Simulation of a Digital Hadron Calorimeter

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Run 208:0 Event 158

Time: 6838157
Hits: 30 Energy: xxx mips

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Outline

I Digital Hadron Calorimeter
II Vertical Slice Test
III Simulation strategy
IV Calculating the rate capability
V Simulating Muons
VI Simulating Positron Showers
VII Simulating Pion Showers
VIII Studies of Larger Systems
IX Conclusions

Monte Carlo Simulation = Integration of current knowledge of the experiment

**Perfect knowledge** → **Perfect agreement with data**
Missing knowledge → Not necessarily disagreement with data
**Disagreement with data** → **Missing knowledge, misunderstanding of experiment**
Perfect agreement with data → Not necessarily perfect knowledge
I  Digital Hadron Calorimeter

Idea

Replace small number of towers with high resolution readout with large number of pads with single-bit (digital) readout

Energy of hadron shower reconstructed (to first order) as sum of pads above threshold

Concept provides high segmentation as required by the application of PFAs to jet reconstruction

Active element

Resistive Plate Chambers

→ Simple in design
→ Cheap
→ Reliable (at least with glass as resistive plates)
→ Large electronic signals
→ Position information → segmented readout
II Vertical Slice Test

Small prototype calorimeter
Up to 10 RPCs, each 20 x 20 cm²
(Up to 2560 channels)

RPCs
Used up to 10 RPCs for muons
Only used RPC0 – RPC5 in analysis of $e^+$, $\pi^+$
Only used RPC0 for rate capability measurements

Absorber
Steel (16 mm) + Copper (4 mm)

Test beam
Collected data in Fermilab’s MT6 beam line
Used
Primary beam (120 GeV protons) with beam blocker for muons
Primary beam without beam blocker for rate measurements
Secondary beam for positrons and pions at 1, 2, 4, 8, and 16 GeV/c
III Simulation Strategy

Experimental set-up
Beam (E, particle, x, y, x’, y’)

GEANT4

Points (E depositions in gas gap: x, y, z)

RPC response simulation

Hits

Measured signal Q distribution

Parameters
Exponential slope $a$
Threshold $T$
Distance cut $d_{\text{cut}}$
Charge adjustment $Q_0$

Comparison

DATA

Hits

With muons – tune $a$, $T$, $(d_{\text{cut}})$, and $Q_0$
With positrons – tune $d_{\text{cut}}$
Pions – no additional tuning
Generated charge distributions for different HV settings

Measured charge distribution for HV = 6.2 kV

Measure charge distribution as function of y in the pick-up plane

Throw 10,000 points in x,y plane, calculate charge Q(r), sum up charge on 1 x 1 cm² pads

Overall reconstructed charge with 10,000 throws
IV Calculating the Rate Capability

Developed analytical model to calculate drop in efficiency

Based on assumption of voltage drop due to current through RPC

Measurements in FNAL test beam

Fits theoretically motivated

Analytical prediction

Effect not (yet) implemented in simulation

Published in 2009 JINST 4 P06003
V Simulating Muons

Broadband muons
from FNAL testbeam (with 3 m Fe blocker)
Used to measure efficiency and pad multiplicity of RPCs
→ calibration constants

Tuned
slope $a$
threshold $T$
charge adjustment $Q_0$

→ reproduce the distributions of the sum of hits and hits/layer

Data
Monte Carlo simulations after tuning

Published as B.Bilki et al., 2008 JINST 3 P05001
Published as B.Bilki et al., 2009 JINST 4 P04006
VI  Simulating Positrons Showers

Positrons at 1, 2, 4, 8, 16, GeV

from FNAL testbeam (with Čerenkov requirement)

Tuned

distance cut $d_{\text{cut}}$

→ reproduce distributions in individual layers (8 GeV data)

Published as B.Bilki et al., 2009 JINST 4 P04006
Data
Monte Carlo simulations – 6 layers
Monte Carlo simulations – Infinite stack

Published as B.Bilki et al., 2009 JINST 4 P04006
Longitudinal shower shape

Lateral shower shape for 2GeV e^+  

Effects of high rates seen

Published as B. Bilki et al., 2009 JINST 4 P04006
### VII Simulating Pion Showers

<table>
<thead>
<tr>
<th>Momentum [GeV/c]</th>
<th>Stack of iron bricks</th>
<th>Number of events</th>
<th>Beam intensity [Hz]</th>
<th>Fraction of events without veto from the Čerenkov counters [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>No</td>
<td>1378</td>
<td>547</td>
<td>6.0</td>
</tr>
<tr>
<td>2</td>
<td>No</td>
<td>5642</td>
<td>273</td>
<td>5.9</td>
</tr>
<tr>
<td></td>
<td>Yes</td>
<td>1068</td>
<td>80</td>
<td>57.3</td>
</tr>
<tr>
<td>4</td>
<td>No</td>
<td>5941</td>
<td>294</td>
<td>15.5</td>
</tr>
<tr>
<td>8</td>
<td>No</td>
<td>30657</td>
<td>230</td>
<td>24.6</td>
</tr>
<tr>
<td>16</td>
<td>No</td>
<td>29889</td>
<td>262</td>
<td>28.0</td>
</tr>
</tbody>
</table>

Trigger =

Coincidence of 2 scintillator paddles + veto from either Čerenkov counter

6 layer stack corresponding to 0.7 $\lambda_I$

Accepted for publication in JINST
# Event Selection

<table>
<thead>
<tr>
<th>Requirement</th>
<th>Effect</th>
</tr>
</thead>
<tbody>
<tr>
<td>At least 3 layers with hits</td>
<td>Rejects spurious triggers</td>
</tr>
<tr>
<td>Exactly 1 cluster in the first layer</td>
<td>Removed upstream showers, multiple particles</td>
</tr>
<tr>
<td>No more than 4 hits in first layer</td>
<td>Removed upstream showers</td>
</tr>
<tr>
<td>Fiducial cut away from edges of readout</td>
<td>Better lateral containment</td>
</tr>
<tr>
<td>Second layer</td>
<td></td>
</tr>
<tr>
<td>At most 4 hits</td>
<td><strong>MIP selection</strong></td>
</tr>
<tr>
<td>At least 5 hits</td>
<td><strong>Shower selection</strong></td>
</tr>
</tbody>
</table>

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Brick data

Secondary beam with +2 GeV/c selection

Fe blocks in front of RPCs

~ 50 cm deep corresponding to 3 $\lambda_I$
  $\rightarrow$ 97% of $\pi$ interact
  $\rightarrow$ $\Delta E_\mu \sim 600$ MeV

Sum of hits in the DHCAL (RPC0 – RPC5)

$\rightarrow$ Emperically fit to

$$ y = \alpha e^{-\frac{1}{2} \frac{(x-\beta)^2}{\gamma}} + \delta(x - x_0)\epsilon e^{\phi(x_0-x)} $$

Calibration close to expected values
  $\rightarrow$ no corrections applied

In the following this will be our $\mu$ signal shape

Accepted for publication in JINST
MIP Selection

Fit to 3 components

- **Muons** (from brick data)
- **Pions** (from MC, not shown)
- **Positrons** (from MC)

(red line sum of 3 components)

MC curves = absolute predictions, apart from general scaling due to efficiency problems (rate)

Accepted for publication in JINST
Shower Selection

Fit to 2 components

- Pions (from MC)
- Positrons (from MC)

MC curves = absolute predictions, apart from general scaling due to efficiency problems (rate) at 16 GeV (9%)

Reasonable description by simulation

Positron contamination at low energies

Not many pions at low energies

Accepted for publication in JINST
VIII  Simulating Larger Systems

Reasonable Gaussian fits for $E > 2$ GeV
Discontinuity at $E \sim 8$ GeV (surprising, changes with physics list)
Non-linearity above $E \sim 20$ GeV (saturation)
Resolution $\sim 58\% / \sqrt{E}$(GeV) (for $E < 28$ GeV)
Resolution degrades above 28 GeV (saturation)
Resolution of $1 m^3$ with containment cut somewhat better than for extended calorimeter
Study of different extended RPC-based calorimeters

Efficiency and pad multiplicity have only minor effect on resolution (Small $\mu$ might be desirable for PFAs)

However values need to be known

Linear calibration corrections for $\varepsilon, \mu$ will work ($P_1 \sim 0$)
IX Conclusions

Analog RPC paper – published in NIM

Instrumentation paper – published in IEEE Nuclear Transactions

Muon calibration paper – published in JINST

Positron paper – published in JINST
  First showers in a DHCAL, validity of concept, understanding of DHCAL response

Rate dependence paper – published in JINST
  Unique contribution to understanding of RPCs, essential for operation of DHCAL

Pion paper – accepted for publication in JINST
  Including predictions for larger prototype calorimeters

Environmental dependence paper – draft exists, plots (almost) finalized
  Essential information for operation of DHCAL

Qingmin Zhang’s talk
Have acquired detailed knowledge about RPCs

Developed MC program for the simulation of RPCs with segmented readout

Reasonable agreement between measurements in test beam and simulation

- Muons (used for tuning of the simulation)
- Positrons (1 additional parameter tuned)
- Pions (absolute predictions)

Simulation of larger system

- Reasonably linear response for pions
- Acceptable energy resolution \( \sim 58\%/\sqrt{E(\text{GeV})} \)
- To be compared to test beam data with 1 m\(^3\) physics prototype
Study with different physics lists