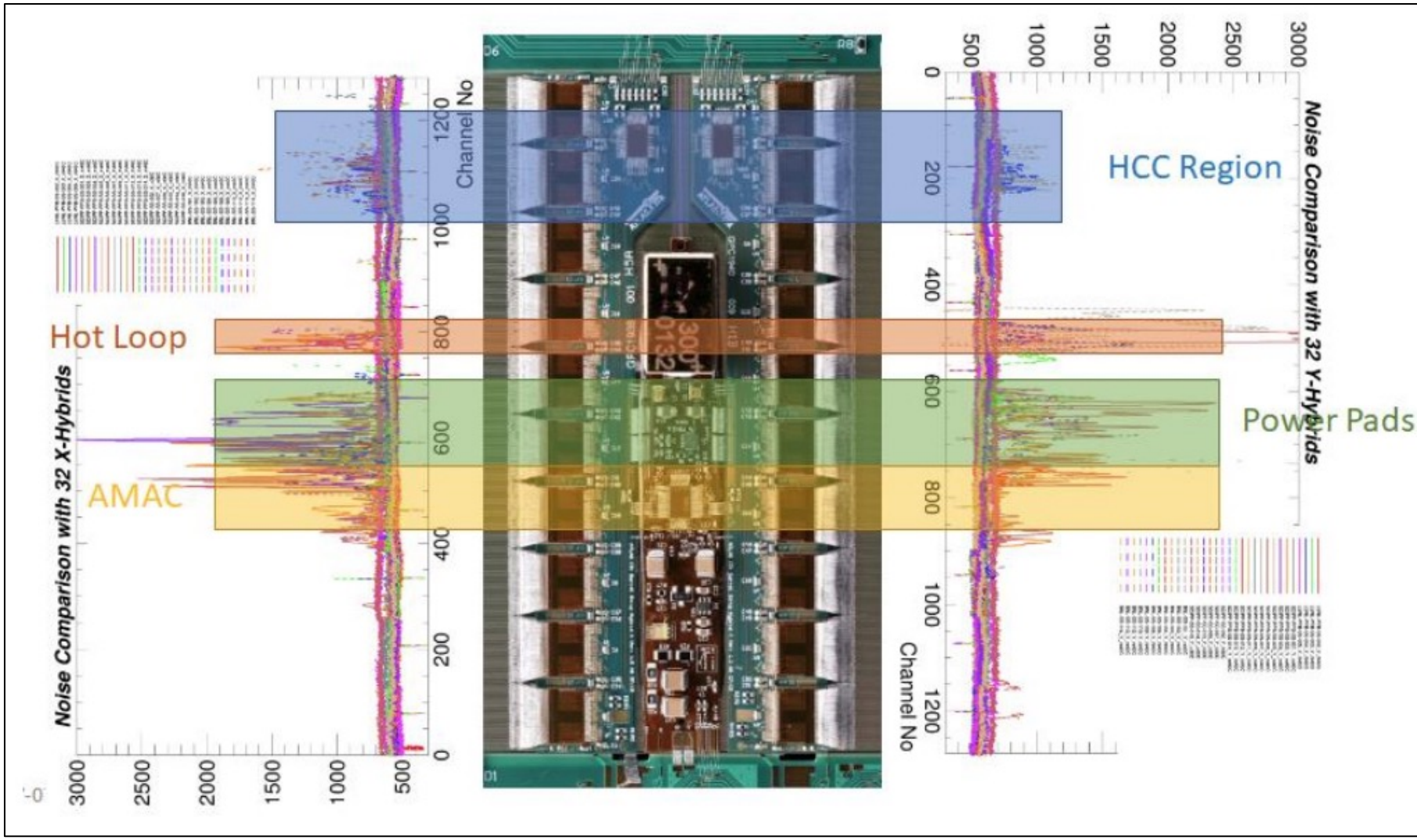
ITk Strip Module Cold Noise

Ian Dyckes

On behalf of the LBNL ITk Strip Modules Team

Outline

- Intro to ITk strip module.
- Threshold scans and noise.
- Cold noise.
  - General observations.
  - Some interesting tests.
  - What's next.



ITk Strip Barrel Module

Silicon sensor:

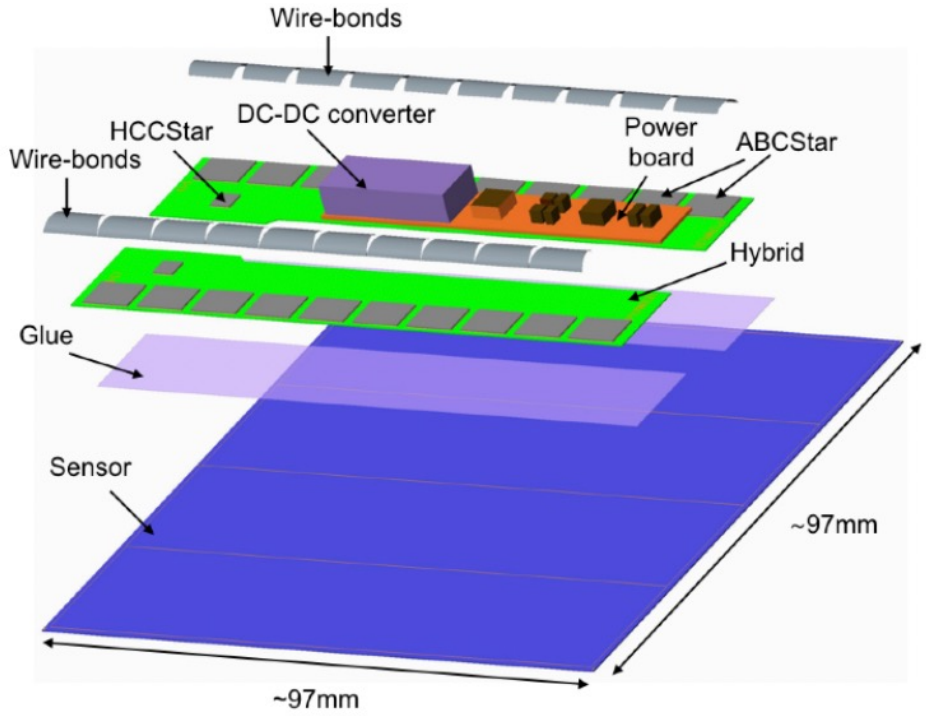
- Multiple rows of 1280 strips with a $75\ \mu m$ pitch.
  - Long-strip sensor → 2 rows, strip length ≈ 5 cm.
  - Short-strip sensor → 4 rows, strip length ≈ 2.5 cm.

Hybrid:

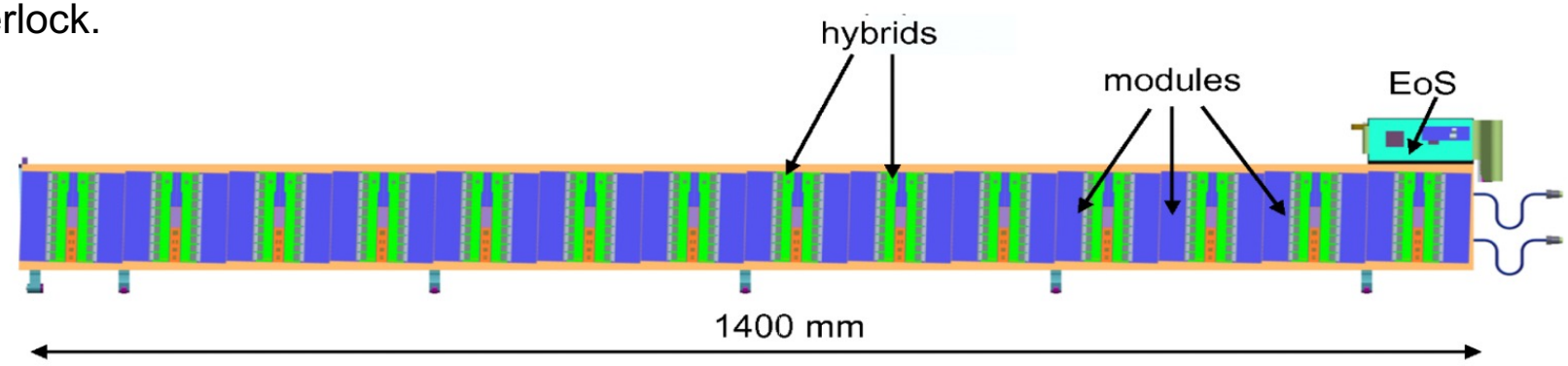
- Printed circuit board holding the read-out ASICs.
  - 10 ABCs: amplify and discriminate signal.
  - 1 HCC: interface between ABCs and back-end electronics.

Powerboard:

- LV step-down for ASICs and HV-switching for sensor biasing.
- Monitoring and interlock.



Short-strip module



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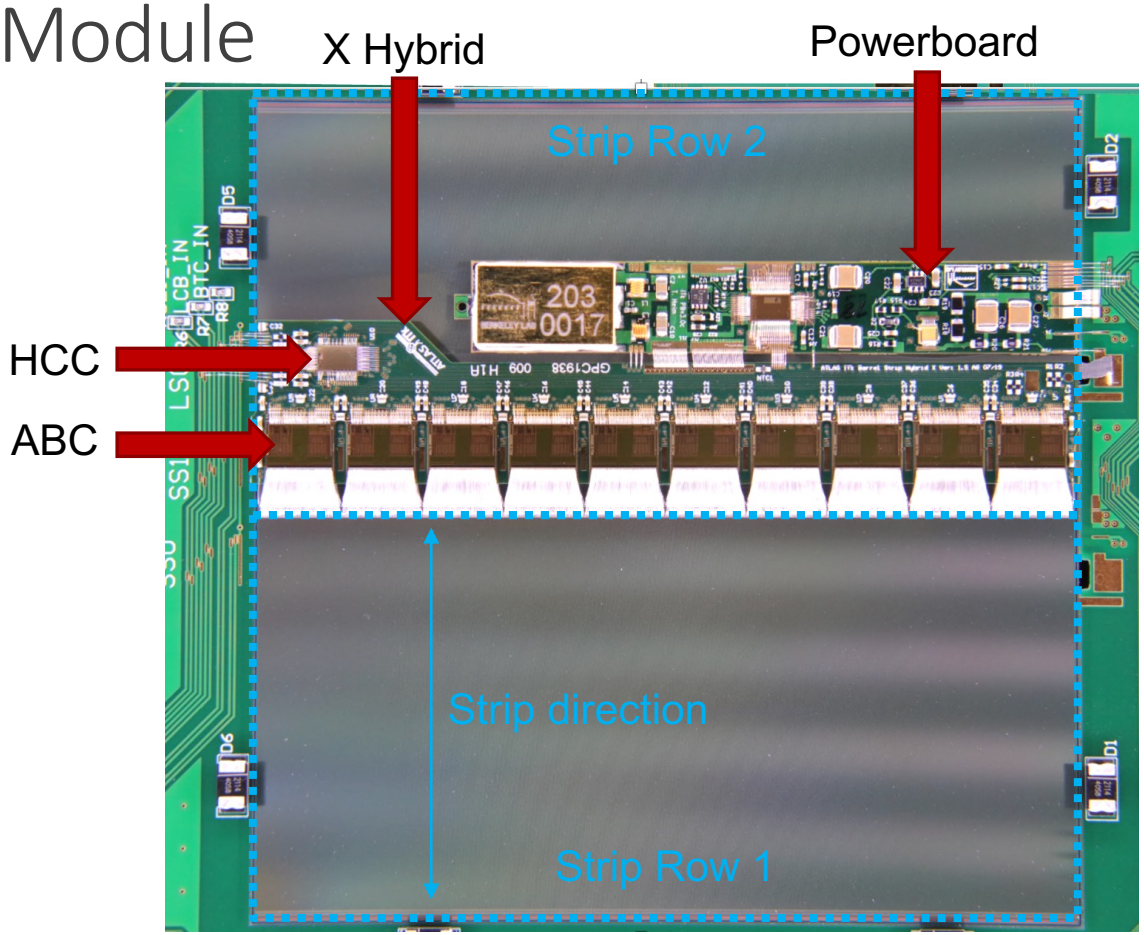
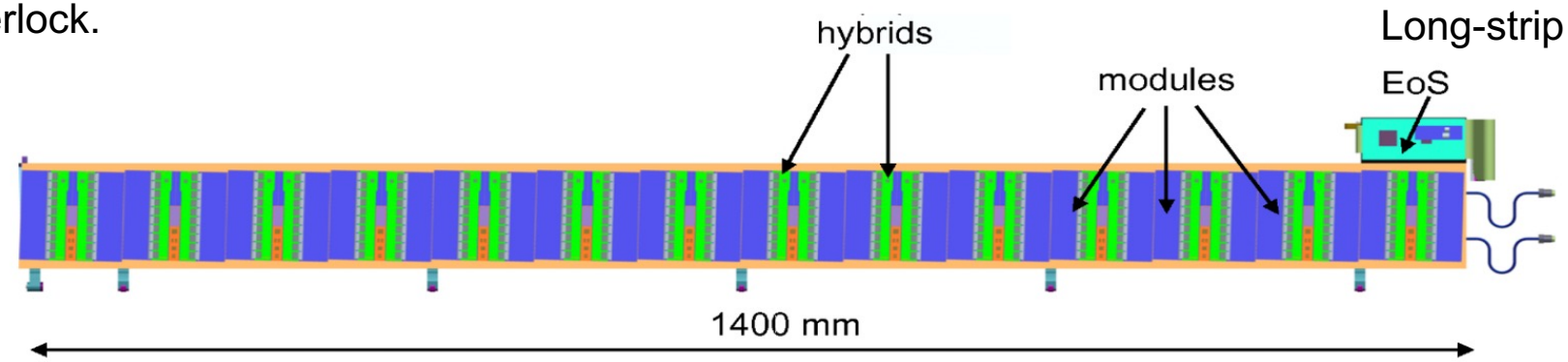


Long-strip module



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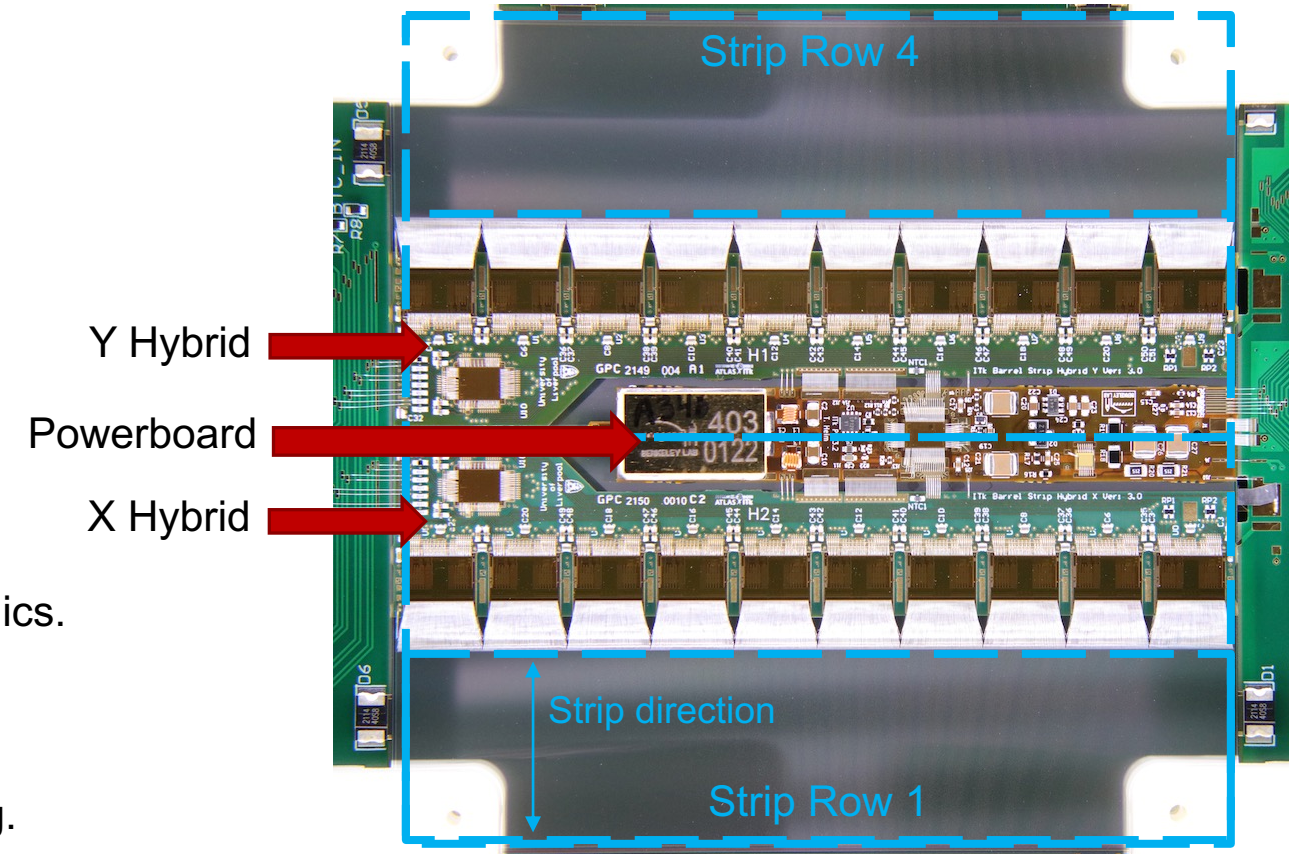
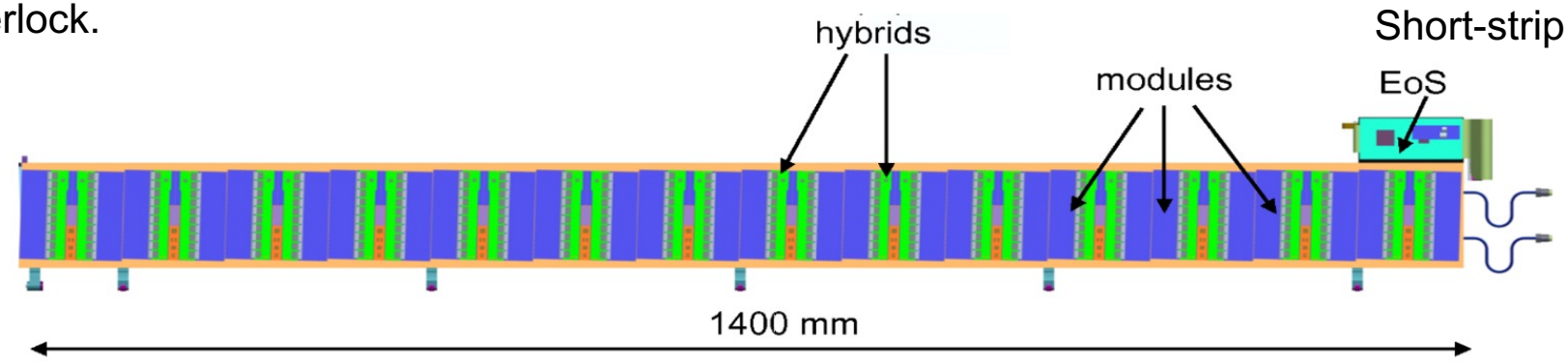


Short-strip module

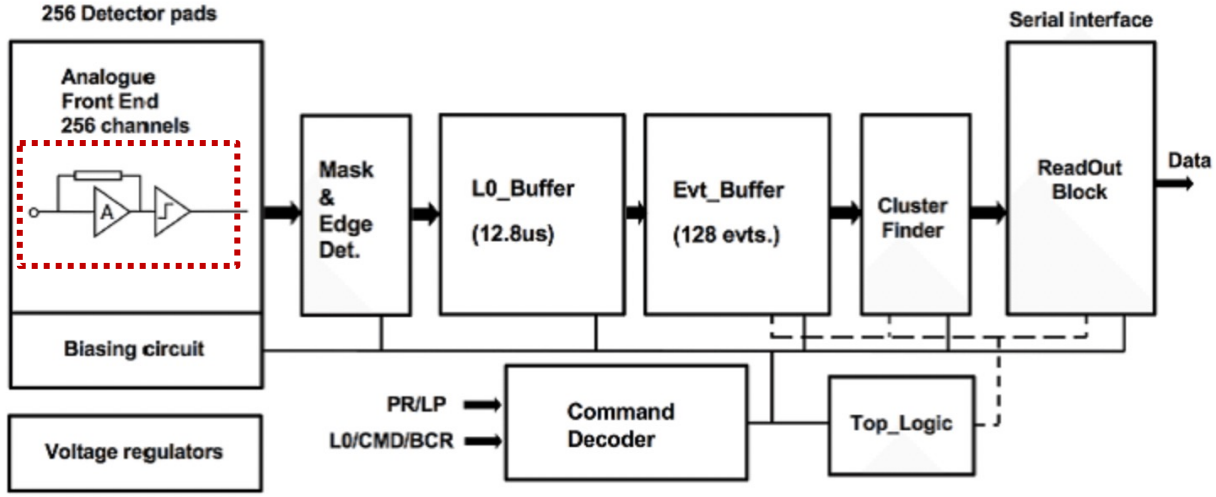


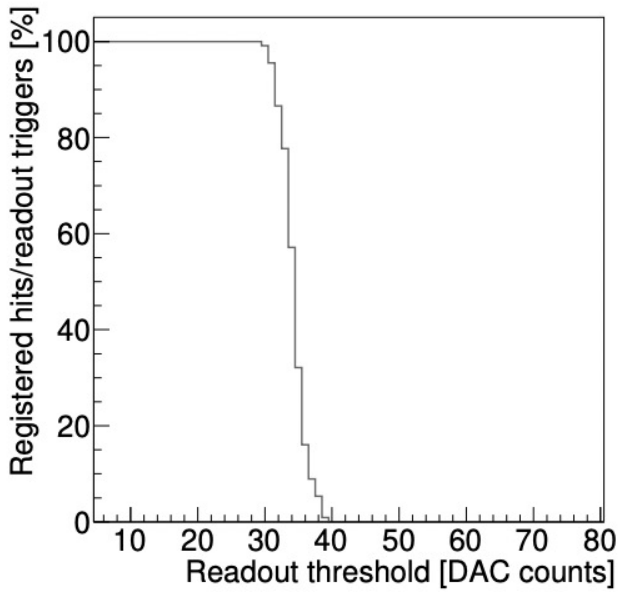
Threshold Scans, S-Curves, vt50 & Noise

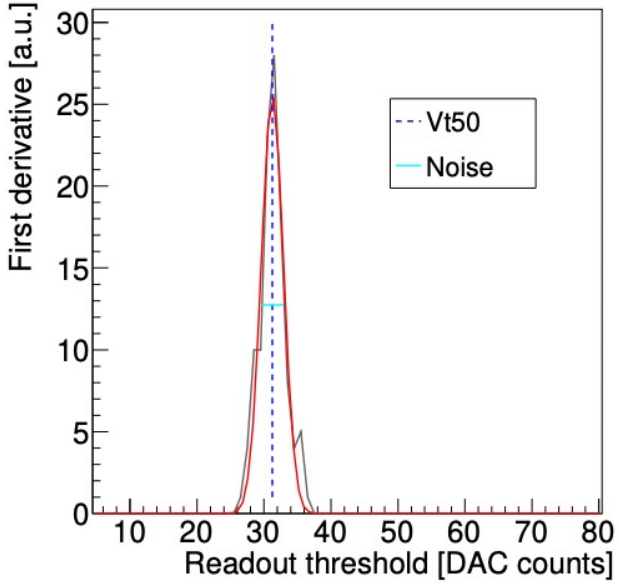
Front-end basics:
- ABCs amplify, shape, and discriminate signal from strips.
- Discriminator threshold can be tuned.
  - Balancing signal efficiency vs. noise.

S-curves:
- Scan over threshold, triggering N times at each step.
  - With or without charge injection.

- Occupancy vs. threshold → S-curve (error function)
  - Derivative is a gaussian.
    - Mean → vt50.
    - Width → output noise.



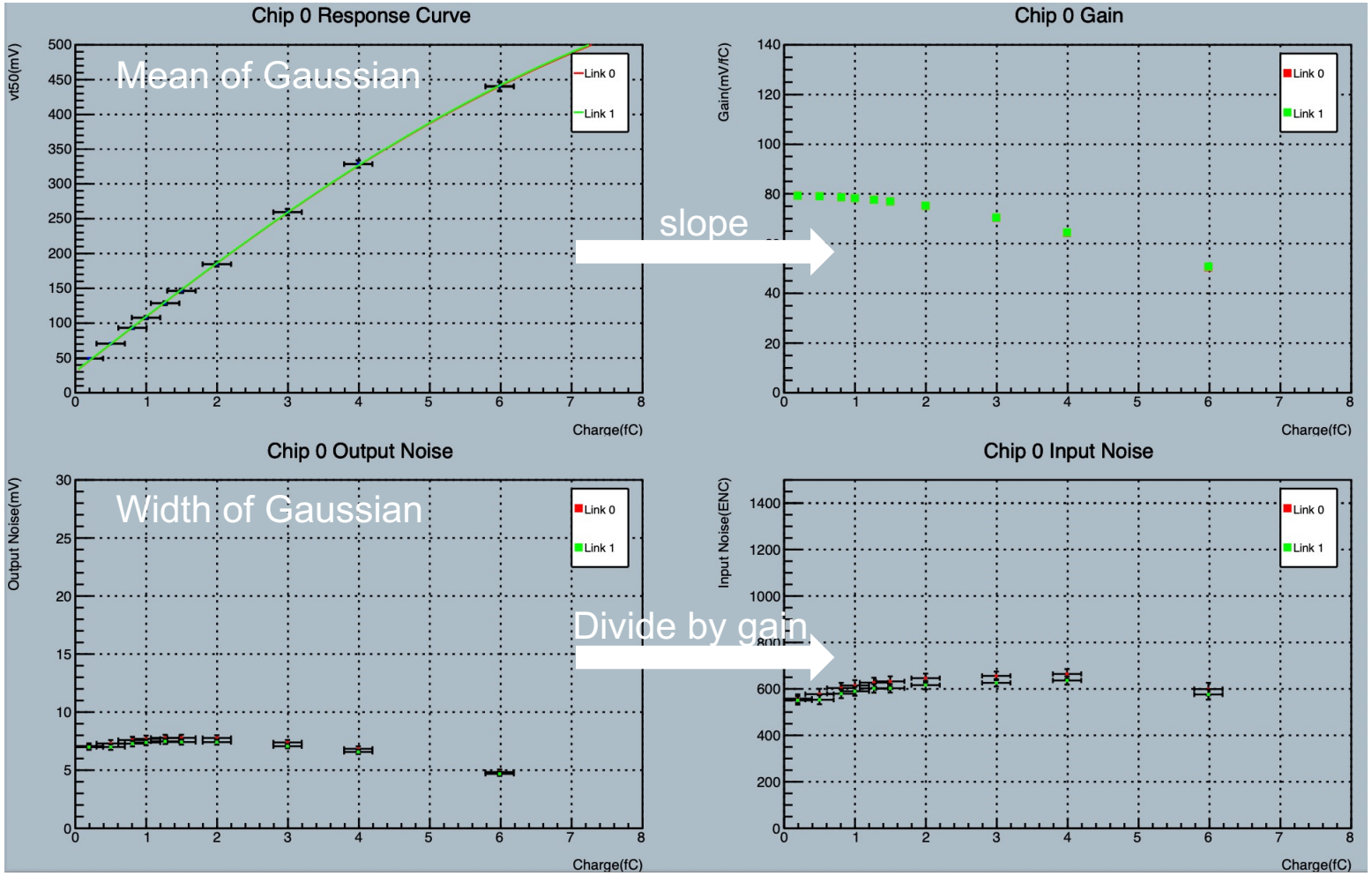




Response Curve

Response Curve:

- Perform threshold scans while varying injected charge.
- For each charge injection, get s-curve.
  - Mean → vt50.
  - Width → output noise.
- Plot vt50 vs. injected charge → response curve.
- Slope of RC → gain.
- Input noise = output noise / gain.



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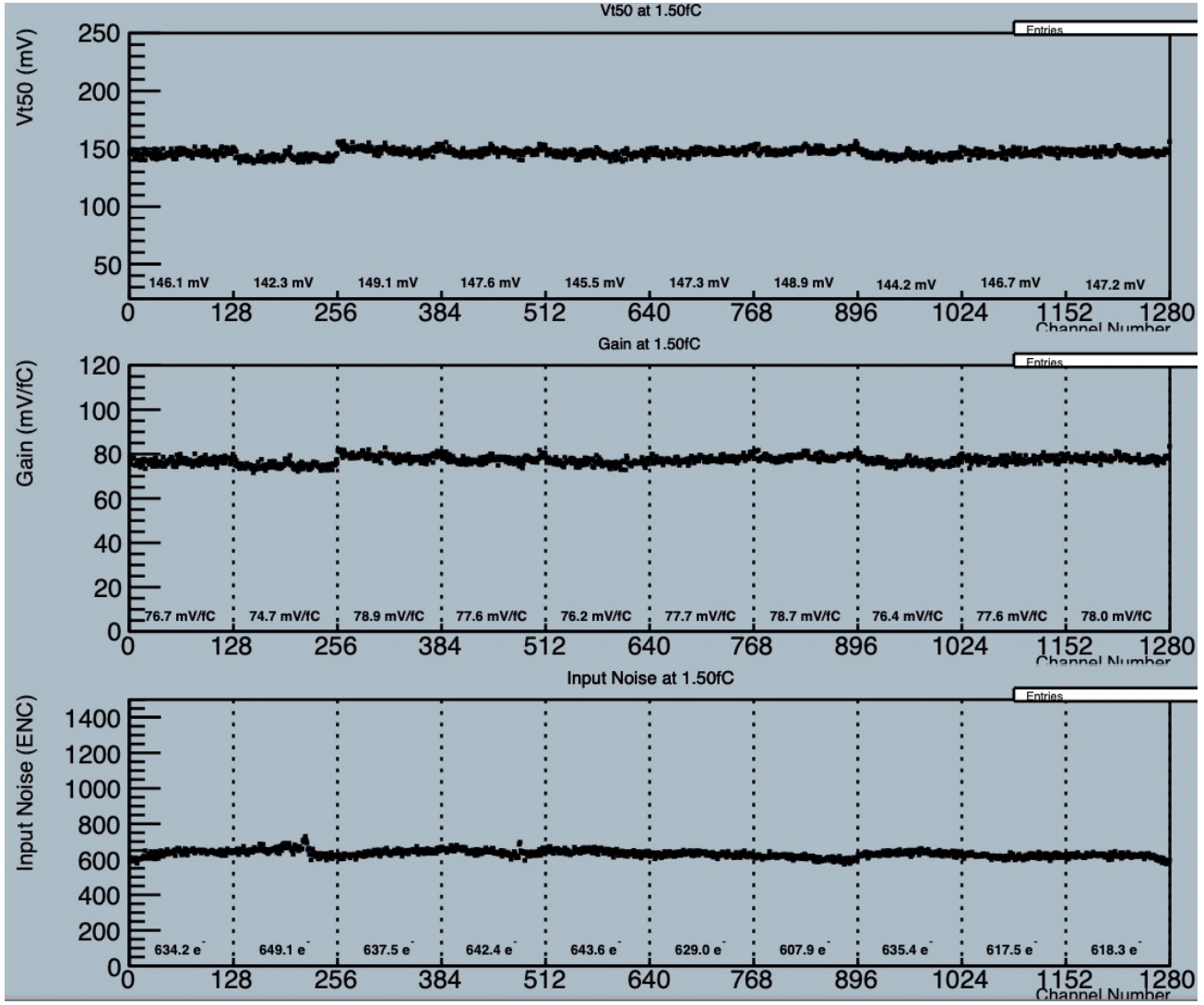
Results for 1 row of strips



Cold Noise Intro

Background:

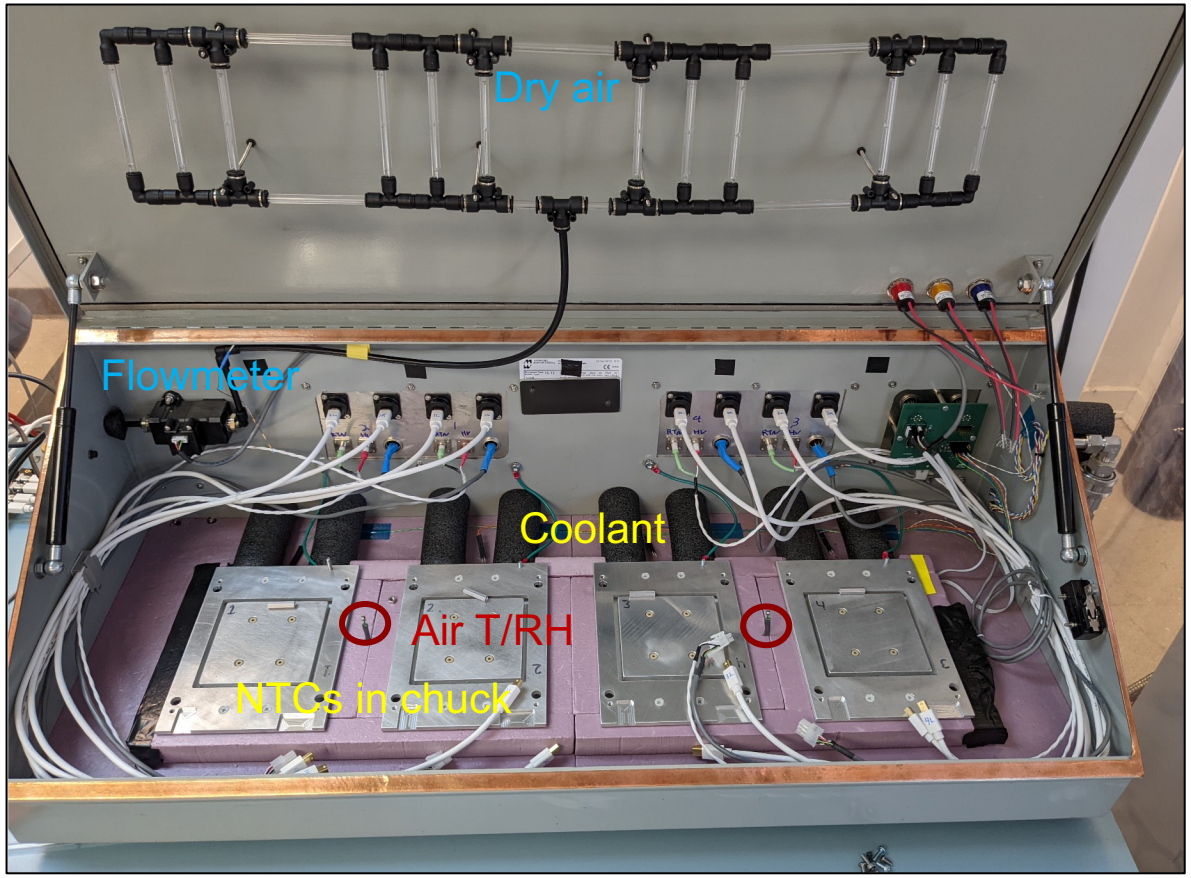
- BNL has been thermal cycling modules before gluing them to staves.

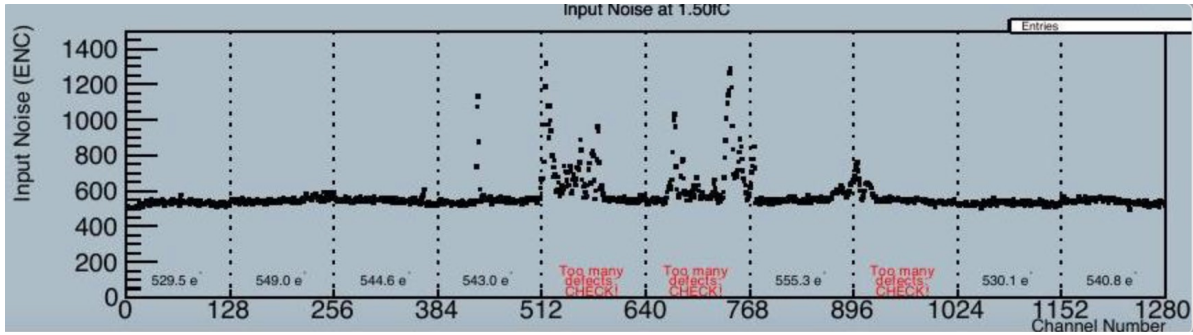
- Earlier this year, BNL noticed noise appearing when testing pre-production modules at cold temperatures.
  - Was not clear if there was something wrong with their setup.
  - But seen in modules from BNL, SCIPP, and LBNL.

- Eventually confirmed by other sites in their cold boxes.
  - Also observed on the stave.

- Eventually decided to pause pre-production to investigate.

- Cause not yet understood.





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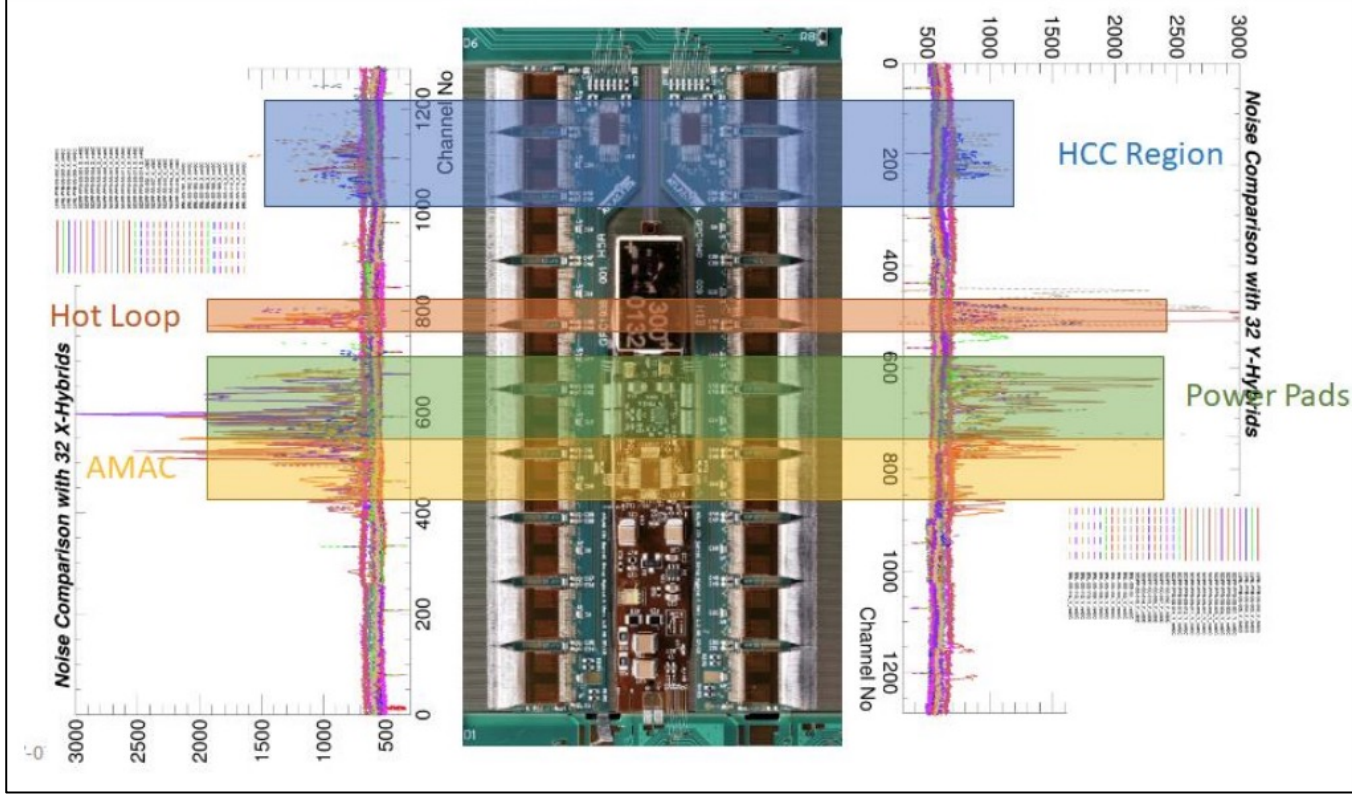


Observations:

- Always in the strip rows under the hybrids & PB.

- Tends to appear in certain regions.
  - Power pads between hybrids and PB.
  - DCDC converter.
  - HCC.

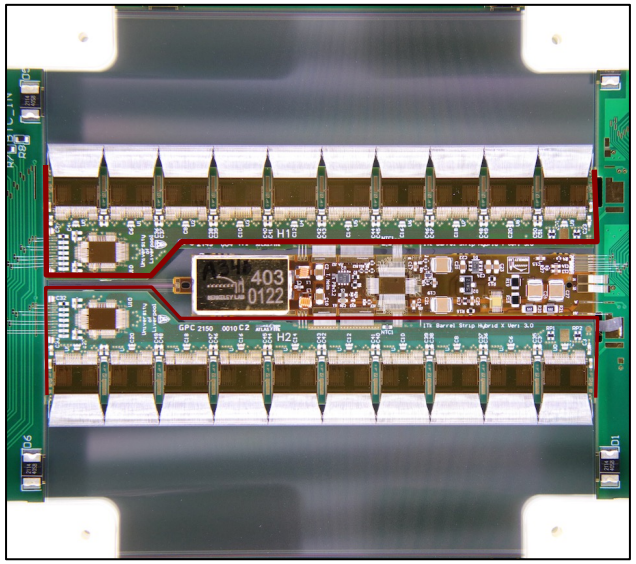
- Some variation between thermal cycles:
  - Turn-on temperature changes after 1st cycle.
  - Same region gets cold noise each cycle.
    - But worst strips move around.

- Worse on short-strip modules than long-strip.
  - But seen on LS if cold enough or if increase load on PB via shunts.

- *Usually* worse on X hybrids than Y hybrids.
  - Backend edges slope down towards sensor, worse on X. Related?

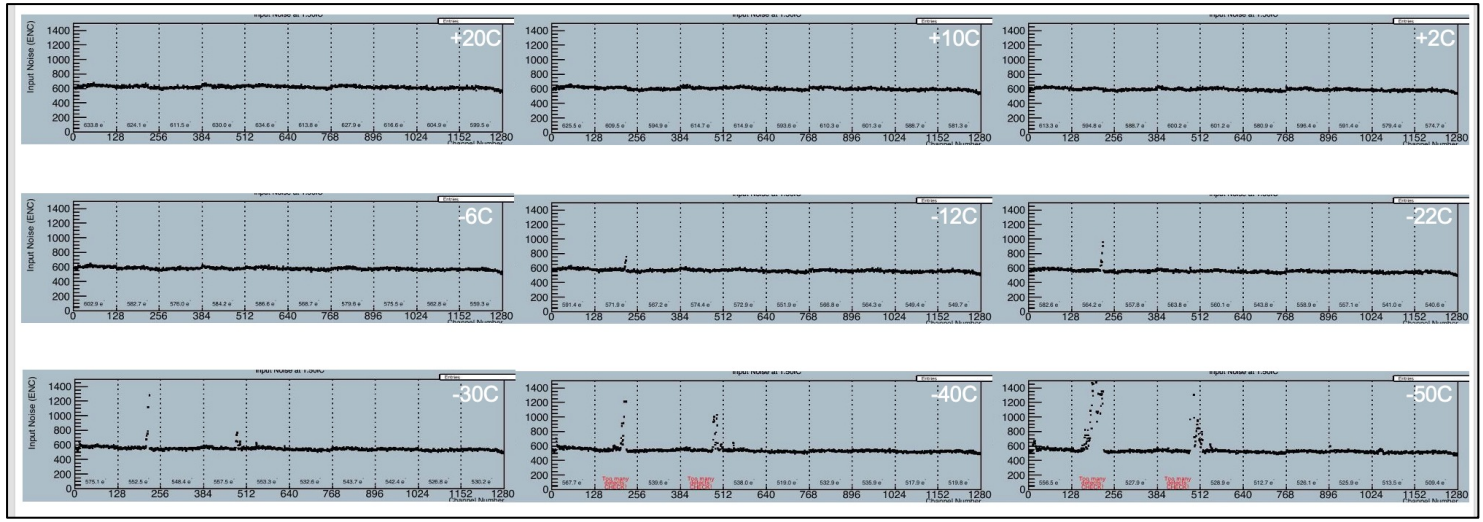
- *Usually* goes away at room temperature.

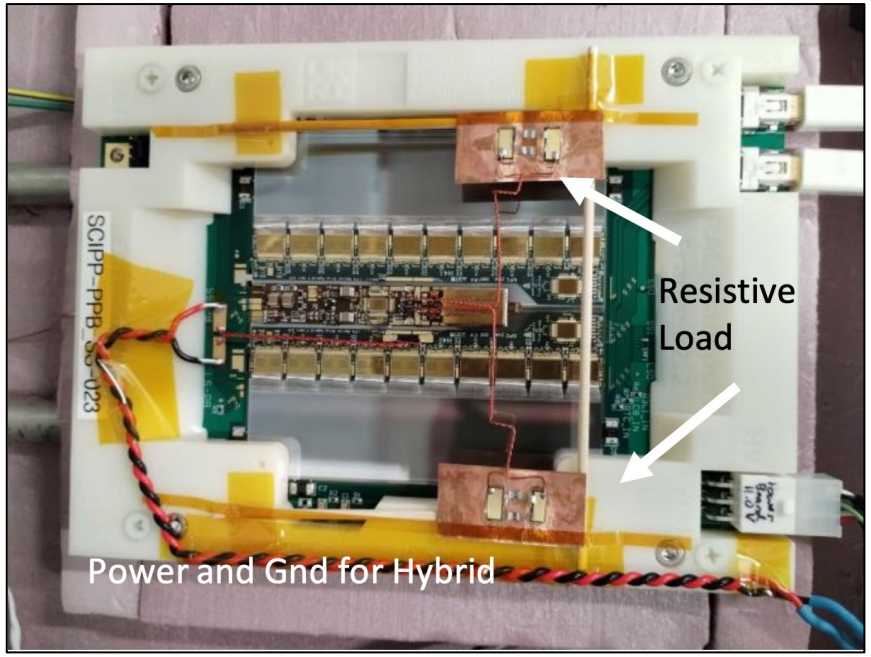
- Seen on pre-production modules (A & B), but not prototype.
  - A & B are similar, but many changes since prototype.

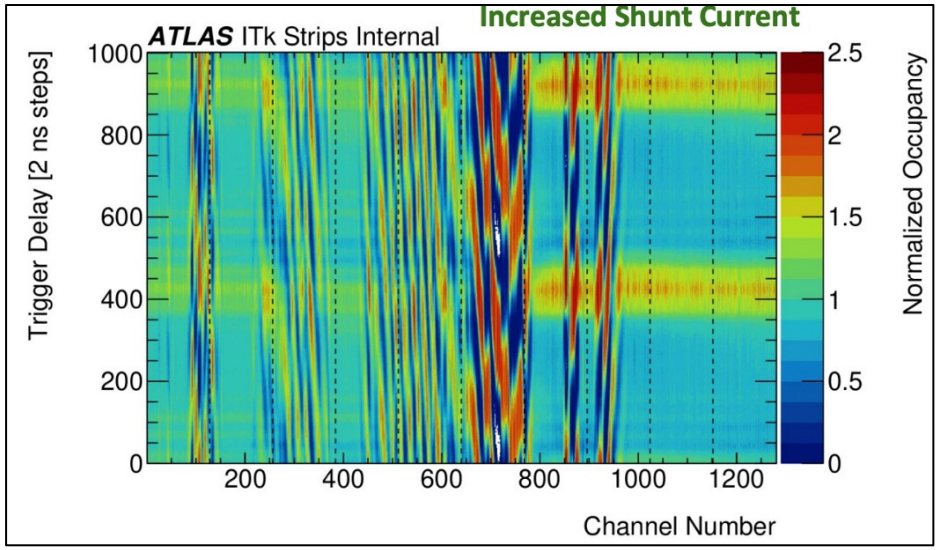


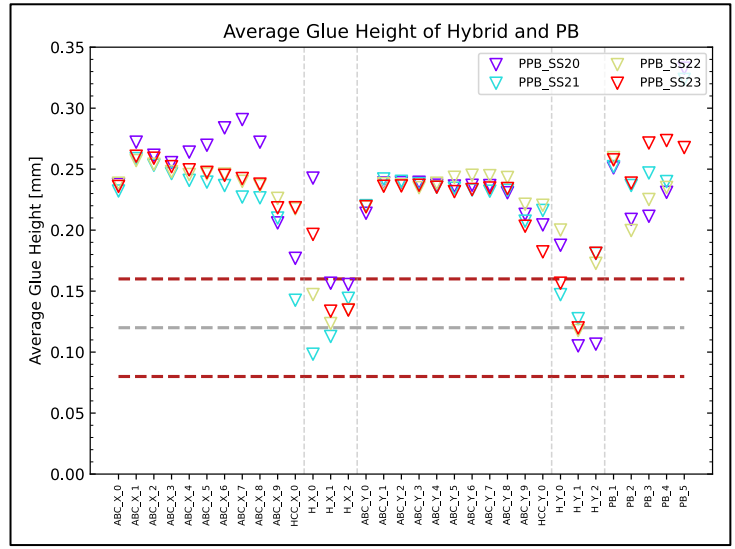
Interesting Tests

1. Repeatability/progression & turn-on.
2. Bypassing the PB for hybrid power.
3. Magnetic triggering.
4. Mitigation: increasing hybrid & PB glue heights.









Repeatability & Turn-On (LBNL)

Outline & General Observations

Process:

- Performed multiple careful thermal cycles on 4 PPB SS modules.
  - 10C steps from +20C to -40C.
  - Measured noise at each step (down-cycle & up-cycle).

General Observations:

- Cold noise seen on both hybrids on all 4 modules.

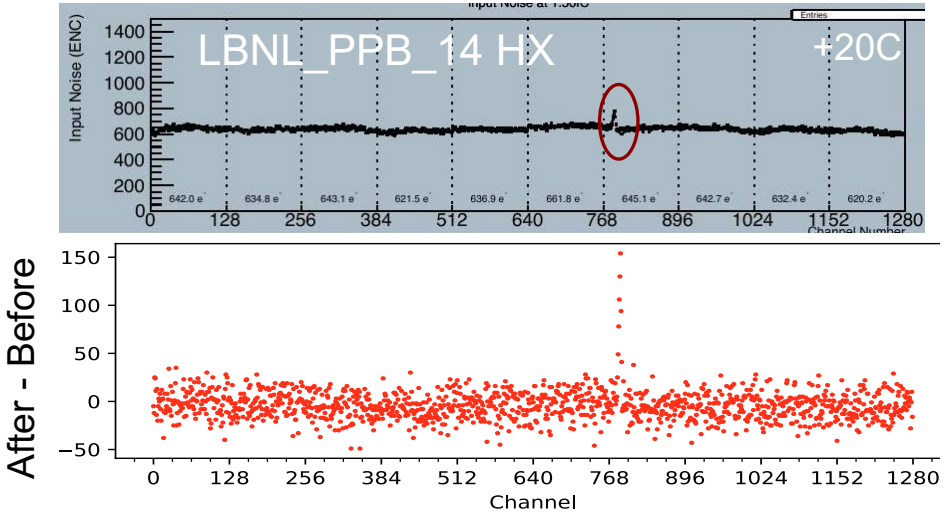
- Usually worse after 1st down-cycle
  - 1st down-cycle has less noise than 1st up-cycle, 2nd down-cycle, etc.

- Cold noise progression shifting towards warmer temperatures.
  - Can even persist all the way back up to +20C!
  - Cause is not purely electrical (e.g. bPol switching freq. vs. temp).

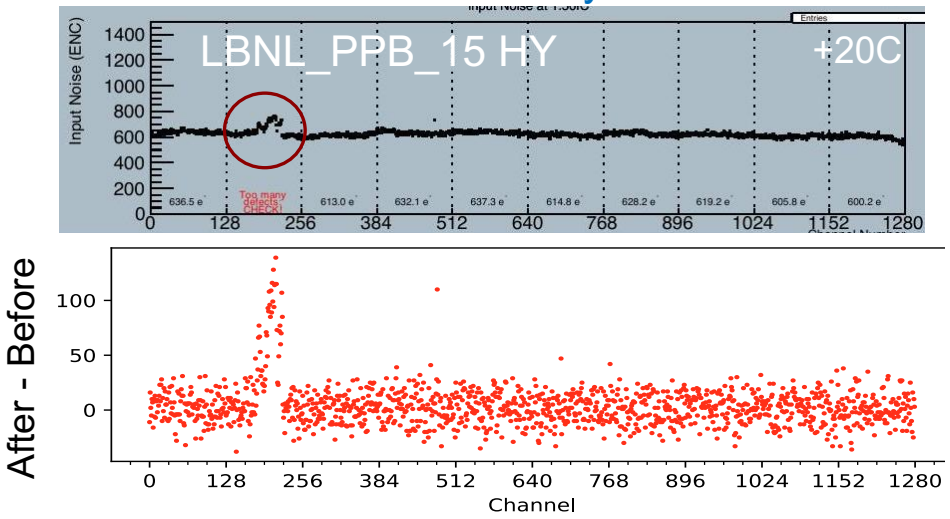
- Appears that noise ”freezes in”.
  - But can be “baked-out”.

- Will now show details of worst hybrid.

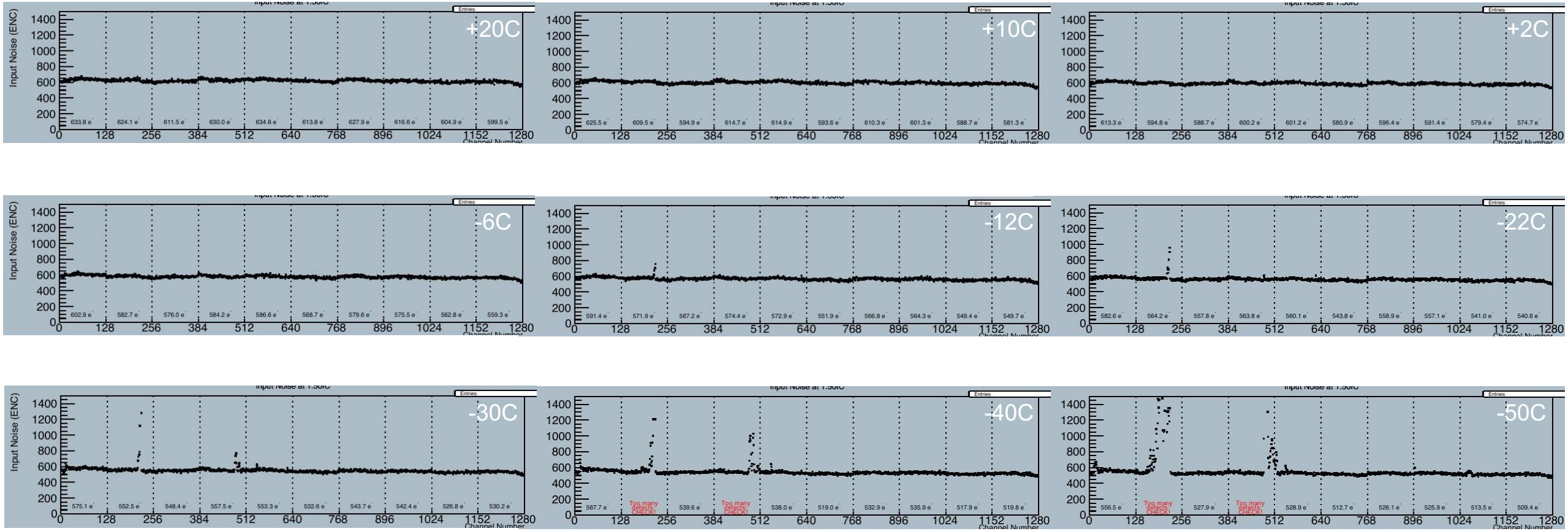
“Cold” noise after 1st cycle at +20C



“Cold” noise after 1st cycle at +20C

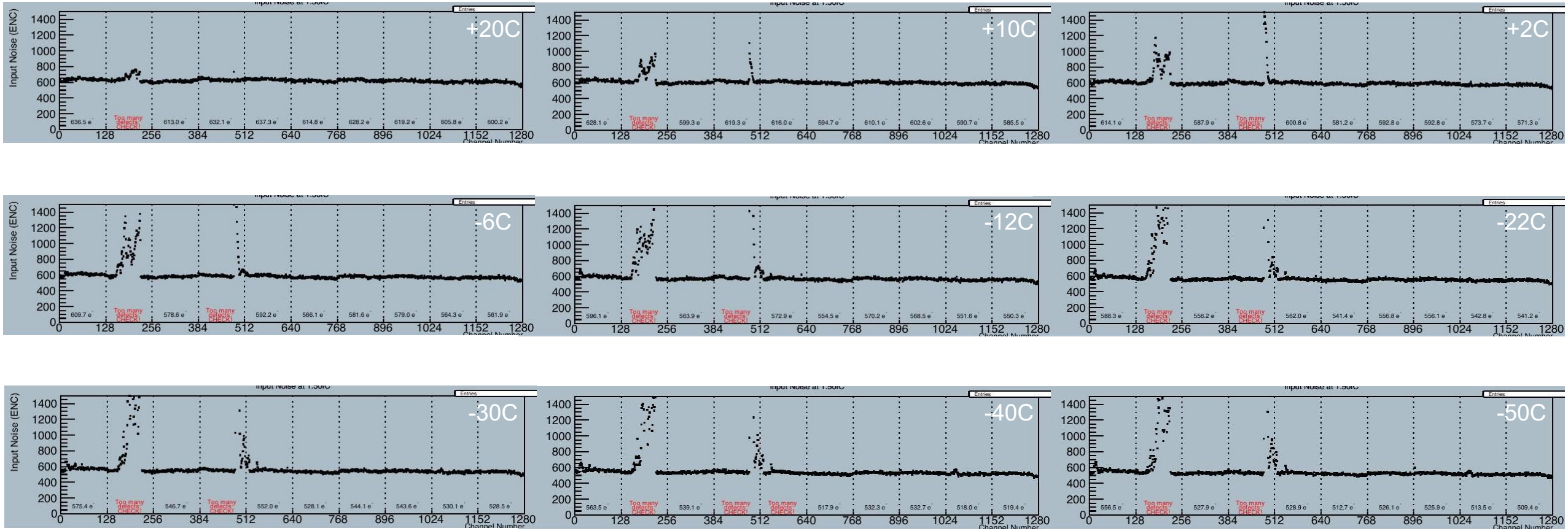


LBNL_PPB_SS_15 HY: Cycle 1 Down



- Cold noise starts around chuck = -12C.

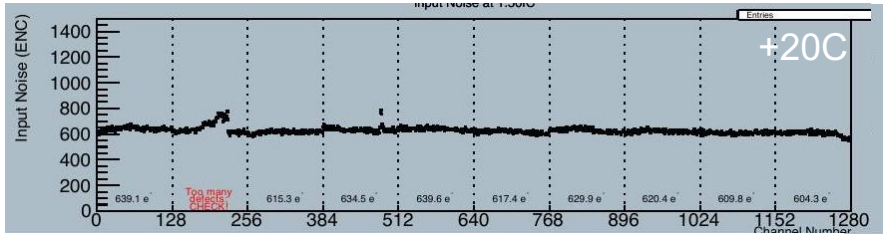
LBNL_PPB_SS_15 HY: Cycle 1 Up

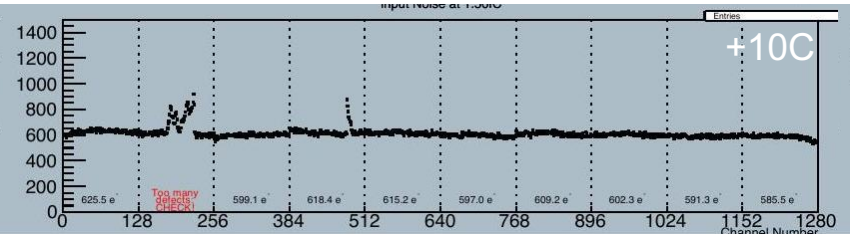


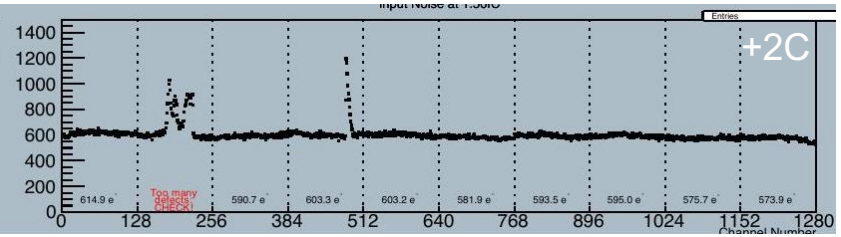
- Cold noise “freezes-in” & persists all the way back up to chuck = +20C!

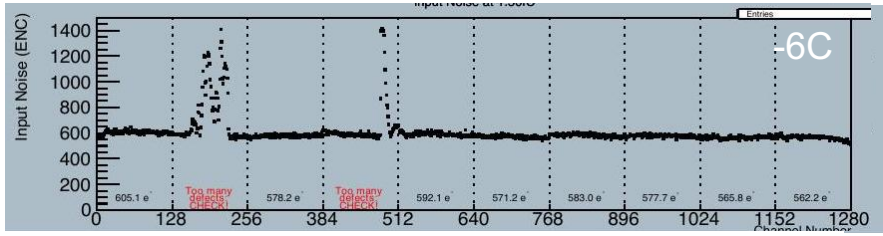
- Left modules unpowered overnight in cold box.
  - Noise still there the next day at 20C.
  - Also still present after opening and closing cold box lid.

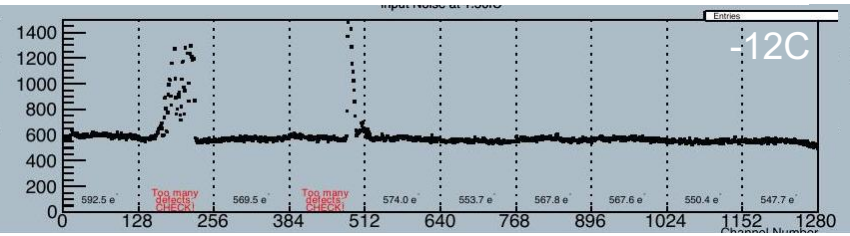
LBNL_PPB_SS_15 HY: Cycle 2 Down

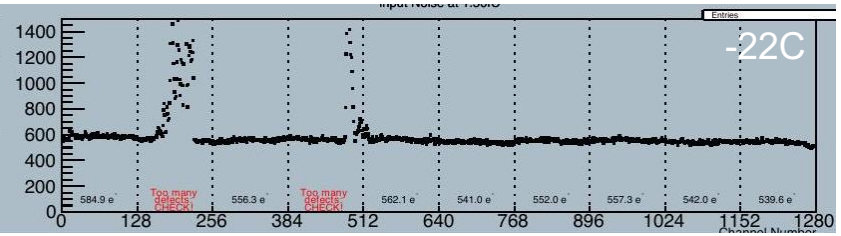


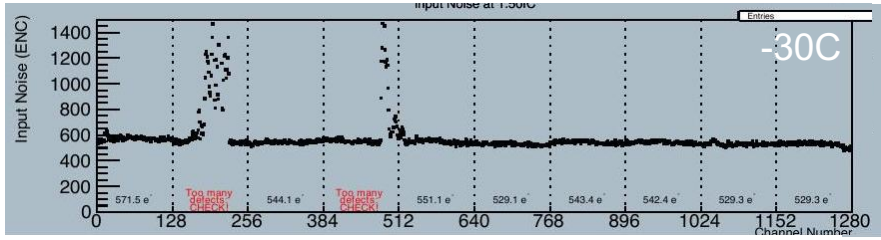


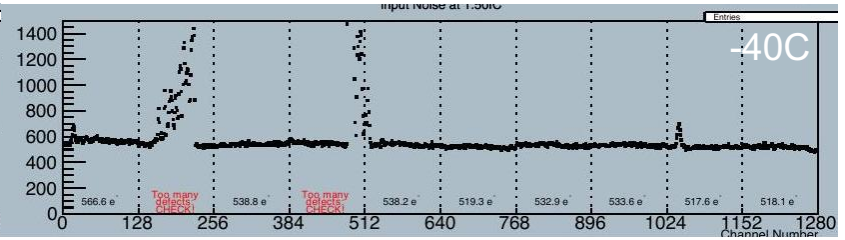








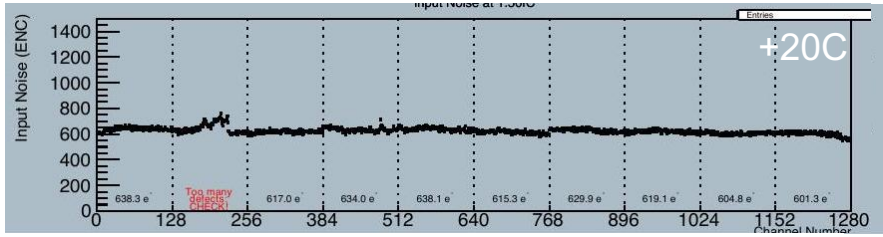


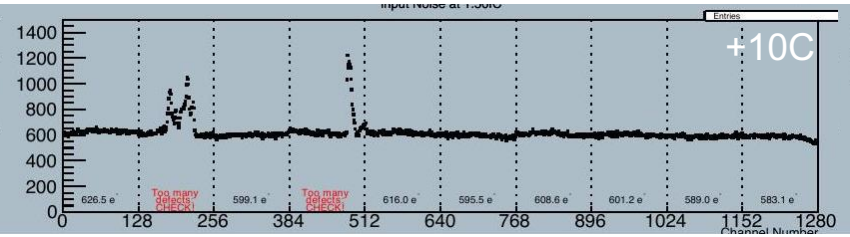


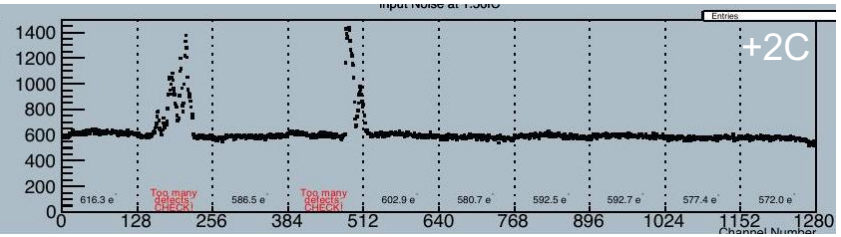
- Stopped here after target temperature discussion.

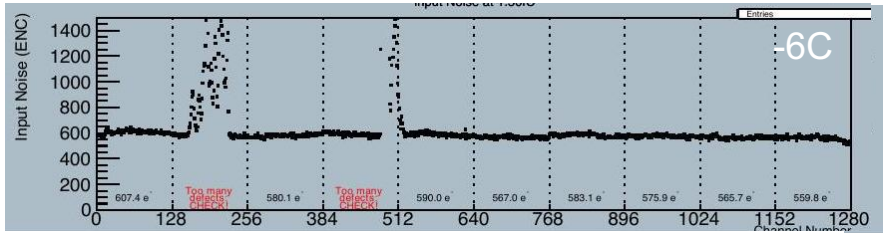
- Cold noise still present at +20C, 2 days after 1st cycle.

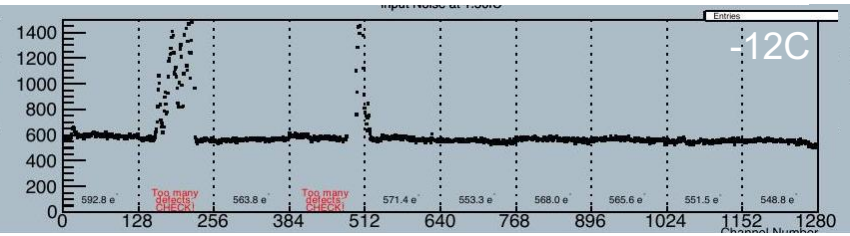
LBNL_PPB_SS_15 HY: Cycle 2 Up

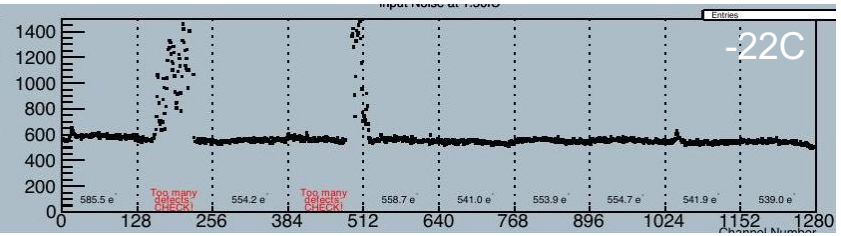


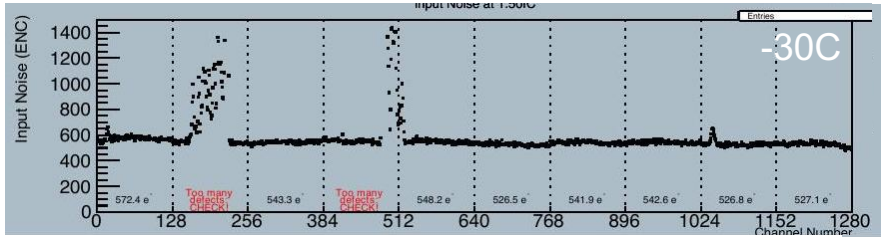


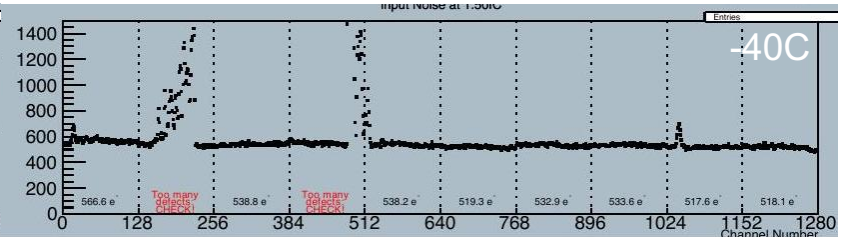










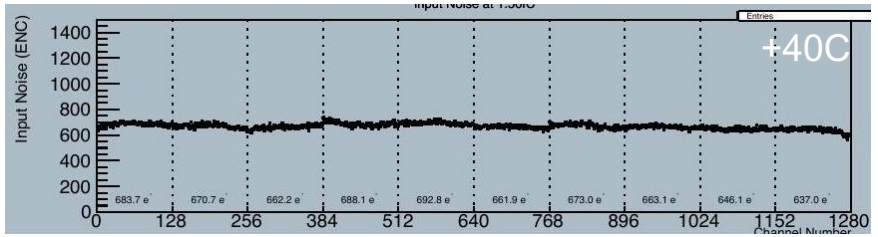


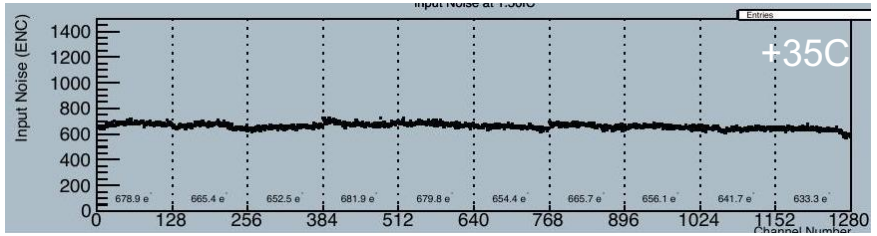
- Stopped here after target temperature discussion.

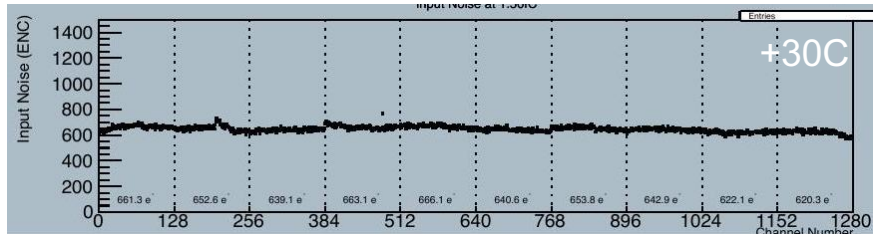
- Cold noise again persists back up to +20C.

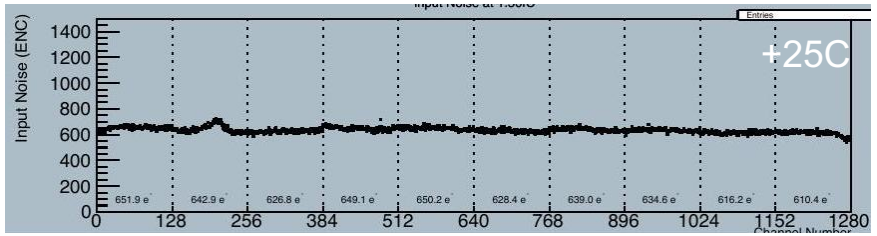
LBNL_PPB_SS_15 HY: Bake-Out

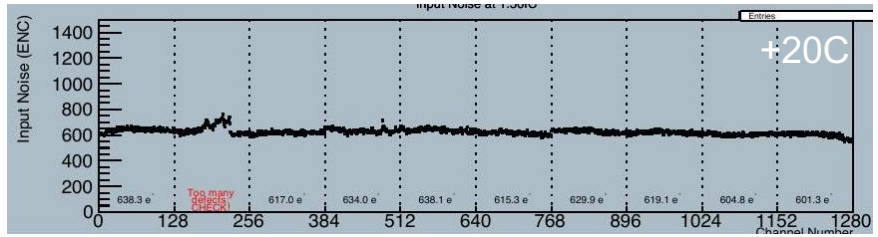
- Next, cycled +20C → +40C → +20C.
- Appears to help.

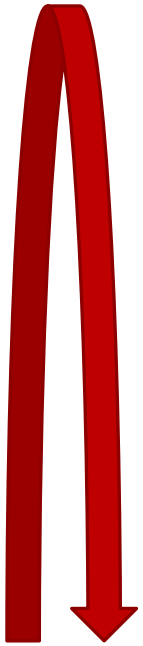




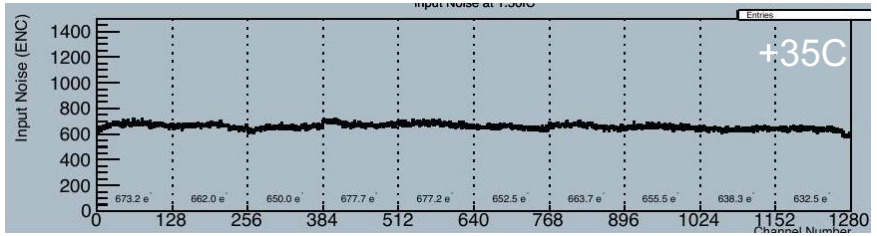


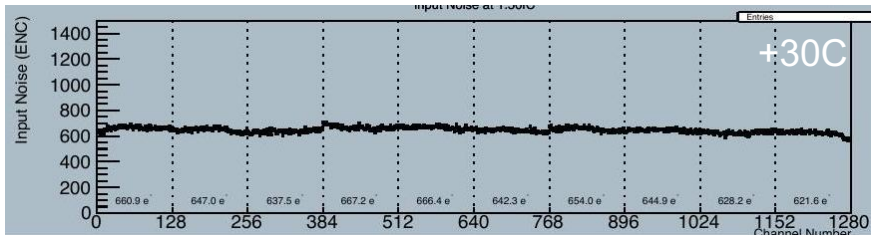


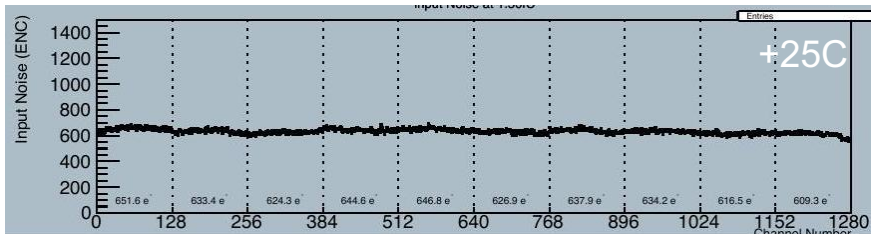


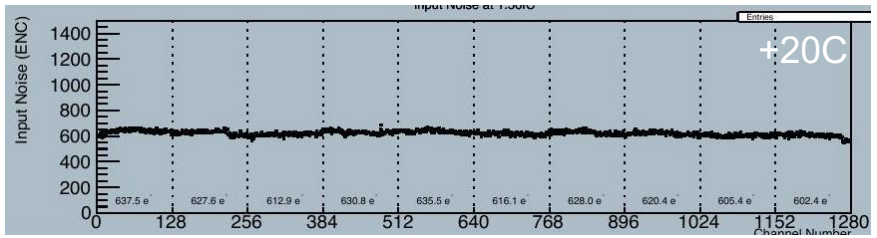


Test order





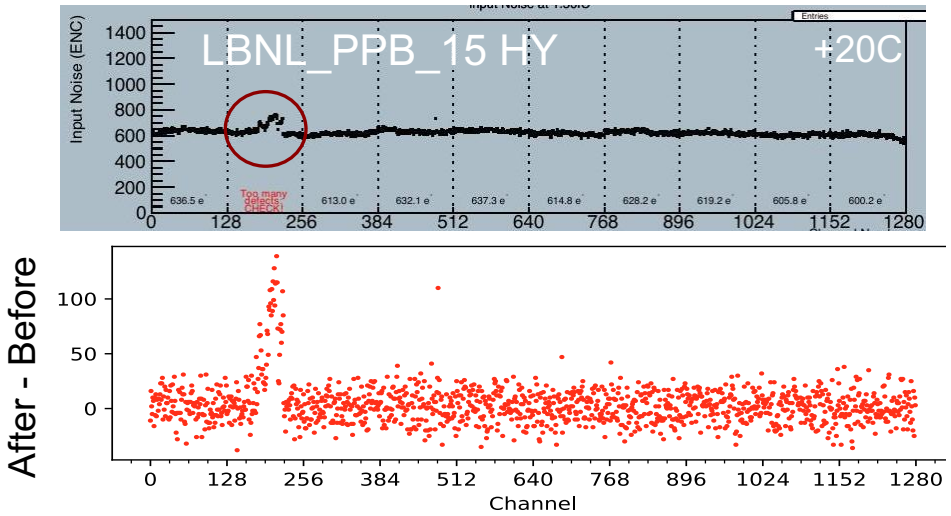




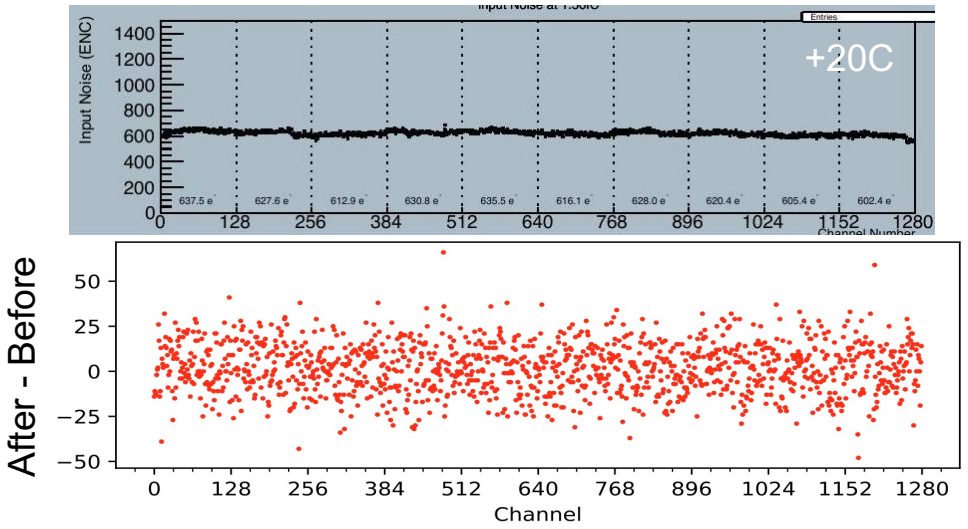
LBNL_PPB_SS_15 HY: Bake-Out

- Next, cycled +20C → +40C → +20C.
- Appears to help.

After 1st cycle vs. before cycling



After 2 cycles & bake-out vs. before cycling

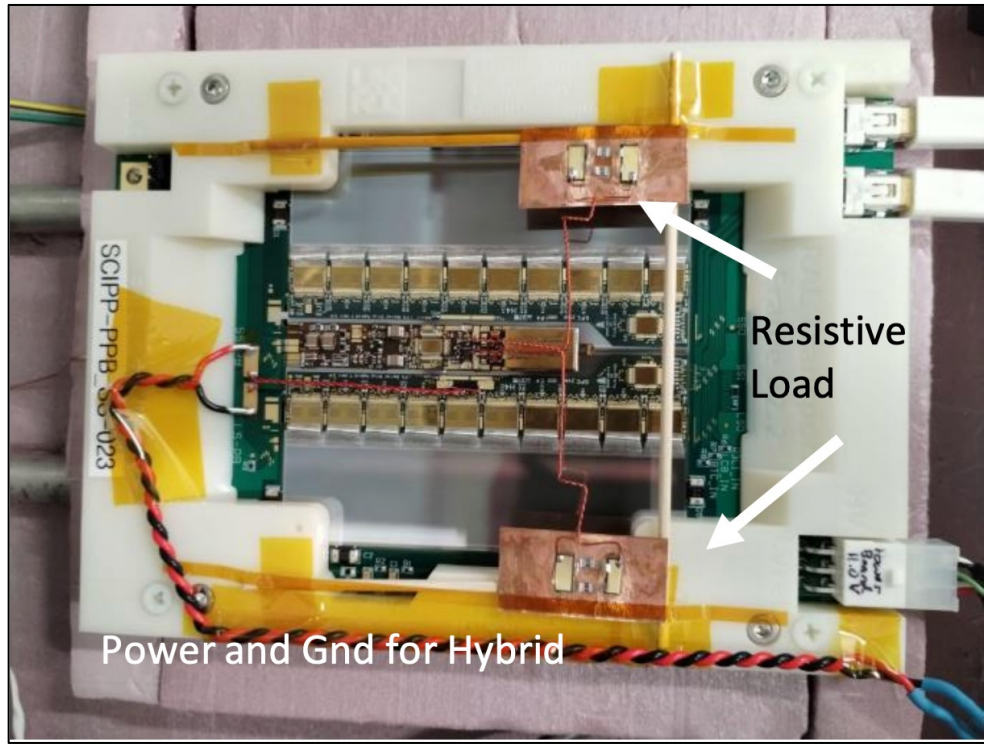


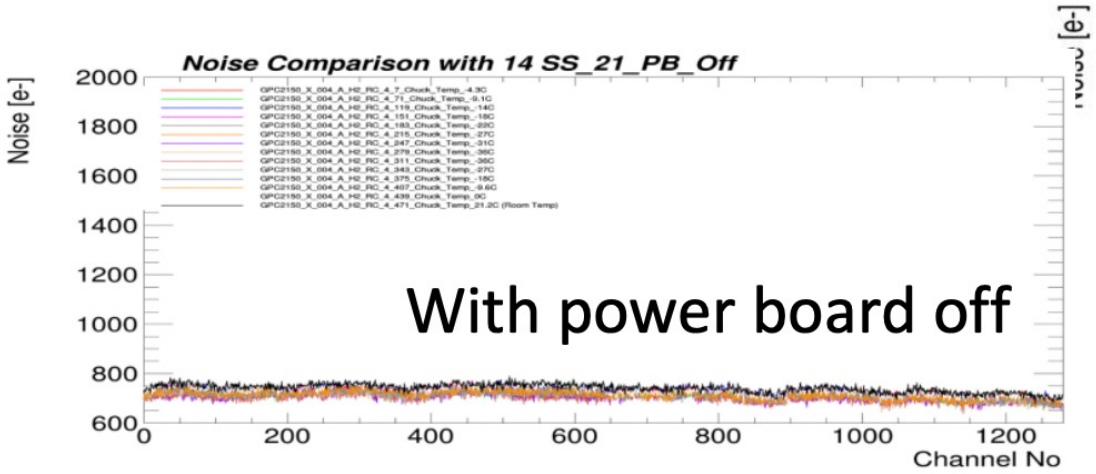
- Performed 1 more cold cycle after bake-out → similar to 2nd cold cycle.

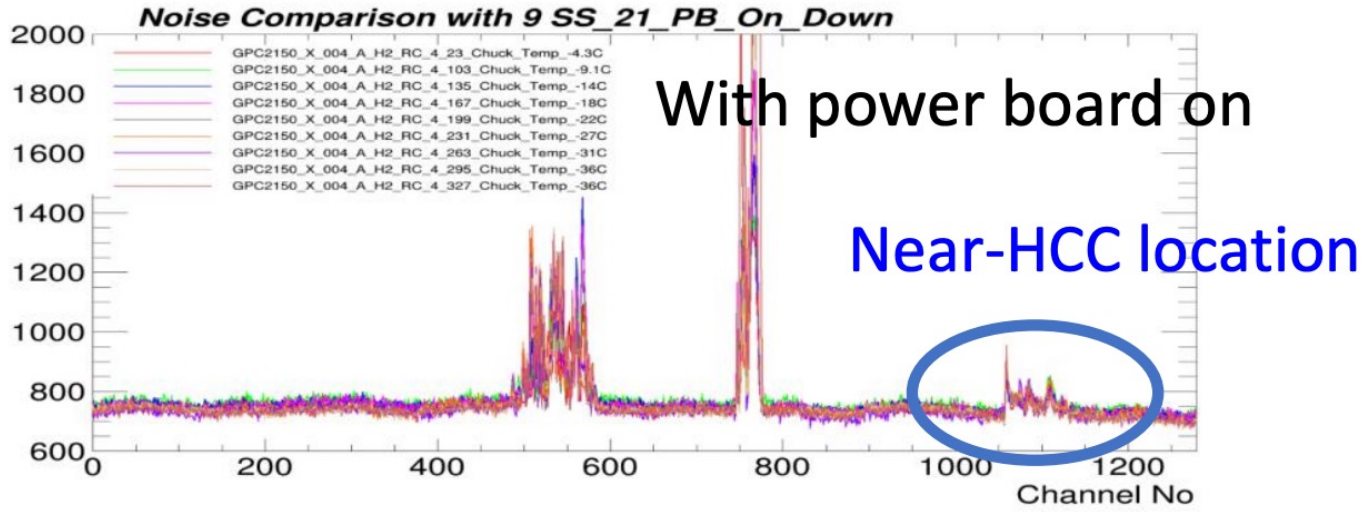
Bypassing the Powerboard (SCIPP)

Bypassed Powerboard

- Removed connections between hybrids and PB on a SS module.
  - Except hybrid LV GND to PB LV GND.
- Separately powered hybrids & added resistive load for PB.
- PB on → still see cold noise. PB off → cold noise disappears.
  - Noise must be coupling into strips.
- Strange that noise still appears by HCC. Far from PB.
  - Expected it to disappear without the PB-to-hybrid bonds.



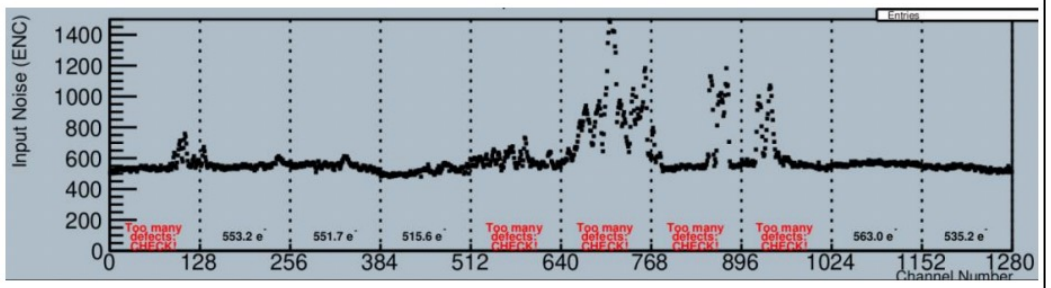




Magnetic Triggering (UBC)

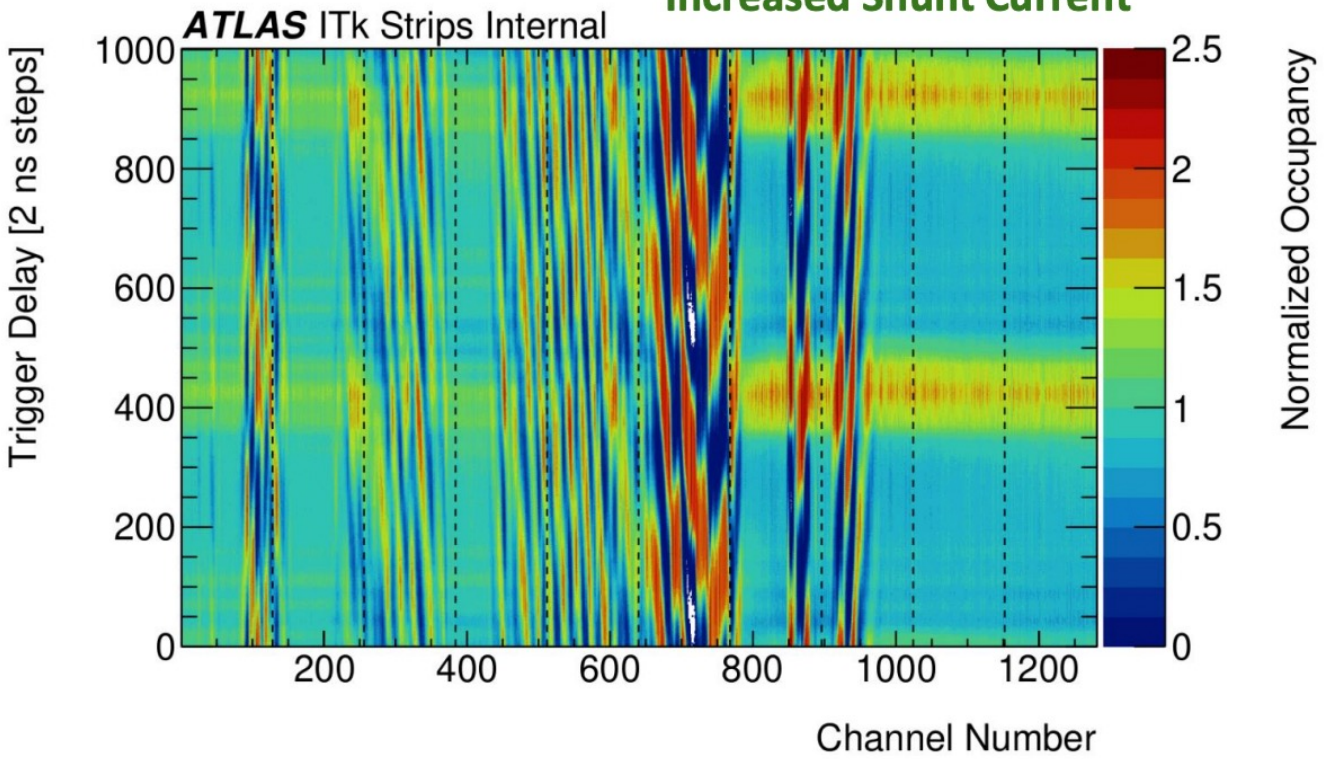
Magnetic Triggering (UBC)

- Measure noise occupancy triggered by phase of bPOL12V with magnetic loop
  - Exact phase of bPOL12V with respect to trigger delay is not understood
- Shows the cold noise is in-phase with bPOL12V
  - One pushing channels up, one down
- Could be magnetic, conducted noise or mechanical
  - Conducted noise unlikely
- We don't understand the diagonal striping.
  - May be sign of vibrations?? Consistent with speed of sound
  - Trying encapsulation of capacitors to "dampen" effect on module with known cold noise
- Urgently need to confirm results with 2nd system



LBNL SS PPA 0001 -26C

Increased Shunt Current



Tony's ITk slides

We're working on it

Increased Glue Under Hybrid and Modules (LBNL & BNL)

Extra Glue

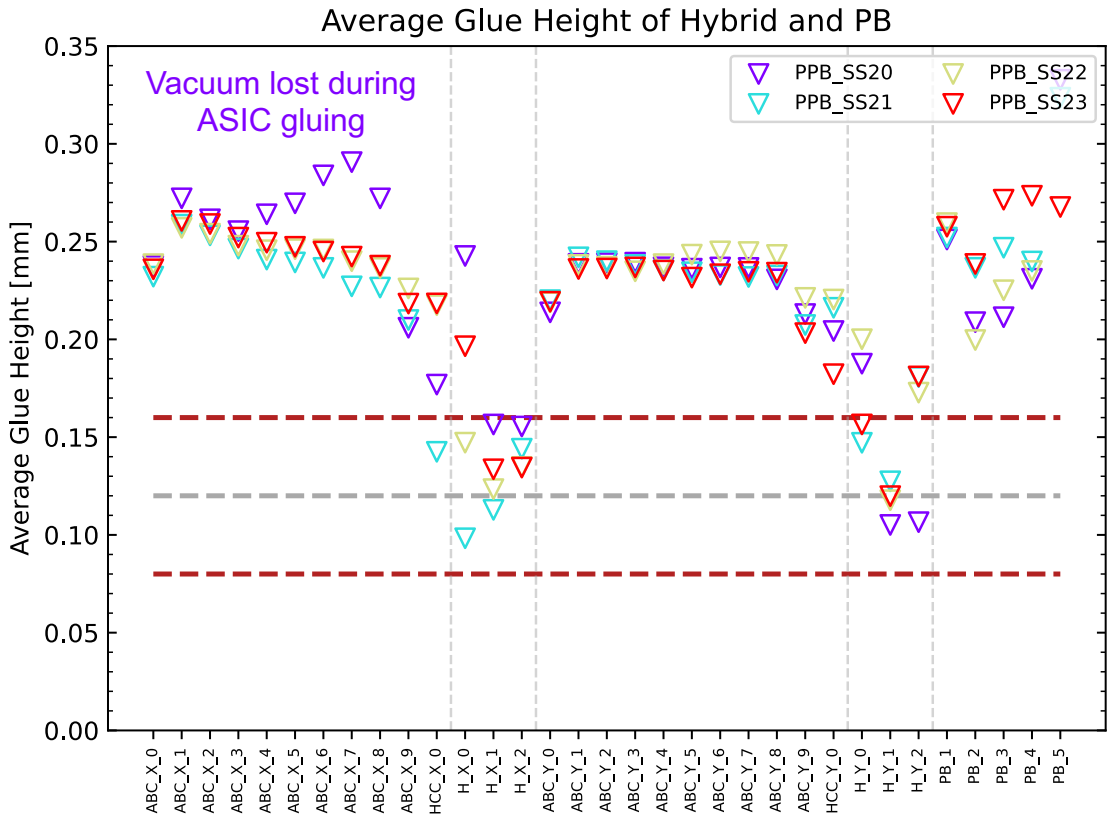
Modification:
- LBNL Built 4 PPB short-strip modules with ~2x the hybrid & PB glue.
  - Doubled the glue volume.
  - Shimmed tools to double the hybrid & PB glue height.

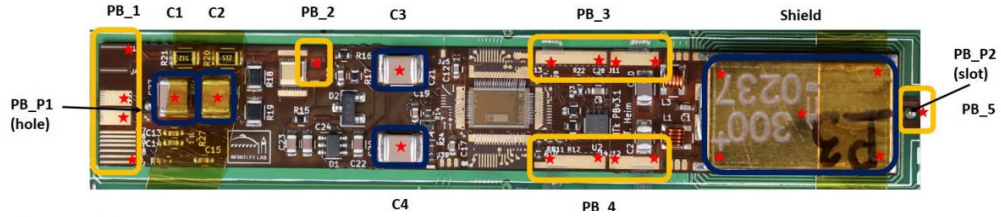
Motivation:
- Extra glue height might reduce noise coupling from hybrid/PB into sensor.

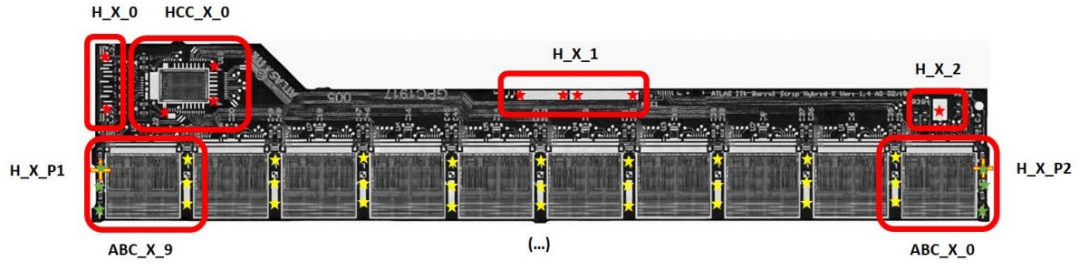
- Some people are suspicious of bPol (DC-DC converter ASIC) performance at cold temperatures.
  - Extra glue should keep it warmer.

- Some people are suspicious of hybrid flex bottoming-out on sensor.

	Glue weight / nominal		
Module	HX	HY	PB
PPB_SS_20	2.0	2.1	1.1
PPB_SS_21	1.9	2.1	2.1
PPB_SS_22	1.9	2.1	1.5
PPB_SS_23	1.7	2.2	1.7





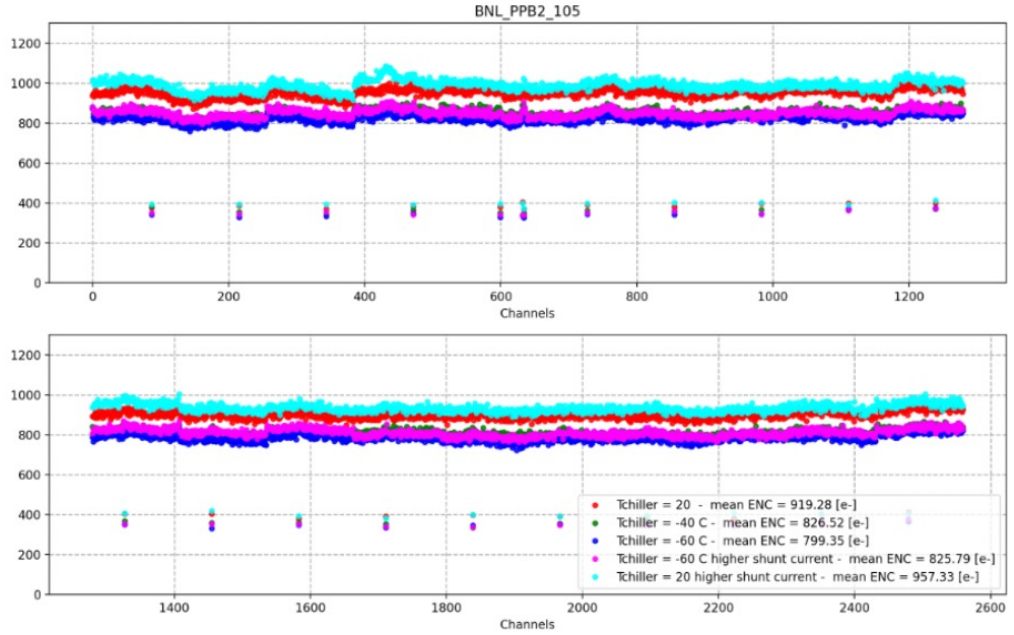


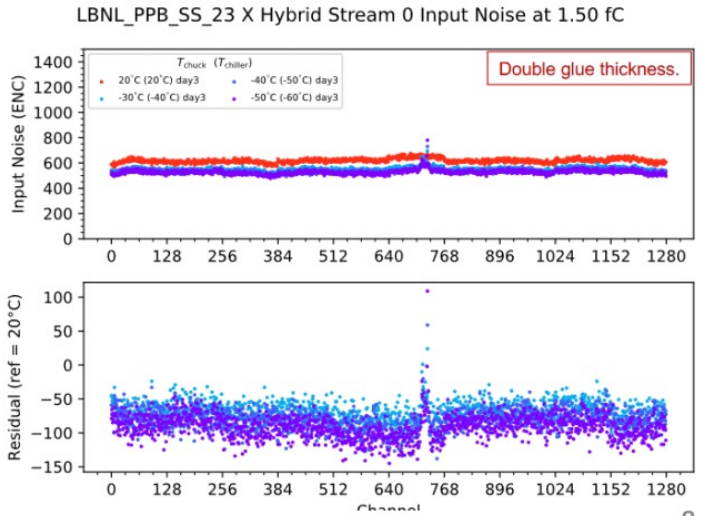
Mitigations (Thicker Glue)

- Module built with thicker glue layers for hybrids + PBs
  - BNL: 5 LS PPB with 300 um
  - LBL: 4 SS PPA with 240 um

BNL →
- No cold noise seen in LS modules down to -55 C chuck temperature

LBNL →
- Less cold noise (number of channel/level of noise/temperature) in SS modules





[Tony's ITk slides]

- Is improvement coming from warmer PB, less coupling, or less mechanical stress?

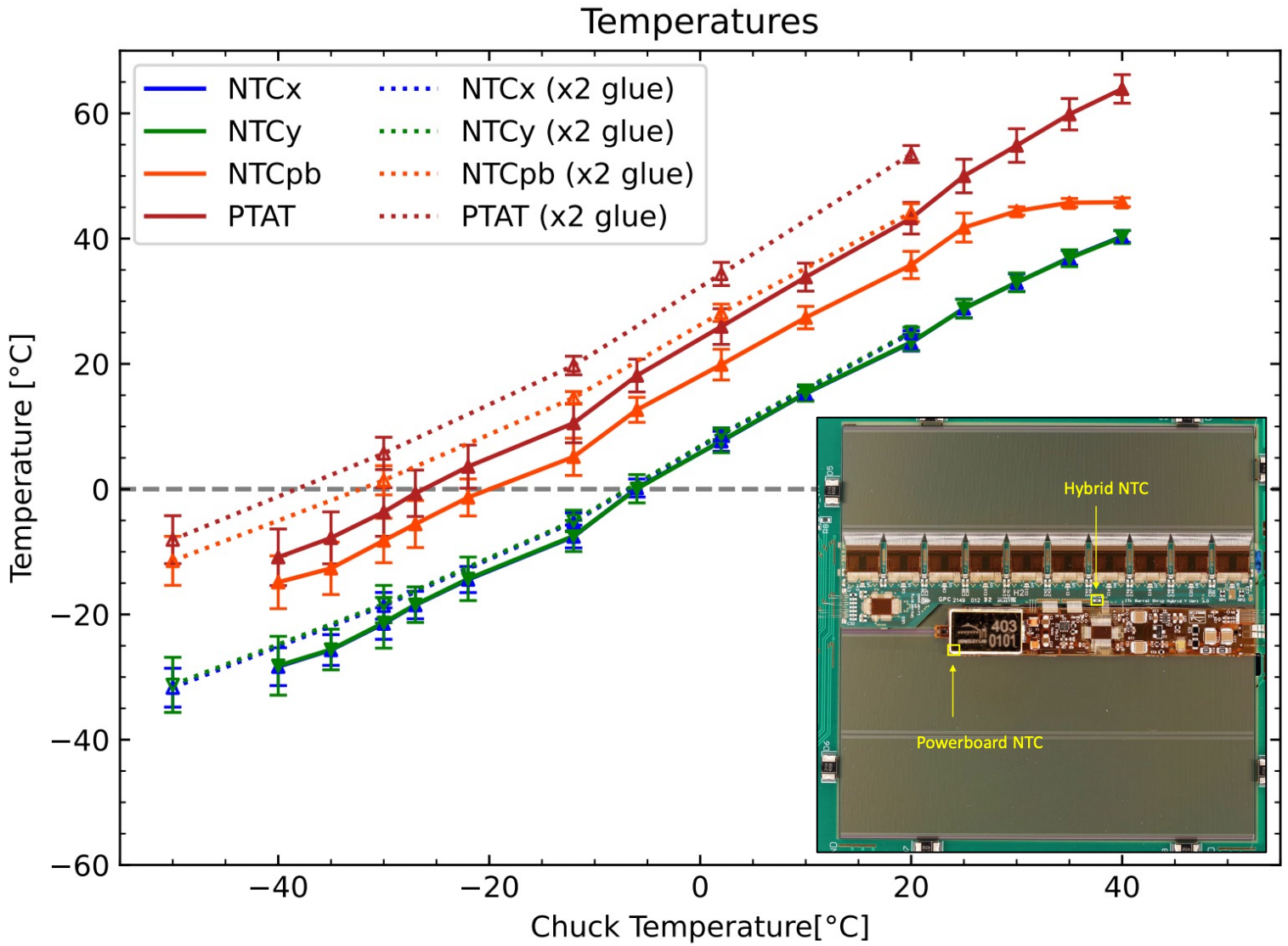
Temperature Comparison

Comparison:

- Temperatures for nominal vs. 2x glue modules.
  - NB: PTAT in bPol (DCDC converter ASIC).
- Extra glue → warmer PB.

Thoughts:

- Extra glue mitigates cold noise.
- Could be due to warmer bPol?
  - Maybe bPol switching freq. changes with temperature are culprit…
  - But fact that cold noise can persist back up to +20C makes it unlikely.
- Could be thermomechanical?
  - CTE mismatch?
  - Extra glue → less stress?
  - We know hybrids & PBs are bowing at cold temperatures.
- Increased separation → less noise coupling from PB into strips?

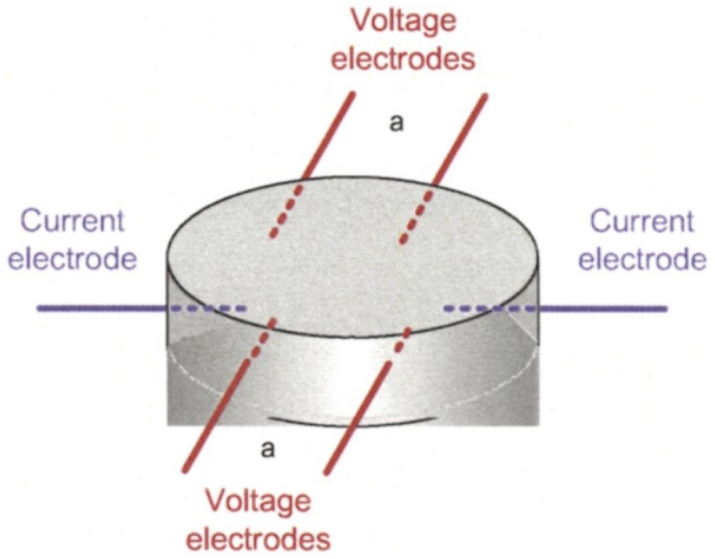


What’s next?

What's Next

LBNL:

- Building more LS module with increased hybrid & PB glue heights.
- Building module(s) with more elastic glue: Sylgard 186 (LBL), SE4445 (RAL?).
- Magnetic triggering.
- Check if noise is in-time?
- Metrology on modules with residual "cold" noise at +20C before & after bakeout.
- Test glue electrical properties vs temperature?



Community:

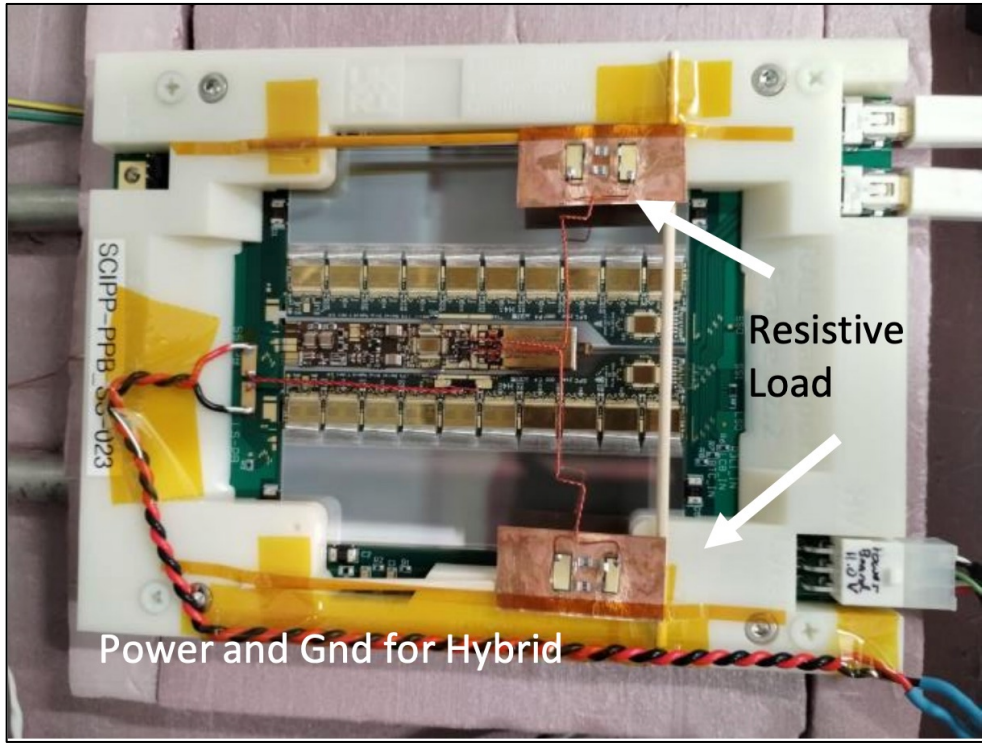
- Building 1 SS & 1 LS stave with modified glue heights.
  - 280 um glue thickness
  - 1/3rd standard, 1/3rd PB only raised, 1/3rd PB + hybrids raised
- Build another module bypassing PB for hybrid power, but make PB height adjustable.
- Add extra shield under hybrids/PB.
- Modify hybrid/PB loading (C7/C8 capacitors, pi-filter inductors, extra capacitor between ground/power on hybrids, thicker ground/power connections between PB/hybrid).

Backup

Bypassed Powerboard

Bypass powering scheme:

- Biased like IV scan: HV directly to HVtab, bias ring to frame bond for HVret.
- Now stick hybrid on top with its own LV+/-.
  - Have hybrid to bias ring bonds, so strip pads not floating.
- Now stick PB on top with its own LV+/-.
  - Add hybrid GND to PB GND bonds.
  - So hybrid GND = PB GND.
- But is HVret = hybrid GND = PB GND?
  - Yes, since powering PB via frame.
    - HVret and LV ground tied together on frame.
  - So HVret = PB GND = HVret = hybrid GND.

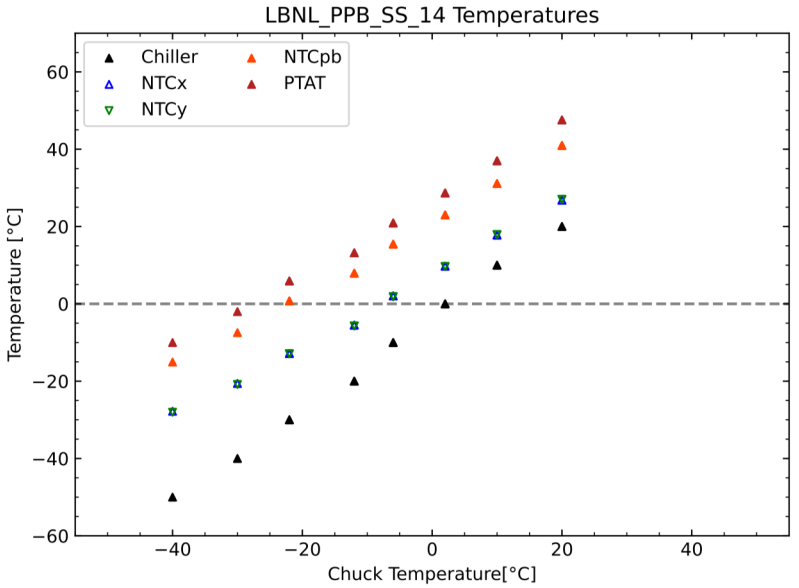


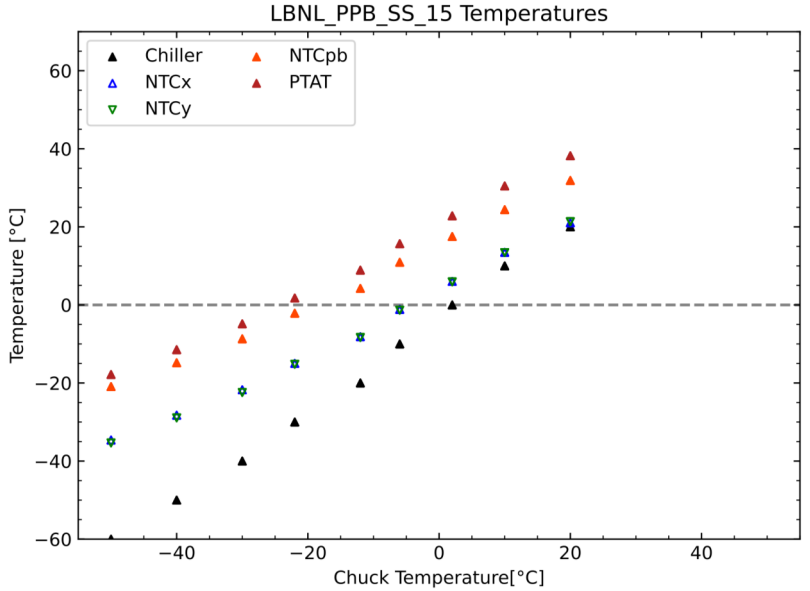
Normal biasing/powering scheme:

- HV from frame → PB → frame → HV tab → sensor backplane.
- Bond from bias ring to hybrid for HVret.
  - Bias ring connected to implants. Hybrid connected to strip bond pads.
- HVret bond from hybrid to PB.
- HVret and LV GND tied together on PB (and also on frame).
- Hybrid gets LV and LV GND from PB.

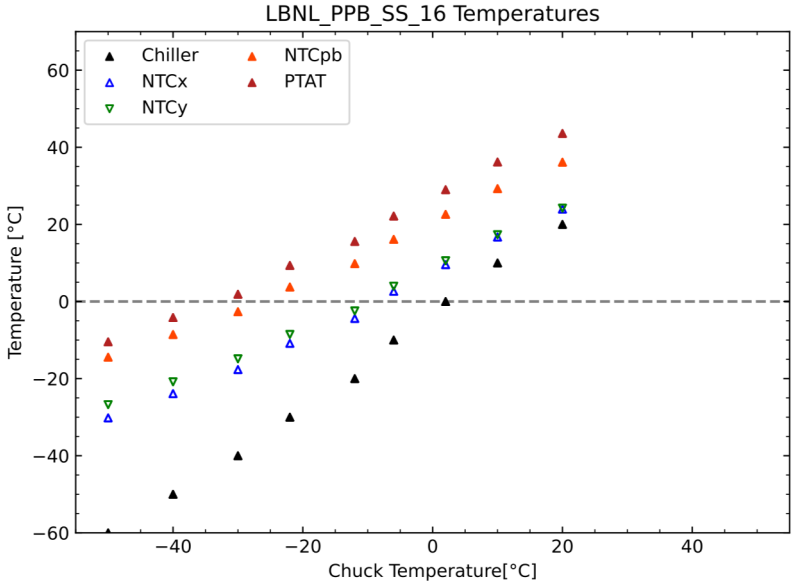
Temperature Monitoring

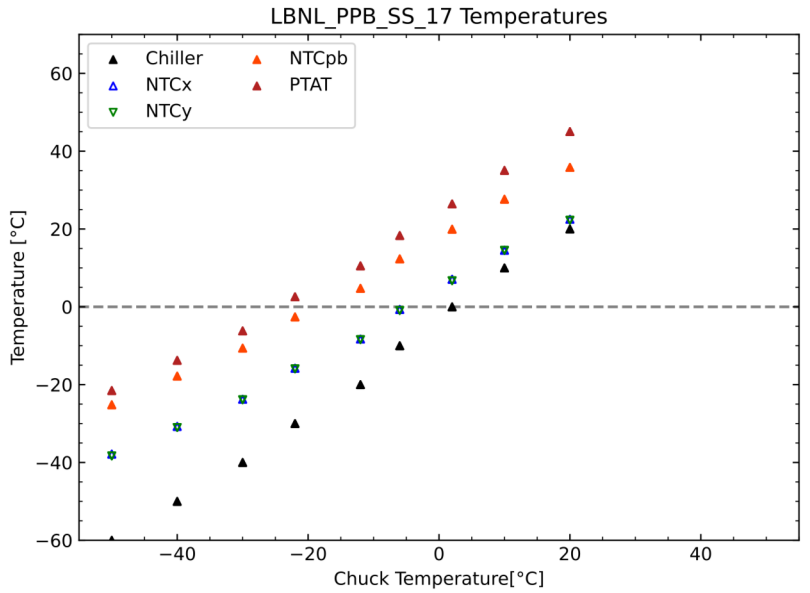
- Four nominal PPB SS modules.
- Monitored with powertools, not ITSDAQ.
  - But know they agree (backup).
- Plotting temps at time of RC test.
- Determine PTAT offset at 20C with DCDC off.
- Constantly recalibrate throughout cycle.





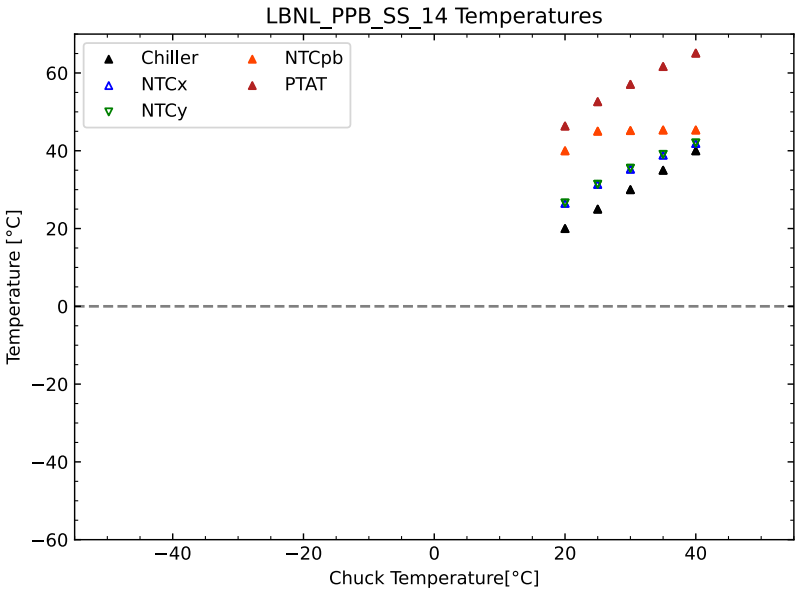
Measured during down cycle from 20C

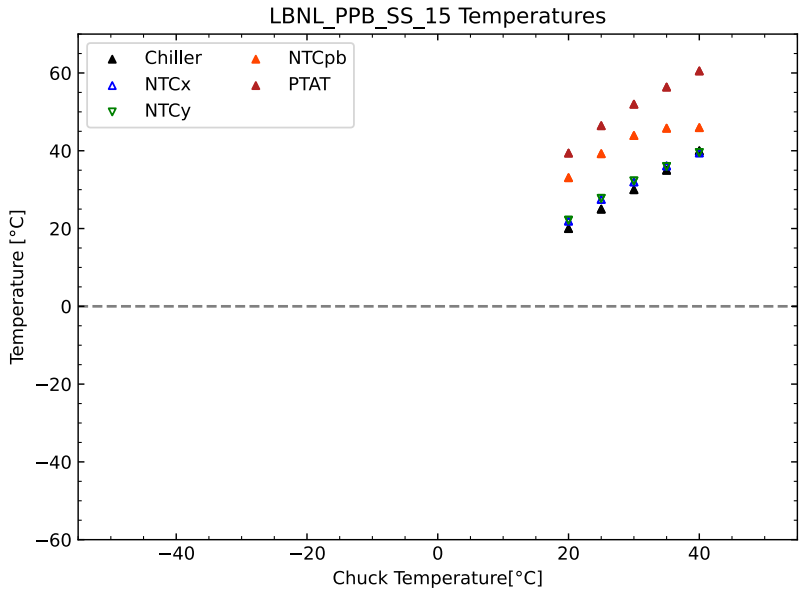




Temperature Monitoring

- Four nominal PPB SS modules.
- Monitored with powertools, not ITSDAQ.
  - But know they agree (backup).
- Plotting temps at time of RC test.
- Determine PTAT offset at 20C with DCDC off.
- Constantly recalibrate throughout cycle.
- Saturating NTCpb?
  - PTAT has voltage divider on PBv3.2.





Measured during bake-out (+20C → +40C).