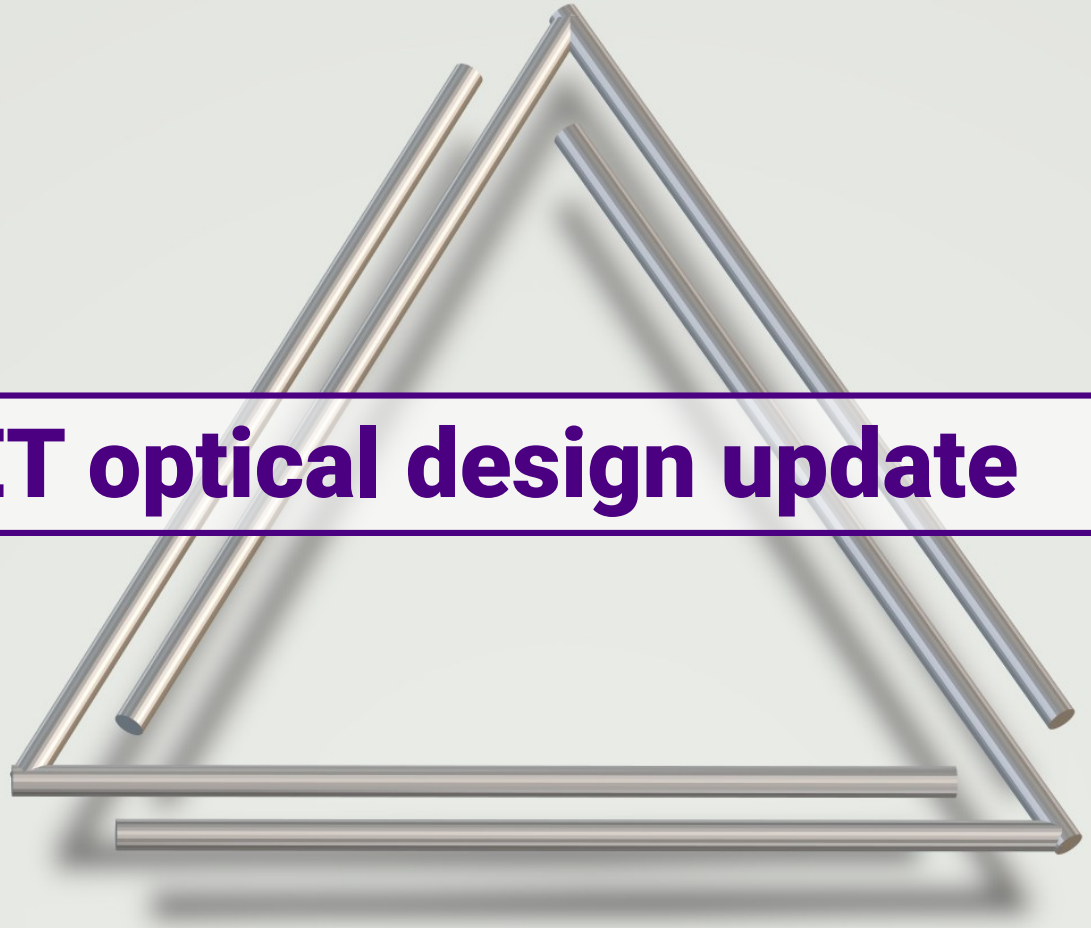
ET optical design update



J. Degallaix for the ET team

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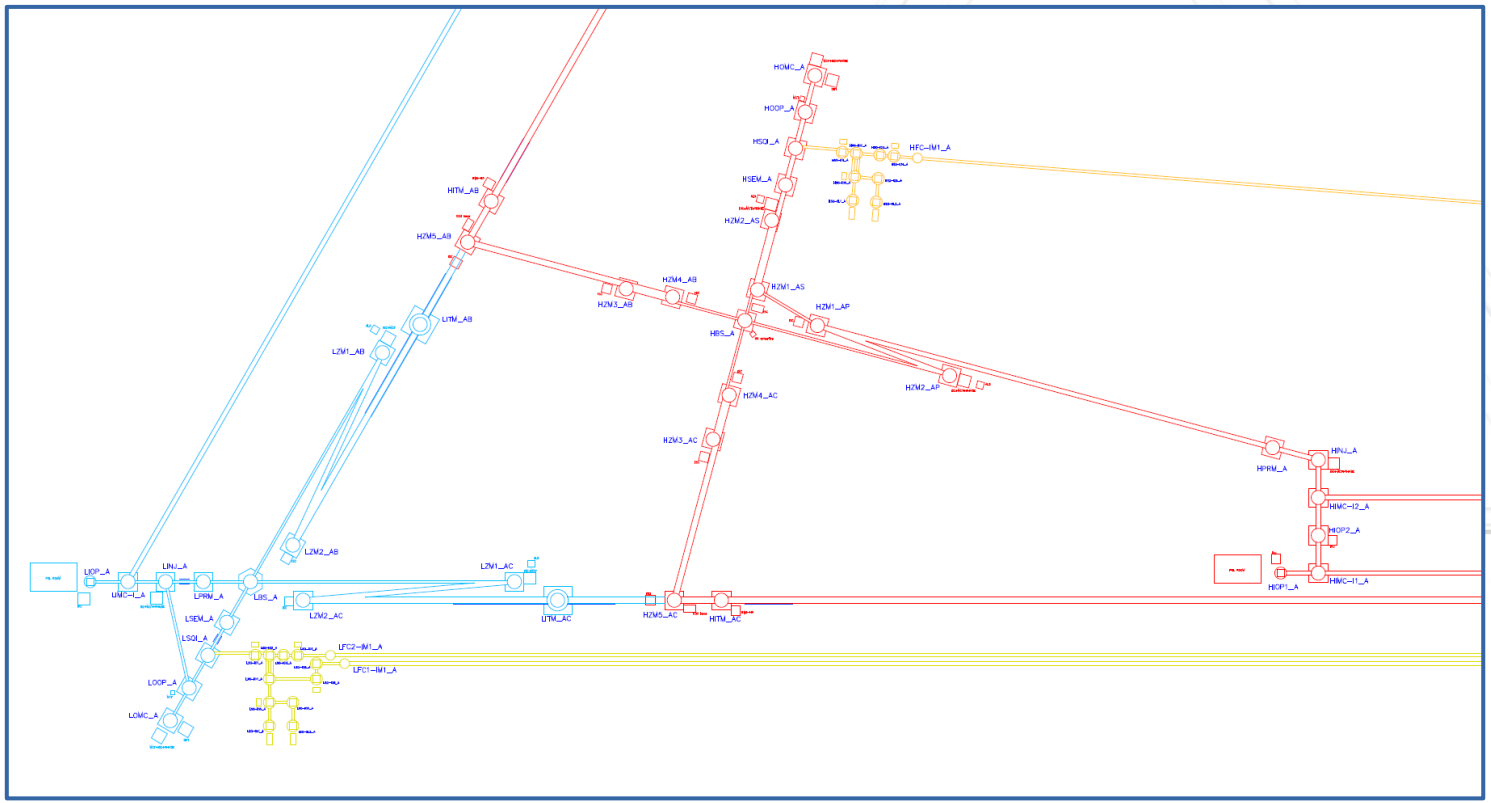
Why updating the detector layout ?

One year ago, I presented the functional layout:



Reminder: this is not the physical layout.

Optimisation to be done to minimise the infrastructure cost

End of 2024: creation of the ETO task force

A focused small group with a clear mandate from the ETO directorate:

3 Mandate

The aim of the task force is to adapt, in a short time, the detector layouts of ET towards an acceptable preliminary costing for the civil infrastructure while maintaining ET's scientific performance. In particular, it will:

- review and update the detector layout for the triangle configuration
- review and update the detector layout for the 2L configuration.

Must provide all the technical documents to the local teams for the engineering studies

End of 2024: creation of the ETO task force

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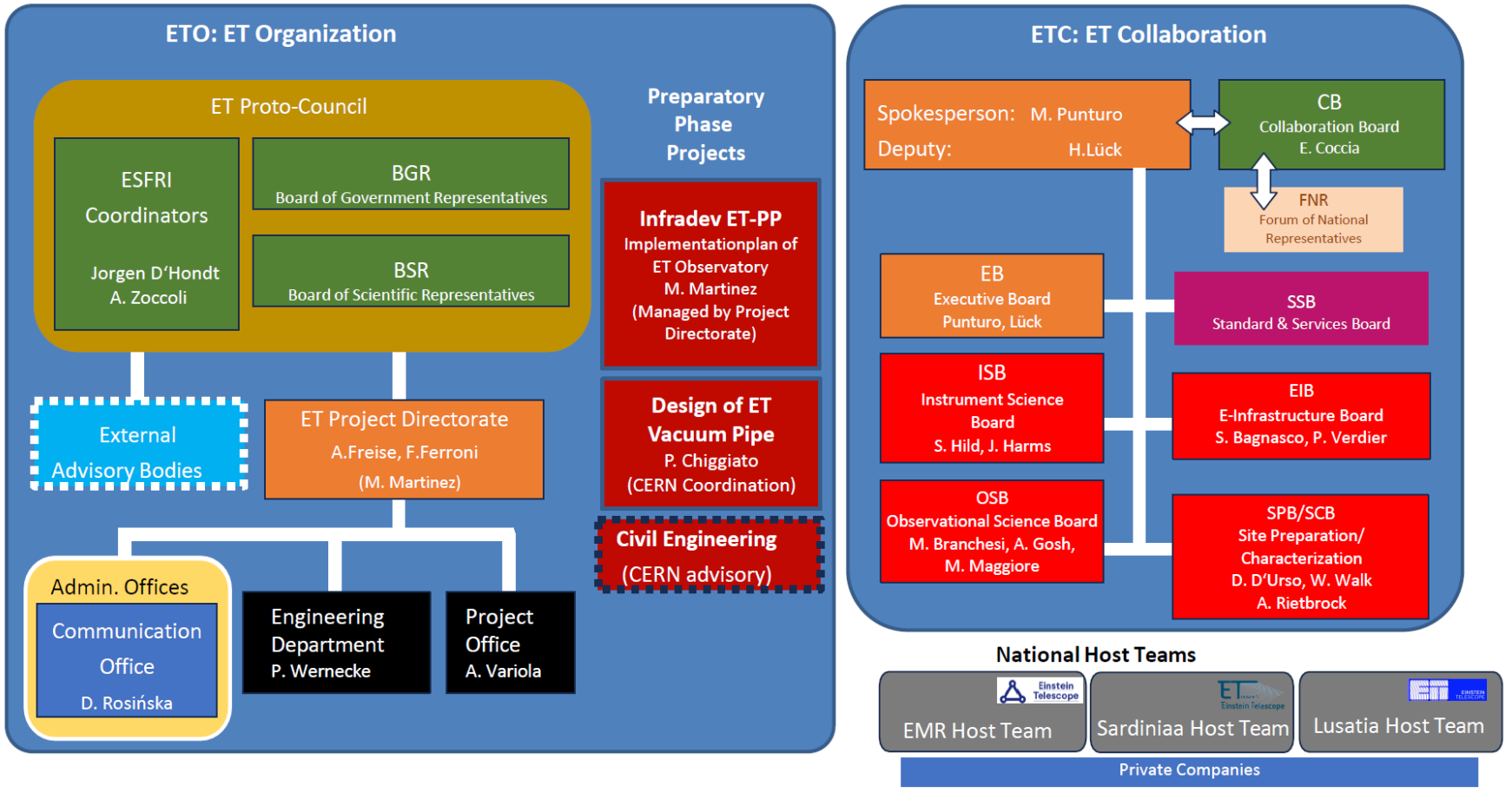
- review and update the detector layout for the triangle configuration
- review and update the detector layout for the 2L configuration.

Reduce the cost!!!!

Must provide all the technical documents to the local teams for the engineering studies

A little reminder about the ET organisation



End of 2024: creation of the ETO task force

A task force of 40 people including:
- members of the collaboration
- and members of the ETO, engineering department

First time, we had such an integrated team, intense work over 6 months with weekly meetings and 3 in-person meetings

How to reduce the cost ?

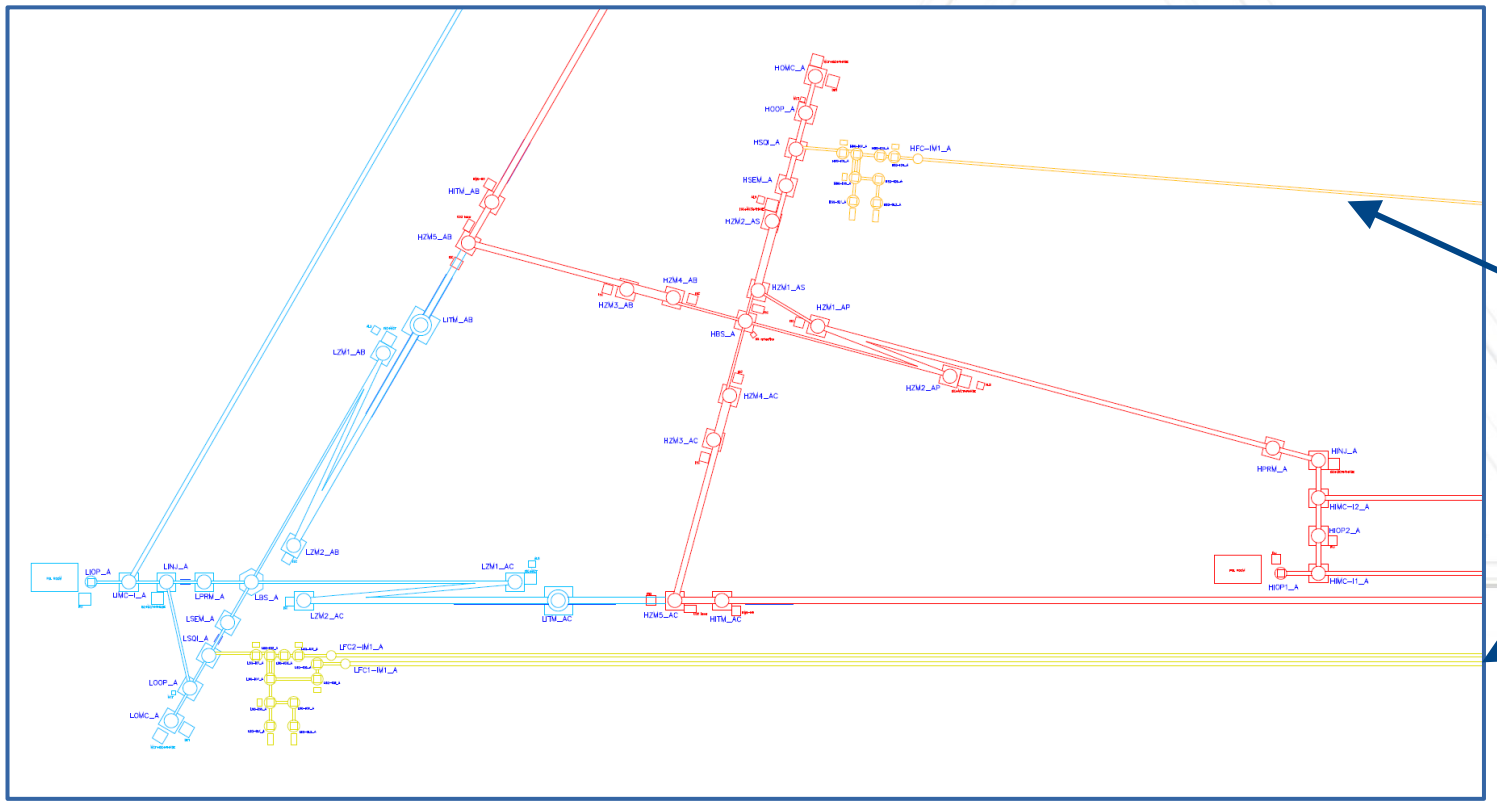
Reduce the volume of the excavation! The first ideas:

- share the same tunnels
- reduce auxiliary tunnel lengths
- reduce the volume of the central caverns

And also:

- exploit flexibilities
- compromise: technical changes vs infrastructure cost

The most obvious...



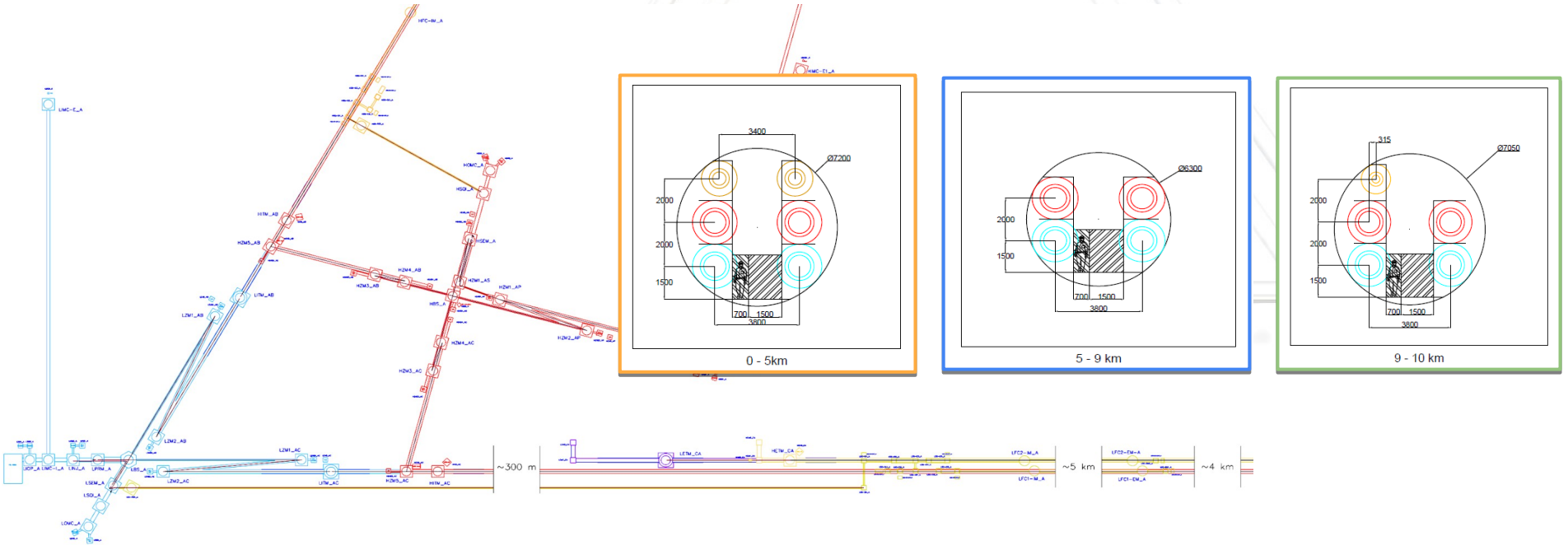
Combine the filtering cavities in the arm tunnels

x2

The 2024 design

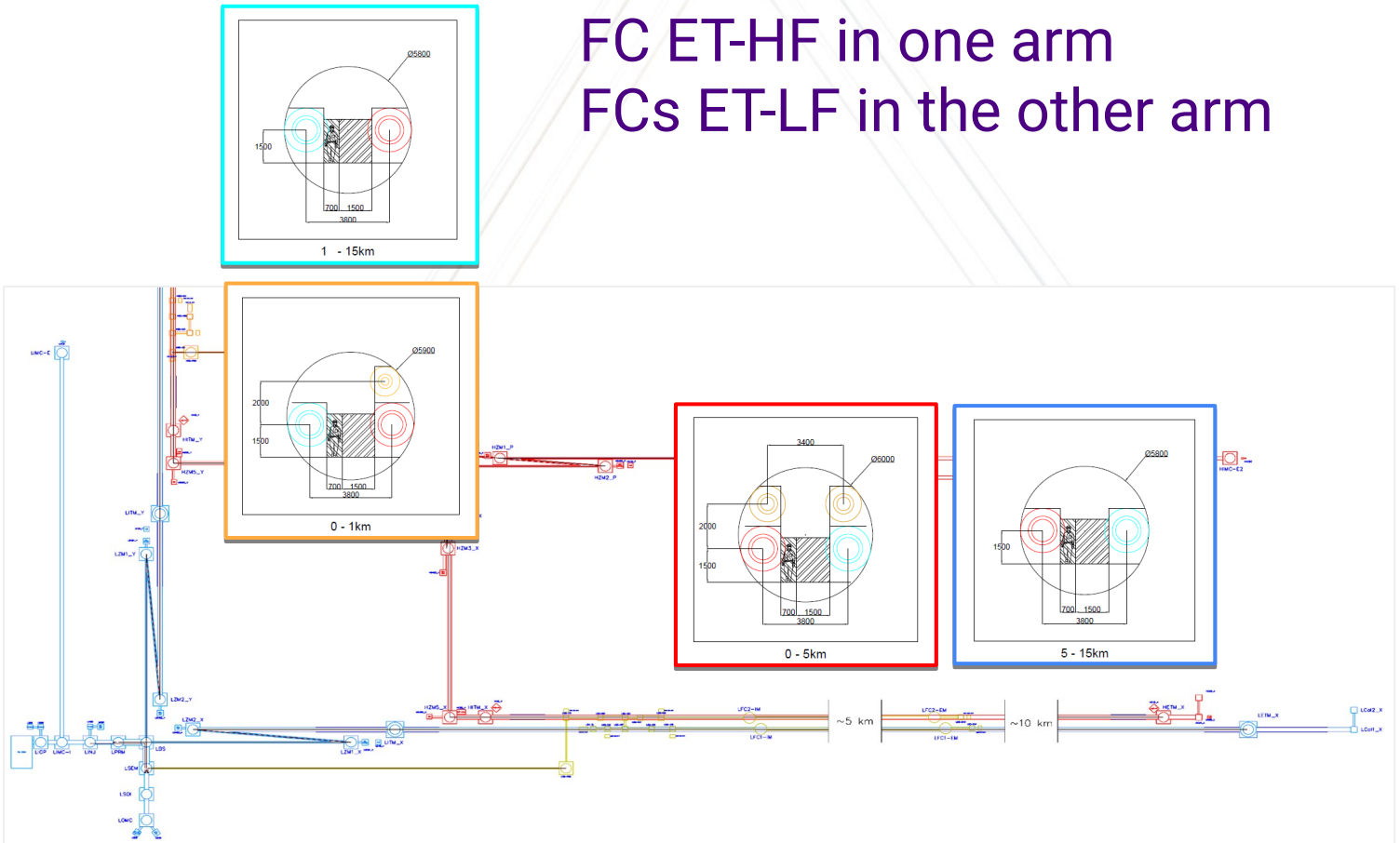
Bring the filtering cavities to the arm tunnels

Only one solution: stack the pipes in the tunnel, FC above the arm cavities, example for ET-HF:



Easier for the L shape

FC ET-HF in one arm
FCs ET-LF in the other arm



Re-shuffling of the squeezing benches

- Addition of periscopes of 2-4 m for the SQZ path (extra noise ? polarisation mixing ?)
- Relocation of the squeezing clean rooms
- From 3 to 2 mirrors FCs
- Smaller vacuum pipes

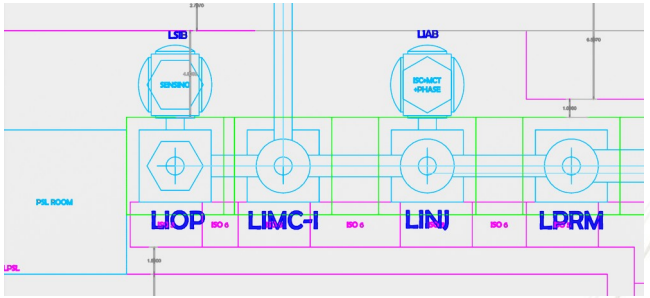
	2024 Reference	2025 Triangle	2025 2L
Position of FCs	Separate tunnel	ITF Arms Tunnel	ITF Arms Tunnel
Number of FC Mirrors	3	2	2
Diameter of FC Beampipes	1 m (LF and HF)	62 cm LF, 40 cm HF	62 cm LF, 40 cm HF
FC Center-to-Center Distance	4.5 m (LF)	3.4 m (LF)	3.4 m (LF)
Length of Periscope	–	2.0 m (HF), 4.0 m (LF)	2.0 m (HF, LF)
Position of Periscope (HF)	–	Near SQZ Lab	Near SQZ Lab
Position of Periscope (LF)	–	Near the Vertex	Near SQZ Lab
SQZ Lab to Interferometer Distance	∼50 m	∼550 m	∼120 m
# of Suspended Benches (SQZ Lab)	8 HF, 12 LF	6 HF, 11 LF	6 HF, 10 LF
Dimension of Suspended Benches	1.5 × 1.5 m	1.5 × 1.5 m	1.5 × 1.5 m

Other changes in the design

- IMC length for LF, triangular 300m → 120m
- IMC layout redesign for HF (reduced foot print, 2 in the same tunnels)
- No extra pipe for the BHD local oscillator (LF), routed by the existing vacuum vessels
- Co-locate optics in vacuum tanks
- Re-asses the needs of benches/clean rooms for auxiliary optics

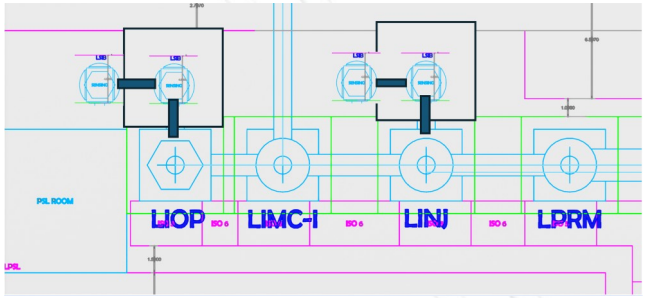
Examples

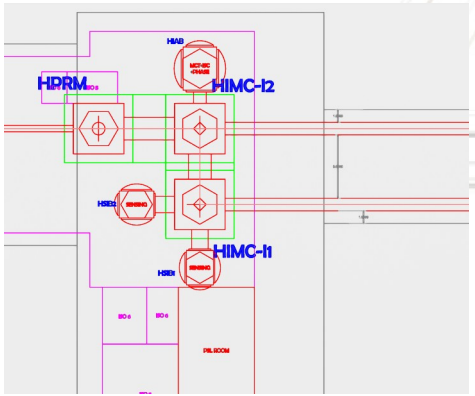
2024

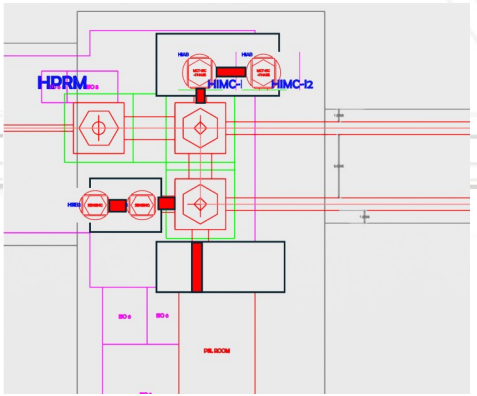


2025

M. Majoor / A. Chiummo







Flexibility Envelope

This information is collected together with each primary layout parameter* (positions, lengths, and footprints).

Included in 2024 layout outputs, but now *standardised* into a 'traffic light' system with clearer definitions:

- **Free** - unconstrained
- **Minor redesign** - likely possible
  Some moderate impact on local optical layout
- **Major redesign** - some limited flexibility
  Significant impact on the global optical layout
- **None** - completely constrained
  Only to be altered by the optical layout team - completely constrained by other parameters/requirements

Taken from : **ET-0228A-25**

Tolerances are further provided on many parameters, giving further insight into the likely degree of flexibility that can be exploited.

*Changes to those values will have a corresponding impact on derived optical parameters (e.g. radius of curvature), indicated by the classifications above.

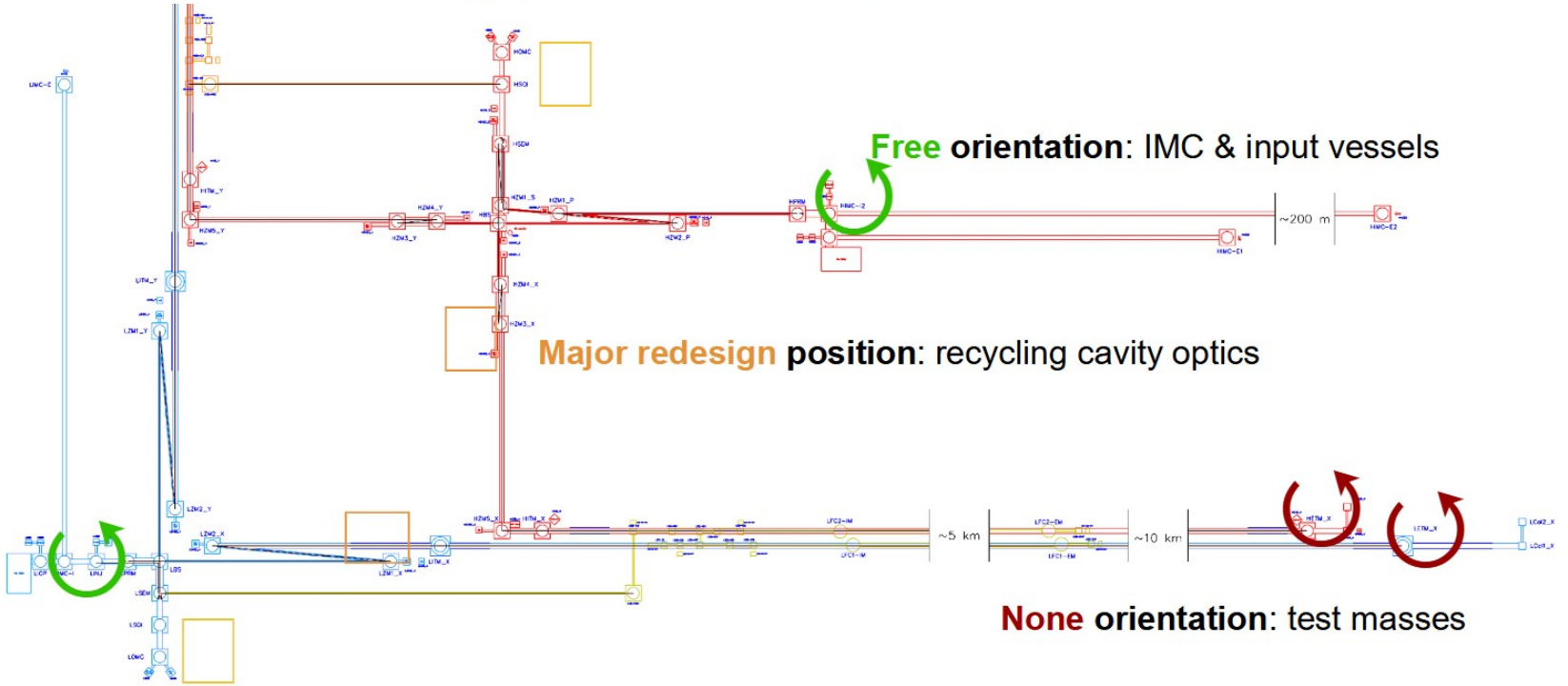
Flexibility Envelope: some examples

Minor redesign position: input and output vessels

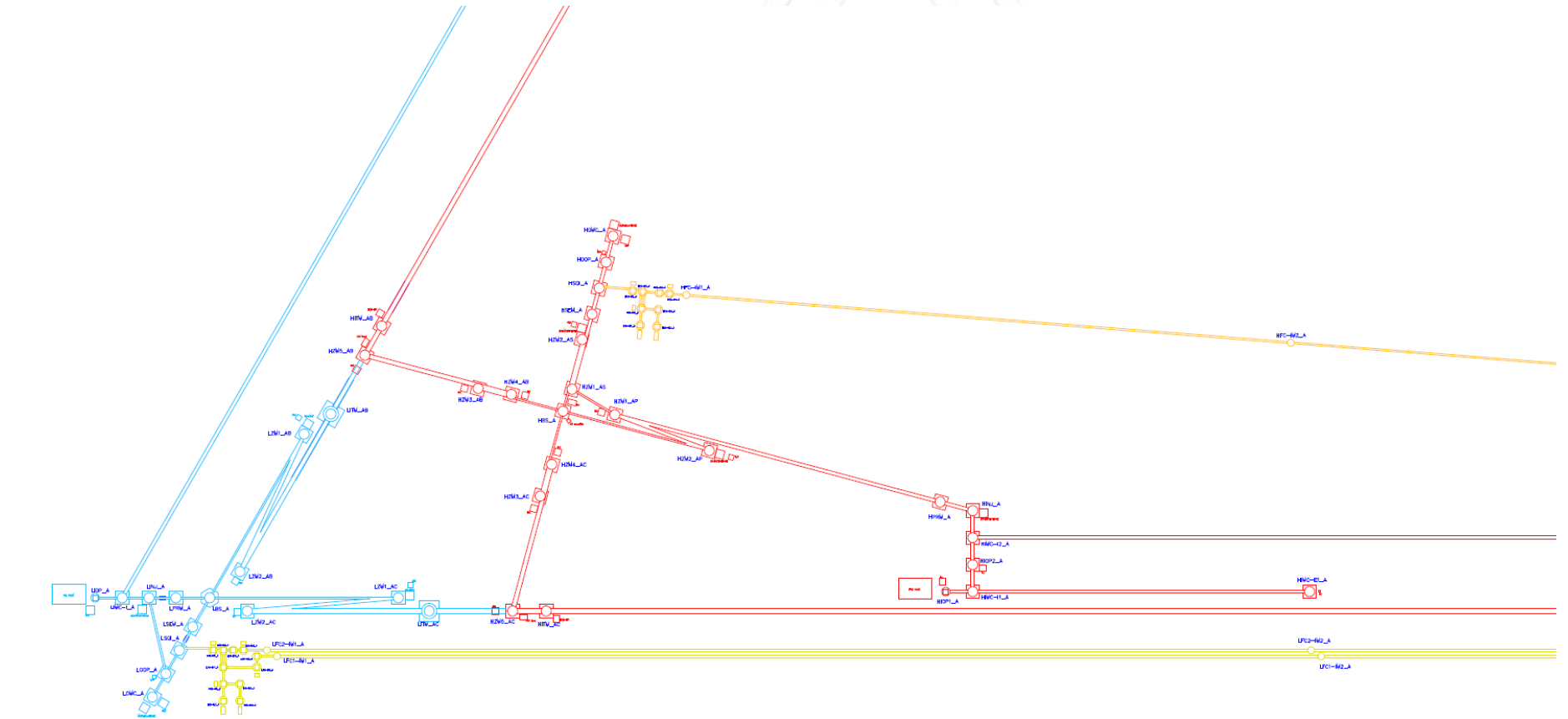
Free orientation: IMC & input vessels

Major redesign position: recycling cavity optics

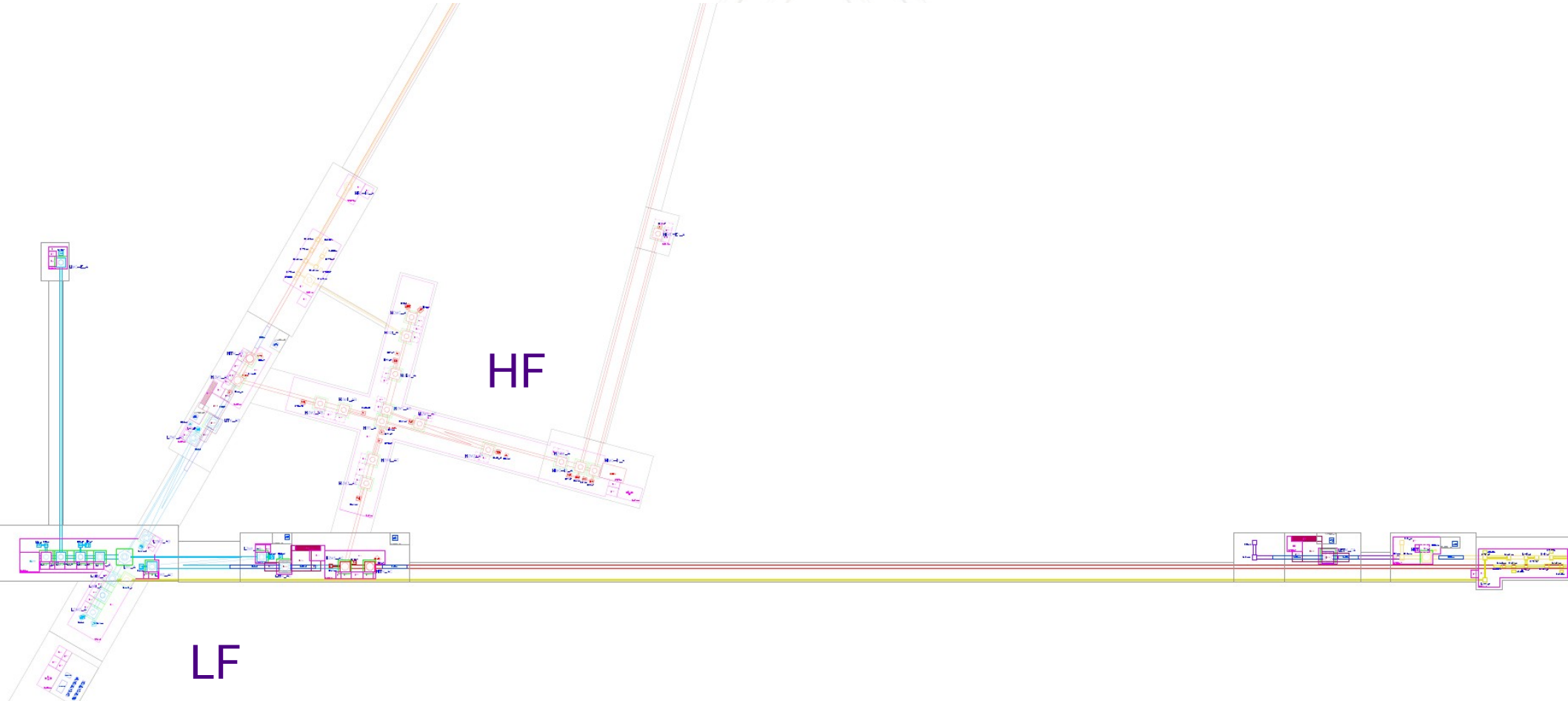
None orientation: test masses



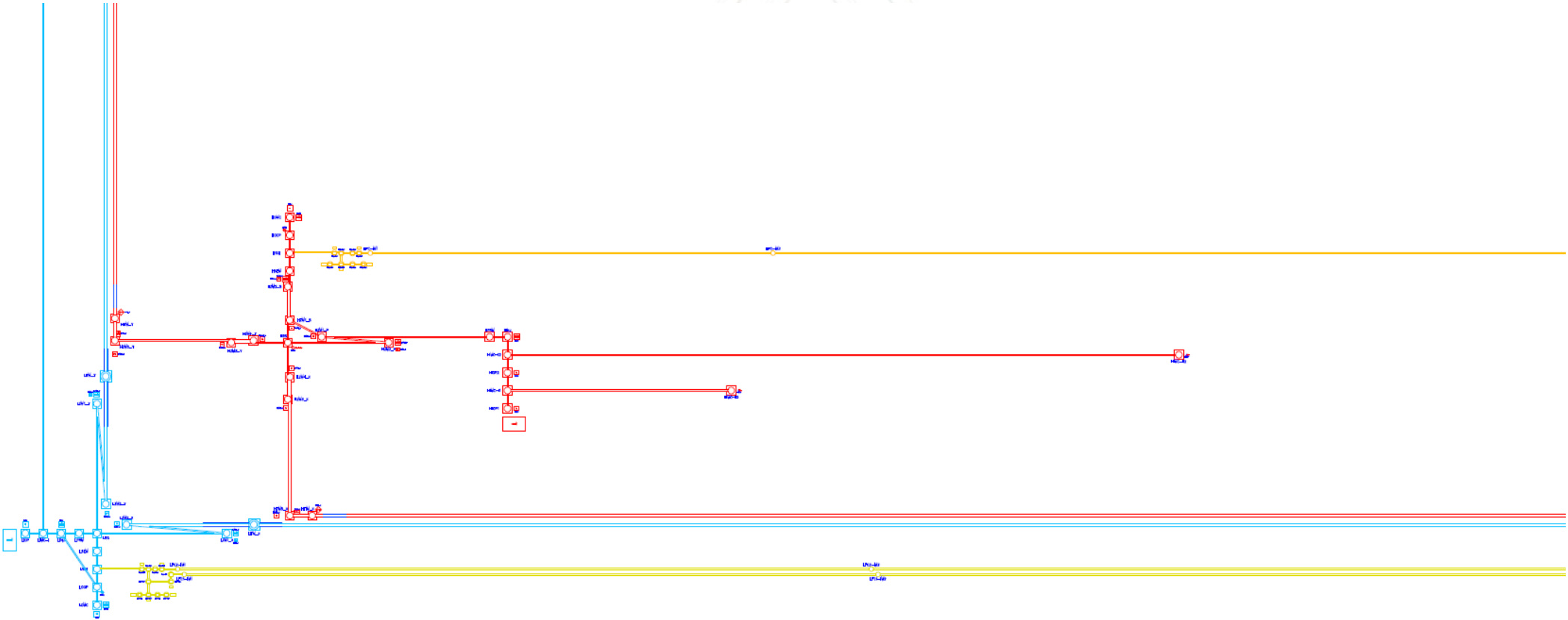
Triangle design 2024



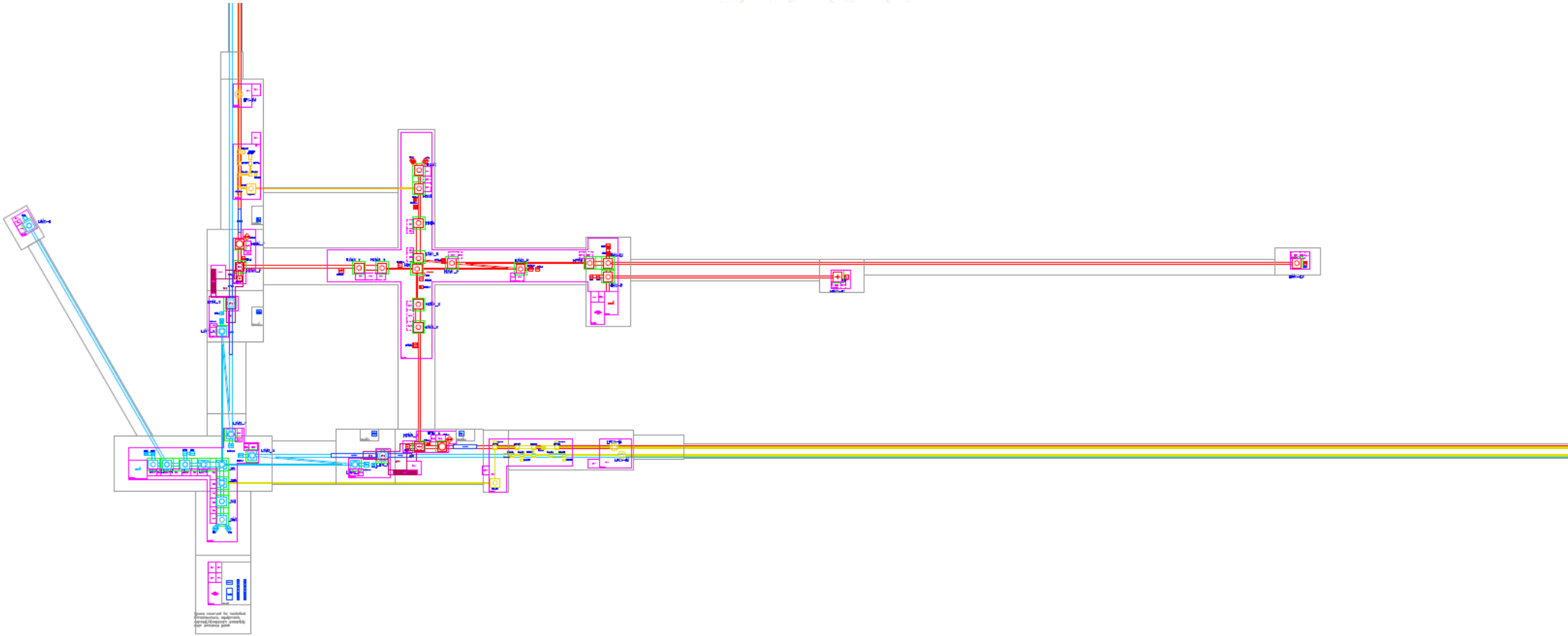
Triangle design 2025



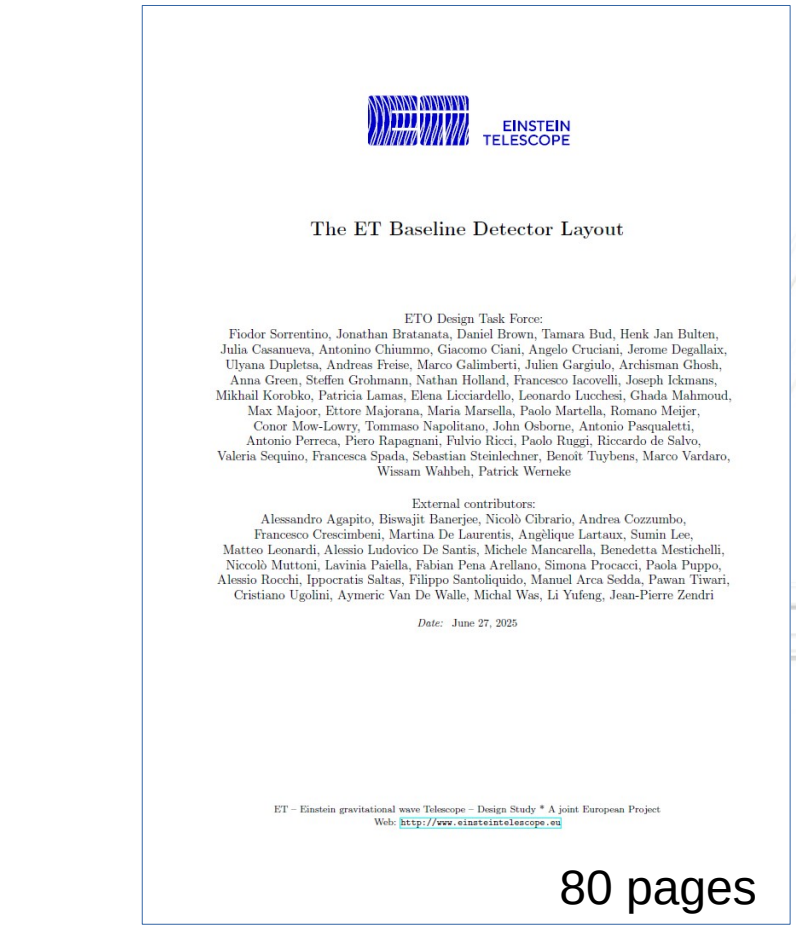
L design 2024 (not completed last time)



L design 2025



The update is all described in 2 reports



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The ET Baseline Detector Layout

ETO Design Task Force:
Fiodor Sorrentino, Jonathan Bratanata, Daniel Brown, Tamara Bud, Henk Jan Bulten, Julia Casanueva, Antonino Chiummo, Giacomo Ciani, Angelo Cruciani, Jerome Degallaix, Ulyana Dupletsa, Andreas Freise, Marco Galimberti, Julien Gargiulo, Archisman Ghosh, Anna Green, Steffen Grohmann, Nathan Holland, Francesco Iacovelli, Joseph Ickmans, Mikhail Korobko, Patricia Lamas, Elena Licciardello, Leonardo Lucchesi, Ghada Mahmoud, Max Majoor, Ettore Majorana, Maria Marsella, Paolo Martella, Romano Meijer, Conor Mow-Lowry, Tommaso Napolitano, John Osborne, Antonio Pasqualetti, Antonio Perreca, Piero Rapagnani, Fulvio Ricci, Paolo Ruggi, Riccardo de Salvo, Valeria Sequino, Francesca Spada, Sebastian Steinlechner, Benoît Tuybens, Marco Vardaro, Wissam Wahbeh, Patrick Werneke

External contributors:
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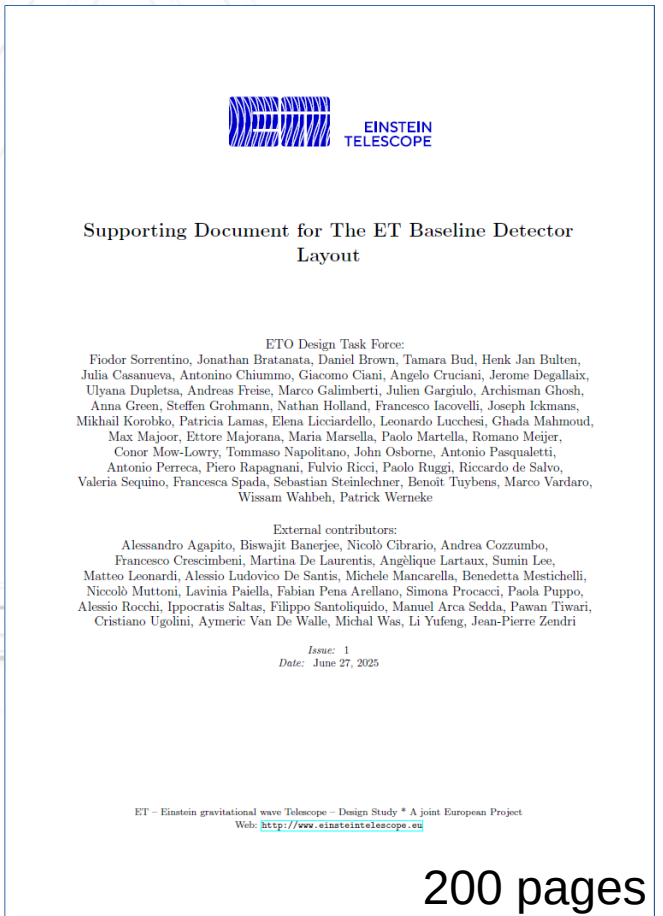
Date: June 27, 2025

ET – Einstein gravitational wave Telescope – Design Study * A joint European Project
Web: http://www.einsteintelescope.eu

80 pages



EINSTEIN TELESCOPE

Supporting Document for The ET Baseline Detector Layout

ETO Design Task Force:
Fiodor Sorrentino, Jonathan Bratanata, Daniel Brown, Tamara Bud, Henk Jan Bulten, Julia Casanueva, Antonino Chiummo, Giacomo Ciani, Angelo Cruciani, Jerome Degallaix, Ulyana Dupletsa, Andreas Freise, Marco Galimberti, Julien Gargiulo, Archisman Ghosh, Anna Green, Steffen Grohmann, Nathan Holland, Francesco Iacovelli, Joseph Ickmans, Mikhail Korobko, Patricia Lamas, Elena Licciardello, Leonardo Lucchesi, Ghada Mahmoud, Max Majoor, Ettore Majorana, Maria Marsella, Paolo Martella, Romano Meijer, Conor Mow-Lowry, Tommaso Napolitano, John Osborne, Antonio Pasqualetti, Antonio Perreca, Piero Rapagnani, Fulvio Ricci, Paolo Ruggi, Riccardo de Salvo, Valeria Sequino, Francesca Spada, Sebastian Steinlechner, Benoît Tuybens, Marco Vardaro, Wissam Wahbeh, Patrick Werneke

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Issue: 1
Date: June 27, 2025

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200 pages

Reduction in the excavation volume (and cost)

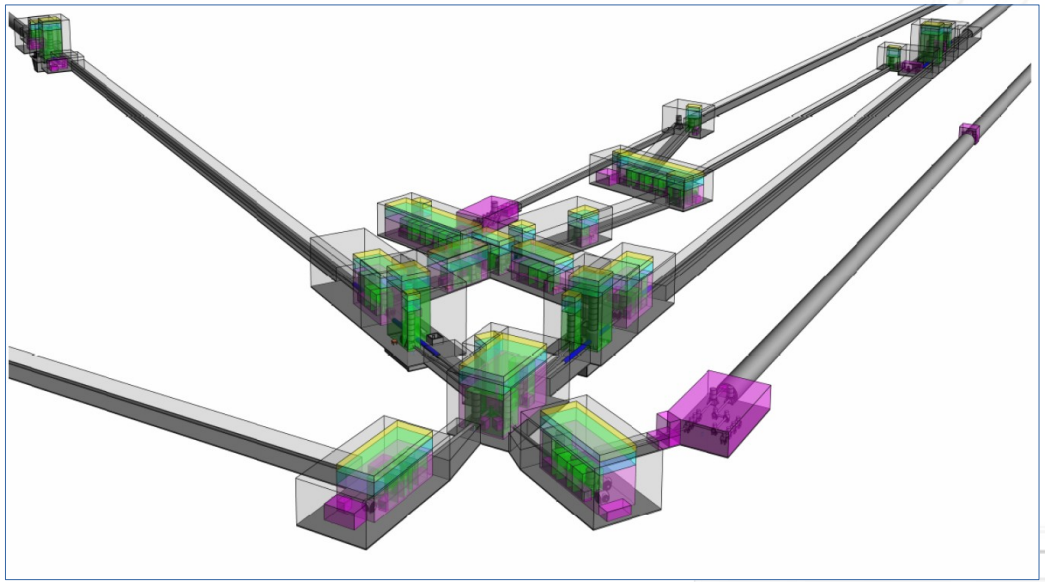
Example for the triangle:

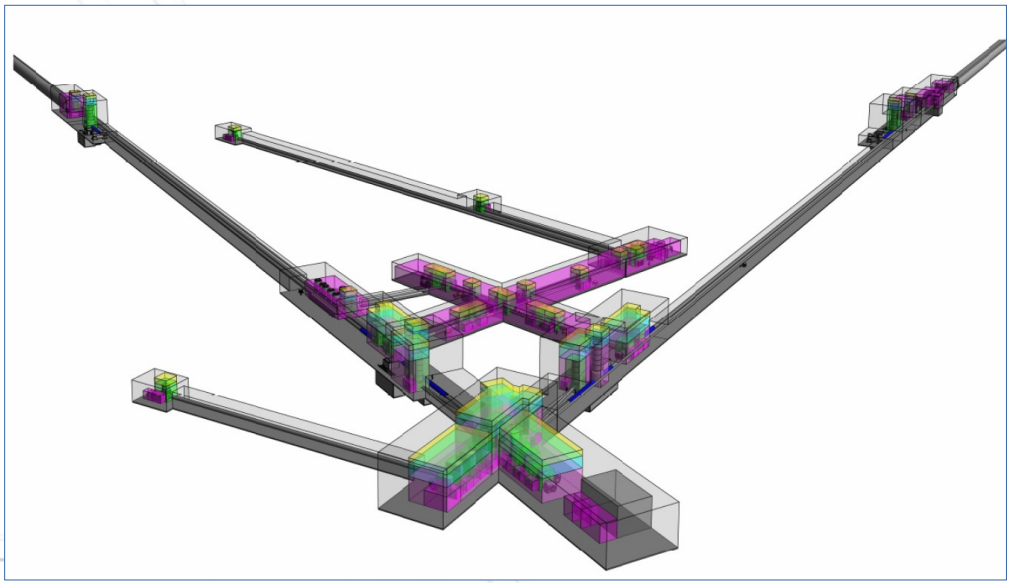
Triangle		Baseline		2024		Relative Difference		v.s. total
Est. Vol. (m3)	Total	2.794 mil. m^3	100.0%	3.723 mil. m^3	100.0%	-0.929 mil. m^3	-24.9%	
	Caverns	1.023 mil. m^3	36.6%	1.132 mil. m^3	30.4%	-0.110 mil. m^3	-9.7%	-2.9%
	Tunnels	0.250 mil. m^3	9.0%	0.668 mil. m^3	18.0%	-0.418 mil. m^3	-62.5%	-11.2%
	TBM Tun.	1.521 mil. m^3	54.4%	1.922 mil. m^3	51.6%	-0.401 mil. m^3	-20.9%	-10.8%
Est. Cost	Total		100%		100%		-29%	
	Caverns	m€ 716	37%	m€ 793	29%	m€ (77)	-10%	-3%
	Tunnels	m€ 175	9%	m€ 468	17%	m€ (293)	-63%	-11%
	TBM Tun.	m€ 1,060	54%	m€ 1,493	54%	m€ (432)	-29%	-16%

Table 8: Relative Differences - Triangle - Baseline vs Reference 2024 Layout

Cost is site dependent, it is just an estimation.
Same exercise has been done for the L shape (~ 40% cheaper)

3D rendering evolution for the triangle

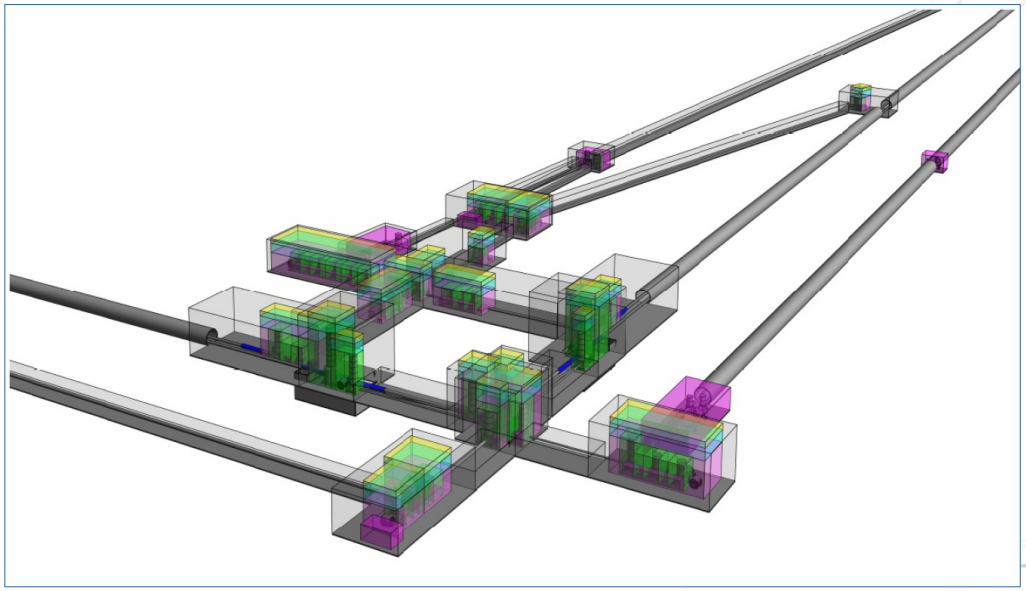


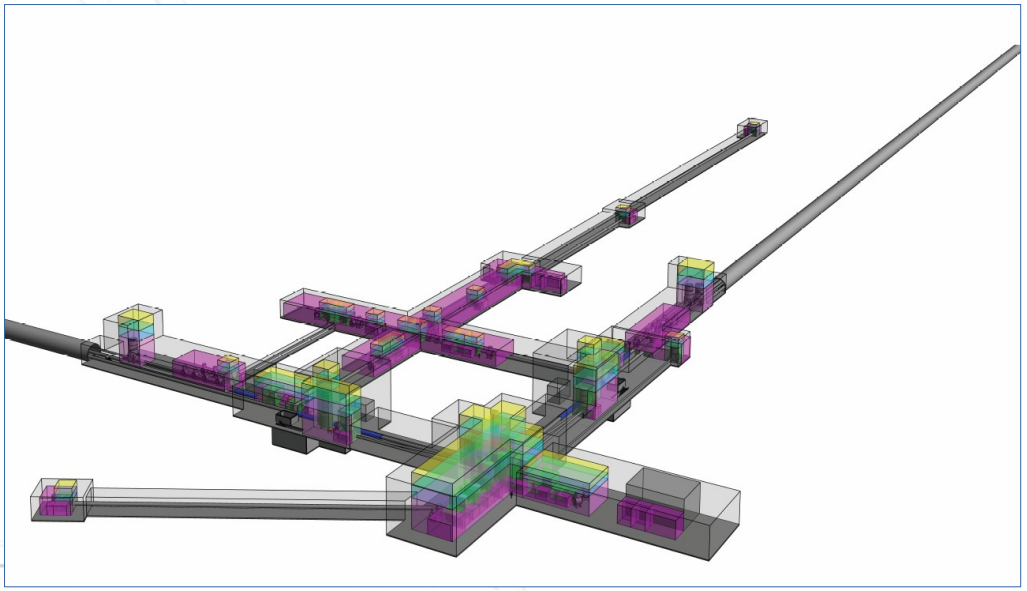


2024

2025

3D rendering evolution for the L shape



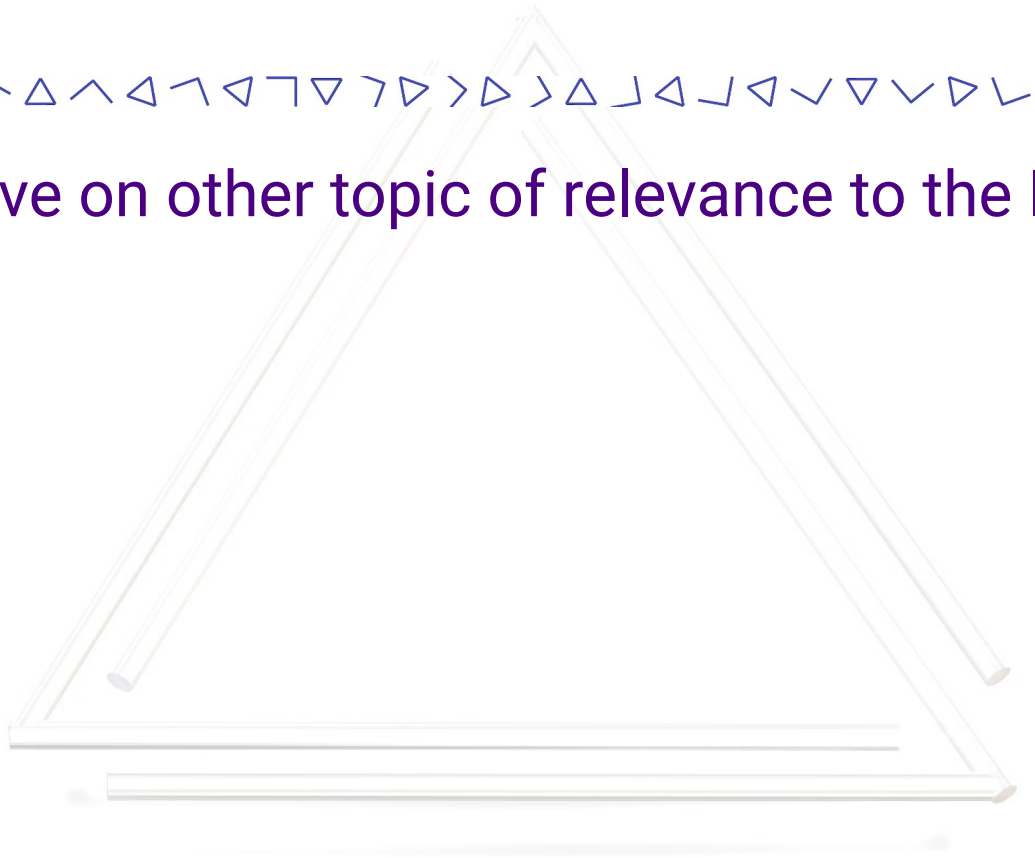


2024

2025

Questions ?

… before we move on other topic of relevance to the ISB.



The completion of the PBS v2

PBS = Product Breakdown Structure
must include all the items we need to build ET

1	Level	PBS code	Level 1	Level 2	Level 3	Level 4	Level 5	
2	1	1	Einstein Telescope					
3	2	1.1		HF instrument				
4	3	1.1.1			Suspensions			
5	4	1.1.1.1				Suspension chain		
17	4	1.1.1.2				Test-mass suspension		
21	4	1.1.1.3				Seismic isolation platform		
31	4	1.1.1.4				Payload for test masses		
49	4	1.1.1.5				Other large optics payloads		
56	4	1.1.1.6				Auxiliary suspensions		
72	4	1.1.1.7				Production and assembling Tools for the TM suspension		
80	4	1.1.1.8				Front end analog and digital electronics		
86	4	1.1.1.9				Cabling		
91	4	1.1.1.10				Modeling and Simulations		
109	3	1.1.2			Optics			
110	4	1.1.2.1				Core Optics		
141	4	1.1.2.2				Lasers		

The completion of the PBS v2

Example for the laser system:

1	Level	PBS code	Level 1	Level 2	Level 3	Level 4	Level 5	Level 6	Level 7
110	4	1.1.2.1				Core Optics			
141	4	1.1.2.2				Lasers			
142	5	1.1.2.2.1					ET-HF laser		
143	6	1.1.2.2.1.1						seed laser system	
144	7	1.1.2.2.1.1.1							NPRO laser head
145	7	1.1.2.2.1.1.2							NPRO controler
146	7	1.1.2.2.1.1.3							NPRO beam conditioning
147	7	1.1.2.2.1.1.4							NPRO modulation
148	6	1.1.2.2.1.2						low power amplifier	
149	7	1.1.2.2.1.2.1							low power laser amplifier
150	7	1.1.2.2.1.2.2							low power amplifier diode box (incl. pu
151	7	1.1.2.2.1.2.3							low power amplifier digital control unit
152	6	1.1.2.2.1.3						high power amplifier	
153	7	1.1.2.2.1.3.1							high power laser amplifier
154	7	1.1.2.2.1.3.2							MOPA interface box (incl. FI)
155	7	1.1.2.2.1.3.3							high power amplifier diode box (incl. pu

Each line is a set of parameters

Let’s look at one PBS parameter file

Timing distribution – Timing source				1.1.3.2.2.1		Clock that serves as the
FUNCTIONAL (or identifying) PARAMETERS						
Parameter	Value	Units	Design margin +\-	Type	Description	Reference (plot links, CD
Type of timing source				Specification		
Output signal	White Rabbit, or 10 MHz + 1 PPS			Estimated guess	general evolution of all the big experiments to using WR for the timing	
Space for GPS antenna	Somewhere at the surface				Needs unobstructed view of the sky to receive signals from multiple satellites without reflections.	
Phase noise		Hz/rtHz				

+ integration parameters

In total 23 000 parameters

What the PBS should become...

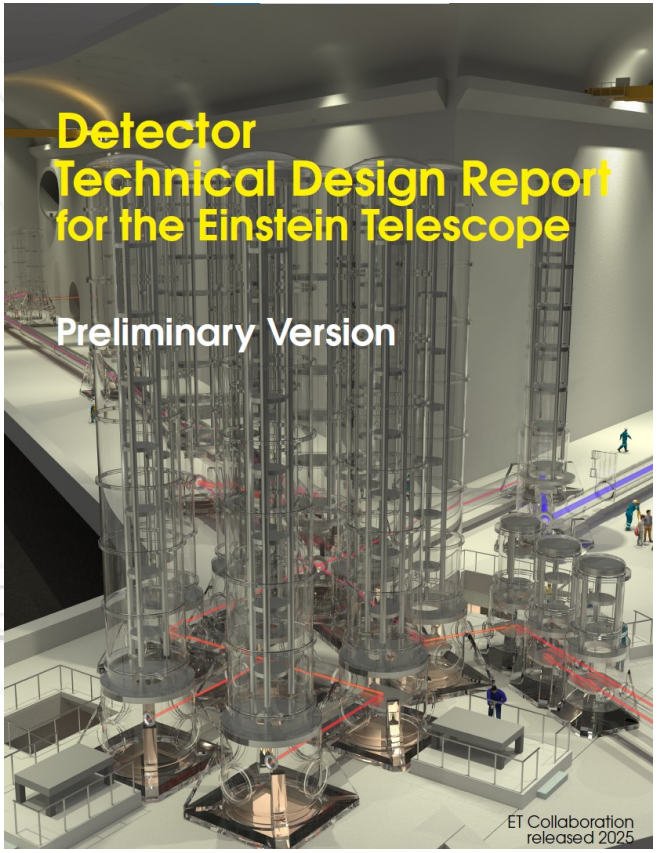
The backbone to build the detector!

Each item in the PBS could:

- be managed by one person (or a group)
- have a TRL associated
- have a cost associated
- with all the parameters linked to each other (in a bigger framework)
- be the single source of truth

It will also help to write down the preliminary TDR

- A follow up of the ET Design Report update 2020
- Half of written text, half of automatic extraction of the PBS
- Write down for Δ and L
- Must be completed beginning of 2026



Definition of a core program for the ET collaboration

ET Collaboration Members

This section provides information relating to the Members that constitute the ET Collaboration.

There are currently **1877** Members in the ET Collaboration, representing **271** Institutions in **31** different countries.

- 500 FTE in total, including 208 FTE for the ISB
- Are they all working to built ET ?

Definition of a core program for the ET collaboration

Role of the ET program

- The ET program should aim to support the achievement of different objectives:
  - Increasing the efficiency of the collaboration:
    - The categorization of the activities (and of the typology) of the ETC members is a first step toward a better knowledge of “who does what”
  - Optimization of the inclusion process of new RU:
    - Do we lack human resources in some activities? Do we have a complete panorama of the activities?
  - Support the ET editorial policy
    - We had difficulties in define an editorial policy in ET. Knowing “who-does-what” helps the definition of a policy
  - Formalization of the “contract” (CAD-Collaboration Agreement Document) between the RU and the ET collaboration
  - Realization of an ET R&D plan

ET-0416A-25

3

Definition of a core program for the ET collaboration

RATIONALE FOR WRITING THE PP: ITEM OPERATIVE STATUS (IOS)

I. The Science and Data Analysis — chapter

1. Science cases — Section

1.1 Fundamental Physics and Cosmology (x.X) — Item

...

Each chapter has the same structure

II. The Hardware Implementation

1 Interferometer

1.1 The interferometer layout

III. The Site

1 Seismic Characterization

1.1 Surface and underground seismic noise

The program is defined by describing the ITEM OPERATIVE STATUS (IOS) **Rather intuitive to write for chapter II and III**

Example for 1.1, The interferometer layout

II.1.1.A The basic layout

II.1.1.B Short-term R&D (solution expected by 5y) e.g. once fixed today the layout, what is the tolerance to accommodate the possible evolutions matured through specific R&Ds ?)

II.1.1.C Backup solutions (in case of B failure, this is meant to be studied since the beginning !)

II.1.1.D Medium and Long-term R&D (solution expected by > 5y) e.g. NONE

ET-0054A-25

Conclusion

- The optical design has converged, useful to design other systems
- So far we work in parallel for Δ and L
- Always looking for people to contribute
- In few years time, new chances to update the configuration