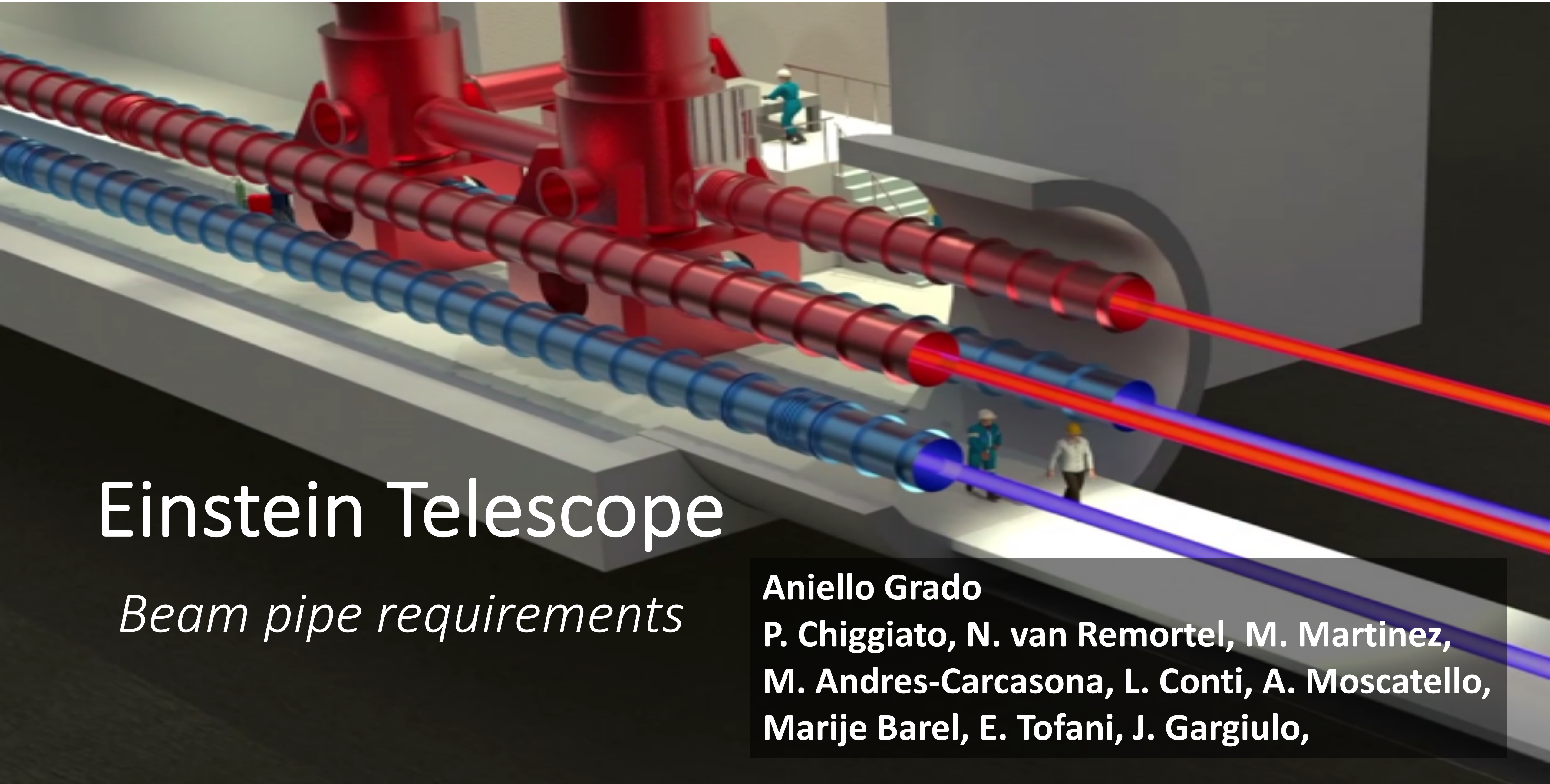


Einstein Telescope

Beam pipe requirements

Aniello Grado
P. Chiggiato, N. van Remortel, M. Martinez, M. Andres-Carcasona, L. Conti, A. Moscatello, Marije Barel, E. Tofani, J. Gargiulo,

ET Symposium 21st May 2023, ET Vacuum& Cryo – WP IV.2

Global planning

In charge of the ET Colalboration

	First year				Second year				Third year			
	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4	Q 1	Q 2	Q 3	Q 4
Functional specifications												
Roles and agreement with Institutes												
Optimisation of baseline, including cost analysis												
Definition of alternative solutions												
Cost & performance of alternative solutions												
Optimisation of interfaces with services/infrastructures												
Decision about vacuum design for pilot sector at CERN.												
Prototyping of the selected solutions.												
Technical design report (ET vacuum system).												

ET beam tubes requirements from ET technical report 2020

LARGEST UHV VOLUME ever made

- Tube diameter ~ 1m
- Total lenght 120 km

Surface: 3.8×10^5 m^2
Volume: 9.4×10^4 m^3

- Total residual pressure: H_2 10^{-10} mbar, H_2O 5×10^{-11} mbar, N_2 10^{-11} mbar (more stringent reqs comes from ET-HF)
- Hydrocarbon partial pressure < 10^{-14} mbar
- Material ?(2G detectors: SS 304L or 316L)
- Life time: 50 years

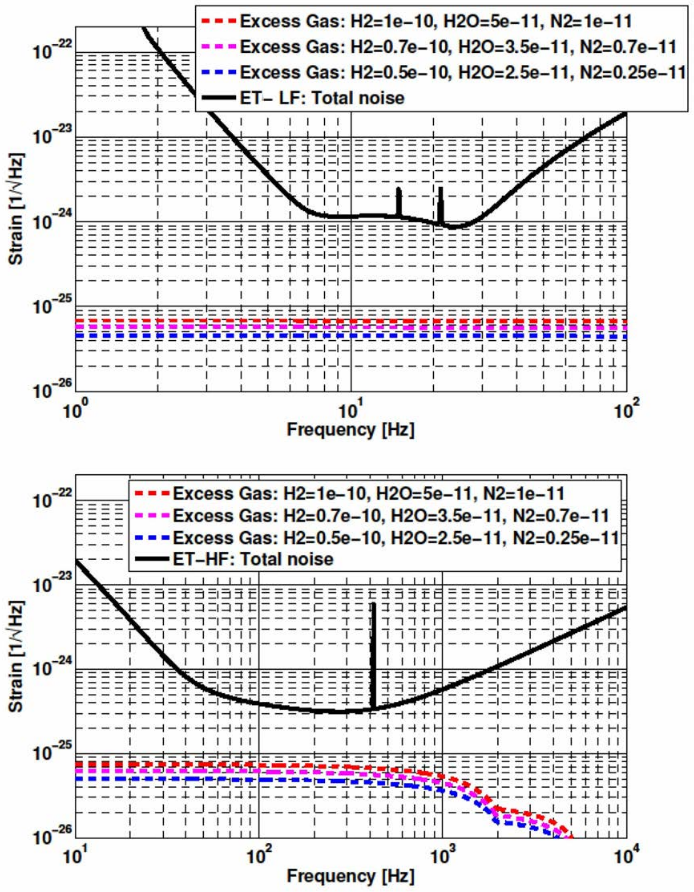


Figure 6.16: Phase noise given by the residual gases compared to the expected sensitivity, computed for the appropriate beam profile for different gas compositions. (Goal gas composition: Hydrogen [1 10^{-10} mbar], Water [$5 \cdot 10^{-11}$ mbar], Nitrogen [1 10^{-11} mbar])

ET technical report 2020

- Since January we have regular by-weekly teleconf
- We are writing a requirement document on beampipe

https://www.overleaf.com/read/xxhqmbhzyqwk

Contents

High priority parameters

- Light scattering →
  - Tube diameter
  - Cavern size
  - Number and characteristics of baffles
  - Amount of steel
  - Tube production
- Vacuum pressure →
  - Thermal treatments
  - Pumps size and distribution
  - Tube production
- Contamination level →
  - Tube production
  - Assembly and integration

(both dust and hydrocarbon contamination)

General consideration

We should agree on what is the margin we want for each noise contribution taking into account:

- future ET upgrade
- uncertainties on the noise model

For the scattered light can we use one of the running detector (in particular GEO600 since it is easier to shake the beam pipe) to test the noise model ?

Some test was done in LIGO but not conclusive (M.Zucker private comm.)

See the section: "*Scattered light in the arms for the vacuum pipe design*'' on Wednesday 9.45 by M. Martinez

Vacuum pressure

A. Grado

Fluctuations of residual gas density induces a fluctuations of refractive index and then of the laser beam optical path

Power spectral density fluctuations of optical path

Gas optical polarizability

Interferometer arm lenght

Molecules number density

$$S_L\left(f\right) = \frac{\left(4\pi\alpha\right)^2}{v_0} \int_0^L \frac{\rho\left(z\right)\,\exp\left[-2\pi f\, w\left(z\right)/v_0\right]}{w\left(z\right)}\,dz$$

Average molecules speed

Laser beam gaussian radius

S. E. Whitcomb. Optical pathlength fluctuations in an interferometer due to residual gas. Technical report, California Institute of Technology, October 1984.

ET-HF total margin 9.1

5000 l/s pumping speed every 500 m

Gas species	Specific outgassing rate (mbar l /s cm^2)	Max pressure (mbar)	Margin @ 272 Hz
H_2	$1x10^{-14}$	$5.3x10^{-11}$	18.7
H_2O	$1x10^{-15}$	$9.5x10^{-12}$	20
N_2	$5x10^{-16}$	$5.5x10^{-12}$	23
CO	$2x10^{-16}$	$2.2x10^{-12}$	31
CO_2	$1.5x10^{-16}$	$2x10^{-12}$	26
C_2H_4	$1x10^{-16}$	$1x10^{-12}$	21

With these parameters the margin for ET-LF would be ~ 20

ET-LF total margin 9.8

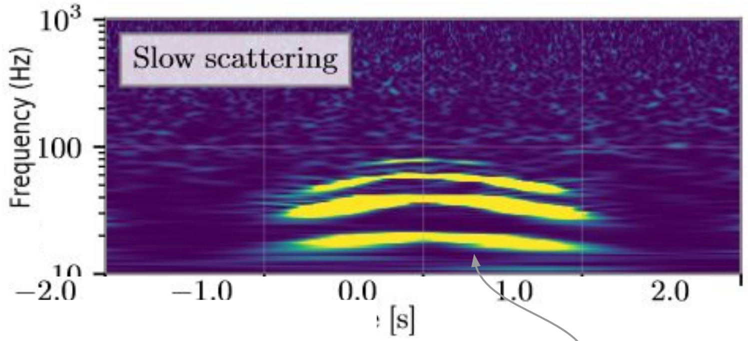
5000 l/s pumping speed every 500 m

Gas species	Specific outgassing rate (mbar l /s cm²)	Max pressure (mbar)	Margin@ 24 Hz
H_2	$6x10^{-14}$	$3.2x10^{-10}$	16.9
H_2O	$1x10^{-14}$	$9.5x10^{-11}$	13.4
N_2	$1x10^{-15}$	$1.1x10^{-11}$	75
CO	$2x10^{-16}$	$2.2x10^{-12}$	66
CO_2	$1.5x10^{-16}$	$2x10^{-12}$	54
C_2H_4	$1x10^{-16}$	$1x10^{-12}$	44

OR we can relax the spec on pumping distances. Using the previous outgassing rates and a distance among pumps of 2000 m the margin would be 9.6 ***reducing the cost*** *of the pumping system of a* ***factor 4***

Dust contamination

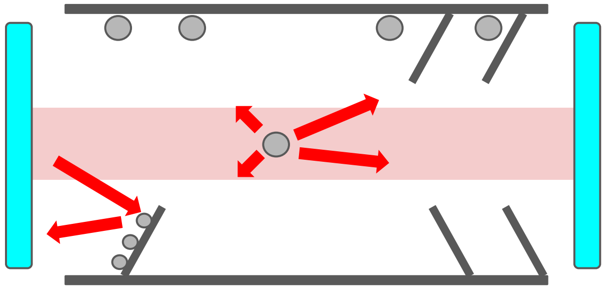
A. Moscatello, L. Conti, G. Ciani, M. Bazzan (ET-0098A-23)



stray light as excess power in the detector

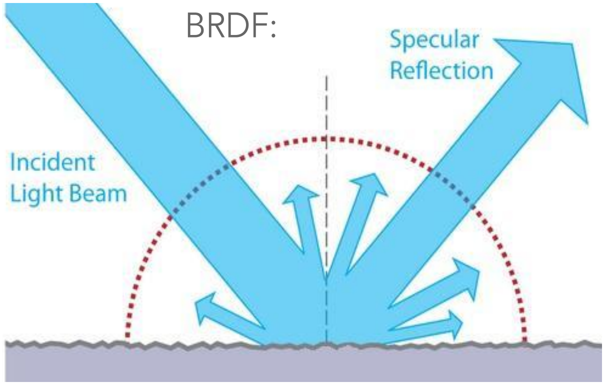
Straylight caused by dust ($D \geq 0.1\ \mu m$)

- Dust on baffles
- Dust crossing the laser beam



- main effect: increase BRDF (BRDF: scattered light fraction as a function of the scattering angle per unit solid angle)

BRDF (i.e. scattering) of the baffles: this increases if dust is present



detector strain noise due to baffles backscattering

Baffle backscattering

$$\tilde{h}_{bs,M1}(f) = \frac{\epsilon\kappa}{\sqrt{3\pi}}\frac{\lambda X(f)}{LR}\sqrt{\mathrm{BRDF}(60^\circ)}\sqrt{\ln\left(\frac{z_{last}}{z_{first}}\right)}$$

ET-0182A-22, following Vinet et. al. Phys.Rev.D 56, number 10 (1997)

3

From A.Moscatello "Beampipes for GW detectors 2023", CERN 27-29 March 2023

See also: A. Moscatello ''Dust in ET beampipes: contribution to noise and cleanliness requirements'' (Poster section)

Dust on Baffles: CL in Clean Rooms

The Cleanliness Level CL increases with increasing time exposure, and depends on the ISO class of the environment [*Optical Engineering, 31(8):1775 – 1784, 1992*]

$$\log_{10}(\mathrm{CL}) = \sqrt{\frac{1}{S}\left[\log_{10}(h) + \log_{10}(\rho) + \log_{10}(t) + 0.773\log_{10}(X_c) - 1.24\right]}$$

- h: optics orientation (1 for horizontal, 0.1 for vertical)
- **ρ**: number of air-change per hour in the environments (ρ=2851 for an average non-laminar flow clean room)
- t: surface exposure time, in days
- X_C: air cleanliness class (related to ISO)

e.g. CL=200 can be obtained in 10 days for an horizontal surface in a ISO 6 clean room
→ DET lab @Virgo

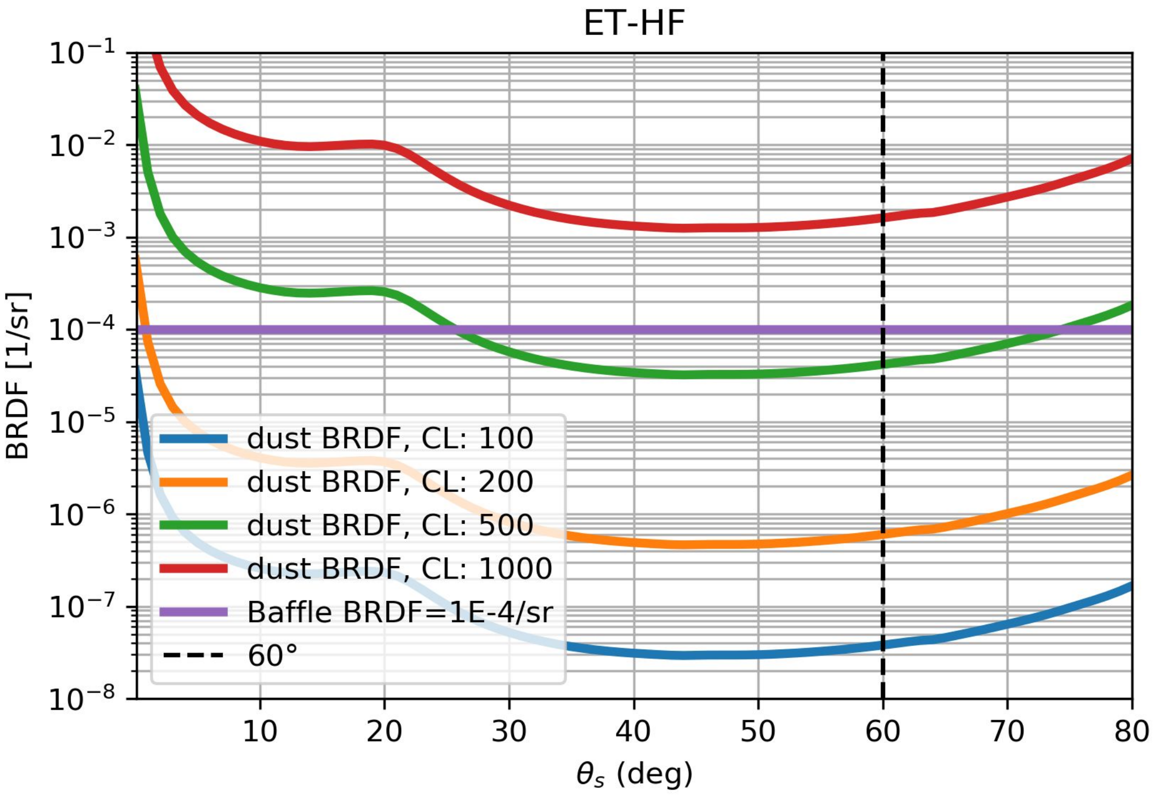
CL is the cleanliness level of the surface: CL=200 means 1 particle of >200um in 0.1m^2 (if S=-0.926 is assumed)

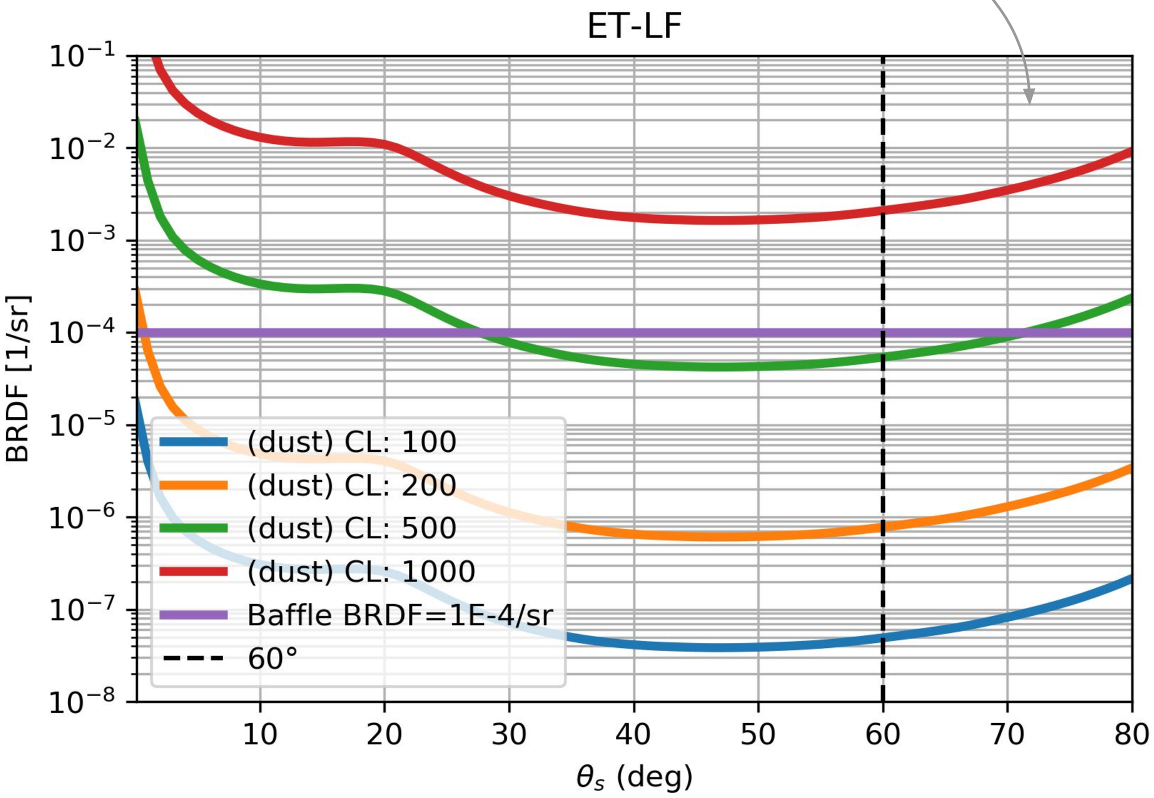
- CL < 100 for pristine surfaces
- CL = 600 for visible clean surfaces
- CL > 1000 for visible dirty surfaces

Dust on Baffles: BRDF vs CL

- Assuming the IEST dust distribution, the BRDF of the dust is computed from the CL level (both for ET-LF and ET-HF, since dust scattering is dependent on wavelength).
- Total BRDF is given by the linear sum of baffle's only and dust contribution

Those estimates assumes preliminary values ET-0212A-22:
- baffles BRDF(60°)=10^{-4}/sr
- baffles reflectivity: 10^{-2}





DUST on baffles: increase of BRDF

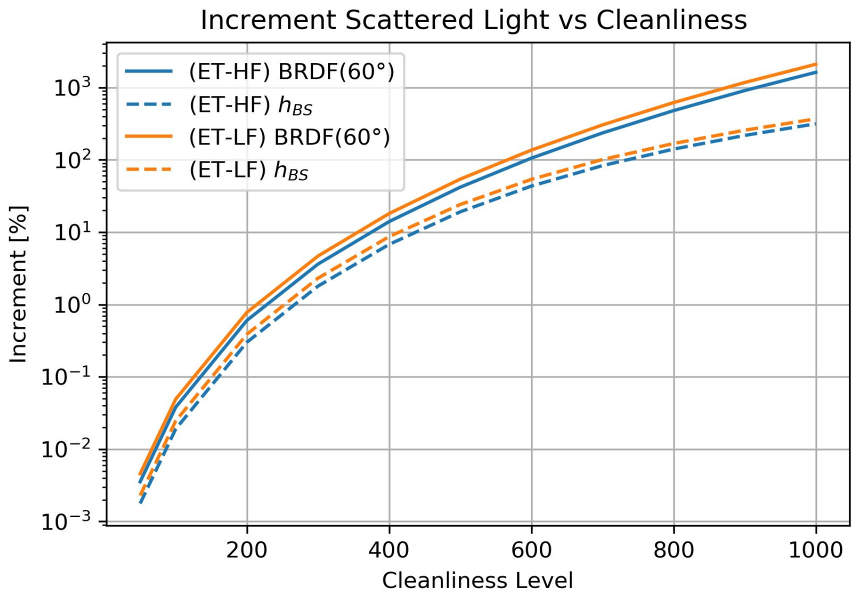
If typical operations are ≈10^1 days:

- CL≈100-200 with ISO 6 → ΔBRDF≈1%
- CL≈100 with ISO 5 → ΔBRDF <0.1%

Exposure in cleanrooms does not seem harmful…

- but this is valid only if all the cleanliness procedures and standards are fulfilled
- attention must be paid to particles released by particular operation/machineries or procedures not respected

… the ISO class must be fulfilled even when work is performed!



Dust on Baffles: Pumps/Pipe walls/Gate valves

Dust is also released when the system is closed:

- pumps operation
- shocks on tube walls
- opening/closing of gate valves

In "Rev. Sci. Inst. 69, 3818 (1998)" dust contamination is measured in UHV:

- Ion Pump:
  - particles release at ignition, no particles during operation
  - N=30 particles on average (new pump) + and not diminishing along successive start/stop cycles
- Shocks on walls:
  - after 5-10 impacts no more particles but no data→ but if strength or place of impact is changed particles are released again
  - particles mainly accelerated by gravity
- Gate valves
  - distribution: 2400 particles, 90% with D<2um, and 50% with D<0.5um (over 6 open-close cycles)
  - with more open/close cycles: half particles after 10 cycles, then constant up to 30 cycles

DUST from pumps/pipe wall/gate valves

By accounting for all the pumps (~180) and gates (~150) (from "*ET Design Report 2020*" [ET-0007B-20]), we can compare the contamination (0.5um<D<2um) due to pumps and clean rooms:

- pumping/gate valves (no info on shaking): ~ $5*10^5$ part per arm (~10^2 baffles)

- e.g. @CL200 (≅10^2 days in ISO6) ~ $3*10^5$ part/m^2 → 10^5 part per baffle
  → Radius of tube: 0.6m
  → Baffles height: 0.08m
  → Baffles assumed flat

$$A_{baffle} = \pi R^2_{tube} - \pi(R^2_{tube} - h^2_{baffle}) \cong 0.3m^2$$

From ET-0182A-22 (provisionary) and assuming flat baffle

Contribution from pumps/valves seems not significant (no info on shaking)

Contribution to scattering light due to dust crossing the beam is under study

Requirements on welding underground M. Barel

- Welding beampipe modules can contaminate the vacuum vessel
  - Can be minimized using lips at the modules end as done in Virgo
- Safe working condition underground

Legal framework:

- Directive 89/391/EEC contains measures to promote the improvement of the safety and health of workers at work.

- Directive 98/24/EC of the Council concerning the protection of the health and safety of workers from the risks related to chemical agents

- Directive 2004/37/EC of the European Parliament and of the Council on the protection of workers from the risks related to exposure to carcinogens or mutagens at work (amended by Directive (EU) 2017/2398.

knowing the type of welding, people involved and exposure time, we can put the requirements on the ventilation. First rough estimation: 5 time swap out/h of the confined space volume.

The occupational exposure limit (OEL) is stated to be a maximum of 1 mg/m3 of occupational exposure to welding fumes per person per day [NL] (depends on the country)

THANKS

To people interested on beampipe requirements:

Please join the dedicated section on Wednesday at 15.30