# R&D to study 2GEMs+MMG setup as Gain Structure in a High Rate TPC and in Cherenkov / RICH Detectors

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# Motivation

- Possibility to construct / upgrade TPC without Gating Grid but with “acceptable” Space Charge Distortions.

  ALICE TPC upgrade program.

- Gas Cherenkov / RICH Detectors without “windows” (like PHENIX HBD)

# Constrains

- ***TPC***

 -- preserve ( or improve) momentum reconstruction performance in a compromise with read-out pad size (number of FEE channels)

 -- minimize IBF ( < 0.5%) for an average Gas Amplification (<GA>) ~2000 ( S/N ratio). It means: ϵ - parameter < 10.

 -- preserve dE/dX performance: E-resolution for Fe55  σ/Mean <= 12%.

 -- can be used for different options of TPC "working" gas mixtures

- ***Cherenkov / RICH***

 -- CsI as UV – convertor

 -- 2d – 3d readout

 -- <GA> ~ n * $10^5$

# What was known ~two years ago

- ***Multi GEMs setup:***

-- Detail study from Novosibirsk team: the best IBF for 3-GEM setup and drift field >0.1 kV/cm:
>1.% ( A. Bondar, et al, NIM A496 (2003), 325 )

-- careful and comprehensive 4 years R&D; CERN, TUM and Frankfurt teams:
3-GEM setup, drift field = 0.4 kV/cm; IBF ~1.%
4-GEM setup, drift field = 0.4 kV/cm: IBF = (0.6-0.7)%
and control E-resolution.
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.

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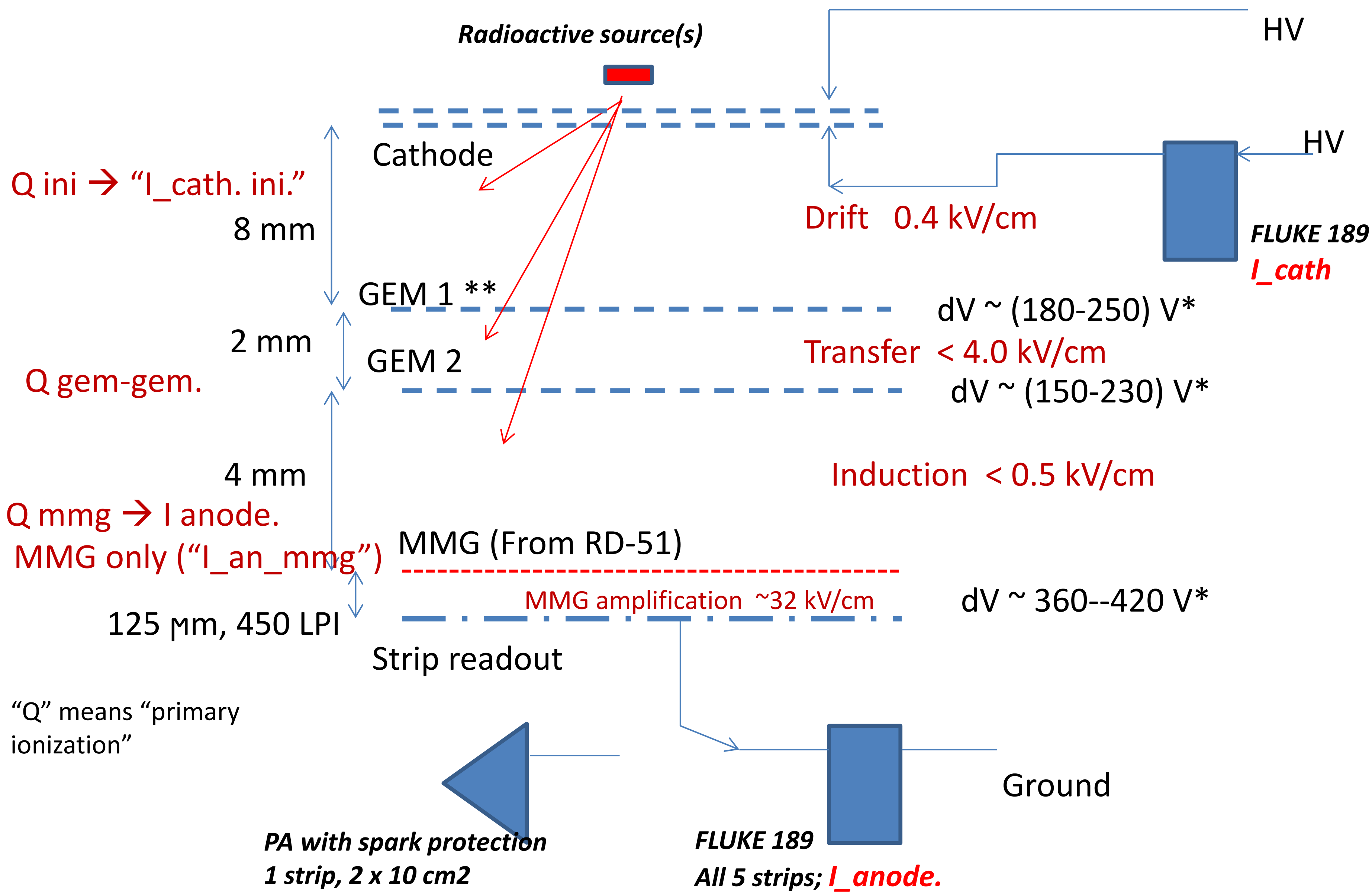
- ***TPC response simulation was done (as precise as possible) to check micro-pattern technology for gas amplification option in a comparison with MWPCh (dPt/Pt and dE/dX performance ).***
- ***( all details are in appendix)***

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



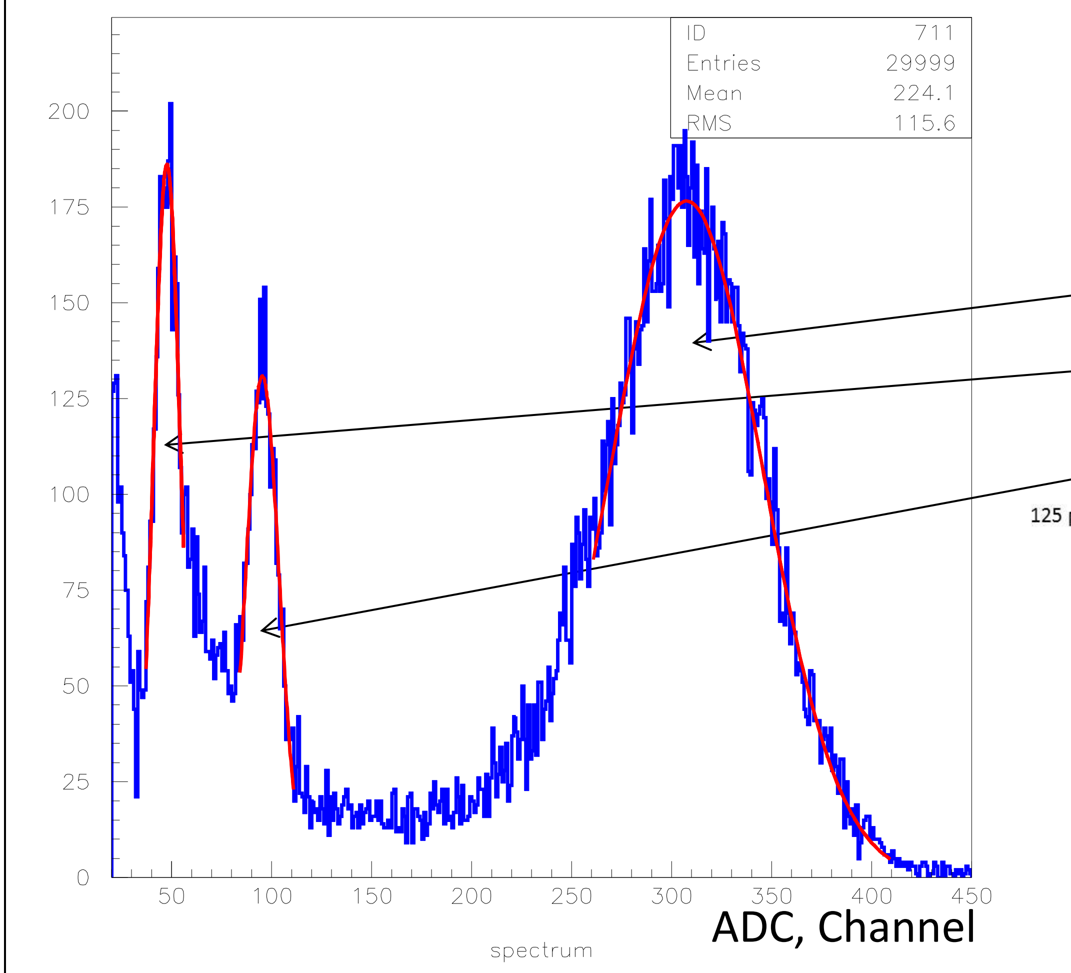

** - GEM foils are in 90deg rotation position

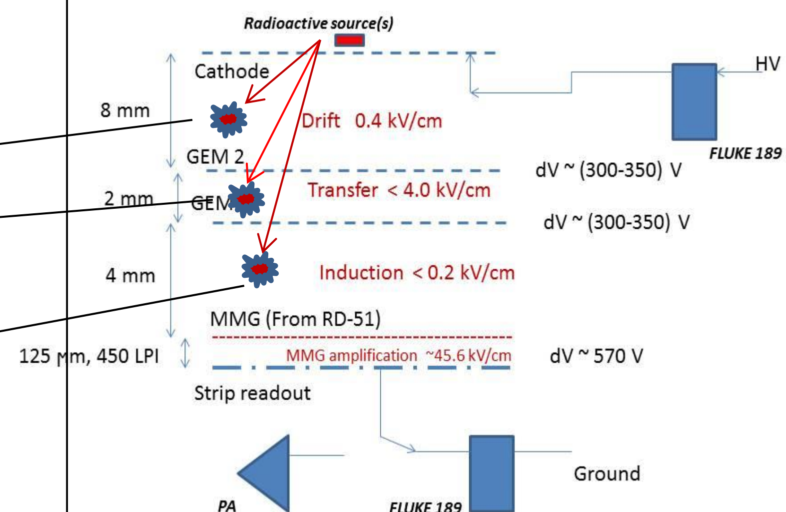
* -- for Ne + $CO_2$ gas

# 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




GA GEM 1 ~= 0.52

GA (GEM 2 & GEM 1) ~= 3.2

GA GEM2 ~= 6.15

First measurements with ***Ar+CO2(30%)***

Fe55 and Sr90 sources.

E drift = 0.4 kV / cm

E transfer = 3.5 kV / cm

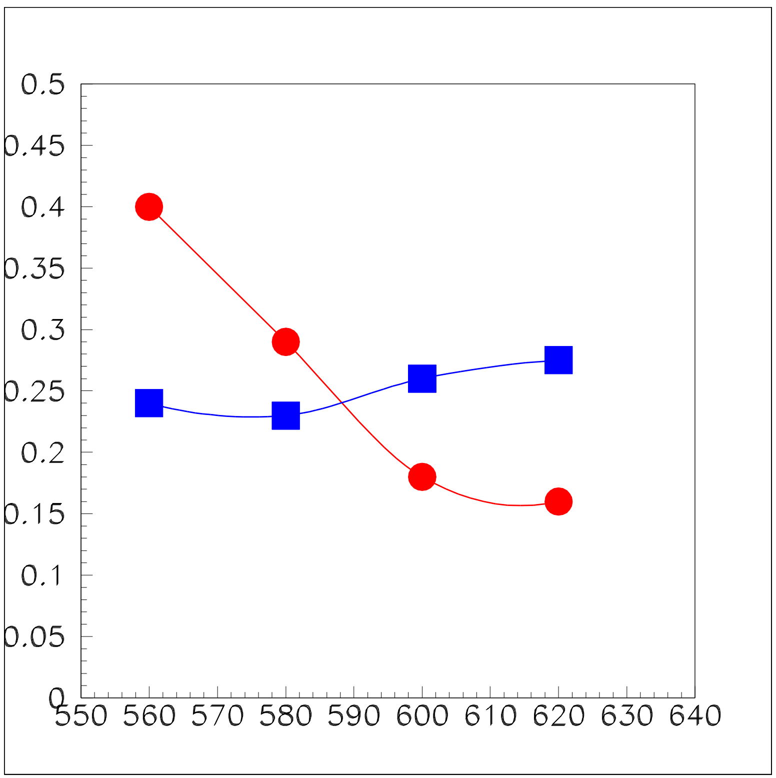
E induction = 0.125 kV /cm

<G.A.> = (5.5+/- 0.5) * e3

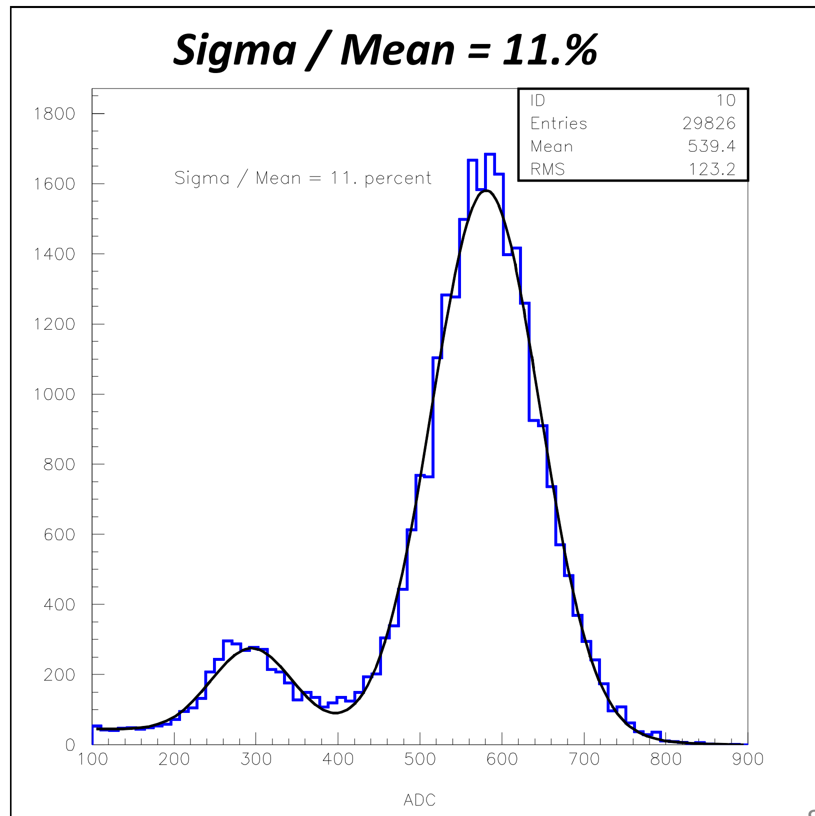
( tune GEM voltages to keep GA the same)

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

Blue boxes: FWHM / Mean, Fe55

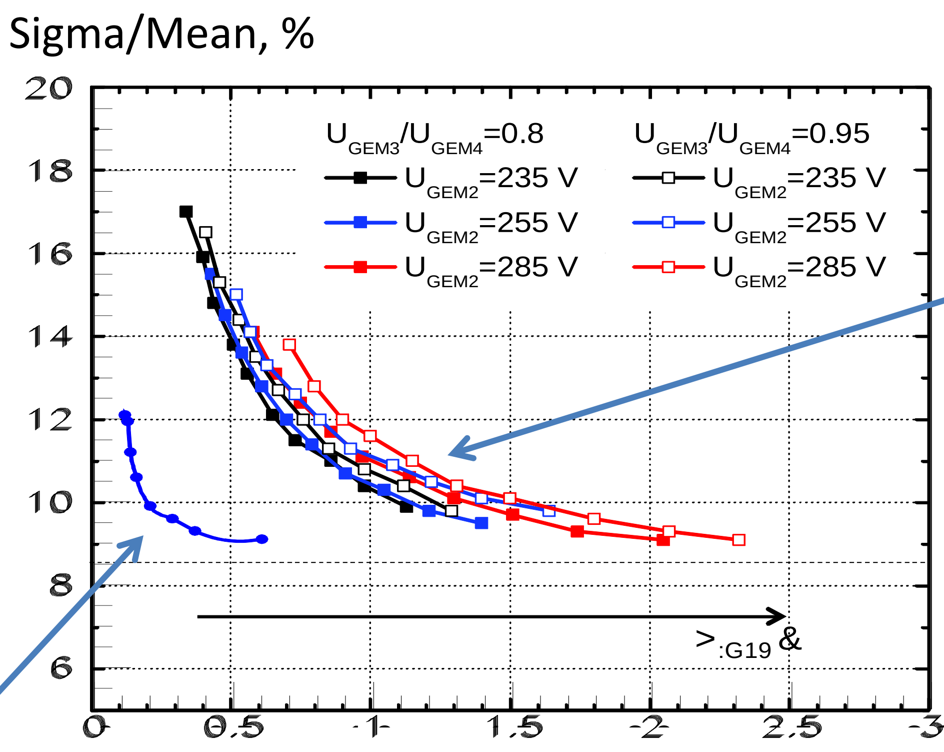



MMG Mesh HV, V



# IBF performance and energy resolution

## Ne + $CO_2$(10%)



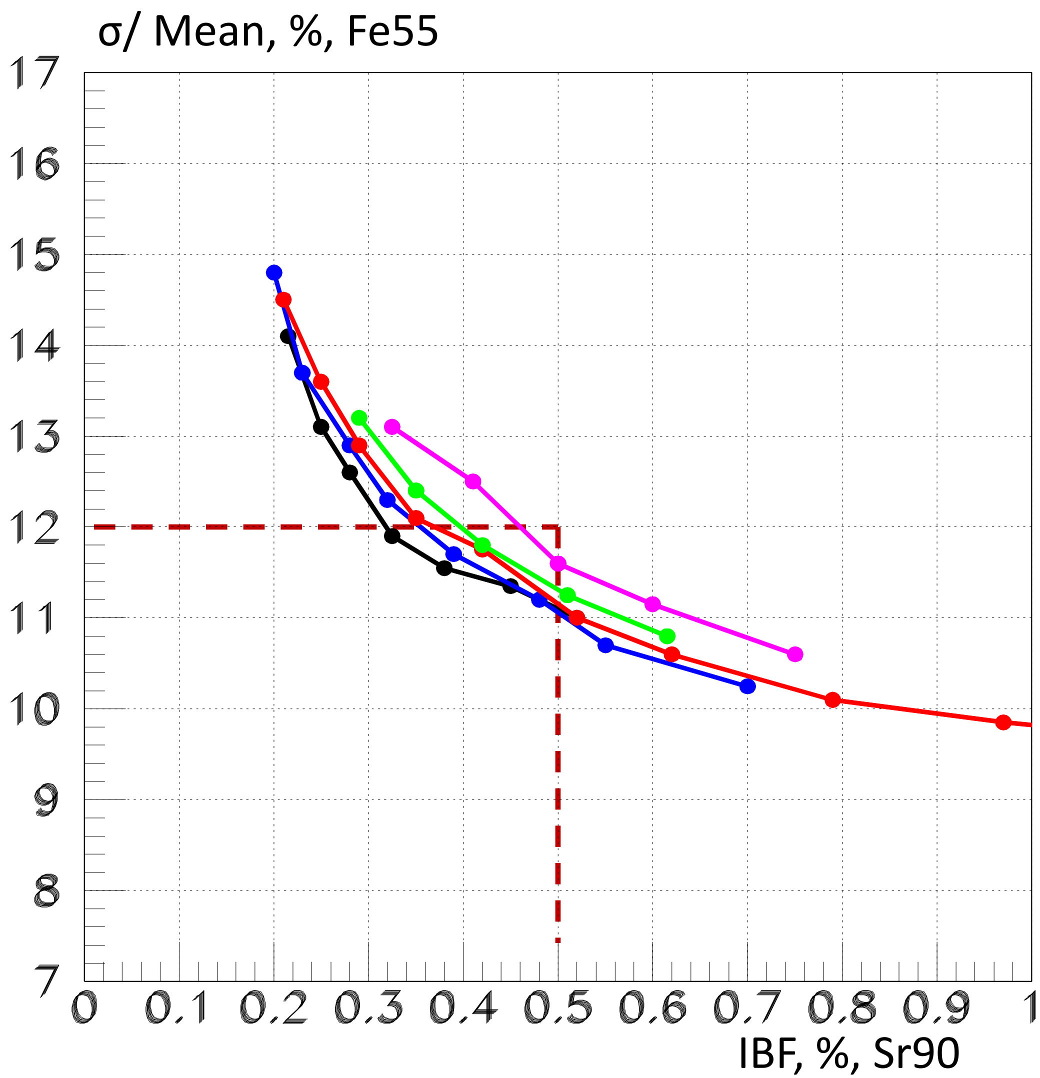

4 GEMs setup
(ALICE TPC upgrade TDR)
<GA> ~2000

2 GEMs + MMG setup, <GA> ~5000

Ne+CO2(10%)

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

**<GA> ~ 2000.**




Blue: dV GEM2 = 190 V

Red: dV GEM2 = 210 V

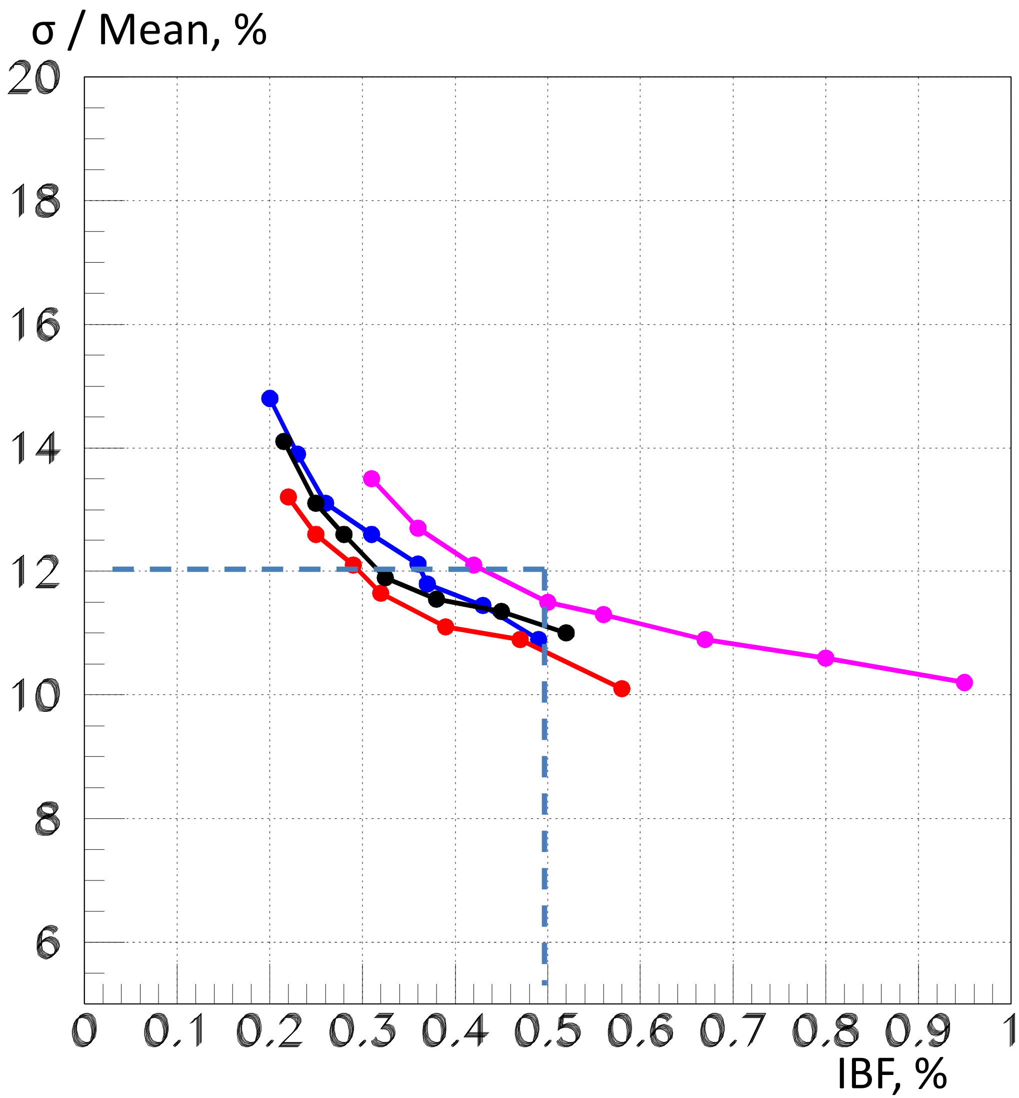
Green: dV GEM2 = 220 V

Magenta: dV GEM2 = 230 V

V MMG and dV GEM1 are varying

Black: “some optimization”

# Comparison for different gas mixtures




Red: Ne + CO2 + CH4 (80-10-10)
Black: Ne + CO2(10%)
Blue: Ne + CO2 + N2 (90-10-5)
Magenta: Ne + CO2 + CF4 (80-10-10)

# What was done more, and more data available

- Data for Ne+CO2+N2 (90-10-5)

  -- is any reason to continue study for this gas mixture ?

  -- Gain sensitivity was checked to:

  N2 (+/- 1%), d(voltages) all three amplification steps, and Gas pressure.

- Data for Ne+CO2+CH4 (80-10-10), C10, P10

- Small (10x10 cm2) detector with the same pad and via structure as IROC; test sparking and E-resolution with collimated Fe55 source.

- 3 small (10x10 cm2) detectors to test different pad size / shape options.

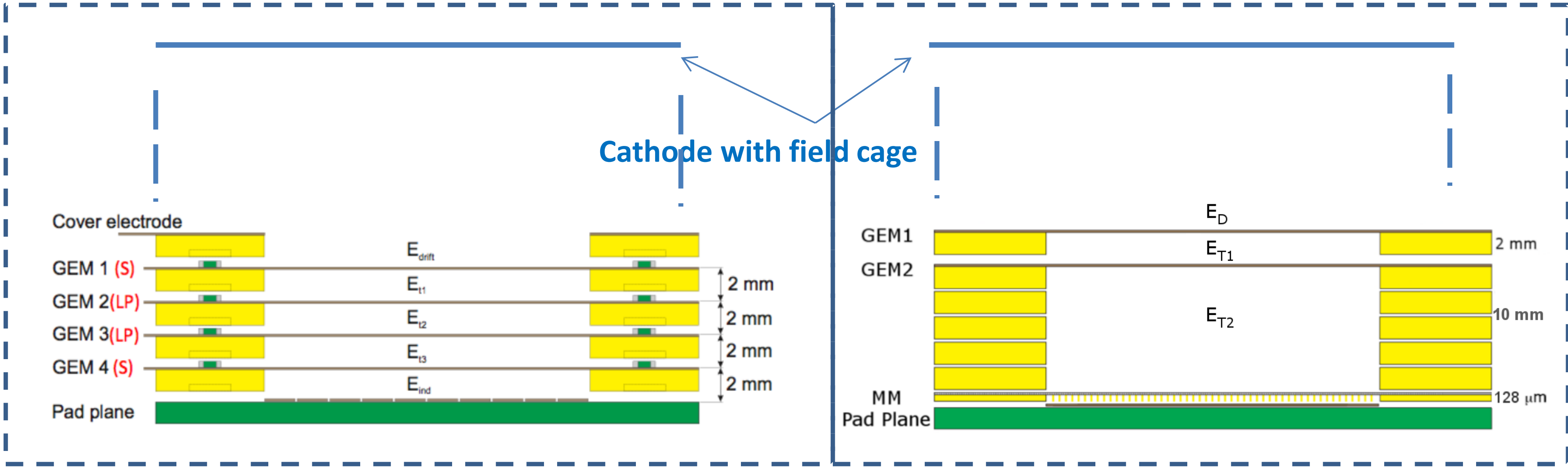
- Participation in a preparation of IROC (ALICE TPC) read-out board with MMG mesh for test-beam.

- In a parallel 2 detectors with 21x26 cm2 active size (available GEM foils from HBD ) were prepared and tested (preliminary data for the chamber with 5 cm drift distance and 10 mm distance between GEM2 and MMG mesh)

| | 4 GEMs | 2 GEMs + MMG (no R-layer) |
|---|---|---|
| IBF | (0.6 - 0.7)% | 0.3% |
| <GA> | 2000 | 2000 |
| ϵ - parameter | 12 - 14 | 6 |
| 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)<br>Sparking, test-beam Ne+CO2+N2<br>Possible main problem | $<3.*10^{-9}$<br>$\sim 6.4*10^{-12}$<br>short sector of the foil | $< 3.*10^{-7}$ (Ne+CO2)<br>$< 2.*10^{-8}$ (Ne+CO2+C2H4)<br>$\sim 3.5*10^{-10}$<br>lost FEE channel |
| Pad structure | Any, but improvement with Chevron | Not Chevron |

# CERN test-beam. Prototypes

- 4-GEM configuration (baseline ALICE TPC upgrade choice)
  - Full-sized inner-readout chamber, 2nd test beam
- 2-GEM+MMG configuration
  - Yale Prototypes: Two 21x26cm 2-GEM+MMG chambers



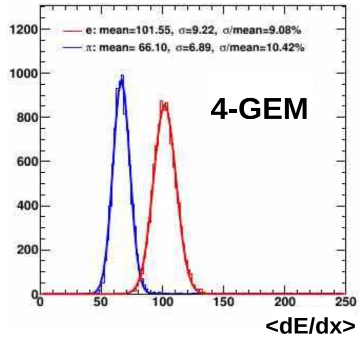

- Beam test: November-December 2014 at CERN
  - PS beam for dE/dX, SPS for sparking rate

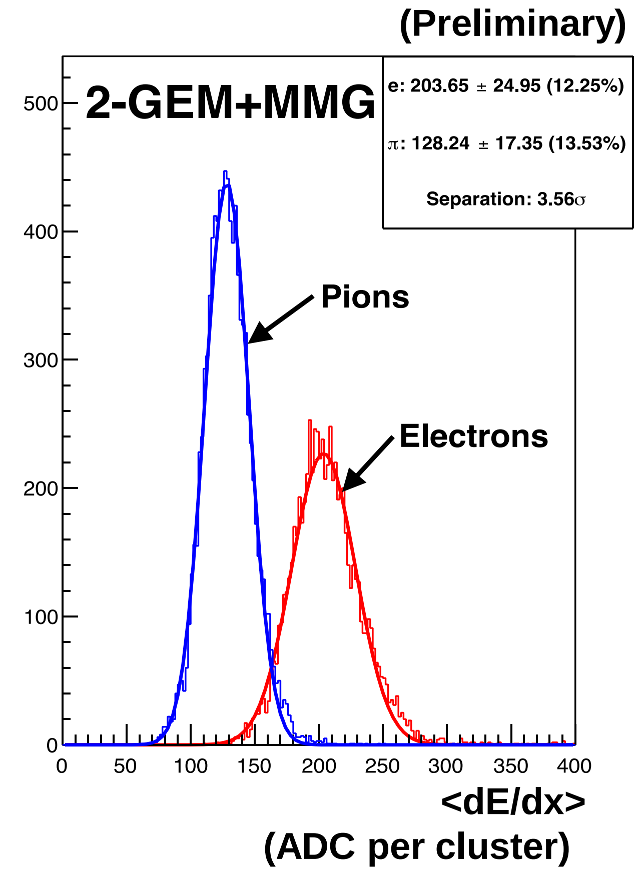
# PID Performance. 1.0 GeV/c PS beam: Results

- Separation:

$$S_{\mathrm{AB}} = \frac{2\,|\langle \mathrm{d}E/\mathrm{d}x\rangle_{\mathrm{A}} - \langle \mathrm{d}E/\mathrm{d}x\rangle_{\mathrm{B}}|}{\sigma\,(\mathrm{d}E/\mathrm{d}x)_{\mathrm{A}} + \sigma\,(\mathrm{d}E/\mathrm{d}x)_{\mathrm{B}}}$$

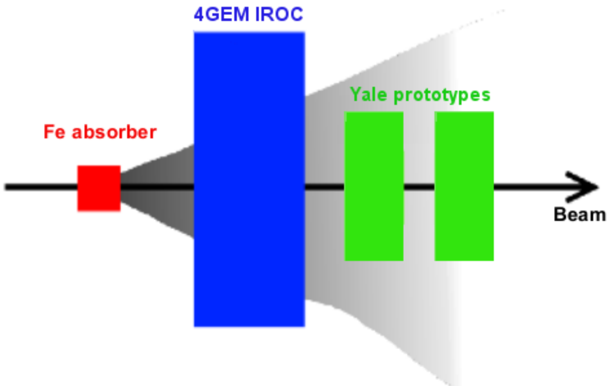
- Yale 2-GEM+MMG Prototypes:
  - $S_{\pi e}$ = 3.6 (Preliminary)
  - Ongoing questions:
    - Origin of excess low-Q clusters
    - Cause of gain map correlations
- 4-GEM:
  - $S_{\pi e}$ = 4.4

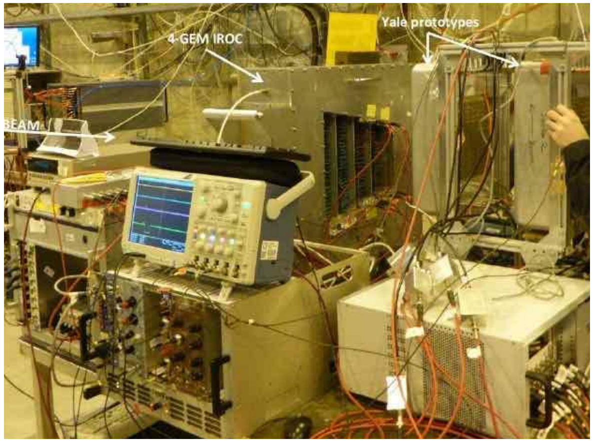


# SPS Beam Test: Sparking Rate

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



# Sparking Rate: Results

- 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 (~µs)

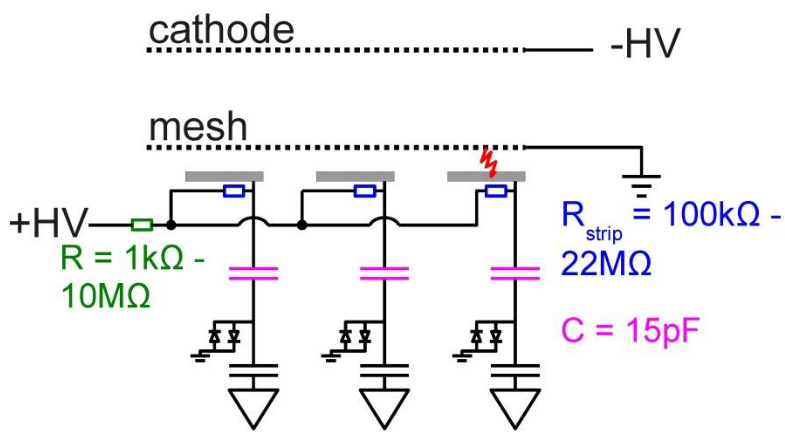
| # | $\Delta U_{GEM1}$ (V) | $\Delta U_{GEM2}$ (V) | $V_{MM}$ (V) | gain | Discharge probability |
|---|---|---|---|---|---|
| 1 | 250 | 210 | 440 | 2050 | $(2.0 \pm 0.6) \times 10^{-9}$ |
| 2 | 260 | 220 | 420 | 2000 | $(3.5 \pm 1.0) \times 10^{-10}$ |
| 3 | 0 | 0 | 420 | 450 | $(1.7 \pm 0.5) \times 10^{-10}$ |

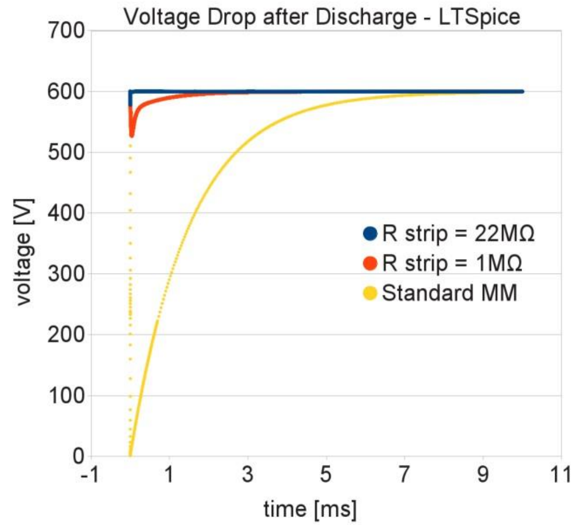
- 4-GEM:
  - ~6.4 x $10^{-12}$ per chamber particle (3 sparks observed)
  - Dead time ~ seconds to minutes

From Jona Bortfedt (RD-51) presentation



## LTSpice Simulation




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

global voltage drop affects whole detector

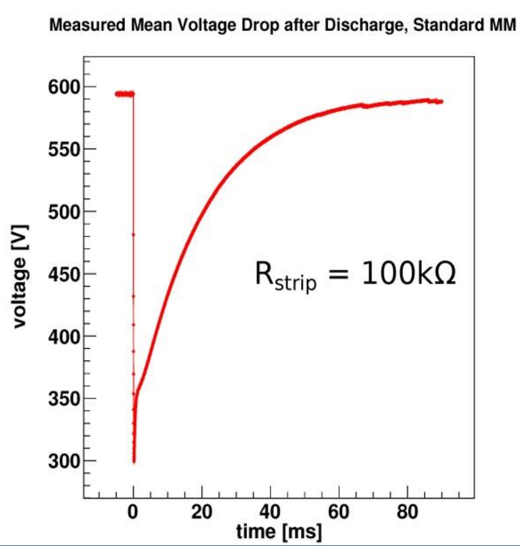
- standard Micromegas: complete discharge of mesh possible
- Floating Strip Micromegas: massive reduction of voltage drop and recharge time

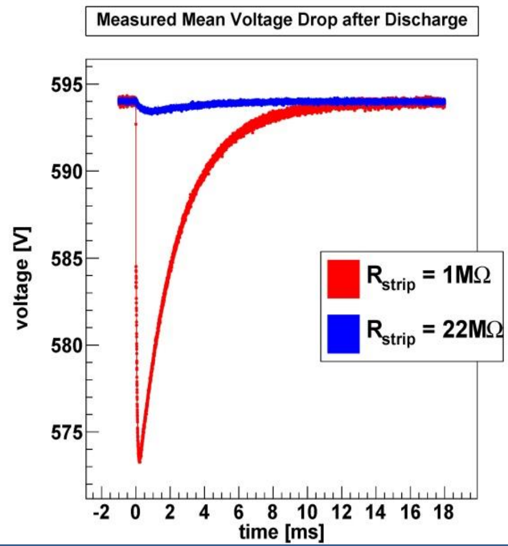
From Jona Bortfedt presentation



# Voltage Drop Measurement in $6.4 \times 6.4\,cm^2$ Micromegas

- mixed nuclide $\alpha$-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 $\rightarrow$ 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)

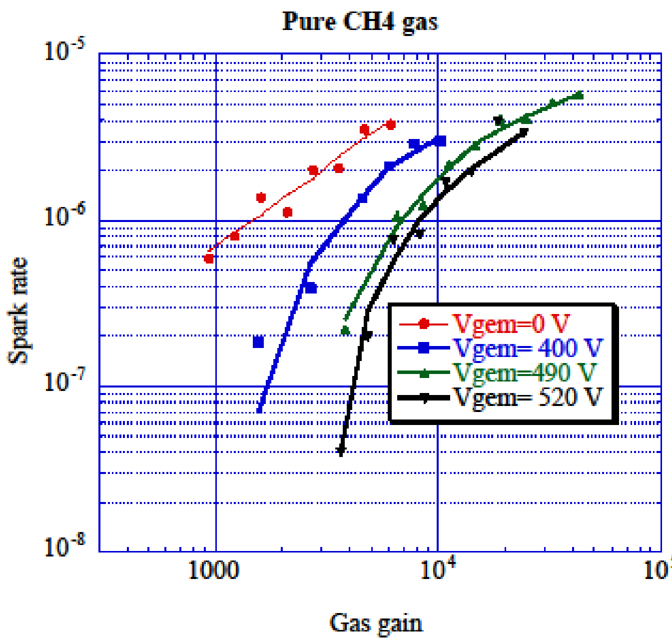
- 2  small (10x10 cm2) detectors to test all parameters with R-layer (different MΩ/ sq) for TPC application ( each pad-row -- as a strip ).
- Measure MMG high voltage drop in a case of sparking with 4x6 mm2 “floating” pad read-out structure.
- Preparation for next test-beam (FNAL !?).
- Start to prepare the setup for UV – Detector(s).

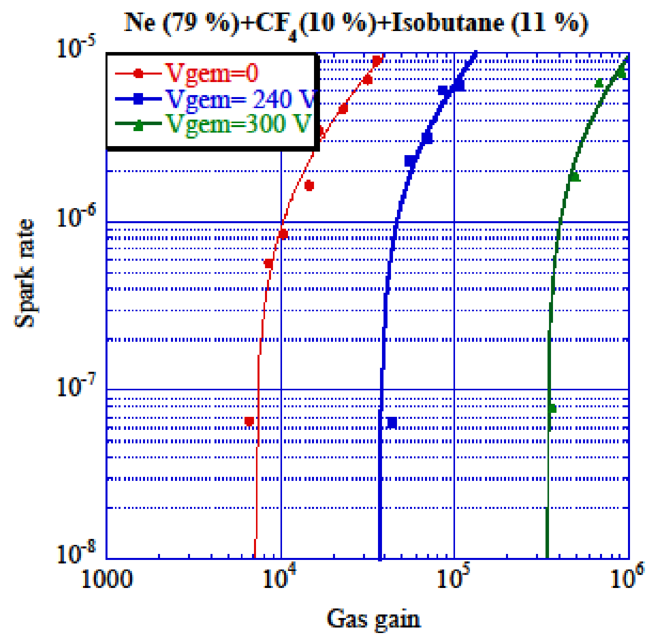
- Stop here.
- Back up slides and Appendix.

# 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

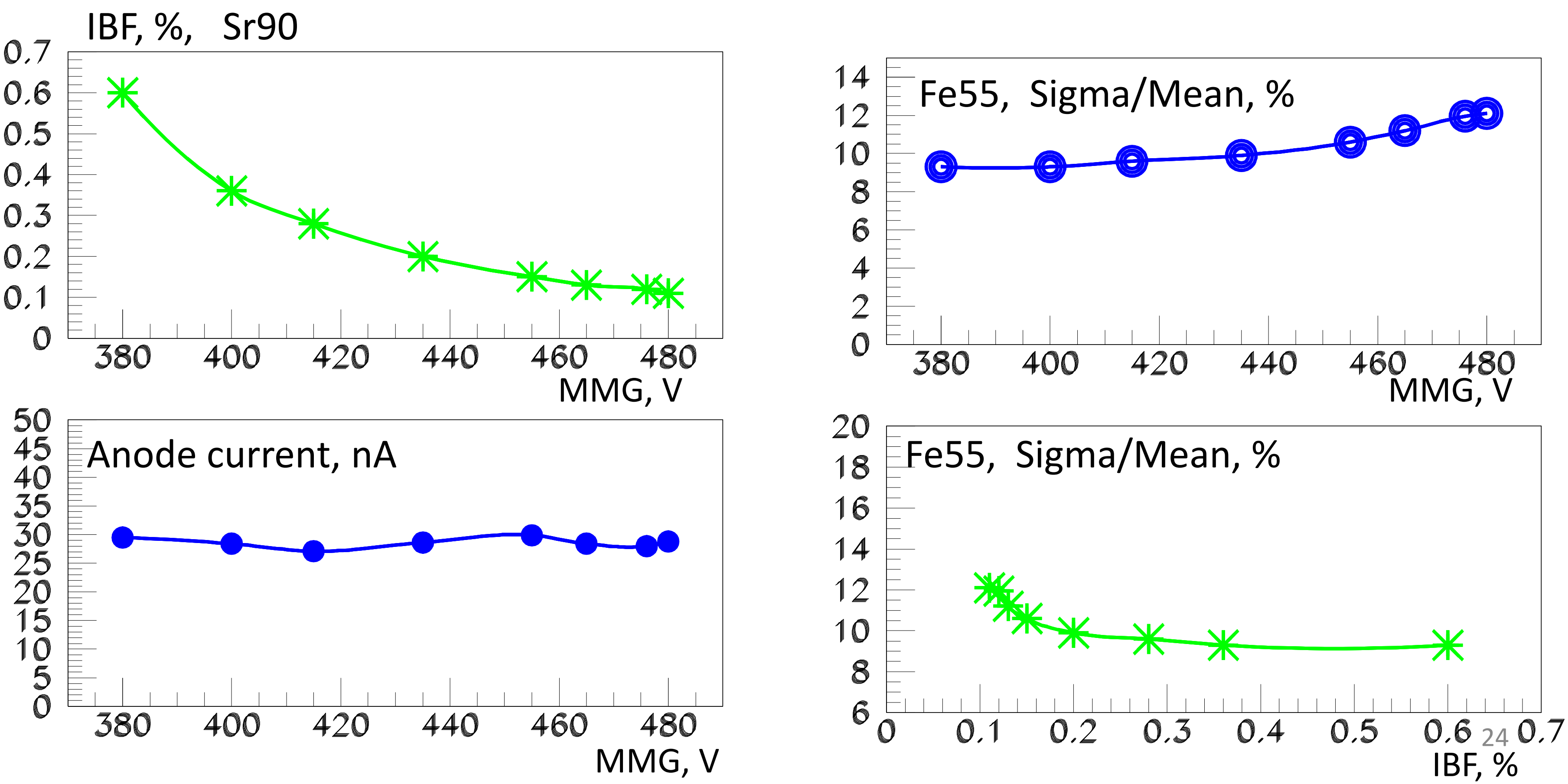


## *Ne+CO2(10%),* MMG – GEM 1( top) voltage scan, keep gas amplification .

Drift field = 0.4 kV/cm
Transfer field = 2.5 kV/cm
Induction Field = 0.1 kV/cm
dV2 (GEM) = 200 V

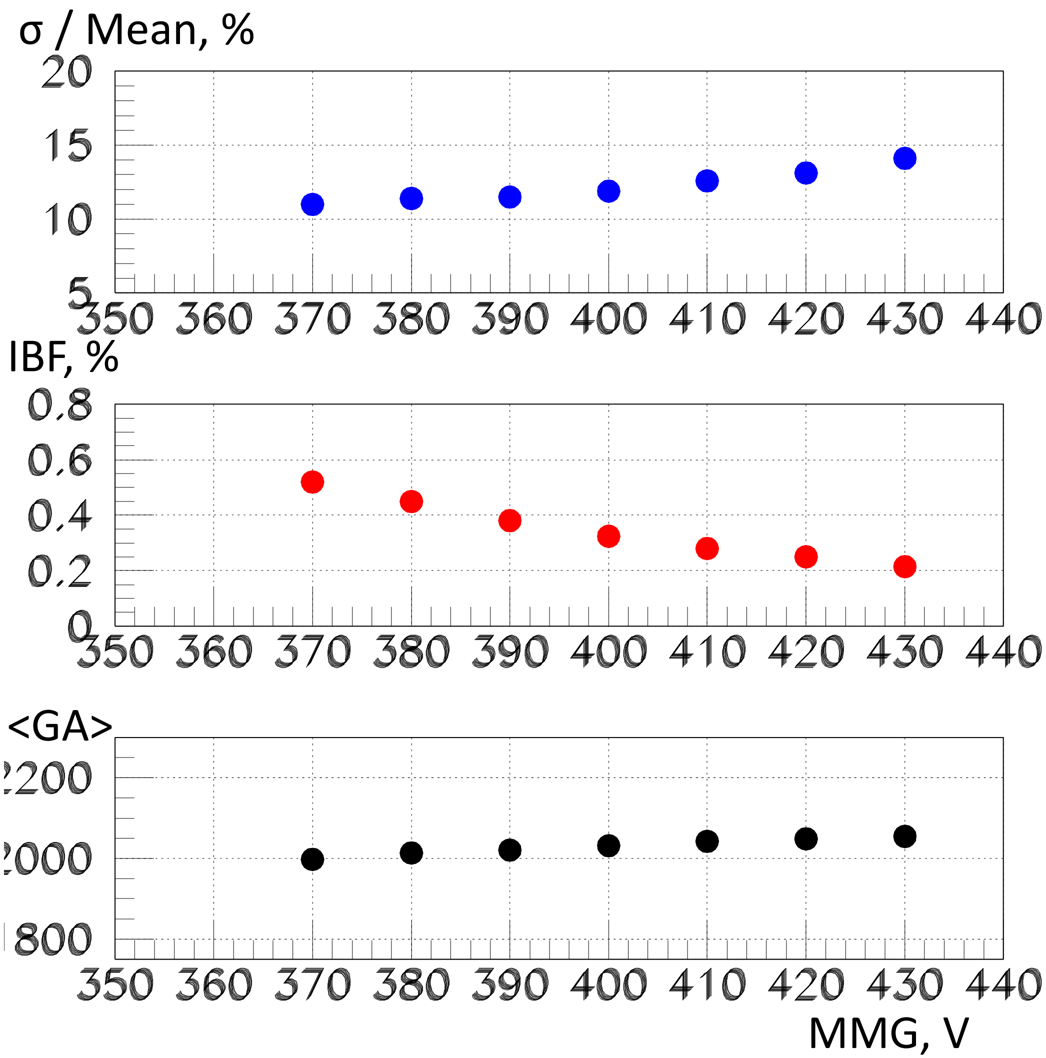
<GA> = 5.5+/-0.5



Ne+CO2(10%)

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

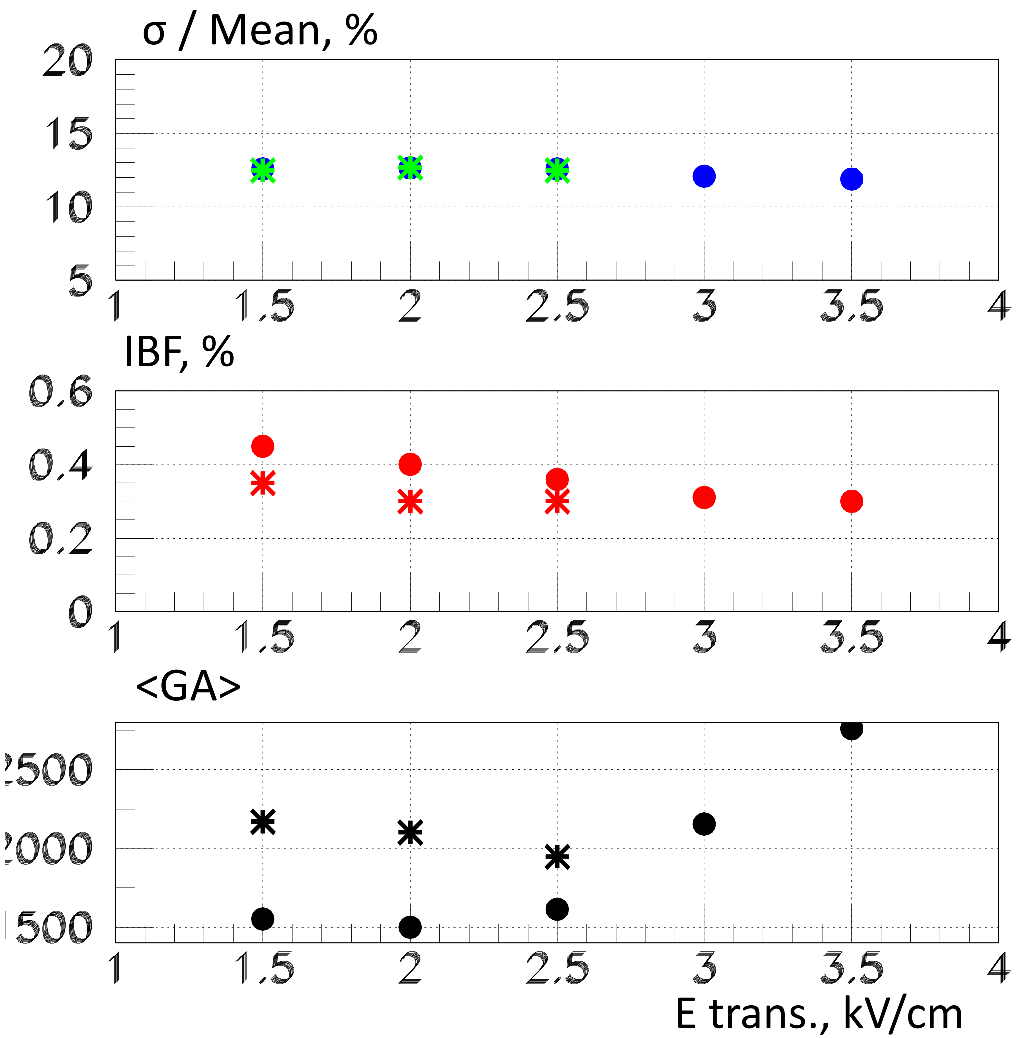
<GA> ~ 2000.




Data from black points p12.

dV GEM1 and 2 are varying

# Ne+CO2(10%): Transfer field scan (GEM – GEM)
# V MMG = 400 V, dV GEM1 = 210 V, dV GEM2 = 195 V, Eind.=0.075 kV/cm



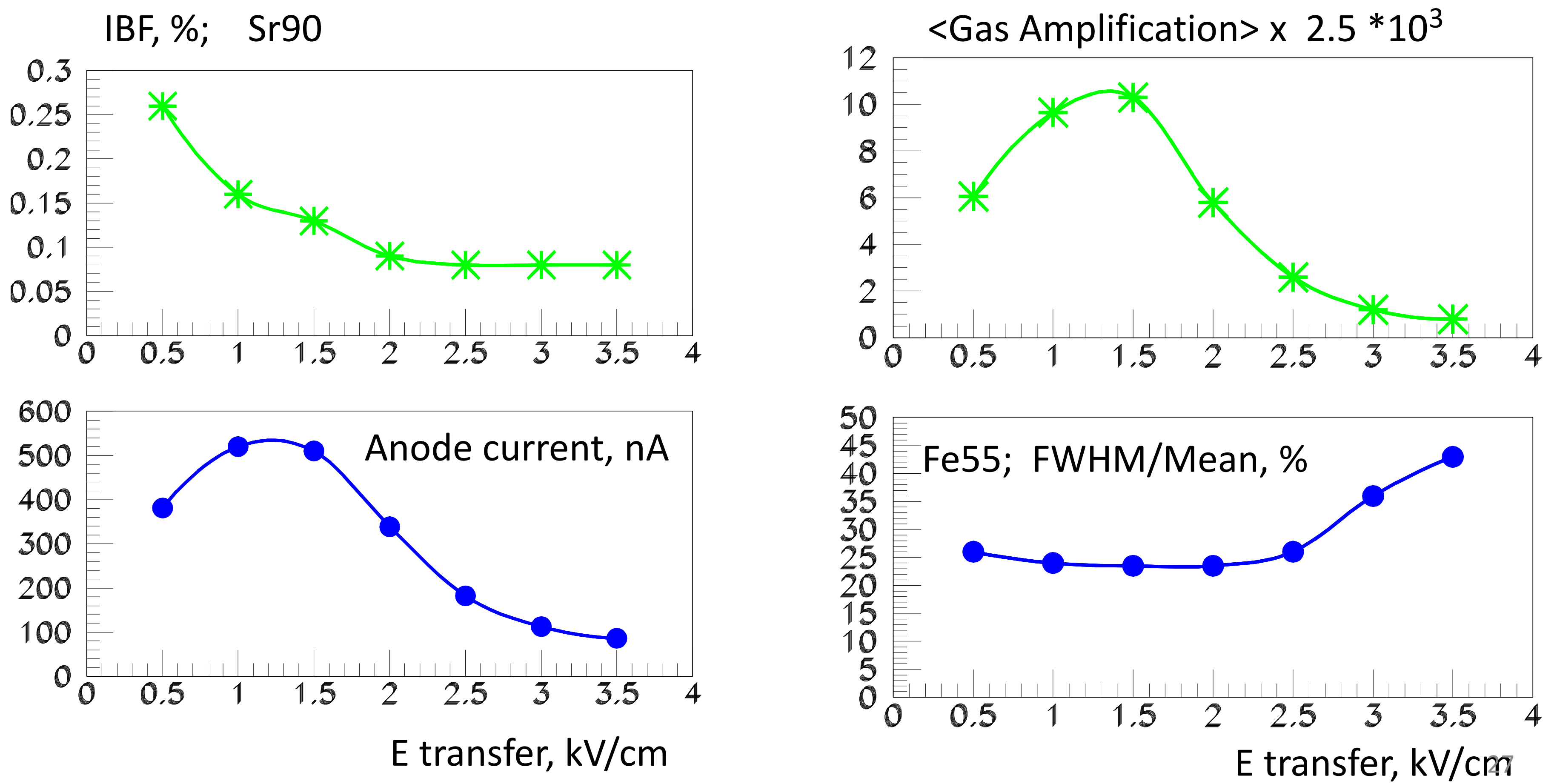

“Star” points:

Increase V MMG to get <GA> ~ 2000

# 2 GEMs+MMG; Ne+CF4(10%)

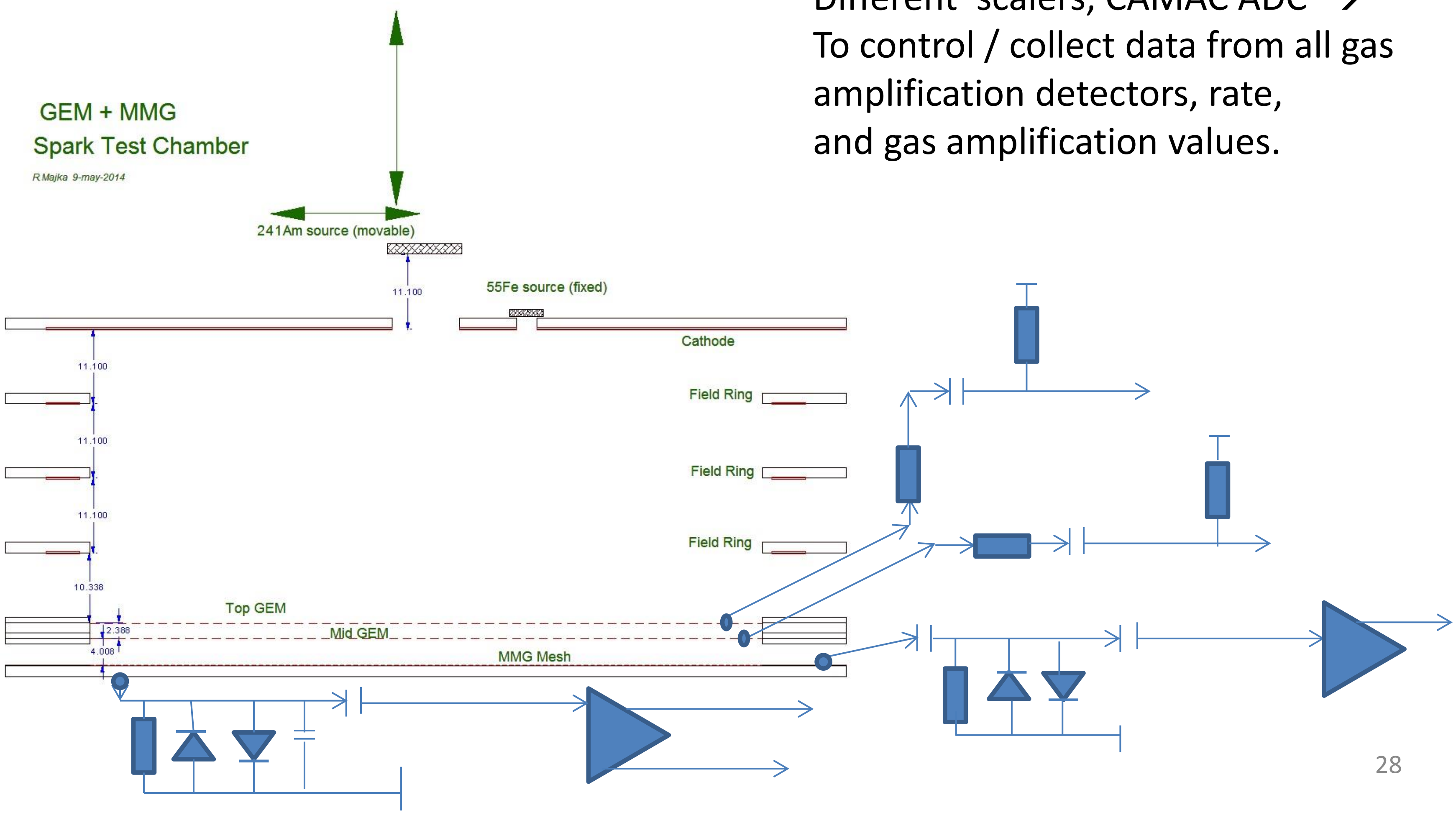
## Transfer E-field Scan

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 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.



# 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 + $CO_2$(10%)), V mmg = 400 V, dV GEM1 = 210 V, dV GEM2 = 175 V
E transf. = 3. kV/cm, E ind. = 0.15 kV/cm

(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%

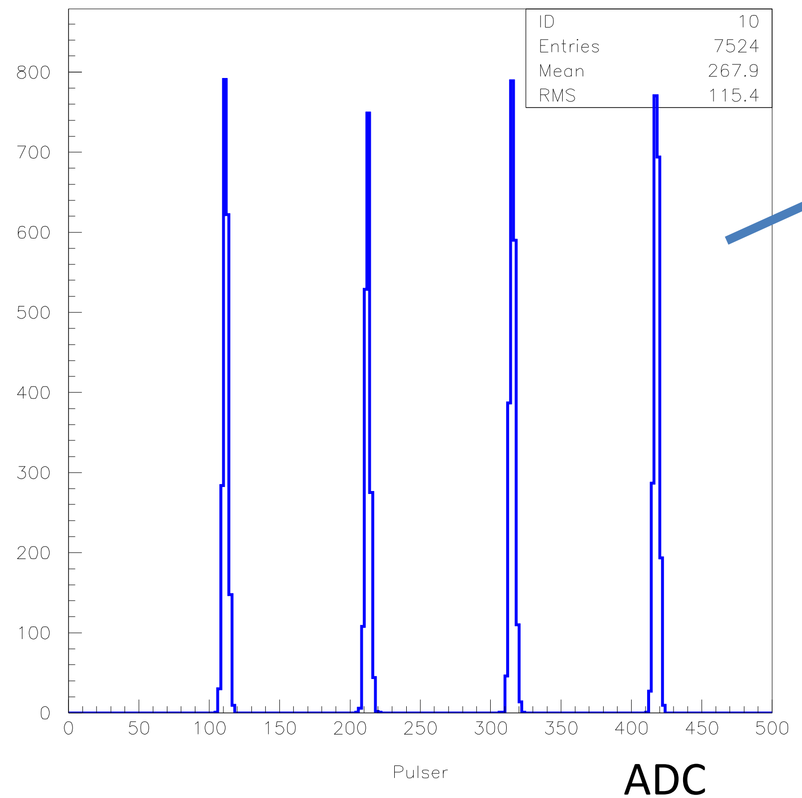
<GA> (current ratio ) = ( 27.78 – 3.21) / 0.012 = 2049.

# E– resolution (Fe55, σ/Mean).
# Gas Amplification.

q = V *C =
= K (“gas amplification”) * N $_{\text{ioniz. Electrons}}$

“mv”e-3 * 4.5 e-12 = K * (6.0 e3 / ϵ ) * 1.6e-19
ϵ = 35.5 ev (Ne+CO2(10%));
= 26. ev (Ar+CO2(10%))

ADC for 10, 20, 30, 40 mv pulse;
C = 4.5 pF connected to readout strip;
Gauss Fit, σ = 1.75 ch.




Pulser data, line fit;
“mv” = 0.098 *ADC – 0.4

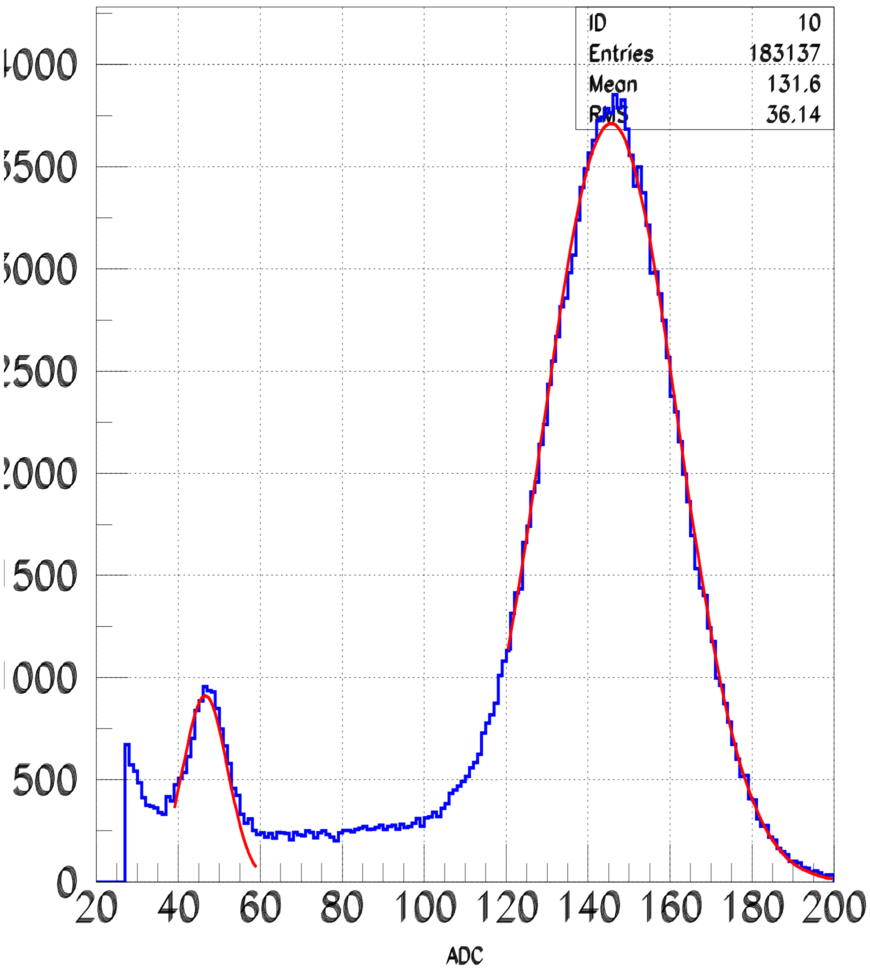
ADC offset = 4.0 ch.

Example: Fe55 spectrum,
Gauss Fit: Mean = 134.8, σ = 16.13
***{ SQRT(16.13**2 – 1.75**2) = 16.04 }***
Res: 16.13/(134.8 -4) = 12.3%

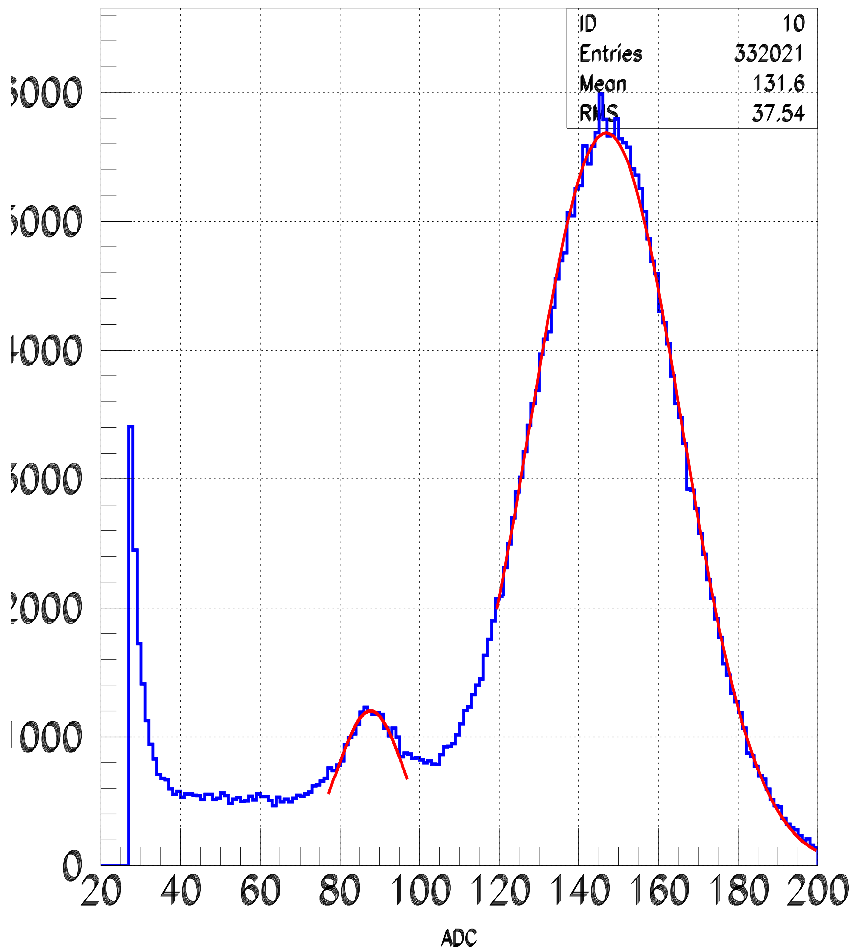
“mv” = 0.098 * 134.8 – 0.4 = 12.81
<GA> (K) = 2131.

# Two examples of Fe55 spectrum

V MMG = 390 V (see table)



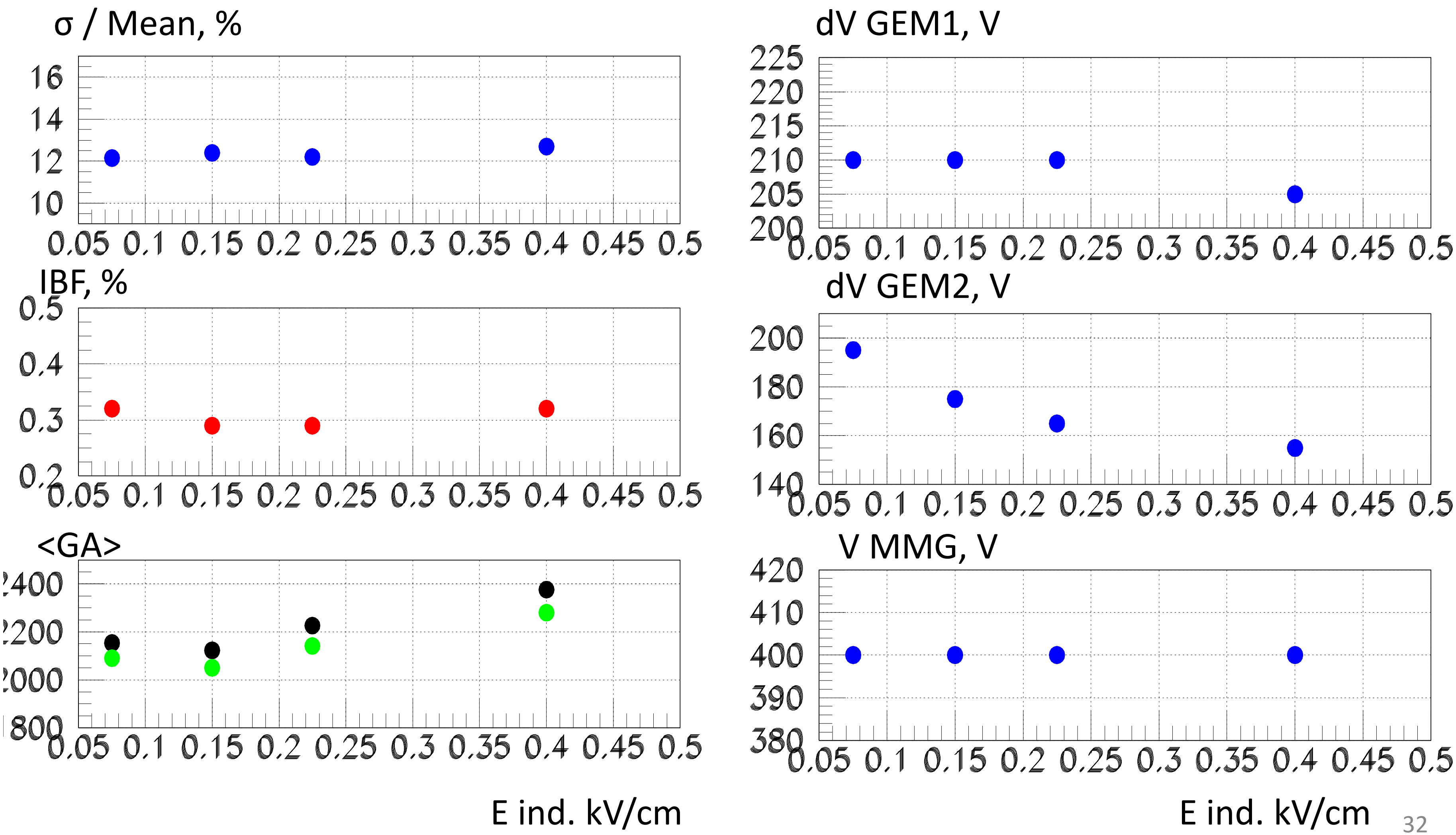

V MMG = 420 V (see table)



# Ne+CO2(10%); Induction field scan (GEM – MMG)

## V MMG = 400 V, Etran.=3.0 kV/cm .

## Green points: <GA> from currents ratio



# Can we discuss TPC working gas (for micro-pattern gas amplification technology) ?!
(may be there is a sense to check TESLA, NA-49 experience with Ar+CO2+CH4 gas mixture)

| Gas mixture | Electron drift velocity, cm/us ( E-field -- 0.4 kV/cm) | T diffusion (0.5 T B-field.) | 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* |

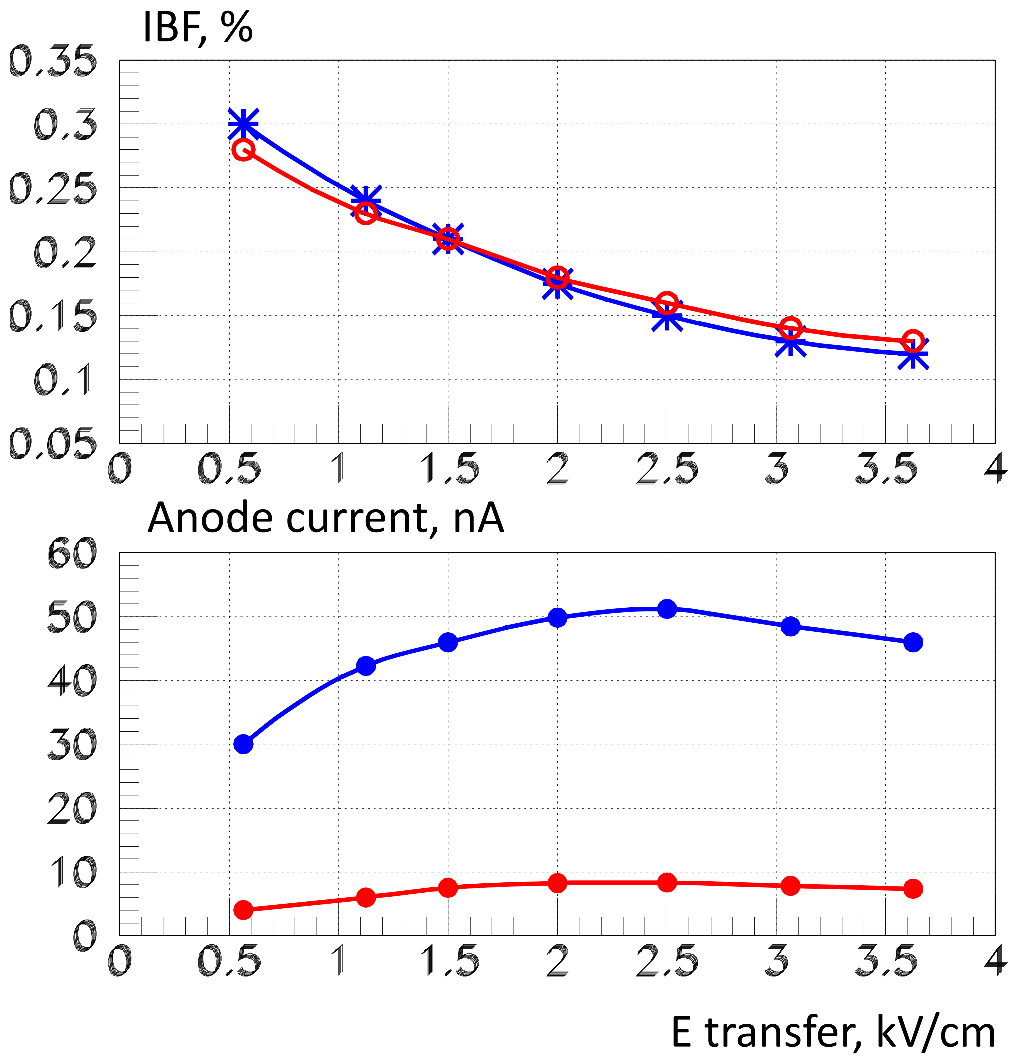
(keeping in mind that CF4 was not recommended to be used for ALICE TPC)

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) }

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

## Transfer E-field Scan



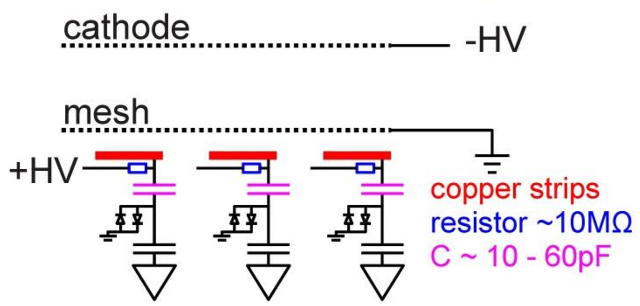

V mesh = 485 V
Drift field = 0.4 kV/cm
Induction Field = 0.125 kV/cm
dV1 (GEM) = 195 V
dV2 (GEM) = 225 V

Red points: Fe55
Blue points: Sr90

# From Jona Bortfedt (RD51) 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**

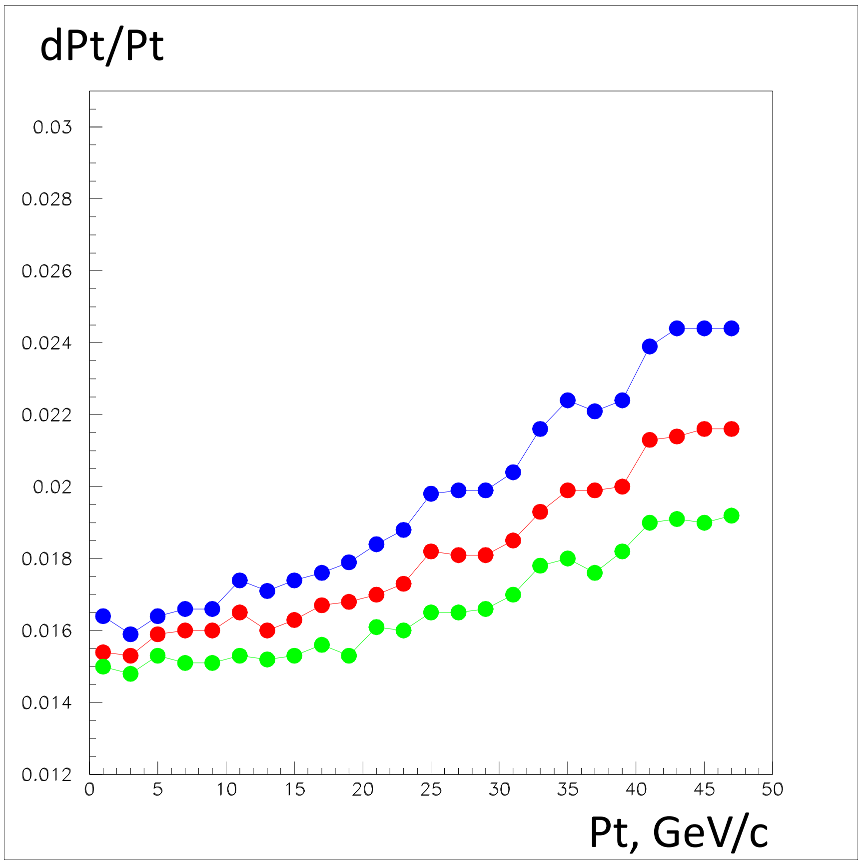
- discharge suppression not as effective as in resistive strip Micromegas
- 2-dim. readout questionable

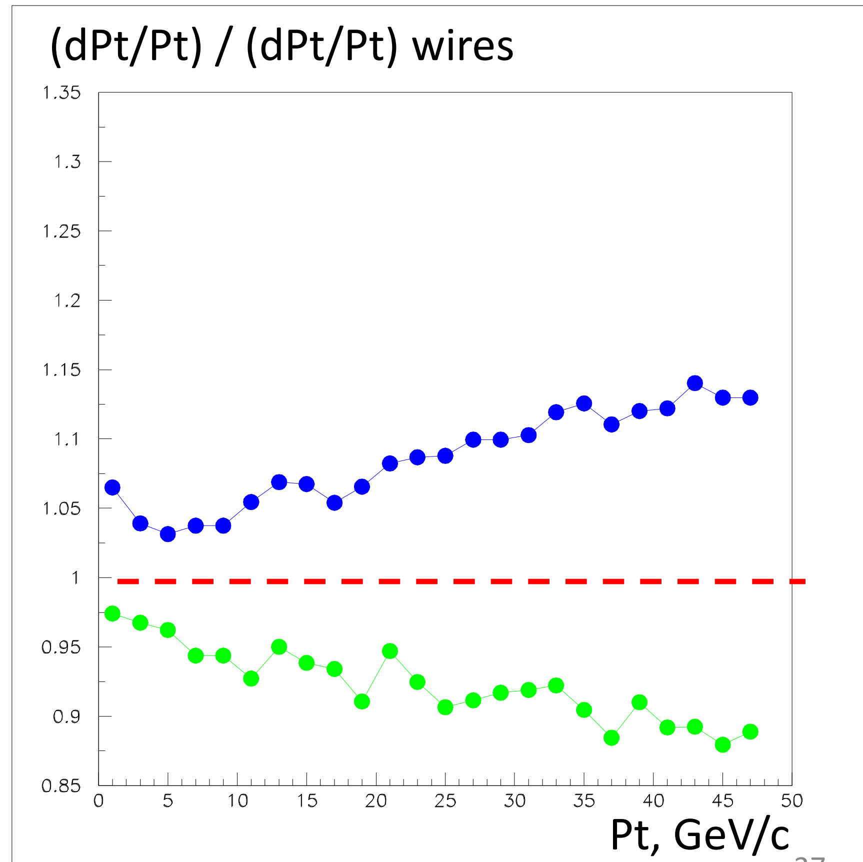
- ***TPC response simulation details***.
- **First step.**
- For all options of TPC readout pad size and shape look-up tables were prepared. Charge on 3x3 pad structures was simulated as a function of single electron position on the "central" pad ("face" of the "first" GEM foil):
- Select the nearest 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/

# 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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