Texas A&M
Department of Physics and Astronomy

IMPROVING THE SENSITIVITY OF THE CDMS DETECTOR TO DARK MATTER PARTICLES:
UNDERSTANDING AND REJECTING SOURCES OF NOISE IN THE EXPERIMENT

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Master's Defense

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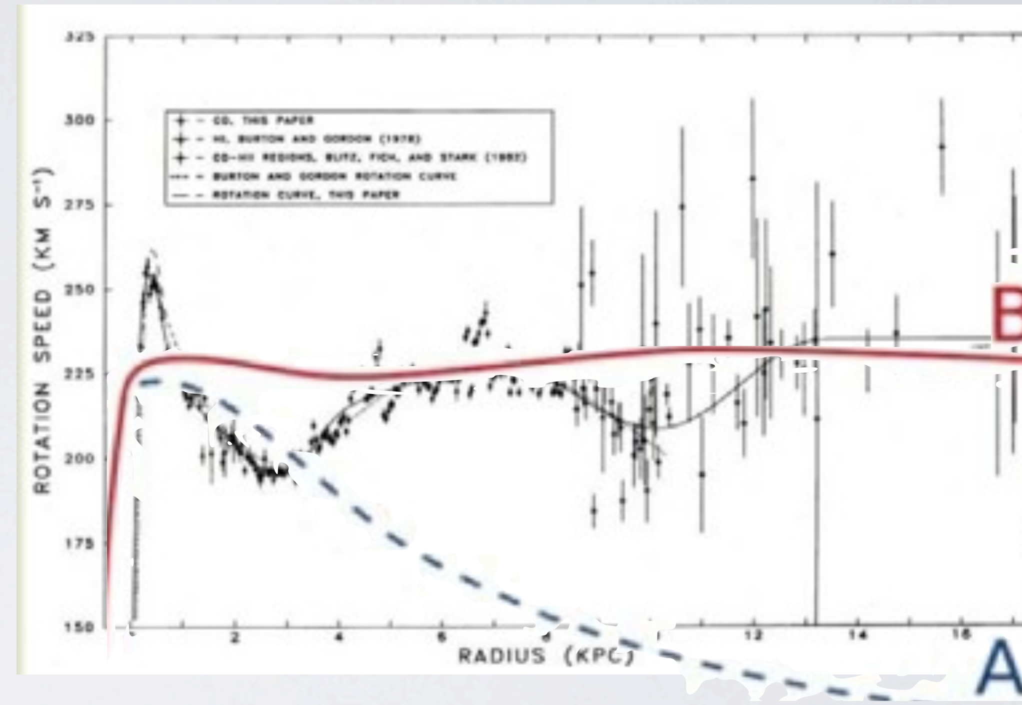
OUTLINE

- I. Motivation: Understanding Dark Matter in the Universe
- II. The CDMS Experiment and the Hunt for Dark Matter Particles
- III. Separating Real Particles From Noise
- IV. Identifying Potential Sources of Noise: Methods and Results
- V. Looking Towards the Future
- VI. Conclusions

EVIDENCE OF DARK MATTER FROM MULTIPLE SOURCES



Example 1

- The rotational velocity of stars in the outer part of a galaxy ‘should’ match the amount of mass observed from stars and gas in the inner part of the galaxy
- Observed velocity is what you would expect if there is a large amount of mass you can’t see

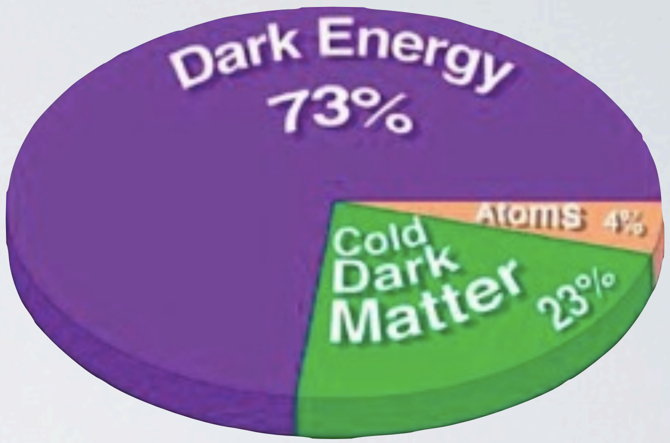
Example 2

- Einstein ring: Large amounts of dark matter in a "near" galaxy can lens the light from a galaxy behind it.

EVIDENCE OF DARK MATTER FROM MULTIPLE SOURCES Continued...

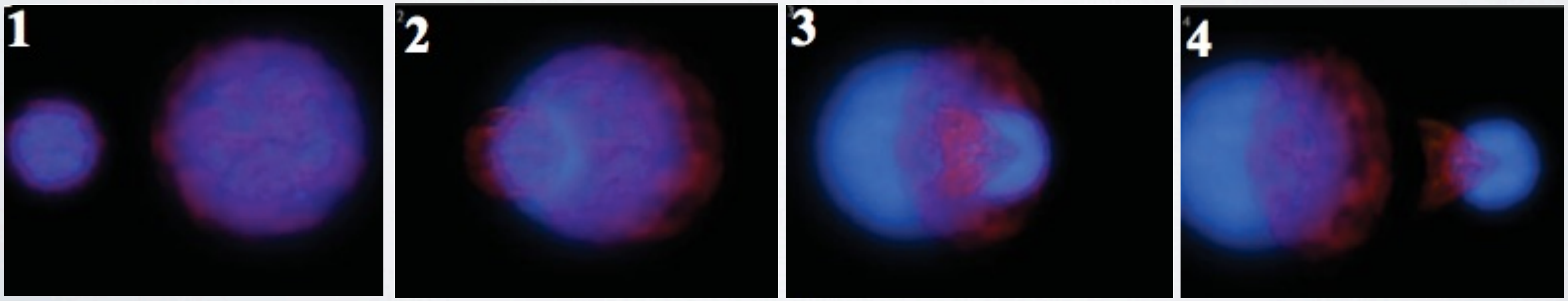
Example 3

- Cosmic Background Radiation measurements indicate that there is a large amount of mass in the universe not in atoms.



Example 4

- Colliding clusters of galaxies provide evidence that Dark Matter is likely to be a particle



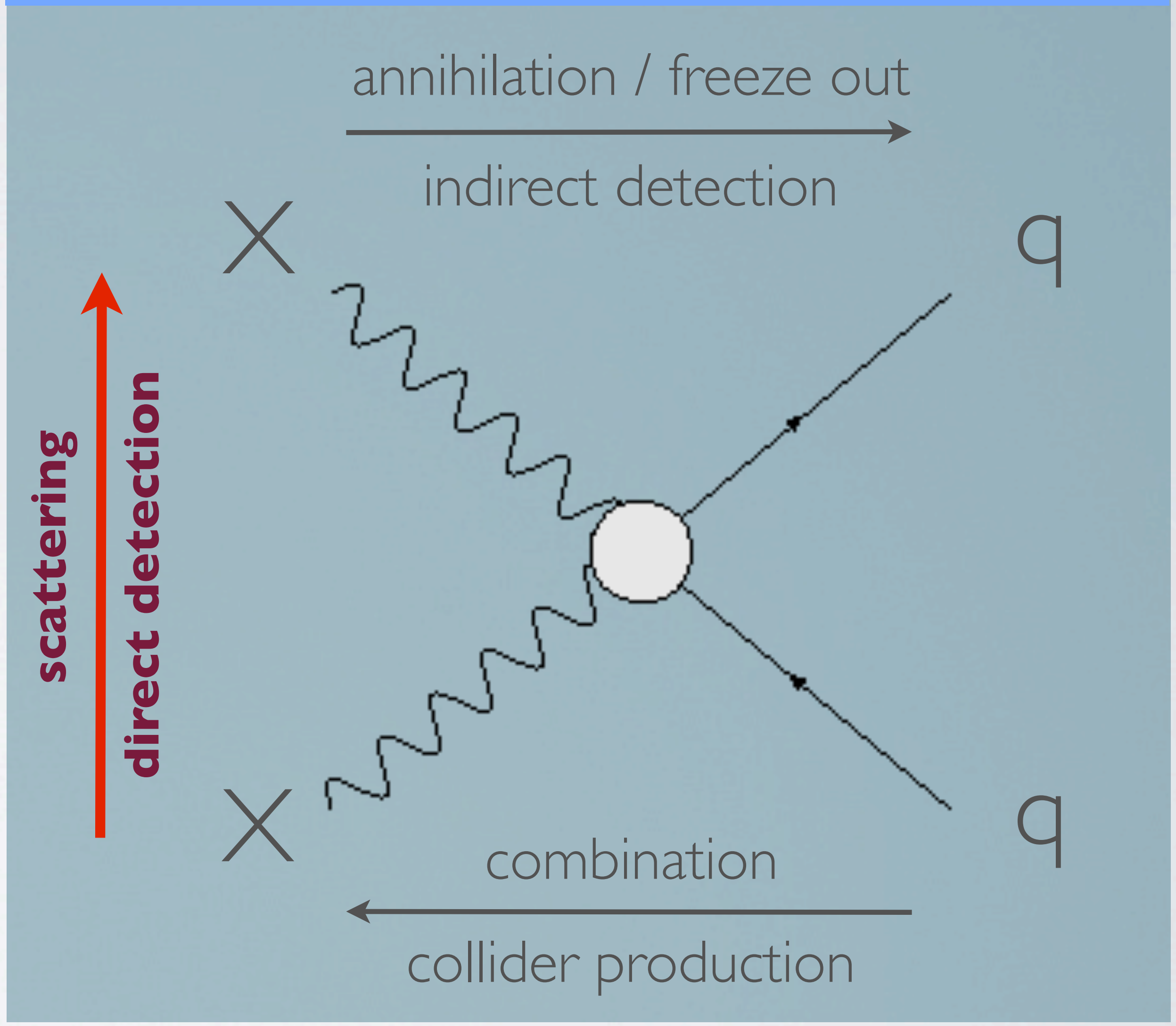
IF DM IS A PARTICLE, WHAT DO WE KNOW ABOUT IT? HOW CAN WE DISCOVER IT?

- Weakly Interacting
- Massive Particle

WIMP

- Neutral
- Neutrinos are ruled out
- Most believe it must be a new particle, i.e. from Supersymmetry

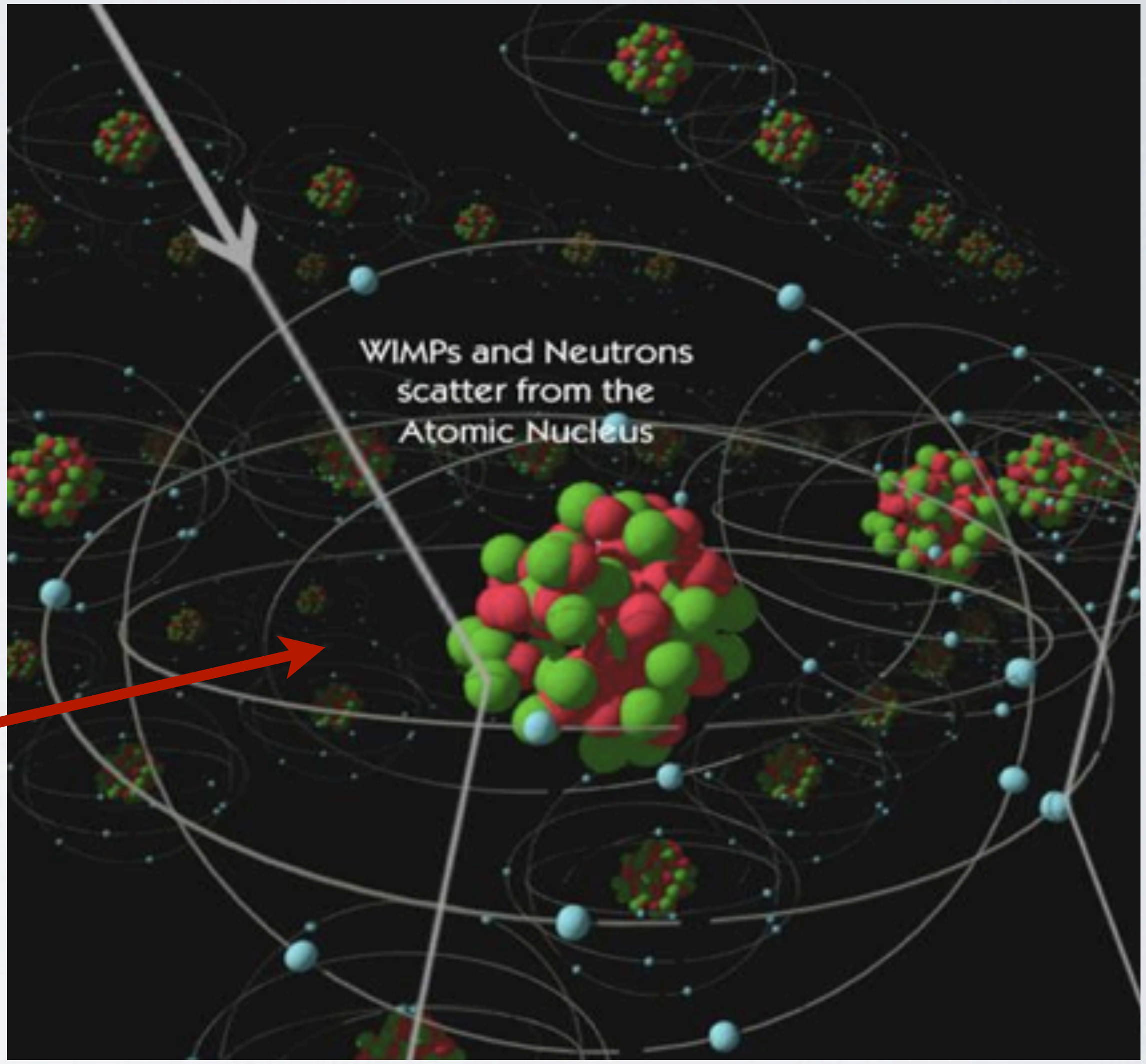
Possible ways to discover DM:



CDMS is an experiment designed to detect DM interactions with SM particles in a detector (diagram with time going vertically upward)

DARK MATTER PARTICLES AND THE CDMS DETECTOR

- Earth is moving through the DM Halo of the Milky Way
- Look for an interaction between a DM particle and a heavy nucleus in a sensitive detector (CDMS)

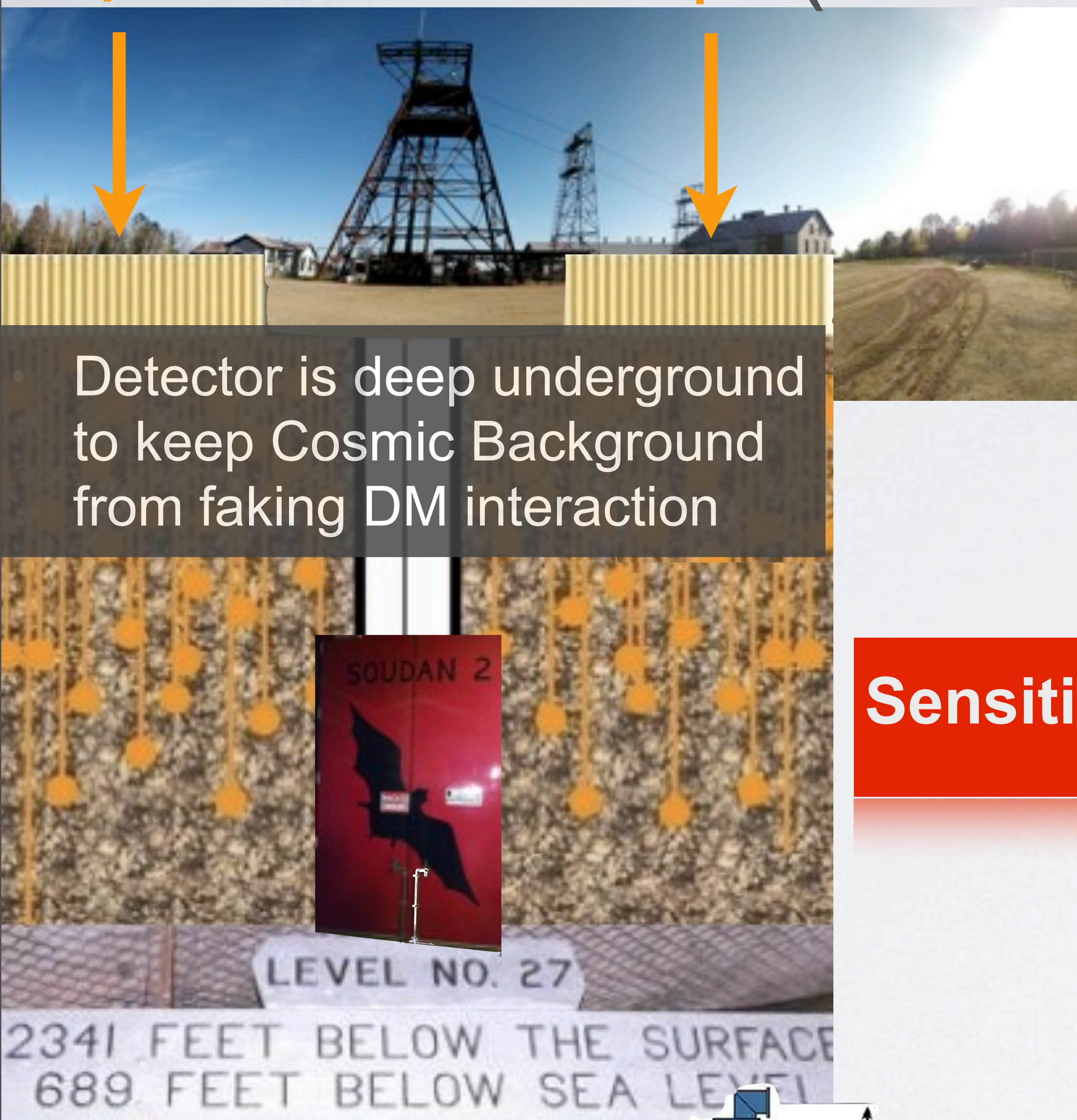


Nuclear Recoil produces vibrations (phonons) that propagate in the lattice

Few keV of energy deposited in the crystal lattice (depends on DM mass)
How often this happens depends on the DM-nucleon cross section

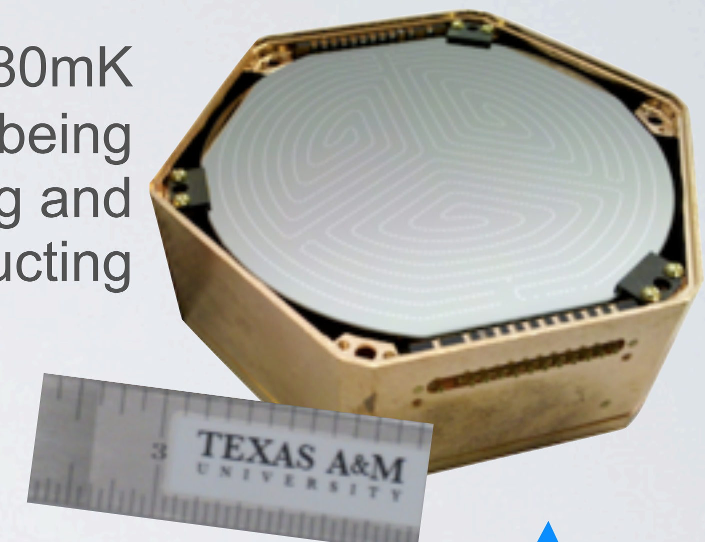
CRYOGENIC DARK MATTER SEARCH (CDMS) EXPERIMENT

μ μ

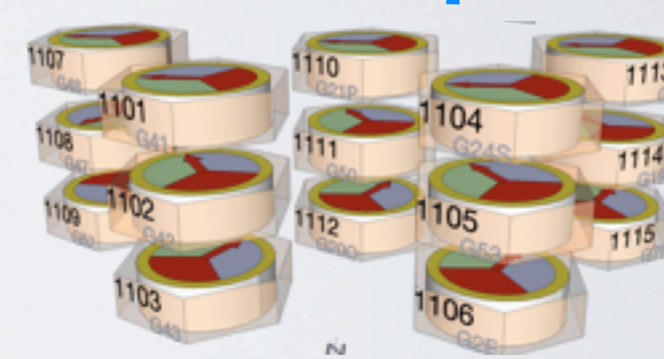


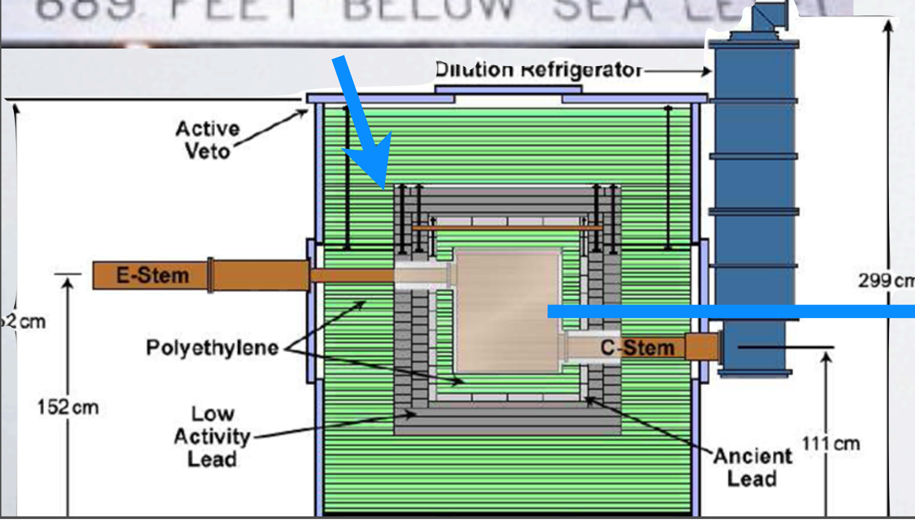
Detector is deep underground to keep Cosmic Background from faking DM interaction

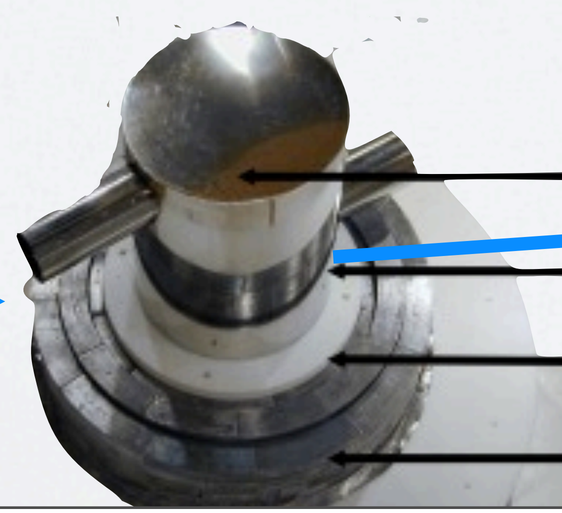
Detectors at 80mK
Right at transition between being normal conducting and superconducting



Sensitive to 7keV of energy deposit







Shielding:
- Polyethylene
- Ancient Lead
- Low Activity Lead

FROM A PARTICLE INTERACTION TO A SIGNAL OUT OF A **T**RANSITION **E**DGE **S**ENSOR (**TES**)

- A DM particle will interact and create vibrations in the lattice: Phonons

- Phonon production and collection process:

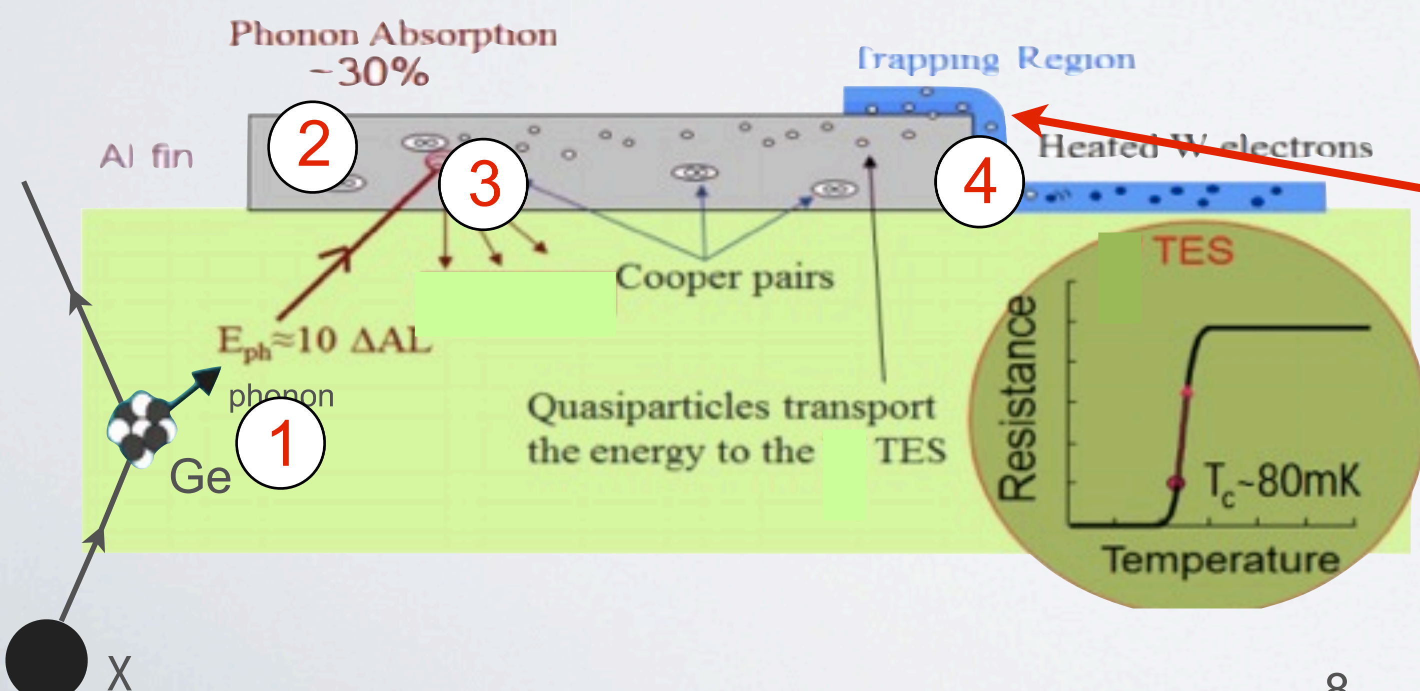
1 phonons created in the interaction

2 phonons travel to the aluminum

3 break up Cooper Pairs and couple to one of the electrons in the pair

4 electrons are absorbed by the Transition Edge Sensor (TES) changing it's temperature (which changes its resistance, and the amount of current that flows through it)

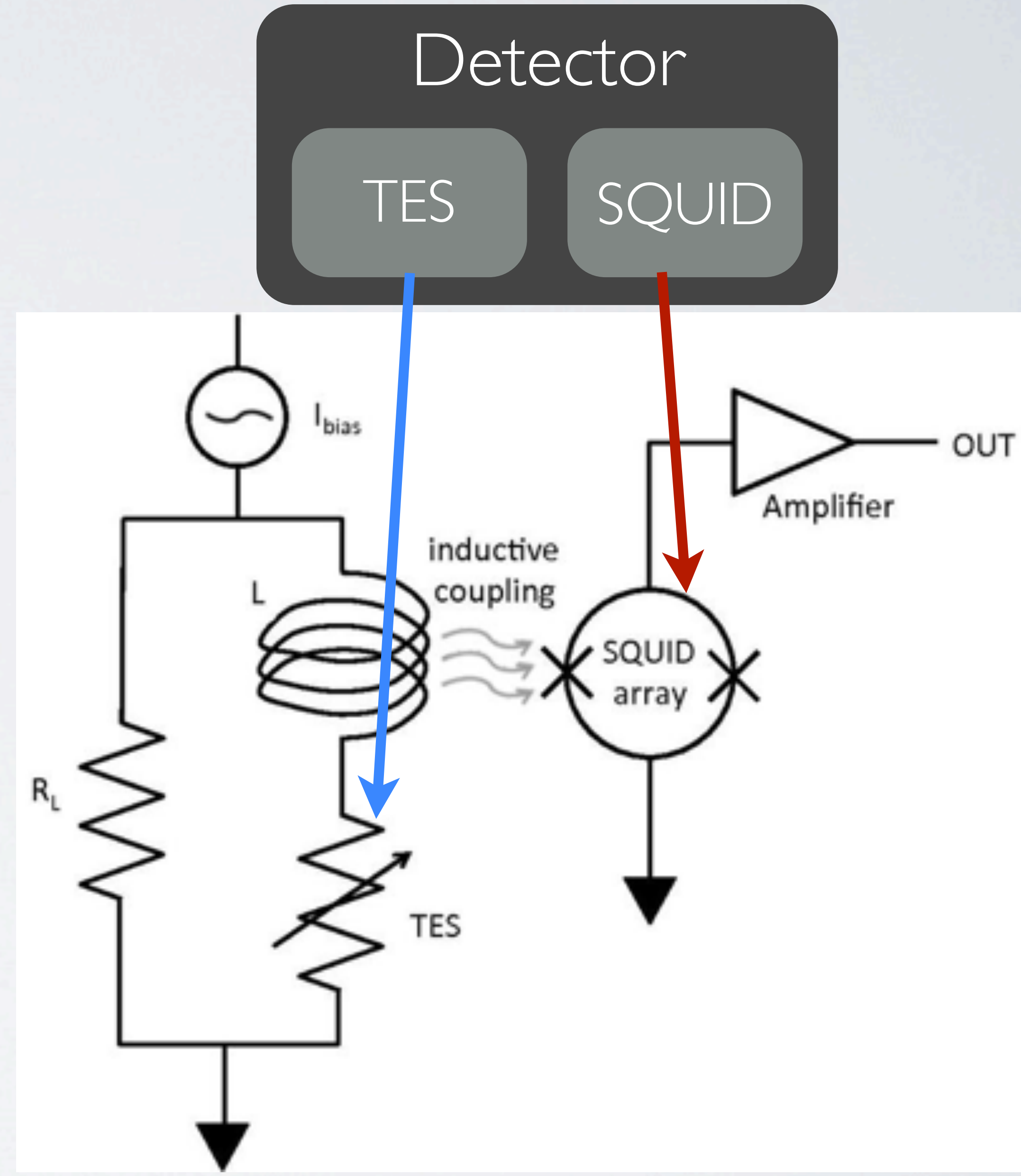
Phonon Trap



Transition Edge Sensor (TES):

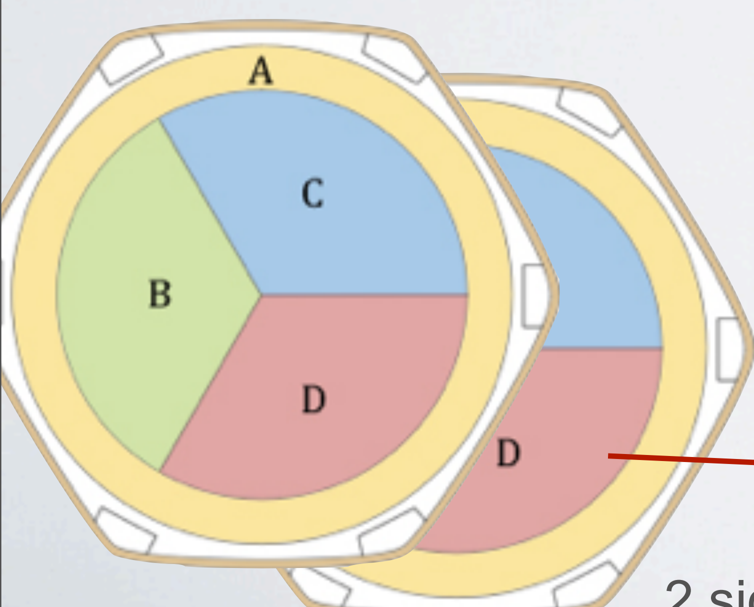
Resistance as function of temperature in the transitioning phase (Super/Normal - conducting) → the changing resistance creates a signal

FROM THE TES TO THE SQUID: GETTING SIGNALS OUT OF THE DETECTOR



- Superconducting QUantum Interface Device (SQUID): measures the current change of the TES. It's output is what we call the 'phonon pulse'

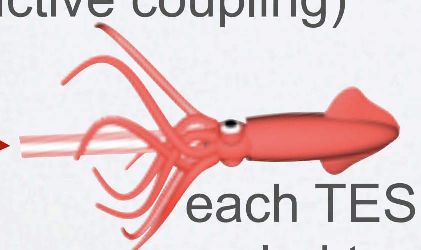
TES



2 sides

each side 4 sectors

(inductive coupling)



each TES sector coupled to a SQUID

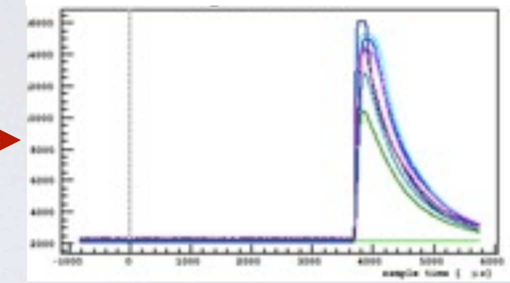
Each SQUID provides a PULSE

PULSE is sent to Downstream Electronics

PHONON SIGNAL READ-OUT

V_{bias} Control → Detector [TES, SQUID] → Other Electronics (Amplification, Triggering, Filtering) →

Pulse from interacting particle



1

The TES operation is controlled by a bias voltage, V_{bias}. Can change the detector between Normal Conducting, Super Conducting or Transition Conducting (normal data taking mode)

2

After phonons are generated in the crystal, the TES has an increase in temperature which in turn changes its resistance (and the amount of current that flows)

3

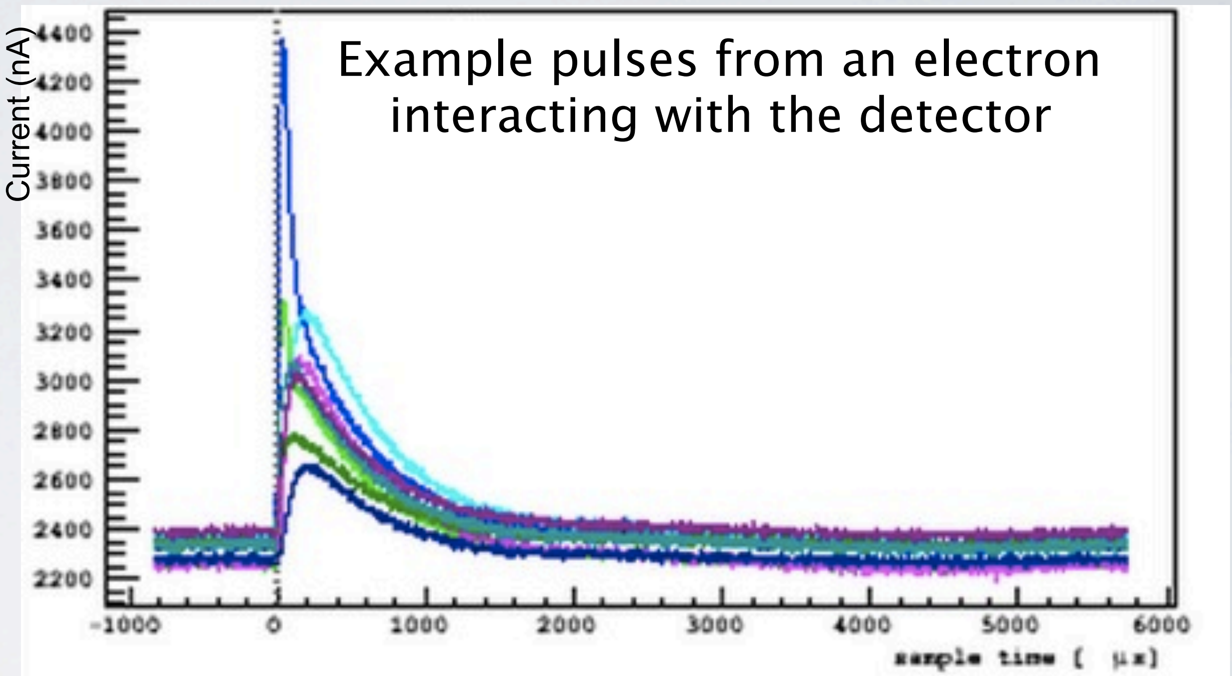
The SQUID measures the change in the current of the circuit. Its output is a pulse

4

Other Electronics take the pulse and do the rest of the data acquisition chain. Amplification, Triggering, Filtering, etc

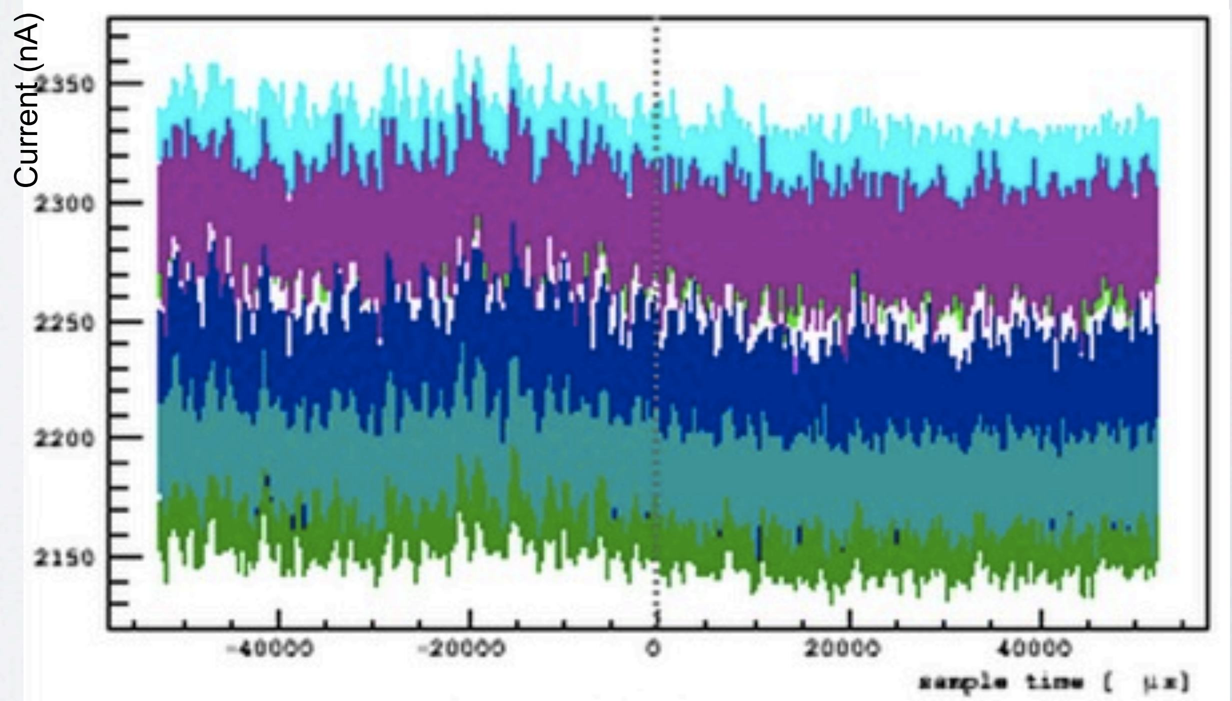
LOOKING AT DETECTOR PHONON PULSES

- When a particles interacts we get phonon pulses:
  - A signal in all 8 channels
  - Can determine where the particle hit in the detector
  - Can measure how much energy the particle deposited



- When no particle hits the detector:
  - Just read out 'noise' from detector (see right)

- Problem: Signal from a DM particle is not as big as above, so we need to be really sensitive and distinguish between a small pulse from the noise (below)



PURPOSE OF THIS STUDY

- Want to be sensitive to light DM particles which don't deposit much energy in the detector
- Sensitivity is determined by the ability to separate small real-particle-pulses (signal) on top of the detector output when there is no particle (noise)
- The amount of noise also affects our ability to measure the amount of energy deposited if we believe the pulse is from a real particle

GOALS:

- **Understand the sources of noise**
- **Make suggestions on how to reduce them**

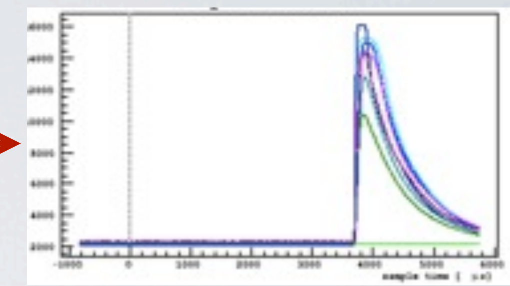
HOW DO WE STUDY THE AMOUNT OF NOISE FROM THE DETECTOR?

- Take data when no particle interactions are occurring
- Randomly select a time to start writing out data:
  - unlikely to have real particles interacting
  - pure sample of ‘noise’
- The longer the time, the better information we have for noise analysis
  - 750μs is a typical real particle pulse time
  - Total time > (2x before + 750μs + 5x after)
  - Total time ~ 100,000 μs
- Ratio of interaction of a Cosmogenic particle is ~1 per minute so our total time is ok

IV. Potential Sources of Noise: Method

POSSIBLE SOURCES OF NOISE IN THE EXPERIMENT

V_{bias} Control → Detector (TES, SQUID) → Other Electronics (Amplification, Triggering, Filtering) →



1

V_{bias} Electronics:

Electronics that set the V_{bias} level could inject noise into the experiment

2

Non-interaction Phonon Production:

Vibrations of the detector, occurring in the crystal, measured accurately by the TES, and sources of noise

3

Detector Level Inductive Coupling:

Could get noise from the TES-SQUID electronics

4

Other Electronics:

Could get noise from the electronics after the detector, for example in the amplification, triggering, or filtering process

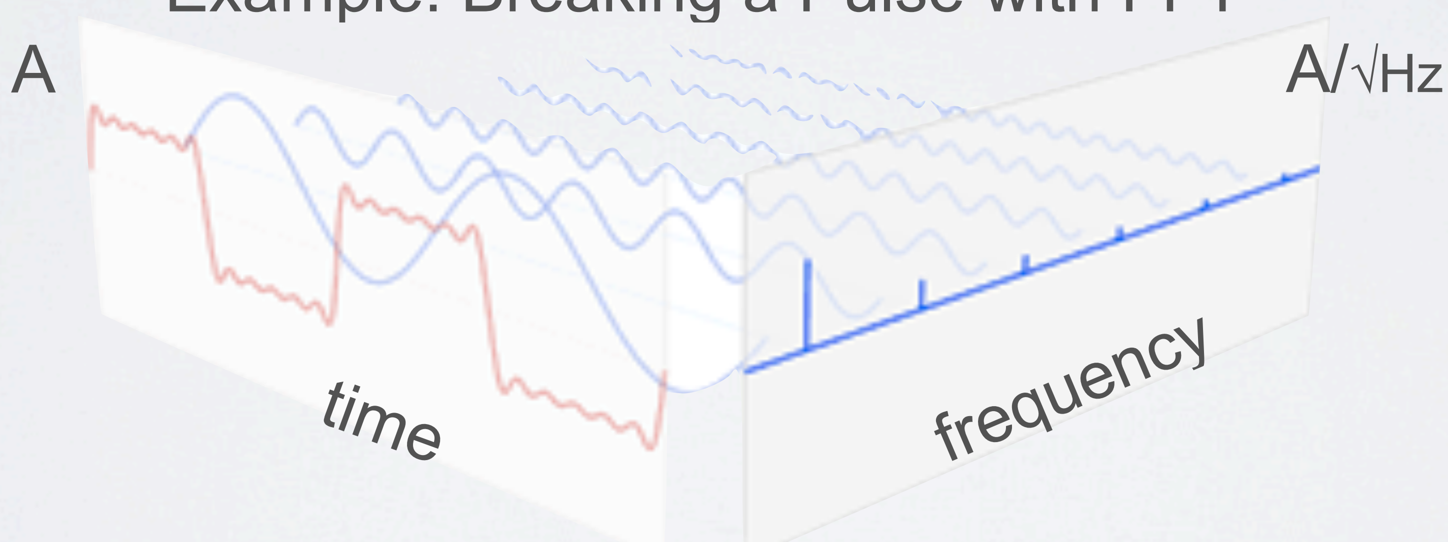
METHODS FOR STUDYING THE AMOUNT OF NOISE

- Sources of noise expected to occur at specific frequencies
- Look at the data in the Frequency Domain
- Use Fast Fourier Transforms (FFT) → Power Spectral Density Function (PSD)

Example: Breaking a Pulse with FFT

- y: amplitude

- x: time

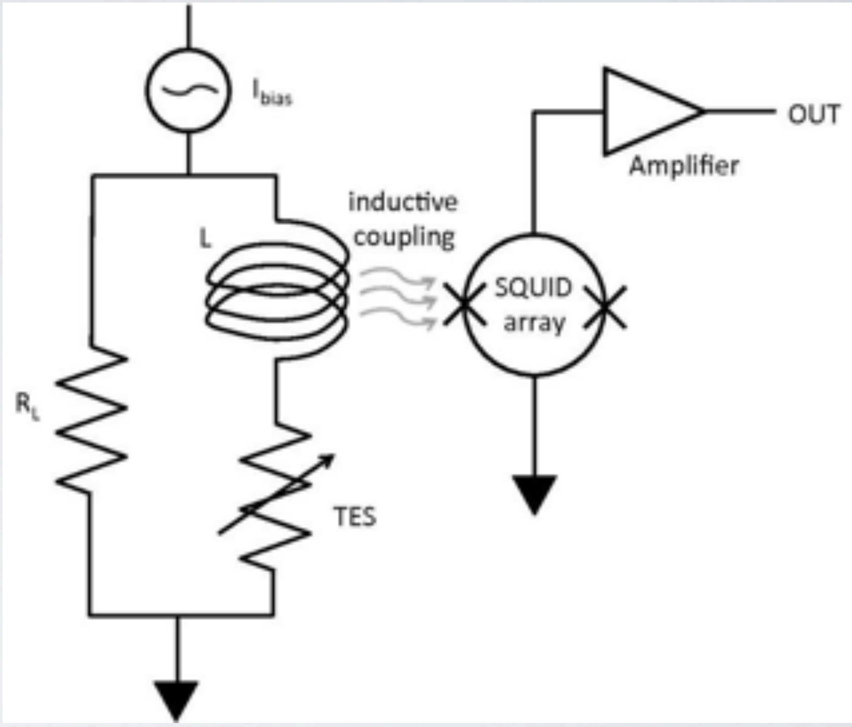


- y: amplitude in the Power Spectrum

- x: frequency

- Look at many events (lots of noise) to see which frequency is most prevalent

BASE NOISE OF THE TES/ SQUID CIRCUIT



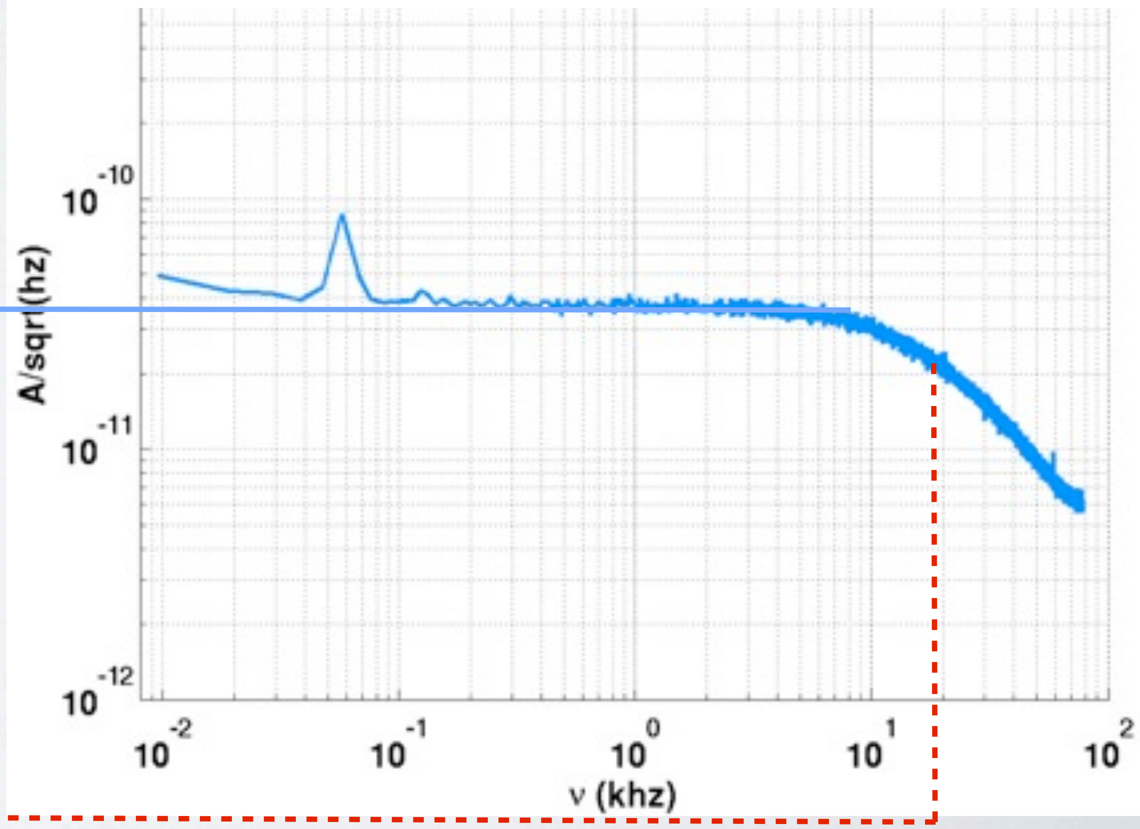
Baseline

- ‘Johnson Noise‘
  - Intrinsic to the TES/SQUID circuit
  - Characteristic of the amplification of the TES/SQUID pulse
- Depends on the Resistance and Temperature of the elements in the circuit, it is proportional to the Resistance and Temperature product of each element.

Cut-off frequency

- The cut-off frequency is determined by the impedance

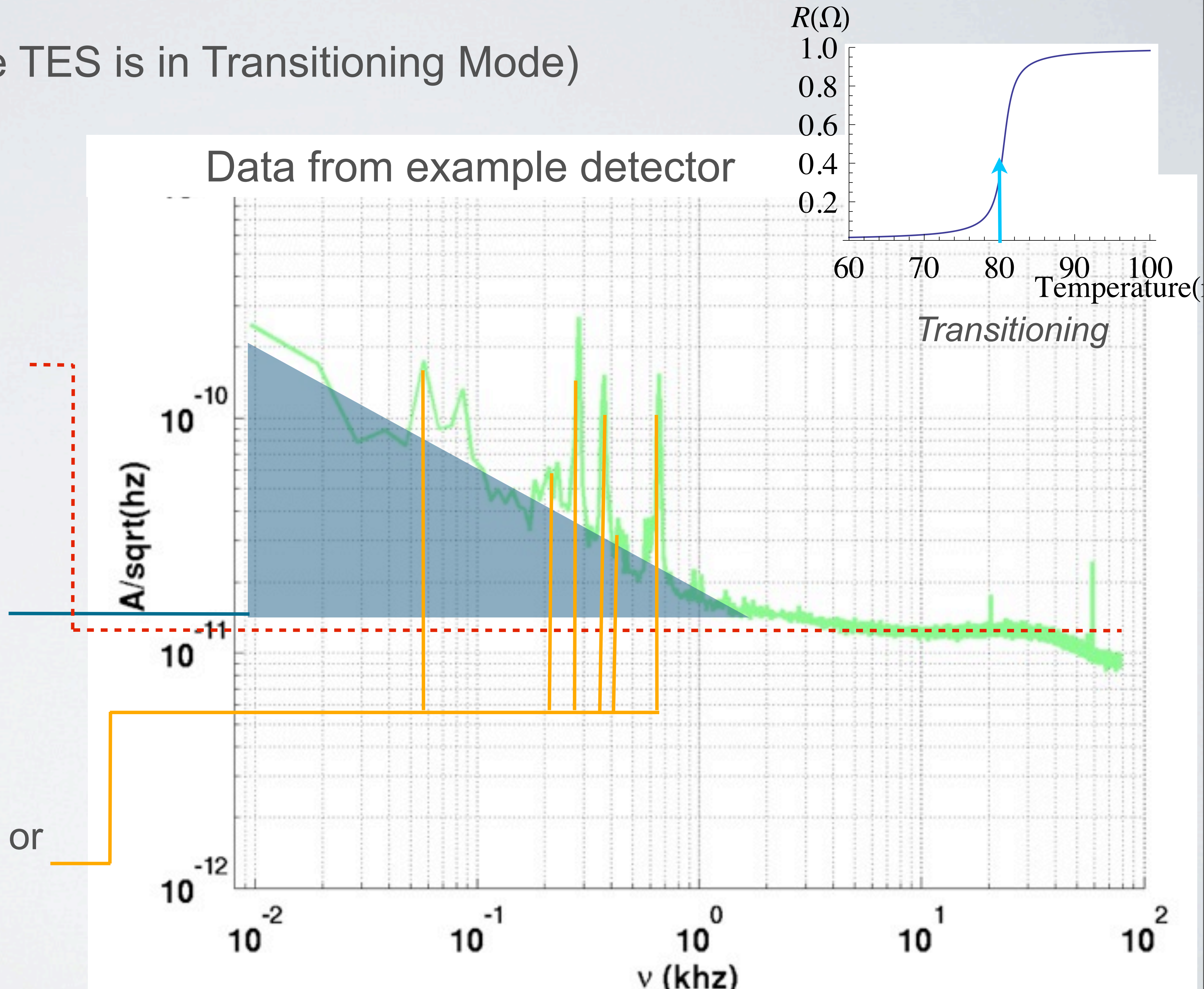
Superconducting PSD example



STANDARD CONFIGURATION DATA

(V_{bias} is set so that the TES is in Transitioning Mode)

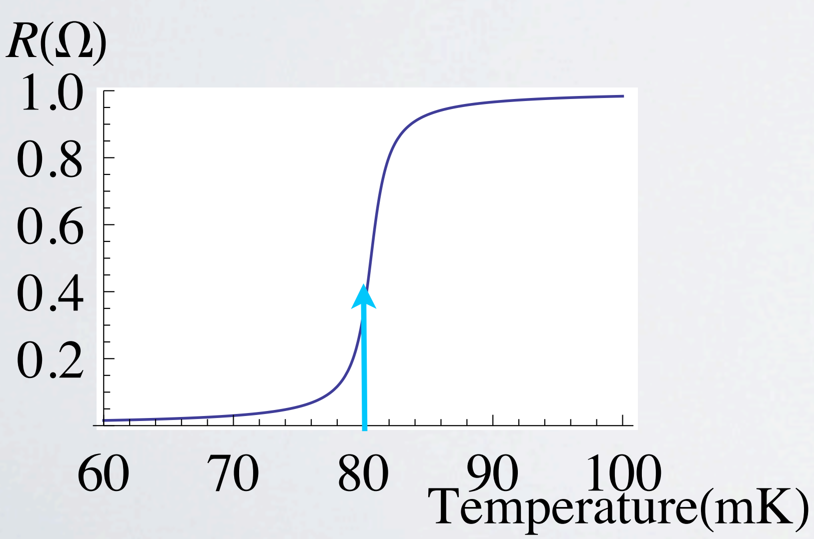
- Baseline Noise: from TES/ SQUID electronics (Johnson Noise)
- Rising region: will show this is from low frequency detector vibrations < 60 Hz
- Spikes: noise from various sources 100 Hz - 1kHz (phonon, detector electronics, or other electronics noise)



COLLECTING SAMPLES OF NOISE IN DIFFERENT DATA TAKING CONFIGURATIONS

A. Standard Configuration
Usual configuration for data
$V_{bias} = V_{threshold}$

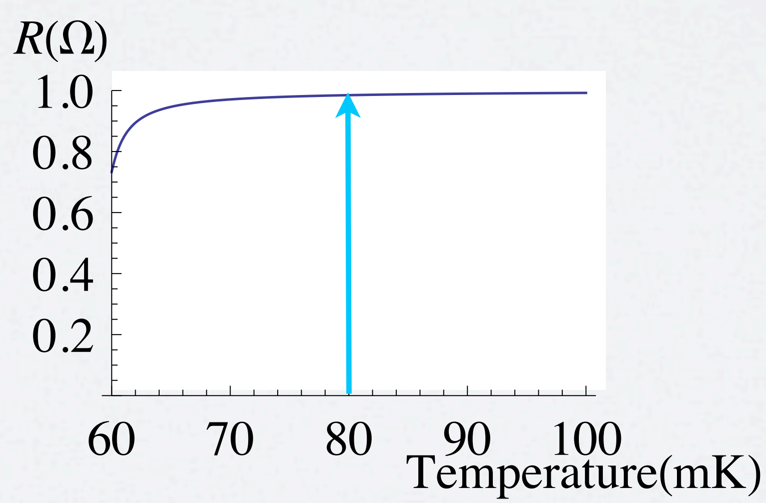
- TES is in transitioning phase between normal conducting and superconducting
- Phonons are collected and detector is sensitive to them (gives pulses)



Standard / Transitioning
Sensitive to phonons

B. Normal Conducting
Bias current set at 1000uA
$V_{bias} >> V_{threshold}$

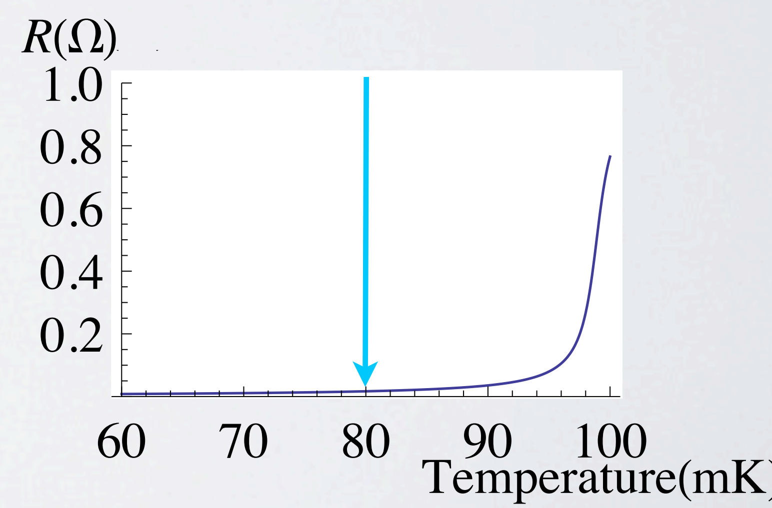
- Resistance never changes much, (amplified) current of SQUID is always small
- So phonons from the detector don't create output signals
- There is minimum amplification of any noise from TES/SQUID



Normal Conducting
Insensitive to phonons

C. Super Conducting
Bias current set at 0uA
$V_{bias} << V_{threshold}$

- Resistance never changes much, (amplified) current of SQUID is always large
- Phonons are not amplified so no output signal from phonons
- Maximum amplification from any TES/SQUID noise



Superconducting
Insensitive to phonons

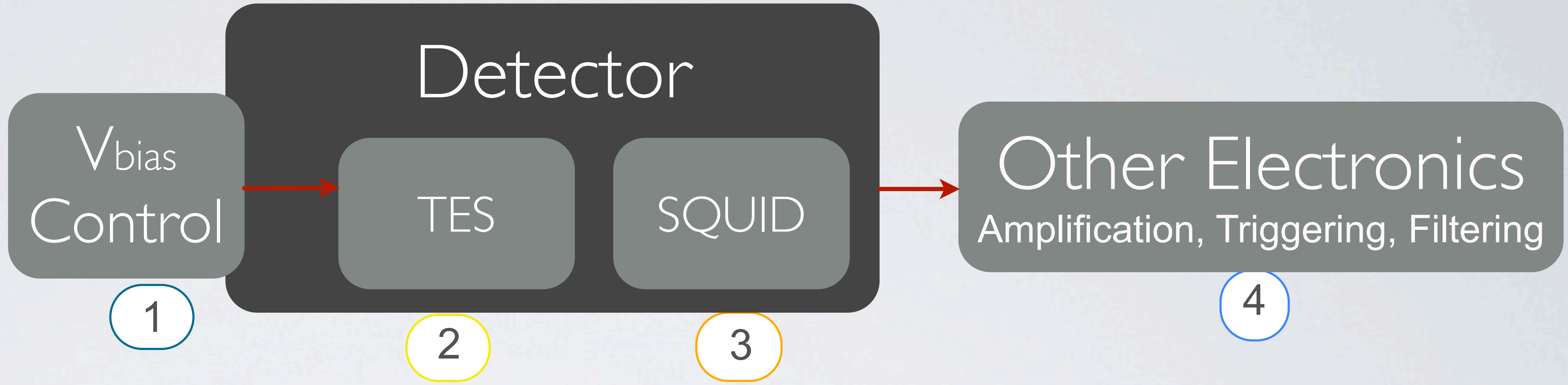
HOW TO UNTANGLE THE SOURCES OF NOISE

Experiment Modes

A. Standard Configuration

B. Normal Conducting

C. Super Conducting



1. V_{bias} Electronics: If peaks are due to noise from the V_{bias} control then they should be bigger or smaller depending on the the overall resistance in the circuit. The amount is known, so the ratio of the peaks should follow this ratio
 A/B ~ 1/3 A/C ~ 7

2. True Phonon Production: If noise is due to detector vibrations, then we should not see any noise when we are not sensible to phonons (modes B & C)

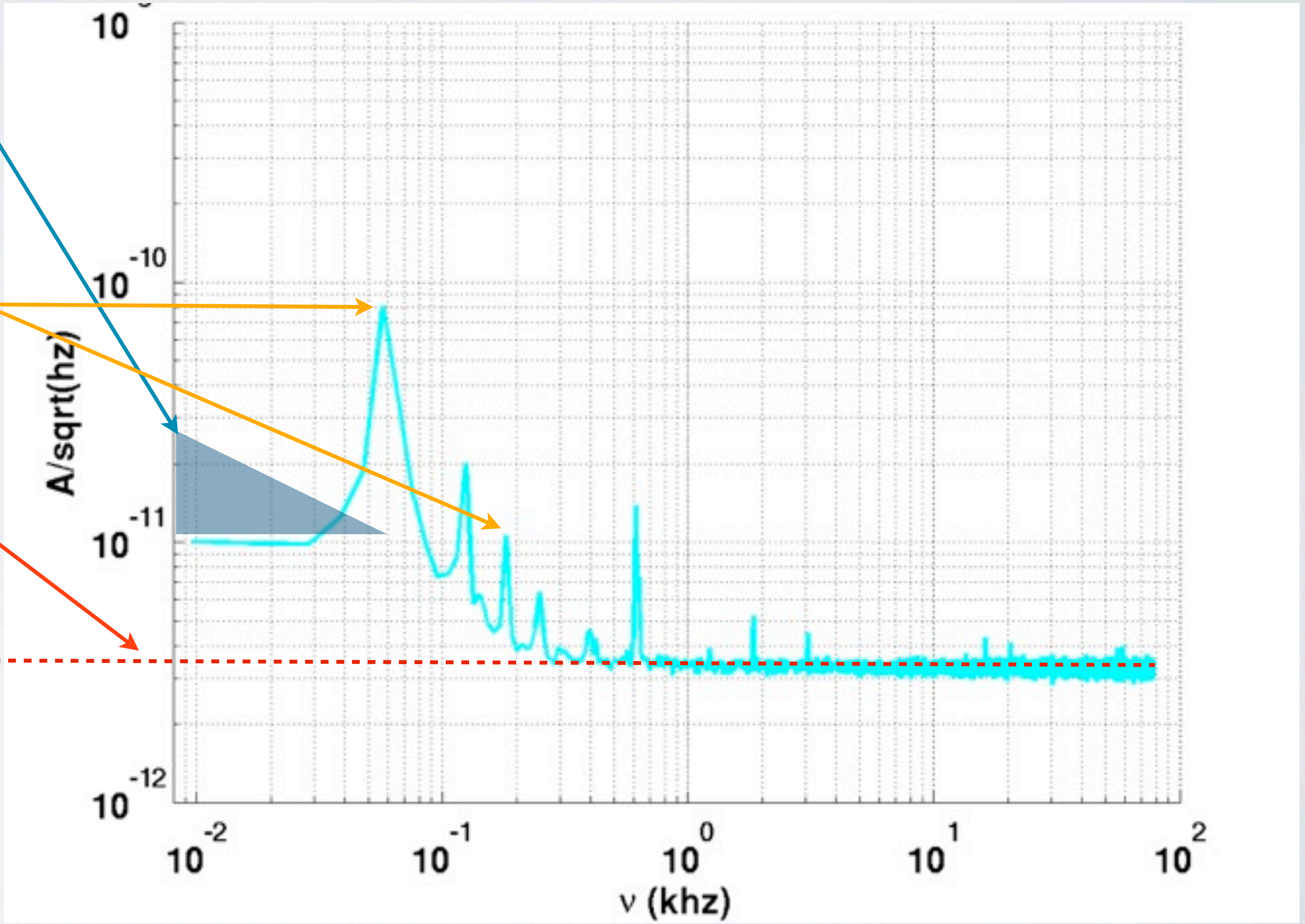
3. Detector Level Inductive Coupling: From PSDs it is the same as Vbias 1 , but we can look at correlation between channels/detectors depending on the connections/card dependencies of the channels within each detector

4. Other Electronics: If the noise is due to the electronics after the SQUID (Other Electronics), then the peaks should be in the same place and have the same size regardless of the experiment mode

DETECTOR READOUT IN NORMAL CONDUCTING DATA

- When the TES has a Temperature/V_{bias} configuration that makes it normal conducting, the readout signal is insensitive to phonons in the detector

- No big slope at low frequencies. Noise in the previous plot must be due to phonons 'intrinsic' to the detector somehow
- Spikes still exist, must not be due to phonons, but to some part of the electronics. Note the big spike at 60Hz (suggestive number)
- Lower baseline, but that's expected because there is more resistance
- No 'cut-off' here because its off scale.



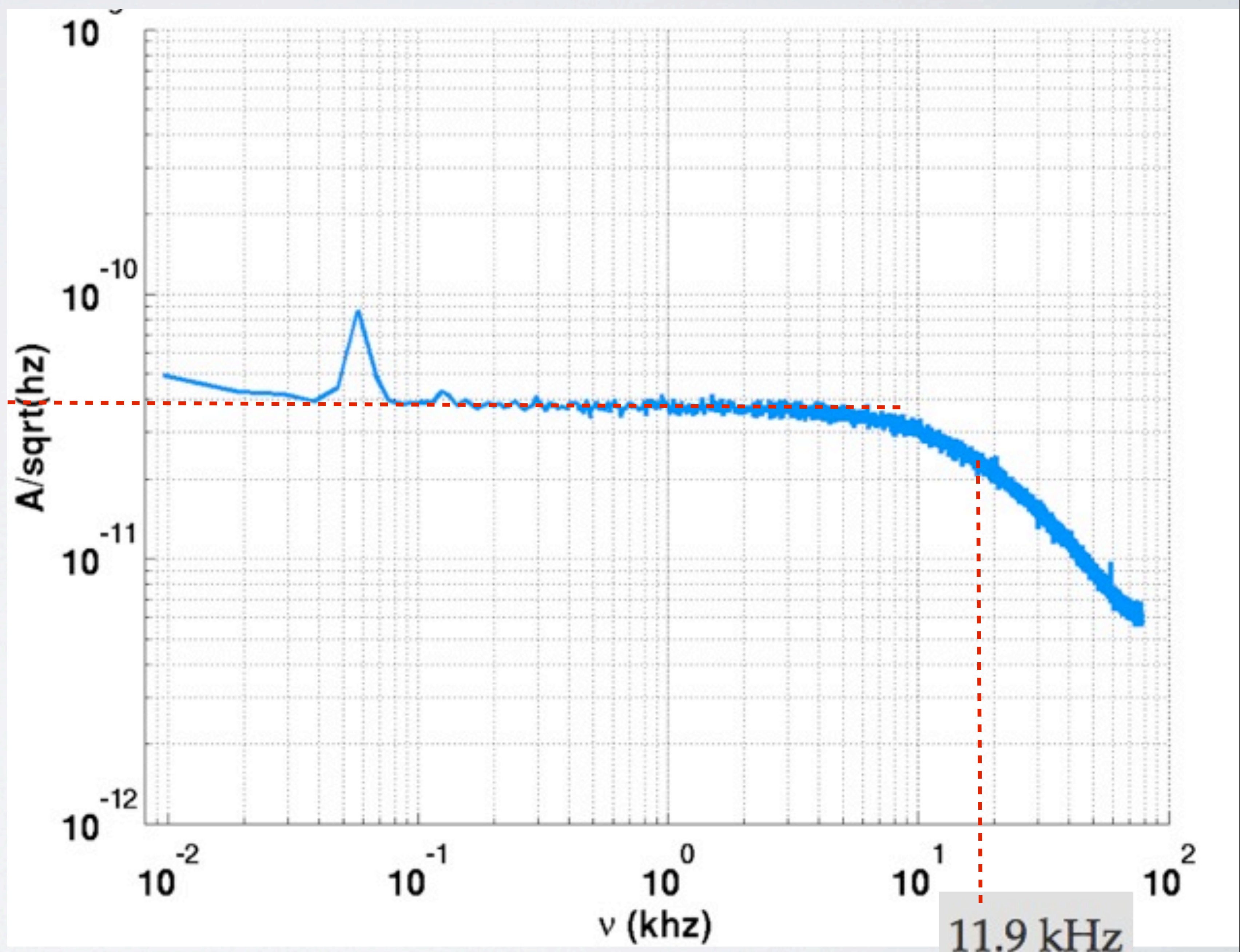
Amplitude Baseline From Johnson Noise: $3.63\ \mathrm{pA}/\sqrt{\mathrm{Hz}}$

Cut-off frequency from Impedance: 250 kHz (Out of range)

DETECTOR READOUT IN SUPERCONDUCTING DATA

- When the V_{bias} sets the TES in superconducting mode, again the readout signal is insensitive to phonons in the detector.

- Smaller TES resistance gives greater baseline noise
- Only see one spike at 60Hz again. Other spikes are gone, perhaps swamped with baseline noise?
- Lower threshold Cut-off as expected



Amplitude Baseline From Johnson Noise: $44\ \mathrm{pA}/\sqrt{\mathrm{Hz}}$

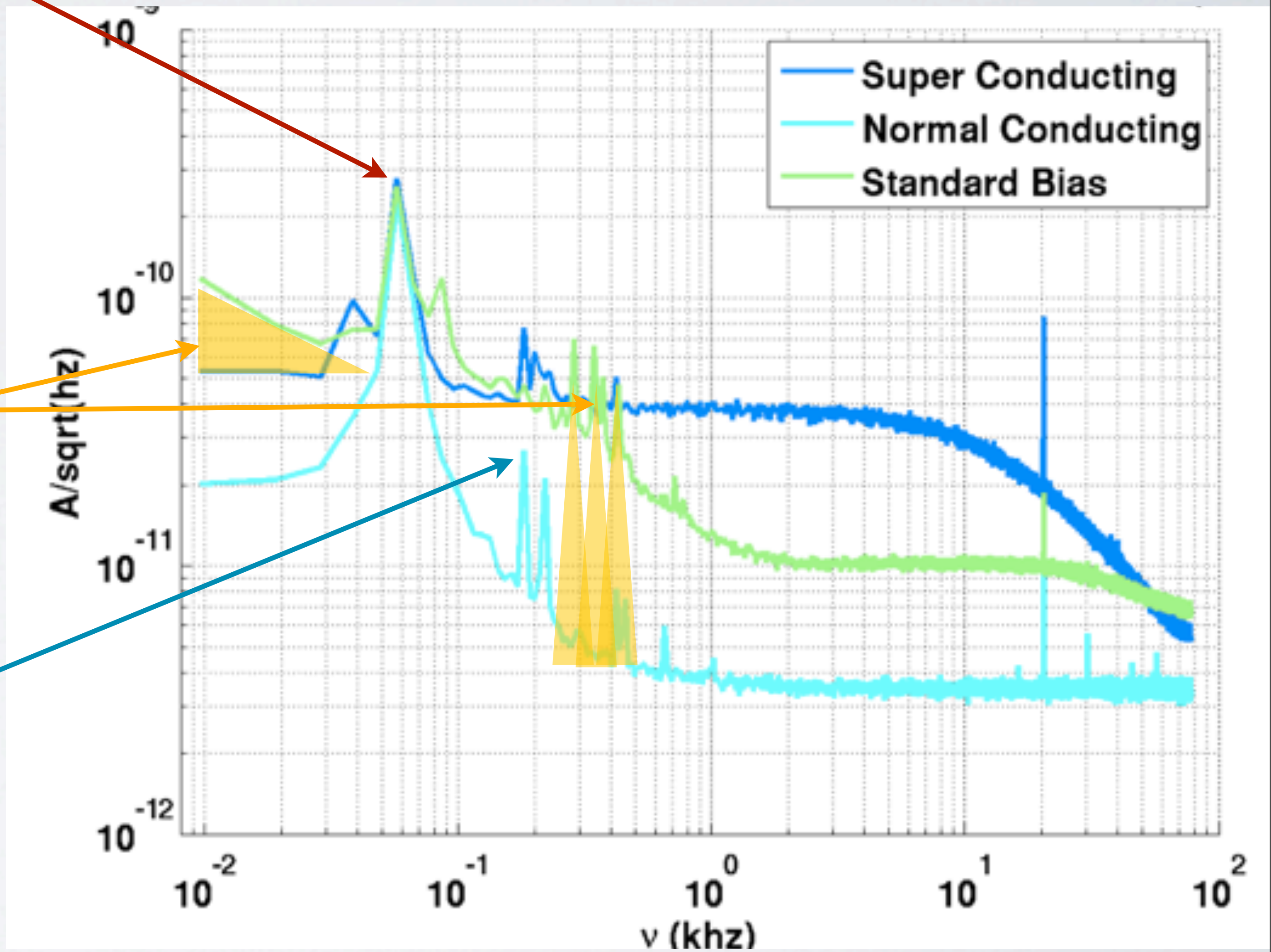
Cut-off frequency from Impedance

COMPARING ALL THREE SETS OF DATA AT THE SAME TIME (FOR A SINGLE DETECTOR) AND DRAWING QUALITATIVE CONCLUSIONS

- Other Electronics:
  - 60 Hz noise always present. This tells us it is likely to be in the electronics. Especially since the amount of noise at this frequency is always the same
  - Peaks of this kind are 1 to 1 ratio regardless of mode

- Noise from Phonons:
  - Only see this rising noise in Standard Mode (not in Superconducting nor Normal Conducting). Indicates it is due to phonons that are always present in the detector
  - Also see some phonon spikes (not present in modes insensitive to phonons)

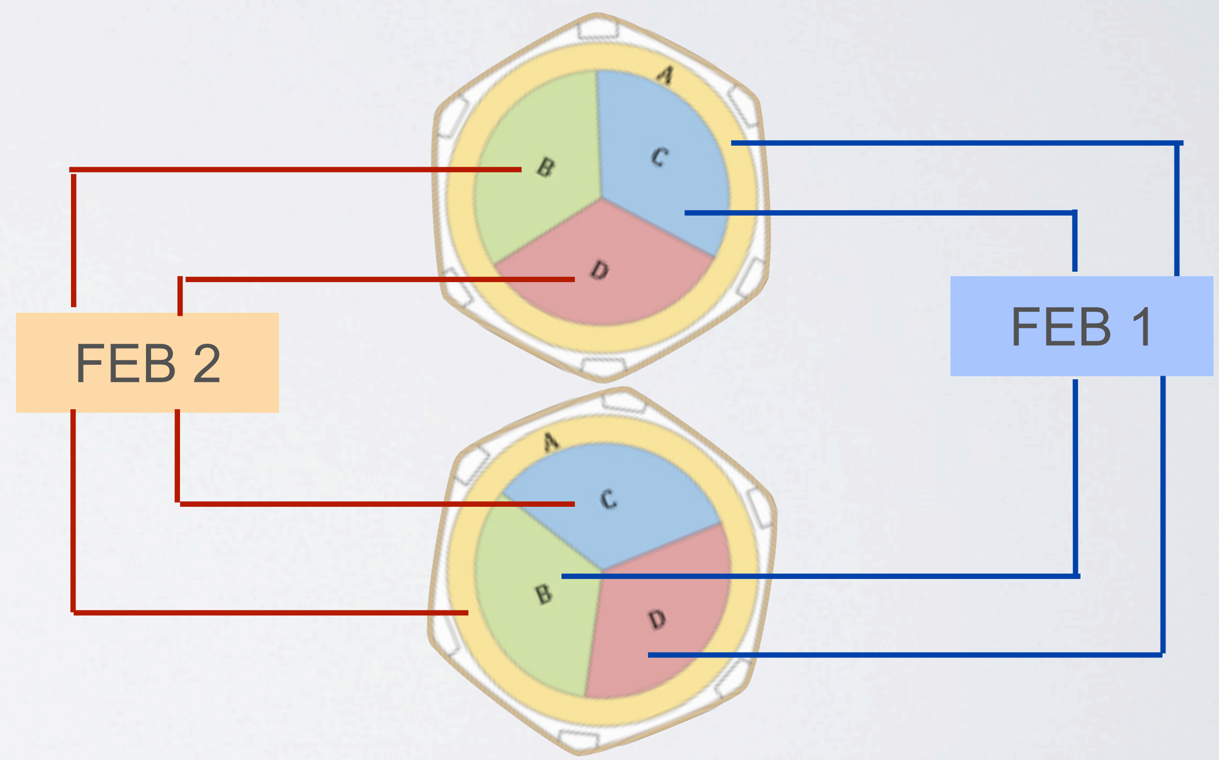
- Spikes due to V_{bias} Electronics / Inductive Coupling:
  - Change in the amplitude of peaks (they depend on resistance ratio of the different modes, but some mixing with 'Other Electronics' could change it)
  - Std/NC~1/3 Std/SC~7 NC/SC~21

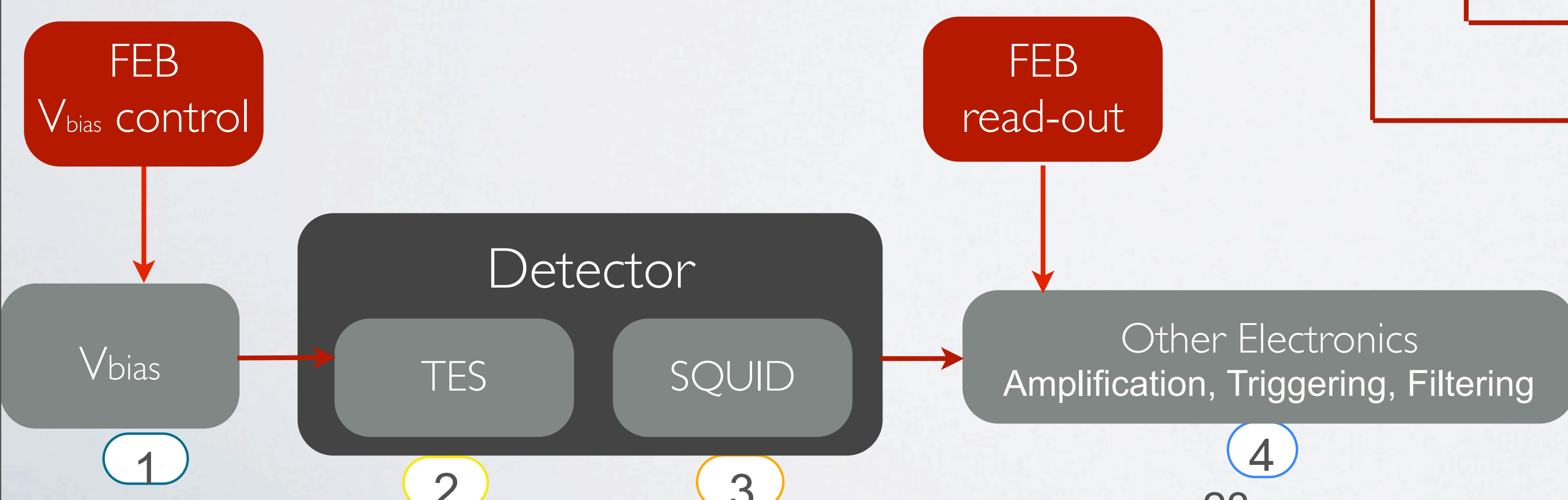


LIMITATIONS OF THE STUDY

- Unfortunately we are not able to discriminate between a capacitively coupled (TES V_{bias}) noise and an inductively coupled (SQUID) noise, but we can see if the noise is common to phonon channels connected to the same electronics board - Front End Board (FEB) - as opposed to a detector

- The FEB connections to the TES channels are combined:
  - 2 cards per detector
  - 2 channels per side in each card

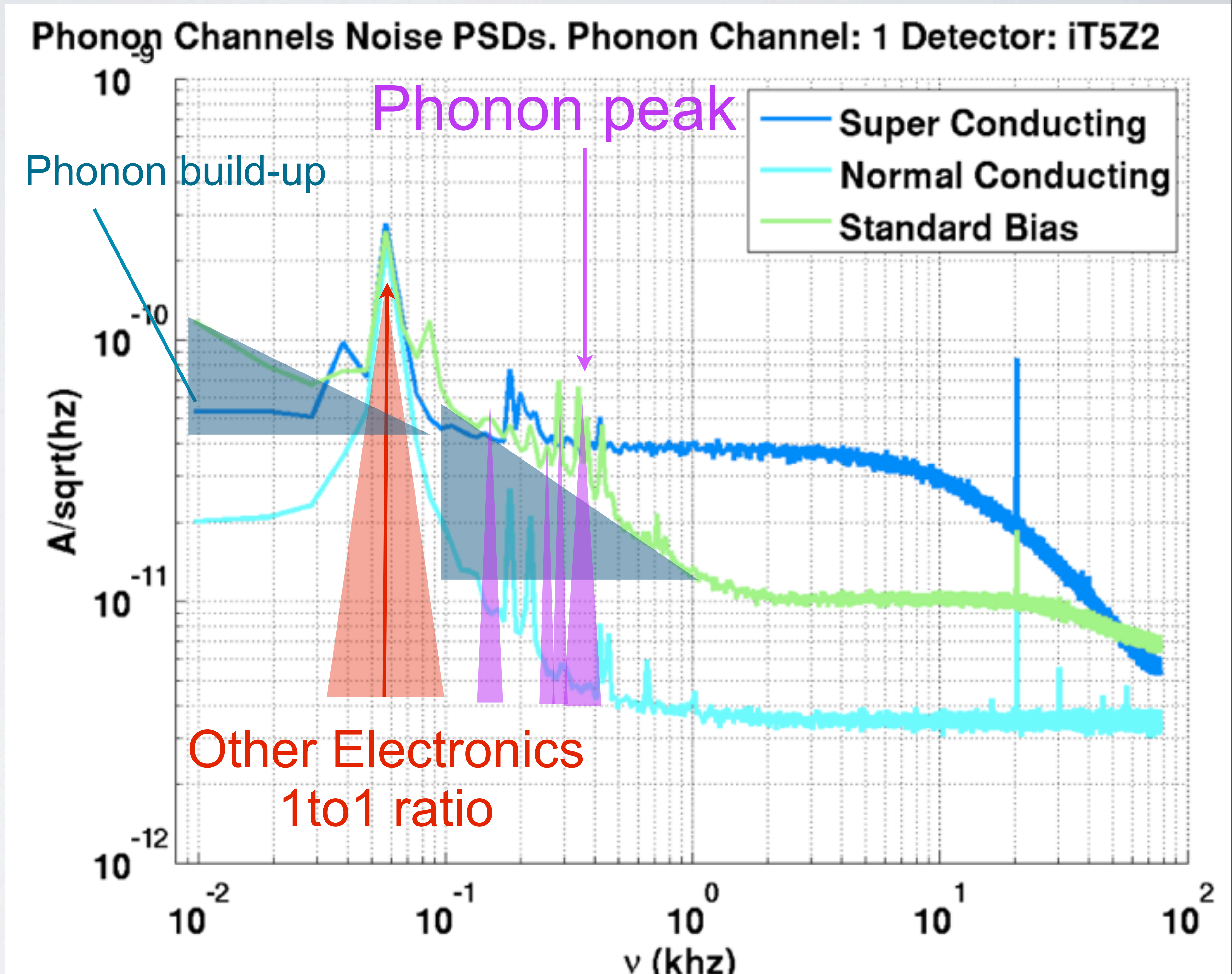




IV. Potential Sources of Noise: Results

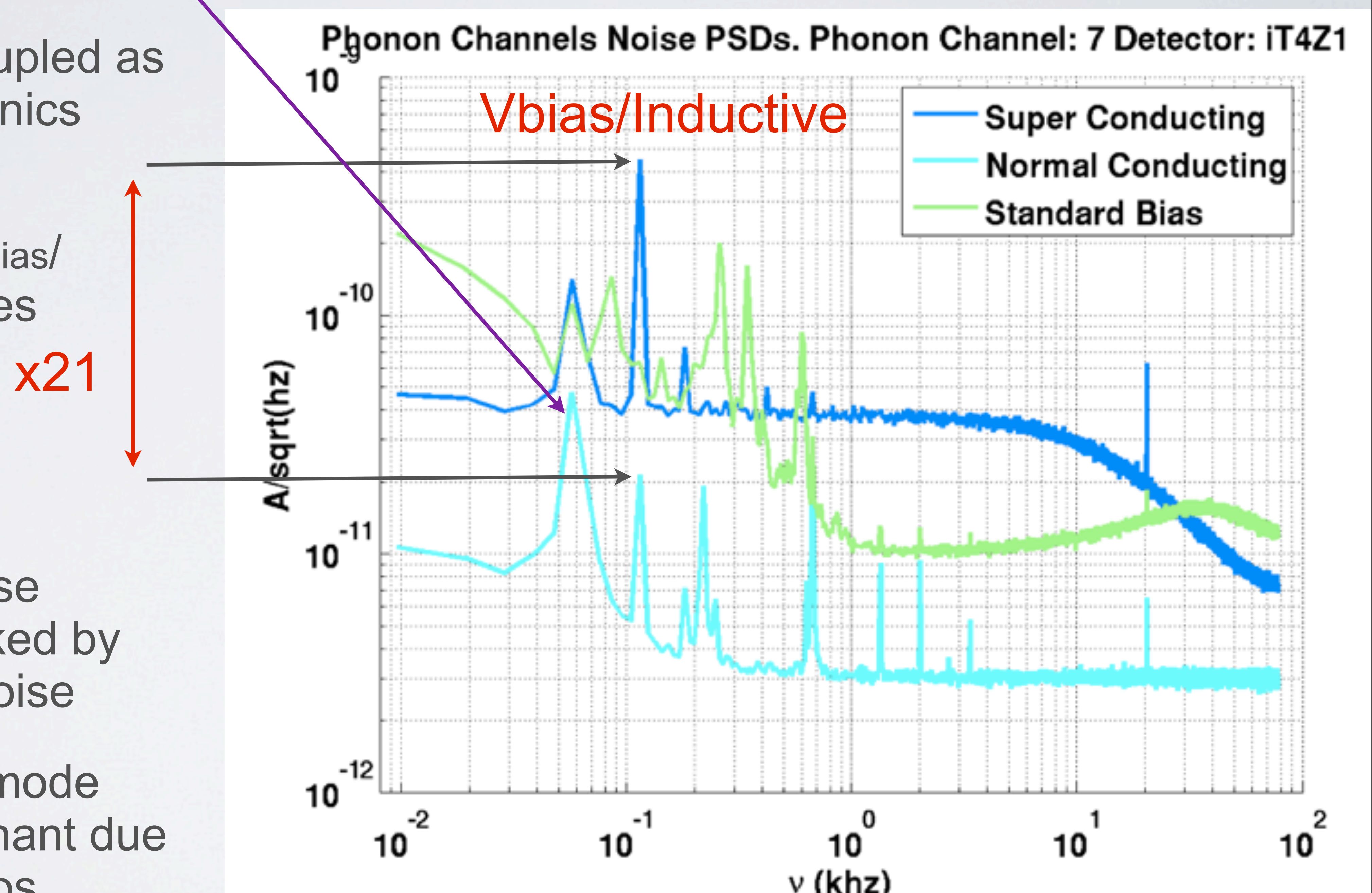
MOVING FROM OUR EXAMPLE DETECTOR TO NOISE IN OTHER DETECTORS. NOT ALL DETECTORS ARE THE SAME

- Again see the 60 Hz peak (true for most detectors)
- Some detectors have spikes due to "phonon peaks", not just the slope (build-up). Due to cryogenics?
- Many peaks/features are combined electronics noise (from Vbias/Inductive and Other Electronics)



THIRD EXAMPLE: V_{BIAS}/INDUCTIVE PEAKS

- 60Hz peak is not the same, it is possible that Vbias/ Inductive noise is coupled as well as Other Electronics noise
- Clear peak due to Vbias/ Inductive noise, scales accordingly:
  - Std/SC ~ 7
  - Std/NC ~ 1/3
  - NC/SC ~ 21
- In Standard Bias these peaks could be masked by baseline + phonon noise
- In Superconducting mode peaks must be dominant due to the resistance ratios

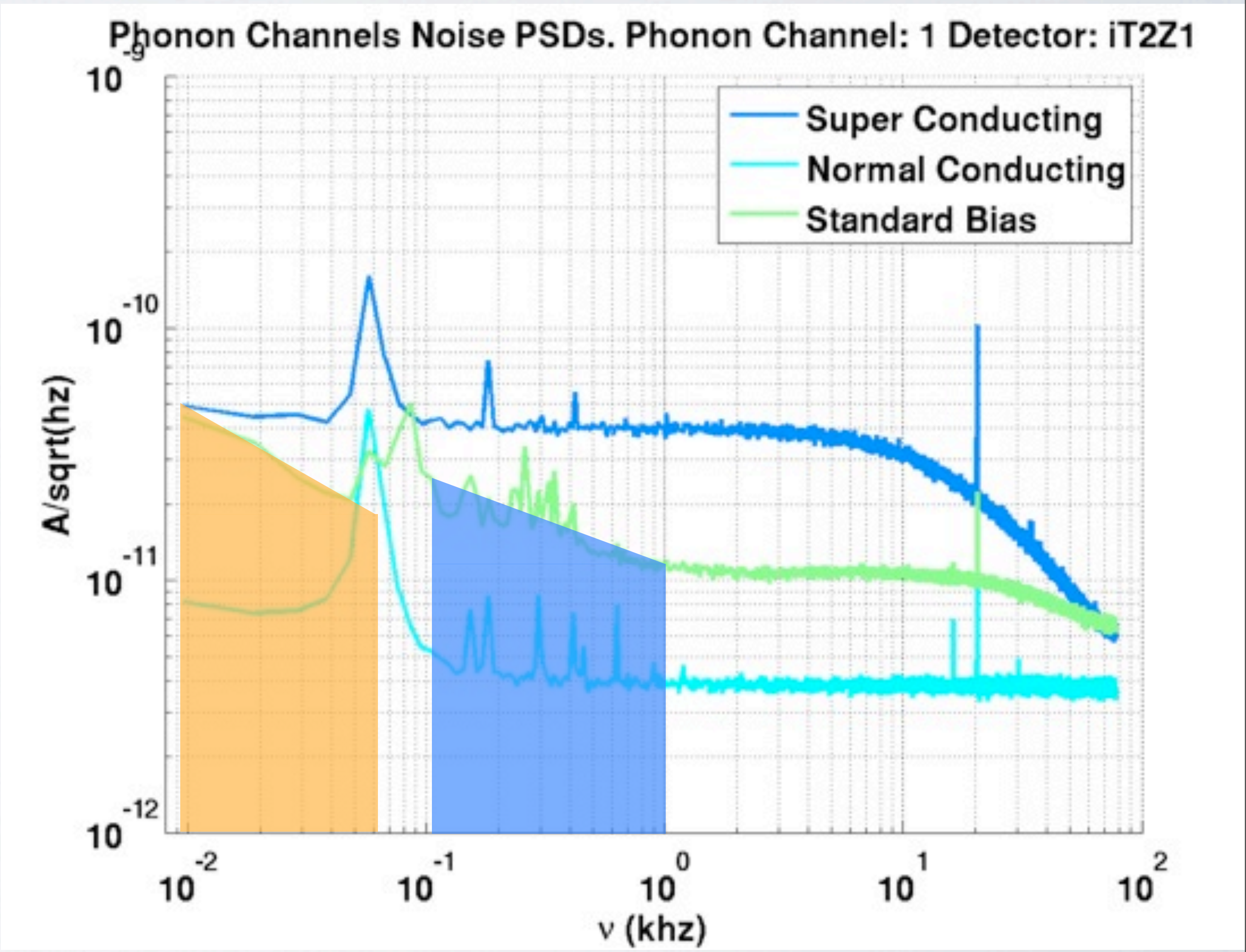


RESULTS FOR THE FULL SET OF DETECTORS

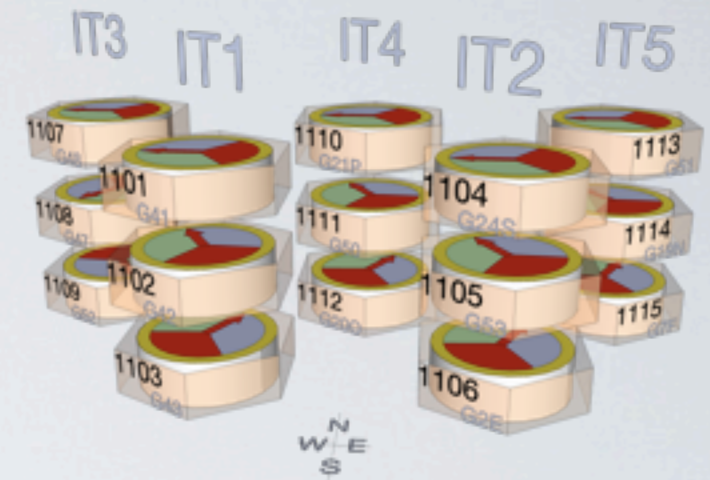
- For each detector we have qualitatively identified the principal sources of noise in two regions

- Comment on noise in two different regions:

  - < 60 Hz Background
  - 100 Hz - 1 kHz peaks



RESULTS FOR ALL DETECTORS



- < 60 Hz Background Results:
  - Most of the detectors clearly show real phonon noise

Phonon Dominated (affecting all channels): Not as Intense, or Not Clear:

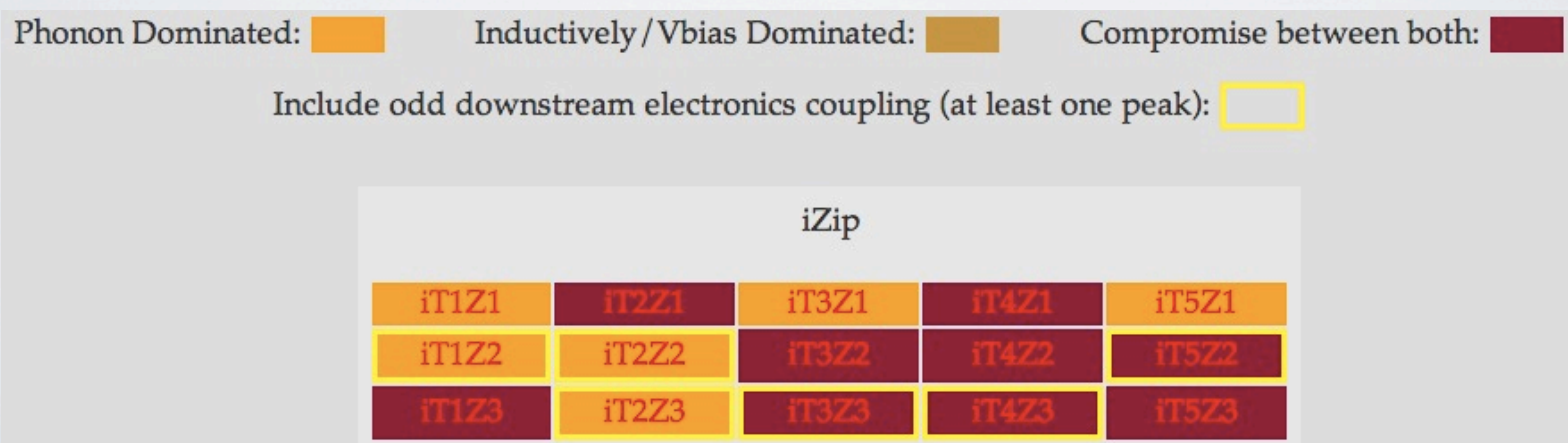
iZip

iT1Z1	iT2Z1	iT3Z1	iT4Z1	iT5Z1
iT1Z2	iT2Z2	iT3Z2	iT4Z2	iT5Z2
iT1Z3	iT2Z3	iT3Z3	iT4Z3	iT5Z3

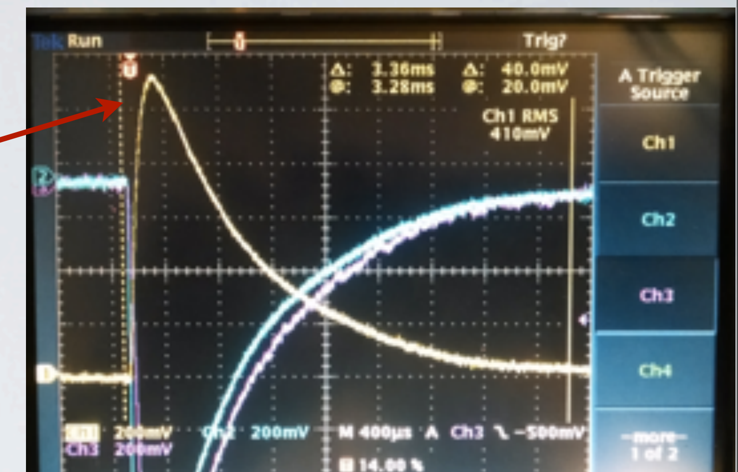
RESULTS FOR ALL DETECTORS Continued...

- 100 Hz - 1 kHz peaks

 - Different detectors show different noise sources, but overall noise is similar in all channels of the same detector (as opposed to some channels)
 - Other Electronics noise doesn't appear in all channels of same detector
 - All detectors show real phonon source peaks
 - Some show additional V_{bias}/Inductive peaks, others show no sources of this kind



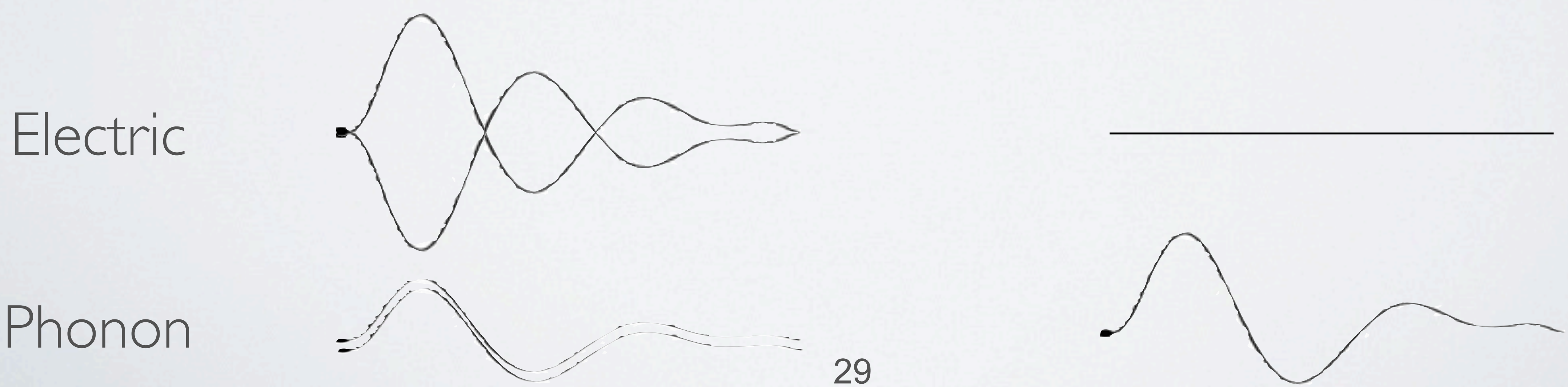
IDEAS TO REDUCE/CANCEL NOISE IN THE FUTURE



- Flip the Polarity of half of the channels:
  - Invert V_{bias} of 4/8 channels
  - Real phonon signal should flip
  - After-amplification signal will not (i.e. 'Other Electronics' noise)

- Potentially cancel the 'Other Electronics' noise

- Complications:
  - Noise should be properly identified and STRONGLY correlated between channels, if not, then it means that noise is not matching exactly the same frequency, so we are killing more than just noise
  - This type of noise should be strongly correlated in the NC mode (since in principle it is where electronics noise should be dominant)



SUGGESTIONS FOR SNOLAB EXPERIMENT

- The SnoLAB Experiment was just approved!
- All detectors have noise that appears to be due to vibrations, so better Casing and Supporting Structure is needed for Next Generation - most noise is phonon related
  (independent studies relate the Cryocooler noise with the pulses)
- Better Electronics to suppress all electronics noise, mostly at TES/squid level, but also downstream - some electronics peaks
- Inverting Bias on half of the output channels may lead to electronics (post TES) noise suppression - currently exploring this idea, we are not certain if it is possible to do without suppressing too much signal

CONCLUSIONS

- CDMS is one of the most sensitive experiments
- Noise in the detector impacts our sensitivity to low mass Dark Matter particles
- Have uncovered and understood (qualitatively) a number of sources of noise in the experiment and made recommendations to help remediate some of them
- Looking forward to the next generation of the CDMS Experiment with improved detectors, casing, and readout equipment at SnoLAB which was just approved

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Guy Almes

Sriteja Upadhayula

BACKUP

DIRECT DETECTION

Sensitive to 7keV of energy deposit (LUX: ~3.3 keV , SCDMS-II: 2keV)

- CDMS (Cryogenic DM Search) → Super CDMS
- DAMA (100 kg sodium iodide crystal) → DAMA/LIBRA (250 kg, Gran Sasso, Italy)
- XENON10 (15kg liquid xenon) → XENON100
- KIMS (Korea Invisible Mass Search)
- XMASS (800 kg spherical liquid Xe, Japan)

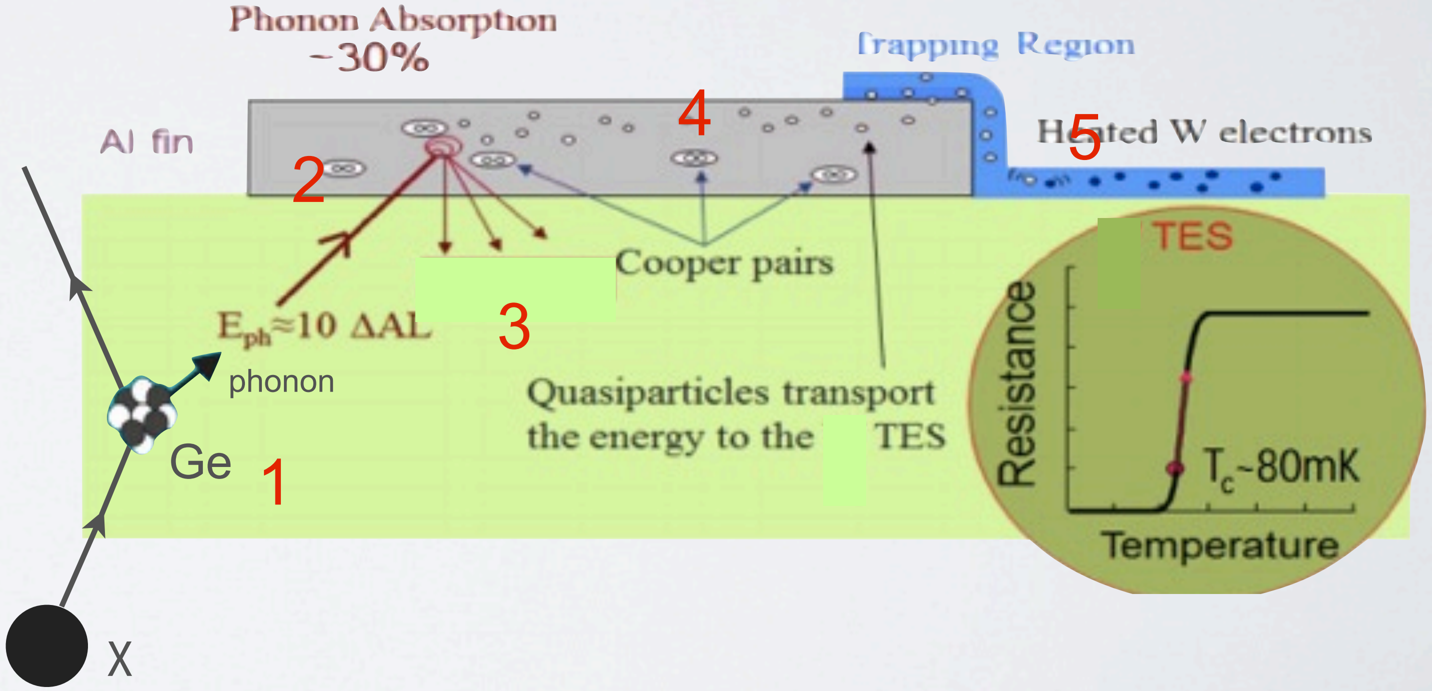
- Ionization (eV, ε~20%)
- Scintillation (keV, ε~1%)
- Phonon (meV, ε~100%)

FROM A PARTICLE INTERACTION TO A SIGNAL OUT OF A **T**RANSITION **E**DGE **S**ENSOR

- A DM particle will interact via vibrations of lattice: Phonons

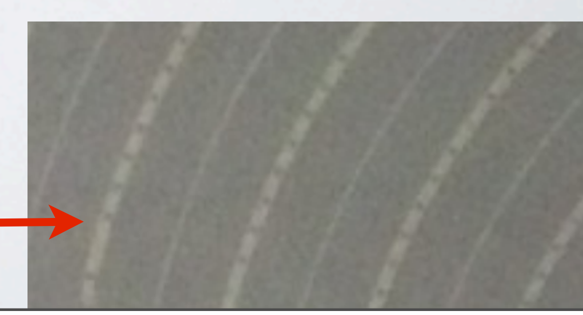
- Phonon production and collection process:

  1 super-rapid phonons (*athermal*)
  2 phonons break superconducting cooper pairs
  3 cascade phonons are produced
  4 phonons couple to freed electrons
  5 finally they diffuse into the tungsten Transistor Edge Sensor (TES)



athermal: more energetic than typical energy; at least 2 superconducting AL gap

Phonon Trap



COSMOGENIC BACKGROUND

- 750μs is a typical real particle pulse time
- Total time of our samples ~ 100,000 μs
- Cosmogenic background (muons mostly) interact with the detector (passing the scintillating veto)
  - 1 every 64.4 ± 0.1 s
  - energy threshold choice is 1 V (≈ 6.9 MeV)

http://cdms.berkeley.edu/Dissertations/fritts.pdf

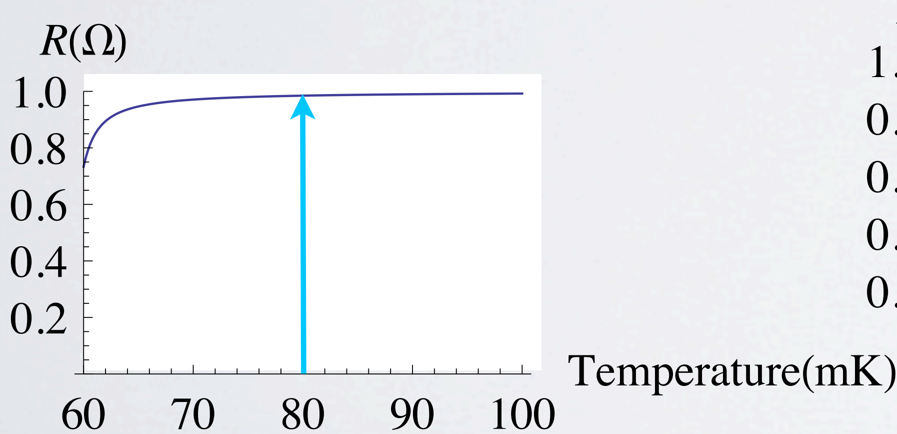
V_{BIAS} AND FRONT END BOARD

- The V_{bias} is actually on the Front End Board, which ALSO does a part of the read-out electronics

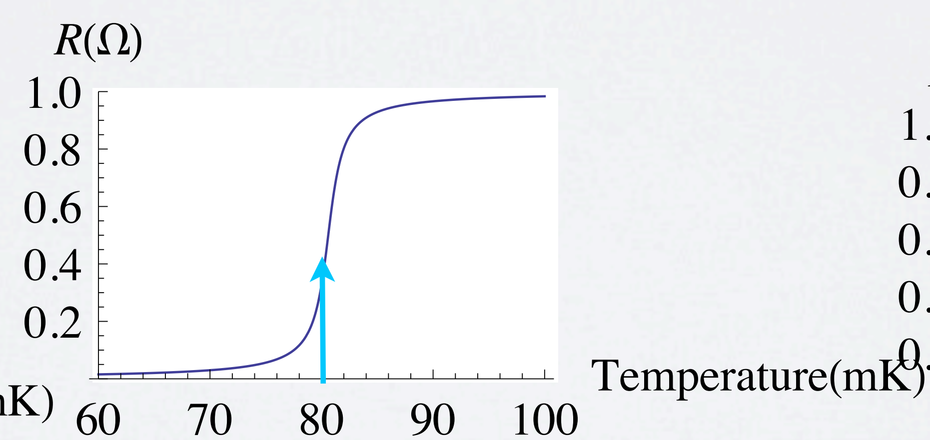
V_{bias} Control → TES needs V_{bias} to operate → Front End Board provides V_{bias}

- Vbias sets the TES R vs. T Curve

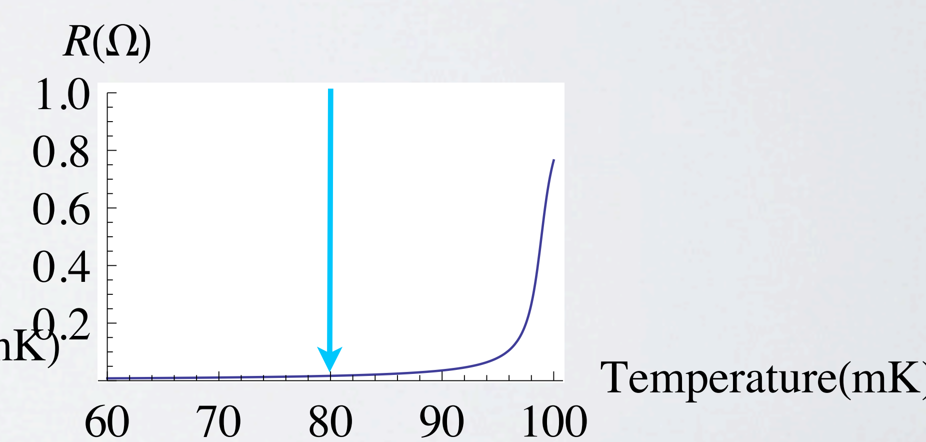
Temperature is fixed at 80mK



Normal Conducting



Transitioning



Superconducting

IV. Potential Sources of Noise: Method

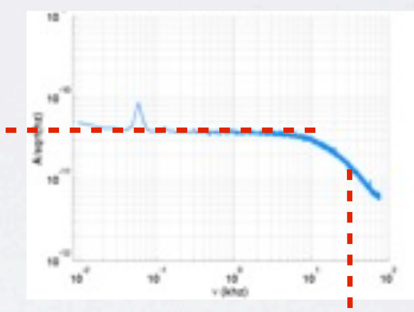
BASE NOISE OF THE TES CIRCUIT

- 'Johnson Noise'
  - Intrinsic of the TES/SQUID circuit
  - Characteristic of the amplification of the TES SQUID pulse

- Depends on the Resistance and Temperature of the elements in the circuit

Amplitude of J-Noise in PSD:

$$S_I^2 = \frac{4\,k_\beta\,(\Sigma R_i T_i)}{(\Sigma R_i)^2}$$

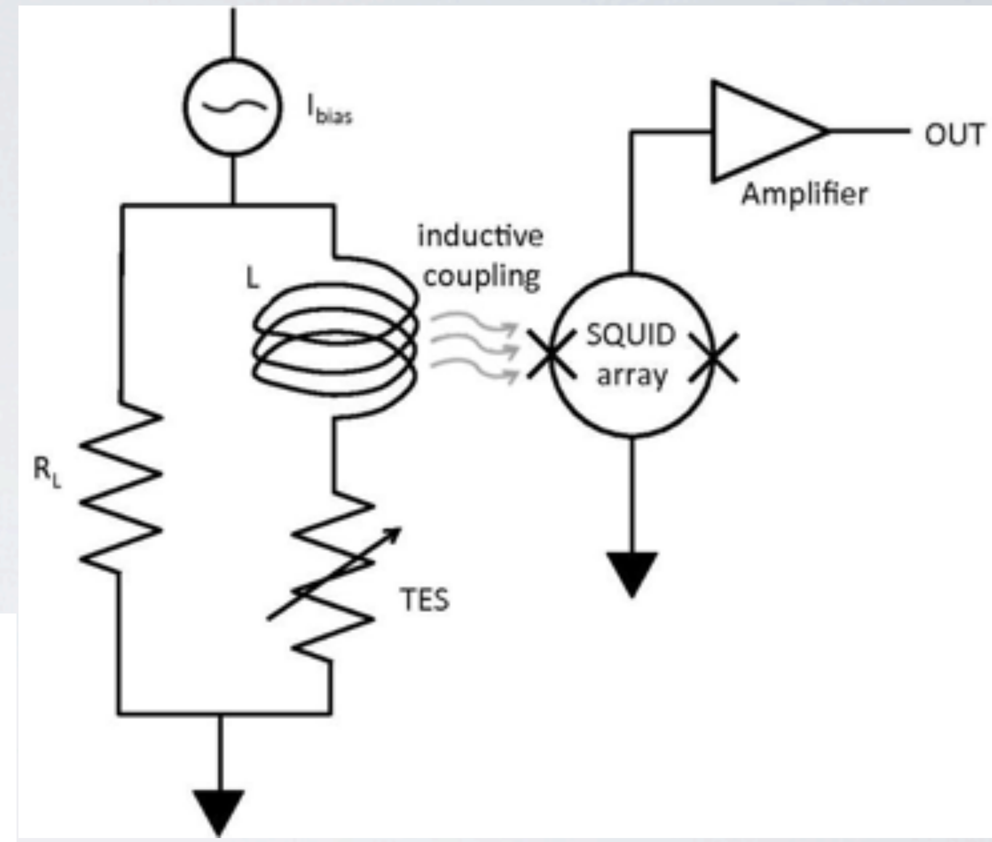


- The cut-off frequency is determined by the impedance

$$\frac{dI}{dV} = \frac{1}{Z} = \frac{1}{(R_L + R_{TES} + \omega L j)}$$

Cut-off frequency

- By setting a Vbias/Ibias (from FEB), we set the TES resistance in the circuit



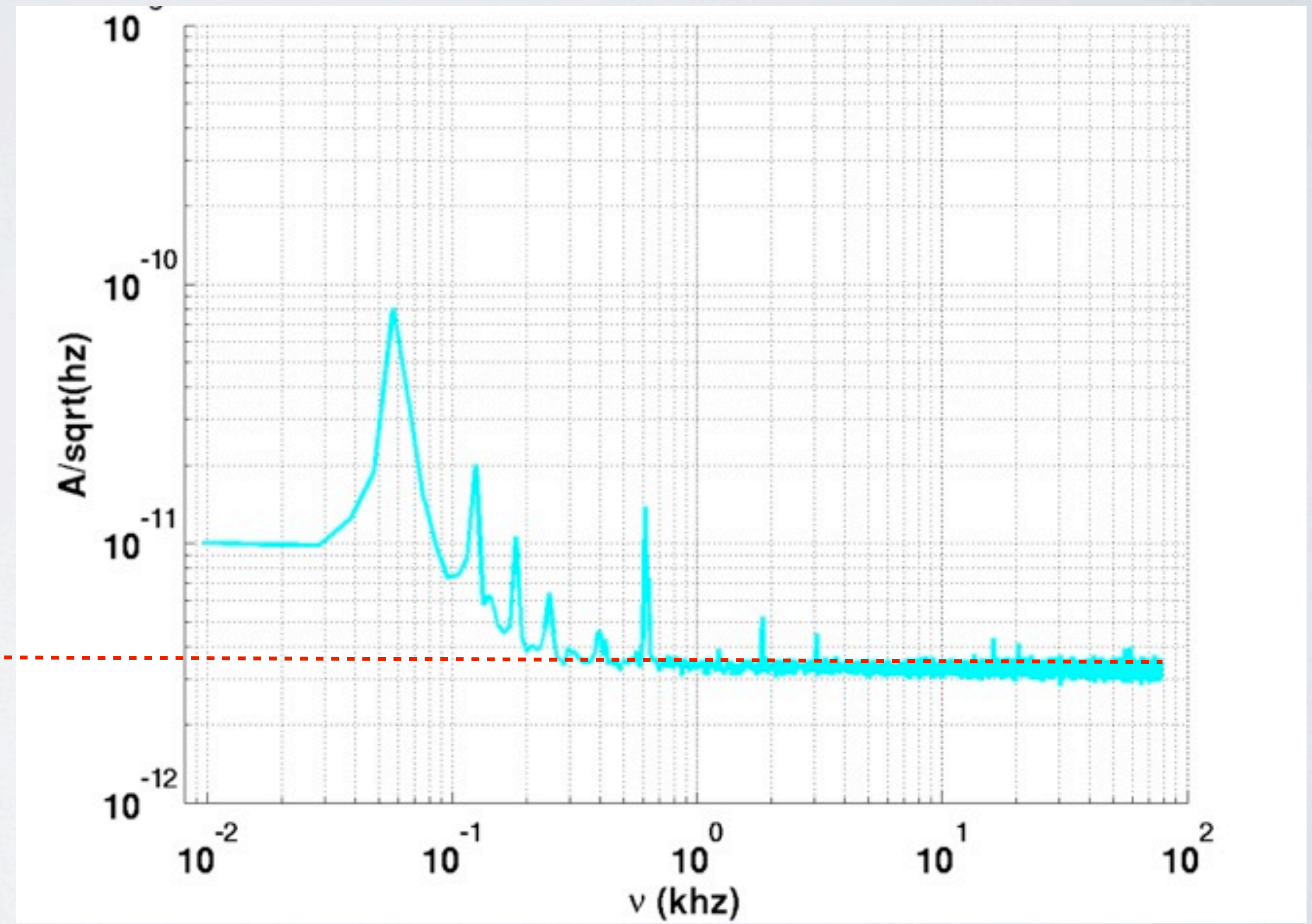
R and T values of the Circuit

Element	Resistance	Temperature
R_L	34 mΩ	1.2 K
R_{TES}	(0 or 600) m Ω	80 mK

B. NORMAL CONDUCTING DATA

- This plot shows what the readout looks like when we are insensitive to phonons

- No big slope at low frequency
- Spikes still exist
- Lower baseline, but that's expected because there is more resistance
- No cut-off here because its off scale.



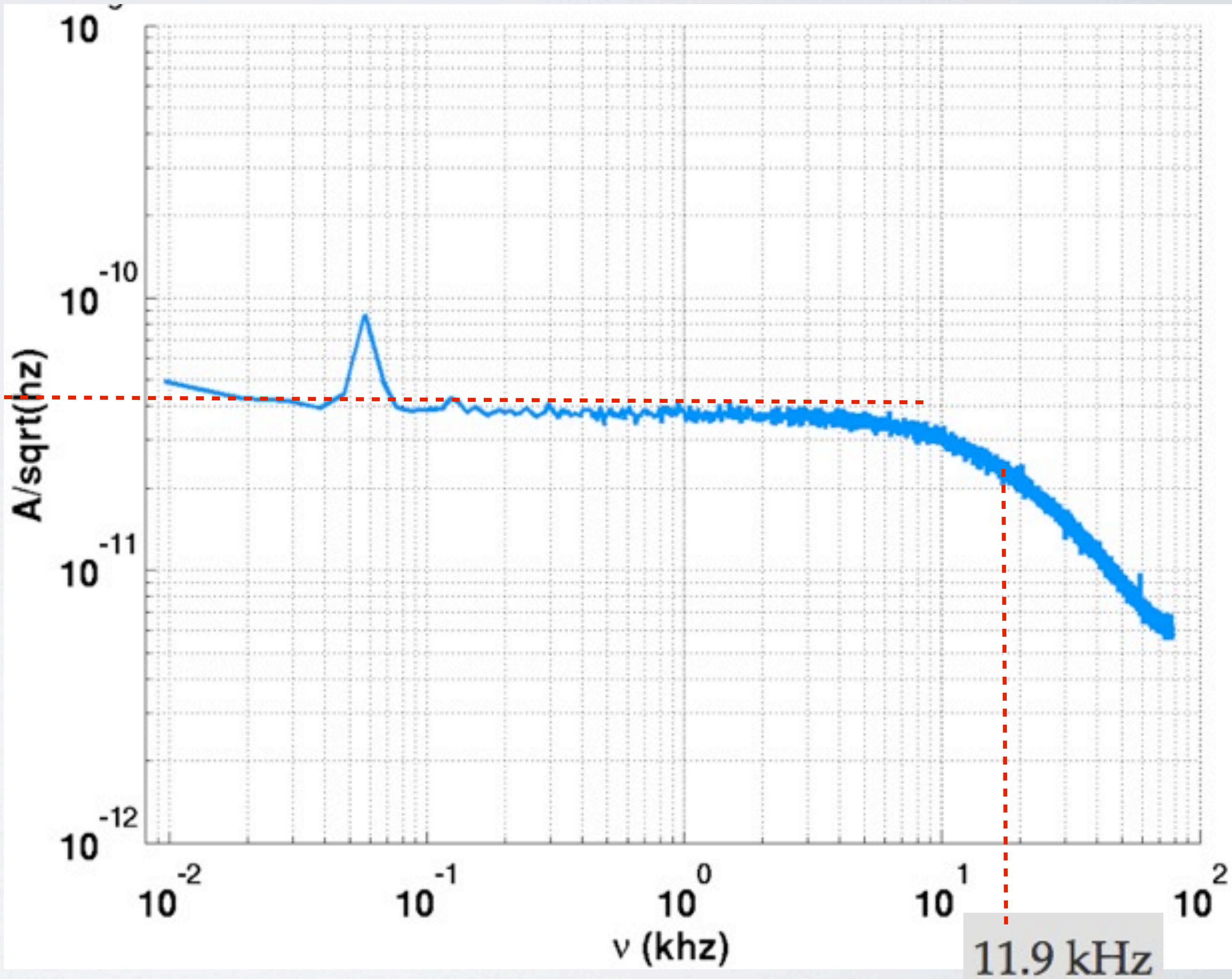
Amplitude Baseline From J-Noise: 3.63 pA / √Hz

Cut-off frequency from Impedance: 250 kHz (Out of range)

C. SUPERCONDUCTING DATA

- This plot shows what the readout looks like when we are insensitive to phonons, but the amplification on the TES/SQUID circuit is maximum

- Smaller TES resistance gives greater baseline noise
- Spikes are swamped but if spikes persist they are other electronics or (if scaled accordingly) Vbias/Inductive noise
- 55-60 Hz electronics noise (Mains Hum)
- Lower threshold Cut-off as expected



Amplitude Baseline From J-Noise: $44\ \mathrm{pA}/\sqrt{\mathrm{Hz}}$

11.9 kHz

Cut-off frequency from Impedance

JOHNSON NOISE AND PARASITIC RESISTANCE

$$S_I^2 = \frac{4\, k_\beta\, (\Sigma R_i T_i)}{(\Sigma R_i)^2}$$

$$S_{II} = \frac{\sim 1\ \text{pA}}{\sqrt{\text{Hz}}}$$

NC: $G_T \approx 3.63\ \text{pA}/\sqrt{\text{Hz}}$.

SC: $G_T \approx 44\ \text{pA}/\sqrt{\text{Hz}}$.

- Johnson Current
- Parasitic Resistance (Average)
-

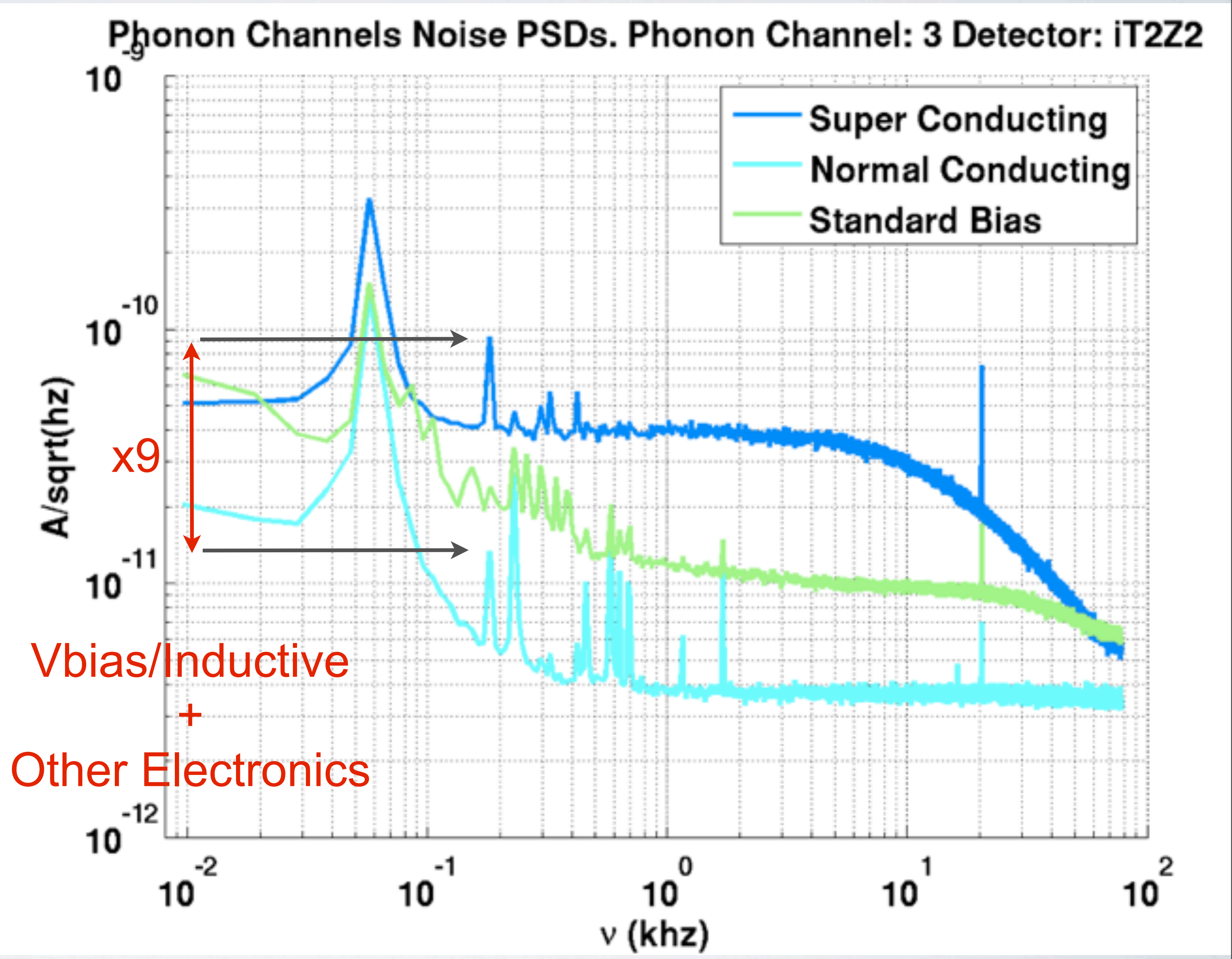
Element	Resistance	Temperature
R_L	34 mΩ	1.2 K
R_{TES}	(0 or 600) m Ω	80 mK

Element	Resistance	Temperature
R_{shunt}	20 mΩ	1.1 K
$R_{Al\ wire\ bonds}$	2 × 4 mΩ	1.1 K
$R_{pins(a)}$	2 × 1 mΩ	4 K
$R_{pins(b)}$	2 × 1 mΩ	1.1 K
$R_{pins(c)}$	2 × 1 mΩ	80 mK
R_L	**34 m Ω**	**1.2 mK**

Std/NC=230mΩ/630mΩ ~ 1/3 Std/SC=230mΩ/30mΩ ~ 7

4TH EXAMPLE: BORDERLINE V_{BIAS}/ INDUCTIVE PEAKS

- Vbias/Inductive noise can combine with Other Electronics noise
- Don't see a perfect ratio, the downstream electronics noise adds, but it is clearly not a phonon noise (because it is not dominant in Std)



WHAT WE KNOW ALREADY

- Low frequency vibrational noise pickup appears in all channels of same detector
- Same noise appears in two different electronics chains with same magnitude
- Other detectors in same tower present different vibrational coupling
- This disfavors:

~~2. Vbias Electronics: at the TES level, capacitive coupling affecting the voltage bias (Vbias)~~

~~4. Downstream Electronics: in the read-out, triggering, or filtering process~~

SUMMARY

- Mostly coupled by athermal phonons, or, for non-vibrating detectors through a vbias +downstream coupling mechanism.
  (Of course excluding the ~60Hz Mains Hum, which affects pretty much all detectors).
- The baseline noise (background) in the range < 600Hz (and possibly <500Hz) is phonon coupled, and affects noticeably 13 detectors in all working channels.
- The peaks in the range 100 - 1kHz are both phonon and electronically (vbias +downstream) coupled, a list of dominant mechanism per detector is provided, and few (4/15) detectors include signs of downstream electronics noise (only in some channels 17/28 channels in total).
- Now that we know that the predominant noise is athermal phonon coupled or Vbias +downstream coupled, we can try to make a covariance/correlation study of each phonon channel within the same detector. This can not only tell us effectively if the noise is detector correlated, but it can tell us which frequencies are preferrably correlated between channels, and ultimately it may provide ways of supressing some modes.

http://titus.stanford.edu/cdms_restricted/Soudan/R133/ebook/140707_jm/

REMARKS

- 100 - 1000 Hz peaks:
  - Most cases it is electronically coupled and phonon coupled
  - Some seem like fft harmonics of the 60Hz peak that keep the SC/Std and NC/Std factors, so it is electronically (Vbias) coupled
  - In other cases the noise turns on when the detector is in the transitioning phase, which means there is also a phonon coupling
  - Also, in fewer cases some downstream electronics peaks appear (keeping the 1-to-1 ratio)

- A lot of the noise disappears in the Super Conducting mode, the persisting peaks should be electronically coupled, although only the stronger ones persist, and whenever SC/NC show a factor close to 21 the noise is electronics (Vbias/Inductively) related

- For phonon dominated detectors, since the noise peaks seem to be detector related, not FEB/squet/dib related, this helps to discard the downstream electronics and Vbias coupled electronics, although some exceptions occur in the 60Hz peak

REMARKS

- <60Hz: phonon coupled: most detectors show relatively flat SC and NC PSDs in this range, while the Std shows an intense background (detailed count in the following section)

- Homogenously decreasing background from 10 - 1kHz: again, seems to be a tail from the <60Hz region

- 60Hz peak:
  -Electronically coupled possibly the common 'Mains Hum' affecting all electronics, both downstream electronics and detector electronics
  - In some cases it is also downstream because the peaks are 1-to-1
  - But in other cases it seems like the noise couples inductively (i.e. SC/Std is close to a factor of 7, and NC/Std close to 1/3)

- 100 - 1000 Hz peaks: complicated but most important region

- 2kHz: inductively/vbias coupled (doesn't appear in all detectors/channels)