RD51

Micromegas for imaging calorimetry

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Overview

1. Micromegas semi-digital HCAL for future linear colliders
   Where do we stand in the CALICE technology tree?

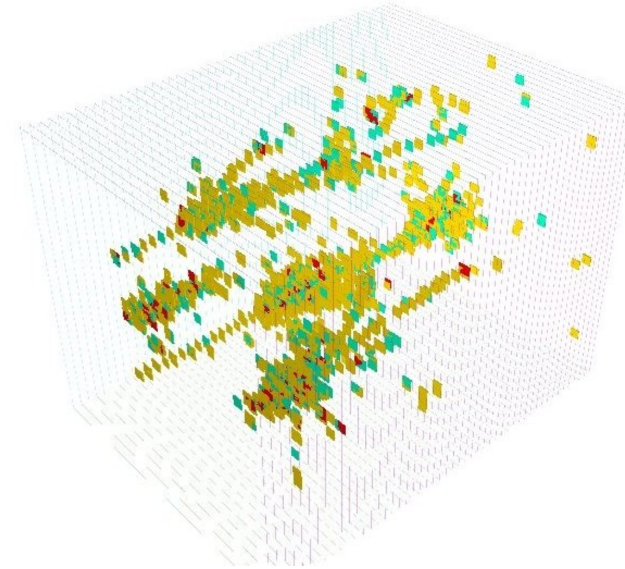
2. Large size chambers for the active layers of an SDHCAL
   How do we built Micromegas chambers of 1 m^2 ?

3. Achieved performance
   Noise, response to MIPs and hadron showers

4. Conclusions and prospects towards LC-like modules

Calorimetry at a future linear collider

<u>Physics case for an e+/e- collider</u>
EWSB mechanism, SM precision measurement, SUSY spectrum
→ **Very demanding on calorimetry.**



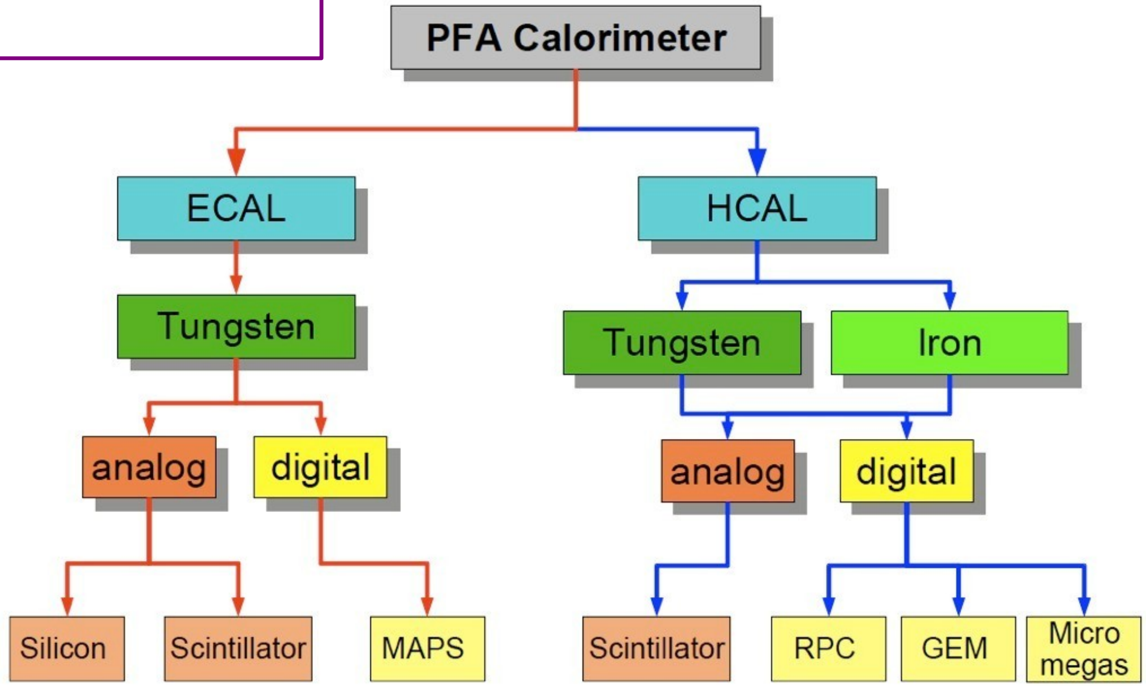
At 500 GeV ILC: jet energy scale of ~ 100 GeV

Often quoted benchmark:
Separation of hadronic decays of di-boson final states

→ Jet energy resolution of 30% / √E [GeV]

<u>Dual readout approach</u>
Push calorimeter standalone performance to its limit
→ **DREAM project**

<u>Particle Flow approach</u>
Turn calorimeter into an imaging device
→ **CALICE projects**

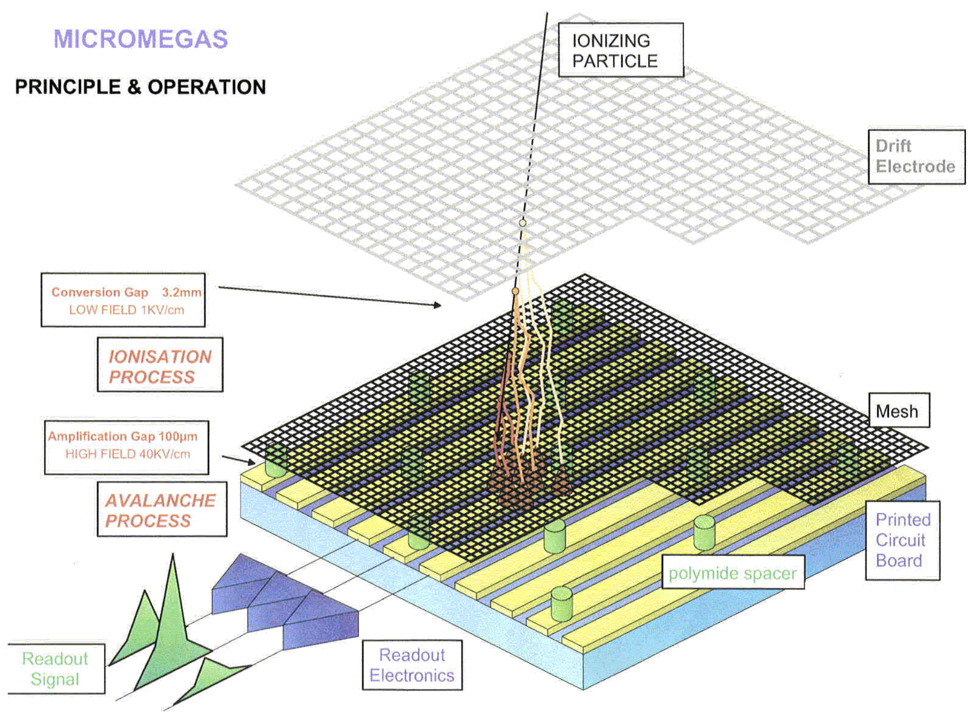


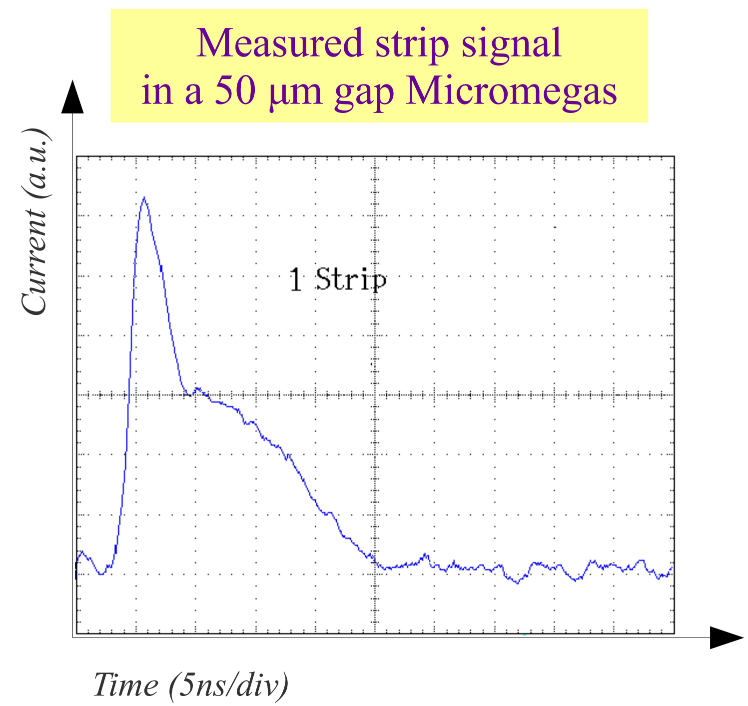
Micromegas operation principle

Primary ionisation (in 3 mm Ar): follows Landau distribution, on average 30 e^-

Drift of primary e^- towards mesh, takes 50-100 ns

Multiplication of primary e^- by factors up to a few 10^4 in 1/100 ns for e^-/i^+ (for a 128 μm gap)





Narrow avalanches + fast collection of avalanche charge + moderate gas gains
→ **no space charge effects**

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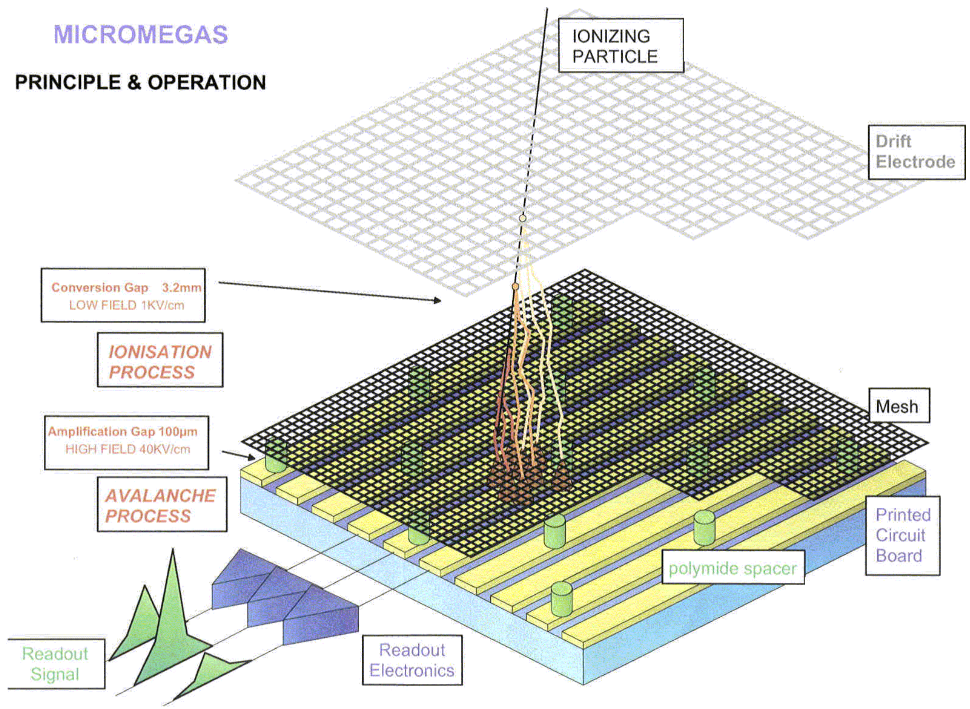

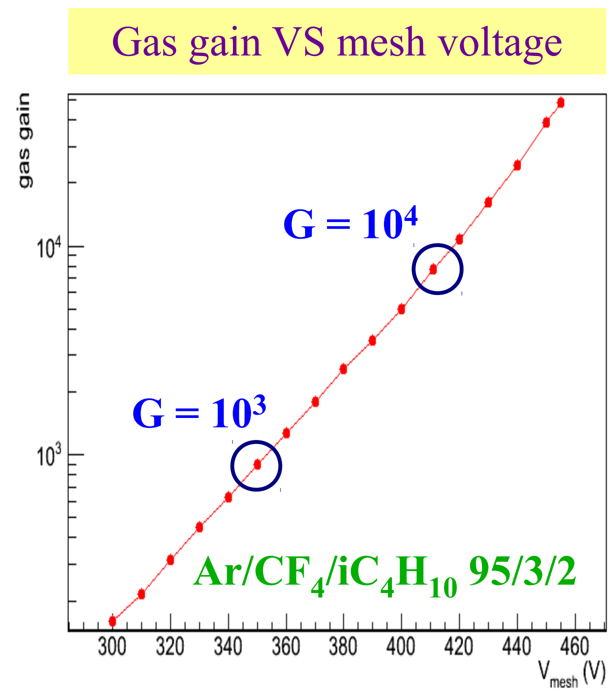

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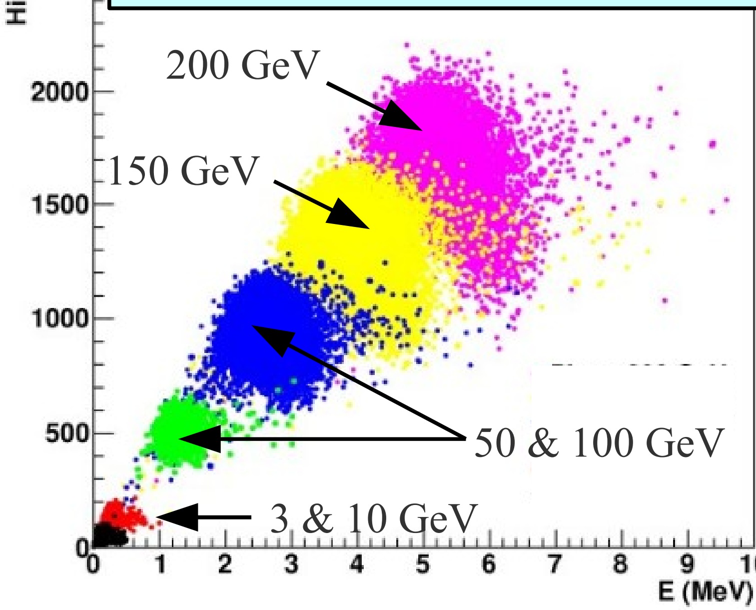
→ **no space charge effects**

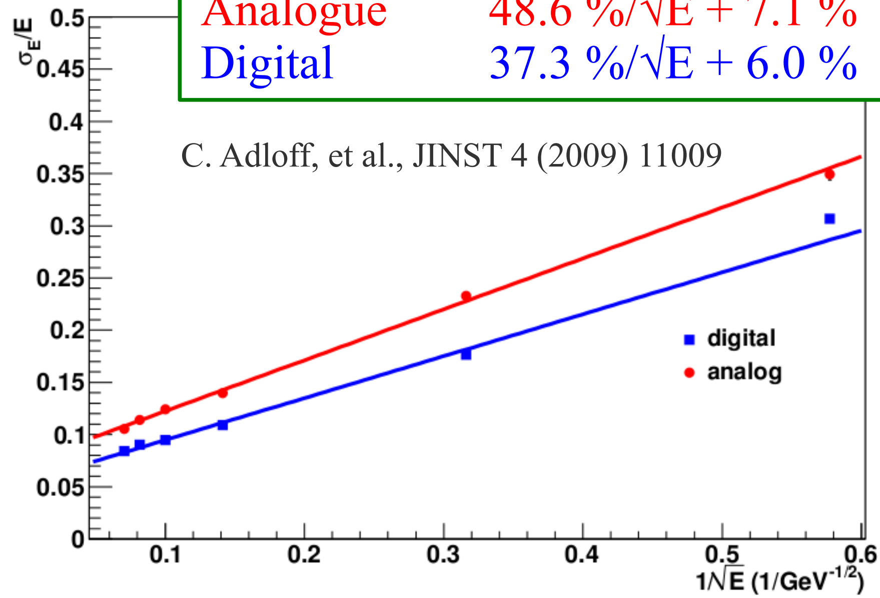
Micromegas for a sampling HCAL (1/2)

If cell size << shower transverse size, counting isn't worse than measuring charge...
Resolution actually better, linearity worse but can be improved with 3 thresholds instead of 1
… and should make calibration & monitoring simpler.

Sim: π in 9 λ_{int} Fe: N_{hit} VS $E_{visible}$



Resolution to π in Fe ([E] = GeV)
Analogue 48.6 %/√E + 7.1 %
Digital 37.3 %/√E + 6.0 %



Pros of Micromegas w.r.t. RPC DHCAL

Use of 3 thresholds & high rate capable ← No space charge

Neutron signal in H-rich mixtures ← Freedom in gas choice

Superior imaging capability ← 1 particle = 1 hit

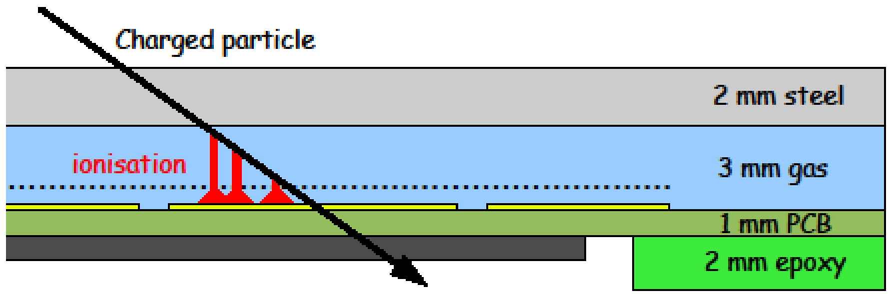
Low-noise ← HV < 500 V, Gain ~ O(10^3), weak P/T effect (+1% / K)

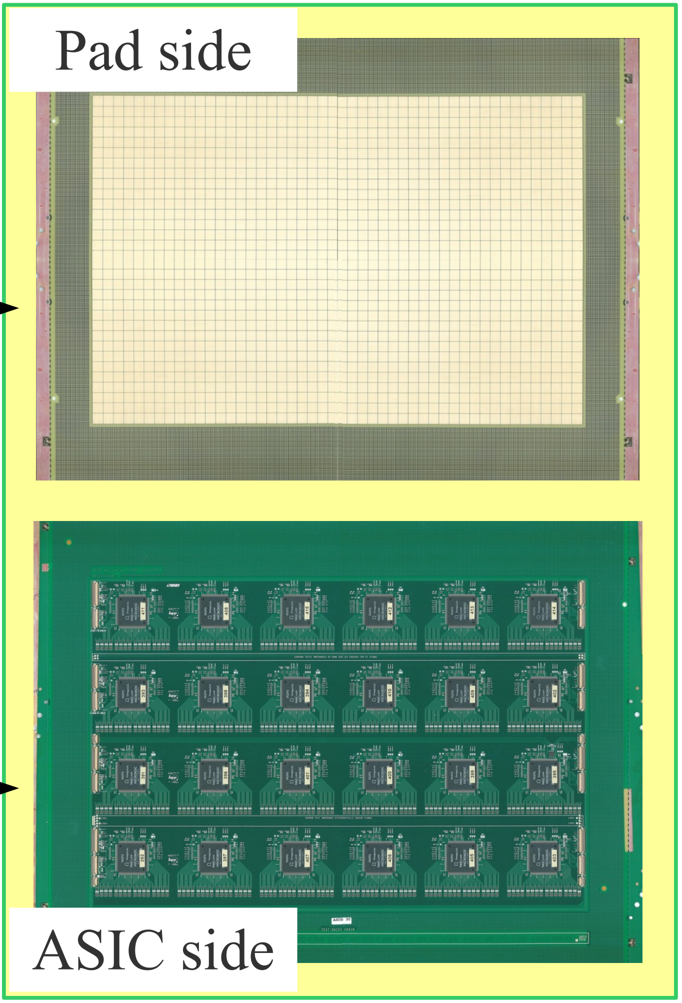
Micromegas for a sampling HCAL (2/2)

Micromegas is a relatively new technology (1996)
A lot of R&D work at LAPP to

Fabricate large area detectors
Basic blocks are called Active Sensor Units (ASU)
48x32 cm^2 PCB assembled with minimum dead zones

Reduce chamber thickness
Integrate ASIC directly on PCBs





Develop low noise front-end electronics (FEE): MICROROC (CNRS collaboration LAL/Omega-LAPP)

Reduce discharge rate and protect FEE

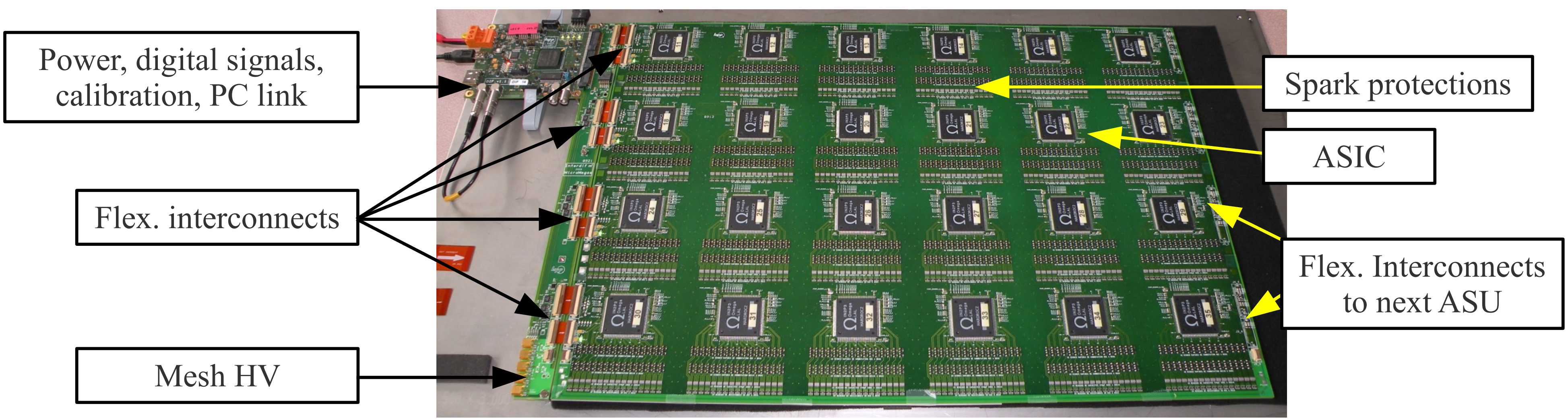
Detector basic block: Active Sensor Units (ASU)

Contain both the multplying mesh and front-end readout on a single board.
→ 1536 channels readout by 24 MICROROC ASIC + external boards

Made in 3 steps: PCB with routing and pads → connect ASIC → laminate Bulk mesh

Flexible interconnection on both sides of ASU allow chaining several of them
→ **Scalability**

32x48 pads of 1 cm^2 on back side



Detector front-end chip: MICROROC

MICROROC is a 64 channel ASIC optimised for the detection of signals of Micro Pattern Gas Detectors (MPGD) such as Micromegas or GEM.

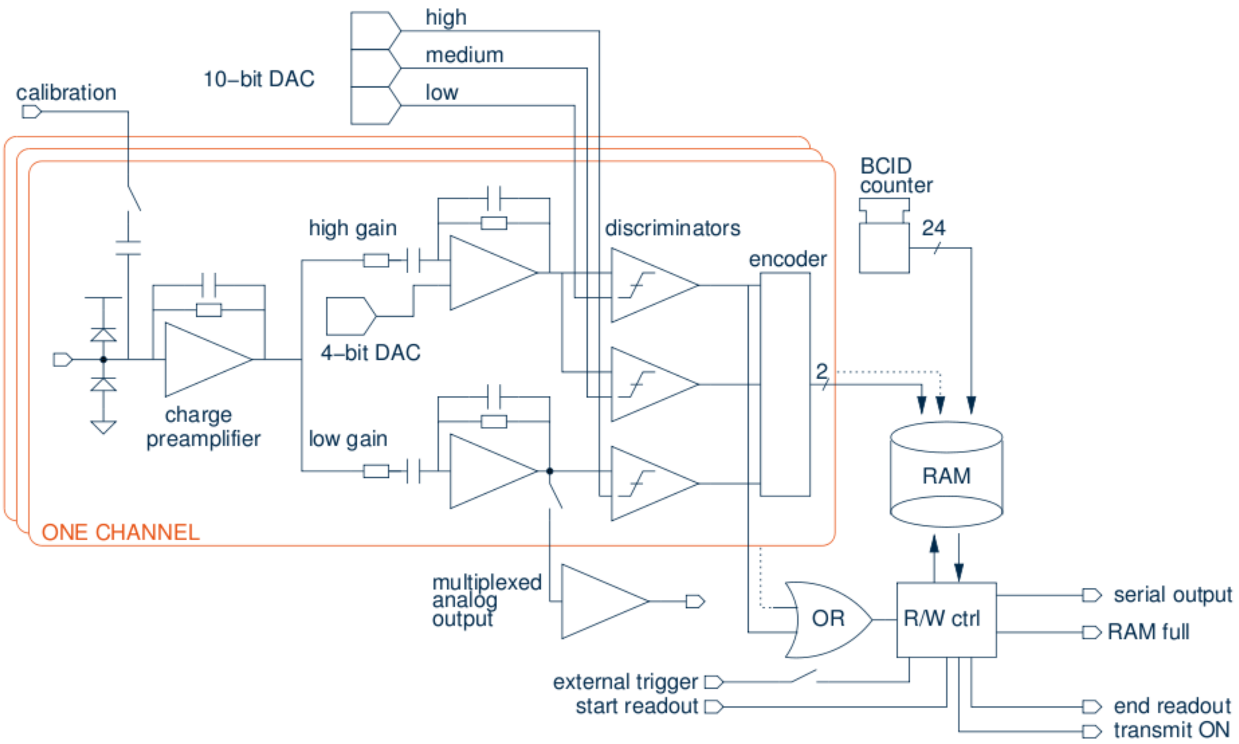
Charge preamplifier with a **noise of 1500 ENC** only (Cdet = 80 pF)!
+ channel-to-channel adjustable threshold

→ High sensitivity

2 shapers followed by **3 discriminators**, timestamping of 200 ns and **127 event depth memory**

Protection
Spark protection network in Si

Consumption
3.75 mW/channel
Can be reduced by power-pulsing



Design: LAPP/LAL-Omega

Test of Active Sensor Units

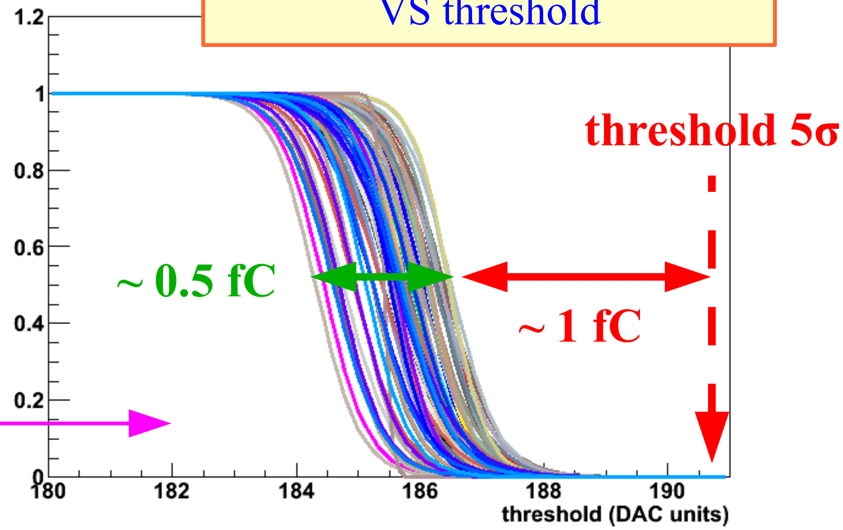
Electronics tests : MICROROC calibration

Spread of shaper gains < 2%

Detection threshold of 1 channel: 5*noise ~ 1 fC

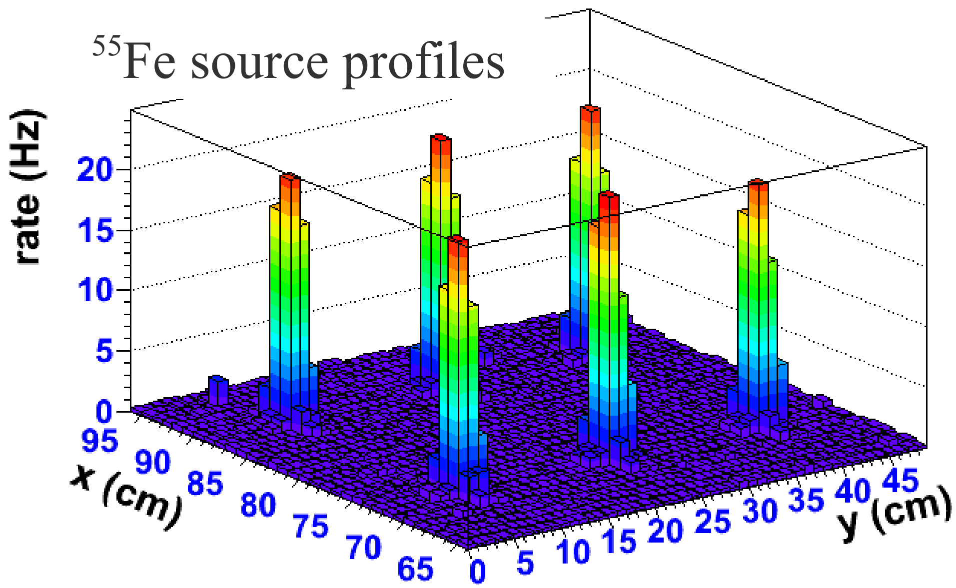
Add pedestal dispersion of 64 channels ~0.5 fC

Trigger efficiency @ 0 charge VS threshold



Pedestal dispersion can be reduced by half thanks to channel adjustment bit

^{55}Fe source profiles



Full ASU test: ^{55}Fe X-rays in gas

Photopeak (230 e$^-$) seen at gas gain of 100 only

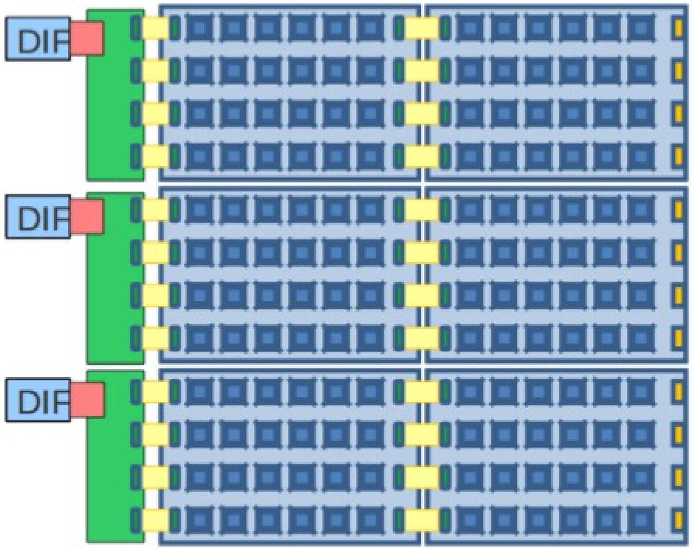
Similar counting rate measured on 6 positions / ASU

→ Gas gain of a few 10^3 should be enough for MIPs!

Scaling the detector to 1 m^2

1 ASU of 1 m^2 ?
Technically difficult to fabricate & higher spark current

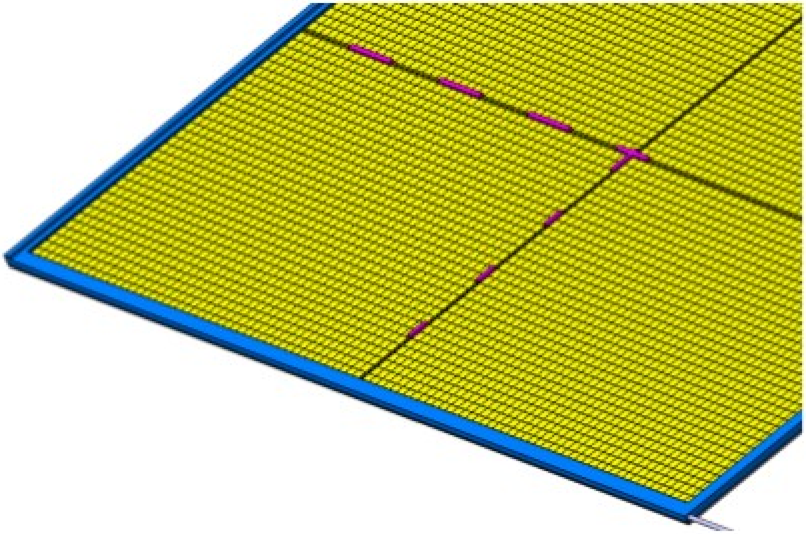
Instead: 6 ASU inside same gas chamber (9216 channels)
Interconnection by flexible cables

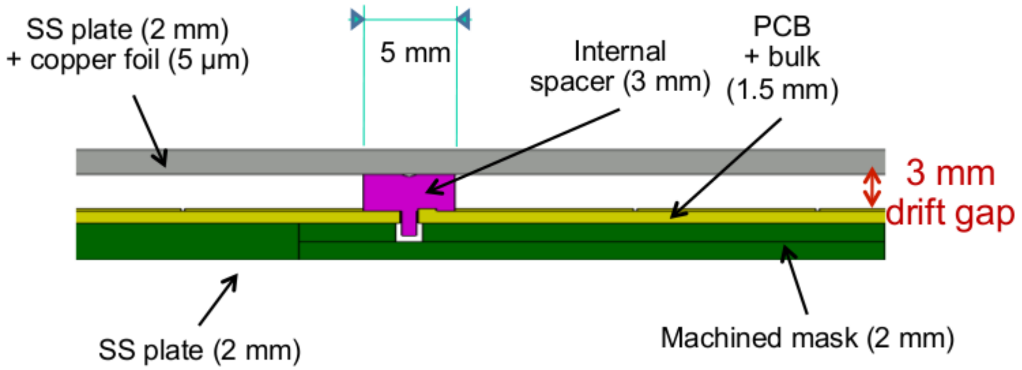


Minimize dead zone
while maintaining a constant 3 mm drift gap

Use 1 mm between ASU for spacers
Adds up to 2 mm insulating line at ASU edges

→ 2 % dead area





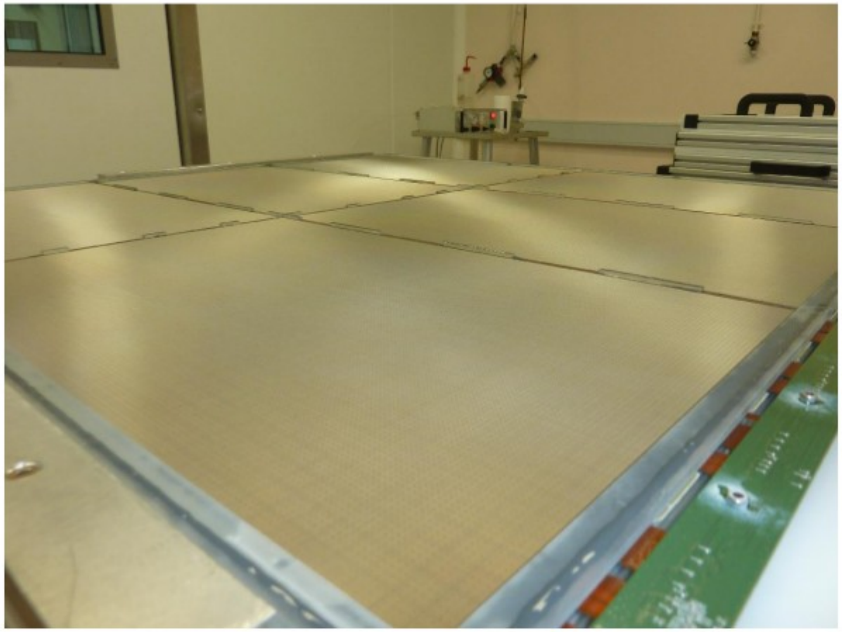
Micromegas prototype of 1 m^2

Assembly takes one week

First prototype constructed in May 2011, second by end of 2011.

Today, we have enough Active Sensor Units for constructing 2 more.

We expect to have 4 prototypes by the end of 2012



Test beams and studies

Test beam campaigns

Standalone (2011)
MIP setup: telescope + 1 prototype
Shower setup: telescope + 1 λ_{int} Fe block + 1 prototype

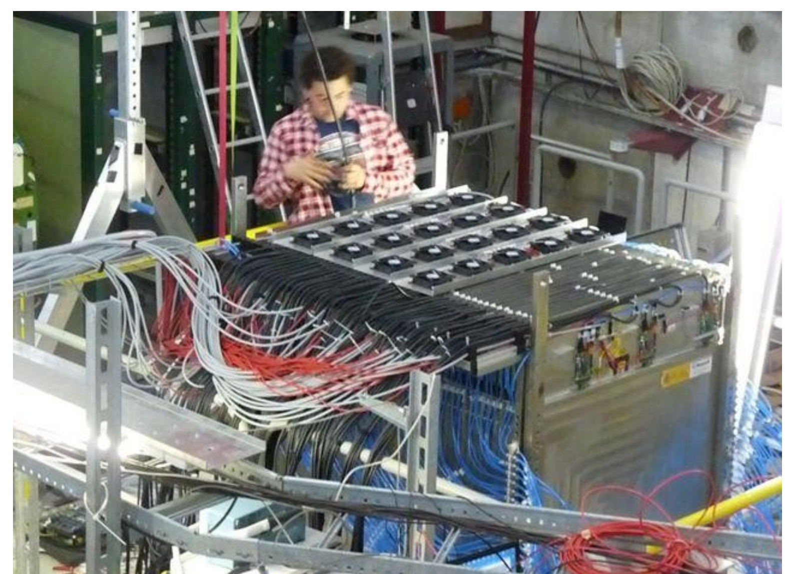
Inside RPC-Fe SDHCAL (2011-2012)
Prototypes behind ~ 5 λ_{int} Fe absorbers (layer # 48-50)
With common DAQ & reconcstruction

Studies

Noise and hit occupancy

Response to MIP
Efficiency & multiplicity

Response to hadron showers
Number of hits, stability, thresholds



Noise conditions

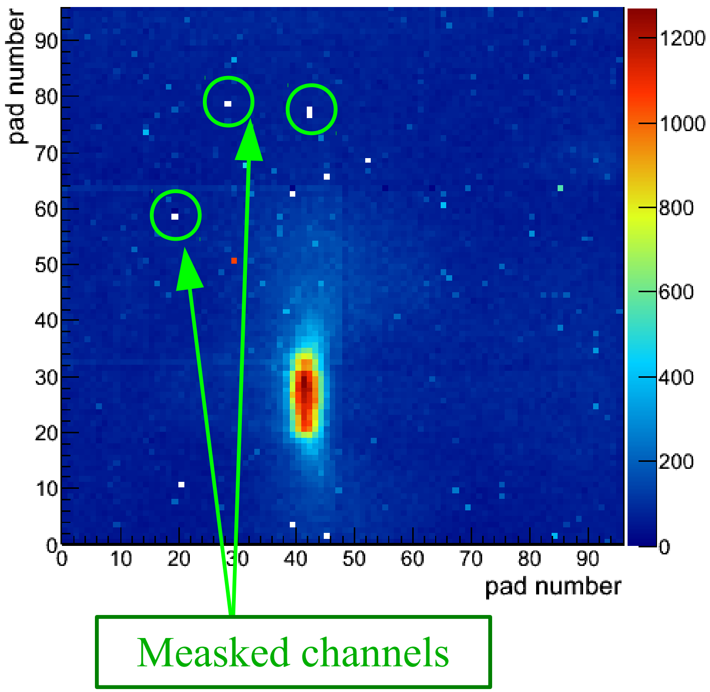
Without voltage on the mesh and no beam = no activity in gas volume
Nois rate ~ 0.1 Hz over all 9216 channels, masking about 10 channels!

With 390 V on the mesh in a 150 GeV/c muon beam (MIP efficiency ~ 1, cf. next slides)

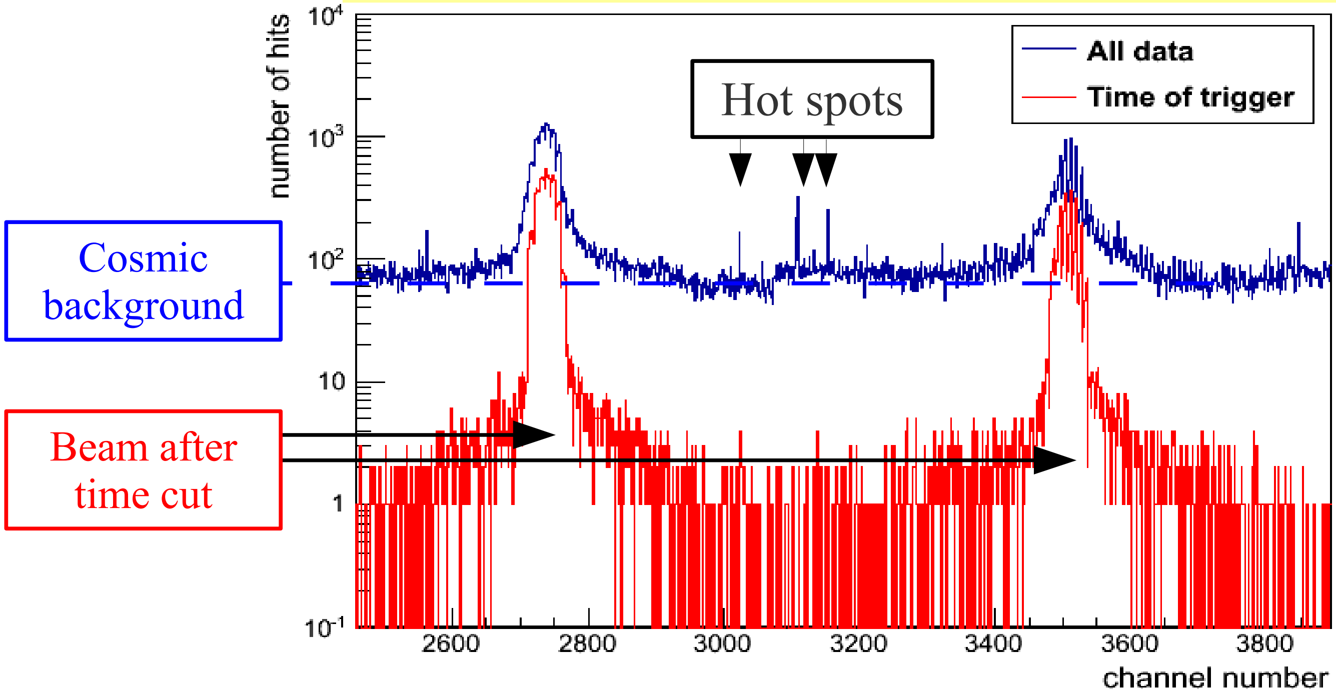
Occupancy plot shows Beam + cosmic background + a few "hot spots".

→ Raw data are almost noise free! After cut on time to trigger, S/N > 300.

Occupancy Nhit VS XY



Channel occupancy Nhit VS channel#



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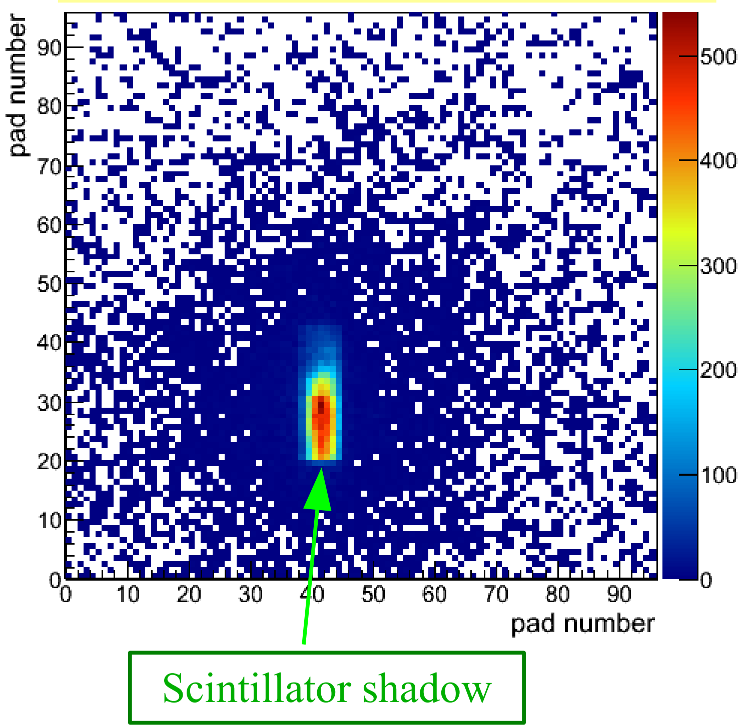
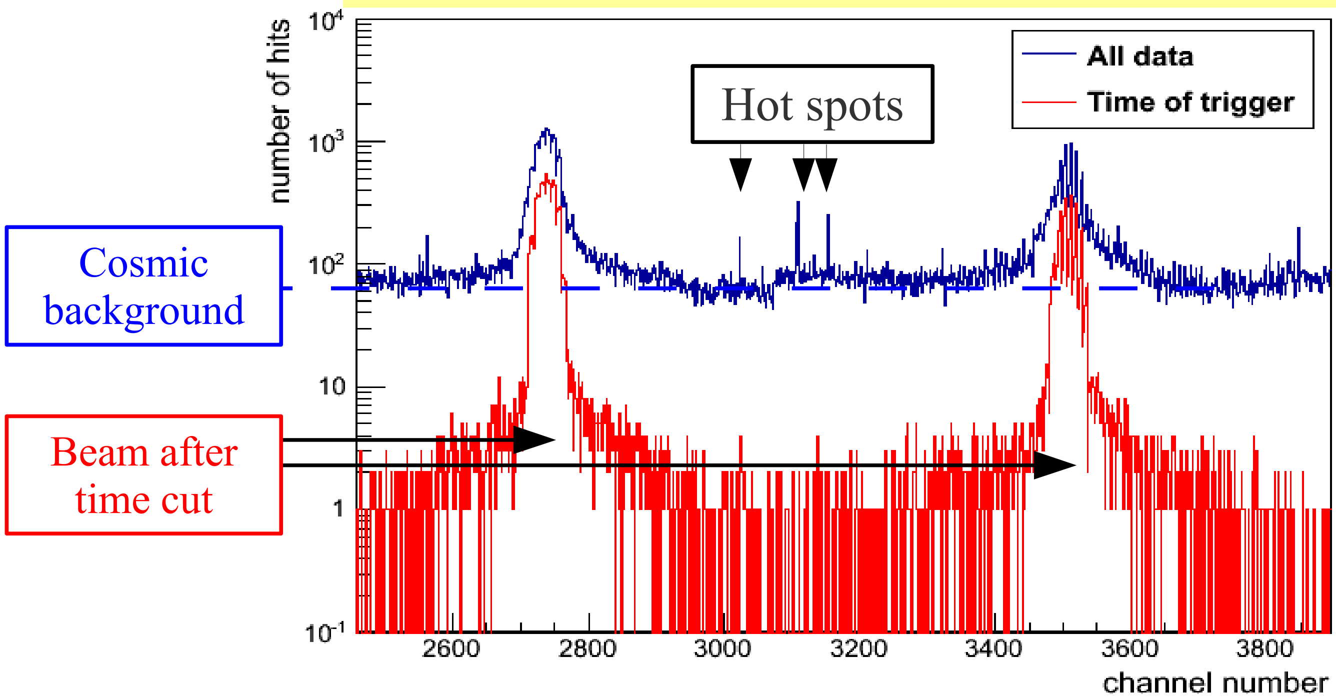
Occupancy after time cut



Channel occupancy Nhit VS channel#



Response to MIP

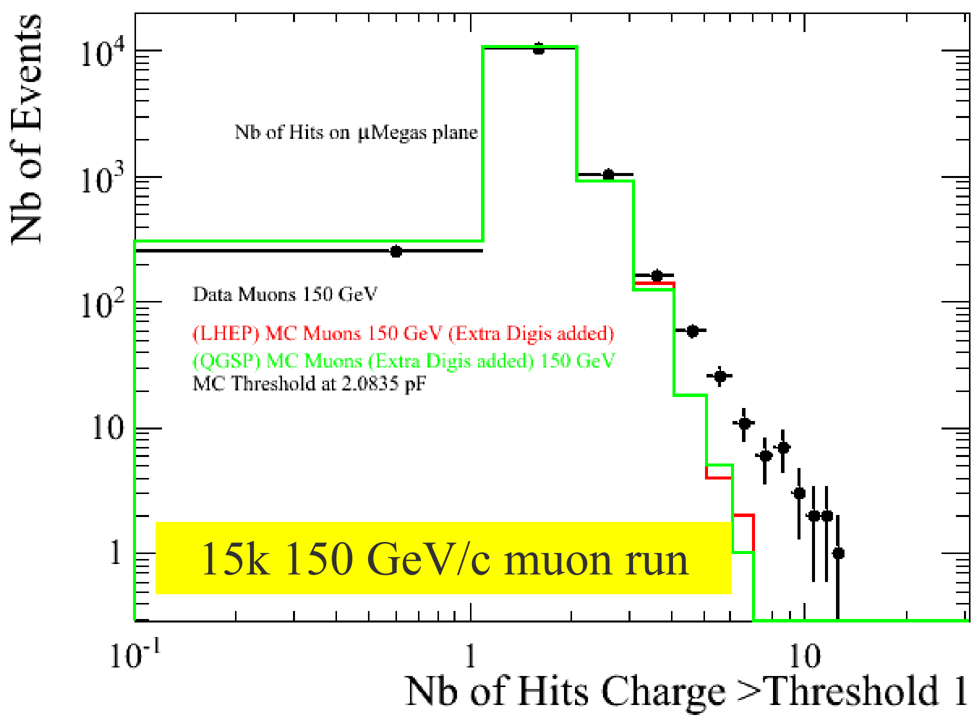
Method

Extrapolate track from telescope to prototype, given the resolution on the impact position, **we count hits in 5x5 pad regions around extrapolated point.**

Prototype response = number of hits in 5x5 pad regions

Distribution shows a large peak at 1 and a short tail

→ **high efficiency and low multiplicity**



Monte Carlo prediction

Use Geant4 for primary charge
+ simple diffusion model
+ adjust bin 1 to data

Tail is hard to reproduce
Still working on it.

Efficiency to MIP

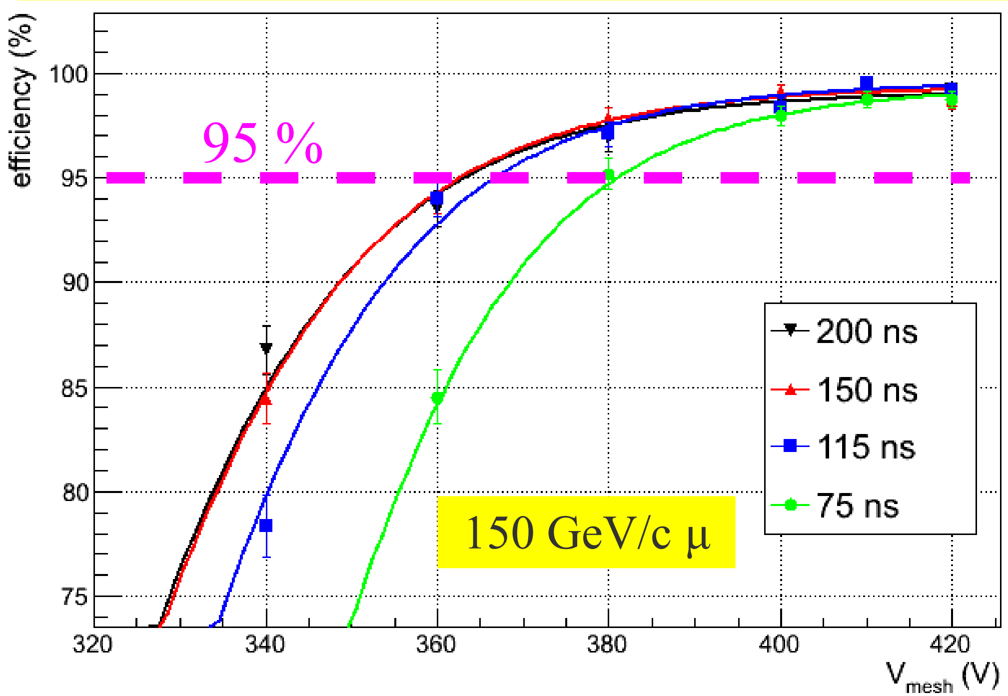
Variation with gas gain (beam directed at center of ASUs over ~ 100 pads)

We use a mixture of $Ar/CF_4/iC_4H_{10}$ 95/3/2 (non-flammable)

At a gas gain of 1000 (365 V) and using a shaping time > 150 ns, the efficiency reaches 95%

Cranking up to 3000 (390 V), the efficiency reaches 98 %, this on all 6 ASUs

Efficiency VS Vmesh for ≠ shaping times



MICROROC chip

Peaking time can take 4 values from 75-200 ns.

Should be > 150 ns for 128 μm gap Micromegas

Shorter peaking times could be interesting for GEM/THGEM which deliver only e^- signal.

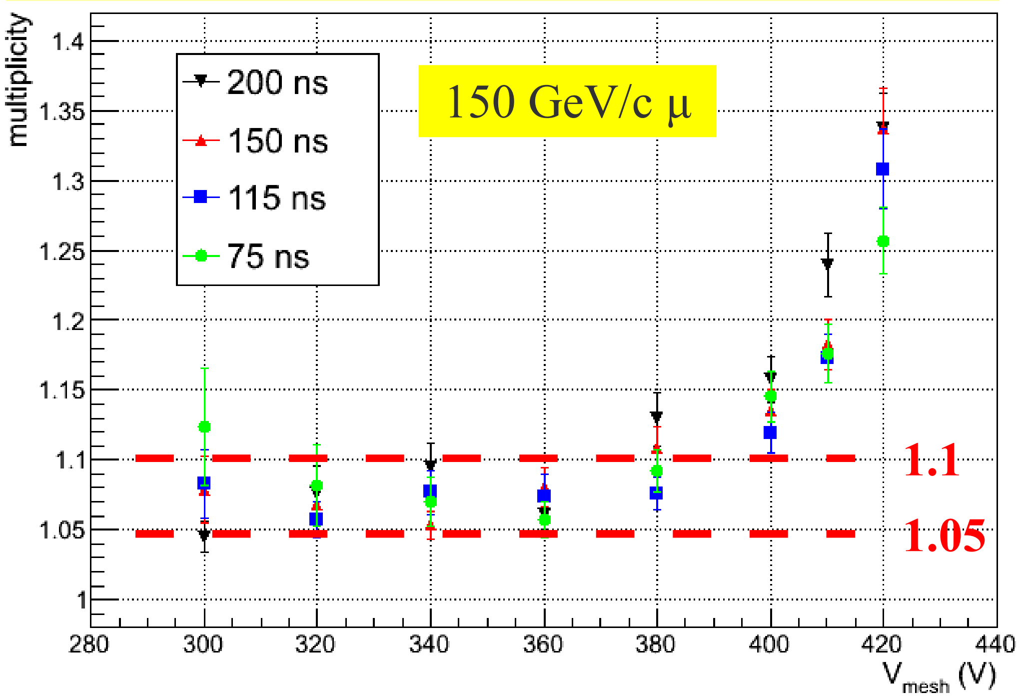
Multiplicity to MIP

Lowest hit multiplicity of CALICE gaseous HCAL: remains ~ 1.1 up to 390 V.

Above 390 V, neighboring pads become sensitive to single primary electrons.

This increases the multiplicity.

Hit multiplicity VS Vmesh



Lower limit on multiplicity

Is about 1.05, so we are close.
Is set by the transverse diffusion of the gas and the size of the pads.

Response uniformity to MIP

An efficiency map was obtained on 2 prototypes (May 2012)

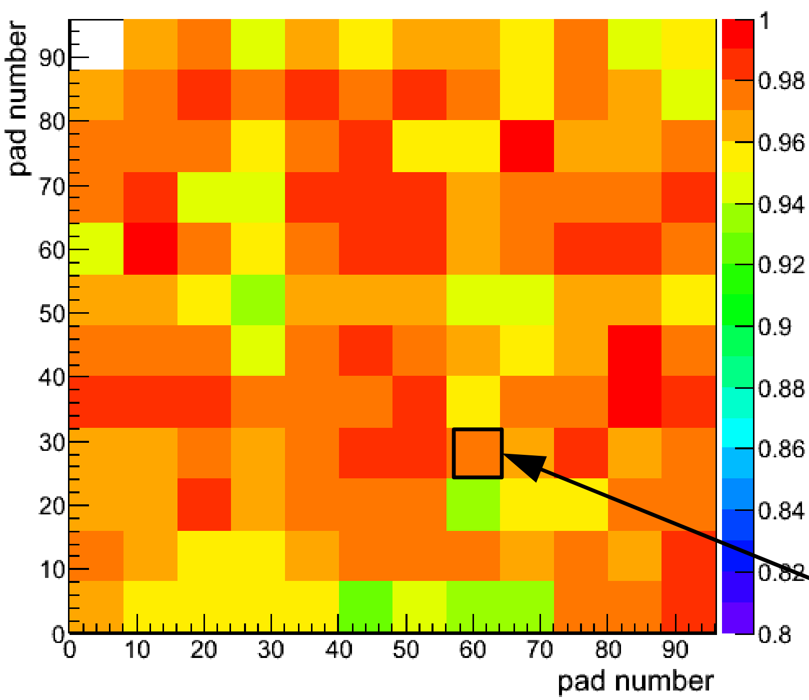
Inside GRPC-Fe SDHCAL after 5 λ_{int}: use GRPC as tracker to find penetrating MIPs (100 GeV/c μ).

Chamber intrinsic inefficiency from dead area is 2% when MIP traverses between ASU.

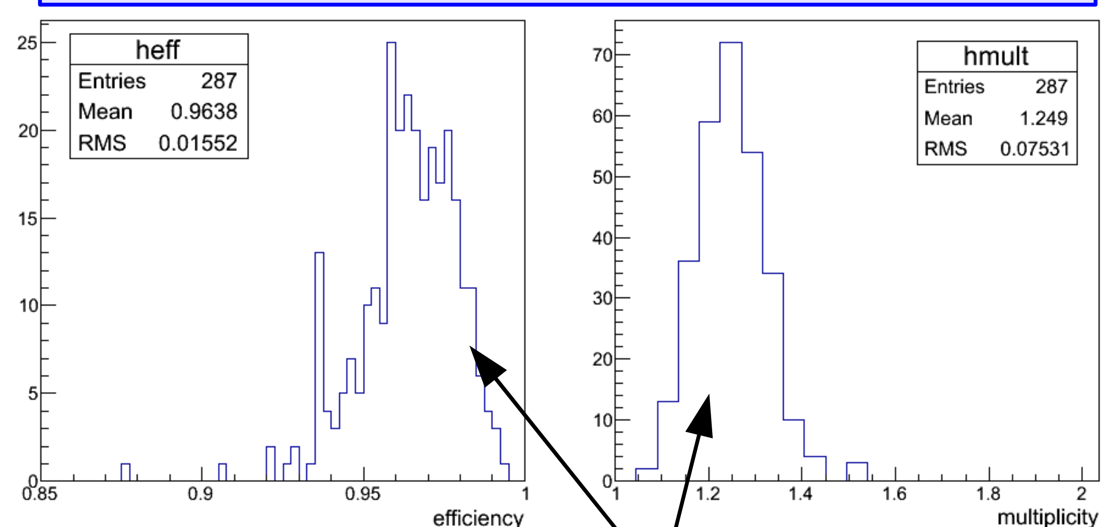
Otherwise, **the average ASIC efficiency (8x8 cm^2) is ~ 96%.**

→ Drift gap, gas gain and thresholds are well uniform.

2D efficiency map – 1 prototype



Efficiency and multiplicity – 2 prototypes



1 ASIC = 8x8 cm^2

287 ASIC

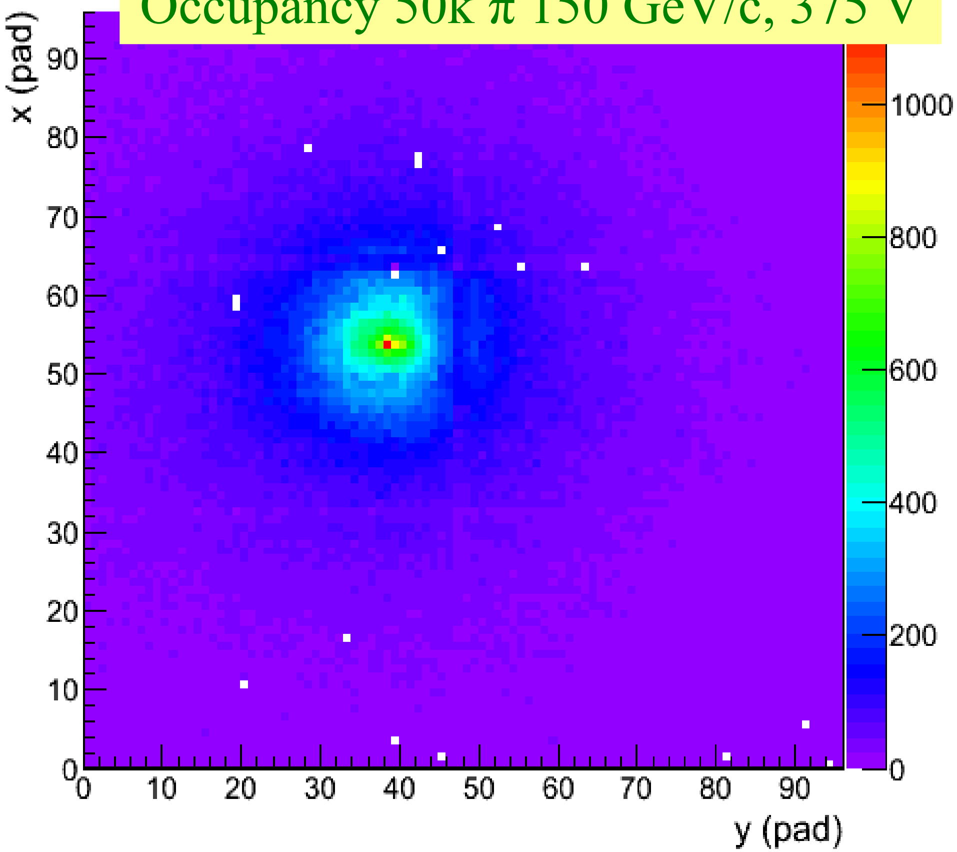
Response to hadron showers (1 λ_{int} Fe)

Ionising particle spectrum in showers can have dE/dx larger by orders of magnitude than MIP!
→ It is more likely to reach the discharge limit in hadron showers than in a MIP beam.

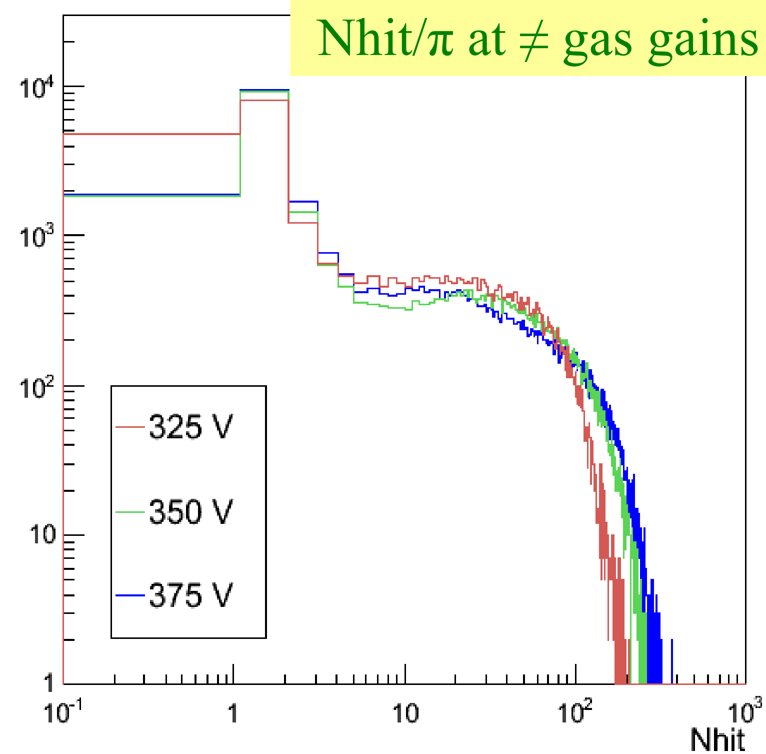
Test: direct a 150 GeV/c pion beam at a 1 λ_{int} steel block upstream of the prototype.
Measure response at various mesh voltages.

Number distribution hardly changes above 350 V!
→ Gas gain of 10^3 is enough for showers.
Very stable operation.

Occupancy 50k π 150 GeV/c, 375 V



Nhit/π at ≠ gas gains

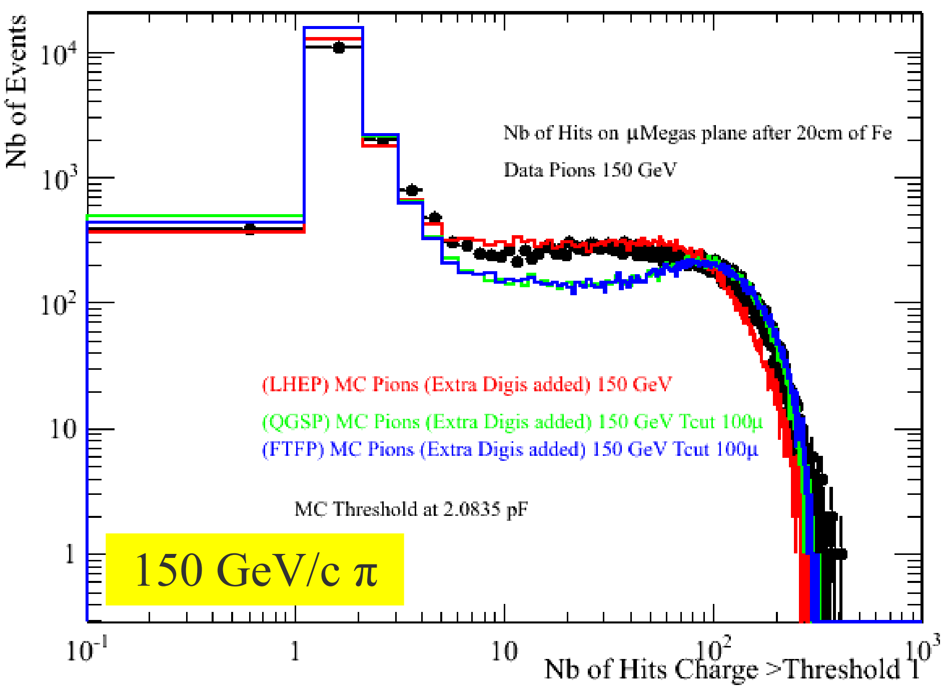


Response to hadron showers (1 λ_{int} Fe)

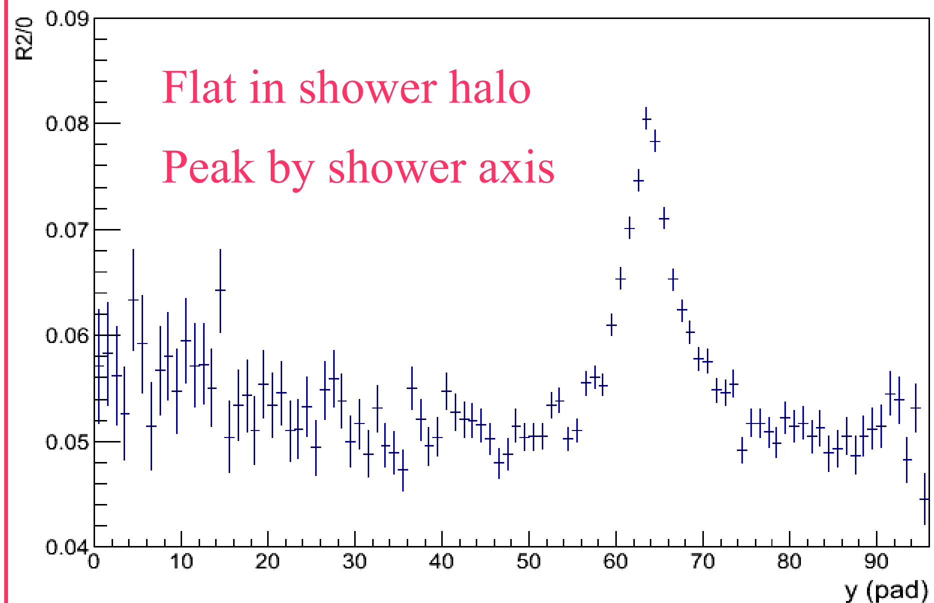
On-going simulation work

We have a digitisation procedure

and perform first comparison to G4 models.



Nhit above first threshold
Data & MC, 150 GeV/c π after 1 λ_{int} of Fe



Position distribution of
Nhit(high trh.) / Nhit(low thr.)

Semi-digital RO works

Signal pass higher thresholds by the shower axis.

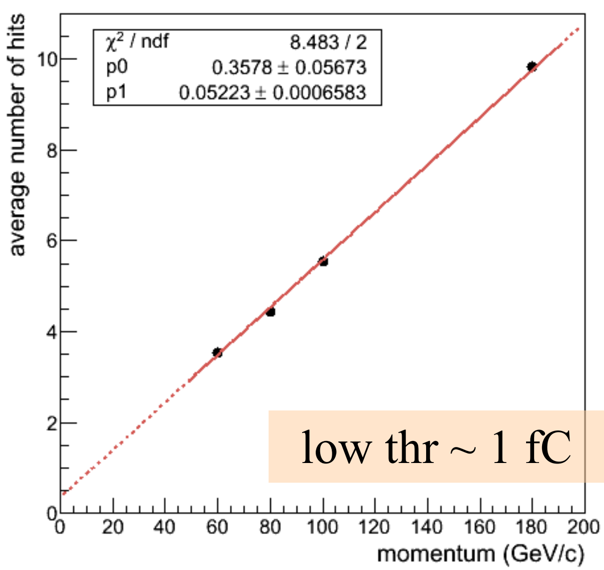
Response to hadron showers (5 λ_{int} Fe)

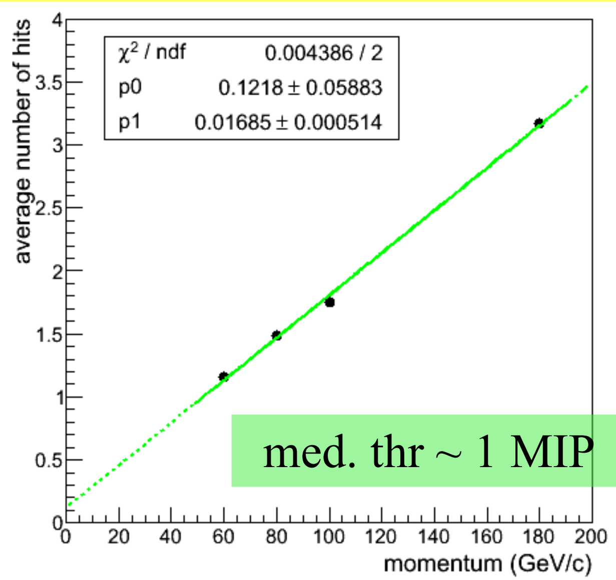
Linearity

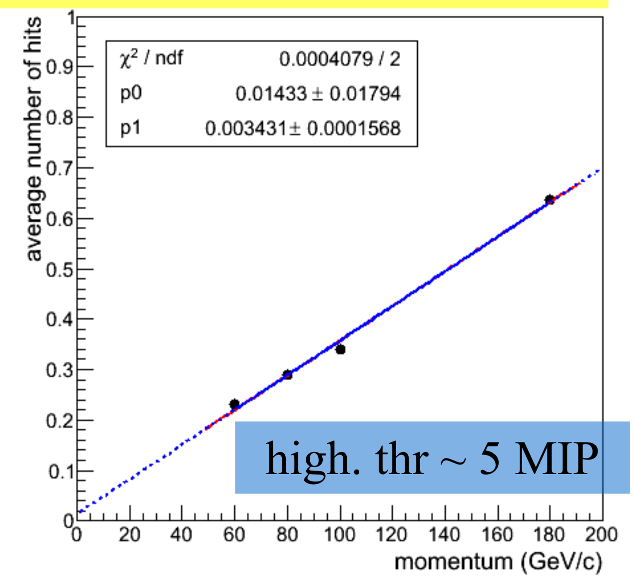
At layer #47 of SDHCAL, **linear trend of Nhit with pion energy up to 180 GeV/c**.

This for the 3 thresholds: ~1 fC, 1 MIP and 5 MIP.

Average Nhit @ layer # 47 VS π momemtum, 50-100k events / point, 60,80,100,180 GeV/c







Good prospect for a full calorimeter.

But next: measure the trends closer to shower max.

→ Test beam of 4 Micromegas in Oct. 2012 inside RPC-SDHCAL: layer # 5, 15, 25 & 35.

Conclusion on the 1 m^2 prototypes

A lot of progress since last CALOR conference in 2010!

Micromegas prototypes show excellent performance.
The key is the operation at low gas gain, made possible by the use of MICROROC ASIC.

Nice set of measurements.
Still need to converge on a **complete quantitative understanding** of the test beam results.

What about true calorimetric measurements in a Micromegas sDHCAL?

2 DHCAL projects already well on track, difficult to get more Micromegas layers funded...

This fall: 4 layers inside GRPC SDHCAL at CERN (October).
Will try to extract as much Micromegas-specific results.

So, we should focus on improving the technical aspects.

Prospects towards LC-like module

Scalability: transverse dimension

1 m^2 prototype design makes scaling to larger size straightforward.

With current scheme, ASIC chain can be as long as "3 meters" (i.e. 6 ASU).

Thickness: longitudinal dimension

Reduce thickness (or increase sampling) of HCAL and possibly costs.

→ Embed PCB spark protection networks inside PCB

OR: at gas gain below 10^3, MICROROC diodes are sufficient ? → remove PCB diodes

If thin enough: possibly interesting for an W-ECAL

Time resolution: 4th dimension

Timestamping help to remove background at CLIC: **Implement TDC in MICROROC.**

Long term operation

Micromegas ages well and handles rates, **weak P/T dependence of signal can be removed.**

Thanks for your attention