Comparative study of resistive MPGDs with VMM3a/SRS readout

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on behalf of Weizmann group

(side-part of the RD51 Common project, MPGD-CALO)

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Introduction

- Goal: compare three resistive MPGD technologies
 - MM (~ 50 MΩ/□ DLC)
 - uRWELL (~ 100 M Ω / \Box DLC)
 - RPWELL (2 G Ω bulk Glass)
 - <u>RD51 Common project</u>
- VMM3a/SRS readout of 384 × 1 cm² pads
- Gas mixture
 - MM, RPWELL: Ar₍₉₃₎CO2₍₅₎iC4H10₍₂₎
 - uRWELL: Ar₍₉₃₎CO2₍₅₎iC4H10₍₂₎ Ar₍₇₀₎CO2₍₃₀₎, Ar₍₄₅₎CO2₍₁₅₎CF4₍₄₀₎
- Drift gap = 6 mm amplification gap RL/RP
- Performance in terms of:
 - Detection efficiency
 - Charge and time response
 - Stability





<u>uRWELL</u>







Readout anode

- Pad readout
 - 1×1 cm² pad area
 - 384 pads routed in 3 PCB layers to three Hirose connectors
- Resistive layer/plate
 - Micromegas
 - Double DLC layer
 - ~ 50 MΩ/□
 - uRWELL
 - Single DLC layer
 - ~ 100 M Ω / \Box
 - RPWELL
 - Fe-doped glass
 - $2 G\Omega$ bulk
 - Coupled to anode with epoxy-graphite mixture





Cosmic test bench

- Three 150×250 mm² scintillators (SC)
- Acceptance ~ $150 \times 175 \text{ mm}^2$
- Max angle $\sim 44^{\circ}$
- Coincidence logic:
 PMTs → Discr → logic AND unit → <u>NIM injector</u> → VMM
- Trigger rate ~ 0.8 Hz





Data acquisition

- Continuous with <u>VMM3a/SRS¹</u>
- 380 active channels (3 deead, 1 masked) + 1 for the trigger
 - 4 VMM hybrids
 - Powered with DVMM
 - 1 FEC
- 3 mV/fC VMM3a gain
- 200 ns shaping time
- Analog signal monitor
 - 1 channel per chip
- Noise: 5 10 mV (10⁴ 2.10⁴ electrons)
- Threshold: average per channel ~ 30 mV, equivalent to 6.10^4 el

Methodology – data analysis

- Cluster reconstruction with <u>vmm-sdat</u>
 - first neighbors with max one missing pad
 - center-of-mass algorithm
- Time correlation between the trigger and the detector
 - dt = t_trigger t_cluster
- Efficiency calculation
 - Fit dt to Normal distribution
 - Find mean (µ) and sigma (σ) of the fit
 - Count clusters under the "bell" as efficient (μ ± 3σ)
 - In case > 1 cluster found within the selection, choose the one closer in time



MM 500V

Time results



- Timing depends on the technology and gas mixture
- RPWELL delay is larger due to the slower signal
- RPWELL time resolution is slightly worse (not decoupled from the system time resolution)

Efficiency results



 $\mathbf{E} = \frac{clusters \ within \ \mu \pm 3\sigma \ of \ dt}{no \ of \ triggers}$

Drift fields

- MM: 1 kV/cm
- RPWELL: 2.5 kV/cm
- uRWELL (ArCF4CO2): 4 kV/cm
- uRWELL (ArCO2iC4H10): 2.0 kV/cm
- uRWELL (ArCO2): 3.5 kV/cm

In ArCO2 70:30 and ArCO2iC4H10 93:5:2, uRWELL is approaching discharge regime, will drop these results from now on

Observing drop of efficiency for MM and RPWELL at high gain

Efficient clusters charge



- At high gain, charge saturation is observed
- At max point saturating events predominate





- dt tail observed at high gains
- Saturated clusters delayed by $dt > 3\sigma$
- \rightarrow Reconsidering dt selection



- Increasing dt selection
 - $(\mu \pm 3\sigma) \rightarrow (\mu 3\sigma) \& (\mu + 10\sigma)$
- Plateau value at 96.6 \pm 0.3 %
- Restored clusters are indeed in saturation









- MM eff.plateau at 96.6 ± 0.3 %
 - Acquisition with 3 dead channels
 → correction of 1 %
 - Trigger acceptance
 → correction of 1-2 %



\rightarrow MM efficiency > 98%

RPWELL measurements

- Saturation similar to MM
- Increasing the selection ($\pm 3\sigma \rightarrow \pm 10\sigma$) results in 94 % efficiency
- Different effect:
 - non-correlated clusters, including saturation





RPWELL instability

Analog signals from the RPWELL





- Saturated signals not correlated with the trigger
- Function of HV
- Dead-time at higher source rate (beam)
- We believe it is a major design-related problem WELL design
- * self trigger on ch1
 * one channel per VMM
 * 2 us/div

RPWELL design

- Electrical instabilities observed at the edges (RPWELL irradiated with 22 keV X-Rays)
 - At gluing points
 - At cross pattern corners
 - Attributed to field non-uniformity
- \rightarrow Optimizing the design in the next iteration
 - No pad pattern
 - Hexagonal holes pattern
 - Larger holes diameter at the edges



uRWELL measurements

- Different from RPWELL and MM (no saturation)
- Random low amplitude hits
- Hit rate similar to RPWELL
- Under further investigation







Conclusion and outlook

- Efficiency > 90 % reached for three detectors
- Charge saturation affects the dt with the trigger delay
- Performance of RPWELL and uRWELL affected by random hit rate and has to be further understood
- Currently, building a common setup to test three detectors simultaneously with triple GEM based tracker
 - Planning to join SPS TB in September 2024

SPS NA H4 Test Beam plans

- Aiming to join the last 2024 TB (September)
- Building the setup with 3 SCs, 3 tracking GEMs, and 4 pad detectors (MM, RPWELL, uRWELL + RWELL with lower resistivity and/or different WELL pattern)
- 25 VMM hybrids (12 tracking + 12 pad + 1 trigger)
- Goal
- Comparative study
 - Efficiency
 - Gain
 - Uniformity
 - Pad multiplicity
 - Rate capability
 - Address dead time



Thank you!

Backup

Threshold effect

- Threshold level set per channel with the calibration procedure provided in Slow Control
- Affects the measurements at low gain
- Threshold was first set for uRWELL (the highest noise level)
- Kept at the same level for MM & RPWELL for consistency

Measurements with uRWELL in ArCO2iC4H10



uRWELL

Noise

- Noise level estimated from analog output
- Acquisition with random external trigger
- uRWELL
 - ~10 mV
 - 2.10⁴ el equivalent
- MM & RPWELL
 - ~ 5 mV
 - 10⁴ el equivalent



RPWELL



Drift field

• Drift field values were set according to the optimal values of efficiency (max) and dt_mean (min)





RPWELL



Dead channels

Three dead channels (non-zero counts due to the reconstruction of size>1 clusters with missing pad)

Taking average number of the clusters in the surrounding neighbors, true efficiency is estimated to be 1% higher

	20.0			2D Map of Efficient Clusters																			
	20.0 -			10	10	9	10	18	18	19	29	26	17	13	18	10	10	12	9				- 500
				13	25	42	48	67	82	84	90	73	88	63	46	42	36	22	14				
	17.5 -	7	11	23	58	119	106	165	171	204	248	238	193	201	144	130	82	63	24	16	7		
		11	8	19	74	162	215	238	300	370	390	402	314	290	268	179	153	88	32	13	7		
		13	10	19	95	218	260	326	383	442	432	444	432	350	310	251	189	92	38	9	8		- 400
	15.0 -	7	17	21	105	16	314	406	443	487	545	563	496	467	346	290	209	115	36	18	5		400
	12.5 -	5	17	28	114	221	279	386	478	545	578	556	530	479	415	302	229	122	47	23	10		
		2	18	26	91	211	309	364	433	533	575	550	555	420	401	288	210	129	38	19	15		
_	10.0 - 7.5 -	38	14	18	109	222	281	379	440	544	555	544	489	436	343	291	212	124	44	23			
ition		5	13	33	125	200	332	375	413	451	512	553	454	444	357	286	221	99	46	13	9		- 300 ¥
Pos		12	11	23	111	212	9	354	391	455	528	500	461	397	308	281	147	109	38	10	9		Coul
\succ		4	13	23	105	177	244	325	376	430	450	451	393	335	330	240	165	111	41	16	10		
		16	14	29	96	153	234	280	337	374	418	461	417	313	291	228	147	82	36	7	7		
		10	10	25	76	129	212	269	261	331	397	348	315	303	272	199	129	83	31	15	12		
		11	10	24	68	136	175	209	220	280	298	325	281	241	207	13	135	55	23	10	9		- 200
	5.0 -	7	9	13	57	97	133	178	207	256	264	274	241	188	169	134	91	52	20	14	6		
		10	4	15	43	89	103	135	163	158	184	194	198	144	113	107	77	54	23	9	4		
	2.5 -	3	12	8	33	56	61	90	122	107	142	117	112	96	93	53	48	29	9	9	9		
			1	9	18	28	35	39	66	73	65	66	74	58	33	40	27	20	9				- 100
				5	8	25	19	19	26	23	26	27	27	37	22	23	15	11	8				100
	0.0 -	0		2.5		5.	.0		7.5		10	0.0		12.5		15	.0		17.5		20	.0	
)	(Pos	sitio	n										

Acceptance

With higher statistics it can be seen that the acceptance region od the SCs is not symmetrically positioned. Lower row of pads has order of magnitude more counts than the highest. Correcting the values to the asymmetry, is estimated to be 1–2 % higher

	20.0		2D Map of Efficient Clusters																				
	20.0 -			18	15	9	25	17	29	26	21	19	26	17	11	17	15	9	11				- 400
				17	47	75	96	119	117	115	121	119	110	100	102	86	65	29	12				
	17.5 -	9	14	52	118	181	266	274	286	312	256	268	286	268	284	214	133	79	20	14	5		
		5	15	52	163	246	339	383	400	396	360	418	413	419	366	292	174	110	22	16	14		
	15.0	7	14	47	185	269	387	403	401	392	456	441	398	423	410	314	203	108	35	17	10		
	15.0 -	9	18	58	173	299	409	426	391	461	433	428	455	412	419	338	229	129	30	20	8		
		16	14	61	178	274	409	446	403	425	405	464	458	423	406	351	219	132	36	18	11		- 300
	12.5 -	3	17	56	181	286	366	417	469	418	416	421	449	407	386	336	242	122	37	13	12		
		14	21	60	145	260	348	407	417	401	432	408	438	407	414	334	233	119	37	21	9		
		19	28	61	178	282	401	395	428	414	403	422	404	420	387	334	214	117	26	9	8		nts
	10.0 -	7	17	62	174	237	356	411	408	419	404	391	386	419	375	325	226	128	25	14	9		Coul
		16	18	47	164	280	355	370	419	410	412	395	415	415	400	306	223	124	31	16	9		
	7.5 -	11	10	50	148	252	342	407	398	377	387	429	415	370	373	282	209	123	43	9	9		- 200
		19	15	48	143	247	330	377	388	409	390	385	370	368	355	274	201	98	42	19	10		
		15	18	48	156	241	330	370	375	374	378	358	376	351	376	306	206	112	28	12	10		
	5.0 -	9	16	44	120	197	293	307	357	326	362	345	322	348	308	267	196	94	23	15	11		
		15	18	46	124	184	250	271	287	304	287	323	295	316	285	227	140	86	30	10	6		
	2.5 -	11	17	39	104	164	198	236	219	239	245	214	229	245	217	175	116	64	27	17	4		100
	2.0			35	75	116	146	177	191	181	169	155	187	162	176	128	104	54	19	2			- 100
			1	31	41	91	87	124	132	118	106	141	119	123	131	94	58	47	27				
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