PFA Oriented Gaseous Calorimeter & its digitization: G2CD

Manqi

Digitization, what is it?

- Two steps of the simulation
  - Geant4 – Mokka: energy deposition in sensitive volume
    - ~MeV/mm in solid
    - Nature unit of energy deposition: MIP
  - Digitization: estimate the electronic response from the energy deposition
- Digitizer
  - Indispensable component of full simulation
  - Should include/model all the important response of detector: efficiency, fluctuation, noise, pedestal, …
  - Request profound understanding of the physics/mechanism of detection

Content

- Introduction to Glass RPC Digital Hadron calorimeter
  - PFA oriented, gaseous calorimeter for the ILC
  - RPC & it's characteristics
  - RPC performance: measurement at Test Beam & modeling at the Digitizer

- G2CD Digitization, an simple example of reconstruction

PFA Oriented Calorimeter

Jet resolution & PFA

Particle Flow Algorithm:

Measure jet particles in different sub detector!

$$E_{jet} = E_{charged\ tracks} + E_{\gamma} + E_{h^0}$$

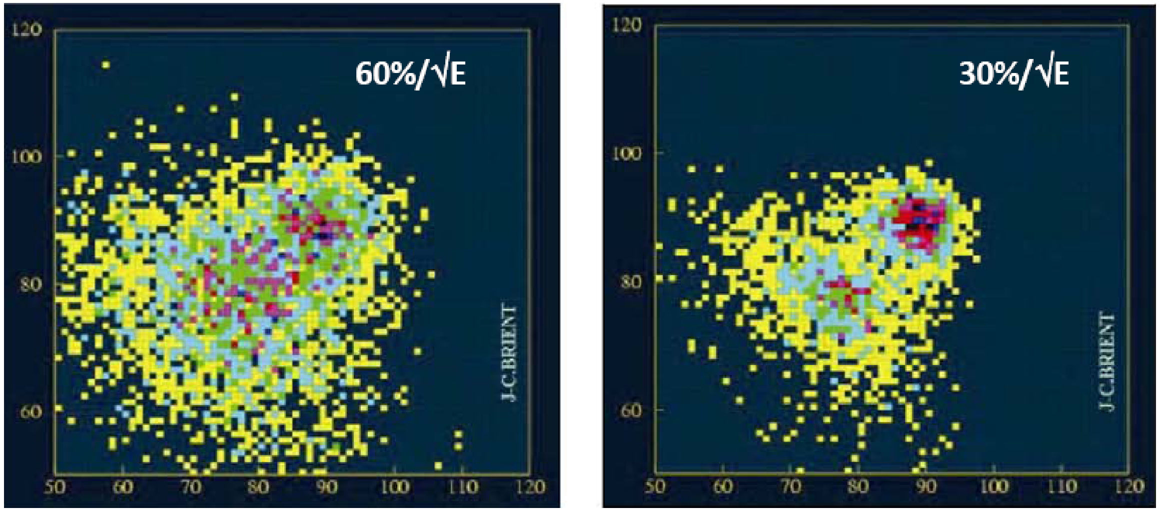
fraction: 65% (charged tracks), 26% (γ), 9% (h^0)

Charged Particle – Tracker:
$\Delta p/(p^*p) \sim$ 2E-5 (1/GeV)
Photon – ECAL:
$\Delta E/\text{sqrt}(E) \sim 15\%$
Neutron Hadron – HCAL:
$\Delta E/\text{sqrt}(E) \sim 50\%$

Final states in e+e- interaction up to 1 TeV c.m.s

Multi bosons	Multifermions + Boson(s)
ZH	e^+e^- H , e+e− Z
WW	$\nu\nu$ H , $\nu\nu$ Z
ZZ	ttH
ZHH	e ν W
ZZZ	$\nu\nu$ WW, $\nu\nu$ ZZ
ZWW	ttbar

Di-jet mass for WWvv & ZZvv @ 500GeV

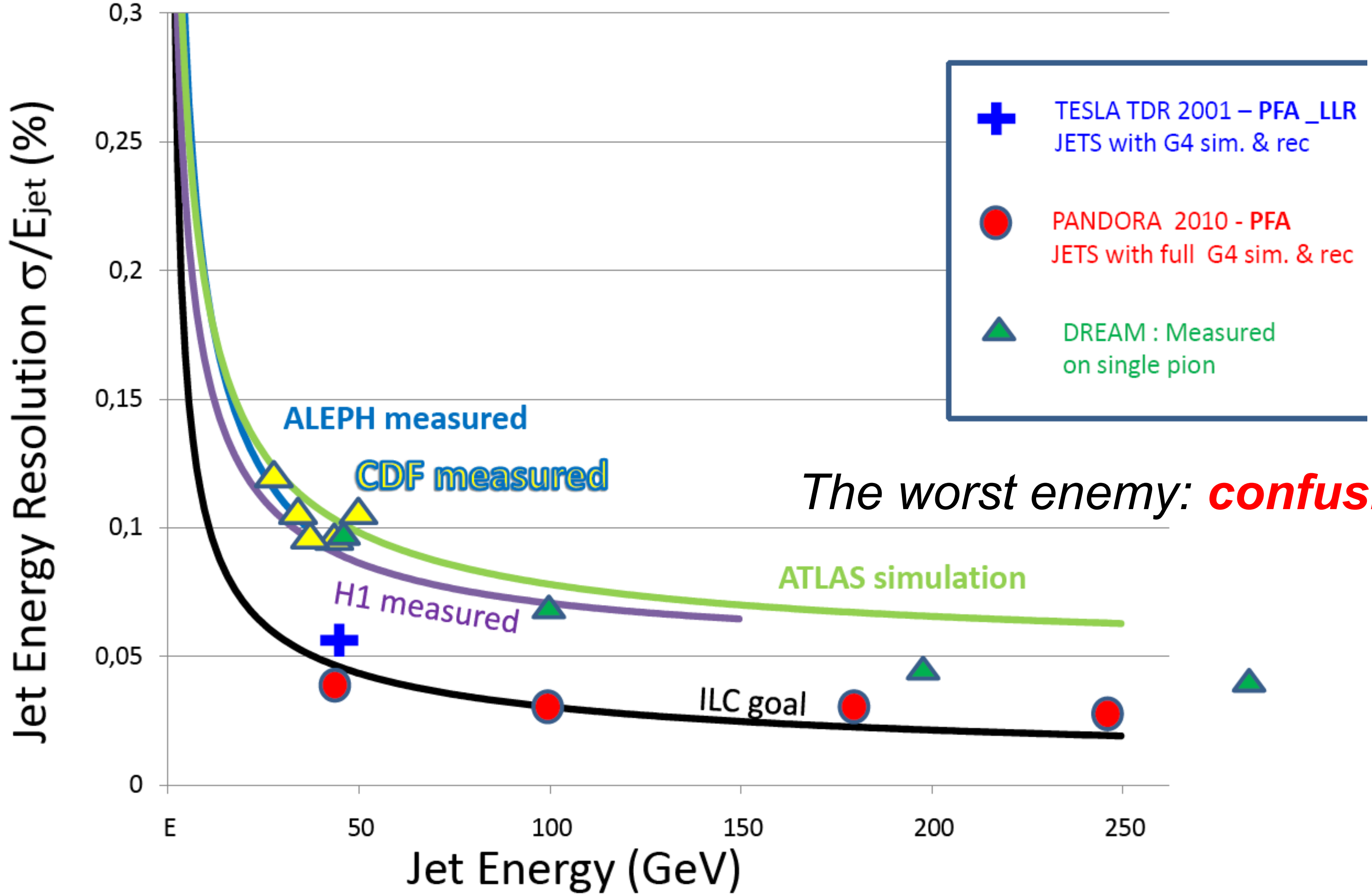


J-C. Brient - IWLC 2010

Given a perfect detector with no confusion:

$$\sigma^2_{jet} = \sigma^2_{ch.} + \sigma^2_{\gamma} + \sigma^2_{h^0} \quad \text{gives about} \quad (0.14)^2 E_{jet}$$

Jet energy resolution



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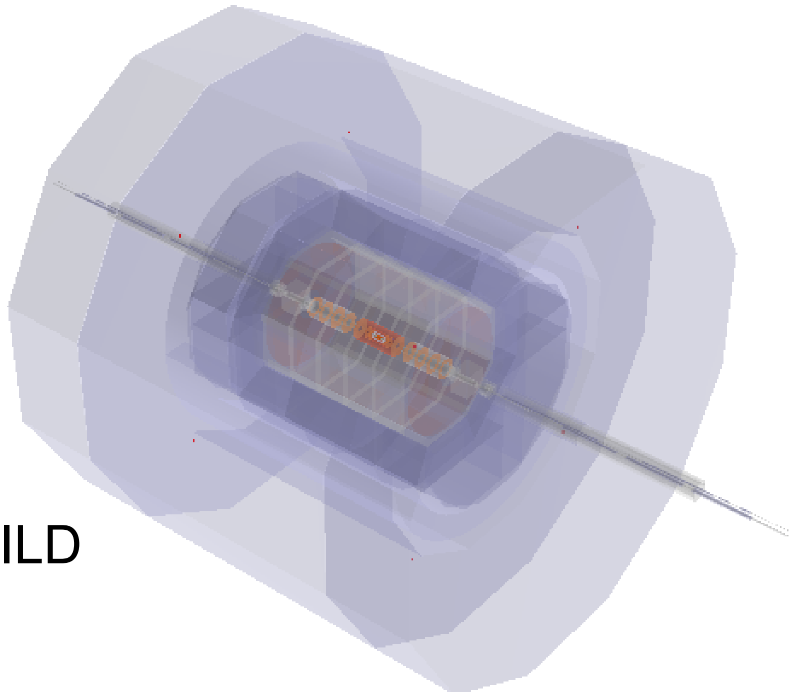
The worst enemy: ***confusion***

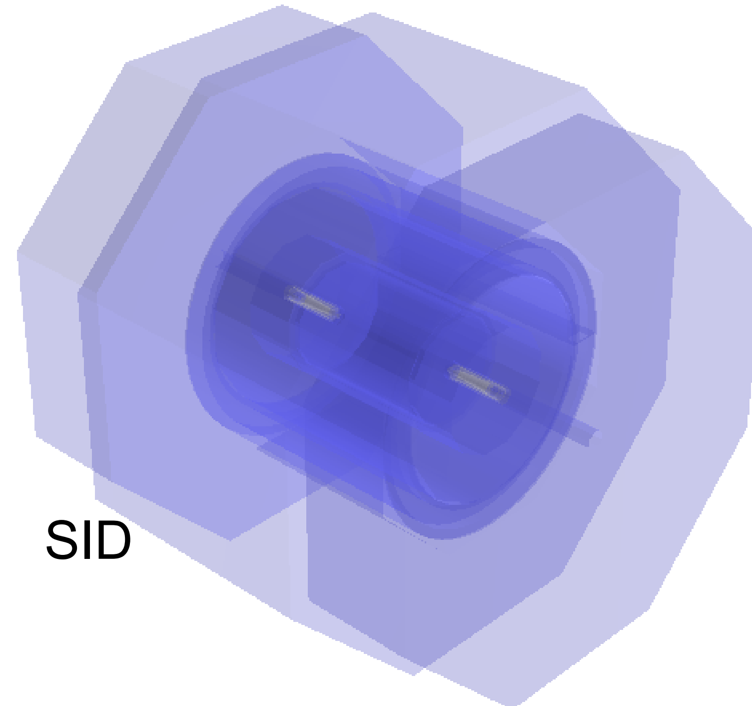
Real life and real detector →

- σ^2threshold → Energy threshold to be rec. (depends on species)
- σ^2efficiency → loss of particles (not reconstructed)
- σ^2confusion → Mixing between particles in the calorimeter

PFA Oriented LC detectors



ILD



SID

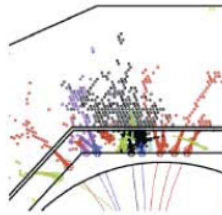
- PFA: less confusion ~ good separation ~ high granularity
  Granularity > Energy Resolution for the Calorimetry...
  (exception: 4^{th} concept with dual readout HCAL)

Calorimeter for ILC

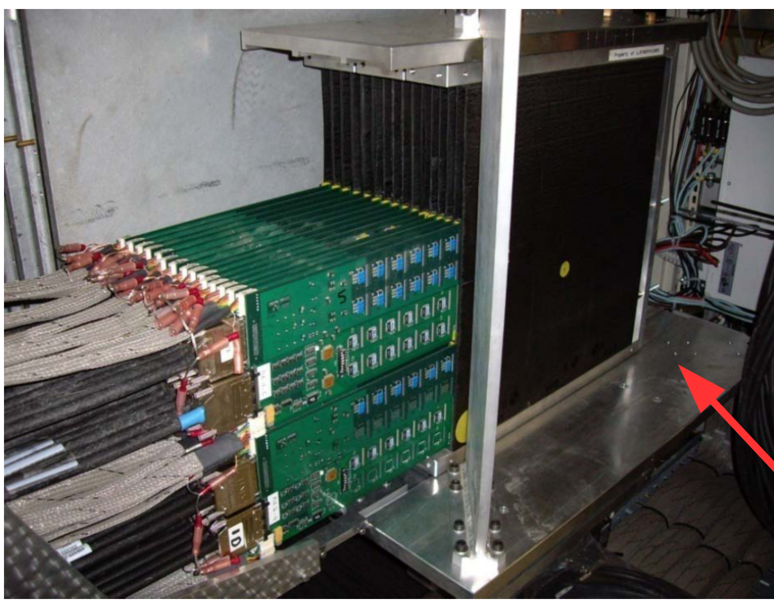
- PFA Oriented detector (both have ILC/CLIC Versions):
  - ILD (European + Asia, International Large Detector): TPC (+ Silicon inner detectors) tracking with B = 3.5T
  - SiD (US, Silicon Detector): Silicon tracking with B = 4T

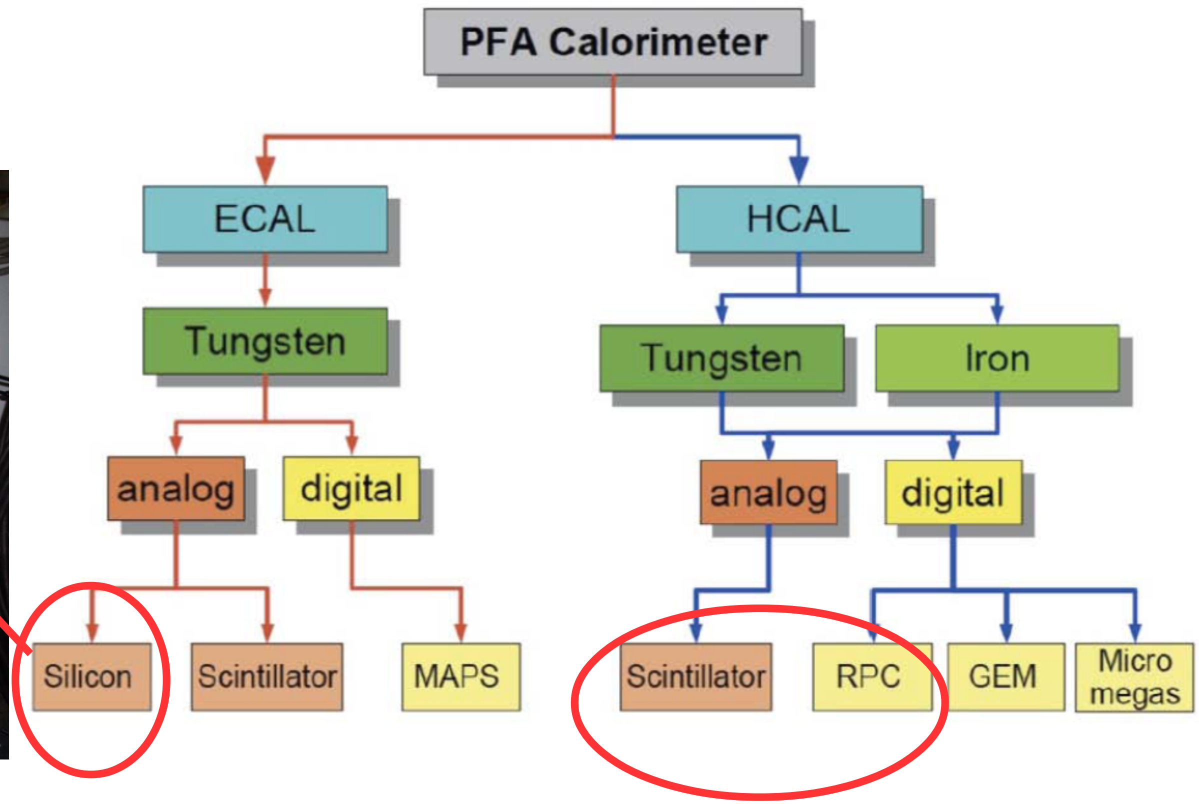
High granularity Calorimetry

eg: ECAL Prototype, 10k channels in a cube of 18 cm side ~ 1/8 of CMS ECAL



Technology tree

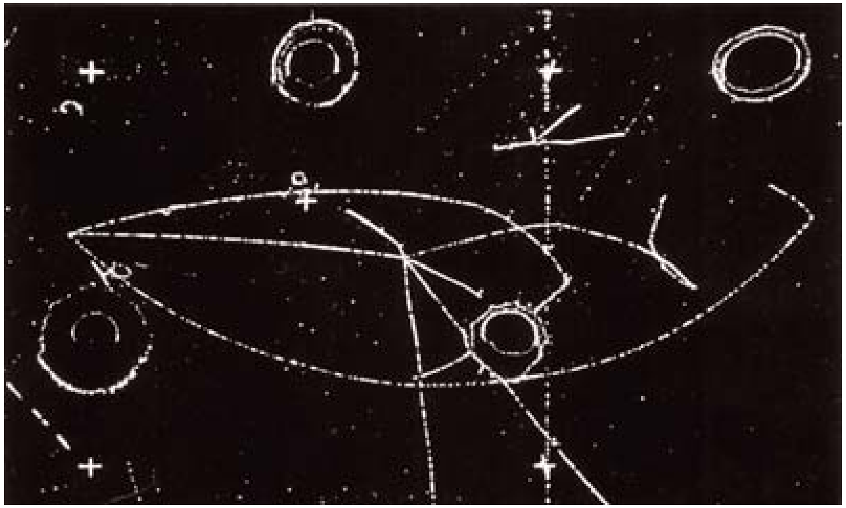


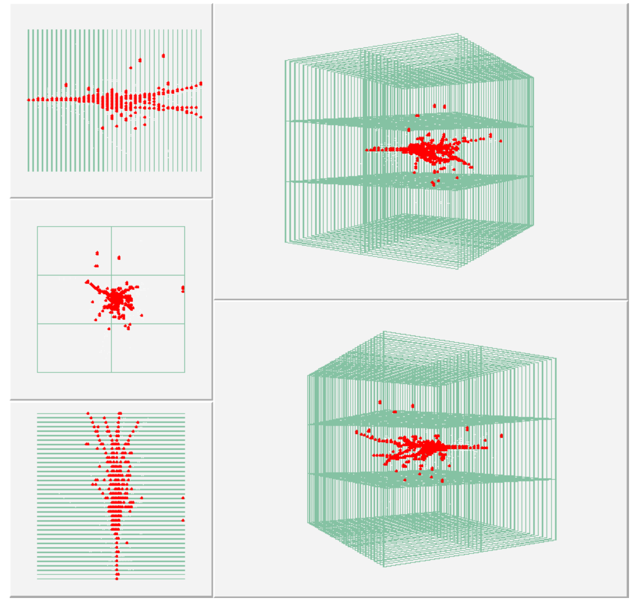


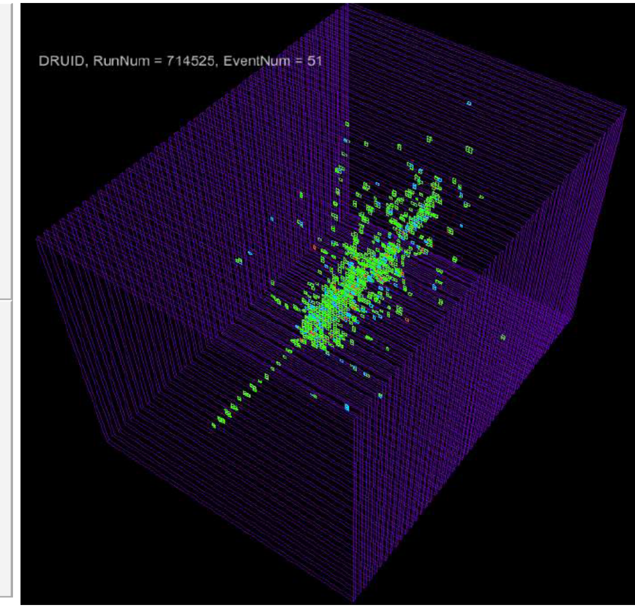
Scintillator AHCAL with 3 * 3 cm cell @ DESY

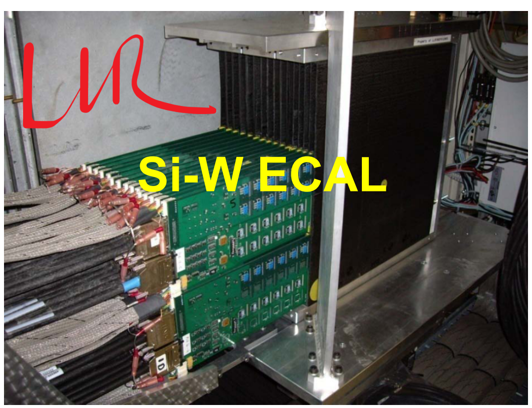
2 GRPC Digital HCAL with 1 * 1 cm cell: SDHCAL @ IPNL et al
DHCAL @ Fermi Lab

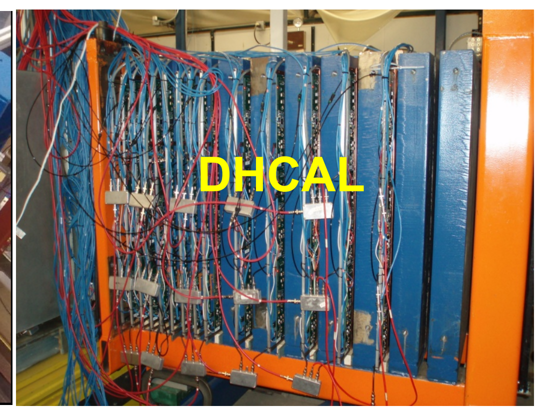
Calorimeter R&D for ILD







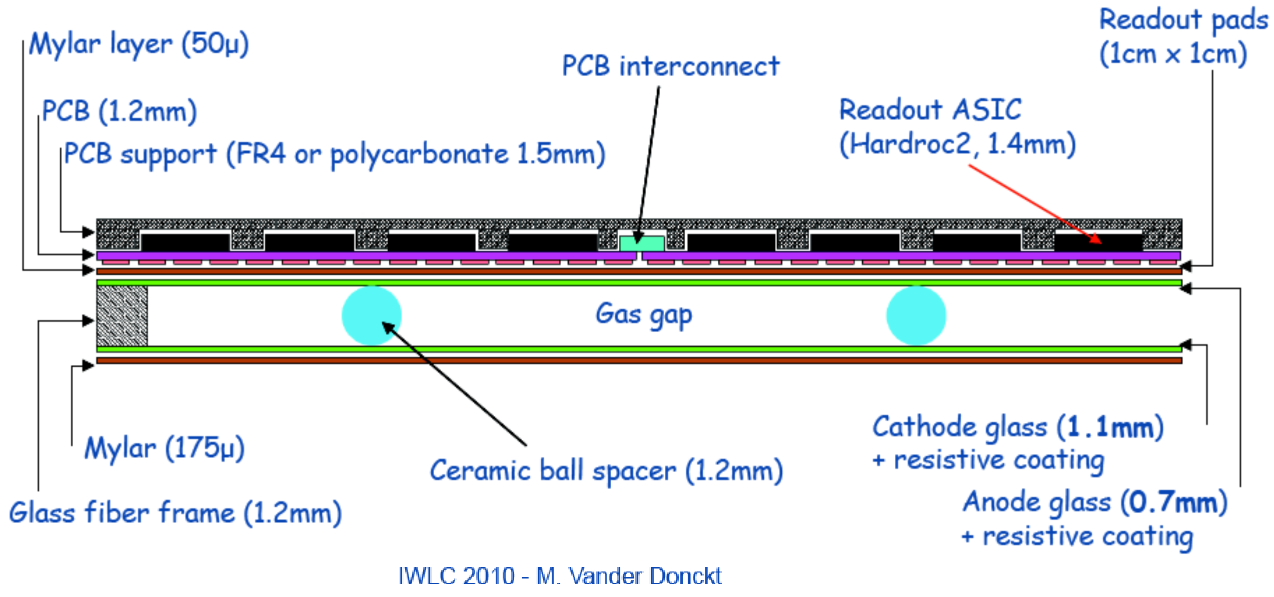




Ultra high granularity ~ 1 channel cm^{-3}. 3d, 4d or 5d image...

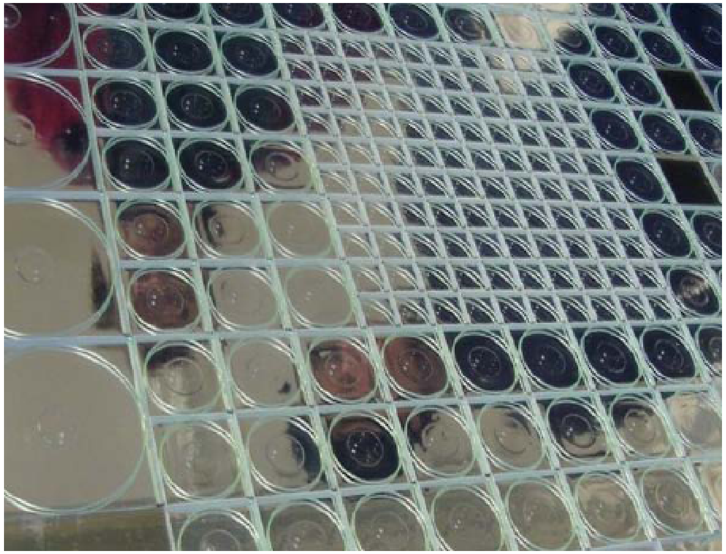
Gas Vs Scintillator

Gas: High granularity (1*1 cm) @ low cost



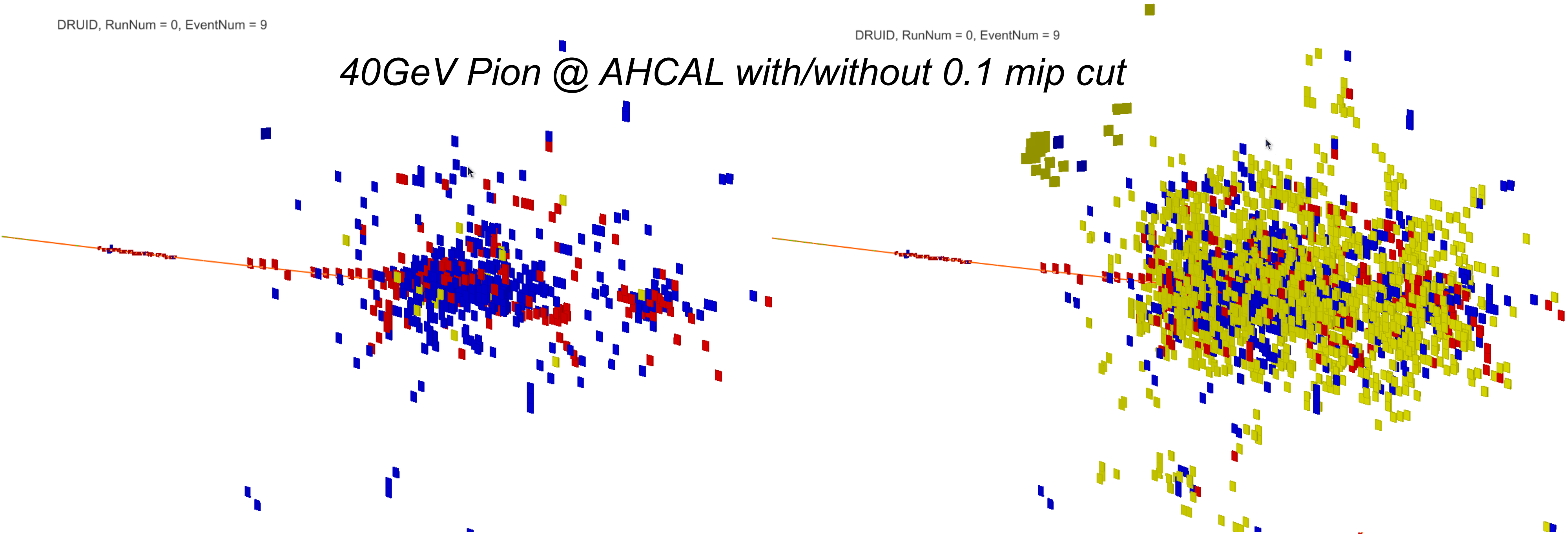
To compare:

Sensor layer in Scintillator AHCAL. Cell size: 3*3 cm, 6*6 cm & 12 * 12 cm

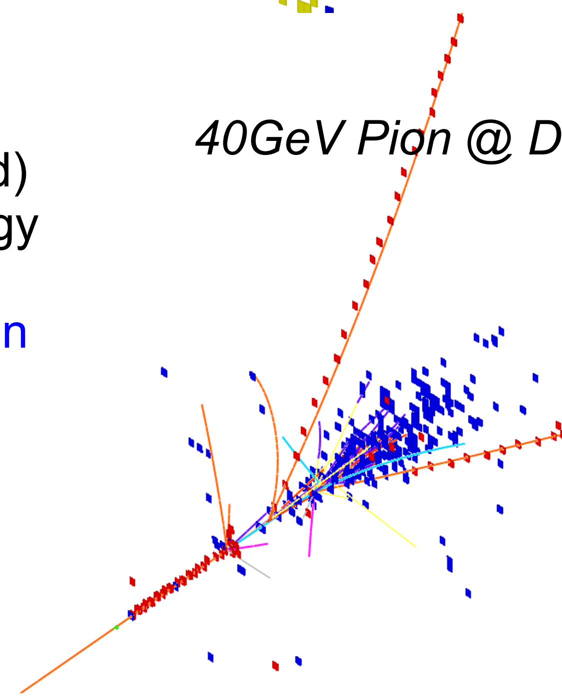


- Gaseous detector:
  - RPC: High efficiency, homogeneous, low cost, robust...
  - Huge fluctuation on induced charge: Semi-digital (channel coded on 2 bits)
  - Free of neutron hits

Neutron hits



40GeV Pion @ AHCAL with/without 0.1 mip cut



40GeV Pion @ DHCAL

Hit Colour: EM (blue), Neutron (yellow) or hadronic (red)

- AHCAL: Shower centre surrounded by lots of low energy neutron hits
- Needs carefully analysis: Confusion & Energy resolution

Modeling of GRPC Performance & development of G2CD

Avalanche @ gaseous detector

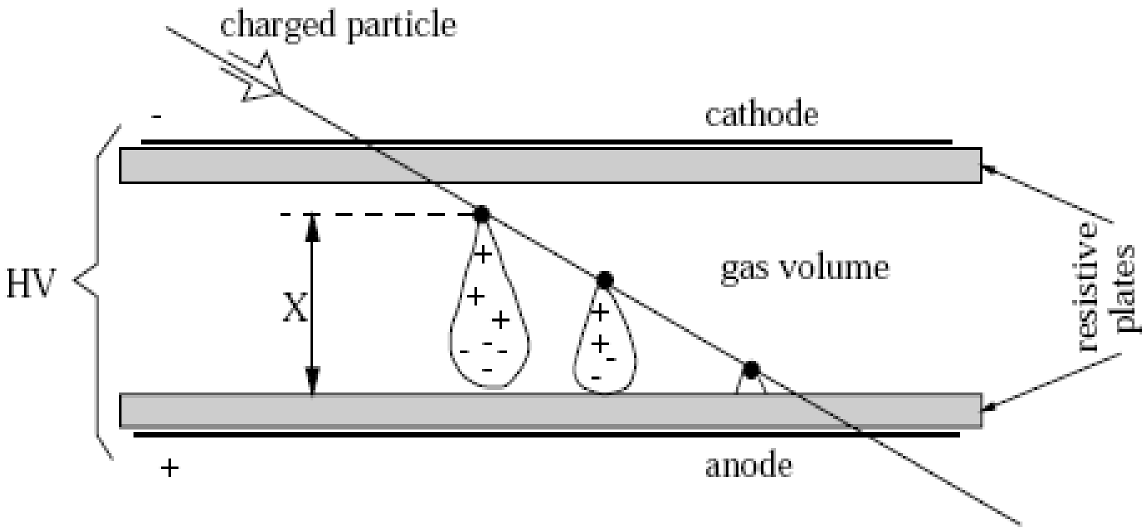
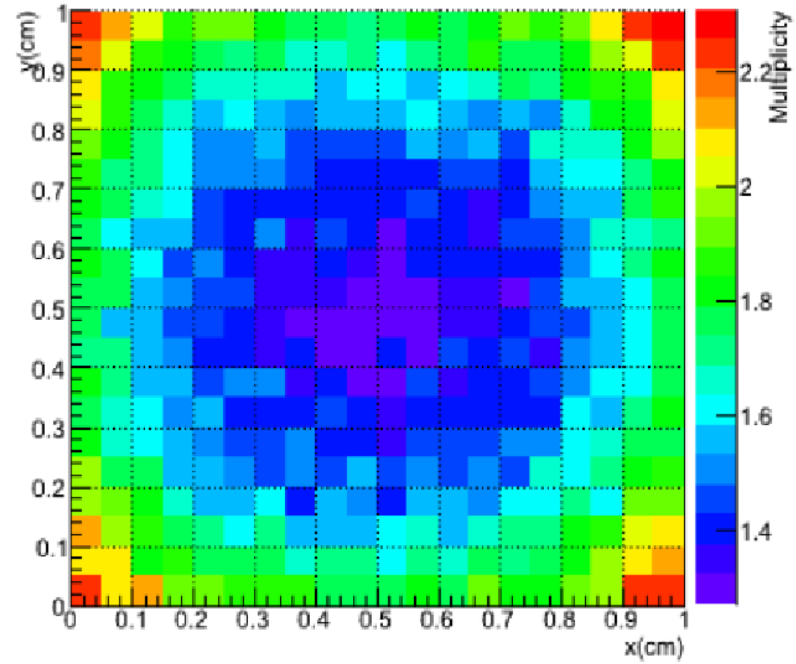


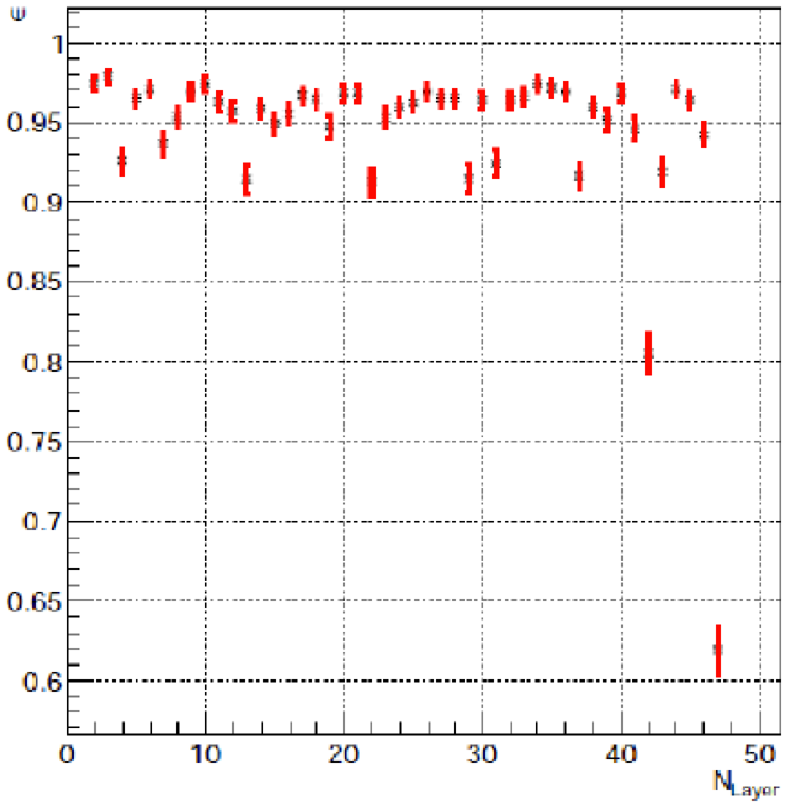
Fig. 1. Sketch of RPC gap.

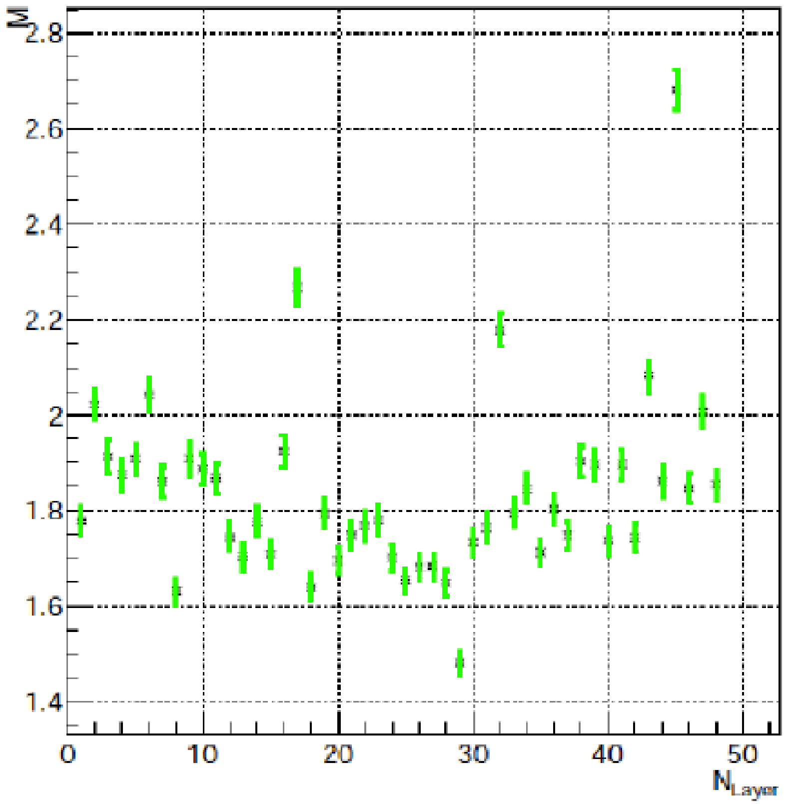


- Once one charged particle sailing though the RPC:
  - Efficiency: chance to create a hit (~ Induced charge > Threshold)
  - Multiplicity: number of hits in one lighted layer ~ number of cells with Induced charge > Threshold
    - Typical value ~ 1.4 – 1.8 at GRPC, ~ 1.1 at MicroMegas
    - Charge Image scale ~ 1mm (depending on resistive plates thickness)

Both can be measured at Test Beam

Measurement of efficiency and multiplicity





Efficiency and Multiplicity of the 48-layer GRPC prototype measured at CERN
Test beam data: using MIP event

Efficiency & Multiplicity: from the P.o.V of induced charge

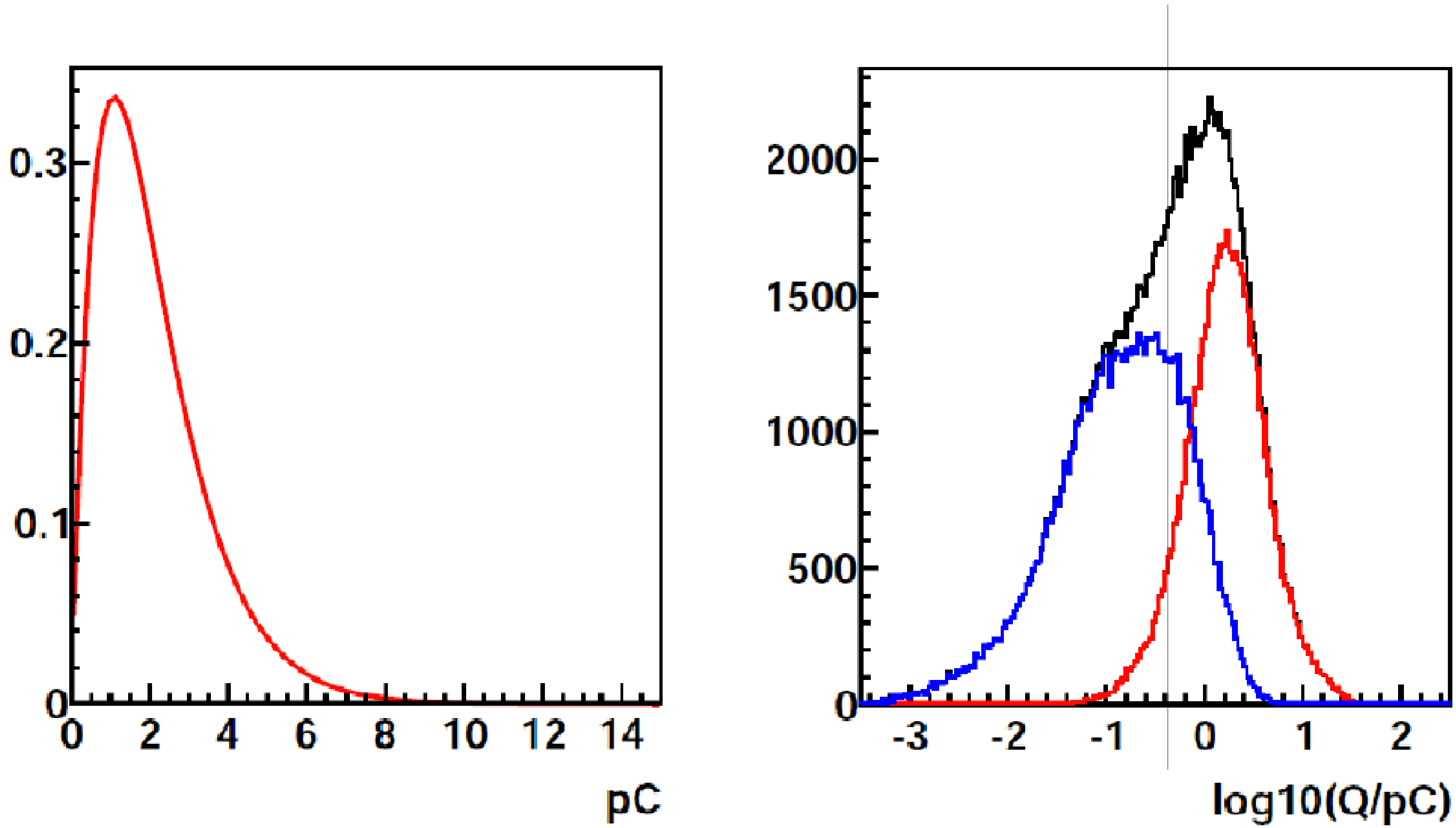


Figure 9. May 2012 GRPC SPS test beam: (left) Induced charge spectrum for 1 mm simulated hits and (right) Resolved induce charge spectrum for direct hits (red) and multiplicity hits (blue)

Multiplicity hits: hits where no charged particle hit on it directly

Resolve the induced charge spectrum from efficiency-threshold scan

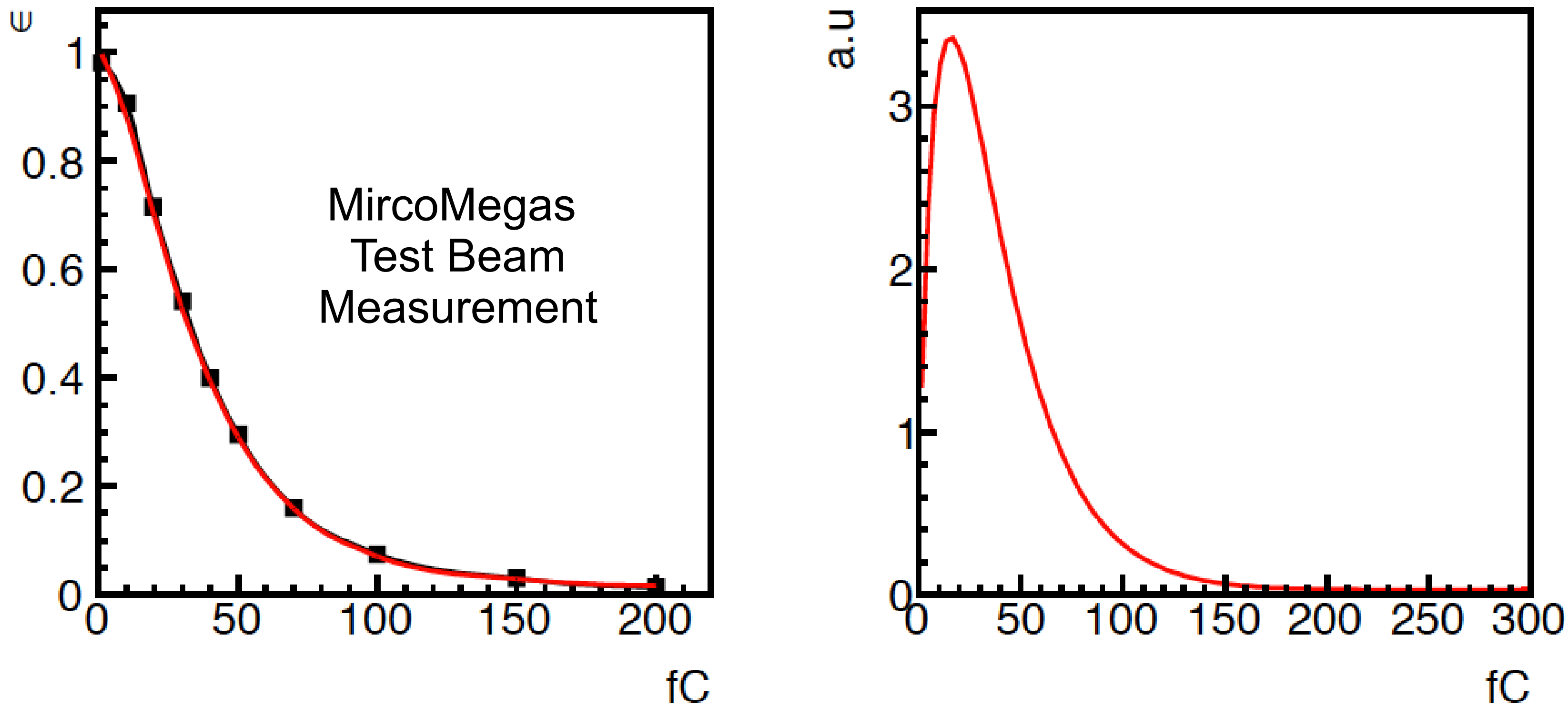


Figure 4. MicroMegas: (Left) Efficiency versus threshold curve. Black spots: experimental measurement. Red curve: G2CD reproduced curve (right) Resolved probability distribution function $P(x) = Nx^{0.7}e^{-0.045x} + 0.03$ defined in a domain of (0, 300) fC

Induced Charge spectrum can also be measured from Analogy readout:
However, bias might be induced since the readout system is different from digital...

To characterize the avalanche

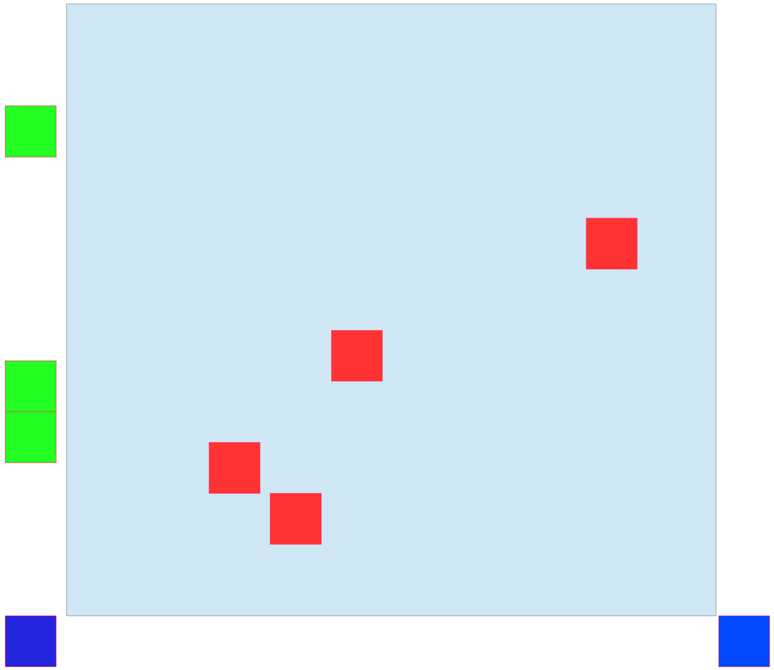
- Charge image at the anode
  - Total induced charge: measured from the eff-threshold scan
    - Polya function with only 2 parameters

$$P(x) = N x^a e^{-bx}$$

  - Spatial distribution of the charge: measured from the multiplicity-position dependence
    - Summarized into a numeric table

How many mips - avalanches can there be?

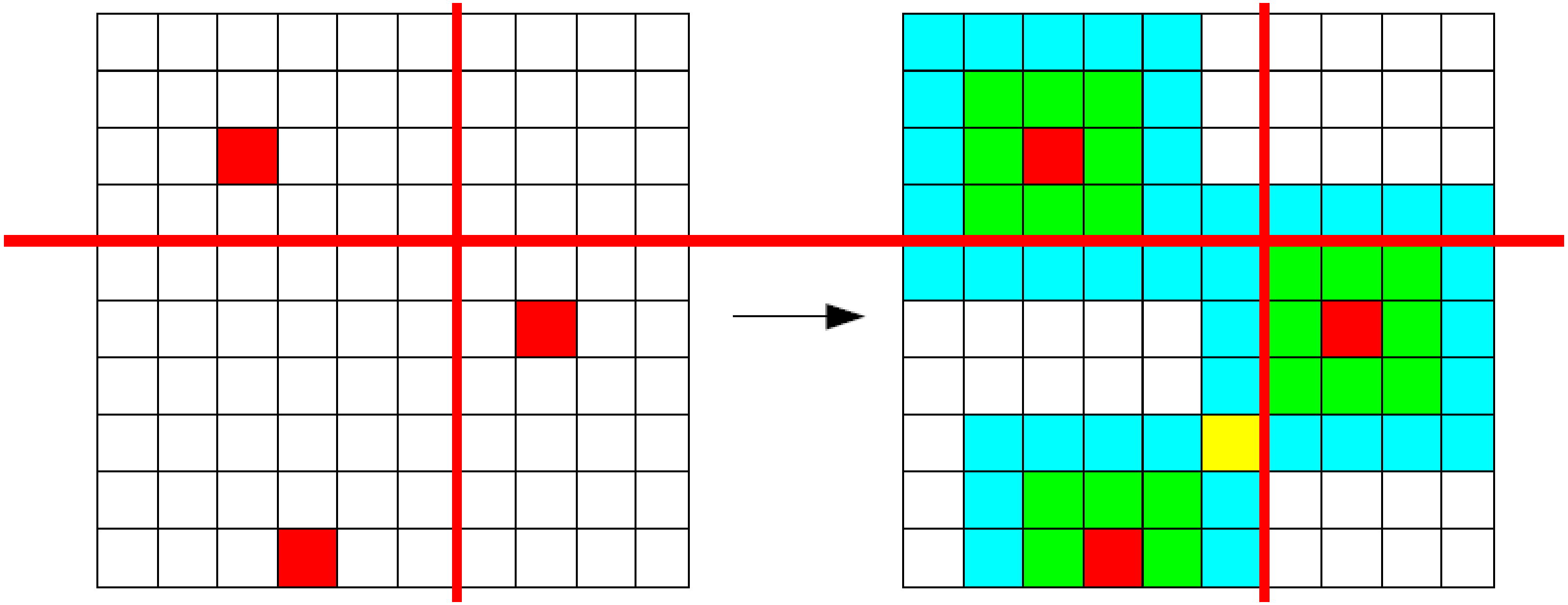
- Charge image ~ 1 mm^2
  - To 1st order, MIPs separated with distance > 1mm should be independent
  - MIPs hits too close should be regarded as only one hit, since the discharge process is saturated



Key Idea

Keep simulation level information to 1mm cells: count corresponding number of hits in/nearby each Digitized cell

Accumulate the induced charge in each Digitized cell



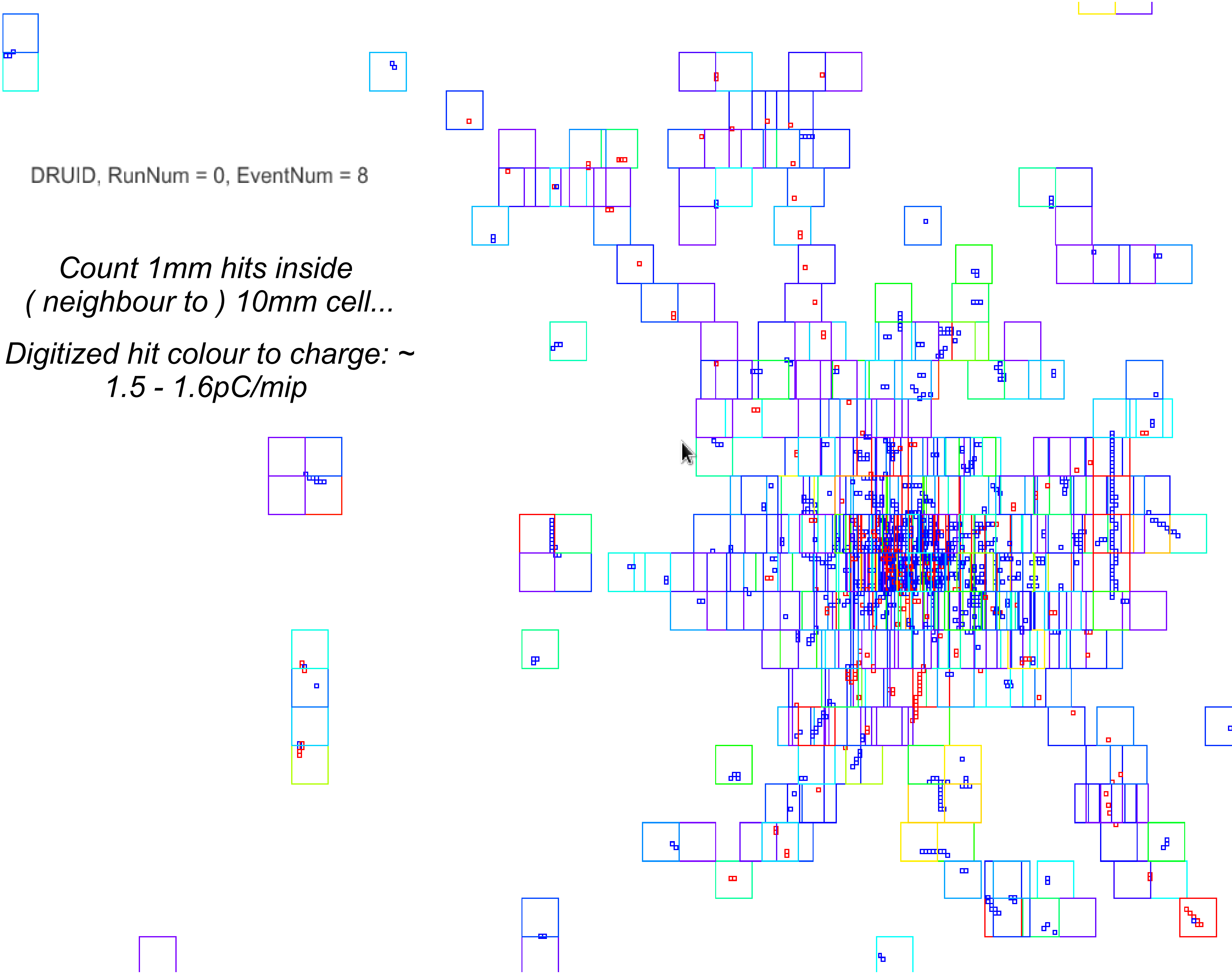
Key Idea

- Advantages:
  - Natural cut off: 1mm ~ size of charge image
    - Self Saturation & easy to integrate other saturation effects
  - Reliable estimation of multiplicity
  - Samples: available for other analysis (optimized cell size, fractal dimensional analysis...)
- Cost:
  - Machine time: the same
  - Data size: increased **~ 5%** (ParticleCont recorded & Nhits increased by 2 – 3 times, *Test on 20GeV Klong sample with only PRC HCAL & B Field:*)
  - Negligible at full detector event: ***Utilize as Simulation base line***

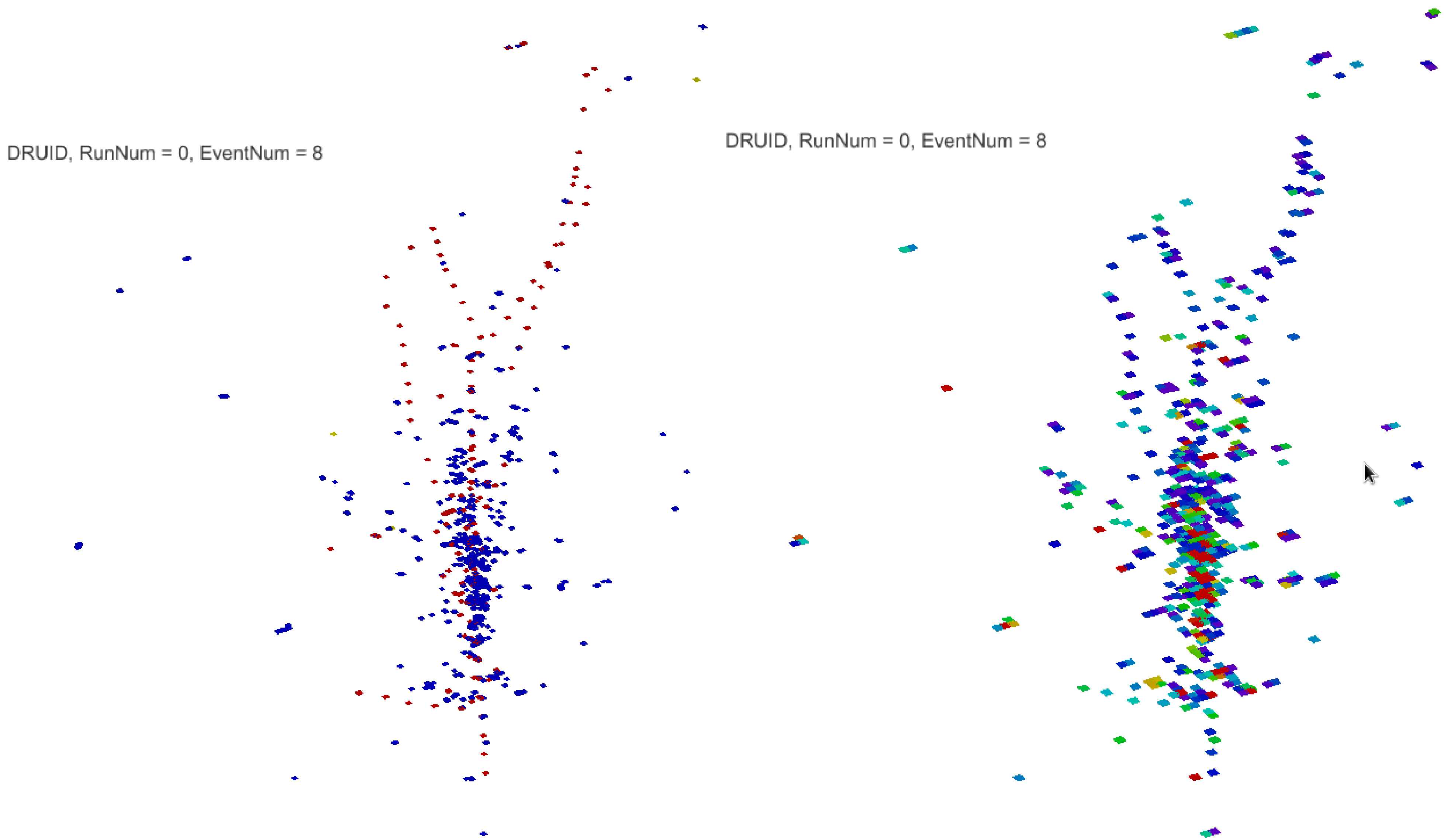
DRUID, RunNum = 0, EventNum = 8

Count 1mm hits inside (neighbour to) 10mm cell...

Digitized hit colour to charge: ~ 1.5 - 1.6pC/mip



Simu & Digi hits



Left: simulation level (1 mm cell: size zoned by 5 for display. Colour: EM, MIP or Neutron hit)
Right: Digitization level (10mm cell. Colour according to Charge)

Comparison with the test beam measurement

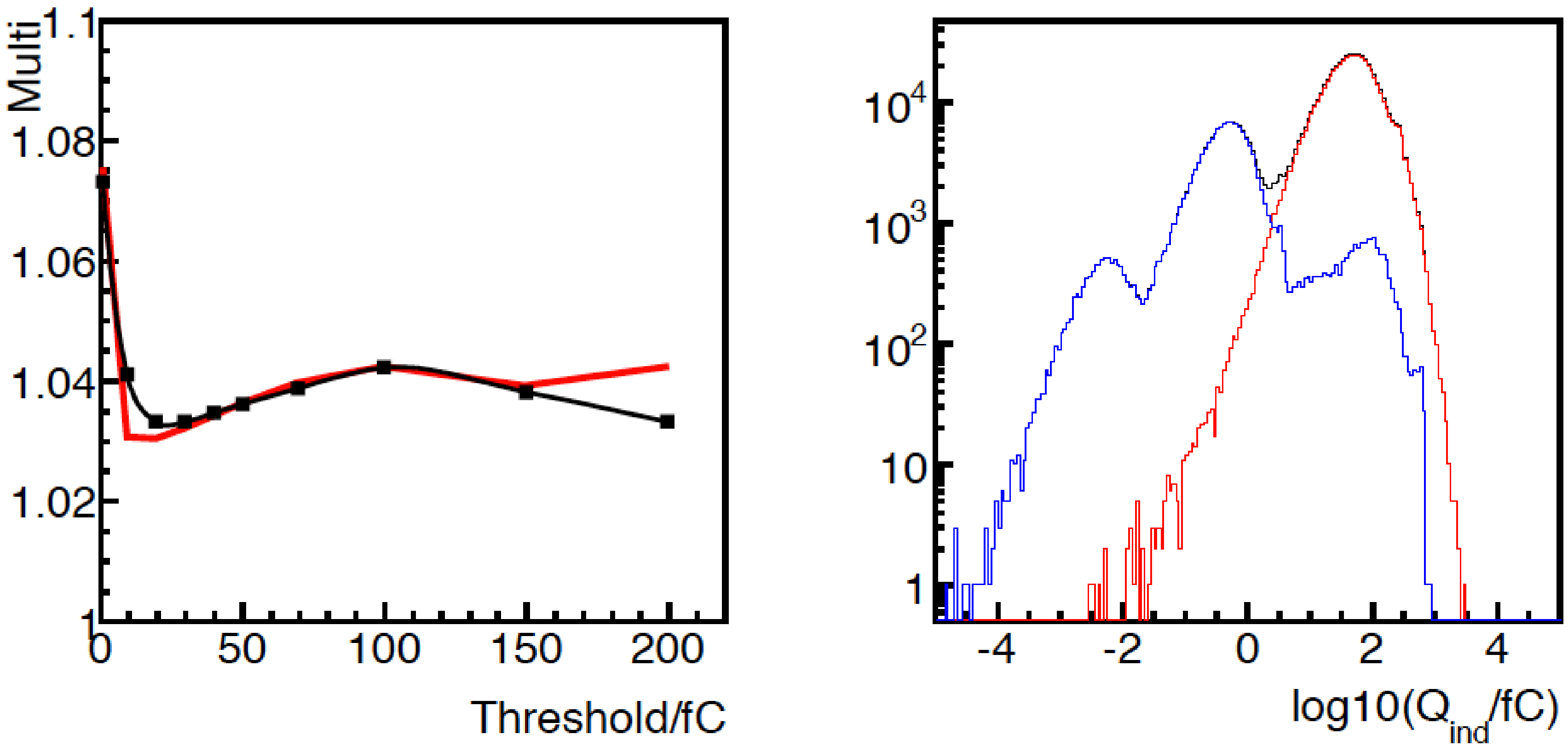
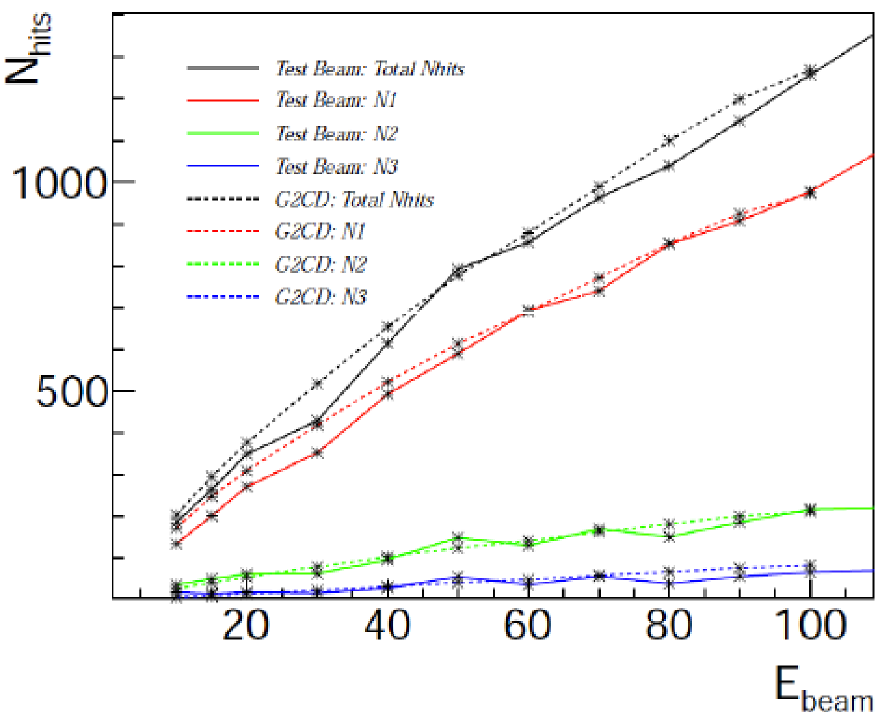
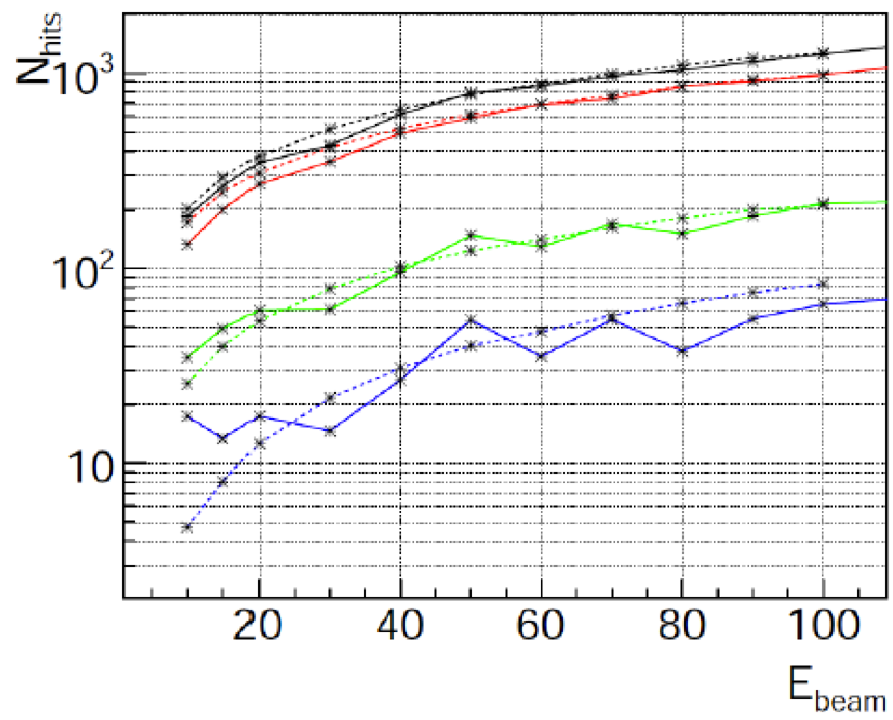


Figure 5. MicroMegas: (Left) Multiplicity versus threshold curve. Black spot, experimental measurement. Red curve, G2CD reproduced ones. (right) Resolved induce charge spectrum for direct hits (red) and multiplicity hits (blue)

Comparison with the test beam measurement





Reproduced efficiency, multiplicity for of MIP event for MicroMegas & GRPC

Reproduced number of hits for pion event at GRPC

Now, let's have a look at the Kitchen...

```
[manqi@lxslc507 src]$ pwd
/afs/ihep.ac.cn/users/m/manqi/Analysis/Arbor/ArborF1/src
[manqi@lxslc507 src]$
[manqi@lxslc507 src]$
[manqi@lxslc507 src]$ ls -ltr
total 192
-rwxr-xr-x 1 manqi physics 41512 Aug 12 23:25 Ranger.cc
-rwxr-xr-x 1 manqi physics 19614 Aug 12 23:25 G2CD.cc
-rwxr-xr-x 1 manqi physics  9060 Aug 12 23:25 BushMeasure.cc
-rwxr-xr-x 1 manqi physics 45651 Aug 12 23:25 BushConnect.cc
-rwxr-xr-x 1 manqi physics 16149 Aug 12 23:25 BranchConnect.cc
-rwxr-xr-x 1 manqi physics 10287 Aug 12 23:25 BranchAna.cc
-rwxr-xr-x 1 manqi physics 27784 Aug 12 23:25 ArborTool.cc
-rwxr-xr-x 1 manqi physics  9093 Aug 12 23:25 ArborPID.cc
[manqi@lxslc507 src]$
[manqi@lxslc507 src]$
```

G2CD

- Short code ~ 650 lines of source code
- Standard Marlin module
  - Compiled with Cmake tools
  - Called as Marlin Dynamic Linked Library
- Function:
  - Input: Simulated Calorimeter Hits (SimuCalorimeterHit)
    - ECAL: 5 mm cell
    - HCAL: 1 mm cell
  - Output: Digitized Calorimeter Hits (CalorimeterHit)
    - ECAL: scale the energy deposition by an Calibration constant
    - HCAL: calculate the induced charge at real cell

G2CD: steering

```
.begin MyG2CD
ProcessorType G2CD

CalibrECAL   60.91 81.81

ChanceOfKink   0

ChargeSpatialDistribution   1.0

DigiCellSize   10

DigiECALCollection   ECALBarrel ECALEndcap ECALOther

DigiHCALCollection   HCALBarrel HCALEndcap HCALOther

ECALCollections   EcalBarrelSiliconCollection EcalEndcapSiliconCollection EcalEndcapRingCollection

ECALThreshold   5e-05

HCALCollections   HcalBarrelCollection HcalEndCapsCollection HcalEndCapRingsCollection

KinkHitChargeBoost   1

NumThinEcalLayer   20

PolyaParaA   1.1

PolyaParaB   1.0

PolyaParaC   0.0

PositionShiftID   0 0 0

UsingDefaultDetector   0

.end   ----------------------------------------------
```

```
registerProcessorParameter( "UsingDefaultDetector",
                            "Flag Parameter Setting (0 ~ self definition, 1 ~ MircoMegas, 2 ~ GRPC_PS, 3 ~ GRPC_SPS)",
                            _UsingDefaultDetector ,
                            0);
```

G2CD: Header

```
#include <EVENT/LCCollection.h>
#include <EVENT/MCParticle.h>
#include <EVENT/SimCalorimeterHit.h>
#include <EVENT/CalorimeterHit.h>
#include <EVENT/LCFloatVec.h>
#include <EVENT/LCParameters.h>
#include <IMPL/CalorimeterHitImpl.h>
#include <IMPL/LCCollectionVec.h>
#include <IMPL/LCFlagImpl.h>
#include <IMPL/LCRelationImpl.h>
#include "UTIL/CellIDDecoder.h"

#include <values.h>
#include <string>
#include <iostream>
#include <cmath>
#include <stdexcept>
#include <sstream>

#include <TFile.h>
#include <TTree.h>
#include <Rtypes.h>
#include <TMath.h>
#include <TF1.h>
#include <TMath.h>
#include <TRandom.h>
#include <TVector3.h>
```

Calling IMPL/*.h

To create new collections and write into lcio file

ECAL Digitization

```
LCFlagImpl flag;
flag.setBit(LCIO::CHBIT_LONG);                  //To set position & ID1
flag.setBit(LCIO::CHBIT_ID1);
flag.setBit(LCIO::RCHBIT_ENERGY_ERROR); //In order to use an additional FLOAT

for (unsigned int k0 = 0; k0 < _ecalCollections.size(); ++k0)
{
        try{
                LCCollection *Ecalcol = evtP->getCollection( _ecalCollections[k0].c_str() ) ;
                CellIDDecoder<SimCalorimeterHit> idDecoder( Ecalcol );
                int NumEcalhit = Ecalcol->getNumberOfElements();
                LCCollectionVec *ecalcol = new LCCollectionVec(LCIO::CALORIMETERHIT);
                ecalcol->setFlag(flag.getFlag());
                string EcalinitString = Ecalcol->getParameters().getStringVal(LCIO::CellIDEncoding);
                ecalcol->parameters().setValue(LCIO::CellIDEncoding, EcalinitString);

                for(int k1 = 0; k1 < NumEcalhit; k1++)
                {
                        SimCalorimeterHit * SimEcalhit = dynamic_cast<SimCalorimeterHit*>( Ecalcol->getElementAt( k1 ) ) ;
                        HitEn = SimEcalhit->getEnergy();
                        LayerNum = idDecoder(SimEcalhit)["K-1"];
                        if(LayerNum < _NEcalThinLayer)
                                DigiHitEn = HitEn * _calibCoeffEcal[0];
                        else
                                DigiHitEn = HitEn * _calibCoeffEcal[1];
                        if(HitEn > _thresholdEcal)
                        {
                                CalorimeterHitImpl * DigiEcalhit = new CalorimeterHitImpl();
                                DigiEcalhit->setPosition(SimEcalhit->getPosition());
                                DigiEcalhit->setCellID0(SimEcalhit->getCellID0());
                                DigiEcalhit->setCellID1(SimEcalhit->getCellID1());
                                DigiEcalhit->setEnergy(DigiHitEn);
                                ecalcol->addElement(DigiEcalhit);
                                LCRelationImpl *rel = new LCRelationImpl(DigiEcalhit, SimEcalhit, 1.0);    //only keep the leading contribution
                                relcol->addElement(rel);
                        }
                }

                evtP->addCollection(ecalcol,_outputEcalCollections[k0].c_str());

        }catch(lcio::DataNotAvailableException zero) { }
}
```

HCAL Digitization: More complex

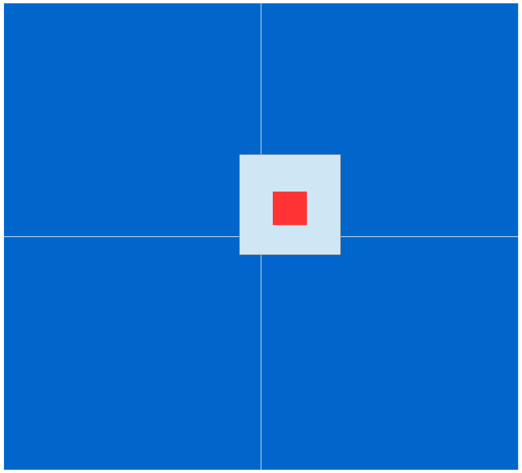
- Read each 1mm cell:
  - Generate a random number according to the Polya function

```
_QPolya = new TF1("QPolya", "x^[0]*exp(-1*x*[1]) + [2]", 0, PolyaDomain);
_QPolya->SetParameters(_PolyaParaA, _PolyaParaB, _PolyaParaC);

RndCharge = _QPolya->GetRandom();
```

- According to its position, calculate the charge partition in current cell and 3 neighboring cells

```
std::vector<float> ChargeSpatialDistri;
ChargeSpatialDistri.push_back(0.1);
ChargeSpatialDistri.push_back(0.2);
ChargeSpatialDistri.push_back(0.4);
ChargeSpatialDistri.push_back(0.2);
ChargeSpatialDistri.push_back(0.1);
registerProcessorParameter("ChargeSpatialDistribution" ,
                "Spactial Distribution of MIP charge X*Y;" ,
                _ChargeSpatialDistri,
                ChargeSpatialDistri);
```



- For each digitized cell, accumulate all the charge in its area

HCAL Digitized Hit

```
for(std::map <int, DigiHit>::iterator ff = IDtoDigiHit.begin(); ff!=IDtoDigiHit.end(); ff++)
{
        CalorimeterHitImpl * calhit = new CalorimeterHitImpl();
        LCRelationImpl *rel = new LCRelationImpl(calhit, ff->second.LeadSimCaloHit, ff->second.ChargeShare);
        relcol->addElement(rel);

        calhit->setCellID0( ff->first );
        calhit->setEnergy(ff->second.digihitCharge);            //Charge
        calhit->setCellID1(SingleMCPPID);       //Use ID1 & Energy Error to denote the MCP info...
        calhit->setEnergyError(SingleMCPPEn);
        /*
           DigiHitPos[0] = ff->second.PosX;
           DigiHitPos[1] = ff->second.PosY;
           DigiHitPos[2] = ff->second.PosZ;
           */
        DigiHitPos[0] = IDtoPos[ff->first].X();
        DigiHitPos[1] = IDtoPos[ff->first].Y();
        DigiHitPos[2] = IDtoPos[ff->first].Z();

        calhit->setPosition(DigiHitPos);
        hcalcol->addElement(calhit);
}

evtP->addCollection(hcalcol,_outputHcalCollections[i].c_str());
IDtoDigiHit.clear();
```

Summary

- Gaseous sensor + ultra high granular digital readout is a promising technology for the PFA orientated detector
- Digitizer is the indispensable part of full detector simulation, which request profound understanding of physics processes at detection
- G2CD, use simple modeling of avalanche charge image, provide a common Digitization tool for gaseous detector
  - Tested on both MicroMegas and GRPC
  - *Include 4 parameter sets according to different TB*

- Reconstruction, in some sense, is to read lcio informations and to write new collections into the same file: use IMPL classes in LCIO