Detector R&D

Niels van Bakel

Nikhef

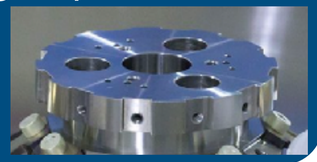
SAC Visit - June 5 - 2025

DR&D Group

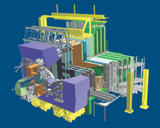
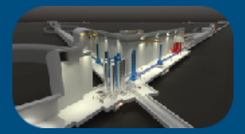
DR&D Program

Collaboration is key

Nikhef
Engineering departments

Nikhef
Experimental groups

Detector R&D strategy 2023:

- Smart and fast pixel detectors
- Gravitational wave detector instrumentation
- Blue-sky R&D

High-tech research institutes and industry

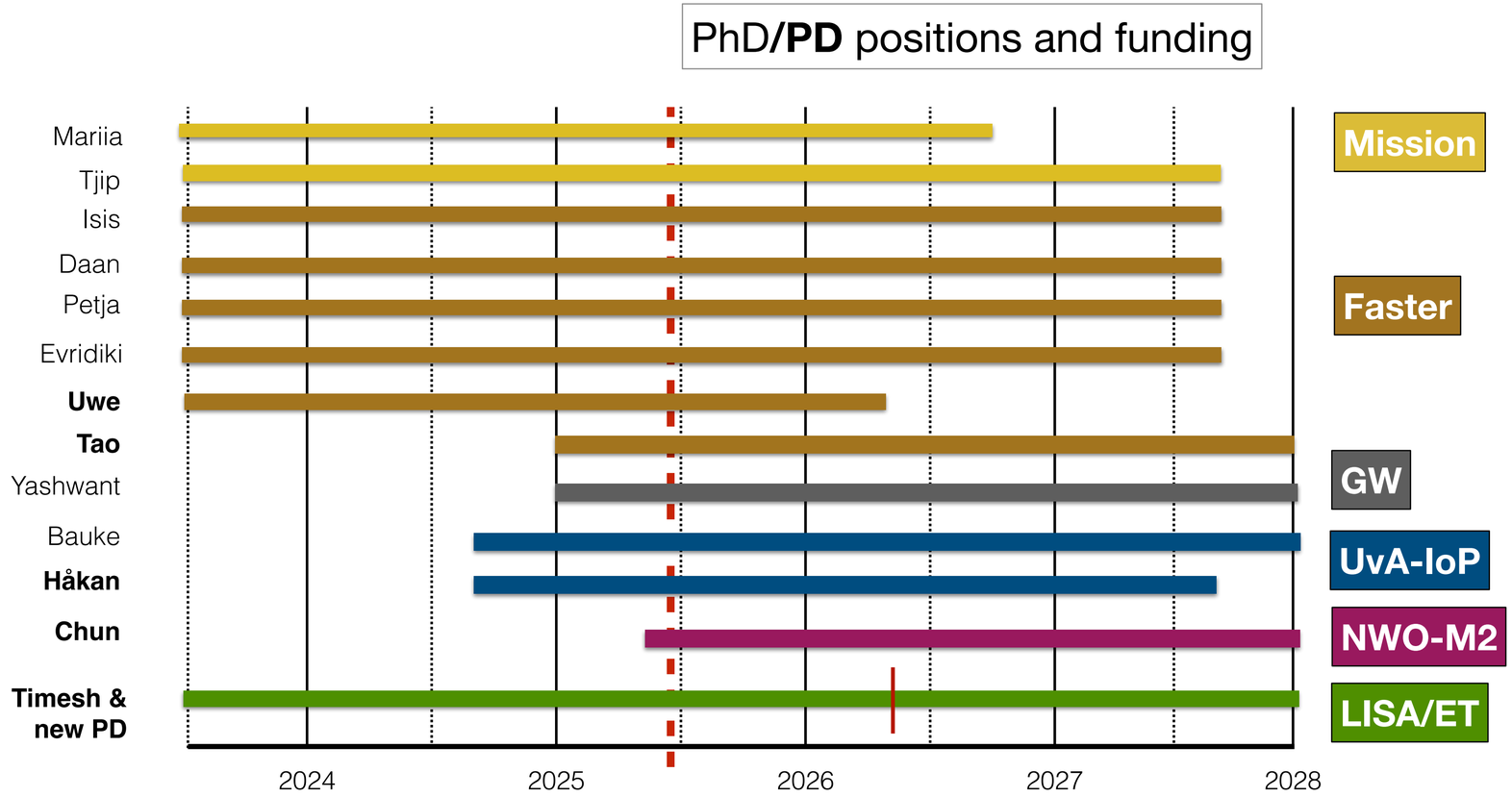
- Detector research requires substantial resources.
- Instrumentation grant proposals are often only awarded after initial seed investments by Nikhef.
- To stay at the forefront of technology, Nikhef invests, *and should keep investing*, in enabling technologies.

DR&D Group

Interplay with other groups

Current staff count:

- Niels v Bakel, Martin v Beuzekom, Martin Fransen, **Kevin Heijhoff**, and Matteo Tacca



SAC April 2023: " … *encourages Nikhef to continue developing an **impactful R&D plan for 4D-tracking devices, aligned with the DRD** collaborations being established in the international landscape, and to **explore opportunities to contribute to applications of 4D tracking outside of HEP**. While the areas of **quantum sensing and quantum technology** programs are rapidly emerging, the SAC advises Nikhef **to remain informed about ongoing efforts and initiatives** in the Netherlands and internationally, for example at CERN.…*"

DR&D Program

Resources and risks

- Currently, the funding situation is good.
  - Only 1.5 PhD is funded through Nikhef's mission budget, while all other PhDs and postdocs are supported by external funding.
  - The LISA/ET roadmap allocates budget for three postdocs and hardware to develop various photodiodes for LISA and ET.
  - The MEMS accelerometer secured funding for ASIC & MEMS submissions in collaboration with Nikhef spin-off Innoseis.
  - The phase camera and coating thermal noise setup are funded by the GW program.
- However, the FASTER PhDs and postdocs will all complete their research by 2027
  - Will have a significant impact on fast timing activities.
  - Start exploring a new funding proposal for detector research.
- Most external funding covers personnel costs (PhDs and postdocs) but not hardware
  - It is crucial to ensure sufficient hardware resources that align with the needs of the DR&D group, including funding for costly submissions and testing infrastructure.
  - We depend on the FASTTRACK LHC roadmap proposal to fund hardware for blue-sky research.

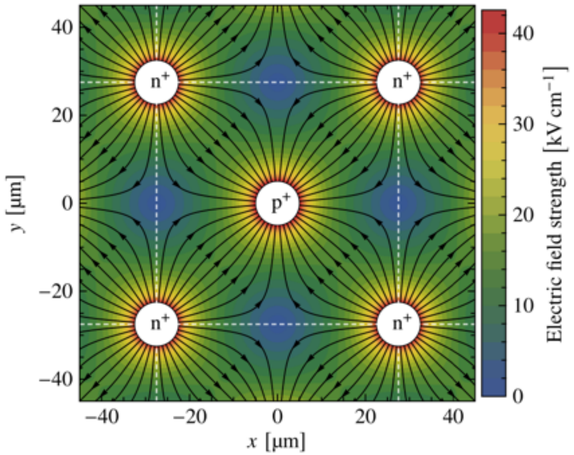
Ultrafast detectors for 4D tracking

To distinguish multiple particle interactions within a bunch crossing

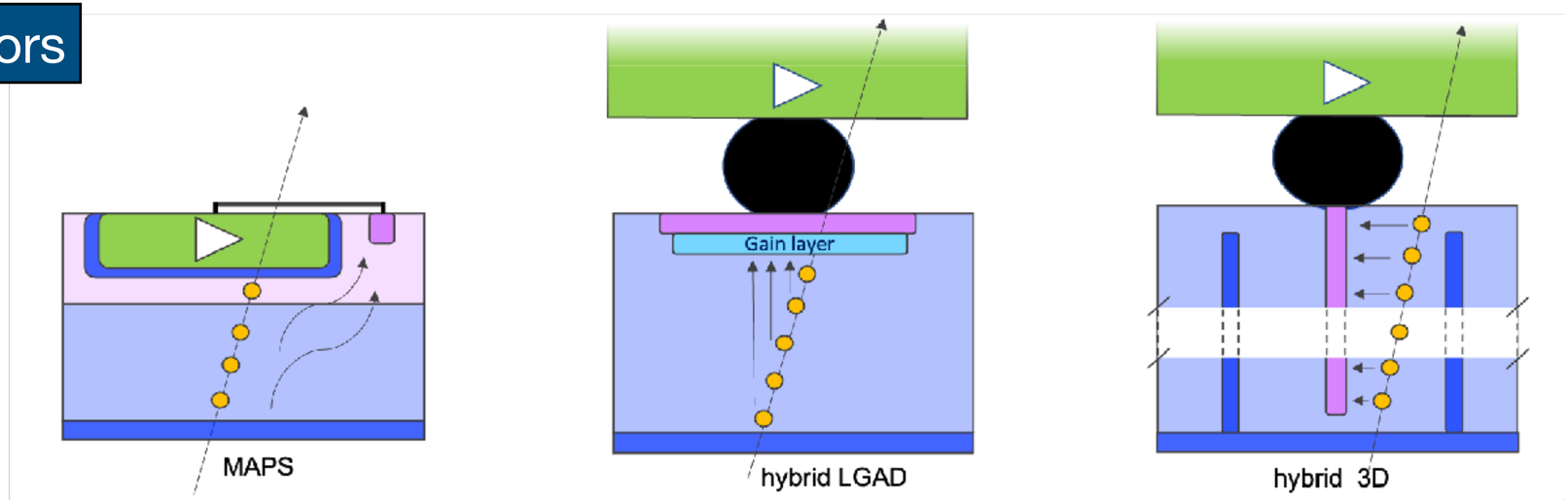
Goals

- Achieve a timing precision of 10–50 picoseconds for tracking detectors with small pixels
- Develop new hybrid sensors with better spatial resolution, and explore the possibility of gain.
- Optimise Monolithic Active Pixel Sensors (MAPS) for improved timing resolution and radiation hardness.

Simulations



Fast sensors

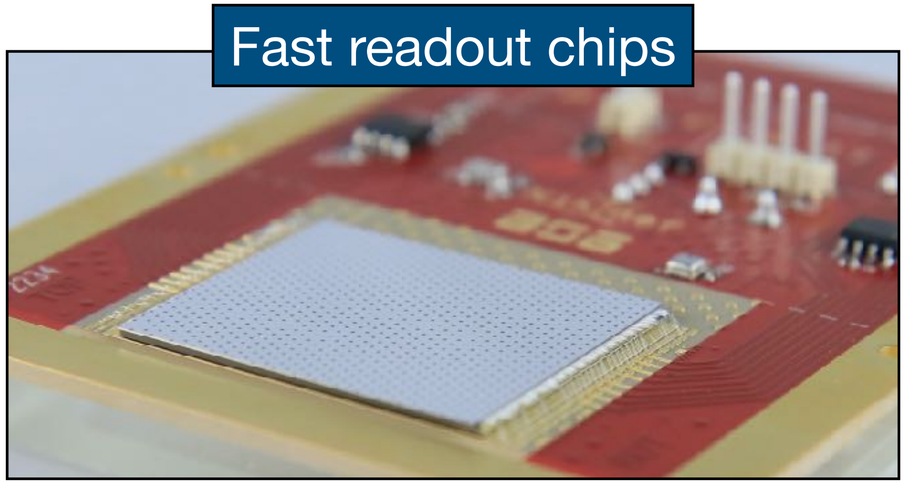


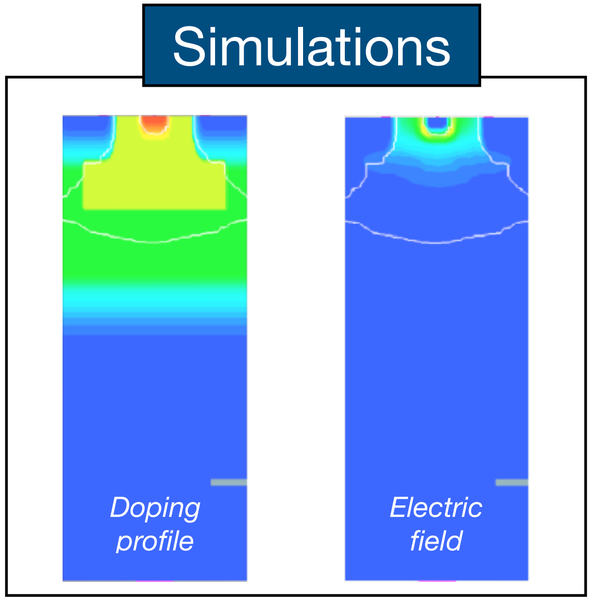
Involved in Medipix, AIDAinnova, CERN R&D, and ECFA DRD (2,3,5,7 & 8)

Ultrafast detectors for 4D tracking

Recent achievements I

- **Fast Sensors**:
  - Developing various sensor technologies and characterized them in test-beams at CERN: 3D, inverted LGAD, trench-isolated LGAD, HV-MAPS, high-resistivity MAPS (Alpide).
  - Determined time resolution (TPX4, APTS, DPTS)—currently at 100 ps for some technologies, aiming for 50 ps in a couple of years.
- **Sensor Modeling**:
  - Studied geometric gain in a 3D sensor, understanding efficiency and gain of TI-LGAD, and developed a first-order model for charge collection efficiency in MAPS.
  - Ongoing work includes simulations for deep-junction LGAD and a Silicon Electron Multiplier sensor.



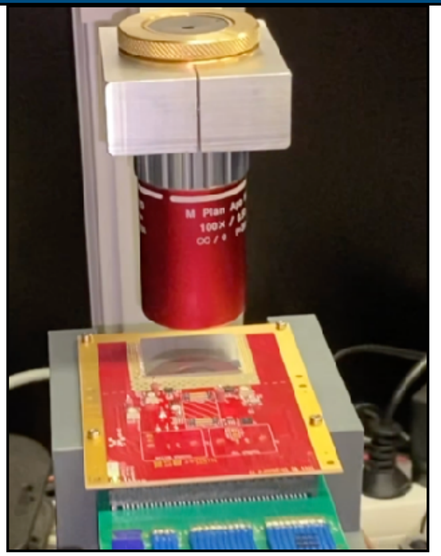


Ultrafast detectors for 4D tracking

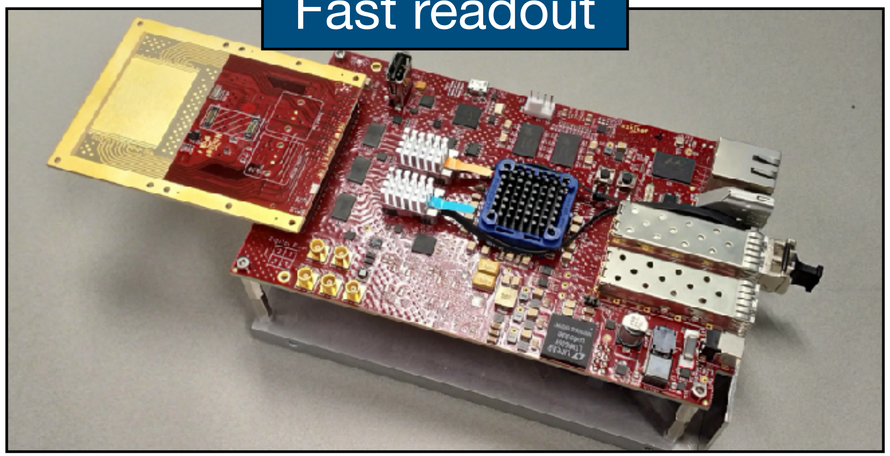
Recent achievements II

- **Infrastructure**:
  - Made the TPX4 beam telescope fully operational (NIM paper submitted).
  - Re-commissioned the two-photon-absorption laser setup with a modified laser.
  - Developed a fast electron (MIP) detector characterization setup.
- **ASIC Performance**:
  - Characterized TPX4 and MOST readout ASICs in detail—implemented corrections to improve time resolution, including time-walk and VCO corrections.
- **SPIDR4 Readout**:
  - Achieved higher bandwidth—5 Gbps per link is stable, aiming for 10 Gbps.

Two-Photon-Absorption Laser



Fast readout



Ultrafast detectors for 4D tracking

Short & Long term goals

- **Short-term goals** for the coming year
  - Gaining a deeper understanding of the limitations of new hybrid and monolithic sensors and readout electronics, for large and complex detector systems.
  - Design ASIC blocks for readout chips with fast timing: PicoPix and Mosaix.
  - Start development of a test environment for the new PicoPix readout chip.
- **Long term goals** for the coming five years
  - Achieve a timing resolution of 50 ps or better with silicon trackers within five years, with a longer-term goal of reaching around 10 ps, which is primarily relevant for the FCC-hh.
  - Relies heavily on sensor modeling and the development of new sensor production processes.

Ultrafast detectors for 4D tracking

Blue sky R&D

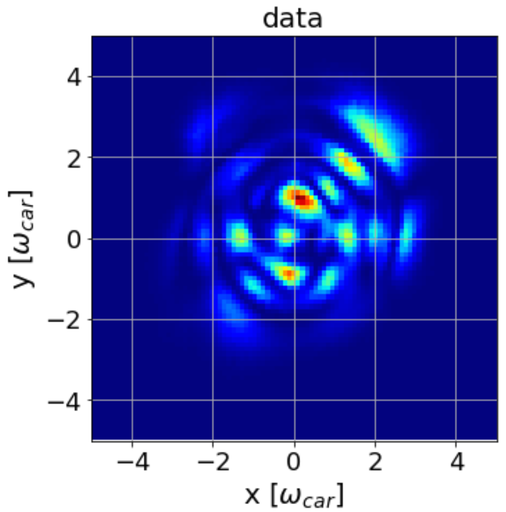
- Alternative (for industry non-standard) sensor doping profiles and geometry.
- Integrate part of the electronics in the sensor layer to separate functionality.
- Alternative sensor materials (e.g. SiC)
- Alternative methods and structures for measuring with precise timing the passage of particles.
- Exploration of new detector technologies, such as “quantum sensors”

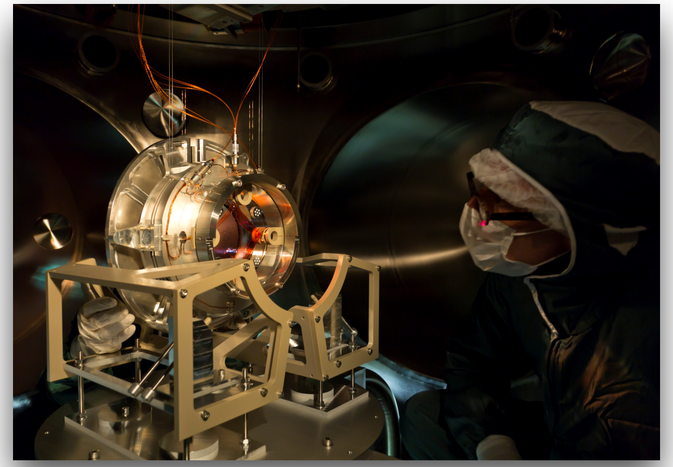
Gravitational wave detector instrumentation

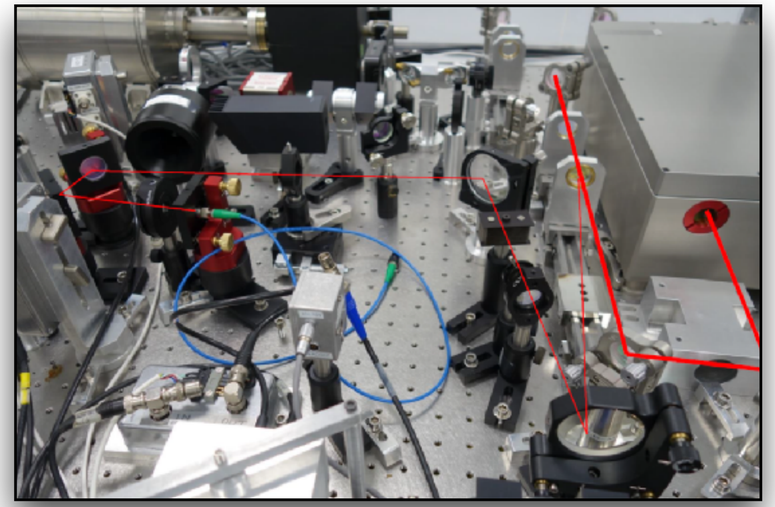
Improving the sensitivity

Goals

- Make available a cryogenic facility for the GW community to measure the thermal noise of coating samples directly.
- Upgrade the Nikhef phase camera, used to correct for the thermal aberrations introduced by the increased circulating optical power, to allow absolute phase measurements.
- Develop the quadrant photodiode (QPD) systems for LISA, Virgo, and ET.

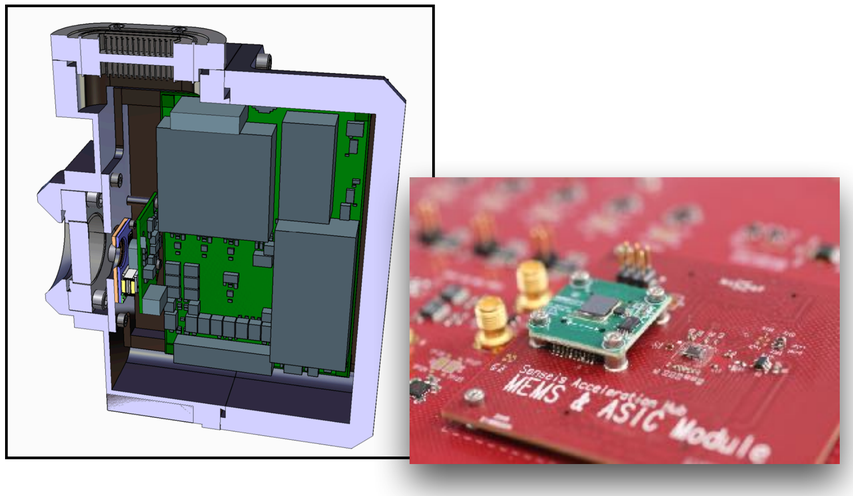




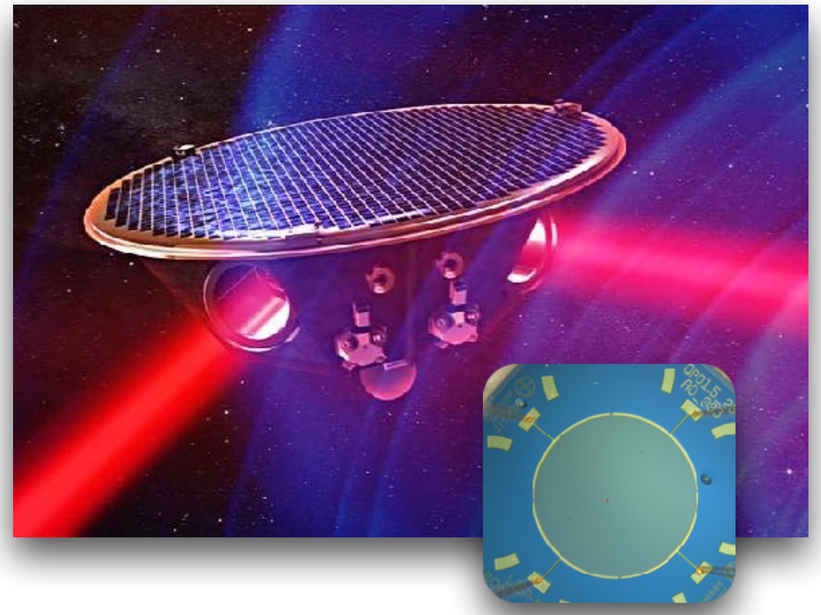


Gravitational wave detector instrumentation

Recent achievements



- **Virgo DC QPD Upgrade**:
  - Upgrading the Virgo DC QPD systems to significantly reduce scattered light. A new readout board has been designed and fabricated.
- **Phase Camera Development**:
  - Developing a phase camera (PC) to address thermal lensing issues and optimizing the Virgo detector's performance. A prototype is currently operational in the optics lab to analyse PC images in collaboration with Sioux.
- **MEMS Accelerometer**:
  - CMOS readout for a MEMS accelerometer for the Einstein Telescope (ET). The latest readout ASIC is currently under test with a MEMS sensor.
- **LISA Quadrant Photodiodes (QPDs)**:
  - Tests of the second batch of LISA QPDs show high dark current issues that remain unexplained—additional fabrication runs will be necessary.
  - New readout electronics has been designed for large-area LISA QPDs intended for ETpathfinder.



Gravitational wave detector instrumentation

Short & long term goals

- **Short-term goals** for the coming year
  - Sensors for GW: Upgrade the Virgo DC QPD systems, submit the next MEMS readout ASIC, and test the LISA QPR engineering model, including a new Run 2 QPD that meets specifications.
  - Build an additional phase camera with upgraded hardware and a phase noise cancellation system.
  - The thermal-coating noise set-up operational in the DR&D labs.
- **Long term goals** for the coming five years
  - A functional readout chip for the MEMS that meets the sensitivity requirements for both scientific applications (Einstein Telescope) and industrial applications (Innoseis).
  - Testing and delivering the LISA QPR Flight Models according to the LISA planning, along with a detailed performance model of the QPR system.
  - Develop photodiodes for long wavelength light for the Einstein Telescope.
  - Build another Phase Camera for Virgo, including image analysis, and integrate the phase camera into the control system of the Virgo interferometer.

DR&D strategy

Short & Long term goals

- **Short-term goals** for the coming year
  - Assessing the future needs of the Nikhef Astroparticle Physics (APP) groups for after the next five years.
  - Exploring the potential contributions of Quantum Sensing and Emerging Technologies (DRD5) to various Nikhef research programs.
  - Proposal to hire new PhD's and postdocs: '*Fast sensors*'.
- **Long term goals** for the coming five years
  - New instrumentation developments to support the diverse Nikhef science programs, ensuring that in five years there remains a relevant R&D program that can attract students and secure funding.
  - **Blue-sky research**: initiate exploratory 'seed' projects.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