Development of Digital Hadron Calorimetry for the Linear Collider Using Gas Electron Multiplier Technology

Andy White
U.Texas at Arlington
(for J.Yu, J.Li, M.Sosebee, S.Habib, V.Kaushik)

01/07/04 SLAC/ALCPG
Digital Hadron Calorimeter Development

Linear Collider calorimetry development path at UTA:

- Motivated by the physics potential!
- Can digital + energy flow approach work ??
- Search for robust/low cost/flexible technology
- GEM technology has required characteristics

But

- need to understand/operate GEM systems (done)
- need to develop GEM/DHCAL design - in progress
- need to prototype/test GEM active DHCAL layer(s)
- need to develop full calorimeter design
Digital Hadron Calorimeter Development

UTA SIMULATIONS

TESLA detector with scintillator replaced (in MOKKA) with:

(a) detailed GEM layer
(b) GEM material “mix”

=> Linear relation energy vs. hits

(see talk by Jae Yu on UTA simulation results)

Studies -> need “pixel” size of ~1 cm² to do tracking and measure the number of hits in a cluster for energy determination
Digital calorimetry - counting cells

### Mokka GEM - GainFactor 3500

#### h2

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#### Mokka GEM - GainFactor 3500

#### h2d

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A new concept of gas amplification was introduced in 1996 by Smir: the Gas Electron multiplier (GEM) [27]. Manufacturing by using standard printed circuit wet etching technique as schematically shown in Fig. 14(a). Confining within (3-50 µm) Kapton foil, double sided clad with Copper, holes are perforated through (Fig. 14(b)). The two surfaces are maintained at a potential gradient thus providing the necessary field for electron amplification as shown in Fig. 14(c), and an avalanche of electrons as in Fig. 14(b).

Fig. 14(a) Electric Field and (b) an avalanche across a GEM channel.

Coupled with a drift electrode above and a leadout electrode below, it acts as a highly performing microstrip detector. The essential and advantageous feature of this detector is that amplification and detection are decoupled, and the leadout is at zero potential. Potentiating charge transfer to a second amplification device, this opens up the possibility of using a GEM in tandem with an MSGC or a second GEM.
Double GEM schematic

Create ionization

Multiplication

Signal induction

Fig. 1. Schematics of a double GEM detector.

From S. Bachmann et al. CERN-EP/2000-151
Design for DHCAL using Triple GEM

- Embedded onboard readout
- Ground to avoid cross-talk

GEM-BASED DHCAL CONCEPT

NOT TO SCALE
1st multichannel prototype

- A 3 x 3 array of 1 cm² pads.
- Allows one central pad with neighbors for cross-talk tests.
- Use a single layer board for simplicity.
- Anode board built, prototype reworked.
- First results.
UTA GEM-based Digital Calorimeter Prototype
Nine Cell GEM Prototype Readout
Landau Distribution from Cs\textsuperscript{137} Source
CERN GDD group measurements

Measured UTA GEM Gain

12/9/00

Effective Gain

S-D-T GEM Gains - V

10^6

10^5

10^4

10^3

10^2

300

350

400

450

500

550

ΔV_{GEM} (Volts)

10^6

10^5

10^4

10^3

10^2

UTA Prototype

TGEM

DGEM

Ar-CO_2 70-30

Equal ΔV_{GEM}

SGEM

CERN GDD group measurements
GEM Foil Production

- Original production at CERN - but slow, low volume, manpower intensive and expensive.

- Interest in U.S. domestic foil production by LC tracking developers and GEM/DHCAL.

- 3M Corporation (Microinterconnect Systems Division), Austin, Texas has successfully produced GEM foils on 16 inch wide, 500 feet long roll.

- UTA will combine initial order with La. Tech.
Mass Production is based on a 3M Proprietary Flex Circuit Manufacturing Technique

- **3M Microinterconnect Systems Division** Reel-to-reel process, rolls of 16”x16” templates of detachable GEMs in any pattern. Optional processes possible.
- First batch of 1,980 GEMs recently produced. Low cost per unit! (~2 USD/GEM not counting R&D)
- Two fabrication techniques (additive, subtractive) tested.
Subtractive 3M Mass Produced GEM

SEM Courtesy Fabio Sauli
GEM foil profile for large scale prototype(s)

Approximate size of large-scale drawer

- 16 inches
- 10 x 10 cm²
- 12 inch wide active width
- 500 ft roll
Multichannel Electronics

- UTA is working with DHCAL-RPC group and Fermilab PPD to specify requirements for readout electronics.

- Currently using 32-channel boards developed for silicon detector readout at Fermilab.

- Use of same readout scheme for GEM and RPC solutions – with optional gain changes (high for GEM, lower for RPC/avalanche mode).

- ASIC (including HV) system work with Fermilab. Develop a 64-channel(?) solution – 8x8 cm² array of 1x1 cm² cells.
Cell to ASIC connections on 9-layer board

Anode layer one of 9 layers

GEM/RPC amp/disc concept

Serial readout line

1x1 cm² GEM cell

64 channel amp/disc
GEM Prototype with preamp/voltage amp used for original studies at UTA
32-channel board from Fermilab
Current status:

Fermilab system requires very efficient RF shielding between input and output stages to prevent oscillations/noise - suitable enclosure under development.

Use of this system is a temporary measure - will use for cosmic stack until joint GEM/RPC system is developed (discussions at this meeting).
Pulse from Fermilab
32-channel electronics board

![Graph showing pulse from Fermilab 32-channel electronics board. The graph includes a waveform with specified settings: Tek Stop: 125MS/s, 61 Acqs, Ch2 Coupling Impedance, DC, AC, GND, Ω, 1M 50, Coupling AC, Bandwidth 20 MHz, Fine Scale 50.0mV/div, Position -500mdiv, Offset 0 V, Cal Probe Initialized.]
Development of module concepts

TESLA - HCAL Layout
DHCAL/GEM Module concepts

- Side plates alternate in adjacent modules
- Include part of absorber in GEM active layer - provides structural integrity
- GEM layer slides into gap between absorber sheets
DHCAL-GEM Layer structure

- GEM layer + electronics layer ~9mm
- Absorber thickness 16mm x 40 layers
-> ~ 4 interaction lengths for HCAL (plus ~1\(\lambda\) for ECAL)

This needs to be studied/optimized!
  - do we need 40 layers?
  - do we need uniform depth segmentation?
- 10x10 mm\(^2\) cell size \(\rightarrow\) ~1.5 \(\times\) 10\(^7\) channels for DHCAL-GEM (with 40 depth layers)
Development of GEM sensitive layer

Requirements:

- minimize overall thickness
- develop robust design
- maintain 1mm, 3mm gaps in GEM structure
- maintain active layer flatness - absorber slice
- minimize “dead” boundary areas
- maintain integrity of gas volume
- design for ease of construction!
Development of GEM sensitive layer

Absorber strong back

Cathode layer

9-layer readout pc-board

GEM foils

Gas inlet/outlet (example)

Non-porous, double-sided adhesive strips

Anode(pad) layer

Fishing-line spacer schematic

3 mm

1 mm

1 mm

(NOT TO SCALE)
Development of GEM module assembly technique
1mm fiber spacer
Timeline for detector development - FY04

- Further studies of small, multi-channel (4 x 4, 5 x 5, etc.) prototypes

- Integration of Fermilab/PPD electronics into prototype(s) (in progress)

- Explore common readout electronics with RPC group

- Develop techniques and jigging for assembly of single GEM drawer (in progress)

- Build series of mechanical drawers as needed (starting)

- Develop concepts for calorimeter module and test beam stack
FY04 -> FY05 (as personnel/costs allow)

- Build and operate a complete working drawer
- Refine drawer design and construct several working drawers
- Build vertical arrangement of several drawers and demonstrate track finding for cosmic rays.
- Develop readout scheme for test beam stack
- Engineering studies for calorimeter module and test beam stack

FY05 -> FY06

- Complete test beam stack design and readout scheme design
- As funding allows: acquire materials to construct 40-layer stack (drawers, plates, supports, electronics)

As funding allows: begin construction of drawers for 40-layer stack, and begin steel stack assembly
- Aiming for a 40-layer DHCAL stack “1m³”
- Joint approach with RPC/DHCAL group:
  -> interchangeable GEM <-> RPC layers
  -> common electronics (only front-end gain varies) with RPC + HV Control?
- Agreement that UTA will build the stack
- Exploring use of the stack at Fermilab/MTBF
CONCLUSIONS

- Further prototype development
- Exploring electronics solutions with Fermilab/PPD + DHCAL-RPC group
- Availability of U.S. domestic GEM foils
- Investigating active layer construction techniques
- Working towards test beam stack
INVITATION

To groups interested in LC Calorimetry:
GEM technology offers an excellent solution to digital hadron calorimetry
JOIN US in this exciting development work!
Talk to me or Jae Yu at this meeting.

awhite@uta.edu or jaehoonyu@uta.edu