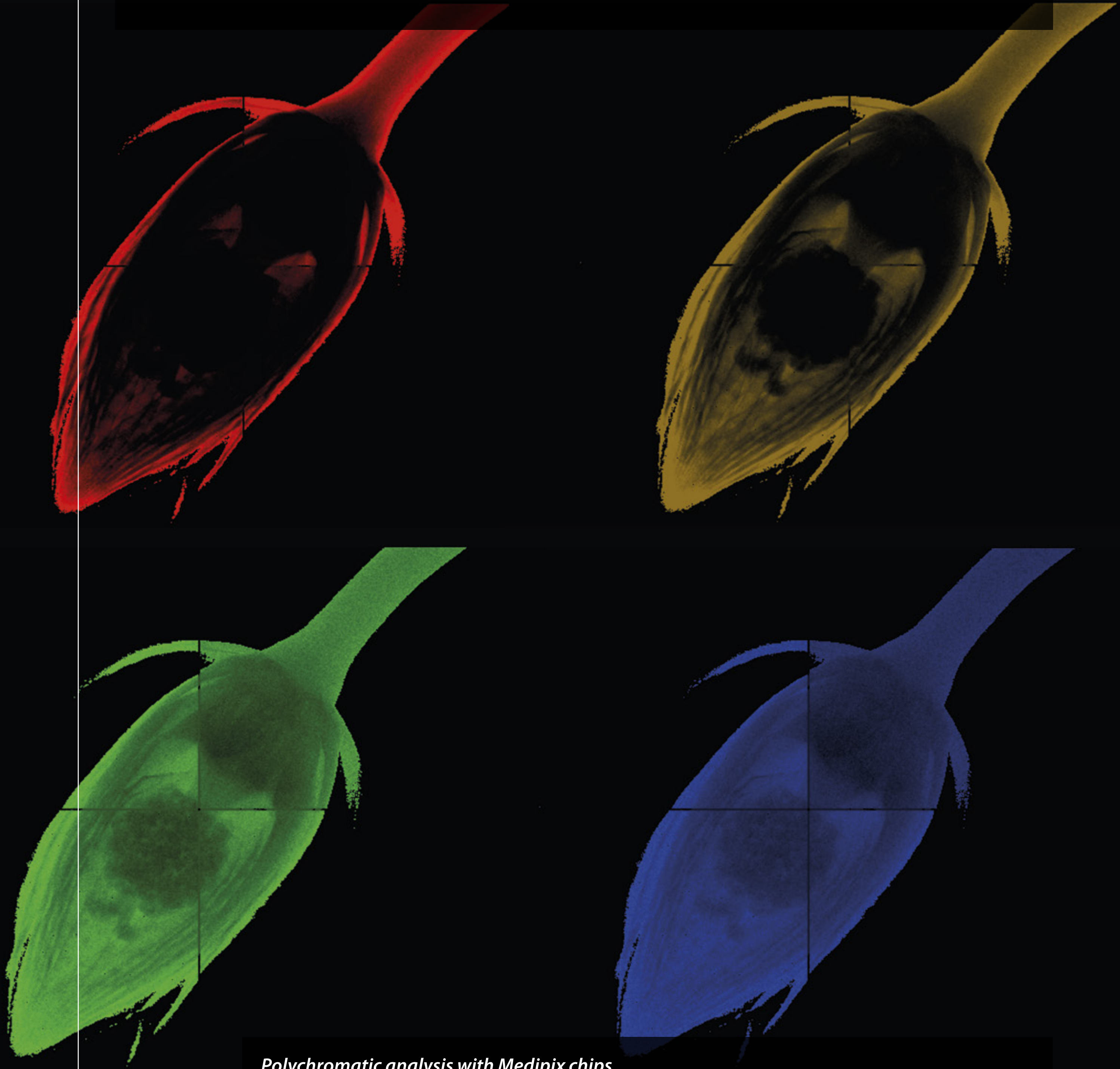
Detector R&D



Polychromatic analysis with Medipix chips.
By using polychromatic x-rays it becomes visible how Rontgen absorption is strongly energy-dependent. Shown here are Rontgen photo's of a flower bud of about 2 cm with photon energies of 7 keV till 25 keV. Red corresponds here to 7 keV and blue to 25 keV. The detector is made of 4 Timepix chips with a 0.3 mm silicon sensor, read-out by a Nikhef ReLaXd system. Timepix chips are developed by the Medipix collaboration of which Nikhef is a member. Special of this setup is the combination of excellent spatial and spectral resolution,

Figure 1. Project leader Martin van Beuzekom together with electronics engineers Bas van der Heijden and Guido Visser, and chip designer Vladimir Gromov (shown right to left) next to the Velopix test stand at Nikhef.

Management
dr. N. van Bakel

Answering the biggest mysteries in physics requires pioneering experiments. New instrumentation ideas need to be initiated and developed long before they can be implemented in Nikhef's scientific experiments. Two examples are presented here. In addition, today's push for knowledge transfer to industry leads to international cross-disciplinairy collaborations. Nikhef's role in such scientific instrumentation consortia is highlighted at the end of this section.

Particle tracking with forty million 'smart' images per second

The LHCb collaboration decided already in 2013 to replace the current silicon microstrip detectors in the Vertex Locator (VELO) detector,with a new pixel detector in 2019. The VELO looks closely at the collision region to reconstruct the particle interaction vertices with micrometer precision. After the upgrade, LHCb should be able to read out all collision events at the full rate of 40 MHz, an order of magnitude more data than was foreseen with the current set-up.

The new VELO detector will operate only a few millimetres from the LHC beams, exposing the pixel detector to a high flux of particles. Hence, the VELO will accommodate forty million pixels, each measuring 55 square micrometer, and requires new readout electronics that can handle data rates around 2.5 Tbits/s. To develop state-of-the-art pixel electronics, the DR&D group is closely involved in the Medipix/Timepix collaboration since 1998. The VeloPix chip has been developed for LHCb's new pixel detector and is derived from the Timepix3 chip, however the VeloPix is further optimised for speed and radiation hardness. The chip readout is data driven and zero suppressed: meaning that only pixels with data are readout without instruction from a central control unit. In order to meet the huge data output rate requirement while keeping the power consumption within the budget a dedicated 5.12 Gbit/s output serialiser, the GWT (Gigabit Wireline Transmitter), has been developed.

Each Velopix chip reads out an array of 256 by 256 pixels, is designed in a 130 nm CMOS technology, and a total of 624 chips are needed for the full VELO readout. In order to ensure cooling of the chips within the LHC secondary vacuum the power consumption is limited to less than 3 Watts per chip.

The ASIC was submitted in May 2016 and the first wafers were delivered in September 2016. Excellent results have so far been obtained from the validation testing. Measurements of the noise and threshold uniformity conform to expectations from simulation and promise low threshold operation (below 1,000 electrons). Also the power consumption is about a factor two lower than accounted for. A first assembly with a VeloPix bump bonded to a 200 micrometer thick Silicon sensor has been successfully tested with a charged particle beam at the SPS at CERN, using our SPIDR readout system. The radiation qualification of the Velopix chip is ongoing.

A new vacuum electron multiplier

By placing, in vacuum, a stack of transmission dynodes (tynodes) on top of a CMOS pixel chip, a single free electron detector could be made with outstanding performance in terms of spatial and time resolution. The essential enabling element is the tynode: an ultra (5 nm) thin membrane, which emits, at the impact of an energetic electron on one side, a multiple of electrons at the other side. This defines the Transmission Secondary Electron Yield (TSEY). By means of Micro Electro Mechanical System (MEMS) technology, tynodes and test samples have been realised. The electron yields of tynodes have been measured and calculated by means of GEANT-4 Monte Carlo simulations, applying special low-energy extensions. The secondary electron yield of several samples has been measured and the maximum yields 5.5 .

With a stack of tynodes mentioned above, a practical vacuum electron multiplier could be made: placed on top of a pixel chip, a new generic digital With a stack of tynodes mentioned above, a practical vacuum electron single electron detector is within reach. By capping the system with a traditional photocathode, a highly sensitive single soft photoncounter (Timed Photon Counter TiPC 'Tipsy') can be realised. The time resolution of this device can be in the order of a few ps since the electron crossing paths between two tynodesis straight, uniform and two orders of magnitude smaller than in photomultipliers

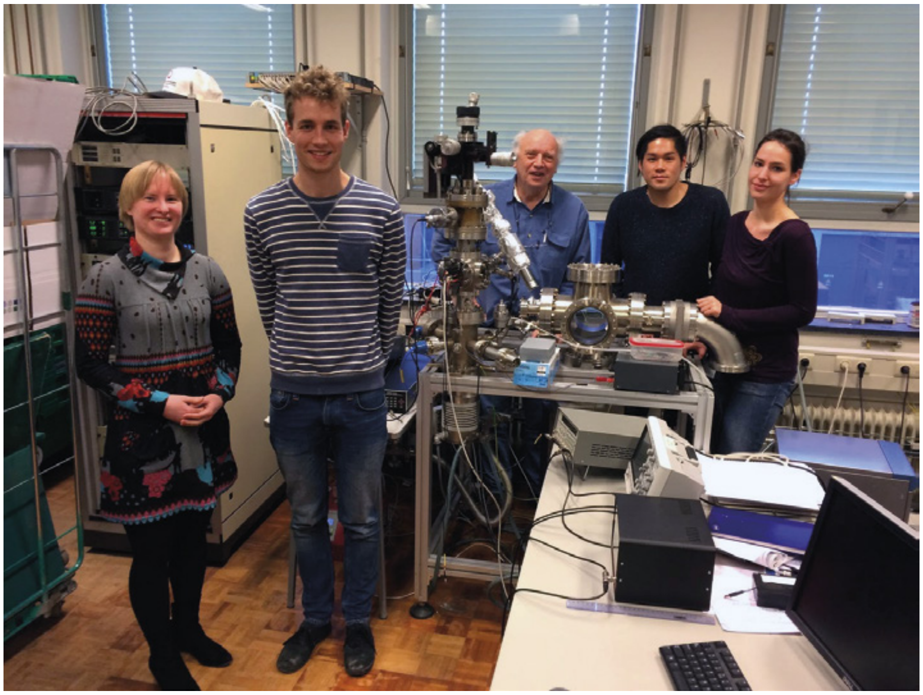


Figure 2. The MEMBrane Group (left to right): Annemarie Theulings (PhD), Wouter de Landgraaf (master student), Harry van der Graaf, Hong-Wah Chan (PhD), Violeta Prodanovic (PhD) around the DyTest: a vacuum chamber with electron gun and four bare TimePix chips, used to measure the Transmission Secondary Electron Yield (TSEY).

Figure 3. Participants of the Annual ENLIGHT Meeting and Training Event, held in Utrecht

With a TSEY of 5.5, a stack of 5 tynodes results in charge pulses of 5,000 electrons, enough to drive the pixel circuitry of the Timepix3 chip. By manually stacking these tynodes onto the pixel chip, a hybrid Tipsy prototype can be made. A stack of 6 of these tynodes would create 27,000 electrons, enough to drive the circuitry of an all-digital CMOS pixel chip, omitting an amplifier per pixel. After that, MEMS wafer post-processing could be developed to create monolithic detectors. In parallel, the search for higher TSEY at lower primary energy should continue, reducing the required number of tynodes.

Highlights

- In June 2016 we have pitched three “Trends, Wishes and Dreams” at the ATTRACT Symposium on Detection and Imaging Technologies. ATTRACT is a new pan-EU initiative to accelerate the development of these technologies for market – through a process of co-innovation with other labs, SMEs, industry and universities. The pitch on *Smart pixels* foresees a large impact on single photon counting and spectral X-ray imaging for medical and industrial tomography systems. The second pitch on *A pixelised detector for thermal neutrons* describes a new generation of neutron detectors with ground-breaking properties. Specifically we expect to realise new generation of detectors by combining CMOS pixel chips with MEMS-built structures, and push for a time resolution down to the picosecond regime. With *The sixth sense: a new detector to observe the universe* we propose detector systems based on novel opto-electronics, (MEMS) accelerometers, and sensitive readout electronics to reduce limiting noise sources in laser interferometry, especially at low frequencies.
- In September 2016 we organised the ENLIGHT Annual Meeting and Training Event. The ENLIGHT network coordinates European efforts in hadron therapy, so that traditionally separate communities like clinicians, physicists, biologists and engineers with experience and interest in particle therapy are working together. Hadrontherapy allows a precise definition of the specific region to be irradiated. This means a tumour can be irradiated with protons while the damage to healthy tissues is less than with X-rays but this requires accurate imaging of the patient. Nikhef works on several techniques to improve medical imaging for hadron therapy.
- Testbeam experience of PhD student Stergios Tsigaridas: *“Detectors often have to cope with a harsh radiation environment and the liberated electrical charge could develop into a discharge which might damage the detector electronics. The purpose of our testbeam experiment was to operate the detector in extreme conditions and test a so-called protection layer. The feeling during the testbeam period is unique. Cern is an amazing place where you have the possibility to meet with experts around the world, socialise and work in a multicultural environment. Definitely preparing and conducting a testbeam is one of the most exciting moments during my PhD.”*