Combined of Gas Electron Multipliers and Micromegas as Gain Elements in a High Rate Time Projection Chamber

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Motivation

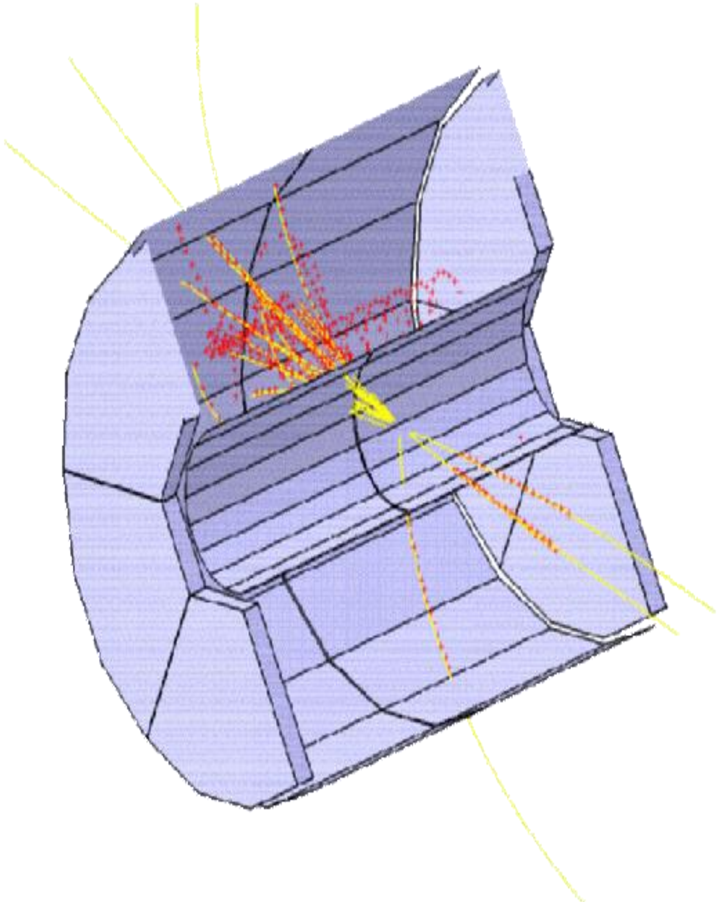
Time Projection Chamber (TPC) is detector of choice for low mass precision tracking, pattern recognition, momentum reconstruction and particle identification. It is crucial to keep as uniform as possible both electric and B-fields.

But build up of positive ions in the drift volume (from "primary" ionization" and Ion Back Flow (IBF) from gas gain structures) leads to electric field distortion and distortion of the ionization electron tracks as they drift to the endcaps (Space Charge Distortion: SCD) .

SCD is a "function" of many parameters: Physics, beam structure and collision rate, TPC size, E-field, "working" gas, …. But IBF is a main "contributor", and it is crucial to minimize this ions flow to be as small as possible.

Different options have been used, proposed, tested: wire structure (gating grids), single or double MMG, multi GEMs setups with / without using "top" foil as a gate, …. All options have its own PRO and CON.

Follow Physics demands ALICE collaboration decided to upgrade TPC for a continuous readout (eliminate the gating grid).



Conclusion after 3.5 years dedicated R&D activities. ALICE TPC upgrade team

From J. Wiechula presentation

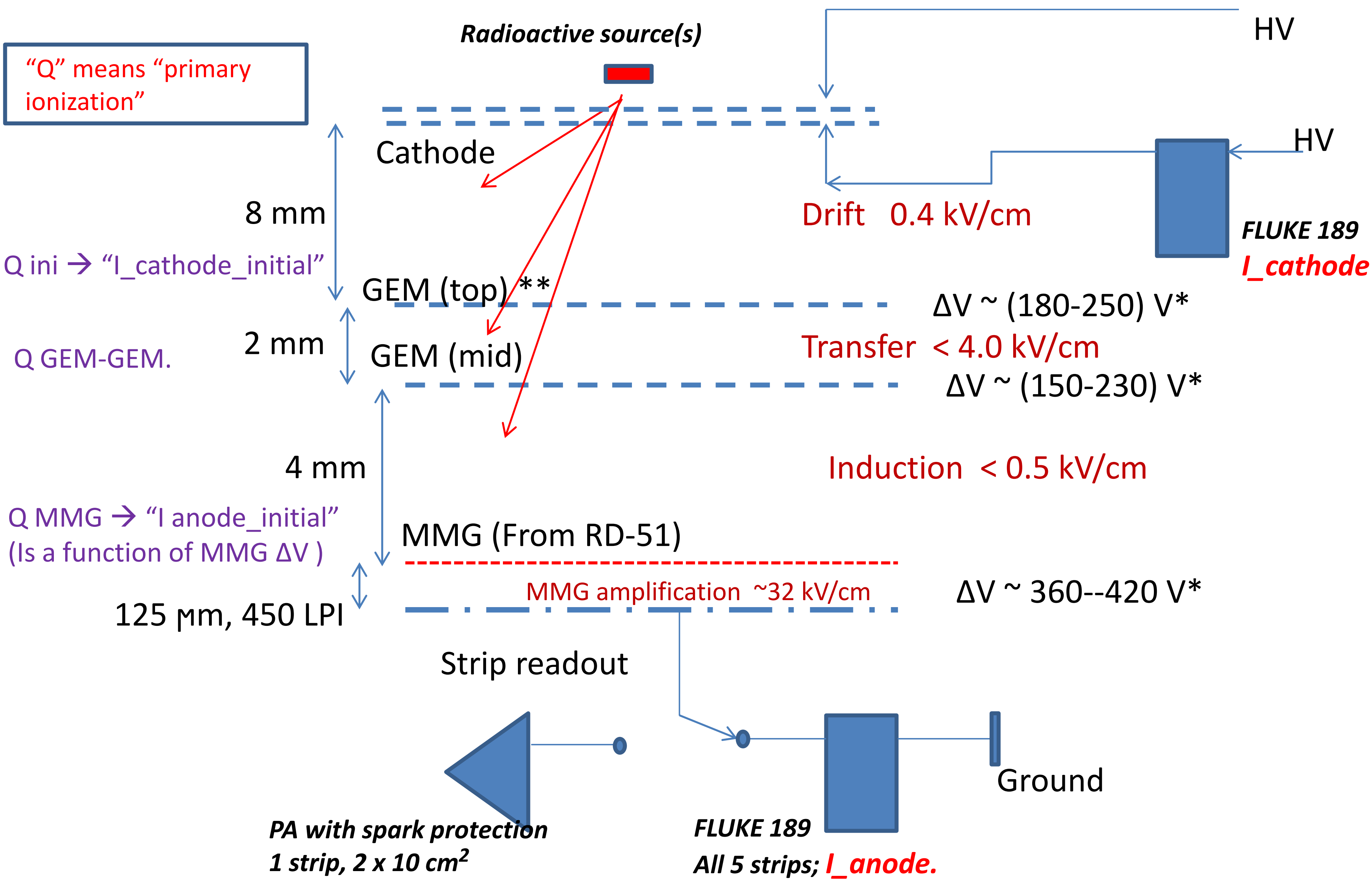
- TPC data taking at 50kHz Pb–Pb possible using a 4-GEM system
- Major challenges in calibration/reconstruction
- Continuous readout → Interaction time estimate
- Fast online reconstruction to perform compression
- Large distortions due to space-charge (20cm max.)
- Pile-up: ~5 events overlapping
- Update of calibration for data in 5ms
- TPC upgrade (TDR: CERN-LHCC-2013-020) was approved and recommended for “mass-production-installation”.

Gas amplification configuration option for high rate TPC

- Our group was asked to “think” on an alternative option for ALICE TPC upgrade
- And we did our best …
- We proposed and investigated the performance of a novel configuration for TPC gas amplification: 2-GEMs plus a Micromegas (MMG).
- This allows:

— using a MMG as the “main” gas amplification (gain) step with a maximal ratio of E-fields in the amplification gap vs induction gap (& minimize MMG IBF)
— using the “top” GEM with convenient E-fields in the drift and transfer (to “middle” GEM) gaps, and with voltages providing an effective gain (5 — 10) and good energy resolution (amplification and transmission of primary ionization electrons), and to minimize the IBF through the “top” GEM.
— using the “middle” GEM with an effective gain ~1 to transfer electrons from a strong E-field (transfer gap) to lower one in front of the MMG, smearing electrons in space, and to provide additional IBF suppression due to “hole geometry” and any misalignment (foil rotation and/or difference in hole structure).
— all gas amplification elements to operate at modest voltage and gain values thus minimizing the discharge probability.

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



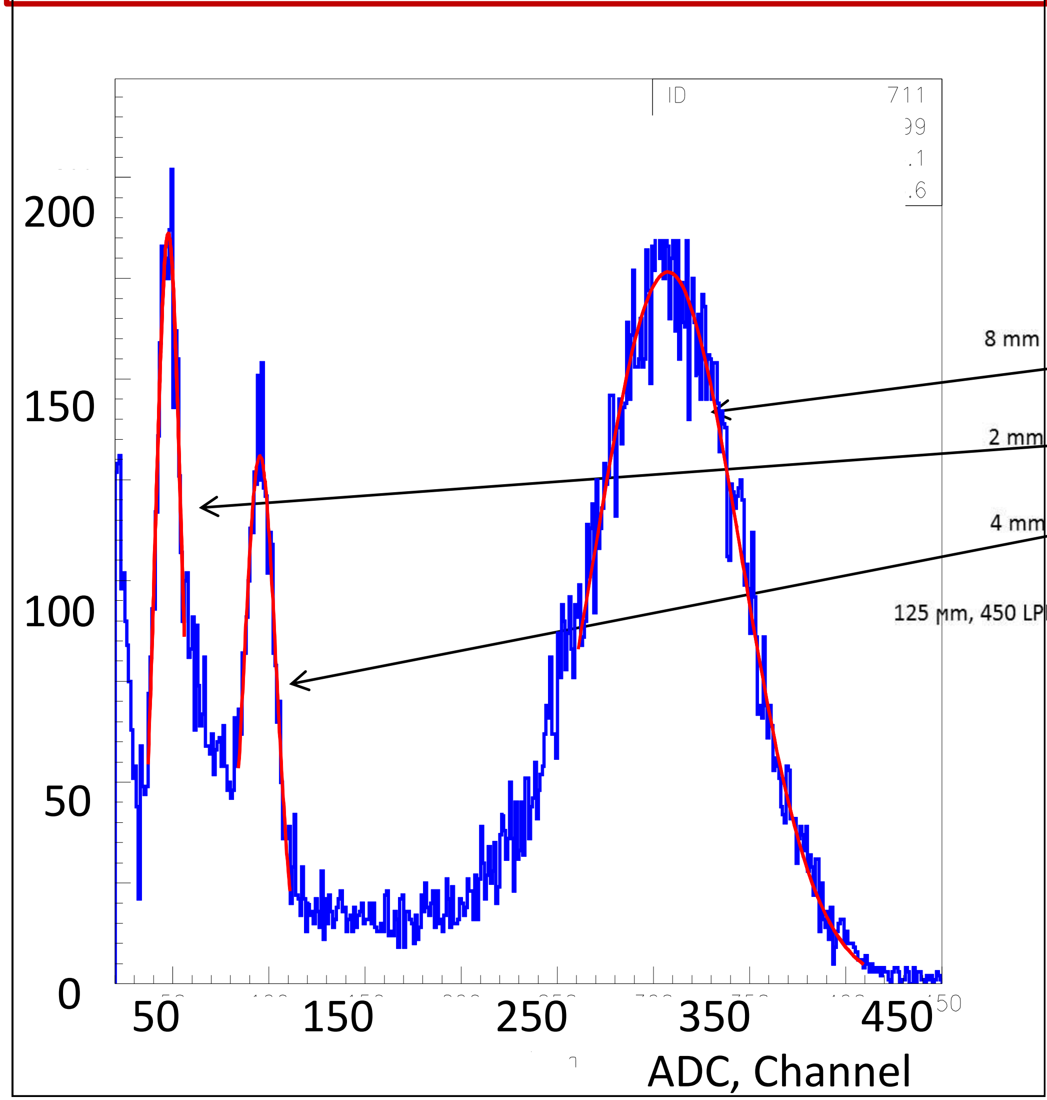
** GEM top foil hole pattern rotated 90deg wrt GEM mid

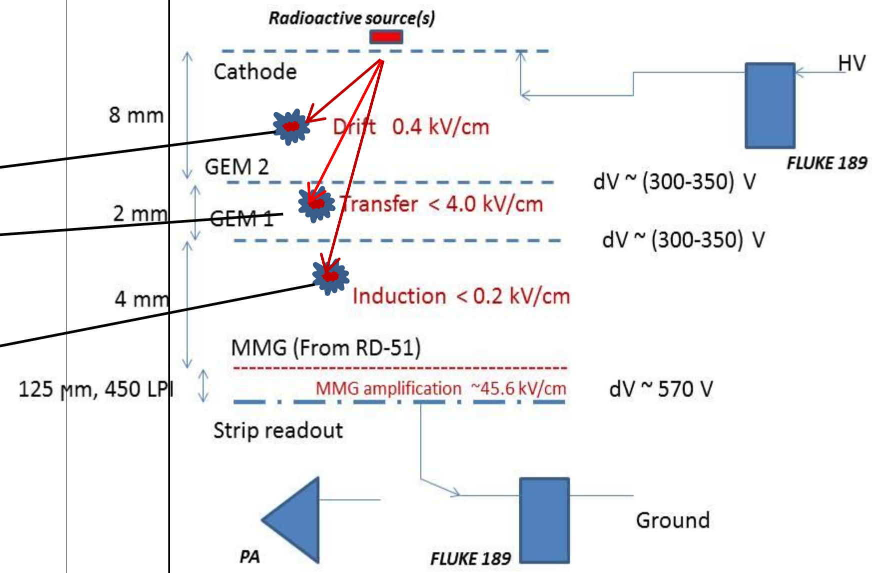
* for Ne + CO_2(10%)

2 GEMs+MMG; Ne+CO_2(10%); ^{55}Fe
Example of Spectrum (E transfer = 1.5 kV/cm)

14.1% 8.5% 12.0% Sigma/ Mean

Gaussian Fit, Red





Gain GEM mid ~= 0.52

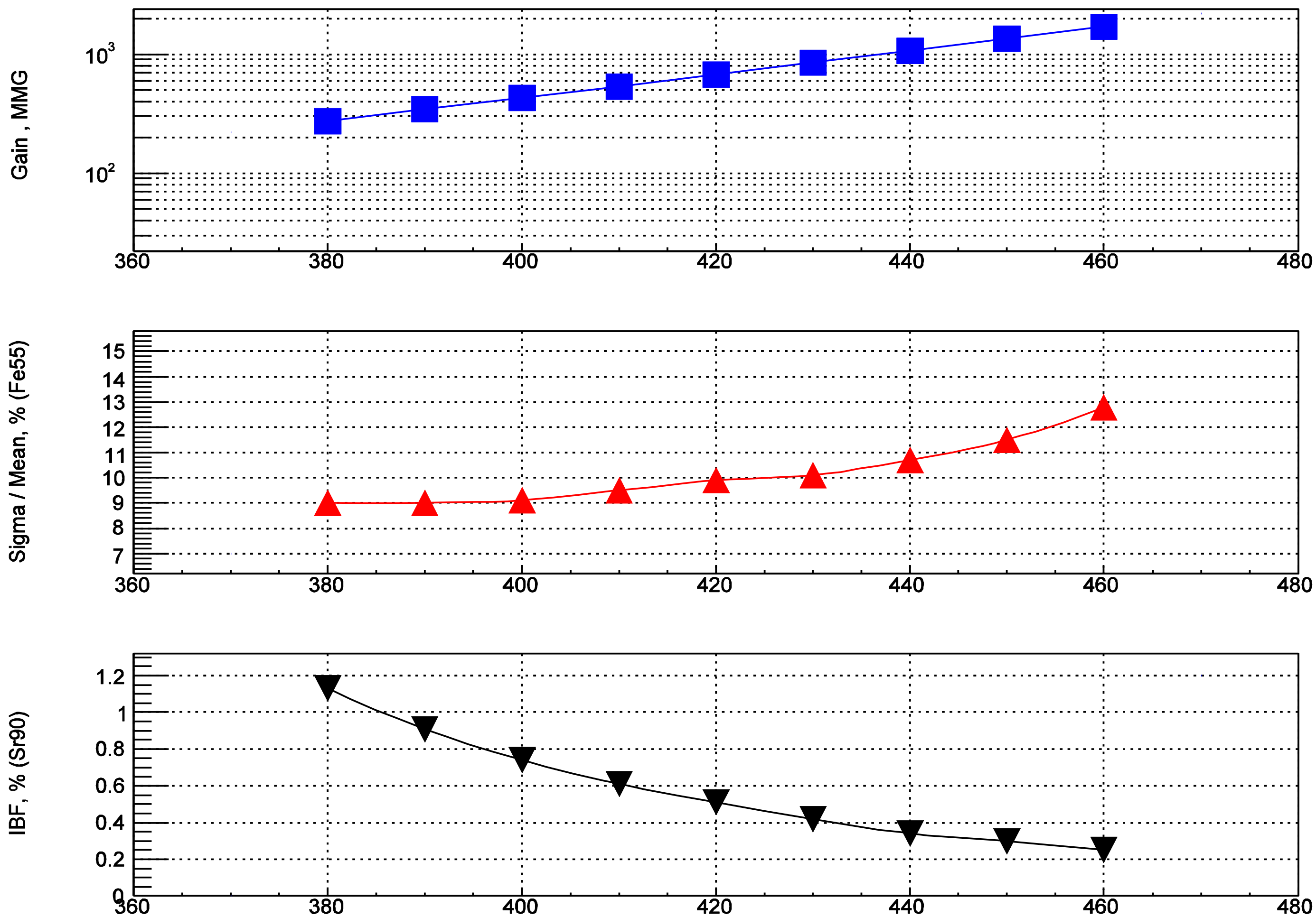
Gain (GEM top & GEM mid) ~= 3.2

Gain GEM1 top ~= 6.15

2 GEMs+MMG, Ne + CO2 + CH4 (82-9-9%)

Edrift =0.4 kV/cm, Etran. = 3.0 kV/cm, Eind.=0.075 kV/cm

^{55}Fe source, Gain ~2100.



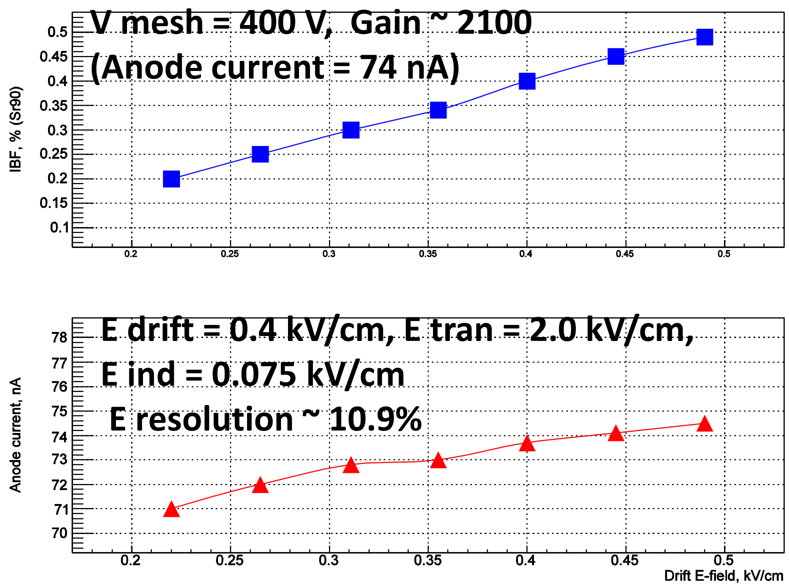
MMG Mesh, V

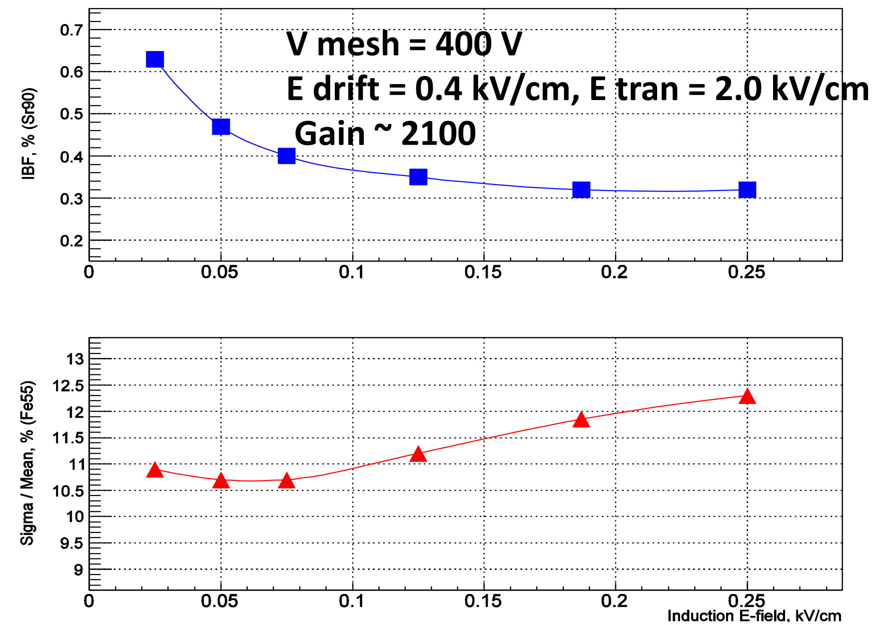
Measurement uncertainties:

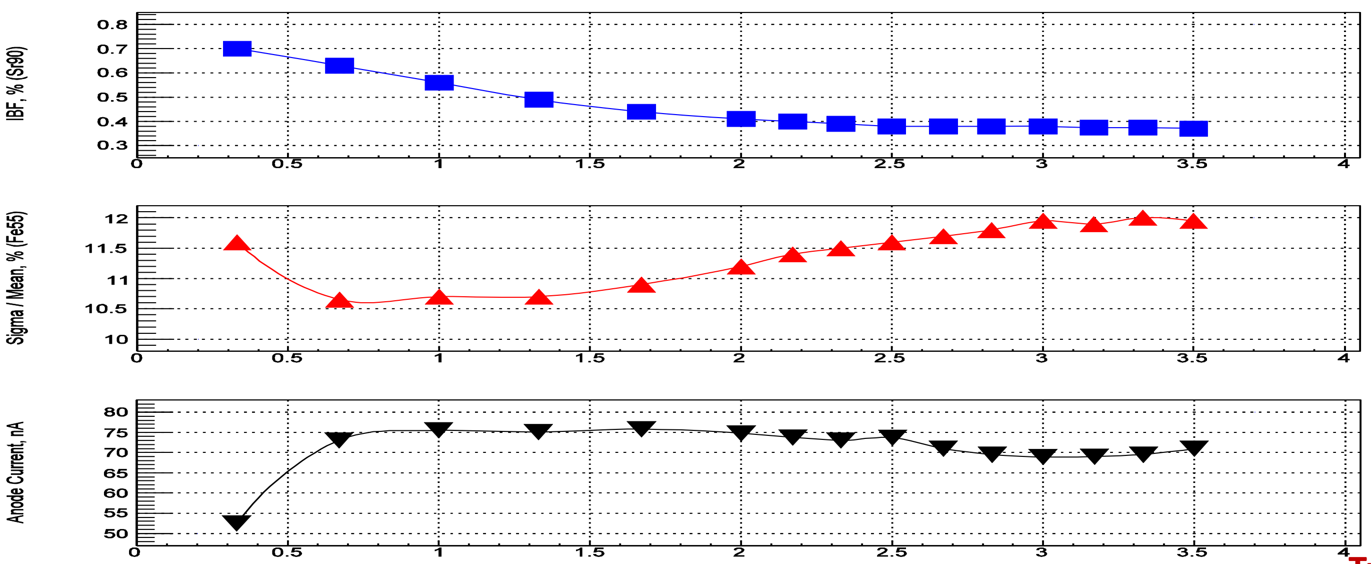
E – res: 3-5 %

IBF: 10-15 %

Ne+CO_2(10%), Drift, Transfer and Induction E-fields scan





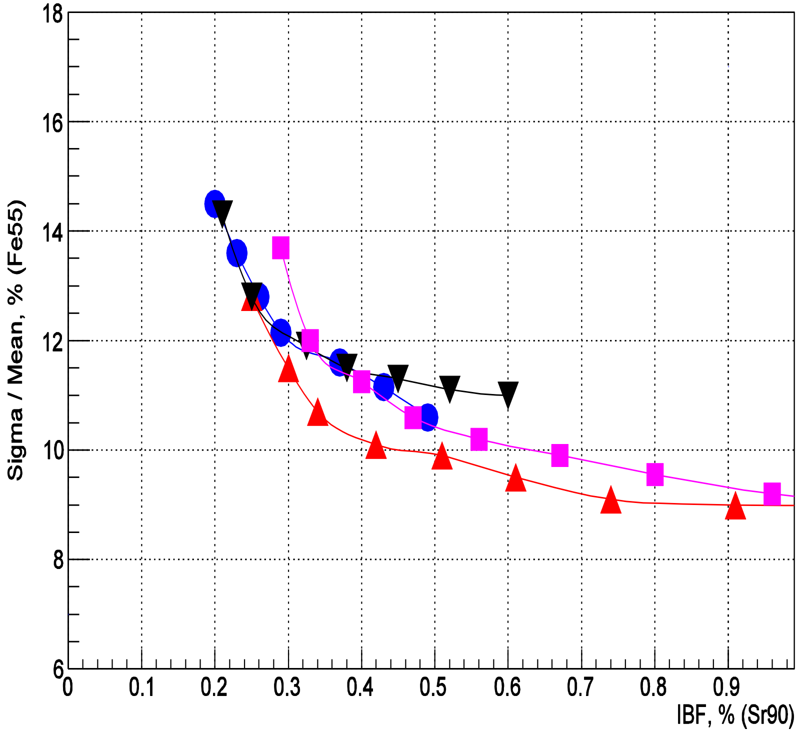


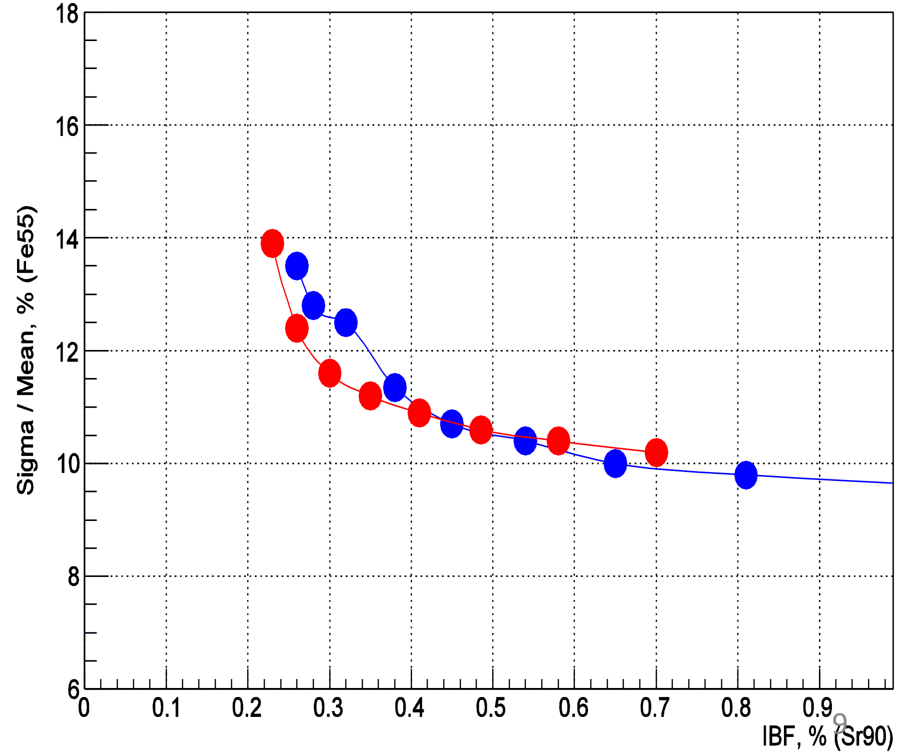
V mesh = 400 V
ΔV1 (top) = 242 V
ΔV2 (mid) = 185 V
E drift = 0.4 kV/cm
E ind = 0.075 kV/cm

Energy resolution (Sigma/Mean for ^{55}Fe) vs. ion backflow (IBF) for various gas mixtures and different MMG and GEMs voltages

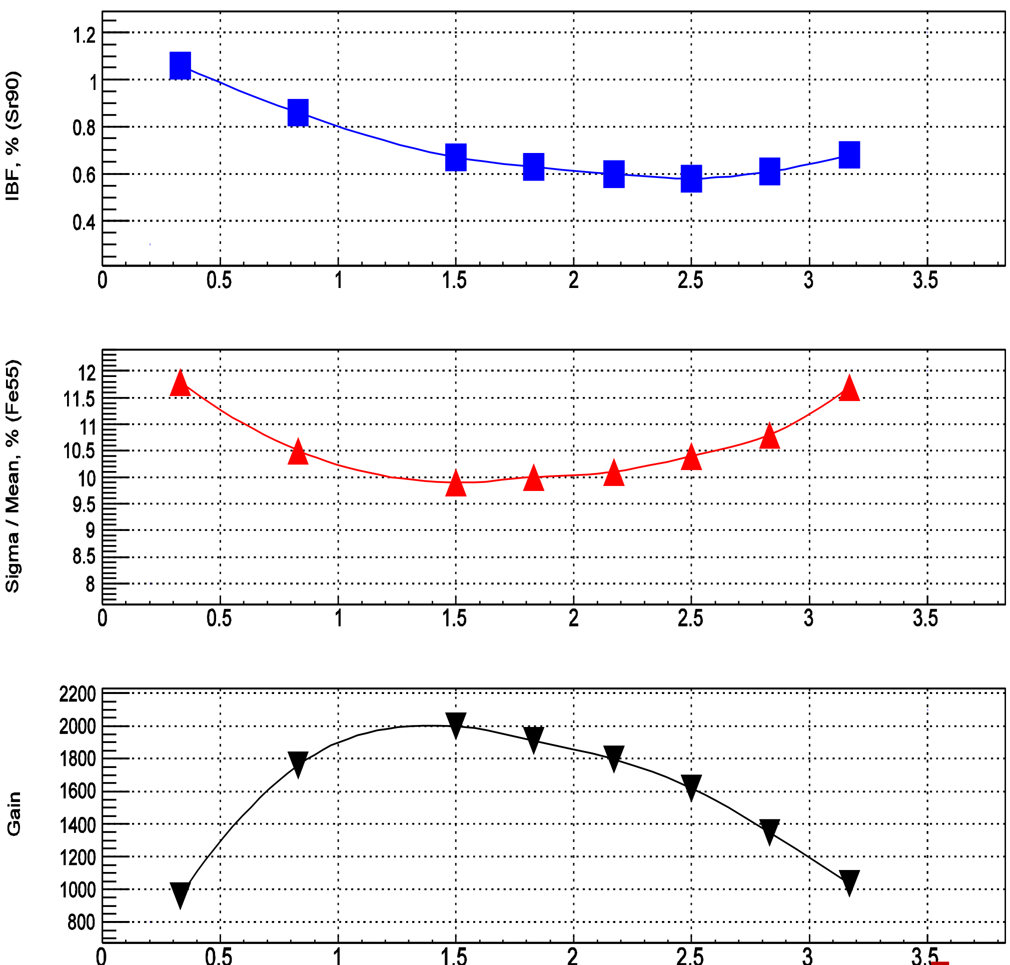
Red ▲ : Ne+CO2+CH4 (82-9-9%),
Blue ● : Ne+CO2+N2 (85.71-9.52-4.77%),
Black ▼: Ne+CO2 (10%),
Magenta ■ : Ne+CO2+CF4 (82-9-9%).

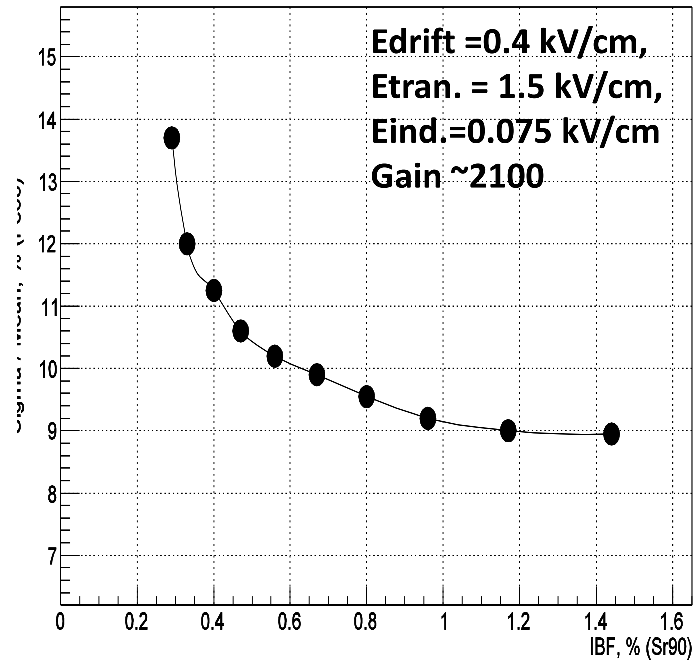
Red ● : P10.
Blue ● : C10.





Ne+CO2+CF4(82-9-9%), Transfer E-fields scan and E-resolution – IBF plot.



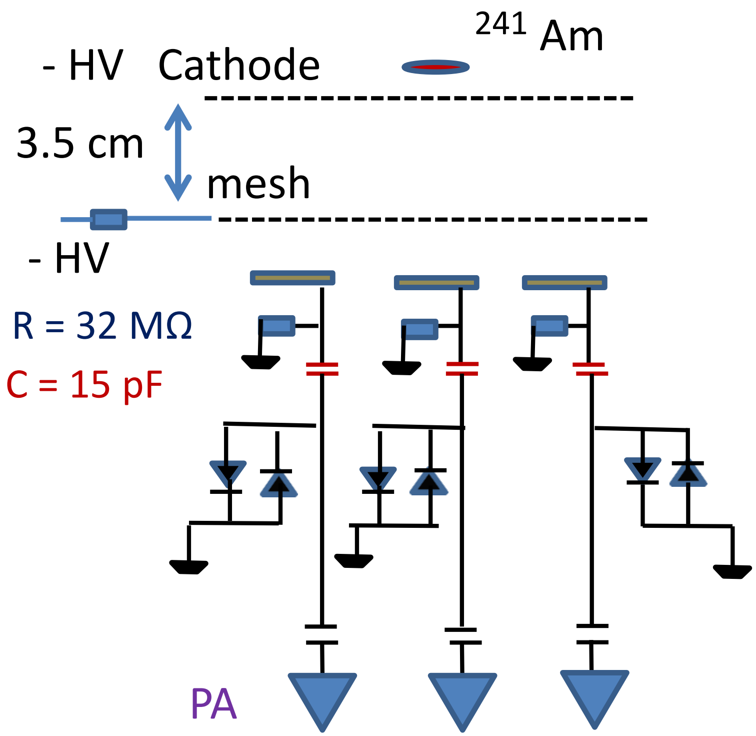


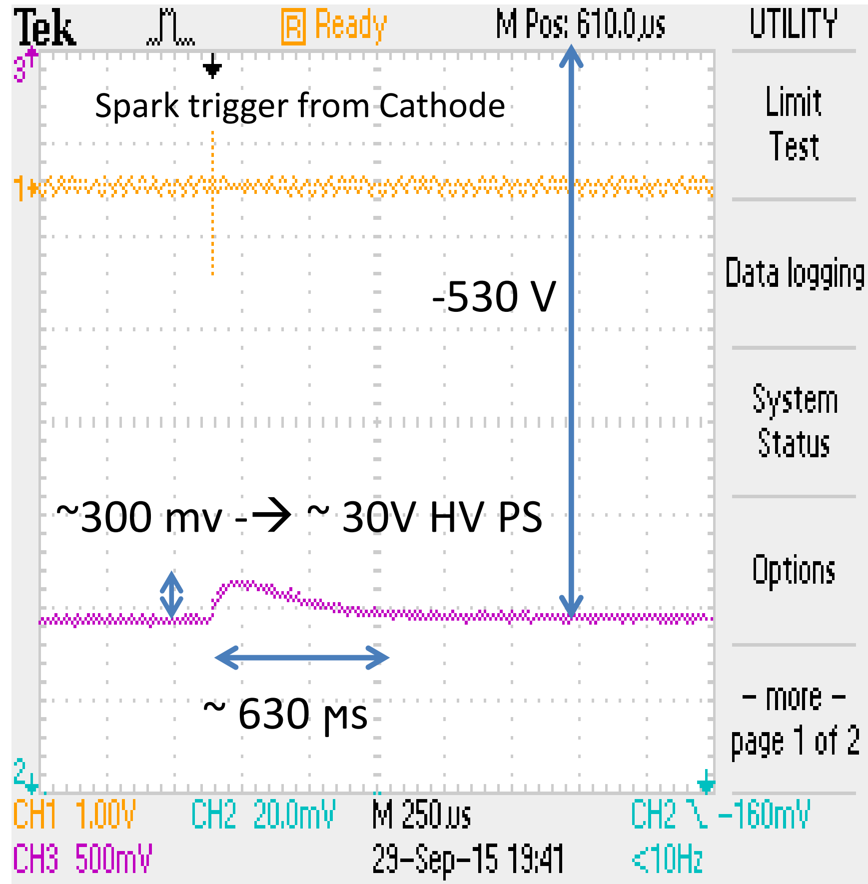
' mesh = 430 V
.V1 (top) =271 V
.V2 (mid) =206 V
drift = 0.4 kV/cm
ind = 0.075 kV/cm

	4 GEMs	2 GEMs + MMG (no R-layer)
IBF	(0.6 - 0.7)%	(0.3 – 0.4)%
<GA>	2000	2000
ϵ - parameter	12 - 14	6 - 8
E – resolution	<12%	<12%
Gas Mixture (3 components)	Ne+CO2+N2 (Et “problem” with + CF4)	Ne+CO2+N2, Ne+CO2, Ne+CF4, Ne+CO2+CH4
Sparking (Am241) Sparking, test-beam Ne+CO2+N2	$<3.*10^{-9}$ $\sim 6.4*10^{-12}$	$< 3.*10^{-7}$ (Ne+CO2) $< 2.*10^{-8}$ (Ne+CO2+C2H4) $\sim 3.5*10^{-10}$
Possible main problem	short sector of the foil	lost FEE channel
Pad structure	Any, but improvement with Chevron	Not Chevron Cross-talk effect

MMG mesh Voltage drop measurement,
10x10 cm2 MMG with Pad (4x7.5 mm2) readout
Spark trigger – from Cathode. V Mesh = - 530 V. Sparking rate: ~1 /20 s.
Signal from R-divider connected to MMG mesh

C10 gas mixture



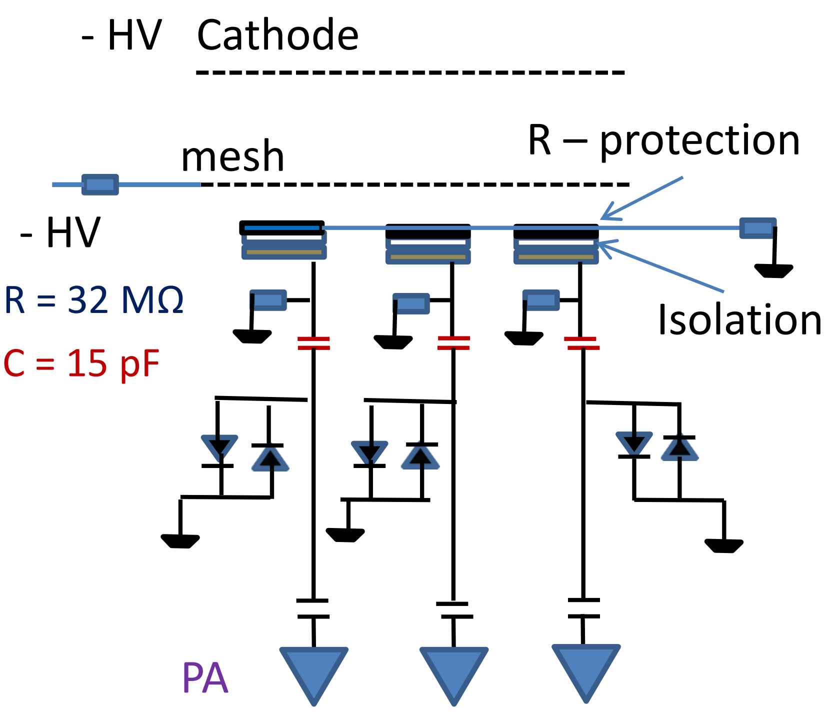


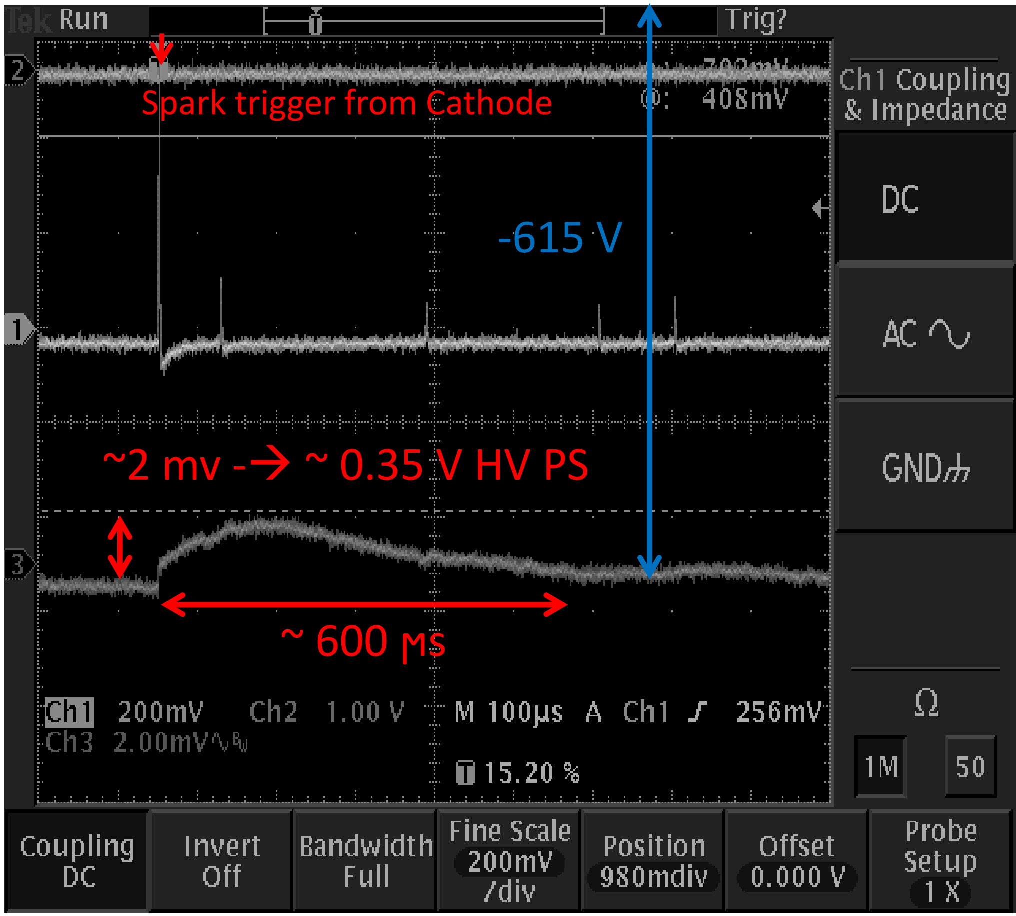
*) signal integration takes place on oscilloscope input capacitor

HV drop: ~ 30V *)
Recovery time: ~ 650 µs *)

The same setup but with Resistive layer protection (1. MΩ / □),
its own for each pad-row.
V Mesh = - 615 V. Sparking rate: ~ 1/20 s

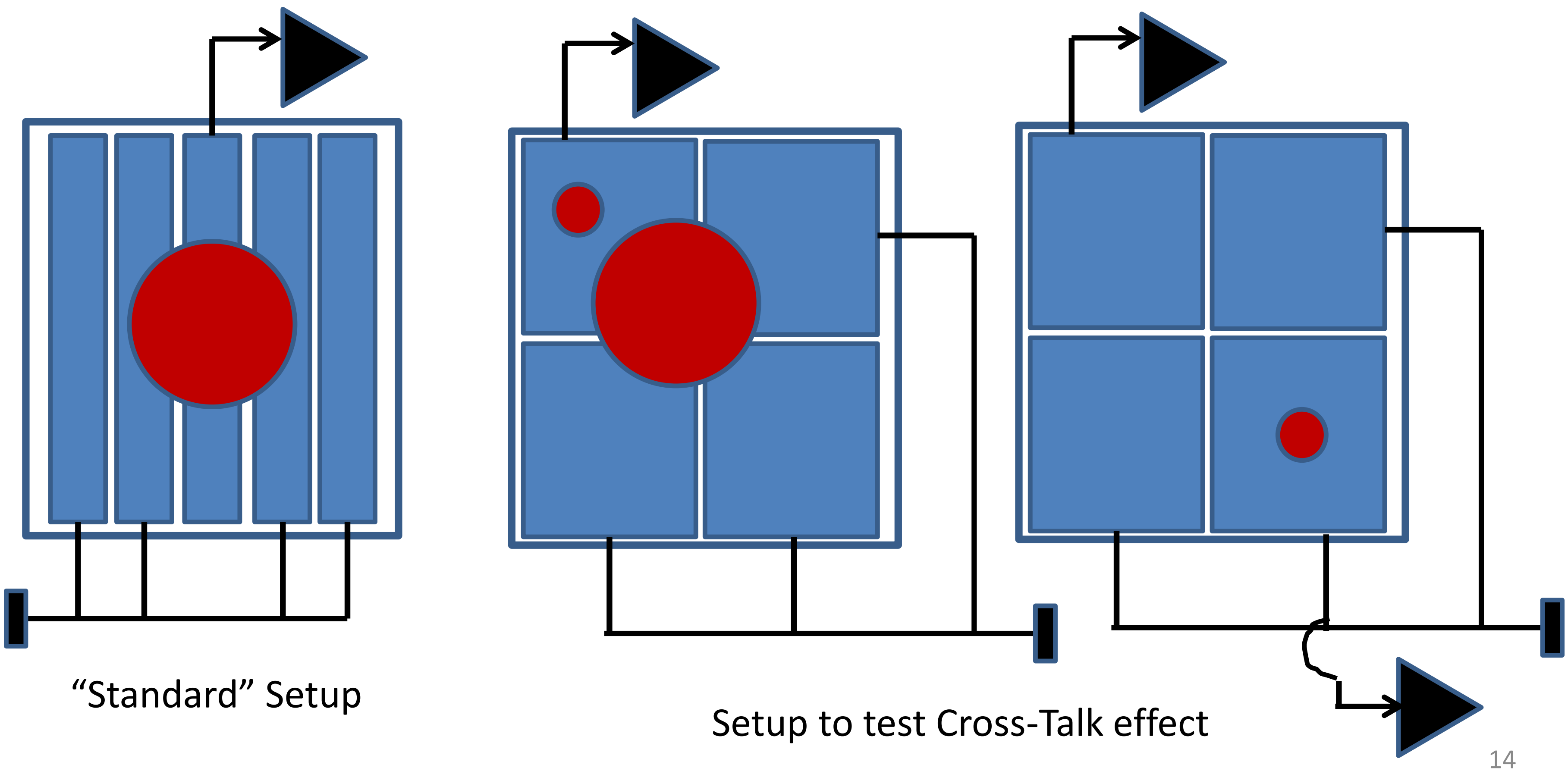
HV drop: ~ 0.4 V *)
Recovery time: ~ 600 μs *)





^{55}Fe Radiation spot on Cathode, 10x10 cm^2 setup, E-resolution and crosstalk measurements.
Three options; & different ^{55}Fe source collimations

Inverse polarity crosstalk amplitude of ~0.4% per cm^2 pad size,
With the expectation that crosstalk is proportional to the readout pad to mesh capacitance



“Standard” Setup

Setup to test Cross-Talk effect

Backup

IBF calculation

- IBF = (I_cath – I_cath_ini – I_offset – I_cath_mmg_only) / (I_anode – I_anode_mmg_only – I_offset)
- Contribution from Q_gem_gem ignored
- IBF precision (in our measurements) ~ 10%

Example: (Ne + CO2(10%)), V mmg = 400 V, dV GEM top = 210 V, dV GEM mid = 175 V
E transf. = 3. kV/cm, E ind. = 0.15 kV/cm
<GA> (^{55}Fe) = 2010

(HV ON, No Source)
I_anode_offset = 0.05 nA, I_cath_offset = 0.0016 nA

Source ON; MMG mesh, E induction, E drift ON (All GEM voltages are the same):
I_anode_mmg_only = - 3.21 nA (400 V), I_cath_ini. = 0.012 nA

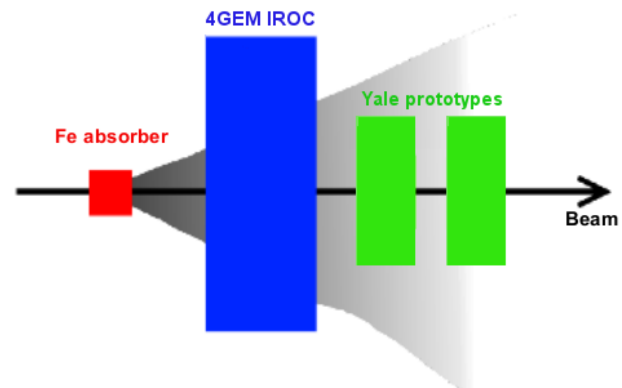
All Voltages ON: I_anode = - 27.78 nA , I_cath = 0.083 nA

IBF = (0.083 – 0.012 – 0.0016) / (27.78 – 3.21 + 0.05) = 0.29%

<GA> (current ratio) = (27.78 – 3.21) / 0.012 = 2049.

SPS Beam Test: Sparking Rate

- SPS beam: 150 GeV/c pions incident on Fe absorber (hadrons & EM showers)
  - Beam perpendicular to pad plane
  - $Ne-CO_2-N_2$ (90-10-5)
- Oscilloscope records spark signal
- ~5 x 10^{11} chamber particles accumulated in test bear
  - 1 month of Pb-Pb in ALICE: ~7x10^{11} per GEM sector



- 2-GEM+MMG:

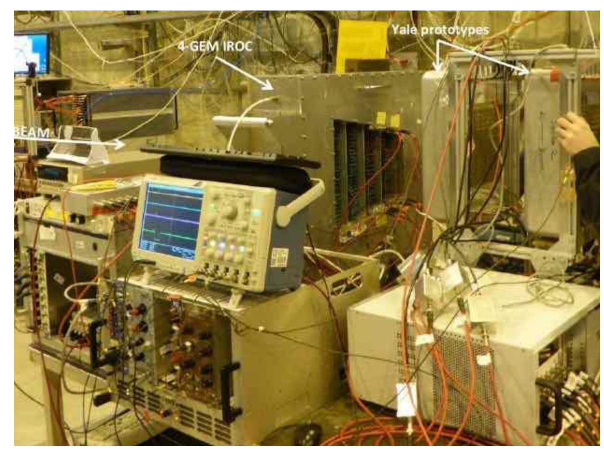
  At optimal HV setting: P~3.5 x 10^{-10} per chamber particle

  Spark rate depends on hadron interaction with MMG mesh

  Spark does not harm MMG, but gives dead time (~100 µs)
- 4-GEM:

  ~6.4 x 10^{-12} per chamber particle (3 sparks observed)

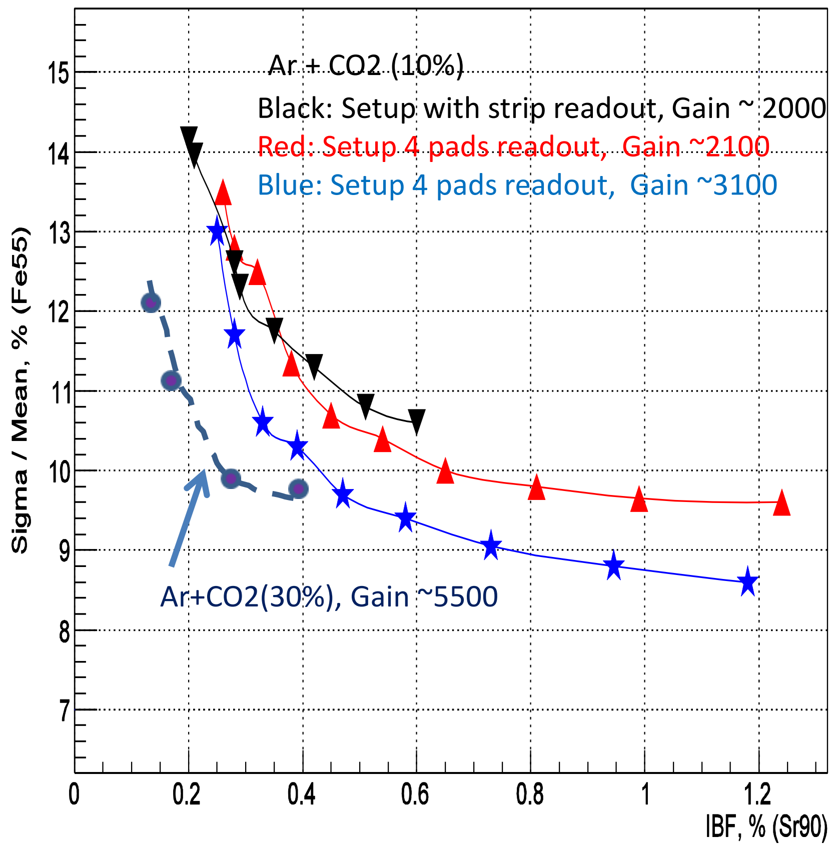
  Dead time ~ seconds to minutes

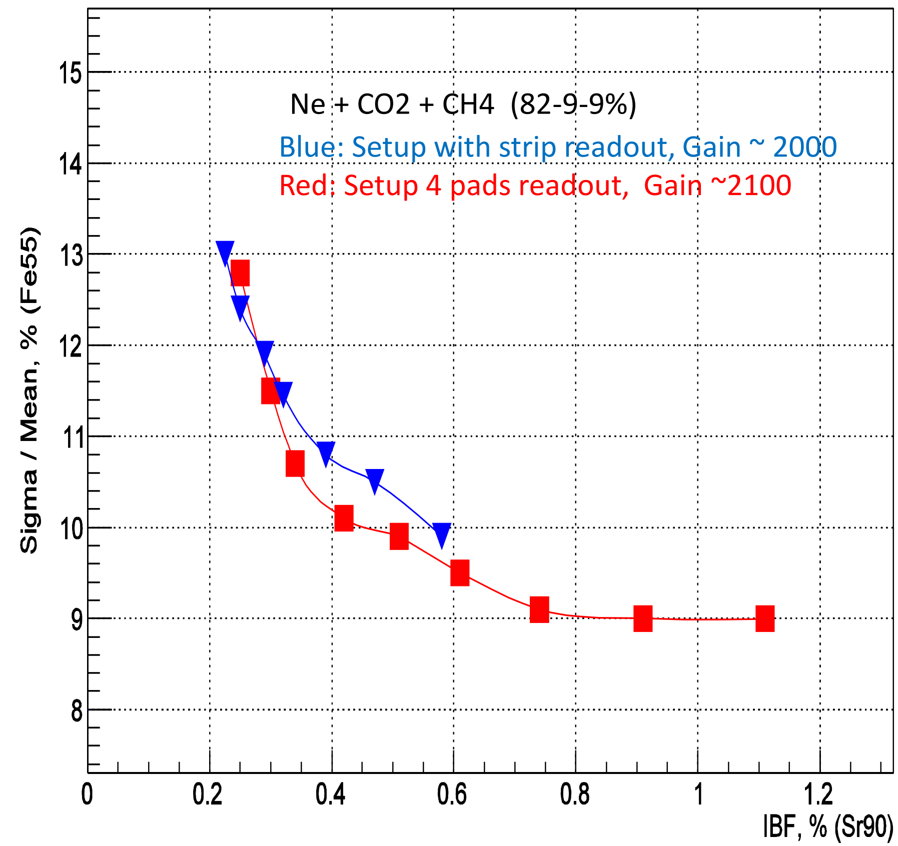


Two Setups comparison

Edrift =0.4 kV/cm, Etran. = 3.0 kV/cm, Eind.=0.075 kV/cm

^{55}Fe, Source "weak" (standard) collimation





Two Setups and ^{55}Fe Source Positions / Collimation comparison
Edrift =0.4 kV/cm, Etran. = 3.0 kV/cm, Eind.=0.075 kV/cm
Gain ~2100

Ar + CH_4 (10%)
Blue: Setup with strip readout, Source “standard” collimation
Black: Setup 4 pads readout, Source “standard” collimation
Red: Setup 4 pads readout, Source “strong” collimation

Ne + CO_2 (10%), Setup 4 pads readout
Blue: source “standard” collimation
Red: source “strong” collimation