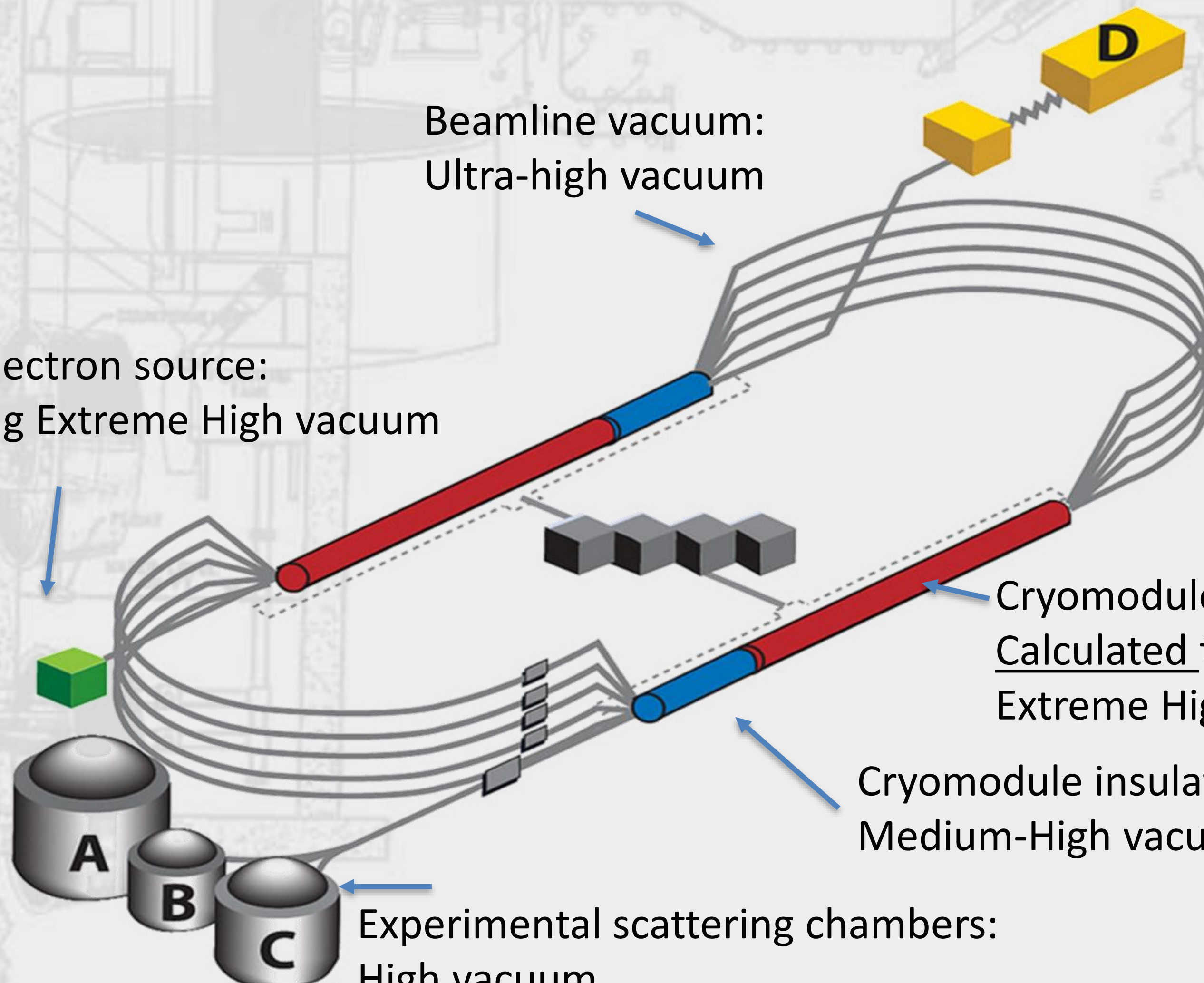
Extreme High Vacuum

Marcy Stutzman, Ph.D. Jefferson Lab Center for Injectors and Sources

Outline

- Jefferson Lab
  - Polarized Electron Source
- Pumps
- Measurement
- Modeling
- Summary

Jefferson Lab vacuum



Beamline vacuum:
Ultra-high vacuum

Polarized electron source:
Approaching Extreme High vacuum

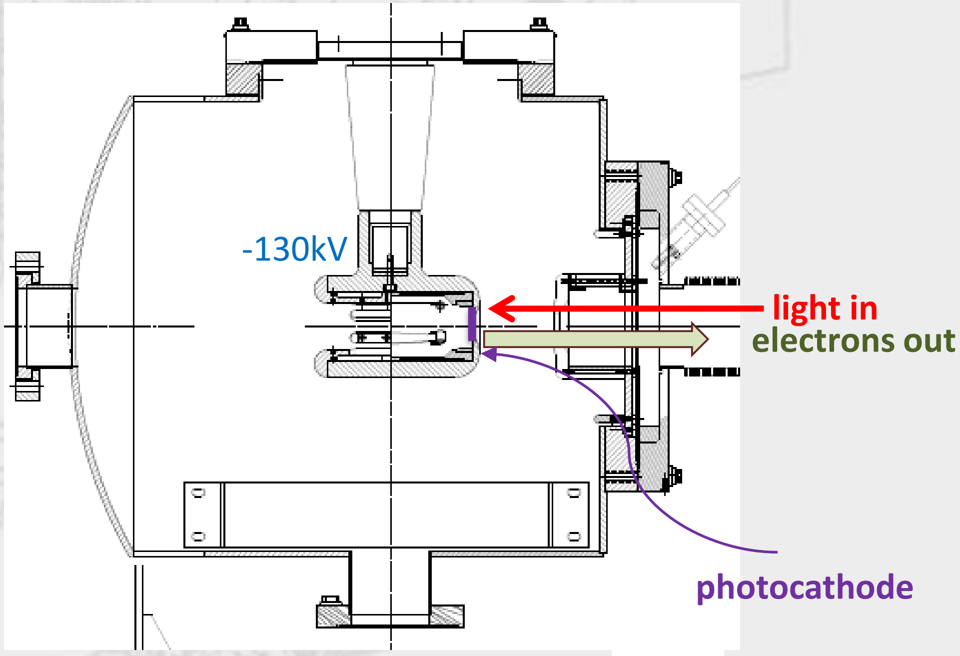
Cryomodule vacuum at 2K:
<u>Calculated </u>to be
Extreme High vacuum

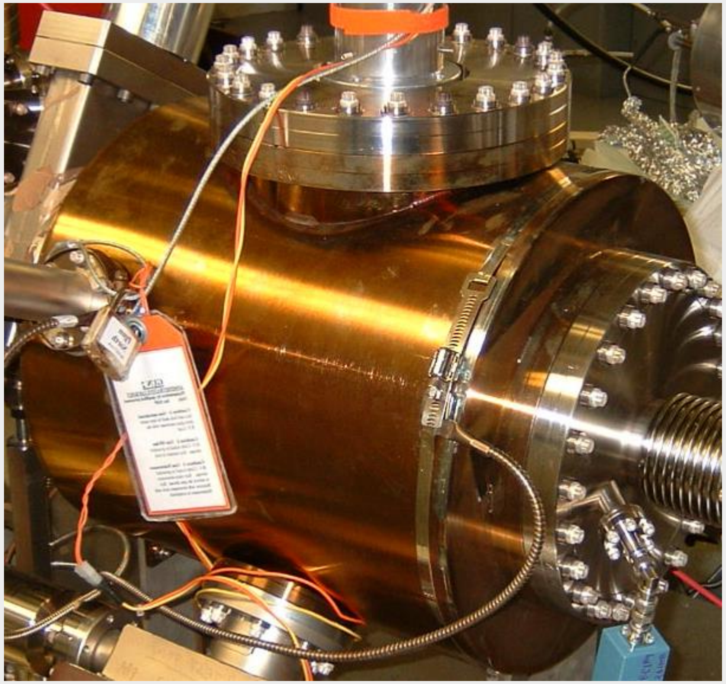
Cryomodule insulating vacuum
Medium-High vacuum

Experimental scattering chambers:
High vacuum

Photoemission Source

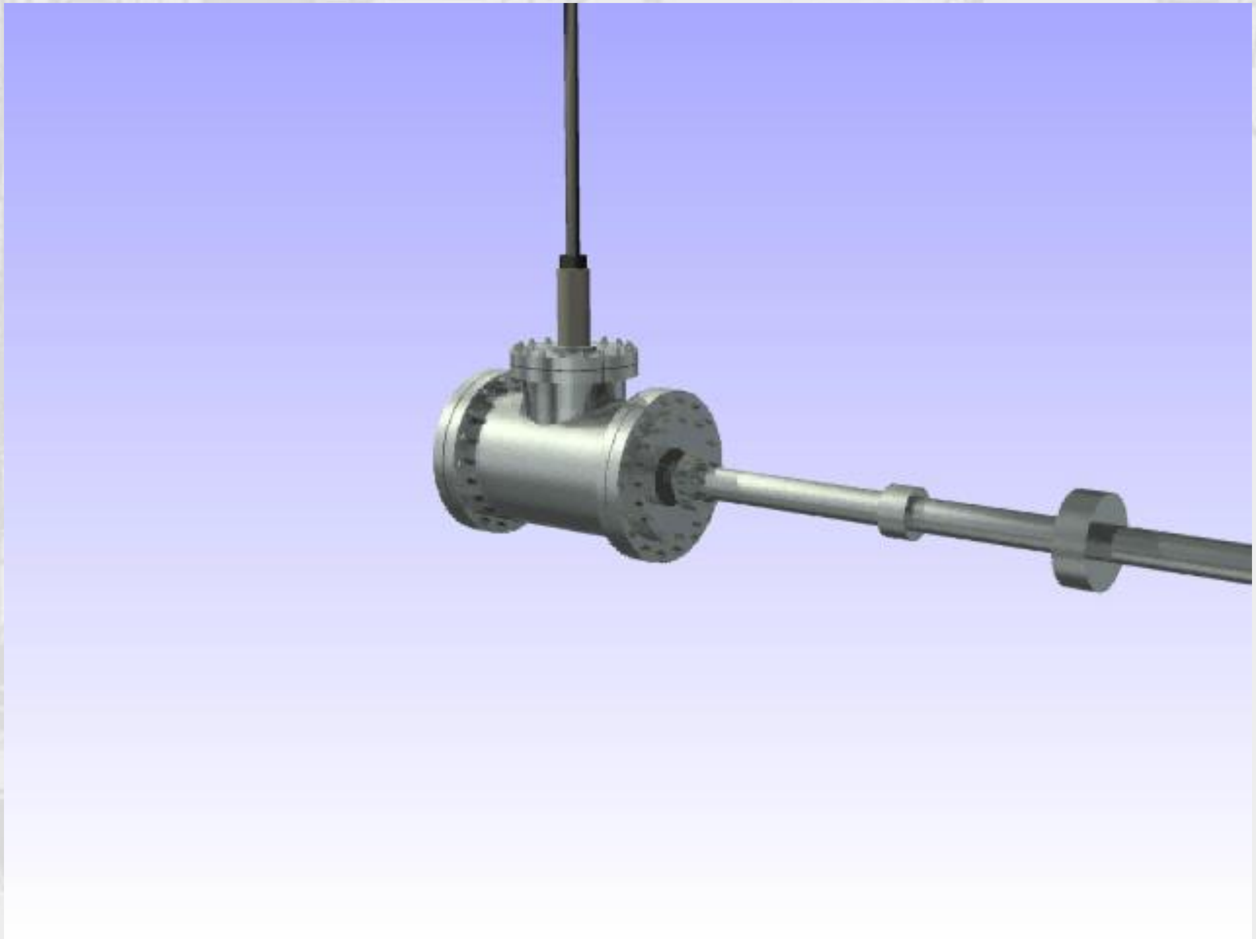
- -130 kV DC (*vs.* RF) electrode bias
- x-ray standard "inverted" insulator
- Pumps with NEG modules and ion pump
- Base pressure approaching XHV ≡ $P < 1 \times 10^{-12}$ Torr





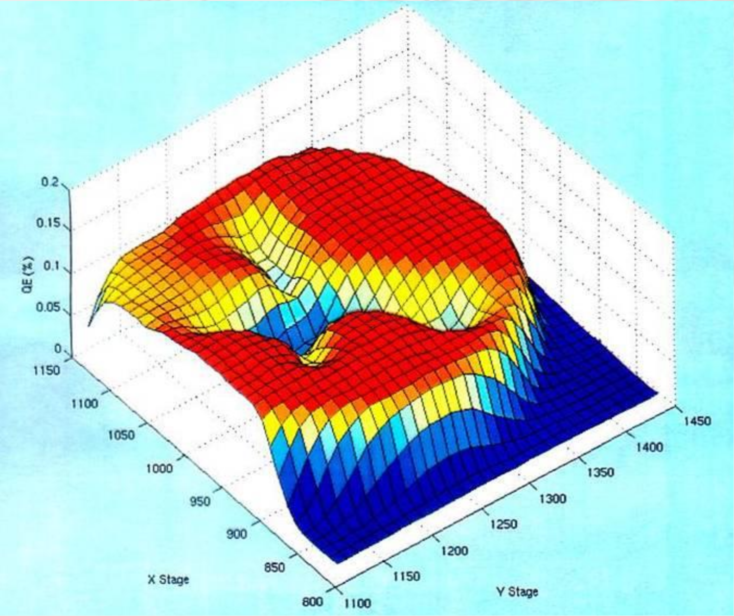
Jefferson Lab

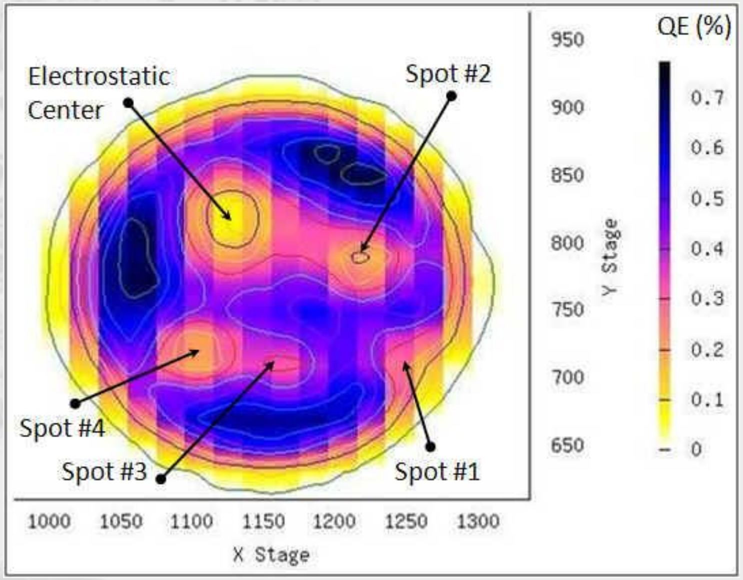
Any gas in chamber can be ionized by electron beam, accelerated back toward the photocathode and limit photocathode operational lifetime



Photocathode Lifetime

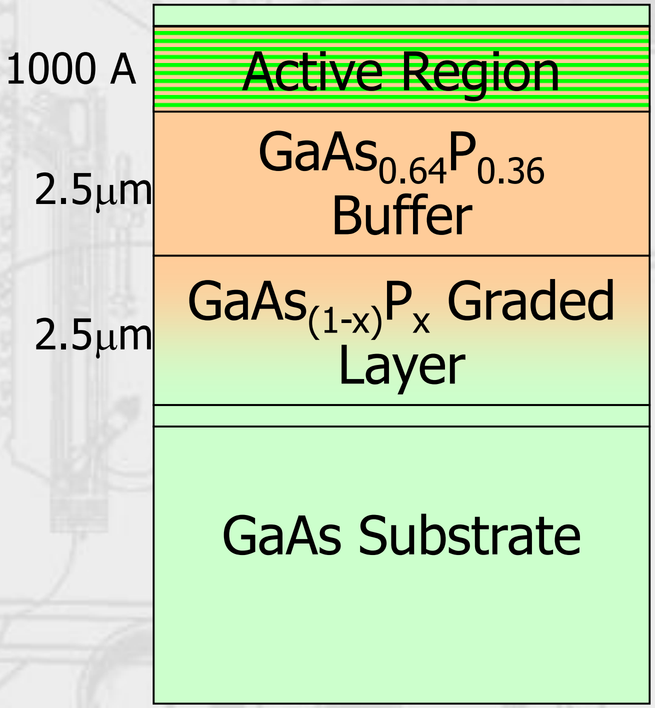
- Ion bombardment – with characteristic QE "trench" from laser spot to electrostatic center of photocathode – **damages NEA** of GaAs
- High energy ions are focused to electrostatic center: create QE "hole"
  Don't run beam from electrostatic center.
- QE can be restored, but takes about 8 hours to heat and reactivate

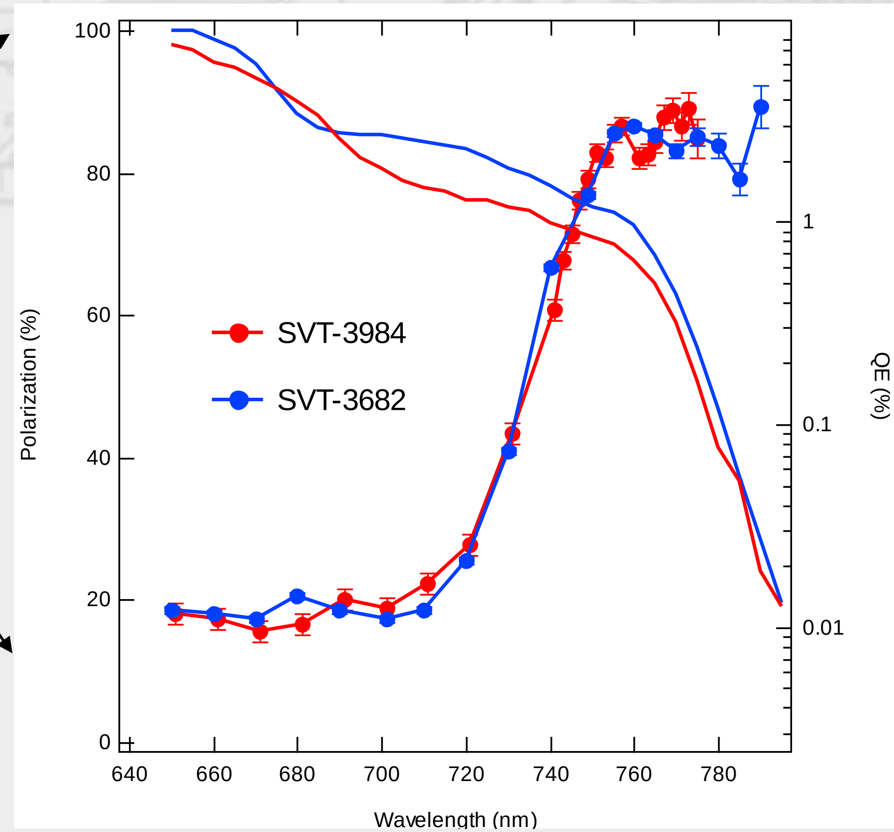




Strained-Superlattice GaAs/GaAsP

QE 1% and Polarization 85%





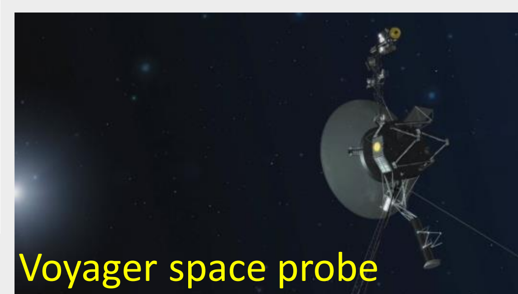
D. Luh et al, SLAC, PESP2002

From Aaron Moy, SVT Assoc and SLAC, PESP2002

Vacuum levels

	Example	Pressure (Torr)	atoms/cm^3
Atmosphere	Atmosphere at sea level	760	27,000,000,000,000,000,000 or 2.7×10^{19}
Low vacuum (1-300 Torr)	Atmosphere on Mount Everest	252	1×10^{19}
	Pressure in bell jar experiment, Mars	1-10	$1\text{-}3 \times 10^{17}$
Medium vacuum (1 Torr-1mTorr)	Insulating vacuum, atmosphere on Pluto	10^{-3}	10 quadrillion
High vacuum (1 mTorr- 1×10^{-7})	Scattering chambers	10^{-5}	100 trillion
Ultra high vacuum (UHV, 1×10^{-7} – 1×10^{-12})	Vacuum tubes, Cathode Ray tubes, beamline vacuum	10^{-8}	100 million
	Pressure outside Space Station (400 km)	10^{-10}	1 million
	JLab Electron Gun	10^{-12}	10,000
Extreme high vacuum (XHV <1×10^{-12})	Interstellar space estimate ~ 1 atom / cm^3	10^{-17}	1

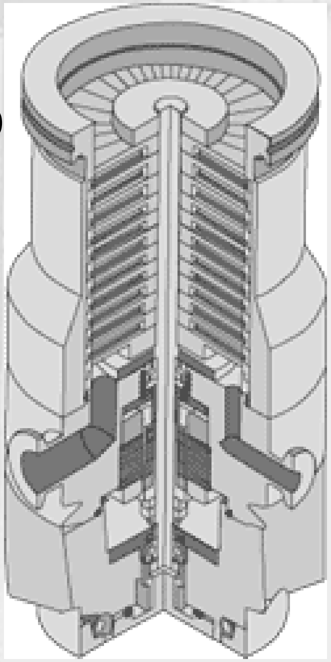


Modern Vacuum Pumps

Gas Transfer Pumps

- Rotary vane pump
- Roots pumps
- Turbo pumps



Compress rarified gas
Move gas to higher pressure exhaust

Capture Pumps

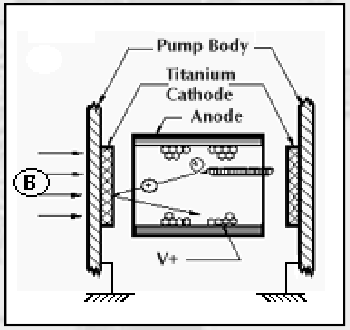
- Ion pumps
- Getter pumps
- Cryopumps

Remove molecules from *gas phase*

Capture Pumping

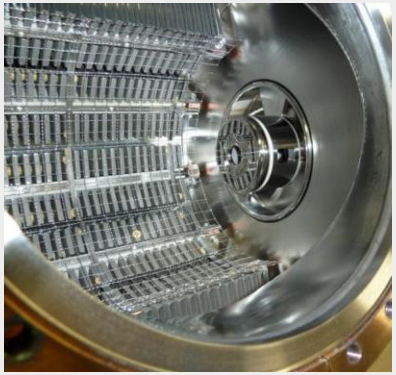
Ion pumps

- Gas ionized
- High voltage accelerates ions into plates
- Ion implant in plates - captured



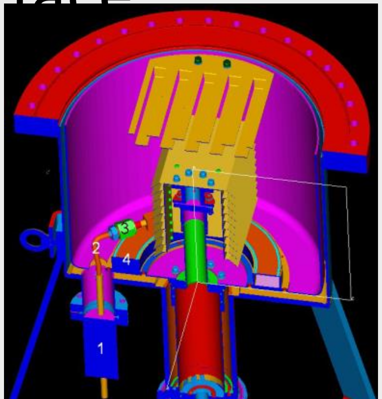
Getter pumps

- Chemically reactive surface
- Gas molecules incident on surface stick
- Chemisorption removes gas



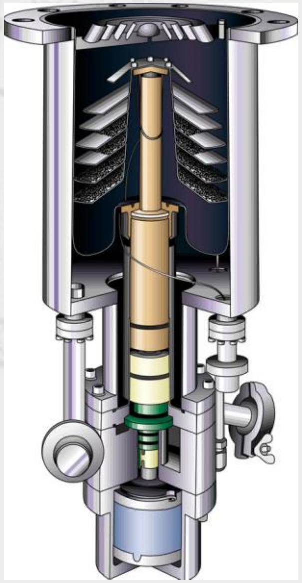
Cryopumping

- Large surface area material
- Cooled below freezing temperature of desired gas
- Gas incident on cold surface sticks

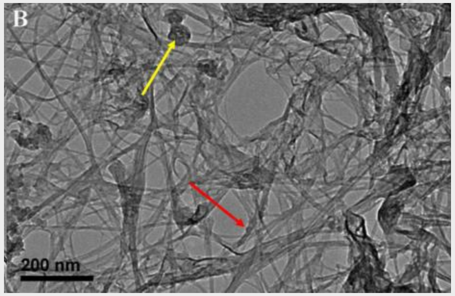


New cryosorber: Nanomaterial

- Typical cryopumps glue charcoal to cold surface
  - Large surface area allows cryosorption rather than cryocondensation
  - Lower pressure
- Requires Low temperature adhesives
  - Can't bake system well



- Boron-Nitride Nanotubes have
  - Huge surface area
  - Good thermal
  - Are freestanding
  - Are manufactured across street (JLab spin-off)
- Can we use these for cryosorber material?

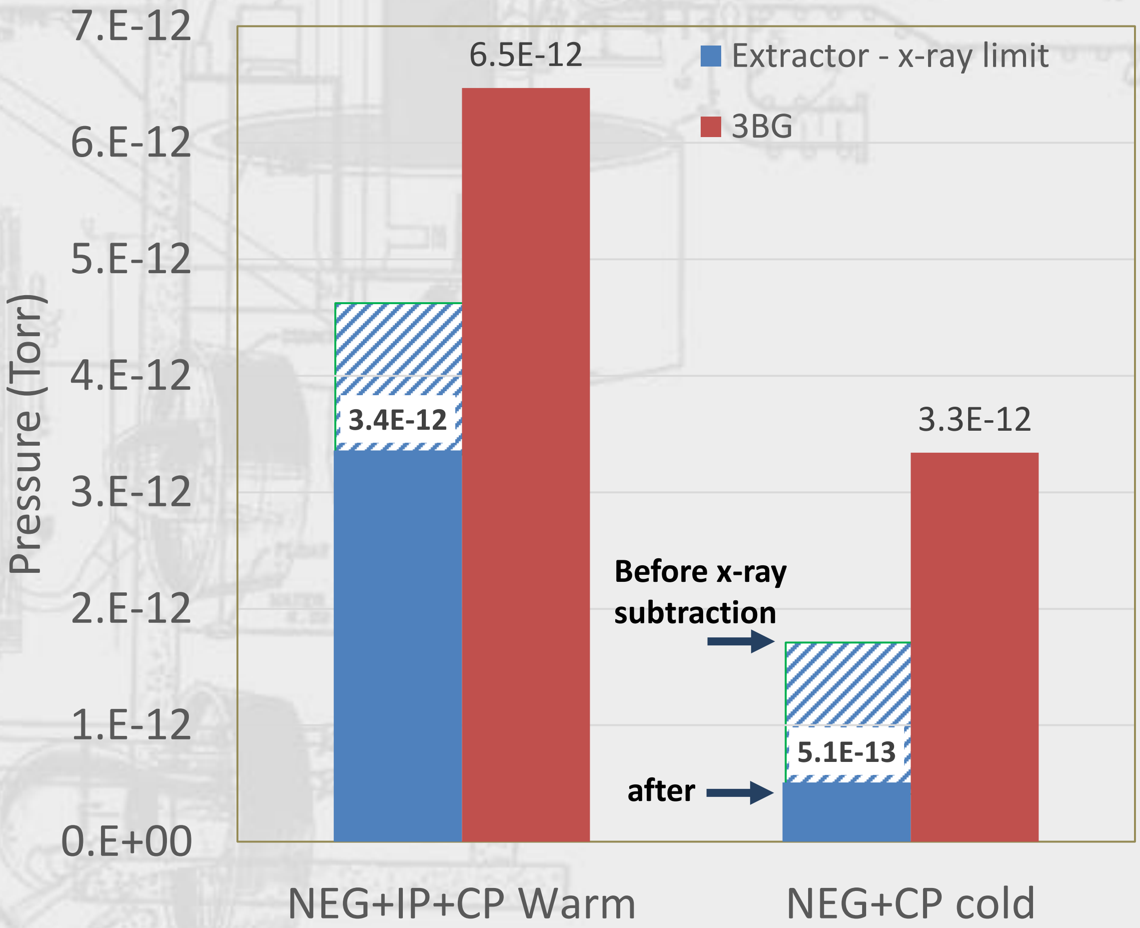


Mounting BNNT for Cryopumping

1 g BNNT material
Copper grid

~4 g BNNT material
"sewn on" with wires
SULI Student, 2016

Results

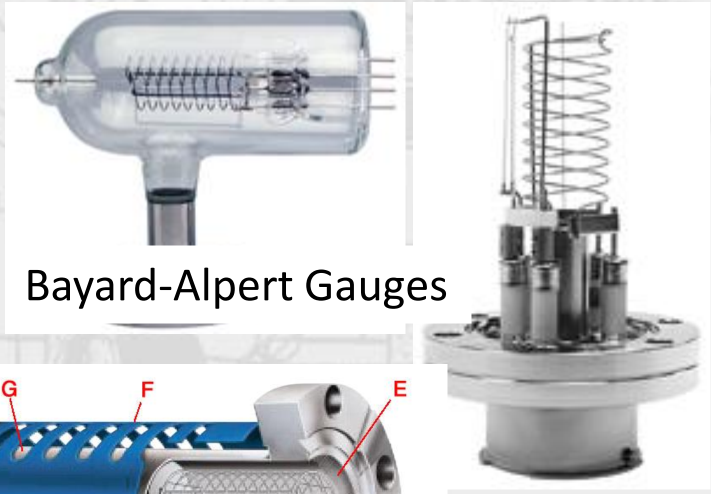


- BNNT outgassing low
  - No valve
  - P~$3x10^{-12}$ Torr BNNT warm
- Cryopump reduces pressure
- x-ray limit $1.2x10^{-12}$ Torr dominates extractor gauge reading
- 3BG readings still have good signal:background, negligible x-ray effect

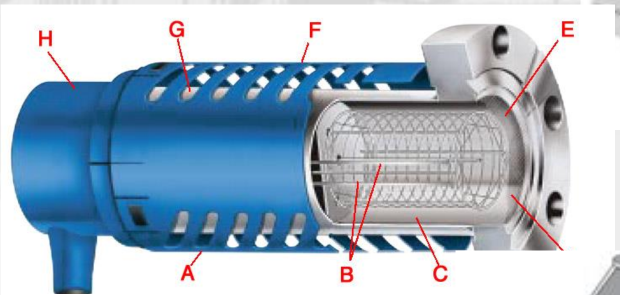
Marcy Stutzman, Roy Whitney and Kevin Jordan “Nano-materials for adhesive-free adsorbers for bakable extreme high vacuum cryopump surfaces” Patent US9463433B2

Jefferson Lab

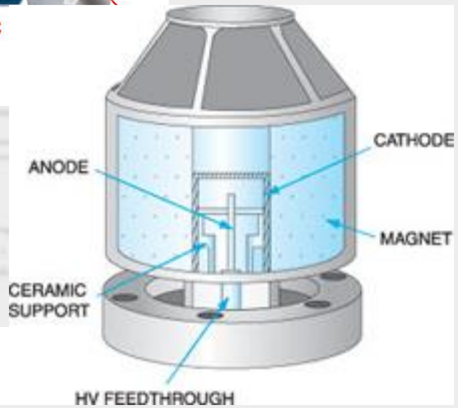
High/Ultra High Gauges



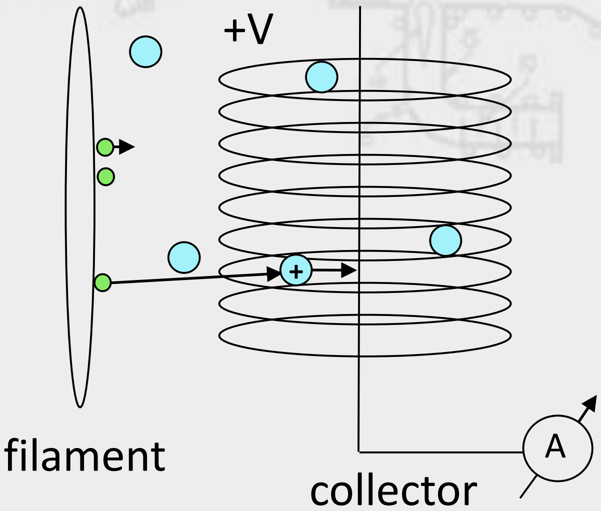
Bayard-Alpert Gauges



Stabil-Ion gauge



Cold Cathode gauge



- Lowest pressures:

  10^{-8} Torr – 10^{-11} Torr

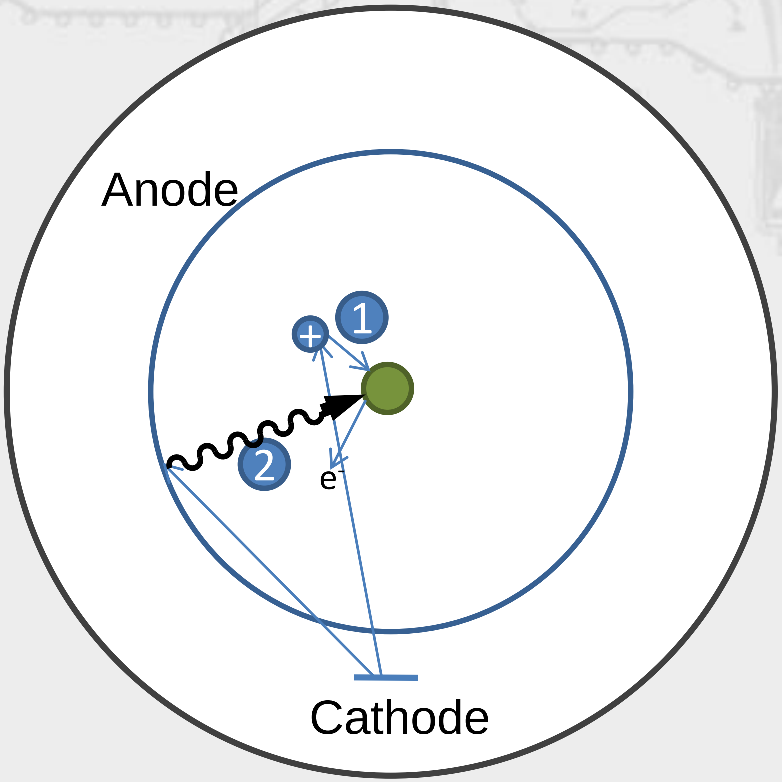
  up to $4,000

Measure Pressure:
Hot cathode gauge operation and errors

1. True gas ionization
   - Positive current
2. X-ray effect
   - e- on anode -> photons emitted
   - Photons on collector -> electrons emitted
   - Extra positive current

Additional effects:

3. Inverse X-ray effect
4. Electron Stimulated Desorption



$$I^{+} = I_{real} + I^{-}_{x-ray} - I^{-}_{inv.x-ray} + I_{ESD}$$

Ionization gauge pressure calibration

- Chamber evacuated
- Gauge energized
- Current measured
- Calibration factor to translate measured current to pressure

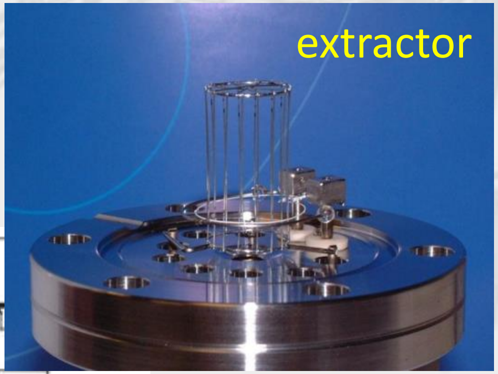
$$P = \frac{\textbf{ion current}}{\textbf{Sensitivity} * \textbf{emission current}}$$

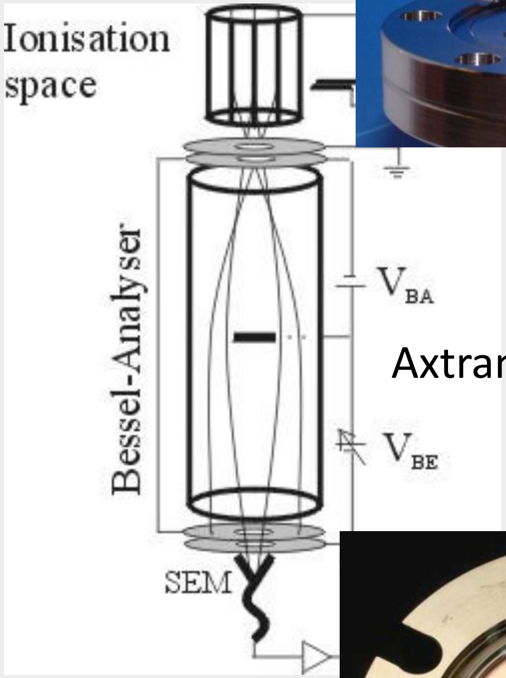
- x-ray limit determines lowest pressure that can be measured

XHV gauges: reduce x-ray limit

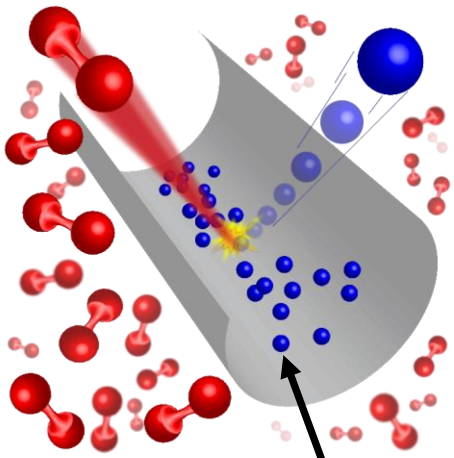
Hot filament

- Extractor gauge
  - available commercially for decades
  - x-ray limit reduced through geometry
  - x-ray limit quote: **7.5x10^{-13} Torr**
  - $4,300
- Axtran gauge
  - Bessel box energy discrimination
  - electron multiplier to assist in low current measurements
  - Quoted limit: **3.75x10^{-13} Torr**
  - $7,500
- Watanabe BBB (Bent Belt Beam) gauge
  - Uses Leybold IE540 controller
  - 230° deflector BeCu housing
  - JVSTA **28**, 486 (2010)
  - Quoted limit: **4x10^{-14} Torr**
  - $13,000 + Ext. controller ($2,600)





Cold Atom Vacuum Standard (CAVS)



- World's only absolute UHV/XHV sensor and standard

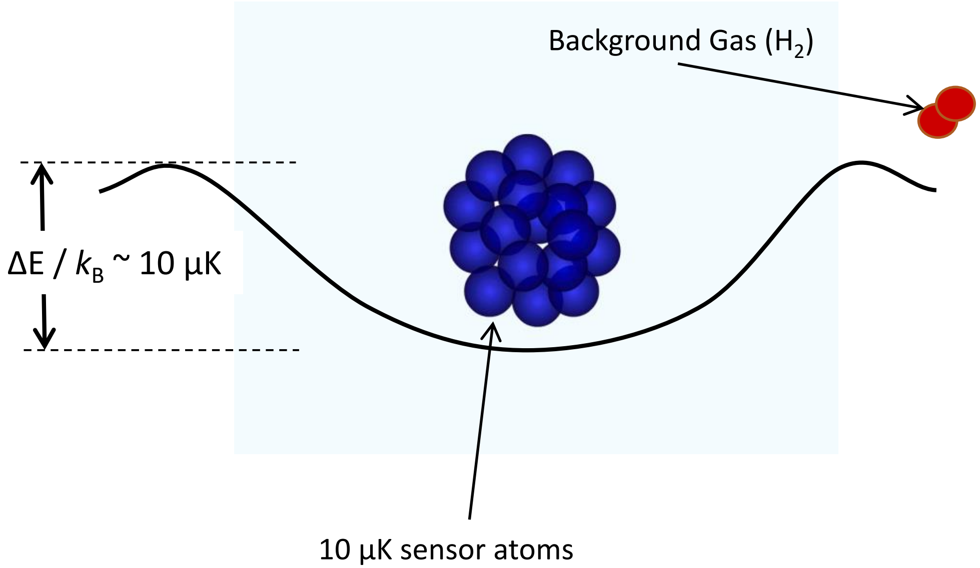
- Cover range of 10^{-10} to 10^{-5} Pa
  - Presently no primary standards

- Move from classical to quantum based standard

- Two Versions: Lab Scale
  Miniature (portable) scale

Thanks to Julia Scherschligt and Jim Fedchak

Ultra-cold atoms make ideal vacuum sensors

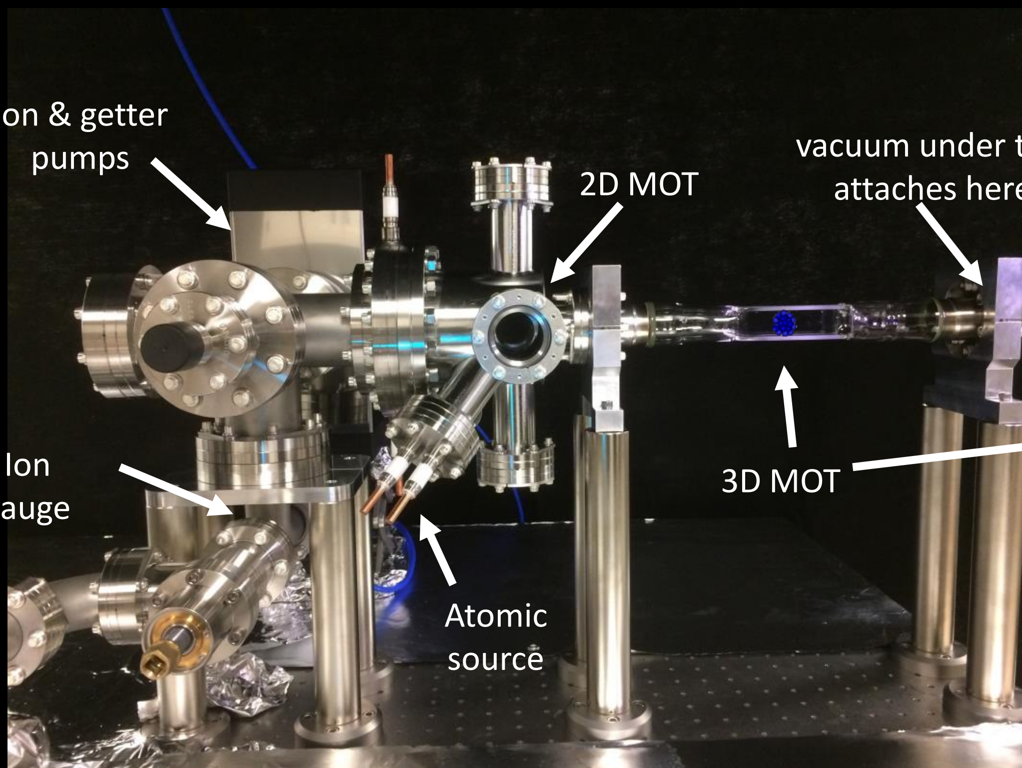


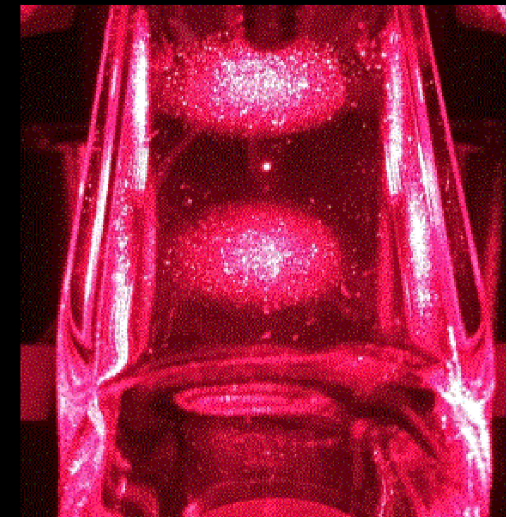
- Laser cool sensor atoms to ~10 μK
- Transfer cold atoms to shallow magnetic trap
- 300 K background atoms easily kicks 10 μK atoms from magnetic trap
- **Loss rate of cold-atoms is a measurement of vacuum**

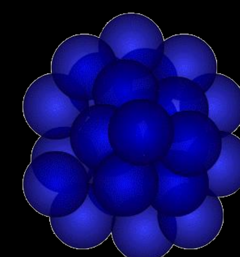
Depends on:

- Collision rate coefficient (atomic property)
- Density of background gas

Basis of the CAVS







Pressure system Modeling

Desirable to know what pressure to expect before building systems

- Calculations are tedious
- Test particle Monte Carlo simulation software available

$C=lW=qpV\Delta p$

$Cges=C1+C2+\cdots+Cn$

$1Cges=1C1+1C2+\cdots+1Cn$

$qpV=A\cdot c^{-}4\cdot(p1-p2)$

Formula 1-23: Orifice flow

$Cor,mol=A\cdot c^{-}4=A\cdot kT2\pi m0------\surd$

$Cor,mol=11.6\cdot A$

Formula 1-25: Orifice conductivity for air

$Cpipe,lam=\pi\cdot d4256\cdot\eta\cdot l\cdot(p1+p2)=$

$\pi\cdot d4128\cdot\eta\cdot l\cdot p^{-}$

$Cpipe,lam=1.35\cdot d4l\cdot p^{-}$

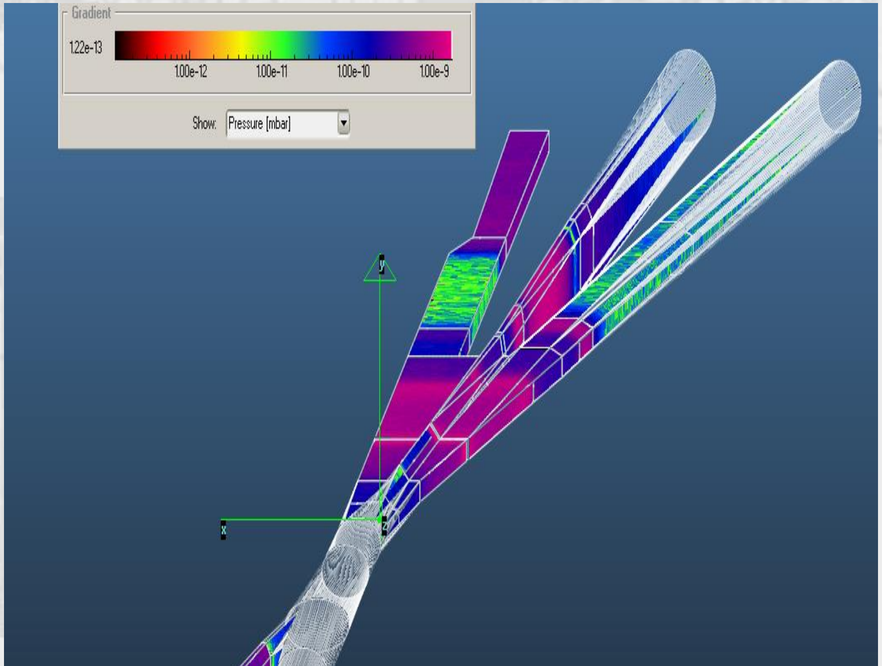
$Cpipe,mol=Corifice,mol\cdot Ppipe,mol$

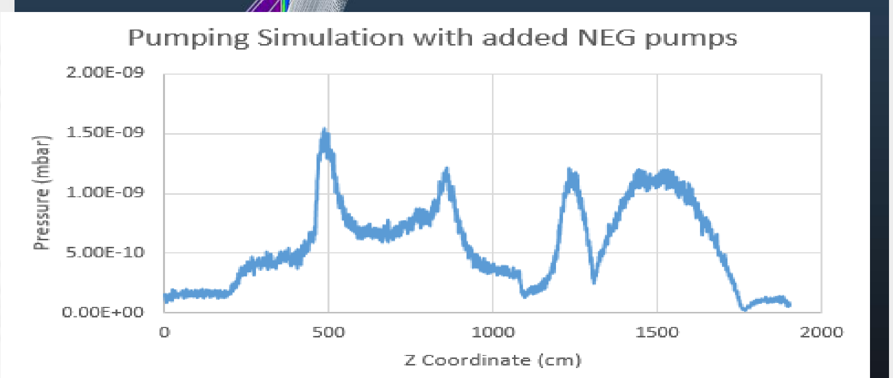
$Ppipe,mol=43\cdot dl\text{l}$

$Cpipe,mol=c^{-}\cdot\pi\cdot d312\cdot l$

$Cpipe,mol=12.1\cdot d3l$

Molflow+ modeling software

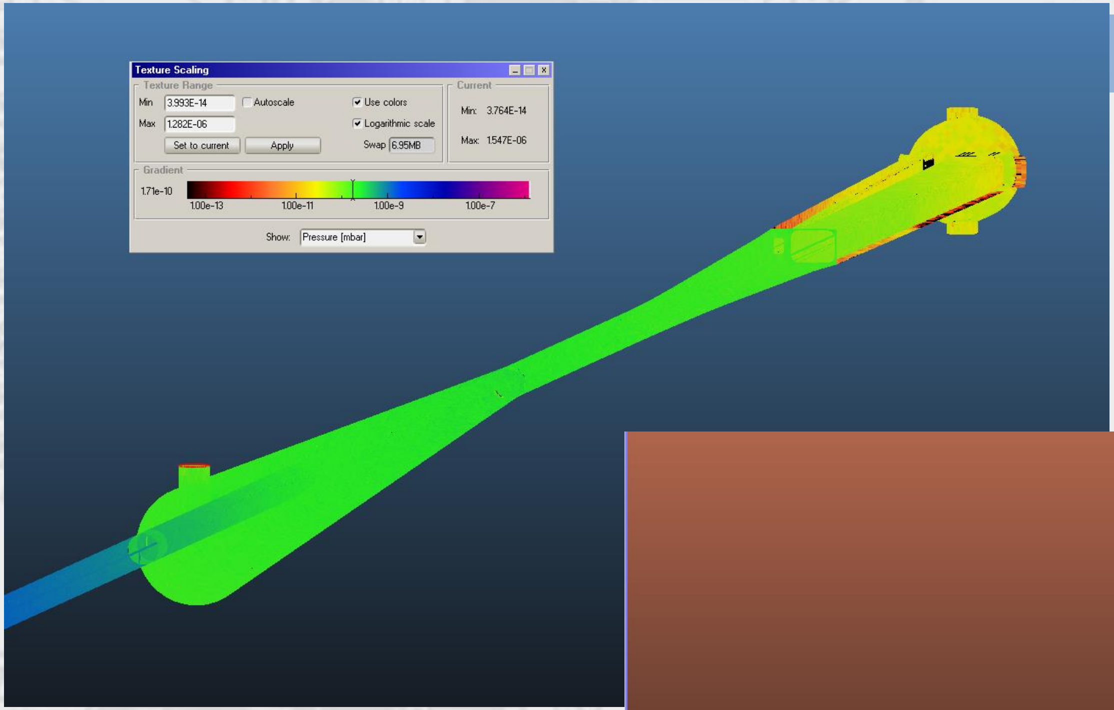




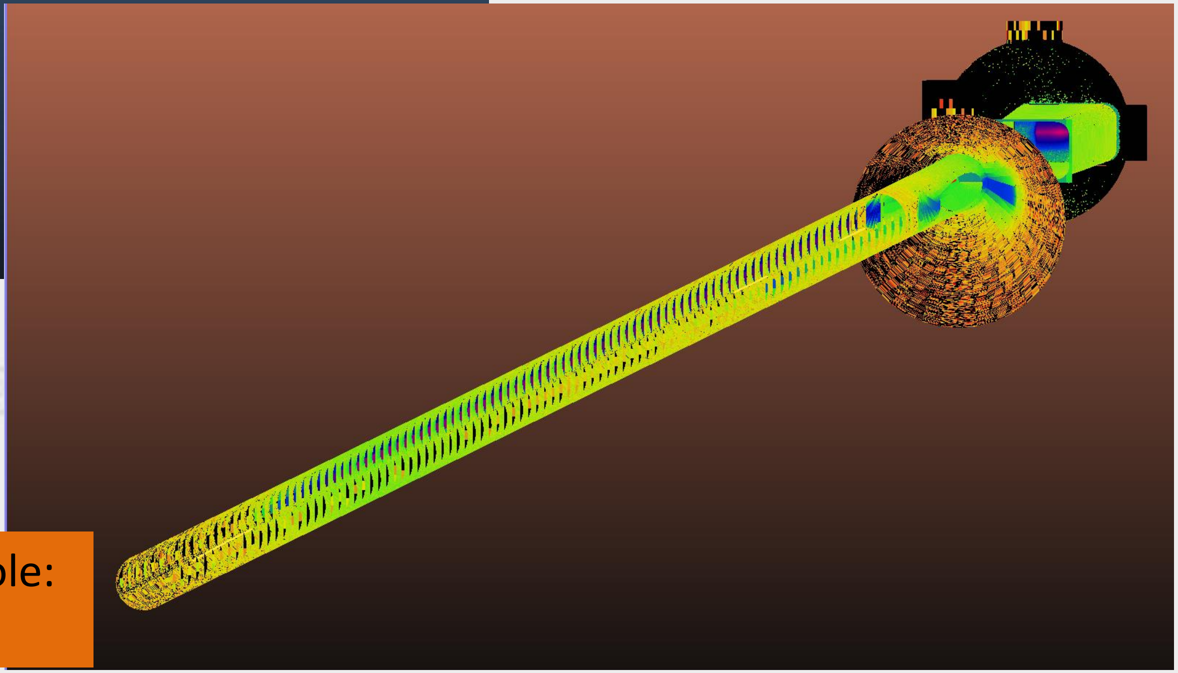
- Build geometry
  - 3D modeling software
  - Built in modeling tools
- Add sources of gas
  - Outgassing
  - Heat/photon loads from beam
- Add pumping
- Test Particle Monte Carlo -> Pressure Profile
- Used in all new accelerator designs - JLEIC

Simulation by Adam Hutchinson, SULI
HERA interaction region model
Poster Friday

Modeling for the Electron Ion Collider

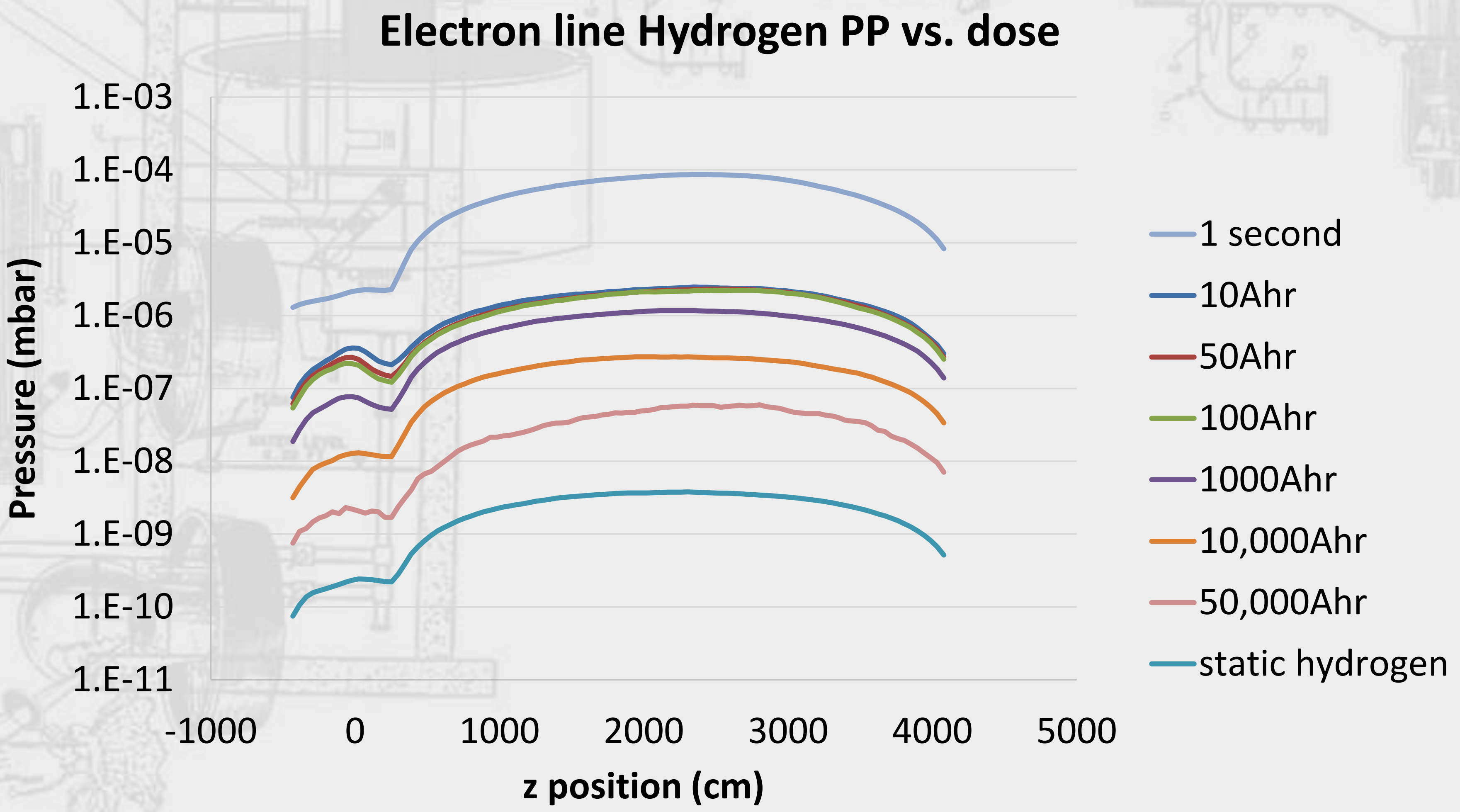


Vacuum levels without beam

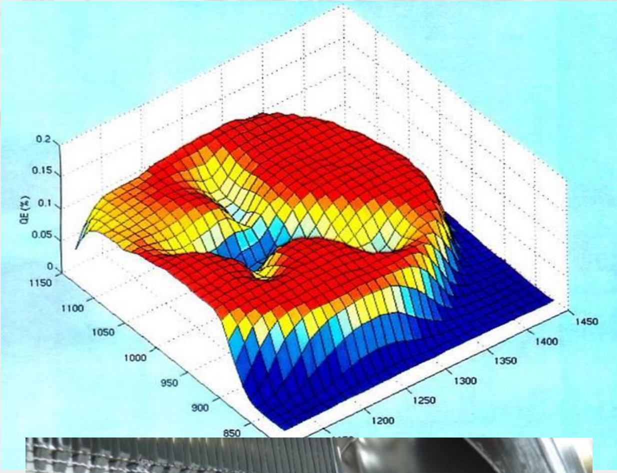


Synchrotron Radiation from dipole:
Photon Stimulated desorption

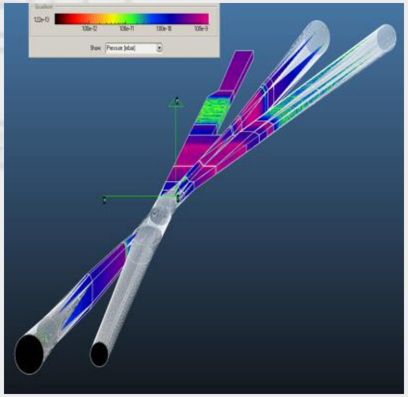
EIC: Pressure vs. Ahr

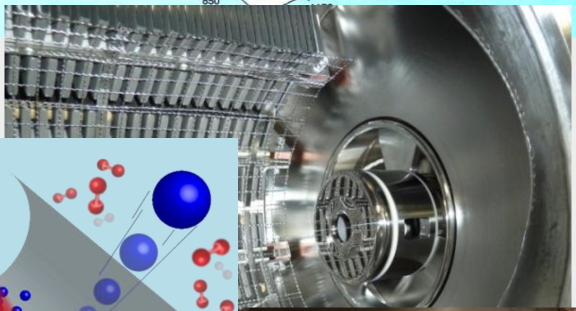


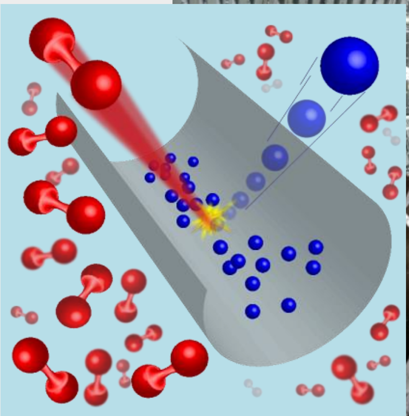
Summary

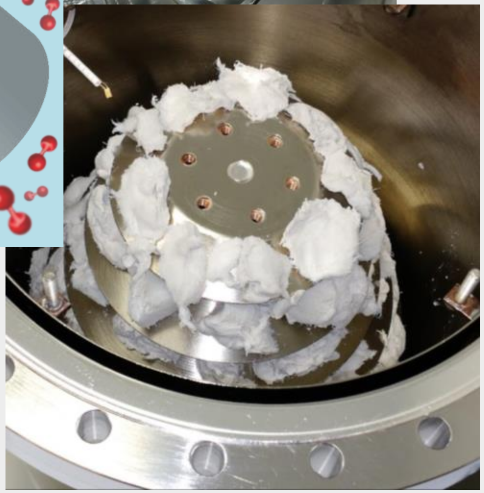


- High polarization photocathodes require vacuum near or at XHV for long lifetime
- We're optimizing the existing pumps and innovating on new XHV pumping
- Current ionization gauges may be replaced by Quantum standards and gauges
- Modeling required for new machine designs









Questions?

Jefferson Lab Center for Injectors and Sources

Matt Poelker, Joe Grames, Bubba Bullard
Marcy Stutzman, Scott Windham, Shukui Zhang
Carlos Hernandez Garcia, Phil Adderley, Riad Suleiman