

Testbeam results of the MiniCACTUS_v2

Joaquim Pinol on behalf of CACTUS

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CEA/Irfu

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University of Liverpool

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IMB-CNM, CSIC

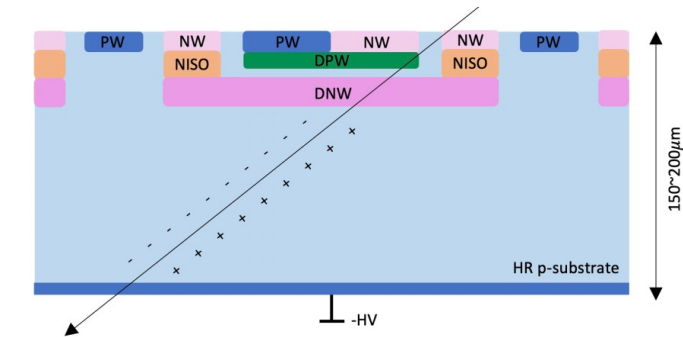


4th DRD3 week on Solid State Detectors R&D

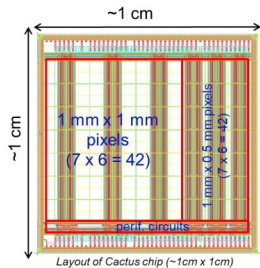
10th November 2025

- Monolithic timing using Lfoundry 150nm HV-CMOS
- Meant to provide a reliable and cheaper solution for timing layers with large pixels
- Large fill factor (Electronics inside the n-well)
- Upcoming prototype featuring sensors with gain, more details on the next talk of this session:

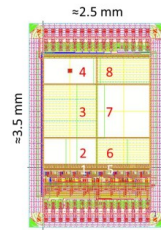
[Development of sensors with intrinsic gain](#)



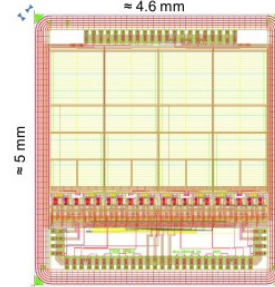
Cross section of the MiniCACTUS_v2



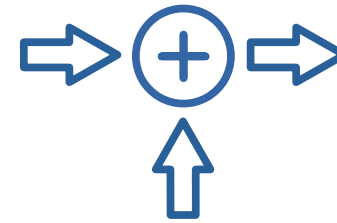
CACTUS Demonstrator
2017



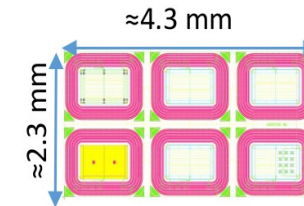
MiniCACTUS_v1
2020



MiniCACTUS_v2
2023



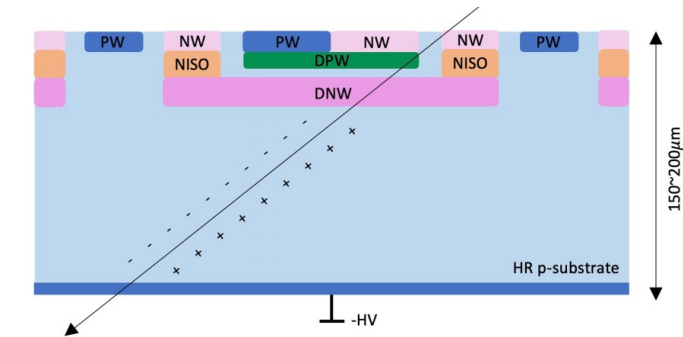
MiniCACTUS_v2
with gain
2026?



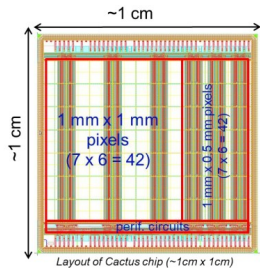
CACTUS-GL
2024

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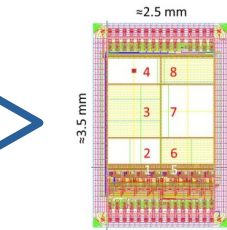
[Development of sensors with intrinsic gain](#)



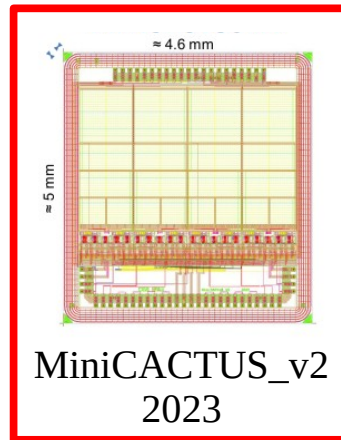
Cross section of the MiniCACTUS_v2



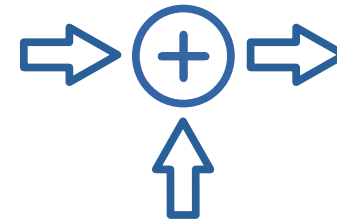
Layout of Cactus chip (~1cm x 1cm)



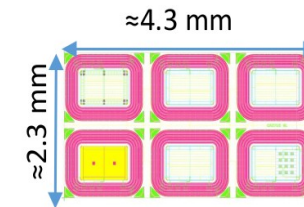
MiniCACTUS_v1
2020



MiniCACTUS_v2
2023

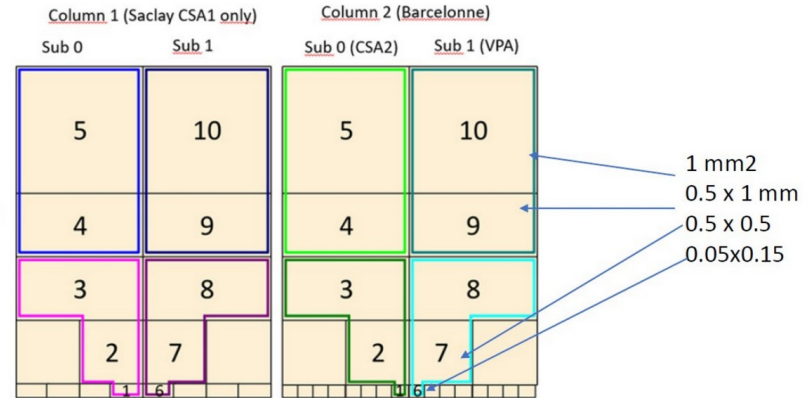


MiniCACTUS_v2
with gain
2026?

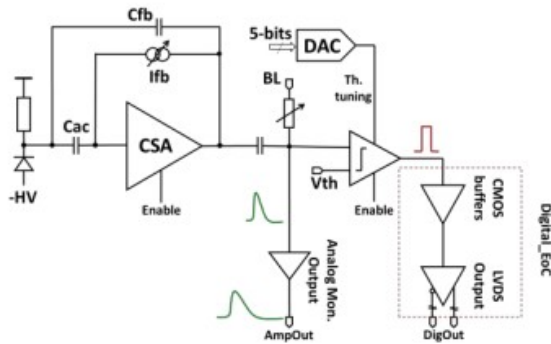


CACTUS-GL
2024

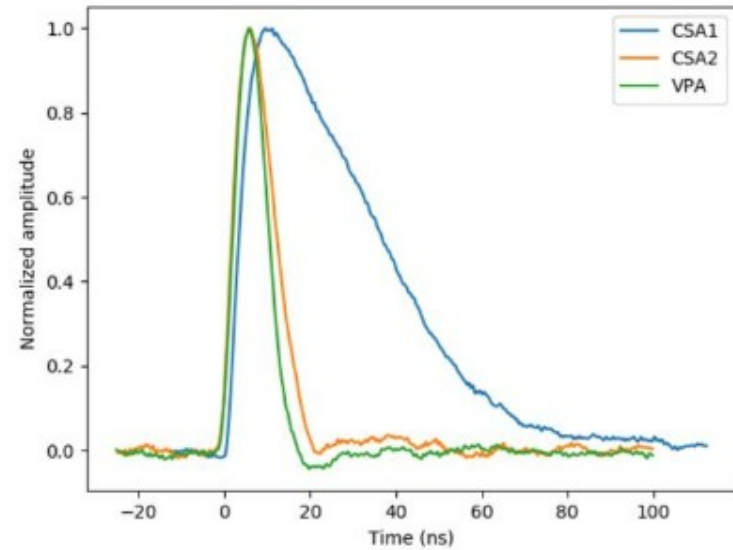
- CEA-IRFU and IFAE collaboration
- Slow control, DACs and bias on-chip
- Pixel sizes: $1 \times 1 \text{ mm}^2$, $1 \times 0.5 \text{ mm}^2$, $0.5 \times 0.5 \text{ mm}^2$
- Post-processed samples to 150, 175 and $200 \mu\text{m}$
- No gain on sensor
- Featuring three pre-amplifiers:
 - Two CSA and one VPA
 - Different return-to-baseline times



Pixels overview

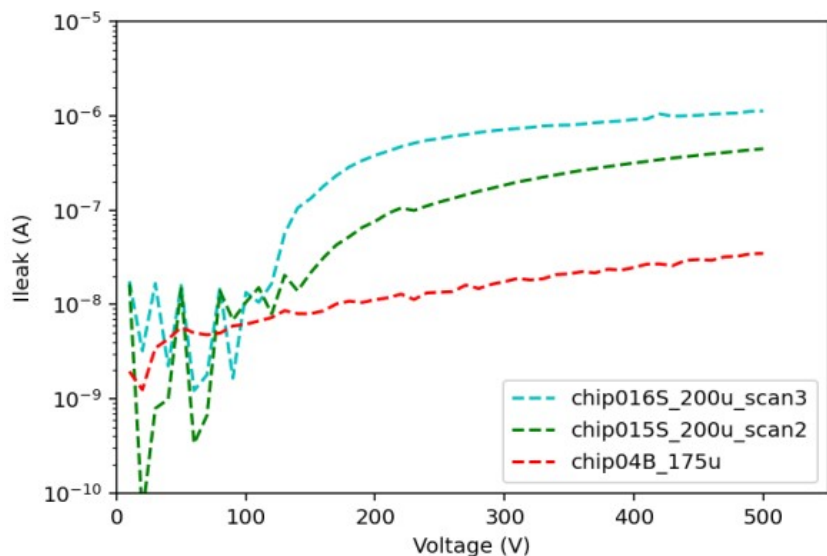


Sensor FE architecture

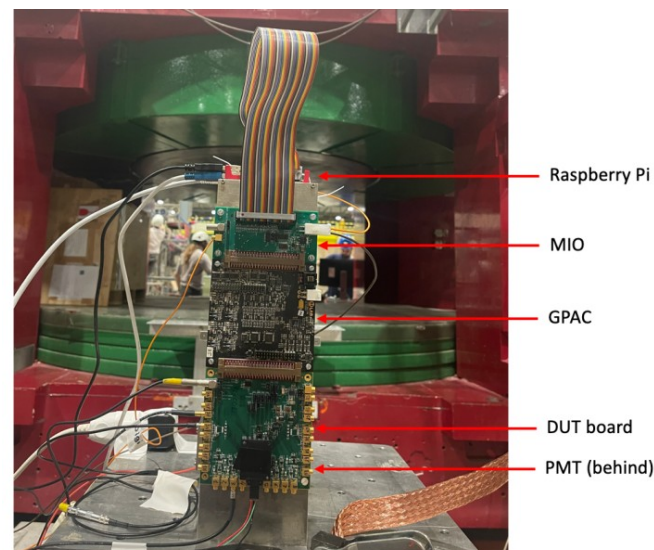


Return-to-baseline time

- Three testbeam campaigns at CERN SPS:
 - July 2024 (parasitic DRD1, muons)
 - July 2025 (parasitic DRD1, muons + pions)
 - October 2025 (DRD3, pions)

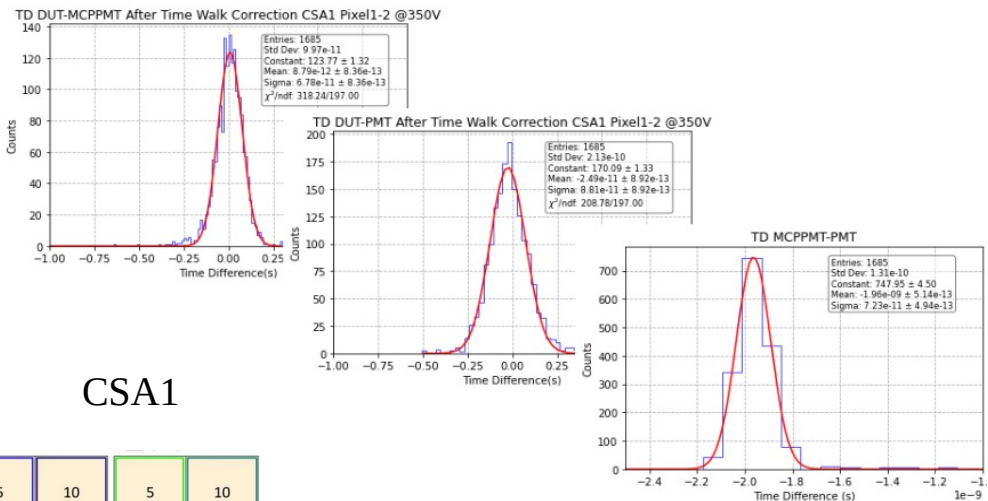
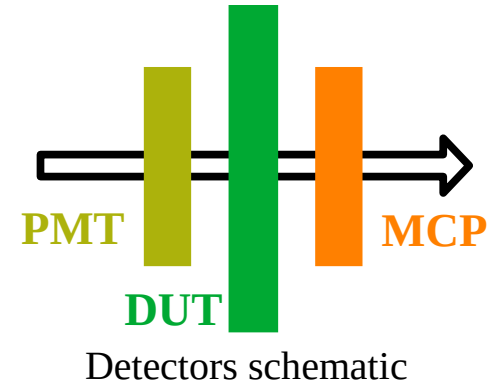


Sensor IVs: breakdown voltages generally $> 500V$



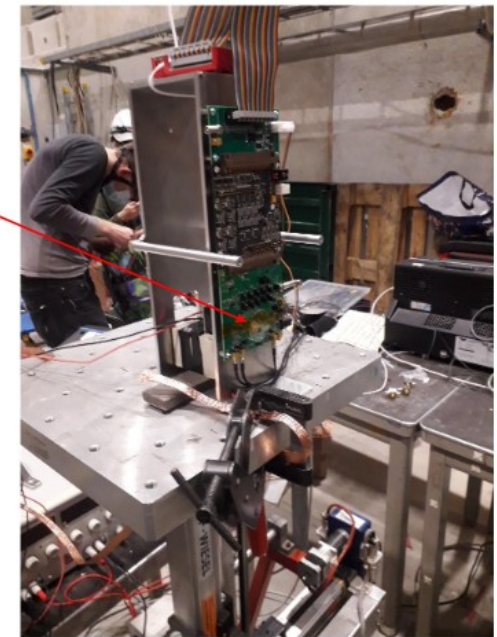
DUT setup

- CERN SPS/H4 North Area with muons
- 12 bit, 10 GS/s, 1 GHz bandwidth scope
- Issue with DUTs getting shorted on the sensor HV, understood later
- Best result of ~ 60 ps on 0.5×0.5 mm² pixel with CSA1 with 175 μ m thickness @ 350V: [P.Schwemling et al., PIXEL, 2024]
- Similar resolution with CSA2: 63ps obtained on 0.5×0.5 mm² pixel @300V [Yuging Gan, PhD thesis, 2025]



CSA1

MiniCactus_v2

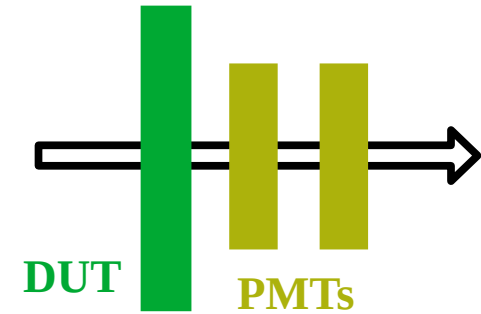


DUT setup at TB

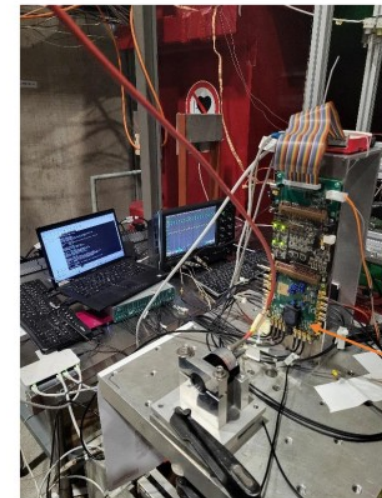
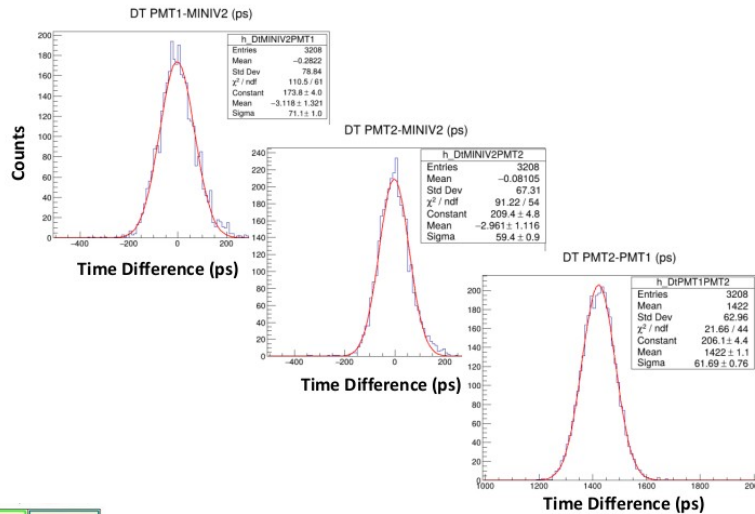
Sigma (DUT)	Sigma (PMT)	Sigma (MCP)
59.9 ps	64.4 ps	32.5 ps

5	10	5	10
4	9	4	9
3	8	3	8
2	7	2	7

- CERN SPS/H4 North Area with muons and pions
- 12 bit, 10 GS/s, 1 GHz bandwidth scope
- HV issue solved:
 - Increased HV lines isolation on PCB
 - Reducing amount of HV wire bonds over guard-rings
- Best result of ~ 49 ps on 0.5×0.5 mm² pixel with 175 μ m thickness @ 500V



Detectors schematic



DUT

DUT setup

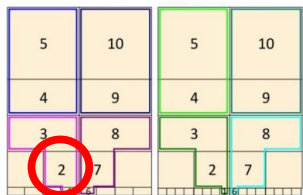
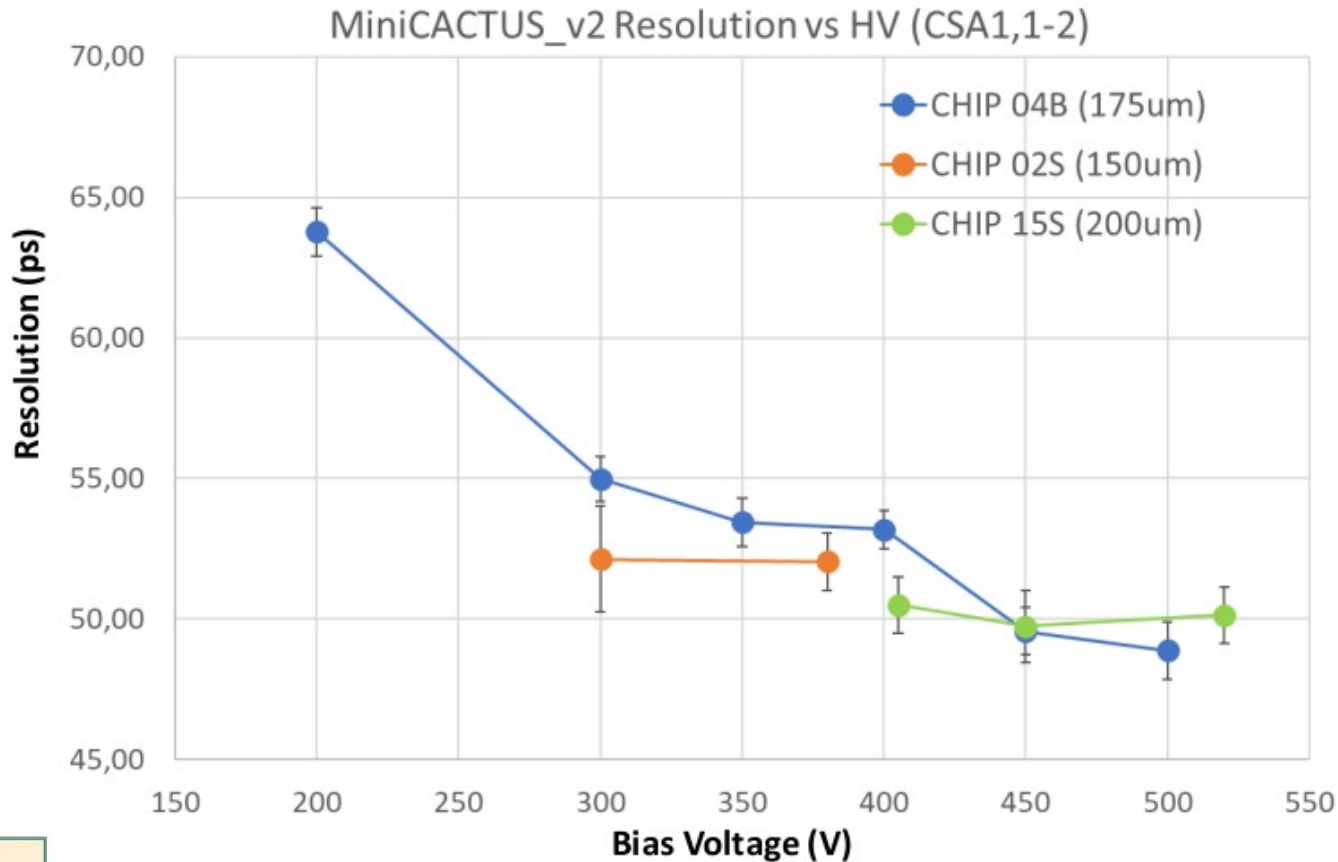
5	10	5	10
4	9	4	9
3	8	3	8
2	7	2	7

Sigma (DUT)
48.88 ps

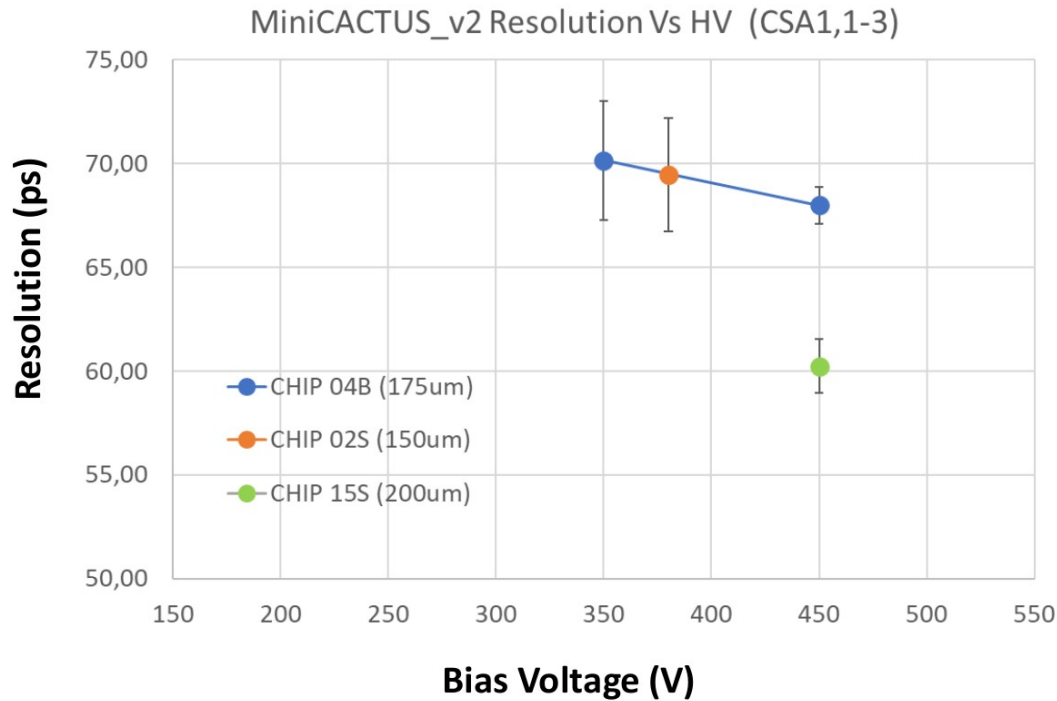
Sigma (PMT1)
51.64 ps

Sigma (PMT2)
33.76 ps

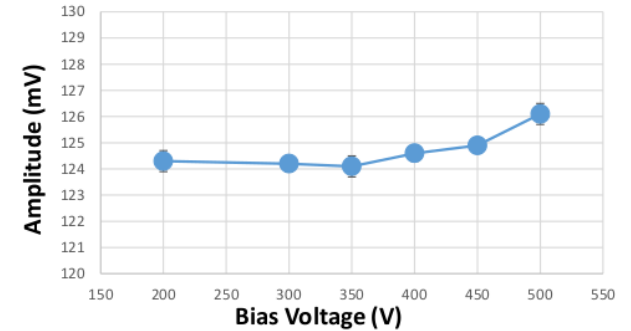
- Time resolution better sub 55 ps above 300 V up to 48.9 ps



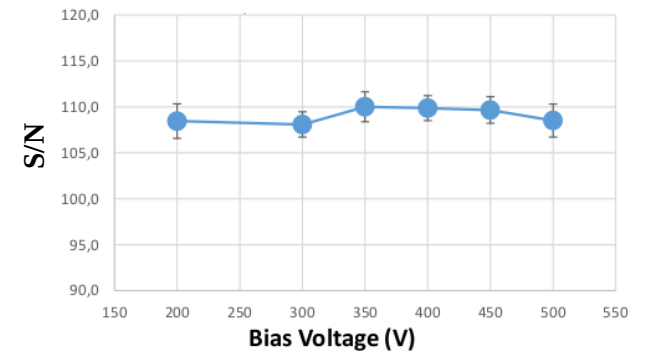
- Time resolution between 60 and 70 ps



Sensor output amplitude MPV vs HV



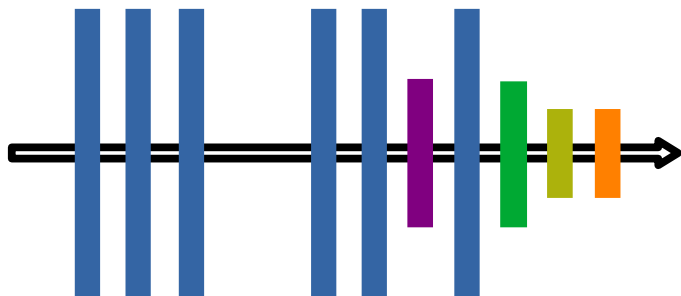
Sensor output Signal to Noise vs HV



- CERN SPS/H6 North Area with pions
- 12 bit, 50 GS/s, 5 GHz bandwidth scope
- Using EUDAQ framework and Corryvreckan
- Adding tracking capabilities
- Detectors setup:
 - **EUDET Telescope**: tracking
 - **CROC**: For triggering ROI, 50x50 μm pitch
 - **DUT**: MiniCactus_v2
 - **PMT**: Auxiliar timing reference
 - **MCP**: Timing reference, calibrated to 8-10 ps



Zoom on DUT setup

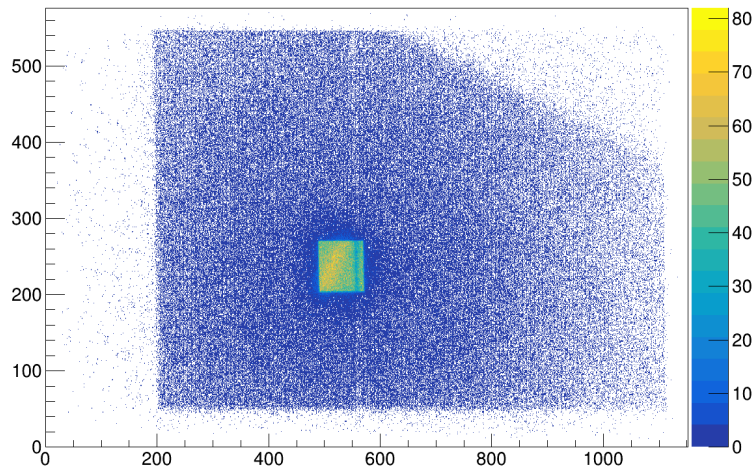


Detectors schematic



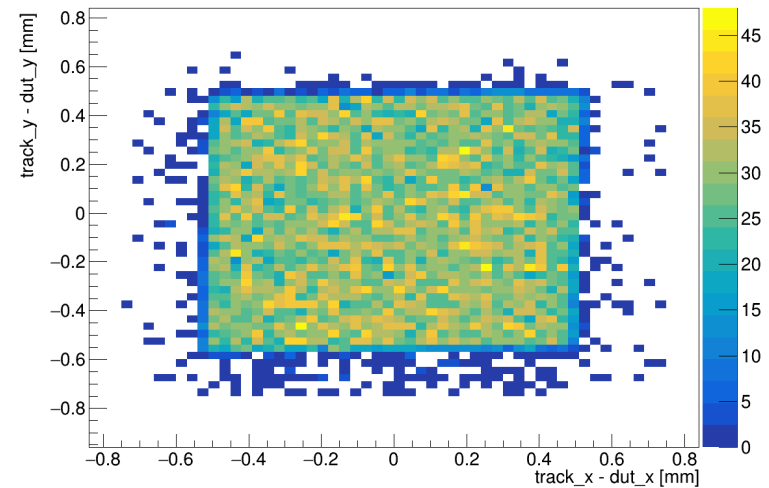
DUT setup

local intersect, col, row



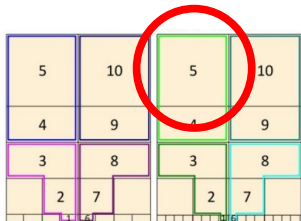
MIMOSA reference plane showing the ROI selected on the CROC, about 1.1x 1.2 mm²

distance between track and hit

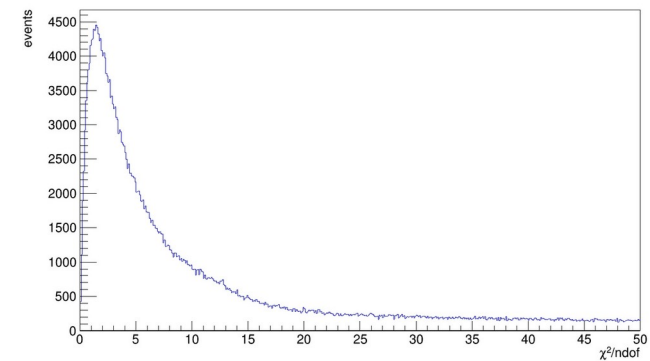


Distance from the tracks with hits - on the DUT from the center of the DUT pad

- We assumed a hit if the analog output signal of the DUT was higher than 0.06 V
- Events for the efficiency calculated where selected for:
 - Single track/event
 - Event detected on at least 4 planes
 - Events intercepting the DUT



Track χ^2/ndof

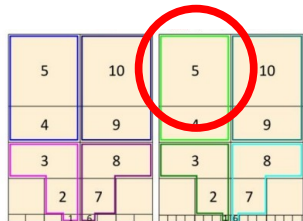
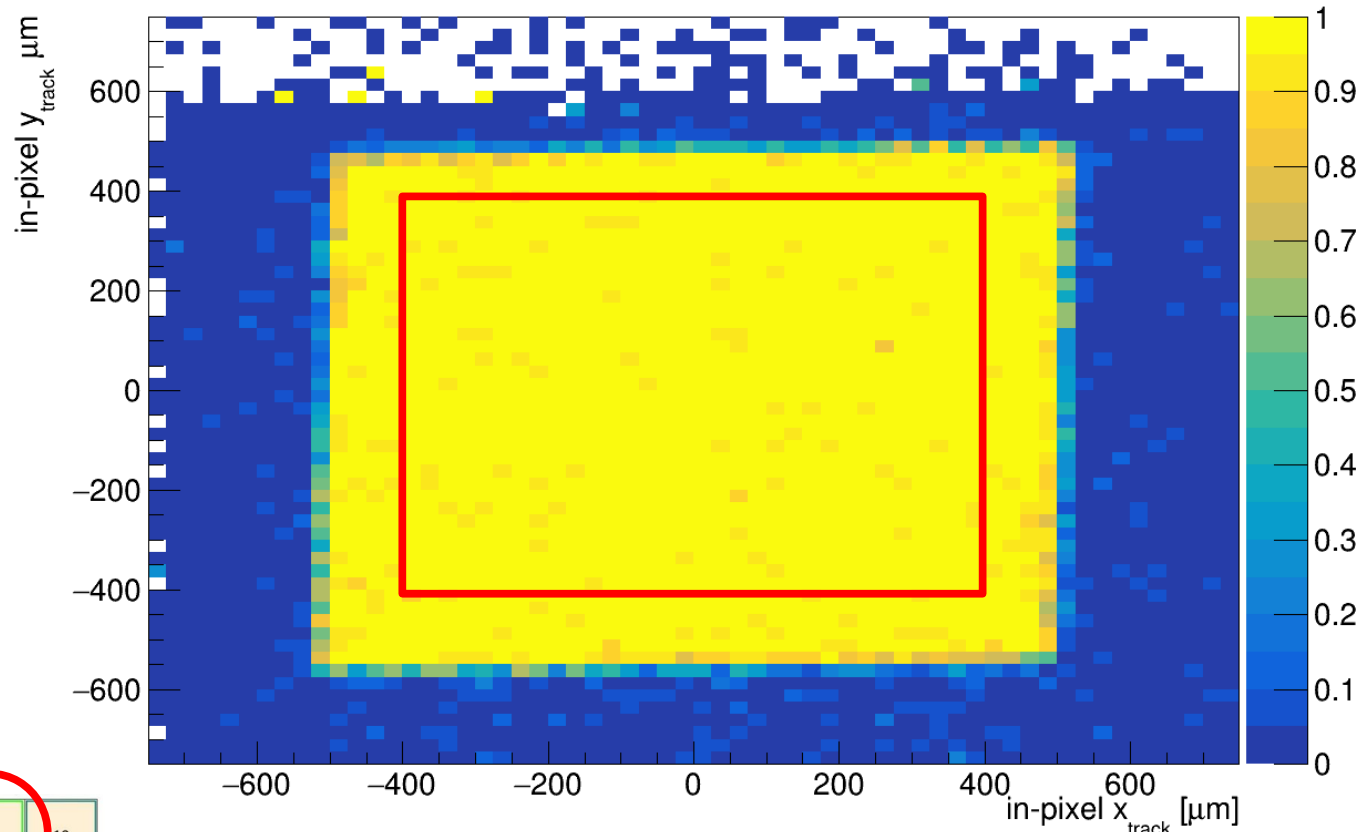


Track χ^2/ndof

Preliminary – Ongoing analysis

Tracking efficiency of 99.0 ± 0.1 % on the central part on the pixel (in red, $0.8 \times 0.8 \text{ mm}^2$) @350 V

MCv2_0 Pixel efficiency map

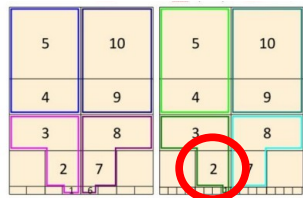
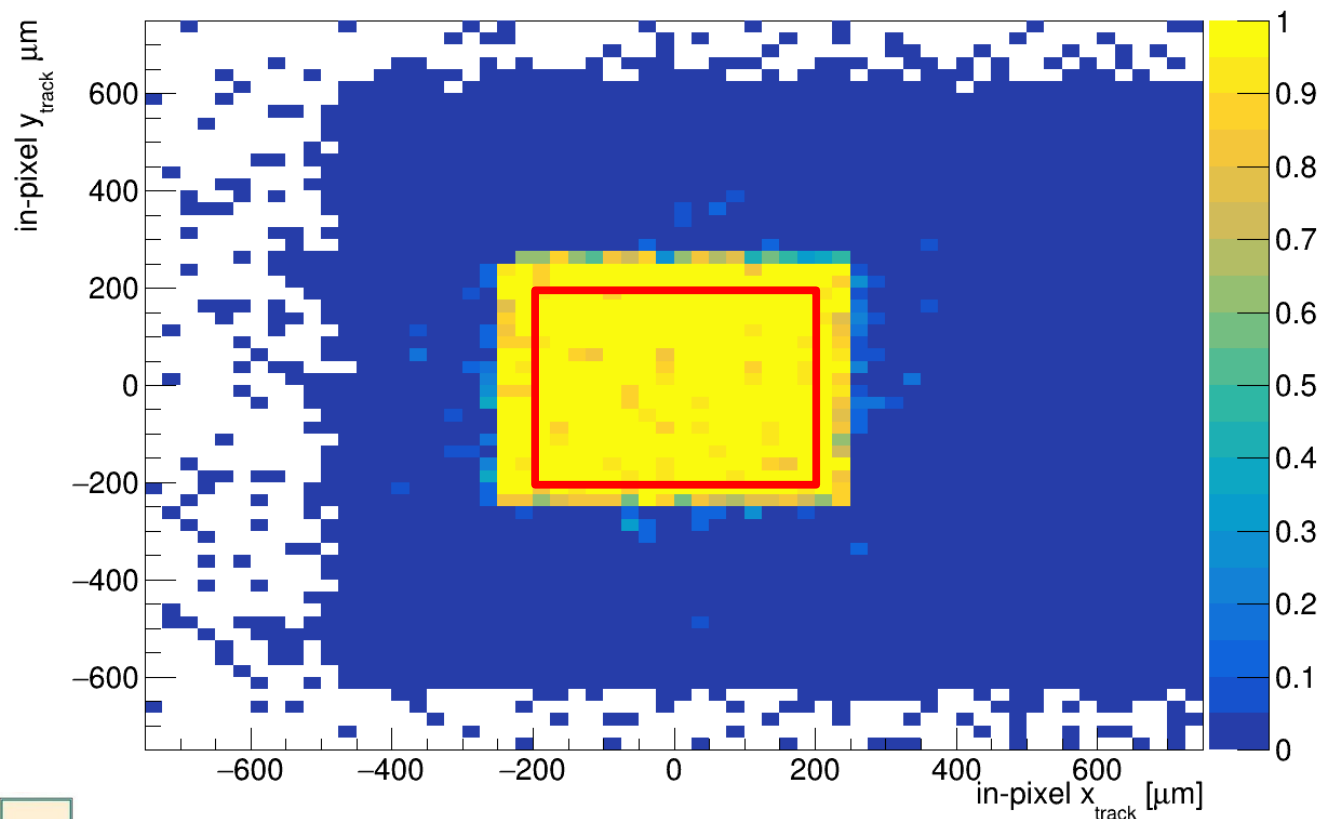


Efficiency calculated by tracks intercepting our detector over detected tracks on single track events

Preliminary – Ongoing analysis

Tracking efficiency of $98.6 \pm 0.3 \%$ on the central part on the pixel (in red, 0.4x0.4mm²) @400 V

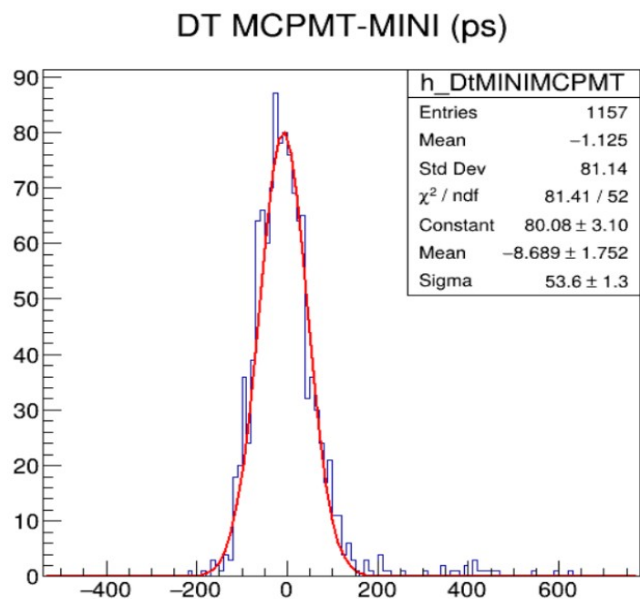
MCv2_0 Pixel efficiency map



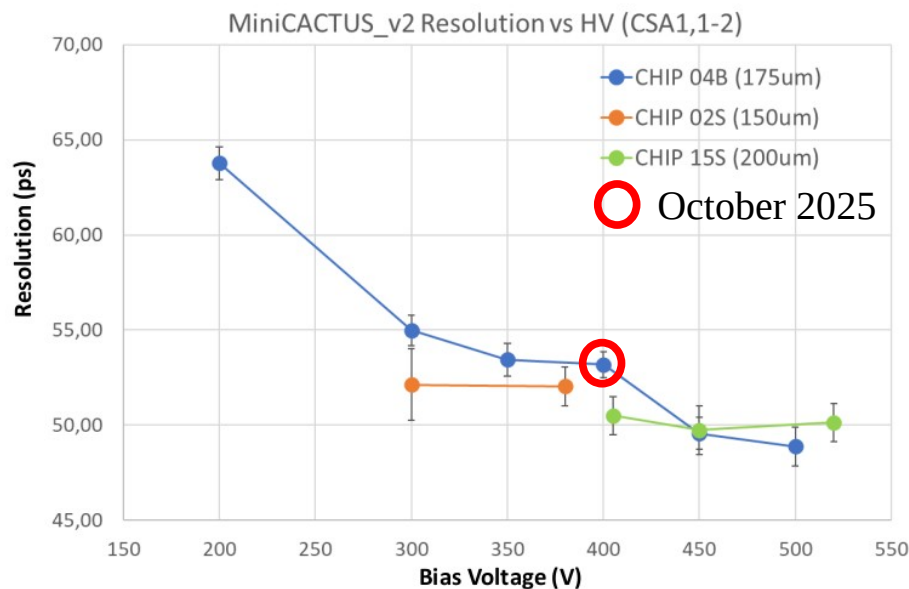
Efficiency calculated by tracks intercepting our detector over detected tracks on single track events

Preliminary – Ongoing analysis

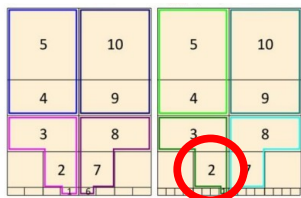
- Result of ~ 53.6 ps on 0.5×0.5 mm² pixel with 175 μ m thickness @ 400V (same conditions as previous slide)
- Few runs analysed show compatible with previously obtained resolution on CSA 1 of 54 ps:



CSA2 0.5×0.5 mm² @400V



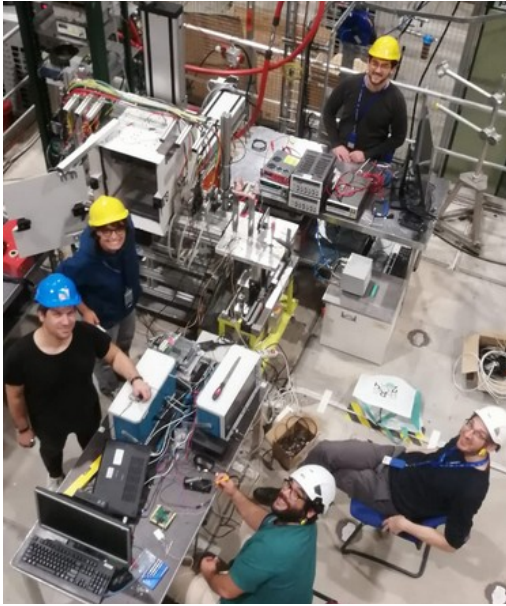
July 2025 Summary plot on 0.5×0.5 mm²



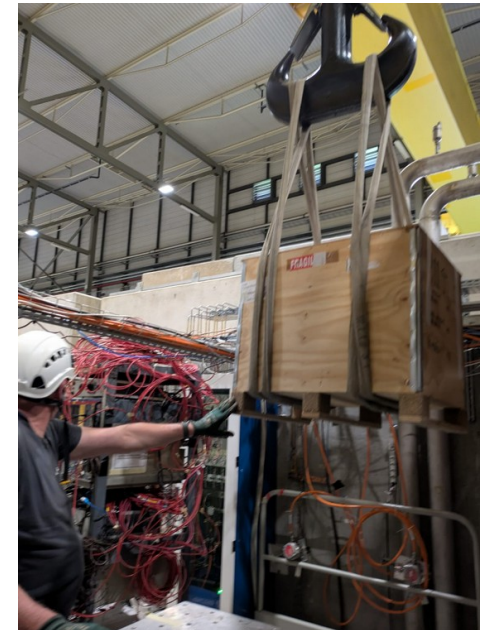
Preliminary – Ongoing analysis

- Timing performance of the MiniCACTUS_v2 has been measured in multiple testbeams:
 - Best result up to now is **49 ps** on the 0.5x0.5 mm² pixel @ 500 V
- New testbeam setup tested for tracking efficiency + timing measurements:
 - First preliminary results showing a tracking **efficiency of ~99%** on central area of **both pixels** measured
- More testbeams foreseen in the upcoming months
 - To establish timing performance with **gain layer**
 - To assess radiation hardness on **irradiated devices**

Thanks for your attention

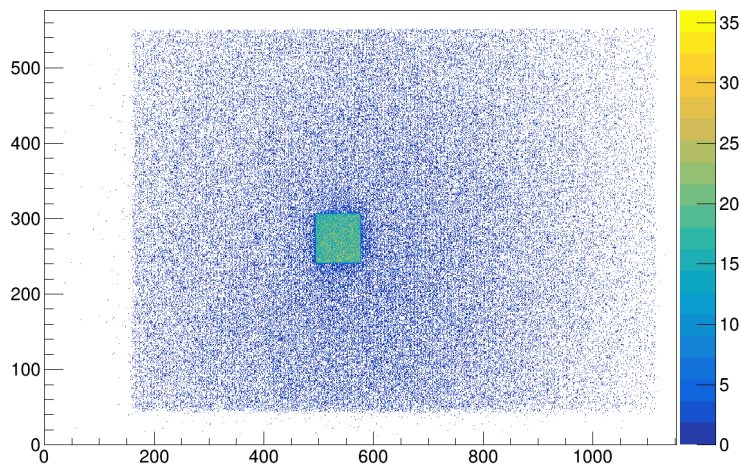


The end...



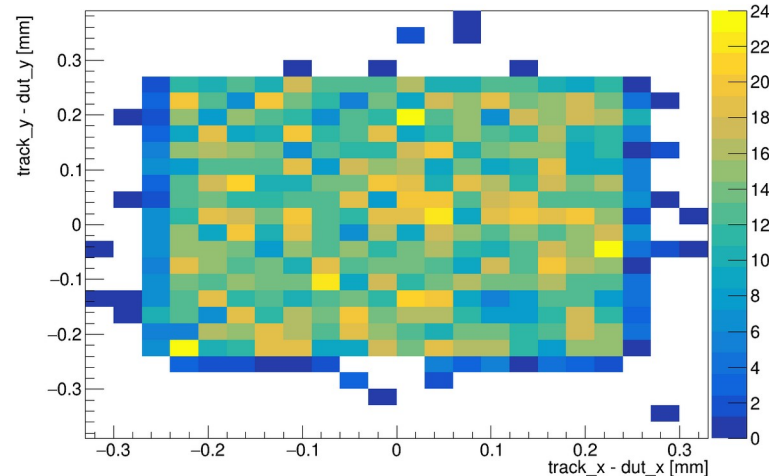
... for now

local intersect, col, row



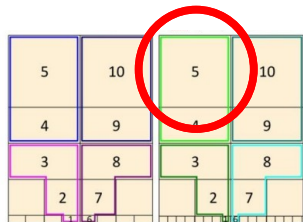
MIMOSA reference plane showing the ROI selected on the CROC, about 1.1x 1.2 mm²

distance between track and hit

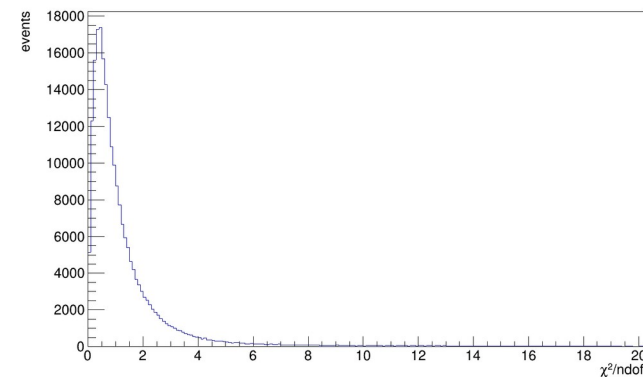


Distance from the tracks with hits on the DUT from the center of the DUT pad

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 - Single track/event
 - Event detected on least 4 planes
 - Events intercepting the DUT



Track χ^2/ndof



Track χ^2/ndof

Preliminary – Ongoing analysis

1x1 mm²

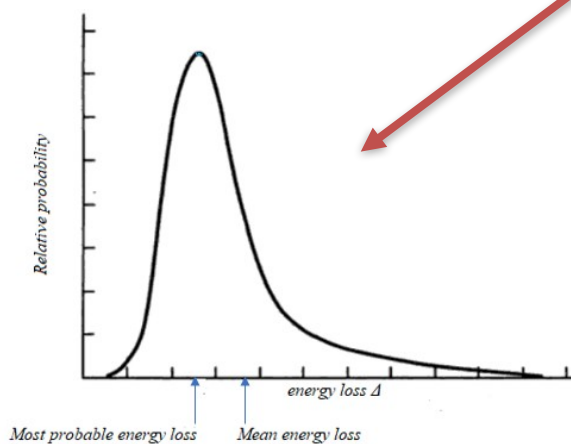
```
[11:45:31.786] (STATUS) =====| Finalising modules |=====
[11:45:32.927] (STATUS) [F:DUTAssociation:MCv2_0] In total, 152747 clusters are associated to 152747 tracks.
[11:45:32.927] (INFO) [F:DUTAssociation:MCv2_0] Number of tracks with at least one associated cluster: 152747 vs total number of tracks: 645037
[11:45:32.947] (STATUS) [F:AnalysisEfficiency:MCv2_0] Track selection flow:      645037
* rejected by chi2          -182109
* track outside ROI        -54776
* track outside DUT        -386333
* track close to masked px -0
* track close to frame edge -0
* track without an associated cluster on required detector - 0
Accepted tracks:          21819
[11:45:32.948] (STATUS) [F:AnalysisEfficiency:MCv2_0] Total efficiency of detector MCv2_0: 99.0284(+0.0664381 -0.0710914)%, measured with 21607/21819 matched/total tracks
```

0.5x0.5 mm²

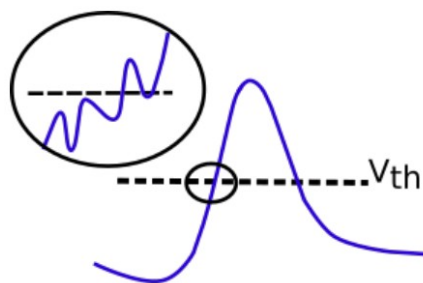
```
[11:28:20.965] (STATUS) [F:AnalysisEfficiency:MIMOSA26_0] Total efficiency of detector MIMOSA26_0: 0(+100 -0)%, measured with 0/0 matched/total tracks
[11:28:21.141] (STATUS) [F:AnalysisEfficiency:MCv2_0] Track selection flow:      238098
* rejected by chi2          -4
* track outside ROI        -5808
* track outside DUT        -229781
* track close to masked px -0
* track close to frame edge -0
* track without an associated cluster on required detector - 0
Accepted tracks:          2505
[11:28:21.141] (STATUS) [F:AnalysisEfficiency:MCv2_0] Total efficiency of detector MCv2_0: 98.6826(+0.227255 -0.269562)%, measured with 2472/2505 matched/total tracks
```

Main contributions to the time resolution on timing measurement:

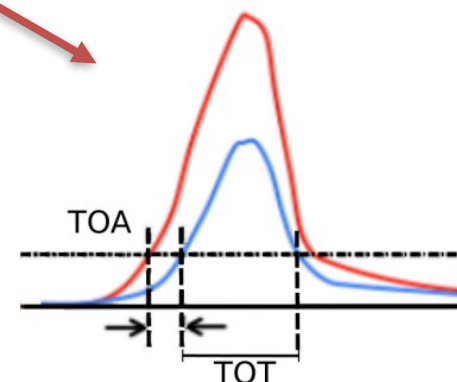
$$\sigma_{T_{hit}}^2 = \sigma_{Landau}^2 + \sigma_{jitter}^2 + \sigma_{TW}^2 + \sigma_{clock}^2 + \sigma_{TDC}^2$$



Non-uniform energy deposit along the path on silicon by a charged particle



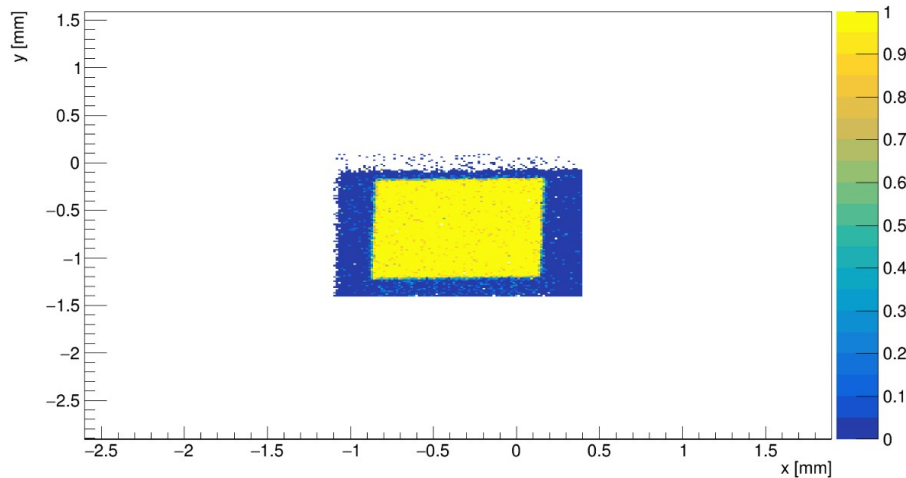
Sensor signal jitter before the discriminator



Time Walk affecting the TOA measurement

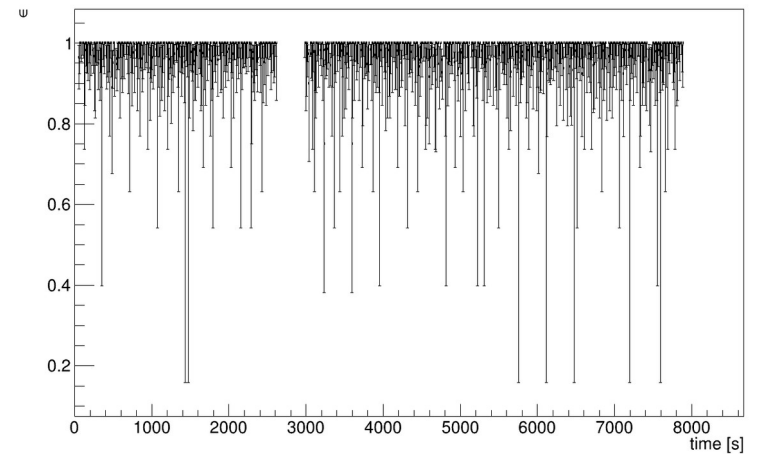
- No **clock** for now
- No **TDC** for now

MCv2_0 Global efficiency map



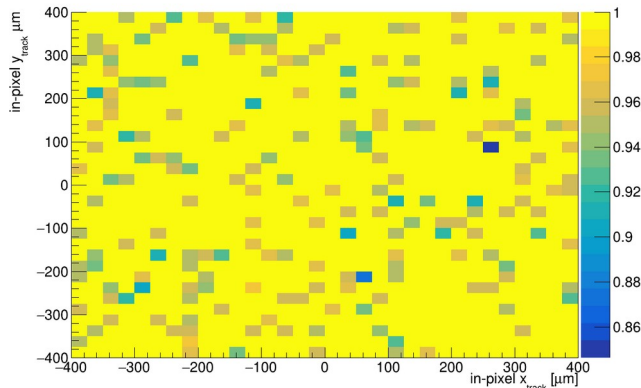
Sensor efficiency zoom out:
 Blue region corresponds to the ROI set on CROC
 Yellow to our sensor

Efficiency vs. time

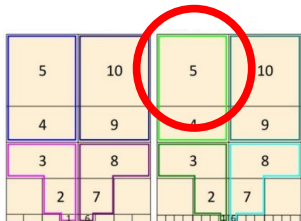


Sensor efficiency over several hours
 (huge error bars due to low stat for each)

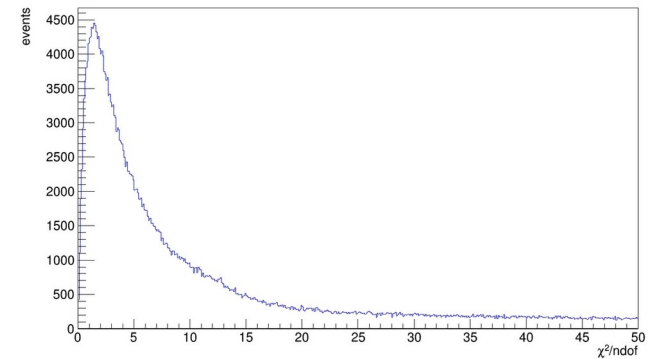
MCv2_0 Pixel efficiency map



Sensor efficiency on
 central 0.8x0.8 mm²



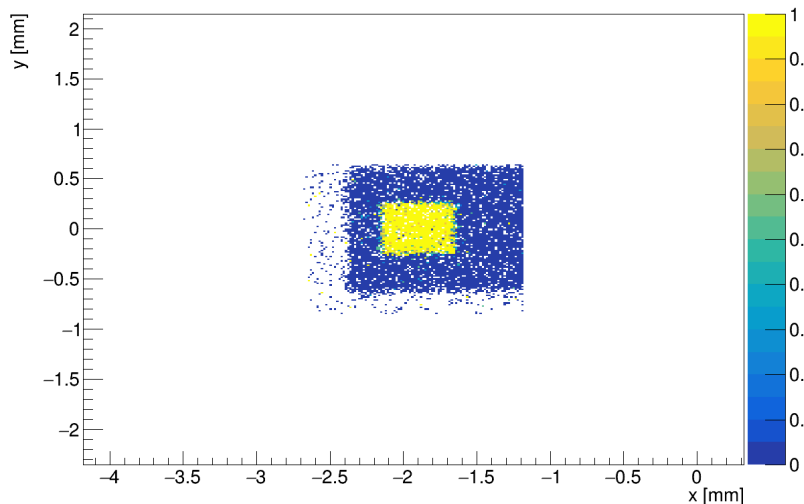
Track χ^2/n_{dof}



Track χ^2/n_{dof}

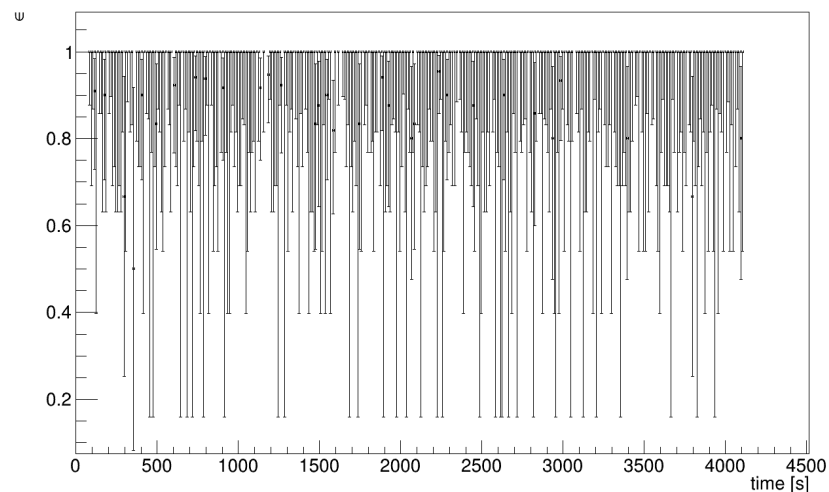
Preliminary – Ongoing analysis

MCv2_0 Global efficiency map



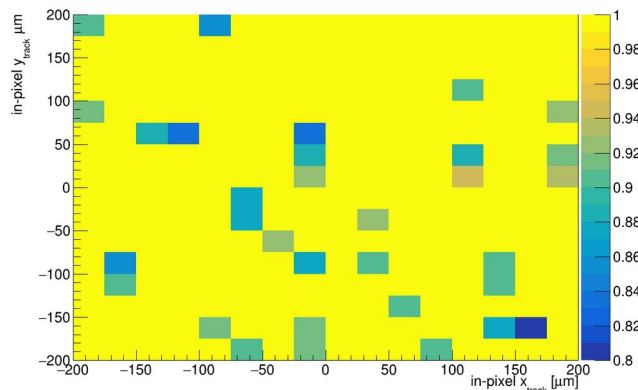
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Efficiency vs. time

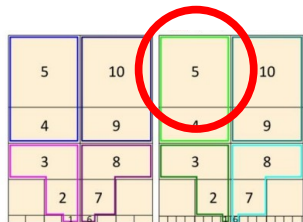


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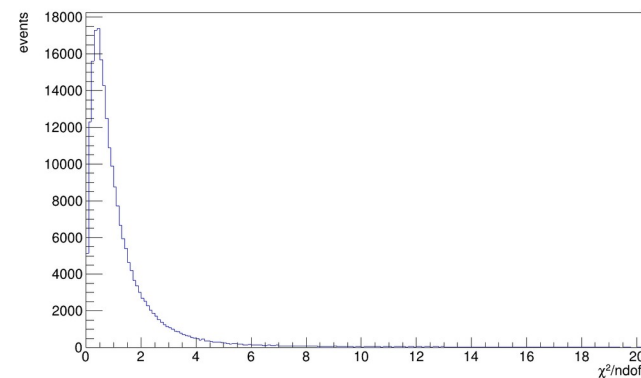
MCv2_0 Pixel efficiency map



Sensor efficiency on
 central $0.4 \times 0.4 \text{ mm}^2$



Track χ^2/ndof



Track χ^2/ndof

Preliminary – Ongoing analysis