# TJ 65nm – Limits of Spatial Resolution

## How Much Charge Information Do We Need?

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# The Question

## To Motivate the Design of a Pixel Sensor for a Future Lepton Collider

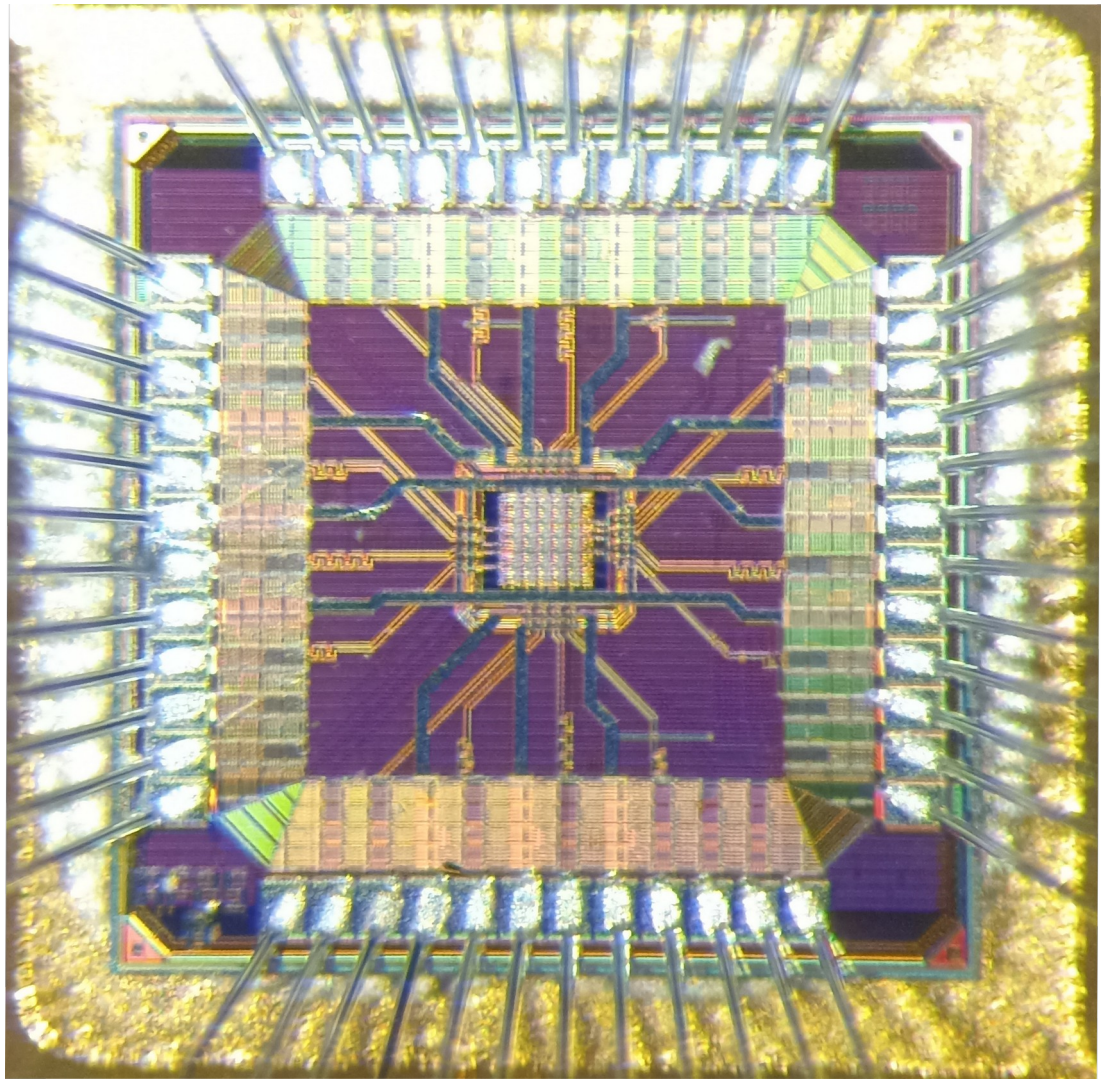
Key questions; concerning spatial resolution

- What are the limits achievable with a certain design (standard, n-blanket, n-gap)?
- How do these limits depend on the pixel pitch and threshold?
- How much potential for improvements does charge information offer?
  - How many bits do we need in order to lever this potential?
  - What about two thresholds?

# The Data

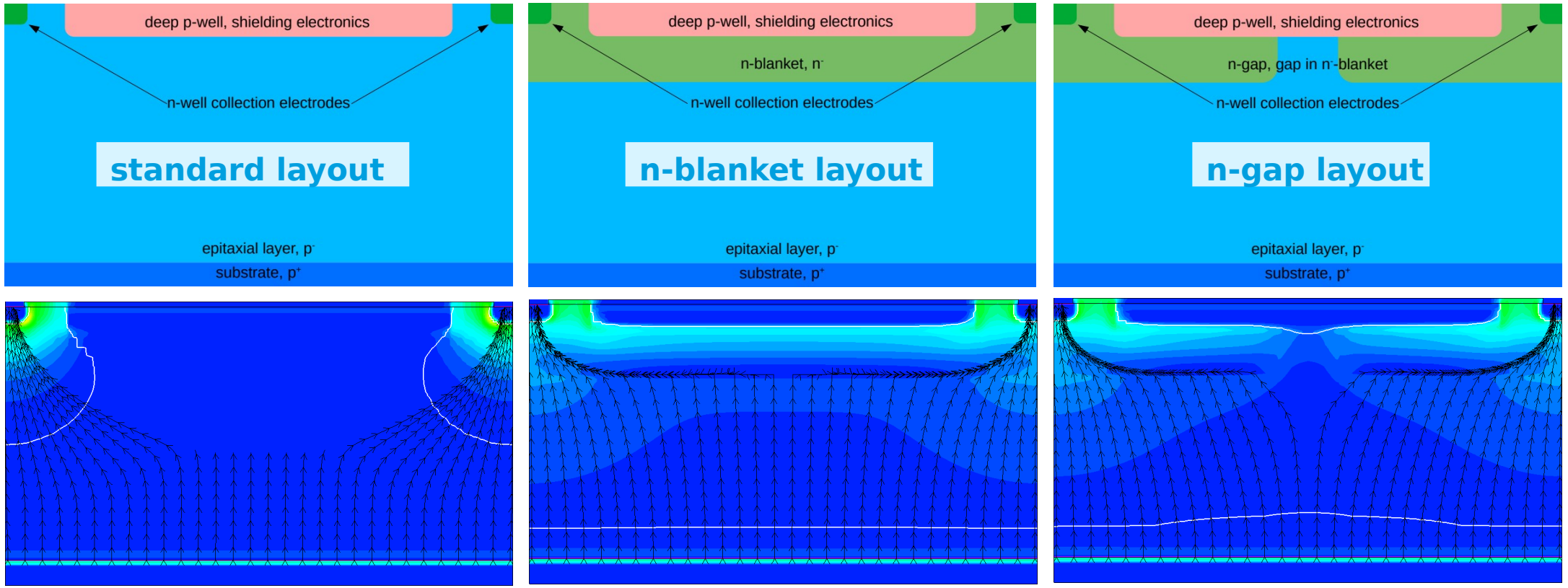
## Test-Beam Campaign at DESY with Analog Pixel Test Structures (APTS)

- Designed by ALICE as investigator for ITS3 [ref. pub.]
  - Three design flavors (standard, n-blanket, n-gap)
  - Pitch between 10 um and 25 um
- Readout developed with CERN EP R&D based on Caribou
  - We have quasi analog charge information without threshold
- Tested at DESY II Test-Beam Facility at about 4 GeV
- Charge calibration with $^{55}Fe$
- Corryvreckan analysis of our data already done
  - ClusteringAnalog: allows offline threshold scans



# Introducing Process Modifications

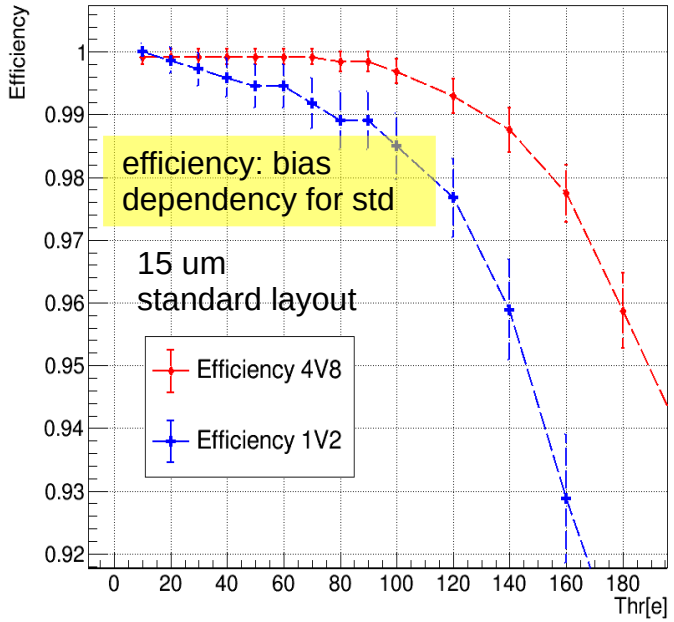
## The Trade-Off Between Charge Collection and Spatial Resolution

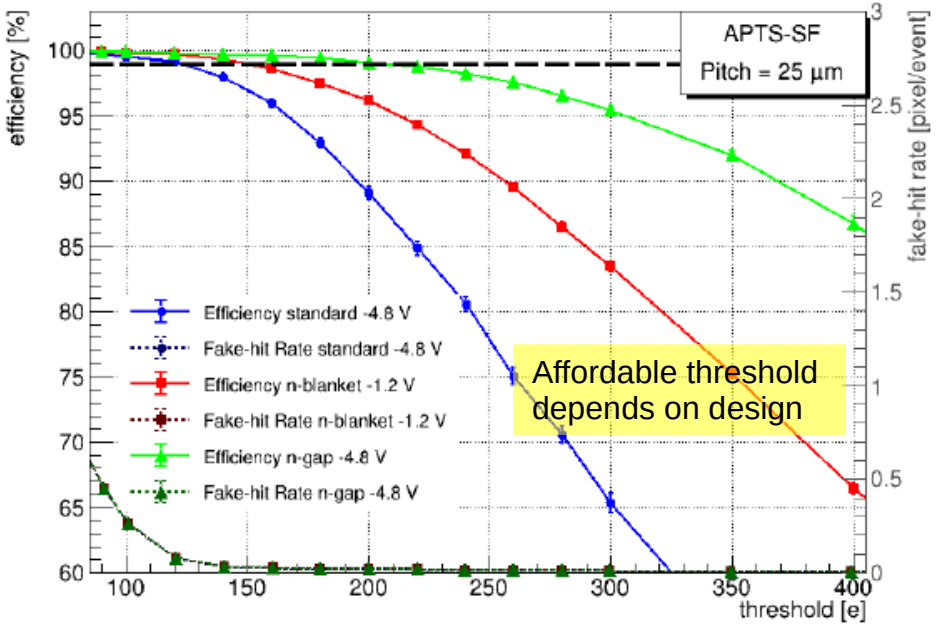


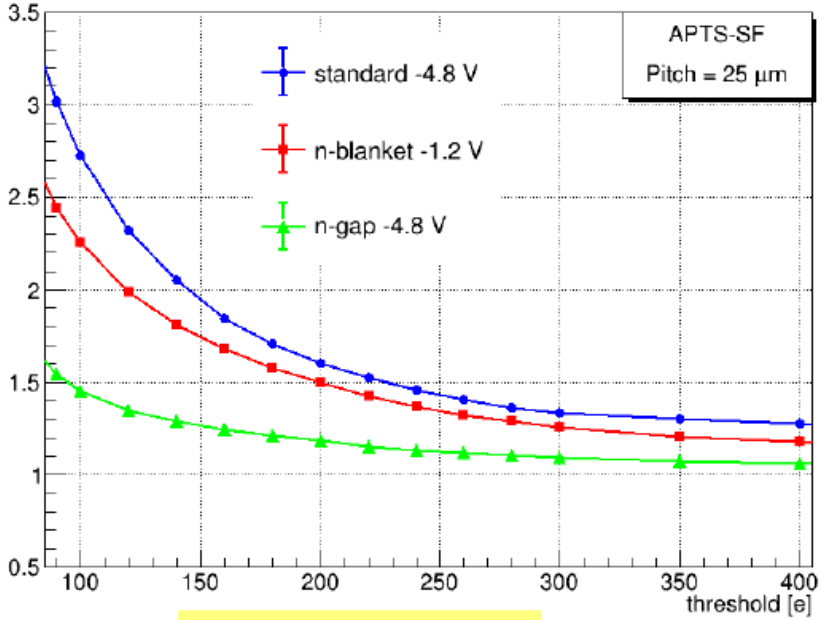

charge collection, detection efficiency

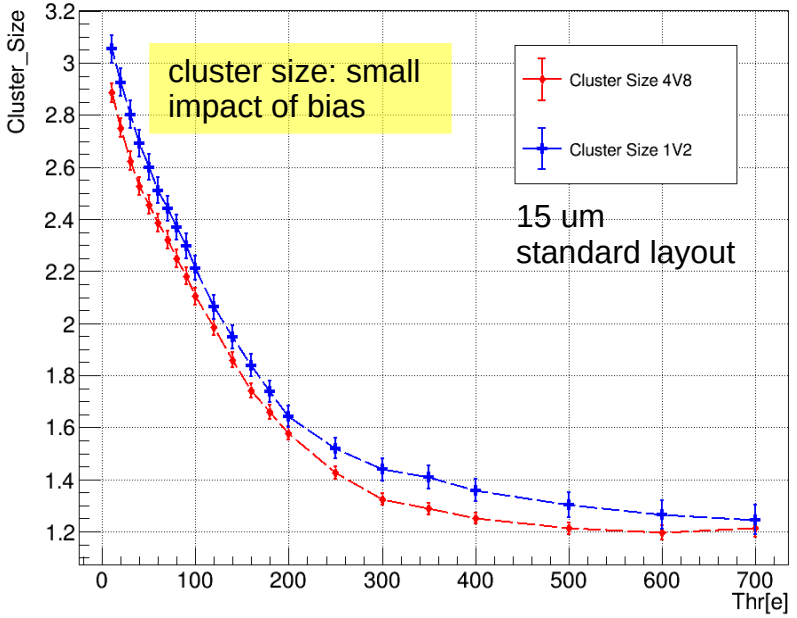
cluster size, spatial resolution

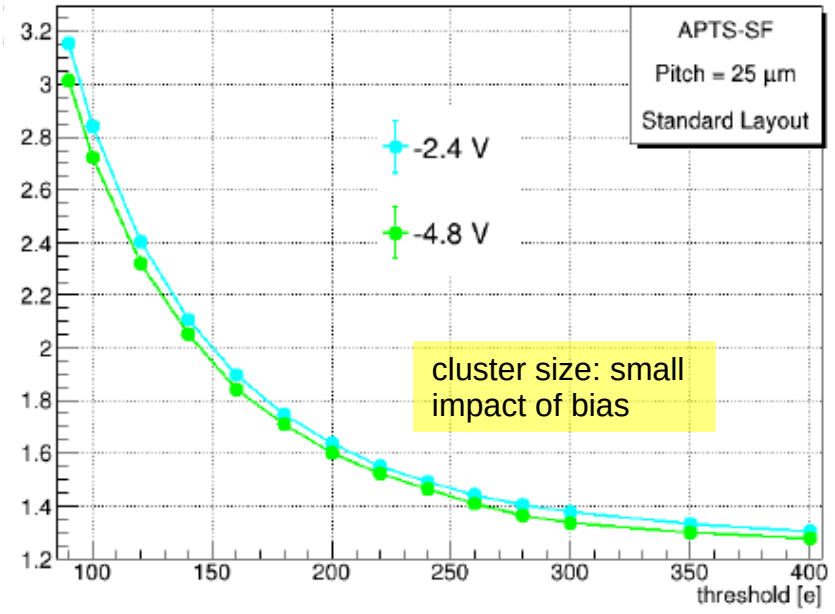
and this becomes worse with decreasing thickness, increasing pitch, and increasing threshold



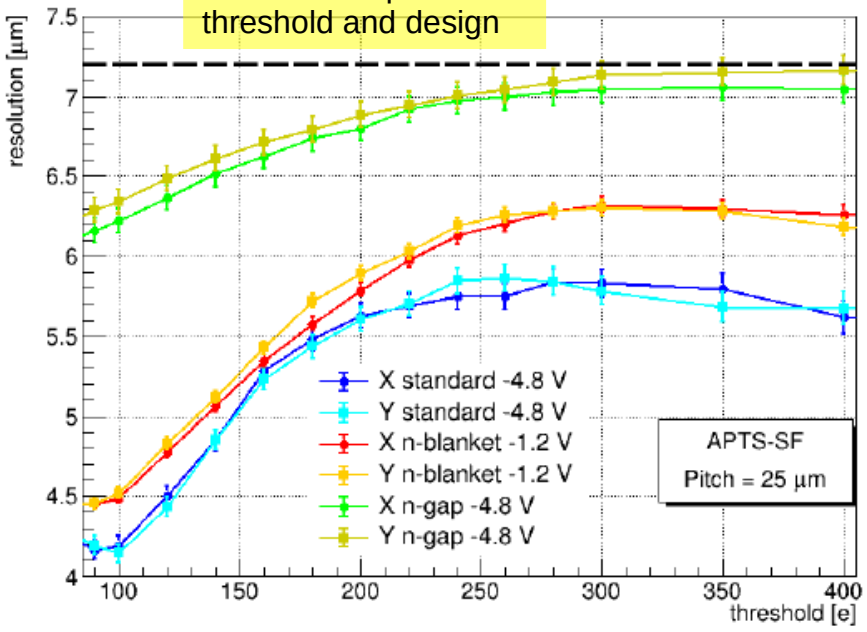




resolution depends on threshold and design

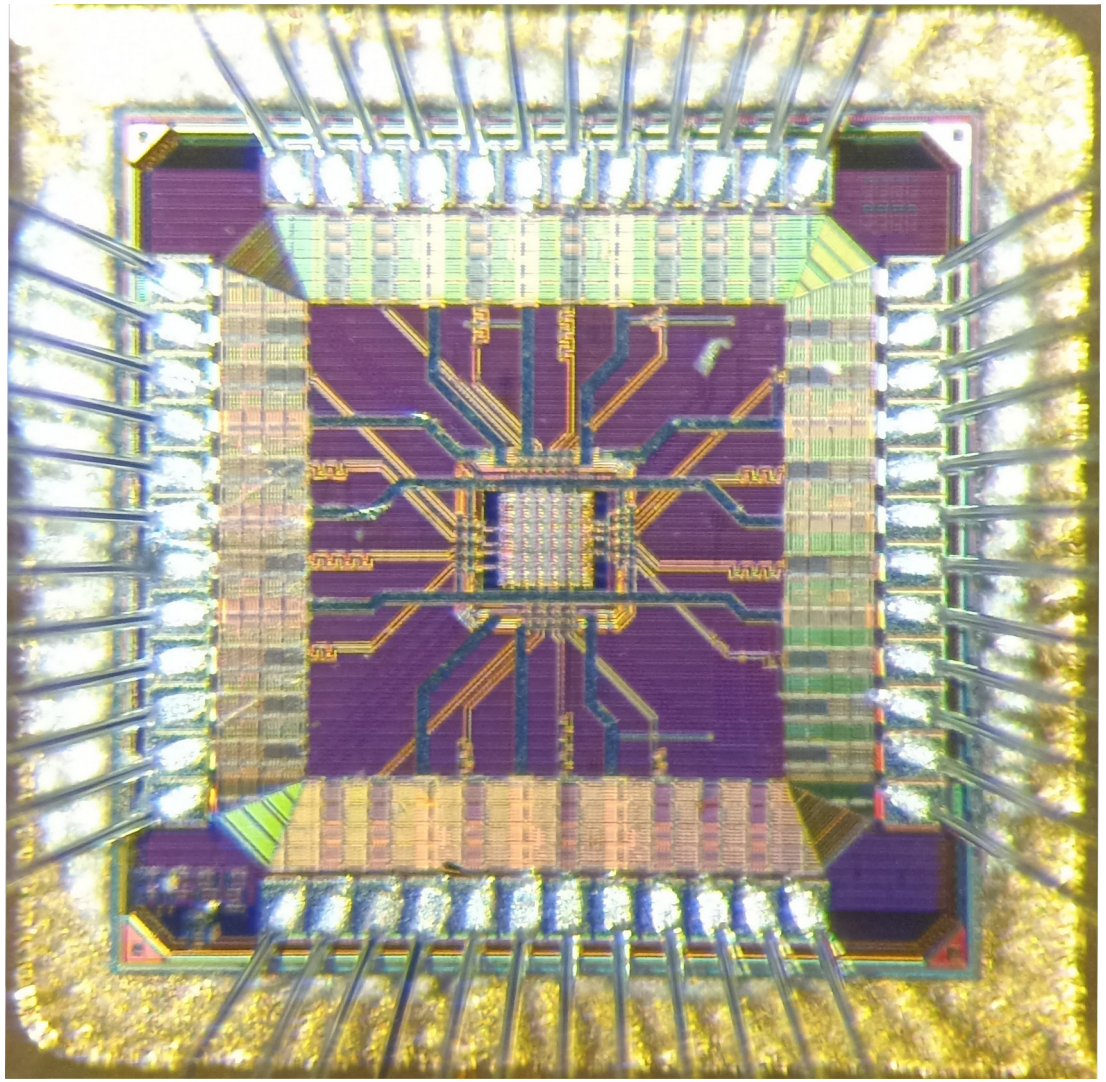


# Selected Conditions

## Use What We Have

- Use 4.8 V, if available
  - not expecting strong dependence for n-blc
- Use three thresholds if that allows efficient operation
- Get some complementary data points from ALICE publication

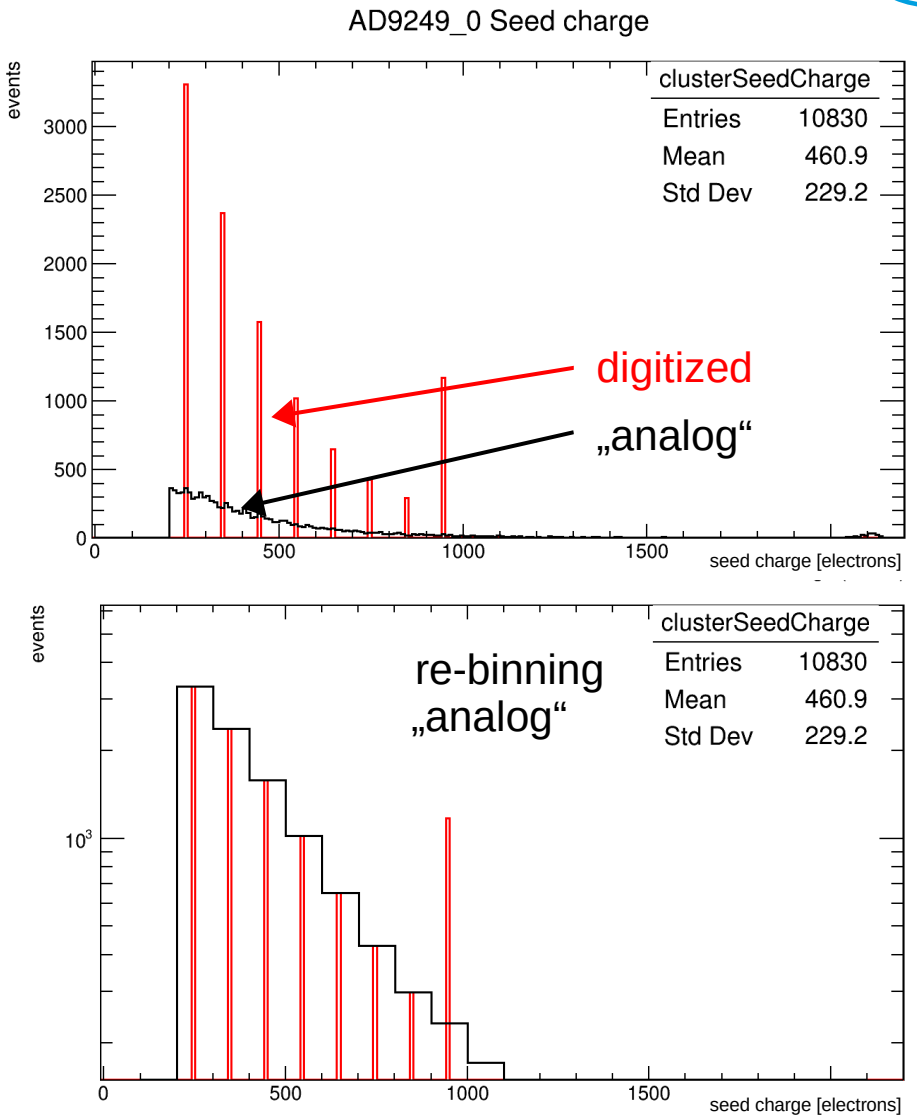
| Pitch [um] | Type | Bias [V] | Thresholds [e] |
|---|---|---|---|
| 15 | std | -4.8 | 100, (150) |
| 25 | std | -4.8 | 100 |
| 25 | n-blc | -1.2 | 100, 150 |
| 25 | n-gap | -4.8 | 100, 150, 200 |



# Tools and Methods

## Offline Digitization

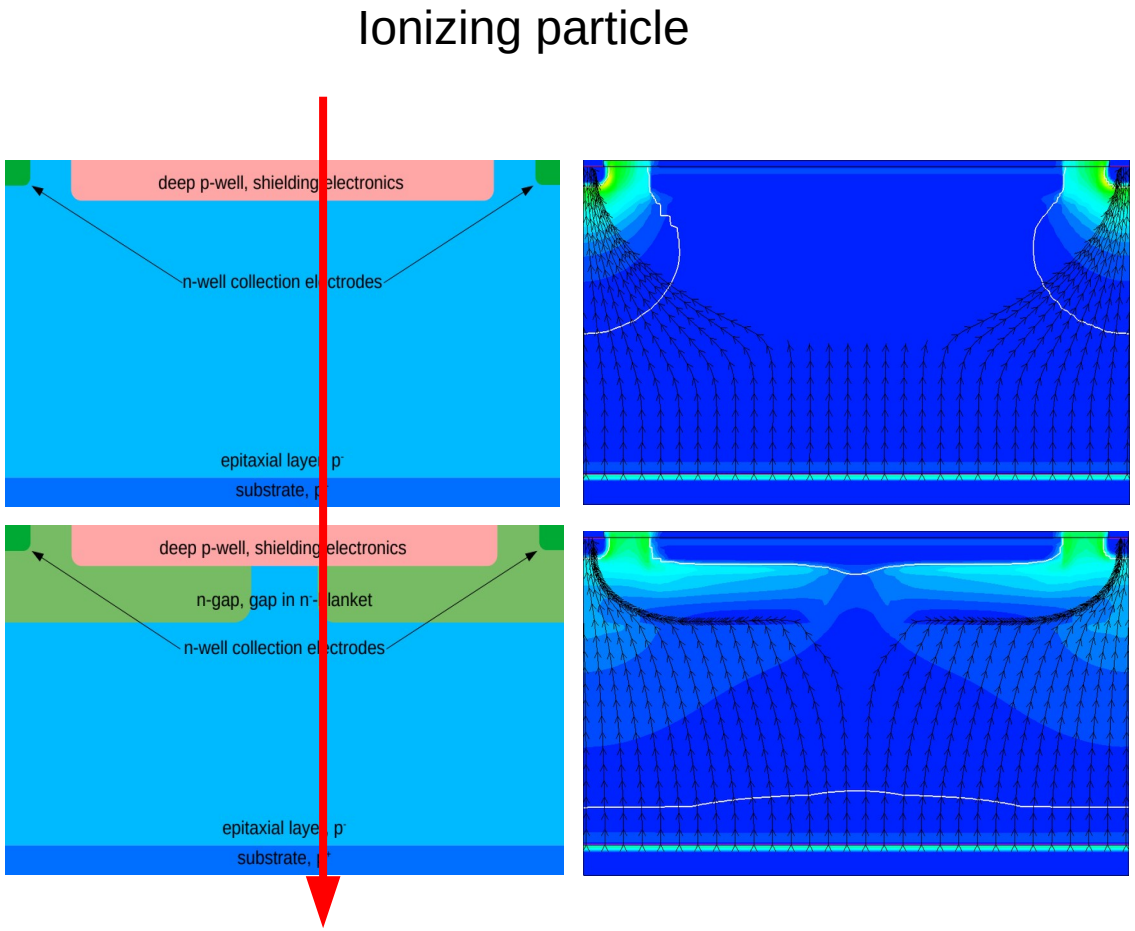
- Our analysis chain makes use of `ClusteringAnalog`
- This allows easy offline threshold adjustment
- Added digitization feature with two parameters
  - `digitizerBinWidth`; example 100 e
  - `digitizerBinNumber`; example 8 bins
- Scanning
  - Bin width from 10 e to 1000 e (increasing step size)
  - Number of bins 0 (analog), 1(binary), 2, 4, 8, 16
- Problem
  - Charge weighting will not yield optimal resolution
  - Need to apply eta correction for all studied cases (3x3x6x15 = 810)



# Motivating

## Eta Correction

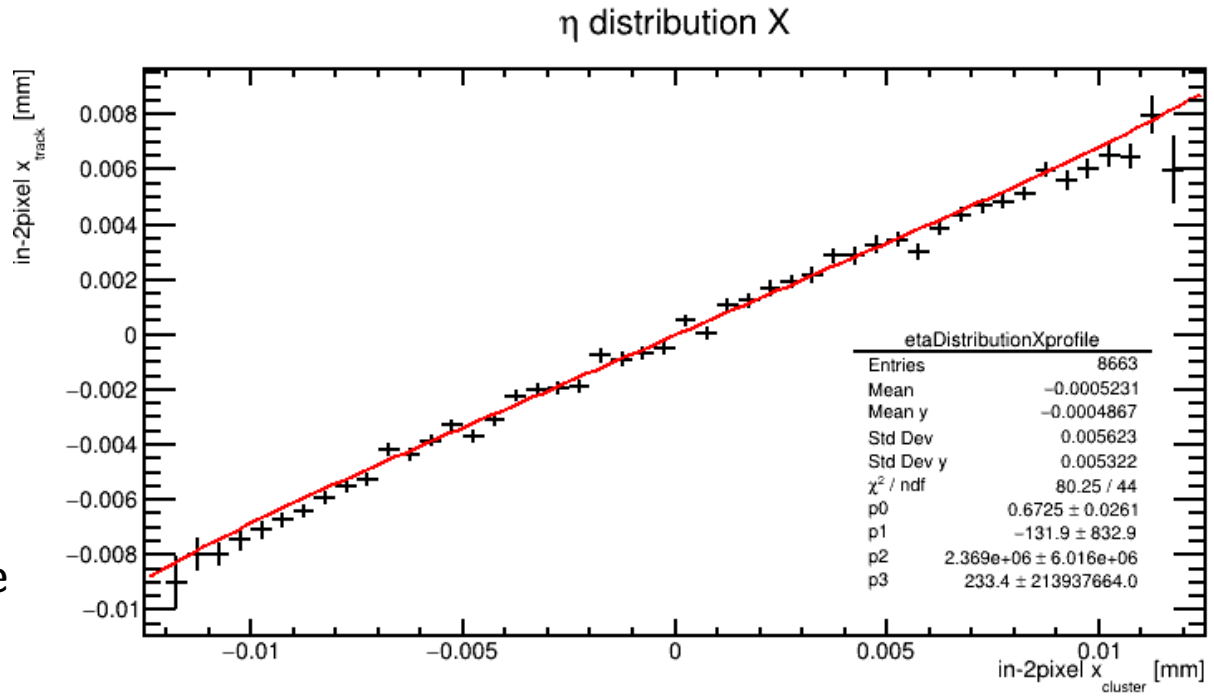
- Imagine a particle hitting our detector close to the pixel boundary
- The charge collected in each electrode depends on the electric field
  - Standard layout: low field, diffusion component, charge sharing close to 50-50
  - n-gap layout: larger field, collection by drift, charge sharing close to 0-100
- In both cases, we estimate the particle position using a charge weighted center of gravity – This is wrong
- It is the job of the eta correction to find out how wrong this is and to correct for the effect



# Tools and Methods

## Correcting Bias of Spatial Residuals – Eta Correction

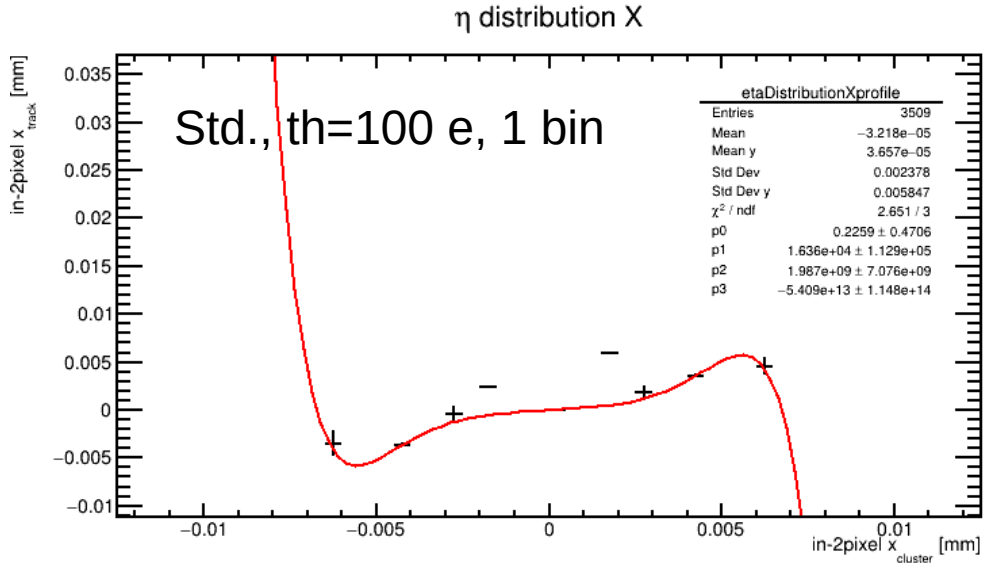
- Using modules `EtaCalculation` and `EtaCorrection`
- The Idea is simple
  - Plot the intercept of an associated track as a function of the reconstructed position (both in-pixel / modulo the pitch)
  - This reveals the bias of the reconstruction (deviation from diagonal)
  - Fit appropriate function (polynomial with 4 odd terms)
  - Use the fit to correct for the bias (in a next iteration over the run)
- This is not 100 % stable if the number of bins is small

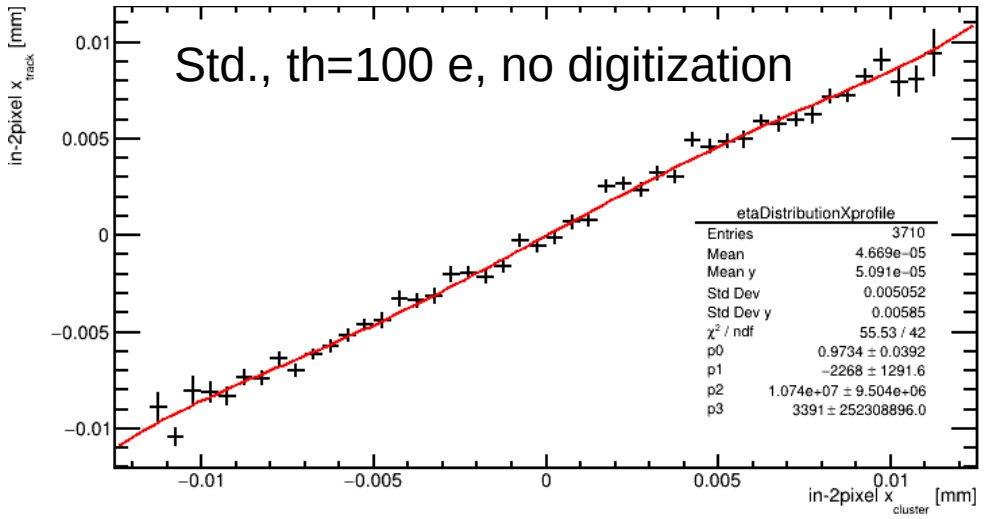


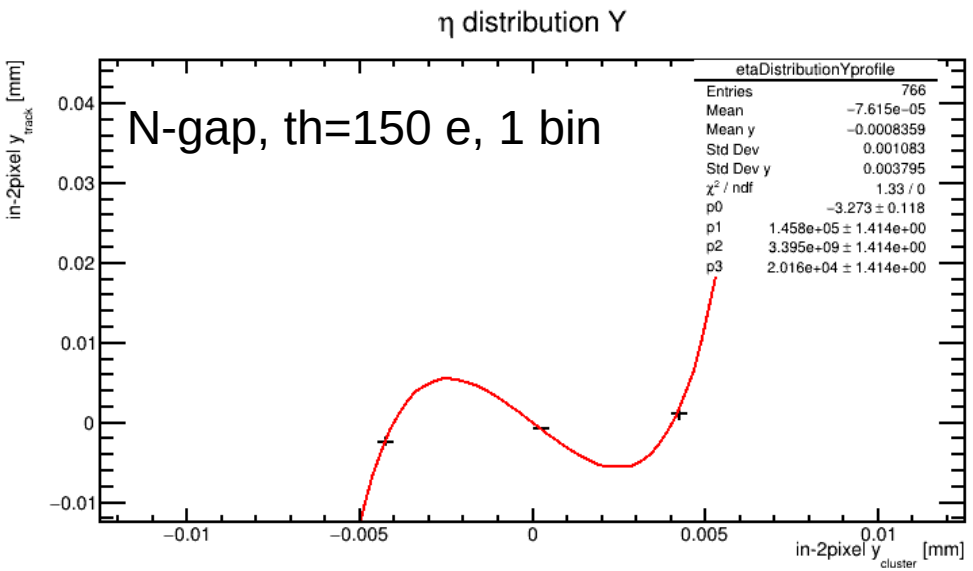

Example, eta correction for n-gap at 100 e

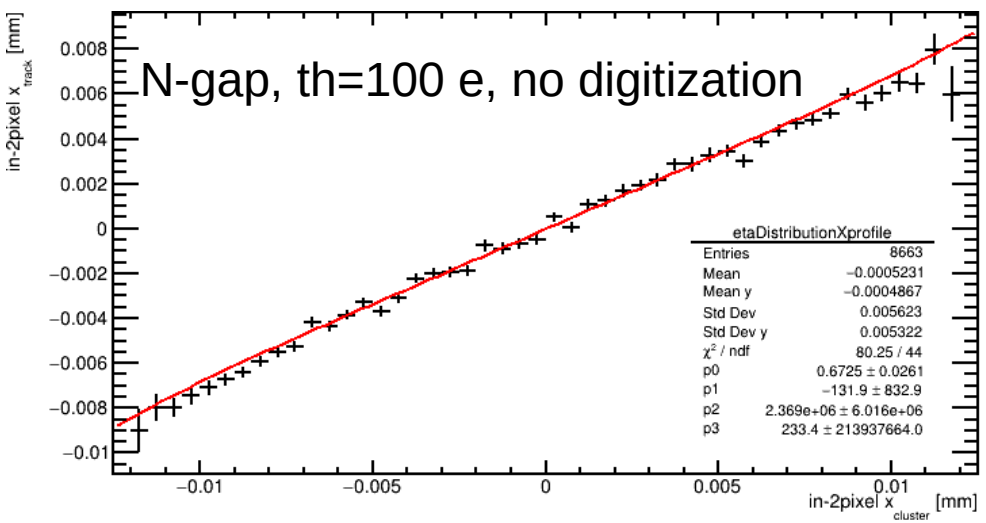
# Tools and Methods

## Eta Correction – Examples



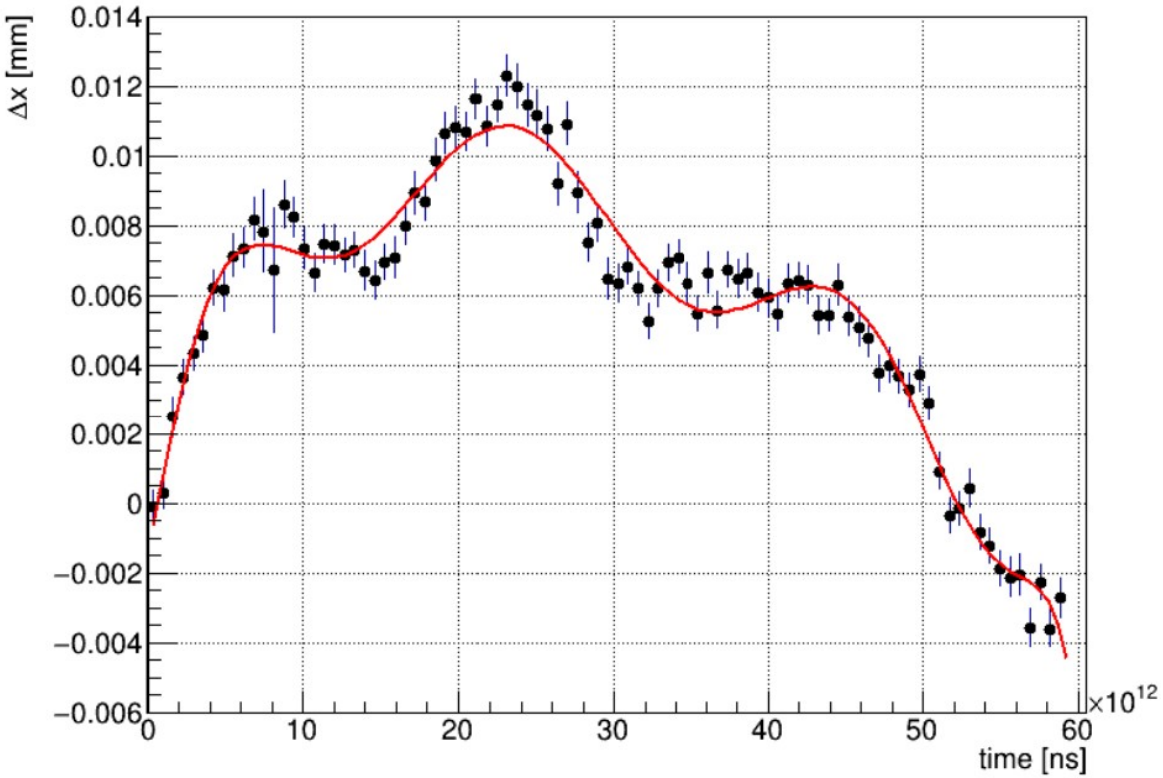



# Tools and Methods

## Extracting Spatial Resolutions and Comments on Systematic

In my opinion this is the biggest issue with this study

- Characterizing residual width using iterative RMS(0.997)
- Need to subtract track resolution ($\sigma_{meas} = \sigma_{tel} + \sigma_{dut}$)
- But how to get the track resolution?
  - Use the GBL resolution calculator
    - Probably underestimates track resolution (time dependence)
  - Use a method similar to [Antonello]*
    - Cut on abs(eta) = $|(c_l - c_r) / (c_l + c_r)| < 0.1$ and cluster charge $< 700$ e
    - Assume DUT resolution is sub-dominant (checked with simulation)
    - Potentially overestimates track resolution




- Alignment dependents on time
- Impact depends on run duration

# Tools and Methods

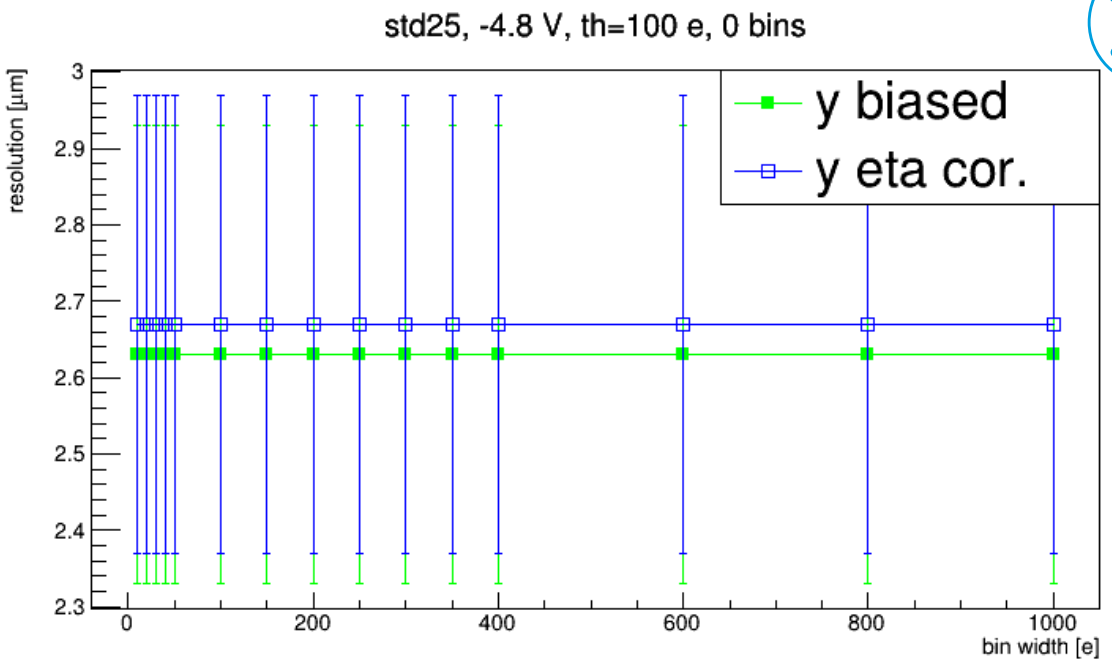
## Overview Track Resolution

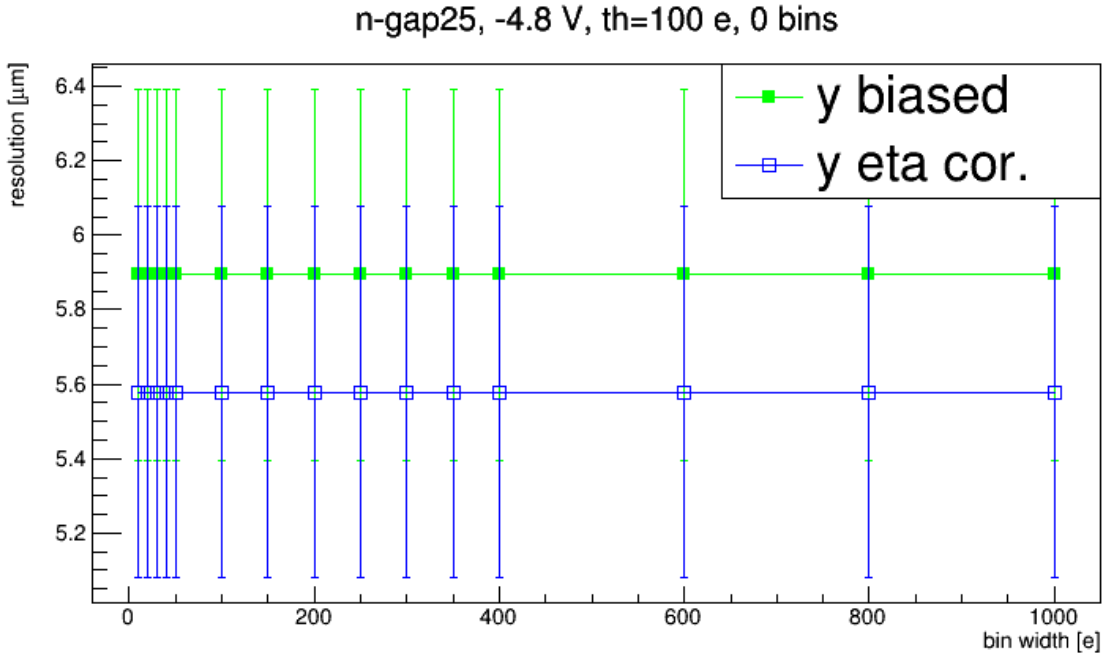
| Design | Pitch [um] | Voltage [V] | Track GBL [um] | Track Eta [um] |
|---|---|---|---|---|
| n-gap | 25 | -4.8 | 2.5 | 3.7 |
| | | y | 2.5 | 3.4 |
| n-blc | 25 | -1.2 | 2.5 | 4.0 |
| | | y | 2.5 | 4.3 |
| std | 25 | -4.8 | 2.5 | 5.0 |
| | | y | 2.5 | 4.0 |
| std | 15 | -4.8 | 1.9 | 4.0 |
| | | y | 1.9 | 4.4 |

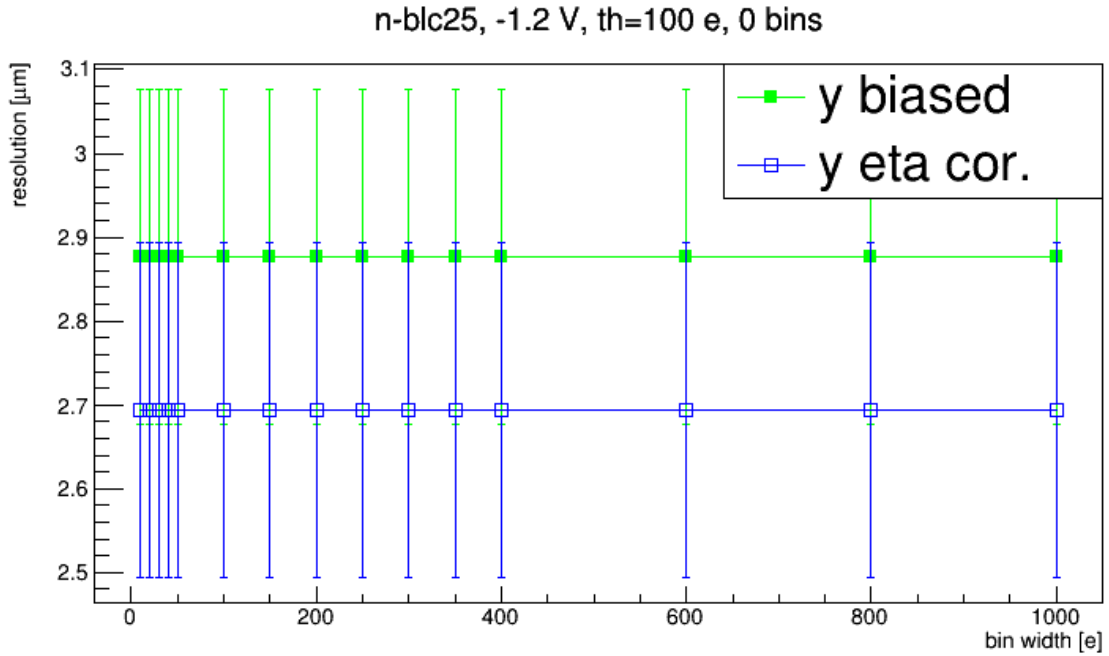
# The „Eta-Potential“

## How much can we gain from the Eta-Correction?*

- Especially at low thresholds
- Overall not that impressive
  - Either small cluster size (n-gap)
  - Or relatively linear charge sharing (std)
- However, this does not mean that charge info is useless!

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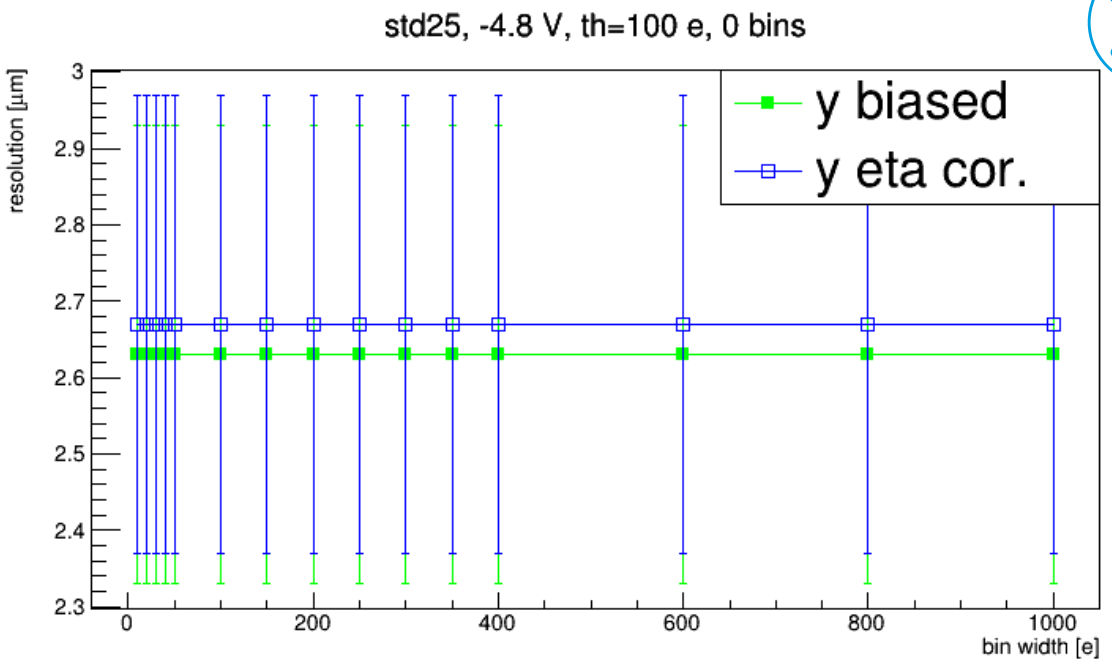


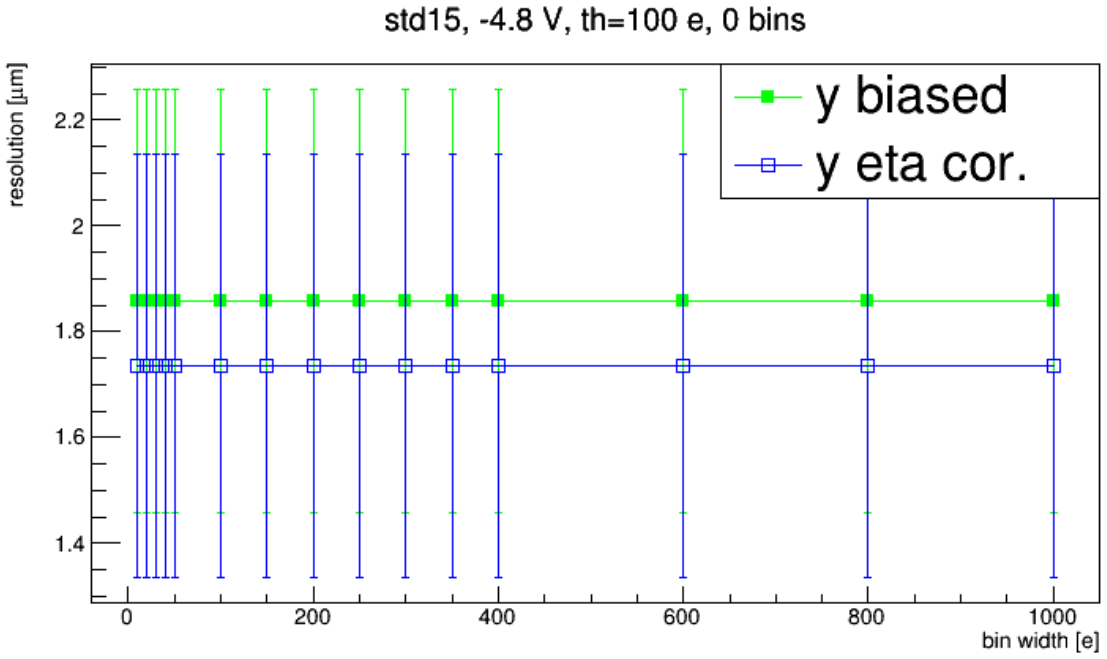


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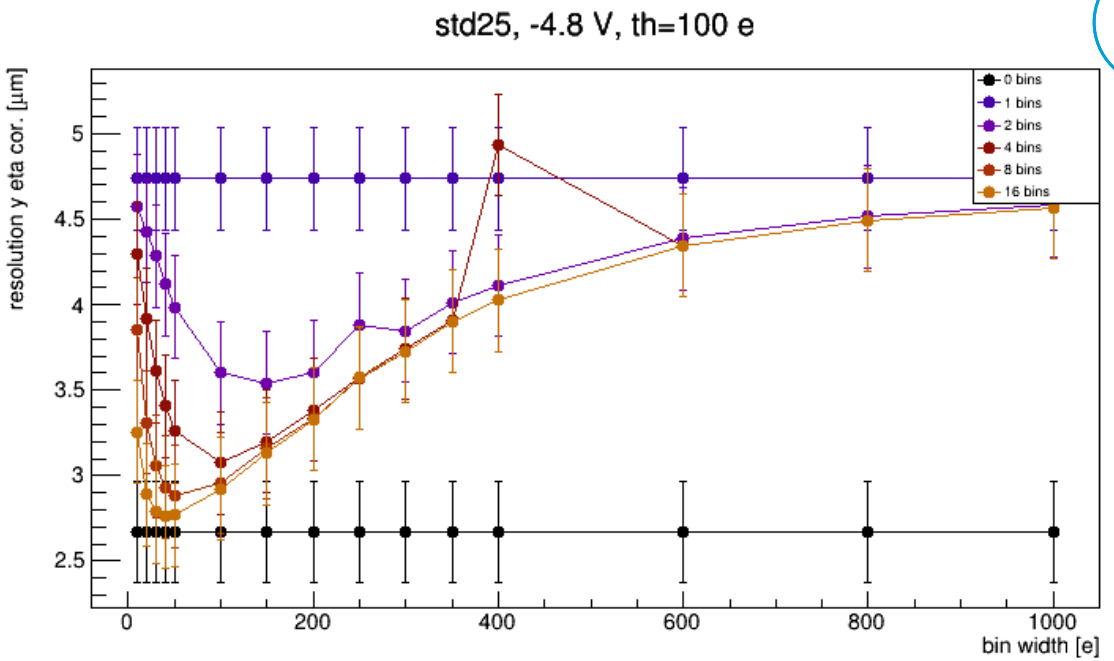
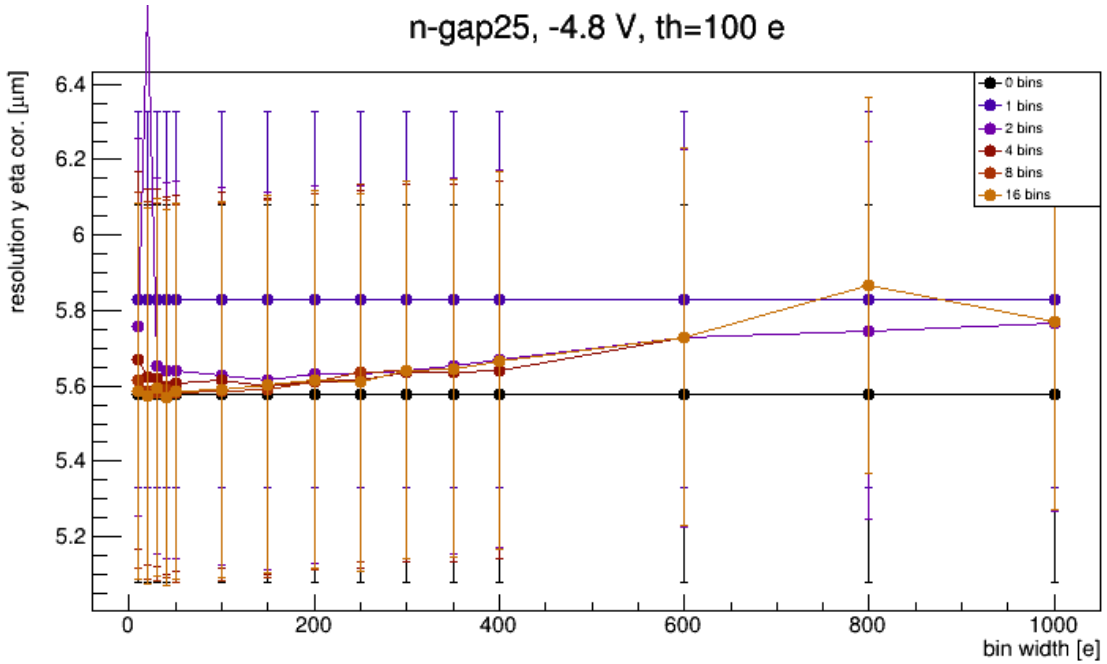
# Results

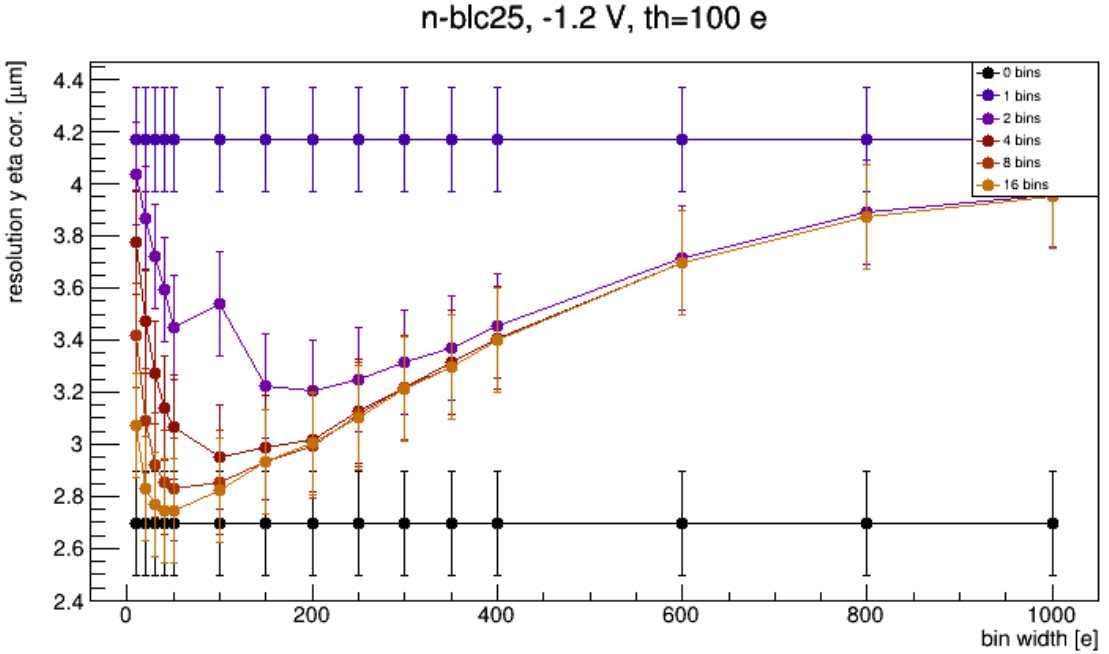
## Low Thresholds

This is interesting!

- We do indeed profit from charge info, std $>$ blc $>$ gap
- Already two bins enough to lever $>$ 50 % of the potential



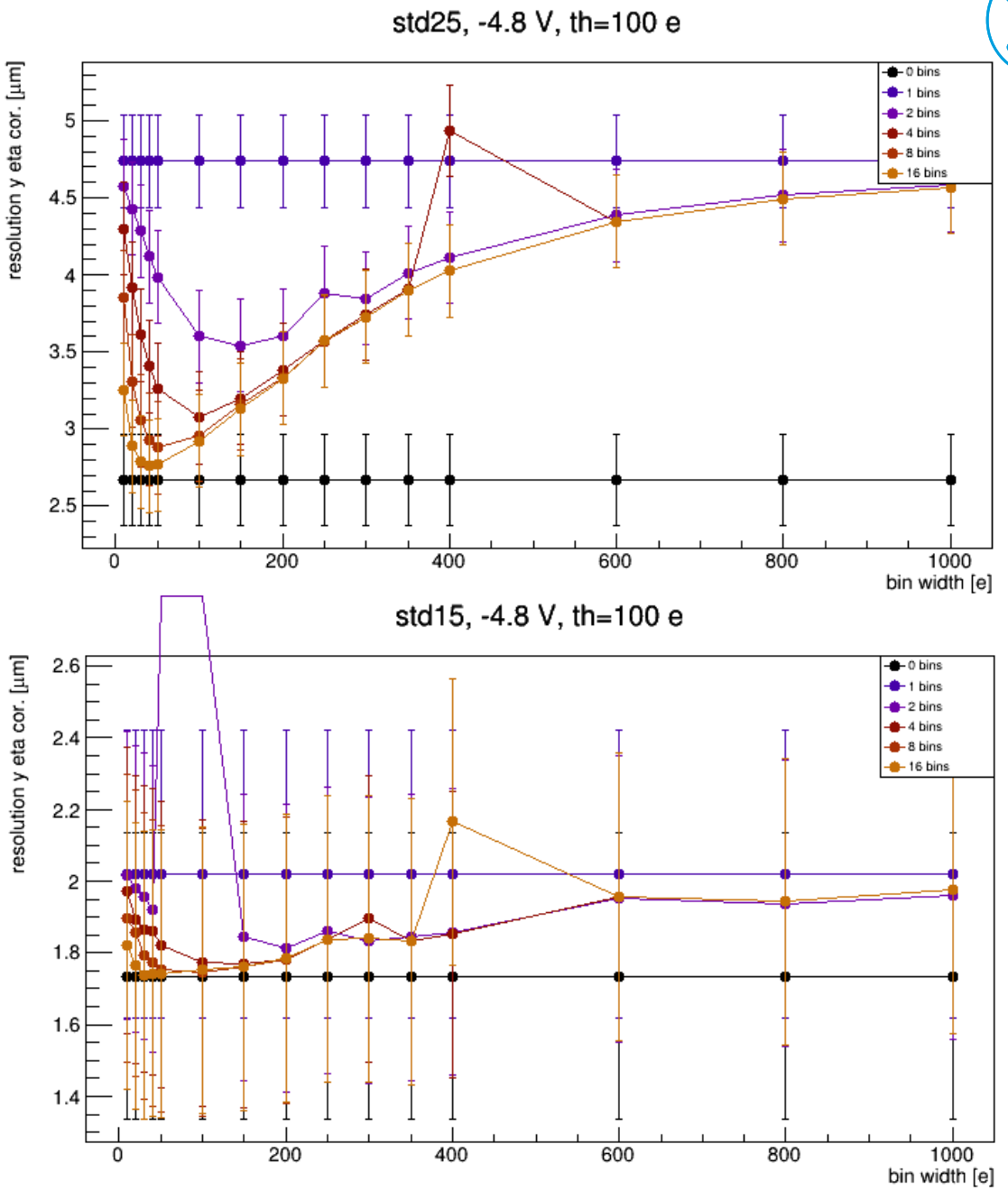



# Results

## Low Thresholds

This is interesting!

- We do indeed profit from charge info, std > blc > gap
- Already two bins enough to lever > 50 % of the potential
- The effect of the charge info reduces with
  - Decreasing pitch
    (limited by noise?)



# Results

## Low Thresholds

This is interesting!

- We do indeed profit from charge info, std > blc > gap
- Already two bins enough to lever > 50 % of the potential
- The effect of the charge info reduces with
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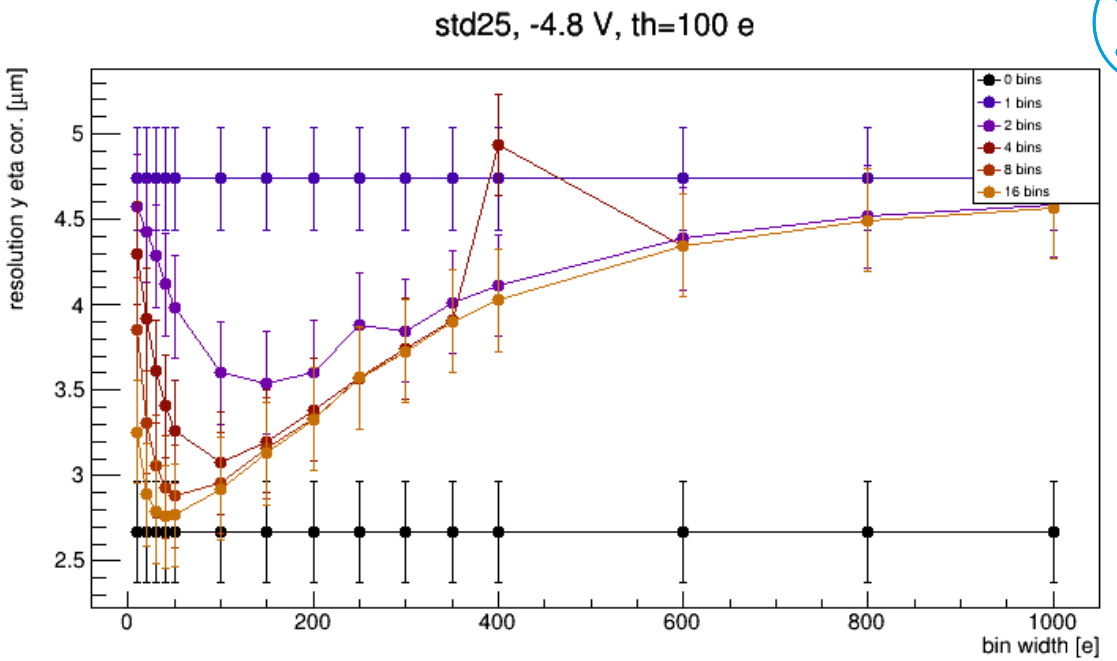
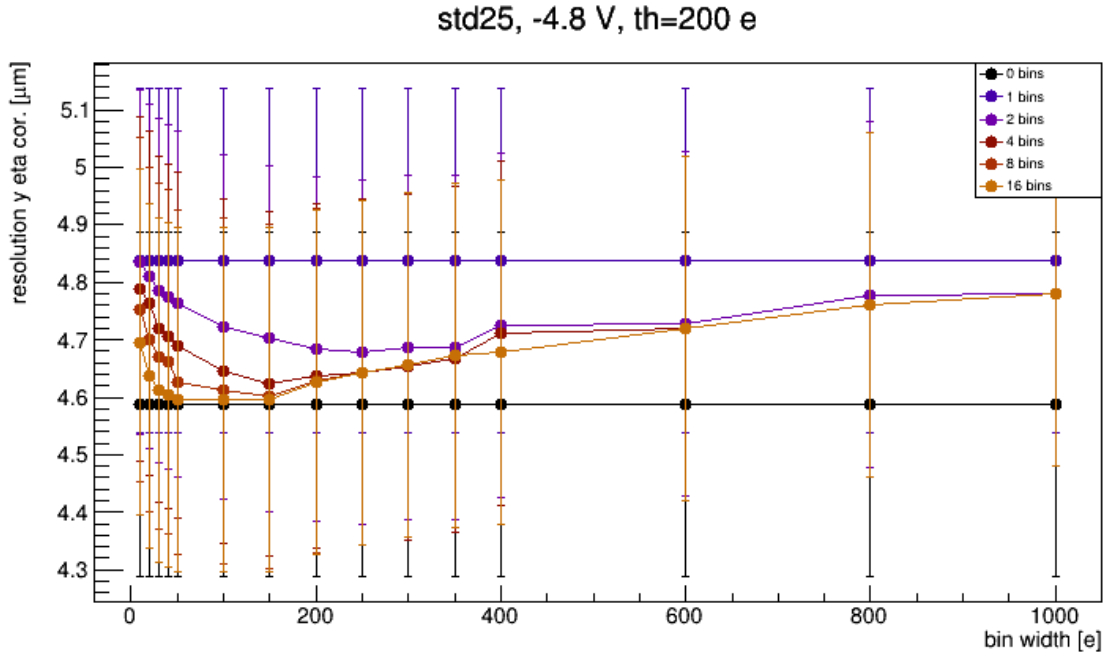
    (limited by noise?)
  - Increasing threshold
    Cluster size (efficiency) decreases

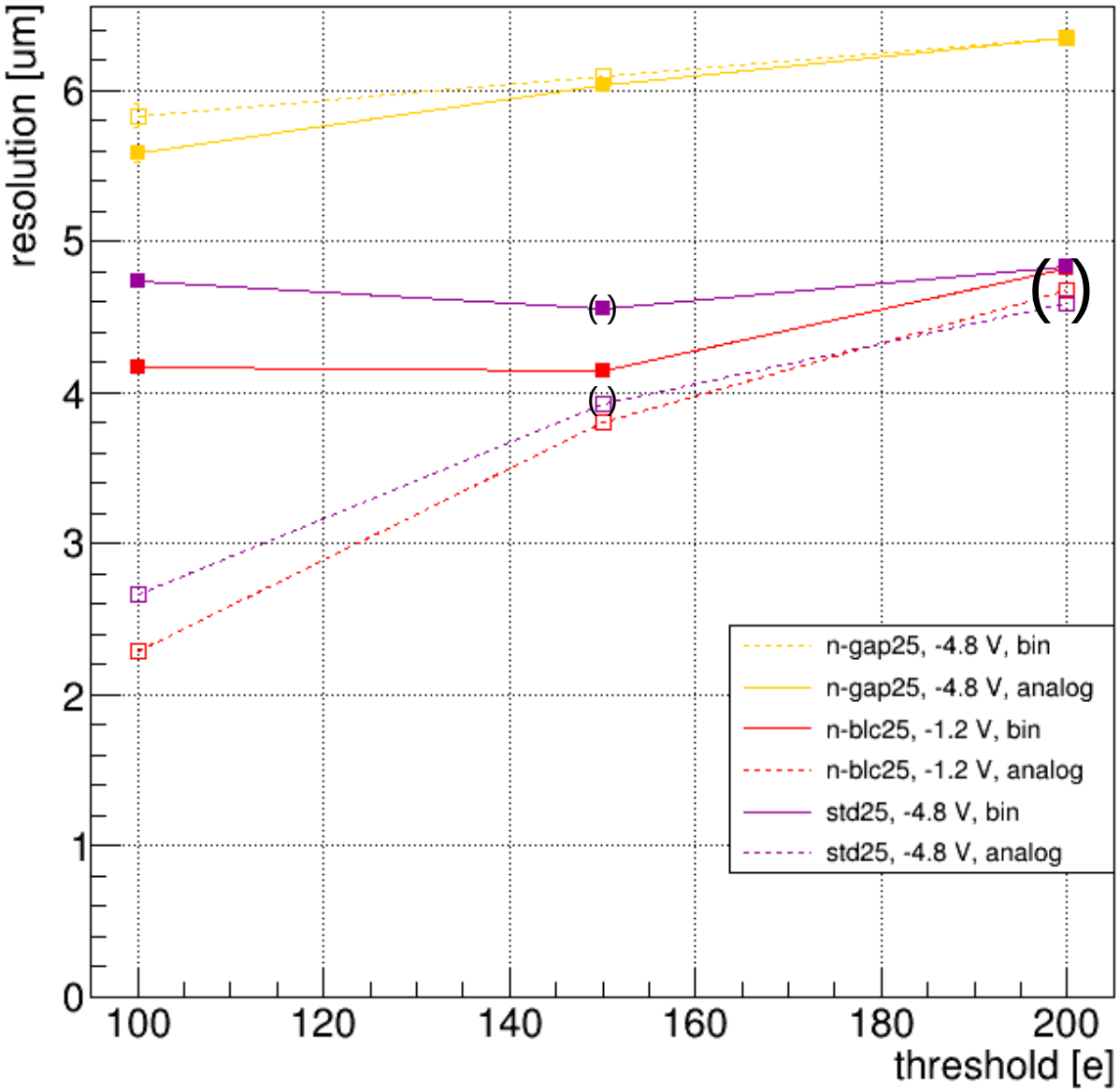


# Results

## Threshold Dependence

- Caveats
  - Points in () are below 99% efficiency
  - Systematic uncertainties between designs (telescope resolution)
- Threshold has comparably large impact
  - n-gap: resolution gains from threshold larger thank resolution gains from charge info
  - n-blanket and standard: need low threshold to profit from charge info



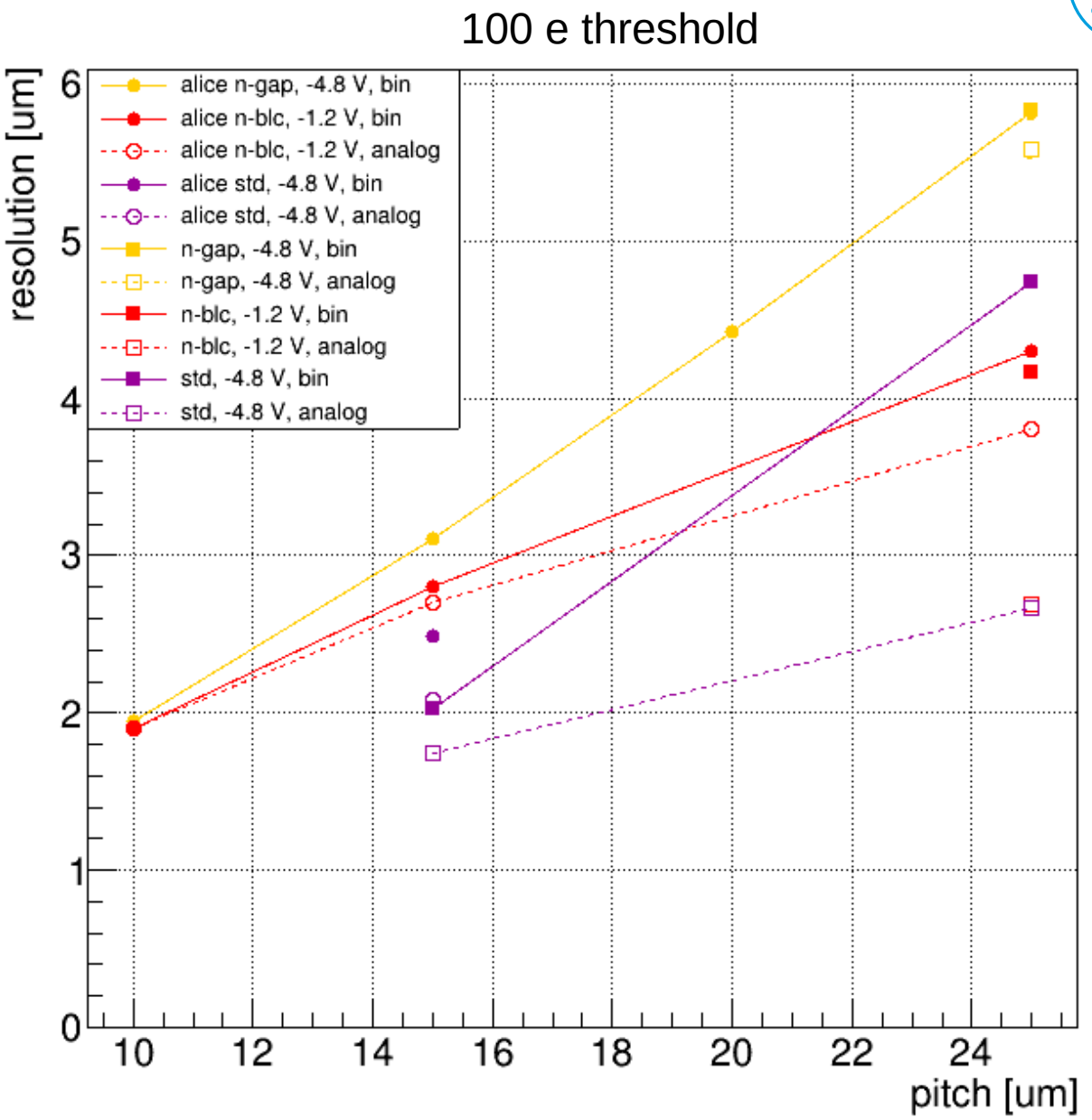
# Results

## Pitch Dependence

- Alice data is from APTS [ref. pub.]
  - Pitch has clear, strong, linear impact on spatial resolution for n-gap and n-blanket design
  - Alice results indicate lower impact of charge info
    - Especially n-blanket 25 um
- Data for standard layout is a bit scarce/ confusing
  - 15 um: small tension between Alice and us
  - 25 um, binary: I am puzzled and intend to double check everything!

To achieve a resolution better than 3 um:

- Pitch and design are crucial, threshold too
- Impact of charge info might make difference



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Key questions; concerning spatial resolution

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  - What about two thresholds?

# Thank you

## Contact

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