SM2 Micromegas Gas Studies in the LMU Cosmic Ray Facility

Maximilian Herrmann

Ludwig-Maximilians-Universität München - Lehrstuhl Schaile

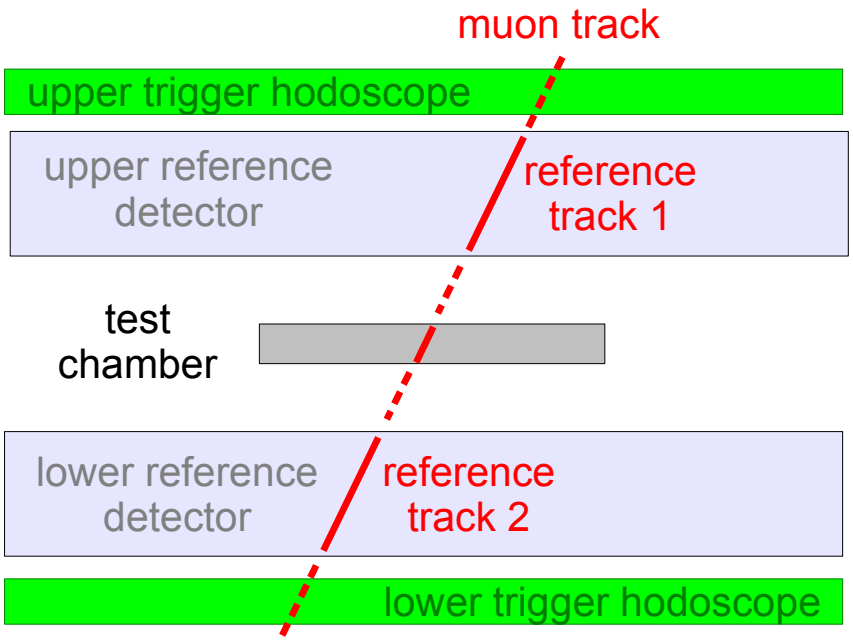
Muon Week 02.07.2019

LMU LUDWIG-MAXIMILIANS-UNIVERSITÄT MÜNCHEN

Bundesministerium für Bildung und Forschung

Outline

Cosmic Ray Facility

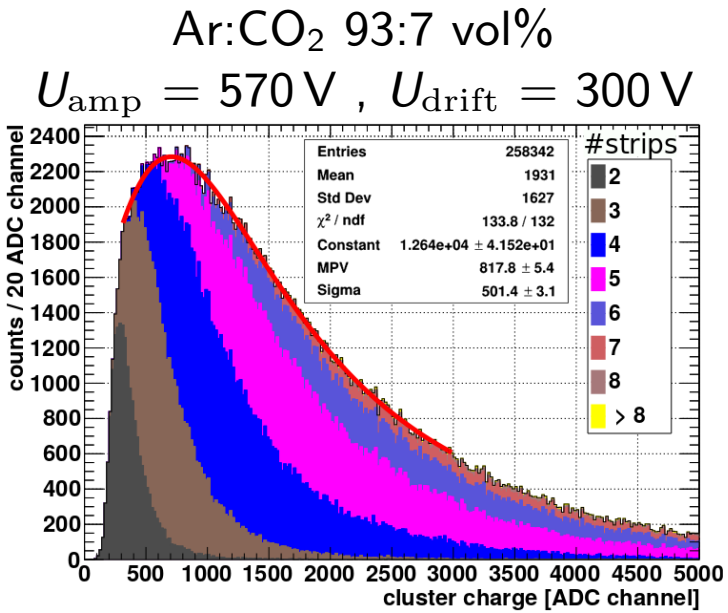


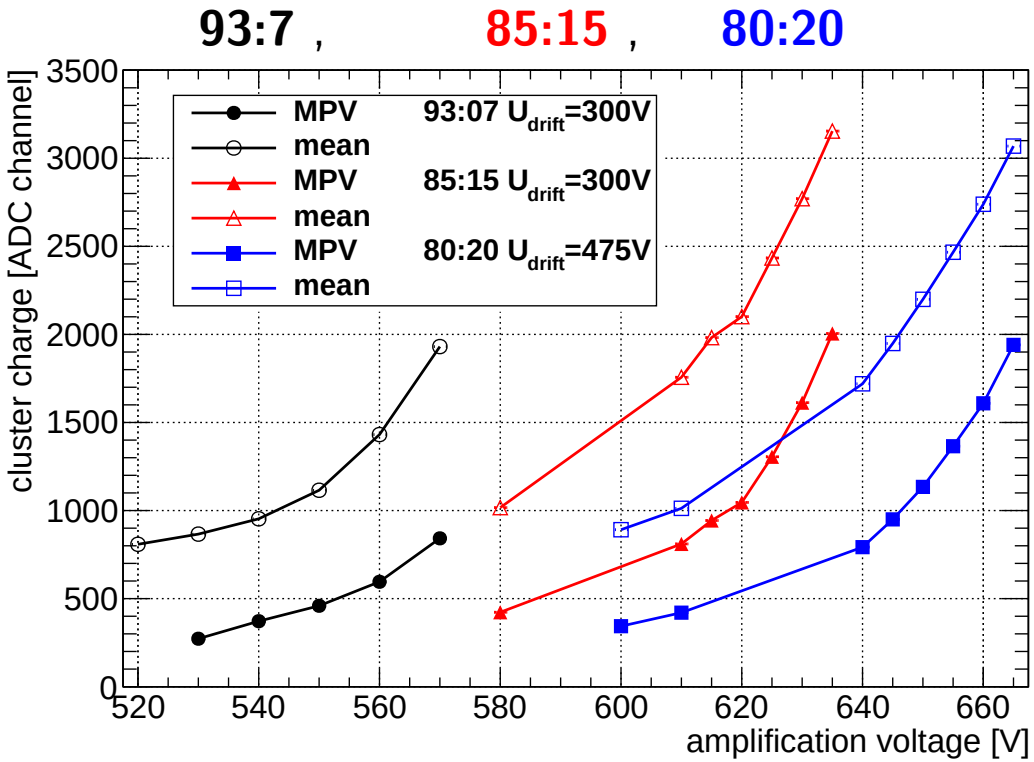
trigger	scintillator hodoscope
track reconstruction	2 × Monitored Drift Tube chambers (MDTs)
active area	2.2 m × 4 m
angular acceptance	± 30°
energy cut	iron absorber (32 cm)
readout (full SM2)	12288 channels
	→ 96 APVs (frontend electronics)
	→ 6 FECs (scalable readout system)
readout rate	100 Hz (online zerosuppression)
	→ 70 Hz for 1.5 Modules

Measurement Overview - M8 & eta3 doublet

Ar:CO_2 93:7 vol%				Ar:CO_2 85:15 vol%				Ar:CO_2 80:20 vol%			
date	trig. 10^6	U_{amp} [V]	U_{drift} [V]	date	trig. 10^6	U_{amp} [V]	U_{drift} [V]	date	trig. 10^6	U_{amp} [V]	U_{drift} [V]
28.05.	4.8	570	300	16.05.	4.9	620	300	23.05.	3.2	640	475
29.05.	3.8	560	300	17.05.	3.9	625	300	24.05.	2.8	645	475
30.05.	2.2	570	300	17.05.	3.9	630	300	24.05.	4.0	650	475
30.05.	2.4	550	300	18.05.	4.7	635	300	25.05.	1.9	655	475
30.05.	2.9	540	300	19.05.	5.3	615	300	25.05.	3.7	660	475
31.05.	2.8	530	300	20.05.	1.8	610	300	26.05.	1.9	665	475
31.05.	n.a.	520	300	20.05.	5.4	580	300	26.05.	2.4	600	475
				21.05.	3.4	620	380	27.05.	2.7	610	475
				22.05.	2.5	635	380				
				22.05.	2.8	635	450				

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





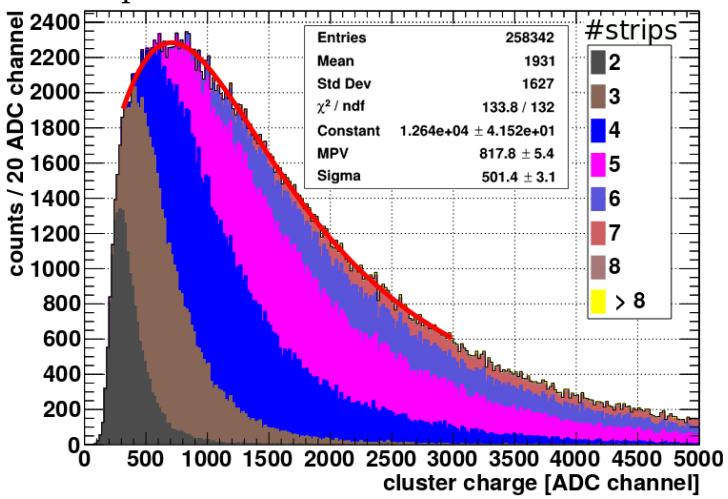
$\Rightarrow$ for higher fractions of CO_2, larger gains ($\sim$ efficiency) can be reached

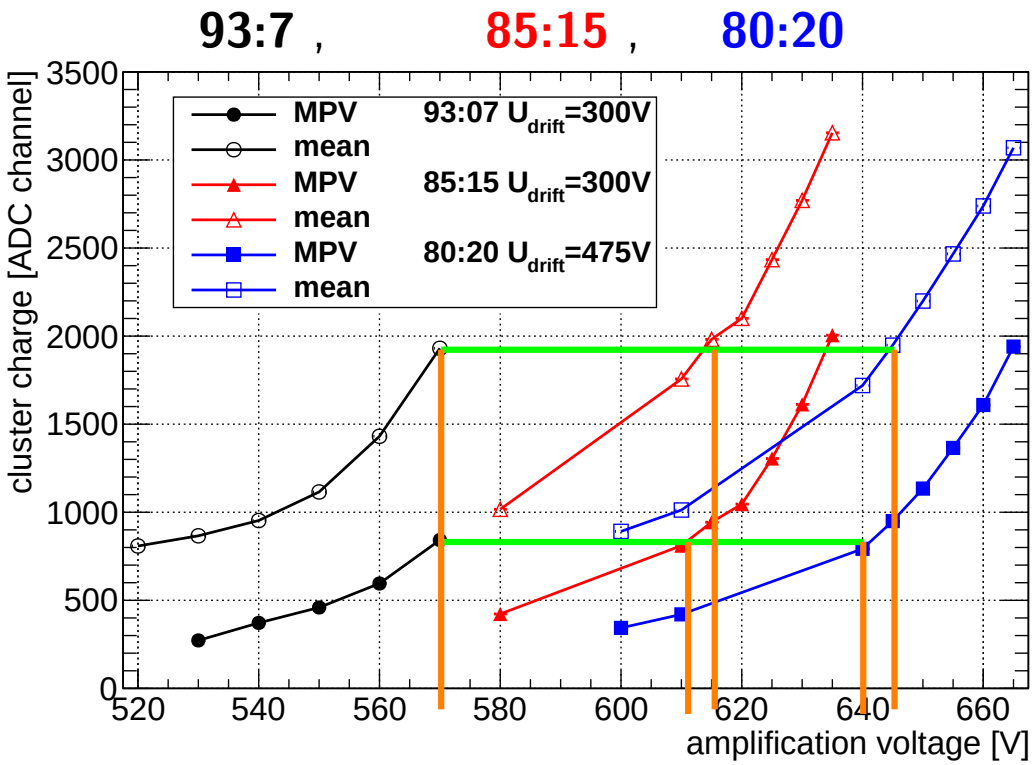
dependence on board quality (e.g. pillar height)?

$\Rightarrow$ 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

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

⇒ compare voltages at same pulse height

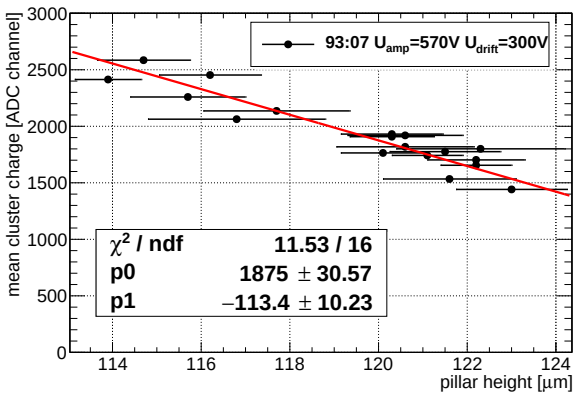
[V]	93:7	85:15	80:20
mean	570	615	645
MPV	570	610	640

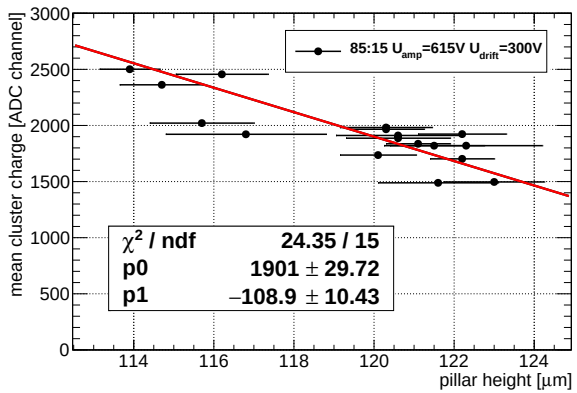
Cluster Charge Dependence on Pillar Height

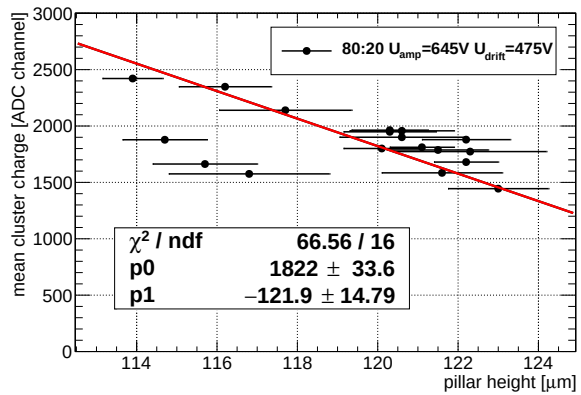
pillar heights measured at CERN (mean and std. dev.)

$\Rightarrow$ correlate at equal efficiency ($\approx 90\%$)
mean pulse height and pillar height

Ar:CO_2 **93:7** vol%	Ar:CO_2 **85:15** vol%	Ar:CO_2 **80:20** vol%
$U_{\mathrm{amp}} = 570\,\mathrm{V}$	$U_{\mathrm{amp}} = 615\,\mathrm{V}$	$U_{\mathrm{amp}} = 645\,\mathrm{V}$
$U_{\mathrm{drift}} = 300\,\mathrm{V}$	$U_{\mathrm{drift}} = 300\,\mathrm{V}$	$U_{\mathrm{drift}} = 475\,\mathrm{V}$





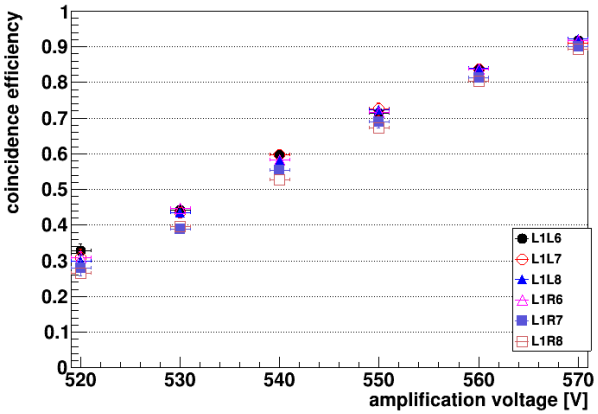


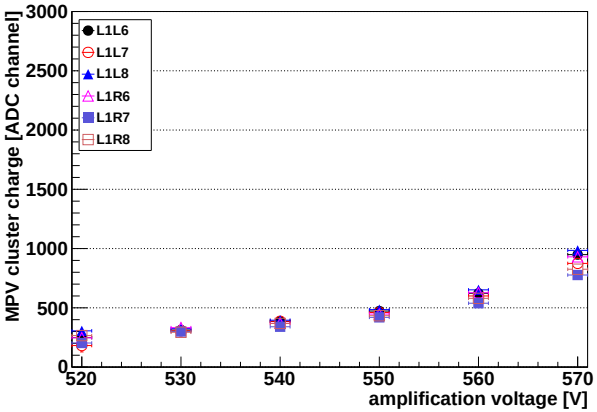
$\Rightarrow$ mean pulse height change per increased pillar size

-(6.0±0.6)%/µm	-(5.7±0.6)%/µm	-(6.7±0.8)%/µm

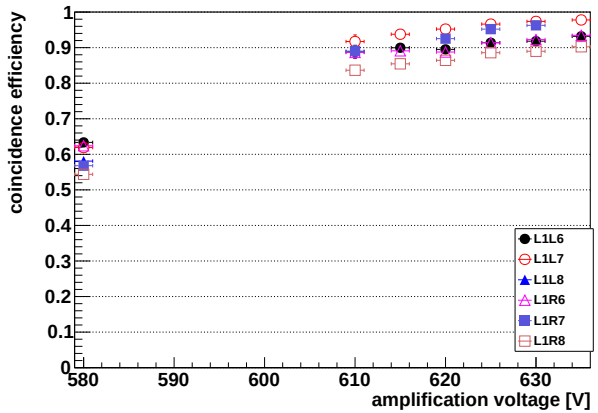
Efficiency Dependence on Cluster Charge (eta out = L1)

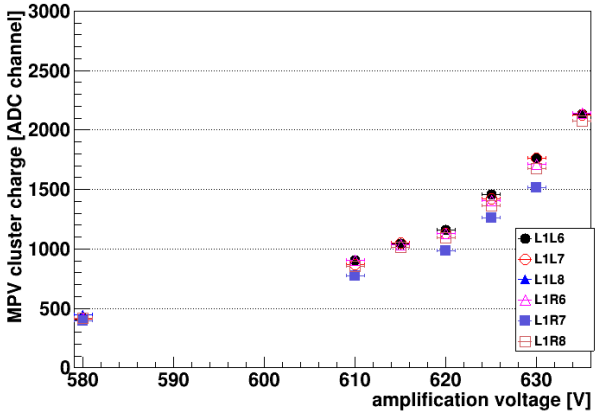
Ar:CO_2 **93:7** vol%
$U_{\mathrm{drift}} = 300\,\mathrm{V}$



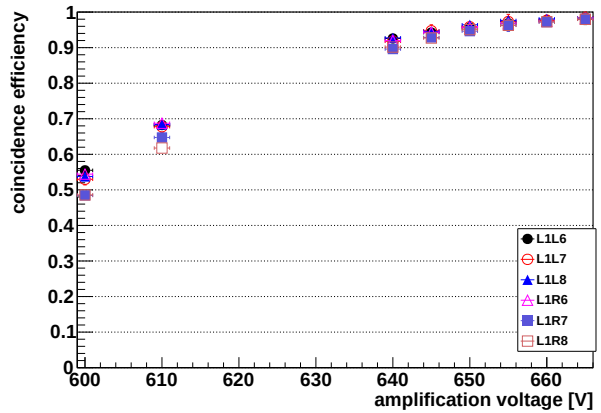


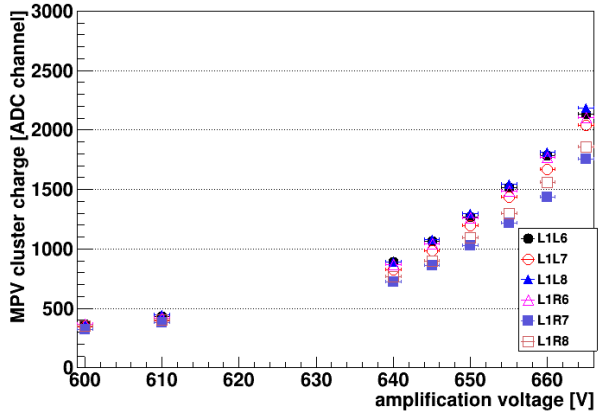
Ar:CO_2 **85:15** vol%
$U_{\mathrm{drift}} = 300\,\mathrm{V}$





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

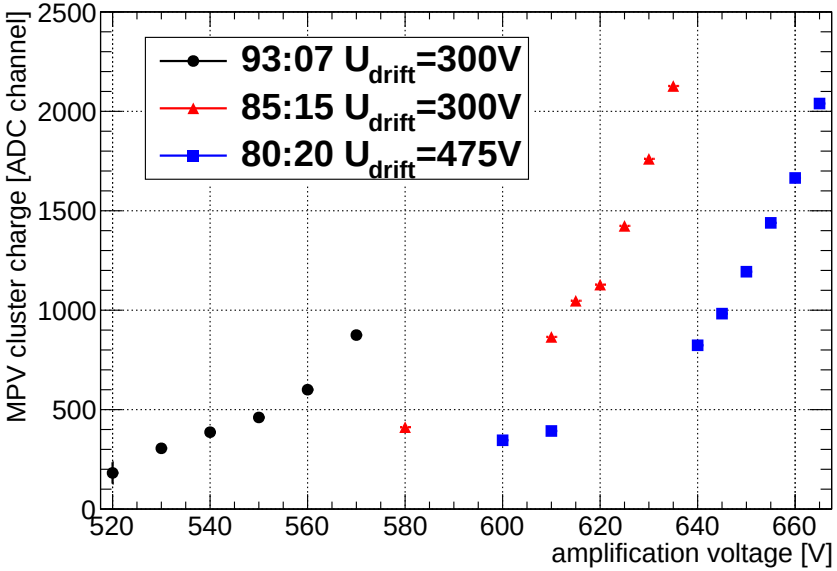




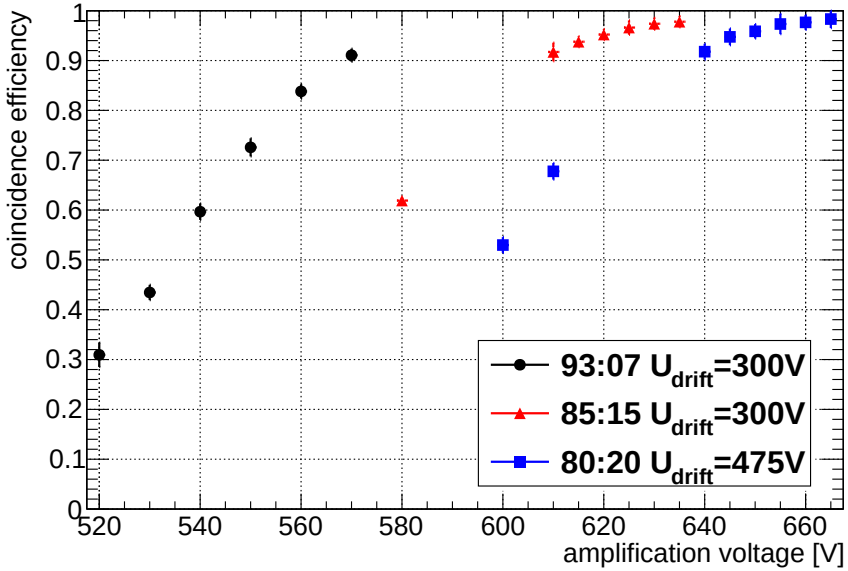
Efficiency Dependence on Cluster Charge (eta out = L1)

amplification scan (HV sector L6)

MPV cluster charge



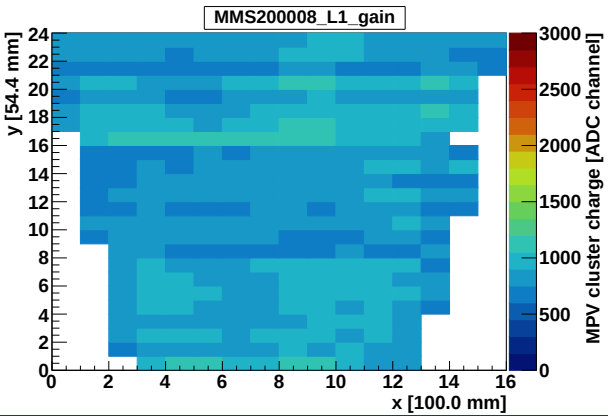
coincidence efficiency



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

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

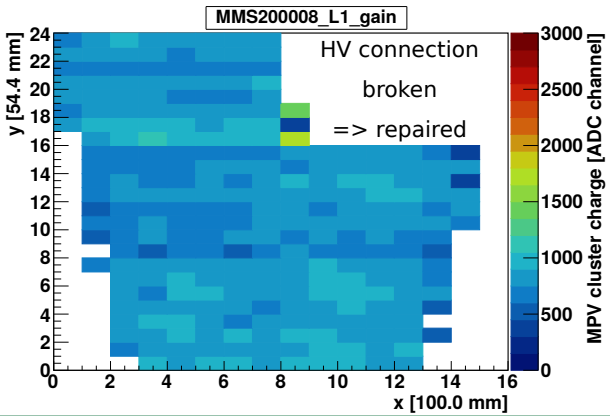
$U_{\mathrm{drift}} = 300\,\mathrm{V}$



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

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

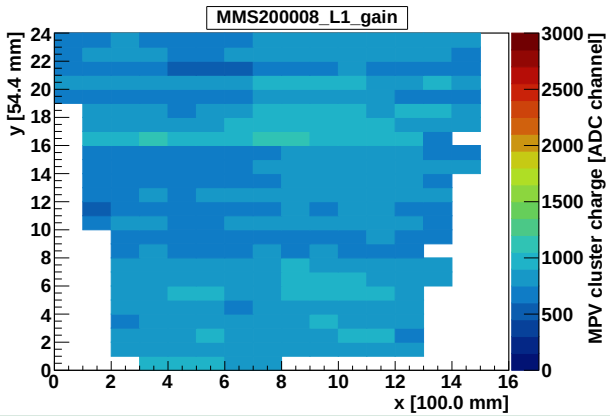
$U_{\mathrm{drift}} = 300\,\mathrm{V}$



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

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

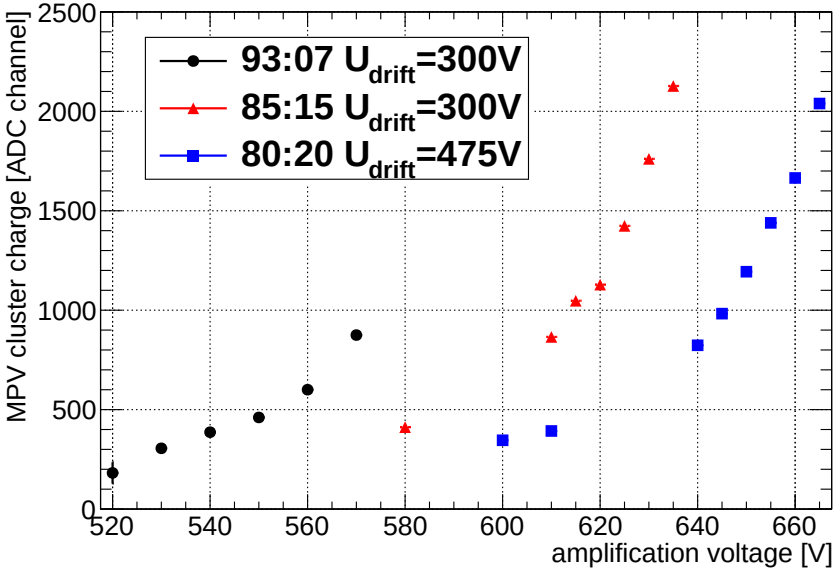
$U_{\mathrm{drift}} = 475\,\mathrm{V}$



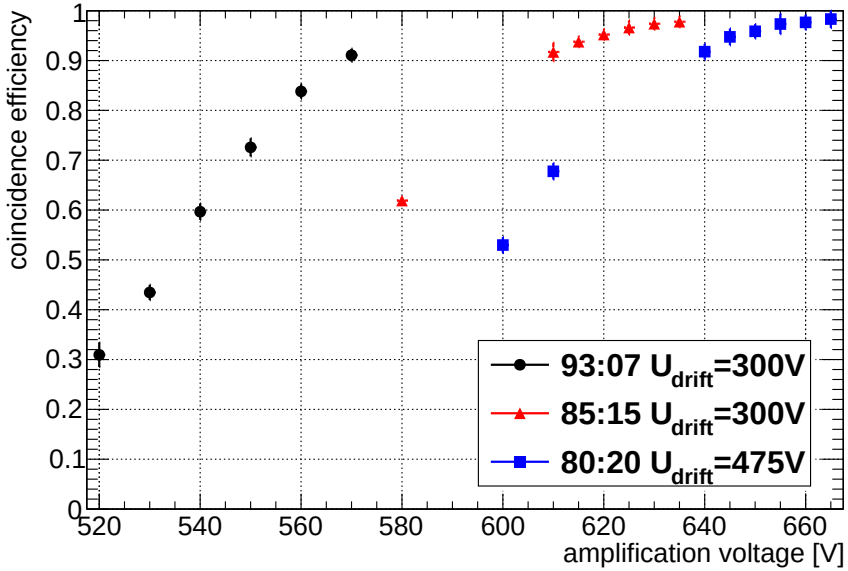
Efficiency Dependence on Cluster Charge (eta out = L1)

amplification scan (HV sector L6)

MPV cluster charge



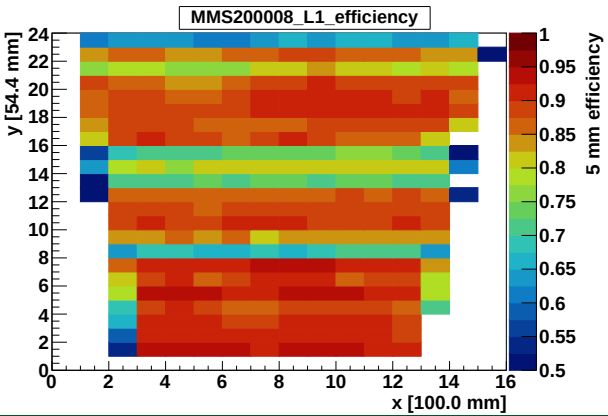
coincidence efficiency



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

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

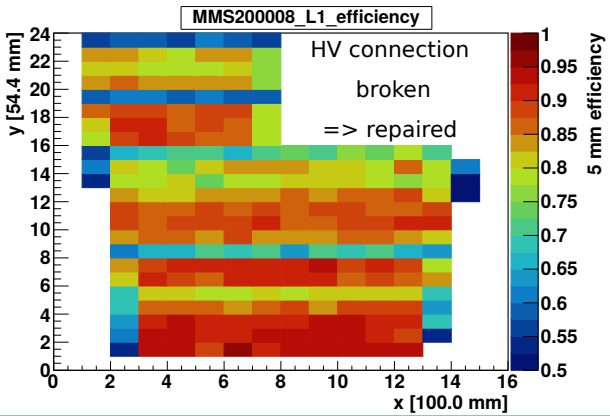
$U_{\mathrm{drift}} = 300\,\mathrm{V}$



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

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

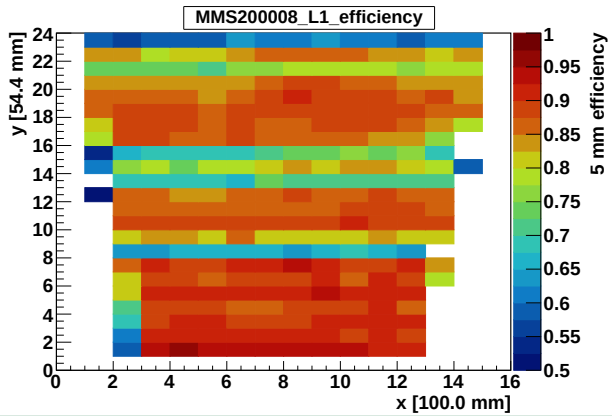
$U_{\mathrm{drift}} = 300\,\mathrm{V}$



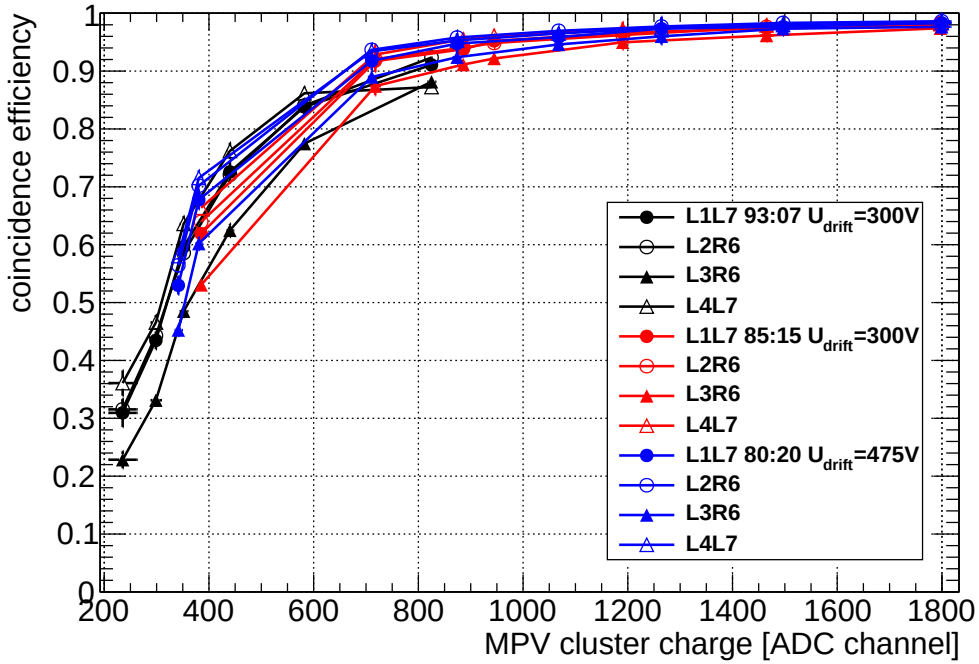
Ar:CO_2 **80:20** vol%

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

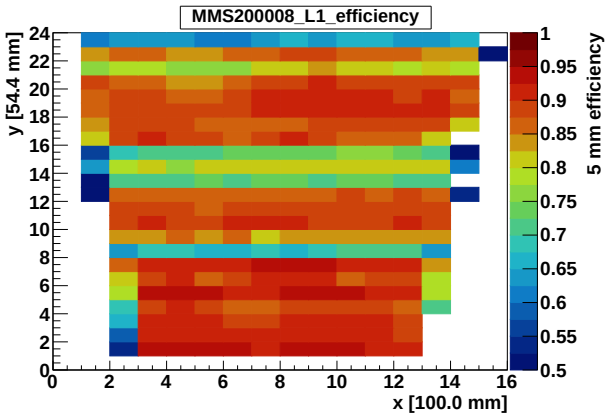
$U_{\mathrm{drift}} = 475\,\mathrm{V}$



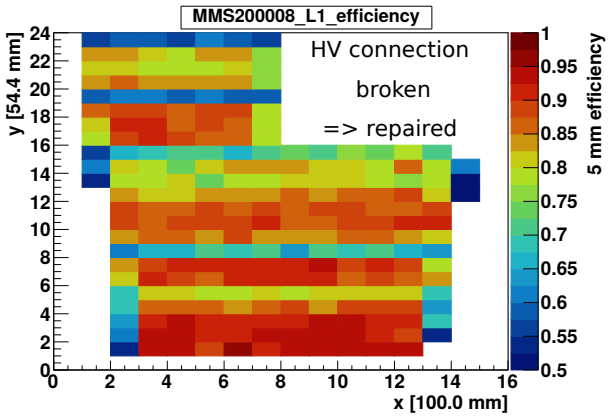
Efficiency Dependence on Cluster Charge (eta out = L1)



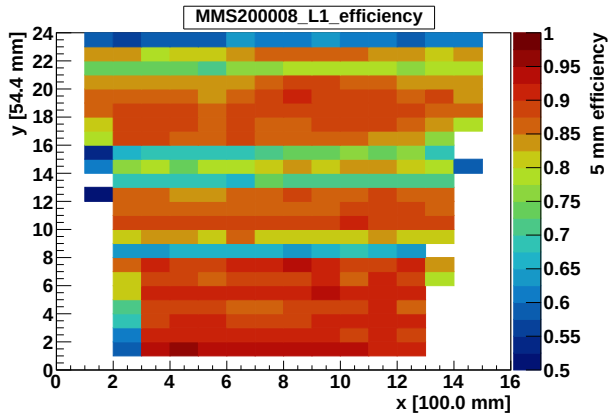
Ar:CO_2 **93:7** vol%
$U_{\mathrm{amp}} = 570\,\mathrm{V}$
$U_{\mathrm{drift}} = 300\,\mathrm{V}$



Ar:CO_2 **85:15** vol%
$U_{\mathrm{amp}} = 610\,\mathrm{V}$
$U_{\mathrm{drift}} = 300\,\mathrm{V}$

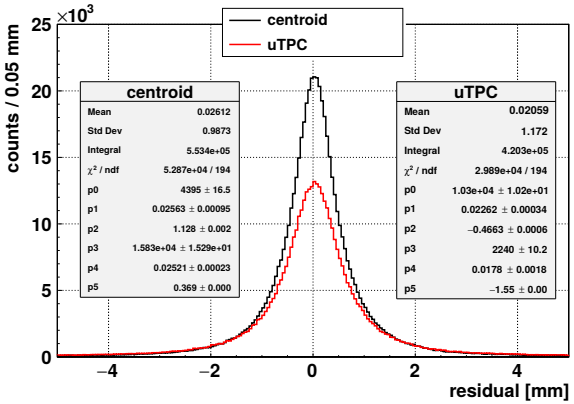


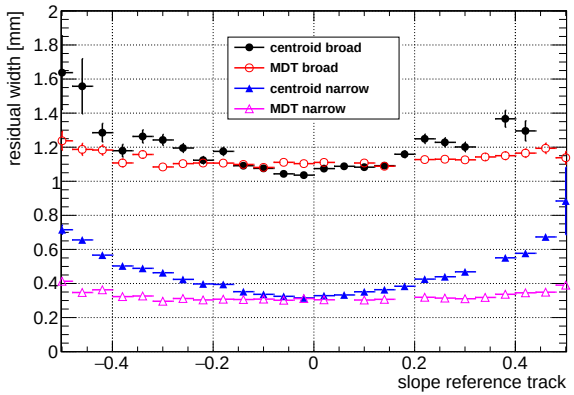
Ar:CO_2 **80:20** vol%
$U_{\mathrm{amp}} = 640\,\mathrm{V}$
$U_{\mathrm{drift}} = 475\,\mathrm{V}$



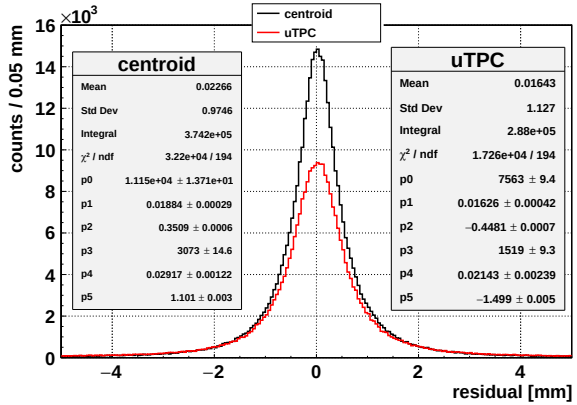
Residual Width

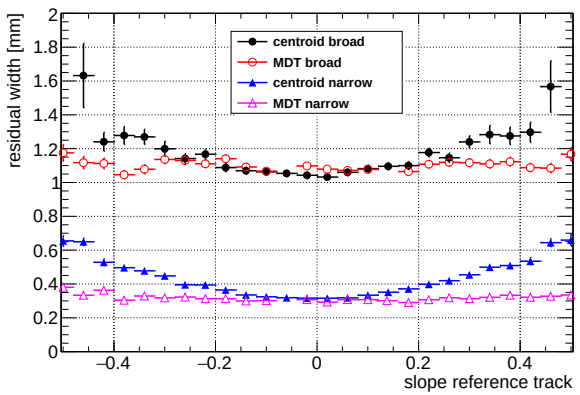
Ar:CO_2 **93:7** vol%
$U_{\mathrm{amp}} = 570\,\mathrm{V}$
$U_{\mathrm{drift}} = 300\,\mathrm{V}$



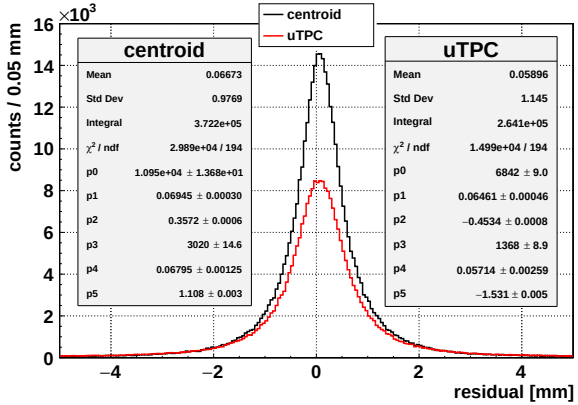


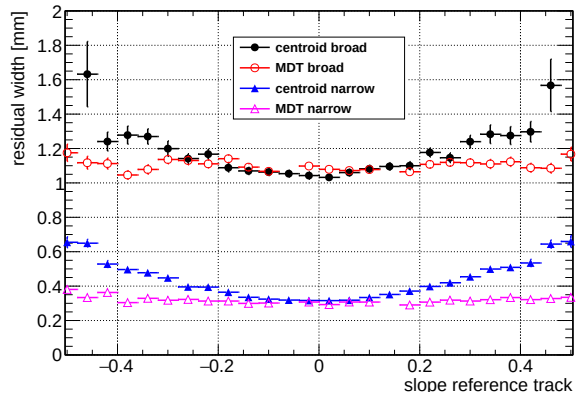
Ar:CO_2 **85:15** vol%
$U_{\mathrm{amp}} = 620\,\mathrm{V}$
$U_{\mathrm{drift}} = 380\,\mathrm{V}$





Ar:CO_2 **80:20** vol%
$U_{\mathrm{amp}} = 640\,\mathrm{V}$
$U_{\mathrm{drift}} = 475\,\mathrm{V}$



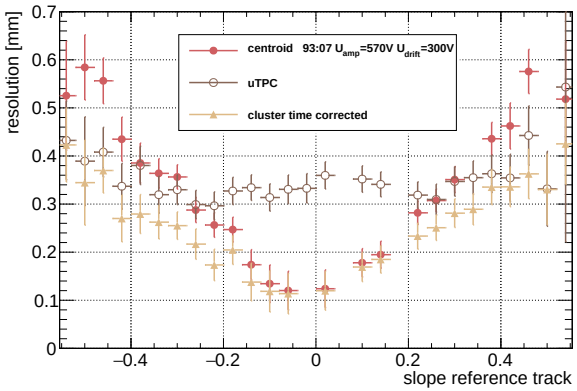


multiple scattering broadens residual distributions for Micromegas, as for MDTs

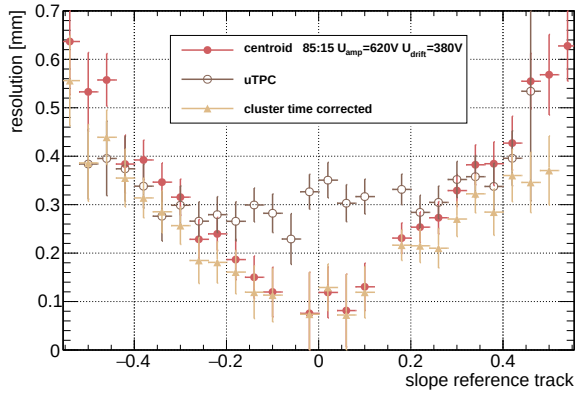
$\Rightarrow$ consider only width of narrow Gaussian ($\sim$ resolution)

Residual Dependence on Gas and Amplification Voltage

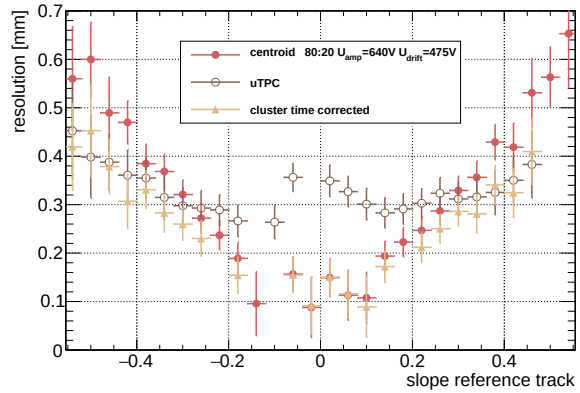
Ar:CO_2 **93:7** vol%
$U_{\mathrm{amp}} = 570\,\mathrm{V}$
$U_{\mathrm{drift}} = 300\,\mathrm{V}$



Ar:CO_2 **85:15** vol%
$U_{\mathrm{amp}} = 620\,\mathrm{V}$
$U_{\mathrm{drift}} = 380\,\mathrm{V}$

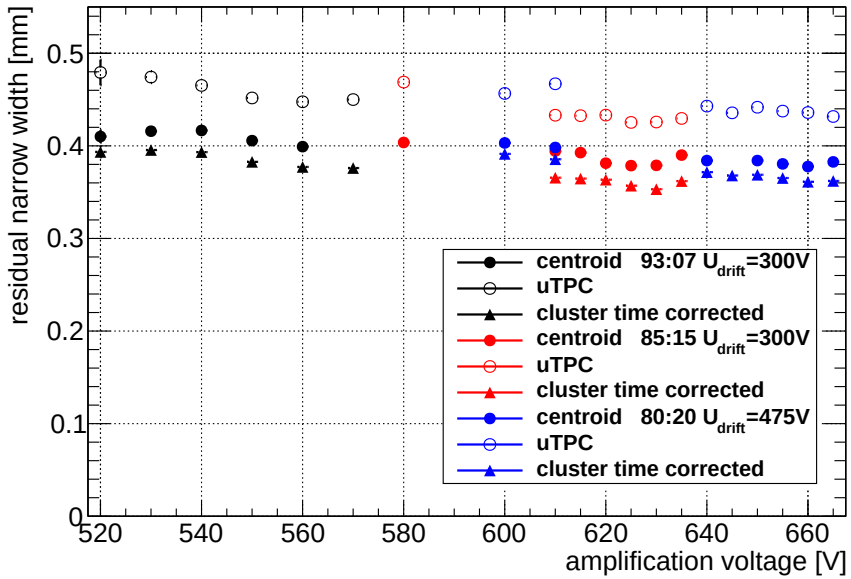


Ar:CO_2 **80:20** vol%
$U_{\mathrm{amp}} = 640\,\mathrm{V}$
$U_{\mathrm{drift}} = 475\,\mathrm{V}$

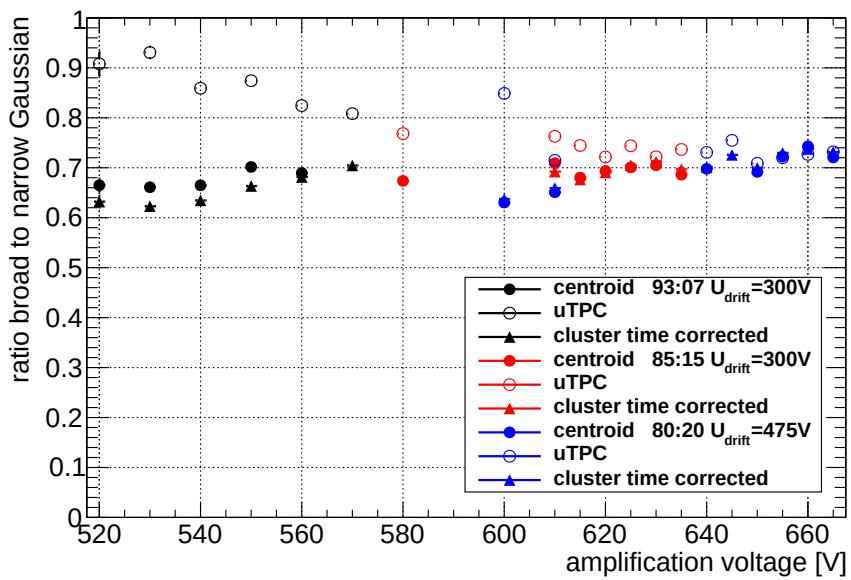


amplification scan

residual narrow width



ratio of broad to narrow Gaussian



Summary

- higher fractions of CO_2 $\Rightarrow$ larger safety margin
- all mixtures show almost the same
  pulse height reduction for increasing pillar height $\approx 6\,\%/\mu m$
  $\Rightarrow$ favors larger fraction of CO_2 to profit by higher reachable gain
- efficiency directly coupled to cluster charge (=gain)
  $\Rightarrow$ larger efficiency-plateaus for 85:15 and 80:20 than 93:7
- resolution estimation despite limitation due to multiple scattering of cosmics
  $\Rightarrow$ similar behavior for all three gas-mixtures:
    - $\sim 100\,\mu m$ perpendicular incident
    - $\sim 300\,\mu m$ at $\sim 15^\circ \Rightarrow$ µTPC
    - $\sim 400\,\mu m$ at $\sim 25^\circ \Rightarrow$ cluster-time-corrected

  $\Rightarrow$ residual width ($\propto$ resolution) improves with higher gain

Backup

Pillar Heights

layer	board	mean [µm]	std. dev. [µm]
M8 eta out	6	120.3	1.9
(=L1)	7	120.1	1.9
	8	120.3	2.3
M8 eta in	6	120.6	3.1
(=L2)	7	121.1	1.6
	8	120.6	2.6
M8 stereo in	6	121.6	3.0
(=L3)	7	122.2	1.6
	8	123.0	2.5
M8 stereo out	6	121.5	2.5
(=L4)	7	122.2	2.2
	8	122.3	3.8
eta3 top	6	113.9	1.5
(=gs1)	7	117.7	3.3
	8	116.2	2.3
eta3 bot	6	114.7	2.1
(=gs2)	7	116.8	4.0
	8	115.7	2.6

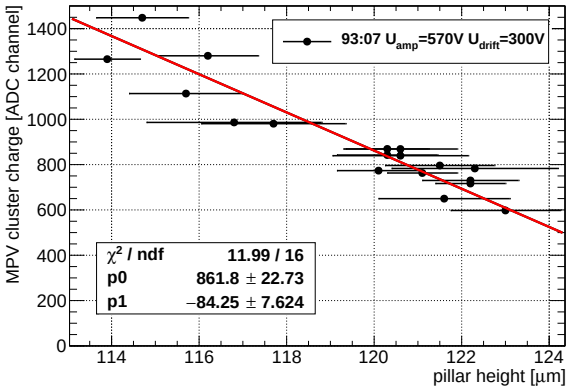
Cluster Charge Dependence on Pillar Height

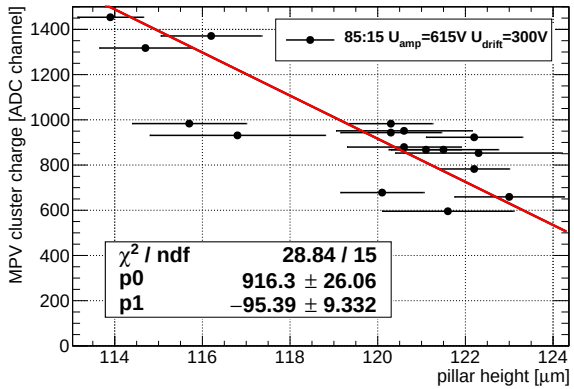
pillar heights measured at CERN (mean and std. dev.)

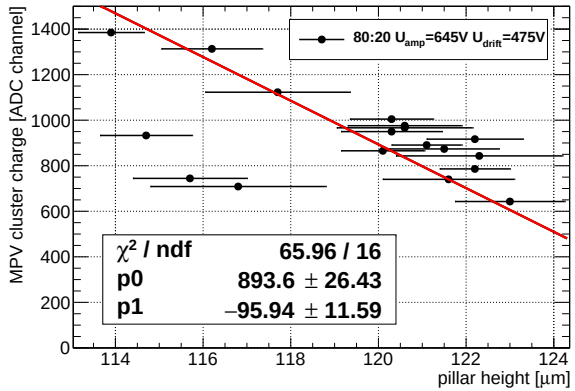
$\Rightarrow$ correlate at equal efficiency ($\approx 90\%$)

MPV pulse height and pillar height

Ar:CO_2 93:7 vol%	Ar:CO_2 85:15 vol%	Ar:CO_2 80:20 vol%
$U_{\mathrm{amp}} = 570\,\mathrm{V}$	$U_{\mathrm{amp}} = 615\,\mathrm{V}$	$U_{\mathrm{amp}} = 645\,\mathrm{V}$
$U_{\mathrm{drift}} = 300\,\mathrm{V}$	$U_{\mathrm{drift}} = 300\,\mathrm{V}$	$U_{\mathrm{drift}} = 475\,\mathrm{V}$





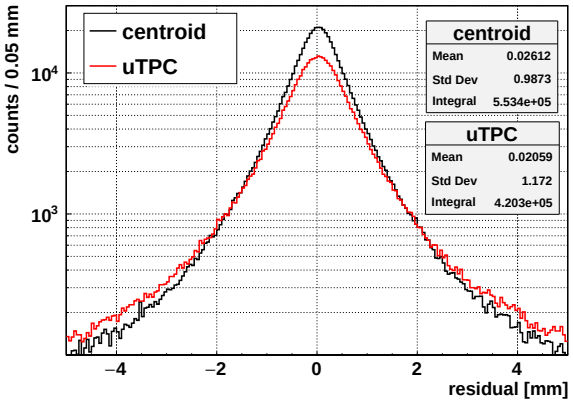


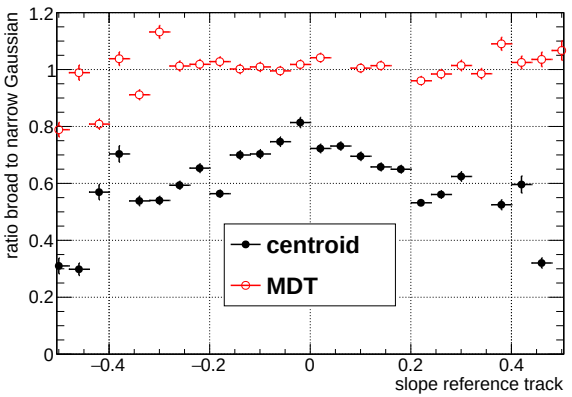
$\Rightarrow$ MPV pulse height change per increased pillar size

-(9.8±1.0)%/µm	-(10.4±1.1)%/µm	-(10.7±1.1)%/µm

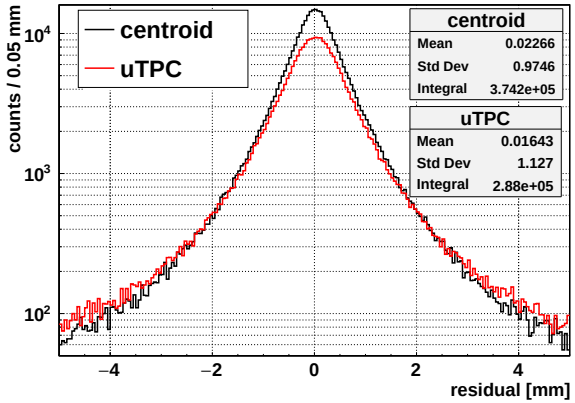
Residual Dependence on Gas and Amplification Voltage

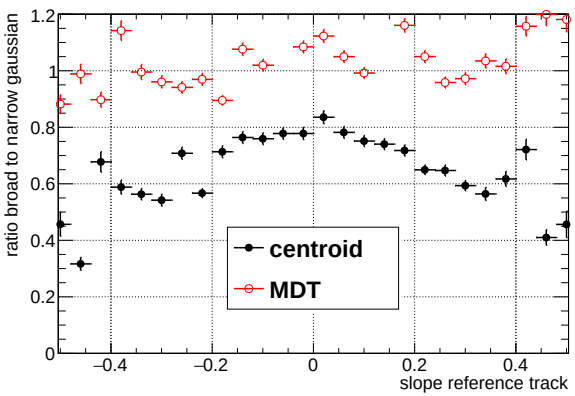
Ar:CO_2 93:7 vol%
$U_{\mathrm{amp}} = 570\,\mathrm{V}$
$U_{\mathrm{drift}} = 300\,\mathrm{V}$



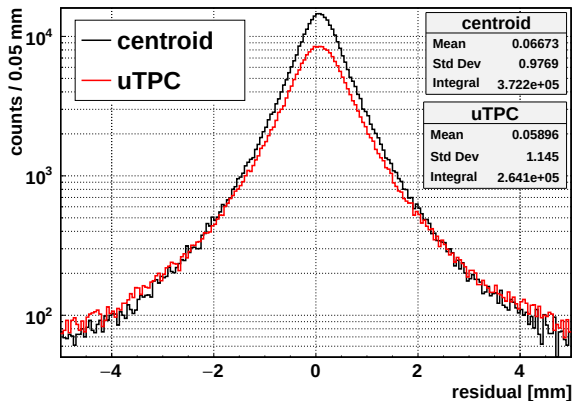


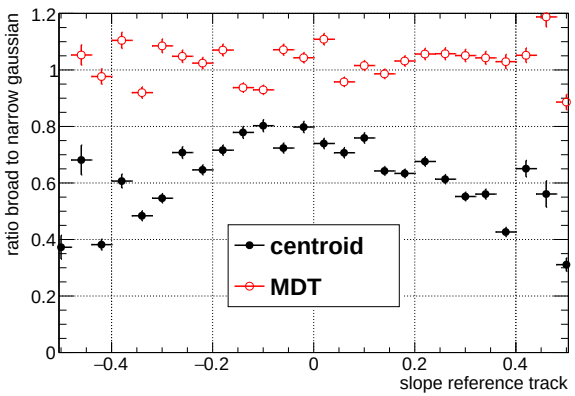
Ar:CO_2 85:15 vol%
$U_{\mathrm{amp}} = 620\,\mathrm{V}$
$U_{\mathrm{drift}} = 380\,\mathrm{V}$





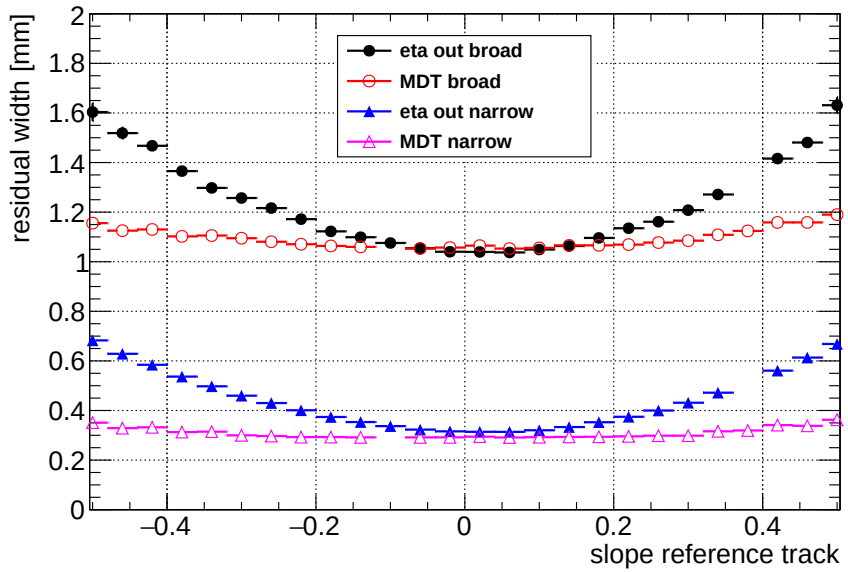
Ar:CO_2 80:20 vol%
$U_{\mathrm{amp}} = 640\,\mathrm{V}$
$U_{\mathrm{drift}} = 475\,\mathrm{V}$

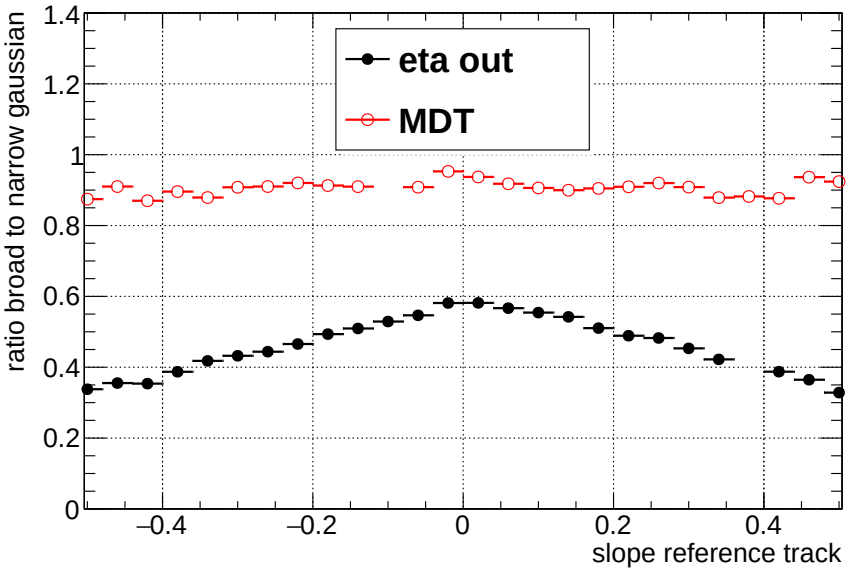




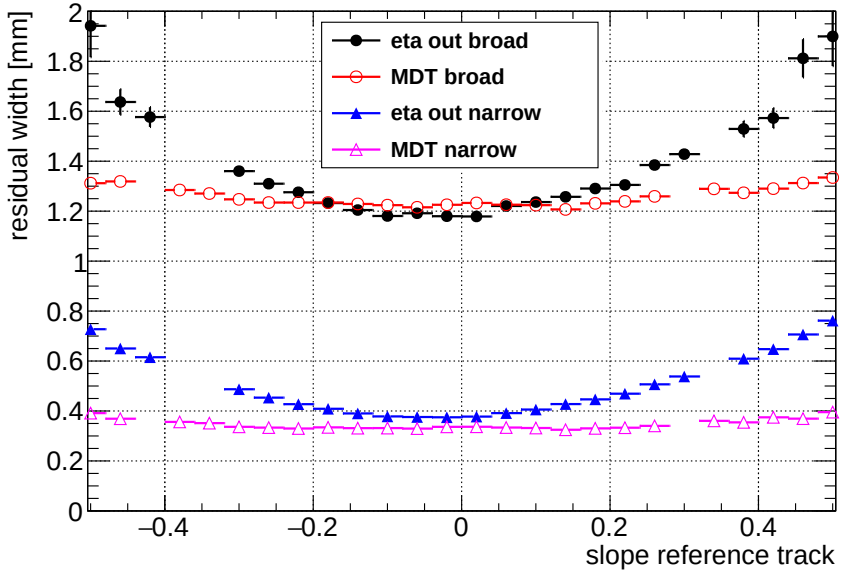
Influence of Multiple Scattering

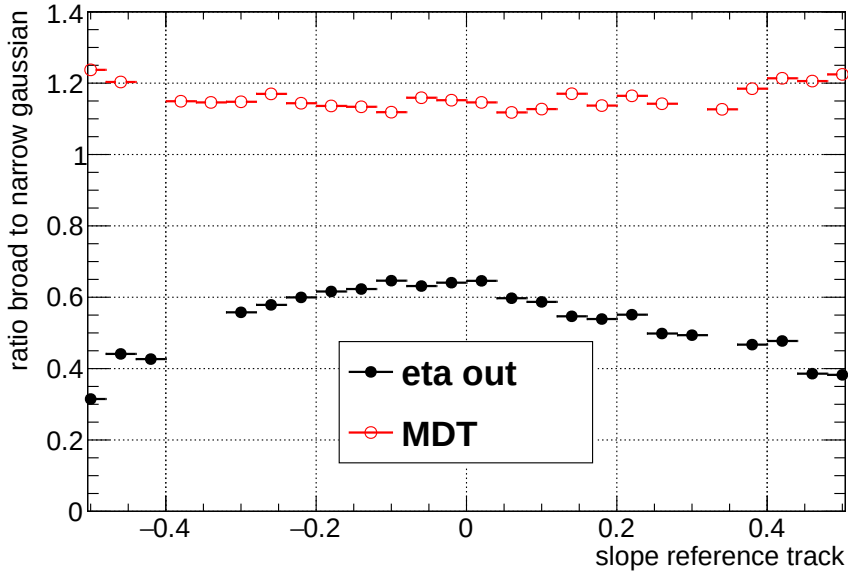
M3 (only)





M6 with eta3 doublet

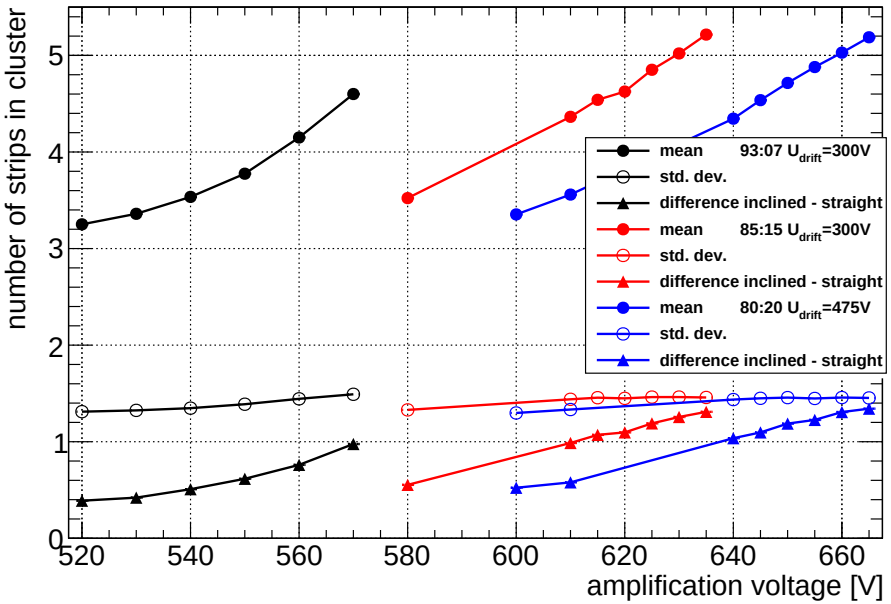




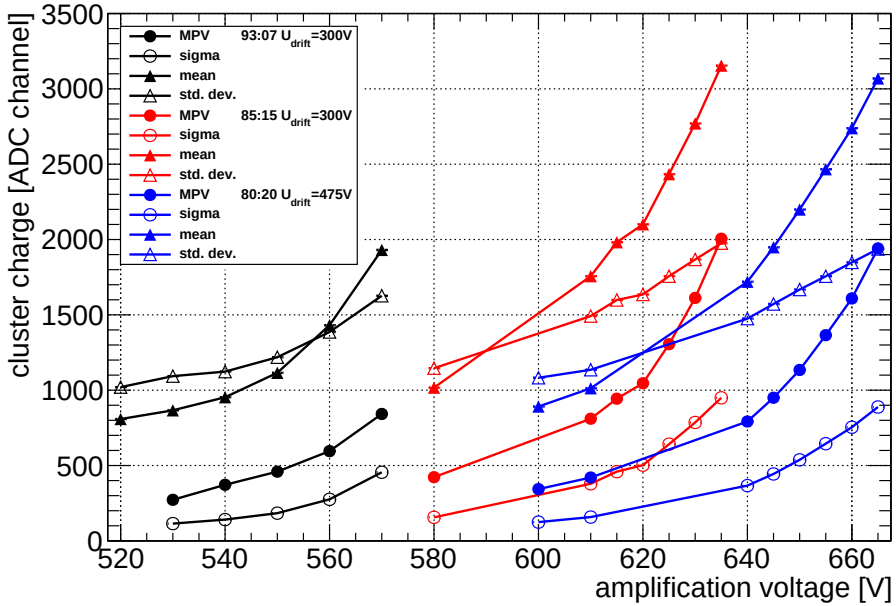
Cluster Properties (M8 eta out board 8)

93:7 **85:15** **80:20**

multiplicity



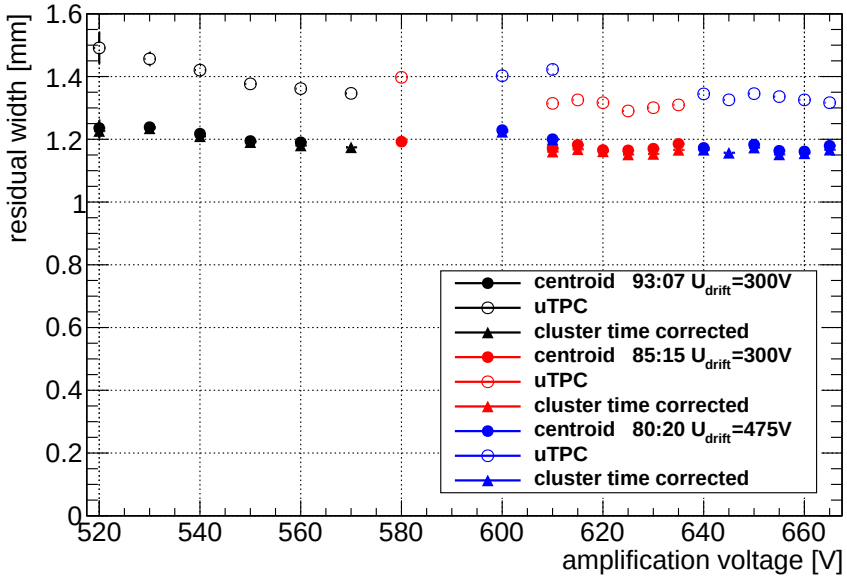
cluster charge



$\Rightarrow$ multiplicity and charge not at limit at 570 V for Ar:CO_2 93:7, but sparking prevent further voltage increase

Residual Properties

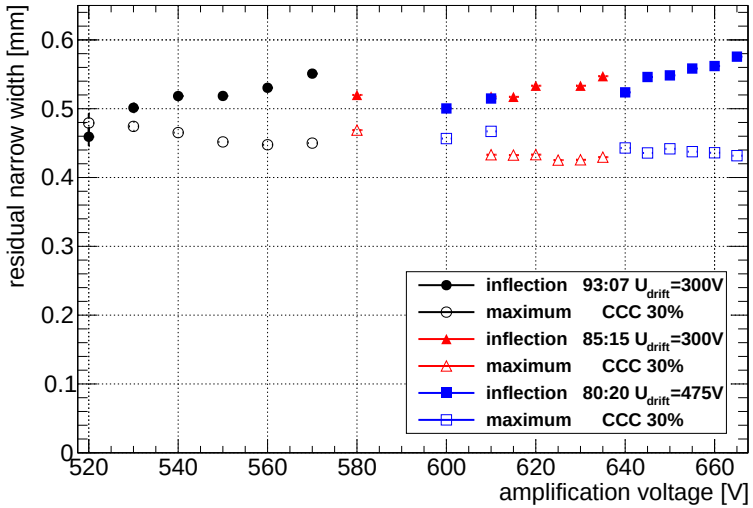
broad Gaussian width



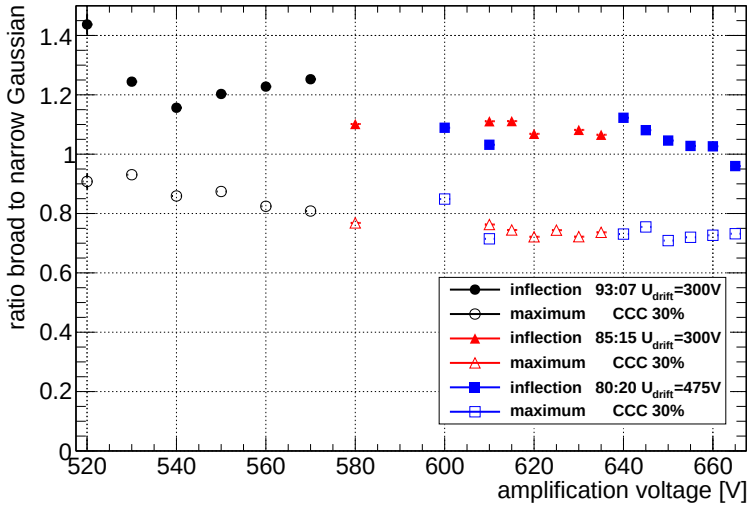
- broad Gaussian same magnitude as for MDTs
  $\Rightarrow$ due to multiple scattering
- µTPC resolution improves for signal evaluation at maximum
- correction for capacitive coupling (CCC) required

µTPC

residual width

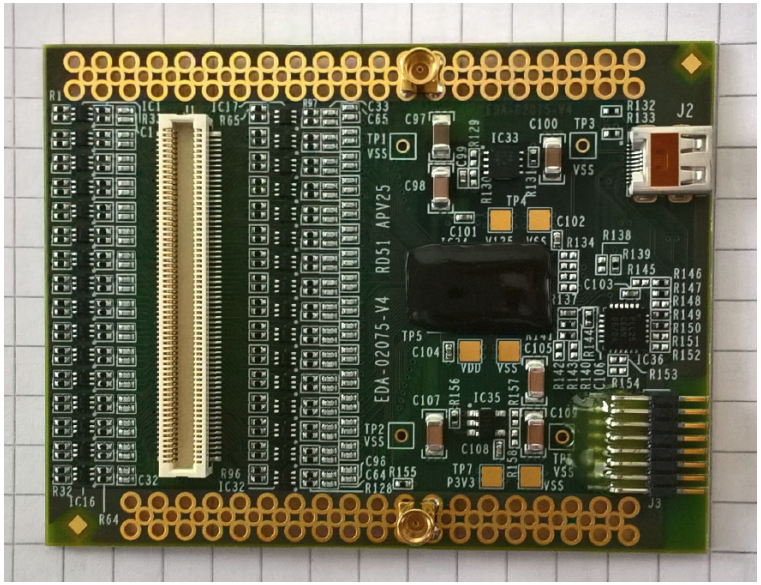


ratio broad to narrow Gaussian



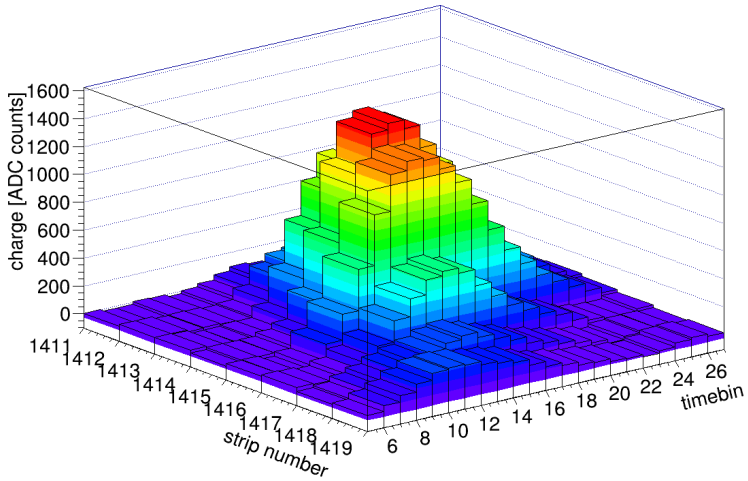
APV25 Frontend Electronics

APV25

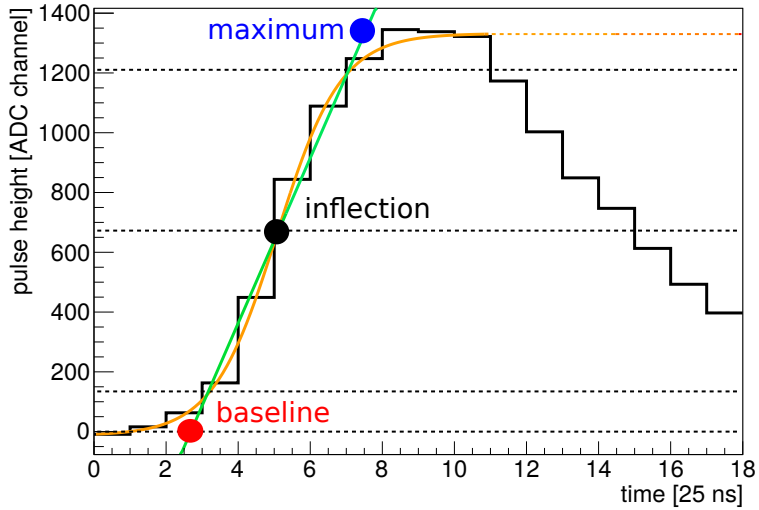


- 128 input channel
- charge-sensitive preamplifier
- analog pipeline memory
- 40 MHz clock
  $\Rightarrow$ 25 ns sampling

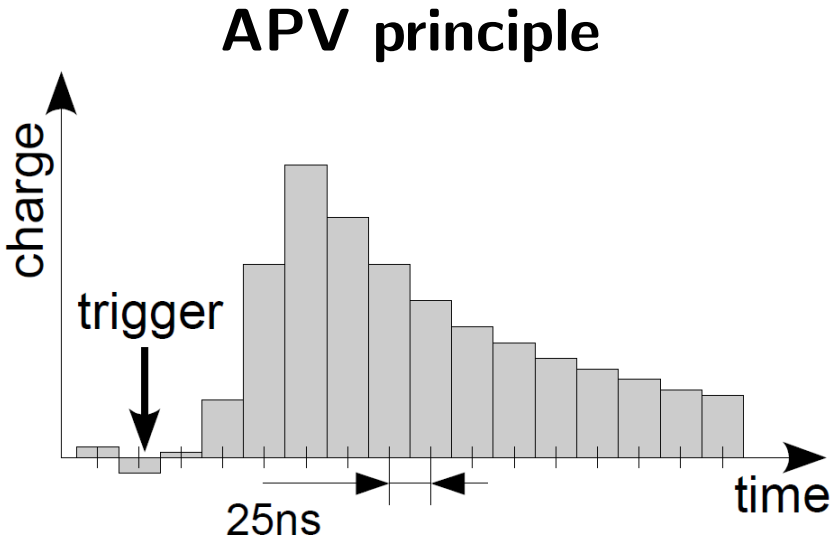
eventdisplay

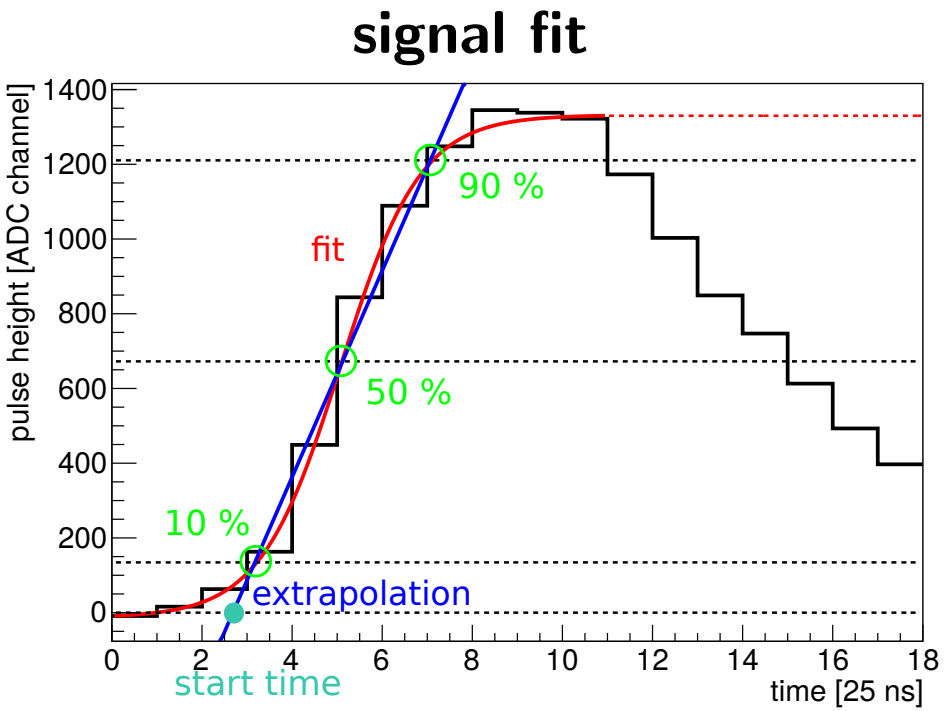


single strip signal



Signal Fit for APV Readout



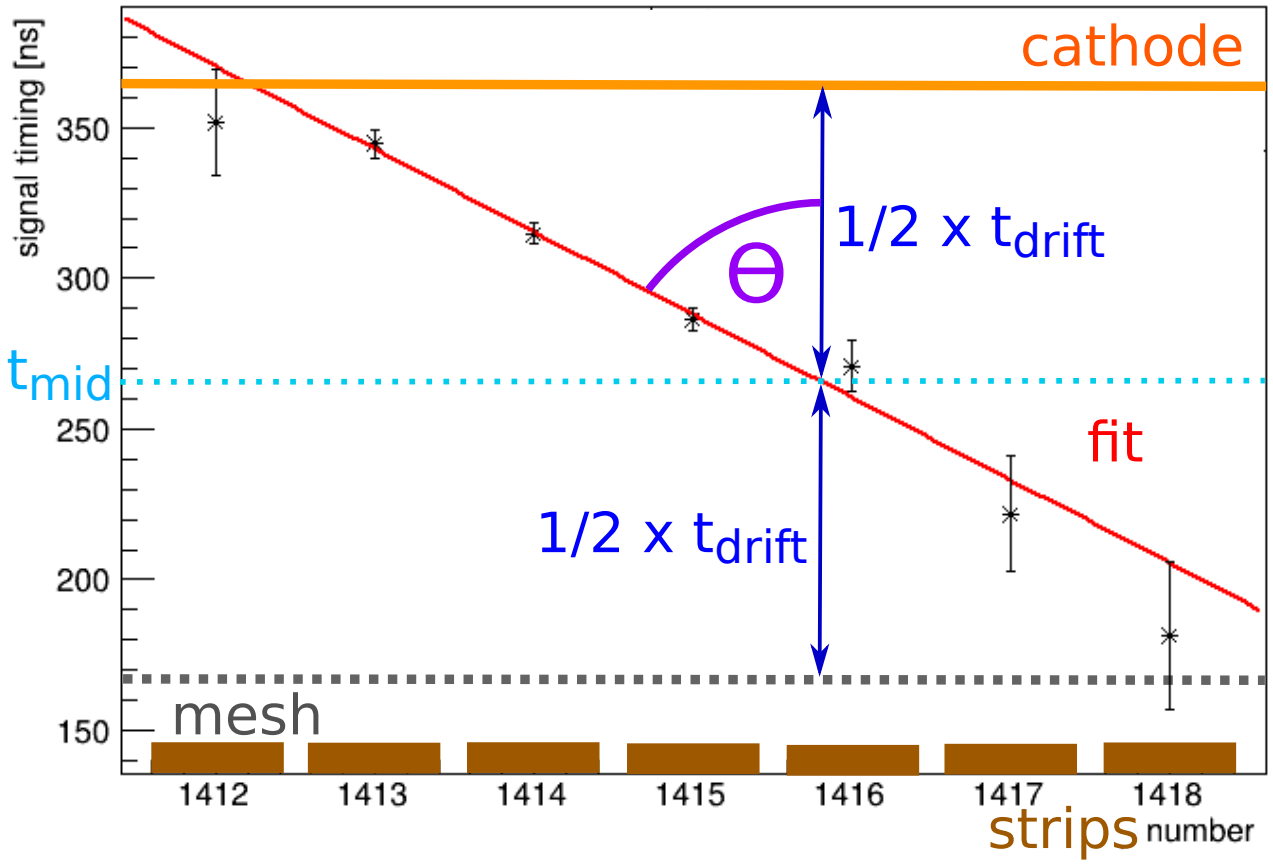


- single strip APV readout
- APV is sampling charge in 25 ns steps
- charge on strip corresponds to maximum value of APV signal
- fit signal with inverse Fermi function:

$$q(t) = \frac{p_0}{1 + \exp[(t - p_1)/p_2]} + p_3$$

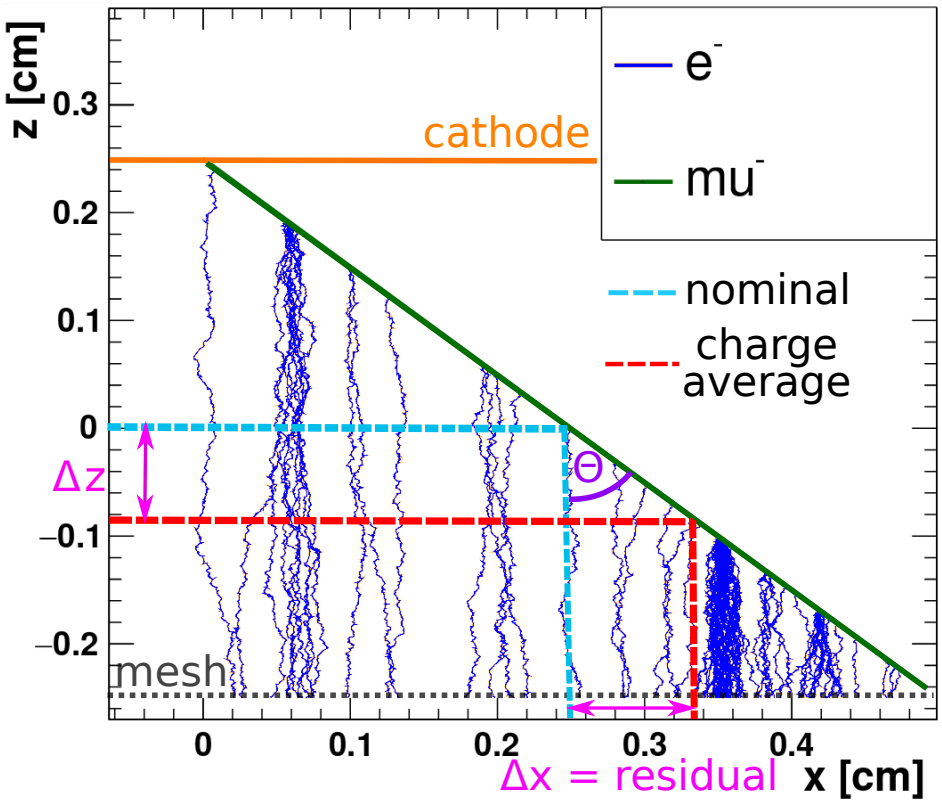
  - p_0 : maximum charge
  - p_1 : turn time ($\hat{=}$ 50%)
  - p_2 : rise time
  - p_3 : offset (≈ 0)
- 25 ns time jitter due to 40 MHz sampling recorded via TDC

Recapitulation µTPC Formulas



- angle reconstruction: $\theta = \arctan\left(\frac{\text{pitch}}{\text{slope} \cdot v_{\text{drift}}}\right)$
- position reconstruction: $\text{pos}_{\mu\text{TPC}} = \frac{t_{\text{mid}} - \text{intercept}}{\text{slope}} \cdot \text{pitch}$

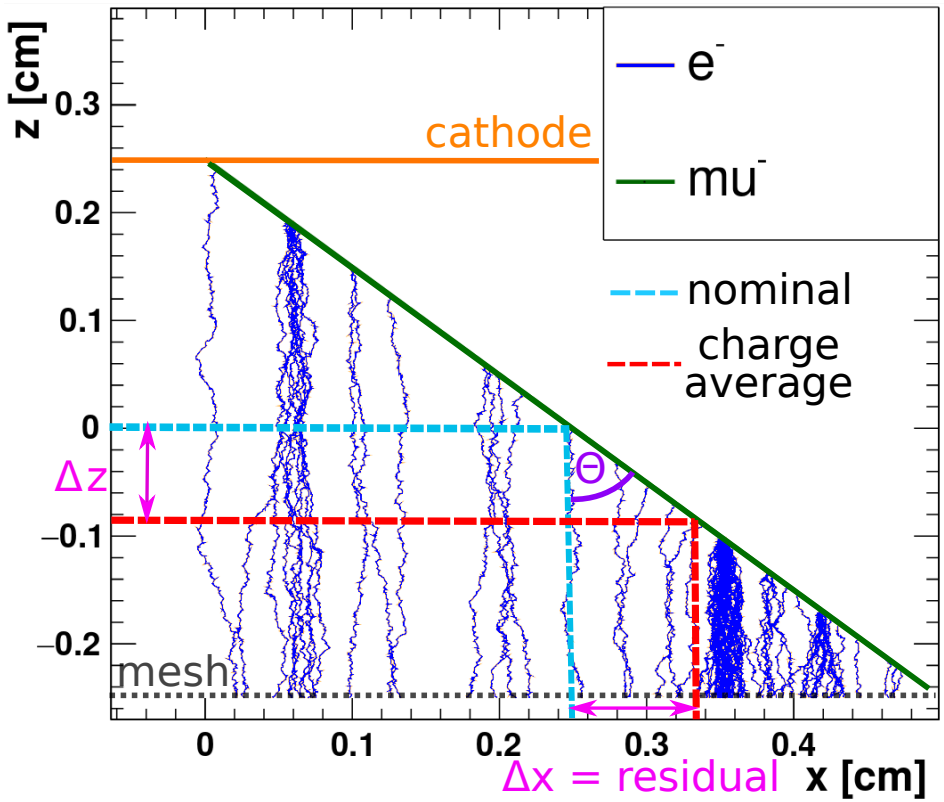
Concept for Charge Weighted Timing Reconstruction



$$\triangle x = \triangle z \cdot \tan\theta$$

$$= (t_c - t_{mid}) \cdot v_{drift} \cdot slope_{ref}$$

Concept for Charge Weighted Timing Reconstruction



$$\text{centroid} = \sum_{\text{strips}} \text{strip} \cdot q_{\text{strip}} \; / \; \sum_{\text{strips}} q_{\text{strip}}$$

$$t_{\text{c}} = \sum_{\text{strips}} t_{\text{strip}} \cdot q_{\text{strip}} \; / \; \sum_{\text{strips}} q_{\text{strip}}$$