Micromegas for calorimetry at CLIC

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CLIC Detector & Physics Collaboration meeting
1-2/10/2013, CERN

→ Gaseous calorimetry at a future LC

→ Digital calorimetry: expected single pion performance

→ Large area prototypes: detector design and testbeam results

Gas detectors for calorimetry

Pros

Cheap, cover large areas, no shielding against light necessary

Can be finely segmented → position / angle resolution

Age well + sustain heavy dose / rate → easier calibration/monitoring w.r.t. light sensitive devices

But

Low density → sampling calorimetry only

Low sampling fraction → modest energy resolution, especially for measuring EM showers
(can be improved if gas density is increased)

Imaging (Particle Flow) calorimetry for the measurement of jet energy

Use the most precise detector to measure the jet particles (→ shower separation necessary)
Expected performance are impressive (W/Z separation) even with modest calorimeter resolution

→ Highly granular HCAL using gaseous active elements
and 1-bit or 2-bit readout to minimise power consumption & heat dissipation in the calorimeters

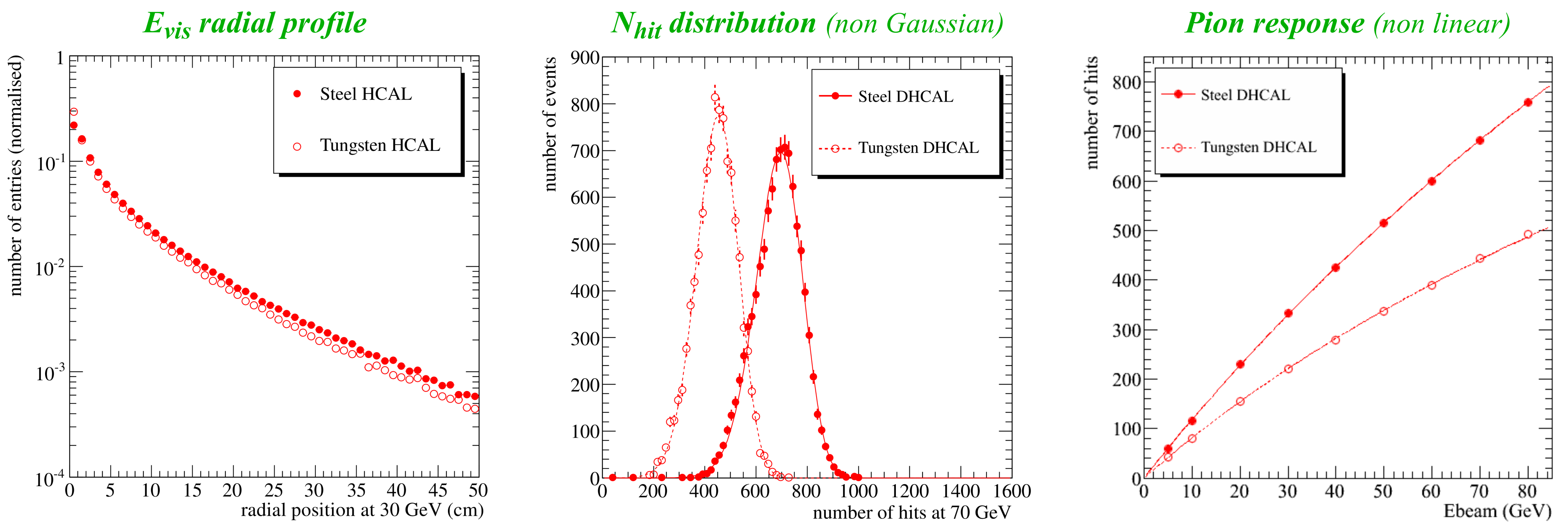
Digital calorimetry at a future LC (1/2)

Simulation study of a 11 λ_{int} deep SiD-like SDHCAL with Geant4 (v5.8, QGSP_BERT)

Pion showers in an Argon/Steel (ILC) and Argon/Tungsten (CLIC) calorimeters

100 layers of 100x100 cm^2 with 1x1 cm^2 cells

Argon thickness of 3 mm, absorber thickness adjusted to obtain 11 λ_{int}



Pion showers are more collimated in W (EM energy more concentrated)

→ Lower number of hits in W than in Fe & stronger saturation of the response

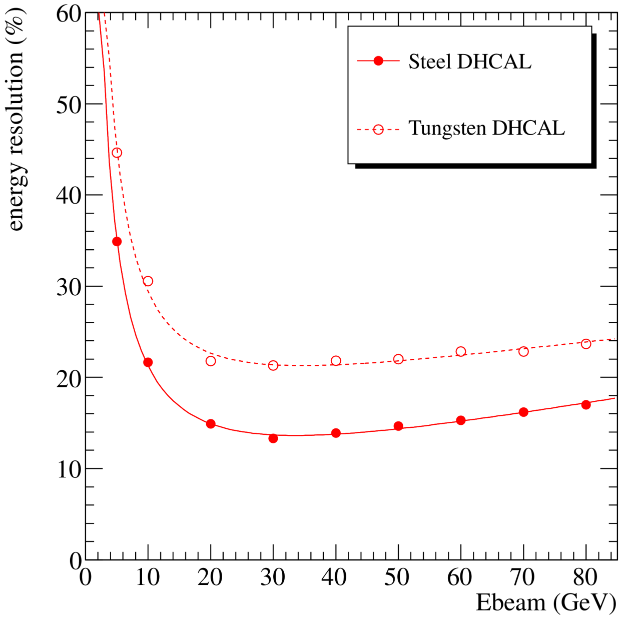
Digital calorimetry at a future LC (2/2)

The saturation of the response results in a degradation of the energy resolution

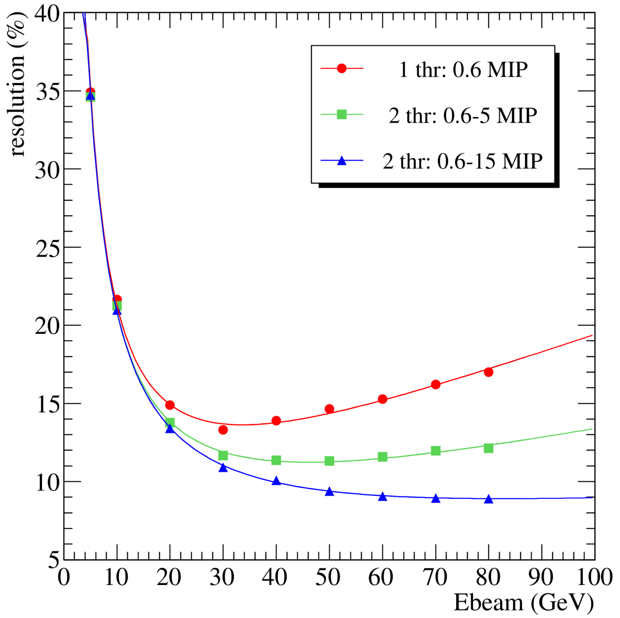
→ W shows worse resolution due to a stronger saturation and lower number of hits

Using information from 1 additional threshold, it is possible to mitigate the effect of saturation
→ works in both HCAL, with an optimal value for the 2nd threshold of 15 MIP for steel absorbers

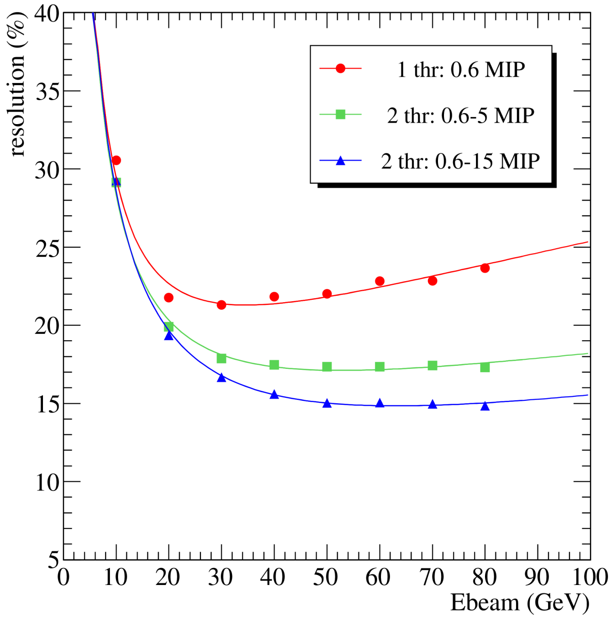
DHCAL resolution



SDHCAL steel

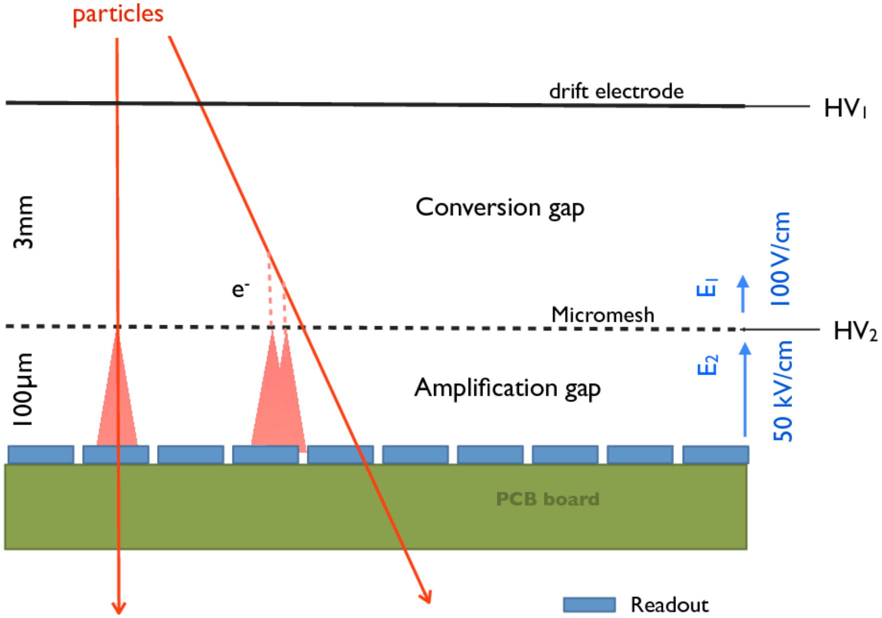


SDHCAL tungsten



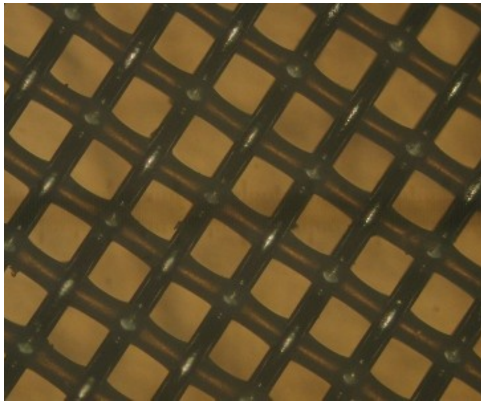
Other compensation techniques *based on the detailed spatial information exists (use hit density, MIP ID...)*

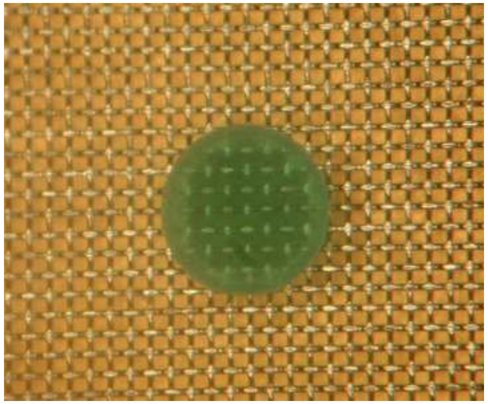
Micro mesh gaseous structure (Micromegas)



<u>Bulk manufactured Micromegas</u>

Steel mesh held between small equally spaced pillars
Robust and good signal uniformity





<u>Operating principle</u>

Ionisation → drift of primary electrons → multiplication of electrons

(avalanche ions collected at the mesh in 50-100 ns → no space charge effect (& high rate capability)

<u>in a 3 mm argon gap</u>

Primary charge: 30 e- on average per MIP

Drift of electrons to the mesh in ~ 50 ns

Maximum multiplication factor given by the spark limit: e.g. 10^4-10^5 for X-rays

Single electron signal has a fast (~1 ns) and a slow (~50-100 ns) component

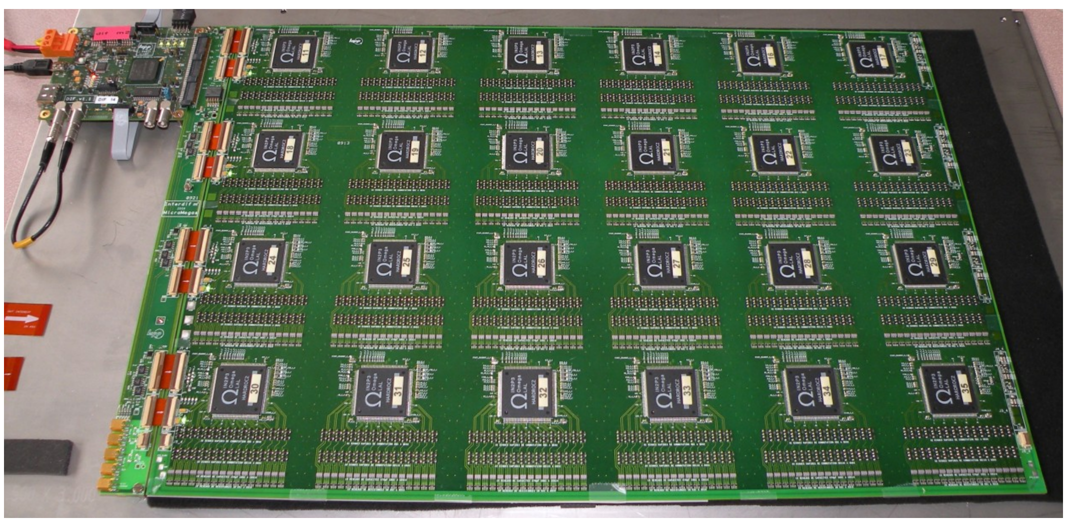
Micromegas for calorimetry

Particle Flow approach

Imaging power → high granularity and channel density → embedded front-end electronics

Calorimeters should be inside the solenoid → *compact design and thin active layers*

Printed circuit board (8 layers, 1.2 mm) with Bulk mesh + 1x1 cm^2 anode pads + ASICs
= Active Sensor Unit or ASU



MICROROC circuitry

Low noise preamp (1500 e- noise)

2 shapers ≠ gains and variable peaking time

3 discriminators

127 event depth memory + timestamping

At a gas gain of 10^3

S_{MIP} / N = 5 fC / 0.25 fC = 20

Shaper1 dynamics = 200 fC ~ 40 MIP

Shaper2 dynamics = 500 fC ~ 100 MIP

No room inside the calorimeters for active cooling → low power electronics

MICROROC

3.7 mW /channel @ 3.5 V + power-pulsing + 3 threshold / channel → **SEMI-DIGITAL READOUT**

Large area Micromegas

Large area chambers are built from 6 ASUs of 32x48 cm^2

A 1x1 m^2 prototype consists of 3 slabs with DIF + interDIF + ASU + ASU

This design introduces very little dead zone (below 2%) and is fully scalable to larger sizes

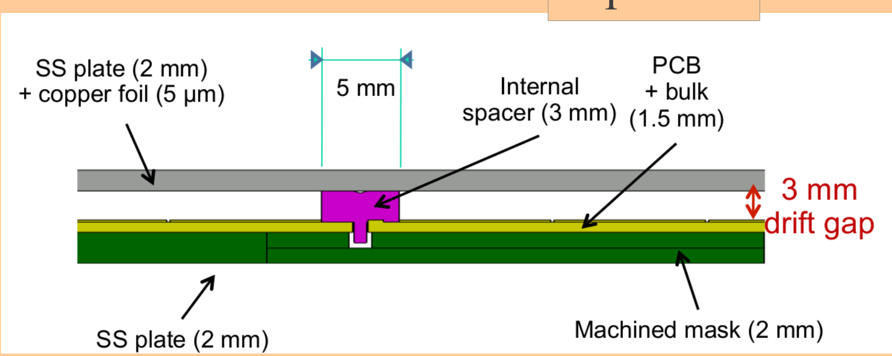
The drift gap is defined by 3 mm spacers inserted between ASUs and a frame

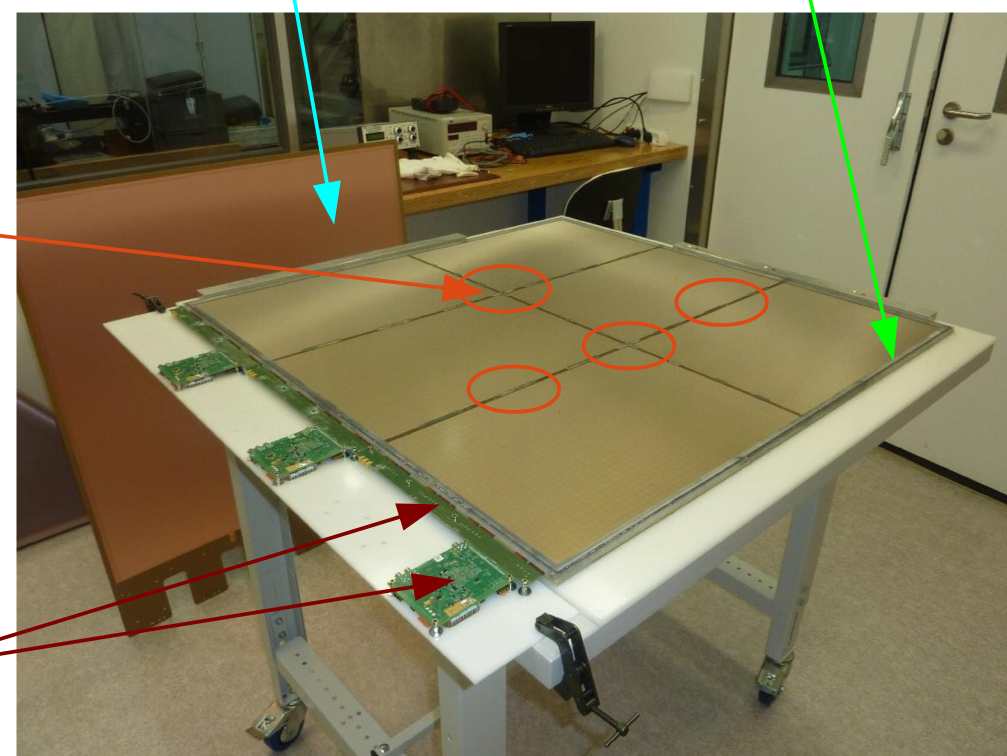
The final chamber thickness is 9 mm

Drift cover

Frame with 2 gas pipes

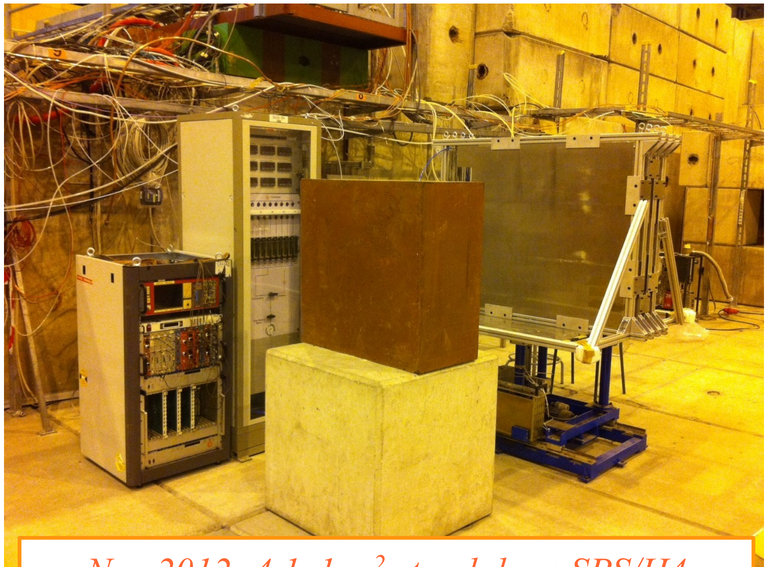
Spacers



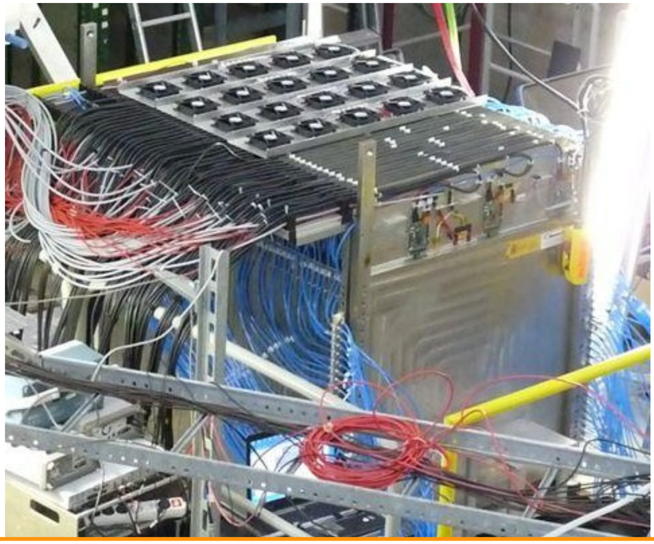


Readout boards (DIF+interDIF)
Also provide ASIC LV & mesh HV

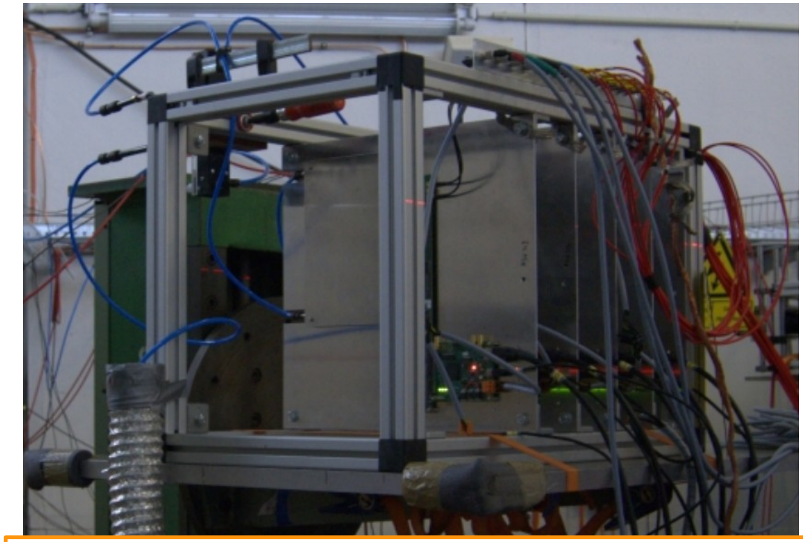
Prototypes in test beams



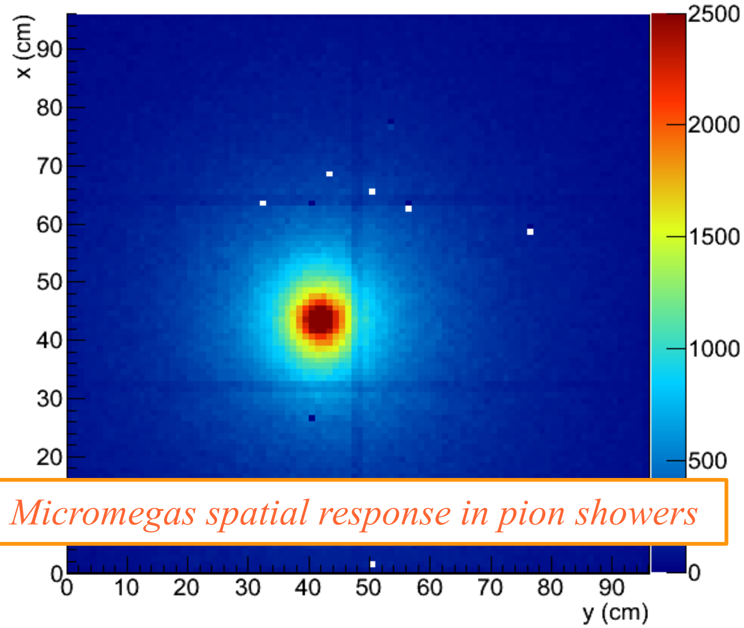
Nov 2012: 4 1x1 m^2 standalone SPS/H4



Nov 2012: 4 1x1 m^2 in RPC-SDHCAL SPS/H2



July 2013: 5 16x16 cm^2 standalone DESY/TB22

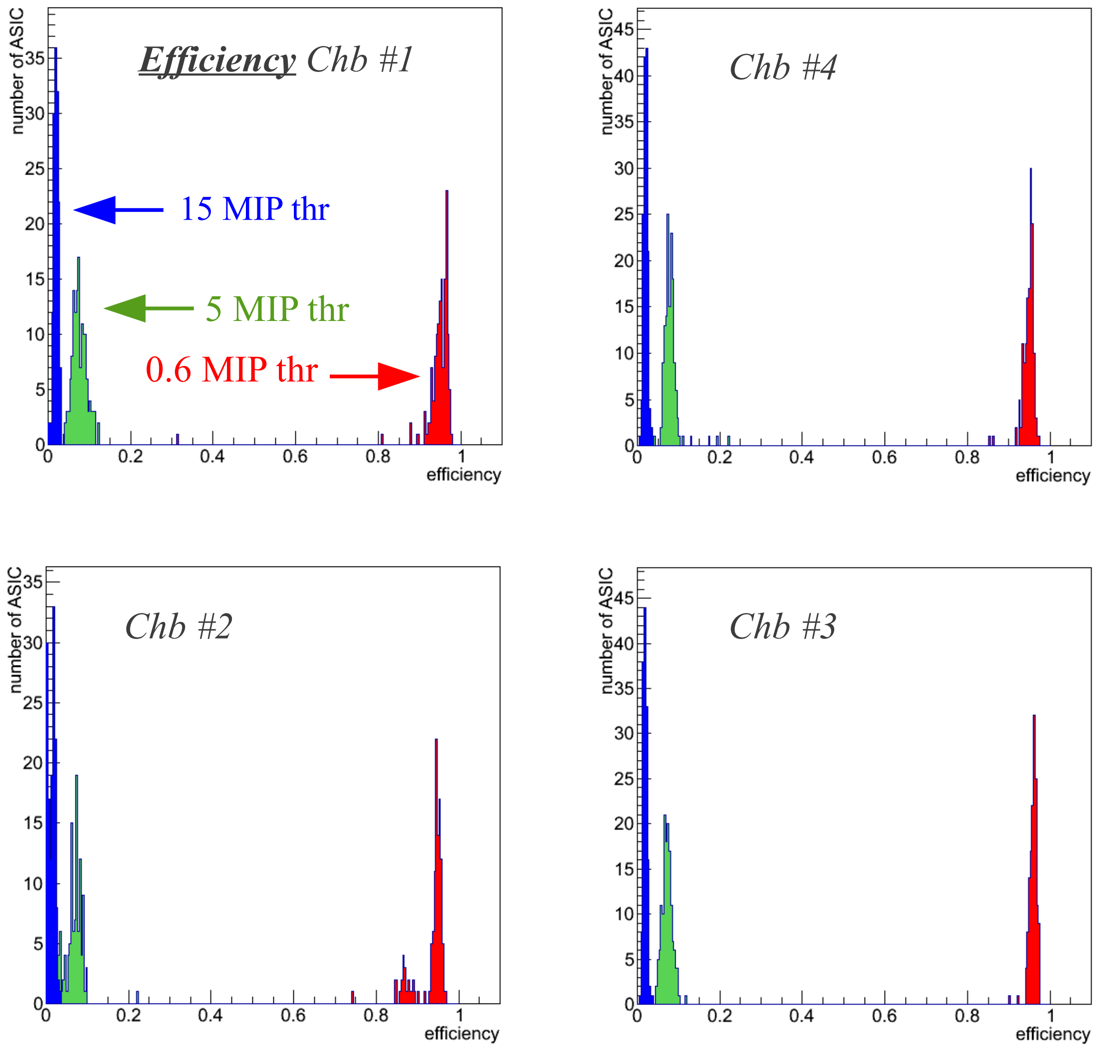


Micromegas spatial response in pion showers

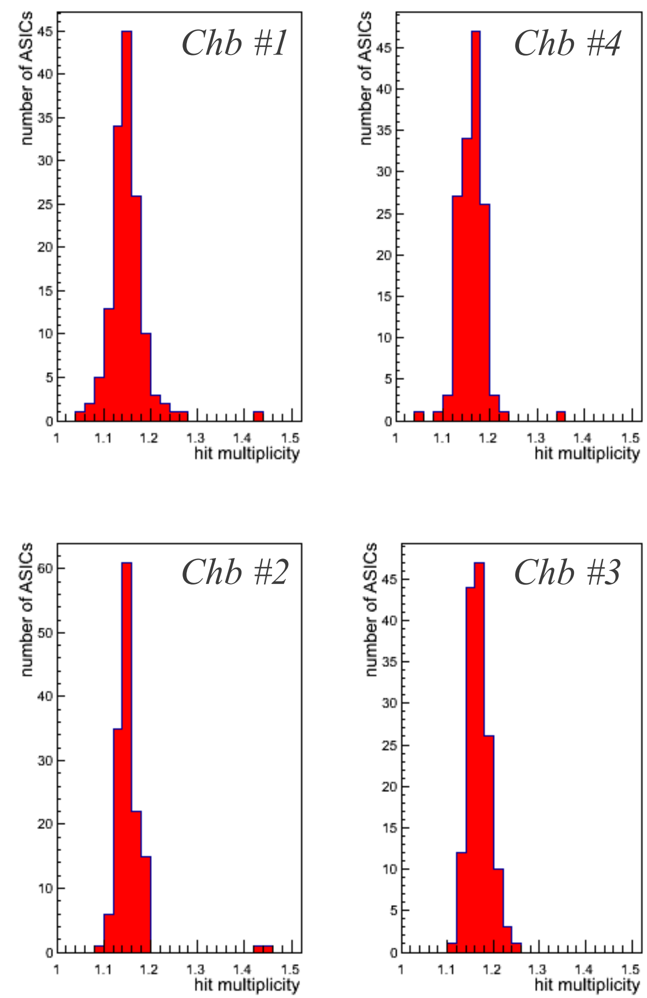
Response to MIPs

November 2012: <u>4 large Micromegas tested in the CALICE RPC-Fe-SDHCAL</u> (Micromegas @ layer 10,20,35 50)

→ Position scan (1 measurement / ASIC) on whole prototype area possible using RPCs as telescope



Hit multiplicity



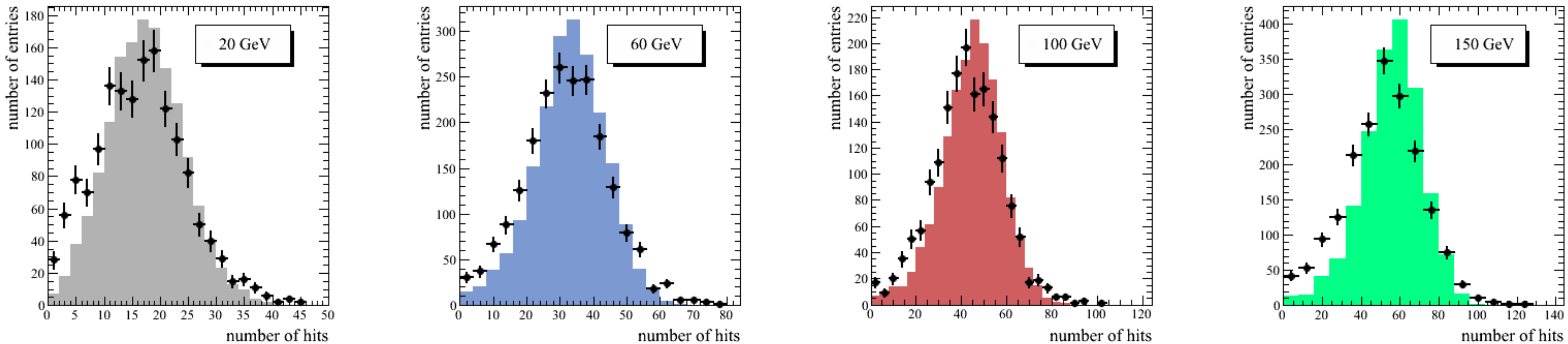
Uniform performance over 4 m^2 → precise calibration, reproducible manufacturing process

Number of hits in pion showers

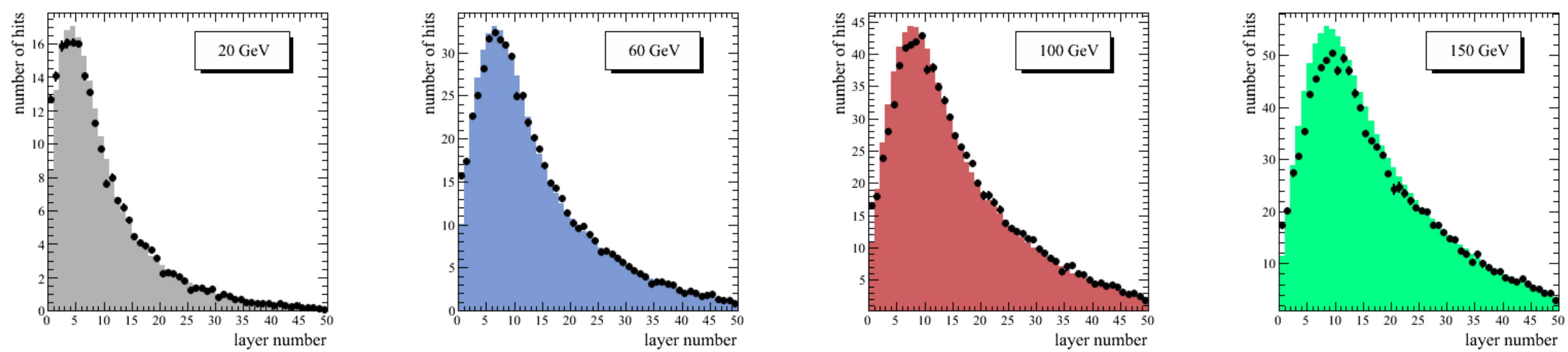
November 2012: 4 large Micromegas tested in the CALICE RPC-Fe-SDHCAL (Micromegas @ layer 10,20,35 50)

→ Energy scan from 20 to 150 GeV (RPC used to identify the shower starting layer) → $N_{hit}(z)$ with Micromegas

Testbeam/Monte Carlo: *N_{hit} distribution at shower max at 20, 60, 100 & 150 GeV (available for any layer)*



Testbeam/Monte Carlo: *Longitudinal profile at 20, 60, 100 & 150 GeV (each point is the mean of N_{hit} distribution)*

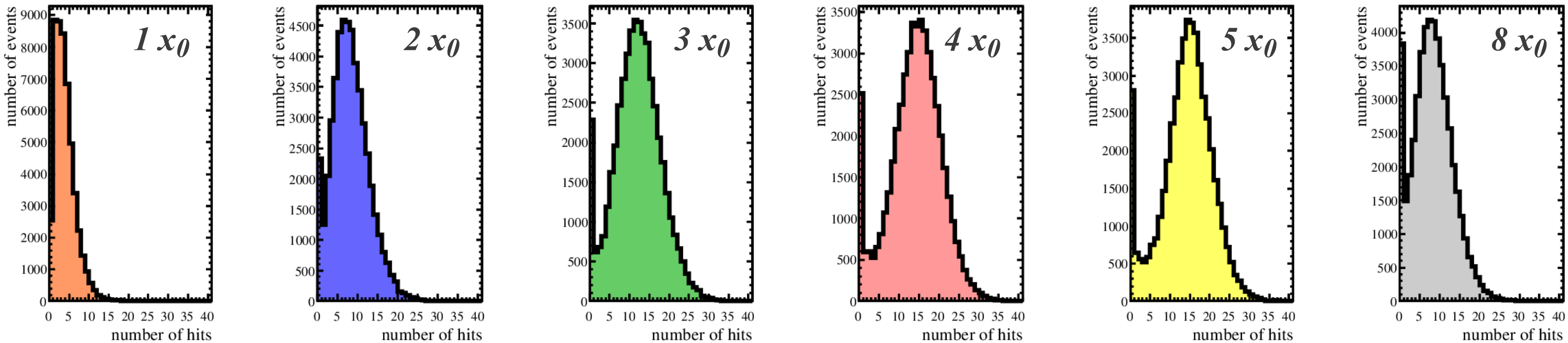


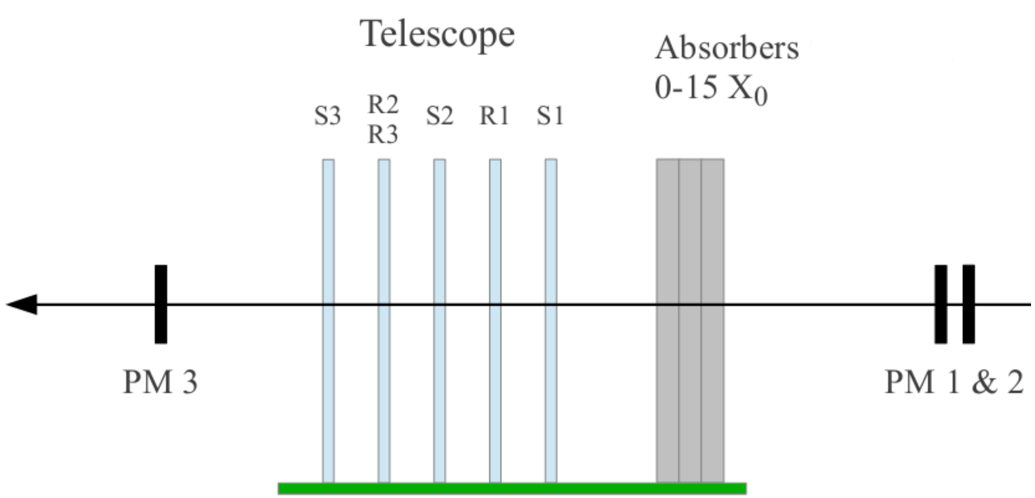
Number of hits in electron showers

July 2013: standalone test of small prototypes at DESY ($16x16\ cm^2$) with various thickness of steel in the beam line

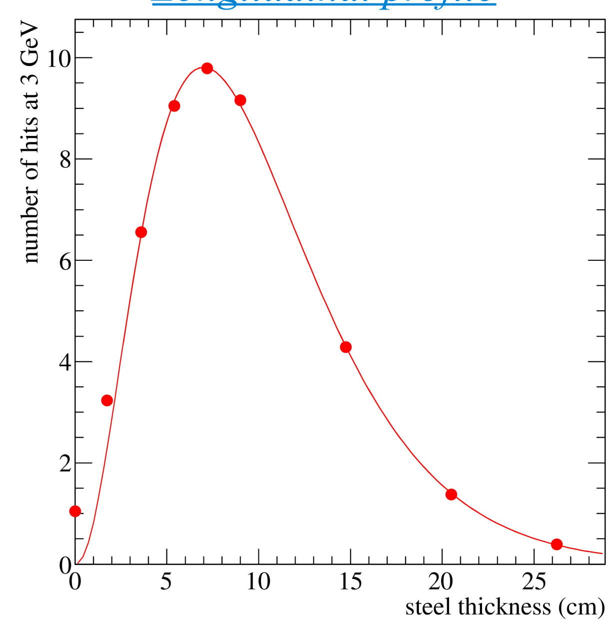
→ Energy scan from 1 to 5 GeV (measure N_{hit} in first chamber) → N_{hit}(Fe thickness) ~ N_{hit} (z)

Number of hits – 3 GeV electrons





Longitudinal profile



Response of a Micromegas SDHCAL

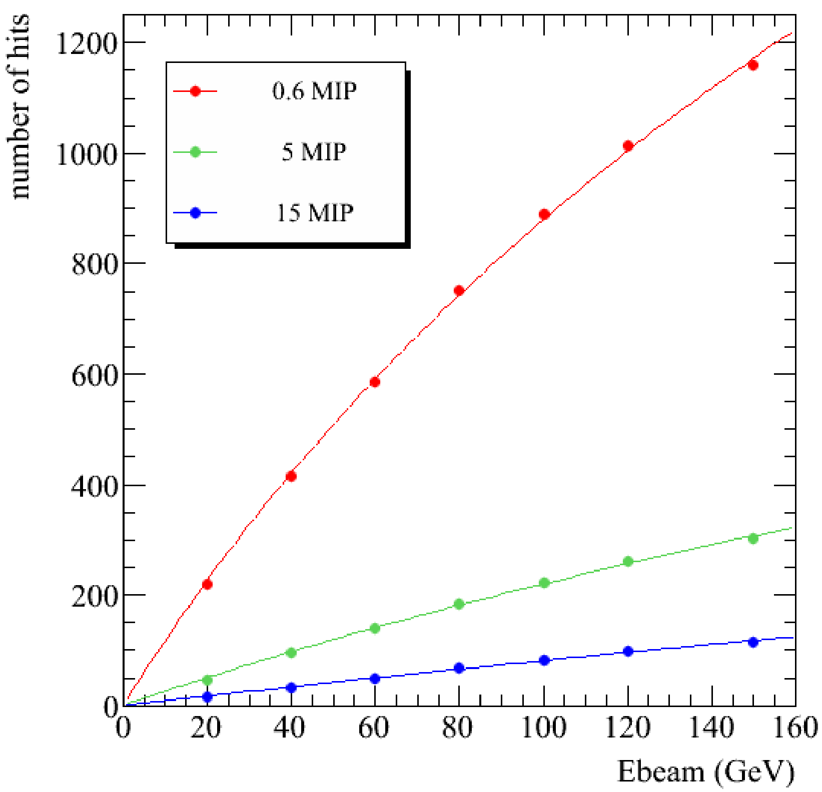
The response is obtained by integration of the longitudinal profiles (available for the 3 readout thresholds)

For the electron data, that requires converting steel thickness into number of SDHCAL absorbers

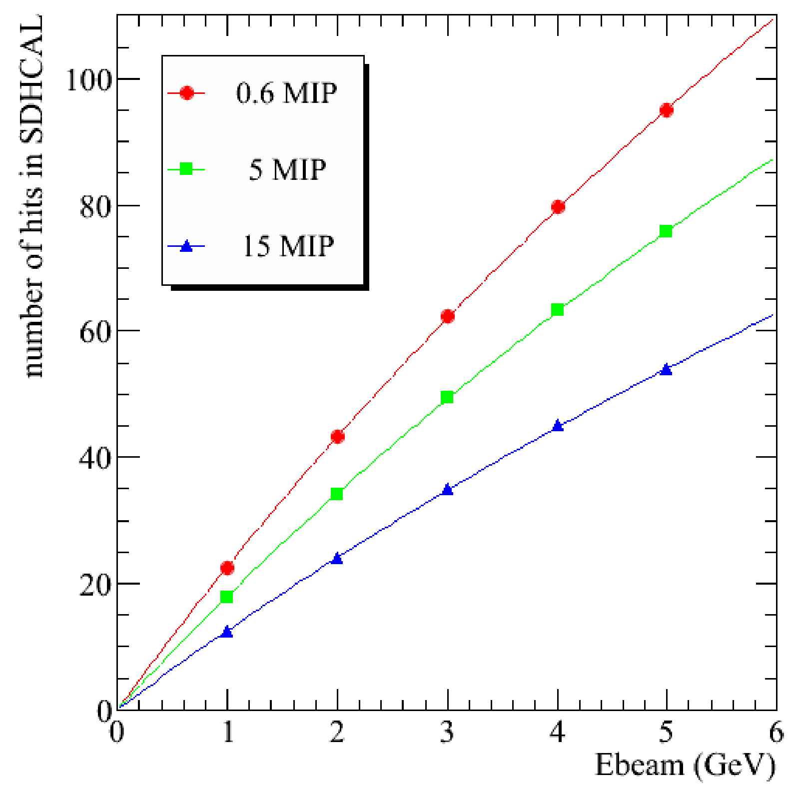
EM shower more dense → Probability to cross higher thresholds is higher than in pion showers

Lots of physics with a few layers, comparison to Monte Carlo simulation on-going.

Pions 20-150 GeV (SPS)



Electrons 1-5 GeV (DESY)

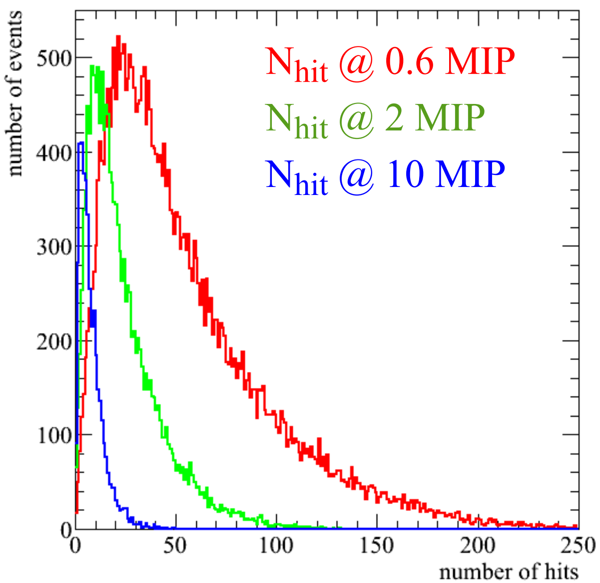


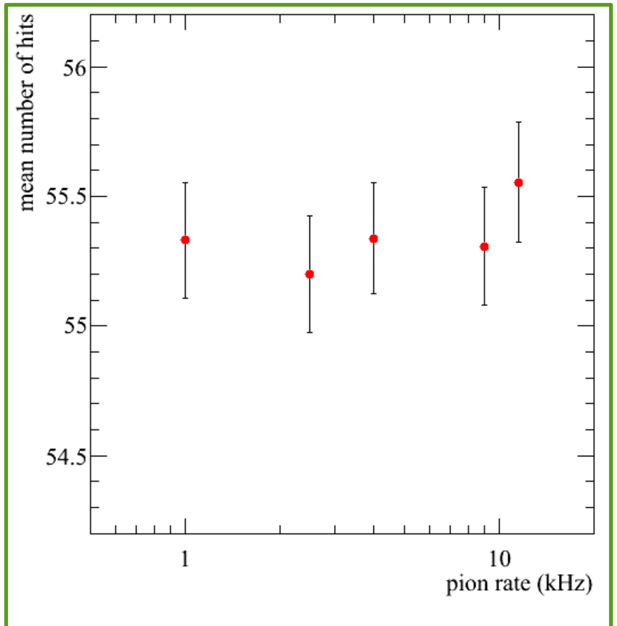
Effect of pion shower rate

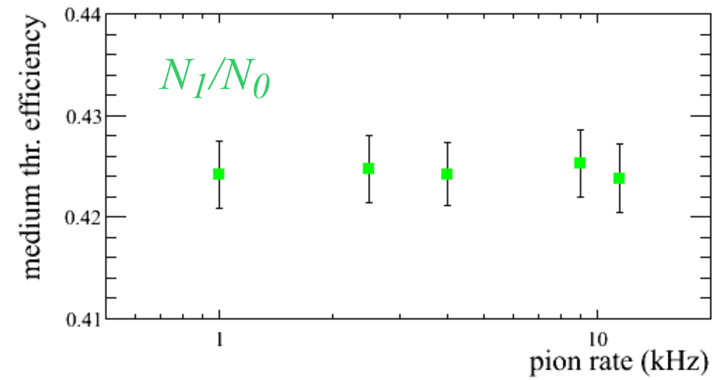
Expected and verified: no rate dependence of the response (at least up to 10 kHz pion rate)

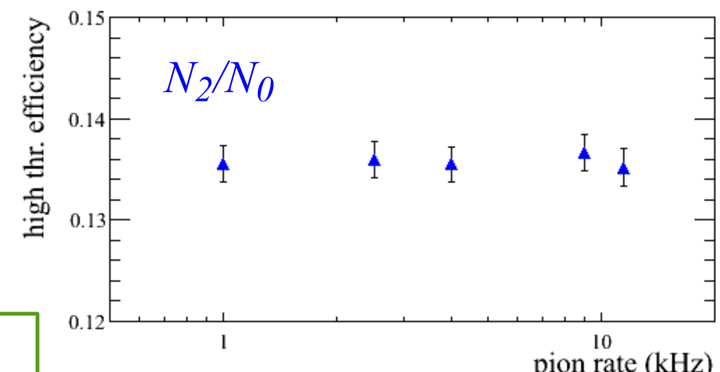
Mean number of hits is constant+ the fraction of hits above higher threshold is constant → No space charge effects

N_{hit} of 3 thr @ 1 kHz	***Mean N_{hit0} VS rate***	***Ratio N_{hit1}/N_{hit0} & N_{hit2}/N_{hit0} VS rate***









On average 55 hits are recorded per showering pion

At 10 kHz → at least 550 000 shower particles cross the chamber per second!

Stable HV behaviour of the chamber, a few sparks at the highest rate (→ little dead time)

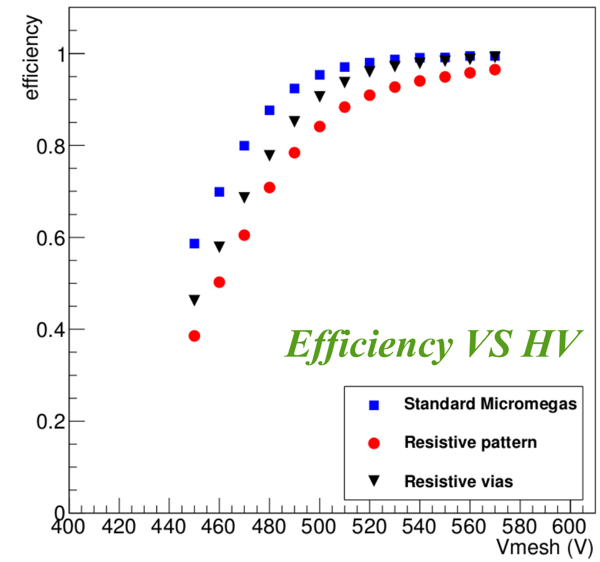
Spark-less Micromegas

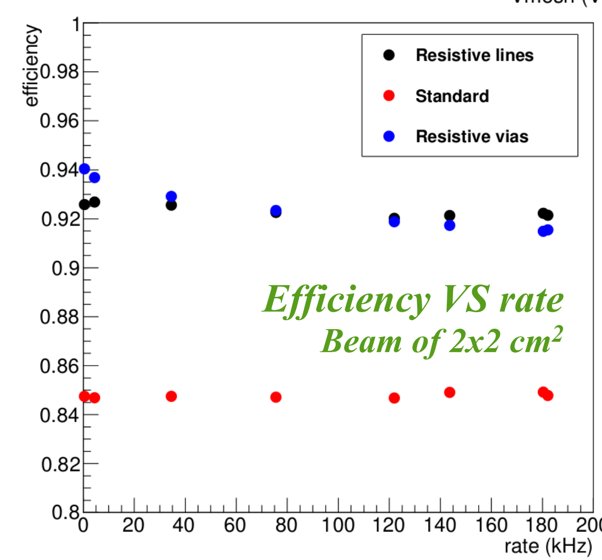
Replace standard ASIC protections against sparks (diodes) by resistive coatings on the anode pads

→ less components on PCB, industrialisation of the process possible

Small loss of signal compensated by increased of gas gain

Loss of rate capability expected (not observed yet)





Conclusions

Active R&D on Micromegas for calorimetry at LAPP

Electronics, mechanics, readout system (DAQ)...

Successful beam-test campaigns

→ excellent performance of 1x1 m^2 prototypes to MIPs & pion showers

→ resistive spark-protection implemented and tested on 16x16 cm^2 prototypes

Monte Carlo study of semi-digital hadron calorimetry (single particle) performance

→ Mechanisms behind saturation being understood

→ SDHCAL for CLIC : smaller pads or multi-bit readout?

Testbeam data available for validation of Monte Carlo simulation