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Stray light by particle contamination in the ET arms

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Introduction

Goal: set cleanliness requirements for the installation of ET pipes

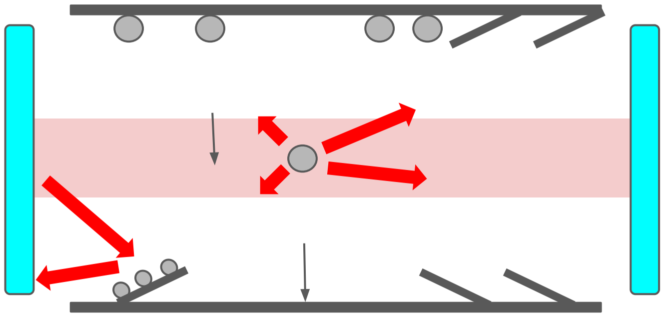
Focus on straylight caused by dust contamination in the arms (we only consider the beampipes, excluding the cryotraps and TM towers)

Dust can **enter inside the arms**:

- during installation: production and assembly of the pipe with installation of baffles
- pumpdown and venting operations
- when in vacuum due to the pumps and gate valves

Dust produce **different effects**:

- dust deposited on baffles contribute to scatter the light that reaches the baffles
- particles moving in space (e.g. if falling under gravity) can cross the light beam and scatter light



Dust on Baffles: Introduction

The effect of dust deposited on baffles is to increase baffle’s BRDF: higher scattering and higher strain noise.

strain noise due to baffles backscattering →

M.Andres, ET-0182A-22

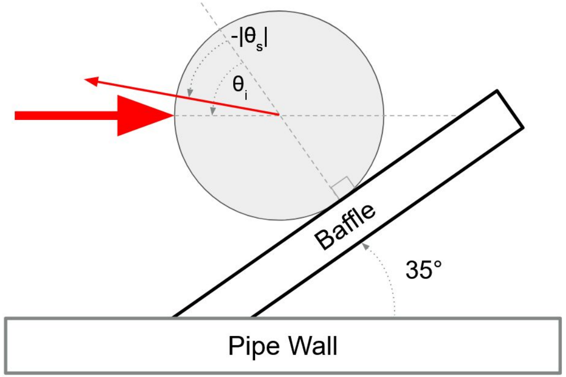
$$h(f) = \frac{\varepsilon\kappa}{\sqrt{3\pi}} \frac{\lambda X(f)}{LR} \boxed{\sqrt{\text{BRDF(-55°)}}} \sqrt{\frac{z_{last}}{z_{first}}}$$

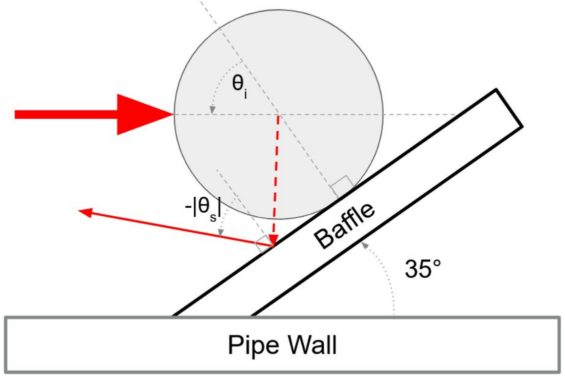
↑

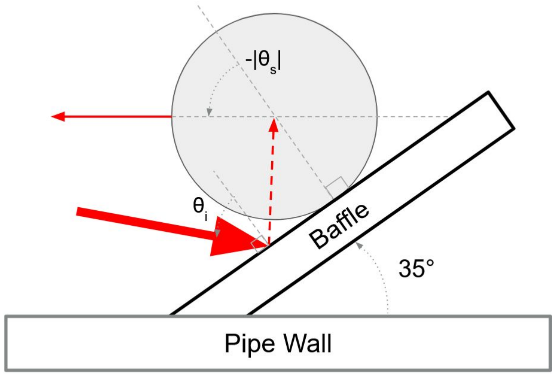
$\text{BRDF}_{\text{baffle}} + \text{BRDF}_{\text{dust}}$

Given our specific geometry, light must be scattered at θ_s=-55° (i.e. almost exactly back-scattered to return to the TM)

Three cases for scattering light back to the TM:







Dust on Baffles: How the limit is set

Goal: set the cleanliness requirements to have the straylight noise below a certain level.

How:

1. from size-numerosity of dust particles on baffles, the BRDF from the dust is computed (Mie Theory)
2. the maximum numerosity-size distribution of particles allowed on the baffle is set such that

$$\mathrm{BRDF}_{\mathrm{dust}} = \mathrm{BRDF}_{\mathrm{baffle}} = 10^{-4}\ 1/\mathrm{sr}$$

← baffle's BRDF (10.1103/PhysRevD.108.102001)

The deposited dust distributions are computed for different assembly steps from dust fallout models and compared to the limit above

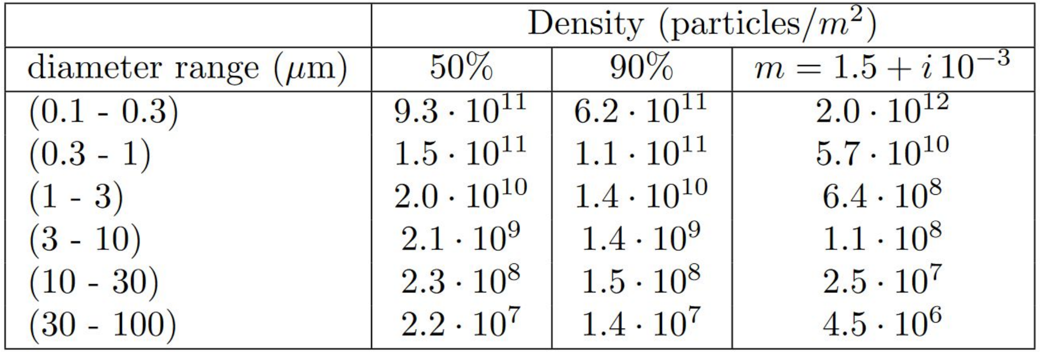
- handling in clean rooms and installation inside the tube
- Tube sectors exposure before pumping

They depend on exposure time, clean room ISO and surface orientation

Dust on Baffles: Dust size-numerosity limit

The BRDF is given by the particular size-numerosity distribution. What we do:

1. divide the 0.1-100 um particle diameter range in 6 intervals
2. assume a flat distribution inside each interval range and m =(1.3, 1.8)+i(10^{-4}, 0.8) with uniform distribution (for particles in urban environment m=1.5+i10^{-3} is reported to be the most likely)
3. compute the maximum particles density such that $BRDF_{dust}(D_i) = BRDF_{baffle}$



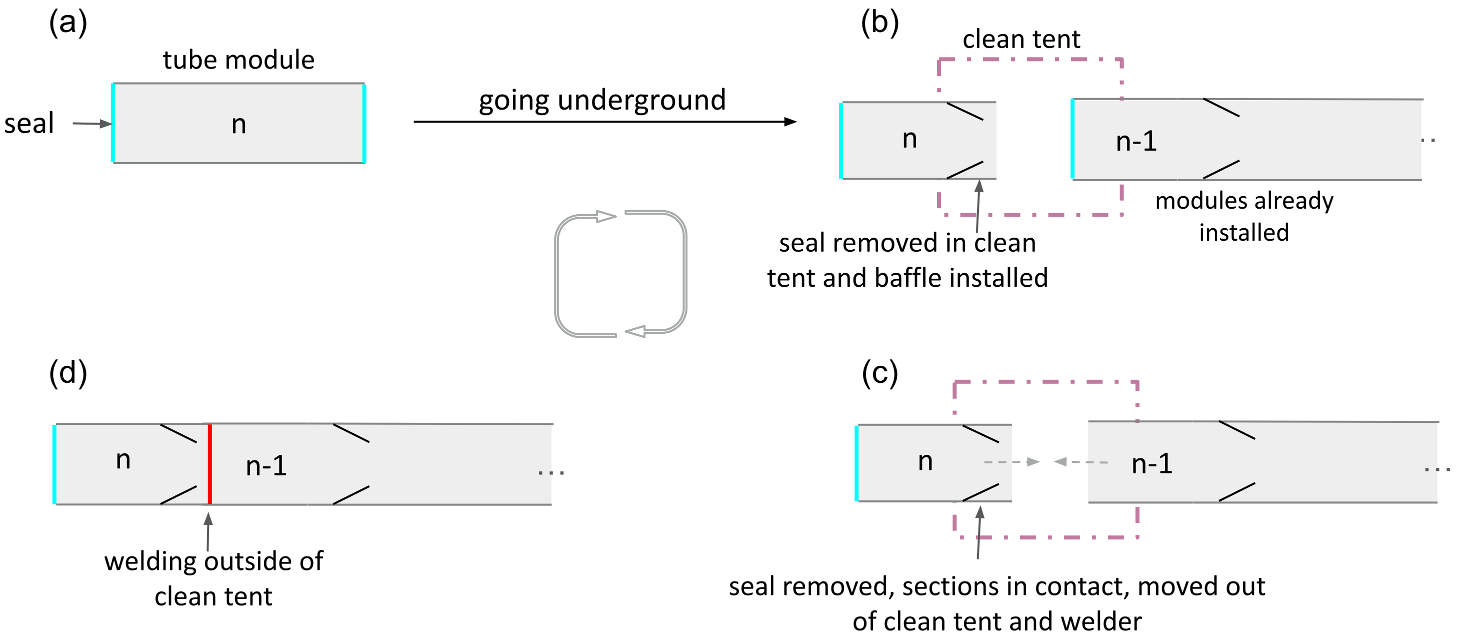
	Density (particles/m^2)		
diameter range (μm)	50%	90%	$m = 1.5 + i\,10^{-3}$
(0.1 - 0.3)	$9.3 \cdot 10^{11}$	$6.2 \cdot 10^{11}$	$2.0 \cdot 10^{12}$
(0.3 - 1)	$1.5 \cdot 10^{11}$	$1.1 \cdot 10^{11}$	$5.7 \cdot 10^{10}$
(1 - 3)	$2.0 \cdot 10^{10}$	$1.4 \cdot 10^{10}$	$6.4 \cdot 10^{8}$
(3 - 10)	$2.1 \cdot 10^{9}$	$1.4 \cdot 10^{9}$	$1.1 \cdot 10^{8}$
(10 - 30)	$2.3 \cdot 10^{8}$	$1.5 \cdot 10^{8}$	$2.5 \cdot 10^{7}$
(30 - 100)	$2.2 \cdot 10^{7}$	$1.4 \cdot 10^{7}$	$4.5 \cdot 10^{6}$

we consider the m values that give the 50th and 90th percentile of the BRDF to exclude extreme values

this sets the **cleanliness limit** that any contamination process must obey

Dust on Baffles: Pipe Installation Problem

Proposed procedure for installation of baffles and welding tube modules to minimize the contamination:



Dust on Baffles: Pumps/Pipe walls/Gate valves

Dust is also released when the system is closed:

- pumps operation
- opening/closing of gate valves

In literature dust contamination is measured in UHV for different items:

- Ion Pump: N=30 particles release only at ignition ($P_{ignition}$ =10^{-5}mbar)
- NEG pumps: they are found to be compatible with clean environments
- Gate valves: N~2k particles released in 6 open-close cycles: 90% with D<2um, and 50% with D<0.5um

By accounting for all the pumps (~50) and gate valves (~75), we can compare the contamination (0.5um<D<2um) due to pumps and clean rooms:

- pumping + gate valves: ~ 2k particles per baffles
- for air exposure in clean room (neglecting storage):
  - 1 day in ISO6: ~ 80k part per baffle
  - 1 hour in ISO6: ~ 3k part per baffle

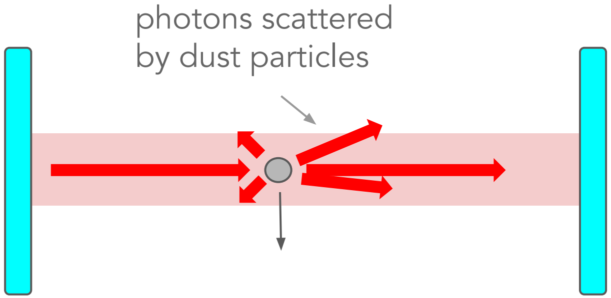
Contribution from pumps/valves seems **not as significant**

Dust Crossing the Beam (work in progress…)

Dust particles crossing the beam can scatter light that reaches the TMs: we focus only on light scattered and directly reaching one TM.

The power scattered by the particle depends on:

- particle's position along the tube and transverse to the beam, in the horizontal direction
- particle's vertical position, which depends on time
- particles properties, e.g. dimension



Montecarlo simulation:

1) ensemble of N particles detaching at random times and positions
2) compute the scattered field as a function of time using Mie Theory
3) compute amount of scattered field that couples with cavity mode
4) compute phase and amplitude fluctuations
5) compute strain noise

Summary

- **Dust particles** inside the arm:
  - deposit on baffles and add a BRDF term
  - cause scattering when falling and crossing the beam
- **Results**:
  - set cleanliness requirements for the production and installation of ET arms
  - **running pumps/venting**: our estimate seems to suggest that it is not impacting as much as dust deposited during in-air operations
  - **handling and installation of baffles**: we estimated that 1 day of exposure in ISO6 clean room is tolerable
  - the issue of **tube modules storage** has emerged: risk of being the critical step
- **Open issues**:
  - uncertainties in physical parameters: dust index of refraction, shape, and release rate from the walls
  - no solid estimates of particles deposition velocity in clean rooms
  - particles crossing the beam: work in progress

Backup Slides

Dust on Baffles: BRDF vs Dimension

We consider particles in the 0.1-100 um range as it the expected range for urban environmental dust…

…but the scattering is heavily dependent on the size-numerosity distribution of the particles.

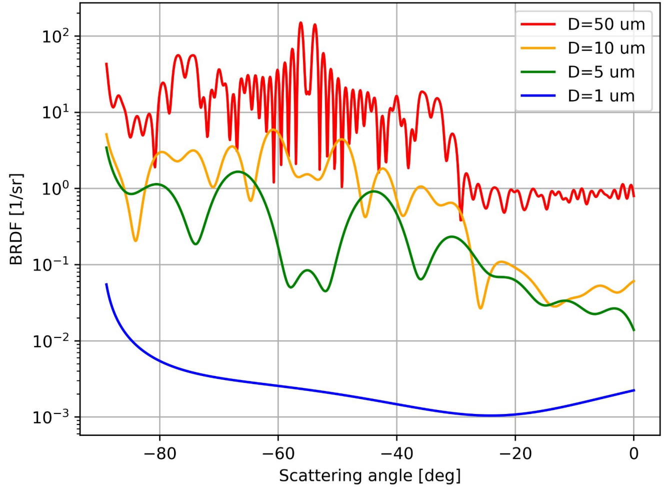
- larger particles tend to scatter more and at smaller angles wrt small particles
- smaller particles are typically more numerous

Accounting for the higher numerosity, the smaller particles contribution becomes relevant

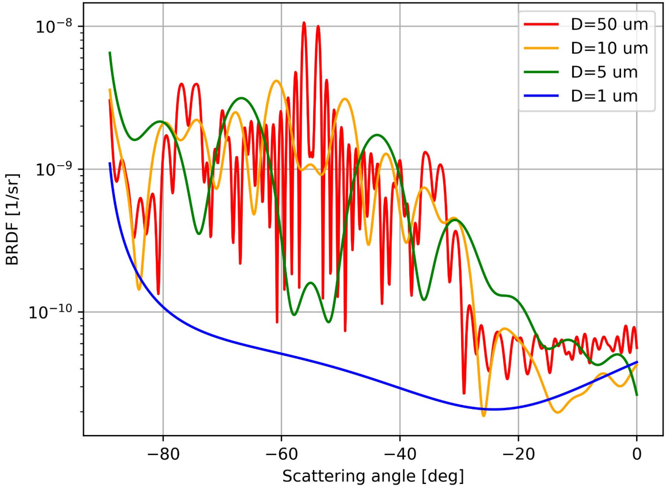
↓

Effect of smaller (D<0.1um) and larger (D>100um) particles will be subject of future study

Flat distribution (n=1 particle/μm^2), $\lambda = 1064nm$

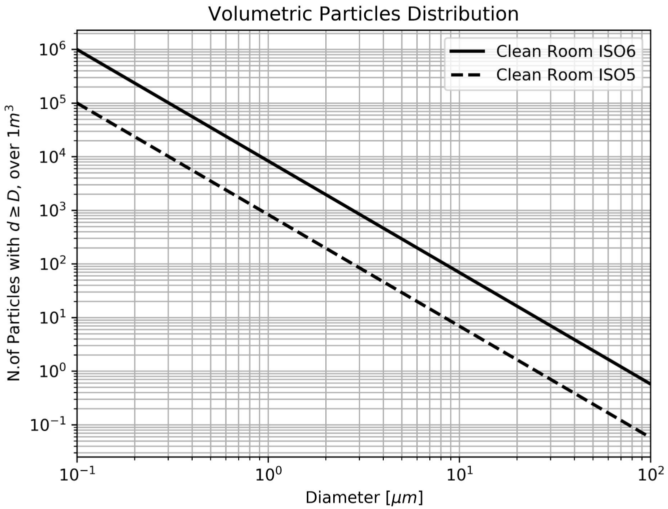


ISO distribution (ISO6, 1h exposure), $\lambda = 1064nm$



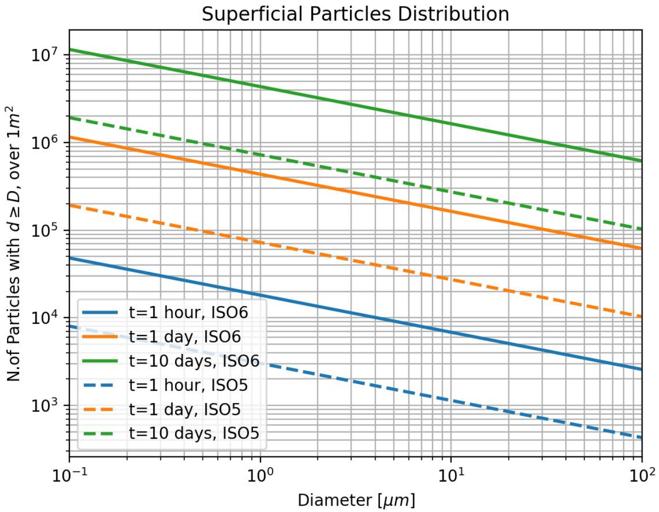
Dust on Baffles: Particles distribution

Exposure of baffle's surface to air is a source of contamination even in clean rooms.



deposition velocity

$$v_D = 2.02\,10^{-4} \cdot D^{1.656}\ \left[\frac{m}{s}\right]$$



depends on ISO class

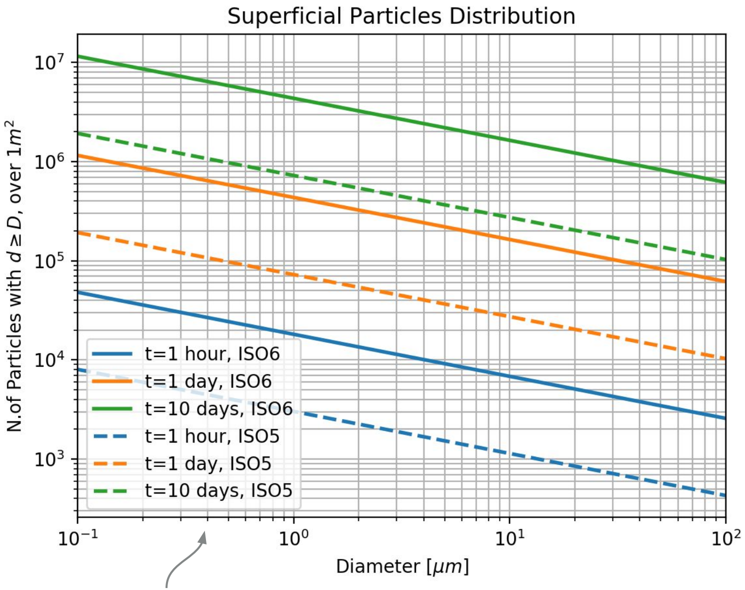
$$C_n(D) = 10^{N_{ISO}} \left(\frac{0.1}{D}\right)^{2.08} \left[\frac{1}{m^3}\right]$$

depends on ISO class, exposure time and deposition velocity

$$N(D) = C_n\, v_D\, t \left[\frac{1}{m^2}\right]$$

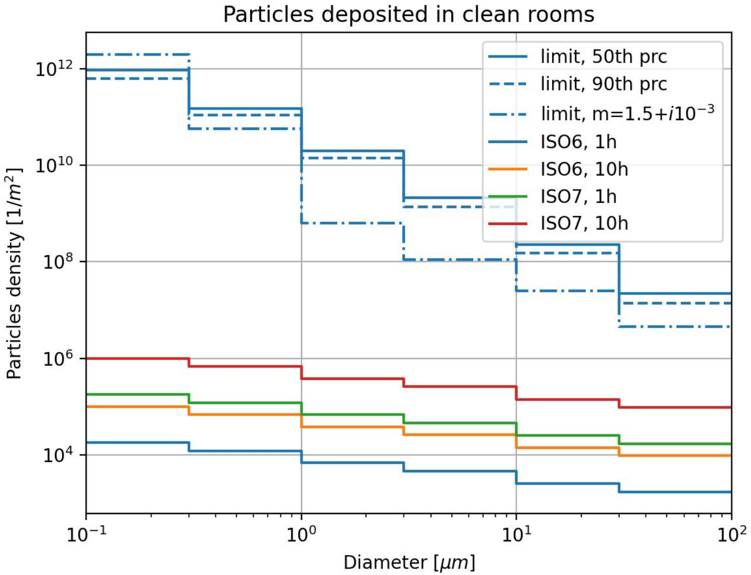
Dust on Baffles: Baffles in Clean Rooms

The particles deposited density is computed starting from different ISO and exposure time scenarios, then compared to the maximum limit established previously.



Superficial Particles Distribution

depends on ISO class, exposure time and deposition velocity



Particles deposited in clean rooms

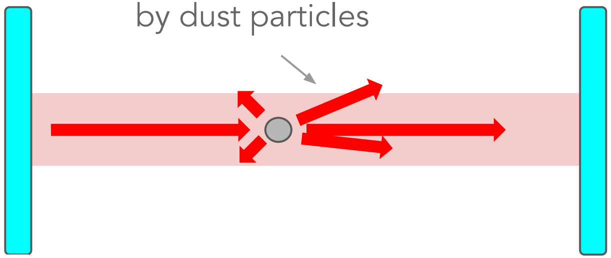
contamination is **acceptable** but the ISO standard must be maintained with people/machineries at work

Dust Crossing the Beam

Dust particles crossing the beam can scatter light that reaches the TMs: we focus only on light scattered and directly reaching one TM.

The power scattered by the particle depends on

- particle’s position along the tube and transverse to the beam, in the horizontal direction
- particle’s vertical position, which depends on time
- particles properties, e.g. dimension



photons scattered by dust particles

$$E^s_{1,2}(\vec{x_0}, \vec{x}, t, t_0) = \frac{e^{-ikr(t,t_0)}}{ikr(t,t_0)} \cdot S_{1,2}(\theta_s, D, m) \cdot \mathrm{TEM00}(\vec{x_0}(t,t_0))$$

scattered field

k: beam wavevector
r(t): vector from particle to point on TM

Mie scattering, depends on
- complex index of refraction (m)
- particles size (D)
- scattering angle

TEM00 mode incident on the particle