Micromegas for Particle Flow Calorimetry

Application for gaseous sampling hadron calorimetry with multi-thresholds readout

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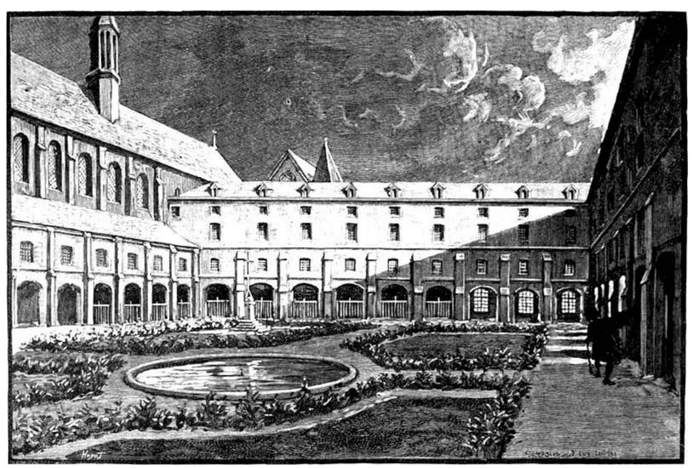

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- Overview of the R&D (3)
  - Large area Micromegas with integrated front-end electronics
  - PCB and ASIC design, protection against gas discharges
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- Conclusion and future challenges (1)

Introduction: Micromegas in the CALICE collaboration

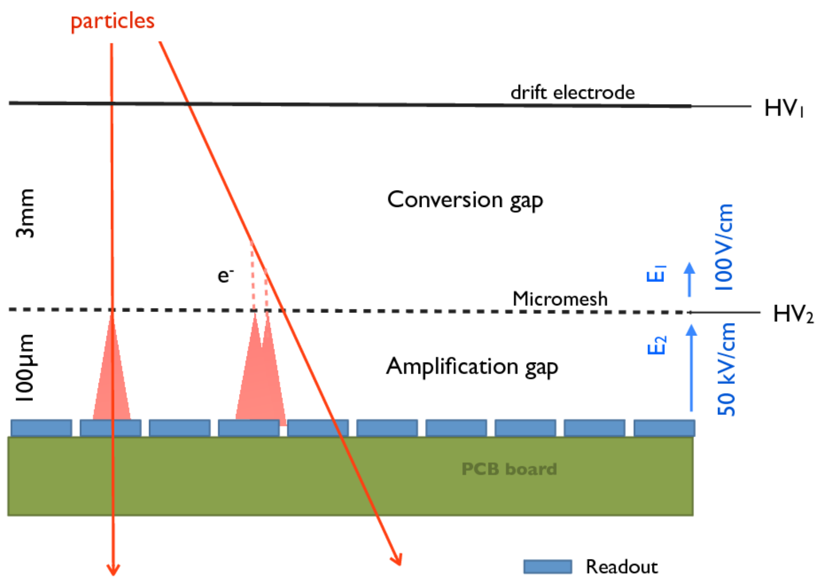
Operating principle

Ionisation in 3 mm gap filled with argon
30 pairs in 3 mm from MIPs

Drift
Collection at the mesh in 50 ns

Multiplication in 128 µm gap
By factor > 10^4, controlled by the mesh voltage
Takes ~1 ns for electrons and ~100 ns for ions

MIP signal
Between 1-20 fC depending on mesh voltage

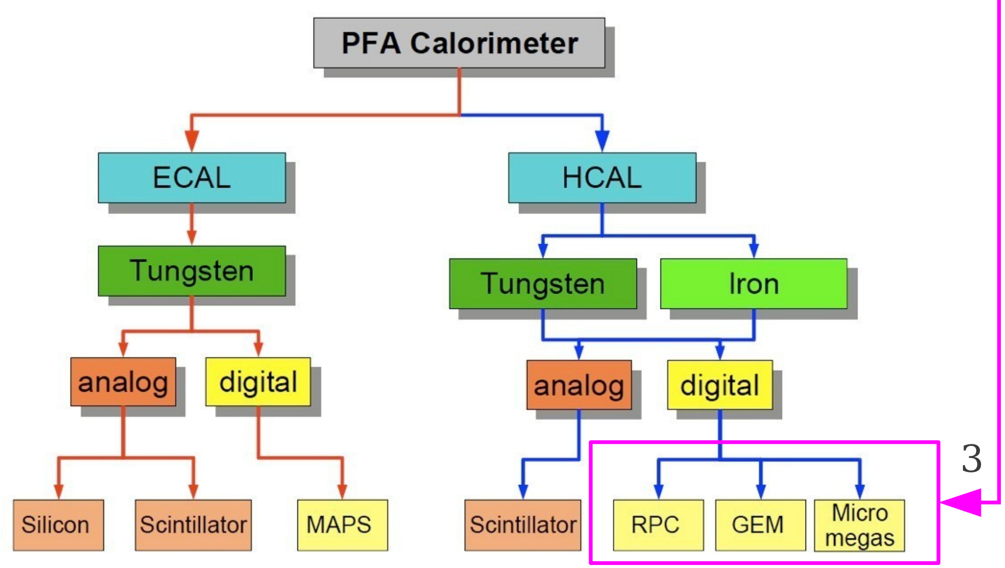


R&D in CALICE

Focuses on sampling calorimeters
with fine transverse & longitudinal segmentation
→ silicon & scintillators for the ECAL
→ scintillators & gas for the HCAL

The CALICE digital HCAL

Steel (4.5 λ_{int} deep in ILC-SiD) or tungsten absorbers
Gaseous detectors with 1x1 cm^2 pads
Sampling fraction ~ 10^{-5}
→ digital readout 1-bit → DHCAL

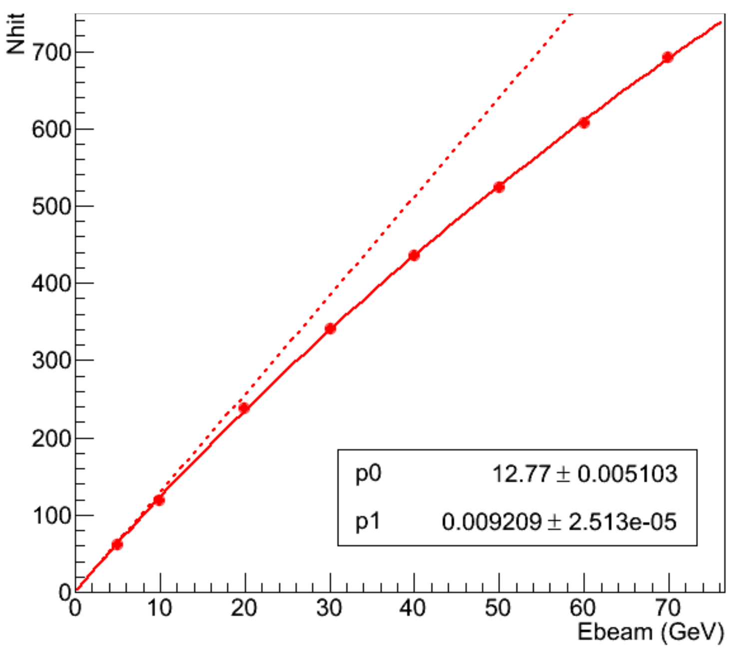


Fe-DHCAL: energy resolution for single pions (Monte Carlo study)

Calorimeter model in Geant4

100 layers of 1x1 m^2 (~10 λ_{int} deep)
Passive layers: mainly 17 mm of steel
Active layers: 3 mm of gas with 1x1 cm^2 pads
Threshold / cell ~ 0.1 MIP
10^4 pion / energy from 5-70 GeV

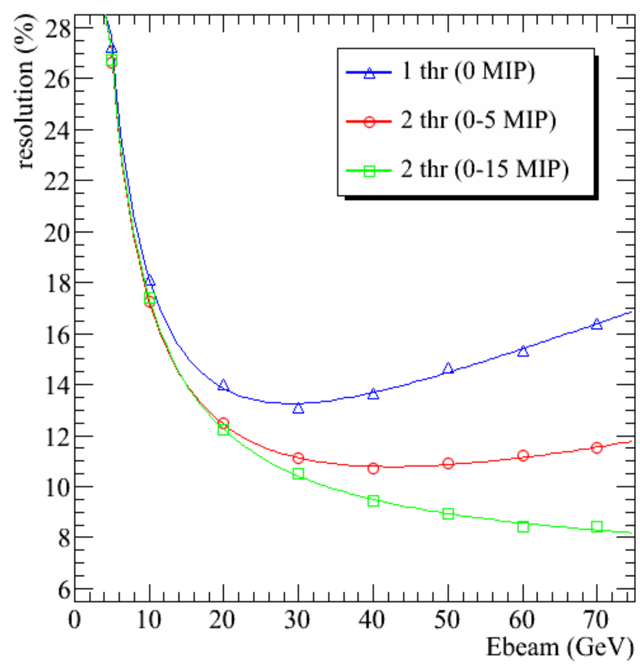
Saturation of the pion response because of the concentrated EM energy:
Shower size (R_M & X_0) VS pad size!



Energy resolution with 1 or 2 thresholds

1 threshold (DHCAL)
Degradation of the energy resolution above 30 GeV

2 thresholds (semi-digital HCAL, SDHCAL)
Correction of the saturation possible at least up to 70 GeV



Need at least 2 thresholds → 2-bit electronics
Need gas detector free of space charge effects otherwise signal (2 MIP) ≤ 2.signal(1 MIP) → **Micromegas**

R&D: large area Micromegas with integrated electronics

Large area chambers are built from a basic unit called Active Sensor Unit (or ASU) of 32x48 cm^2

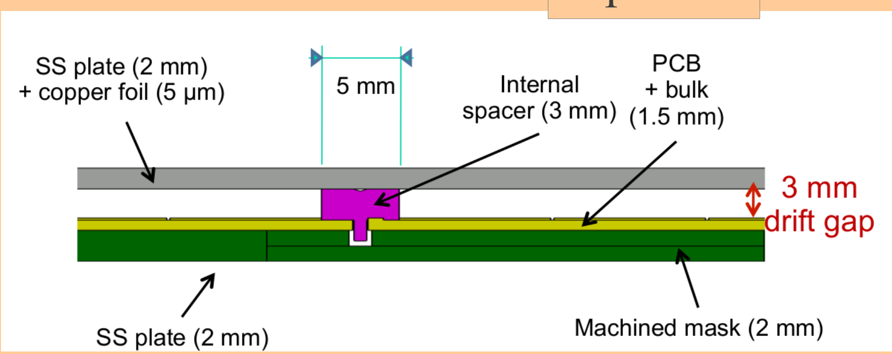
A 1x1 m^2 prototype consists of 3 slabs with DIF + interDIF + ASU + ASU

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

The drift gap is defined by small spacers and a frame

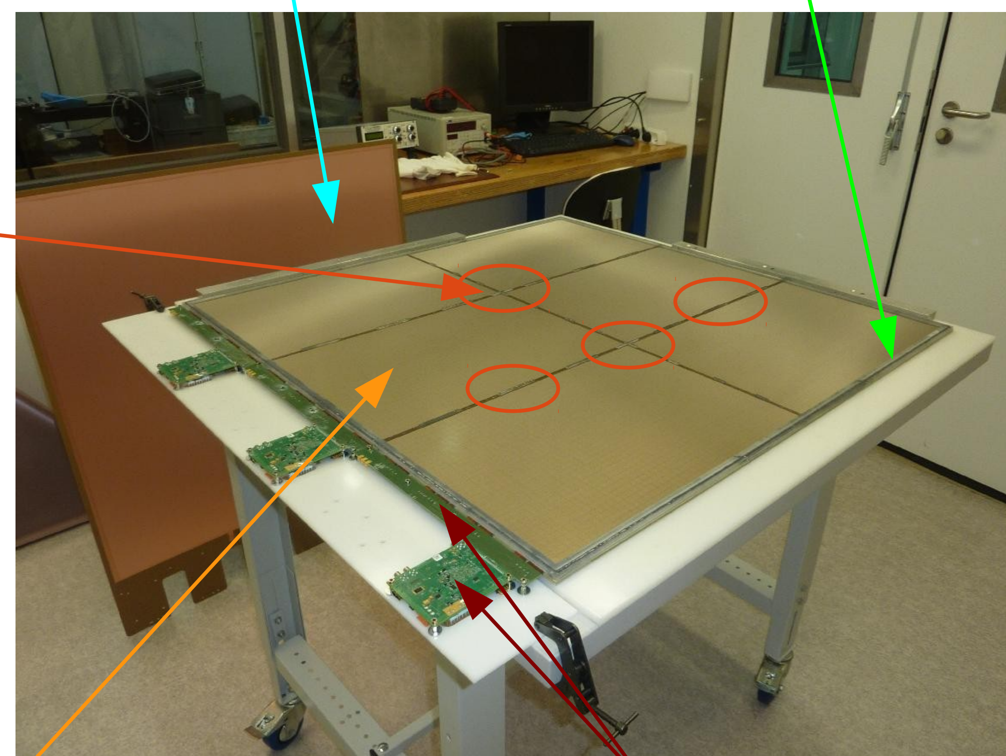
The final chamber thickness is 9 mm

Spacers



Drift cover

Frame with 2 gas pipes



ASU = ASICs + Micromegas

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

R&D: Printed Circuit Board and ASIC design

Active Sensor Unit (ASU)

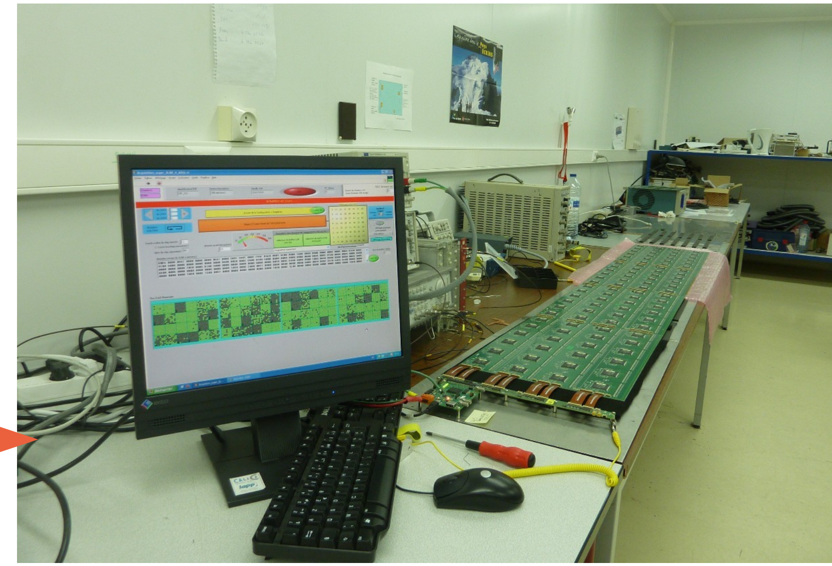
= PCB with 1536 pads + 24 ASICs + 1 Micromegas mesh

Possibility to read out analogue signals to the DIF

Spark protections = 1 diode network / channel

Flexible interconnection on two opposite sides

→ **ASU chain successfully tested over 2 m** (= 4 ASUs)



The MICROROC ASIC (LAPP/Omega)

64 self-triggered channels → matrix of 8x8 pads

Low noise charge preamplifier

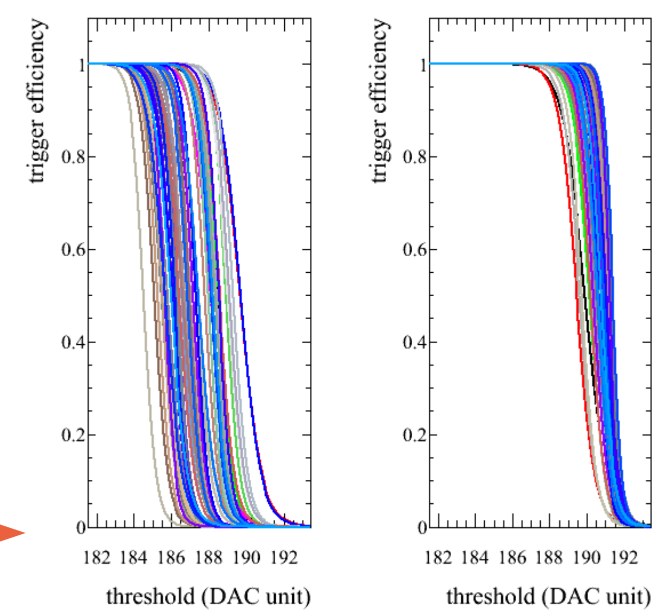
2 shapers of ≠ gain (100 & 500 fC dynamic range)

3 discriminators (= 3 thresholds)

Digital memory of 127 events, 200 ns time-stamping

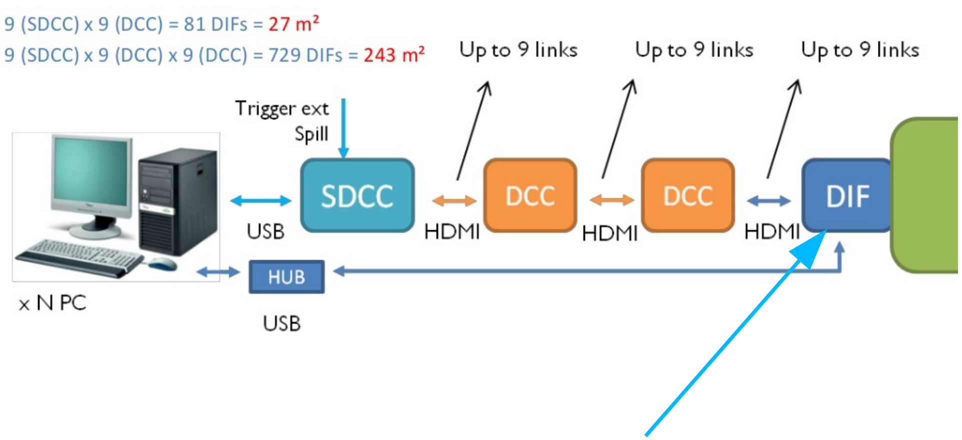
Power-pulsing

Pedestal alignment → threshold/channel of ~ 1 fC reached



R&D: data acquisition system and software

We are using a DAQ developed by LAPP and IPNL for operating the SDHCAL in 2012
Compatible with RPCs and Micromegas; successfully tested up to 50 layers
Architecture based on Data Concentrator Cards (DCC) and Detector Interface boards (DIF)



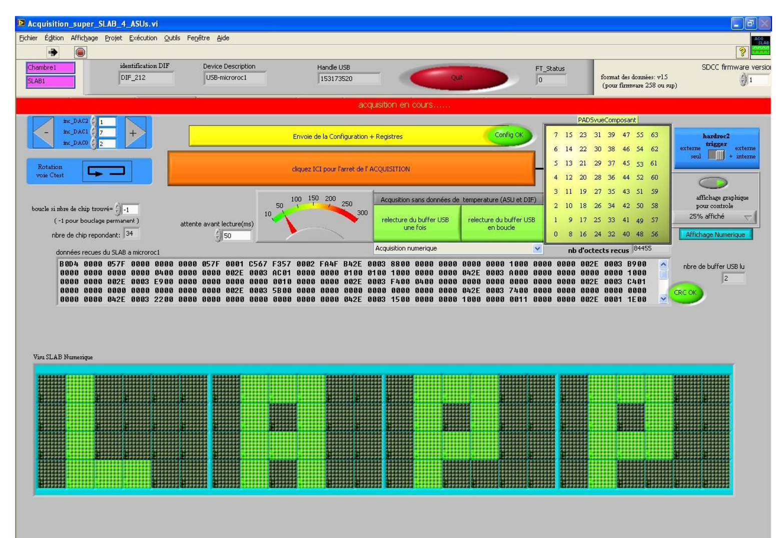
DIF: interface between DAQ and detector

Distribute power and clock to the ASIC
Write ASIC configuration, read ASIC data
Control acquisition signals (trigger, busy...)

USB port → transmit data
HDMI port → transmit clock and control signals

Software for small number of layers

Labview based program
Suitable for calibration and physics runs
Provide easy control of all ASIC parameters



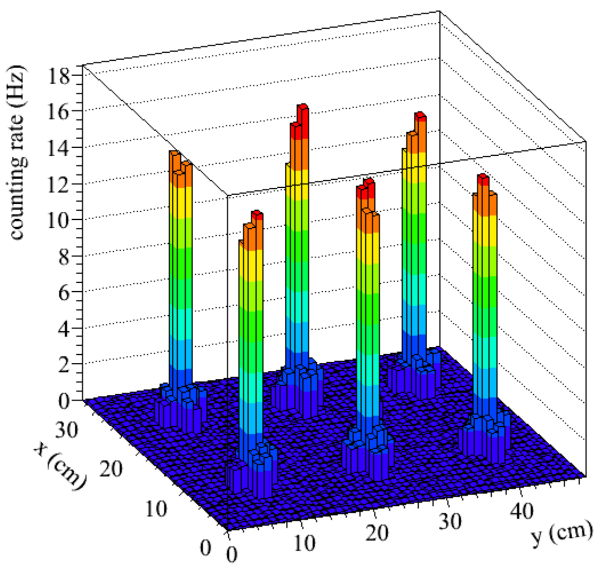
Screen capture of Labview window
Acquisition with 4 chained ASUs

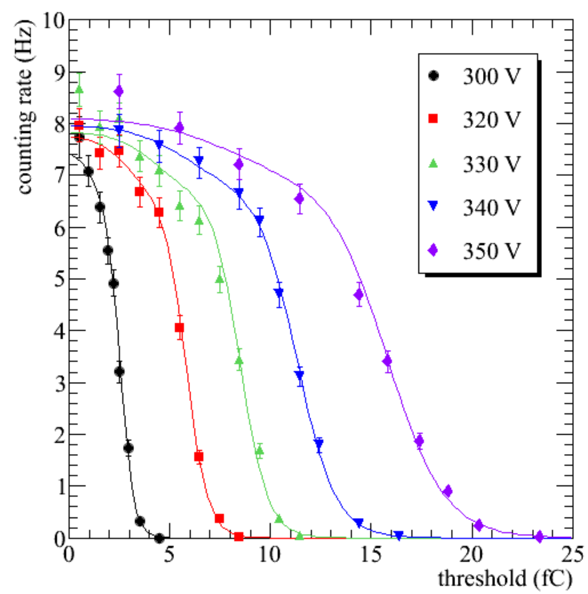
X-ray results in a gas mixture of $Ar/CF_4/iC_4H_{10}$ 95/3/2

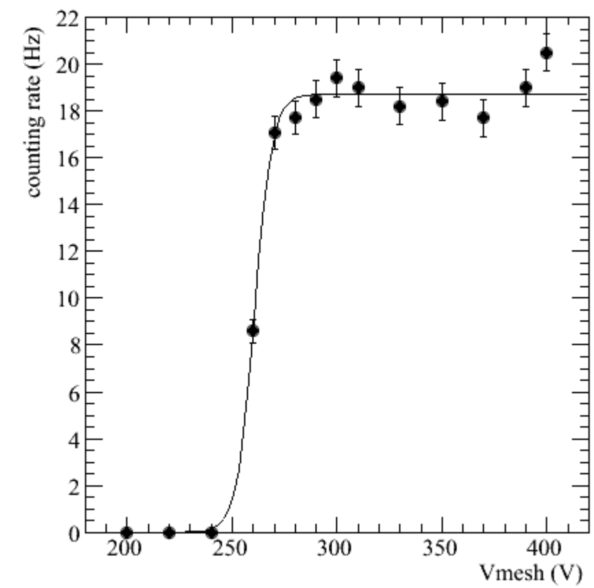
All ASUs are tested in a gaseous chamber before assembly inside a 1x1 m^2 prototype

The chamber steel cover is perforated so the response of any channels can be tested with an ^{55}Fe source

Position scan | *Threshold scan* | *Mesh voltage scan*







Measurement of the ^{55}Fe quanta counting rate over ASU surface

→ Variations below 3% RMS

Gas gain is measured from the trend of inflexion point VS mesh voltage

→ $G = 1.8 \times 10^{-3} \times \exp(0.035 \times V_{mesh})$

At 260 V, the threshold is equal to the ^{55}Fe photopeak charge

→ Minimum threshold ~ 1 fC

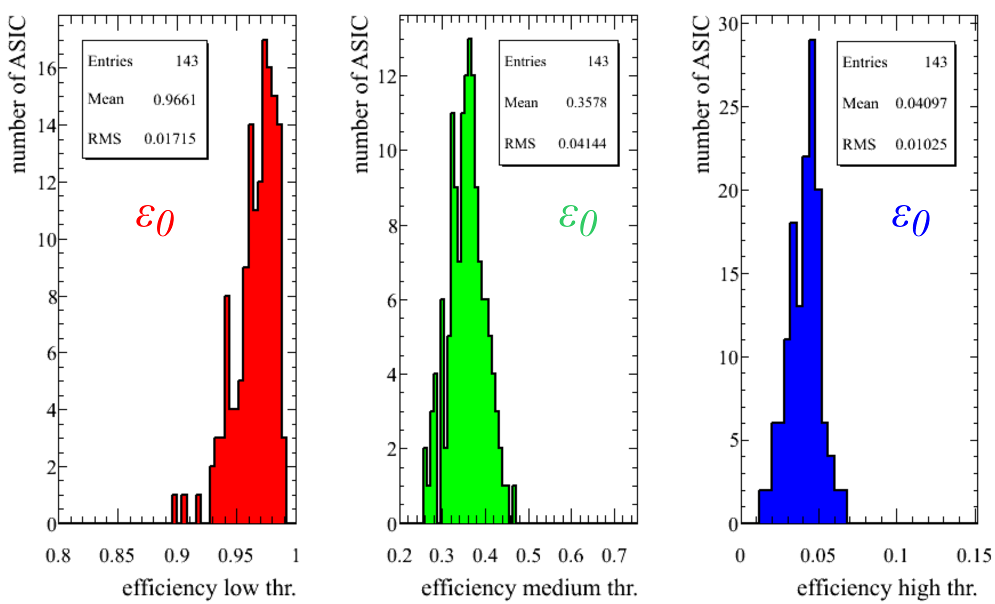
MIP results: efficiency and hit multiplicity

Performance to 100 GeV/c muons measured inside the SDHCAL using RPCs as telescope

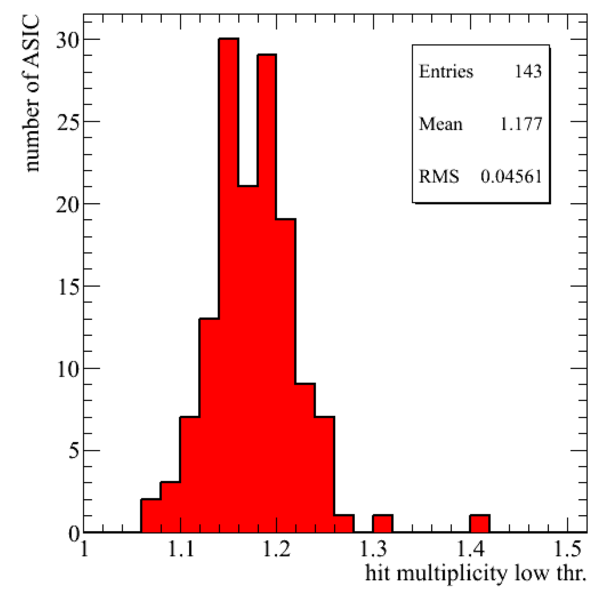
→ Map of efficiency and hit multiplicity per ASIC (i.e. 8x8 cm^2 regions) for the 3 thresholds

Threshold settings for this run are (~0.25 , 2 , 10) MIPs, mesh voltage of 400 V (gas gain ~ 2000)

Efficiency - three thresholds (ε_0 > 96%)



Hit multiplicity – low thr. (m_0 < 1.2)



Relative efficiency variations of 2%, 12% and 25% for low, medium and high thresholds respectively

→ reflects gas gain and thresholds non-uniformity over channels

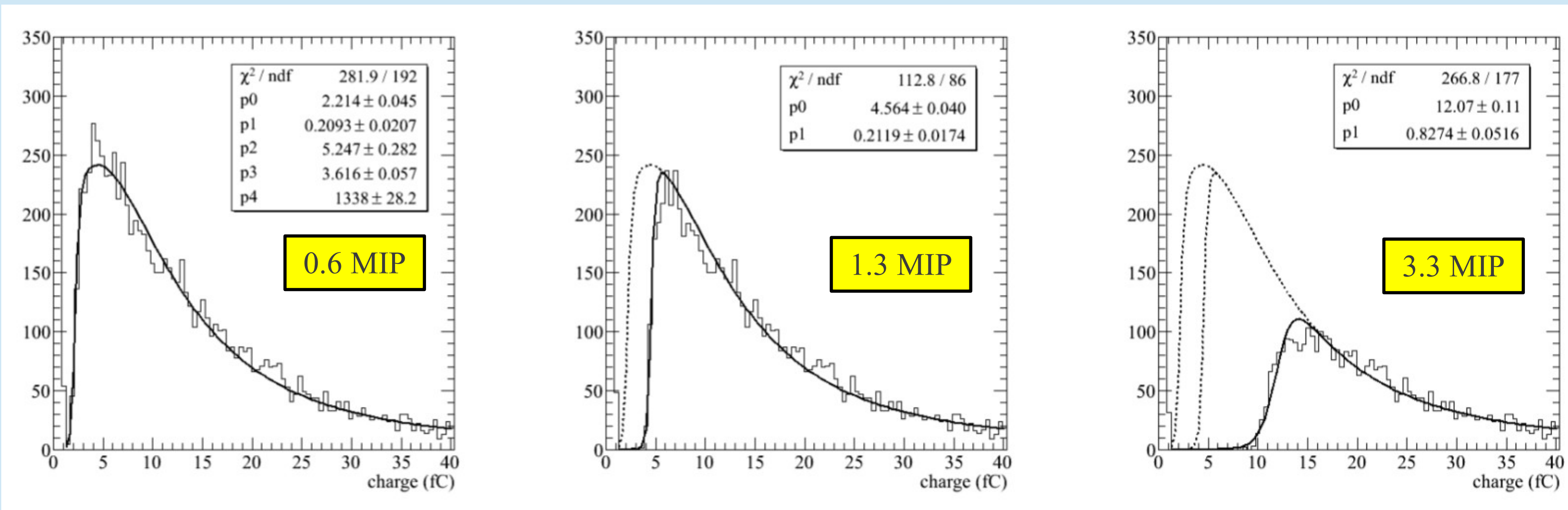
Variations of threshold efficiency will eventually impact on the compensation performance of a SDHCAL!

→ The analogue readout can be used to measure and adjust correctly the thresholds.

MIP results: analogue readout of shaper signals

Combine analogue and digital information → Landau distribution with cuts on passed thresholds

Landau distribution measured on 3 ASICs (~ 200 cm^2) with cuts on the passed thresholds



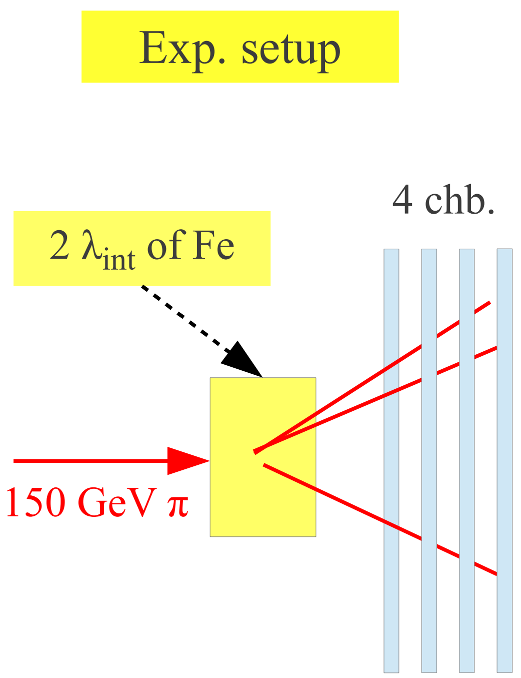
The thresholds can be measured in MIP units which is the natural energy unit of a calorimeter

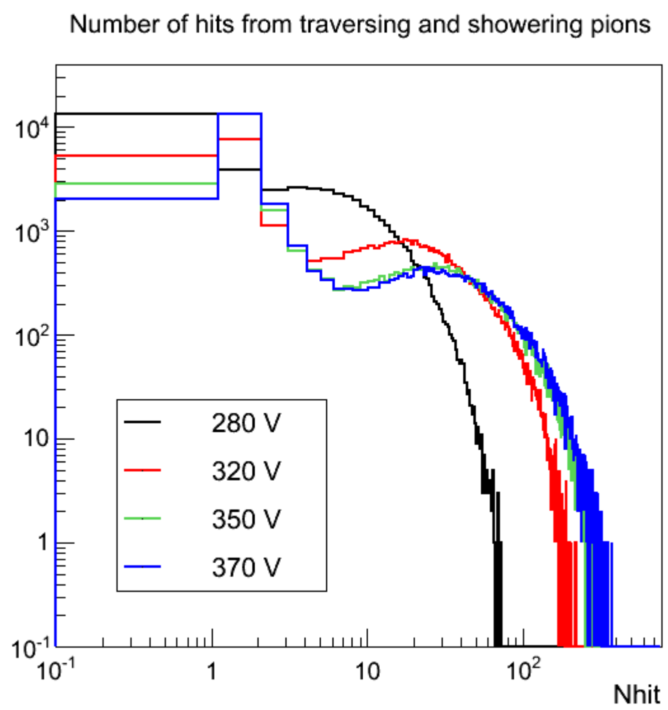
No knowledge of gas gain or electronic gain involved!

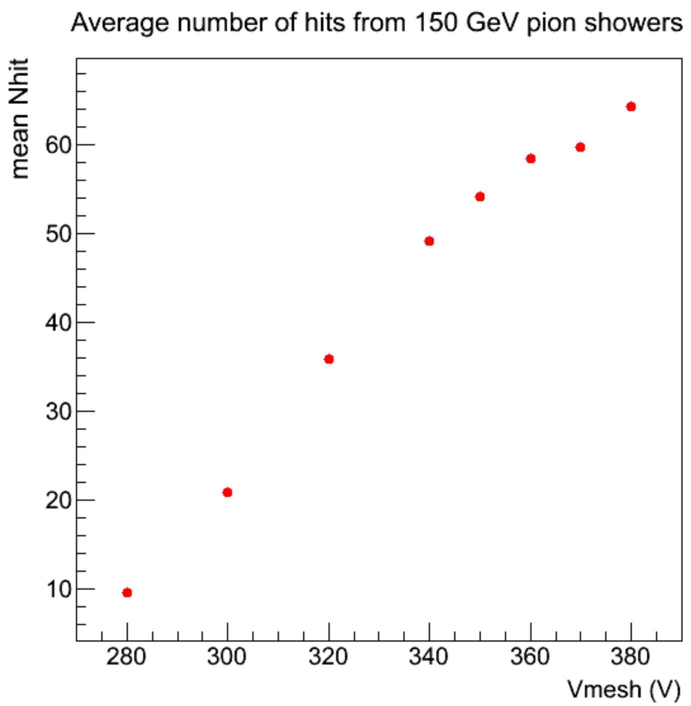
→ Dedicated calibration runs to monitor the thresholds

Pion shower results: operating gas gain

Operation at low gas gain is always preferred and possible!







The number of hits from 150 GeV pions measured after 2 λ_{int} reaches a plateau at 360 V

→ A gas gain of 500 only is sufficient to image most of the shower!

The 4 chambers are used to tag traversing and showering pions: > 90% of pions start a shower.

Above 370 V, the average number of hits increases due to the increased single particle hit multiplicity.

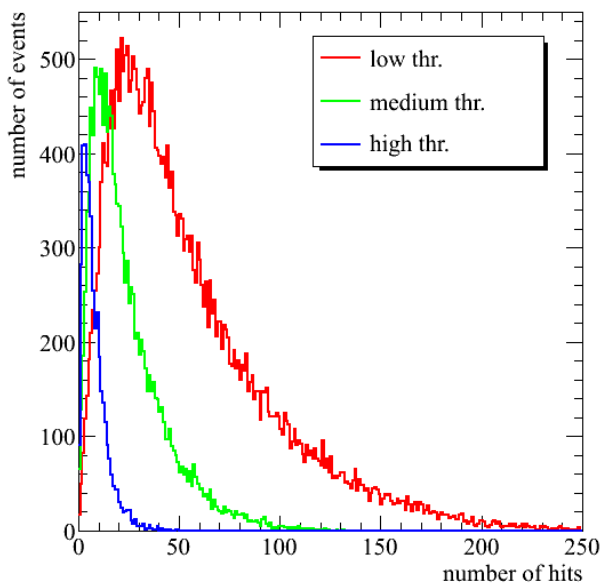
Pion shower results: effect of beam rate

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

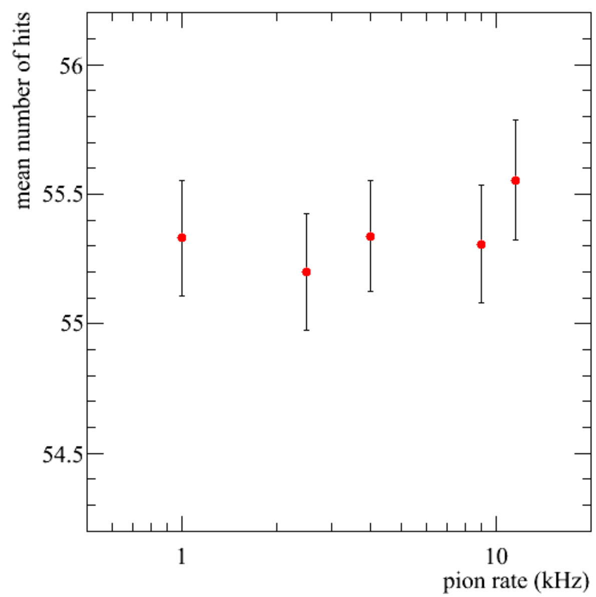
The 4 chambers are used to tag traversing and showering pions: > 90% of pions start a shower

Mesh voltage of 360 V → Gas gain ~ 500 → Very stable operation

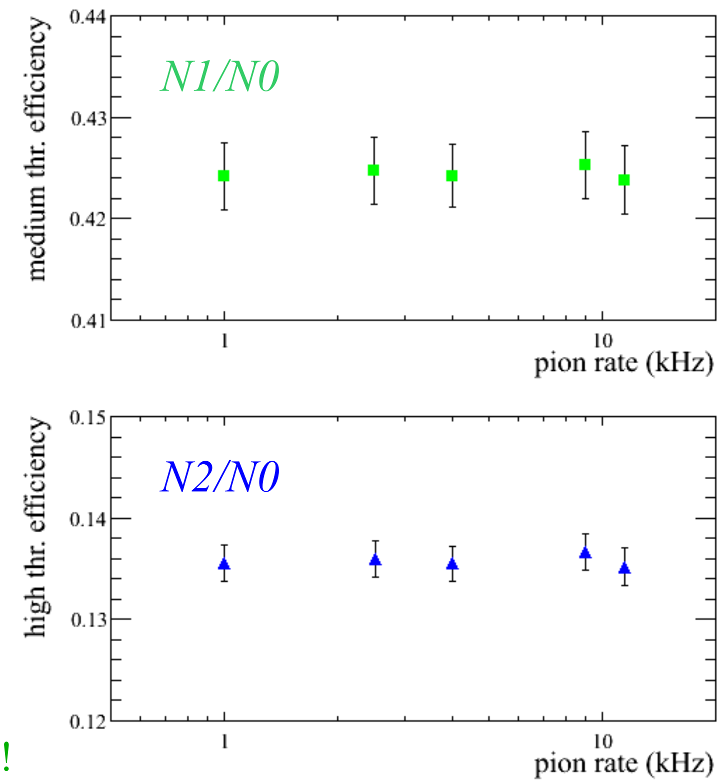
Nhit of 3 thr @ 1 kHz



Mean Nhit0 VS rate



Ratio Nhit1/Nhit0 & Nhit2/Nhit0 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!

<u>High rate capability</u> of Micromegas → can be applied in barrel and endcaps of a LC experiment!

Pion shower results: longitudinal profiles

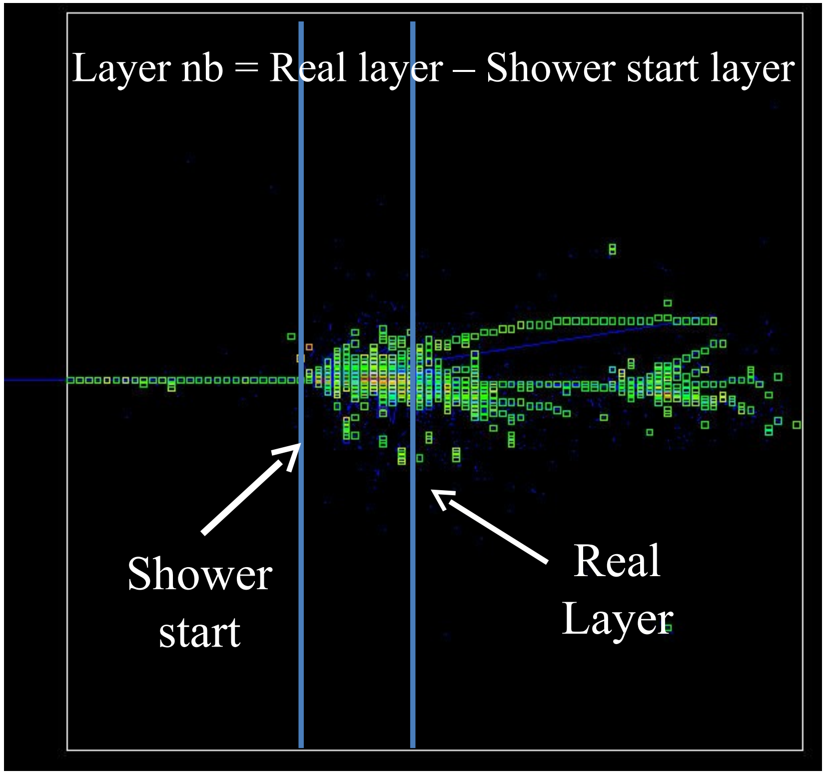
Set-up: the SDHCAL with 46 RPCs and 4 Micromegas (layer 10, 20, 35, 50) at the CERN/SPS

Take advantage of the large fluctuations of the starting point of hadron showers

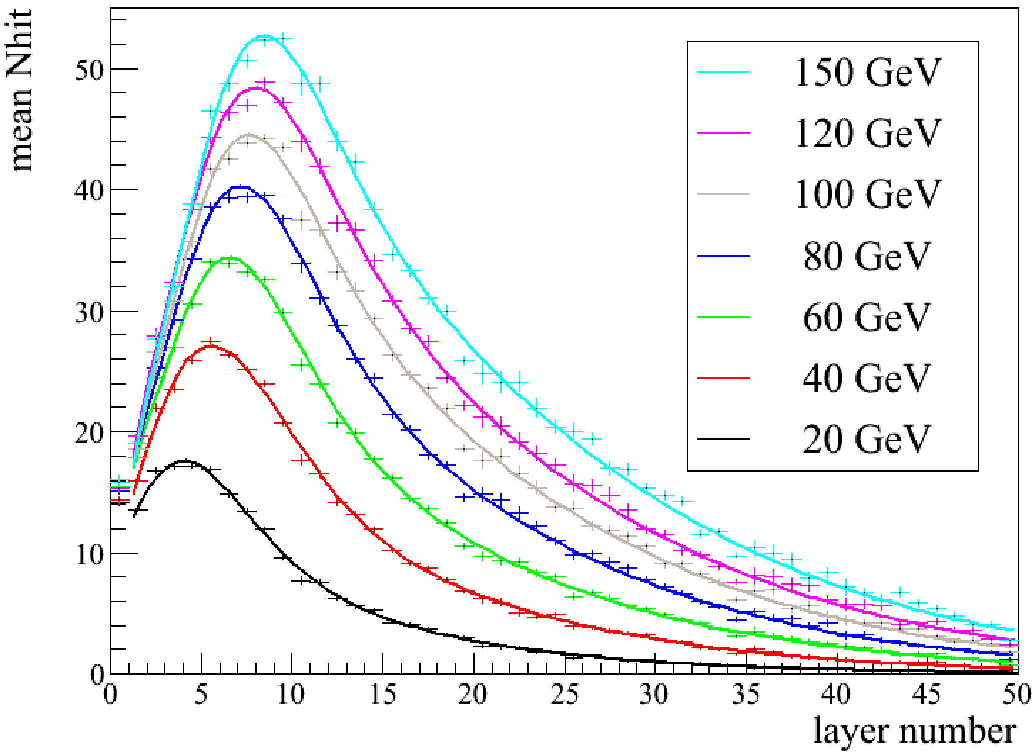
→ At each event, Micromegas chambers shift w.r.t. the shower start

Find the shower start using all SDHCAL chambers & measure Nhit in Micromegas chambers only

→ longitudinal profile of pion showers in a virtual 50 layers Micromegas SDHCAL!



Longitudinal profile of pions showers (low thr.)

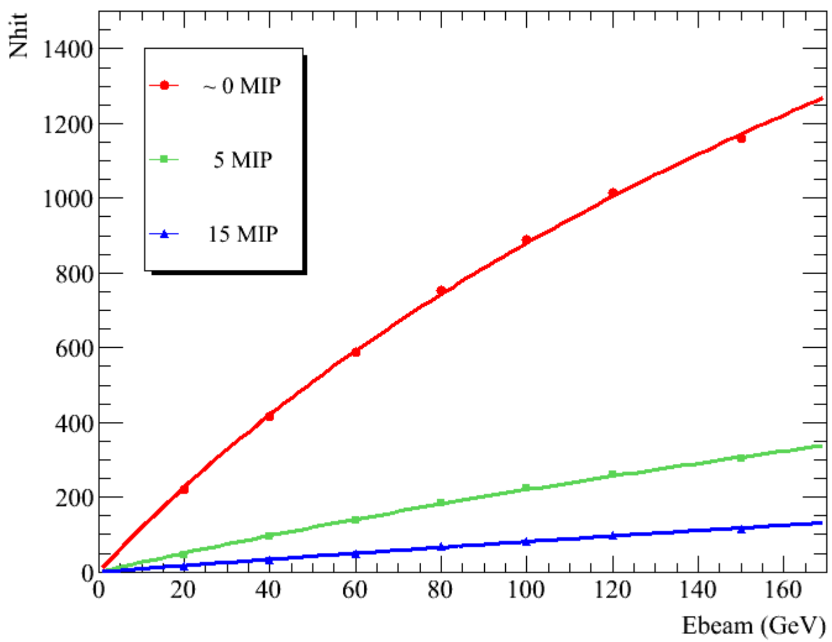


Pion shower results: calorimeter response (Data & Monte Carlo)

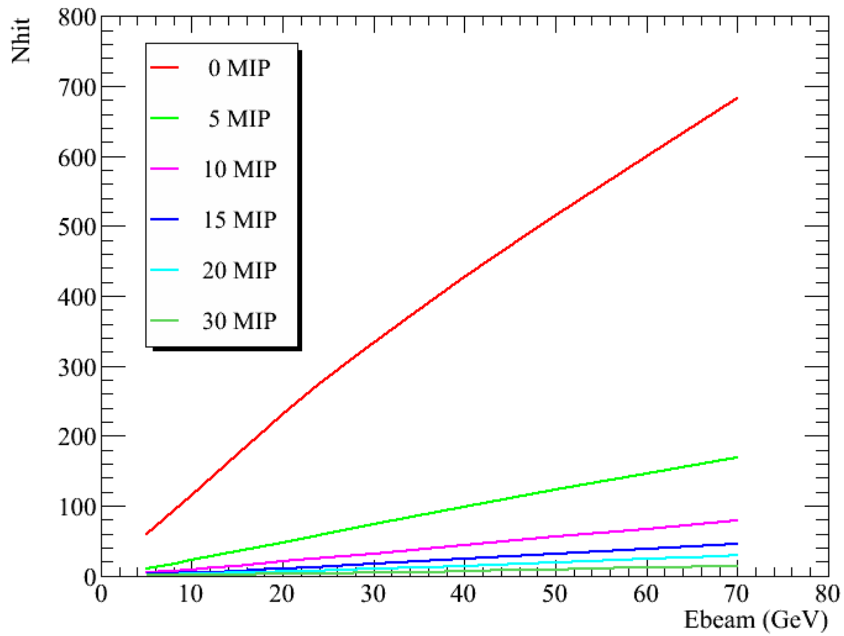
By integration of the profiles, we measure the response of a virtual 50 layer Micromegas SDHCAL for the 3 thresholds!

We are now comparing the testbeam data with the simulation, exciting work ahead...

Testbeam data (20-150 GeV)



Geant4 simulation (5-70 GeV)



On-going analysis work

Conclusion and future plans

- We are studying Micromegas detectors for hadron calorimetry at a future LC
  - Four chambers of 1x1 m^2 were built & tested
  - Excellent performance measured so far

- A Geant4 model of a Micromegas SDHCAL has been implemented
  - Data and Monte Carlo comparison is on-going
  - It also predicts that the single pion energy resolution of a gaseous Fe-HCAL can greatly benefit from a multi-threshold readout

    For such SDHCAL, Micromegas is more than competitive with RPCs

- Future challenge: simplify the chamber design and lower the costs
  - Replace PCB components for spark protection by a resistive layer on the anode

    = RPC quenching principle without the drawbacks (much lower space charge)
  - Go beyond 1x1 m^2 area with a single mesh → new mechanical design