ALICE-US R&D for the ALICE TPC upgrade

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RD-51 meeting. June, 2014.

- ***Goal of Alternative R&D*** *(as it was formulated ~ 2 years ago)*

➢ In addition to the baseline TPC upgrade, alternative R&D is necessary to study and recommend possible improvements on the detector performance.

➢ The following key issues have been addressed and will need further investigation before a final design decision:

- Preserve (or improve) momentum reconstruction performance
- Minimize IBF (~0.1-0.2%) for average gas amplification ≥ 2000
  {to guarantee good signal-to-noise value}.
  It means: ϵ - parameter <=5.*)
- But control E-resolution (Fe55, Sigma/Mean) <=12%
- And keep the same number and size for TPC read-out pads.
- Minimize number of overlap events for 50 kHz continuous readout (Investigate performance of Ne+CF4 (~10%) as a working TPC gas)

*) (ALICE Upgrade LOI). "At a typical gas gain of 2000 the requirements translate into an ion back flow probability of less than 0.5%, …" .

What was known ~ 1.5 years ago

- Multi GEMs setup:

  -- Detail study from Novosibirsk team: the best IBF for drift field >0.1 kV/cm: >1.%
  (A. Bondar, et al, NIM A496 (2003), 325)
  -- careful and comprehensive R&D from CERN, TUM and Frankfurt teams: IBF = (0.6-0.7)%;
  at least factor 10 improvement.
  (TDR ALICE TPC, CERN-LHCC-2013-020)

- COBRA GEMs

  -- some basic R&D from Tokyo.
  -- IBF is much below 1% but resolution and charge up are issues.

- MicroMeshGas (MMG).

  -- IBF ~ 1% its own (close to fields ratio)
  -- but sparking, and there is no charge spread on a readout board ("destroy" Pt-reconstruction performance).

- GEM + MMG available data; "COMPASS" experience.

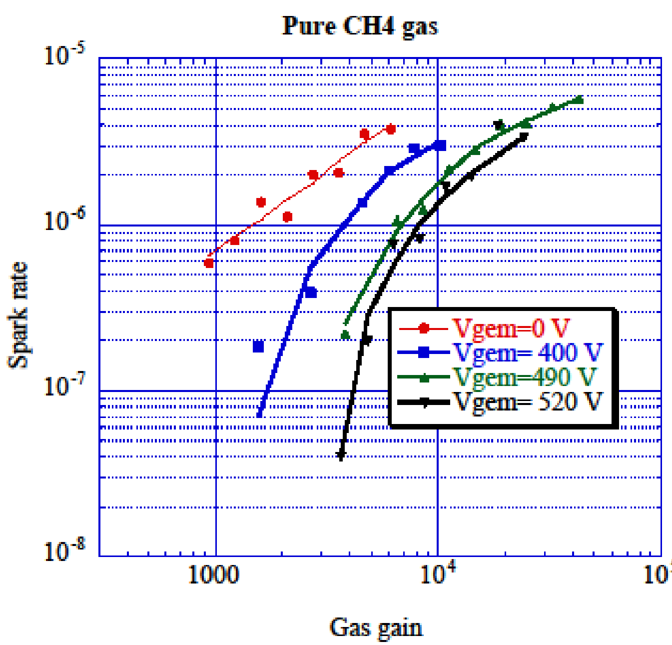
- ***Proposed: 2 GEMs + MMG.***

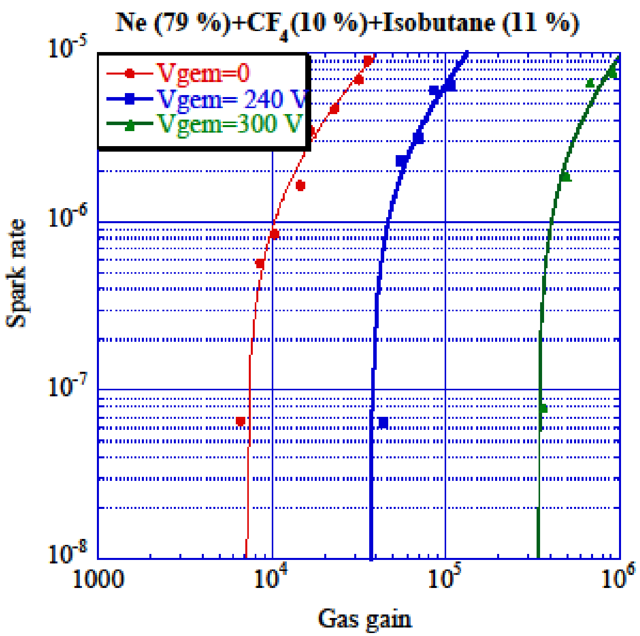
  -- IBF {(1%) & (10%)} → 0.1%
  -- 2 GEMs gas amplification ~5 → MMG gas amplification ~400
  (all detectors are in a very "comfortable" condition from HV point of view →
  minimize sparking probability. As an example: GEM+MMG setup in COMPASS)
  -- 2 GEMs will "provide" additional spread of electrons on the Mesh surface → improve Pt reconstruction (with Chevron pad shape) and minimize sparking probability.

MMG + GEM spark rate test, Purdue University team + Y.G.

Low spark rate with the GEM

Beam test at CERN with 10 GeV/c protons (June, 2001)
With the right gas mixture 10E-8 spark rate
at gas gain of 10E 5 region



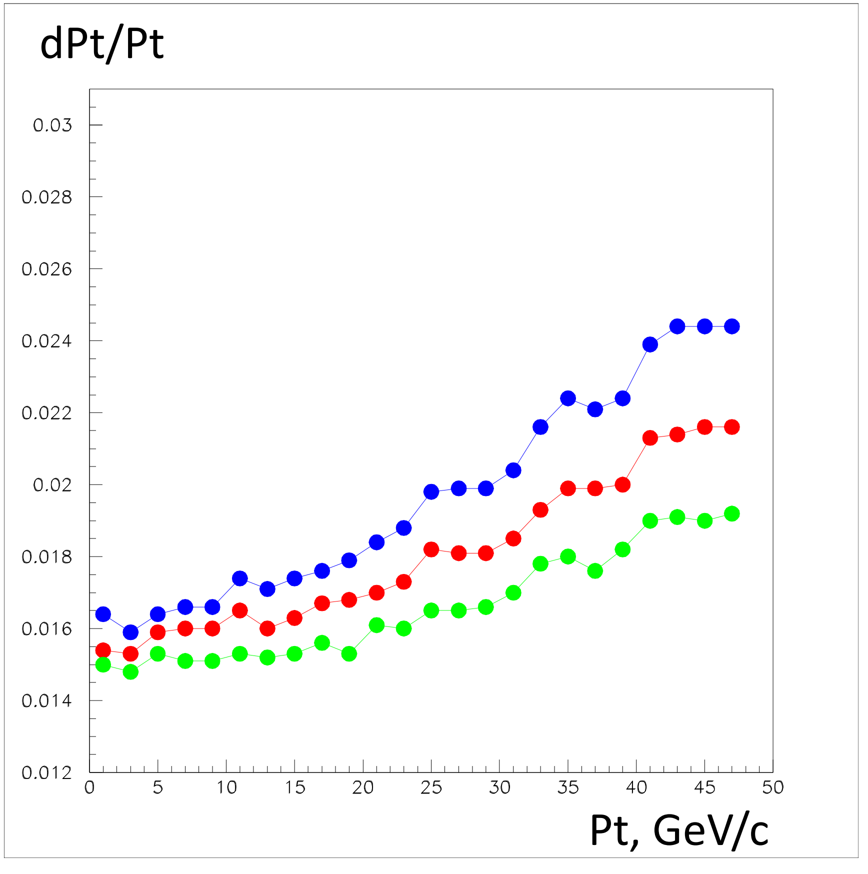


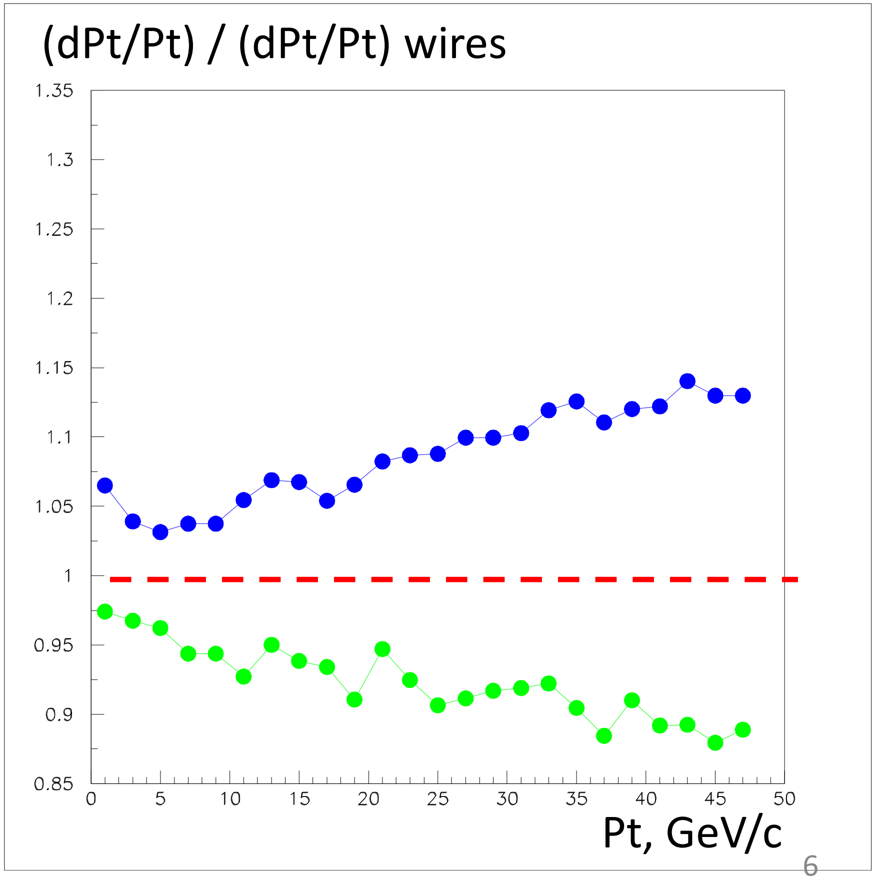
- ***TPC response simulation was done (as precise as possible) to check micro-pattern technology for gas amplification in a comparison with MWPCh.***
- ***(all details are in appendix) .***

Momentum Reconstruction
ALICE, ITS+TPC

(100% hit & track finding efficiency)

Red: wires read-out option; Ne+CO2(10%)
Blue: 3-GEMs; Ne+CO2(10%)
Green: 2-GEMs+MMG;
Ne+CO2(10%)+CH4(5%),
chevron (6 zigzags)





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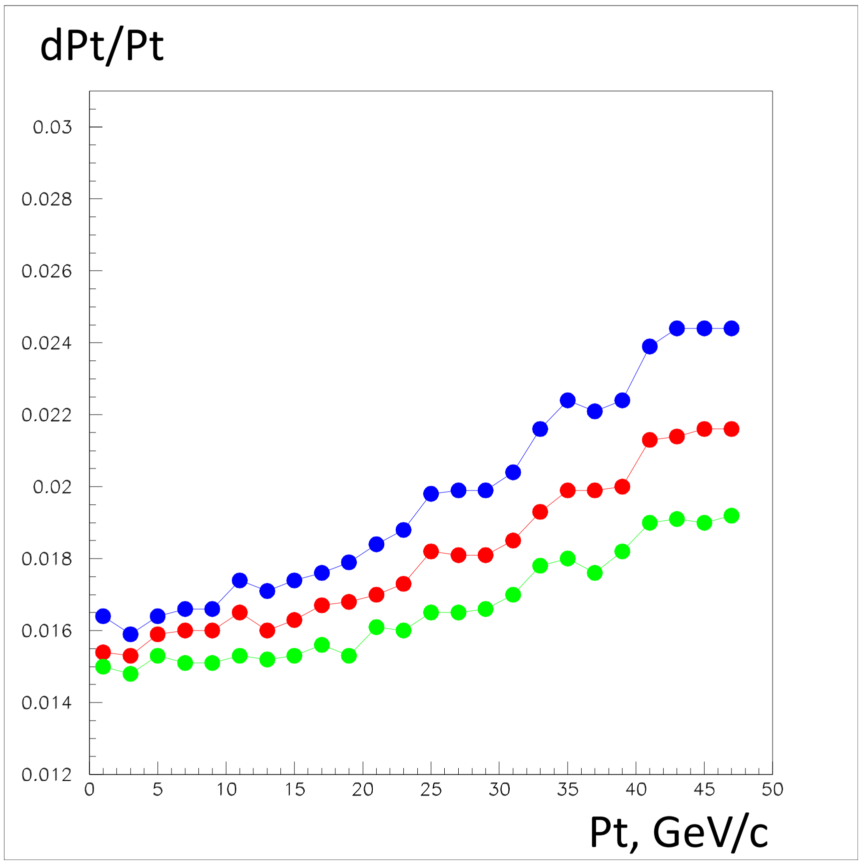
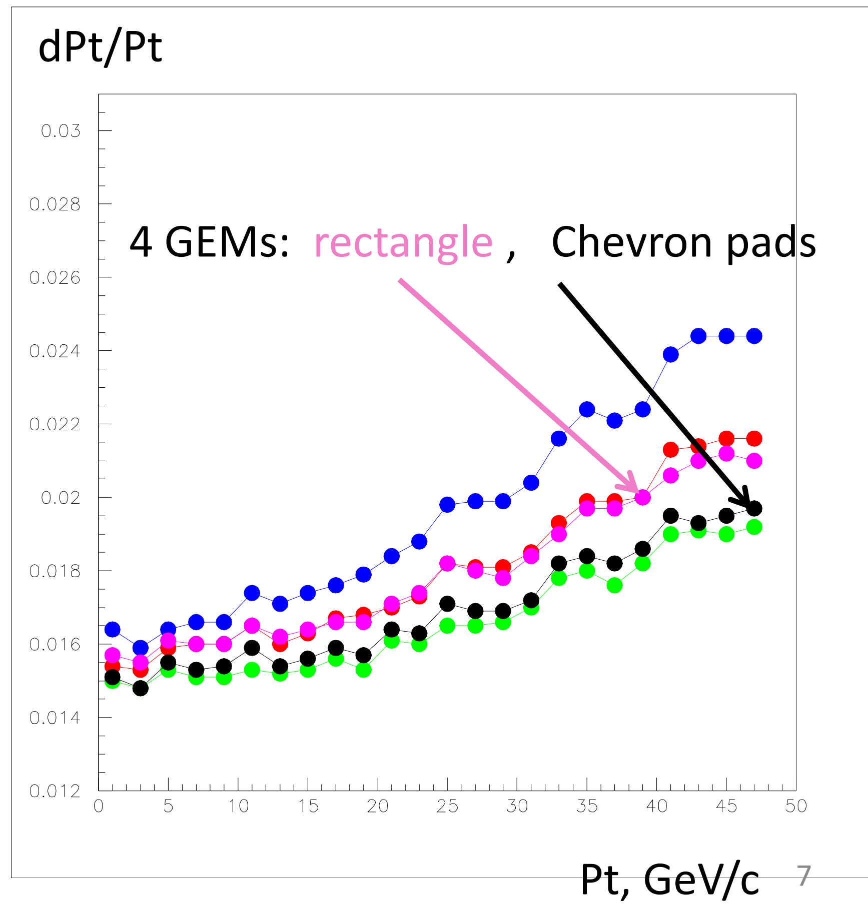
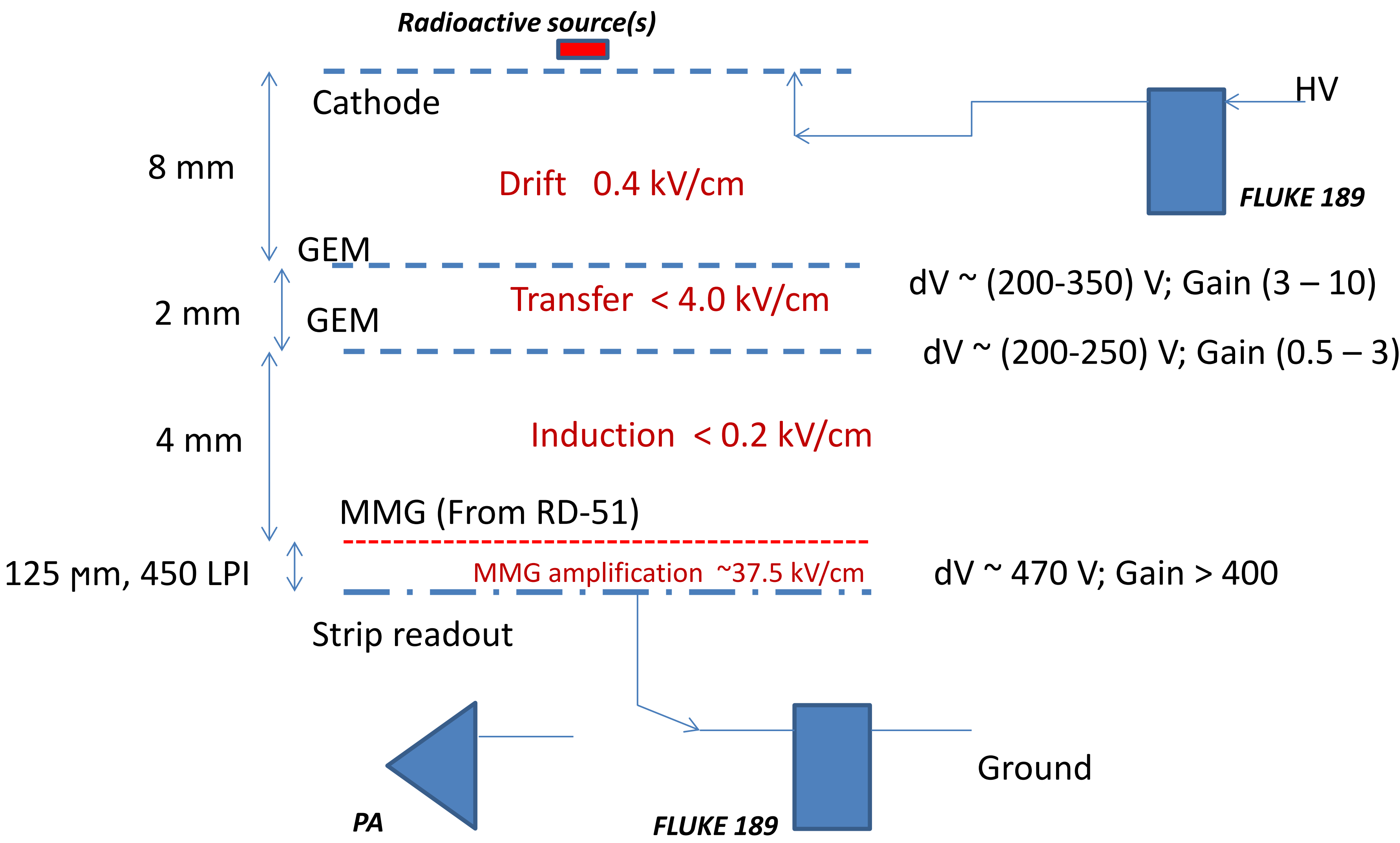




Setup for IBF and E-resolution measurements of combined 2 GEMs + MMG.



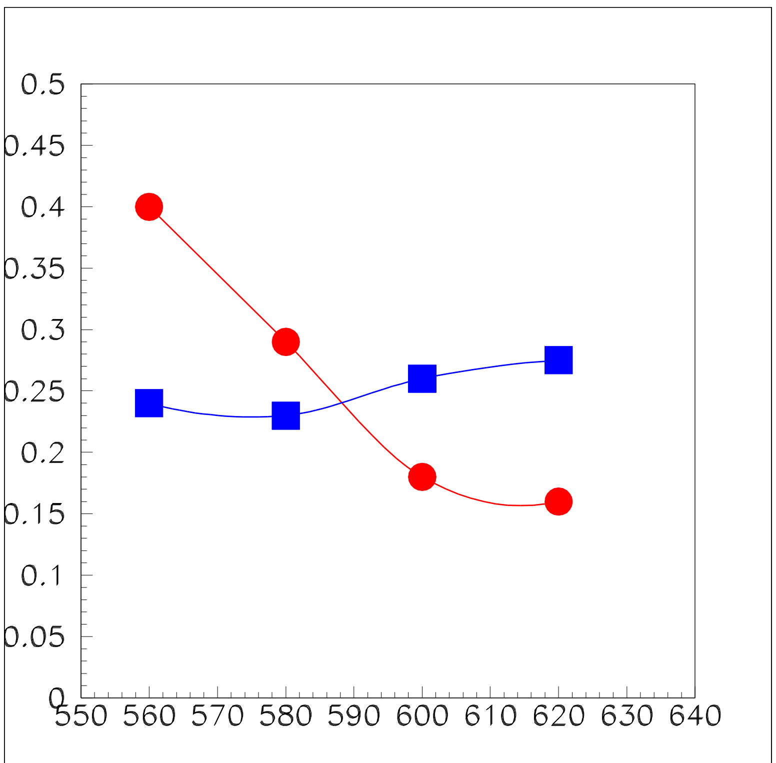
First measurements with Ar+CO2(30%) and Sr90 source

E drift = 0.4 kV / cm
E transfer = 3.5 kV / cm
E induction = 0.125 kV /cm

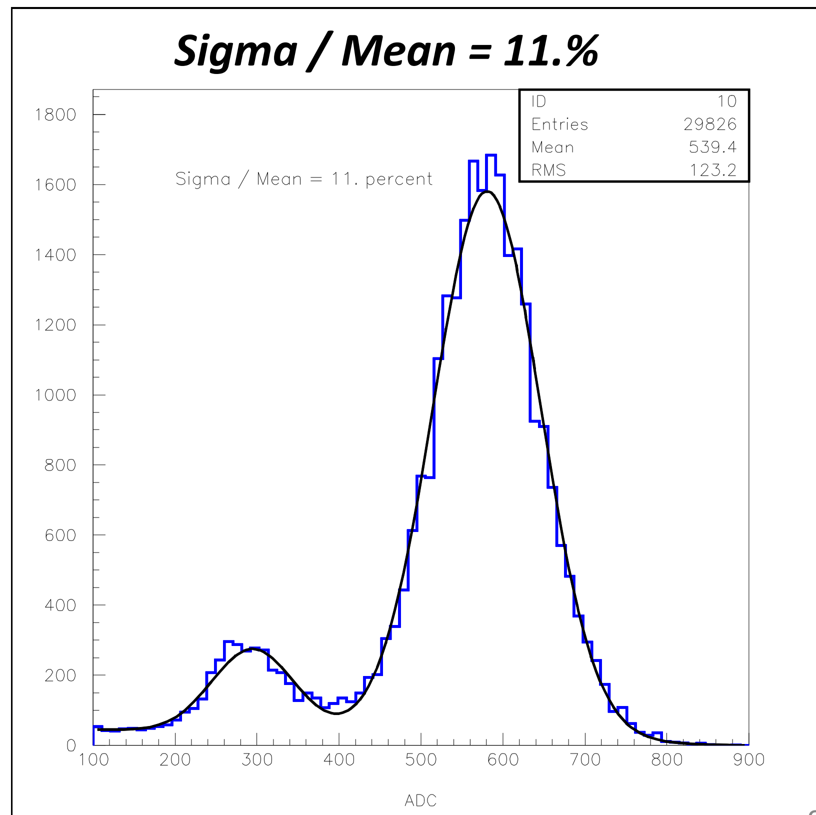
<G.A.> = (3.5+/- 0.5) * e3
(tune GEM voltages to keep GA the same)

Red points : I cathode / I anode, %; Sr90

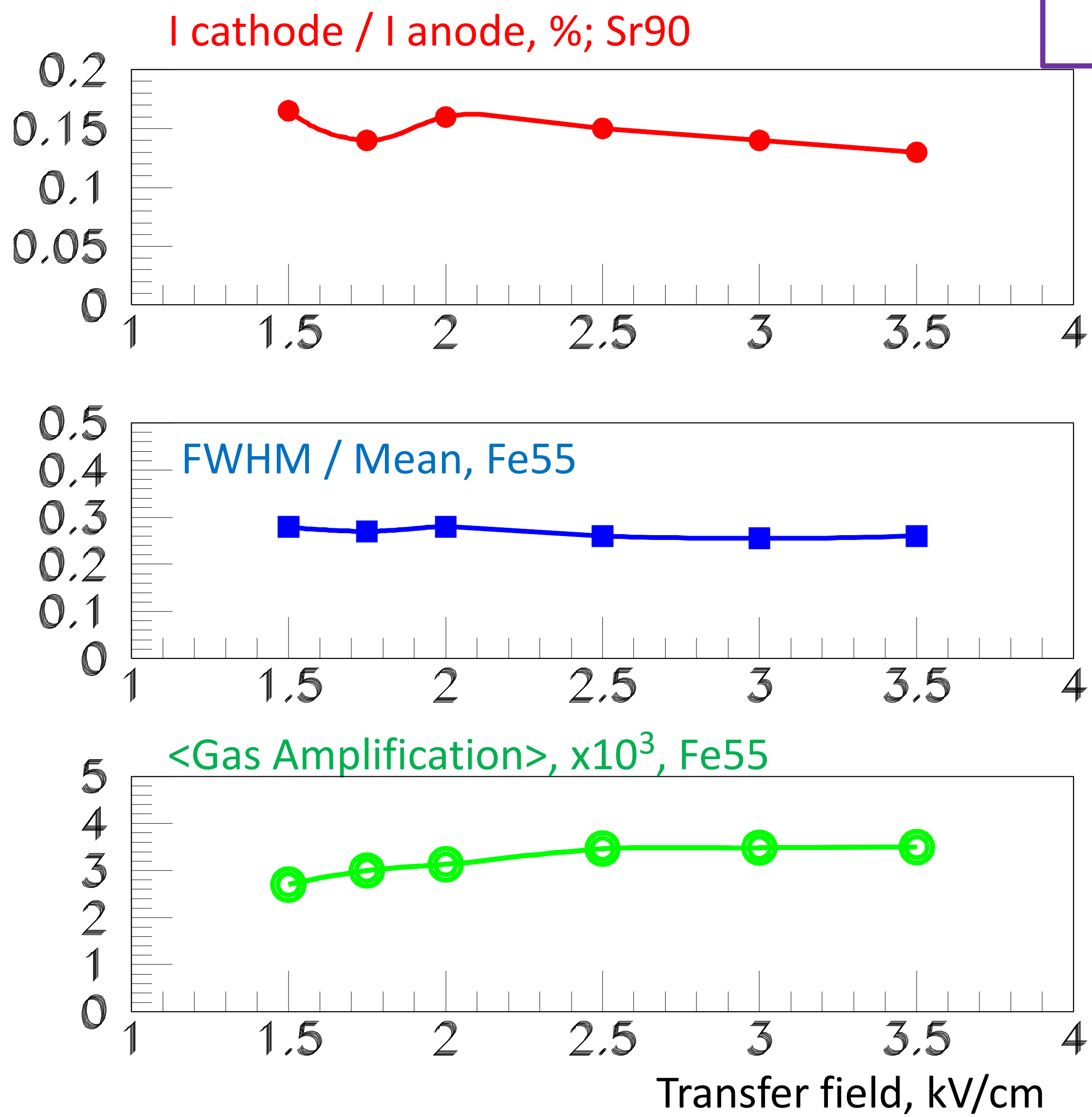
Blue boxes: FWHM / Mean, Fe55



MMG Mesh HV, V



IBF, E-resolution and <GA> as function of Transfer Field
Ar + CO2 (30%)



MMG Mesh – 620 V

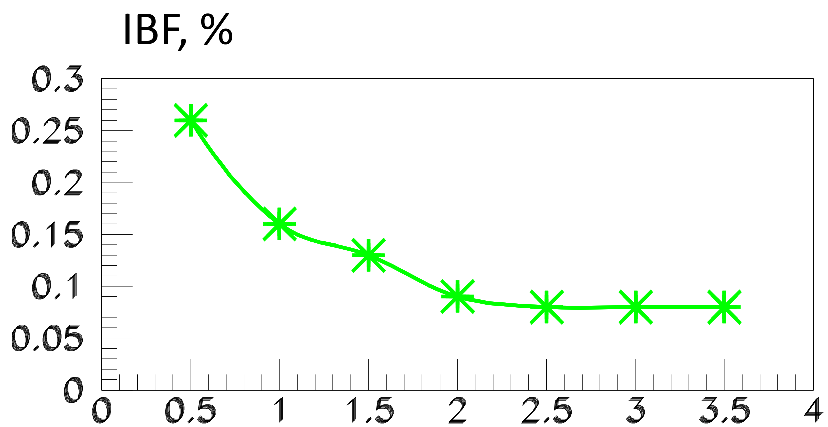
Drift Field – 0.4 kV/cm

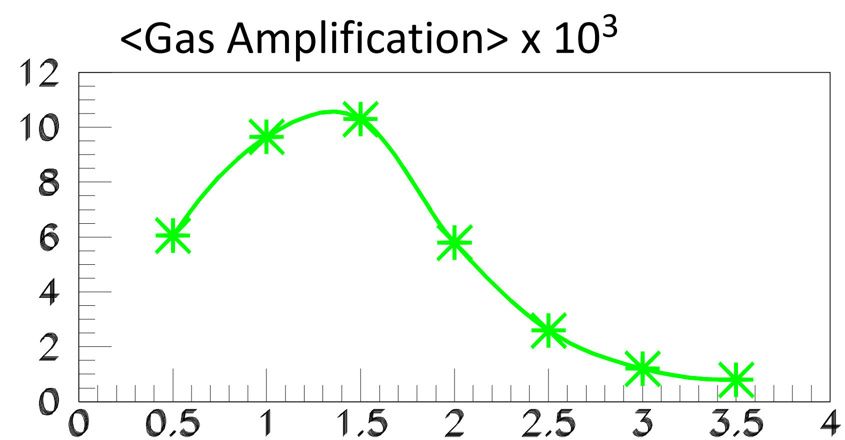
Induction Field – 0.125 kV/cm

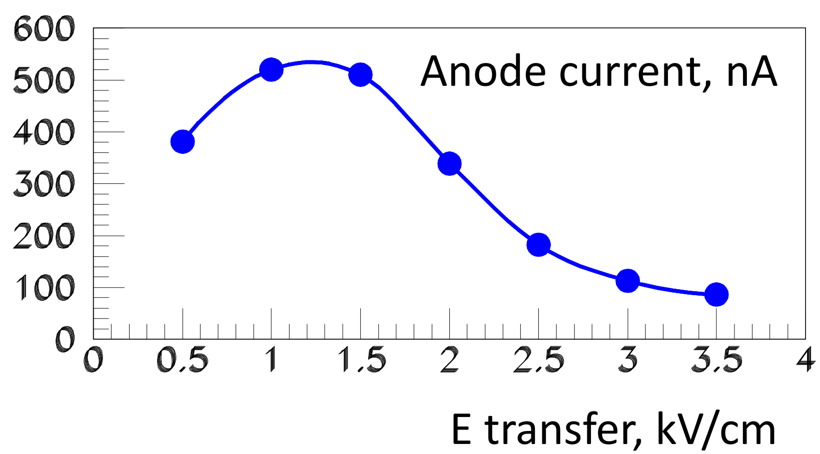
2 GEMs+MMG; Ne+CF4(10%); Sr90.

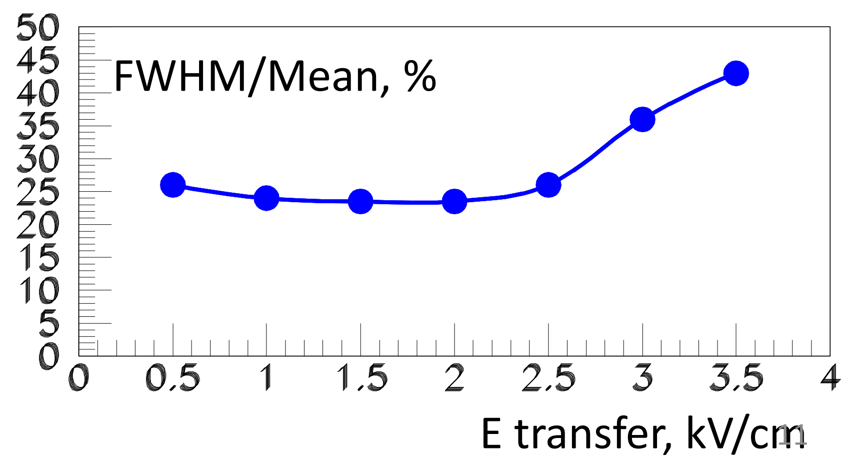
Transfer E-field Scan

V mesh = 496 V
Drift field = 0.4 kV/cm
Induction Field = 0.125 kV/cm
dV1 (GEM) = 200 V
dV2 (GEM) = 230 V





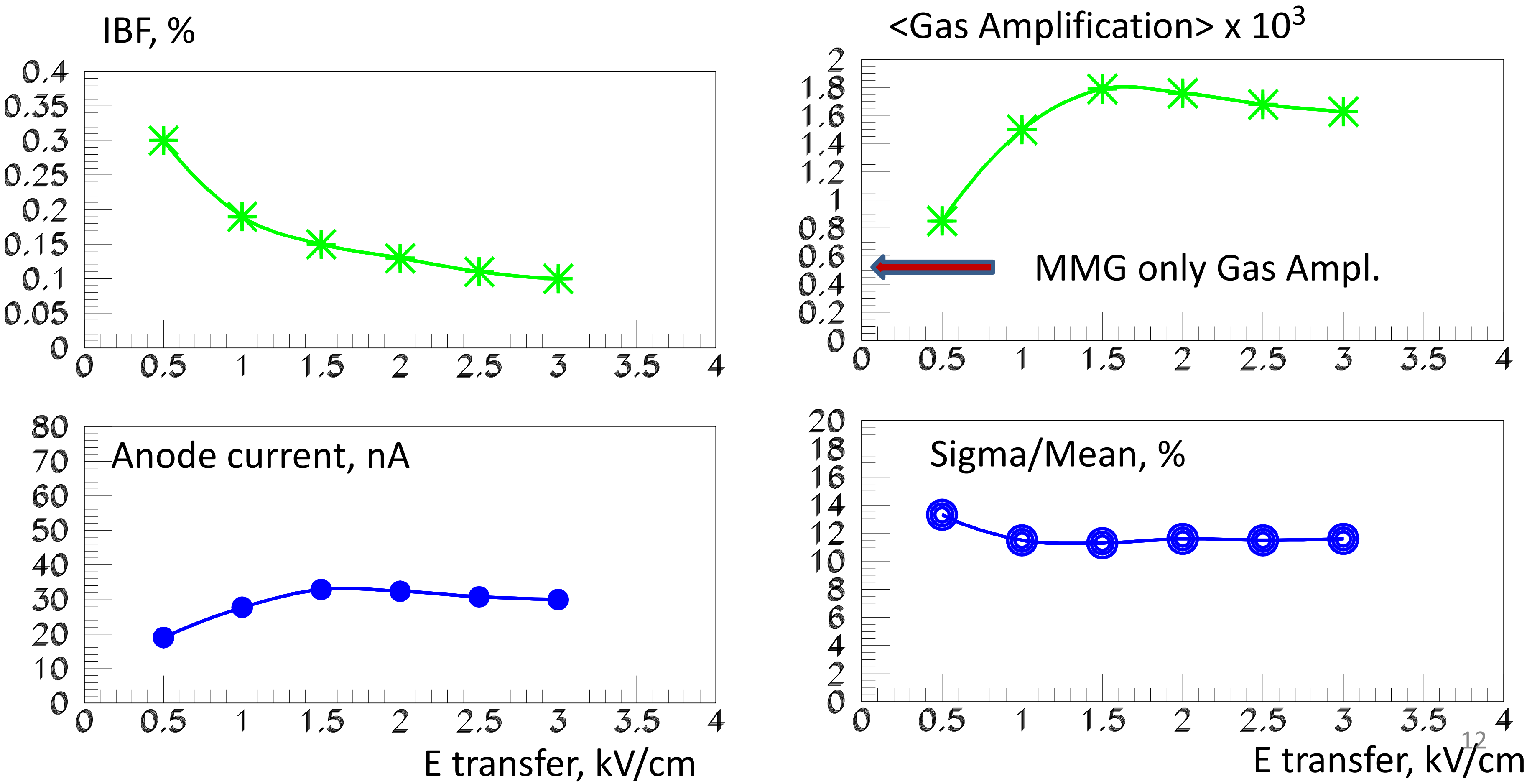




2 GEMs+MMG; Ne+CO_2(10%); Sr90.

Transfer E-field Scan

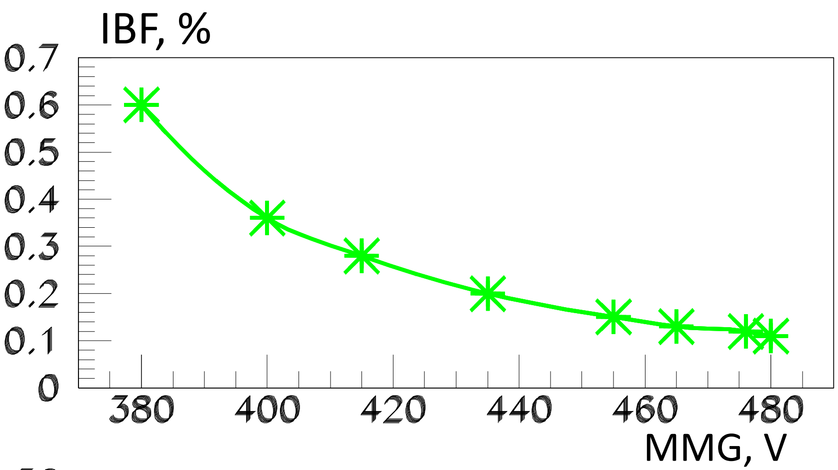
V mesh = 473 V
Drift field = 0.4 kV/cm
Induction Field = 0.1 kV/cm
dV1 (GEM) = 200 V
dV2 (GEM) = 240 V

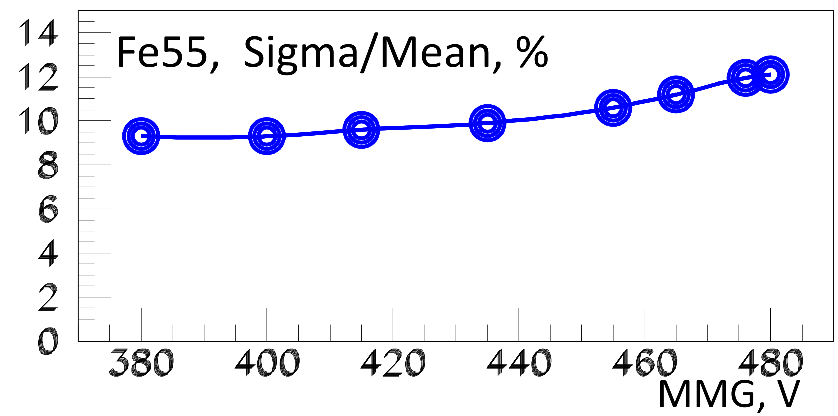


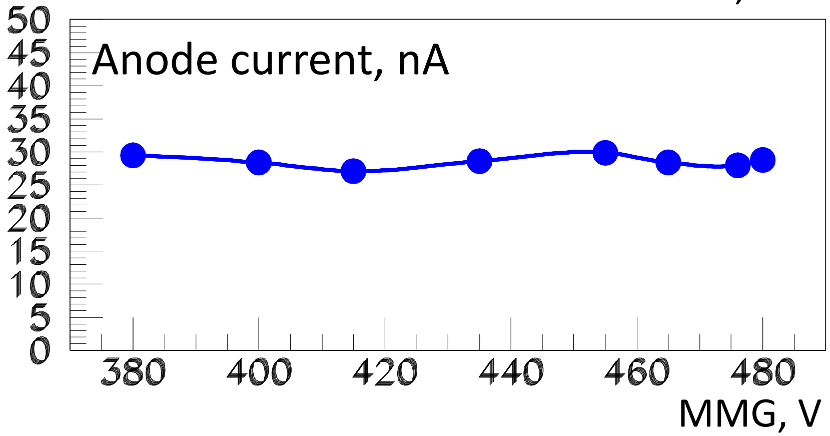
Ne+CO_2(10%), MMG – GEM 2(top) voltage scan, keep gas amplification . Sr90

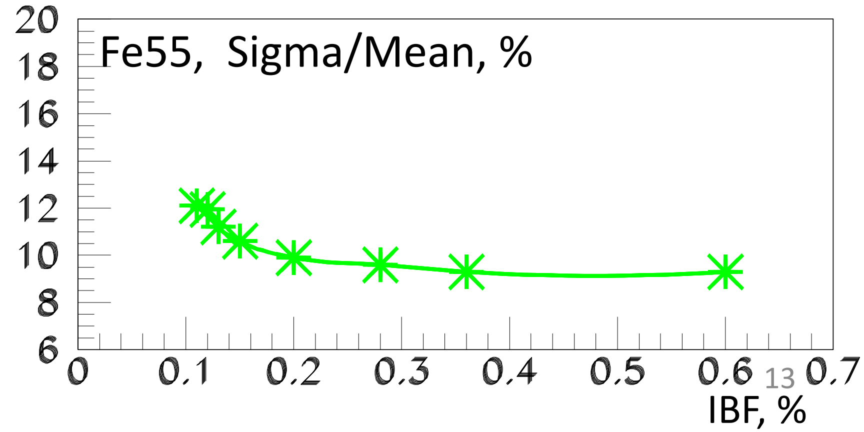
Drift field = 0.4 kV/cm
Transfer field = 2.5 kV/cm
Induction Field = 0.1 kV/cm
dV1 (GEM) = 200 V

<GA> = 2.45+/-0.05

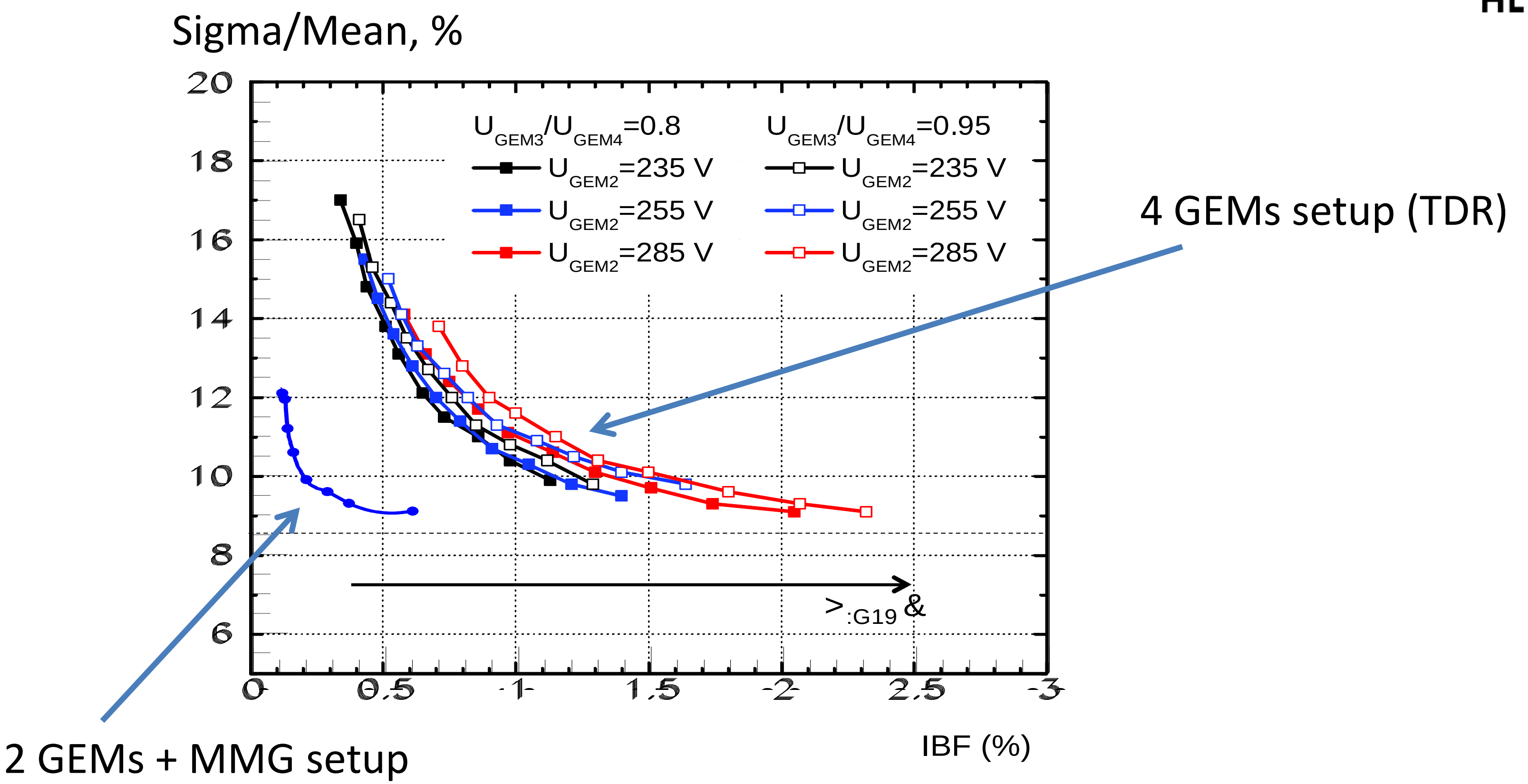






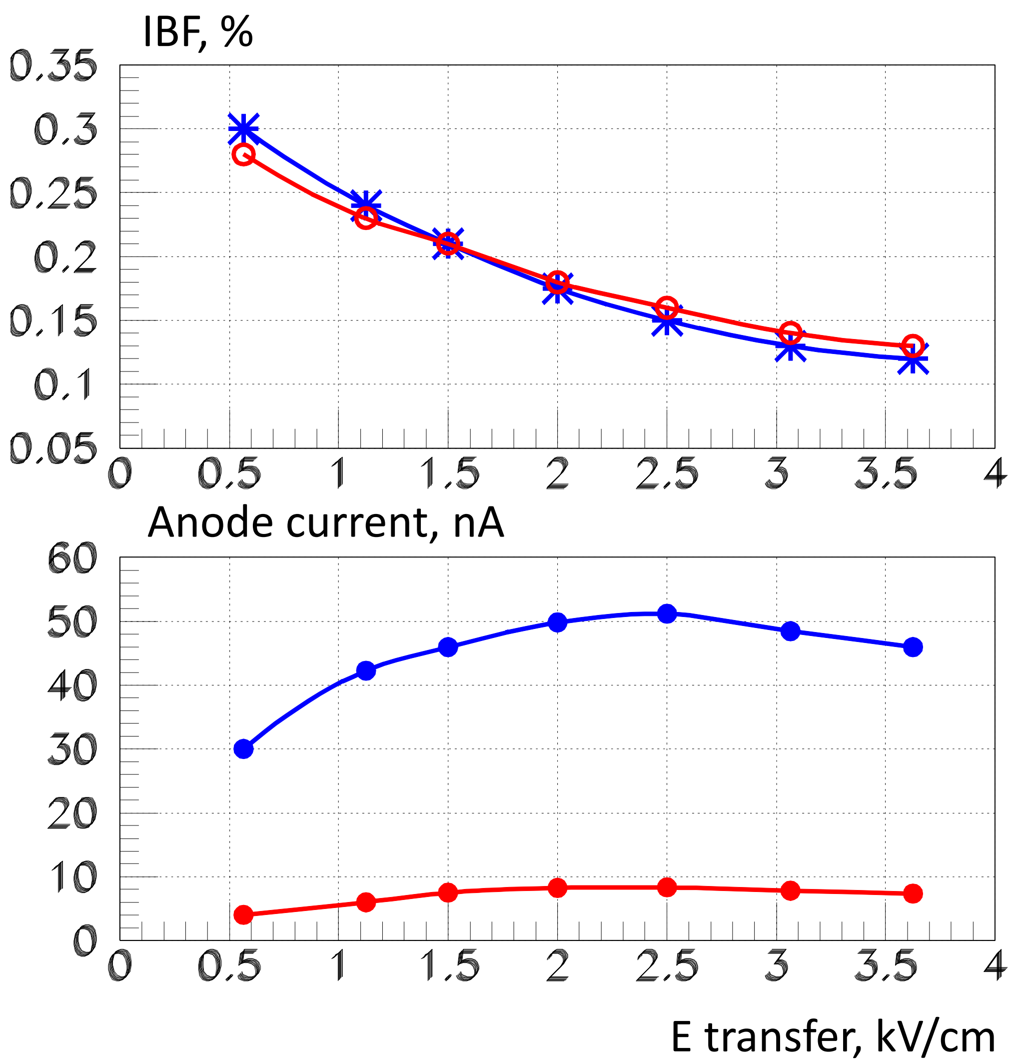


IBF performance and energy resolution



2 GEMs+MMG; (Setup #2). Ne+CO2(10%); Sr90 and Fe55

Transfer E-field Scan



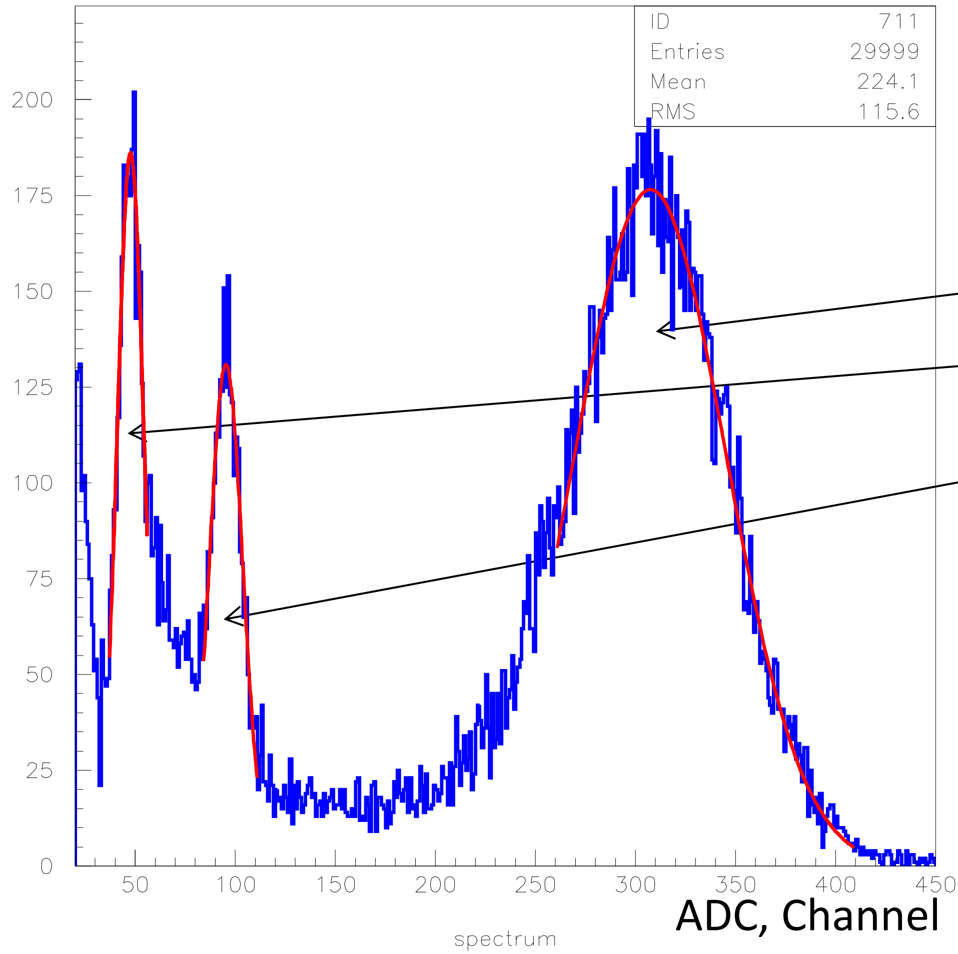
V mesh = 485 V
Drift field = 0.4 kV/cm
Induction Field = 0.125 kV/cm
dV1 (GEM) = 195 V
dV2 (GEM) = 225 V

Red points: Fe55
Blue points: Sr90

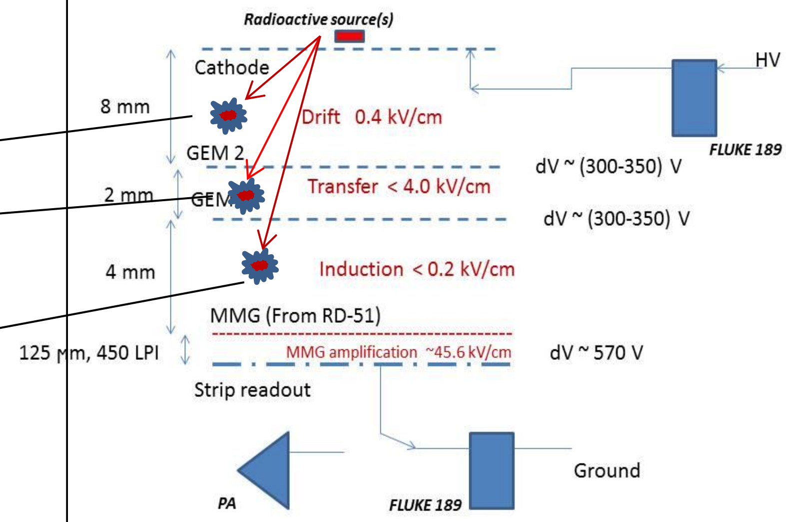
2 GEMs+MMG; Ne+CO2(10%); Fe55
Example of Spectrum (E tr = 1.5 kV/cm)

14% 8.5% 12.% Sigma/ Mean

Gaussian Fit, Red



ADC, Channel



GA GEM 1 ~= 0.52

GA (GEM 2 & GEM 1) ~= 3.2

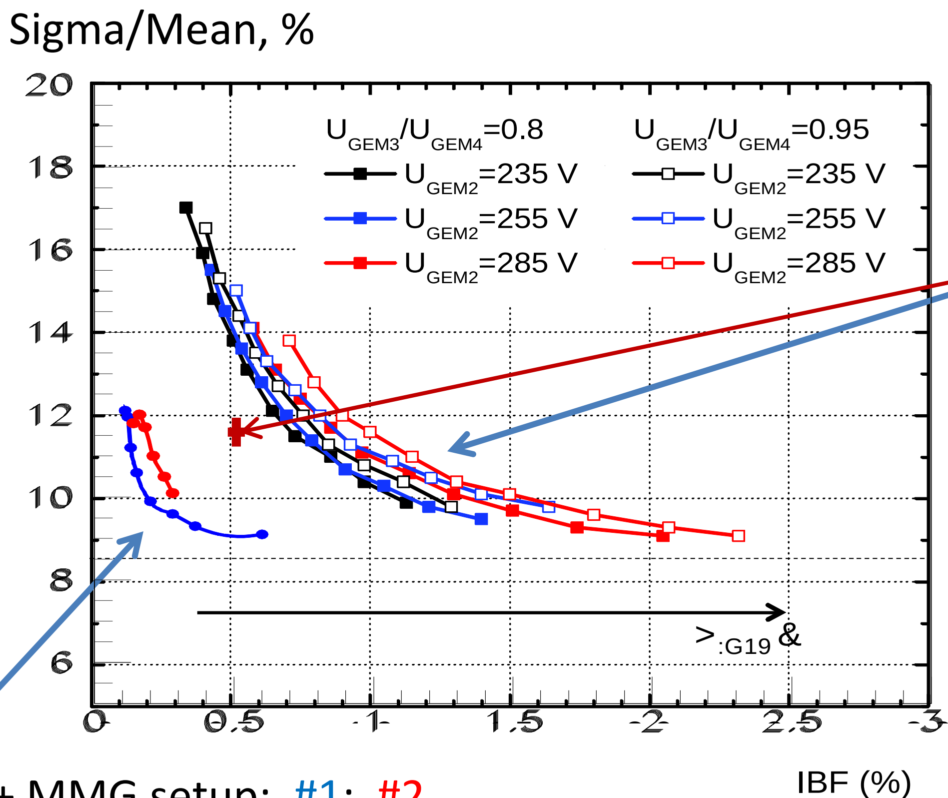
GA GEM2 ~= 6.15

(MMG -- GEM 2) voltage Scan (setup #2)
Ne+CO2(10%), Fe55 source(s)

MMG, V	<GA>, MMG	dV, GEM 2, V	<GA> (x e3)	Sigma /Mean, %	Anode current, nA	IBF, %
435	265	260	1.85	10.2	14.0	0.28
445	339	250	1.90	10.6	14.5	0.25
455	411	240	1.95	11.1	15.2	0.21
465	519	230	1.99	11.8	15.9	0.18
475	656	225	2.05	12.1	18.3	0.16
485	838	220	2.15	11.9	19.4	0.14

Drift – 0.4 kV/cm;   dV GEM 1 – 210 V;   Transfer – 3.0 kV/cm; Induction – 0.08 kV/cm

IBF performance and energy resolution

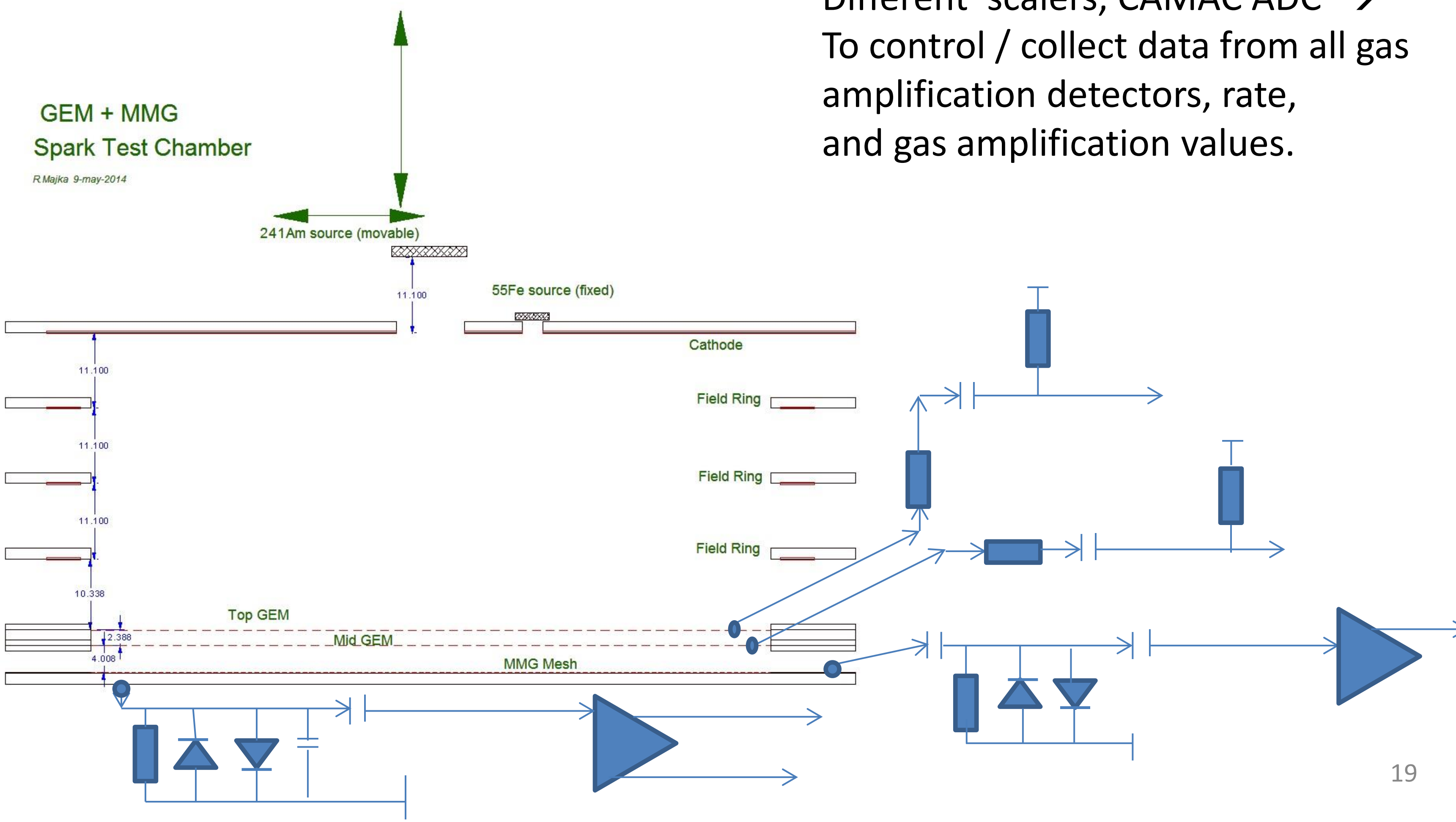


4 GEMs setup: (TDR),
Last (S-S-LP-SP) data

2 GEMs + MMG setup: #1; #2

2 GEMs + MMG spark test setup, ^{241}Am
Distance Cathode – Top GEM ~ 4 cm.
(follow recommendations from Collaboration)

Different scalers, CAMAC ADC →
To control / collect data from all gas amplification detectors, rate,
and gas amplification values.



2 GEMs+MMG spark test

^{241}Am, Ne + CO_2(10%), dV GEM mid = 210 V, E drift = 0.2 kV/cm, Rate ~ 400 Hz.

MMG, V	dV, GEM top, V	<GA>, MMG	<GA> (x e3)	Statistics	Number of sparks (MMG)	Number of sparks (GEM)
460	230	500	1.9	1.06 e8	0	0
475	225	656	2.05	1.15 e8	0	0
485	220	838	2.15	1.2 e8	0	0
505	220	1315	3.37	5. e4	25	0
	E drift = 0.4 kV/cm; Barometric pressure went down					
465	230	~ 598	~ 2.3	1.08 e8	20	0
475	225	~ 754	~ 2.35	~ 1. e7	~ 2.5	0
	E drift = 0.3 kV/cm; Barometric pressure went down (during the Run)					
475	225	~ 760 ~ 805	~ 2.35 ~ 2.5	3. e7 2. e7	0 3	0 0
	Ne+CO2+C2H4 (90-10-10), E drift = 0.4 kV/cm					
510	270 (245 mid GEM)	~ 670	~ 2.1	4.6 e7 gas done	0	0

	4 GEMs	2 GEMs + MMG (no R-layer)
IBF	(0.5 - 0.6)%	<0.2%
<GA>	2000	2000
ϵ - parameter	10 - 12	<4
E – resolution	<12%	<12%
Gas Mixture (3 components)	Ne+CO_2+N_2 (Et "problem" with + CF_4)	Ne+CO_2, Ne+CF_4, Ne+CO_2+CH_4
Sparking (Am241) Possible main problem	<3.*10-9 short sector of the foil	< 3.*10-7 (Ne+CO_2) < 2.*10-8 (Ne+CO_2+C_2H_4) lost FEE channel
Pad structure	Any, but improvement with Chevron	Chevron

Can we discuss TPC working gas (for micro-pattern gas amplification technology) ?!

Gas mixture	Electron drift velocity, cm/us (E-field -- 0.4 kV/cm)	T diffusion	L diffusion
		0.5 T B-field.	
Ne+CO2+N2 (90-10-5)	*2.6*	*217*	*220*
Ne+CO2+CH4 (90-10-5)	*2.9*	*208*	*232*
Ne+CO2+CH4 (90-5-10)	*4.0*	*270*	*240*
Ne+CO2+CH4 (90-10-10)	*3.05*	*210*	*230*
Ne+CH4 (91-9) (0.3 kV/cm plateau)	*3.4*	*400*	*280*

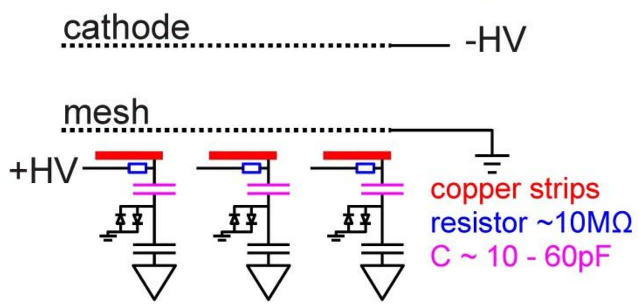
(keeping in mind that CF4 was not recommended to be used for ALICE TPC)

Lowest Ionization Potential (eV): Ne – 21.56, CO2 – 13.81, CH4 – 12.99

Mobility (Ne+CH4, 10%) / Mobility (Ne+CO2, 10%) = 1.17 {Wigner RCP group data and G. Schultz, G. Charpak and F. Sauli, Rev. Phys. Appl. (France) 12, 67 (1977) }

From Jona Bortfedt presentation

Floating Strip Micromegas



"floating" copper strips:

- individually connected to HV via 10MΩ
- capacitively coupled to readout electronics via pF HV capacitor
- discharges: only two or three strips charge up

proposed by: A. Bay, I. Giomataris et al., Nucl.Instrum.Meth. A488:162-174, 2002

PRO

- relatively easy to produce
- no rate dependant charge up
- metal strips → less aging expected
- discharges: small capacitance $C_{\mathrm{FS}} \sim C_{\mathrm{std}} \times 0.01$ $(\tau = RC)$
- discharges: only one or two strips affected, 1/#strips efficiency decrease

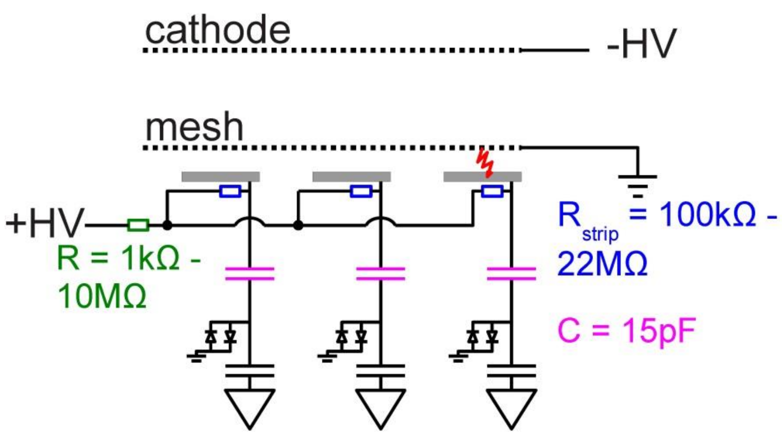
→ low deadtime and efficiency drop

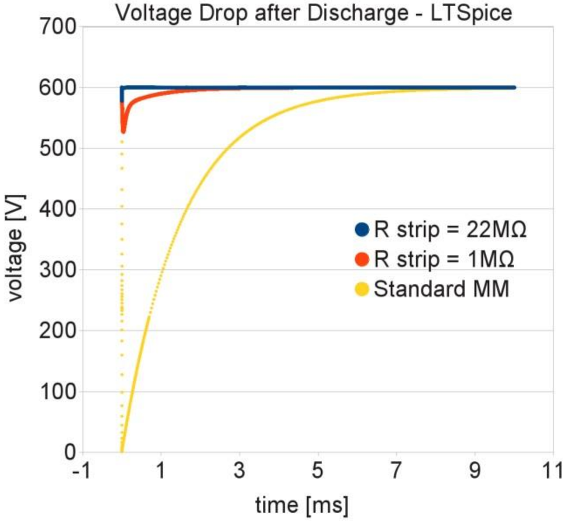
CON

- discharge suppression not as effective as in resistive strip Micromegas
- 2-dim. readout questionable

From Jona Bortfedt presentation

LTSpice Simulation





- simulate discharges from mesh onto one strip
- vary R_{strip}
- adapt recharge R such that $I_{\mathrm{recharge}} \leq 60\,\mu\mathrm{A}$

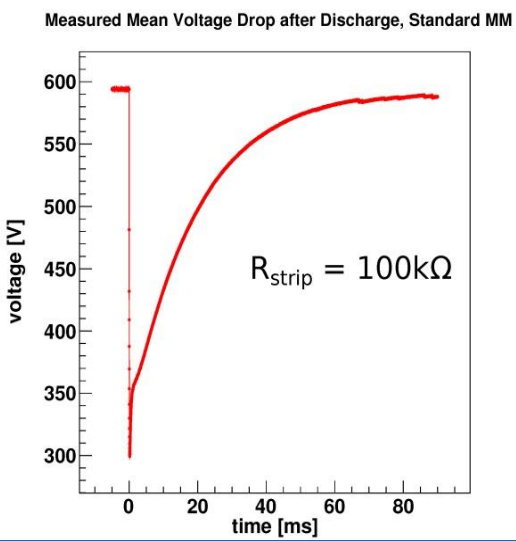
global voltage drop affects whole detector

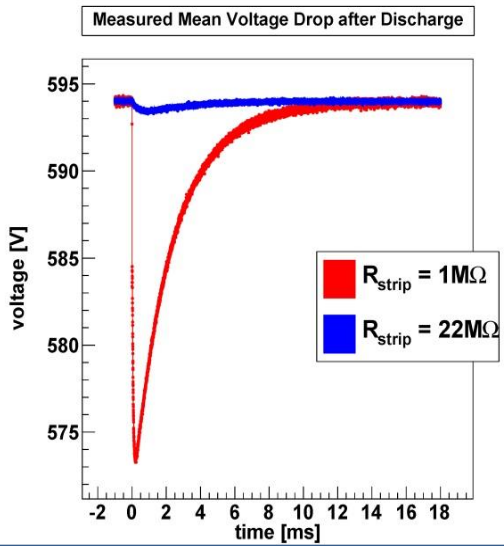
- standard Micromegas: complete discharge of mesh possible
- Floating Strip Micromegas: massive reduction of voltage drop and recharge time

From Jona Bortfedt presentation

Voltage Drop Measurement in $6.4 \times 6.4\,\mathrm{cm}^2$ Micromegas

- mixed nuclide α-source: induce discharges in detector @ $\sim$1 Hz
- measure global voltage drop with high-ohmic voltage divider
- 100 kΩ strip resistor: standard MM-like
- 1 MΩ strip resistor: $\sim$25 V drop
- 22 MΩ strip resistor: $\sim$0.5 V drop → negligible





We are going to measure these parameters with 4x6 mm2 pad read-out structure, and apply HV to Mesh.

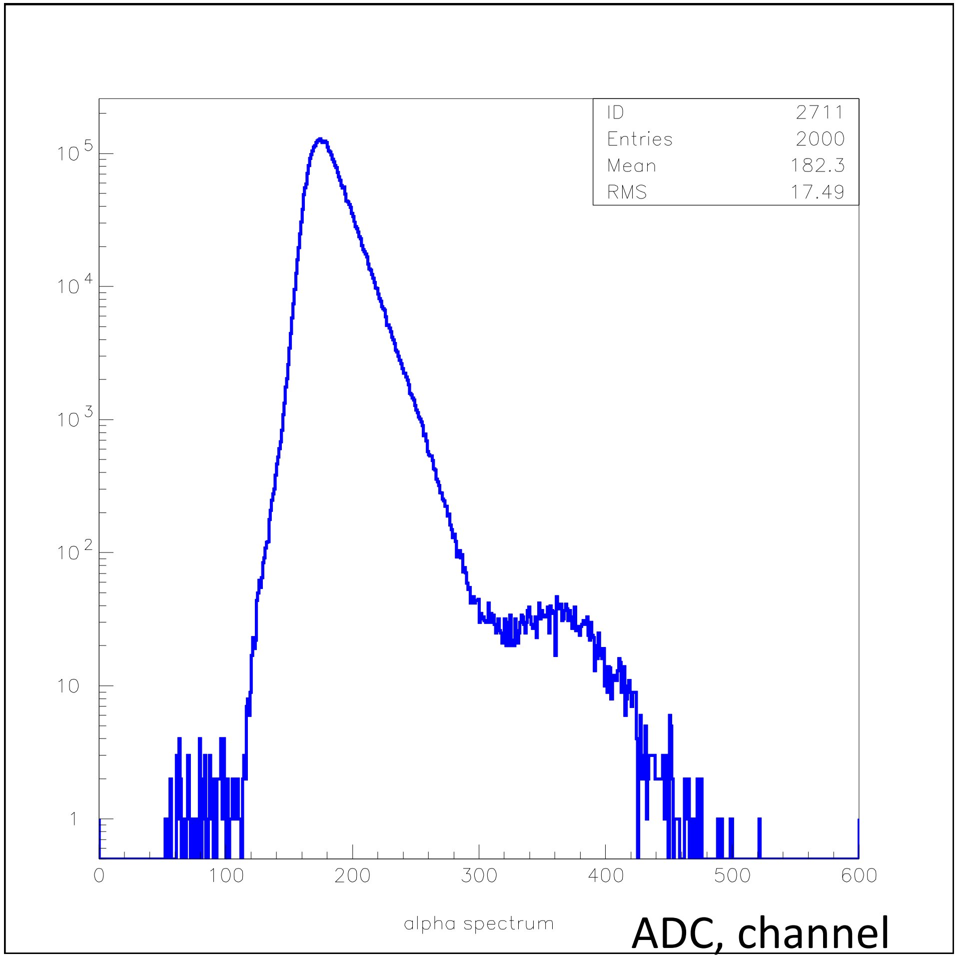
Plan of activities
(2 GEMs + MMG setup option)

- 3 components gas mixture (including hydrocarbon quencher); Measure IBF – E-resolution, <Gas Amplification>, Stability (with Am241 source) .
- Small (10x10 cm2) detector with the same pad and via structure as IROC; test sparking and E-resolution with collimated Fe55 source.
- 3 different small (10x10 cm2) detectors to test all needed steps for a mass production (mesh support, segmentation).
- Measure MMG high voltage drop in a case of sparking with 4x6 mm2 “floating” pad read-out structure.
- Active participation in a test of IROC read-out board with MMG mesh, as preparation for test-beam.
- Prepare in a parallel 2 detectors with 21x26 cm2 active size (available GEM foils) and different pad shape (rectangle, chevron).

Conclusion

- It looks like our collaboration has more than one option for future upgrade
- Final decision should be done after test beam.
- All comments, recommendations will be appreciated.

Example of (peak sensitive) ADC spectrum, Am 241, spark test setup, ~450 Hz rate.



- ***TPC response simulation details***.
- **First step.**
- For all options of TPC readout pad size and shape look-up tables were prepared. Charge on 3x3 pad structures was simulated as a function of single electron position on the "central" pad ("face" of the "first" GEM foil):
- Select the nearest GEM hole and simulate the position in the hole
- Simulate gas amplification (Polya distribution + some parameters using GARFIELD GEM simulation results)
- Transfer each e- after the amplification step to the next GEM foil (diffusion parameters are from GARFIELD)
- Select a hole for the next GEM foil
- Repeat gas amplification and electron transfer steps for the second, third (and forth) GEM foils (or MMG).
- "Collect" electrons on pad structure
- This was repeated for a few hundreds positions, and 1000 times for every initial position.
- The parameters for this simulation step are: readout structure geometry, E-field, average amplification for each foil, diffusion. Each foil was randomly rotated and shifted to skip alignment issues.
- **Second step.**
- GEANT3 was used to describe ITS and TPC geometry and materials. Then a single pion track from the primary interaction vertex inside the 0.5 T B-field in selected limits for Pt and rapidity is simulated. For the simulated track input-output points in space for all ("active") ITS detectors and TPC pad-rows were saved as a output structure together with track parameters. Repeat to obtain sufficient statistics.
- **Third step.**
- To simulate ITS detector response a simple "fast" (Gaussain) hit smearing was used.
- For each TPC pad-row the number and position of "ionization" electrons were simulated as a function of gas mixture parameters and particle momentum (βɣ) including so-called δ–electrons *). Using diffusion parameters and drift speed for the working TPC gas mixture the position on the face of first GEM foil can be generated for each ionization electron; and a look-up table is used to select a pad response (in number of electrons) and arrival time (including simulating FEE response). When this procedure was finished for all ionization electrons, the pedestal with noise was added to each active pad. Then cluster finding and coordinate reconstruction were done. Using all smeared hits from ITS and reconstructed hits from TPC, a helix fit and momentum reconstruction were done. All needed information is saved for next analysis step.
- *) all details can be found: H.Bichsel, NIM A562 (2006) 154.
- http://faculty.washington.edu/hbichsel/