Imaging Calorimetry with RPCs

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Introduction

Imaging calorimetry

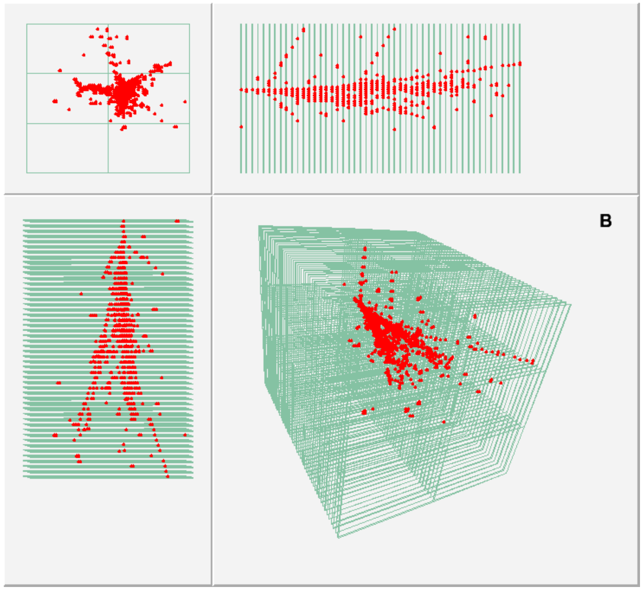
Clear trend in design of calorimeters for future experiments
(Dual readout concept still unproven)

Resistive Plate Chambers - RPCs

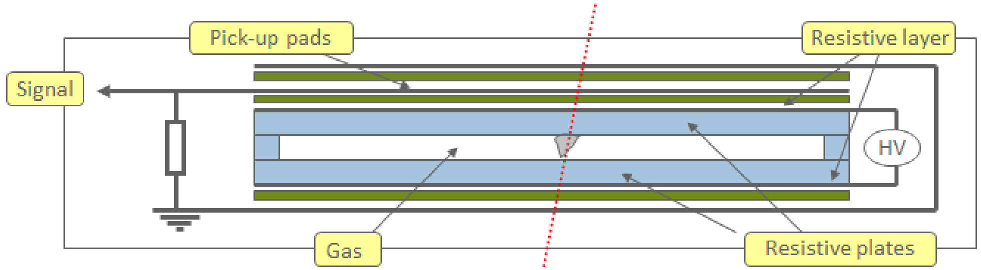
Excellent choice as active as active medium
Cheap, reliable, thin, flexible in design…

The DHCAL

Large prototype built as part of the CALICE project
>50 layers each a 1 x 1 m^2
Just short of 500,000 readout channels
Extensive tests in the Fermilab and CERN test beams



Resistive Plate Chambers for Calorimeters



RPCs are essentially digital devices

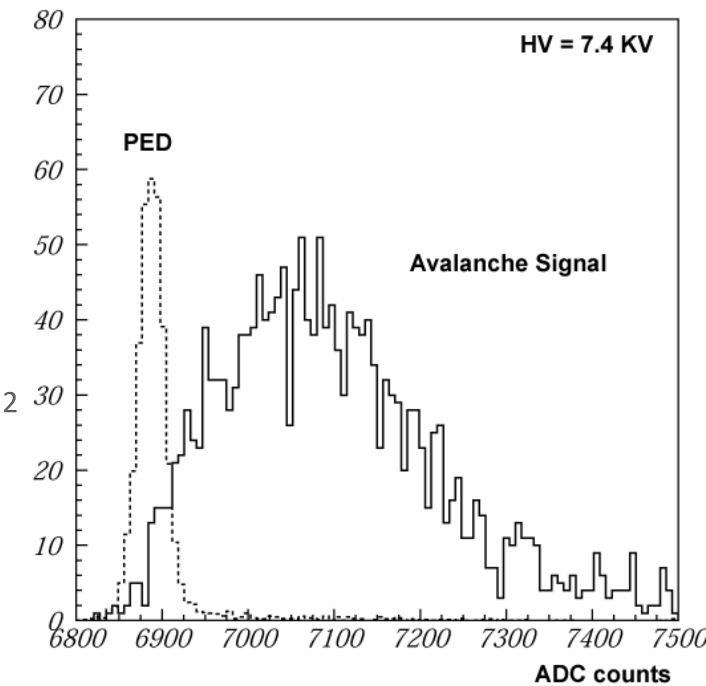
Broad avalanche charge spectrum

Low density gas, little hydrogen

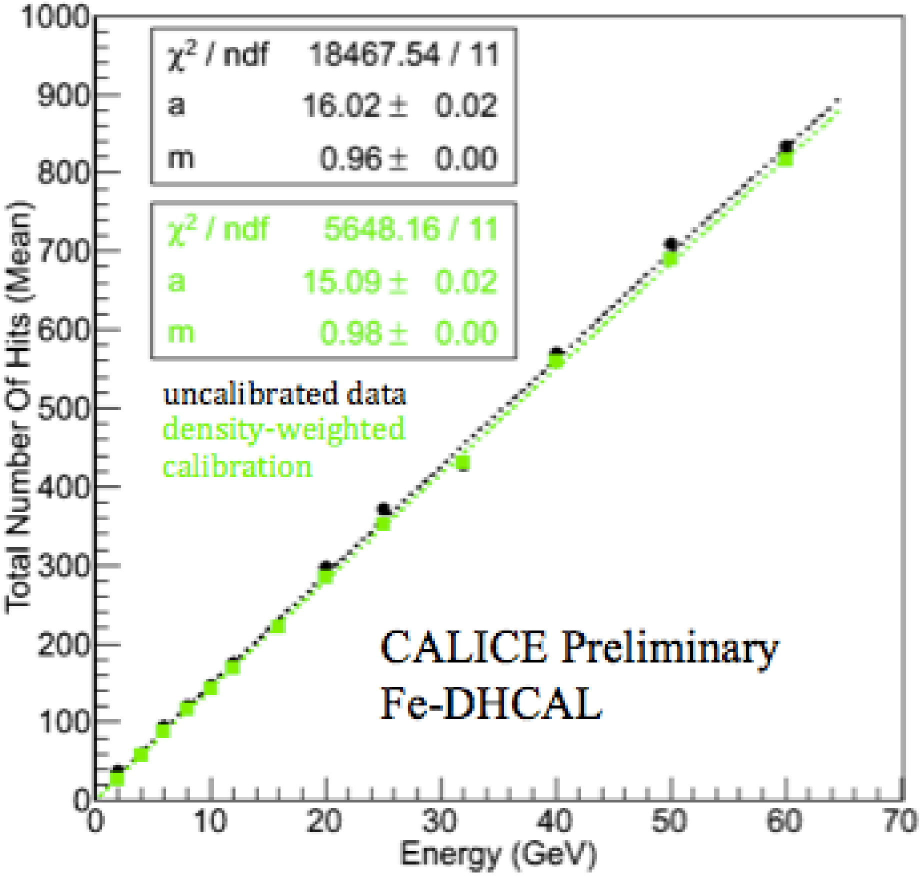
Not sensitive to low energy neutrons, photons

Very fine segmentation of the readout possible

2-glass design: average pad multiplicity ~1.6 for 1 x 1 cm^2
1-glass design: average pad multiplicity ~ 1.05 for 1 x 1 cm^2
→ possibility for even finer segmentation



Response of the DHCAL to pions



(Density-weighted) calibration improves linearity

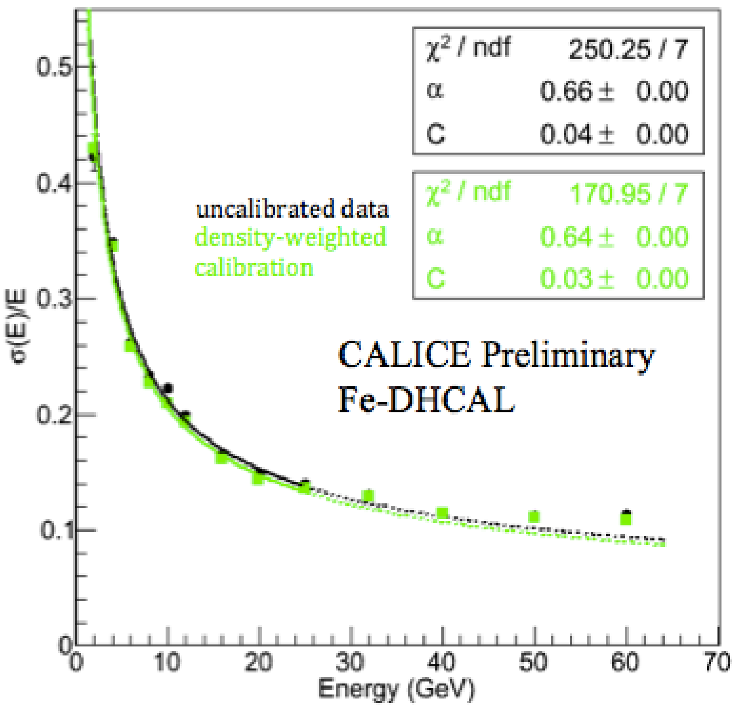
Close to linear up to 60 GeV

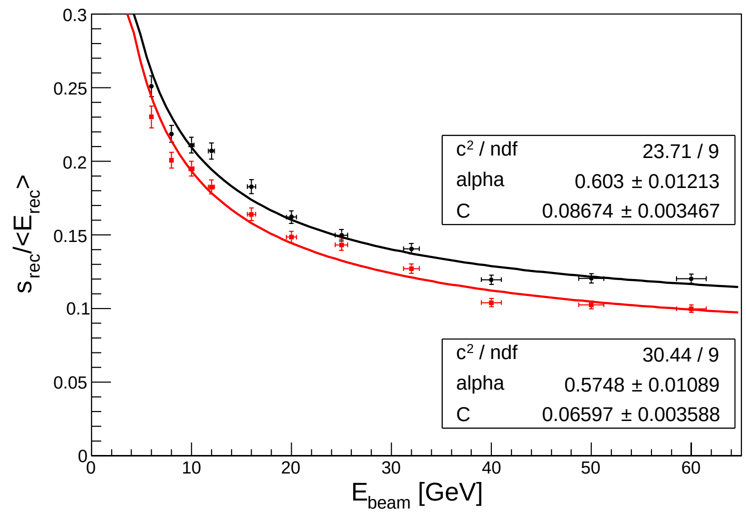
Fit to power law aE^m, where **m** is a measure of saturation

DHCAL - Resolutions

Hadronic Resolution

Calibration improves resolution somewhat
Saturation (=multiple hits/pad) degrades resolution > 30 GeV
Stochastic term of 64%/√E (adequate for hadron calorimetry)





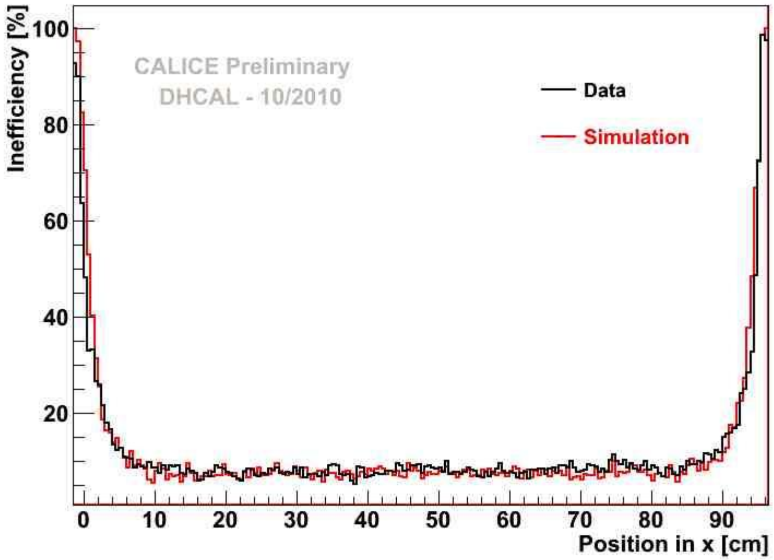
Software compensation

Assume that density of hits correlated to density of particles
Apply weights to each hit depending on the density of hits

→ **Significant improvement of 7 – 15%**

The power of imaging calorimeters

Design/construction problems

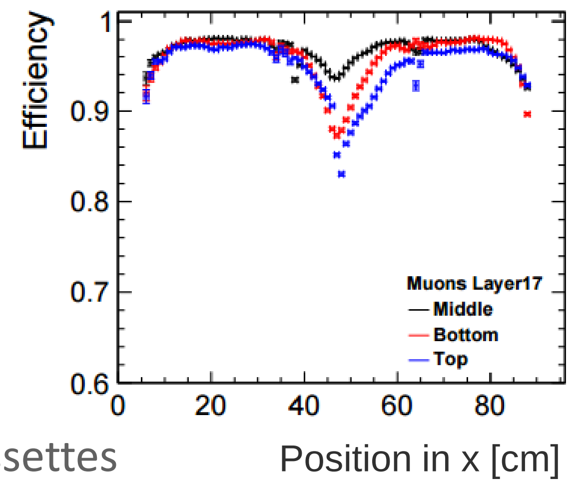


Plastic channels

Used to enclose the gas volume
Extrusion not perfect
Sides not perfectly parallel

→ Thickness of gas gap larger at edges
→ Losses of efficiency at edges

➡ Need better tolerances on channels



Bending of Readout boards

Initially boards were perfectly flat
Noticed some bending two years after construction
Reasons for bending not known
Leads to loss of efficiency at center of chamber

➡ Need to constrain boards mechanically within cassettes

Design/construction problems

Loss of efficiency for whole chambers

Used some ‘two-component artist paint’ as resistive layer
During operation of DHCAL in test beam loss of efficiency for entire chambers (<5%)
Problem traced back to chemical reaction at HV lead leading to high resistance
Some chambers recovered by increasing the HV

➡ Use of Kapton foil as resistive layers (commercially available)

Operational Problems

Strong temperature dependence of response

→ Need to lower power consumption and have better temperature control

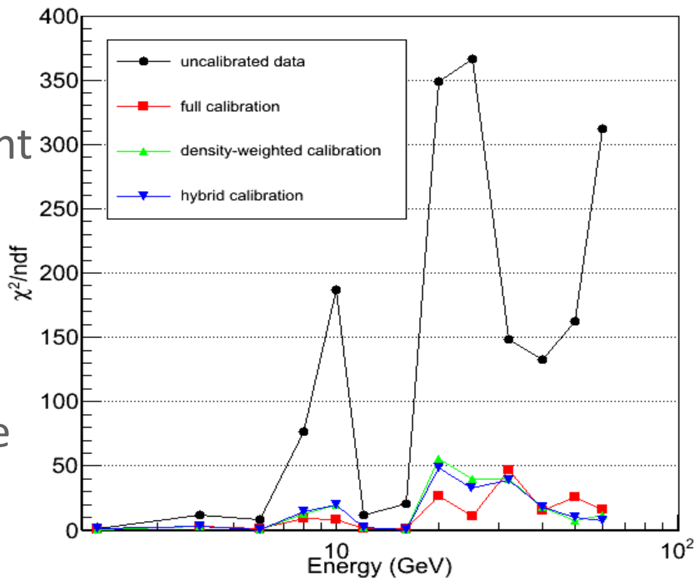
Gas venting

Default avalanche gas is bad for the environment

R134a (95%) has a GWP of 1,430
SF_6 (0.5%) has a GWP of 22,800

Currently gas being vented into the atmosphere

→ Need a gas recycling system



Started assembly of a prototype → **no support to complete work**

Issues with the data analysis

Calibration = Equalization of the RPC responses

A) Particle dependence of equalization

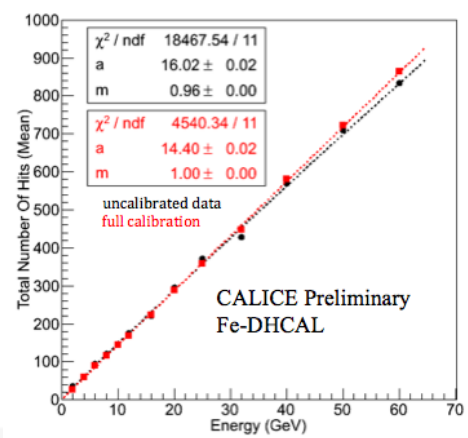
➡ Individual equalization for each particle type

B) Density dependence of equalization

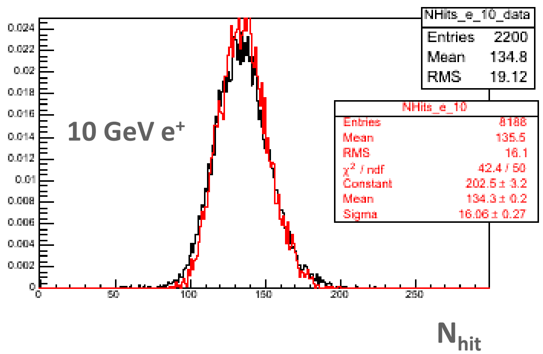
Low efficiency irrelevant for high density sub-showers
Standard equalization procedure leads to overestimation of hits at high energies
Assume density of hits correlated with density of particles in sub-shower

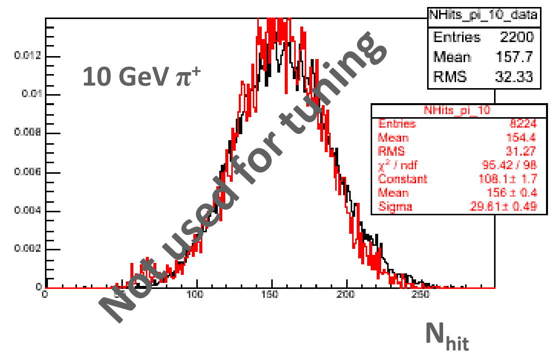
➡ Development of density-weighted equalization schemes

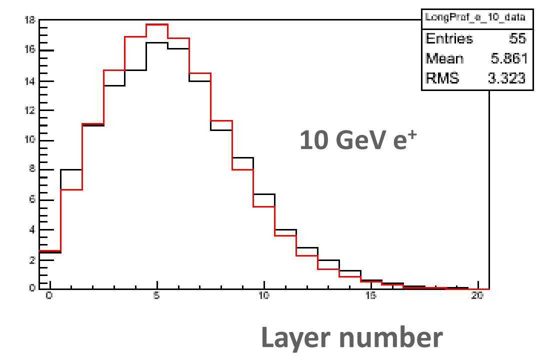
Work in progress

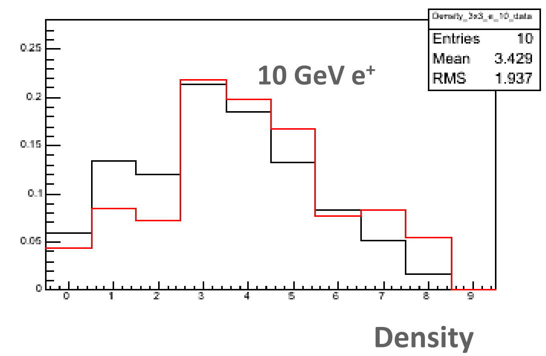


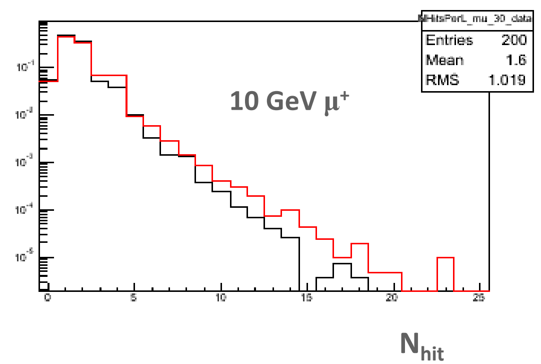
Simulation of the RPC response











Showers

Simulated with GEANT4
Energy deposits in gas volume of RPCs taken as seeds for avalanches

Avalanches

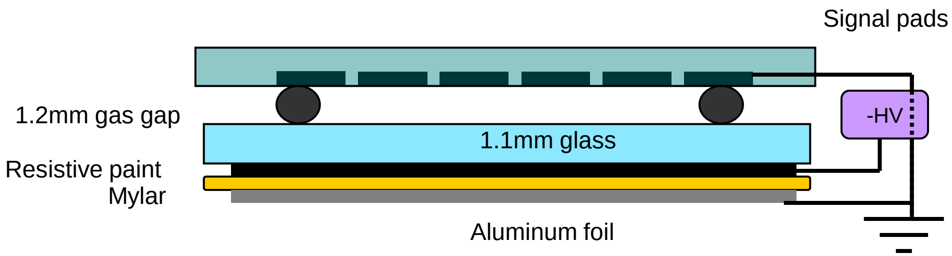
Simulated with a standalone program: **RPC_sim**

RPC_sim

5 parameters (lateral spread, charge offset, threshold)
→ tuned with muons
1 parameter (distance between avalanches)
→ tuned with electrons

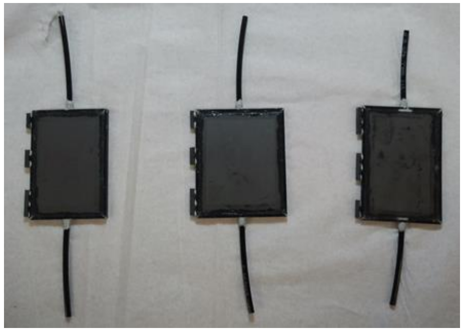
➡ **Absolute prediction for pions**

Next Generation DHCAL I



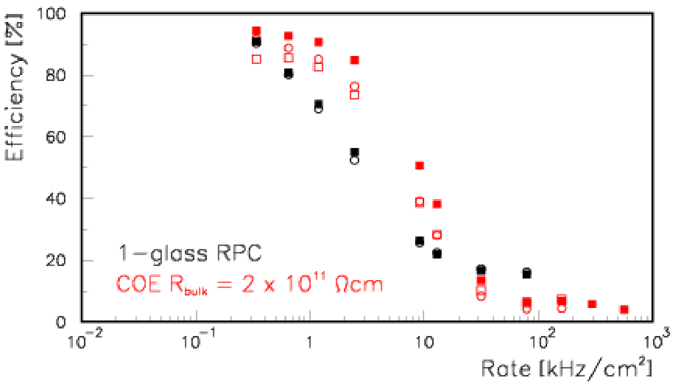
RPC design

1-glass design (thinner, average pad multiplicity close to 1, higher rate capability)
First tests encouraging (arXiv: 1501.05907, submitted to JINST)
In the future will consider 1-glass design as **default**
Overall thickness, including readout board ~ 3 – 4 mm



Resistive Plates

Current RPCs show loss of efficiency for rates > 100 Hz/cm^2
Soda-lime glass (default) has a bulk resistivity of ~10^{13} Ωcm
Together with COE college (Iowa) developing semi-conductive glass with R_{bulk} ~ 10^8 – 10^{10} Ωcm
Built 3 mini-RPCs and tested in Fermilab test beam



Efforts not supported by the DOE

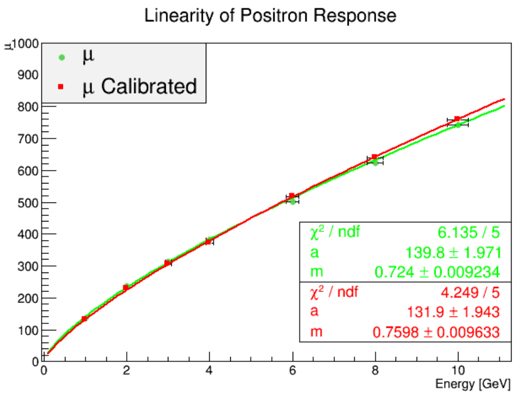
Next Generation DHCAL II

Electronic readout

Remain with 1-bit
Token ring passing
Lower power consumption (currently ~0.5 mW/channel) → power pulsing?
Single readout board containing both pads and FE-electronics
(currently use conductive epoxy to join separate pad and front-end boards)

Effort not supported by the DOE

RPC-DHCAL as ECAL?



Imaging calorimeters do not need to be linear

Saturation of response

Due to 'large' pad size
Smaller pad size not meaningful, due to average pad multiplicity of 1.6

1-glass design

With cosmic rays find an average pad multiplicity close to 1

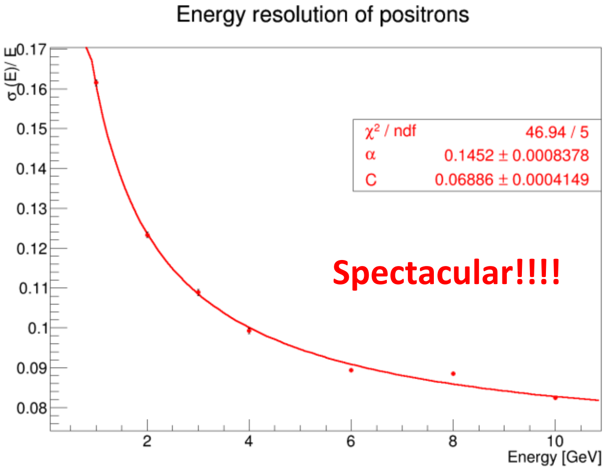
But in simulation

Need to eliminate avalanches close to another one
  Limitation for use as ECAL?

Tests needed

1-glass RPC stack
Very fine segmentation, say 0.25 x 0.25 cm^2

Measurements with minimal absorber



Conclusions

The DHCAL

A RPC-based based hadron calorimeter with 1-bit resolution per channel

Extensive tests

In the Fermilab and CERN test beams
→ **Validation** of this technical approach

Several issues discovered

Requires design changes or more sophisticated data treatment
→ All have (proposed) **solutions**

This technology for an ECAL?

Probably possible, but needs further tests

Support for the DHCAL in the U.S.

All but vanished