# SM2 Micromegas Modules in the Cosmic Ray Facility

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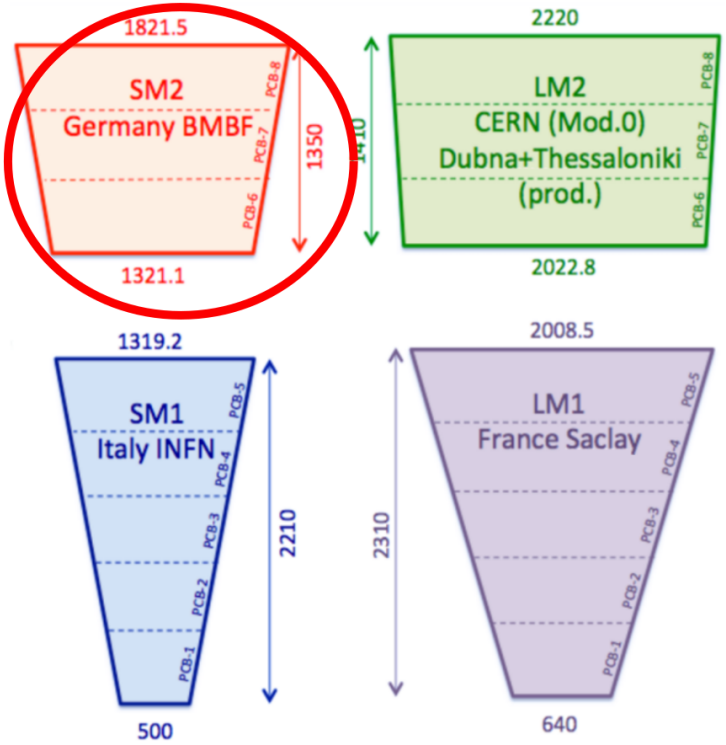
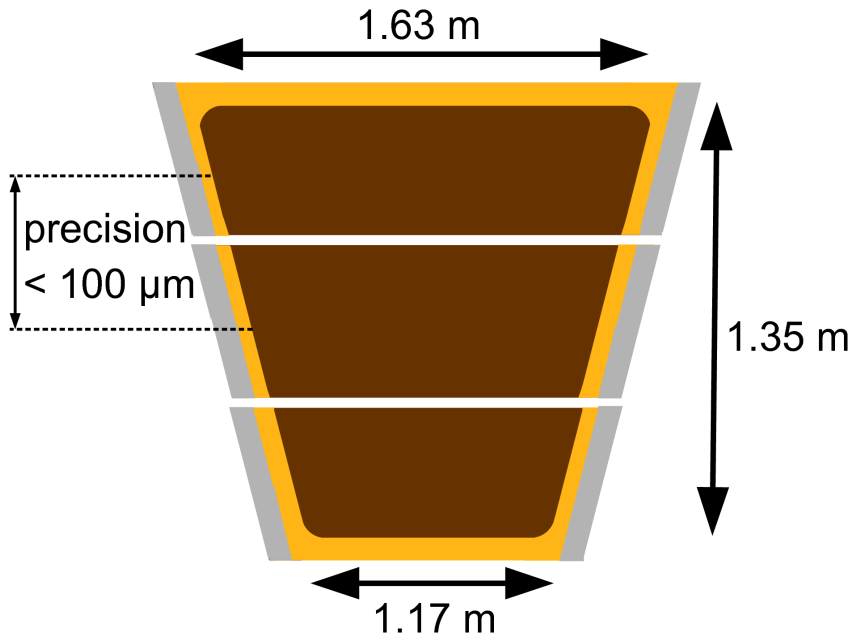
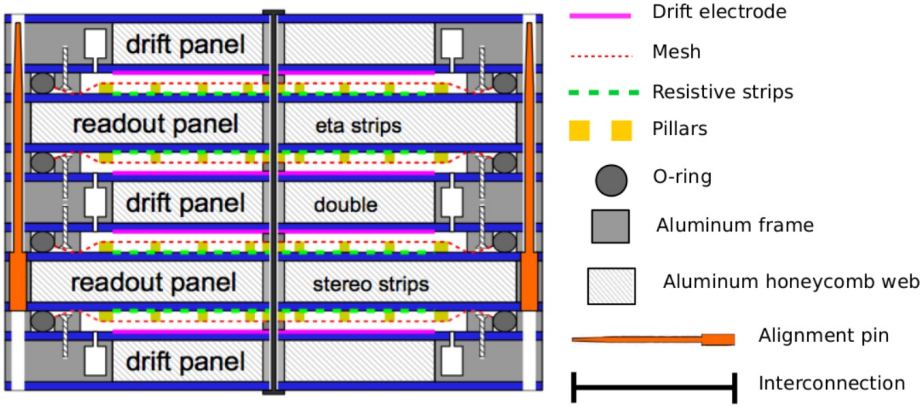
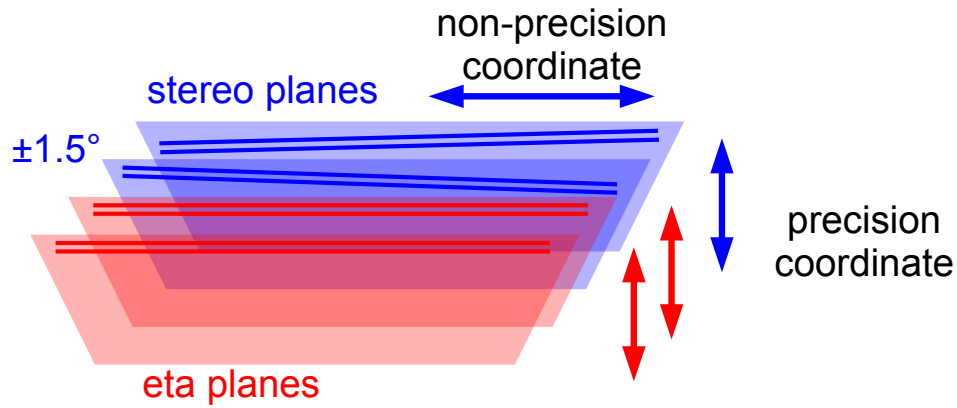
# SM2 Micromegas Modules for the NSW

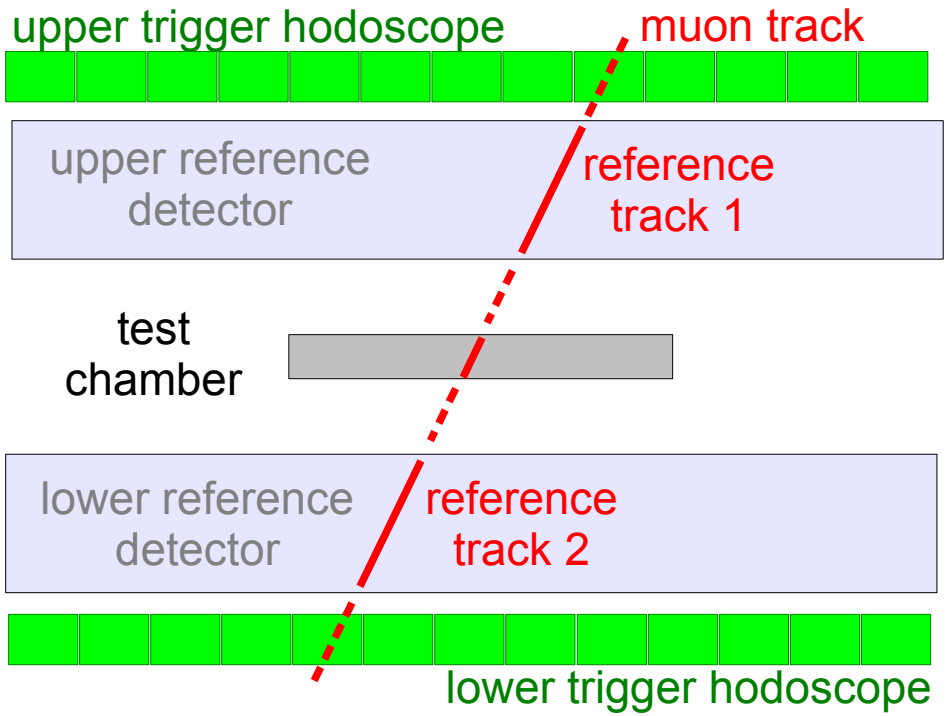


# Cosmic Ray Facility

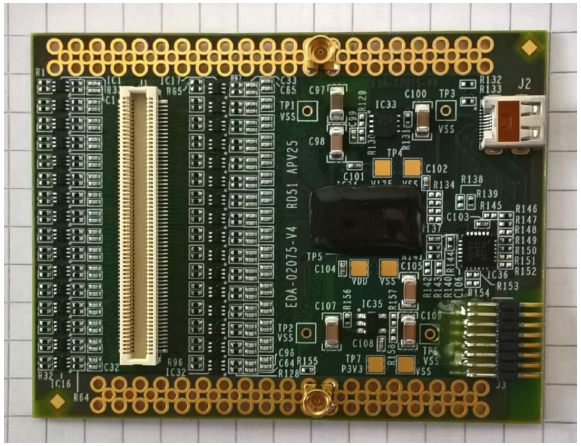




| | |
|---|---|
| trigger | 2 × scintillator hodoscopes |
| track reconstruction | 2 × Monitored Drift Tube chambers (MDTs) |
| active area | 2 m × 4 m |
| angular acceptance | ± 30° to zenith |
| energy cut (hardware) | iron absorber (34 cm) → $E_\mu > 600$ MeV |
| readout | 12288 channels |
| | → 96 APVs (frontend electronics) |
| | → 6 FECs (scalable readout system) |
| readout rate | 100 Hz (muon rate) |

# Charge and Time Resolved Readout using APV25 Electronics

96 × APV25-chips



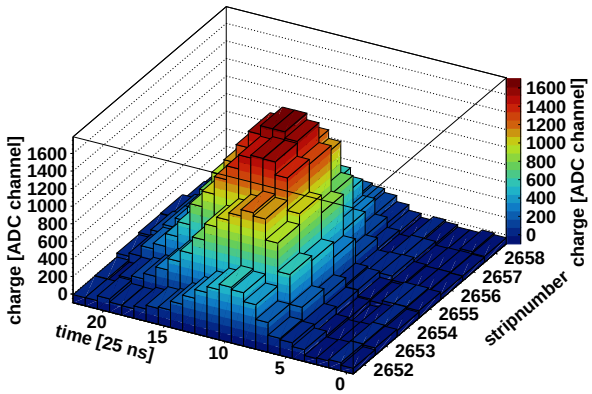
6 × FEC-cards

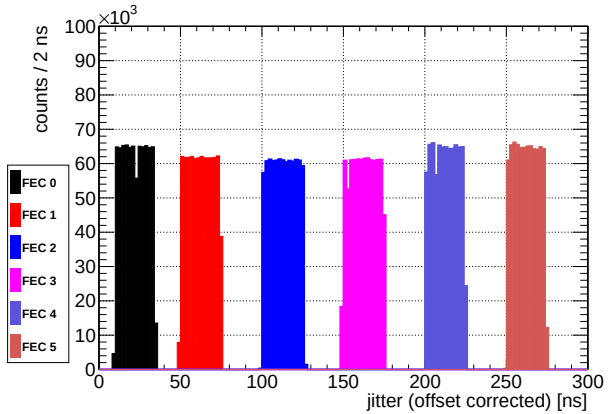

strips parallel to MDT-wires

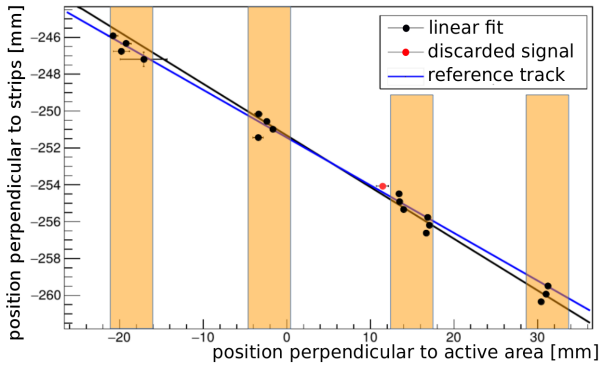
128 channel
charge sensitive preamplifier
40 MHz signal sampling

jitter recorded individually
⇒ unbiased time-evaluation

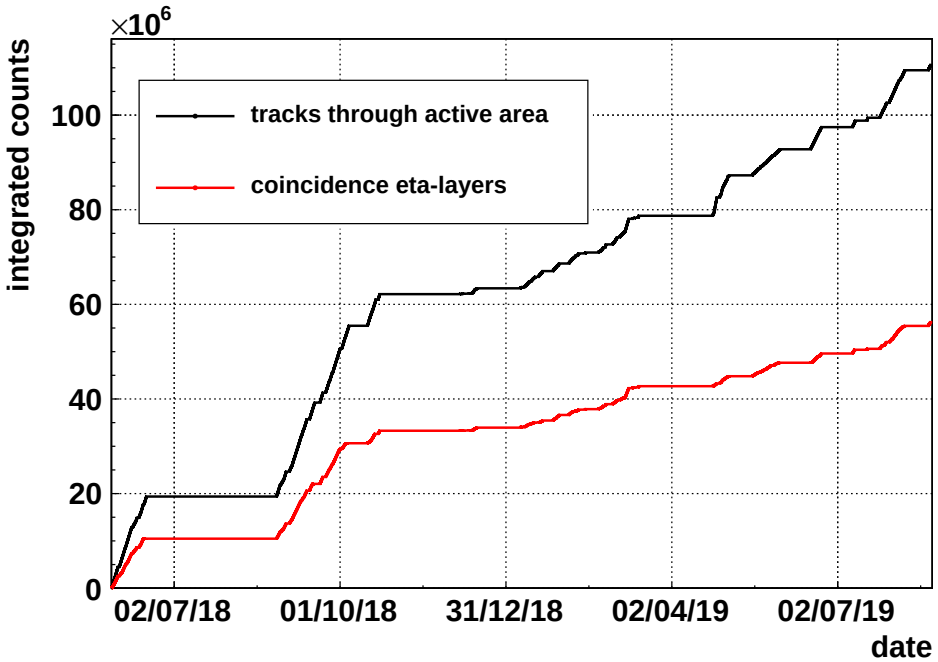
reference track
⇒ efficiency and resolution

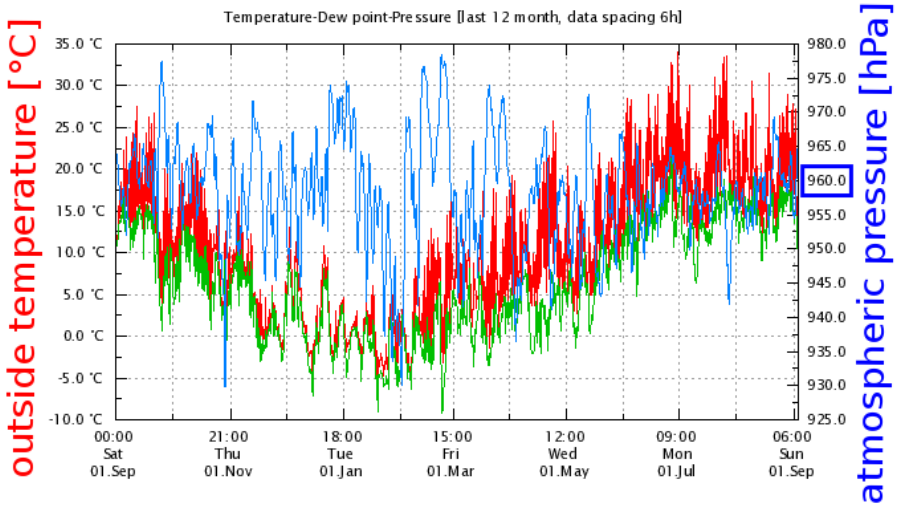


# Measurement Overview




- central part of active area

  $\Rightarrow$ 96 cm $\times$ 78 cm

  overall more than $\frac{1}{2}$ billion trigger
- counts integrated over all amplification voltages

  $\Rightarrow$ also low gain measurements
- CRF average pressure : 960 hPa

  ATLAS-cavern : 980 hPa

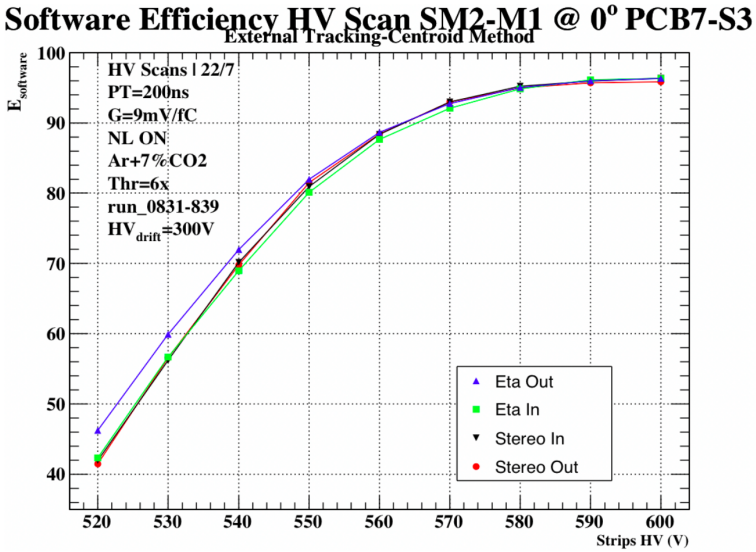
  $\Rightarrow$ different gain
- CRF temperature : 21 °C

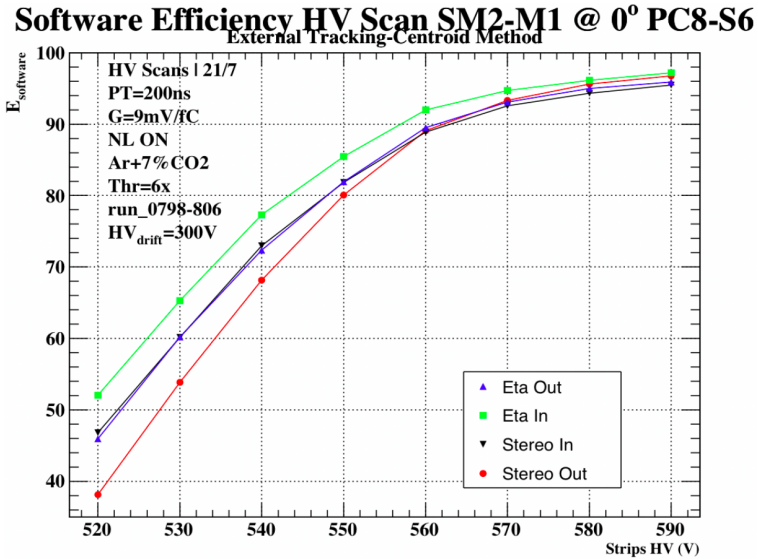
  controlled to about $\pm$2 °C
- modules measured:

  0, 1, 3, 5, 6, 7, 8, 9, 11, 12, 13, 14, 15, 16

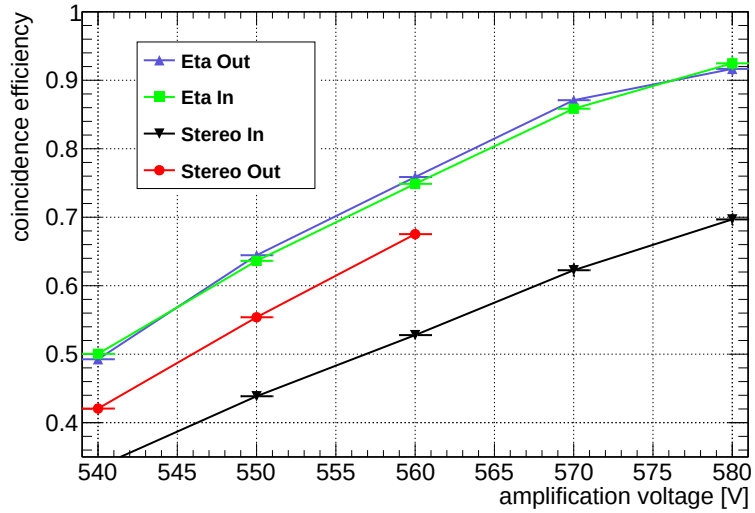
# Efficiency Turn On Curves (Module 1)

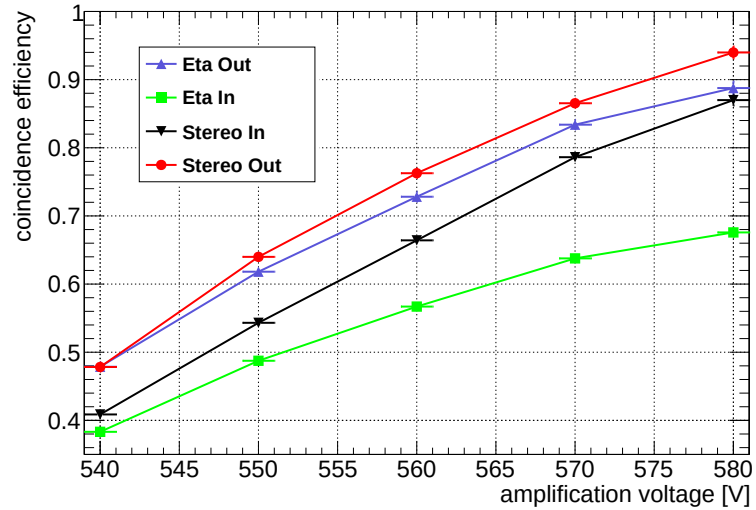
H8 testbeam 2018
9 cm × 9 cm



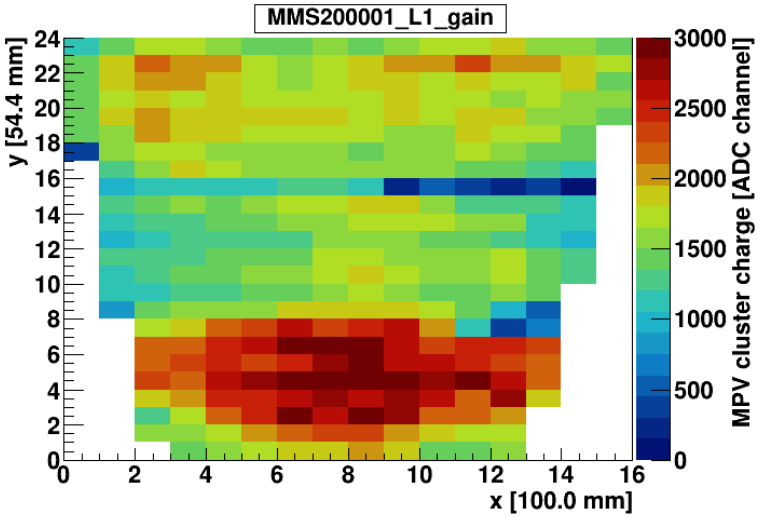

CRF
32 cm × 18.6 cm

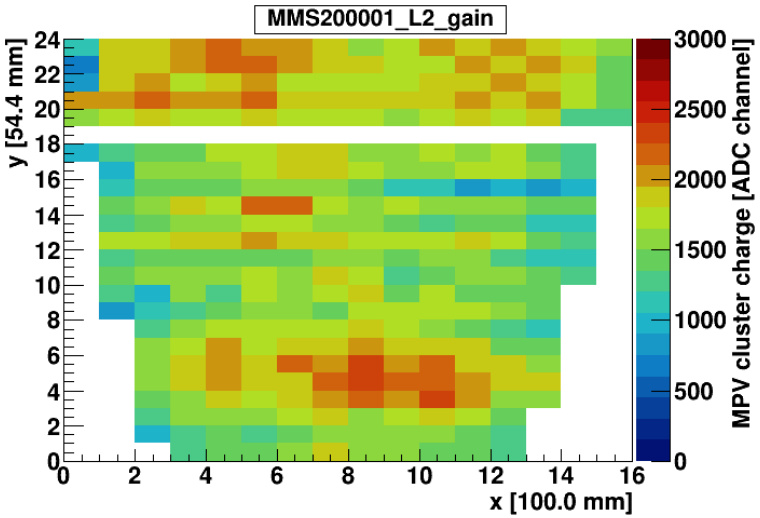


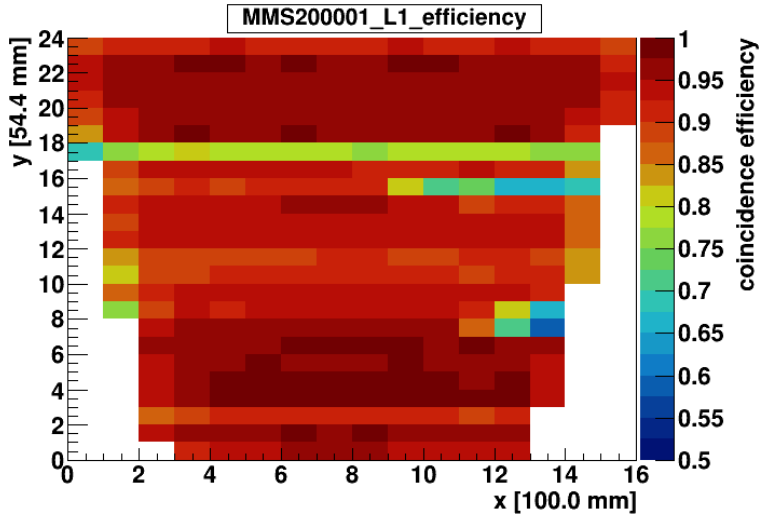
# Pulse Height and Efficiency Maps (Module 1, eta-layers @ $U_{\mathrm{amp}} = 580\,\mathrm{V}$)

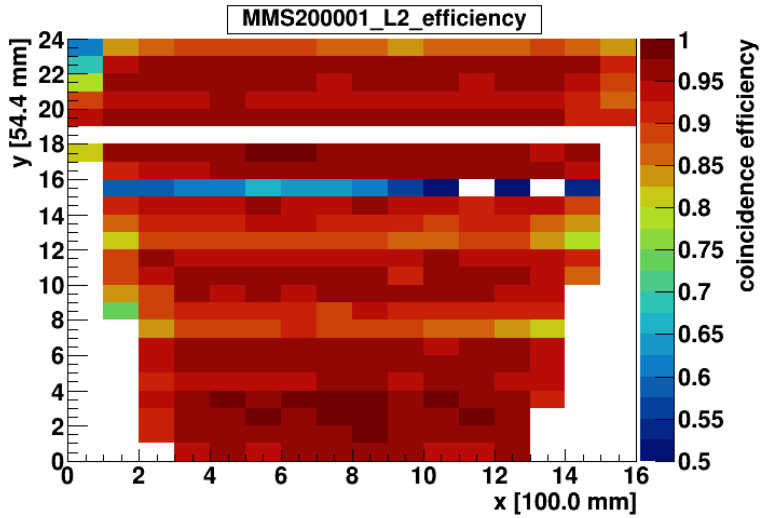
## pulse height map



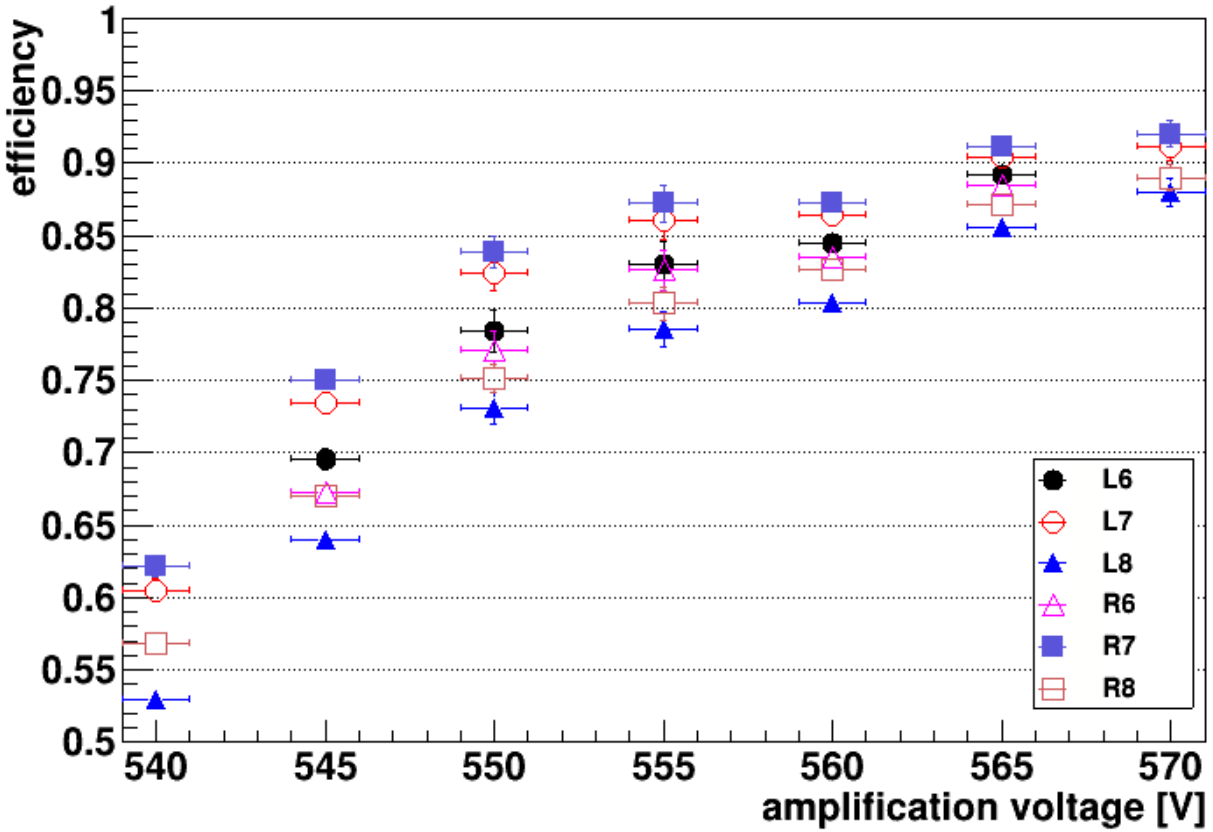



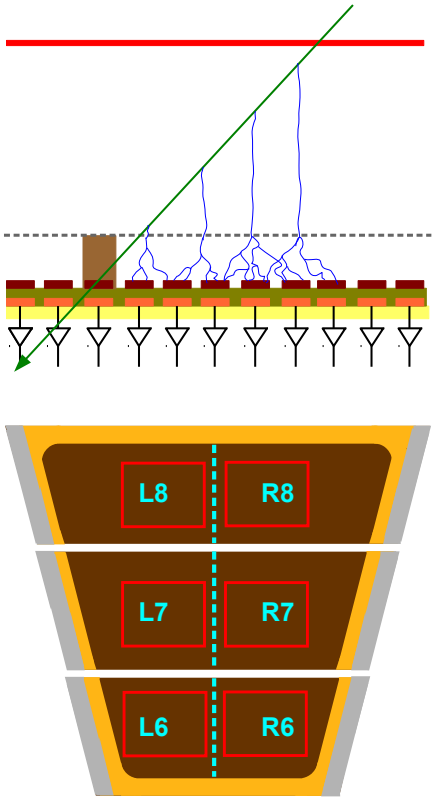

## efficiency map



# Efficiency Turn On Curve (Module 3, eta-in)



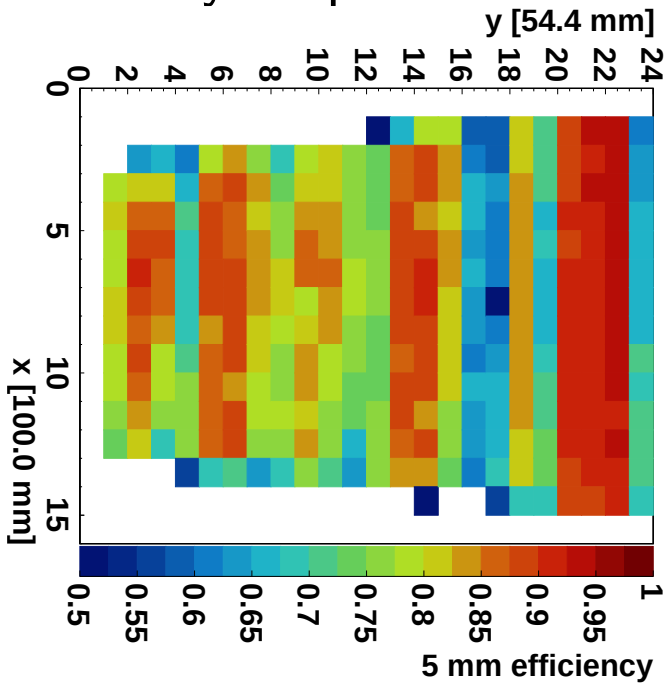



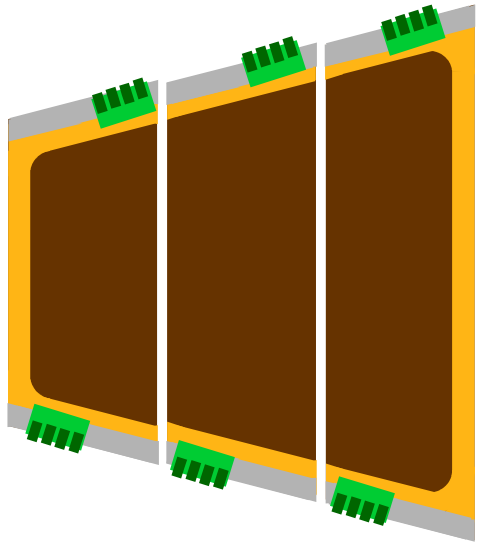

central parts of active area for single High-Voltage Sectors

$\Rightarrow$ 32 cm $\times$ 18.6 cm

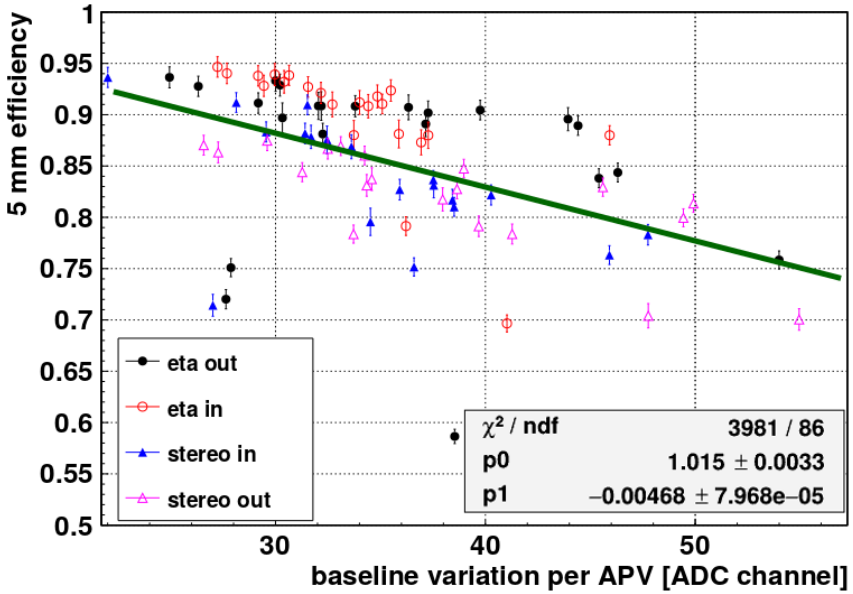
# Efficiency spoiled by Noise of Preliminary Electronics (Module 7)

## efficiency map - stereo-in

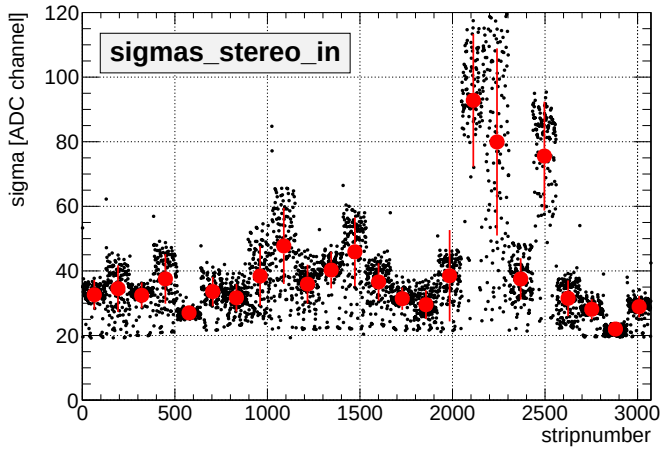


## efficiency VS electronic noise

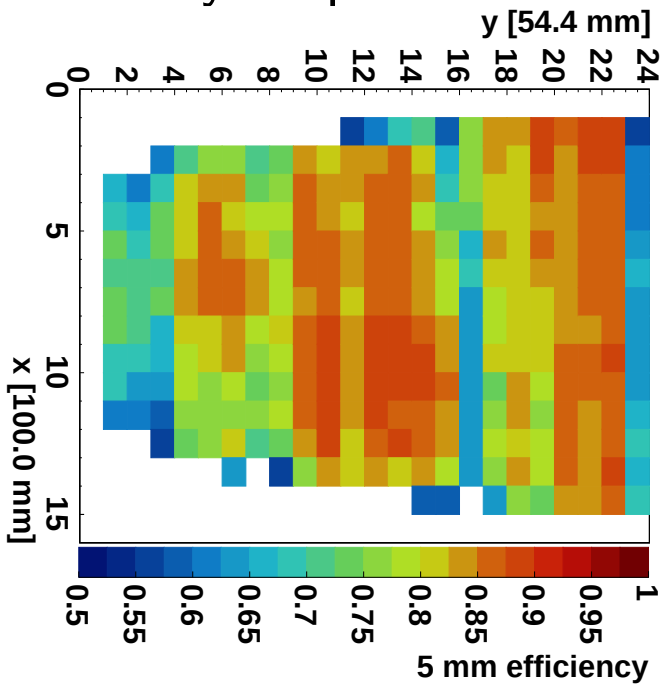


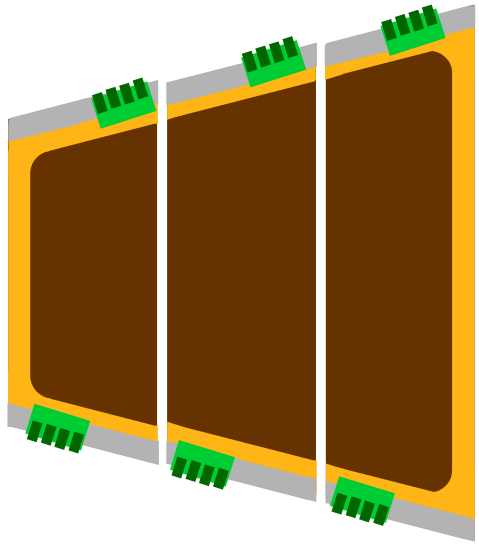

## electronic noise per readout chip



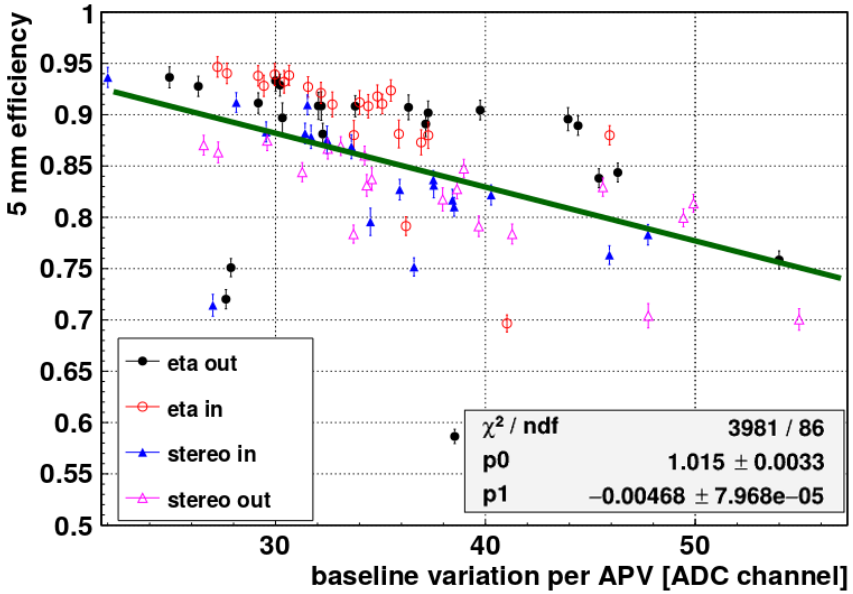
# Efficiency spoiled by Noise of Preliminary Electronics (Module 7)

## efficiency map - stereo-out



## efficiency VS electronic noise

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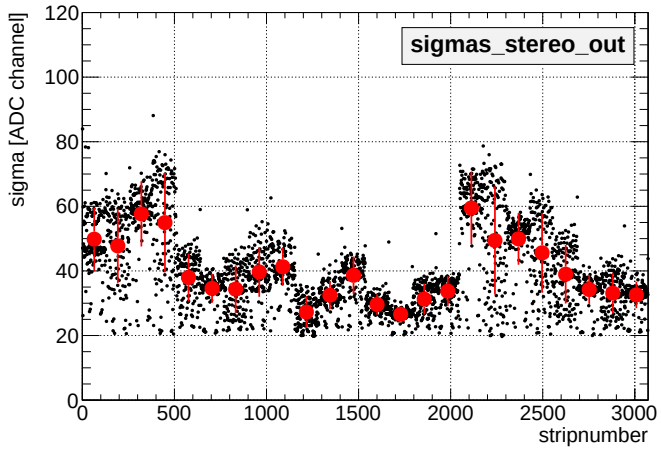

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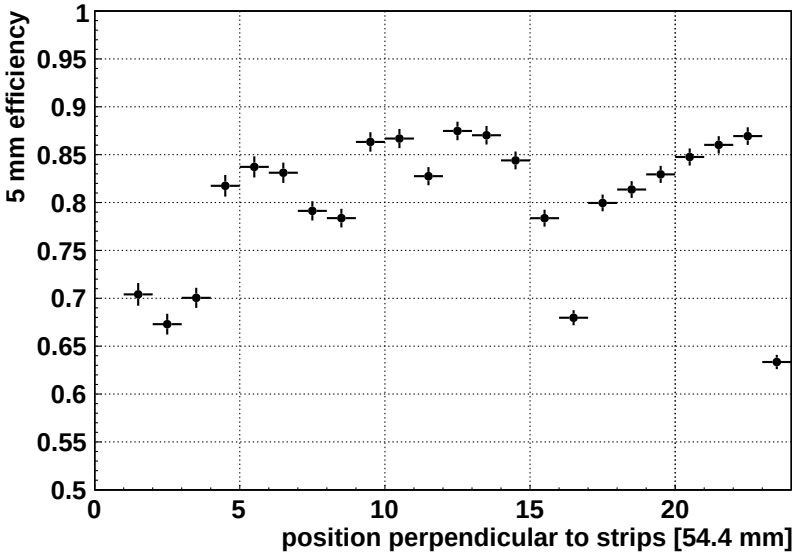
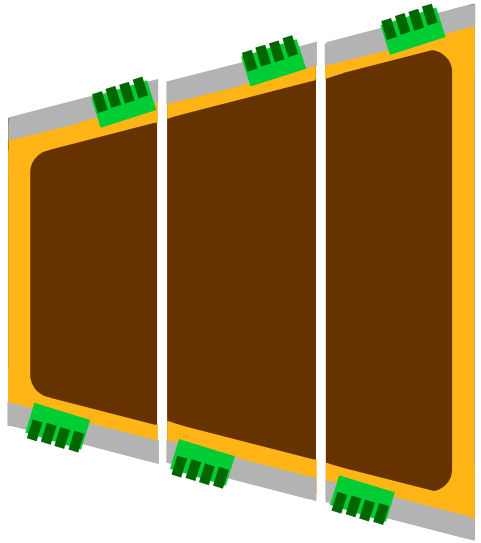
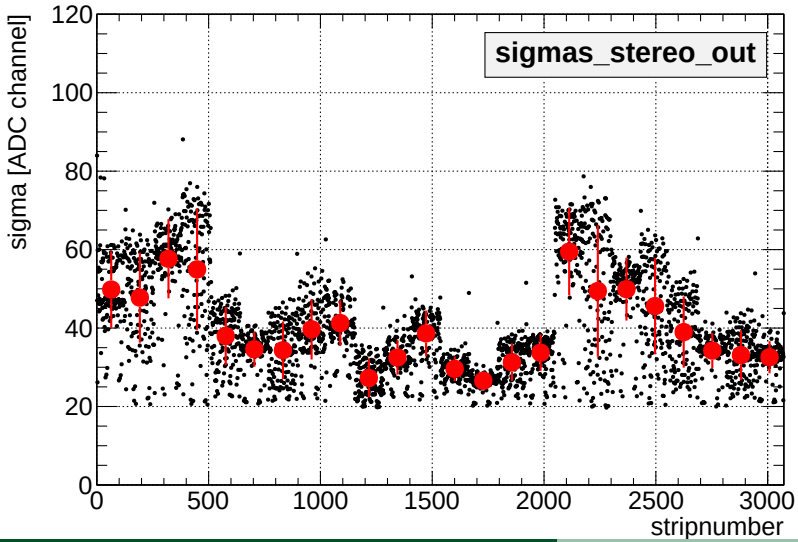
## efficiency per readout chip

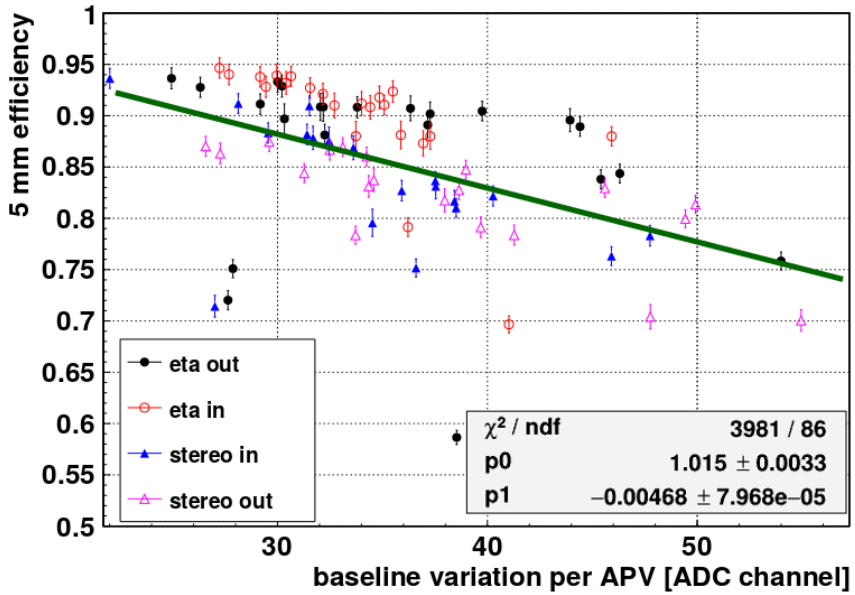


## electronic noise per readout chip

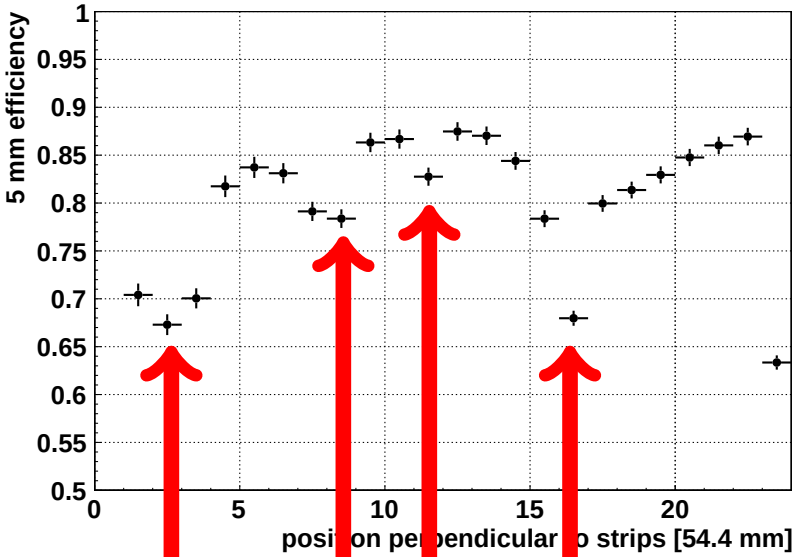


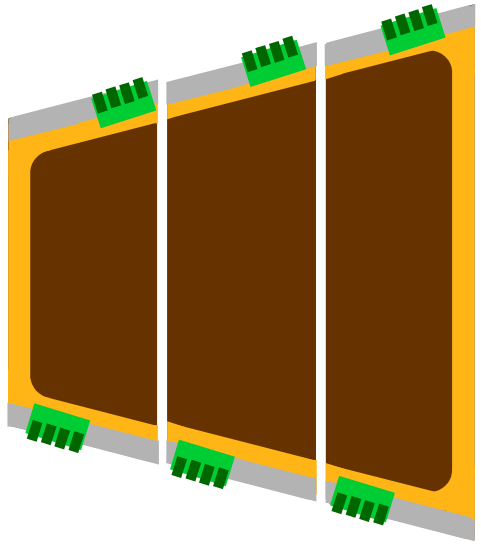

## efficiency VS electronic noise



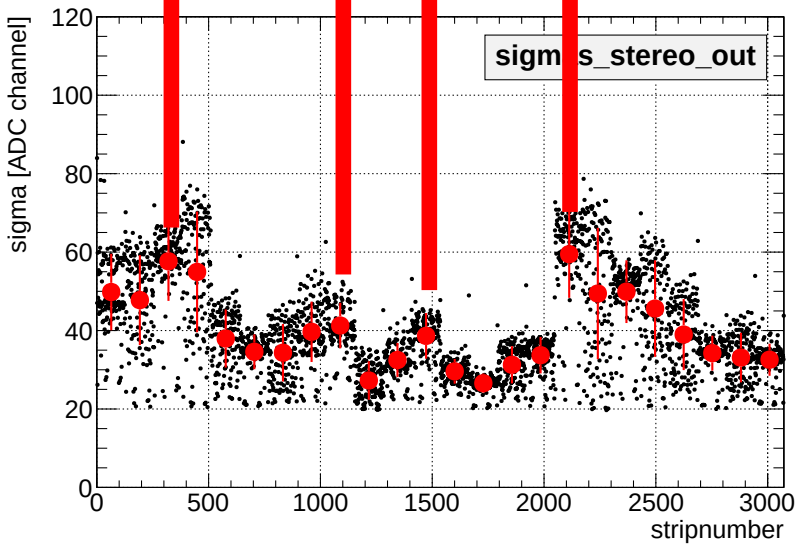
# Efficiency spoiled by Noise of Preliminary Electronics (Module 7)

efficiency per readout chip

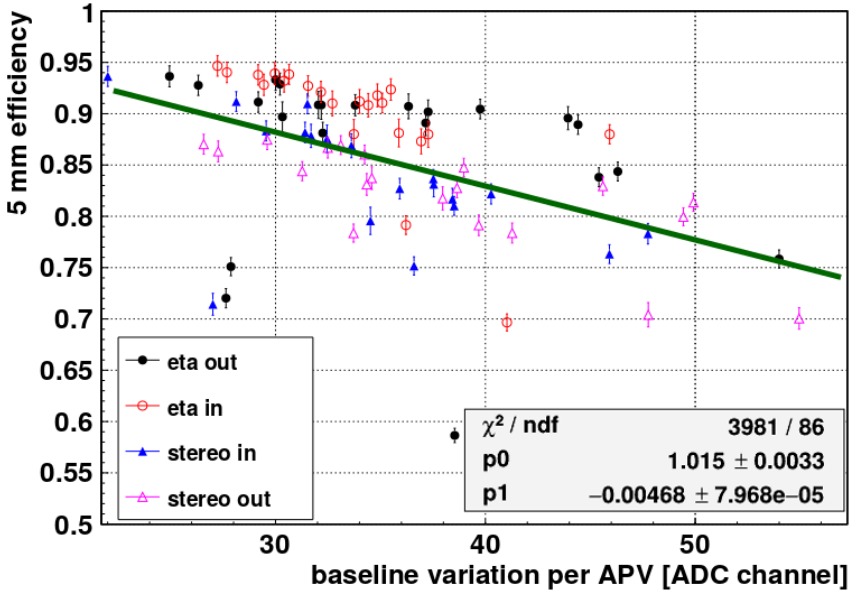


electronic noise per readout chip

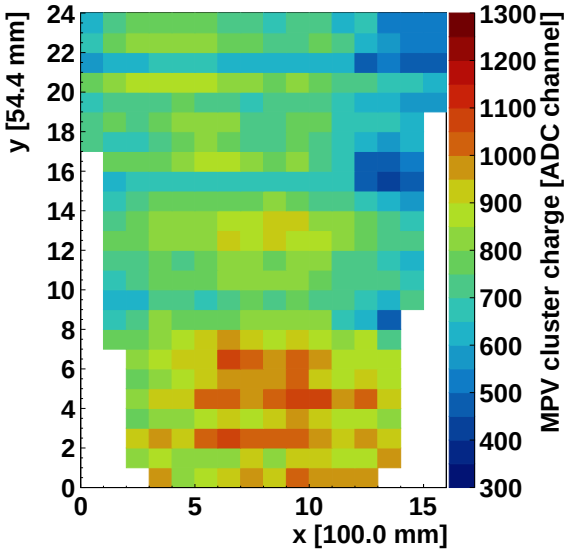



efficiency VS electronic noise

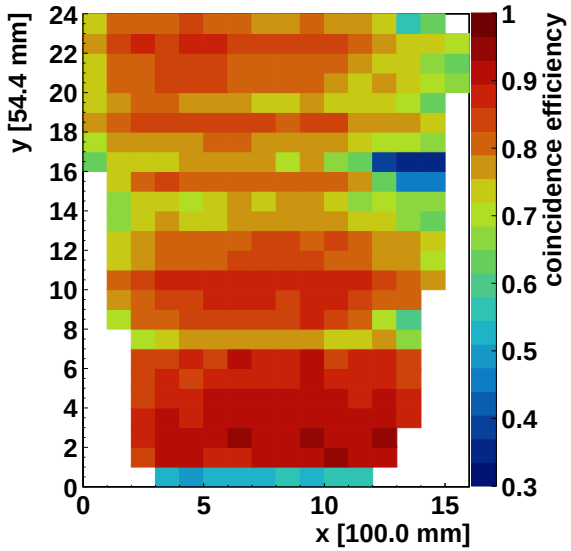


# Efficiency influenced by Pulse Height

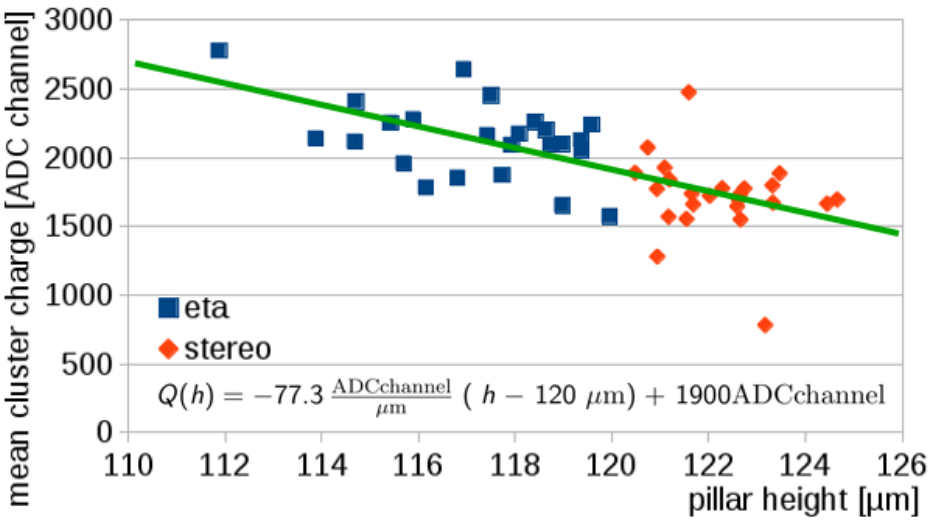
pulse height map - m3, eta out

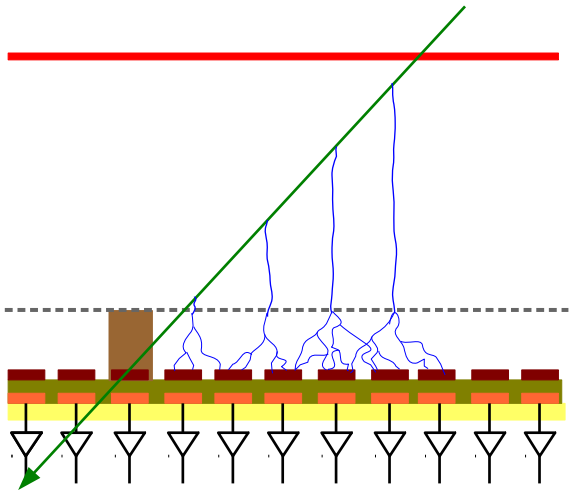



efficiency map - m3, eta out



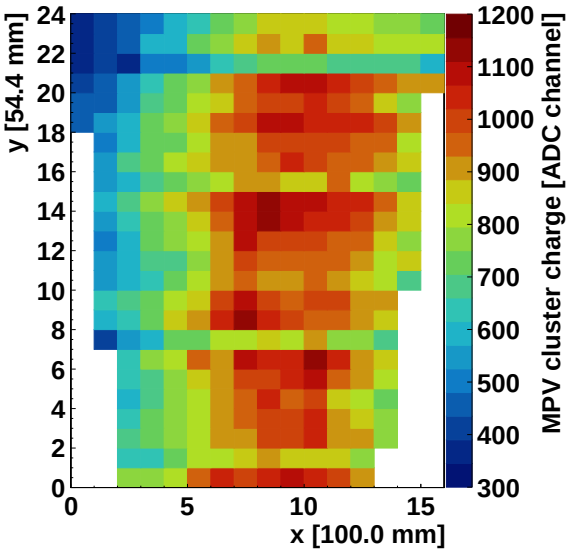

mean pulse height VS pillar height



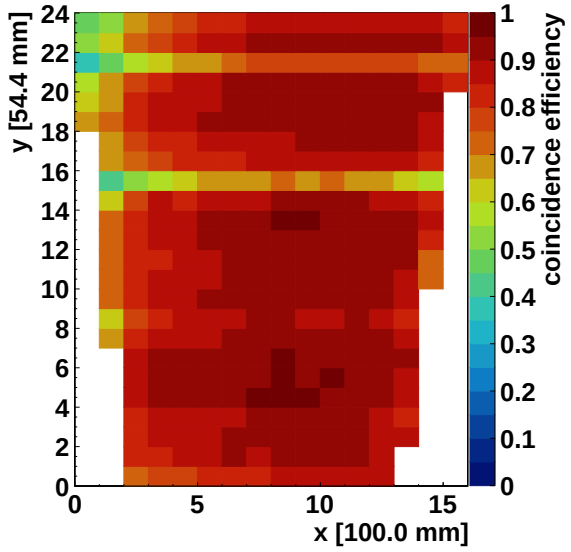



# Efficiency influenced by Pulse Height

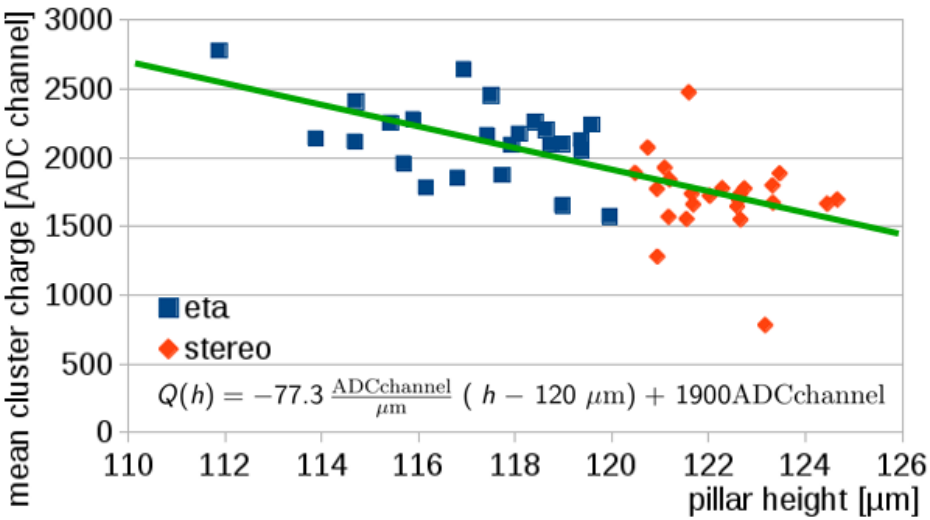
pulse height map - m12, eta in

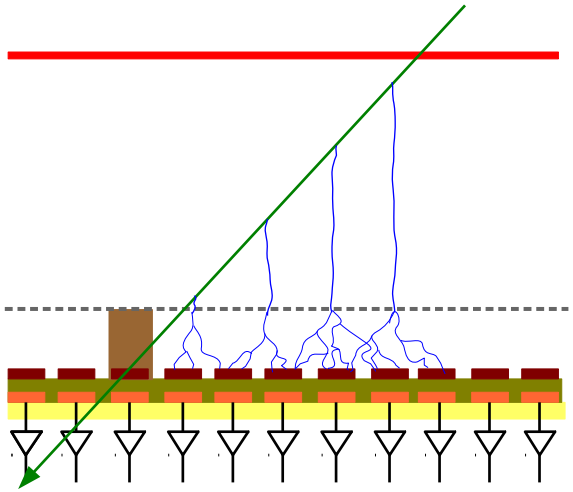



efficiency map - m12, eta in

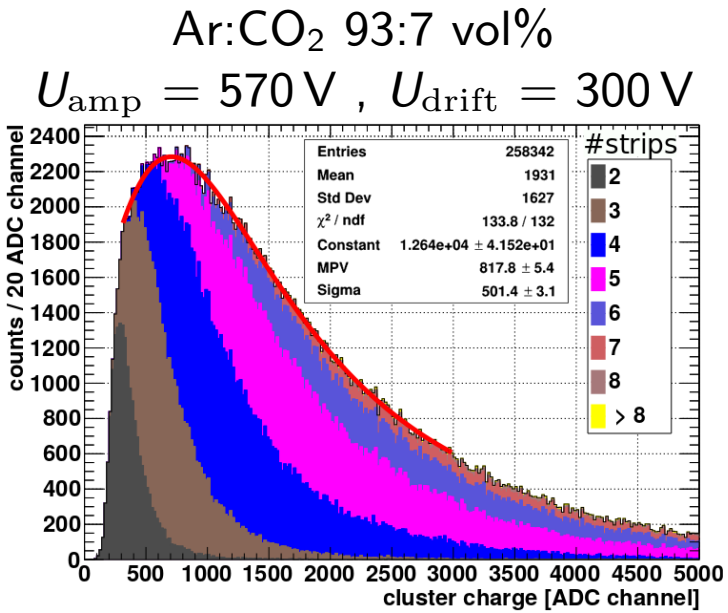


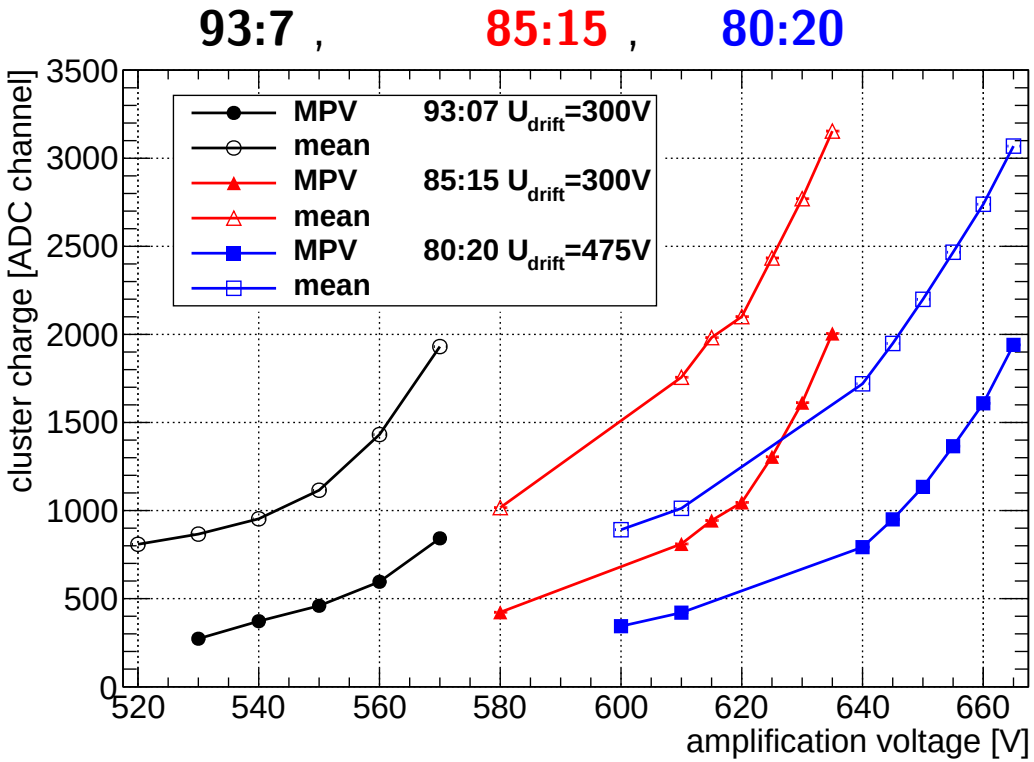

mean pulse height VS pillar height



# Cluster Charge Evaluation - M8 eta-out (=L1) board 8



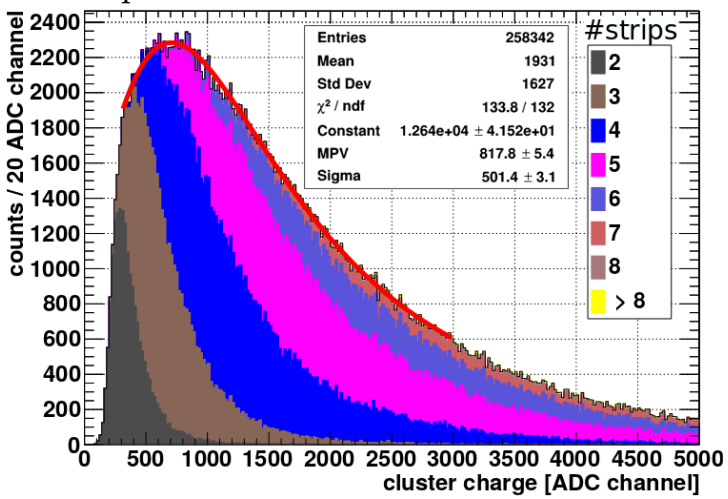

$\Rightarrow$ for higher fractions of $CO_2$, larger gains ($\sim$ efficiency) can be reached

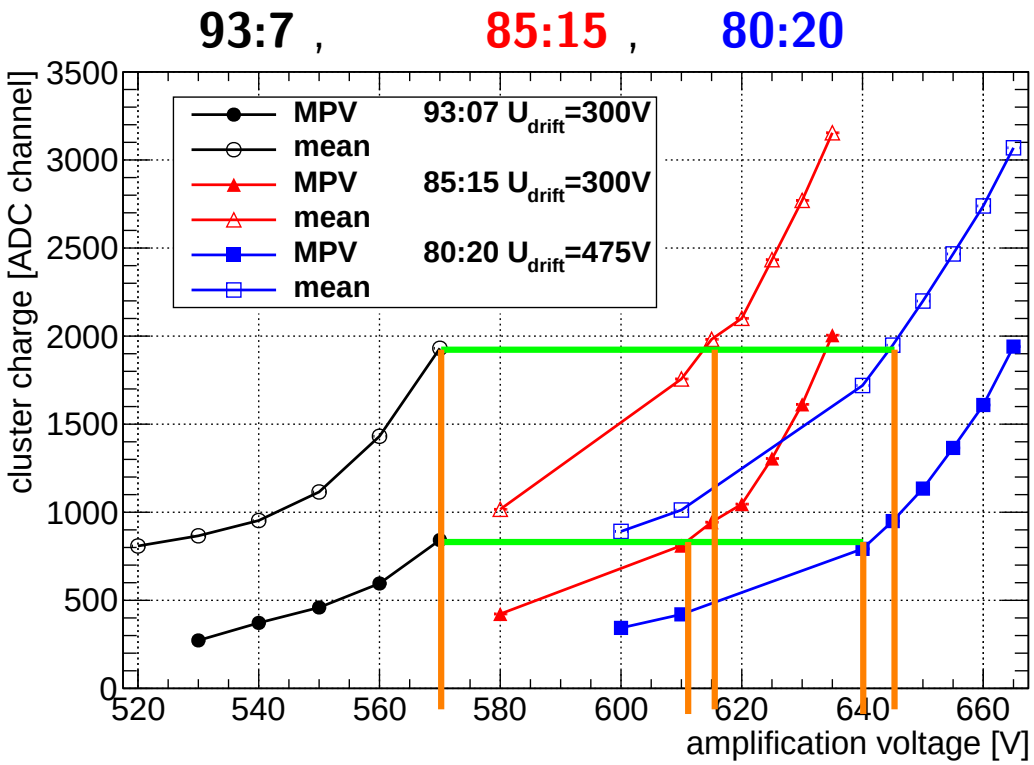
dependence on board quality (e.g. pillar height)?

$\Rightarrow$ compare voltages at same pulse height

| [V] | 93:7 | 85:15 | 80:20 |
|---|---|---|---|
| mean | 570 | 615 | 645 |
| MPV | 570 | 610 | 640 |

# Cluster Charge Evaluation - M8 eta-out (=L1) board 8




⇒ for higher fractions of $CO_2$, larger gains ($\sim$ efficiency) can be reached

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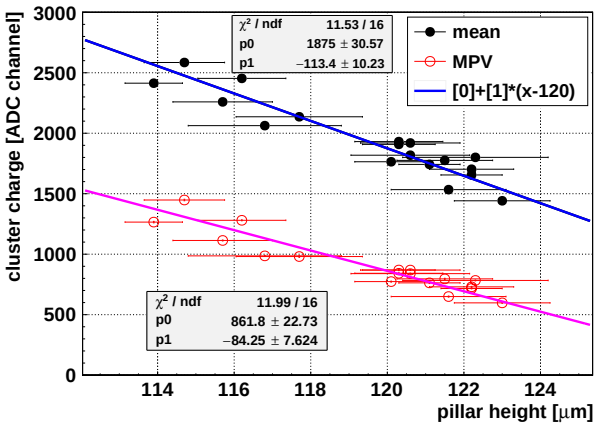
⇒ compare voltages at same pulse height

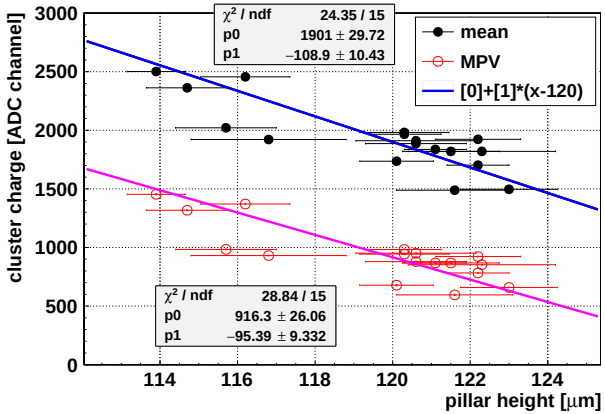
| [V] | 93:7 | 85:15 | 80:20 |
|---|---|---|---|
| mean | 570 | 615 | 645 |
| MPV | 570 | 610 | 640 |

# Pulse Height Dependence on Pillar Height (M8 , eta3)

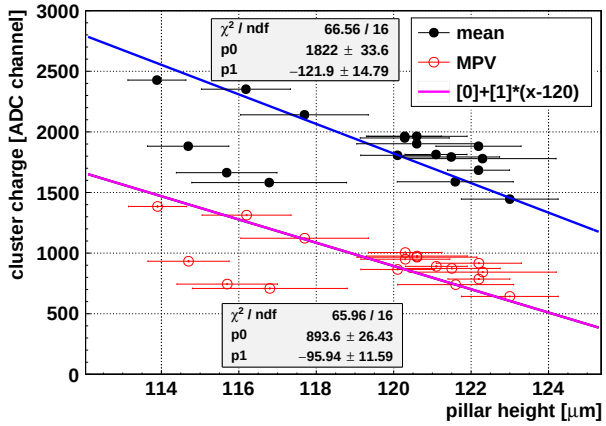
Ar:$CO_2$ **93:7** vol%
$U_{\mathrm{amp}} = 570\,\mathrm{V}$
$U_{\mathrm{drift}} = 300\,\mathrm{V}$




Ar:$CO_2$ **85:15** vol%
$U_{\mathrm{amp}} = 615\,\mathrm{V}$
$U_{\mathrm{drift}} = 300\,\mathrm{V}$



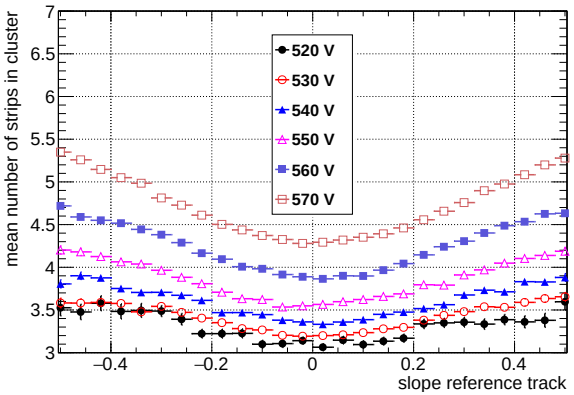

Ar:$CO_2$ **80:20** vol%
$U_{\mathrm{amp}} = 645\,\mathrm{V}$
$U_{\mathrm{drift}} = 475\,\mathrm{V}$

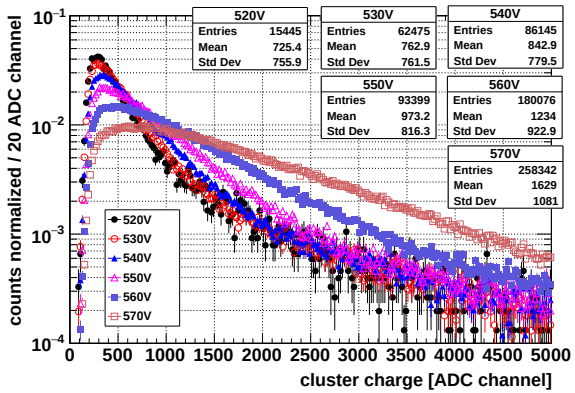



| Ar:$CO_2$ vol% | **93:7** | **85:15** | **80:20** |
|---|---|---|---|
| mean %/μm | -(6.0±0.6) | -(5.7±0.6) | -(6.7±0.8) |
| MPV %/μm | -(9.8±1.0) | -(10.4±1.1) | -(10.7±1.1) |

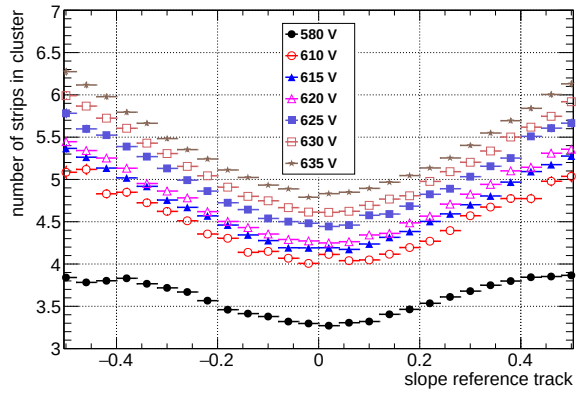
# Cluster Properties (M8, eta-out, board 8)

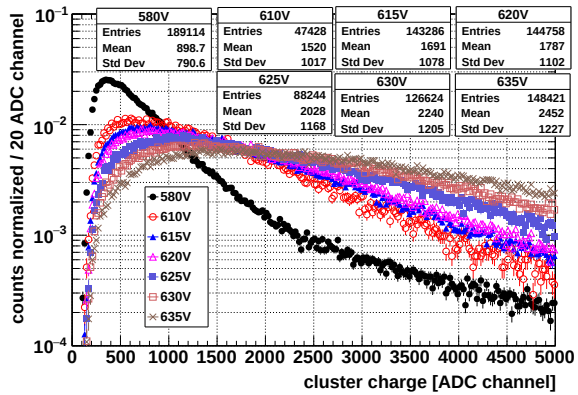
Ar:$CO_2$ **93:7** vol%
$U_{\mathrm{drift}} = 300\,\mathrm{V}$



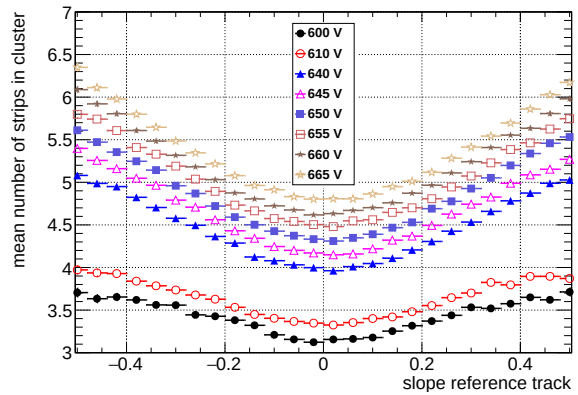



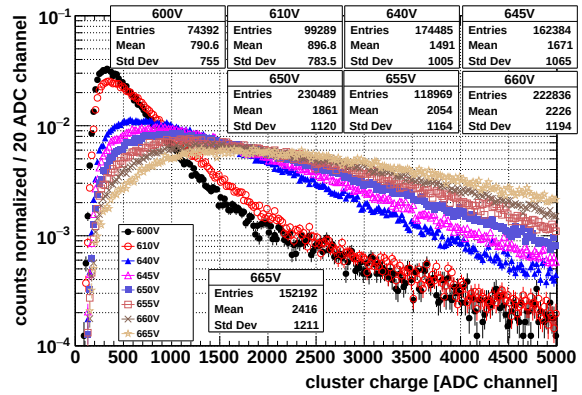

Ar:$CO_2$ **85:15** vol%
$U_{\mathrm{drift}} = 300\,\mathrm{V}$




Ar:$CO_2$ **80:20** vol%
$U_{\mathrm{drift}} = 475\,\mathrm{V}$

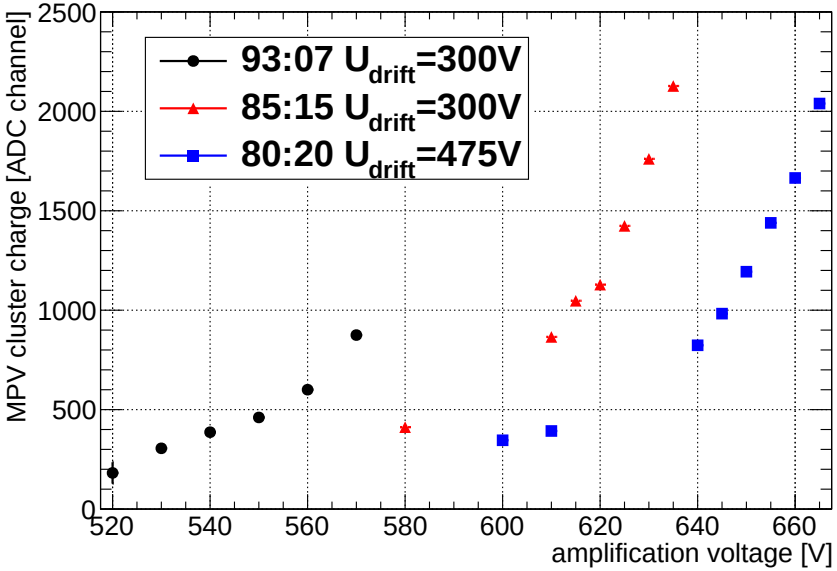


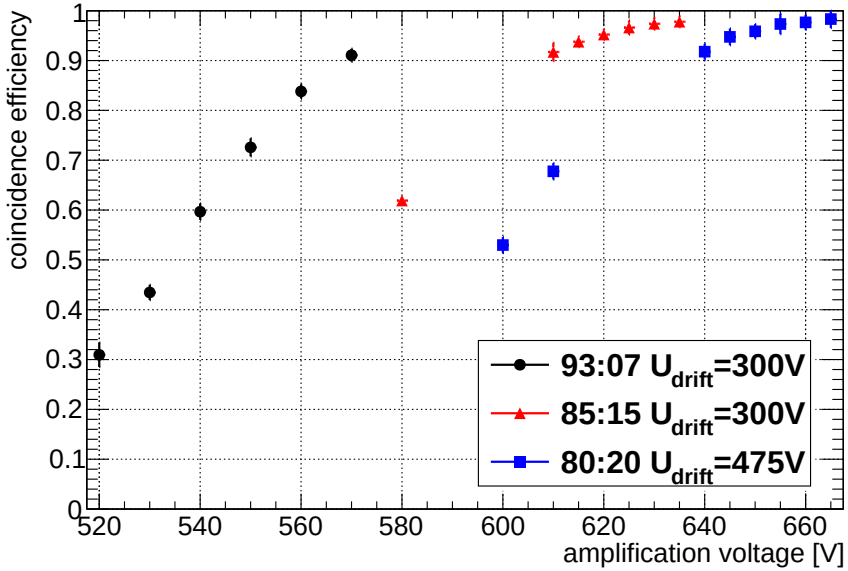
# Efficiency Dependence on Cluster Charge (M8, eta-out = L1)

amplification scan (HV sector L7)

MPV cluster charge



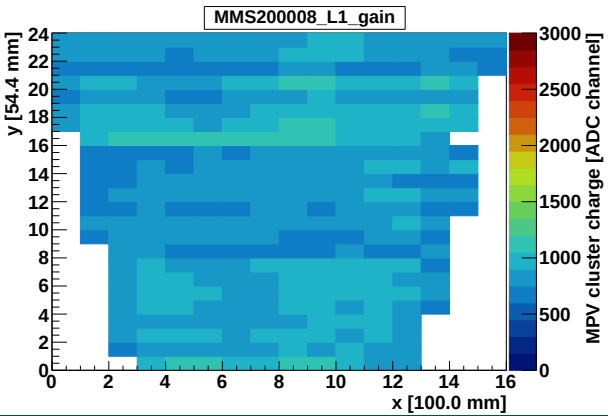

coincidence efficiency




Ar:$CO_2$ **93:7** vol%

$U_{\mathrm{amp}} = 570\,\mathrm{V}$

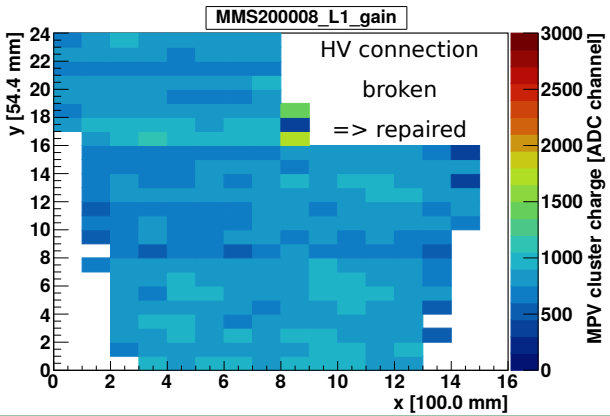
$U_{\mathrm{drift}} = 300\,\mathrm{V}$




Ar:$CO_2$ **85:15** vol%

$U_{\mathrm{amp}} = 610\,\mathrm{V}$

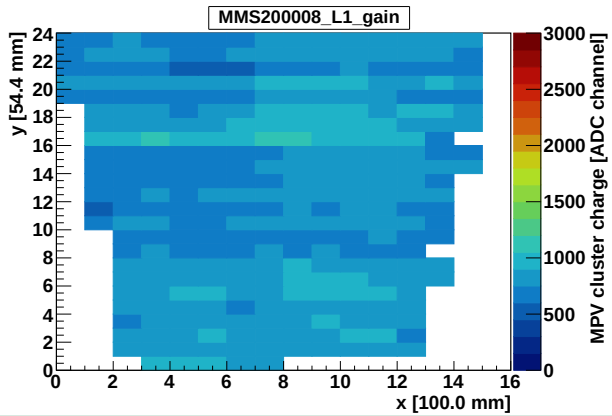
$U_{\mathrm{drift}} = 300\,\mathrm{V}$




Ar:$CO_2$ **80:20** vol%

$U_{\mathrm{amp}} = 640\,\mathrm{V}$

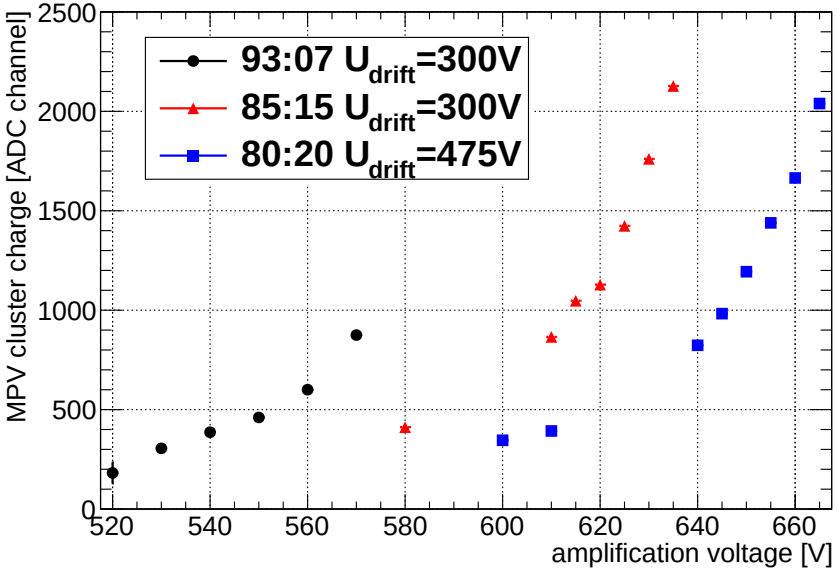
$U_{\mathrm{drift}} = 475\,\mathrm{V}$



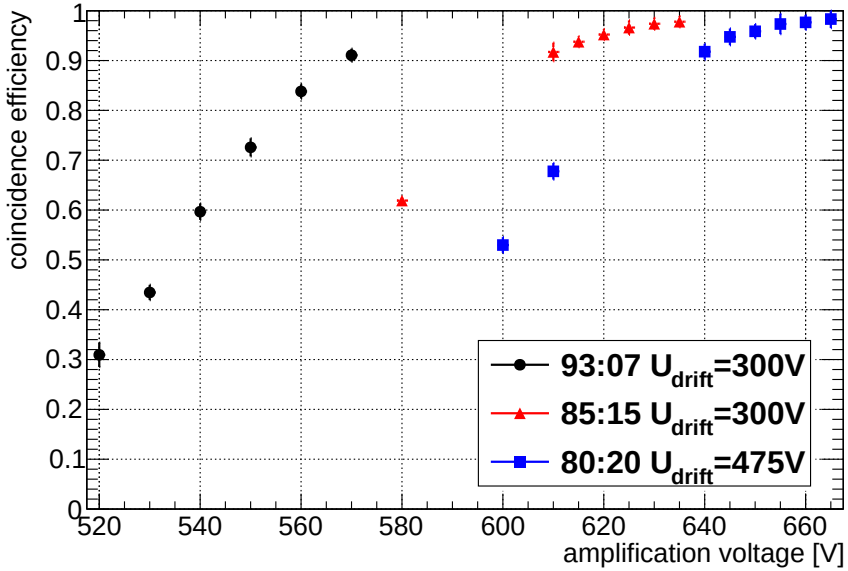
# Efficiency Dependence on Cluster Charge (M8, eta-out = L1)

amplification scan (HV sector L7)

MPV cluster charge



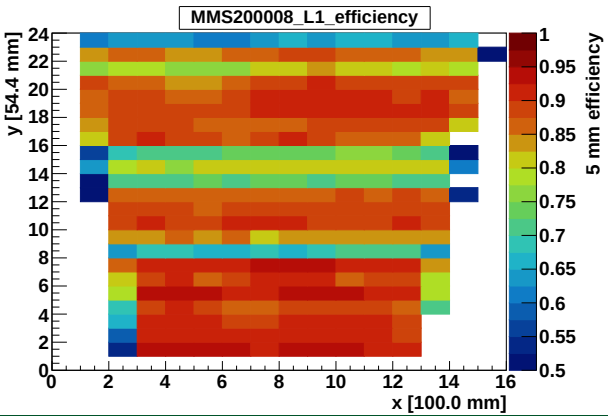

coincidence efficiency




Ar:$CO_2$ **93:7** vol%

$U_{\mathrm{amp}} = 570\,\mathrm{V}$

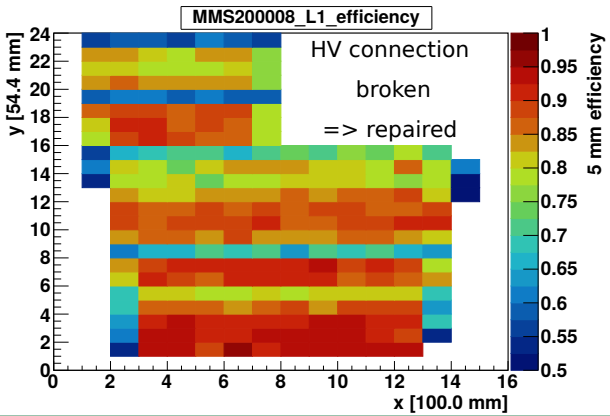
$U_{\mathrm{drift}} = 300\,\mathrm{V}$




Ar:$CO_2$ **85:15** vol%

$U_{\mathrm{amp}} = 610\,\mathrm{V}$

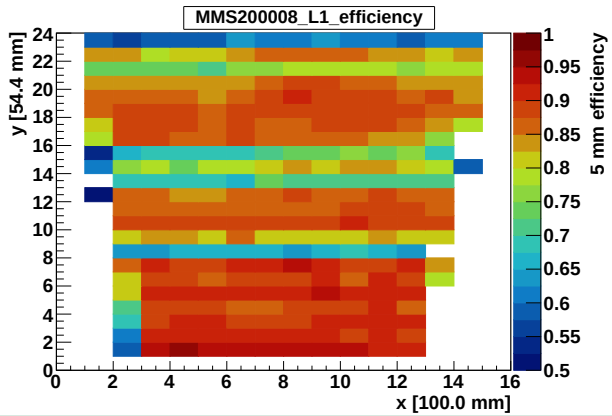
$U_{\mathrm{drift}} = 300\,\mathrm{V}$




Ar:$CO_2$ **80:20** vol%

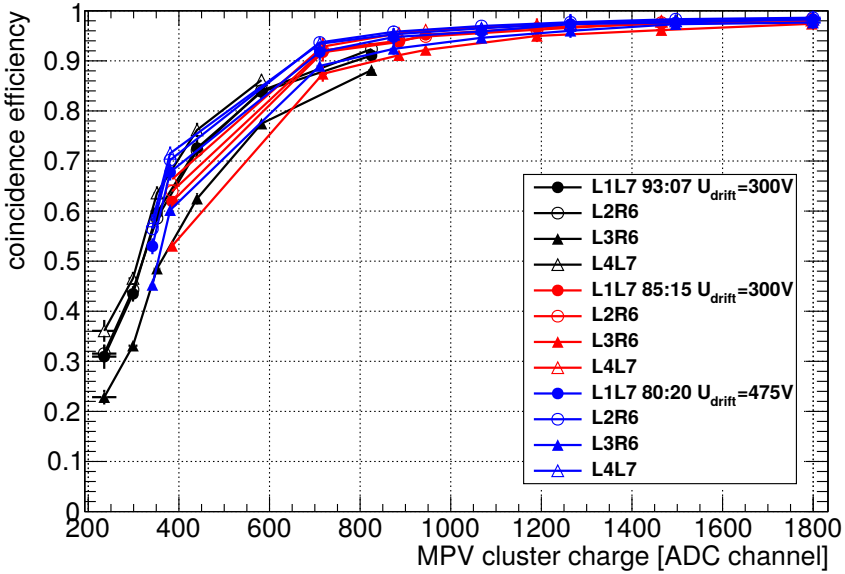
$U_{\mathrm{amp}} = 640\,\mathrm{V}$

$U_{\mathrm{drift}} = 475\,\mathrm{V}$

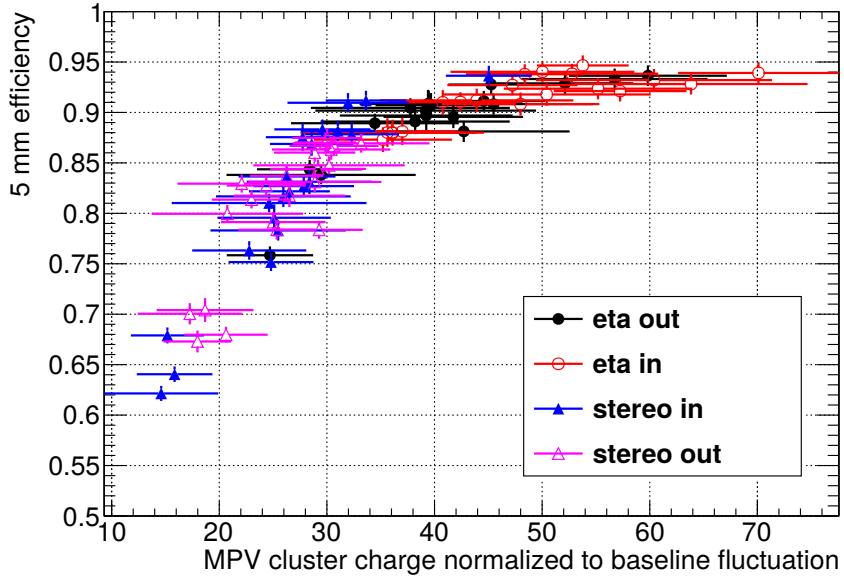


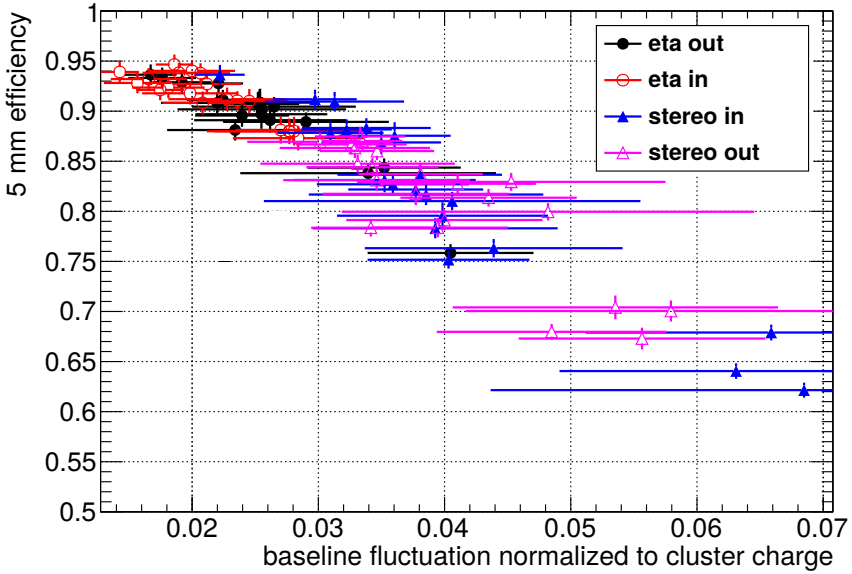
# Efficiency Dependence on Pulse Height and Noise

Gas Study with Module 8



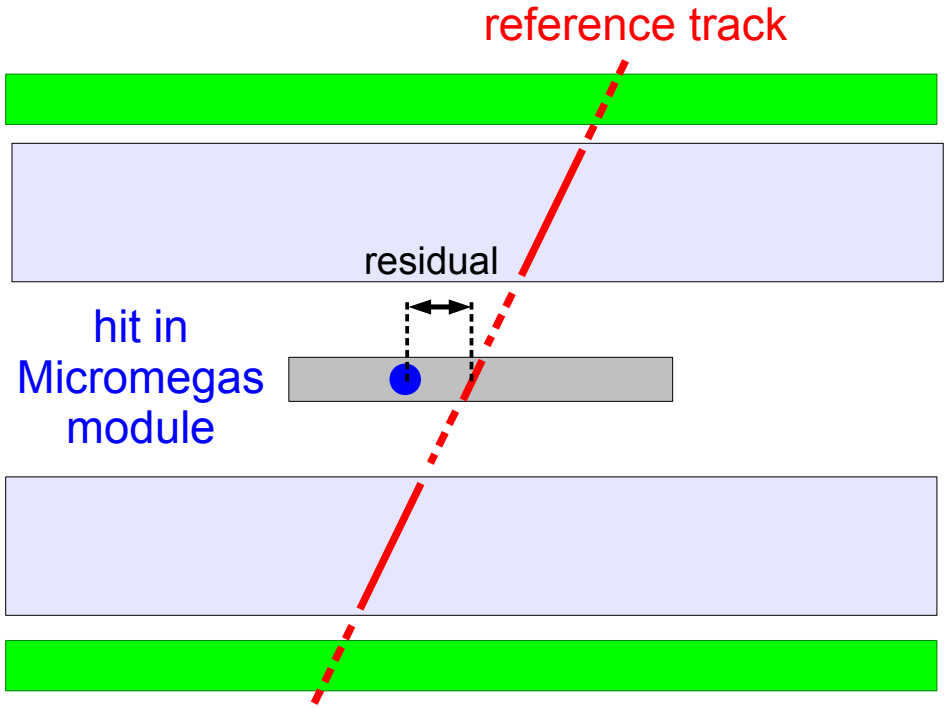

Noise Study with Module 7




- all gas-mixtures show a similar behavior
- for 90%-efficiency ⇒
  MPV of pulse-height has to exceed about 40 times the noise-level
- vice versa:
  noise should be kept below a 2%-level of pulse-height to reach 90%-efficiency

# Tracking in the Cosmic Ray Facility

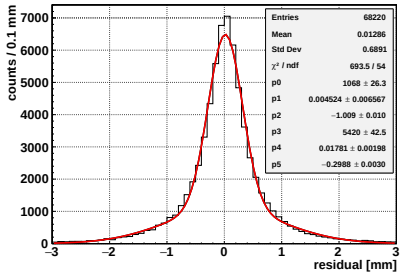




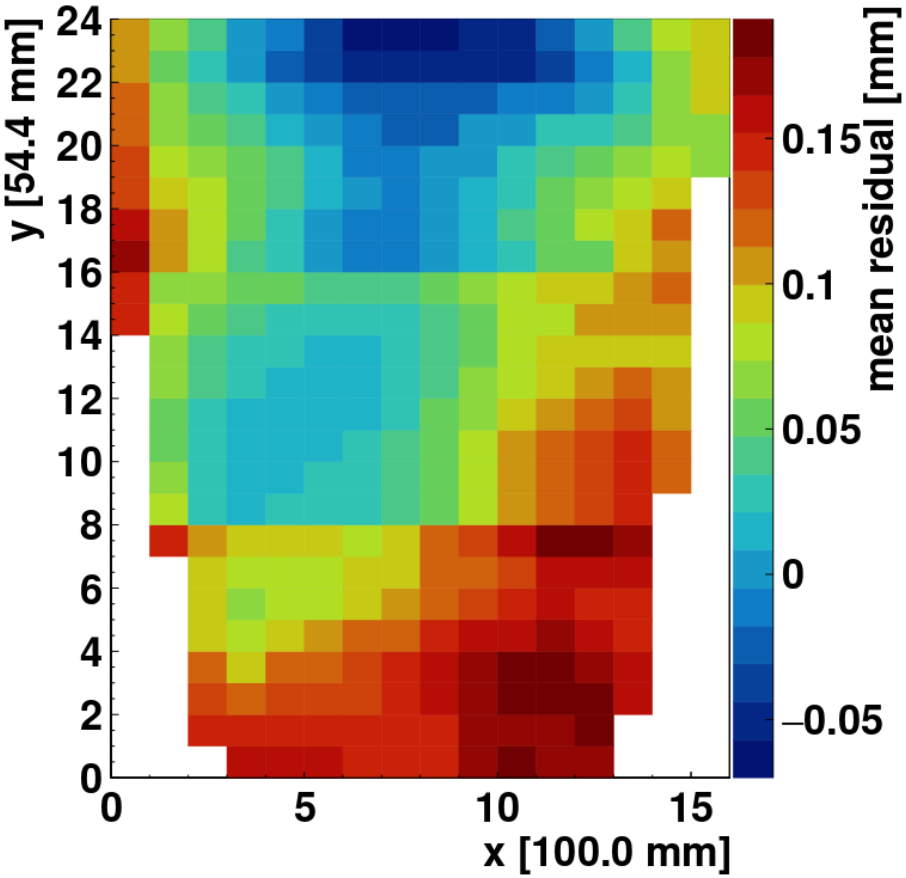
$$\text{residual} = \text{measured} - \text{reference}$$

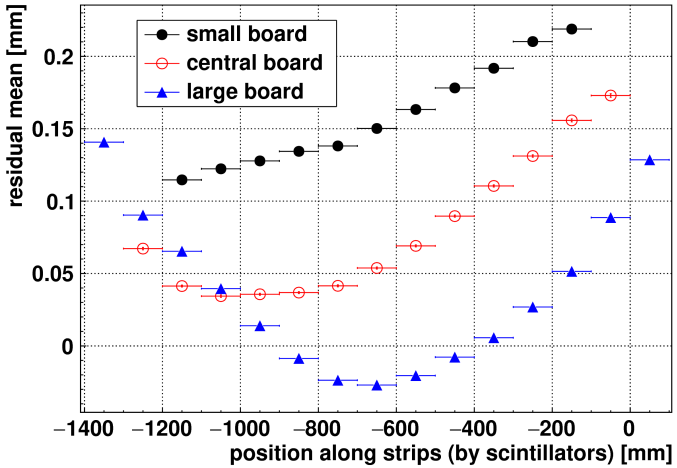
$$= \text{centroid} \times \text{pitch} - \text{track}_{\text{MDTs}} \text{ @ MM}$$

# Reconstruction of Readout Board Alignment (Module 1, eta-in)

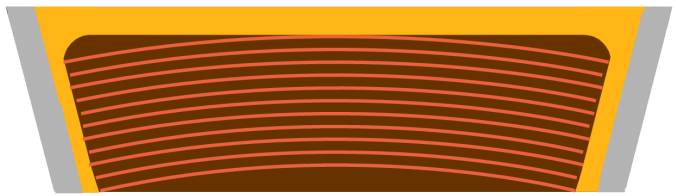



$\Rightarrow$ mean residual



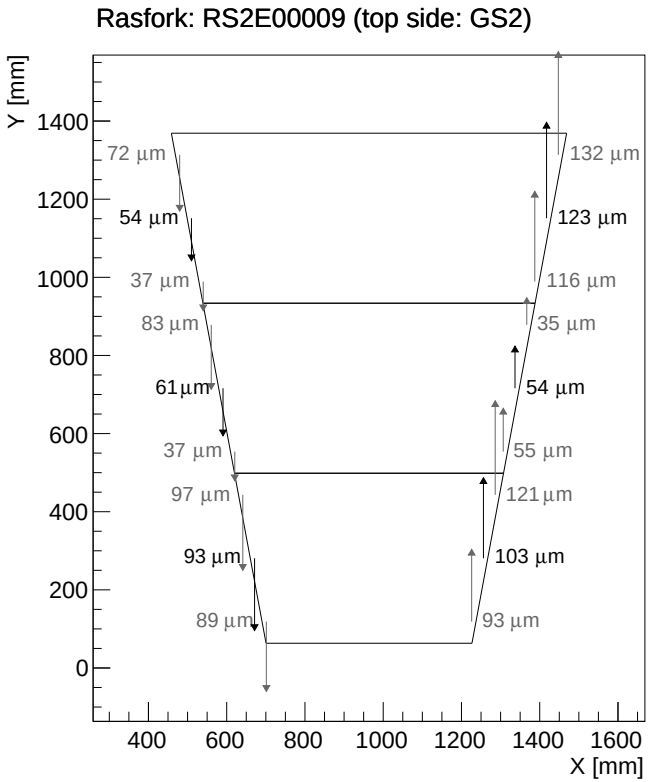

undesired strip shape
$\Rightarrow$ calibration needed



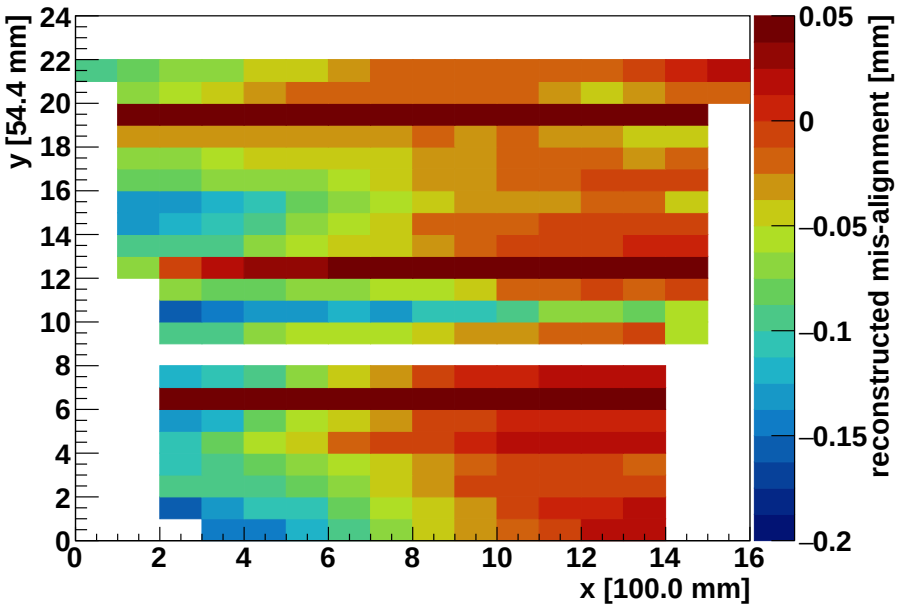
humidity causes
deviation from design:
$\Rightarrow$ known issue

# Alignment Reconstruction Comparison (eta-panel 9)

Rasfork measurement



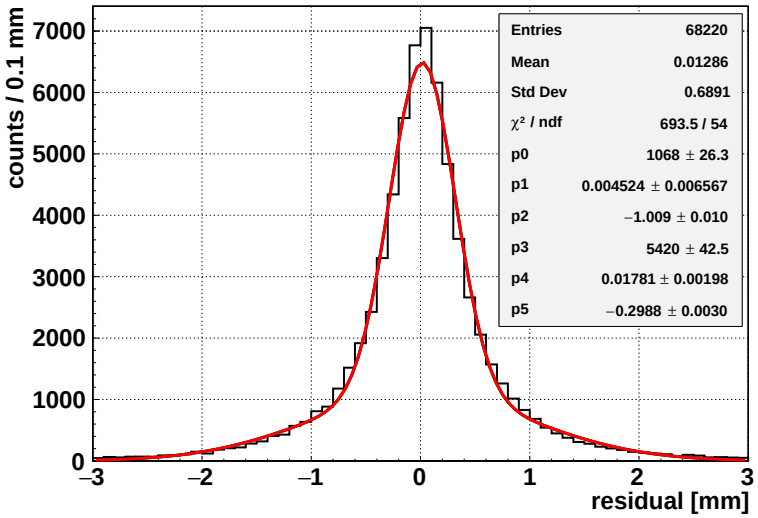

mean hit-position-difference between eta-layers



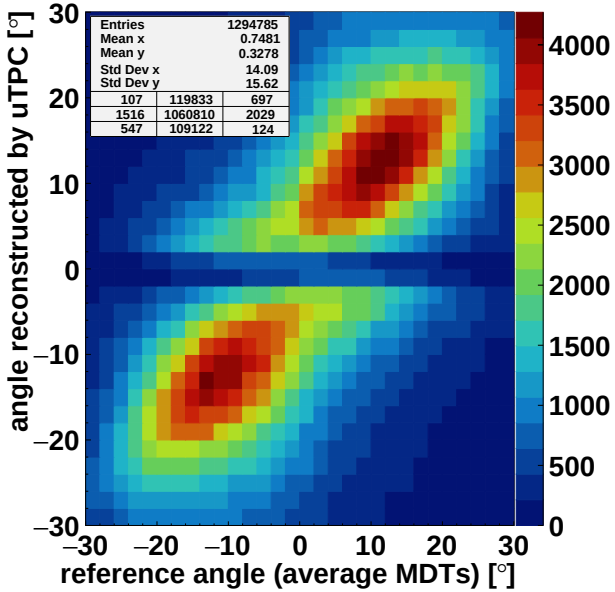

$\Rightarrow$ rotation between layers reconstructable in both measurements

# Position Reconstruction using Charge and Drift-Time Measurements (M1)

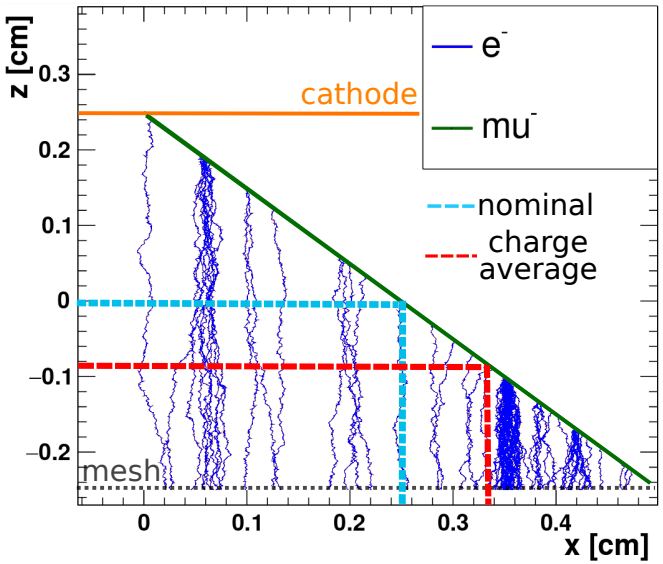
## residual normal tracks



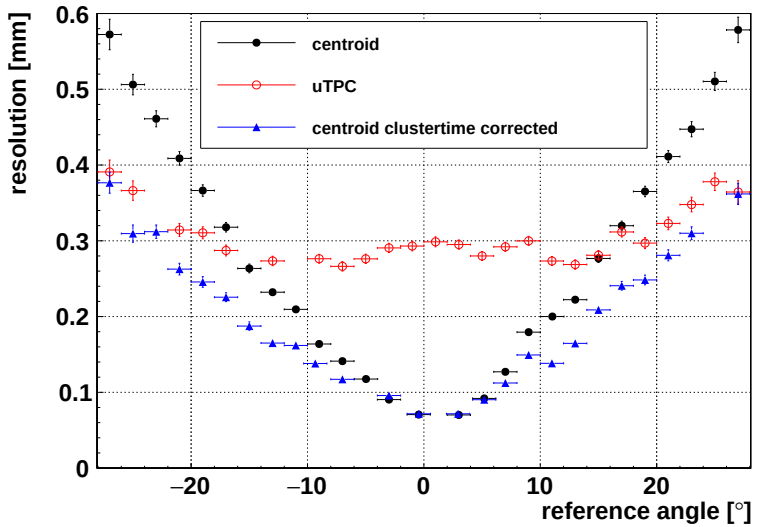

## angle reconstruction



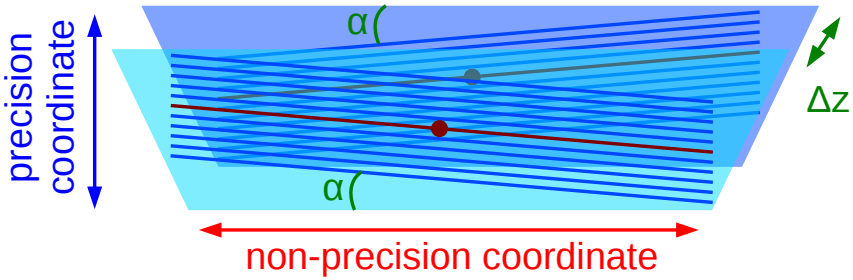

## simulation




## resolution VS angle



# Position Reconstruction using two Layers of Inclined Strips




precision

= stereos mean / tan $\alpha$

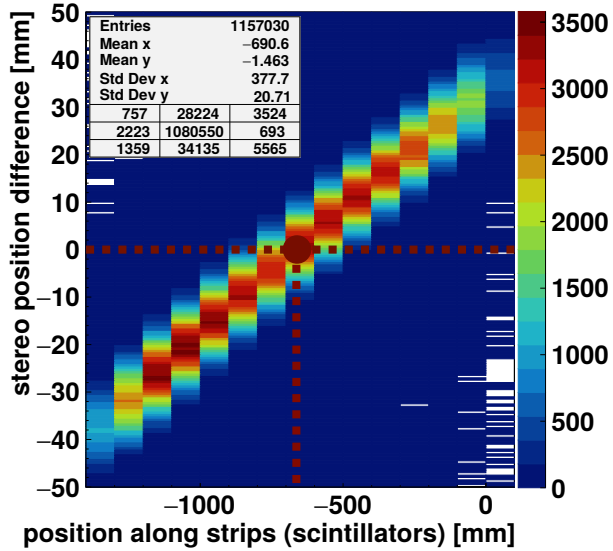
non-precision

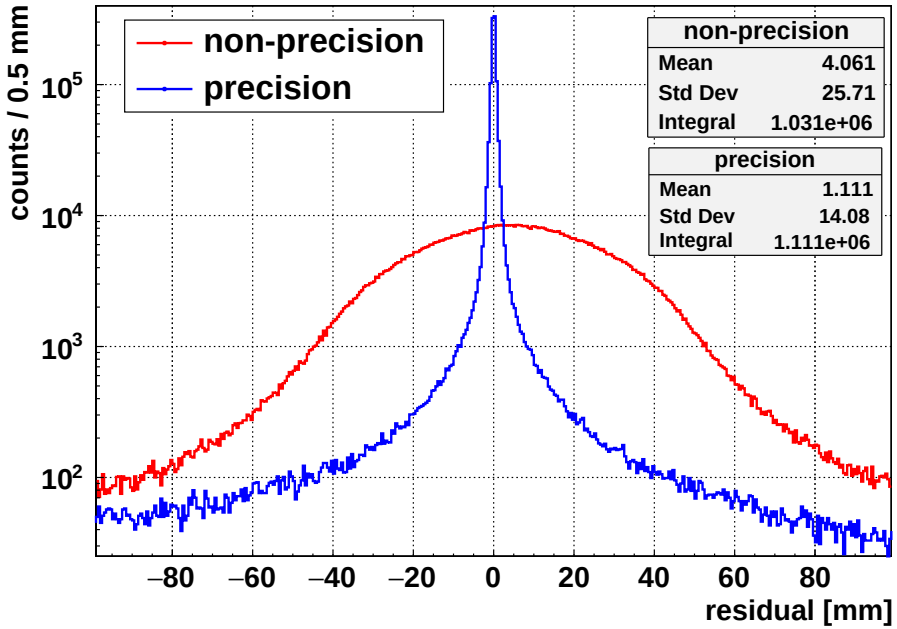
= stereos difference / 2 / tan $\alpha$

$\Rightarrow$ alignment

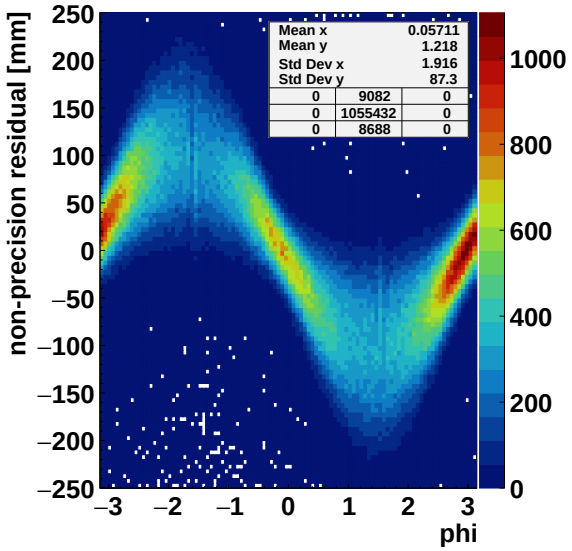
non-precision coordinate

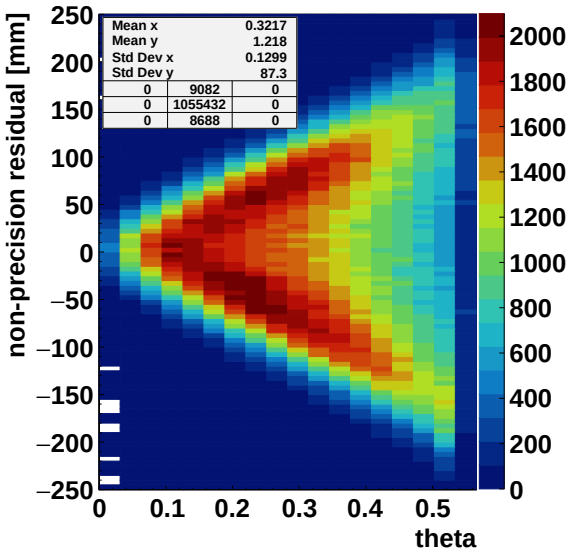
$\Rightarrow$ non-precision residual spoiled by coarse scintillator resolution

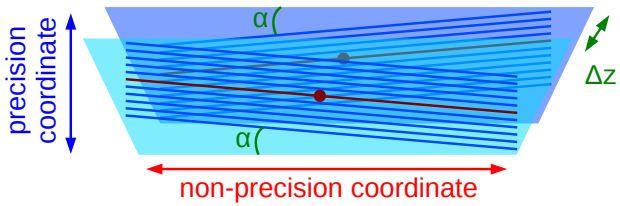


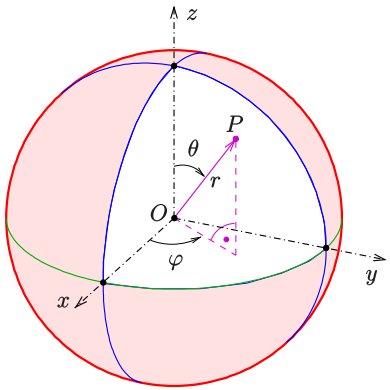



# Stereo-Reconstruction Dependencies on Track-Inclination




precision $=$ mean $/ \cos\alpha$

non-precision $=$ difference $/\ 2\ / \sin\alpha$

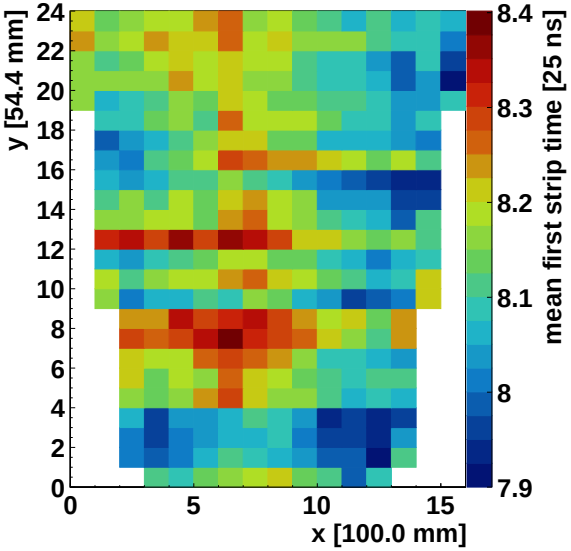
track-inclination-correction :

$$-\frac{1}{2\tan\alpha} \cdot \triangle z \cdot \tan\Theta \cdot \sin\Phi$$

# Timing Resolution

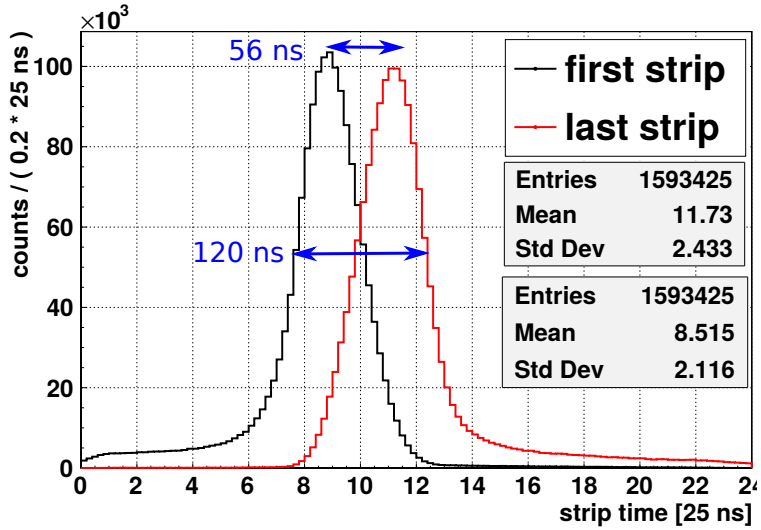
M11, eta-in

$U_{\mathrm{amp}} = 570\,\mathrm{V}$ , $U_{\mathrm{drift}} = 300\,\mathrm{V}$



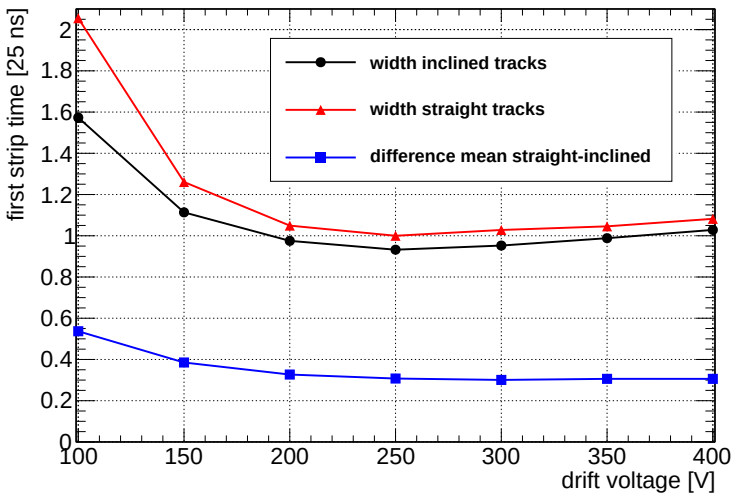

M1, eta-in

$U_{\mathrm{amp}} = 570\,\mathrm{V}$ , $U_{\mathrm{drift}} = 300\,\mathrm{V}$

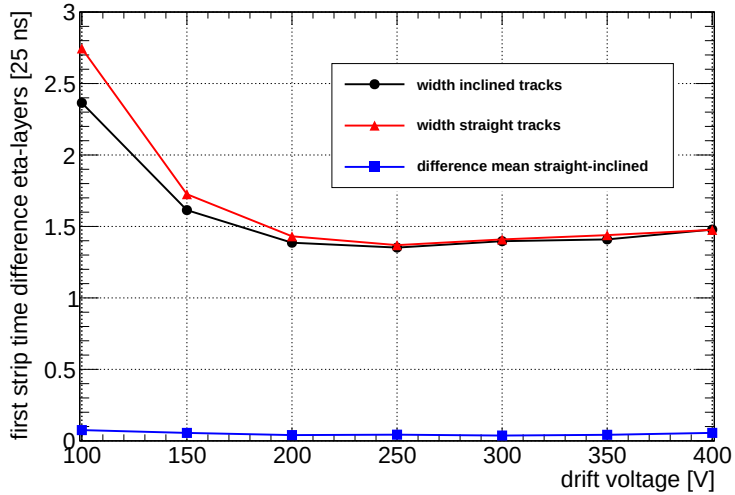



module 3 , board 7

single layer first-strip time-width (eta-in)




eta-layers first-strips time-difference



# Summary

- about 13 SM2-Micromegas investigated in the Cosmic Ray Facility
- efficiency influenced by
  - noise behavior of preliminary APV25-electronics
    local setup : 30 - 40 ADC channel
  - pulse-height coupled to amplification-gap-height
    MPV : -10%/µm

  $\Rightarrow$ MPV of pulse-height has to exceed

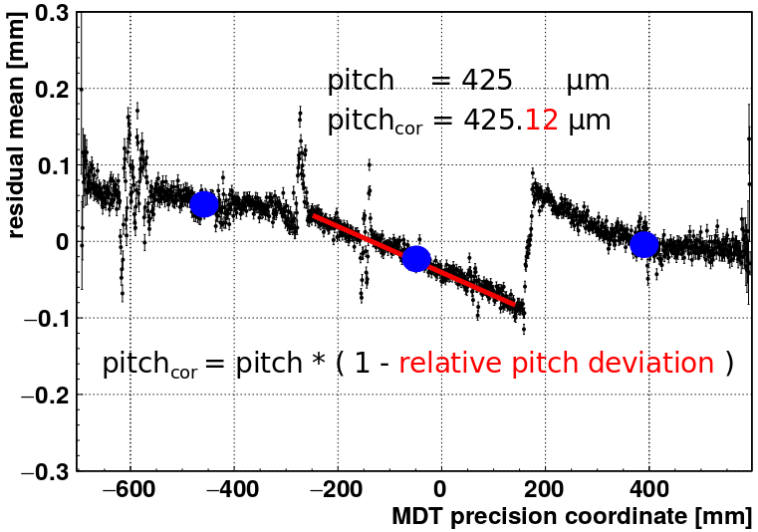
  40 times noise-level to reach

  90%-efficiency
- reference-tracking enables
  - alignment-reconstruction
    $\Rightarrow$ calibration of deviations
  - resolution estimation
    $\Rightarrow$ centroid similar results as testbeam
  - position-reconstruction using inclined strip-layers works as intended

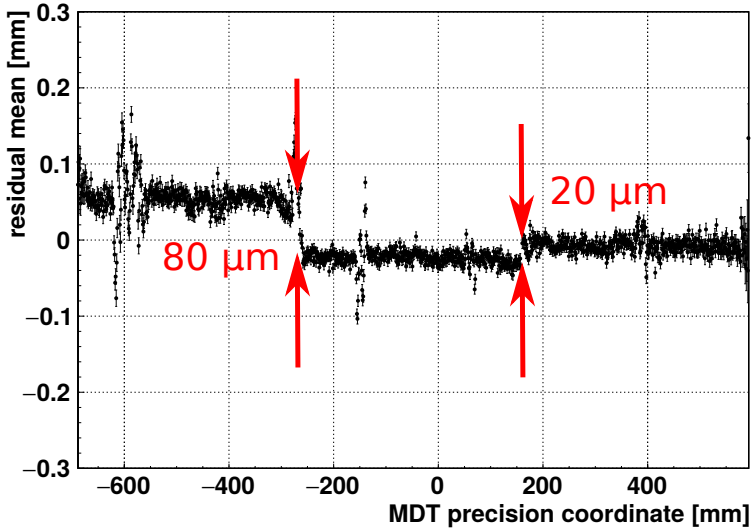
# Backup

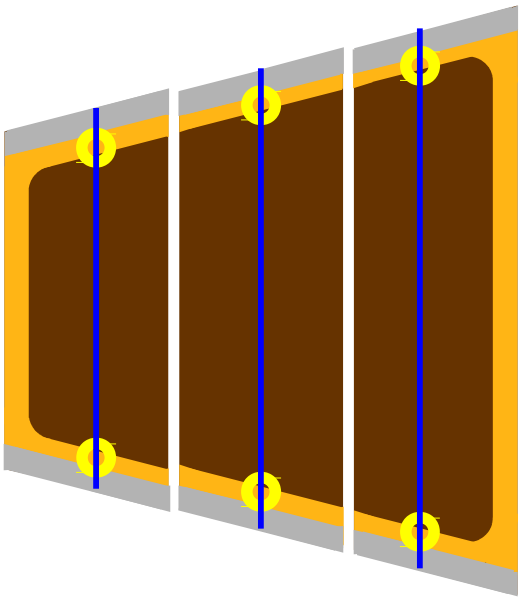
# Reconstruction of Pitch Deviations and Readout Board Alignment

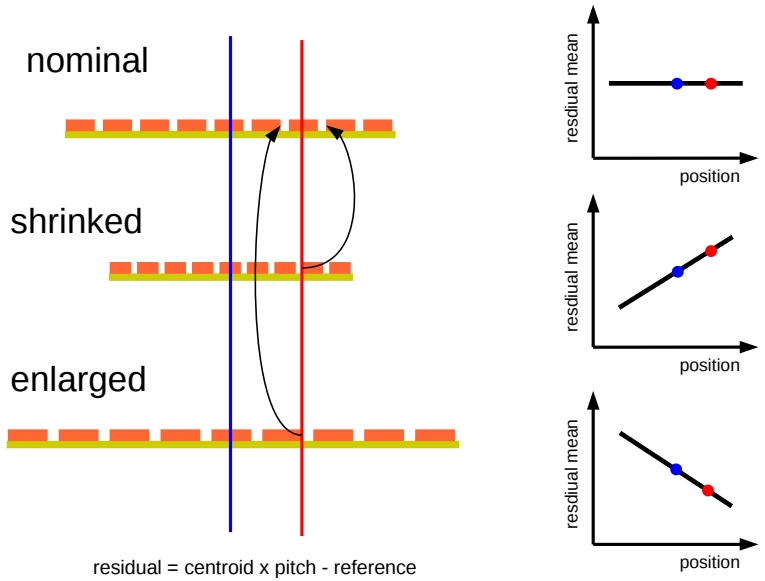
## without correction




## pitch deviation considered





# Gain Dependencies

$$G = \exp(\alpha \cdot d)$$

$$= \exp\left[ \frac{Apd}{T} \cdot \exp\left( -\frac{Bpd}{TU} \right) \right].$$

Taylor-series-expansion up to first order:

$$G(d) = \exp\left(a \cdot d_0 \cdot e^{-b \cdot d_0}\right) + a \cdot (1 - b \cdot d_0) \cdot \exp\left(-b \cdot d_0 + a \cdot d_0 \cdot e^{-b \cdot d_0}\right) \cdot (d - d_0) + \mathcal{O}\left((d - d_0)^2\right) \quad ,$$

where

$$a = \frac{A \cdot p}{T} \quad \text{and} \quad b = \frac{B \cdot p}{T \cdot U} \quad .$$