Performance of the ATLASPix1 pixel sensor prototype in ams aH18 CMOS technology for the ATLAS ITk upgrade

Moritz Kiehn
for the ATLAS ams/TSI CMOS groups

PIXEL2018
Academia Sinica, Taipei, 13.12.2018

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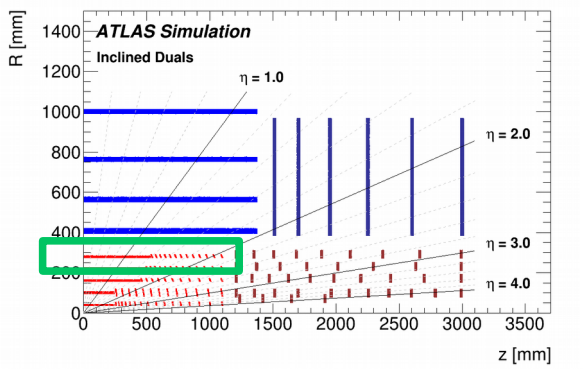
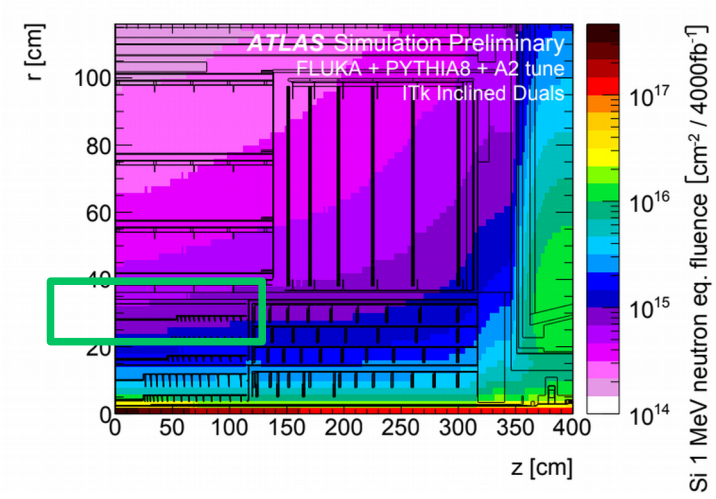
Reminder: ATLAS ITk upgrade





From ATLAS ITk Pixel TDR

Why monolithic CMOS for pixel layer L4?

Largest surface & moderate radiation

Requirements:

- Efficiency > 99%
- Timing within 25ns
- NIEL up to 1.5×10^{15} n_{eq}/cm^2
- TID up to 0.8 MGy
- Drop-in compatibility

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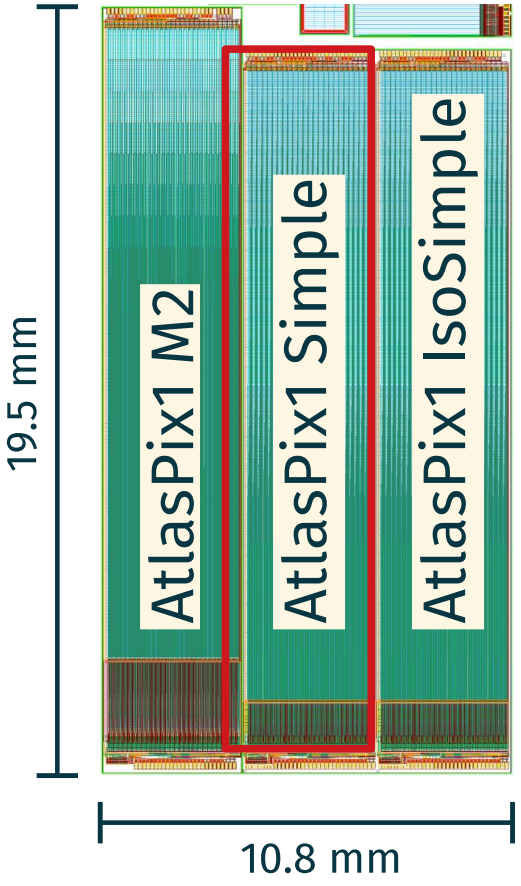
ATLASPix1 prototype

Designed by Ivan Peric et al.



Simple, IsoSimple:

25 x 400 pixels
130µm x 40µm pitch
6bit time-of-arrival
10bit time-over-threshold
Streaming architecture

M2:

56 x 320 pixels
60µm x 50µm pitch
Triggered architecture

Engineering run:

Preproduction (Batch 1)
Production (Batch 2)

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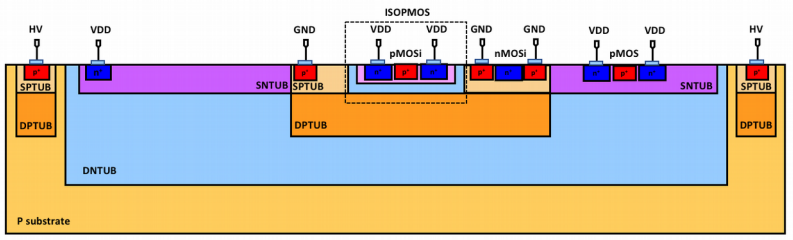
ATLASPix1 design

Large electrode design



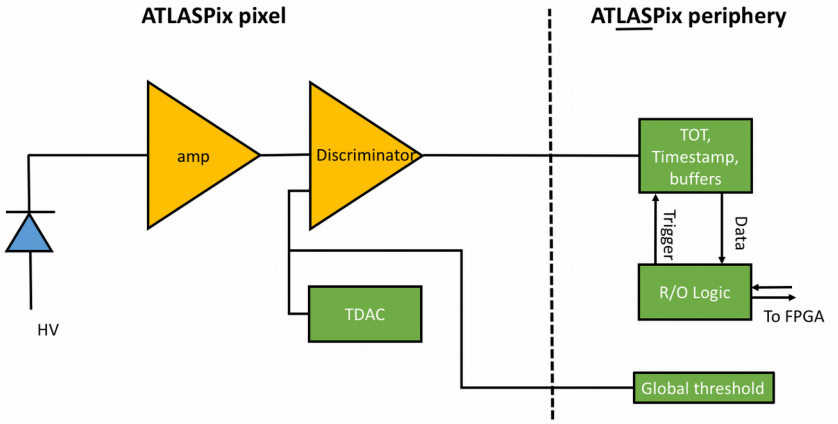
Uniform electric field

Short drift distance

Large(r) capacitance

Produced in ams aH18
180nm HV process

Comparator in pixel/ Logic in periphery



Per-pixel:

3 bit TDAC
1 bit enable

Unused due to issues

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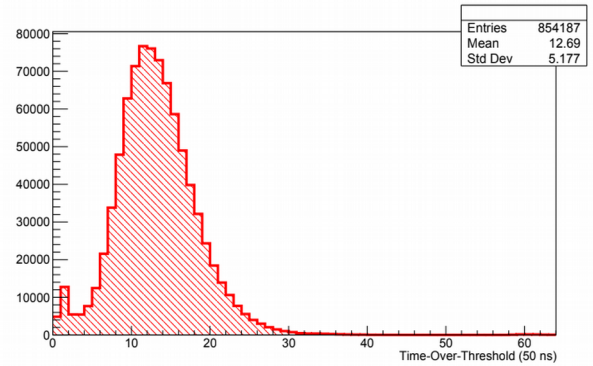
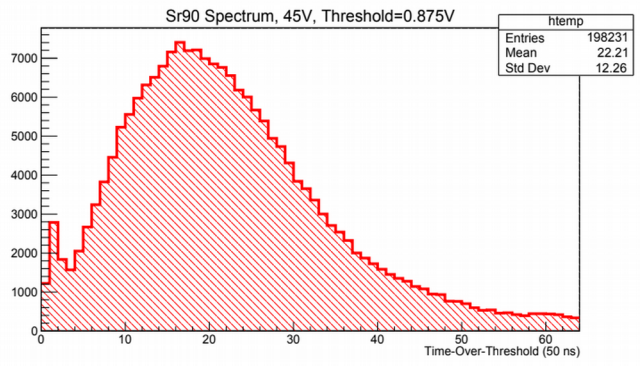
Time-over-threshold and charge calibration

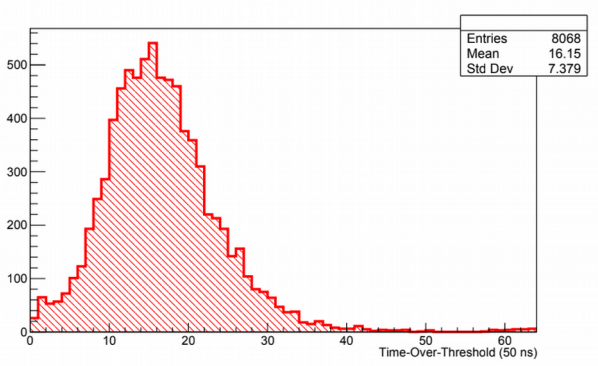
^{55}FE

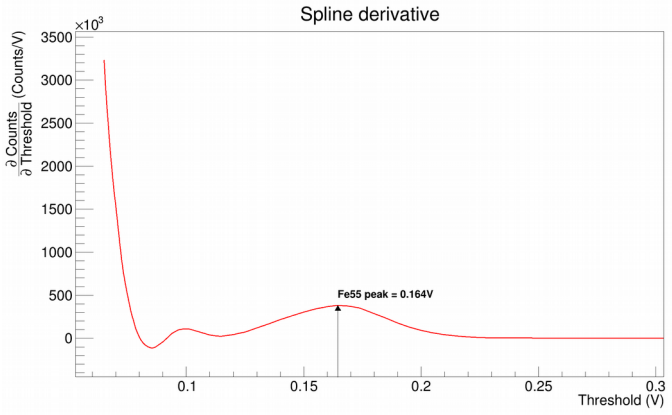


^{90}Sr



^{3}H





Threshold scale
1620 e / 164 mV

45V HV
Threshold 75mW
200 Ωcm
Unirradiated

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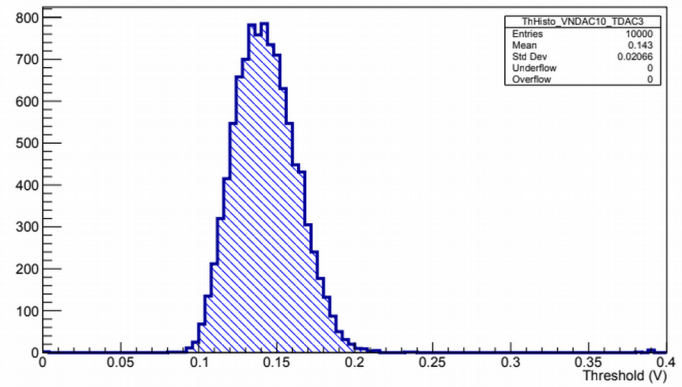
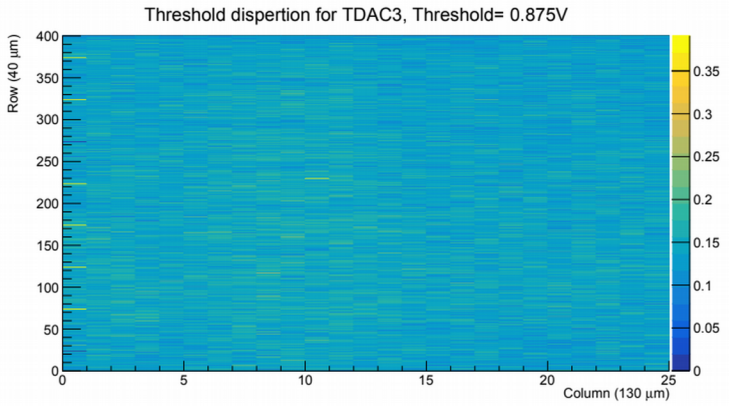
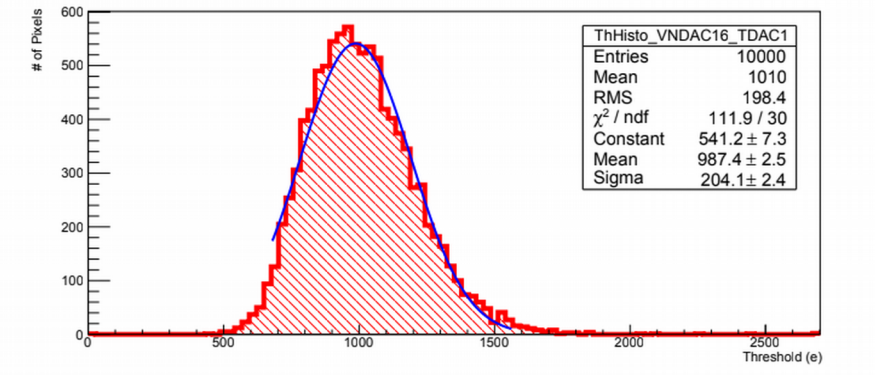
Threshold and noise distribution

Unirradiated





n-irradiated to 10^{15} n_{eq}/cm^2



Untuned threshold dispersion

~ 200 e

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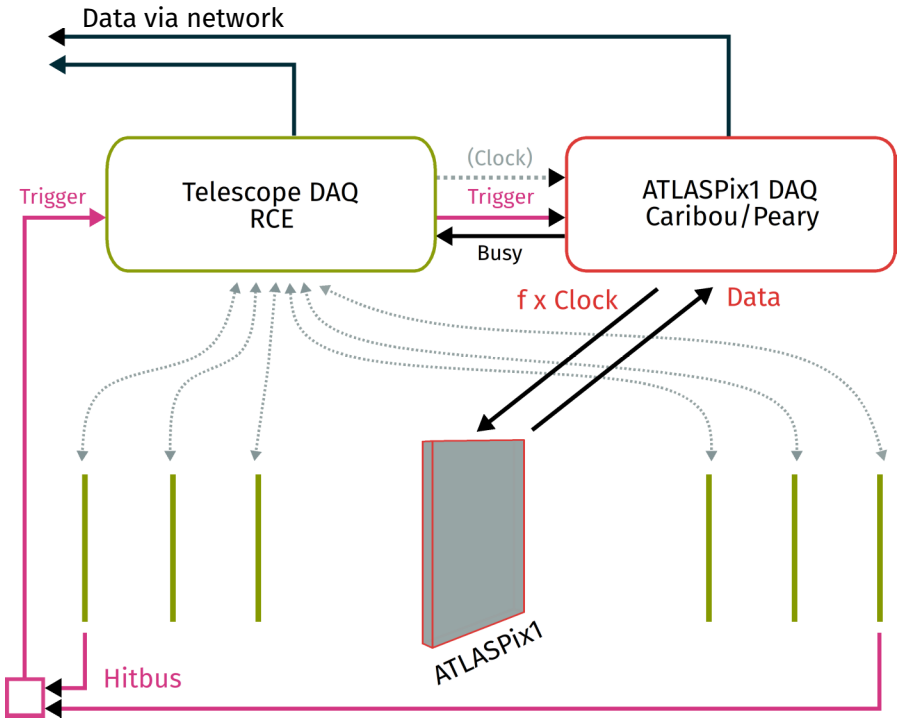
Geneva telescope setup



Geneva FE-I4 telescope

- Trigger/busy scheme
  ATLASPix1 trigger on FPGA

Input clock 50-160 MHz

Data rate (x10) 500-1600 Mbit/s

Timestamps (/2) 25-80 MHz

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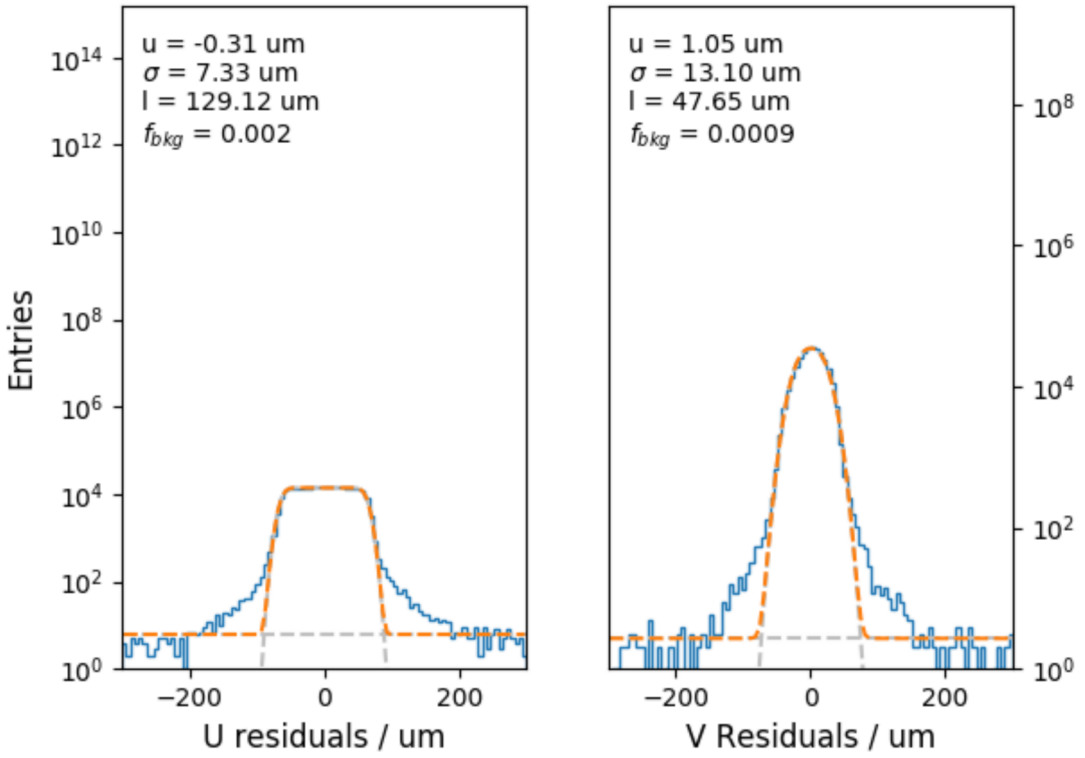
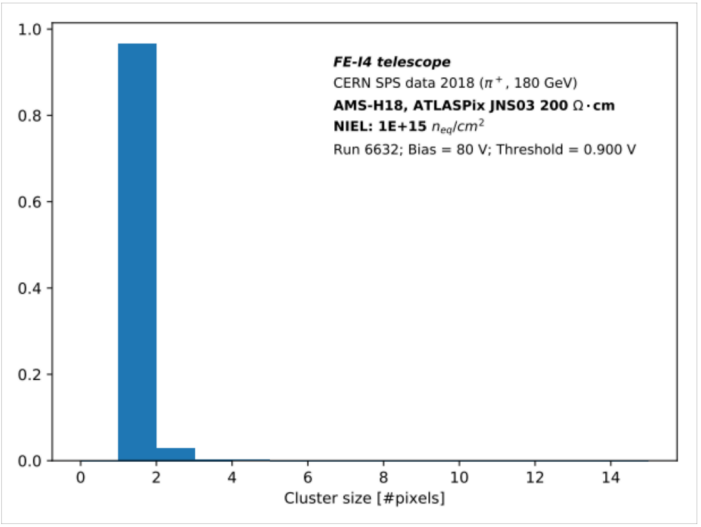
Matching residuals / n-irradiated 10^{15} n_{eq}/cm^2



Cluster size



Cuts

- 6 points on track
- χ^2 / d.o.f. < 5
- Δ u,v < 300 µm

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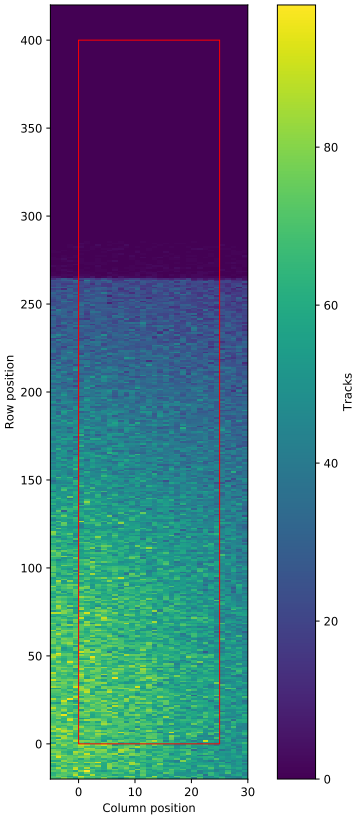
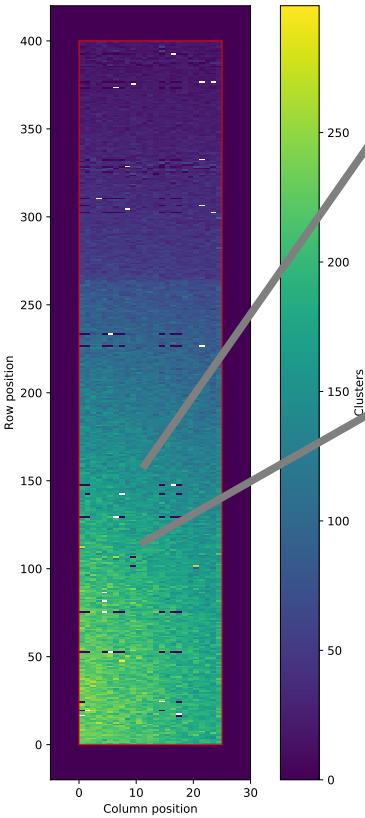
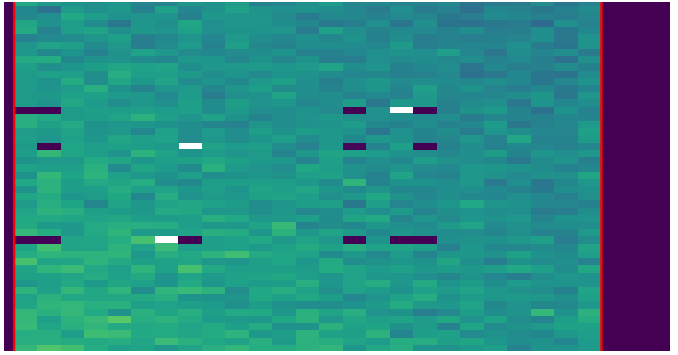
Occupancies / n-irradiated 10^{15} n_{eq}/cm^2

Tracks



Clusters





Masked pixels effect other in row

Known RAM grounding issue

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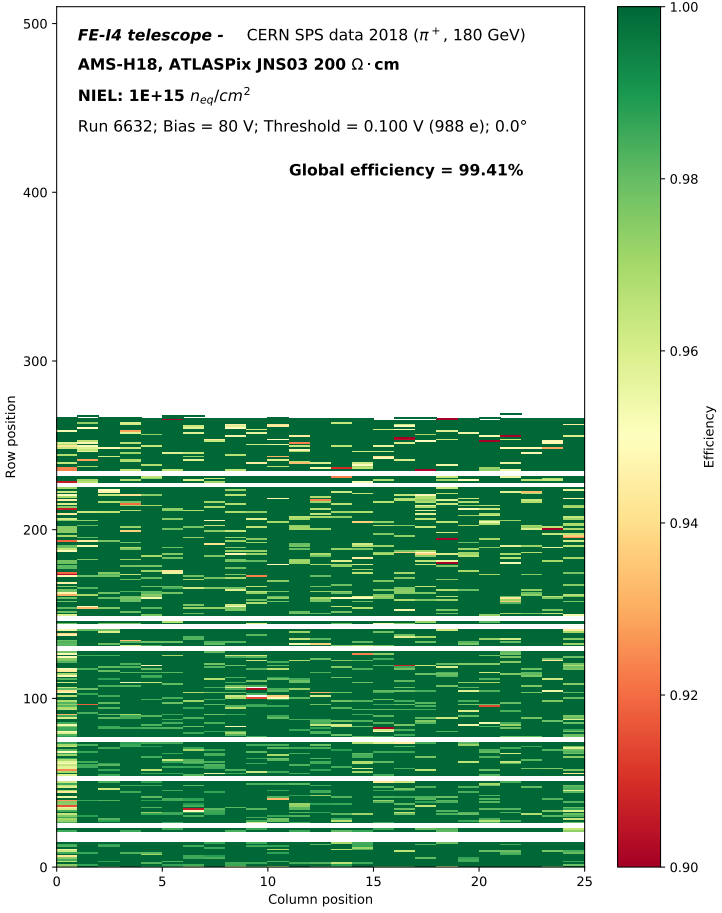
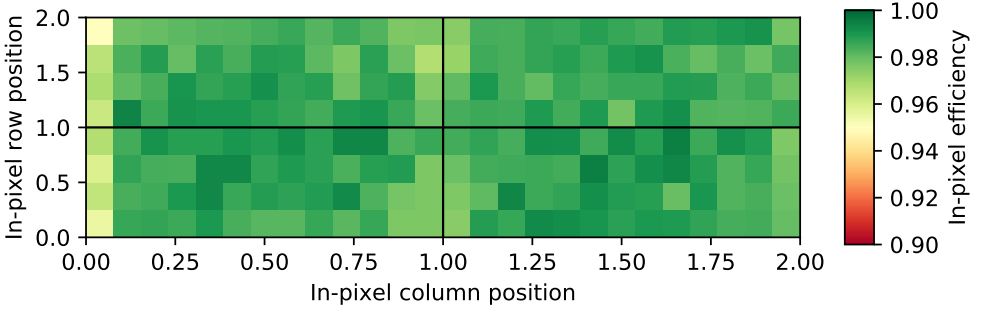
Efficiency / n-irradiated 10^{15} n_{eq}/cm^2



2x2 folded submatrix



Uniform response

Global efficiency 99.4%
(w/o masked lines)

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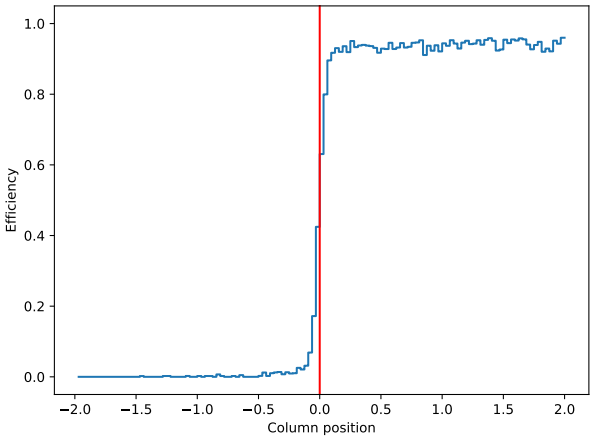
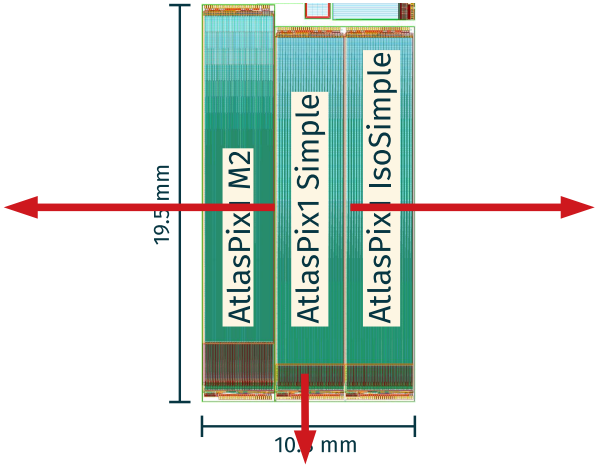
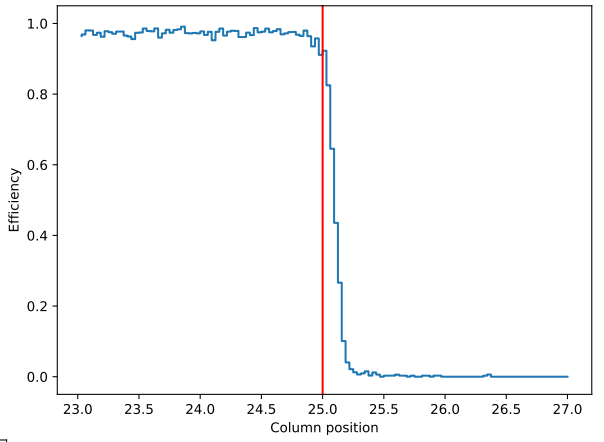
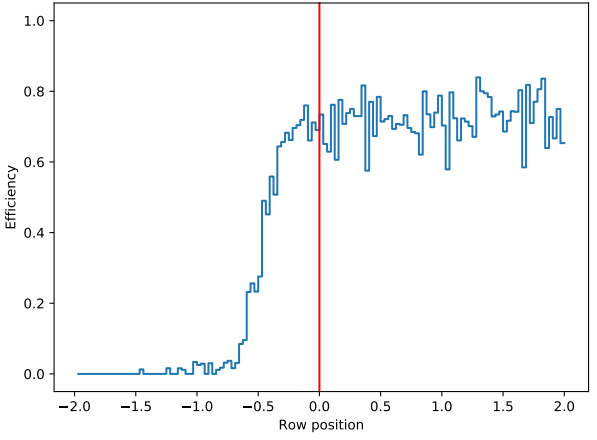
Edge efficiency / n-irradiated 10^{15} n_{eq}/cm^2









Efficient up to sensor edge

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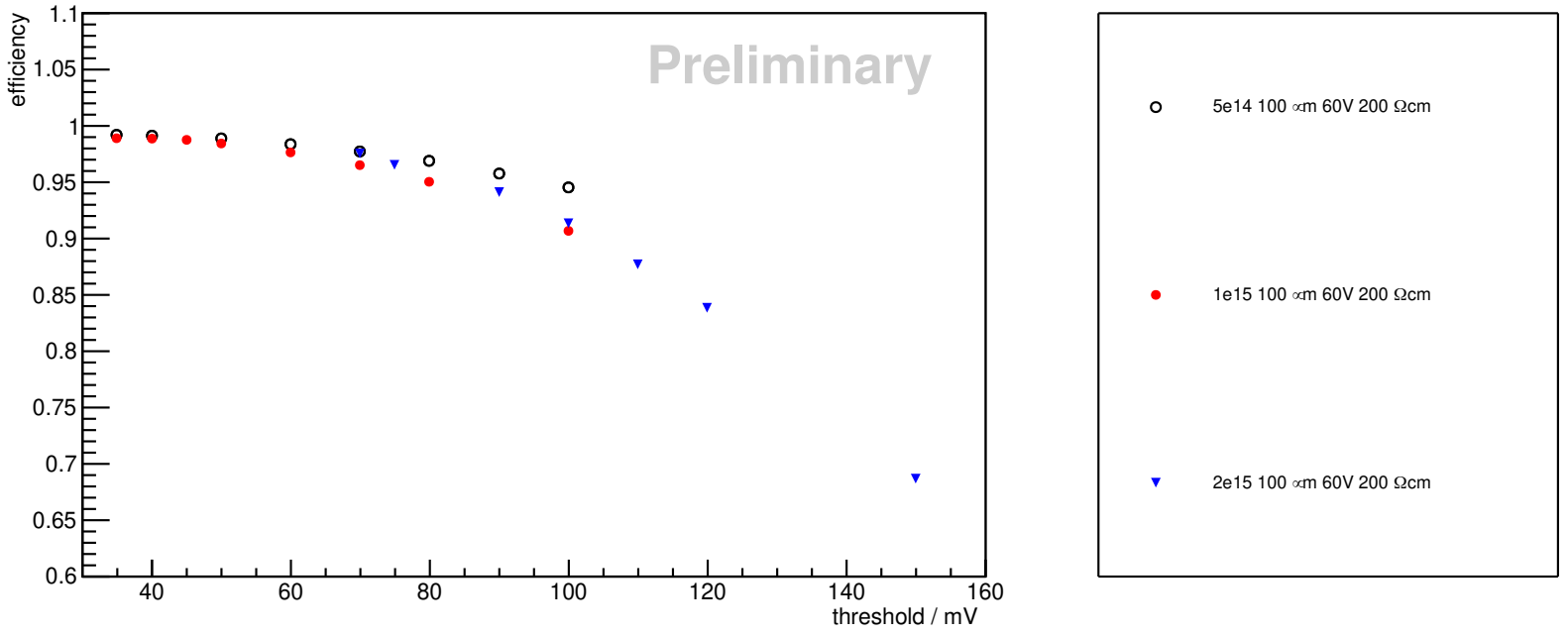
Efficiency scan / n-irradiated

A. Herkert et al. Universität Heidelberg



Data taken w/
MuPix telescope

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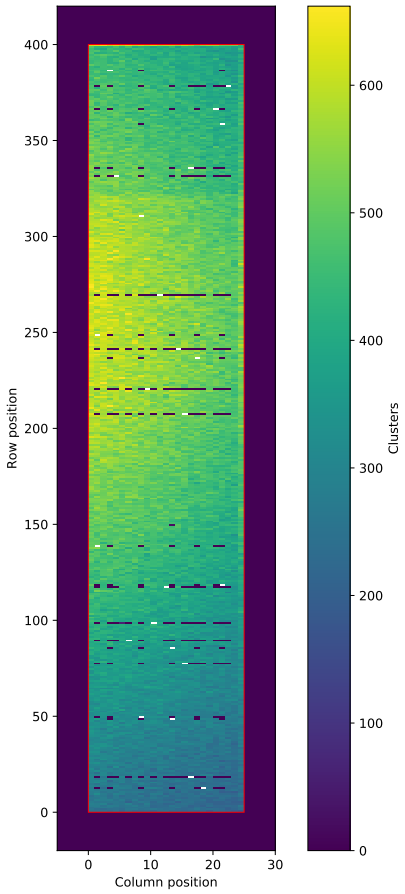
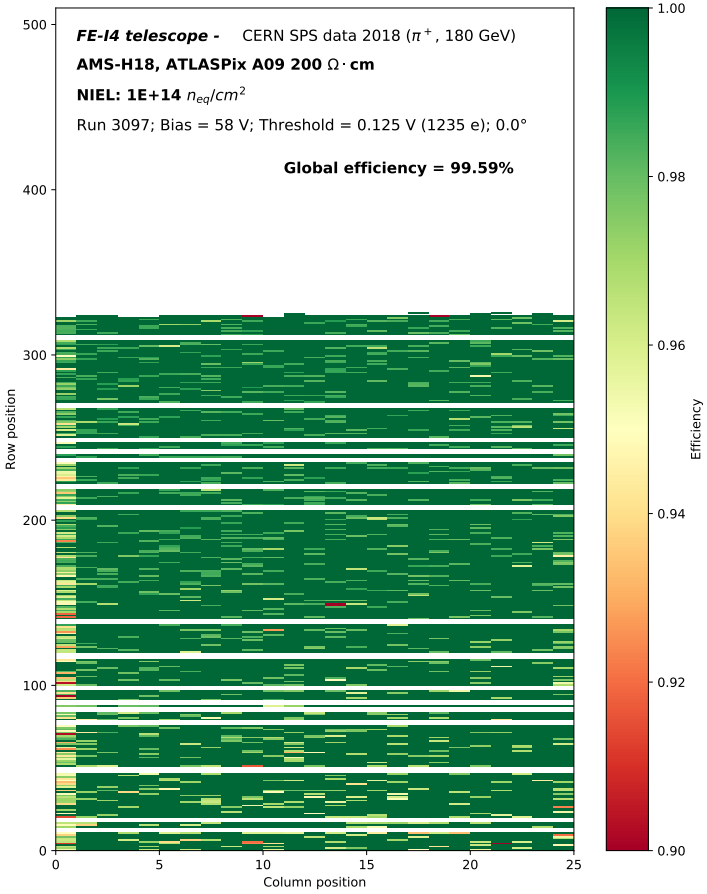
Efficiency / p-irradiated 10^{14} n_{eq}/cm^2

Occupancy



Efficiency



Irradiated under bias

Batch 1 preproduction

58V HV

Threshold 125mV / 1235e

Efficiency 99.59%

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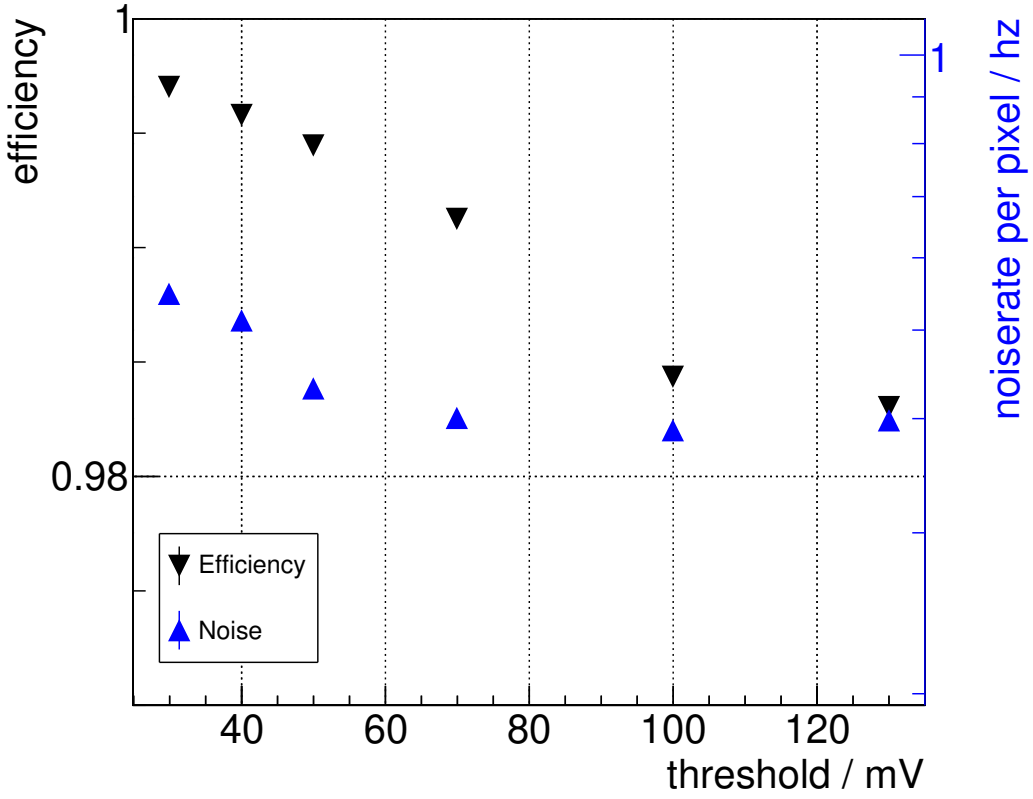
Efficiency scan / p-irradiated 5x10^{14} n$_{eq}$/cm^2



Irradiated under bias

70V HV

Data taken w/ MuPix telescope

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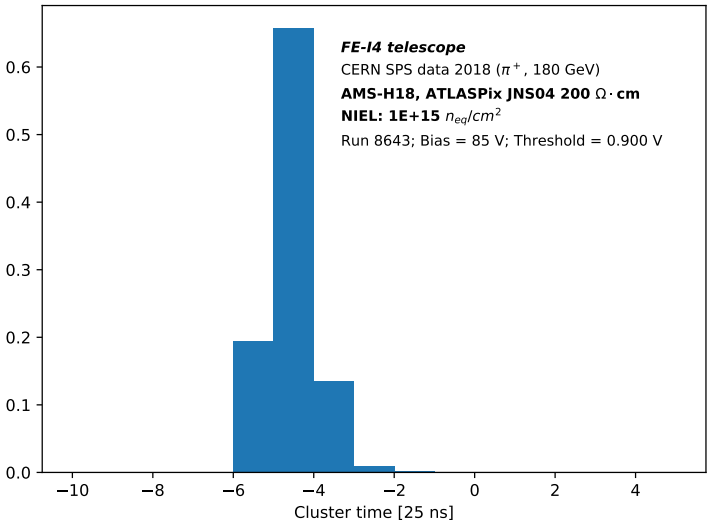
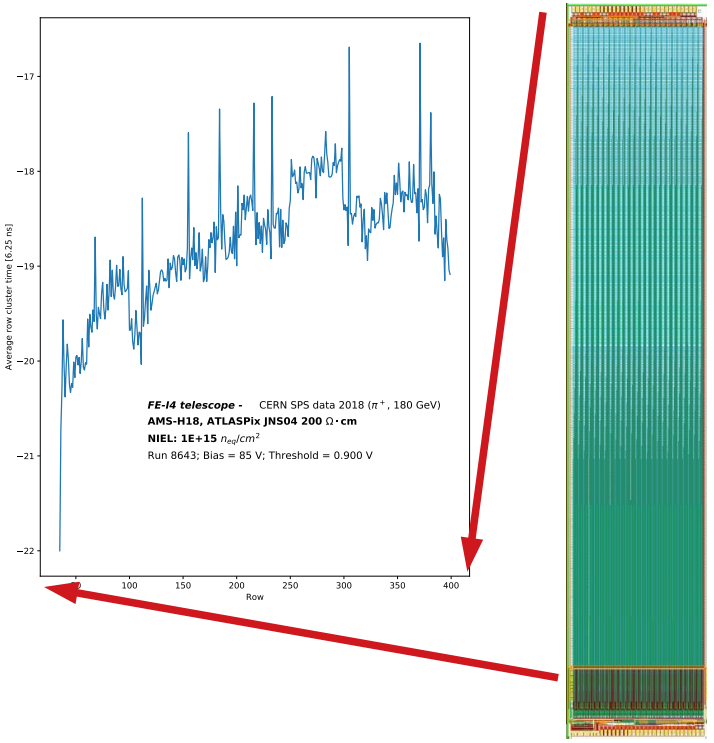
Naive timing

Cluster time = ToA - Trigger



Average cluster time per row



Length/ capacitance dependence of periphery connection

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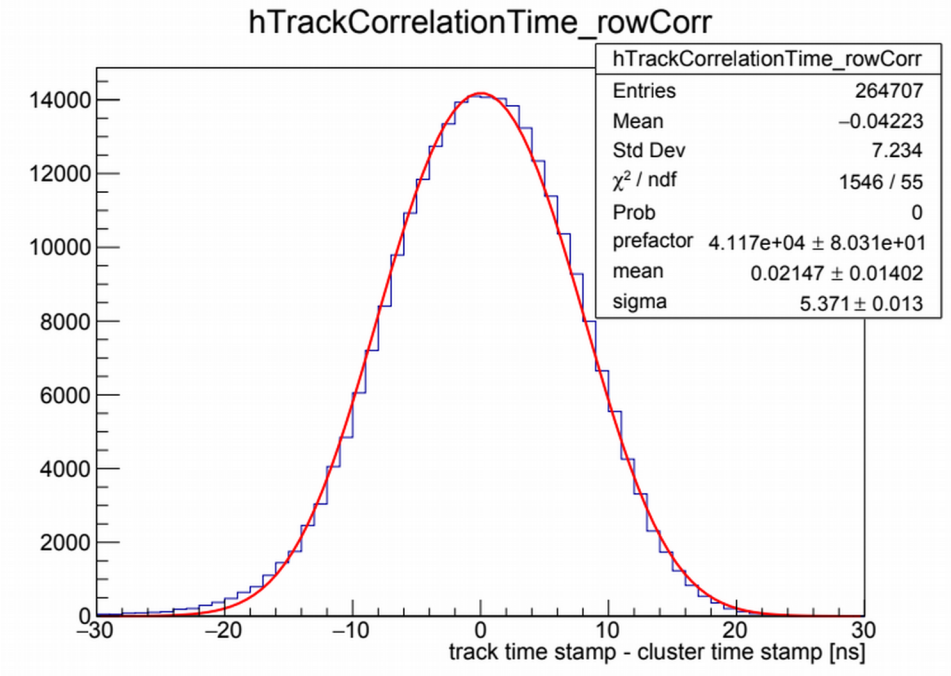
Corrected timing

J. Kröger et al. CERN CLICdp



Measured in CLICdp
Timepix3 telescope

Telescope time resolution ~ 1.2 ns

Row-dependence correction

No timewalk correction (negligible)

RMS ~7.2ns

Fit box+Gauss σ ~5.4ns

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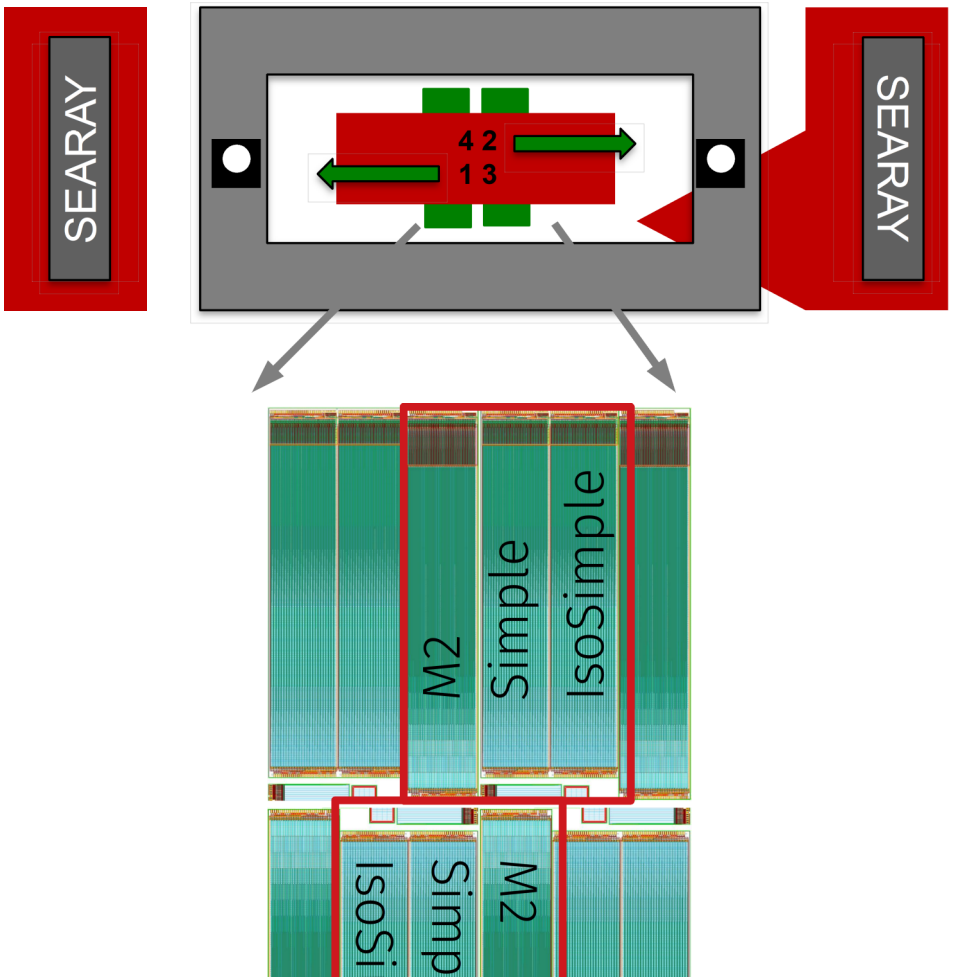
ATLASPix1 module prototype



Four sensor module protoype

Compatible w/ existing Caribou readout system

Flex designed and in production

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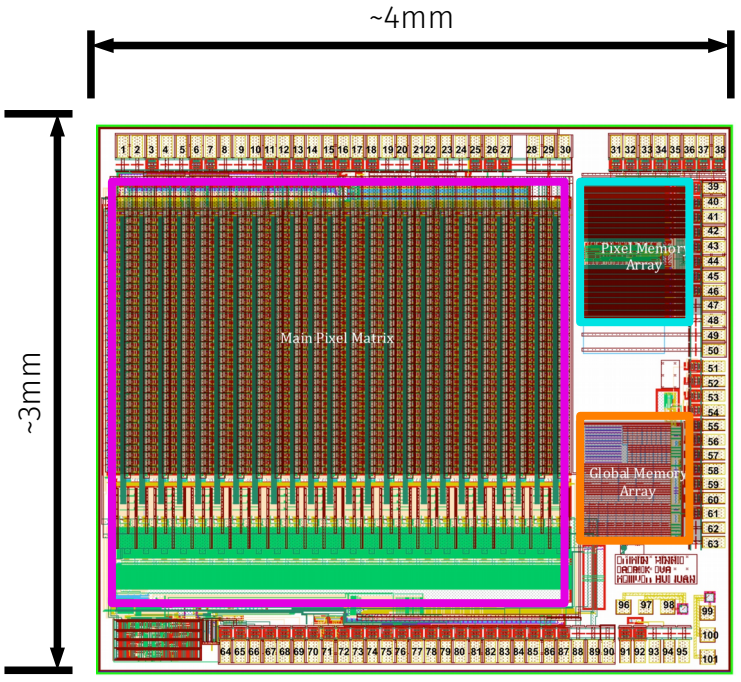
ATLASPix2



Small protoype w/ focus on periphery

- SEU-tolerant global memory
- Different pixel memory types
- RD53A compatible command decoder
- Aurora 64/66 serializer

Available in ams aH18 and TSI 0.18µm

Currently being tested

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Foundry availability

Based in Austria
(formerly Austria Mikro systems)

aH18 0.18 µm HV process

Prototypes: ATLASPix1, ATLASPix2

Does not accept submissions anymore

Compatible

Based in California

0.18 µm HV process

Prototypes: ATLASPix2, ATLASPix3, …

Replacement

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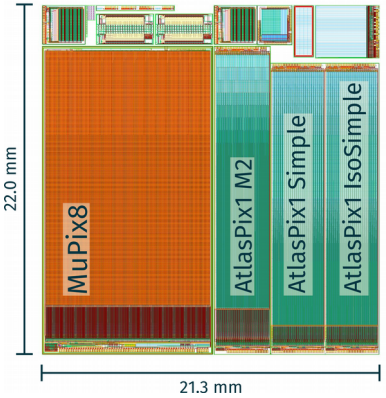
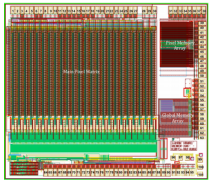
Timeline

ATLASPix1



ATLASPix2



ATLASPix3

Full scale Preproduction Prototype

ATLASPix4/ CMOS1

2017

2018

2019

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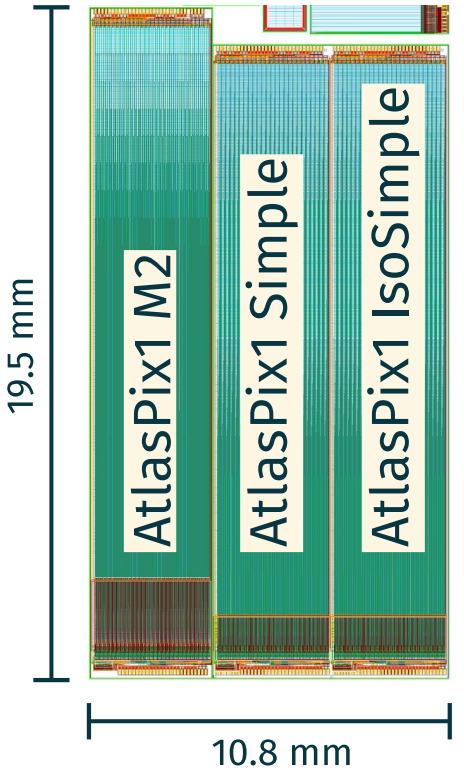
Collaborators

Summary

ATLASPix1 results

- Efficiency unirradiated > 99.5%
- Efficiency @ 10^{15} n_{eq}/cm^2 > 99%
- Time resolution < 10 ns

Towards production module:

- Single event effects
- Full-scale design
- Qualification of TSI process

Successful prototype and measurement campaign