G2CD: Genaral Gaseous Calorimeter Digitizer

Y. Haddad, V. Boudry, M. Ruan
haddad@llr.in2p3.fr

LLR, École polytechnique, IN2P3-CNRS

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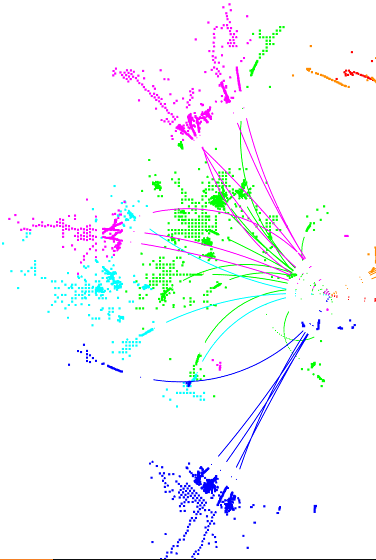
PFA & Digital Hadron Calorimeter

- Particle Flow Approach (PFA) require high longitudinal and transverse granularity in calorimetry for precise JET measurement
- It implies a highly segmented sampling hadron calorimeter (HCAL)
- Digital calorimeter (DHCAL) using gaseous detectors such as GRPC or MicroMegas can provide fine segmentation $(1\ cm^2) \rightarrow$ High granularity
  - Digital $\Rightarrow$ 1-bit readout system
- Motivation : Able to reproduce in simulation the gaseous detector response.

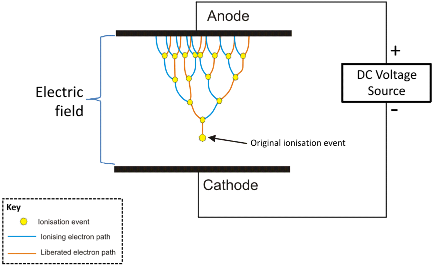


Software digitization for Digital hadron calorimeters

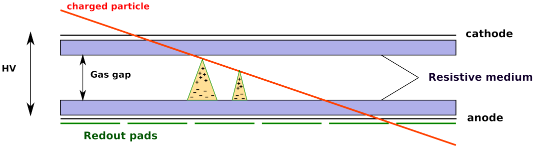
- The energy estimation in DHCAL is based on Hit Counting
- The systematical effects are caracterized by the Efficiency & pad multiplicity in case of the gaseous detector
- To complete the simulation tool (data/MC comparison)
  - Need a general method to estimate the pad response ⇒ Digitization
  - Able to reproduce the efficiency and multiplicity
  - Use the spatial information from simulation done @ high granularity
  - Can be applied to various type of gaseous sensors (such as MicoMegas & GRPC)
- Two digitization approaches :
  - Standard approach
  - Small cell approach (G2CD : General Gaseous Calorimiter Digitizer)

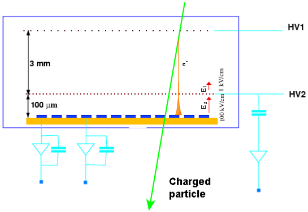
Gaseous detectors Principle

- Gaseous detectors follows allmost the same principle
  - A charged particle passing trough the sensor ionizes the gas
  - The ionization electrons drifts in the gas under an electric field ⇒ multiplication (Towsand avalanche)
  - The movement of both electrons and ions leads to an induced charge in the readout pads



GRPC & MicroMegas sensors





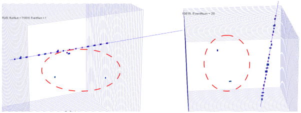
- GRPC
- Gas : $\mathrm{TFE/CO_2/SF_6}$ (93/5/2%)
- HV : ~ 7 kV in avalanche mode $\rightarrow$ Rate up to $100\ \mathrm{Hz/cm^2}$
- readout pads $1 \times 1\ \mathrm{cm^2}$
- Efficiency $\geq 95\%$

- MicroMegas
- Gas : $\mathrm{Ar/CO_2}$ (80/20%)
- Mesh voltage : $\sim 500\mathrm{V}$
- readout pads $1 \times 1\ \mathrm{cm^2}$
- Efficiency $\geq 95\%$

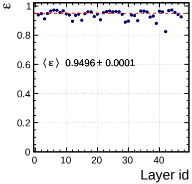
Used Data

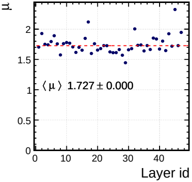
- SDHCAL data :
  - The SDHCAL(Semi-Digital Hadron Calorimeter) prototype is a digital calorimeter with 50 GRPC sensor layer of $1m^2$ each separated by a gap of 2.8 cm
  - Muons do not interact in the calorimeter providing minimum ionizoing particle (MIP) $\rightarrow$ appropriate for the GRPC characterization
  - Test beam data taken @CERN in 2012 within CALICE collaboration.
- MicroMegas data :
  - August 2008 Small chamber with muon beam (2009 JINST paper, doi :10.1088/1748-0221/4/11/P11023)

Mip track reconstruction, efficiency & multiplicity estimation



- Muon reconstruction follows few steps :
  - Hits clustering in layer using nearest neighbor clustering
  - Center of gravity of hits on each cluster → cluster position
  - isolated hits are drooped
  - Track reonctructed based on χ^2 minimization
- The efficiency and multiplicity estimation :
  - Efficiency(ε) : presence of at least one hit within $2\ \mathrm{cm}$ around the projected impact point.
  - Multiplicity(μ) : number of hits in each plate
  - This estimation is done for each layer using the clusters of other layers to define a track



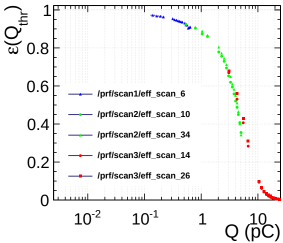


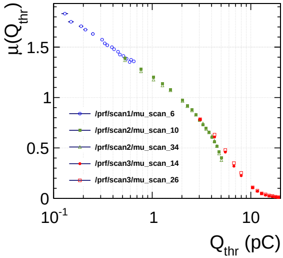
Charge threshold scan

- Threshold scan for ε and μ
- for each run, the value of the threshold was changed for different chambers

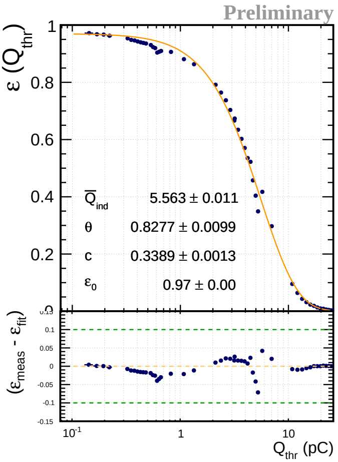
Threshold	chamber no	range
t1	6, 18, 30	$[0, \quad 0.8]\mathrm{pC}$
t2	10, 22, 34	$[0.8, \ 1.4]\mathrm{pC}$
t2	14, 26, 38	$[0.2, \quad 11]\mathrm{pC}$

- The colors corresponds to the scanned threshold range.





Charge threshold scan



- The induced charge spectrum folows a polya function :

$$\mathrm{P}(q;\theta,\bar{q}) = \left(q\frac{(1+\theta)}{\bar{q}}\right)^{\theta} \exp\left\{-q\frac{(1+\theta)}{\bar{q}}\right\}$$

  - $\bar{q}$: mean charge
  - θ : the function width

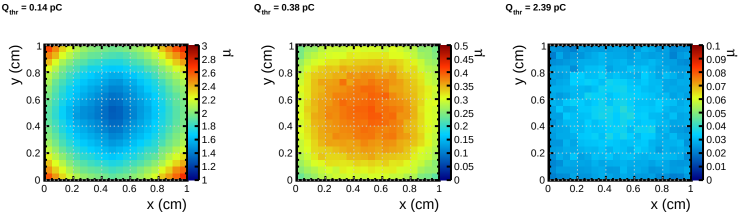
- The measurement of efficiency versus the threshold $\rightarrow$ Ingreation over the charge spectrum :

$$\varepsilon(q_{thr}) = \varepsilon_0 - c\int_0^{Q_{thr}} p(q;\theta,\bar{q})\mathrm{dq}$$

  - ε_0 efficiency at $Q_{thr} = 0$ pC
  - c normalization constant

Multiplicity map in cell

- The mean multiplicity as a function of the projected track position in cell



- This measurement gives an idea of a fraction of shared charge in function of ionization position in the cell.
- To reproduce the multiplies effect → need position information at millimeter precision.

Standard analogue approach

- The fraction of the charge induced on each pad is inferred from the 2D integration of a known profile and the precise position of the GEANT4 hits.
- The value of the induced charge is drawn randomly following a Polya distribution.
- The charge profile is tuned to reproduce ε & μ on the data.
- This method requires the storage of each GEANT4 hit if post-processing is need.
- But, which smearing charge function will be used to roproduce the multiplicity effect ?

Toy model simulation

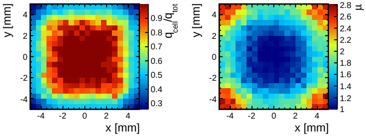
- The analogue approach can be implemented in a toy simulation to validate the the model of charge splitting function.
- Can be resumed in few steps :
  - The hits are replaced by a random positions in one cell of $1 \times 1\ cm^2$
  - The charge are splited using a function $\sigma(x,y)$
  - Make a multiplicity map for given threshold.
- we choose in this study a sample Gauss function as the splitting function,

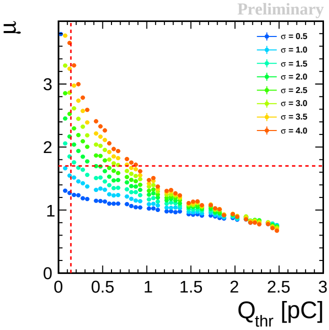
$$\sigma(x,y) = \frac{q}{2\pi\delta^2}\exp\{-\frac{(x-x_0)^2+(x-x_0)^2}{\delta^2}\} \quad (1)$$

- Then the analogue aproach is applied with the Polya prameters gotten from data.

Toy model simulation

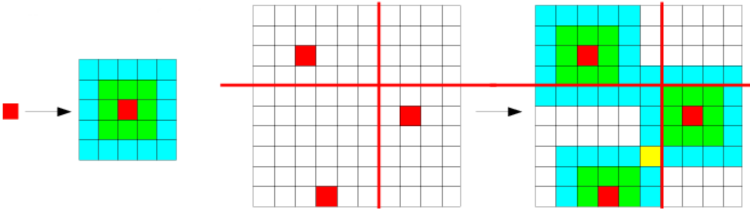
- The fraction of chared charge in function of the position in the cell
  - The charge fraction decrease in the border of the cell → increase the probability to pass the threshold in the neigbor cell.
- Multiplicity as function of the threshold scan for diffrent value of δ gives the widght of the spacial charge distribution → second digitizer input



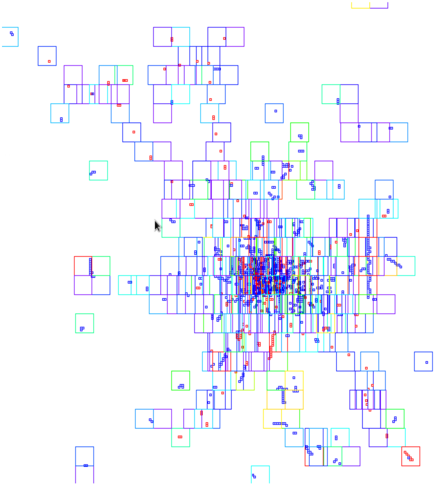


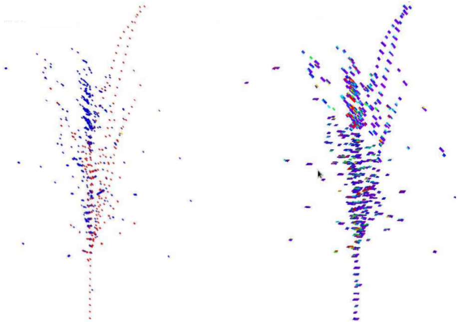
Small cell Approach (G2CD)

- from the multiplicity scan on cell → need position information in milliliter precision :
- The idea :
  - Parametrize 1mm simulated hit with :
    - Induced charge from Polya distribution
    - Charge distribution table → The charge smearing
  - Accumulate charge within target area respect the real cell size (digitized hit 10×10 mm)
  - No need to store individual hits → better suited for linear collider detector optimization studies (variable size of cell, geometry ...)



G2CD example





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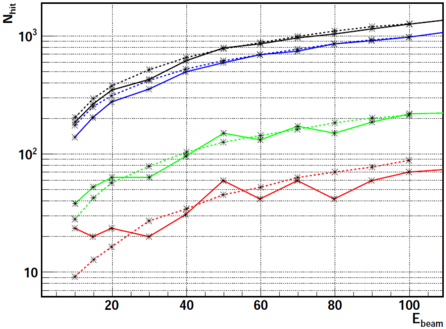
G2CD : Validation with GRPC-SDHCAL data

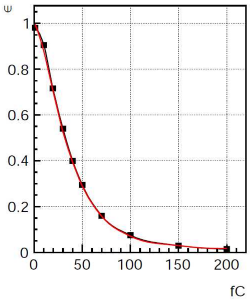
- GRPC-SDHCAL test beam with cubic meter data, pion+muon.

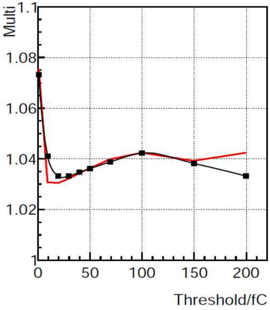


- Multiplicity for hadronic showers was reproduced with a good agrement.
- Solid line : TB measurement. Dashed line : Simulation + Digitization
- The color corresponds to diferent threshold (0.114,5.0,15 pC)

G2CD : Validation with MicroMegas data

- MicroMegas Aug 2008 small chamber muon (2009 JINST paper, doi :10.1088/1748-0221/4/11/P11023)





- The bumb at $Q_{thr} = 100$ fC explained as a delta-ray effect.

Conclusion

- Two gaseous detector digitizations were developed for the SDHCAL prototype : an analogue and a digital (G2CD)
- The Results using G2CD was shown.
- G2CD offers more flexibility in optimization sudies
- It was tested with good agrement data/MC for MicroMegas and GRPC sensors with muons & pions shower in linear linear collider hadronic calorimeter prototypes.