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

ECFALC workshop, May 30th – June 5th, 2016, Santander (Spain)

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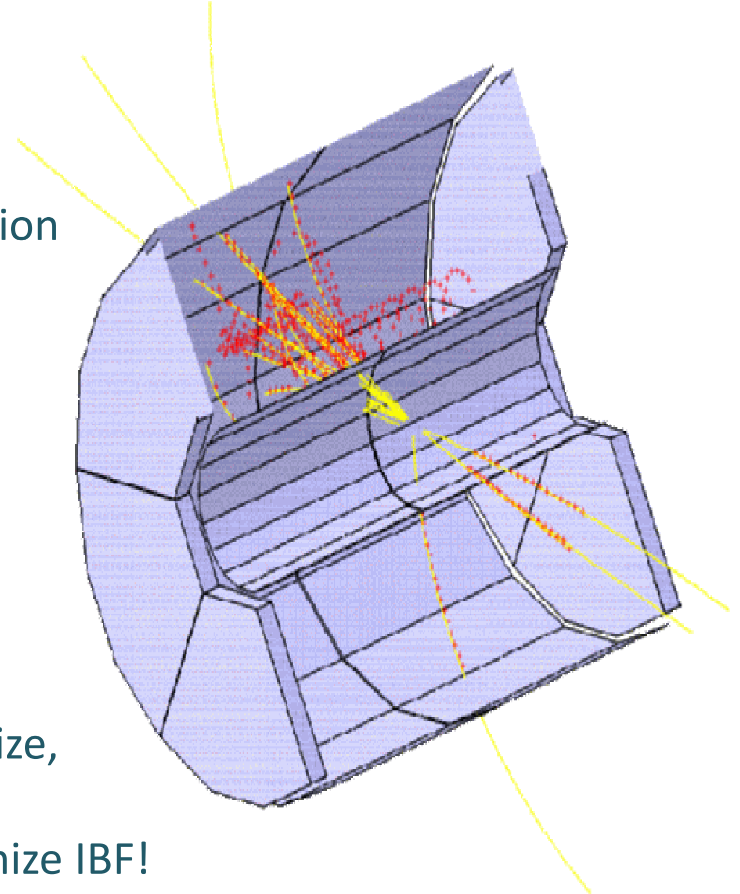
Motivation

- Time Projection Chamber (TPC) for
  - low mass precision tracking
  - pattern recognition
  - momentum reconstruction & particle identification
- Requires E- and B-fields (as uniform as possible)
- Downside: positive ion build-up in drift volume from "primary" ionization" and Ion Back Flow (IBF) from gain structures →
  - E-field distortion
  - Distortion of drifting ionization electron tracks (i.e. Space Charge Distortion: SCD)
- SCD is a "function" of many parameters:
  - Physics, beam structure and collision rate, TPC size, E-field, "working" gas, ….
- IBF is a primary "contributor", thus it is crucial to minimize IBF!
  - Various options used, proposed, tested:
    - wire structure (gating grids)
    - single or double MMG
    - multi GEMs setups (with / without "top" GEM" as a gate)
    - , ….
  - All options have PROs and CONs
- ALICE has decided to upgrade TPC for continuous readout (eliminate the gating grid)



Conclusion after 3.5 years dedicated R&D activities.

From J. Wiechula presentation

- TPC data taking at 50kHz Pb–Pb possible using a 4-GEMs 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:

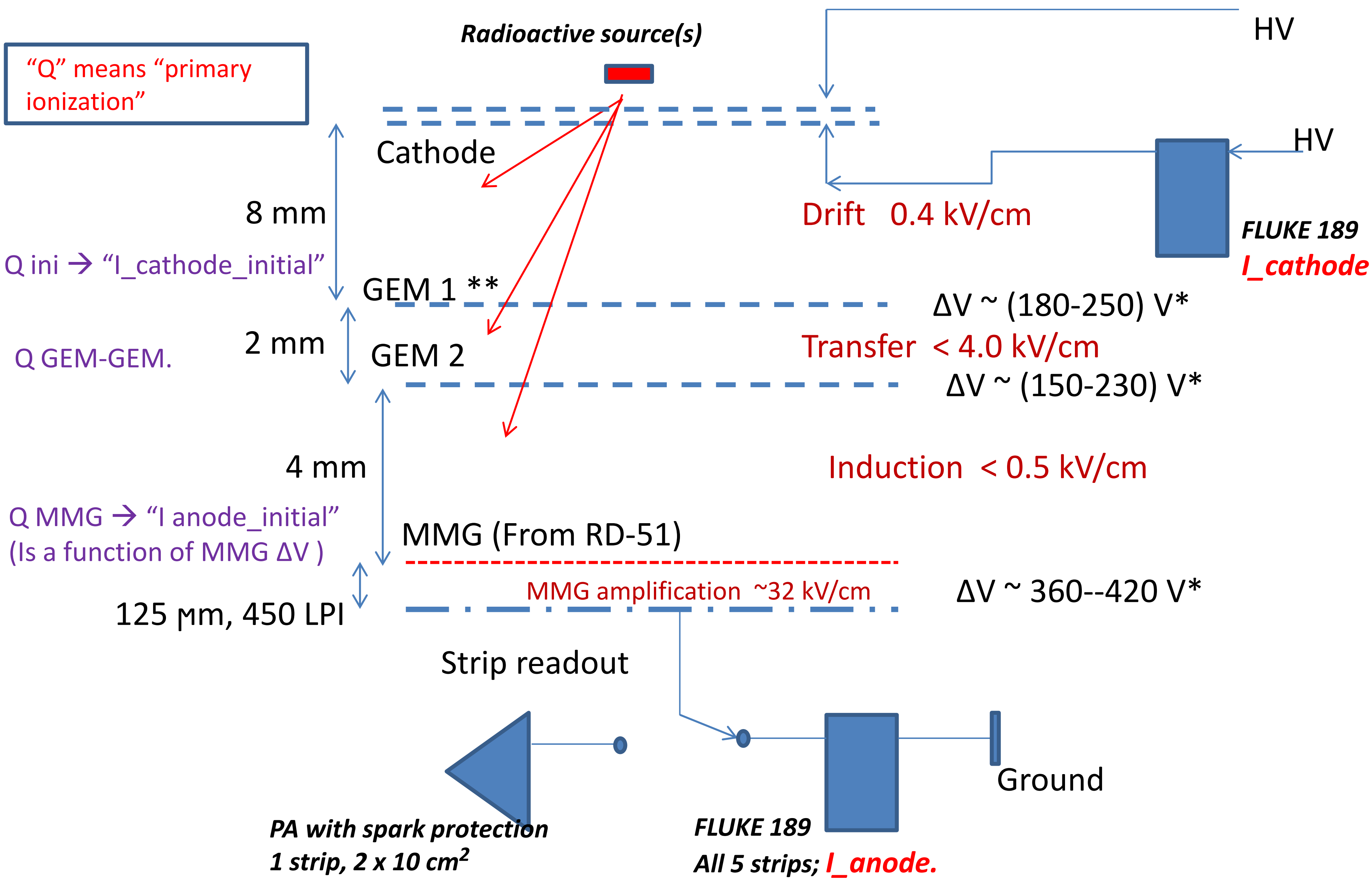
— using a MMG as the “main” gas amplification (gain) step with a maximal ratio of E-fields in the amplification gap vs induction gap (& minimize MMG IBF)

— 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.



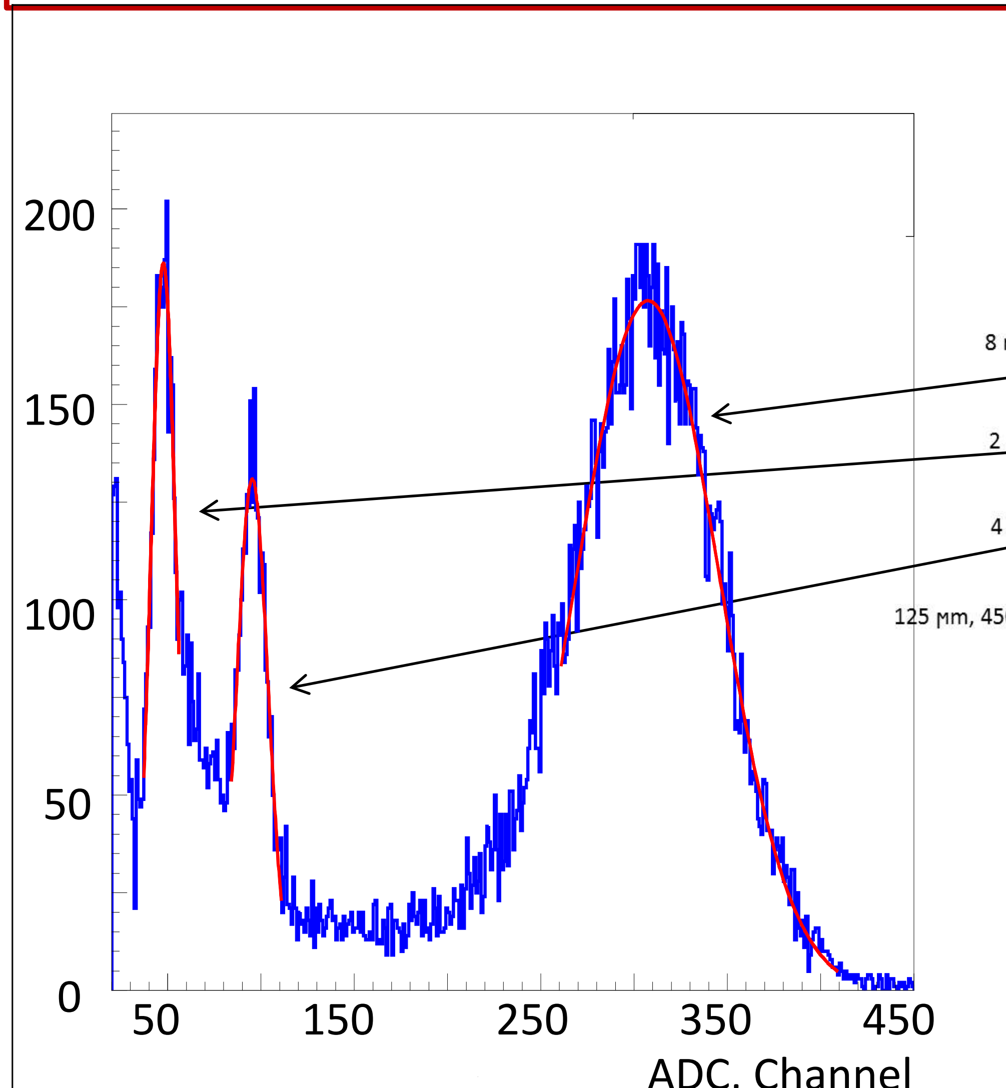
** GEM 1 foil hole pattern rotated 90deg wrt GEM 2

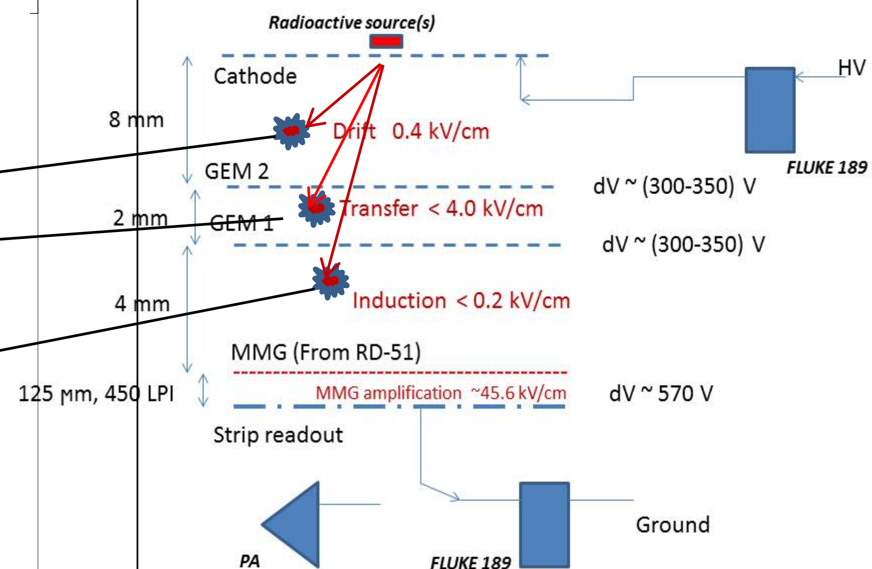
* for Ne + CO_2(10%)

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 2 (bot) ~= 0.52

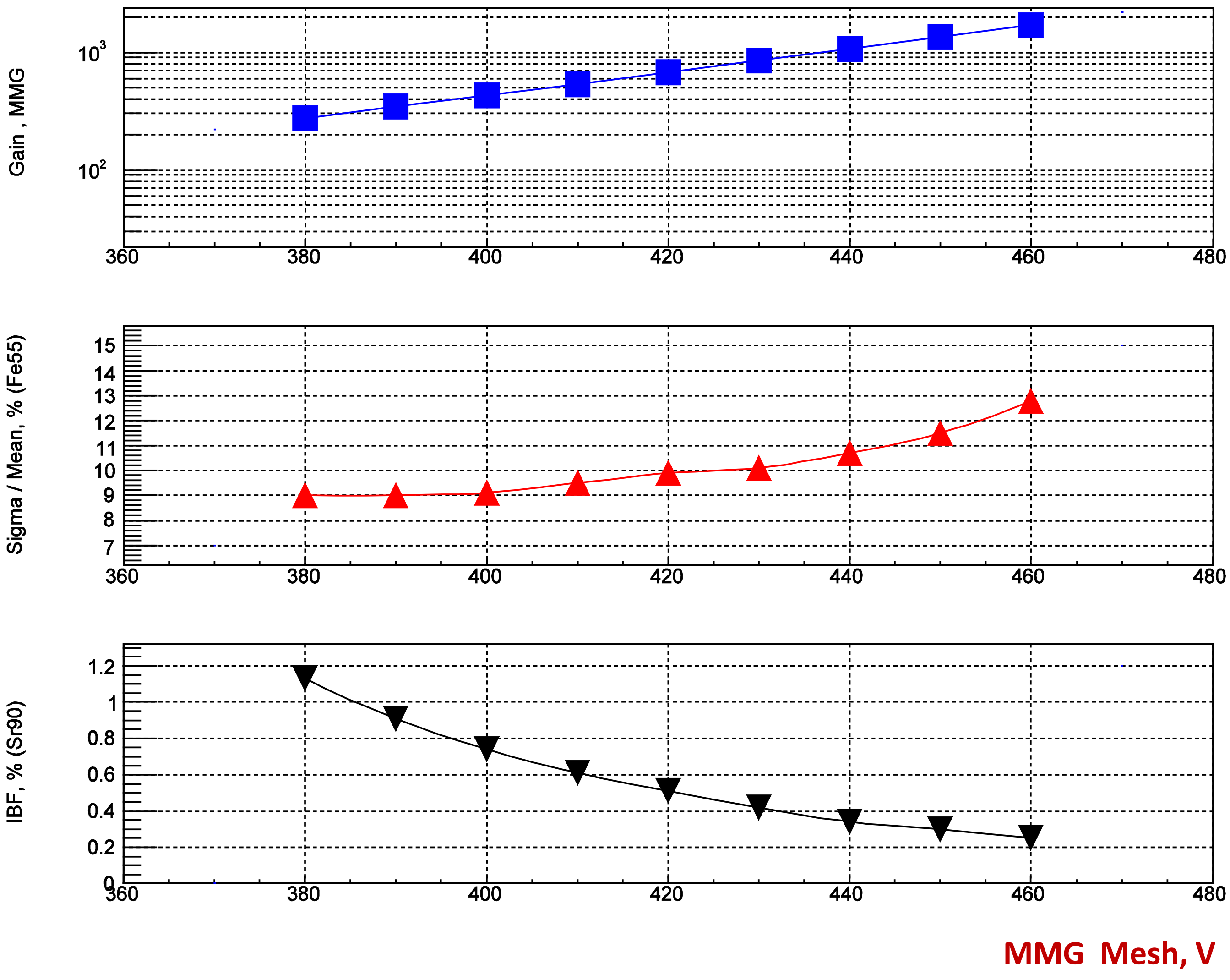
Gain (GEM 2 & GEM 1) ~= 3.2

Gain GEM1 (top) ~= 6.15

2 GEMs+MMG, Ne + CO_2 + CH_4 (82-9-9%)

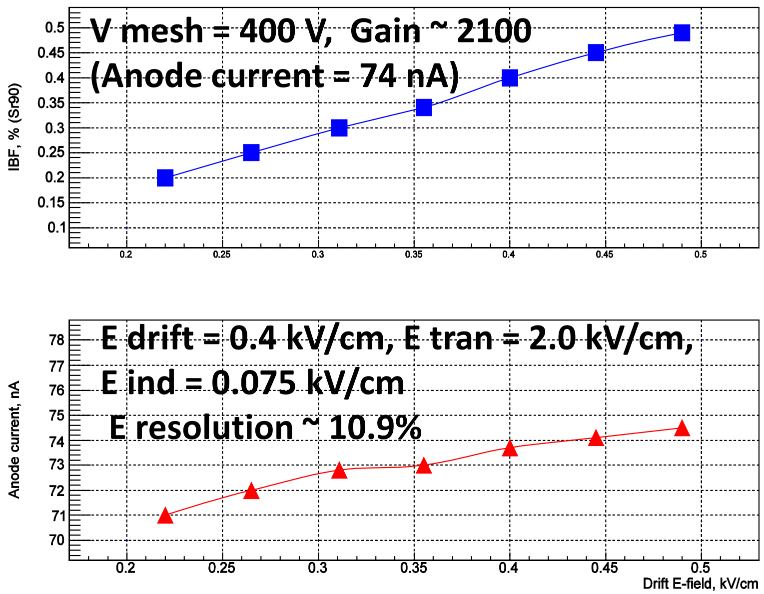
Edrift =0.4 kV/cm, Etran. = 3.0 kV/cm, Eind.=0.075 kV/cm

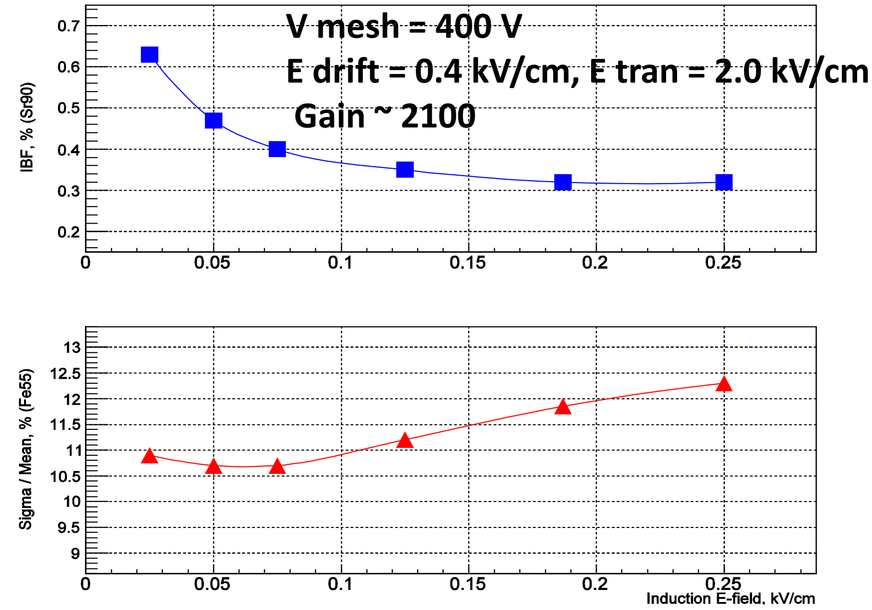
^{55}Fe source, Gain ~2100.

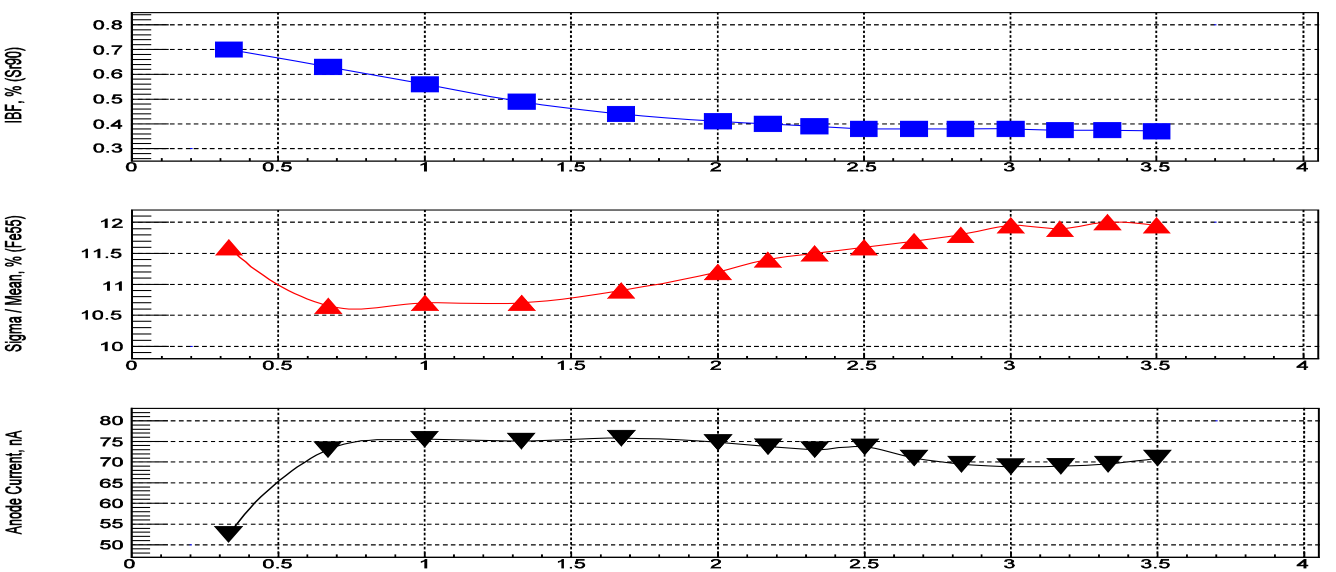


Measurement uncertainties:
E – res: 3-5 %
IBF: 10-15 %

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





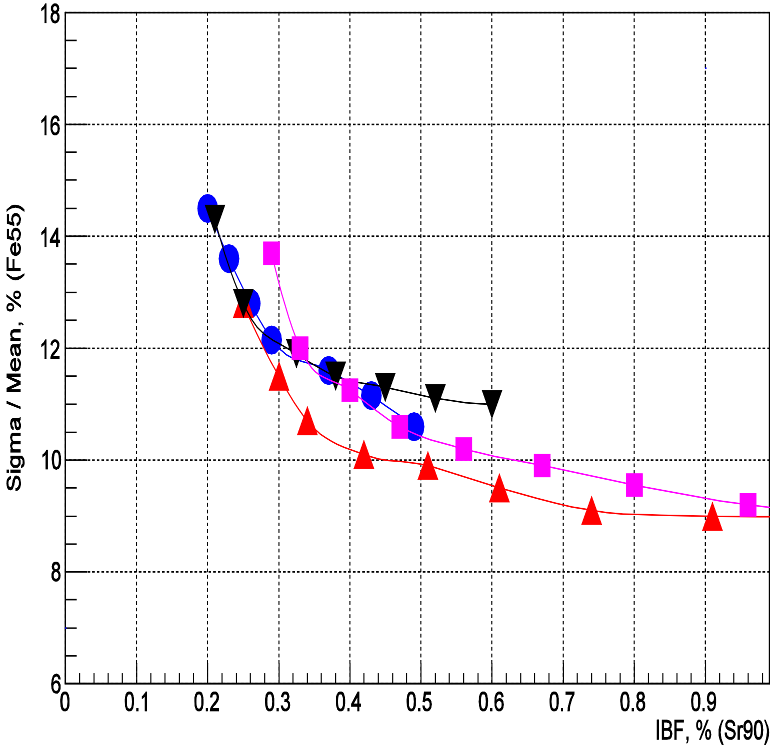


V mesh = 400 V
ΔV1 (top) = 242 V
ΔV2 (bot) = 185 V
E drift = 0.4 kV/cm
E ind = 0.075 kV/cm

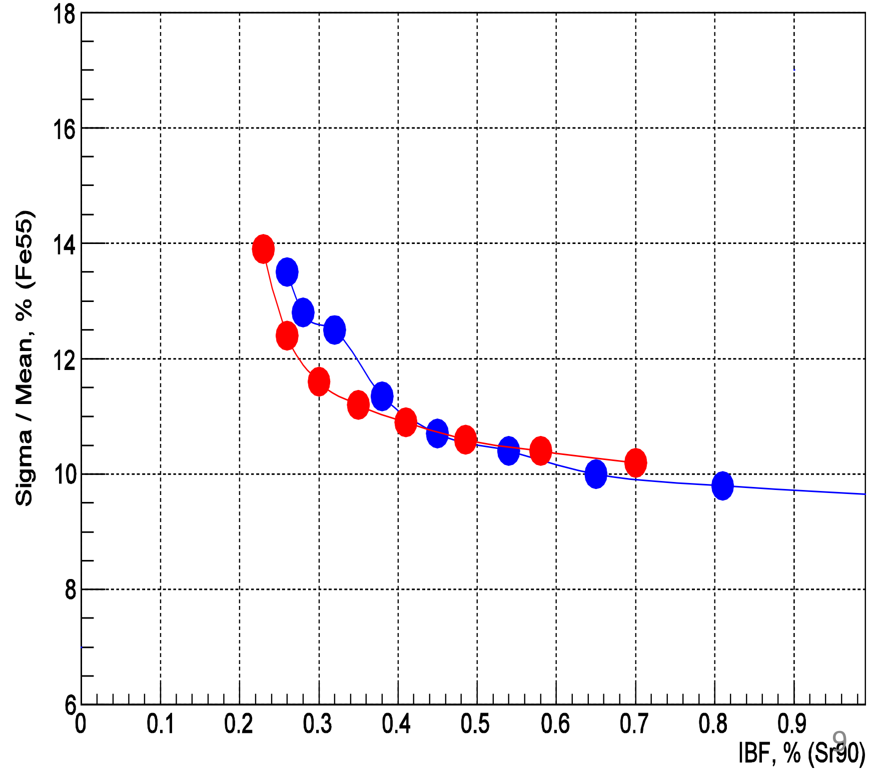
Transfer E-field, kV/cm

Energy resolution (Sigma/Mean for ^{55}Fe) vs. ion backflow (IBF) for various gas mixtures and different MMG and GEMs voltages.
Gain ~2000, E drift = 0.4 kV/cm, E transfer = 1.5-3. kV/cm, E ind = 0.075 kV/cm

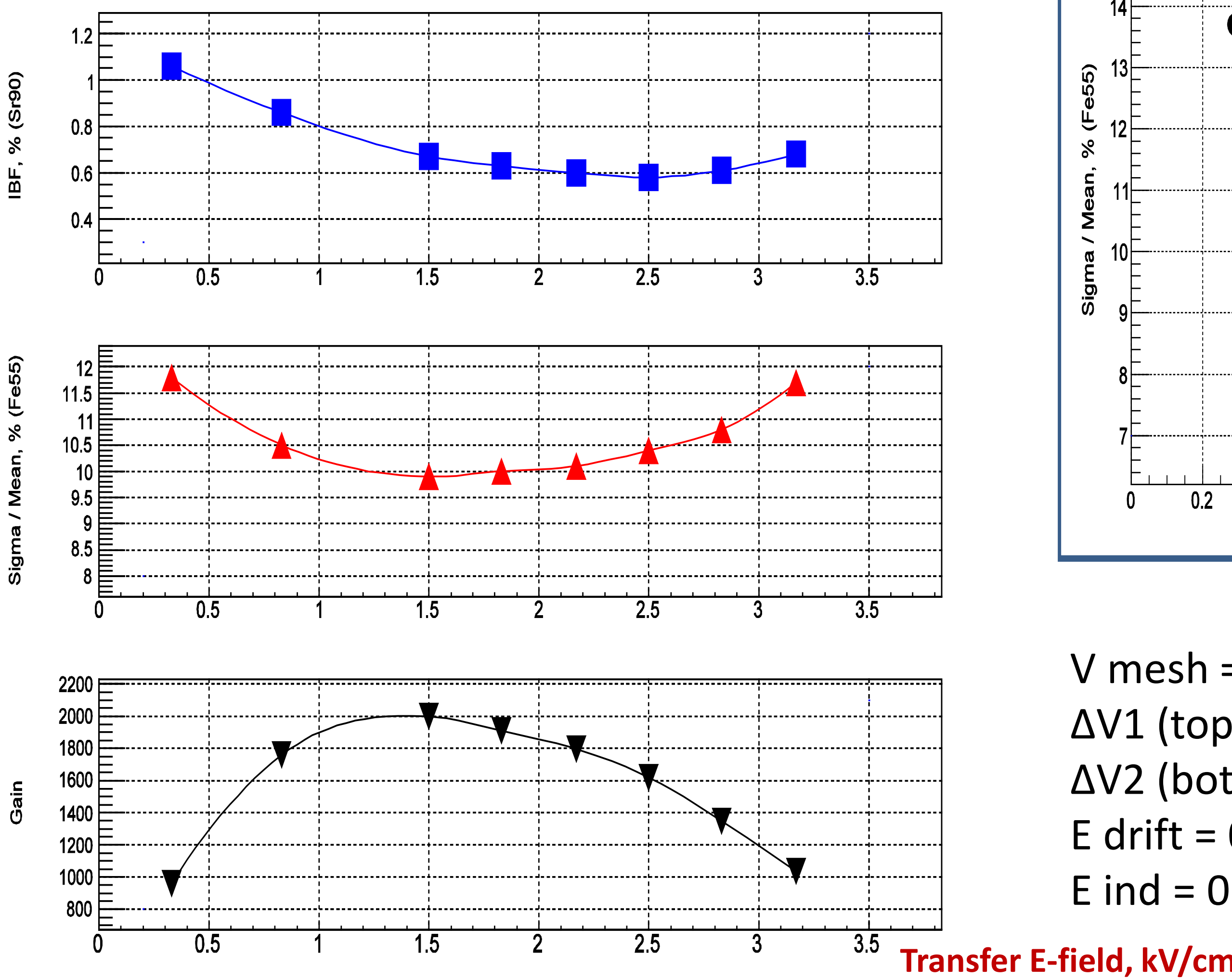
Red ▲ : Ne+CO2+CH4 (82-9-9%),
Blue ● : Ne+CO2+N2 (85.71-9.52-4.77%),
Black ▼: Ne+CO2 (90-10%),
Magenta ■ : Ne+CO2+CF4 (82-9-9%).

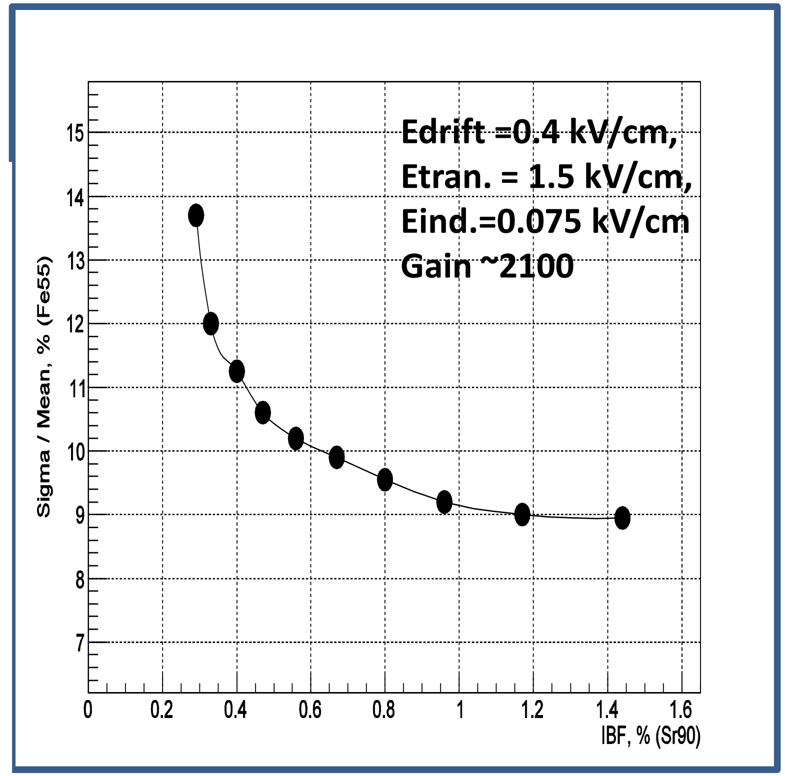


Red ● : Ar+CH4(90-10%).
Blue ● : Ar+CO2(90-10%).



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





V mesh = 430 V

ΔV1 (top) =271 V

ΔV2 (bot) =206 V

E drift = 0.4 kV/cm

E ind = 0.075 kV/cm

	4 GEMs	2 GEMs + MMG 450 LPI, (no R-layer)	MMG only 450 LPI
IBF	(0.6 - 0.7)%, E drift=0.4 kV/cm	(0.3 – 0.4)% E drift = 0.4 kV/cm	(0.4 – 1.5)% Edrift = (0.1 – 0.4) kV/cm
<GA>	2000	2000	2000
ϵ - parameter (=IBF*GA)	12 - 14	6 - 8	8 – 30
E – resolution	<12%	<12%	<= 8%
Gas Mixture (2-3 components)	Ne+CO2+N2 (Et “problem” with + CF4)	Ne+CO2+N2, Ne+CO2, Ne+CF4, Ne+CO2+CH4	X + iC4H10 (Ar+CF4+iC4H10)
Sparking (^{241}Am) Sparking, test-beam Ne+CO2+N2 (85.71-9.52-4.77%) Possible main problem	$<3.*10^{-9}$ $\sim 6.4*10^{-12}$ short sector of the foil	$< 3.*10^{-7}$ (Ne+CO2) $< 2.*10^{-8}$ (Ne+CO2+C2H4) $\sim 3.5*10^{-10}$ lost FEE channel	$\sim 10^{-7}$ (S. Procureur report)
Pad structure	Any, but improvement with Chevron	Not Chevron Cross-talk effect	##

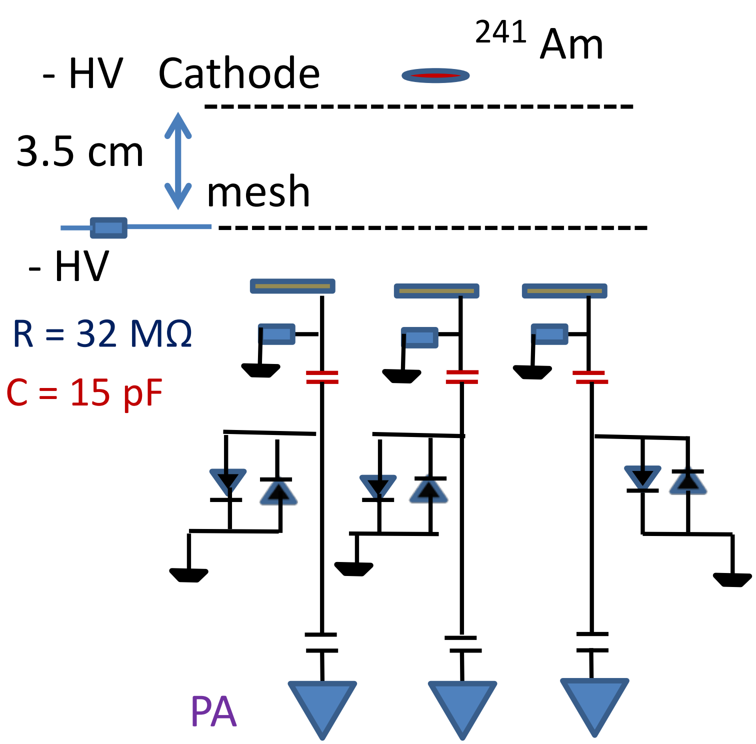
MMG sparking. Mesh Voltage drop measurement,

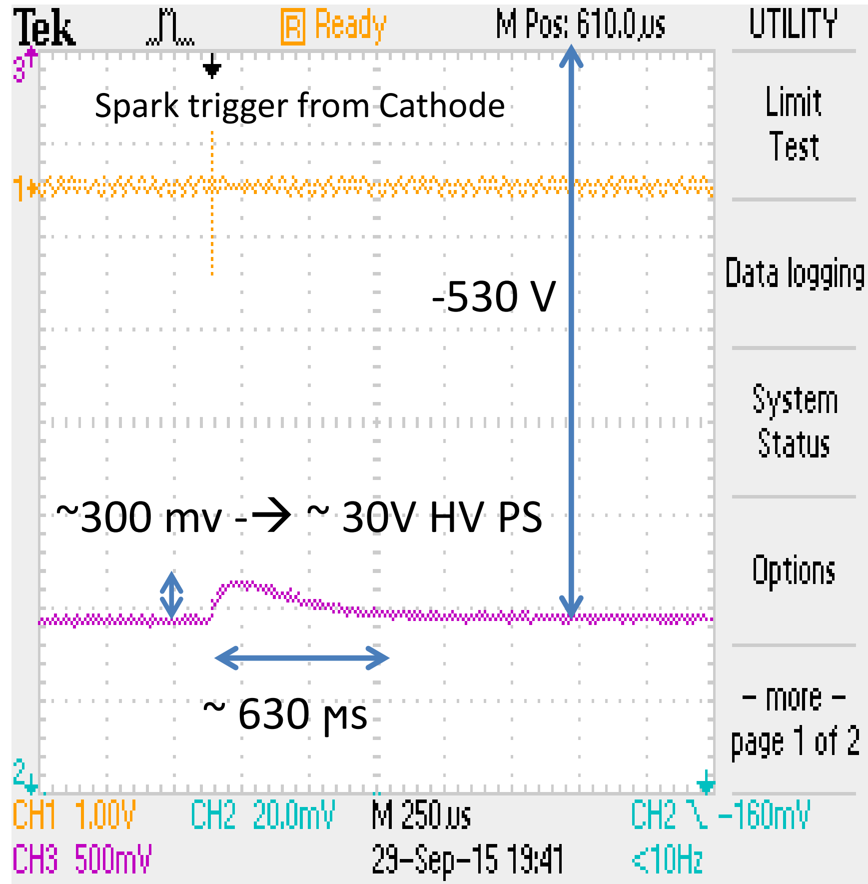
10x10 cm2 MMG with Pad (4x7.5 mm2) readout

Spark trigger – from Cathode. V Mesh = - 530 V. Sparking rate: ~1 /20 s.

Signal from R-divider connected to MMG mesh

Ar+CO2(10%) gas mixture



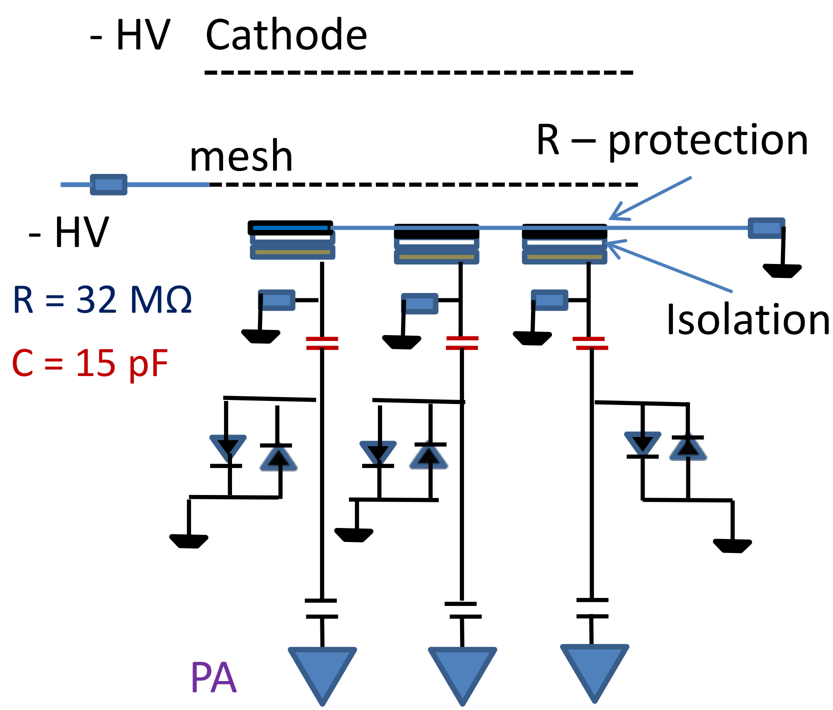


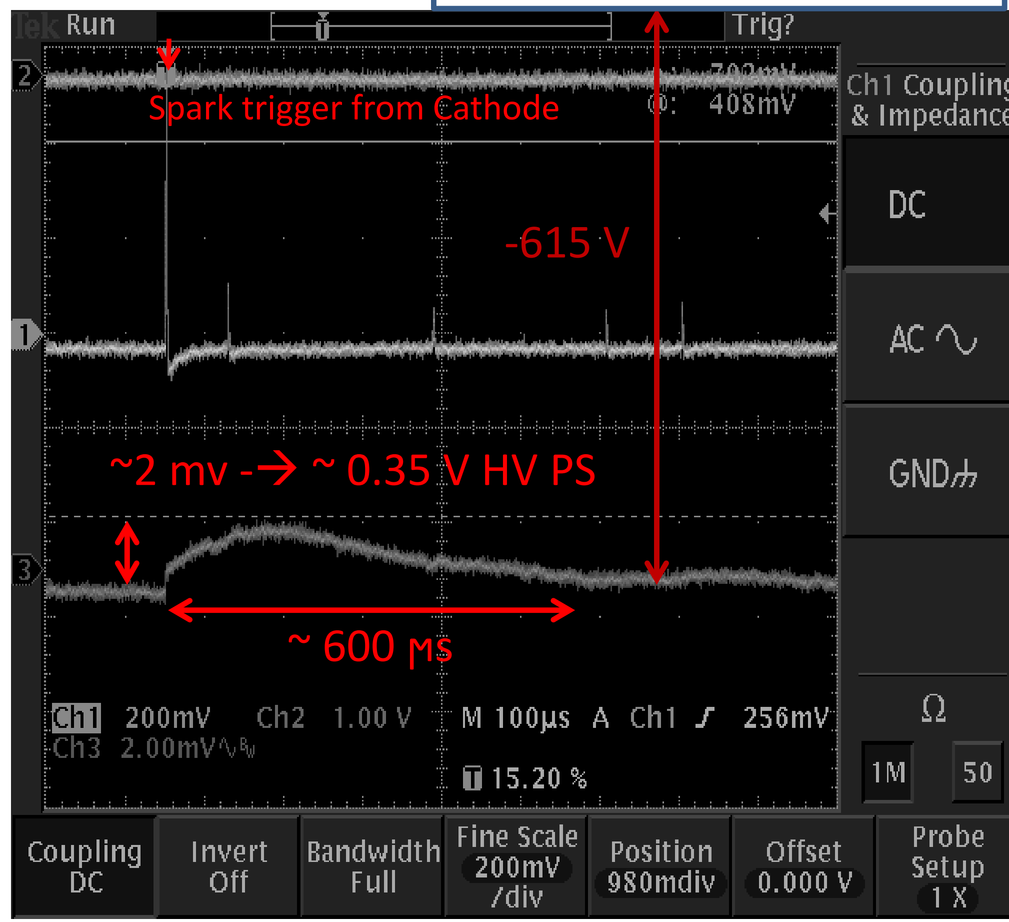
*) signal integration takes place on oscilloscope input capacitor

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

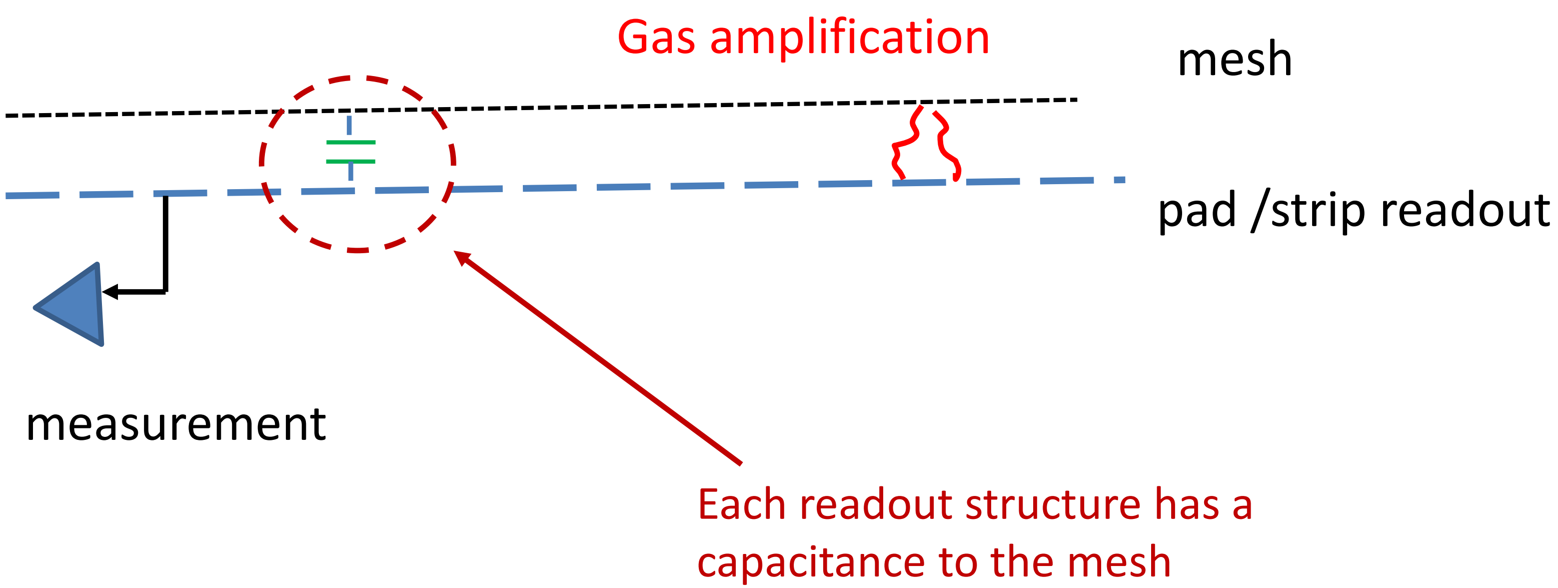
The same setup but with Resistive layer protection (1. MΩ / □),
its own for each pad-row.
V Mesh = - 615 V. Sparking rate: ~ 1/20 s

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



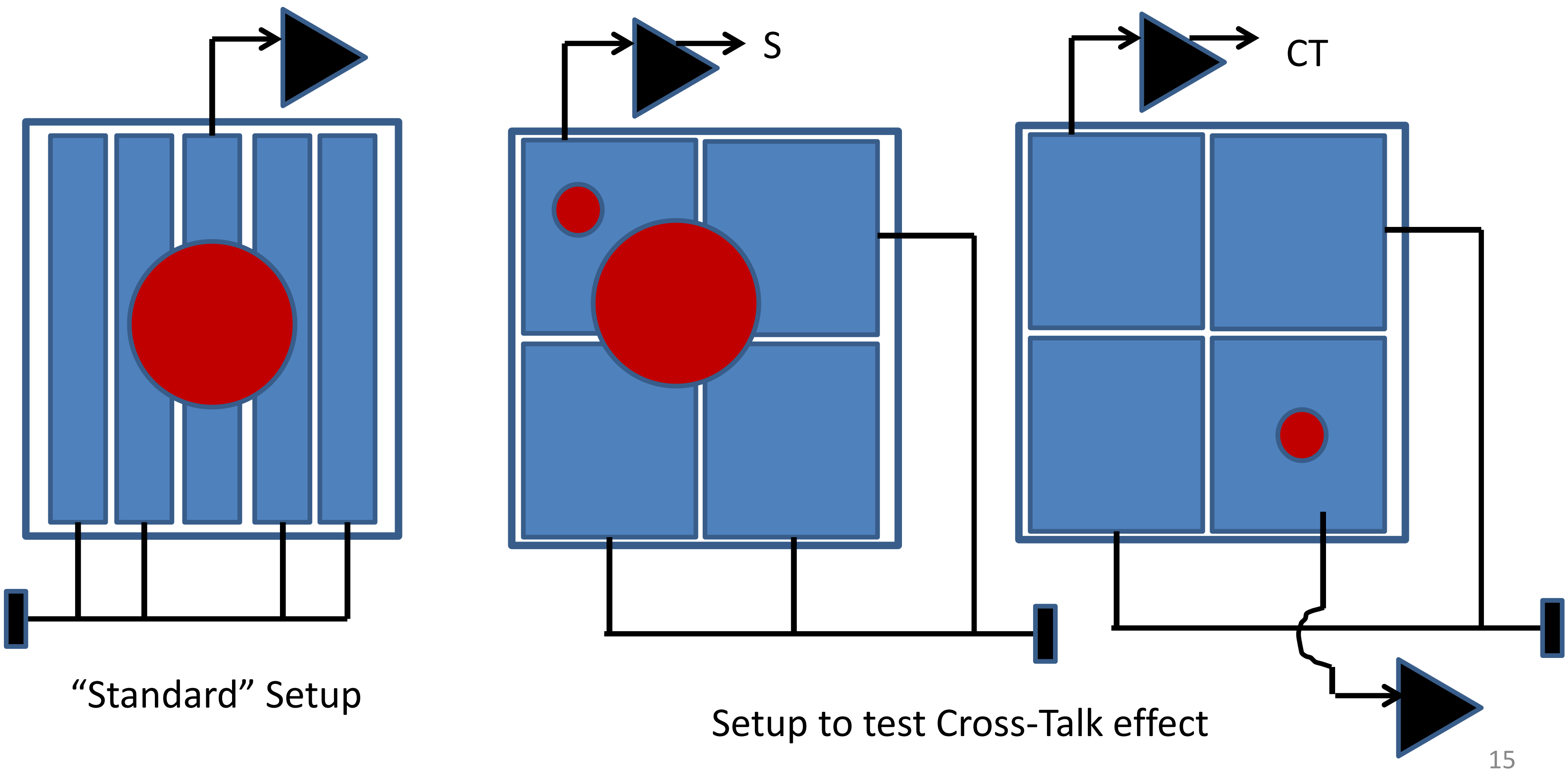


What kind of MMG "cross-talk" we are speaking about.



^{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 (CT/S) of ~0.4% per cm^2 pad size,
With the expectation that crosstalk is proportional to the readout pad to mesh capacitance



Conclusions

- TPC gas amplification setup 2GEMs+MMG investigated as a high rate TPC option without the standard gating grid
- A combination of MPGDs was selected with the intention to minimize the E_{ind}/E_{MMG} ratio independent of TPC drift field, while keeping good energy resolution (dE/dx).
- We achieved simultaneously

  IBF < 0.4% and E-resolution > σ/E = 12% for ^{55}Fe at a gain ~2000

  in a variety of gas mixtures (with standard MMG and GEM detectors).
- If the correction of SCDs is the main factor for spatial resolution and momentum reconstruction performance: Neon-based gas mixtures (without iC4H10) are suitable due to their large ion drift speed (ion mobility and E-drift), but less primary ionization (Ar – Ne).

  Thus, we focused on Ne-based gas mixtures.
- Using double GEM foils structure allows: both an additional IBF suppression & minimization (as a “pre-amplification”) of MMG discharge rate down to ~$5.*10^{-10}$ ($Ne+CO_2+N_2$; Gain ~ 2000). GEM sparking not seen.
- With an R-layer protection - MMG sparking “became invisible” from MMG mesh voltage drop value & timing parameters. Chevron style pads/strips can be considered again.
- The hybrid MPGDs allows for TPC design that can operate in a continuous mode, and serve as a viable option to limit SCD in high-rate TPCs.

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 GEM1 = 210 V, dV GEM2 = 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

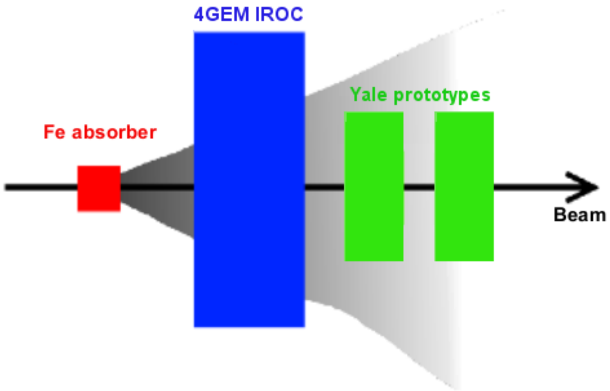
All Voltages ON: I_anode = - 27.78 nA , I_cath = 0.083 nA

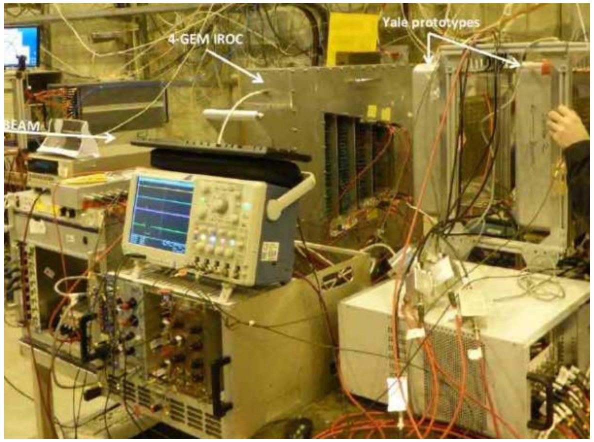
IBF = (0.083 – 0.012 – 0.0016) / (27.78 – 3.21 + 0.05) = 0.29%

<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 beai
  - 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:

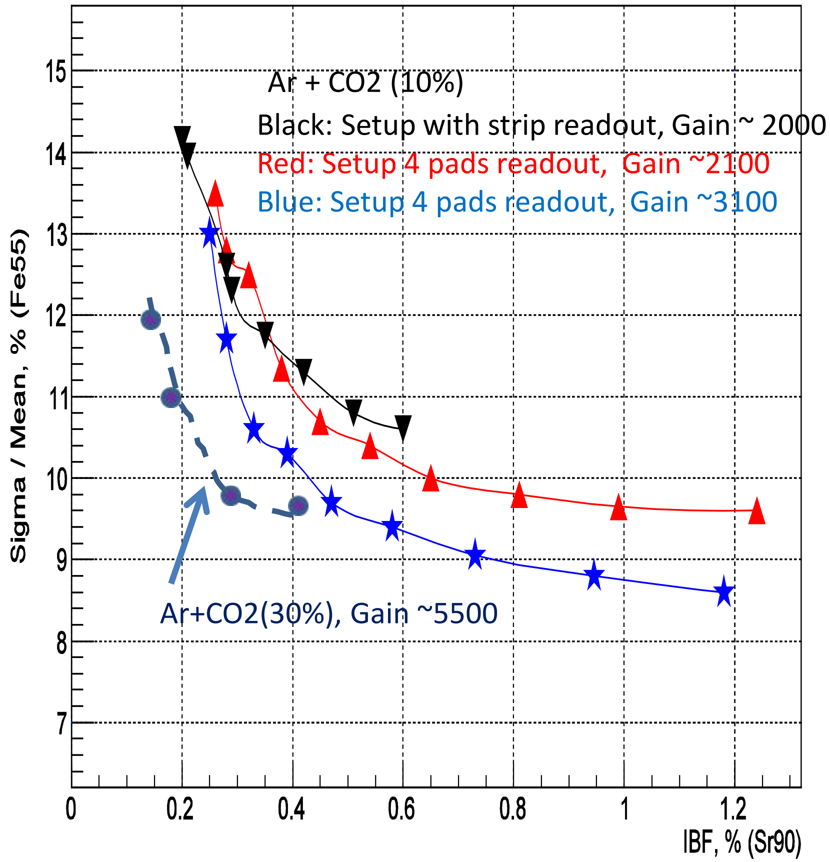
  ~6.4 x 10^{-12} per chamber particle (3 sparks observed)

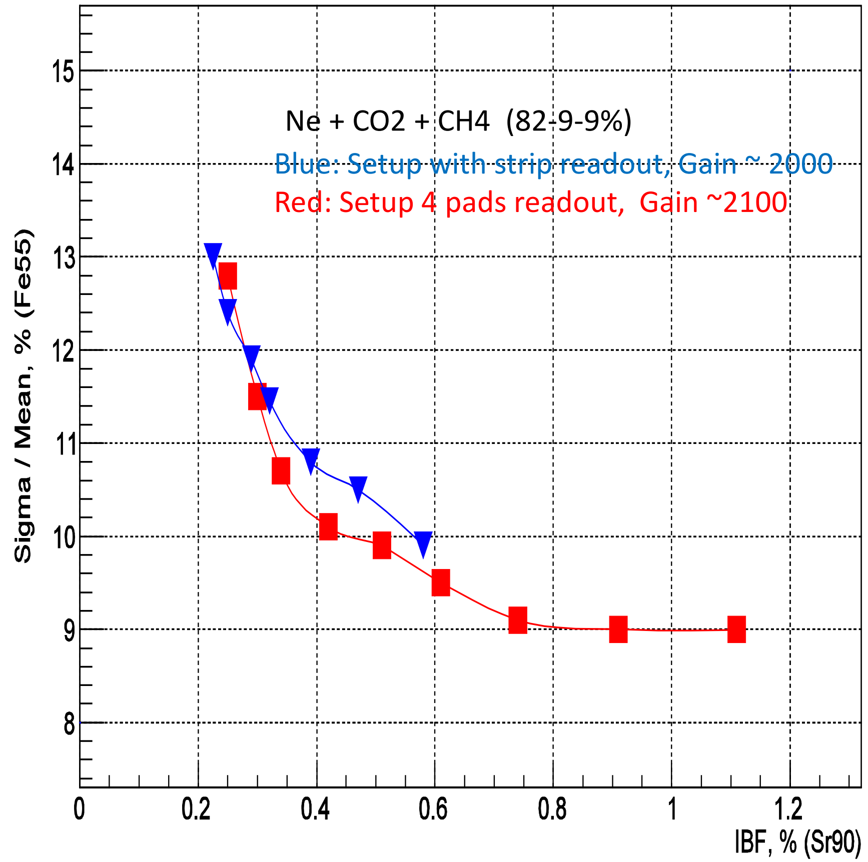
  Dead time ~ seconds to minutes

Two Setups comparison

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

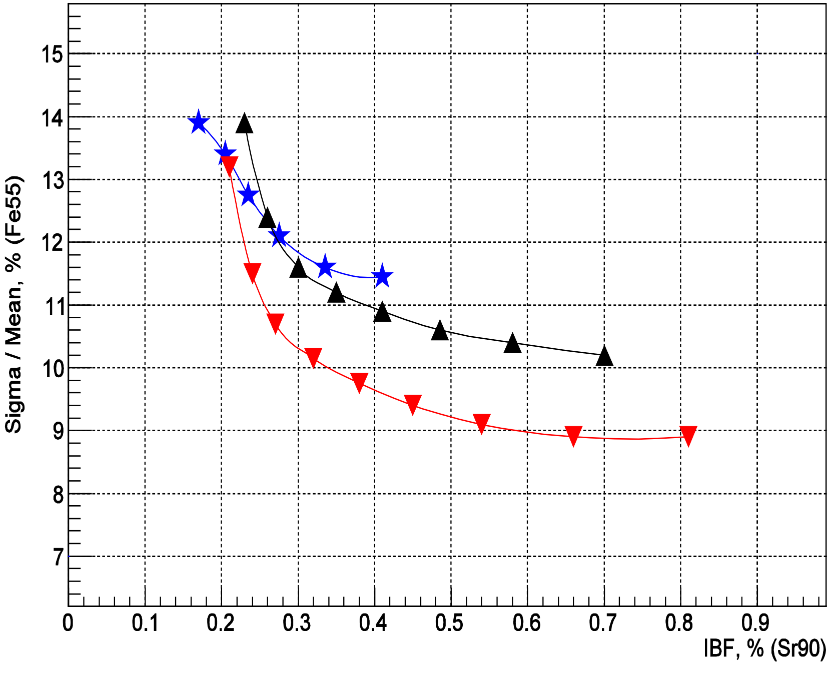
^{55}Fe, Source “weak” (standard) collimation



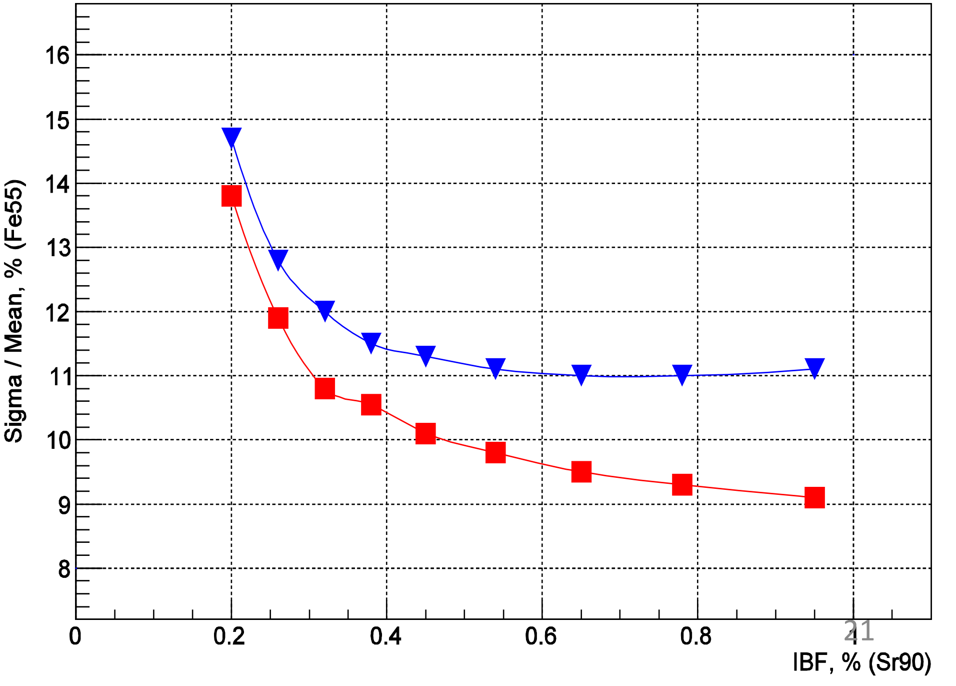


Two Setups and ^{55}Fe Source Positions / Collimation comparison
Edrift =0.4 kV/cm, Etran. = 3.0 kV/cm, Eind.=0.075 kV/cm
Gain ~2100

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

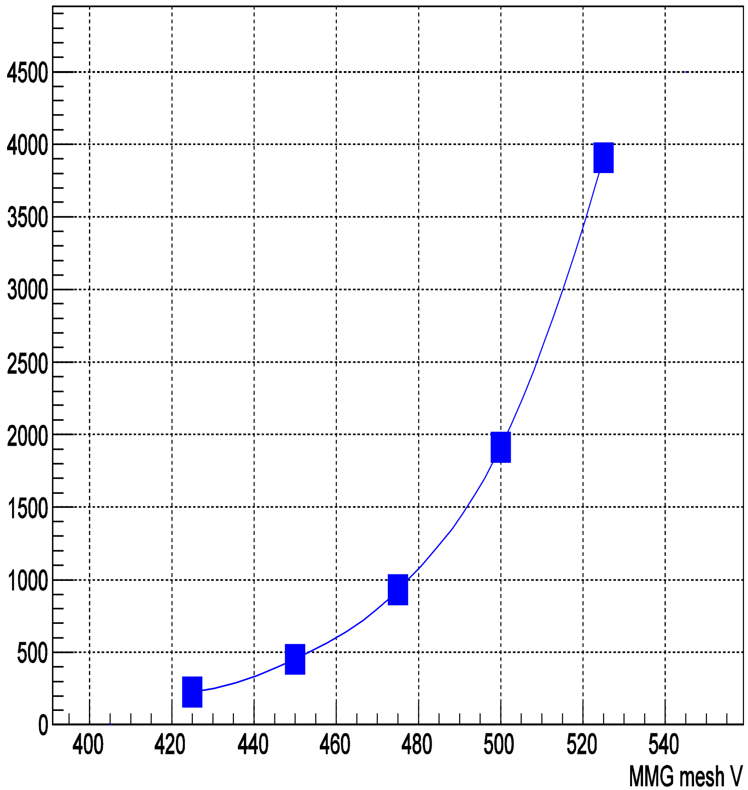


Ne + CO_2 (10%), Setup 4 pads readout
Blue: source “standard” collimation
Red: source “strong” collimation

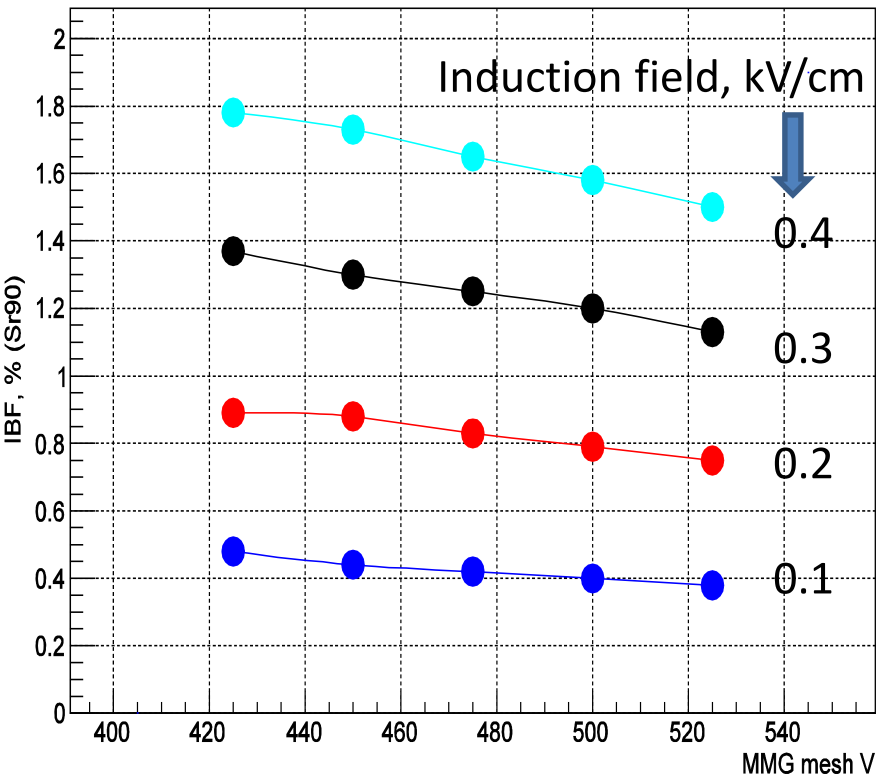


MMG from Rui's workshop: 126 μm gap, 450 LPI.
Ar+CO2 (9.8%) gas mixture.
E – resolution, ^{55}Fe, (Sigma/ Mean): (8 – 8.5) %
IBF = (I cathode – I cathode_ini) / I anode

< Gas Amplification >



IBF, %

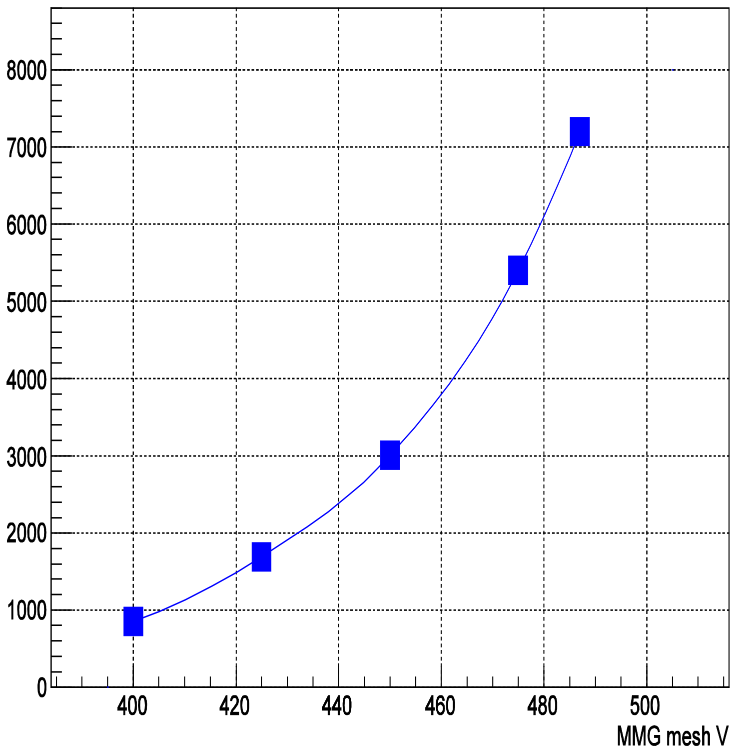


Ne+CO2 (10%) gas mixture.

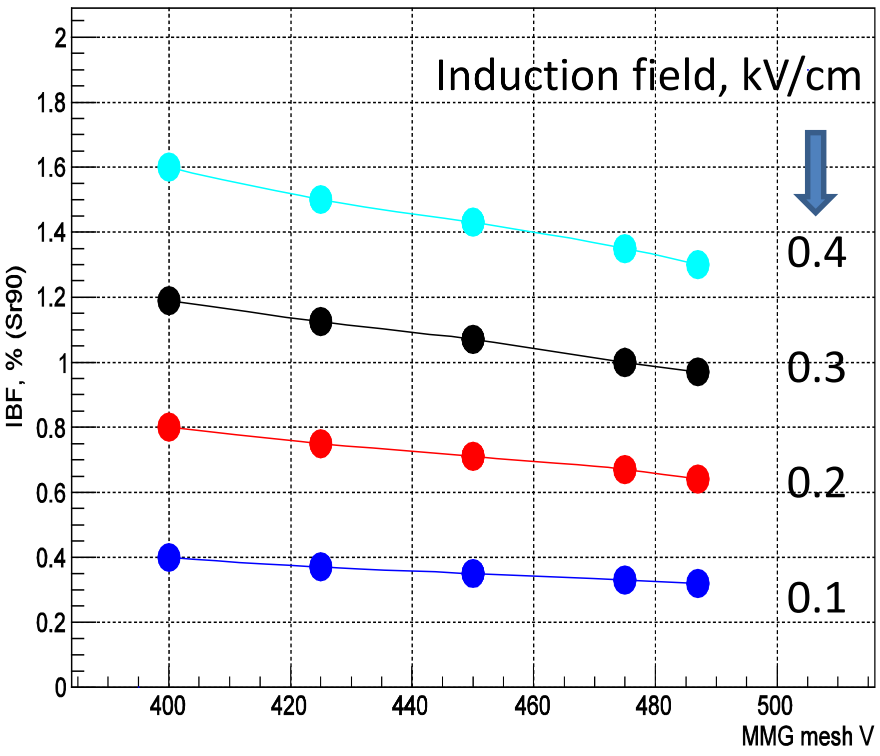
E – resolution, ^{55}Fe, (Sigma/ Mean): (7 – 7.5) %

IBF = (I cathode – I cathode_ini) / I anode

< Gas Amplification >



IBF, %



IBF as a function of MMG Field Ratio: E amplification / E induction