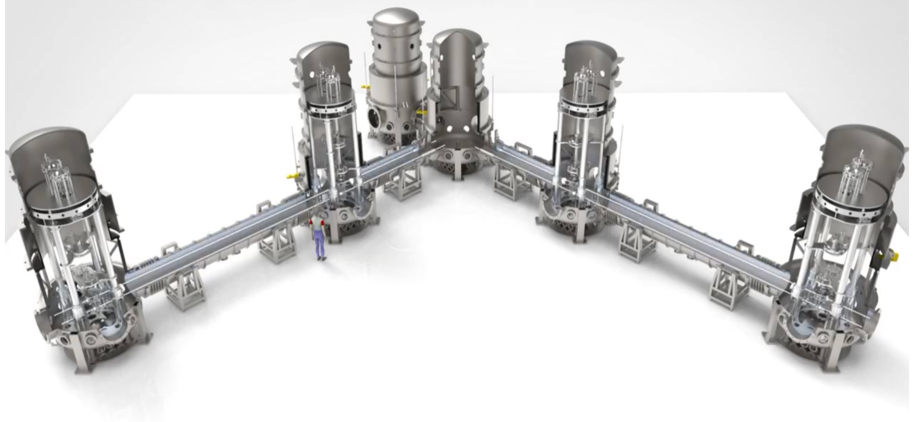
ETpathfinder

Prof Stefan Hild, University of Maastricht & Nikhef

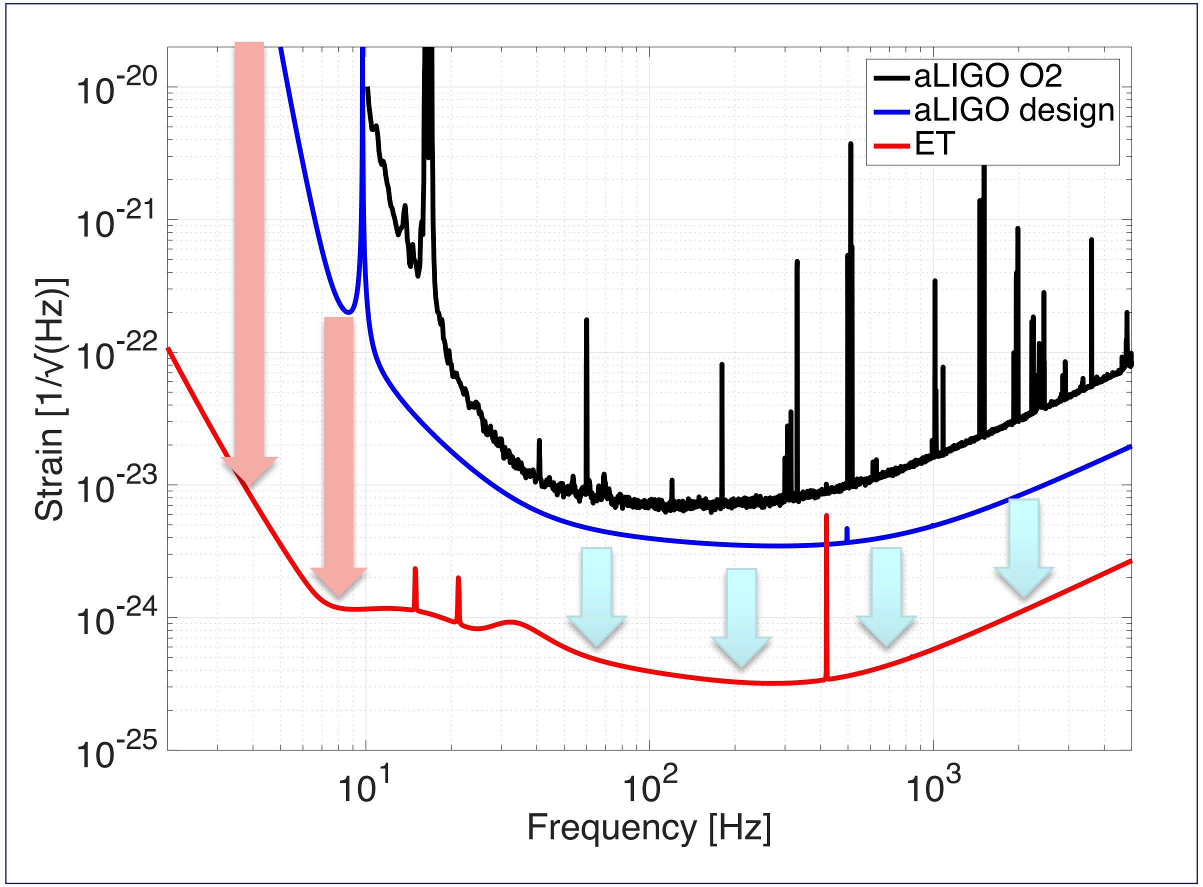
www.einsteintelescope.nl / www.etpathfinder.eu



Why ETpathfinder needed?

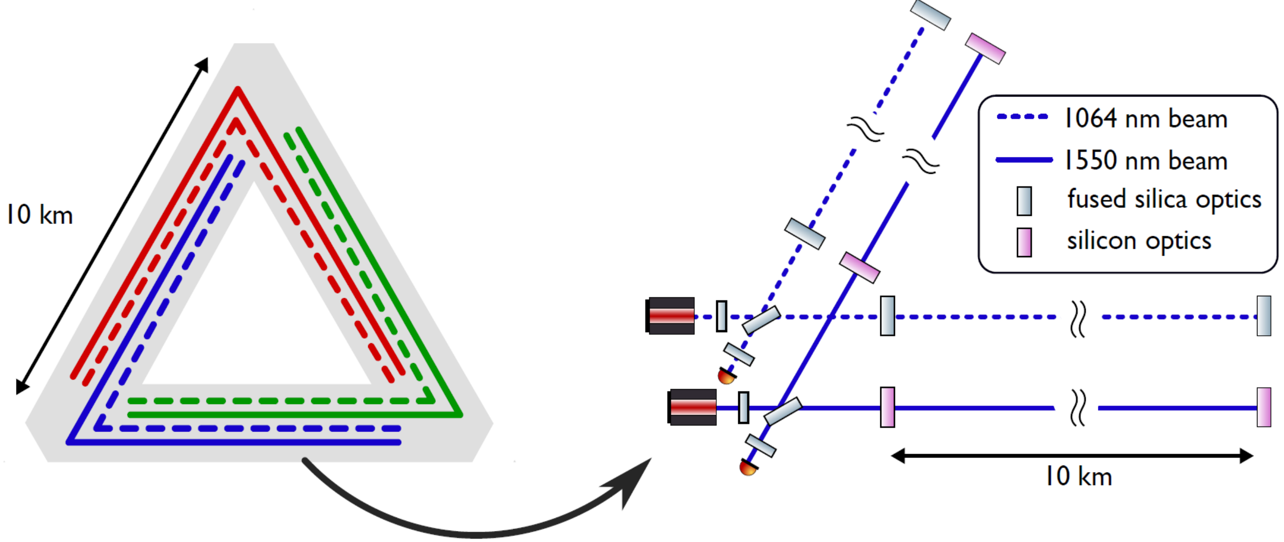
The Low-Frequency Challenge:

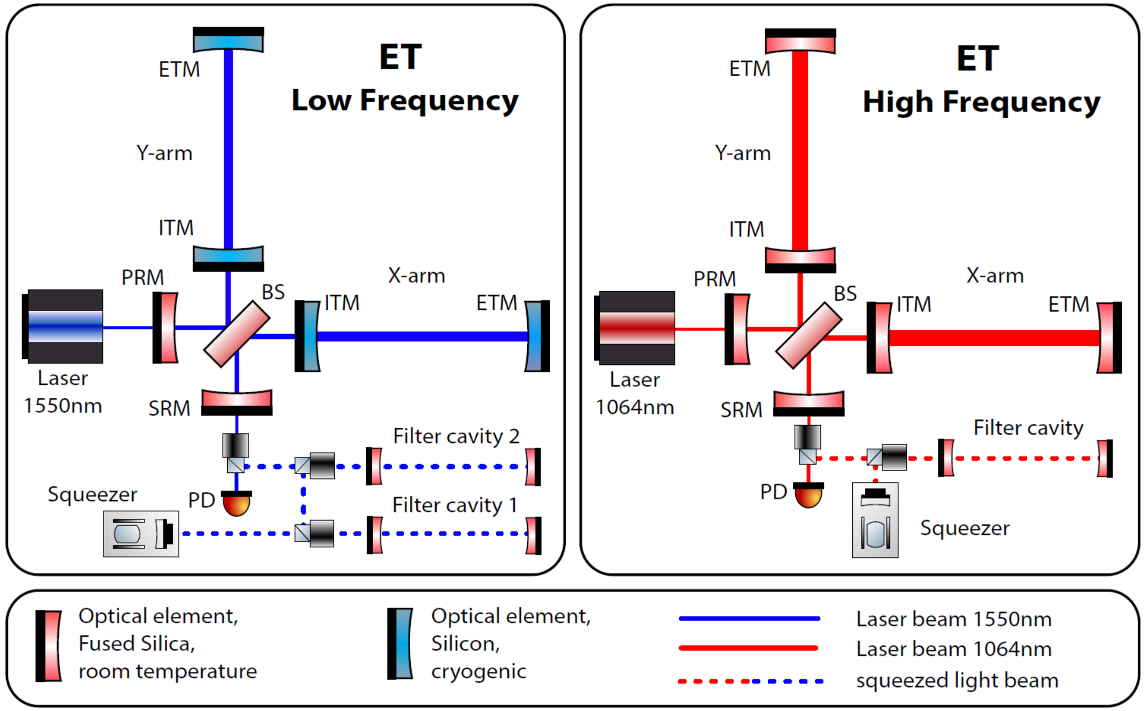
- At mid and high frequency we aim for factor ~10 improvement.
- At low frequency we are aiming for factors 100, 1000 and more improvement.
- **Needs fundamental changes in technology and concepts, that need testing and prototyping.**



Einstein Telescope design

Parameter	ET-HF	ET-LF
Arm length	10 km	10 km
Input power (after IMC)	500 W	3 W
Arm power	3 MW	18 kW
Temperature	290 K	10-20 K
Mirror material	fused silica	silicon
Mirror diameter / thickness	62 cm / 30 cm	45 cm/ 57 cm
Mirror masses	200 kg	211 kg
Laser wavelength	1064 nm	1550 nm
SR-phase (rad)	tuned (0.0)	detuned (0.6)
SR transmittance	10 %	20 %
Quantum noise suppression	freq. dep. squeez.	freq. dep. squeez.
Filter cavities	1×300 m	2×1.0 km
Squeezing level	10 dB (effective)	10 dB (effective)
Beam shape	TEM_{00}	TEM_{00}
Beam radius	12.0 cm	9 cm
Scatter loss per surface	37 ppm	37 ppm
Seismic isolation	SA, 8 m tall	mod SA, 17 m tall
Seismic (for f > 1 Hz)	$5 \cdot 10^{-10}\,\mathrm{m}/f^2$	$5 \cdot 10^{-10}\,\mathrm{m}/f^2$
Gravity gradient subtraction	none	factor of a few





New Technologies

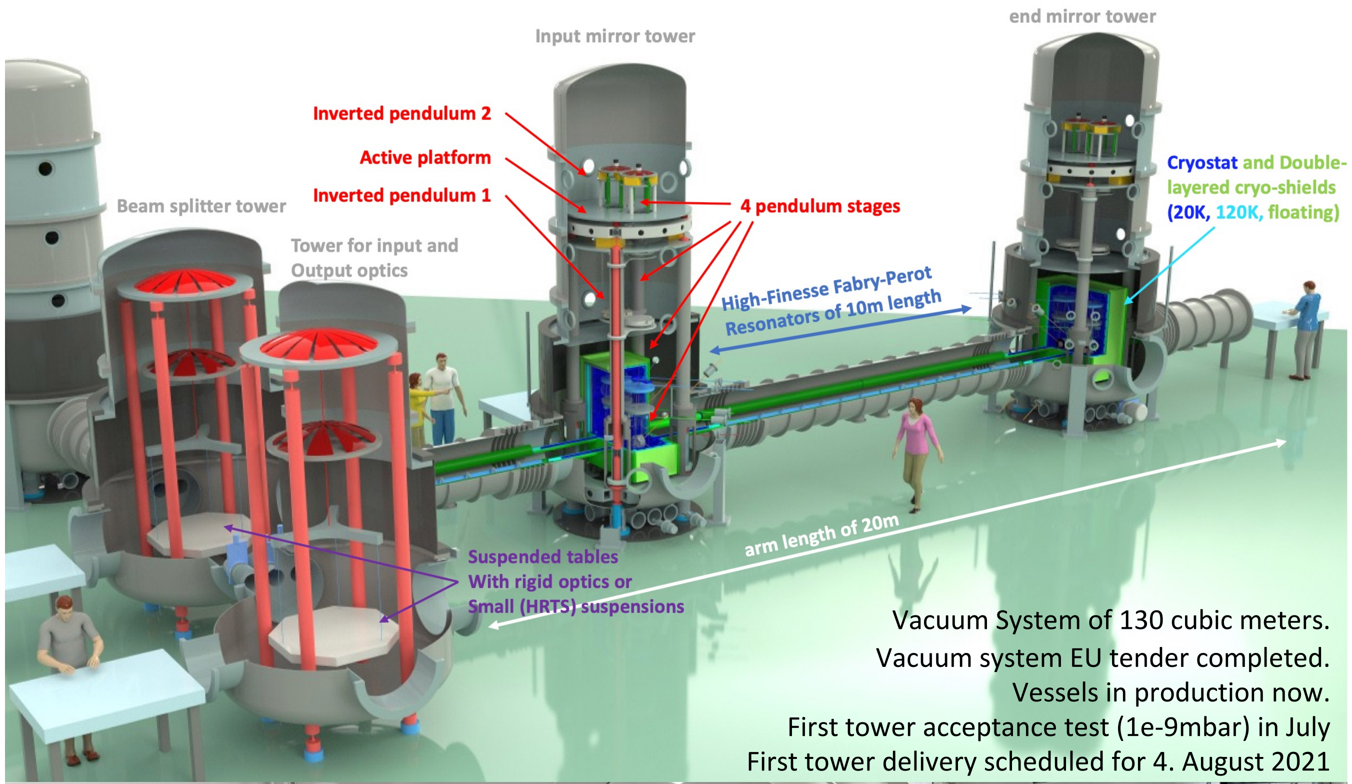
Nikhef

ET requires technological advances on all fronts:

- New mirror material => Silicon
- New temperature => 10-20K
- New laser wavelength => 1.5-2.1 microns
- Advanced quantum-noise-reduction schemes

ETpathfinder Overview

- New facility for testing ET technology in a low-noise, full-interferometer setup.
- Key aspects: Silicon mirrors (3 to 100+kg), cryogenics cryogenic liquids and sorption coolers, water/ice management), “new” wavelengths (1550 and 2090nm), coatings …
- Start with 2 FPMI, one initially at 120K and one 15K
- 20+ partners from NL/B/G/FR/SP/UK/PL
- Initial capital funding of 14.5 MEuro.
- Detailed Design Report available at apps.et-gw.eu/tds/?content=3&r=17177
- Open for everyone interested to join.
- www.etpathfinder.eu



ETpathfinder Partners

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provincie limburg

Ministerie van Onderwijs, Cultuur en Wetenschap

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VUB VRIJE UNIVERSITEIT BRUSSEL

IFAE Institut de Física d'Altes Energies

EXCELENCIA SEVERO OCHOA

LAPP Laboratoire d'Annecy de Physique des Particules

Nikhef

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vito

RWTH AACHEN UNIVERSITY

University of Glasgow

TNO

Fraunhofer ILT

UNIVERSITY OF TWENTE.

KIT Karlsruher Institut für Technologie

UHASSELT

UCLouvain

ETpathfinder: a cryogenic testbed for interferometric gravitational-wave detectors

A. Utina[1,2], A. Amato[1,2], J. Arends[3], C. Arina[4], M. de Baar[5], M. Baars[2], P. Baer[6], N. van Bakel[2], W. Beaumont[7], A. Bertolini[2], M. van Beuzekom[2], S. Biersteker[3], A. Binetti[8], H. J. M. ter Brake[9], G. Bruno[4], J. Bryant[10], H. J. Bulten[2], L. Busch[11], P. Cebeci[6], C. Collette[12], S. Cooper[10], R. Cornelissen[2], P. Cuijpers[1], M. van Dael[5], S. Danilishin[1,2], D. Dixit [1,2], S. van Doesburg[2], M. Doets[2], R. Elsinga[2,3], V. Erends[2], J. van Erps[20], A. Freise[2,3], H. Frenaij[2], R. Garcia[13], M. Giesberts[6], S. Grohmann[11], H. Van Haevermaet[7], S. Heijnen[2], J. V. van Heijningen[4], E. Hennes[2], J.-S. Hennig[1,2], M. Hennig[1,2], T. Hertog[8], S. Hild[1,2], H.-D. Hoffmann[6], G. Hoft[2], M. Hopman[2], D. Hoyland[10], G. A. Iandolo[1,2], C. Ietswaard[2], R. Jamshidi[12], P. Jansweijer [2], A. Jones[14], P. Jones[10], N. Knust[15], G. Koekoek[1,2], X. Koroveshi[11], T. Kortekaas[3], A. N. Koushik[7], M. Kraan[2], M. van de Kraats[2], S. L. Kranzhoff[1,2], P. Kuijer[2], K. A. Kukkadapu[7], K. Lam[2], N. Letendre[16], P. Li[7], R. Limburg[3], F. Linde[2], J.-P. Locquet[8], P. Loosen[6], H. Lueck[15], M. Martínez[13], A. Masserot[16], F. Meylahn[15], M. Molenaar[3], C. Mow-Lowry[2,3], J. Mundet[13], B. Munneke[2], L. van Nieuwland[2], E. Pacaud[16], D. Pascucci[17], S. Petit[16], Z. Van Ranst[1,2], G. Raskin[8], P. M. Recaman[8], N. van Remortel[7], L. Rolland[16], L. de Roo[2], E. Roose[7], J. C. Rosier[3], D. Ryckbosch[17], K. Schouteden[8], A. Sevrin[18], A. Sider[12], A. Singha[1,2], V. Spagnuolo[1,2], A. Stahl[19], J. Steinlechner[1,2], S. Steinlechner[1,2], B. Swinkels[2], N. Szilasi[4], M. Tacca[2], H. Thienpont[20], A. Vecchio[10], H. Verkooijen[2], C. H. Vermeer[9], M. Vervaeke[20], G. Visser[2], R. Walet[2,3], P. Werneke[2], C. Westhofen[19], B. Willke[15], A. Xhahi[9], T. Zhang[10]

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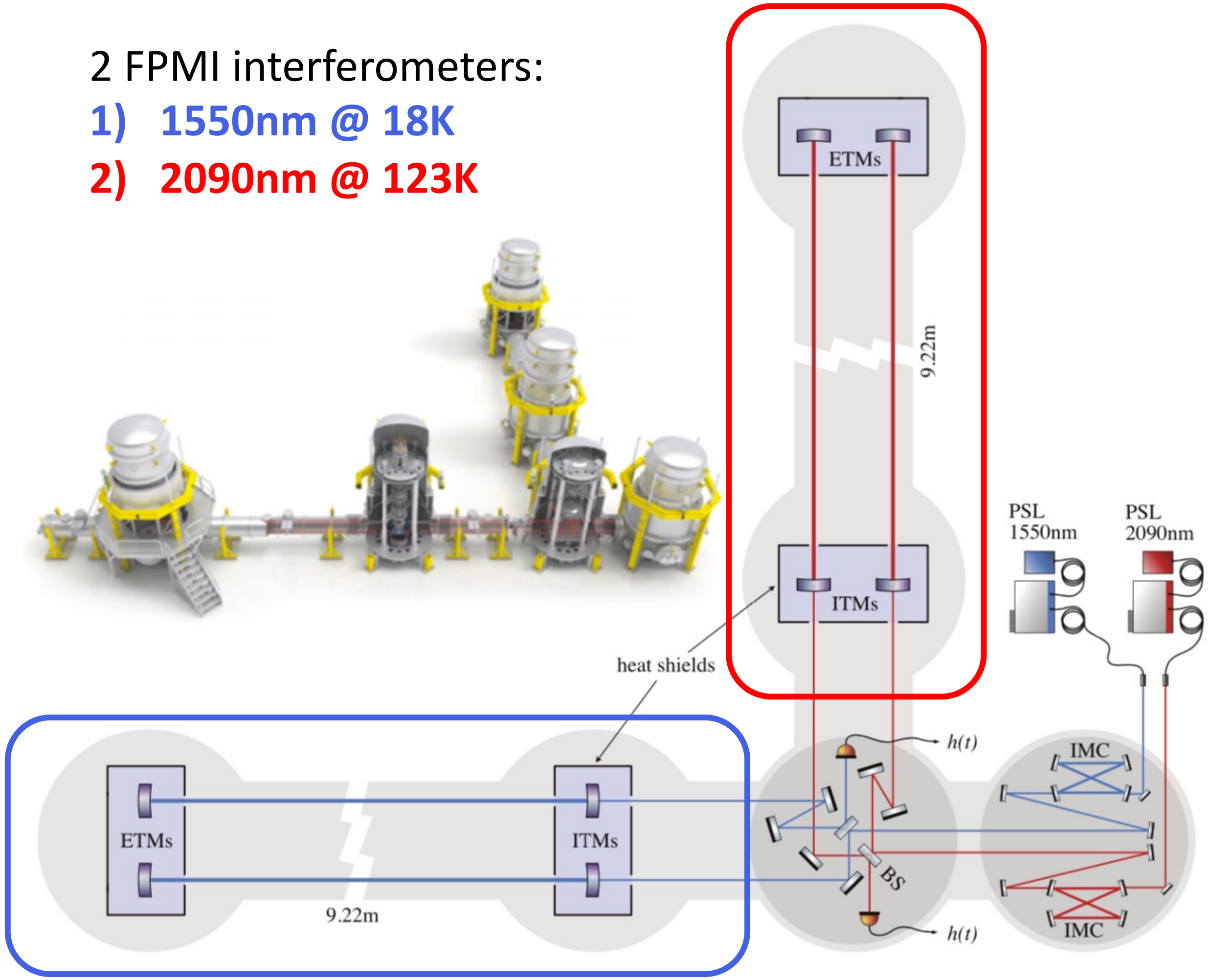
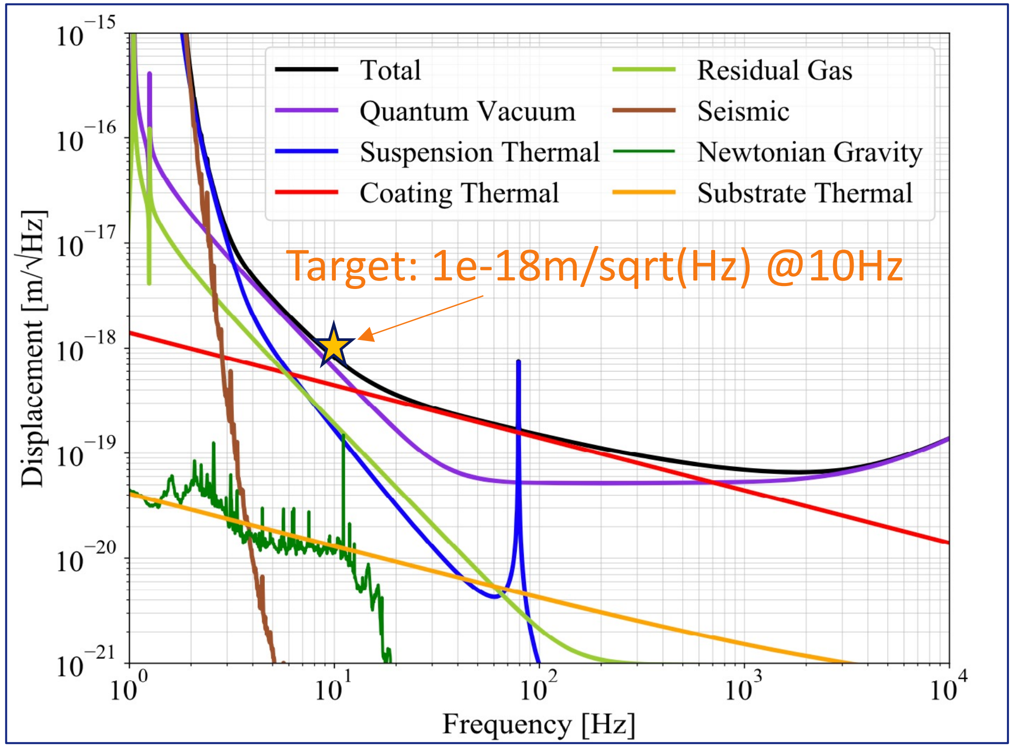
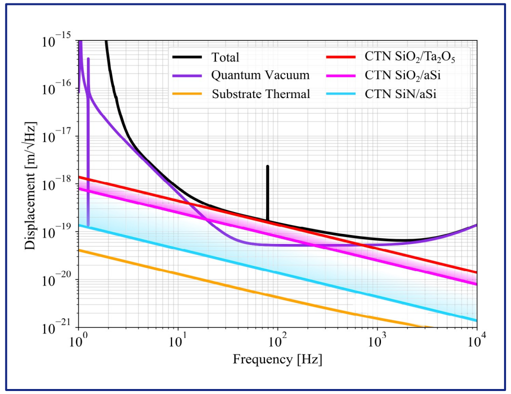
Top-Level layout

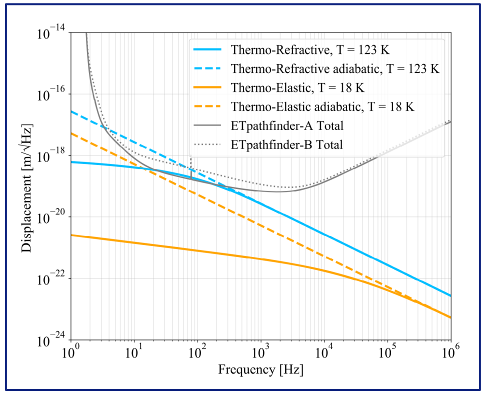
2 FPMI interferometers:

1) **1550nm @ 18K**
2) **2090nm @ 123K**







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Summer 2020


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- 2 x 2 to
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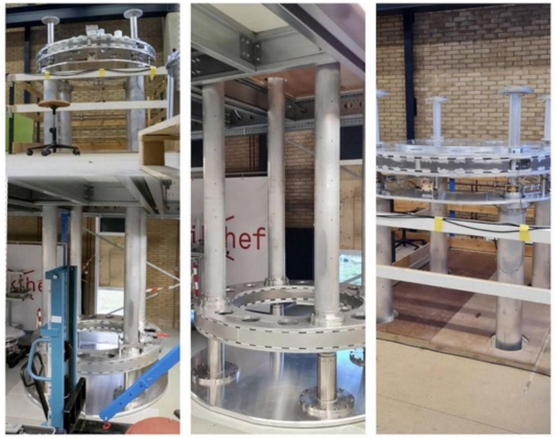
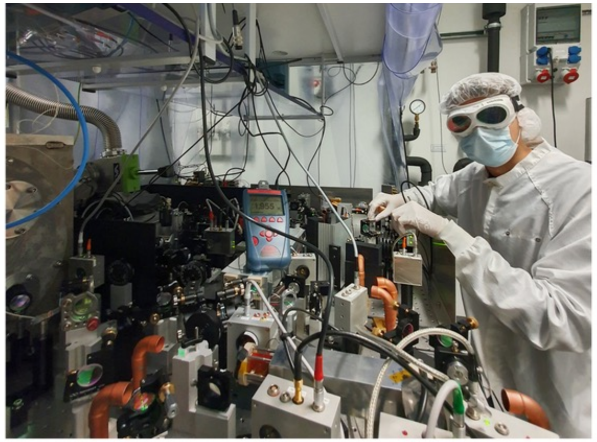
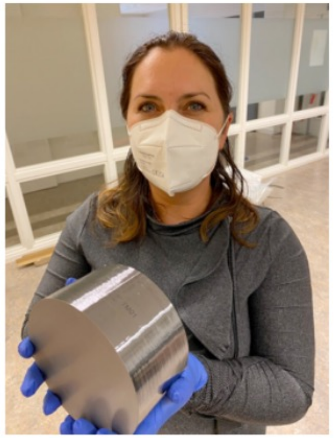
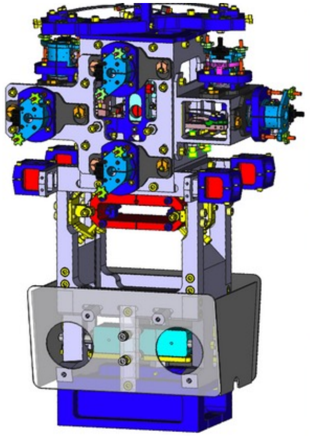
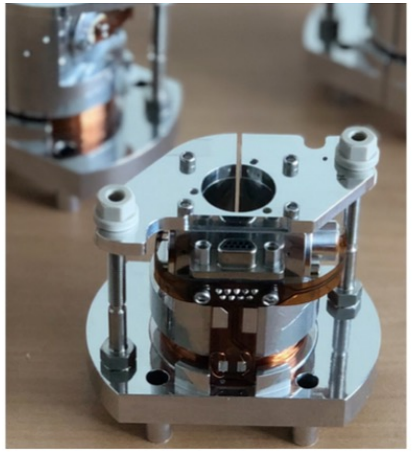
Some Impressions ETpathfinder Activities

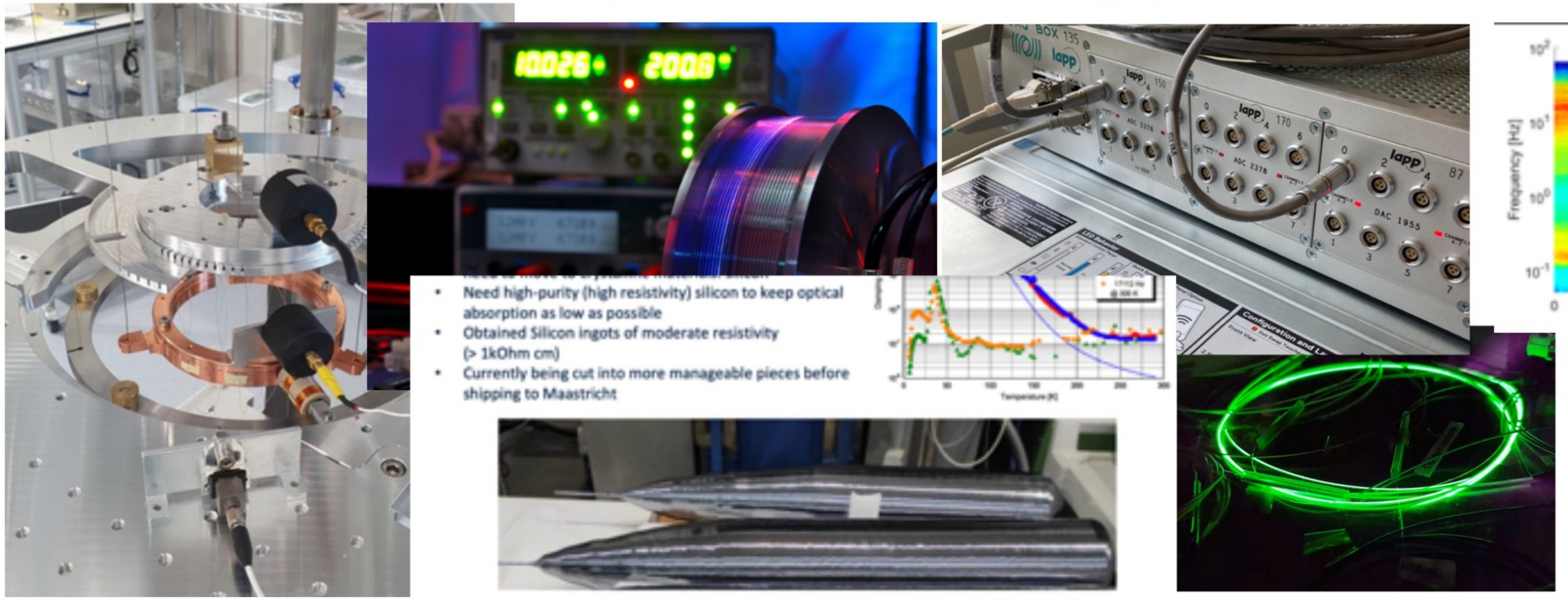


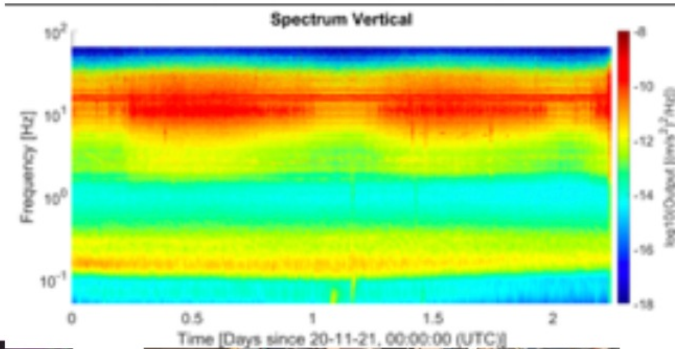




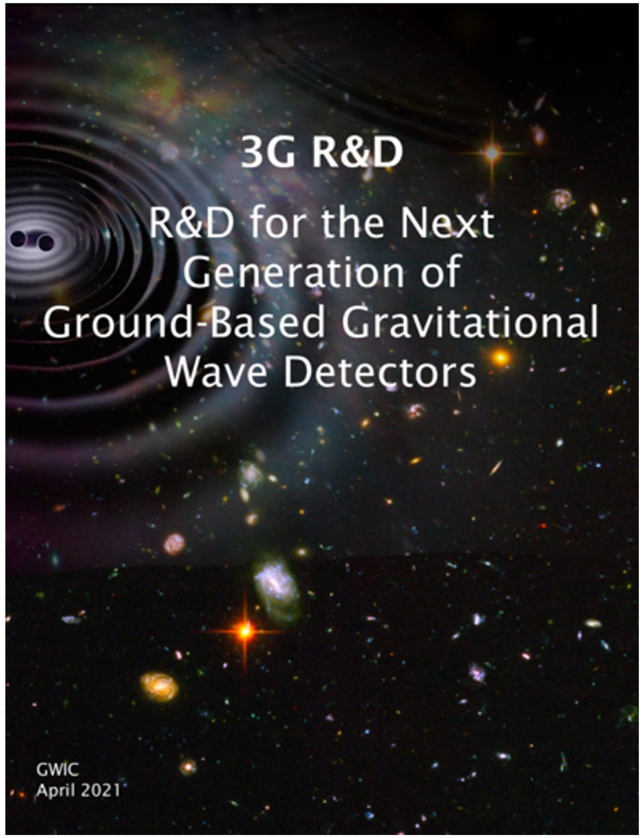


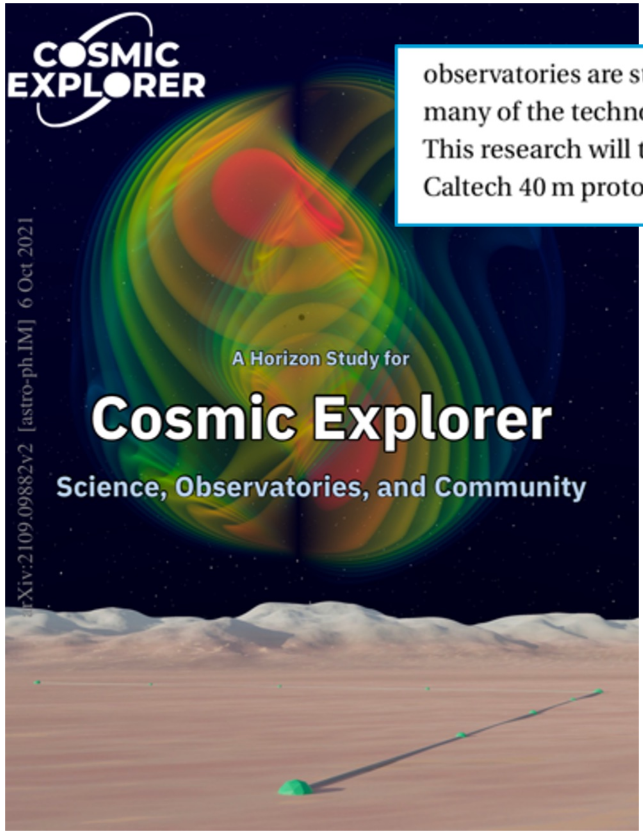






ETpathfinder beyond ET



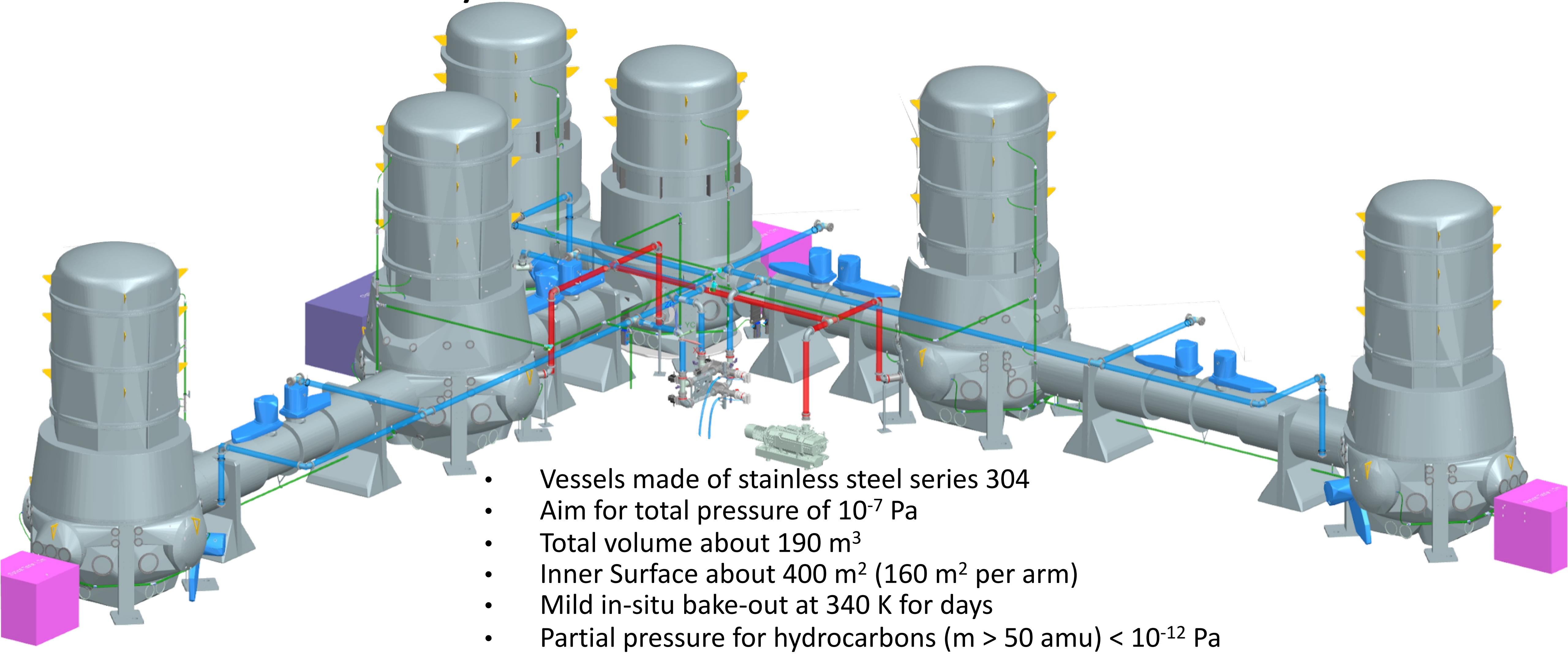


observatories are still operational. In addition to ensuring that CE will achieve its full potential, many of the technologies required for CE may also be used to enhance existing observatories. This research will take place in collaboration with other projects like ETpathfinder[38] and the Caltech 40 m prototype.[37]

Detailed Topics

- Vacuum
- Cryogenics
- Seismic isolation
- Optics
- Controls

The Vacuum System - Overview

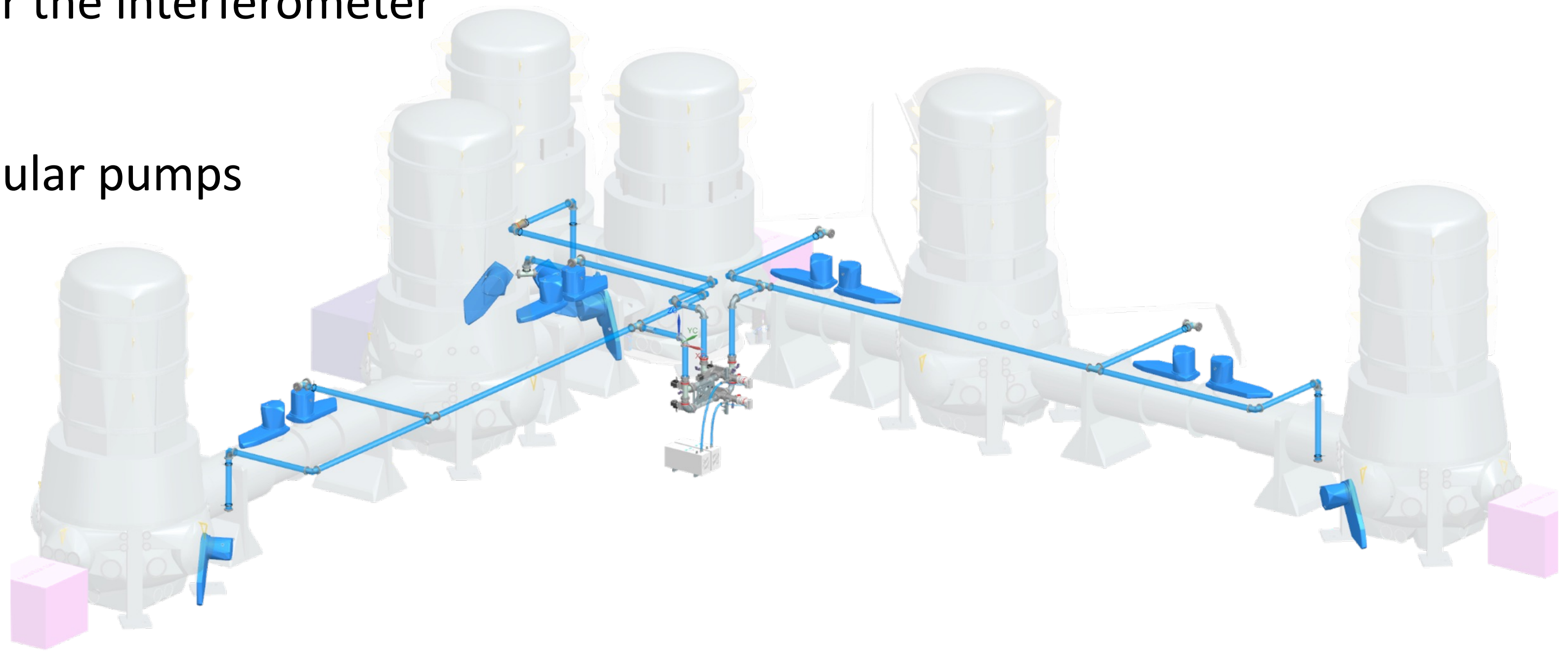


- Vessels made of stainless steel series 304
- Aim for total pressure of 10^{-7} Pa
- Total volume about 190 m^3
- Inner Surface about 400 m^2 (160 m^2 per arm)
- Mild in-situ bake-out at 340 K for days
- Partial pressure for hydrocarbons (m > 50 amu) < 10^{-12} Pa
- 3 vacuum systems: UHV (blue), roughing (red), differential (green)

The Vacuum System - Overview

The UHV system:

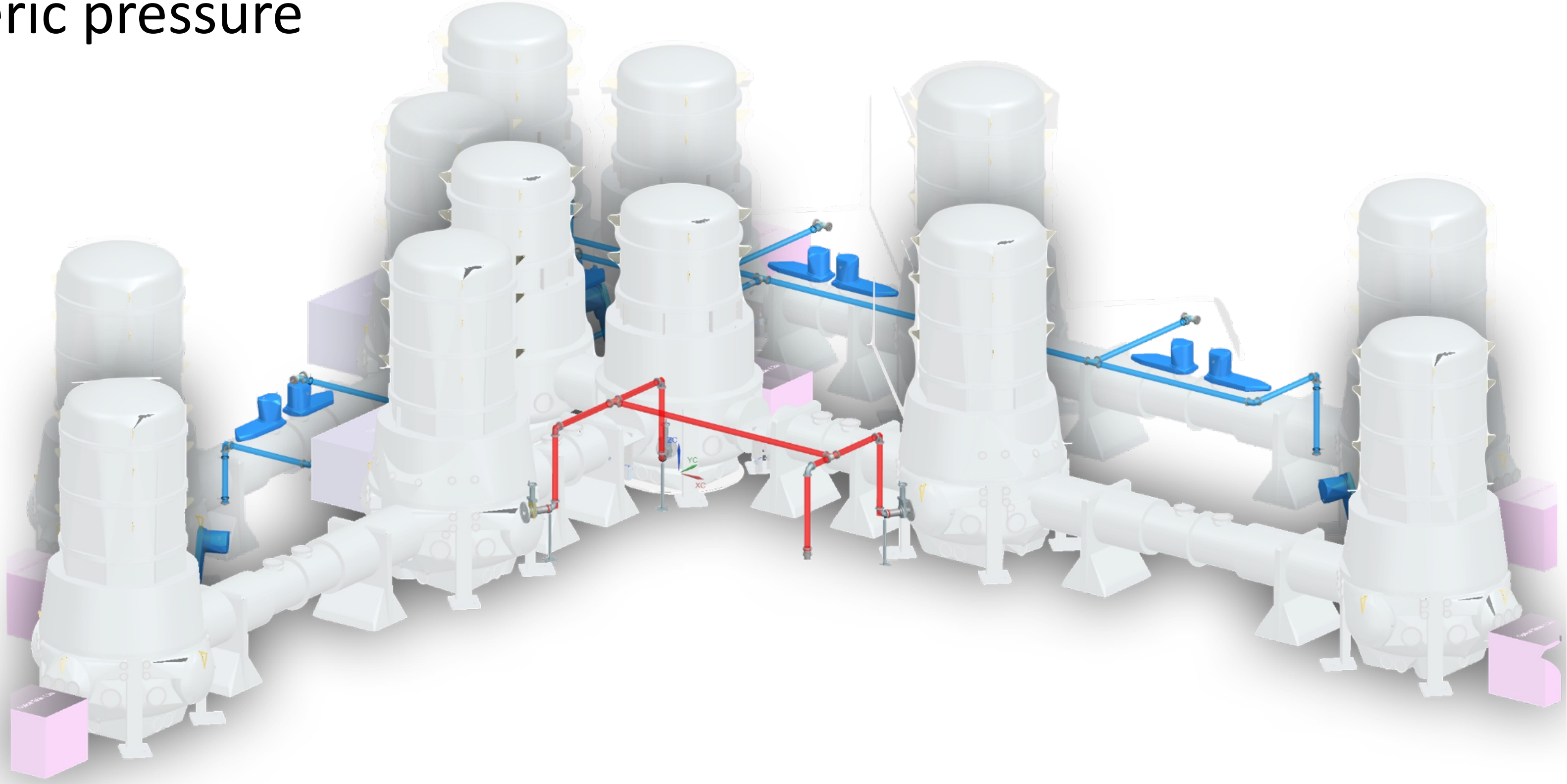
- Provides the vacuum environment for the interferometer
- 3 sections = 2 arms + central section (separated by 3 DN200 valves each)
- 14 magnetically-levered turbo-molecular pumps (3200 l/s for N_2 per TMP)
- Cascaded pumping system with small (380 l/s) TMPs
- Fore-vacuum behind TMPs provided by 2 multi-roots pumps.
- Ultimate pressure below 10^{-7} Pa



The Vacuum System - Overview

The roughing system:

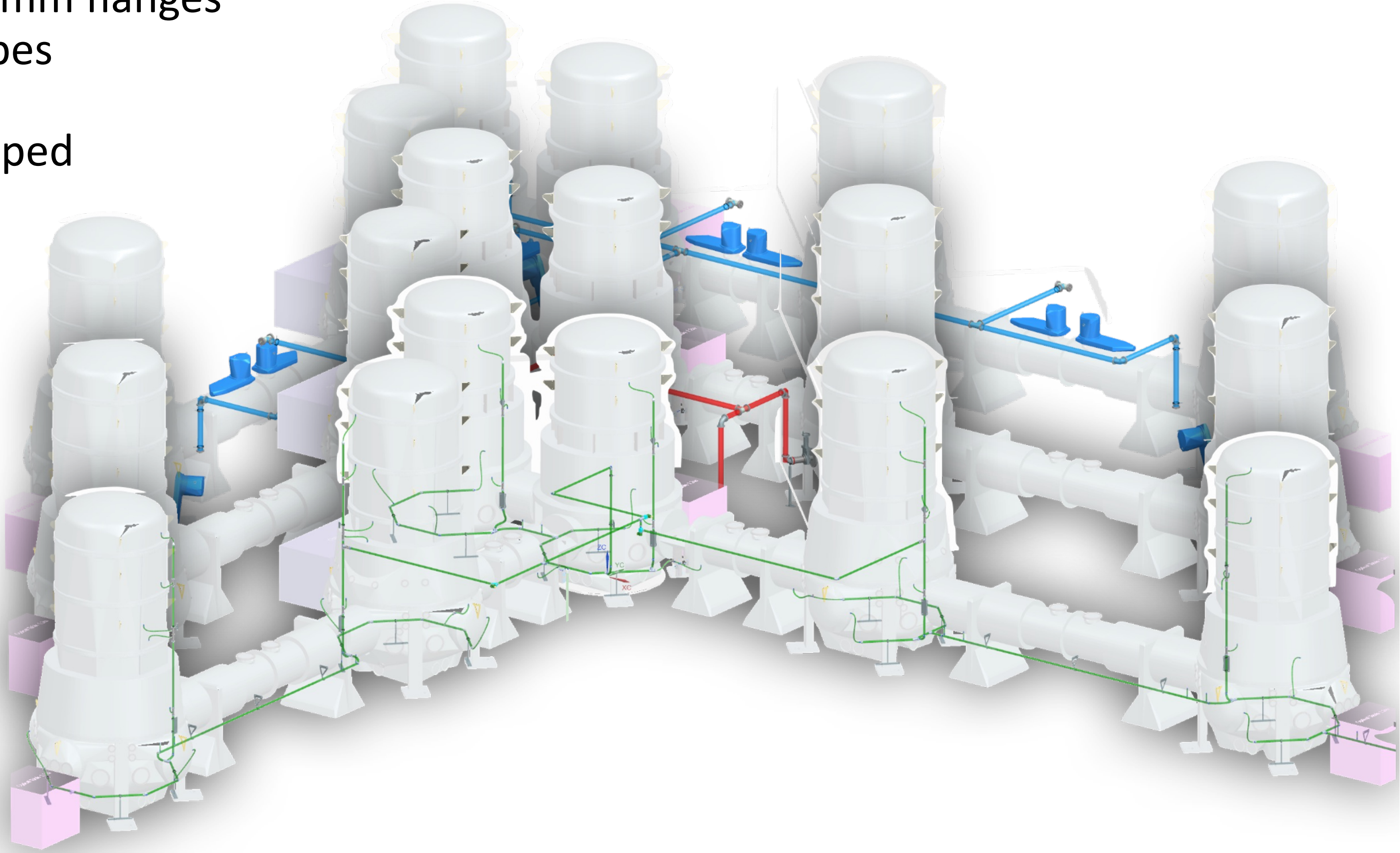
- Pumping down from atmospheric pressure
- Venting with dry nitrogen



The Vacuum System - Overview

The differential system:

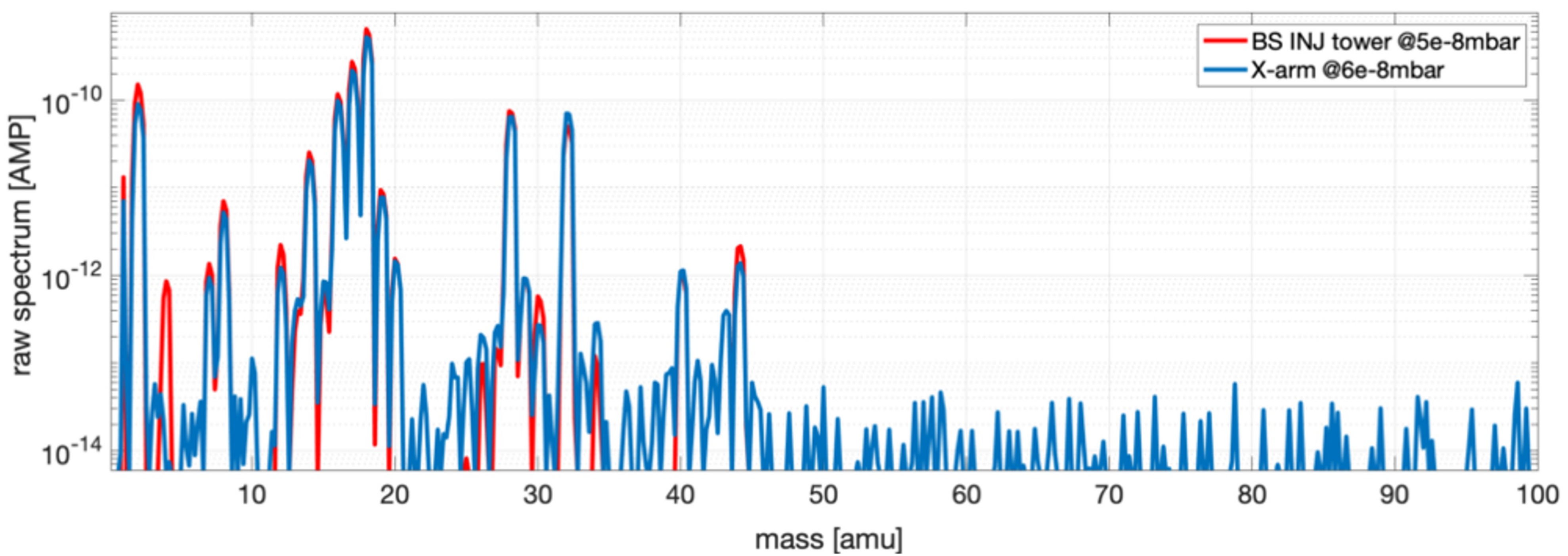
- Segments of the towers and the 800-mm flanges on the towers, bellows, and beam pipes contain double viton O-rings.
- Volume between O-rings can be pumped by 3rd multi-roots pump.
- Pressure between O-rings to be in the 0.1 Pa range.

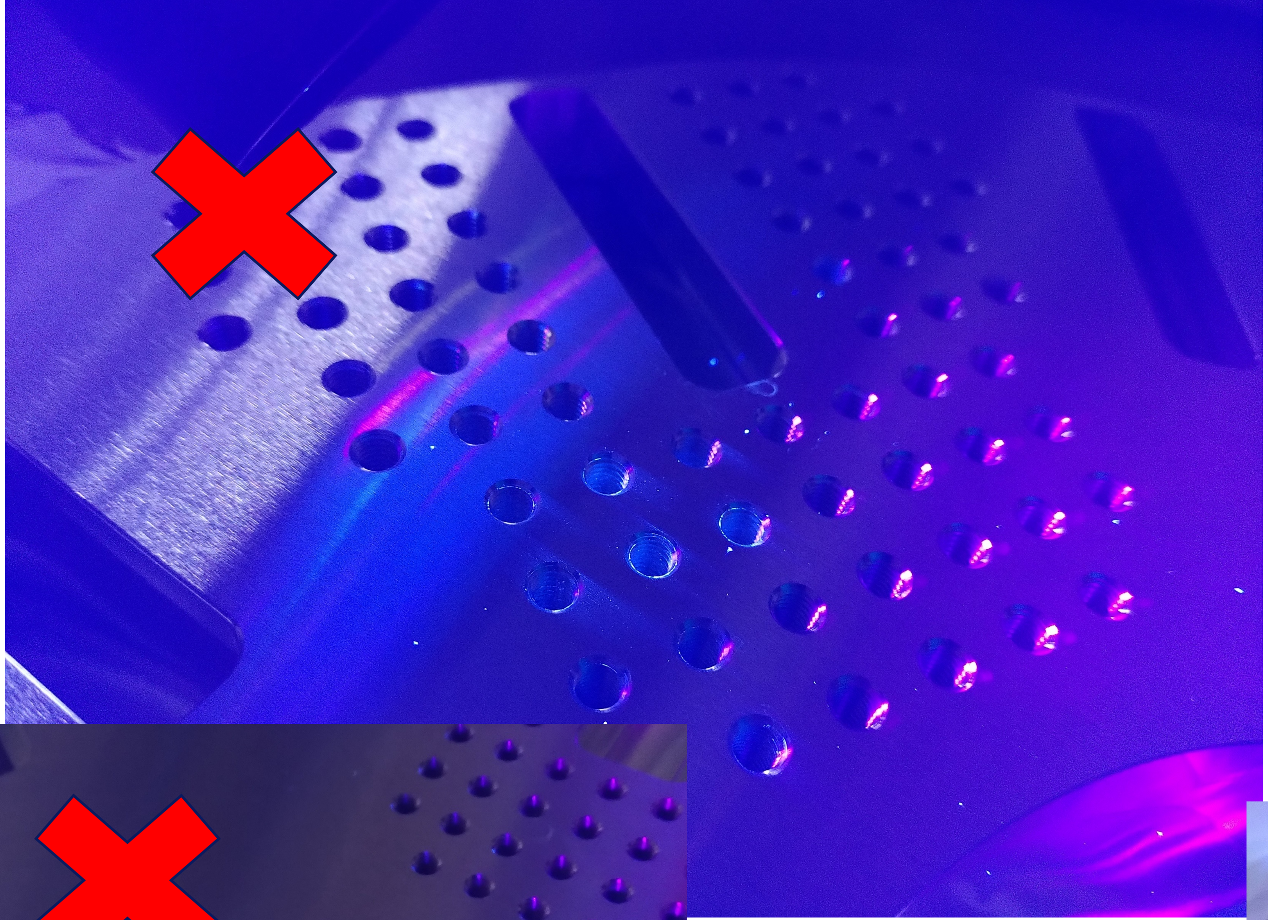


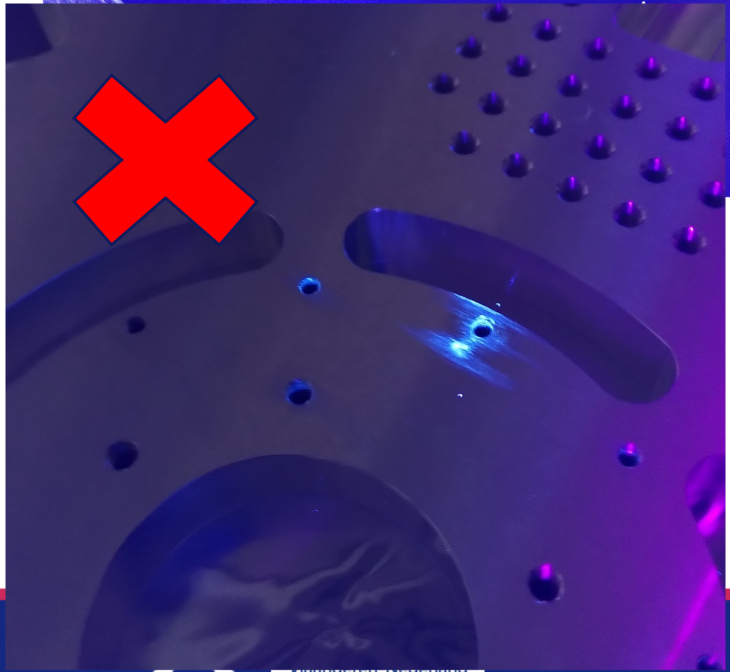
Vacuum Quality

Recap from STAC Nov. 2022:

- RGA measured at 5×10^{-6} Pa in the x-arm and injection section.
- Dominant contribution from H_2O.
- Sizable contribution of H2, CO2 (mass 44), CO/N2 (mass 28), O2 (mass 32).
- All hydrocarbons (mass > 45) are negligible.





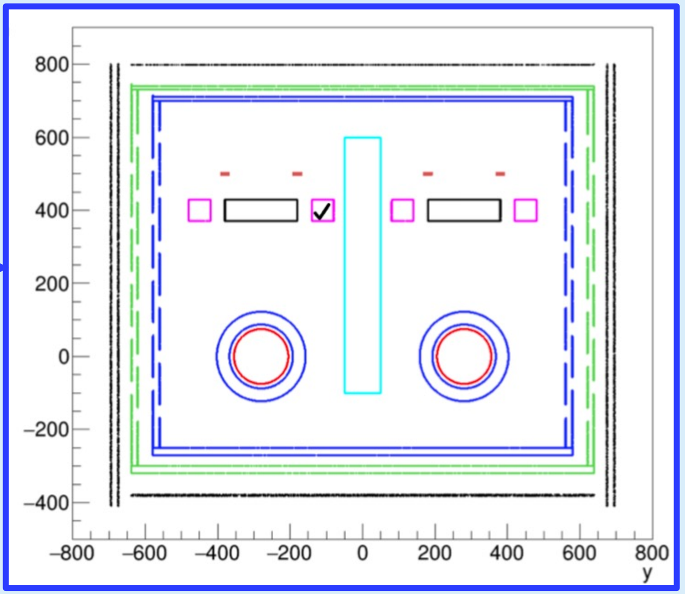


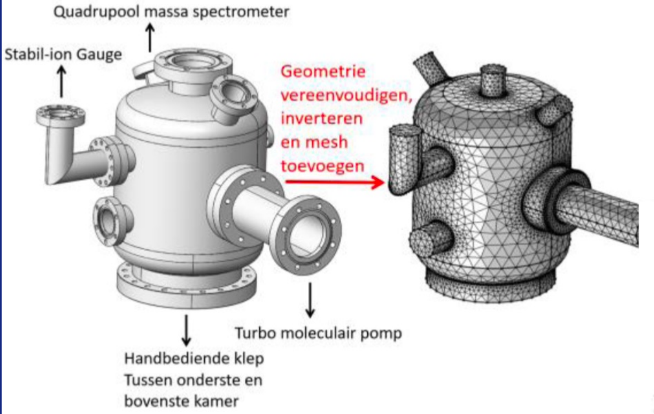
Detailed Topics

- Vacuum
- Cryogenics
- Seismic isolation
- Optics
- Controls

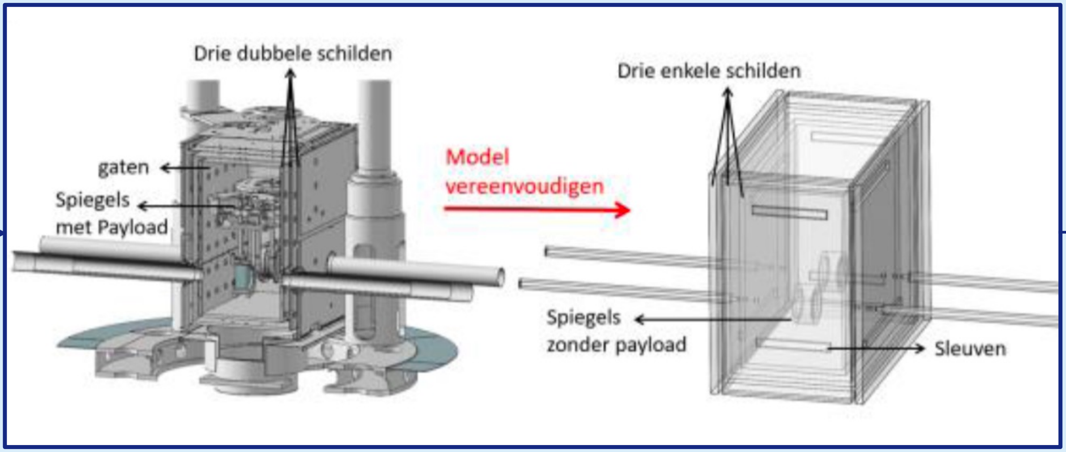
Vacuum / cryogenic simulations

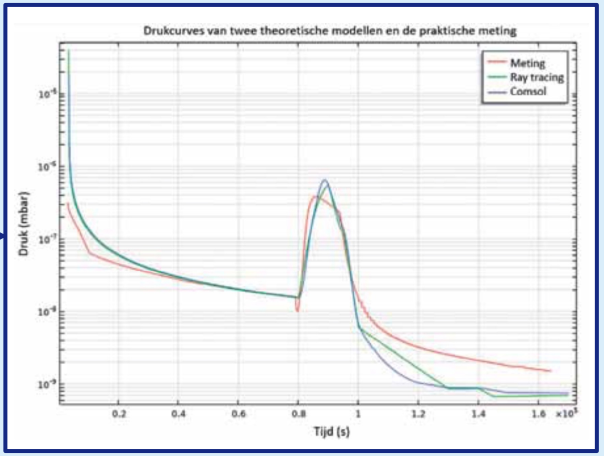
- Modeling:
  - ETpathfinder is a test facility: pump-down should be quick and part of the system will be vented quite often. Largest challenge: water (monolayer of water that will bind to the surface after each venting).
  - In CDR: we developed a simulation package that tracks water molecules : adsorption and desorption on the walls, permeation through Viton O-rings, molecular flow, compression factor of turbo pumps etc.
  - Molfflow and Comsol were not capable of doing these calculations (no pressure-dependent, time-dependent and coverage-dependent parameters for the surfaces, and the ETpathfinder geometry was too detailed).
  - Calibrated the calculations against Molflow and Comso using a outgassing set-up at Nikhef (Vera Erends, Berend Munneke, HJB)





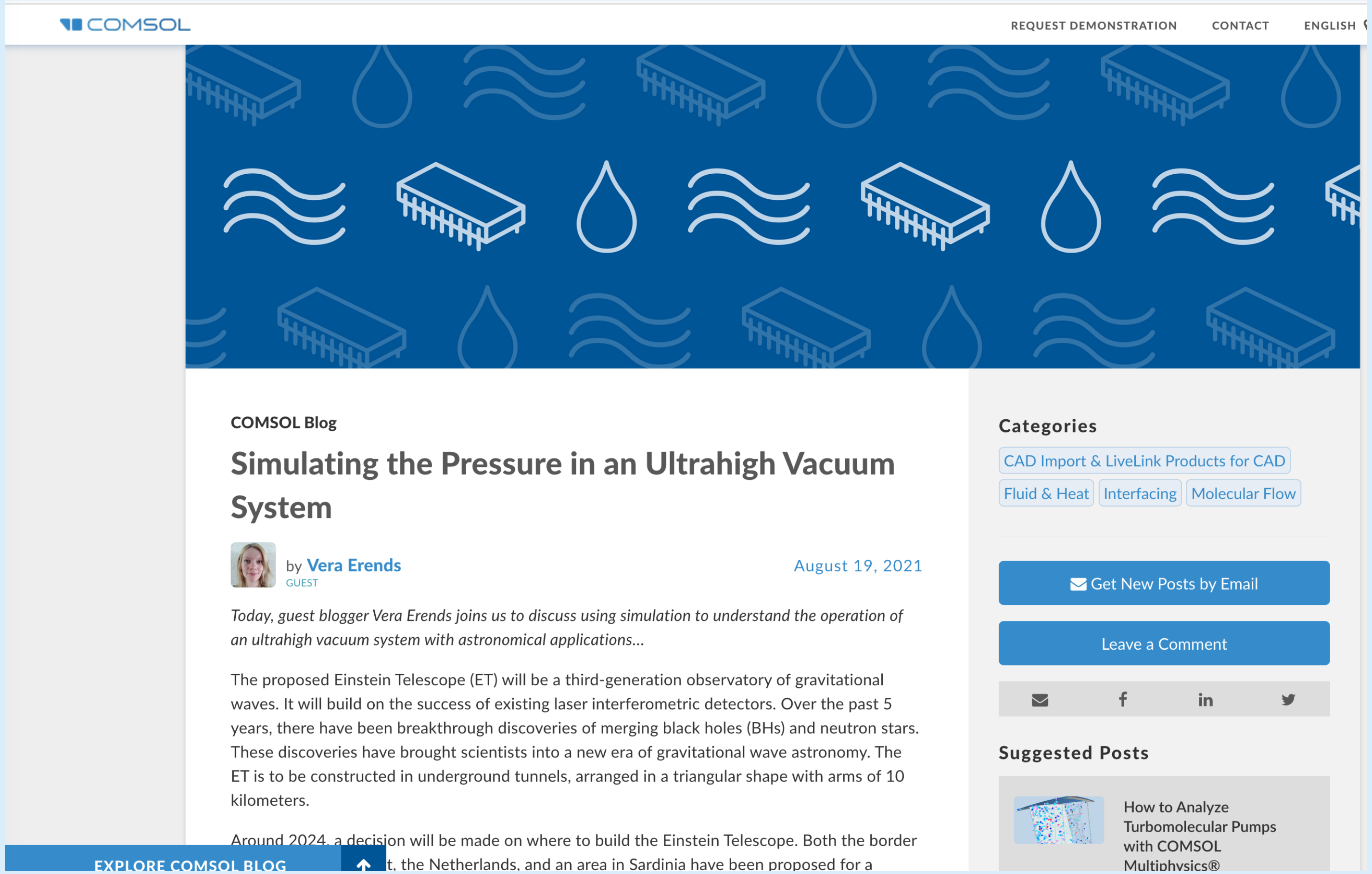
Figures from Publication:
Vera Erends, NEVAC, Oct 2020.





Pics from Article by Vera:
https://nevac.nl/archief_pdf/pdf_208.pdf

Maastricht University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COMSOL Blog

Simulating the Pressure in an Ultrahigh Vacuum System

by Vera Erends
GUEST
August 19, 2021

Today, guest blogger Vera Erends joins us to discuss using simulation to understand the operation of an ultrahigh vacuum system with astronomical applications…

The proposed Einstein Telescope (ET) will be a third-generation observatory of gravitational waves. It will build on the success of existing laser interferometric detectors. Over the past 5 years, there have been breakthrough discoveries of merging black holes (BHs) and neutron stars. These discoveries have brought scientists into a new era of gravitational wave astronomy. The ET is to be constructed in underground tunnels, arranged in a triangular shape with arms of 10 kilometers.

Around 2024, a decision will be made on where to build the Einstein Telescope. Both the border … t, the Netherlands, and an area in Sardinia have been proposed for a

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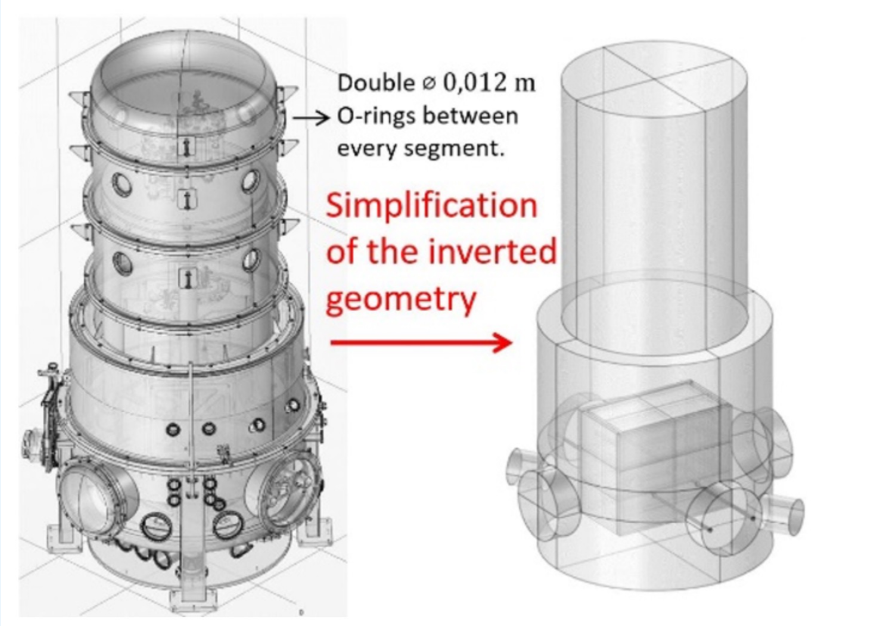
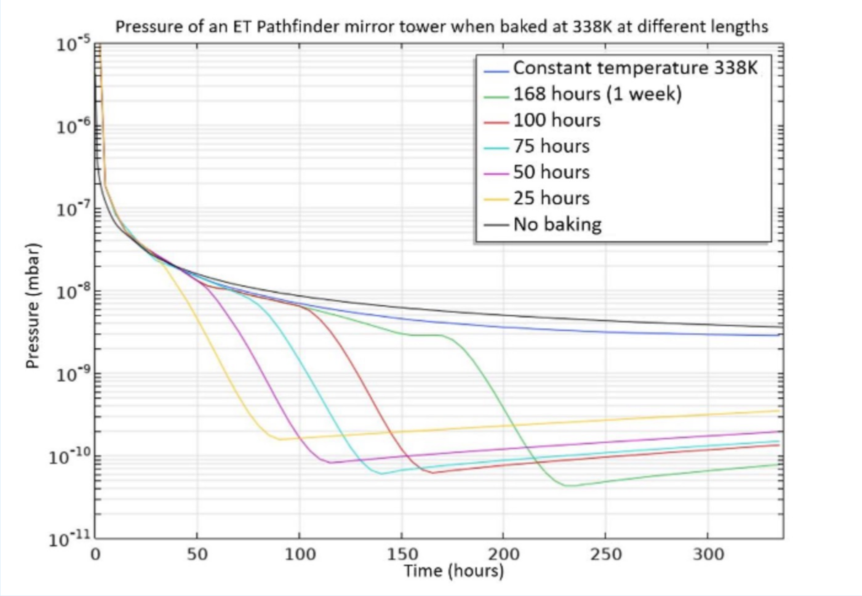
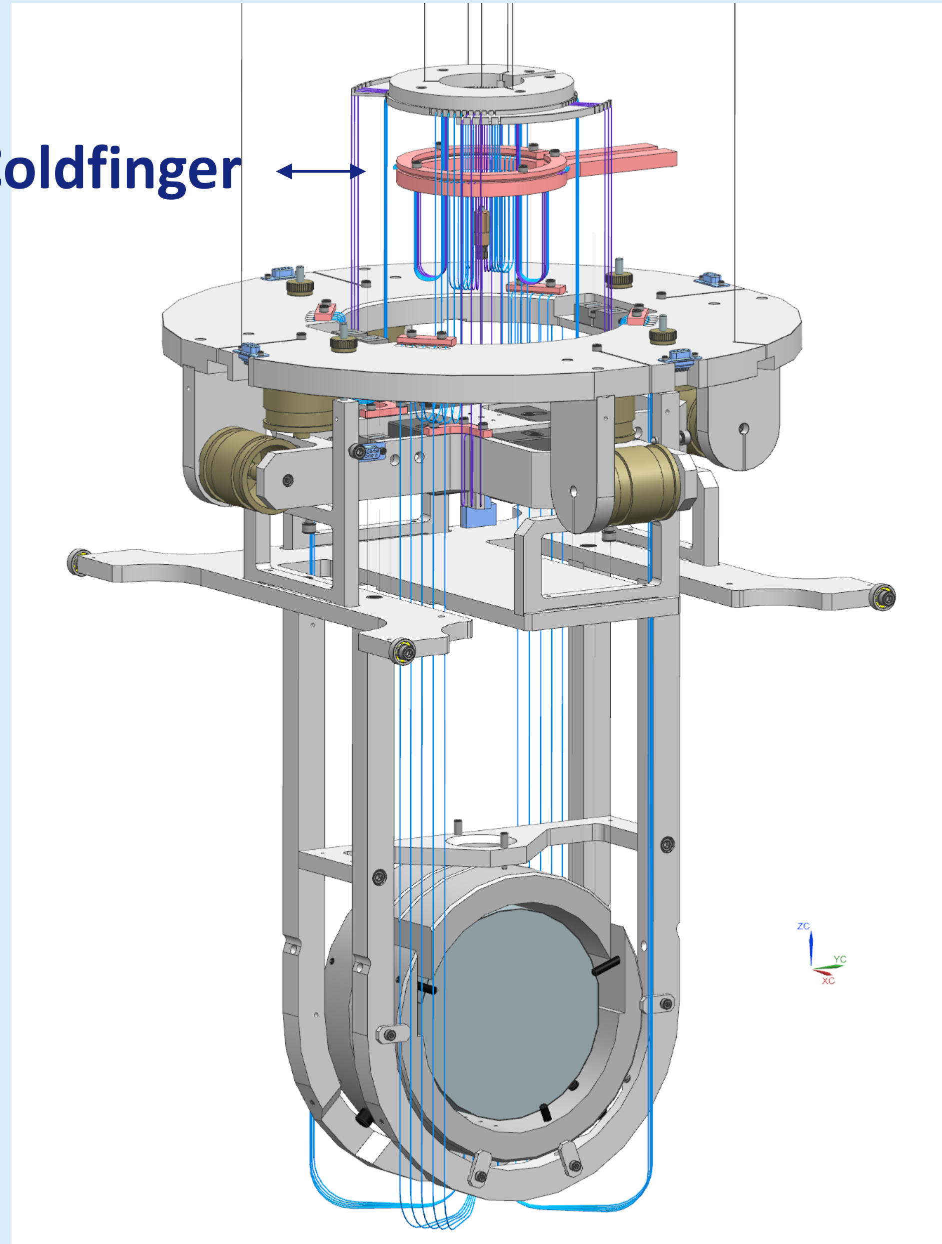




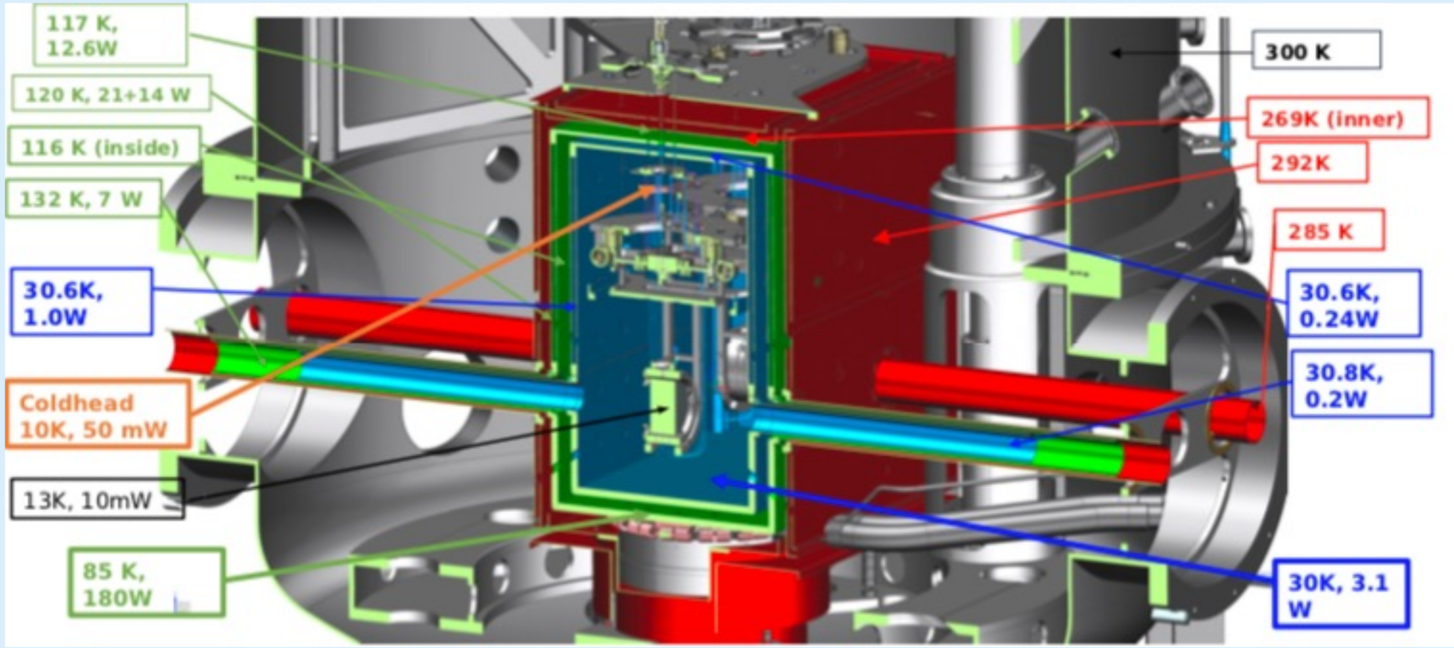
Cryogenics (I)

- Mirrors need to be cooled to cryogenic temperatures (~15K, 123K), without introducing noise, i.e. cooling only possible via thin suspension wires.
- General approaches under consideration:
  - Dry system: pulse-tubes. Challenge = reduce and isolate vibrational noise.
  - Sorption coolers (base line in ETpathfinder) = more quite, less cooling power.
  - Cryogenic Liquids: LN2, He, He-II. Challenges = avoid bubbling; transfer liquids from surface 300m above the caverns …



Cryogenics (II)

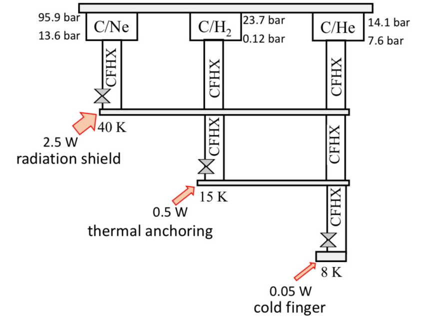
- Need avoid ice on the mirrors and find ways to deal with ice if it builds up (reduce its thermal noise and optical influence)? – Will use 3 pairs of metal-cryo-shields.



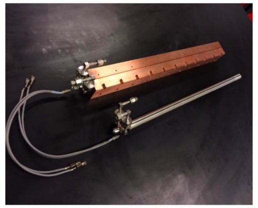
- Complex heat extraction matrix (vastly different powers, at different temperatures and with different noise requirements).
- Not only steady state operation sets requirements, but many come from cool-down requirements.
- No off-the-shelf simulation tools available that cover essential functionality. ☹

ELT design-based (3 stages, cold finger at 8K)

T heat sink	Ne	H_2	He	Total
80 K	25 cells 313 W	5 cells 80 W	12 cells 146 W	42 cells 63 liter 505 W
70 K	17 cells 206 W	4 cells 63 W	5 cells 58 W	26 cells 39 liter 327 W



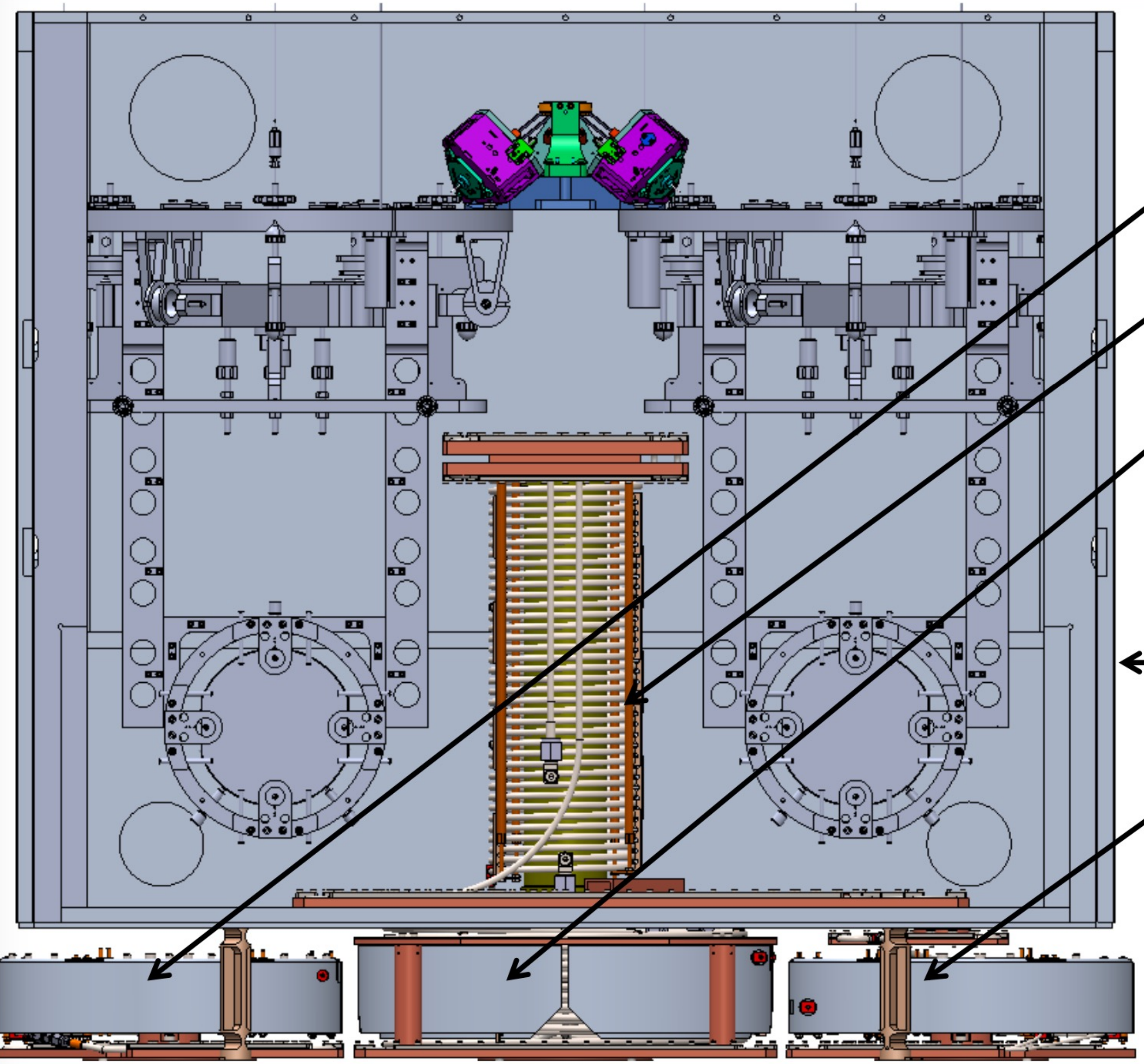
This power is taking from a wall socket (no problem) BUT it is dumped in the LN_2 bath (doubles roughly the required flow!), now anticipated load is ca 420 W



1 compressor cell housing: 5 x 5 x 60 cm^3 = 1,5 liter

Sorption cooler

3. Cryolines



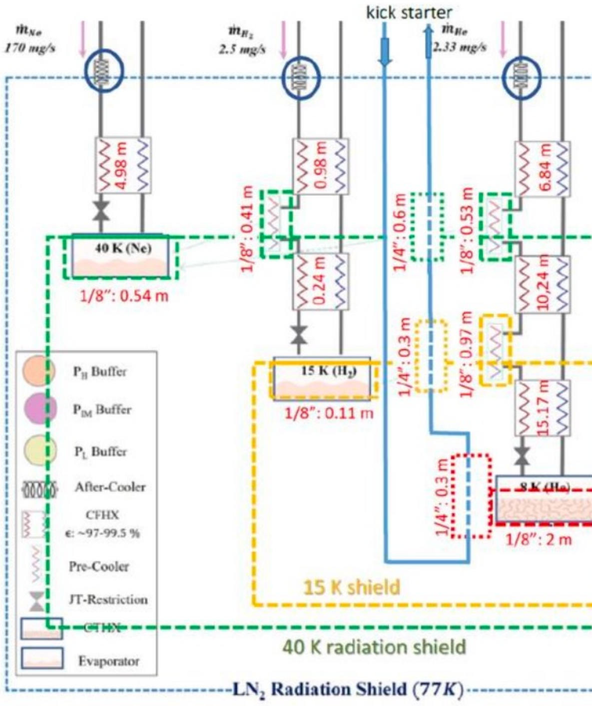
Ne stage

He stage + KS above 15K Shield

He stage + KS beneath 15K Shield

15K Cryoshield

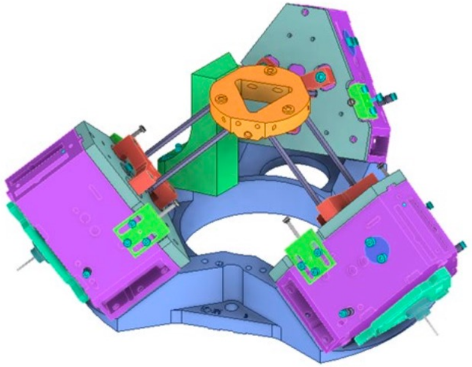
H_2 stage



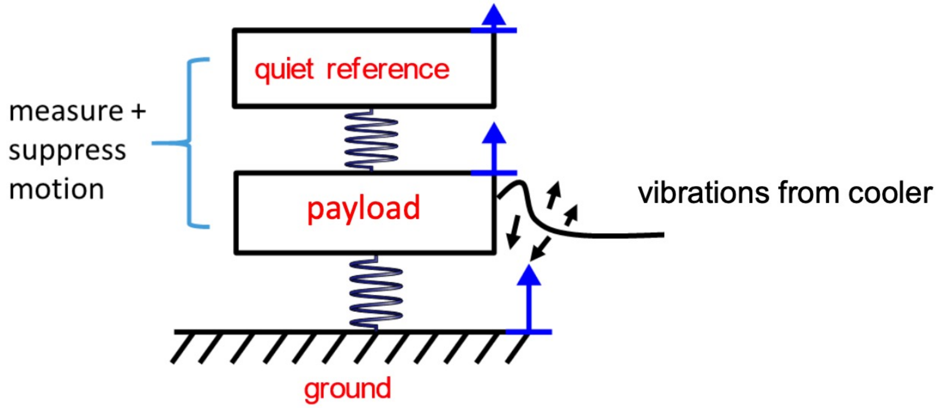
3D Cryogenic Active Vibration Isolator (CAVI)

~ 264mm diameter, 111mm height, mass 2.3kg
3x 1DoF units tilted by 36.24deg, gravity compensation

JPE
Driven by innovation



Was finally delivered in
mid December 2023



Sensing

Attocube sensor heads

Displacement Measuring Interferometer

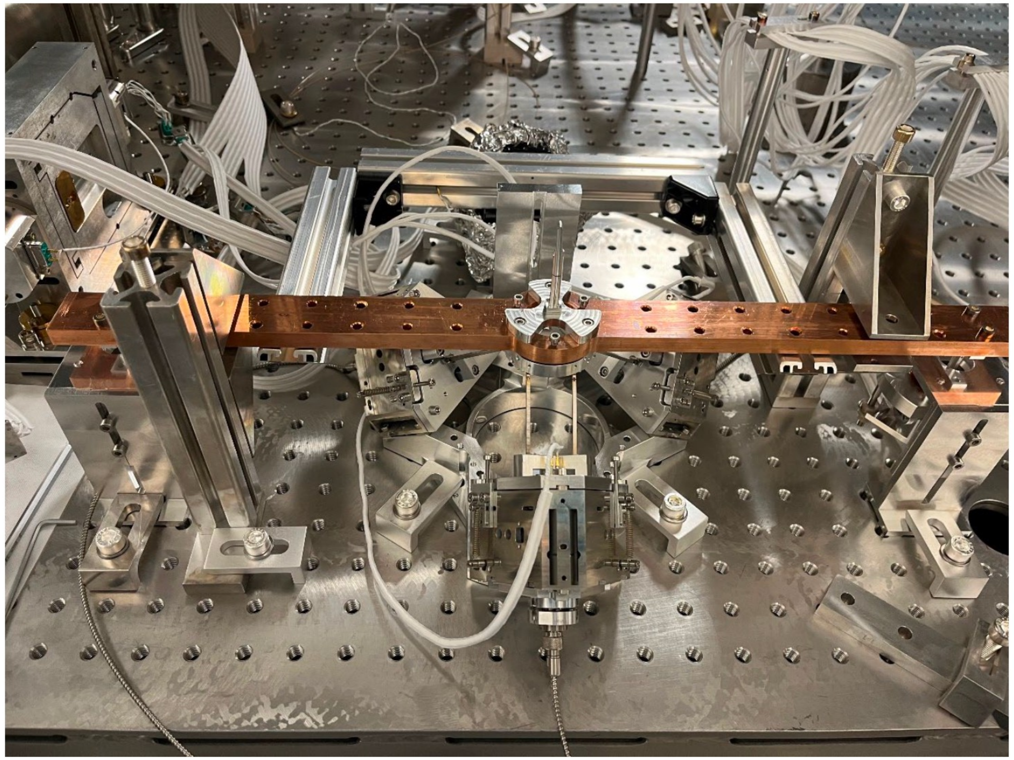
optical fibres

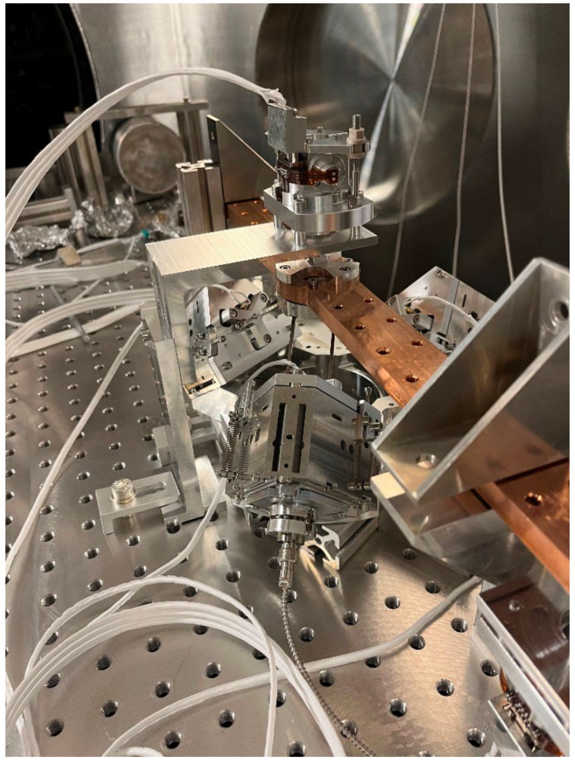
digital and analog
signal outputs

Actuating

JPE Cryo Voice Coil Actuator

Loading the 3D CAVI platform





Maastricht University

Luise Kranzhoff
01-02-2024

Nikhef

Example: Cryocooling for ET/ETpathfinder

Test facilities
Maastricht University

Cryogenic precooler
STIRLING CRYOGENICS

Cryogenic vibration suppression
JPE — Driven by innovation
Universiteit Leiden

Cryogenic transfer lines
cryoworld — advanced cryogenics

System Architect
Nikhef

LN_2 infrastructure
DEMACO

Zero-vibration Sorption Cryocooler
DEMCON
KRYOZ
UNIVERSITY OF TWENTE.
COOLL

Example:Cryocooling for ET/ETpathfinder

Einstein Telescoop - 10 Kelvin trillingsvrije cryokoeling

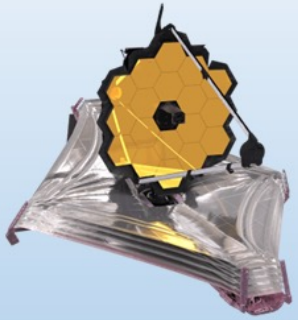
Life-sciences & materiaal onderzoek

(bio)sample onderzoek bij extreem lage temperaturen

Halfgeleider industrie

supergeleidende lineaire motoren voor wafer steppers

Ruimtevaart



cryogeen gekoelde optische sensoren in ruimtevaart satellieten

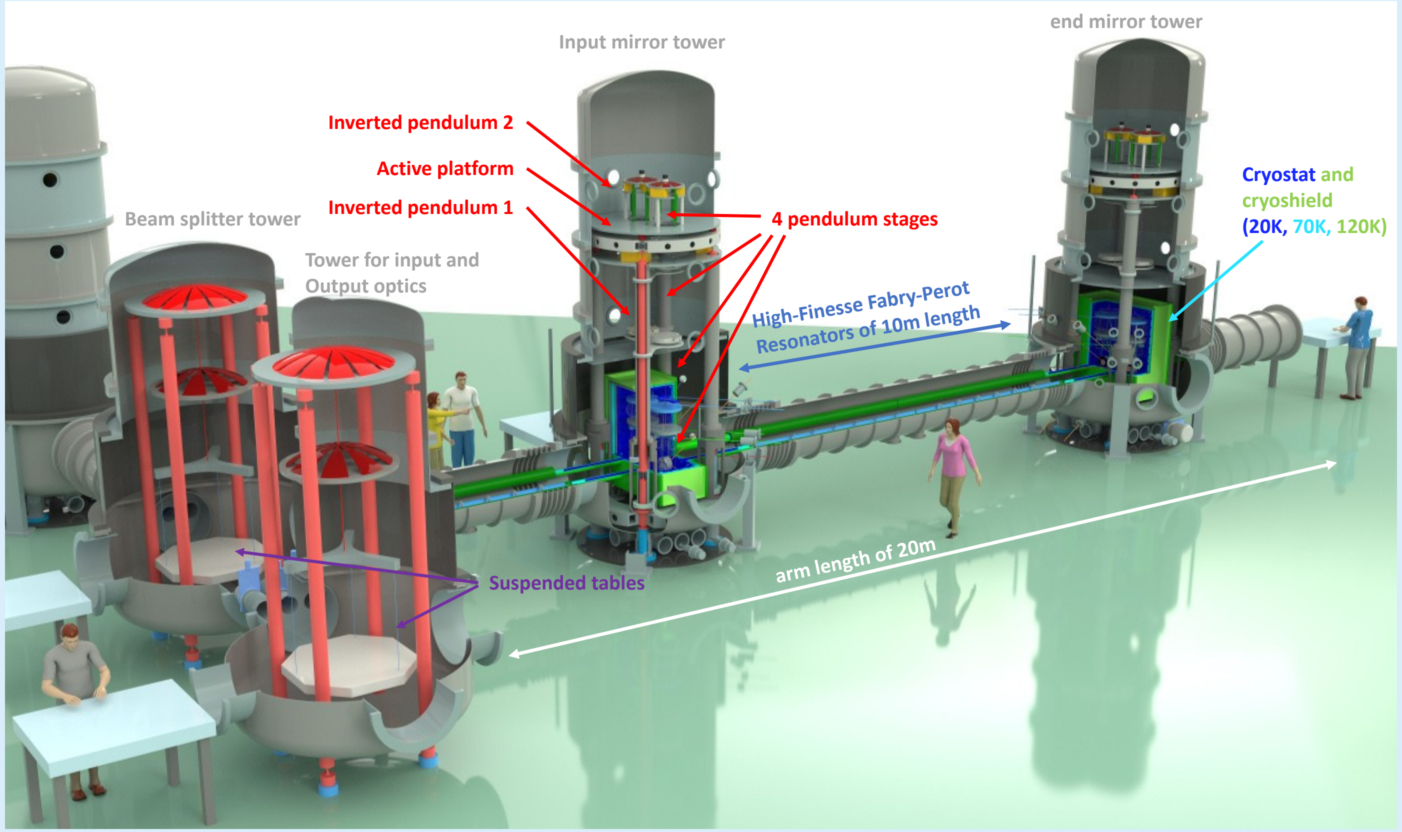
Quantum computing

(kosten) efficiënte Qubit cryokoeling voor quantum computers

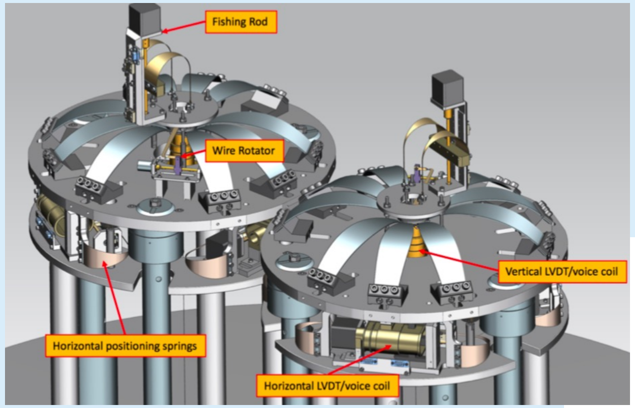
Detailed Topics

- Vacuum
- Cryogenics
- Seismic isolation
- Optics
- Controls

Seismic Isolation



2 different designs: Mirror towers and table towers



F0 platform

Short IP

Filter 1

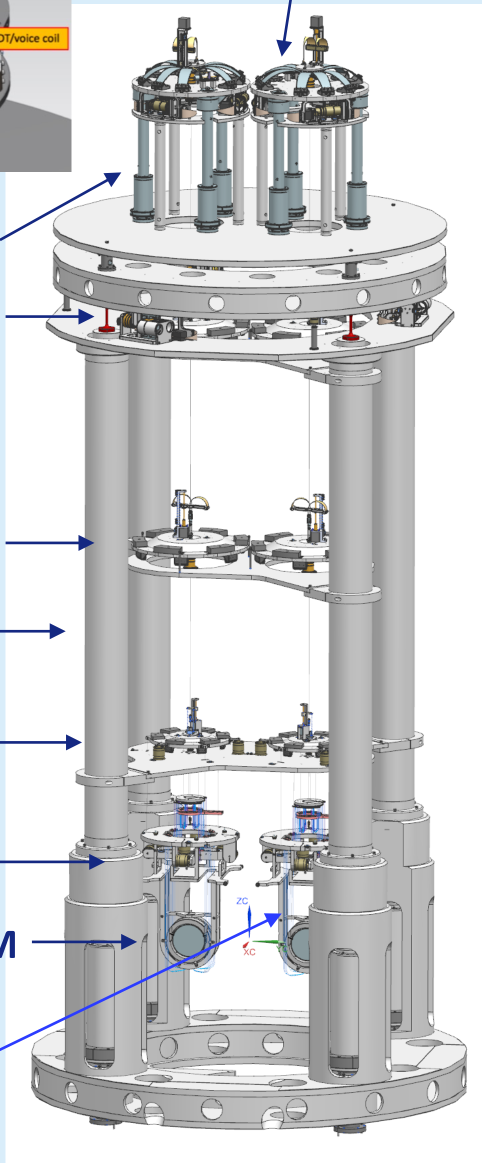
Filter 2

Long IP (~3m)

Steering
Filter

Marionetta + RM

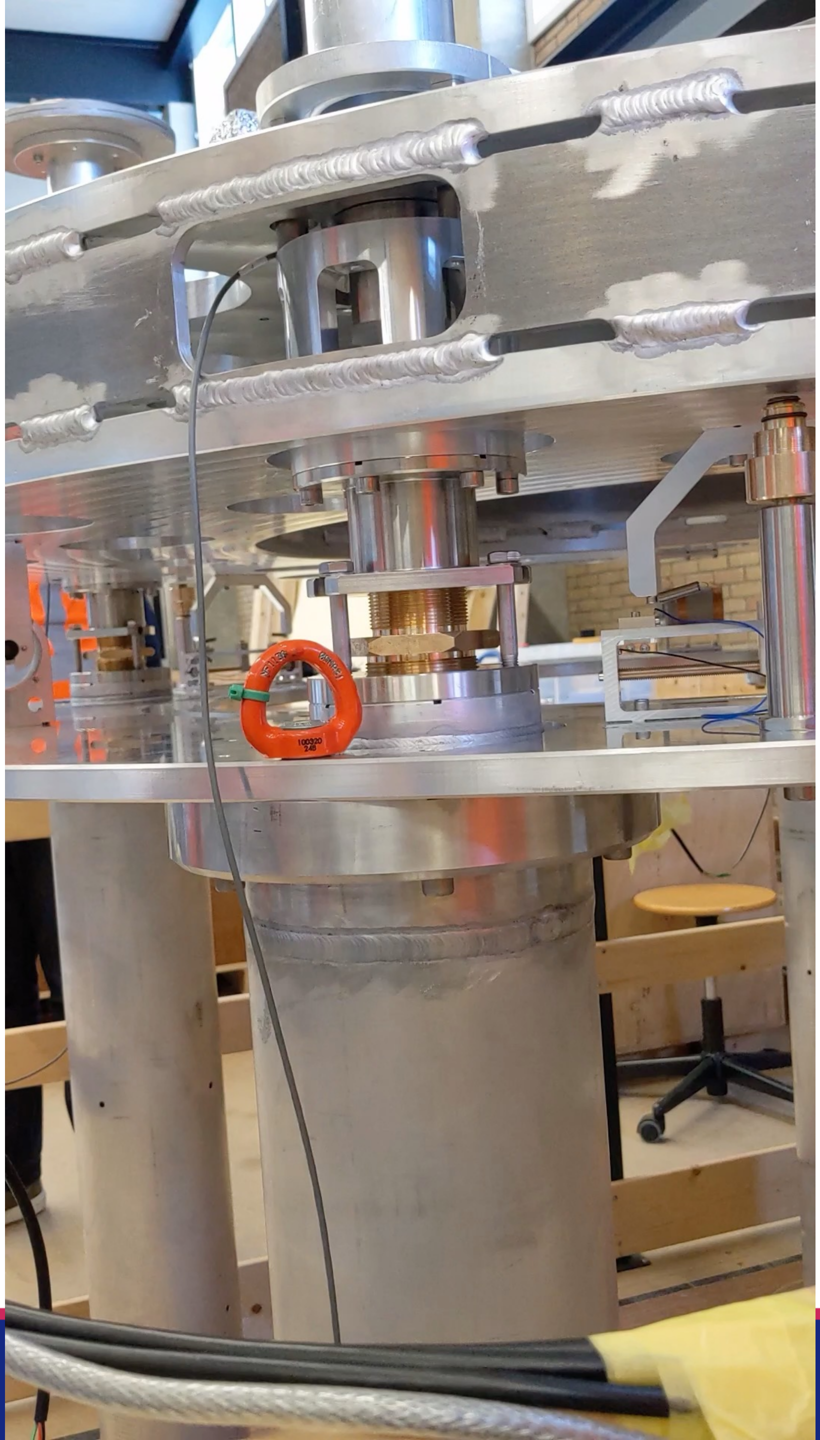
Mirror + RM

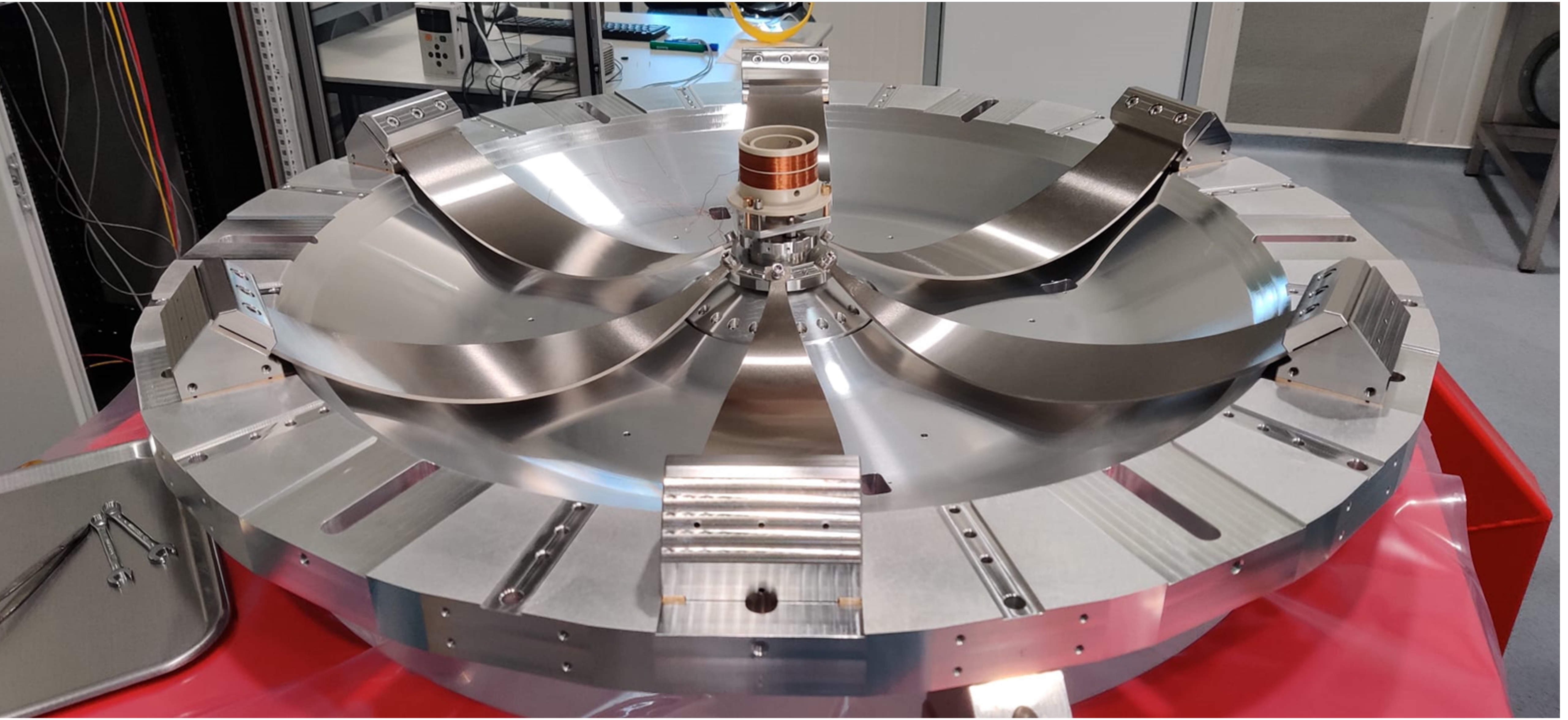


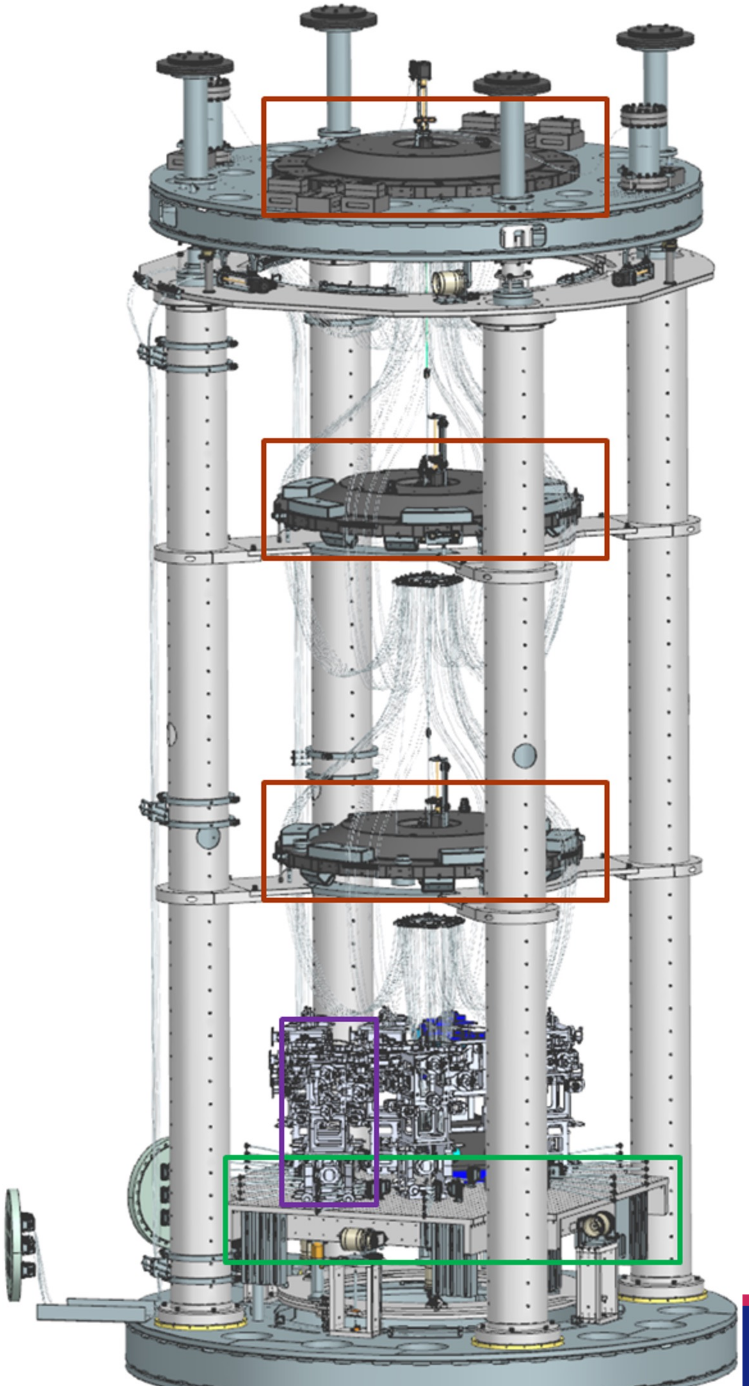
Final stage = 0.7mm Silicon
fibres of 40cm length and

IP leg prototype in action

Timelapse video at 10x speed





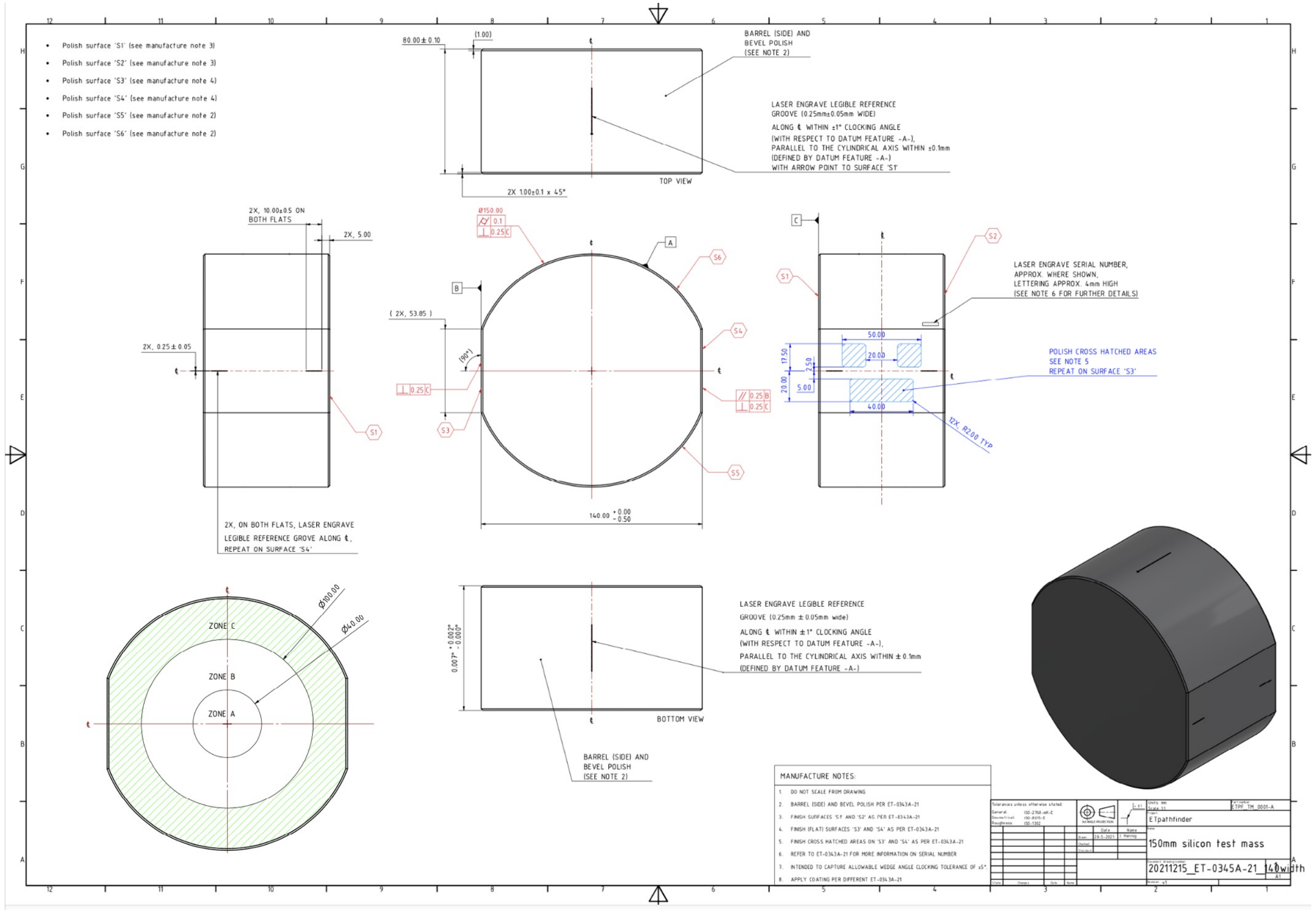


[S.Hild, Maastricht &Nikhef]

Detailed Topics

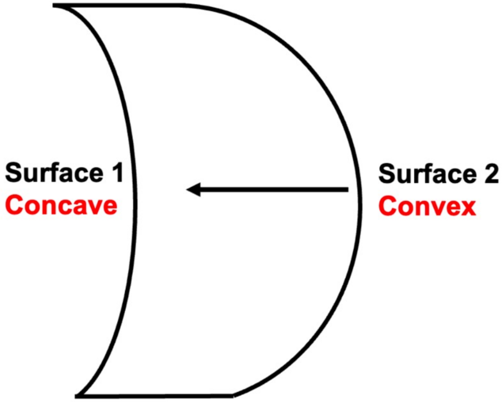
- Vacuum
- Cryogenics
- Seismic isolation
- Optics
- Controls

Main mirror requirements



12 Radius of curvature

Refer to the sketch in Figure 1 below for an exaggerated visual representation of S1 and S2 ROC.
Surface 1: The ROC of S1 shall be spherical, concave. ROC: 14.5 m ±0.1 m.
Surface 2: The ROC of S2 shall be spherical, convex. ROC: 9 m ± 0.1 m.



13 Surface figure

Surface 1:

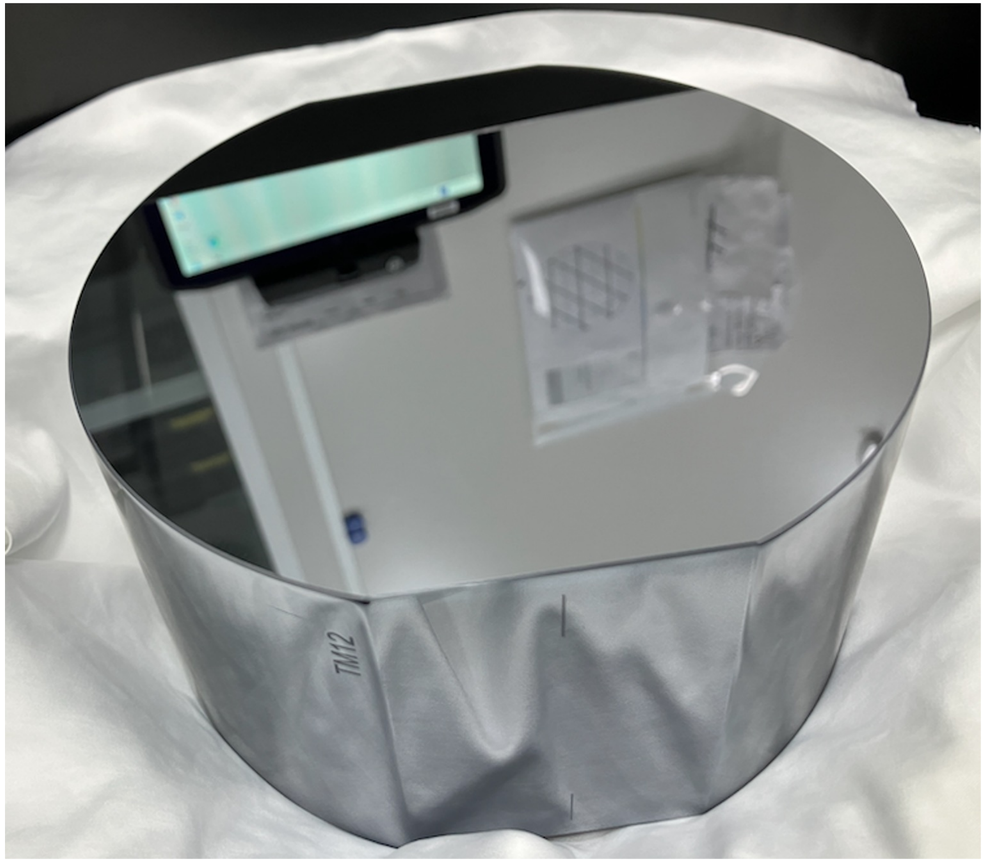
- Zone A: Surface error shall be < 1 nm RMS measured over the totality of Zone A; Micro-roughness shall be < 0.1 nm over the same area (super polish).
- Zone B: Micro-roughness shall be < 5 nm over Zone B, no surface error requirement.
- Zone C: No surface error or microroughness requirement.

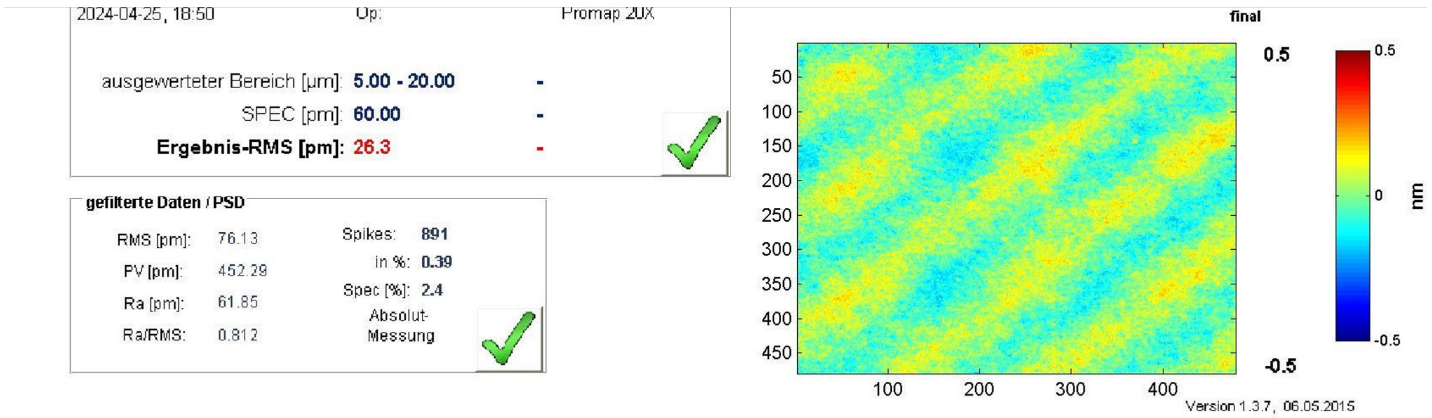
Surface 2:

- Zone A: Surface error shall be < 2 nm RMS measured over the totality of Zone A; Micro-roughness shall be < 0.1 nm over the same area (super polish).
- Zone B: Micro-roughness shall be < 5 nm over Zone B, no surface error requirement.
- Zone C: No surface error or microroughness requirement.

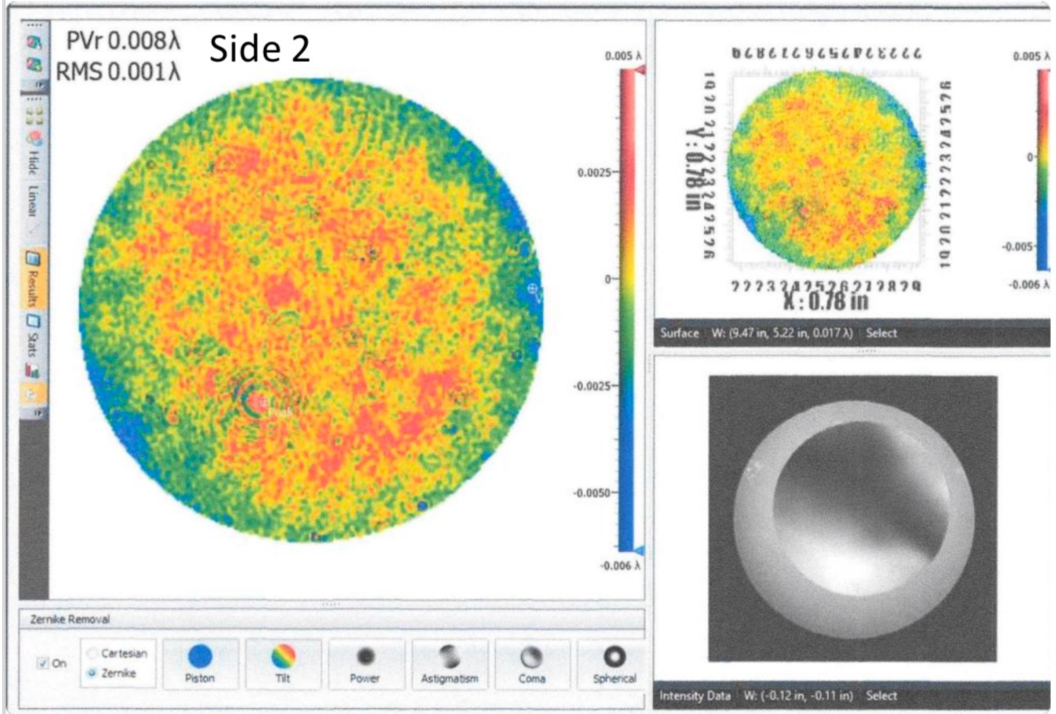
Mirror polishing

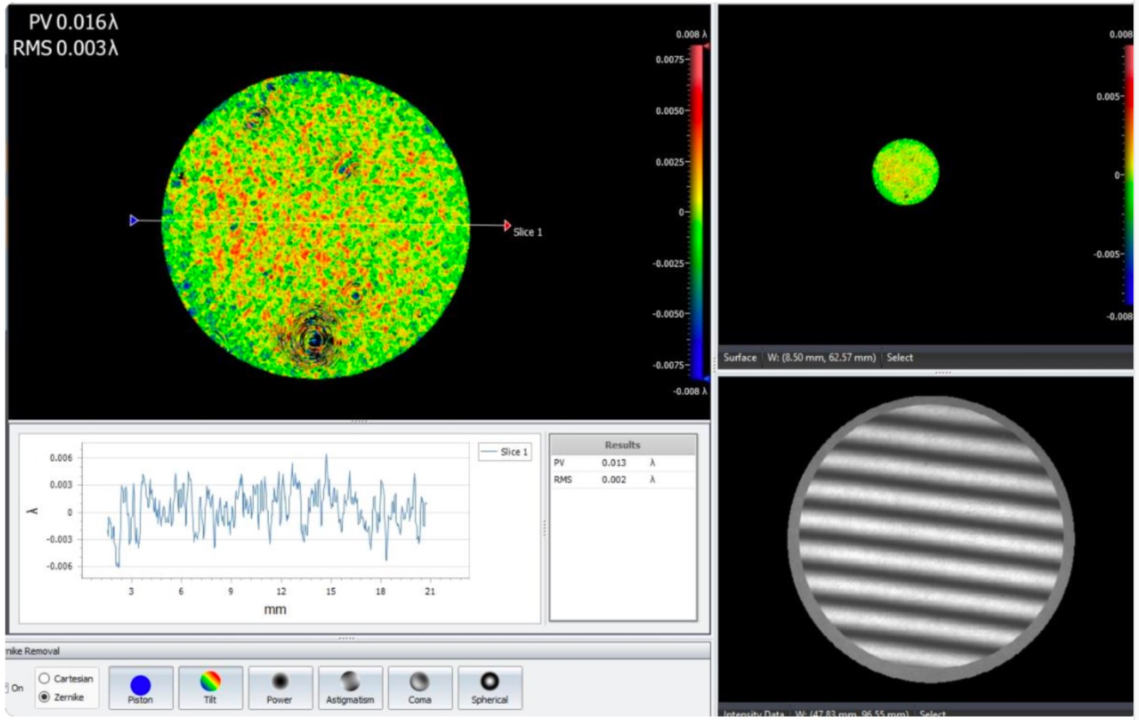
- long procedure with some learning curve and several delays, but hopefully leading to an established procedure.
- information shared by manufacturer so far sounds promising, but hard to estimate the full picture





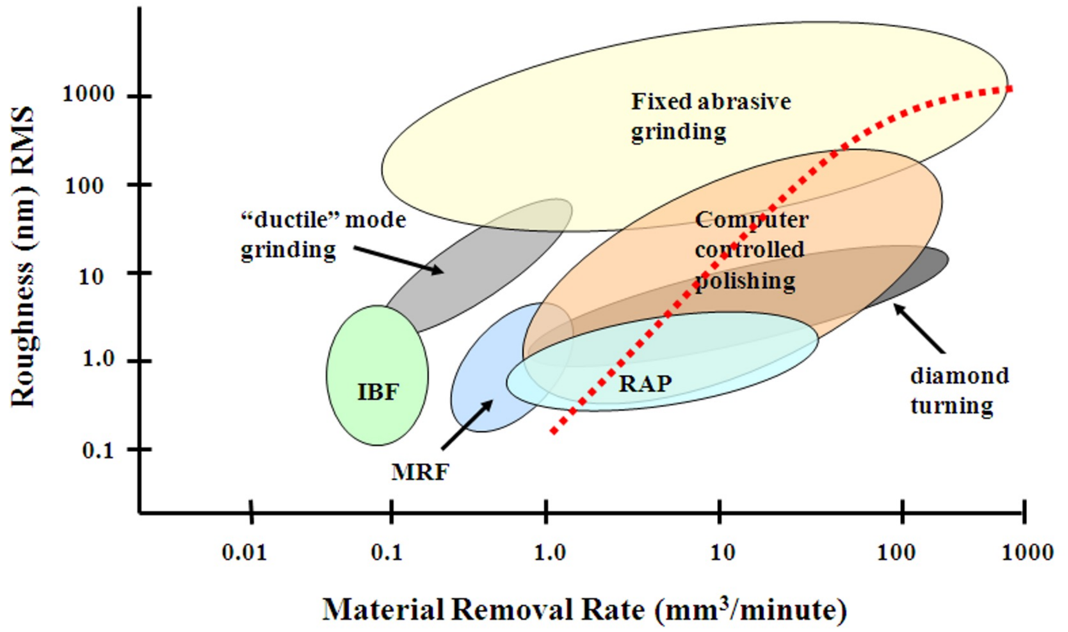
HTRS mirror metrology (Coastline vs B-PHOT)





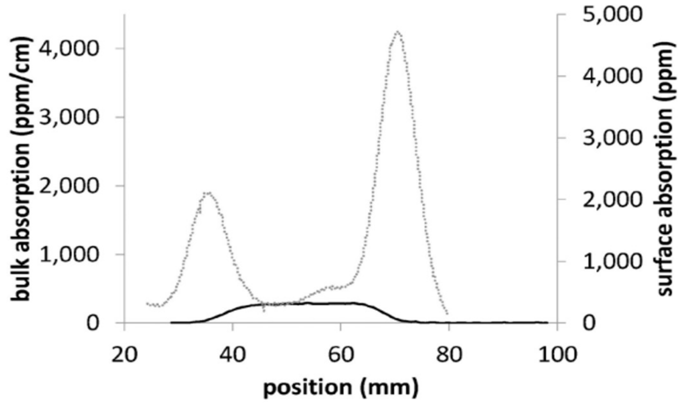
Investigating other (and more local) avenues

- ETpathfinder optics specifications were intentionally demanding (but not unrealistic), to test how suppliers would react
  - there is scope for downgrading the specifications and still make ETpathfinder work, e.g., with respect to surface roughness, alignment of front and back radii, wedge
  - but at which point do we no longer learn anything?
- at the same time, need to build up metrology for silicon mirrors (e.g., transmitted wavefronts)

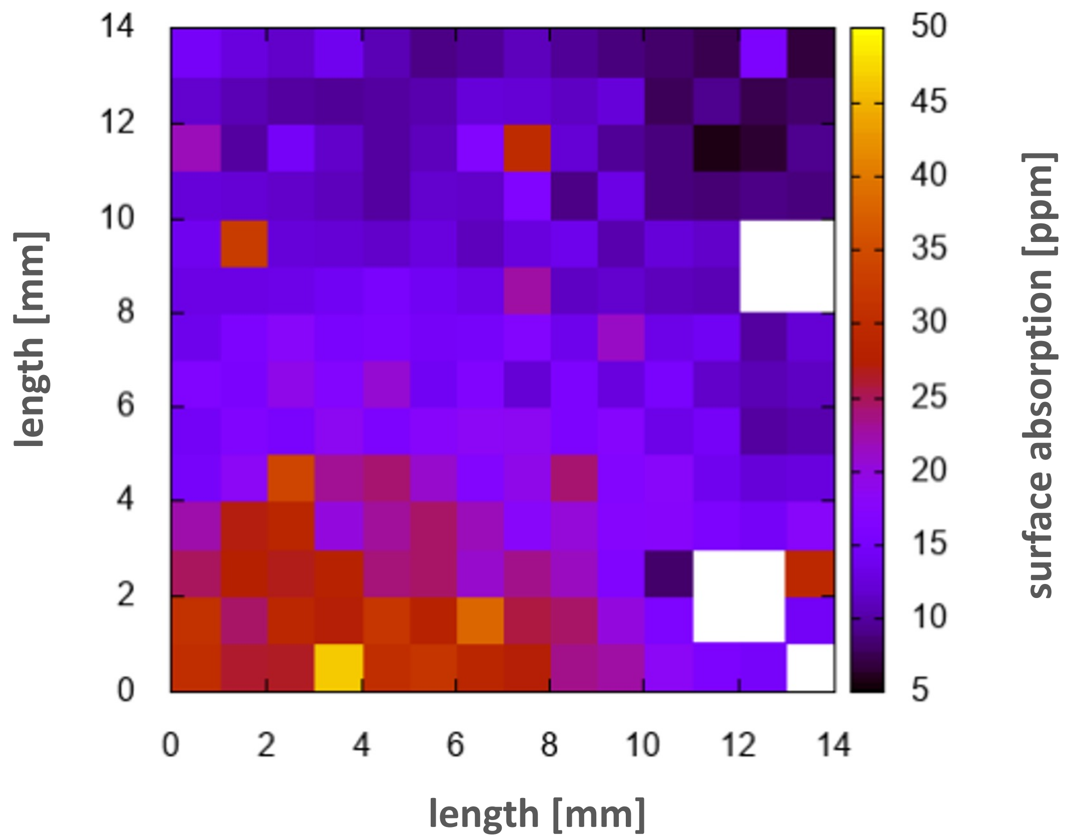


Silicon absorption measurements at UM

- initial tests with the PCI setup at UM
- known issue: measuring low absorption needs high power densities, which in silicon produces two-photon absorption
- main focus right now (also with view to measure polishing test samples) is on measuring surface absorption (Bell et al, 2017) - induced during polishing, but exact cause still unknown at least to us



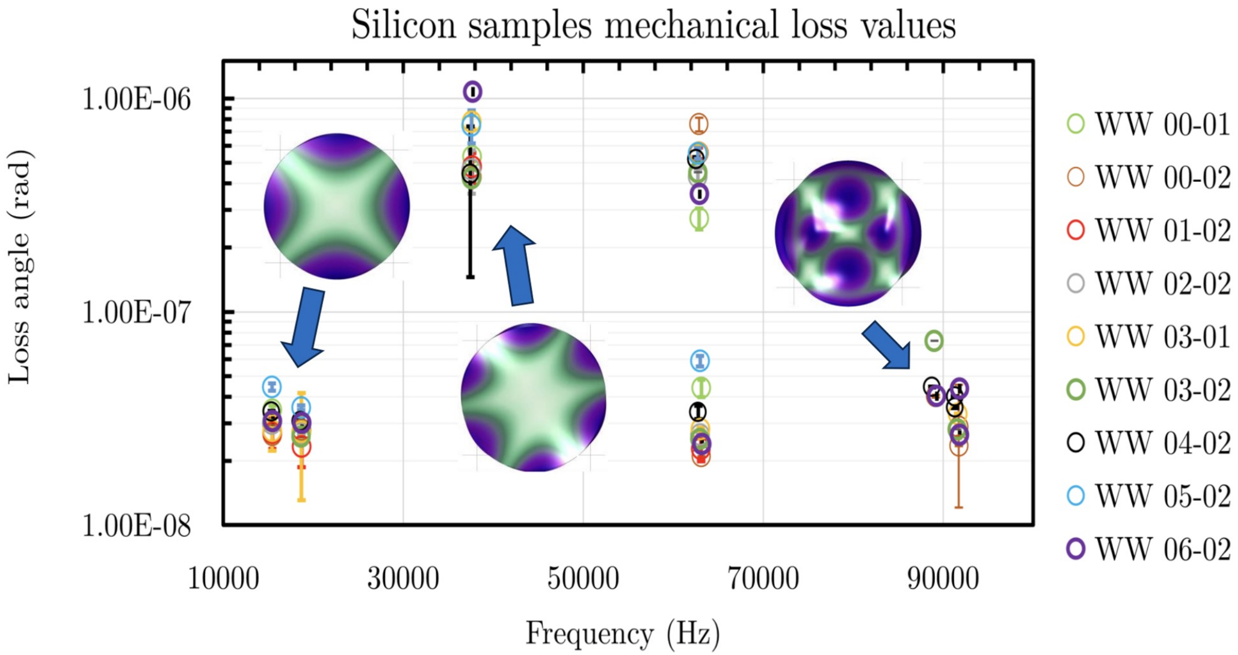
particularly bad example of contamination with Ge during polishing (from Bell et al.)

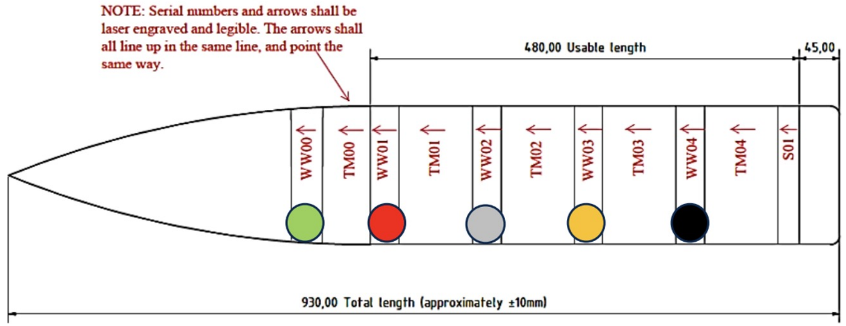


measurement of a 14mm x 14mm square on the end surface of a 1” diameter sample, polished by Pilz Optics

Silicon mechanical loss measurements at UM

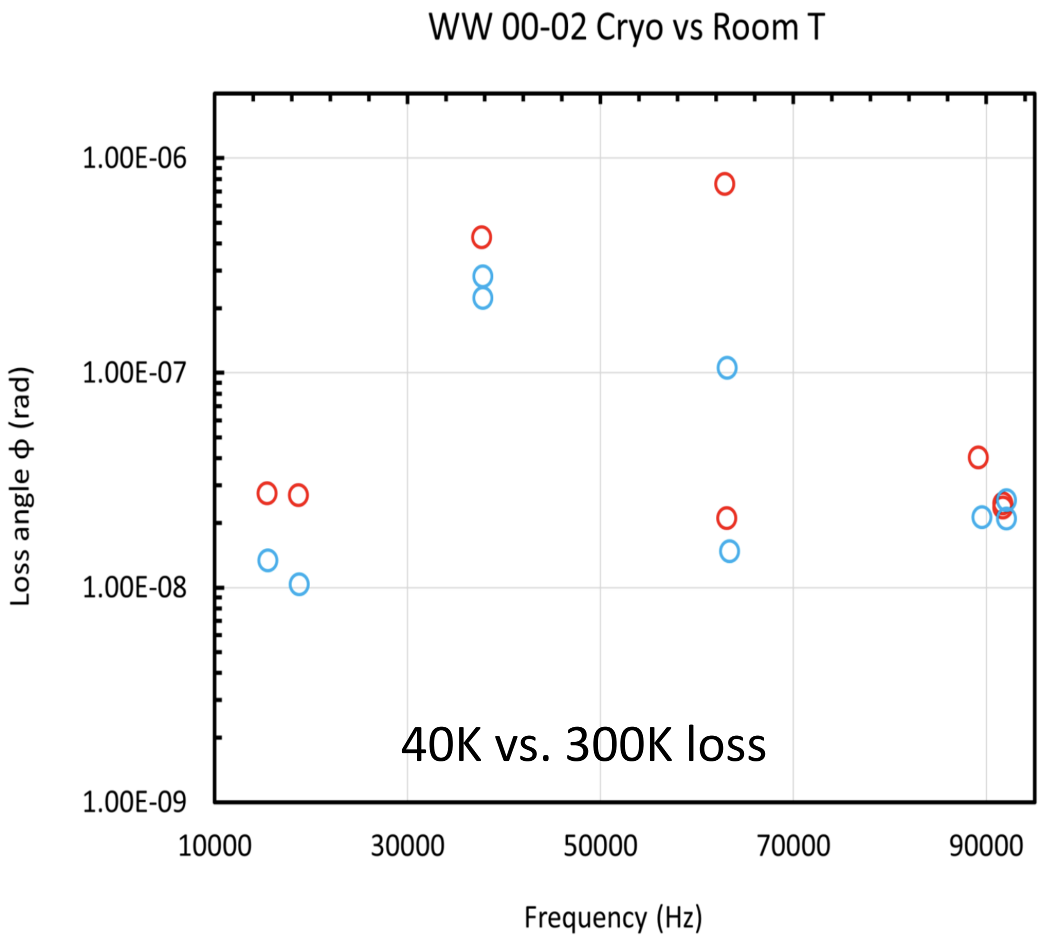
- cryogenic GeNS setup now operational
- measured several silicon disks (50mm x 5mm) obtained from witness wafers along the axis of the silicon ingots (FZ, grown by IKZ)
- very nice loss levels in the few 10^{-8} region obtained

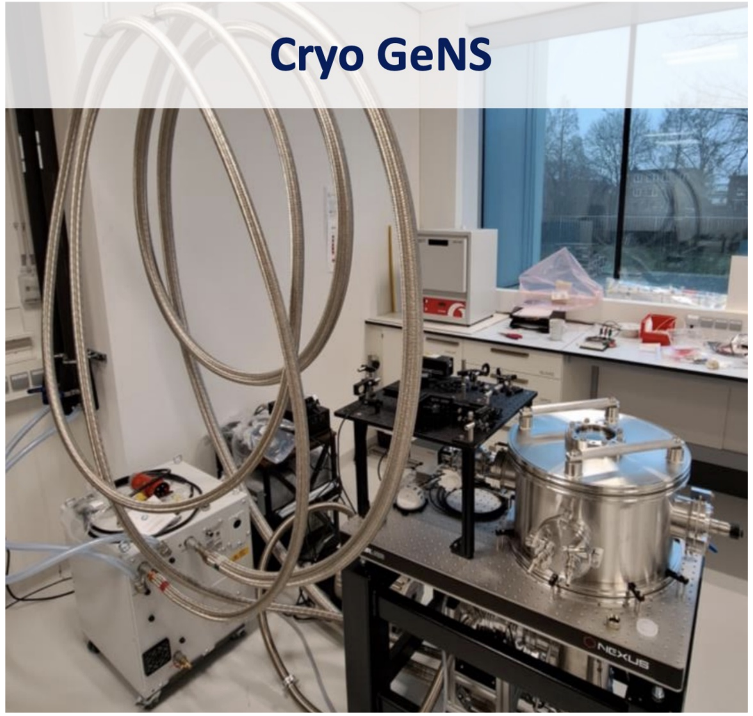




Silicon loss cont'd

Maastricht University

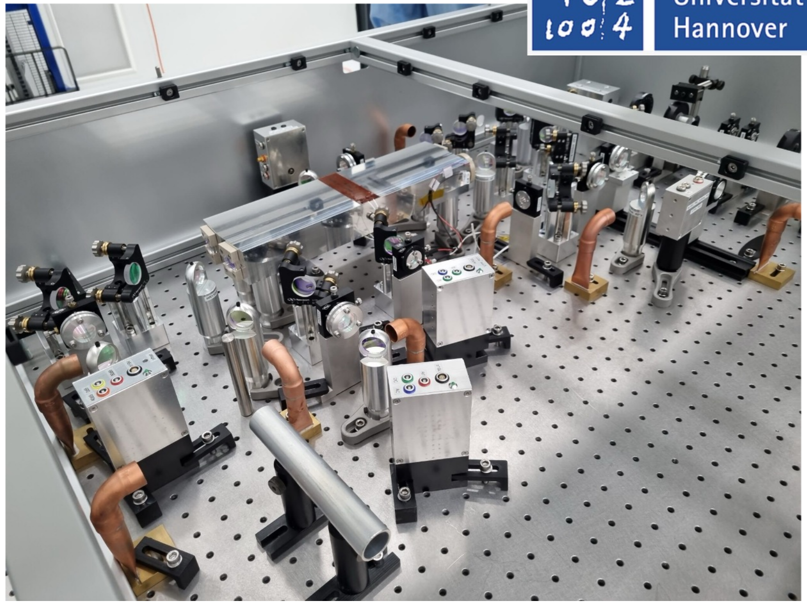


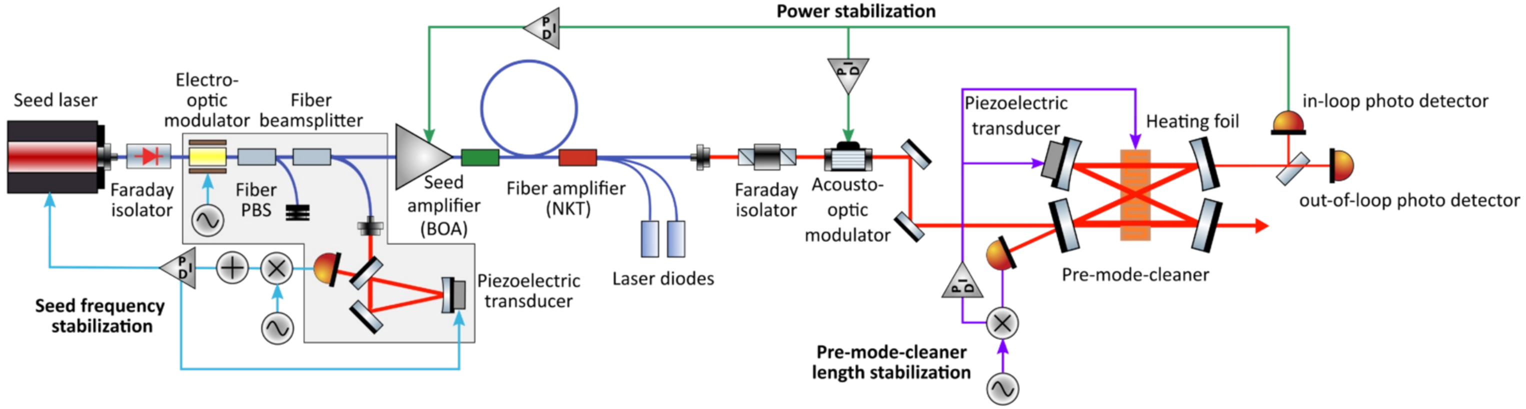


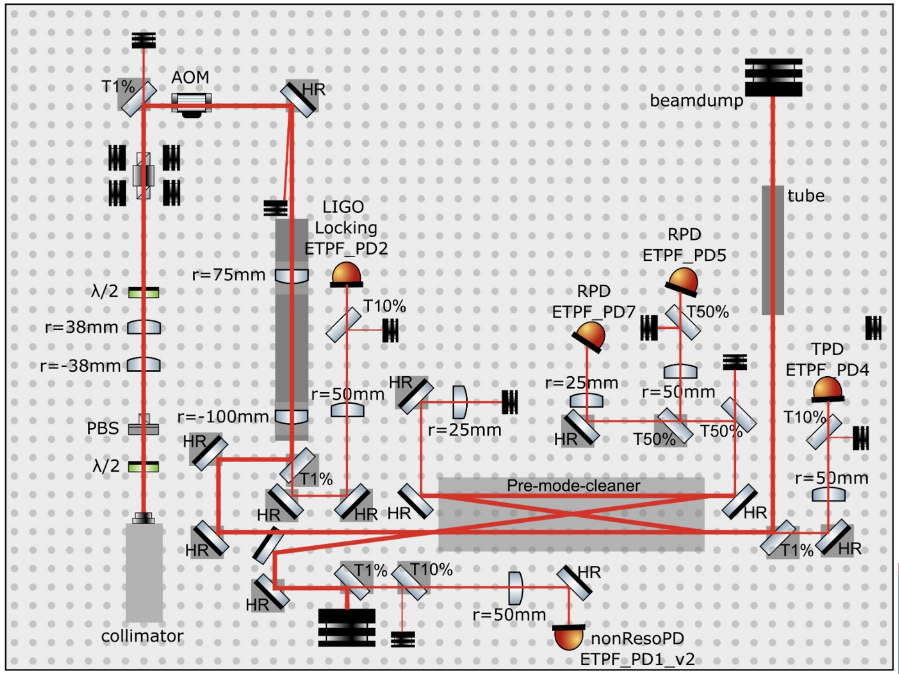
AEI 1550nm Laser Development

1550nm pre-stabilised laser system developed at AEI (Nicole Knust, Fabian Meylahn; group of Benno Willke)

- diode seed laser (Orion) with frequency pre-stabilisation
- fibre pre-amplifier (booster optical amplifier) followed by NKT Photonics fibre amplifier
- pre-mode cleaner for additional filtering and pointing stability, followed by power stabilisation loop

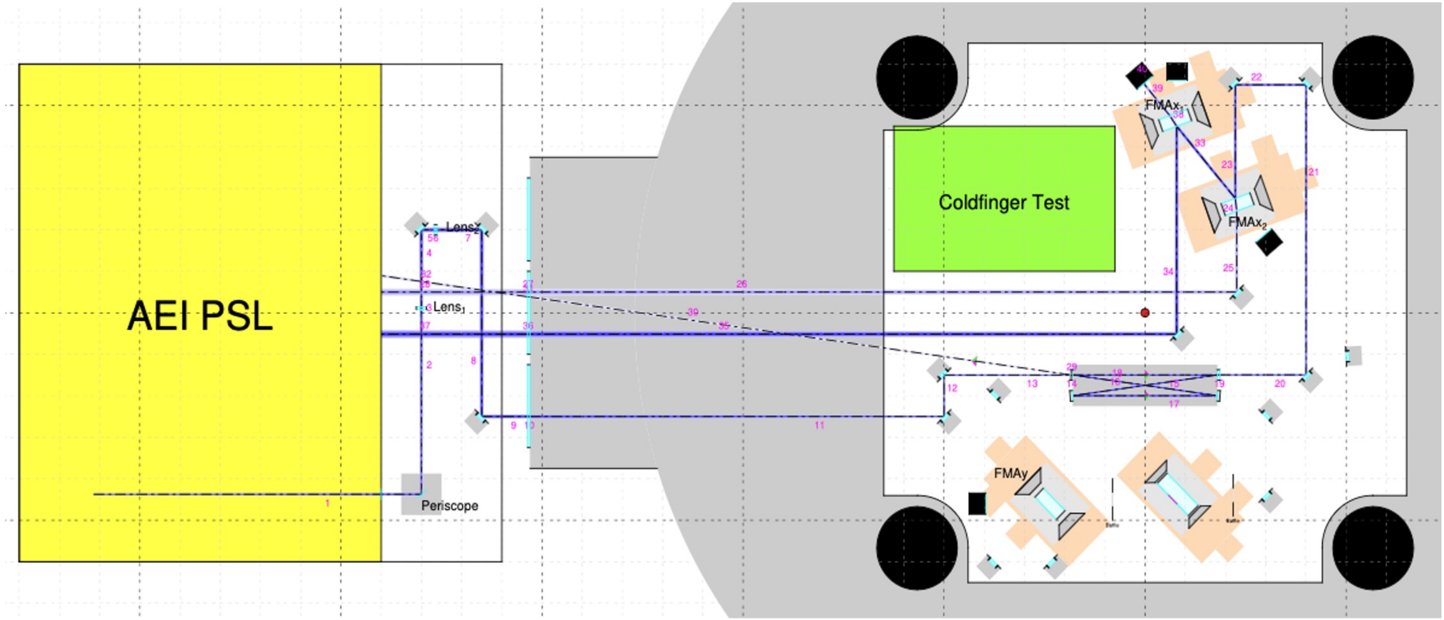






Plans for the 1550nm laser

- stabilisation of laser to PMC-style mode cleaner on first suspended bench should deliver interesting results, potentially improving low-frequency stability of the laser significantly



NPRO laser development within E-TEST

Fraunhofer ILT

Two different NPRO coatings were tested

- First coating: Operation at 2120nm
- Second coating: Operation at 2090nm

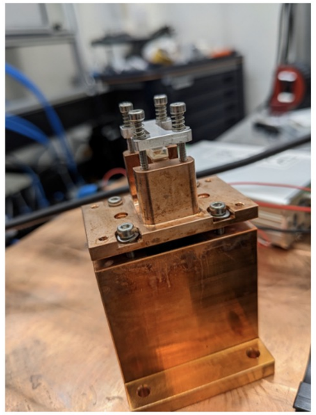
2120nm laser:

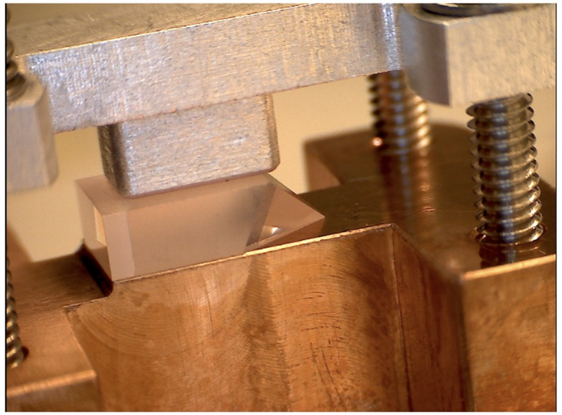
- Low linewidth operation at 2122nm
- Up to 480 mW output power
- Long term power stability
- Single mode beam quality

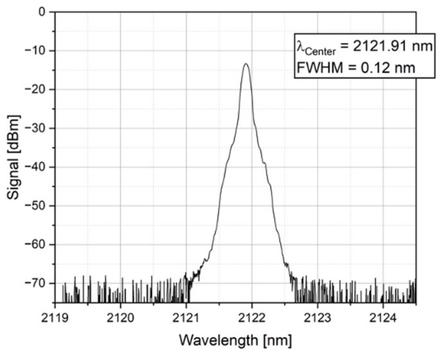
2090nm laser:

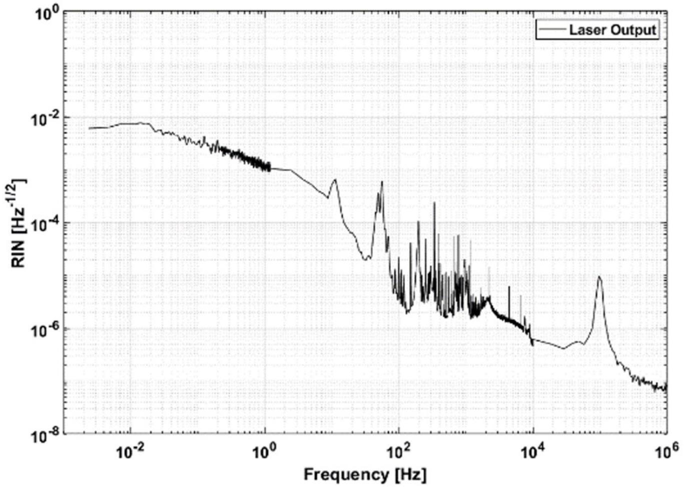
- Low linewidth operation at 2090nm
- Up to 50 mW output power

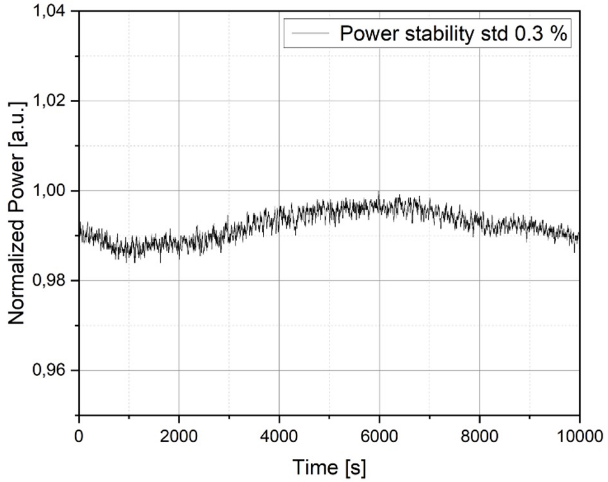
At higher power levels emission at 2120nm can be observed









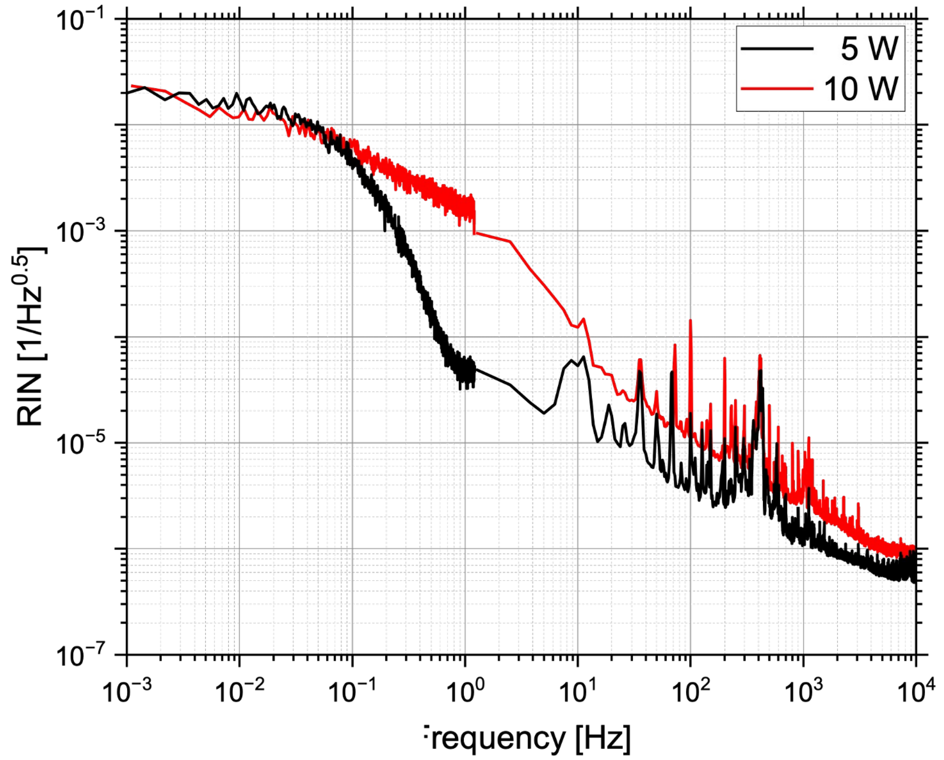


High-power (E-TEST) amplifier

Final Holmium-doped Fiber Amplifier (Ho2)

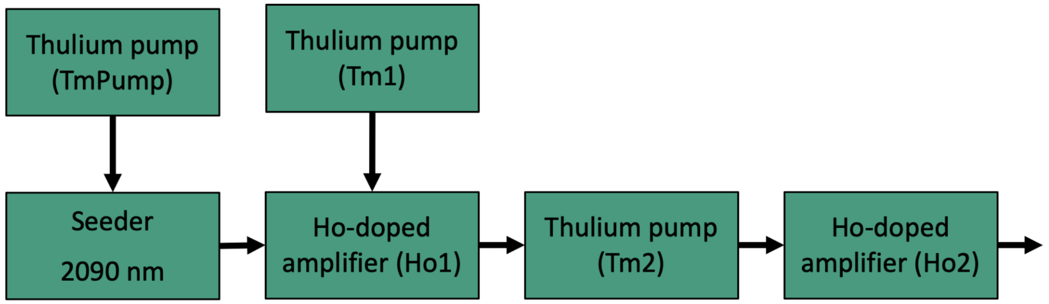
Main results:

- Output power >10 W
- PER: 26 dB
- Center wavelength: 2095 nm
- ASE level approx. 50 dB
- Beam quality $M^2 = 1.18$



RIN:

- 100 Hz: $<10^{-5}$ $Hz^{-0.5}$
- Power dependent RIN
  - currently under investigation



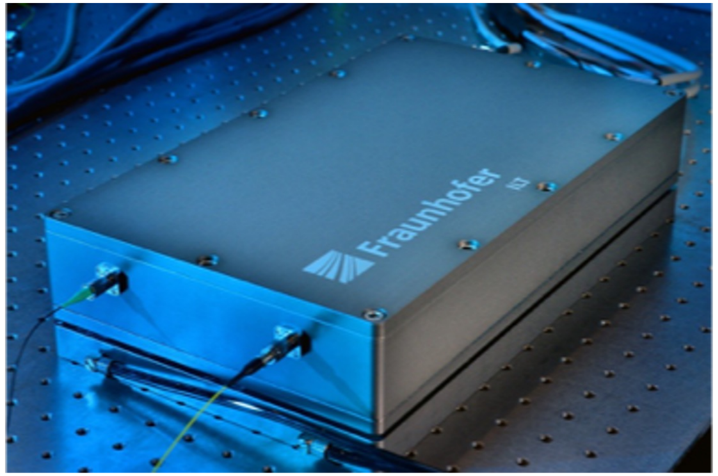
Interreg
Vlaanderen-Nederland
Europees Fonds voor Regionale Ontwikkeling

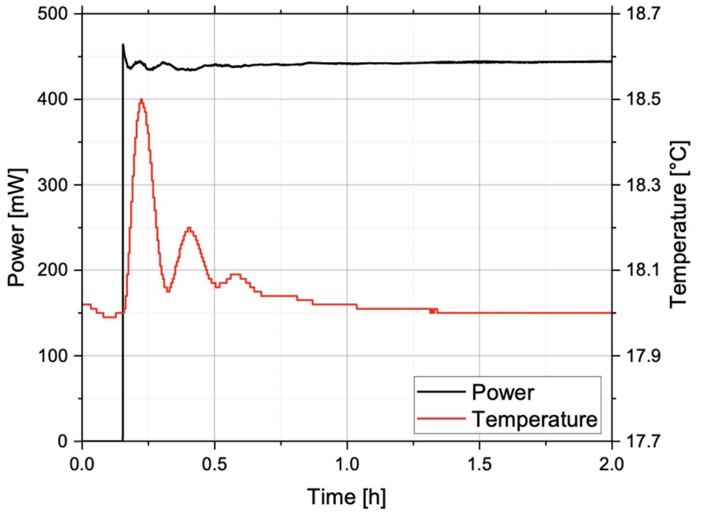
Fiber amplifier development

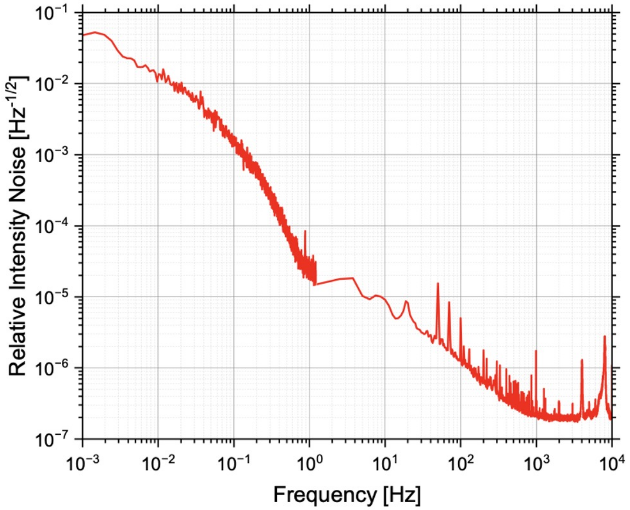
Fraunhofer ILT

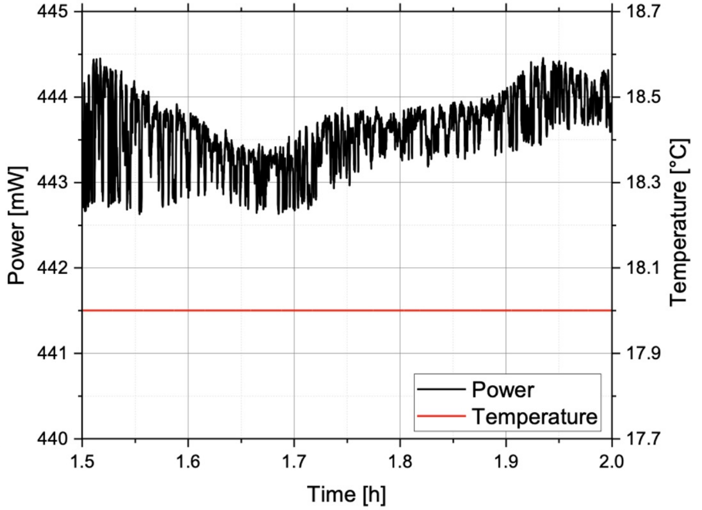
Laser System Specifications / Goals

- Wavelength: 2090 nm (dependent on used seed laser)
- Linewidth: 2 MHz (dependent on used seed laser)
- Continuous wave operation
- Output power: > 100 mW
- Linear Polarization (PER > 20 dB)
- Robust lab demonstrator packaging
- Active actuators (Pump current, Seed diode current, Seed diode temperature)
- Exchangable seed diode via fiber connectors









Other R&D activities

- design of an output mode cleaner for ETpathfinder, taking into account new optics manufacturing techniques
- investigating possibilities and advantages of “new” simulation tools (VirtualLab, RP Resonator, etc.)
- simulating suppression of higher-order modes, sidebands, and HOMs of sidebands

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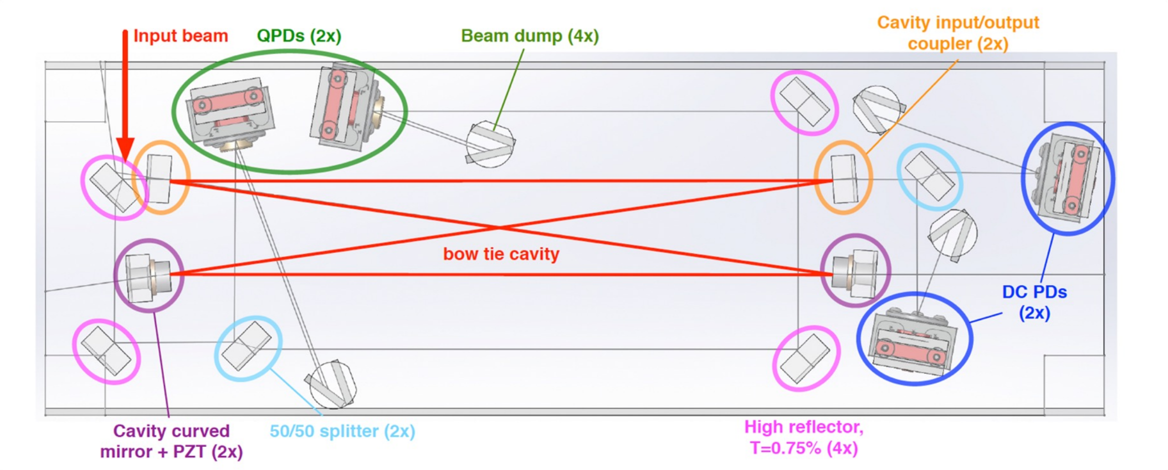
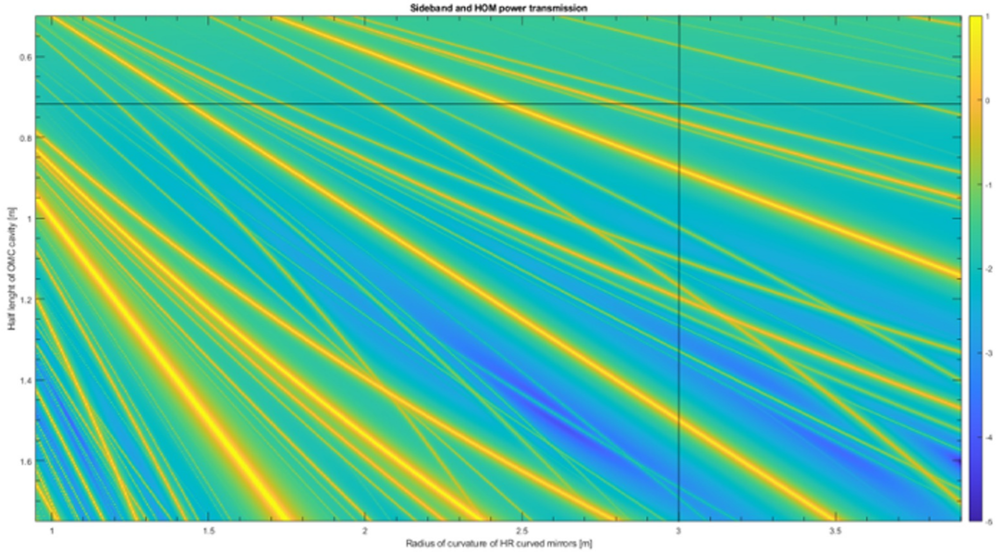
VUB VRIJE UNIVERSITEIT BRUSSEL

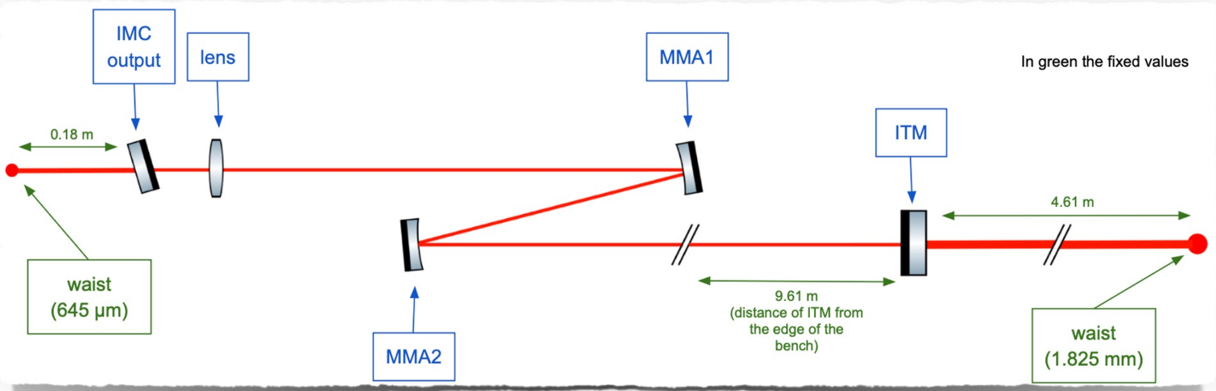


LIGO-T1000276-v5

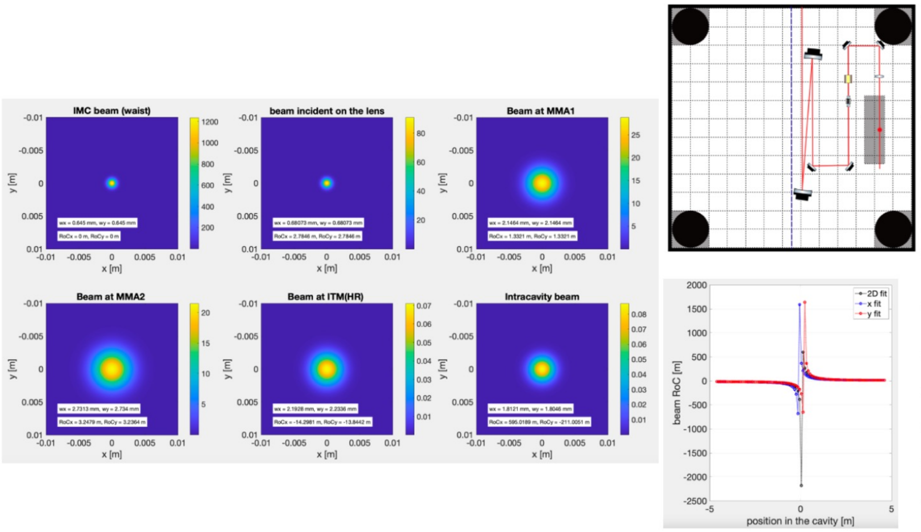


Other R&D activities cont'd

- design of mode-matching telescopes for ETpathfinder
- getting acquainted with capabilities of Zemax, VirtualLab, OSCAR, …
- multiple possible solutions, decision still tbd with regard to implementation strategy (e.g., non-FP Michelson needs different mode-matching)



V4 layout: beam profile and layout



Distance IMC-lens	0.10 m
Distance lens-MMA1	1.68 m
Distance MMA1-MMA2	0.70 m
Distance MMA2-ITM(AR)	10.61 m
Distance IMC-ITM(AR)	13.09 m
AoI on MMA*	4°
Lens focal length	0.4 m
RoC MMA1	5.5 m
RoC MMA2	5.5 m

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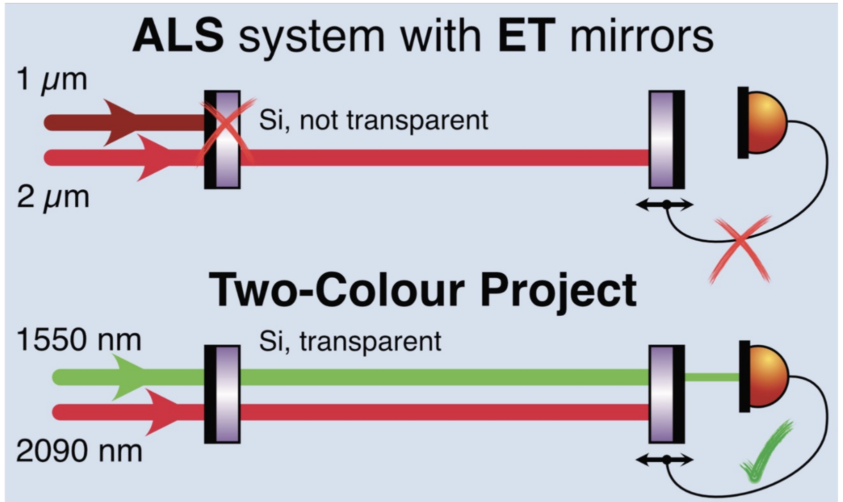
Other R&D activities cont'd

- new 2µm R&D lab now available at UGhent
- planned location for OMC tests
- planned characterisation of photo detectors

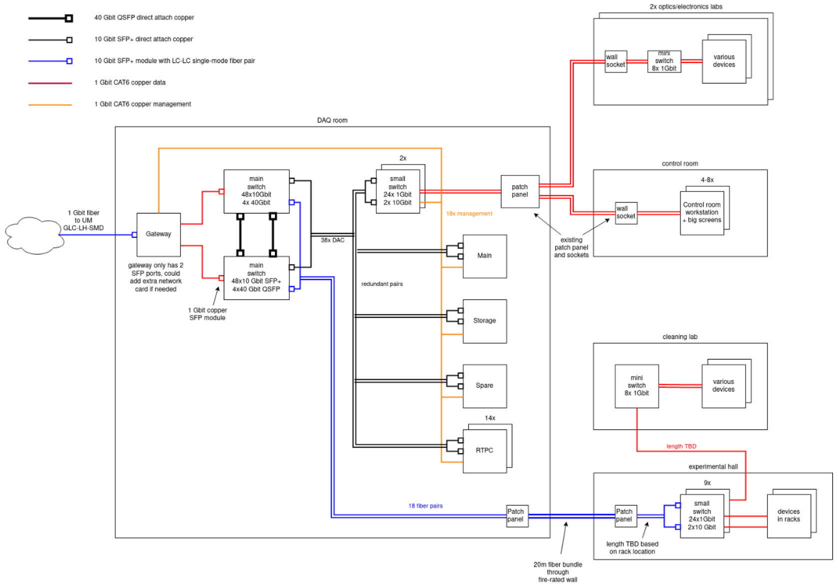
- two-colour experiment (2090nm + 1550nm) being set up in Maastricht; possible solution to ALS-style locking scheme for silicon mirrors (NWO Vidi S. Steinlechner)
- squeezed light source at 1550nm being built up for tests of QND readout schemes (ERC AdV S. Hild)



Detailed Topics

- Vacuum
- Cryogenics
- Seismic isolation
- Optics
- Controls

General computing



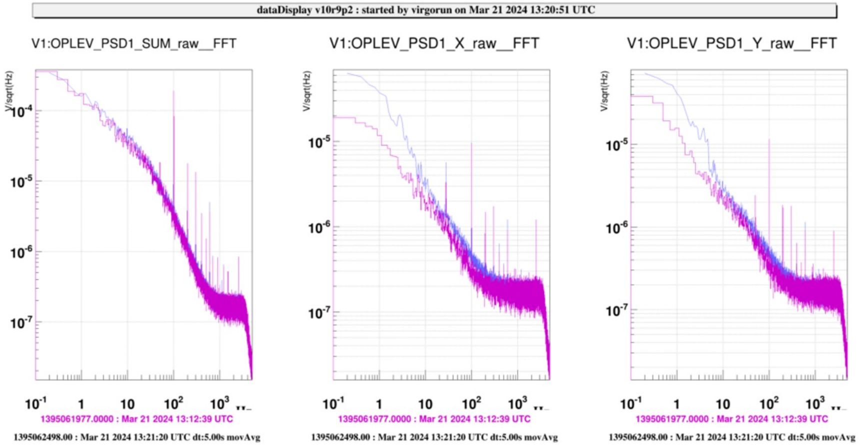
Done recently:

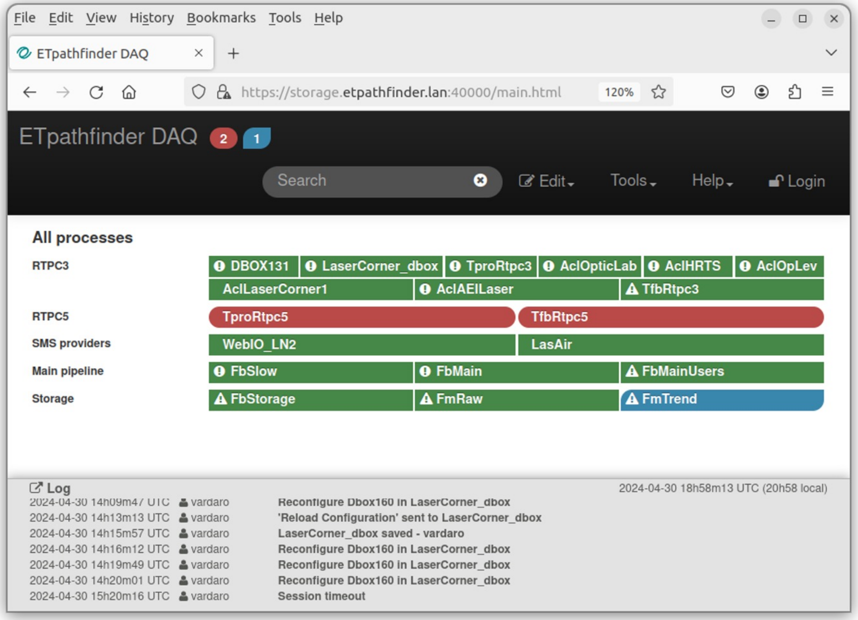
- All hardware received, many parts already in active use
- Remote network access via SSH gateway is working well
- FreeIPA used for user management, onboarding of new users/machines fully automated
- Fast storage machine with 46 TB SSDs (30 TB effective) now used as NFS server and DAQ pipeline
- Automated installation of operating system on control room machines real-time PCs

Next steps:

- Upgrade gateway from CentOS 7 (**EOL in 2 months!**) to latest Rocky Linux. Will have to run some outdated machines behind the gateway for a while
- Implement backup strategy (nightly, offsite, …)
- Reorganize network to use redundant fiber links and switches
- Implement remote desktop (X2Go, ThinLinc, …) to allow working from home
- Automatic alerts via mail/SMS in case of failures (DMS, Nagios/Icinga, …)
- Online overview plots (VIM) displayed on big screens in control room

Data Acquisition (DAQ)





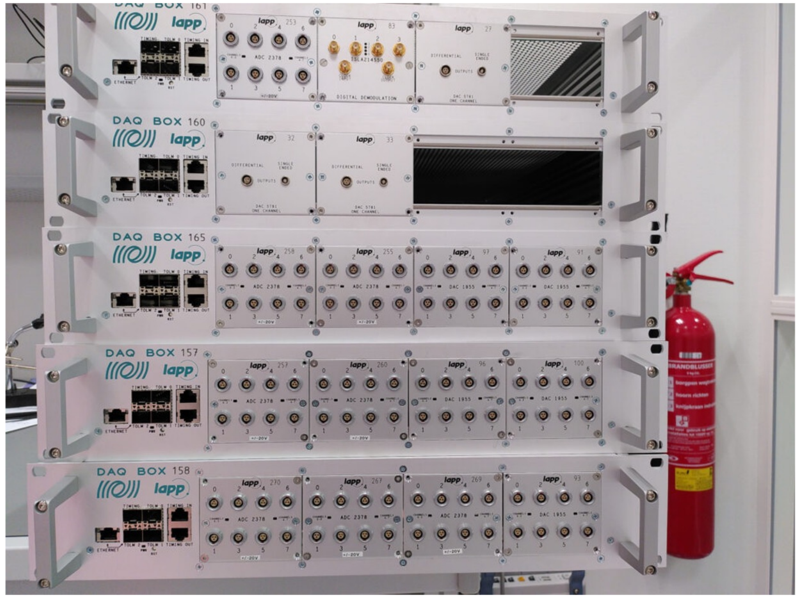
Done recently:

- Final DAQ pipeline set up on main storage server, already in use for some student experiments
- First few processes that gather slow data
- Network booting of DAQbox, needed for automating the configuration of firmware. Now in active use for first tests with OpLevs, HRTS, OpticsLab
- Stand alone RTPCs for tuning suspension filters @Nikhef, suspension electronics @Antwerp

Next steps:

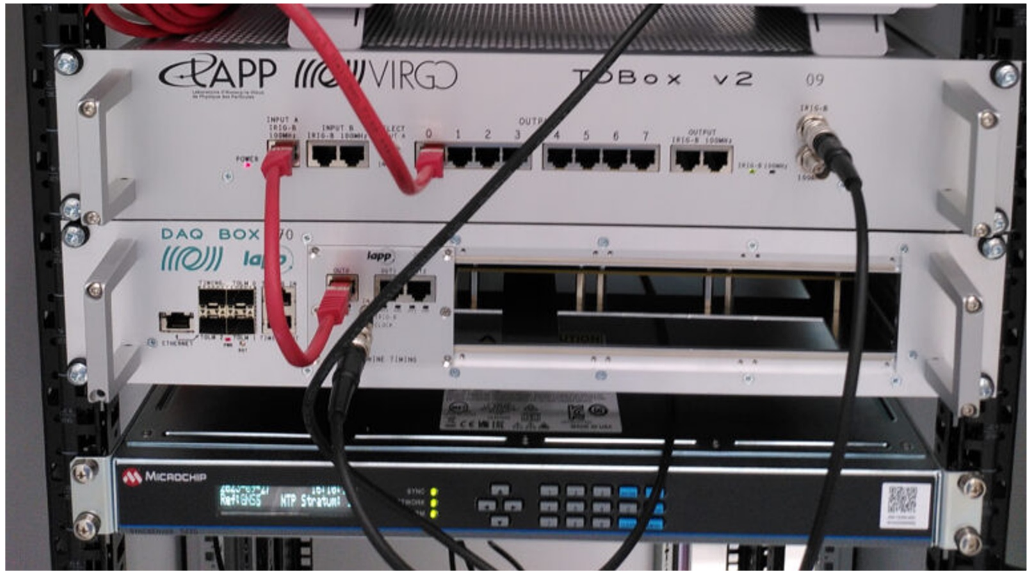
- Integrate HVAC data with DAQ
- Integrate data from Newtonian Noise system
- Get dataDisplay working on Rocky Linux (doesn't compile yet)
- Integrate data from vacuum PLCs
- Upgrade RTPC to newer OS (work in progress at LAPP, could deploy at ETpf before Virgo)

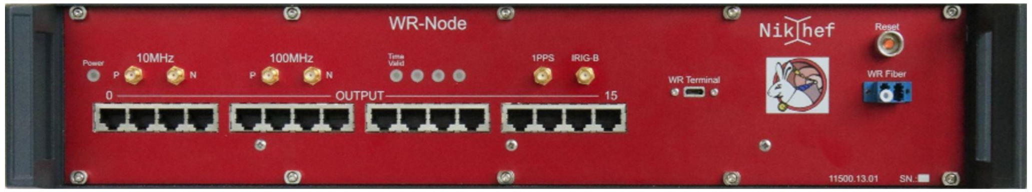
DAQ: number of available ADC/DAC

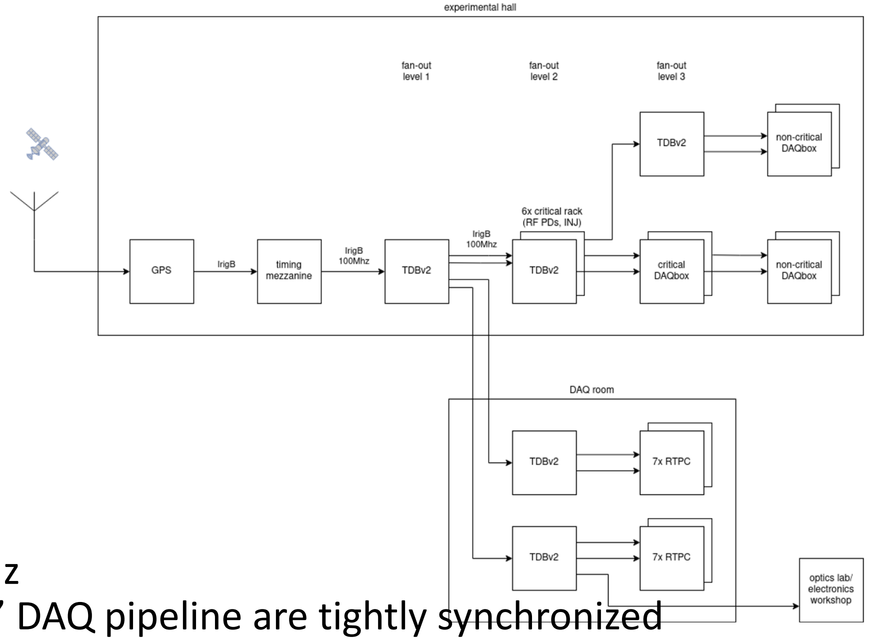


- Acquired decent amount of DAQ hardware from LAPP, piggybacking on a large production for Advanced Virgo (~2019-2021). We knew it was not enough to run 2 complete interferometers, but were limited by tender limits
- Enough ADC/DAC channels available to run at least one complete interferometer, but already request to borrow DAQboxes for table-top experiments: **need for more DAQ hardware in few years**
- We might profit again from production run for Virgo (stable cavities upgrade), which will need redesign due to obsolete components. Virgo profits since we can deploy and test first.
- Long term, we need completely new hardware for ET. Several groups have funding for R&D, but no clear idea about timeline. Aiming to participate to this R&D ourselves, and use ETpathfinder as a testbed

Timing distribution







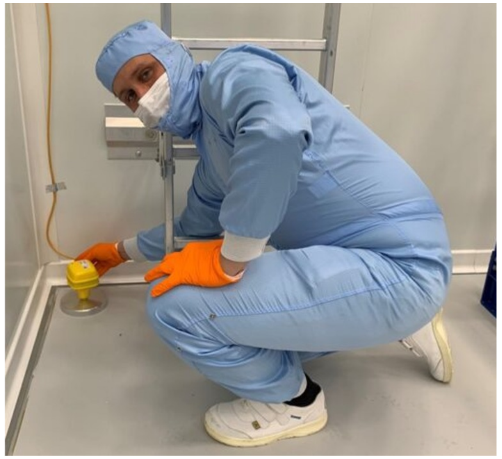
Done

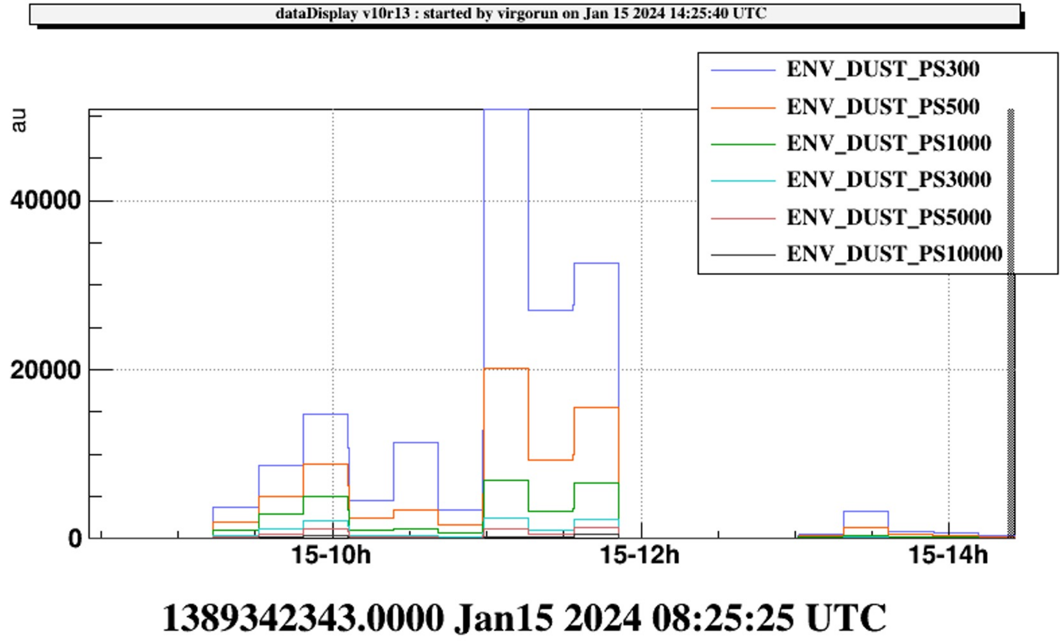
- GPS antenna installed on the roof, connected via 100 m coax cable to cleanroom
- GPS receiver creates IRIG-B time stamp
- LAPP timing mezzanine and timing distribution boxes to distribute IRIG-B and 100 MHz
- Same GPS server used as local NTP server, so real-time electronics and ‘soft real-time’ DAQ pipeline are tightly synchronized

Next:

- Nikhef is developing White Rabbit nodes to replace obsolete system at Virgo, can be tested at ETpathfinder before deployment at Virgo

Environmental monit





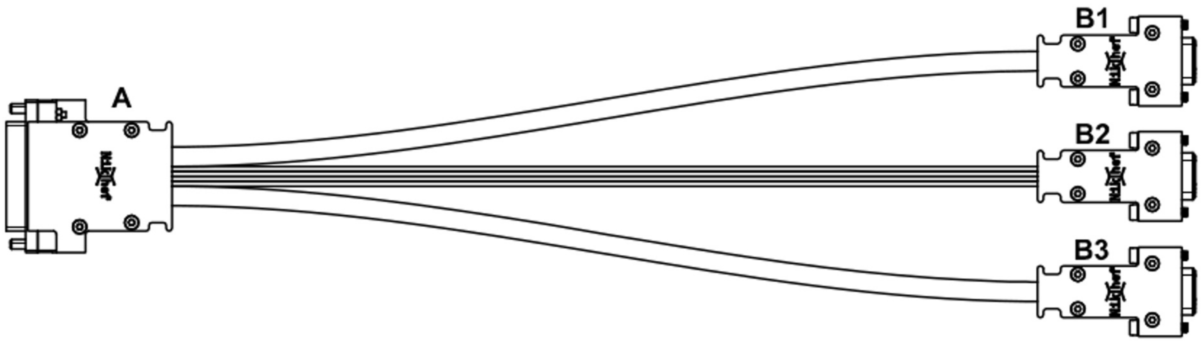
Done

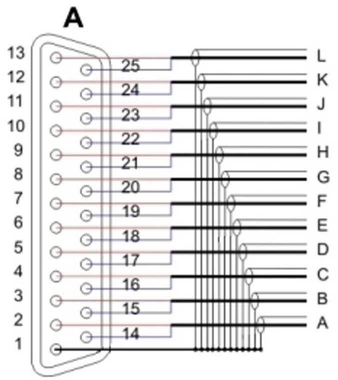
- Installation of Newtonian Noise sensor array by PolGrav group (2 types of seismometers, infrasound microphones), data currently acquired in stand-alone mode
- Measurement of background EMC noise, see Mathijs' presentation
- Already acquiring some slow signals from external LN2 tank, dust monitoring, HVAC

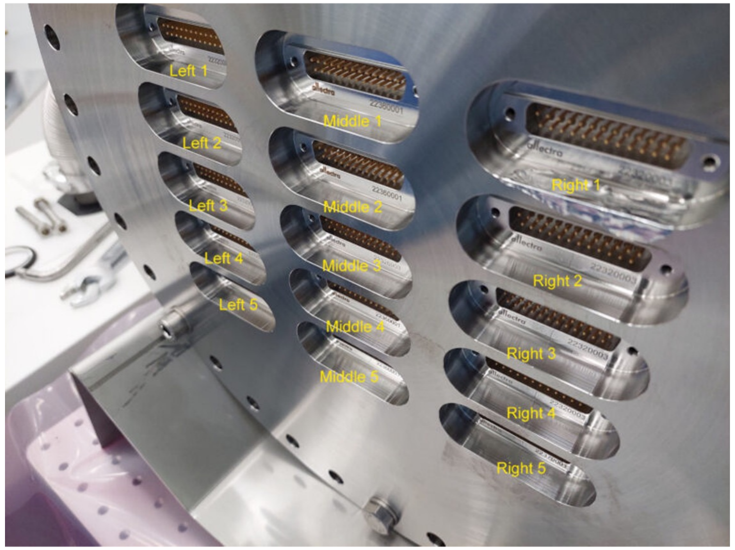
Next steps

- Order dataloggers for readout of temperature and other sensors: settled on a nice model, but no longer available due to change in EU regulations. Ready to order alternative system
- Install permanent sensors (temperature, pressure, magnetometers, current/voltage monitors)

Vacuum cabling

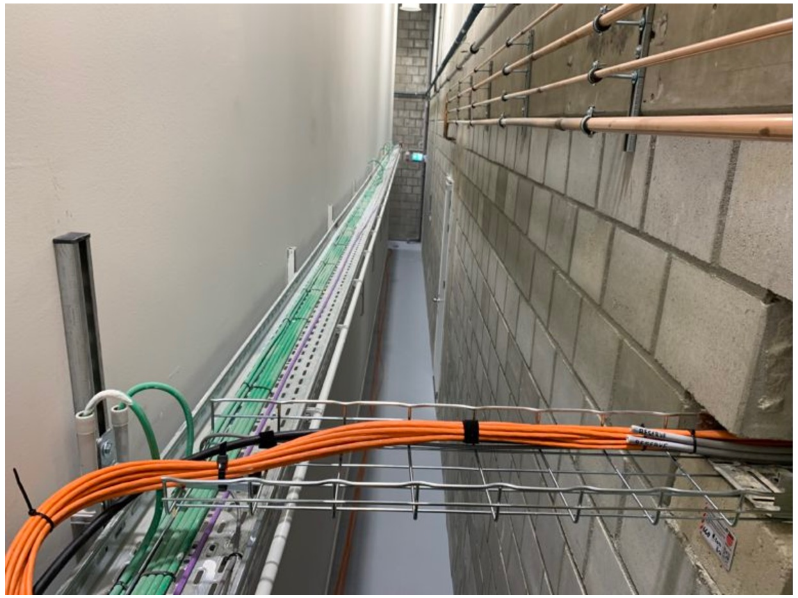


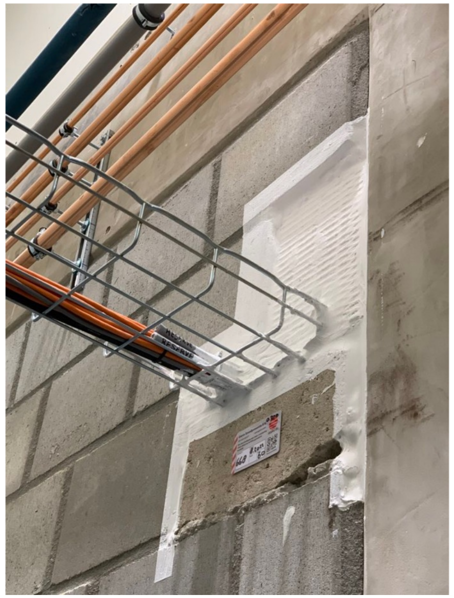


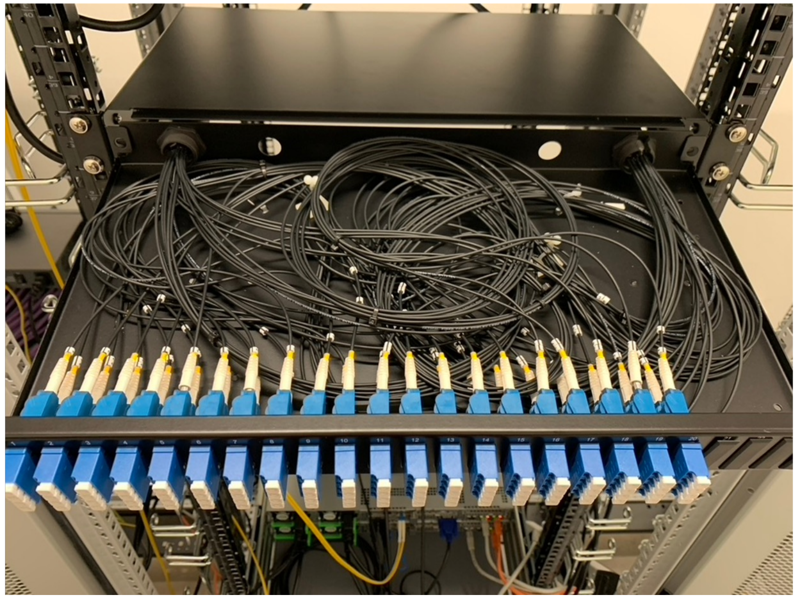


- 15 km of teflon-coated, shielded twisted pair vacuum cable delivered recently (**6 month delay**)
- Standard vacuum cables (e.g. Dsub25 to 3x Dsub9): lost a lot of time (cleanliness issues, incompatible connectors, tendering …) Final parts sent to assembly company this week, hope that production starts soon. **Close to critical path for first bench tower assembly**
- BOSEM cable (LIGO quadrupus equivalent, Dsub25 to 4x uDsub9): took lot of time to find supplier able to produce what we need. Now finally ordered
- Vacuum feed-throughs: custom CF300 flange with 15x Dsub25. Issues with shipping damage, leaky connectors. About half sent back for repairs, but some still leaking after repairs. Producer clearly underestimated the complexity, but is helpful in resolving the issues. No impact on schedule

In-air cabling







- Pulled trunk fiber and ethernet cables between DAQ room and cleanroom/labs
- Big Dsub25 to Dsub25 between flange and racks on order (after rejecting production by different company)

To be done:

- Few smaller in-air cables (e.g. between vacuum electronics and DAQ) still to be produced. One issue seems availability of LEMO connectors
- Finish routing of cables through cable trays (route of cherry picker), still need to order off-the shelf fibers and timing cables
- Installation

Various electronics

- Prepared first few water-cooled racks to be placed in the cleanroom
- Suspension electronics for first bench tower mostly finished
- Stepper motor crates finished
- ‘LIGO electronics’ for control of BOSEMs: fully produced and tested, now used for commissioning of first HRTS

In progress:

- Readout of accelerometers for suspension top platform (Trillium120 in airpod)
- Optical Levers readout
- Discussions with Nikhef R&D about RF (quadrant) photodiodes, might use custom silicon made for LISA

Thanks for your attention!
Questions?

ETpf design report

ETpf sensitivity paper

[Research – ETpathfinder](#)

[ETpathfinder: a cryogenic testbed for interferometric gravitational-wave detectors - IOPscience](#)