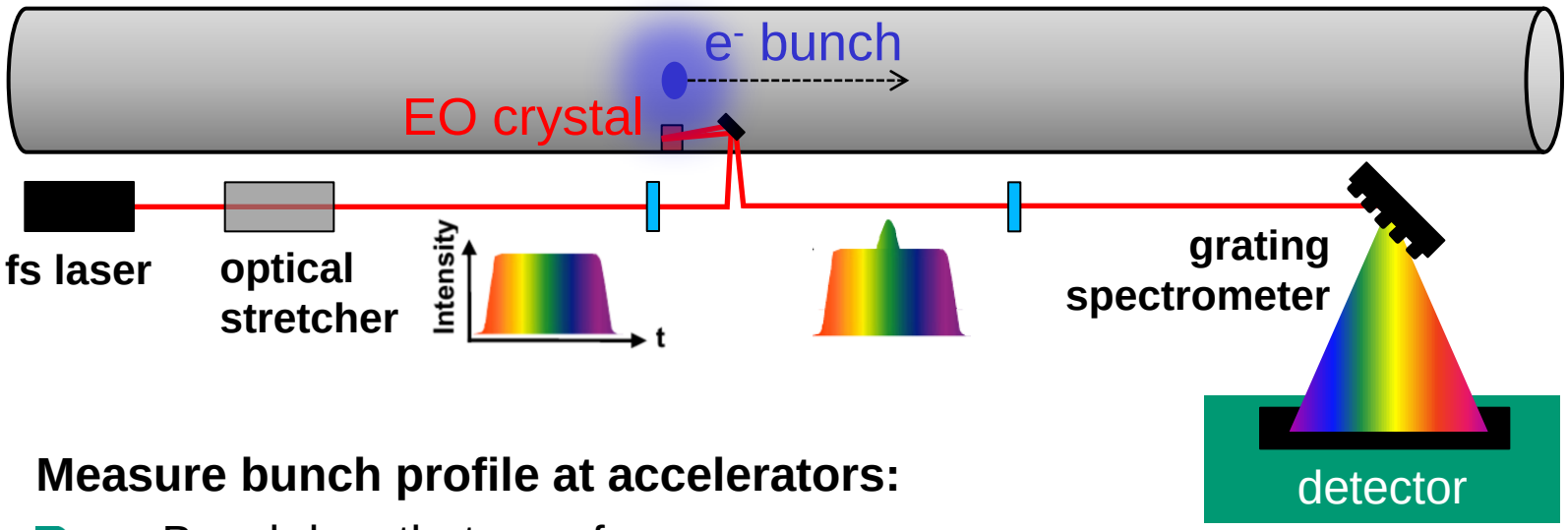


Measure bunch profile at accelerators:

- Bunch length: tens of ps

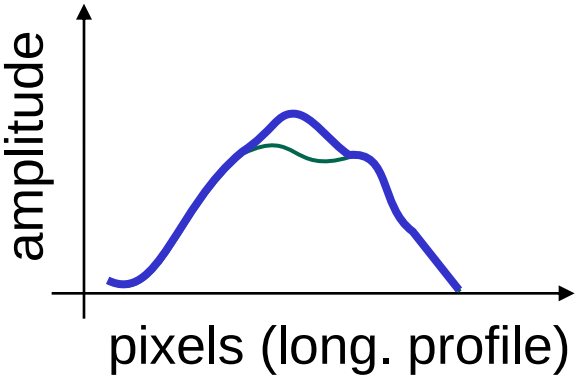


Electro-Optical Spectral Decoding



Measure bunch profile at accelerators:

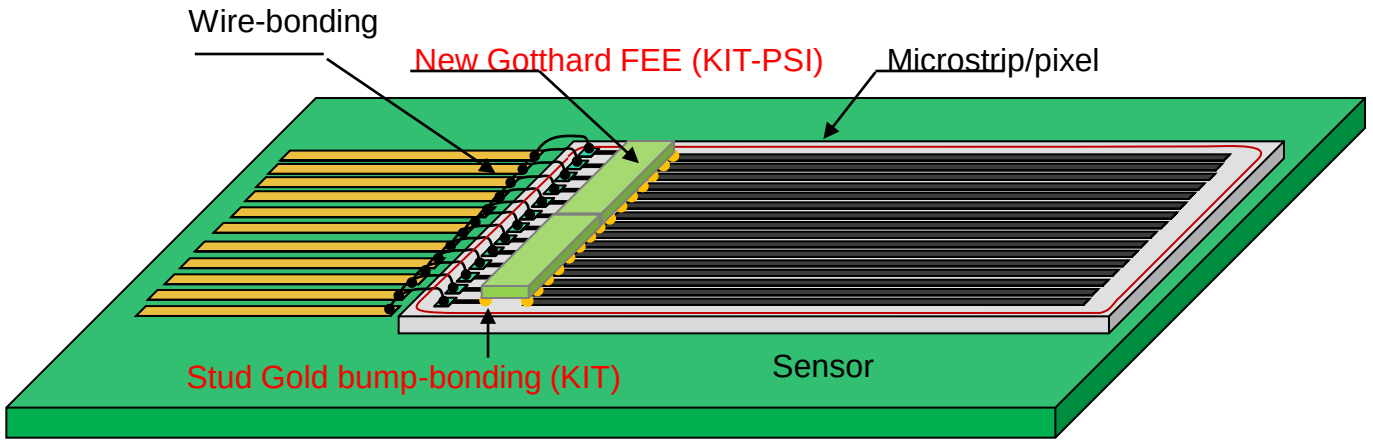
- Bunch length: tens of ps
- modulation magnitude: 10% of original signal
  - ➢ $SNR_{bunch\_shape} = 0.1 \times SNR_{laser\_signal}$



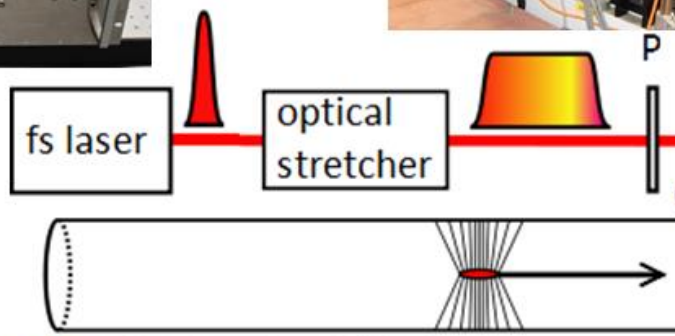
KALYPSO 3.0

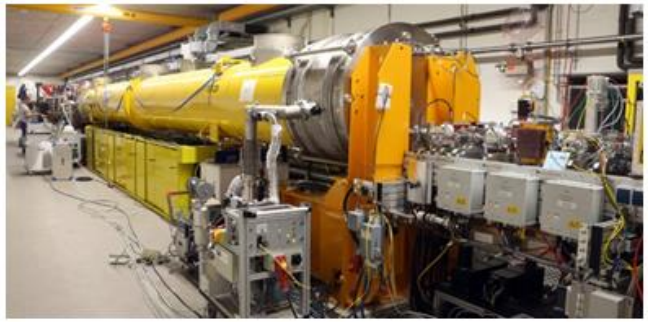
Design new Si sensor (by master student M. Patil):

- Optimized geometry
  - 25 um resolution, reduced capacitance (noise)
- Front-end chip bump-bonded to sensor

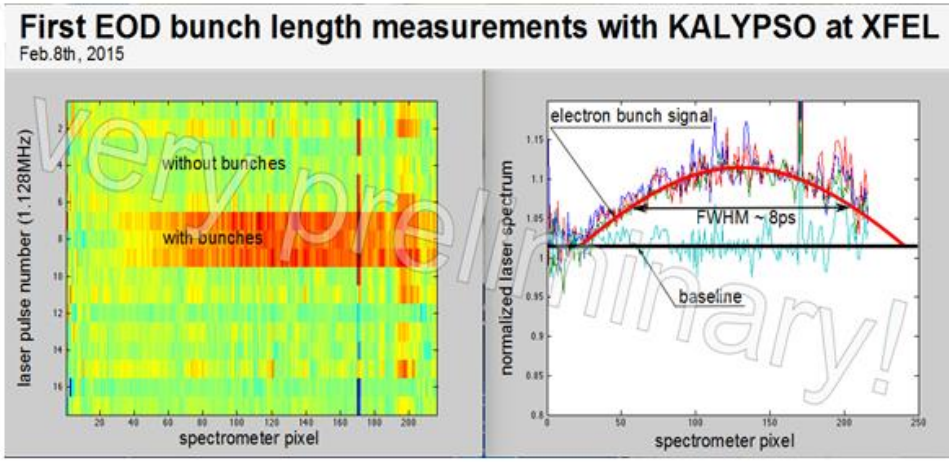


Electro-Optical bunch length Detection at XFEL Injector with 1 MHz bunch rate





- For the Electro-Optical bunch length Detection (EOD) the electric field of the electron bunch is sampled with an fs laser pulse in an Gallium Phosphide crystal.
- With the KALYPSO line detector EOD can provide bunch length measurements with 1.13MHz rate over the XFEL bunch train.
- Full system (including laser, detector, MTCA crate, synchronization electronics, motor drivers, power supply, ect.) mounted in climatized 19" rack underneath the beamline



- First system now ready for (expert) operation at the XFEL-injector