Vacuum Considerations for Electron-Induced Desorption in the PXIE Absorber Test Stand

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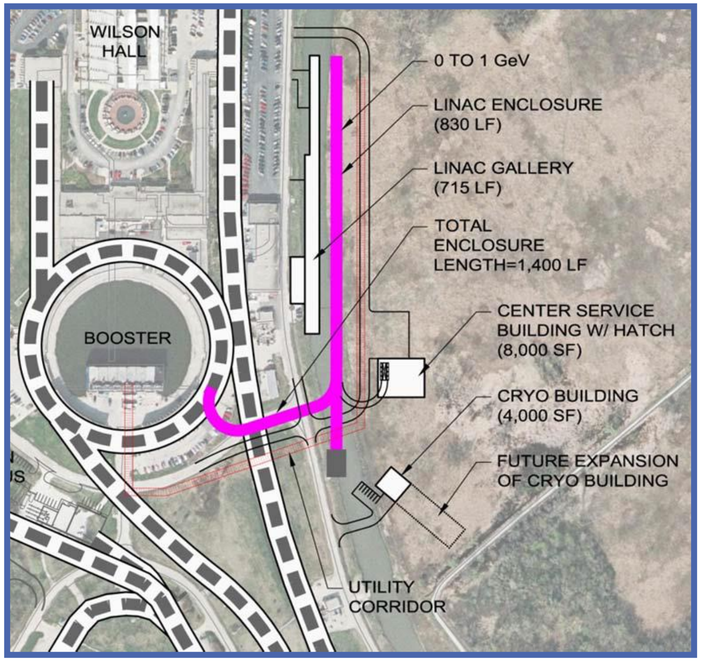
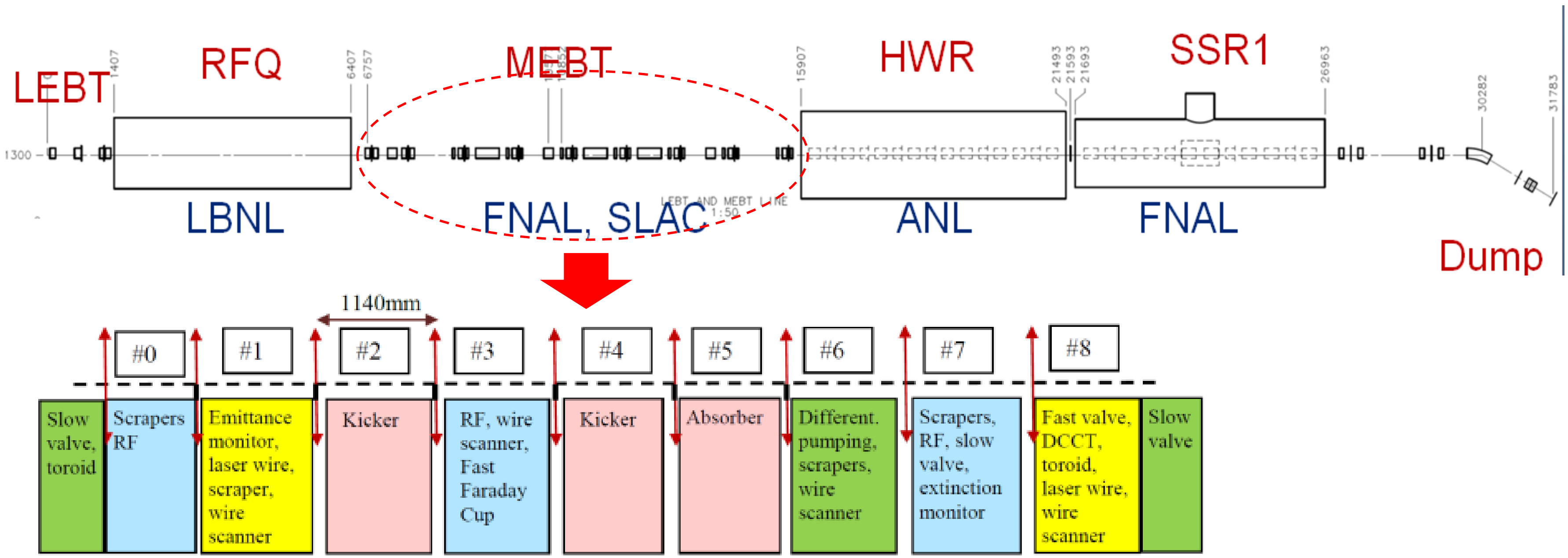
Project Overview: PIP-II[1]

- Goals:
  - Prepare Fermi to "host a world-leading long baseline neutrino research program" → LBNE
  - Replace Linac; Upgrade Booster, Recycler, Main Injector
  - Build a system with long-term upgrade flexibility



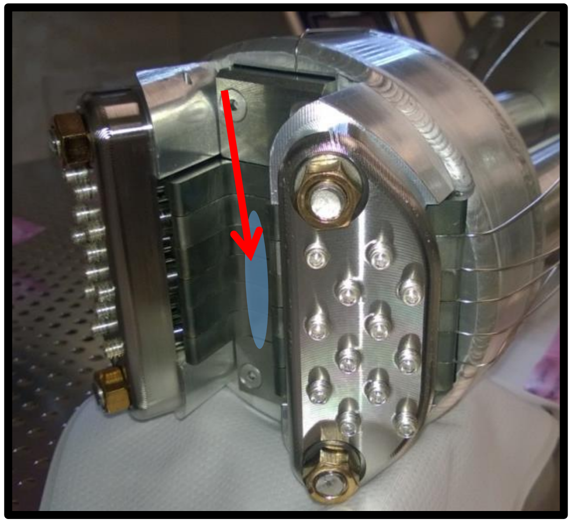
Project Overview: PXIE[2]

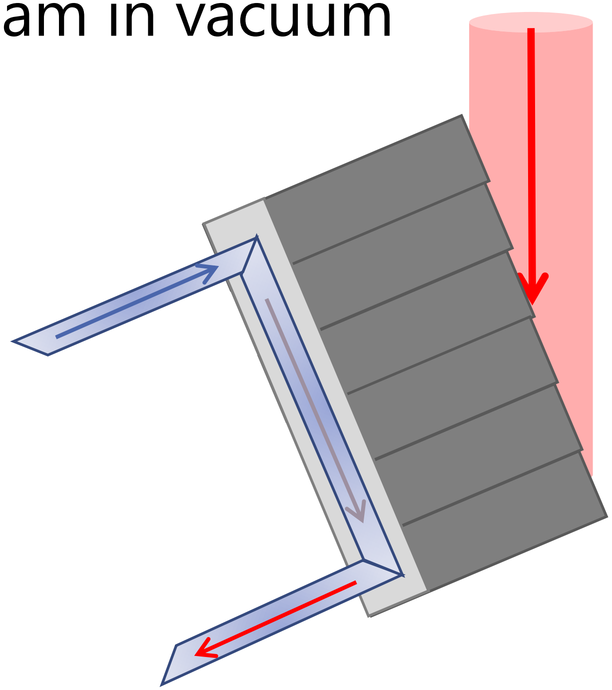
- Goals:
  - High power continuous beam, bunch-by-bunch chopper
  - Allow different bunches of the same beam to be directed to different end users



Project Overview: Absorber

- Goal:
  - Design material and structure capable of absorbing sustained high power PXIE beam in vacuum





- Material: TZM (Molybdenum alloyed with Ti, Zr)[3]
- Structure: angle, steps, aluminum plate, coolant, “lobes”

Test Stand Measurements

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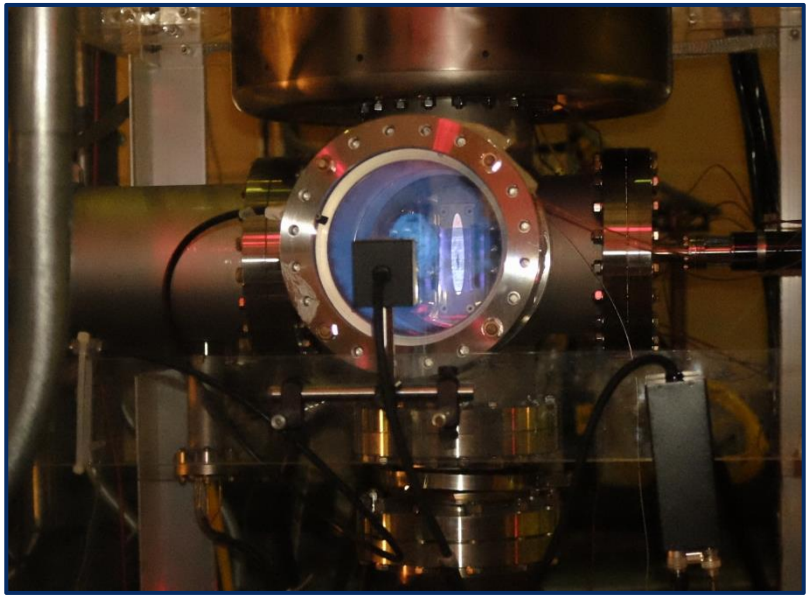
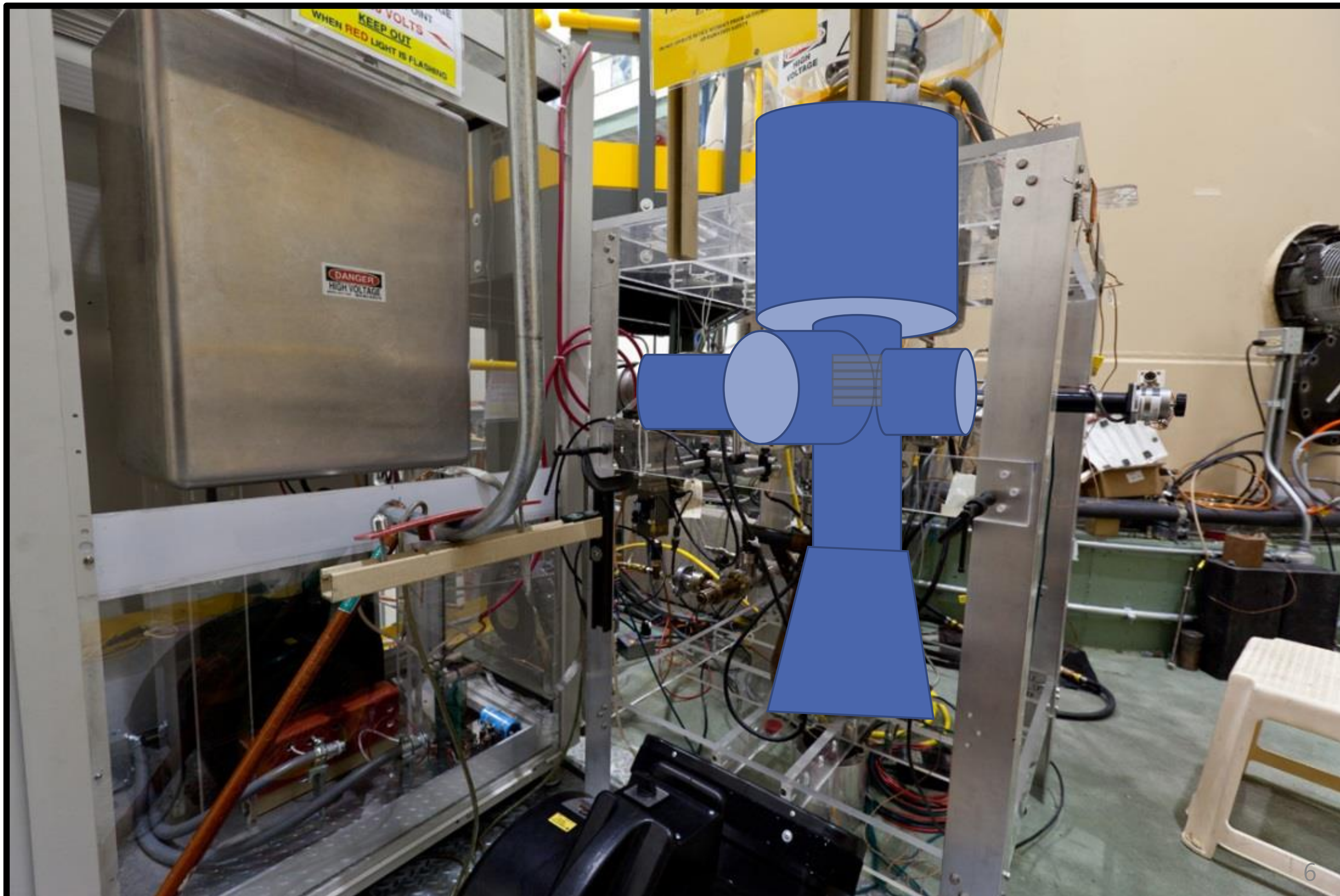
- Increase of Vacuum Pressure with Current **today's focus**
- Temperature of Thermocouples with Position
- Light Intensity of Beam
- Change in Temperature of Water Coolant



Test Stand Assembly



Why Do We Need Vacuum?

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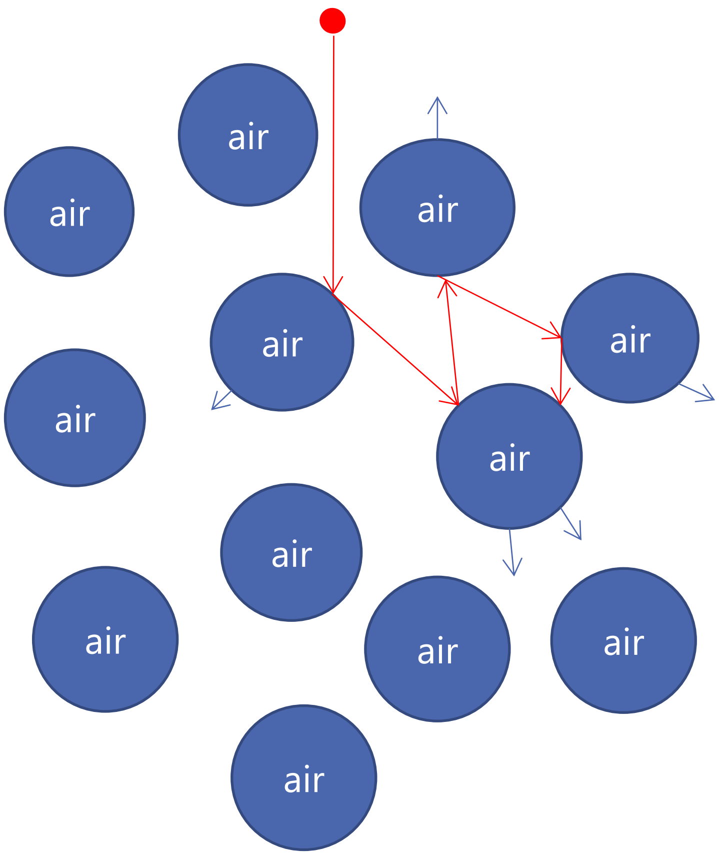
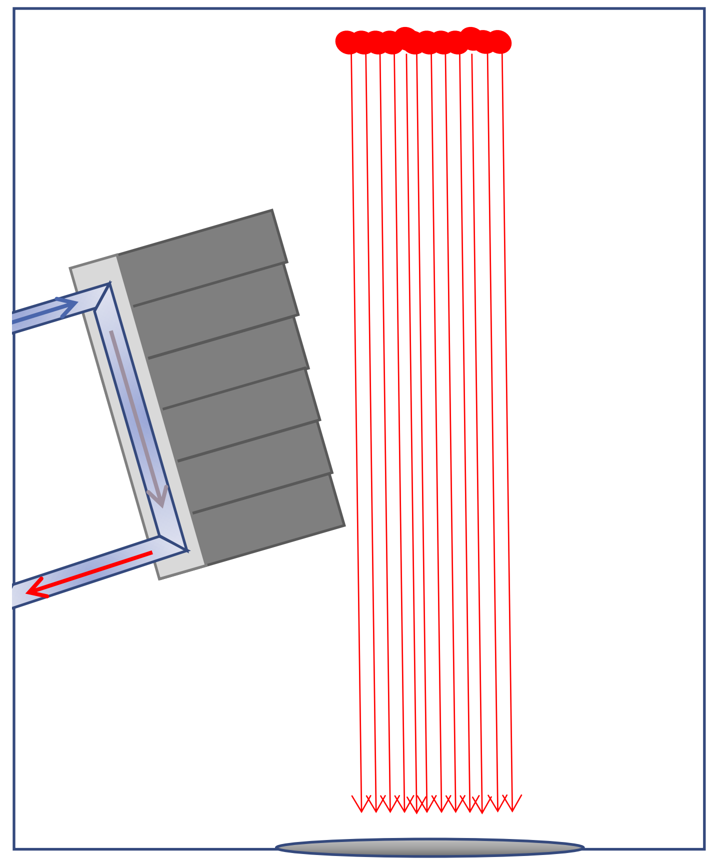
In Air



In Vacuum



How much vacuum?

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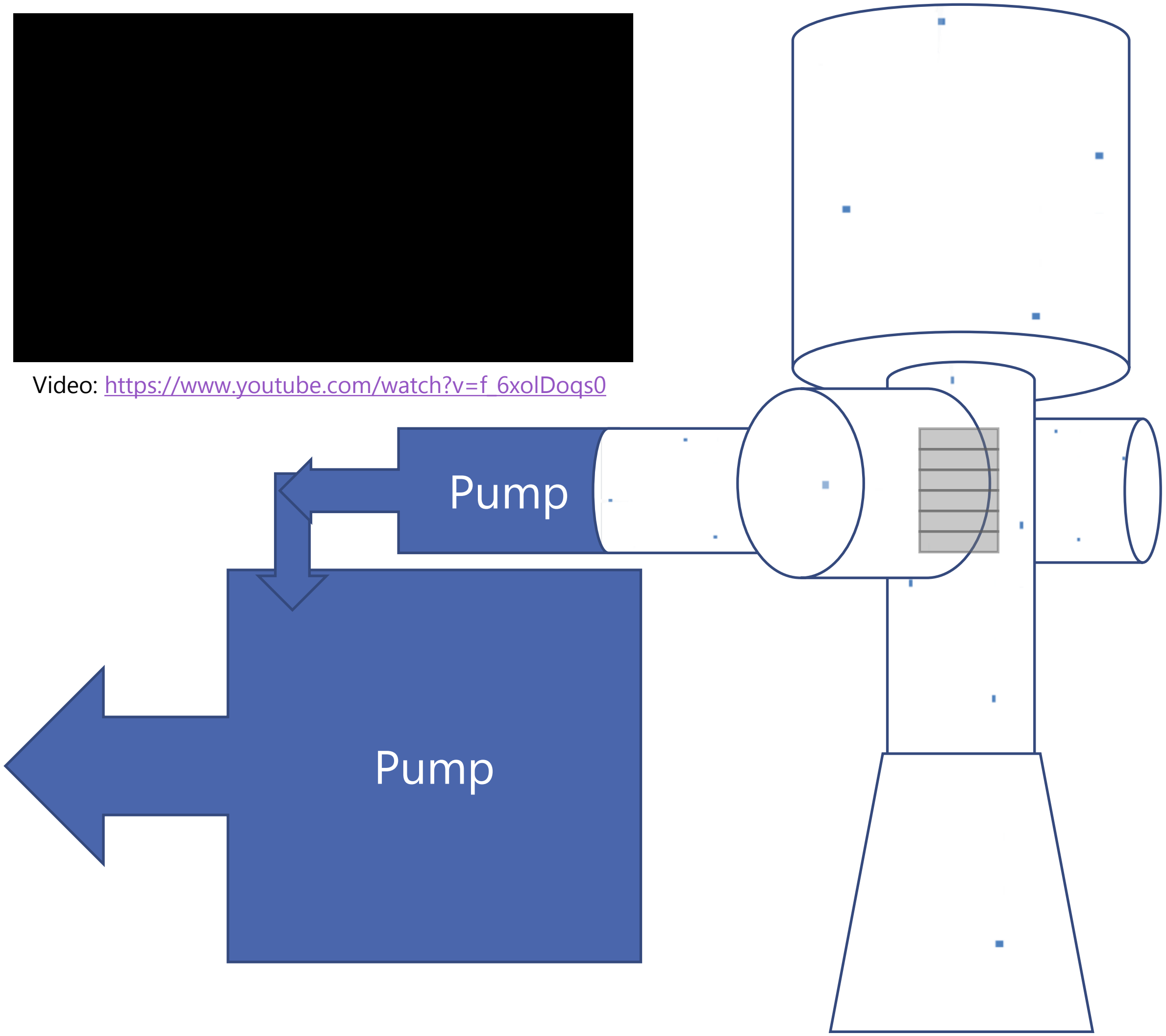
PXIE goal

Pressure ranges of each quality of vacuum in different units

Vacuum quality	Torr	Pa	Atmosphere
Atmospheric pressure	760	$1.013\times10^{+5}$	1
Low vacuum	760 to 25	$1\times10^{+5}$ to $3\times10^{+3}$	1 to 0.03
Medium vacuum	25 to 1×10^{-3}	$3\times10^{+3}$ to 1×10^{-1}	
High vacuum	1×10^{-3} to 1×10^{-9}	1×10^{-1} to 1×10^{-7}	
Ultra high vacuum	1×10^{-9} to 1×10^{-12}	1×10^{-7} to 1×10^{-10}	
Extremely high vacuum	$<1\times10^{-12}$	$<1\times10^{-10}$	
Outer space	1×10^{-6} to $<3\times10^{-17}$	1×10^{-4} to $< 3\times10^{-15}$	
Perfect vacuum	0	0	0

Vacuum Pumps (turbo+scroll)

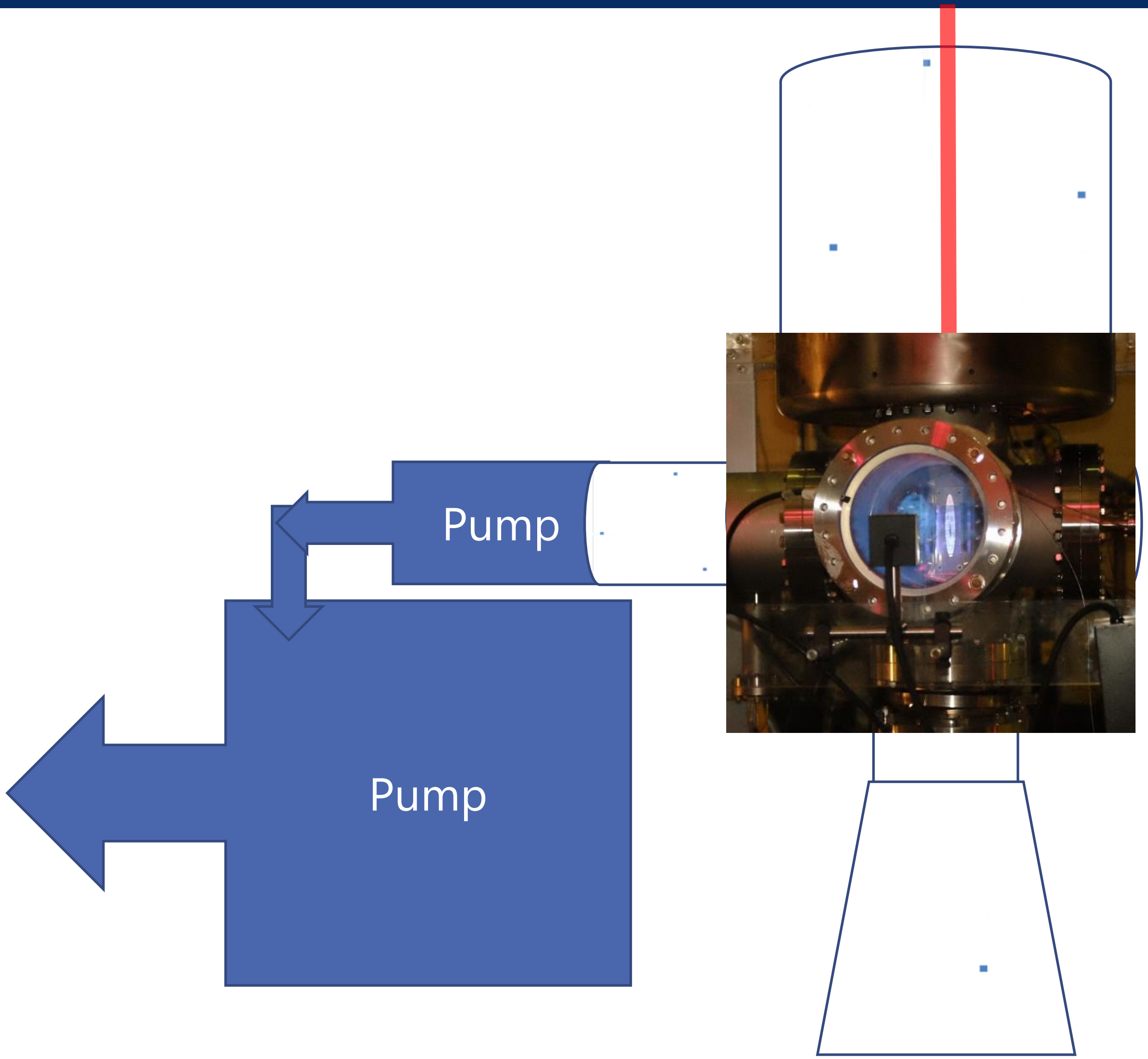
Video: https://www.youtube.com/watch?v=f_6xolDoqs0



Video: https://www.youtube.com/watch?v=wIbIzCS1jHU

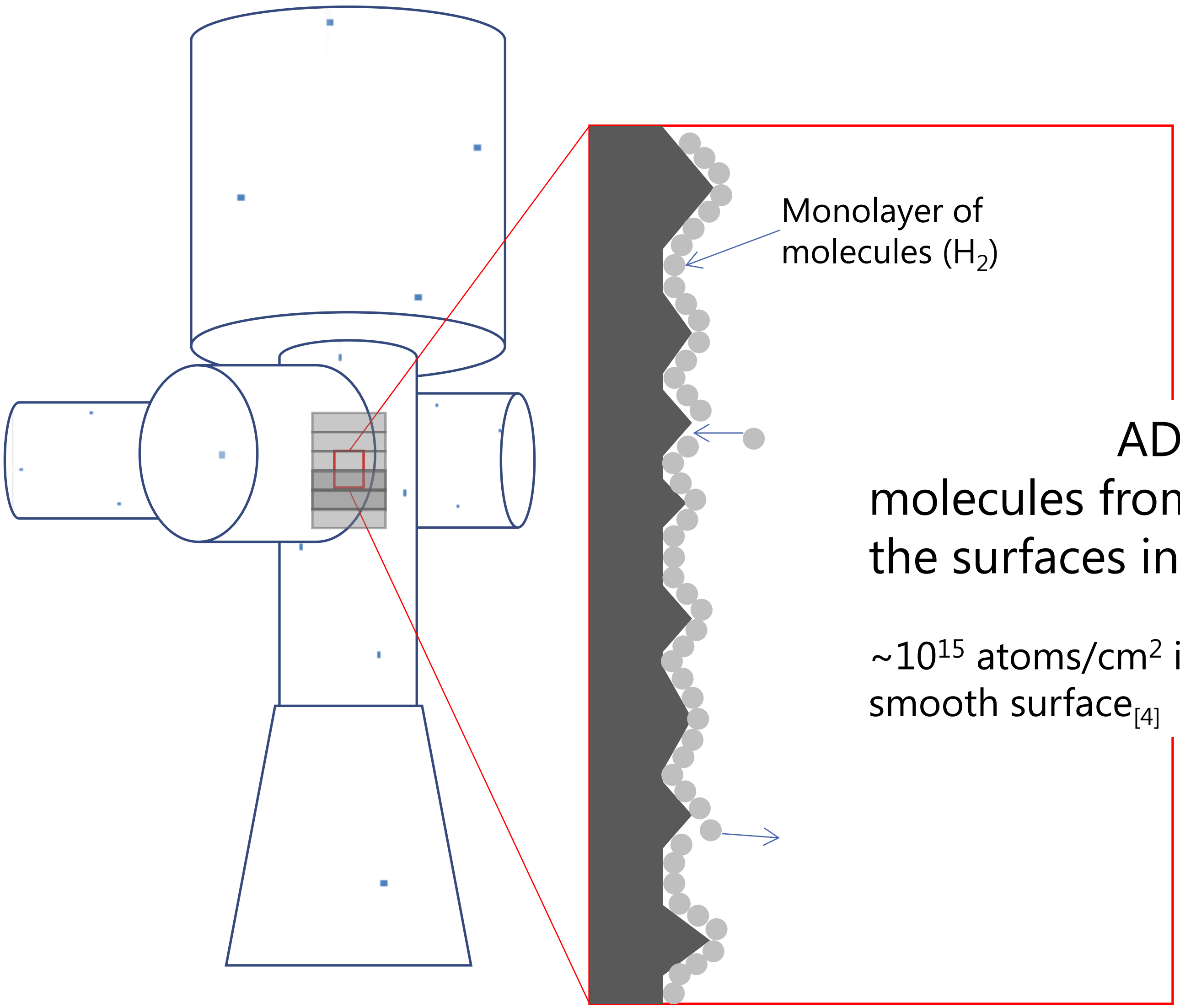
1×10^{-8} Torr

Turn on the electron beam!



1×10^{-7} Torr

Meanwhile…

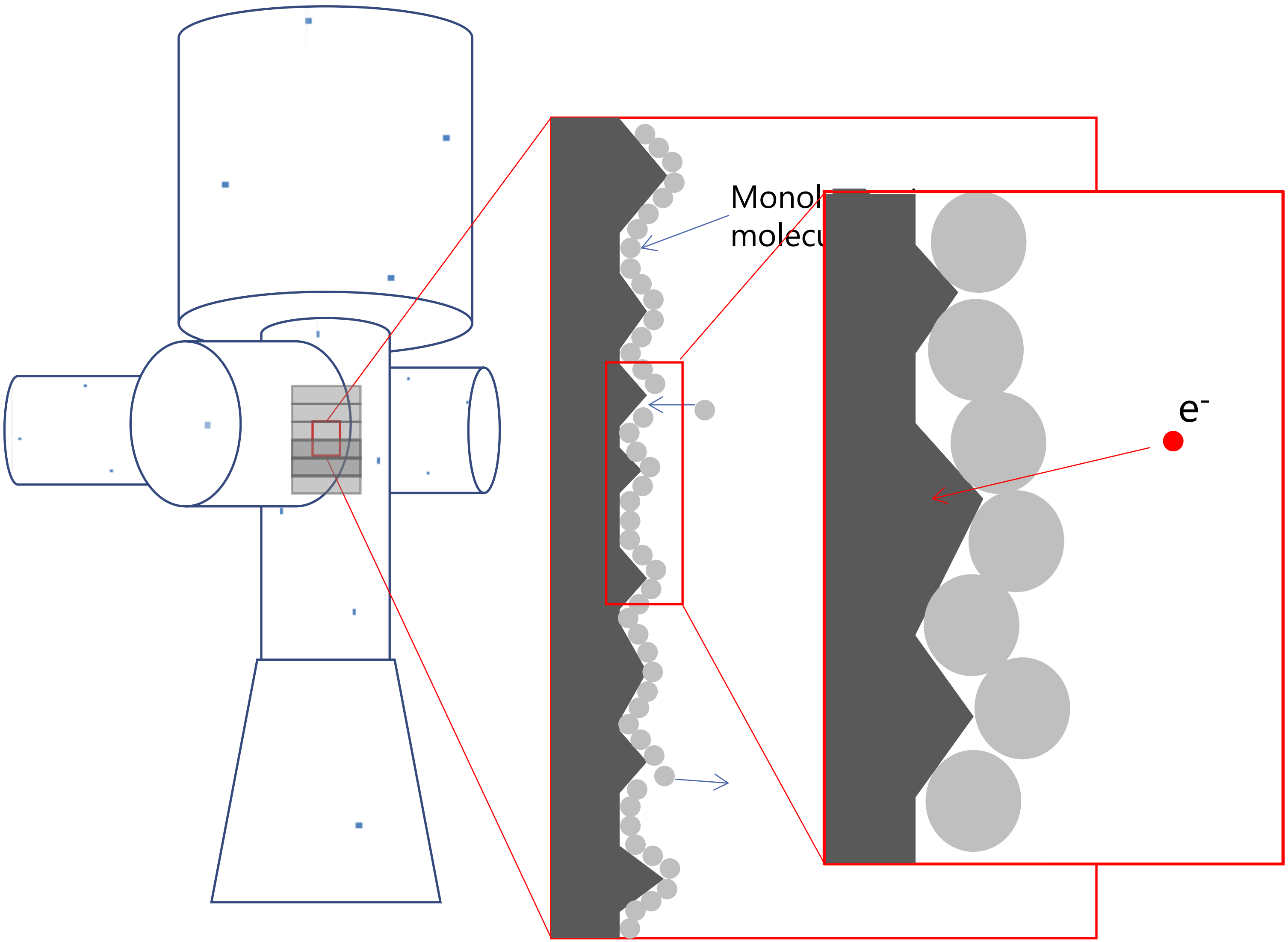


ADSORPTION

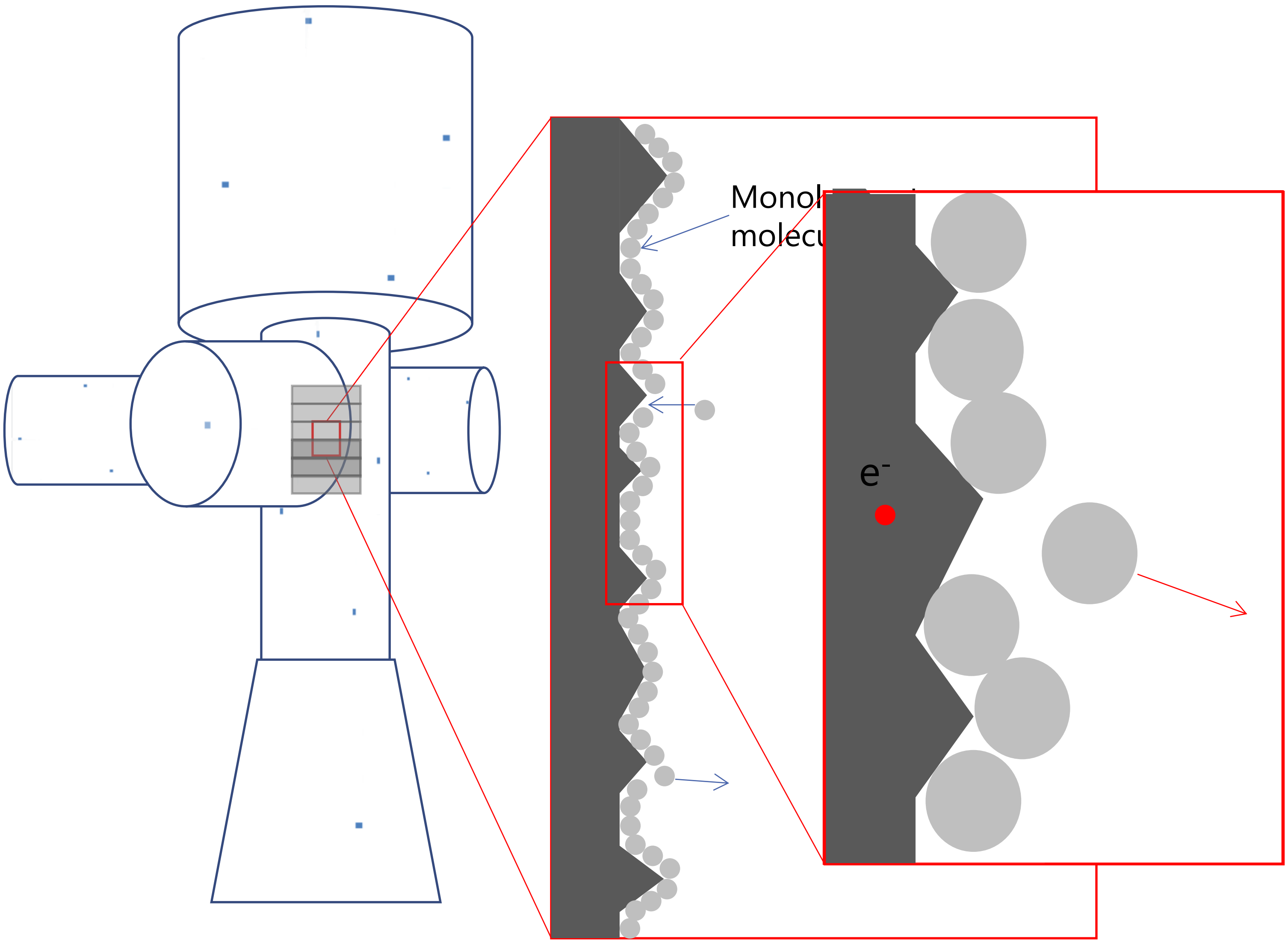
molecules from air weakly bond to the surfaces in the vacuum

~10^{15} atoms/cm^2 in a monolayer on perfectly smooth surface[4]

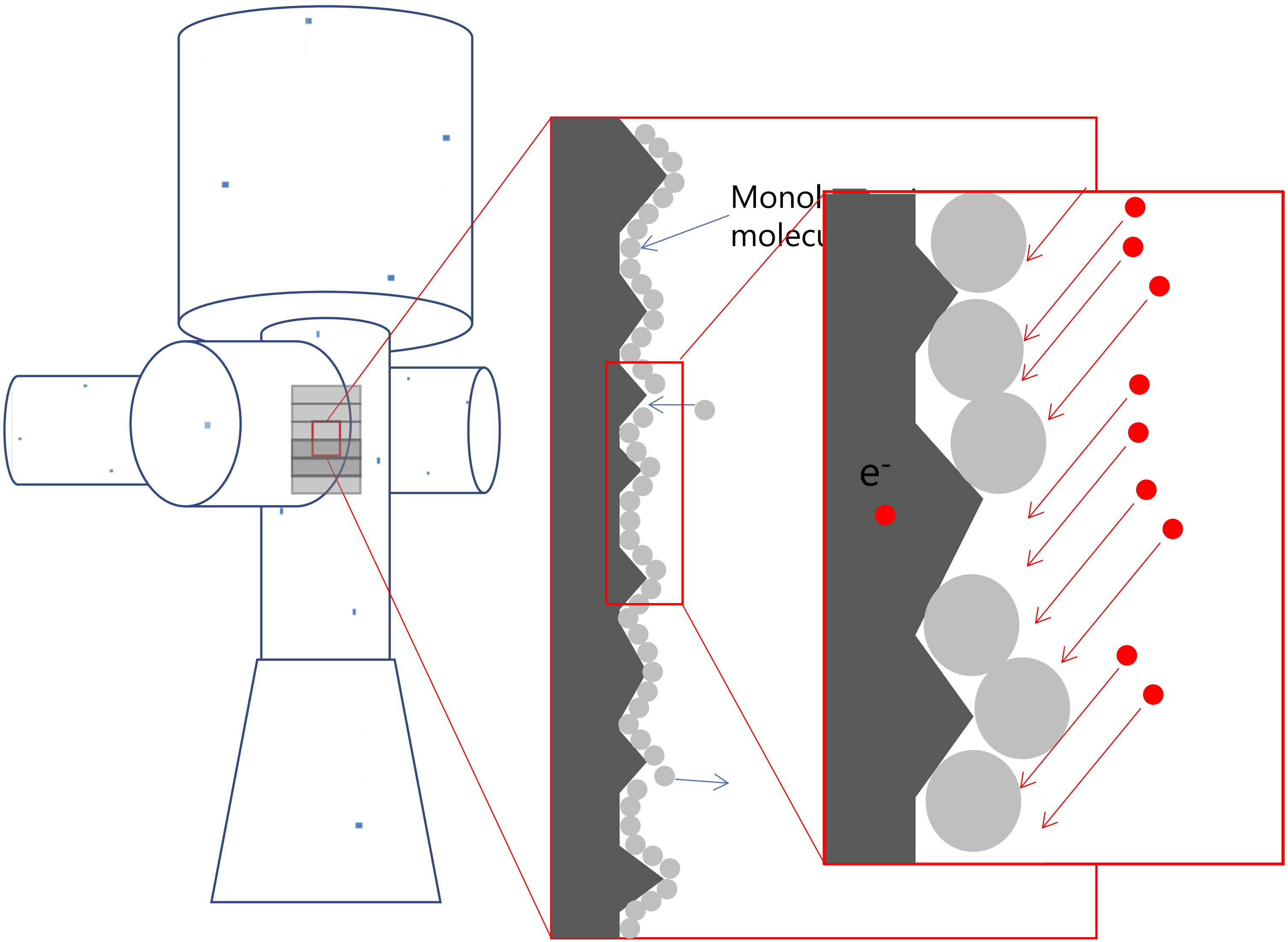
Electrons hit absorber surface



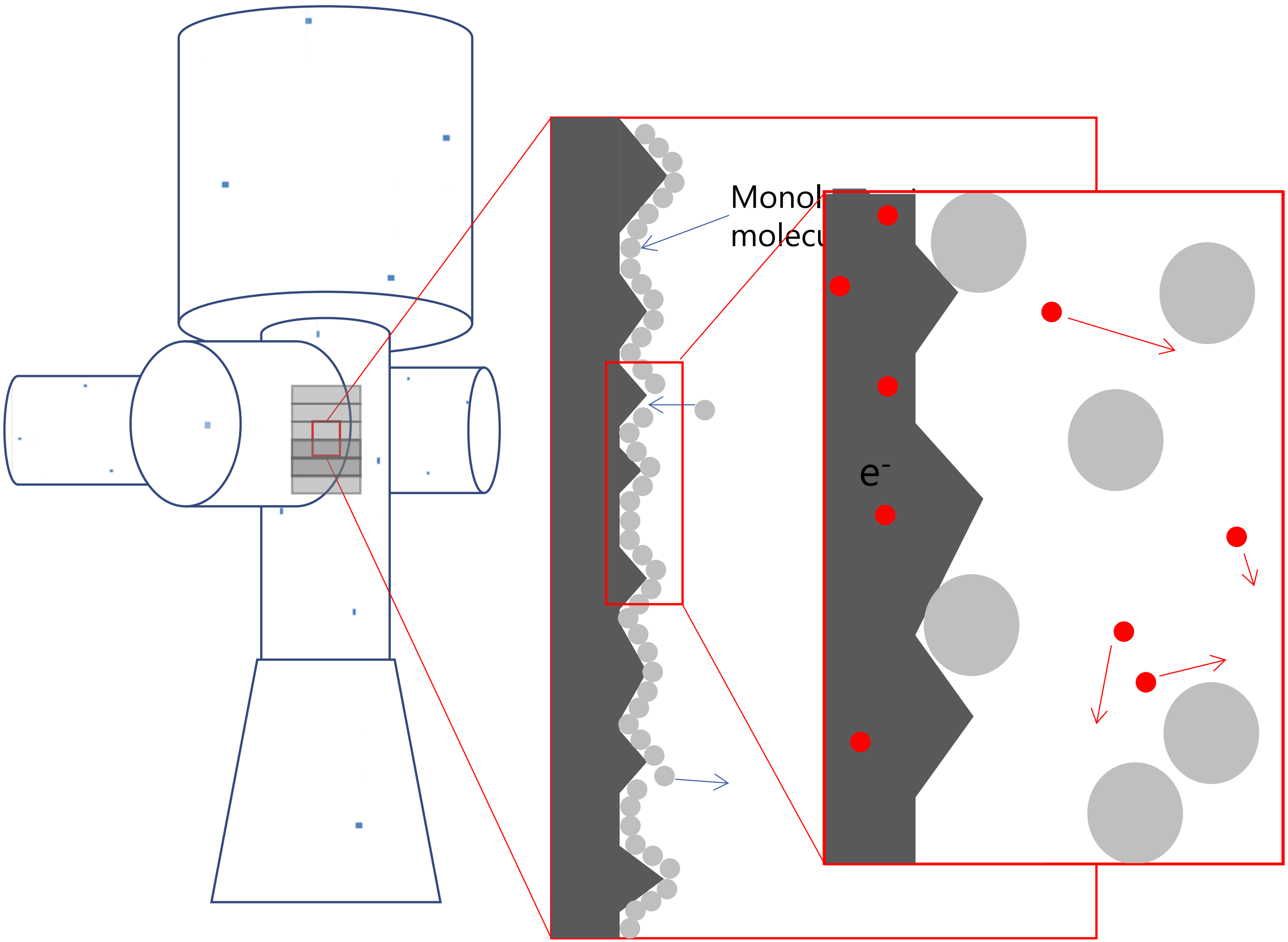
Molecules are Desorbed



More Electrons = More Desorption



More Electrons = More Desorption



More Electrons = More Desorption

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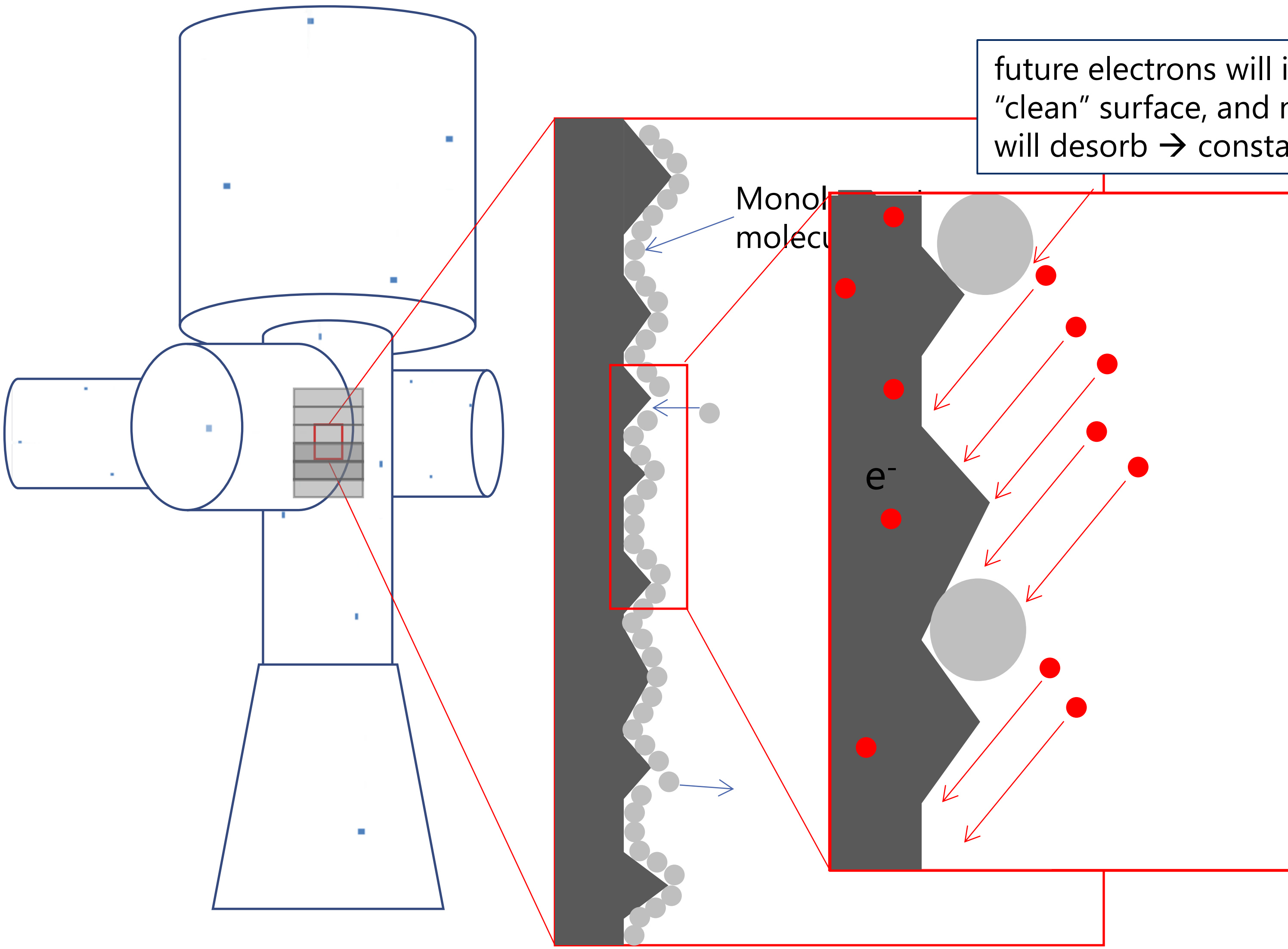
future electrons will interact with a "clean" surface, and no new molecules will desorb → constant pressure



Pressure and Current

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- $PV = nRT$ OR $PV = N_m k_B T$
- $\therefore P\frac{V}{\Delta t} = \frac{N_m}{\Delta t} k_B T$
- $\therefore P = \frac{N_m}{S \cdot \Delta t} k_B T$
- $\therefore \Delta P = \frac{\Delta N_m}{S \cdot \Delta t} k_B T$
- $I = \frac{q}{\Delta t}$
- $q = e * N_e$
- $I = \frac{e * N_e}{\Delta t}$
- $\Delta I = \frac{e * \Delta N_e}{\Delta t}$

$n = moles\ of\ a\ substance;$
$N_m = molecules\ of\ a\ substance;$
$k_B = \frac{R}{N_A}$

Desorption is a change in the number of molecules in the vacuum!

Current is a measure of the number of electrons hitting the surface!

$$\boxed{\frac{\Delta P}{\Delta I} = \frac{\Delta N_m}{\Delta N_e} \cdot \frac{k_B \cdot T}{S \cdot e}}$$

The First Beam: 07/03/2014

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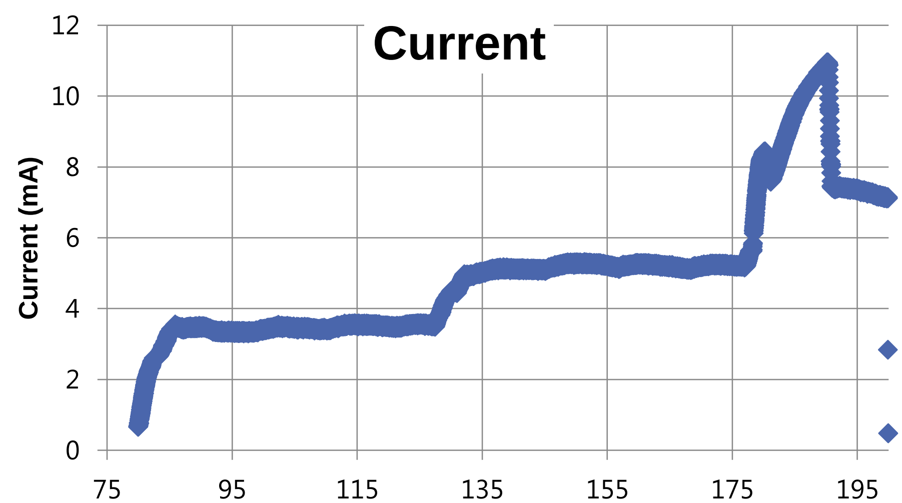
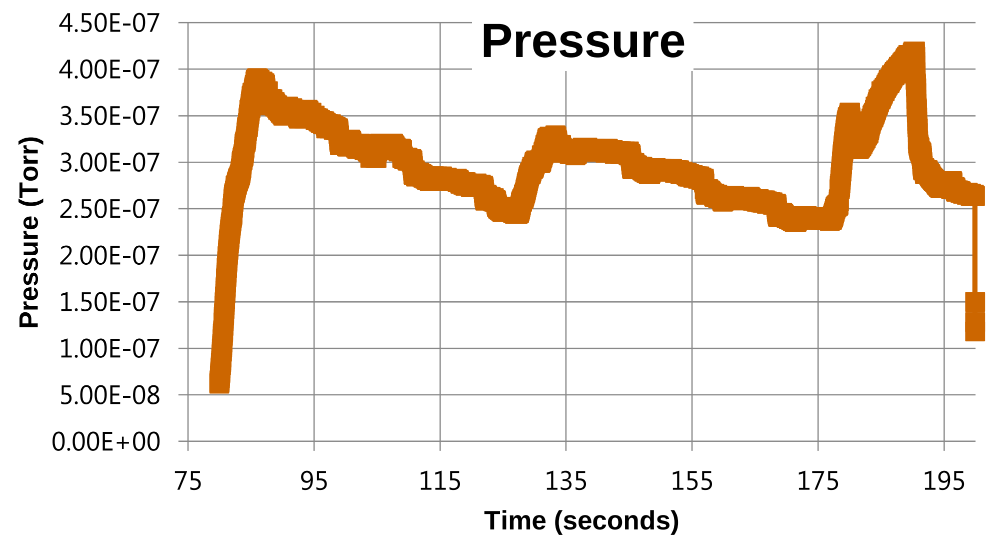
An increasing flow of electrons continuously increases desorbed molecules, ∴ Pressure ↑

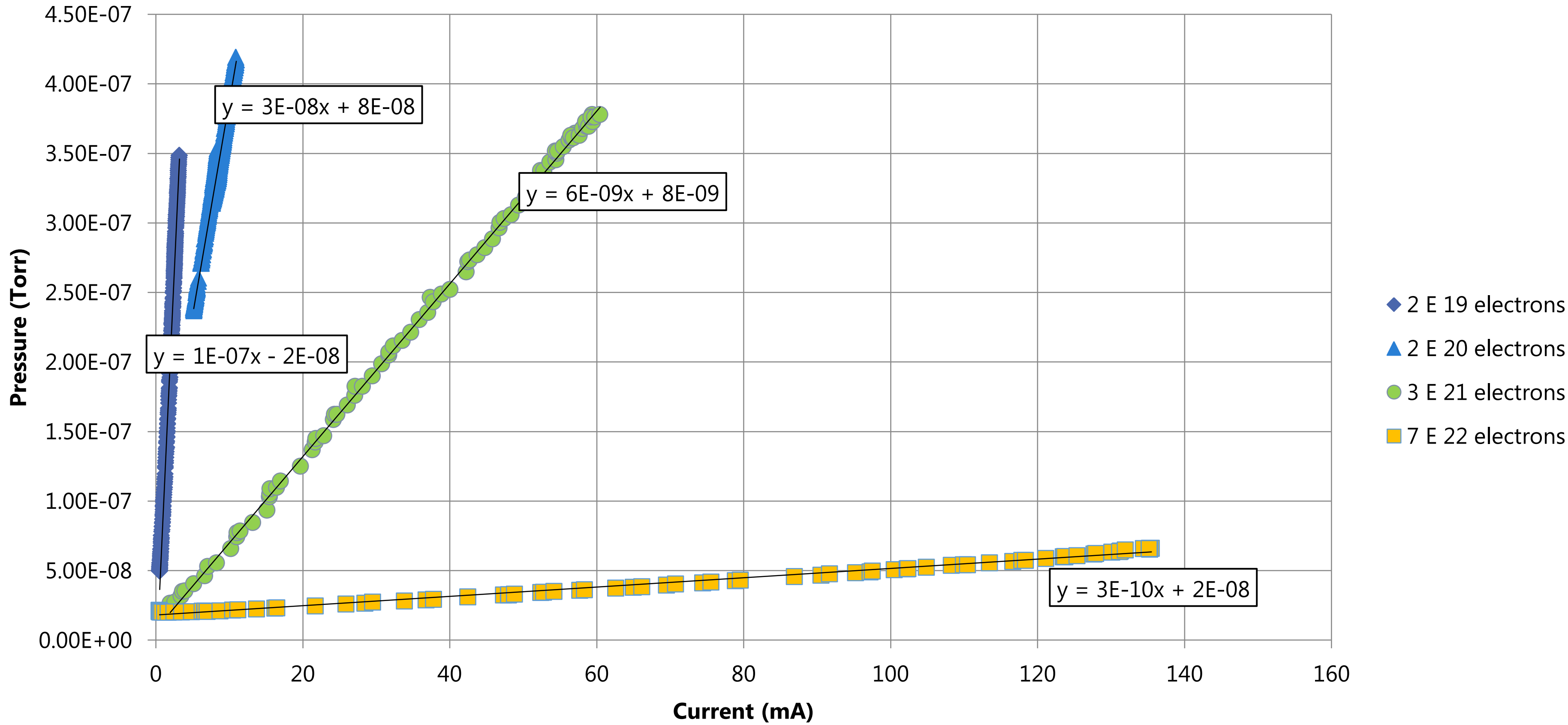
A constant flow of electrons are incident on increasingly clean surfaces. Less desorption, ∴ Pressure ↓

This effect was most drastic when the beam was first turned on the absorber.





Desorption Decreases with e⁻ dose



Comparing $\frac{\Delta P}{\Delta I}$ with increasing electron dose shows that the absorber surface was significantly more clean after 7×10^{22} electrons.

Coefficient of Desorption

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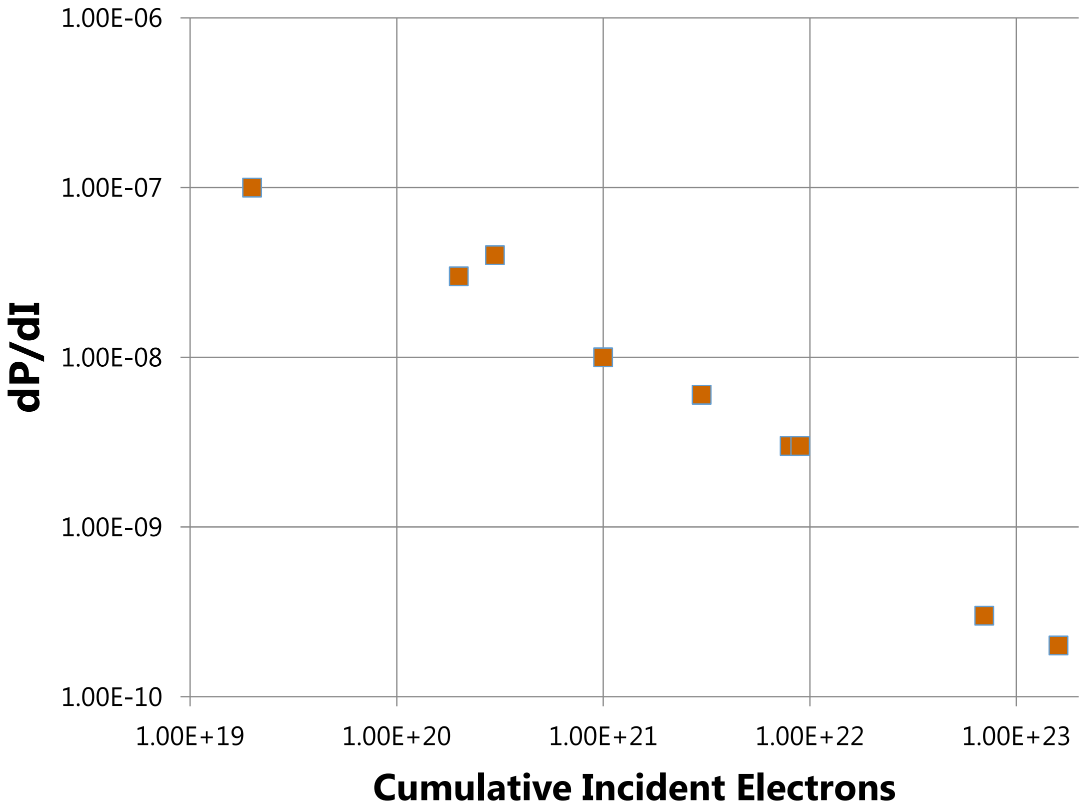
- $\frac{\Delta P}{\Delta I} = \frac{\Delta N_m}{\Delta N_e} \cdot \frac{k_B \cdot T}{e \cdot S} = 6 \times 10^{-7} \cdot \frac{\Delta N_m}{\Delta N_e} \left[\frac{Torr}{mA}\right]$



Date	$\frac{dP}{dI}\left[\frac{\text{Torr}}{\text{mA}}\right]$	e^-
2014-07-03	1×10^{-7}	2×10^{19}
2014-07-03	3×10^{-8}	2×10^{20}
2014-07-07	4×10^{-8}	3×10^{20}
2014-07-08	1×10^{-8}	1×10^{21}
2014-07-09	6×10^{-9}	3×10^{21}
2014-07-14	3×10^{-9}	8×10^{21}
2014-07-15	3×10^{-9}	1×10^{22}
2014-07-16	3×10^{-10}	7×10^{22}
2014-07-17	2×10^{-10}	2×10^{23}

Results

The number of molecules desorbed by the surface decreased by 90% with a dose of 10^{21} electrons.

Future design engineers may use this data to guide their choices (ie pump size) by knowing expected gas load from desorption.

Спасибо, Thank You, Merci, and Danke to:

Alexander Shemyakin, Curtis Baffes, Lionel Prost, Bruce Hanna, Harry Cheung, and Bjoern Penning for a fantastic opportunity this summer.

References

- [1] (2013) PIP-II White Paper: Proton Improvement Plan-II. Batavia, Illinois.
- [2] (2012) PXIE White Paper: Project X Front End R&D Program. Batavia, Illinois.
- [3] A. Shemyakin, C. Baffes (2014). Design and Testing of a Prototype Beam Absorber for the PXIE MEBT. Projext X Document 1259. Batavia, Illinois.
- [4] M. H. Hablanian (1997). High-Vacuum Technology. New York.
- [5] D.C. Giancoli (1984). Physics For Scientists and Engineers. New Jersey.