Sensors Dark Noise Studies

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Summary

- Introduction
- Results
  - FUSION, FLASH and BSI Express comparison
    - Sensors sensitivity using ^{55}Fe source
    - Read Noise
      - Entire sensor
      - By regions
    - Telegraph Noise
  - FUSION - air vs water cooling using different exposure time
- Final considerations

Introduction

- **3 sensors tested in Dark:**
  - ORCA-Flash4.0 V3
  - ORCA-Fusion C14440-20UP
  - Prime BSI Express *(2 gain modes LG and HG)*

Read noise
Exposure time = 40 ms

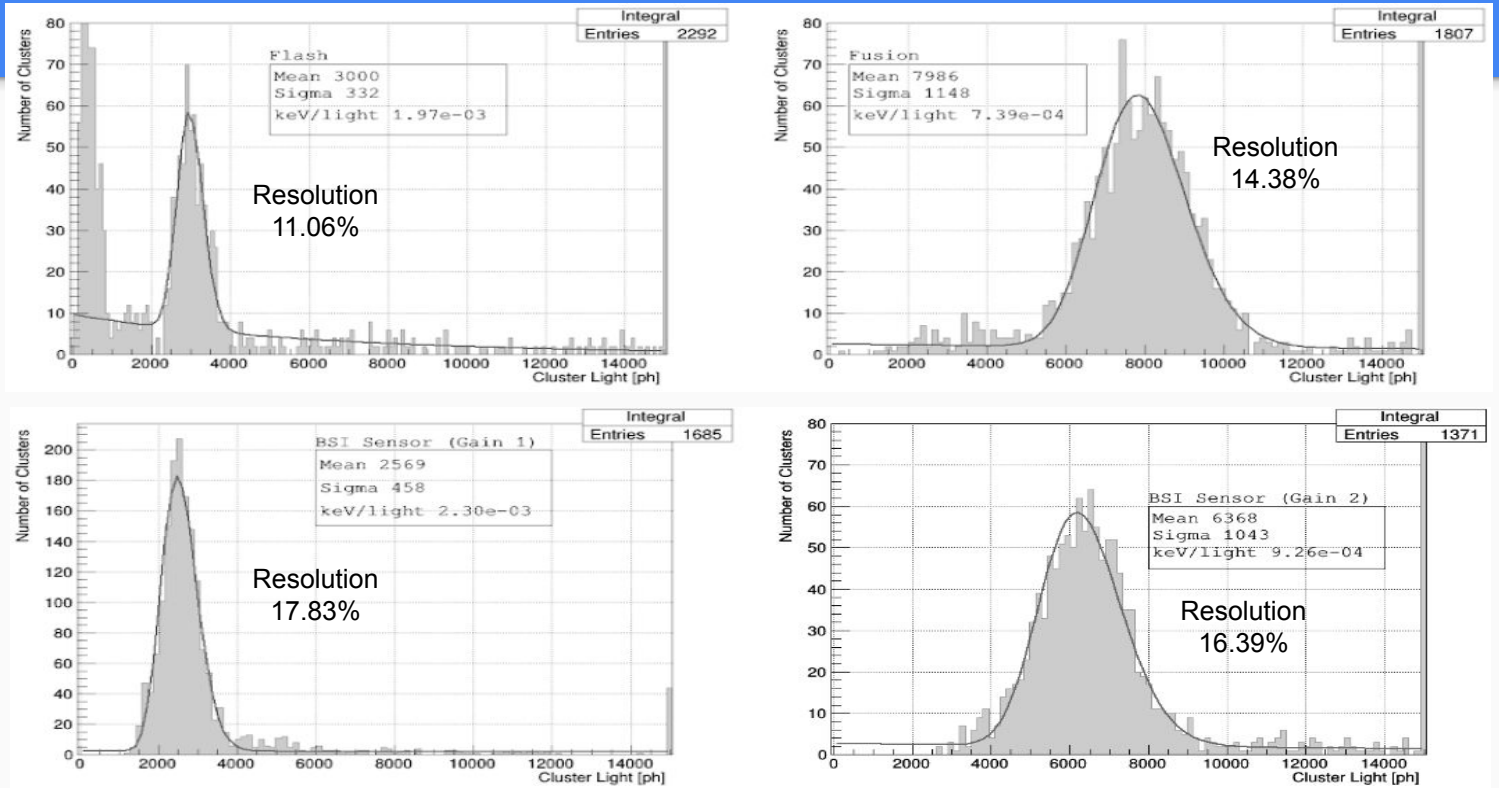
- ***Fusion and Flash tested with different exposure times:***

Read noise + Dark current
Exposure time = from 10 ms to 10 s

- **All of them with same pixel size** ***(6.5μm x 6.5μm)***
- **Datasheet related information:**

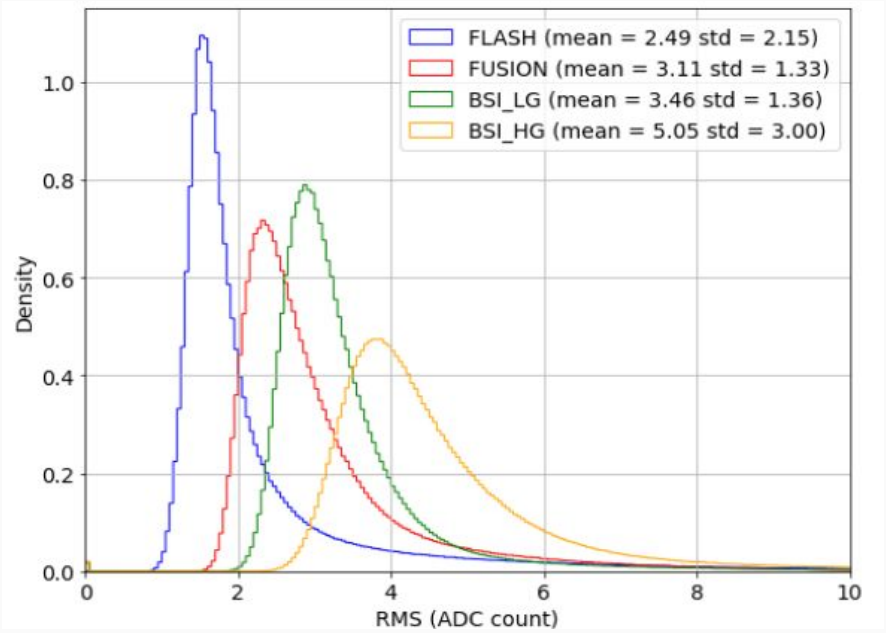
	Read noise (electrons)	Dark current (electrons/pixel/s)
Flash	1.4	0.06
Fusion	0.7	0.5
BSI_LG	1.1	1.5
BSI_HG	1.8	1.5

Sensitivity to ^{55}Fe source (LEMON)

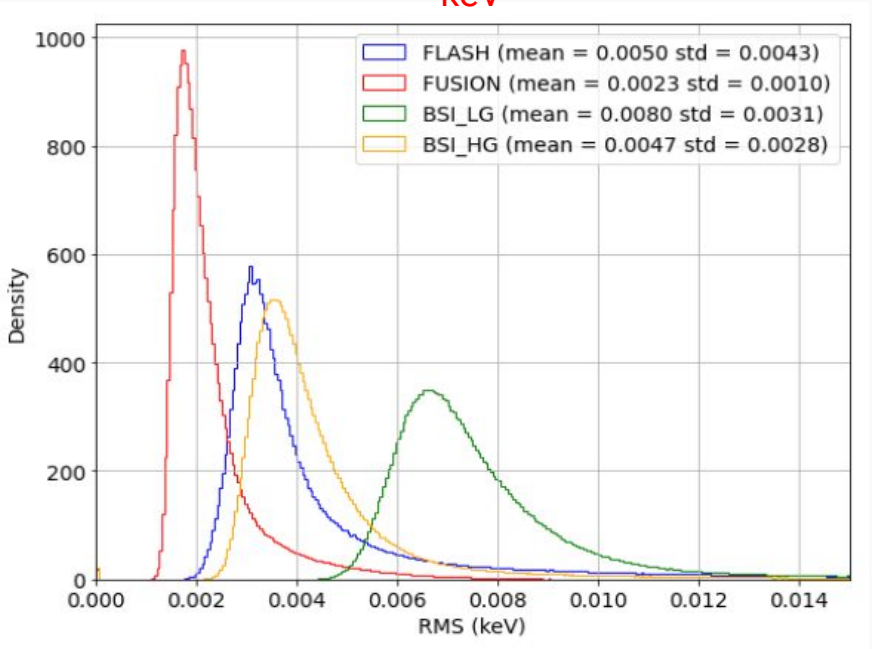


Read noise - entire sensor

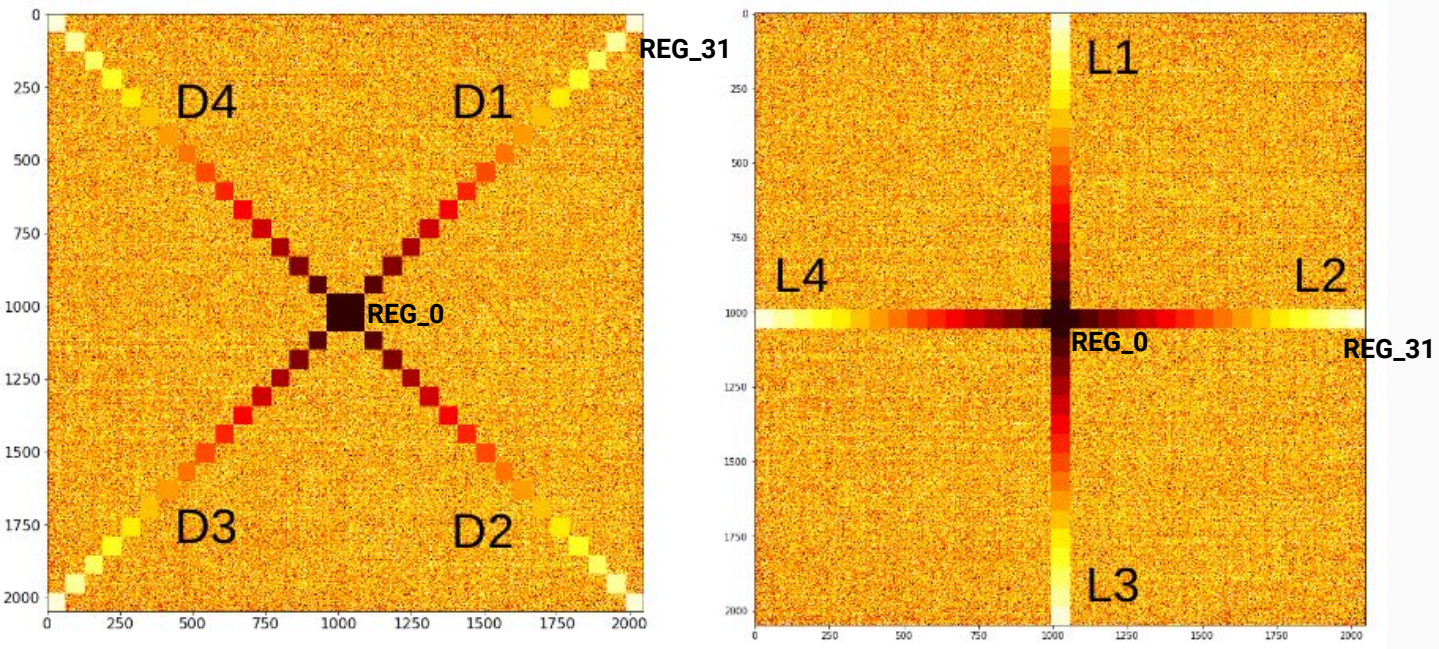
ADC count



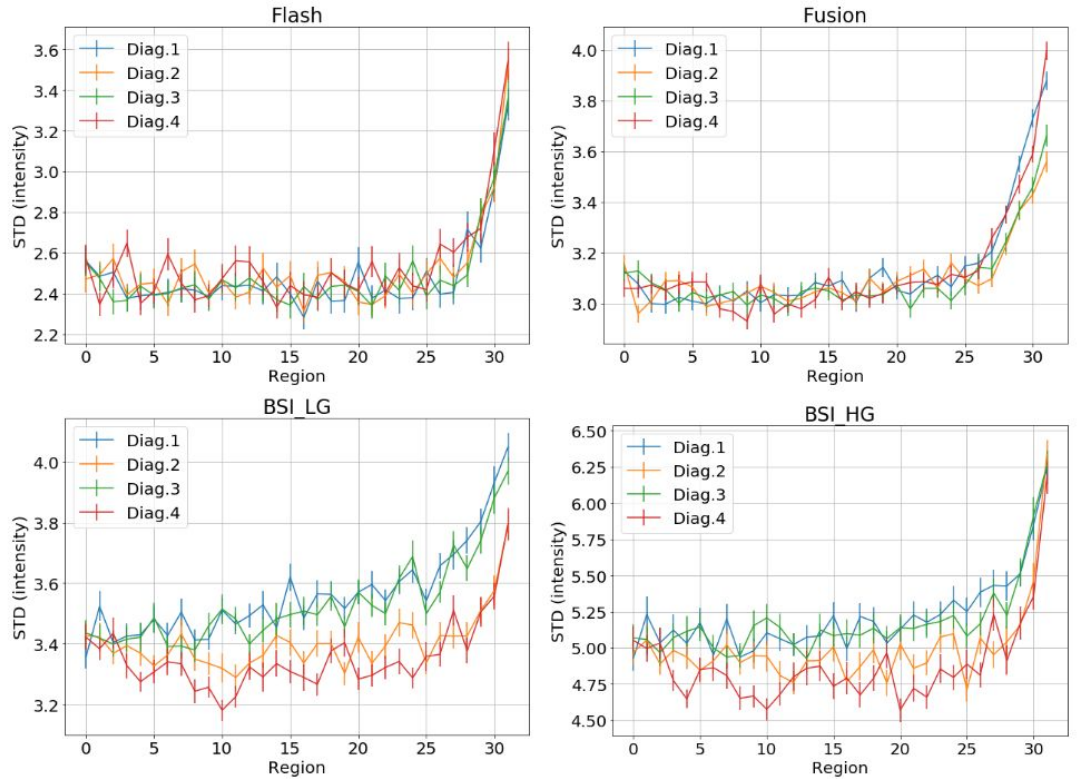
keV

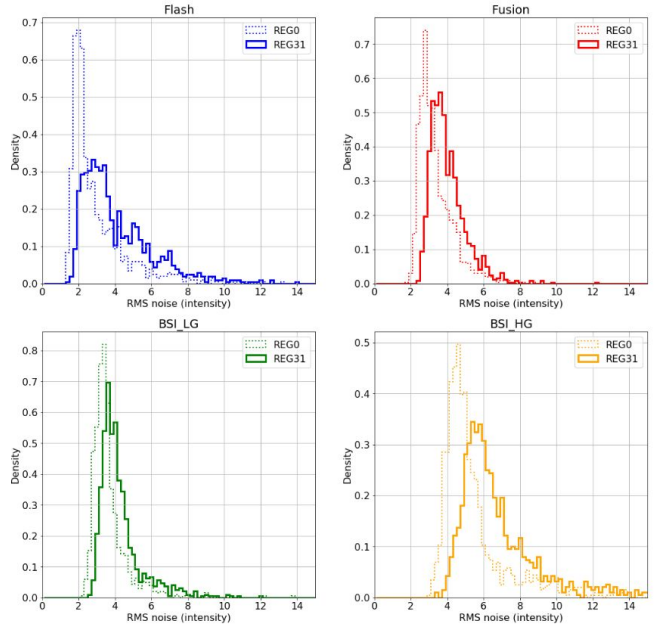


Read noise - by regions

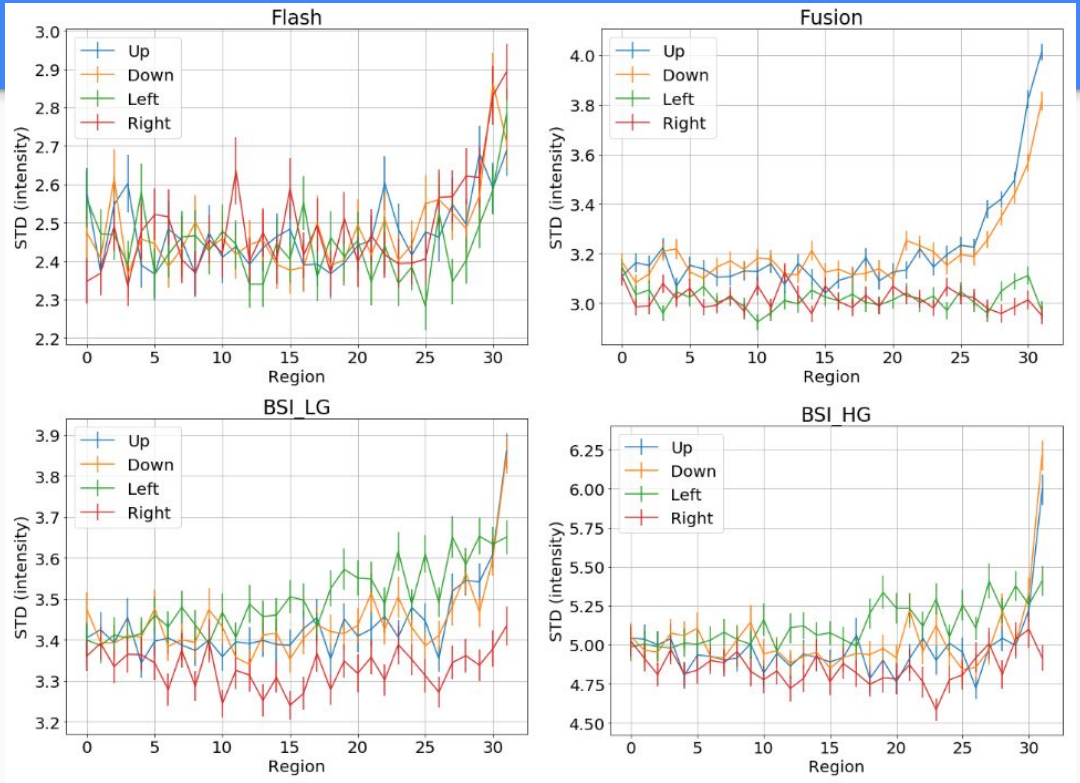


Read noise - by regions (DIAGONAL)



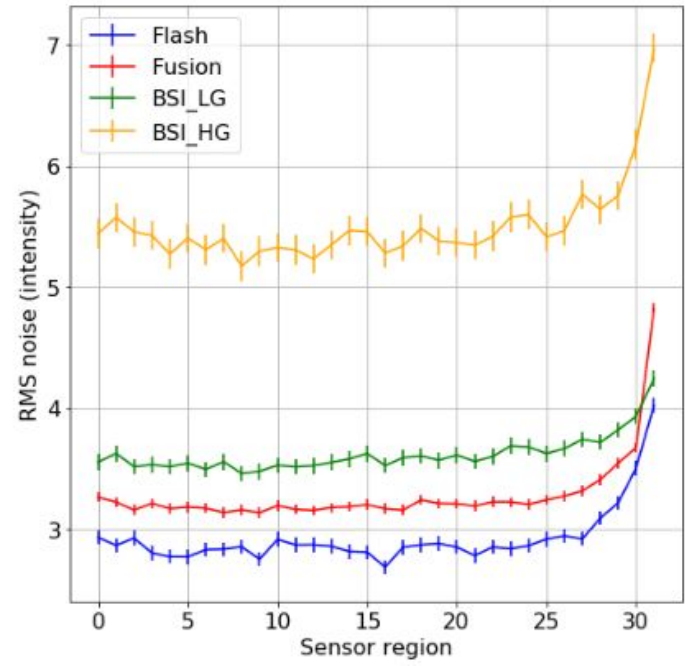


Read noise - by regions (LATERAL)

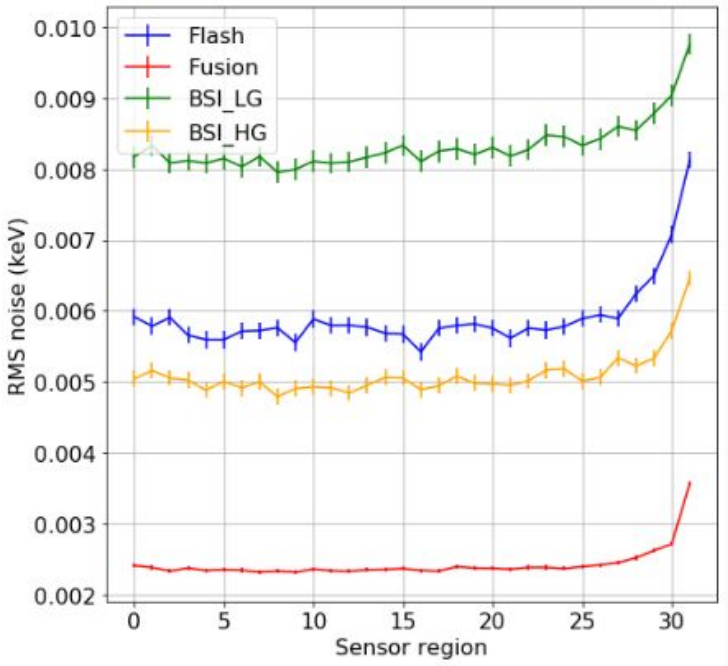


Read noise - all together

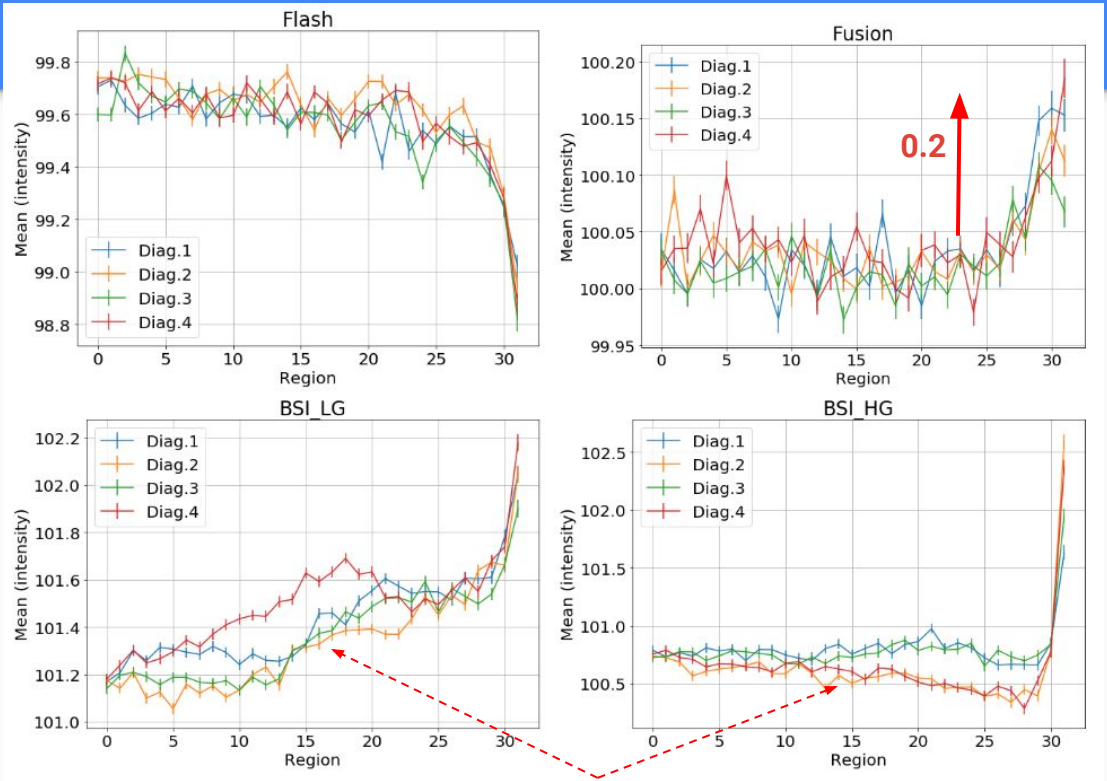
ADC count

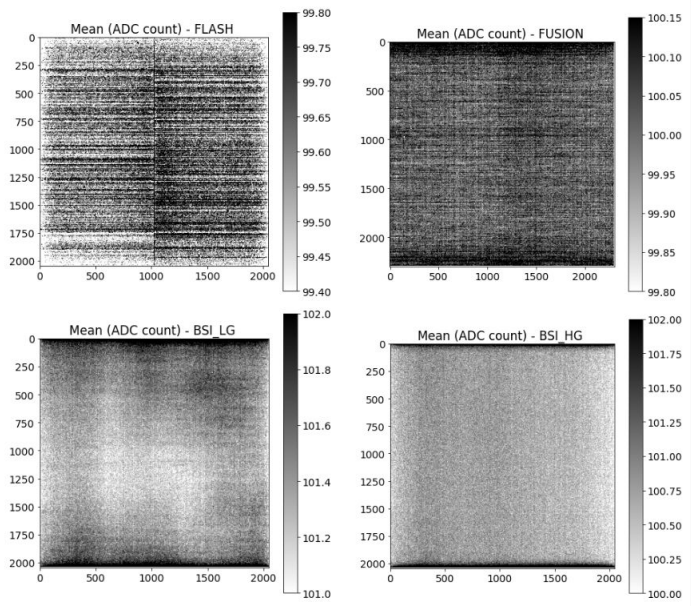


keV

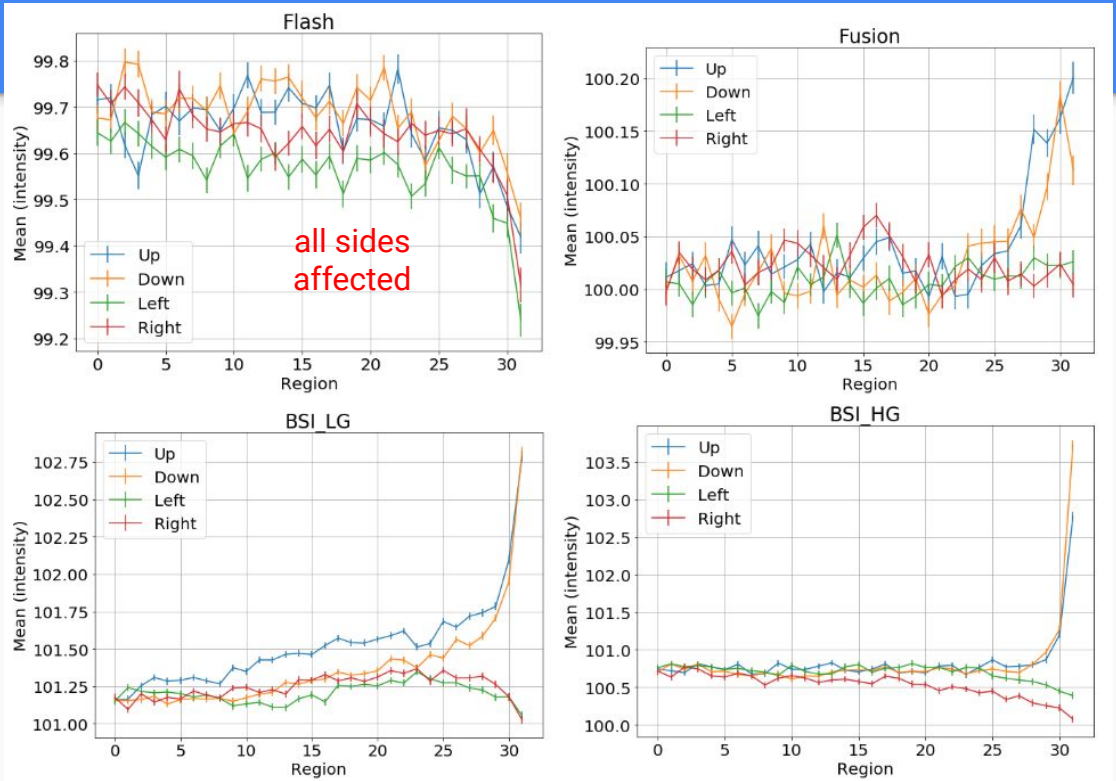


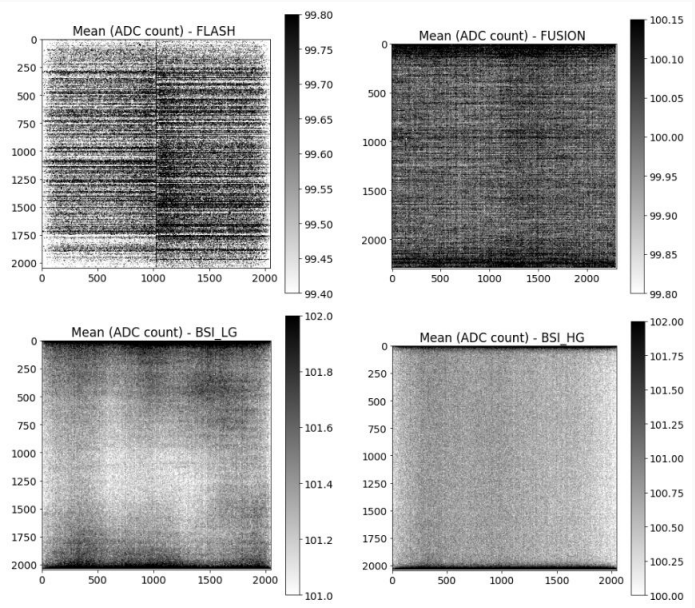
Offset - by regions (DIAGONAL)





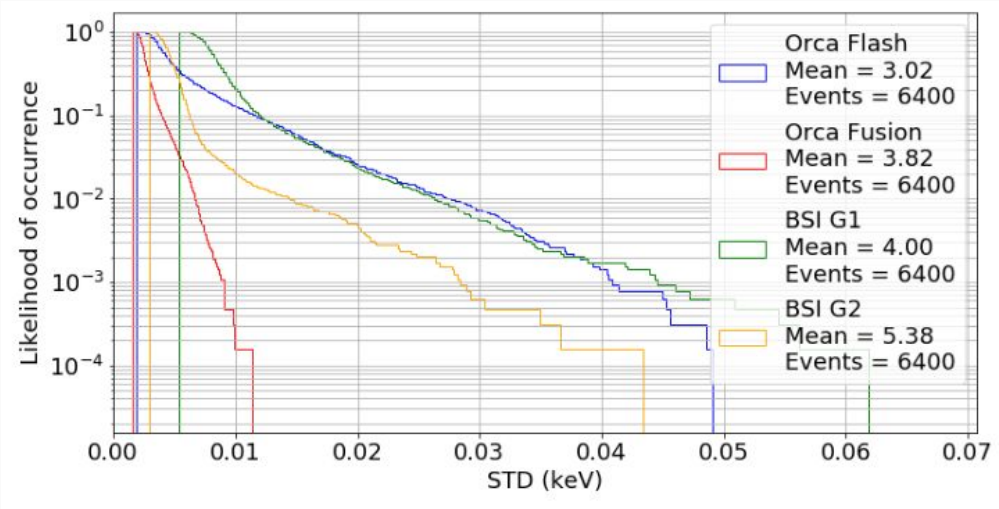
Offset - by regions (LATERAL)

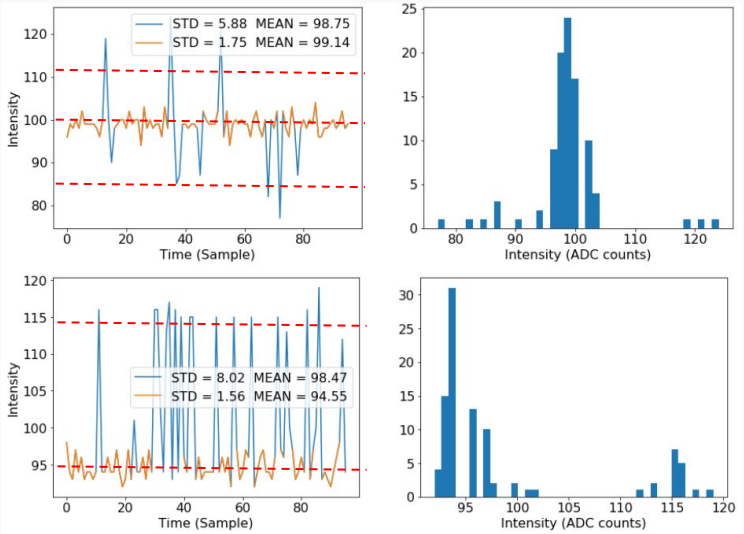




Telegraph noise

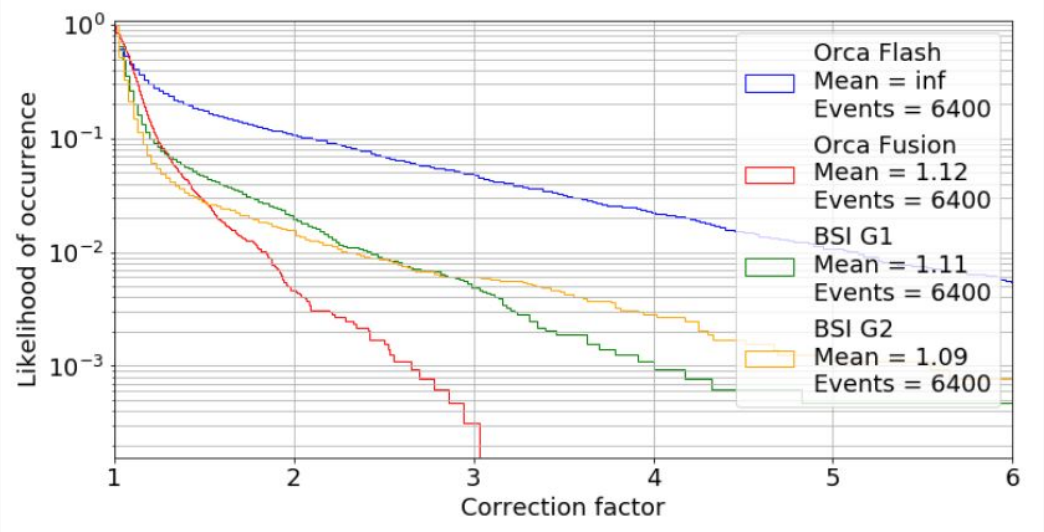
- **Sensors noise with heavy tail (apart from Fusion)**
- **Most of it caused by *Telegraph noise***

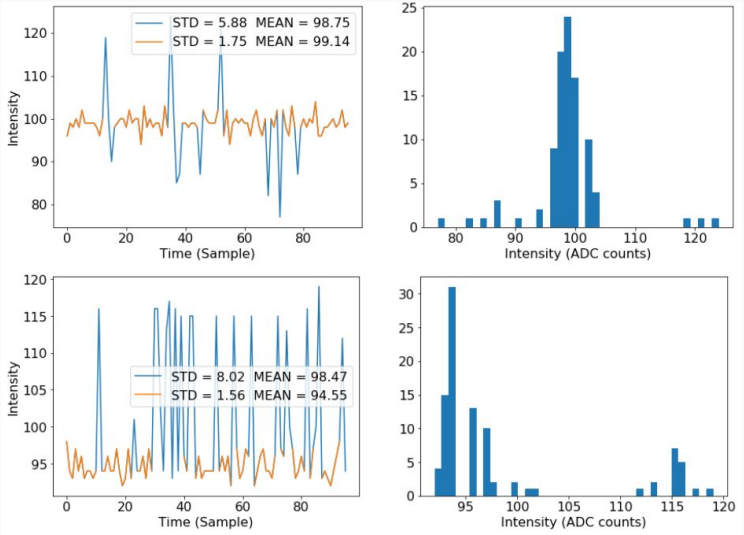




Telegraph noise

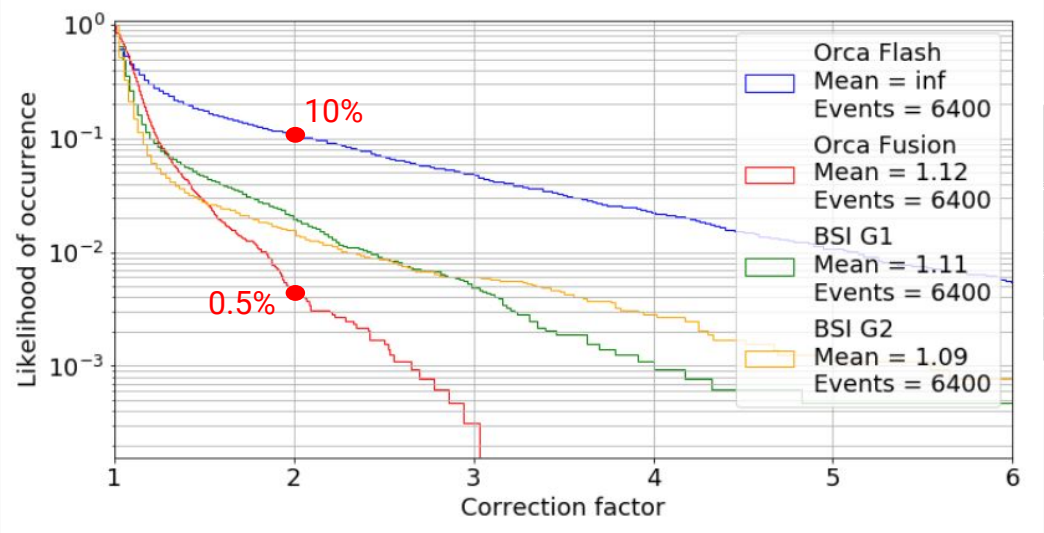
- **Correction Factor = ratio between $RMS_{original}$ and $RMS_{clipped}$**





Telegraph noise

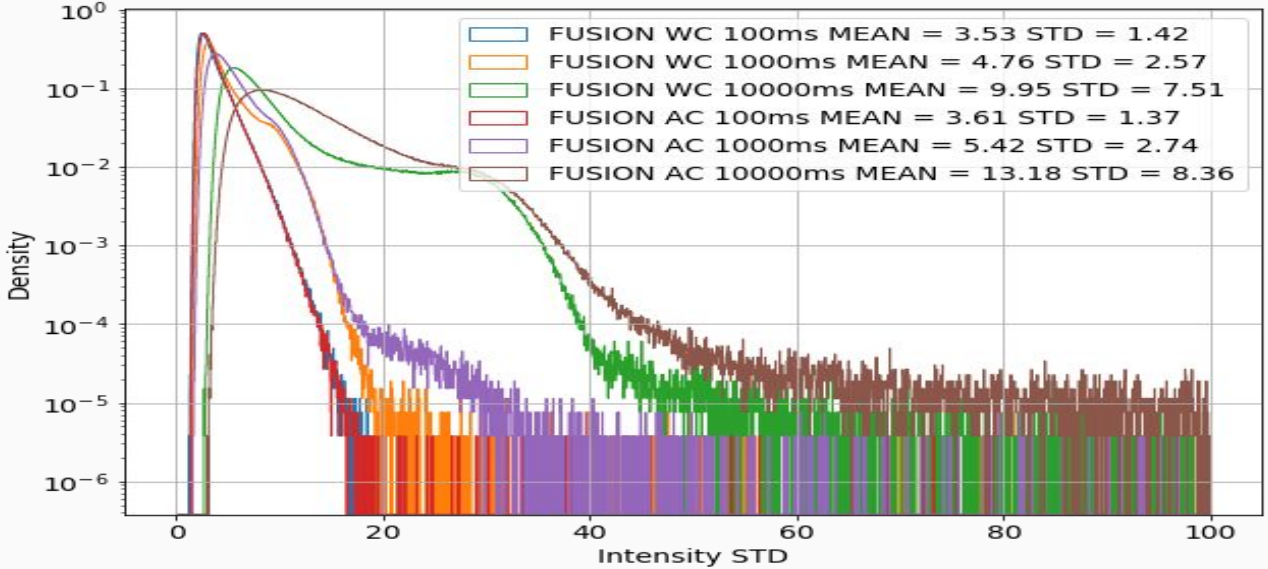
- More than 10% of the Flash pixels have a CF > 2 while Fusion has only 0.5% of pixels.
- BSI_HG and BSI_LG values go to about 1.5% and 2.0%.



	CF > 2 (%)	CF > 3 (%)	CF > 4 (%)	CF > 5 (%)	CF > 6 (%)
O.FLASH	11.0	4.0	2.0	1.0	0.5
O.FUSION	0.5	0.04	0.0	0.0	0.0
BSI_LG	2.0	0.5	0.01	0.05	0.05
BSI_HG	1.5	0.6	0.03	0.1	0.08

FUSION - Air vs Water Cooling - RMS

- STD @ 100 ms about the same
- STD difference starts at 1000 ms



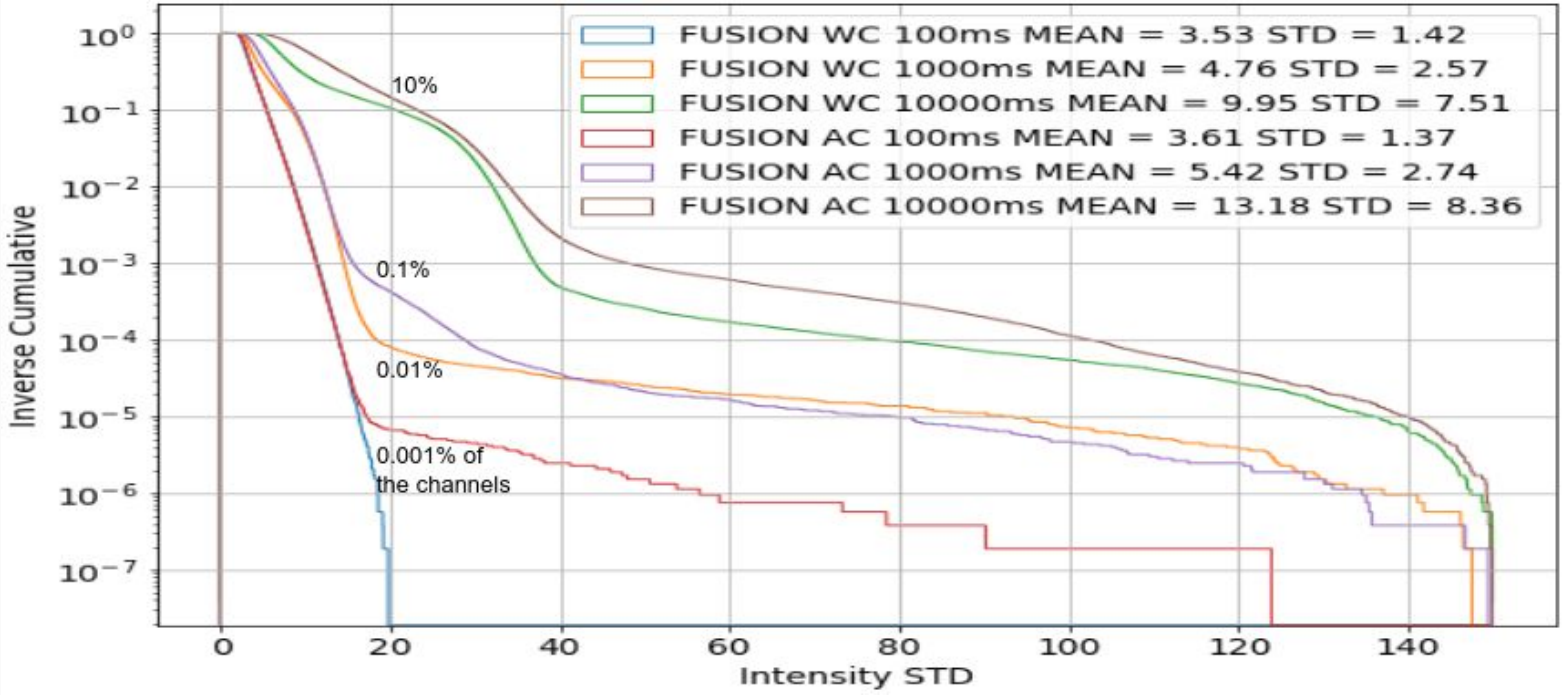
SUMMARY

STD HISTOGRAMS (MEAN / STD)

EXP. TIME ms	FUSION WC	FUSION AC
100	3.53 / 1.42	3.61 / 1.37
1000	4.76 / 2.57	5.52 / 2.74
10000	9.95 / 7.51	13.18 / 8.36

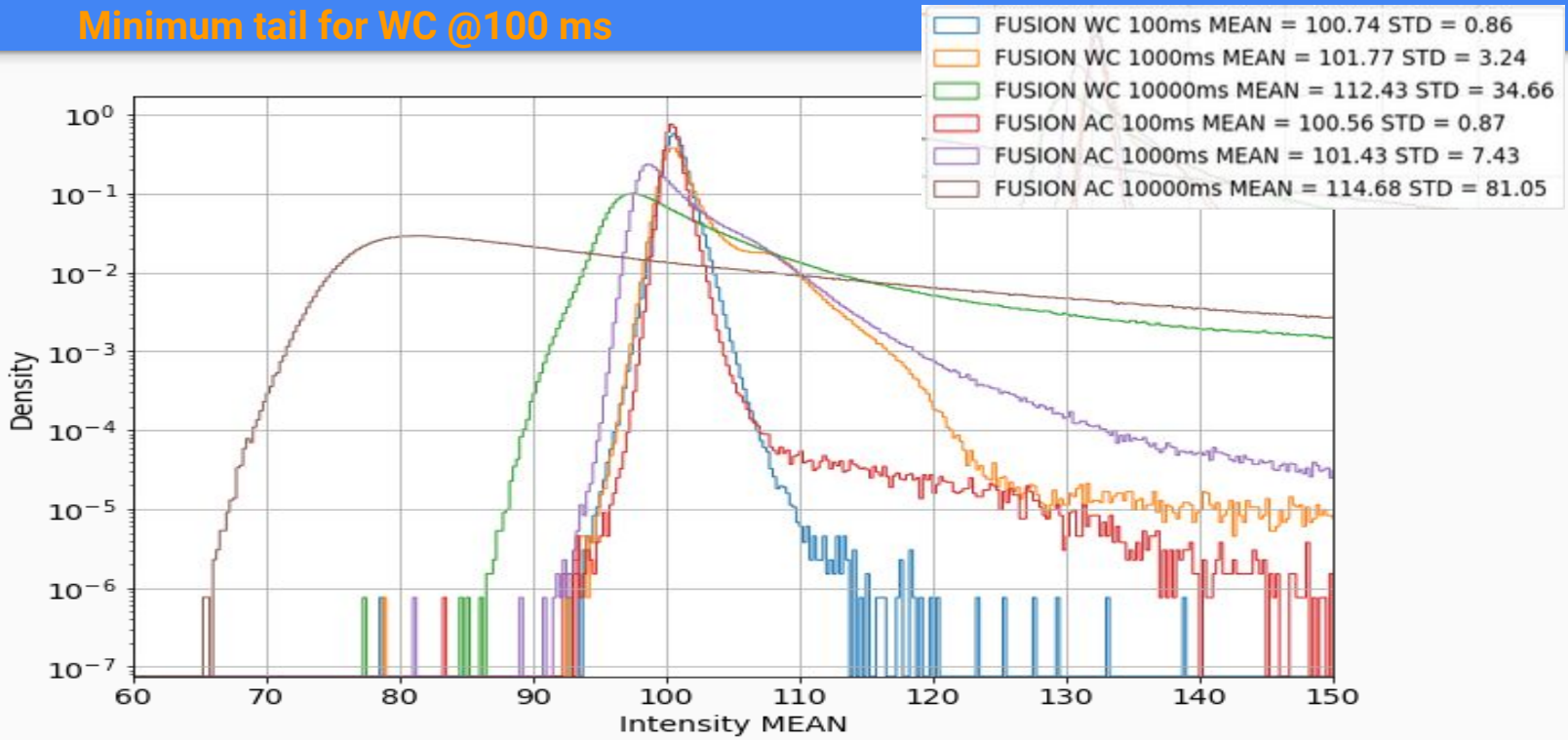
FUSION - Air vs Water Cooling - RMS

Log scale (WC @100 ms shows a tail difference from AC)



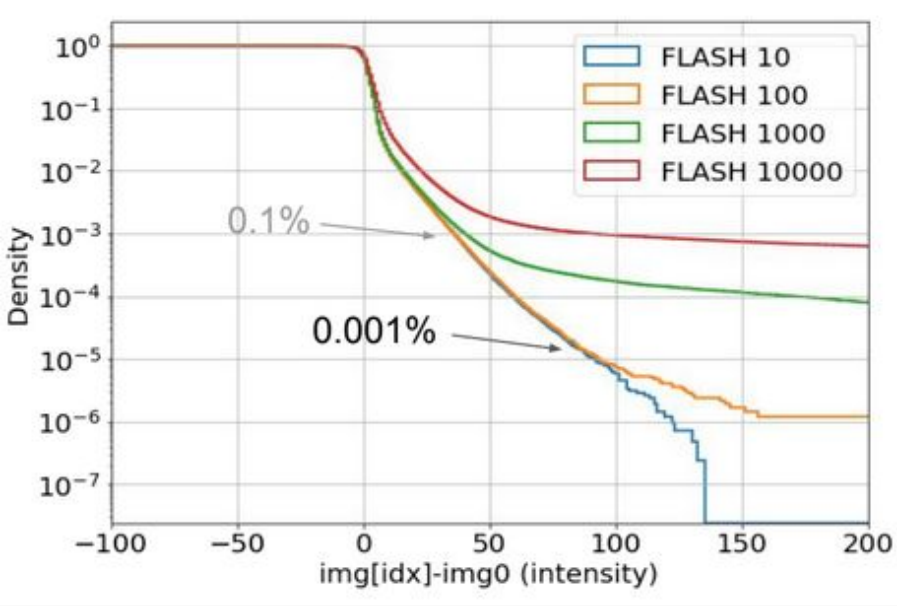
FUSION - Air vs Water Cooling - MEAN

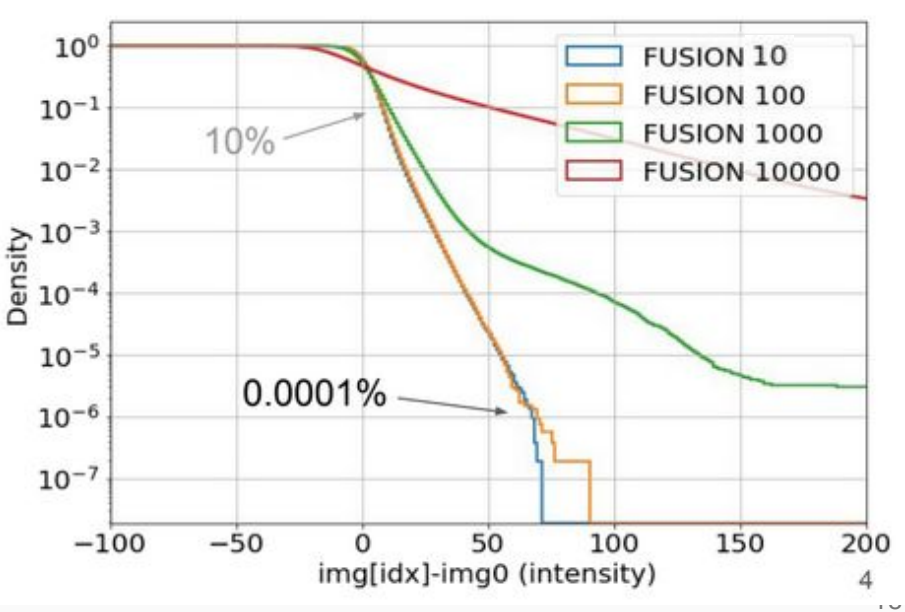
Minimum tail for WC @100 ms



Read Noise - Exposure Time (Flash vs. Fusion)

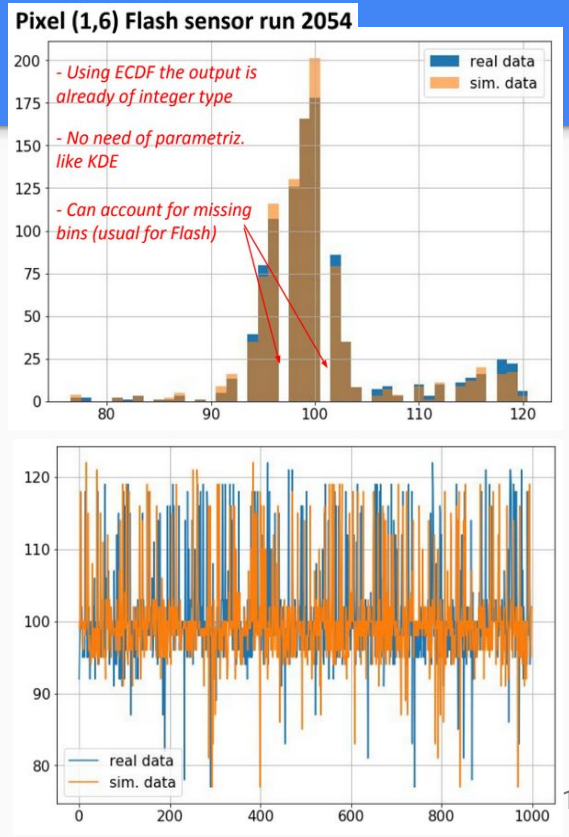
AIR COOLING





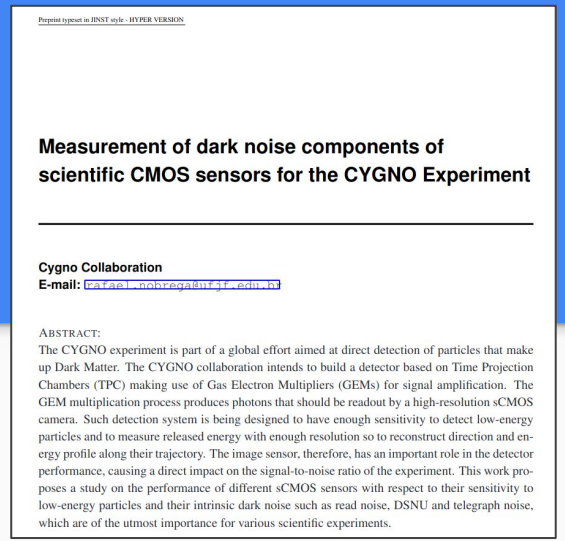
Simulation of noise based on CYGNO's dark images

- **The performed study has leaded us to use non-parametric noise estimation**
  - **can deal with non-gaussianity and presence of spikes**
- **Empirical CDF to simulate noise**
  - **the precision would depend only on the number of images used as input of the CDF generator**
- **A code to generate noise is available in github**



Final considerations

- **BSI Express, Flash and Fusion sensors compared**
  - Fusion had the best results (up to 1000 ms)
  - Paper in final stage (40 ms)
    - noise found for the BSI chip was doubled when compared to datasheet
- **Fusion Air vs. Water cooling tested**
  impact on detector must be studied
- **NEXT STEPS:**
  - Finish the paper to send to collaboration review
  - Other sensors to be evaluated
    - Orca Fusion BT 15440
    - Orca Fusion Quest 15550
  - New publication considering AC, WC and exposure time



Preprint typeset in JINST style - HYPER VERSION

Measurement of dark noise components of scientific CMOS sensors for the CYGNO Experiment

Cygno Collaboration
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ABSTRACT:
The CYGNO experiment is part of a global effort aimed at direct detection of particles that make up Dark Matter. The CYGNO collaboration intends to build a detector based on Time Projection Chambers (TPC) making use of Gas Electron Multipliers (GEMs) for signal amplification. The GEM multiplication process produces photons that should be readout by a high-resolution sCMOS camera. Such detection system is being designed to have enough sensitivity to detect low-energy particles and to measure released energy with enough resolution so to reconstruct direction and energy profile along their trajectory. The image sensor, therefore, has an important role in the detector performance, causing a direct impact on the signal-to-noise ratio of the experiment. This work proposes a study on the performance of different sCMOS sensors with respect to their sensitivity to low-energy particles and their intrinsic dark noise such as read noise, DSNU and telegraph noise, which are of the utmost importance for various scientific experiments.

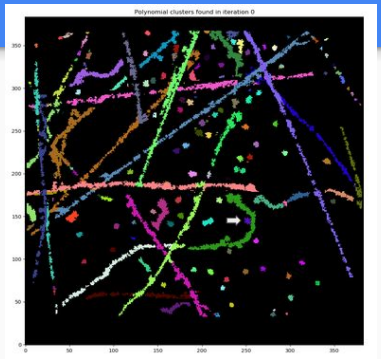
FLASH 1.22 electrons (1.4)
FUSION 0.74 electrons (0,7)
BSI_LG 2.08 electrons (1,1)
BSI_HG 3.03 electrons (1.8)

Read Noise:	Correlated Multi-Sampling (CMS)	1.0e⁻ (Median) 1.1e⁻ (RMS)
	Combined/High Gain	1.6e⁻ (Median) 1.8e⁻ (RMS)
Full-Well Capacity		45,000e⁻ (Combined Gain) 10,000e⁻ (High Gain) 1,000e⁻ (CMS)
Dynamic Range		25,000:1 (Combined Gain)
Bit Depth		16-bit (Combined Gain) 12-bit (CMS) 11-bit (High Gain)
Readout Mode		Rolling Shutter Effective Global Shutter Programmable Scan Mode (PCI-E only)
Binning		2x2 (on FPGA)
Linearity		>99.5%

UFJF and CBPF other activities

in collaboration with INFN groups

- Noise study and simulation
- Development of clustering algorithms
- Image filtering studies
- DAQ related studies
- Development of Trigger Electronics
- Development of PMT readout Electronics



Algorithm	Total time (869)(1 core)
dev20	55h 30m
lime21	to be done
median	**12h 04m**
U-Net (1x GPU P4 16 Gb)	**5h 32m**