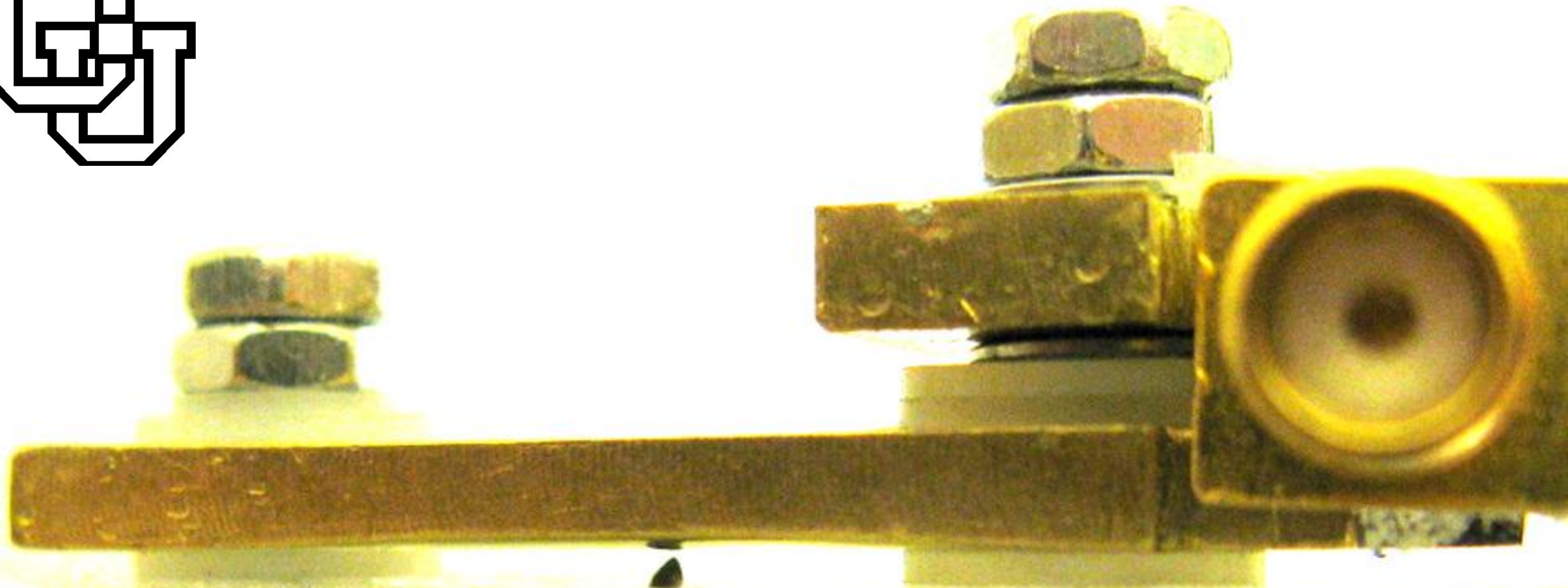


Shot Noise in Tunneling Junctions

Eric V. Eason

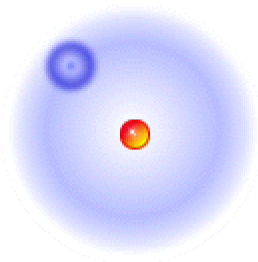
Prof. Kyle P. McElroy

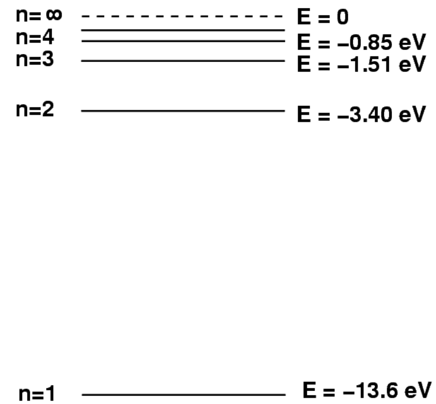
8/6/08

A simple explanation of electron tunneling

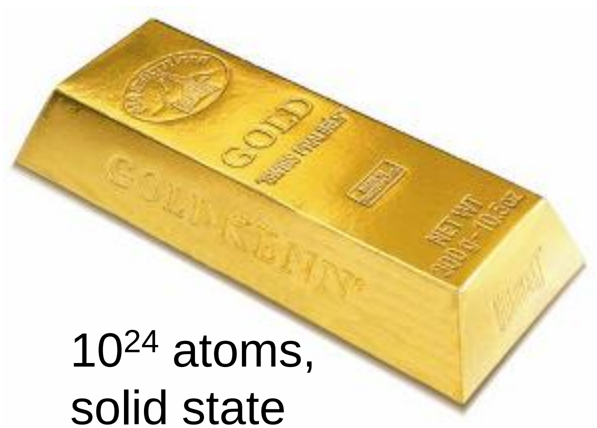
With lots of pictures and no equations

1 atom

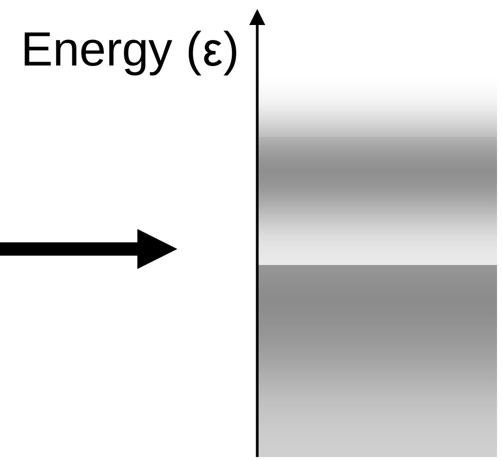




Discrete levels



10^{24} atoms, solid state



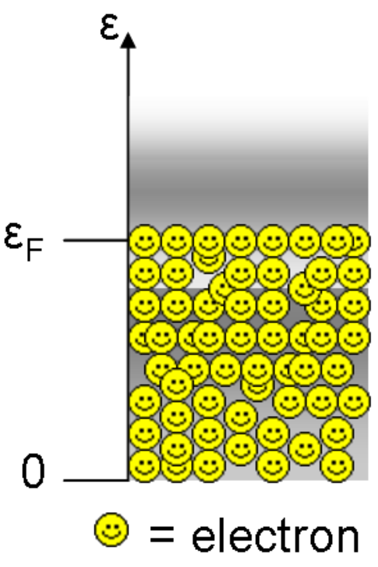
Electronic bands

Pauli exclusion principle: electrons are unfriendly

- Electrons not allowed to occupy identical states

Electrons pile on top of each other to fill up energy states

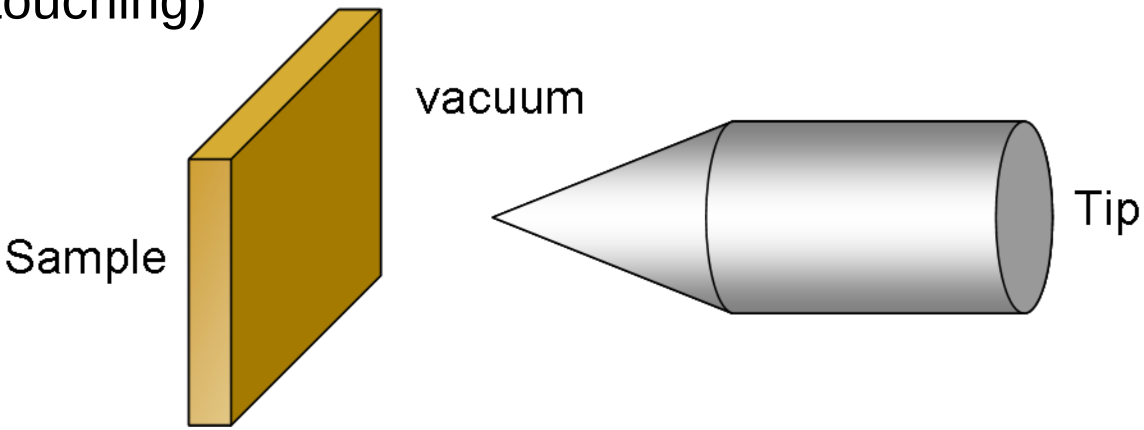
- Until you run out of electrons at ε_F

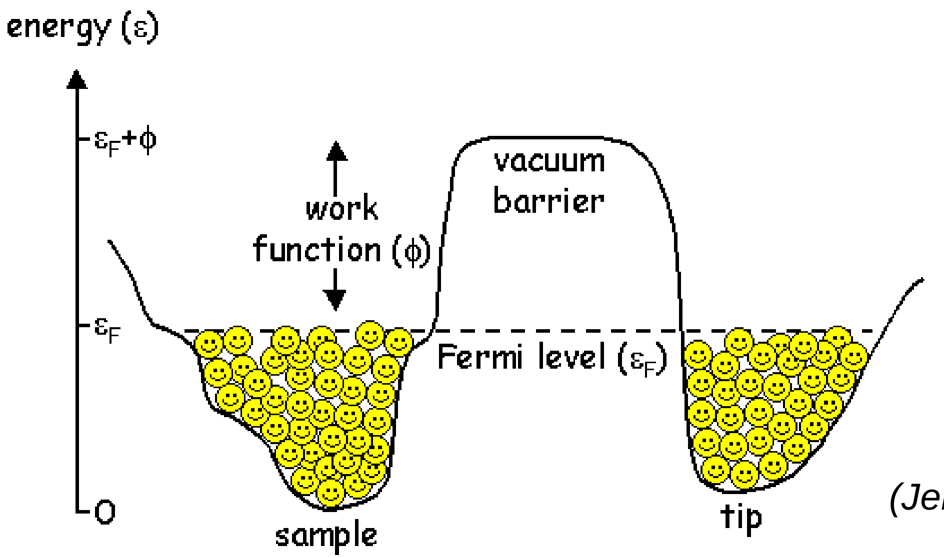


Fermi energy ε_F = top energy level at which electrons sit

Take two pieces of metal and bring them extremely close

(but not touching)



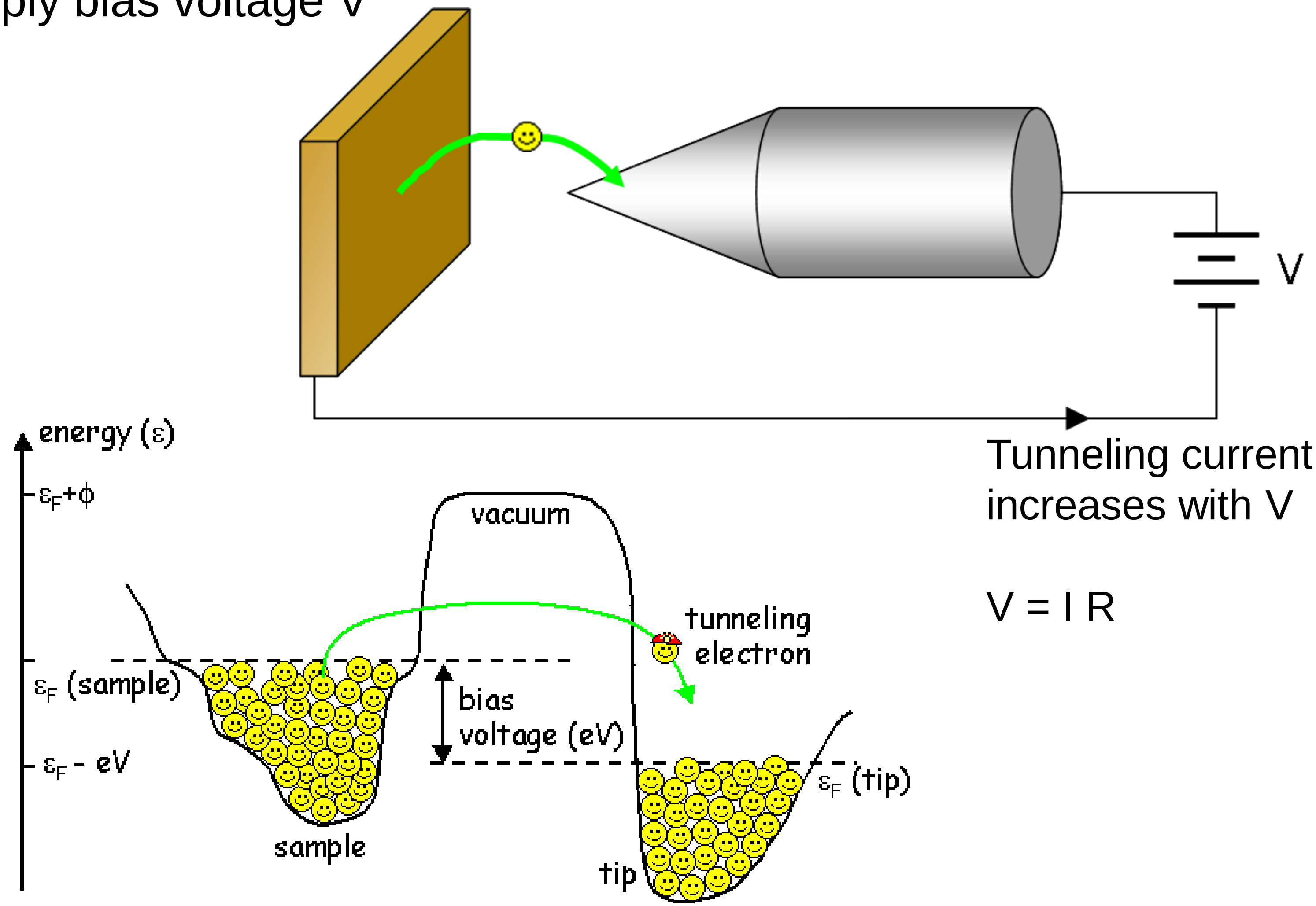


Electrons can tunnel through vacuum barrier

(Jenny Hoffman Lab)

For tunneling, electrons need empty states to tunnel into

Apply bias voltage V



Tunneling current increases with V

$V = I R$

A simple explanation of electronic shot noise

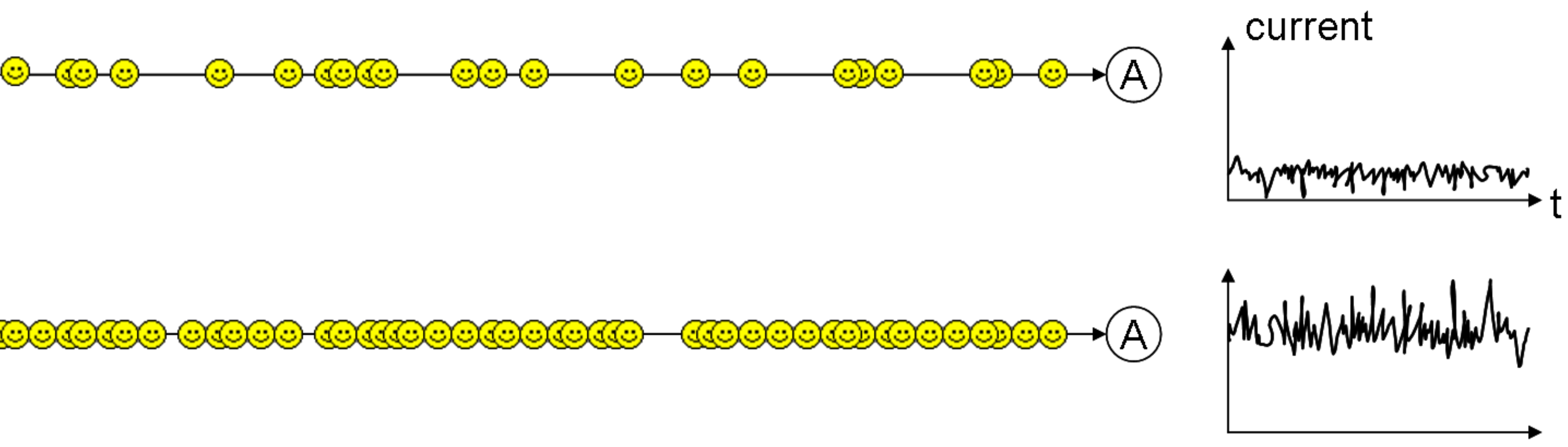
Electrons have discrete charge

Any current of electrons has small random fluctuations called shot noise

Shot noise is white (flat frequency distribution) and Gaussian

Shot noise increases with current: $i_n = \sqrt{2eIB}$

Only becomes significant for very small currents

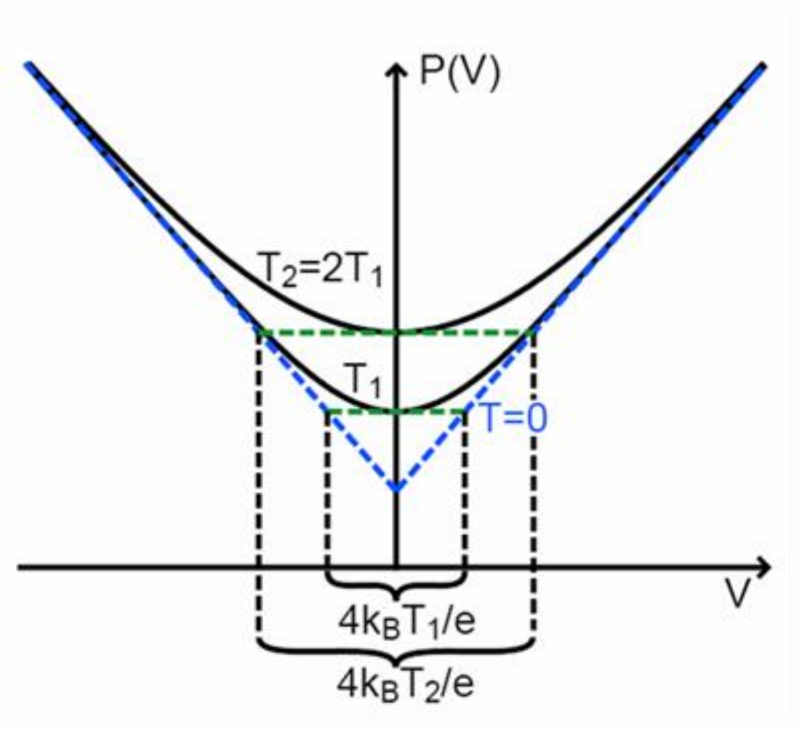


Tunneling current is usually very very small: ~ 10^{-9} A

So shot noise becomes significant in tunneling junctions

Shot noise does not go to zero (except at absolute zero)

Thermal (Johnson) noise always present



$$P \propto {i_n}^2 \propto V \coth\left(\frac{eV}{2k_BT}\right)$$

(Lafe Spietz)

So what's this experiment all about?

Goal: develop high-frequency, low-noise instrumentation to measure the shot noise in a tunneling junction

Why high-frequency? Remember $i_n = \sqrt{2eIB}$

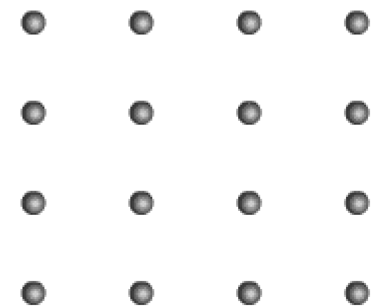
So more bandwidth means a better measurement

Eventually we want to implement this on a scanning tunneling microscope (STM)

Shot noise STM

What happens if a group of particles behaves like a single quasiparticle?

- This happens in certain materials at certain conditions
- Can have charge 2e, e/3, e/5, e/7, etc.



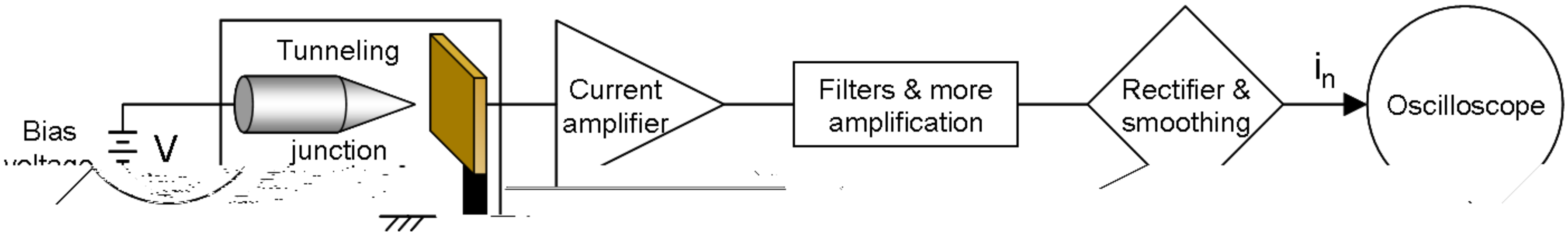
Shot noise becomes $i_n = \sqrt{2qIB}$

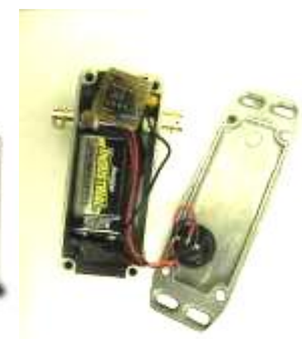
- Curve changes in measurable way

So with shot noise STM we can find quasiparticles

- Map out their locations

Experimental apparatus



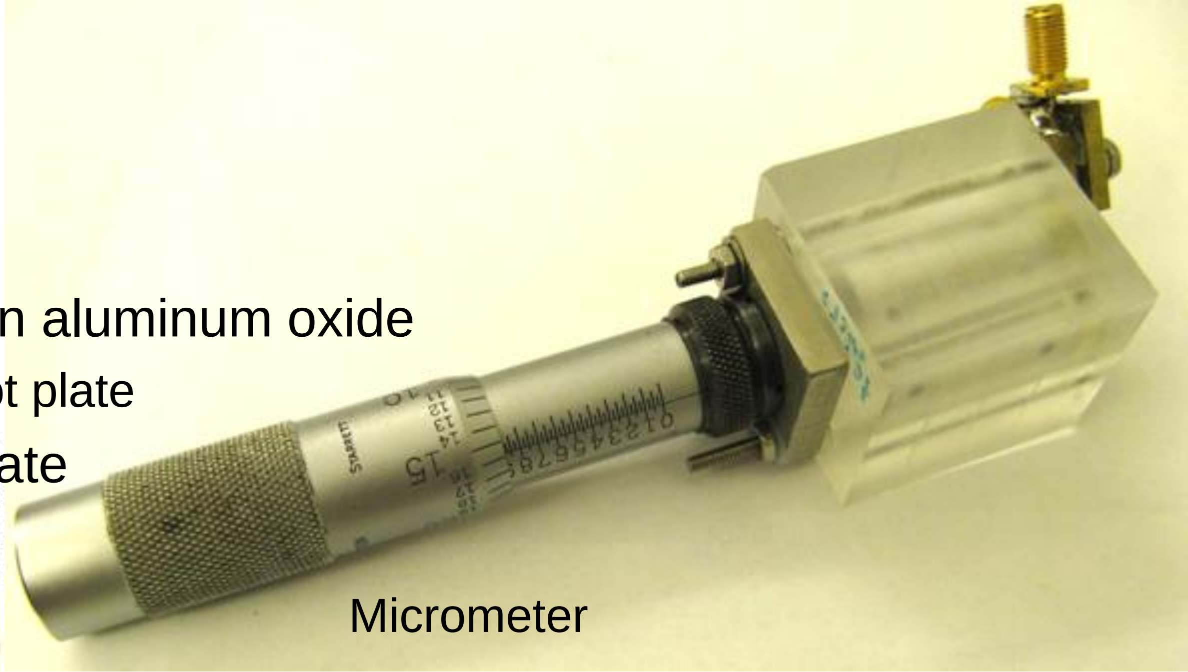


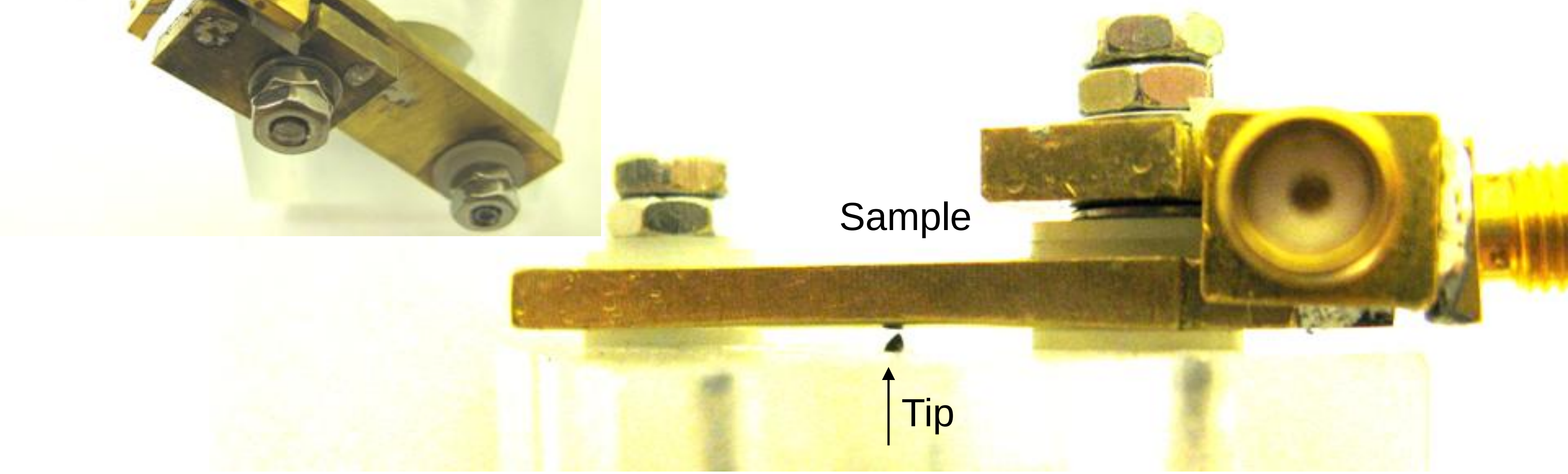
Tunneling junction

Tip: Niobium wire coated in aluminum oxide

Vapor deposition with hot plate

Sample: polished brass plate





Current amplifier

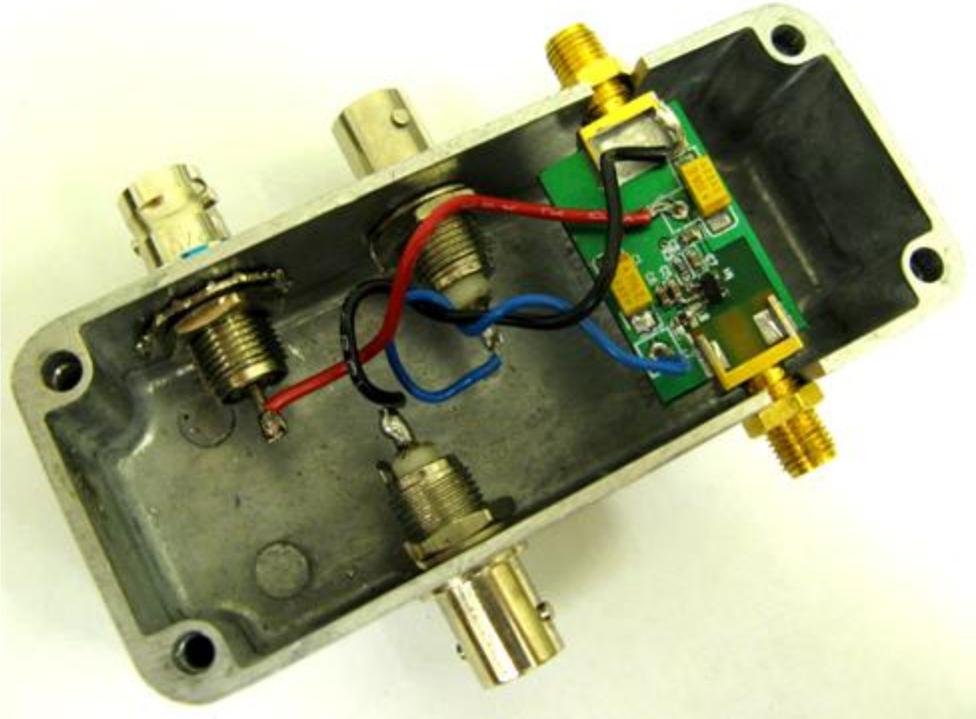
3 dB bandwidth: 4.2 MHz

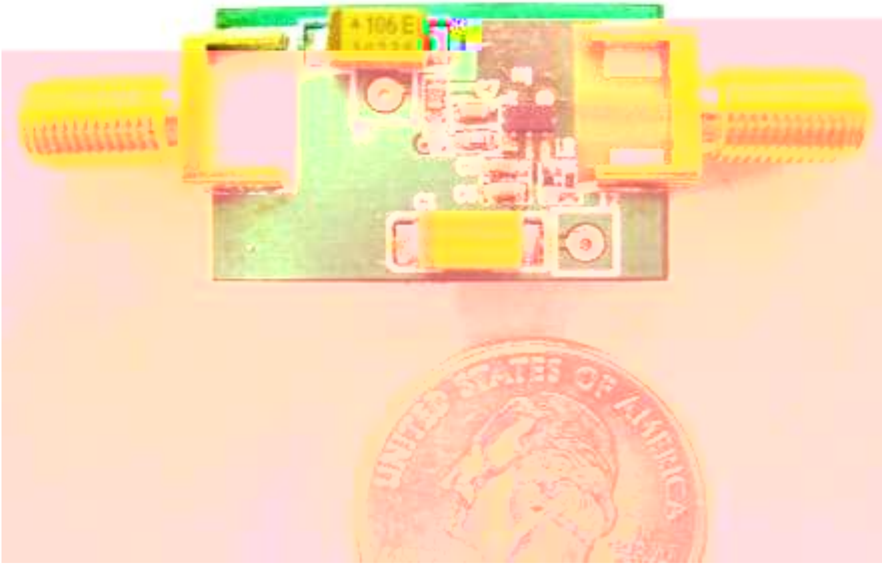
I-to-V gain: 50 kΩ

Uses AD8067 FET op-amp

- High gain-bandwidth product
- High speed
- Low noise

Total RMS output voltage noise through 150kHz: 34.5 μV

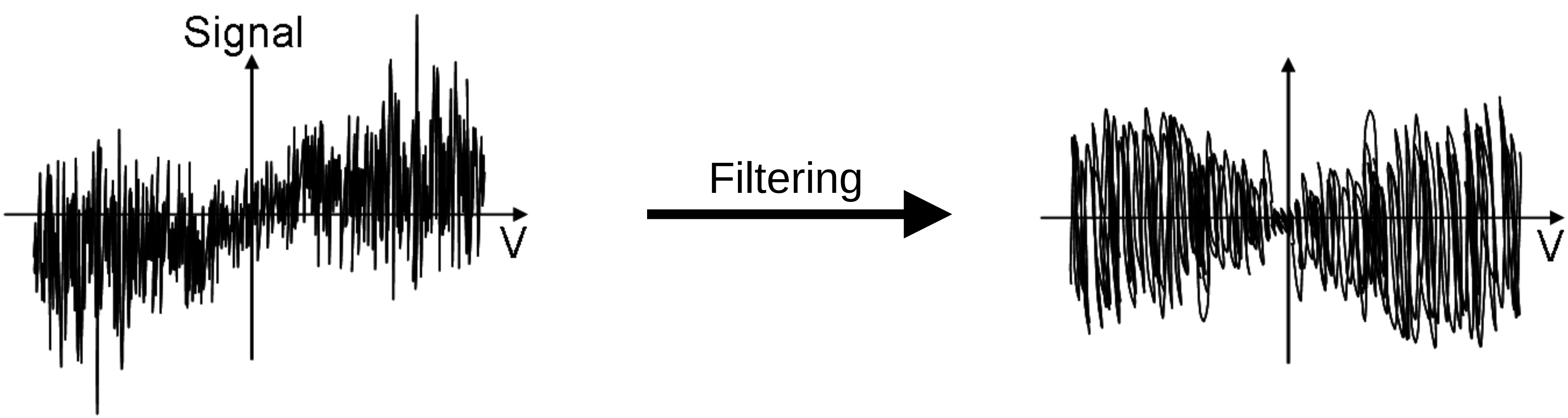




Filters and preamp

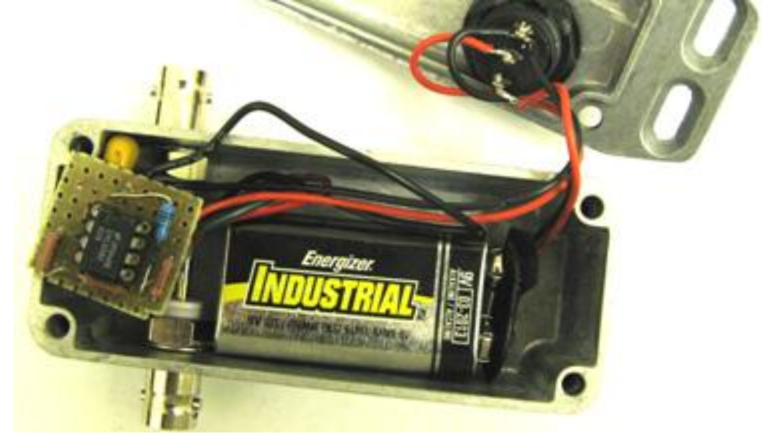
SR560 preamp

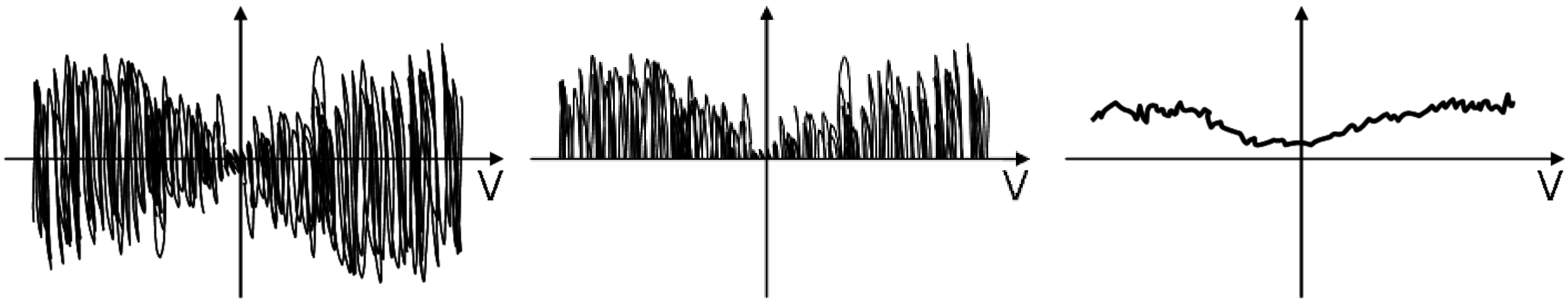
- V-to-V gain: 10^4
- 10 kHz high-pass, 100 kHz low-pass (first order)
- Effective bandwidth: 143 kHz



Rectifier & Smoothing

Automatically measures noise amplitude

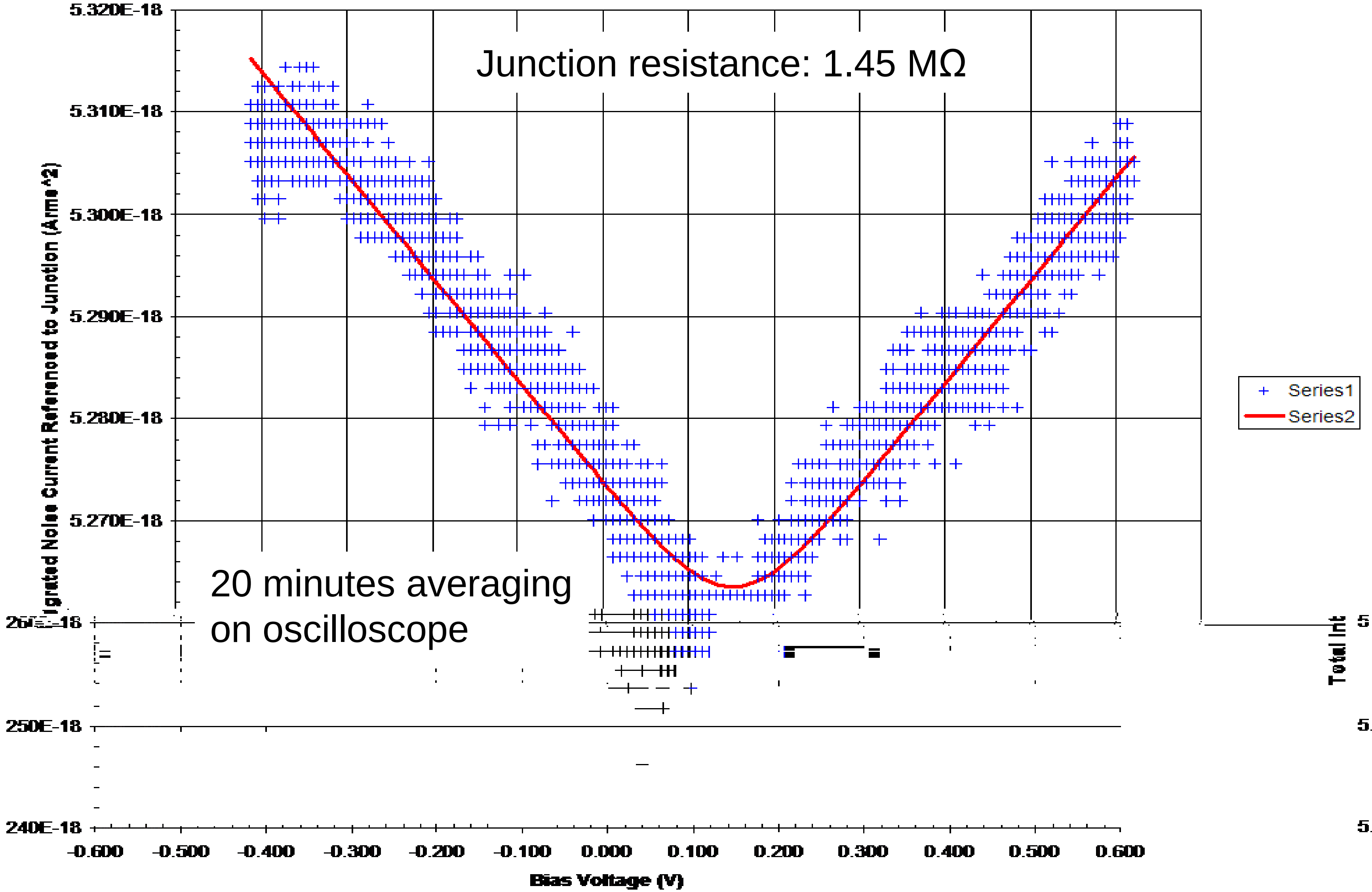




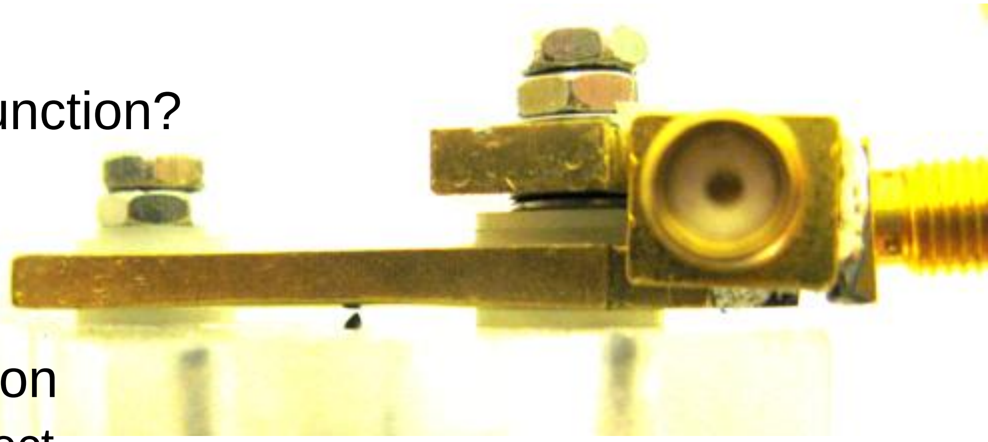
Signal from preamp → Rectifier → ½ signal → Smoothing → Smoothed ½ signal

Smoothed ½ signal is directly proportional to RMS noise amplitude

Can now fit this data to $V \coth\left({eV}/{2k_BT}\right)$


Junction resistance: 1.45 MΩ
20 minutes averaging
on oscilloscope
5.320E-18
5.310E-18
5.300E-18
5.290E-18
5.280E-18
5.270E-18
250E-18
240E-18
-0.600
-0.500
-0.400
-0.300
-0.200
-0.100
0.000
0.100
0.200
0.300
0.400
0.500
0.600
Bias Voltage (V)
Series1
Series2
Total Int

Conclusion



Measure shot noise on tunneling junction?

- Probably – data looks pretty good
- Need better data to be sure

Biggest weakness: tunneling junction

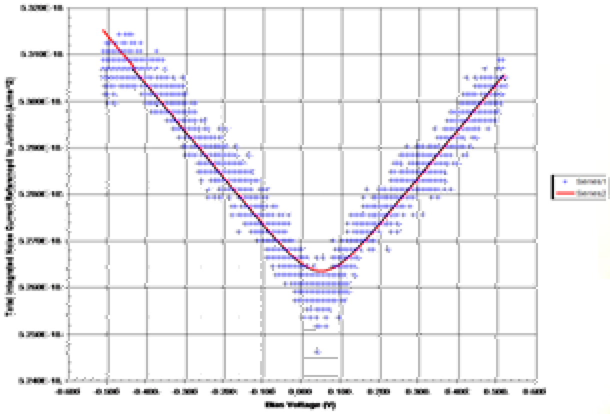
- Nonlinear tunneling resistance effect
- Resistance changing slowly and unpredictably

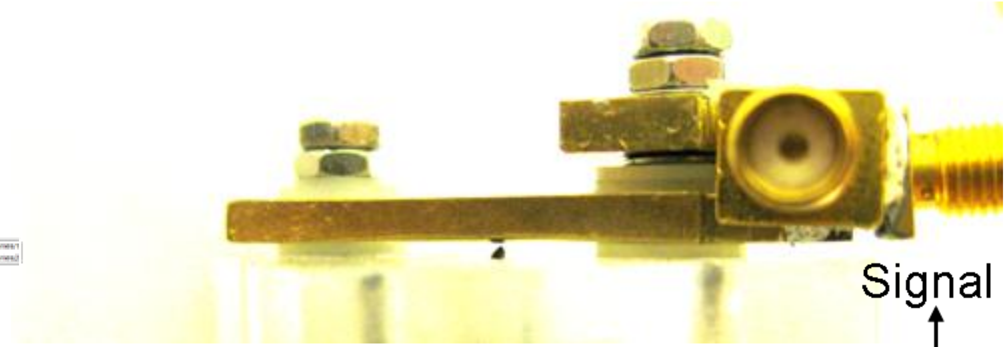
Even if data is bogus, this experiment shows that I have enough resolution to detect shot noise on tunneling junctions.

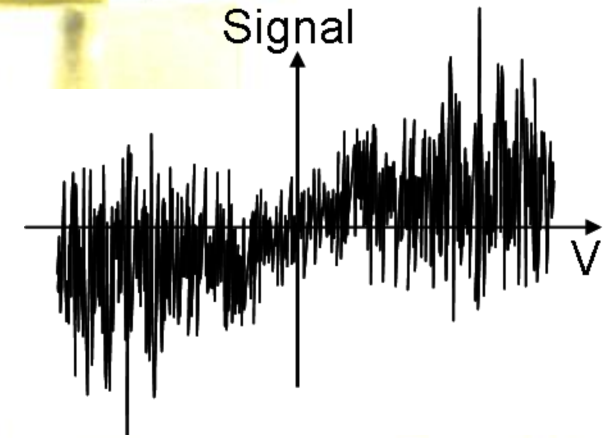
Instrumentation

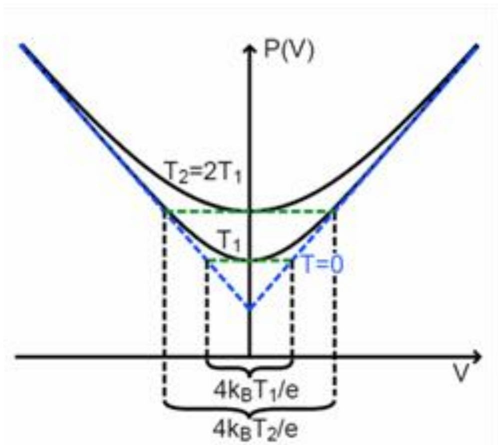
- Should be easy to install on STM
- Custom-built electronics are robust

Questions?









$$P \propto i_n^{\,2} \propto V \coth\left(\frac{eV}{2k_B T}\right)$$