Charge-up effects in resistive Micromegas
Their impact on sparking & detector performance.

RD51 mini-week, Dec. 9th, 2015

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Based on work with Demokritos (T. Geralis) and Saclay (M. Titov) around spark-free Micromegas-based calorimetry

Introduction

Resistive Micromegas, of specific design, are not subject to sparking :
not only is the spark current limited : sparking is suppressed.
At high rates, however, they experience a loss of gain.

ATLAS mu — Tracking at moderate rates (e.g. kHz/cm2) : charge-up is negligile.

COMPASS -like — Tracking at high rates (e.g. 100 kHz/cm2) :
one might need to reduce R to maintain tracking efficiency.

ILC CALO — Calorimetry : we need to measure thousands of primary electrons
Linearity over very large dynamical range (up to hundreds of MIPs in EM showers).

CMS HGCAL — In the forward region, things get even worse.

This brings the question : how low can we go with the resistivity ?
Or : **what is the resistivity necessary for spark suppression ?**
Is it only the resistivity that matters ? What about the capacitance and the RC ?

Strategy : vary R over several orders of magnitude.

R-detector model & hot topics

Resistive detector = resistive electrode + readout electrode connected through RC

C is responsible for the charging up of the R-electrode surface
And therefore for the drop of field across the amplification gap

R allows the surface to discharge so the field is restored

The relaxation time is given by RC
Allows to define low (dt>>RC) and high rate (dt<<RC) regimes

<u>Sparking</u>
The larger the charge arriving on the surface, the larger the field drop
→ sparks are suppressed (but don't completely disappear)

<u>Rate capability (high rate regime)</u>
After transient time (~ RC), balance between incoming and outgoing charge :
$G = G_0 . \exp(-B.dV)$ with $dV = RI$ and $I = I(R = 0) = q_e.N_p.G_0.f$

<u>Linearity : for large dE, we are in the high rate regime even at low event rate</u>
Primaries arrive one by one at the mesh
With a 3 mm gap, max. collection time is 50 ns, if larger than the RC :
Last electrons might feel a lower field than first ones.

R-configurations & the burried resistor

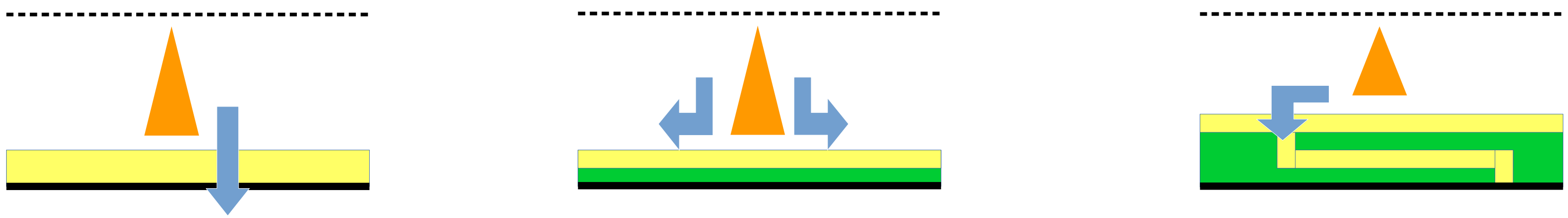
1 Simplest resistive configuration is a continuous layer deposited on the anode plane.

Here, R = rho . d / S d : thickness and S : avalanche transverse area

Also, C = epsilon . S / d so at the end :

RC = rho . epsilon independent on S and d

Changing R through rho only (i.e. choice of material).



2 TPC resistive configuration (Madhu, Colas et al.)

An insulating layer between resistive film and anode plane

Charge evacuated on the panel side → spread on the pad row → better c.o.g.

For Particle Flow calorimetry we don't want to sperad the charge on the pads !

3 The burried resistor gives one more degree of freedom to change the RC :

resistive-pad → burried R → readout-pad

Changing R through the shape and resistivity of the burried resistor.

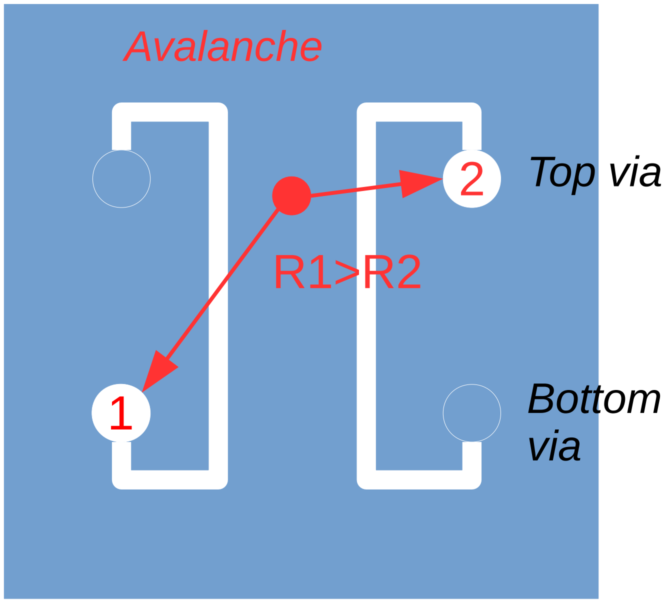
R-prototypes with burried resistors

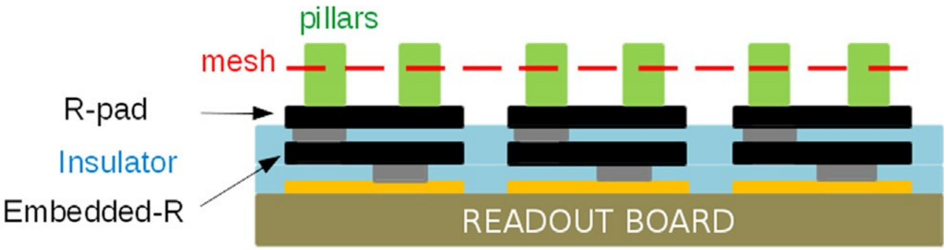
Total R = pad R (depends where the avalanche takes place) + burried R (constant)
Total C = ? $= (1/C_{Rpad} + 1/C_{burriedR})^{-1}$ ← can we write this ?

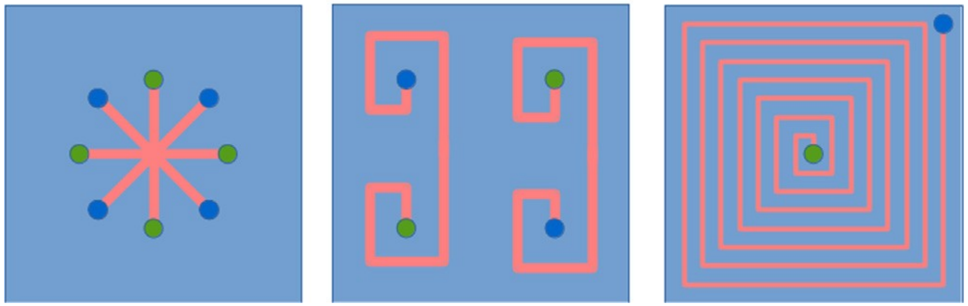
We don't know how to calculate the RC.
We don't have a model of the charge spreads over the R surface.

Technology : made by screen printing at CERN workshop.
Pad boards : 10x10 cm2 active area with 1x1 cm2 pads

Different patterns of burried R (star, mirror, snake) and R pad. (full, segmented)
Different resistivity of the paste (100 kΩ/sq., 1 kΩ/sq.).



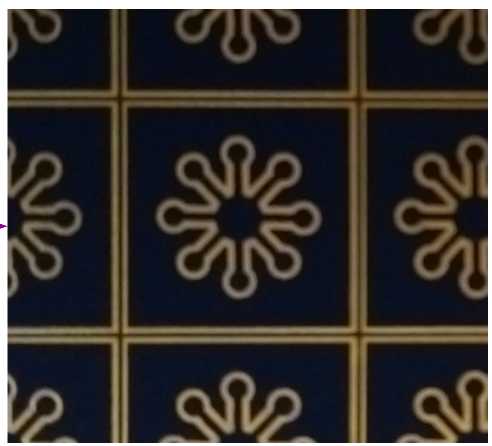


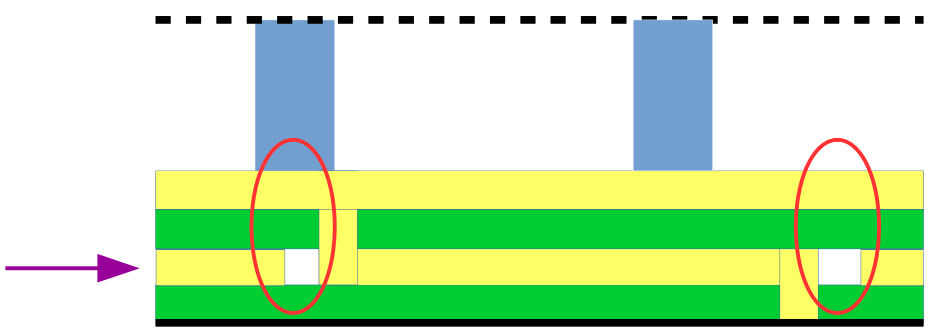


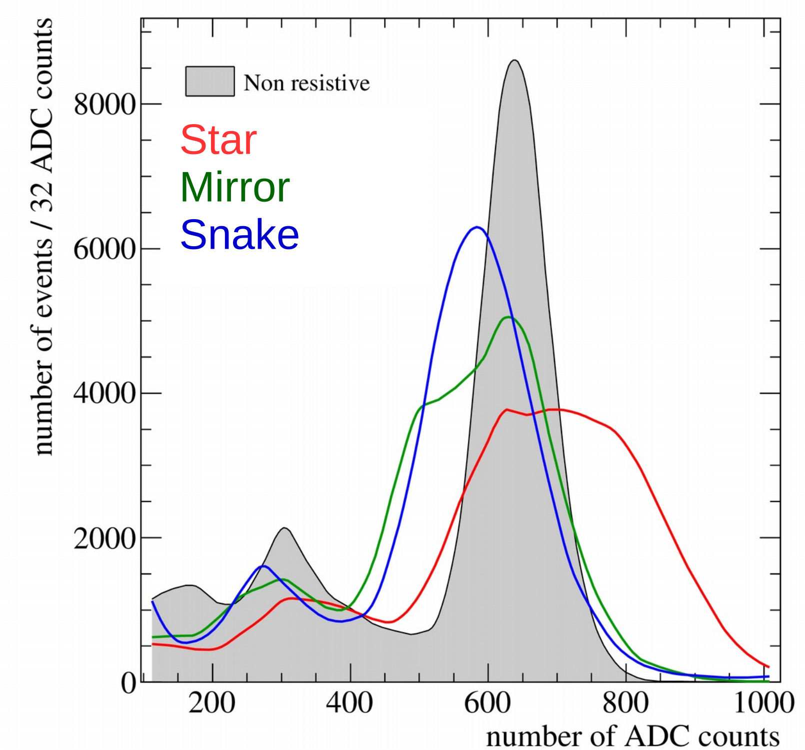
Screen printing & flatness

Insulating layers (12.5 um thick coverlay) pressed on PCB, then on burried R.
Burried R surrounded by passive layer that fills the square area.
This gives rise to some topography on the R pad surface.
If a pillar is later printed at the junction, the amplification gap will be smaller.

We think that it explains the poor energy resolution (best is for the snake-pattern).







Performance_1 : rate capability

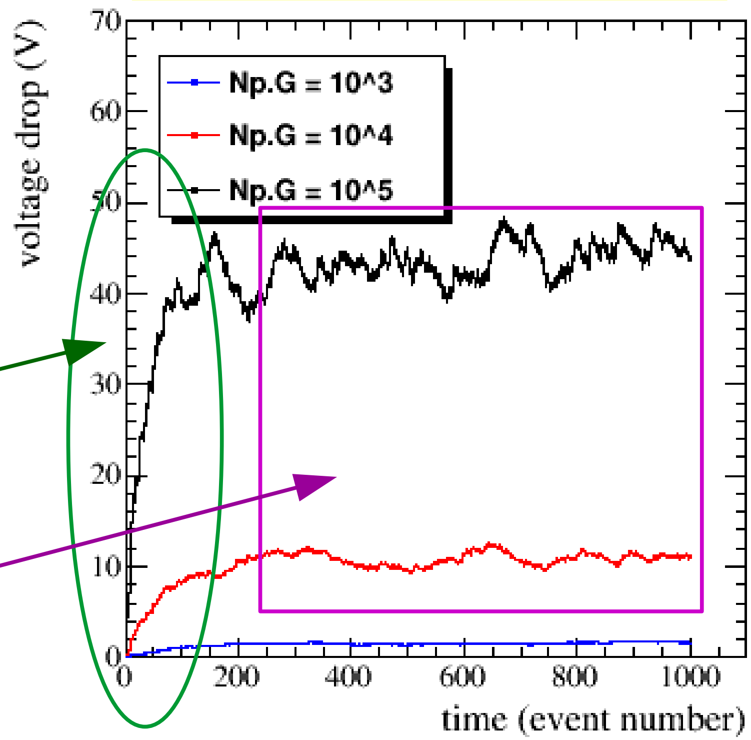
Experimental protocol :
MIP efficiency VS rate (beam test) or anode current versus rate (X-gun).
Deviations from efficiency plateau or from linear response indicate charge-up…
But do not say anything about the RC (= duration of the transient regime).

Rate capability is difficult to define (MIPs ? What gain ? What efficiency loss ?).
Here : linearity deviations less than 1 % at G = 4200, for 8 keV Xrays & 1 MHz/mm2

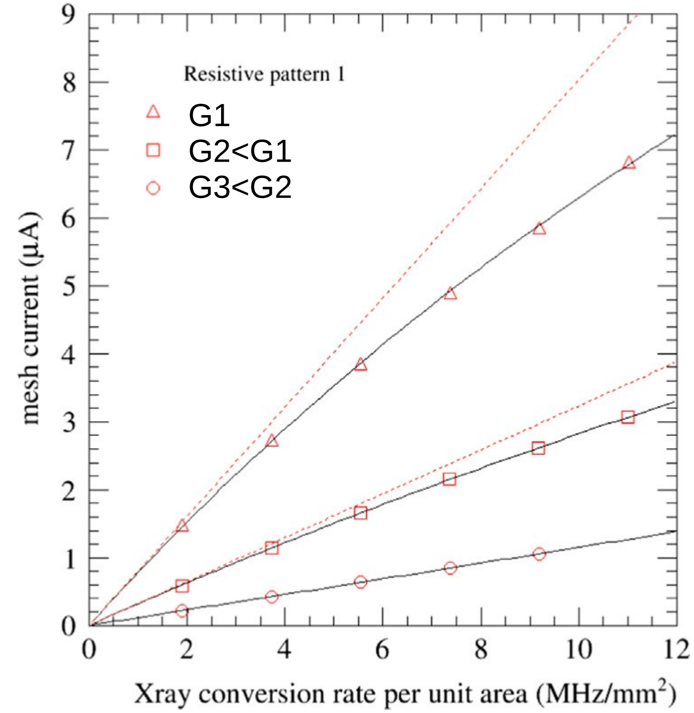
Transient regime
Duration ~ RC
dV/dt > 0
on average

Constant regime
dV/dt = 0
on average

Monte Carlo (RC.Rate = 100)



Data points (Xgun)
In the constant regime

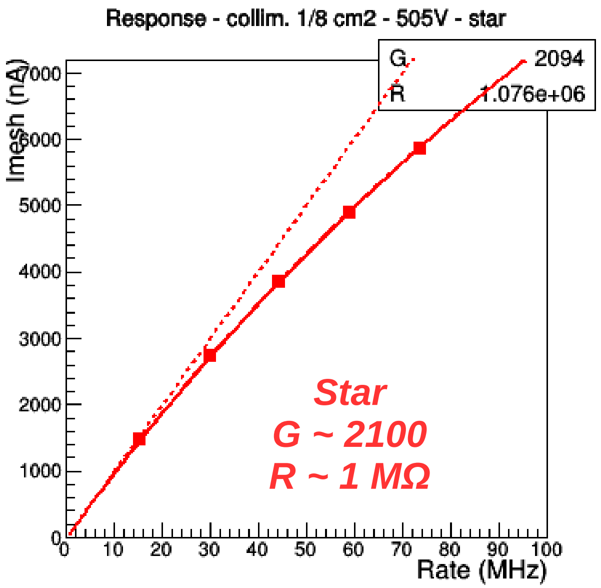


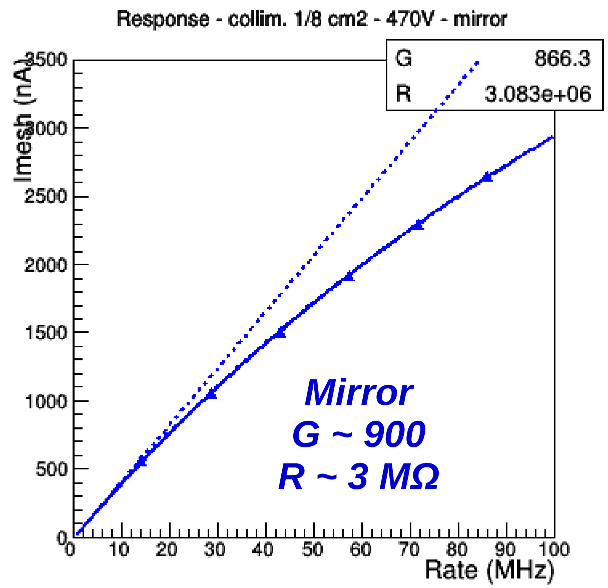
Rate capability

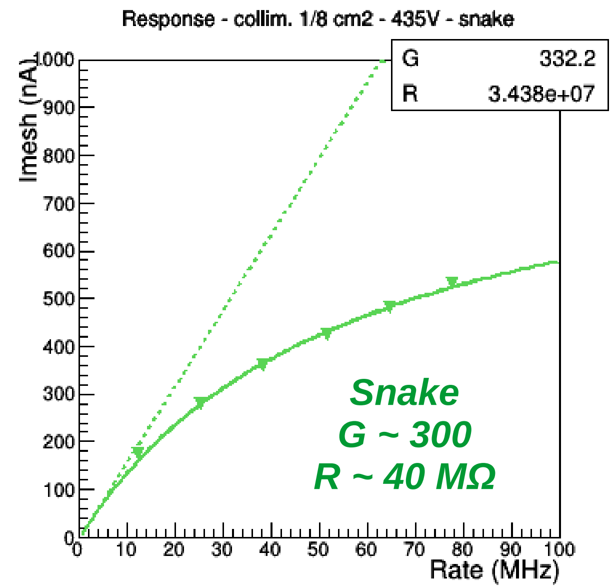
Here : linearity deviations less than 1 % at G = 4200, for 8 keV Xrays & 1 MHz/mm2
Can be extrapolated to other running conditions (better for MIPs, worse for showers)
Anyway, 1 MHz/mm2 remains impressive.

Response curves (current I VS rate f) are described by : **$I(f) \sim Q_0.f / (1+B.R.Q_0.f)$**
[B] = 1/V, slope of gain curve ; $Q_0 = q_e.N_p.G_0$, primary charge * G(dV=0)

→ (G_0,R) are fitted to the data.
Useful for characterisation.



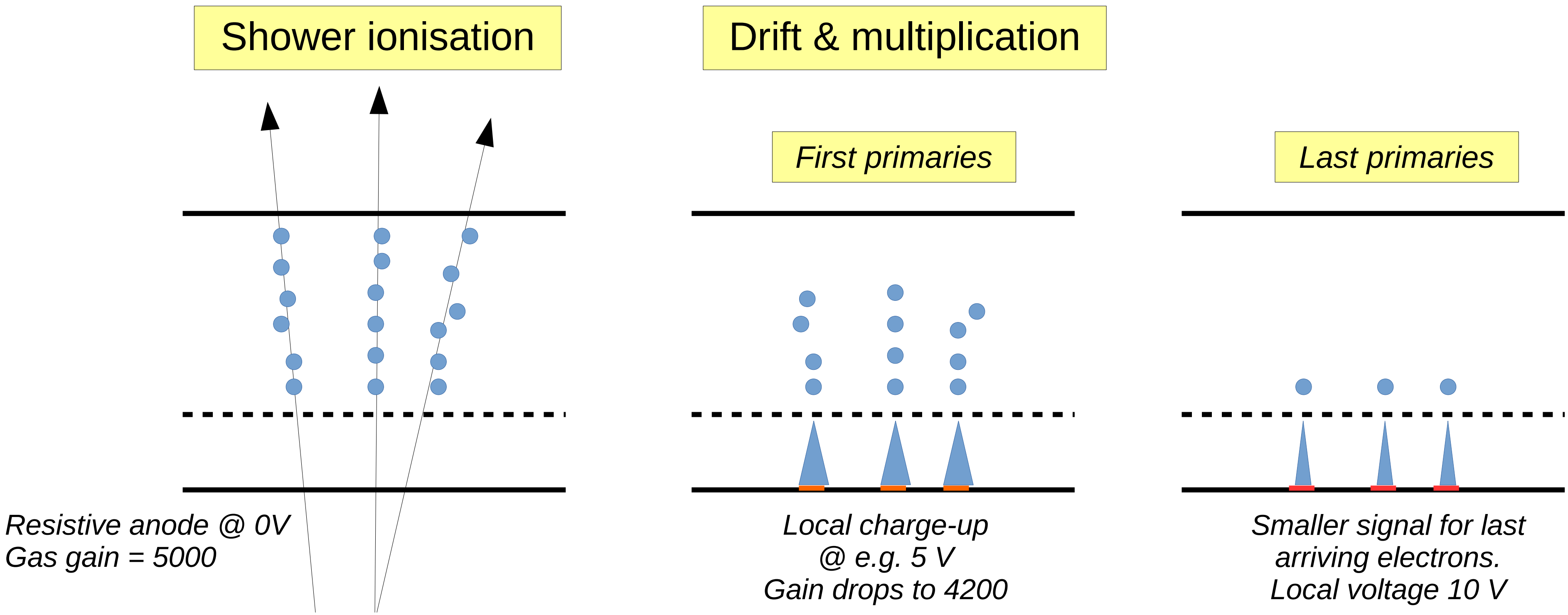




Performance_2 : linearity

Primary electrons are multiplied after drift and diffusion.
Depending on primary pattern (MIP, Xrays, showers) and drift parameters,
last electrons arriving at the mesh might feel a reduced field compared to first ones.

Might be irrelevant for MIPs but might spoil proportionality of Micromegas for large dE.



PS: in reality there are way many more tracks in the shower core which makes avalanche overlap very likely

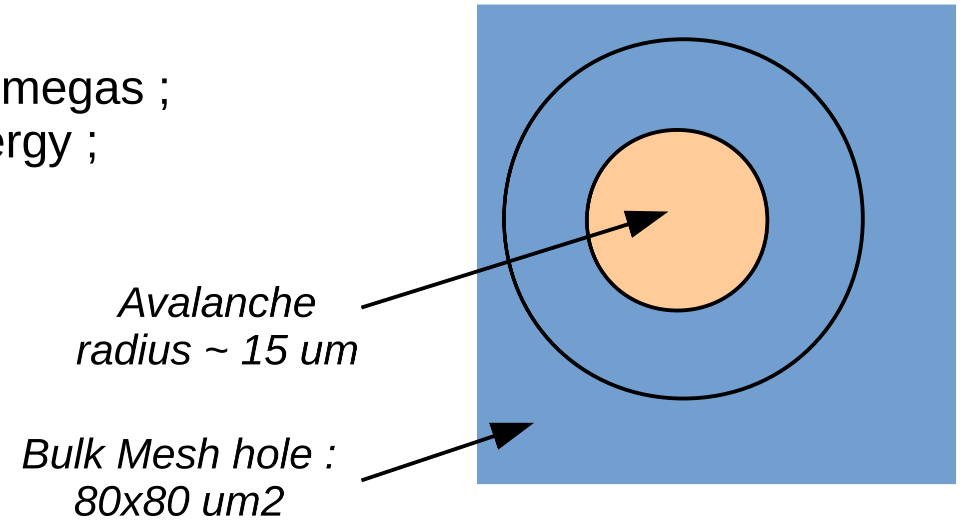
Linearity, how much charge-up ?

If maximum collection time (50 ns in our case) << RC constant, the resistive pad can be considered as an insulator. Charge-up will be governed solely by the capacitance C.

To estimate C, we consider the area influenced by a single electron avalanche, namely a circle of radius equal to 2 sigma_t (transverse diffusion in the gain gap ~ 15 um RMS) and d the total thickness of the layer stack (40 um) :
C = epsilon . S/d ~ 1 fF

10 primaries (in same mesh hole) at gain of 3000 → q ~ 5 fC (if cst. gain & inf. R)
Yield voltage drop across gap of V = q/C = 5V
Yield gas gain drop of 15 % (1 - exp(-B.V) = 1 - exp(-0.035*5))

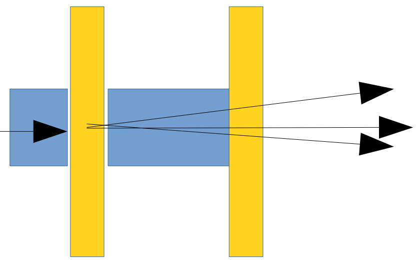
Should give rise to measurable effects.
Experimental protocols :
* GEM injector above resistive Micromegas ;
* Electron showers at increasing energy ;



Linearity and EM response (1/2)

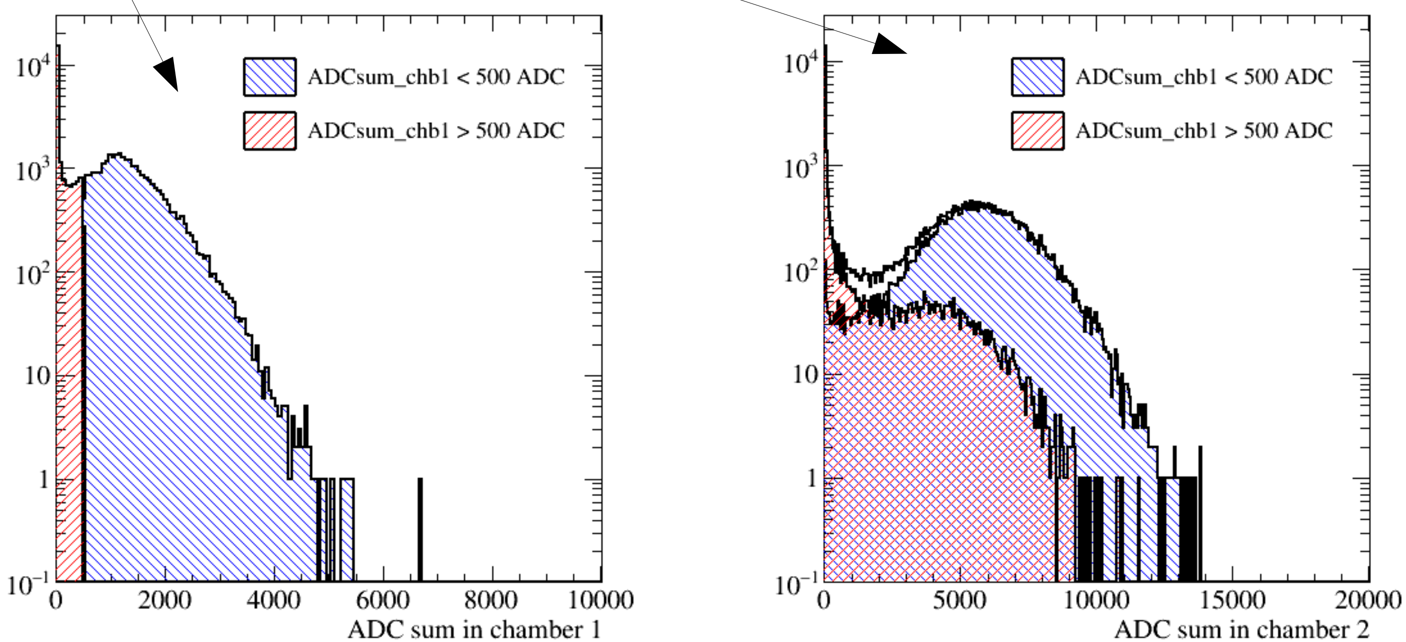
Charge-up effects should show as reduced energy distribution.

50-200 GeV electrons



Comparison of energy response between resistive and non-resistive prototype (at low rates) with SPS electron beam. Use most resistive prototype (RC>>50 ns).

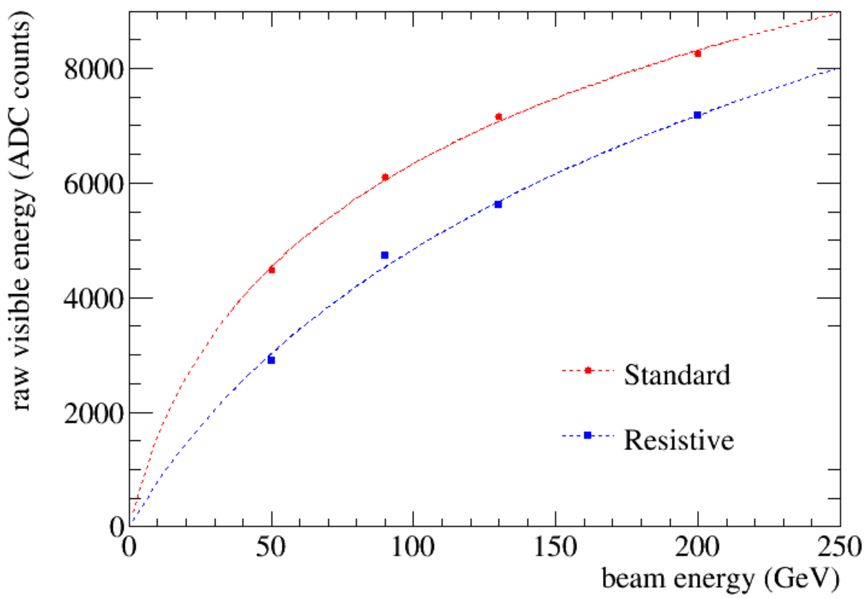
Small pion contamination in electron beam
Use preshower chamber before chamber under test
2 X0 Fe + PreShw + 6 X0 + Test
→ Test chamber @ shower max

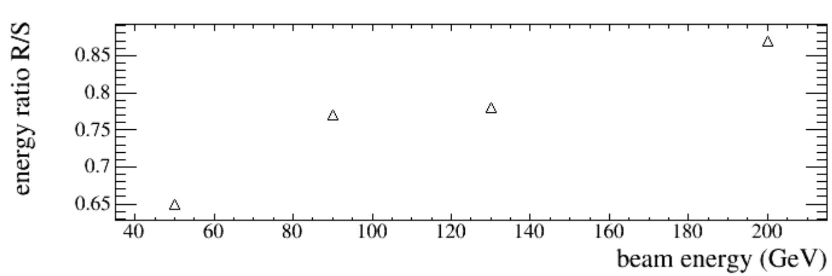


Linearity and EM response (2/2)

Charge-up is dV=Q/C(S), should depends on:
the charge arriving on the R-layer surface (Q) and the area collecting the charge (S).

Runs at different Ebeam, gas gain and different drift field (transverse diffusion).
By comparing the energy distribution between 1 resistive and 1 non-resistive, we observe small differences. Energy is reconstructed as sum of pad signals.





<u>Ratio of energy sum (Ebeam scan)</u>

The ratio Resistive/Standard should be constant if charge-up is negligible.

One would expect the ratio to decrease with beam energy. We observe the opposite.

Systematics to be understood
+ Monte Carlo of ionisation pattern.

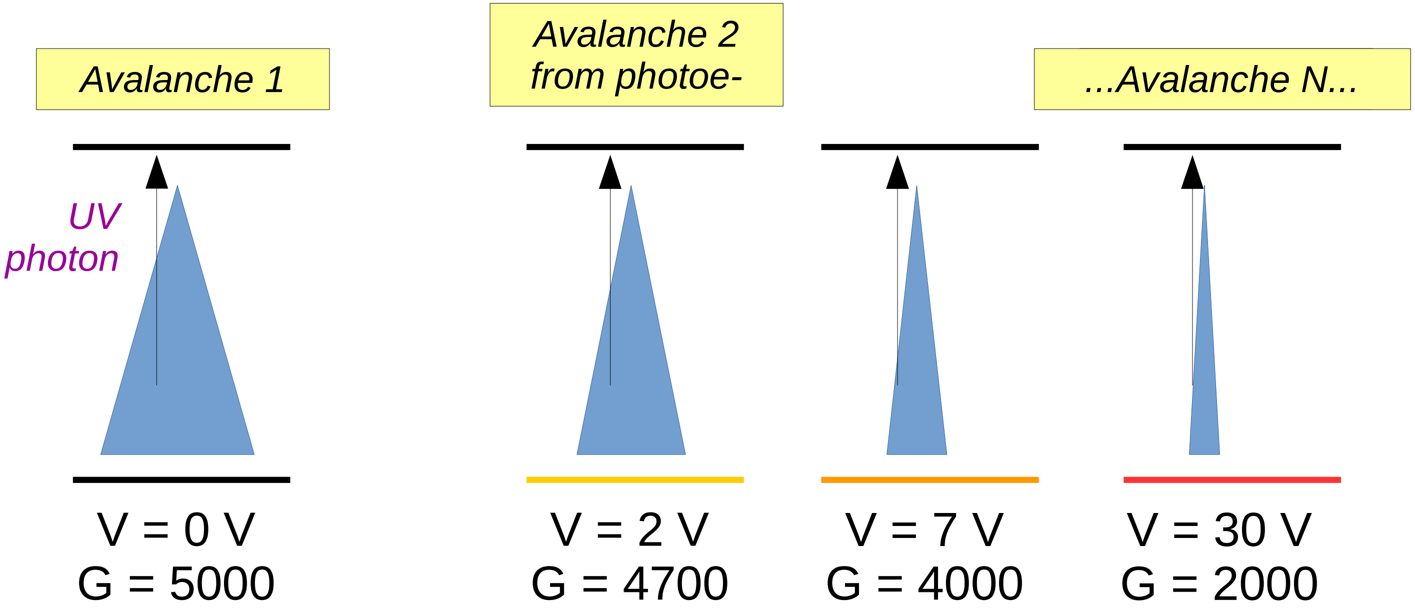
Spark suppression

Raether limit = spark when too much charge in the amplification region :
* Heavily ionising particle (alpha, nuclear recoil), tens of thousands of primaries
* Photon feedback (primaries → avalanche → UV → photoelectrons ...)

2 limit cases :

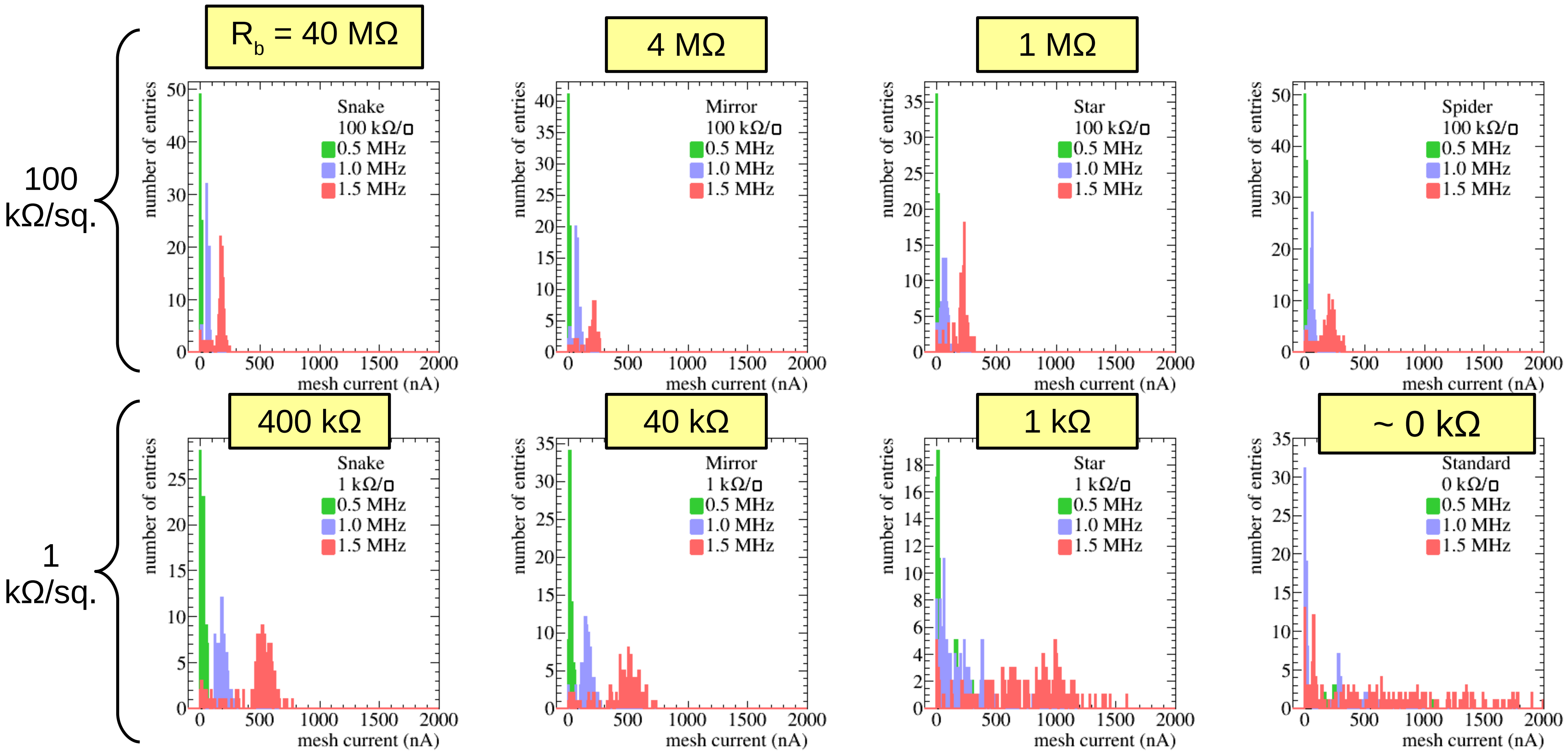
RC = inf., pad is a perfect insulator, charge accumulates until there is no field
RC = 0, pad is a perfect conductor, field is maintained until breakdown.

In reality, we are in between. We might infer that the RC should be longer compared to the development time of the streamer. This way we insure that the field is not restored before photon feedback stops.



Testbeam data

We have 6 prototypes with same layer thickness but different resistance.
They are placed in a high intensity hadron beam behind an absorber.
(1 MHz 150 GeV pion beam showering inside a 2 lambda_int steel block !)
Below a certain R, the mesh current during spill fluctuates, just like a non-resistive prototype. Above this R, the current is ~ constant (iosation current).



Outlook

We have 6 prototypes with same layer thickness but different resistance.
They are placed in a high intensity hadron beam behind an absorber.
(1 MHz 150 GeV pion beam showering inside a 2 lambda_int steel block !)
Below a certain R, the mesh current during spill fluctuates, just like a non-resistive prototype subject to sparking. Above this R, the current is ~ constant (iosation current).

This critical R suggest that there is a threshold RC below which spark suppression is not effective anymore. At this moment we try to get an estimate of the capacitance involved. This time constant should relate to the timescale of some physics processes in the gas.

Can we actually measure the RC ?
Now, we are investigating the operation of our R-prototype in pure argon and measure streamer development close to the spark limit. Recorded signals are huge and rather long (10 us). We aim this way at **better understanding the time evolution of streamer and eventually relate it to the RC**.

Sparks

We have 6 prototypes with same capacitance but different resistance.
They are placed in a high intensity hadron beam behind an absorber.
(1 MHz 150 GeV pion beam showering inside a 2 lambda_int steel block !)
Below a certain R, the mesh current during spill fluctuates a lot, just like a non-resistive prototype. Above this R, the current is ~ constant (iosation current).

At this moment, we attempt to calculate the (R, C and) RC.
We expect that the critical RC will be of the order of the avalanche development time, ~ 10 ns in our case (128 um gap).