Micromegas for sampling calorimetry

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TIPP conference, Amsterdam 2-6 June 2014

Outline

Calorimetry with gaseous detectors
Pros & cons, the case of Particle Flow, Expected Performance

Large-area Micromegas
Design Constraints, Operational characteristics, Shower Measurements

Resistive Micromegas
Sparking, Charging-up & Linearity, Future Plans

GASEOUS CALORIMETRY & PARTICLE FLOW

Pros: Cheap, large areas instrumented with a single sensor, readout easily segmented insensitive to neutrons in H-free gas mixtures (narrower showers)

MPGD: age well (Ar/CO_2), sustain heavy dose and high rates, non-uniformity under control

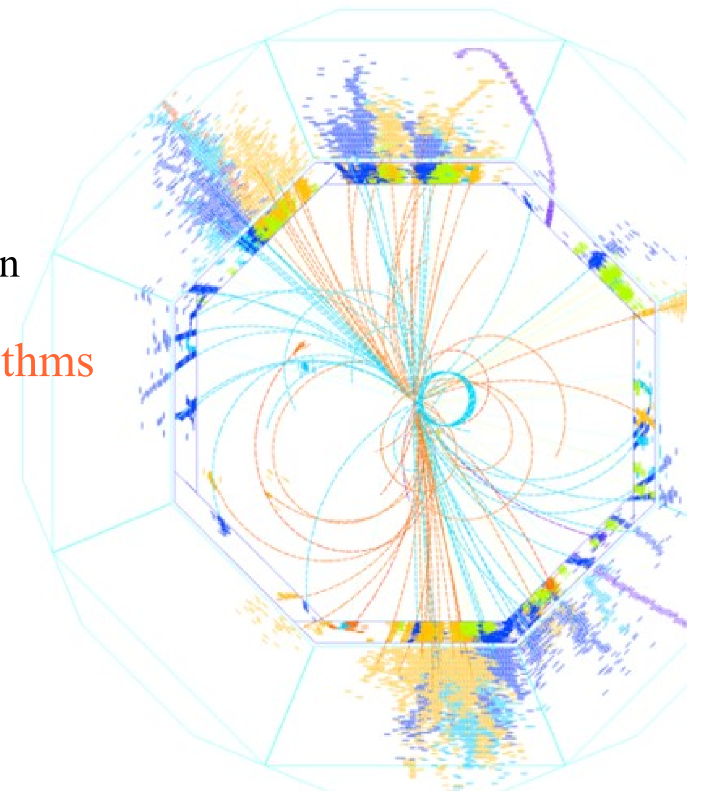
But: low sampling fraction (10^{-5}) → Intrinsic energy resolution is modest

Imaging (Particle Flow) calorimetry

Use the most precise detector to measure particles in jets

Jet energy resolution of 3-4% possible with modest calorimeter resolution

→ Granular calorimeters + precise tracker + sophisticated algorithms



Targeted granularity

→	Si/W ECAL for ILD	100 M cells of 5x5 mm^2
→	Gas/Fe HCAL for SiD	30 M cells of 1x1 cm^2

DIGITAL HADRON CALORIMETRY

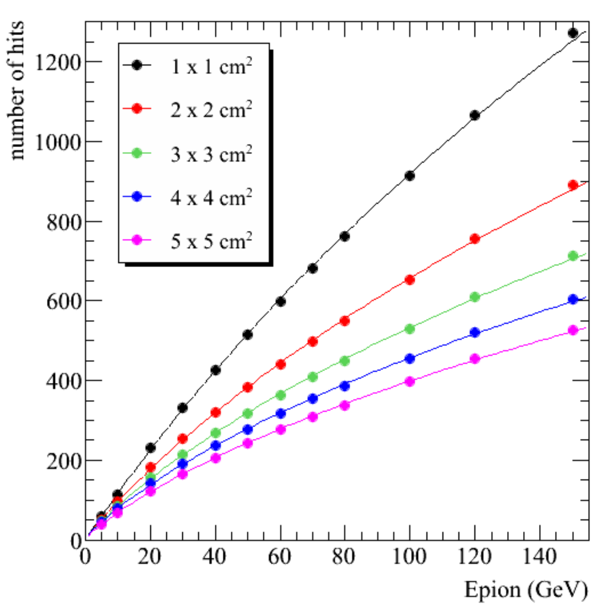
Extreme granularity for HCAL

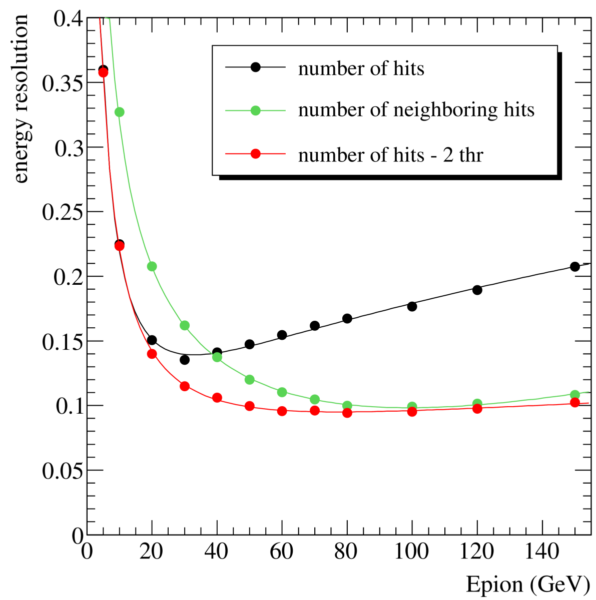
Reduce power-consumption & heat gradient with simple threshold electronics

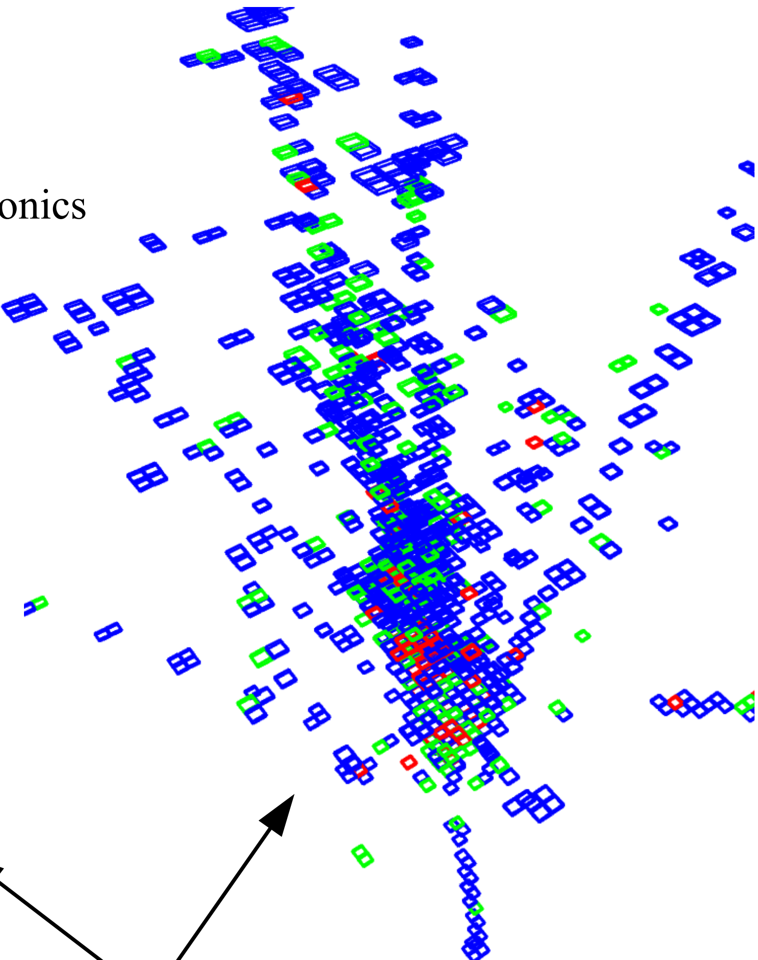
→ Digital HCAL or DHCAL

Saturation & energy resolution

Cell size (1x1 cm^2) is of the order of the (Molière radius)^2.π







Pion shower in the RPC-SDHCAL
blue=thr1, green=thr2, red=thr3

Offline compensation based on the information from <u>additional thresholds</u> or hit density

LARGE-AREA MICROMEGAS for the SDHCAL

Requirements

Active medium

Proportional response, large dynamic range, low noise, good uniformity

Mechanics

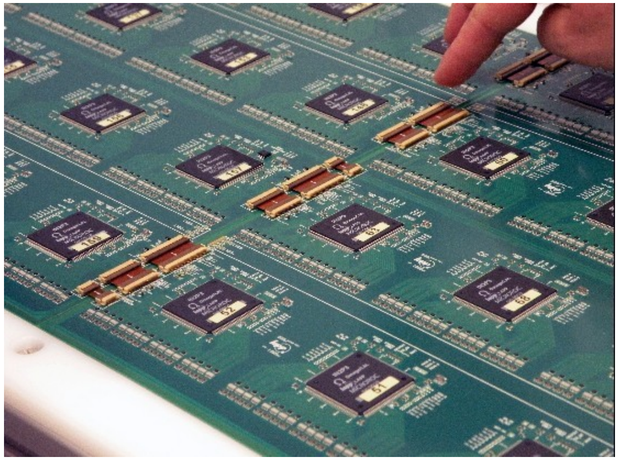
Longitudinal segmentation → compact design (1 cm / layer), minimal dead zones (large-area)

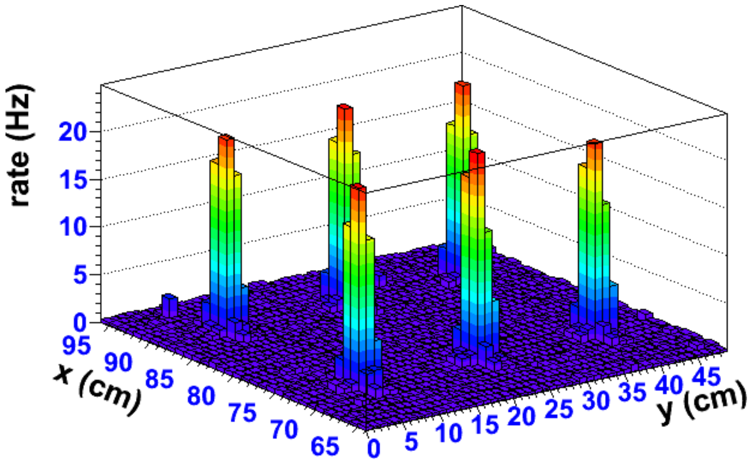
Electronics

Lateral segmentation → large number of channels, power-pulsing, self-triggering+memory

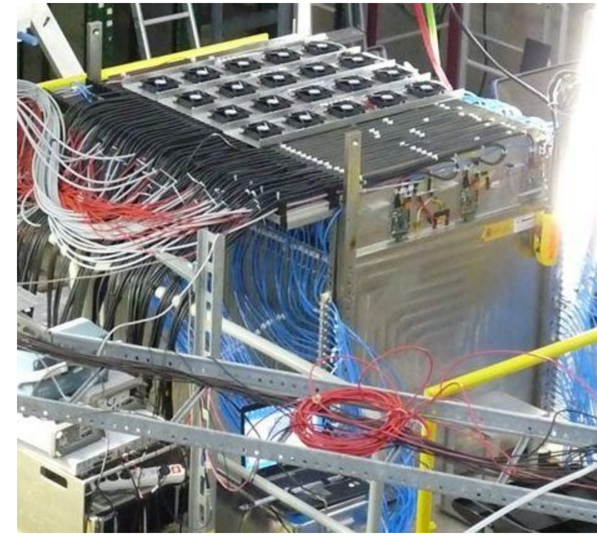
Active Sensor Unit, 32x48 cm^2 → 1x1 m^2 prototype

PCB with pads, font-end electronics (ASIC), flat inter-connects and Bulk Micromegas





TESTBEAMS



CALICE SDHCAL

4 Micromegas prototypes of 1x1 m^2 constructed

Tested at CERN without and inside the CALICE RPC-SDHCAL

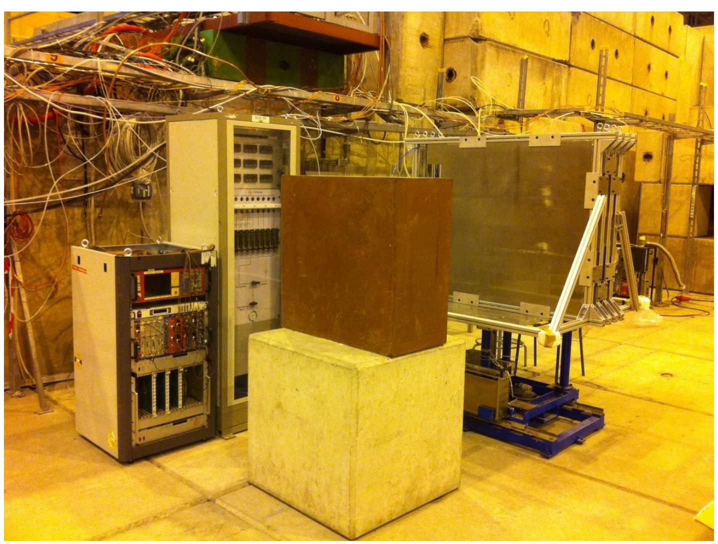
Standalone test

150 GeV muons and pions → operational characteristics

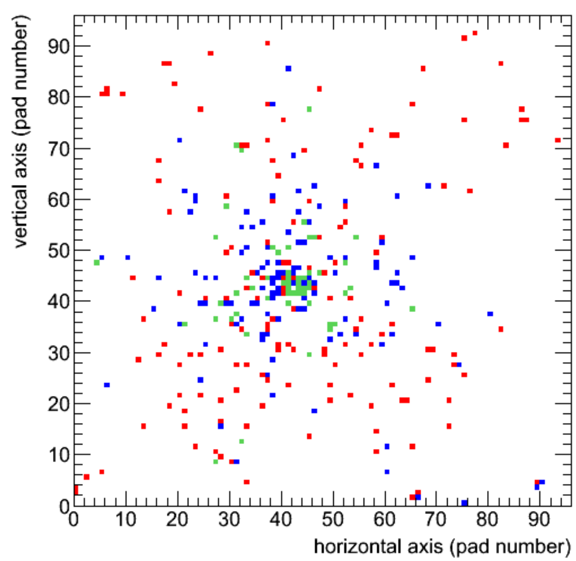
Inside the SDHCAL

Use RPCs to identify shower start → shower profiles with Micromegas only

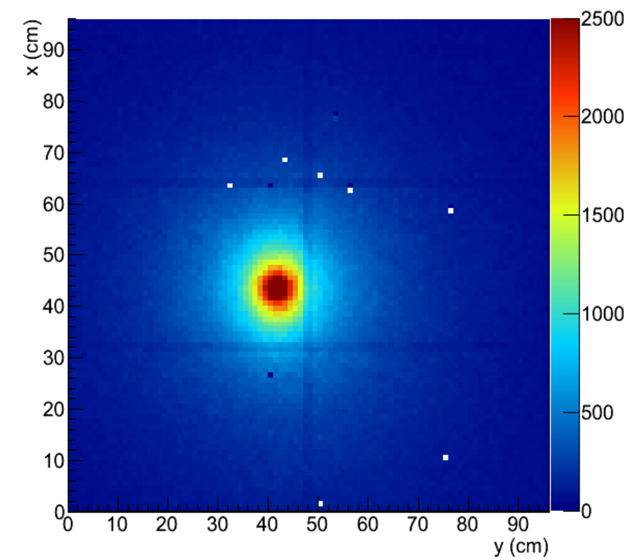
Standalone setup



1 pion shower event



50 k pion shower events



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RESPONSE TO HIGH-ENERGY MUONS

Response measurement

Beam muons (20-150 GeV) traverse the SDHCAL

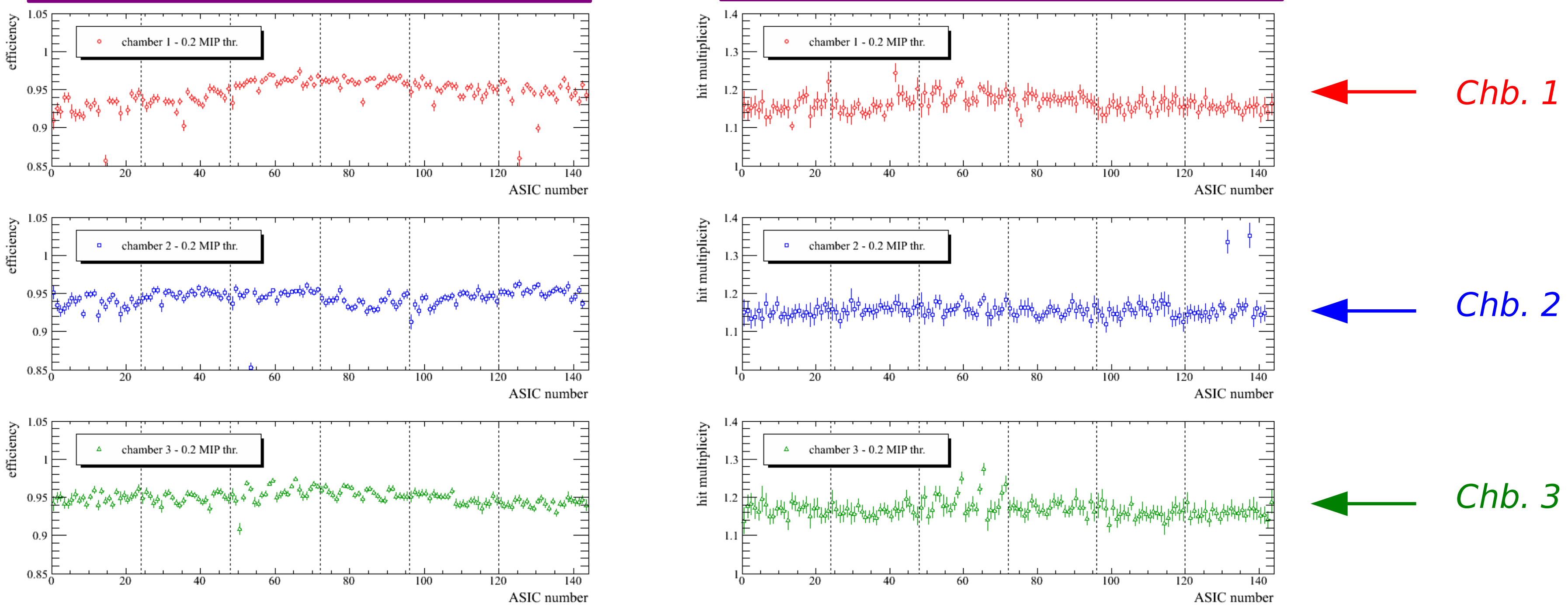
Use RPC layers as telescope → test Micromegas layers over whole area

Build ASIC map → 144 regions of 8x8 cm^2

Excellent uniformity → good for calorimeter resolution at high energy (small constant term)

Efficiency = 95%, var. 1% RMS

Multiplicity = 1.15 hit / muon



NOISE DURING OPERATION (1/2)

Threshold settings: 1-2 fC achieved, S/N of 20 at working gas gain of 1500

ASIC (MICROROC) noise at preamlifier input is 0.25 fC → 5σ threshold of 1.25 fC

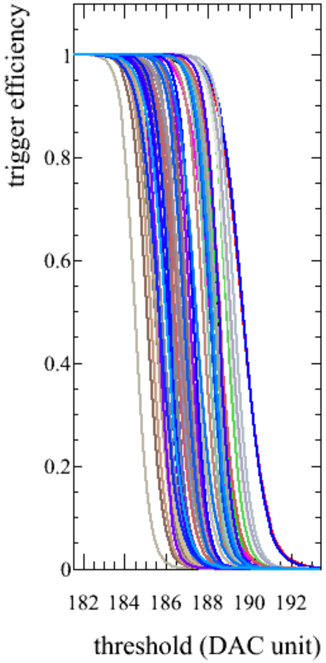
A DAC can be used to reduce the pedestal spread to 0.25 fC RMS

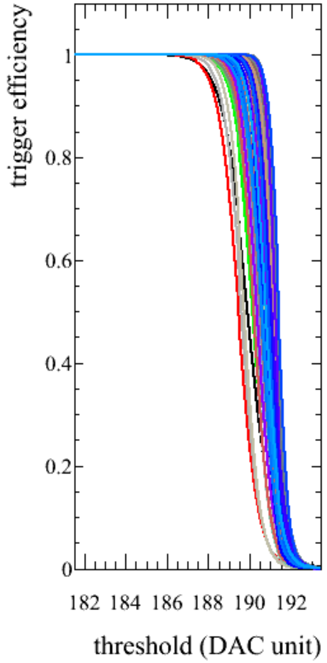
Noise measurement

SDHCAL is self-triggered → records everything until 1 ASIC memory is full

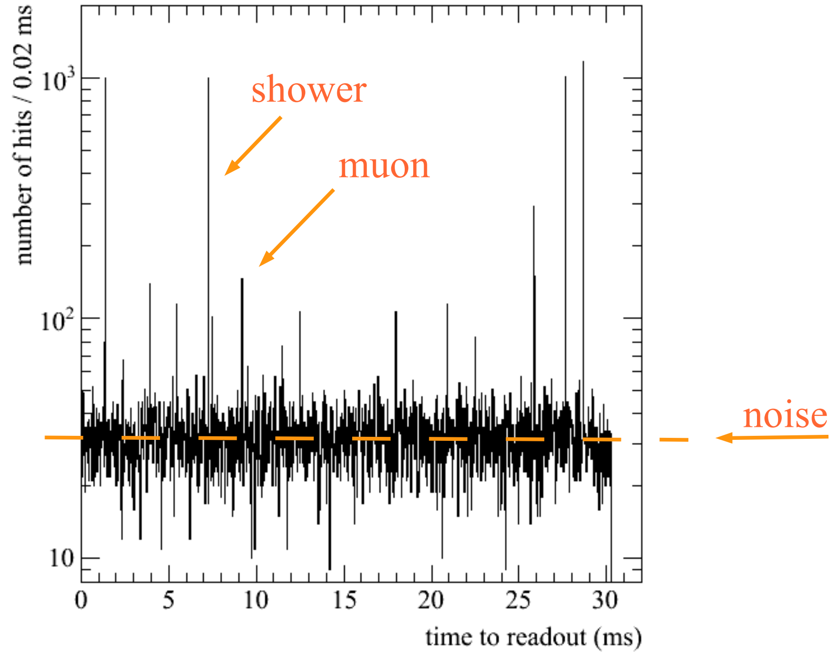
Number of hits recorded during the time between physics events → noise rate

Scurves before/after pedestal alignment





Time spectrum of hits in RPC-SDHCAL

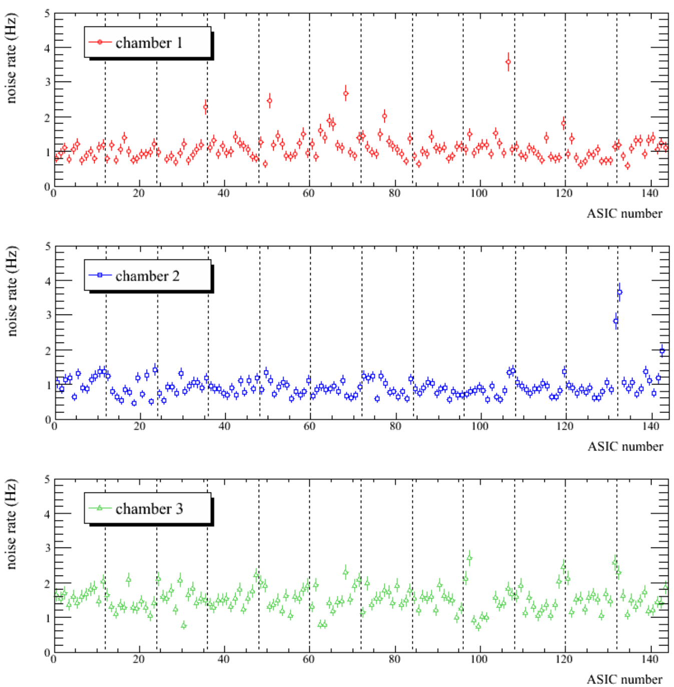


NOISE DURING OPERATION (2/2)

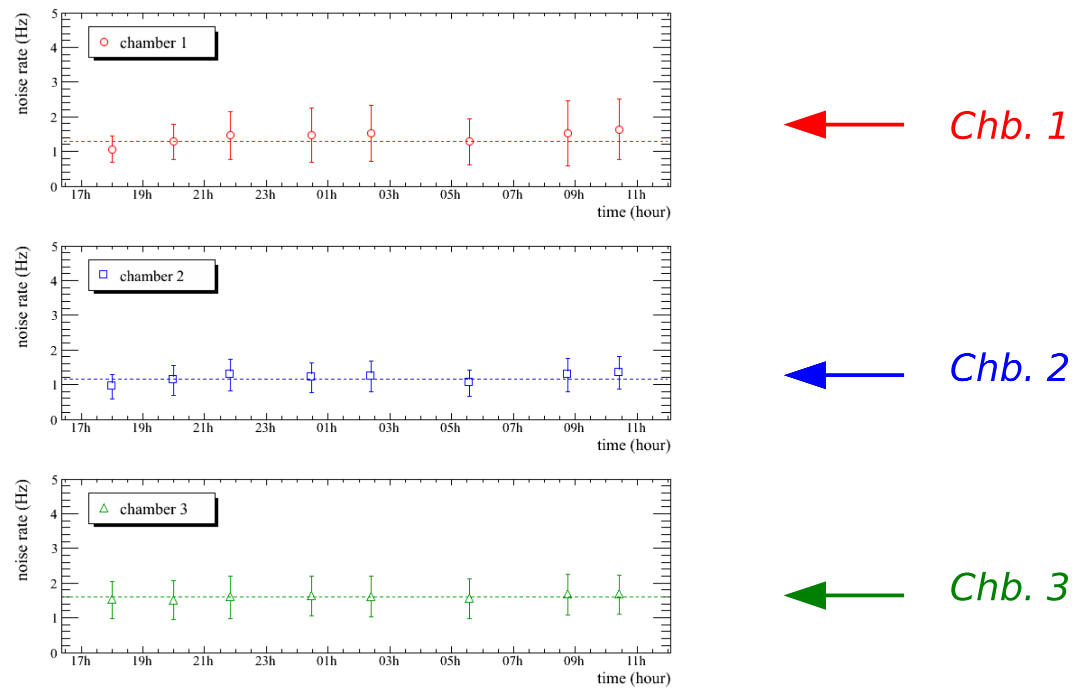
Readout when 1 ASIC memory is full (127 event depth) → **relevant quantity is noise rate / ASIC**
1 Hz/ASIC is achieved. Stable with time.

Compared to clock period of 200 ns → Negligible event contamination by noise & impact on resolution
Compared to ILC spill-time of 1 ms → No dead-time during collisions (full use of luminosity)

Noise / ASIC ~ 1 Hz



Stability over time (17 hours)

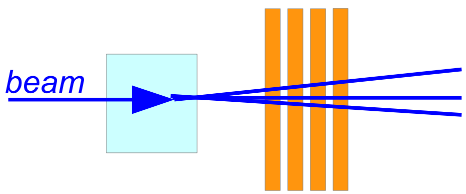


EFFECT of SHOWER RATE on RESPONSE

- Response = distribution of number of hits per shower

  Standalone setup = 150 GeV focused on 2 λ_{int} thick iron block + Micromegas prototypes downstream

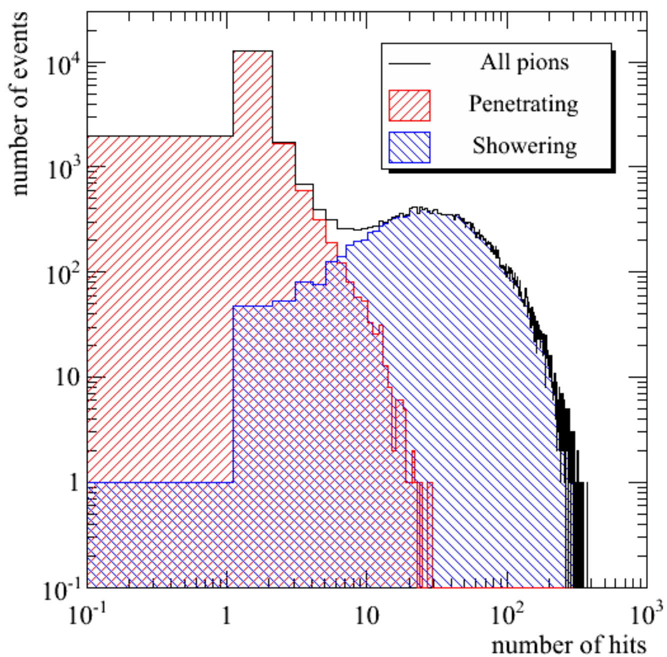
  → 90% of pions are showering inside the block & Shower energy is on average highest at the rear of the block

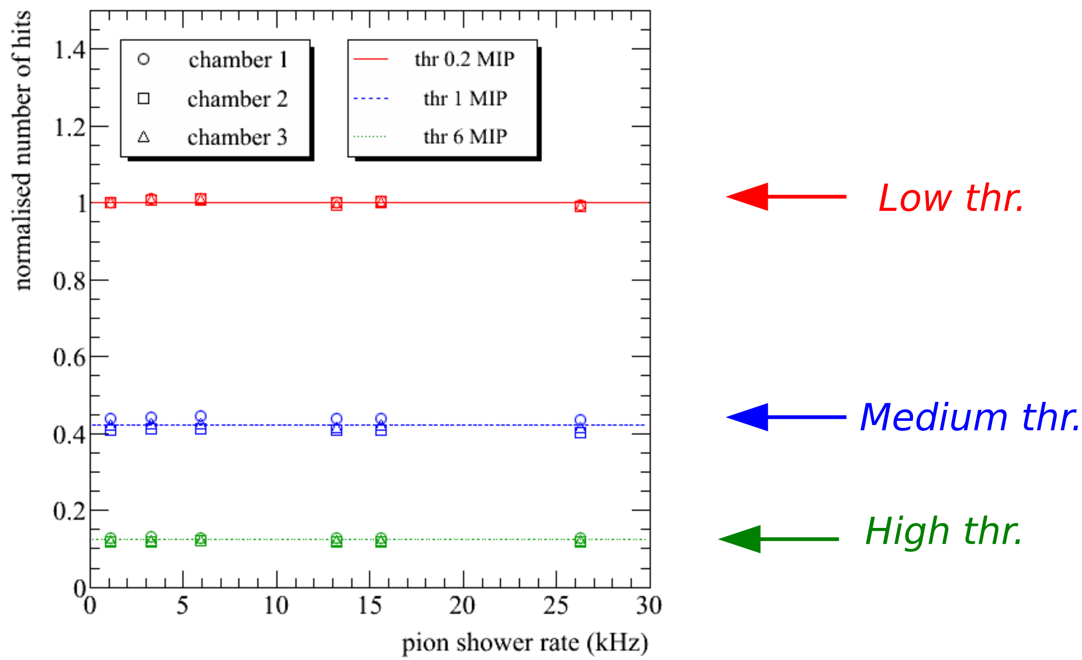


Beam rate up to 30 kHz on 1x1 cm^2 on the block surface

Mean N_{hit}=62, normalised to t_0 and 1st downstream prototype

Stable response for the 3 thresholds → constant gas gain





SPARKING in HADRON SHOWERS

Same setup. **Identify sparks as current peaks on HV slow-control system**

Count peaks and divide by the expected number of 150 GeV pion showers during spills

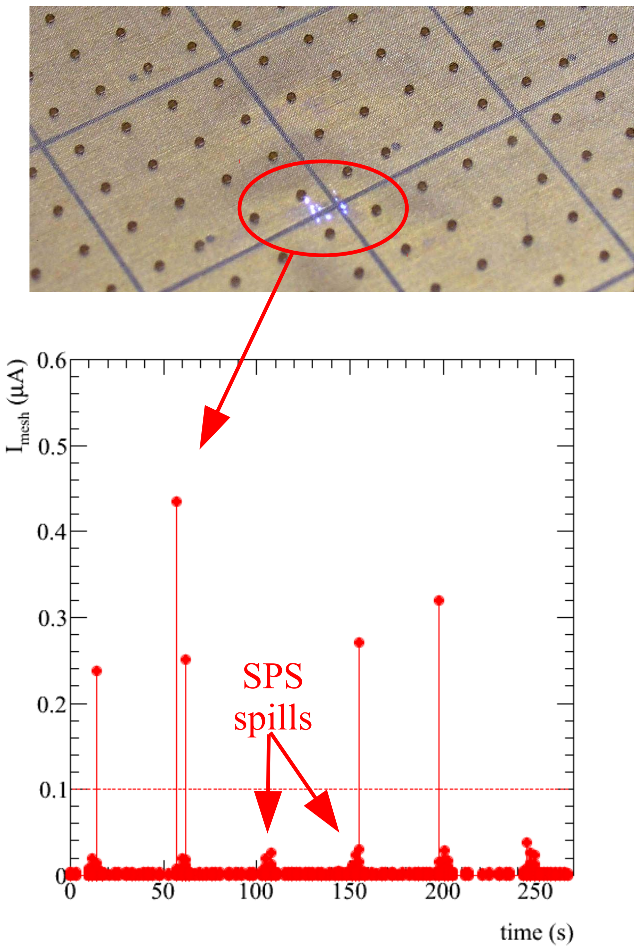
→ spark probability per showering pions

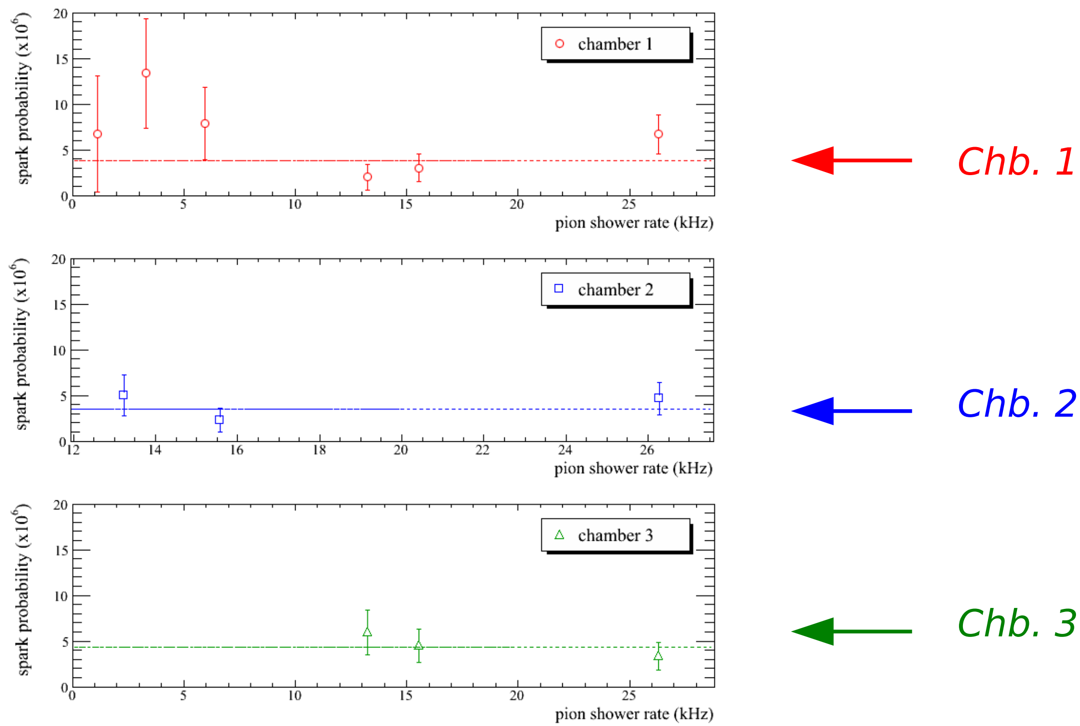
Probability / shower independent of rate, as expected

We measure a value of 5×10^{-6} / shower (at the shower maximum)

Expected hit rates at ILC in HCAL barrel < 100 Hz/cm^2

→ should be fine





PION SHOWER PROFILE (in a virtual Micromegas SDHCAL)

SDHCAL with 46 RPC and 4 Micromegas

Identify shower starting layer ($\sigma = \lambda_{int} \sim 10$ layers) & measure number of hits in Micromegas layers

→ N_{hit} distribution at various depths w.r.t. shower starting layer → longitudinal profile

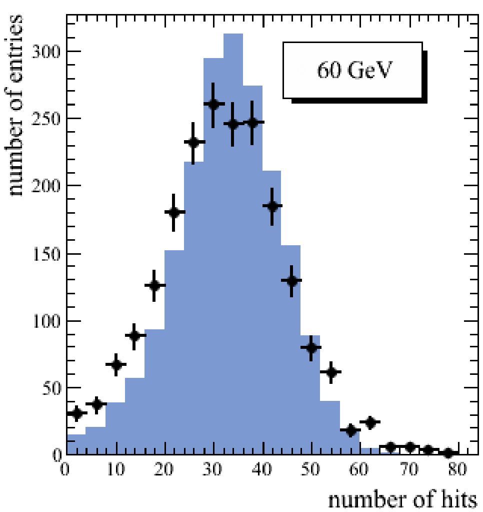
Shower profile measured at 20...150 GeV

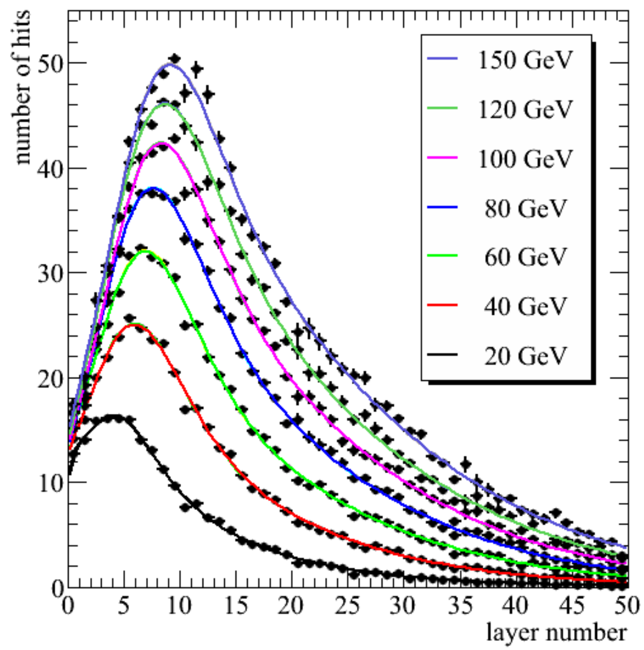
Fit the right function and integrate → mean N_{hit} that would be measured in a Micromegas-SDHCAL

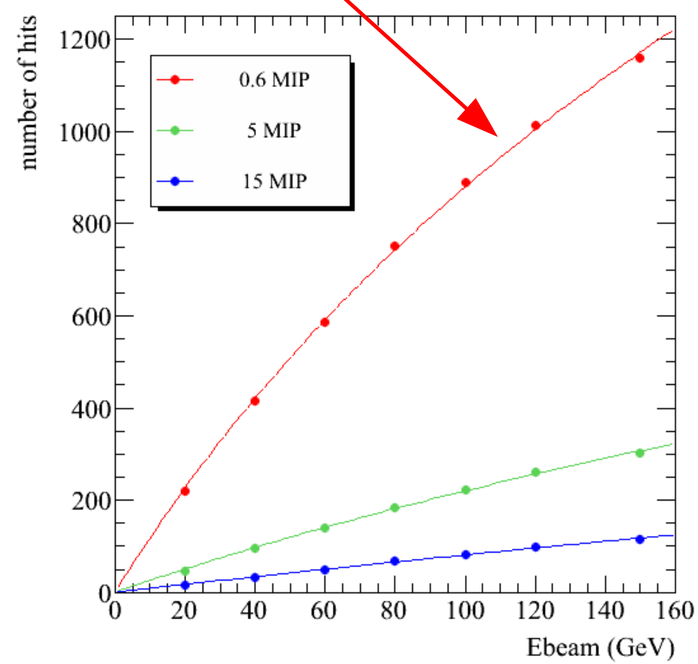
Calorimeter response for 3 values of threshold, expected saturation observed

(data being used to validate Monte-Carlo)

N_{hit} @ shower max







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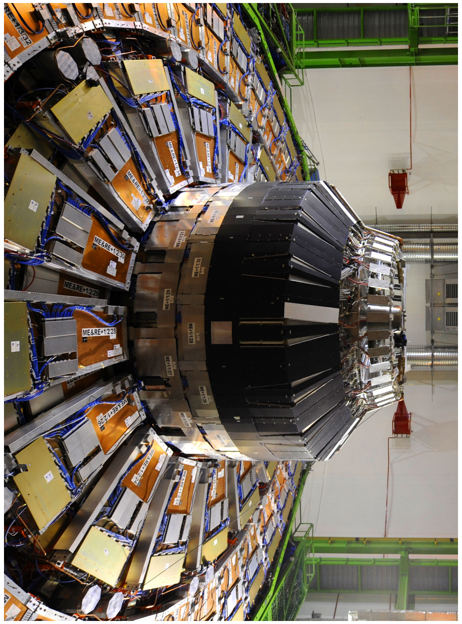
INTEREST for RESISTIVE MICROMEGAS

Beyond ILC: CMS is planning an upgrade of its forward calorimeters

Particle Flow option: GEM or Micromegas for the backing part

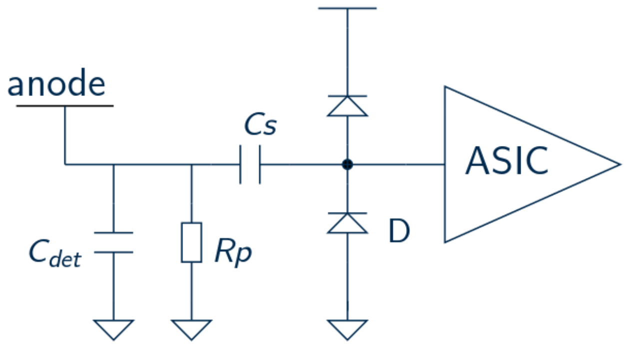
→ particle rates of several tens of kHz/cm^2 expected

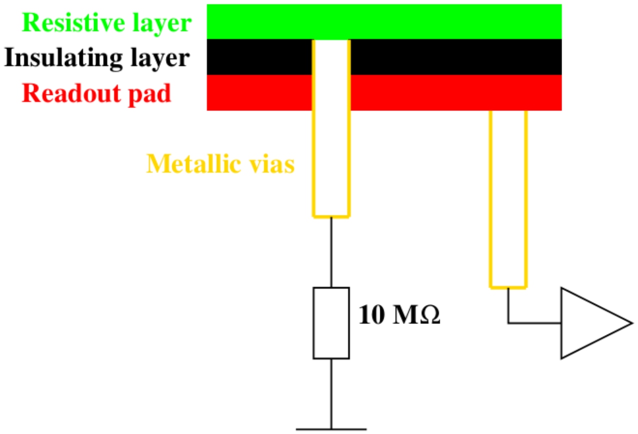


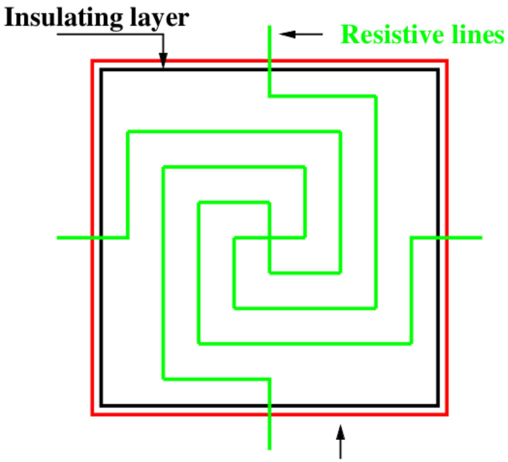
1x1 m^2 prototypes: Diodes on PCB (pads to preamps) & also integrated in ASIC

→ many components on PCB + does not quench discharge

Resistive coatings: no sparks, simpler PCB design & lower overall cost







Open questions & Prototyping work

Impact on spark probability, dynamic range, proportionality, rate-capability, hit multiplicity?

Small prototypes of 16x16 cm^2 with charge evacuation on PCB sides and through PCB.

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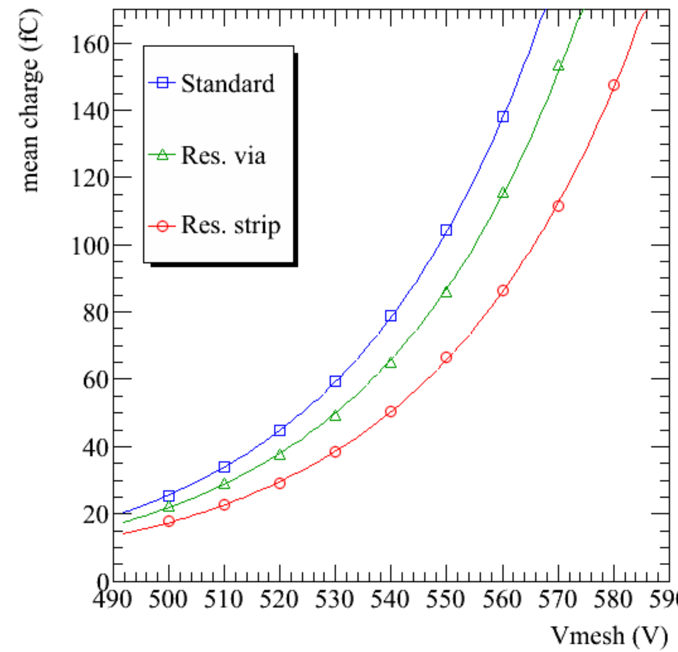
HV SCAN, SPARKING



DESY testbeam

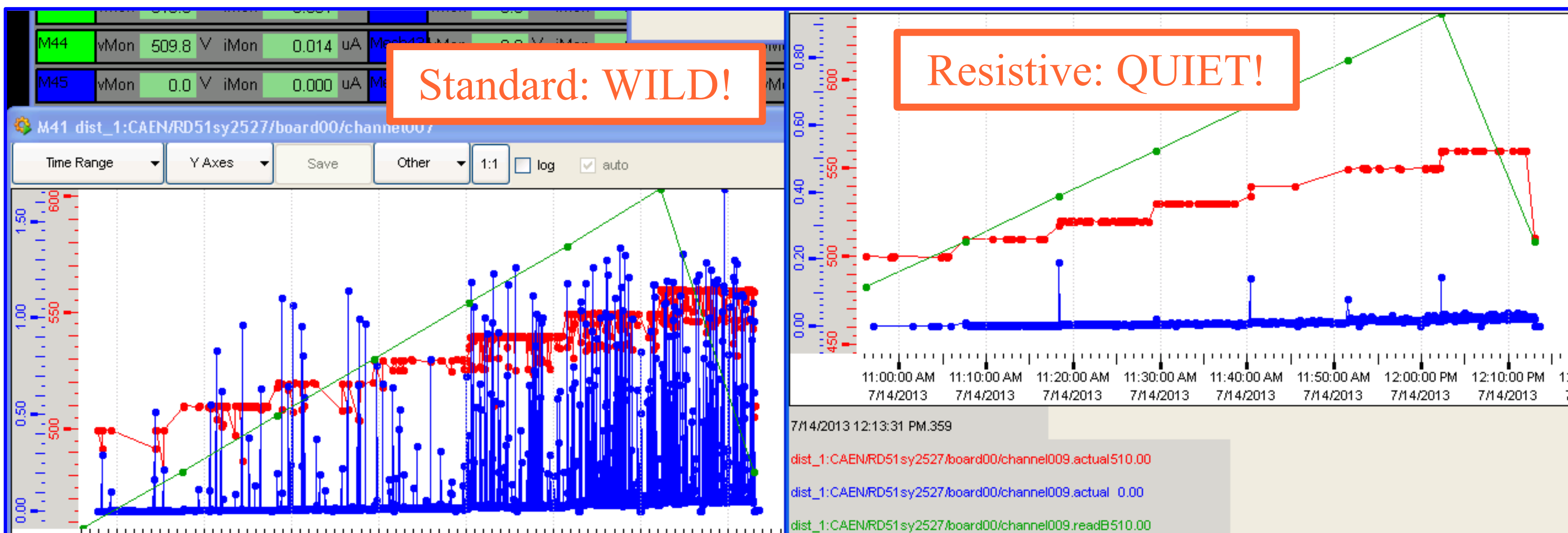
Stack of resistive & non-resistive (or standard) prototypes

Electron beam (1-5 GeV), Ar/CO_2 90/10, digital + analogue readout

In 1 kHz electron beam

Picked-up *signal in resistive prototypes is smaller* (@ given HV)

The 2 resistive configurations show *suppression of sparking*



Mesh current (blue) during HV (red) scan

RATE SCAN, EFFICIENCY

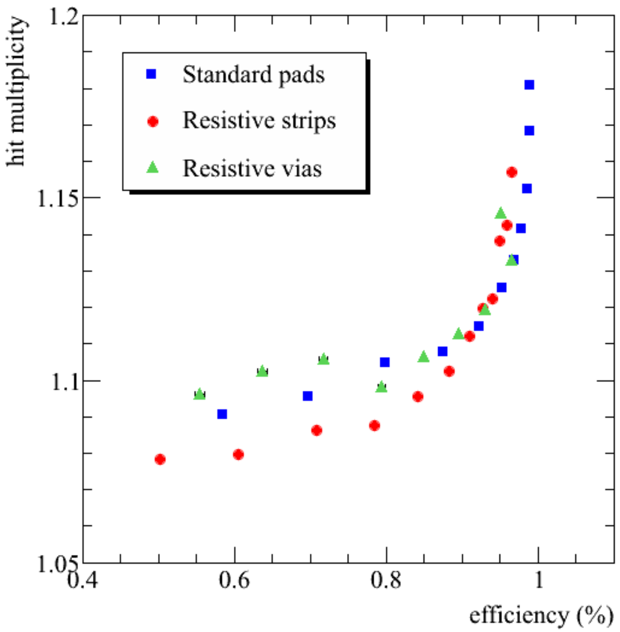
At low rates, the responses to traversing electrons of std. & resistive prototypes are similar

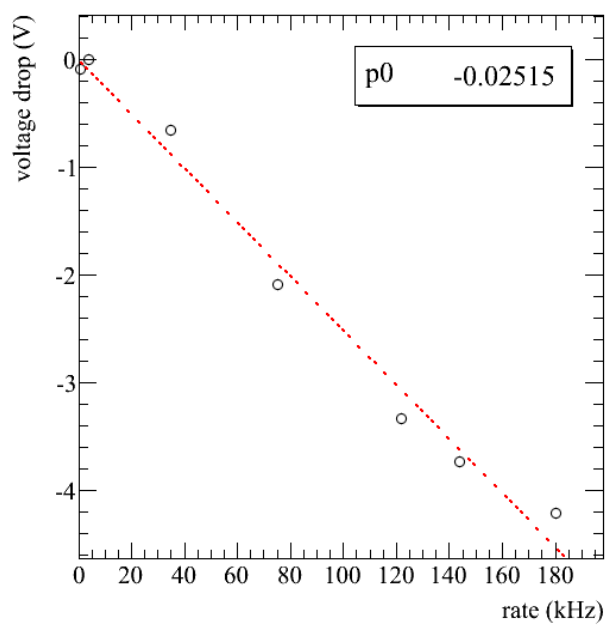
efficiency larger than 95% & hit multiplicity below 1.15

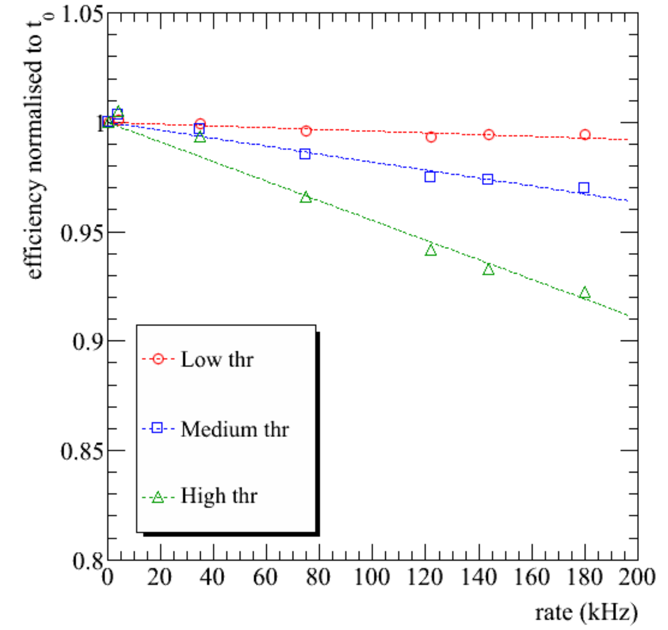
Threshold-dependent loss of efficiency with rate (beam spot 2x2 cm^2) in resistive prototypes

Plotting versus rate, one verifies the Ohmic law → R value of the prototypes of ~ 2 GΩ.

PS: 1 kHz beam → $10^3 * 30\ e^- * 1.6.10^{-19}\ C * 3.10^3 \sim 1.6.10^{-2}$ nA



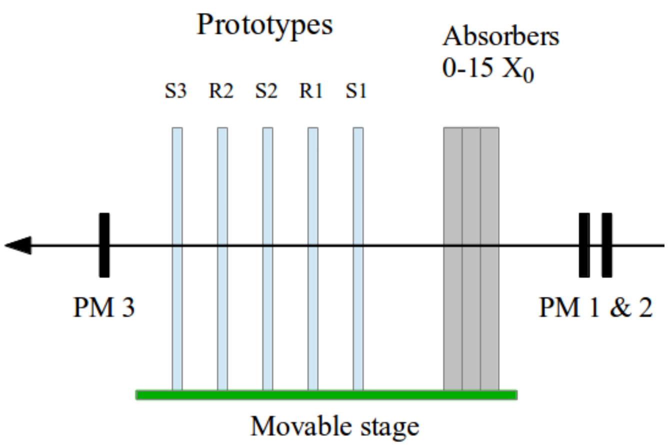




LINEARITY in e^- SHOWERS

At low rate (1 kHz/cm^2), is linearity spoiled by resistive layer?

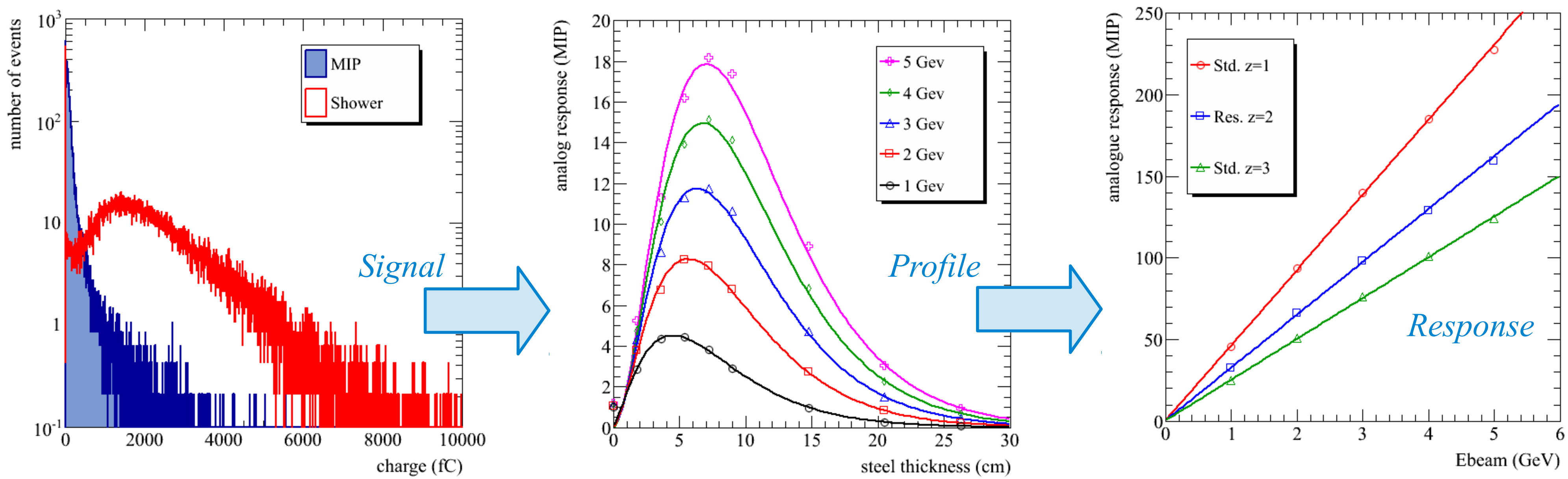
→ Comparison of analogue response of Std. & Res. prototypes



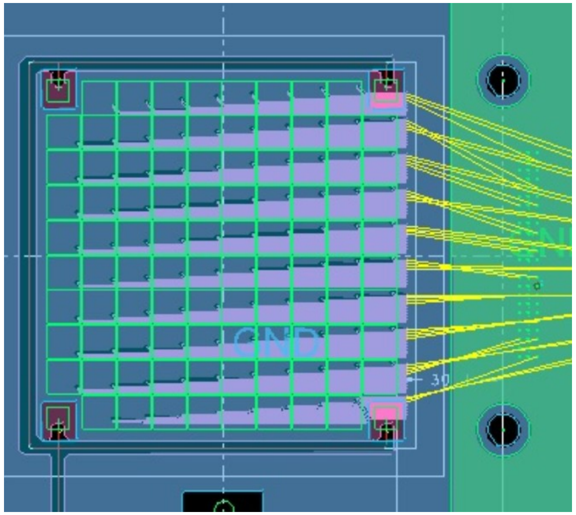
Measurement of Calorimeter EM-response with single layers

At various energies: add absorbers, measure signal distribution
Build & integrate longitudinal profiles → EM-response

Slopes are different (downstream prototypes see more material), but linearity seems preserved



FURTHER STUDIES



Loss of signal observed at high rates (as loss of efficiency)
but not observed for high energy deposits (as loss of EM-linearity)
Should probably show up at higher energy (> 5 GeV)

Optimisation of resistivity for best linearity
→ New prototypes with coatings varying over a wide range of resistivity
Common R&D project with IRFU (Saclay) and NCSR (Demokritos)
→ testbeam SPS in 2015

CONCLUSIONS

Micromegas can be applied as a sensitive element in a sampling calorimeter at a future LC

No calorimeter yet but single layers of 1x1 m^2 show excellent performance

While waiting for a LC, higher rate applications with resistive Micromegas are investigated

Will resistive Micromegas be adequate for calorimetry? We'll find out!

!Thank you for your attention!

For more details:

Test in a beam of large-area Micromegas chambers for sampling calorimetry
arXiv:1405.1024 [physics.ins-det]

Construction and test of a 1×1 m2 Micromegas chamber for sampling hadron calorimetry at future lepton colliders
Nucl.Instrum.Meth. A729 (2013) 90-101