Thin active elements for DHCAL based on Thick-GEMs

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Summary

1. Digital Hadron Calorimetry for ILC
2. Thick-Gas Electron Multiplier (THGEM)
3. Detector performance
4. Integration with KPiX ASIC
5. Optimization approaches
6. Conclusions and near future work
Digital Hadron Calorimetry for ILC

**Digital calorimetry**

associate “hits” with charged tracks, remove hits, measure neutrals in calorimeter using **hits** vs. **energy**

Particle Flow Algorithms now achieve the required energy resolution!

- Requires thin, efficient, highly segmented, compact, robust medium
- Possible technologies: D-GEM, Micromegas, RPC, **THGEM**

**ILC:** Separate W,Z boson masses on event-by-event basis

60%/\sqrt{E} 

Best Jet resolution with traditional calorimetry

Need 30%/\sqrt{E} 

Generally need $\sigma/E_{jet} \sim 3-4\%$

**Digital Hadron Calorimetry for ILC**

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Elements for DHCAL based on THGEMs

KPiX

Optimization

Conclusions
Design within the SiD Detector Concept, but also as part of the CALICE collaboration.
New concept for DHCAL: THGEM

A. White et al UTA

General detector scheme

2 sampling layers (out of 40) with THGEM-based elements

Sampling jets + advanced pattern recognition algorithms

→ Very high-precision jet energy measurement.

Reconstructed jet:
Simulated energy resolution
\[ \frac{\sigma}{E_{\text{jet}}} \sim 3\% \]
(CALICE)
THGEM–based Digital Hadron Calorimeter concept

Aims

• Thickness of sensitive region: 6–8 mm, including readout electronics.
• 95% efficiency;
• up to 1.7 particles/pad overlap is acceptable.
Thick Gas Electron Multiplier (THGEM)

~~ 10-fold expanded GEM ~~

**THGEM advantage for DHCAL:**
- SIMPLE, ROBUST, LARGE-AREA
- Cheap: Printed-circuit technology
- Digital counting ➔ gain fluctuations not important

**THGEM Recent review:**
NIM A **598** (2009) 107

- Robust, if discharge no damage
- Effective **single-electron** detection
- Few-ns RMS time resolution
- Sub-mm position resolution
- **>MHz/mm²** rate capability
- Broad pressure range: **1 mbar - few bar**
Higher gain in Ne mixtures
but: lower ionization — $n_{tot} \sim 40 \text{ e/MIP}$

2-THGEM: higher gains/lower HV
but: too thick.
The detector

THGEM chamber

- THGEM area: $10 \times 10 \text{ cm}^2$;
- Gas volume: $\sim 280 \times 180 \times 32 \text{ mm}^3$;
- Gas: Ne/CH$_4$ (95:5) (non-flammable);
- Single THGEM, gaps: 3/2 mm (d/i) or Double THGEM, gaps: 3/2/2 mm (d/t/i).

Integration with KPiX readout electrode in course.
Performance in Ne/CH$_4$ (95:5), using $^{55}$Fe

Data taken using RD51 Scalable Readout System.

$\frac{\Delta E}{E} < 20\%$ at moderate/safe gain (no sparks).
Performance in Ne/CH$_4$ (95:5)

Cosmic data, standard analog electronics.
Operation at huge gain (~ 65k)!
Beam tests

- RD51 test beam facility at CERN (SPS/H4),
- Several geometries tested.
- System triggered with 3 $10 \times 10 \text{ cm}^2$ scintillators, plus one small $1 \text{ cm}^2$ to select different smaller regions on THGEM area.
Beam tests - $\mu$ vs $\pi$

**PIONS**

- $\pi$ in single THGEM
  - $\chi^2$/ndf: 1909/762
  - Constant: $529.1 \pm 3.608$
  - MPV: $2.062 \pm 0.01217$
  - Sigma: $0.9212 \pm 0.008742$

  $t = 0.4$ mm, with MCA
  - Gaps (mm): 3 / 2
  - $\Delta V_{THGEM} = 200 / 640 / 200$ V
  - Total counts: 1844
  - Gas flux: 16 l/h
  - Rate: 5000/spill (500 Hz/cm$^2$)
  - Detection efficiency: 94 %
  - Detector gain: 1100
  - Spark rate: zero/20 min.

**MUONS**

- $\mu$ in Single 0.4 mm THGEM
  - $\chi^2$/ndf: $3.192e+04$ / -3
  - Constant: $3038 \pm 12.44$
  - MPV: $2.72 \pm 0.009726$
  - Sigma: $1.194 \pm 0.006326$

  Detector Gain: 1400
  - Gaps (mm): 3 / 2
  - Total counts: 13343
  - Rate: 3000/spill

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**Measured very low discharge rates even with pions @ rates >> ILC**

THGEM: 0.4mm
Gain: 1200-1400

- Muons and pions easily measured, but charge signals very low;
- Spark rate was fine, but KPiX might need higher signals.
Maximum detection efficiency ($\epsilon = 96\%$) was reached very early, even with a small drift gap.
Developed for Si/W ECAL at SLAC,
• KPiX 9: 512 13-bit ADC (our THGEMs only use 64),
• Self-Calibrating (distributions can immediately be given in fC).
KPiX charge readout chip

- 64 pads in a $8 \times 8$ cm$^2$ matrix.
- Communication with a PC by USB through interface and FPGA boards.
- Very low efficiency ($\sim 4\%$) due to ILC synchronized timing structure.
KPiX with X-rays

Non collimated $^{55}$Fe source.
KPiX in beam

- Integral of charge in each channel.
- Each pad has 1 cm$^2$. 
KPiX with MIPs

Cosmics

<table>
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<tr>
<th>MergedCosmicHits</th>
<th>hCosmic</th>
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<td>RMS</td>
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<td>$\chi^2$/ndf</td>
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<tr>
<td>Constant</td>
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<tr>
<td>MPV</td>
<td>9.559±0.553</td>
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<tr>
<td>Sigma</td>
<td>3.842±0.354</td>
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</table>

Double THGEM with large drift gap, operating at low gain (~ 1000)

Muons

<table>
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<tr>
<th>KPiX: Muon Hits, Gain = 5300</th>
<th>hBeam</th>
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<tr>
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<tr>
<td>RMS</td>
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<tr>
<td>$\chi^2$/ndf</td>
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<tr>
<td>Constant</td>
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<tr>
<td>MPV</td>
<td>11.41±0.19</td>
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<tr>
<td>Sigma</td>
<td>4.609±0.090</td>
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</table>

- Electronics very sensitive to sparks. Got damaged before end of tests in beam.
- Problem partially solved, but sparks still originate glitches in the LV power circuit and strange things happen in KPiX (latch up in some channels and software crashes).
Two different fronts to keep optimizing

Improving KPiX robustness against sparks

- application of protection resistors and diodes in the circuit to prevent latching up of channels due to sparks,
- Application of inductances in the LV power supply lines to avoid propagation of the sparks to the interface and FPGA boards.

Minimize spark probability

- THGEMs used in more recent works seem to have a lower discharge probability,
- Noise optimization might allow to work at lower gain,
- Use resistive well geometry (see next slides).
Resistive Well-THGEM

Advantages
- No induction gap
- Ground on both external electrodes
- Spark-protection of electronics

Under investigations at Weizmann
Acquisition with standard electronics chain (KPiX was not working);
Very high gain with no sparks (∼5600);
Charge pulses more than enough for KPiX;
Still unclear how it works when reading from separate pads.
Conclusions and near future work

Conclusions

- Very promising structure, with a low cost per unit area,
- Results have shown that it is possible to see MIPs within 6 mm,
- Integration with KPiX about to be achieved thanks to close cooperation with SLAC.

Near future

- Establish working conditions of THGEM + KPiX in RD51 test beam,
- Combine with RD51 GEM/MicroMegas tracker information to determine multiplicity,
- Test chamber performance in the presence of hadronic showers.
Thank you for your attention!