IDEA DUAL-READOUT CALORIMETRY HARDWARE

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For a significant measurement of the Higgs boson couplings to the IVBs, it is mandatory to statistically separate the 4j final states from $H \to WW$ and $H \to ZZ$, where the only discriminant is the W/Z invariant mass. This requires to reconstruct the IVB masses with a resolution of 3-4 GeV, i.e. a jet energy resolution of ~30%/√E. Such an energy resolution has already been achieved with calorimeters compensating through neutron boosting, for single hadron detection, but not for jets. Dual-readout calorimetry aims at providing such a performance, with the same time, excellent electromagnetic resolution and particle identification capabilities, without being affected by any of the drawbacks coming from neutron signal amplification. We present the recent development of a new light readout system based on Silicon PhotoMultipliers (SiPMs) that allows to sample showers with an unprecedented spatial resolution.

Dual-readout calorimetry

Shower induced by hadrons are made of two components:

Electromagnetic component: electrons, positrons, photons (from $\pi^0$ decays)
Neutral hadronic/charged components: (Average values in lead)
charged hadrons (20%), nuclear fragments (25%), neutrons (15%), invisible energy (40%)

Usually, the calorimeter response to the two components is different (non compensation): $E_{\text{comp}} = \frac{E_{\text{hadrons}}}{X} + \frac{E_{\text{VIs}}}{X}$

The electromagnetic fraction, i.e. the fraction of the shower energy deposited by the electromagnetic component, has an asymmetric distribution and increases on average with the energy.
Non compensating calorimeters:
- have a resolution spoiled by fluctuations between these two components
- are non linear detectors
- have a non-gaussian response

In a dual-readout fibre sampling calorimeter it is possible to measure, event by event, the electromagnetic fraction by means of two signals:
C: Cherenkov photons produced in clear anodes
S: Photons produced in scintillating fibres

Dual-readout with SiPMs

The brass (Cu$^{295}$) calorimeter used for the beam test was 112 cm long, with a lateral cross section of 15 x 15 mm$^2$. The active part was composed of 64, 1 mm diameter, optical fibres, 32 scintillating (Kuraray SC5F-78) and 32 clear plastic (Mitsubishi SK40). Each fibre was interfaced to a SiPM.
Sensors were mounted, in chessboard-like arrangement, on a two-tier board, providing individual bias and on-board temperature measurement. The channels were read out with two Multichannel Analog to Digital Acquisition systems (MADA) [1]. Each board integrates 32 channels, with 80 MS/s and 14-bit ADCs, performing real-time charge integration.

ADVANTAGES of SiPMs (respect to PMTs)
(1) Compactness
(2) Higher photon detection efficiency
(3) Magnetic field insensitivity
(4) Possibility to separate the calorimeter into longitudinal segments
(5) Independent readout of each fibre, allowing to sample showers with a millimetric resolution
(6) Potential combination of the dual-readout method with Particle Flow Analysis

DRAWBACKS: response non-linearity, signal saturation effects and optical crosstalk between scintillating and Cherenkov fibres.

RESULTS

We verified that the Cherenkov light yield (28.4 fired cells/GeV) for electromagnetic showers is constant over the 6–125 GeV energy range. By taking into account an average shower containment of ∼36% the experienced light is ~70 mW/GeV. The 2.3 times larger than what estimated with PMTs [2]. This increase alone, keeping the same geometry, improves the stochastic term in the e.m. energy resolution from ~14%/√E to ~10%/√E.

The optical crosstalk was estimated by illuminating a scintillating fibre (covering all the others) with a pulsed LED (Picocount PDL 800). The distribution of the Cherenkov signals has a mean value that is ~0.3% of the scintillating signal. This is an upper limit for the optical crosstalk.

RESULTS (Scintillation) [3]
For the scintillation signal SiPMs saturation and response non linearity are major concerns. Even with a PDE of ~20% we experienced a decrease of about a factor 2 in the "hottest" fibre and ~25% in the remaining 31. By correcting for occupancy saturation we almost completely restored linearity and estimated a scintillation light yield of ~3000 fired cells/GeV and a S/C ratio of ~46.

Spatial Resolution

Data & Geant4

All the DREAM/RD52 publications are available at:
http://www.phys.iu.edu/~dream/index.html


REFERENCES