Anode charge-up in resistive Micromegas and its quenching effect on spark development

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Intro

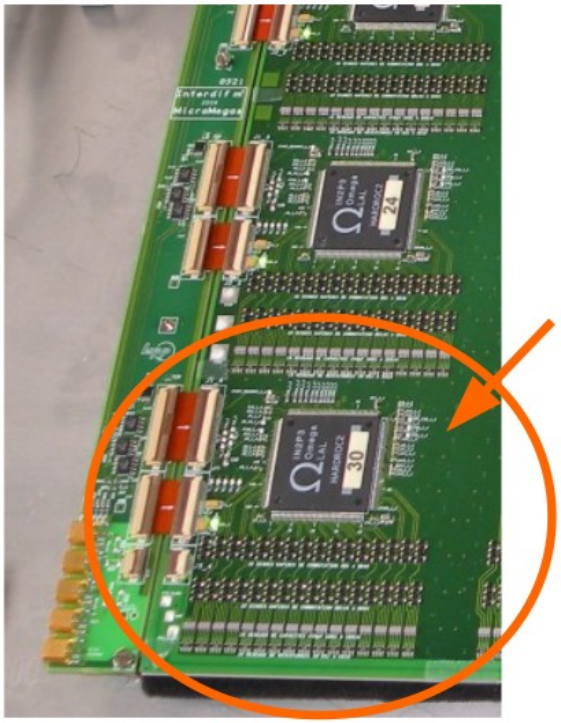
This is a side-study of our main project : Micromegas calorimetry

More specifically Micromegas for a LC-SDHCAL or a HL-LHC forward detector

Calorimetry = large energy deposits = we need spark protections

Diodes on PCB are not elegant for a 10^6 channel system

+ spark dead-time prohibitive for high-rate applications



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Supress sparks with R-electrodes

Several on the market !

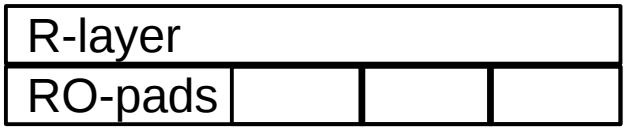
R-Layer on the readout electrodes (à la RPC, GridPix)

R-layer + Insulator (à la Dixit)

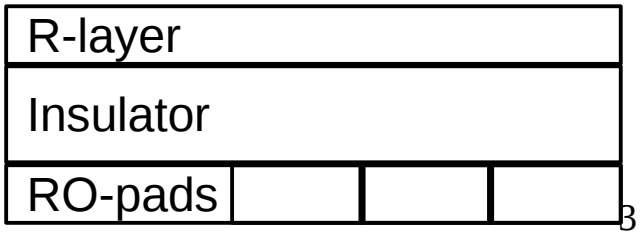
R-layer + metalic grid (à la Rwell THGEM)

R-layer + Insulator + through-PCB via

Embedded-R



Last one turned out to be surprisingly interesting...



Embedded resistors

Charge evacuation is vertical

No spread of signal to neighboring pads to fully exploit RO granularity
LC-calorimetry = imaging calorimetry = SDHCAL with 1x1 cm2 cells

Resistance can be tuned (shape of embedded-R)

Nice to optimise for high-rate capability !
Which brings the question :

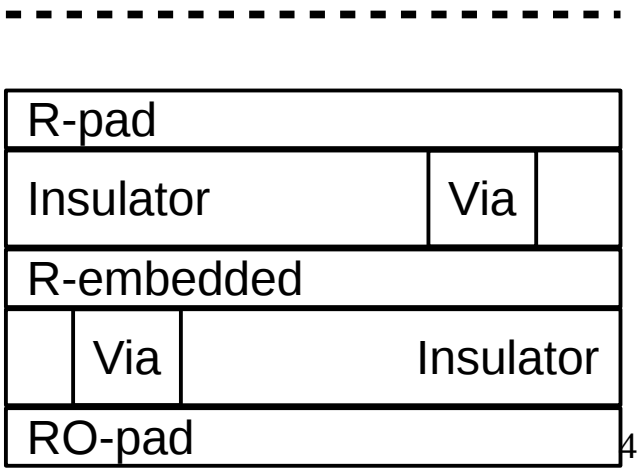
How low can we go with the resistance ?

Too high : RPC-like rate capability and no spark
Too low : MPGD-like rate capability with sparks

PS : we have segmented pads,
so we don't mind low-R

Charge can not be shared with neighbors

First : try to predict what happens… not sure !
Quickly after : make prototypes of ≠ R



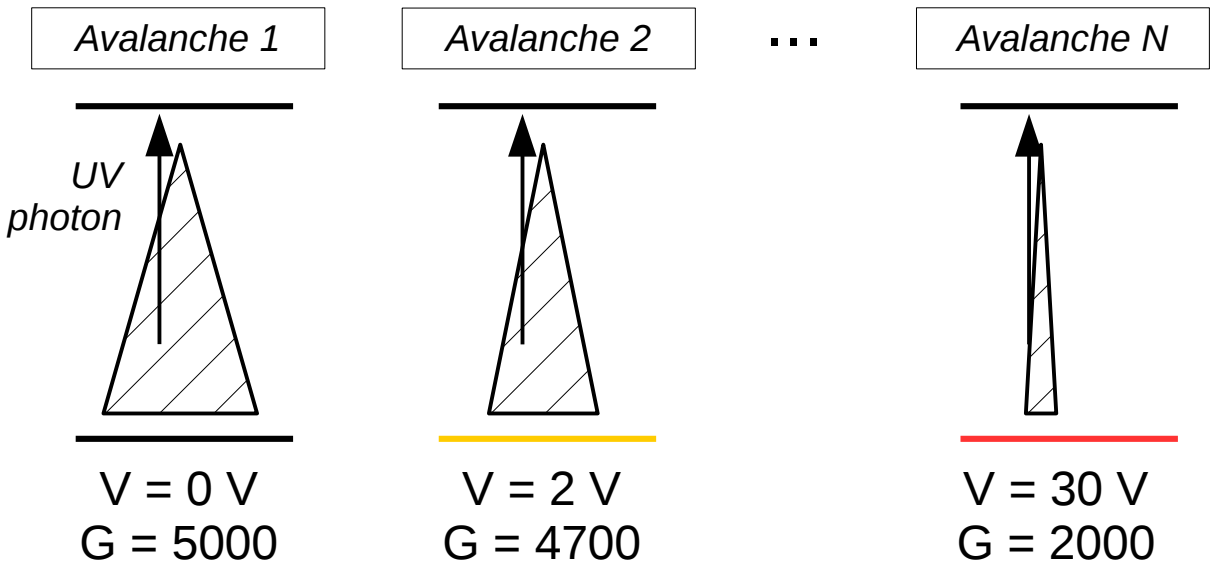
Spark quenching

Spark development

Is a diverging process involving an initiating avalanche + its successors
Initiating avalanche : traversing particles (or mechanical imperfections, edges…)
Successors : photon-feedback, photo-ionisation of impurities in the gas

Our (current) understanding

R-surface charges-up which reduces the field and stops the photon feedback
After some time, the excess charge is evacuated and the field is restored

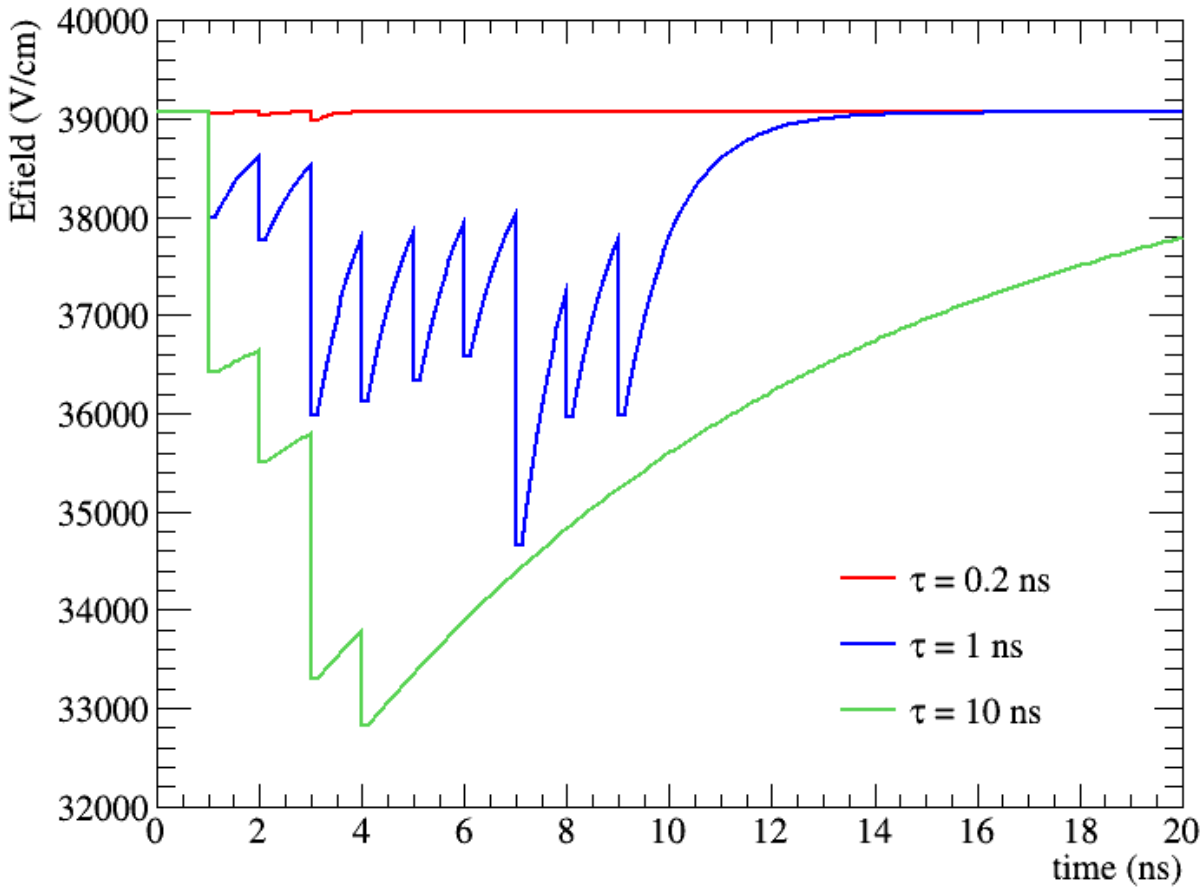


Spark quenching & timing

Relaxation time (τ) should not be too short !

Otherwise successors will feel the full field (= metallic anode)

Toy Monte Carlo of Efield versus time : large field drop when τ > Δt (= 1 ns here)



Δt = time interval between successors = e-drift time in ampli. gap (~ 1 ns)

Feedback : ~ 3 photoe- from intiating avalanche (Poisson)

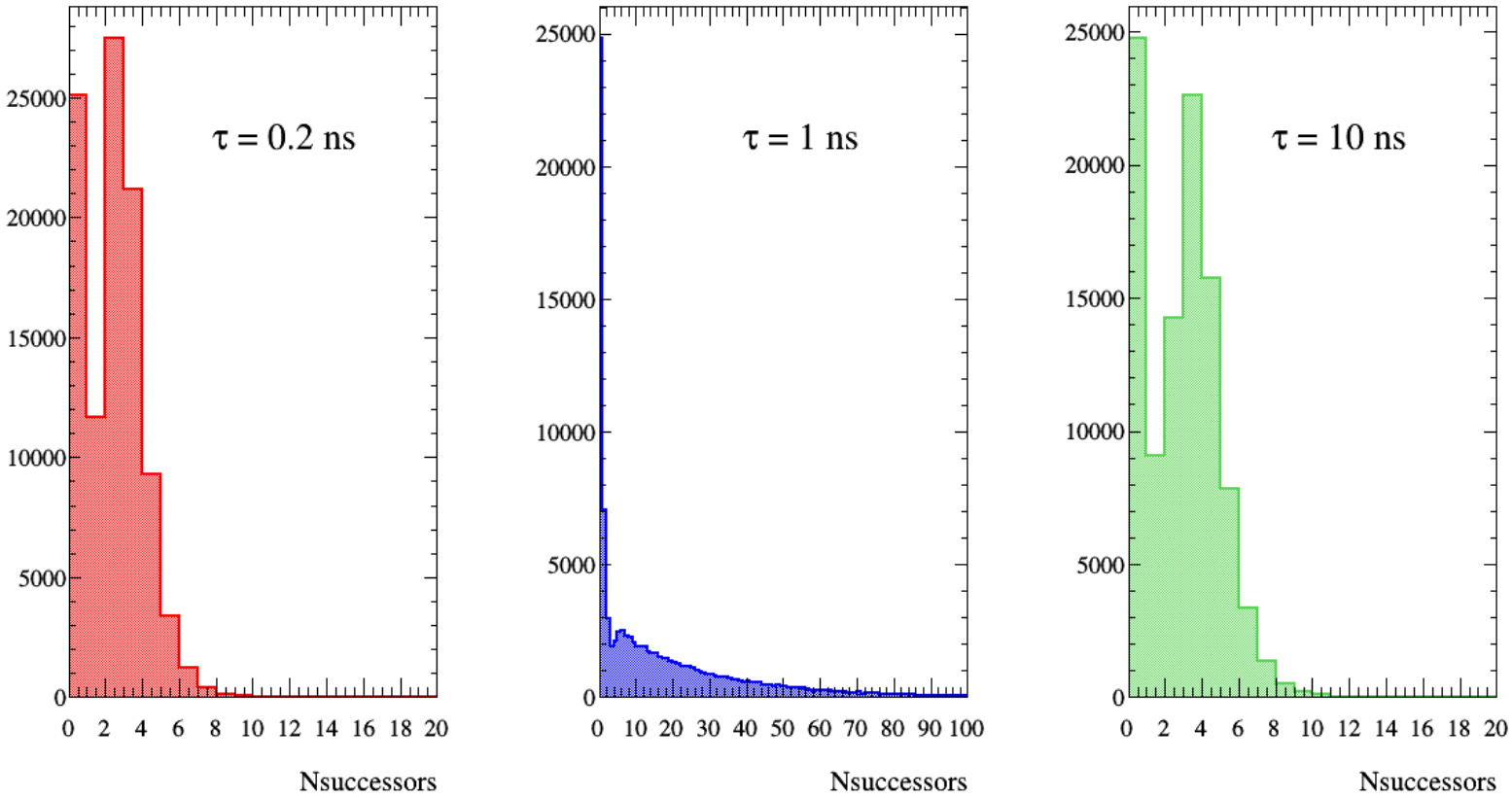
Successors are multiplied by a factor that depend on the anode voltage

Anode voltage :
(+) charge from gas gain
(–) charge drained out

Spark quenching & timing

$\tau << \Delta t$ Field readily restored, quickly goes to spark, few successors
$\tau \sim \Delta t$ Field oscillations, instable regime, several successors
$\tau >> \Delta t$ Field strongly reduced, spark is avoided, few successors

The critical value of τ is given by the timescale of the avalanche development.



Δt = 1 ns

128 μm gap
40 kV/cm
Ar/CO2 90/10

Testing the model

Build prototypes of different τ by changing the value of R

Use paste of different resistivity (100 kΩ/□ & 1 kΩ/□)

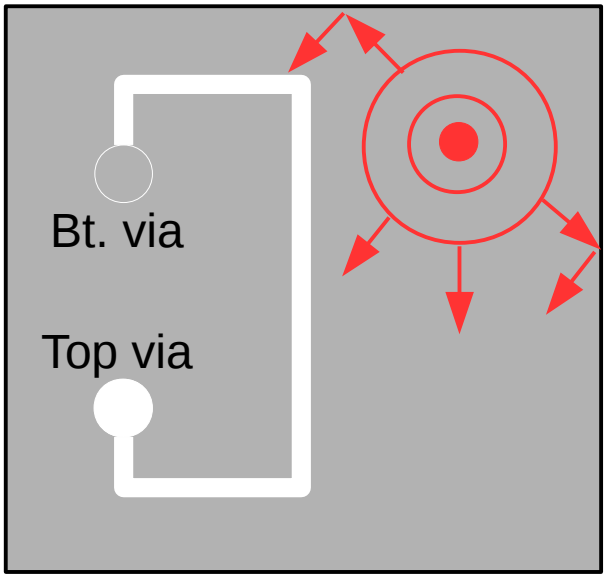
Use embedded resistors of different pattern (shape & number of via)

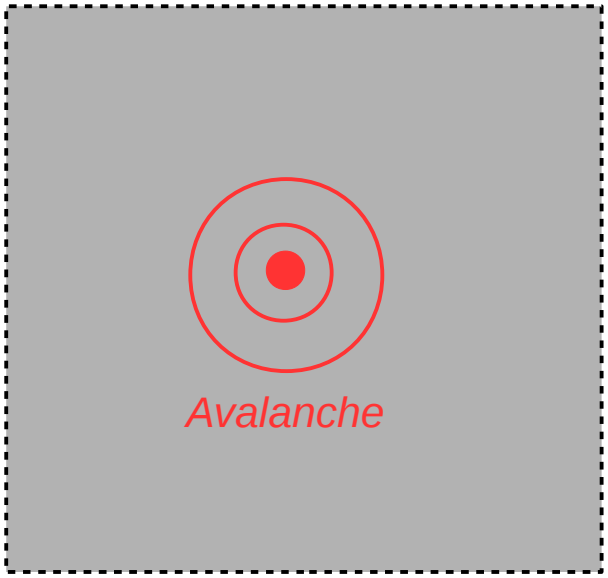
Not exactly sure how this will affect the value of τ

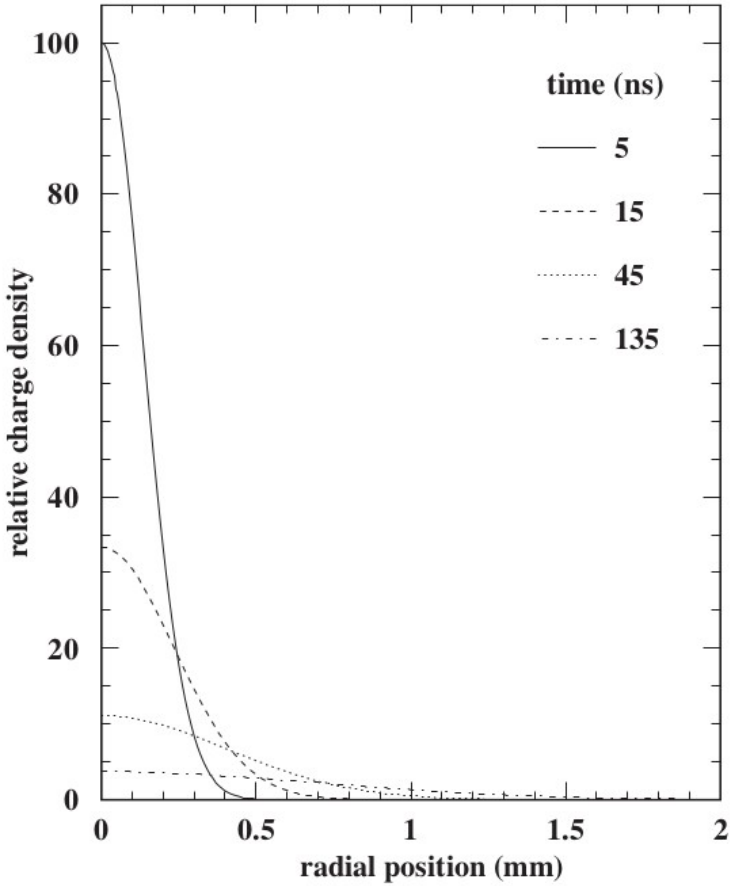
= RC only in case of an ideal geometry :

infinite R-layer (grounded on sides) on insulator

Complicated charge motion (only way out is the via)







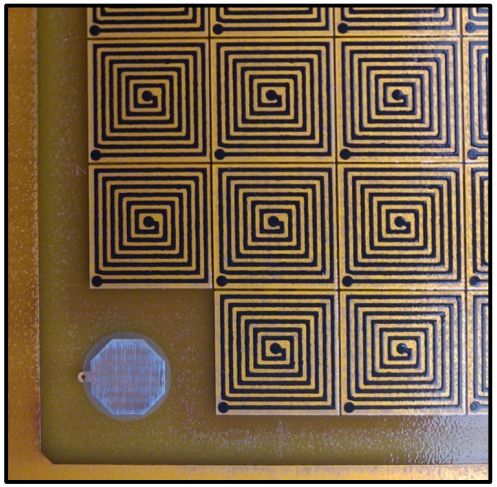
The prototypes

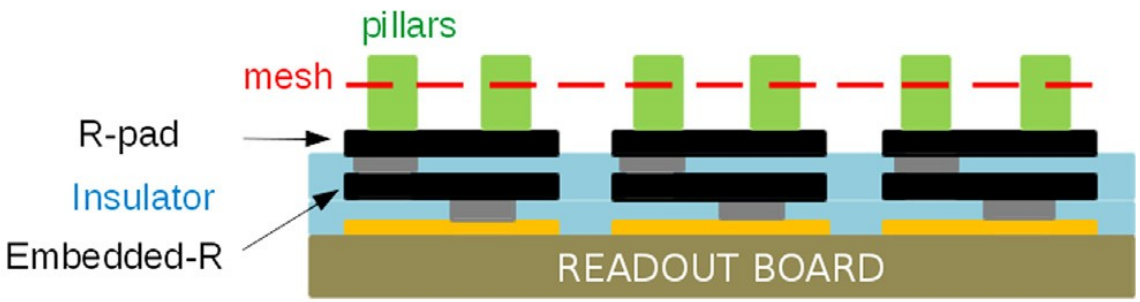
Pad boards

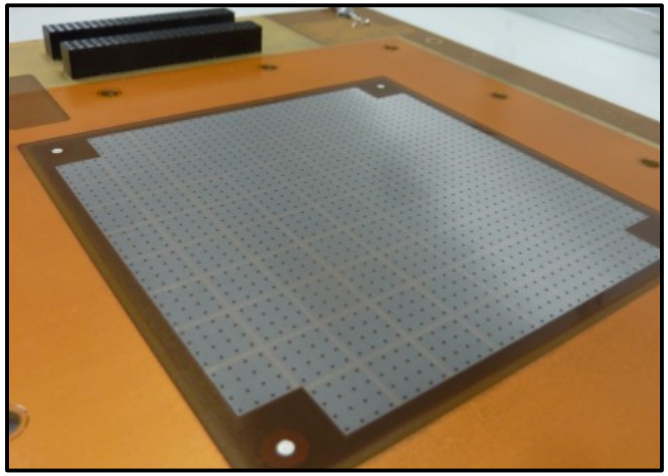
10X10 matrix of 1x1 cm2 pads
Routing on the outside to a 'Gassiplex' connector (96 channels)

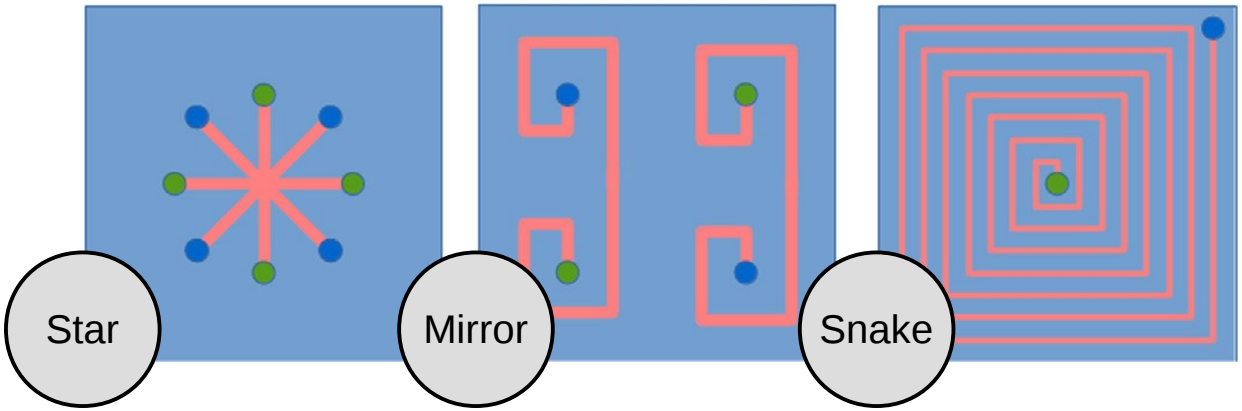
R-structures and Bulk-Micromegas

Serigraphy and photolithography at CERN MPGD workshop









Interlude 1 : energy resolution

We are not breaking records !

Top coverlay pressed on the embedded-R

Pattern probably transferred to the R-pad surface = poor ampli. gap uniformity

Can be improved by polishing

Digital calorimetry = counting hits…

Resolution does not matter

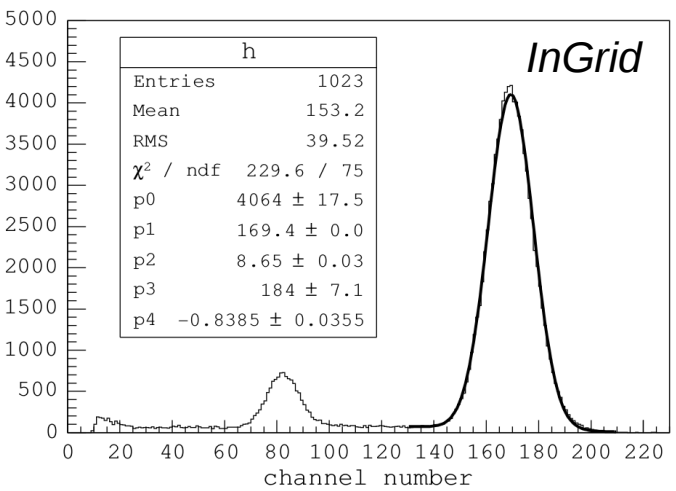
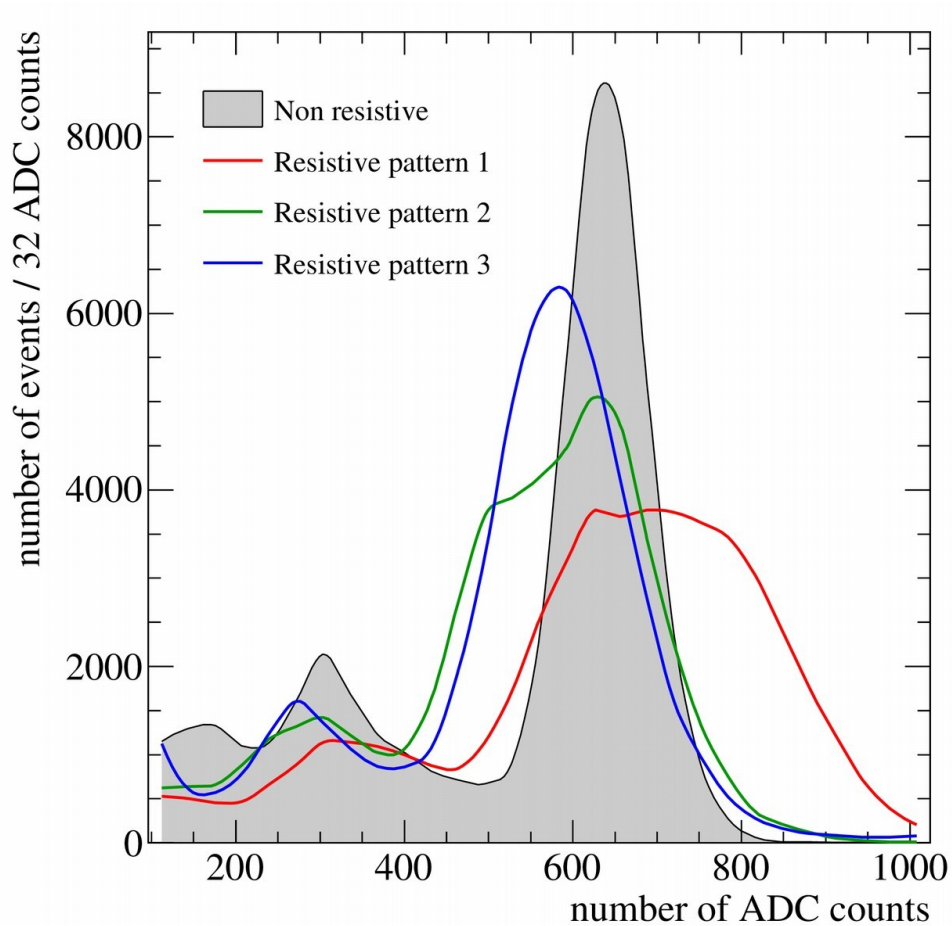


Figure 6.14: ^{55}*Fe spectrum recorded in a P10 mixture. The K_β line was strongly absorbed by a 10 μm thin Cr foil. The parameters of a gaussian (p_0–p_2) and a linear (p_3, p_4) function were adjusted to the photo-peak.*



Interlude 2 : signal proportionality

Mesh to R-pad capacitance ~ 70 nF/m^2 : loss of proportionality for point-like events ?

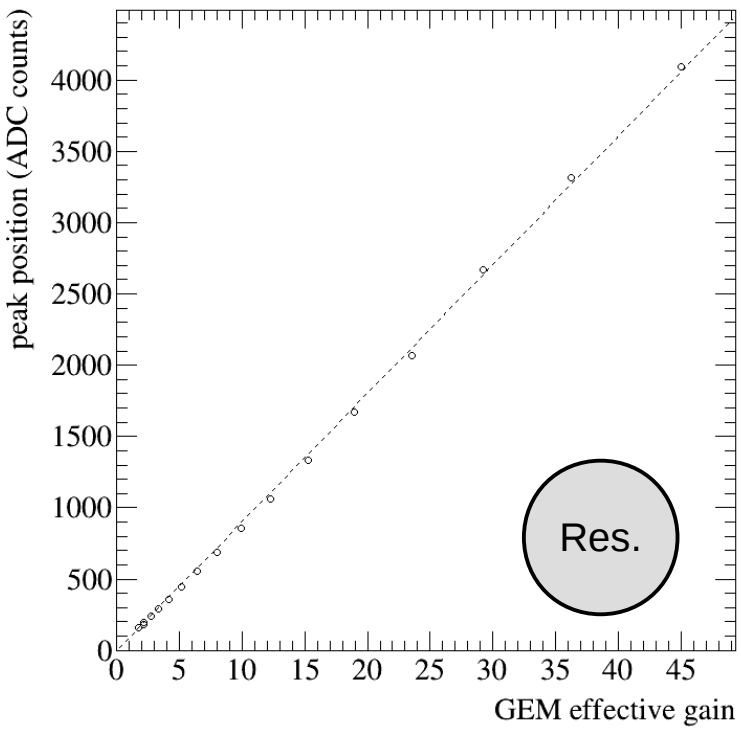
e.g. when several primary electrons arrive in the same mesh hole

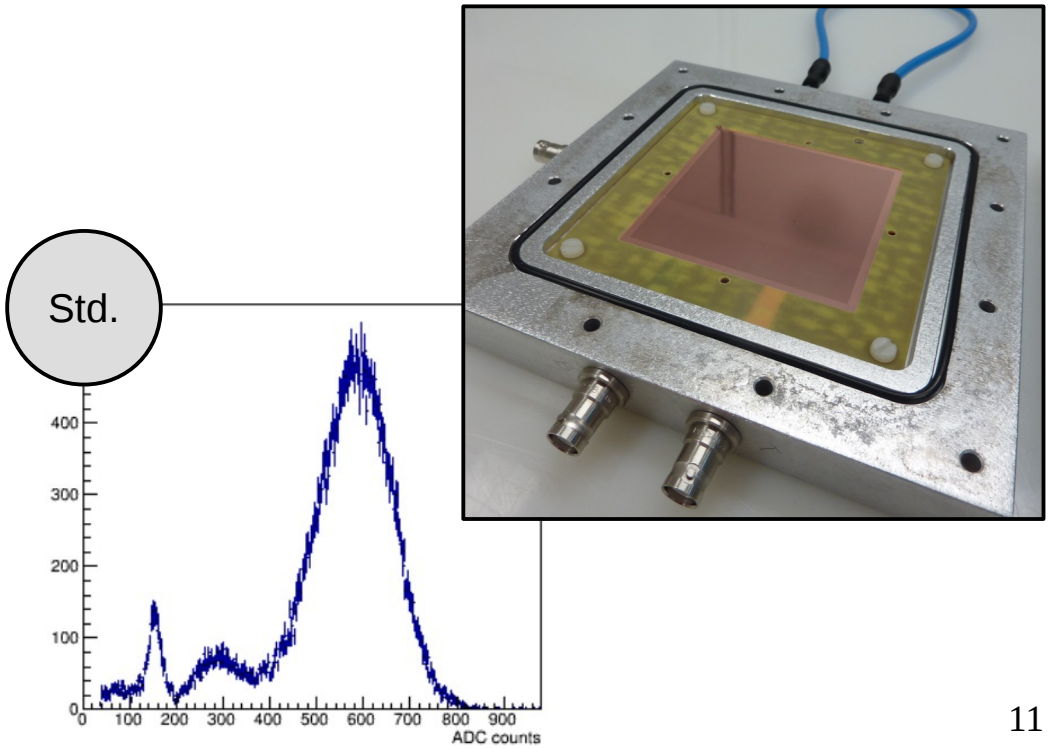
Last arriving electrons might feel a reduced field = non-linear response

Drift distance above/below GEM injector ~ 10/3 mm (Ar/CO2 90/10)

230 primaries in ~5 GEM holes, each secondary in ~ 5 mesh holes

Response is linear up to testable GEM gains





Measuring the relaxation time

Let's use an Xgun !

The detector current will saturate at high rate, this should tell us about τ …

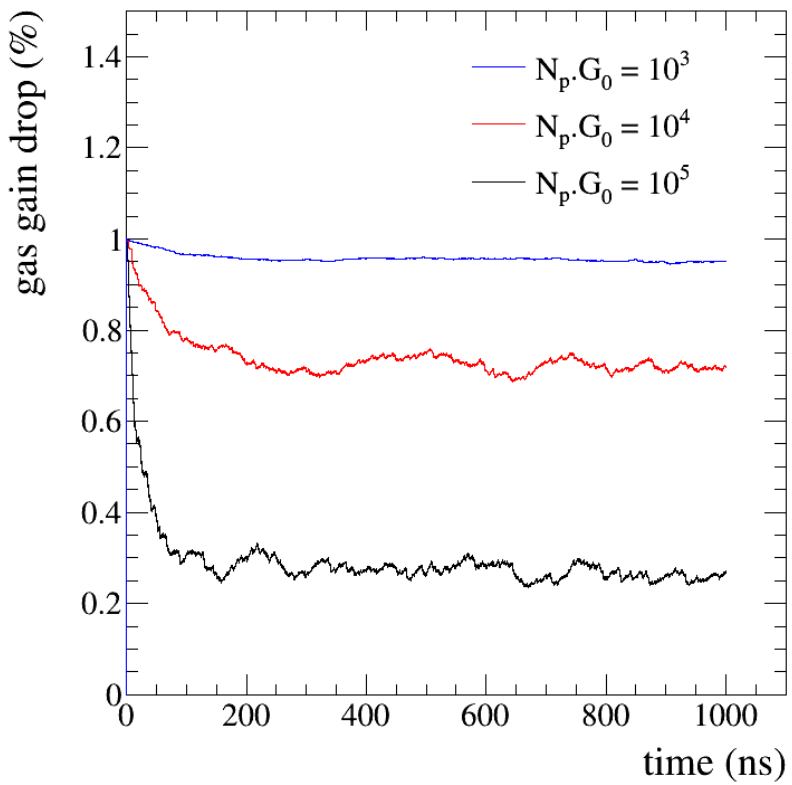
Mesh current : $I \sim I_0 / (1 + B\,R\,I_0)$

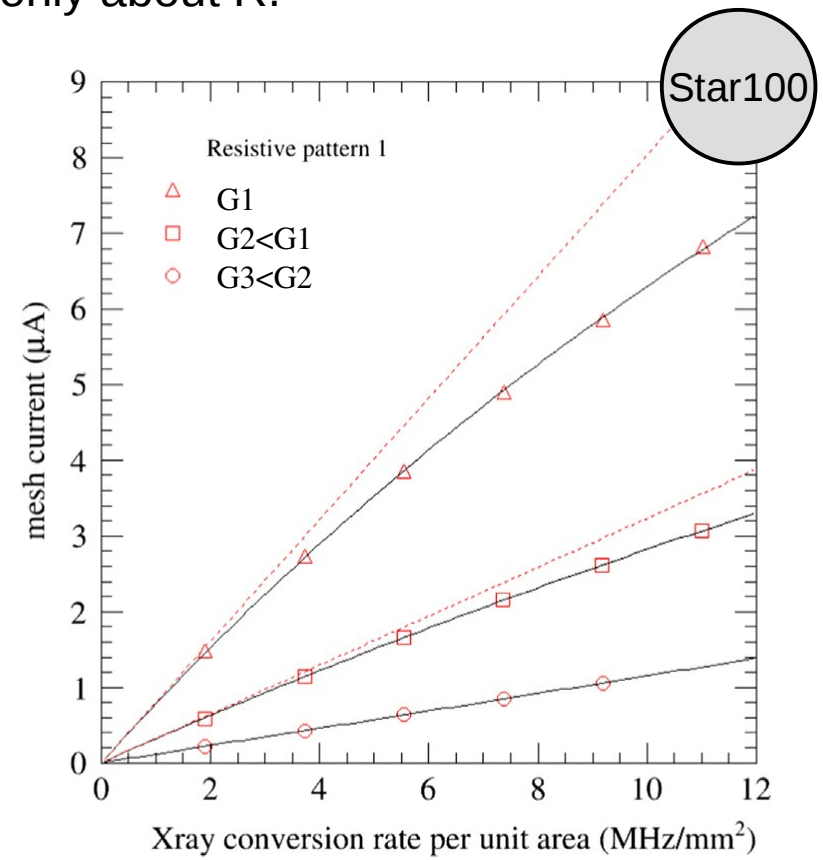
$I = \Phi\, N_p\, G = \Phi\, N_p\, G_0 \exp(-B\,\Delta V) = I_0 \exp(-B\,R\,I) \sim I_0\,(1 - B\,R\,I)$

The asymptotic current does not tell us about τ, only about R.

(left)
Toy MC
Φ = 1 GHz
τ = 100 ns

(right)
Xgun data
Φ < 80 MHz
τ = ?





Measuring the resistance

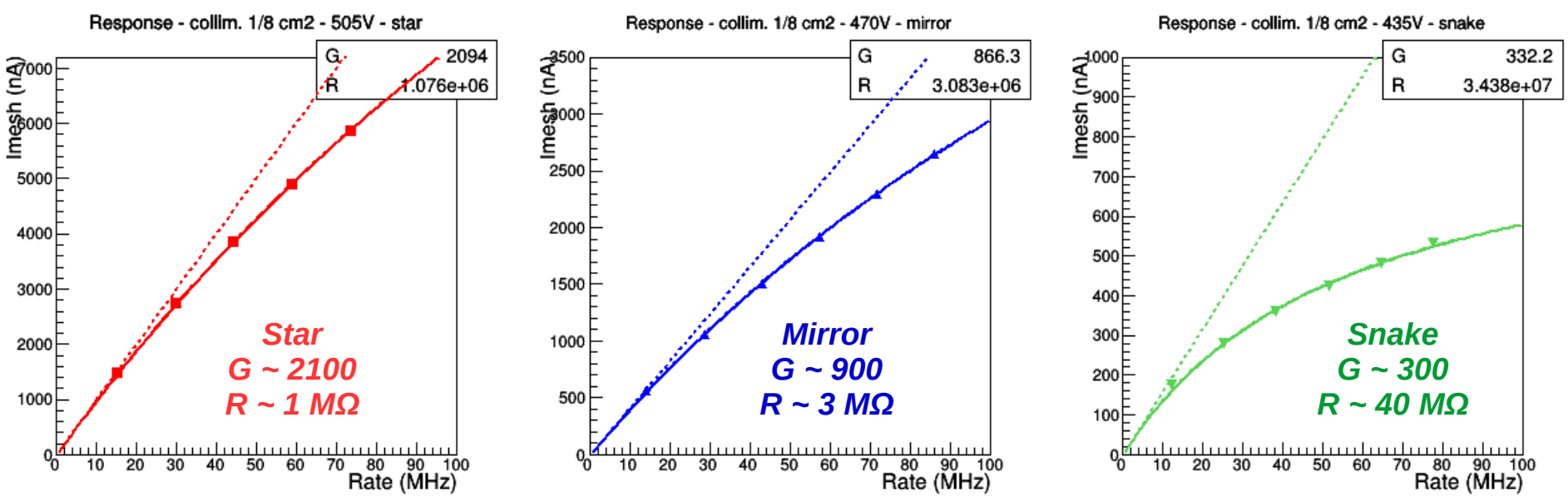
Mesh current : $I \sim I_0 / (1 + B\,R\,I_0)$

The asymptotic current does not tell us about τ, only about R.
Replacing I_c by $(\Phi\, N_p\, G_c)$, one can fit the gain and R to the data

Nota Bene : the X-ray beam (8 keV) collimation is 8 mm^2

The prototypes withstand rates up to 10 MHz/mm^2 with no sparks

The one with R = 1 MΩ shows little deviations from linearity up to 1 MHz/mm^2
= **Efficiency plateau up to 1 MHz/mm^2**



Measuring the relaxation time, once again

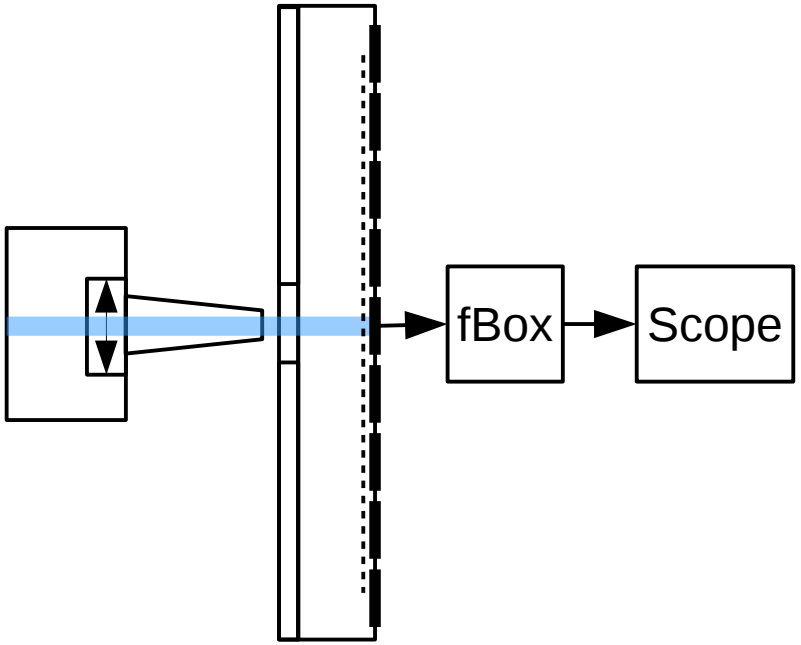
We see only the steady regime and miss the initial current peak

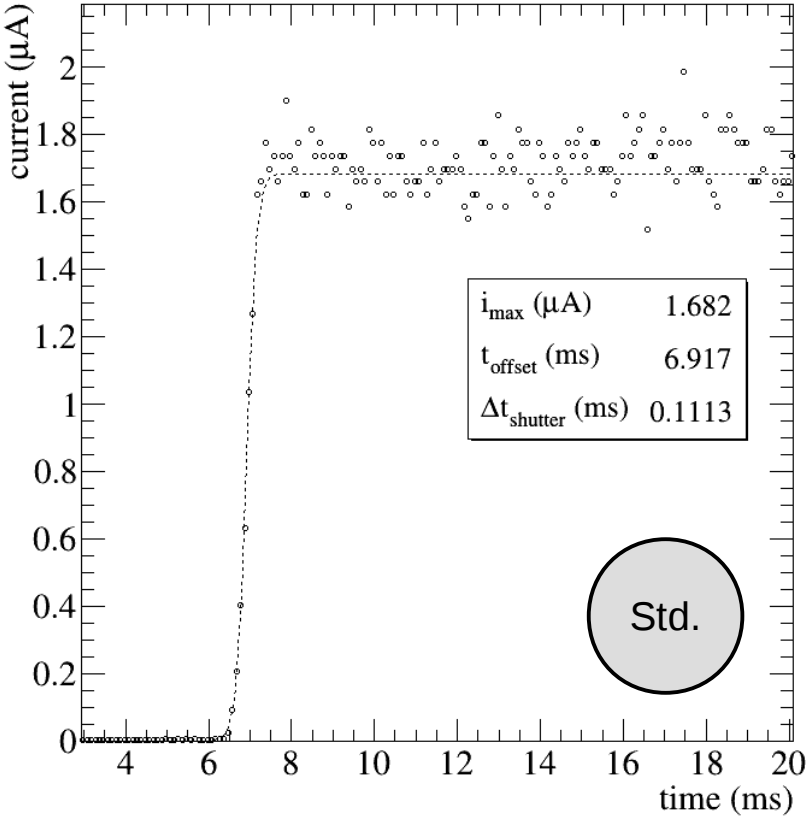
Try a faster readout : reading power supply → recording pad-current on scope

Sensitive current-meter ('FemtoBox') available in RD51 lab. at CERN

With a non-resistive prototype, we measure a shutter time of ~ 110 μs

This means, the measurement is sensitive to relaxation time larger than 100 μs





Measuring the relaxation time, once again

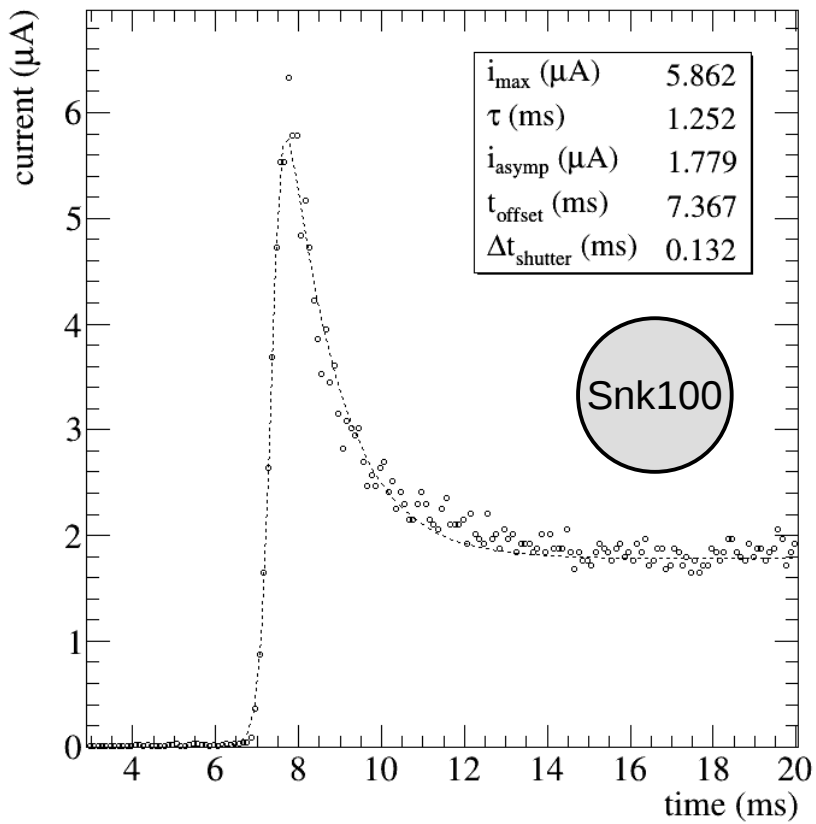
We see only the steady regime and miss the initial current peak

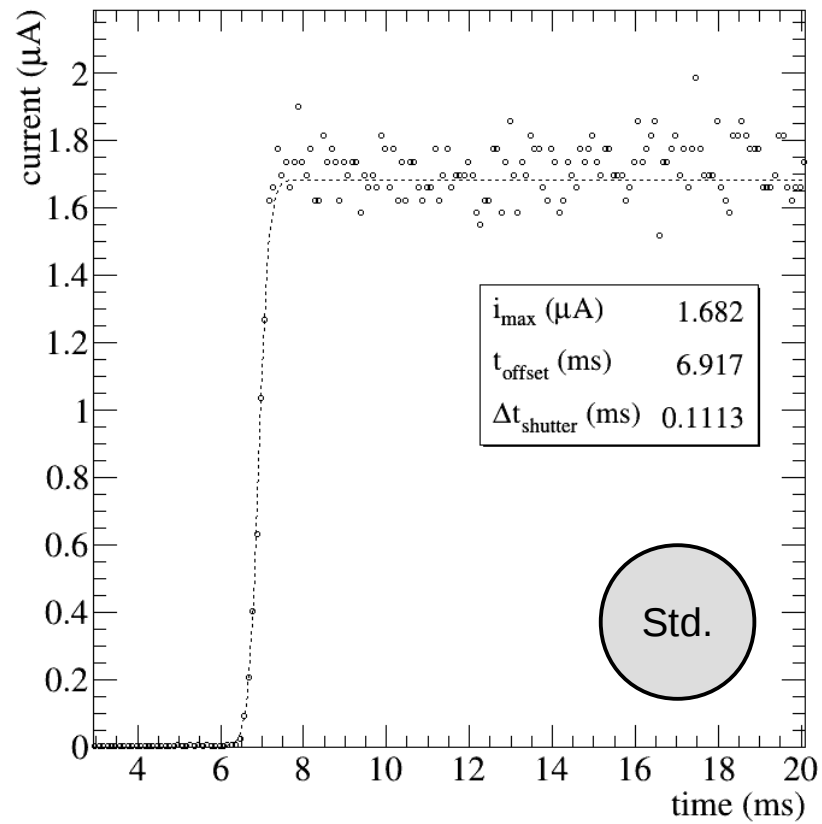
Try a faster readout : reading power supply → recording pad-current on scope

Sensitive current-meter ('FemtoBox') available in RD51 lab. at CERN

With the highest-R prototype, we measure a relaxation time of ~ 1.3 ms

We fit τ to the data (implicitely implies that the current decay is exponential)





Extrapolating the relaxation time

Reminder : 6 prototypes

2 different R-paste (100 VS 1 kΩ/□)

3 different patterns (shape and number of via)

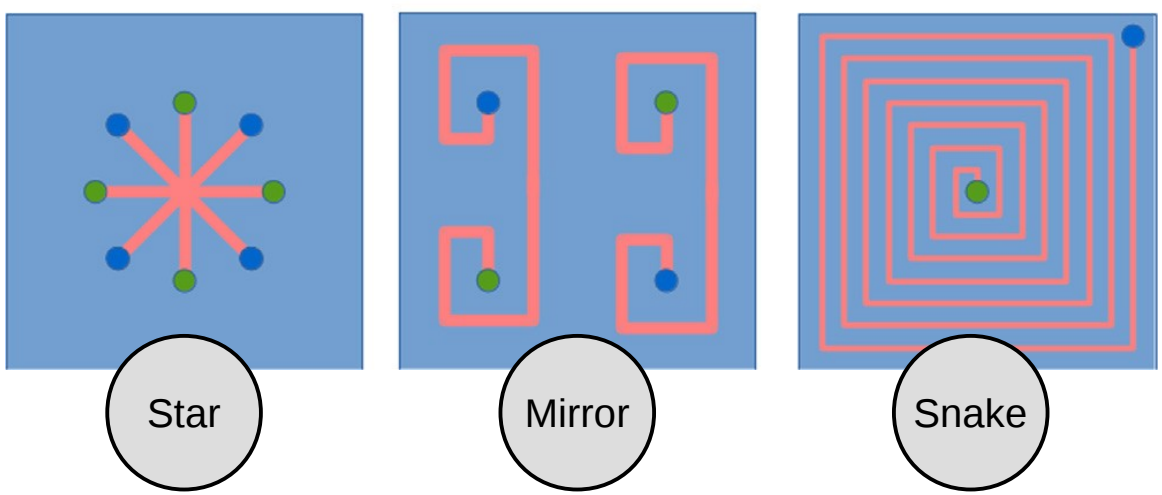
Likely : τ (Snake1) = 10^{-2} . τ (Snake100) ~ 10 µs

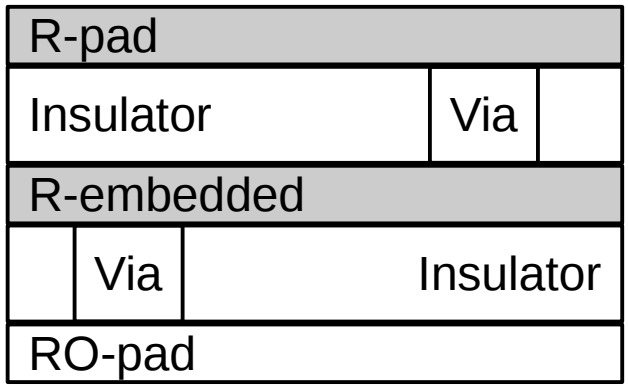
Capacitance is the same for a given pattern

Likely : τ (Snake) > τ (Mirror) > τ (Star)

Indeed : R-embedded decreases (40-3-1) and N_{via} increases (1-2-4)

Lacking a diffusion model, difficult to be more quantitative





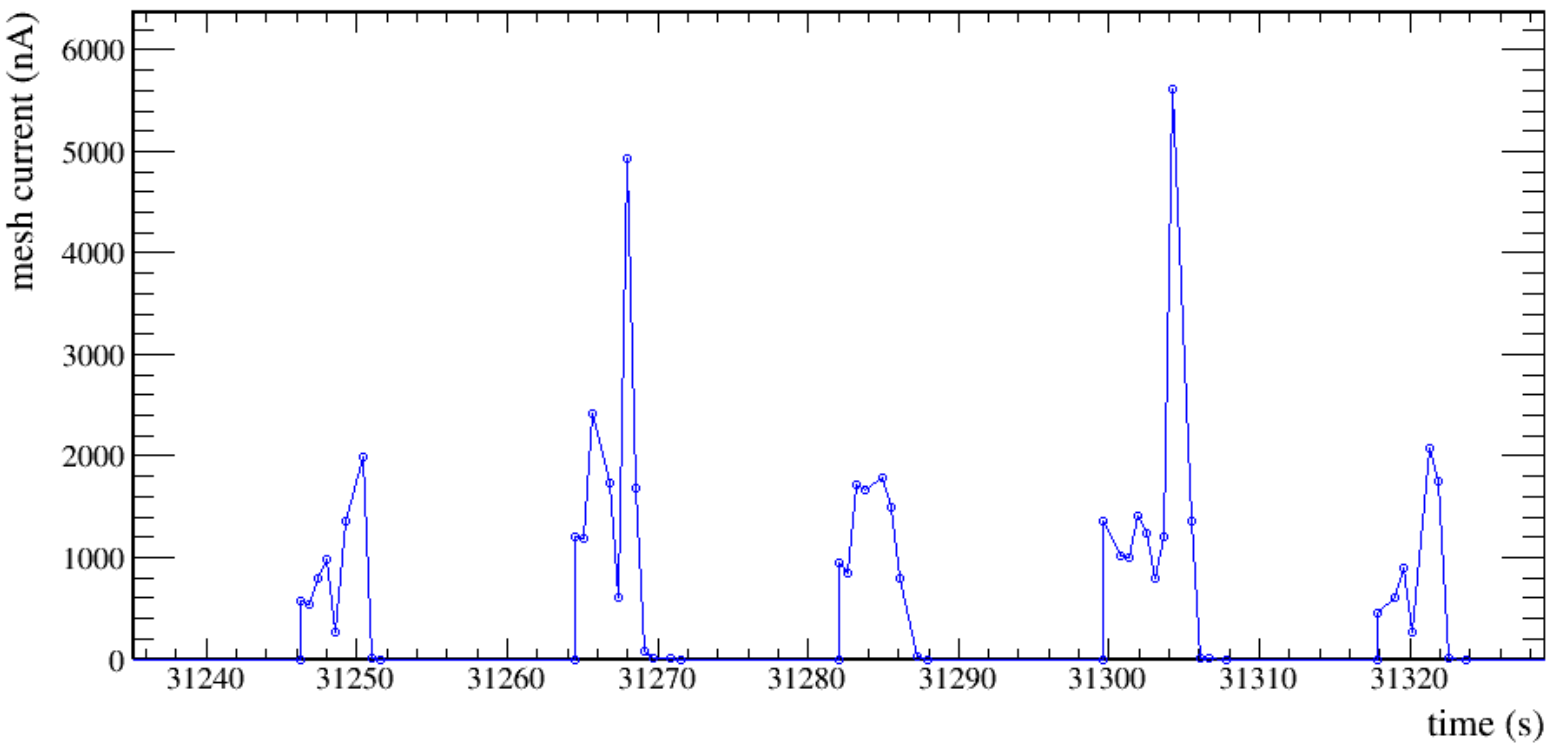
Measuring sparks

Create the 'conditions' :
High-energy (200 GeV) high-intensity (0.5-1-1.5 MHz) pion beam

Directed at a 2 λ_{int} thick steel absorber, prototype placed behind

Monitor mesh current, erratic behaviour signs occurrence of sparks

Compare trends from different prototypes



Std.

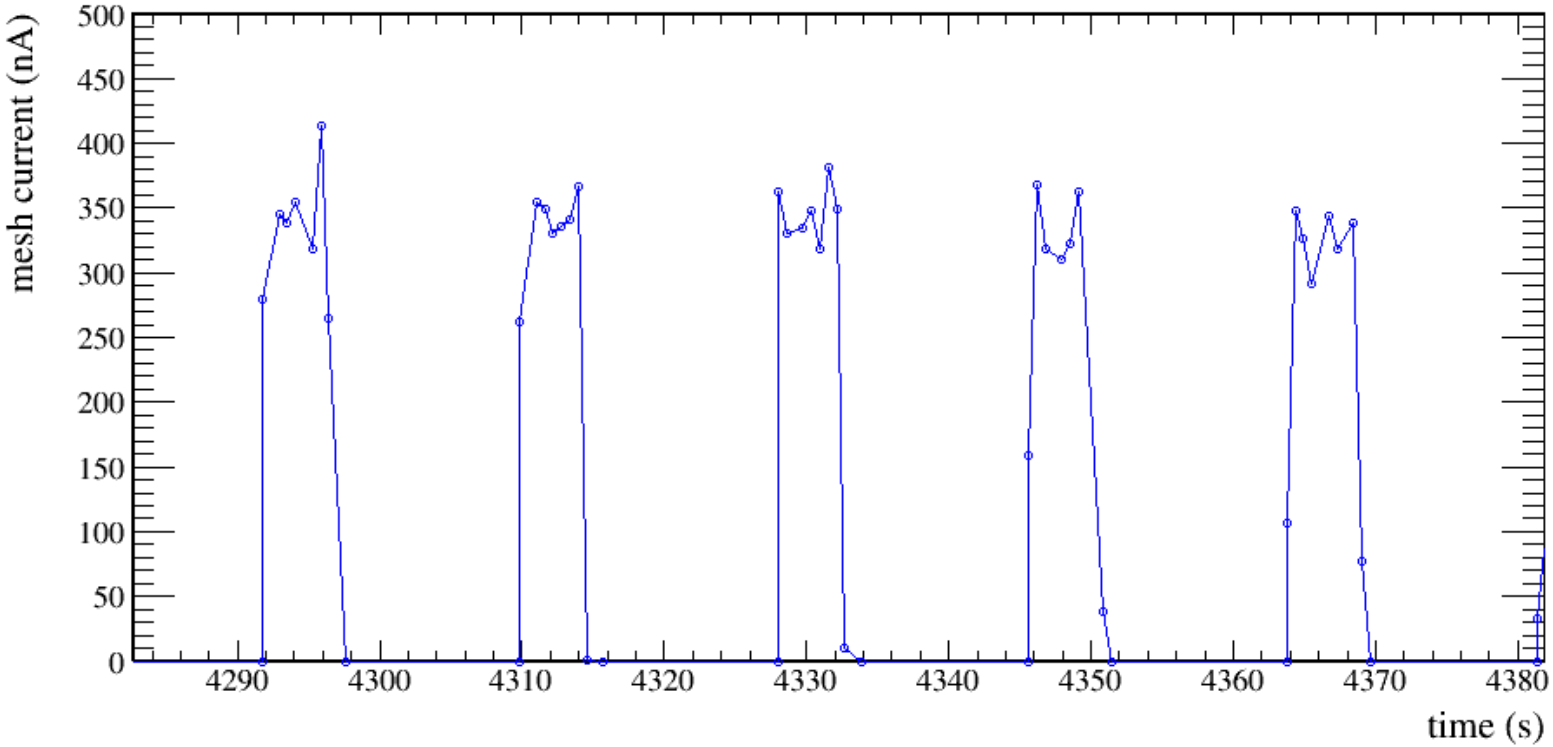
Measuring sparks

Create the 'conditions' :
High-energy (200 GeV) high-intensity (0.5-1-1.5 MHz) pion beam

Directed at a 2 λ_{int} thick steel absorber, prototype placed behind

Monitor mesh current, erratic behaviour signs occurrence of sparks

Compare trends from different prototypes



Snk100

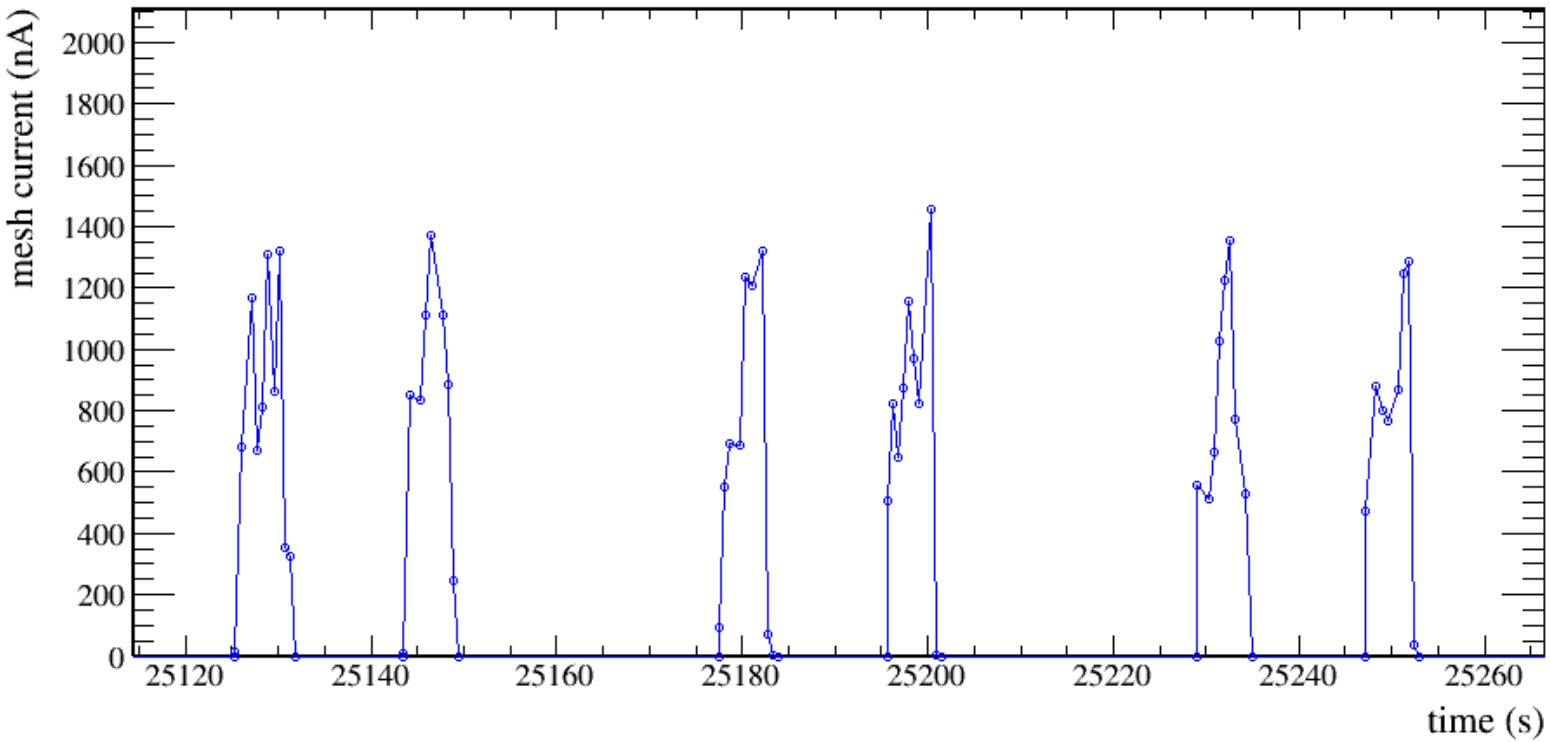
Measuring sparks

Create the 'conditions' :
High-energy (200 GeV) high-intensity (0.5-1-1.5 MHz) pion beam

Directed at a 2 λ_{int} thick steel absorber, prototype placed behind

Monitor mesh current, erratic behaviour signs occurrence of sparks

Compare trends from different prototypes

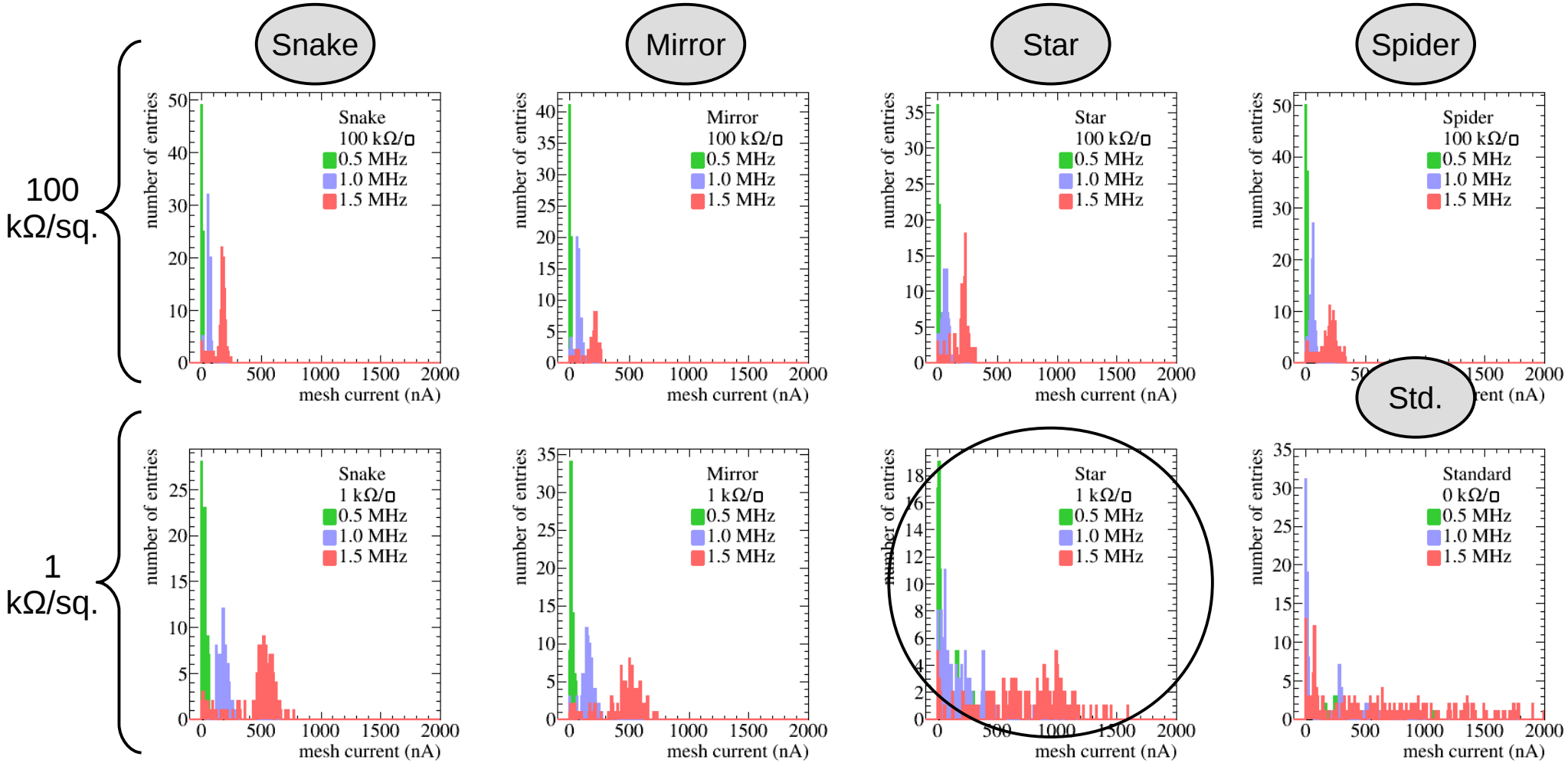


Star1

Measuring sparks

Compare trends from different prototypes : mesh-current distribution in spills

Indicate a Loss of spark quenching for the prototype of lowest R



Outro. 1

Naive extrapolation of τ based on R-ratio between Snake100 & Mirror1

Spark quenching is lost for τ shorter than 1 ms / 100 / 10 = 1 μs

Way larger than the time between successors of 1 ns but :

Extrapolated τ is probably over-estimated

Does not take into account the number of vias

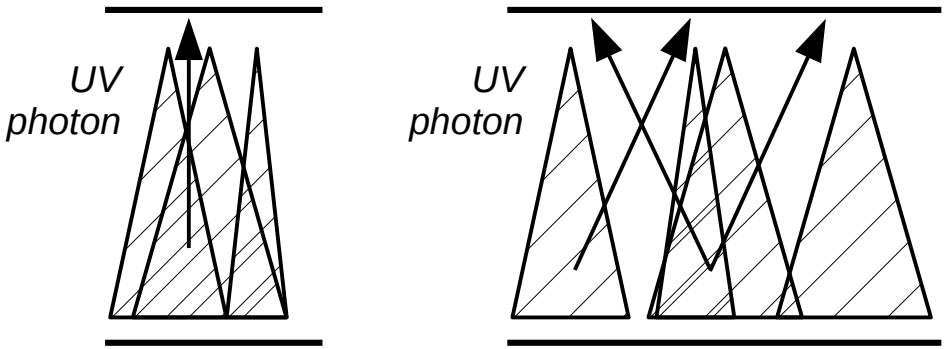
Model Δt is probably under-estimated

Toy MC does not account for lateral dispersion of successor avalanches

To conclude, we need

A better model of spark development (from 0-D to at least 2-D) → Δt

A model of charge diffusion on R-pad → τ



Outro. 2

Spark-free operation at very-high rates (MHz/mm^2) possible with embedded-R

Could be pushed even higher with 'closed' geometries, e.g. WELL-like
(as lateral photon feedback (or photo-ionisation) would be constrained)
Provided that each hole has its own embedded-R

Theoretical rate capability limit of such device could be Δt^{-1} / hole

That is : 1 GHz / hole (for a 128 µm ampli. gap) or beyond with smaller gaps