Ionic Neutralization of Mirror Surface Charge

Lisa Barsotti
Matt Evans
John Miller
Richard Mittleman
Brett Shapiro
Rainer Weiss
Mike Zucker

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Primitive model of electrostatic fluctuating forces on insulators

Markov Process: Charge hopping on surface driven by surface charge electric fields.

Step time or relaxation time: $\tau_0 = \frac{\varepsilon}{\sigma} = \varepsilon_0 \kappa \rho$

on clean SiO_2 : weeks to years in vacuum

Average Force:

$$\langle F \rangle = \frac{E^2_{surface} A}{16\pi^2}$$

Fluctuating Force from charge hopping

$$F^2(f) = \frac{2\langle F^2 \rangle}{\pi\tau_0\left(\left(\frac{1}{\tau_0}\right)^2 + (2\pi f)^2\right)}$$

Leads to

$$x(f) \propto \frac{1}{f^3}$$

when $f >> 1/\tau_0$

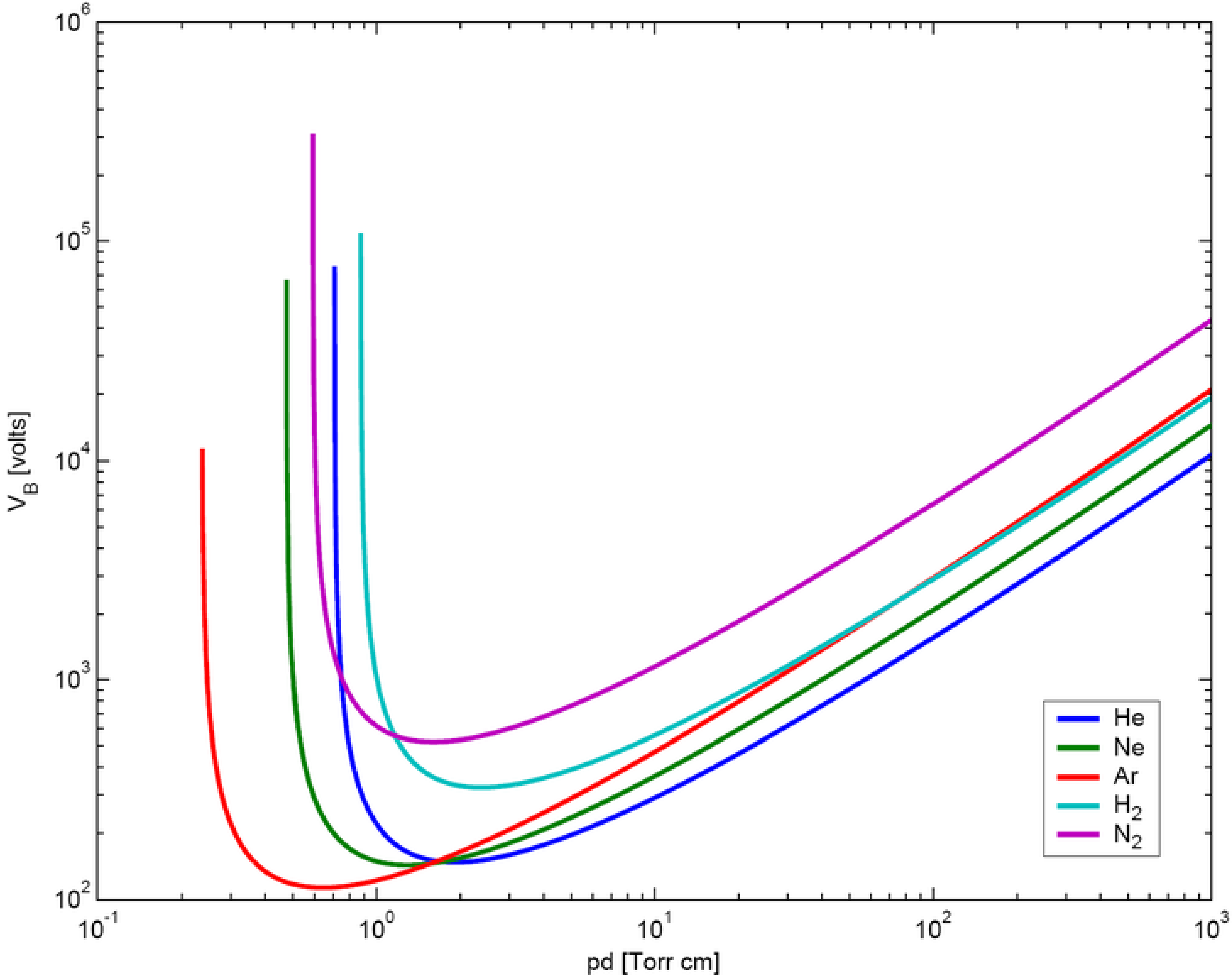
Typical surface charge densities in good vacuum

$10^{-14} < \sigma_{surface} < 10^{-10}$ Coulombs/cm^2 $\quad$ $10^5 < e_{surface} < 10^9$ electrons/cm^2

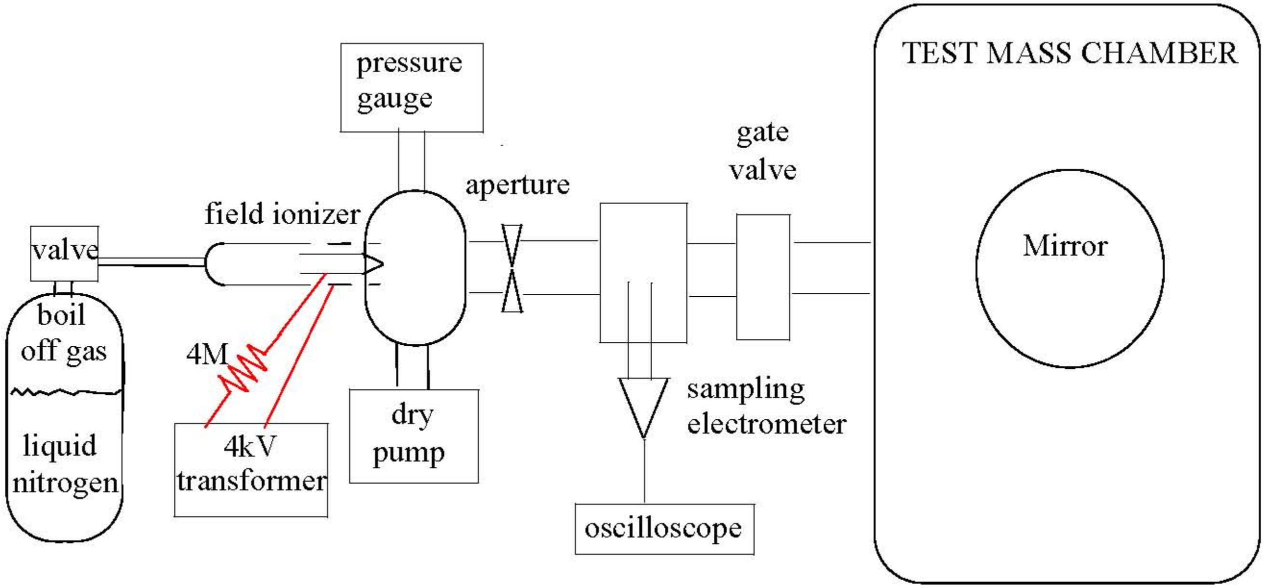
IONIC NEUTRALIZATION OF SURFACE CHARGE ON MIRRORS

- Technique
  - + and – nitrogen ions introduced from outside
  - Boil off from liquid nitrogen
  - Neutralization by E field driven thermal diffusion
- Advantages
  - Easy to do - all external
- Disadvantages
  - Requires stopping run ~ 1 day
  - Requires written procedure to avoid mistakes

Paschen Discharge Curves

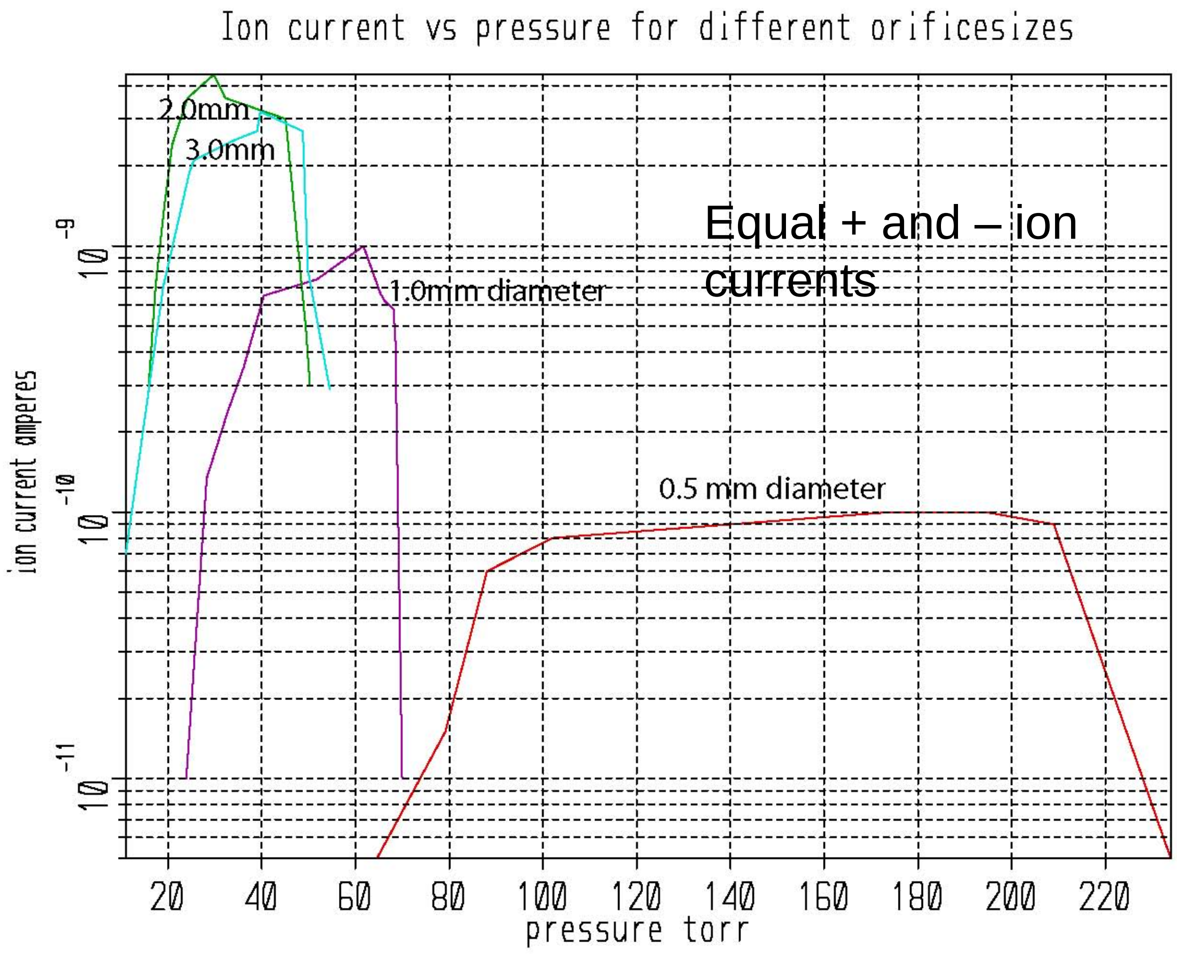


Schematic diagram of neutralization technique



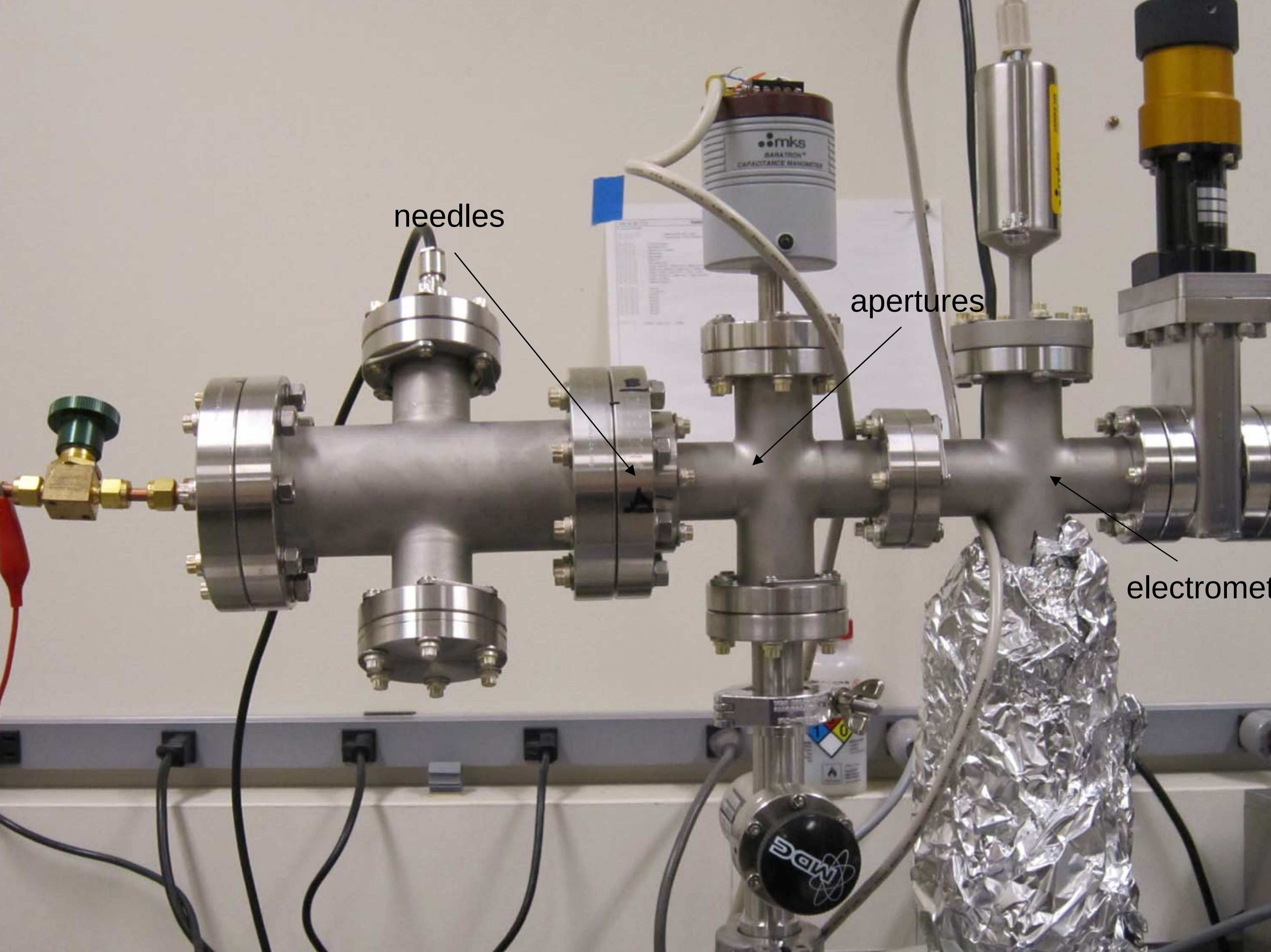
Physics

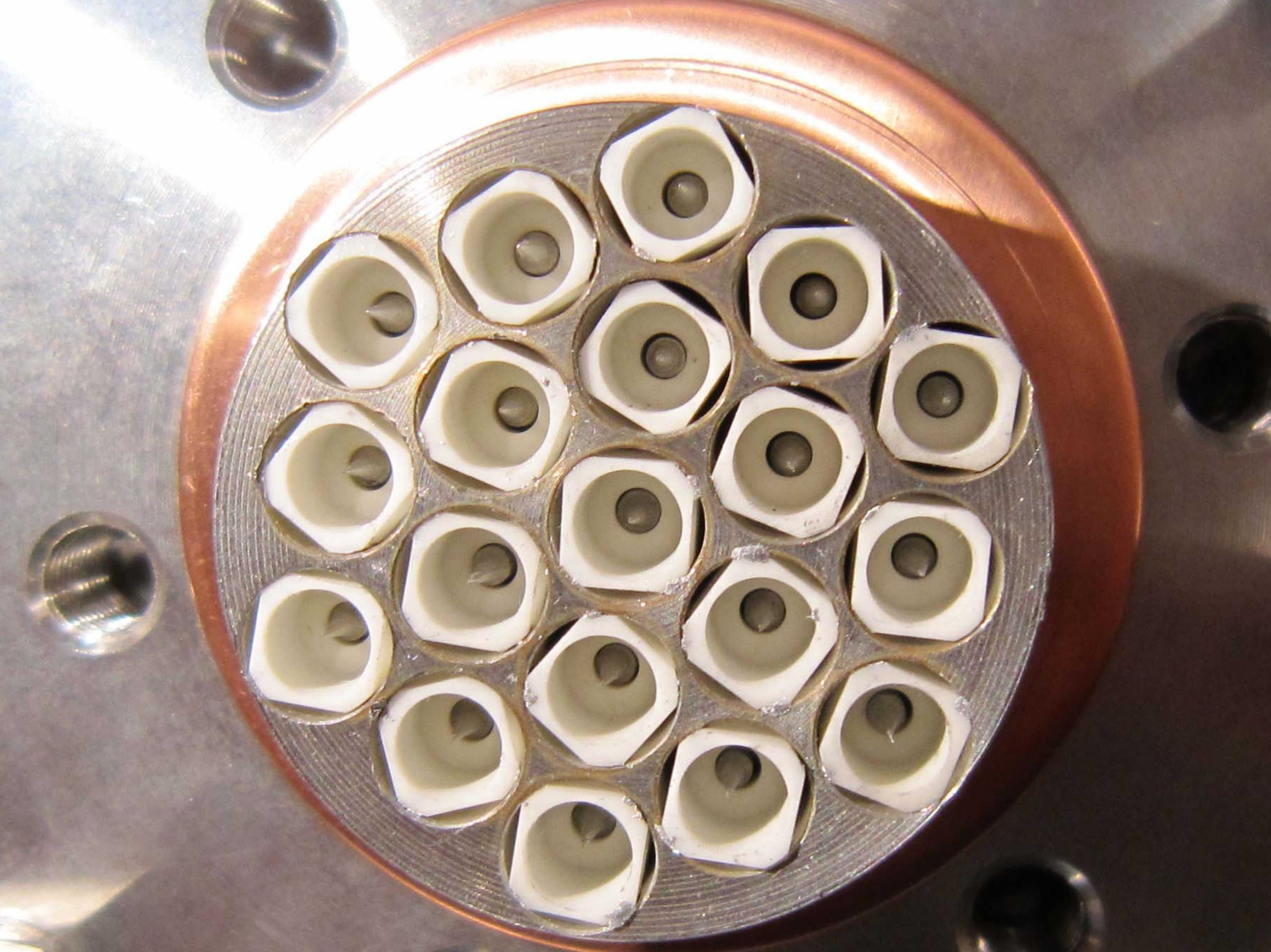
- In source and aperture:
  - competition between recombination and diffusion to walls
  - source pressure above ionization minimum of Paschen curve
  - turbulent flow in aperture reduces diffusion to wall
- In test mass chamber:
  - ions flow with neutral gas
  - E field driven diffusion to surfaces dominates,
  - recombination unimportant

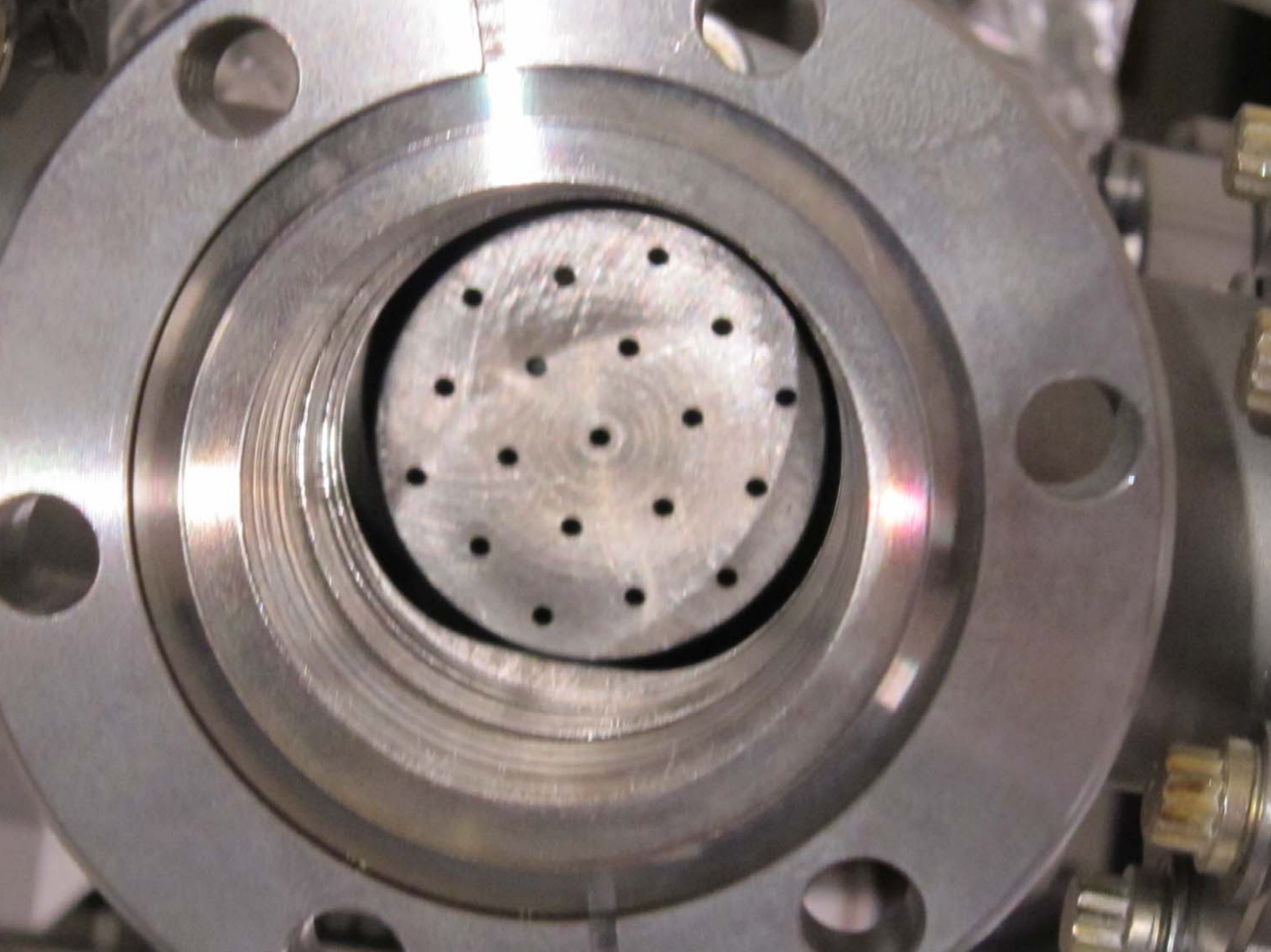


Ion current in 0.1 torr chamber – surrogate for the test mass chamber

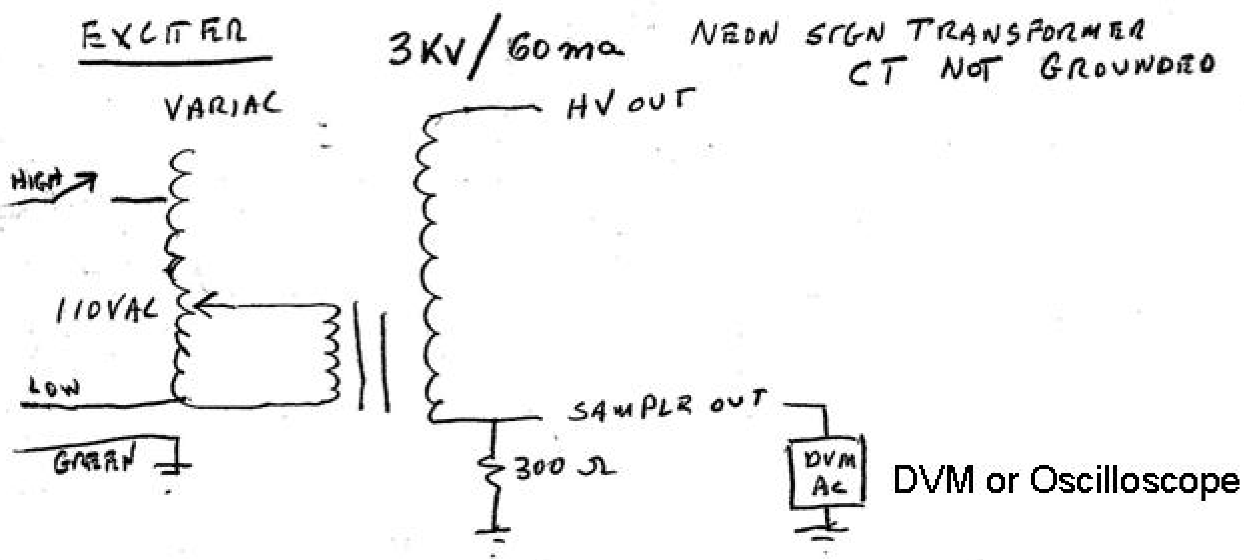
Nitrogen pressure in the source chamber


needles
apertures
electromet

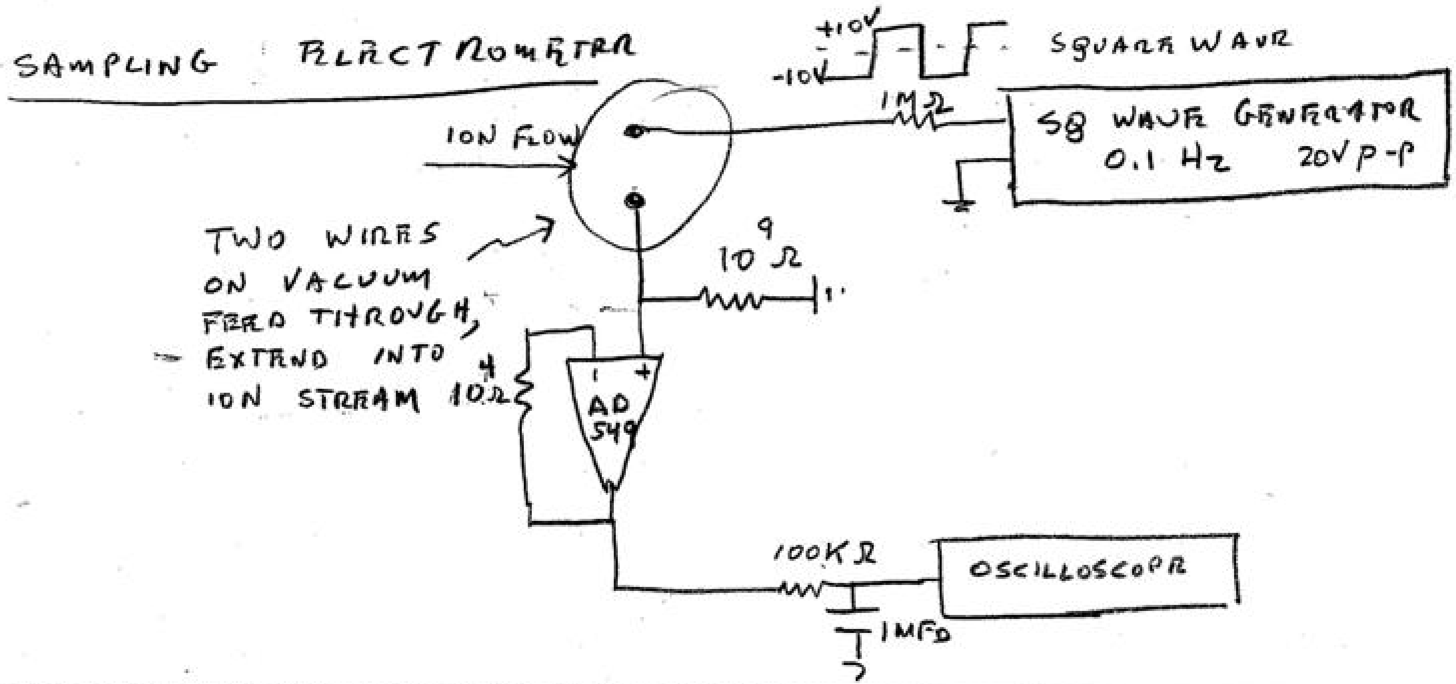




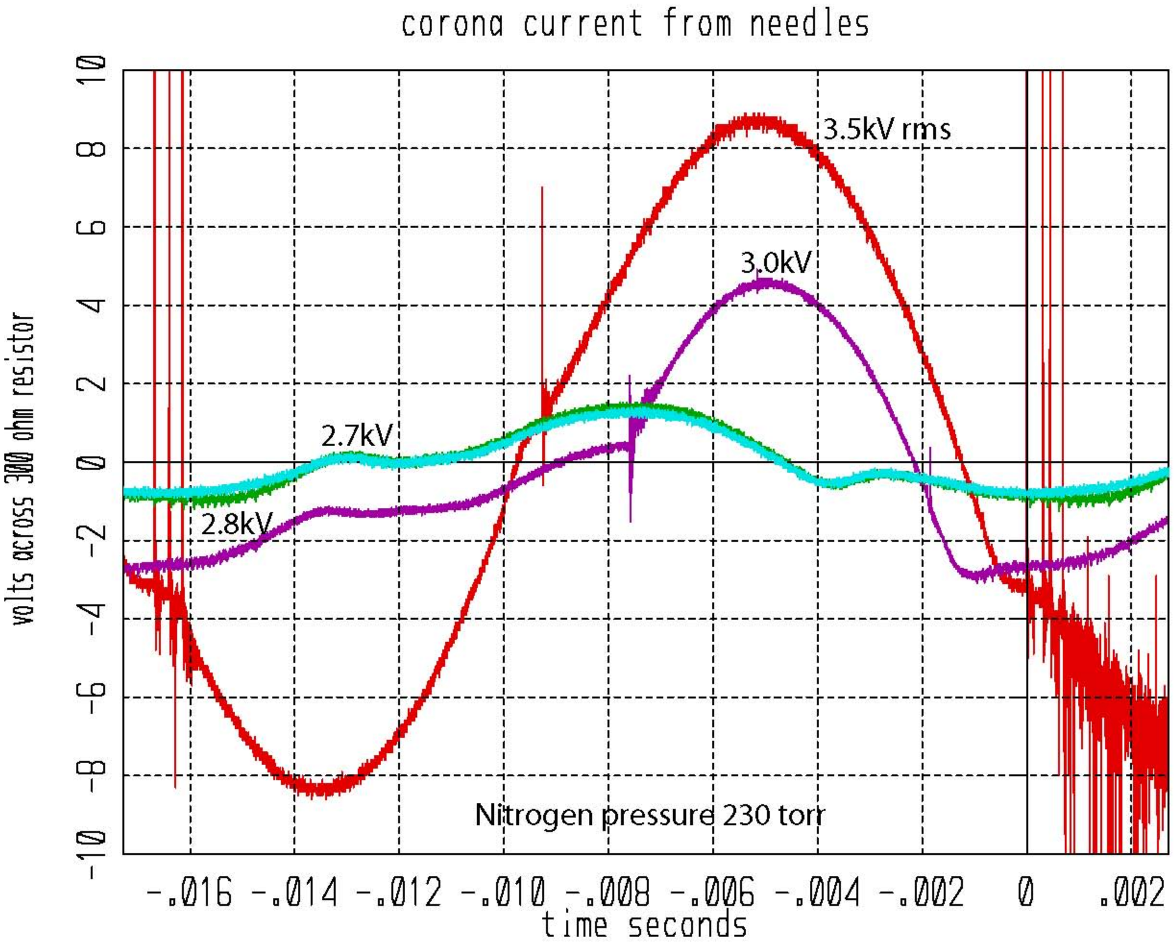
CIRCUITRY



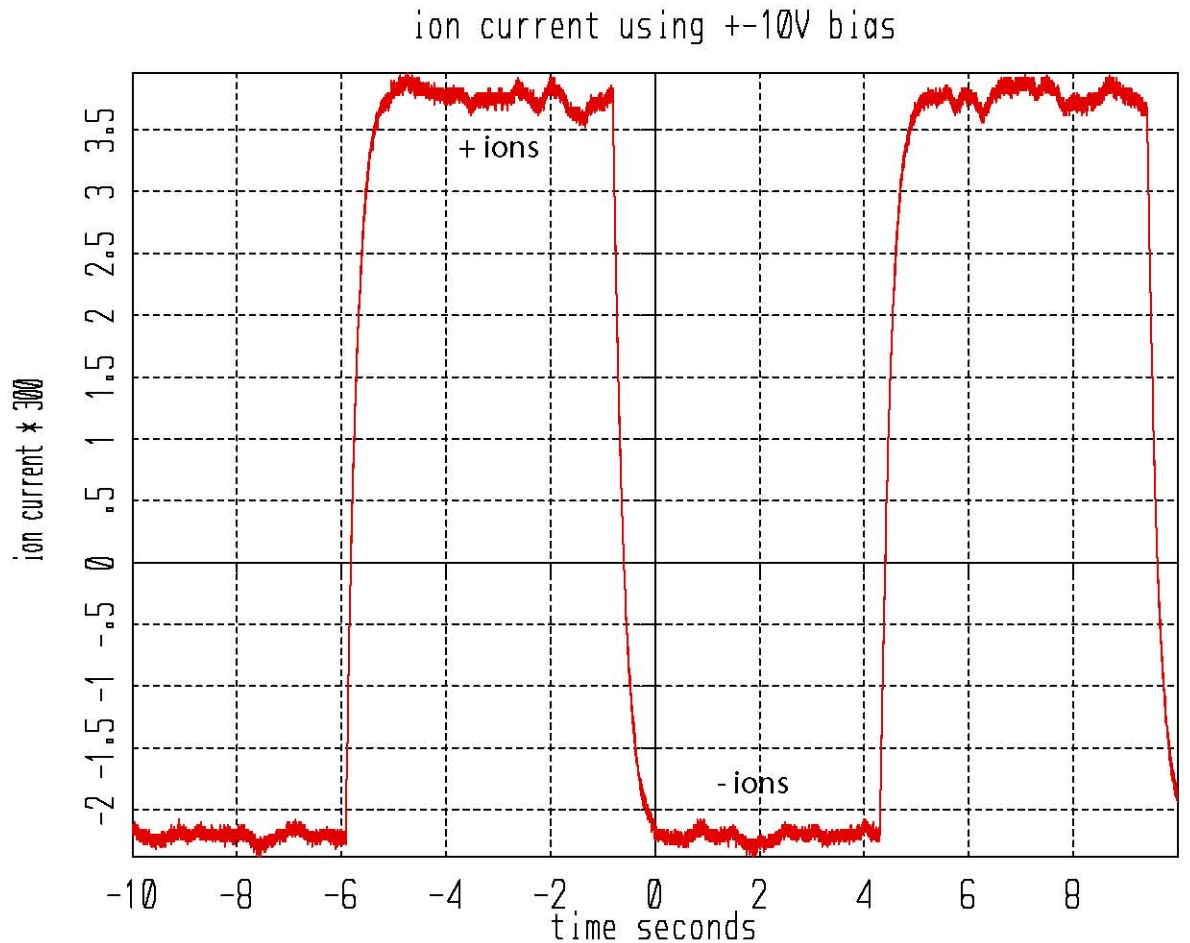
EXCITER
3KV/60ma
NEON SIGN TRANSFORMER
CT NOT GROUNDED
VARIAC
HV OUT
HIGH
110VAC
LOW
GREEN
SAMPLE OUT
300 Ω
DVM AC
DVM or Oscilloscope



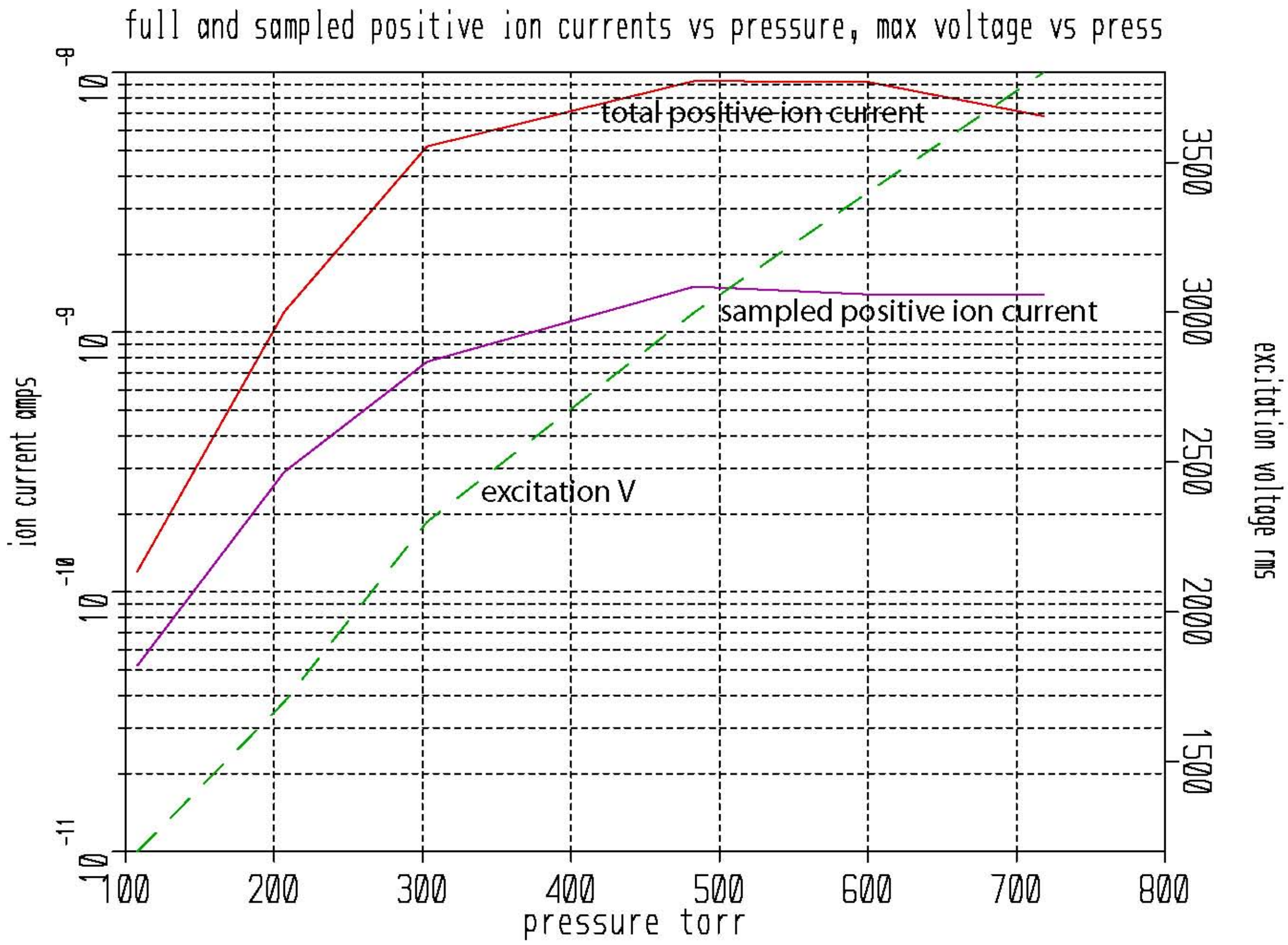
SAMPLING ELECTROMETER
+10V
-10V
SQUARE WAVE
1MΩ
SG WAVE GENERATOR
0.1 Hz
20V P-P
ION FLOW
TWO WIRES
ON VACUUM
FEED THROUGH,
EXTEND INTO
ION STREAM
10⁹ Ω
10⁴ Ω
AD
549
100KΩ
OSCILLOSCOPE
1MFD

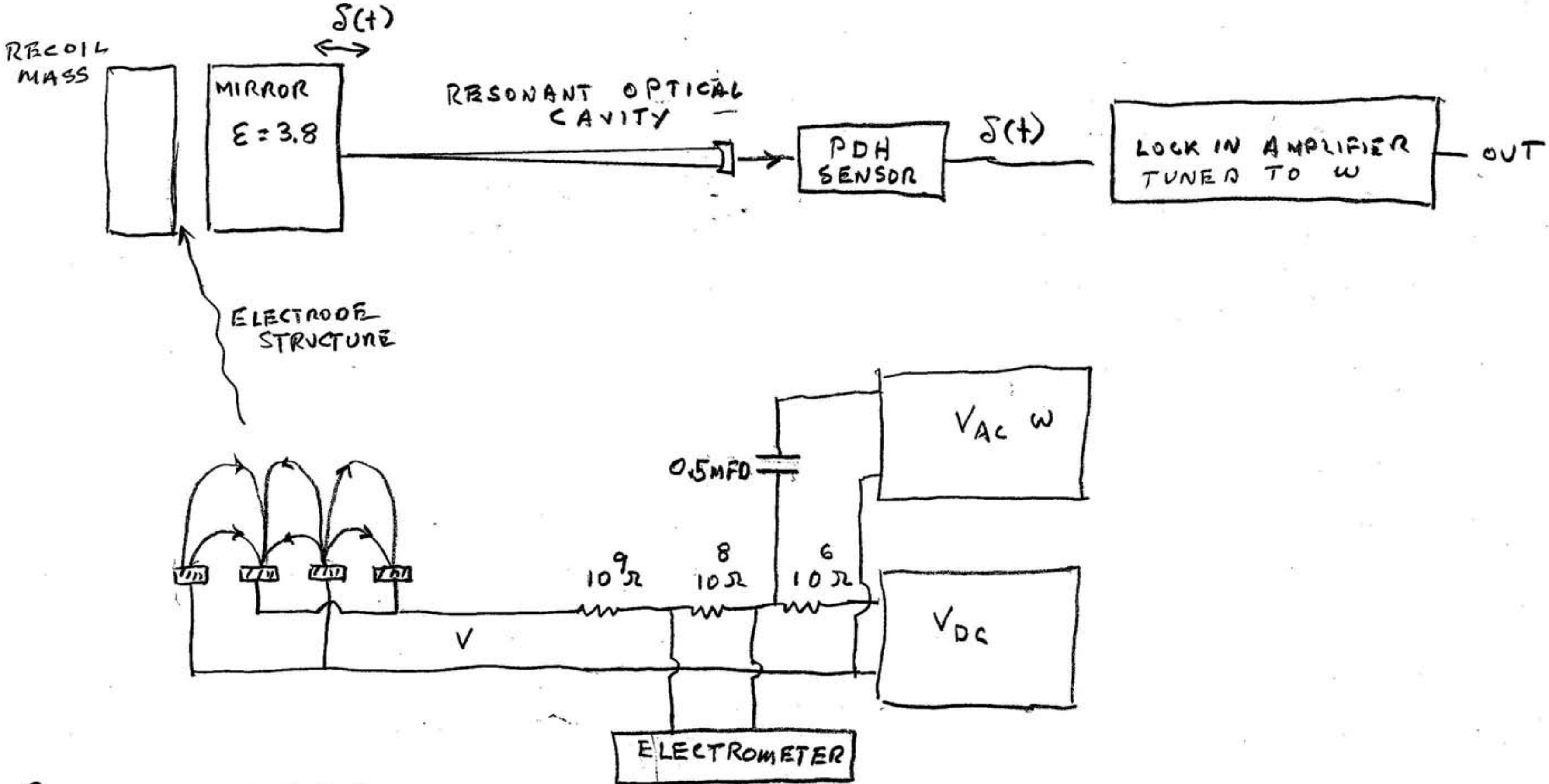


corona current from needles
volts across 300 ohm resistor
time seconds
3.5kV rms
3.0kV
2.7kV
2.8kV
Nitrogen pressure 230 torr
10
8
6
4
2
0
-2
-4
-6
-8
-10
-.016
-.014
-.012
-.010
-.008
-.006
-.004
-.002
0
.002



Conditions:
412 torr on needles
6 mA rms ion current at 60 Hz
4.5kV rms excitation voltage
+-10V square wave bias for electrometer, wires without plates in electrometer collector


full and sampled positive ion currents vs pressure, max voltage vs press
total positive ion current
sampled positive ion current
excitation V
ion current amps
excitation voltage rms
pressure torr
10^-8
10^-9
10^-10
10^-11
3500
3000
2500
2000
1500
100
200
300
400
500
600
700
800



POLARIZATION FORCE

$$F_{POL} = \alpha \left[V_{DC} + V_{AC} \sin \omega t\right]^2$$

CHARGE FORCE

$$F_{CH} = \beta Q \left[V_{AC} \sin \omega t\right]$$

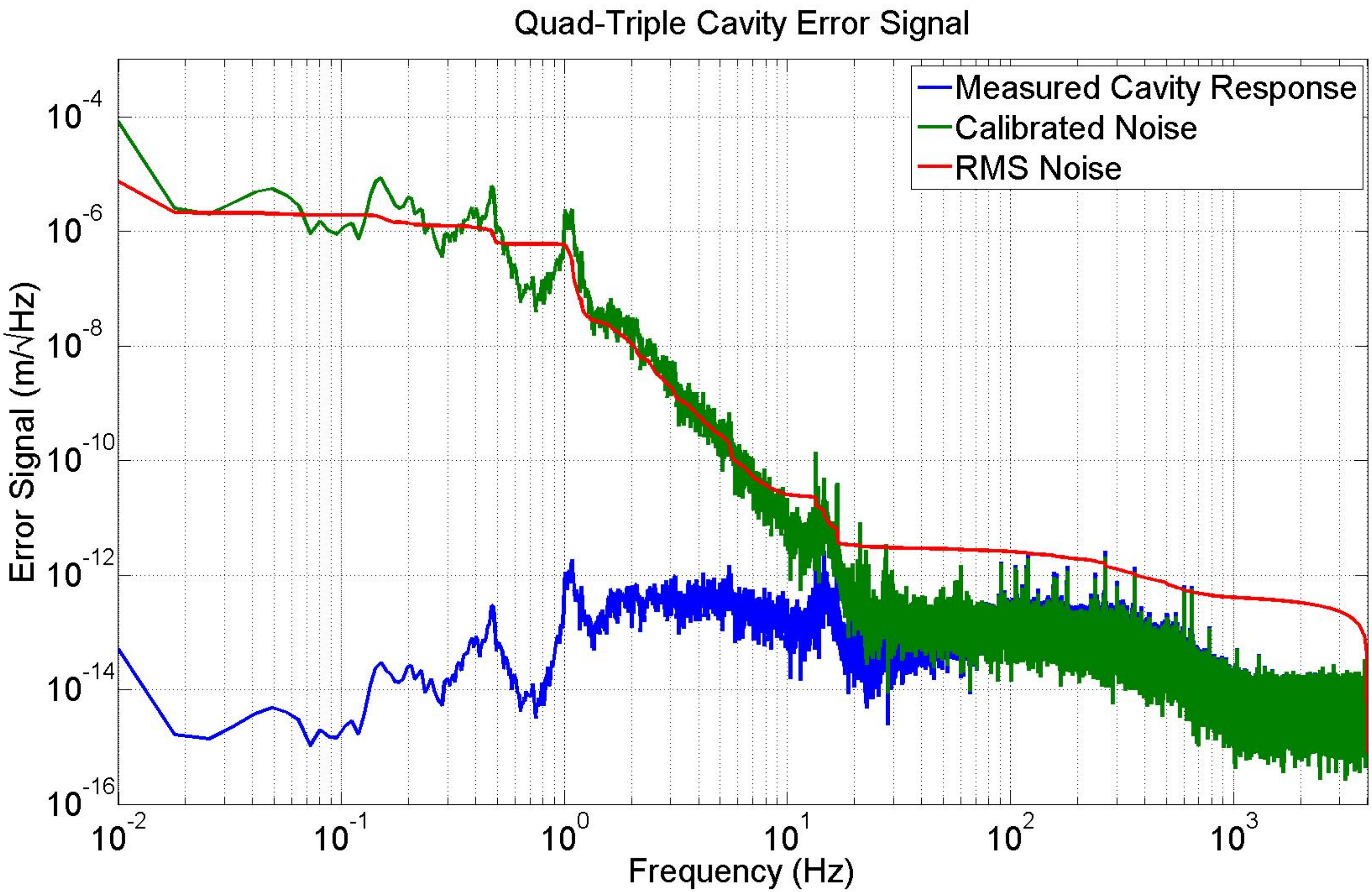
TYPICAL VALUES

$f = 25\,Hz$

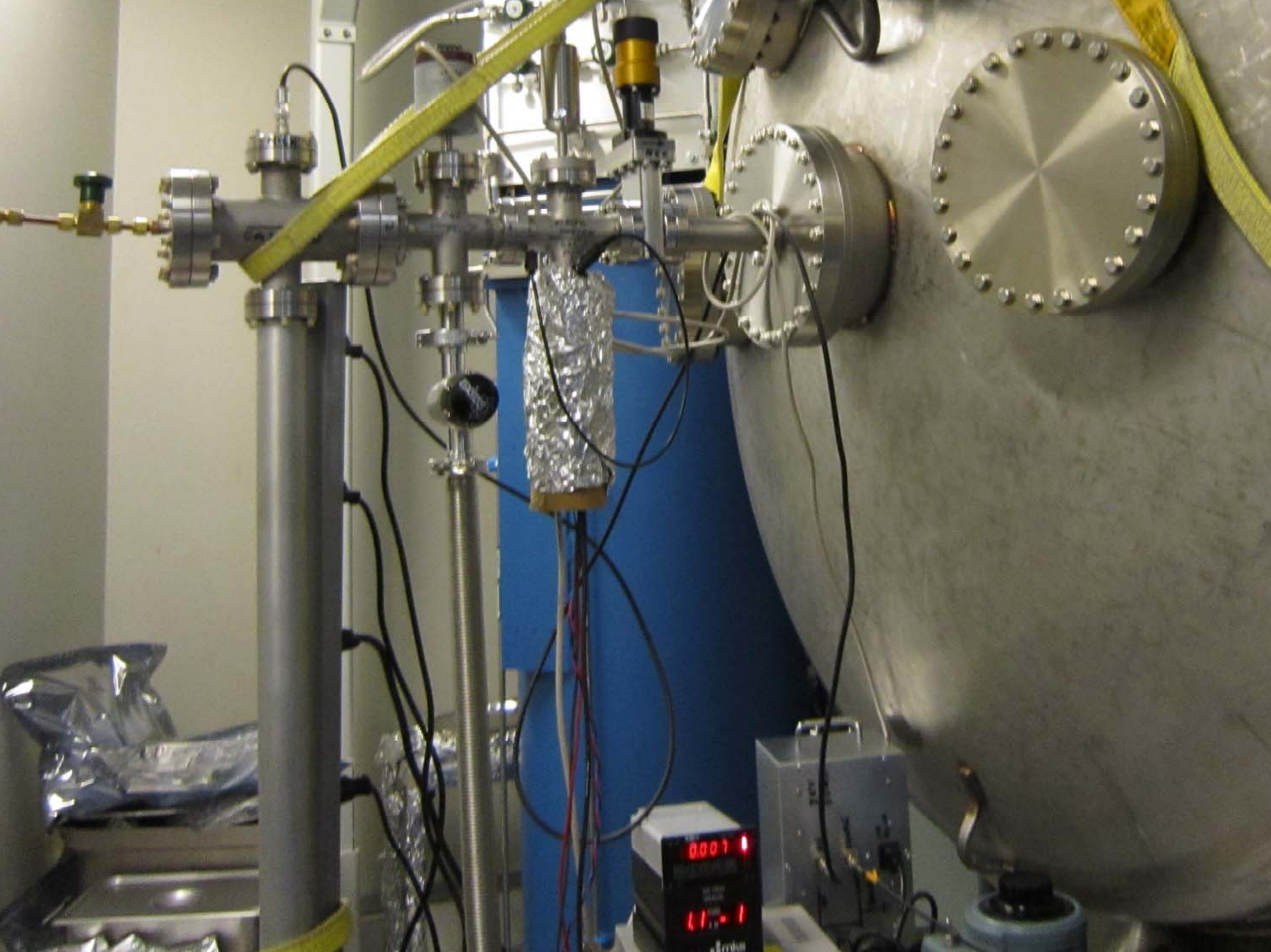
$V_{AC} = 200\,V$ pk

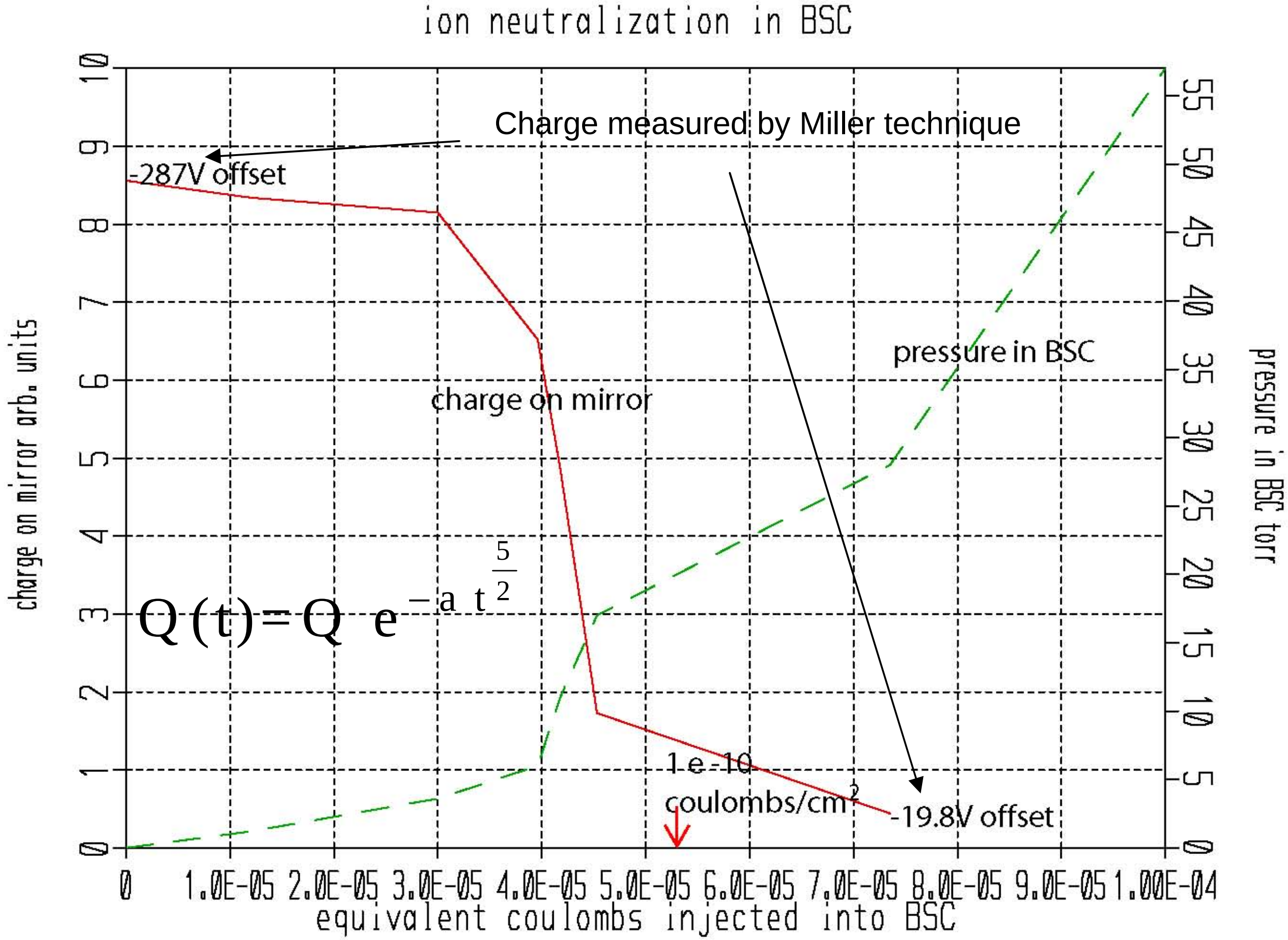
$V_{DC} = 400\,V$

$\alpha = 2.9 \times 10^{-10}$ NEWTONS/VOLT^2



Brett Shapiro


0.001



ion neutralization in BSC
Charge measured by Miller technique
-287V offset
charge on mirror
pressure in BSC
$Q(t) = Q\ e^{-a\ t^{\frac{5}{2}}}$
1 e -10
coulombs/cm^2
-19.8V offset
charge on mirror arb. units
pressure in BSC torr
equivalent coulombs injected into BSC
0 1.0E-05 2.0E-05 3.0E-05 4.0E-05 5.0E-05 6.0E-05 7.0E-05 8.0E-05 9.0E-05 1.00E-04
0 1 2 3 4 5 6 7 8 9 10
0 5 10 15 20 25 30 35 40 45 50 55

Estimates

If recombination rate << diffusion rate $\qquad$ P(neutrals) < 1 torr

and

mean free path of ions in neutral gas << mirror diam $\qquad$ P(neutrals) > 10^{-4} torr

$$t_{fill} > \frac{A_{surface}\sigma_{mirror}}{\frac{dN_{in}}{dt}}$$

t_{fill}	Fill time in seconds	1000 sec
$A_{surface}$	Surface area in chamber	6×10^{5} cm^2
$\frac{dN_{in}}{dt}$	Ion current in	3×10^{-8} amp
σ_{mirror}	Surface charge on mirror	5×10^{-11} coulombs/cm^2 varies between 10^{-14} to 10^{-10}