UNIVERSITÀ DEGLI STUDI DI MILANO

ATLASPIX3.1 Beam Telescope Testbeam results

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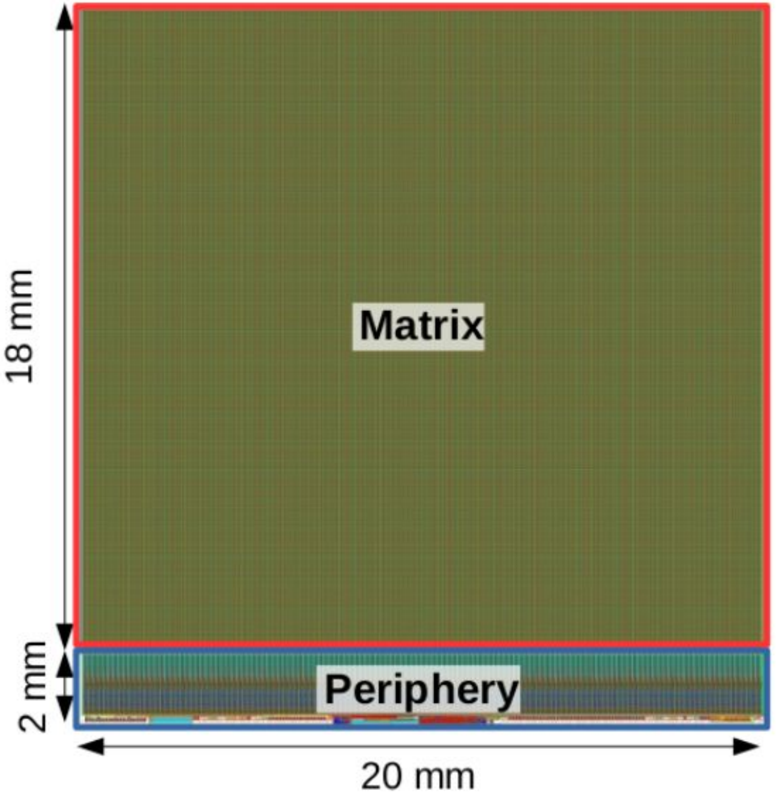
CEPC workshop 2023 - Edinburgh

Introduction

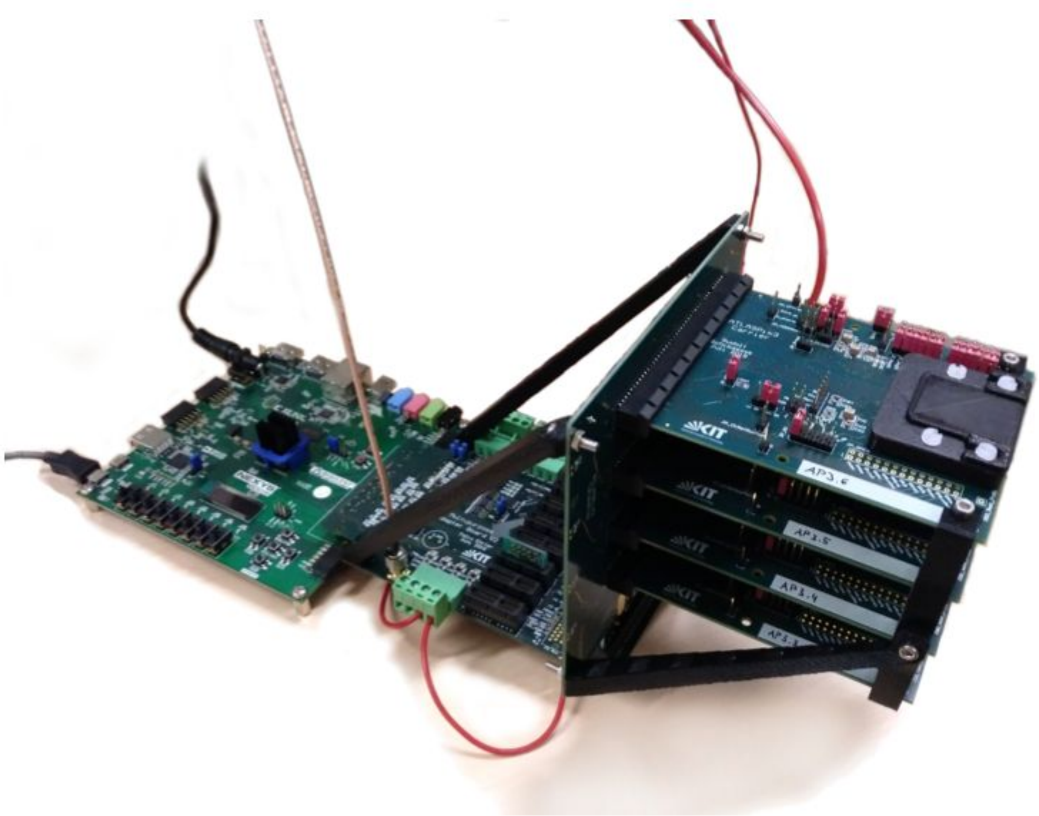
- **ATLASPix3 general features**
  - Depleted Monolithic Active Pixel Sensor (**DMAPS**)
  - **HVCMOS** technology
  - **TSI 180 nm process** on 200 Ωcm substrate
  - **132 columns of 372 pixels**
  - full-reticle size **20×21 mm^2** monolithic pixel sensor
  - **pixel size 50×150 μm^2** (25×150 μm^2 on recent prototypes)
  - **breakdown voltage ∼-60 V**
  - up to **1.28 Gbps downlink**
  - **25 ns timestamping**
- **INFN**, **KIT**, **China**, **UK** collaboration



Single Chip Setup

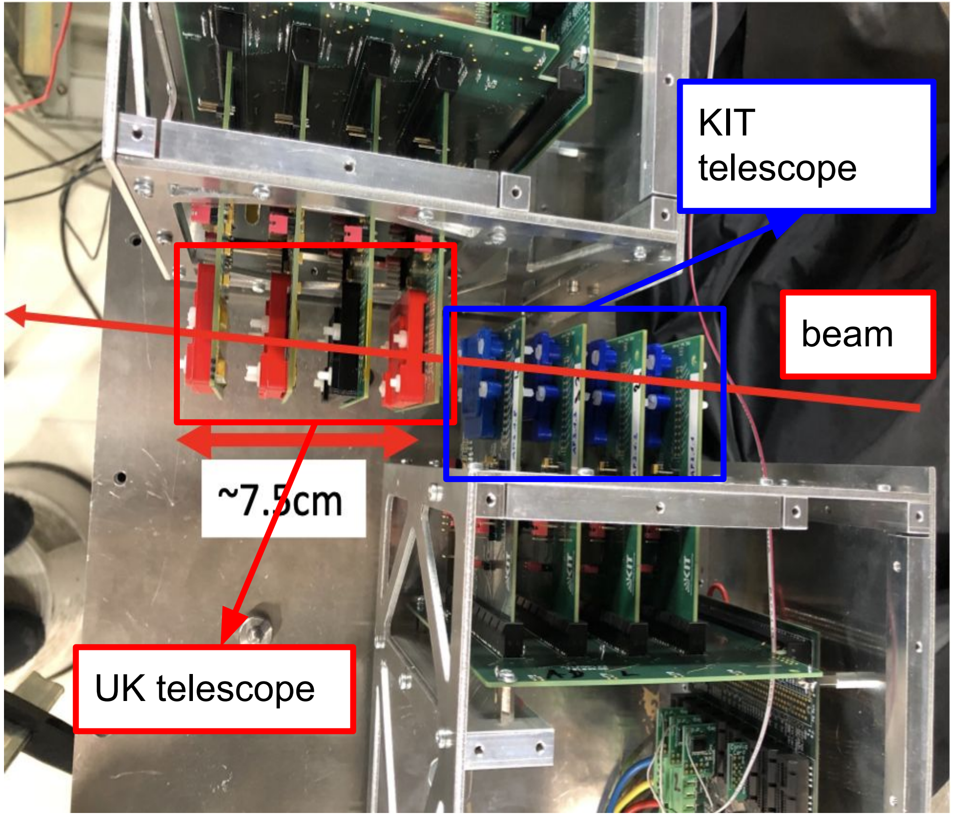
- Readout using **GECCO** (GEneric Configuration and COntrol) system for single chip, quad and telescope
  - Diligent Nexys Video FPGA board + firmware
  - **GECCO board** (middle) with function card slots
  - Single chip card (can be swapped out)
  - Qt-based software GUI

Beam Telescope



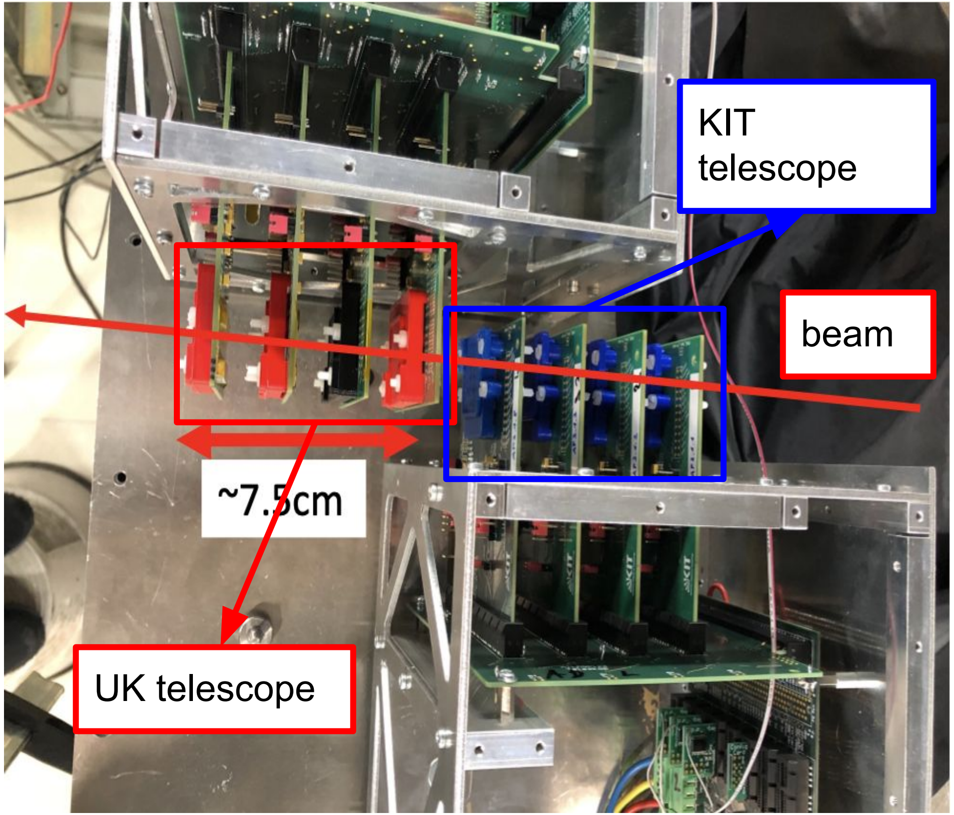
- Using the same **GECCO system** with additional function cards
- One telescope adapter card provides slots for **4 planes** with a **distance of 2.54 cm**
- Telescope firmware and software (similar to single chip)
- All **telescope planes share** the **same HV** and **LV** (voltages can be fine-tuned for each plane if regulators are used)
- in figure a simple model used for early tests

DESY Testbeam April 2022 (1)



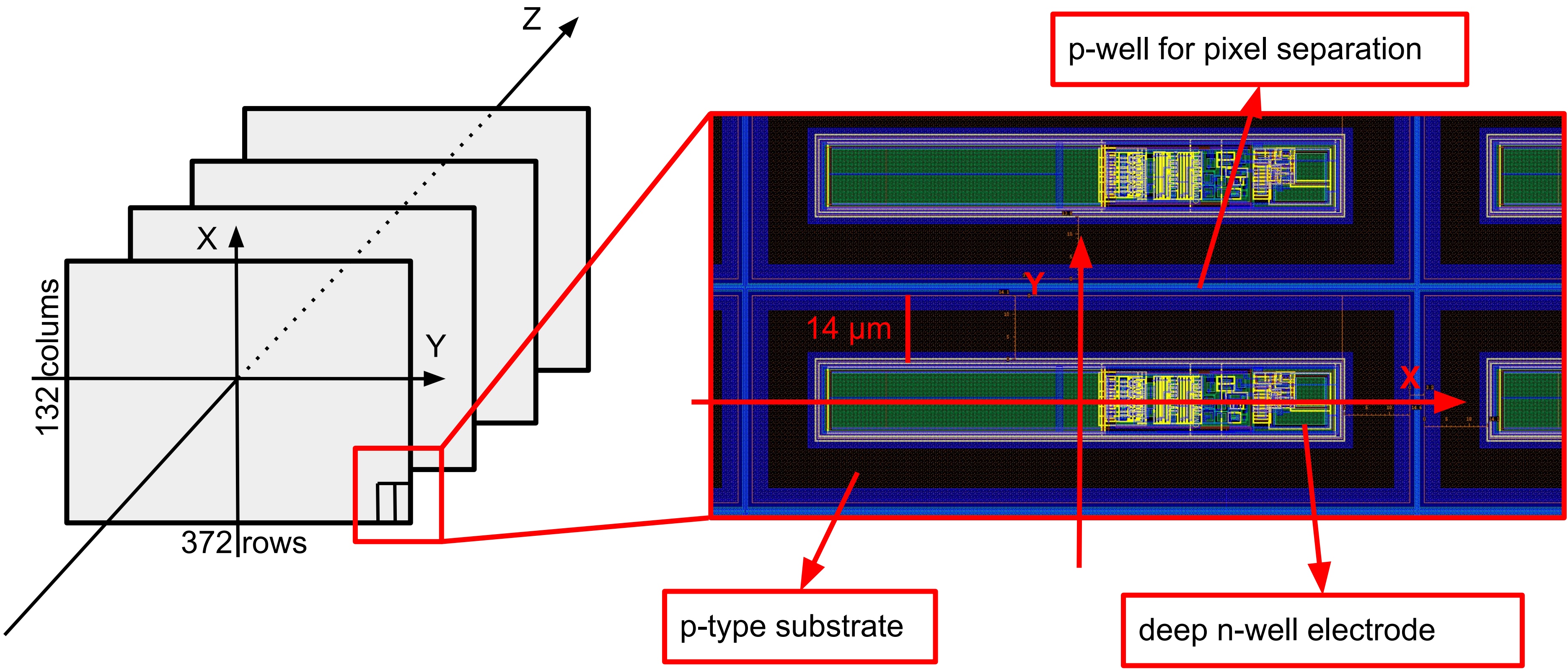
- Two telescopes (**KIT** and **UK**) in standalone systems tested at **DESY** with electron beams
- For the presented data analysis
  - **3-6 GeV electrons** beams
  - **perpendicular** beams
  - hit-driven RO
  - KIT and UK telescopes placed as in figure
  - **HV scan for the UK telescope** (2, 5, 10, 15, 20, 30, 40, 50 V)
- Data reconstruction
  - **Corryvreckan**
  - use **L1** (ref), **L2** and **L4** as telescope planes for iterative **alignment** and **tracks reconstruction**
  - associate **L3** as **DUT** plane
    - selected tracks with χ^2/ndof<5
    - cluster associated if within 0.6mm from track interception

DESY Testbeam April 2022 (2)

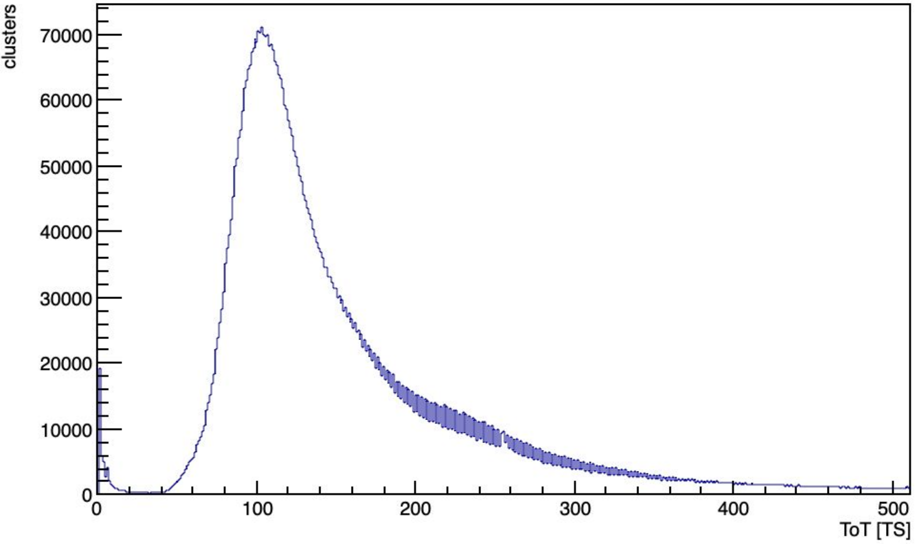


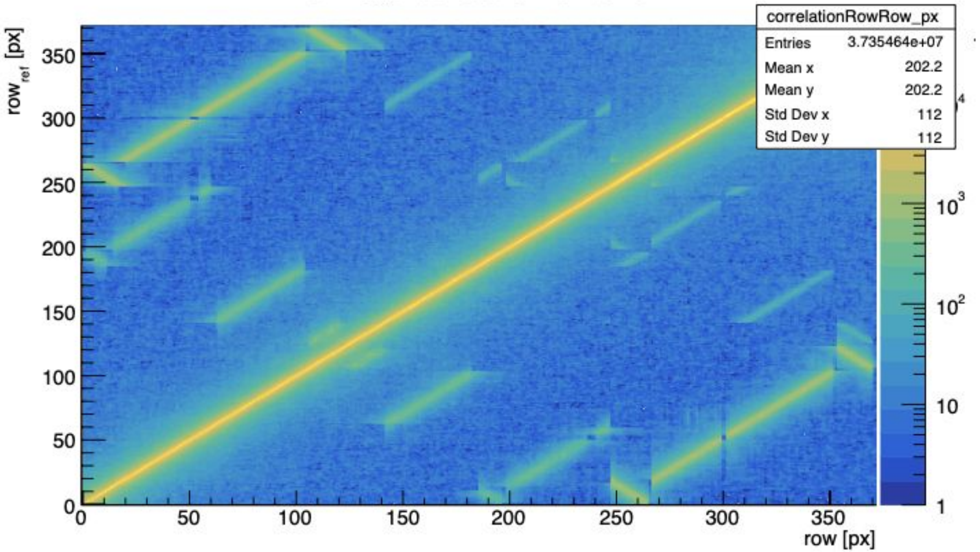
- **Very new results presented in this talk**
- Find **previous results** here
  - First Results of ATLASPix3.1 Telescope, The 31st International Workshop on Vertex Detectors, Talk, October 2022
  - First results of ATLASPix3.1 telescope, 10th International Workshop on Semiconductor Pixel Detectors for Particles and Imaging, Poster session, December 2022

Reference system



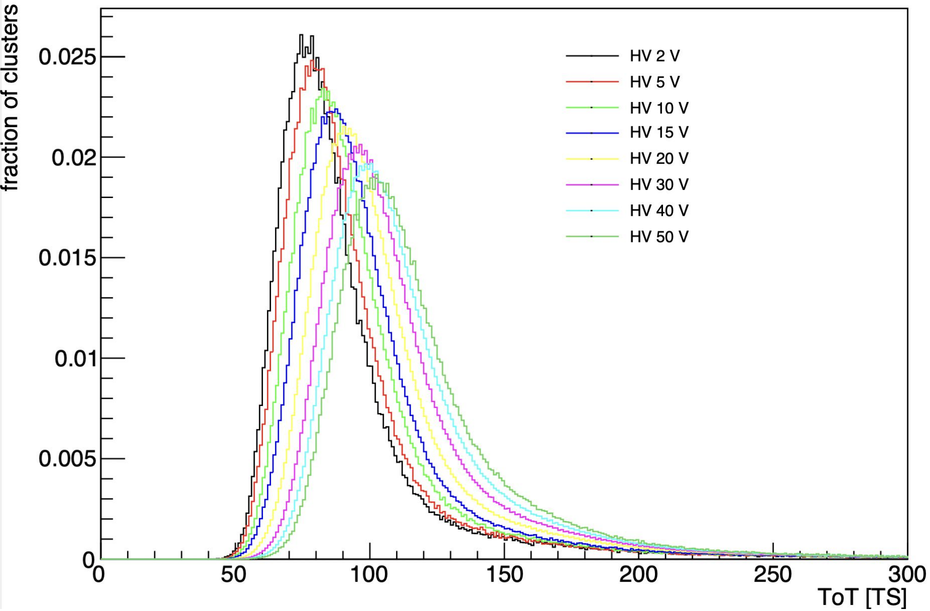
Cross-talk

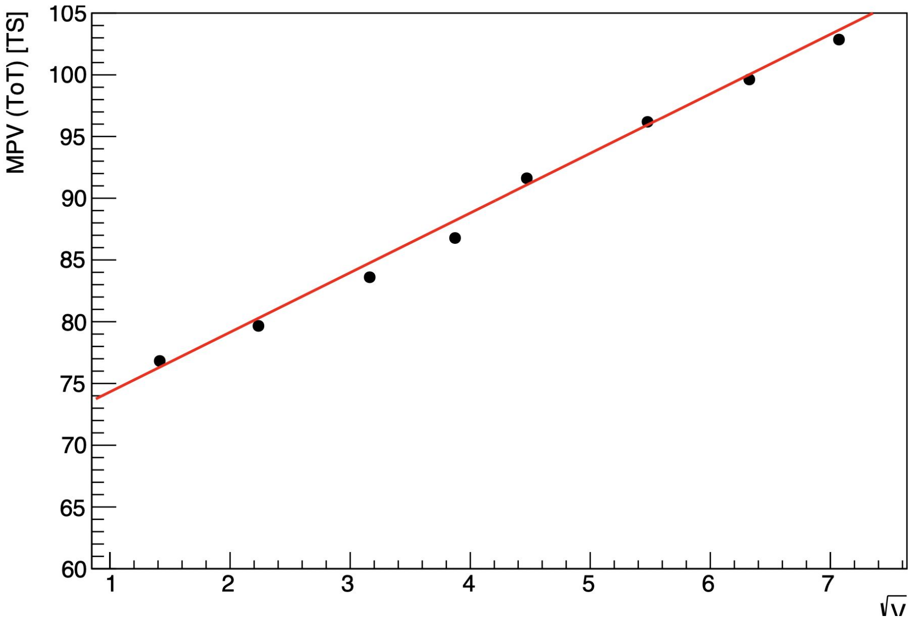




- **Cross-talk** between pixels due to the capacitive coupling of the transmission lines between the matrix and the end-of-column logic is **limited to ~1%** of total hits
  - cross-talk hits shows up in self correlation plots
  - they are contained in the low ToT peak

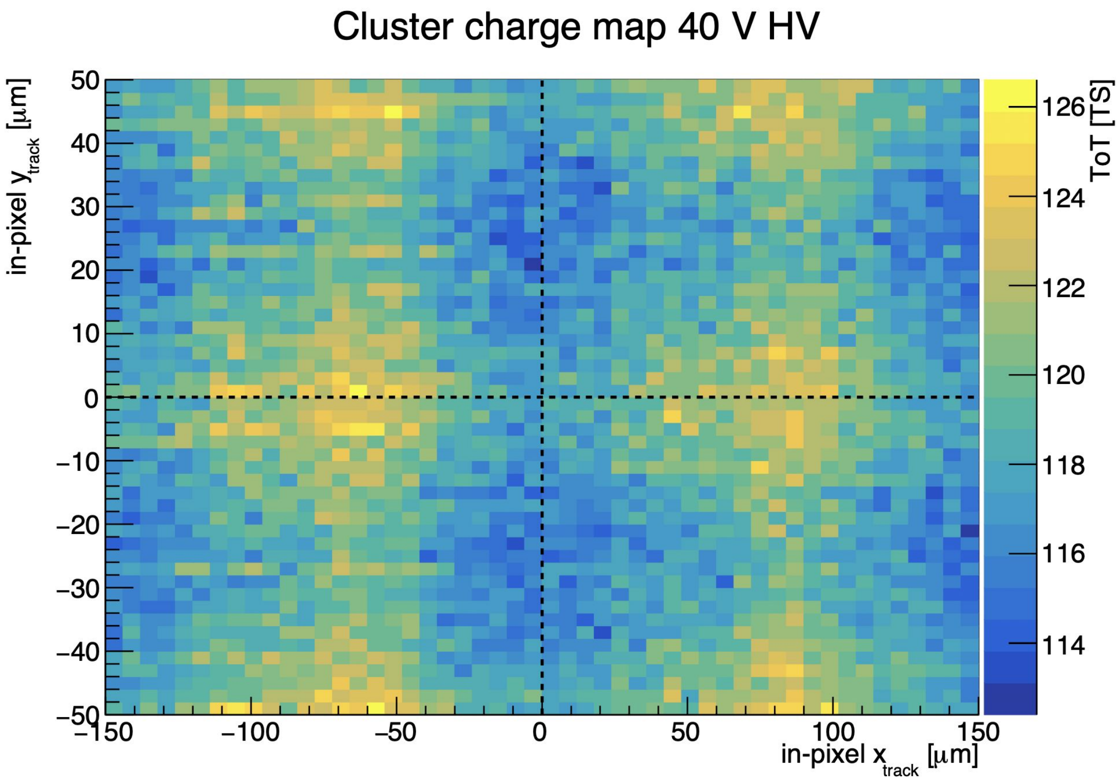
Time over Threshold (1)





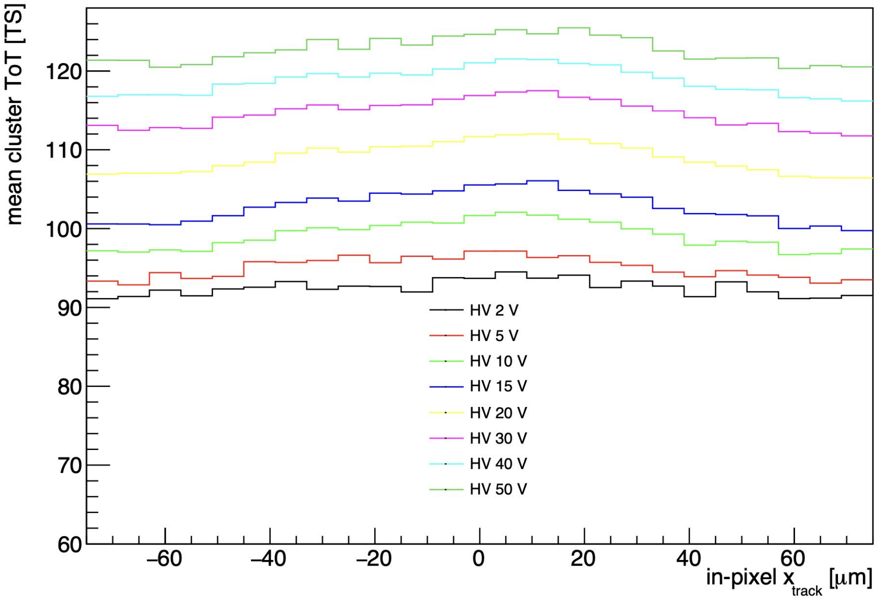
- ToT **increases with HV**
- **MPV** (Most Probable Value) has **linear** behavior with **√V**
- ToT~69 at 0V from extrapolation

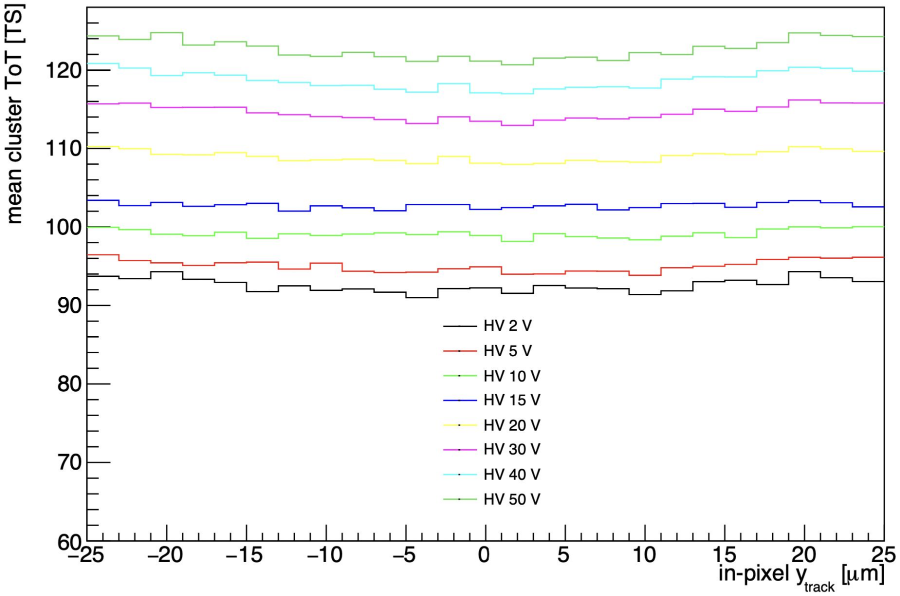
Time over Threshold (2)



- **2x2 pixel matrix**
- **Example** for **HV=40V**
- **Higher** clusters **ToT** for tracks passing at the **Y edge** between two pixels

Time over Threshold (3)

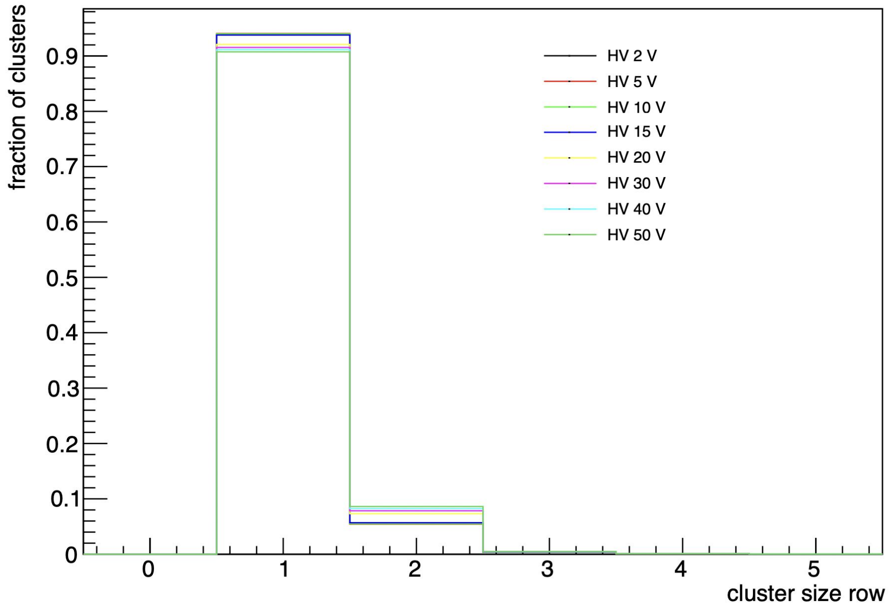


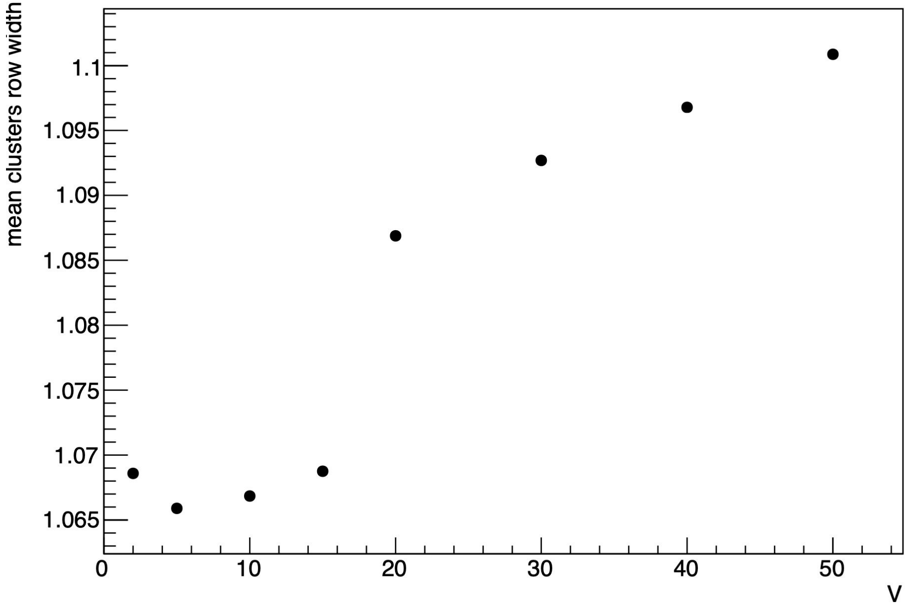


- **in-pixel X projection** for each HV
- Almost **uniform** clusters **ToT**
- ToT **slightly lower** at pixels **sides**

- **in-pixel Y projection** for each HV
- Almost **uniform** clusters **ToT**
- ToT **slightly higher at pixel sides** where the **charge** is **shared** between two pixels

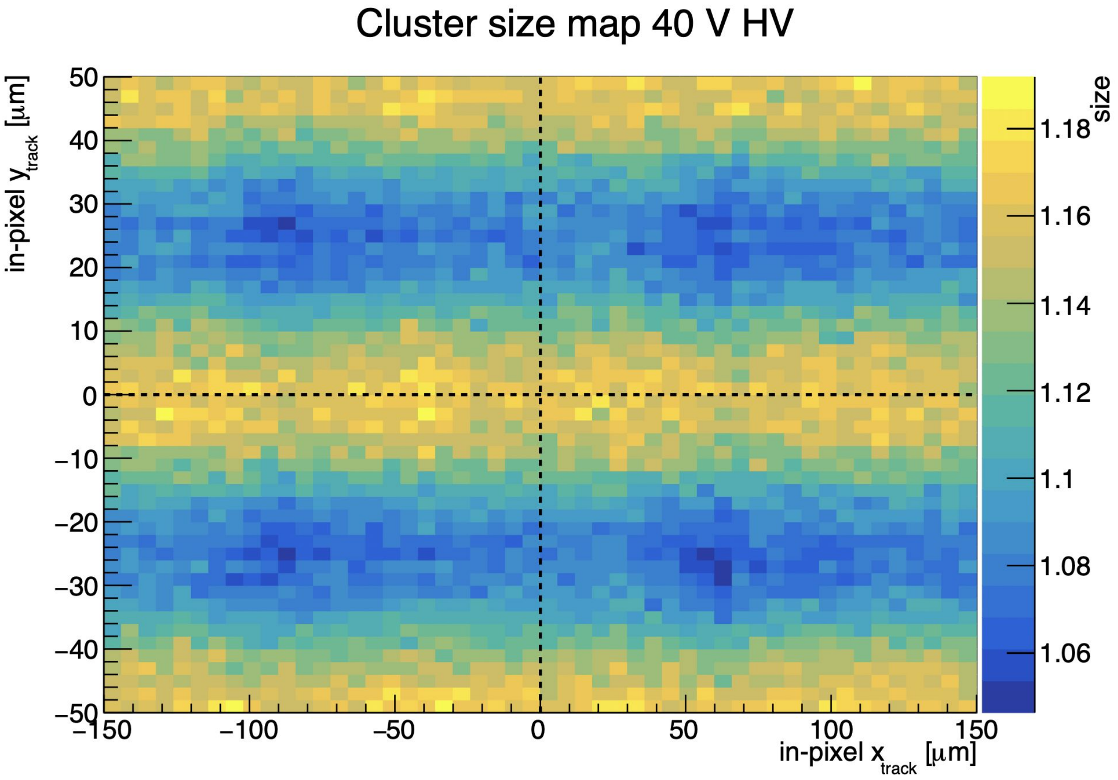
Clusters row width





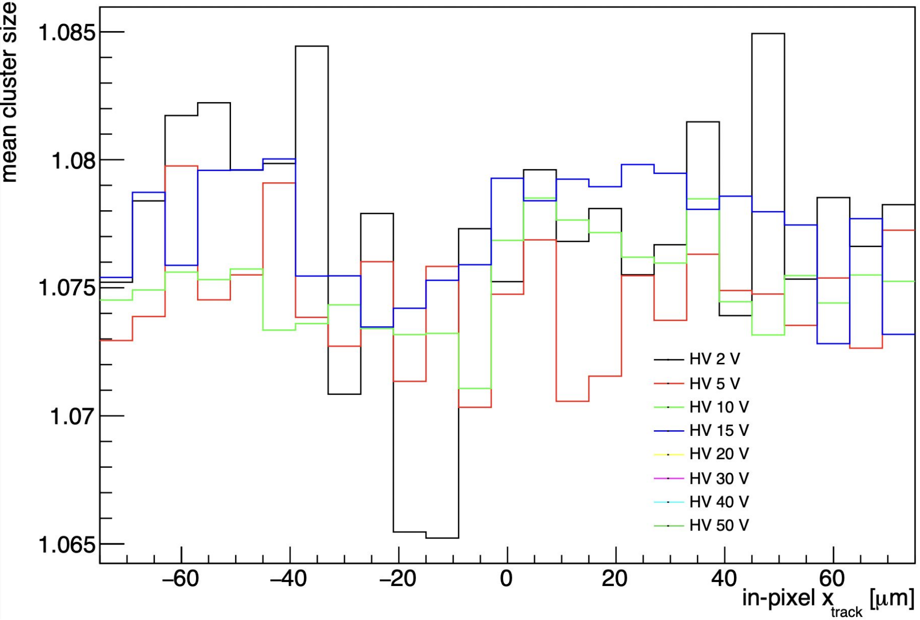
- **Distribution of cluster size** projection in **row** direction (50 µm pitch)
- Slightly **increase with HV**
- For **HV>20V** the **region between pixels gets depleted**
- In column direction (150 µm pitch) almost all cluster are single pixel due to the bigger pitch

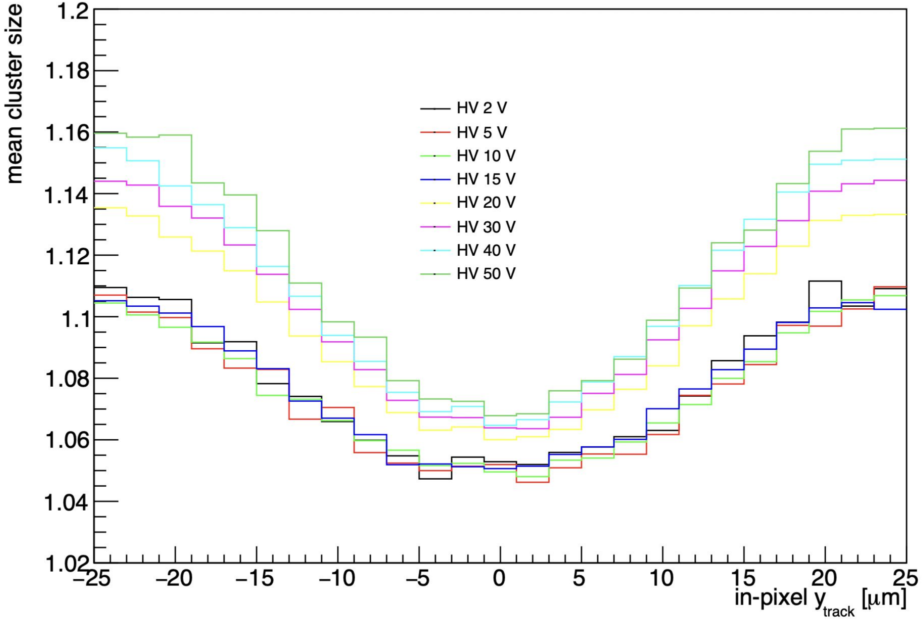
Clusters size (1)



- **2x2 pixel matrix**
- **Example** for **HV=40V**
- **Higher** clusters **size** for tracks passing at the **Y edge** between two pixels
- Cluster **size** almost **constant** for tracks passing at the **X edge** between two pixels

Clusters size (2)



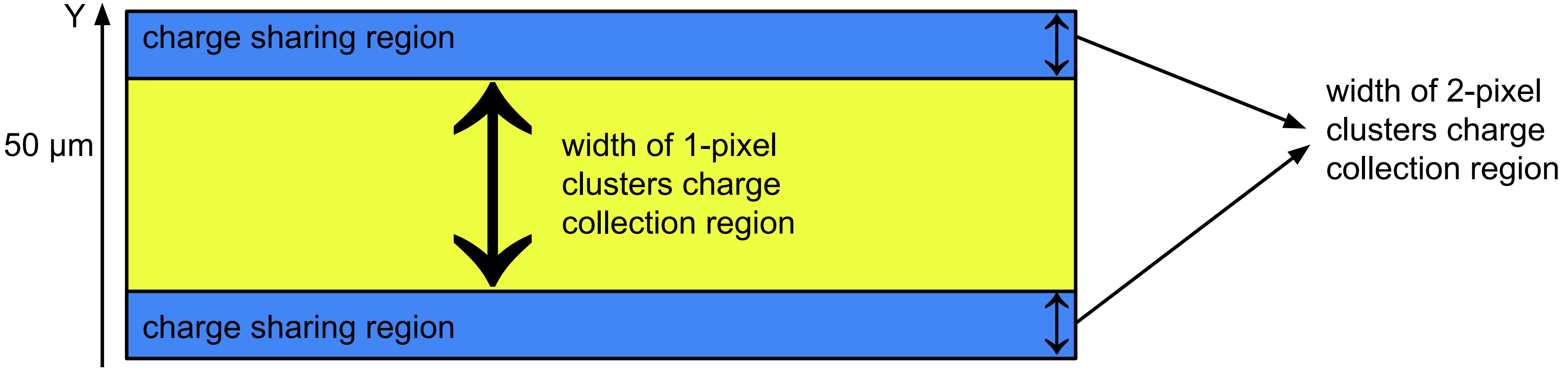


- **in-pixel X projection** for each HV
- Almost **uniform clusters size** even at pixel edges

- **in-pixel Y projection** for each HV
- Mean **clusters size increases** at pixel **edges**
- **Discontinuity between 15V and 20V** when the region between pixels gets depleted (as observed before)

Resolution

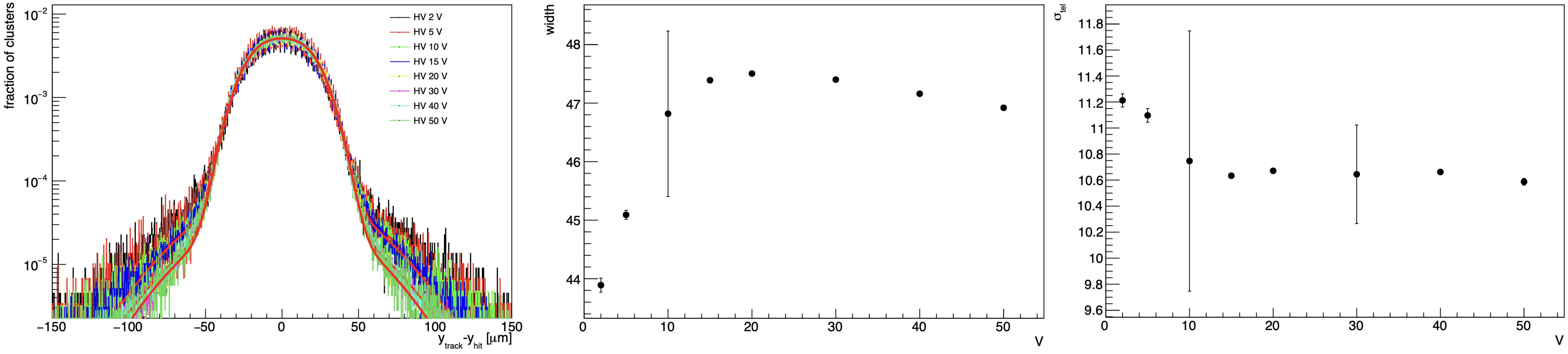
- **Resolution for 1-pixel and 2-pixels** (row projection) **clusters** in **precise Y direction** (50 µm pitch)
- Distribution of residuals in Y fitted with function $f(x) = [S(x|l,r,C)+G_{bkg}(x|\mu_{bkg},\sigma_{bkg})]*G_{tel}(x|\mu_{tel},\sigma_{tel})$ where
  - $S(x|l,r,C) = \begin{cases} C & l<x<r \\ 0 & elsewhere \end{cases}$ is a **step-function** describing the **charge collection region**



Resolution

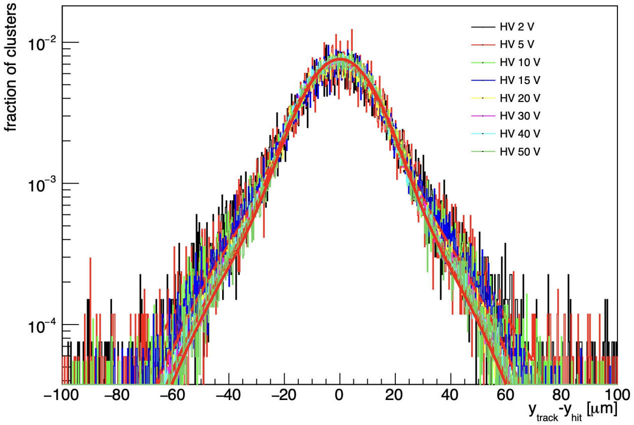
- **Resolution for 1-pixel and 2-pixels** (row projection) **clusters** in **precise Y direction** (50 μm pitch)
- Distribution of residuals in Y fitted with function $f(x) = [S(x|l,r,C)+G_{bkg}(x|\mu_{bkg},\sigma_{bkg})]*G_{tel}(x|\mu_{tel},\sigma_{tel})$ where
  - $S(x|l,r,C) = \begin{cases} C & l<x<r \\ 0 & elsewhere \end{cases}$ is a **step-function** describing the **charge collection region**
  - $G_{bkg}(x|\mu_{bkg},\sigma_{bkg})$ is a Gaussian background which accounts for tails in the resolution function, for example, due to δ-rays or bremsstrahlung
  - $G_{tel}(x|\mu_{tel},\sigma_{tel})$ is a Gaussian function which describes the **telescope resolution**
- width of the step-function ($l+r$) and σ_{tel} extrapolated from fit to study their **variation with HV**

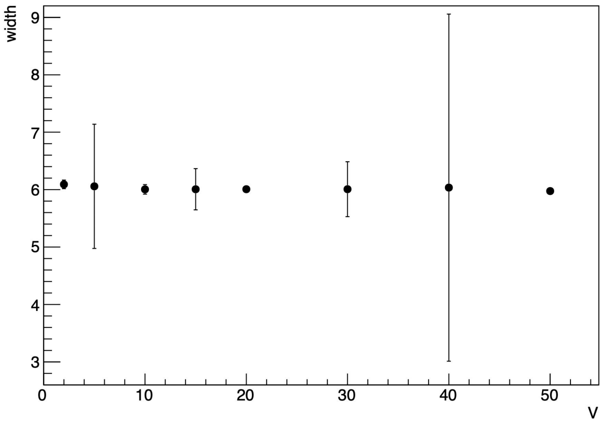
1-pixel clusters Y resolution

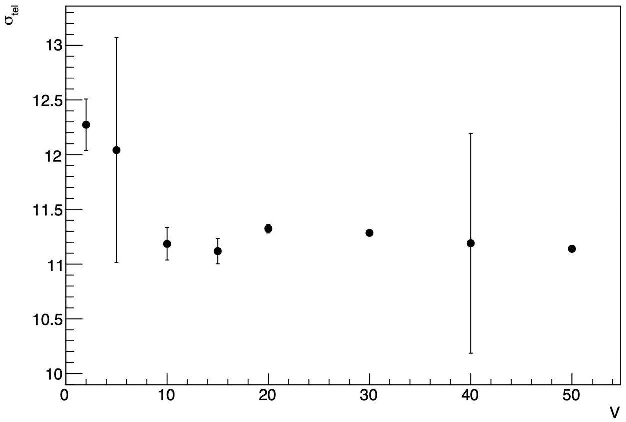


- Fit function **describes the shape of the Y residuals for 1-pixel clusters**
- **Width of the step function increases** from ~44 μm at 2V to ~47 μm at 50 V
- **Telescope resolution σ_{tel} improves** with increasing HV from ~11.2 μm to ~10.6 μm

2-pixel clusters Y resolution

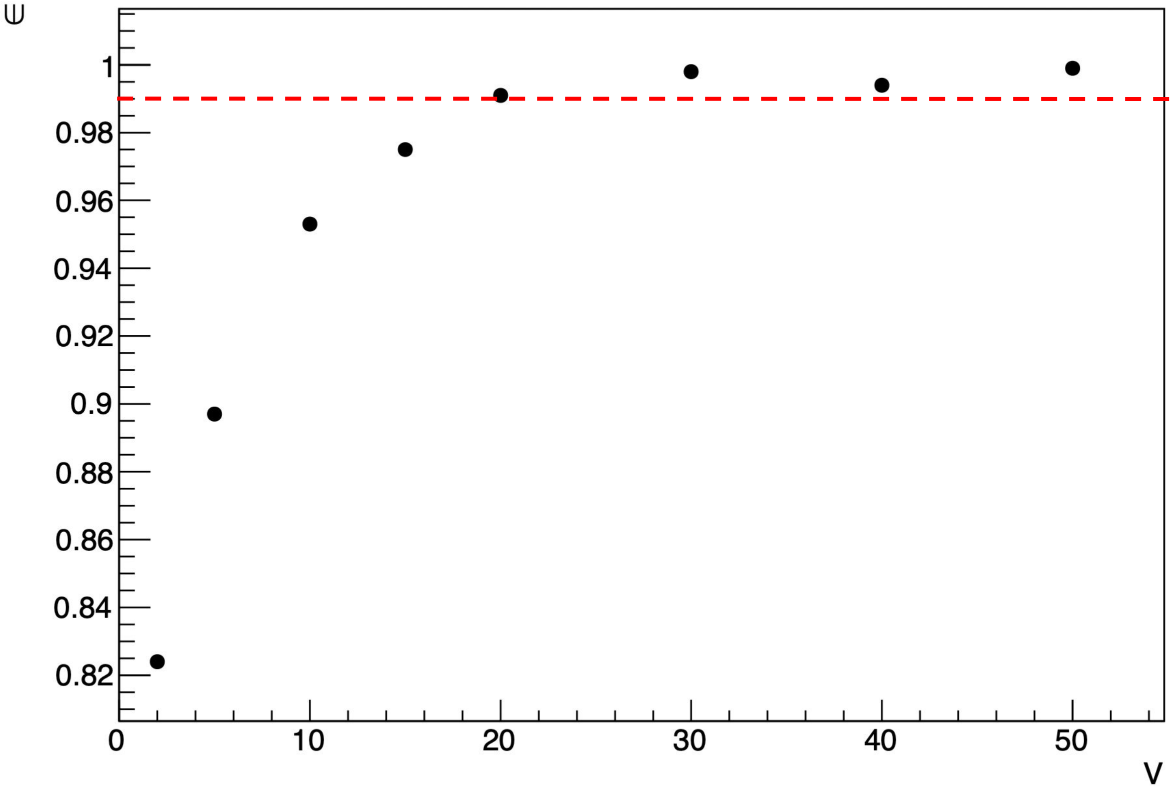






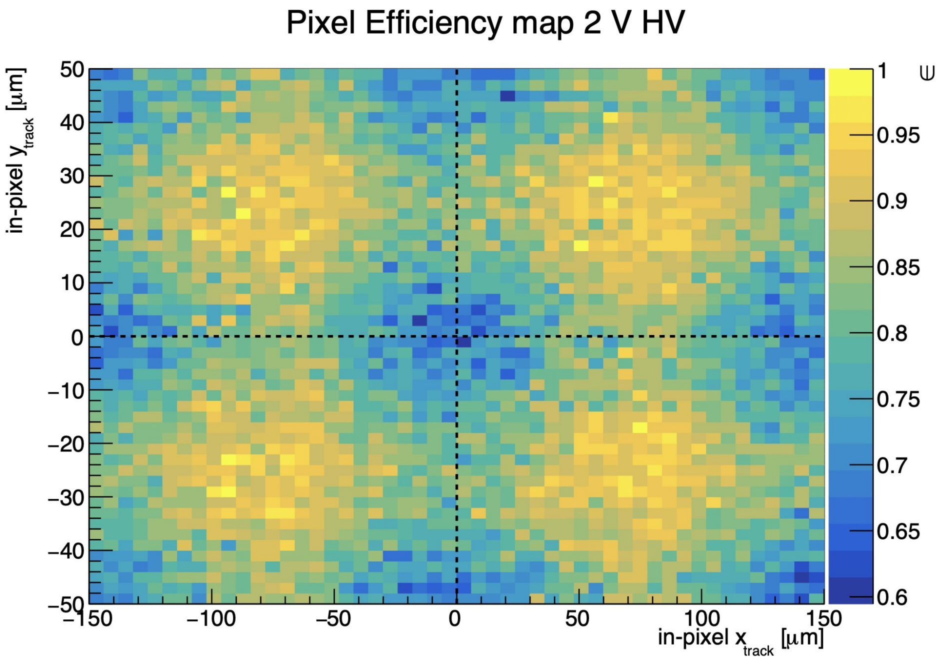
- Fit function **describes the shape of the Y residuals for 2-pixel clusters** (size projection along row)
- **Width of the step function is constant** with HV at ~6 μm
- **Telescope resolution σ_{tel}** is very similar to the previous case and **improves** with increasing HV

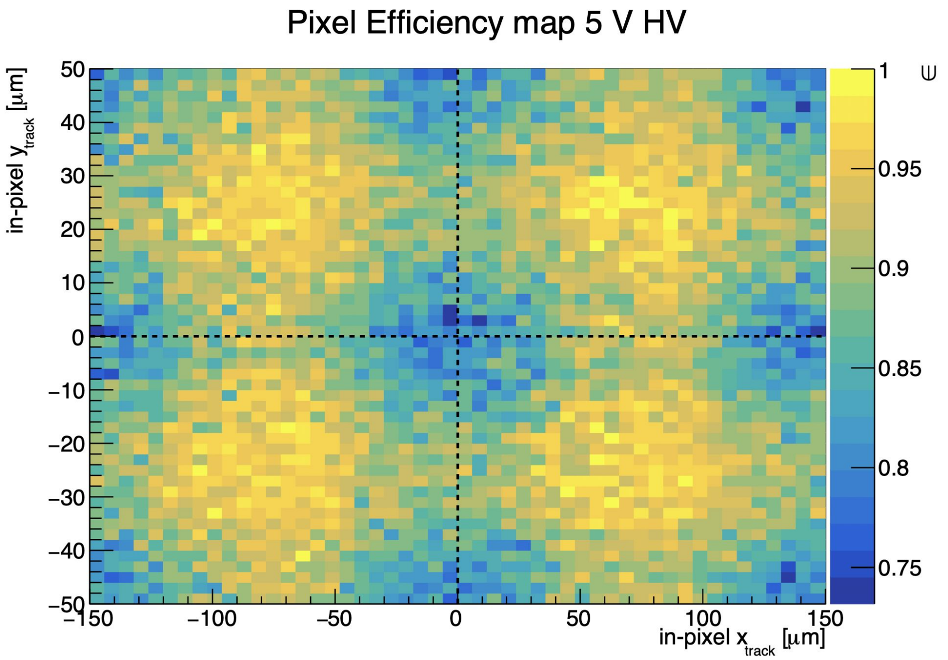
Efficiency



- **Efficiency increase** with HV from ~82.5% at 2V to ~99.8% at 50 V
- **Efficiency ~constant** for **HV>20V** when the whole detector area is depleted

In-pixel efficiency (1)

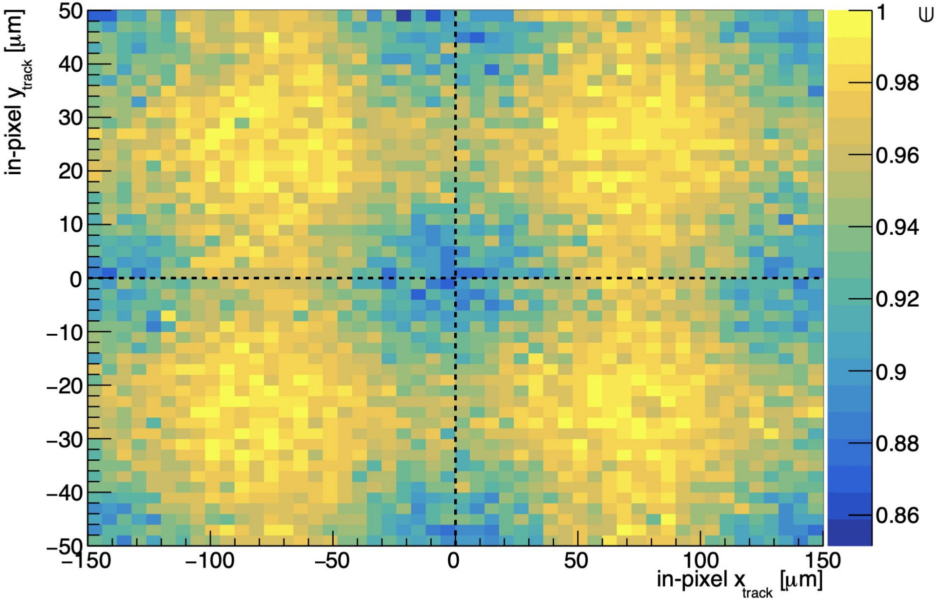




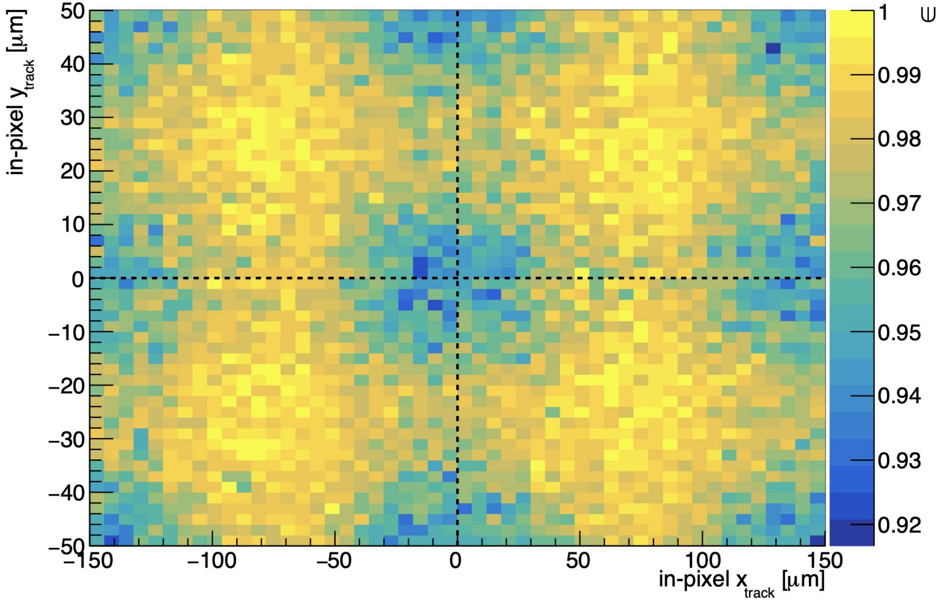
- Grouped **2x2** pixel **matrix**
- **Higher efficiency in pixel centre**, **lower efficiency** at the **edges** and at the **corners**, where the charge is shared between four pixels

In-pixel efficiency (2)

Pixel Efficiency map 10 V HV

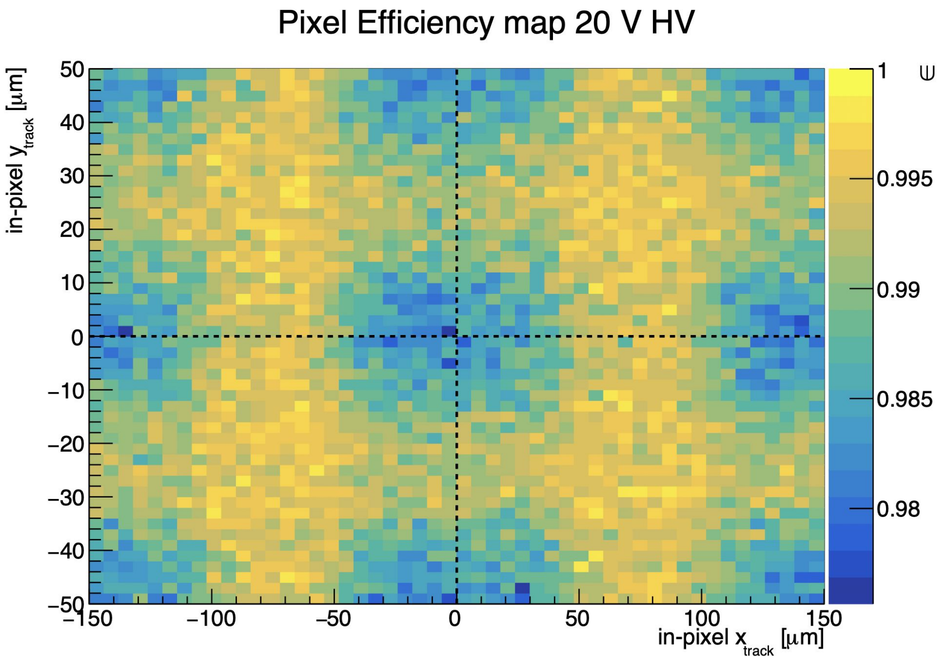


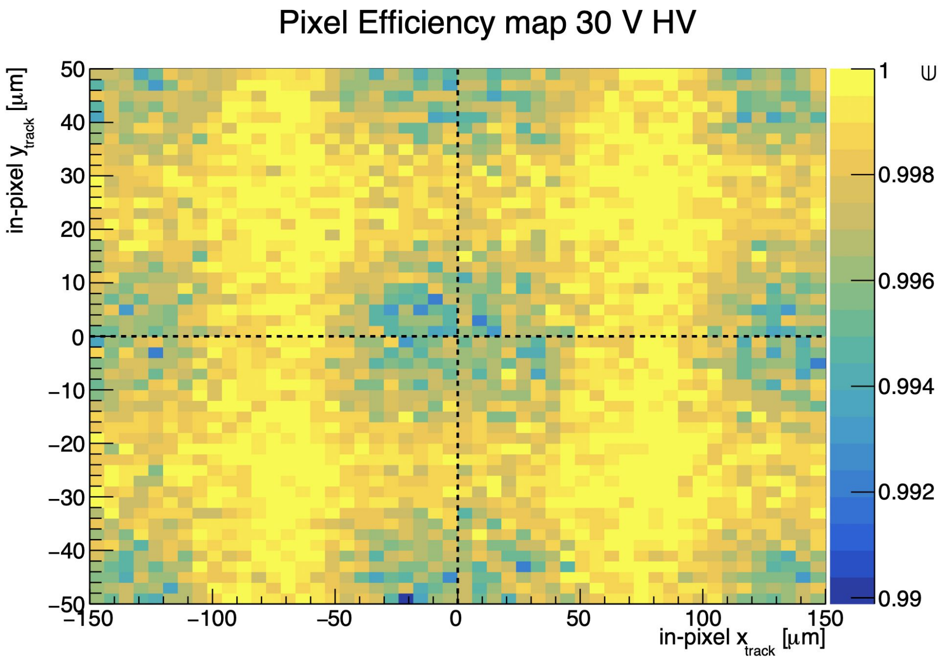
Pixel Efficiency map 15 V HV



- Grouped **2x2** pixel **matrix**
- **Efficiency become more uniform** across the pixel (note the different Z-scale)

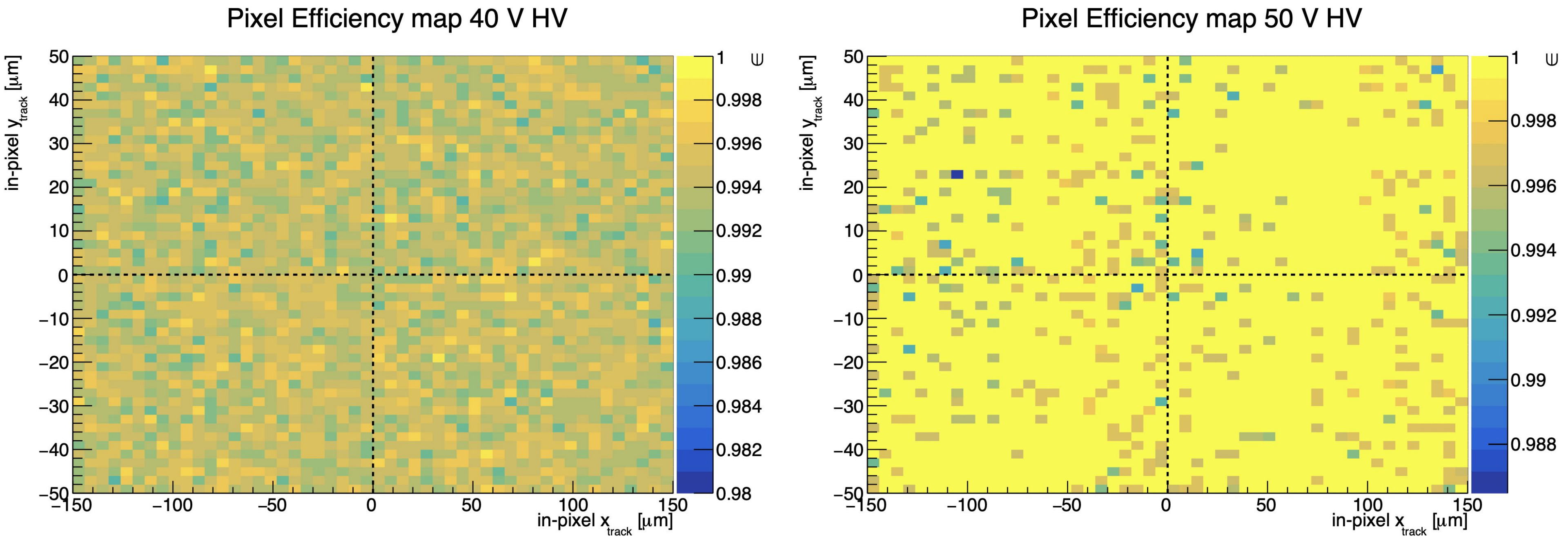
In-pixel efficiency (3)





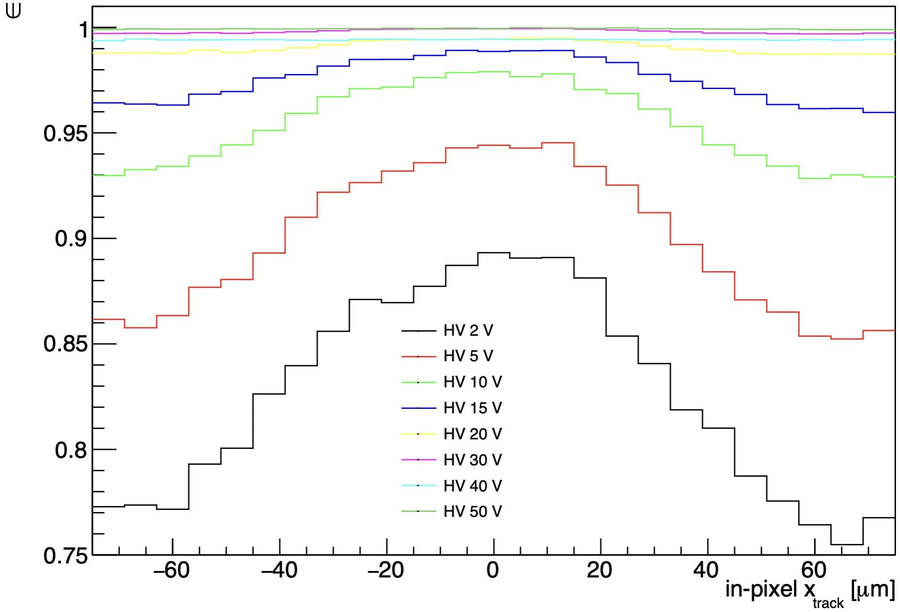
- Grouped **2x2** pixel **matrix**
- **Efficiency become more uniform** across the pixel (note the different Z-scale)

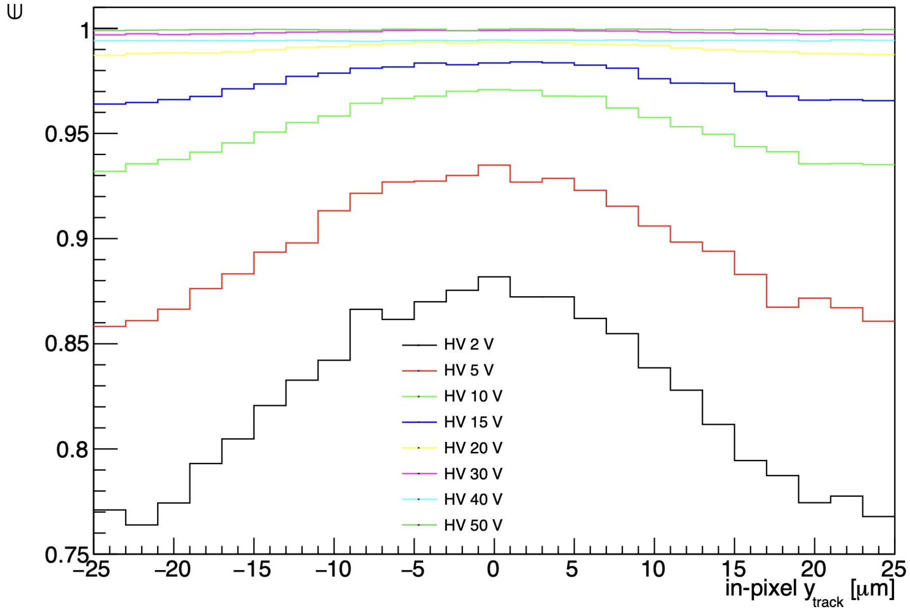
In-pixel efficiency (4)



- Grouped **2x2** pixel **matrix**
- **Efficiency** becomes **uniform** across the pixel for HV≥40 V

In-pixel efficiency (5)





- In-pixel efficiency **projection along X** (long side) **and Y** (short side)
- **Bigger efficiency at pixel centre** in both directions
- Efficiency becomes **uniform** in both direction when the **whole detector area is depleted**

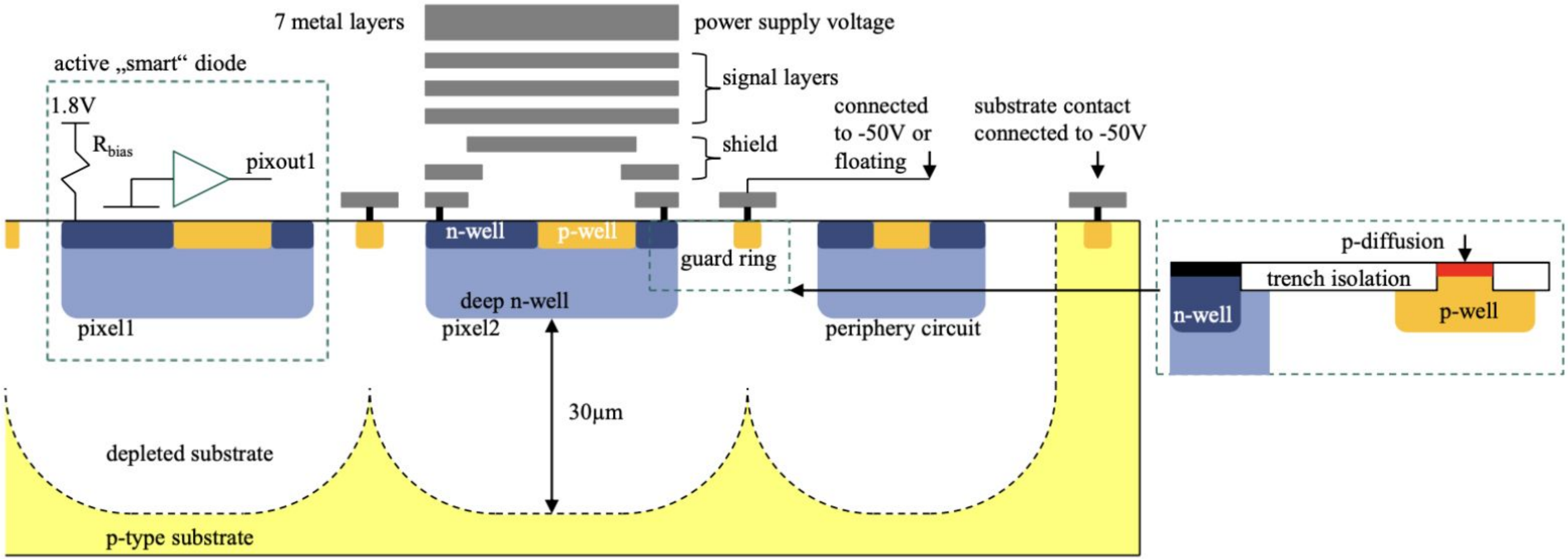
Conclusions and future perspectives

- **ATLASPix3** is one of the **candidates for the CEPC Silicon Tracker** and with the presented analysis we have observed that:
  - **cross-talk hits** can be reduced to **~1%** of the total hits
  - the **performance** is **uniform** for **HV>20V**:
    - **efficiency >99%**
    - **avoid charge losses**
  - the **telescope resolution gets better for increasing HV**
- Many **other data** have been **collected** at the **DESY Testbeam**
  - different **energies**
  - different **angles**
- **More precise extrapolation is needed to achieve a more precise mapping of efficiency and charge collection**

THANKS FOR THE ATTENTION

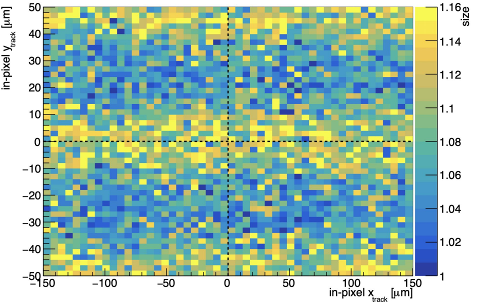
BACKUP

Pixel cross-section

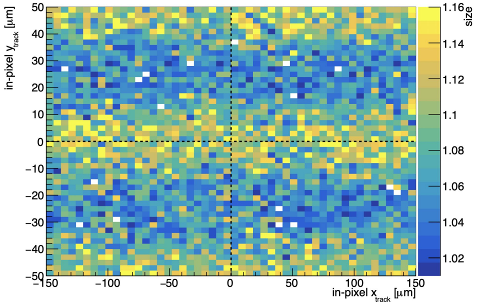


Cluster size (1)

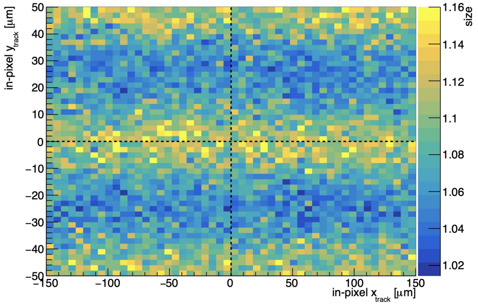
Cluster size map 2 V HV



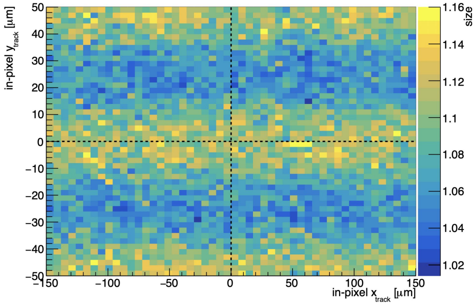
Cluster size map 5 V HV



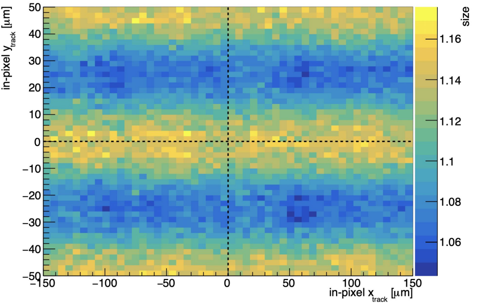
Cluster size map 10 V HV



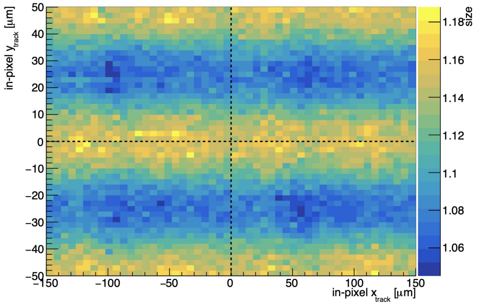
Cluster size map 15 V HV



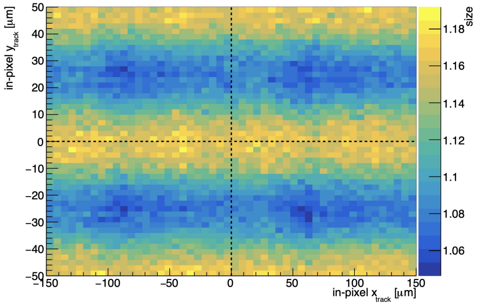
Cluster size map 20 V HV



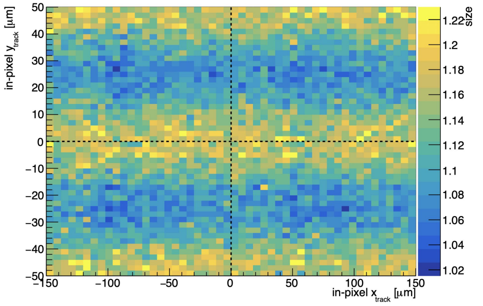
Cluster size map 30 V HV



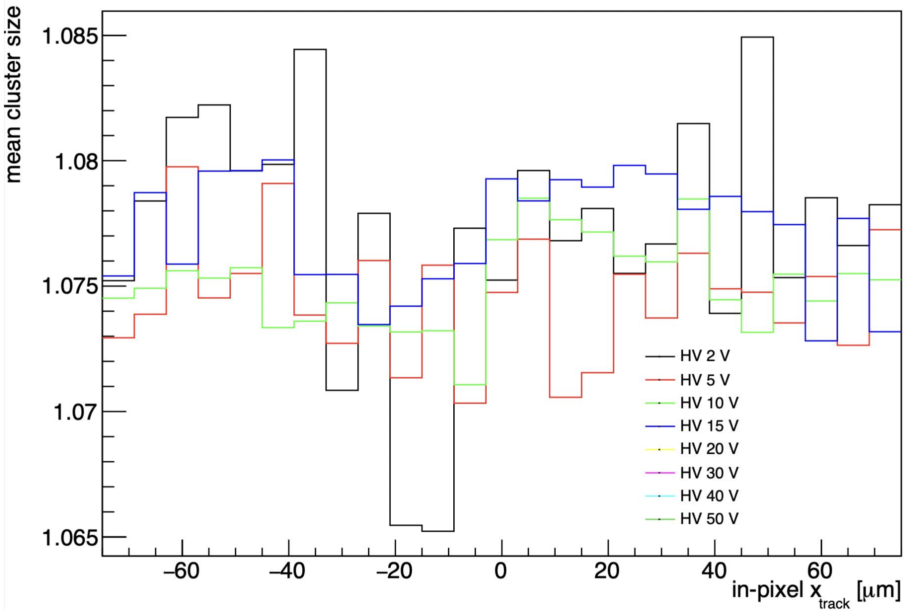
Cluster size map 40 V HV

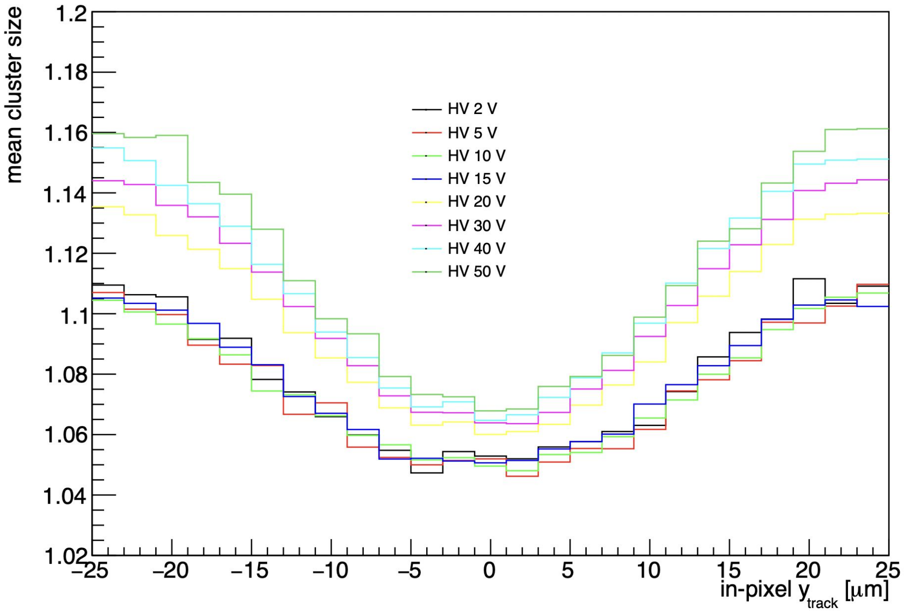


Cluster size map 50 V HV



Cluster size (2)





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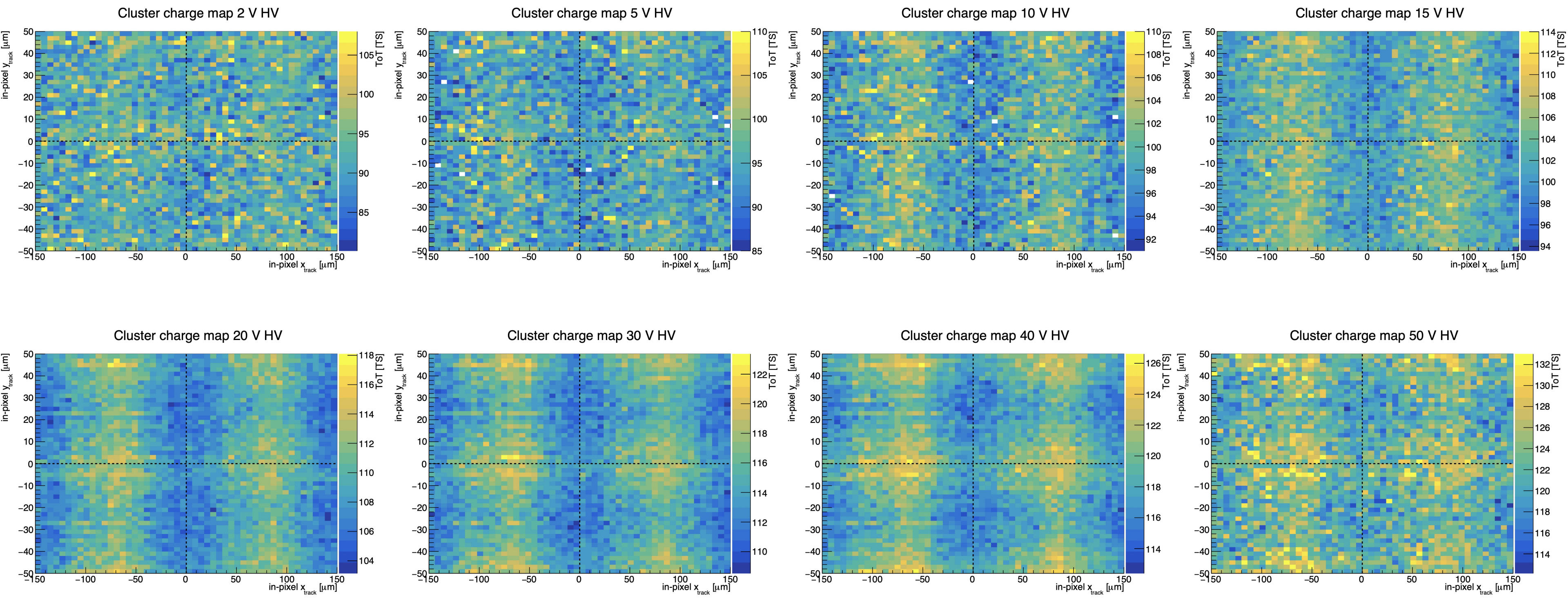
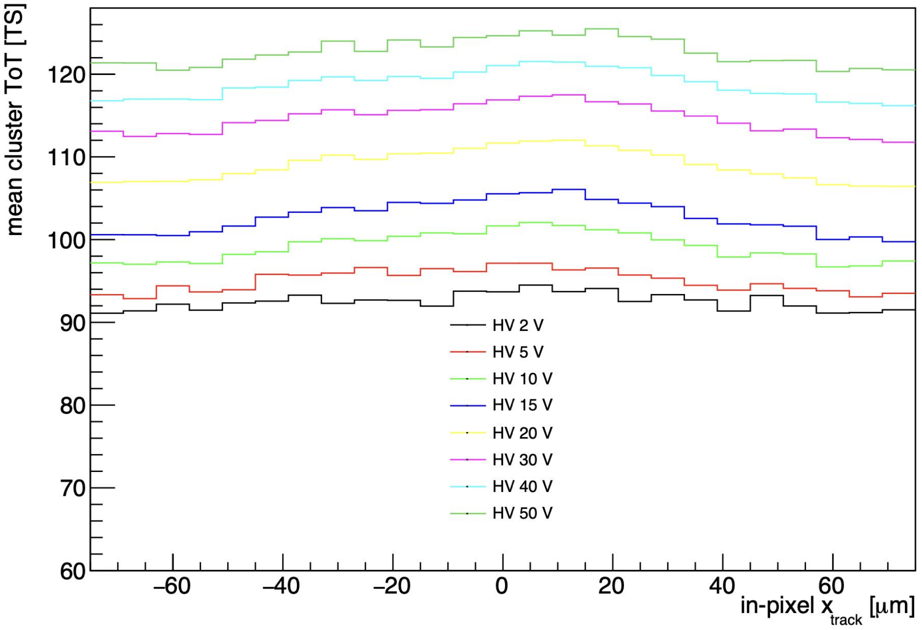
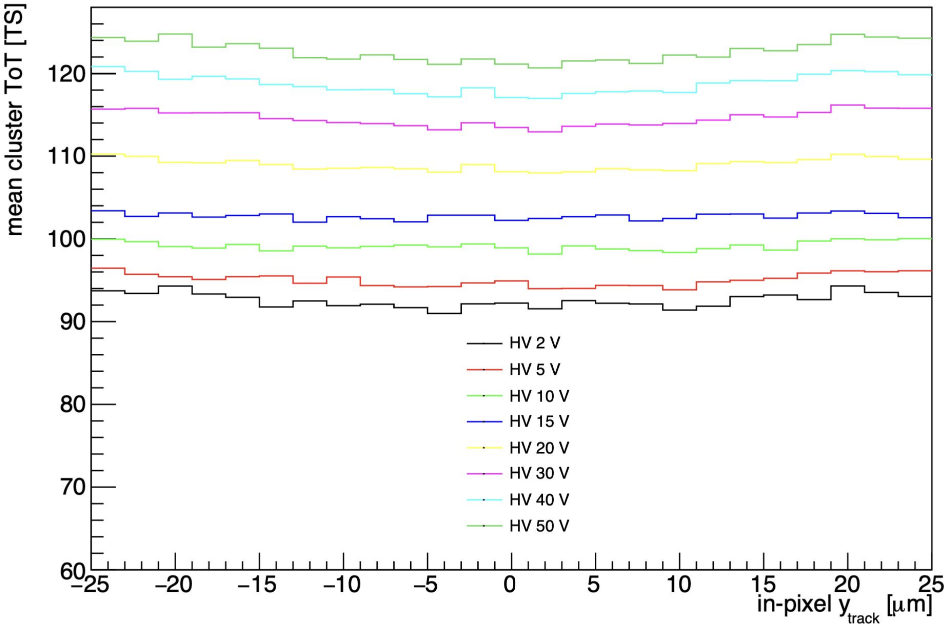
Cluster charge (1)

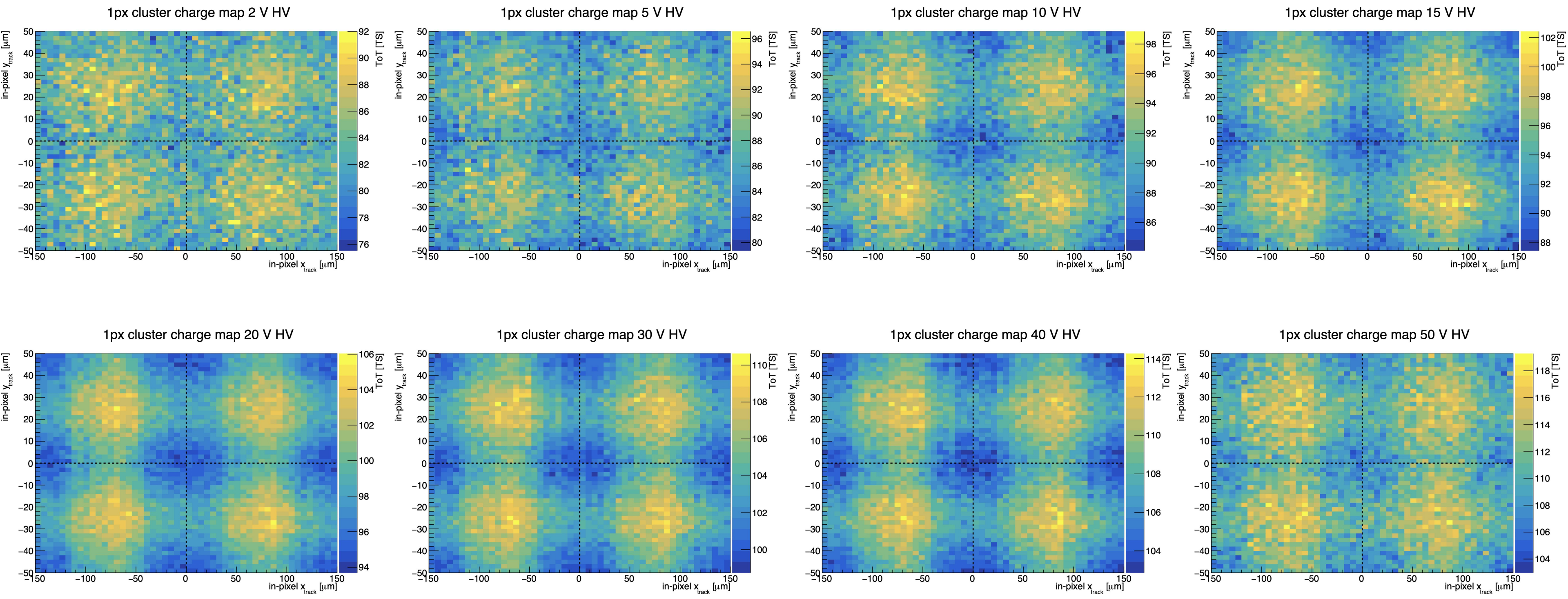


Cluster charge (2)

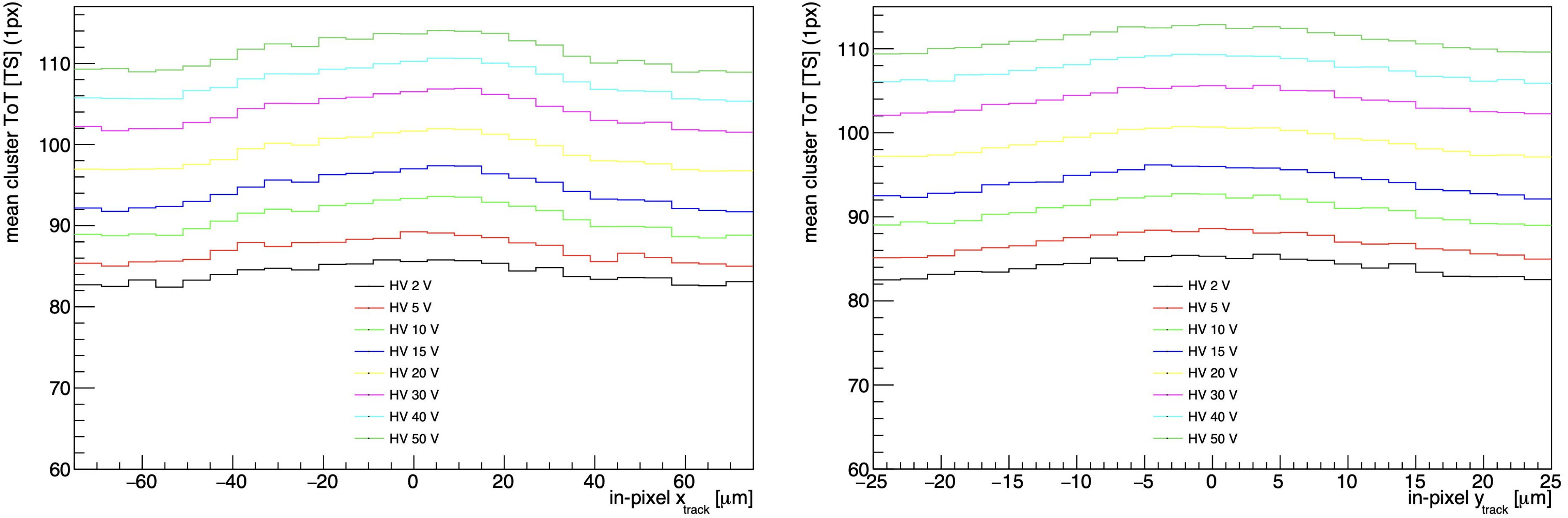




1-pixel cluster charge (1)

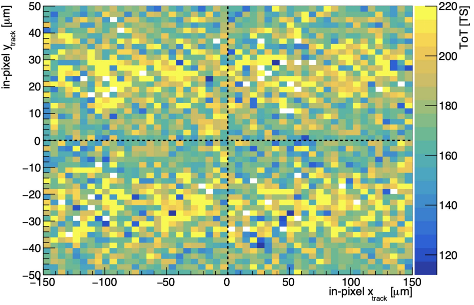


1-pixel cluster charge (2)

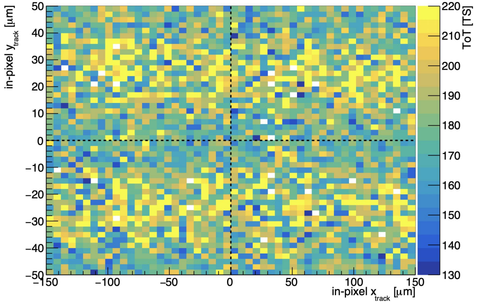


2-pixel cluster charge (1)

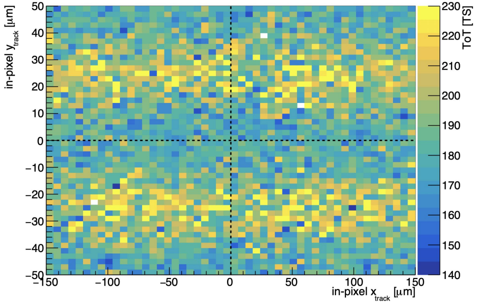
2px cluster charge map 2 V HV



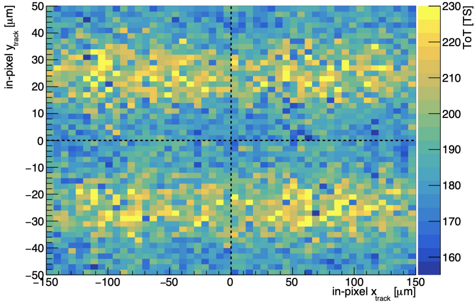
2px cluster charge map 5 V HV



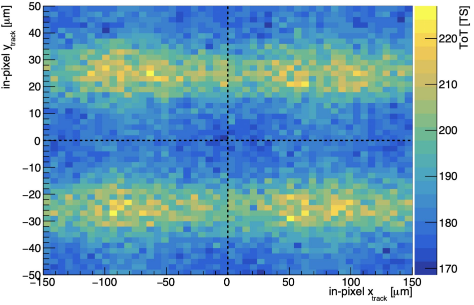
2px cluster charge map 10 V HV



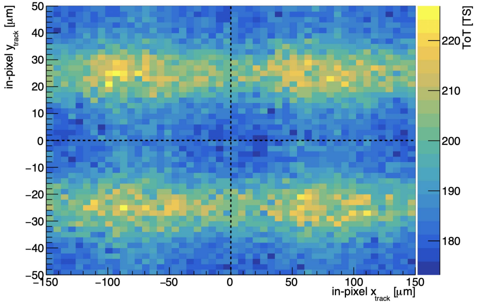
2px cluster charge map 15 V HV



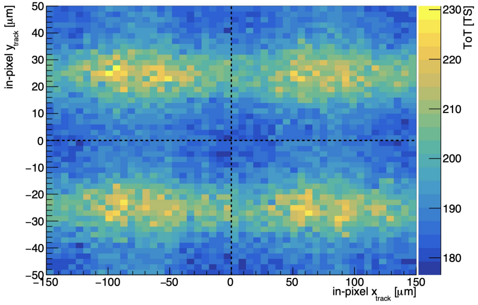
2px cluster charge map 20 V HV



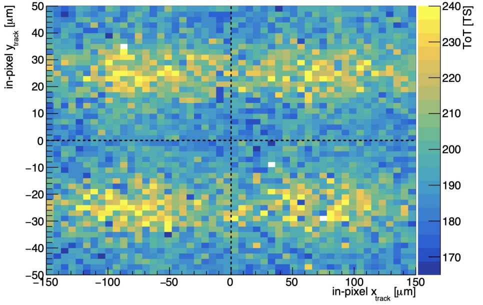
2px cluster charge map 30 V HV



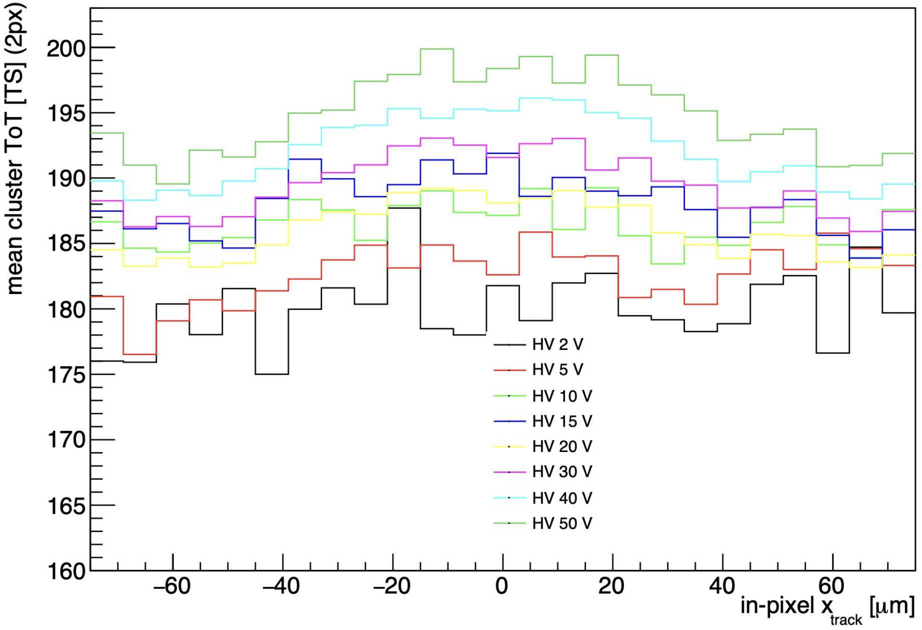
2px cluster charge map 40 V HV

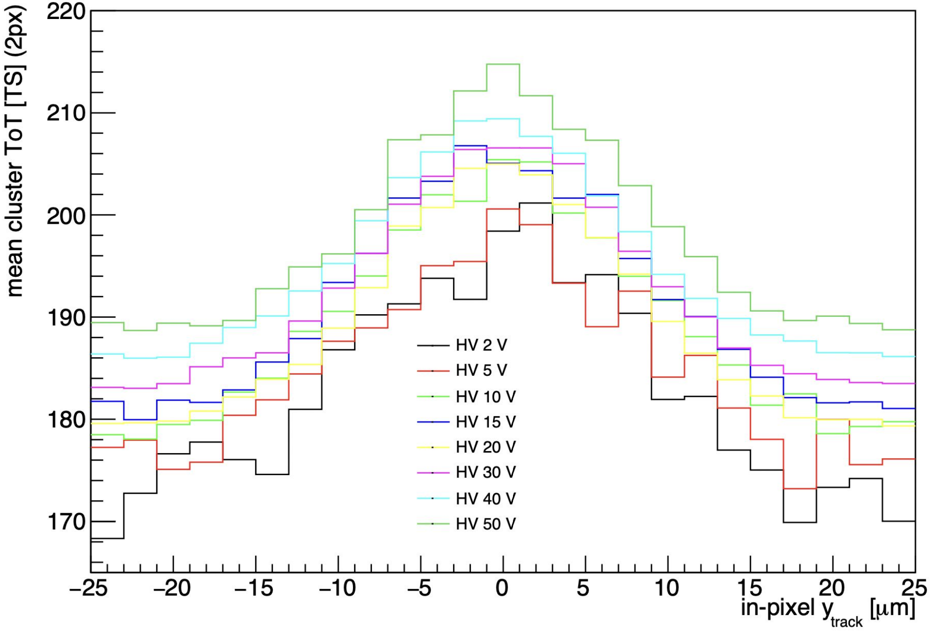


2px cluster charge map 50 V HV

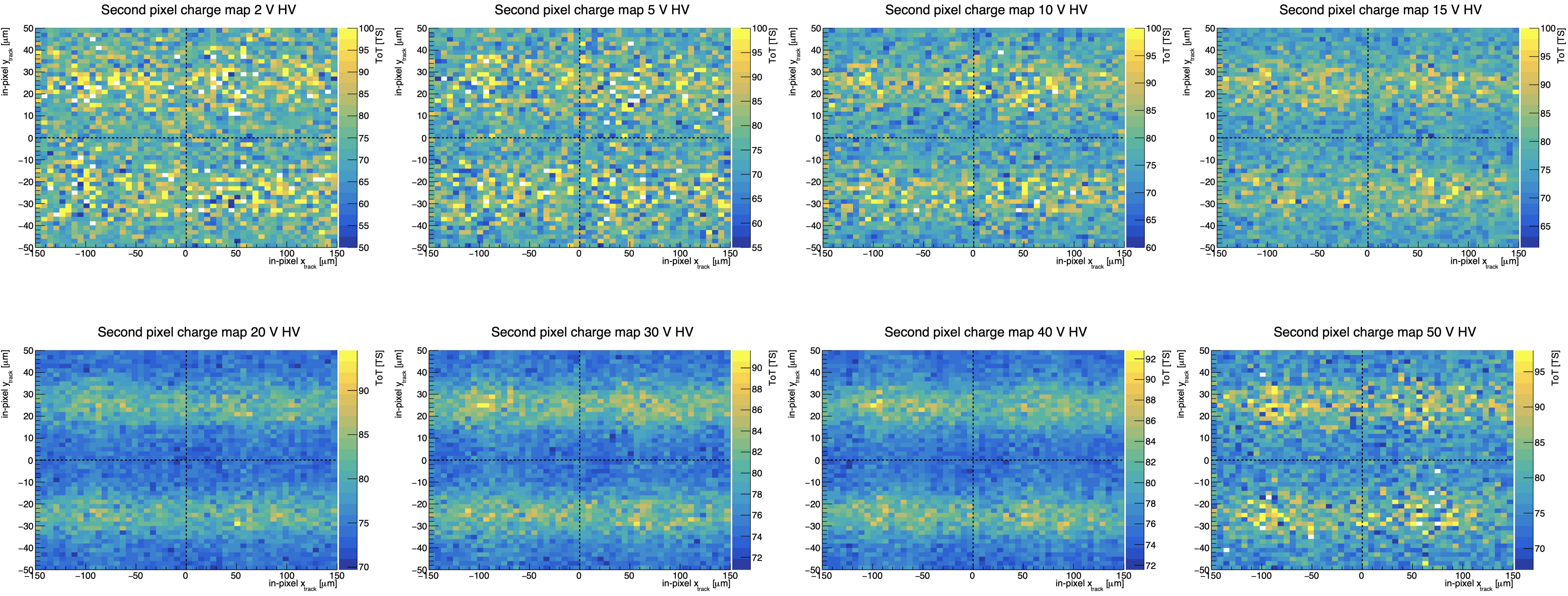


2-pixel cluster charge (2)

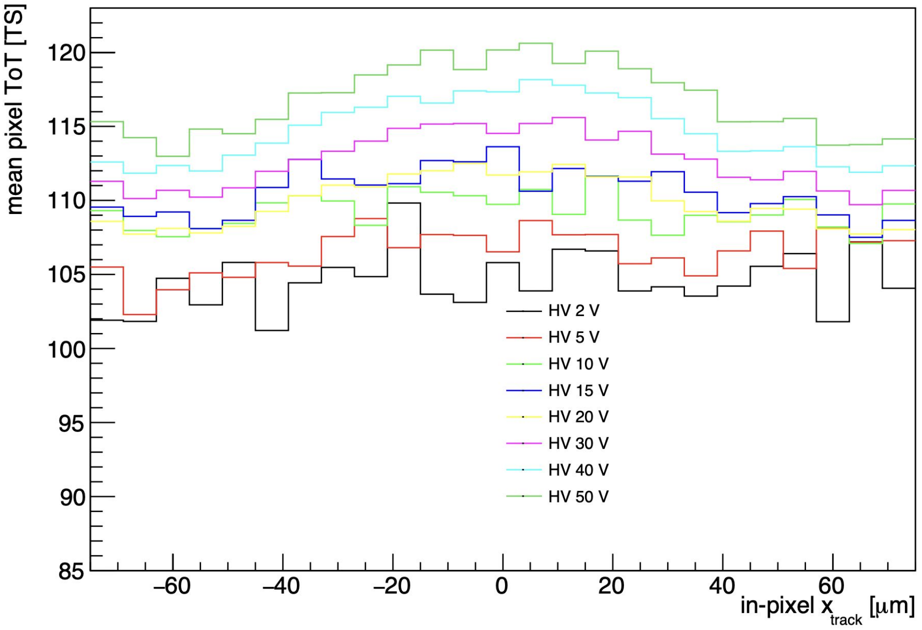


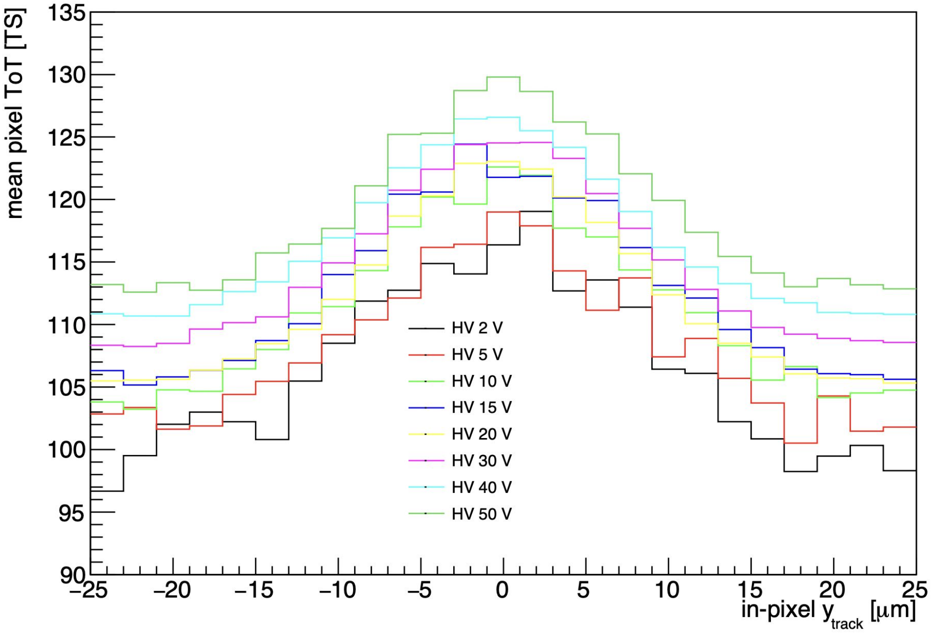


2-pixel cluster charge - seed pixel (1)

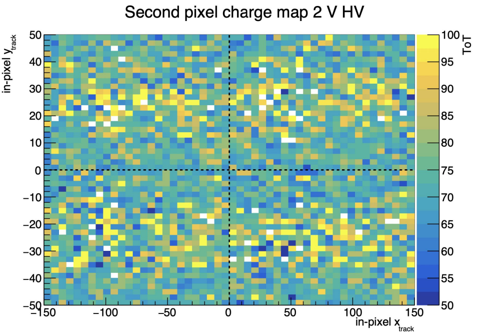


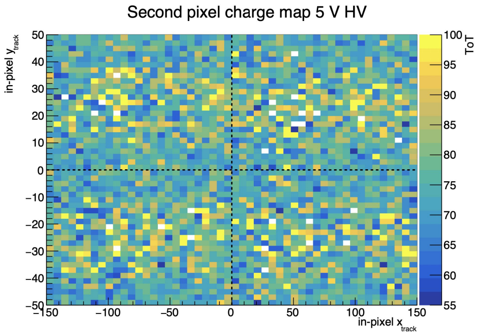
2-pixel cluster charge - seed pixel (2)

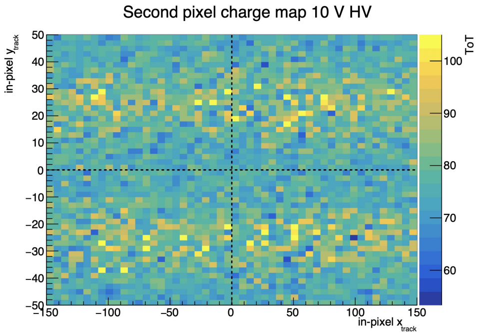


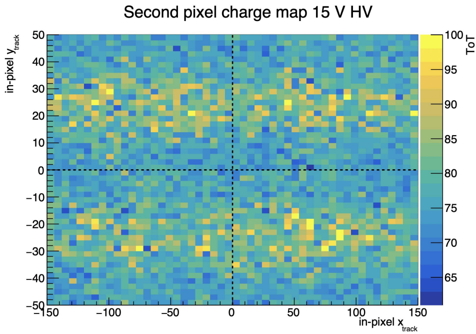


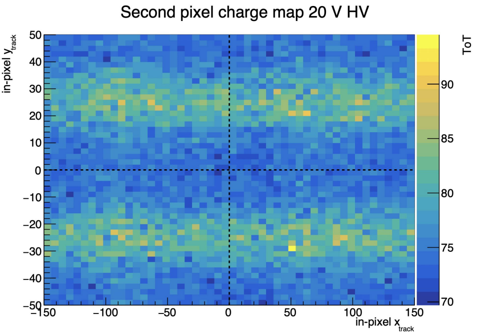
2-pixel cluster charge - second pixel (1)

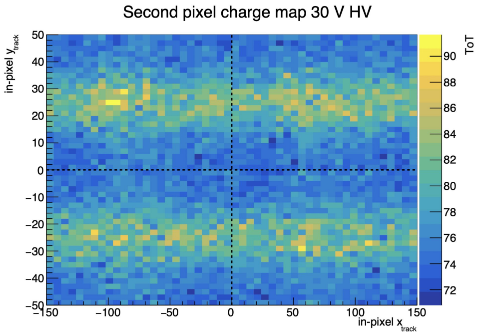


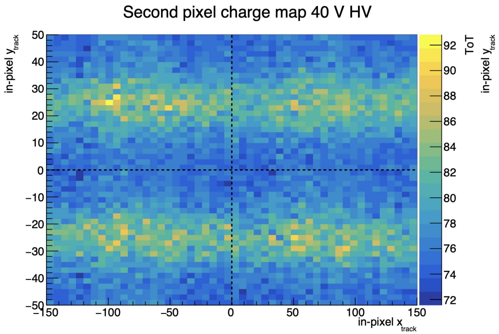


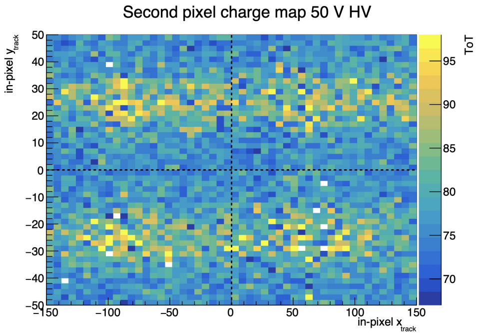




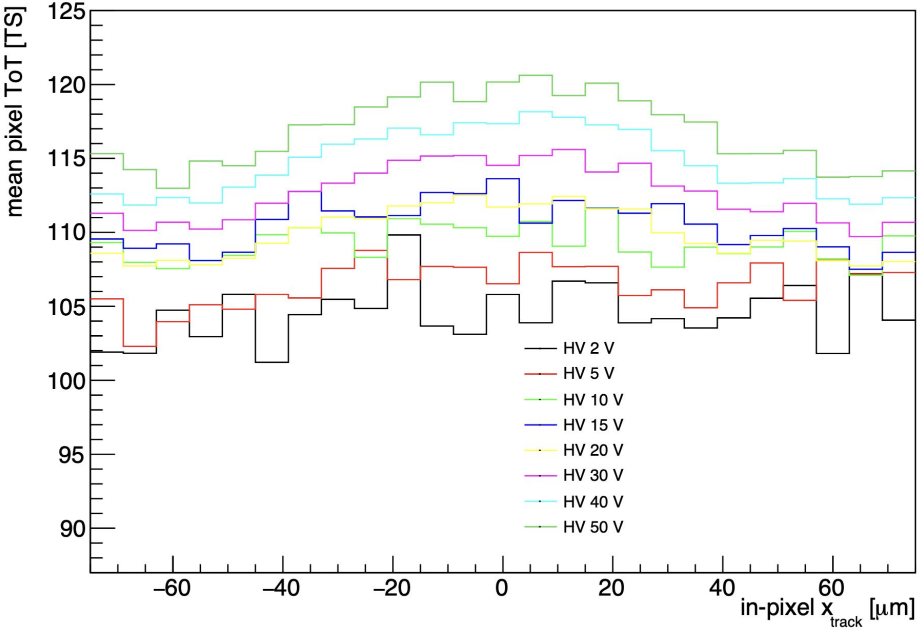


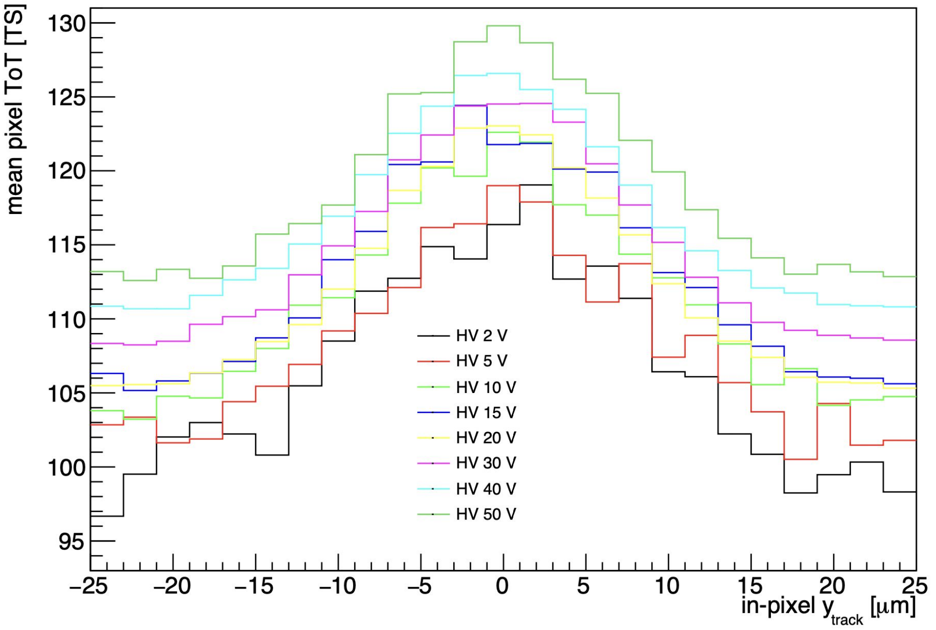




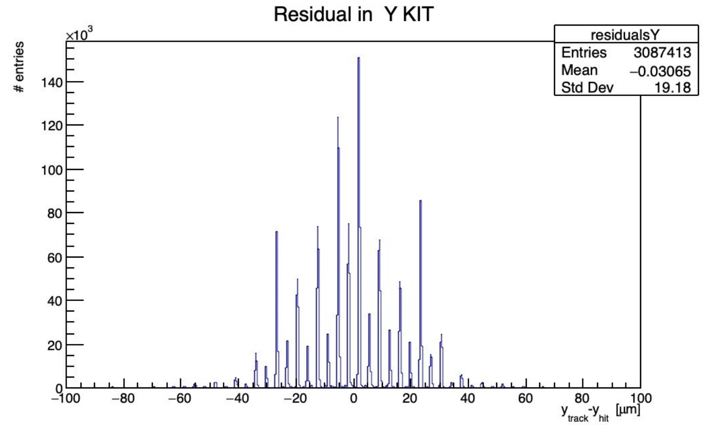


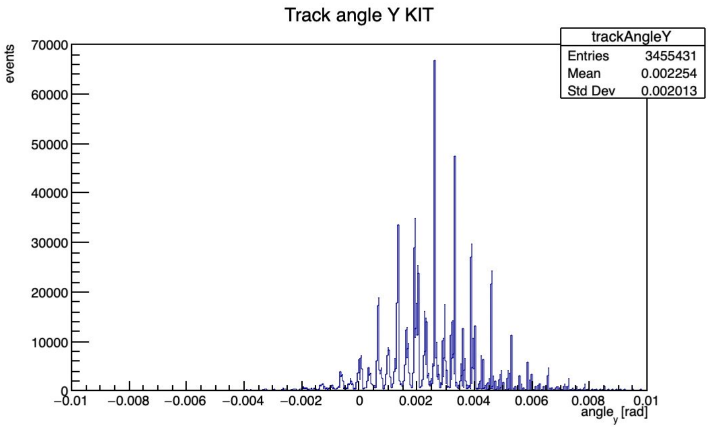
2-pixel cluster charge - second pixel (2)

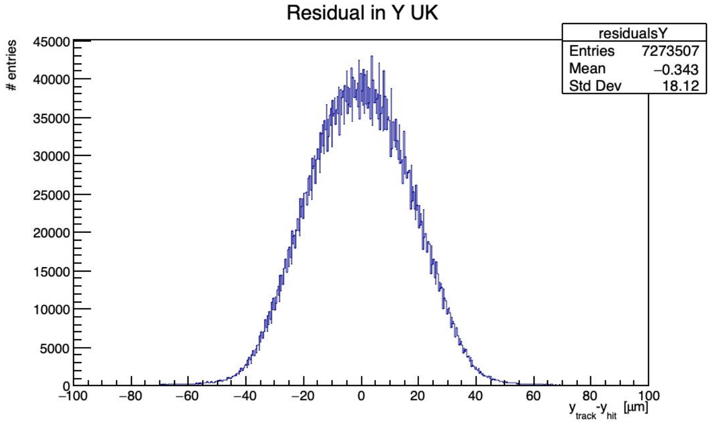


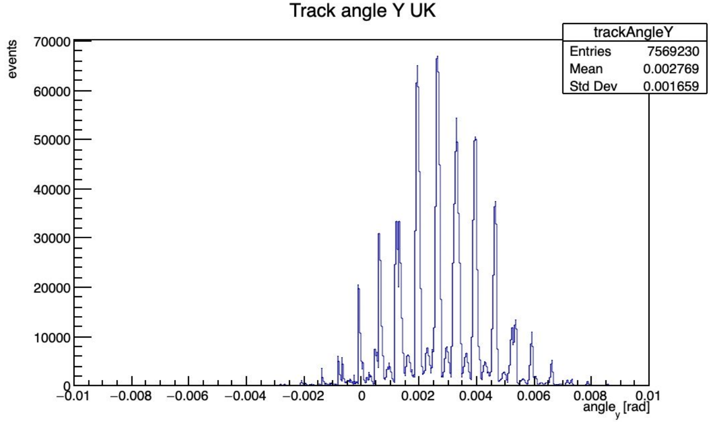


Residuals


Residual in Y KIT
residualsY
Entries 3087413
Mean −0.03065
Std Dev 19.18
entries
×10^3
y_track-y_hit [µm]


Track angle Y KIT
trackAngleY
Entries 3455431
Mean 0.002254
Std Dev 0.002013
events
angle_y [rad]


Residual in Y UK
residualsY
Entries 7273507
Mean −0.343
Std Dev 18.12
entries
y_track-y_hit [µm]


Track angle Y UK
trackAngleY
Entries 7569230
Mean 0.002769
Std Dev 0.001659
events
angle_y [rad]