A Large Ion Collider Experiment

DISCHARGE STUDIES WITH SINGLE- AND MULTI-GEM STRUCTURES IN A SCOPE OF THE ALICE TPC UPGRADE

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RD51 Collaboration meeting
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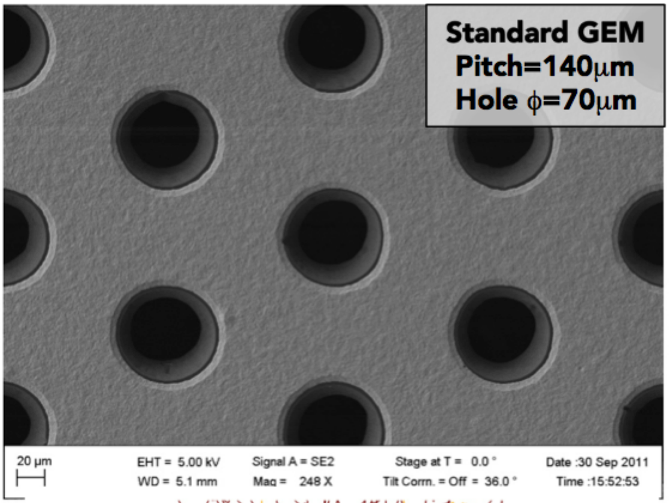
OUTLINE

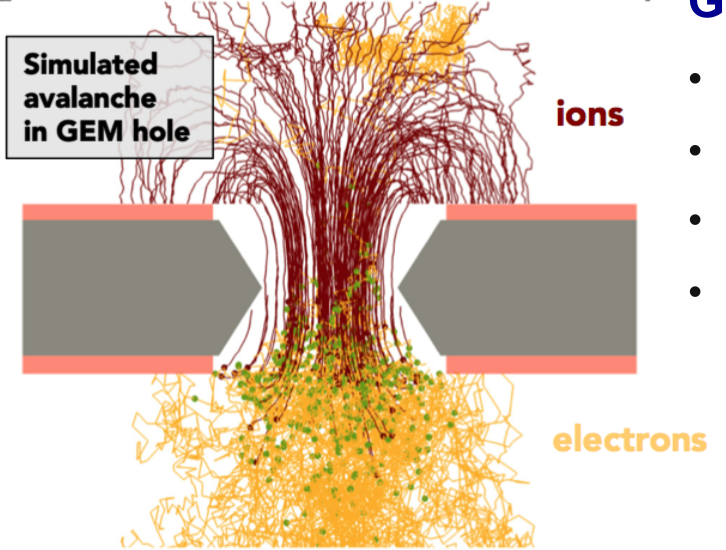
1) Motivation for discharge studies
2) Stability of ALICE GEM TPC baseline solution – R&D
3) **Discharge probability in GEM detectors – R&D**
4) **Propagation probability – R&D**
5) Summary and Outlook

ALICE TPC UPGRADE

ALICE TPC UPGRADE FOR RUN 3



Standard GEM
Pitch=140μm
Hole ϕ=70μm



Simulated avalanche in GEM hole

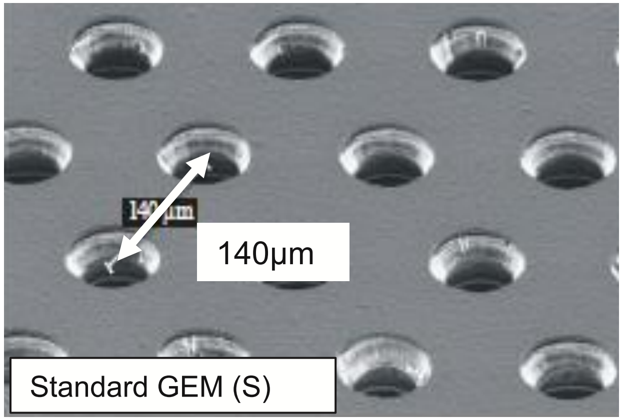
Requirements for GEM readout:

- Operate at the gain of 2000 in Ne-CO_2-N_2
- IBF < 1% at Gain = 2000 → ε = 20
- Local energy resolution < 12% for ^{55}Fe
- Stable operation under LHC conditions

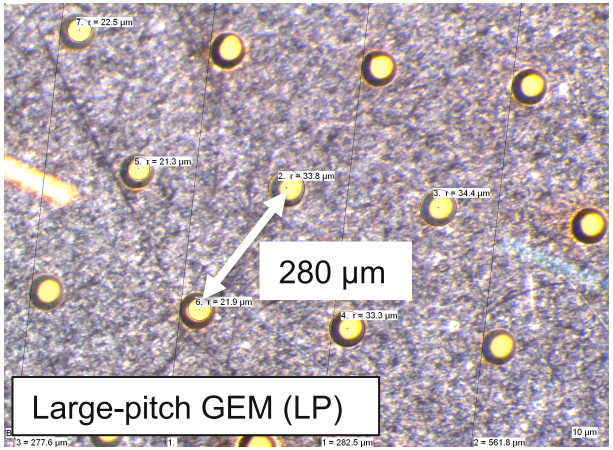
GEM-based readout chamber

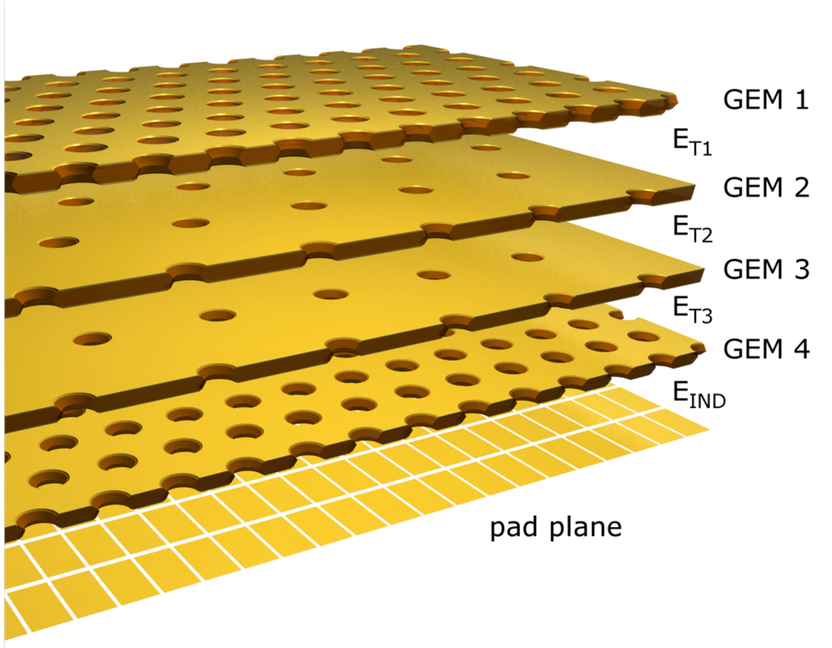
- Low ion backflow
- High rate capability
- No ion tail
- Continuous readout possible

BASELINE SOLUTION: 4-GEM SETUP

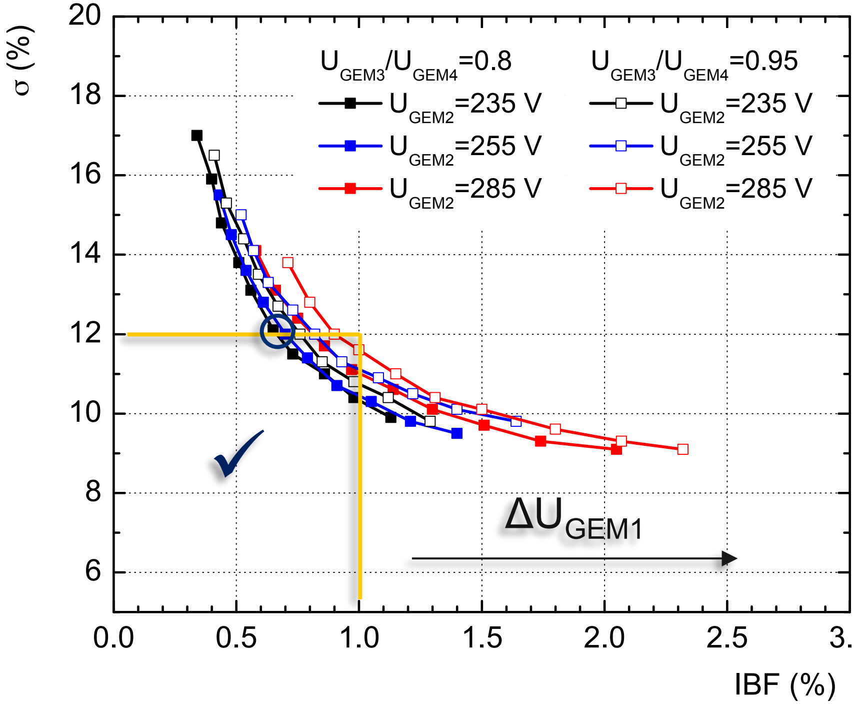


- Requirements not fullfilled with a standard 3-GEM configuration
- New readout chambers employ standard (S) and large-pitch (LP) GEMs in a configuration S-LP-LP-S
- Optimized HV settings





HV SETTINGS OPTIMIZATION



Baseline solution (S-LP-LP-S) performance:

IBF = 0.6-0.7 %

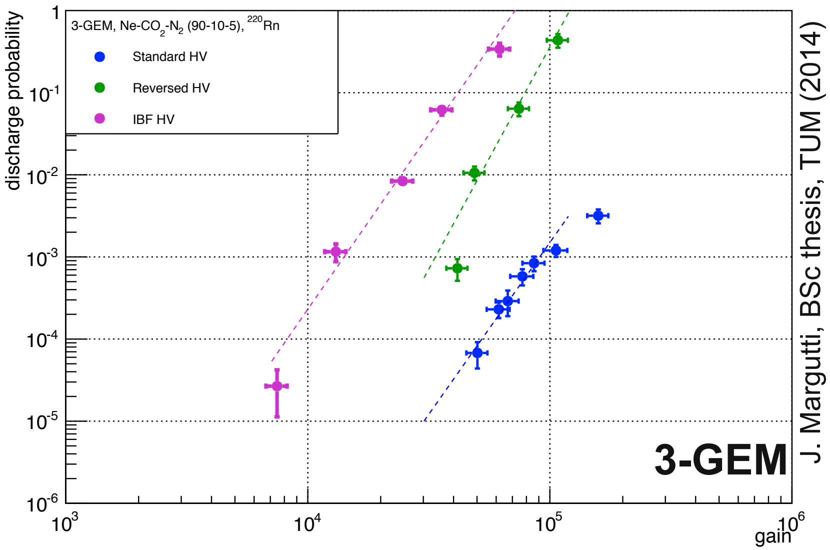
σ_E/E ≈ 12 % for 5.9 keV (^{55}Fe)

- “Standard” HV settings used with (e.g. COMPASS) not optimal for low IBF
  - **$\Delta_{GEM1} > \Delta_{GEM2} > \Delta_{GEM3}$** (largest amplification in GEM1 → stability)
- IBF optimized settings:
  - **$\Delta_{GEM1} > \Delta_{GEM2} \approx \Delta_{GEM3} << \Delta_{GEM4}$** (largest amplification in GEM4)
  - **High E_{T1}, E_{T2}** (high electron extraction from the first GEM stages)
  - **Low E_{T3}** (ion blocking)

STABILITY STUDIES
OF THE
BASELINE 4-GEM SOLUTION

DISCHARGE STUDIES WITH ALPHA PARTICLES

Baseline HV solution for the ALICE Upgrade



J. Margutti, BSc thesis, TUM (2014)

- Different HV settings have been tested with a 3-GEM configuration
- "<u>Standard</u>" → "<u>IBF</u>"
  - Standard – optimized for stability (COMPASS)
  - IBF → optimized for IBF (ALICE)
- Significant drop of stability while using IBF settings with a typical 3-GEM configuration

- **4-GEM configuration,** optimized for energy resolution and IBF is also stable against electrical discharges

	S-S-S	**S-S-S-S**		**S-LP-LP-S**		
	'standard' HV G = 2000	*IB* = 2.0% G = 2000	*IB* = 0.34% G = 1600	*IB* = 0.34% G = 3000	*IB* = 0.34% G = 5000	*IB* = 0.63% G = 2000
^{220}Rn $E_\alpha = 6.4$ MeV rate = 0.2 Hz	$\sim 10^{-10}$			$< 2\times10^{-6}$	$< 7.6\times10^{-7}$	
^{241}Am $E_\alpha = 5.5$ MeV rate = 11 kHz						$< 1.5\times10^{-10}$
^{239}Pu+^{241}Am+^{244}Cm $E_\alpha = 5.2+5.5+5.8$ MeV rate = 600 Hz		$< 2.7\times10^{-9}$	$< 2.3\times10^{-9}$	$(3.1\pm0.8)\times10^{-8}$		$< 3.1\times10^{-9}$
^{90}Sr $E_\beta < 2.3$ MeV rate = 60 kHz					$< 3\times10^{-12}$	

ALICE TPC Upgrade TDR Addendum, CERN (2015)

RATE CONSIDERATIONS FOR RUN 3

Typical yearly Pb-Pb run: $\mathbf{10^6}$ **s**

Charged particle multiplicity: $\langle \mathrm{d}N_{\mathrm{ch}} / \mathrm{d}\eta \rangle = 500$

Coverage of the TPC read-out plane: **1*η* unit**

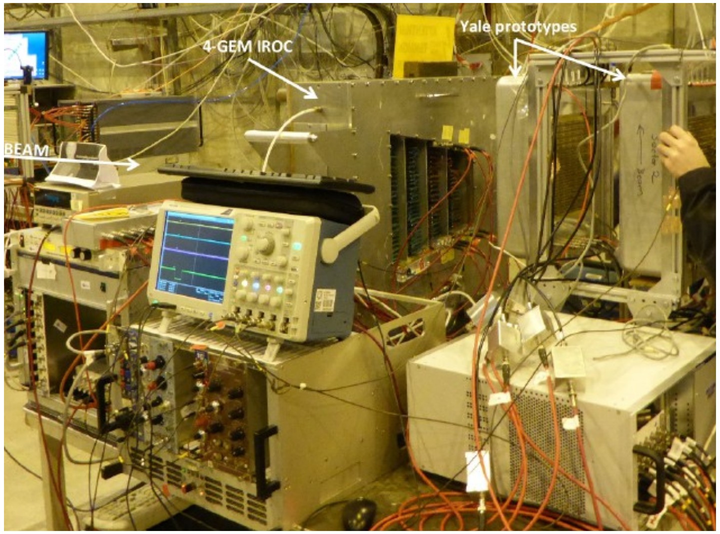
No. particles expected in the TPC at 50 kHz: $500 \times 2 \times 50000 \times 10^6 = \mathbf{50 \times 10^{13}}$

Background: **× 2**

Number of particles accumulated per stack (1 of 144): $\mathbf{7 \times 10^{11}}$ per Pb-Pb year

STABILITY STUDIES AT SPS (RD51 BEAMTIME)

with a full-size 4-GEM IROC prototype



150 GeV/*c* high intensity pion beam hitting Fe absorber: ~5×10^{11} particles accumulated

Discharge probability measured: (6.4±3.7)×10^{-12} per incoming hadron

All measured discharges were non destructive!

Performance similar to **standard** triple GEMs measured in similar conditions

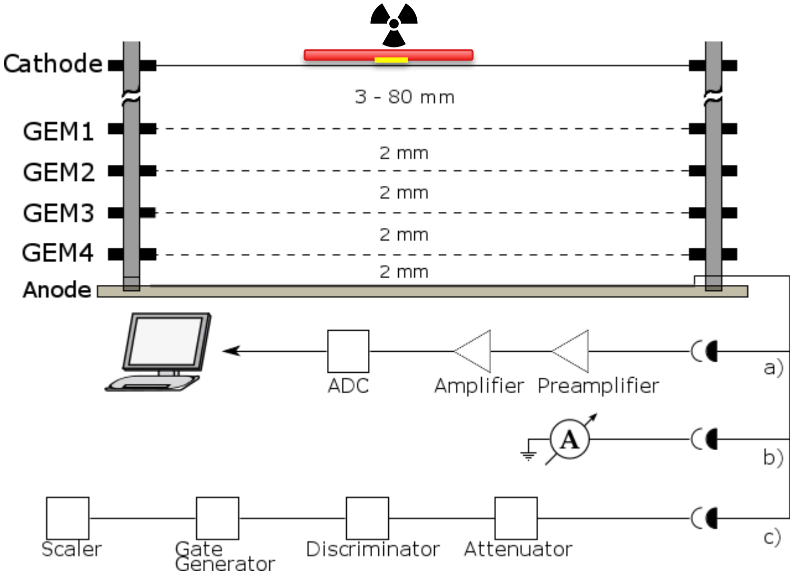
(G. Bencivenni et al. NIM A 494 (2002) 156)

Estimate for RUN3:

- 650 discharges in the TPC per typical yearly Pb-Pb run
- 5 per stack
- Safe operation guaranteed

DISCHARGE PROBABILITY STUDIES
- R&D WITH ALPHA PARTICLES -

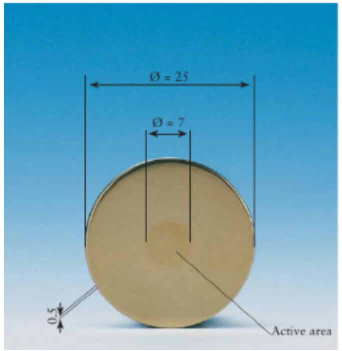
EXPERIMENTAL SETUP

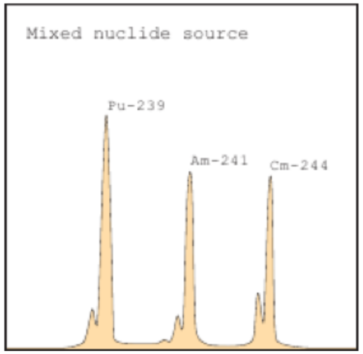


- 10x10 cm^2 GEMs

  (140 um – 240 um pitch, double-mask)

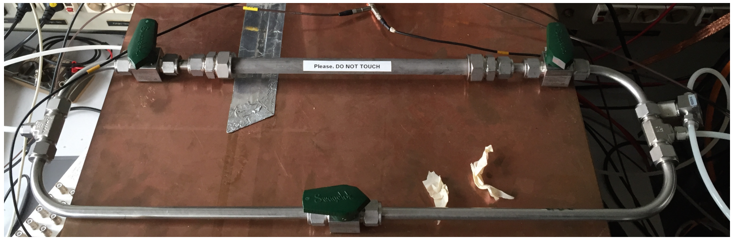
  (CERN, TECHTRA)
- Modular setup, no FC
- 1 – 4 GEM stacks
- Adjustable drift gap
- Current/discriminator readout
- Drift field: 400 V/cm (if not stated differently)





“Coin” mixed source

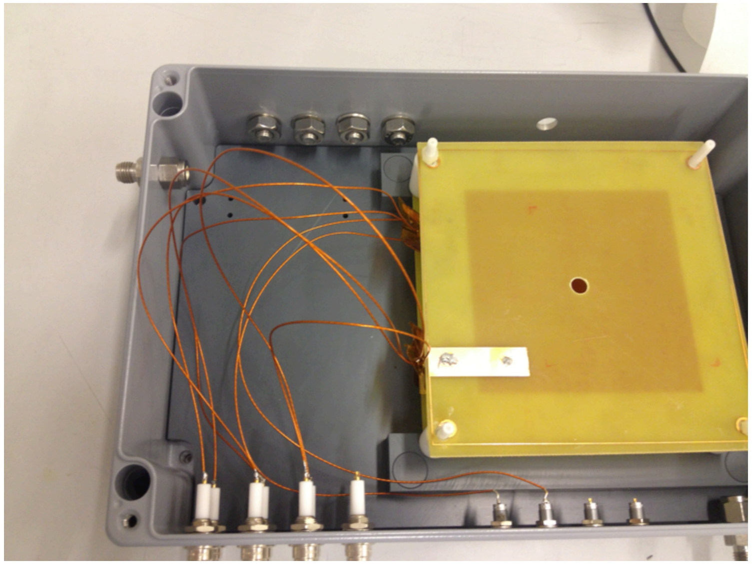
- **^{239}Pu + ^{241}Am + ^{244}Cm,**
- 5.2 MeV + 5.5 MeV + 5.8 MeV
- A = 3 kBq (each)
- Rate = 500-600 Hz



Gaseous sources

- **^{220}Rn**
- 6.4 MeV
- Rate = 0.5 – 15 Hz

EXPERIMENTAL SETUP



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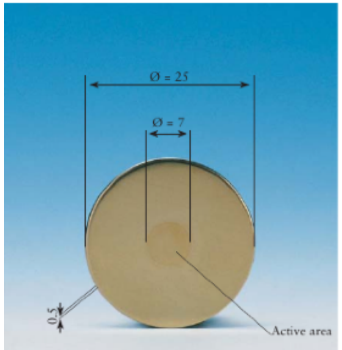

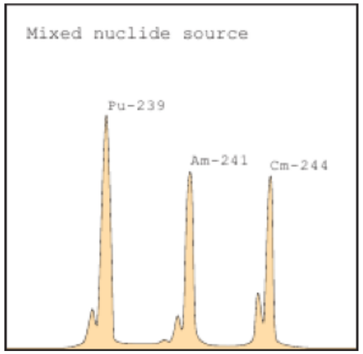

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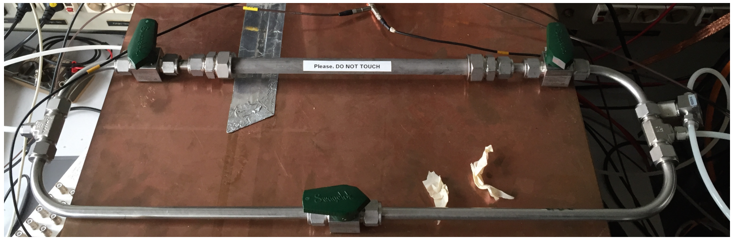

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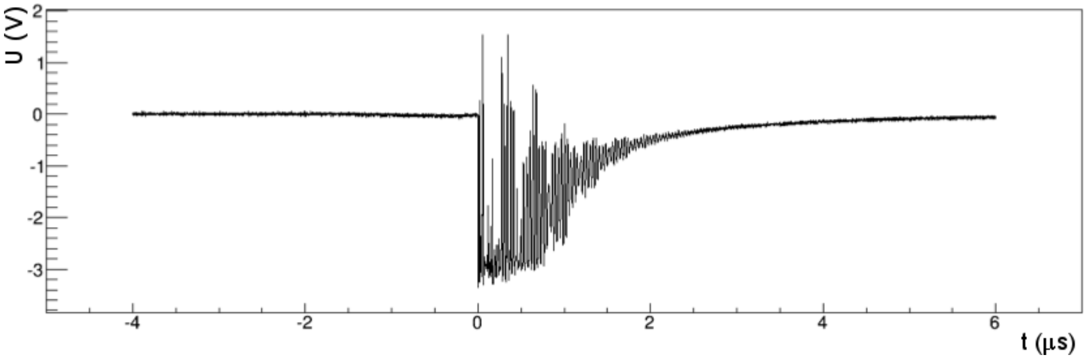
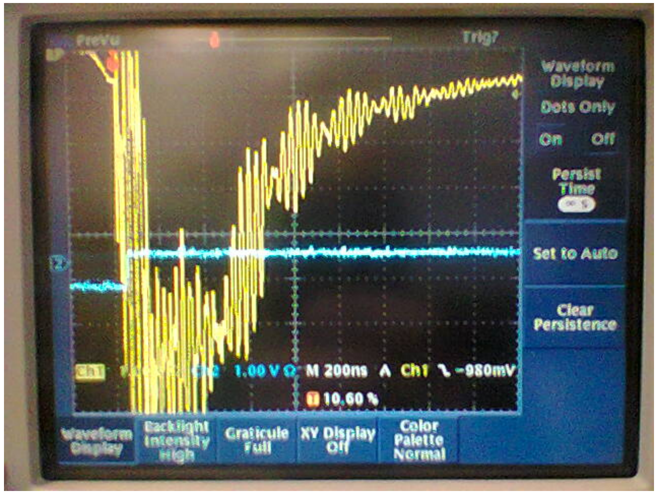
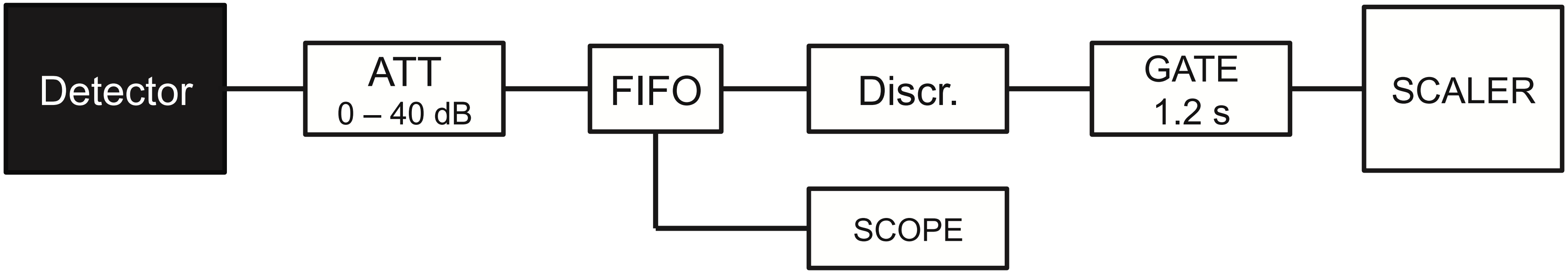
DISCHARGE MEASUREMENTS






Detector

ATT
0 – 40 dB

FIFO

Discr.

GATE
1.2 s

SCALER

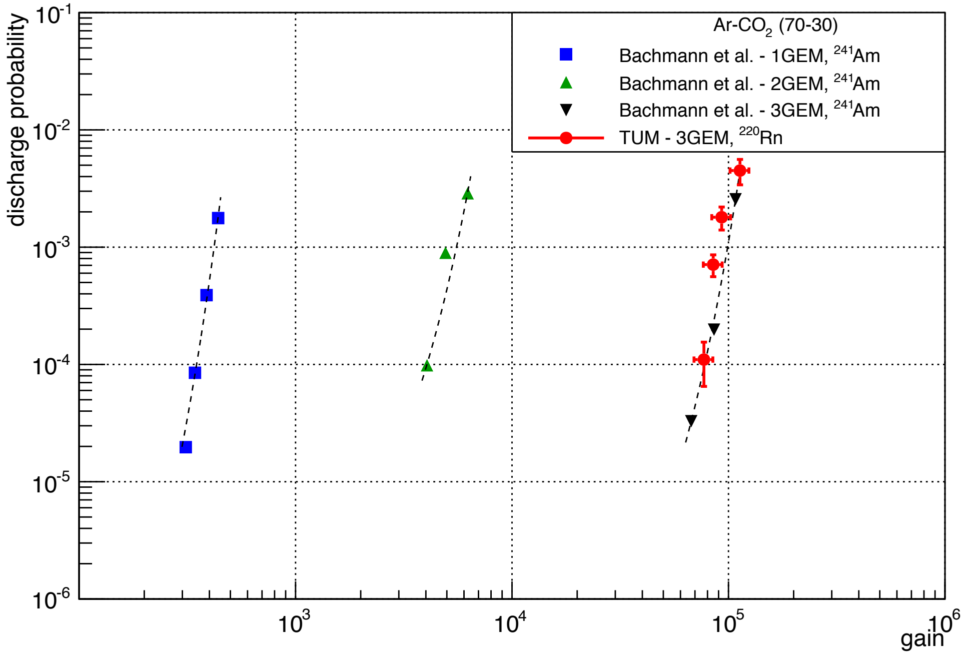
SCOPE

- 10 Mohm loading resistance on top side of GEM (if not stated differently)
- Resistor chain or independent channels HV supply
- $P = N_{spark}/(t*rate)$

3GEM STUDIES

CROSS-CHECK WITH LITERATURE

F. Sauli et al. NIM A 479 (2002) 294

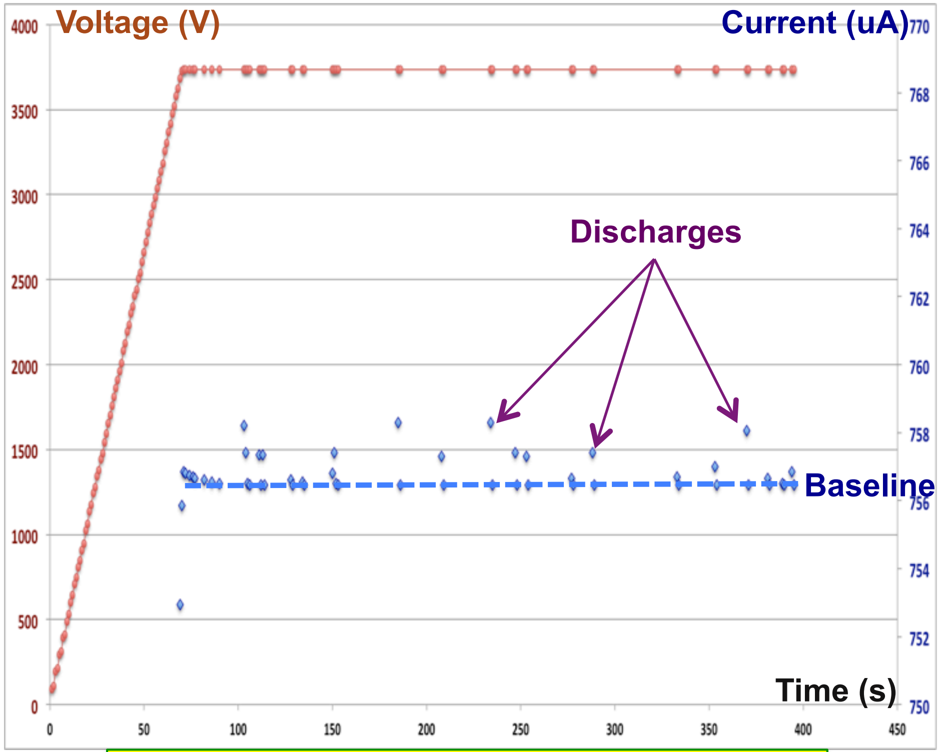


- Low intensity ^{220}Rn source (TUM)
- Standard HV settings;
- Gain measured with ^{55}Fe
- Fairly good agreement

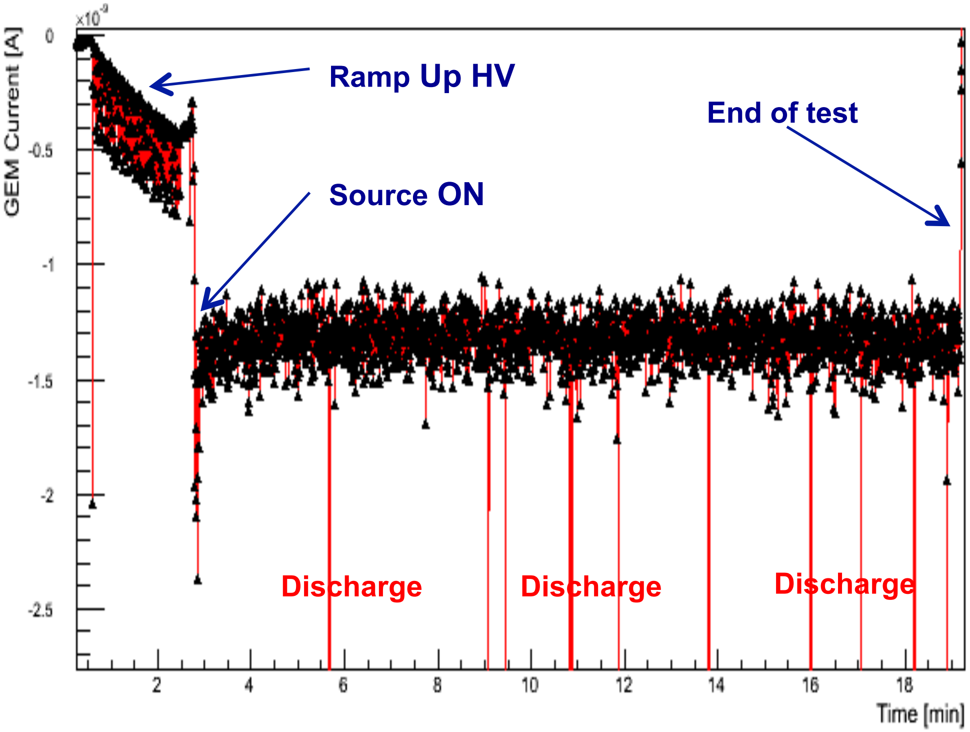
FOR COMPARISON: CMS RESULTS

Courtesy of Jeremie Merlin, 16.06.2014, ALICE TPC Workshop

10x10 GEM reference measurements: discharge probability



Power supply I/V measurements



Readout current (pico-ammeter)

→ HV power supply and pico-ammeter not fast/sensitive enough to detect all discharges

FOR COMPARISON: CMS RESULTS

Courtesy of Jeremie Merlin, 16.06.2014, ALICE TPC Workshop

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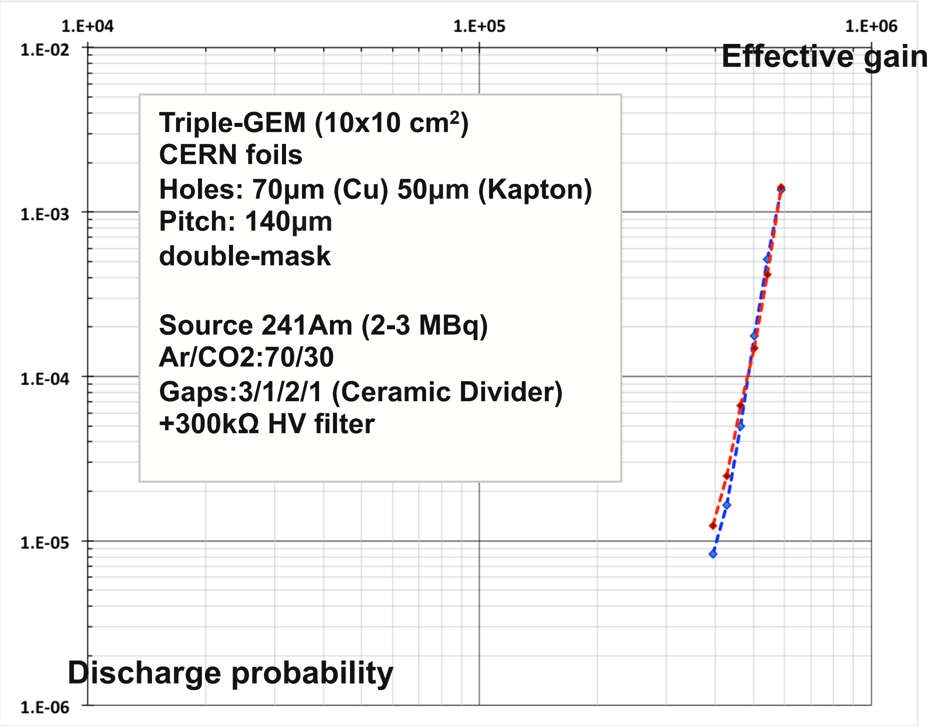
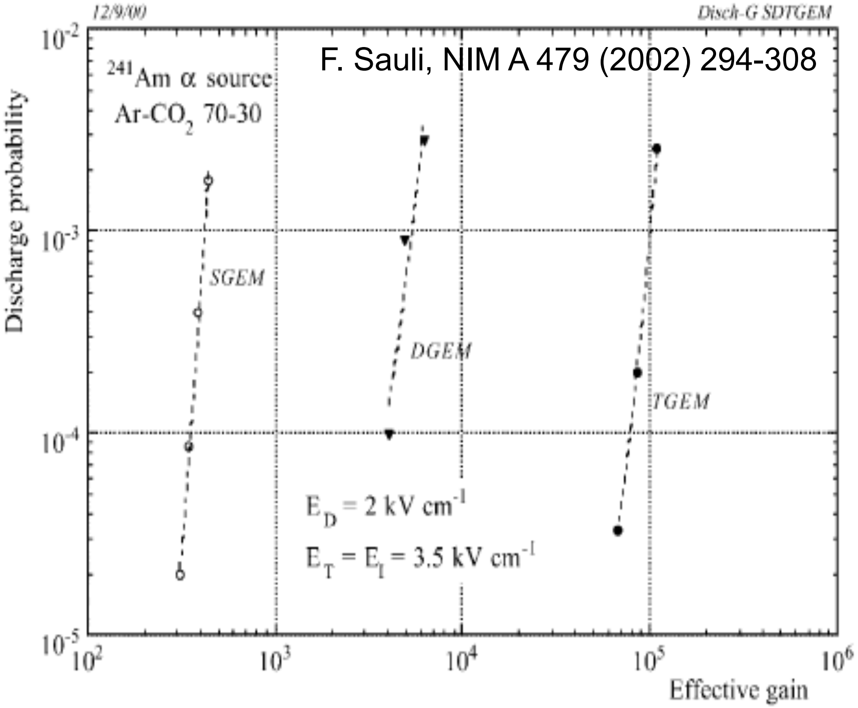


Triple-GEM (10x10 cm^2)
CERN foils
Holes: 70µm (Cu) 50µm (Kapton)
Pitch: 140µm
double-mask

Source 241Am (2-3 MBq)
Ar/CO2:70/30
Gaps:3/1/2/1 (Ceramic Divider)
+300kΩ HV filter

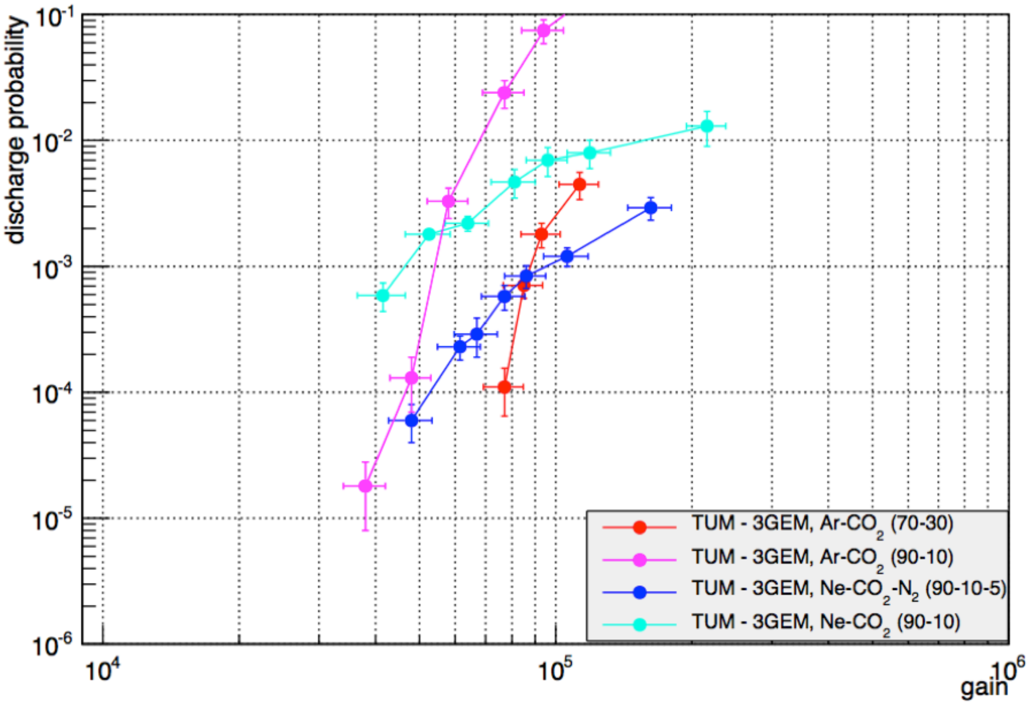


F. Sauli, NIM A 479 (2002) 294-308

@Gain=6.10^5 (3700V/740uA) : ΔV_{GEM1}= 416V ΔV_{GEM2}= 407V ΔV_{GEM2}= 389V

DEPENDENCE ON GAS MIXTURE

3-GEM, 220Rn source, Standard HV



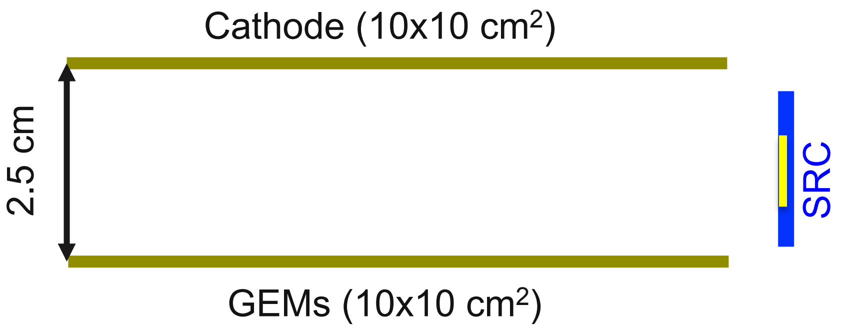
- **<u>Standard HV settings;</u>**
  <u>Gain measured with ^{55}Fe</u>
- Measurement for TPC gas mixtures:
  Ar-CO_2 (90-10), **Ne-CO_2 (90-10)**,
  Ne-CO_2-N_2 (90-10-5)
- Different slopes for Ar- and Ne-based mixtures.
- Clear influence of additional quencher

- Measurements at a very high gain
- Saturation effects?
- Not clear dependence towards lower gains

- <u>Switch to high-rate source</u>

FIRST RESULTS WITH HIGH RATE SOURCE

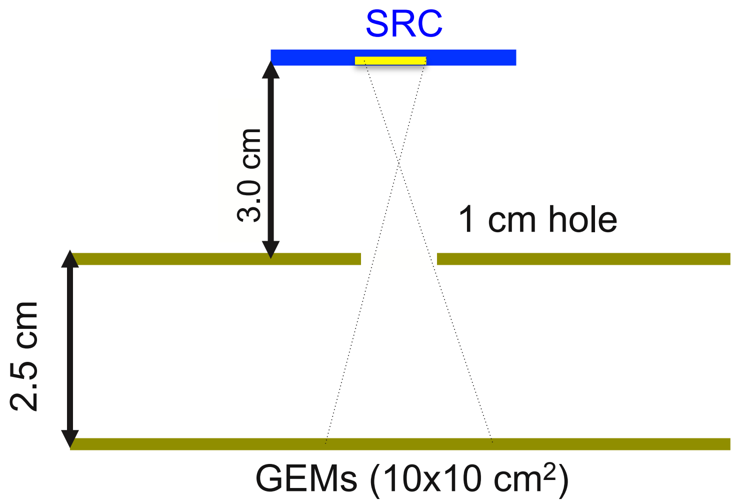
- First results were very surprising. Measurements in Ne-CO_2-N_2 (90-10-5) at G=100000 (^{55}Fe) have shown factor of 1000 lower discharge probability in comparison to measurements with ^{220}Rn source
- This led us to have a closer look at drift (field/gap) dependency



First try:

discharge probability $(2.4 \pm 1.4)\times10^{-6}$

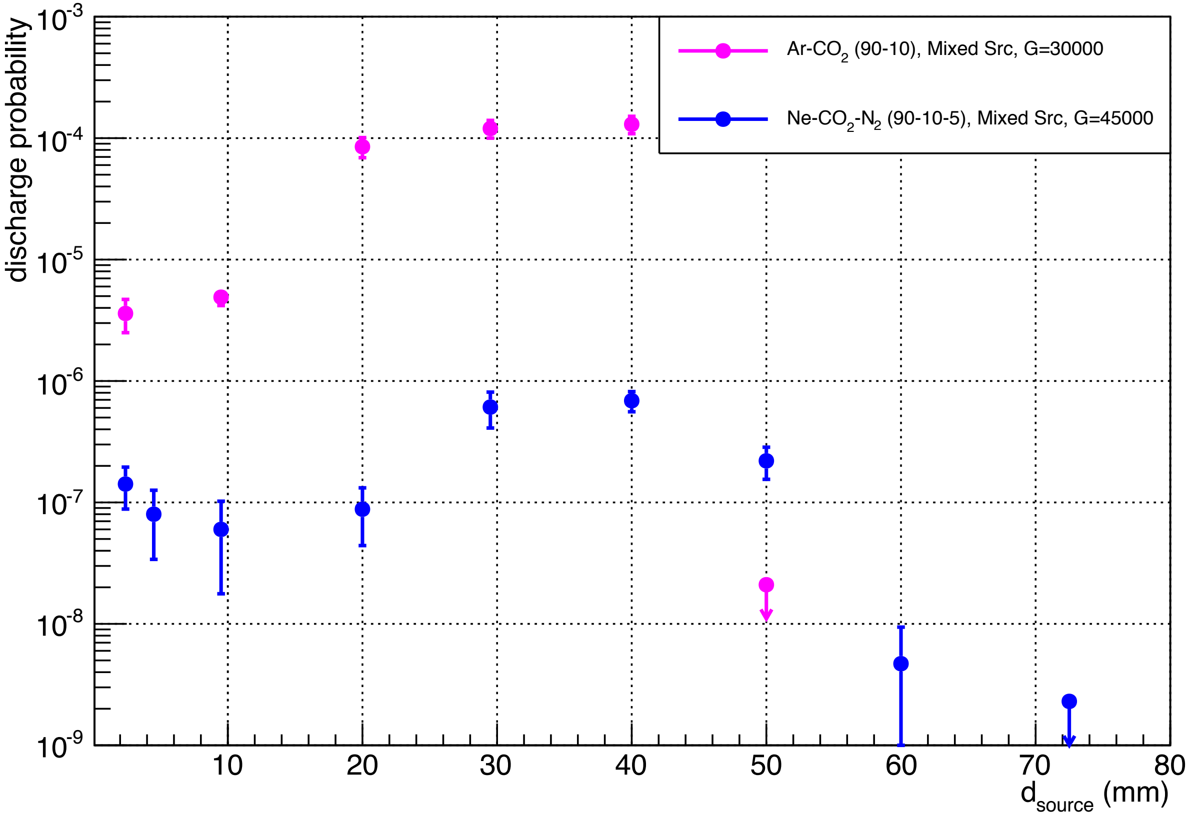
With ^{220}Rn: $\mathcal{O}(10^{-3})$



First try:

Upper limit: $P < 5\times10^{-5}$

DRIFT GAP SCANS WITH STANDARD SETTINGS

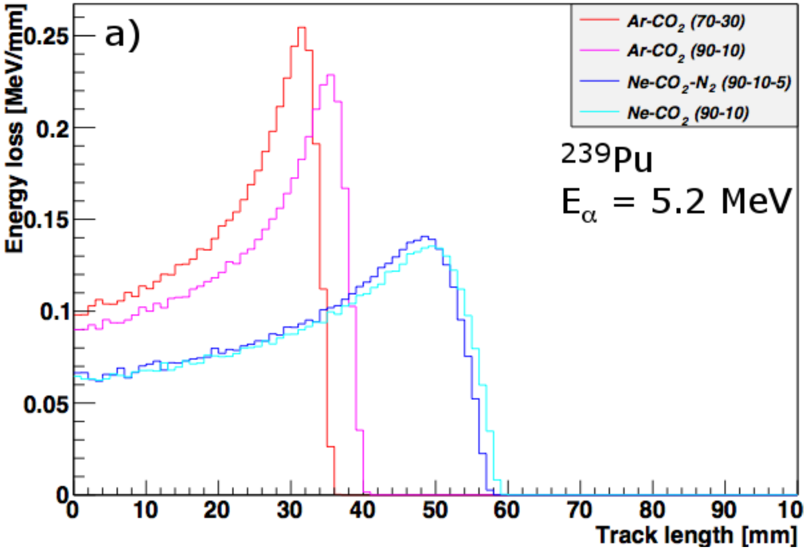


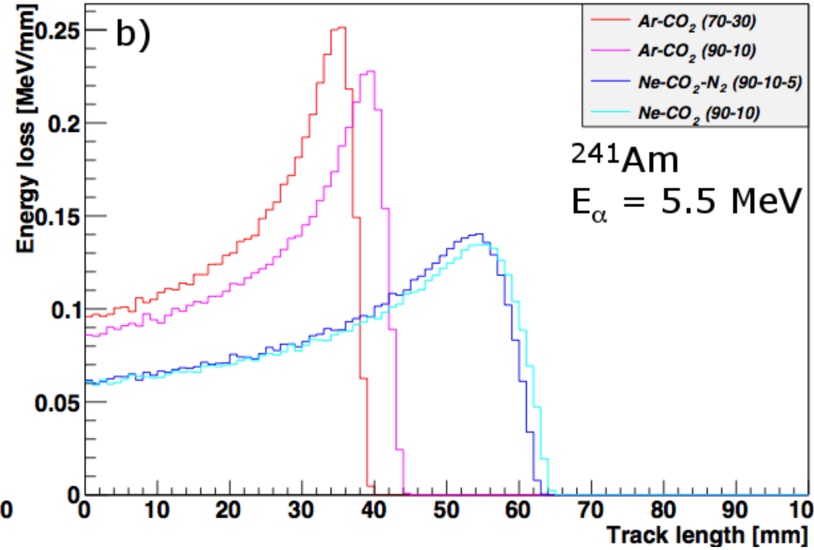
- Measurement performed with a mixed source – fixed position and solid angle
- Discharge probability drops significantly after d>40 mm in Ar-CO2 and d>60 mm in $Ne-CO_2-N_2$
- ↓ - upper limit (no spark measured in a given time)
- See: Bragg curves

- **ALCIE Stability studies with d_{source} in a plateau region**

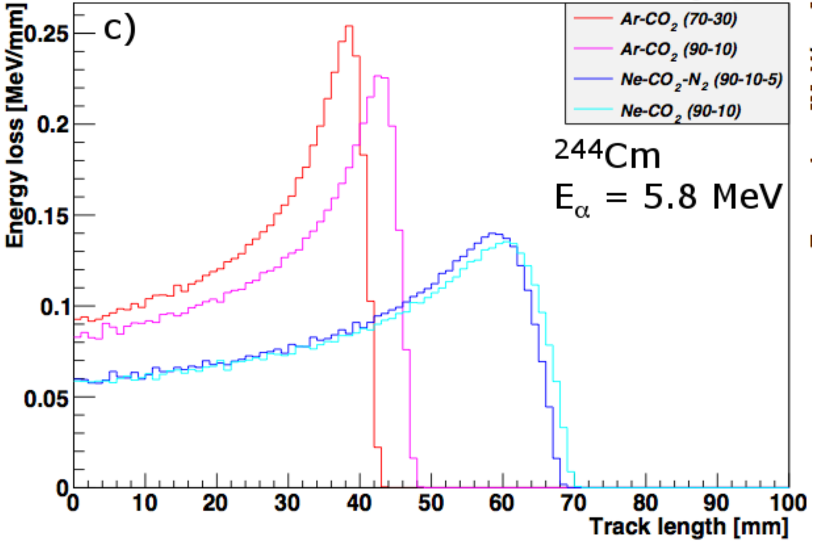
BRAGG CURVES FOR THE MIXED SOURCE

G4 simulations





F. Dreher, BSc thesis, TUM (2014)



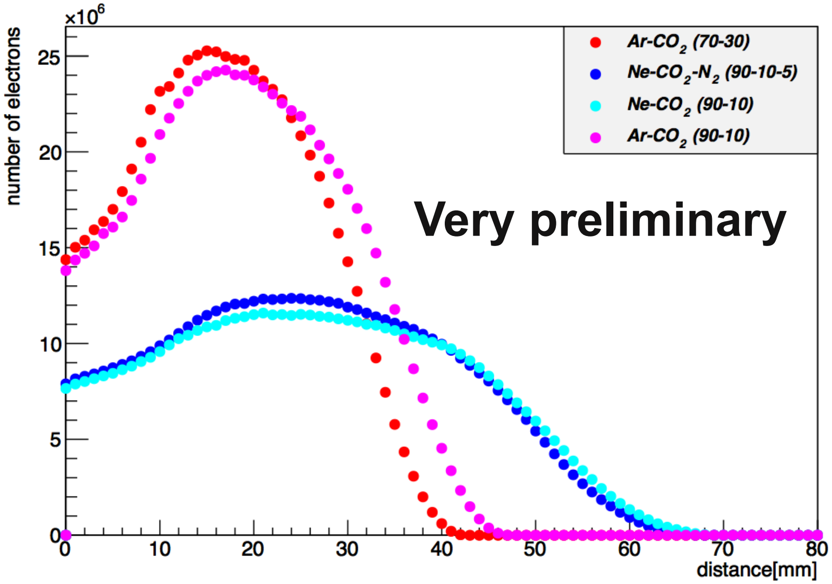
- Alpha ranges in Ar- and Ne- based mixtures coincide with discharge dependency on drift gap

- Great role of primary charge density!

SIMPLE G4 SIMULATIONS

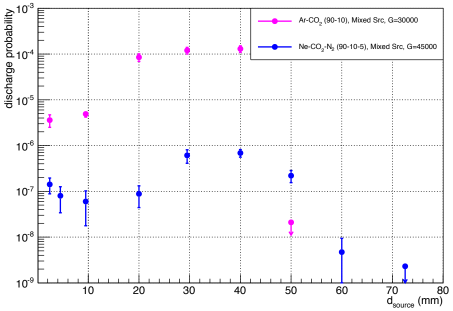
Simulations of > 4000 events from the mixed source ($E_D = 0$)

Plot number of electrons liberated at the given distance from the source, integrated over 10x10 cm^2 area (GEM plane)



Very preliminary

F. Dreher, BSc thesis, TUM (2014)



Shape of discharge curves may already be explained with this simple geometrical studies

- Steep slope for Ar-, softer for Ne-
- Plateau

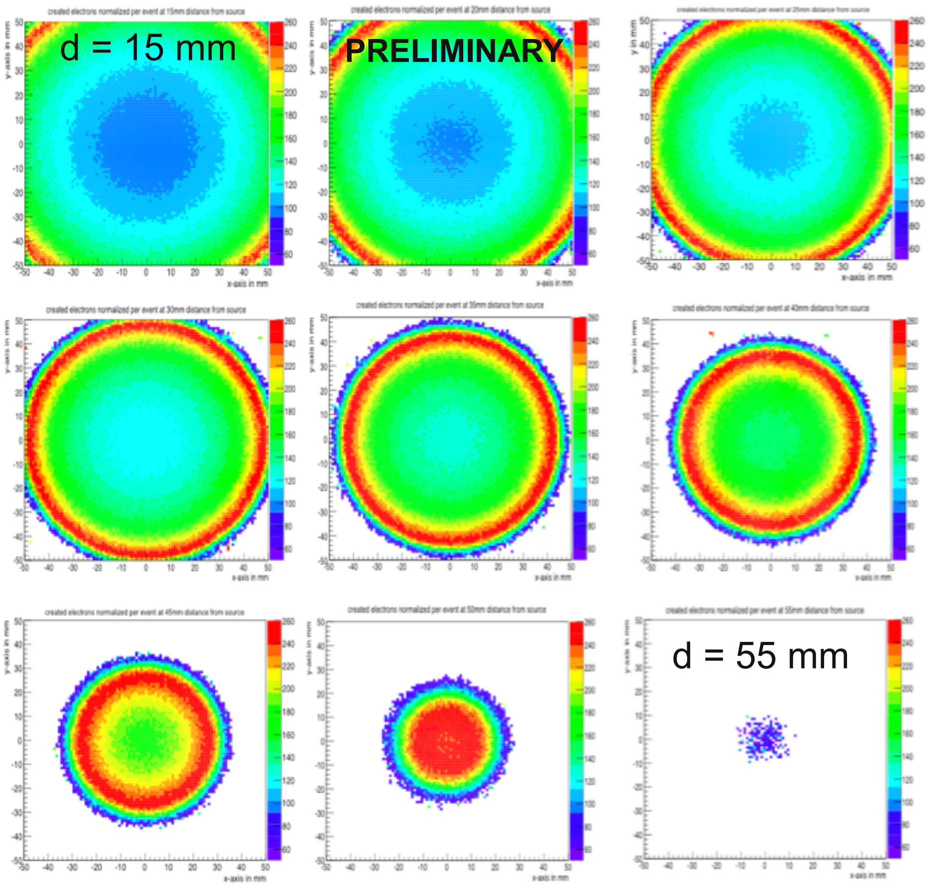
Still few inconsistencies to be understood and solved.

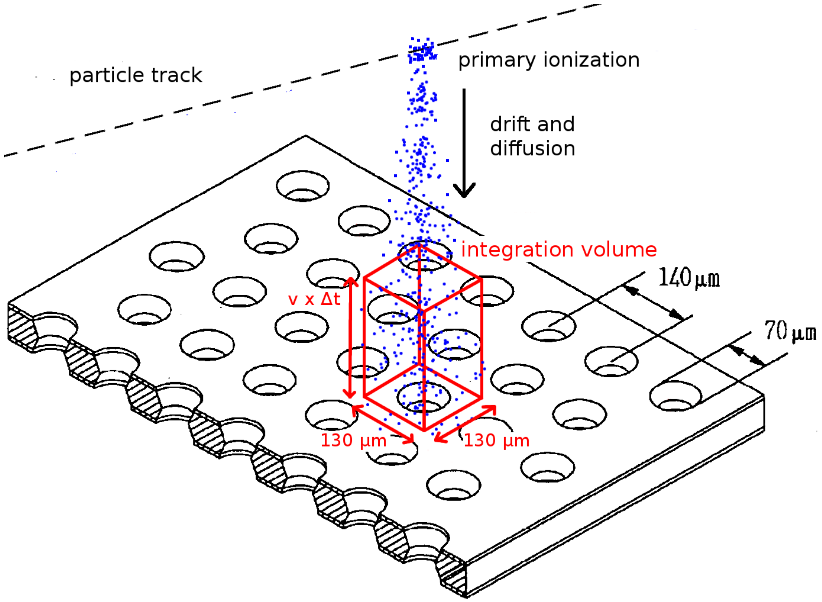
NEXT STEPS

Ongoing – more results soon!

Plot number of high ionization clusters as a function of drift gap; add drift and diffusion; 1GEM measurement!

G. Querimi, BSc thesis, TUM (2015)

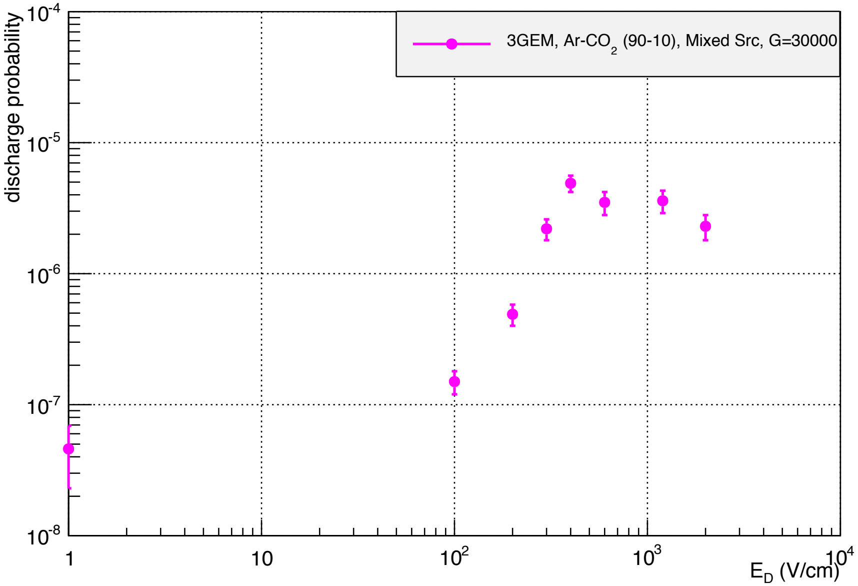




J. Margutti, MSc thesis, TUM (2014)

Electron density maps (e^-/mm^2) for mixed source in Ar-CO_2 (90-10) for different distances between SRC and 10x10 cm^2 GEM. E_D = 0

DISCHARGE PROBABILITY VS. DRIFT FIELD



← Measurement in Ar-CO_2 (90-10) with 9.5 mm drift gap.

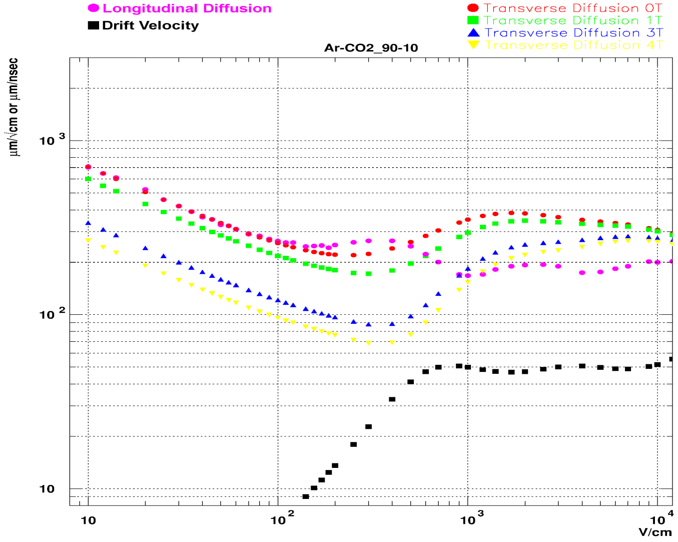
Gain = 30000 (^{55}Fe); standard HV settings

Dependence of discharge probability on a drift field E_D

- gas properties (drift velocity, diffusion)
- Primary electron recombination at low E_D
- Attachment
- Others?

Non-zero probability for **E_D = 0**

All R&D with E_D = 400 V/cm (ALICE)

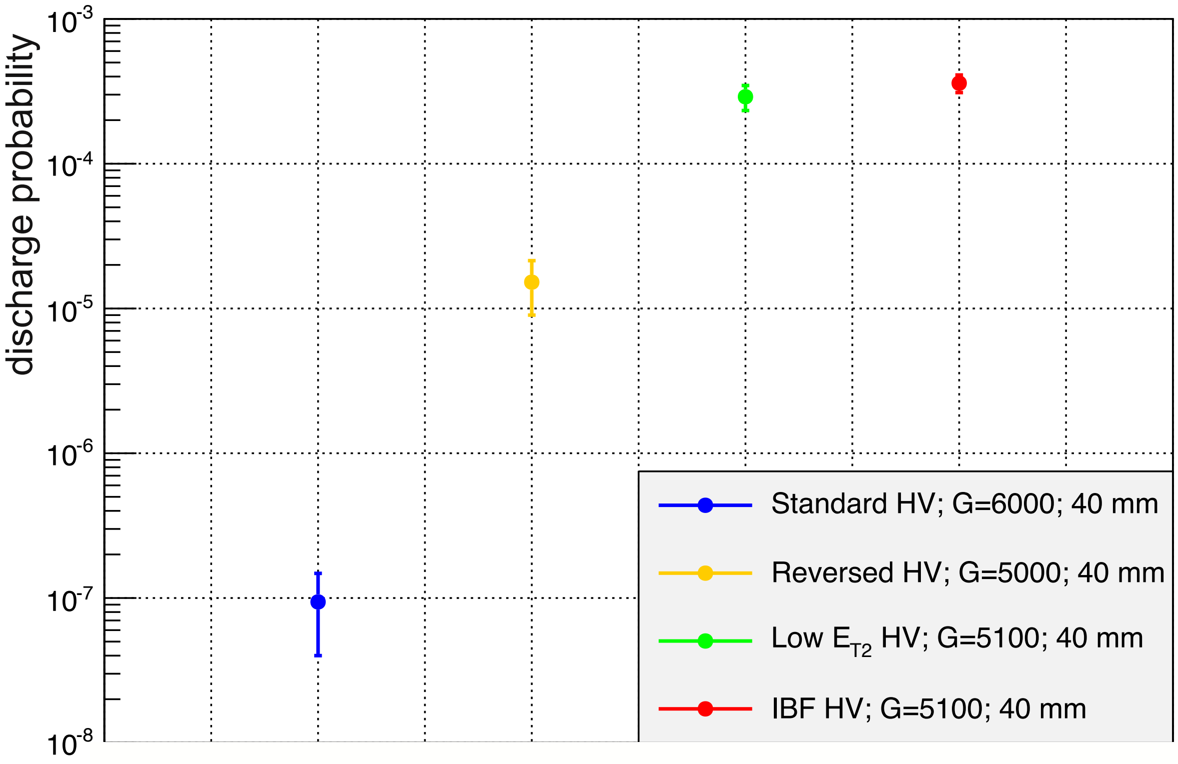


Simulated gas properties for Ar-CO2 (90-10)

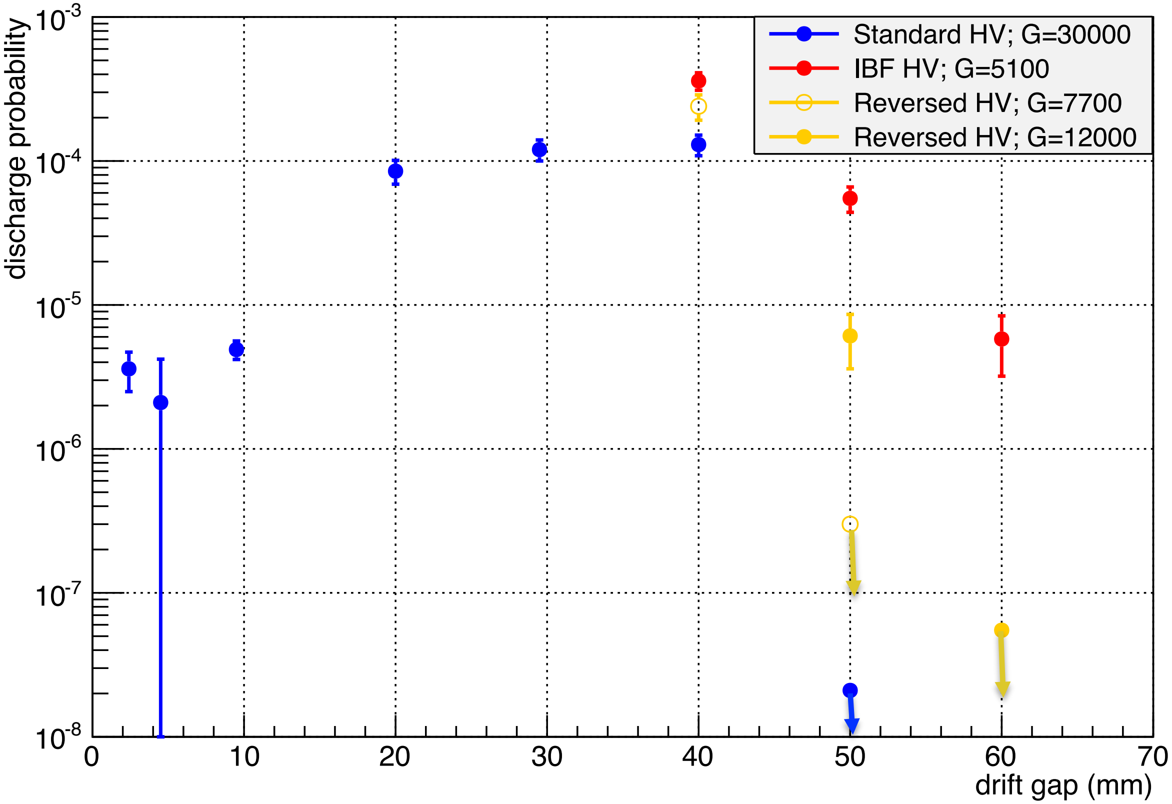
http://www-hep.phys.saga-u.ac.jp/ILC-TPC/gas/

FIELD SCAN WITH HIGH RATE SOURCE

- **Standard, Reversed**, **Low E_{T2}**, **"IBF"**
- Comparison at **G=5000-6000**, drift gap: 40 mm; **gas: Ar-CO_2 (90-10)**
- Results → similar to ^{220}Rn; significant increase of probability toward IBF settings
- Focusing effect of low ET_2 enhances discharge probability?



DRIFT GAP SCAN FOR DIFFERENT SETTINGS



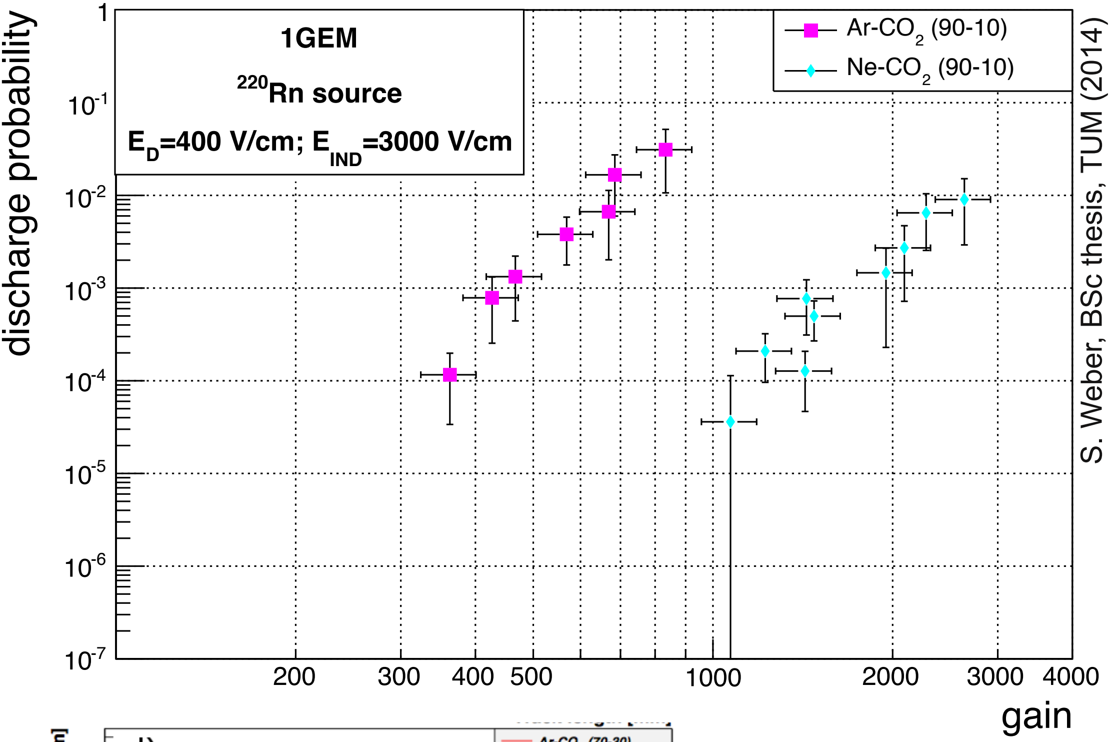
- Upper limits

- Gas: **Ar-CO_2 (90-10)**
- Influence of high charge deposition still visible
- Drop of probability at **d > range** less steep (at least for IBF settings)

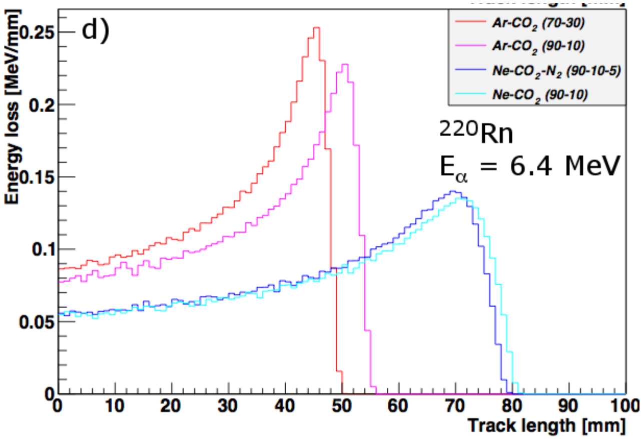
– influence of IBF settings, reversed amplification order, low ET_2

1GEM STUDIES

DISCHARGE PROBABILITY FOR DIFFERENT GAS MIXTURES

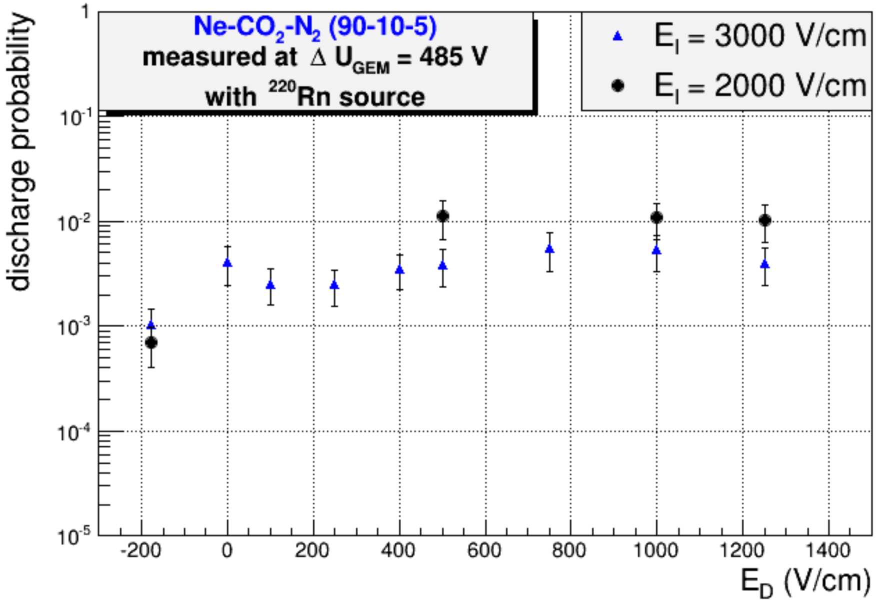


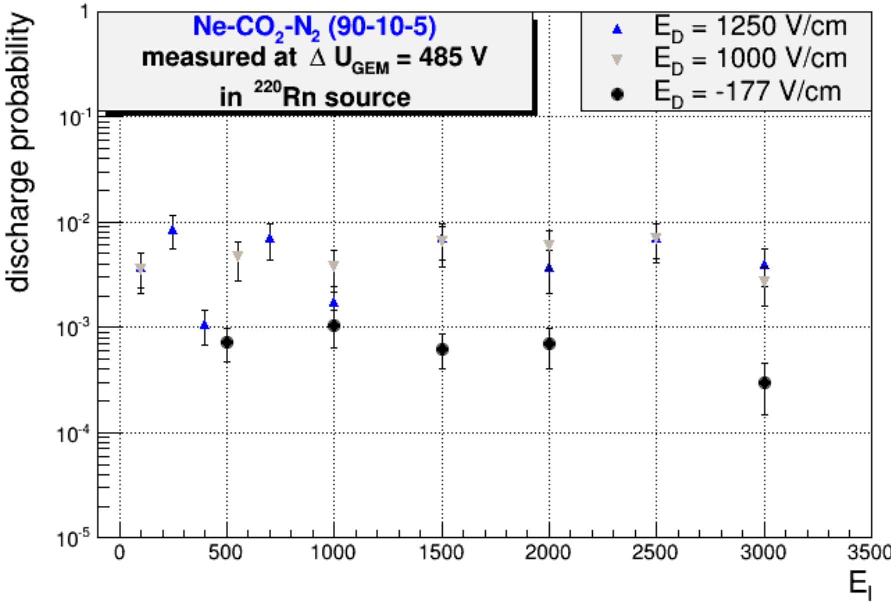
S. Weber, BSc thesis, TUM (2014)



- Ne-CO2 (90-10) more stable than Ar-CO2 (90-30)
- high charge density at a single GEM hole
  - consider Bragg peaks
- In principle, discharge curves follow the hypothesis of charge density
- Additional factors (e.g. gas properties: drift velocity, diffusion for a given E_D) may influence the final numbers
  - May be more significant in multi-GEM structures

E_D AND E_{IND} CONSIDERATION (Ne-CO_2-N_2)

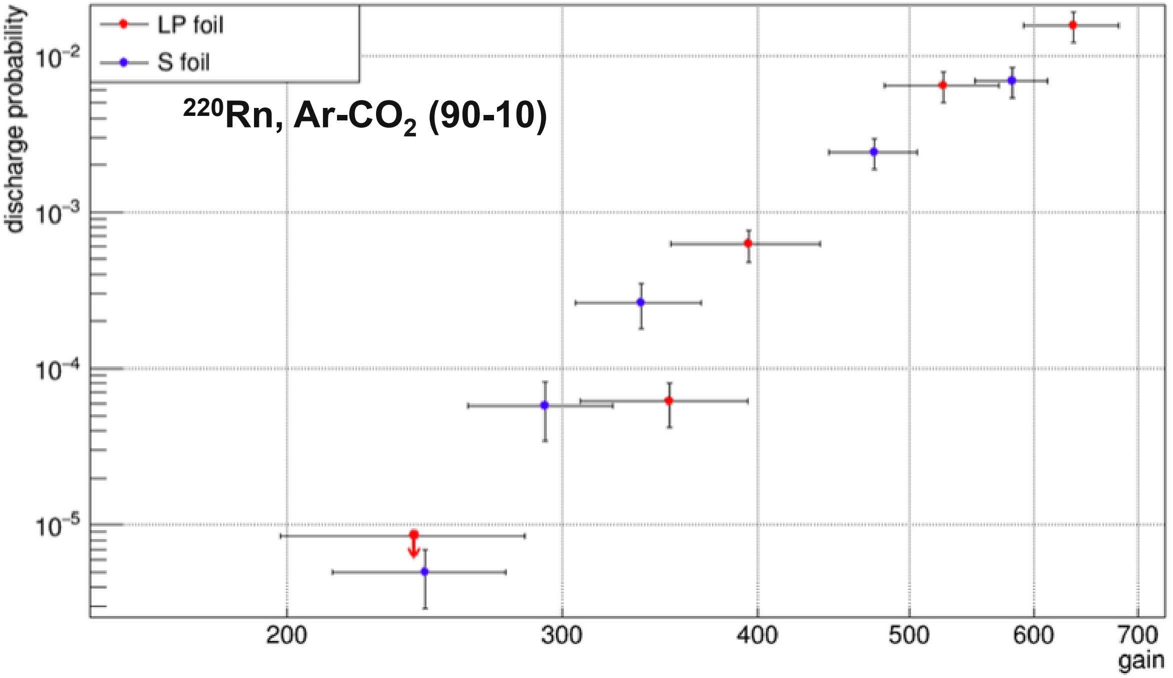




S. Weber, BSc thesis, TUM (2014)

- Slight dependence on E_D (drift, diffusion)
- P≠0 also for E_D<0 → high ionization close to a GEM hole
- No dependence on E_I

1-GEM: S VS. LP



J. Padberg, BSc thesis, TUM (2015)

- Comparison of discharge curves (220Rn source) for **S**tandard (140 um) and **L**arge **P**itch (280 um) foils
- Different detector (42 mm drift, field cage)
- Different foils → nice agreement with previous 1GEM measurement
- No significant difference between S and LP → for higher gains discharge probability factor ~2 larger in LP
  → larger pitch, higher charge density per hole?

SUMMARY OF DISCHARGE PROBABILITY STUDIES

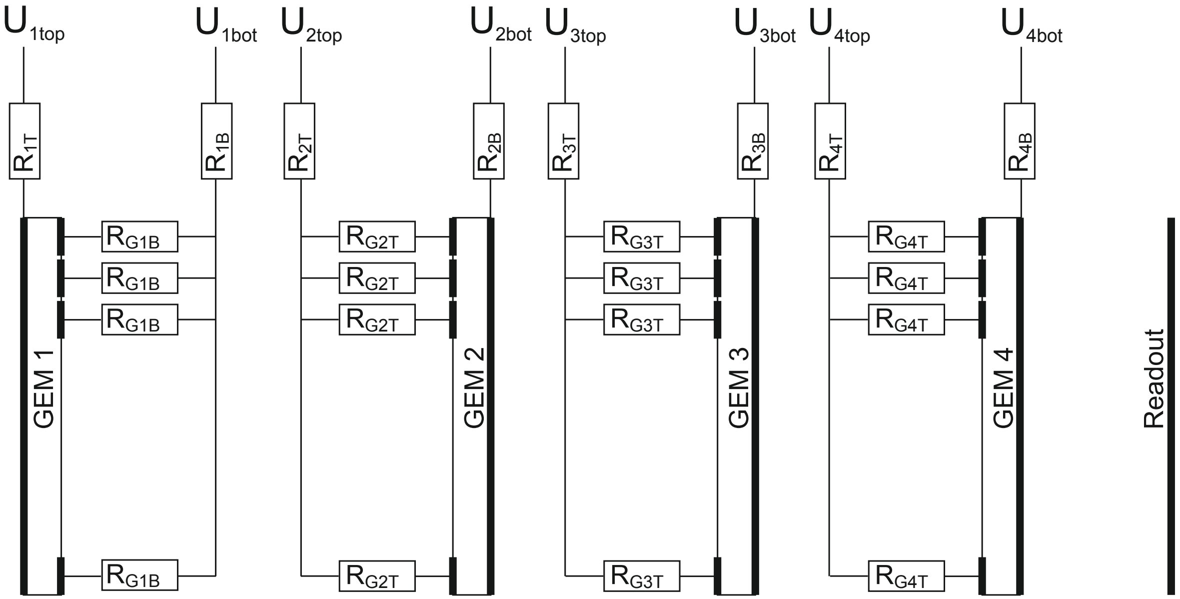
- Extensive R&D on GEM stability for the ALICE TPC upgrade launched
- Stability of the baseline solution for the upgraded TPC (4-GEM optimized for IBF) comparable to the “standard” 3-GEM configuration. Tests with alphas and at the SPS.

- Discharge studies with single- and multi-GEM structures point to the charge density hypothesis as a main contribution to the spark induction
- Try to reproduce measurements with a simple G4 simulation of alpha energy loss in detector medium – work ongoing
- Studies continue

DISCHARGE PROPAGATION STUDIES

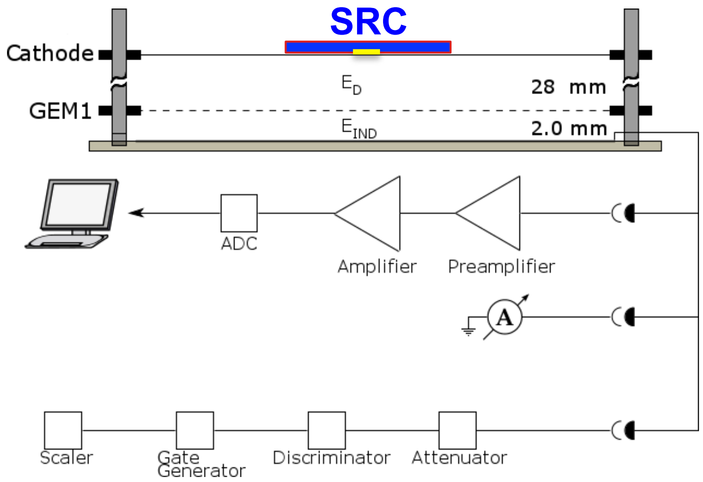
POWERING SCHEME FOR GEM-ROC FOR THE ALICE TPC UPGRADE

- **GEM1**: not segmented side facing Central Electrode (drift volume)
  - Minimize distortions in case of a shortened segments
  - Minimize distortions at the chamber edges (functionality of a Cover Electrode)
- **GEM2,3,4**: segmented side facing Central Electrode

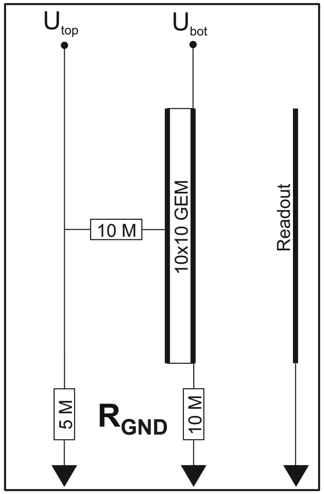


- **CONCERN: DISCHARGE PROPAGATION AFTER SPARK IN GEM1**

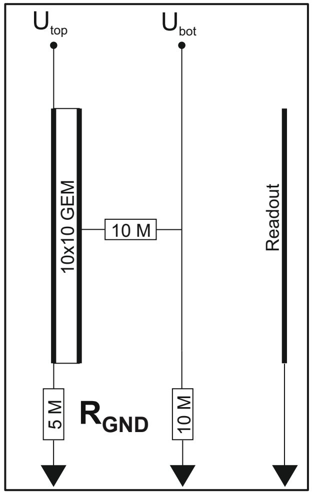
SETUP



HV – "standard"



HV – "flipped"



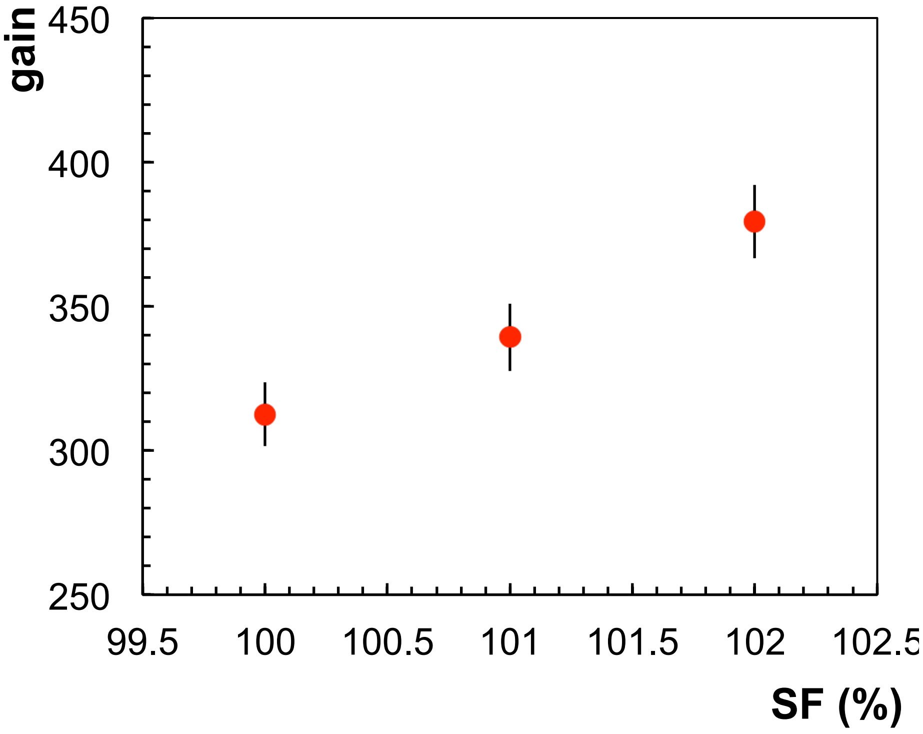
- Standard GEM (CERN, 140 um pitch, double mask)
- Alpha source (Pu, Am, Cm) shooting through a 7 mm diameter hole in a 1.5 mm thick PCB cathode
- **Rate = 569 ± 3 Hz**
- **Gas mixture: Ar-CO_2 (90-10)**
  - Learn and debug the system
  - Define thresholds

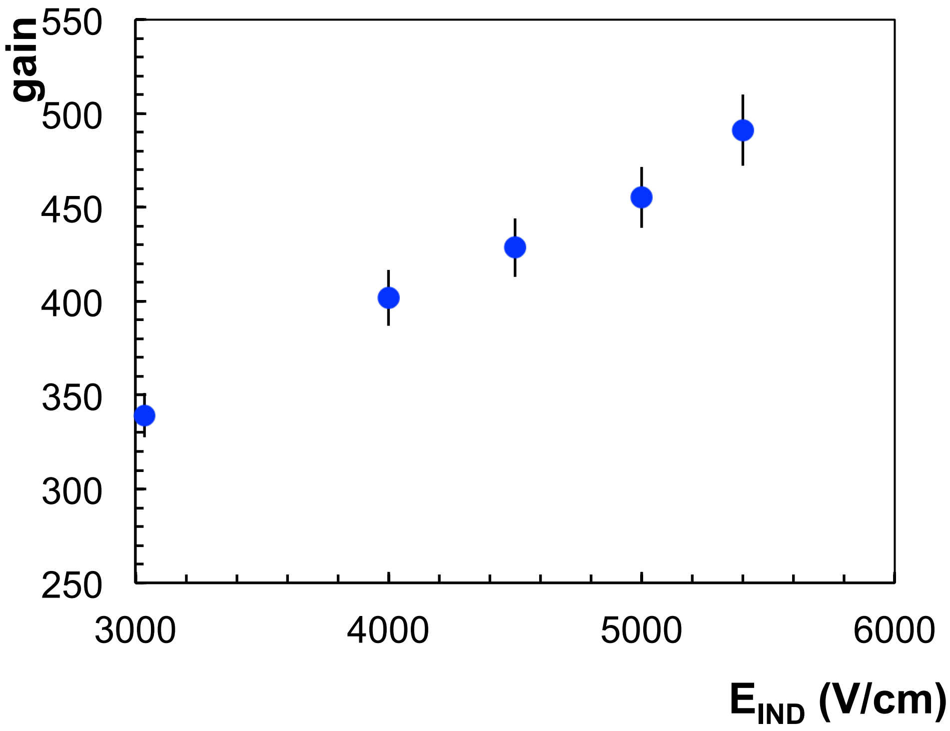
- Also resistor chain supply
- **HV settings (SF=100%):**
  - **E_{drift} = 400 V/cm (constant)**
  - **ΔV = 399 V**
  - **E_{IND} = 3006 V/cm**

EFFECTIVE GAIN

Measured using **$I_{anode}/I_{primary}$** technique (with alphas)

Fair agreement with other 1GEM setups we used





DISCHARGE PROPAGATION

Methodology

- Increase ΔV and observe “normal” (GEM) discharges.

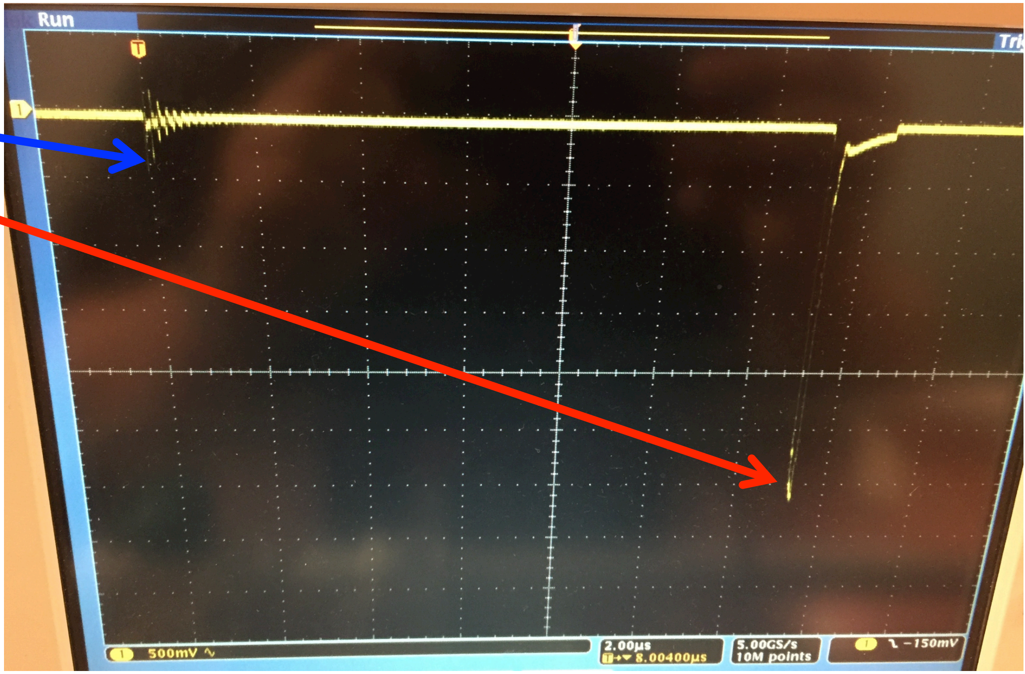
- Slowly increasing E_{IND}, at some point one starts seeing propagated discharges.

- Amplitude of a propagated discharge ~order of magnitude higher than “normal” one.

- Large signal can be associated with a spark development between GEM_{Bottom} and padplane.

Experiment:

- ΔV = 403 V (SF=101%), ~40 dB attenuator
- **GEM discharge amplitude: ~300 mV**
- **Propagated discharge amplitude: ~3 V**
- **Count GEM and propagated discharges**
    - $U_{THR\text{-}GEM}$ = 150 mV
    - $U_{THR\text{-}PROP}$ = 1 V
- **Save waveforms and measure signal details**
    - amplitude, shape, width, time of occurrence
    - photography, LV script in preparation



COMPARISON TO LITERATURE

F. Sauli et al. NIM A 479 (2002) 294

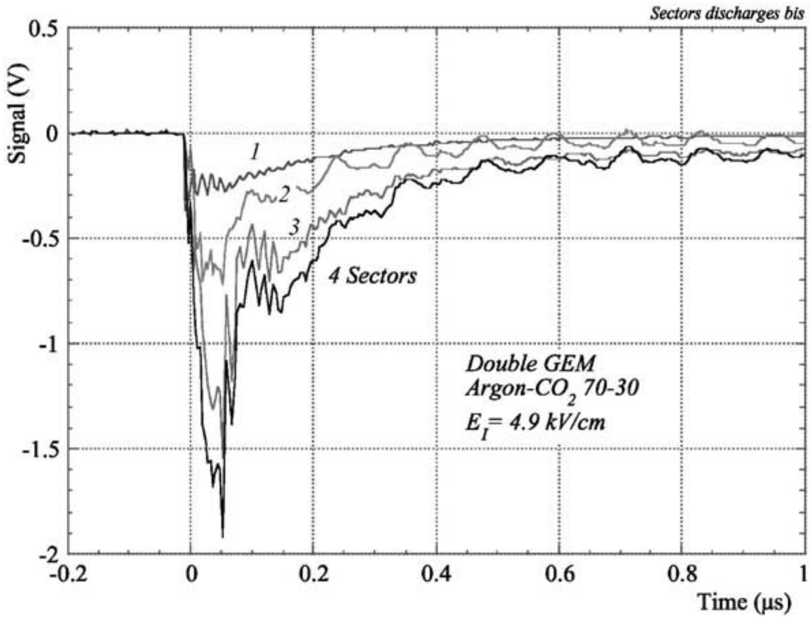


Fig. 15. Discharge signals on anodes for increasing GEM capacitance, obtained by grouping one to four sectors.

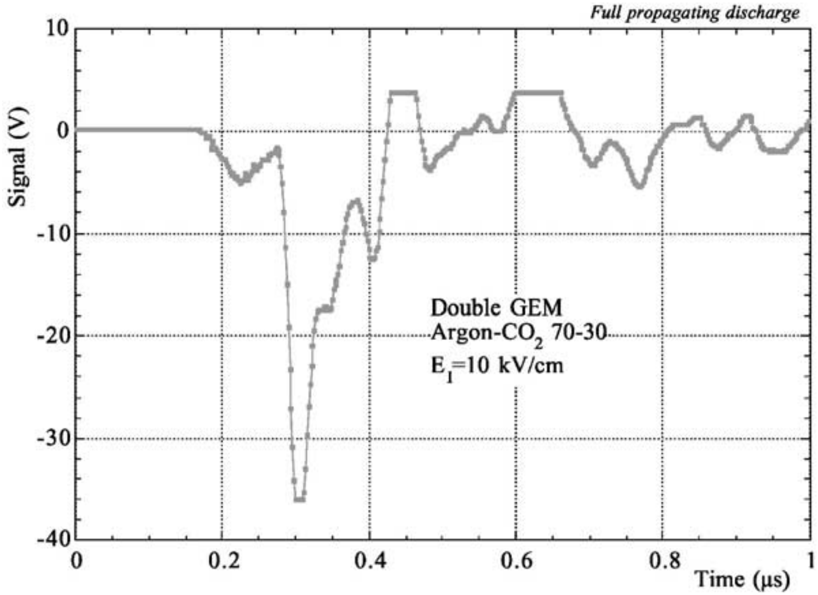
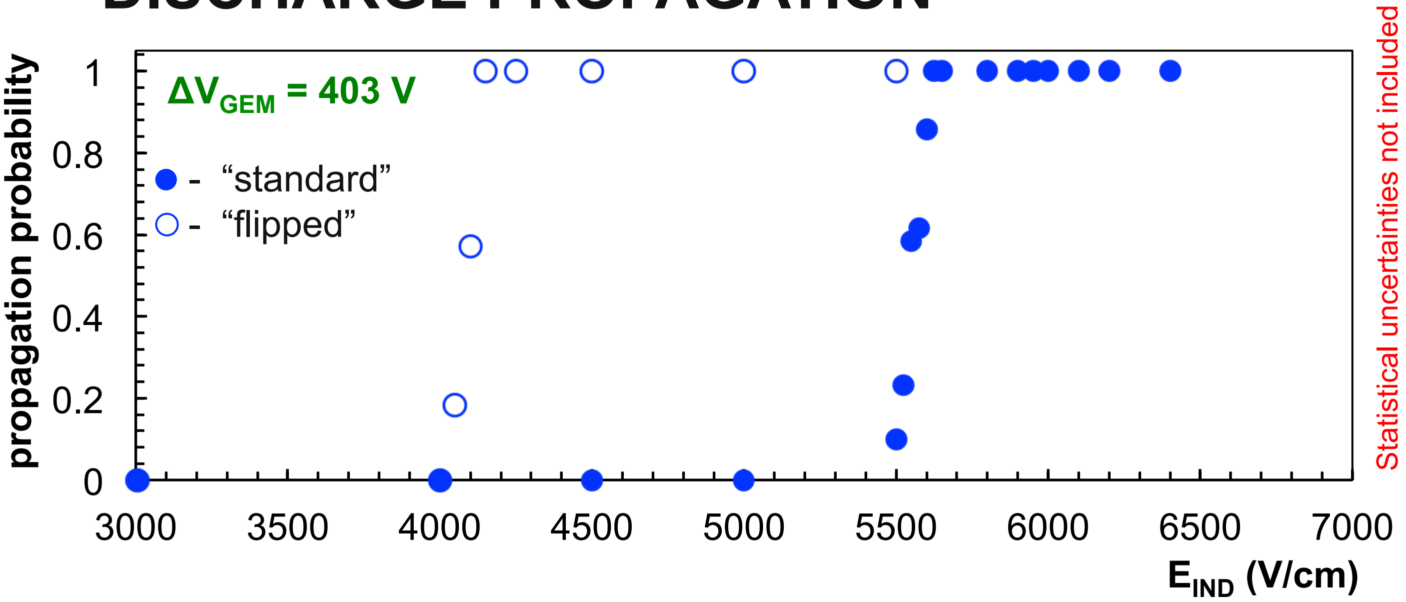


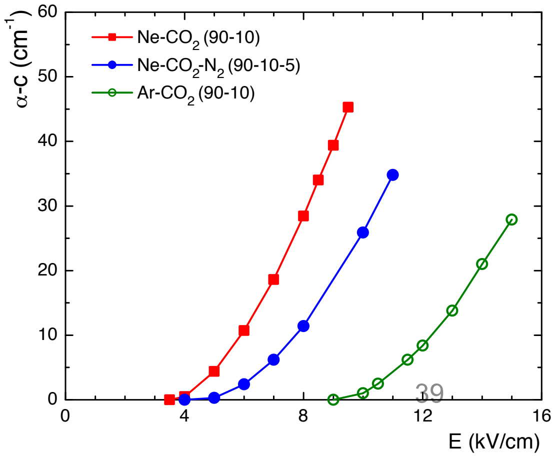
Fig. 16. Anode signal for a fully propagating discharge.

DISCHARGE PROPAGATION



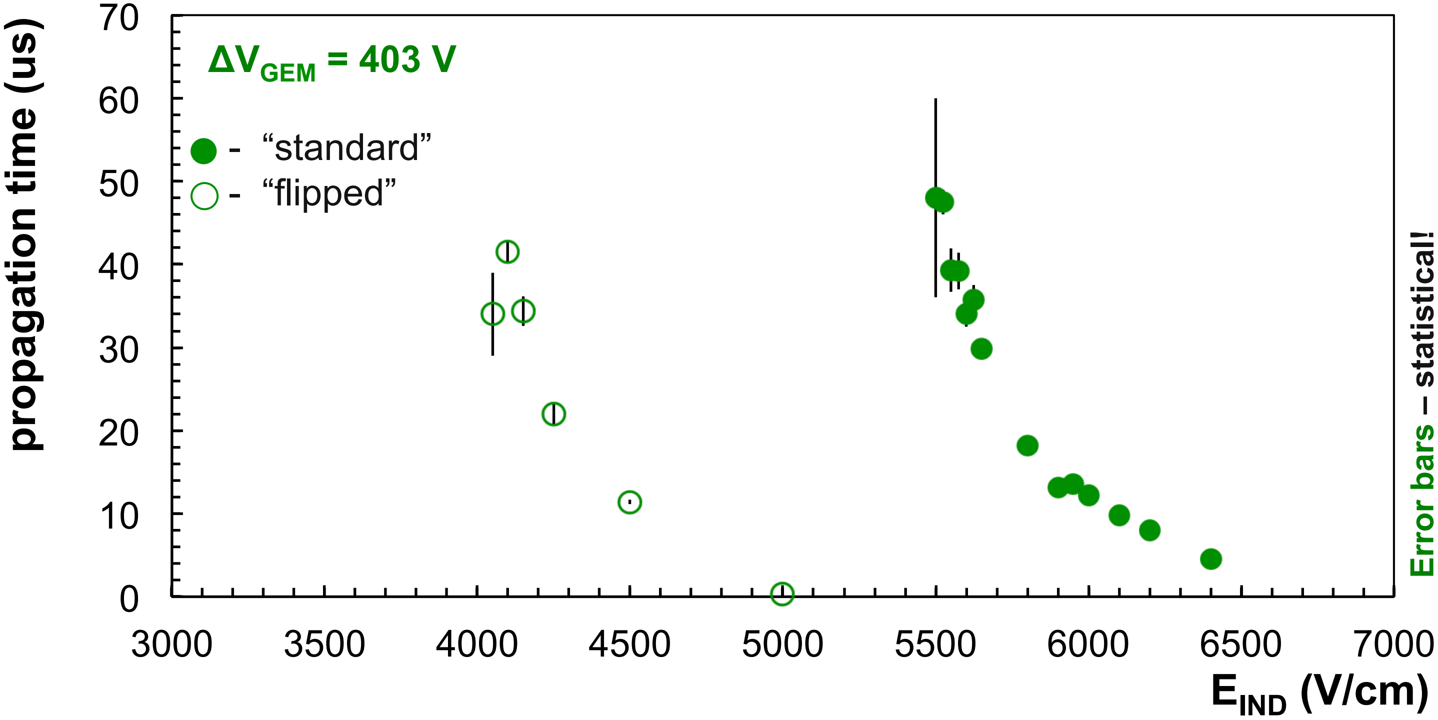
Statistical uncertainties not included

- **<u>Clear separation of both curves</u>**.
- Onset of propagation for field values below Townsend amplification points to the streamer mechanism
- Propagation probability depends on primary spark energy (ΔV_{GEM})
- In case of a spark in a flipped foil, U_{BOT} increases towards U_{TOP}, thus E_{IND} goes up resulting in enhanced probability of full propagation.



PROPAGATION TIME

Time between primary and propagated discharge

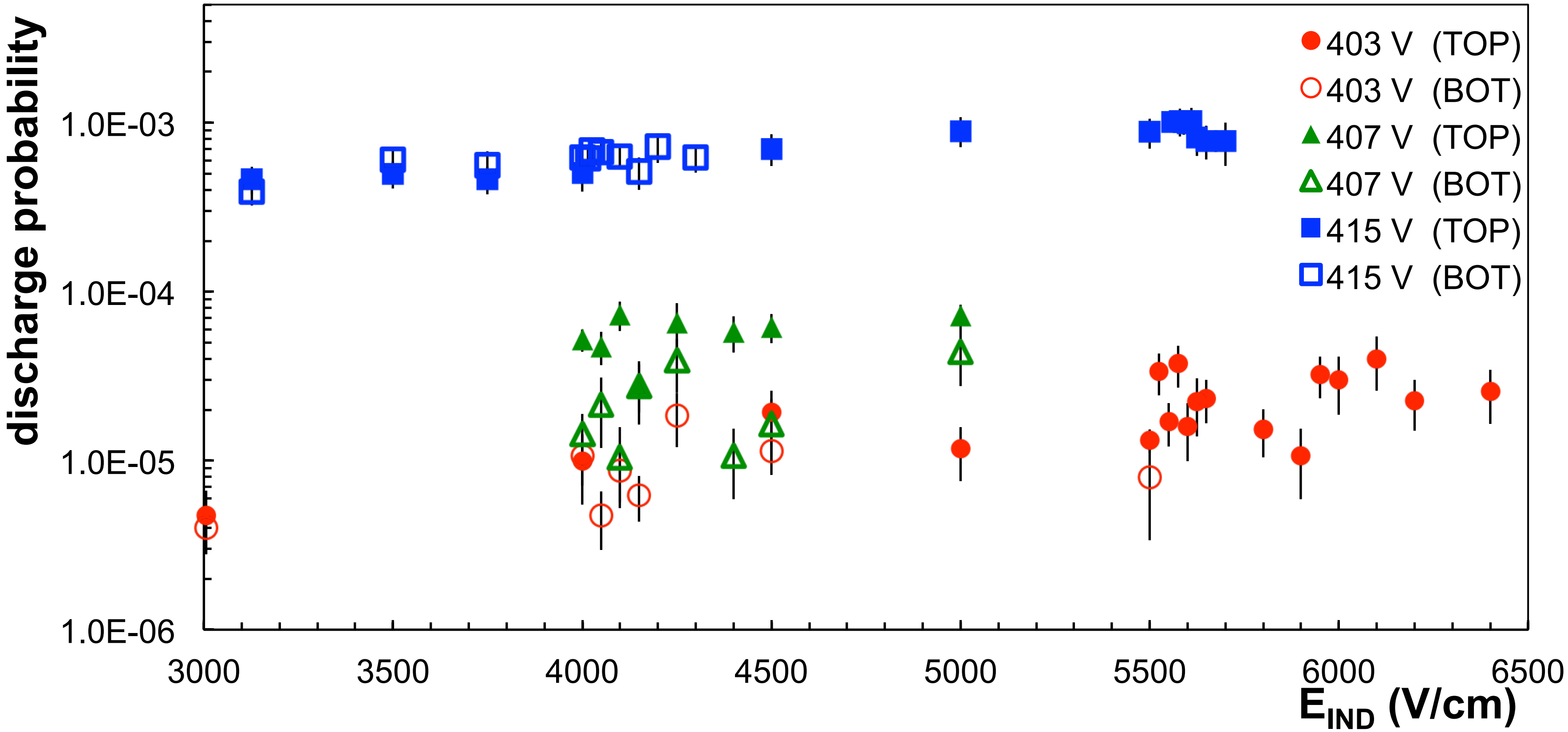


Error bars – statistical!
- standard deviation of a mean value
- readout error (scale) not included

- Finite propagation time; clear dependence on E_{IND}
- Points to the electron/ion streamer mechanism of propagation? (photon mechanism would be immediate)

ΔV DEPENDENCE

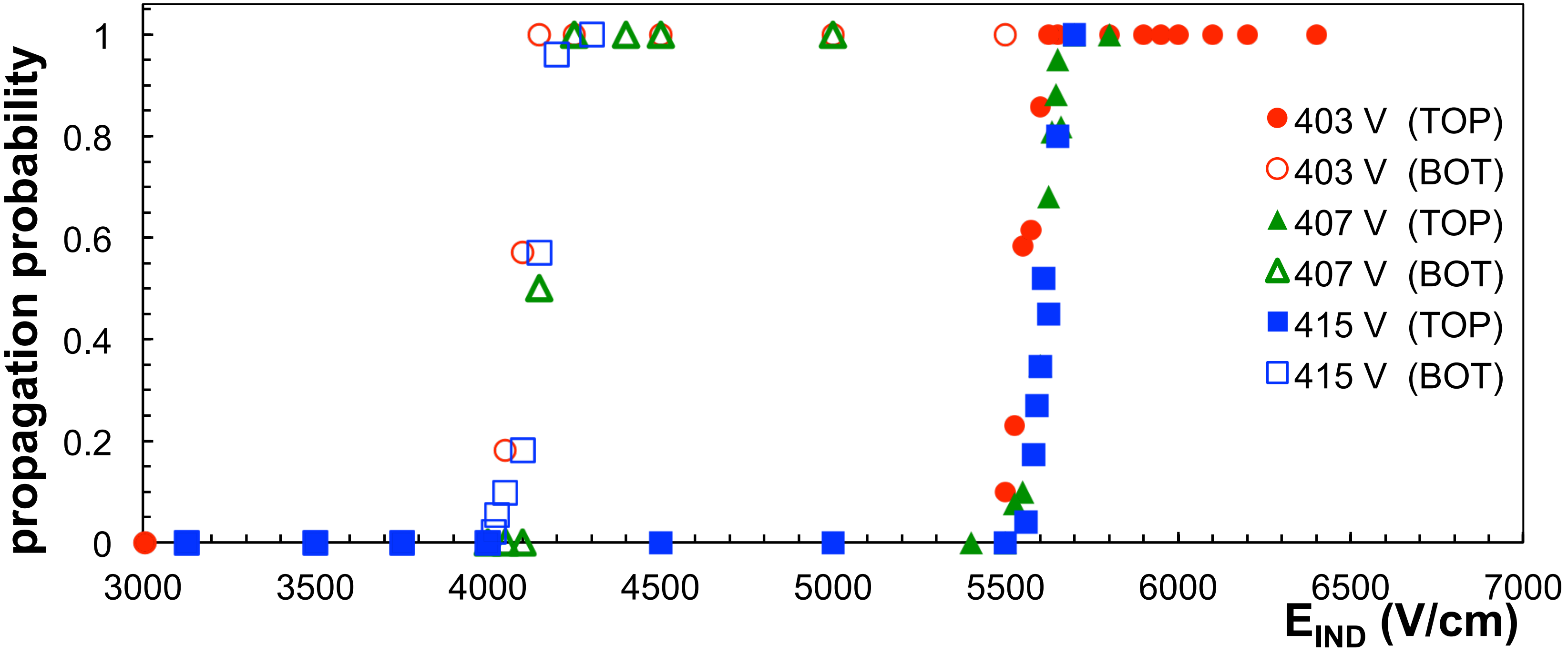
Ar-CO_2 (90-10), R_L = 10 MΩ, INDEP. HV, $R_{GND-T/B}$ = 5/10 MΩ



- Slight dependence on E_{IND}
- Absolute value at 415 V biased by 1.2 s gate after a discharge signal (dead time) → underestimated

ΔV DEPENDENCE

Ar-CO_2 (90-10), R_L = 10 MΩ, INDEP. HV, $R_{GND-T/B}$ = 5/10 MΩ



- No significant dependence on ΔV in this narrow range (403-415 V, *SF* = 101 – 104%)
  - discharge rate too low for SF < 101 % or too high for SF >104%
  - Discharge propagation should depend on the energy of a primary spark: **$E_{capacitor}$ = ½ C×ΔV^2**

LITERATURE

Primary spark energy dependence

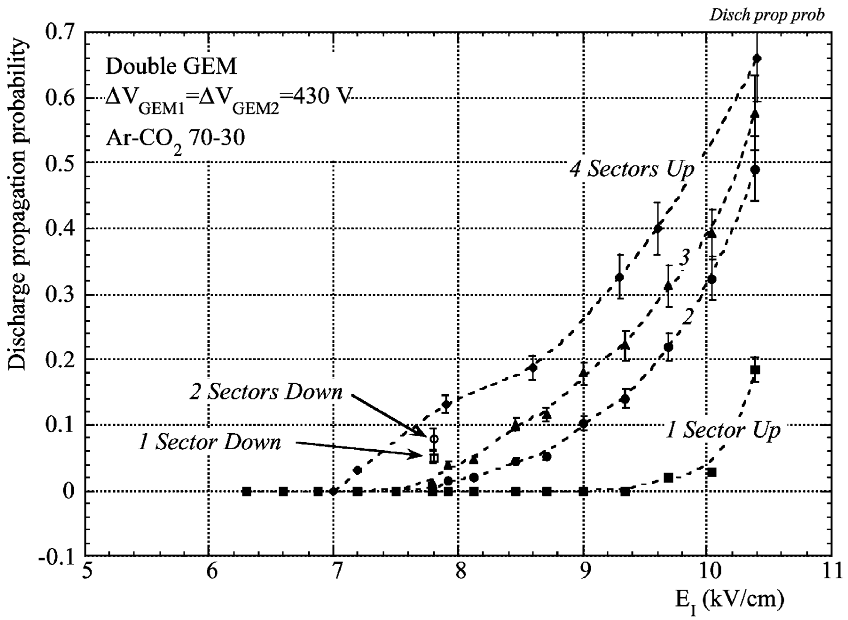


Fig. 17. Discharge propagation probability as a function of induction field for a sectored GEM.

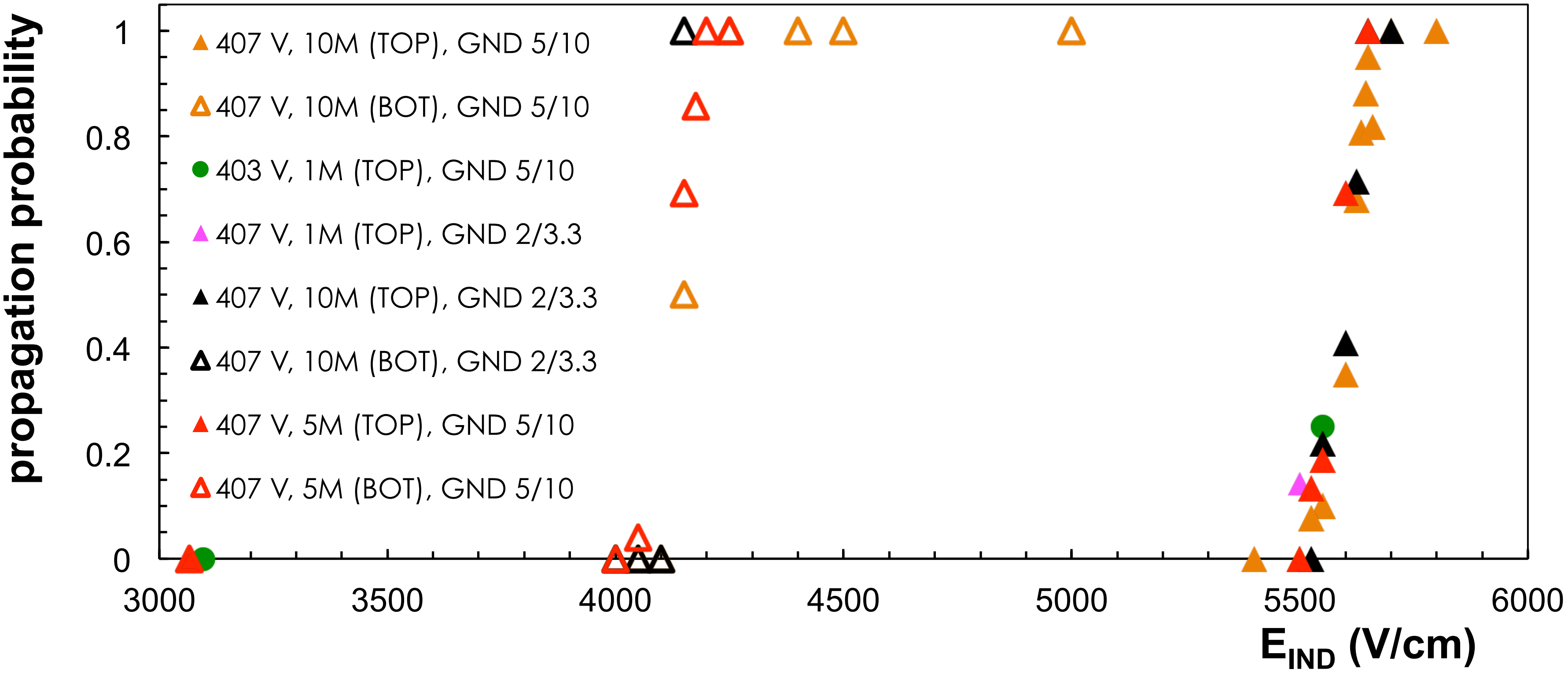
C studies (F. Sauli et al.)

- 1 sector (*x* nF) – propagation onset @ 9.5 kV/cm
- 4 sectors (4*x* nF) – propagation onset @ 7 kV/cm
- Visible probability spread for 4x or 2x larger capacitance (→ energy)

ΔV studies (this work):

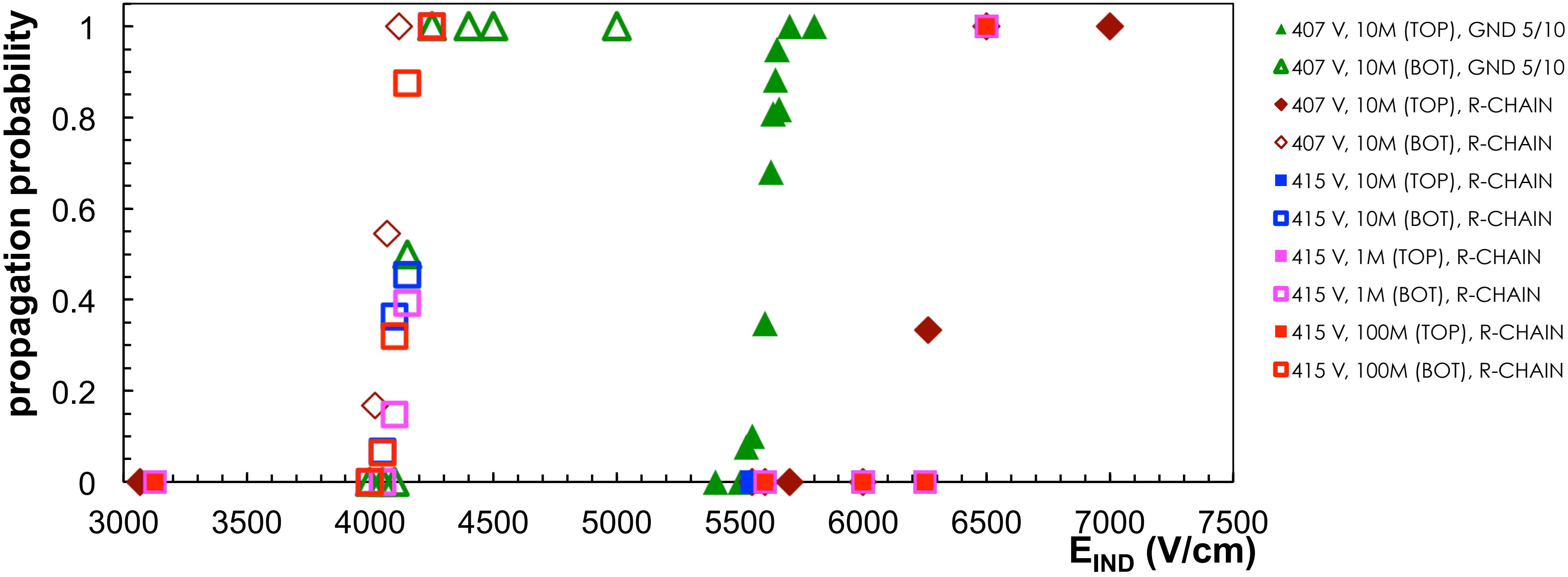
- $(415\text{ V})^2/(403\text{ V})^2 = 1.06$
- Too small differences to see anything?
- What about R_L, R_{GND} used in a setup?

INFLUENCE OF R_L AND R_{GND}



- No significant influence of the resistors values
- Same onset of propagation for both (TOP/BOT) configurations
- R_L quenches the discharge, limits the current flowing from the PS, but do not influence the energy of a primary discharge, thus propagation probability

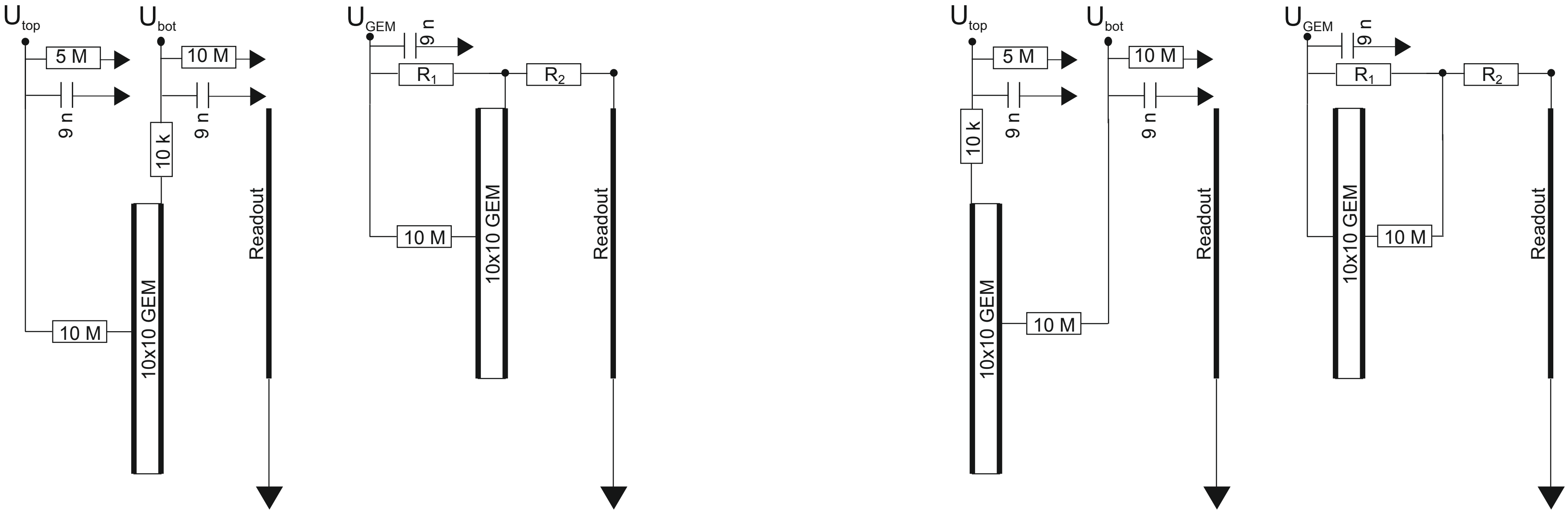
RESISTOR CHAIN



- In case of a resistor chain (I_{RC} = 0.5 mA) the propagation onset is shifted by750-1000 V/cm towards higher fields for the standard orientation
- No (significant) change for the flipped option (onset at ~4 kV/cm)

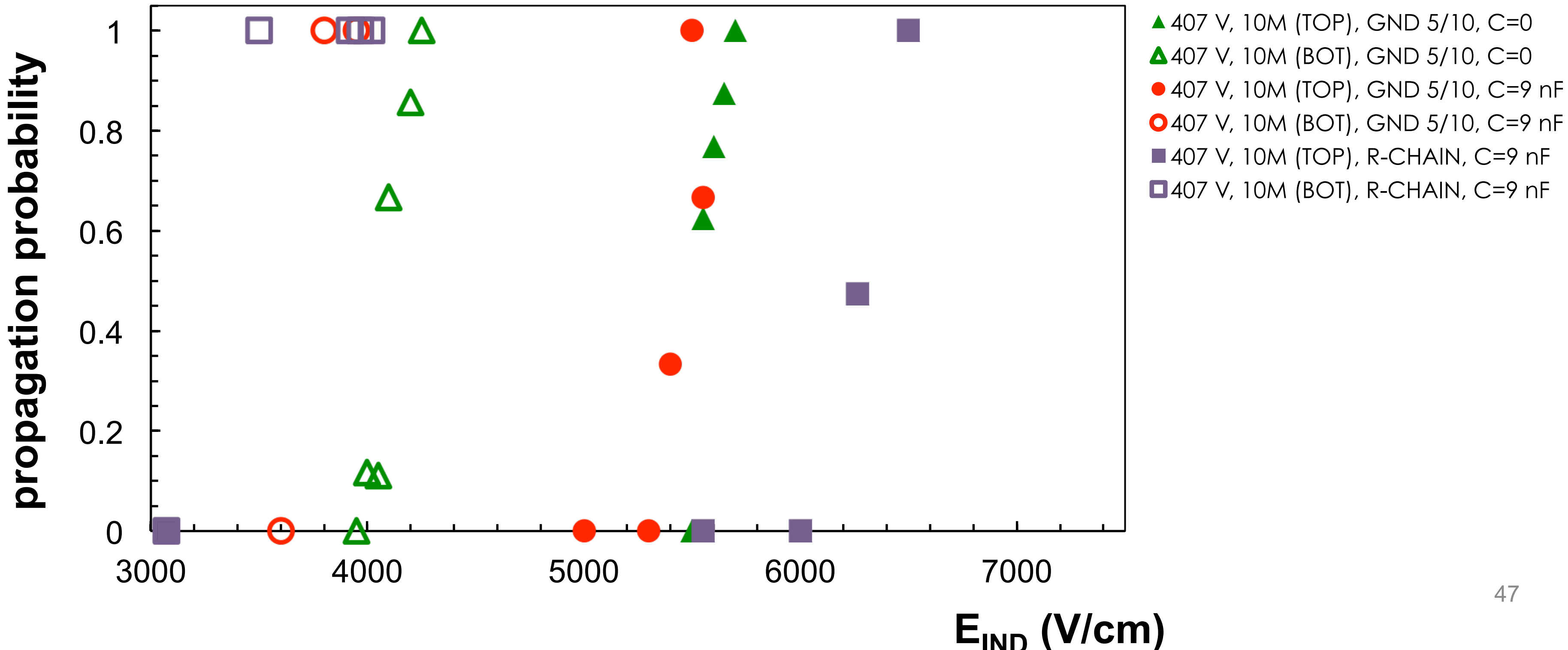
9 nF TO GND

- To simulate an 80m HV cables 9 nF capacitors to GND were added in each HV channel.
- Two scenarios: R_L TOP or BOTTOM
- Two HV supply systems: Independent (grounded with $R_{GND\text{-}T/B}$ = 5/10 M) channels and resistor chain
- 10k decoupling resistor in case of the electrode connected directly to HV (see indep. channels)
- No decoupling resistance in R-Chain “flipped” scenario (a mistake!)



9 nF TO GND

- **Many trips → low stat. Propagation probability may be overestimated; onset should be well described**
- **R_L on TOP:**
  - Independent channels: propagation starts with 100 – 150 V/cm lower fields
  - R-chain: no influence of additional capacitance
- **R_L on BOT:**
  - Independent channels: onset of propagation at ~200 V/cm lower fields
  - R-chain: onset of propagation at ~500 V/cm lower fields!! *<u>No decoupling resistance?</u>*

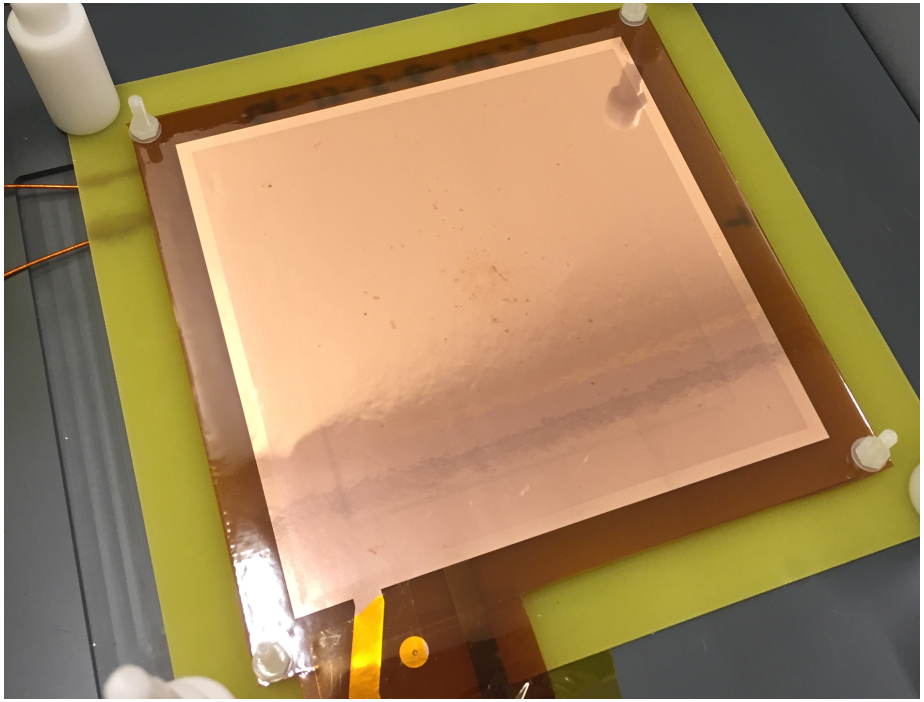


SUMMARY OF DISCHARGE PROPAGATION STUDIES

- Discharge propagation studied in Ar-CO_2 (90-10) for many HV configurations
- Discharge probability depends on gain (obviously)
- Propagation probability depends on energy of the primary discharge (only?)
  - No differences observed for different ΔV (small variations studied)
  - No differences observed for different R_L, R_{GND}
  - Higher propagation threshold when using R-Chain and R_L on top
  - Lower propagation threshold when adding C-to-GND (additional energy stored in the system)
- In parallel: SPICE simulation of different HV supply systems to understand the tripping behavior
- **OUTLOOK:** studies in Ne-CO_2-N_2 for the evaluation of the final ROC design

BONUS

GEM FOIL



- Hundreds (thousands?) of sparks
- Hundreds of propagated discharges
- “Repeated” discharges
- Many mistakes:
  - Trip only one channel
  - Set wrong ΔV (>500 V)

- $I_{leak} < 100$ pA
- Stable gain

DISCHARGE CINEMA

https://indico.cern.ch/event/496113/session/7/contribution/26/attachments/1242032/1827063/Sparks_SD_new.mp4