9th "Trento" Workshop
on Advanced Silicon Radiation Detectors
Genova, 26-28 February 2014

# Highlights from IBL 3D Module Production

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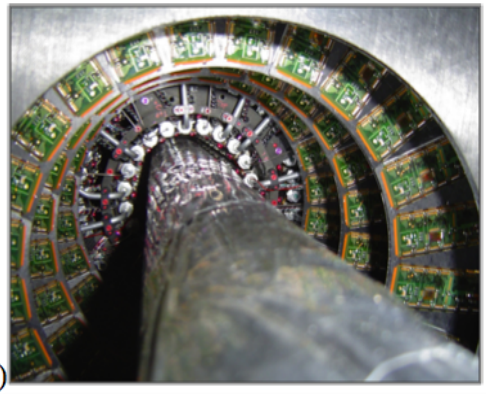
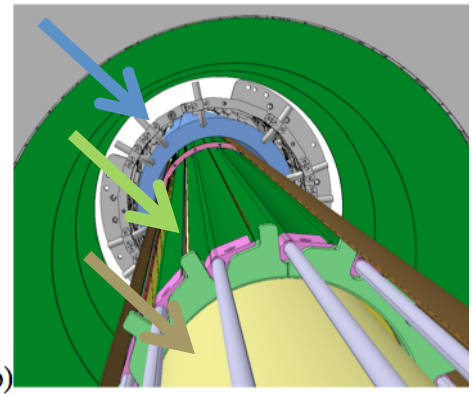
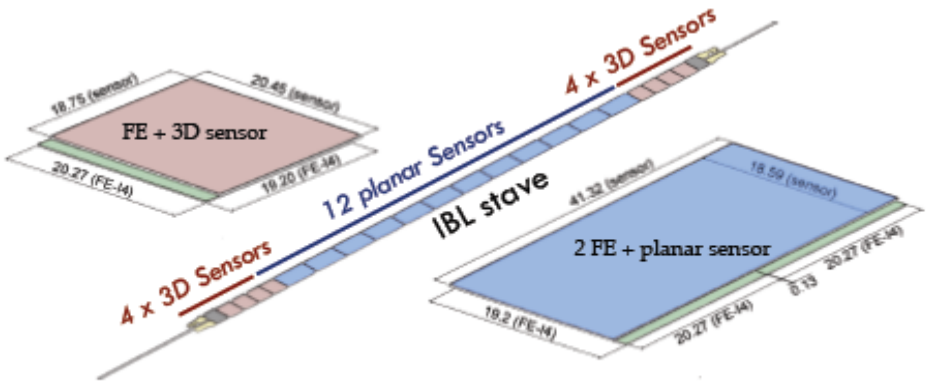
# IBL & Staves Overview

**Actual Detector**

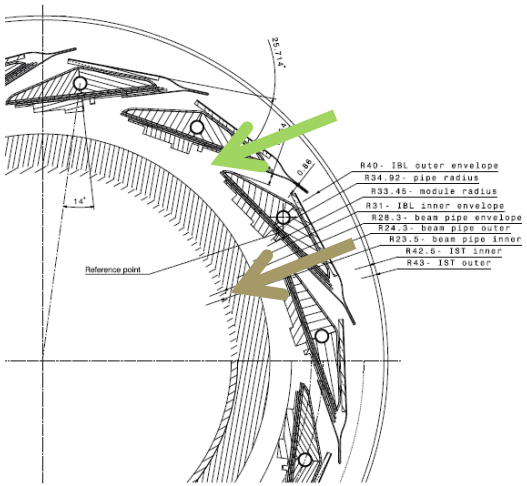


**IBL & pixel**






→ Actual Pixel Detector
→ IBL
→ New Beam Pipe




**The Insertable B-Layer (IBL) is the first upgrade of the ATLAS Pixel detector and it is going to be installed in LS1.**

IBL is composed by 14 Staves and each is equipped with:

- ✓ Central region: **12** Double-chip modules (Planar/CiS)
- ✓ Forwarded regions: **4+4** Single-chip modules **(3D FBK & CNM)**

A total of **112** 3D Modules are in the IBL

**12 MILIONS of channels**

↘A new Front End electronics has been developed (**FE-I4**)

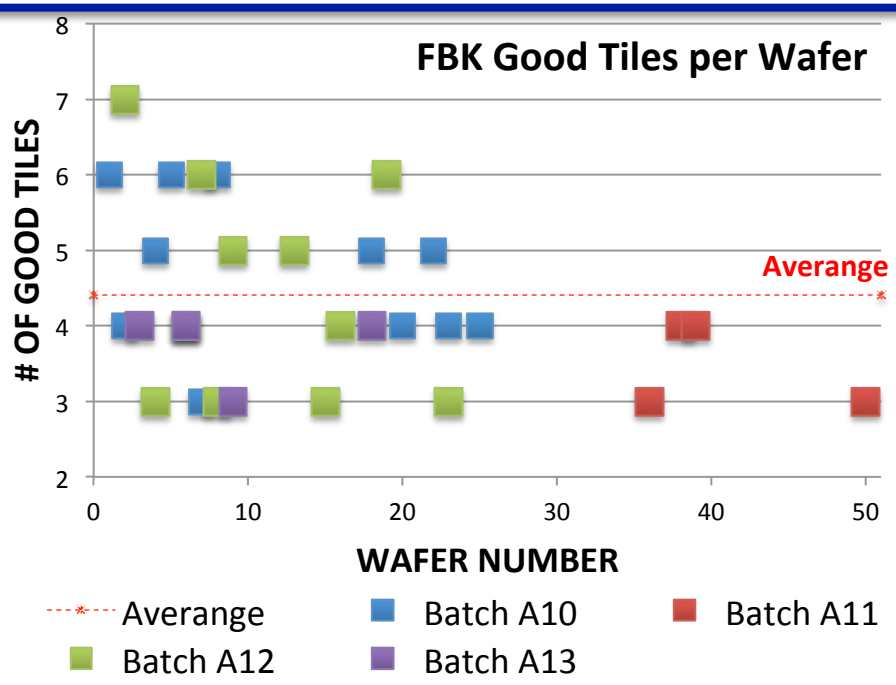
**see Didier's Talk for more details**

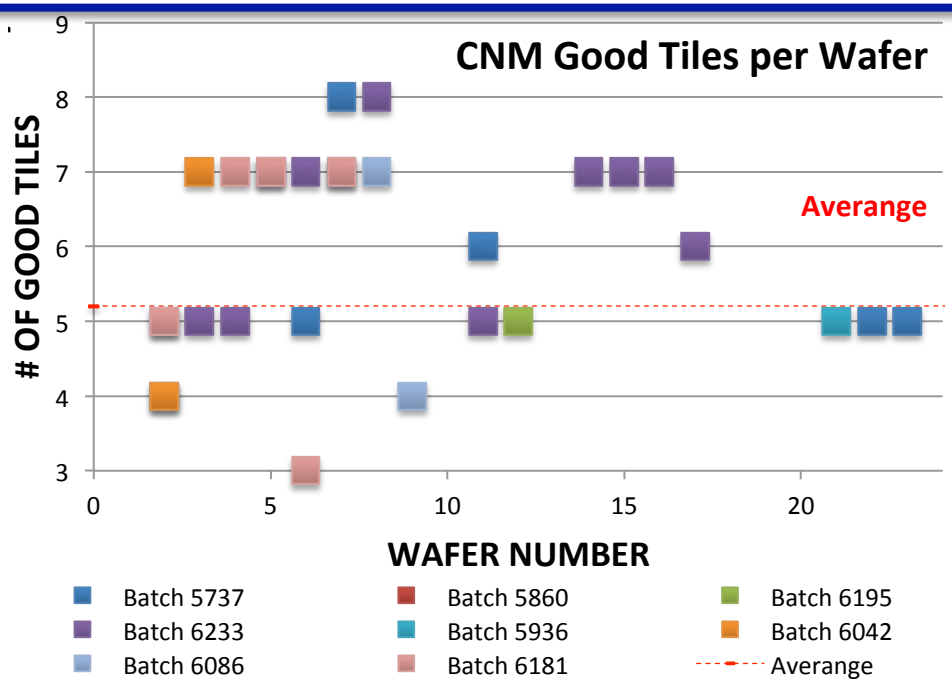
# Summary of Production 3D

| | Wafer Produced & Tested | Selected Wafer |
|---|---|---|
| **CNM** | 50 | 41 |
| **FBK** | 70 | 33 |

| | Selected Good Tiles | Delivered Modules to Labs |
|---|---|---|
| **CNM** | 228 | 167 |
| **FBK** | 134 | 124 |

**$V_{bd}$ IBL Requirement to select tiles is 25 V → A wafer is selected if it has at least 3 good tiles.**
**CNM yield is higher than FBK but FBK measurement on full device, CNM on Guard ring only.**



# Assembly and Qualification of Modules

**BARE**

- Check mechanical integrity and sensor IV.

**ASSY**

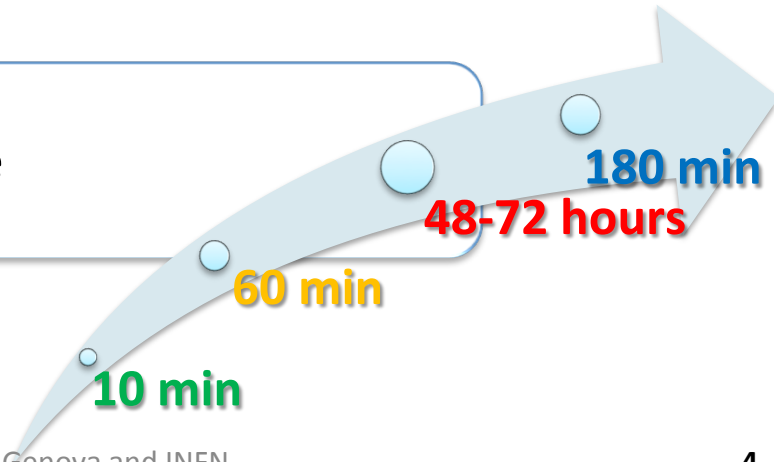
- Electrical test at ambient temperature, in which is checked the proper basic functioning of the module (e.g. IV Curve, bumps connectivity). Also done the Tuning at working point of 3ke Threshold and 9BC @ 20ke

**BURN**

- Module is thermal cycling (-40, +40 °C for 2-3 days) and retested at ambient temperature.

**FLEX**

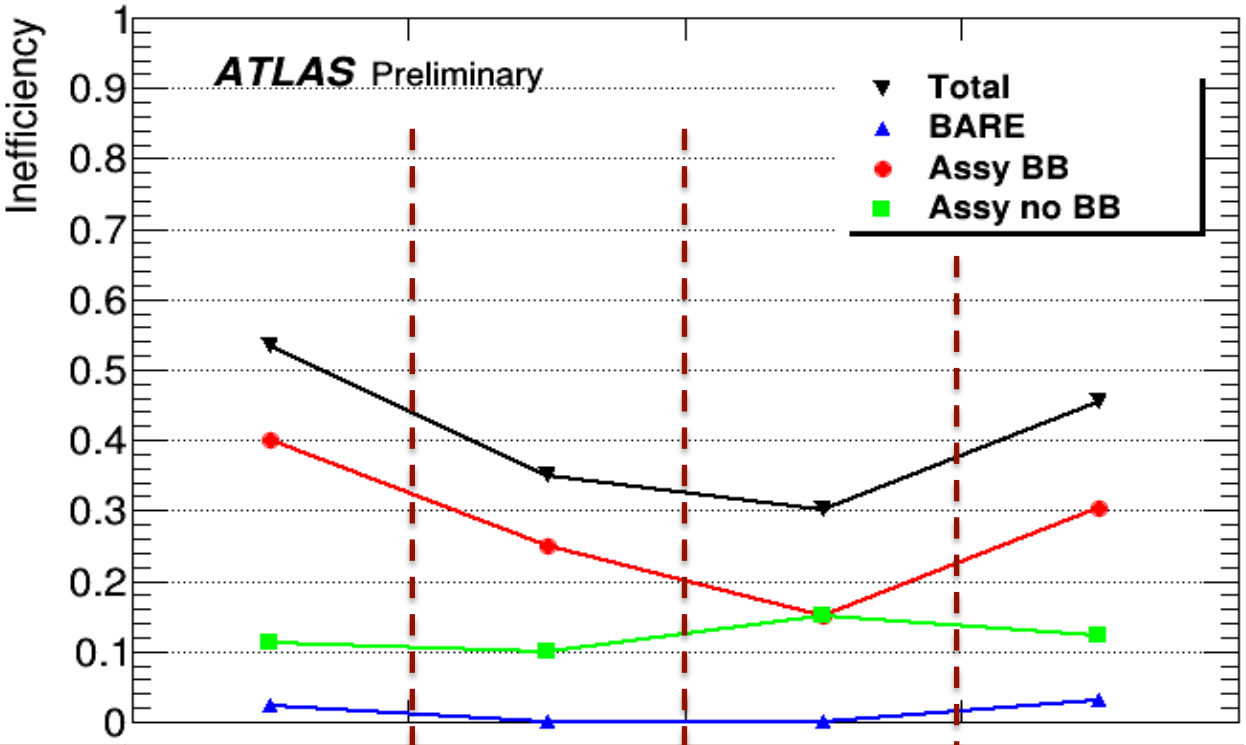
- Complete calibration of the module.
- A functionality test with $^{241}$Am is done
- All tests are executed at -10 °C.



# Yield of 3D Production

**FBKs have a bump bonding failure of ~20% (Vs 10 % of CNMs) but a electrical failure rate (including electronics and IV) of only 10%.**

**FBK YIELD (from 4 onwards): 62%**



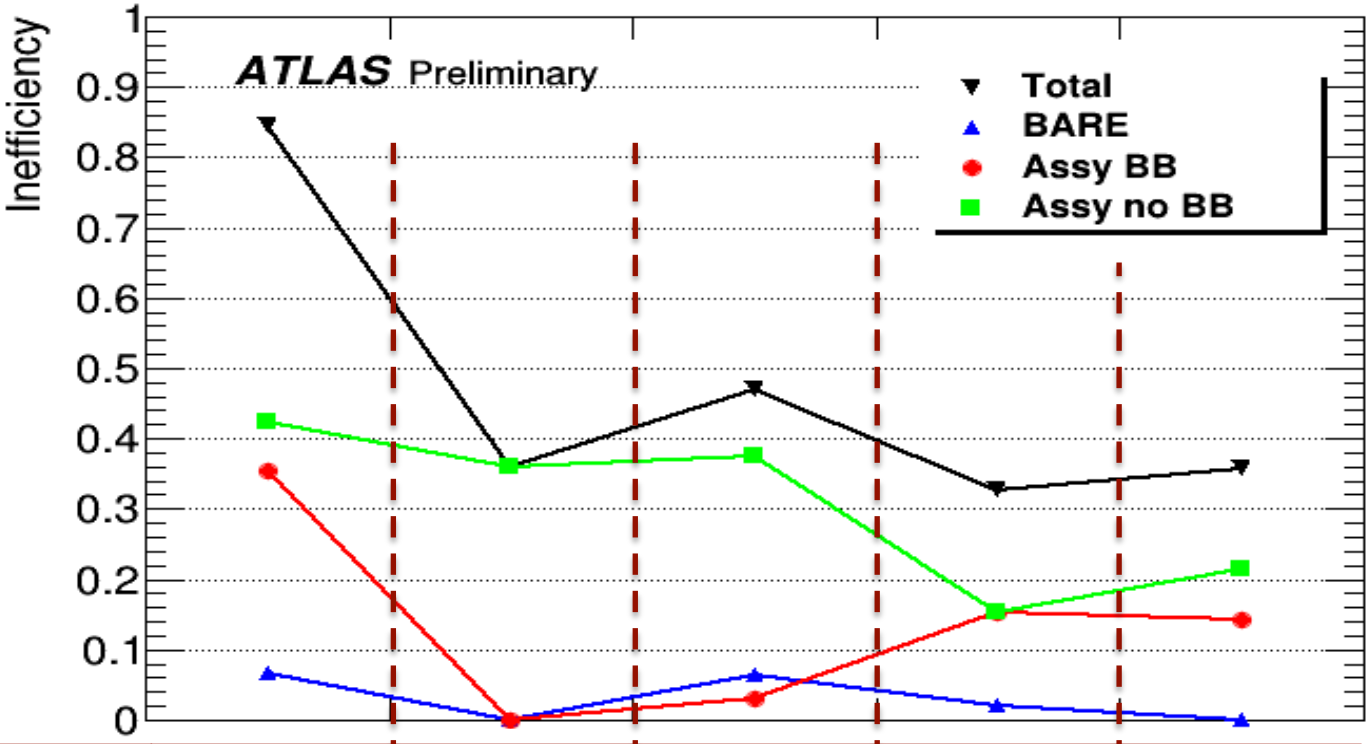

| Batch | 1,2,3 | 4,6 | 5,8,13 | 9 |
|---|---|---|---|---|
| | Tamarack 45 Modules | Tamarack 20 Modules | Goettingen 20 Modules | Tamarack 33 Modules |

Plot by C. Gemme

# Yield of 3D Production

**CNMs bump bonding failure rate is better than FBKs (10 % Vs 20%) but they have more electrical failure (mainly IV failure).**

**CNM YIELD (from 4 onwards): 62%**

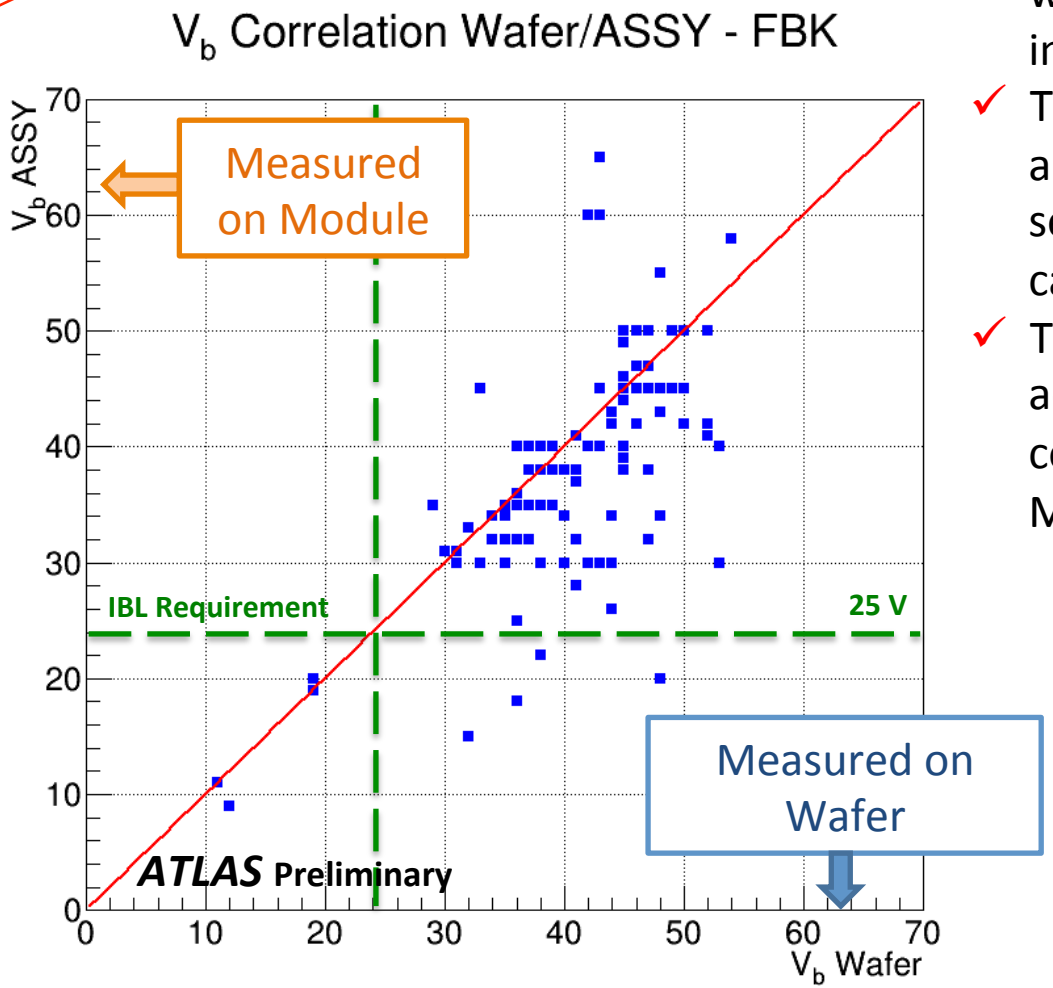



| Batch | 1,2,3 | 4,6,7 | 5,6 | 9,10,12 | 11,13 |
|---|---|---|---|---|---|
| | Tamarack 45 Modules | Tamarack 25 Modules | Goettingen 32 Modules | Tamarack 52 Modules | Goettingen 14 Modules |

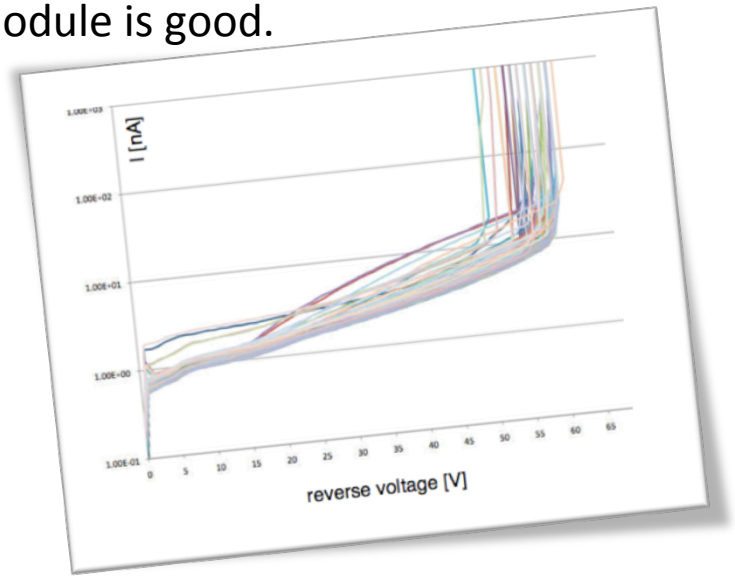
Plot by C. Gemme

# Sensors V Breakdown Changes after the Assembly (FBK Modules)

See Ivan L.'s Talk for CNM




- ✓ FBK deposits a temporary metal layer which allows I-V tests to be performed in each tile.
- ✓ The measurement is performed automatically on the 80 columns of sensors by using a dedicated probe card.
- ✓ Thanks this method is possible to select accurately good tiles and the correlation of $V_b$ between Wafer and Module is good.



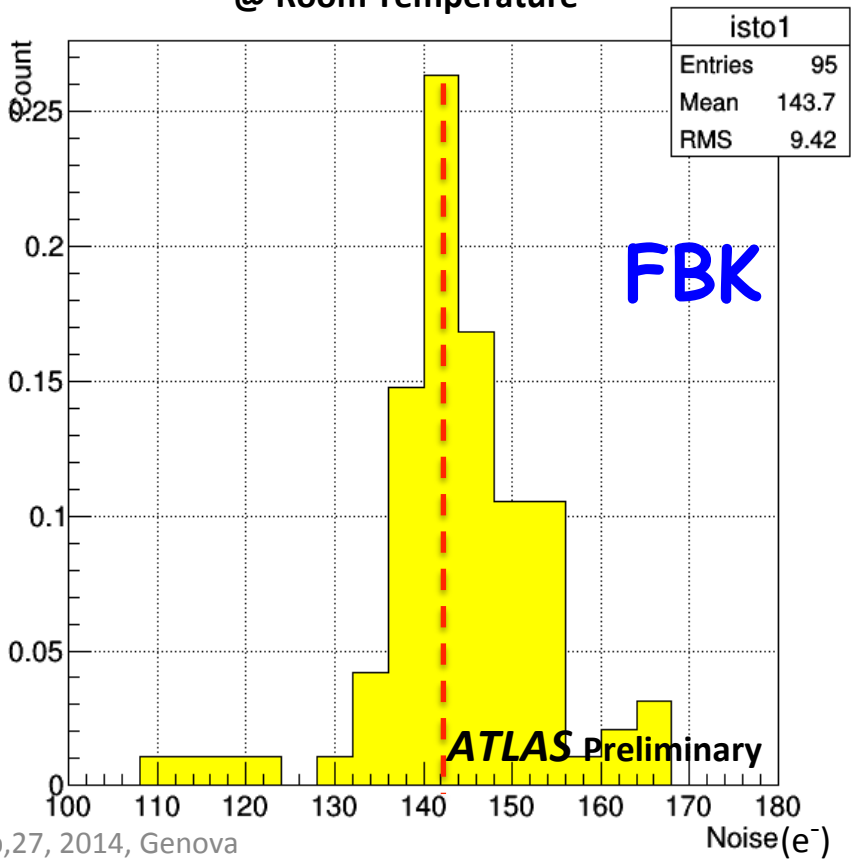
# Noise Comparison

The **noise** depends on $V_{bias}$, temperature and sensor type.

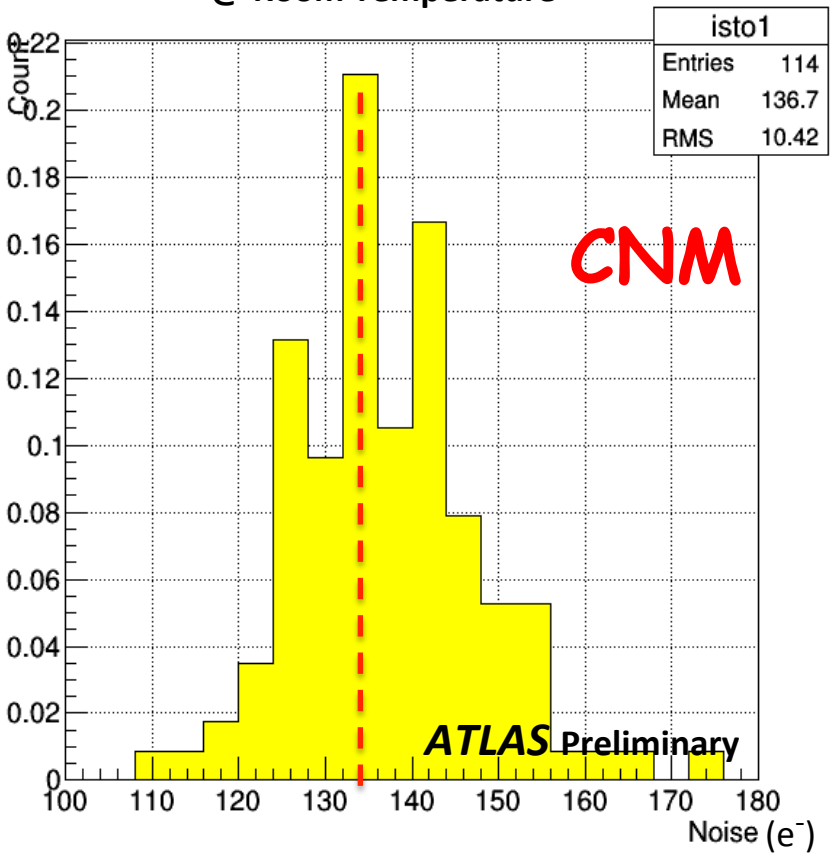
**At room temperature and $V_{bias}$ = 20 V average values are ~144e- for FBK and ~137e- for CNM (140 e- and 130 e- at -10°C).**

**Here is reported the Noise distribution of all CNM and FBK modules produced (in which the statistic was available)**

**FBK NOISE distribution @ Room Temperature**




**CNM NOISE distribution @ Room Temperature**

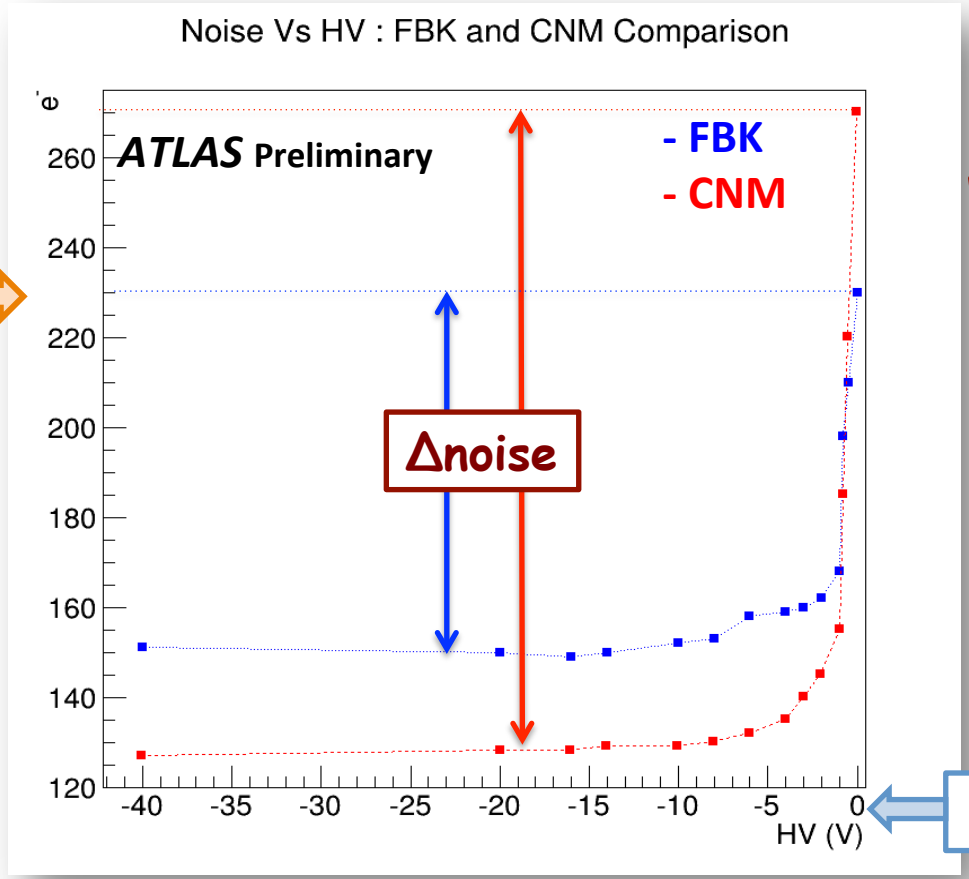


# Noise VS High Voltage

**Comparison between an FBK and a CNM device at room temperature for different values of $V_{bias}$.**

**The difference of noise between $V_{bias}$ On and Off of FBK is less than CNM.**

Noise

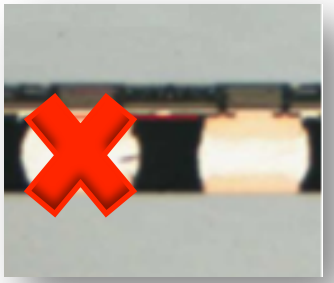



High Voltage

Δnoise is defined as NoiseHVoff-NoiseHVon

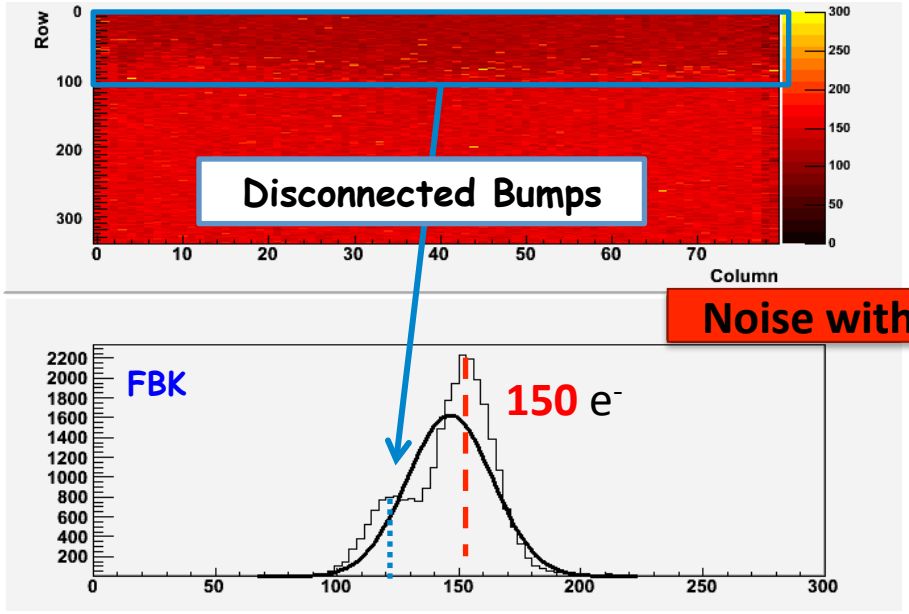
At low temperature the Δnoise is reduced of a ~ factor 2.

# Noise VS High Voltage

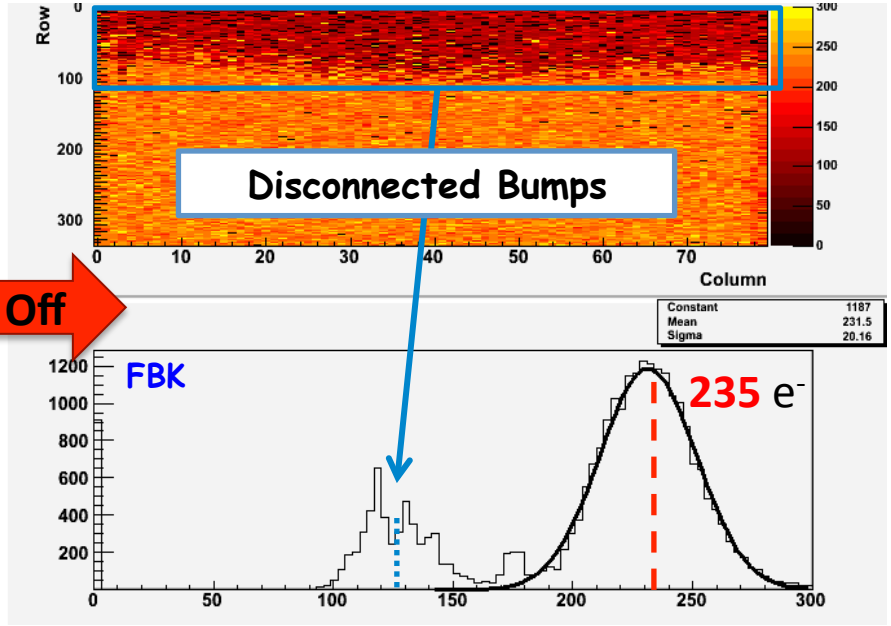


- ✓ **For unconnected bumps the noise is less than the normal** and **remains the same** if the $V_{bias}$ of the sensor is turned off while for connected bumps becomes much higher.
- ✓ From the difference between the distributions of noise with and without HV (**Δnoise**) and placing an appropriate cut on **Δnoise is possible to estimate the number of unconnected bumps.**

**↘A cut of Δnoise=20 e⁻ is very efficient.**

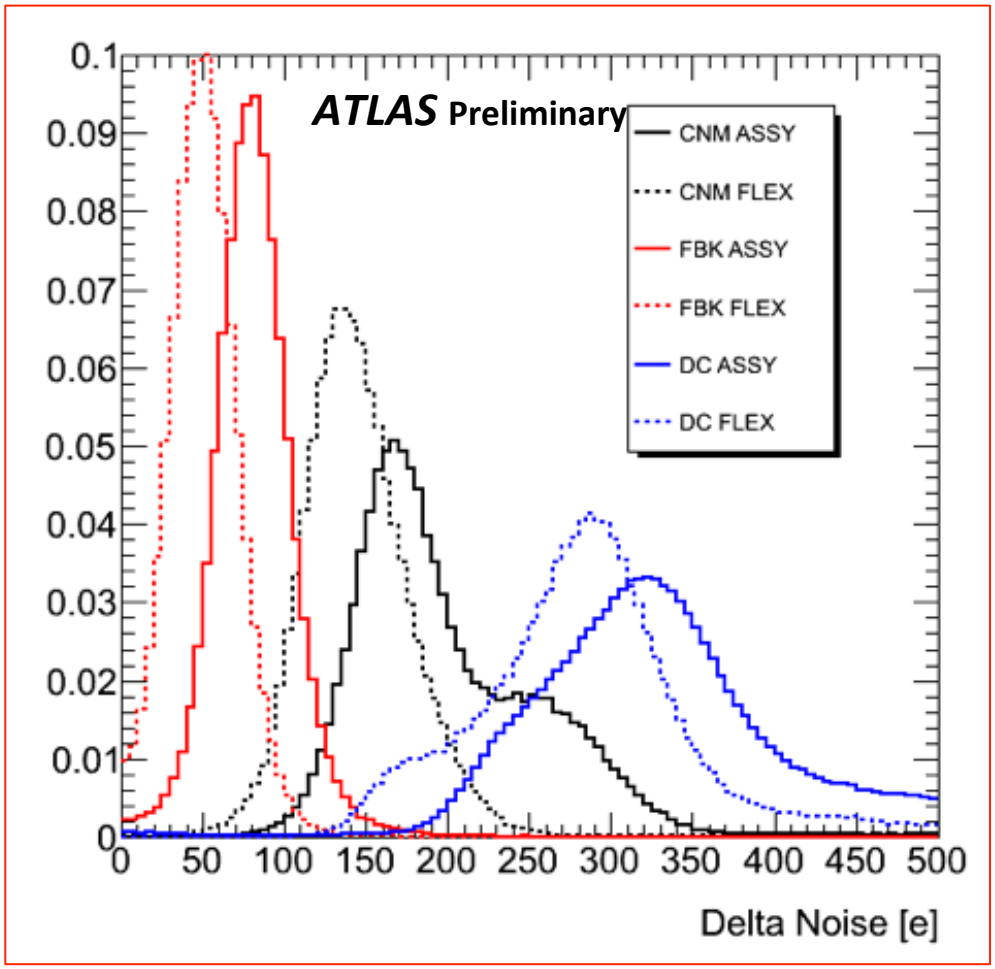



**Noise with HV Off**



# Noise VS High Voltage

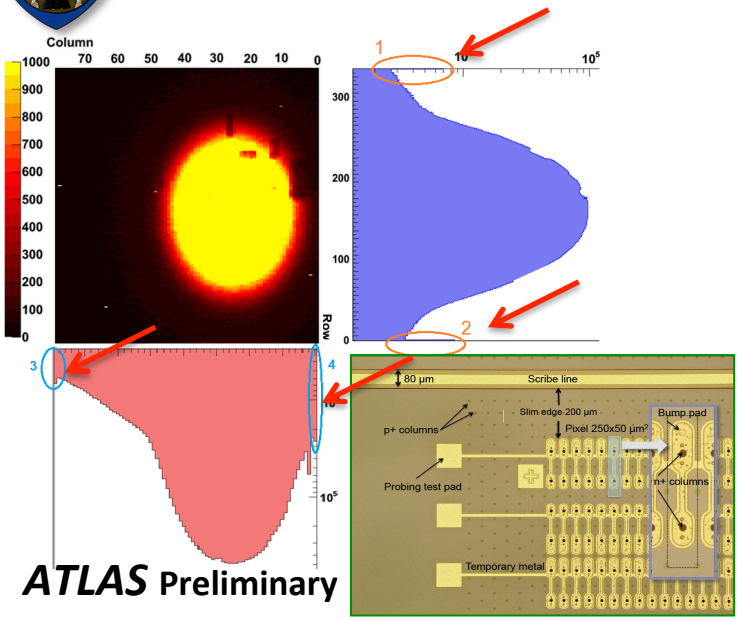
**The described method at low temperature detects ~10% of faked for FBK.**
**For this reason also a source scan is used during the the qualification.**




Plot by K.Motohashi

# Charge collection at sensor edge

FBK

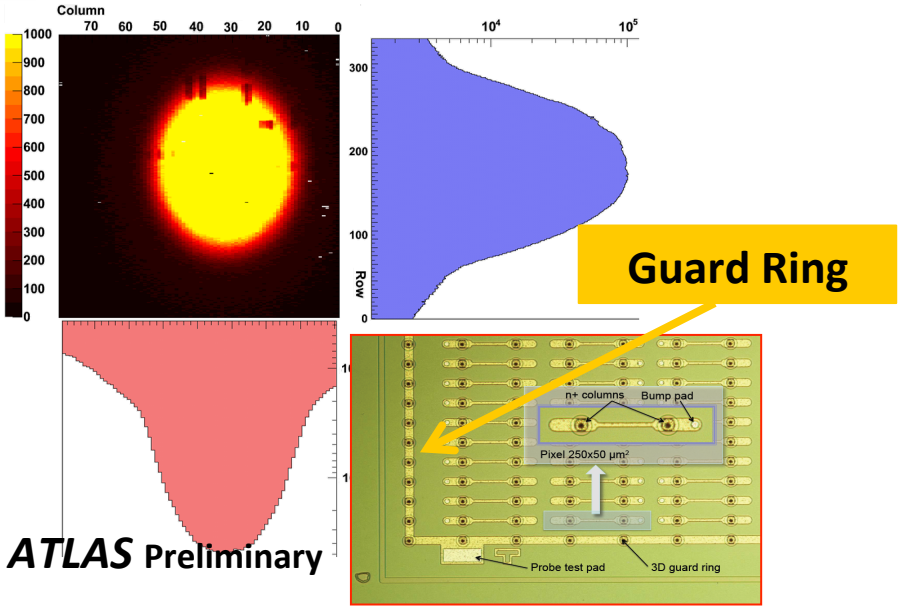



…See Test Beam results in Joern L.'s Talk

The **FBK** edges are partially active: hit occupancy of edge pixels is larger than for the internal pixels.

**Source Used**: $^{241}Am$

CNM



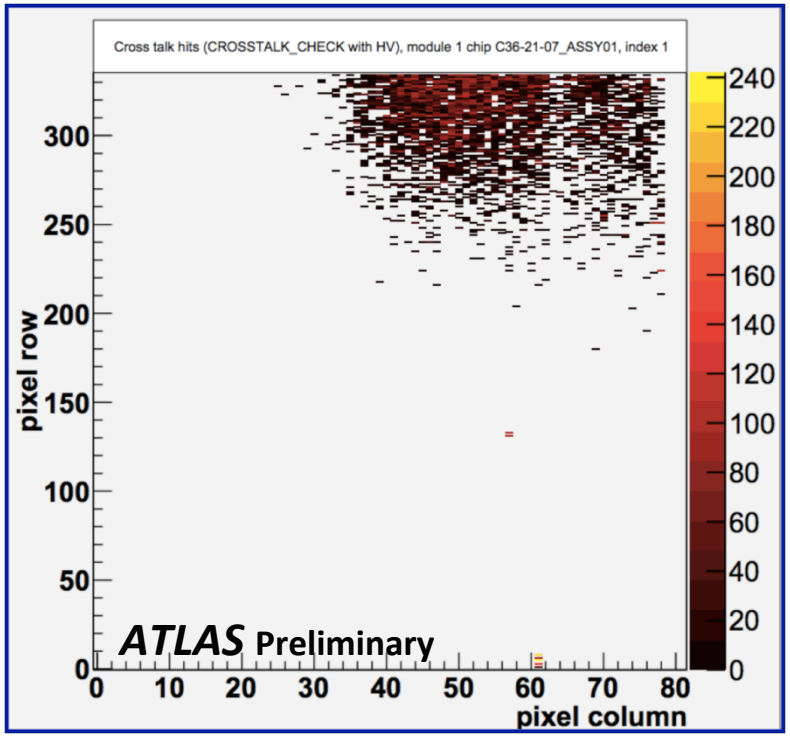

For **CNM** sensors, the guard ring collects the charge outside the pixels area: the hit occupancy of peripheral pixels is therefore the same as the internal ones

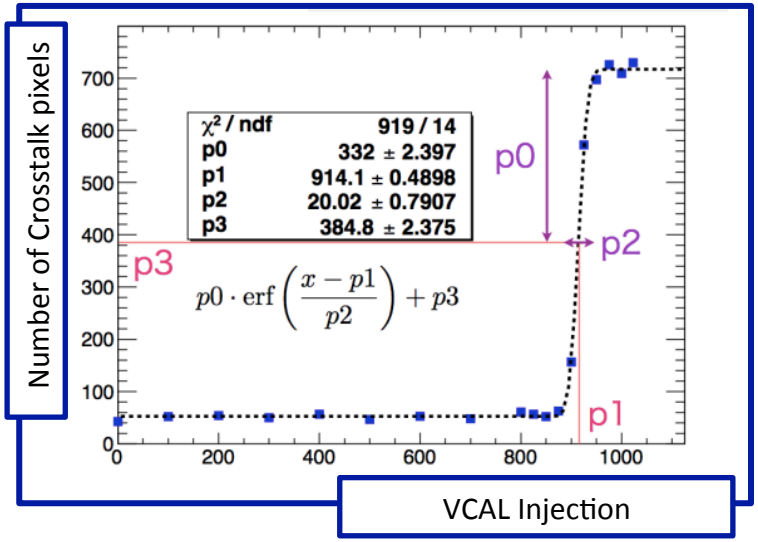
# Cross-Talk in CNM Devices

**The Cross-Talk** test consists in injecting the maximum charge (the default is a DAC VCal of 1023 equivalent to 55ke$^-$ charge) in two neighbouring pixels and measure if any hit is observed. The test is run routinely at 3 ke- threshold and usually the cross-talk is lower than ~3%.

✓ **In some CNM devices High Xtalk has been observed (never in FBK).**

↘**This is not worrisome for the data-taking performance.**



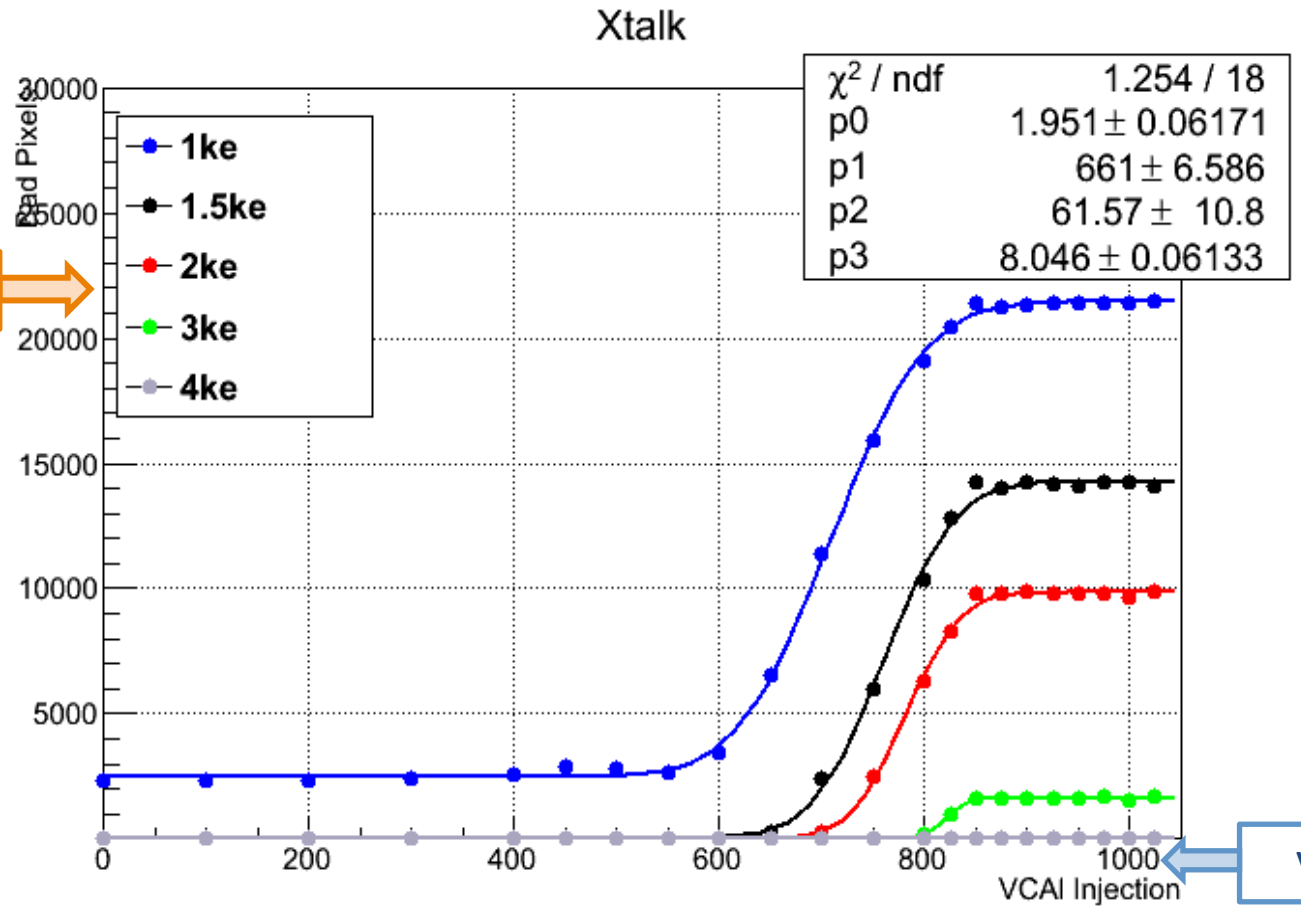




Plot by K.Motohashi

| | |
|---|---|
| **CNM Modules with High Xtalk (on the total CNM mounted)** | **~5%** |
| CNM Modules with High Xtalk in Good Modules (IBL Quality) | ~9% |

# Cross-Talk Vs Threshold

**Crosstalk Pixels Vs charge injected for different values of Threshold.**
**The Cross-Talk drops at the increase of threshold**



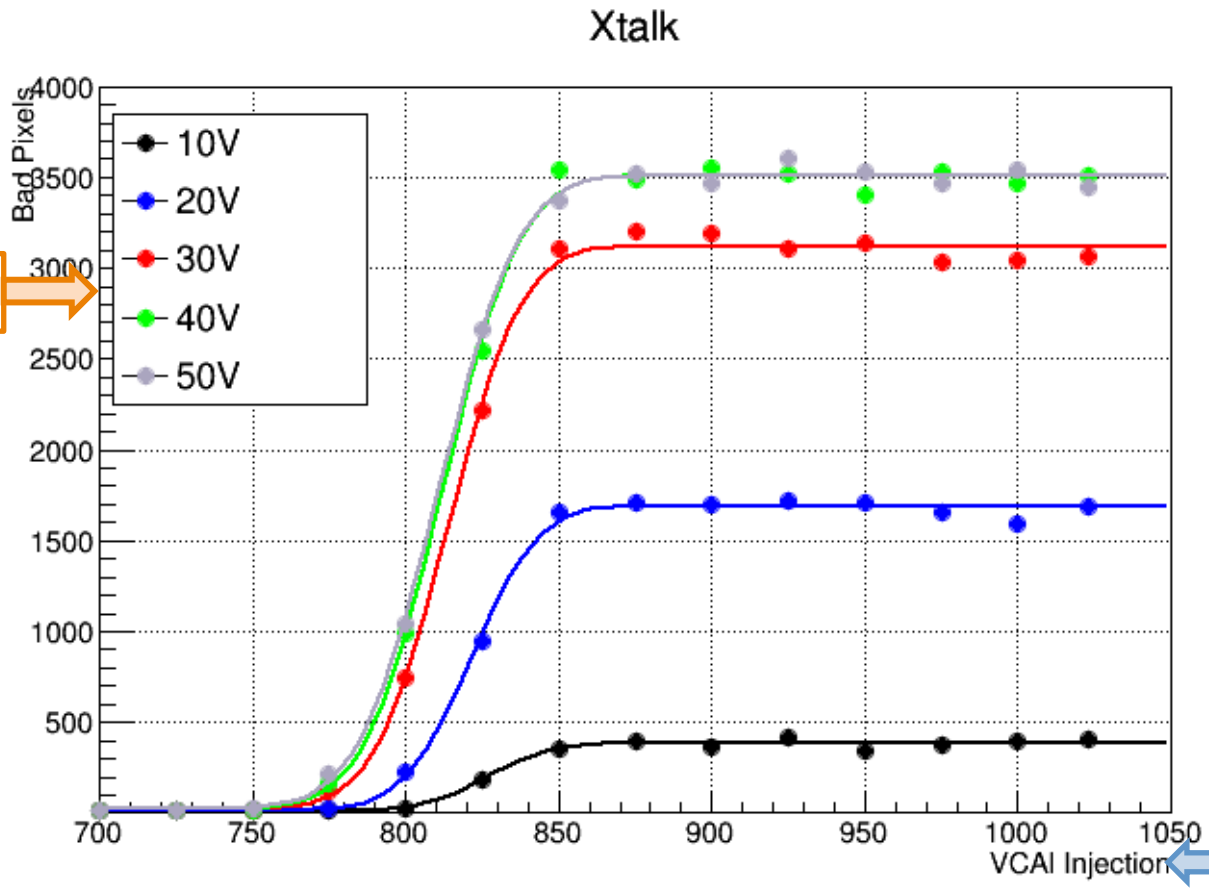

Bad Pixels

VCAL Injection

Plot by C. Gemme

# Cross-Talk Vs HV

**Crosstalk Pixels Vs charge injected for different values of $V_{bias}$.**
**The Cross-Talk increases with $V_{bias}$ up to saturation.**




Bad Pixels

VCAL Injection

Plot by C. Gemme

# Conclusions

- ✓ **The IBL is the first "large scale" 3D detector.**
- ✓ **3D module production has been a positive experience.**
  - ↘ **The large statistic production has spotted some minor but interesting effects that could be important to future developments.**

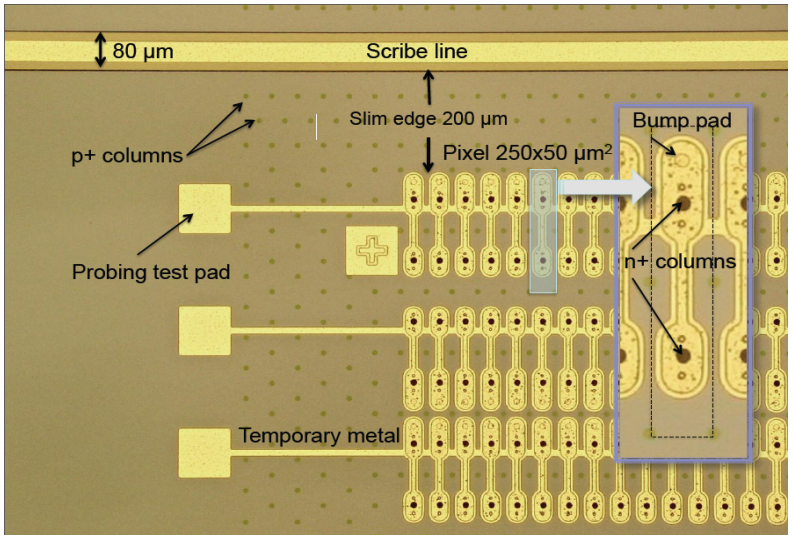
  **A better QA at wafer level is certainly welcome to improve yield and reduce costs.**

Thank you!

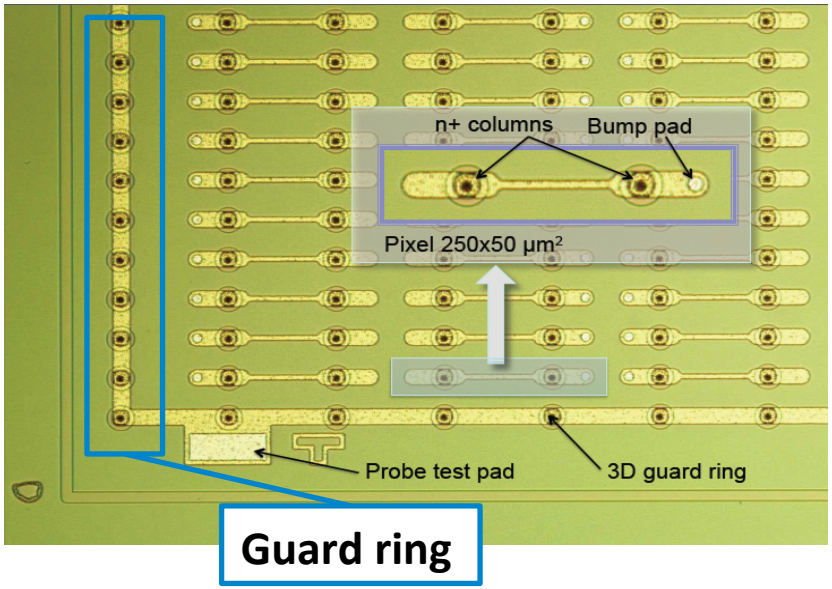
# SPARE

# FBK CNM Sensors

FBK




CNM



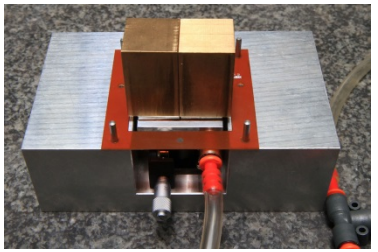

During the Ileak measure all pixels are connected

CNM:The Ileak current is measured only on the guard ring

# Building and Qualification of Modules

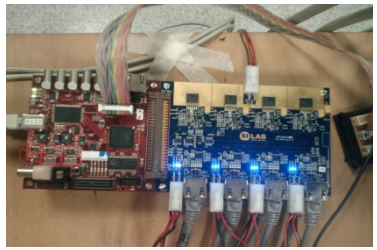
Sensors are flip-chipped at IZM and then delivered to Genova and Bonn for module assembly and testing.

- ✓ Assembly of a module starts with gluing a module pigtail on bare module (SC/DC).

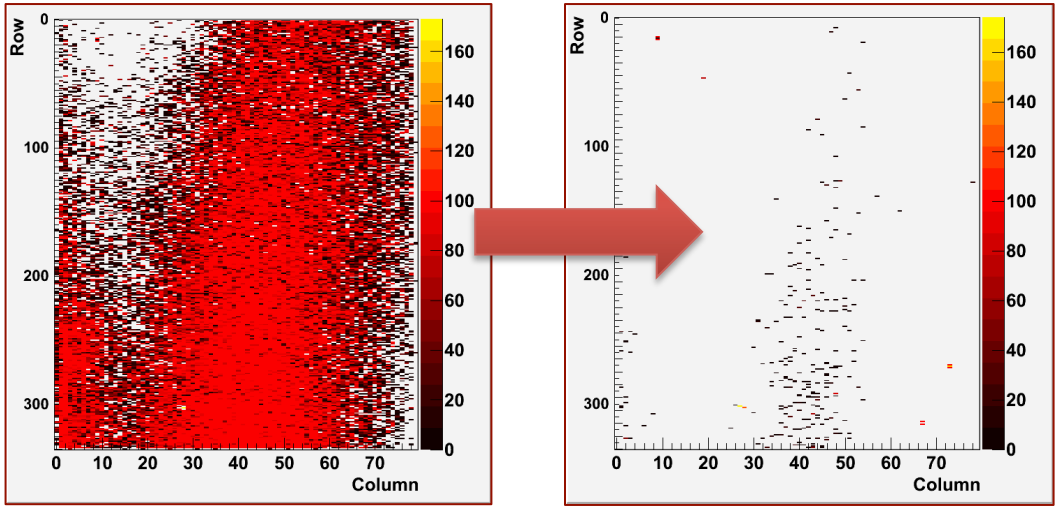


- ✓ Wirebondings are done to the FE pads, to the HV and to the test pads. It is also done a pull test to qualify the quality.

- ✓ Module is tested with USBPix readout system

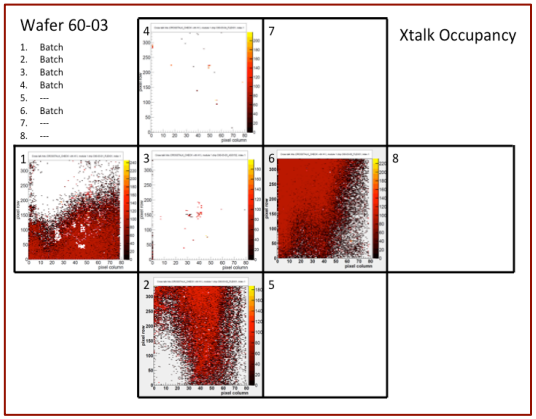


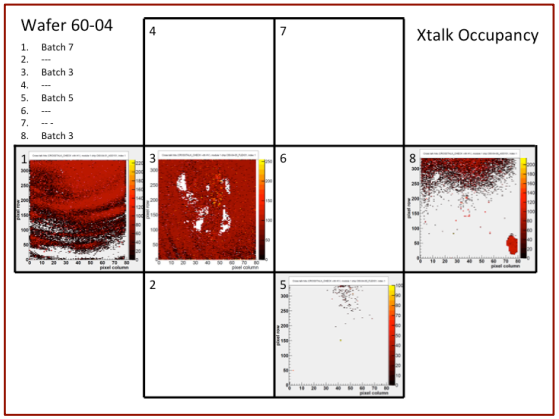
# Cross-Talk




- ✓ To observe that changing the injected charge (Vcal = 800) the Xtalk disappear.
- ✓ For this reason has been implemented during the production Xtalk scans with both charge injection (1023 and 800)

It is also interesting to observe that a good part of CNM modules with high Crosstalk seems to derive from the same wafers.



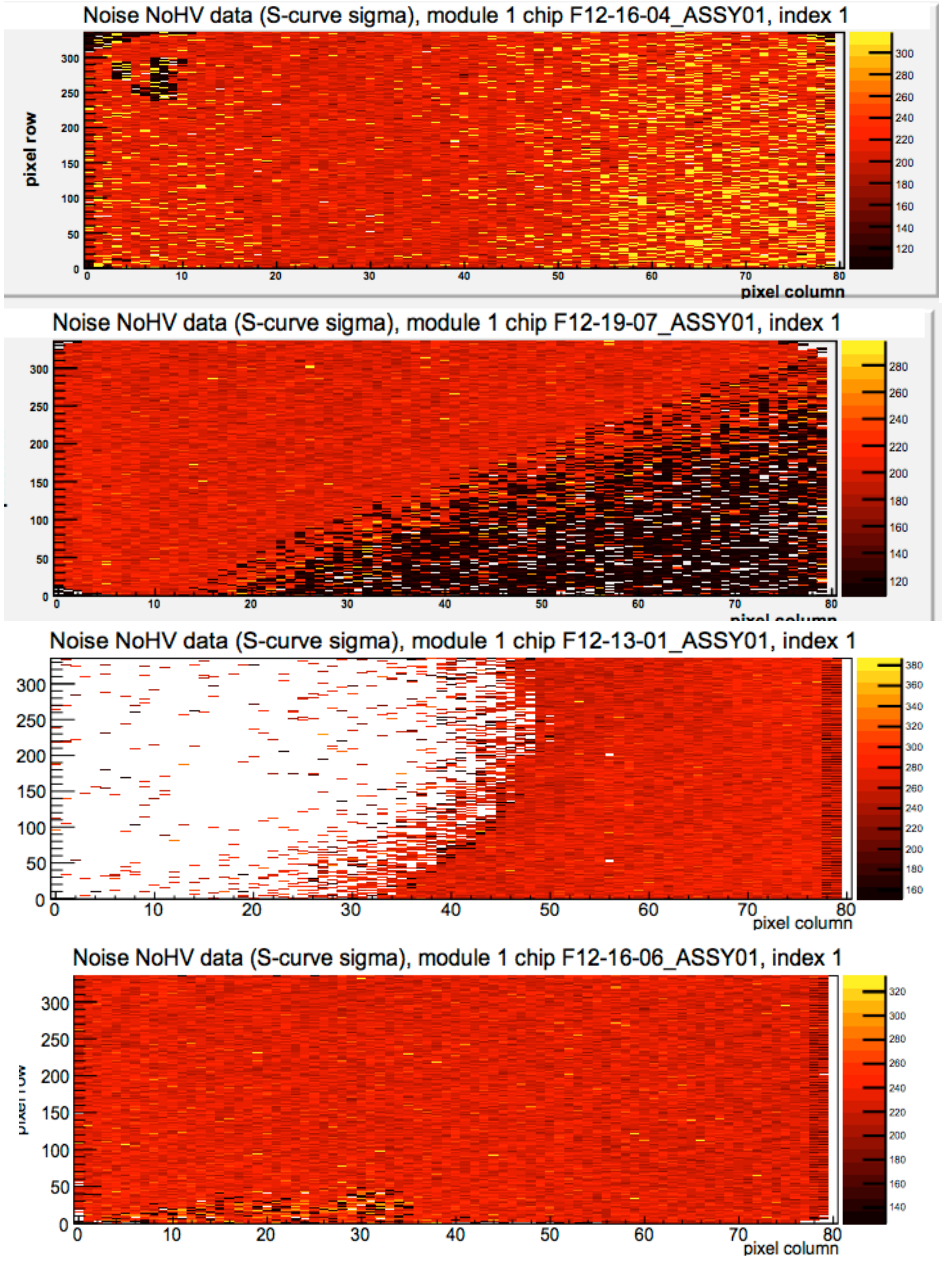




**Pictures by I.Lopez**

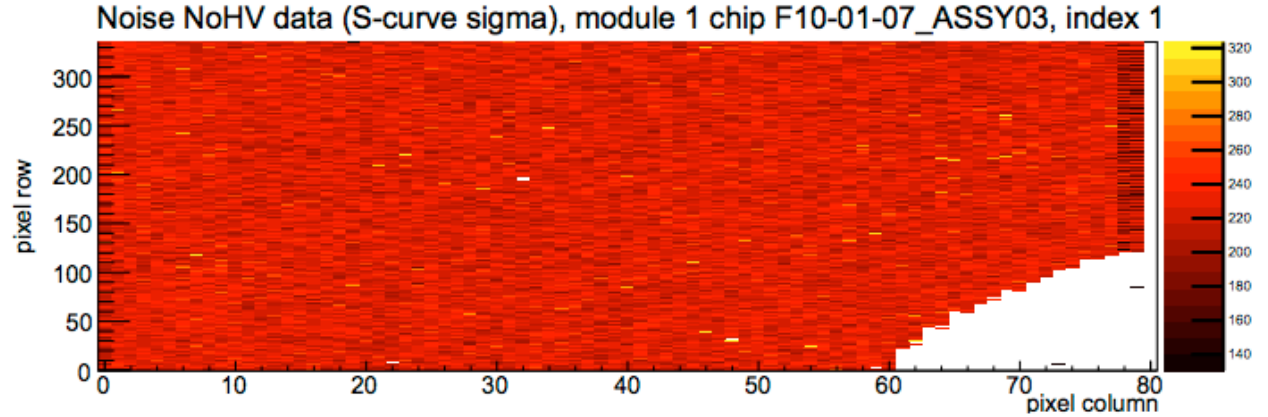
# Table of FBK Rejected Bumps

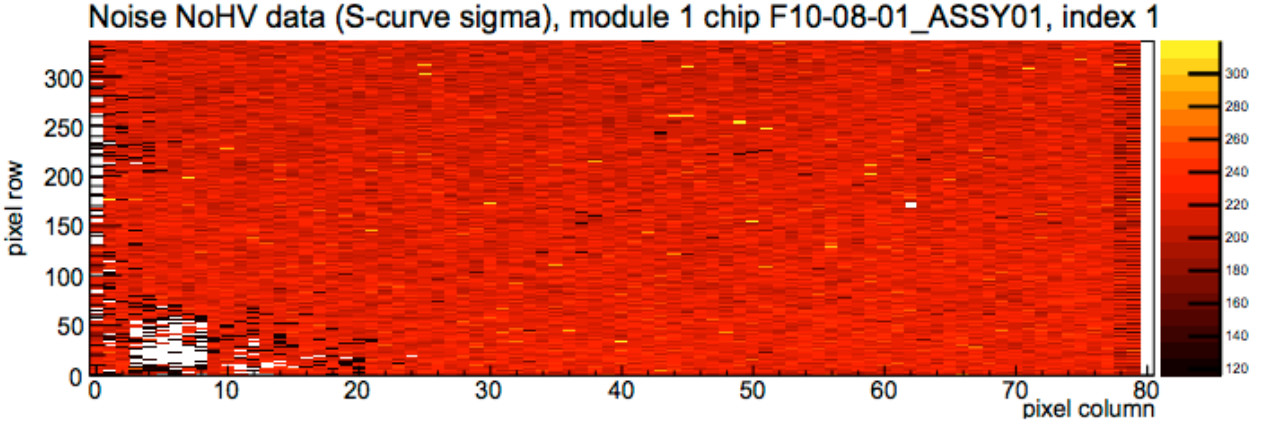
| | | |
|---|---|---|
| F10-18-02 | 1 | Tamarack |
| F10-18-06 | 1 | Tamarack |
| F10-22-08 | 1 | Tamarack |
| F10-07-01 | 2 | Tamarack |
| F10-07-03 | 2 | Tamarack |
| F10-18-08 | 2 | Tamarack |
| F12-02-02 | 2 | Tamarack |
| F12-02-08 | 2 | Tamarack |
| F12-19-05 | 2 | Tamarack |
| F10-08-03 | 2 | Tamarack |
| F12-13-01 | 2 | Tamarack |
| F10-20-07 | 2 | Tamarack |
| F10-04-03 | 3 | Tamarack |
| F10-18-07 | 3 | Tamarack |
| F12-07-05 | 3 | Tamarack |
| F10-02-06 | 3 | Tamarack |
| F12-07-08 | 3 | Tamarack |
| F12-19-02 | 3 | Tamarack |
| F10-01-07 | 5 | Götttingen |
| F10-04-06 | 5 | Götttingen |
| F12-13-01 | 6 | Tamarack |
| F12-16-06 | 6 | Tamarack |
| F12-13-05 | 6 | Tamarack |
| F12-16-04 | 6 | Tamarack |
| F12-19-07 | 6 | Tamarack |
| F10-08-01 | 13 | Göttingen |
| F12-13-03 | 14 | Göttingen |
| F12-19-02 | 14 | Göttingen |
| F12-02-07 | 14 | Göttingen |
| F13-09-08 | 14 | Göttingen |
| F10-07-02 | 14 | Göttingen |
| F12-02-07 | 9 | Tamarack |
| F12-13-03 | 9 | Tamarack |
| F13-09-08 | 9 | Tamarack |
| F13-09-05 | 9 | Tamarack |
| F13-09-03 | 9 | Tamarack |
| F12-23-01 | 9 | Tamarack |
| F12-23-06 | 9 | Tamarack |
| F13-06-04 | 9 | Tamarack |
| F12-02-06 | 9 | Tamarack |

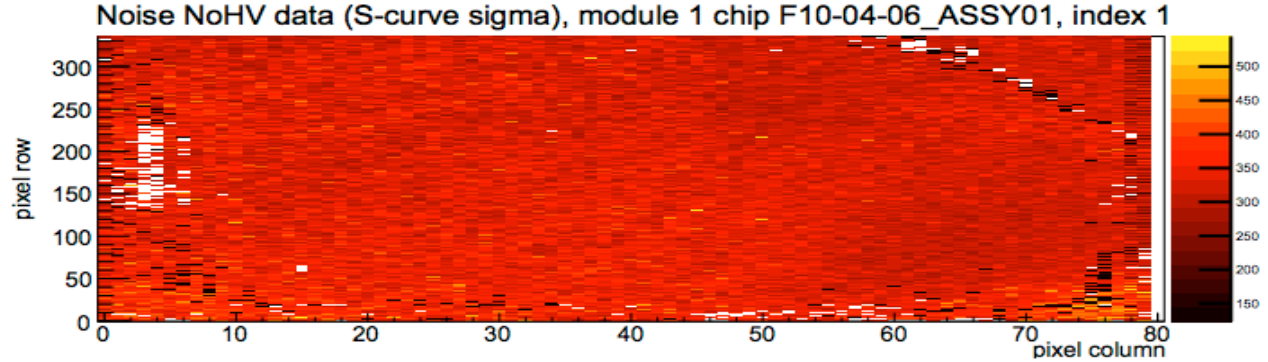
# FBK Rejected Bumps (Batch 4,6)



# FBK Rejected Bumps (Batch 5,8,13)



# FBK Rejected Bumps (Batch 9)