Impact of the gas choice and the geometry on the breakdown limits in MPGD detectors

מכון ויצמן למדע
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December 11-16, 2022

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1 GSI
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SHORT OVERVIEW


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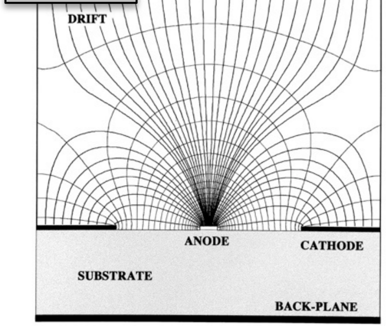
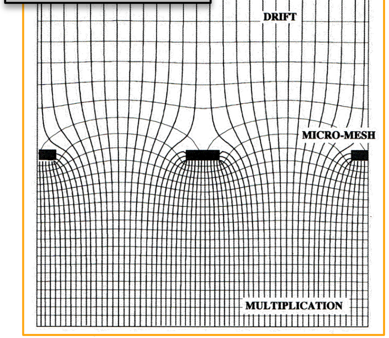
Discharges in MPGDs

Following: V. Peskov, „ Discharge phenomena in gaseous detectors “, RD51 Meeting, Munich 2018 (link)

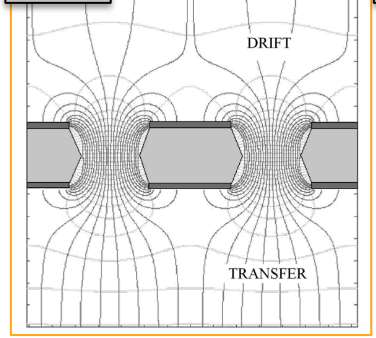
MSGC



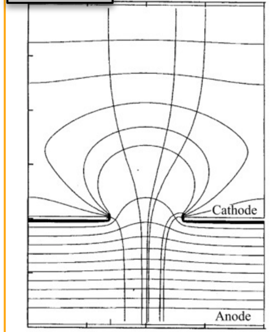
Micromegas



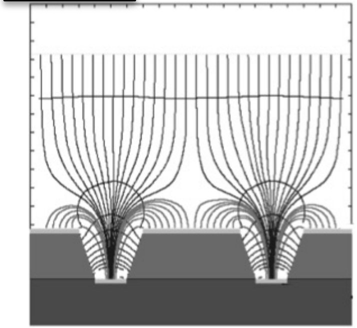
GEM



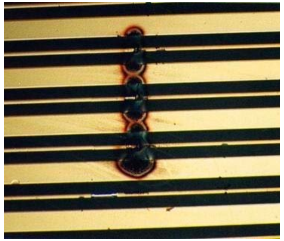
CAT



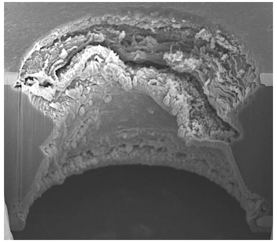
MGC

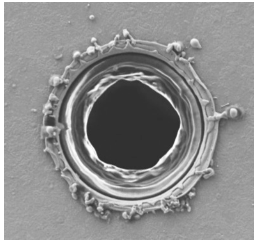


- In all these structures, there are regions with ∼parallel field lines
- Streamers can develop by the same mechanism as in PPAC
- No quenching by field reduction, when streamers reach the cathode → full breakdown

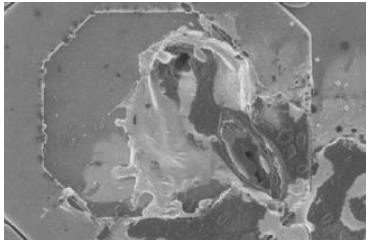


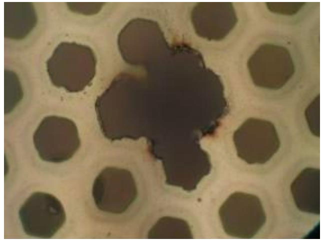
F.Sauli, IEEE NSS 2002



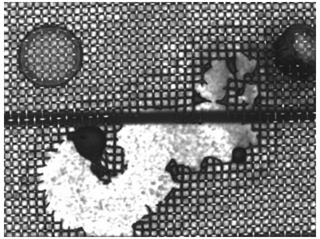


J. Merlin, *“Single-hole discharges in GEMs”*, RD51 Meeting, TUM 2018 (link)





M. Chefdeville (NIKHEF), „The pixel readout of TPCs“, (link)



J.Galan, RD51 meeting (link)

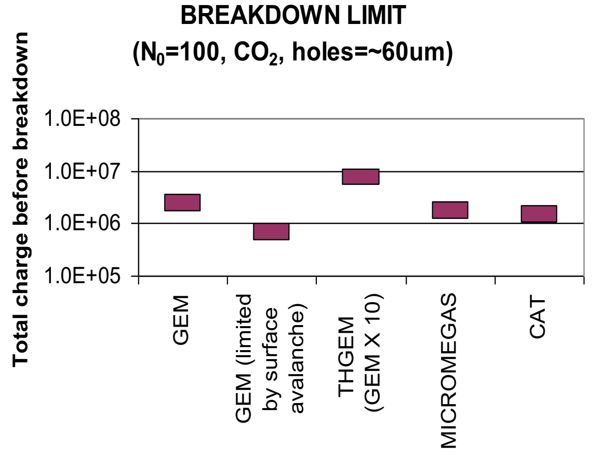
Critical charge in MPGDs

- In case of MPGDs we mainly discuss the streamer mechanism and spark discharges
- Critical charge measurements in MPGDs point to a **limit of 10^6-10^7 *e***, depending on the reference
- Different geometries, gases, sources (x-ray, alphas, etc.)
- Is the limit the same if studied differentially?

F. Sauli, Report at the RD51 collaboration meeting in Amsterdam, 2008

	DETECTOR	**MAX GAIN**	**MAX CHARGE**
i	MSGC	2000	$4\ 10^7$
ii	ADV PASS MSGC	1000	$2\ 10^7$
iii	MICROWELL	2200	$4.4\ 10^7$
iv	MICROMEGAS	3000	$6\ 10^7$
v	GEM	2000	$4\ 10^7$

P. Fonte, Simulations of discharge phenomena, RD51 meeting, Munich, 2018



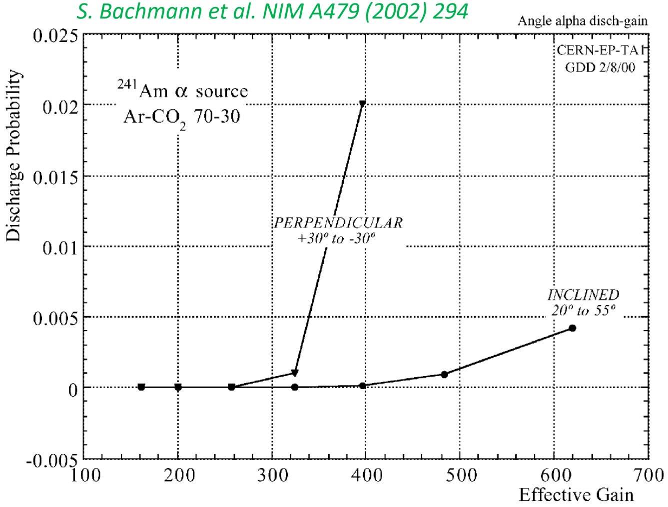
BREAKDOWN LIMIT

(N_0=100, CO_2, holes=~60um)

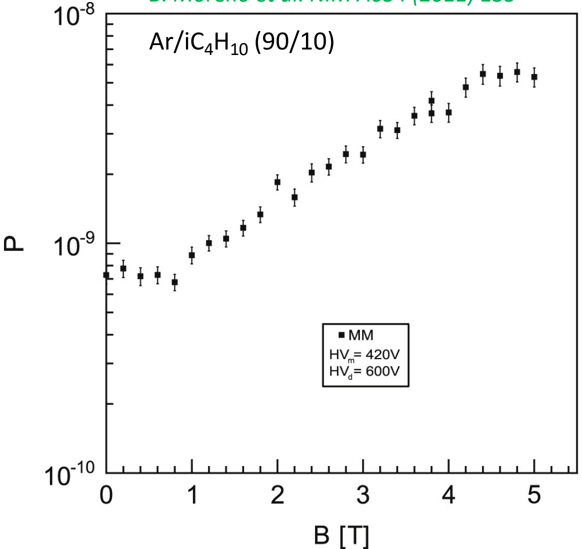
Charge density limit

- Primary charge density is a more relevant parameter than the total number of electrons
- Source inclination studies – higher charge densities per hole for perpendicular tracks impinging a GEM
- B||E studies – reduced transverse diffusion – higher (surface) charge density

S. Bachmann et al. NIM A479 (2002) 294



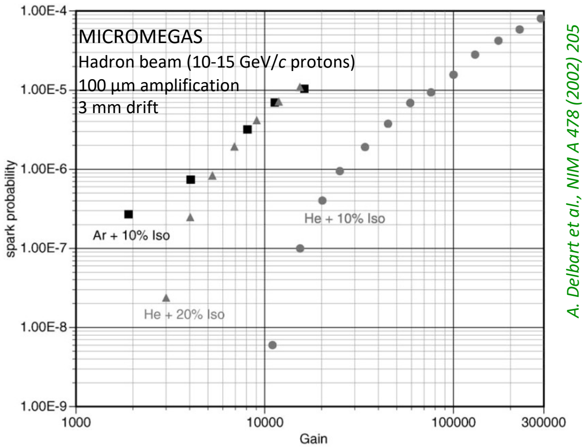
B. Moreno et al. NIM A654 (2011) 135



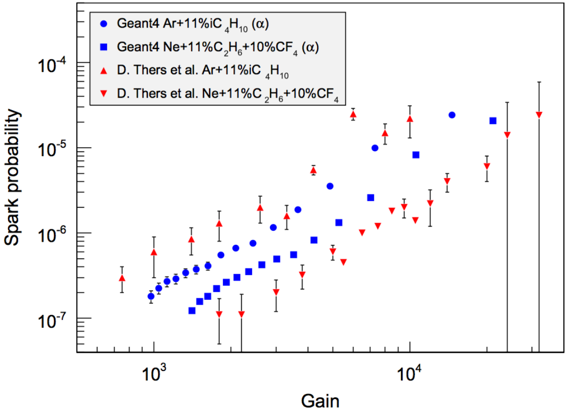
Critical charge in MPGDs

- Clear gas dependencies
- Discharge probability reduced for lighter gases ➞ charge density
- Clear correlation between discharge rate and ⟨*Z*⟩ of a gas mixture

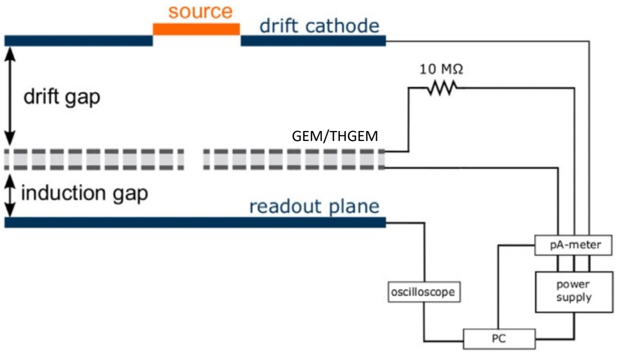
- Simulations cannot describe Ne- and Ar- data using only W_i (effective ionization potential) weights
- Intrinsic properties of the working gas (transport, amplification, streamer development) could possibly explain the differences – more studies needed
- **Charge limits – different for different mixtures?**



A. Delbart et al., NIM A 478 (2002) 205



S. Procureur et al. NIM A621 (2010) 177



GEMs and THGEMs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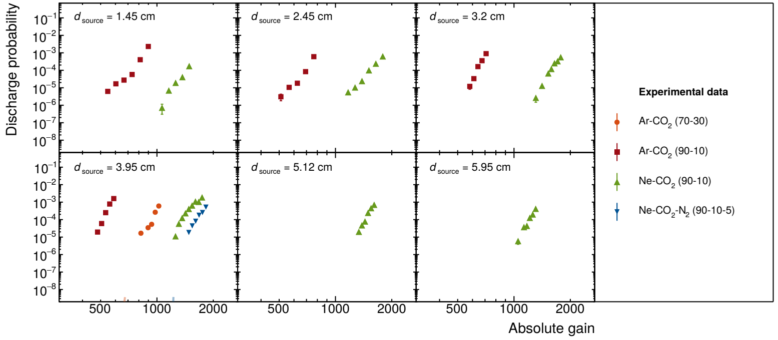
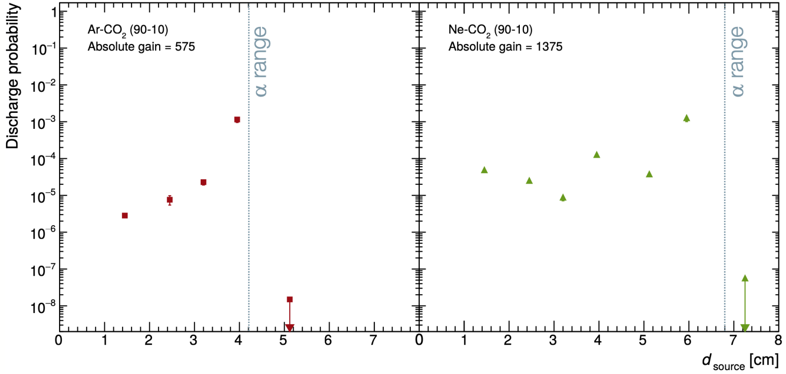
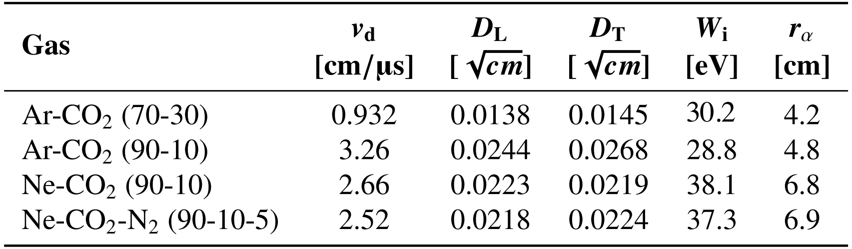
GEM discharge probability

NIM A 870 (2017) 116





- Discharge probability of a single, standard GEM upon irradiation with alpha particles:
  - – Lower breakdown limits in Argon than Neon-based mixtures
  - – Abrupt drop of discharge rate for source distances larger than alpha range
  - – Observations consistent with the primary charge density hypothesis
    - Alpha range in Ne longer than in Argon
    - W_i (Ar) < W_i (Ne)



Gas	v_d [cm/μs]	D_L [$\sqrt{cm}$]	D_T [$\sqrt{cm}$]	W_i [eV]	r_α [cm]
Ar-CO$_2$ (70-30)	0.932	0.0138	0.0145	30.2	4.2
Ar-CO$_2$ (90-10)	3.26	0.0244	0.0268	28.8	4.8
Ne-CO$_2$ (90-10)	2.66	0.0223	0.0219	38.1	6.8
Ne-CO$_2$-N$_2$ (90-10-5)	2.52	0.0218	0.0224	37.3	6.9

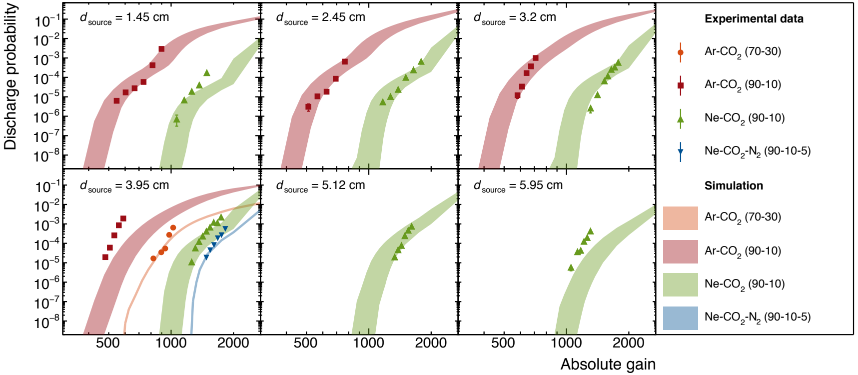
Critical charge limits in GEMs

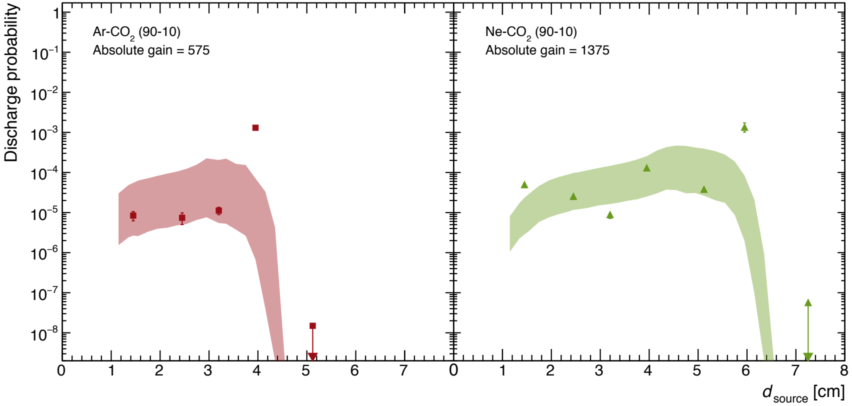
NIM A 870 (2017) 116

- GEANT4 – based model describes data fairly well over several orders of magnitude
- Only primary ionization and basic gas properties taken into account (D_L, D_T, v_d)
- No additional normalization!

Gas	Q_{crit}
Ar-CO$_2$ (90-10)	$(4.7 \pm 0.6) \times 10^6$
Ne-CO$_2$ (90-10)	$(7.3 \pm 0.9) \times 10^6$

- **Primary charge density → driving factor for discharge formation**
- **Different Q_{crit} for different gases → no universal Raether limit.**

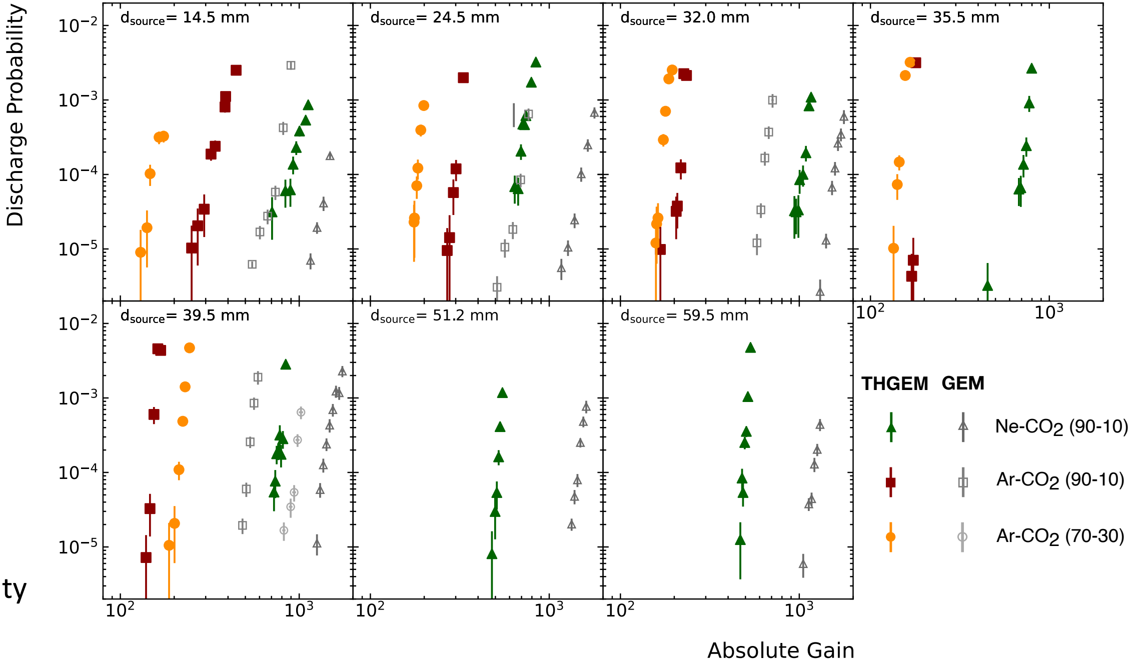




THGEM Discharge probability

NIM A 1047 (2023) 167730

- Single THGEM (COMPASS-RICH)
- ⟨*Z*⟩ dependence
    - Ne more stable than Ar ➞ charge density
- d_{source} dependence
    - Abrupt drop of the discharge rate for d_{source} > alpha range
- Quencher content dependence
    - Larger CO_2 content does not increase stability
- THGEMs less stable than GEMs
    - Primary electrons shared by lower number of holes in THGEMs



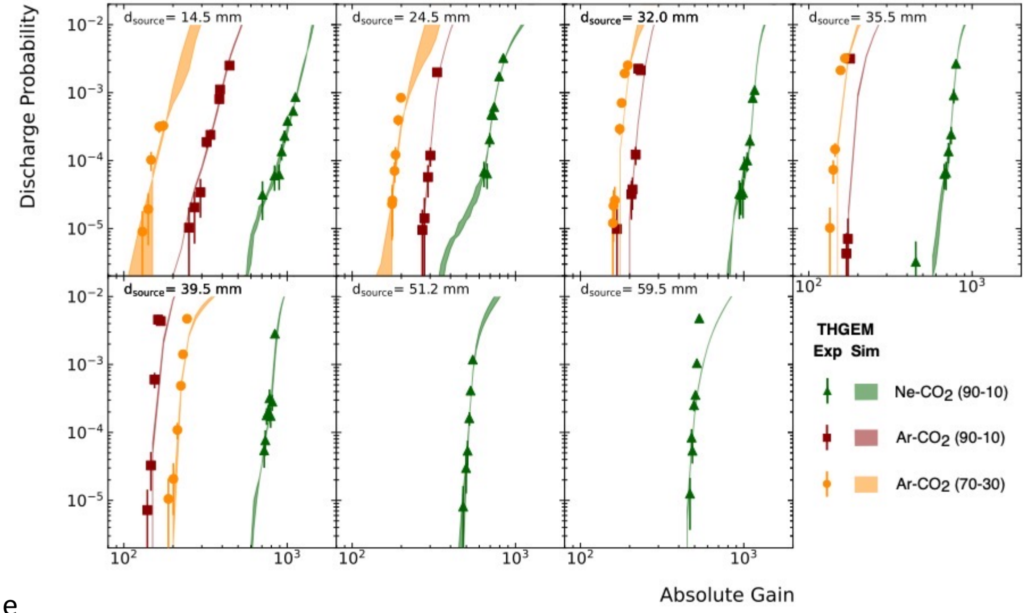
Simulation fits

NIM A 1047 (2023) 167730

- Simulated discharge curves are fitted to the data by means of χ^2 minimization for each gas and d_{source}

Q_{crit} extracted individually for each distance and averaged using a weighted mean method

- Gas dependency observed again!
- Q_{crit} for both structures agree with each other, in spite of geometrical differences!
- The primary charge limits shall be considered per single holes, not normalized to the hole volume.

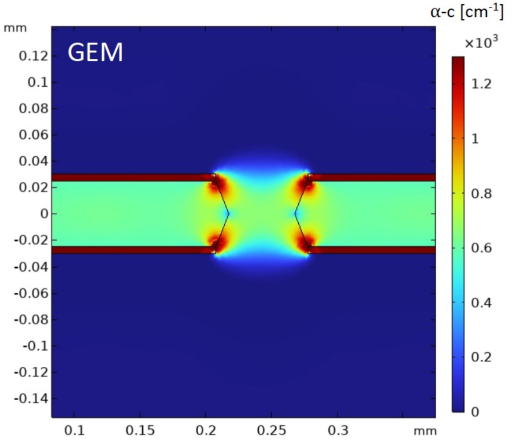


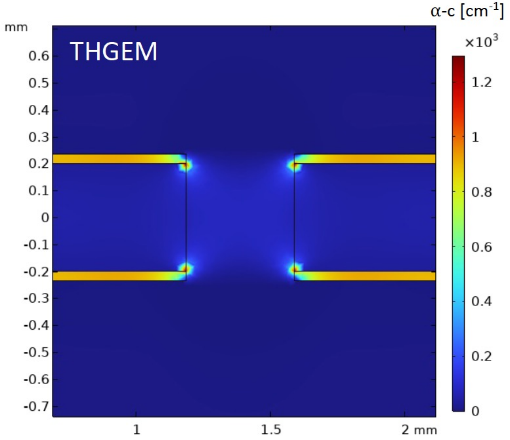
Gas	THGEM	GEM
	$\langle Q_{crit} \rangle$ $[\times 10^6\ e]$	Q_{crit} $[\times 10^6\ e]$
$Ne\text{-}CO_2$ (90-10)	7.1 ± 2.2	7.3 ± 0.9
$Ar\text{-}CO_2$ (90-10)	4.3 ± 1.5	4.7 ± 0.6
$Ar\text{-}CO_2$ (70-30)	2.5 ± 0.9	–

Townsend maps

- Q_{crit} for both structures agree with each other, in spite of geometrical differences!
- Townsend coefficient maps for a GEM and a THGEM geometry (Comsol® electric field simulation convoluted with Townsend coefficients)
- The "effective volume" of a streamer creation in a THGEM may be comparable to the size of a GEM hole

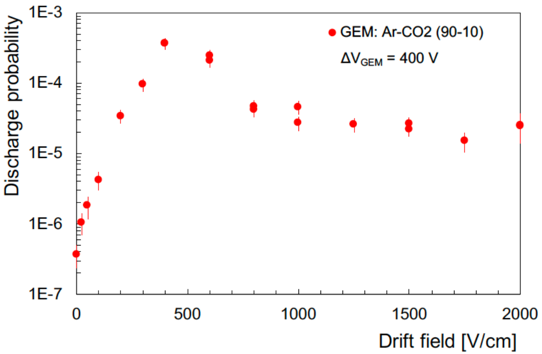
- **Detailed simulations of streamer formation are necessary! Also to understand gas dependency of Q_{crit}**

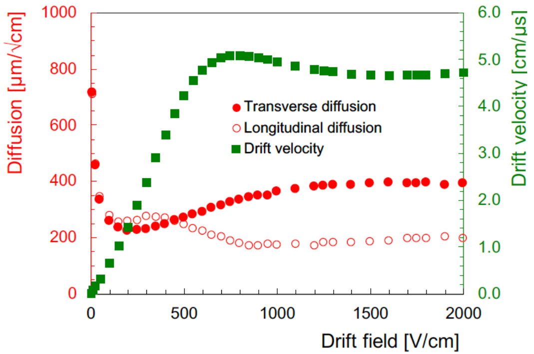


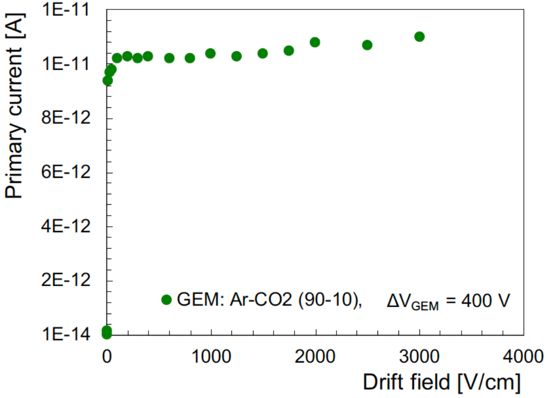


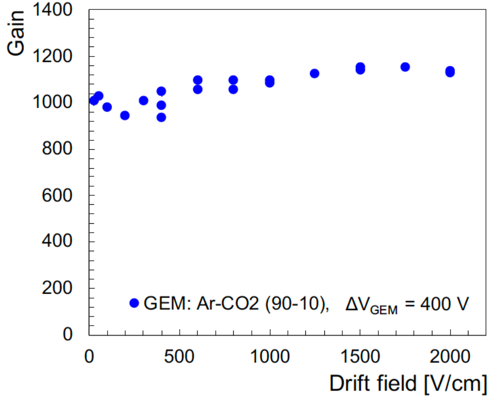
Electric field above GEM

- Clear influence of a field **above** the GEM on its stability
- Correlation with drift parameters: diffusion → charge density → discharge probability
- Increase for *E* < 400 V/cm not related to gain
- Drop for *E* > 400 V/cm not related to the collection efficiency









MICROMEGAS

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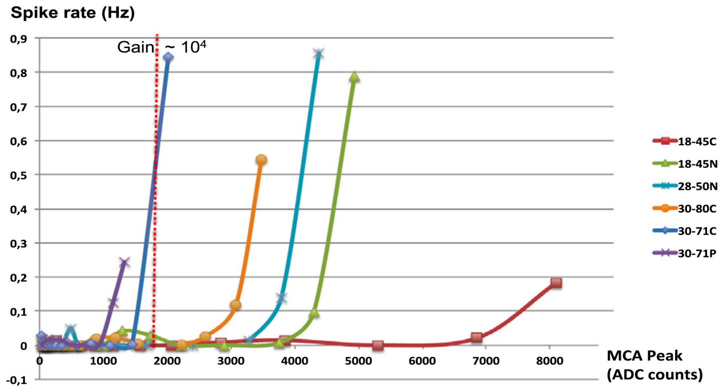
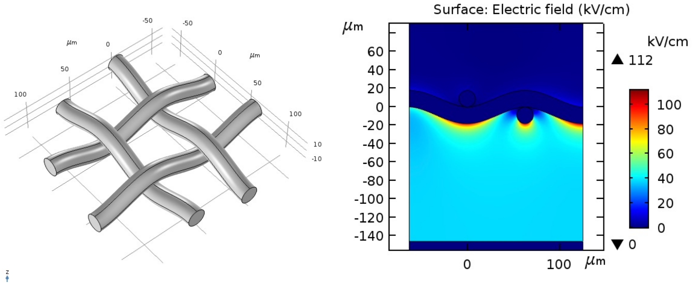
Situation in Micromegas

- Can Micromegas mesh cells be considered as individual amplification units, as GEM holes?
- If so → discharge probability shall scale with the MMG mesh cell size, i.e. higher discharge rate for large-cell meshes (small LPI)
- Difficulty → mesh parameters strongly influence E-field (high fields may further reduce the stability of the detector)
- Measurements with ^{55}Fe suggest using high-LPI meshes (Alviggi et al.)
- Field considerations with COMSOL® suggest low-LPI and thick meshes (Bhattacharya et al.)



M. Alviggi et al., NIM A 958 (2020)162359



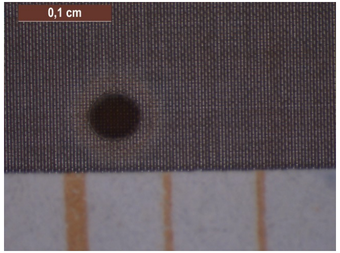
Geometry (μm)	Maximum (kV/cm)	Average (kV/cm)	$\eta(max/ave)$
18/45	112.0	38.7	2.9
22/56	110.0	38.0	2.9
25/67	109.0	37.5	2.9
28/50	104.0	38.2	2.7
30/70	104.0	37.2	2.8
30/85	106.0	36.5	2.9

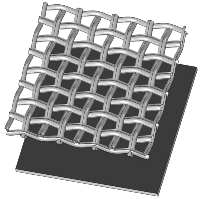
D.S. Bhattacharya et al., J. Phys. Conf. Ser. 1498 (2020) 012032

Micromegas studies

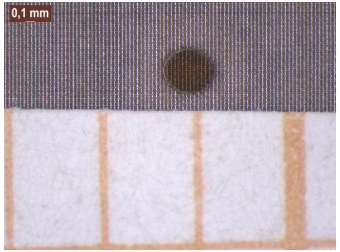
B. Ulukutlu and T. Waldmann (TU München)

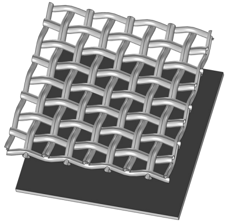
- **MMG1 - 22/13/128**
  - Wire distance: 22µm, Wire thickness: 13µm
  - Amp. gap: 128µm, LPI: 730, T_{optical} = 39.5%



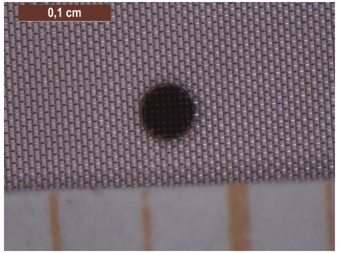


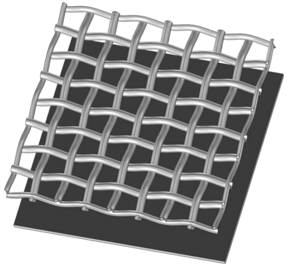
- **MMG2 - 25/15/128**
  - Wire distance: 25µm, Wire thickness: 15µm
  - Amp. gap: 128µm, LPI: 640, T_{optical} = 39%



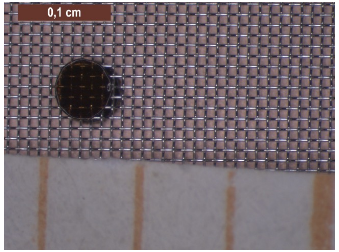


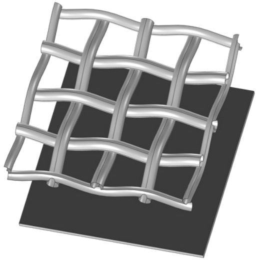
- **MMG3 - 45/18/125**
  - Wire distance: 45µm, Wire thickness: 18µm
  - Amp. gap: 125µm, LPI: 400, T_{optical} = 51%





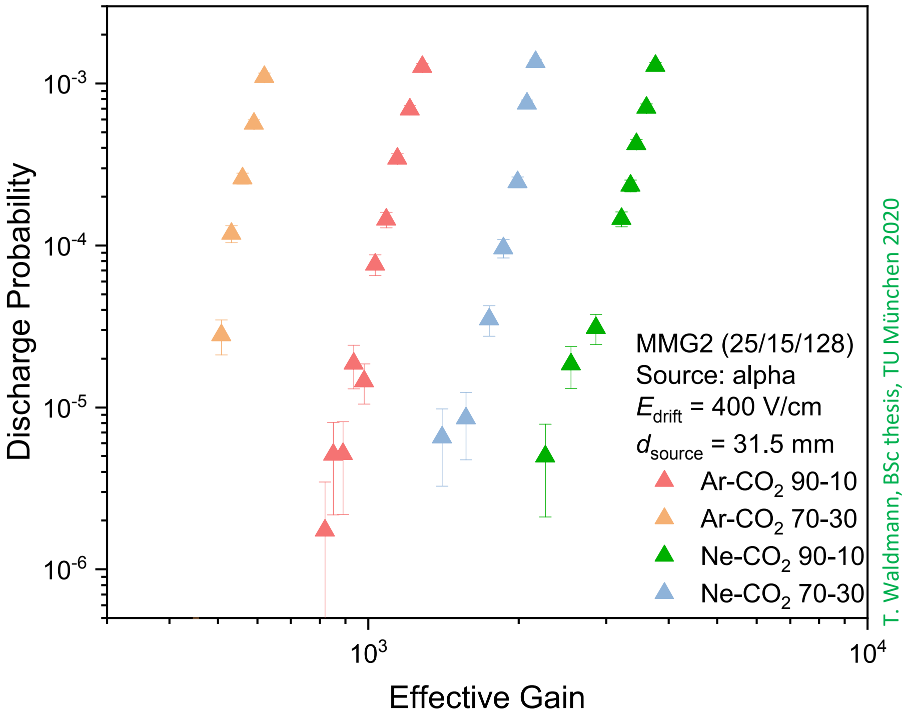
- **MMG4 - 80/30/200**
  - Wire distance: 80µm, Wire thickness: 30µm
  - Amp. gap: 200µm, LPI: 230, T_{optical} = 52%





⟨Z⟩ dependence

- Same dependency on the gas mixture as in previous measurements with GEMs and THGEMs
- For streamer and spark discharge development, more quencher does not mean more stability!
- Same order observed with other MMG types
- Primary charge density!

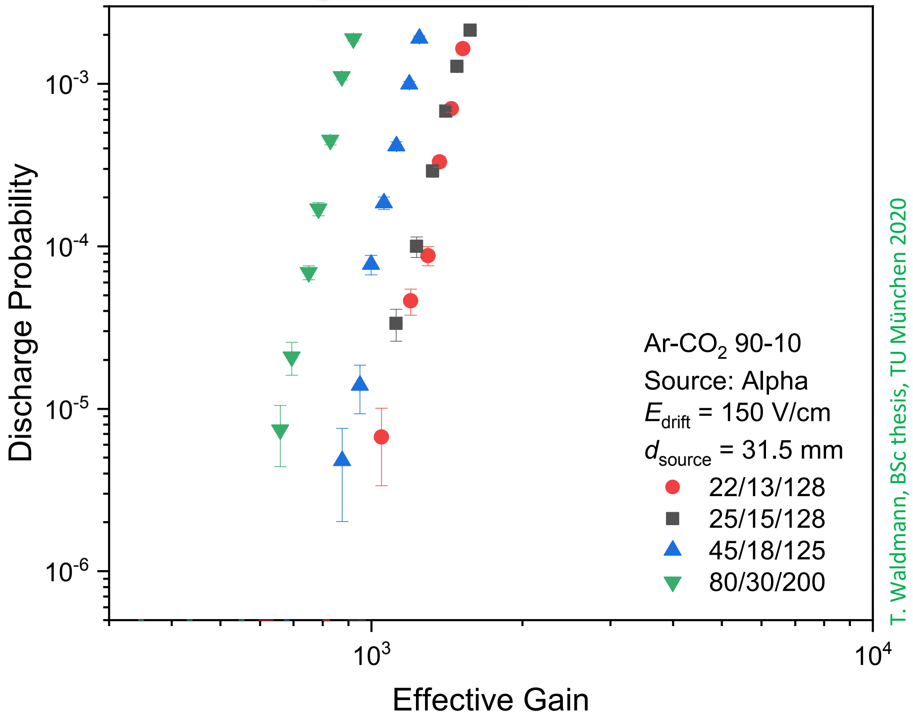


T. Waldmann, BSc thesis, TU München 2020

Discharge stability

- Electron transparency ~98% for all MMG
- d_{source} shorter than alphas maximum range
- Discharge rate scales with the mesh cell size (optical transparency)
- The influence of high fields can be disregarded by measurements with low charge densities
- Mesh cell as an independent amplification structure

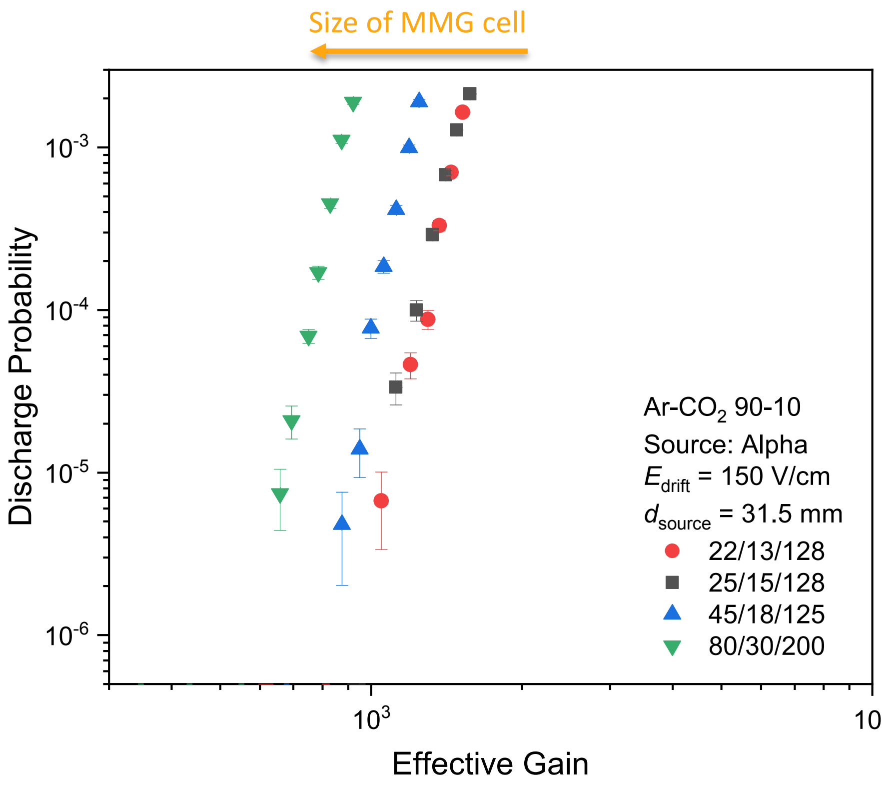
Size of MMG cell



T. Waldmann, BSc thesis, TU München 2020

Discharge stability

- High-rate & wide dynamic range operation
  - → number of cells shall be increased
  - → quencher plays a role in terms of charge densities
- Operation at high gains & lower charge densities
  - → field uniformity (peak fields, woven/calendered mesh, etc)
  - → better quenchers needed (open geometry) to reduce photon feedback
- See e.g. discussion on TMM detector (K. Liang, MPGD22, link)



T. Waldmann, BSc thesis, TU München 2020

SUMMARY

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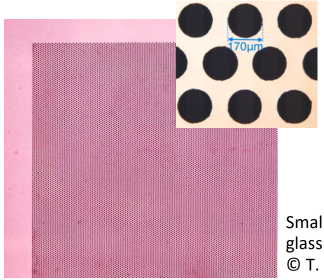
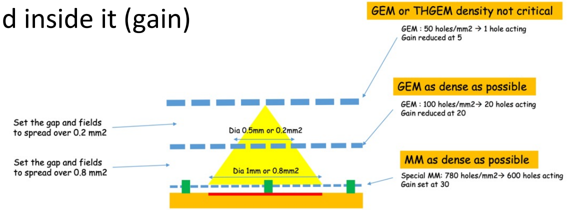
Discharge probability reduction

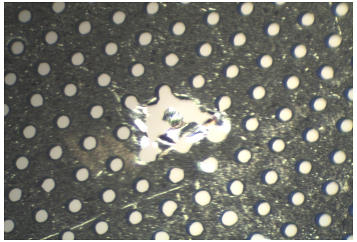
- **Reduce charge density per single amplification cell**
  - Small-pitch GEMs ➞ but production quality (glass GEMs? T. Marley, “The Migdal Experiment”, MPGD22 (link))
  - Large-LPI Micromegas ➞ but electron transparency
- **Build stacks**
  - Charge spread between several independent holes – ***Q*$_{\text{crit}}$ per hole stays the same!**
  - Optimize the electric field above/below the MPGD (diffusion, focusing, extraction/collection) and inside it (gain)
- **Optimize gas**
  - Light noble gases are preferable
  - Quencher content – optimize primary charge density and electron transport properties
  - Open geometries (e.g. Micromegas): UV photons feedback at high gains may lead to a Townsend discharge ➞ well-quenched gases preferable but watch out charge densities!
- **High absolute voltages and high fields shall be avoided**
  - High fields around defects and residual contamination may lead to instabilities (e.g. glow discharge in neon)
  - Careful detector design (rounded corners, electrode edge effects)
  - **<u>Quality control of the upmost importance</u>** (see ALICE JINST 16 (2021) P03022, CMS NIM A 1034 (2022) 166716, ATLAS NIM A 1026 (2022) 166143)



Small pitch
glass THGEM
© T. Marley



R. De Oliveira, RD51 Dynamic range workshop 18.11.21 (link)



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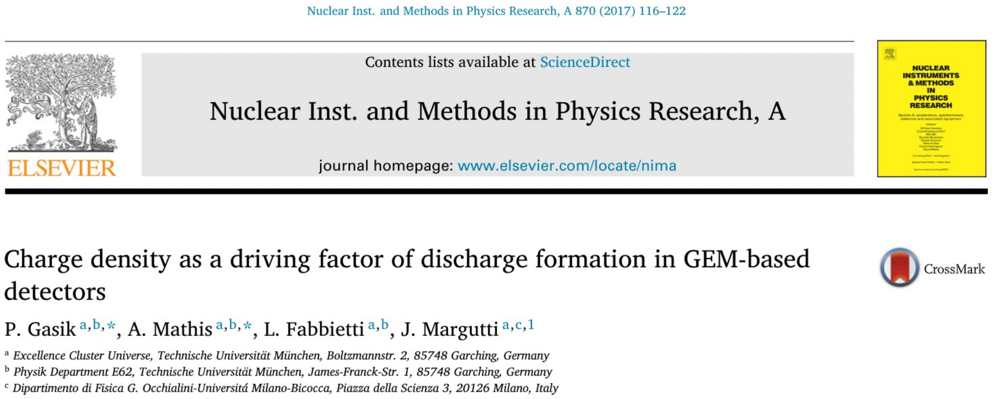

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Charge density as a driving factor of discharge formation in GEM-based detectors

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Systematic investigation of critical charge limits in Thick GEMs

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