EP-DT
Detector Technologies

EP R&D

ACF bonding update and analysis of ACF interconnect yield from Timepix3 ACF test-beam data from DESY

WG vertex and tracking meeting
20/05/2021

Mateus Vicente (CERN)

ACF in the industry

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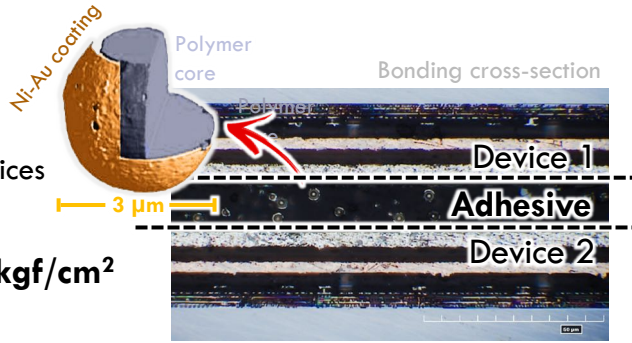
ACF is the **dominating interconnection** technology in the **display industry**

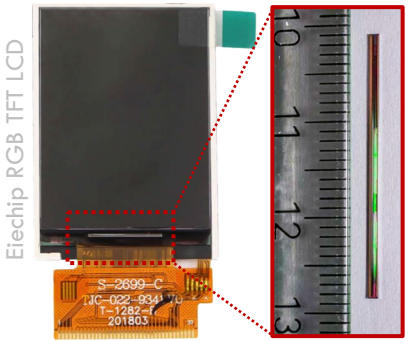
- **Adhesive film** embedded with **conductive micro-particles** (CP)
  - Particles are **compressed** (only vertically) and connect electrically the pads of the devices
    - **Mechanical attachment** is achieved with the thin adhesive layer

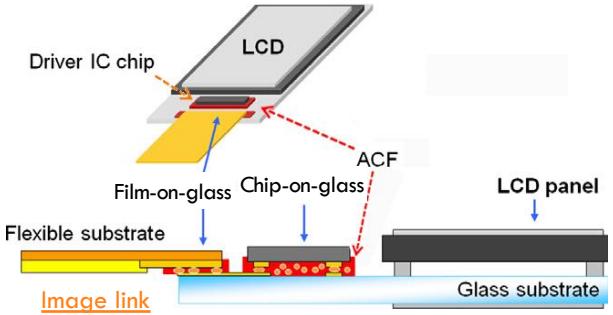
"Hybridization" ACF: **18 µm** thick with **3 µm** CPs: **Bonding** pressure of **300~800 kgf/cm²**

- Timepix3: 256x256 * 320 µm² ≈ 0.20 cm² ➔ **61~163 kgf**

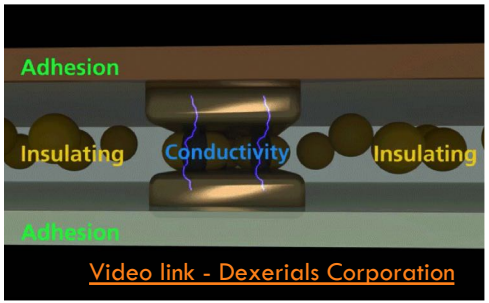


Display driver chip

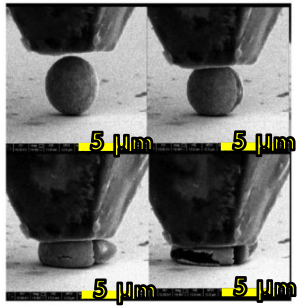




ACF on contact pads



ACF particle deformation



In-house flip-chip hybridization

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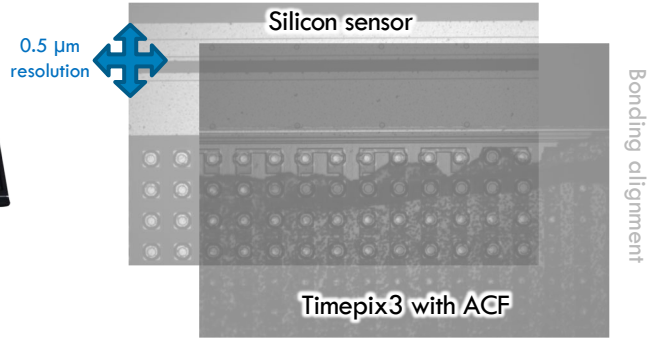
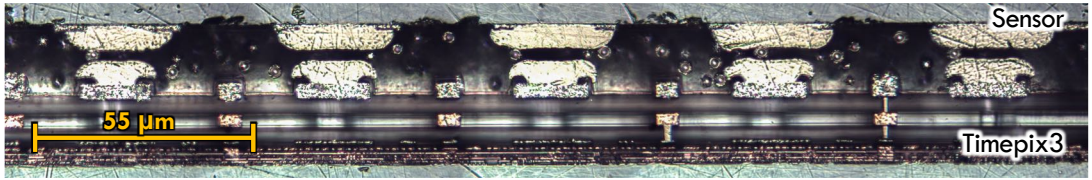
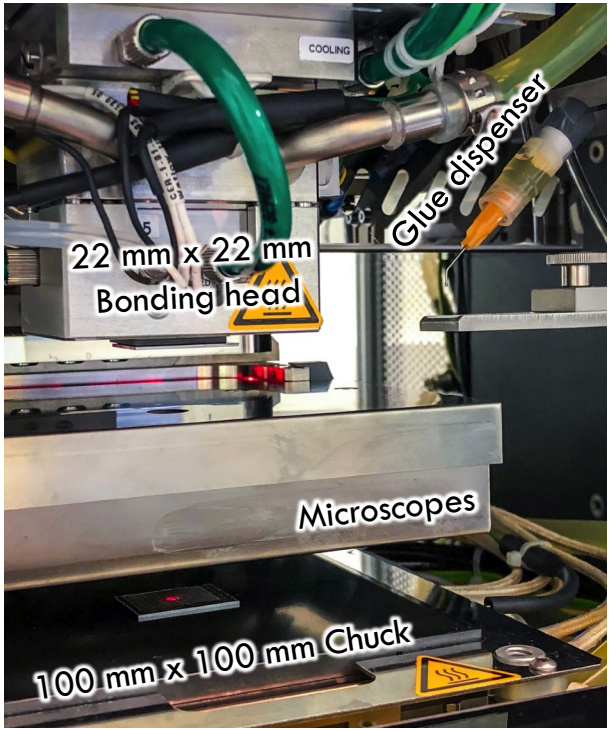
- **Semi-automatic flip-chip** bonder, installed at Geneva University
  - Post-bonding accuracy **1-2 µm** achieved and planarity **< 100's µrad**
  - Heating up to **400 ˚C** and force applied by bonding arm up to **100 kg**



Timepix3-ACF-sensor assembly cross-section





Timepix3 hybridization with ACF

first tests – Bonding optimization

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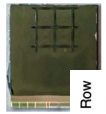
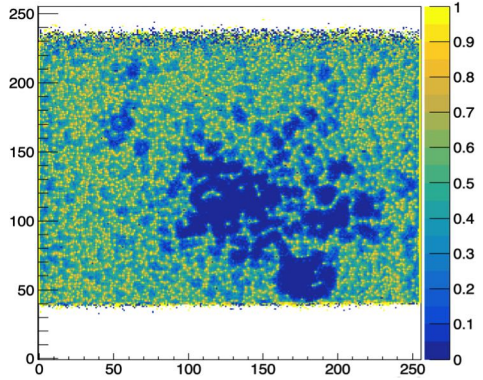
1. Timepix3 matrix **fully covered** with ACF ➔ Low connectivity yield (<500 pixels)
2. sample covering **~30%** of the matrix ➔ **Uniform** and **high yield** connectivity)
3. sample with **~50%** coverage ➔ **Large area** with **good connectivity,** low yield in the central region

Proof-of-concept achieved: Successful pixel matrix bonding of **up to 1 cm²** (so far)

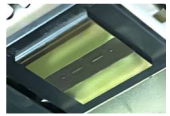
- Optimization on going to reduce the necessary bonding force

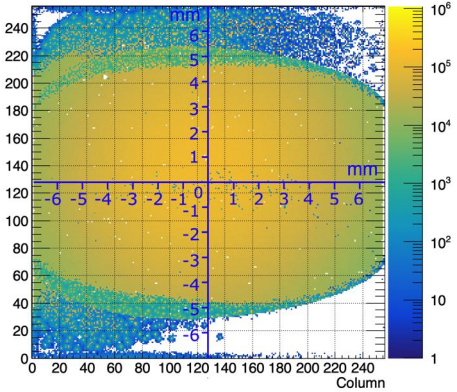
1. 100% ACF coverage
Test-beam efficiency



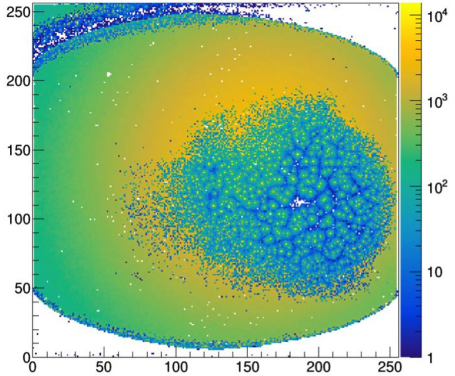


2. 30% ACF coverage
Sr-90 hit map





3. 50% ACF coverage
Sr-90 hit map



Timepix3 hybridization with ACF

Bonding/UBM optimization

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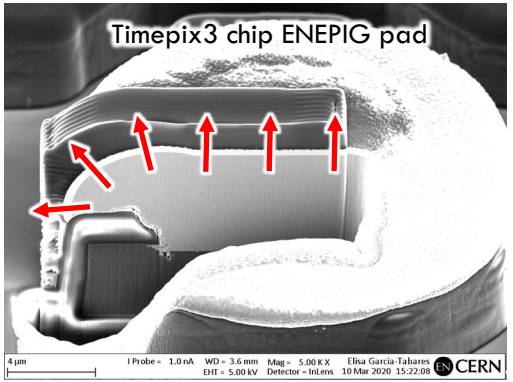
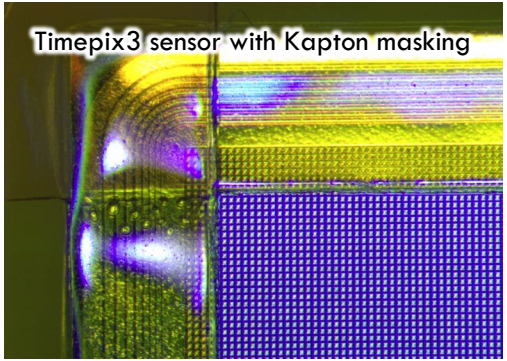
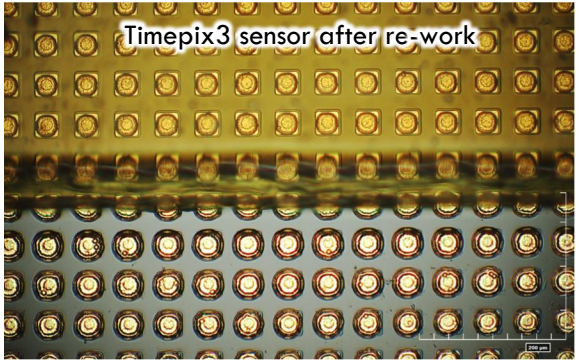
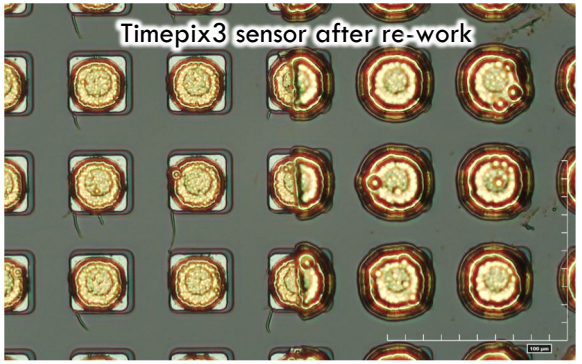
- ENIG/ENEPIG can be re-worked (only increasing, not decreasing)
- **First idea:** To increase the size of the UBM pad in one of the devices
  - A **higher UBM pad** might decrease the volume of glue being squeezed out
    - One device keeps the UBM original size, making the bonding area to remain the same
- Two Timepix3 sensor devices (ENEPIG platted at PacTech) were reworked at CERN
  - **+5 µm Ni** added to the already existing Pd
    - One sample for mechanical cross-section and one for source measurement









Timepix3 hybridization with ACF

Bonding optimization – Resulting assemblies

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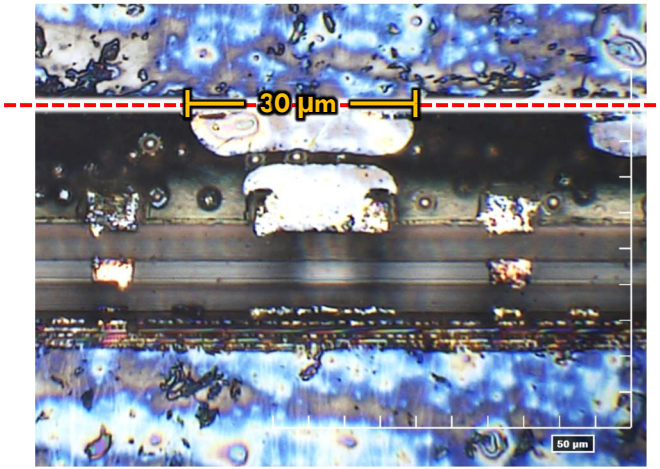
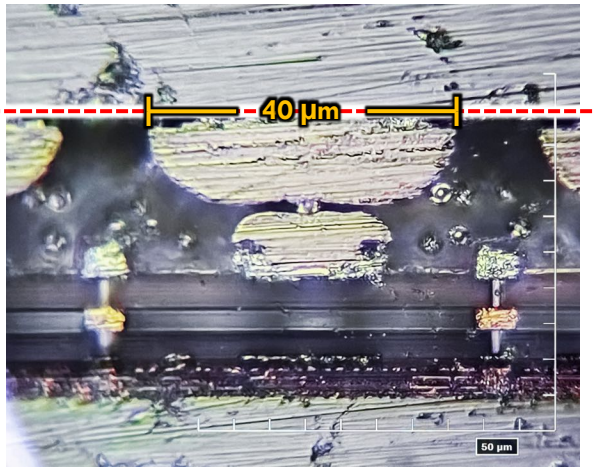
- Cross-section indicates +5 µm of additional Ni
  - Pad isotropic growth: +10 µm in diameter and +5 µm in height
- Source measurement (sample with 100% ACF coverage) indicates possible bonding improvement

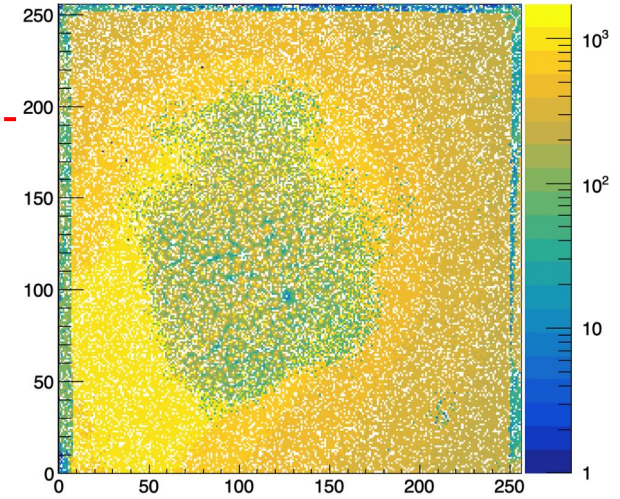
Timepix3 assembly with original ENEPIG



Timepix3 assembly with re-worked pad



W43-E11 Sr^{90} source hit map



Test-beam at DESY

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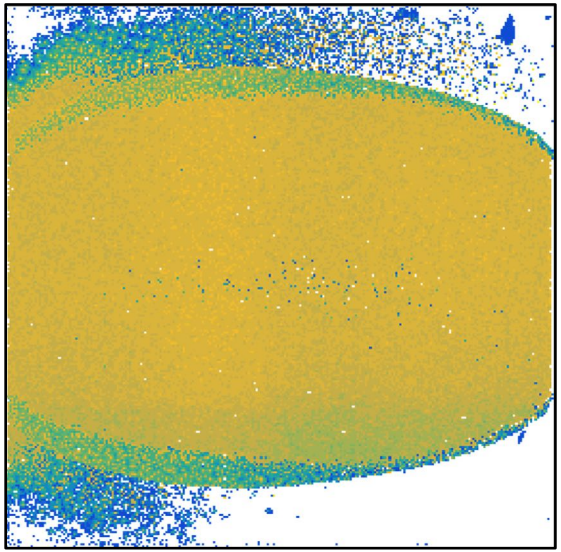
Many thanks for the team at DESY!

DESY telescope and W43-I3 sample

W43-I3 in the beam

W43-I3 Hitmap



Track reconstruction

Tracks Chi2/ndof and 3rd plane residuals

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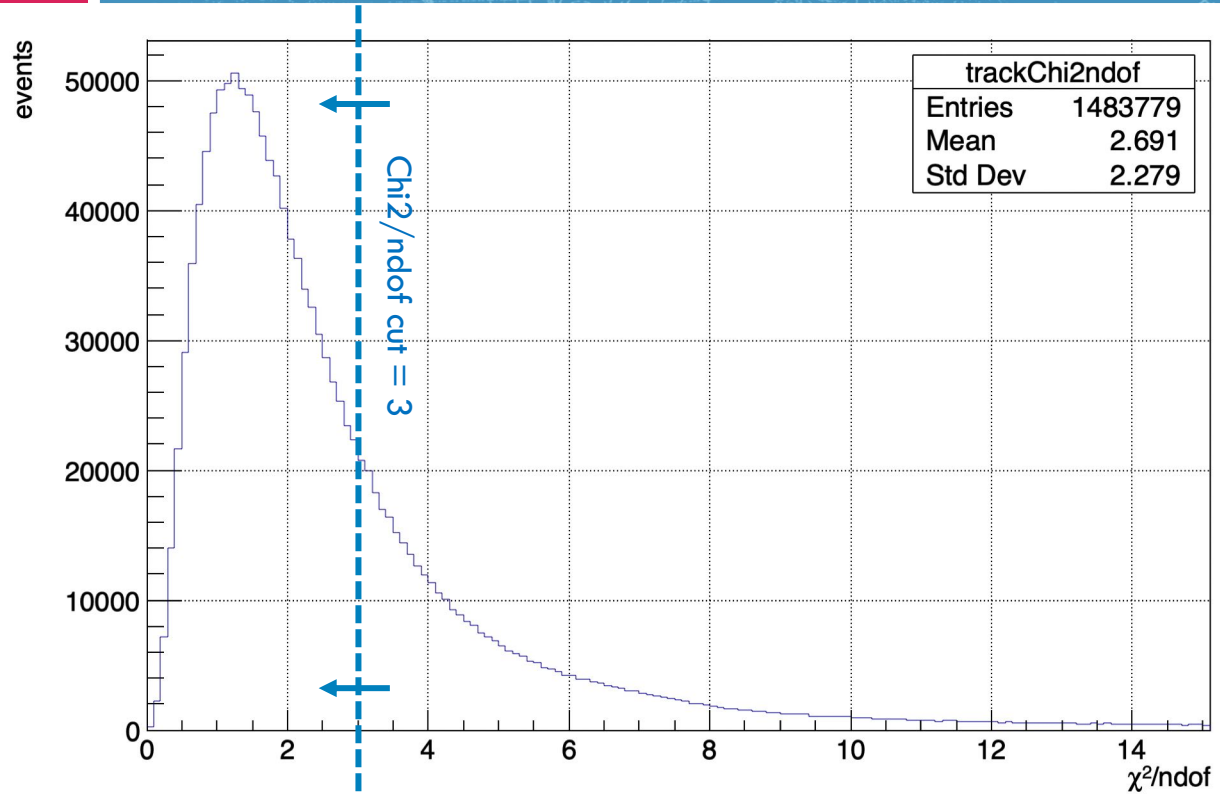

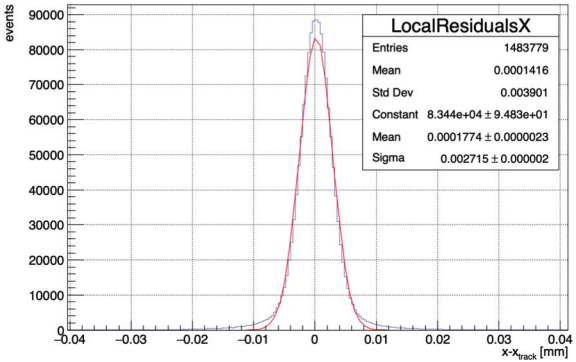

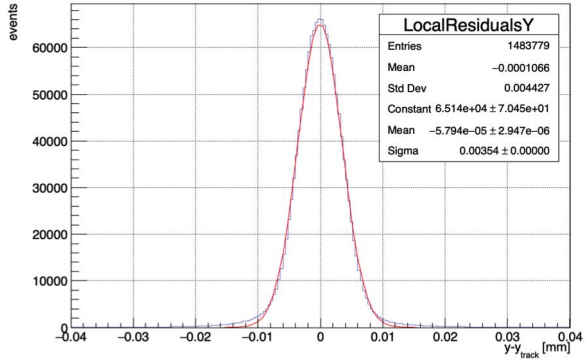

ACF Timepix3

W43-I3 – Hit Map

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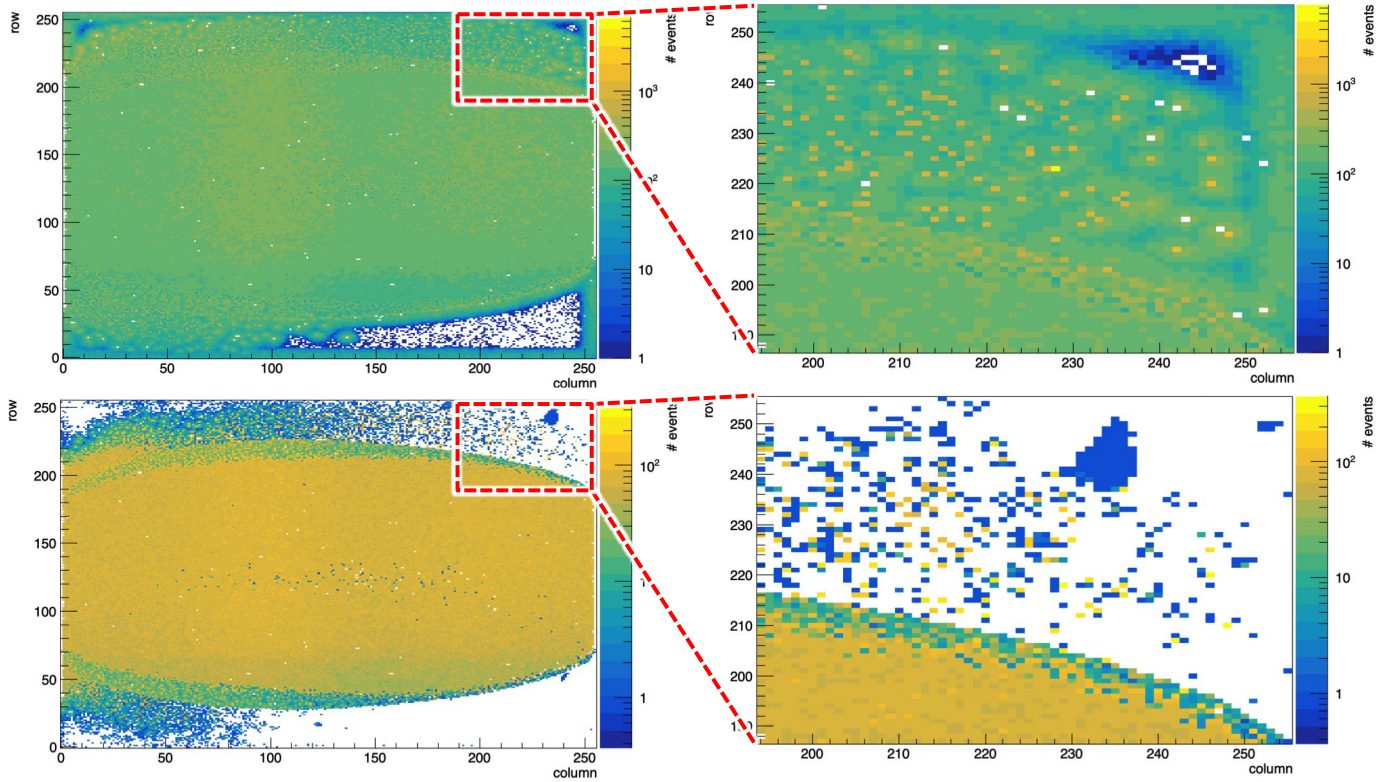
Low threshold (run 6601)

High threshold (run 6614)



ACF Timepix3

W43-I3 – Associated Clusters

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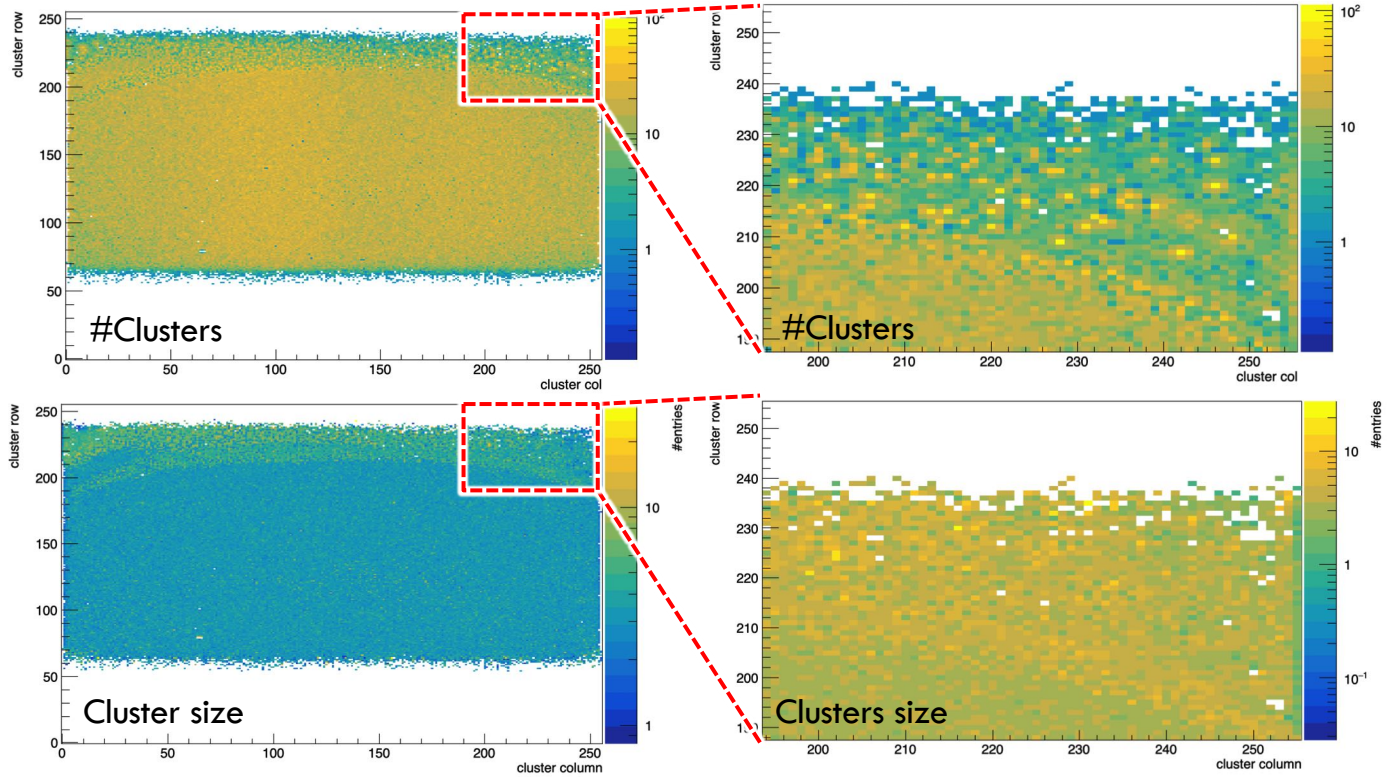
Low threshold (run 6601)



ACF Timepix3

W43-I3 – Associated Clusters

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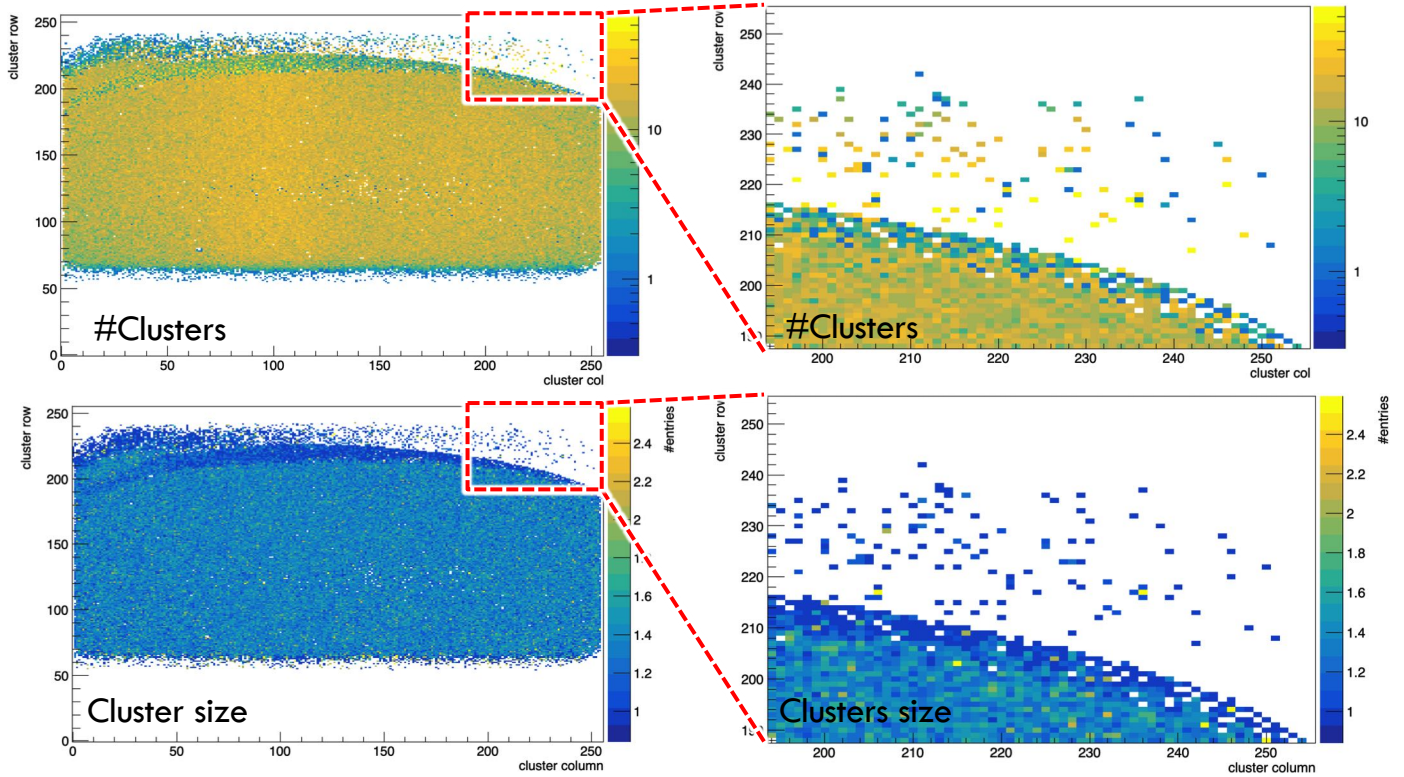
High threshold (run 6614)



ACF Timepix3

W43-I3 – DUT residuals and cluster size

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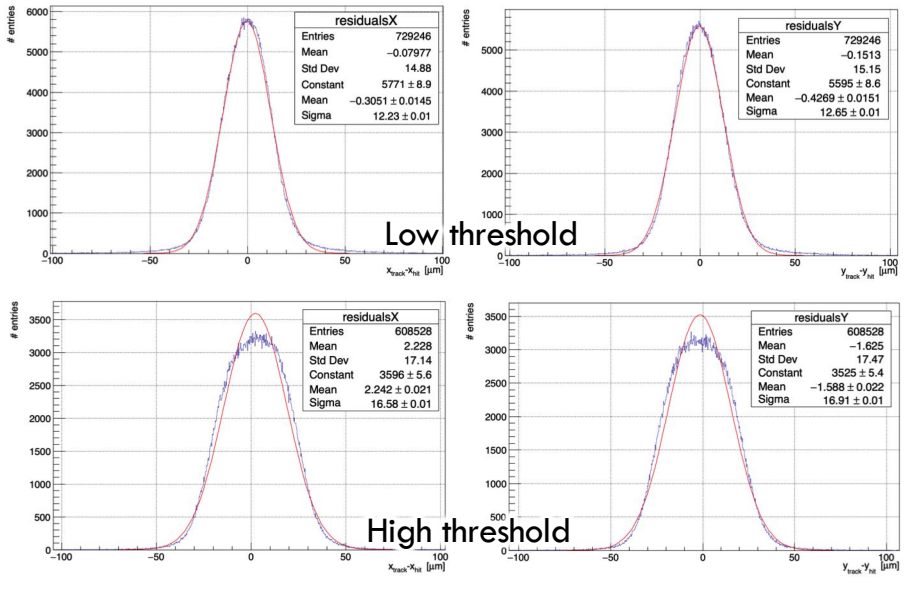

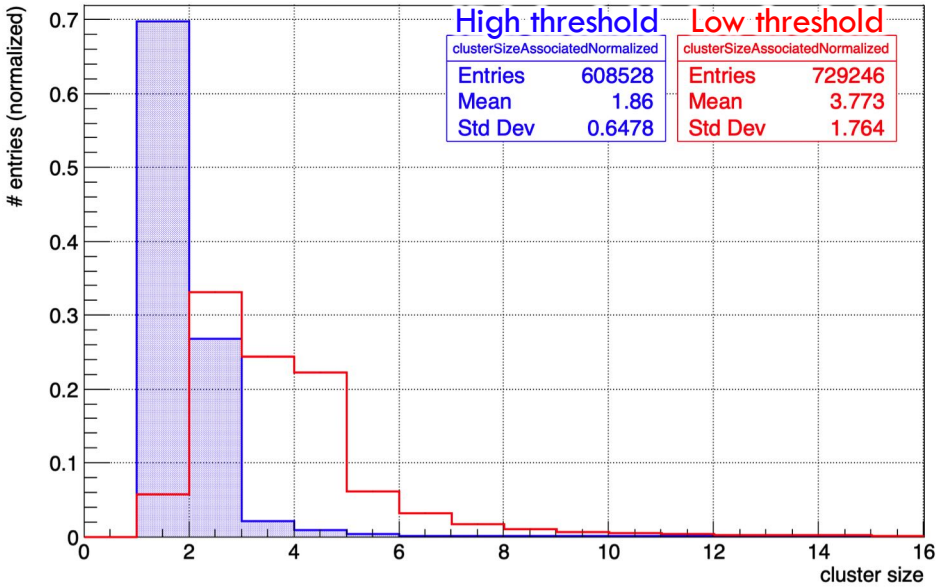

Efficiency profiles in corry

Simplified code

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```
for(auto& track : tracks) {
   bool has_associated_cluster = false;
   auto globalIntercept = DUT->getIntercept(track.get());
   auto localIntercept = DUT->globalToLocal(globalIntercept);

   auto associated_clusters = track->getAssociatedClusters(DUT);
   if(associated_clusters.size() > 0) {
         auto cluster = track->getClosestCluster(DUT);
         has_associated_cluster = true;
          auto pixels = cluster->pixels();
          for(auto& pixel : pixels) {
                if(pixel->column() == static_cast<int>(DUT->getColumn(localIntercept)) &&
                  pixel->row() == static_cast<int>(DUT->getRow(localIntercept))) {
                     pixelEfficiency_TProfile->Fill(pixel->column(), pixel->row(), true);
                     if(track_within_inPixel_ROI) pixelEfficiencyROI_TProfile->Fill(pixel->column(), pixel->row(), true);
                }
          }
   }

   if(!has_associated_cluster){
         pixelEfficiency_TProfile->Fill(DUT ->getColumn(localIntercept), DUT->getRow(localIntercept), false);
         if(track_within_inPixel_ROI) pixelEfficiencyROI_TProfile->Fill(DUT ->getColumn(localIntercept), DUT ->getRow(localIntercept), false);
   }

   hChipEfficiencyMap_trackPos_TProfile->Fill(DUT->getColumn(localIntercept),  DUT->getRow(localIntercept), has_associated_cluster);
}
```

ACF Timepix3

W43-I3 – Chip Efficiency (track position)

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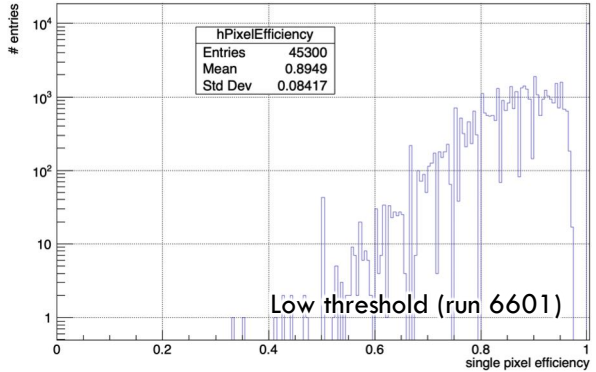
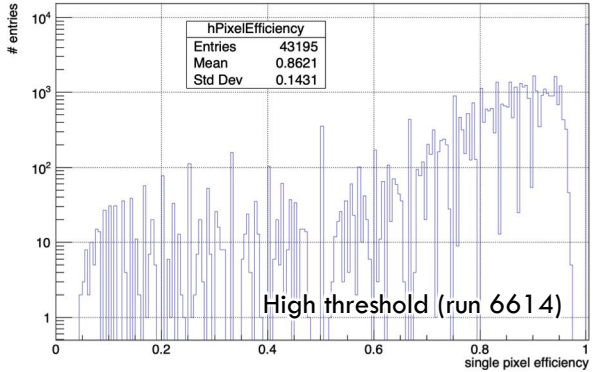
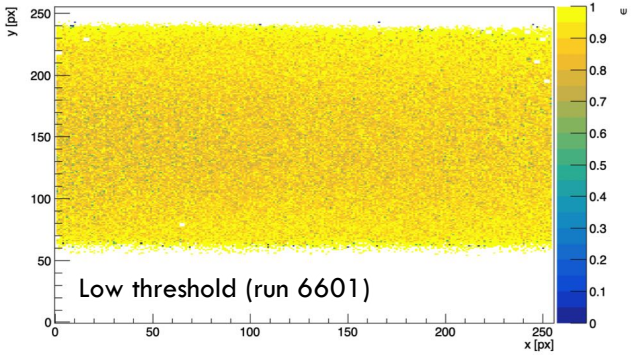
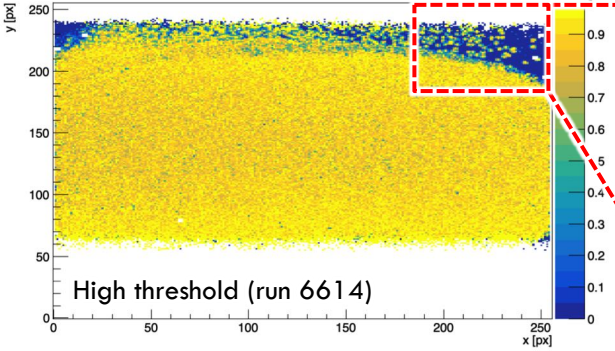
hChipEfficiencyMap_trackPos_Tprofile

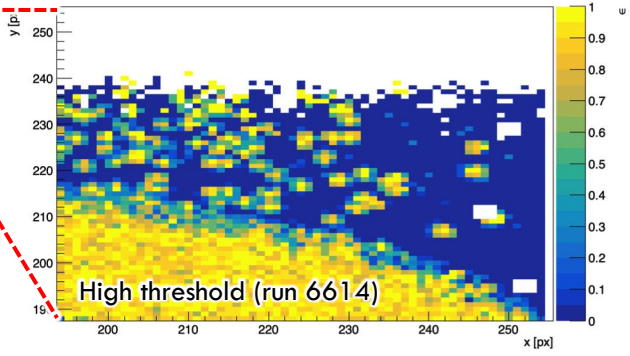
->Fill(DUT->getColumn(localIntercept),
DUT->getRow(localIntercept),
has_associated_cluster)











ACF Timepix3

W43-I3 – Chip Efficiency (associated pixel pos.)

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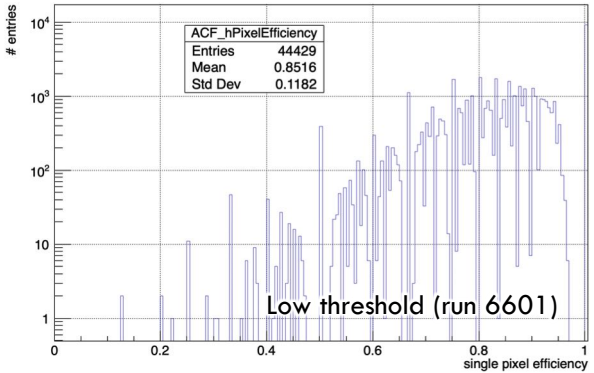
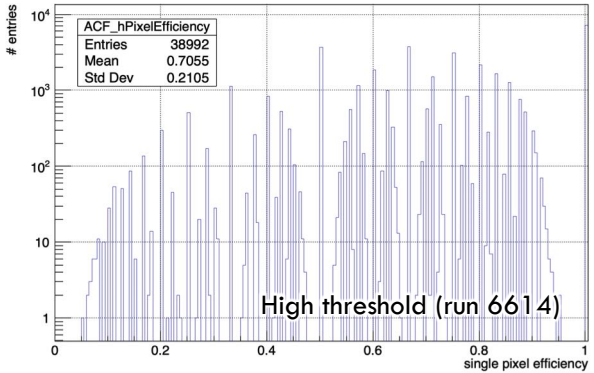
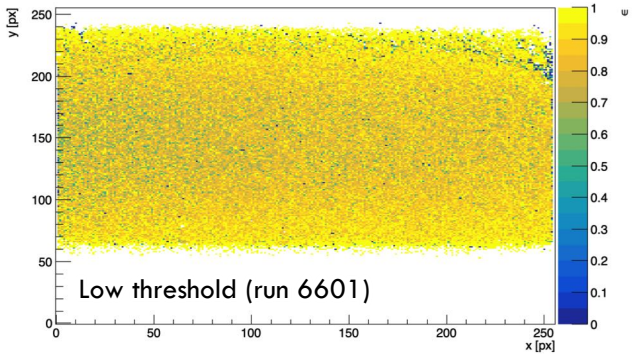
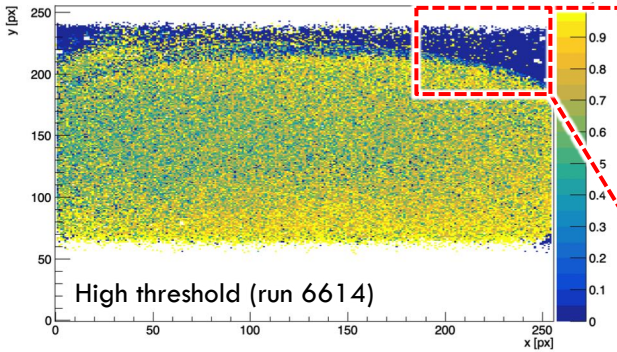
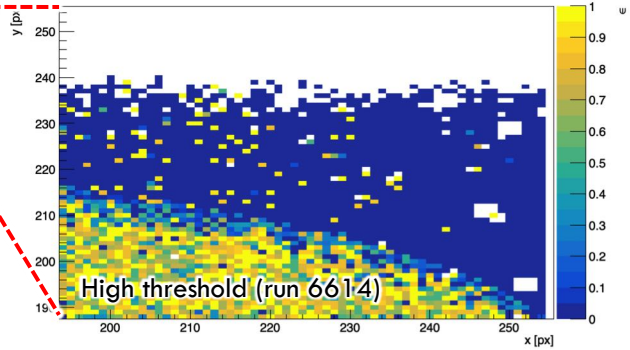
```
if(cluster_pixel(x,y) == track_intercept(x,y))
   pixelEfficiency_Tprofile
      ->Fill(pixel->column(),
             pixel->row(),
             true);
if(!has_associated_cluster)
   pixelEfficiency_Tprofile
      ->Fill(DUT ->getColumn(localIntercept),
             DUT->getRow(localIntercept),
             false);
```











ACF Timepix3

W43-I3 – Chip Efficiency (associated pixel-ROI)

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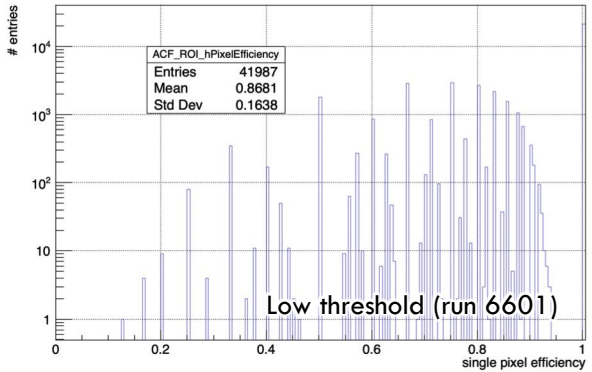
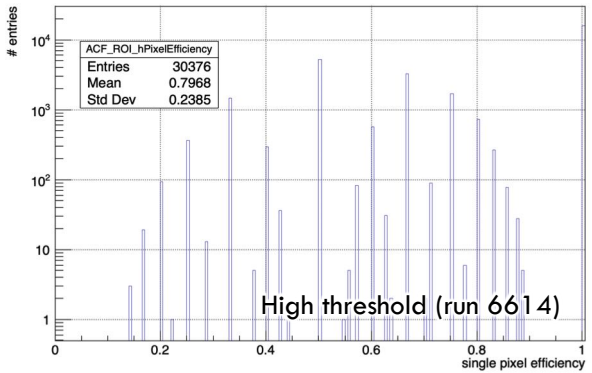
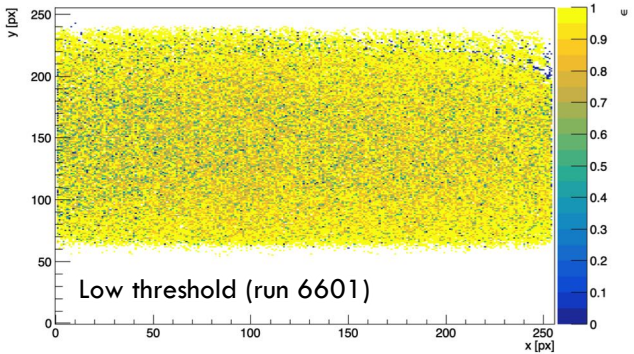
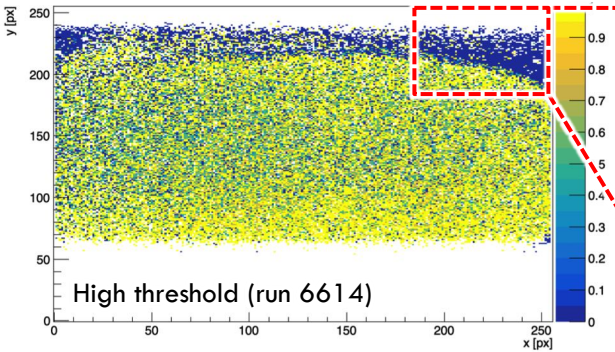
if(track_within_inPixel_ROI)

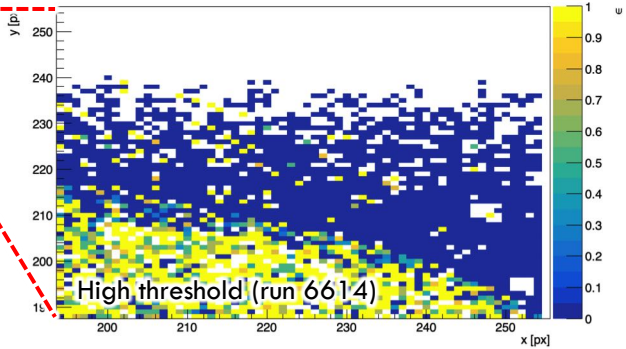
```
if(cluster_pixel(x,y) == track_intercept(x,y))
    pixelEfficiency_ROI_Tprofile
        ->Fill(pixel->column(),
               pixel->row(),
               true);
if(!has_associated_cluster)
    pixelEfficiency_ROI_Tprofile
        ->Fill(DUT ->getColumn(localIntercept),
               DUT->getRow(localIntercept),
               false);
```











Summary and next steps

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- Optimization of the device bonding topology might help to increase pixel hybridization yield
  - Re-work of UBM pad possible at CERN
    - Requires close follow-up for consistent platting and results
  - Estimated 5µm increase in the pad height
- New sample with 100% ACF coverage and with increased pad shows a bonding improvement
  - w.r.t. the first sample (also with 100% ACF coverage)
- Tested ACF Timepix3 assembly (with 30% ACF coverage) at DESY TB
  - Data analysis and interpretation still on-going
    - Next: Per-pixel efficiency curve (as function of threshold and bias-voltage)
      - Quantitative results limited by statistics available
- Two more samples to be tested at DESY TB when possible
  - Sample with 50% ACF coverage (#3 @ slide 7) and new sample with re-worked UBM pad
- CLICpix2 assemblies with new sensors from FBK and particle aligned ACF