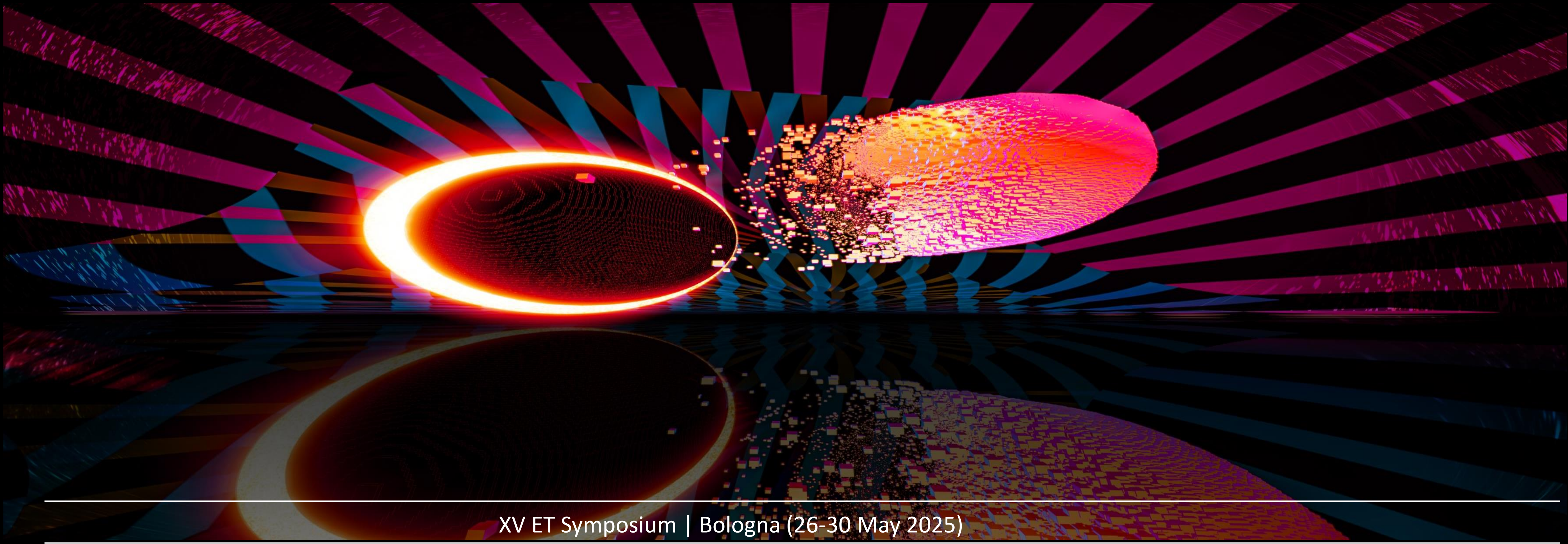

Risk management critical role: Risk assessment status and risk management evolution

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EINSTEIN TELESCOPE

Introduction:

This presentation focus on the following points:

- Why we perform Risk Management ?

- When were Risk Studies performed in ET by the ETO PO ?

  - The ETO PO Risk Campaign and examples of outcomes
    (note: detailed outcome examples cannot be shared at this time)

  - The ETO Task Force activities

- Additional tools used to support Risk Studies, such as Technology Readiness Level (TRL) assessments and Design Structure Matrix (DSM)

Why Risk Management ?

Risk management in the Einstein Telescope (ET) is not an “extra step,” but rather a fundamental engineering and governance backbone. It enables structured decision-making within the context of a complex, multi-partner scientific infrastructure project like ET.

Risks are typically assessed based on their potential impact on three critical areas of the project: **cost**, **schedule**, and **scope**.

These dimensions are also the foundational constraints of all aspects of project management like cost management and many others.

Objectives:

- Identify and manage **uncertainties** : Technical, organizational, scheduling, financial, and more.
- Provide a **risk response strategy** that defines how **risks impact cost, schedule, and scope.**
- Support the policy framework for enabling **technology development.**
- Guide **design trade-offs** and informed technology choices.
- Enhance **fundability, credibility, and project resilience.**

When were Risk Studies performed in ET by the ETO PO ?

Phase	Risk-Related Activity
2024 – 2025	- **ETO PO General Risk Campaign** **(starting June 2024)** : First General structured, collaborative risk campaign across **technical groups** (All ISB Subsystems : Interferometer Group , Optics Group, Suspension Group , Vacuum and cryogenics Group, ANM Group; and Engineering Department) - **It Delivers the First Full Risk Register for ET** - **TRL Assessments**
2025	- **Continuing with the ETO PO General Risk Campaign** : Review , other Stakeholders (ETO ; ETC ; OSB; SCB) - **ETO Taskforce :** • **TRL assessments** • **Comparative risk studies** between different Configurations of 2L and Triangle Geometries • Flexibility (**DSM**) and Penalty of change (**trade-off analysis between designs and cost impact evaluation**) studies
Now	• Cross-cutting risk integration (identifying, analyzing, and managing risks that affect multiple **subsystems, teams, or domains simultaneously**) • Starting integrating Risks into MBSE (Jama and 3DX)

Outcome of the ETO PO General Risk Campaign

- **~200 risks (mostly technical)** identified and assessed across major subsystems (Interferometer, Active Noise Mitigation (ANM), Vacuum & Cryogenics, Optics, Suspension, Engineering Department)

- Risk identification was **strongly collaborated with technical and scientific teams that participated** , ensuring ownership and technical accuracy. **The availability and participation of ALL the invited groups should be increased,**

- **Identification of other systemic risks :**

  - Highlighted **critical interdependencies** between subsystems (Risks caused by **unclear requirement ownership).**

  - Risks caused by **unclear performance specs**, **undefined interface roles**, and **incomplete design assumptions** .

- Moving from Assessing risks only to transforming **risk mitigations into real design enabler**.

Example on a Technical Risk from the ETO PO General Campaign causing a trade off

Risk Description:

A risk that the required specifications for the ET-LF test mass (TM) substrates may not be met.

ET-LF lack of substrate availability in suitable dimensions (actually 45 cm diameter) and with suitable optical properties.

Cause:

The test mass substrates must possess **both large dimensions** **and** **exceptional optical characteristics,** including **low optical absorption and low birefringence**.

At present, materials that meet these criteria (silicon and sapphire) are not available at the required size and quality.

Birefringence is a particularly significant challenge for sapphire.

Impact:

If the necessary substrates cannot be procured, the **ET-LF detector may not be constructed according to its current design.**

This would compromise its ability to meet scientific objectives, potentially requiring reductions in beam size and TM mass.

Suggested Mitigations :

- Continue parallel R&D efforts into both silicon and sapphire substrates.
- Conduct trade-off studies to assess the feasibility of tolerating higher optical absorption levels.
- Explore alternative optical layouts that are compatible with smaller mirror sizes.
- Investigate the viability of other materials designs.

Factor	Value
Severity	5 /5
Likelihood	5/5
Overall Risk	High

Impacts analysis - trade off : example on a cost variation scenario

Example :

If we suggest reducing the diameter of LF TM from 45 cm to 35 cm (to give more time for developing R&D) then the arm length will be maximum 10 KM → we can't construct a 2L configuration for ET with 15 KM armlength (we will be able to construct 10 KM 2L Configuration instead) and the triangle ET Configuration of 10 KM armlength won't be not affected.

Example on the cost change :

- **Cost Impact : Cost difference of possible 24,98 % reduction of the excavated volumes with respect to the 2025 2L Configuration (15 KM) one.**
- **The triangle cost remains unchanged.**

The trade off should take into account the impact of the length reduction on the scientific scope, also on the upgradability.

ETO TaskForce

The ETO Task Force revised the 2024 Einstein Telescope (ET) layout for both the Triangle and 2L configurations to balance cost and performance.

The updated baseline designs reduce civil infrastructure costs while maintaining scientific objectives and aiming for ensuring flexibility for future development.

A detailed ETO TaskForce study outlines:

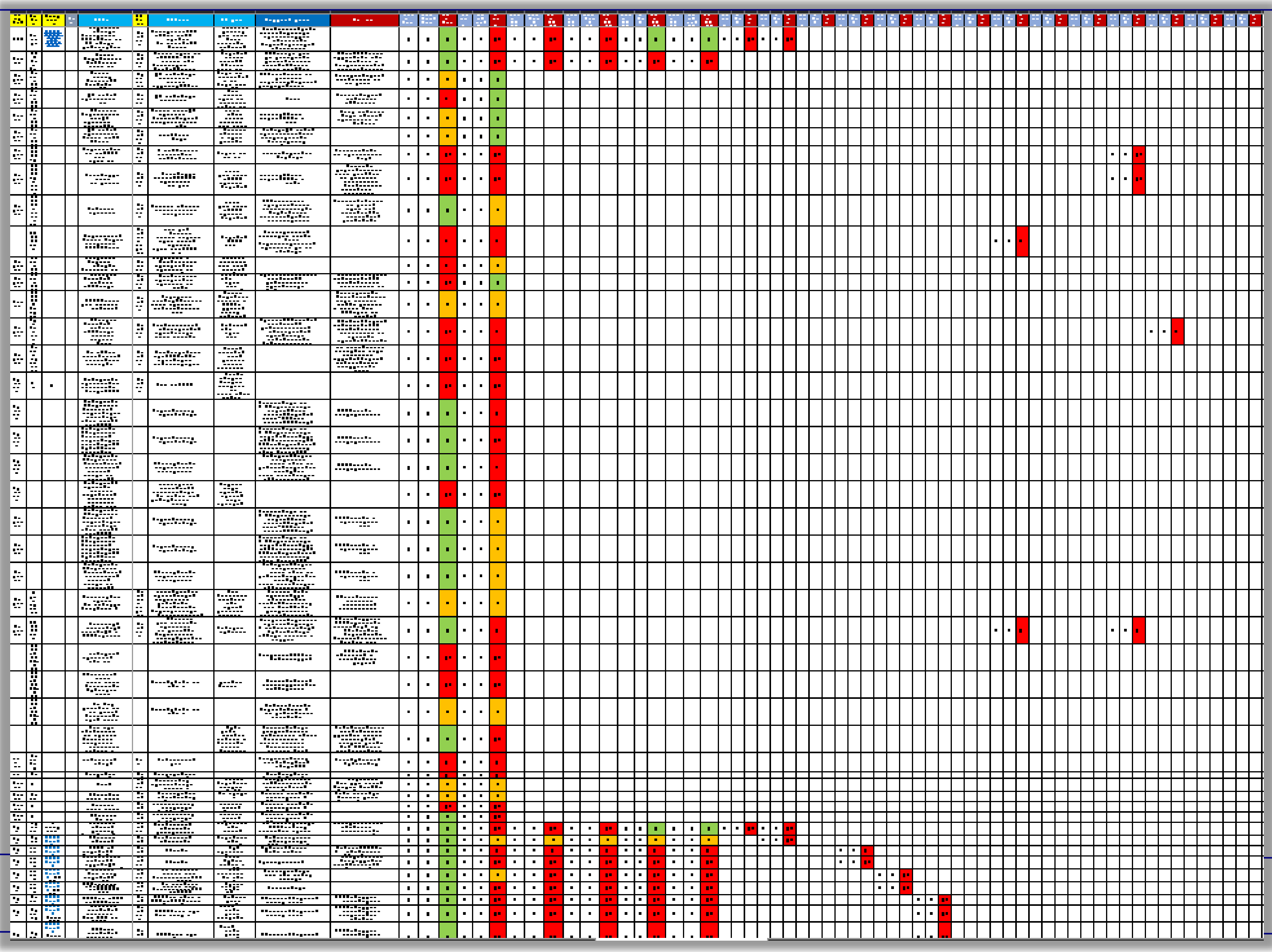
- **The design logic**
- **Alternative configurations**
- **Technical risk assessments**

ETO TaskForce

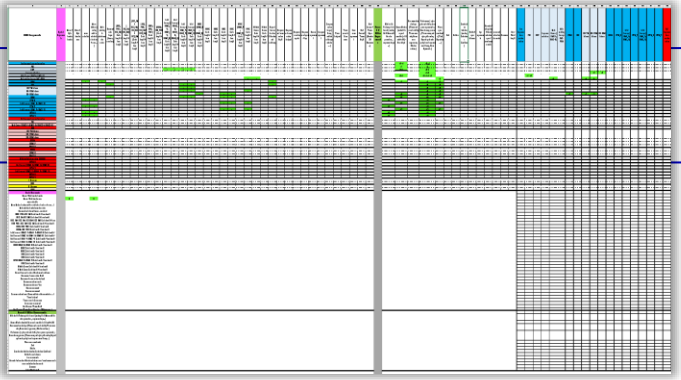
To support a comprehensive technical Risk evaluation, the following risk studies and tools were employed:

- A **Comparative Risk Study** between the 2024 Configuration and the 2025 Task Force Baseline Configuration for both geometries (2L 15 km and Triangle 10 km).
- A **Comparative Risk Study** for Alternative configurations and options for the 2025 Taskforce Baseline
- A **Technology Readiness Level (TRL) Assessment**, followed by a **Technological Risk Study**.
- A **Design Structure Matrix (DSM)** was initiated to analyze system rigidity and interdependencies.
- Several **trade-off scenarios** were analyzed, assessing their cost implications on the overall project.

Comparative Risk Study



What’s a DSM : ETO Taskforce



A **Design Structure Matrix** is a visual tool that maps the **dependencies and interactions** between elements of a complex system. It helps identify how different parts of a project (subsystems, components, requirements) **influence each other**, either directly or indirectly.

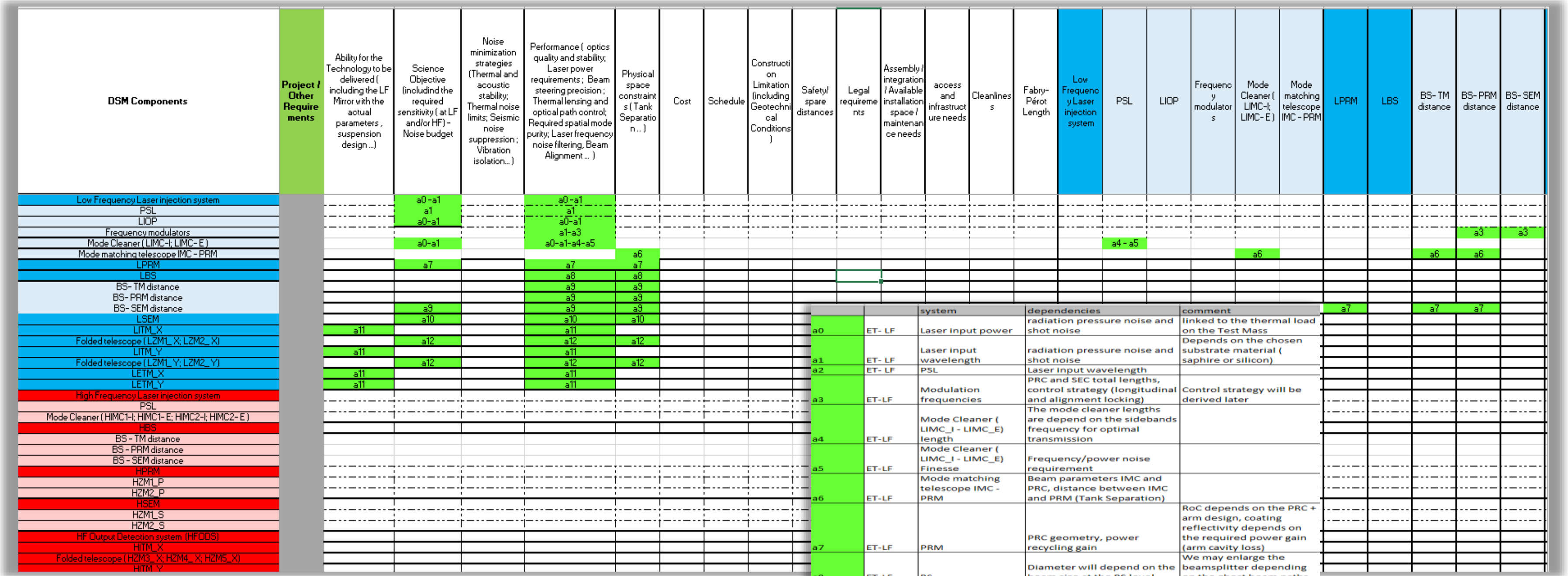
Purpose:

- Understand interdependencies
- Support smarter design and planning

Benefits:

- Identifies **rigid vs. flexible areas**
- Reveals **cross-system impacts**
- Helps **sequence design steps efficiently**

It’s a Very efficient tool, to be implemented.



		system	dependencies	comment
a0	ET- LF	Laser input power	radiation pressure noise and shot noise	linked to the thermal load on the Test Mass
a1	ET- LF	Laser input wavelength	radiation pressure noise and shot noise	Depends on the chosen substrate material (saphire or silicon)
a2	ET- LF	PSL	Laser input wavelength	
a3	ET-LF	Modulation frequencies	PRC and SEC total lengths, control strategy (longitudinal and alignment locking)	Control strategy will be derived later
a4	ET-LF	Mode Cleaner (LIMC_I - LIMC_E) length	The mode cleaner lengths are depend on the sidebands frequency for optimal transmission	
a5	ET-LF	Mode Cleaner (LIMC_I - LIMC_E) Finesse	Frequency/power noise requirement	
a6	ET-LF	Mode matching telescope IMC - PRM	Beam parameters IMC and PRC, distance between IMC and PRM (Tank Separation)	
a7	ET-LF	PRM	PRC geometry, power recycling gain	RoC depends on the PRC + arm design, coating reflectivity depends on the required power gain (arm cavity loss)
a8	ET-LF	BS	Diameter will depend on the beam size at the BS level	We may enlarge the beamsplitter depending on the ghost beam paths
a9	ET-LF	PRC, SEC distances	Lengths given the constraint to have the right beam size and gouy phase	Constraints given also by the tower separation, optical losses from astigmatism
a10	ET-LF	SEM	SEC geometry, reflectivity will impact the quantum noise curve	
a11	ET-LF	ITM / ETM	Cryogenic mirrors, must find the suitable substrates meeting the optical, thermal, mecahnical requirement	Not clear technological solution at that time (2025)
a12	ET-LF	PRC/SEC Telescope	Specifications on the beam size, Gouy phase, space constraint from infrastructure or noise	

TRL Study

- TRL already provides a **non-contextualized risk score** for technologies.
- However, when placed within the **ET project context**, a structured **risk-based analysis** of TRLs can offer critical insights.
- This approach helps identify **gaps, uncertainties, and dependencies** in technology development.
- It supports the creation of a **realistic and informed development plan**, aligned with ET's technical and scientific goals.

ID	Subsystem / Group	Technology Title	Technology Description	Configuration (Technology)	Global Detector Configuration / Layout	Date	Justification / Reference for Current TRL	Comments for the Actual TRL Level	Actual TRL (Q1 2025)	Expected TRL (for 2029)	R&D Status/ Level (Q1 2025)	Comments on R&D Status	Comments on expected TRL level	Comments (Please also mention your name beside your comment- Thank you)
	Seismic Isolation and Suspension systems	ET-LF Test-Mass Suspensions	Single cavern suspension system for ET-LF cryogenic test-mass.	Any 12m option. In consideration of the ISB-SUS division's analysis, we only consider 'short' suspensions of 12m height - the 17m single-cavern design is	Single Cavern	21/02/2025	https://www.overleaf.com/read/bgcyqgrtrdmc#03d933	Concepts are easy to sketch, using building blocks from existing technologies, but have minimal performance validation and detail.	TRL 2	TRL 3	High	Mutliple groups pursuing different concepts.	Technology is extremely complicated, large and expensive. Individual laboratories may only be expected to achieve ≤ TRL 4 without ET project assistance.	(Conor) Actual inertial performance validation will be impossible in short-baseline facilities. Rotational inertial noise may depend on the technical infrastructure. **The integration with cryogenic systems is identified as a potential showstopper for several reasons (heat transport, vibration,**
	Seismic Isolation and Suspension systems	ET-LF Test-Mass Suspensions	Multi-cavern suspension system for ET-LF cryogenic test-mass.	Any option	Multi-cavern	21/02/2025	Similar to KAGRA test-mass suspension, which exists in a large scale interferometer format, not yet operating under designed cryogenic conditions.	Concepts are easy to sketch, using building blocks from existing technologies, but lack any performance validation or necessary detail.	TRL 2	TRL 3	Low	R&D is part of core commissioning pathway for KAGRA. Fully operational KAGRA would achieve	Best case scenario is KAGRA demonstrates systems integration aspects, but they cannot test the vacuum/ice performance nor the residual motion.	(Conor) KAGRA can test some aspects of systems design and functional integration, but they cannot de-risk performance.
	Seismic Isolation and Suspensio	ET-LF CAT5 BB Suspensions	Bottom loaded benches and modular payloads for ET-LF PRM, SEM, BS and short arm Michelson folding mirrors.	Any option	Any	21/02/2025	Based on existing technologies, similar to supperattenuator + active platform	Concepts are plausible to sketch, using building blocks from existing technologies, but lack any performance validation or necessary detail.	TRL 2	TRL 4	Low	Design options being explored at Nikhef	Technology is large and expensive. Individual laboratories may only be expected to achieve ≤ TRL 4 without ET project assistance.	(Conor) We expect flow-down of design solutions from the test-mass suspensions to these Cat 5 suspensions. The biggest risk for these suspensions is improper requirements leading to infrastructure limitations.
	Seismic Isolation and Suspensio	ET-LF CAT 5 MO Suspensions	Multi-cavern, multiple optic (MO) suspension system for ET-LF LZM1 nodes.	Any option	Multi-cavern	21/02/2025	Based on existing technologies, similar to supperattenuator + active platform	Concepts are easy to sketch, using building blocks from existing technologies, but lack any performance validation or necessary detail.	TRL 2	TRL 4	Low	Design options being explored at Nikhef	Technology is large and expensive. Individual laboratories may only be expected to achieve ≤ TRL 4 without ET project assistance.	(Conor) We expect flow-down of design solutions from the test-mass suspensions to these Cat 5 suspensions. The biggest risk for these suspensions is improper requirements leading to infrastructure limitations.
	Seismic Isolation and Suspensio	ET-LF CAT4 TB Suspensions	Top loaded benches and modular payloads for ET-LF IMC, SQI and INJ nodes.	Any option	Any	21/02/2025	Based on existing technologies, similar to supperattenuator + active platform	Concepts are plausible to sketch, using building blocks from existing technologies, but lack any performance validation or necessary detail.	TRL 2	TRL 4	Low	None ongoing.	Technology is large and expensive. Individual laboratories may only be expected to achieve ≤ TRL 4 without ET project assistance.	(Conor) Requires input from IFO experts to determine residual motion requirements. Improper requirements are a significant risk.
	Squeezing	meter-size periscope	(suspended?) periscope able to shift the optical plane by about 2-2.5 m while maintaining tight stability requirments	Not applicable	LF: FC in tunnel, only if in different level HF: FC in tunnel, in any case	20/02/2025	cm scales periscope are implemented in Virgo/LIGO. 2 m scale periscope technology not yet defined	Signifi[illegible] size [illegible]erece wr[illegible]hat has been pro[illegible]far	TRL 1	TRL 2	Low	Occasional discussion		
	Squeezing	beam(-pipe) crossing	SQZ beam and vacuum pipe has to intersect with RC vacuum (between BS and ITM)	Not applicable	LF FC in tunnel @ ITF level	20/02/2025	Technology identifie[illegible]acuum cont[illegible]shou[illegible] studied	Not [illegible]mmon[illegible]ver) done. Cna have [illegible] of vacuum contaminatio, stray light...	TRL 2	TRL 2	Zero			
	Squeezing	Finesse tuning	Implement a cupled cavity to use the tuning of the first cavity to control the overall finesse	Variable finesse with 3-mirror cavity	3-mirror FC	20/02/2025	Sii[illegible]tion[illegible] progress, g[illegible]t subm[illegible] for founding R&D	Concept not sufficiently developed, even on paper	TRL 2	TRL 2.5 (if grant approved)	Low			
	Squeezing	Finesse tuning	Controlling the FC IM reflectivity by tuning ethalon effect with temperature	Variable finesse with ethalon	2-mirror FC	20/0[illegible]25	10.3390/galaxies8040080	Used in Virgo, but a design matching ET FC requirements has not been studied	TRL 3	TRL 3	Low			
	Squeezing	Finesse tuning	Change the cavity finesse by replancing cavity mirror(s)	Variable finesse with mirror replacement	2-mirror FC	[illegible]/2025	Idea plausinble should be defined a method with suspension/vacuum group to do it fastly	Can be done for sure, but concept of how to do it "conveinently" (low risk/fast operation) has not been studied	TRL 2	TRL 2	Zero			
	Squeezing	Stray light control in FC (beampipe size)	A sufficient baffling strategy (number and size) must be developed to enure stray light is	Not applicable		20/02/2025	https://arxiv.org/abs/2307.14104	More detailed stray-light studies are needed to confirm FC beampipe inner diameter (adaptation of work done for arm	TRL 2	TRL 2	Moderate			
	Cryogenics	Central helium cryoplant with transfer system	State-of-the-art technology in large-scale experimental physics, e.g. LHC	Underground coldbo[illegible] centra[illegible]ervice c[illegible]rn, providi[illegible]ooli[illegible]ower to a[illegible] consume[illegible] in a [illegible]	any		https://iopscience.iop.org/article/10.1088/1757-899X/1240/1/012095 ET-0605A-24	Necessity of seismic isolation of the colcbox vs. distance t.b. investigated	TRL 5	TRL 7	Moderate	Measurements at CERN and KEK	Modeling of coldbox isolation requirements	
	Cryogenics	Individual pulse tube cryocoolers	State-of-the-art technolog[illegible] implemented e.g. in KAGRA	[illegible] individ[illegible]al plant[illegible] to [illegible]onsu[illegible]wer dissipation [illegible]avern, v[illegible]onal noise (c[illegible]pressors in noisy rooms)	any		KAGRA paper...	Not scalable to ET requirements, in particular regarding cryopumps	TRL 5	TRL 7	High			We may not use this technology in ET
	Cryogenics	Sorption cooling with LN2	LN2 distribution system and 3-stage sorption cooling system with Ne, H2 and He	Only for payloads and cryostats, not for cryopumps	Any		ET-0605A-24 (+ET Pathfinder)		TRL 2	TRL 7	Moderate	Ongoing activity @NIKHEF	this will be for a prototype at smaller scale.	Scalability for ET-requirements not yet demonstrated

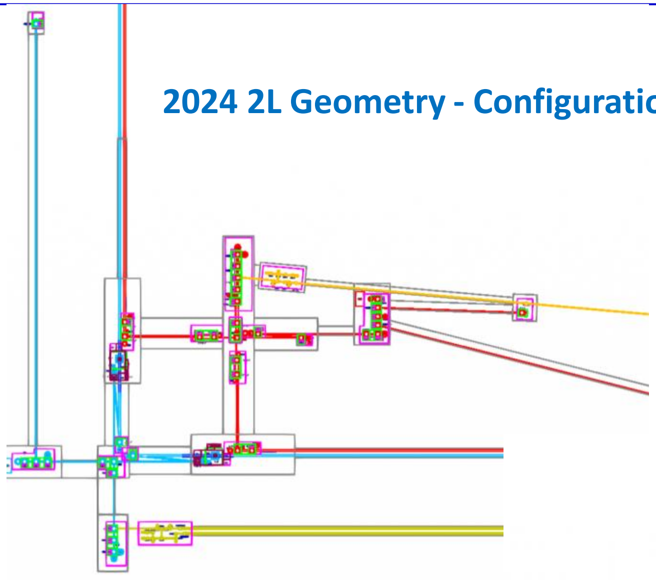
Work in Progress

TRL Level								
Identify the stage of development			Check for component testing		Look for prototype testing in real-world		Assess readiness for deployment	
1	2	3	4	5	6	7	8	9
Initial Research	Concept Development	Experimental Testing	Component Validation	Integrated Technology Testing	Prototype Demonstration in Relevant Setting	Operational Environment Testing	Final Product Testing	Real-World Deployment

What Changed : (2025 ETO TaskForce Configuration- 2L and Triangle)

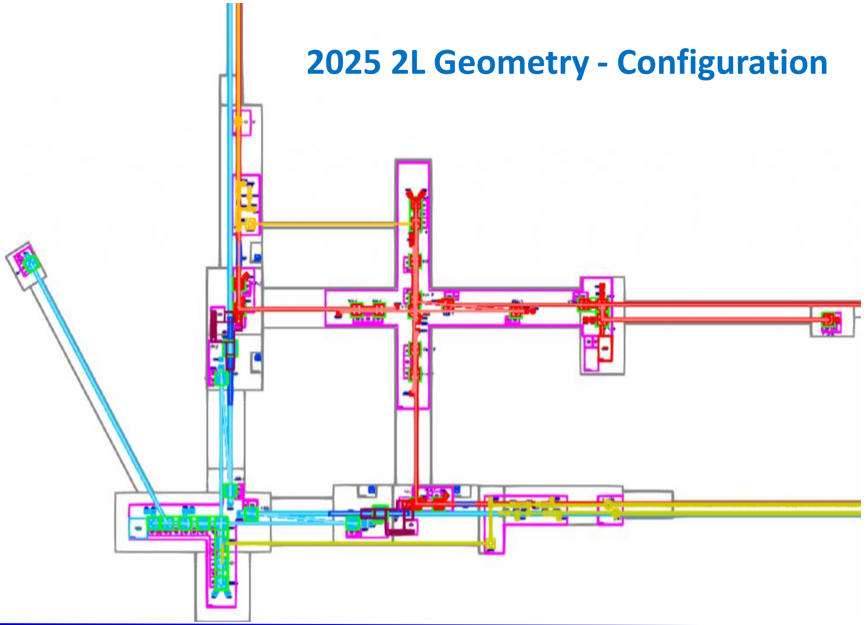
- LF Squeezing FCs in X arm with Periscope (2m heigh for 2L ; 4m for Triangle) routed through the LSEM Tower to the LSQI Tower

- HF Squeezing FC in Y arm with Periscope directly routed to the HSQI Tower
- 2- Mirror FC with reduced pipe diameter from 1m to 650 mm
- Reduced Length of LF IMC from 300 m to 120 m
- Merging HF IMCs in same tunnel
- Route BHD through BS in LF Ifo
- Other reshuffling in central area to adapt to the new changes
- Reduced LF TM susp heigh from 17 m to 13 m
  Reduced Tower height for other HFI Optics
- Reduced footprint of CAT1 Benches


2024 2L Geometry - Configuration

Alternative Options :

- Double Cavern
- No periscope for LF_FC
- Alternative routing for SQZ beam
- Bow-tie IMC
- Reduced tower heigh for HF TM
- Reduced Tower height for LFI Optics
- Reduced Cryostat size


2025 2L Geometry - Configuration

Risks and impact analysis in the TaskForce

Infrastructure-Based Mitigations

Pros: Often straightforward and effective.

Cons: Can involve **higher upfront costs**

No-Cost Mitigations with Trade-Offs

Pros: Lower cost.

Cons: could introduce **new technical risks or limitations**.

Systems Design Changes and R&D-Based Mitigations

Pros: Can lead to innovative, long-term solutions.

Cons: Typically require **additional time, cost, and resources**, and may introduce **schedule delays**.

LF Squeezing FCs in X arm with Periscope (2 m heigh for 2L ; 4 m heigh for Triangle) routed through the LSEM Tower to the LSQI Tower

Risk Description:

Risk of degraded squeezing,

Using a **tall (2 m or 4 m) periscope** in the ET-LF filter cavity introduces **phase noise** into the squeezed light. This **degrades the squeezing** injected into the interferometer, especially at low frequencies where ET-LF is most sensitive.

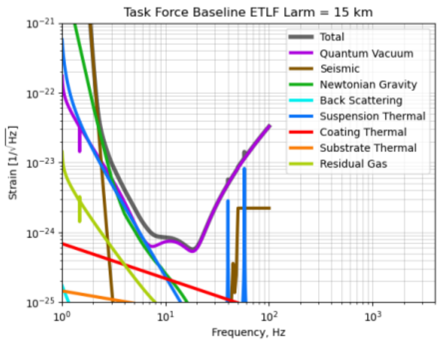
Cause:

The periscope can:

- **Vibrate or flex**, leading to **mechanical instability** → **should** cause **mirror misalignment**

→ Introduce **phase fluctuations** in the squeezed beam path

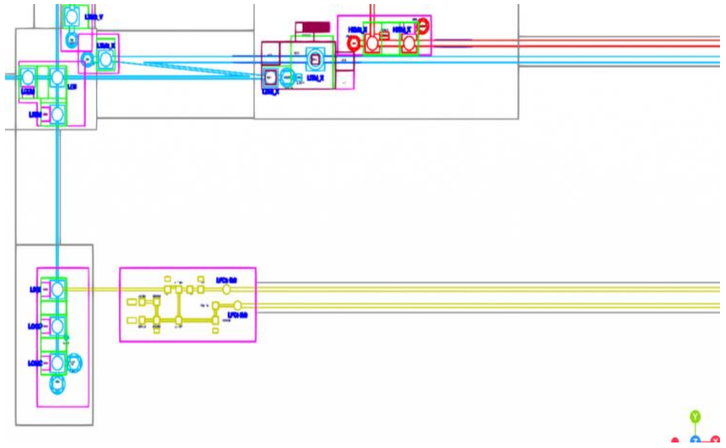
These effects result in **decoherence** or **loss of squeezing**.



Impact:

- Reduced squeezing means **higher quantum noise** → **lower sensitivity** of ET-LF.
- This is **more severe at low frequencies** (<30 Hz), which are critical for detecting **massive black hole mergers.**

2024 2L Configuration



Suggested Mitigation

1. Remove the Periscope

The best mitigation is **architectural**: Place the **ET-LF interferometer and its squeezing/filter cavity on the same horizontal plane**

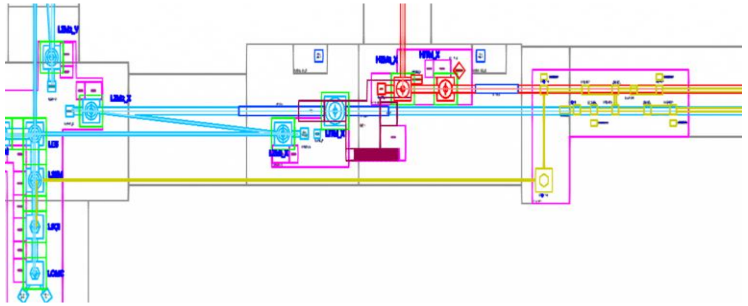
(Less Risky – Trade off scenarios (from less costly to more costly))

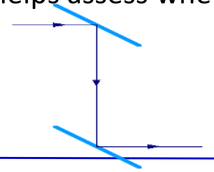
2. Prototype Testing (Mechanical stability, Impact on squeezing) **(More Risky – Delay - Cost)**

Before ruling out periscopes entirely : **Implement a periscope** in an existing gravitational-wave detector .

This helps assess whether periscopes could be made stable enough with special materials or isolation systems.

2025 ETO TaskForce 2L Configuration





Factor	Value 2L	Value Triangle
Severity	5/5	5/5
Likelihood	3/5	4/5
Overall Risk	High	High
Applies to	ET-LF mainly	ET-LF mainly
Less impact on	ET-HF	ET-HF

Example – trade off. Cost vs risk minimization

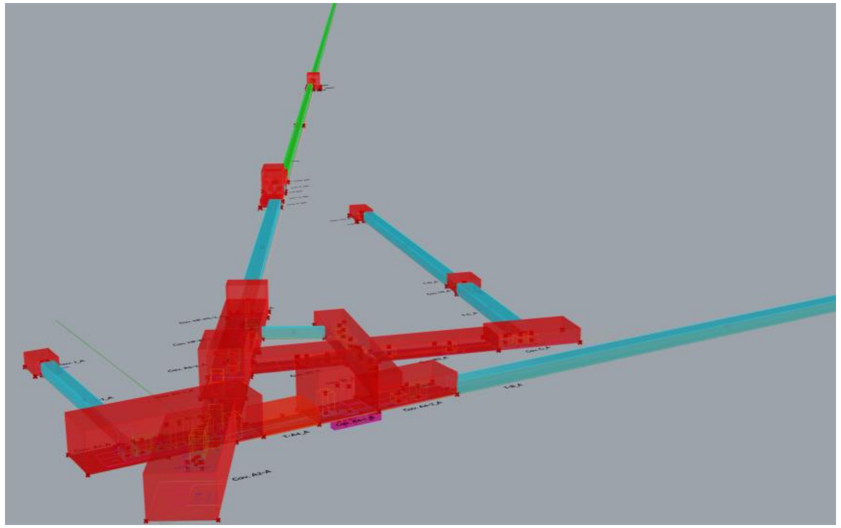
2025 Triangle configuration but considering the 2024 configuration for the LF Filter Cavity (No periscope for LF FC - no change in HF FC)

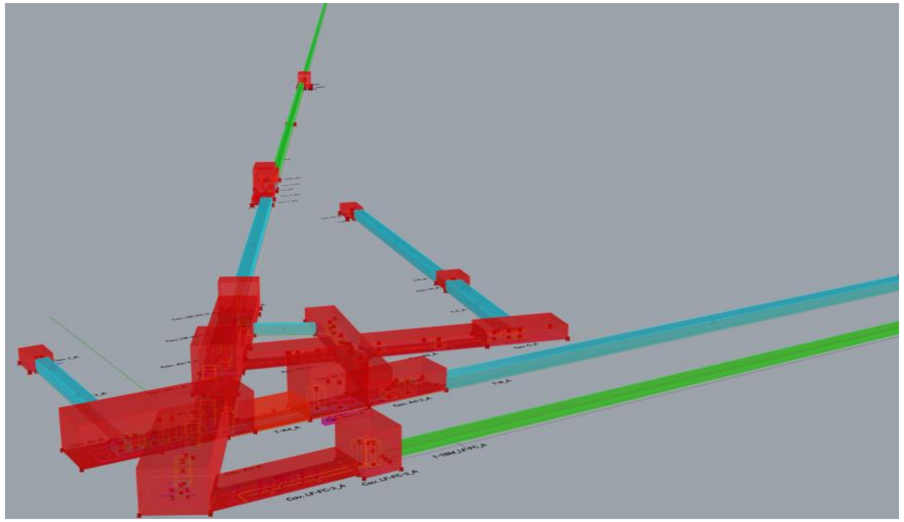
Cost Impact : Cost difference of possible +16, 24 % increase of the excavated volumes with respect to the 2025 Triangle Configuration one.

2025 2L configuration but considering the 2024 configuration for the LF Filter Cavity (No periscope for LF FC - no change in HF FC)

Cost Impact : Cost difference of possible +14, 01 % increase of the excavated volumes with respect to the 2025 2L Configuration one.

Trade off should be analysed between a cost increase and the risk minimization for the performances of the squeezing cavity





Alternative design options : No Periscope for LF_ FC , the LF_FC is in the main tunnel and is directly routed from the Beam Splitter

Factor	Value 2L and Triangle
Severity	2/5
Likelihood	5/5
Overall Risk	High

Impact or Risk Description:

Increase the astigmatism in the y arm recycling arm. Risk not to find a suitable configuration in the design.

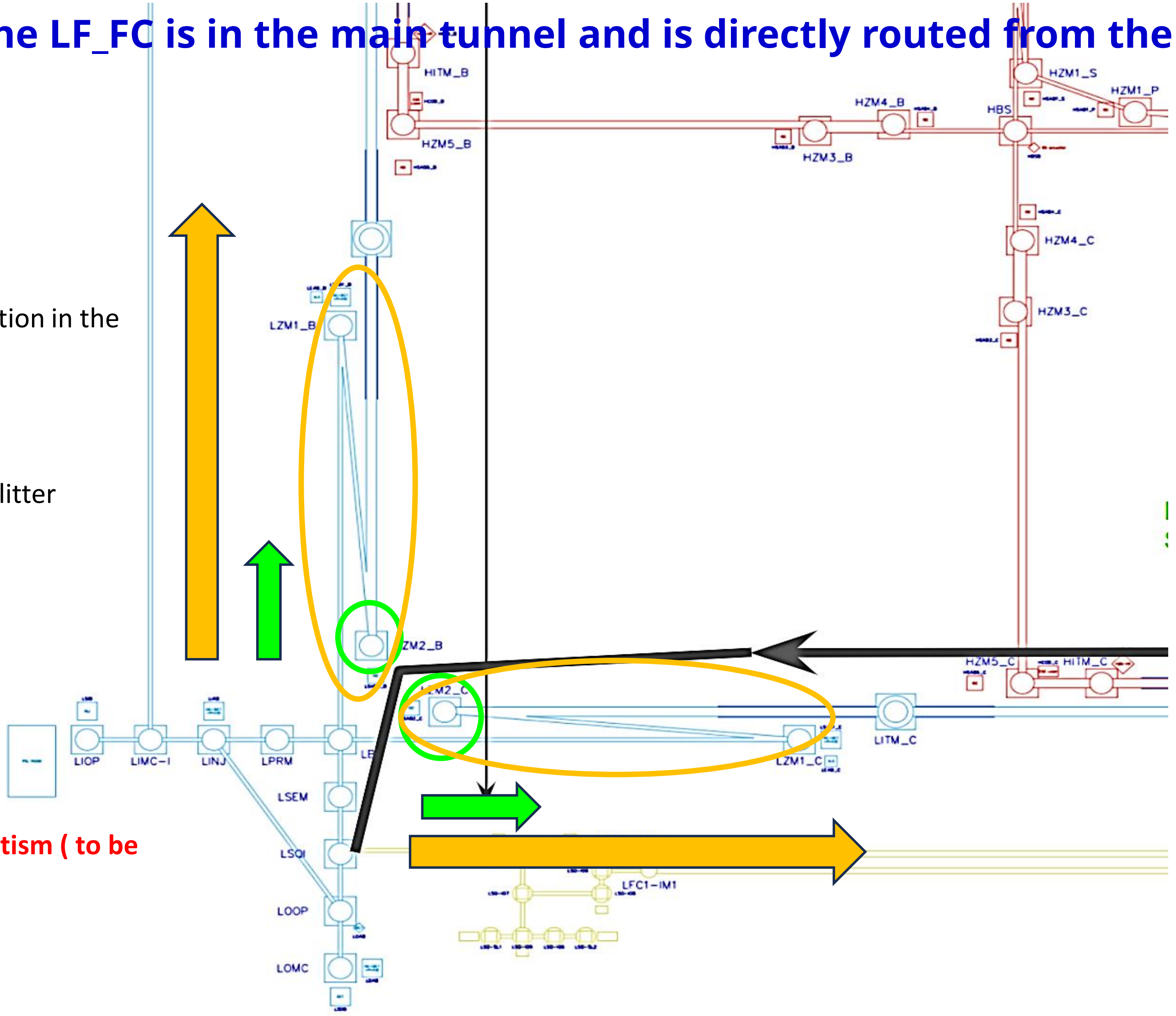
Cause:

Movement of the mirror LZM2_Y to allow passage of SQI ⇄ SQZ beam through Beam Splitter

Suggested Mitigation

Optimizing the optical design of the telescope - use of freeform optics

Two scenarios for not considering the periscope in LF : one introduce a risk of astigmatism (to be mitigated) and one does not increase the astigmatism (but increase the cost)



Reduced Length of LF Input Mode Cleaner from 300 m to 120 m

Impact or Risk Description:
If the IMC is **too short (120 m instead of 300 m)**, it may **not effectively filter out high-frequency and high-amplitude noise** in the laser beam.
This noise then enters the main interferometer and **compromises the sensitivity** of the detector.
Risk of not be able to implement the design mitigation strategies to maintain the cleaner performance.

Cause:
A shorter IMC:
•Has less **optical path** to average out fluctuations
•Cannot suppress high-frequency noise as well
•Is less effective at stabilizing the beam's **phase, amplitude, and geometry**

Impact:
•**Frequency noise** from the laser isn't fully removed
•**Amplitude noise** remains, adding false signals
•These noise sources enter the **main interferometer**

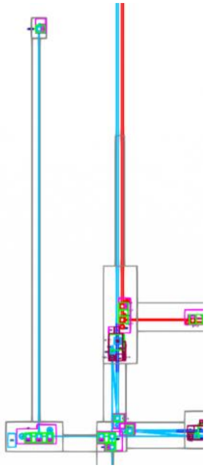
Suggested Mitigation
Use a High-Finesse IMC

This comes at a cost:
•More complex control systems are needed
•**Thermal and optical losses** are more sensitive
•The system becomes **harder to stabilize and maintain**

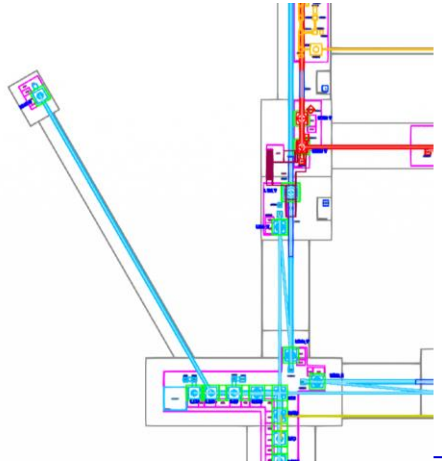
So, while it reduces the risk, it introduces new technical challenges. (Delay)

Factor	Value 2L and Traingle
Severity	5/5
Likelihood	2/5 – 3/ 5 cost of the trade off
Overall Risk	High
Applies to	ET-LF mainly

2024 2L Configuration



2025 ETO TaskForce 2L Configuration



Example - trade off : cost vs detector performance

2025 Configuration Triangle + 300 m LF Input Mode Cleaner instead of 120m

Cost Impact : Cost difference of possible +1, 31 % increase of the excavated volumes with respect to the 2025 Triangle Configuration one.

2025 Configuration 2L + 300 m LF Input Mode Cleaner instead of 120 m

Cost Impact : Cost difference of possible +0, 81 % increase of the excavated volumes with respect to the 2025 2L Configuration one

Trade off to be analysed between the cost increase and the IMC performance (to be evaluated)

Reduced LF TM susp heigh from 17 m to 13 m

Risk Description:
Risk of not find a suitable design fulfilling the LF TM suspension requirements, due to the cavern height available (13m tall LF TM suspension)

Cause:
The actual performance of the suspension is not compliant with the design one (i.e.: not enough pendulum length to observe from 1 Hz to 3 - 4 Hz)

Impact:
Underperforming detector; Reduced scientific reach in the critical 1–10 Hz band

Suggested Mitigation
Keep an adequate safety margin (can be going to 5m) on the caverns height / Update the design adding some active seismic filtering (platform)

Factor	Value
Severity	5/5
Likelihood	2/5 (the likelihood depends on both the science objective (LF) and the decision on the heigh of the cavern) the likelihood may increase to 3 or 4
Overall Risk	High
Applies to	ET-LF mainly / TM

Trade off : cost vs risk mitigation

2025 Configuration Triangle + 12 Caverns are affected : LF TM Cavern : 5m safety margin (+ 3 m)

Cost Impact : Cost difference of possible +0,78 % increase of the excavated volumes with respect to the 2025 Triangle Configuration one

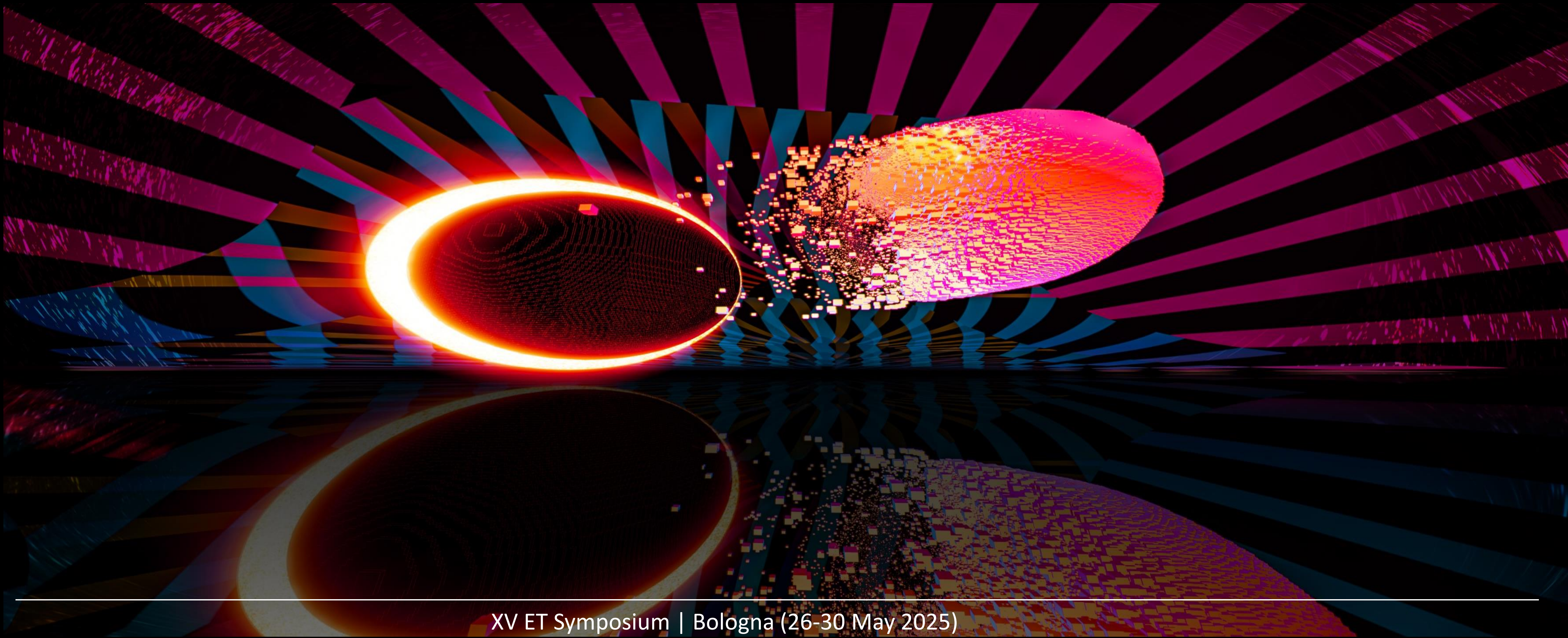
2025 Configuration 2L + 8 Caverns are affected : LF TM Cavern : 5m safety margin (+ 3 m)

Cost Impact : Cost difference of possible +0, 42 % increase of the excavated volumes with respect to the 2025 Triangle Configuration one

Trade off between cost increase and minimization of the risk associated to the suspensions system technical design

Outlook

- **The ETO PO Risk Campaign will be continued, involving different identified and selected stakeholders**
- **DSM and TRL analysis will be expanded out of the TaskForce context**
- **For professional risk management and risk traceability the risk data will be inserted in JAMA and 3DX in collaboration with Aachen University**



EINSTEIN
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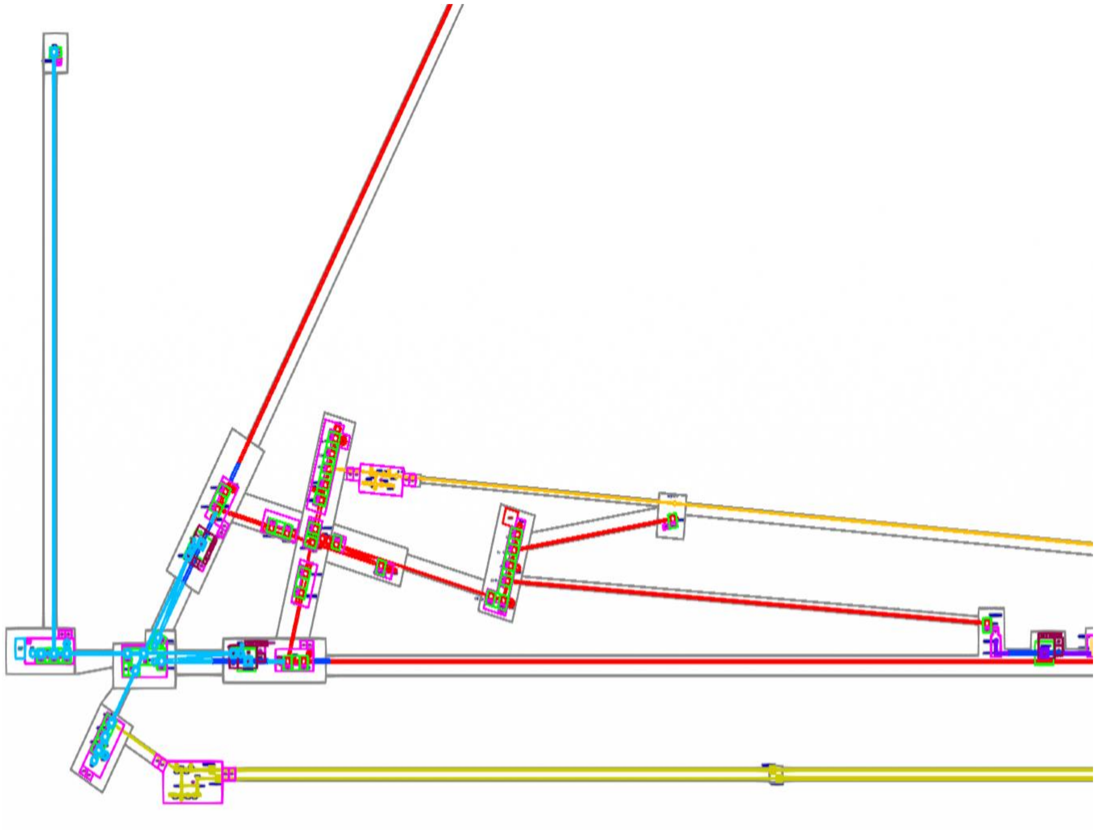
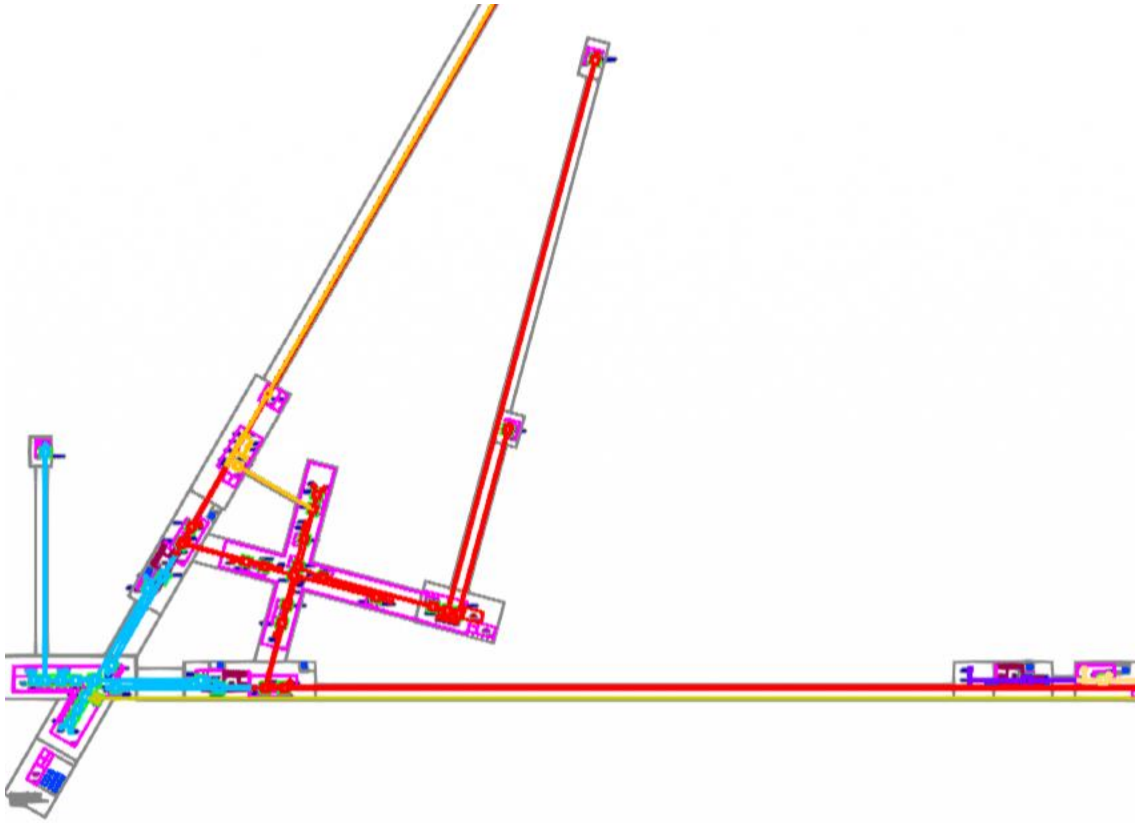
Thank you !

2024 Triangle Geometry - Configuration



2025 Triangle Geometry - Configuration



Reduced footprint of CAT1 Benches

Risk Description:
The optical Layout (Flexibility of choice) is limited by the super-attenuators capacities / Design no mature

Cause:
Unable to locate sub-modular suspended optics within a single interferometer node.

Impact:

Reduced flexibility for optical layout.

Suggested Mitigation
Significant R&D needed to understand IF it is possible to colocate sub-modularly suspended optics within a single node / May need to Redesign suspension or split the optics into two groups with the seperate vacuum

Factor	Value
Severity	**4/5**
Likelihood	**5/5 (Likelihood depends on the results of the R&D needed to verify if we can colocate more optics on the suspended benches)**
Overall Risk	**High**

Alternative options analysis : Bow-Tie IMC

Risk Description (design not mature):

Use of bow-tie cavity induced shorter tunnel length / No demonstration of long bow-tie cavity for IMC

Cause:

4 mirrors cavities allows more compact IMC / All current interferometers use linear 3 mirrors cavities for IMC

Impact:

Limitation of the upgradibility if tunnel too short. Not possible to go back to linear 2 cavities. / Degradation of the input beam quality, low transmission due to higher losses

Suggested Mitigation

Optical simulations of the performances

Factor	Value
Severity	**4/5 – 5/5**
Likelihood	**4/5 – 3/5**
Overall Risk	**High**

Alternative options analysis : Reduced Cryostat size

Risk (design not mature) :
Risk of Not having enough space for the attenuation system within the integrated tower - Reducing the cryostat size reduce the performance of the cryogenic

Cause:
Reducing the cryostat size limits thermal shielding, increases heat load density, restricts cryocooler capacity, and reduces space for vibration isolation and suspension systems

Impact:

This leads to higher thermal noise, reduced cooling efficiency, increased mechanical vibrations, and overall degradation of detector sensitivity

Suggested Mitigation
Redesign and Prototype of the cryostat (and maybe the integrated tower) - Reducing size is possible if the design / prototyping / testing are took into consideration , it requires an adapted design to increase the performance (R&D)

Factor	Value
Severity	**4/5**
Likelihood	**5/5**
Overall Risk	**High**

Alternative options analysis : Double Cavern (TM LF)

Issue:
Increase in cost

Cause:
the construction of double cavern / and the access to the top cavern is technically more complex and increase the cost because it needs additional volume to be excavated

Comment
Double cavern or compact cryostat is the solution for Mechanical Interference between inverted pendulum and cryostat Affecting the sensitivity due to vibrational noise especially in the low frequency

Factor	Value
Severity	**3/5**
Likelihood	**4/5**
Overall Risk	**High**