Controlling Particulates and Dust in Vacuum Systems

Lutz Lilje
DESY, 14.6.2017

Before we start: Definition of the Problem

- Cleaning has been discussed by Mauro
- Some cleaning techniques are of course dual use and remove both problems - hydrocarbons and particulates – efficiently i.e. ultrasonic cleaning

- Dust is composed of particulates.
  - A particle accelerator accelerates particles: electrons, protons, ions

- When people aim for „particle-free“ vacuum systems, they mean a vacuum system with the lowest possible count of particulates
  - A truly particulate-free accelerator is difficult – if not impossible – to achieve.

Outline

- Dust and Particulates
- Problems caused in Particle Accelerators by Dust Particulates

- Properties of Particulates
- Cleaning and Keeping Components clean

- Mechanical Design and Particulates

- Particulate Production in Accelerators

- Building a „Particle-free“ accelerator
  - Example: European XFEL
- Segmentation

Outline

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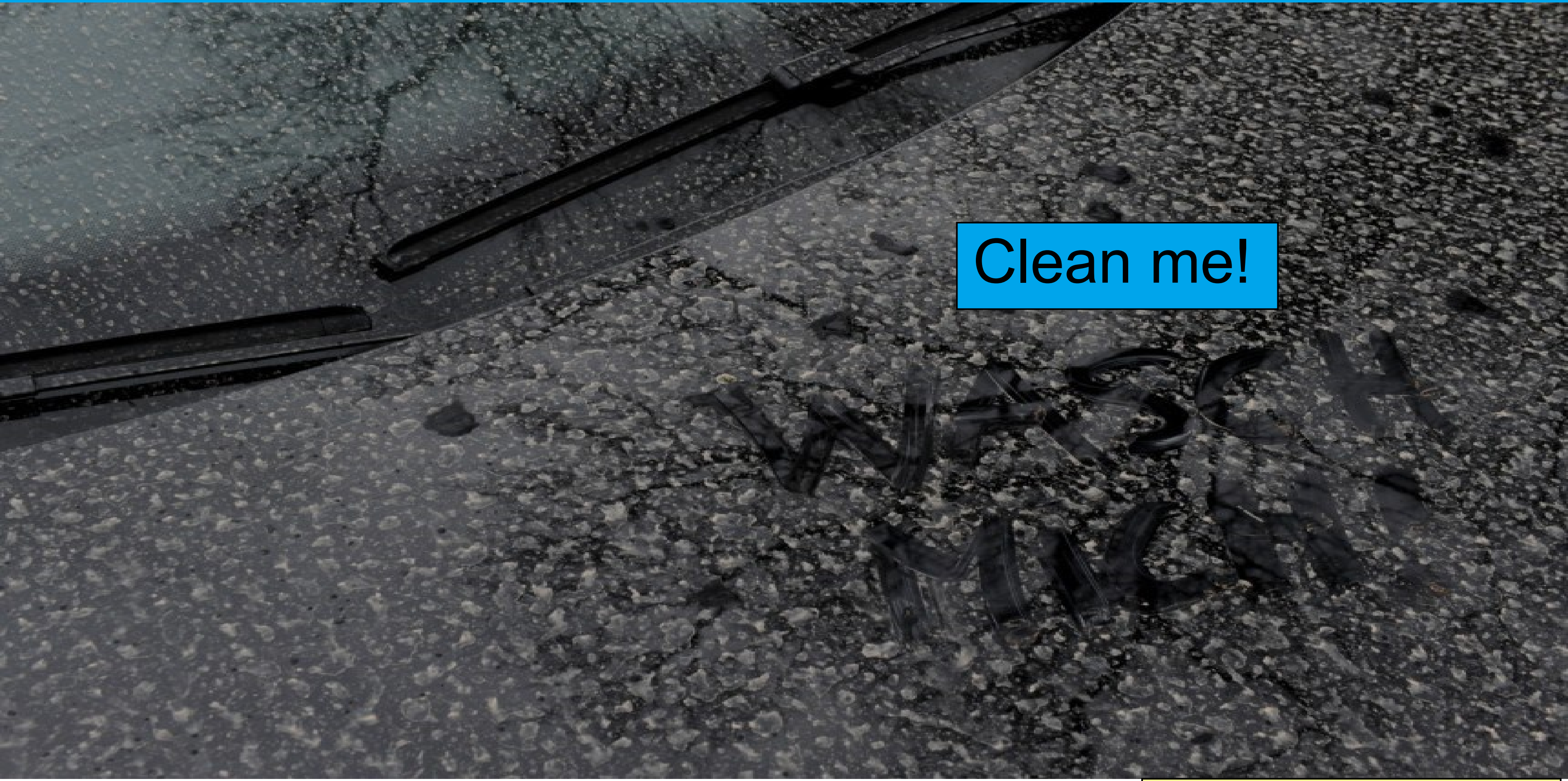
  - Example: European XFEL
- Segmentation

Dust and Particulates

By:A,Ocram – Own Work, CC0, https://commons.wikimedia.org/w/index.php?curid=47821242

- „Dust“ is known by everybody
- It is so mundane…
- But it needs continuous attention:
- 6,2 mg per m^2 per day in a typical german household (according „Quarks & Co“)

More Dust

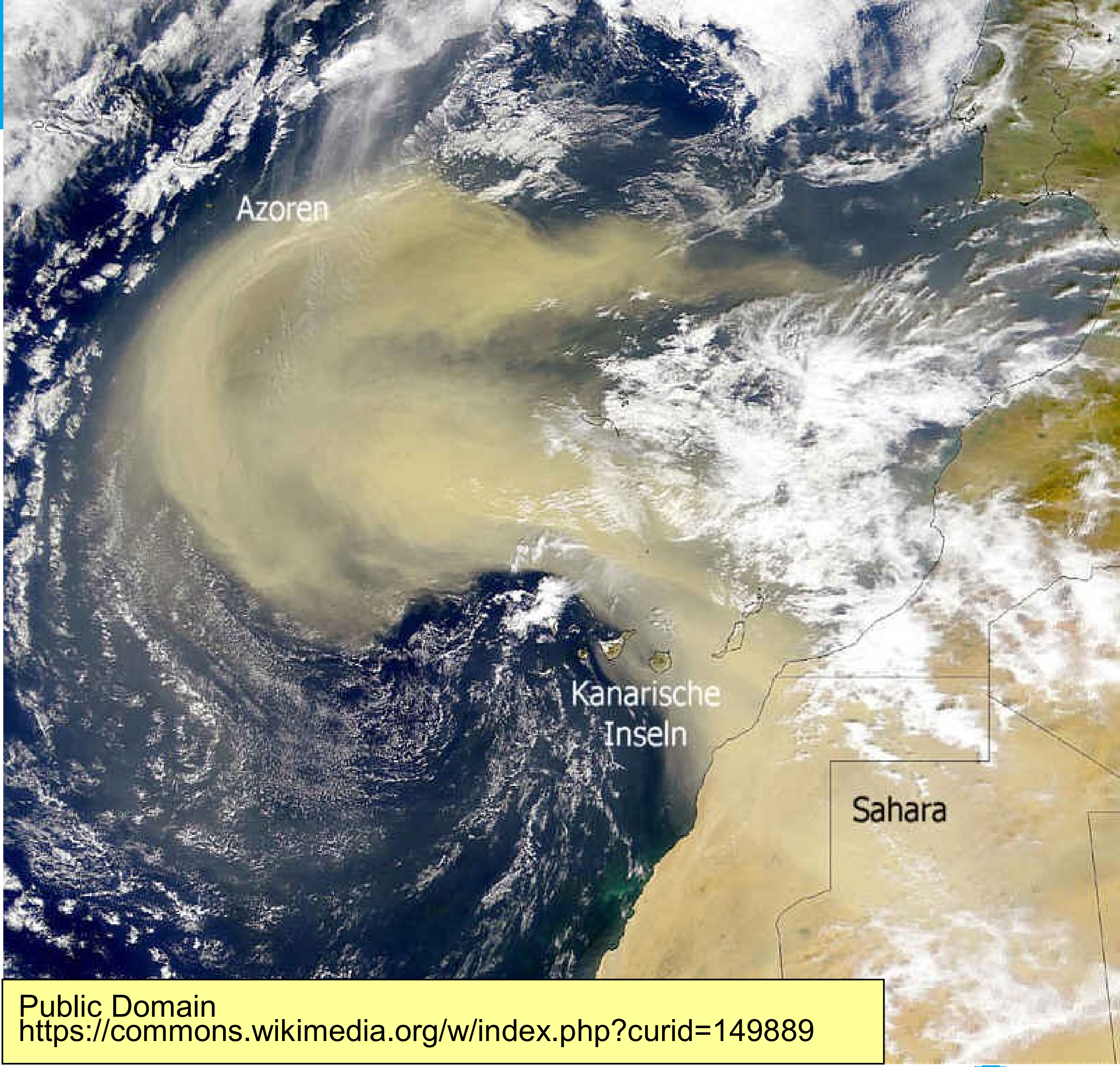


Süddeutsche Zeitung 19. Februar 2014

- Dust on a german car …
- No - we are not talking Diesel engine problems…
- … but what is this, then?

A lot of Dust!

- Sahara Dust near Canarian Isles and Azores



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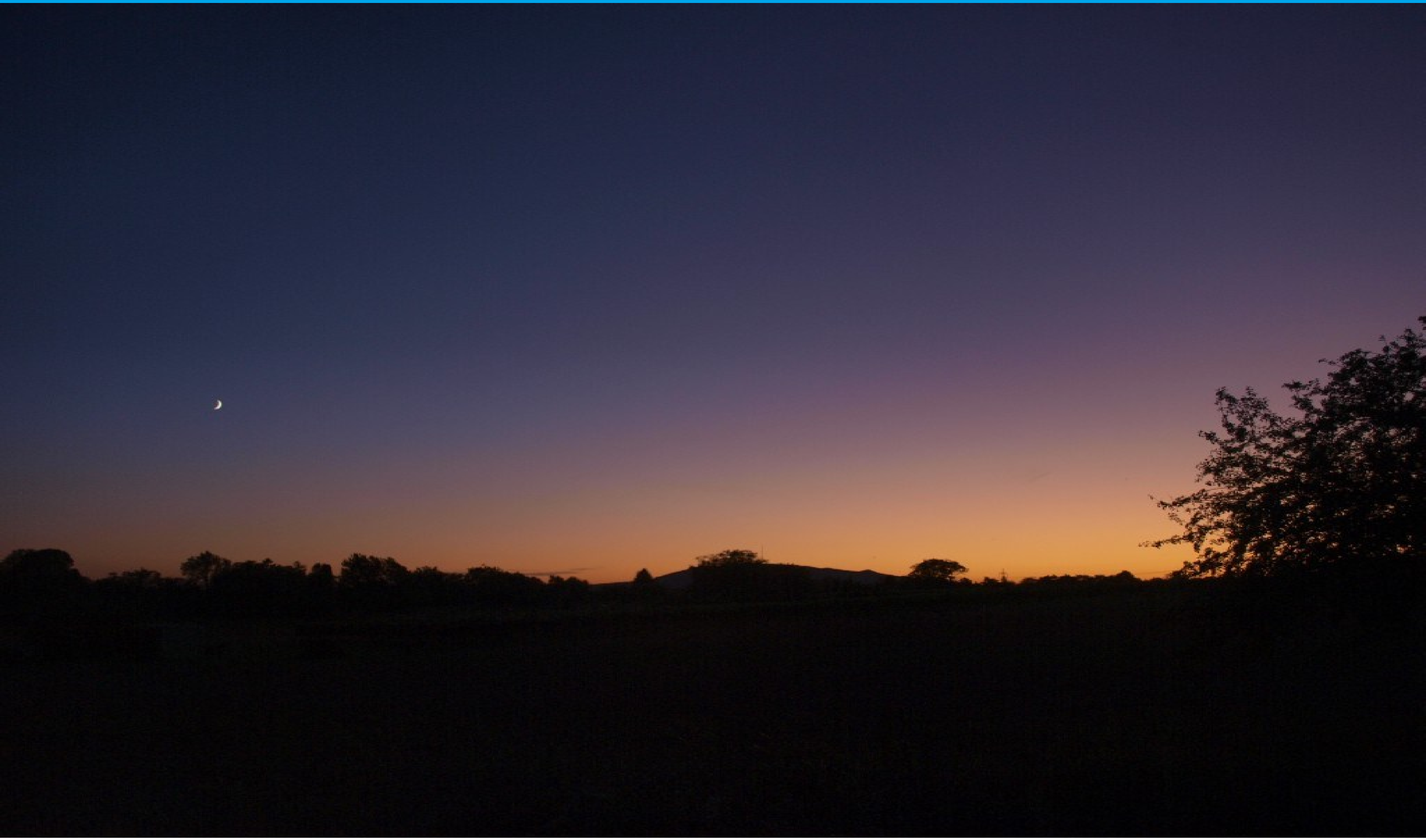
Sun in Hamburg – but with Sahara Dust

n-tv,
03. April 2014

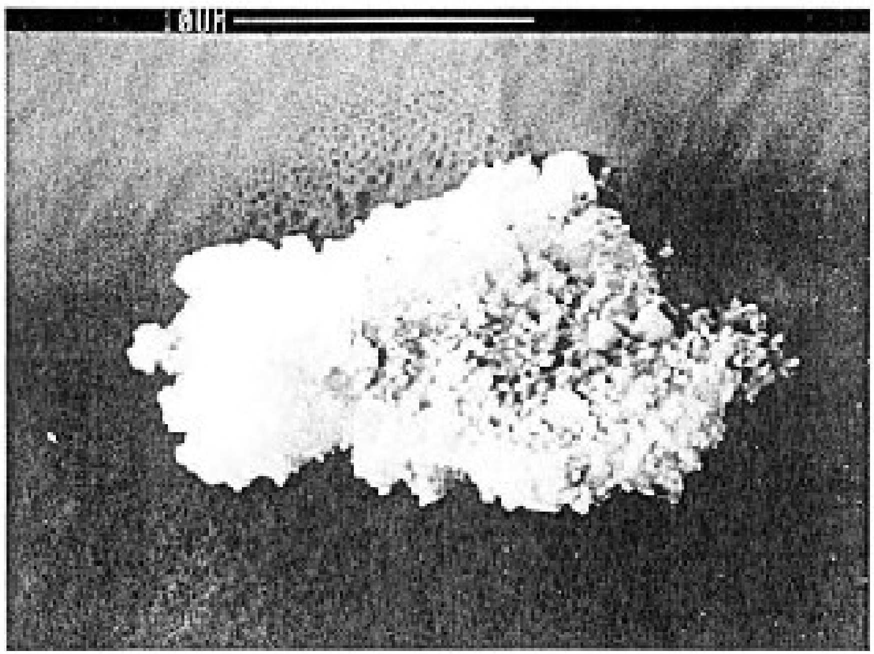
And for the Night Owls: Moon with Sahara Dust



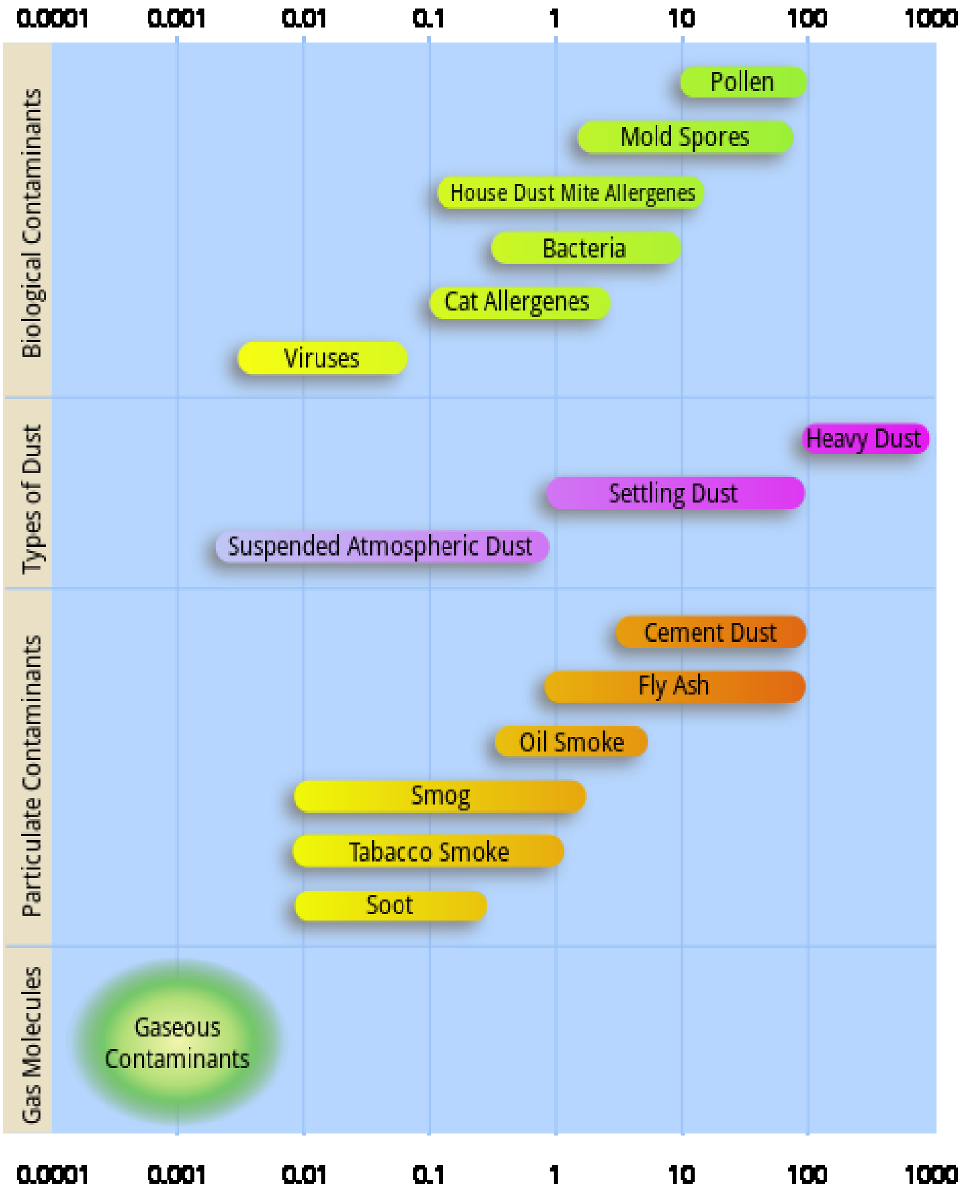
W. Vollmann, Wien

What are Particulates?

- Particulates can both be airborne e.g. dust or being generated during the assembly processes e.g. while bolting down screw connections.
- Which dust source is missing?



H. Padamsee, Supercond. Sci. Technol., 14 (2001), R28 –R51



From Wikipedia "Particulates" Sizes in micrometers

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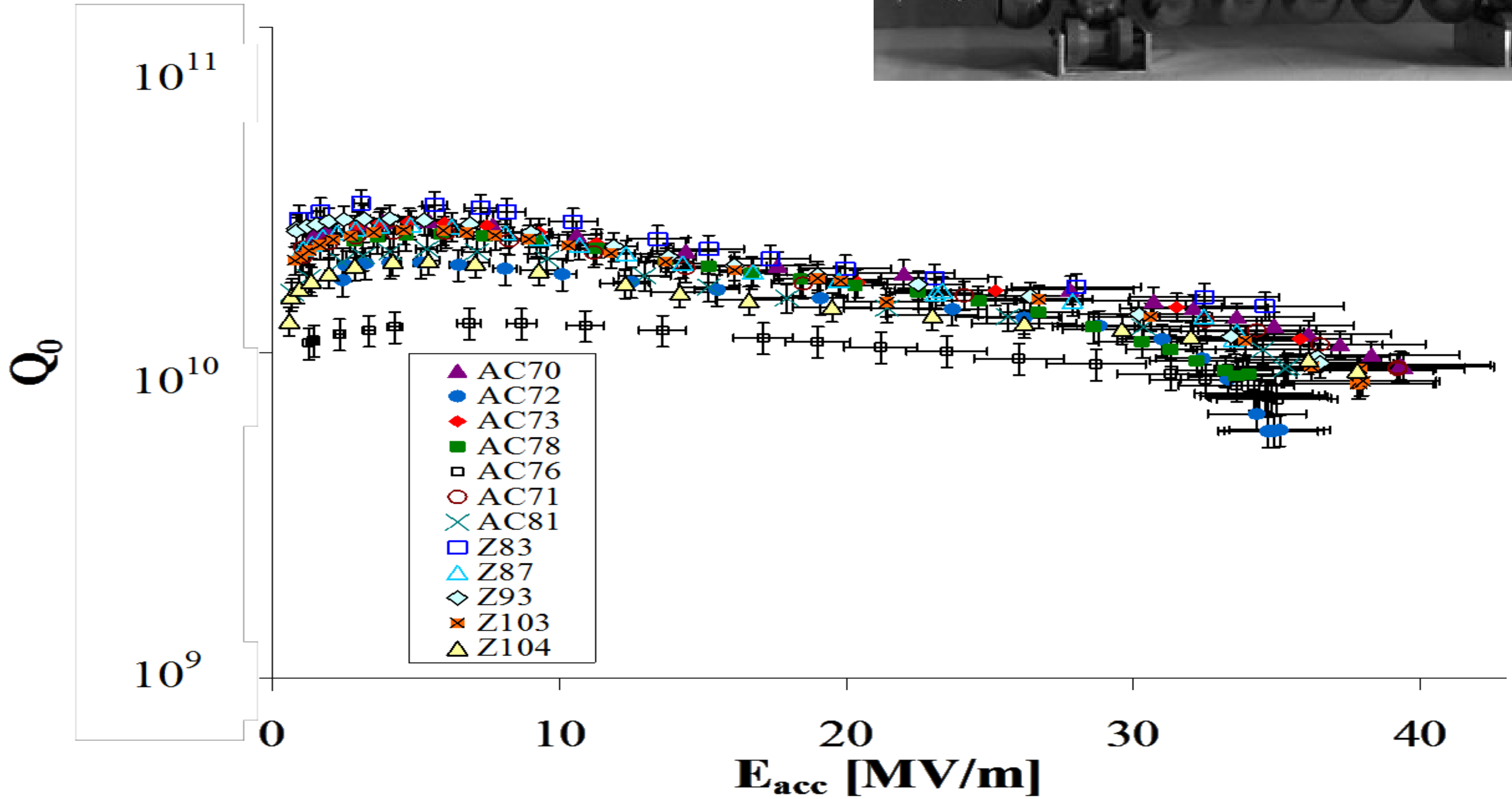
Why is „Particle-Free“ important?
Dust and Particulates in Particle Accelerators

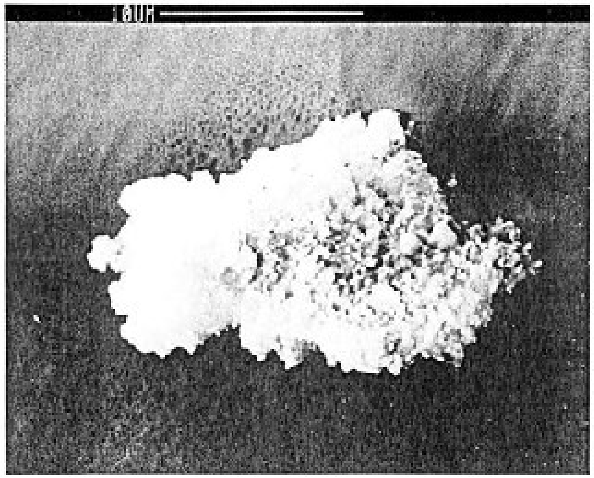
- Dust and Particulates are not just a nuisance
- Several components in accelerators are sensitive to contaminations with particulates
- Severe, permanent performance deterioration might occur in components
- RF or pulsed magnetic fields
  - Superconducting accelerating structures
    - Field emission, thermal breakdown
  - Electron guns
    - Field emission leading to dark current
  - Pulsed kicker magnets
- Mirrors
  - E.g. in photon beam lines
- Complete accelerators
  - Capture of particulates by electron beams
    - Beam life-time reduces drastically
  - Beam aborts due to falling particles

Superconducting Accelerating Cavity Performance

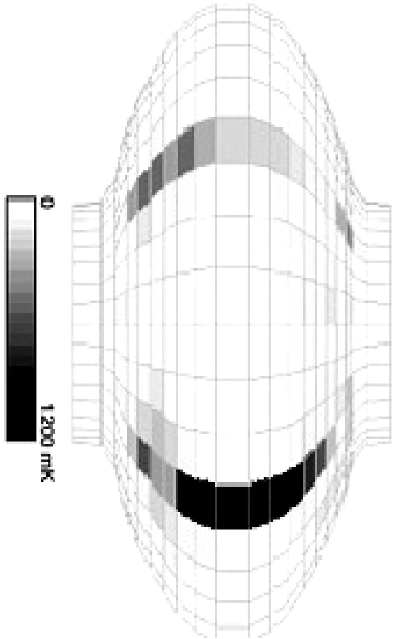


- High quality factor and high accelerating gradient at T=2K
- Very efficient tool to accelerate particle beams even when cryogenic efficiencies are included
- European XFEL uses ~800 of these

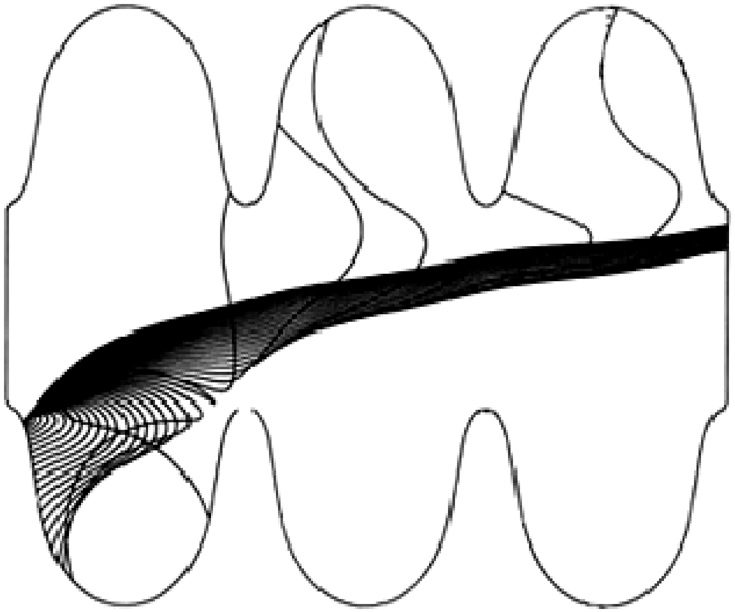
Particulate-related Degradations:
Field Emission in Superconducting Accelerating Caviites



Particle causing field emission



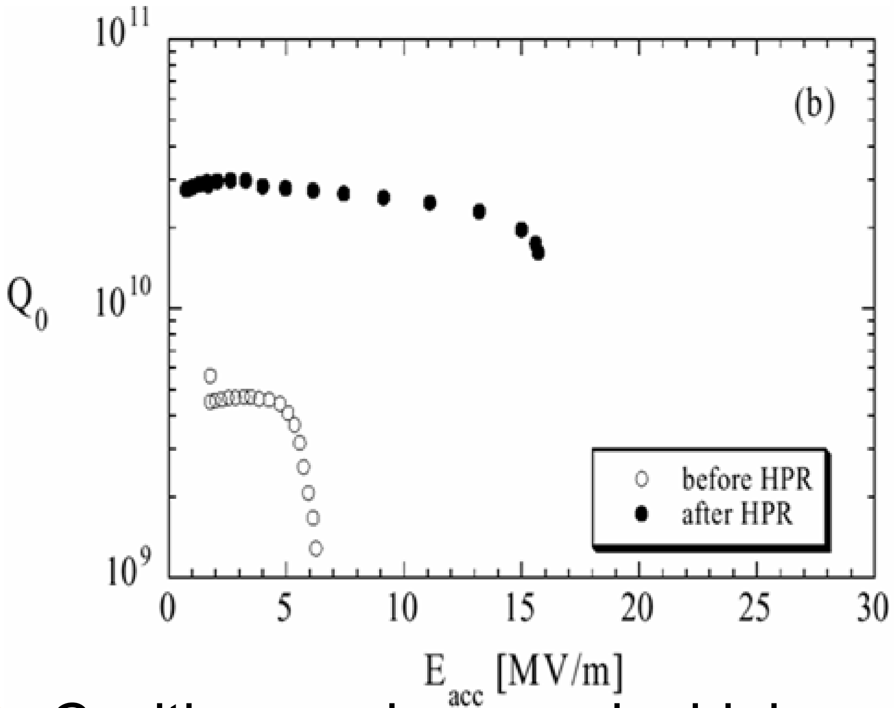
Temperature map of a field emitter

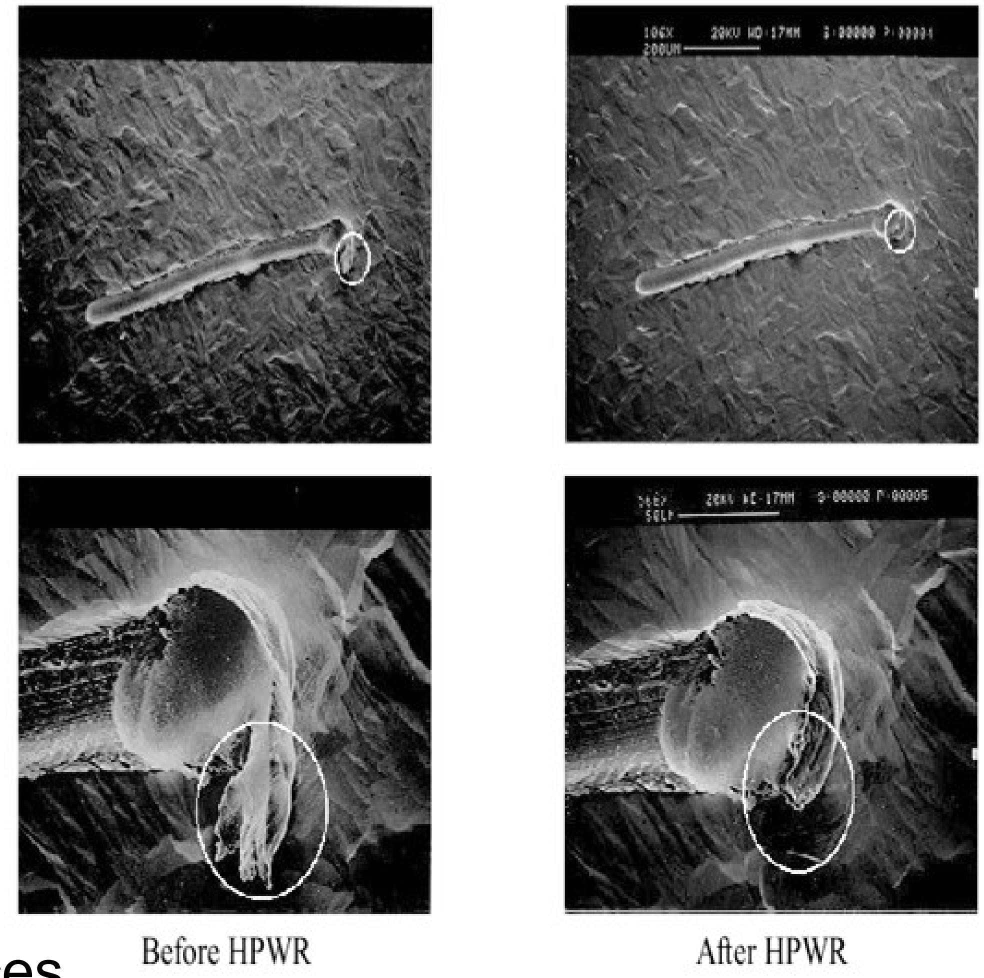


Simulation of electron trajectories in a cavity

Pictures taken from: H. Padamsee, Supercond. Sci. Technol., 14 (2001), R28 –R51

Possible Cures for Field Emission: High Pressure Water Rinsing



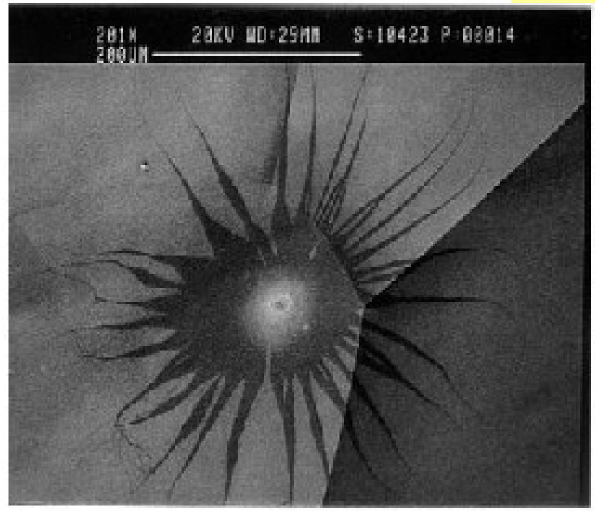


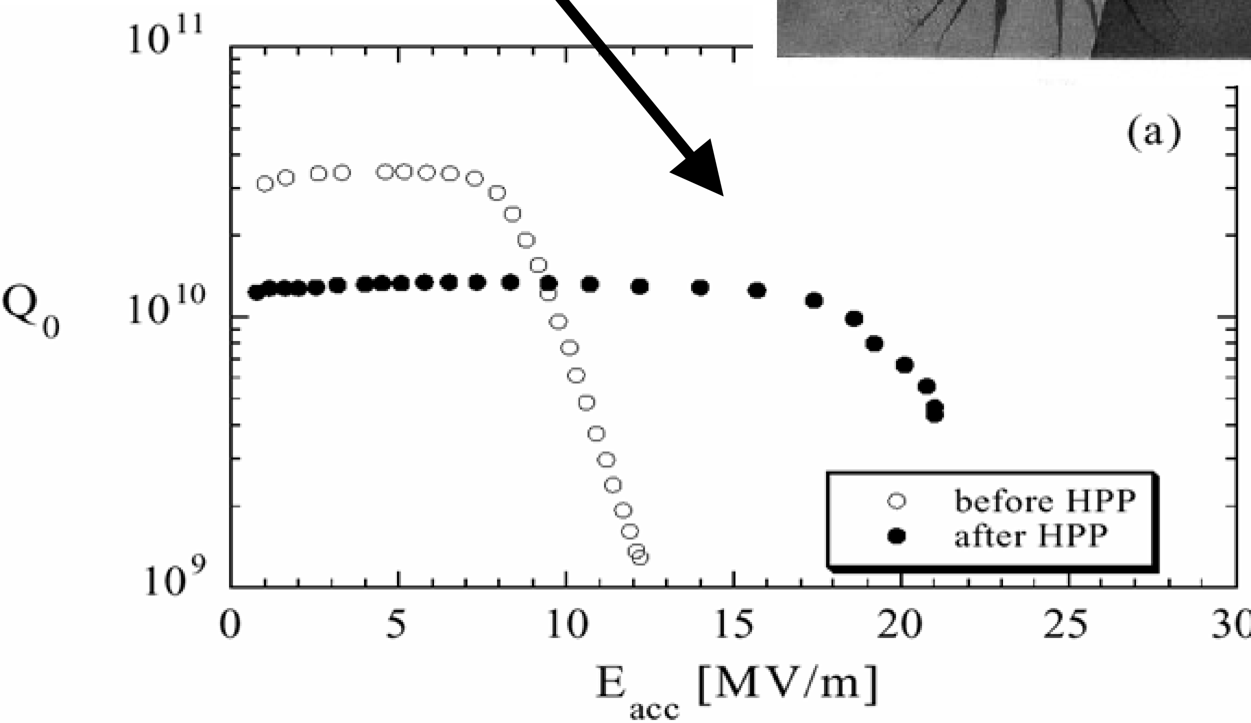
- Cavities can improve by high pressure water rinses
- Particle removal
- Samples show modification of surfaces due to the water jet forces
- Not an In-situ method

Possible Cures for Field Emission: High Power RF Conditioning

SEM Pictures taken from: H. Padamsee, Supercond. Sci. Technol., 14 (2001), R28 –R51

In some cases applying high RF power to the cavity can cause the destruction of field emitters and improve the cavity gradient



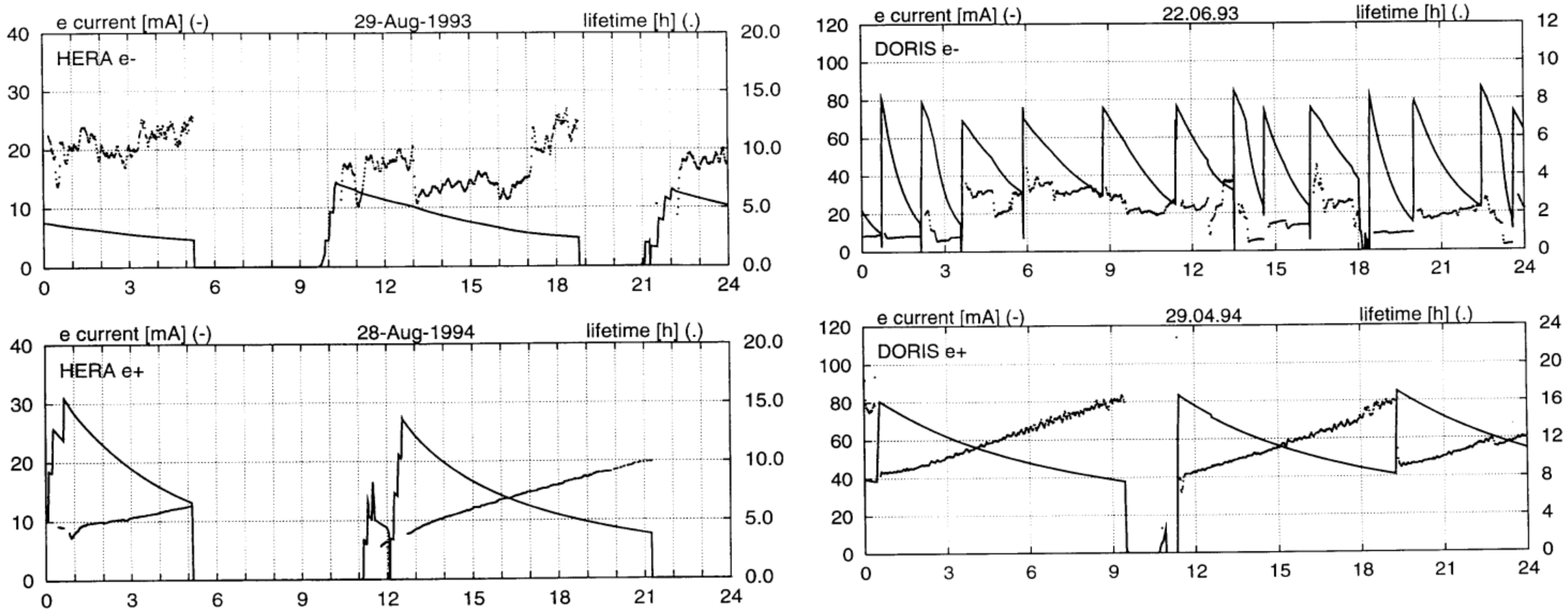


SEM pictures of molten particle after application of high RF power

In-situ processing can sometimes cause new problems

Particulate-related Degradations: Beam Lifetime in HERA and DORIS

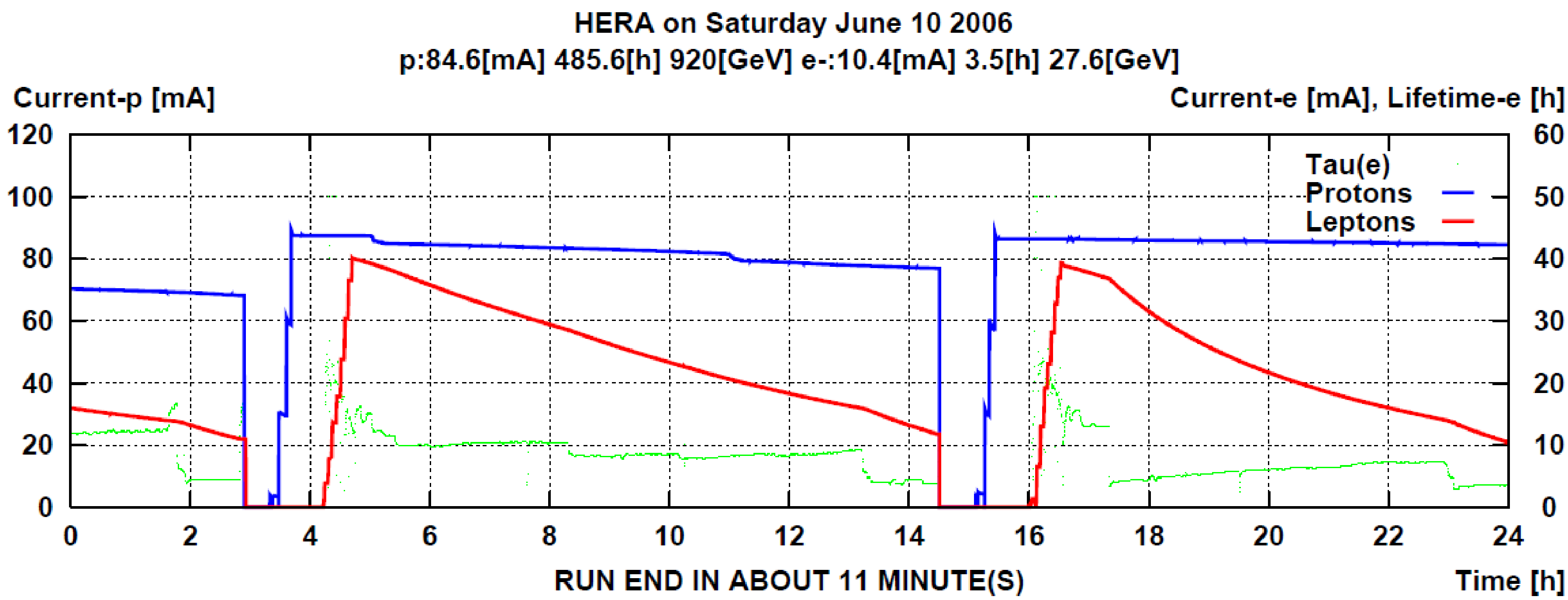
Daren Kelly, Many-Event Lifetime Disruption in HERA and DORIS , DESY HERA 95-02



- When the accelerators where operated with electrons (TOP) beam lifetime showed unexpected degradations.
- Operation with positrons does not show this phenomenon (BOTTOM).

Particulate-related Degradations: Beam Lifetime in HERA and DORIS

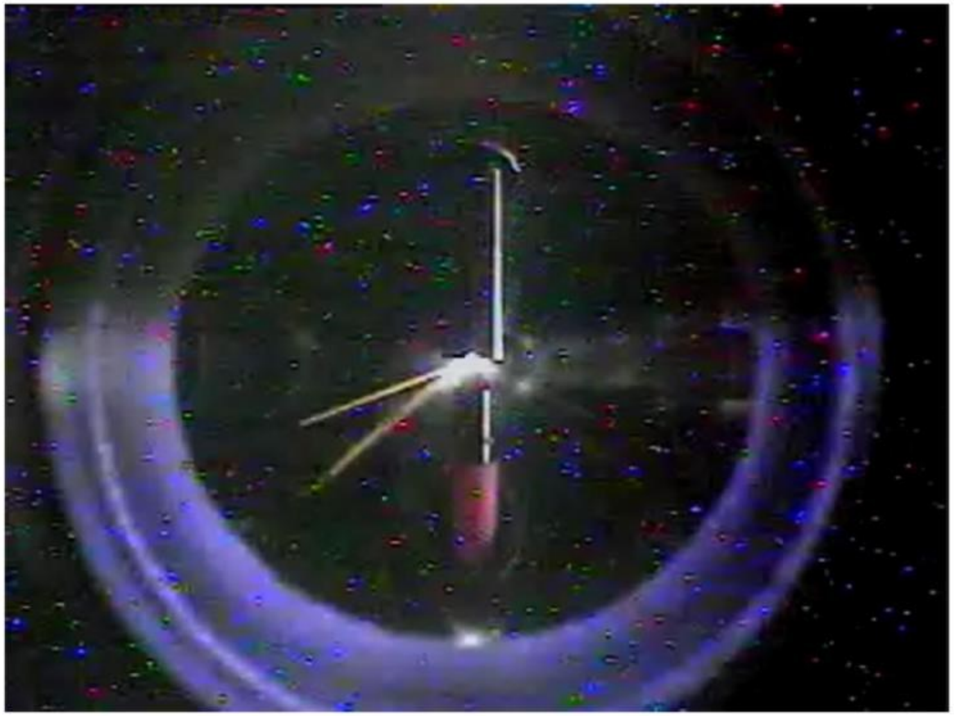
Alexander Kling, Dust particles in HERA und DORIS, EPAC 2006

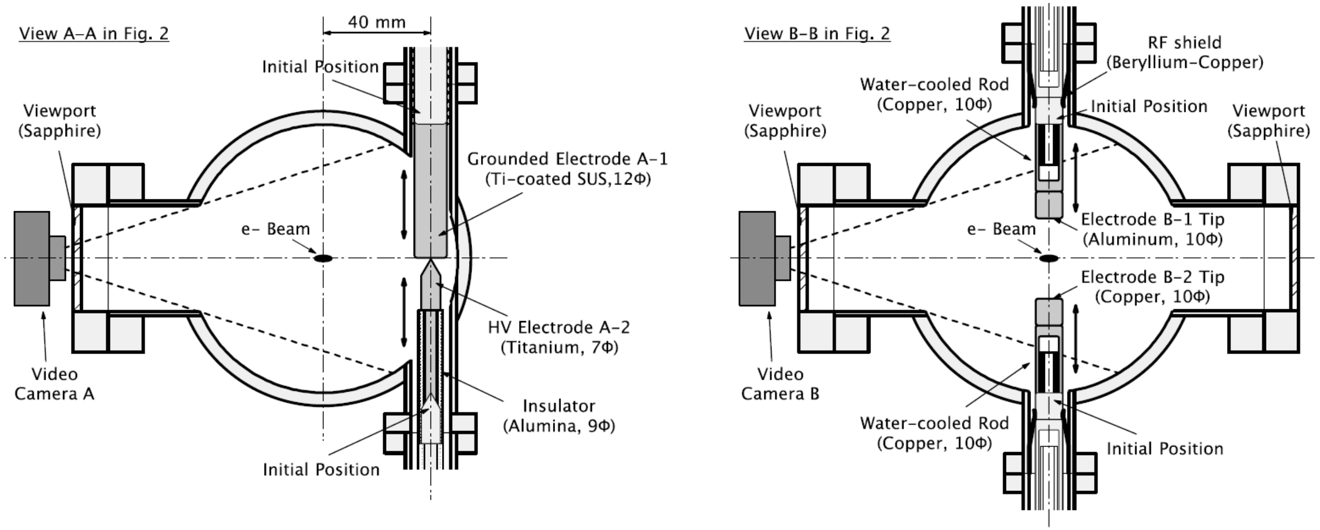


- Events have been traced to positively charged particulates which have been emitted by the sputter-ion pumps integrated in the vacuum chamber.
- Titanium particles have been identified as primary suspect.
- Even after exchange of the chambers to a system with integrated NEG strips the effect could be observed albeit less pronounced
- HERA and DORIS have been operated with positrons most of the time after this discovery.
- Colleagues at KEK‘s photon factory observed it, too.

Particulate-related Degradations: KEK Photon Factory

- Dedicated experiment to demonstrate the effect of dust particles
- Movable electrodes on and off the beam axis
- Picture of a captured particle which evaporates





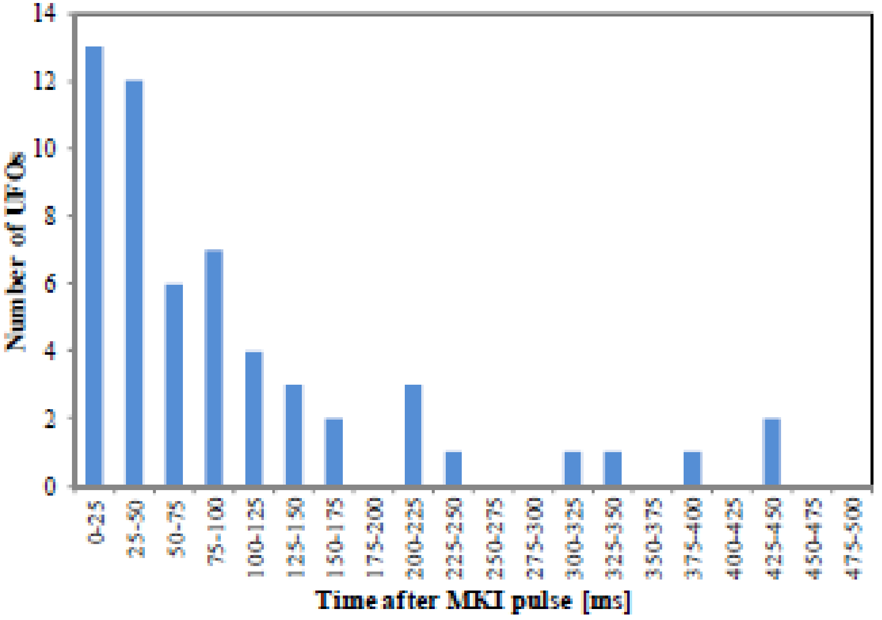
Experimental demonstration and visual observation of dust trapping in an electron storage ring, Yasunori Tanimoto, PRST-AB 12, 110707 (2009)

Particulate-related Degradations: LHC Beam Losses

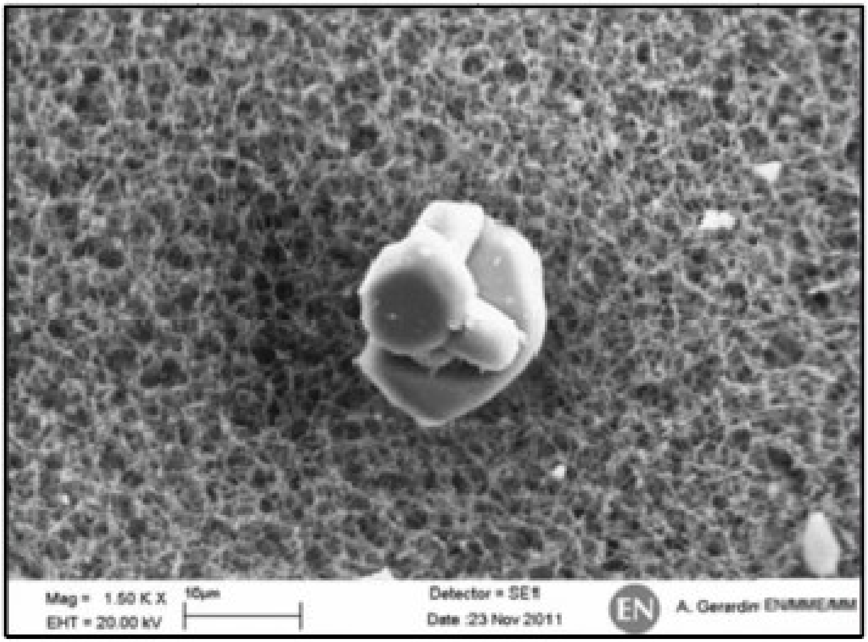
TRANSIENT BEAM LOSSES IN THE LHC INJECTION KICKERS FROM MICRON SCALE DUST PARTICLES

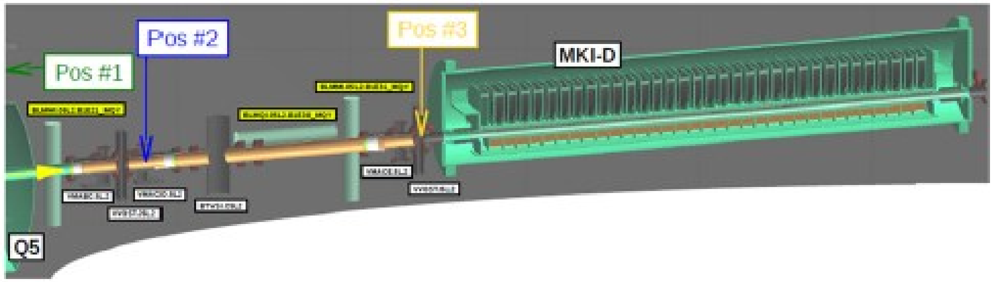
B. Goddard et al., IPAC2012, TUPPR092

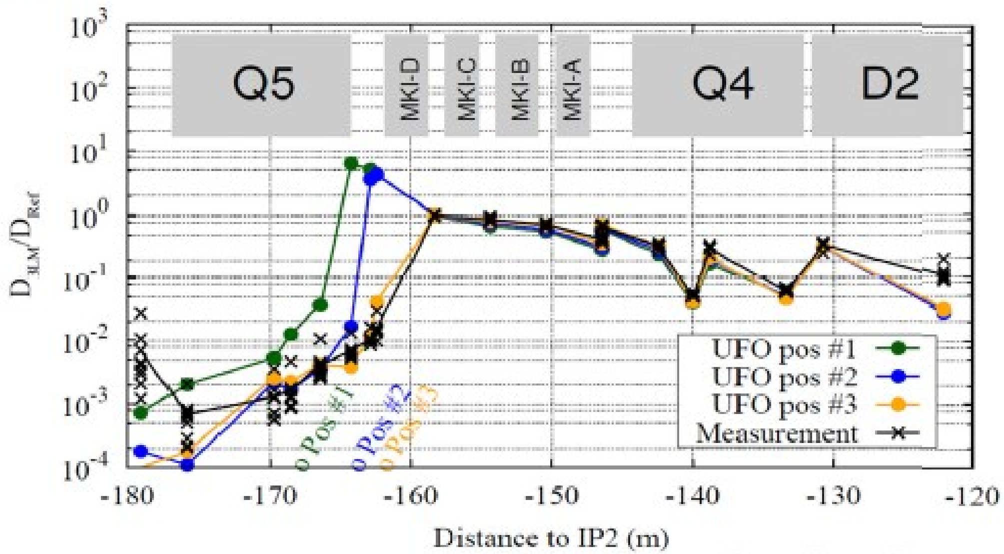
- 2010 and 2011 beam losses leading to 35 protection beam dumps were observed
- With improved diagnostics information of about 7800 suspicious events detected
- UFOs !
  - Unidentified Falling Objects
- 6% of these events could be attributed to the injection kickers which are only 0,06% of the LHC length
- Other kickers were not showing is anomaly
- Clear correlation to kickers being pulsed



Particulate-related Degradations: LHC Injection Kicker



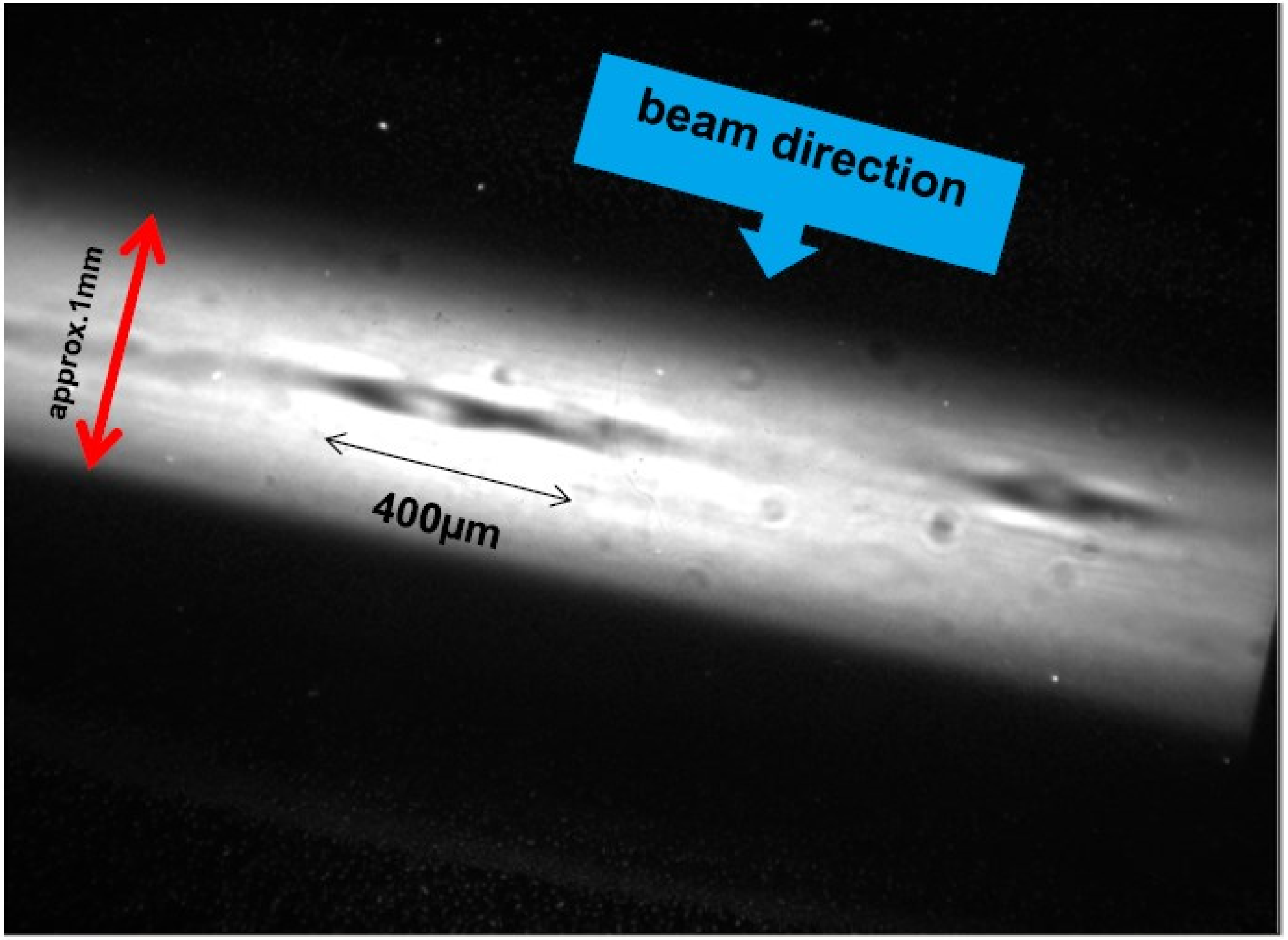




- Added beam loss monitors confirm location
- Kicker vibrates when pulsed
- Aluminum oxide particles were found in abundance after one item removed from the accelerator
  - Other kickers have metallic coating

Particulate-related degradations: X-ray Monochromator

- Photon beam at PETRA III
- Particles on the monochromator can be clearly identified.
- This area cannot be used anymore



monochromator crystal @ P10 PETRA III

M. Hesse, Clean Vacuum Systems, OLAV V

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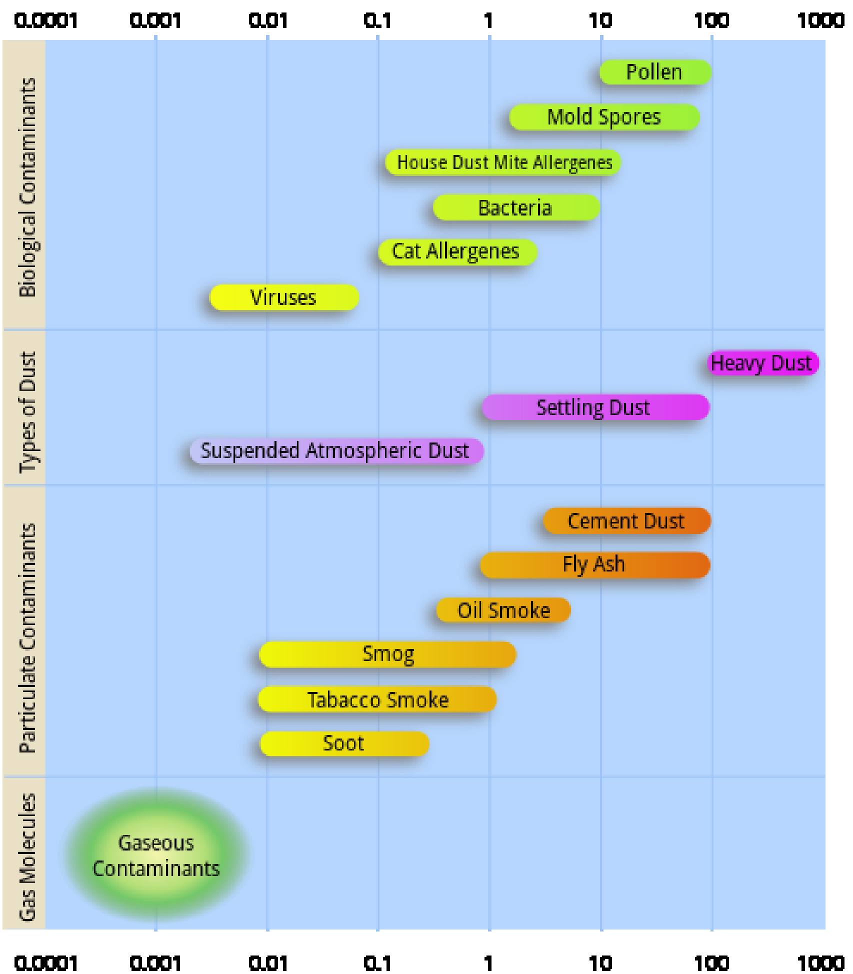
Origin of Particulates: Know your enemy….

> Particulates are from several origins

- Air pollution
  - Sahara, Diesel engines etc.
- Fabrication
  - Machining, Drilling etc.
- Assembly
  - Humans, friction
- Operations
  - Friction, Charging, Aging

> Particle Properties

- Size, Mass and Forces are very diverse
- Nonetheless these help to develop countermeasures



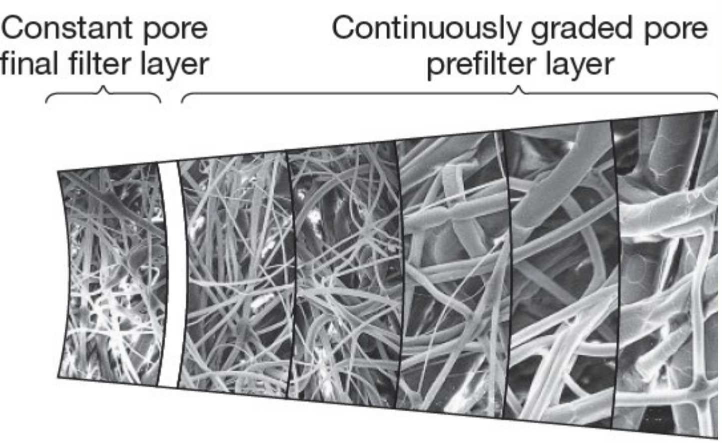
From Wikipedia "Particulates"
Sizes in micrometers

Size of Particulates

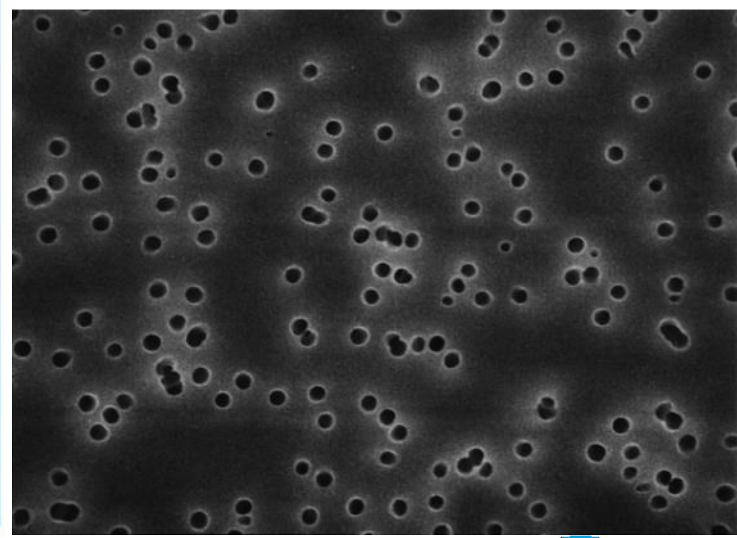
High efficiency particulate air (HEPA) filters , Spring8

- Typical particulates are of micrometer size
- Countermeasures:
- Filter media like air and process fluids appropriately
- Depth and membrane filters
  - 0,3 µm filters are readily available and standard nowadays
  - Air filters i.e. cleanroom environment
  - Filter liquid media
    - Water for rinsing e.g. HPR for superconducting cavities

Examples of depth filter Material, PALL brochure



Membrane filter 0,4 µm , Merck/Millipore

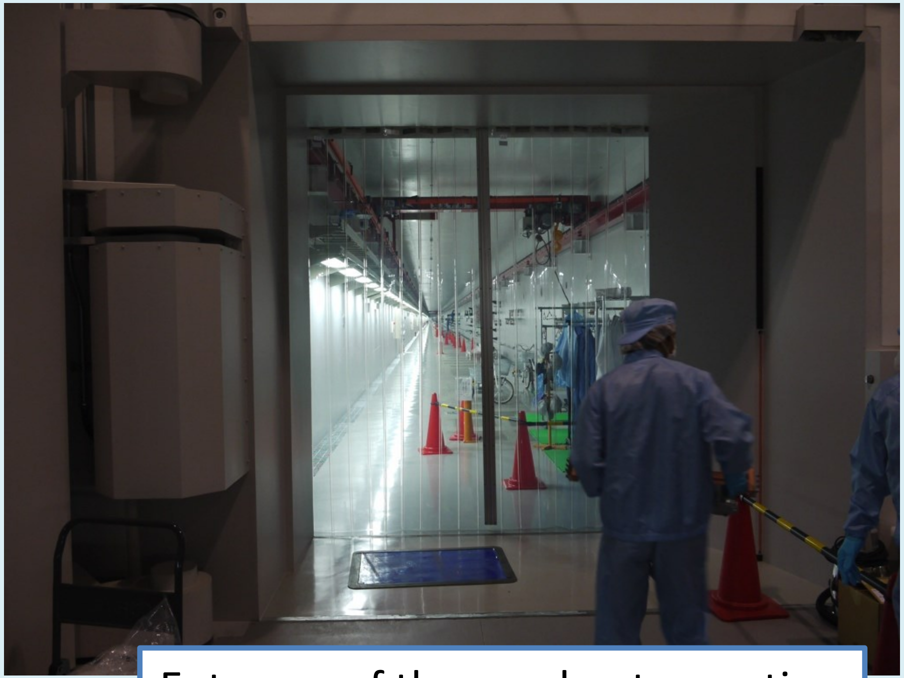


ISO 14644-1 Cleanroom Standards

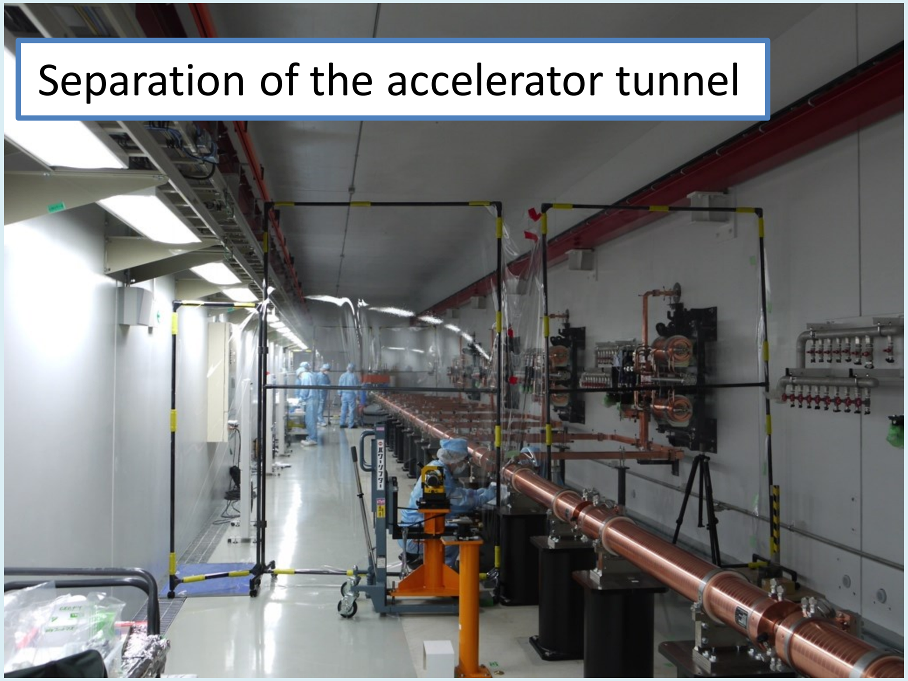
Class	maximum particles/m³						FED STD 209E equivalent
	≥0.1 µm	≥0.2 µm	≥0.3 µm	≥0.5 µm	≥1 µm	≥5 µm	
ISO 1	10	2.37	1.02	0.35	0.083	0.0029	
ISO 2	100	23.7	10.2	3.5	0.83	0.029	
ISO 3	1,000	237	102	35	8.3	0.29	Class 1
ISO 4	10,000	2,370	1,020	352	83	2.9	Class 10
ISO 5	100,000	23,700	10,200	3,520	832	29	Class 100
ISO 6	1.0×10^6	237,000	102,000	35,200	8,320	293	Class 1,000
ISO 7	1.0×10^7	2.37×10^6	1,020,000	352,000	83,200	2,930	Class 10,000
ISO 8	1.0×10^8	2.37×10^7	1.02×10^7	3,520,000	832,000	29,300	Class 100,000
ISO 9	1.0×10^9	2.37×10^8	1.02×10^8	35,200,000	8,320,000	293,000	Room air


Accelerator Installation at Spring8
Partition

Entrance of the undulator section



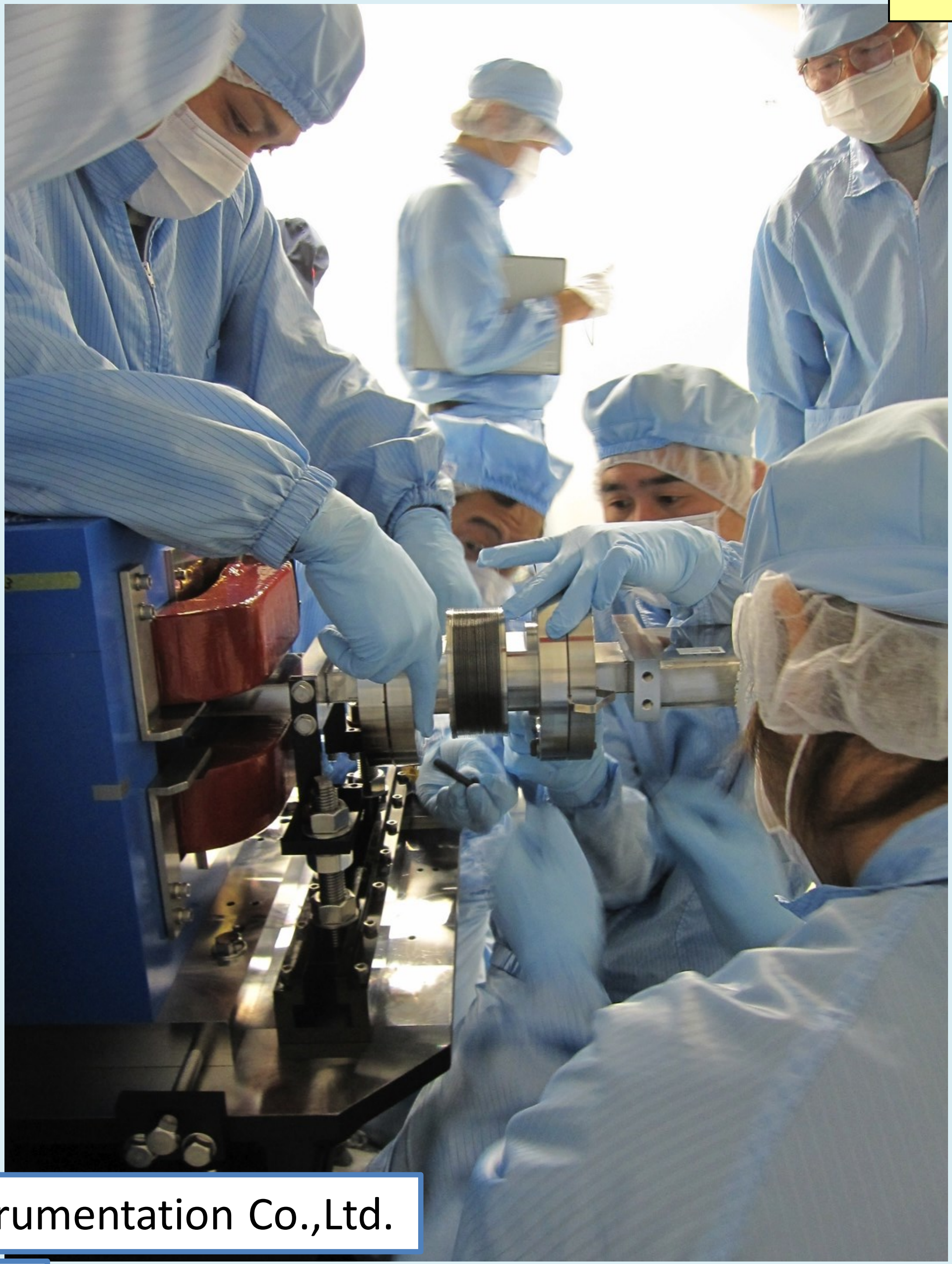
Entrance of the accelerator section



Separation of the accelerator tunnel

Separations of plastic film sheets were set to decrease the dust from outside.

Assembly

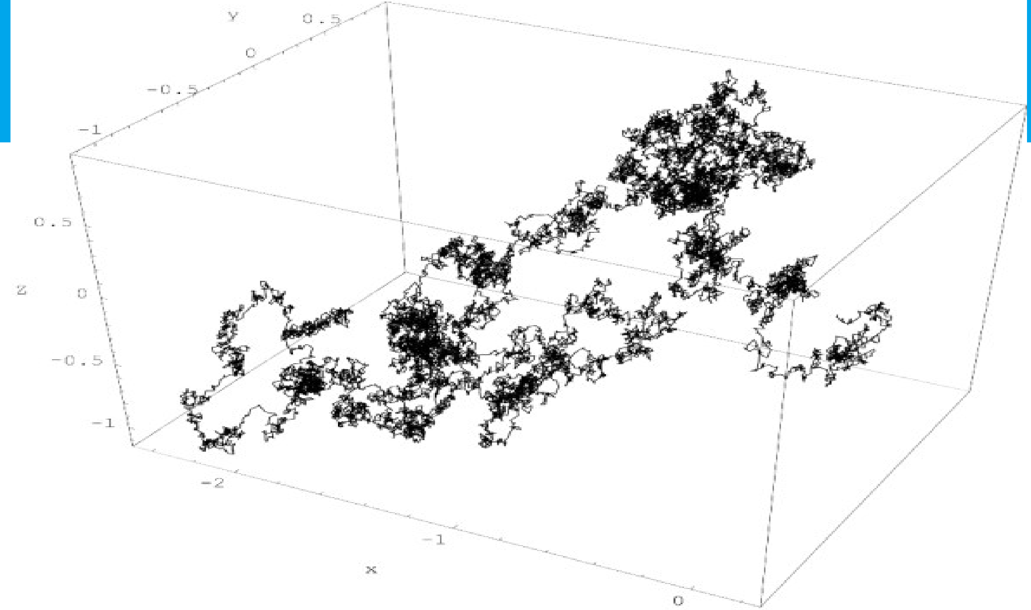


IHI Inspection & Instrumentation Co.,Ltd.

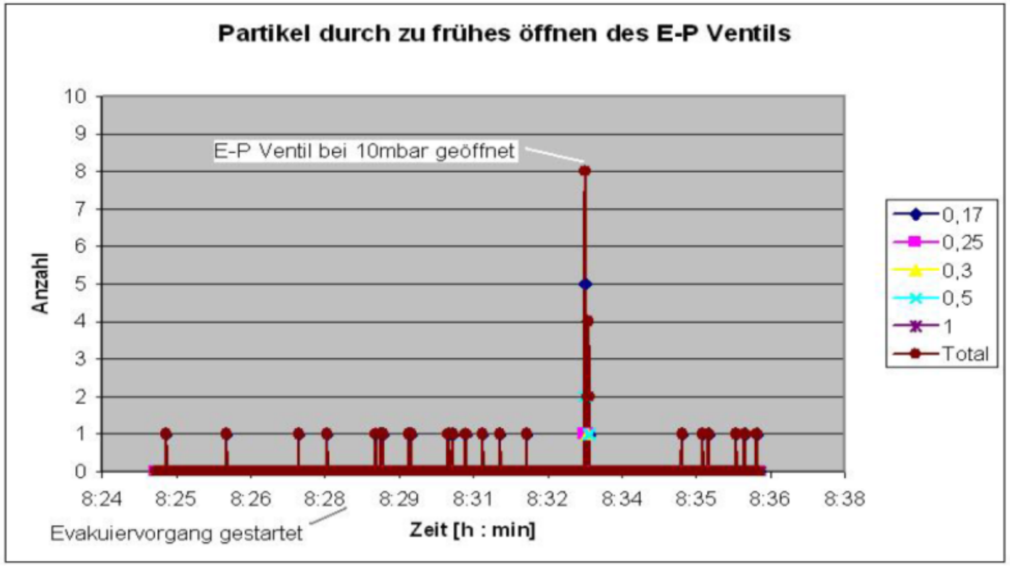
KURIHALANT CO.,LTD.

Mass of Particulates

- **>** They have mass
  - 6,2 mg per m^2 per day …
- **>** In vacuum they fall down
  - A particle needs a few ten milliseconds to traverse a typical beam pipe (if only accelerated by gravity)
- **>** BUT: They have only a small mass
- **>** They will be transported in gaseous media at pressures above 1 mbar.
  - Opening an angle valve at 10 mbar while pumping a system



By Original uploader was Sullivan.t.j at English Wikipedia. - The description as originally from Wikipedia., CC BY-SA 3.0, https://commons.wikimedia.org/w/index.php?curid=2249027

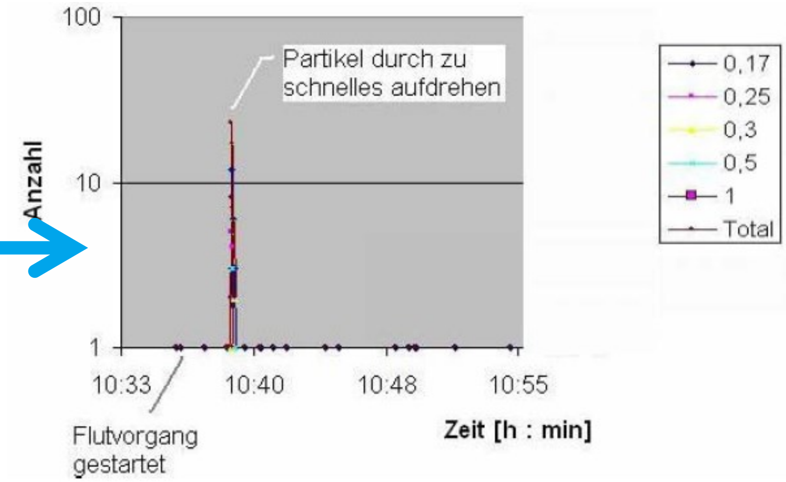


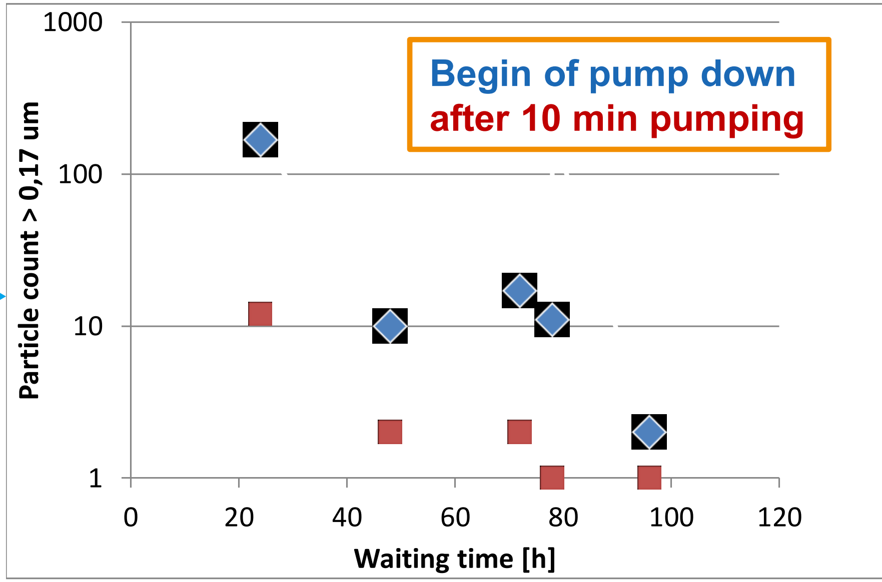
machine vacuum systems

Lutz Lilje

Transport of Particulates

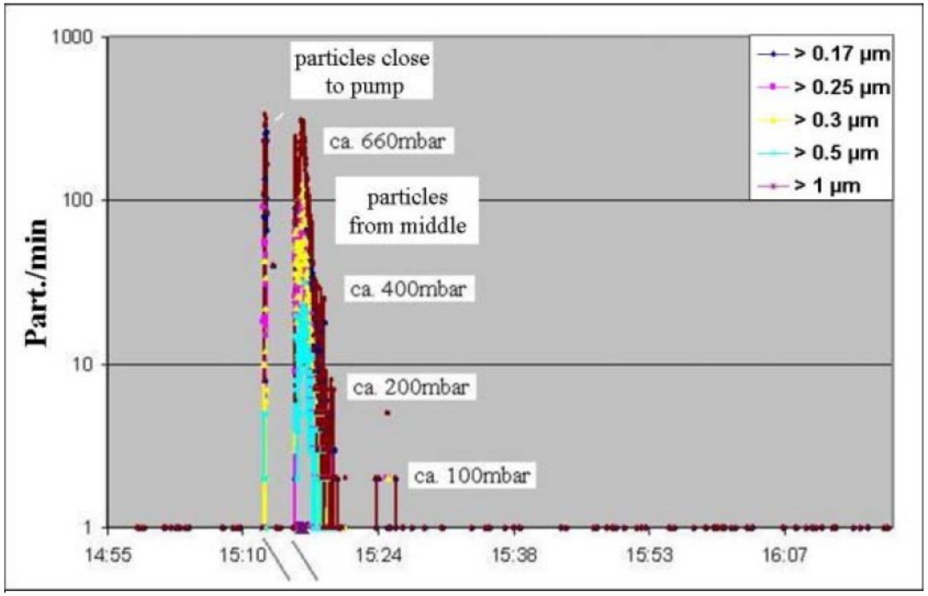
- Particulates can be dislodged from the surface if subjected to …
  - Mechanical vibrations
    - E.g. valve opened too quickly
  - Turbulent gas flow e.g. during pump down
  - Charging up
- Particles can be transported for significant distances in gaseous media even when the gas does not move itself
  - E.g. observation of Brownian motion using dust particles
  - It takes several hours in vented vacuum systems for all particles to settle on the surface
- In vacuum things are very different
  - Particles will fall down and do not move further unless severe vibrations or charge up occur
  - Van der Waals force helps

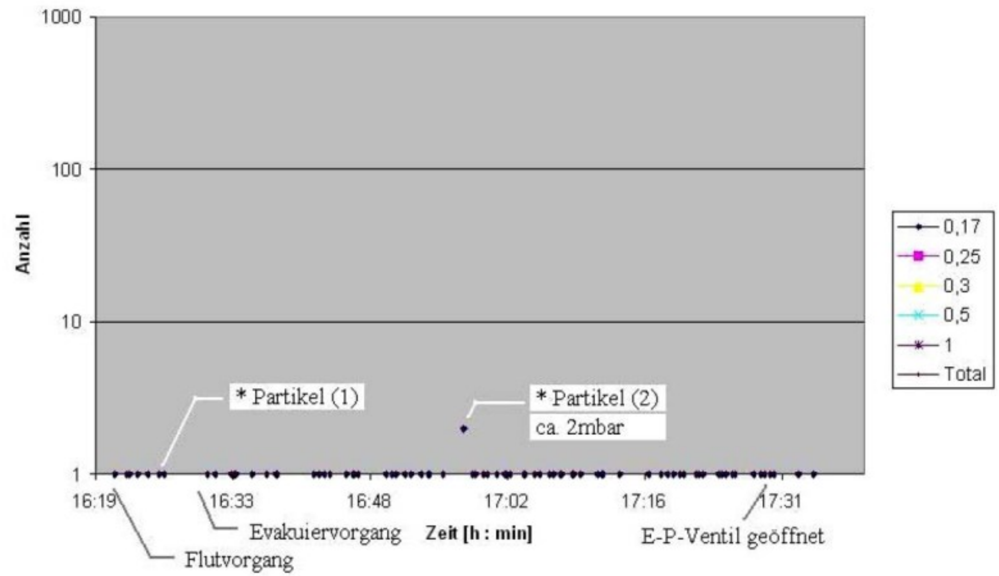




Avoiding Particulate Transport during Pumpdown and Vent

- Particle transport will be avoided by careful operation of the vacuum system
- Avoiding vibrations is mandatory in general
  - When there is no vacuum, this is even more important
- Use laminar gas flow while venting and pumping vacuum systems
  - Avoid turbulences
  - Even with laminar gas flow mechanical vibrations can lead to long distance particle transport

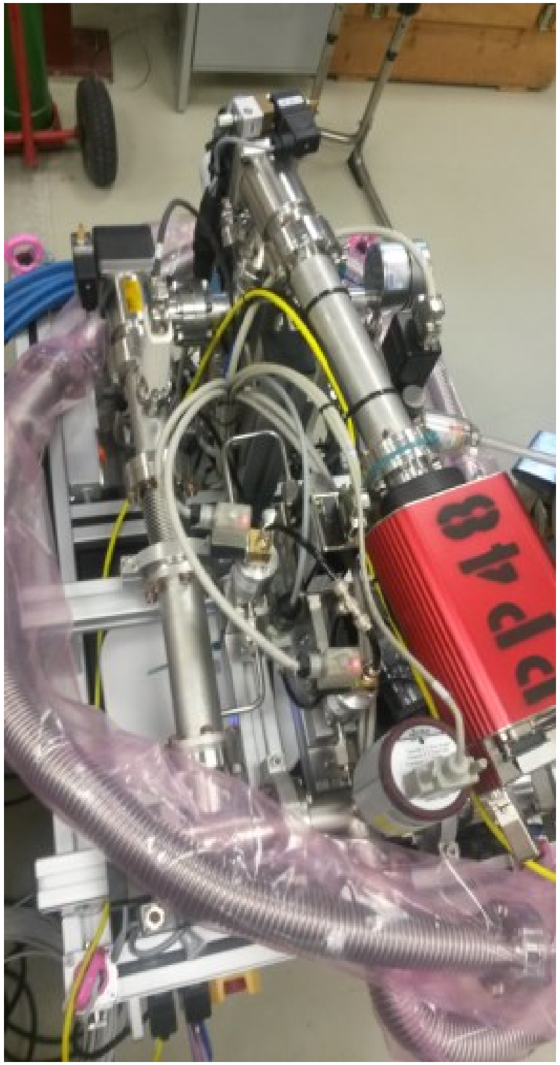




K. Zapfe, J. Wojtkiewicz
SRF2007, WEP74

Venting and Pump Down of "Particle Free" Sections

- There are and always will be particles in the vacuum system!
- Developments of pumping / venting procedures by means on in-vacuum particle counter. No particles are transported if either:
- **Flow ≤ 3 l_n/min, or**
- **Pressure < 1 mbar**
- Automatic pumping / venting units developed
- Constant flow of 3 l_n/min of nitrogen or argon, by means of mass flow controllers.
- Units have been widely used for XFEL



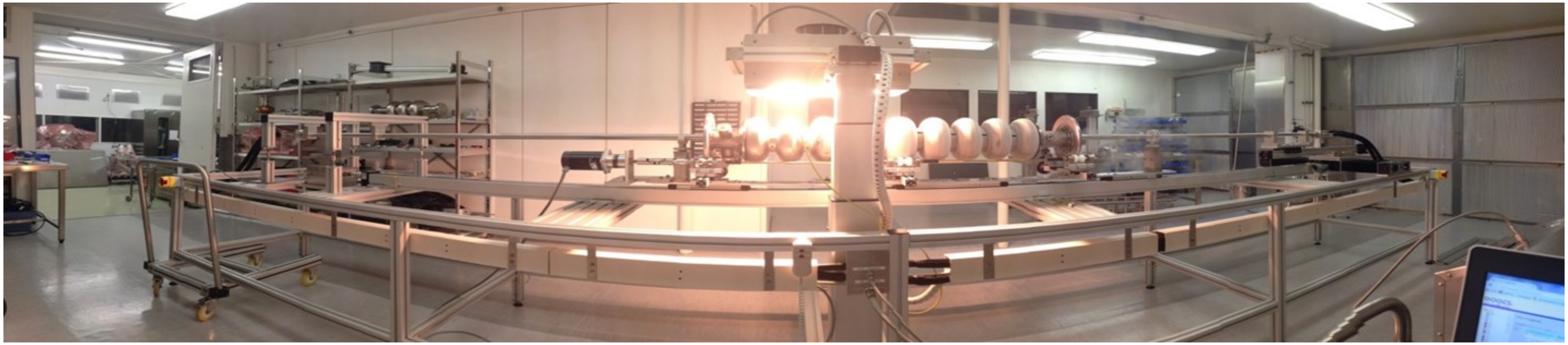
Forces on Particulates

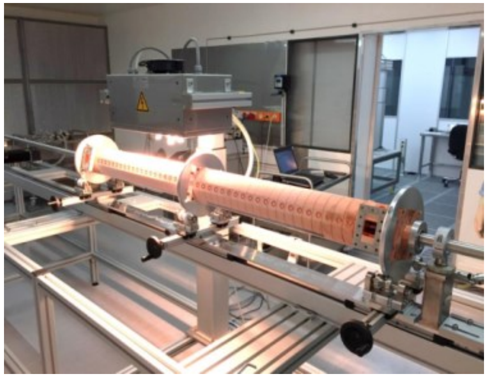
- They stick to the surface: Van der Vaals
- BUT: They can be detached easily by mechanical vibration already
- A vented vacuum system needs more care
  - Particles can be dislodged and moved too places where they might really hurt

- Countermeasures using forces for cleaning:
  - Ionized nitrogen blowing
  - Ultrasonic cleaning
  - High pressure water rinsing
  - Dry-ice cleaning

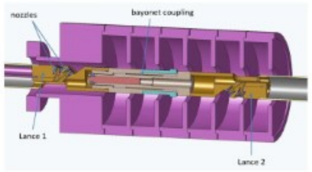
Dry-Ice Cleaning for Normalconducting RF Structures

- Alternative particle free cleaning – esp. applied for normal-conducting RF-structures: dry ice (CO_2) cleaning

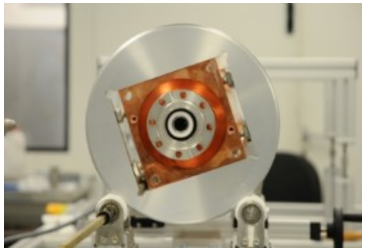




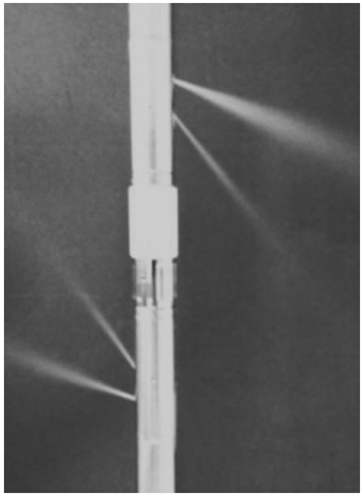
TDS dimensions:
1700mm long, 40mm beam pipe Ø

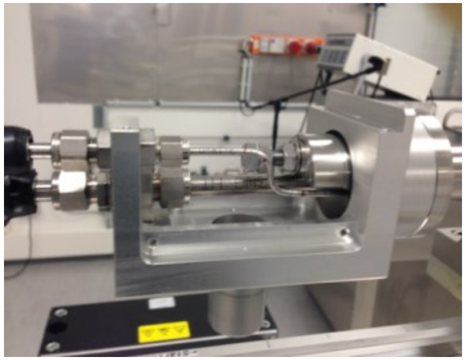


Sketch of 2 coupled lances inside TDS



Frontview of TDS with lance inside (no bending)

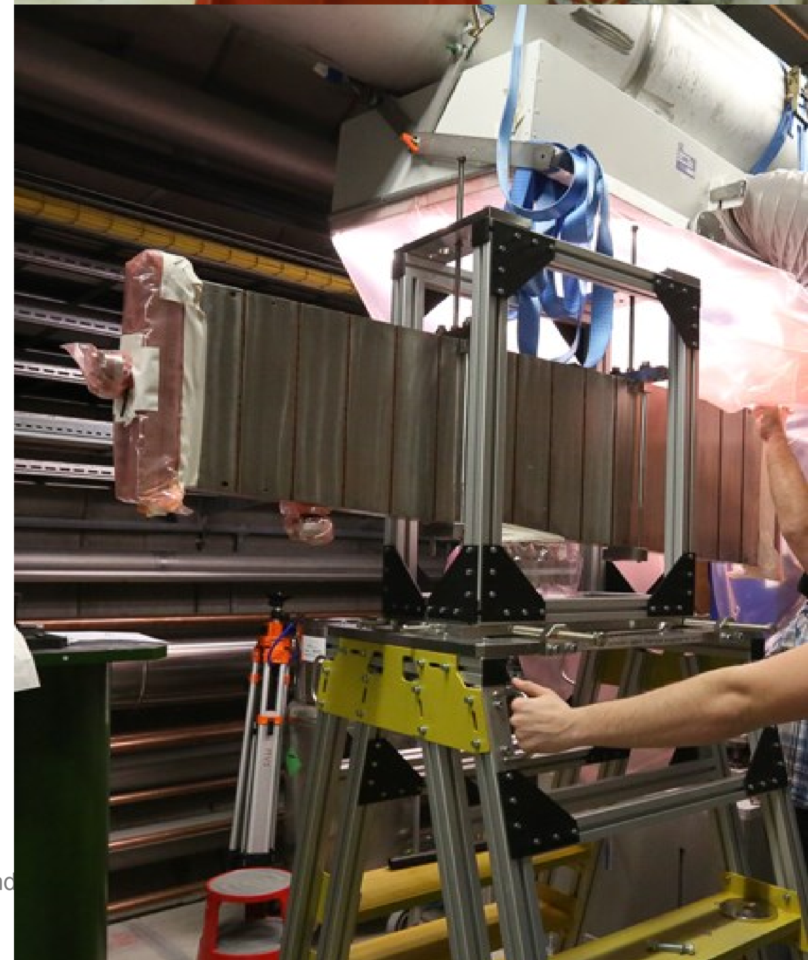




Brinkmann, J. Ziegler, LINAC2016, MOPRC032

Storage and Transport of Cleaned Vacuum Components

- Inside
  - Vacuum
    - Pro: Particulates will not move
    - Con: More effort e.g. additional valves, gauges, pumpdown and venting
    - Justified for the most critical components (cavities and modules)
  - Filtered Nitrogen backfill
    - Pro: Less effort
    - Con: Components more sensitive to particulate transport which have been dislodged by vibration
    - Use for simpler components like bellows
    - Or even not so simple ones….
- Outside
  - Double bagged in antistatic foil



machine vacuum systems

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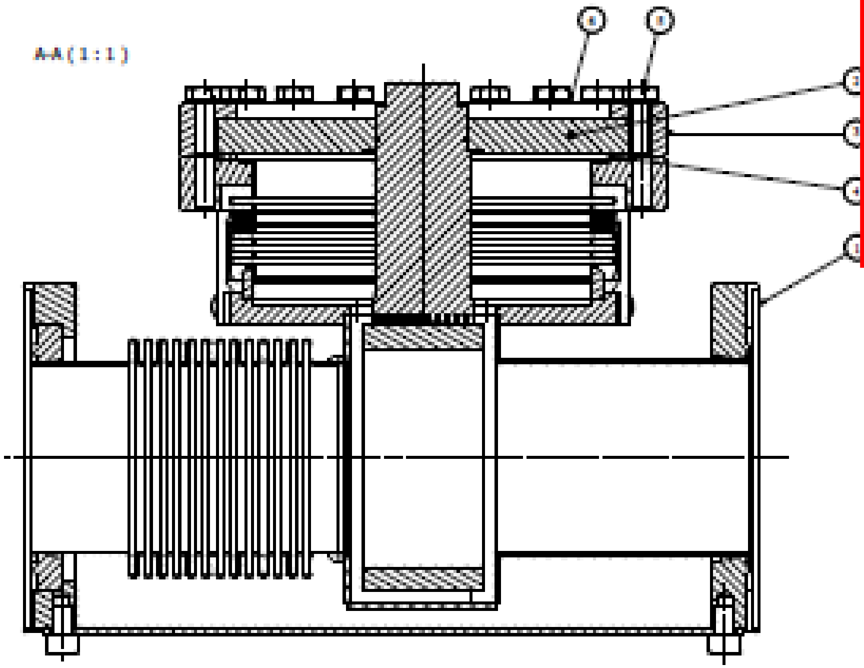
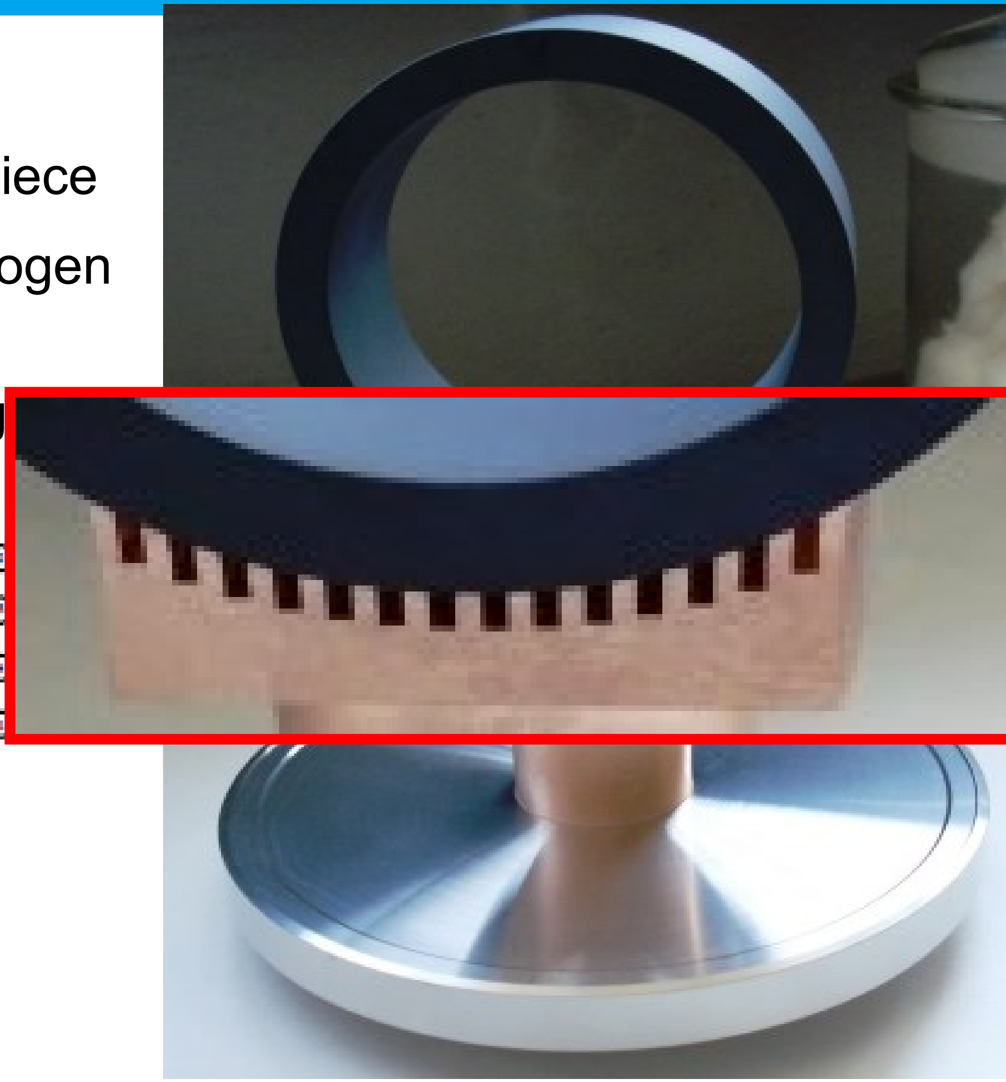
Avoiding Particulates by Better Mechanical Design

- Components have to be compatible with cleaning procedures
  - Using fluids for cleaning
  - Blowing with ionized nitrogen
- Installation environment allows setup of a local cleanroom
  - Reliable, efficient cleanroom setup improves quality and needs less time
- A lot of details to be considered
  - Incomplete penetration welds
  - Welded bellows vs. hydroformed bellows
  - …

Mechanical Design and Particulates

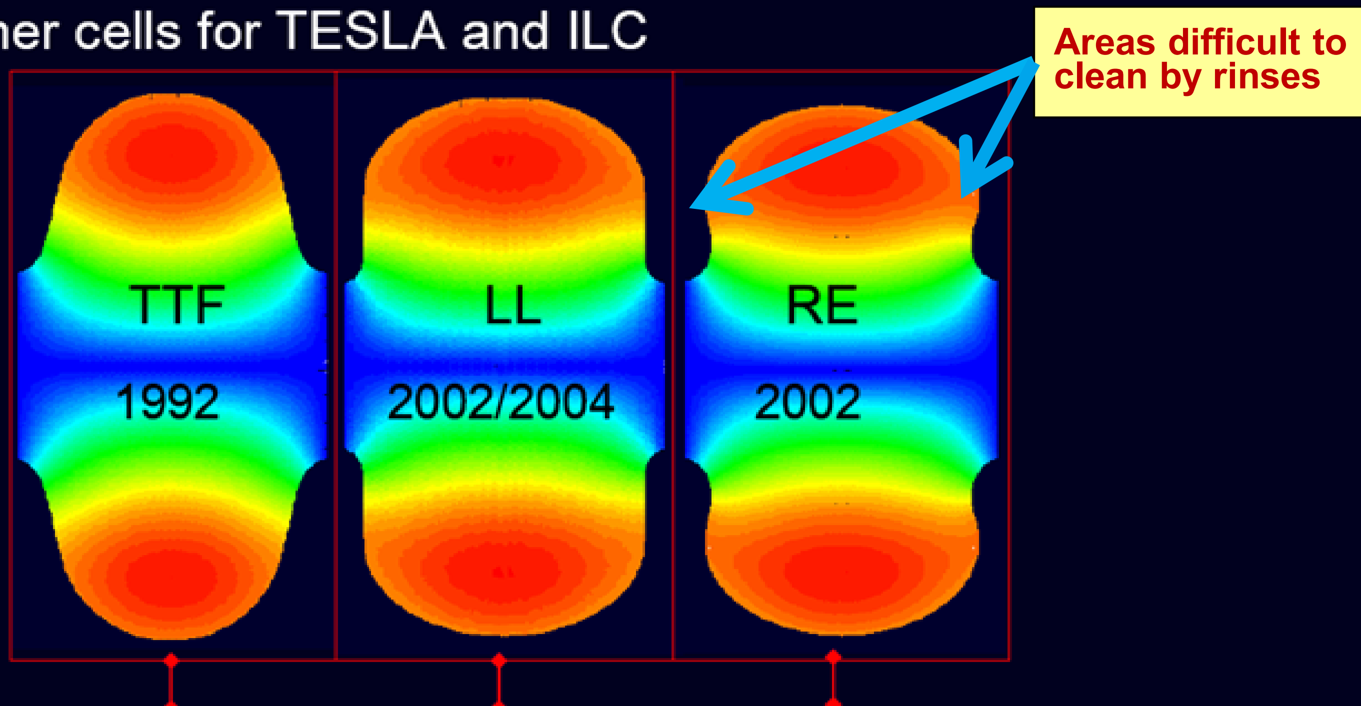
- Broadband RF absorber for XFEL
- Ceramic ring soldered to copper piece
- Difficult to access with ionized nitrogen blowing
- In addition: Fissures in the brazing





Mechanical (and Electrical) Design and Particulates: ILC Cavity Shapes

Example: 1.3 GHz inner cells for TESLA and ILC



r_{irisb}	[mm]	35	30	33	
k_{cc}	[%]	1.9	1.52	1.8	field flatness
E_{peak}/E_{acc}	-	1.98	2.36	2.21	max gradient (E limit)
B_{peak}/E_{acc}	[mT/(MV/m)]	4.15	3.61	3.76	max gradient (B limit)
R/Q	[Ω]	113.8	133.7	126.8	stored energy
G	[Ω]	271	284	277	dissipation
R/Q*G	[Ω*Ω]	30840	37970	35123	dissipation (Cryo limit)

Outline

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- Cleaning and Keeping Components clean
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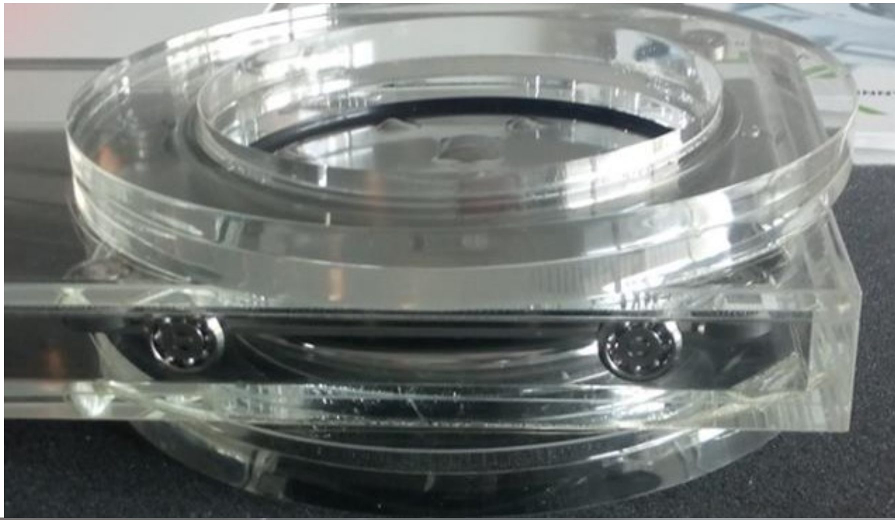
- **Particulate Production in Accelerators**
- Building a „Particle-free“ accelerator
  - Example: European XFEL
- Segmentation

Particulate Sources in Accelerator Operation

- Accelerator operation inevitably leads to the production of particulates
- Moving components generate dozens to hundreds of particles
  - Diagnostic components e.g. screens
  - Valves
- Movements of valves should be minimised in critical areas
  - Only in emergency
  - Persons entering the area
- RF fingers and sliding contacts
  - Electrical contact required
  - Movements generate particulates
  - Experiences?
- (Beam hitting material)
- Pumps



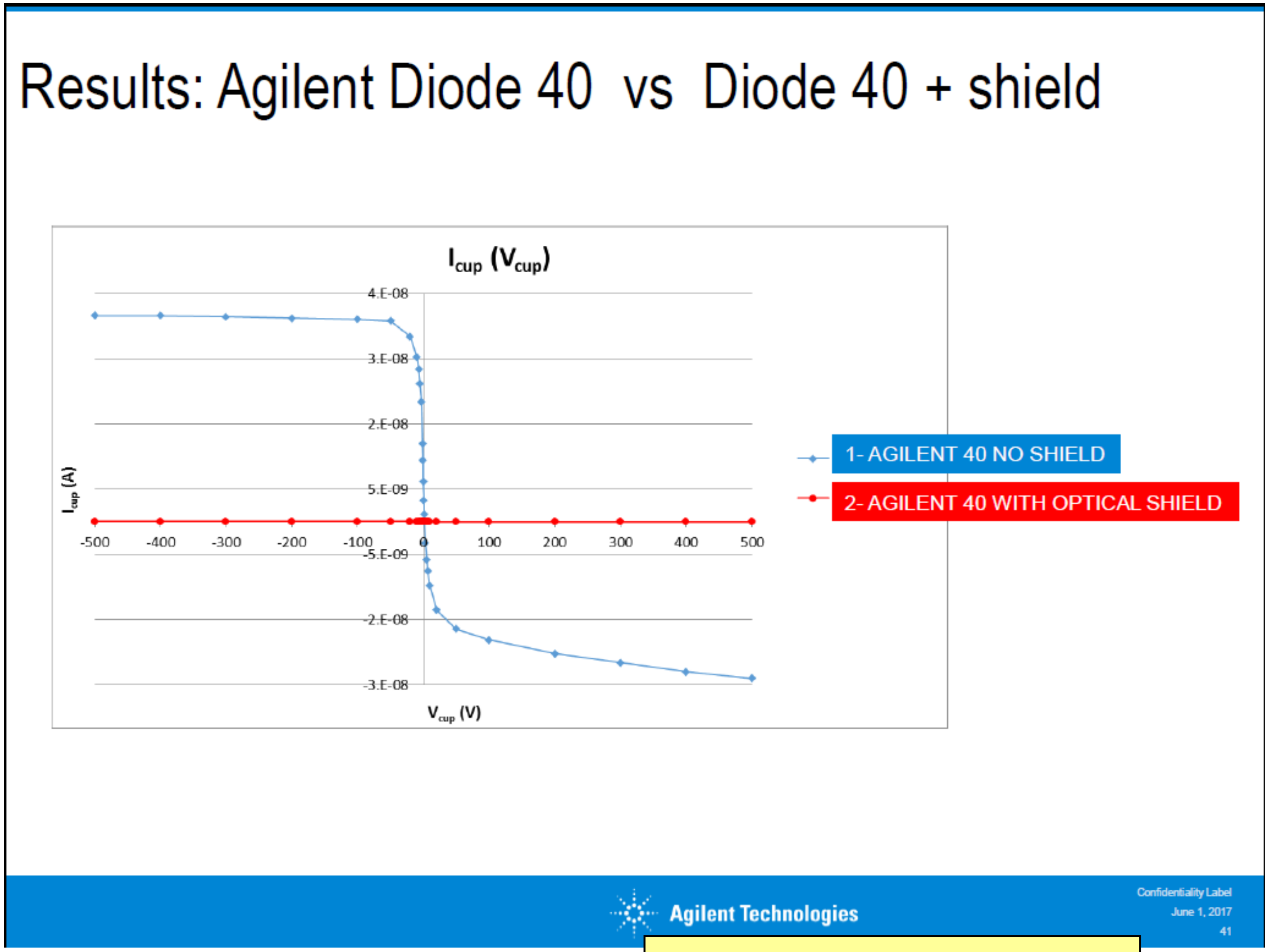
Pumps and Particulates: Mechanical Pumps

- Particle Production is certainly possible
- E.g. Scroll Pumps
- Photo is probably an exaggeration
- With regular maintenance and quality control, scroll pumps have not shown to be an issue (yet)
- Design of the pumping stations is crucial
  - Additional valve for protection mandatory
- DESY has experience during XFEL assembly and installation

Mechanical Vacuum Pumps
H. Barfuss (Pfeiffer Vacuum)

Pumps and Particulates: Sputter Ion Pumps

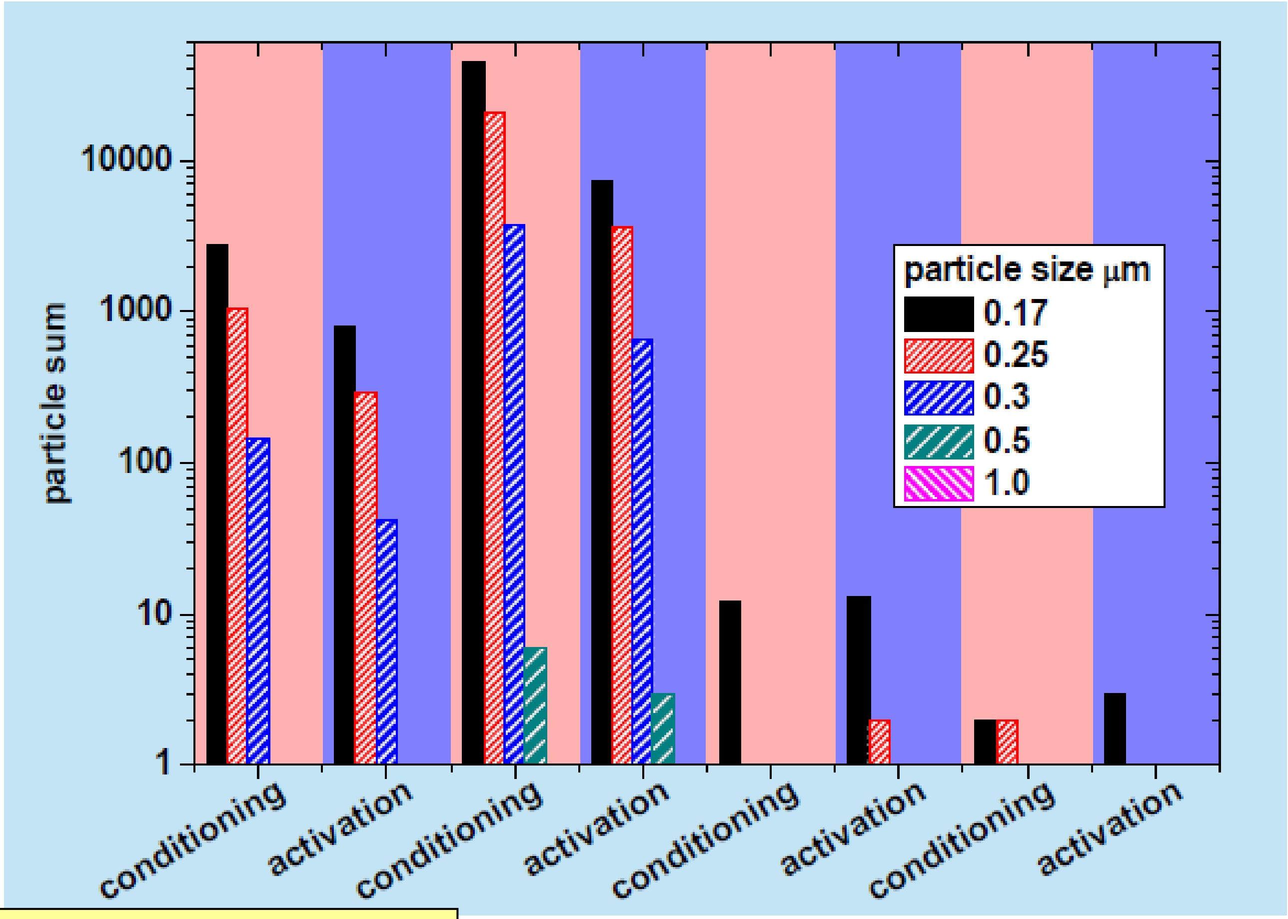
- Have shown problems when integrated into vacuum chambers e.g. HERA
- Standard ion pumps have shown particle production
  - Initial start-up
  - At high pressures
- Measures exist to reduce particle transport e.g. optical shields



Ion Getter Pumps
C. Maccarrone (Agilent)

Pumps and Particulates: NEG cartridges

- Tests on CapaciTorr pumps for several conditioning and activation cycles
- Number of particulates generated is at acceptable levels after 4 repetitions



S. Lederer et al., IPAC 2017

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Basic Rules for a „Particle-free“ Accelerator

- Avoid particulates at every stage and include it in the mechanical design
- Remove particulates at every stage possible
- Do not produce particulates especially during installation and operation
- Never transport particulates

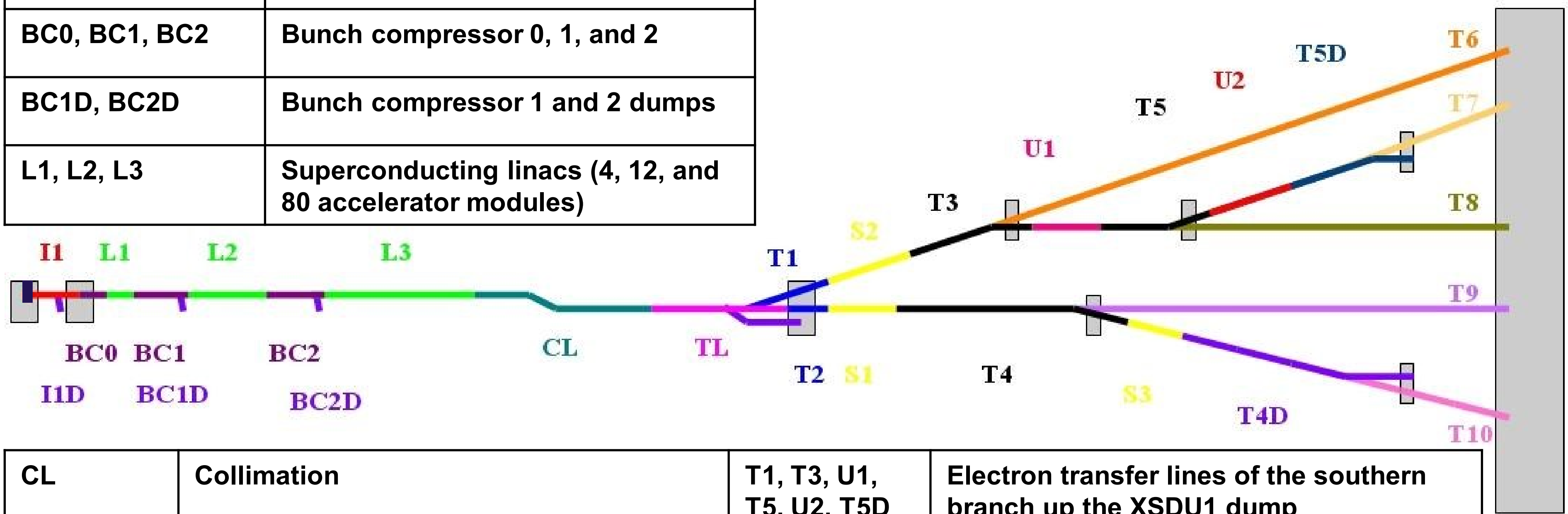
- … be prepared for reasonable compromises!

How to built an „Particle-free“ Accelerator?

- Layout and segmentation
- Design and manufacturing
- Cleaning of components is mandatory
- Handling of components in clean environments is necessary
  - Clean rooms
- Even after clean assembly particulates can be produced in the system
  - Movement of valves, fast shutters, view screens, sliding contacts
- A macroscopic vacuum system of several kilometers will not be completely free of particulates – even when maximum care is being taken.
  - Transport of these particulates must be avoided
- Procedures during operation have to reflect this
  - Controlled slow venting with filtered gas

Example XFEL: Overview

I1, I1D	Injector, Injector dump
BC0, BC1, BC2	Bunch compressor 0, 1, and 2
BC1D, BC2D	Bunch compressor 1 and 2 dumps
L1, L2, L3	Superconducting linacs (4, 12, and 80 accelerator modules)



CL	Collimation	T1, T3, U1, T5, U2, T5D	Electron transfer lines of the southern branch up the XSDU1 dump
TL, TLD	Switch-Yard, electron transfer line to XS1 dump	S2	SASE section of the southern branch
T2,T4, T4D	Electron transfer lines of the northern branch up the XSDU2 dump	T6, T7, T8	Photon transfer lines of the southern branch *
S1, S3	SASE sections of the northern branch		
T9, T10	Photon transfer lines of the northern branch *		

European XFEL

machine vacuum systems

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Example XFEL:
What are critical components and regions?

- RF gun in the Injector
- Superconducting cavities

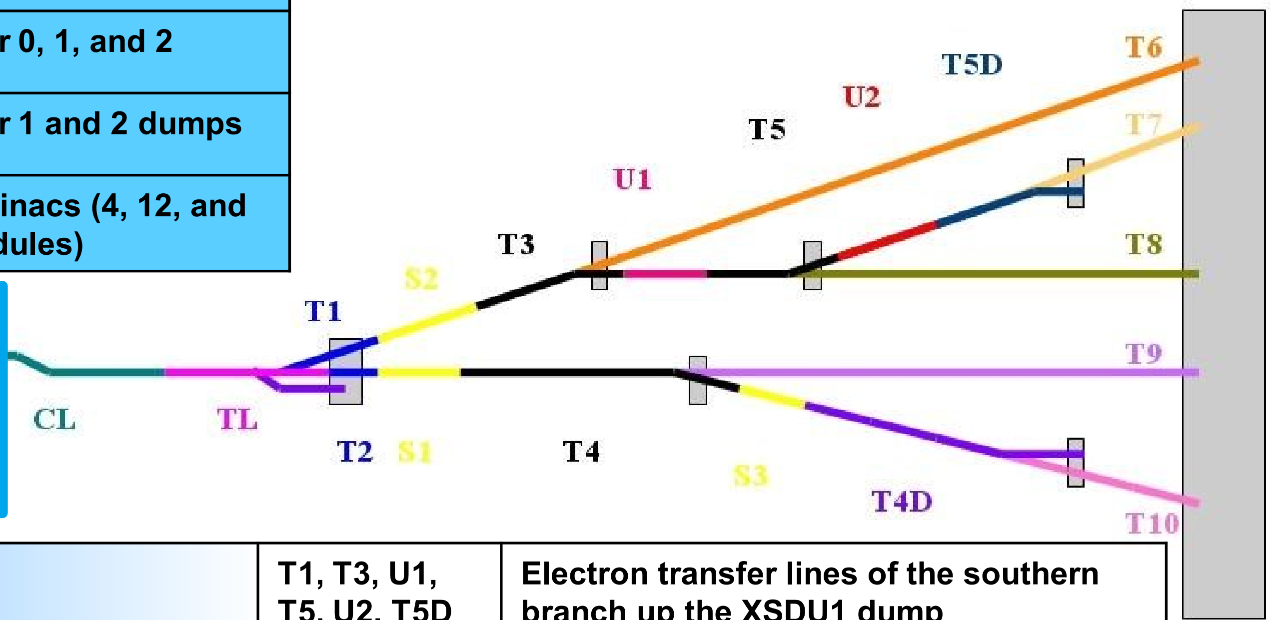
- Kickers?
- Screen monitors?

- How many meters do we keep clean aside from the critical parts?
- One possible answer: 30 m
  - Reaction time of a fast shutter to intercept a pressure wave (in a catastrophic event) is a few tens of milliseconds
  - (You might want to measure that for your system)
  - Speed of sound: 340 m/s
  - Include safety factor


European XFEL
ABB

Example XFEL:
Overview of “Particle-Free” sections

I1, I1D	**Injector, Injector dump**
BC0, BC1, BC2	**Bunch compressor 0, 1, and 2**
BC1D, BC2D	**Bunch compressor 1 and 2 dumps**
L1, L2, L3	**Superconducting linacs (4, 12, and 80 accelerator modules)**



CL	**Collimation**	**T1, T3, U1, T5, U2, T5D**	**Electron transfer lines of the southern branch up the XSDU1 dump**
TL, TLD	**Switch-Yard, electron transfer line to XS1 dump**	**S2**	**SASE section of the southern branch**
T2,T4, T4D	**Electron transfer lines of the northern branch up the XSDU2 dump**	**T6, T7, T8**	**Photon transfer lines of the southern branch ***
S1, S3	**SASE sections of the northern branch**		
T9, T10	**Photon transfer lines of the northern branch ***		

And the X-ray optics areas, too.

Better call Raúl ….

…Villanueva-Guerrero from European XFEL

European XFEL

machine vacuum systems

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Vacuum systems of the XFEL accelerator
Warm beam line vacuum

Requirements from beam dynamics

Except μ_r and RF-shielding absolutely new requirements on an accelerator vacuum system

	Material properties			alignment		RF shielding		**)
	conductivity	rel. magnetic permeability μ_r	R + 50*O	max. step at flanges	max. longitudinal gap	Flanges, bellows, pumps, valves		Average pressure
	μΩcm		nm	mm	mm			mbar
RF-gun (up to L0)	75	<1.01	---	---	---	---		$< 10^{-10}$
I1, BC0, BC1-, BC2-chicane	3	1.01	1250	0.2	0.5	YES		$< 2\ 10^{-8}$ *
I1, BC1, BC2 dump	3	1.05	2000	0.2	0.5	NO		$< 2\ 10^{-8}$
BC1,2	3	1.05	1250	0.2	0.5	YES		$< 2\ 10^{-8}$ *
CL, TL, T1, T2, T3. T4, T4D, T5, T5D, U1, U2	3	1.05	1250	0.2	0.5	YES		$< 2\ 10^{-8}$ *
S1, S2, S3	3	1.01	550	0.1	0.5	YES		$< 2\ 10^{-7}$
Right in front of main dumps	3	1.05	2000	0.2	0.5	NO		$< 2\ 10^{-8}$

(*) close to SRF modules 10^{-10} mbar

(**) In addition all components have to be in accordance to the DESY vacuum specification

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- Building a „Particle-free“ accelerator
  - Example: European XFEL
- **Segmentation**

Particle Cleanliness: Segmentation

- Segmentation is important
  - Pumpdown time needs to be acceptable
  - Efficient leak searches
  - Cleaning of subsections in an optimised environment i.e. normal clean room
  - Steel flanges , plastic caps
- Reduction of types and number of flange connections to be made in the tunnel
  - Better reproducibility
  - Time saving

Particle Cleanliness: Segmentation of Accelerator Modules

Outline

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- **Building a „Particle-free“ accelerator**
  - **Example: European XFEL**
- Segmentation

Particle Cleanliness: Cleaning Procedures

- ALL components mounted in these areas have to be particle free cleaned in addition the UHV-cleaning
  - Superconducting accelerator structures: ISO 4 or better
  - Normal conducting vacuum systems: ISO 5 or better

- Standard wet particle free cleaning process:
  - Ultrasonic bath in ultra-pure water and suitable detergent
  - Ultrasound e.g. 3 to 6 times for 5 min. by short rinsing (at least 1 min)
  - Rinsing with ultra-pure water until a residual bath resistance of > 12 MΩm is reached.
  - Drying in particle-free (better than class ISO 5) air.
  - Alternatively: laboratory washing machine with ultra-pure water and suitable detergents; unloading in a room with class ISO 5 or better.
- Wet cleaning is very efficient and fast
  - Components need to be designed for being compatible with wet cleaning

- Particle Cleanliness: Special Cleaning
  - Components that cannot be cleaned using ultrasonic and rinsing bath (e.g. mirrors, detectors etc.) have to be placed in a clean room in particle-free air flow (better than class ISO 5) for several hours before assembly.
  - Blowing with ionized nitrogen
  - Potentially very time consuming

Particle Cleanliness: Clean Room Facility

- Clean room facility used by MVS in collaboration with photon vacuum group

- Mounting area
- Pump carts for QA
- Lock system for big items

Particle Cleanliness: Quality Checks

- The absence of particles has to be controlled in a clean room class ISO 5 or better. Therefore the components will be cleaned with particle free ionized nitrogen. After 5 minutes using a gas throughput of 28 l/min there should be at maximum 10 particles/minute ≥ 0.3 µm be detected.

- The assembly of components and the joining of vacuum parts has to be performed in a environment according to the specified clean room class. Control with standard particle counters.

- Gaps in flange connections need to be masked on the outside with clean room compatible adhesive tape to avoid particle contamination in the flange area.

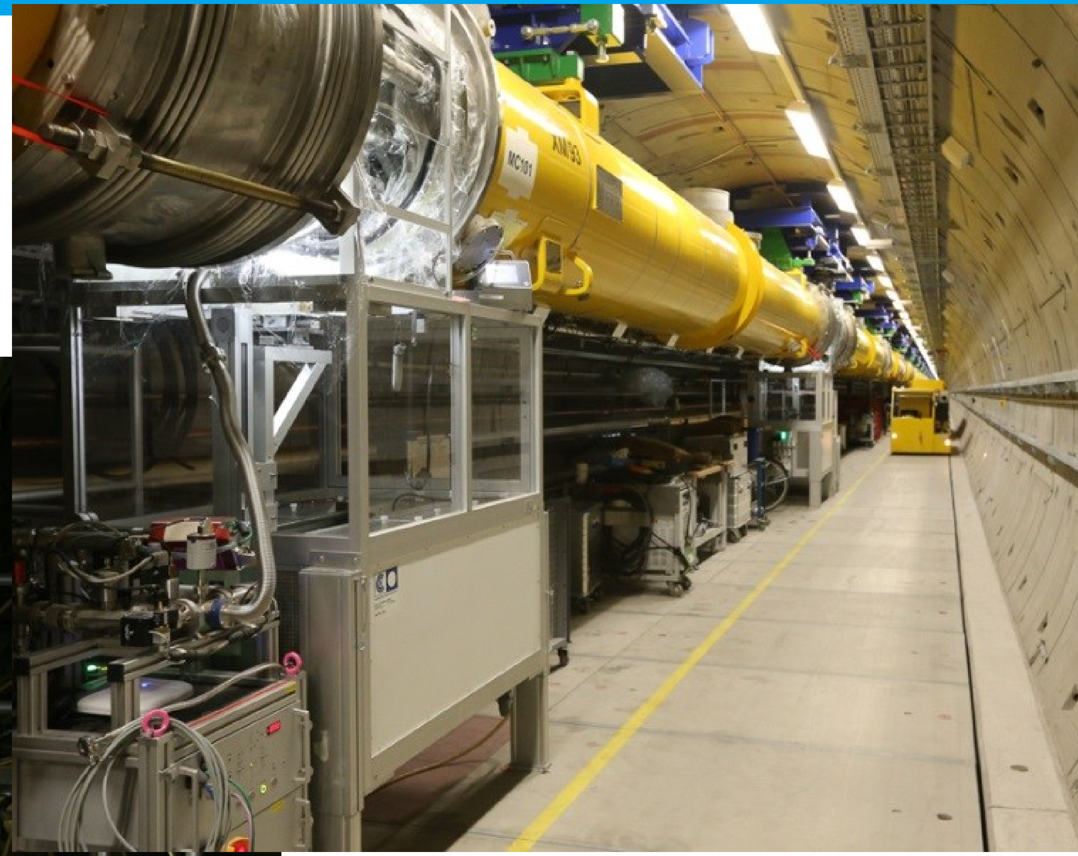
- (Standard vacuum checks: RGA and leak check)

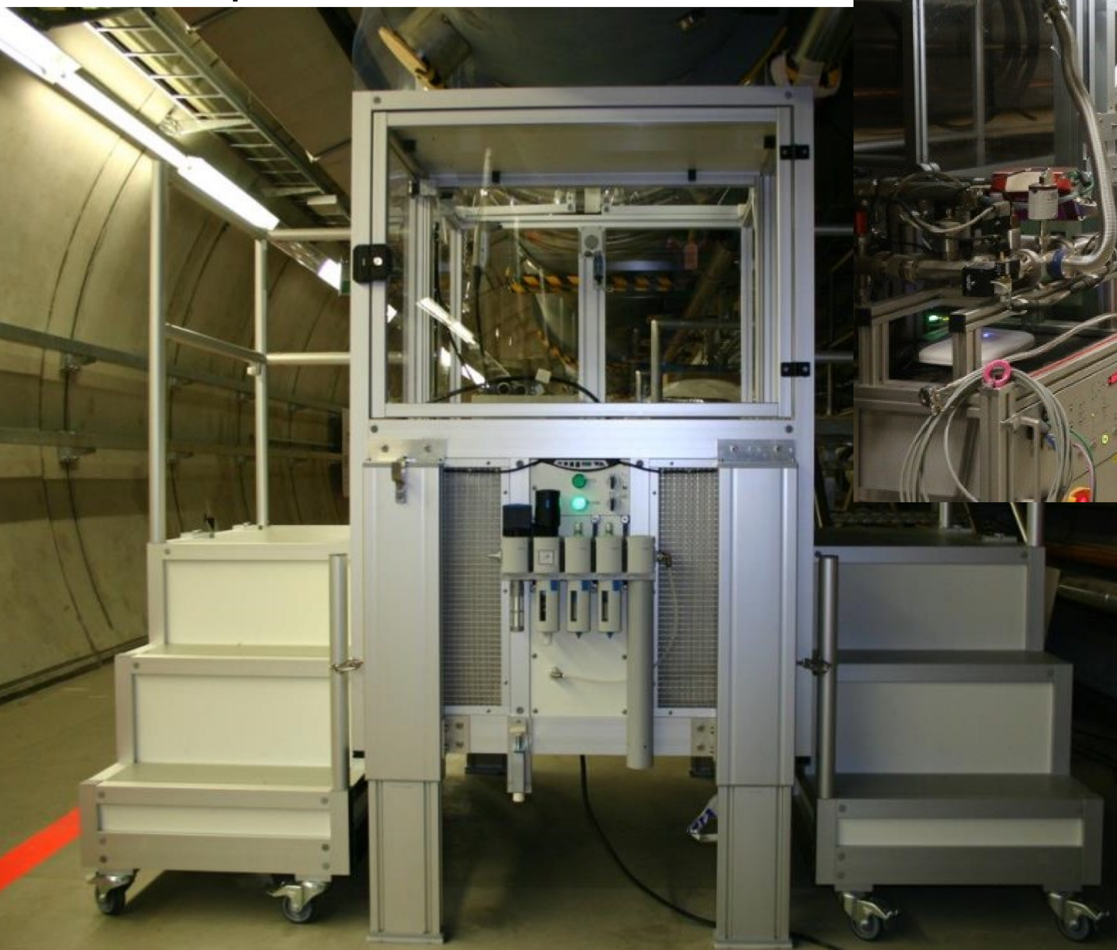
Particle Cleanliness: Installation of “Particle-free” Sections inside the Accelerator

- Installation to be done under local clean room environments
- Direction of clean air flow can be adapted to the needs in the specific location
- Pre-configured local clean rooms are useful
  - E.g. module connection is needed about 100 times
  - Good reproducibility and efficiency
- Flexible clean rooms needed too
  - Good experience with separation of filter unit and ventilation
  - Very high flexibility
- Concept and Size depends on the task
  - Glove-box-like e.g. module connection
  - Sufficient size for people standing inside e.g. bunch compressor chicanes or injector version
  - Space for tools, fixtures etc. not to be forgotten
  - Lighting
- Supporting personnel on the outside always needed

Mobile Clean Rooms: Example XFEL HOM-Absorber

- Air flow from below
- Access from both sides
- Handling system for the component





- Stairs can be removed for transports

European XFEL

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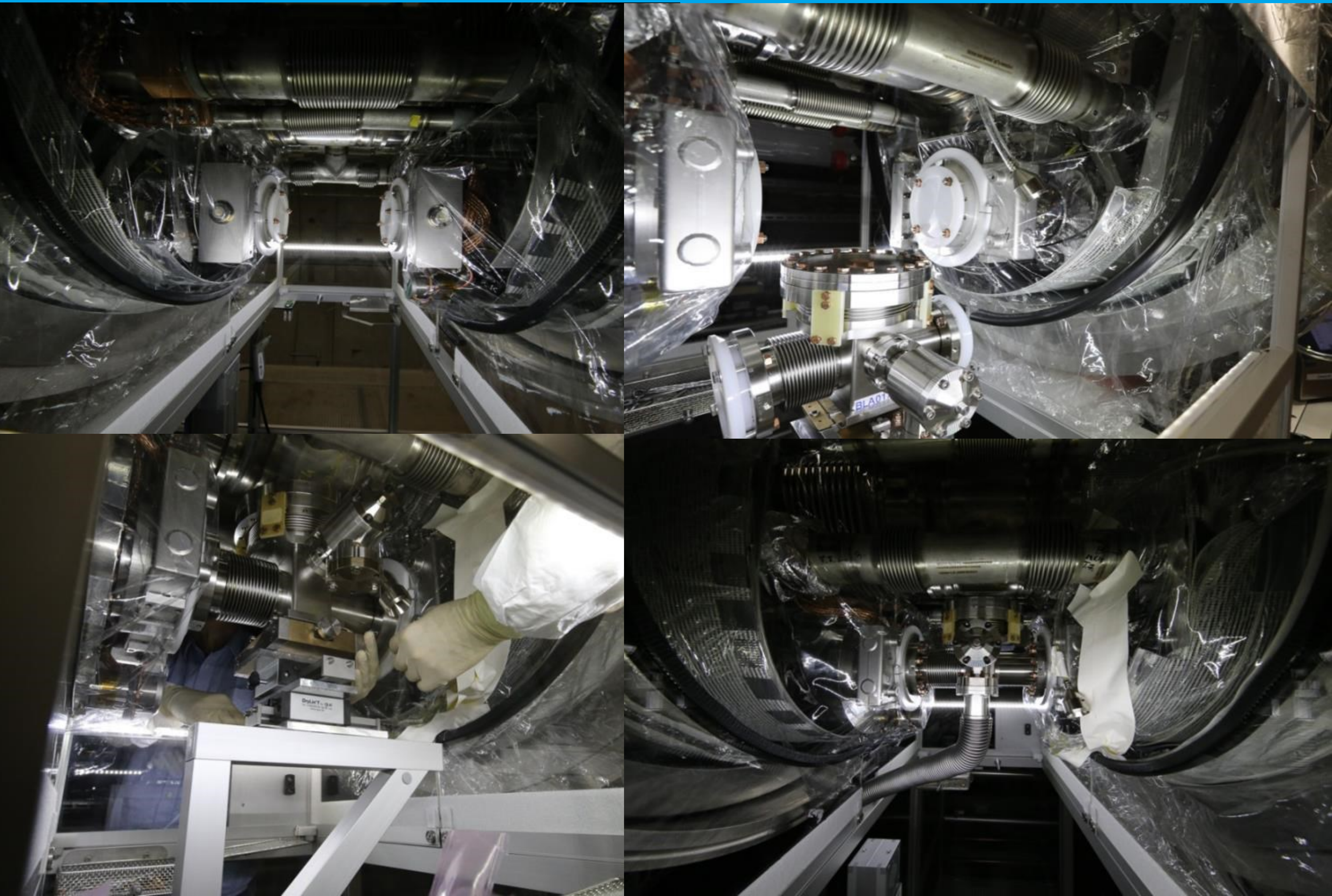
Mobile Clean Rooms: Example XFEL HOM-Absorber

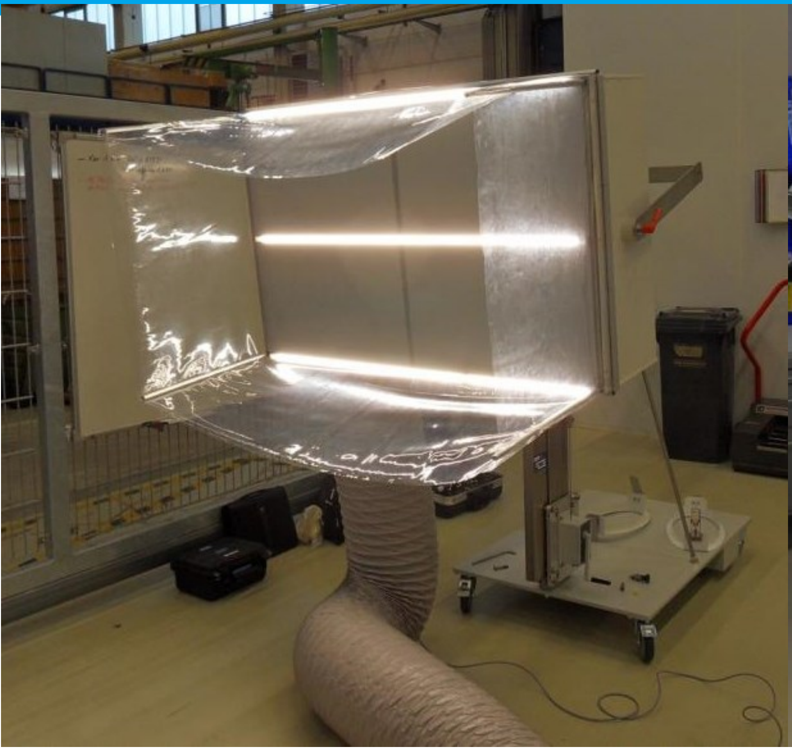


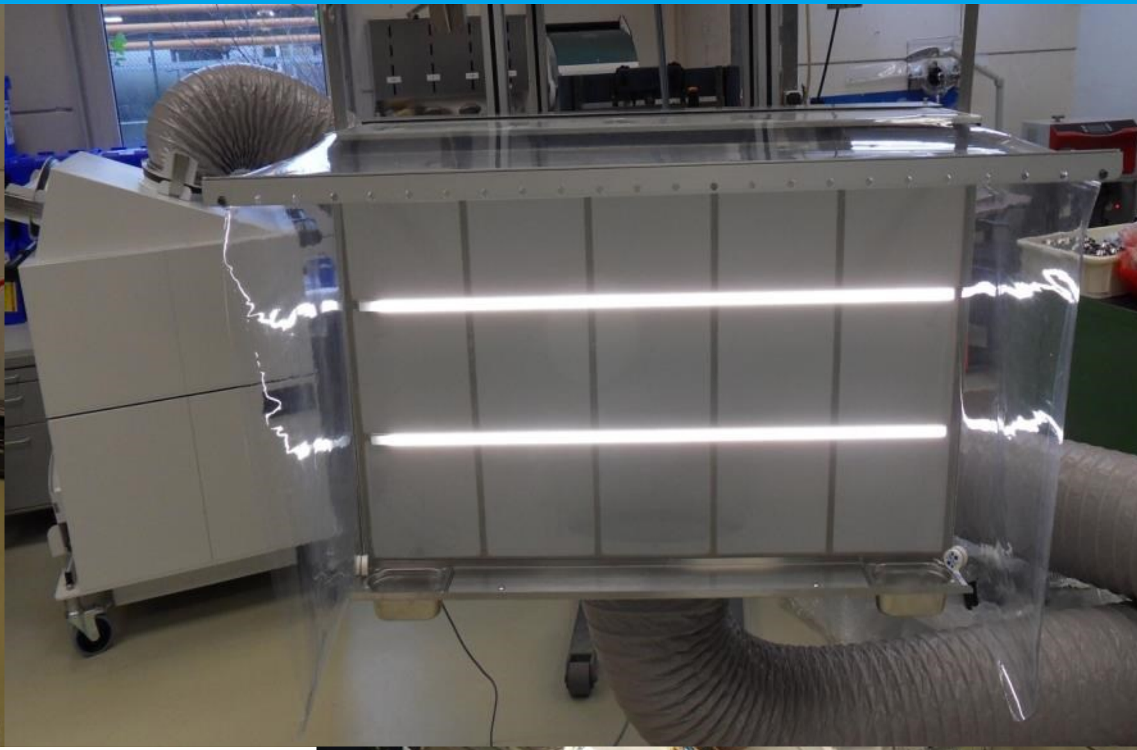
Mobile Clean Rooms: Injector Version

- Filter system attached to blower unit and can be tilted
- Access with two people possible

Mobile Clean Rooms: Injector Version

Mobile Clean Rooms: Filter and Blower separated

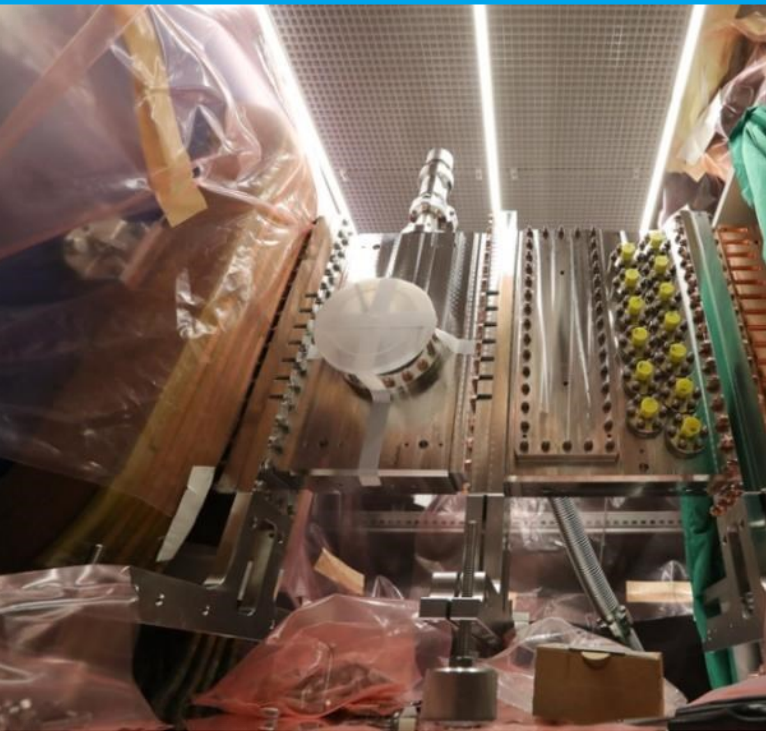




- Filter unit is light
  - Could be suspended from cryogenic bypass tubes (while still warm)
- Long hose
- Blower can be put to the side enabling transports

machine vacuum systems

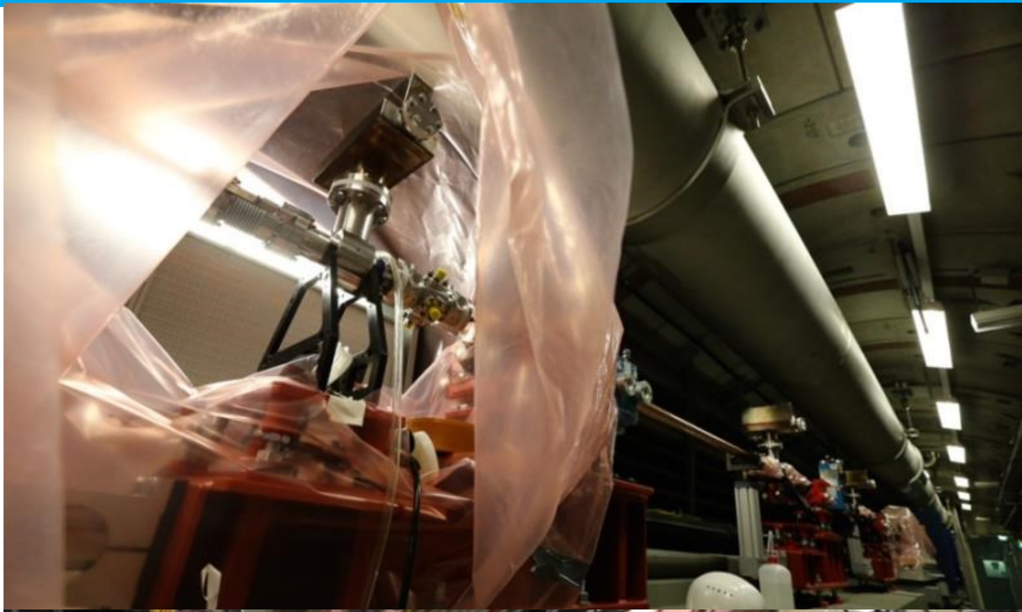
Mobile Clean Rooms: Filter and Blower separated



- Tent needs to be adapted
- More time-consuming
- Size needed for this assembly (bunch compressor chicanes) interfered with transports

Mobile Clean Rooms: Filter and Blower separated

- Filter unit tilted by about 45 degrees
- Glove-box like tent for bellow assembly



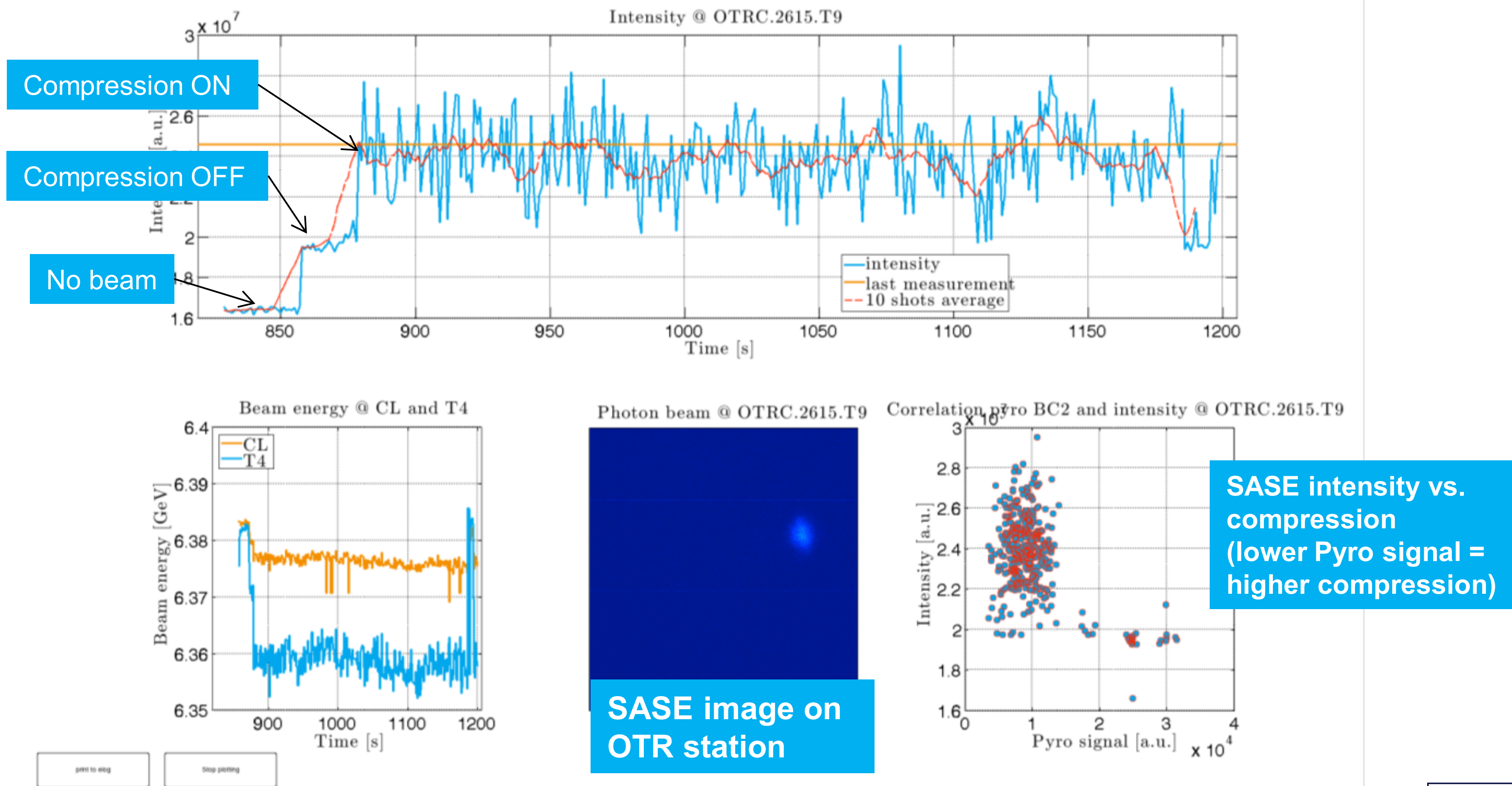
- Accelerator tunnels are too crowded – always …

machine vacuum systems

XFEL „Particle-free“ Highlights in Numbers

- 1 RF Gun including cathode handling system
  - Very delicate components, very little space, very demanding requirements
- 38 girders with 5 m each
  - More than 500 different pieces
  - Tubes, pumps, compensators, diagnostics incl. transverse deflecting structure,
- Laser heater chicane
- 3 Bunch Compressor Chicanes
  - Long chambers
  - Large flanges
- 6 pressure stages at warm cold transition
- 3 dump lines
- 60 m warm beam line at the end of the cold linac as a buffer zone
- For the 100 accelerator modules
  - 200 all metal date valves
  - 800 cavity and 800 coupler bellows
  - 200 coupler pump lines with TSP, sputter ion pump
  - 100 HOM Absorbers
  - Plus testing, installation etc.
- **More than 1,5 km of vacuum chambers have been cleaned (without the cavities)**

First Lasing at European XFEL – 2nd of May 2017



6.3 GeV electron beam energy
500 pC buch charge, 1 Hz, single bunch
→ **0.8 nm SASE wave length**

Now:

10 GeV, 2 Angström, few 100 uJ

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Remember: Basic Rules for a „Particle-free“ Accelerator

- Avoid particulates at every stage and include it in the mechanical design
- Remove particulates at every stage possible
- Do not produce particulates especially during installation and operation
- Never transport particulates

- … be prepared for reasonable compromises!

Summary

- Remember the basic rules
- Layout and mechanical design need to take into account cleaning and installation
- Transport of particulates must be avoided
  - Methods to avoid turbulent flows during pump-down and venting are available
- Large-scale infrastructures can be built “particle-free”
  - A large part of the European XFEL accelerator vacuum system is „particle-free“
  - … and it works!