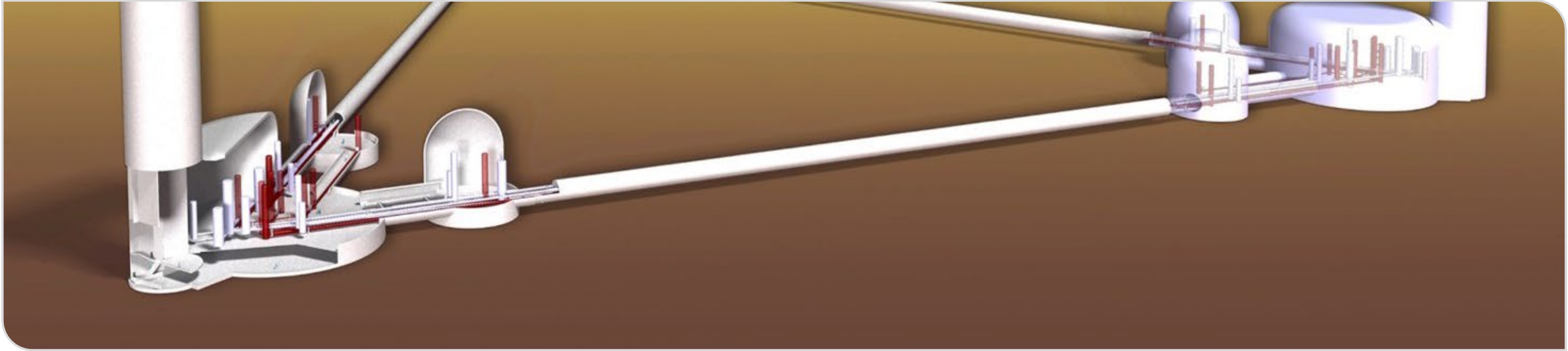
Einstein Telescope - Challenges of vacuum

Christian Day / Stefan Hanke



Current ET interferometer design

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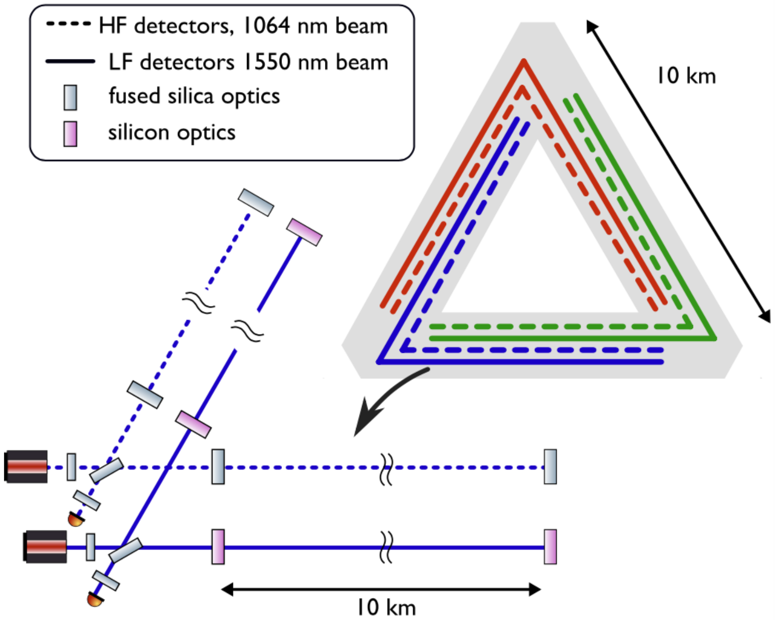
- Design is based on a Michelson interferometer with Fabry-Perot cavities in the arms and recycling

- HF interferometers
  - Fused silica optics at room temperture
- LF interferometers
  - Silicon (or sapphire) optics at cryogenic temperature for input and end mirrors



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Artistic view of ET

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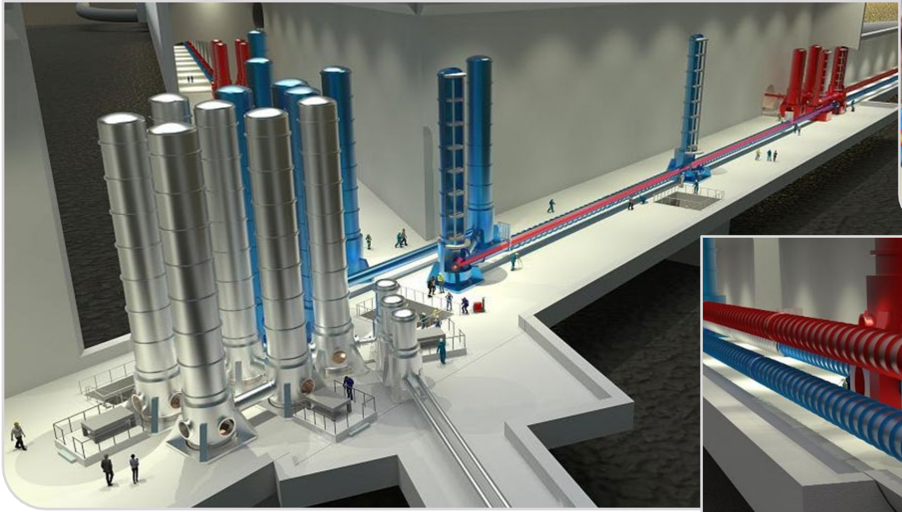
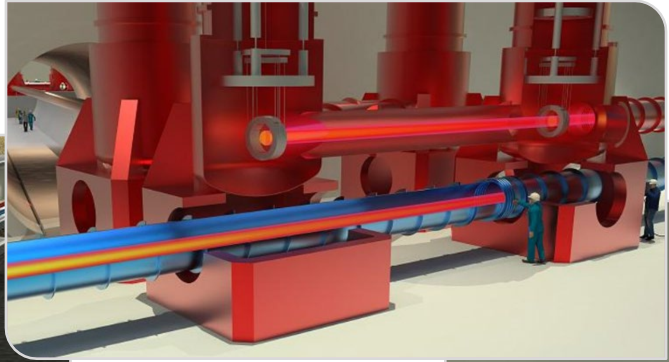
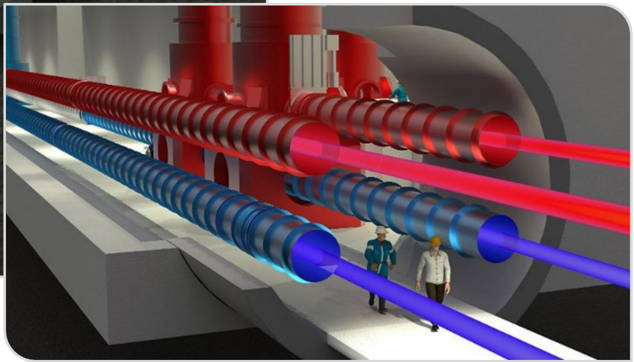
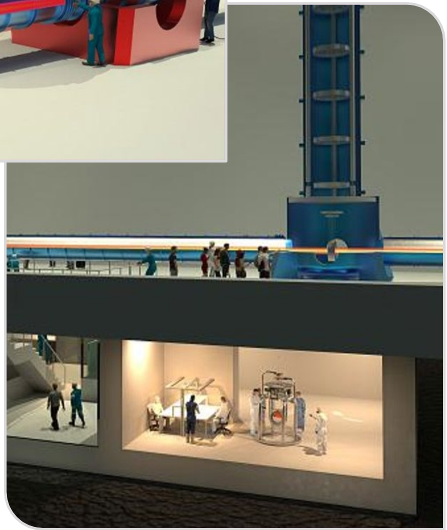
Beam pipe arms in 10 km long tunnels
and suspension towers for optics



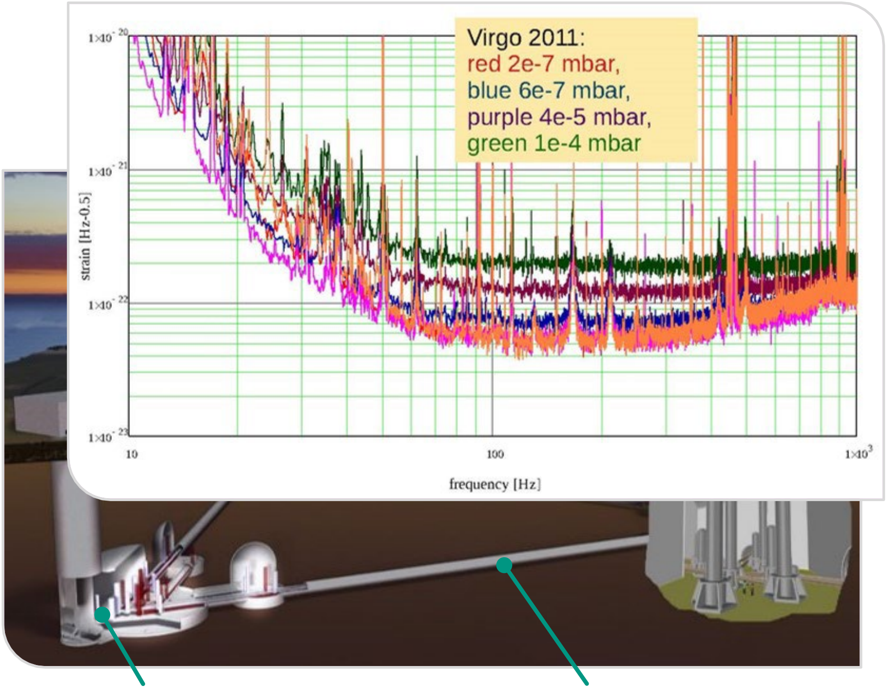






https://www.nikhef.nl/pub/departments/mt/projects/EinsteinTelescoop/Artistic/2020/

Noise reduction - Improving vacuum



Reduction of seismic background 200-300 m underground

Amplification of the measurement signal 10 km long arms

- The **sensitivity** of the measurement **depends on the residual gas pressure**
  - Particles disturb the signal in the interferometer (fluctuations of the refractive index ≠ 1),
  - transfer unwanted momentum to the mirrors,
  - adsorb on the mirror
- From **Virgo**: A factor of 2 improvement is achieved per decade of total pressure

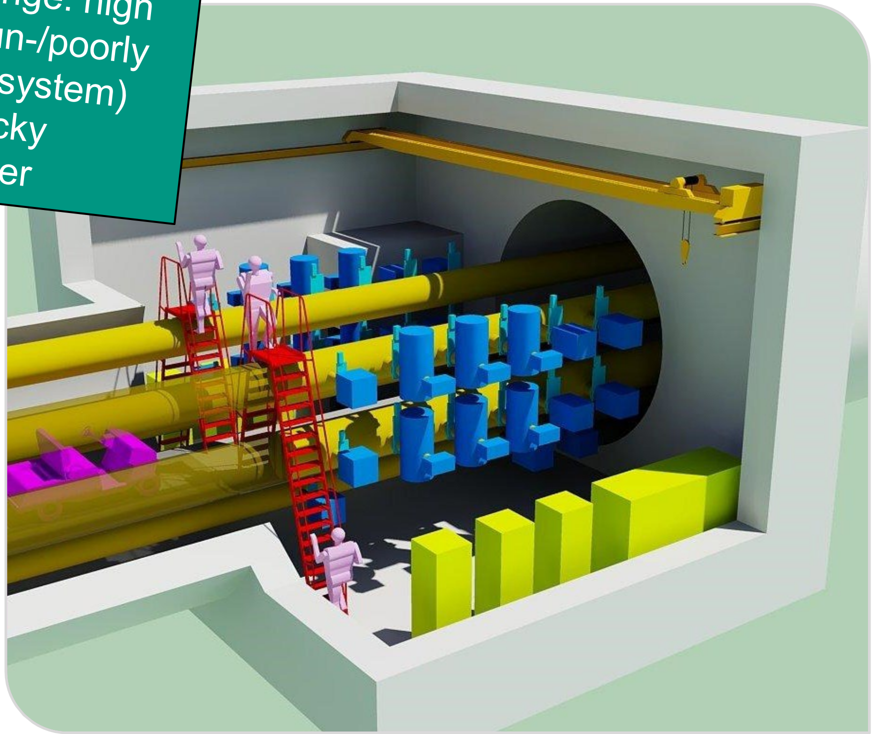
→ **Ultra high vacuum requirements**

- **Cooling of the mirrors** for the low frequency measurement with superfluid helium (new concept KIT)

Vacuum requirements (to be confirmed)

- Beam pipe vacuum
  - **Total residual pressure ~ 10^{-10} mbar**
  - Partial pressure of hydrocarbons (> 100 amu) ~ 10^{-14} mbar
  - Partial pressure of water ~ 10^{-12} mbar
  - Filter cavities total pressure ~ 10^{-7} mbar
- Separation between towers (HV) and arms (UHV) by differential pumping or cryotraps

Challenge: high load (un-/poorly baked system) and sticky character



Vacuum System of ET – Starting considerations

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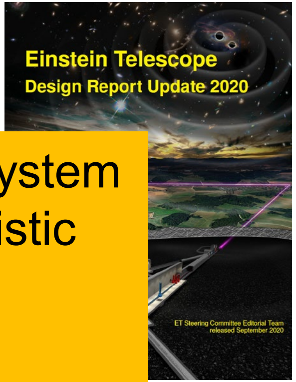
- Pipe vacuum system
  - 5000 l/s pumping groups every 500 m: 3x 2500 l/s Ti sublimation pump coupled to 300 l/s ion pump (alternative: NEG pumps)
- Initial evacuation and bakeout
  - 2x 2000 l/s turbo pumps with scroll fore pumps
- Cryotraps near towers
  - HF 20 m away from towers, LF 50 m cryotrap
- Towers vacuum system
  - Size 3 m diameter, 10 (HF) to 20 (LF) m height, with 2-3 v
  - Pumping by turbo and scroll pumps or large cryopumps
- Vacuum instrumentation
  - Vacuum gauges at pumping groups + 3x RGA at every 10 km pipe
- Separation of pipe sections
  - UHV gate valves 100x diameter 0.5-1 m



→ This lacks a system integrated holistic view

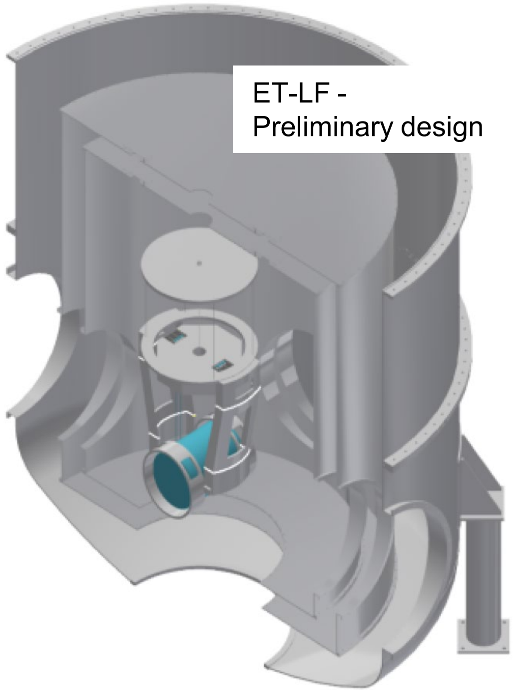
→ Probably not consistent to fulfill requirements

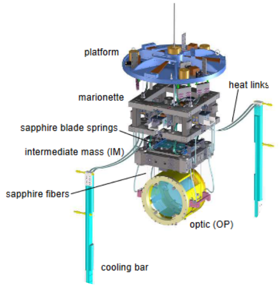
Special considerations at cryogenic mirror (LF)

- Residual gas such as water critical regarding **frost on cryogenic mirrors**
- Design of cryostat and outgassing of materials from room temperature parts needs R&D

→ The maximum outgassing rates of tower and pipe arms should be low, especially for water and hydrocarbons

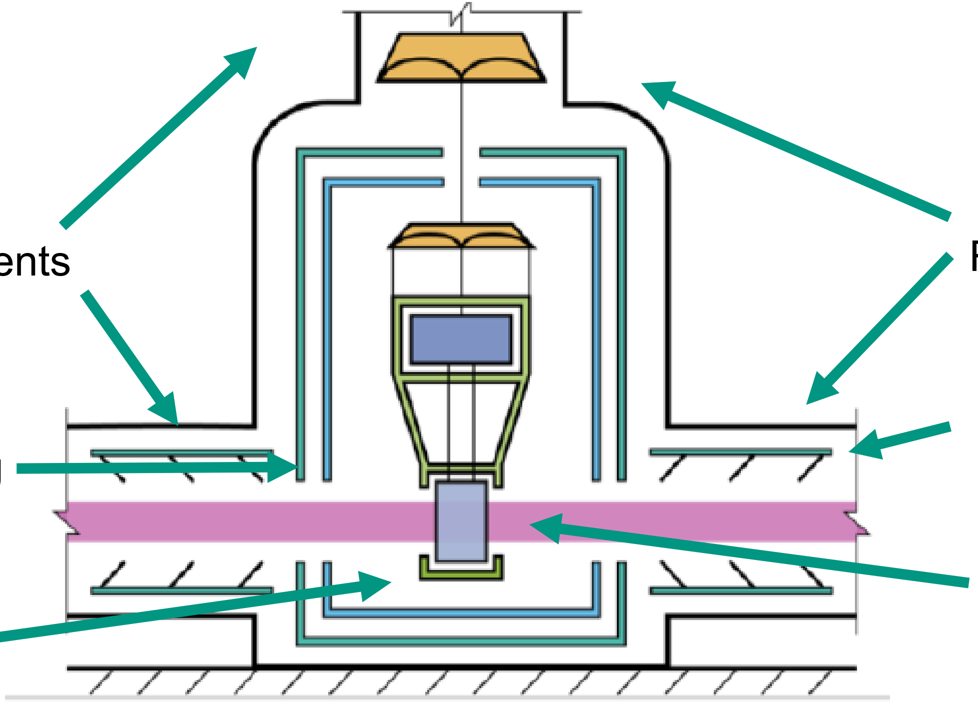
→ Passive and active frost mitigation strategies need to be developed





Example KAGRA

Sensitivity study



Pumping requirements

Design of shielding

Resulting local pressures

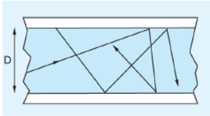
Reduction of outgassing

Design of cryopumps

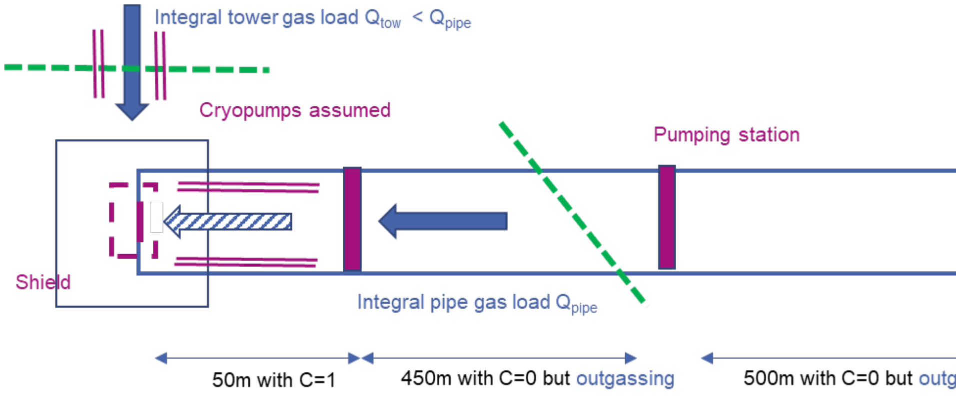
Frost formation and recovery

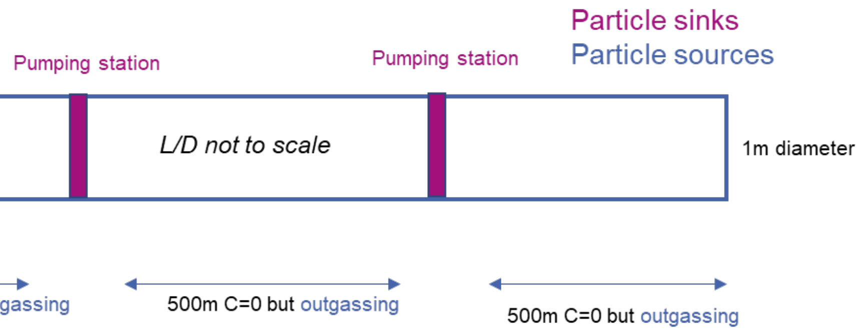
Simple model for studying sensitivities

With parametric scans around an initial guess for the parameters



Kn high → Collision-free particle movement





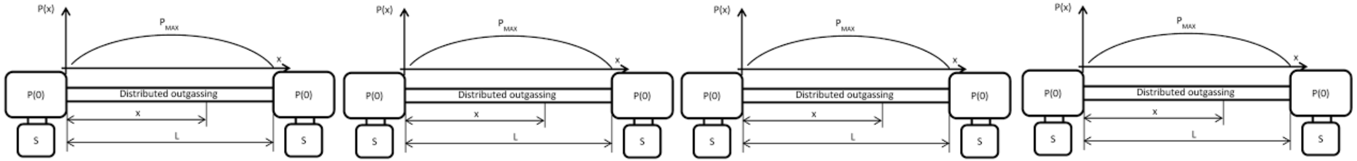
0.09m with C=1

0.09m with C=1

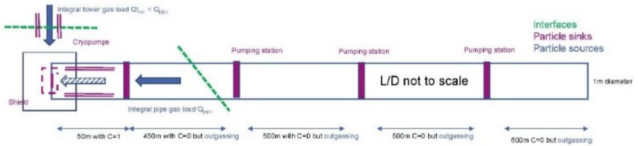
0.09m with C=1

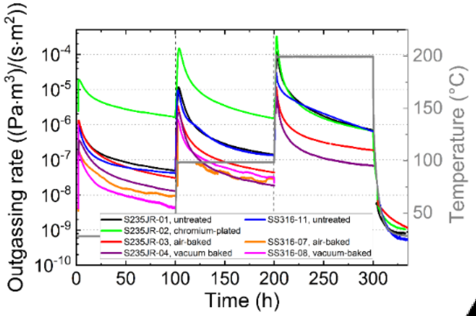
Capture coefficient
c=Strength of the flowrate through a given surface

$$Q = p \cdot c \cdot A \cdot \sqrt{\frac{R \cdot T}{2\pi M}}$$

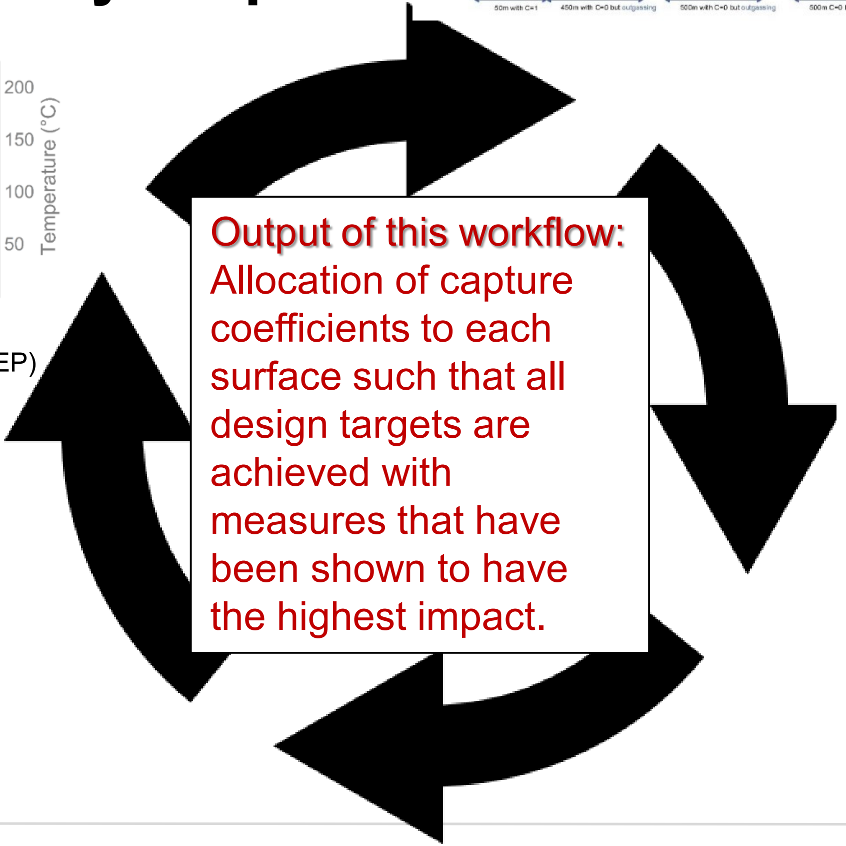


Sensitivity study output



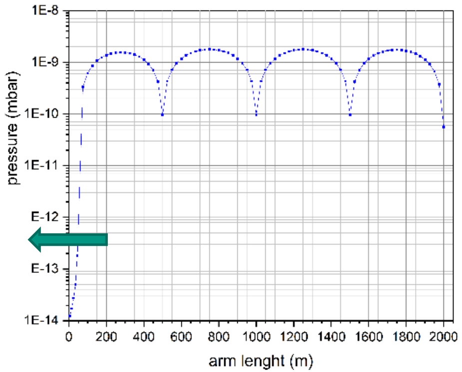


(determined with the OMA facility at ITEP)



Output of this workflow:
Allocation of capture coefficients to each surface such that all design targets are achieved with measures that have been shown to have the highest impact.

Translates the physics requirements into engineering requirements



Typical result

Operational time given by arriving particle flow at the mirror of ~ 10^{11} particles/s: Monolayer formation time of ~ 200 days

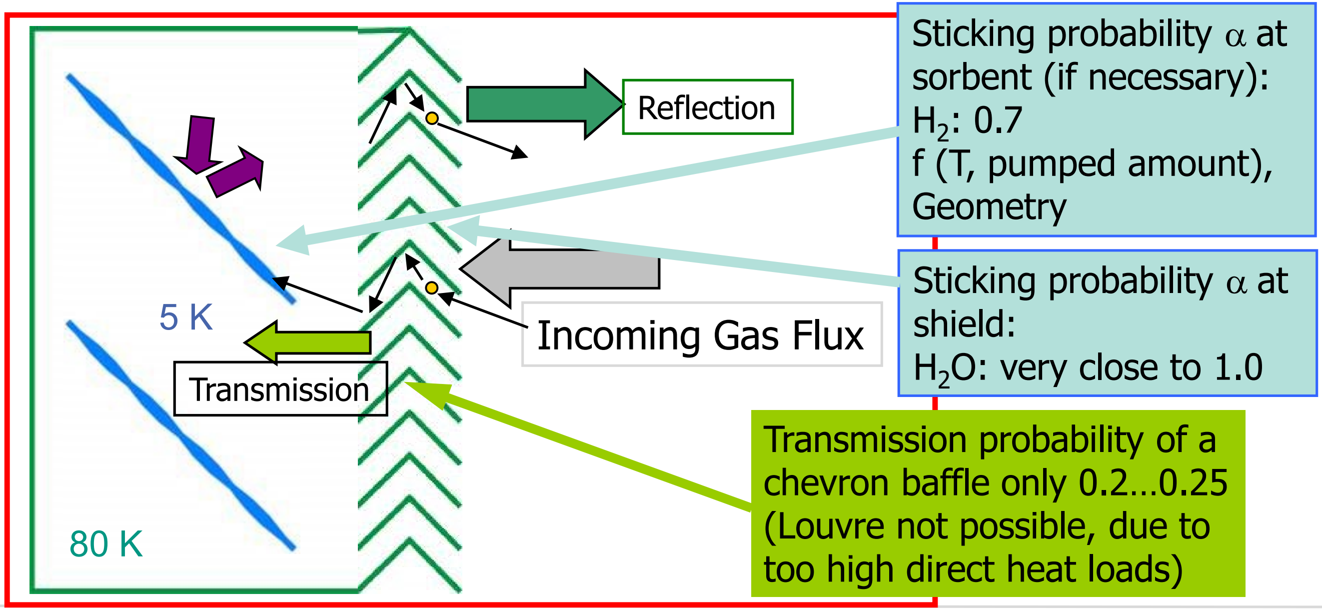
(for pumping stations with 125 m³/s, 50 m cryotrap and outgassing of $8 \cdot 10^{-10}$ Pa m³/(s m²) for mild steel)

Classical cryopump / shield design

$c=c(\alpha,t)$

The capture coefficient has two contributions:

- the limited molecular transmission probability t of a particle on the way from the vessel volume on the pumping surface →
- the non 100% sticking probability a of a particle at the pumping surface.



Summary

- ET has stringent requirements on the particle flux on the cryogenic mirror of the LF interferometer.
- The challenge comes from the establishment of the necessary vacuum conditions in a very large vacuum system at imperfect surface treatment history.
- KIT competence in solving the challenges is three-fold:
  - Outgassing characterization of materials
  - Particle modelling
  - Customized cryopump design