Discharge and stability studies for the readout chambers of the upgraded ALICE TPC

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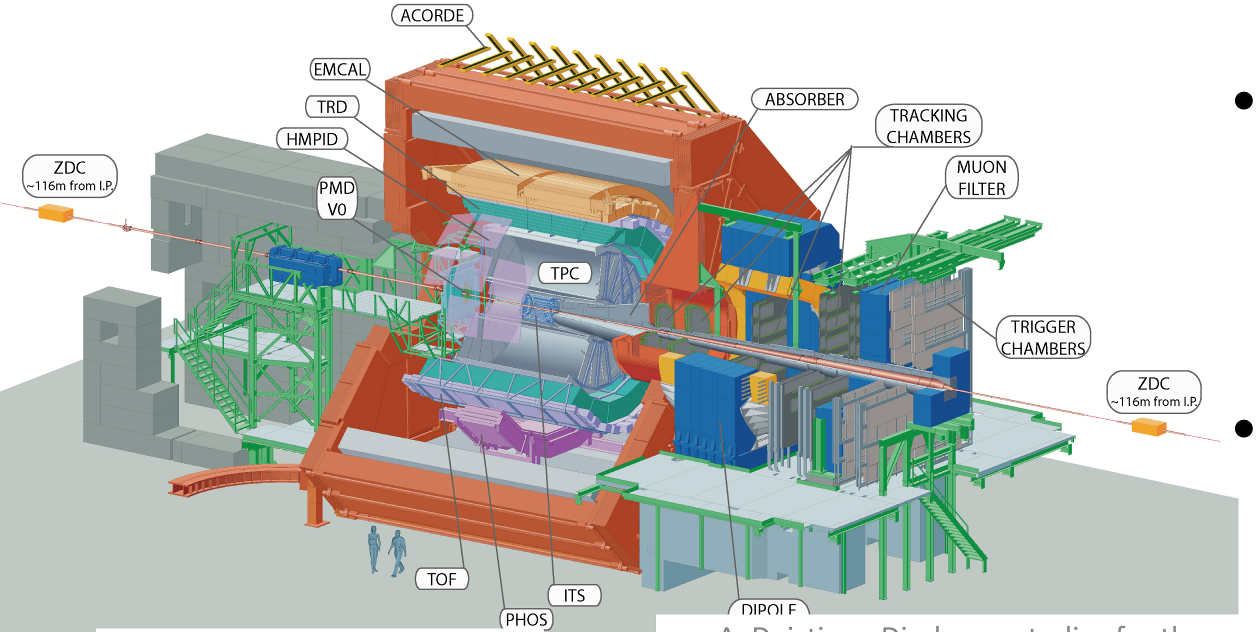
HGS-HIRe for FAIR
Helmholtz Graduate School for Hadron and Ion Research

GSI

ALICE

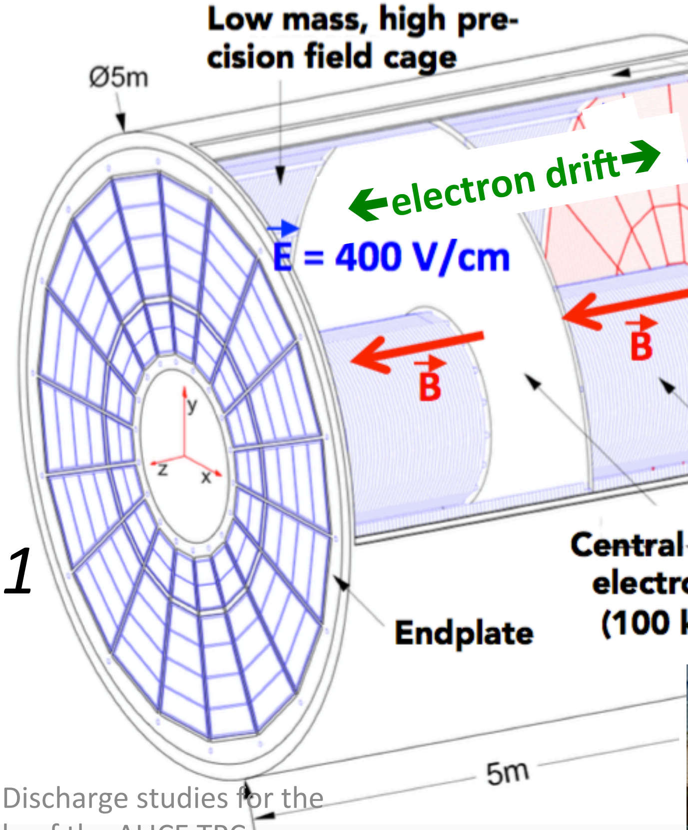
A Large Ion Collider Experiment

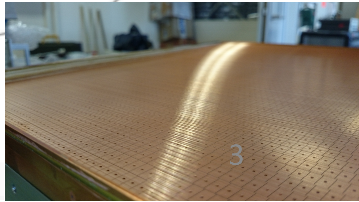


- Located at the LHC
- Dedicated experiment to study heavy-ion collisions
- TPC as main tracking device in the central barrel

ALICE TPC

- Equipped with 36 inner and outer readout MWPCs
- Successfully operated with Ne-CO_2(-N_2) (90-10(-5)) and Ar-CO_2 (90-10) during LHC *Run 1* and *Run 2*

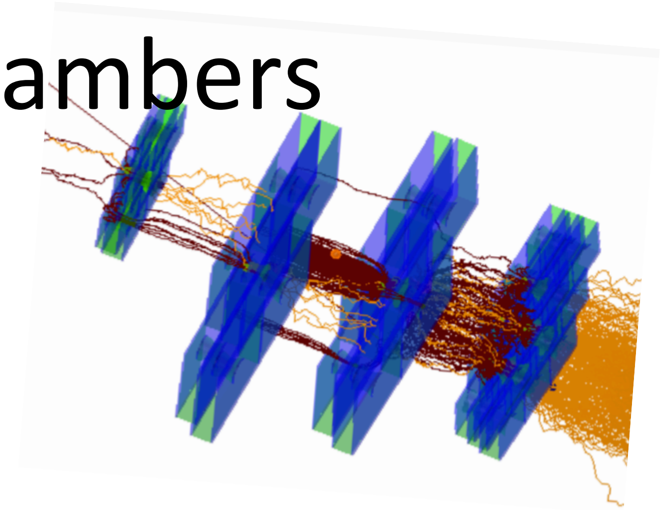




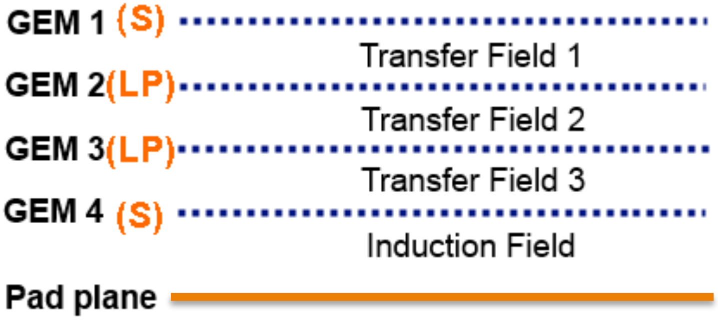
ALICE TPC Upgrade

- Interaction rates of 50 kHz (lead-lead) from 2021 onwards
- Gated readout of the MWPC no longer feasible
- Move to a continuous readout, while preserving the performance of the current TPC

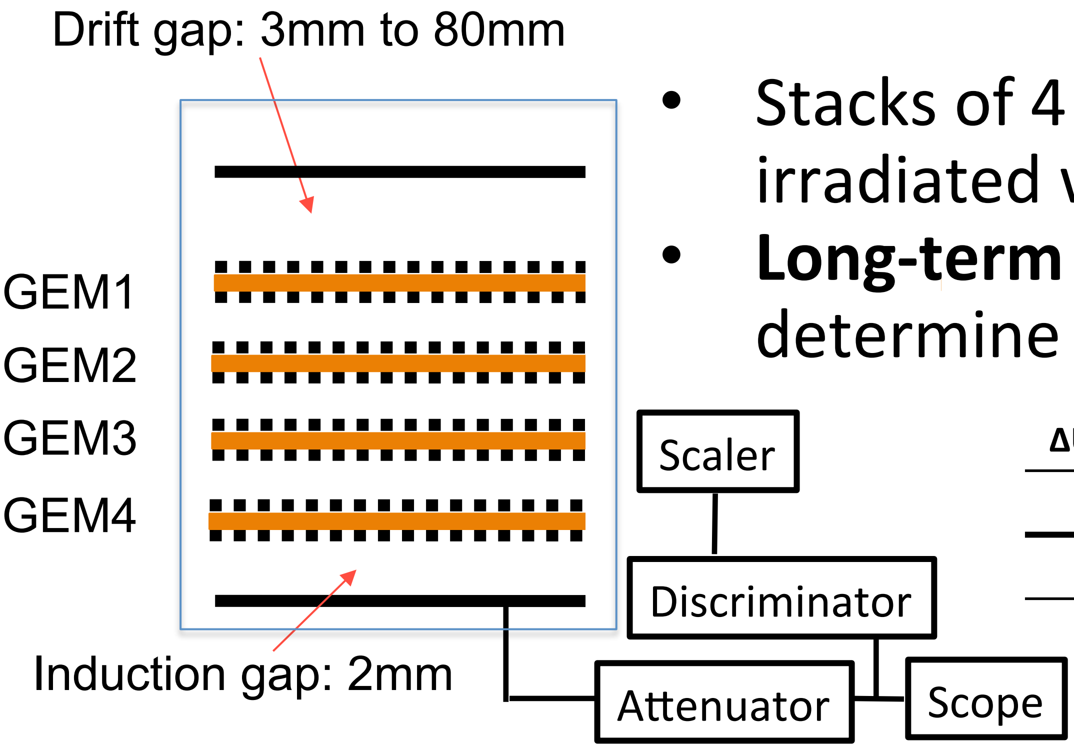
The new readout chambers



- Employ a quadruple GEM stack
- Allow for continuous readout
- Ion-backflow below 1% and at the same time an energy resolution of 12% σ/E at the ^{55}Fe photopeak
- Operational stability under LHC conditions ➔ low discharge probability



Stability tests of the baseline settings



- Stacks of 4 GEMs (10cm x 10cm) are irradiated with alpha sources
- **Long-term** measurements to determine the discharge probability

ΔU (GEM1)	ΔU (GEM2)	ΔU (GEM3)	ΔU (GEM4)
270V	250V	270V	340V
E (T1)	**E (T2)**	**E (T3)**	**E (Ind)**
4kV/cm	2kV/cm	0.1kV/cm	4kV/cm

Limits on the discharge probability

			S-LP-LP-S $IB = 0.63\%$		
	G = 1000	G = 2000	G = 3300	G = 4000	G = 5000
^{239}Pu+^{241}Am+^{244}Cm $E_\alpha = 5.2+5.5+5.8$ MeV rate = 600 Hz		$< 3.1\times10^{-9}$		5×10^{-9}	$(1.8\pm1.1)\times10^{-8}$
^{241}Am $E_\alpha = 5.5$ MeV rate = 11 kHz	$< 1.1\times10^{-8}$	$< 1.5\times10^{-10}$	$< 7.1\times10^{-10}$		

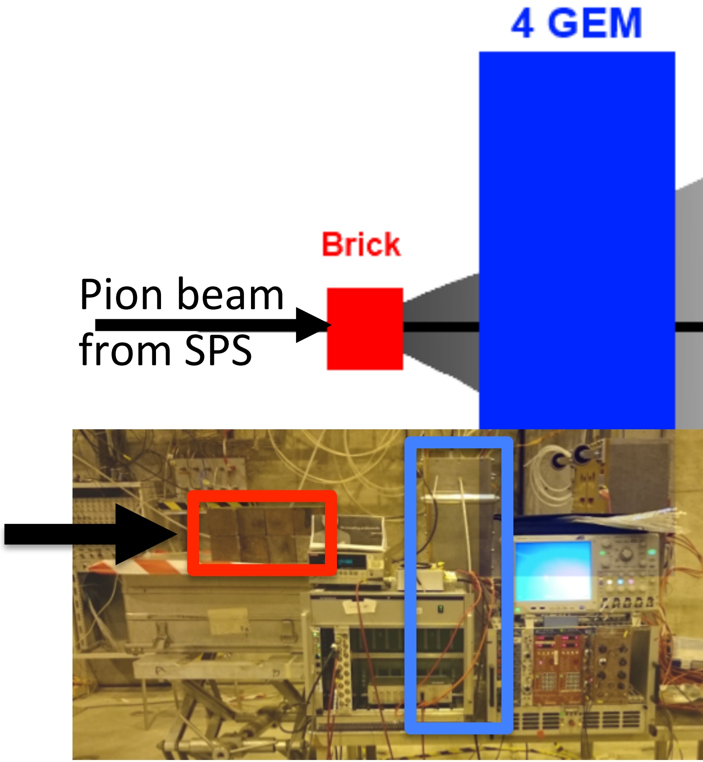
Measured in the baseline gas mixture: Ne-CO_2-N_2 (90-10-5)

- Only upper limits could be obtained in the lab

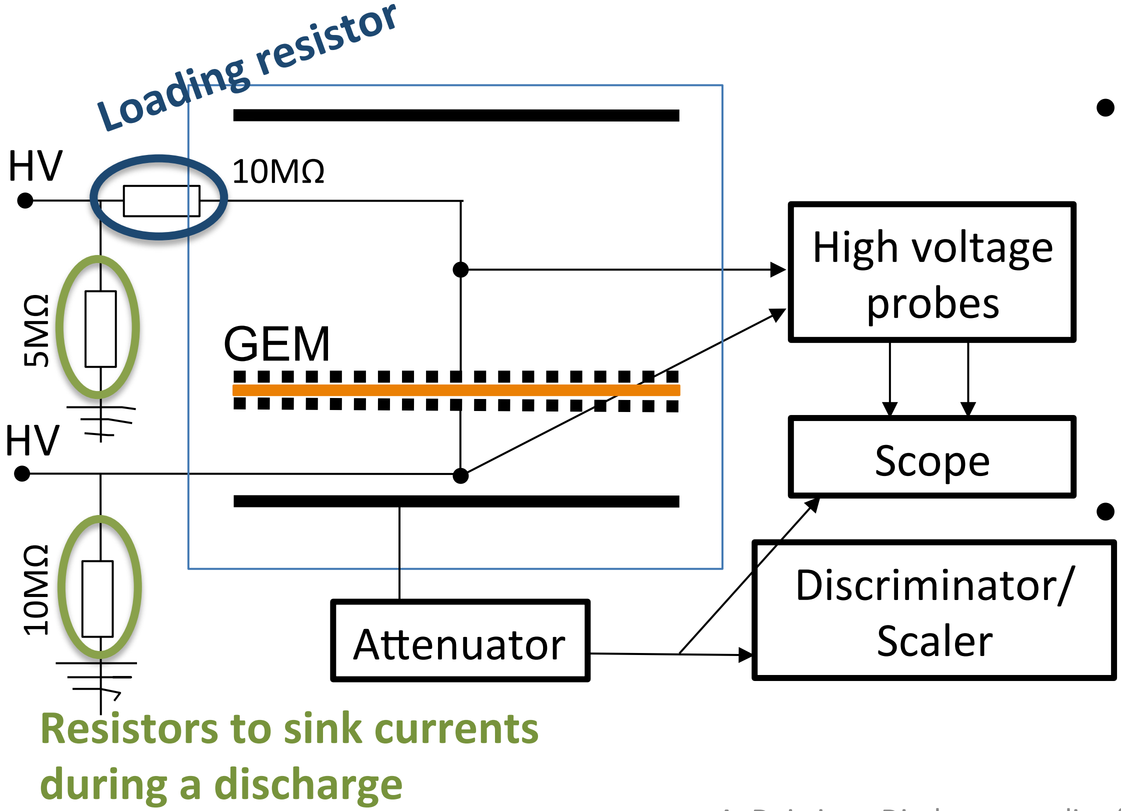
➢ Test campaign at CERN's SPS accelerator

Result from the test at SPS:

- Three measured discharges
  → $(6.4 \pm 3.7) \times 10^{-12}$ discharges/ incoming hadron
- Comparing to: 7×10^{11} particles hitting a GEM stack during one month of lead-lead data taking in LHC *Run 3*
- Study of the actual discharge mechanism: → Back to the lab



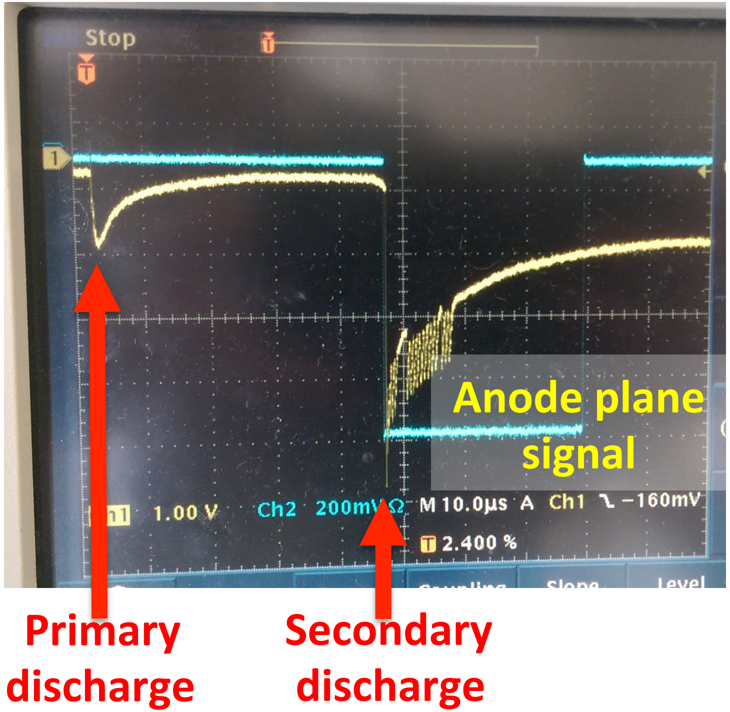
Detailed studies of discharges



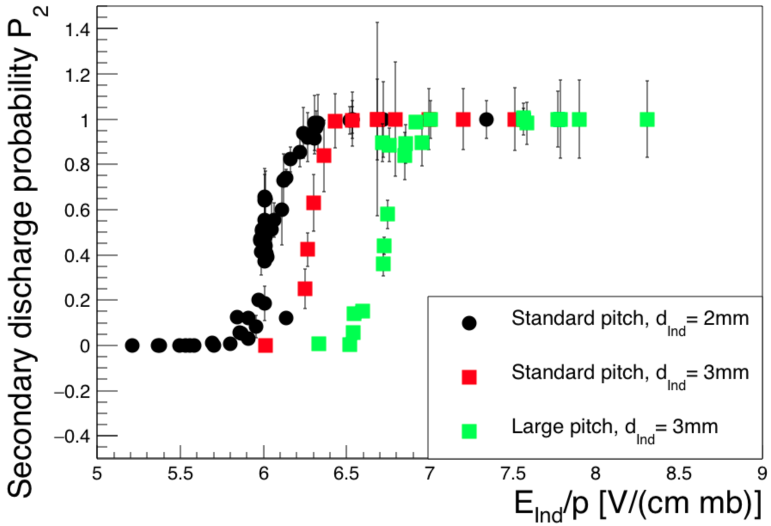
- Induce discharges by a combination of a high voltage across the GEM foil and α-sources
- Study the influence of the biasing scheme on the discharge probability

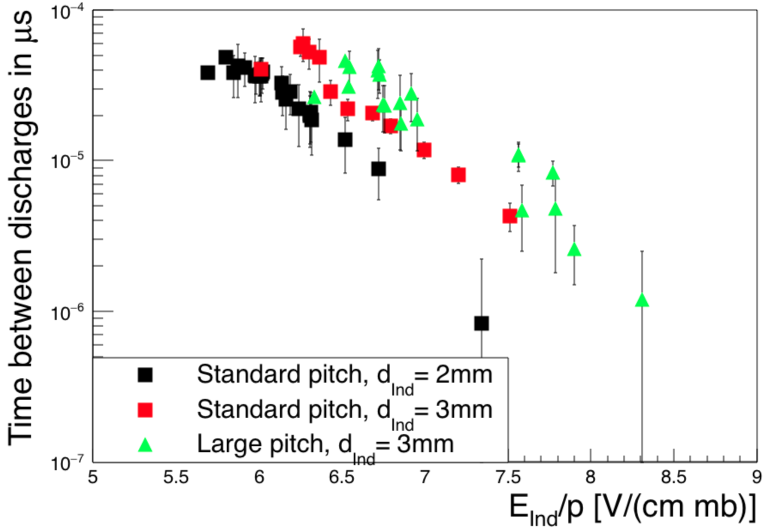
Observation of secondary discharges

- An additional, high signal is observed at the anode plane
  ➔ Observation @TUM started extensive studies for the upgrade project
- Several "10s"µs after the initial ("primary") discharge appears
- Appear only if the field is high enough



Dependence on the induction field

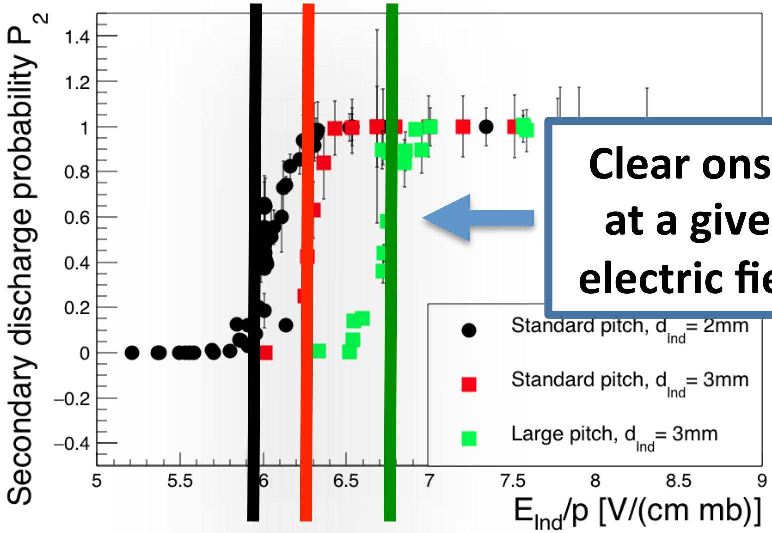




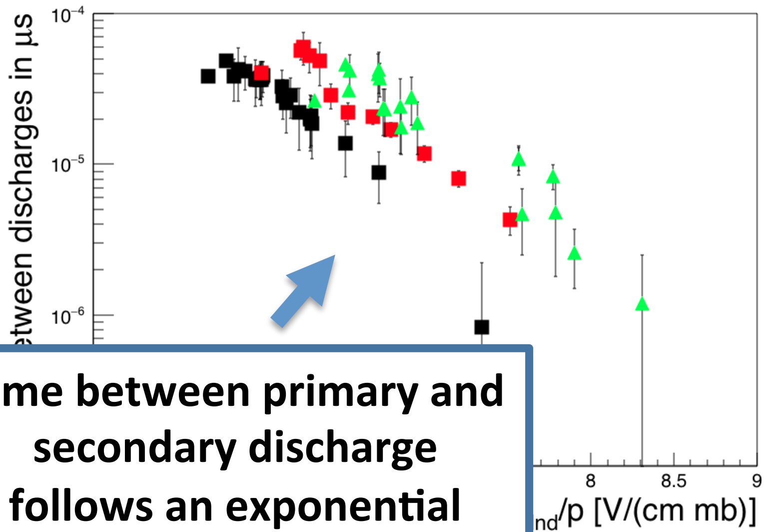
measured in Ar-CO_2 (90-10)

The qualitative behavior stays the same for different gas mixtures, but the slope of the onset as well as the necessary fields change *(first observed at TUM)*

Dependence on the induction field



Clear onset at a given electric field



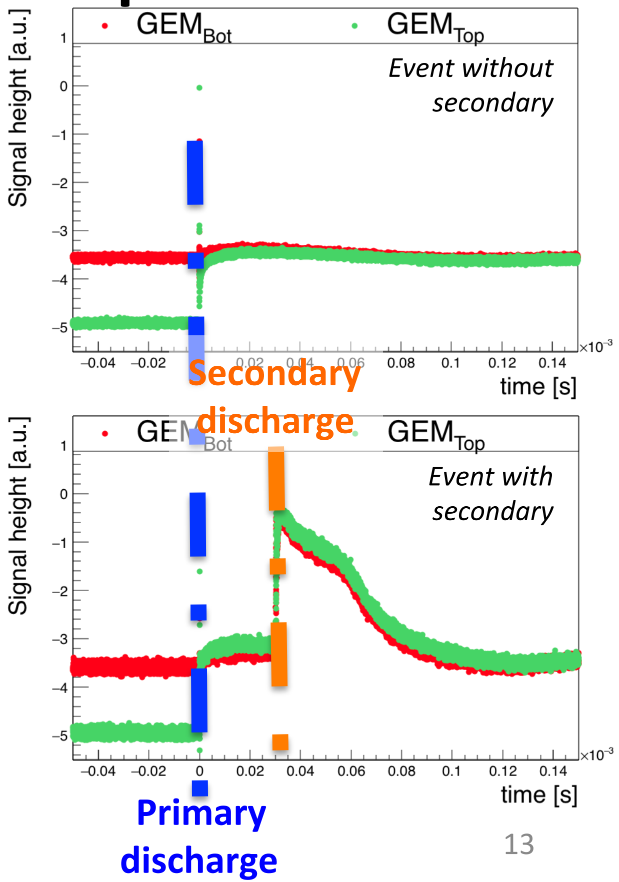
Time between primary and secondary discharge follows an exponential

measured in Ar-CO_2 (90-10)

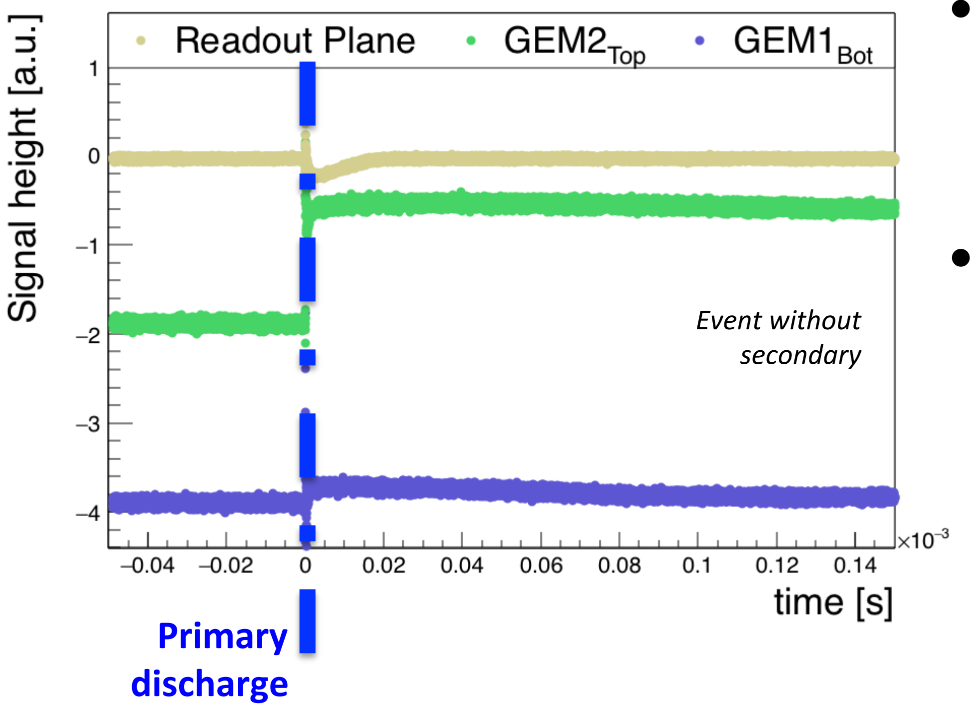
The qualitative behavior stays the same for different gas mixtures, but the slope of the onset as well as the necessary fields change *(first observed at TUM)*

Potential analysis with HV probes

- High Voltage (HV) probes allow to examine the potentials of the discharging system
- Primary discharge: $\Delta U_{GEM} \rightarrow 0$
- Secondary discharge: U_{GEMTop} & $U_{GEMBot} \rightarrow$ anode plane potential
- It is not possible to predict a secondary discharge from the measured potentials

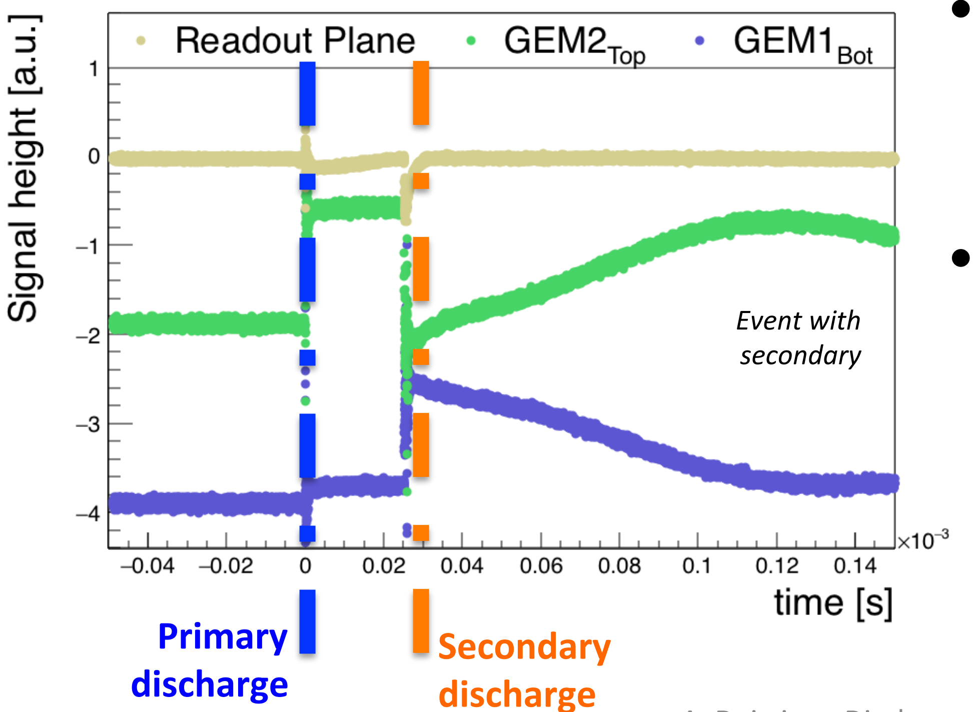


Studies with a double GEM setup



- Secondary discharges occur as well in the **transfer gaps**
- The qualitative behavior is the same as for the discharges in the induction gap.

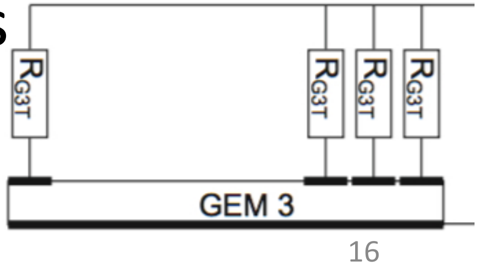
Studies with a double GEM setup



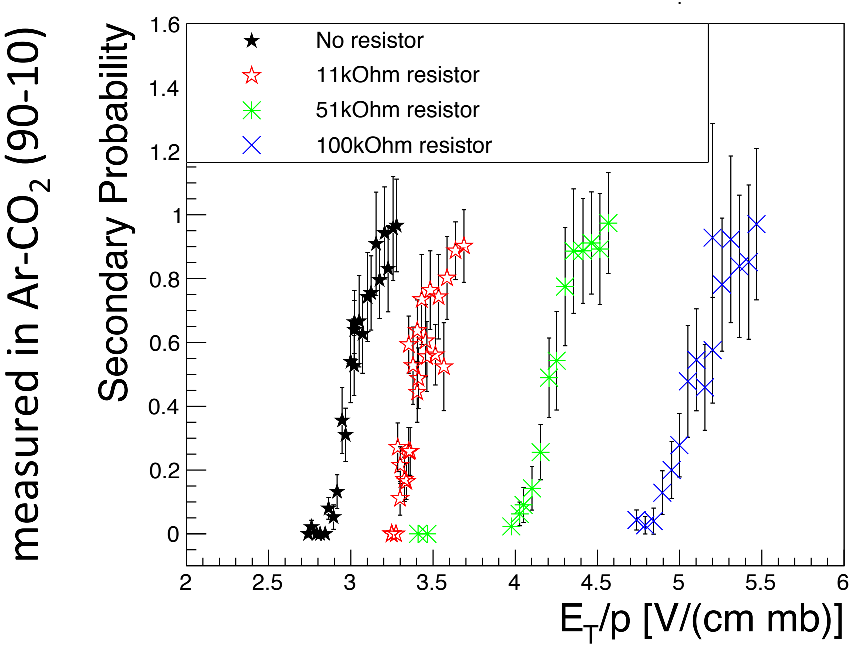
- Secondary discharges occur as well in the **transfer gaps**
- The qualitative behavior is the same as for the discharges in the induction gap.

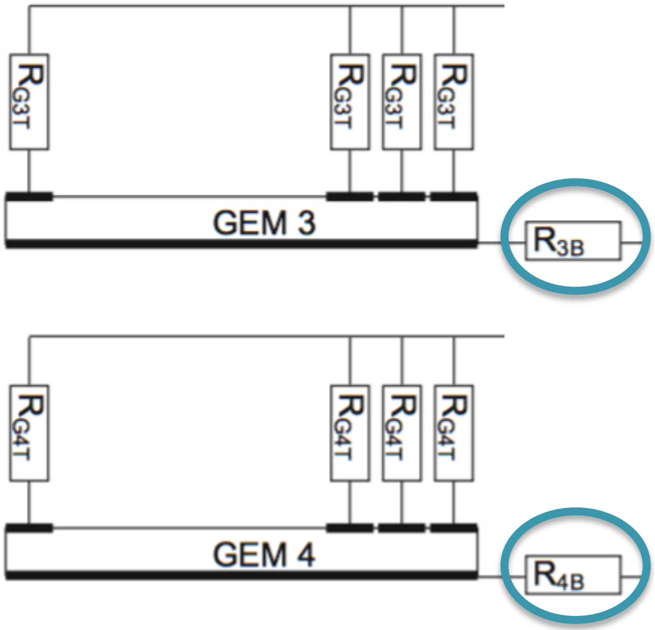
Additional observations:

- Secondary discharges occur as well for inverted field direction (e.g. inverted induction field)
- Simulations (software, as well as with a mockup setup) are able to reproduce the qualitative features of the primary and secondary discharges – however a process in the gas is needed to explain the full picture
- A secondary discharge affects all segments of a segmented GEM



Mitigation via decoupling resistors





- **The onset field for secondary discharges increases with increasing decoupling resistance**

Conclusions

- The quadruple GEM configuration for the readout chambers of the ALICE TPC upgrade has a sufficiently low discharge probability.
- Secondary discharges have been observed to occur in O(10μs) after the initial discharge. They are characterized by a “sharp” onset at a given electric field above or below the GEM.
- The physical origin of these is not yet clear, however their occurrence can be moved to higher fields by introducing additional resistors

Backup

Further reading:

Technical Design Report:

Upgrade of the ALICE Time Projection Chamber. CERN-LHCC-2013-020. https://cds.cern.ch/record/ 1622286

Addendum to the Technical Design Report for the Upgrade of the ALICE Time Projection Chamber.
CERN-LHCC-2015-002. https://cds.cern.ch/record/1984329

Discharge Studies:

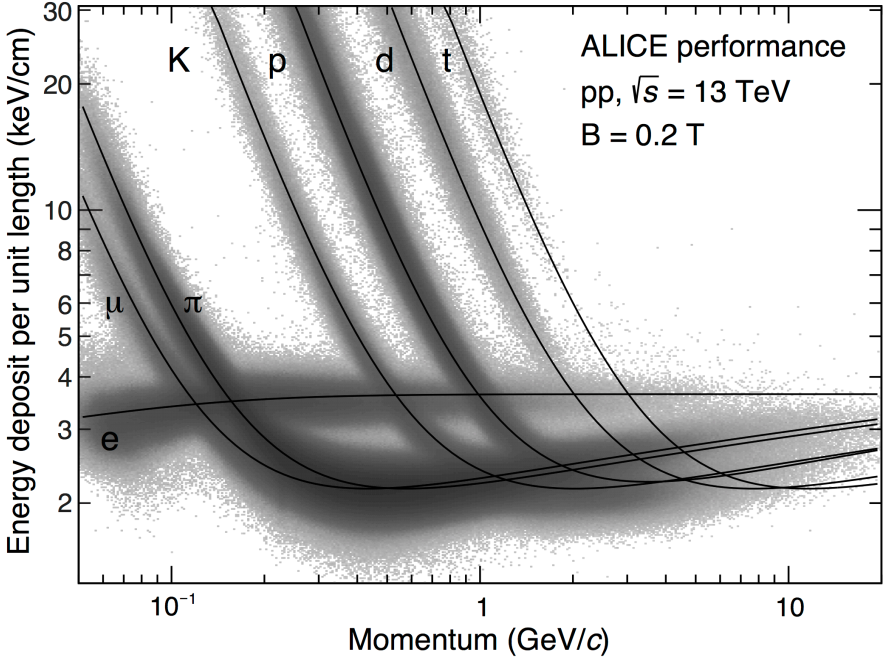
Piotr Gasik, *DISCHARGE STUDIES WITH SINGLE- AND MULTI-GEM STRUCTURES IN A SCOPE OF THE ALICE TPC UPGRADE*
https://indico.cern.ch/event/496113/contributions/2008281/attachments/1242032/1827187/gasik_11032016_sparks_RD51.pdf

Alexander Deisting, *DISCHARGE STUDIES WITH SINGLE GEMS*
https://indico.cern.ch/event/532518/contributions/2187809/attachments/1286129/ 1913118/RD51-meeting-7-6-16.pdf
A. Datz, (*University of Heidelberg)* Bachelor Thesis in preperation

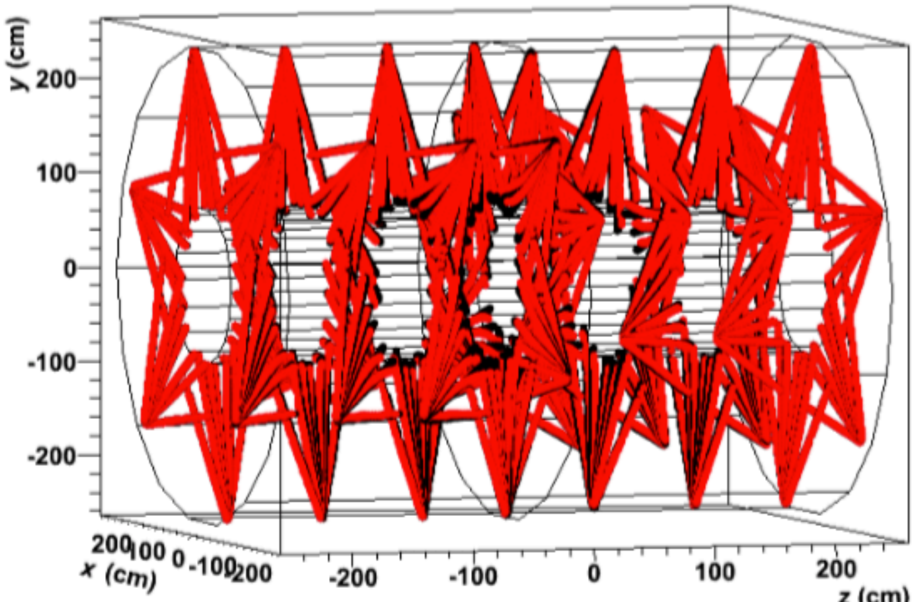
Recent ALICE TPC Upgrade overview talk:

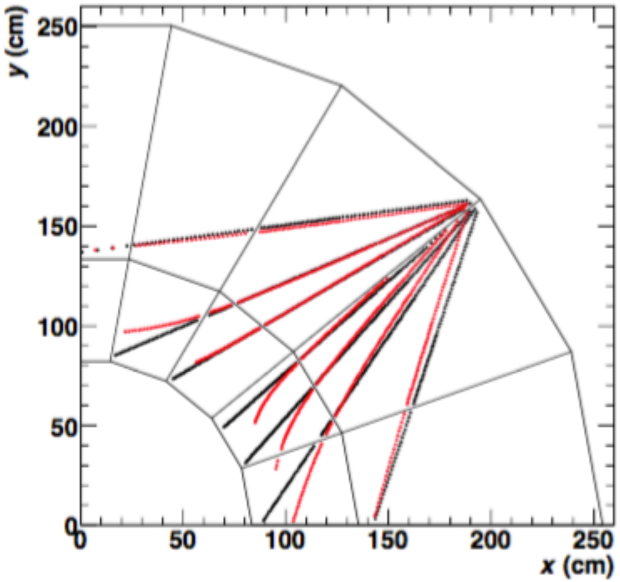
The ALICE TPC Upgrade Project - *Richard Majka (Yale University) for the ALICE Collaboration*
Talk at Quark Matter 2017

dE/dx performance of the current ALICE TPC



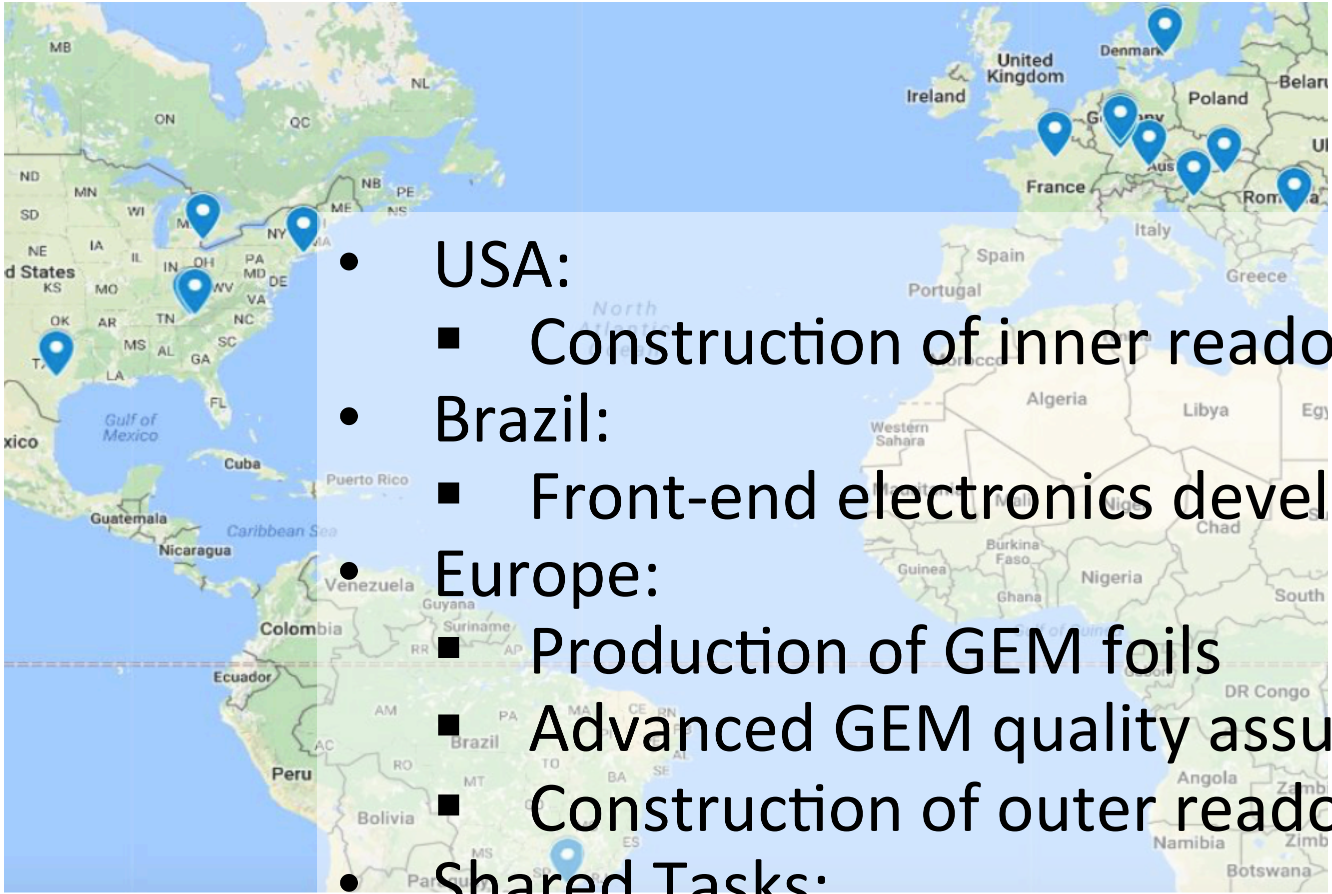
Laser system of the TPC





Upgrade status

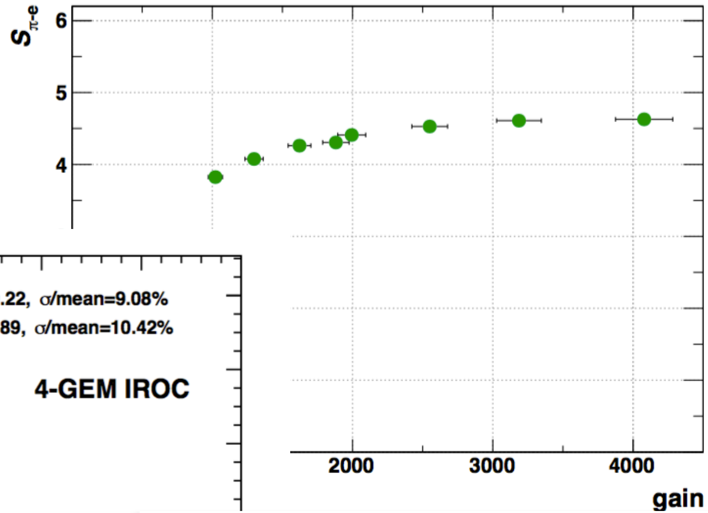
- Prototypes of inner- and outer readout chambers have been build and tested at PS, SPS and recently in the vicinity of the beam-pipe at ALICE
- The mass production of GEM foils is running since mid 2016
- First chambers of the final design have been build

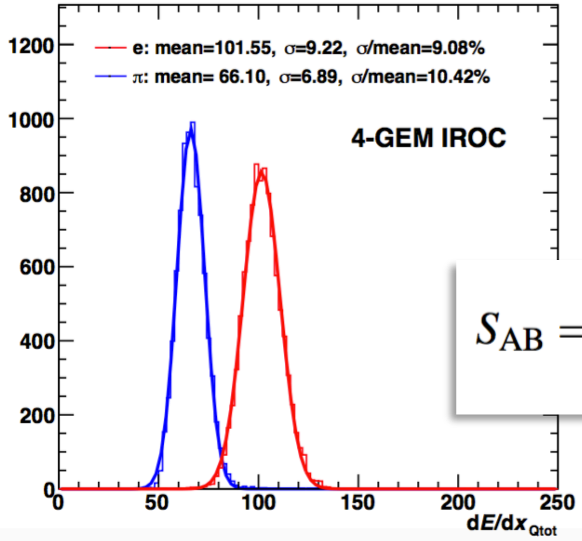


- USA:
  - Construction of inner readout chambers
- Brazil:
  - Front-end electronics development
- Europe:
  - Production of GEM foils
  - Advanced GEM quality assurance
  - Construction of outer readout chambers
- Shared Tasks:
  - Development of the front-end electronics

dE/dx performance of a 4GEM IROC

- At PS an IROC was tested with 1GeV/c electrons and pions
- As a reference PID provided by an additional Cherenkov detector was used

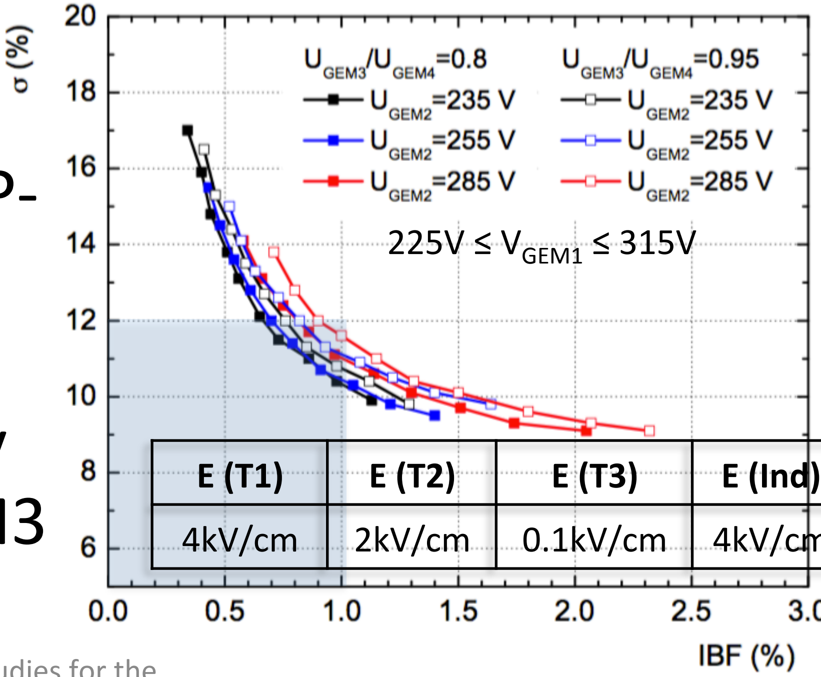




$$S_{AB} = \frac{2\left|\langle \mathrm{d}E/\mathrm{d}x\rangle_A - \langle \mathrm{d}E/\mathrm{d}x\rangle_B\right|}{\sigma(\mathrm{d}E/\mathrm{d}x)_A + \sigma(\mathrm{d}E/\mathrm{d}x)_B}$$

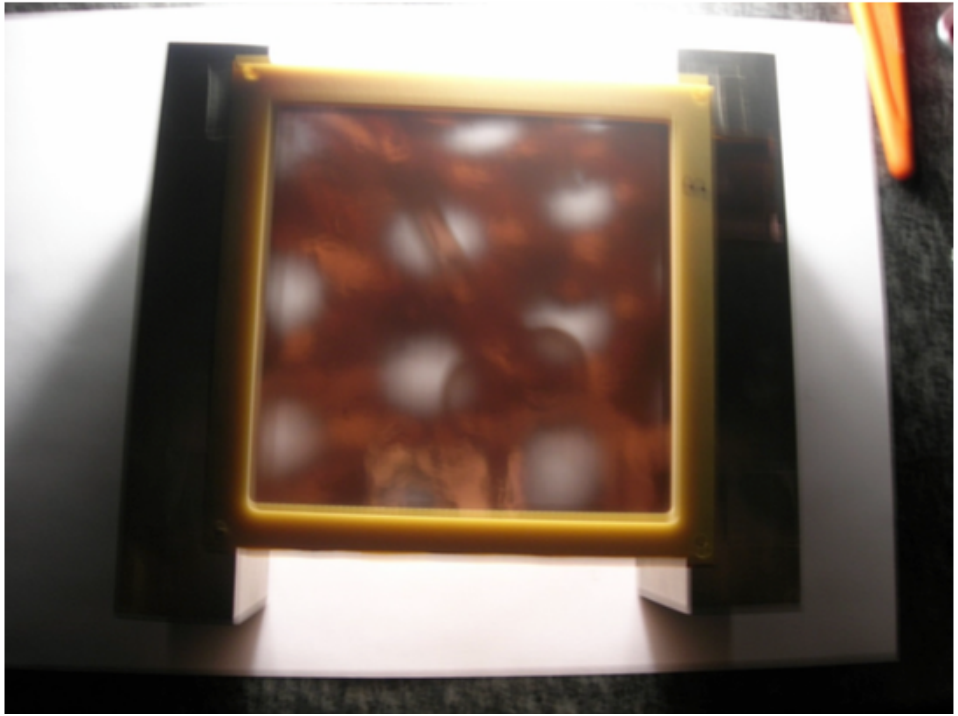
Ion backflow (IBF) and energy resolution

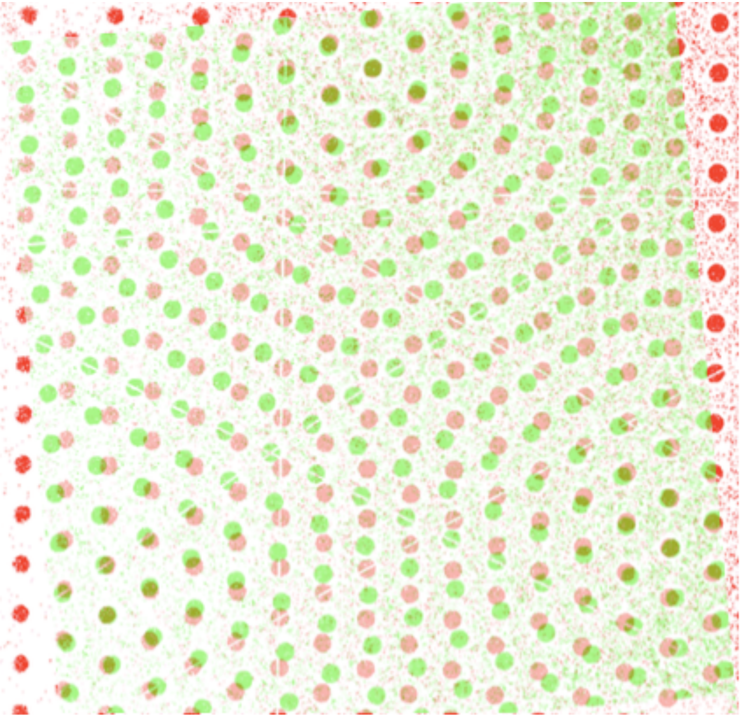
- IBF & the local energy resolution (σ_E/E at the ^{55}Fe photopeak) studies with quadruple GEM stack (S-LP-LP-S) and the baseline gas mixture were conducted.
- The gain was kept at 2000, by adjusting the voltages in GEM3 and GEM4.



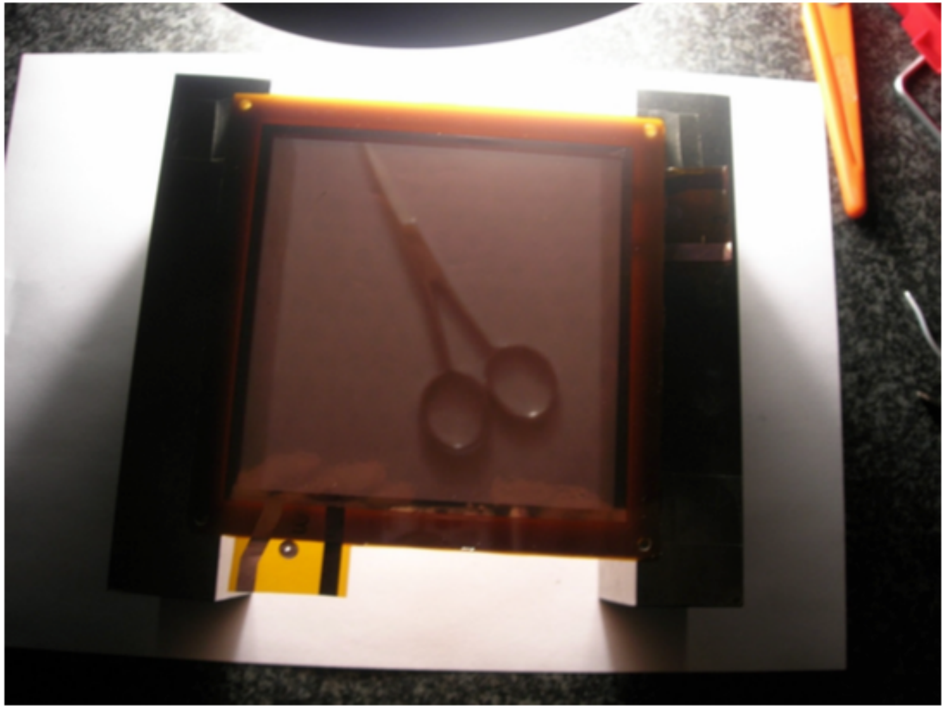
E (T1)	E (T2)	E (T3)	E (Ind)
4kV/cm	2kV/cm	0.1kV/cm	4kV/cm

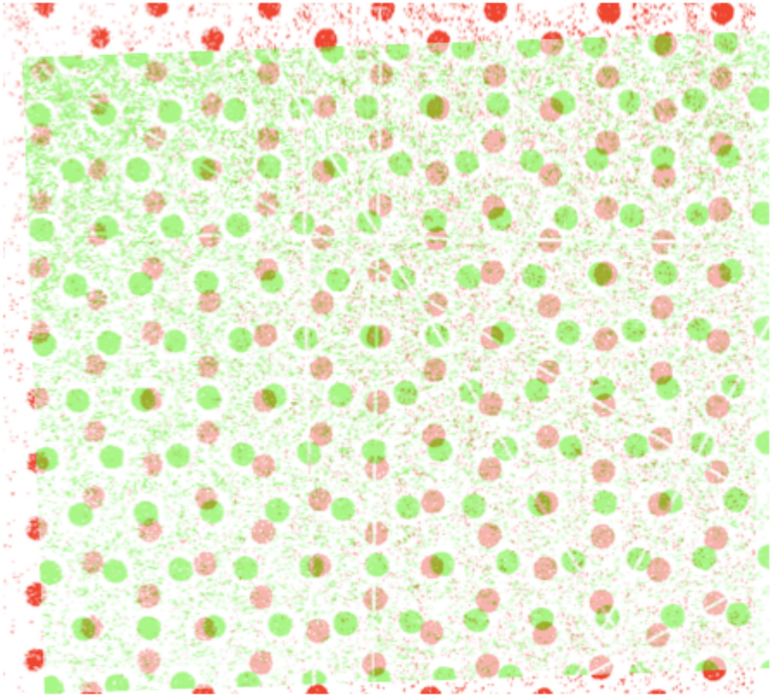
2 GEMs: Not rotated



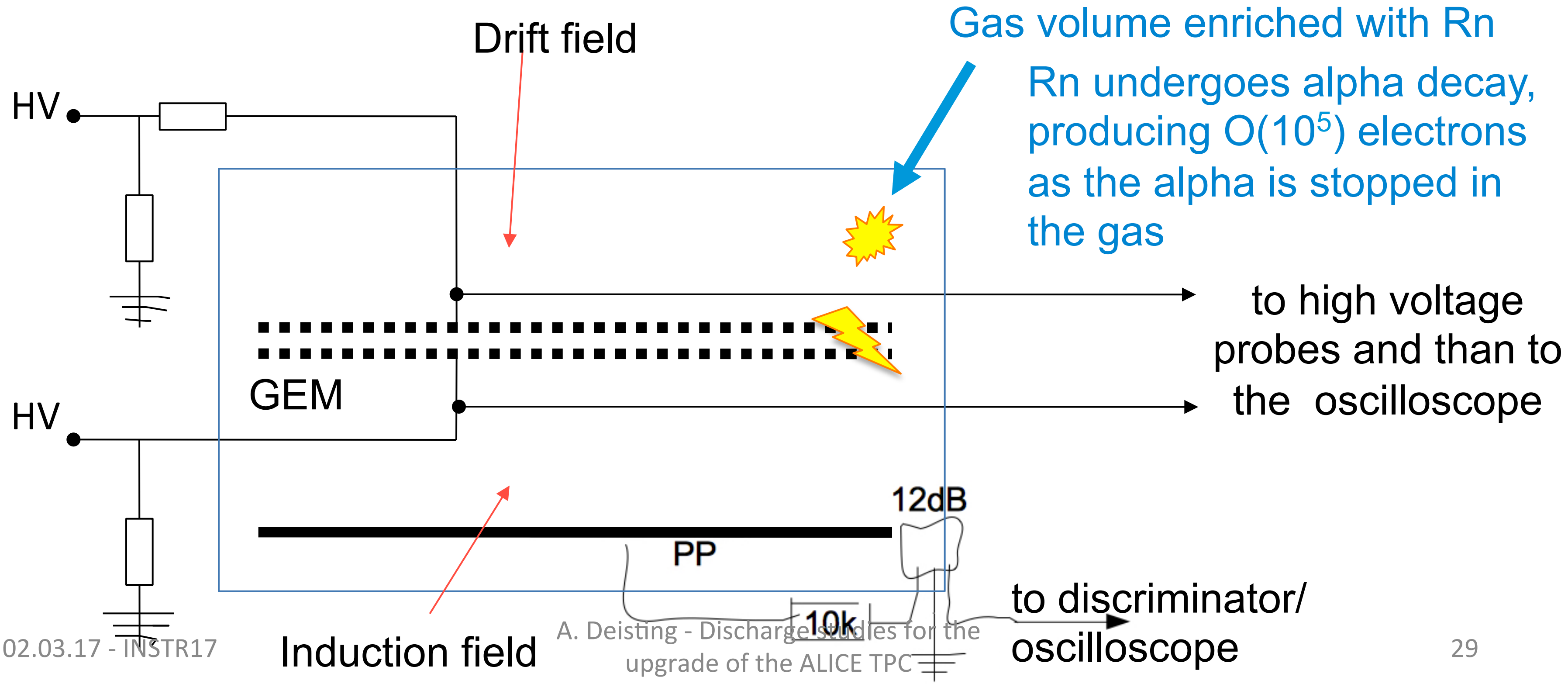


2 GEMs: rotated by 90 degrees





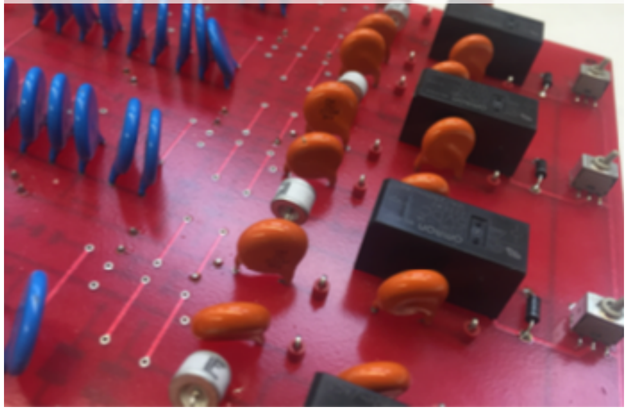
Discharge studies with one GEM



Our current understanding:

- Secondary and primary discharges can be qualitatively modeled in spice and with mockups containing only circuit elements: Part of the process is driven by the RC constant of the system
- However, to explain the full picture of the creation of these discharges a process in the gas is needed

TUMunich GEM PCB simulator



Consequences:

- Secondary discharges can affect more than one GEM (segment) in the stack -> Dead-time for the whole stack and not only a segment
- Several potentials are affected: The possibility of producing even more discharges rises