CALICE Prototype Calorimeters
for linear collider detectors

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CALICE leads R&D effort for Imaging Calorimetry

- The next lepton collider detector will be optimized for Particle Flow Algorithms (PFA’s) → calls for Imaging Calorimetry
- CALICE collaboration developed new concepts and technologies for such kind of devices
- Many 1st generation prototypes have been tested in beam

- 2005
- 2006-07
- 2008-09
- 2010-11

Year of beam test

Readout cell size: 144 - 9 cm$^2$ → 4.5 cm$^2$ → 1 cm$^2$ → 0.25 cm$^2$ → 2.5x10^{-5} cm$^2$

Technology:
- Scintillator + SiPM/MPPC
- Scintillator + SiPM/MPPC
- Gas detectors Silicon
- Silicon
- Silicon (MAPS)
CALICE 1\textsuperscript{st} generation calorimeter prototypes

- These prototypes address ‘proof of principle’ for detector concept
  - Some technical issues for a real detector are left out, to get physics results in early stage
- The analog prototypes have successfully completed their test beam program
  - Analog: measuring energy in each cell, with Silicon, or Scintillator+SiPM
  - The beam data produced excellent physics results, please see Misha’s talk
- The digital\textsuperscript{1}/semi-digital\textsuperscript{2} prototypes using gas detector as active medium are being tested now / will be tested soon
  - Using gas detector for calorimetry is a NOT a new idea (L3, CDF, etc.)
  - Digital readout: count particles in shower $\rightarrow$ perfect match for gas detectors
  - Current status
    - RPC DHCAL: has been in test beam for ~ 1 year, data analysis started
    - RPC sDHCAL: started test beam this summer, 1\textsuperscript{st} physics data expected this fall
    - Micromegas, GEM based (s)DHCAL: preparing for test beam

\textsuperscript{1}: Digital readout: signal is compared to a single threshold $\rightarrow$ above threshold (hit) or below (no hit)
\textsuperscript{2}: Semi-digital readout: signal is compared to a few thresholds, instead of 1 in digital readout
RPC DHCal prototype

- **Main features**
  - 1cm$^2$ readout pads
  - Digital readout (1 threshold, yes or no)
  - ~1m$^2$ for each layer (cassette)
  - 52 (38 + 14) layers in total
  - ~2cm Fe absorber for each first 38 layers, thicker Fe absorber for last 14
  - Total CH. count: ~500,000

- **RPC’s**
  - Glass electrodes
  - 32 x 96 cm$^2$ in size, readout by 2 FEB’s
  - 3 RPC’s for each layer/cassette

- **Readout system: very challenging**
  - Embedded FE readout (2nd gen. feature)
  - Signal ~100fC to ~1pC
  - Built around a 64-ch asic (DCAL)
  - FEB host 24 asic’s + data concentrator
  - FEB & pad board glued together with conductive epoxy
  - 2 levels of data concentration (data concentrator[x24] + collector[x12])
  - VME readout at the end
  - Triggered & Trigger-less readout

- **Construction**
  - Started 2008, ended 2/2011
  - 1$^{st}$ beam test 10/2010
RPC DHCAL test beam at Fermilab

• Had 4 test beam runs so far
  – 10/2010: 38 layers
  – 2/2011: completed 38 + 14 during run
  – 4/2011: SiW ECAL + RPC DHCAL
  – 6/2011: RPC DHCAL alone
  – More test beam in 2011 - 2013

• Both RPC’s and readout system worked amazingly well

**Graphs:**
- Efficiency [%]
- Multiplicity
- Calibration factor

**Notes:**
- DHCAL: first 38 layers with 2cm absorbers
- TCMT: last 14 layers with thicker absorbers
- Tail catcher (TCMT) is cooler → lower efficiency, multiplicity
RPC DHCAL: 1\textsuperscript{st} look at data
RPC DHCAL: 1st look at data

Muons
RPC DHCAL: 1\textsuperscript{st} look at data

32 GeV Positron
RPC DHCAL: 1\textsuperscript{st} look at data

32 GeV Pion

EPS - HEP2011, Grenoble
RPC DHCAL: 1\textsuperscript{st} look at data

120 GeV Proton \sim 1400 hits!
RPC DHCAL: 1\textsuperscript{st} look at data

Neutral hadron!
RPC DHCAL: 1\textsuperscript{st} look at data

Preliminary results: no calibration yet!

Positron response/resolution

\[ N = a + bE^m \]

\[ \chi^2 / ndf \]
\[ a = -10.15 \pm 3.149 \]
\[ b = 28.66 \pm 2.127 \]
\[ m = 0.6906 \pm 0.022 \]

Neutral hadron!

Uncorrected for non-linearity
Corrected for non-linearity

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RPC DHCAL: 1\textsuperscript{st} look at data

Preliminary results: no calibration yet!

**Muons**
- 32 GeV Positron
- 32 GeV Pion
- 120 GeV Proton ~1400 hits!

Neutral hadron!

**Positron response/resolution**

**Pion response/resolution**

Uncorrected for non-linearity
Corrected for non-linearity

Standard pion selection
+ No hits in last two layers
RPC semi-DHCAL prototype

- **Semi-digital approach**
  - 2-bit / 3-threshold readout to improve particle counting
    - Thresholds at 0.2, 5, 10 MIP
    - Distinguishing 0, 1, several and a lot of particle on one pad
  - Have the potential to improve
    - Linearity
    - Energy resolution at high E

- **Main features**
  - 1cm$^2$ pad / 1m$^2$ cassette
  - 1m$^2$ RPC’s
  - 2-bit, embedded readout
  - FE asic power pulsed
  - 2 FEB chained together and readout from one side
  - Thin active element (~6mm)
  - Self-supporting structure

- **Construction status**
  - Finished ~40 layers by 6/2011
  - First beam run 6-7/2011
  - Next beam run 9-10/2011

**Red**: 2$^{nd}$ generation features

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RPC semi-DHCAL test beam at CERN

- The prototype successfully assembled at CERN
- Tested front end readout and detector behavior with beam
- More beam test / physics run expected in 9-10/2011
Micromegas and GEM (s)DHCAL prototypes

- CALICE collaboration is also developing (s)DHCAL with Micromegas and GEM detectors
  - Both detectors can handle very high rate
  - Prototype layers has been constructed / expected (1cm² pad, 1m² layer)
  - Beam test of prototype layer is done / expected
Calice 2\textsuperscript{nd} generation calorimeter prototype

- These prototypes address all issues in building a ‘real detector’
  - Embedded readout
  - Embedded calibration system
  - Power reduction / heat dissipation / cooling
  - Cables / connections / service / supplies
  - **Realistic geometry:** compact, with minimum dead space
  - Self-support mechanical structure
  - Industrialize detector building when possible

- Several such prototypes are being developed/constructed, or planned
Embedded electronics – parasitic effects?

Exposure of front end electronics to electromagnetic showers

Comparison: Beam events
(Interleaved) Pedestal events

Chips placed in shower maximum of 70-90 GeV e.m. showers

Possible Effects: Transient effects
Single event upsets

- No sizable influence on noise spectra by beam exposure
  $\Delta$Mean $<$ 0.01\% of MIP $\Delta$RMS $<$ 0.01\% of MIP
- No hit above 1 MIP observed
  $\Rightarrow$ Upper Limit on rate of faked MIPs: $\sim$7$\times$10$^{-7}$

Also RPC/DHCAL test beam: embedded electronics subjected to EM/hadronic showers
no ‘side effect’ ever seen

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Si-W ECAL 2\textsuperscript{nd} gen. prototype

- \( \sim 2/3 \) of final module size (partially instrumented, 18 \( \times \) 18 cm\(^2\) tower)
- 9x9 cm\(^2\) sensors, with 0.5 \( \times \) 0.5 cm\(^2\) cell size (factor of 4 smaller than 1\textsuperscript{st} gen.)
- FE power pulsed (0.25 \( \mu \text{w} / \text{ch} \)), FE readout embedded
- FEB's chained together, extremely compact design
- Realistic cooling scheme (leak less water cooling)

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Some of the challenges

Detector slab
- Compact assembly of 2 layers of 1 to 8 ASU’s + W core
  - ASU = 1 Kapton cable + Si wafer + PCB + thermal drain (copper)
- PCB is critical: 1mm thick, 8 layers
  - 1% flatness
  - chips bounded into the board
- Smaller cells: 5 x 5 mm²
  - 325 μm thick
  - Improved guard ring
  - working with industry to understand and reduce cost

SKIROC chip
(Silicon Kalorimeter Integrated ReadOut Chip)
- Technology: SiGe 0.35 μm AMS
- 64-ch, variable gain charge amp
- 12-bit ADC, digital logic
- Power pulsed → 25 μw / ch

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Scintillator AHCAL 2nd generation prototype

- Target at scalable LC detector prototype
- No spacer between layers
- Minimize dead space between wedges
- Minimize gap between barrel and endcap
- Octagonal shape, 16 equivalent wedges, segmented in two along z
- PCB with 4 ASICs, 144 scintillator tiles, SiPM readout
- Integrated readout electronics

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Some of the challenges

- Active elements are scintillator tiles of $3 \times 3 \times 0.3 \text{ cm}^3$
- Wavelength shifting fiber embedded into tile, and coupled to SiPM
- Tiles plugged into PCB with ‘lego’ like pins: nominal tile distance 100μm

Embedded LED calibration system
- Provide Gain / saturation calibration for SiPM
- LED mounted on PCB, couple directly to tile

SPIROC2: specific chip for SiPM readout
- Input DAC for channel-wise bias adjustment (36-ch)
- Power pulsing $\rightarrow$ 25 μw / ch
- (Auto) dual-gain setup per channel
- Auto-trigger mode
- Timestamp (300ns ramp, 12-bit TDC)
- PCB hosts 4 asics (144 ch), 6 PCB’s are chained together in a row

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Summary

• Imaging calorimeter is a key ingredient of a detector system optimized for PFA

• CALICE collaboration devoted the last ~10 years into the R&D and developed 2 generations of prototypes
  - The 1st generations provide ‘proof of principle’
    • SiW, SciW ECAL and Sci AHCAL achieved the goal
    • Gaseous DHCAL, sDHCAL are almost there
  - The 2nd generations provide scalable prototypes for a real detector system
    • Several prototypes are being developed / planned