Detector R&D

Niels van Bakel

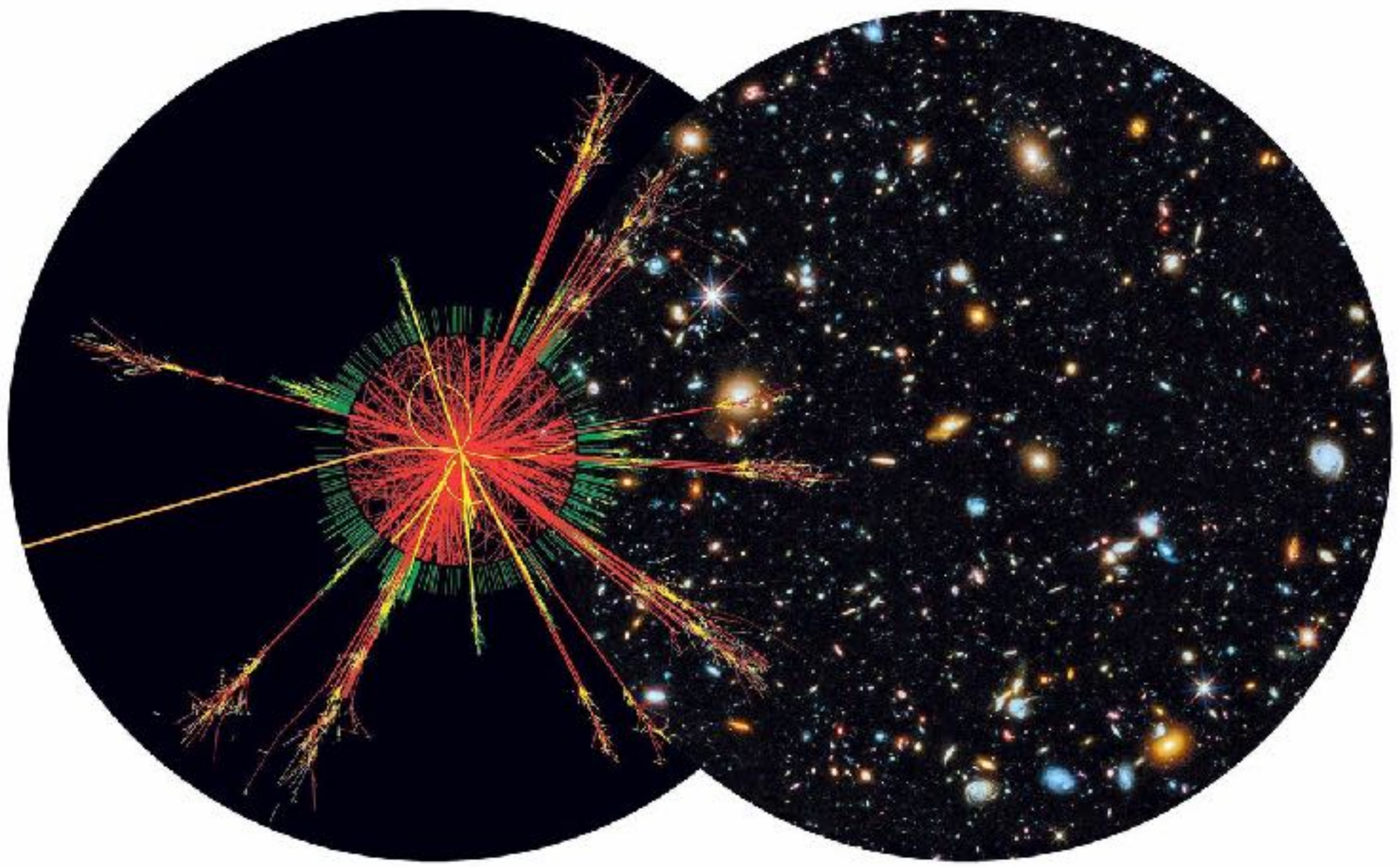
Nikhef

Vista Update – October 21, 2020

DR&D Group

Detector R&D strategy 2017:

- Smart and fast pixel detectors
- Gravitational wave detector instrumentation
- Collaborate with high-tech industry



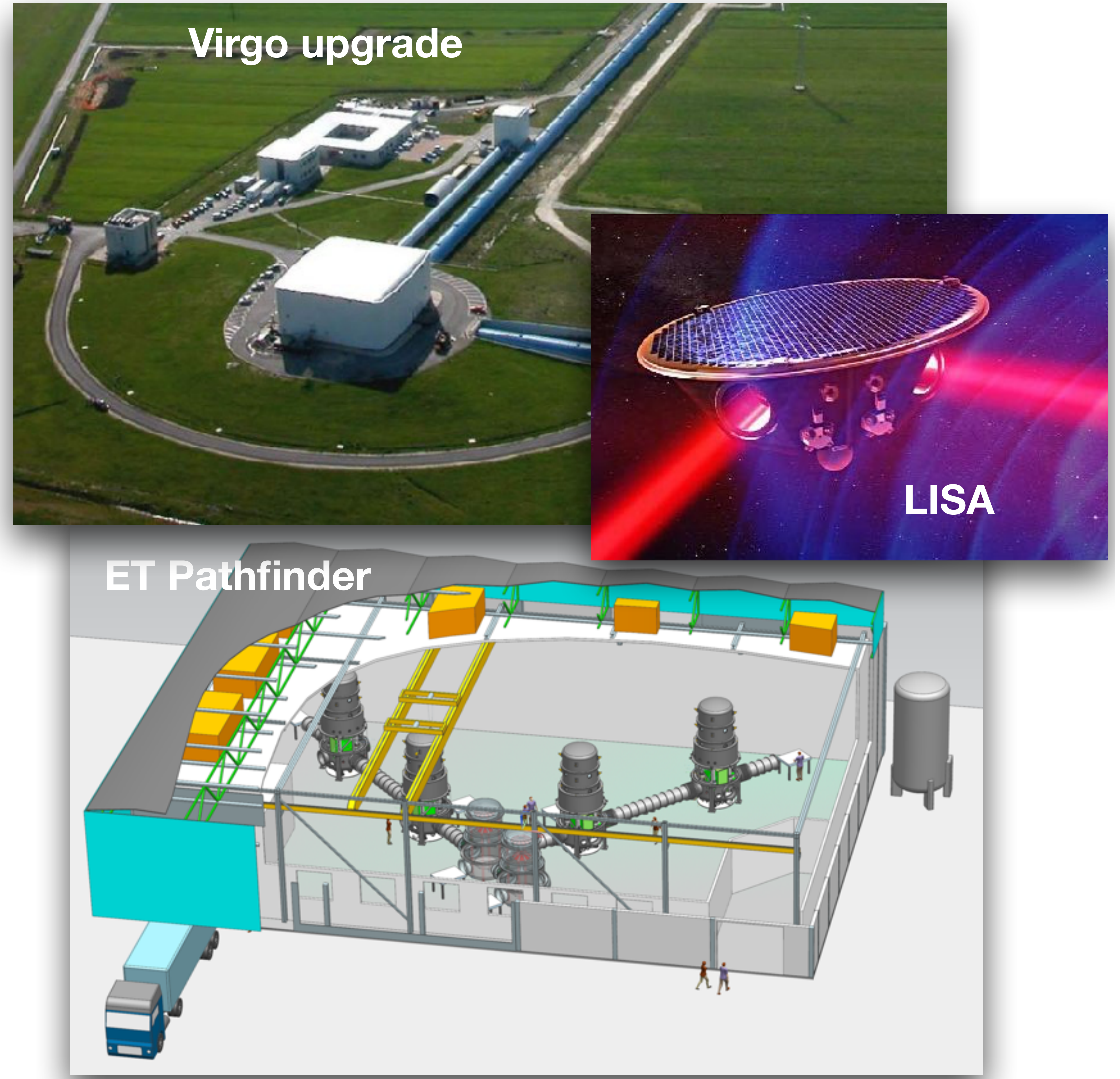
Current staff count:

- Niels v Bakel, Martin v Beuzekom, Martin Fransen, Jory Sonneveld, and Matteo Tacca

Experimental groups:

- Kazu Akiba (LHCb), Hella Snoek (Atlas), Alessandro Grelli (Alice), Alessandro Bertolini (GW), Conor Mow-Lowry (GW), Bas Swinkels (GW)

DR&D strategy



[ECFA Detector Panel Report 2018]

Most promising future R&Ds	# answers (380 total)
Precision timing	210
Precise position resolution	63
Precise energy measurements	25
Radiation Hardness	29
CMOS HV-MAPS monolithic	24
High granularity imaging calorimetry	21
Artificial intelligence / Machine Learning	16
Fast (tracker) triggers (online)	16
High rate capability	14
Low power consumption in detector systems/electronics,	14
4D tracking	14

Table 11: Perceived most promising future R&D topics (top-11).

Looking back

Vista25 in 2017

Detector R&D

- Strengths
  - Scientific ambition well connected to Nikhef science program
  - R&D group has unorthodox multi-disciplinary 'thinkers'
  - Innovation built on strong technical departments
- Weaknesses
  - Some research lines rely on external technology (MEMS fabrication lab) ⬆️
  - Not all PhD students easily embedded in sub-atomic physics school
  - Difficult to push innovation to industry applications 🌶️
- Opportunities
  - Intensified collaboration with (technical) universities & NWO institutes
  - Extend work on GW instrumentation 👍
  - Transfer knowledge to industry & society 🙂
- Threats
  - Reduced group size limits new initiatives
  - R&D staff do not easily obtain personal grants
  - R&D group members key functions in running experiments - creativity under stress
  - Key R&D group members retiring

(😐 marks the last three Threats items)

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- ⬆️ = increased, need funding and skills
- 🌶️ = not very successful
- 👍 = now a strength!
- 🙂 = via spin-offs
- 😐 = equal

Looking back

Vista25 in 2017

Gravitational waves

- Strength
  - Biggest hit of the last few years - complete new field in particle physics, astronomy, cosmology, astroparticle physics
  - Nikhef visibility in aVirgo and LIGO - both h/w and analysis
- Weakness
  - aVirgo is still not running. Getting it to the design sensitivity
- Opportunity
  - Close collaboration with astronomy - timeline agreement SKA vs ET
  - ET as game-changer in Netherlands
  - Instrumentation and science program with LISA 🙂
  - Strong valorisation and PPS - Innoseis, Senseis 🙂
- Threats
  - Einstein Telescope may not be realised in NL
  - Single point failure with Jo van den Brand

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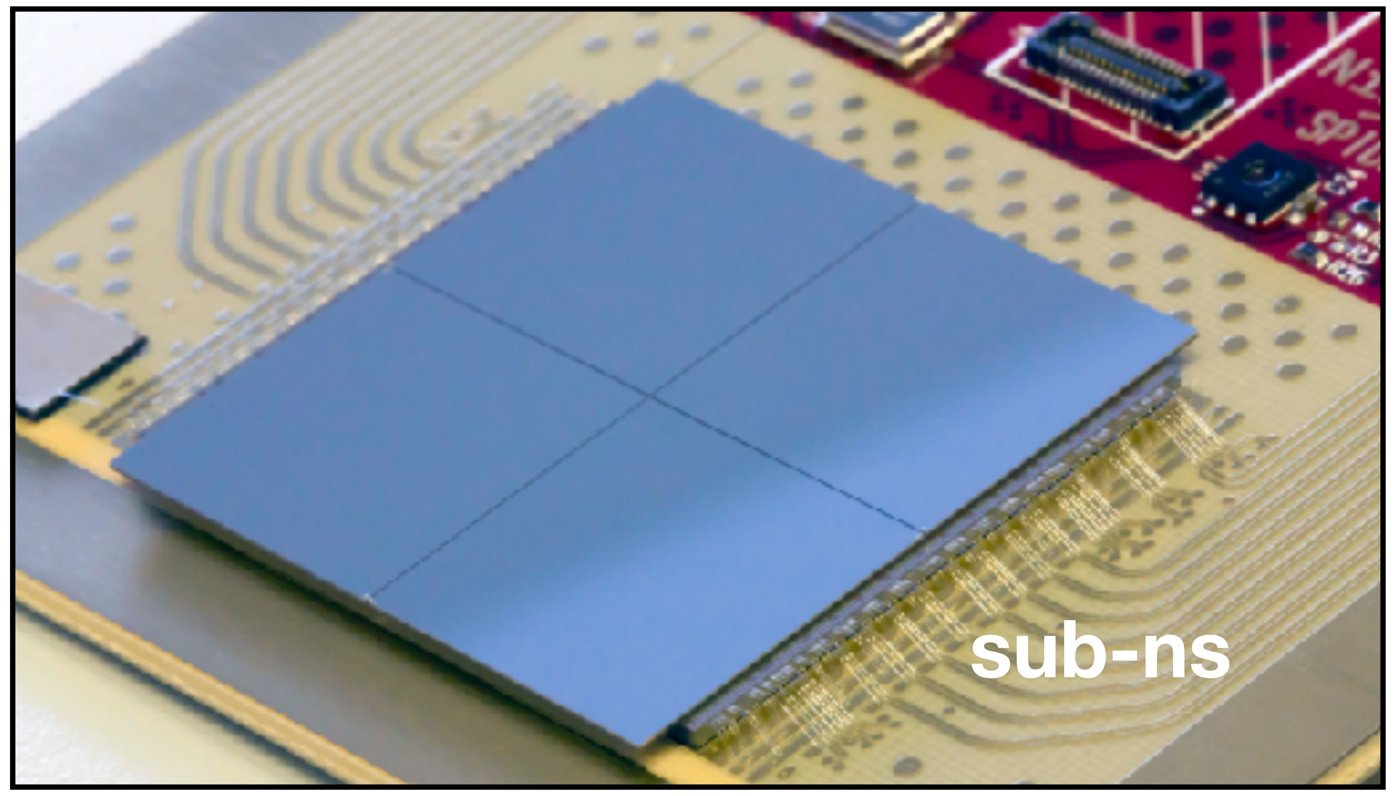
Fast semi-conductor detectors

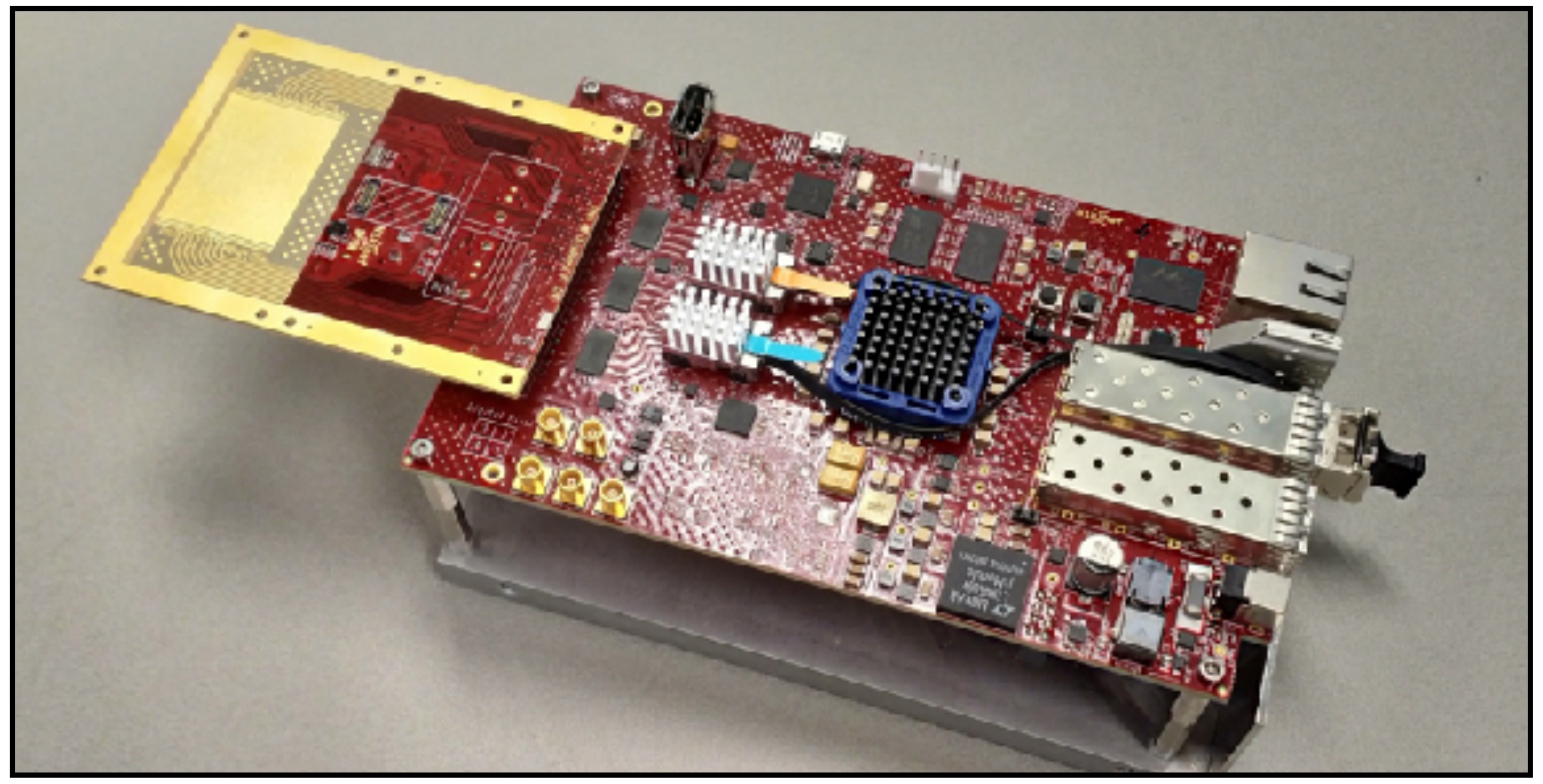
- Future pixels need fast timing, and high readout bandwidth
  - Pay off from our chip and readout system developments
  - ***Develop 'fastest' pixel electronics***
  - 4D Tracking & Time resolved imaging

Fast chips



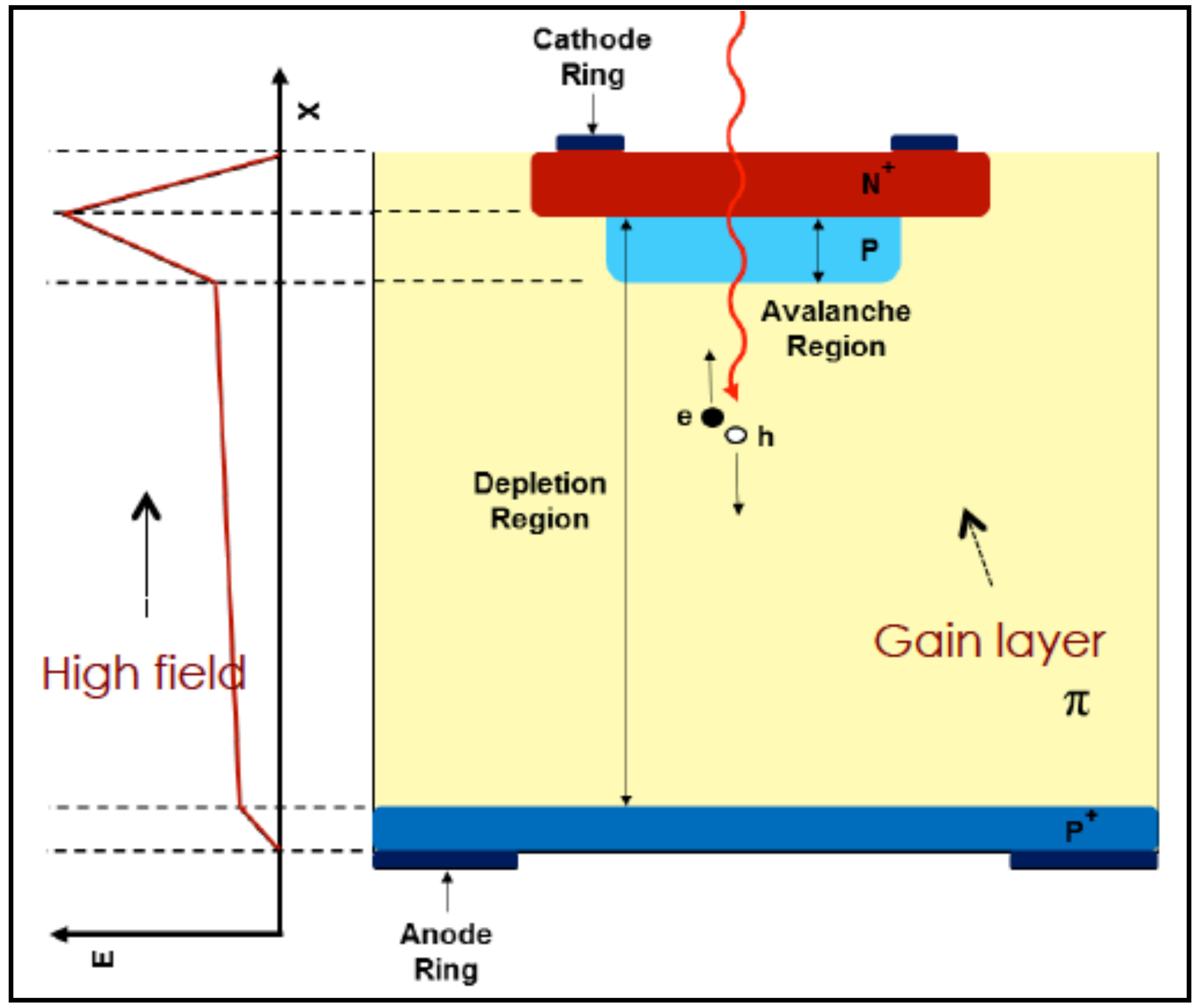
- *A first step: ~100 ps timing*
- *Ideas on 20 ps resolution exist*

Fast readout



- *160 Gbps data out*
- *1 TB per minute per chip*

Fast sensors



LHC Memo to Nikhef management

Nikhef

Expression of Interest to Invest in R&D and Detector construction for LHC Si detectors

Authors: Kazu Akiba, Niels van Bakel, Martin van Beuzekom, Paul Kuijer, Marcel Merk, Raimond Snellings, Hella Snoek, Wouter Verkerke

Internationally there are exciting developments of new Silicon semiconductor detectors, largely pointing in the direction of large surface area, fast, thin, and radiation hard technologies. For Alice the short term goal (LS3) is a large area, lightweight, solution based on Monolithic Active Pixel Sensors (MAPS), while for LS4 the focus will be on fast timing. In LHCb Velo it is on very fast hybrid detectors while long-term challenges include combinations of both. The central goal of the developments can be captured within the theme of "4D-tracking", increasing the surface area and adding time to the usual spatial detector hit. Internationally there are collaborative activities like the Alice and LHCb experiments and the Timespot project, who are developing such technology.

We advocate starting a combined R&D and LHC group activity at Nikhef, aiming at projects that include *both R&D as well as detector construction* for future Silicon tracking detectors. Various hardware deliverables within this project are also essential for other detector developments at Nikhef. A fast 'picosecond' pixel chip, for instance, is necessary for a new type of photon detector. Depending on the technology choice for a future lepton collider, such a pixel chip could also be a prime candidate to read out a gaseous TPC, or even for a fast 4D silicon tracker.
In that framework we propose to apply for funding in the upcoming NWO-Groot investment, where the project will include on the one hand infrastructure for R&D (two-photon laser setup, probe station, possibly DLTS and SIMS) toward ultrafast timing (~30 ps), as well as prototyping and construction of the Alice Inner Tracker detector layers and (optionally) the LHCb Mighty Tracker, both to be installed in LS3. It would include ASIC submissions for the picosecond chip.

We foresee that in the long run larger investments will be required to implement 4D

- Current Nikhef and DR&D goals for fast timing
  - ***Hybrid technology****: interest from LHCb & Atlas, develop fast sensors*
  - ***MAPS technology****: interest from Alice & Atlas*
  - ***Both*** *need* ***fast timing circuits*** *in CMOS,* ***fast data links****, and* ***radiation hardness***
- Electronics Department
  - ***Interested in 28 nm CMOS*** *technology for fast timing and fast data links*
  - *Will follow* ***CERN MAPS technology****: currently 180 nm but will move to 65 nm*

ASIC developments

Nikhef

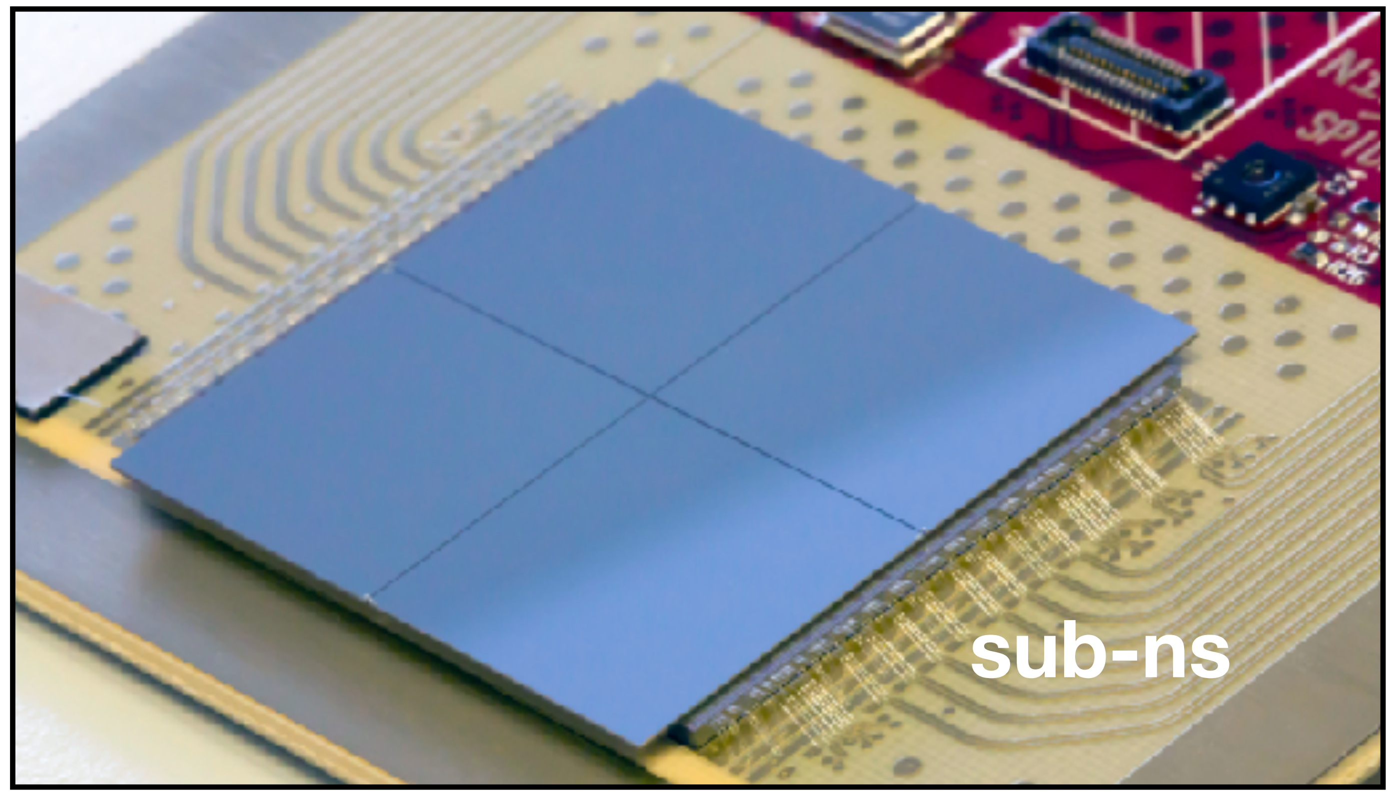
- **Fast timing pixel chips** ⇨ *“Timepix -like”*
  - *To be combined with novel fast sensor layers*
- First standard **blocks for Alice LS3 MAPS**
  - *Start soon with circuitry for ‘fast’ MAPS*
- **Serializers** for increasing data rates in scientific instruments
  - *In radiation environments*
- Low-noise low-power **readout for MEMS** accelerometers

Involved in Medipix, RD50 & RD53, AIDA-Inova, and CERN EP strategic R&D work packages

Fast semi-conductor detectors (now)

- Future pixels need fast timing, and high readout bandwidth
  - Pay off from our chip and readout system developments
  - *Develop 'fastest' pixel electronics* ⇨ ***Hybrid & MAPS detectors***
  - 4D Tracking

Fast chips



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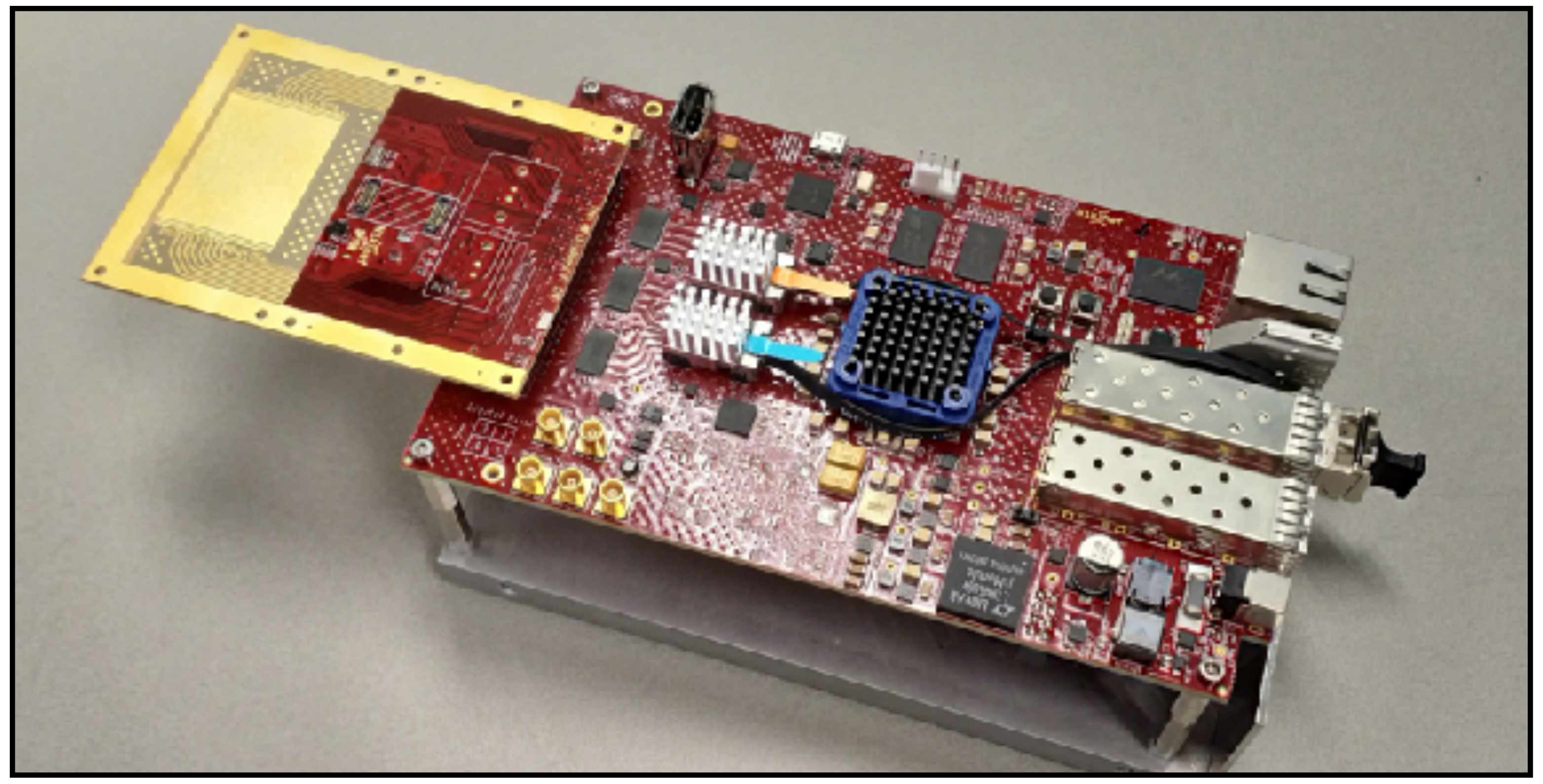
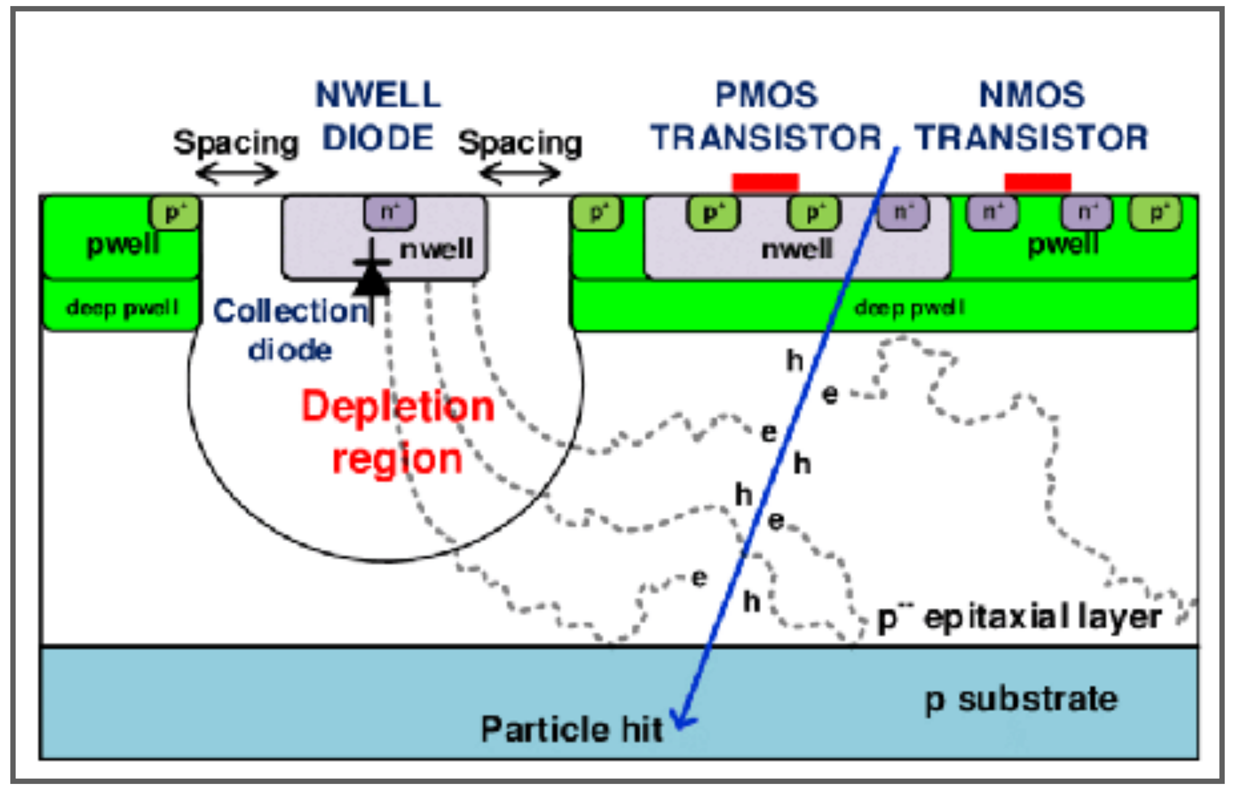
Fast readout

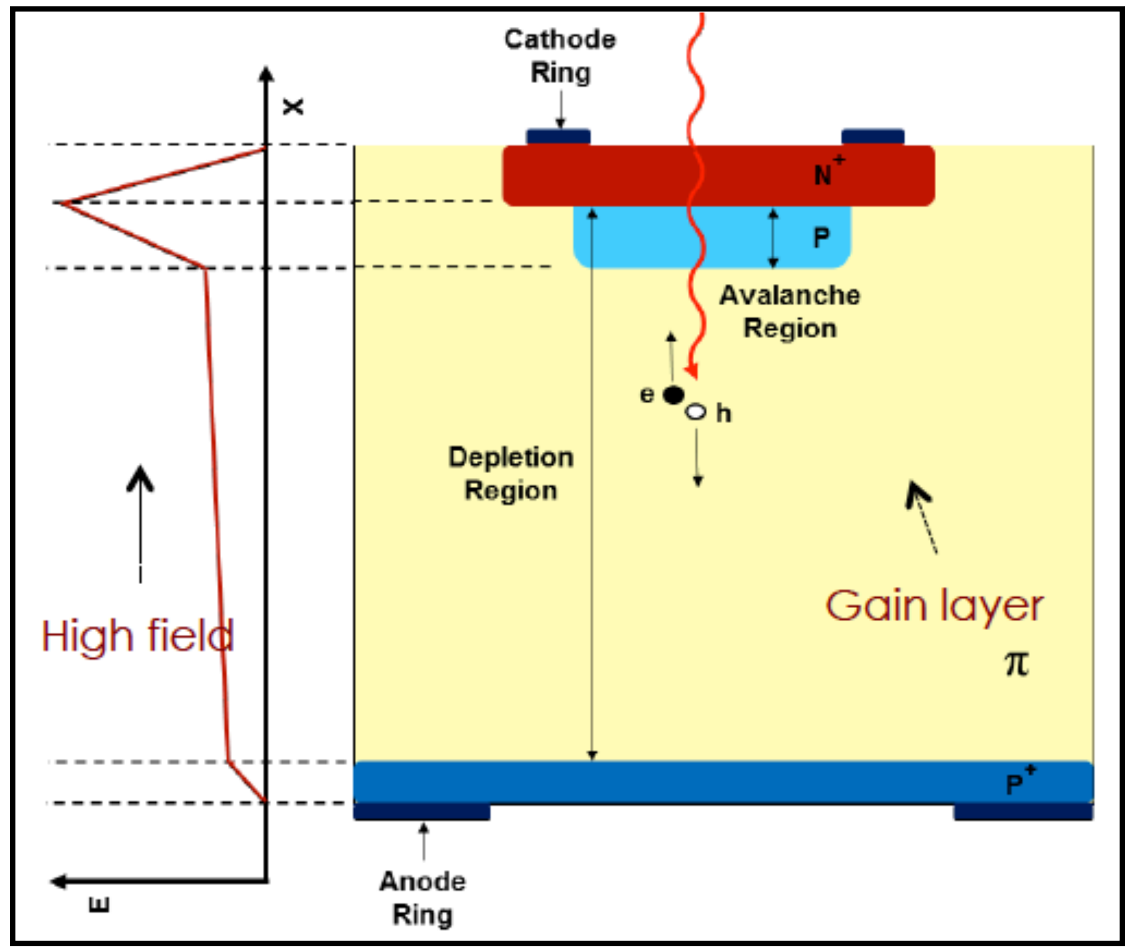


- *160 Gbps data out*
- *1 TB per minute per chip*

Fast MAPS

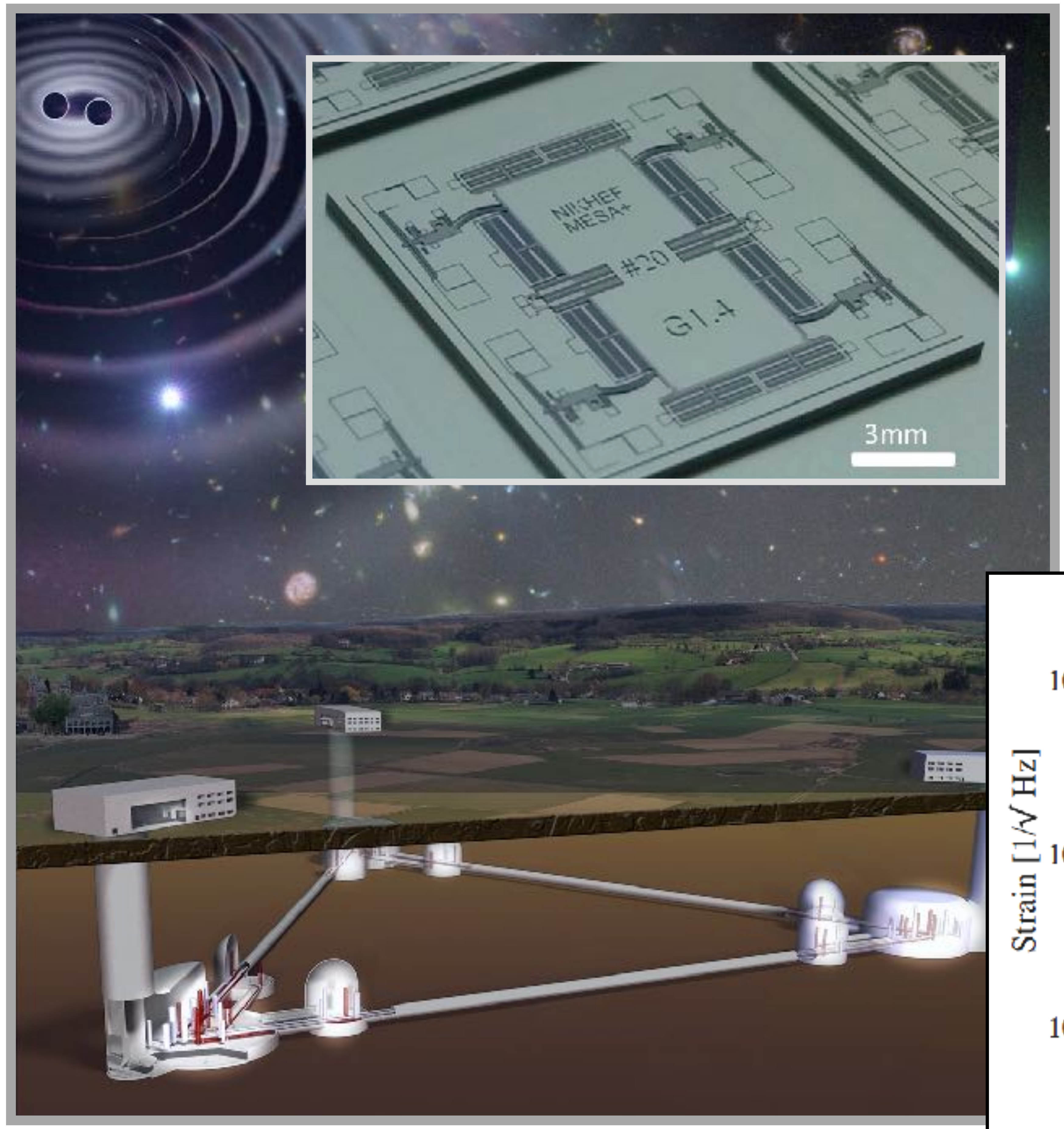


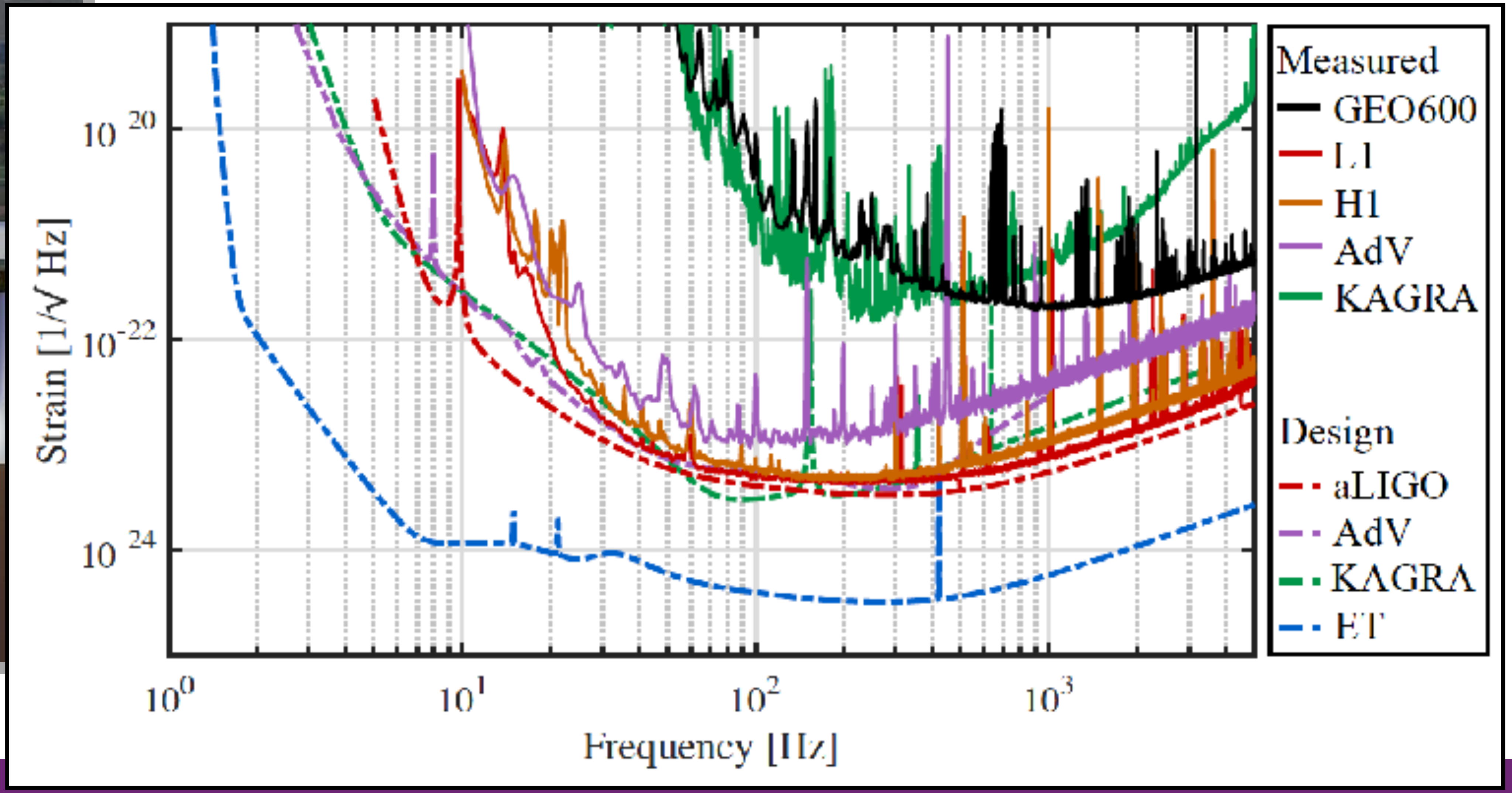
Fast sensors

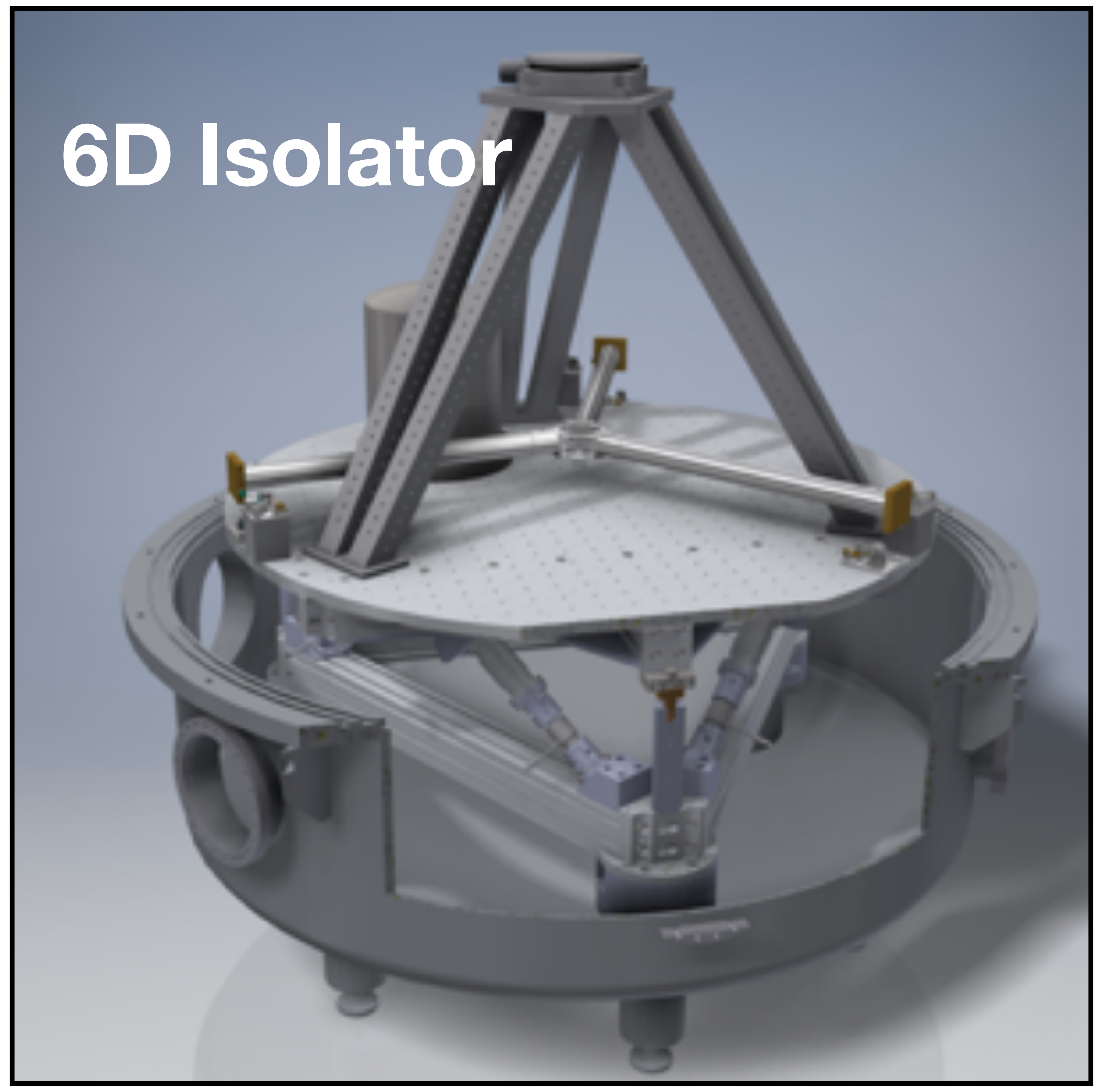


Suspensions & Seismic sensors

- Develop the **most sensitive and compact accelerometer** in the low-frequency regime
  - ➡ *Applications in subsurface imaging for geothermal development & space navigation*
- Active & passive **suspension systems**
- Ultimately apply these at the **Einstein Telescope**







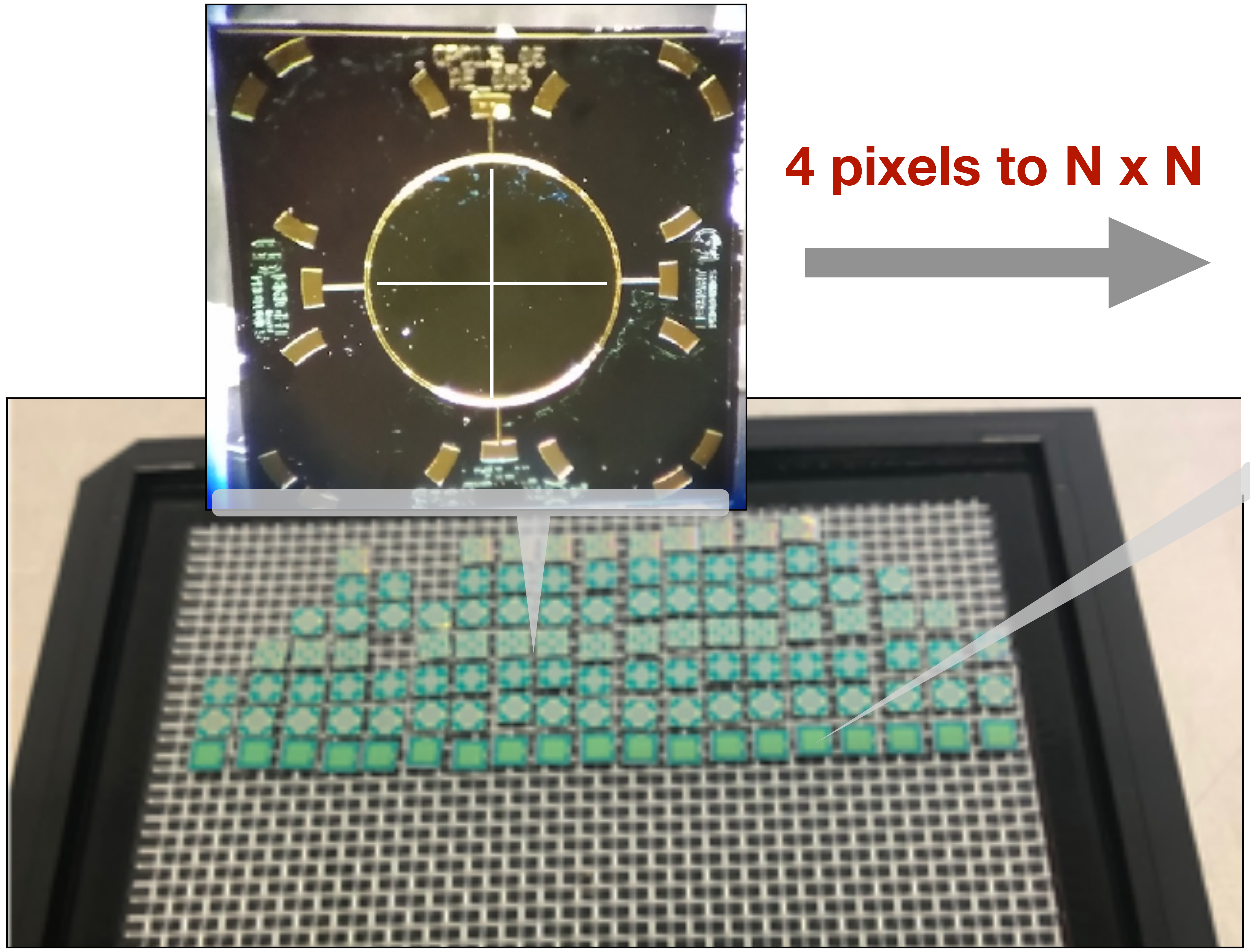
Infrastructure - Optical lab

Go beyond the current limit of fundamental noises

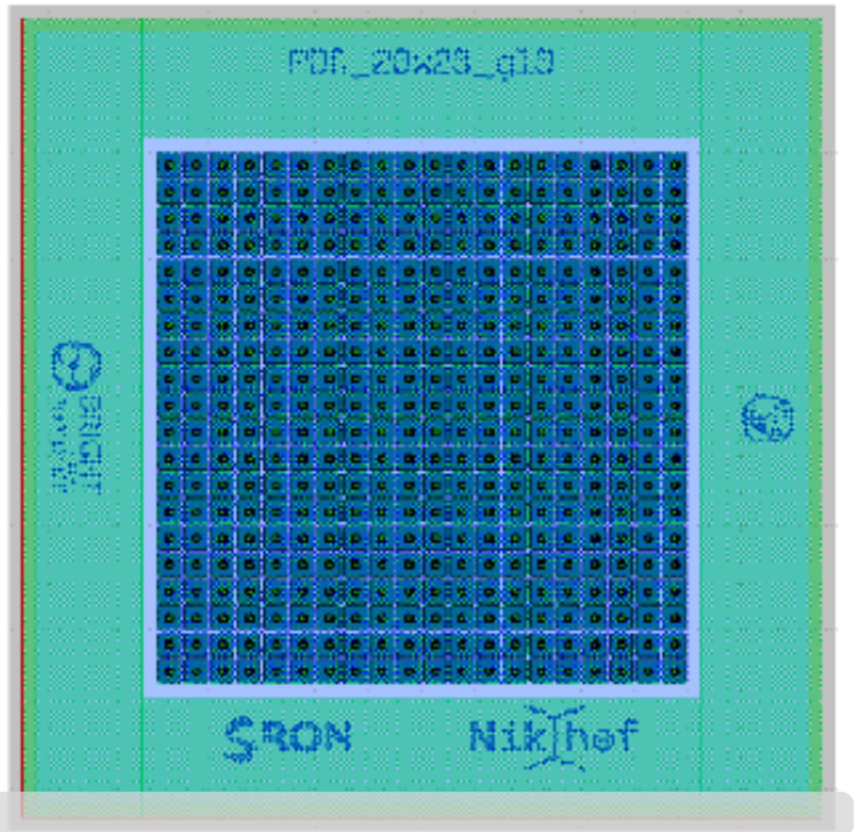
- Frequency dependent squeezing
  - ***Test optical and mechanical components***
- Study higher-order-modes and non-gaussian beams
  - ***Different beam profiles with compatible mirrors***
- Improve sensing and controls schemes
  - ***Small IFO with suspended mirrors***
- Student projects

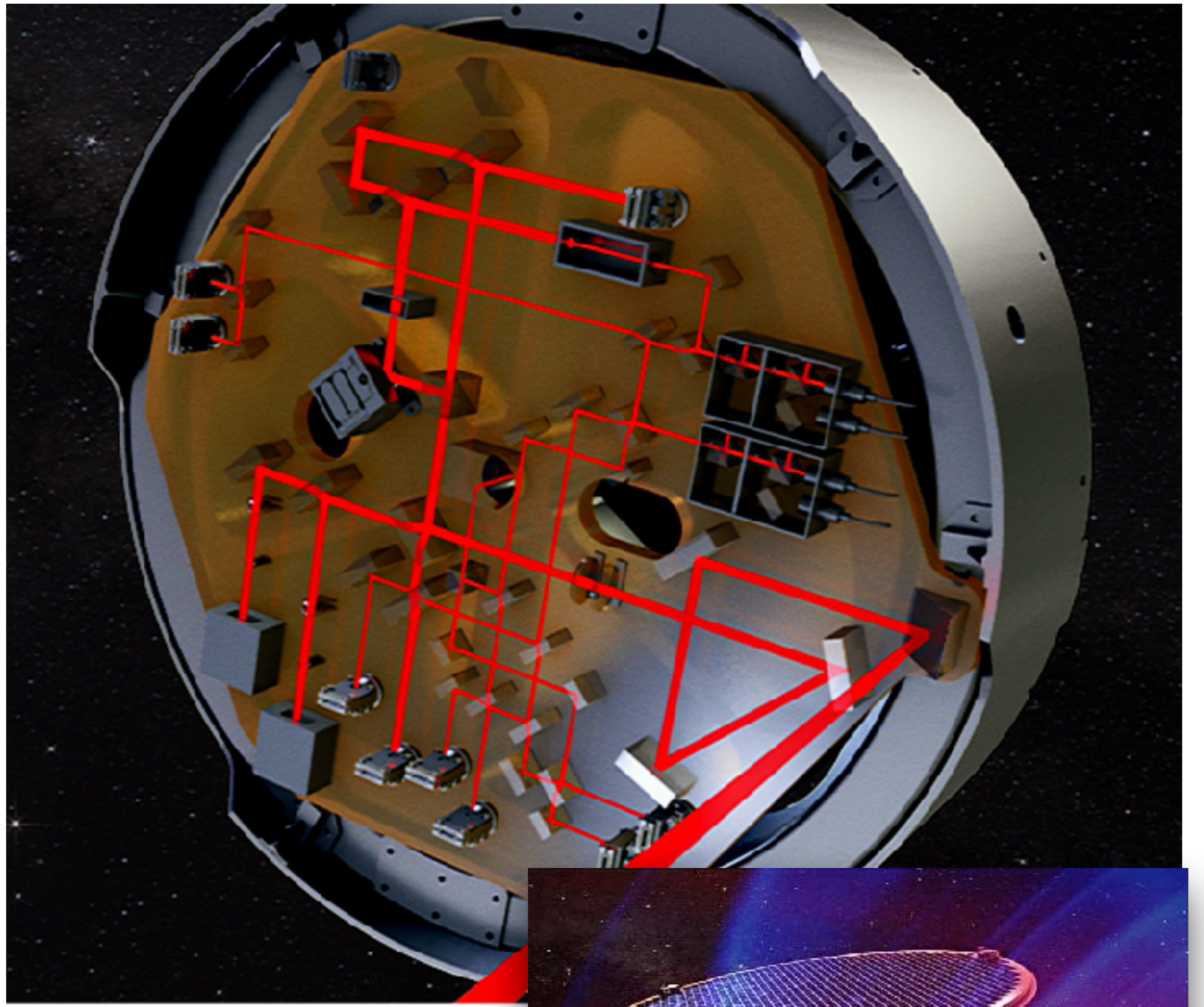
Wavefront cameras for GW detectors

- Signal detection and Alignment
  - First batch of **Quadrant Photo Diodes** for LISA (August 2020)
  - Will lead to photo diode development for **Einstein Telescope**



4 pixels to N x N





Instrumentation for Advanced Virgo, ET Pathfinder, Einstein Telescope, and LISA

ECFA-EPS 2019 (Newsletter #3)

Many examples show that it can take 10-15 years to mature a technology from the demonstrator stage to an established technique suited for large-scale production. Today, experiments last a lifetime with thousands of people. Hence, this scheme poses a host of ineluctable challenges, which were discussed in Granada, organised around three major themes.

a) *The coordination of R&D:* should it be distributed everywhere in an independent way, or centralised in laboratories and consortia? Based on the obvious evidence that expertise is distributed across many institutions, the general opinion converged on the conclusion that R&D should not be centralised exclusively in large-scale facilities. There is evidence that the current R&D collaborations (RD#, AIDA2020, CALICE, etc.) are effective models of collaboration: hence we should reflect on establishing new ones and on optimising their reviewing process, implementing regular reassessments in addition to the internal collaboration procedures. Additionally, collaboration must be enhanced among physics communities in order to search for synergies and exchange information between physics fields, technology specialisations and industry.

b) *The human factor:* how can we give recognition to young people? How can we foster recruitment? How can we provide effective long-term training? First, it is felt that instrumentation activities must be recognised as fundamental research that guarantees a valuable PhD thesis and grants equal career opportunities. Next, priority must be given to the training of young researchers, offering adequate instrumentation courses at university and providing maximal support to the organisation of specialised training platforms in large laboratories and institutes.

- Long term commitments
- Focus @ Nikhef
- Strong network
- Discussed in Vista?!

ECFA-EPS 2019 (Newsletter #3)

c) *Should R&D be guided by existing experiments, or should "blue sky R&D" be better supported?* It is historically proven that major detector technologies (TPC, RICH, MPGD, etc.) have not flourished due to R&D performed within large collaborations where, most of the time, studies are unavoidably polarised by internal challenges. It is therefore important to maintain an active generic R&D community that fosters new ideas for future detectors, eventually suited for applications outside fundamental physics. For this last point, experience shows that this step can be significantly sped up if adequate attention is given to early technology transfer programmes in close collaboration with industry. However, a recent survey on the status of R&D in Europe showed that only 30% of projects exploit technology transfer strategies and, when this is done, almost 70% of the groups feel that they do not get enough support in solving financial, workforce, technical and legal issues. To conclude: we all agreed that it is necessary to bring fundamental research closer to the needs of the whole of society; therefore, we need to review and strengthen our technology transfer model.

- Not only for LHC LS3/ LS4 but also for FCC or ILC

Recap

Nikhef

- Focus & critical mass
- Fast timing takes off
  - *After years of investments in chip and readout R&D*
  - *Critical mass ⇨ on forefront!*
  - *Start Monolothic detector development*
- Extended R&D on GW instrumentation
  - *Active member of LISA space mission*
- Decrease x-ray imaging activities in 2021