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

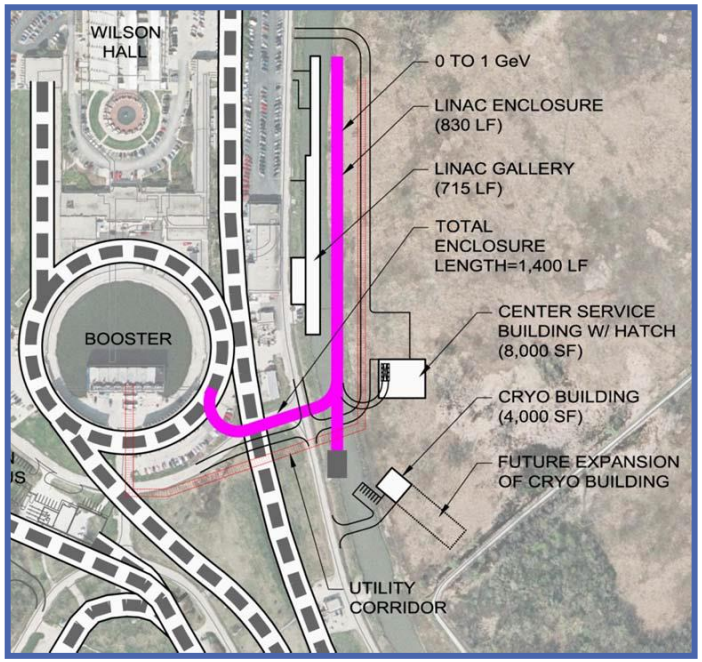
Presenter: Kerbie Reader
Forest Ridge School of the Sacred Heart, Seattle, WA

Mentor Scientist: Alexander Shemyakin
Fermi Accelerator Division

Project Overview: PIP-II[1]

Fermilab

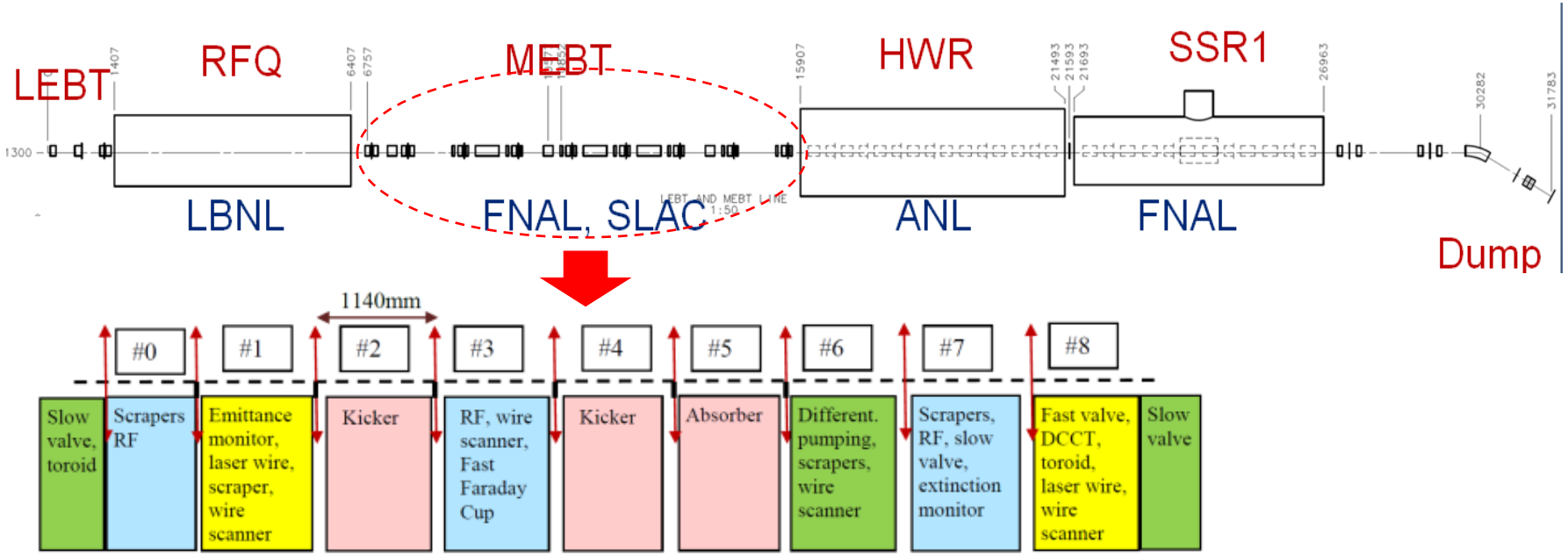
- Goals:
  - Prepare Fermi to "host a world-leading long baseline neutrino research program" → LBNE
  - Replace Linac; Upgrade Booster, Recycler, Main Injector
  - Build a system with long-term upgrade flexibility



Project Overview: PXIE[2]

Fermilab

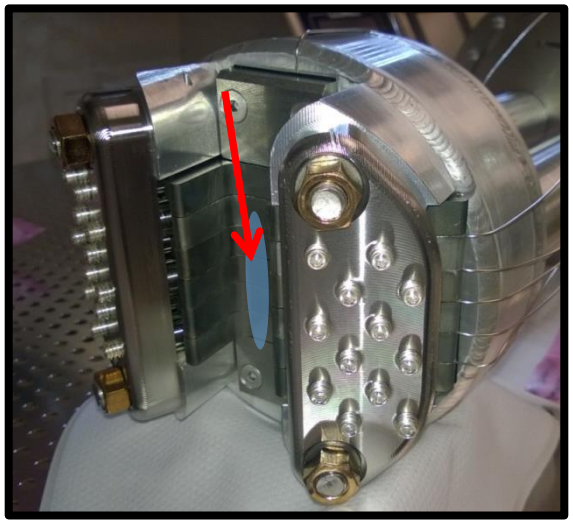
- Goals:
  - High power continuous beam, bunch-by-bunch chopper
  - Allow different bunches of the same beam to be directed to different end users

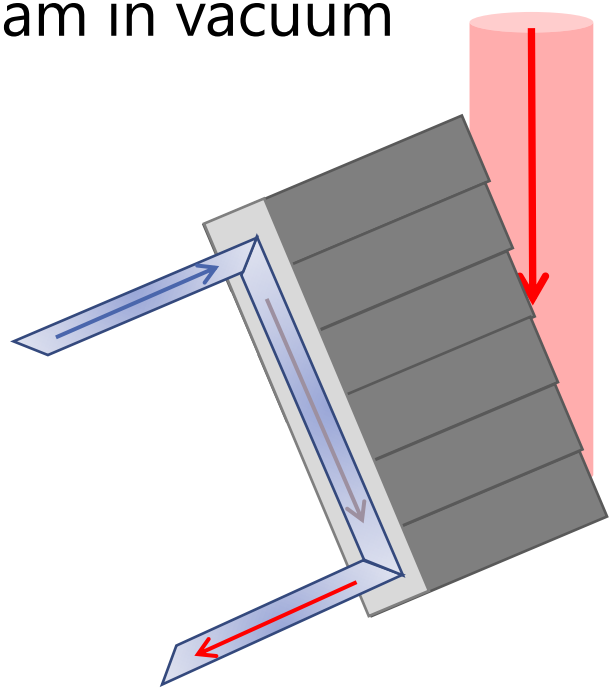


Project Overview: Absorber

Fermilab

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



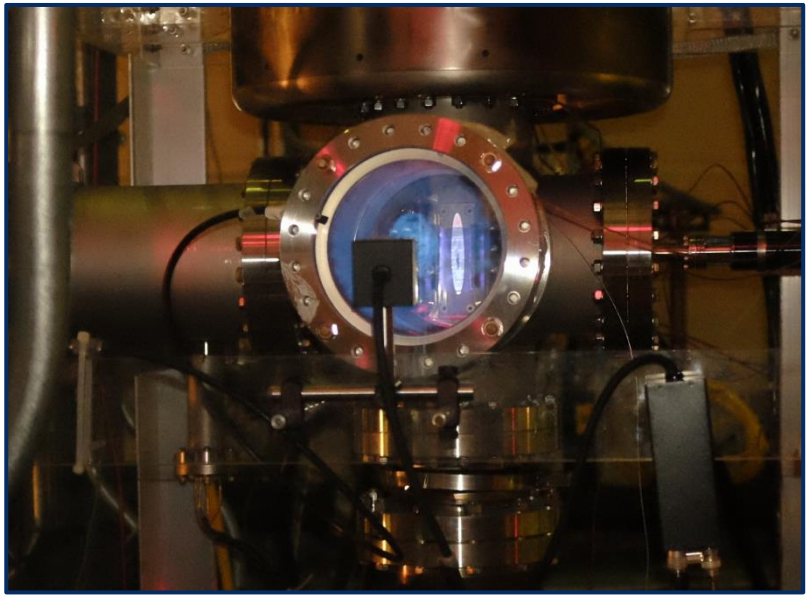


- Material: TZM (Molybdenum alloyed with Ti, Zr)[3]
- Structure: angle, steps, aluminum plate, coolant, "lobes"

Test Stand Measurements

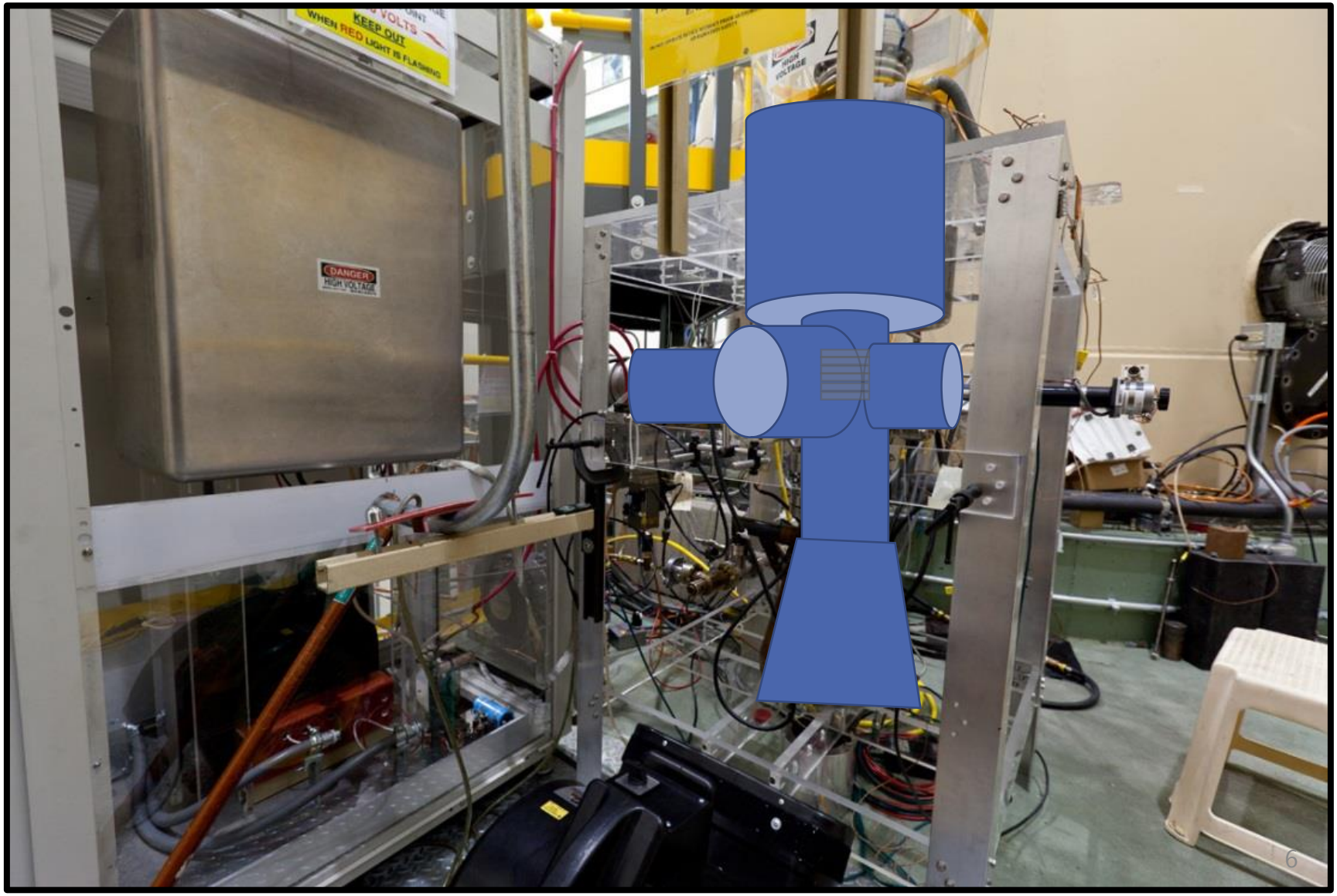
Fermilab

- 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

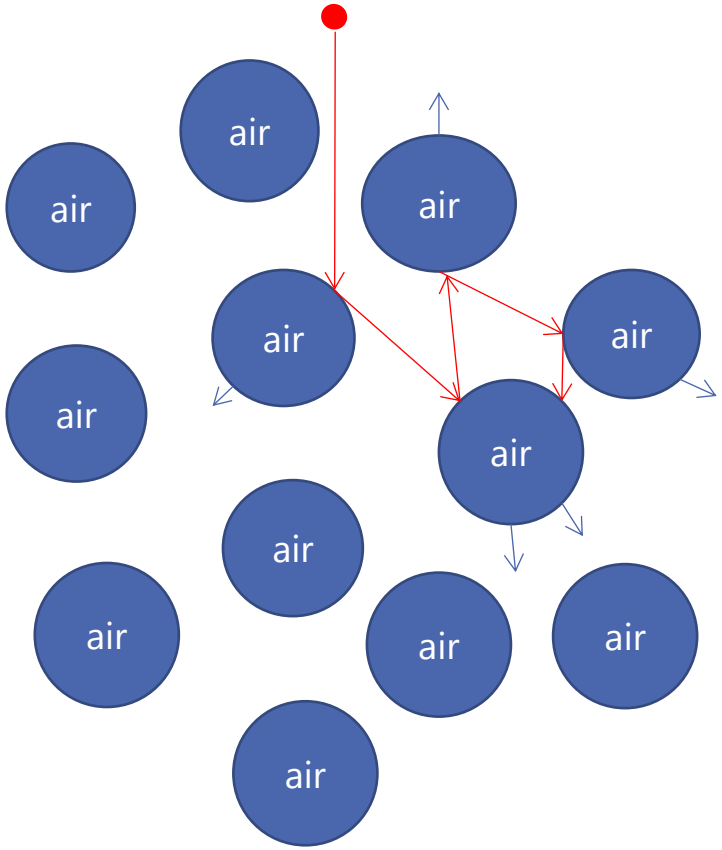
Fermilab



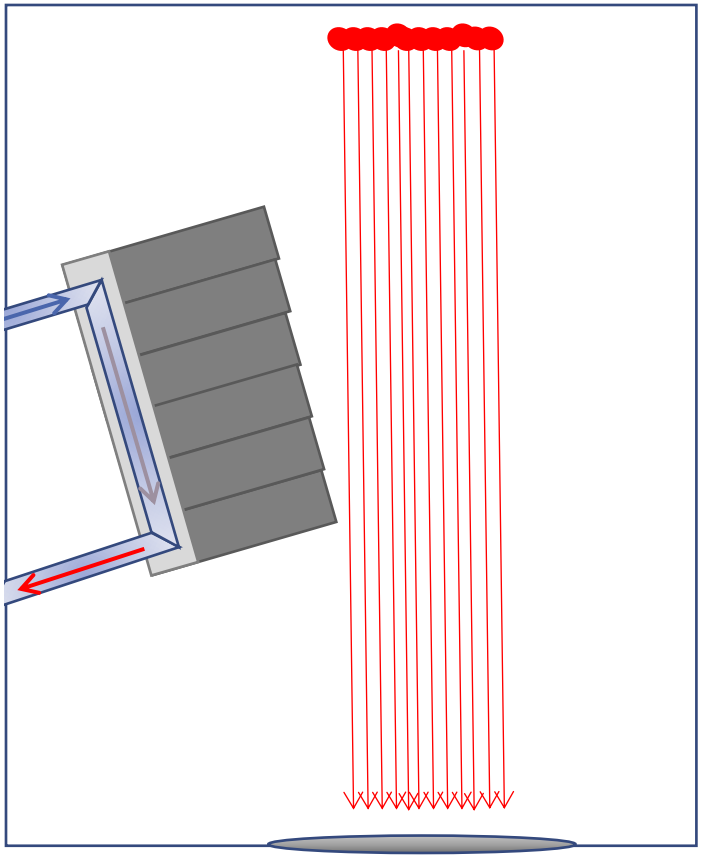
Why Do We Need Vacuum?

Fermilab

In Air



In Vacuum



How much vacuum?

Fermilab

PXIE goal

Pressure ranges of each quality of vacuum in different units

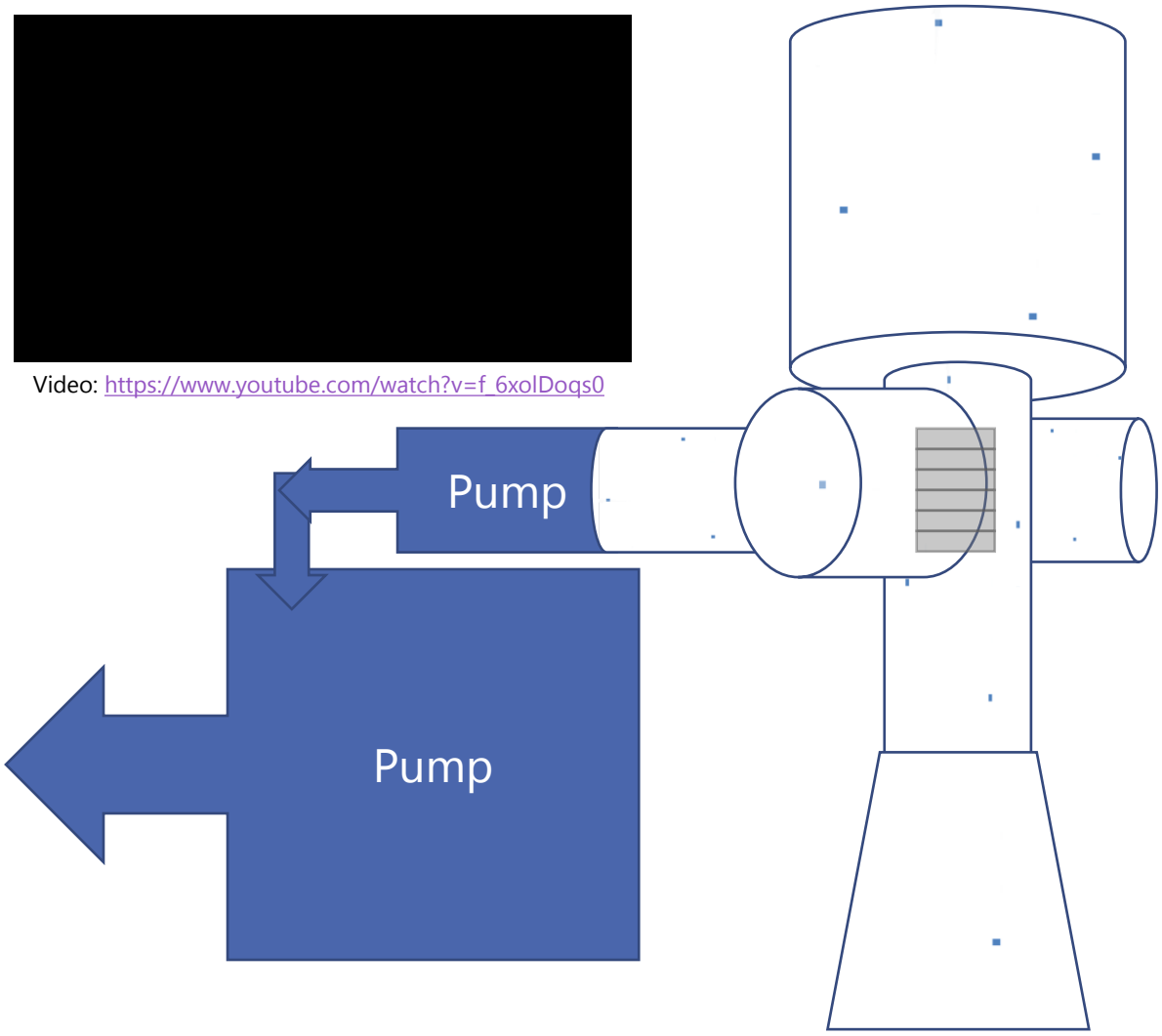
Vacuum quality	Torr	Pa	Atmosphere
Atmospheric pressure	760	$1.013\times10^{+5}$	1
Low vacuum	760 to 25	$1\times10^{+5}$ to $3\times10^{+3}$	1 to 0.03
Medium vacuum	25 to 1×10^{-3}	$3\times10^{+3}$ to 1×10^{-1}	
High vacuum	1×10^{-3} to 1×10^{-9}	1×10^{-1} to 1×10^{-7}	
Ultra high vacuum	1×10^{-9} to 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)

Fermilab

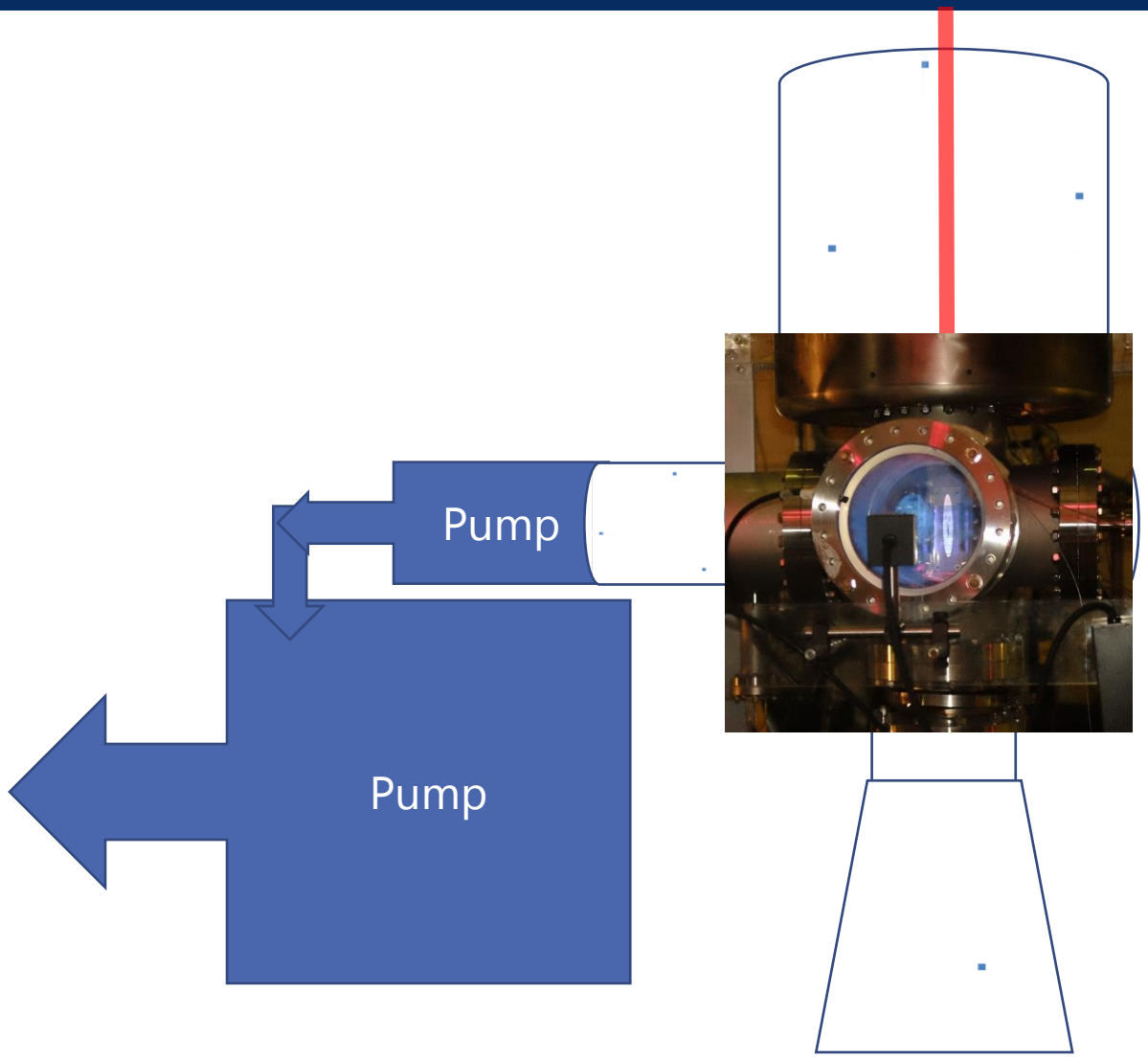
Video: https://www.youtube.com/watch?v=f_6xolDoqs0

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



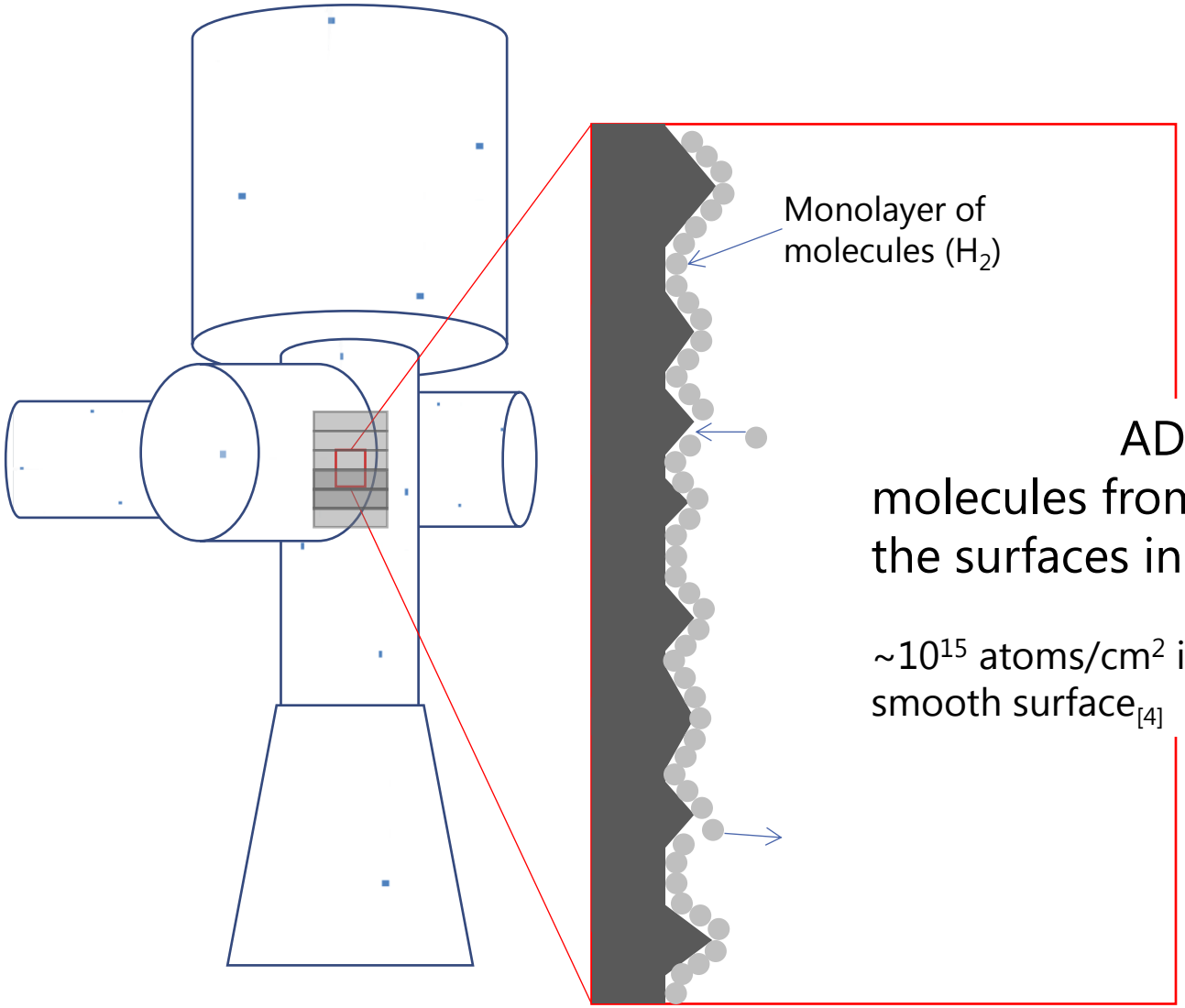
1×10^{-8} Torr

Turn on the electron beam!



1×10^{-7} Torr

Meanwhile…



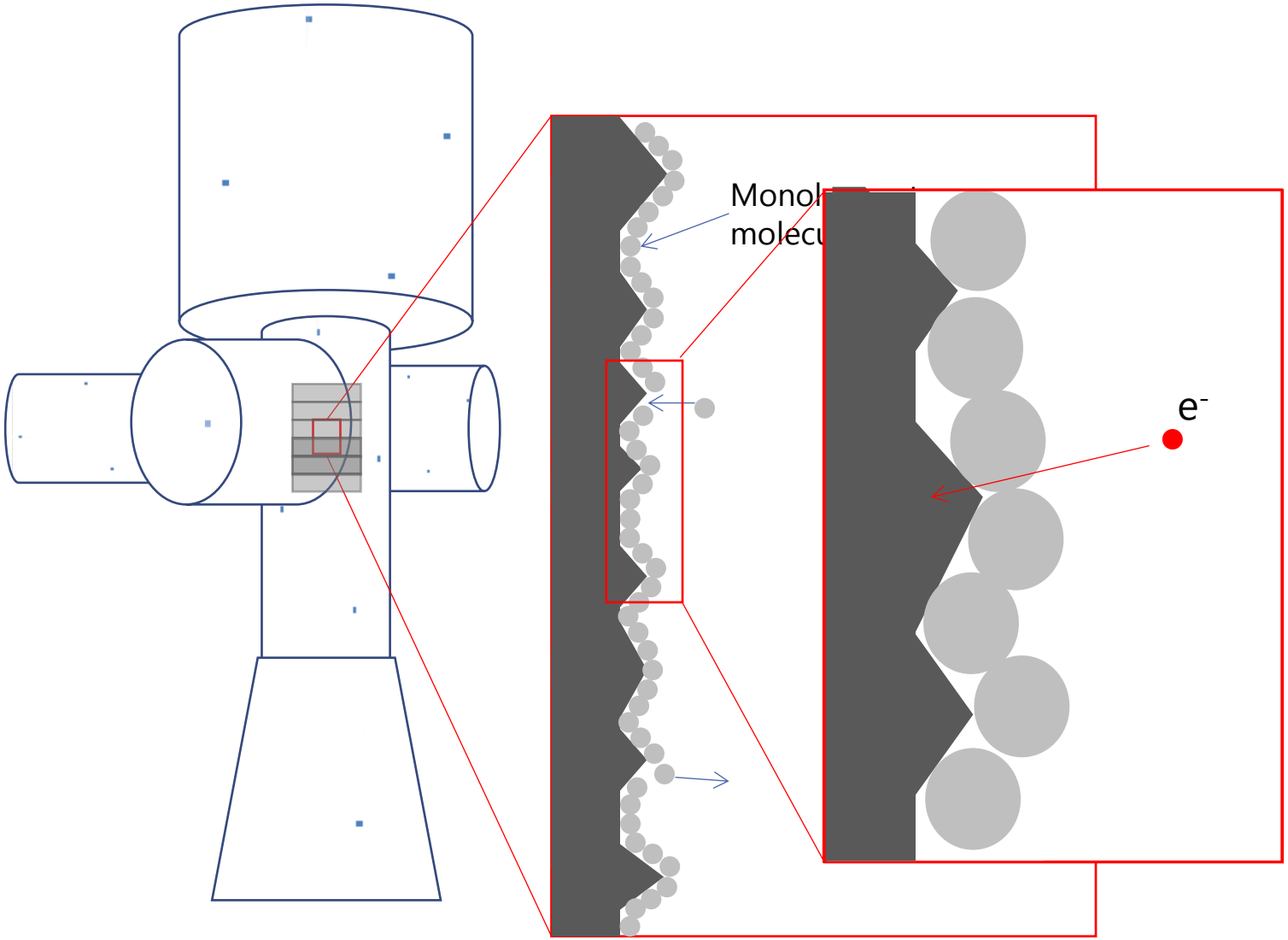
ADSORPTION

molecules from air weakly bond to the surfaces in the vacuum

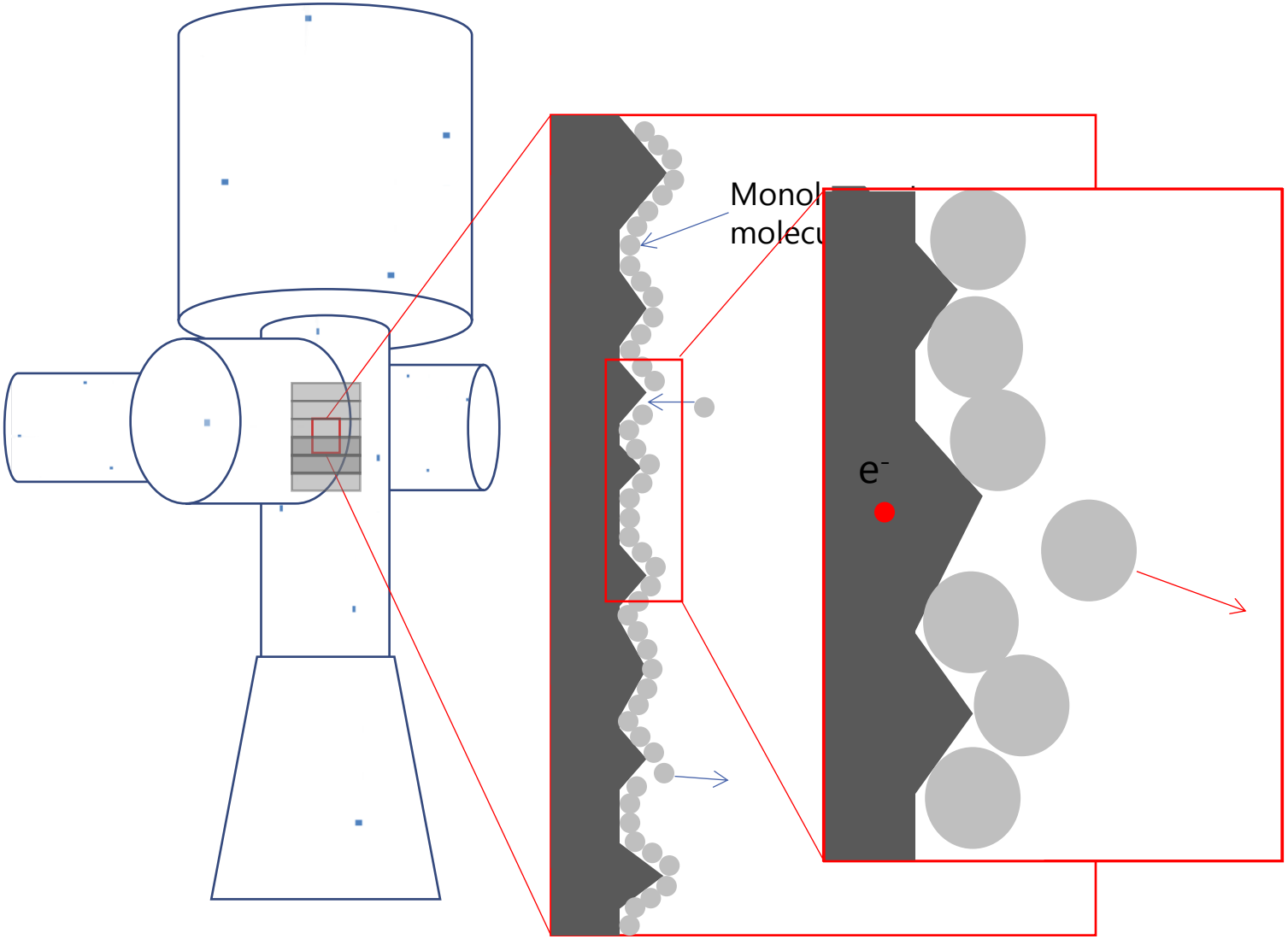
~10^{15} atoms/cm^2 in a monolayer on perfectly smooth surface[4]

Electrons hit absorber surface

Fermilab

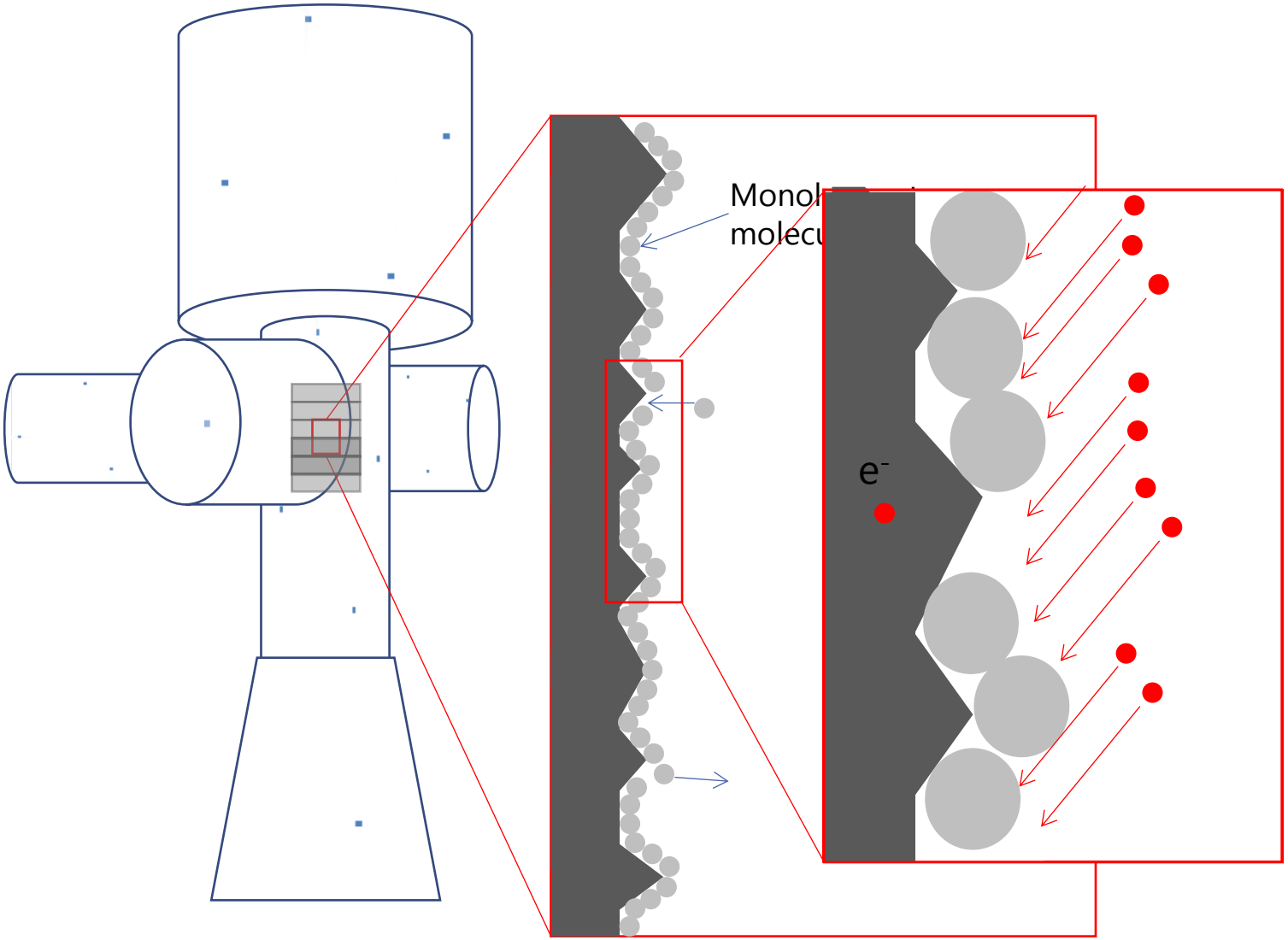


Molecules are Desorbed



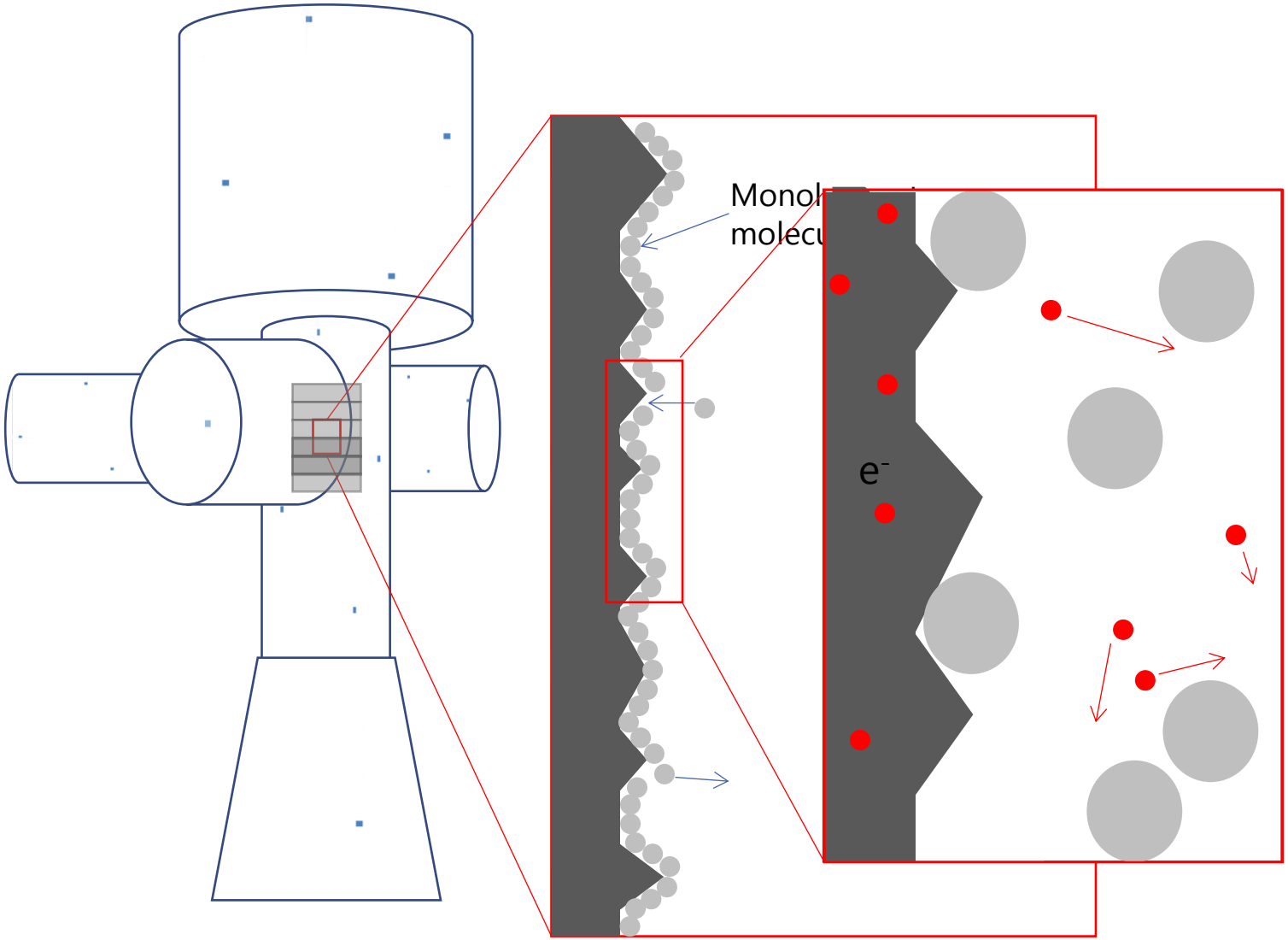
More Electrons = More Desorption

Fermilab



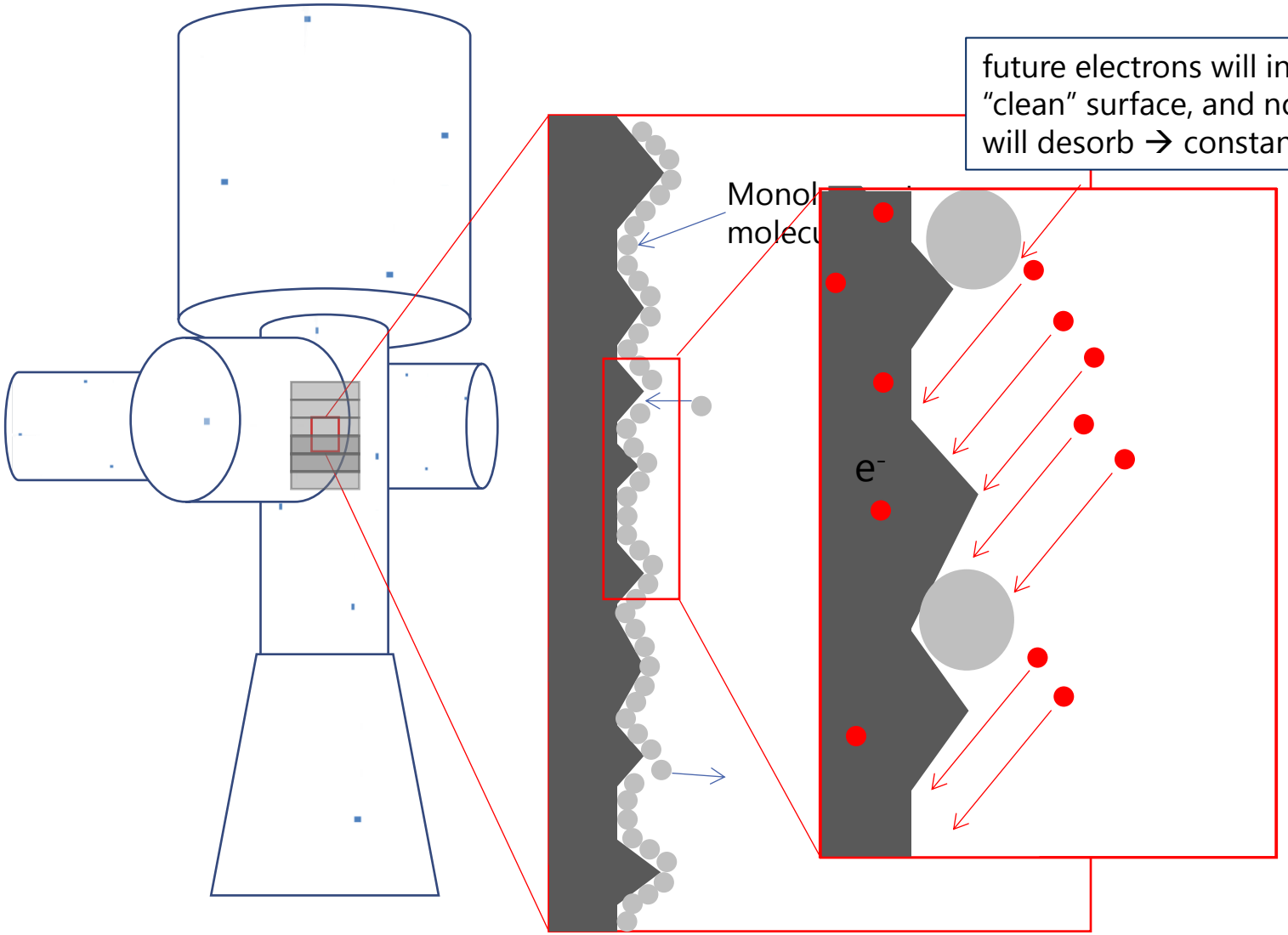
More Electrons = More Desorption

Fermilab



More Electrons = More Desorption

Fermilab



Pressure

Fermilab

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

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

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

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

- $I = \frac{q}{\Delta t}$
- $q = e * N_e$
- $I = \frac{e * N_e}{\Delta t}$
- $\Delta I = \frac{e * \Delta N_e}{\Delta t}$

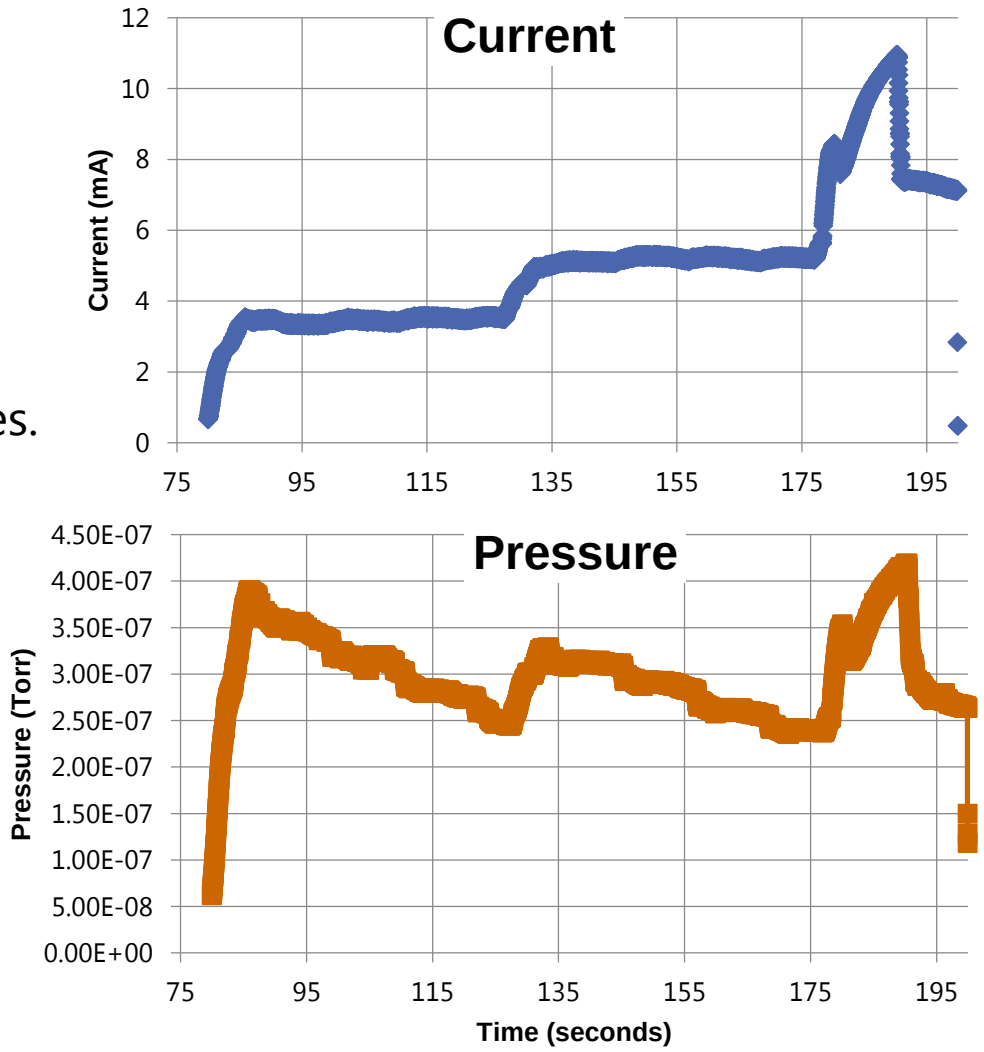
Current is a measure of the number of electrons hitting the surface!

The First Beam: 07/03/2014

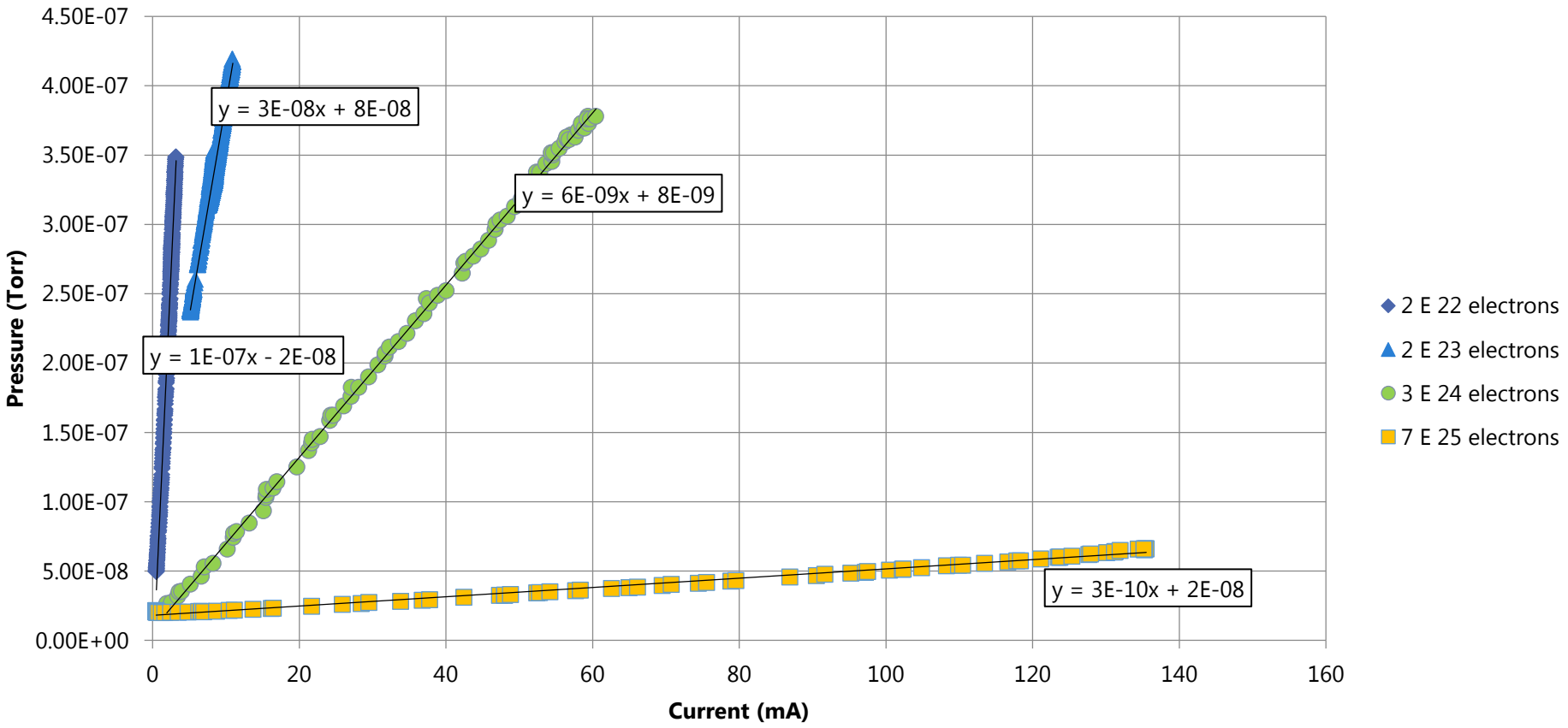
An increasing flow of electrons continuously increases desorbed molecules, ∴ Pressure ↑

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

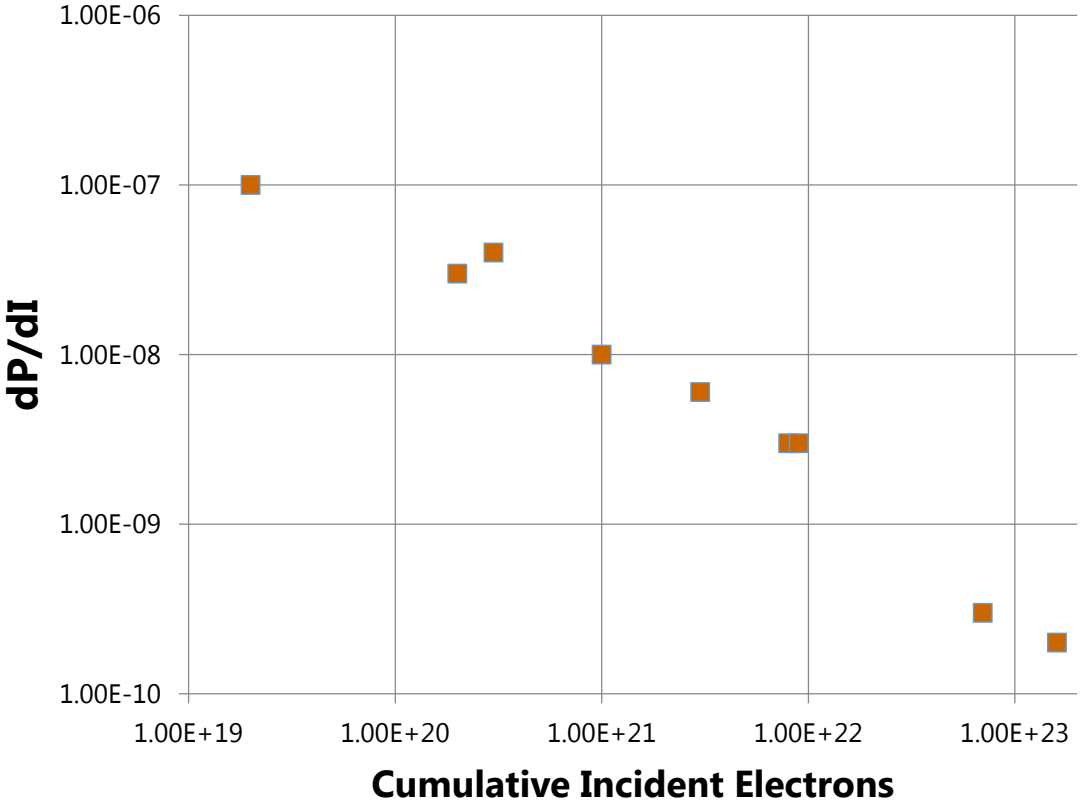


Comparing $\frac{\Delta P}{\Delta I}$ with increasing electron dose shows that the absorber surface was significantly more clean after 7×10^{25} electrons.

Coefficient of Desorption

Fermilab

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



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

Fermilab

The number of molecules desorbed by the surface decreased by 90% with a dose of 10^{24} 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.