Simulation Studies of GEM-DHCal

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- GEM Analog and Digital Performance Studies
- “Jet” Energy Resolution Study
- Initial Development of Particle Flow Algorithm
- Conversion to LCIO Incorporated Mokka
- Magnetic Field Impact Study
- Conclusions

*On behalf of the HEP group at UTA.*
Introduction

• DHCAL: a solution for keeping the cost manageable for EFA
• Fine cell sizes are needed for efficient calorimeter cluster association with tracks and subsequent energy subtraction
• UTA focused on DHCAL using GEM for
  – Flexible geometrical design, using printed circuit pads
  – Cell sizes can be as fine a readout as in a GEM tracking chamber!
  – Gains, above $10^{3-4}$, with spark probabilities per incident $\pi$ less than $10^{-10}$
  – Fast response
    • 40ns drift time for 3mm gap with Ar$\text{CO}_2$
  – Relatively low HV
    • A few 100V per each GEM foil
  – Possibility for reasonable cost
    • 3M produces foils in large quantities (12”x500ft rolls)
Mokka-based UTA GEM Simulation

- Use old version of Mokka as the primary simulation tool
  - Kept the same detector dimensions as TESLA TDR
  - Replaced the HCAL scintillation counters with GEM (18mm SS + 6.5mm GEM, 1cmx1cm cells)

- Single Pions used for performance studies
  - 5 – 100 GeV single pions
  - Analyzed them using ROOT
  - Compared the results to TDR analog as the benchmark
    - GEM Analog and Digital (w/ and w/o threshold)
    - ECal is always analog

- “Jet” Energy Resolution
- Two pion studies for PFA development
TESLA TDR Geometry

Existing Geometry of Digital Hadron Calorimeter

- 8 staves each having 5 modules
- Each module has 40 layers, each layer with plates of 18 mm of Fe and 6.5 mm of polystyrene scintillator
- Hcal hits are collected Polystyrene scintillator, in cells of ~1 cm²
- Hcal end-caps are build as 32 side Polyhedrons, with 40 layers inside, each layer with plates of 18 mm of Fe and 6.5 mm of Polystyrene scintillator

Courtesy: Paulo deFrietas

Replace with GEM
TDR / Hcal02 Model chosen for modification

- Fe-GEM sub-detector instead of the existing Fe-Scintillator
- New driver for the HCal02 sub-detector module
- Local database connectivity for HCal02 ➔ Database downloaded and implemented at UTA

Courtesy: Paulo deFrietas
UTA Double GEM Geometry

Fig. 1: Schematics of a double-GEM detector.

3.4 mm

3.1 mm

ArCO$_2$

GEM

6.5 mm

Cu

Kapton

G10

Drift D

Ionization

Charged track

Transfer T

Induction I

$V_D$

$E_D$

$V_{1U}$

$E_I$

$V_{1E}$

$V_{1L}$

$V_{2D}$

$\Delta V_{GEM1}$

$\Delta V_{GEM2}$

GEM DHCAL Studies at UTA
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Performance Comparisons of Detailed and Simple GEM Geometries

- 25 sec/event for Simple GEM vs 44 sec/event for Detailed GEM
- Responses look similar for detailed and simple GEM geometry
- Simple GEM sufficient
GEM-Digital: $E_{\text{live}}$ vs # of hits for $\pi^-$

98% Threshold
EM-HCAL Weighting Factor

- $E_{\text{Live}} = \Sigma E_{\text{EM}} + \mathcal{W} \Sigma G E_{\text{HCAL}}$
- For analog:
  - Landau + Gaussian (L+G) fit is used to determine the mean values as a function of incident pion energy for EM and HAD
  - Define the range for single Gaussian (G) fit using the mean
  - Take the mean of the G-fit as central value
  - Choose the difference between G and L+G fit means as the systematic uncertainty
- For digital:
  - Gaussian for entire energy range is used to determine the mean
  - Fit in the range that corresponds to 15% of the peak
  - Choose the 15% G fit mean as the central value
  - Difference between the two G as the systematic uncertainty
- Obtained the relative weight $\mathcal{W}$ using these mean values for EM only v/s HCAL only events
- Perform linear fit to Mean values as a function of incident pion energy
- Extract ratio of the slopes $\Rightarrow$ Weight factor $\mathcal{W}$
- $E = C \times E_{\text{Live}}$
GEM Analog & Digital Converted: 15 and 50 GeV $\pi^-$
Does more Gaussian Behavior of GEM digital make sense?

- Gas detectors have small number of primary ionization electrons ➔ Very Landau like distributions
- Large amplification only stretches out the Landau distribution
  - Amplification does not increase the number of primary electrons
  - It only worsens the fluctuation
- The cells with large energy due to the fluctuation get saturated
  - Suppressing the large energy tail
  - While preserving low energy distributions
GEM HCAL Responses and Resolutions

- Tesla TDR: $22.15 \pm 0.2741$
- GEM - Analog: $26.54 \pm 0.6979$
- GEM - Digital: $27.67 \pm 0.7415$

DHCAL w/ 98% Threshold
GEM Performance Study Summary

• GEM digital and analog responses comparable
  – Large remaining Landau fluctuation in analog mode observed
  – Digital method removes high-end fluctuation ➔ Becomes more Gaussian

• GEM Energy resolutions
  – Digital comparable to TESLA TDR at most energies
    • Low energy performance seems worse than TDR
  – Analog resolution worse than GEM digital or TDR
Analysis of $e^+e^- \rightarrow \bar{t}t \rightarrow 6\, jets$

- Energy distribution of final state particles in jets
- Choose a $\Delta R = 0.5$ cone around a quark to define a particle jet
- Jet energy resolution study
  - Smear individual particles in jet using single particle energy resolution
  - Measure the jet energy resolution, smearing each particle in the jet
- EFA study
  - Determine the relative distances between all pairs of charged, neutral particles in the cone
  - Use two pions to study effective charged hadron energy subtraction
Particle Jet Energy of $e^+e^- \rightarrow t\bar{t} \rightarrow 6 \text{jets}$

$\sqrt{s} = 1 \text{ TeV}$
Re-produced Single Particle Energy Resolution

\[ \frac{\sigma}{\langle E \rangle} = 78.62 \pm 0.20\% + 5.69 \pm 0.03\% \]

\[ \chi^2 / \text{dof} = 5.56 / 7 \]
Smeared Jet Energy/Particle Jet Energy

<table>
<thead>
<tr>
<th>h23</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Entries</td>
<td>29927</td>
</tr>
<tr>
<td>Mean</td>
<td>1.001</td>
</tr>
<tr>
<td>RMS</td>
<td>0.1071</td>
</tr>
</tbody>
</table>
Jet Energy Resolution

- $\frac{\sigma}{\langle E \rangle} = 38.14 \pm 1.89\% + 3.08 \pm 0.17\%$ Mokka - TDR
- $\frac{\sigma}{\langle E \rangle} = 46.50 \pm 4.34\% + 5.8 \pm 0.39\%$ GEM - Analog
- $\frac{\sigma}{\langle E \rangle} = 80.34 \pm 2.26\% + 0.8 \pm 0.20\%$ GEM - Digital (98%)
- $\frac{\sigma}{\langle E \rangle} = 30.08 \pm 1.41\% + 1.39 \pm 0.17\%$ GEM - Digital with EFA

$\langle E \rangle$ (GeV)
Particle Properties in a jet

\[ \langle E_{\pi^\pm} \rangle = 7.5 \text{GeV} \]

<table>
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<tr>
<th>Type</th>
<th>E/\pi^0</th>
<th>RMS</th>
</tr>
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<tbody>
<tr>
<td>EM</td>
<td>26.55</td>
<td>19.33</td>
</tr>
<tr>
<td>CH</td>
<td>69.59</td>
<td>19.49</td>
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<tr>
<td>NH</td>
<td>3.299</td>
<td>6.832</td>
</tr>
</tbody>
</table>

\[ \Delta R \]

Entries: 5843814
Mean: 0.2461
RMS: 0.165

3/14/2005

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Energy Flow Studies with two $\pi^-$

- Based on the studies of particles in jet events
  \[ e^+ e^- \rightarrow t\bar{t} \rightarrow 6 \text{jets} \quad \sqrt{s} = 1.0 \text{TeV} \]
- Pions $\langle E_{\pi^-} \rangle = 7.5$ GeV chosen for study
- Chose the distance between two pions $\Delta R = 0.12$
- Develop an algorithm to subtract charged pion energies
- Use the density weighted method

\[
d_i = \sum_{j=1, j \neq i}^{n} \frac{1}{R_{ij}} \\
\bar{\theta}_i = \frac{\sum_{j=1}^{n} d_{ij} \theta_{ij}}{\sum_{j=1}^{n} d_{ij}} \\
\bar{\phi}_i = \frac{\sum_{j=1}^{n} d_{ij} \phi_{ij}}{\sum_{j=1}^{n} d_{ij}}
\]

Half the mean separation
Two $\pi$ Energy Flow Algorithm

1. Fit the tracks in TPC and extrapolate to Hadronic Calorimeter
2. Find the maximum density cell in each HCAL layer
3. Associate cells with each $\pi$ based on distance to the extrapolated track position
4. Compute cal-centroid using the max cells
5. Draw fixed size cones w/ radius half the distance between the two $\pi$ cal-centroids
6. Compute the density weighted center of each $\pi$ shower in each layer
7. Re-determine the cal-centroid using the density weighted center
8. Use the new centroid to add energy in the cone of half the distance of the two $\pi$
TPC and Cal-Centroid Match: First Pass

\[ \Delta \phi_{\pi} \]

\[ \Delta \theta_{\pi} \]

\[ N_{\pi} \]

Anti-correlated

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GEM DHCAL Studies at UTA
Energy in the cluster

\[ E_{\pi} \]

\[ E_{\pi 1} + E_{\pi 2} \]

15GeV

\[ E_{\text{remainder}} \]

\[ E/P \]

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Energy Subtraction Performance

![Data plots showing energy subtraction performance with tables of mean values and RMS values.]
Mokka Conversion

- Conversion to LCIO incorporated version of Mokka in progress
  - Have been working on this for over 1.5 months
  - We barely got Mokka 03.02 working
    - Working on getting 03.04 failed due to the lack of a module, LCIOwritemode.
      - Successfully linked and ran with a small test job over the weekend

- Need to reproduce previous results to
  - Verify the workings of new Mokka w/ the GEM geometry
  - Develop analysis framework using LCIO
  - Continue onto developing universally usable PFA

- Will commit GEM Geometry driver to the central database
Mokka Conversion Trouble and Suggestions

• Mokka is extremely sensitive to local setups and OS
  – Different flavors of Redhat linux caused a whole lot of difficulties
• MySQL.h is assumed to be in mokka/CGA/include/mysql and hard coded (should be changed)
• GNUMakefile in each area must be carefully examined for local/env variables assumed (but not documented)
  – Had to practically write a brand new make file to get it working
• MySQLclient.a is not always bugfree
• GEANT 4.6.x: gcc 2.96 is a disaster for geant4.6.X installation ➔ full of bugs
• NO PROPER DOCUMENTATION FOR MOKKA INSTALLATION
  – VK working on writing up off-site Mokka installation
  – VK found a few helpful web sites: http://www.desy.de/~gaede/
    • Mokka install: http://www.desy.de/~gaede/run_mokka/run_mokka.html
    • LCIO install: http://lcio.desy.de/v01-00/doc/manual_html/manual.html
  – VK wants to thank F. Gaede from DESY for these…
• Very hard to obtain useful help in a timely manner
Magnetic Field Impact Study

• Concerns on possibly spiral of ionization electrons, causing unwanted signal spread and amplification due to the perpendicular E and B

• Have two UG students working on this subject

• Use Maxwell to generate field lines
  – Completed an initial implementation of prototype chamber structure implementation
    • 11 holes suffice for our purpose
  – First run on double GEM for E field completed
    • Some interesting features are being investigated

• Feed the output of Maxwell into Garfield
Maxwell Geometry and E field

Top and bottom of a GEM foil (60µm) at 400V

3mm at 500V
1mm at 300V
1mm at 500V
Conclusions

• **GEM-based DHCAL performance studies completed**
  – Digital mode (w/ 95% MiP threshold) seems to perform better than analog mode for gas calorimeter

• **PFA-based jet energy resolution seems to be right where we expect**

• **Initial results of PGA study using two-single pion completed**
  – Will need to make the algorithm more sophisticated

• **Graduated two MS students**
  – Two undergraduate student currently working on this project
  – One MS student candidate in line..

• **Conversion to LCIO-based Mokka in progress**
  – GEM geometry to be implemented to the central Mokka geom database
  – Making Mokka more universally adaptable would be helpful

• **Impact of magnetic field under study**

• **Implement more systematic jet reconstruction algorithms**