

ETpathfinder

Stefan Hild

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for the ETpathfinder Team

Nikhef, Maastricht University, University of Antwerp, Ghent University, Katholieke Universiteit Leuven, Université Catholique de Louvain, Hasselt University, Vrije Universiteit Brussel, Fraunhofer Institute for Laser Technology, RWTH Aachen, University of Twente, Eindhoven University of Technology, Liege Université, VITO, TNO + LAPP Annecy, Vrije Universiteit Amsterdam, Albert Einstein Institute Hannover, Birmingham University, Karlsruhe Institute of Technology (KIT) ...

www.etpathfinder.eu

Interreg
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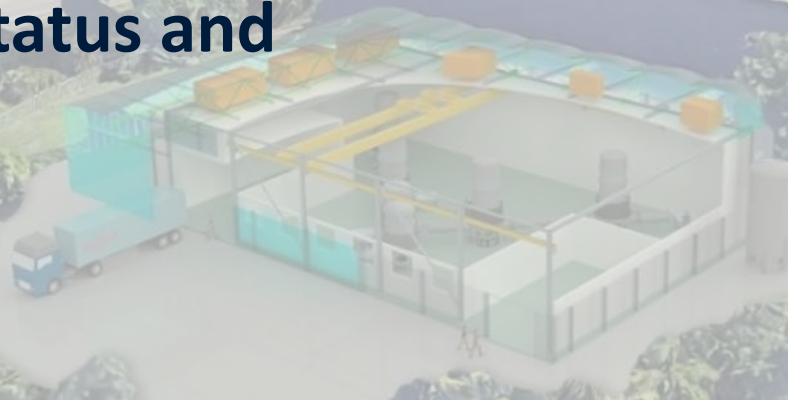
Maastricht University

Nikhef

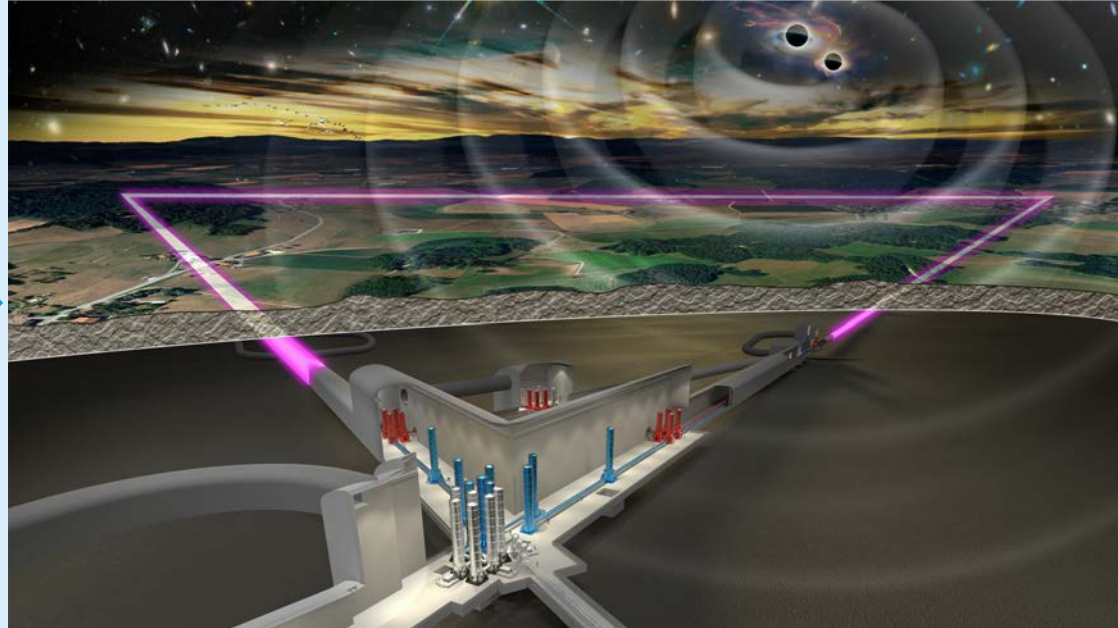
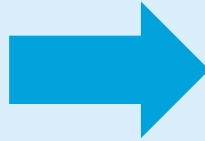
ET-0078A-20

Outline

- Overview of ETpathfinder
- Some examples of targeted R&D
- Current status and outlook



From Current Detectors to 3G/Einstein Telescope



- ET can reward us with same of the most amazing Science!
- First though we have to solve many, many challenges!

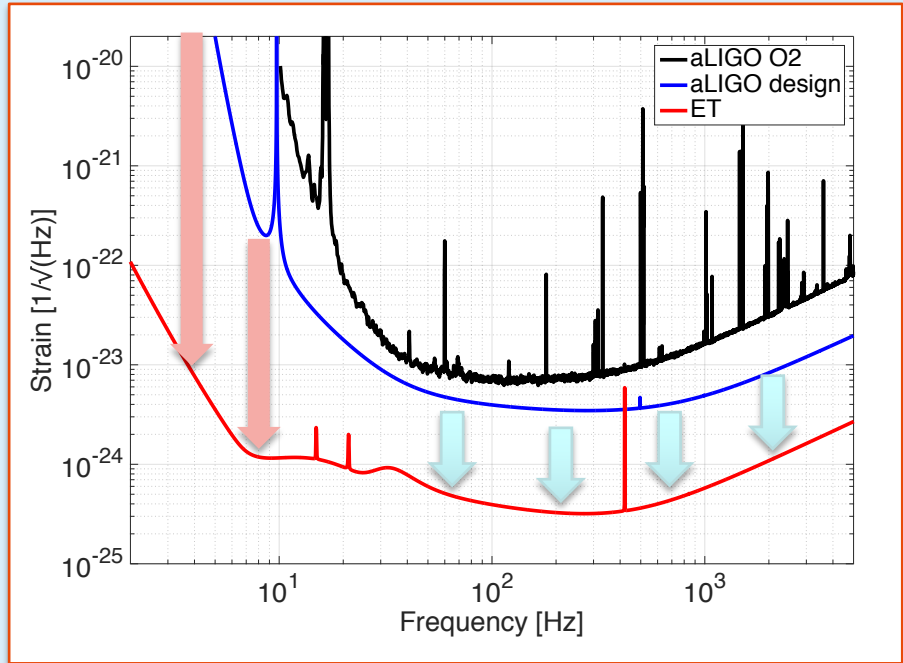
Low Frequency Challenge

At mid and high frequency we aim for factor ~ 10 improvement.

At low frequency we are aiming for factors 100, 1000 and more improvement.

-> **Huge Challenge**

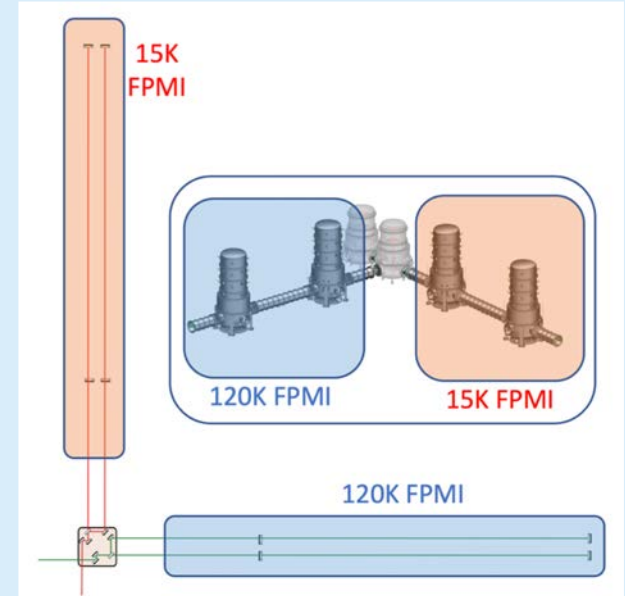
Need to do fundamental changes in technology and concepts. => Need to test, demonstrate, engineer and optimise those!



This is where we believe ETpathfinder can play a role!

Aim of ETpathfinder

- Provide a **low-phase noise, easy access, fast turn-around** interferometer testbed for the Einstein Telescope.
- Allows tests at the **system level** (not just individual subsystems on their own) and to learn about **dependency and interplay of different subsystems**.
- Can facilitate an interferometer with 4 cryogenic test masses of 100+kg.
- Will run initially two independent interferometers with small mirrors (15cm diameter) to **explore the ET/Voyager/CE matrix of cryogenic temperatures (123K and ~15K) and wavelengths (~2.1 and 1.55 microns)**.



New Technologies



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 = Collaborative Effort!

1. *Nikhef*
2. *Maastricht University*
3. *Eindhoven University of Technology*
4. *University of Leuven*
5. *Ghent University*
6. *University of Antwerp*
7. *University of Hasselt*
8. *University of Liège*
9. *Vrije Universiteit Brussel*
10. *Université catholique de Louvain*
11. *Fraunhofer Institute for Laser Technology (ILT)*
12. *RWTH Aachen University*
13. *University of Twente*
14. *Flemish Institute for Technological Research (VITO), Mol*
15. *Netherlands Organisation for Applied Scientific Research (TNO), Delft*

+ LAPP Annecy, Albert
Einstein Institute
Hannover, Birmingham
University, Karlsruhe
Institute of Technology
etc

€14.5m capital investment
(Interreg, institutions,
governments, provinces)

Nice side effect: Many new
partners from outside GW
joined (and some now also
started to contribute to
current detectors, i.e. Virgo.)

Open for everyone to join in
the effort!

German Universities funding to support ET + ETpathfinder



The Federal Ministry of Education and Research supports the development of the Einstein Telescope

For the next generation of gravitational-wave detectors on Earth: Laser development and squeezed-light research in Hannover

JULY 24, 2020

Fourteen German universities and non-university research institutions will receive a total of approximately 2 million Euros from the Federal Ministry of Education and Research (BMBF). This funding enables physicists and geophysicists to conduct research on various technological aspects of the Einstein telescope. These include, for example, seismic measurements and the development of crystalline fibers for suspending the mirrors.

At the Institute for Gravitational Physics of Leibniz Universität Hannover, in close cooperation with the Max Planck Institute for Gravitational Physics and the QuantumFrontiers Cluster of Excellence, a laser source for the Einstein Telescope Pathfinder – a prototype of the observatory – is to be developed and tested in Hannover and installed in the prototype in Maastricht. In addition, the participating researchers will investigate questions concerning the generation of squeezed light and the use of this technology in 3rd generation gravitational wave detectors. The BMBF funds will be used to finance an additional doctoral student position in Hannover.

Read more on about this in a news item on einstein telescope.nl.



Spokespersons of the Verbund: A.Stahl (RWTH)

ETpathfinder Raad

Chair: Koenraad Debackere
Secretary: Thomas Cleij, Daisy Blaauw
Treasurer: Linda Lemmens

Nikhef = Stan Bentvelsen, Bas Swinkels
TU/Eindhoven = Marco de Baar
Maastricht = Thomas Cleij, Bakir Bulic
Antwerpen = Ronny Blust, Nick van Remortel
Hasselt = Marc D'Olieslaeger, Milos Nesladek
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Brussel = Mieke Gijsemans, Alexandre Sevrin
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Liège University = Christophe Collette
Louvain la Neuve = Giacomo Bruno
TNO = Christa Hooijer, Ernst-Jan Buijs
Twente University = Jennifer Herik, Marcel ter Brake
VITO = Ben Laenen

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Kazuhiro Yamamoto - Toyama

Project Leader

Stefan Hild (Maastricht)

Valorisatie Raad (VR)

Health and Safety Committee (HSC)

Bram van der Gaag (Nikhef/Amolf)
Fokko Zandbergen (Maastricht)
Nico Reem (Nikhef)
PL and deputy PLs
All WP leads and deputies

Workpackage Leaders

WP1: Organisation

Lead: Stefan Hild (Maastricht)

Deputy: Frank Linde (Nikhef) & Nick van Remortel (Antwerp)

WP2: Communication

Lead: Mariette Wennekers (Maastricht)

Deputy: Martine Oudenhoven (Nikhef)

WP3: Cleanroom

Lead: Paul Kuijer (Nikhef)

Deputy: Marieke Hopman (Nikhef)

WP4: Vacuum and Cryogenics

Lead: Henk-Jan Bulten (Nikhef)

Deputy: Dirk Ryckbosch (Gent)

WP5: Seismic Isolation

Lead: Alessandro Bertolini (Nikhef)

Deputy: Eric Hennes (Nikhef)

WP6: Optics

Lead: Jean Pierre Locquet (Leuven)

Deputy: Sebastian Steinlechner (Maastricht)

WP7: Controls

Lead: Bas Swinkels (Nikhef)

Deputy: Wim Beaumont (Antwerp)

Legal/Purchases Team

Daisy Blaauw (Maastricht)
Linda Lemmens (Maastricht)
Dylan Brepoels (Maastricht)
Claudie Abbink (Maastricht)
Stefan Rademakers (Maastricht)

+ legal and finance team
representatives from the
ETpathfinder partner
institutions

Hall Con- struction Team

Maastricht University Facility
Services. Contact: Jacques
Knoppen + Aronsohn
Management

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Sheila Rowan - Glasgow

Kazuhiro Yamamoto - Toyama

From ETpathfinder Advisory Board (STAC) report

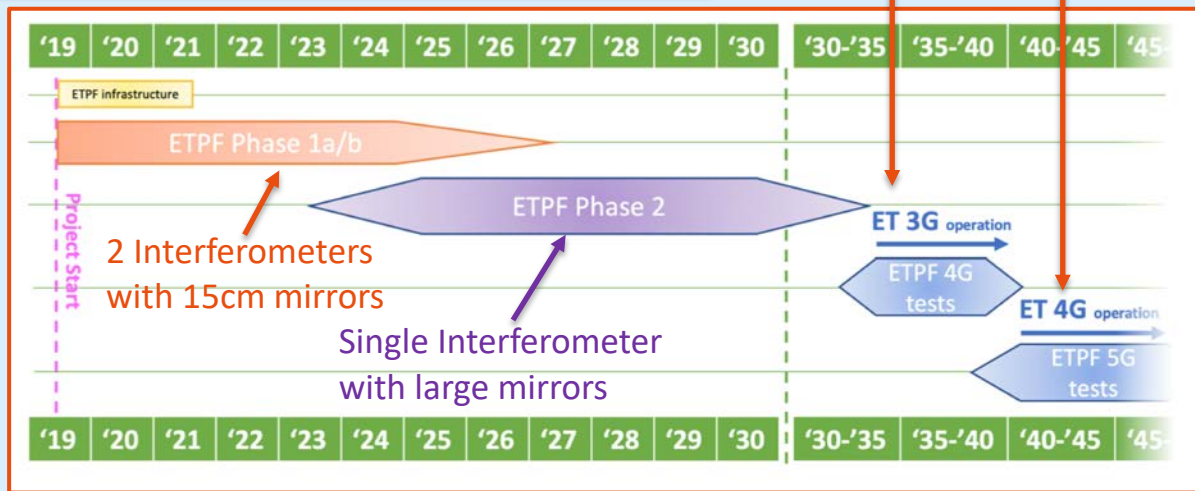
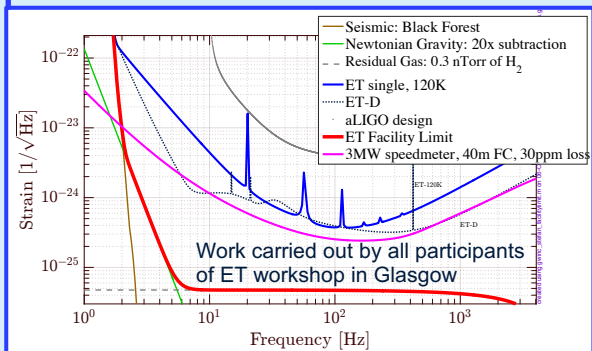
[...] Overall, the ETPF-STAC was very impressed with the vision for the facility, the technical capability of the leader and team, and the scope of the effort. It will be transformative for the field to have a facility and a research program covering the foreseen capabilities of the installation, and it can become a very natural center for technical innovation and scientific breakthroughs in precision measurement, interferometry, cryogeny for gravitational-wave detectors, and for the formation of a next generation of gravitational-wave scientists (to handle the next generation of gravitational-wave detectors). The growth of the team (and of the institutions interested in participating) is an exciting development and speaks to the timeliness and centrality of this infrastructure. [...]

The ETPF-STAC is very excited to be part of the establishment and exploitation of this unique facility and this dynamic team.

ETpathfinder is a longterm activity!

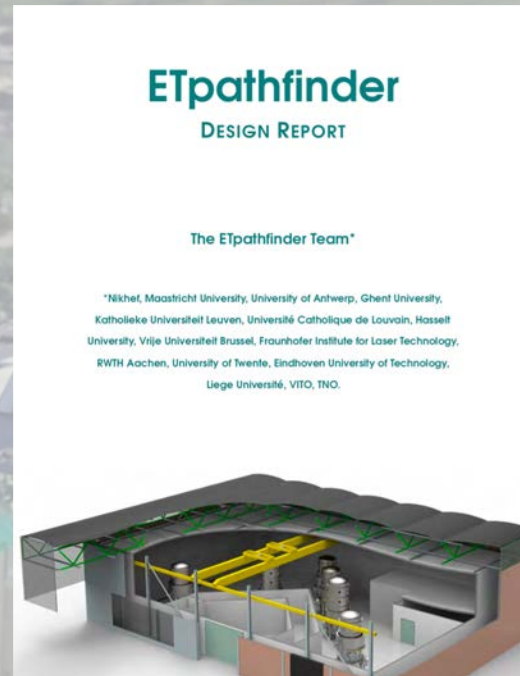
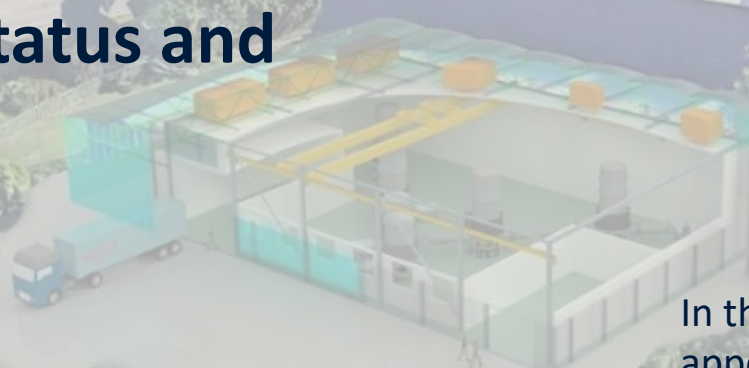
- ESFRI application states ET will be operational from 2035 to 2085.
- Expect many ET detector upgrades over the 50 years.

- While ET operates and observes in “generation X technology” ETpathfinder can do R&D for “generation X+1 technology”



Outline

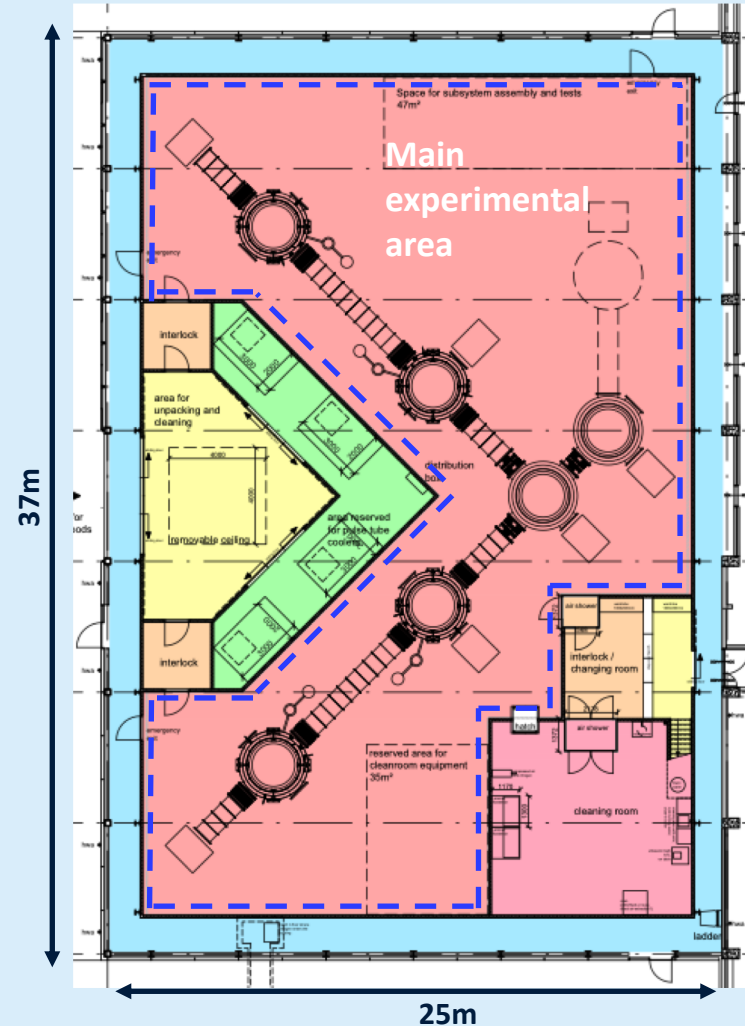
- Overview of ETpathfinder
- Some examples of targeted R&D
- Current status and outlook



In this talk I will only be able to present appetizers. Please see ETpathfinder for more details: <https://www.etpathfinder.eu/wp-content/uploads/2020/03/ETpathfinder-Design-Report.pdf>

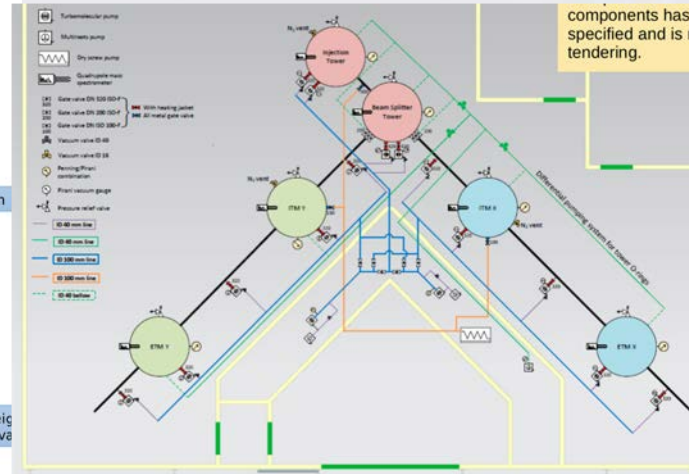
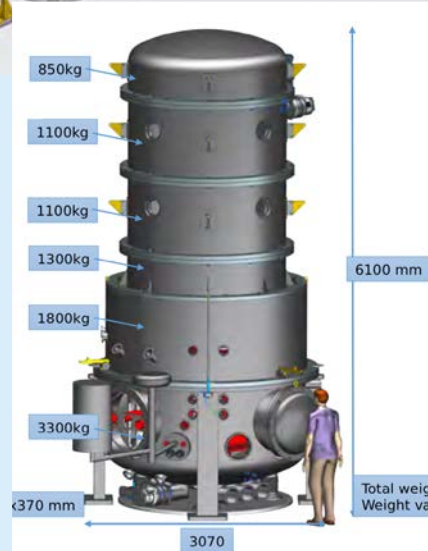
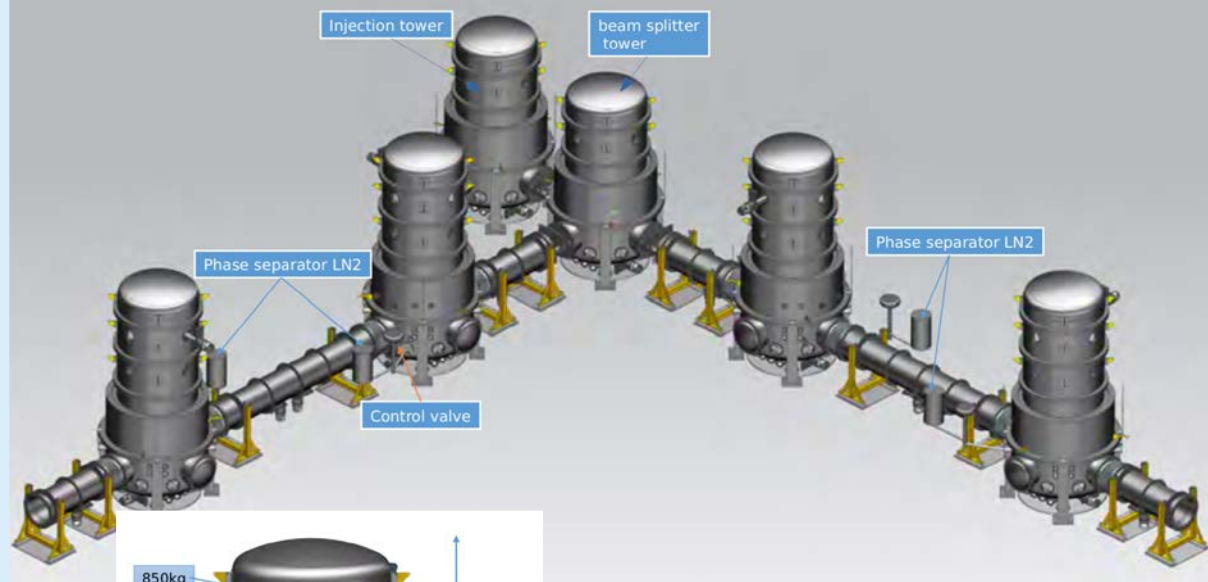
Cleanroom Infrastructre

- Inner dimensions of cleanroom (class 8, volume of 6000m^3 , 10 circulations/h) is $34.3\text{m} \times 22\text{m} \times 8.1\text{m}$.
- **Two separate foundations** ---- (both 45cm thick concrete sitting on top of 170 piles drilled 5.8m into the ground) to decouple **main experimental area** from rest of building, AC, pumps etc.
- Special emphasis in tender on: 1) **quiet air handling and filter units** 2) **improved acoustic isolation of cleanroom walls**.
- Design includes a **special compartment** for noisy equipment (pumps, cryocoolers etc)



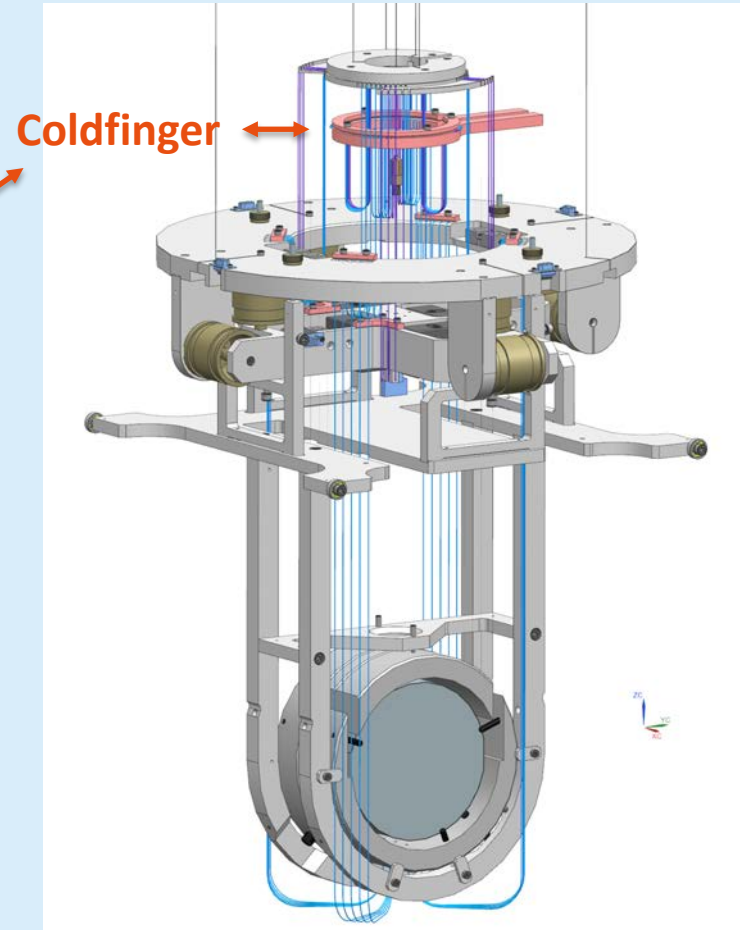
Vacuum

- 6 towers (4 mirror towers and 2 table towers); 80cm tubes; 20m arm length;
- Total volume about 130m³
- Target pressure of 10⁻⁹mbar
- Aiming for fast and easy access, i.e. to allow frequent venting etc: 1) access via mantle ring; 2) need to deal with lots of water => plan to have possibility to bake towers on regular basis at 90deg C.



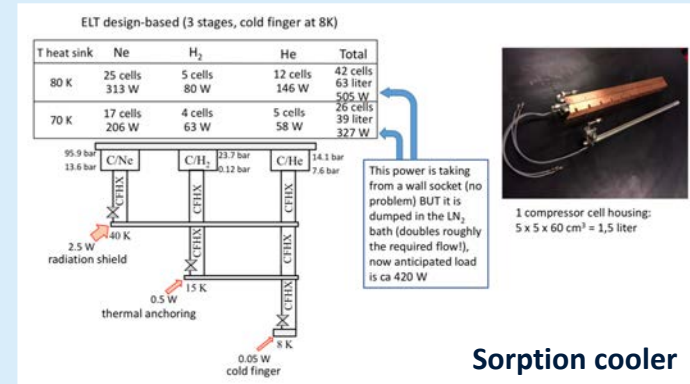
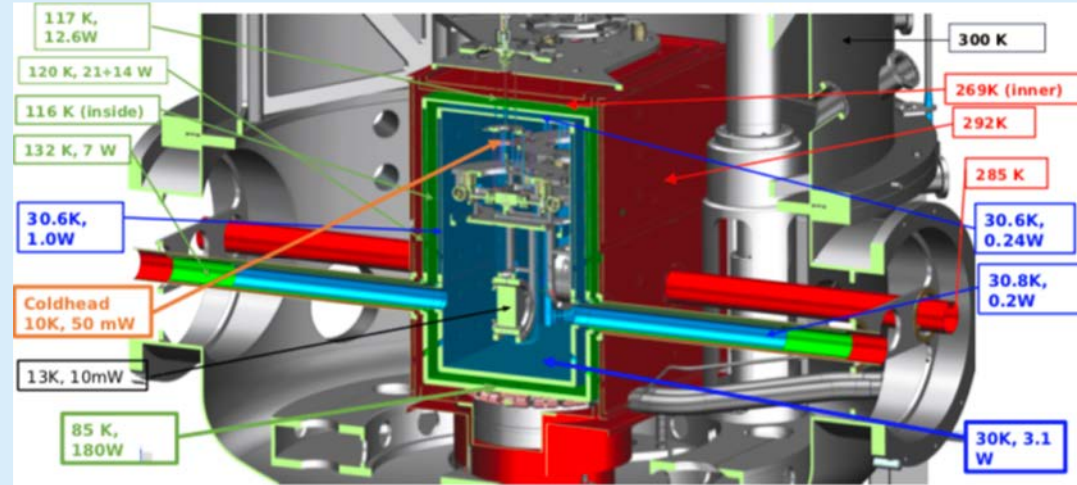
Cryogenics (I)

- Mirrors need to be cooled to cryogenic temperatures ($\sim 15\text{K}$, 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 quiet, less cooling power.
 - Cryogenic Liquids: LN_2 , He, He-II. Challenges = avoid bubbling; transfer liquids from surface 300m above the caverns ...

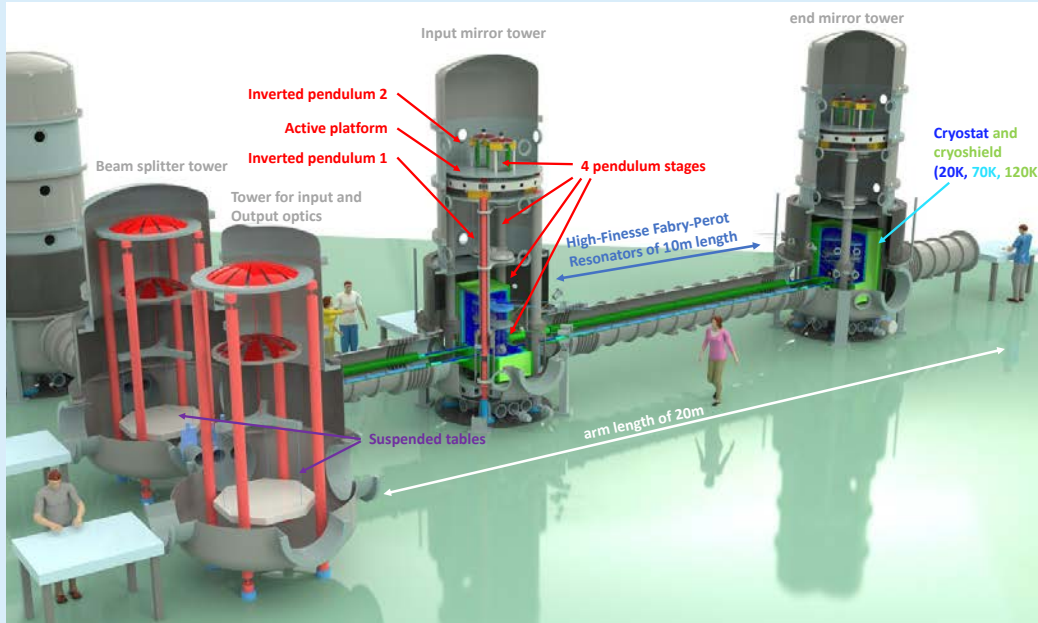


Cryogenics (II)

- 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. ☹



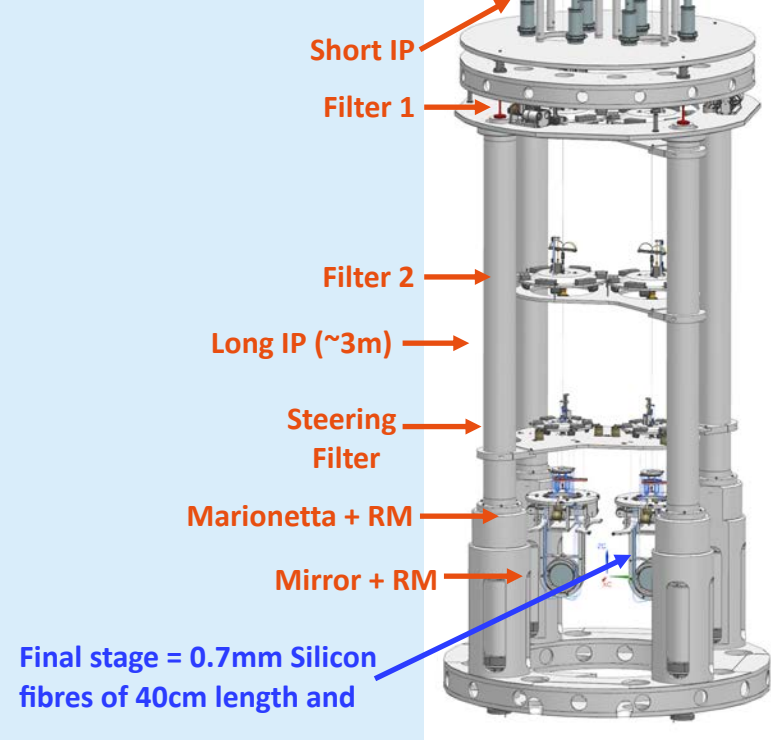
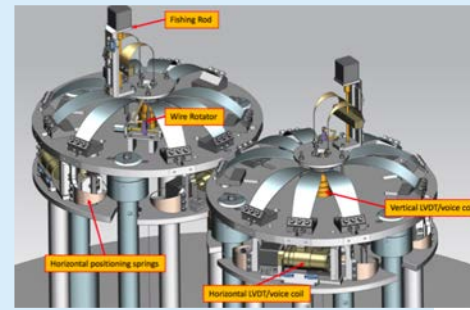
Seismic Isolation



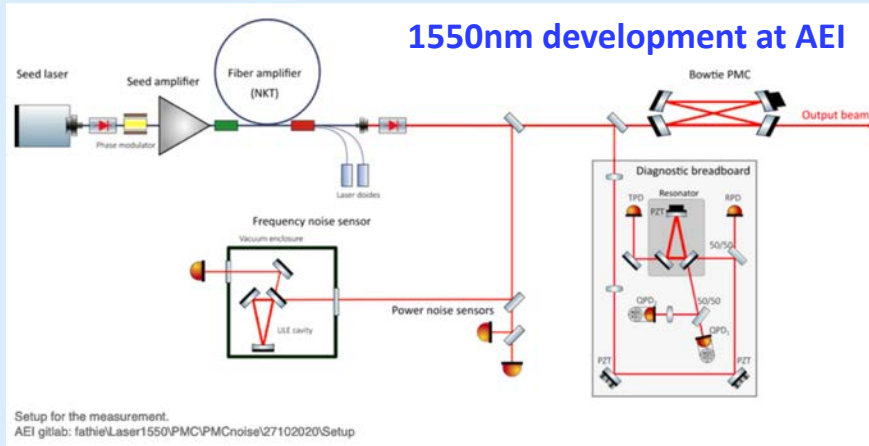
2 different designs: Mirror towers and table towers



Maastricht University



Lasers: 1550 nm and 2090nm



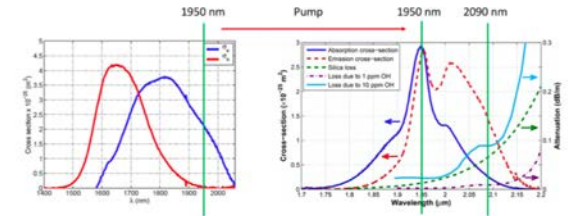
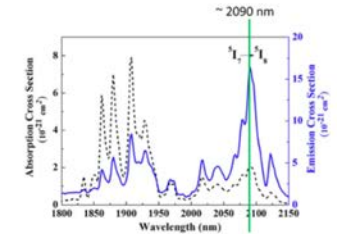
2μm laser development

Planned setup (Fraunhofer ILT / E-TEST):

- Ring resonator based on Ho:YAG
- Single-frequency operation
- Emission wavelength 2090nm
- Output power 4W cw

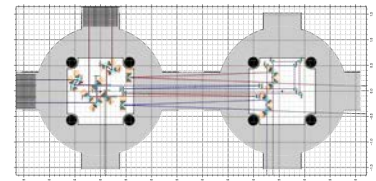
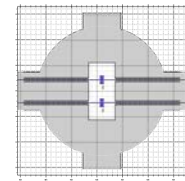
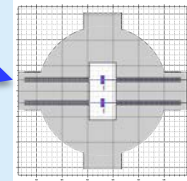
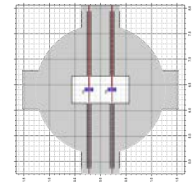
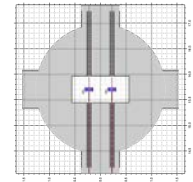
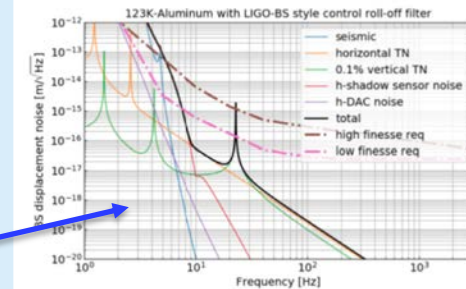
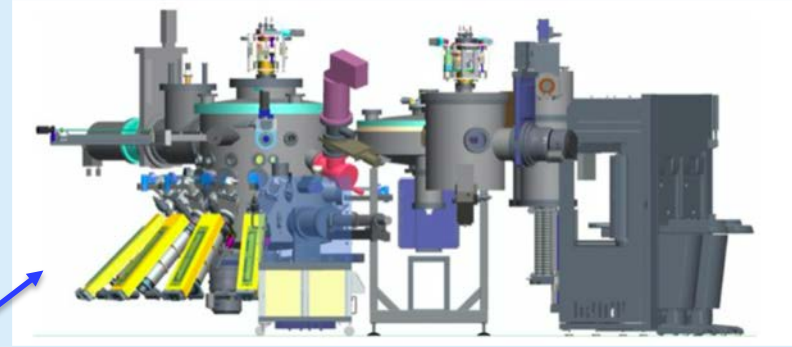
Amplifier:

- Holmium fibre
- Pumped by Thulium fiber laser/amplifier



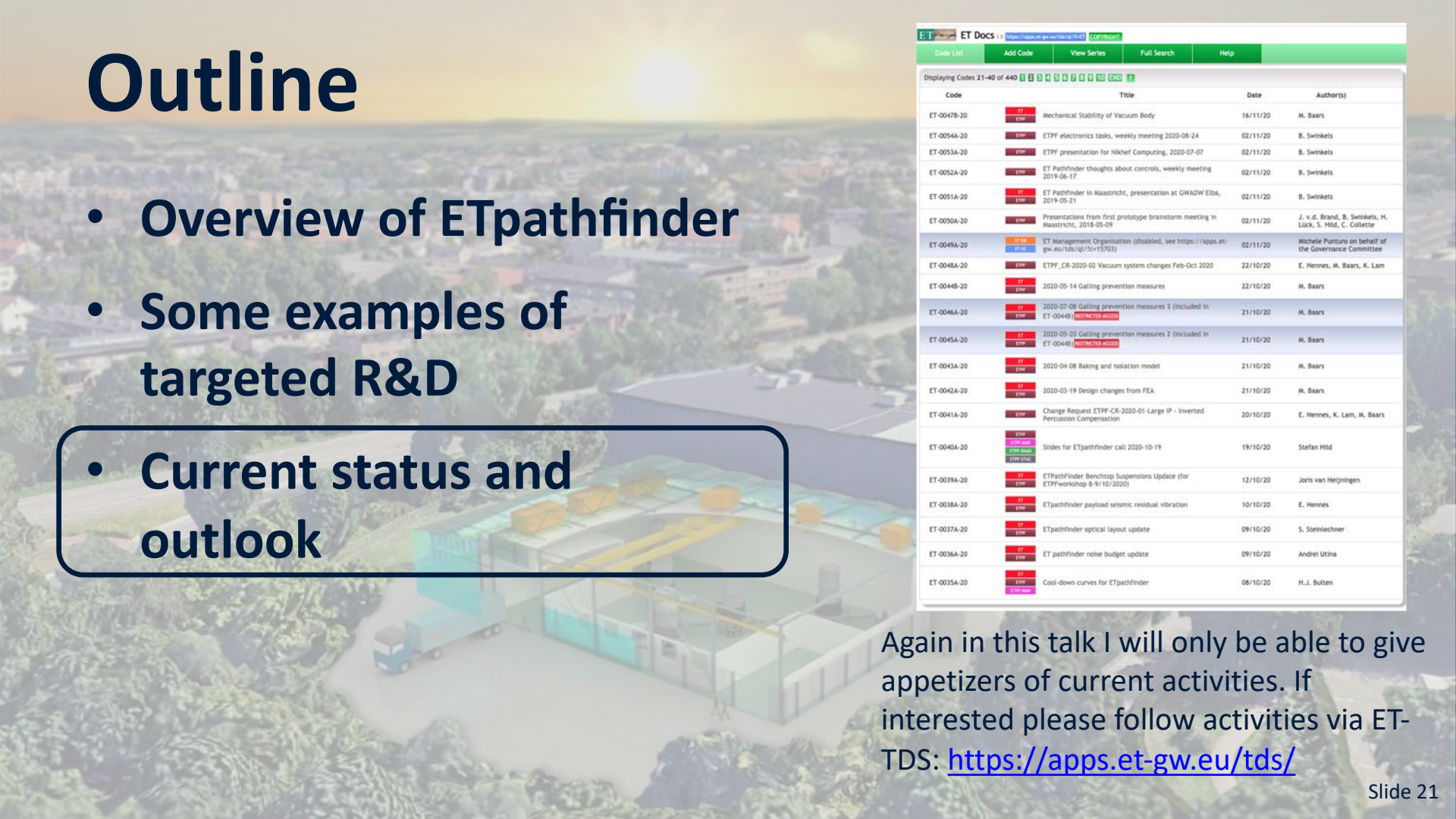
Optics + Coatings

- Main mirrors (silicon 15cm diameter, 8cm thickness, FZ, $R > 14\text{k}\Omega\text{m cm}$)
- First interferometer will explore currently available coatings (Silica/tantala? amorphous silicon? Multi-material coatings etc).
- Longer-term initiative @ KU-Leuven: Setting up an MBE system (crystalline coatings of different metal oxides)
- Arm cavity Finesse chosen as 800 (trade-off between lock-acquisition, compatibility of QN reduction schemes, Seismic isolation requirements of CITF etc)
- Optical layout for 2 interferometers (one per arm)



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ET Docs 1.0

Code List	Add Code	View Series	Full Search	Help
Displaying Codes 21-40 of 440				
Code		Title	Date	Author(s)
ET-0047B-20	ET EWP	Mechanical Stability of Vacuum Body	16/11/20	M. Baars
ET-0054A-20	ETPF	ETPF electronics tasks, weekly meeting 2020-08-24	02/11/20	B. Swinkels
ET-0053A-20	ETPF	ETPF presentation for Nikhef Computing, 2020-07-07	02/11/20	B. Swinkels
ET-0052A-20	ETPF	ET Pathfinder thoughts about controls, weekly meeting 2019-06-17	02/11/20	B. Swinkels
ET-0051A-20	ET EWP	ET Pathfinder in Maastricht, presentation at GWADW Elba, 2019-05-21	02/11/20	B. Swinkels
ET-0050A-20	ETPF	Presentations from first prototype brainstorm meeting in Maastricht, 2018-05-09	02/11/20	J. v.d. Brand, B. Swinkels, H. Lück, S. Hild, C. Collette
ET-0049A-20	ET EWP	ET Management Organisation (disabled, see https://apps.et-gw.eu/tds/q/?c=15703)	02/11/20	Michele Punturo on behalf of the Governance Committee
ET-0048A-20	ETPF	ETPF_CR-2020-02 Vacuum system changes Feb-Oct 2020	22/10/20	E. Hennes, M. Baars, K. Lam
ET-0044B-20	ET EWP	2020-05-14 Galling prevention measures	22/10/20	M. Baars
ET-0046A-20	ET EWP	2020-07-08 Galling prevention measures 3 (Included in ET-0044B) RESTRICTED ACCESS	21/10/20	M. Baars
ET-0045A-20	ET EWP	2020-05-20 Galling prevention measures 2 (Included in ET-0044B) RESTRICTED ACCESS	21/10/20	M. Baars
ET-0043A-20	ET EWP	2020-04-08 Baking and isolation model	21/10/20	M. Baars
ET-0042A-20	ET EWP	2020-03-19 Design changes from FEA	21/10/20	M. Baars
ET-0041A-20	ETPF	Change Request ETPF-CR-2020-01-Large IP - Inverted Percussion Compensation	20/10/20	E. Hennes, K. Lam, M. Baars
ET-0040A-20	ETPF ETPF ETPF	Slides for ETpathfinder call 2020-10-19	19/10/20	Stefan Hild
ET-0039A-20	ET EWP	ETPathfinder Benchtop Suspensions Update (for ETPF workshop 8-9/10/2020)	12/10/20	Joris van Hetjningen
ET-0038A-20	ET EWP	ETpathfinder payload seismic residual vibration	10/10/20	E. Hennes
ET-0037A-20	ET EWP	ETpathfinder optical layout update	09/10/20	S. Steinechner
ET-0036A-20	ET EWP	ET pathfinder noise budget update	09/10/20	Andrei Utina
ET-0035A-20	ET EWP	Cool-down curves for ETpathfinder	08/10/20	H.J. Bulten

Again in this talk I will only be able to give appetizers of current activities. If interested please follow activities via ET-TDS: <https://apps.et-gw.eu/tds/>



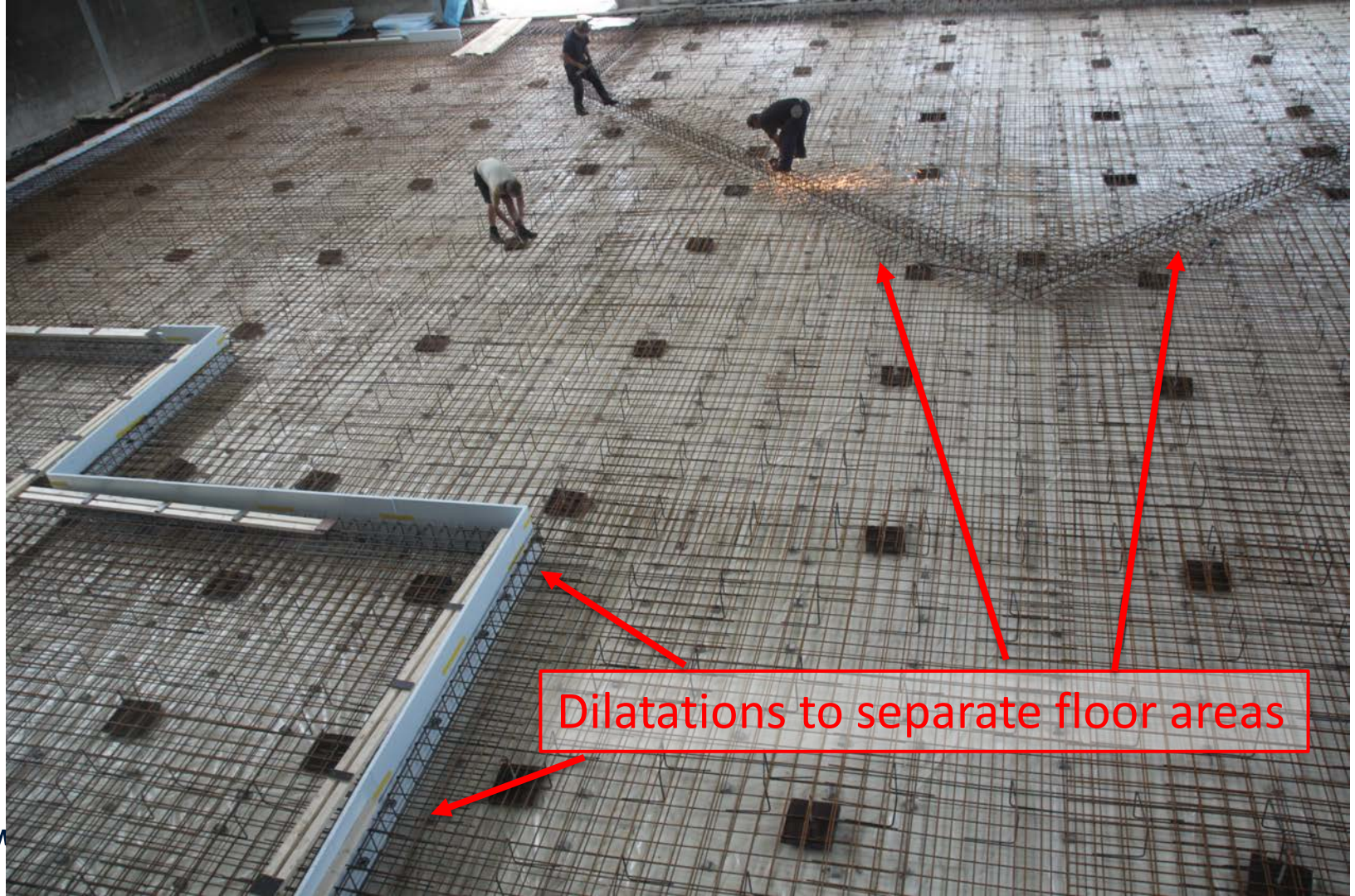
Feb 2020

April 2020



Timelaps of hall re-construction

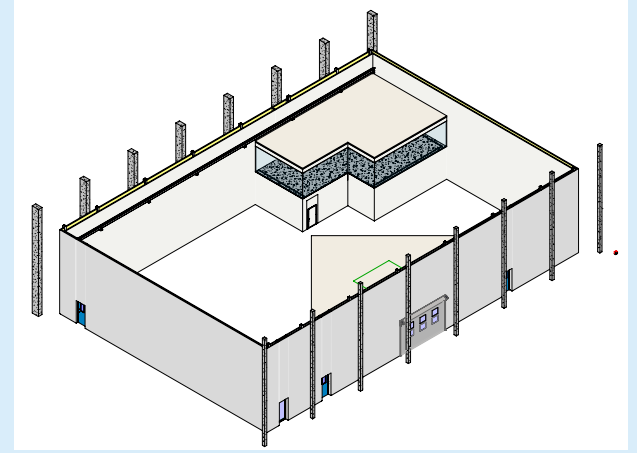




Dilatations to separate floor areas



Status: Cleanroom

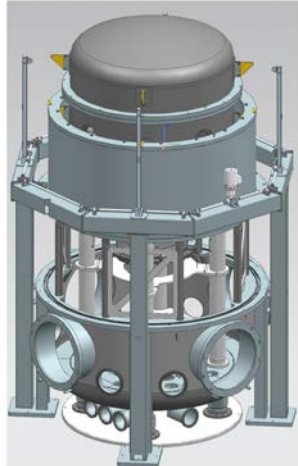


Vacuum system tender

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Code List	Add Code	View Series	Full Search	Help
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Code		Title	Date	Author(s)
ET-0070A-20	ET ETPF	Technical construction file vacuum vessel tender	24/11/20	M. Baars for the ETpathfinder team
ET-0047B-20	ET ETPF	Mechanical Stability of Vacuum Body	16/11/20	M. Baars
ET-0048A-20	ETPF	ETPF_CR-2020-02 Vacuum system changes Feb-Oct 2020	22/10/20	E. Hennes, M. Baars, K. Lam
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ET-0041A-20	ETPF	Change Request ETPF-CR-2020-01-Large IP - Inverted Percussion Compensation	20/10/20	E. Hennes, K. Lam, M. Baars
ET-0031A-20	ET ETPF	Technical Specification Lifting System ETpathfinder	27/08/20	Frank Kayzel, Frank Linde, Paul Kuijter, Kenny Lam, Mathijs Baars, Eric Hennes
ET-0030A-20	ET ETPF	Technical Specification Vacuum Vessel ETpathfinder	27/08/20	Frank Kayzel, Frank Linde, Paul Kuijter, Stefan Hild, Kenny Lam, Mathijs Baars, Henk-Jan Bulten, Eric Hennes, Berend Munnikse

Title:
Technical Specification Lifting System



Document number:
ET-0031A-20

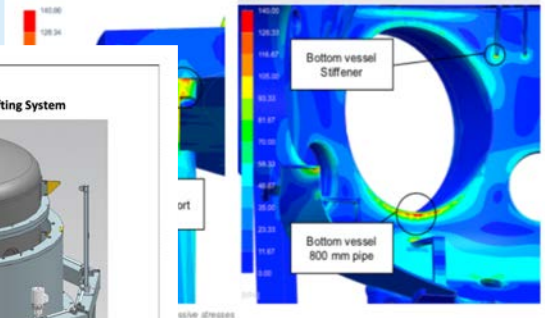
Author:
Frank Kayzel, Frank Linde, Paul Kuijter, Kenny Lam, Mathijs Baars, Eric Hennes, Maastricht University/Nikhef

Abstract
The object of this Technical Specification is to describe the requirements of the Lifting System for

The shown stresses (Figure 14") vary per case ('a/b') and with different mesh methods and sizes and with different connection methods, but are always larger than the allowed 140 MPa. The only exception is the vessel support, which does not give excessive stresses when glue is used instead of modeling the bolt.

The bottom vessel stiffener only shows excessive stress in case 'b'. The 800 mm pipe weld has shown stress for both cases'.

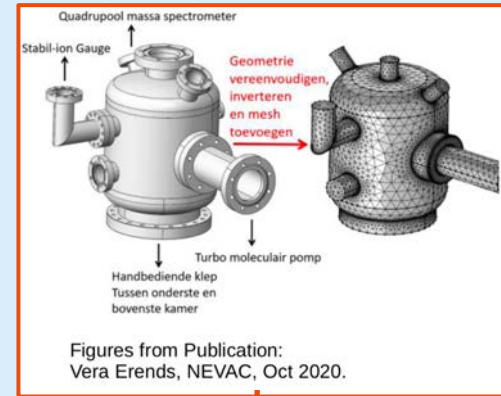
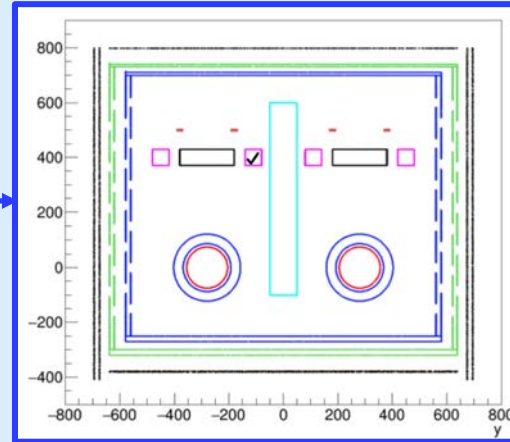
The elaborate review of the results is given in Appendix 2 - with corresponding screenshots shown in Appendix 6 -



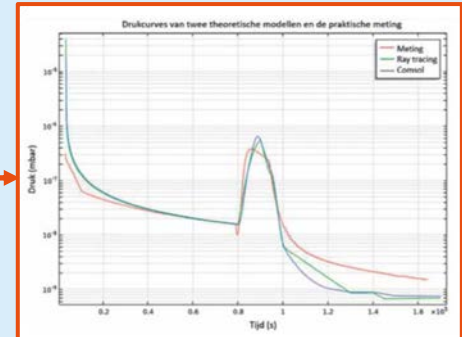
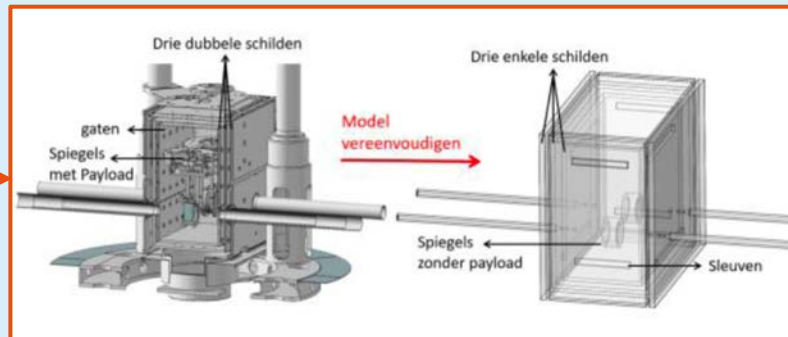
Vacuum / cryogenic simulations

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.
- Molflow 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 Comsol using a outgassing set-up at Nikhef (Vera Erends, Berend Munneke, HJB)



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

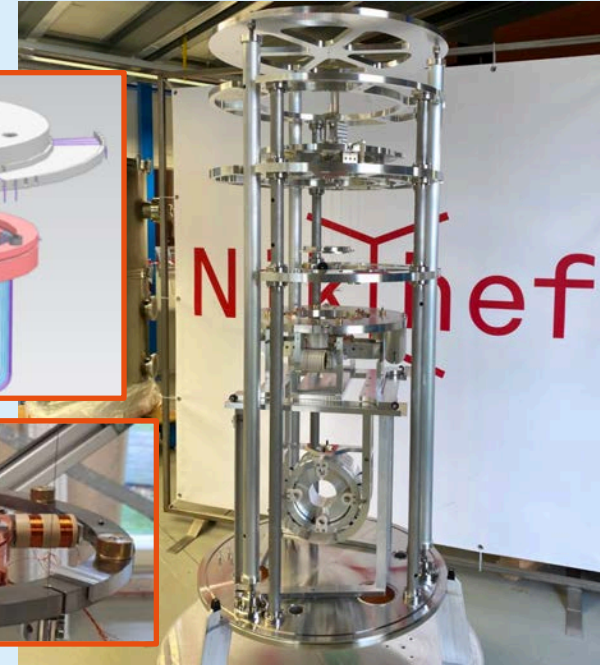
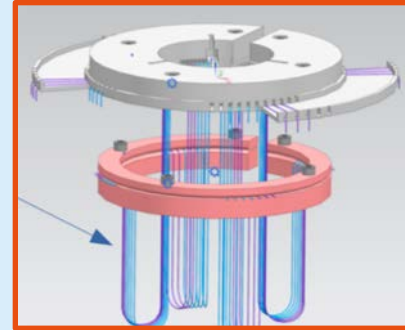
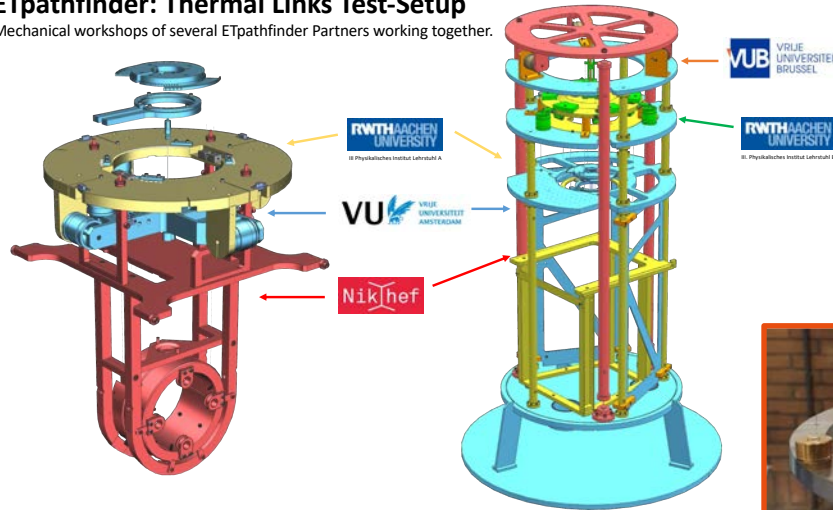


Test setups

- Various test setups are underway for cryogenics and seismic isolation.
- A nice example of collaboration combining efforts from several mechanical workshops (Jelly fish heat link mechanical coupling measurements):

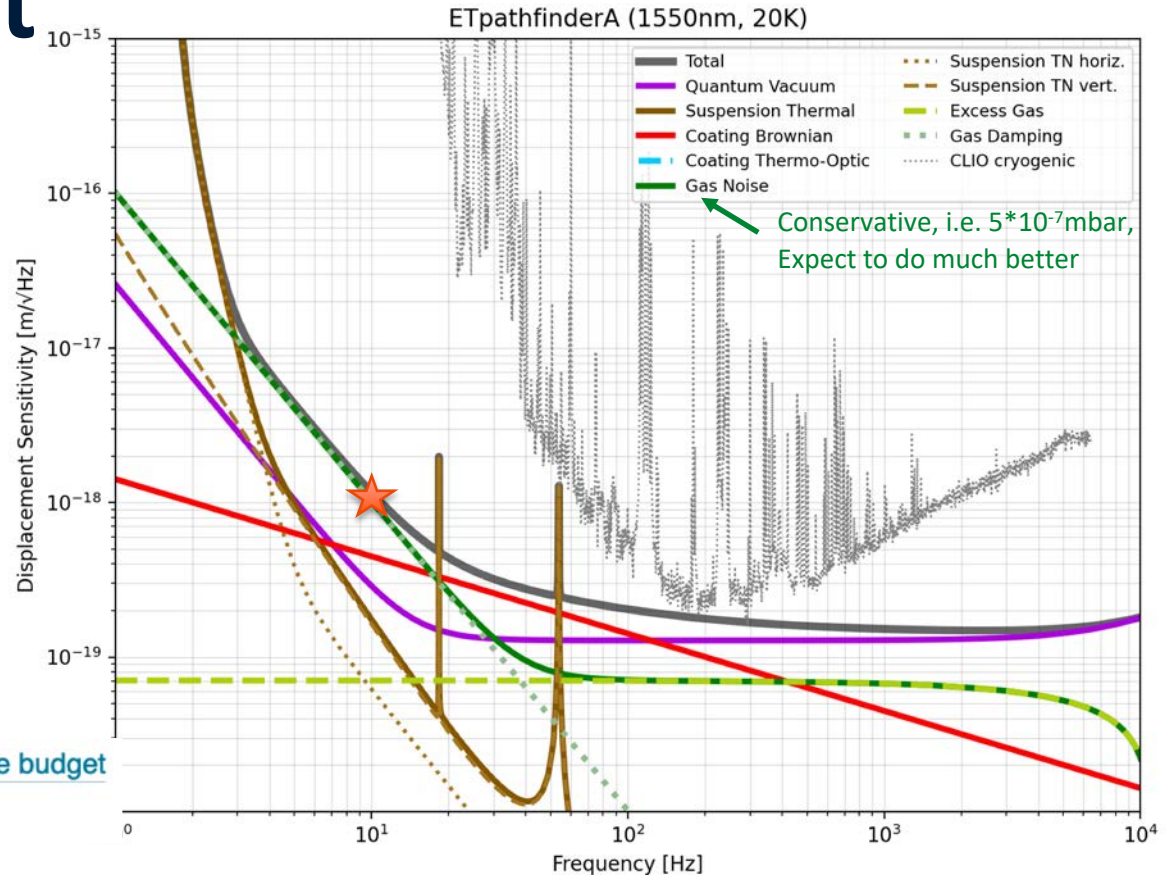
ETpathfinder: Thermal Links Test-Setup

Mechanical workshops of several ETpathfinder Partners working together.



Noise budget

- Main target for Phase 1a/b was set as $10^{-18}\text{m}/\sqrt{\text{Hz}}$ at 10Hz.
- Developing noise budget to guide designs and choice of R&D priorities.
- Target noise budget will be adjusted during lifetime of ETpathfinder.



 Merging Clío noise curves to ETPA noise budget

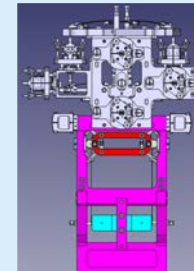
 1054  Andrei Utina and Sebastian Steinlechner  Edit
 November 14, 2020 at 11:15 pm

Many things on the go ...

- Tenders in preparation for: 1) large bellows, 2) vacuum pumps and diagnostics tools, 3) Gate valves, 4) MBE coating system, 5) Optical tables ...
- Silicon mirror substrates currently in production at IKZ Berlin
- Vacuum system lifting system final design checks (Antwerp)
- Control system assembly at LAPP
- 1550nm laser being set up at AEI
- 2090nm laser source under development at Fraunhofer Institute Aachen
- Silicon polishing tests underway at Vrije University of Brussels



Benefits go both ways, from a recent Virgo financial document:
"DAQ.03: Mezzanine ADC2378 production: The production is cheaper than expected. The production of ADC mezzanines for Adv+ was carried out at the same time as the production of ETpathfinder. A higher volume of cards lowers the unit price of a card and lowers the price for Adv+."



Take-away-points

- ETpathfinder is reality now (you can see, touch, breath it, if you stop by in Maastricht).
- **ETpathfinder is a long-term initiative and independent of the site decision** (i.e. ETpathfinder will not vanish in 2025, but be available to the ET community for the next decades.)
- ETpathfinder is huge opportunity to test new technology vital for ET. Let's use it to **increase (our and the communities and funder's) confidence into ET.**
- **Everybody is welcome to join the ETpathfinder team. Lots of work available for new groups to take charge of. Please get in contact.**

Thank you for your attention.

Any questions?

(Please ask, but also feel free to get into
contact via email at any time!)

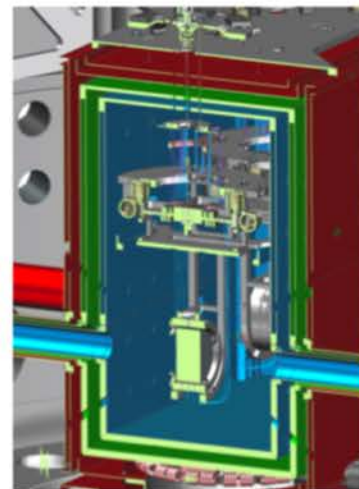
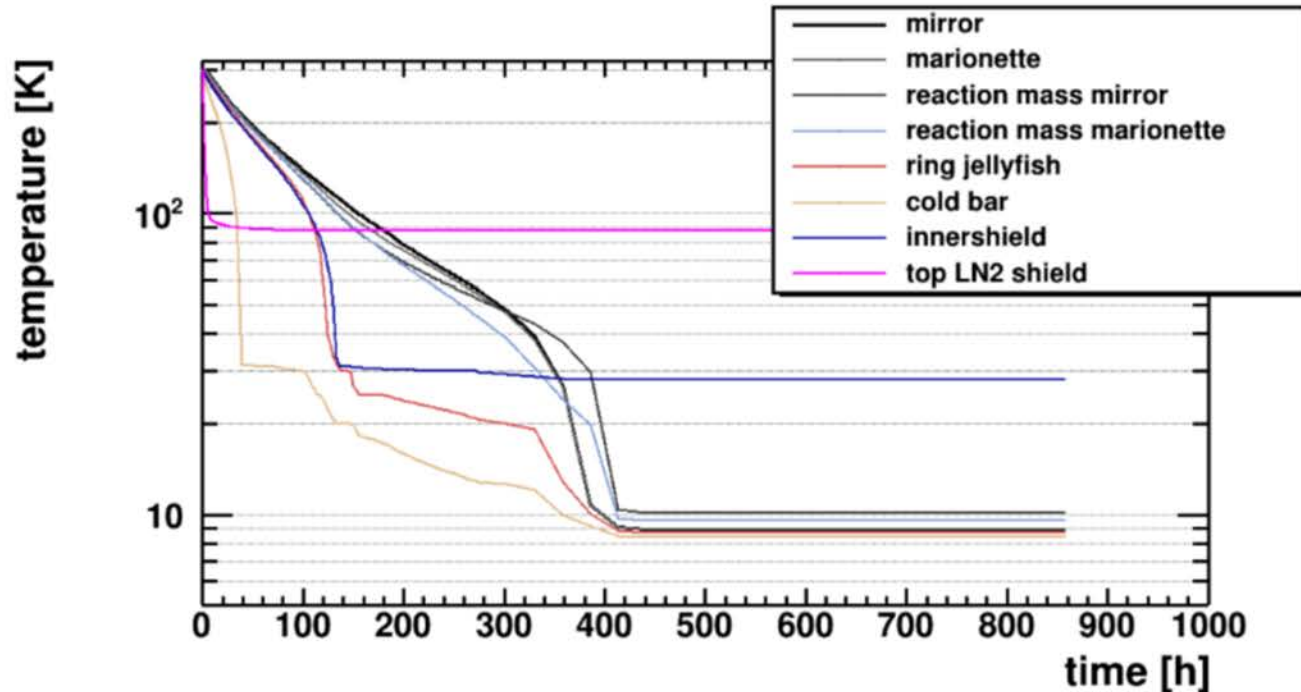


EXTRA SLIDES

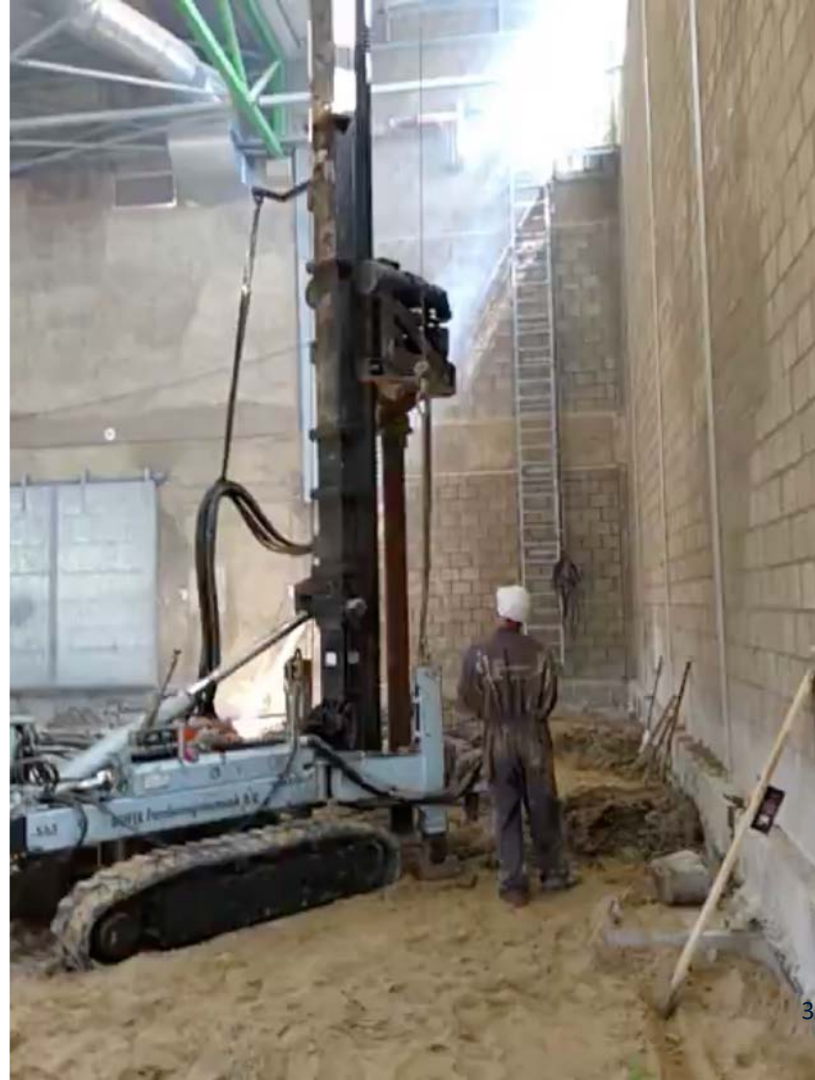
Cool-down curves

Calculations with 30W cooling power (both shields and cold finger) above 30K

Temperature as a function of time for several elements. Results for high-emissivity coatings. Final temperatures and equilibrium are reached in 400 h, about 5 times quicker than with low-emissivity



Masses mirror 3.3kg, marionette 8kg, reaction masses 10 and 5 kg, cold finger 20 kg, 70kg of cryogenic mass. Shield weigh about 130 and 150 kg






New
roller
gates ,
escape
doors
etc

The image shows the interior of a large industrial building with a high ceiling supported by a green steel truss system. The walls are made of light-colored concrete blocks. On the left, there are large windows and a white van with 'METAL' and 'www.frigometal.nl' on its side. In the center, a red scissor lift is extended towards the ceiling. On the right, there are vertical grey steel beams and a red scissor lift. The floor is a smooth, light-colored concrete. The lighting is bright, coming from overhead fixtures.

New
heating,
cooling,
lighting

New H
beams
for crane

New service
(electricity, cooling
water etc)

A large-scale construction project is underway outdoors. In the foreground, a large, flat concrete slab is being prepared, bordered by wooden formwork. To the right of this slab, a deep, narrow trench has been excavated, lined with concrete walls and reinforced with wooden bracing. A yellow hose runs along the edge of the trench. In the background, a red concrete pump truck with a long articulated boom is parked on a dirt area. The site is surrounded by lush green trees and a metal fence. The overall scene depicts the early stages of building a large underground facility.

Lots of space for LN2 tanks
outside the hall (with underground
Tunnel for pipes into the hall)

New 360kW
cooling water unit
installed on the
roof of
neighboruring hall



From STAC report , Feb 2020

The interactions with the other major efforts in the GW field are important for the ETPF. The Einstein Telescope Project has a lot of overlap with staff and objectives; it would be good to have a compact description of that special relationship (is ETPF obligated to pursue priorities determined by ET leadership? Is the ET Project obligated to adopt designs developed at ETPF?). It would be advantageous that the ETPF also be seen by the US Cosmic Explorer and Voyager undertakings as a partner to address technical issues and to exchange staff and visitors, and we encourage ETPF to invest some energy in being visible to that community. Further steps could be to organize a joint meeting at Maastricht of LSC-Virgo-KAGRA scientists engaged in 3G detectors, and/or to suggest for a US LVK meeting to have a significant session on ETPF where input to the program is invited (and the program of course presented).

The 'joint citizenship' in LSC and Virgo is a good first step. The plan for Virgo is to have those interested in ET to have a significant engagement in today's Virgo; this feels like it is compatible with the ETPF planning. It is important to continue the discussions in both the LSC and Virgo on 'credit' for 3rd generation detectors and the relationships that enforces between 3G detectors and LSC-Virgo. KAGRA has unique overlap with the ETPF scope in addressing the challenges of ~20K cryogenics for GW detectors, and a deep relationship between KAGRA and ETPF would appear to be mutually rewarding.

The ETPF-STAC recommends that there be a written document describing the relationship between ETPF and the ET project (this might end up into an MoA at some point).