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RESEARCH FOR
GRAND CHALLENGES

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MT Annual Meeting 2021

Detector Technologies and Systems (DTS)

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ST1 – Detection and Measurement

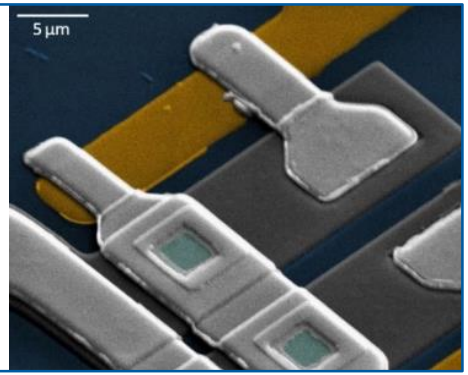
Recent Highlights and Outlook

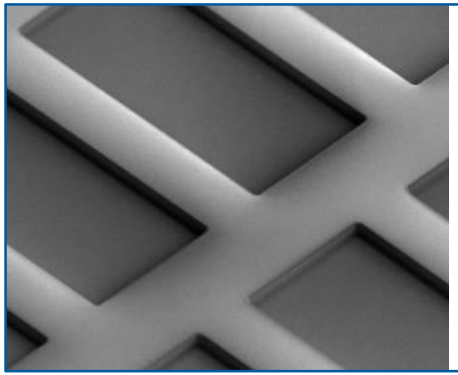
ST1 – Detection and Measurement

DTS excels in sensors and ASICs

Superconducting sensors

A mature technology with broad applications, ideal fit to Helmholtz



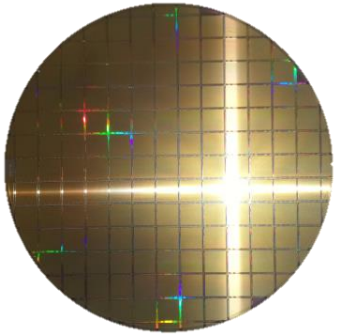


Post-processing silicon sensors

High quantum efficiency for soft X-rays, sensors tailored to specific application

High-Z semiconductor sensors

High quantum efficiency for hard X-rays



Innovative ASIC technology

Highest integration density, radiation-tolerance, speed

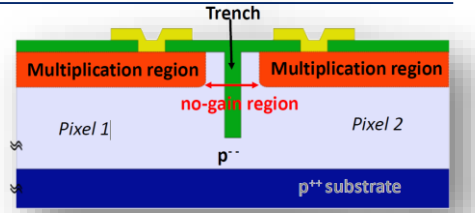
few technologies, many applications

Sensing

Silicon sensor for greater time, energy, and position resolution

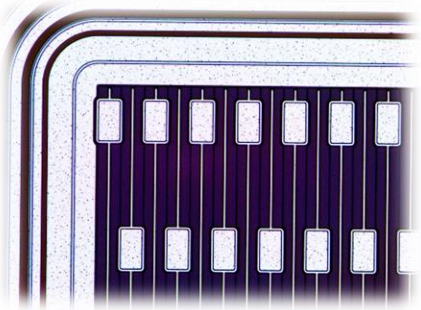
- Low-gain Avalanche Detectors (LGAD)
  Time resolution down to tens of ps, high-spatial resolution, higher fill-factor, edgeless design

- TANGERINE: innovative silicon detector design (DESY, GSI and KIT):
  - Trench Isolation LGAD,
    First TI-LGAD, several structures produced by FBK:
    - channel pitch of 50 µm optimized for photon sciences
    - channel pitch of 100 µm optimized for HEP
  - Resistive layer and AC coupling (RSD-LGAD) with in-pixel AI



Trench isolated LGAD structure
no-gain region of ~ few µm

Plenary talk: I. Gregor



DTS talk: M. Patil (ST3), J. Pietraszko (ST3)

DTS talk: E. Trifonova (ST1)

First in the world TI-LGAD with channel pitch of ***50 µm*** *(KIT)*

DTS-2: Establish availability of sensors with high spatial (20 µm) and time resolution (20 ps) for charged particles (2024)

Sensing

Advanced sensors technologies

- Enhanced Lateral Drift Detector (ELAD)

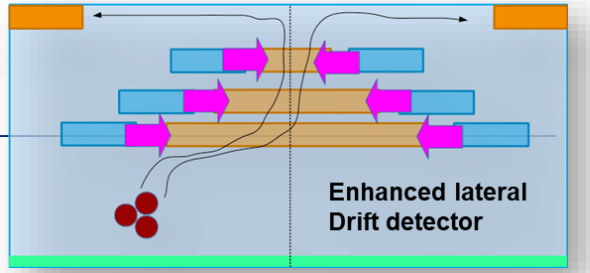
  Thin, fast & precise pixel detectors by linear charge sharing

  DTS talk: A. Velyka (ST1)

- High-Z sensor technologies
  - Cover the full spectrum of X-ray energies
  - GaAs and CdZnTe sensors for X-ray detectors

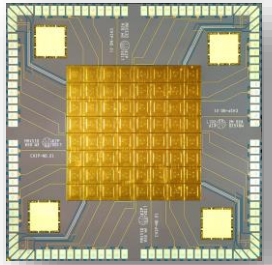
  DTS talk: M. Fiederle (ST3)

- Superconducting sensors
  - Metallic magnetic calorimeters
  - Establish superconducting sensor production capacity (DDL)



ELAD sensor, basic concept

CdZnTe detector measurements with Timepix

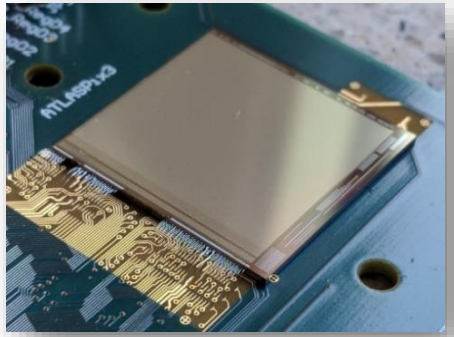


Pixelated MMC sensor

Monolithic CMOS sensors

High spatial resolution, ultra-low material budget

- Depleted CMOS sensors
  - 16 chips submitted in 2020
  - High temporal resolution and dynamic range by BiCMOS



Full-reticle ATLASPix3

- TANGERINE (WP1)

  Explore monolithic CMOS sensors in TSMC 65 nm CMOS imaging process and add in-pixel intelligence

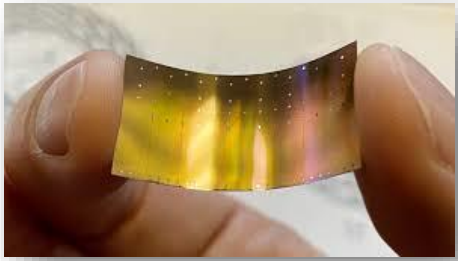
- Micro Vertex Detector of the CBM experiment

  MIMOSIS CMOS Monolithic Active Pixel Sensor

  DTS talk: M. Deveaux (ST1)

- ALPIDE – Alice pixel detector
  - Explore Tower Semiconductor 65 nm CMOS technology
  - Ultra-thin curved Monolithic Active Pixel Sensors

  DTS talk: B. Blidaru (ST1)

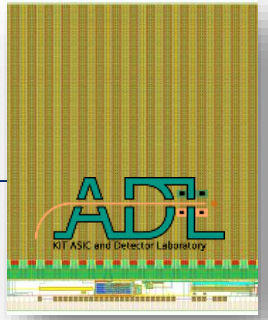


Ultra-thin pALPIDE-1

ASIC

Sophisticated readout chip for science applications

- Multi-purpose ReadOut Chip with TimE stamps
  - Front-end for CdZnTe and LGAD sensors
  - Plasmed-X (Helmholtz Innovation fund)



Layout of MPROC front-end chip

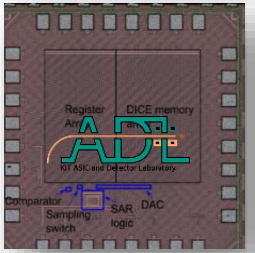
- ASIC for 3D-Ultrasound Computer Tomography

  Technology transfer project

Detectors components and front-end chip

- Evaluation of 28 nm CMOS technology

  ADC and SEU-tolerant RAM cell design in TSMC 28 nm CMOS technology



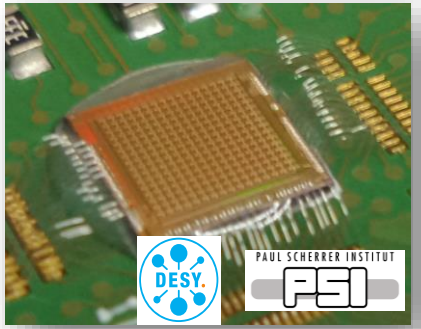
ADC and DICE RAM test chip in 28 nm

ASIC

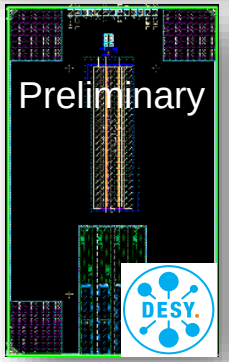
Terapixel per second imaging and advanced optical driver

- ecAGIPD - Electron-Collecting AGIPD
  - Photon science at EuXFEL
  - Advanced front-end ASICs for High-Z sensors: GaAs, CdTe, CZT
  - IBM 120 nm CMOS technology

DTS talk: T. Laurus (ST3)



- Advanced modulator driver for optical communication
  - Fiber-to-Front end communication
  - up to 30 Gbps (single channel) & 120 Gbps (4-channel: PAM-4)
  - GF 90 nm CMOS technology



Layout of the ASIC driver in 90 nm CMOS technology

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ST2 – System Technologies

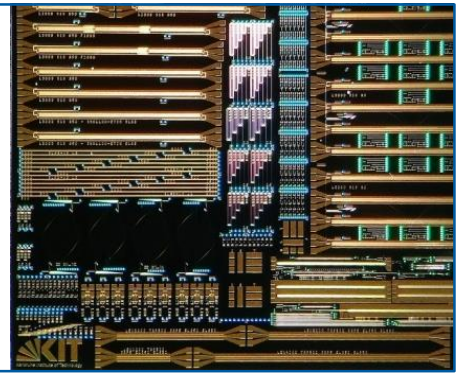
Recent Highlights and Outlook

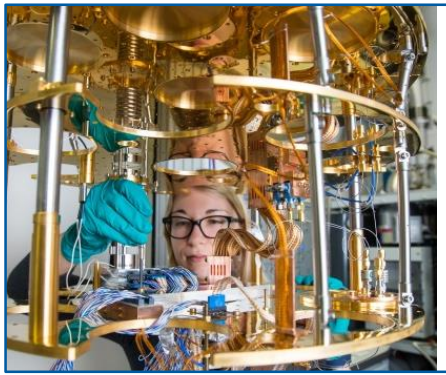
ST2 – System technologies

Critical technologies for coping with the data deluge

Silicon photonics

A game-changing technology, enabling trigger-less detectors





Cryogenic readout

Enabling 1k-pixel sensors, superconducting electronics
spin-off: Quantum Computing

Real-time data acquisition

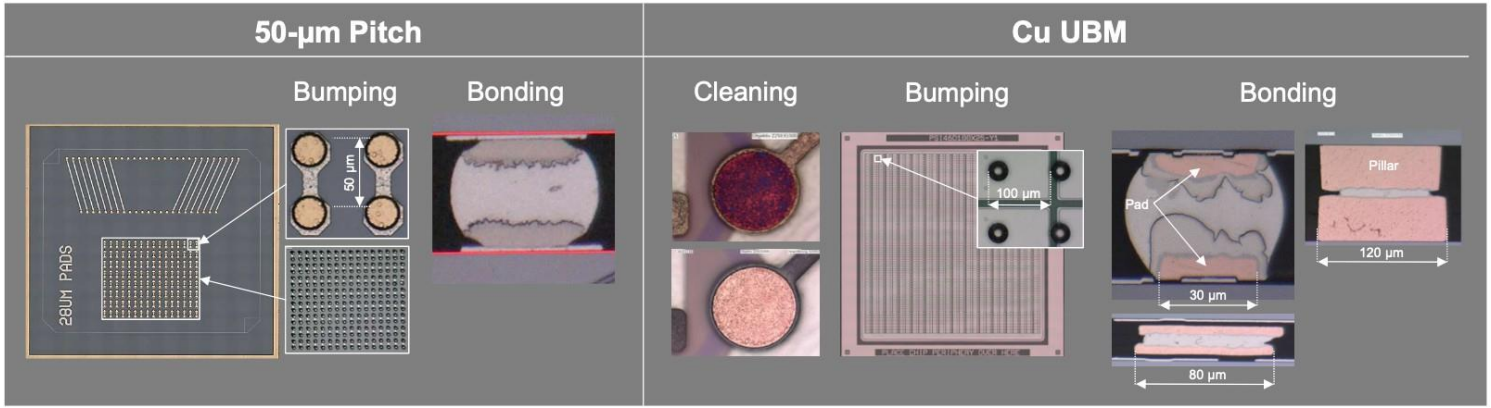
Scaling-up to Terabit/s, advanced algorithms, detector intelligence

Novel engineering techniques

High-density electronic integration, micro-fabrication, thermo-mechanical designs

Electronics packaging and microfabrication

Advancing Bump Bonding: Towards smaller pitches and copper metallization



- All processes in-house available now
- Ball placement, bonding & reflow tested for 50 µm pitch & Cu under-bump metallization (UBM)
- First Cu UBM application for the upcoming CMS Pixel Luminosity Telescope

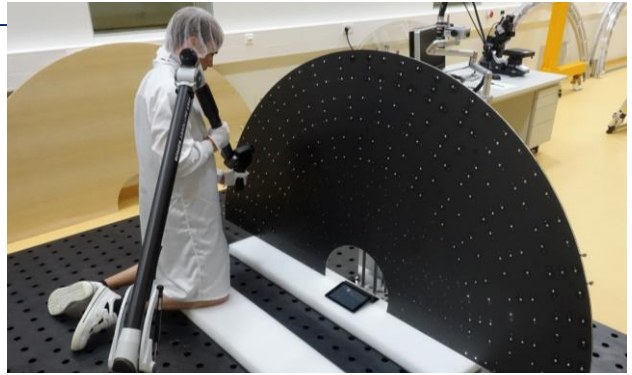
Fine-pitch copper cable for CBM tracker

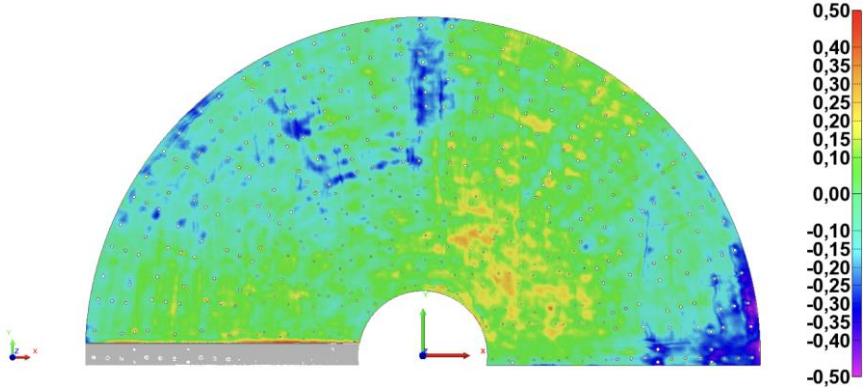
DTS talk: P. Pfistner

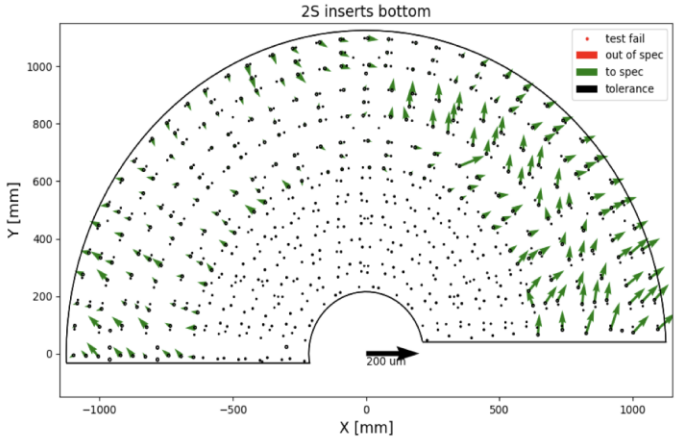
Novel engineering techniques

Local support structures

- First full-size prototype of highly-integrated local support structure produced in industry available
  - Insert positions mostly within specifications
  - Flatness within specification
- Thermal characterization will be performed next



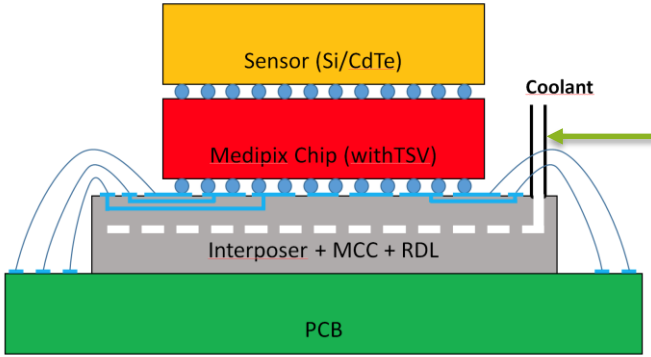


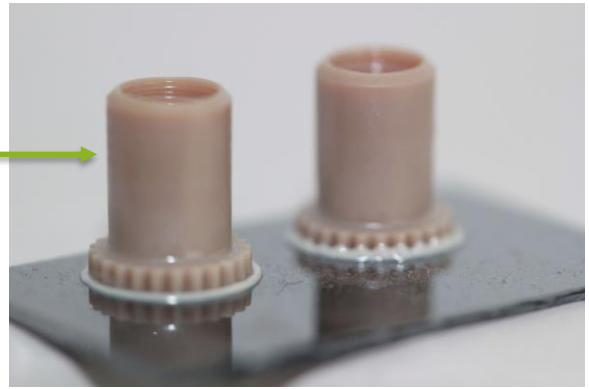


Novel engineering techniques

Micro-channel cooling for photon detectors

- Motivation: reduce the complexity, increase robust systems, fewer dead areas through TSVs
- Micro-channel cooling (MCC) demonstrator based on silicon interposer with redistribution layer (RDL) and integrated micro-channels
- Great interest from HEP and other communities





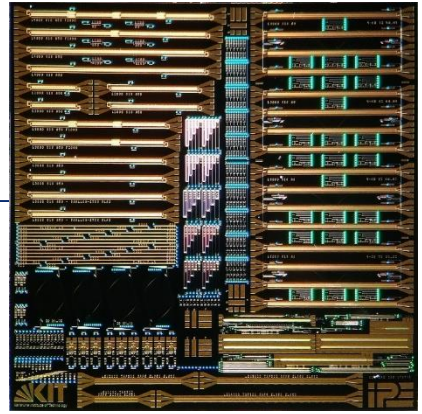
Advanced Data Transmission

Optical Data Transmission: Photonic WDM transmitter chips

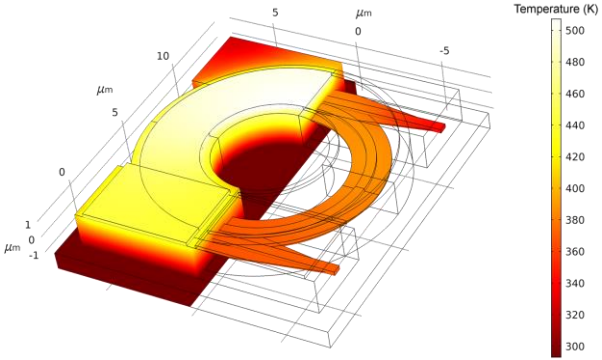
- Pioneering silicon photonics for detector instrumentation
- Motivation: less material, low power, radiation-hardness

- Designed a variety of optical components:
  Echelle gratings for (de-)multiplexing, Mach-Zehnder modulators, multimode-interferometers
- Exploring different fab, new process, new material

- ATTRACT project “SiPhoSpace – Radiation-tolerant high-speed optical data transmission for space applications”, Phase 1 finished



Transmitter demonstrator
9.3 × 9.3 mm²



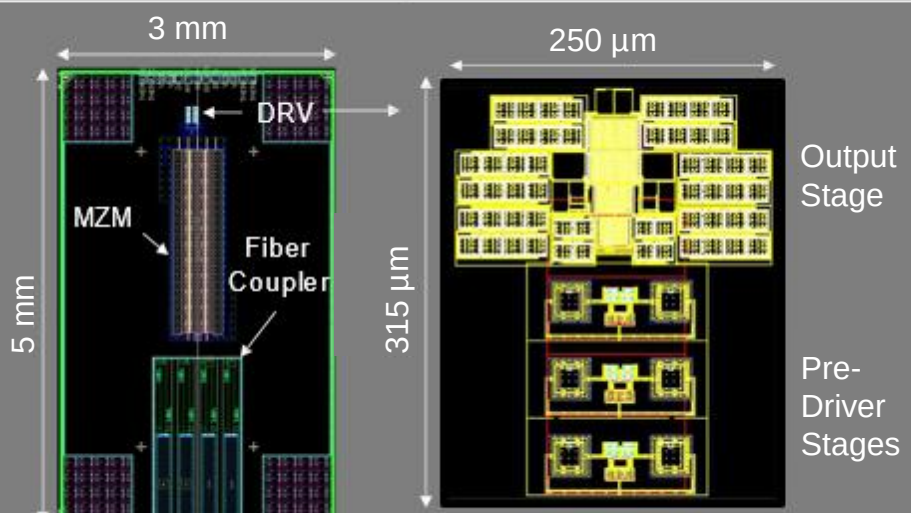
Ring modulator

Advanced Data Transmission

Silicon photonics design in GF's 90-nm CMOS

Goal: monolitic integration of Si-proven active and passive electro-optical devices (modulator, couplers, Ge-PDs) in O or C band

1st Layout Blocks



- MZM:
  - Bandwidth up to 30 GHz
  - $V_\pi L$ = 1.6V-cm
  - IL_{F2MZM} = 4.5 dB
  - ER = 7 dB
- Driver:
  - Output Swing 2 or 4 V_{p-p}
  - Power = 8.6 pJ/bit @ 20 Gbps
  - BER ≤ 10^{-12}
- Receiver:
  - PD 1.0 A/W at -1 V
  - Output Swing: 500 mV_{p-p}
  - Power: 10.7 pJ/bit @ 20 Gbps

DAQ for superconducting sensors (MMCs)

Measuring with highest resolution

- DAQ is extremely challenging and requires high-performance online processing
- First set of fully functional boards available

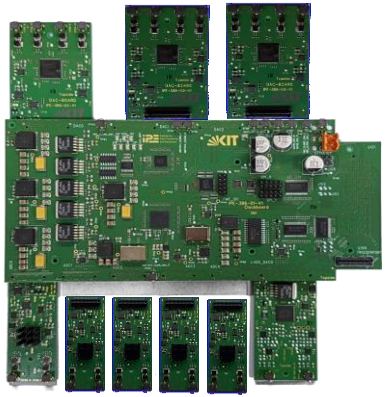
Applications:

- Neutrino physics: Baseline for readout in ECHo-100k *– first milestone in 2022*
- Astro/CMB: candidate for Qubic and LLAMA
  – double PhD program with UNSAM, Argent.
- Spin-off: Quantum Computing

DTS talks: R. Gartmann, L. Ferreyro

HiFlex-2 MPSoC board

RF conversion V3.0



Modular conversion stage

Channels	400
Pixels	800
Freq. range	4-8 GHz
ADC	5x2x1 GSPS
DAC	3x4x2.8 GSPS
LVDS DAC	2x500 MSPS
Raw data in	20 GB/s

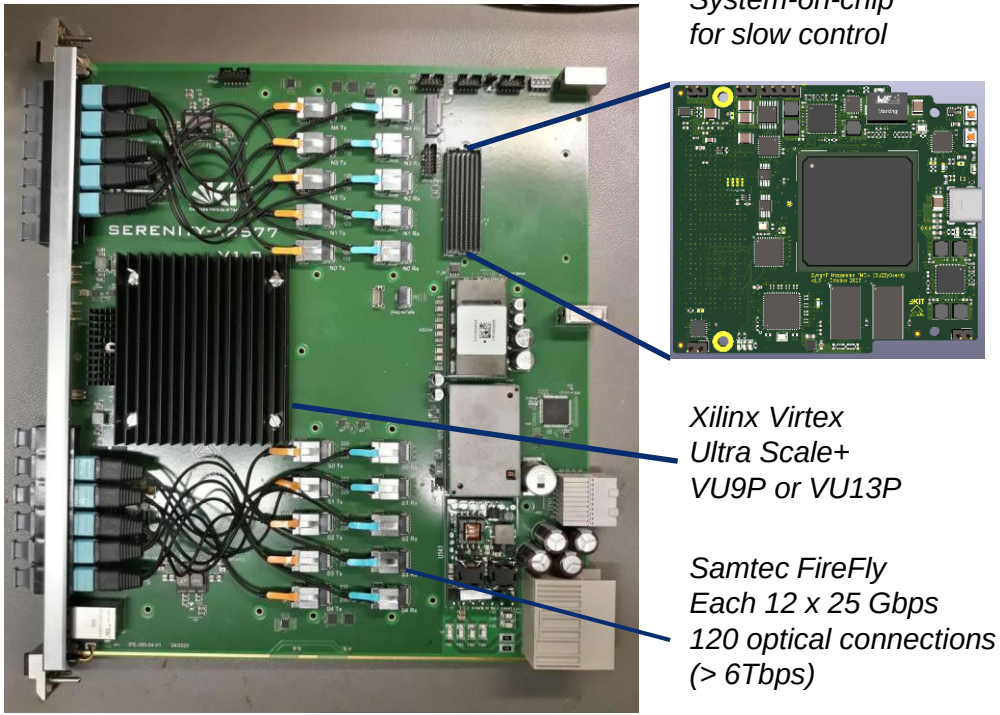
DAQ for next generation particle physics

Managing highest data rates and trigger at Tb/s

- Scalable DAQ platform for advanced algorithms
- Extreme data bandwidth and highly complex FPGA
- Powerful and flexible ZynqUS+ mezzanine for management and slow control

Applications:

- CMS Track Trigger
- KATRIN upgrade TRISTAN



System-on-chip for slow control

Xilinx Virtex Ultra Scale+ VU9P or VU13P

Samtec FireFly Each 12 x 25 Gbps 120 optical connections (> 6Tbps)

DTS talks: L. Ardila, T. Dritschler, S. Bähr

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ST3 – Science Systems

Recent Highlights and Outlook

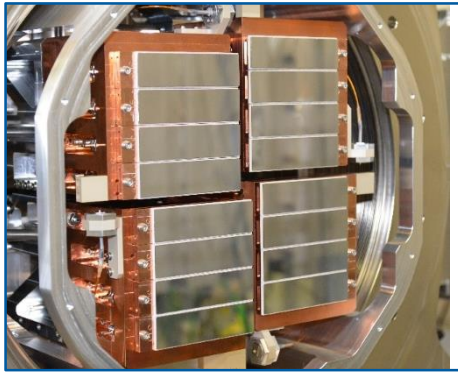
ST3 – Science systems

Build and characterize demonstrator systems ready for science

Particle physics

Ultra-low material silicon detectors with excellent time and spatial resolution

MU



Photon Science

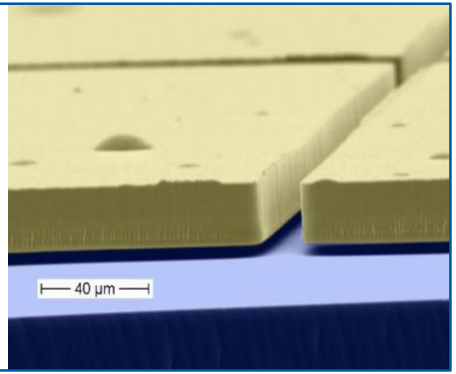
Megapixel detectors for soft X-rays, high-Z detectors,
MHz- frame rates

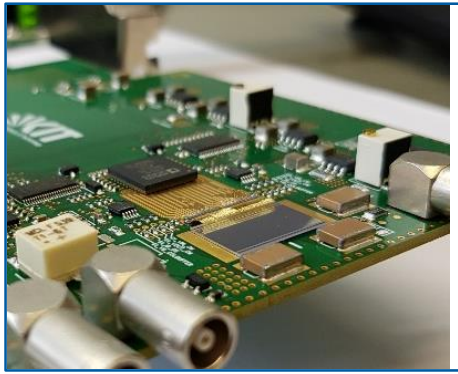
MML

Astroparticle physics

Cryogenic detectors of unique energy resolution for dark matter searches and neutrino physics

MU





Beam physics

Multi-spectral THz detectors for beam diagnostics,
6D THz camera

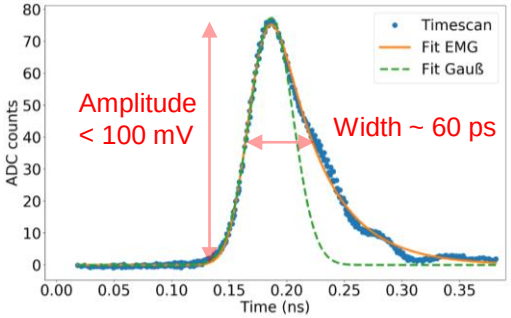
MTARD

Beam Physics

Diagnostic detectors for extreme beam conditions

- KAPTURE version 2
  - Local sampling frequency > 300 GS/s with a pulse rate of 1 GPulse/s, with excellent SNR
  - Commissioning to *KARA*

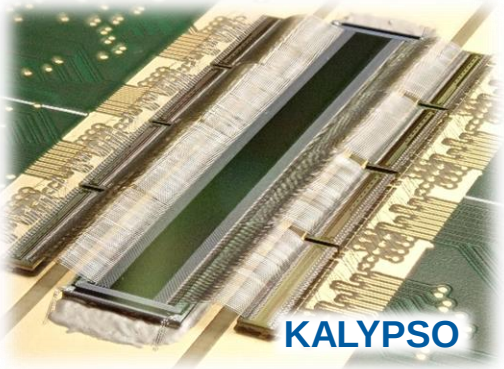
DTS talk: A. Ebersoldt



Ultra-short pulse from THz sensor sampled by ***Kapture v.2***

DTS talk: M. Patil

- KALYPSO version 2
  - 1024 pixels @ 25 µm, wide spectrum sensitivity (300 nm – 5 µm)
  - First fine pitch TI-LGAD for beam diagnostics
  - Commissioning of several systems to *KARA*
  - Commissioning to Kiel/DESY for beamline diagnostics at *FLASH*

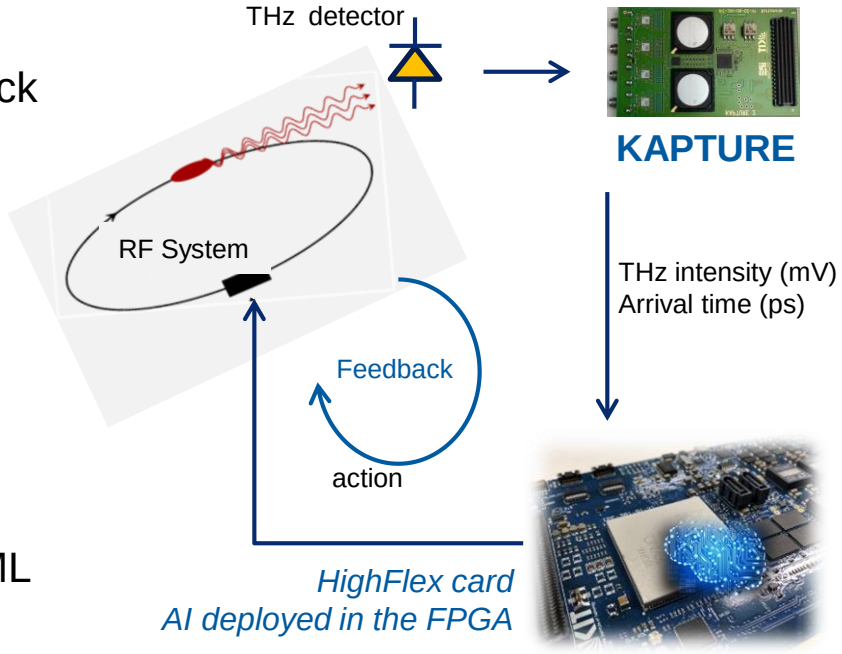


Beam Physics

Machine Learning toward Autonomous Accelerators

- **Motivation:** to stabilize the high-brilliance THz beam source by an intelligent longitudinal feedback system based on Reinforcement Learning (RL)
- **Target applications:** KARA, FLUTE, ARES and more
- **Status**: first beam control on FPGA developed within *AMALEA* → will continue in ACCLAIM (Helmholtz Innovation fund)
- Relevant experience in the development of fast ML inference deployed in FPGA and design of sophisticated custom readout cards optimized for AI applications

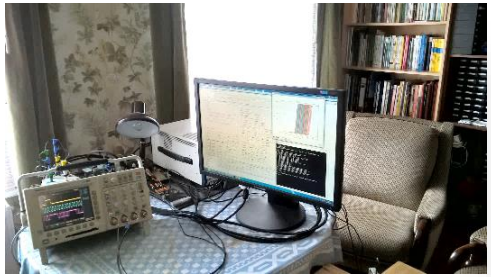
DTS talk: A. Ebersoldt



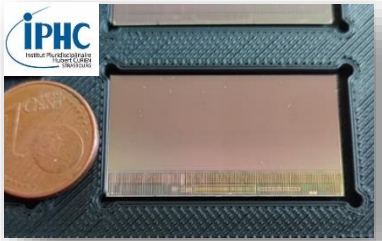
From sensors to systems

MIMOSIS: CMOS Sensor

- Design goals: spatial precision < 5 µm, time resolution < 5 µs at low power
- Applications: CBM and more
  (CREMLIN+, Higgs-factory, FAIR upgrade, …)



MIMOSIS-1, DAQ R&D



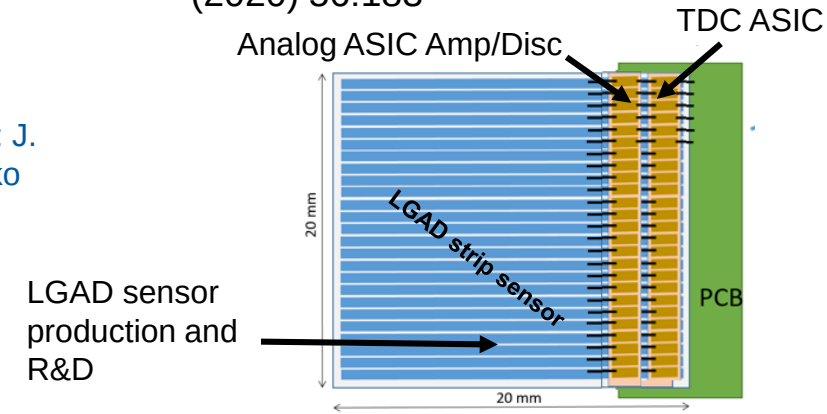
MIMOSIS-1, 60µm thick

- Status: full-size prototype MIMOSIS-1 available, promising first test results

LGADs

- Design goals: time resolution 20-30 ps, spatial precision < 30 µm for 4D tracking
- Applications: HADES Forward Wall system, T0 system for CBM @ FAIR (+ many more)
- Publication: J. Pietraszko et al., Eur. Phys. J. A (2020) 56:183

DTS talk: J. Pietraszko

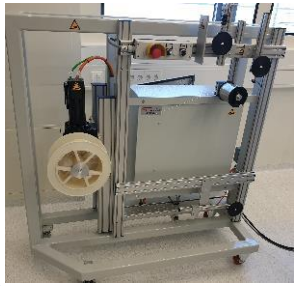
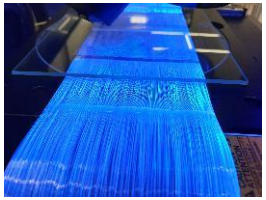
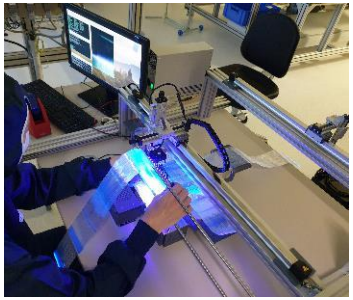


LGAD sensor production and R&D

Scintillating Fiber Tracker

4D-tracking at high rate with high dynamic range

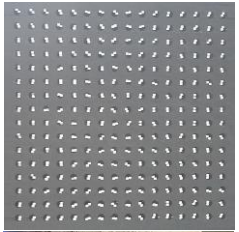
Upgrade infrastructure

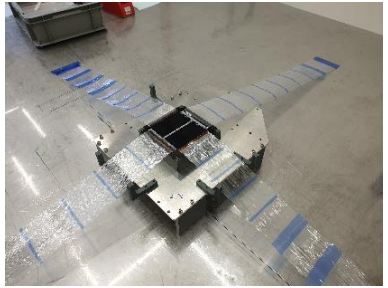





DTS talk: C. Ceasar

Ongoing and finished detector production





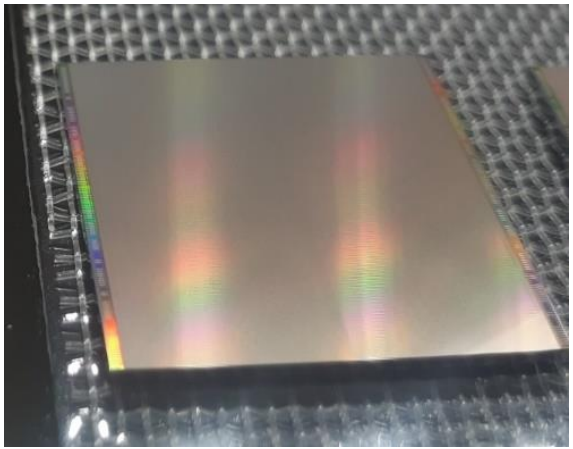


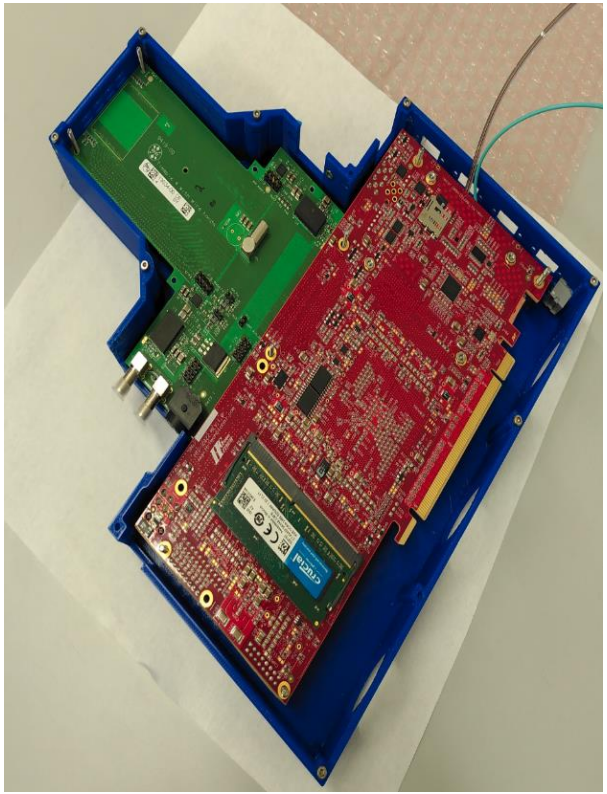
Testing glue / materials

Photon Science

Timepix4 readout electronics

- Timepix4 chip recently produced at CERN with timestamping and photon counting modes
- Single-chip readout system in development
  - Suitable for a variety of experiments
  - Test of high-speed readout (5-10 Gigabit on-chip transceivers, fast FPGA, 100 Gigabit Ethernet)





DTS talk: D. Pennicard

Photon Science

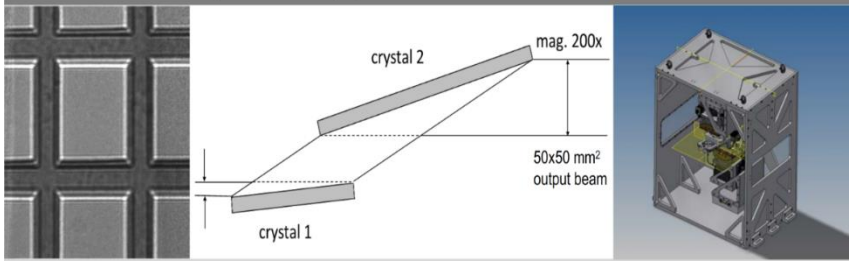
Applications of high-Z detector: Bragg Magnifier

- Implementation of high-Z semiconductor detectors
- Highly efficient detectors allow low-dose imaging
- Bragg Magnifiers yield high-resolution X-ray microscopy (< 1 µm)

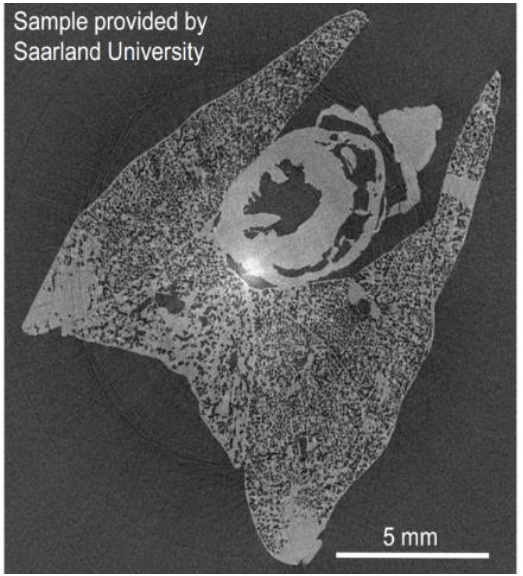
Bragg Magnifier Optics Coupled to High-Z Medipix Detector for High Resolution and Dose-Efficient X-Ray Imaging at Synchrotrons

H. Hessdorfer, E. Hamann, R. Pretzsch, M. Hurst, V. Bellucci, P. Vagovic, M. Fiederle and T. Baumbach

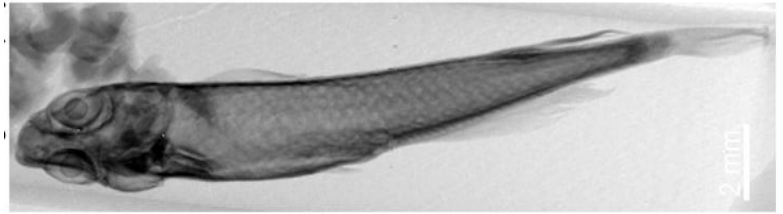
Institute for Photon Science and Synchrotron Radiation (IPS)



DTS talk: M. Fiederle



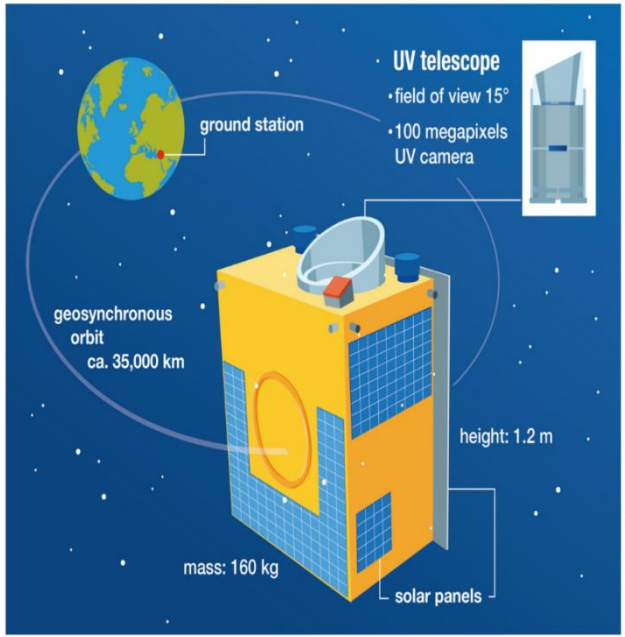
Images recorded with X-Spectrum GaAs LAMBDA 250k, 512x512 pixels, 55 µm pixel size

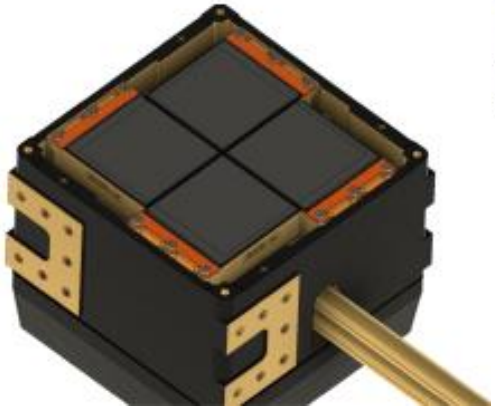


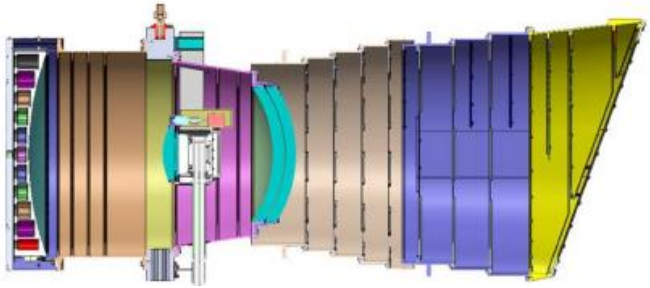
ULTRASAT Mission

Looking at supernova explosions, colliding neutron stars and black holes

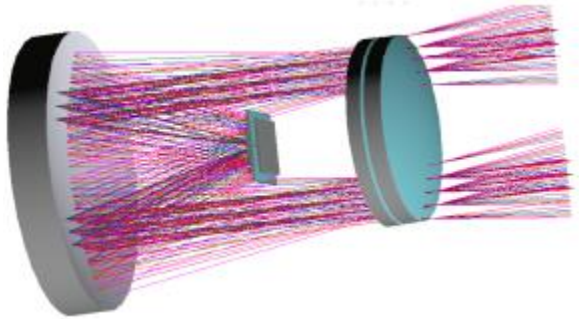
- 200 deg² field of view
- 220-280 nm UV sensitivity







- *91M pixel camera at focal plane*
- *Custom back-side illuminated CMOS*



Distributed Detector Laboratory (DDL)

Map of high-tech facilities

Test beam facilities

Electron test beam

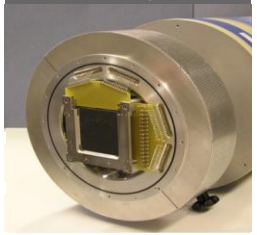
Photon test beam

Platform for heavy-ion test beams

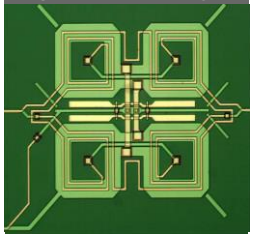
Sensor production facilities

Silicon sensor post-processing facility

High-Z semiconductor facility

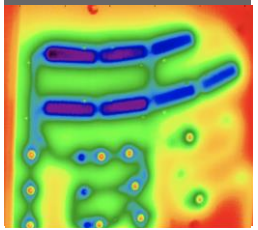


Cryogenic sensor production facility

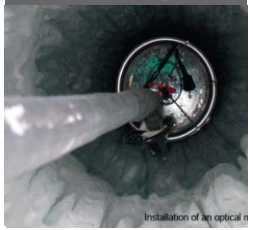


Detector integration, diagnostics and characterization

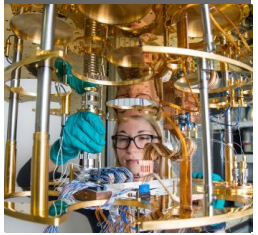
Advanced engineering center



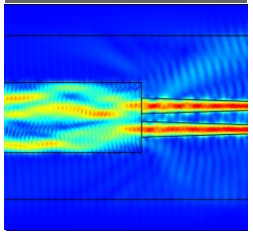
Extreme conditions laboratory



Cryogenic application center



Silicon photonics characterization



Competence center

Status of DDL

Proposal was presented to **Helmholtz FIS commission** on Feb. 18, 2020

- We are asked to elaborate more on user access, technology transfer and propose scenarios for funding in two phases

Refined proposal is ready

- Technology transfer offices of DESY, GSI, KIT and HI-Jena started supporting proposal: „*Industrial Links & Liaison @ Helmholtz Distributed Detector Laboratory (DDL*)“
- Detailed list of provided services, planned applications and further applications fields
- Further changes on societal impact, user access, longer funding time, risk analysis, …

Next **Helmholtz FIS commission only in 2022;** dead line for proposals mid 2021

Summary

- DTS had a great evaluation just one year ago.
- Corona has markedly changed the way we work and collaborate, but we are coping rather well.
- Although PoF IV has barely started, there is a wealth of results and activities already.
- The DDL proposal is of great strategic importance for DTS and MT. We have addressed the comments and are eagerly waiting for the next opportunity to submit the proposal.

- We are looking forward to an exciting and productive meeting.

Thank you!!